FEL2022

40th International Free Electron Laser Conference
Trieste, Italy | August 22-26

CONFERENCE GUIDE AND ABSTRACT BOOKLET

Hosting organization

Elettra Sincrotrone Trieste

FEL2022

40th International Free Electron Laser Conference
Trieste, Italy | August 22-26

www.fel2022.org

The FEL2022 app, available in both the Apple and Android app stores, provides the most up-to-date information on the conference.

ANDROID APP ON Google Play | Available on the App Store

https://www.fel2022.org/app

CONFERENCE GUIDE AND ABSTRACT BOOKLET

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Welcome

On behalf of the International Executive Committee of the FEL Conference series, we are pleased to announce the **40th International Free Electron Laser Conference (FEL2022)**, to be held at the Trieste Convention Center (TCC) in Trieste, Italy, from August 22th to August 26th, 2022.
FEL 2022 will focus on recent advances in free electron laser theory and experiments, electron beam, photon beam, and undulator technologies, and applications of free electron lasers.
This edition is organised by Elettra Sincrotrone Trieste, an international, multidisciplinary research centre specialised in the generation of synchrotron and free-electron laser radiation together with their applications in material and life sciences.
The conference programme will include an optional tour of FERMI and the Elettra Storage ring.

Luca Giannessi & Michele Svandrlik

Elettra Sincrotrone Trieste

Conference Organization

Local Organizing Committee

Chairs
Luca Giannessi and Michele Svandrlik

Program Committee Chairs
Giovanni De Ninno and Simone Di Mitri

Editor in Chief
Ivan Andrian

LOC Coordinators
Giuseppe Penco and Annamaria Accettulli

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Heung-Sik Kang (PAL/POSTECH)
Vladimir N. Litvinienko (Stony Brook University & BNL)
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Sven Reiche (PSI)
Joerg Rossbach (DESY & Hamburg University)
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Hitoshi Tanaka (RIKEN SPring-8 Center)
Richard P. Walker (Diamond Light Source)
Ying K. Wu (Duke University)
Zhentang Zhao (SARI)

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Mikhail Yurkov (DESY)
Marie-Emmanuelle Couprie (Soleil)
Hiroyuki Hama (Tohoku Un.)

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Chao Feng (SINAP)
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Avi Gover (Tel-Aviv Univ.)
Jan Gruenert (EU-XFEL)
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Erik Hamsing (SLAC)
Jang-Hui Han (PAL)
Toru Hara (RIKEN Spring-8)
Rasmus Ischebeck (PSI)
Young Jeong (KAERI)
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Marie Labat (SOLEIL)
Vladimir Litvinenko (BNL)
Alex Lumpkin (FNAL)
Alberto Lutman (SLAC)
Agostino Marinelli (SLAC)
Claudio Masciovecchio (Elettra)
Atoosa Meseck (HZB)
Hideoki Ohgaki (IAE)
Eduard Prat (PSI)
Jia Qika (USTC)
Eléonore Roussel (CNRS)
Steven Russell (LANL)
Fernando Sannibale (LBNL)
Oleg Schevchenko (BINP)
Evgeny Schneidmiller (DESY)
Roseanne J. Sension (Un. of Michigan)
Svitozer Serkez (EU-XFEL)
Frank Stephan (DESY)
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Kiyoshi Ueda (Tohoku Un.)
Mathias Vögt (DESY)
Dong Wang (SINAP)
Sverker Werin (MAX-IV)
Juhao Wu (SLAC)
Ying K. Wu (DUKE)
Alexander Zholents (ANL)

Student Grant Committee

Agostino Marinelli (SLAC)
Giuseppe Penco (Elettra, Chair)
Joerg Rossbach (DESY & Hamburg University)
Zhentang Zhao (SARI)

Organizing Secretariat

the office
registration@fel2022.org
fel2022@theoffice.it
www.theoffice.it

Conference Venue Info

TCC | Trieste Convention Center
Viale Miramare 24/2 | 34135 Trieste TS | ITALY

TRIESTE CITY CENTRE TO TTC CONFERENCE VENUE

The Conference provides a shuttle bus service from Trieste Railway Station, Largo Città di Santos, to the Conference venue, at the following schedule:

Dates	Trieste centre / Conference venue	Conference venue / Trieste centre
Sunday 21 August	from 16:30 to 19:00	from 19:30 to 20.30
Monday 22 August	from 8:00 to 9:30	from 18:45 to 19:30
Tuesday 23 August	from 8:00 to 9:30	from 8:45 – to 19:30 one ride at 20.00
Wednesday 24 August	from 8:00 to 9:30	from 17:45 – to 19:30
Thursday 25 August	from 8:00 to 9:30	from 12:45 – to 14:00
Friday 26 August	from 8:00 to 9:30	from 12:45 – to 14:00

BY BUS

Trieste Piazza della Libertà take **bus line no. 6 till** "viale Miramare 77 (cavalcavia) stop"
Duration: Approx. 13 minutes

- http://www.mycicero.eu/ | (download app) to check timetables and purchase ticket.

Tickets for the urban line can be purchased at tobacconists, newsagents, vending machines (blue machines) near the main bus stops, cash is preferrable. 10 trip ticket is available

- Connection to Trieste city centre

TAXI

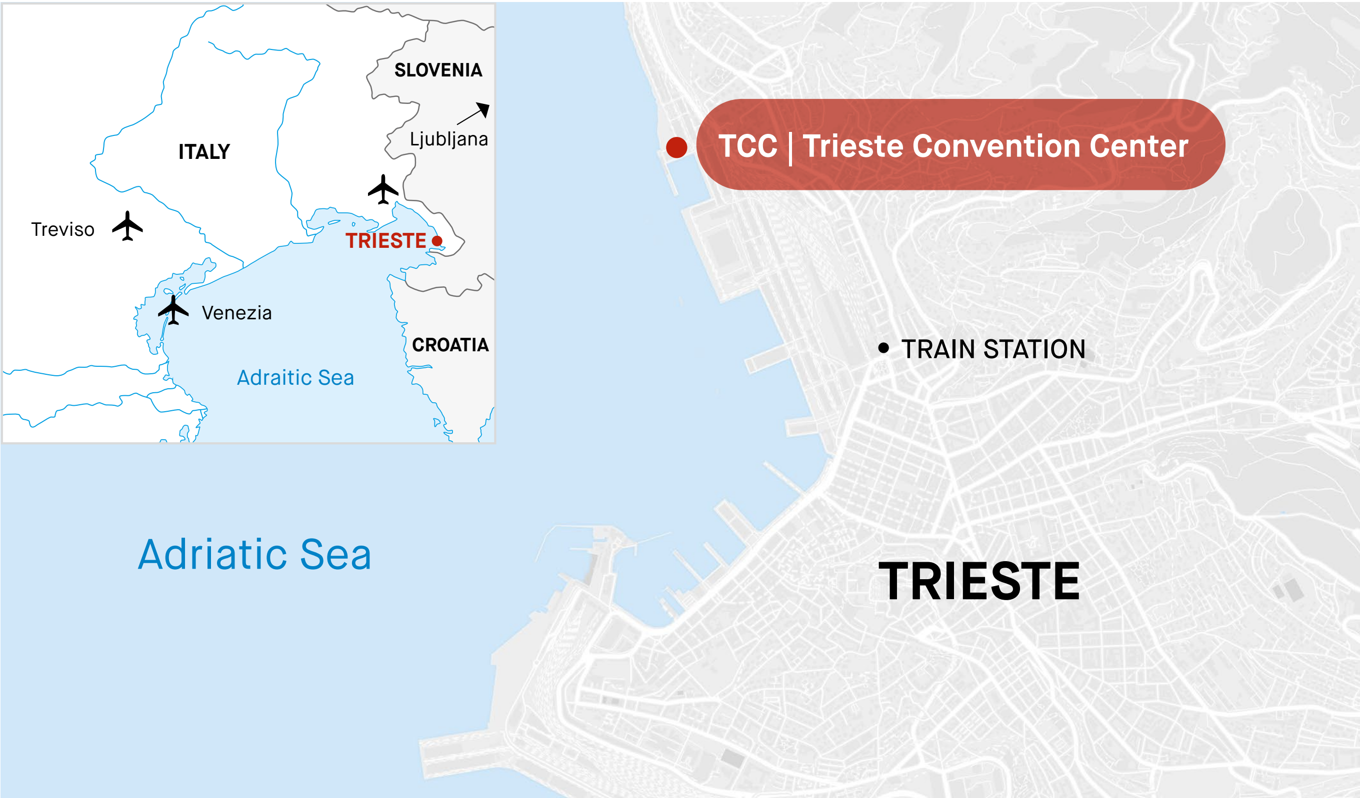
Radiotaxi Trieste | +39 040 307730
Cost: Approx €10/€15 from the city centre.

- Radiotaxi Trieste - https://radiotaxitrieste.it/
- AppStore (iOS)
- Google Play (Android)

BIKE

You can use the bike sharing service BicinCittà Plenty of bicycle racks can be found in the city centre, that you can rent to reach TCC: outside the conference centre there is a rack to leave your bike to.
Download the app!

- AppStore (iOS)
- Google Play (Android)



HOW TO REACH TRIESTE

BY PLANE

TRIESTE REGIONAL AIRPORT
33 km from Trieste
Trieste Airport train stop

- Trieste Airport - https://triesteairport.it/en/
- Connection to Trieste city centre

VENICE INTERNATIONAL AIRPORT
120 km from Trieste
bus routes and shuttle buses connect the airport to Venice-Mestre train station.

- Venice Airport - https://www.veneziaairport.it/en/
- Connection to Trieste city centre

TREVISO INTERNATIONAL AIRPORT
145 km from Trieste
bus routes and shuttle buses connect the airport to the railway station of Venice-Mestre and Treviso. Direct connections via shuttle bus available (example: www.goopti.com)

- Treviso Airport - https://trevisoairport.it
- Connection to Trieste city centre

LJUBLJANA AIRPORT (SLOVENIA)
114 km from Trieste

- Ljubljana Airport - https://lju-airport.si/
- Connection to Trieste city centre

BY TRAIN

Railway routes:
Trieste – Gorizia – Udine
Trieste – Monfalcone – Cervignano – Venezia

- Trenitalia - https://www.trenitalia.com/en.html
- Italotreno - https://www.italotreno.it/en

Railway routes (Slovenia):
Ljubljana – Opicina
Trieste – Ljubljana

- Slovenian railways - https://potniski.sz.si

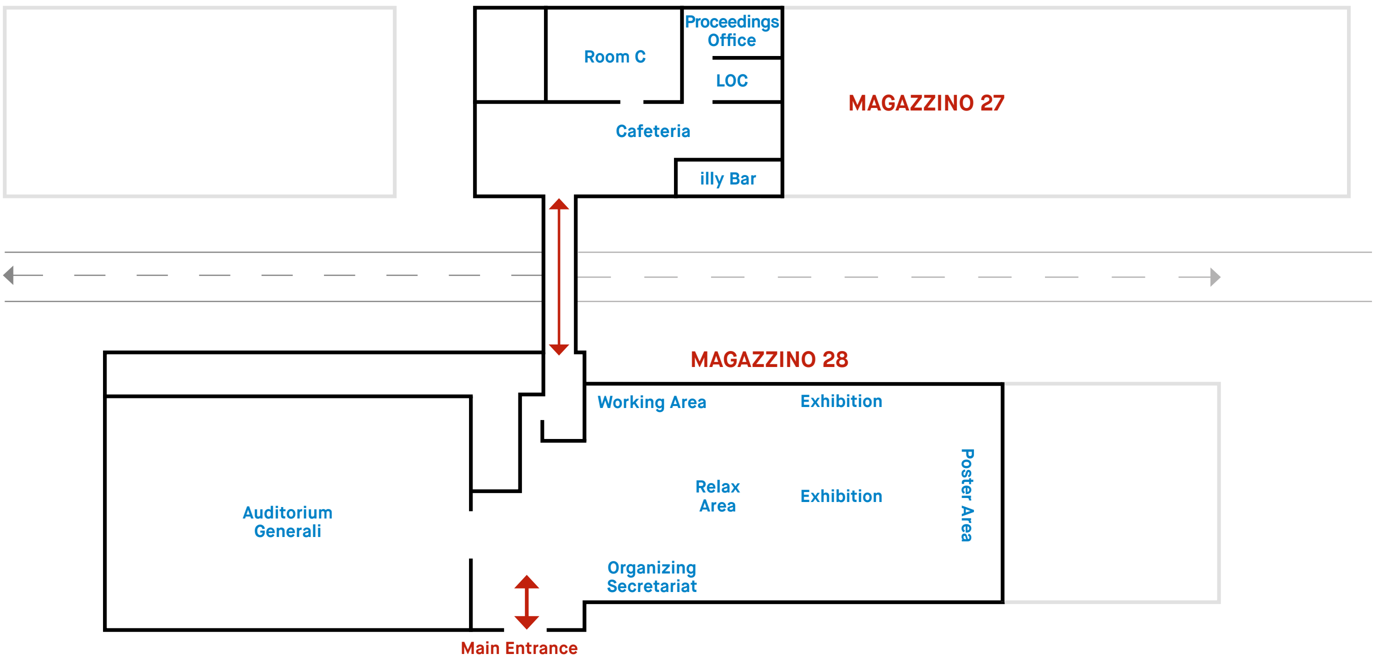
BY BUS

Daily trips to Graz, Vienna, Monaco, Frankfurt, Venice, Milan, Rome, Bologna and many other Italian and European cities.

- https://autostazionetrieste.it
- Öbb-Intercitybus - https://obb-italia.com

Conference Venue Layout

The conference will take place in the Trieste Convention Center (TCC) located in the area of the old harbour (Porto Vecchio), where 5,000 m^2 exhibition area, open spaces and a 1800 seats conference room will provide a safe workplace for the meeting.



Registration and Information Desk

ORGANIZING SECRETARIAT

The Organizing Secretariat desk will be open on
Sunday 21 August from 17:00 – to 20:00
Monday 22 August 8:00 – 18:00
Tuesday 23 August 8:00 – 18:00
Wednesday 24 August 8:00 – 18:00
Thursday 25 August 8:00 – 13:00
Friday 26 August 8:00 – 13:00

REGISTRATION FEES

Registration Fee	Onsite fee
Conference attendance	€ 800,00

Registration fees include attendance to the Scientific Sessions, the conference kit, coffee breaks, Welcome Reception (Sunday 21 August), Conference Dinner (Thursday 25 August).
Attendance to the Welcome Reception (Sunday 21 August from 18.00 to 20.00)

ID BADGE

Your personal ID badge will be ready for you at the Conference Registration Desk.
For security reasons, delegates, accompanying persons and exhibitors will be asked to wear their ID badges during the whole Conference and at all social events.

CERTIFICATES OF ATTENDANCE

Your certificate should be available in your User Area after the Meeting.

WIFI

The eduroam Wi-Fi network is available throughout the TCC.
If you do not have an eduroam account please ask the registration desk to connect to the **FEL2022-guest** network.

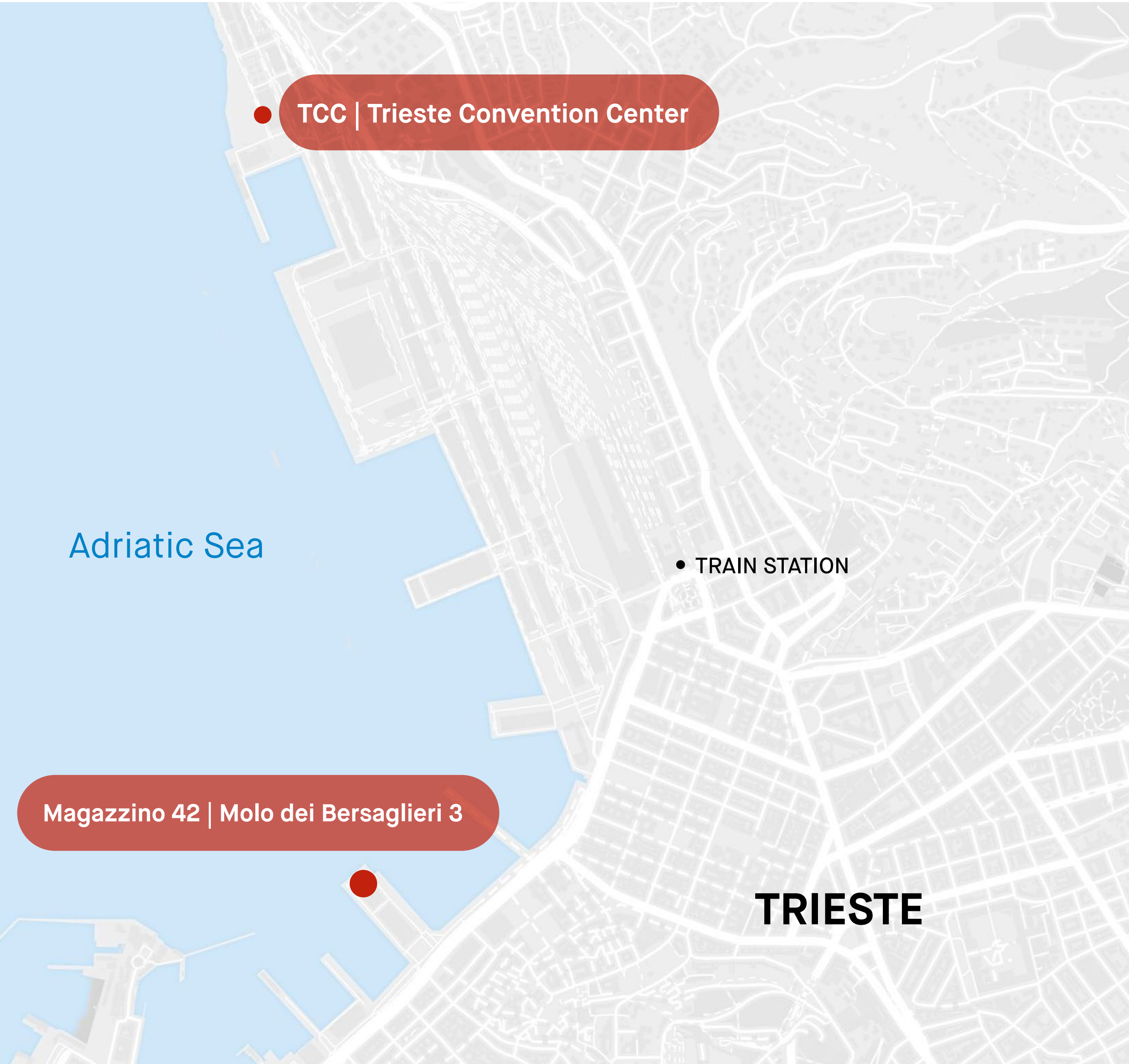
LUNCHES AT THE CONFERENCE

Food and beverages will be available at the illy Bar located in the Conference venue. Remember to make a lunch reservation directly at the illy Bar when you arrive at the Conference. Skip the line: lunch tickets can be purchased in advance at the bar counter.

Welcome reception and Conference Dinner info

WELCOME RECEPTION
Sunday 21 August 2022
from 18:00 to 20:00 at Magazzino 28, TCC Trieste Conference Center

CONFERENCE DINNER
Thursday 25 August 2022
from 19:15 at Room "Ambriabella", Warehouse
Magazzino 42, Molo dei Bersaglieri 3, Trieste



Student Grants

15 students from all over the world have been selected for student grants.
We would like to acknowledge and thank the following institutes for their student support:

DESY

Elettra Sincrotrone Trieste

INFN

MAX IV

Paul Scherrer Institut

Sacla

Shanghai Advanced Research Institute

Slac

STUDENT GRANT COMMITTEE
Agostino Marinelli (SLAC)
Giuseppe Penco (Elettra, Chair)
Joerg Rossbach (DESY & Hamburg University)
Zhentang Zhao (SARI)

Sponsors and Industrial Exhibition

The industrial exhibition will be held in the Hall of MAG 28 from Monday through Friday.
See floorplan map at page 104.

Exhibition hours:

Monday 22 August 2022	8.00 – 19.00
Tuesday 23 August 2022	8.45 – 18.00
Wednesday 24 August	8.45 – 19.00
Thursday 25 August	8.45 – 14.15
Friday 26 August	8.45 – 13.00

Elettra Sincrotrone Trieste

Elettra Sincrotrone Trieste

KYMA

CAEN ELS s.r.l.

CAENels Gear For Science

Communications & Power Industries LLC

CPI Communications & Power Industries

Cycle GmbH

Cycle

Faraday Motion Controls

FARADAY MOTION CONTROLS

Instrumentation Technologies, d.o.o.

INSTRUMENTATION TECHNOLOGIES

IRELEC - ALCEN

Kashiyama Europe GmbH

Pfeiffer Vacuum Italia S.p.A.

Phytron GmbH

R&K Company Limited

SAES Getters SpA

Scandinova

FuG Elektronik GmbH

T.E.E.S. srl

Vacuum Fab

Energy Technology (Ampegon - Ocem)

Elettra Sincrotrone Trieste visit

GUIDED VISIT OF THE RESEARCH CENTER

Thursday 25 August 2022, 14:10

Departure by bus from TCC Trieste Conference Center to Elettra Sincrotrone Trieste for a tour of the laboratory (approximately 3 hours).

At the end of the visit the buses will return to the city center.

Only for a limited number of participants, check availability with conference secretariat.

Proceedings & Proceedings Office

The final FEL2022 conference proceedings will be published on the JACoW website:
https://www.jacow.org/Main/Proceedings?sel=FEL

Proceedings Office
In case of major problems with the paper the author must contact the Author Reception Desk in room D and arrange to see an Editor for help.
The Proceedings Office is located in Room E.

Proceedings Office hours:
Monday 8:15 – 18:30
Tuesday 8:15 – 18:30
Wednesday 8:15 – 18:30
Thursday 8:15 – 18:30
Friday 8:15 – 13:00

Authors are requested to check on the status of their submitted paper by logging in to the JACoW FEL2022 Indico page at https://indico.jacow.org/e/FEL2022

JACoW Editorial Team
Ivan Andrian (Elettra-Sincrotrone Trieste, Italy, Editor-in-Chief)
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Volker Schaa (GSI, Germany)
Filippo Sottocorona (Elettra-Sincrotrone Trieste, Italy)

Oral presentations

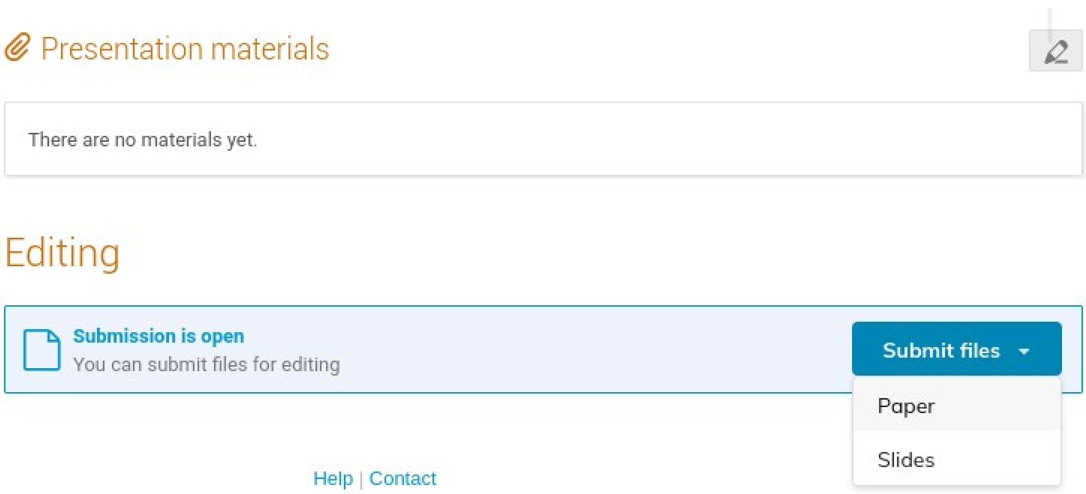
Oral presentations will be held in the Auditorium "Generali".
A speakers' preparation room with help by experts (if needed) is available.
We accept PowerPoint or LibreOffice Impress presentations, as well as PDF slides files.
The format can be 16:9 or 4:3 - 16:9 however is recommended due to the shape of the projecting wall.
Please note that all speakers must give their presentations using the computer system available in the lecture hall. We will provide a Windows laptop with Microsoft Office.
Use of individual laptops cannot be accommodated.
All talks MUST be uploaded at least 24 hours in advance using Indico.
Speakers are requested to pass by the Speakers' Ready Room/Slide Centre at least by the preceeding session (or day) and check their presentations.

Submission of electronic files

Only files named according to the paper's program code can be uploaded. Example for paper code MOP99:

- MOP99_slides.ppt
- MOP99_slides.pptx
- MOP99_slides.odp
- MOP99_slides.pdf

File upload via Indico
1. Once all files are ready for submission, **login to the FEL2022 Indico** and upload your files.
2. After login, use the lefthand menu to access "**My Conference > My Contributions**".
3. Open the contribution you want to upload files for and scroll all the way down to the bottom.
4. **Ignore** the "**Presentation materials**" section (see figure down below).
5. Click on the "**Submit files**" button and choose the **Slides** file type (see figure down below)



Poster presentation

The Poster Sessions will be located in Exhibition Hall. They will take place from Monday (22 August) to Wednesday (24 August) between 16:00 and 17:30/18:00.

Poster Size
Please prepare your posters in ISO A0 size, portrait only.
A0 dimensions are 841 mm wide x 1189 mm high or 33.1 inches wide by 46.8 inches high.

Poster-ID
All contributions to the conference will have a program code whereby the first two letters correspond to the day of presentation, Monday, Tuesday (i.e. MO, TU). The third will give the type of representation, with P indicating a poster presentation. Each poster board is numbered with a Poster-ID corresponding to the program code (e.g.: MOP99 -> Monday Poster session, board number 99).

Poster Title
The title of the poster must be identical to that in the paper. Name(s) of author(s) and institution should be on the poster and correspond to the paper as well.

Mounting the Posters
Posters should be mounted during the lunch break.
Posters must be manned throughout the entire session. All necessary material for poster display (pins, etc) will be provided by the conference organizers.

Authors are reminded that papers, where the corresponding poster is not presented at the conference, will be excluded from the proceedings. Furthermore, the Program Committee reserves the right to refuse for publication work not properly presented in the poster sessions.

Please contact info@fel2022.org if you have questions.

Tutorials

How to expand your research network

Networking, access and project opportunities for FEL and Laser research in Europe

Monday August 22nd 17:30-19:00 (Auditorium Generali, Magazzino 28)

TIME	TITLE	SPEAKER
17:30 – 19:00	**How to enlarge your research network**	
Part A	Networks and European projects	
17:30 – 17:45	**LEAPS overview and opportunities**	B. Redlich
17:45 – 18:00	**Laserlab-Europe access and networking**	S. Jacquemot
18:00-18:15	**Questions**	
Part B	How to write a successful project proposal	
18:15 – 18:35	**Calls overview and best practices examples**	C. Blasetti
Part C	Introduction to 1-to-1 meetings on day 2&3	
18:35 – 18:45	**How to book your slots with the experts**	C. Blasetti
18:45 – 19:00	**Any other question**	

Tuesday August 23rd 16:00-18:00 (Hall, Magazzino 28)

Participants will have the chance to pre-book 15-minutes meetings on the following topics:

a. **wayforlight and beamtime proposals:** Discover the **wayforlight.eu** portal to find out the most suitable instruments for your research and get useful tips to draft a successful beamtime proposal
b. **Laserlab-Europe:** Become aware of transnational access support tools, joint research and training opportunities offered by the **Laserlab-Europe** Consortium
c. **Horizon Europe programmes and grants for all stages of research careers:** Get introduction and assistance on funding possibilities for researchers from all over the world

Wednesday, August 24th 16:00-17:30 (Hall, Magazzino 28)

Participants will have the chance to pre-book 15-minute meetings on the following topics:

a. **wayforlight and beamtime proposals:** Discover the **wayforlight.eu** portal to find out the most suitable instruments for your research and get useful tips to draft a successful beamtime proposal
b. **Laserlab-Europe:** Become aware of transnational access support tools, joint research and training opportunities offered by the **Laserlab-Europe** Consortium
c. **Euraxess - an European network to support mobility and career development for researchers:** Get information on how to apply for research jobs in Europe

Meeting the editor

Wednesday August 24nd 17:30-19:00 (Auditorium Generali, Magazzino 28)

Chair: G. De Ninno

Serena Dalena (Physical Review Letters)
Oliver Graydon (Nature Photonics)

Where can you publish your best FEL-related research results? Should your target be the FEL community, or do your results deserve the attention of a broader audience? How can you publish the best possible paper, taking advantage of the interaction with editors and referees? If you are curious and want to know more about editorial and publication practices and procedures, please joint this event. Two special guests will be there to answer: Serena Dalena, editor of Physical Review letters, and Oliver Graydon, editor of Nature Photonics.

Scientific Program

21 August 2022

17:30-20:00
Registration

18:00-20:00
Welcome Reception

22 August 2022

8:45-9:15
Welcome Addresses

9:15-9:30
In memory of M. Billardon
M.-E. Couprie

9:30 - 10:35
Session 1: First Lasing
(Chair: F. Curbis)
G. Geloni, E. Prat, A. Trebushinin, M.-E. Couprie, V. Shpakov, P. Musumeci, Z. Zhu, M. Krasilnikov

10:35-11:00
Coffee & Exhibition

11:00-12:55
FEL Prize Talks
(Chair: V. Litvinenko)
G. Stupakov, E. Allaria, A. Lumpkin, J. Duris, C. Feng

12:55-14:10
Lunch break

14:10-16:00
Session 2: FEL Theory *(Chair: A. Gover)*

14:10-14:40
Population inversion X-ray laser oscillator at LCLS
Aliaksei Halavanau (SLAC)

14:40-15:10
Attosecond polarization modulation of x-ray radiation in a free-electron laser
Jenny Morgan (Univ. of Strathclyde, SLAC)

15:10-15:35
Proposal for a Quantum Free Electron Laser driven by Ultracold Electrons
Brian H. Schaap (TU/e)

15:35-16:00
Quantum diffusion in coherent radiation
Gennady Stupakov (SLAC)

16:00-17:30
Coffee, Posters & Exhibition

17:30-19:00

Tutorial 1: How to expand your research network and write a successful project proposal
(Chair: C. Blasetti)
B. Redlich, S. Jacquemot, C. Blasetti

23 August 2022

08:45 - 10:35
Session 3: SASE FELs
(Chair: E. Schneidmiller)

8:45-9:15
Cascaded amplification of attosecond X-ray pulses: towards TW-scale ultrafast X-ray FELs
Paris Franz (Stanford Univ.)

9:15-9:45
Short pulses and 2-color capabilities at the SASE3 FEL line of the EU-XFEL
Svitozar Serkez (EU-XFEL)

9:45-10:10
Demonstration of enhanced FEL performance with optical klystron and helical undulators
Christoph Kittel (PSI)

10:10-10:35
Two-Colored FEL generation Using Phase Shifters at Undulator
Myung-Hoon Cho (PAL)

10:35-11:00
Coffee & Exhibition

11:00-12:50
Session 4: Seeded FELs
(Chair: R. Hajima)

11:00-11:30
Coherent and ultrashort soft x-ray pulses from echo-enabled harmonic cascade FEL
Chao Feng (SINAP)

11:30-12:00
Enhanced Self-Seeding with Ultrashort Electron Beams
Zhen Zhang (SLAC)

12:00-12:25
Comparison of transverse coherence properties in seeded and unseeded FEL
Mihai Pop (MAX IV)

12:25-12:50
First observation of laser-beam interaction in a dipole magnet
Jiawei Yan (EU-XFEL)

12:50-14:10
Lunch break
SPC Lunch Meeting, Room C - Mag27

14:10-16:00
Session 5: FEL Oscillators and IR-FELs
(Chair: Y. K. Wu)

14:10-14:40
Observation of Burnham-Chiao ringing with pi-phase jumps in a high-efficiency superradiance FEL oscillator
Heishun Zen (IAE Kyoto Univ.)

14:40-15:10
FEL Lasing below 170 nm using an oscillator
Ying Wu (Duke Univ.)

15:10-15:35
Single pass high efficiency THz FEL
Andrew Fisher (PBPL)

15:35-16:00
THz FEL oscillator synchronized soft X-rays via Thomson back-scattering: a new dual source technique
Marcel Ruijter (Univ. of Milan, INFN)

16:00-18:00
Coffee, Posters & Exhibition

18:00-20:00
IEC Meeting, Room C - Mag27

20:00
Dinner IEC & Chairs

24 August 2022

08:45 - 10:35
Session 6: Electron Sources
(Chair: F. Sannibale)

8:45-9:15
Review of recent photocathode advancements
Laura Monaco (LASA, Univ. of Milan)

9:15-9:45
First Commissioning of LCLS-II Injector
Feng Zhou (SLAC)

9:45-10:10
Continuous-wave operation of a low-emittance DC-SRF photocathode gun
Senlin Huang (Peking Univ.)

10:10-10:35
Chirped Pulse Laser Shaping for High Brightness Photoinjectors
Christian Koschitzki (DESY, PITZ)

10:35-11:00
Coffee & Exhibition

11:00-12:50
Session 7: Electron Beam Dynamics
(Chair: S. Thorin)

11:00-11:30
Comparison of Eulerian, Lagrangian and Semi-Lagrangian Simulations of Phase-Space Density Evolution
Phlipp Amstutz (DESY)

11:30-12:00
First evidence of intrabeam scattering in an electron linac and impact on short wavelength FELs
Giovanni Perosa (Univ. of Trieste, Elettra)

12:00-12:25
Energy spread blow-up by intra-beam scattering and micro-bunching at the SwissFEL injector
Eduard Prat (PSI)

12:25-12:50
Characterization of the European XFEL pulses in the presence of Microbunching instability
Najmeh Mirian (EU-XFEL)

12:50-14:10
Lunch break

14:10-16:00
Session 8: Novel Acceleration and FEL Concepts
(Chair: A. Ghaith)

14:10-14:40
Free-electron Lasing Based on a Laser Wakefield Accelerator
Wentao Wang (SIOM, CAS)

14:40-15:10
First SASE and Seeded FEL Lasing based on a beam driven wakefield accelerator
Mario Galletti
(University of Rome "Tor Vergata", INFN-LNF)

15:10-15:35
First laser plasma accelerator based seeded FEL
Marie Labat (SOLEIL)

15:35-16:00
Bridging the gap of storage ring light sources and linac-driven FELs
Simone Di Mitri (Elettra, Univ. of Trieste)

16:00-17:30
Coffee, Posters & Exhibition

17:30-19:00
Tutorial 2: Meeting the editor
(Chair: G. De Ninno)
S. Dalena (Physical Review Letters)
O. Graydon (Nature Photonics)

25 August 2022

08:45-10:35
Session 9:
Electron Diagn., Timing, Synch. & Controls
(Chair: M. Labat)

8:45-9:15
Machine learning-based virtual diagnostic
Adi Hanuka (Eikon Therapeutics)

9:15-9:45
Coherent 3D microstructure of laser-wakefield-accelerated electron bunches
Maxwell LaBerge (University of Texas, HZDR)

9:45-10:10
Self-synchronized and cost-effective time-resolved measurements at x-ray FELs with femtosecond resolution
Philipp Dijkstal (PSI)

10:10-10:35
Ultimate pulse-to-pulse stability in non-linear bunch compressors
Erik Mansten (MAX IV)

10:35-11:00
Coffee & Exhibition

11:00-12:50
Session 10: Photon Beamline Instrum. & Undulators
(Chair: J. Gruenert)

11:00-11:30
Development of APPLE-III Undulators for FLASH
Markus Tischer (DESY)

11:30-12:00
XFEL sub-10 nm focusing mirror system at SACLA for achieving 10^{22} W/cm^2 intensity
Jumpei Yamada (Osaka Univ.)

12:00-12:25
Ringdown Demonstration of a Low-Loss 14 m Hard X-ray Cavity
Rachel Margraf (Stanford Univ.)

12:25-12:50
AC/DC: the FERMI FEL split and delay optical device for ultrafast X-Ray science
Alberto Simoncig (Elettra)

12:50-14:10
Lunch break

14:10-18:00
Visit to Elettra Sincrotrone Trieste

18:00-19:00
Transfer to Trieste

19:00-22:00
Social Dinner and FEL Prize ceremony

26 August 2022

08:45-10:35
Session 11: User Experiments
(Chair: K. Ueda)

8:45-9:15
Probing transient structures of nanoparticles by single-particle X-ray diffraction
Akinobu Niozu (Hiroshima Univ.)

9:15-9:45
Novel Lattice Instability in Ultrafast Photoexcited SnSe
Yijing Huang (Stanford Univ.)

9:45-10:10
Ultrafast dynamics in $(TaSe_4)_2I$ triggered by optical and x-ray excitation
Federico Cilento (Elettra)

10:10-10:35
FLASH2020+ Pump-Probe Laser Upgrade: Concept and Current Status
Skirmantas Alisauskas (DESY)

10:35-11:00
Coffee & Exhibition

11:00-12:50
Session 12: End-to-end Experiments
(Chair: F. Capotondi)

11:00-11:30
Experiments with phase-controlled multi-pulses from FERMI
Carlo Callegari (Elettra)

11:30-12:00
Observation of coherent electronic motion with X-ray FELs
James P. Cryan (SLAC)

12:00-12:25
The role of light possessing orbital angular momentum in ptychographic imaging experiments
Matteo Pancaldi (Elettra)

12:25-12:50
A perfect X-ray beam splitter and its applications to time-domain interferometry and quantum optics exploiting FELs
Sven Reiche (PSI)

Close-out (ends at 13:00)

Abstracts

MOX – Special Session

MOX01 / 09:15

In memory of M. Billardon

Marie-Emmanuelle Couprie (Synchrotron Soleil)

MOA – First lasing

22 August 9:30 – 10:35

Chair: Francesca Curbis (Lund University)

MOA01 / 09:30

The Hard X-ray Self-Seeding system at the European XFEL

Gianluca Geloni (European XFEL GmbH)

This contribution describes, on behalf of the HXRSS team, design, installation, commissioning and operation of the Hard X-Ray Self-Seeding (HXRSS) system at the SASE2 FEL line of the European XFEL. We have reached up to mJ-level self-seeded pulses at 9-10 keV and the tested operational range is 6-13 keV. The setup can work in burst mode, that is following the bunch pattern of the European XFEL. The peculiarities of the European XFEL, that are high-repetition rate and long, tuneable undulators will be discussed, together with the impact of two-chicanes simultaneous seeding on the crystal heat loading. A discussion on possible future developments, including the production of self-seeded radiation at a harmonic of the fundamental, will complement the description of the current performance of the system.

MOA02 / 09:38

First lasing of Athos, the soft X-ray FEL beamline of SwissFEL

Eduard Prat (Paul Scherrer Institut)

Athos is the soft X-ray FEL beamline of SwissFEL at PSI in Switzerland. Its novel undulator layout consists of short Apple-X modules, capable of providing full polarization control, interleaved with short magnetic chicanes. This flexible configuration allows for many unique operational modes, giving control over FEL properties such as peak power, pulse duration and longitudinal coherence. This contribution presents the first lasing results of Athos, including SASE and some of the special operation modes.

MOA03 / 09:46

Attosecond at harmonics at the European XFEL: first results at SASE3

Andrei Trebushinin (European XFEL GmbH)
Natalia Gerasimova (European XFEL GmbH), gianluca geloni, Marc Guetg (Deutsches Elektronen-Synchrotron), Giuseppe Mercurio, Svitozar Serkez, Evgeny Schneidmiller (Deutsches Elektronen-Synchrotron)

We report on the first observation of short, single-spike events generated at the SASE3 beamline of European XFEL via the "attosecond at harmonics method". The approach was first proposed in [1]. We created bunching in the linear regime at around 0.5 keV and then, after bunching optimization by means of a magnetic chicane, we amplified the 4th harmonic bunching with a part of the undulator set to 2 keV. Due to the non-linear transformation of the bunching during the harmonic jump, radiation generated using this scheme occasionally exhibits single spike spectra (about a percent of the shots, which makes it attractive to use the method at high repetition-rate FELs). We expect those to correspond to single spikes in time-domain. We replicated the experiment numerically with the help of the GENESIS code.

MOA04 / 09:54

First lasing of the COXINEL Seeded Free Electron Laser driven by the HZDR laser plasma accelerator

Marie-Emmanuelle Couprie (Synchrotron Soleil)
Anthony Berlioux (Synchrotron Soleil), Yen-Yu Chang (Helmholtz-Zentrum Dresden-Rossendorf), Sébastien Corde (LOA), Jurjen Couperus Cabadag (Helmholtz-Zentrum Dresden-Rossendorf), Carlos De Oliveira (Synchrotron Soleil), Alexander Debus (Helmholtz-Zentrum Dresden-Rossendorf), Yannick Dietrich (Synchrotron Soleil), Jean-Pierre Duval (Synchrotron Soleil), Christoph Eisenmann (Helmholtz-Zentrum Dresden-Rossendorf), Moussa El Ajjouri (Synchrotron Soleil), Julien Gautier (Laboratoire d'Optique Appliquée), Rene Gebhardt (Helmholtz-Zentrum Dresden-Rossendorf), Amin Ghaith (HZDR), Simon Grams (Helmholtz-Zentrum Dresden-Rossendorf), Uwe Helbig (Helmholtz-Zentrum Dresden-Rossendorf), Christian Herbeaux (Synchrotron Soleil), Nicolas Hubert (Synchrotron Soleil), Arie Irman (Helmholtz-Zentrum Dresden-Rossendorf), Charles Kitegi (Synchrotron Soleil), Olena Kononenko (Laboratoire d'Optique Appliquée), Michael Kuntzsch (Helmholtz-Zentrum Dresden-Rossendorf), Maxwell LaBerge (The University of Texas at Austin), Marie Labat (Synchrotron Soleil), Stephane Le (Synchrotron Soleil), Bruno Leluan (Synchrotron Soleil), Alexandre Loulergue (Synchrotron Soleil), Victor Malka (Weizmann Institute of Science), Fabrice Marteau (Synchrotron Soleil), Manh Huy N Guyen (synchrotron SOLEIL), Driss Oumbarek Espinos (Osaka University), Richard Pausch (Helmholtz-Zentrum Dresden-Rossendorf), Damien Pereira (Synchrotron Soleil), Thomas Püschel (HZDR), Jean-Paul Ricaud (Synchrotron Soleil), Patrick Rommeluere (Synchrotron Soleil), Pascal Rousseau (LOA), Eléonore Roussel (Laboratoire de Physique des Lasers, Atomes et Molécules), Susanne Schöbel (HZDR), Mourad Sebdaoui (Synchrotron Soleil), Keihan Tavakoli (Synchrotron Soleil), Cédric Thaury (LOA), Patrick Ufer (HZDR), Mathieu Valléau (Synchrotron SOLEIL), Marc Vandenberghe (Synchrotron SOLEIL), José Vétéran (Synchrotron SOLEIL), Ulrich Schramm (HZDR)

The COXINEL line has been designed at Synchrotron SOLEIL for electron beam manipulation in view of a seeded free electron laser using Laser plasma acceleration (LPA). After first studies on electron beam transport and undulator radiation in the spontaneous emission regime using LPA from Laboratoire d'Optique Appliquée (Ecole Polytechnique, France), the line has been moved to the HZDR, Dresden, Germany, for high quality LPA electrons driven by the DRACO laser. We report here on the demonstration of a seeded FEL at 275 nm driven by the HZDR LPA.

MOA05 / 10:02

SASE and Seeded FEL powered by PWFA electron beam

Vladimir Shpakov (Istituto Nazionale di Fisica Nucleare)
Mario Galletti (Istituto Nazionale di Fisica Nucleare), Alessandro Cianchi (Università di Roma II Tor Vergata), Luca Giannessi (INFN-Laboratori Nazionali di Frascati, Elettra-Sincrotrone Trieste), Massimo Ferrario (Istituto Nazionale di Fisica Nucleare)

We report on our first SASE and Seeded lasing achieved with electron beam accelerated with beam driven plasma wake-field acceleration technique.

MOA06 / 10:10

First lasing of UCLA high efficiency THz FEL

Pietro Musumeci (University of California, Los Angeles)

Here we report on the first lasing of the high efficiency THz FEL operating at the UCLA Pegasus laboratory. The FEL is operated in the zero-slippage regime where a circular waveguide is used to match the radiation and electron-beam velocities in a 0.96 m long tapered helical undulator, allowing resonant interaction with the ultrashort 200-pC 5.5-MeV electron beam from the RF photogun over an extended region. Electron-beam spectrum measurements, supported by energy and spectral measurement of the terahertz FEL radiation, indicate an average energy efficiency of ~10%, with some particles losing >20% of their initial kinetic energy.

MOA07 / 10:18

First lasing of the Shanghai Soft X-ray FEL user facility

Zihan Zhu (Shanghai Institute of Applied Physics), Chao Feng (Shanghai Advanced Research Institute)

Here we report on the first lasing of the Shanghai Soft X-ray FEL user facility (SXFEL). We have achieved the saturation of SASE at 2 nm based on FEL-I and saturation of harmonic lasing self-seeding at 3 nm based on FEL-II. We have also achieved the first lasing of EEHG with a wavelength as short as 5.3 nm.

MOA08 / 10:26

First Lasing of the THz SASE FEL at PITZ

Mikhail Krasilnikov (Deutsches Elektronen-Synchrotron DESY at Zeuthen)

Zakaria Aboulbanine (DESY, Zeuthen), Gowri Adhikari (DESY, Zeuthen), Namra Aftab (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Prach Boonpornprasert (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Georgi Georgiev (Deutsches Elektronen-Synchrotron DESY at Zeuthen), James Good (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Matthias Gross (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Andreas Hoffmann (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Xiangkun Li (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Anusorn Lueangaramwong (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Raffael Niemczyk (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Anne Oppelt (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Houjun Qian (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Christopher Richard (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Frank Stephan (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Grygorii Vashchenko (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Tobias Weilbach (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Evgeny Schneidmiller (Deutsches Elektronen-Synchrotron), Markus Tischer (Deutsches Elektronen-Synchrotron DESY), Pavel Vagin (Deutsches Elektronen-Synchrotron), Mikhail Yurkov (Deutsches Elektronen-Synchrotron), Axel Brachmann (SLAC National Accelerator Laboratory), Norbert Holtkamp (SLAC National Accelerator Laboratory), Heinz-Dieter Nuhn (SLAC National Accelerator Laboratory)

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) develops a prototype of an acceleratorbased high-power tunable THz source for pump-probe experiments at the European XFEL. The PITZ injector used for THz generation is also a site for the development and preparation of the high-brightness electron source for the main linac of the European XFEL and has the same pulse train structure as the X-ray photon source of the XFEL. For the proof-of-principle experiments on high-power THz generation an LCLS- I undulator (on loan from SLAC) is installed in the tunnel annex downstream of the existing accelerator. The extension of the beam line consists of a bunch compressor and a collimation system in the main PITZ tunnel, as well as a matching section, the undulator and the THz diagnostic setup in the tunnel annex. A Self-Amplified Spontaneous Emission (SASE) FEL is considered to generate the THz pulses. High radiation power can be achieved by utilizing high charge (up to several nC) electron bunches from the PITZ photo injector. A beam energy of ~17 MeV is used to generate THz radiation with a center wavelength of 100 um. A transport of this space charge dominated electron beam and its thorough matching into the planar LCLS-I undulator with a strong vertical focusing is one of the project challenges. The vacuum of the first THz beamline setup was closed in summer 2022 and commissioning with electron beam started. A specially developed procedure for a high charge beam matching into the undulator was successfully tested resulting in a first THz pulse generation. The start-up THz diagnostics is based on pyrodetectors. First measurements of the THz generation from a 1 nC bunch have been taken, the statistics properties analysis reflects the expected SASE performance. First measurements already show good perspectives for the proposed accelerator-based THz source.

MOB – FEL Prize

22 August 11:00 – 12:55

Chair: Vladimir Litvinenko (Stony Brook University)

MOBI1 / 11:00

Echo effect in FELs, accelerators, and elsewhere

Gennady Stupakov (SLAC National Accelerator Laboratory)

In recent years, echo-enabled harmonic generation (EEHG) demonstrated that it is capable to upshift the seed frequency in an FEL by almost two orders of magnitude. In this presentation, I will talk about the EEHG concept in FELs and show its connection to the echo effect known in other areas of physics (such as spin echo, plasma echo, echo in accelerators, etc.). The physics of the EEHG will be discussed as well is its major limitations.

MOBI2 / 11:25

Shaping and control of radiation properties with seeded FELs

Enrico Allaria (Elettra-Sincrotrone Trieste S.C.p.A.)

The use of external lasers to initiate the FEL process has been introduced as a way to prepare the electron beam before entering the FEL radiator and to allow the generation of radiation pulses with increased brightness in shorter undulator. Over the recent years, new methods have been proposed and implemented to extend the capabilities of external seeding toward shorter wavelengths. The experience gained at the FERMI seeded FEL user facility has boosted the developments of experimental techniques taking full advantage of the high degree of coherence of FEL pulses and the possibility to accurately control the radiation properties such has amplitude and phase. Recent results together with future plans for externally seeded FEL facilities will be reported.

MOBI3 / 11:50

Microbunching in Relativistic Electron Beams

Alex Lumpkin (Argonne National Laboratory)

One of the fundamental facets of microbunching in relativistic electron beams is the potential for generation of coherent radiation at the wavelengths that characterize that periodic longitudinal modulation. This microbunching is an inherent process in the free-electron laser (FEL) mechanism for both single-pass and oscillator configurations. Besides the FEL output, diagnostics of these microbunched electron beams can be performed using coherent optical transition radiation (COTR) and imaging techniques in the former case. In these cases, the COTR from the microbunched portion of the beam in 6-D space generally dominates the images. Other mechanisms include the longitudinal-space-charge-induced microbunching in ultra-bright beams and laser-induced microbunching such as observed in laser wakefield accelerator beams. More recently, we consider the diagnostics of the TESSA** FEL concepts where a seed laser co-propagating with the electron beam through a short modulator and chicane may result in bunching fractions of >10 % leading to COTR enhancements of >22 million. Examples of these past, present, and future investigations will be discussed.

**Tapering Enhanced Super-radiant Stimulated Amplification (TESSA)

MOBI4 / 12:15

Laser Controlled Free-Electron Lasers

Joseph Duris (SLAC National Accelerator Laboratory)

Laser manipulation of electron beams is important for controlling free-electron lasers. In this talk, I will discuss how strong seeding can enable powerful, efficient FELs and high gradient acceleration when paired with strong tapering. I will then show how laser driven optical compression led to attosecond X-ray FEL pulses at LCLS and plans to use lasers to generate high repetition rate femtosecond and attosecond X-rays at LCLS-II.

MOBI5 / 12:35

Laser assisted beam manipulation techniques for fully coherent and ultra-short FEL generation

Chao Feng (Shanghai Advanced Research Institute)

Laser assisted beam manipulation has been extensively used in modern high gain FELs to tailor the output properties. In this talk, I will focus on several advanced techniques on high harmonic generation and ultrashort pulse generation with assistant of external UV or IR lasers. With the help of state-of-the-art laser technologies, it's very likely these techniques will open new opportunities for coherent light sources.

MOC – FEL Theory

22 August 14:10 – 16:00

Chair: Avraham Gover (University of Tel-Aviv)

MOCI1 / 14:10

Population inversion x-ray laser oscillator at LCLS

Aliaksei Halavanau (SLAC National Accelerator Laboratory), Andrei Benediktovitch (CFEL, DESY), Claudio Pellegrini (SLAC National Accelerator Laboratory), James Rosenzweig (University of California - Los Angeles), Margaret Doyle (University of California - Berkeley), Nathan Majernik (University of California - Los Angeles), Nina Rohringer (University of Hamburg), Noah Welke (University of Wisconsin), Pratik Manwani (University of California - Los Angeles), Spela Krusic (Jozef Stefan Institute), Thomas Kroll (SLAC National Accelerator Laboratory), Uwe Bergmann (University of Wisconsin)

Cavity-based XFEL systems will potentially offer much higher spectral quality of the hard x-ray beam compared to traditional XFEL SASE and self-seeded sources. A promising cavity-based concept is the population inversion x-ray laser oscillator, dubbed XLO, where the SASE beam is used as a pump, and a transition metal serves as a gain medium. We will report on the progress in design and construction of the XLO, using LCLS as an x-ray pump, being developed by a SLAC, CFEL, University of Hamburg, University of Wisconsin, and UCLA collaboration. Initially, XLO will be demonstrated at the Coherent X-ray Imaging (CXI) LCLS end-station, as a two pass Regenerative Amplifier operating at the Copper Kalpha1 photon energy of 8048 eV. In the later phase of the project, it will utilize LCLS multi-bunch mode, with up to 8 x-ray pulses. Finally, XLO will generate fully coherent transform limited pulses with about 50 meV FWHM bandwidth. We expect the XLO will pave the way for new user experiments, e.g. in inelastic X-ray scattering, parametric down conversion, quantum science, X-ray interferometry.

MOCI2 / 14:40

Attosecond polarization modulation of x-ray radiation in a free-electron laser

Jenny Morgan (SLAC National Accelerator Laboratory)

Polarization is a fundamental property of light used in experiments to probe various properties of matter such as the chirality of molecules and crystal structures. There is increasing interest in generating bespoke radiation pulses for experiments with increasingly complex structures of polarization. At short wavelengths, free electron lasers offer an avenue to control the polarization structure at the point where the radiation is emitted through manipulation of the electron beam, removing the requirement for polarizing optics not readily available at x-ray wavelengths. This talk discusses a method for manipulating the polarization of FEL generated light based on temporal intensity modulation of radiation emitted in orthogonally polarized undulators. Simulations demonstrate the method can produce radiation that switches between orthogonal polarization states at attosecond timescales. Implementation of this ultra-fast polarization switching would provide a valuable new tool to the scientific community.

MOCO3 / 15:10

Proposal for a Quantum Free Electron Laser driven by Ultracold Electrons

Sander Schouwenaars (TU/e), Brian Schaap (Technische Universiteit Eindhoven), Coen Sweers (TU/e), Max van der Schans (TU/e), Jom Luiten (Technische Universiteit Eindhoven)

Operation of a Quantum Free-Electron Laser (QFEL) could provide fully coherent X- and gamma-rays in a compact setup. Imperative to experimental realization is allowing for decoherence of either spontaneous emission or space-charge to take place, having opposing constraints [1]. Here, for the first time, we discuss a comprehensive QFEL model that takes into account both decoherence effects. Then, we use this model to investigate the ultracold electron source (UCES) [2] as a potential QFEL electron injector. The UCES, based on near-threshold photoionization of laser-cooled and trapped atomic gas, has the unique property of allowing highly charged electron bunches to be extracted while maintaining ultralow transverse emittance. We find that the ultracold electron bunches meet the stringent requirement for potential QFEL operation with commercially available laser systems.

MOCO4 / 15:35

Quantum diffusion in coherent radiation

Gennady Stupakov (SLAC National Accelerator Laboratory)

Quantum diffusion is caused by the recoil effect that a particle experiences when it emits a photon [1]. Quantum diffusion due to the synchrotron radiation in high-energy electron and positron circular accelerators defines the main parameters of the beam: its energy spread and hence the bunch length, as well as the horizontal emittance. It is calculated as a single particle effect assuming incoherent radiation. This assumption is not valid in FELs where the radiation is coherent. In this work, we develop theory of the quantum diffusion in coherent radiation and show that it leads to the energy diffusion of the particles that is correlated between the different positions in the bunch.

MOP – Poster session

22 August 16:00 – 17:30

FEL Theory, SASE FELs, FEL Oscillators and IR-FELs, User Experiments

MOP01

Bunching evolution in drifts

Alexander Brynes (Elettra-Sincrotrone Trieste S.C.p.A.), Carlo Spezzani (Elettra-Sincrotrone Trieste S.C.p.A.), Enrico Allaria (Elettra-Sincrotrone Trieste S.C.p.A.), Eugenio Ferrari (Deutsches Elektronen-Synchrotron), Evgeny Schneidmiller (Deutsches Elektronen-Synchrotron), Filippo Sottocorona (Elettra-Sincrotrone Trieste S.C.p.A.), Giovanni De Ninno (Elettra-Sincrotrone Trieste S.C.p.A.), Giovanni Perosa (University of Trieste, Elettra Sincrotrone Trieste), Giuseppe Penco (Elettra-Sincrotrone Trieste S.C.p.A.), Luca Giannessi (Elettra Sincrotrone Trieste and Istituto Nazionale di Fisica Nucleare), Mauro Trovo (Elettra-Sincrotrone Trieste S.C.p.A.), Primoz Rebernik Ribic (Elettra-Sincrotrone Trieste S.C.p.A.), Shaukat Khan (TU Dortmund), Simone Spampinati (Elettra Sincrotrone Trieste)

The typical layout adopted in a seeded harmonic generation free-electron laser is based on radiator undulators placed immediately after the dispersive section, where the bunching is created.
With the advent of new and more complex seeding schemes, this solution cannot always be implemented and cases, where the bunched beam needs to be propagated in free space before entering the radiator, should be investigated. The evolution of the density modulation in a drift may also plays a role on long intra-undulator sections in short wavelength FELs. We report here on recent studies aimed at investigating the impact of bunching evolution in a drift space on coherent harmonic emission. Experimental results collected at the FERMI free-electron laser are compared with theoretical and numerical predictions.

MOP03

Gaussian random field generator SERVAL: a novel algorithm to simulate partially coherent undulator radiation

Andrei Trebushinin (European XFEL GmbH), gianluca geloni, Svitozar Serkez

We propose a computationally-efficient algorithm to calculate the field of partially coherent synchrotron radiation pulses from undulators. Wavefront propagation simulations play a pivotal role in designing beamline optics at new synchrotron radiation sources. However, they do not account for the stochastic behaviour of the initial radiation field, which is due to shot noise in the electron beam with finite transverse size and divergence. We present an algorithm that allows us to obtain and propagate radiation fields containing multiple transverse stochastic modes within undulator resonance. The proposed algorithm relies on a method for simulating Gaussian random fields. We initially generate the field as Gaussian white noise, and then we restrict its extent in the direct and in the reciprocal domains by using averaged radiation size and divergence. Strictly speaking, this procedure shapes the correct correlation function of the field only under the assumption of quasi-homogeneity. However, we show that the method can be applied with reasonable accuracy also outside of this assumption. We check consistency of the algorithm with the help of well-established approaches in simulating partially coherent undulator fields. Finally, the proposed method is well-suited for educational purposes.

MOP04

Quantum Statistical Properties of Plasma-Wave-Pumped Free Electron Laser in the Presence of an Axial Magnetic Field

Masoud Alimohamadi (Farhangian University)
Arezou Zarei (Shahrood University of Technology)

The operation of the quantum free-electron lasers (QFELs) with a plasma whistler wiggler and in the presence of an axial-guide magnetic field is considered. The quantum Hamiltonian of single particle has been derived in the Bambini-Renieri (BR) frame. Time dependent wave function and three constants of motion are obtained. The Raman-Nath equation (RNE) and its approximation solution have been calculated, and then the resulted solution has been employed to obtain the quantum gain, photon statistics parameter and squeezing parameter. A quantum approach has been used to get quantum statistical properties of the FEL and the photon gain formula for the small signal gain limit. The conditions for positive (bunching) and negative (antibunching) gain have been studied numerically.

MOP06

Bringing Genesis to the Cloud with Sirepo

Christopher Hall (RadiaSoft LLC), Paul Moeller (Bivio Software Inc.)
Jonathan Edelen (RadiaSoft LLC), Evan Carlin (RadiaSoft LLC), Michael Keilman (RadiaSoft LLC), Gurhar Khalsa (RadiaSoft LLC), Robert Naglar (RadiaSoft LLC), Raven O'Rouke (RadiaSoft LLC)

Genesis is widely used in the free electron laser community as a simulation tool for studying both simple and complex FEL systems. Until now, this has necessitated learning the command line interface, which can be challenging for new users. Sirepo Genesis provides an intuitive graphic interface for building Genesis simulations in the browser that can then be run using our cloud computing services. Our interface also provides the ability to export simulations for command line use, simulation post-processing with publication quality graphics and the power to share their results with the click of a button to anyone, anywhere, in the world. This poster describes our new GUI and highlights the notable features that have been developed.

MOP07

Spectrometer-based x-ray free-electron laser pulse duration measurements of chirped beams

Alberto Lutman (SLAC National Accelerator Laboratory), Aliaksei Halavanau (SLAC National Accelerator Laboratory), David Cesar (SLAC National Accelerator Laboratory), River Robles (SLAC National Accelerator Laboratory)

Lutman et al. presented a method for measuring the pulse duration of x-ray free-electron laser pulses from spectral measurements in [1]. Their analysis was based on a statistical analysis of the radiation from a bunch of discrete particles employing the Green's function of the 1D FEL equations for a monoenergetic electron beam. With this simple analysis they were able to simultaneously obtain both the resolution of the spectrometer measurements as well as the FEL pulse duration by fitting a two parameter function to the spectra. In practice, FEL linacs are often operated with an energy-chirped electron beam due to the difficulties associated with removing the chirp from RF and wakefield effects. We present a revised statistical analysis in the style of [1] employing the Green's function solution for the 1D FEL equations with a chirped beam. We then show that with a three-parameter fitting scheme, we may extract the spectrometer resolution, FEL pulse duration, and electron beam energy chirp. We test the extended method against artificial spectral measurements extracted from 1D FEL simulations, then apply it to experimentally measured spectra taken at the Linac Coherent Light Source.

[1] Lutman, A. A., et al. "Femtosecond x-ray free electron laser pulse duration measurement from spectral correlation function." Physical Review Special Topics-Accelerators and Beams 15.3 (2012): 030705.

MOP09

Origin of Echo-Enabled Harmonic Generation

Vladimir Litvinenko (Stony Brook University)

Echo-Enabled Harmonic Generation (EEHG) became a very promising and very popular technique after original publication [1]. As it commonly happens, this was the reinvention of already known technique, which was not broadly known in FEL community. EEHG vaguely reminded me of theory developed at Novosibirsk Institute of Nuclear Physics (BINP), but I was not sure that my memory is correct. Recently, BINP made their preprint available on the web and I was able to confirm that technique proposed by I.G. Idrisov and V.N. Pakin [2,3] based on the same principles as described in [1]. In this presentation I would like to briefly review this original invention and to give historic perspective to EEHG.

[1] G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)
[2] I.G. Idrisov and V.N. Pakin, "High efficiency cascade bunching using a single frequency modulation" Preprint 80-197 of Institute for Nuclear Physics, October 3, 1980, Novosibirsk, Russia (in Russian)
[3] I.G. Idrisov and V.N. Pakin, "High efficiency bunching of ultra-relativistic beams using magnetic compressors", Preprint 80-192 of Institute for Nuclear Physics, October 3, 1980, Novosibirsk, Russia (in Russian)

MOP10

Ponderomotive Prebunching for Spontaneous Superradiant and Stimulated Thomson Scattering

Brian Schaap (Technische Universiteit Eindhoven), Coen Sweers (Tu/e), Max van der Schans (TU/e), Sander Schouwenaars (TU/e), Jom Luiten (Technische Universiteit Eindhoven)

Compact sources offering high-brightness radiation in the EUV to X-ray regime are highly desired. Thomson scattering, in which an electron beam colliding with a laser pulse produces radiation, is a source of X-rays of increasing prevalence in modern labs, complementing large scale facilities like synchrotrons and X-ray free electron lasers. By imposing a density modulation on the electron beam the brilliance of a Thomson source can be enhanced by orders of magnitude via superradiant emission. However, microbunching at the beam energy relevant to Thomson sources is a challenge that has yet to be met. Here, we analytically and numerically analyze electron beam modulation via the ponderomotive force from the copropagating beat wave formed by two laser pulses at different frequencies. First, we find that energy modulation favorably scales with electron beam energy, but is limited by the interaction length imposed by the finite size of the laser pulses. Next, we quantify

the brightness of a Thomson source including a ponderomotive buncher that is optimized for superradiant emission. Last, we investigate under which conditions the spontaneous superradiant Thomson regime transitions into a stimulated Thomson (FEL-)regime, potentially allowing for even further increase of source brightness.

MOP11

VARIABLE POLARIZATION STATES IN FREE-ELECTRON LASERS*

Henry Freund (University of New Mexico)
Peter van der Slot (University of Twente)

Free-electron lasers (FELs) produce different optical polarizations including linear, elliptic and circular polarizations corresponding to the polarizations of the undulators used. X-ray FELs depend upon long undulator lines consisting of a sequence of short undulators. Linearly polarized undulators are most commonly used; hence the optical output is linearly polarized. Elliptic or circular polarizations are possible by varying the undulator orientation. Alternately, APPLE-II or Delta undulator designs produce undulating magnetic fields with arbitrary polarizations. We present a three-dimensional, time-dependent formulation that self-consistently includes two optical orientations and, therefore, treats any given sequence or combination of undulator including undulator imperfections and degradation.1 There are two principal characteristics of the formulation that underpin this capability. First, particles are tracked using the full Newton Lorentz force equations with analytic models of the undulators fields. This permits an accurate model of the interaction of the electrons with a large variety of undulator fields and orientations. Second, the electrons can couple simultaneously to two independent electromagnetic polarizations and, therefore, the optical polarization evolves self-consistently along the undulator line. We present the numerical model and give some examples using prevailing undulator configurations.

1. H.P. Freund and P.J.M. van der Slot, "Variable Polarization Control in Free-Electron Lasers," J. Phys. Commun. 5, 085011 (2021).
*This research used resources provided by the University of New Mexico Center for Advanced Research Computing, supported in part by the National Science Foundation.

MOP12

ANALYSIS OF ULTRA-SHORT BUNCHES IN FREE-ELECTRON LASERS*

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Free-electron lasers (FELs) operate at wavelengths from millimeter waves through hard x-rays. At x-ray wavelengths, FELs typically rely on self-amplified spontaneous emission SASE emission which contains multiple temporal "spikes" that limit the longitudinal coherence of the optical output; hence, alternate methods that improve on the longitudinal coherence of the SASE emission are of interest. In this paper, we consider electron bunches that are shorter than the SASE spike separation.1 In such cases, the spontaneously generated radiation consists of a single optical pulse with improved longitudinal coherence than is found in typical SASE FELs. To investigate this regime, we use two FEL simulation codes. One (MINERVA) uses the slowly-varying envelope approximation (SVEA) which breaks down for extremely short pulses. The second (PUFFIN) is a particle-in-cell (PiC) simulation code that is considered to be a more complete model of the underlying physics and which is able to simulate very short pulses. We first anchor these codes by showing that there is substantial agreement between the codes in simulation of the SPARC SASE FEL experiment at ENEA Frascati. We then compare the two codes for simulations using electron bunch lengths that are shorter than the SASE spike separation. The comparisons between the two codes for short bunch simulations elucidate the limitations of the SVEA in this regime but indicate that the SVEA can treat short bunches that are comparable to the cooperation length.

1. L.T. Campbell, H.P. Freund, J.R. Henderson, B.W.J. McNeil, P. Traczykowski, and P.J.M. van der Slot, "Analysis of Ultra-Short Bunches in Free-Electron Lasers," New. J. Phys. 22, 073031 (2020).

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MOP13
MINERVA CODE RELEASE ANNOUNCEMENT
Henry Freund (University of New Mexico), Peter van der Slot (Univerity of Twente)

MINERVA is a 3-D, time-dependent simulation code of FEL amplifiers, low-gain/high-Q and high-gain/low-Q oscillators, optical klystrons (including high-gain harmonic generation) and SASE configurations [1-7]. Oscillator simulations are done in conjunction with OPC [8]. MINERVA uses the Message Passing interface on Linux, Macintosh and Windows systems and has been successfully benchmarked against many experiments. Particle dynamics are treated using the full Lorentz force equations to track particles through the optical and magnetostatic fields. Hence, MINERVA treats both fundamental and (linear and nonlinear) harmonic generation from first principles. The optical field is a superposition of Gaussian modes using the slowly-varying envelope approximation in which the x- and y-components of the field are integrated independently, and tracks the particles and fields as they propagate along the undulator line from the start-up through linear growth and into the nonlinear regime using either 2nd or 4th order Runge-Kutta integrators. MINERVA includes 3-D descriptions of planar, helical, and elliptical undulators (including a model of an APPLE-II undulator) with the fringing fields in the entry/exit transition regions. Magnetostatic field models for quadrupoles and dipoles are also included. As such, MINERVA implicitly simulates the evolution of the polarization of the optical field through an arbitrary sequence of undulators. MINERVA and OPC can be downloaded from
MINERVA:https://gitlab.utwente.nl/tnw/ap/lpno/public-projects/MINERVA/-/releases
OPC: https://gitlab.utwente.nl/tnw/ap/lpno/public-projects/Physics-OPC/-/releases
as well as user manuals, release notes and sample scripts showing to run MINERVA/OPC.

1. H.P. Freund, P.J.M. van der Slot, D.L.A.G. Grimminck, I.D. Setya and P. Falgari, "3-D, time-dependent simulation of FELs with planar, helical, and elliptical undulators," New J. Phys. 19, 023020 (2017).
2. H.P. Freund and P.J.M. van der Slot, "Studies of a terawatt x-ray FEL," New J. Phys. 20, 073017 (2018).
3. H.P. Freund, P.J.M. van der Slot, and Yu. Shvyd'ko, "An x-ray Regenerative Amplifier FEL using diamond pinhole mirrors," New J. Phys. 21, 093028 (2019).
4. L.T. Campbell, H.P. Freund, J.R. Henderson, B.W.J. McNeil, P. Traczykowski, and P.J.M. van der Slot, "Analysis of ultra-short bunches in FELs," New. J. Phys. 22, 073031 (2020).
5. H.P. Freund and P.J.M. van der Slot, "Variable polarization control in FELs," J. Phys. Commun. 5, 085011 (2021).
6. P.J.M. van der Slot and H.P. Freund, "3-D, time-dependent analysis of high- and low-Q FEL oscillators," Appl. Sci. 11, 4978 (2021).
7. H.P. Freund, D.C. Nguyen, P.A. Sprangle, and P.J.M. van der Slot, "3-D, time-dependent simulation of a Regenerative Amplifier FEL," Phys. Rev. ST-AB 16, 010707 (2013).
8. J.G. Karssenberg, P.J.M. van der Slot, I.V. Volokhine, J.W.J. Verschuur and K.-J. Boller "Modeling paraxial wave propagation in FEL oscillators," J. Appl. Phys. 100, 093106 (2006).

MOP14
AN X-RAY REGENERATIVE AMPLIFIER FREE-ELECTRON LASER USING DIAMOND PINHOLE MIRRORS*
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X-ray free-electron lasers (FELs) rely on SASE due to the lack of seed lasers and the difficulty in obtaining mirrors. Progress in diamond crystal Bragg mirrors enables the design of x-ray FEL oscillators. Regenerative amplifiers (RAFELs) are high gain/low-Q oscillators that out-couple most of the optical power. An x-ray RAFEL based on the LCLS-II at SLAC using a six-mirror resonator out-coupling 90% or more through a pinhole in the first downstream mirror is analyzed using the MINERVA and OPC to model the optical field within the undulator and the remainder of the resonator respectively.1 Results show substantial powers at the fundamental (3.05 keV) and 3rd harmonic (9.15 keV).

1. H.P. Freund, P.J.M. van der Slot, and Yu. Shvyd'ko, "An X-Ray Regenerative Amplifier Free-Electron Laser Using Diamond Pinhole Mirrors," New J. Phys. 21, 093028 (2019).

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MOP15
Quantum state features of the FEL radiation from the occupation number statistics
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The coherence of free-electron laser (FEL) radiation has so far been accessed mainly through first and second order correlation functions. Instead, we propose to reconstruct the energy state occupation number distribution of FEL radiation, avoiding the photo-counting drawbacks with high intensities, by means of maximum likelihood techniques based on the statistics of no-click events. The theoreticla framework, numerical results and the proposed experimental set-up for the verification of our pedictoins are illustrated. Though the ultimate goal regards the FEL radiation statistical features, the interest of the proposal also resides in its applicability to any process of harmonic generation from a coherent light pulse, ushering in the study of the preservation of quantum features in general non-linear optical processes.

MOP16

Progress on the Argonne/SLAC/SPring-8 cavity-based free-electron laser project

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One promising way to increase the spectral brightness of X-ray FELs relies on an X-ray cavity to recirculate the radiation over many amplification passes in the undulator. Longitudinal coherence is built up over time, such that the steady-state X-ray output can be fully coherent. Argonne, SLAC, and SPring-8 are collaborating to test the physics and engineering involved in building such a device, with plans to install an X-ray cavity at the LCLS-II that will demonstrate the cavity performance and measure two-pass FEL gain. We have recently completed the final design of major components including the chicanes, the crystal nanopositioning stages, and a suite of minimally-invasive diagnostics. In addition to these developments, this contribution will also describe recent advances in diamond crystal procurement and machining, along with our commissioning plans for the experiment.

MOP17

An X-Ray Laser Oscillator in the Low Gain Regime

Jeong-Wan Park (Argonne National Laboratory), Kwang-Je Kim (Argonne National Laboratory), Ryan Lindberg (Argonne National Laboratory)

An X-Ray Laser Oscillator (XLO) was proposed to generate intense, coherent X-rays [1], in which an atomic gain medium is pumped by an X-ray free-electron laser (FEL). Since the gain in the proposed XLO is high, it is an alternative to an X-ray regenerative amplifier FEL [2]. We explore the feasibility of an XLO in the low-gain regime as an alternative to the X-ray FEL oscillator [3]. Since gain guiding is not operative in this case, we have developed a 3D code for simulating the XLO by adding the diffraction terms to the 1D field equations [4]. Numerical simulations using this code show that an XLO in the low gain regime is feasible with reduced requirements on the SASE pump power and/or the atomic density of the jet as compared to the high gain case.

MOP18

Signatures of misalignment in x-ray cavities of cavity-based x-ray free-electron lasers

Peng Qi (Paul Scherrer Institute), Yuri Shvyd'ko (Argonne National Laboratory)

Cavity-based x-ray free-electron lasers (CBXFEL) will allow use of optical cavity feedback to support generation of fully coherent x-rays of high brilliance and stability by electrons in undulators. CBXFEL optical cavities comprise Bragg-reflecting flat crystal mirrors, which ensure x-rays circulation on a closed orbit, and x-ray refractive lenses, which stabilize the orbit and refocus the x-rays back on the electrons in the undulator. Depending on the cavity design, there are tens of degrees of freedom of the optical elements, which can never be perfectly aligned. Here [1], we study signatures of misalignment of the optical components and of the undulator source with the purposes of understanding the effects of misalignment on x-ray beam dynamics, understanding misalignment tolerances, and developing cavity alignment procedures. Betatron oscillations of the x-ray beam trajectory are one of the characteristic signatures of cavity misalignment. The oscillation period is in the general case a non-integer number of round-trip passes of x-rays in the cavity. This period (unlike the amplitude and offset of the oscillations) is independent of the type of misalignment and is defined by cavity parameters. The studies are performed on an example of a four-crystal rectangular cavity [2] using analytical and numerical wave optics as well as ray-tracing techniques.

References:
[1]. Peng Qi and Yuri Shvyd'ko, *Phys. Rev. Accel. Beams*, **25** (2022) 050701
[2]. G. Marcus, et al., CBXFEL R&D: A Joint Argonne National Laboratory and SLAC National Laboratory Collaboration, *FEL2019, doi:10.18429/JACoW-FEL2019-TUD04*

MOP19

Status and First Commissioning of the Proof-of-Principle Experiment on a THz SASE FEL at the PITZ Facility

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Research and development of an accelerator-based THz source prototype for pump-probe experiments at the European XFEL are ongoing at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). A proof-of-principle experiment to generate THz SASE FEL radiation by using an LCLS-I undulator driven by an electron bunch from the PITZ accelerator has been prepared. The existing PITZ beamline is extended downstream into a tunnel annex. The beamline extension consists of a bunch compressor, a collimation system, an LCLS-I undulator, two beam dumps, magnets, screen stations, and other diagnostic devices. After four years of designs and construction, the first beam commissioning is expected to be done in the summer of 2022. In this contribution, the latest status of the beamline extension, the first beam commissioning experience and results will be presented and discussed.

MOP20

Optical-cavity based seeded FEL schemes toward higher repetition rate and shorter wavelengths

Georgia Paraskaki (Deutsches Elektronen-Synchrotron)

More and more high-gain SASE FELs operate at high repetition rates, either in burst or in continuous wave mode of operation, offering an unprecedented number of electron bunches per second. External seeding techniques provide high quality FEL pulses of full coherence and shot-to-shot stability but cannot keep up with MHz repetition rates of such FELs due to their dependence on the seed laser repetition rate. One attractive solution to overcome this limitation is to employ an optical cavity to store radiation that acts as a seed for the electron bunches arriving at high repetition rates. Such a scheme not only allows seeded operation at multi-MHz repetition rates but also introduces the possibility to achieve seeded radiation at shorter wavelengths, overcoming the hurdle of insufficient power availability of seed laser systems in the vacuum ultraviolet (VUV) wavelength range. Here, we present different optical-cavity-based schemes and we give an overview of their unique capabilities together with simulation results.

MOP21

Generation of X-Ray Vortex Beams in a Free-Electron Laser Oscillator

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Light with orbital angular momentum (OAM) provides new insights into a wide range of physical phenomena and has engendered advanced applications in various fields. Additionally, research interest in X-ray OAM has been rapidly increasing. Here, we report a straightforward method capable of generating intense OAM beams from an X-ray free-electron laser oscillator (XFELO). This method leverages Bragg mirrors and longitudinal-transverse mode coupling to enable mode selection in a conventional XFELO configuration, thereby natively producing fully coherent hard X-ray beams carrying OAM. Simulation results indicate that fully coherent hard X-ray OAM beams can be generated without the need for optical mode converters. This simple approach can significantly advance the creation of X-ray OAM while stimulating the development of novel experimental

MOP22

Simulation studies for the ASPECT project at European XFEL

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Intense attosecond pulses generated by x-ray free-electron lasers (XFEL) are promising for attosecond science, for example, to study the quantum mechanical motion of electrons in molecules. This paper presents numerical simulations of the generation of attosecond soft and hard x-ray FEL pulses with the chirp-taper and Enhanced SASE schemes, based on the parameters of the European XFEL. To overcome the coherence time barrier, a modification of the chirp-taper scheme [1] is used in the case of soft x-rays. The results show that several hundred attosecond pulses can be obtained at photon energies of both 700 eV and 6 keV.

MOP23

2-color Upgrade of the IR FEL at FHI Berlin

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Since coming on-line in November 2013, the Fritz-Haber-Institut (FHI) der Max-Planck-Gesellschaft (MPG) Free-Electron Laser (FEL) has provided intense, tunable infrared radiation to FHI user groups. It has enabled experiments in diverse fields ranging from bio-molecular spectroscopy to studies of clusters and nanoparticles, nonlinear solid-state spectroscopy, and surface science, resulting in 85 peer-reviewed publications so far. A significant upgrade of the FHI FEL is now nearing completion. A second short Rayleigh range undulator FEL beamline has been added that will permit lasing from < 5 microns to > 160 microns in the far IR. Additionally, a 500 MHz kicker cavity has been installed. It will permit simultaneous two-color operation of the FEL from both FEL beamlines over an optical range of 5 to 50 microns by deflecting alternate 1 GHz pulses into each of the two undulators. We will describe the upgraded FHI FEL physics and engineering design and present the current status of commissioning.

MOP24

Optimization of waveguide and wire-grid-polarizer for waveguide-based optical resonator of compact THz FEL

Varun Pathania (Korea Atomic Energy Research Institute)
Sangyoon Bae (Korea Atomic Energy Research Institute), Jang Kyu-Ha (Korea Atomic Energy Research Institute), Kitae Lee (Korea Atomic Energy Research Institute), Young Uk Jeong (Korea Atomic Energy Research Institute)

At KAERI we are developing compact Terahertz(THz) Free Electron Laser(FEL) for a commercial application like security inspection. We are using a waveguide-based optical resonator for our FEL system. Firstly, we report on the selection of low loss and small cross-section waveguide candidate to enhance the gain of THz FEL. We performed a detailed analysis of waveguides with different shapes and size via COMSOL Multiphysics simulation. Based on the simulation result, we found that a waveguide with a special eye-shaped cross-section has a very small cross-sectional area of 4 mm^2 at full width at half maximum (FWHM) and a very low wave loss of less than 2.5% for 1-m propagation at an operating wavelength of 300–600 μm. Secondly, we accomplished the optimization of the Wire-Grid-Polarizer (WGP) design parameter via COMSOL Multiphysics code, we calculated the optimized values of grating length and grating period of the WGP i.e., 20 μm and 100 μm, which have less than 10% of loss for the wavelength of 300–600 μm. The material which we used for WGP simulation is Tungsten coated with gold because it has a high extinction ratio and transmission as compared with common grating material.

MOP25

Origin of the complex beam profile of a hole-coupled free electron laser oscillator

Heishun Zen (Kyoto University)
Hideaki Ohgaki (Kyoto University)

Infrared FEL oscillators generally use hole-coupling to extract intracavity laser power. The hole-coupling inherently causes a non-Gaussian beam profile at user stations, which are more than 10 m apart from the coupling hole. It is due to the existence of the Airy pattern in the extracted laser beam. We demonstrated that the beam profile can be changed from a non-Gaussian to a nearly Gaussian distribution by removing the Airy pattern in the experiments and physical optics calculations [1]. This work was supported by MEXT Q-LEAP (JPMXS0118070271).

MOP26

Protected mirrors enabling storage ring FEL lasing below 170 nm

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In a storage ring free-electron laser (FEL) the cavity mirrors have to resist the harsh operational conditions due to high-energetic and background radiation in an ultra-high vacuum environment. For the wavelength between 120 and 190 nm only fluoride materials are suitable as coating material for high reflective mirrors. However, used in the bare form, they are not stable for extreme FEL operation conditions. Until this work, it was not possible to achieve the lasing below 176 nm with an oscillator FEL. The collaboration between DUKE University/TUNL and Laser Zentrum Hannover e.V. has recently demonstrated the storage-ring FEL lasing between 169.6 and 176.7 nm. For this work, different coating techniques such as ion beam sputtering, thermal evaporation, and atomic layer deposition were employed to produce samples of a single-layer, multilayers, and a version with a protection layer. All samples were irradiated using Duke FEL undulators and characterized with VUV spectrometry from 140 to 230 nm. We have found that the SiO_2-protected fluoride coatings have good thermal stability and radiation resistance. Several sets of mirrors have been coated and used to demonstrate the FEL lasing in a new VUV range with a reasonable lifetime. These mirrors have also been used to generate 120 MeV gamma rays via Compton scattering. The newly developed coating strategies are expected to enable the storage-ring FEL to operate in even shorter wavelengths.

MOP27

Unaveraged simulation of superradiance in FEL oscillators

Ryoichi Hajima (National Institutes for Quantum and Radiological Science and Technology)

Generation of few-cycle FEL pulses with a high extraction efficiency was achieved at JAERI-FEL [1] and KU-FEL [2]. The observed lasing can be understood as superradiance, radiation from bunched electrons in the slippage region. In the superradiance FEL oscillators, the high-extraction efficiency is accompanied by significant energy variation of the electrons during the undulator. Therefore, numerical studies of such FELs should be conducted by unaveraged simulation codes, in which macro-particles are not bound to bunch slices. In this paper, superradiant FEL pulse evolution in the FEL oscillators is studied by using one-dimensional [3] and three-dimensional [4] simulation codes.
This work was supported by MEXT Q-LEAP (JPMXS0118070271) and JSPS KAKENHI (22H03881).

MOP28

Laser-induced gas breakdown at KU-FEL

Heishun Zen (Kyoto University), Ryoichi Hajima (National Institutes for Quantum and Radiological Science and Technology), Hideaki Ohgaki (Kyoto University)

Laser-induced breakdown has been observed in various combination of gases and lasers. It is known from previous studies that breakdown occurs when the number of electrons exceeds a threshold value through the following stages: generation of seed electrons, acceleration of electrons by inverse Bremsstrahlung, and avalanche multiplication of electrons by impact ionization. We have observed laser-induced breakdown of gases at KU-FEL, the FEL oscillator at Kyoto University. In the thermionic cathode mode (2856 MHz repetition rate, 10 um), breakdown was observed in air, nitrogen, and argon, while no discharge was observed in the photocathode mode operation (29.75 MHz, 9 um). The difference in the two operation modes can be explained by the diffusion of electrons between the micropulses.
This work was supported by MEXT Q-LEAP (JPMXS0118070271), IAE ZE Research Program (ZE2022B-23) and JSPS KAKENHI (22H03881).

MOP29

A High-Performance Hybrid Incoherent and Coherent Photon Source at Jefferson Lab

Yuhong Zhang (Thomas Jefferson National Accelerator Facility)

Jefferson Lab is exploring opportunities for an advanced photon source utilizing its existing 12 GeV recirculating SRF linear accelerator. One concept currently under study is a ring-based source supporting both incoherent synchrotron radiation beamlines and multiple XFELs. The XFELs are based on the XFELO concept which utilizes high-reflectivity Bragg crystal type optical cavities [1]. The envisioned facility could potentially deliver superior performance, similar to the capabilities of the Argonne National Lab Advanced Photon Source Upgrade for incoherent radiation, and delivering higher brightness and coherence than SASE-type XFEL facilities for coherent radiation. In addition, the facility will be able to support a large diversified user base. In this paper we present the design concept, facility schematic layout and estimated performance of this photon source, and briefly discuss accelerator physics issues that arise from the design.
[1] "Tunable optical cavity for an x-ray free-electron-laser oscillator", Kwang-Je Kim and Yuri V. Shvyd'ko, PRAB 12, 030703 (2009)

MOP31

Analysis Supporting the 2-Color Upgrade to the IR FEL at FHI Berlin

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This paper provides a summary of the analysis that led to the definition of the 2-color upgrade of the IR FEL at FHI Berlin. We briefly cover several different aspects of the design, beginning with the beam dynamics of the second far-IR beamline, engineering considerations of that physics design, and the FEL physics that defined the short-Rayleigh range undulator as well as aspects of the undulator design itself. Additionally, we touch on the approach to 2-color commissioning with pulse picking, as well as considerations for the far-IR optical transport to users. The status of commissioning is described in a parallel paper at this Conference by W. Schöllkopf et al.

MOP32

Modelling of sub-wavelength effects in a FEL oscillator

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Brian McNeil (University of Strathclyde)

Previous studies of FEL oscillators typically use averaged simulation codes which cannot model sub-wavelength effects, such as Coherent Spontaneous Emission from the electron pulse. In this paper, the unaveraged FEL simulation code Puffin is used with the optics code Optical Propagation Code to model the FEL in three dimensions, enabling sub-wavelength effects to be modelled at the FEL interaction and cavity length scales. The parameters used are very similar to those of the IR-FEL of [1]. Results show that CSE does drive the FEL interaction during the start-up phase in the cavity. Further, cavity detuning effects at the sub-wavelength scale can have an effect upon the FEL output from start-up through to the steady state output. While the effects are demonstrated here at the fundamental level, it can be expected that they may be reduced due to limitations such as electron beam and/or cavity length jitter at the wavelength scale. Such effects will need to be further investigated.

MOP33

Report on the FELIX wavelength range extension

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The FELIX Laboratory, located at Radboud University in Nijmegen, The Netherlands, is operating a suite of FELs serving an international user community with infrared and THz radiation from 5 to 1500 micron operating three FELs in parallel and providing beam to 16 dedicated user end stations. Recently, FELIX has upgraded its most frequently used FEL-2 beamline. The 38 period, 65 mm Halbach-type SmCo undulator, originally built for the UK-FEL project in the mid 80's, which had been successfully used for the short-wavelength FEL for almost 30 years, was replaced by a new undulator. This 50 period, 40 mm NdFeB hybrid undulator was built in close collaboration with STI magnetics and the FEL group of FHI/MPG in Berlin. Together with a new resonator cavity it allows an extension of the fundamental range from 5 μm to sub-3 μm, while keeping the desirable good spectral overlap with the longer wavelength FEL-1 branch. The upgraded FEL-2 beam line produced first light at the end of April 2022 and commenced serving regular user experiments in early May. Initial results concerning gain, tuning and stability which are quite satisfactory will be presented together with first user applications.

MOP34

Lasing Performance of the European XFEL

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The European XFEL operates with 3 different SASE FELs served by variable gap undulators. In addition, the electron energy of the superconducting linear accelerator is varied between 8.5 and 16.5 GeV to cover a photon energy range from 500 eV to 30 keV. We will present SASE performance data collected over the past 5 years of operation and compare them with theoretical predictions.

MOP36

Flexible operation modes for EuXFEL

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A major challenge in single-linac - multiple undulator setups like EuXFEL is the generation of individual shaped photon pulses, in particular, when working in a mode where a single pulse train, or cw stream, feeds all undulator lines. This work presents the experimental verification of a flexible delivery scheme producing photon pulses for each of the three undulator lines with their electron bunches individually shaped in charge, compression and optics on a single RF pulse burst.

MOP37

Status of the Free-Electron Laser User Facility FLASH

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FLASH, the free-electron laser user facility at DESY, delivers XUV and soft X-ray radiation for photon experiments since 2005. It is driven by a superconducting linear accelerator, and has two undulator lines (FLASH1 and FLASH2). A third electron beam line hosts the plasma wakefield experiment FLASHForward. Presently, the FLASH facility is undergoing an extensive refurbishment and a substantial upgrade (FLASH2020+). In this paper we summarize the FLASH operation in 2019 - 2021, and report on the main upgrades realized in a long installation shutdown from November 2021 to summer 2022.

MOP38

Corrugated structure system for fresh-slice applications at the European XFEL

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Fresh-slice lasing using wakefield induced time-dependent orbit oscillation is capable of producing high intensity two-color XFEL pulses and high power short pulses at femtosecond level. At the European XFEL, a corrugated structure system for fresh-slice applications for both the hard x-ray beamline SASE1 and the soft x-ray SASE3 beamline is being developed and implemented. In this contribution, we present the novel design of the corrugated structure and the application to advanced lasing schemes.

MOP39

An attosecond scheme overcoming coherence time barrier in SASE FELs

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In Self-Amplified Spontaneous Emission Free Electron Laser (SASE FEL) based short-pulse schemes, pulse duration is limited by FEL coherence time. For hard X-ray FELs, coherence time is in a few hundred attosecond range while for XUV and soft X-ray FELs it is in the femtosecond regime. In this paper the modification of so-called chirp-taper scheme is developed that allows to overcome the coherence time barrier. Numerical simulations for XUV and soft X-ray FEL user facility FLASH demonstrate that one can generate a few hundred attosecond long pulses in the wavelength range 2 - 10 nm with peak power reaching hundreds of megawatts.

MOP40

SASE optimization approaches at FLASH

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The free-electron laser FLASH at DESY can produce SASE-FEL pulses in the extreme ultraviolet to the soft X-ray regime. A superconducting linear accelerator drives two undulator lines (FLASH1 and FLASH2). The FLASH1 undulator beam line

contains six fixed gap undulator which implies that the SASE wavelength can only be changed via the electron beam energy, while FLASH2 contains twelve variable gap undulators. Preparing different charges and compression schemes to the two parts of the bunch trains for the two undulator beamlines allows to adjust the phase space in wide range and meeting the various requirements of photon pulse trains properties. In order to improve the SASE performance reference files for standard energies and standard charges are regularly prepared. In the FLASH2 undulator beamline beam-based alignment and phase shifter scans have been applied to improve SASE operations and FEL beam quality. Improving set-up and tuning procedures allow to decrease setup times and optimize performance and stability. Procedures and optimization of FEL parameters towards a reliable SASE-FEL operation as well as the achieved results are discussed.

MOP41

A combination of harmonic lasing self-seeded FEL with two-color lasing

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The free-electron laser FLASH at DESY can produce SASE-FEL pulses in the extreme ultraviolet to the soft X-ray region. The flexibility of the variable gap undulators in the FLASH2 beamline opens a wide range of scientific opportunities. Different advanced lasing schemes have been tested in the past years, like the ``frequency doubler`` scheme, two-color lasing, and ``harmonic lasing self-seeded FEL (HLSS)``. A recent user experiment required parameters not yet provided: a similar power in the fundamental and the third harmonic. To fulfill these requirements, a new way of lasing had to be developed ad hoc. A combination of HLSS and two-color lasing has been identified as the appropriated scheme to deliver a tailored two-color beam to the user experiment. In this article we describe difficulties of the setup and discuss the results achieved.

MOP42

Status of FAST-XPD: Photon data base for the European XFEL

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XPD project - Photon data base for the European XFEL is a joint effort of DESY and European XFEL [1-2]. The project has been launched in 2009, and is in use by users since 2012. The goal of the XPD project is to provide users with full temporal, spatial, and spectral patterns of the radiation fields for different regimes of the European XFEL operation. Tracing of these fields with advanced user simulation tools from the source (undulator) via photon beam line (mirrors, gratings, etc) with subsequent simulation of user experiment (interaction with a sample, simulation of physical processes, simulation of detection process of related debris like photons, electrons, and ions) is of key importance for planning future user experiments [3-5]. XPD photon data base is produced in a chain of massive simulations with numerical simulation codes. Electron beam parameters at the undulator entrance are based on the results of start to end numerical simulations of the electron beam [6]. FEL amplification process is simulated with tree dimensional, time dependent simulation code FAST [7]. FEL simulation code predicts all the details of the output radiation pulses from x-ray FEL (3D maps of radiation fields for the fundamental and higher frequency harmonics) with a high degree of reliability. Full maps of the radiation fields are stored in the mass storage service dCache (disc cache system) at DESY. A web application (https://in.xfel.eu/fastxpd) allows to pick up a selected photon pulse data in the HDF5 format for any given XFEL operation mode (electron energy, charge/photon pulse duration, active undulator range etc) suitable for statistical analysis, propagating through the optical system, interaction with the sample, etc. The pulses post processing data, including the gain curve, time structure, source size and far field angular divergence are also provided as data sets in HDF5 file for the pulse.

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MOP43

Temporal and spatial coherence properties of the odd harmonics of the radiation from X-ray free electron laser with planar undulator

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We present analysis of coherence properties (both, temporal and spatial) of the odd harmonics radiated from a SASE FEL with planar undulator. Nonlinear mechanism of harmonic generation is under study. Temporal and space correlation functions, coherence time and degree of transverse coherence are calculated by means of numerical simulations with the code FAST [1]. Similarity techniques have been used to derive general coherence properties of the radiation from optimized x-ray FEL. We consider free electron laser (FEL) amplifier - device in which electron bunch amplifies electromagnetic radiation during single pass of an undulator. The FEL collective instability in the electron beam produces an exponential growth (along the undulator) of the radiation and the modulation of the electron density on the scale of undulator resonance radiation wavelength. Amplification process in a Self Amplified Spontaneous Emission (SASE) FEL starts from the shot noise in the electron beam. When the electron beam enters the undulator, the presence of the beam modulation at frequencies close to the resonance frequency initiates the process of radiation. The fluctuations of current density in the electron beam are uncorrelated not only in time but in space, too. Large number of transverse modes is excited, but the fundamental TEM00 mode with the highest gain dominates when the undulator length progresses. Coherence time and degree of transverse coherence grow in the exponential amplification stage, and reach maximum values near the saturation point. Saturation length is limited from nine to eleven field gain length for VUV and x-ray FELs which fundamentally define coherence properties of the radiation. Poor longitudinal coherence also affects transverse coherence. Radiation from SASE FEL with planar undulator contains visible contribution of the odd harmonics. Comprehensive studies of nonlinear harmonic generation have been performed in [2] in the framework of the one-dimensional model. General features of harmonic radiation have been determined. It was found that coherence time at saturation falls inversely proportional to harmonic number, and relative spectrum bandwidth remains constant with harmonic number. In this paper we extend studies of higher harmonics taking into account diffraction effects. We consider parameter range when intensity of higher harmonics is mainly defined by nonlinear harmonics generation mechanism. The results have been obtained with time-dependent, three-dimensional FEL simulation code FAST performing simulation of the FEL process with actual number of electrons in the beam. Using similarity techniques we present universal dependencies for the main characteristics of the SASE FEL covering all practical range of optimized X-ray FELs [3]. Present studies cover results for the 1st, 3rd, and 5th harmonic.

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MOP44

Analysis of temporal and spatial coherence of the radiation at FLASH FEL beamlines

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Radiation amplification process in a SASE FEL develops from the shot noise in the electron beam. Random wavepackets (spikes) are formed and evolve in the amplification process. Interaction of electromagnetic radiation and electrons is strong in the exponential gain regime which results in gradual increase along the undulator of the coherence time and corresponding decrease of the spectrum width. This feature scales as square root of the undulator length. Transverse coherence is formed by two essentially different physical mechanisms. In the exponential gain regime transverse coherence is improved due to the radiation mode selection process such that fundamental symmetric TEM¬¬00 mode takes advantage over higher radiation modes. Transverse mode selection process develops exponentially along the undulator length, and one can expect nearly full transverse coherence for diffraction limited electron beams. However, this does not happen because of the radiation slippage effect. Radiation in each slice is superposition of the radiation fields emitted from retarded points with different phasing of the emitters (electron beam bunching). As a result, we always deal with this noise effect, and after completing mode selection process the degree of transverse coherence still slowly approach to unity, just as square root of the undulator length. When amplification process enters nonlinear stage, we occur significant degradation of the coherence properties (both, longitudinal and transverse) which happens due to reduction of coupling strength between radiation and electrons and corresponding increase of the slippage effects. With practical parameters of modern SASE FELs maximum value for the degree of transverse coherence is up to 0.94 for diffraction limited beams, and falls down with the growth of the diffraction parameter [1]. In our early studies we analyzed coherence properties of the radiation from FLASH beamlines [2]. It has been pointed out that expected maximum value of the degree of thransverse coherence at FLASH1 is of about 0.8, and it is only a bit higher at FLASH2. Here we extend our analysis for the popular practical case of FLASH operation with the number of radiation modes in the range M ~ 4 ... 8. Typically this regime is tuned with 100 – 150 pC bunch charge. Standard tuning procedure (for maximum pulse energy at full undulator length) results in visible energy chirp along the electron bunch such that spectrum bandwidth is increased to about 1% fwhm, visibly wider than natural FEL bandwidth. These features were taken in the current consideration.
Simulation results with numerical simulation code FAST [3] are illustrated for the radiation wavelength 18 nm, 13.5 nm and 8

nm. As it was predicted earlier, maximum value for the degree of transverse coherence at FLASH1 is in the range of 0.8, and it is a bit better for the case of FLASH2. Actual value is dependent on the stage of amplification process, and can be visibly lower in the deep post saturation regime. Several experiments on measurements of the degree of transverse coherence have been performed at FLASH1 and FLASH2 so far, and we believe that the results presented here will be useful for analysis of experimental data. From our side we compare simulation results with coherence characteristics measured with statistical methods [4-6], and find good agreement.
We put raw simulation data (radiation fields) in the X-ray Photon Data Base XPD data base [7] which contains simulation parameters for the European XFEL and FLASH and is accessible worldwide (https://in.xfel.eu/fastxpd). These data can be used by potential users for simulation of experiments relying on coherence properties and numerical analysis of experimental data.

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MOP45

SASE-FEL stochastic spectroscopy investigation on XUV absorption and emission dynamics in silicon

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High-resolution emission/absorption spectroscopy with picosecond time resolution appears to be strategic in fundamental matter physics investigation as well as in functional materials characterization. Such a method typically requires a pulsed radiation source and high energy resolution, along with a large data statistic. In this work we demonstrate the possibility to retrieve high resolution absorption and emission spectra with picosecond time resolution, by exploiting the stochastic nature of the wide-band self-amplified FEL radiation provided by FERMI. In this work we get advantage of the two spectrometers present on the TIMEX beamline to reconstruct a 2D emission/absorption spectrum of a Si sample. To do so, we applied the singular value decomposition on the single-pulse incoming and outgoing spectra; by applying Tikhonov regularization, we were able to obtain spectra with an energy resolution of few tens of meV. In addition, we performed a time resolved characterization of the Si L23-edge and Si emission line at 99.3 eV by pumping the Si sample with visible laser below damage threshold. The result of this measurement allow us to claim for a bond softening phenomenon on the picosecond time-scale.

MOP46

FEL performance of the EuPRAXIA@SPARC LAB AQUA beamline

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The AQUA beamline of the EuPRAXIA@SPARC_LAB infrastructure consists of a Free-Electron Laser facility driven by an electron beam with 1 GeV energy, produced by an X-band normal conducting LINAC followed by a plasma wakefield acceleration stage, with the goal to deliver variable polarization photons in the 3-4 nm wavelength range. Two undulator options were considered for the AQUA FEL amplifier, a 16 mm period length superconducting undulator and an APPLE-X variable polarization permanent magnet undulator with 18 mm period length. The amplifier is composed by an array of ten undulator sections 2m each. Performance associated to the electron beam parameters and to the undulator technology is investigated and discussed.

MOP47

Simulation Studies of Superconducting Afterburner Operation at SASE2 Beamline of European XFEL

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European XFEL is a multi-beamline x-ray free-electron laser (FEL) user facility driven by a superconducting accelerator with a nominal photon energy range from 250 eV to 25 keV. An afterburner undulator based on superconducting undulator technology is currently being planned to enable extension of the photon energy range towards harder x-rays. This afterburner undulator would be installed downstream of the already operating SASE2 FEL beamline, emitting at the fundamental or at a harmonic of the upstream SASE2 undulator. In this contribution we describe the potential photon output based on numerical simulations.

MOP49

The Sabina Terahertz/Infrared FEL at SPARC-Lab Facility

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SABINA, the acronym for "Source of Advanced Beam Imaging for Novel Applications ", will be a self-amplified spontaneous emission Free Electron Laser (SASE FEL) providing a wide spectral range (from THZ to MIR) of intense, short, and variable polarization pulses for investigation in physics, chemistry, biology, cultural heritage, and material science. In order to reach these goals high brightness electron beams within a 30-100 MeV energy range, produced at SPARC photo-injector, will be transported up to an APPLE- X undulator through a dogleg. Space charge effects and Coherent Synchrotron Radiation (CSR) effects must be held under control to preserve beam quality. Studies on beam transport along the undulator and of the properties of the radiation field have been performed with "Genesis 1.3" simulation code. A downstream optical setup will propagate the THz beam from the SPARC-Lab to a new user lab facility nearly 25 m far away from the SPARC laboratory. The beamline, open to user experiments, will be equipped with a 5 T magnetic cryostat and will be synchronized with a fs laser for THz/IR pump, VIS/UV probe experiments.

MOP50

Proposed FEL schemes and their performance for the Soft X-ray Free Electron Laser (SXL) at the MAX IV Laboratory

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The existing MAX IV 3 GeV linac could drive, with minor improvements, a soft X-ray Free Electron Laser and the aim of the SXL project has been so far to deliver a conceptual design of such a facility in the 1—5 nm wavelength range. The project was initiated by a group of Swedish users of FEL radiation and the design work was supported by the Knut and Alice Wallenberg foundation and by several Swedish universities and organizations (Stockholm, Uppsala, KTH Royal Institute of Technology,

Stockholm-Uppsala FEL center, MAX IV laboratory and Lund University). In this paper we will focus on the baseline FEL performance based on two different accelerator operation modes (medium and short pulses) and give some hints of future developments after the first phase of the project such as 2 color/2pulses and HB-SASE.

MOP51

Short FEL pulses with tunable duration down to sub-fs from transversely tilted beams at SwissFEL

Adrian Rutschmann (ETH Zurich), Alexander Malyzhenkov (Los Alamos National Laboratory), Philipp Dijkstal (Paul Scherrer Institut), Eduard Prat (PSI), Sven Reiche (PSI)

FEL pulses with an easily tunable duration are of great benefit to user experiments with high requirements on the temporal resolution. A linear beam tilt is well suited to shorten the pulse duration in a controlled manner. We consider two methods of tilt generation: leaked dispersion in combination with an energy chirp, and transverse wakefields. This contribution shows simulations and measurements from the hard X-ray beamline Aramis at SwissFEL. We use three methods of photon diagnostics: monochromator scans for a strongly energy-chirped beam, spectral analysis, and power profile measurements with a passive wakefield streaker. The shortest measured pulse durations are sub-femtosecond.

MOP52

Demonstration of Large Bandwidth Mode with a Spatially Tilted Beam at SwissFEL

Camila Bacellar Cases da Silveira (Paul Scherrer Institute), Sven Reiche (Paul Scherrer Institut), Eduard Prat (Paul Scherrer Institut), Eugenio Ferrari (DESY), Pavle Juranic (Paul Scherrer Institut), Philipp Dijkstal (Paul Scherrer Institut)

X-ray absorption spectroscopy (XAS) with a SASE signal can be improved if the full XAS and reference spectrum are taken on a shot-to-shot basis, thus eliminating the impact of the intrinsic SASE fluctuations in the spectrum. This can be further improved if the FEL pulse has the frequency information encoded in its spatial position. The spatial encoding is achieved when a spatially tilted electron beam with a strong energy chirp is injected into a focusing-free undulator channel. We report on the demonstration of this mode at the hard X-ray beamline Aramis at SwissFEL. Possible applications and an outlook for further studies are discussed.

MOP53

Two-color FEL by laser emittance spoiler

Alberto Lutman (SLAC National Accelerator Laboratory), Alexandre Trisorio (PSI), Andreas Dax, Carlo Vicario (Paul Scherrer Institut), Christopher Arrell (Paul Scherrer Institut), Eduard Prat (PSI), Martin Huppert (PSI), Philipp Dijkstal (Paul Scherrer Institut), Simona Bettoni (Paul Scherrer Institut), Sven Reiche (PSI)

A novel and noninvasive method for two-color x-ray emission is demonstrated at SwissFEL. In the setup, a laser emittance spoiler pulse is overlapped with the primary photocathode laser to locally spoil the beam emittance and the FEL emission. This results, together with a chirped electron pulse, in X-ray emission at two colors. High-energy, high stability, independent control of the duration and of the intensity of the two colors is demonstrated. The laser emittance spoiler enables shot-to-shot selection between one and two-color FEL emission and further, it is compatible with high repetition-rate FELs, as it does not contribute to beam losses.

MOP54

First study of fresh-slice multi-stage amplification at SwissFEL

Guanglei Wang (Paul Scherrer Institut)
Philipp Dijkstal (Paul Scherrer Institut), Alexander Malyzhenkov (Paul Scherrer Institut), Eugenio Ferrari (DESY), Sven Reiche (Paul Scherrer Institut), Kirsten Schnorr (PSI), Eduard Prat (Paul Scherrer Institut)

We report on the first demonstration of generating high-power and short FEL pulses using the fresh-slice multi-stage amplification scheme at Athos, the soft X-ray beamline of SwissFEL. We use a transversely tilted electron beam traveling through the unique Athos layout with magnetic chicanes between every two undulator modules. Our first results show the production of FEL radiation with pulse energies of few hundreds microjoules and pulse durations at the femtosecond level. This operation mode will allow us to advance the scientific opportunities of single-particle imaging experiments.

MOP55

Numerical study on the production of a train of attosecond pulses in a Free-electron-laser by utilizing delaying chicanes between undulator modules and a linear taper within modules

Longdi Zhu (Paul Scherrer Institut)
Eugenio Ferrari, Sven Reiche (PSI)

The slippage limits the performance of ESASE or slicing at a constant K parameter inside an undulator, particularly at soft X-ray FEL wavelengths. In this contribution, we investigate two improvements. First, the use of inter-undulator delaying chicanes in order to compensate for the accumulated slippage in the previous undulator module. Second, the potential to set a linear taper within the Apple-X undulator module. In our approach, the linear taper profile is provided by rotating each undulator module in a transverse gradient undulator (TGU) configuration at a small angle and projecting the gradient in the longitudinal direction. Based on the parameters of the soft X-ray FEL beamline Athos at SwissFEL, we show that even for long FEL wavelengths a train of attosecond pulses can be generated.

MOP56

Improvement of XFEL Brightness at PAL-XFEL

Heung-Sik Kang (Pohang Accelerator Laboratory), Teyoun Kang (Pohang Accelerator Laboratory)

We (PAL-XFEL) have improved the PAL-XFEL performances remarkably since the user-service operation in 2017. We achieved the self-seeded XFEL with a peak brightness of 3.2×10^35, the highest to date, and reached a SASE FEL intensity of 3.2 mJ due to the improved beam emittance of 0.3 mm-mrad. The statistics of the SASE FEL intensities over the past three years show that the SASE FEL performance is critically dependent on the injector emittance.

MOP57

Low-emittance beam injection from SACLA to SPring-8

Toru Hara (RIKEN SPring-8 Center)
on behalf of RIKEN and JASRI project team

The SACLA linear accelerator has been successfully used as a full-energy injector of the SPring-8 storage ring since 2020. In order to perform the beam injection in parallel with XFEL operation, three accelerators are virtually constructed in a control system. Thus the electron beam parameters, such as the beam energy, are independently tuned for the beam injection and the two XFEL beamlines. By shutting down dedicated old injector accelerators, the electricity consumption has been reduced by roughly 20-30 % and its maintenance cost is no more necessary. SACLA will also provide the electron beam for the future SPring-8-II, which requires low-emittance beams for injection due to its small beam aperture. In this presentation, we summarize the beam injection scheme developed at SACLA including observed emittance increase at a beam transport caused by quantum excitation of synchrotron radiation, a synchronization system between the two accelerators, and a purification method of the electron bunch in the storage ring.

MOP58

Second order moments and beam transfer matrix for photon beams

David Cesar (SLAC National Accelerator Laboratory)

We present a simple approach to modeling a SASE photon beam by calculating moments of the Wigner distribution (xx, xx', x'x') directly from the electric field on a slice-by-slice basis. These moments can then be transported by a transfer matrix, in direct analogy to the propagation of the second moments of an electron beam. This close analogy allows us to easily see how mismatch within the electron beam can imprint itself on the photon beam. We use start-to-end simulations at LCLS as a case study to show how CSR induced transverse-longitudinal coupling of the electron bunch appears as an increase in the photon beam etendue (emittance).

MOP59

Suppression of 3rd harmonic lasing at the LCLS soft X-ray beamline

Isleydys Silva Torrecilla (SLAC National Accelerator Laboratory), Timothy Maxwell (SLAC National Accelerator Laboratory), Yuantao Ding (SLAC National Accelerator Laboratory), Zhen Zhang (SLAC National Accelerator Laboratory)

Several studies have been done about enhancing nonlinear third harmonic lasing in free-electron laser sources, however, for certain user experiments the background from third harmonic light is undesirable. Third harmonic backgrounds for soft x-ray FELs are especially harmful in experiments where attenuation is needed to suppress undesired visible light or to reduce intensity at the fundamental wavelength, where contaminating third harmonic transmission remains high. Examples are measurements of the X-ray wavefront, and when trying to observe nonlinear phenomena with small cross-sections such as the two-photon ionization process. SASE FELs show a strong nonlinear harmonics generation near the saturation point of

the fundamental power. This higher harmonic radiation is especially sensitive to three-dimensional effects like increased energy spread and beam emittance values. In this study, we have attempted to suppress the 3rd harmonic bunching on the soft X-ray line at the Linac Coherent Light Source with the use of three alternative methods; increasing the energy spread of the electron beam while heating up the beam with a laser heater, increasing the effective beam emittance by varying the magnetic field in the injector solenoid, and by manipulating the ponderomotive phase between the electron beam and the fundamental radiation. We have experimentally demonstrated a suppression of the 3rd harmonic power in all three scenarios. The experimental results are compared with expected values from a Genesis simulation.

MOP60

Smart*Light: A tunable Inverse Compton Scattering (ICS) X-ray source for Imaging and Analysis

Brian Schaap (Technische Universiteit Eindhoven), Jom Luiten (Technische Universiteit Eindhoven), Peter Mutsaers (Technische Universiteit Eindhoven), Tim de Raadt (Technische Universiteit Eindhoven)

A tunable, tabletop, Inverse Compton Scattering (ICS) hard X-ray source is being designed and built at Eindhoven University of Technology as part of a European Interreg program between The Netherlands and Belgium. This compact X-ray source will bridge the gap between conventional lab sources and synchrotrons: The X-ray photon energy will be generated between 1 and 100 keV with a brilliance typically a few orders of magnitude above the best available lab sources. Smart*Light will find applications in material science, cultural heritage and medical imaging.
In the ICS process photons from a laser pulse bounce off a relativistic electron bunch, turning them into X-ray photons through the relativistic Doppler effect. In the first phase Smart*Light will use a 100 kV DC photogun as electron source and compact X-band linear accelerator technology developed by the CLIC program from CERN to accelerate the electrons further to an energy of 30 MeV. A 12 mJ, 800 nm, 100 fs laser pulse will be focused to a 5 spot and interact with the electron pulse that will be also focused to a spot of about 5 m resulting in an X-ray photon flux of 105 photons per pulse at 1 kHz rep rate, in 1% bandwidth, with an energy up to 40 keV. The setup is currently under construction. First light is expected in 2022.

MOP61

Nonlinear spectroscopy at the THz-beamline TeraFERMI

Johannes Schmidt (Elettra-Sincrotrone Trieste S.C.p.A.)
Andrea Perucchi (Elettra-Sincrotrone Trieste S.C.p.A.), Paola Di Pietro (Elettra-Sincrotrone Trieste S.C.p.A.)

TeraFERMI is a THz beamline at the free-electron laser (FEL) FERMI. After passing the FEL's undulator, the electron bunches are refocused on a thin dielectric slab and generate coherent transition radiation (CTR), namely strong THz pulses. TeraFERMI provides single-cycle pulses with a broadband spectrum in the range from 0.1 THz to 6 THz and strong peak electric fields with up to 4 MV/cm or peak magnetic fields of up to 1 T well-suited for nonlinear experiments driving systems out of equilibrium. The low repetition rate of 50 Hz allows the systems under study to fully relax to their equilibrium state between consecutive pulses, thereby avoiding unwanted thermal effects, a feature which is particularly requested in interdisciplinary experiments in biophysics or chemical physics. A particular property of the THz radiation (CTR-sources) is the radial polarization, which allows for studies with longitudinal spectroscopy exploiting an electric field polarization parallel to the propagation direction of focused beams. Furthermore, all time-resolved experiments benefit from the excellent synchronization between THz-pulses and a local near-infrared laser with a low timing jitter of 66 fs. In this contribution we report about the latest progress at TeraFERMI including a recently implemented diagnostic station as well as experimental setups we provide at TeraFERMI.

MOP62

Terahertz tuning of Dirac plasmons in Bi_2Se_3 topological insulator

Paola Di Pietro (Elettra-Sincrotrone Trieste S.C.p.A.)
Alessandra Di Gaspare (Istituto Nanoscienze-CNR, Laboratorio NEST), Andrea Perucchi (Elettra-Sincrotrone Trieste S.C.p.A.), Federica Piccirilli (Elettra-Sincrotrone Trieste S.C.p.A.), Nidhi Adhlakha (Elettra-Sincrotrone Trieste S.C.p.A.), Stefano Lupi (Sapienza University of Rome)

Topological insulators are a class of materials which have raised a great interest over the last decade, thanks to their intriguing conduction properties. Indeed, they are insulating in the bulk and metallic at the surface. Moreover, these metallic surface states have linear Dirac dispersion [1], thanks to which topological insulators show nonlinear THz behaviour similar to the case of graphene. Bi_2Se_3 is among the most promising topological insulators, since its band structure provides only one Dirac cone, while the bulk gap is pretty large (about 300 meV) [2].
It has been demonstrated that by terahertz-infrared spectroscopy it is possible to detect the Dirac surface state by patterning thin films of Bi_2Se_3 with ribbons of width from 2 to 20 μm. In this way, a Dirac plasmon is excited and its dispersion recovers very well the theoretical dispersion, calculated by using the parameters of the Dirac carriers [3].
In this scenario, we present here our investigation on the nonlinear regime of patterned films of Bi_2Se_3 with ribbons of width of 4 and 20 μm. By exploiting the intense THz electric field of the TeraFERMI beamline, we were able to induce a nonlinear behaviour of the Dirac plasmon. Indeed, we observed a redshift of the plasmonic peak as the incoming THz electric field increases [4].

MOP63

Detail study for the laser activating reflective switch for THz free electron laser

Keigo Kawase (National Institutes for Quantum and Radiological Science and Technology)

THz free electron laser at SANKEN, Osaka university generates a train of THz pulses with the interval of 27 MHz in the repetition of 5 Hz. The number of pulses in a train is about 100. Single pulse energy exceeds 200 \muJ at the carrier frequency of 4.5 THz. To extract a single pulse from the train, the reflective switch of the electron-hole plasma on the surface of Gallium Arsenide wafer driven by the Ti:sapphire laser pulse was constructed and the characteristics of the switch is studied. By evaluating also the characteristics of silicon and germanium wafers, the comparison experiments are performed. In addition, the study for carrier dynamics with the time scale of microseconds by measuring the variations of reflected and transmitted THz pulses with the interval of 27 MHz are being conducted. We report the recent results of the switching for the THz pulse and its time evolution in this conference.

Tutorial 1: How to expand your research network and write a successful project proposal

22 August 17:30 – 19:00

Chair: Cecilia Blasetti (Elettra-Sincrotrone Trieste S.C.p.A.)

Networking, access and project opportunities for FEL and Laser research in Europe

17:30

LEAPS overview and opportunities

Britta Redlich (FELIX Laboratory)

17:45

Laserlab-Europe access and networking

Sylvie Jacquemot (Ecole Polytechnique)

18:15

Calls overview and best practices examples

Cecilia Blasetti (Elettra-Sincrotrone Trieste S.C.p.A.)

TUA – SASE FELs

23 August 8:45 – 10:35

Chair: Evgeny Schneidmiller (Deutsches Elektronen-Synchrotron)

TUAI1 / 08:45

Cascaded amplification of attosecond X-ray pulses: towards TW-scale ultrafast X-ray free-electron lasers

Paris Franz (Stanford University), David Cesar (SLAC National Accelerator Laboratory), Xinxin Cheng, Taran Driver, Joe Duris, Zhaoheng Guo, Andrei Kamalov, Siqi Li, Razib Obaid, River Robles, Nick Sudar, Anna L. Wang, Zhen Zhang, James P. Cryan, Agostino Marinelli (SLAC National Accelerator Laboratory)

The natural time scale of valence electronic motion in molecular systems is on the order of hundreds of attoseconds. Consequently, the time-resolved study of electronic dynamics requires a source of sub-femtosecond pulses. Pulses in the soft x-ray domain can access core-level electrons, enabling the study of site-specific electron dynamics through attosecond pump/probe experiments. As time-resolved pump/probe experiments are nonlinear processes, these experiments require high brightness attosecond x-ray pulses. The X-ray Laser-Enhanced Attosecond Pulses (XLEAP) collaboration is an ongoing project for the development of attosecond x-ray modes at the Linac Coherent Light Source (LCLS). Here we report development of a high power attosecond mode via cascaded amplification of the x-ray pulse. We experimentally demonstrate generation of sub-femtosecond duration soft x-ray free electron laser pulses with hundreds of microjoules of energy. In conjunction with the upcoming high repetition rate at LCLS-II, these tunable, high intensity attosecond capabilities enable new nonlinear spectroscopic techniques and advanced imaging methods. This work was supported by US Department of Energy Contracts No. DE-AC02-76SF00 and the Basic Energy Sciences Accelerator and Detector Research Program.

TUAI2 / 09:15

Short pulses and 2-color capabilities at the SASE3 FEL line of the European XFEL

Svitozar Serkez (European XFEL GmbH)

European XFEL offers a unique combination of high electron energy and soft X-ray SASE3 undulator resonant to low photon energies with high K parameter. The long undulator allows us to employ split-undulator scheme to deliver pump-probe radiation to users. Pulse energies depend on photon energy and range from 100uJ at 2200eV to 900uJ at 600eV per pulse respectively. We plan to install optical delay line in the chicane to reliably scan through zero delay. Strongly compressed 16.5GeV electron beam combined with maximized orbit dispersion allowed us to generate 1keV- and 1mJ-order radiation with predominantly less than 2 spectral spikes. This operation mode was also employed to generate 100uJ-order pump-probe pulses.

TUAO3 / 09:45

Demonstration of enhanced FEL performance with optical klystron and helical undulators

Christoph Kittel (Paul Scherrer Institute), Marco Calvi (Paul Scherrer Institut), Nicholas Sammut (Department of Microelectronics and Nanoelectronics, Faculty of Information and Communication Technology, University of Malta, Msida MSD2080, Malta), Guanglei Wang (Paul Scherrer Institut, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland), Eduard Prat (Paul Scherrer Institut)

This contribution presents the experimental demonstration of improved performance of an X-ray free-electron-laser (FEL) using the optical klystron mechanism and helical undulator configuration in comparison to a standard planar undulator without optical klystron. The demonstration has been carried out at Athos, the soft X-ray beamline of SwissFEL. Athos has variable-polarization undulators and small magnetic chicanes placed between every two undulator modules to fully exploit the optical klystron. It is shown that, for wavelengths between 1 and 3 nm, the required length to achieve FEL saturation is reduced by about a factor of two when using both the optical klystron and helical undulators, with each effect accounting for about half of the improvements. Moreover, it is shown that a helical undulator configuration provides a 20% or higher saturation power than planar undulators. This work represents an important step towards more compact and high-power FELs, rendering this key technology more efficient, affordable, and accessible to the scientific community.

TUAO4 / 10:10

Two-Colored FEL generation Using Phase Shifters at Undulator

Myung Hoon Cho (Pohang Accelerator Laboratory), Teyoun Kang (Pohang Accelerator Laboratoty), Chi Hyun Shim (Pohang Accelerator Laboratoty)

Phase shifters at undulator line are usually used for optimizing FEL intensity by setting 'in-phase' by matching the FEL pulse and electrons phases. π-offset so called 'out-phase' may suppress FEL intensity at the resonant frequency, therefore the 'out-phase' condition is an unwanted state. However, this 'out-phase' setting can arise side band spectrums. This phenomena can be explained by the theory of the spontaneous radiation or low-gain FEL, and it expects that these side band spectrums have two main spectrums with the spectrum difference determined by the number of undulator period. This poster shows amplification of the two-colored spectrum seeded by the spontaneous spectrum feature. Results of two colored FEL is studied by simulations and experiments are performed at PAL-XFEL showing it's intensity grows exponentially along the number of undulator segments and reaches the saturation resulting in hundreds μJ energy.

TUB – Seeded FELs

23 August 11:00 – 12:50

Chair: Ryoichi Hajima (National Institutes for Quantum Science and Technology)

TUBI1 / 11:00

Coherent and ultrashort soft x-ray pulses from echo-enabled harmonic cascade FEL

Chao Feng (Shanghai Advanced Research Institute)

Shanghai Soft X-ray FEL facility (SXFEL) is the first X-ray FEL facility in China. Various external seeding techniques have been adopted for improving the performance of SXFEL. Here we report on the first demonstration of echo-enabled harmonic cascade (EEHC) for generating coherent and ultrashort soft X-ray pulses. Benefiting from the superiority of low sensitivity to the electron beam imperfections and flexible output pulse control of EEHC, nearly transform-limited soft X-ray pulses with tunable pulse durations have been successfully generated. These experiments exceed the current limitations of external seeding techniques and may open up new opportunities for extending external seeded FEL to shorter wavelength range.

TUBI2 / 11:30

Enhanced Self-Seeding with Ultrashort Electron Beams

Zhen Zhang (SLAC National Accelerator Laboratory)
Erik Hemsing (SLAC National Accelerator Laboratory), Aliaksei Halavanau (SLAC National Accelerator Laboratory)

We describe a new method to produce intensity stable, highly coherent, narrow-band x-ray pulses in self-seeded free electron (FEL) lasers. The approach uses an ultrashort electron beam to generate a single spike FEL pulse with a wide coherent bandwidth. The self-seeding monochromator then notches out a narrow spectral region of this pulse to be amplified by a long portion of electron beam to full saturation. In contrast to typical self-seeding where monochromatization of noisy self-amplified spontaneous emission pulses leads to either large intensity fluctuations or multiple frequencies, we show that this method produces a stable, coherent FEL output pulse with statistical properties similar to a fully coherent optical laser. With self-consistent, start-to-end simulations we show that laser heater shaping and cathode shaping techniques both can produce the electron beam current profile needed for the enhanced self-seeding scheme.

TUBO3 / 11:55

Comparison of transverse coherence properties in seeded and unseeded FEL

Alberto Simoncig (Elettra-Sincrotrone Trieste S.C.p.A.), David Garzella (Elettra-Sincrotrone Trieste S.C.p.A. SS 14 - km 163,5 in Area Science Park I - 34149 Basovizza), Enrico Allaria (Elettra-Sincrotrone Trieste S.C.p.A.), Francesca Curbis (Lund University), Carlo Spezzani (Elettra-Sincrotrone Trieste S.C.p.A.), Gianluca Geloni (European XFEL GmbH), Giovanni De Ninno (Elettra-Sincrotrone Trieste S.C.p.A.), Giovanni Perosa (University of Trieste, Elettra Sincrotrone Trieste), Giuseppe Penco (Elettra-Sincrotrone Trieste S.C.p.A.), Laura Foglia (Elettra - Sincrotrone Trieste), Luca Giannessi (Elettra Sincrotrone Trieste and Istituto Nazionale di Fisica Nucleare), Marco Zangrando (Elettra-Sincrotrone Trieste S.C.p.A.), Mauro Trovo (Elettra-Sincrotrone Trieste S.C.p.A.), Michele Manfredda (ELETTRA - Sincrotrone Trieste S.C.p.A.), Mihai Pop (MAX IV Laboratory), Najmeh Mirian (Deutsches Elektronen-Synchrotron), Nicola Mahne (Istituto Officina dei Materiali, CNR, Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy;), Primoz Rebernik Ribic (Elettra-Sincrotrone Trieste S.C.p.A.), Simone Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.), Simone Spampinati (Elettra Sincrotrone Trieste), Sverker Werin (MAX IV Laboratory)

The transverse coherence of the source is an important property for FEL experiments. Theory and simulations indicated different features for seeded and unseeded FELs but so far no direct comparison has been pursued experimentally on the same facility. At FERMI one has the unique possibility to test both configurations (SASE and seeding) within the same operating conditions. In this contribution we present the experimental results of the characterization of transverse coherence with special attention to the evolution of such property.

TUBO4 / 12:20

First observation of laser-beam interaction in a dipole magnet

Jiawei Yan (European XFEL GmbH), Haixiao Deng (Shanghai Advanced Research Institute Chinese Academy of Science), Zhentang Zhao (Shanghai Synchrotron Radiation Facility)

Recently, a self-modulation scheme was proposed and experimentally demonstrated for enhancing energy modulation in seeded FELs [1], thereby significantly reducing the requirement of an external laser system. Driven by this scheme, an electron beam with a laser-induced energy modulation as small as 1.8 times the slice energy spread is used for lasing at the 7th harmonic of a 266-nm seed laser in a single-stage high-gain harmonic generation (HGHG) setup and the 30th harmonic of the seed laser in a two-stage HGHG setup. Moreover, using this scheme, we report the first observation of the laser-beam interaction in a pure dipole magnet [2] in which the electron beam energy modulation with a 40-keV amplitude and a 266-nm period is measured. We demonstrate that such an energy modulation can be used to launch a seeded FEL, that is, lasing at the sixth harmonic of the seed laser in a high-gain harmonic generation scheme. The results reveal the most basic process of the FEL lasing and open up a new direction for the study and exploitation of laser-beam interactions.

TUC – FEL Oscillators and IRFELs

3 August 14:10 – 16:00

Chair: Ying Wu (Duke University)

TUCI1 / 14:10

Observation of Burnham-Chiao ringing with pi-phase jumps in a high-efficiency superradiance FEL oscillator

Heishun Zen (Kyoto University)
Hideaki Ohgaki (Kyoto University), Ryoichi Hajima (National Institutes for Quantum and Radiological Science and Technology)

At the mid-infrared free electron laser oscillator in Kyoto University (KU-FEL), high extraction efficiency (9.4%) operation has been achieved [1] by introducing the dynamic cavity desynchronization technique [2] and photocathode operation of a thermionic RF gun [1]. Because of the interaction between the electron beam and FEL electromagnetic field, a maximum electron energy decrease of 16% was observed. The measured energy decrease was consistent with the measured FEL spectrum. The FEL pulse structure under the high extraction efficiency operation was obtained by a phase retrieval based on the result of fringe resolved autocorrelation measurement [3]. As the result, it was confirmed that the FEL pulse has several sub-spikes after the main spike having a 4.2-cycle pulse length at the wavelength of 11 µm. Moreover, the neighboring spikes has 180-degree different optical phases, i.e. π-phase jumps. The appearance of the sub-spikes and the π-phase jumps are the specific feature of the Burnham-Chiao ringing (or Superradiance ringing) [4], which has been predicted by numerical simulations [5] but not yet fully characterized in experiments. The ringing and the π-phase jumps are clear evidence of the periodic acceleration and deceleration of the microbunched electrons. In this talk, we present an overview of few-cycle FEL lasing with the high extraction efficiency, >9%, and the details of FEL pulse measurements to reveal the Burnham-Chiao ringing. This work was supported by MEXT Q-LEAP (JPMXS0118070271).

TUCI2 / 14:40

FEL Lasing below 170 nm using an oscillator

Ying Wu (Duke University)
Stepan Mikhailov (Duke University), Jun Yan (Duke University), Patrick Wallace (Duke University), Victor Popov (Duke University), Maurice Pentico (Duke University), Gary Swift (Duke University), Mohammad Ahmed (TUNL, North Carolina Central University), Leif Kochanneck (Laser Zentrum Hannover e.V.,), Henrik Ehlers (Laser Zentrum Hannover e.V.,), Lars Jensen (Laser Zentrum Hannover e.V.,)

While the linac based single-pass FEL has been successfully operated in the EUV and x-ray regions for about two decades, the oscillator FEL has been limited to operating in the longer wavelength region due to the limitation of high-reflectivity, thermally stable, and radiation-resistant short-wavelength mirrors. With Duke storage ring FEL, we have recently extended the shortest lasing wavelength of the oscillator FEL to 168.6 nm. We have demonstrated lasing wavelength tuning from 168.6 to 179.7 nm with excellent beam stability. This progress has been made possible by developing a new FEL configuration with substantially reduced undulator harmonic radiation on the FEL mirror, a thermally stable FEL optical cavity, and a new type of high-reflectivity fluoride-based multilayer coating with a protective capping layer. Employing this VUV FEL in Compton scattering, we have also produced the first 120 MeV gamma rays at the High Intensity Gamma-ray Source (HIGS).
Ref: Y.K. Wu et al., J. Appl. Phys. 130, 183101 (2021); doi: 10.1063/5.0064942
This work is partially supported by DOE Grant No. DE-FG02-97ER41033.

TUCO3 / 15:10

Single pass high efficiency THz FEL

Andrew Fisher (Particle Beam Physics Lab (PBPL)), Youna Park (Particle Beam Physics Lab (PBPL)) Max Lenz (Particle Beam Physics Lab (PBPL)), Alexander Ody (Particle Beam Physics Lab (PBPL)), Ronald Agustsson (RadiaBeam), Tara Hodgetts (RadiaBeam), Alex Murokh (RadiaBeam), Pietro Musumeci (Particle Beam Physics Lab (PBPL))

The THz gap is a region of the electromagnetic spectrum where high average and peak power radiation sources are scarce while scientific and industrial applications grow in demand. Free-electron laser coupling in a magnetic undulator can provide radiation generation in this frequency range, but slippage effects require the use of relatively long and low current electron bunches in the THz FEL, limiting the amplification gain and output peak power. We show how a circular waveguide in a meter-long strongly tapered helical undulator can be used to match the radiation and e-beam velocities, extracting energy from an ultrashort 200 pC 5.5 MeV electron beam along the entire undulator. E-beam spectrum measurements, supported by energy and spectral measurements of the THz FEL radiation, indicate an average energy efficiency of 10% with some particles losing >20% of their initial kinetic energy.

TUCO4 / 15:35

THz FEL oscillators produce synchronized soft X-rays via Thomson back-scattering: a new dual source technique

Vittoria Petrillo (Università Statale degli Studi di Milano, INFN-Milan), Alberto Bacci (INFN - Milan), Illya Drebot (INFN - Milan), Michele Opromolla (Università Statale degli Studi di MIlano), Marcello Rossetti Conti (INFN - Milan), Sanae Samsam (University of Rome La Sapienza, INFN - Milan), Marcel Ruijter (University of Rome La Sapienza, INFN - Milan), Luca Serafini (INFN - Milan), Andrea Renato Rossi (INFN - Milan)

We present a scheme to generate synchronized THz and Soft X-ray radiation pulses by using a Free-Electron Laser Oscillator driven by a high repetition rate energy recovery linac. The backward THz radiation in the oscillator cavity produces naturally synchronized Soft/Hard X rays via Thomson back-scattering by interacting with a successive electron bunch. The performances of this dual source are illustrated by means of dedicated simulations assessing the capability of the scheme for typical wavelengths of interest, namely up to 50 μm for the short-THz radiation and close to the water window at 3 nm for the X-rays.

TU121 – One-to-one meetings with experts in project building 1

23 August 16:00 – 18:00

TU1211

Wayforlight and beamtime proposals

Cecilia Blasetti (Elettra-Sincrotrone Trieste S.C.p.A.)

Discover the wayforlight.eu portal to find out the most suitable instruments for your research and get useful tips to draft a successful beamtime proposal

TU1212

Laserlab-Europe

Sylvie Jacquemot (Ecole Polytechnique)

Become aware of transnational access support tools, joint research and training opportunities offered by the Laserlab-Europe Consortium

TU1213

Horizon Europe programmes and grants for all stages of research careers

Marina Kozlik Mercatelli

Get introduction and assistance on funding possibilities for researchers from all over the world

TU1214

Euraxess - an European network to support mobility and career development for researchers

Anna Comini (Consorzio per l'AREA di ricerca scientifica e tecnologica di Trieste)

Get information on how to apply for research jobs in Europe

TUP – Poster Session

23 August 16:00 – 17:30

Seeded FELs, Electron Sources, Novel Acceleration and FEL Concepts

TUP01

A pulse shaper for direct generation of 515 nm 3D ellipsoidal pulses at PITZ

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In this paper, a cathode laser pulse shaper at 515 nm is presented that will be used for emittance optimizations. In case alkali antimonide photocathodes are used, the shaped green pulses can be applied directly for photoemission while Cs_2Te photocathodes requires second harmonic generation to provide UV laser pulses. Recent tests of CsK_2Sb photocathodes in the high gradient RF gun at PITZ are first steps for the future usage of green laser pulses, which would simplify the requirements for the photocathode laser system, especially for CW operation cases envisioned in future. As long the alkali antimonide photocathodes are not in regular use yet, the laser pulses need to be converted into the UV. The green pulse shaper still simplifies the laser system since two conversion stages from IR to green to UV were needed in the past, which dilutes the quality of the shaped laser pulses. In this paper, a pulse shaper for direct generation of 515nm 3D ellipsoidal pulses is presented that is expected to further improve the beam emittance generated by ellipsoidal laser shaping.

TUP02

Measurements of Slice Energy Spread at Low-energy Photoinjectors

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The slice energy spread of the electron beam is one of the key parameters for high performance of linac-driven free electron lasers (FELs). The simulated uncorrelated energy spread in modern XFEL photoinjectors with beam energies of many tens of MeV is on the order of a few keV or even less. Thus, accurate measurement of the slice energy spread is not trivial. Two recent studies on high energy (>100 MeV) photoinjectors at SwissFEL and European XFEL have reported much higher slice energy spread than expected at their XFEL working points (200 – 250 pC). A new method for measuring slice energy spread at a lower beam energy (~20 MeV) is proposed and demonstrated at the Photo Injector Test facility at DESY Zeuthen (PITZ). The contribution will summarize previous results obtained on high energy injectors and then review the details of the technique used at PITZ as well as the experimental results for 250 pC, which are considerably lower than the results measured at high energy injectors.

TUP03

RF Performance of a New Generation L-band RF Gun at PITZ

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A new generation of high-gradient normal conducting 1.3 GHz RF gun with 1% duty factor was developed to provide a high-quality electron source for superconducting linac driven free-electron lasers like FLASH and European XFEL. Compared to the Gun4 series, Gun5 aims for a ~50% longer RF pulse length (RF pulse duration of up to 1 ms at 10 Hz repetition rate) combined with high gradients (up to ~60 MV/m at the cathode). In addition to the improved cell geometry and cooling concept, the new cavity is equipped with an RF probe to measure and control the amplitude and phase of the RF field inside the gun. The first characterization of Gun5.1 included measurements of RF amplitude and phase stability (pulse-to-pulse and along 1 ms RF pulse). The dark current was measured at various peak power levels. The results of this characterization will be reported.

TUP04

Development and test results of multi-alkali antimonides photocathodes from the high gradient RF gun at PITZ

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Multi-alkali antimonide photocathodes can have high quantum efficiency similar as UV sensitive (Cs_2Te) photocathodes, but with the advantages of photoemission sensitivity in the visible region of the light spectrum and a significant reduction in the mean transverse energy of photoelectrons. A batch of three KCs_2Sb photocathodes was grown on molybdenum substrates via a sequential deposition method in a new preparation system at INFN LASA. Afterwards, the cathodes were successfully tested in the high gradient RF gun at PITZ. This contribution summarizes the experimental results obtained in both the preparation chamber and the RF gun. Based on those findings, we are now optimizing the recipe of KCs_2Sb and NaKSb(Cs) photocathodes for lower field emission and longer lifetime, and the measurements for the latest photocathodes with the improved recipe are also presented.

TUP05

Impact of frequency-detuning dependent coupler kick on bunch quality along long bunch trains produced in the photoinjector of the European XFEL

Ye Chen (Deutsches Elektronen-Synchrotron)

We present theoretical studies of the frequency-detuning dependent transverse coaxial power coupler kick in the photoinjector of the European XFEL. The projected transverse emittance along long bunch trains are investigated by simulating the beam dynamics using modelled three-dimensional field maps at each detuned gun cavity frequencies. The results will be shown and possible compensation schemes are discussed in terms of practical FEL operation.

TUP06

Dark current characterization in the electron source of the European XFEL

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A high gradient photocathode RF gun is used as the electron source for the European X-ray Free-Electron Laser providing high brightness electron beams. The unwanted dark current, produced by the field emission in the electron source, can be transported downstream, causing potential risks of radiation damage for electronics and active beam line components, and thus must be avoided / reduced to a satisfying level. Here we present the obtained results for the characterization of the dark current in the gun section under nominal working conditions of the European XFEL. Both numerical and experimental results will be presented and discussed.

TUP07

Photocathodes for the electron sources at FLASH and European XFELEL

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The photoinjectors of FLASH at DESY (Hamburg, Germany) and the European XFEL are operated by laser driven RF-guns. In both facilities cesium telluride photocathodes are successfully used since several years. We present recent data on the lifetime, quantum efficiency (QE), and dark current of the photocathodes currently in operation. In addition we present recent design changes in the photocathode transfer systems in order to further improve the cathode handling.

TUP08

Conditioning and high power test results of first 3.0 m High Gradient structure for FERMI Linac Energy Upgrade

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ERMI is the seeded Free Electron Laser (FEL) user facility at Elettra laboratory in Trieste, operating in the VUV to soft X-rays spectral range. In order to extend the FEL spectral range to shorter wavelengths, an upgrade plan for increasing the Linac energy from 1.5 GeV to 2.0 GeV is actually going on. After successful testing of the short prototype of new high gradient S-band accelerating structure up to an accelerating gradient of 40 MV/m, a full length 3.0 m HG structure has been built in collaboration with Paul Scherrer Institute (PSI). In the first step, two such new structures would be installed in place of S0a and one deflector at K15 increasing the beam energy to 1.7 GeV. In the next phase 14 new HG structures would replace the present Backward Travelling Wave sections reaching to the final goal of 2.0 GeV. Currently first 3.0 m HG structure is under conditioning and high power testing at Cavity Test Facility of Elettra. In this paper we report the low power measurement results as well as conditioning results of 3.0 m HG structure.

TUP09

Generation of a sub-picosecond sheet electron beam using a 100 fs laser.

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The biggest benefit of DC photoelectron-gun driven by the sub-picosecond laser is that such type of guns can be operated with the current density much higher than the Child's low limitation. We demonstrated 0.3 nC bunch generation by irradiating a 100 fs Ti:sapphire laser focused to 0.1 square-cm area onto a tangsten photocathode installed in a diode type 40 kV DC gun. The drawback is the strong Coulomb repulsive force by which electrons may suffer the emittance degradation in the vicinity of the cathode. To reduce the repulsive force at the cathode surface, we are trying to generate a "sheet-like" photoelectron bunch. In our experiments, electron bunches are generated by irradiating the laser pulse shaped in an ellipse onto the photocathode. The ellipticity is set in the range of 0.03-0.05 while the most of sheet-beam experiments were conducted with the ellipticity about 0.1. The smaller the ellipcity, the longer the circumference; this may reduce the radial electric field on the electron bunch side-wall. Moreover the electron bunch shape is rather a "line" than a "sheet" due to the short duration of the drive laser pulse. We conducted a preliminaly experiment and observed that the elliptical photo-electron bunch had much larger divergence angle in the minor axis direction. In the presentation, experimental results, the numerical simulation on the particle motion and the design of the sheet-photo-electron DC gun will be discussed.

TUP10

Experimental demonstration of temporally shaped picosecond optical pulses for driving electron photoinjectors

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Next-generation electron photoinjector accelerators, such as the LCLS-II photoinjector, have increasingly tight requirements on the excitation lasers, often calling for tens of picosecond, temporally flat-top, ultraviolet (UV) pulse trains to be delivered at up to 1 MHz*. We present an experimental demonstration of temporal pulse shaping for the LCLS-II photoinjector laser resulting in temporally flat-top pulses with 24 ps durations. Our technique is a non-colinear sum frequency generation scheme wherein two identical infrared optical pulses are imparted with equal and opposite amounts of spectral dispersion. The mixing of these dispersed pulses within a thick nonlinear crystal generates a second harmonic optical pulse that is spectrally narrowband with a designed temporal profile**. In experiment we achieve upwards of 40% conversion efficiency with this process allowing this to be used for high average and peak power applications. These narrowband pulses can then be directly upconverted to the UV towards use in driving free electron laser photocathodes. Additionally, we present a theoretical framework for adapting this method to shape optical pulses driving other photoinjector based applications.

TUP11

Real-time Programmable Shaping for Electron and X-ray Sources

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The next generation of augmented brightness XFELs, such as LCLS-II, promises to address current challenges associated with systems with low X-ray cross-sections. Typical photoinjector lasers produce coherent ultraviolet (UV) pulses via nonlinear conversion of an infrared (IR) laser. Fast and active beam manipulation is required to capitalize on this new generation of XFELs, and controlling the phase space of the electron beam is achieved by shaping the UV source. However current techniques for such shaping in the UV rely on stacking pulses in time, which leads to unavoidable intensity modulations and hence space-charge driven microbunching instabilities [1]. Traditional methods for upconversion do not preserve phase shape and thus require more complicated means of arriving at the desired pulse shapes after nonlinear upconversion [2]. Upconversion through four-waving mixing (FWM) allows direct phase transfer, convenient wavelength tunability by easily changeable phase matching parameters, and also has the added advantage of greater average power handling than traditional $\chi(2)$ nonlinear processes [3, 4,]. Therefore, we examine a possible solution for e-beam shaping using a machine learning (ML) implementation of real-time photoinjector laser manipulation which shapes the IR laser source and then uses FWM for the nonlinear upconversion and shaping simultaneously. Our presentation will focus on the software model of the photoinjector laser, the associated ML models, and the optical setup. We anticipate this approach to not only enable active experimental control of X-ray pulse characteristics but could also increase the operational capacity of future e-beam sources, accelerator facilities, and XFELs.

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TUP12

Ponderomotive scattering of sub-picosecond ultracold electron bunches

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We are developing an ultrafast and Ultracold Electron Source (UCES), based on near-threshold, two-step, femtosecond photoionization of laser-cooled rubidium gas in a grating Magneto Optical Trap (MOT). This source delivers stable ultrafast electron bunches with a unique combination of high bunch charge and low transverse emittance ~1.9 nm·rad, demonstrating the cold electron temperature ~25 K.
Recent development focused on long term stabilizing the electron beam. By pulsing the high voltage accelerator potential, the effects of surface charge buildup in the accelerator structure are mitigated and secondary electron emission as a result of ion impacts on the cathode is prevented.
This made a high resolution ponderomotive scattering measurement possible, in which a 1.1 mJ, 25 fs, 800 nm laser pulse is focused onto the electron bunch to a waist of 5.9 μm in vacuum. The ponderomotive force scatters the electrons which can be detected in the transverse profile. In this way the electron bunch length inside the self-compression point of the UCES has been measured to be 735±7 fs. Some wavelength dependent temporal structure originating from the ionization process could be observed.

TUP13

ACE injector for burst mode operation in a ICS source

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At Eindhoven university an inverse Compton scattering (ICS) source is being built. The ICS source consists of a 100kV photo gun electron injector, X-band accelerator, and interaction laser. One of the first upgrades for this ICS source is operating in a so-called burst mode. In burst mode, the electron injector is replaced by the advanced continuous electron (ACE) injector and a Fabry-Perot cavity is added to the laser. Both systems work in a 100 nanosecond long burst. Significantly increasing the current x-ray yield and the brilliance of the ICS source.
The ACE injector works by generating a continuous beam with a high current and low emittance through thermionic emission. The continuous electron beam is then chopped into a pulsed beam by a combination of a dual-mode elliptical RF cavity and a knife-edge. The dual-mode cavity uses both the fundamental mode (1.5 GHz) and its second harmonic (3.0 GHz) to increase the duty cycle of the chopping process to approximately 30% with a minimal loss of beam quality. Finally, a second dual-mode elliptical RF cavity compresses the pulse length of the bunches, preparing the beam for injection into an X-band linear accelerator.

TUP14

Advanced Laser Shaping for High-Brightness Electron Beams

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The role of laser shaping in time, frequency, and space is well-known to be paramount to all photoinjectors, thereby making high-fidelity control of the photoinjector drive laser pulse central to the production of high brightness beams. But these pulses, often in the UV range, are complex to control using conventional linear and nonlinear optics approaches. As a result, photoinjector-based accelerators and light sources suffer from this lack of foundational performance optimization. We present an ensemble of theoretical[1] and experimental[2,3] results of novel light-shaping and up-conversion techniques that address high average power, efficient, high quality, stable, and tunable-wavelength photoinjector laser pulse generation with programmable spatio-temporal structure. These methods offer human- or artificial intelligence-based dynamic programmability[4] of the laser and electron beam temporal shapes to reduce emittance and control the 6D phase-space for fast and real-time optimization and photoemission mode multiplexing. These results have the potential for seminal impact across multi-mission facilities in basic energy sciences and high energy physics.

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TUP16

Development of a Smart Transmission Line for Israeli THz FEL based AI

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The design of a Transmission Line (TL) for a wide tunable broad-spectrum THz radiation source is not a simple task. The platform for the future designs of smart TL by using Artificial Intelligence is present. The AI will be used for converting optical and quasi-optical modes. We developed a three-dimensional, space-frequency tool for the analysis and diagnostic of radiation pulse. The total electromagnetic field on the input of the TL is represented in the frequency domain in terms of cavity eigenmodes. This field is converted to geometric-optical rays via the Wigner transform at any desired resolution. The Wigner's function allows describing the dynamics of field evolution in future propagation, which allows determining an initial design of TL. The EM field in terms of rays gives access to the Ray Tracing method and future processing, operating in the linear and non-linear regimes. For fast work and great flexibility one by use parallel processing with graphics cards.

The platform is used to study the phase-amplitude and spectral characteristics of multimode radiation generation in a free-electron laser, operating in various operational parameters. The final goal is to develop a tool for a designing system of specialized (printed) mirrors.

TUP17

Brilliant X-ray Free Electron Laser driven by Resonant Multi-Pulse Ionization injection accelerator

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Laser Wakefield Accelerators are now sufficiently mature to provide GeV scale/high-brightness electron beams capable of driving Free Electron Laser (FEL) sources. Here, we show start-to-end simulations carried out in the framework of the EuPRAXIA project of a Free Electron Laser driven by an LWFA accelerator in the Resonant Multi-Pulse Ionisation Injection (ReMPI) framework. Simulations with this model using a 1 PW Ti:Sa laser system and a 20 cm long capillary, show the injection and acceleration of an electron beam up to 4.5 GeV, with a slice energy spread and a normalized emittance below 4×10−4 and 80 nm×rad, respectively. The transport of the beams from the capillary exit to the undulator is provided by a matched beam focusing with a marginal beam-quality degradation. Finally, 3D simulations of the FEL radiation generated inside an undulator show that ≈ 1010 photons with central wavelength of 0.15nm and peak power of ≃ 0.3GW can be produced for each bunch. Our start-to-end simulations indicate that a single-stage ReMPI accelerator can drive a high-brightness electron beam having quality large enough to be efficiently transported to a FEL undulator, thus generating X-ray photons of brilliance exceeding 10^{25}ph/s/mm^2/0.1%bw.

TUP18

The ASPECT project

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Attosecond pulse production is an important development focus for most major FEL facilities. Chirp/taper and eSASE schemes, both of which will shorten the pulses well below the femto-second level for both hard and soft x-rays, are proposed for implementation at EuXFEL. As a high repetition rate super conducting linac that feeds three 200m long undulator lines for parallel operation, EuXFEL presents distinct challenges but also unique opportunities for the proposed schemes.

TUP19

Stable Multi-Day Performance of a Laser Wakefield Accelerator for FEL Applications.

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We report on the operation of the DRACO Laser Driven electron source for stable multi-day operation for FEL applications. The nC-class accelerator delivers charge densities around 10 pC/MeV, <1 mrad rms divergence at energies up to 0.5 GeV and peak currents of over 10 kA [1]. Precise characterisation is paramount for controlled operation, including: spectrally resolved charge diagnostic, coherent optical transition radiation (TR) to resolve microbunch beam structures [2] and TR-based multioctave high-dynamic range spectrometry for sub-fs resolved characterisation of the 10 fs rms electron bunches [3]. Achieved stability allows for systematic exploration of demanding applications, resulting in the recent demonstration of the first LWFA based Beam-driven Plasma Wakefield Accelerator [4]. Fulfilling the high demands required for FEL operation, the COXINEL manipulation line developed at Synchotron SOLEIL has recently been installed at our facility. Based on successful beam transport of over 13000 shots within 9 experimental days during commissioning, we were able to demonstrate the very first operation of a seeded FEL driven by a laser plasma accelerator [5].

TUP20

Frequency Mixing Experiments at the European XFEL

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Frequency mixing was studied experimentally at SASE3, the soft X-ray undulator of the European XFEL. Two frequencies were generated in the first part of the undulator in alternating K configuration. The mixing process occurred in the second part with detuned undulator segments used to generate R56. Finally, the difference frequency was radiated and amplified in a third part of the SASE3 undulator. Experiments were performed at several electron energies (11.5 GeV, 14 GeV, and 16.5 GeV) with frequency mixing generation at photon energies between 500 eV and 1.1 keV. Pulse energies were on the mJ level, depending on the length of the radiator part. A practical application of frequency mixing at European XFEL is a possible extension of the operating range of the SASE3 undulator towards lower photon energies, by using a relatively short afterburner with longer period.

TUP21

Generation of high-power free-electron laser pulses with orbital angular momentum

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The generation of x-ray pulses carrying orbital angular momentum from an x-ray free-electron laser (FEL) has attracted considerable attention due to the ability to directly change atomic states and develop new material characterization techniques. In this contribution, we report a new method for generating intense x-ray vortices. The method is based on the widely used self-amplified spontaneous emission scheme and does not require additional helical undulators or external laser systems. It can therefore in principle be employed by all existing XFEL facilities with limited hardware additions.

TUP22

A novel method for generating high-repetition-rate and fully coherent EUV free-electron laser

Hanxiang Yang (Shanghai Institute of Applied Physics), Jiawei Yan (European XFEL GmbH), Haixiao Deng (Shanghai Advanced Research Institute Chinese Academy of Science)

High-brightness extreme ultraviolet (EUV) light source is strongly required for high-resolution photoelectron spectroscopy, imaging experiments, and EUV lithography. In this work, the self-modulation technique is introduced into seeded FELs, such as high-gain harmonic generation (HGHG), to significantly reduce the requirement of the seed laser power by enhancing coherent energy modulation. Numerical simulations demonstrated that the modified HGHG configuration with the self-modulation technique could generate high-repetition-rate, fully coherent, stable, and kilowatt-scale EUV pulses at a more compact linac-based light source.

TUP23

Hybrid LWFA-PWFA staging for beam quality booster

Arie Irman (Helmholtz-Zentrum Dresden-Rossendorf)
on behalf of the hybrid collaboration

Beam-driven plasma wakefield accelerators (PWFAs) offer a unique regime for the generation and acceleration of high-quality electron beams to multi-GeV energies. Here we present an innovative hybrid staging approach, deploying electron beams generated in a laser-driven wakefield accelerator (LWFA) as drivers for a PWFA, integrated in a particularly compact setup. This scenario exploits the capability of LWFAs to deliver shortest, high peak-current electron bunches [1] with the prospects for high-quality witness beam generation in PWFAs [2]. The feasibility of the concept is presented through exemplary particle-in-cell simulations, before describing experimental results from extensive campaigns performed at high-power laser facilities; ATLAS (LMU, Munich), SALLE-JAUNE (LOA, Paris) and DRACO (HZDR, Dresden). Using few-cycle optical probing we captured clear images of beam-driven plasma waves in a dedicated plasma stage, allowing us to identify a non-linear plasma-wave excitation regime. Trailing the plasma waves, the impact of ion motion to the transverse modulation of the plasma density was observed over many picoseconds [3]. Furthermore, we demonstrate for the first time the acceleration of distinct witness beams in such LWFA-driven PWFA (LPWFA) setup [4,5], showcasing an accelerating gradient on the order of 100 GV/m. These milestones pave the way towards compact sources of energetic ultra-high brightness electron beams as well as a miniature model for large scale PWFA facilities.

TUP24

High harmonic lasing using attosecond electron pulses combs in photon-induced near-field electron microscopy

Yiming Pan (Israel Institute of Technology)
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Attosecond laser pulses in the extreme ultraviolet/soft X-ray (XUV/SXR) spectral regions are presently available for attosecond pump-probe spectroscopy and extreme ultraviolet lithography for chip manufacturing, ultrafast atomic-scale microscopy, and nonlinear X-ray optics. There are two main approaches to produce attosecond light pulses: high-harmonic generation (HHG) in gas-phase or solid-state matter based on the three-step model, and X-ray free-electron lasers (XFELs) based on self-amplified spontaneous emission (SASE) and laser seeding processes of relativistic free electrons traveling through an undulator. Here, we propose a novel route of producing attosecond laser pulses, based on the generation of attosecond electron pulse trains in photon-induced near-field electron microscopy (PINEM), combined with the SASE principle for light amplification. Our scheme relies on high-density nanotip arrays emitting dense electron bunches that are subsequently modulated with a PINEM-type interaction, enabling high-gain for amplification of XUV/SXR high harmonic radiation. Our PINEM-HHG mechanism using attosecond electron pulses can serve as promising ultra-bright extreme ultraviolet/soft X-ray attosecond laser sources.

TUP25

Free Electron Laser seeded by Betatron Radiation

Andrea Ghigo (Istituto Nazionale di Fisica Nucleare)

The possibility of using a plasma accelerated electron beam to generate Free Electron Laser (FEL) radiation has recently been proven. In the plasma acceleration process an intense broadband spectrum radiation in the X ray region, the betatron radiation, is produced by the electron beam passing through the ionized gas.
In this paper it is proposed to use this radiation, suitably monochromatised, as a seed to stimulate the emission in the Free Electron Laser on the fundamental frequency and on the higher harmonics. This scheme could be adopted from all FEL injected by plasma accelerated electron beams via particle or laser wakefield acceleration.

TUP26

Spectral Control of THz Superradiant Spontaneous Undulator Radiation Driven by Ultrashort Electron Beam with Energy Spread

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Intense coherent THz radiation has been generated from an 18-period, hybrid-type U100 planar undulator as it is driven by short relativistic electron pulses produced from the NSRRC photoinjector. However, it is found that the observed number of optical pulse cycles is much less than the number of undulator periods. Hence, the radiation spectral bandwidth has been broadened. It is found that excessive energy spread introduced into the beam during RF bunch compression in the linac as well as the dispersion of undulator are responsible to this undesired broadening of THz radiation spectrum. In this study, instead of using rectilinear rf bunch compression (i.e. velocity bunching) in photoinjector linac, we investigate the feasibility of using nonlinear magnetic bunch compression for spectral bandwidth control of coherent THz undulator radiation.

TUP27

LAPLACIAN: a step forward for compact LPA based electron accelerators

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The LAPLACIAN (Laser Acceleration Platform as a Coordinated Innovation Anchor) experimental facility inside the MIRAI project framework is the Japanese answer to the global effort for the development of compact accelerators based on laser plasma acceleration (LPA) for its application to free electron laser (FEL). Situated in the SPRING-8 site, LAPLACIAN aims for the generation of X-ray FEL with relativistic electrons (GeV) from an LPA source in a beamline of under 10 m. Even after the recent demonstration of by the SIOM group, achieving proper electron beam parameters in a consistent manner and a reliable coupling with the undulator is non-trivial and still under research. In LAPLACIAN, multiple gas targets and LPA schemes are being studied, including a planned multiple plasma stages setup for GeV electron energies combined with magneto-optics for coupling. In this talk, an overview of the current facility status and some future plans will be given. In addition, we will report in some of the already achieved results and the new planned beamline.

TUP28

LCLS-II MHz X-ray Temporal Shaping

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Shaping techniques traditionally used to produce few femtosecond and even sub femtosecond soft X-ray FEL pulses at LCLS do not scale well to high repetition rates. Here we present the progress of the LCLS-II X-ray temporal shaping project which uses infrared and ultraviolet picosecond lasers to shape the electron beam of the LCLS-II superconducting linac. Quickly switching these shaping lasers on and off will enable multiplexing different beams to different beamlines.

TUP31

Energy-Chirp-based outcoupling scheme for X-ray Regenerative Amplifier FEL

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Cavity-based X-ray Free Electron Lasers (FELs) such as the X-ray regenerative amplifier FEL (XRAFEL) [1] and the X-ray FEL oscillator [2] have drawn great interest as a means of producing high-brightness, fully coherent and stable hard x-ray pulses for high-repetition rate FELs [3]. However, high efficiency outcoupling of the stored cavity x-ray radiation remains challenging. Here we present a novel XRAFEL design to achieve efficient cavity outcoupling or Q-switching by introducing energy chirp in the electron beam while leaving the high-quality X-ray optics intact. During the FEL interaction, electron beam with an linear energy chirp can be slightly compressed or decompressed by the undulator, which leads to a gradual shift of radiation frequency outside the bandwidth of the Bragg crystal for efficient outcoupling. Our simulation results show that substantial power can be outcoupled from the X-ray cavity driven by chirped electron beams at 100 kHz repetition rate. We also discuss parameter tradeoff in such an XRAFEL scheme and a practical way to achieve the desired fast chirp control by a small, normal-conducting RF station in the LCLS-II [4].

[1] Z. Huang and R. D. Ruth. PRL96, 144801 (2006).
[2] K.-J. Kim, Y. Shvyd'ko, S. Reiche, PRL100 244802 (2008).
[3] G. Marcus, et al., PRL125, 254801 (2020).
[4] M. Nasr, et al., in proceedings of IPAC'16 (Busan, Korea,2016).

TUP32

Facility Concept Outlines for a UK XFEL

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In early 2019, the UK initiated a project to develop the science case for a UK XFEL, featuring a diverse team of UK scientists and international advisors. Accelerator scientists were engaged to highlight potential future accelerator developments and to develop concept outlines for a facility design meeting the requirements for world-leading capabilities. The UK XFEL Science Case, featuring the concept outlines, was published in late 2020. Subsequent exercises further demonstrated the support of the UK community and the project is anticipated to enter a more detailed design phase. The concept outlines are reviewed and potential next steps are outlined.

TUP33

FAST-GREENS: A High Efficiency Free Electron Laser Driven by Superconducting RFAccelerator

Alex Murokh (RadiaBeam Technologies), Pietro Musumeci (University of California, Los Angeles)

In this paper we'll describe the status of the FAST-GREENS experimental program where a 4 m-long strongly tapered helical undulator with a seeded prebuncher is used in the high gain TESSA regime to convert a significant fraction (up to 10 %) of

energy from the 240 MeV electron beam from the FAST linac to coherent 515 nm radiation. We'll also discuss the longer term plans for the setup where by embedding the undulator in an optical cavity matched with the high repetition rate from the superconducting accelerator (3,9 MHz), a very high average power laser source can be obtained. Eventually, the laser pulses can be redirected onto the relativistic electrons to generate by inverse compton scattering a very high flux of circularly polarized gamma rays for polarized positron production.

TUP34

Stability assessment for an XFELO at the European XFEL

Harald Sinn, Immo Bahns (University of Hamburg), Jörg Rossbach (Deutsches Elektronen-Synchrotron), Patrick Rauer (Deutsches Elektronen-Synchrotron)

The stability demands for an X-ray free-electron laser oscillator (XFELO), with a roundtrip length in the range of 133m, are very demanding, since angular stability of about 100nrad and energy shifts of about 100μeV are desirable to ensure a stable operation. The tunnel of European XFEL seems to be seismic sufficiently quiet to enable the alignment of an XFELO without active stabilization. Another problem for the stability of an XFELO is heat load introduced dynamical thermal expansion and related deformation wave propagation. It is expected that the performance of the currently planned demonstrator XFELO at the European XFEL will be limited by heat load effects. Nevertheless, a prospective upgrade using thick diamond crystals may overcome this limitation.

TUP35

Simulations of ultrahigh brightness beams from a plasma photocathode injector

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Plasma photocathode injectors may enable electron beams with normalised emittance at the nm-rad level from a Plasma Wakefield Acceleration (PWFA) stage [1]. These electron beams typically have kA-level peak currents leading to ultrahigh 5D brightness beams with the potential to drive advanced light sources [1]. The feasibility of the plasma photocathode was demonstrated at FACET-I at SLAC [2]. Further experimental campaigns are gradually aiming toward ultrahigh 5D and 6D brightness beams at FACET-II [3]. However, a series of milestones must be reached before these beams can be utilised for XFELs. For example, electron beams accelerated in plasma-based accelerators inherently have a significant energy chirp due to the GV/m accelerating gradients involved. Since energy chirp and energy spread can be detrimental to the high-gain FEL interaction, advanced approaches have been developed for energy spread minimisation of the initially ultrahigh 5D brightness beams towards ultrahigh 6D brightness [4]. Here we show within the framework of the PWFA-FEL project that it may also be possible to produce ultrahigh 5D brightness beams with reduced energy spread using beam-loading. We present results aiming at a trade-off between reduced energy spread, increased peak current, and increased emittance and their application to a soft XFEL in the water window.

TUP36

Quantum to classical transition of free electron interaction with light

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We reveal how free electrons interact with radiation in both classical and quantum regimes, which are common to a wide range of radiation sources such as Free Electron Lasers, Cerenkov radiation, and transition radiation. We exemplify our analysis using the Smith-Purcell and dielectric laser acceleration schemes, both of which are based on stimulated radiative interaction in the near field of a grating. These interactions, which are generally studied in terms of point particle physics, correspond to a phenomena known as "photon-induced near-field electron microscopy" in the quantum limit (PINEM). The initial free-electron state is modeled as a coherent quantum electron wavepacket (QEW) interacting with the near field of a grating illuminated by a coherent laser beam. Three universal distinct interaction regimes in phase space, common to all kinds of electron-light interactions, are identified: point-particle acceleration/deceleration, electron energy sidebands generation by multiphoton emission/absorption (PINEM), and a newly reported anomalous PINEM regime (APINEM). We also investigate the emission of optical-frequency modulation-correlated multiple QEWs beams that produce superradiant emission in the quantum regime, similar to classical superradiant FEL (SASE) emission by periodically pre-bunched point-particles beams.

TUP37

Fabrication and testing of the corrugated waveguide for a collinear wakefield accelerator *

Alexander Siy (University of Wisconsin-Madison), Alexander Zholents (Argonne National Laboratory)
Nader Behdad (University of Wisconsin), William Jansma (Argonne National Laboratory)

A significant progress has been made at Argonne National Laboratory in the development of a compact wakefield accelerator based on a corrugated waveguide with a 2-mm ID and fine corrugations on the wall. The fabrication process of 10-cm long corrugated waveguide structures has been established and a high quality of the final product has been confirmed by precision metrology. These results are described. Several samples were tested using the electron beam at Brookhaven National Laboratory's Accelerator Test Facility. Measurements included a characterization of the wakefield, a determination of frequency for the fundamental longitudinal mode of Cherenkov radiation and three higher frequency transverse modes, and a determination of the fundamental mode group velocity. The results were found to be in an excellent agreement with design values calculated using CST Microwave Studio. Both the experimental results and calculations are described. Plans for continued experimental characterization of the corrugated waveguide based wakefield accelerator will be presented.

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TUP38

A design of a compact XFEL*

Alexander Zholents (anl), Joseph Xu (Argonne National Laboratory)
William Jansma (Argonne National Laboratory)

At Argonne National Laboratory, we envision building an x-ray facility having multiple compact XFEL undulators and beamlines to satisfy a growing demand in life science for a diffraction imaging of aperiodic biological molecules with subnanometer spatial and femtosecond time resolutions. The x-rays photons from 5 keV to 11 keV will be generated via ESASE using an innovative miniature gap, short period phase adjustable undulator. Each XFEL will be paired with Argonne's Sub-Terahertz AcceleRator (A-STAR) that will be fine-tuned to specific performance requirements of the experiment. A-STAR is a collinear wakefield accelerator where a cylindrical corrugated waveguide made from copper is used as a retarded medium. It is designed to deliver the electron beam with up to 5 GeV energy. Unique features of the undulator and accelerator designs will be presented as well as the expected XFEL performance parameters.
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TUP39

Improving the realistic modeling of the EEHG seed section in start to end simulations

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A tunable and multicolor light source with near Fourier-limited pulses, controlled delay, and fully coherent beam with precisely adjustable phase profiles enables state-of-the-art measurements and studies of femtosecond dynamic processes with high elemental sensitivity and contrast. The start-to-end simulations efforts aim to take advantage of the available global pool of software and past and present extensive efforts to provide realistic simulations, particularly for cases where precise and fine manipulation of the beam phase space is concerned. Since, for such cases, tracking of beams with billions of particles through magnetic structures and handover between multiple codes are required, extensive realistic studies for such cases are limited. Here we will describe a workflow that reduces the needed computational resources and share studies of the EEHG seed section for the FLASH2020+ [1] project.

TUP40

Simulations of seeding options for THz FEL at PITZ

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A THz FEL is in preparation at PITZ as a proof-of-principle experiment for a high power and high repetition rate THz source and as an option for THz-driven experiments at the European XFEL. Some of these experiments require excellent coherence and CEP stable THz pulses. In SASE regime the coherent properties of the FEL radiation are limited. A seeding scheme can be used instead of SASE to improve the coherent properties and shot-to-shot stability. Several options for seeding are considered in simulation for the THz FEL at PITZ: external laser pulse, pre-bunched electron beam, energy modulated electron beam and additional short spike. The results of the simulations for each method of seeding are evaluated and compared. The improvements over SASE in energy, spectral and temporal stability of the THz pulse are presented.

TUP41

First Demonstration of Parallel Operation of a Seeded FEL and a SASE FEL

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The FLASH facility houses a superconducting linac powering two FEL beamlines with MHz repetition rate in 10 Hz bursts. Within the FLASH2020+ project, which is taking care of facility development, one major aspect is the transformation of one of the two FEL beam lines to deliver externally seeded fully coherent FEL pulses to photon user experiments. At the same time the second beam line will use the SASE principle to provide photon pulses of different properties to users. Since the electron beam phase space conducive for SASE or seeded operation is drastically different, here a proof-of-principle experiment using the existing experimental seeding hardware has been performed demonstrating the possibility of simultaneous operation. In this contribution we will describe the setup of the experiment and accelerator, and discuss the chances and limitations of the experimental seeding hardware. Finally, we will discuss the results and their implications also for the FLASH2020+ project.

TUP42

Status of the seeding upgrade for FLASH2020+ project

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In the framework of the FLASH2020+ project, the FLASH1 beamline will be upgraded to deliver seeded FEL pulses for users. This upgrade will be achieved by combining high gain harmonic generation and echo-enabled harmonic generation with a wide-range wavelength-tunable seed laser, to efficiently cover the 60-4 nm wavelength range. The undulator chain will also be refurbished entirely using new radiators based on the APPLE-III design, allowing for polarization control of the generated light beams. With the superconducting linac of FLASH delivering electron beams at MHz repetition rate in burst mode, laser systems are being developed to seed at full repetition rates. In the contribution, we will report about the progress of the project.

TUP43

High repetition rate, ultra-low noise and -wavelength stable UV seed laser system for tunable two-color EEHG FEL seeding

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Within the FLASH2020+ project the FLASH VUV/XUV FEL facility at DESY (Hamburg, Germany) is currently undergoing a major upgrade to become the first high repetition rate, fully coherent FEL light source worldwide [1]. To reach this goal, one of the two in parallel operated FEL branches will be seeded at a fixed wavelength at 343 nm in a first step (SEED 1) and tunable between 297 nm to 317 nm in a second step (SEED 2) following the two-color Echo-Enhanced Harmonic Generation (EEHG) scheme [2]. The seed laser system is designed to deliver UV pulse energies > 50 µJ and > 100 µJ for SEED 1 and SEED 2, respectively, and with 6000 pulses in one second (1 MHz pulse trains in 600 µs - 10 Hz bursts). In combination with the EEHG seeding principle, this will allow for the generation of high harmonics corresponding to XUV FEL pulses with photon energies of more than 300 eV (down to 4 nm in wavelength). In order to exploit the full capabilities of the narrow-band fully coherent FEL pulses for 24/7 scientific user experiments, the seed laser needs to provide broadly tunable, high power UV laser pulses with pulse durations of 50 fs, excellent beam quality and exceptional high short and long-term stability in respect to the seeding wavelength (< 2e-4), pulse – pulse

energy (< 2%) and pointing jitter (< 20 µrad). Altogether, the requirements on the laser system are beyond state-of-the-art. We will present the concept as well as the first experimental results of our novel high-power seed laser system based on a 5 kW Inno-Slab CPA pump laser system, optical parametric chirped pulse amplification (OPCPA) and a highly efficient UV conversion scheme. An extensive numerical study based on a 3+1 dimensional start-to-end simulation code (chi3D) allows for a precise predictions of system performance in terms of output power, tunability, beam quality and stability in respect to the measured input parameters and respective statistical and systematic fluctuations. The theoretical results are confirmed by first experimental studies being in excellent agreement in terms of UV conversion efficiency, beam quality and the predicated improvement of the pulse-to-pulse stability compared to the OPCPA stability. The insides of this study had major impact on the conceptual design of the laser system, especially the dispersion concept and the best implementation of user controls, such as power attenuation and fast wavelength control, etc.

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TUP44

Phase-locked hard x-ray self-seeding FEL study for the European XFEL

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Phase-locked pulses are important for coherent control experiments. Here we present theoretical analyses and start-to-end simulation results for the generation of phase-locked pulses using the Hard X-ray Self-Seeding (HXRSS) system at the European XFEL. As proposed in Ref. [1], the method is based on a combination of self-seeding and fresh-slice lasing techniques. However, at variance with Ref. [1], here we exploit different transverse centroid offsets along the electron beam. In this way we may first utilize part of the electron beam to produce SASE radiation, to be filtered as seed and then generate HXRSS pulses from other parts of the beam applying appropriate transverse kicks. The final result consists in coherent radiation pulses with fixed phase difference and tunable time delay within the bunch length. This scheme should be useful for applications such as coherent x-ray pump-probe experiments.

TUP45

Towards seeded high repetition rate FEL: Concept of seed laser beam transport and incoupling

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FLASH2020+ is an upgrade project for the FLASH facility at Hamburg. A main goal of the project is to generate fully coherent soft X-ray FEL radiation at a high repetition rate (MHz). The project will utilize two external laser seeding principles in order to produced Seeded FEL with tunable wavelength from 4-60 nm. In order to achieve this goal, both HGHG (High Gain Harmonic Generation) and EEHG (Echo-Enhanced Harmonic Generation) methods provide FEL emission at harmonics of a seed laser. For HGHG, a tunable UV laser system (297-317 nm) and for EEHG a combination of the tunable UV laser and fixed wavelength (343 nm) laser system would be used to cover the whole range of wavelengths between 4-60 nm. In this contribution, we will describe the requirements of the seed laser to initiate the seeding process and will explain the concept of seed laser beam transport and incoupling into the modulators for FEL radiation production. The first seed laser (Seed1) with fixed wavelength is transported about 28 meters from laser lab to the incoupling chicane. The second seed laser (Seed2) with a tunable UV wavelength is transported about 35 meters.
Our concept uses a full relay imaging system and in vacuum components for the laser transport in addition to high repetition rate diagnostics to deliver, monitor and control the beam and pulse parameters at the interaction with electron beam. We investigate the technical and engineering limitations for the design and address those challenges to provide the demanding seed laser parameters for generating high repetition rate seeded FEL.

TUP46

Characterization of coherent seeded FEL pulses in the presence of incoherent electron beam energy modulations

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Over the last few years tremendous progress has been gained in the theoretical understanding and experimental demonstration of seeded FELs. The ultimate spectral limit of seeded FEL, however, remains unclear, because of the broadening and distortions induced in the output spectrum by residual broadband energy modulations in the electron beam. In this talk, we present the mathematical descriptions of the impact of broadband energy modulations on the EEHG, HGHG and self seeding bunching spectrums produced by the microbunching instability through both the accelerator and the FEL line. We will show the agreement of our models with the systematic experimental characterization seeded FEL spectrums in FERMI and Eu-XFEL. Using experimental data of EEHG FEL performance in FERMI in the photon energy range 130–210 eV, we demonstrate that amplification of electron beam energy distortions primarily in the EEHG dispersive sections explains an observed reduction of the FEL spectral brightness proportional to the EEHG harmonic number. Local maxima of the FEL spectral brightness and of the spectral stability are found for a suitable balance of the dispersive sections' strength and the first seed laser pulse energy[1].
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TUP47

Analysis of spectral contents in Hard Xray self-seeded free-electron laser operation at the European XFEL

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Recently, Hard x-ray self-seeding (HXRSS) operations at the European X-ray free-electron laser (EuXFEL) opened a pathway towards the application of pulses with high spectral density (in terms of ph/eV per pulse) in the fields of applied physics, chemistry and biology, where the coherent radiation spectrum is essential. The spectrum of hard x-ray self seeding pulses is generally accompanied by a pedestal around the central seeded photon energy. The pedestal contains two separate components: normal self-amplified spontaneous (SASE) and sideband emissions that can be ascribed to long-wavelength modulations of the electron beam. The pedestal limits the spectral purity and can impact some user applications. In this report, we analyze the purity of HXRSS pulses in the presence of microbunching instability. We look at the spectral contents after and before saturation, and display the contribution of the pedestal in the HXRSS spectrum.

TUP49

Impact of electron beam energy chirp on optical-klystron-based high gain harmonic generation

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External seeding schemes allow the generation of stable and fully coherent free electron laser (FEL) radiation but can be limited in repetition rates in orders of tens of Hz. This limitation is mainly posed by limited average power of the seed lasers that are required to provide hundreds of MW peak power to modulate the electron bunches. An optical-klystron-based high gain harmonic generation (HGHG) scheme, which can be implemented in several existing and upcoming seeded FEL beamlines with minimal to no additional installations, overcomes this limitation by greatly reducing the required seed laser power. In this work, we carefully study the scheme with detailed simulations that include imperfections of electron beam properties such as a quadratic electron beam energy chirp that characterizes existing FEL facilities. We discuss the optimization steps that in these conditions ensure successful operation, opening the path towards exciting science at FELs with fully coherent and high repetition rate FEL radiation.

TUP50

An XFELO Demonstrator setup at the European XFEL

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An X-ray free-electron laser oscillator (XFELO) is a next generation X-ray source promising radiation with full three-dimensional coherence, nearly constant pulse to pulse stability and more than an order of magnitude higher spectral flux compared to SASE FELs. In this contribution, the concept of an R&D project for installation of an XFELO demonstrator experiment at the European XFEL facility is conceptually presented. It is composed of an X-ray cavity design in backscattering geometry of 133 m round trip length with four undulator sections of 20 m total length producing the FEL radiation. It uses cryocooled diamond crystals and employs the concept of retroreflection to reduce the sensitivity to vibrations. Start to end simulations were carried out which account for realistic electron bunch distributions, inter RF-pulse bunch fluctuations, various possible errors of the X-ray optics as well as the impact of heat load on the diamond crystals. The estimated performance and stability derived from these simulations shall be reported and foreseen issues shall be discussed.

TUP51

FLASH2020+ Project Progress: Current installations and future plans

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The FLASH2020+ project has started to transform the FLASH facility to broaden the facility profile and meet demands of future user experiments. In a nine month lasting shutdown until August 2022 the linear accelerator of the FLASH facility has, among others, been upgraded with a laser heater, new bunch compressors and new modules. The latter results in an energy upgrade to 1.35 GeV allowing to reach sub 4 nm wavelength. In the following long shutdown the FLASH1 FEL beamline will be completely rebuild. The design is based on external seeding at MHz repetition rate in burst mode allowing for coherent tunable FEL radiation in wavelength and polarization by installation new APPLE-III undulators. Post compression of the beam downstream of the radiators will allow for high quality THz generation and together with the new experimental endstations and pump probe lasers provide a unique portfolio for next generation user experiments.

TUP52

The New FLASH1 Undulator Beamline for the FLASH2020+ Project

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The 2nd stage of the FLASH2020+ project at DESY will be an upgrade of the FLASH1 beamline to enable HGHG and EEHG seeding with two modulator-chicane stages, and a radiator section with 11 Apple-III undulators to enable FEL radiation with controllable polarization. A key feature of FLASH, namely the capability of providing several thousand FEL pulses in the extreme UV and soft X-ray must not be compromised.
Downstream of the radiator the beamline houses longitudinal diagnostics, a double bend (quasi-) achromat to separate the electrons from the photons and divert the electron beamline from the photon diagnostics, a post-compressor, a THz-Undulator (requires an electron beam that is compressed more strongly than for seeding), and finally the dumpline, capable of safely aborting up to 100 kW electron beam power.
This article describes the conceptional and some technical details of the beamline with emphasis on the upstream part (modulators and radiator) designed for seeding.

TUP53

Future Upgrade Strategy of the FERMI Seeded FEL Facility

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ABSTRACT: FERMI is implementing a development plan to keep the facility in a world-leading position on the base of the requests coming from the user community and the advises from the Scientific Advisory Council and the Machine Advisory Committee. The ultimate goal of this plan consists in doubling the maximum photon energy available and in reducing the pulse duration below the characteristic lifetime of the atomic core levels in the source spectral range. An upgrade of FERMI aimed at reaching the oxygen K-edge requires a profound modification of the FEL configurations and of the main components of the machine, including the linac and the undulator lines. One of the most promising approaches for this upgrade is to implement the echo-enabled harmonic generation (EEHG) scheme, relying on two external lasers to precisely control the spectrotemporal properties of the FEL pulse. The conversion to EEHG of the first stage of the double-stage harmonic cascade presently in use on FEL-2, would allow to reach harmonics as high as 120, enabling to generate coherent pulses down to 2 nm. The main aspects of the upgrade strategy will be discussed in this contribution.

TUP54

Chirped Pulse Amplification in a seeded FEL: Towards the generation of high-power few-femtosecond pulses below 10 nm

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In optical conventional lasers, chirped pulse amplification (CPA) has become an extremely powerful technique for the generation of ultrashort pulses in the infrared and visible spectral ranges. In this contribution we report the successful implementation of CPA in a seeded XUV FEL. A second experiment, using a two-stage harmonic generation scheme (FERMI FEL-2) has the objective to generate coherent and phase-tailored few-femtosecond FEL pulses, with gigawatt peak power in the sub-10 nm spectral range. This second experiment is still in progress. We will discuss the main scientific and technical bottlenecks and the implications.

TUP55

Recent developments of the laser oscillator synchronization for the FERMI Seed laser

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The local laser synchronization is known to be of high importance for Free Electron facilities, affecting both machine performance and pump-probe FEL-external laser experiments. So, there has been a continuous effort to improve the timing jitter of all machine lasers. One of the main contributions to the overall timing jitter comes from the locking of the local laser oscillators to the reference signal of the facility. Here we describe the latest developments and progress in this direction related to the FERMI seed laser system. The first investigated aspects includes the characterization and optimization of the locking performance of the commercial Ti:Sapphire oscillators Vitara T and HP (Coherent). We present data on the performance of three different oscillators of this type, as well as on the effect of adding an additional cavity length control actuator. The second presented aspect is related to the plan to extend the optical synchronization layout: for some planned seed laser operation modes two Ti:Sapphire oscillator need to be synchronized simultaneously. For this purpose, studies of optimum schemes for locking the two oscillators are in progress, first results are presented.

TUP56

Non-linear harmonics of a seeded FEL at the water window and beyond

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The advent of free electron lasers (FELs) in the soft and hard X-ray spectral region has opened the possibility to probe electronic, magnetic and structural dynamics, in both diluted and condensed matter samples, with femtosecond time resolution. In particular, FELs strongly enhanced the capabilities of several analytical techniques, which took advantage of the high degree of transverse coherence provided. FELs based on the harmonic up-conversion of an external seed laser are characterised also by a high degree of longitudinal coherence, since electrons inherit the coherence properties of the seed. At the present state of the art, the shortest wavelength delivered to user experiments by an externally seeded FEL light source is about 4 nm. We show here that pulses with a high longitudinal degree of coherence (first and second order) covering the water window and with photon energy extending up to 790 eV can be generated by exploiting the so-called nonlinear harmonic regime, which allows generation of radiation at harmonics of the resonant FEL wavelength. Moreover, we report the results of two proof-of-principle experiments: one measuring the oxygen K-edge absorption in water (~ 530 eV), the other analysing the spin dynamics of Fe and Co through magnetic small angle x-ray scattering at their L-edges (707 eV and 780 eV).

TUP57

Frequency pulling in a superradiant FEL amplifier

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Free-electron lasers producing ultrashort pulses with high peak power are a resource to extend ultrafast non-linear spectroscopic techniques into the extreme-ultraviolet–X-ray regime. A super radiant cascade was proposed as a method to shorten the pulse duration in seeded FEL. Pulses shorter than the typical duration supported by the FEL gain bandwidth of the FEL amplifier in the linear regime were measured at FERMI. In these conditions we also observed a strong frequency pulling phenomenon that that will be discussed in this contribution.

TUP58

Studies of wavelength control at FERMI

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FEL basic theory indicates that the output wavelength of a seeded FEL operated in the HGHG configuration is determined by the wavelength of the seed laser and light is emitted when undulators are tuned to one of the harmonics of the seed laser. In a more realistic case, when taking into account the electron beam imperfections and the finite bandwidths of the seed and of the amplification process, the output wavelength is influenced by these factors and there is a small variation from this rule. In this work, we consider the effects of the dispersive section, the curvature of the electron beam longitudinal phase-space and the frequency pulling as major contributors. We show how these quantities influence the effective final FEL wavelength. Furthermore, we show how one can reconstruct the electron beam longitudinal phase-space from the analysis of the FEL wavelength sensitivity to the seed laser delay with respect to the beam arrival time.

TUP59

FERMI FEL-1 Upgrade to EEHG

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In order to meet the user request of extending the FERMI FEL spectral range over the whole water window, we are developing an upgrade strategy that is based on the implementation of the Echo Enabled Harmonic Generation (EEHG) scheme. The FERMI upgrade strategy is structured as follow: during a first phase, the single cascade FEL-1 branch will be adapted to operate either in EEHG or in HGHG. This upgrade can be achieved with relatively low cost and impact on FERMI operations and will improve the spectral range, spectral quality and scheme flexibility of FEL-1. Furthermore, it will provide a versatile test bench opening the possibility to explore in details the EEHG scheme potentialities and address many of the possible issues related to the second and more critical phase of the upgrade project: the upgrade of FEL-2. These two phases will proceed in parallel to the LINAC upgrade to increase the nominal energy. Solutions aiming at a peak beam energy of 1.8 and 2.0 GeV are under study. In this contribution we will focus on the upgrade of the FEL-1 branch that has already started and is foreseen to provide light to users with the new configuration by spring 2023.

TUP61

Spectro-Temporal Characterization of an LPA-Based Seeded FEL

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The recent development of Laser-Plasma Accelerators (LPAs), with acceleration over extremely short distance, led to the dream to use alternatively to the state-of-the-art radio-frequency conventional accelerators the miniaturised compact plasma-based ones. Moreover, combining these new compact accelerators with seeding schemes will permit to develop compact sources with full control of the spectro-temporal contents of the FEL pulses with the potential to produce temporally fully coherent pulses. We here unveil that the forthcoming LPA–based seeded FELs will present distinctive spatio-spectral distributions, with a red-shifted FEL emission and interference pattern. Relying on numerical simulations and simple analytical models, we show how those interferometric patterns can be exploited to retrieve, in single-shot, the spectro-temporal content and source point properties of the FEL pulses.

TUP62

Control of the longitudinal phase and benchmarking to HBSASE

Francesca Curbis (Lund University), Saeid Pirani (Lund University), Mihai Pop (MAX IV Laboratory), Sverker Werin (MAX IV Laboratory)

Improvement of the longitudinal coherence in the proposed Soft Xray FEL, the SXL, for the MAX IV Laboratory is an important design aspect to enhance the user case. One of the main considered methods is HBSASE. However the final compression in the MAX IV acceleratos is done at full energy, and thus leaving an energy chirp in the electron pulse. This chirp in longitudinal phase space has to be removed for an efficient implementation of HBSASE. In this paper we show in simulations how the phase space is improved by first overcompressing the pulse, and then correct it by a two-plate wake field de-chirper. The resulting pulse is then shown to have qualities such that, by HBSASE, a significant narrowing of the FEL bandwidth is achieved at 1 nm.

TUP63

EEHG, compensation of a CSR induced energy chirp

Francesca Curbis (Lund University), Mihai Pop (MAX IV Laboratory), Sverker Werin (MAX IV Laboratory)

Echo Enabled Harmonic Generation is a robust method to improve the longitudinal coherence in a FEL. The method uses a two stage process with two seed laser beams, two modulator undulators and two chicanes. The first of these chicanes needs to be strong to enable reaching high harmonics. Such a strong chicane has previously been shown to induce a modulation in energy due to CSR. In this paper we show in simulations how such a modulation can be mediated by tailoring the second seed laser wavelength. By properly matching of the linear or quadratic component, the EEHG bandwidth can be recovered also in the case of CSR.

TUP64

EEHG seeding scheme at SwissFEL Athos FEL

Adrian Cavalieri, Alexandre Trisorio (PSI), Andreas Dax, Carlo Vicario (PSI), Didier Voulot, Eduard Prat (PSI), Eugenio Ferrari, Gabriel Aeppli (PSI), Hans Braun (PSI), Kittel Christoph, Marco Calvi (Paul Scherrer Institut), Martin Huppert (PSI), Nicole Hiller, Pavle Juranic (PSI), Romain Ganter (Paul Scherrer Institut), Stefan Neppl, Sven Reiche (PSI), Xiaoyang Liang (PSI)

In order to improve the brightness and coherence of the soft x-ray FEL line of SwissFEL (Athos), components for an Echo Enabled Harmonic Generation (EEHG) scheme are currently in preparation. The first components have been installed to allow first ESASE operation test in Spring 2022. This first stage consists in a 10 mJ class seed laser, a U200 modulator with individual control of each half period and a four electromagnets dipole chicane (R56 < 800 um). The large magnetic chicane and the second modulator are still in preparation for an installation by end 2022. This paper will give a technical description of the different systems as well as preliminary results of the commissioning with beam.

TUP65

Laser-based seeding of SwissFEL Athos

Alexandre Trisorio (Paul Scherrer Institut)

Sven Reiche (Paul Scherrer Institut), Chris Arrell (Paul Scherrer Institut), Adrian Liebe Cavalieri (Paul Scherrer Institut and Univerity of Bern), Andreas Dax (Paul Scherrer Institut), Chris Michael Deutschendorf (Paul Scherrer Institut), Philipp Dijkstal (Paul Scherrer Institut), Edwin Divall (Paul Scherrer Institut), Eugenio Ferrari (DESY), Romain

Ganter (Paul Scherrer Institut), Nicole Hiller (Paul Scherrer Institut), Martin Huppert (Paul Scherrer Institut), Rasmus Ischebeck (Paul Scherrer Institut), Pavle Juranic (Paul Scherrer Institut), Stephan Neppl (Paul Scherrer Institut), Eduard Prat (Paul Scherrer Institut), Cezary Sydlo (Paul Scherrer Institut), Carlo Vicario (Paul Scherrer Institut), Didier Voulot (Paul Scherrer Institut), Gabriel Aeppli (Paul Scherrer Institut and ETH Zurich)

In the scope of the HERO ERC project, we are implementing a laser-based seeding scheme at the SwissFEL soft X-ray Athos beamline to generate fully coherent X-ray FEL pulses. With this perspective, we designed and built a new laser facility. It consists of a terawatt-class, femtosecond laser system based on Titanium Sapphire technology with wavelength tuning capability, an optical transfer line as well as a launching optical setup and diagnostics to spatially and temporally overlap the laser and the electron bunch inside the modulator, where the seeding process occurs. We present an overview of the facility with details of the laser performance as well as first commissioning results with the electron beam.

TUP66

High brightness X-ray self-seeded X-ray FEL and its applications at PAL-XFEL

Inhyuk Nam (Pohang Accelerator Laboratory), MyungHoon Cho (Pohang Accelerator Laboratory), Changbum Kim (Pohang Accelerator Laboratory), Chi Hyun Shim (Pohang Accelerator Laboratoty), Chang-ki Min (Pohang Accelerator Laboratory), Heung-Sik Kang (Pohang Accelerator Laboratory)

Nearly fully coherent hard X-ray self-seeded (HXRSS) free-electron laser (FEL) pulses with an unprecedented peak-brightness and a narrow spectrum using the forward Bragg-diffraction (FBD) monochromator has been provided. We have achieved outstanding performance of HXRSS FEL over photon energy range covering from 3.5 keV to 14.6 keV at PAL-XFEL. Furthermore, an averaged energy of seed FEL of ~1mJ is obtained in the range from 5 keV to 10 keV. With these pulses single-shot coherent imaging (SSI) experiment and serial femtosecond crystallography (SFX) were performed. We developed x-ray energy scanning program with the help of double crystal monochromator (DCM), which results in improved spectral impurity and fully calibrated energy scale. With this energy scanning program, we have conducted test experiments such as resonant inelastic X-ray scattering (RIXS) and X-ray emission spectroscopy (XES), femtosecond time resolved X-ray absorption near edge structure (TR-XANES). In this presentation, we present recent experimental results by using the hard X-ray self-seeded FEL with energy scanning at PAL-XFEL.

TUP67

Optimization of the FAST LINAC for a GREENS FEL Experiment

Alex Murokh (RadiaBeam Technologies), Christopher Hall (RadiaSoft LLC), Andrew Fisher (Particle Beam Physics Lab (PBPL)), Ilya Pogorelov (RadiaSoft LLC), Jonathan Edelen (RadiaSoft LLC), Pietro Musumeci (University of California, Los Angeles), Stephen Webb (RadiaSoft LLC), Youna Park (Particle Beam Physics Lab (PBPL))

The FAST-GREENS FEL experiment is aimed at demonstrating extraction efficiencies of greater than 10%. This is accomplished with a high-power seed laser and an aggressively tapered undulator to compensate for the energy loss in the electron beam. A proof of concept experiment will be conducted at the Fermilab Accelerator Science and Technology Facility (FAST) using an undulator specifically built for this purpose. To support this experiment, the LINAC requires a unique setup that optimizes the longitudinal current distribution while preserving emittance in the presence of CSR and space-charge effects. This paper summarizes the beam dynamics optimization performed in support of TESSA and provides the nominal working point for the FEL experiment.

TUP68

Single femtosecond TW FEL pulse generation with hard X-ray chirped pulse amplification

Diling Zhu (SLAC National Accelerator Laboratory)

Haoyuan Li, James MacArthur (SLAC National Accelerator Laboratory), Sean Littleton, Zhirong Huang (SLAC National Accelerator Laboratory)

Chirped pulse amplification has been widely recognized as the corner stone of modern day high field and ultrafast science. Its extension into shorter wavelengths, in particular, towards x-ray wavelengths, has met many challenges. In this paper we propose a system design introducing crystal-optics-based stretcher and compressor into the FEL infrastructure of the Linac Coherent Light Source. We show via numerical modeling that single-femtosecond TW hard x-ray pulses with clean temporal profile can be generated consistently. The realization of this scheme in combination with high throughput x-ray nano focusing can bring the next leap forward in strong field physics and x-ray nonlinear optics.

TUP69

High repetition rate seeded free-electron laser with a harmonic optical klystron in high-gain harmonic generation

Hao Sun (Shanghai Institute of Applied Physics), Georgia Paraskaki (Deutsches Elektronen-Synchrotron), Chao Feng (Shanghai Advanced Research Institute)

External seeding techniques like high-gain harmonic generation (HGHG) and echo-enabled harmonic generation (EEHG) have been proposed and proven to be able to generate fully coherent radiation in the EUV and X-ray range. In this contribution, we will present a harmonic optical klystron scheme in high gain harmonic generation. With the harmonic optical klystron scheme as the seeding technique, the efficiency of harmonic radiation generation is increased, and higher harmonics than in a standard single-stage HGHG can be achieved.

TUP70

Preparatory Experimental Investigations in View of EEHG at the DELTA Storage Ring

Benedikt Büsing (TU Dortmund University)
Arne Held (TU Dortmund), Hubertus Kaiser (TU Dortmund), Shaukat Khan (TU Dortmund), Carsten Mai (TU Dortmund), Arjun Radha Krishnan (TU Dortmund University), Zohair Usfoor (TU Dortmund), Vivek Vijayan (TU Dortmund University)

At DELTA, a 1.5-GeV electron storage ring operated by the TU Dortmund University, the seeding scheme coherent harmonic generation (CHG), the counterpart to high-gain harmonic generation (HGHG) without FEL gain, is used to provide ultrashort pulses in the femtosecond regime at harmonics of the seed-laser wavelength. To provide higher harmonics and thus shorter wavelengths, it is planned to upgrade the short-pulse facility to the echo-enabled harmonic generation (EEHG) scheme, which has yet not been implement at any storage ring. To install the needed three undulators and two chicanes, about a quarter of the storage ring needs to be modified. The paper presents the layout of the envisaged EEHG facility and reviews preparatory experimental studies such as testing the overlap of two laser pulses and seeding at a reduced beam energy, which improves laser-induced energy modulation and increases the longitudinal dispersion of magnetic chicanes.

TUP71

Spectro-temporal properties of coherently emitted ultrashort radiation pulses at DELTA

Arjun Radha Krishnan (TU Dortmund University)
Benedikt Büsing (TU Dortmund University), Arne Held (TU Dortmund), Hubertus Kaiser (TU Dortmund), Shaukat Khan (TU Dortmund), Carsten Mai (TU Dortmund), Zohair Usfoor (TU Dortmund), Vivek Vijayan

At the synchrotron light source DELTA operated by the TU Dortmund University, the short-pulse facility employs the seeding scheme coherent harmonic generation (CHG) to produce ultrashort pulses in the vacuum ultraviolet and terahertz regime. This is achieved via a laser-induced electron energy modulation and a subsequent microbunching in a dispersive section. The spectro-temporal properties of the CHG pulses are influenced by the seed laser properties and can be manipulated by varying the laser chirps and the strength of the dispersive chicane. CHG spectra for different parameter sets were recorded and compared with the results of numerical simulations to reconstruct the spectra. Convolutional neural networks were employed to extract the spectral phase information of the seed laser from the recorded spectra. The results of the studies will be presented.

TUP72

Comparison of the Spectro-Temporal Properties of Echo-Enabled and High-Gain Harmonic Generation Free-Electron Laser Pulses at the 15th Harmonic

Fabian Pannek (University of Hamburg)
Sven Ackermann (Deutsches Elektronen-Synchrotron), Eugenio Ferrari (Deutsches Elektronen-Synchrotron), Lucas Schaper (Deutsches Elektronen-Synchrotron), Wolfgang Hillert (University of Hamburg)

The external seeding scheme Echo-Enabled Harmonic Generation (EEHG) utilizes two modulators and two chicanes to manipulate the longitudinal phase space of an electron beam to achieve bunching at higher harmonics of the seed laser wavelength. Different combinations of energy modulation and longitudinal dispersion can result in the same amount of bunching at a certain harmonic. This study investigates the impact of the choice of the energy modulation amplitudes on the bunching properties and the spectro-temporal characteristics of the free-electron laser (FEL) radiation. Finally, a comparison between EEHG and the single modulator-chicane seeding scheme High-Gain Harmonic Generation (HGHG) at the 15th harmonic of the seed laser wavelength is presented. The corresponding numerical modelling and simulations are performed within the parameter range of the future upgrade of the FEL user facility FLASH at DESY.

TUP73

Sensitivity of Echo-Enabled Harmonic Generation to Seed Power Variations

Fabian Pannek (University of Hamburg)
Sven Ackermann (Deutsches Elektronen-Synchrotron), Eugenio Ferrari (Deutsches Elektronen-Synchrotron), Lucas Schaper (Deutsches Elektronen-Synchrotron), Wolfgang Hillert (University of Hamburg)

The external seeding technique Echo-Enabled Harmonic Generation (EEHG) consists of two undulators which are used to

imprint energy modulations to an electron bunch via interaction with a seed laser. Each of these so-called modulators is followed by a chicane introducing longitudinal dispersion. Proper adjustment of the amplitudes of the energy modulations and dispersive strengths allows to achieve bunching at high harmonics of the seed laser wavelength. In the near future, this seeding scheme will be utilized in one of the beamlines of the free-electron laser (FEL) user facility FLASH at DESY to provide stable seeded radiation down to the soft X-ray regime at high repetition rate. Dedicated numerical simulations are carried out within the foreseen parameter space to investigate how variations of the energy modulations due to power fluctuations of the two seed lasers affect the bunching properties and the stability of the generated FEL radiation.

TUP74

Calculation of the CSR effect in EEHG simulations

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Externally seeded FELs can produce fully coherent short-wavelength pulses with the advantage of higher shot-to-shot stability and spectral intensity than SASE radiation. For the FLASH2020+ project, the Echo-Enabled Harmonic Generation (EEHG) seeding technique achieves seeded FEL radiation in the XUV and soft X-ray range down to wavelengths of 4 nm. The implementation of the EEHG requires precise phase space manipulations in the seeding section of the beamline, which would make the performance of the EEHG sensitive to the collective effects, such as Coherent Synchrotron Radiation (CSR) in some working range. Therefore, it is essential to consider the CSR in EEHG simulations and to understand its impact on the electron beam properties. In this work, we compare different methods for calculating CSR and investigate the mechanism of its effect on the EEHG performance.

TUP75

ARIA, a VUV beamline for EuPRAXIA@SPARC_LAB

Luca Giannessi (INFN-Laboratori Nazionali di Frascati, Elettra-Sincrotrone Trieste), Michele Opromolla (Università degli Studi di Milano, INFN-Milan), Alberto Petralia (ENEA), Fabio Villa (INFN-Laboratori Nazionali di Frascati), Marcello Coreno (INFN-Laboratori Nazionali di Frascati, CNR, Elettra-Sincrotrone Trieste), Zeinab Ebrahimpour (INFN-Laboratori Nazionali di Frascati), Federico Nguyen (ENEA), Vittoria Petrillo (Università Statale degli Studi di Milano, INFN-Milan), Andrea Selce (INFN-Laboratori Nazionali di Frascati), Francesco Stellato (University of Rome Tor Vergata, INFN-Rome), Augusto Marcelli (INFN-Laboratori Nazionali di Frascati, CNR, Elettra-Sincrotrone Trieste, RICMASS)

EuPRAXIA@SPARC_LAB is a new Free Electron Laser (FEL) facility that is currently under construction at the Laboratori Nazionali di Frascati of the INFN. The electron beam driving the FEL will be delivered by an X-band normal conducting LINAC followed by a plasma wakefield acceleration stage. It will be characterized by a small footprint and include two different plasma-driven photon beamlines. In addition to the soft-X-ray beamline, named AQUA and delivering ultra-bright photon pulses for experiments in the water window to the user community, a second beamline, named ARIA, has been recently proposed and included in the project. ARIA is a seeded FEL line in the High Gain Harmonic Generation configuration and generates coherent and tunable photon pulses in the range between 50 and 180 nm. Here we present the potentiality of the FEL radiation source in this low energy range, by illustrating both the layout of the FEL generation scheme and simulations of its performances.

TUP76

Transversally separated crossed polarized FEL subpulses

Filippo Sottocorona (Elettra-Sincrotrone Trieste S.C.p.A.), Giovanni Perosa (Università degli Studi di Trieste) Antonio Caretta (Elettra-Sincrotrone Trieste S.C.p.A.), Carlo Spezzani (Elettra-Sincrotrone Trieste S.C.p.A.), David Garzella (Elettra-Sincrotrone Trieste S.C.p.A. SS 14 - km 163,5 in Area Science Park I - 34149 Basovizza), Enrico Allaria (Elettra-Sincrotrone Trieste S.C.p.A.), Filippo Bencivenga (Elettra-Sincrotrone Trieste S.C.p.A.), Giovanni De Ninno (Elettra-Sincrotrone Trieste S.C.p.A.), Giuseppe Penco (Elettra-Sincrotrone Trieste S.C.p.A.), Laura Foglia (Elettra-Sincrotrone Trieste S.C.p.A.), Luca Giannessi (INFN-Laboratori Nazionali di Frascati, Elettra-Sincrotrone Trieste), Mauro Trovo (Elettra-Sincrotrone Trieste S.C.p.A.), Primoz Rebernik Ribic (Elettra-Sincrotrone Trieste S.C.p.A.), Riccardo Mincigrucci (Elettra - Sincrotrone Trieste), Simone Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.), Simone Laterza

The extension of four-wave mixing (FWM) technique to the extreme ultraviolet and soft X-ray ranges allows to monitor the dynamics of coherent excitations of matter, when realized with the exquisite coherent property of bright FEL pulses. We show for the first time a scheme to provide transversally separated pulses with parallel or crossed linear polarizations, realized at FERMI FEL. This configuration paves the way to explore additional features of pump&probe and FWM techniques, and, in particular, the possibility to excite a transient polarization grating on the sample. For this reason, such a technique is important the detection of circular dichroism and chiral properties of matter and the characterization of spin waves and

magnons. By tailoring the electrons trajectory along the undulator line, we demonstrate the possibility of deliver balanced and stable couple of pulses with an horizontal separation of the order of millimeters at the experimental station.

TUP77

Design considerations of high repetition rate VUV FEL

Pavel Evtushenko (Helmholtz-Zentrum Dresden-Rossendorf)
Alec Wodtke (Max Planck Institute for Multidisciplinary Sciences)

A new concept of a high repetition rate VUV FEL is discussed. The FEL is envisioned to operate in the wavelength range from 50 to 250 nm with pulse energies of about 30 μJ throughout the wavelength range, and a pulse length of a few 100 fs. The SRF LINAC technology developed and used at the Helmholtz-Zentrum Dresden-Rossendorf for the Radiation Source ELBE is planned to be used for the driver-accelerator. This allows operating an electron beam with an average current of 1 mA on the order of magnitude, pulse repetition rate of up to 10 MHz, and the bunch charge of 100 pC, as used for the FEL design. We consider using the HGHG to allow the generation of fully coherent pulses. The high repetition rate electron beam makes it possible to construct an FEL oscillator that would be used as the high repetition rate seed of the HGHG amplifier. In the proposed scheme, the SRF LINAC provides beams for the seeding oscillator and the HGHG amplifier simultaneously. The described FEL would create new experimental regimes, not available at any other photon source. These could result in transformative changes in physical chemistry studies in the gas phase and at the interfaces, e.g., heterogeneous catalysis.

WEA – Electron sources

24 August 8:45 – 10:35

Chair: Fernando Sannibale (Lawrence Berkeley National Laboratory)

WEAI1 / 08:45

Review of recent photocathode advancements

Laura Monaco (Istituto Nazionale di Fisica Nucleare)

Photocathodes are routinely used as a source of electrons in high brightness beam photoinjectors. The properties of the photocathode have a significant influence on the parameters of the electron beams and on the operation of the machines. The choice of photocathode materials is an important step in reaching the challenging requirements of modern accelerators. Recent advancements towards more performing photocathodes are here presented and discussed.

WEAI2 / 09:15

First Commissioning of LCLS-II Injector

Feng Zhou (SLAC National Accelerator Laboratory)

The 1-MeV LCLS-II electron source including CW RF gun and buncher was successfully commissioned 2018-2020. Since then, a few upgrades has been implemented. Full scale of LCLS-II injector including the upgraded 1-MeV electron source, one standard 100-MeV Cryomodule, essential diagnostics for beam performance characterizations is being commissioned since late March 2022. This report will present technical progresses and challenges of the injector commissioning and measurements of e-beam performance as well as dark current.

WEAO3 / 09:45

Continuous-wave operation of a low-emittance DC-SRF photocathode gun

Senlin Huang (Peking University)

Dongming Ouyang (Peking University), Fang Wang (Peking University), Fei Jiao (Peking University), Feng Zhu (Peking University), Gai Wang (Peking University), Hang Xu (Institute of High Energy Physics, CAS), Haoyan Jia (Peking University), Huamu Xie (Peking University), Jiankui Hao (Peking University), Juntao Liu (Peking University), Kexin Liu (Peking University), Lin Lin (Peking University), Lina Wang (Peking University), Liwen Feng (Peking University), Manqian Ren (Peking University), Sheng Zhao (Peking University), Shengwen Quan (Peking University), Tao Tan (Peking University), Tianyi Li (Peking University), Tianyi Wang (Peking University), Tong Wu (Peking University), Xiang Zhang (Peking University), Yonglong Zhao (Peking University), Yue Huang (Peking University), Yunqi Liu (Peking University), Zeqin Yao (Peking University), Zhitao Yang (Peking University), Zhongqi Liu (Peking University), Zhongxiang Xu (Peking University), Ziyu Wang (Peking University)

DC-SRF gun, a DC and superconducting rf (SRF) combined photocathode electron source, has been developed at Peking University for nearly 20 years. Recently, a low-emittance version of DC-SRF gun, DC-SRF-II, was brought into stable CW operation with a DC voltage of 100 kV and an SRF cavity gradient of 13 MV/m, under which condition the dark current was measured to be lower than 0.001 nA. Normalized RMS emittances (with 95% particles) of about 0.5 mm-mrad, 0.85 mm-mrad, and 1.25 mm-mrad have been achieved at the bunch charge of 20 pC, 100 pC, and 260 pC, respectively, and with an electron energy gain of 2 MeV. In this work we will present the detailed results of our latest experiments.

WEAO4 / 10:10

Chirped Pulse Laser Shaping for High Brightness Photoinjectors

Christian Koschitzki (Deutsches Elektronen-Synchrotron DESY at Zeuthen)

Zakaria Aboulbanine (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Gowri Adhikari (DESY, Zeuthen), Namra Aftab (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Prach Boonpornprasert (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Georgi Georgiev (Deutsches Elektronen-Synchrotron DESY at Zeuthen), James Good (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Matthias Gross (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Andreas Hoffmann (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Mikhail Krasilnikov (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Xiangkun Li (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Osip Lishilin (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Anusorn Lueangaramwong (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Raffael Niemczyk (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Anne Oppelt (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Houjun Qian (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Frank Stephan (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Grygorii Vashchenko (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Tobias Weilbach (Deutsches Elektronen-Synchrotron DESY at Zeuthen), Winfried Decking (Deutsches Elektronen-Synchrotron), Ingmar Hartl (Deutsches Elektronen-Synchrotron)

Photoemission laser shaping is essential for both beam brightness and advanced accelerator concepts, therefore is an important R&D at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The laser pulse shaper presented here is based on spectral amplitude modulation of chirped laser pulses. In this approach one can do temporal-spatial coupled laser shaping, i.e. 3D shaping. The laser shaping is done at 1030 nm with spatial light modulators, and then converted to 257.5 nm through harmonic generation for photoemission. Experimental results of laser pulse shaping and shape preservation through harmonic generation are presented for different cases: spatial shaping, temporal shaping and full 3D shaping. Electron beam testing results will also be presented.

WEB – Electron beam dynamics

24 August 11:00 – 12:50

Chair: Sara Thorin (MAX IV Laboratory)

WEBI1 / 11:00

Comparison of Eulerian, Lagrangian and Semi-Lagrangian Simulations of Phase-Space Density Evolution

Philipp Amstutz (Deutsches Elektronen-Synchrotron)

Good understanding of the underlying beam dynamics is mandatory for the successful design and operation of Free-Electron Lasers. In particular, it is important that all physically relevant collective effects are adequately represented in simulation codes so that their influence on the phase-space evolution of the bunch can be calculated with sufficient accuracy at all relevant length scales. Besides coherent collective effects such as space charge or coherent radiative interaction also incoherent effects such as intra-beam scattering are suspected to have a significant impact on the efficacy of sophisticated lasing techniques. Most of the well-known and widely-used beam dynamics codes employ the Lagrangian approach, in which the particle bunch is represented by discrete points in phase-space and track the solutions of their equations of motion. In contrast to that, in the Eulerian and semi-Lagrangian approach, the bunch is described by a numerical representation of its phase-space density function. This contribution discusses the working principles of the three classes of simulation methods Lagrangian, Eulerian, and semi-Lagrangian and highlights their respective advantages and short-comings, when applied to the simulation of collective beam dynamics in FELs.

WEBI2 / 11:30

First evidence of intrabeam scattering in an electron linac, and impact on short wavelength FELs

Giovanni Perosa (Università degli Studi di Trieste)

To date, the main obstacle to the extension of free electron lasers' longitudinal coherence to the water window and beyond is the detrimental effect of spurious harmonic content in the longitudinal profile of electron bunches, namely the microbunching instability. Intra-beam scattering is another (less known) collective effect that consists of multiple (small-angle) soft Coulomb scattering of electrons inside a bunch. The inclusion of this electronic scattering in MBI model has proved to be an essential step to more faithful predictions of the beam energy spread and characterization of spurious content. Analytical expressions for intra-beam scattering in single pass linacs and multi-bend transfer lines are presented and included in two different semi-analytical description of microbunching. The overall modeling turns out to be a fast comprehensive tool for the optimization of linac-driven free-electron lasers.

WEBO3 / 12:00

Energy spread blow-up by intra-beam scattering and micro-bunching at the SwissFEL injector

Alexander Malyzhenkov (Paul Scherrer Institut), Eduard Prat (Paul Scherrer Institut), Eugenio Ferrari, Giovanni Perosa (University of Trieste, Elettra Sincrotrone Trieste), Paolo Craievich (Paul Scherrer Institut), Philipp Dijkstal (Paul Scherrer Institut), Simone Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.), Sven Reiche (Paul Scherrer Institut), Thomas Lucas (Paul Scherrer Institut)

High-resolution measurements of the uncorrelated energy spread at SwissFEL indicate energy spread levels much larger than predicted by state-of-the-art particle tracking. This contribution presents measurements of the energy spread at the SwissFEL injector as a function of the electron bunch charge, the optics and the longitudinal dispersion of the lattice. The results indicate that both intra-beam scattering and micro-bunching, not covered in the conventional modeling of injectors, cause a blow-up of the energy spread. The work underlines the importance of considering the energy spread in the optimization and design of high-brightness electron beam sources and the need to develop new models to adequately understand and simulate the observed physics effects.

WEBO4 / 12:25

Characterization of the European XFEL pulses in the presence of Microbunching instabilit

Najmeh Mirian (Deutsches Elektronen-Synchrotron)

One of the serious issues for short electron bunches in electron beam accelerators is the microbunching instability driven by longitudinal wake fields along the accelerator. Over the last decades a tremendous effort has been made in the theoretical understanding and experimental study of the microbunching instability impact on free electron laser performances. At the European XFEL, the compression of the electron beam to high peak current is achieved through three bunch compressors. Normally, the compression factor is more than 100, resulting in around 25 fs RMS bunch length. This high compression factor transfers the microbunching wavelengths to the visible or (very) near infrared radiation wavelength. In this presentation, we discuss our recent MBI study and measurements in European XFEL. By using the matrix model for collective space charge and coherent synchrotron radiation phenomena in electron beam longitudinal phase space and considering existing theories of intera beam scattering, in single pass linacs and multi-bend transfer lines [1], we theoretically characterize the MBI after each bunch compressor at European XFEL machine. We verify our theoretical prediction with longitudinal phase space and FEL radiation measurement.

[1] G. Pasao, S. Di Mitri Scientific Reports 11:7895 (2021)

WEC – Novel acceleration and FEL concepts

24 August 14:10 – 16:00

Chair: Amin Ghaith (Laboratoire de Physique des Lasers, Atomes et Molécules)

WECI1 / 14:10

Free-electron Lasing Based on a Laser Wakefield Accelerator

Wentao Wang (Shanghai Institute of Optics and Fine Mechanics)
Ke Feng (Shanghai Institute of Optics and Fine Mechanics), Ruxin Li (Shanghai Institute of Optics and Fine Mechanics)

Laser wakefield accelerators can sustain accelerating gradients more than three orders of magnitude higher than those of radio-frequency accelerators, and are regarded as an attractive option for driving compact X-ray free-electron lasers. However, the realization of such devices remains a challenge owing to the relatively poor quality of electron beams that are based on a laser wakefield accelerator. After ten years of efforts, we present an experimental demonstration of undulator radiation amplification in the exponential-gain regime by using electron beams based on a laser wakefield accelerator. The amplified undulator radiation, which is typically centred at 27 nanometres and has a maximum photon number of around 1010 per shot, yields a maximum radiation energy of about 150 nanojoules. The results constitute a proof-of-principle demonstration of free-electron lasing using a laser wakefield accelerator, and pave the way towards the development of compact X-ray free-electron lasers based on this technology with broad applications. In future, a laboratory-scale, ultra-brilliant FEL (around 10 m in size), with the advantages of low cost (~US$5 million), high temporal resolution (femtosecond-level), high resolution (nanometre-level), and ultra-high precision timing control (less than 1 fs), could gain popularity.

WECI2 / 14:40

First SASE and Seeded FEL Lasing based on a beam driven wakefield accelerator

Mario Galletti (Istituto Nazionale di Fisica Nucleare)

The breakthrough provided by plasma-based accelerators enabled unprecedented accelerating fields by boosting electron beams to GeV energies within few cm.
This enables the realization of table-top accelerators able to drive a Free-Electron Laser (FEL), a formidable tool to investigate matter at sub-atomic level by generating X-UV coherent light pulses with fs and sub-fs durations.
So far, short wavelength FELs had to rely on the use of conventional large-size radio-frequency (RF) accelerators due to the limited accelerating fields provided by such a technology.
Here we report the experimental evidence of a FEL driven by a compact (3 cm) plasma accelerator. The accelerated beams are characterized in the six-dimensional phase-space and have a quality, comparable with state-of-the-art accelerators. This allowed the observation of amplified SASE radiation in the infrared range with typical pulse energy exponential growth, reaching tens of nJ over six consecutive undulators.
On the basis of these first amplification results starting from spontaneous emission (SASE), we upgraded the setup by seeding the amplifier with an external laser. Compared to SASE, the seeded FEL pulses are characterized by a higher pulse energy, two orders of magnitude larger (up to about 1 uJ) and an enhanced reproducibility (up to about 90%) resulting in a higher shot-to-shot stability.

WECO3 / 15:10

First laser plasma accelerator based seeded FEL

Alexander Debus (Helmholtz-Zentrum Dresden-Rossendorf), Amin Ghaith (Helmholtz-Zentrum Dresden-Rossendorf), Eléonore Roussel (Laboratoire de Physique des Lasers, Atomes et Molécules), Marie Labat (Synchrotron Soleil), Alexandre Loulergue (Synchrotron SOLEIL), Anthony Berlioux (Synchrotron Soleil), Arie Irman (Helmholtz-Zentrum Dresden-Rossendorf), Bruno Leluan (Synchrotron Soleil), Carlos de Oliveira (Synchrotron Soleil), Charles Kitegi (Synchrotron Soleil), Christian Herbeaux (Synchrotron Soleil), Christoph Eisenmann (Helmholtz-Zentrum Dresden-Rossendorf), Cédric Thaury (LOA), Damien Pereira (Synchrotron Soleil), Driss Oumbarek Espinos (Osaka University), Fabien Briquez (Synchrotron SOLEIL), Fabrice Marteau (Synchrotron Soleil), François Bouvet (Synchrotron SOLEIL), Frédéric Blache (Synchrotron SOLEIL), Jean-Paul Ricaud (Synchrotron SOLEIL), Jean-Pierre Duval (Synchrotron Soleil), José Vétéran (Synchrotron SOLEIL), Julien Gautier (Laboratoire d'Optique Appliquée), Jurjen Couperus Cabadag (Helmholtz-Zentrum Dresden-Rossendorf), Keihan Tavakoli (Synchrotron Soleil), Man Huy N Guyen (Synchrotron SOLEIL), Marc Vandenberghe (Synchrotron SOLEIL), Marie-Emmanuelle Couprie (Synchrotron Soleil), Mathieu Valléau (Synchrotron SOLEIL), Maxwell LaBerge (The University of Texas at Austin), Michael Kuntzsch (Helmholtz-Zentrum Dresden-Rossendorf), Mourad Sebdaoui (Synchrotron SOLEIL), Moussa El Ajjouri (Synchrotron Soleil), Nicolas Hubert (Synchrotron Soleil), Olena Kononenko (Laboratoire d'Optique Appliquée), Pascal Rousseau (LOA), Patrick Rommeluere (Synchrotron SOLEIL), Patrick Ufer (HZDR), Philippe Berteaud (Synchrotron SOLEIL), Rene Gebhardt (Helmholtz-Zentrum Dresden-Rossendorf), Richard Pausch (Helmholtz-Zentrum Dresden-Rossendorf), Simon Grams (Helmholtz-Zentrum Dresden-Rossendorf), Stefan Bock, Stéphane Lé (Synchrotron SOLEIL), Susanne Schöbel (HZDR), Sébastien Corde (LOA), Thomas Püschel (HZDR), Ulrich Schramm (HZDR), Uwe Helbig (Helmholtz-Zentrum Dresden-Rossendorf), Victor Malka (Weizmann Institute of Science), Yannick Dietrich (Synchrotron Soleil), Yen-Yu Chang (Helmholtz-Zentrum Dresden-Rossendorf)

We report the first lasing of a seeded FEL fully driven by a laser plasma accelerator. The experiment was performed at HZDR (Germany), coupling the high quality electron beams of the HZDR laser plasma accelerator with the versatile COXINEL beam manipulation line. Using an external seed at 270 nm, the FEL signal was observed at 275 nm. We explain how this slight red-shift confirms previous predictions [1], show the precise control over the FEL wavelength and give evidence of the longitudinal coherence of the emitted pulses. All experimental results are strongly supported by analytic modeling and Genesis numerical simulations. Our results substantiate the continuous progress of LPA technology to enable FEL operation and finally bring temporal coherence to those compact promising sources. [1] M Labat et al 2020 New J. Phys. 22 013051.

WECO4 / 15:35

Bridging the gap of storage ring light sources and linac-driven free-electron lasers

Bruno Diviacco (Elettra Sincrotrone Trieste), Massimo Cornacchia (Elettra Sincortrone Trieste (retired)), Simone Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.), Filippo Sottocorona (University of Trieste, Elettra Sincrotrone Trieste), Giovanni Perosa (University of Trieste, Elettra Sincrotrone Trieste), Simone Spampinati (Elettra Sincrotrone Trieste)

High-gain free-electron lasers (FELs) are driven by short, high-charge density electron beams as only produced at dedicated single pass or recirculating linear accelerators. We describe new conceptual, technical, and modeling solutions to produce subpicosecond, up to ~100 μJ-energy extreme ultra-violet and soft x-ray FEL pulses at high and tunable repetition rates, from a diffraction-limited storage ring light source. In contrast to previously proposed schemes, we show that lasing can be simultaneous to the standard multibunch radiation emission from short insertion devices, and that it can be obtained with limited impact on the storage ring infrastructure. By virtue of the high-average power but moderate pulse energy, the storage ring-driven high-gain FEL would open the door to unprecedented accuracy in timeresolved spectroscopic analysis of matter in the linear response regime, in addition to inelastic scattering experiments.

WE121 – One-to-one meetings with experts in project building 2

24 August 16:00 – 17:30

WE1211

Wayforlight and beamtime proposals

Cecilia Blasetti (Elettra-Sincrotrone Trieste S.C.p.A.)

Discover the wayforlight.eu portal to find out the most suitable instruments for your research and get useful tips to draft a successful beamtime proposal

WE1212

Laserlab-Europe

Sylvie Jacquemot (Ecole Polytechnique)

Become aware of transnational access support tools, joint research and training opportunities offered by the Laserlab-Europe Consortium

WE1213

Horizon Europe programmes and grants for all stages of research careers

Marina Kozlik Mercatelli

Get introduction and assistance on funding possibilities for researchers from all over the world

WE1214

Euraxess - an European network to support mobility and career development for researchers

Anna Comini (Consorzio per l'AREA di ricerca scientifica e tecnologica di Trieste)

Get information on how to apply for research jobs in Europe

WEP – Poster Session

24 August 16:00 – 17:30

Electron Beam Dynamics, Electron Diagn., Timing, Synch. & Controls, Photon Beamline Instrum. & Undulators

WEP01

Design of a New Beamline for the ORGAD Hybrid RF-Gun at Ariel University

Amir Weinberg (Ariel University), Ariel Nause (Ariel University)

The ORGAD Hybrid RF-gun which was commissioned in Ariel University is based on a smaller-scale prototype built at UCLA's Particle Beam Physics Laboratory (PBPL) as an on-going collaboration between the Universities. The main beamline of the hybrid S-band (2856 [MHz]) photo injector is currently driving a 150[kW], short pulse THz-FEL. In order to use the RF gun for other applications, a new and independent beam line is required. The secondary beamline is only feasible with the design of a dispersive beam-line dogleg section. High quality of the secondary beam is crucial for the designated applications such as Ultra-fast Electron Diffraction (UED). We present full 3D GPT (General Particle Tracer) simulations of this secondary beamline in which we manipulate the beam, compress the beam and maintain beam emittance and pulse duration. An optimization procedure of the design was performed to reconstruct the electron beam quality parameters after passing through the dispersive dogleg section. The optimization procedure is based on transfer matrices and simulations using realistic field-maps and fringe fields of the quadrupoles which were designed in-house, and their 3D field maps were exported using CST (Computer Simulation Technology. We present the optimization results with the improved beam quality.

WEP02

Correlation of orbit disturbance in the photoinjector with SASE performance at the European XFEL

Ye Chen (Deutsches Elektronen-Synchrotron)

We present experimental observation for the impact of an introduced orbit disturbance in the photoinjector section on the SASE performance at the European XFEL. An orbit bump is first created and then closed by the orbit feedback downstream, that is, the orbit leaving the injector section stays the same while presumably only causing a disturbance to the bunch. With the same orbit launched into the undulators, first measurement data have shown a correlation between the magnitude of the introduced orbit disturbance in the injector and the SASE intensity in the undulators. Similar behaviors are observed as well for bunch train operation. The results will be shown and the discussions are given.

WEP03

The impact and mitigation of Coherent Synchrotron Radiation for a new set of undulators at the EUXFEL

Stuart Walker (Deutsches Elektronen-Synchrotron)

The EUXFEL at DESY is a 3.4km long linac and the highest energy XFEL in the world. In total 1.7km of the length of the machine is used for acceleration using superconducting RF cavities. Downstream of the acceleration section are sets of undulators, where peak currents on the order of 5kA must be reached to achieve adequate lasing. To make the most use of this high-quality, high-energy beam, the linac bifurcates at about 1.9km along the machine, with the beam delivered to two different tunnels T1 and T2, containing one and two sets of undulators, respectively. Retained as an optional future upgrade is the possibility of digging an extra tunnel (called T20) from the switchyard and installing another set of undulators within. However, bending such a short beam from the switchyard introduces challenging beam quality preservation problems due to the effects of coherent synchrotron radiation (CSR). This increases the beam's transverse emittances and harms the lasing in the undulators. In this paper the impact of CSR, limits on the beam quality in the T20 beamline, as well as possible mitigation strategies for optimal lasing downstream, are presented and discussed.

WEP04

Upgrade to the transverse optics matching strategy for the FERMI FEL

Alexander Brynes (Elettra-Sincrotrone Trieste S.C.p.A.), Mauro Trovo (Elettra-Sincrotrone Trieste S.C.p.A.), Simone Spampinati (Elettra Sincrotrone Trieste)

Good control over the transverse distribution of an electron bunch is crucial for optimising the beam transport through a linear accelerator, and for improving the energy transfer of electrons to photons within the undulators of a free-electron laser (FEL). In order to achieve this, it is necessary to match, as closely as possible, the Twiss parameters of the electron bunch to the design values. This is done, in the case of the FERMI FEL, by finding the optimal quadrupole strengths in various matching sections using a particle tracking code. This contribution reports an upgrade to the matching tools in use in the FERMI control room: the functionalities of two existing programs have been merged into a single tool; and some new options are available in order to provide more flexibility when performing transverse optics matching.

WEP05

Wakefield Calculations of the Undulator Section in FEL-I at the SHINE

He Liu (Shanghai Institute of Applied Physics)

Jiawei Yan (European XFEL GmbH), Haixiao Deng (Shanghai Advanced Research Institute Chinese Academy of Science), Bo Liu (Shanghai Advanced Research Institute Chinese Academy of Science), Hanxiang Yang (Shanghai Institute of Applied Physics)

In free electron lasers (FEL) the accumulative effects of wakefields always lead to critical impacts on the electron bunch, resulting in an energy spread and deviation of transverse position. Thus the lasing performance will be decreased. The Shanghai high-repetition-rate XFEL and extreme light facility (SHINE) is under construction and the wakefields estimations are required. The SHINE contains three different undulator lines (FEL- I- III) designed for different functions. The wakefields of FEL-I undulator section has been studied in our work before. However the wakefields of inner segments between undulators are calculated simply. In this paper, we calculate the wakefields of inner segments considering more exquisite structures in FEL-I. We consider gradual changed connections between beam pipes of different diameters and dechirpers. We compared wakefields of different schemes of inner segments. Based on the results, we give some suggestions for the designation of the inner segments in FEL-I.

WEP06

Laser Plasma Accelerator based seeded FEL commissioning on COXINEL at HZDR

Amin Ghaith (HZDR)

Alex Loulergue (Synchrotron SOLEIL), Marie Labat (Synchrotron SOLEIL), Jurjen Couperus (HZDR), Eleonore Roussel (PHLAM), Marie-Emmanuelle Couprie (Synchrotron SOLEIL), Arie Irman (HZDR), Ulrich Shramm (HZDR)

The tremendous developments on Laser Plasma Accelerators (LPAs) have significantly improved the electron beam properties and stability making it possible to drive a Free Electron Laser (FEL). We report on the electron beam transport and manipulation using the COXINEL beamline implemented at HZDR that has recently led to the first measurements of an LPA-based seeded FEL in the UV region. Our experiment, cross-checked with ELEGANT simulations, shows that the beamline enables the handling of the large divergence via high gradient quadrupoles, reducing the slice energy spread with the help of a chicane, controlling the position and dispersion in both transverse planes using beam pointing alignment compensation and implementing the super matching optics. We also show that the beamline properly allows for the spectral tuning and spatial overlapping between the electron beam and the seed, using electron and photon beam diagnostics, and thus making LPA based FEL amplification within reach.

WEP07

Longitudinal bunch shaping using sextupoles in the MAX IV non-linear compressors

Sara Thorin (MAX IV Laboratory)
Erik Mansten (MAX IV Laboratory), Mathias Brandin (MAX IV Laboratory), Joel Andersson (MAX IV Laboratory)

The MAX IV linac is used for both injection to two storage rings and as a high brightness driver for a short pulse facility (SPF). Compression is done in two non-linear achromat compressors using sextupoles for longitudinal bunch shaping and linearization. In this paper we investigate the sextupole influence on longitudinal bunch shape and bunch length after the first compressor and compare to simulated results.

WEP08

Simulation Study of a Dielectric Beam Energy Dechirper for the Proposed NSRRC EUV FEL Facility

Chih-Kai Liu (Department of Physics, NCU, Taoyuan, Taiwan), Shih-Hung Chen (Department of Physics, National Central University), Wai-Keung Lau (National Synchrotron Radiation Research Center), Shan You TENG (Department of Physics, National Central University), Wei-Yuan Chiang (National Synchrotron Radiation Research Center)

In this report, we present a simulation study of dielectric beam energy dechirper designed for the proposed NSRRC EUV FEL facility. As revealed from ELEGANT simulation of the high brightness driver linac system, a residual energy chirp of about 42 keV/μm is left after bunch compression. It can be corrected by a capacitive dechirper structure when the bunch is slightly over-compressed. We successfully used a 1-m long corrugated pipe to remove the residual energy chirp in such simulation. However, in order to save space and for a simplified mechanical design, we consider also the usage of two orthogonally oriented planar dielectric-lined waveguide (DLW) structures to remove residual energy chirp after bunch compression. Wake fields due to this DLW dechirper has been calculated by CST code and the deduced wake function will be used in particle tracking using ELEGANT.

WEP09

Design Consideration for the Extraction Line of the Proposed Third Beamline Porthos at SwissFEL

Mattia Schaer (Paul Scherrer Institute), Sven Reiche (Paul Scherrer Institut), Paolo Craievich (Paul Scherrer Institut), Thomas Schietinger (Paul Scherrer Institut)

It is planned to extend SwissFEL by a third beamline, named Porthos, operating in the hard X-ray regime. Three bunches will be accelerated within one RF pulse and distributed into the different beamlines with resonant kickers operating at the bunch spacing of a few tens of nanoseconds. While the full extent of Porthos will not be realized before the end of this decade the extraction line from the main linac will also serve the P^3 experiment for the demonstration of a possible positron source for the FCC-ee project at CERN. We present the design of the switchyard, which will serve both purposes with only minimal changes.

WEP10

Orbit Jitter Analysis at SwissFEL

Eugenio Ferrari (DESY), Sven Reiche (Paul Scherrer Institut)

With the beam synchronous readout of the beam position measurement at the hard X-ray FEL beamline Aramis at SwissFEL we analyze the intrinsic orbit jitter, using a classification algorithm and Principal Component Analysis (PCA). The method sorts the jitter in a set of eigenvectors and -values. With the magnitude of the eigenvalues the impact of the different jitter sources can be estimated. From the purely stochastic results we derive also a physical interpretation by matching the linear transport functions to the eigenvectors, reconstructing the orbit jitter in terms of the center of mass jitter of the electron bunch in the transverse positions, momenta, and the mean energy. Any deviation from the theoretical prediction indicates possible wrong set values of the transport magnets or errors in the BPM calibration (sign flip or faulty amplitude calibration). We present the results and give an outlook on extending the analysis to additional channels such as charge, compression and arrival time monitors as well as the FEL output signal.

WEP11

Measurement of Orbit Coupling by the Apple-X Undulator Modules in the Soft X-ray Beamline Athos at SwissFEL

Eugenio Ferrari (DESY), Sven Reiche (Paul Scherrer Institut), Marco Calvi (Paul Scherrer Institut), Romain Ganter (Paul Scherrer Institut)

Orbit response measurements in the soft X-ray beamline of Athos have shown coupling of the beam transport between the transverse planes, which is influenced by the on-axis field strength of the Apple-X undulator modules. A model reproduces this observation if a coupling term is included in the transport matrix of the undulator module. The presentation shows the estimate of the coupling strength as a function of beam energy, undulator field strength and orbit excitation.

WEP12

Application of machine learning in longitudinal phase space prediction at the European XFEL

Zihan Zhu (Shanghai Institute of Applied Physics), Sergey Tomin (Deutsches Elektronen-Synchrotron DESY), Winfried Decking (Deutsches Elektronen-Synchrotron)

For a free-electron laser facility, the longitudinal phase space of the beam is essential to the FEL lasing performance. However, the commonly-used diagnostics device such as the transverse deflecting cavity provides a destructive way to measure the beam longitudinal properties, which is not available during beam delivery. Thus, the convolutional neural network is introduced to construct a virtual diagnostic tool that facilitates bunch-to-bunch nondestructive measurement of the longitudinal phase space distribution.

WEP13

Demonstration of Hard X-ray Multiplexing using Microbunch Rotation through an Achromatic Bend

Rachel Margraf (Stanford University)
James MacArthur (SLAC National Accelerator Laboratory), Gabriel Marcus (SLAC National Accelerator Laboratory), Zhirong Huang (SLAC National Accelerator Laboratory)

Electrons in a X-ray free electron laser (XFEL) develop periodic density fluctuations, known as microbunches, which enable the exponential gain of X-ray power in an XFEL. When an electron beam microbunched at a hard X-ray wavelength is kicked, microbunches are often washed out due to the dispersion and R56 of the bend. An achromatic (dispersion-free) bend with small R56, however, can preserve microbunches, which rotate to follow the new trajectory of the electron bunch. Rotated microbunches can subsequently be lased in a repointed undulator to produce a new beam of off-axis X-rays. In this work, we demonstrate hard X-ray multiplexing in the Linac Coherent Light Source (LCLS) Hard X-ray Undulator Line (HXU) using microbunch rotation through a 10 microrad first-order-achromatic bend created by transversely offsetting quadrupole magnets in the FODO lattice. Quadrupole offsets are determined analytically from beam-matrix theory, and experimental results are compared to simulations. We also discuss the application of microbunch rotation to out-coupling a cavity-based XFEL (CBXFEL) [1].

WEP14

Intrabeam scattering effects in the electron injector of the European XFEL

Erion Gjonaj (Technische Universität Darmstadt, TEMF, Germany)
Herbert De Gersem (Technische Universität Darmstadt, TEMF, Germany), Torsten Limberg (DESY, Hamburg, Germany)

Intrabeam scattering (IBS) causes growth of the uncorrelated energy spread of electron bunches due to multiple small-angle Coulomb collisions over long propagation distances. As such, this effect may be a limiting factor for the beam current and therefore for the achievable photon energy in the SASE process. In addition, IBS influences the noise spectrum of the bunch, thus, interfering with microbunching instability (MBI) effects. An accurate estimation of IBS is, therefore, necessary for the proper application of so-called laser heaters for MBI suppression.
Recent experimental evidence at the FERMI linac, SwissFEL and European XFEL suggests that IBS effects in FELs are important. A large uncorrelated energy spread of the electron beam was observed that could otherwise not be reproduced in numerical simulations. So far, however, this energy spread growth could not be clearly attributed to IBS alone. This is due primarily to the nonlinear, space-charge dominated beam dynamics in the injector for which theoretical IBS models are not applicable. For this reason, we introduce a simulation approach for the full space-charge dynamics in the injector of the European XFEL including IBS effects. The approach is based on a Monte-Carlo technique for modeling Coulomb collisions within an electron bunch of arbitrary distribution. The results for the slice energy spread along the beam line are presented for various operation conditions. This allows to identify exactly the amount by which IBS contributes to the overall uncorrelated energy spread growth in the injector.

WEP15

Protection of the undulators in the European XFEL from the additional losses caused by the insertion of a slotted foil

Andrew Potter (The University of Liverpool)
Frank Jackson (Science and Technology Facilities Council), Shan Liu (Deutsches Elektronen-Synchrotron), Andrzej Wolski (The University of Liverpool)

The undulators in the European XFEL are made of permanent magnets that need to be protected from beam losses that could cause demagnetisation. Under current operating conditions, beam losses in the undulators are prevented by a collimation section downstream of the main Linac and upstream of the switchyard. In the future, a slotted foil may be installed in the European XFEL to reduce the X-ray pulse length; however, the insertion of the foil will spoil the emittance of most of the bunch which increases the probability of particles scraping the collimator and continuing to be transported to the undulator section. In this paper, we report a study to assess the level of the beam losses in the undulators in the European XFEL that would be caused by a slotted foil, and to determine the optimal apertures to use in the collimators to minimise the losses. We also assess whether shielding or an additional collimator in front of the undulator could be added to the beamline to prevent the losses.

WEP16

Investigation of the beam losses and radiation loads for the implementation of a slotted foil in the European XFEL

Andrew Potter (The University of Liverpool)
Bolko Beutner (Deutsches Elektronen-Synchrotron), Julien Branlard (Deutsches Elektronen-Synchrotron), Andre Dehne (Deutsches Elektronen-Synchrotron), Frank Jackson (Science and Technology Facilities Council), Shan Liu (Deutsches Elektronen-Synchrotron), Nicholas Walker (Deutsches Elektronen-Synchrotron), Andrzej Wolski (The University of Liverpool)

Ultra-short X-ray pulses in an XFEL can be generated by means of a slotted foil inserted into a bunch compressor. There is an ongoing study into whether such a technique could be used at the European XFEL. One important factor that must be considered is whether the additional beam losses and radiation load caused by the foil is acceptable with a high repetition rate of up to 4.5MHz at the European XFEL. As there is currently no foil implemented in the European XFEL, experimental investigations were carried out by inserting a screen in the bunch compressor at the location where a foil would be inserted. Simulations have been performed using BDSIM to study losses caused by the insertion of the foil. Neutron radiation measurements and beam loss monitor readings were taken and compared with the simulations to provide validation and calibration of the simulations for the case of a slotted foil.

WEP17

Feasibility of Single-Shot Microbunching Diagnostics for a Pre-bunched Beam for TESSA at 515 nm

Alex Lumpkin (Argonne National Laboratory)
Alex Murokh (RadaiBeam Technologies, LLC), Pietro Musumeci (UCLA), Donald Rule

Co-propagating a relativistic electron beam and a high-power laser pulse through a short undulator (modulator) provides an energy modulation which can be converted to a periodic longitudinal density modulation (or microbunching) via the R56 term of a chicane. Such pre-bunching of a beam at the resonant wavelength and the harmonics of a subsequent free-electron laser (FEL) amplifier seeds the process and results in improved gain in a TESSA** experiment. We describe potential characterizations of the resulting microbunched electron beams after the modulator using coherent optical transition radiation (COTR) imaging techniques for transverse size (50 micron), divergence (sub-mrad), trajectory angle (0.1 mrad), coherence factor, spectrum (few nm), and pulse length (ps). The transverse spatial alignment is provided with near-field imaging and the angular alignment is done with far-field imaging and two-foil COTR interferometry (COTRI). Analytical model results for a 515-nm wavelength COTRI case with a 10% microbunching fraction will be presented. COTR gains of 22 million were calculated for an initial charge of 1000 pC which enables splitting the optical signal for single-shot measurements of all the cited parameters.

**Tapering Enhanced Super-radiant Stimulated Amplification (TESSA)

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WEP18

Considerations on Wakefield Effects in a VUV FEL Oscillator Driven by a Superconducting TESLA-type Linac

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The electron-beam properties needed for successful implementation of a free-electron-laser oscillator (FELO) on a

superconducting TESLA-type linac at the Fermilab Accelerator Science and Technology (FAST) facility include the intrinsic normalized emittance and the submacropulse centroid stability. We have demonstrated that short-range wakefields (SRWs) and long-range wakefields including higher-order modes (HOMs) are generated for off-axis beams in the two, 9-cell capture cavities and eight, 9-cell cavities of a cryomodule in the FAST linac. The resulting degradation of the emittance and centroid stability would impact the FELO performance. At 300 MeV and with the 4.5-m long, 5-cm period undulator, the saturation of a vacuum ultraviolet (VUV) FELO operating at 120 nm has previously been simulated with GINGER and MEDUSA-OPC using the non-degraded beam parameters. The measured electron-beam dynamics due to the SRWs (submicropulse, 100-micron head-tail kicks) and HOMs (submacropulse centroid slew of up to 100s of microns) will be presented. These are mitigated by steering on axis as guided by the minimization of the HOM signals. Simulations using MINERVA:OPC of the effects of submacropulse centroid slew on FELO performance will also be reported.

WEP19

Experimental Slice Emittance Reduction at PITZ using Laser Pulse Shaping

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At the Photo Injector Test facility at DESY in Zeuthen (PITZ) photo electron guns for the use at the X-ray free-electron laser (FEL) facilities FLASH and European XFEL are conditioned. An electron beam with high current and low transverse emittance is required for high performance in an X-ray FEL. As the lasing process occurs on the part of the electron bunch with the highest charge density the emittance of this part is of interest. A scheme to measure the slice emittance which uses a transversely deflecting structure and a single-slit scan has been developed at PITZ. This allows the beam characterisation at low beam energies and high charge densities.
The contribution shows that using laser pulses with temporal flattop shape (and temporal Gaussian shape) or temporal and transverse flattop shape lead to a reduced center slice emittance compared to an electron beam emitted using a laser pulse with temporal Gaussian and transverse flattop shape.

WEP20

Achievements and challenges for sub-10fs long-term arrival time stability at large-scale SASE FEL facilities

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For experiments, where an external laser interacts together with the FEL photon pulses, e.g. for pump-probe experiments, a highly temporal stability between the laser and the FEL pulses is mandatory. A longitudinal intra bunch-train feedback system reduces train to train arrival time fluctuations of the electron bunches down to the sub-10 fs level at the EuXFEL. It has been verified with independent photon arrival time measurements that the low timing jitter is preserved in the generated SASE FEL pulse trains. However, over long measurement periods, additional environmental factors acting on different time scales have to be considered for large scale facilities, like temperature, relative humidity and in case of the EuXFEL ground motions due to ocean activities. Mitigation of the residual timing drifts between laser and FEL pulses requires additional measures to disentangle the overlaid effects. The latest results and future challenges for the long-term arrival time stabilization will be presented.

WEP21

OPTIMIZATION IN THE STRUCTURE OF KLYSTRON DRIVE SIGNAL TO EXTEND RF PULSE FLATTOP LENGTH AT THE EUROPEAN XFEL

Vladimir Vogel (Fogel) (Deutsches Elektronen-Synchrotron)

Currently 26 RF stations are in operation at the European X-ray Free Electron Laser (XFEL) and all RF stations can deliver sufficient power to reach maximum gradients in the accelerating modules, limited only by cavity and coupler properties. It was demonstrated that by activating a dynamic frequency shift (DFS) of the RF drive signal, the requested klystron power can be reduced by up to 20%, keeping the gradient levels unchanged. Currently the high voltage (HV) pulse has a length of 1.7ms and the RF pulse a length of 1.42ms, out of which only 0.6ms can be used for beam acceleration. Currently, the RF pulse starts when the level of klystron HV reaches 99% of the nominal voltage. If one allows the RF pulse to start at the 80% level of the nominal voltage, then the RF pulse length can be increased. In this article we will present a proposal for increasing the XFEL RF pulse flattop length using phase and amplitude compensation during the rise and fall of the HV, as well as applying DFS when filling the cavities of the accelerator. The first demonstration of the proposed procedure with the 10MW multi-beam klystrons (MBK) at the klystron test stand and at the XFEL RF station A10.L3 will be presented as well. The described procedure can be used both to increase the duration of the RF flat top as well as to shorten the duration of the HV, which could lead to energy savings.

WEP22

RF Commissioning and First Beam Operation of the PolariX Transverse Deflecting Structures in the FLASH2 Beamline

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In January 2021 two X-band (12 GHz) PolariX Transverse Deflecting Structures with variable streak polarization were installed into the FLASH2 beamline at FLASH. Since none of the RF components for the FLASH2-PolariX RF-distribution system nor the two PolariX structures could be pre-conditioned, RF-conditioning was and is quite tedious. Nevertheless, after 6 weeks of conditioning, we have already been able to streak the electron beam enough to start commissioning of the PolariX controls and the software.
After 4 months of conditioning in parallel to FLASH2 user operation, we achieved a stable 5.5 MW flat top of 400 ns operation. Next step will be to include RF pulse compression to achieve the design power of 22 MW. Since then operational experience with the PolariX system has continuously evolved and it has quickly become a valuable if not indispensable tool for tuning FLASH2. Even with the reduced power, a measurement resolution of 12 fs could be reached.
In this article we describe key aspects of the conditioning and commissioning process as well as the first experiences and first results of beam measurements both for SASE tuning and for dedicated micro-bunching studies.

WEP23

Optimization and fine tuning of the machine parameters with model-less algorithms

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Despite the use in machine physics of high-performance software for calculating and predicting machine parameters, when these are applied to the real world, optimal operating point search is often necessary to obtain the desired performance.
Furthermore, small configuration changes required by FEL Users during running experiments,lead to search new good working points in a short time. Use of tools based on model-less algorithms such as Nelder-Mead and 1D or 2D scans allow the automatic and online search for the best fine setup of the parameters in short times. The development of MIMOFB (Multi Input Multi Output Feedback) software used as optimizer with model-less algorithms has provided a versatile tool that can be applied in many situations.The ability to concatenate optimizations with pre-programmed batch executions allows to develop complex optimization strategies and iterate them by refining algorithm's parameters. In FERMI MIMOs optimizers are currently used with good results for fine tuning the electron beam magnetic optic and trajectory by acting on quadrupoles and correctors magnets current for FEL signal optimization and terahertz parasitic signal maximization to TeraFERMI line.

WEP24

Infrared spectrometer for microbunching characterization

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The presence of microbunching in the FERMI FEL electron beam is a known nuisance that can impact the performance of the FEL. Microbunching is generated by complex dynamics along the machine where there are several amplification sources. The use of a laser heater, at the cost of an increased energy spread, can improve the quality of the electron beam mitigating the modulation due to microbunching. A new diagnostic has been developed to provide more detailed insight into the microbunching properties. This diagnostic is essentially an Infrared Spectrometer that analyzes the spectrum of the Coherent Transition Radiation emitted when the electron beam passes through a metallic screen. The Coherent Transition Radiation replicates in its spectral content the microbunching properties which, in the case of FERMI, is peaked in a range from 1 to 10 µm. A simple design based on a CaF2 prism has been preferred over the use of diffraction gratings to avoid the superposition of higher diffraction orders. A spherical mirror is employed to improve the signal-to-noise ratio and the resolution of the spectrometer. PbSe and Pyroelectric detectors are used to cover a wavelength range from 0.25 to 10 µm. In this contribution, the design of the instrument together with some preliminary measurements is presented.

WEP25

Virtual Diagnostic for Longitudinal Phase Space Imaging for the MAX IV SXL Project

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Francesca Curbis (Lund University), Sverker Werin (MAX IV Laboratory)

Accurate and high resolution detection of the Longitudinal Phase Space (LPS) of the electron beam is a great advantage for operating and setting up a FEL. In the case of the soft X-ray FEL being proposed at the MAX IV synchrotron facility in Lund, this information is mainly supplied by a Transverse Deflecting Cavity (TDC) which is currently being installed and scheduled for commissioning in the autumn. Performing the LPS measurement with the future TDC is limited in two regards: it is destructive and may be low in resolution as compared to the maximum compression possible in the MAX IV linac. In this project we propose using machine learning tools to implement a virtual diagnostic to retrieve the LPS information non-destructively using fast, non-invasive measurements and critical set-points in the linac as inputs for a neural network. In this paper we summarize the current progress of this project which has thus far focused on simulation studies of the TDC and the training of a virtual diagnostic using the TDC's simulated output.

WEP26

Electron Beam Halo Diagnostics with the Time Resolved Beam Halo Monitor (TRBHM)

Benjamin Rotter (Nalu Scientific, LLC), Kevin Flood (Nalu Scientific, LLC), Isar Mostafanezhad (Nalu Scientific, LLC), John Smedley (Stanford University), Mei Bai (SLAC National Accelerator Laboratory), Alan Fisher, Prabir Roy (SLAC National Accelerator Laboratory)

Advancements in the drivers for XFEL light sources require careful understanding of the dynamics of the beam cross-section and temporal behaviors in order to ensure delivered beam quality and maintain operational sustainability. In order to provide a beam quality tool for measurement and control of beam parameters for the next generation of light sources, Nalu Scientific LLC, a developer of rad-hard, multiple gigasample per second, sample-and-hold digitizers with low power and low cost per channel, is designing and will make commercially available the Time Resolved Beam Halo Monitor (TRBHM). The TRBHM utilizes diamond cross-strip detectors integrated with full waveform digitizing electronics to non-destructively measure bunch-by-bunch electron beam halo spatial and temporal profiles using custom digitizing readout electronics and charge amplification front-end placed in close proximity to detectors, supporting 100s kHz readout rates, timing precision of <10 ps, and ~500um single point spatial resolution. We will present results from our previous accelerator tests of a 4x4 775 diamond um strip (20 um pitch) TRBHM prototype at a synchrotron light source, as well as preliminary results and plans for an upcoming installation at the FACET-II facility at SLAC.

WEP27

Development of the RF systems for the PolFEL accelerator

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PolFEL stands for Polish Free Electron Laser, the first FEL research infrastructure in Poland. This facility is under development, and it will operate in three wavelength ranges: IR, THz and VUV, using different types of undulators. Machine will be driven by 200 MeV linear superconducting accelerator, which will operate in both, pulses wave (PW) and continues wave (CW) modes. This contribution will describe the concept, actual status and the first results of the RF systems development.

WEP28

RF conditioning and first experiences with the PolariX TDS at PSI

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Institut), Thomas Klebb (Paul Scherrer Institut), Thomas Lucas (Paul Scherrer Institut), Fabio Marcellini (Paul Scherrer Institut), Ralf Menzel (Paul Scherrer Institut), Marco Pedrozzi (Paul Scherrer Institut), Eduard Prat (Paul Scherrer Institut), Sven Reiche (Paul Scherrer Institut), Wolfgang Tron (Paul Scherrer Institut), Riccardo Zennaro (Paul Scherrer Institut), Michael D'Amico (Paul Scherrer Institut)

In 2017, a collaboration between DESY, PSI and CERN was established with the aim of developing and building seven advanced X-Band Transverse Deflection Structure (TDS) with the new feature of variable polarization of the deflecting force. Seven deflectors were produced by PSI of which five were installed in three experiments at DESY, while the remaining two were installed in the ATHOS soft X-ray beamline in SwissFEL, with the goal to provide sub-fs resolution for soft X-ray pulse profiles. Early this year the X-band power source of the TDS for SwissFEL was completed and system commissioning started. This contribution summarizes the first deflection experiments performed.

WEP29

Synthesis and characterization of attosecond current spikes capable of driving strong-field quantum dyanmics

Agostino Marinelli (SLAC National Accelerator Laboratory), David Cesar (SLAC National Accelerator Laboratory), James P. Cryan

Over the last several years xFELs have developed novel beam shaping techniques to produce attosecond soft x-ray pulses which can probe electronic motion and photo-chemical energy transfer within complex molecules. Here, we discuss using the same techniques to produce an attosecond x-ray pulse which is intrinsically synchronized and aligned to a 250as, 10kA current spike whose Coulomb field can directly drive strong field physics. We propose to characterize both pulses by performing a pump-probe streaking measurement in a supersonic gas jet. In this measurement, the attosecond x-rays create a distinct population of photo-electrons which are rapidly streaked by the Coulomb field of the electron beam. We model this system using start-to-end simulations of LCLS-II cuS and a strong-field model for the photo-ionization. We show that the modeled spectrogram can be used to reconstruct both Coulomb field and the first-order correlation function of the SASE x-ray pulse.

WEP30

LCLS-II Charge, Energy and Bunch Length Feedback

Christopher Zimmer (SLAC National Accelerator Laboratory)

LCLS-II is a superconducting, MHz repetition rate accelerator-driven FEL that is being commissioned in 2022. The bunch charge, electron beam energy and bunch length must be maintained at several locations along the accelerator in order to ensure a stable and well-performing machine. A slow (~few HZ) charge, energy and bunch length feedback system for LCLS-II is implemented for commissioning and general operations. The feedback design and user interfaces will be detailed, and preliminary beam testing on the LCLS-I room temperature accelerator will be presented. Operational experience using the feedback loops with LCLS-II will also be presented.

WEP31

Machine Learning Developments for CLARA

Amelia Pollard (Science and Technology Facilities Council), Anthony Gilfellon (Science and Technology Facilities Council), David Dunning (Science and Technology Facilities Council), Matthew King (Science and Technology Facilities Council), Nirav Joshi (Science and Technology Facilities Council), Storm Mathisen (Science and Technology Facilities Council), William Okell (Science and Technology Facilities Council)

CLARA is an electron beam test facility being developed in phases at STFC Daresbury Laboratory. The first phase, with up to 35 MeV electron beam energy, has been operated since 2018 for a wide range of accelerator applications. The second phase, presently being installed, will expand the range of applications by taking the beam to 250 MeV energy and via a dog-leg to an experimental station that will feature a new high-power laser. A third phase utilising the 250 MeV beam in the straight-ahead line is also envisaged. Machine learning will play an important role in the future development of the facility, with aims to rapidly deliver bespoke beam properties, to detect and diagnose anomalies, and to provide virtual diagnostics. This paper summarises machine learning developments to date, in the areas of RF breakdown detection, photo-injector laser pulse shaping, and longitudinal phase space shaping. Studies to date have largely been offline or using simulated data but steps towards deployment are also reported.

WEP32

A miniature adjustable phase undulator for a compact x-ray FEL*

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The design of an adjustable phase undulator (APU) with cross section fitting dimensions of 5 inches by 5 inches is presented. The undulator employs a permanent magnet assembly with a < 10-mm period and yields a maximum undulator parameter K > 1. This K affords ~ 20% photon energy tunability in each individual x-ray FEL of a compact x-ray FEL facility, being designed at Argonne National Laboratory. without a need to vary the electron beam energy [1]. The design of a compact array of APUs is presented.

[1] A. Zholents, S. Baturin, D. Doran et al., "A Compact High Repetition Rate Free-Electron Laser Based on the Advanced Wakefield Accelerator Technology," IPAC'20, Caen, France, May 10-15, 2020, https://ipac2020.vrws.de/html/author.htm.

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WEP33

Determination of a High-Power Short THz single pulse Detector for FEL.

Adnan Haj Yahya (Ariel University Center of Samaria)

Terahertz (THz) radiation may pass through dielectric materials, and this ability can be used for a variety of applications. Terahertz (THz) radiation is located between infrared and microwave radiations in the electromagnetic spectrum. FEL produces brief, high-power THz single pulses, and we provide a diagnostic approach for them. The electro optic efficacy is used as a detection method. For the THz pulse, a GaAs crystal is used as a detector. The THz pulse causes the electro-optical crystal to shift polarization, implying that the electro-optic sampling device detects 30psec pulses (or depending on the pulse length of the accelerator). The optical pulse from the electo-optic sampling is coupled to fiber, allowing the optical pulse to be stretched to the order of nanoseconds.

WEP34

Adhesive technologies at manufacture THz mirrors.

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Michael Gerasimov (Ariel University), Jacob Gerasimov (Ariel University), Adnan Haj Yhya (Ariel University), Aharon Friedman (Ariel University)

This project describes different techniques to manufacture THz mirrors with arbitrary surfaces. The research is part of the development of THz transmission line for the compact FEL-THz accelerator.
As an initial phase flat mirrors were 3D printed with FFF (Fused Filament Fabrication) and SLA (Stereolithography Apparatus). The impact of material, layer height and layer direction to mirror's surface quality was exanimated.
In addition, various metal coating was tested, for example vacuum evaporation and metal foil. The 3D printed flat mirror's reflection was measured in TDS (Time Domain Spectroscopy) at 1–5 THz and compared with aluminum metal plate and glass silver coated mirror. The results approve sufficient surface and coating quality.
Further research is manufacture off-axis parabolic mirrors, validate with a beam profiling and manufacture arbitrary surface mirrors optimized to the current accelerator by machine learning.

WEP35

Single-shot temporal characterization of XUV FEL Pulses

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The free-electron laser in Hamburg (FLASH) operates in the extreme ultraviolet (XUV) and soft X-ray region, providing photon pulses of few femtosecond (fs) duration and unprecedented intensity [1]. FLASH operates in the self-amplified spontaneous emission (SASE) regime, meaning that every pulse has a unique combination of energy, spectrum, arrival time and pulse duration. Therefore, it is critical to be able to determine these parameters for each individual pulse. The THz field-driven streaking technique has the potential to deliver single-shot pulse duration information, as well as the XUV arrival time, basically wavelength-independent and over a large dynamic range (in pulse duration and FEL energy) [2, 3].
We present the results of several campaigns measuring the single-shot pulse duration over a wide range from 10 fs to 350 fs (FWHM) [3]. Here we focus on the particular difficulties in the different pulse duration regimes.
Furthermore, correlations between the pulse duration and other radiation parameters as pulse energy and spectrum are compared on a single-shot and average level as well as being compared to simulations [4]. The variable gap undulators at FLASH2 also allow to study the evolution of the XUV pulse duration for the fundamental as well as for the 3rd harmonic radiation pulse as function of contributing undulators. The best agreement between measurement and simulation was found when modeling the SASE process using an energy chirped electron pulse.
Finally, a comparison of the pulse duration determined by THz streaking with an alternative pulse duration diagnostic, a transverse deflecting structure (TDS) measuring the modulation of the electron bunch (analog to [5]) is shown and the advantages, as well as limitations of both techniques, are discussed.

[1] W. Ackermann et al., Nat. Photonics 1, 336 (2007)
[2] Grguras et al., Nature Photonics 6, 852-857 (2012)

[3] R. Ivanov et al., J. Phys. B 53, 184004 (2020)
[4] I. Bermudez et al., Opt. Express 29, 10491 (2021)
[5] C. Behrens et al., Nat. Commun. 5, 3762 (2014)

WEP36

AI Methods for an improved evaluation of FEL diagnosic data

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Free electron lasers (FEL) serve a broad user community in many scientific fields ranging from atomic and molecular physics to plasma and solid state physics as well as chemistry and biology Many experiments could benefit from a non-destructive online photon diagnostic of the provided x-ray pulses. Especially, for free-electron lasers that are operated in the self-amplified spontaneous emission (SASE) regime, where the pulse characteristics fluctuate from pulse to pulse [1], reliable online information on the intensity, spectral distribution, and temporal structure of each individual pulse can be crucial. A fast feedback can significantly improve an on-the-fly evaluation of user experiments. In addition, subsequent sorting of measurement data by, for example, intensity or wavelength can reveal signatures of physical processes that would otherwise be hidden in the fluctuation. Finally, real-time information about the pulse can give a direct feedback for FEL beam tuning.
Neural networks became popular as a powerful analysis tool in all categories of science [2].This is due to their ability to recognize complex relationships in large datasets. There are various architectures of neural networks, each with its own focus on specific tasks. What they all have in common is that they need to be trained during a training process in order to recognize patterns and correlations. A special case of training is performed in unsupervised learning, where the network does not need any expert knowledge about the data. This can be done for example with autoencoder networks [3]. These networks consist of an encoder and a decoder. The encoder learns during the training phase to compress data to lower dimensionality, the so-called latent space, the decoder to reconstruct the input from this compressed representation. This means that, given the decoder, the latent space contains all information needed to reconstruct an input sample. A special form of autoencoder networks are β Variational Autoencoder (β-VAE) networks [4], that allow to balance between the goal of a perfect reconstruction of the data and a perfect disentanglement of the latent space vector components. These networks are found to be able to find the key principles in an unlabeled data set, even if these principles were not known before.
We demonstrate the usage of β-VAEs to characterize SASE X-ray pulses of the free electron laser FLASH in Hamburg. We combine data from different diagnostic devices. We evaluate measured data from the online photoionization spectrometer OPIS [5], that uses 4 electron time of flight spectrometers to monitor each individual FEL pulse. In addition, we include data from an X-band transverse deflecting mode cavity diagnostic system (XTCAV). The latter is simi lar to the XTCAV at the Linac Coherent Light Source [6]. This device measures the position and kinetic energy of the electrons after they have passed the undulator and is therefore able to monitor the differences in the temporal structure of the electron bunches due to the lasing process. We demonstrate that a β-VAE can detect key principles in the XTCAV and the OPIS data, like pulse duration and central wavelength and compare them to other diagnostic devices such as data from a gas monitor device (GMD) [7] and THz field-driven streaking [8]. Without a-priori knowledge the network is able to find directly human-interpretable representations of single-shot FEL spectra, remove noise as well as reveal data artefacts and hence allows for an improved in-depth analysis of photon diagnostics data.

WEP37

The evolution of KAOS, a multipurpose active optics system for EUV/Soft X-rays

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KAOS is the flagship optics of FERMI, the first - and presently only - fully seeded Free Electron Laser facility in the world. The name stands for Kirkpatrick-Baez Active Optical System, and it has been entirely developed in-house. After progressive revisions and upgrades, it presently empowers three out of six beamlines at FERMI, and it also serves two beamlines at FLASH, Hamburg (DiProI, LDM, MagneDyn; FL23 and FL24). Although KAOS grounds on the well-established concept of Kirkpatrick-Baez mirrors, the challenges it addressed and the needs it was built for, ultimately produced a unique system with unique features: a versatile curvature control, a broad spectral range (100 nm<λ<1 nm), and a large demagnification power (>80×).

These features made KAOS an essential and mandatory tool to access the new class of scientific investigations addressed by FERMI, becoming a standard in time resolved spectroscopies, holography, and diffraction. In addition, it also enabled non-custom pump-probe spectroscopy correlation, and made the first realization of transient-grating in the XUV possible.The simple and clean mechanical design combined with the assiduous attention to online wavefront diagnostics did the rest in determining the success of KAOS over time. This contribution aims at telling how KAOS was born and grew up, showing how wavefront sensing made it work at the best, and how it will face the future challenges.

WEP38

Short period Apple-X undulator modeling for the AQUA line of the future EuPRAXIA@SPARC_LAB Facility

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We present the study for a short period Apple-X variable polarizing undulator, with small gap of operation and high magnetic field, which will be the base module for the AQUA line of the EuPRAXIA@SPARC_LAB FEL facility, of next realization at INFN Laboratory of Frascati. The undulator allows to achieve radiation between 3 and 5 nm, the so called water-window, with a 1 GeV electron beam energy, lower than other FELs operating in the world, so giving the possibility to have a Soft X-ray source with a full polarization control in a more cost effective way and with less required space than the state of the art devices. An overview of the magnetic design is given with the main parameters and performances in terms of the field properties, tuning capabilities and the effects on the electron beam motion.

WEP39

Design of the Superconducting undulator for EuPRAXIA@SPARC_LAB

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EuPRAXIA@SPARC_LAB is a new Free Electron Laser (FEL) facility that is currently under construction at the Laboratori Nazionali di Frascati of the INFN. Fermilab is contributing to the project with the design, manufacturing and qualification of a prototype conduction cooled superconducting undulator (SCU) that, if successful, could be integrated in the final machine. The design of the SCU capitalizes on the extensive experience present at Fermilab on cryomodules. Specifically, the system is based on the warm strongback concept developed for the PIP-II project which enables a modular design with multiple undulator coils integrated in a single vacuum vessel. This publication focuses on the overall design concept of the magnet system, its modularity, cost reduction potential and industrialization strategy.

WEP40

Optimal trajectory and beam based alignment for a seeded FEL

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Optimal FEL gain in a seeded FEL requires the careful alignment of different components. As for SASE FELs, the gain is optimized when the electron bunch travels in a straight line along the axis of each undulator in the radiator section.
We have recently developed an alignment strategy for the optimization of the FERMI FELs which combines the beam-based alignment of the magnetic elements (undulators and quadrupoles) with the collinear alignment of spontaneous emission from each undulator.
The method is divided into 3 steps. In the first step we measure the undulator spontaneous emission with a spectrometer to fine-tune each undulator gap and set the best electron beam trajectory for collinear emission of each module. In the second step, the alignment of the undulator axis on the electron trajectory previously defined is achieved by looking at the undulator focusing effect. Finally, the seed laser is superposed on the electrons and aligned to maximize the bunching along the defined direction.
This procedure can lead to an improvement in the control over the electron beam trajectory and results in a more efficient FEL process characterized by more stable and larger energy per pulse and a cleaner optical mode.
A description of the method with the obtained results are reported in this work.

WEP41

The SASE3 soft X-ray beamline at European XFEL: monochromatic operation

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The SASE3 soft X-ray beamline at the European XFEL is equipped with the grating monochromator allowing to reduce SASE FEL bandwidth and to improve longitudinal coherence at the experiments in the photon energy range 250 eV - 3000 eV. The design of the monochromator is challenged by a demand to control both photon energy resolution and temporal resolution; the aim to transport close to transform-limited pulses poses very high demands on the optics quality, in particular on the grating. Presently, the monochromator operates with two gratings: the low-resolution grating is optimized for time-resolved experiments and allows for moderate resolving power of about 2000 - 5000 along with pulse stretching of few to few tens of femtoseconds RMS, and the high-resolution grating reaches resolving power of 10000 at a cost of larger pulse stretching. The examples of time-resolved experiments and experiments performed in high photon energy resolution mode are presented. In addition, being operational in spectrometer mode, the monochromator is regularly used for the spectral characterization of the FEL beam including photon pulse length retrieval.

WEP42

Development of a photoelectron spectrometer for Hard X-Ray photon diagnostics at the European XFEL

Joakim Laksman (European XFEL GmbH)

Development and characterization of an angle-resolved photo-electron spectrometer, based on the electron Time-of-Flight concept, designed for hard X-ray photon diagnostics at the European free-electron laser is described. The objective with the instrument is to provide beamline users and operators with pulse resolved, non-invasive spectral distribution diagnostics, which in the hard X-ray regime is a challenge due to the poor cross-section and often very high kinetic energy of photo electrons for the available target gases. In this contribution we describe development of the device, including electron trajectory simulations, and first tests with hard X-rays at the PETRA III synchrotron where we have characterized the performance and optimized the voltage settings for resolution and electron detection efficiency. We demonstrate a resolving power of better than 5 eV up to at least 20 keV photon energy.

WEP43

Heat load simulations of a crystal monochromators illuminated by hard X-ray pulses with MHz repetition rate

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Due to the high intensity and high repetition rates of photon pulses generated by the European XFEL, the heat load on crystal monochromators can become large and crystal deformation will negatively influence the performance. Here, we present a one-dimensional simulation model of heat load effects on monochromator throughput, which can be applied to the cryo-cooled silicon monochromator operated at European XFEL [1,2] in burst mode with pulse trains arriving at 10Hz and up to 4.5 MHz repetition rate within the train. A previously used one dimensional heat load model [3] is modified and applied to the two-dimensional (in depth and along radius) heat deposition profile [4]. Heat flow need only to be considered along the depth coordinate due to an insignificant radial heat flow for the given experimental parameters [4]. Dynamical diffraction theory [5] is used on the heat deformed crystals to simulate the monochromator reflectivity during a train of X-ray pulses.
Several new FEL facilities [6,7] are planning to operate in the so-called continuous wave (CW) mode with constant repetition rates reaching the MHz regime. In the CW mode, pulses are not divided in trains which has important consequences for the heat load on the crystals. The applicability of the one-dimensional model is discussed and numerical estimations of the monochromator performance in CW mode are presented.

WEP44

Characterisation of a diamond channel cut monochromator designed for high repetition rate operation at the EuXFEL

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The EuXFEL is a unique FEL facility that provides X-ray pulses of high spectral brilliance and high photon flux at a high repetition

rate. However, the high peak power also induces a temperature increase and damages on the hard X-ray monochromators and thereby reducing the transmission. To address this limitation a diamond channel cut monochromator (DCCM) was proposed as an alternative to the current silicon monochromators. The heat load effect of typical EuXFEL pulses at room temperature and cryogenic cooling was simulated by FEA and indicates high transmissivity compared to silicon. The first prototype of the DCCM was built from a type IIa diamond single block and characterised by rocking curve imaging (RCI). The RCI results demonstrated the high crystal quality of the DCCM with rocking curves widths of the same order of the theoretical width and uniform reflected intensity over the surface. The performance as a monochromator was investigated by measuring the double bounce reflection. The resulting images of the RCI showed a diffracted beam of the same size and parallel to the incident beam and confirmed its effectiveness.

WEP45

Magnetic Field Investigation in a Compact Superconducting Undulator with HTS Tape

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The superconducting undulator (SCU) based on the second-generation high-temperature superconducting (HTS) tapes is a promising application for building tabletop free-electron lasers (FELs). The short period < 10 mm undulators with a narrow magnetic gap < 4 mm are especially relevant. The advantage of the HTS tape is that it shows both high critical current density and high critical magnetic field. Each tape has 50 μm thickness and 12 mm width and is further scribed by a laser to achieve a meander structure, hence, providing the desired magnetic field pattern.
Thus, a new approach to a superconducting undulator has been presented in the past and is further developed at KIT: each coil is wound with a single 15 m structured HTS tape. As a result, 30 layers of scribed sections lay above each other, and therefore, provide the required magnetic field. The results of the magnetic field measurements together with the results of the numerical investigation will be presented and discussed.

WEP46

Development of a table-top THz free-electron laser with a microtron accelerator and a hybrid electro-magnetic undulator

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We were able to realize a compact microtron accelerator with 5 MeV electron beam acceleration energy and a hybrid electro-magnetic undulator that can vary the magnetic field of 1.07 T at 0.74 T. The electron beam is accelerated by an RF electric field of a 1-cell acceleration cavity and recirculated by a uniform magnetic field of the microtron main chamber. Through the re circulation process, the electron beam energy 5 MeV, energy spread 0.5%, pulse width 5 μs, and electron beam acceleration current are 48 mA. Hybrid electro-magnetic undulator set Iron buses in hybrid planar undulator structures and generate electro-magnet effects.The undulator has an iron pole in the form of a comb and can easily install one turn of electromagnet coil using a copper tube. This undulator can adjust the applied current to adjust the magnetic field strength to 0.74–1.07T, when the standard deviation of the maximum magnetic field strength distribution is very accurate with less than 0.5%. The trajectory of the electron beam of the undulator inside has the stable less than the 3 mm.

WEP47

Design of the innovative Apple-X AX-55 for SABINA project, INFN - Laboratori Nazionali di Frascati

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Kyma S.p.A. was awarded the design and production of the APPLE-X undulator for SABINA project at INFN - Laboratori Nazionali di Frascati. SABINA (Source of Advanced Beam Imaging for Novel Applications) is a project aimed at the enhancement of the SPARC_LAB research facility. The two user lines that are going to be implemented are; a power laser target area and a THz radiation line.
Here we present the magnetic design and a novel mechanical implementation of this APPLE-X undulator for the THz/MIR radiation line. Undulator is made from three 1.35 m long sections. Each section consist of an APPLE-X magnetic array with 55 mm undulator period, a minimum gap of 10 mm and a mechanical frame. The undulator design is both compact and lightweight. This is achieved by novel mechanical design and implementation of the multiple dynamic corrections through the motion control system.

WEP49

Conceptual design of the THz undulator for PolFEL project

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PolFEL will be the first free-electron laser facility in Poland. It will be driven with RF continuous-wave superconducting linac including an SRF injector furnished with a lead film superconducting photocathode. PolFEL will provide a wide wavelength range of electromagnetic radiation from 0.6 mm down to 60 nm. The linac will be split into three branches. Two of them will feed undulators chains dedicated for VUV, and IR radiation emission, respectively, and a single THz undulator will be settled in the third branch. The design of the THz undulator has been recently accomplished. It consists of a 1560 mm long permanent magnet's structure ordered as a Halbach array of 8 periods. Large blocks dimensions, gap flux zeroing at full opening and 0.5 THz – 5 THz wavelengths range imposed on the undulator significantly influenced the final shape of the device, including blocks holders, girders and frame robustness unto magnetic forces, and hindered manufacturing and assembling processes. The following publication presents the challenges and solutions that were accompanying the conceptual phase.

WEP50

Controlling beam trajectory and beam transport in a tapered helical undulator

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A helical undulator provides a stronger FEL coupling than common planar geometries as the beam's transverse velocity never vanishes. However, a significant challenge lies in tuning and measuring the fields with limited access to the beam axis along the undulator. Confirming the good field region off axis is difficult without space for 3D hall probe scans, and is important for low energy beams used to create THz radiation. We present our tuning procedures developed for the meter-long THESEUS undulators, consisting of two orthogonal permanent magnet Halbach arrays shifted by a quarter period relative to one another. The hall probe and pulsed wire measurements are guided by the general field expansion of helical undulators to correctly tune fields on and near the axis.

WEP51

Fabrication of X-Ray Gratings by Grey-Tone Electron-Beam Lithography and Thermal Oxidation of Silicon

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Diffraction gratings are an essential instrument used at free-electron laser facilities in soft and tender x-ray ranges. Their application ranges from monochromators and analyzers to self-seeding and pulse compression. These gratings are typically around 50-200 mm, up to 500mm in length with pitches from a few micrometers down to a few 100 nm, made on flat or curved substrates. Blazed gratings exhibiting higher efficiency are made by the ruling technique, however, the production of high-quality blazed gratings has become a significant bottleneck due to challenges in their fabrication and few suppliers. In this presentation, we report on a novel method for production of next-generation X-ray diffraction gratings based on gray-tone electron-beam lithography (EBL) and thermal oxidation of silicon. We can take advantage of the greatly enhanced flexibility regarding the grating design, allowing for enhanced optical performance as well as novel optical functionalities. This new technology will enable researchers all around the world to exploit fully the unique opportunities provided by the dramatically enhanced brilliance and coherence of a new generation of light sources.

WEP52

Beam-splitting normalization schemes for femtosecond X-ray absorption spectroscopy using stochastic free-electron laser pulses

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X-ray absorption spectroscopy (XAS) enables the study of the electronic and geometric structural properties of matter. Such investigations can now be realized with femtosecond temporal resolution owing to the availability of X-ray free-electron lasers (XFELs) [1]. However, most XFELs currently utilize self-amplified spontaneous emission (SASE), which causes strong shot-to-shot fluctuations of their intensity and spectral distribution. Consequently, SASE fluctuations represent a challenge for the precise normalization of the measured absorption signal to the incident photon flux.

Here, we have developed normalization schemes utilizing diffractive optics that overcome the SASE fluctuations. The diffractive optics are used to split the incoming XFEL SASE beam into two or three identical copies (±1 and 0th orders). By placing the (solid or liquid jet) sample in one of the diffracted beams, the absorption and reference signals are recorded simultaneously, thus enabling efficient data normalization on a shot-to-shot basis.
In this contribution, we will present diffractive optics for two normalization schemes at SASE XFELs. First, a three beam geometry based on beam-splitting silicon off-axis zone plate [2] for soft XAS implemented at the Spectroscopy and Coherent Scattering beamline at the European XFEL to study L2,3 edges of transition metals will be presented. Secondly, a two-beam configuration for hard X-ray transient absorption spectroscopy of liquid jets (K-edge, an aqueous solution of [Fe(C2O4)3]3-) will be reported. Here, a beam-splitting transmission diamond grating for focused hard X-rays in combination with bent silicon <220> crystal was experimentally tested at the ALVRA station at the SwissFEL (ΔE/E ≈ 3% bandwidth). The results demonstrate high-quality K-edge transient XAS of [Fe(C2O4)3]3- solution without the need to scan the monochromator [3]. These normalization schemes pave the way for ultrafast L- and K-edge XAS measurements of transition metals at XFELs.

WEP55

Development of diamond-based diagnostics for next-generation XFELs

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FELs deliver rapid pulses on the femtosecond scale, and high peak intensities that fluctuate strongly on a pulse-to-pulse basis. The fast drift velocity and high radiation tolerance properties of chemical vapor deposition (CVD) diamonds make these crystals a good candidate material for developing a high frame rate pass-through diagnostic for the next generation of XFELs. We report on two diamond based diagnostic systems being developed by a collaboration of a UC campuses and National Laboratories supported by the University of California and the SLAC National Laboratory.
For the first of these diagnostic systems, we have developed a new approach to the readout of diamond diagnostic sensors designed to facilitate operation as a passthrough detection system for high frame-rate XFEL diagnostics. Making use of the X-ray Pump Probe (XPP) beam at the Linac Coherent Light Source (LCLS), the performance of this new diamond sensor system has been characterized and compared to that of a commercially available system. Limits in the magnitude and speed of signal charge collection are explored as a function of the generated electron-hole plasma density and compared to results from a TCAD simulation.
A leading proposal for improving the efficiency of producing longitudinally coherent FEL pulses is the cavity-based X-ray free electron laser (CBFEL). In this configuration, the FEL pulses are recirculated within an X-ray cavity in such a way that the fresh electron bunches interact with the FEL pulses stored in the cavity over multiple passes. This creates a need for diagnostics that can measure the intensity and centroid of the X-ray beam on every pass around the recirculatory path. For the second of these diagnostic systems, we have created a four-channel, position-sensitive pass-through diagnostic system that can measure the intensity and centroid of the circulating beam with a repetition rate in excess of 20 MHz. The diagnostic makes use of a planar diamond sensor thinned to 43 μm to allow for minimal absorption and wave-front distortion of the circulating beam. We present results on the response and position sensitivity of the diagnostic, again measured using the LCLS XPP beam.

WEP56

Design and measurement of a compact EPU

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A compact elliptically polarized undulator (CEPU) with the period of 16 mm and adopting the Delta similarity magnetic structure has developed in SSRF. The aperture of this magnet array is 5 mm and the dimensions of these magnets are 33*14*4 mm. The peak field is about 1.0 T. This CEPU is compact, lightweight and cost efficient devices. This paper focuses on the physical design, mechanical structure and the measurement of this CEPU.

WEP57

Undulators for the SXFEL user facility

Wei Zhang (Shanghai Synchrotron Radiation Facility) Cheng Yu

The SXFEL user facility, upgraded from the SXFEL test facility, consists of two undulator lines: an in-vacuum undulator SASE line and a normal undulator Seeding line, with the central wavelength of about 2 nm and 3 nm respectively. Two helical undulators locate at the end of the seeding line, aiming to provide the fully polarized coherent radiation pulses. With enhanced electron beam energy, producing of soft x-ray radiation with a wavelength as short as 2 nm has been achieved in 2021. The commissioning results of and the seeding line show great achievements recently. This paper describes the undulator systems for the SXFEL user facility.

WEP58

Investigation of high absorbed doses in the intersections of the European XFEL Undulator Systems

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The European X-Ray Free Electron Laser (XFEL) operates three Undulator Systems to generate high-brilliance and high repetition X-ray pulses. Each System consists of multiple 5-m long undulator segments separated by 1.1-m long intersections. Such intersections contain vacuum systems, diagnostic and correction equipment for the electron's trajectory, and phase shifters (PS) [1] to match the phase of the electron beam and SASE photons. An array of Radfets monitors the absorbed doses at the entrance of each undulator segment since the start of operation in 2017 [2] but no dosimetry is available in the intersections. Recently, some SASE3 phase shifters stopped working and their motors had to be exchanged. This may have been caused by radiation damage. In this work we used Gafchromic films to measure radiation doses and its spatial profile in the intersections and PS vicinity. The measurements showed that significantly higher radiation doses are absorbed in the intersections as compared to the entrance of the next downstream undulator segment and significant radiation is also found near mechanical motors and electronic circuitry. We performed Monte Carlo simulations using the Geant4 code to investigate the composition of the radiation field in the intersections of the Undulator Systems and correlate it with the Gafchromic measurements and possible radiation damage to PS encoders and motors.

WEP59

Microwave cavity resonance spectroscopy of ultracold plasmas

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Ultracold plasmas (UCPs) form a new exotic category of plasmas that can be produced by photo-ionizing laser-cooled atoms in a magneto-optical trap (MOT) near-threshold. With densities up to 10^{18} m^{-3}, temperatures as low as ~100 μK for the ions, and ~1 K for the electrons, they are the ideal model plasmas to study fundamental processes in plasma physics, such as (the competition between) three-body recombination, disorder-induced heating, and collisional and collisionless microwave heating.
To study these plasmas, conventional diagnostics such as Langmuir probes are not suitable, and tools from the field of atomic and particle physics are employed instead: charged particle diagnostics for electrons and ions, and laser-induced fluorescence and absorption imaging for ions. However, these diagnostics are limited by the charged particle's time-of-flight to the detector or require optical transitions available to lasers and cameras, such as present in alkaline earth metals, to work.
At TU/e, we recently developed a novel diagnostic that combines some of the advantages provided by the previous diagnostics. The diagnostic is based on a 5 GHz resonant microwave cavity and uses the shift in the resonance frequency of the cavity, induced by the UCP, to determine the electron dynamics of the plasma. This diagnostic allows us to study the dynamics simultaneously non-destructively, very fast (ns temporal resolution), with high sensitivity, and is a potentially interesting device for other types of plasmas as well, such as plasmas induced by extreme ultraviolet irradiation.

WEP60

Millimeter-wave undulators for compact x-ray free-electron lasers

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Electromagnetic wave undulators have the advantage of a shorter period compared with the permanent magnet undulators when operating at high frequency, therefore producing FEL radiation at the same wavelength with less electron energy. This paper investigates the properties of a Ka-band microwave undulator, and the factors that affect the choice of the high-power drive sources, through the design and beam dynamic study of a 36GHz cavity-type microwave undulator proposed for the CompactLight X-ray FEL. The future research is to prototype a millimeter-wave undulator operating at ~100GHz, which will

have an undulator period of about 1/10 of the state-of-the-art permanent magnet undulators. The millimeter-wave undulator will allow the generation of soft X-ray radiation at much lower beam energy, such as hundreds of MeV, enabling a reduction in the cost of a compact XFEL facility.

WEP61

Upgrade of the 2 Tesla Electro-Magnet and Power Supply of the DEIMOS Beamline at Synchrotron SOLEIL

Miguel Pretelli (OCEM Energy Technology), Edwige Otero (Synchrotron Soleil)
Florian Leduc (Synchrotron Soleil), Fadi Choueikani (Synchrotron Soleil), Loic Joly (Institut de Physique et de Chimie des Matériaux de Strasbourg), Filippo Burini (OCEM Energy Technology), Riccardo Morici (OCEM Energy Technology), Marco Farioli (OCEM Energy Technology), Gabriel Gayrard (SEF-Technologies), Romain Demitra (SEF-Technologies), Damien Neuveglise (SEF-Technologies), Pierre Deguilhem (SEF-Technologies), Philippe Ohresser (Synchrotron Soleil)

DEIMOS (Dichroism Experimental Installation for MagnetOptical Spectroscopies) is the beamline built at French Synchrotron SOLEIL facility intended for soft X-rays magnetic and natural dichroism spectroscopies. It has been designed to enable most challenging measurements in terms of X-rays sample sensitivity and signal detection level. The energies accessible on DEIMOS beamline rank from 350 eV up to 2500 eV, with all polarizations (circular left and right, linear), covering the absorption edges of the elements most relevant to the magnetic nanostructure scientific community, i.e. the first (3d) and second (4d) rows transition metals L-edges, the rare earth elements M-edges and nitrogen, oxygen and sulfur K-edges. While its main end station, a 7 Tesla cryomagnet, allows for measurements down to sub-Kelvin temperature up to room temperature, its second end station, a 2 Tesla electromagnet, is currently under renovation thanks to the partnership between Italian power supply constructor OCEM Power Electronics and French electromagnet manufacturer SEF Technologies. The coil is made of hollow copper to allow direct cooling in order to achieve the required 2 Tesla field strength. The magnetic model of this coil has been studied and validated before manufacturing. The new power supply will have a four quadrant fast switching topology, with a high stability output. To increase the reliability, the architecture is a proven modular technology coming from previous realizations running in other facilities. Once renovated, the so-called MK2T end station will allows for fast switching (1 Hz) between +/-2 Tesla. It will be aimed to host most peculiar inserts such as variable temperature liquid cell, high temperature (1000 K) and multiferroic inserts. Commissioning is expected as early as autumn 2022 and the facility could be available to users through standard review of the SOLEIL program committee, at the upcoming call for proposal.

WEP62

Study of an ERL-based X-ray FEL

Fanglei Lin (Oak Ridge National Laboratory)
Gunn Tae Park (Thomas Jefferson National Accelerator Facility), He Zhang (Thomas Jefferson National Accelerator Facility), Jiquan Guo (Thomas Jefferson National Accelerator Facility), Robert Rimmer (Thomas Jefferson National Accelerator Facility), Vasiliy Morozov (Oak Ridge National Lab), Yuhong Zhang (Thomas Jefferson National Accelerator Facility)

We propose to develop an energy-recovery-linac (ERL)-based X-ray free-electron laser (FEL). Taking advantage of the demonstrated high-efficiency energy recovery of the beam power in the ERL, the proposed concept offers the following benefits: i) recirculating the electron beam through high-gradient SRF cavities shortens the linac, ii) energy recovery in the SRF linac saves the klystron power and reduces the beam dump power, iii) the high average beam power produces a high average photon brightness. In addition, such a concept has the capability of optimized high-brightness CW X-ray FEL performance at different energies with simultaneous multipole sources. In this paper, we will present the preliminary results on the study of optics design and beam dynamics.

Tutorial 2: Meeting the editor

24 August 17:30 – 19:00

Chair: Giovanni De Ninno (Elettra-Sincrotrone Trieste S.C.p.A.)

What is the best place where you can publish your FEL-related research? Should your target be the FEL community, or do your results deserve the attention of a broader audience? How to write a perfect paper, taking advantage of the interaction with editors and referees?

17:30
Physical Review letters
Serena Dalena (American Physical Society)

17:50
Nature Photonics
OLIVER GRAYDON (Springer Nature)

THA – Electron diagnostics, timing, synchronization & controls

25 August 8:45 – 10:35

Chair: Marie Labat (Synchrotron Soleil)

THAI1 / 08:45

Machine learning-based Virtual Diagnostic

Adi Hanuka (Eikon Therapeutics)

Existing beam diagnostics are invasive, and oftentimes cannot operate at the required resolution. In this work we present a Machine learning-based Virtual Diagnostic (VD) tool to accurately predict the Longitudinal phase space (LPS) for every shot using spectral information collected non-destructively from the radiation of a relativistic electron beam. VD is a computational tool based on deep learning that can be used to predict a diagnostic output. VDs are especially useful in systems where measuring the output is invasive, limited, costly or runs the risk of altering the output. We show a few applications (experimental or simulated data) for high repetition-rate machine (LCLS-II) or a high-current, ultra-short bunch facility (FACET-II). Then, given a prediction, we relay how reliable that prediction is, i.e., quantify the uncertainty of the prediction. Finally, we show how VD can be used for machine optimization as aberration corrector tuning with ML-based emittance measurements.

THAI2 / 09:15

Coherent 3D microstructure of laser-wakefield-accelerated electron bunches

Alex Lumpkin (Argonne National Laboratory), Maxwell LaBerge (The University of Texas at Austin), Alexander Debus (Helmholtz-Zentrum Dresden-Rossendorf), Alexander Koehler (Helmholtz-Zentrum Dresden-Rossendorf), Andrea Hannasch (University of Texas - Austin), Arie Irman (Helmholtz-Zentrum Dresden-Rossendorf), Brant Bowers (University of Texas - Austin), Jurjen Couperus Cabadag (Helmholtz-Zentrum Dresden-Rossendorf), Michael Downer (University of Texas - Austin), Omid Zarini (Helmholtz-Zentrum Dresden-Rossendorf), Patrick Ufer (HZDR), Rafal Zgadzaj (University of Texas - Austin), Susanne Schöbel (HZDR), Ulrich Schramm (HZDR), Yen-Yu Chang (Helmholtz-Zentrum Dresden-Rossendorf)

Recent breakthroughs in laser wakefield accelerator (LWFA) technology have allowed them to drive free-electron lasers [1]. This is a significant accomplishment as LWFA electron beams are not as well controlled as beams from conventional accelerators. However, longitudinal structure in LWFA beams could be harnessed to accelerate the self-amplified spontaneous emission (SASE) process. Pre-bunched beams have been shown to achieve gain with shorter saturation length than conventional beams [2]. Because of the nature of the LWFA process, electron beams from LWFAs emerge from the plasma with preformed microstructures. The parameters of the accelerator dictate the shape, size and coherence of these features. Coherent optical transition radiation (COTR) can diagnose features in microbunched portions of the electron beam. We present experimental results across three different LWFA regimes demonstrating extreme visible microbunching (up to 10%), as well as sub mm-mrad emittance substructures in LWFA electron beams. In each regime we examined the near field COTR at eight different wavelengths from a foil directly after the end of the accelerator. Depending on the LWFA operating regime, we observe different levels of bunch substructure. How this structure evolves across optical wavelengths is also LWFA-regime dependent. The COTR point spread function model enables the annular shapes observed in the near field to be remapped as the actual 2D beam distributions [3]. We have also used COTR interferometry to measure sub mm-mrad divergence of the microbunched portion of the beam. In addition, we employed a multi-octave spectrometer to measure the spatially averaged TR spectrum from IR to near-UV wavelengths to characterize longitudinal beam shape. Wavelength-dependent variations in the size and radial distribution of the TR images can be correlated with features in the reconstructed longitudinal profile. Combining the longitudinal information acquired by the multi-octave spectrometer with multi-wavelength images of the foil, we observe features in the 3D beam that are unresolvable using other techniques. Moreover, with the aid of physically reasonable assumptions about the bunch profile, reconstructions of the 3D electron bunch distribution will be presented.

THAO3 / 09:45

Self-synchronized and cost-effective time-resolved measurements at x-ray free-electron lasers with femtosecond resolution

Alexander Malyzhenkov (Los Alamos National Laboratory), Philipp Dijkstal (Paul Scherrer Institut), Eduard Prat (Paul Scherrer Institut), Eugenio Ferrari (DESY), Paolo Craievich (Paul Scherrer Institut), Pavle Juranic (PSI), Romain Ganter (Paul Scherrer Institut), Sven Reiche (PSI), Thomas Schietinger (Paul Scherrer Institut)

Temporal diagnostics of FEL pulses are generally of great benefit to FEL facilites, in particular to provide information to users and for the setup of special modes such as fresh-slice schemes. In this contribution we present FEL power profile measurements with femtosecond resolution at SwissFEL. The FEL temporal profiles are obtained from the longitudinal phase-space of the electrons after the undulator section. We use the transverse wakefields of a corrugated structure to horizontally streak the electron beam, and vertical dispersion to access the energy information. The advantages of this approach, in comparison to the standard streaking using transverse deflecting rf structures, are cost-effectiveness and stability against arrival time jitter.

THAO4 / 10:10

Ultimate pulse-to-pulse stability in non-linear bunch compressors

Erik Mansten (MAX IV Laboratory)

Recent advances in bunch compression and FEL schemes have enabled ultrashort sub-fs electron and X-ray pulses. The timing jitter is, at best, one order of magnitude larger that the pulse duration. This can be handled by high precision pump-probe delay measurements and data sorting. However, only a small fraction of the pulses will be in the relevant time window.
The acceleration and compression in non-linear achromat bunch compressors enables cancellation of the energy and timing jitter caused by modulator high voltage (HV) ripple.
The cancellation works at a specific off-crest acceleration phase, the so-called magic angle.
We present experimental data showing the current performance at the MAX IV linac, and the benefit of operating at the magic angle.
Another major contribution to energy and arrival time jitter is lasers, both for the electron guns and the experiment, and how they are synchronized to the reference RF field. The RF distribution can either be optical or electrical. By extracting the reference RF directly from the gun laser, we have eliminated the relative jitter between the gun laser pulses and the reference field. We show data of the improved performance in our optical master oscillator scheme.
A full synchronization system that includes the experimental lasers is under development.
Our current plan is to base the synchronization system on a continuous wave reference laser to take advantage of the high frequency of optical waves, instead of relying on the envelope of pulsed lasers.
Combining acceleration at or around the magic angle with the high-precision synchronization system we aim at a timing jitter on the order of 1 fs at the end of the linac.

THB – Photon beamline instrumentation & undulators

25 August 11:00 – 12:50

Chair: Jan Grünert (European XFEL GmbH)

THBI1 / 11:00

Development of APPLE-III Undulators for FLASH

Markus Tischer (Deutsches Elektronen-Synchrotron)
Kathrin Götze (DESY), Patrick N'Gotta (DESY), Andreas Schöps (DESY), Pavel Vagin (Deutsches Elektronen-Synchrotron)

The implementation of a helical afterburner undulator at DESY's VUV-FEL source is part of the current FLASH2020+ upgrade program. The device shall be installed downstream of the present FLASH2 SASE undulators and will provide radiation with variable polarization from 1.33 nm to 1.77 nm (890-700eV) and thus also cover the L-edges of the 3d transition metals Fe, Co, and Ni. Despite a moderate energy upgrade of the machine to 1.35 GeV, the required wavelengths and tunability range can only be reached by a high magnetic performance of the undulator.
We report on design and development of an APPLE-III undulator with 17.5 mm period length operating at a minimum magnetic gap of 8 mm which will make use of a magnetic force compensation scheme. A short prototype has been built to verify and iterate both the mechanical and magnetic concept. Details on keeper design, prototype results and the tuning concept will also be discussed. The full length device is presently under construction and shall also verify this concept for the future seeding undulators at FLASH1.

THBI2 / 11:30

XFEL sub-10 nm focusing mirror system at SACLA for achieving 10^22 W/cm2 intensity

Jumpei Yamada (Osaka University, RIKEN SPring-8 Center)
Kazuto Yamauchi (Osaka University), Makina Yabashi (RIKEN SPring-8 Center)

The XFELs with an anomalously high peak brilliance are opening the way to a number of novel X-ray photon research paths. At SPring-8 Angstrom Compact Free-Electron Laser (SACLA) [1], the XFEL pulses with high stability and short pulse duration (6-7 fs) have been regularly provided thanks to the unique electron gun, accelerator, and undulator systems [2]. By focusing these XFELs to 1um-100nm, the peak intensity has been dramatically increased and new phenomena in hard X-ray nonlinear optics have been explored, such as observation of saturable absorption [3], two-photon absorption [4], and the atomic inner-shell laser emission [5]. To further promote the study in the ultra-intense X-ray laser field, we have developed a focusing system that achieves sub-10nm spot size and 10^{22} W/cm^2 intensity. For the sub-10 nm focusing optics, an advanced Kirkpatrick-Baez (AKB) mirror system based on Wolter-type III geometry [6] has been adopted. The AKB consisting of one-dimensional Wolter mirrors can satisfy Abbe's sine condition, which leads to a reduced coma aberration and a high tolerance to the incident angle error. We have designed and developed the AKB mirror system for SACLA BL3-EH4c at a photon energy of 9.1 keV. One of the remarkable challenges for the development was the fabrication of the mirrors with 1-nm accuracy. We applied an X-ray wavefront correction scheme [7] for the precise fabrication, and achieved wavefront accuracy of $\lambda/15$ rms which satisfies Maréchal's criterion. Ptychographic probe measurements revealed the focusing spot size of 6.6 nm (horizontal) × 7.1 nm (vertical), indicating eventually attained focused intensity of 1.21×10^{22} W/cm^2.

References:

[1] T. Ishikawa et al., Nat. Photon. 6 (2012).
[2] For example, I. Inoue et al., Phys. Rev. Lett. 127 (2021). & T. Osaka et al., Phys. Rev. Research 4 (2022).
[3] H. Yoneda et al., Nat. Commun. 5 (2014).
[4] K. Tamasaku et al. Nat. Photon. 8 (2014). & K. Tamasaku et al., Phys. Rev. Lett 121 (2018).
[5] H. Yoneda et al., Nature 524 (2015).
[6] J. Yamada et al., Opt. Express 3 (2019).
[7] S. Matsuyama et al., Sci. Rep. 8 (2018).

THBO3 / 12:00

Ringdown Demonstration of a Low-Loss 14 m Hard X-ray Cavity

Rachel Margraf (Stanford University)

Diling Zhu (SLAC National Laboratory), Gabriel Marcus (SLAC National Accelerator Laboratory), River Robles (SLAC National Accelerator Laboratory), Takahiro Sato (SLAC National Laboratory), James MacArthur (SLAC National Accelerator Laboratory), Aliaksei Halavanau (SLAC National Accelerator Laboratory), Sun Yanwen (SLAC National Accelerator Laboratory), Jacek Krzywinski (SLAC National Accelerator Laboratory), Zhirong Huang (SLAC National Accelerator Laboratory)

Cavity-Based X-ray Free-Electron Lasers (CBXFELs) employ an X-ray cavity formed by crystal mirrors such that X-ray pulses receive periodic FEL-amplification and Bragg-monochromatization. CBXFELs enable improved longitudinal coherence and spectral brightness over single-pass self-amplification of spontaneous radiation (SASE) FELs [1,2] for high-repetition rate FELs. Construction and alignment of a stable low-loss cavity of Bragg-reflecting mirrors has been considered a daunting challenge and has not seen previous experimental implementation in the hard X-ray regime. In this work, we demonstrate stable operation of a low loss 14-m-roundtrip rectangular cavity of four Bragg-reflecting diamond (400) mirrors. 9.831 keV X-rays from the Linac Coherent Light Source (LCLS) were in-coupled into the cavity via a thin diamond transmission grating. X-ray ring-down was characterized using fast photodiodes and a nanosecond-gated camera. Intra-cavity focusing was introduced to further stabilize the cavity, enabling observation of X-ray storage at >50 round trips. This experiment demonstrates feasibility of a stable low-loss hard X-ray cavity that will support future CBXFEL tests and operation [3].

THBO4 / 12:25

AC/DC: the FERMI FEL split and delay optical device for ultrafast X-Ray science

Alberto Simoncig (Elettra-Sincrotrone Trieste S.C.p.A.), Alessandro Abrami (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy), Claudio Fava (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy), Dario De Angelis (Elettra-Sincrotrone Trieste S.C.p.A.), Emanuele Pedersoli (Elettra-Sincrotrone Trieste S.C.p.A.), Flavio Capotondi (Elettra-Sincrotrone Trieste S.C.p.A.), Giulio Gaio (Elettra-Sincrotrone Trieste S.C.p.A.), Lorenzo Raimondi (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy), Marco Zangrando (Elettra-Sincrotrone Trieste S.C.p.A.), Matteo Pancaldi (Elettra-Sincrotrone Trieste S.C.p.A.), Michele Manfredda (Elettra-Sincrotrone Trieste S.C.p.A.), Nicola Mahne (Istituto Officina dei Materiali, CNR, Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy;), Ralf Hendrik Menk (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy), Riccardo Gobessi (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy), Simone Gerusina (Elettra Sincrotrone Trieste S.C.p.A., Area Science Park, S.S. 14 km 163.5, 34149 Basovizza (TS), Italy)

Free-electron lasers (FELs) are currently the most advanced class of light sources, by virtue of their unique capability to lase high-brightness and ultrashort pulses characterized by wavelengths spanning the Extreme-Ultraviolet (EUV), the Soft (SXR) and Hard (HXR) X-Ray spectral domains, alongside with temporal duration lying in the femtosecond (fs) timescale [1]. Specifically, the advent of FELs light sources has recently allowed to perform, in a time-resolved fashion approach, both established spectroscopies, daily employed at synchrotron light sources, and novel non-linear optical methods, mostly combining FELs and laser pulses. Nonetheless, the next step to push the ultrafast X-Ray science standards is widely recognized to be linked to go beyond the current time-resolved schemes, so performing experiments engaging exclusively EUV, SXR and HXR pulses. Indeed, exciting (and probing) matter at its (or nearby) electronic resonance is largely speculated to be one of the key for discriminating and revealing the microscopic mechanisms hiding behind some of the most exotic phases of physical, chemical, and biological systems. Such a challenge calls the design of optical devices capable to both split and delay (in time) FELs pulses, without impacting on their coherence properties, and fully user-friendly in terms of preserving the perfect overlap of the resulting focal spots, even in the few microns spatial domain, a well-known trademark for focusing EUV, SXR and HXR pulses at FELs light sources [2]. At the seeded FERMI FEL (Trieste, Italy) this goal is committed by the novel optical device known as AC/DC, which stands for the Auto Correlator/Delay Creator. AC/DC is purposely designed to double the incoming FEL photon beam into two exact pulse replicas, splitting it by inserting a grazing incidence flat mirror, and further delaying in time, in a controlled way, one of the two pulses, with an intrinsic temporal resolution of approximately 360 attoseconds. A detailed description of AC/DC is highlighted here. Specifically, strong emphasis is dedicated to the opto-mechanical design and the laser-based feedback system, purposely designed and implemented to compensate in real-time any potential drift and pointing mismatch affecting the FEL optical trajectory, ascribable to both mechanical imperfections and residual paraxial errors appearing during a temporal delay scan [3].

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[3] Simoncig A., Manfredda M., Gaio G., Mahne N., Raimondi M., Fava C., Gerusina S., Gobessi R., Abrami A., Capotondi F., De Angelis D., Menk R., Pancaldi M., Pedersoli E., Zangrando M., AC/DC: The FERMI FEL Split and Delay Optical Device for Ultrafast X-rays Science, Photonics, 9(5), 314, 2022

FRA – User experiments

26 August 8:45 – 10:35

Chair: Kiyoshi Ueda (Tohoku University)

FRAI1 / 08:45

Probing transient structures of nanoparticles by single-particle X-ray diffraction

Akinobu Niozu (Hiroshima University)

We report on our recent experimental results of single-shot and single-particle X-ray diffraction of nanoparticles at SACLA. The single-shot diffraction data provided insights into the crystallization kinetics of Xe nanoparticles, where the nanoparticles initially crystallize in the metastable stacking-disordered phase and then transform into the stable fcc phase. In addition, we investigated the ultrafast structural dynamics of nanoparticles triggered by the irradiation of an intense laser pulse.

FRAI2 / 09:15

Novel Lattice Instability in Ultrafast Photoexcited SnSe

Yijing Huang (Stanford University)

Shan Yang (Duke University), Samuel Teitelbaum (Arizona State University), Gilberto de la Pena (Stanford University), Takahiro Sato (SLAC National Laboratory), Matthieu Chollet (SLAC National Laboratory), Diling Zhu (SLAC National Laboratory), Jennifer Niedziela (Oak Ridge National Laboratory), Dipanshu Bansal (India Institute of Technology Bombay), Aaron Lindenberg (Stanford University), Andrew May (Oak Ridge National Laboratory), Olivier Delaire (Duke University), David Reis (Stanford University), Mariano Trigo (SLAC National Laboratory)

There has been growing interest in using ultrafast light pulses to drive materials into nonequilibrium states with novel properties. Using time-resolved X ray scattering, I demonstrated that SnSe, one of the IV-VI resonantly bonded compounds, hosts a novel photo-induced lattice instability associated with an orthorhombic distortion of the rock-salt structure with space group Immm [1]. The new lattice instability is accompanied by a drastic softening of the lowest-frequency Ag phonon (TO phonon), which has previously been identified as the soft mode in the thermally driven phase transition to a Cmcm structure. Therefore, we provide a counterexample of the conventional wisdom that laser pump pulse serves as a heat dump. Density functional theory calculations reveal that the photoinduced Immm lattice instability arises from electron excitation from the Se 4p- and Sn 5s-derived bands (the lone pair orbitals) deep below the Fermi level that cannot be excited thermally. Furthermore, I show results of non-zone-center measurements of time-resolved X-ray scattering, from which I extracted interatomic force constants in the photoexcited states. and identify a certain bond that is largely overlapped with the lone pair orbital as responsible for the observed photoinduced lattice instability. The conclusion is in contrary to the consensus that in thermal equilibrium, the resonant bonding network of chalcogen p orbitals is the main origin for lattice instability and a soft TO mode. And indeed, the photoexcited phonon modes have a significantly longer lifetime, which means less anharmonicity of the lattice, than those in thermal equilibrium, consistent with the observation that interatomic interaction driving the photoinduced lattice instability is different from the thermal.

The results have implications for optical control of the functional properties of monochalcogenides and other resonantly bonded materials. More generally, the results emphasize the importance ultrafast structural probes that reveal distinct atomic-scale dynamics too subtle for conventional spectroscopies.

This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences through the Division of Materials Sciences and Engineering under Contract No. DE-AC02- 76SF00515.

[1] Y. Huang et al., Phys. Rev. X, 12, 011029 (2021)

FRAO3 / 09:45

Ultrafast dynamics in $(TaSe_4)_2I$ triggered by optical and x-ray excitation

Federico Cilento (Elettra-Sincrotrone Trieste S.C.p.A.)

Wibke Bronsch (Elettra - Sincrotrone Trieste), Manuel Tuniz (Università degli Studi di Trieste), Denny Puntel (Università degli Studi di Trieste), Davide Soranzio (Università degli Studi di Trieste), Michela De Col, Giuseppe Crupi, Alessandro Giammarino (Università degli Studi di Trieste), Michele Perlangeli (Università degli Studi di Trieste), Helmuth Berger, Dario De Angelis (Elettra - Sincrotrone Trieste), Danny Fainozzi (Elettra - Sincrotrone Trieste), Ettore Paltanin, Jacopo Stefano Pelli Cresci (Elettra - Sincrotrone Trieste), Gabor Kurdi (Elettra - Sincrotrone Trieste), Laura Foglia (Elettra - Sincrotrone Trieste), Riccardo Mincigrucci (Elettra - Sincrotrone Trieste), Filippo Bencivenga (Elettra - Sincrotrone Trieste), Fulvio Parmigiani (Università degli Studi di Trieste)

Dimensionality plays a key role for the emergence of ordered phases such as charge-density-waves (CDW), which can couple to, and modulate, the topological properties of matter.

In this work, we study the out-of-equilibrium dynamics of the paradigmatic quasi-one-dimensional material $(TaSe_4)_2I$, that exhibits a transition into an incommensurate CDW phase when cooled just below room temperature, namely at TCDW= 263\,K.

We make use of both optical laser and free-electron laser (FEL) based time-resolved spectroscopies in order to study the effect of a selective excitation on the normal-state and on the CDW phases, by probing the near-infrared/visible optical properties both along and perpendicularly to the direction of the CDW, where the system is metallic and insulating, respectively. Excitation of the core-levels by ultrashort X-ray FEL pulses at 47 eV and 119 eV induces reflectivity transients resembling those recorded when only exciting the valence band of the compound - by near-infrared pulses at 1.55 eV - in the case of the insulating sub-system. Conversely, the metallic sub-system displays a relaxation dynamics which depends on the energy of photo-excitation.
Moreover, excitation of the CDW amplitude mode is recorded only for excitation at low-photon-energy. This fact suggests that the coupling of light to ordered states of matter can predominantly be achieved when directly injecting delocalized carriers in the valence band, rather than localized excitations in the core levels.
On a complementary side, table-top experiments allow us to prove the quasi-unidirectional nature of the CDW phase in $(TaSe_4)_2I$, whose fingerprints are detected along its c-axis only.
Our results provide new insights on the symmetry of the ordered phase of $(TaSe_4)_2I$ perturbed by a selective excitation, and suggest a novel approach based on complementary table-top and FEL spectroscopies for the study of complex materials.

FRAO4 / 10:10

FLASH2020+ Pump-Probe Laser Upgrade: Concept and Current Status

Skirmantas Alisauskas (Deutsches Elektronen-Synchrotron DESY), Anne-Lise Viotti (Deutsches Elektronen-Synchrotron DESY), Ayhan Tajalli (Deutsches Elektronen-Synchrotron DESY), Bastian Manschwetus (Deutsches Elektronen-Synchrotron DESY), Huseyin Cankaya (Deutsches Elektronen-Synchrotron DESY), Ingmar Hartl (Deutsches Elektronen-Synchrotron DESY), Marcus Seidel (Deutsches Elektronen-Synchrotron DESY)

Time-resolved experiments are increasingly relevant in modern FEL user facilities. With the FLASH2020+ upgrade project, the pump-probe capabilities of the FLASH will be extended. Besides offering fixed wavelengths (1030 nm fundamental and its harmonics), tunable wavelengths are under development: sub-150 fs long tunable mid-infrared (2-5 microns) pulses for the solid-state community and sub-40 fs long tunable UV-VIS (200-500 nm) pulses for the general chemistry, atomic molecular and optical physics (AMO) communities. The optical pulses will be fully synchronized with the FEL pulses and are generated with up to a 1 MHz repetition rate in bursts of 0.6 ms in length at 10 Hz. Since we are limited by our pump-lasers available fixed average power, we can also reduce the repetition rate to 200kHz or less for delivering higher energy pulses for experiments using small density targets (such as gas phases or clusters).
Here, we present our pump-probe laser concept: from the laser front end to the beam delivery to experimental end-stations and instruments. We would be happy to receive any feedback from the users on their needs so we can adjust our concept as needed.

FRB – End-to-end experiments (machine driven)

26 August 11:00 – 10:50

Chair: Flavio Capotondi (Elettra-Sincrotrone Trieste S.C.p.A.)

FRBI1 / 11:00

Experiments with phase-controlled multi-pulses from FERMI

Carlo Callegari (Elettra-Sincrotrone Trieste S.C.p.A.)

The FERMI Free Electron Laser in Trieste (Italy) has been designed and built as a seeded source, for precise control of the properties of its light pulses. Its excellent longitudinal coherence is inherited from the seed laser, and is its uppermost distinctive feature. In the realm of atomic, molecular and optical science, the use of longitudinal coherence of laboratory lasers as a time reference for precise measurements, as a control parameter for the synthesis of arbitrary waveforms, and for steering the outcome of a photophysical process, has a long history of achievements. One wishes to extend the same concepts to shorter wavelengths, because the latter provide higher spatial and temporal resolution, as well as chemical selectivity. In this talk I will present the challenges faced and the solutions found towards this goal, as well as the applications demonstrated so far, such as: coherent control of photoionization, measurement of photoemission delays, sensitive detection of weak processes, or the generation of periodic waveforms.
The results originate from the joint effort of many international laboratories and of a large number of researchers, whose work is gratefully acknowledged.

FRBI2 / 11:30

Observation of coherent electronic motion with X-ray free-electron lasers

Agostino Marinelli (SLAC National Accelerator Laboratory), James Cryan (SLAC National Accelerator Laboratory)

Electron motion is a key ingredient of every chemical processes. The natural timescale for such electronic dynamics in small molecular systems is typically in the range of tens to hundreds of attoseconds. Here I will present recent experimental results using attosecond x-ray free electron laser pulses and pulse pairs to probe ultrafast electronic motion. X-ray free-electron lasers offer continuous wavelength tunability across the soft x-ray region allowing for atomic-site specific probes of the electron density in molecular systems.

I will present our first results showing isolated attosecond soft X-ray pulses from the FEL, with peak power approaching the terawatt scale. Such high power pulses open the door for nonlinear spectroscopies such as pump/probe spectroscopy, and X-ray wave mixing. We have demonstrated the preparation of a coherent electronic wavepacket by driving stimulated X-ray Raman scattering. Combing attosecond X-ray pulses with an external laser field we are able to time-resolve the photoemission dynamics of core-level electrons in molecules, observing the coherent evolution of a wavepacket of core-excited states. I will also show the first results from a x-ray pump/x-ray probe measurement of ionization induced charge motion.

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FRBO3 / 12:00

The role of light possessing orbital angular momentum in ptychographic imaging experiments

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The use of light beams possessing orbital angular momentum (OAM) is rapidly becoming a way for probing condensed-matter systems, even in the XUV range [1]. The wavefronts of such beams are characterized by an azimuthal angular dependence of the electric field phase, associated with an OAM topological charge $\ell \neq 0$. For imaging purposes, it has been shown that OAM beams can overcome the Rayleigh criterion limit, so enhancing the theoretical resolution with respect to gaussian illumination ($\ell = 0$) [2]. We tested this feature at the DiProI beamline of the FERMI FEL by performing ptychographic experiments with a standard sample [3,4]. As predicted, the ptychographic reconstructions with OAM beams showed a higher image resolution, and the retrieved illumination functions proved to be very sensitive to optical aberrations. This study will potentially provide the basis for new characterization and diagnostic tools, since the extra degree of freedom ℓ can be exploited for tuning the light-matter interaction even during pump-probe experiments.

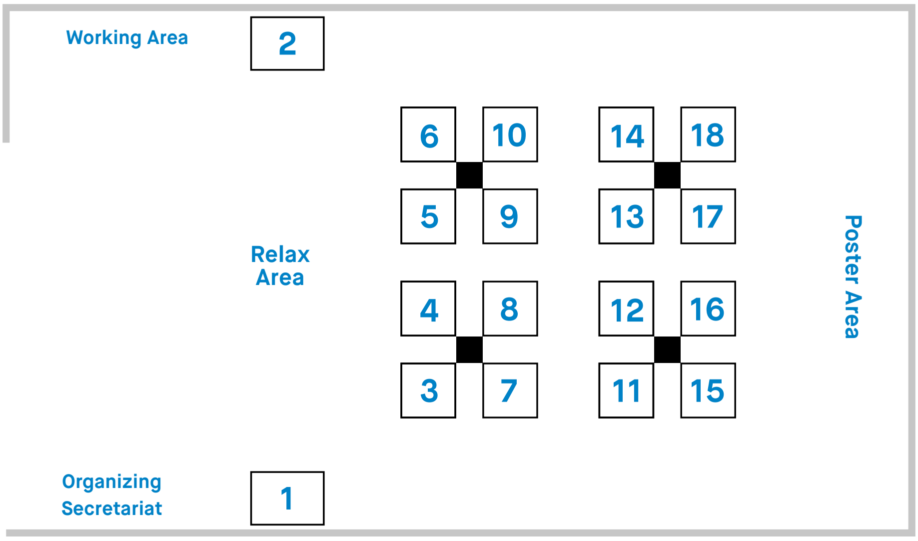
FRBO4 / 12:25

A perfect X-ray beam splitter and its applications to time-domain interferometry and quantum optics exploiting FELs

Bill Pedrini (Paul Scherrer Institute), Eduard Prat (Paul Scherrer Institut), Sven Reiche (Paul Scherrer Institut), Gabriel Aeppli (Paul Scherrer Institut and ETH Zurich), Simon Gerber (Paul Scherrer Institute)

Brilliant, ultrashort, and coherent X-ray FEL pulses allow investigations of dynamics at the inherent time and length scale of atoms. However, the user community still lacks access to phase-locked X-ray pulses, desirable for time domain correlation spectroscopies and coherent quantum control. Based on selective electron-bunch degradation in the accelerator, combined with two-stage, self-seeded photon emission, we propose an FEL mode generating subfemtosecond, phase-locked X-ray pulse pairs with up to 100 fs delay. Splitting the electron bunch in the accelerator, instead of photon pulses in the beamline, avoids relative phase jitter. This enables time-domain interferometry, such as the X-ray analog of the ubiquitous Fourier transform infrared spectrometer, and, more generally, all of nonlinear and quantum optics requiring coherent copies of beams.

MAGAZZINO 28



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