FLASH Operation as an FEL User Facility

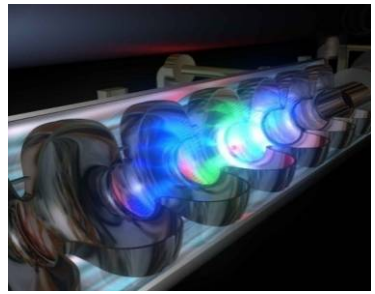
FLASH
Free-Electron Laser in Hamburg

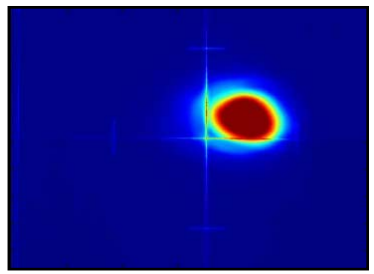
FLASH – The Free-Electron Laser User Facility

The accelerator

Performance and operational issues

Upgrade





Siegfried Schreiber
B. Faatz, J. Feldhaus, K. Honkavaara, R. Treusch
DESY

PAC 2009
Vancouver, Canada
4-9 May 2009

HELMHOLTZ GEMEINSCHAFT

DESY

FLASH at DESY in Hamburg, Germany

FLASH
Free-Electron Laser in Hamburg

FLASH at DESY in Hamburg

FLASH
Free-Electron Laser in Hamburg

- FEL user facility since summer 2005
- Photon wavelength range from vacuum ultraviolet to soft x-rays
- Single-pass high-gain SASE FEL
  - SASE = self-amplified spontaneous emission
- Some first lasing events:
  - Jan 2005 – 32 nm
  - Apr 2006 – 13 nm
  - Oct 2007 – 6.5 nm
- User experiments
  - 1st period: Jun 2005 – Mar 2007
  - 2nd period: Nov 2007 – Aug 2009
  - 3rd period: starting summer 2010
- FLASH is also a test bench for the European XFEL and the ILC

FLASH design goals reached

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Free-Electron Laser in Hamburg

Electron beam energy of 1 GeV

DESY TELEGRAMM 21. September 2007

Design-Strahlenergie für FLASH erreicht!
Elektronenstrahl mit 6 Modulen erstmals auf 1 GeV beschleunigt

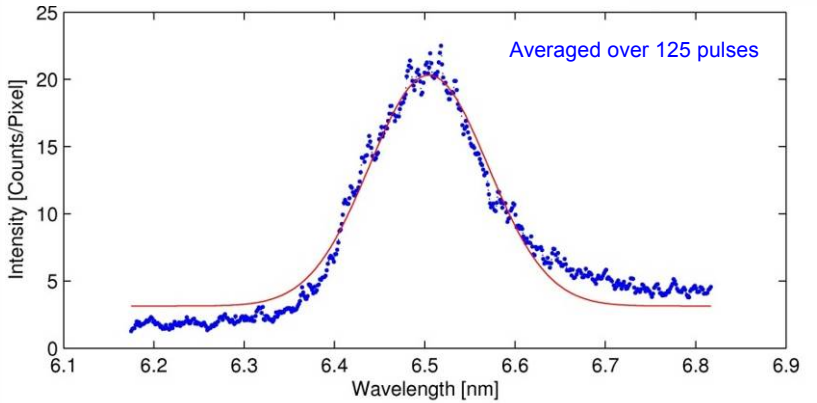
FLASH Reaches Design Beam Energy!
Electron beam accelerated to 1 GeV with 6 modules for the first time

Der Durchbruch passierte wieder in einer Nachtschicht, genauer am 21.9.2007, um 0:57 Uhr. Dieses Mal ging es um das Erreichen der geplanten maximalen Strahlenergie. „Ziel: Betrieb mit höchster Energie – Ergebnis: 1 GeV Energie !! Gemessenes Spektrum der spontanen Emission: ~ 6,3 nm", so der Eintrag im elektronischen Logbuch.

Während der letzten Wartungspause: Einbau des Beschleunigermoduls Nr. 6 in den FLASH-Tunnel.
During the last shutdown: installation of accelerator

As usual, the breakthrough was achieved during a night shift, to be precise: on September 21 at 0:57 a.m. This time, the aim was to reach the planned maximum beam energy. "Goal: Operation to maximum energy—Achievements: 1 GeV!! Spectrum of spontaneous emission measured: ~ 6.3 nm," reads the entry in the electronic logbook.

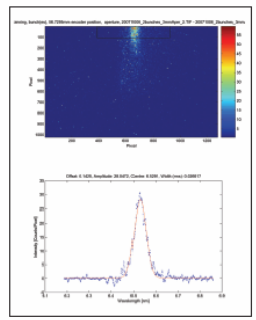
Lasing at 6.5 nm



DESY TELEGRAMM 8. Oktober 2007

-Weltrekord bei FLASH: 6,5 Nanometer!
ter Designwert für die Laserblitze erzielt

World Record at FLASH: 6.5 Nanometers!
esign value for laser flashes reached

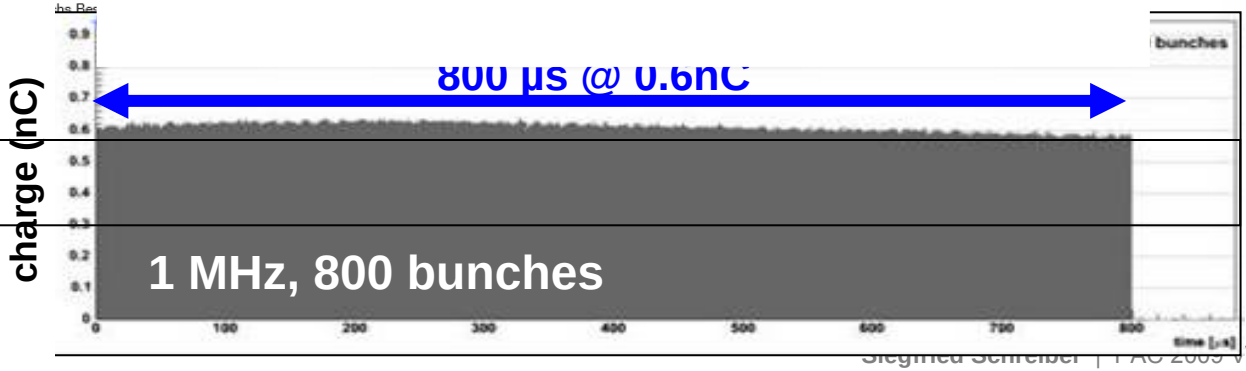


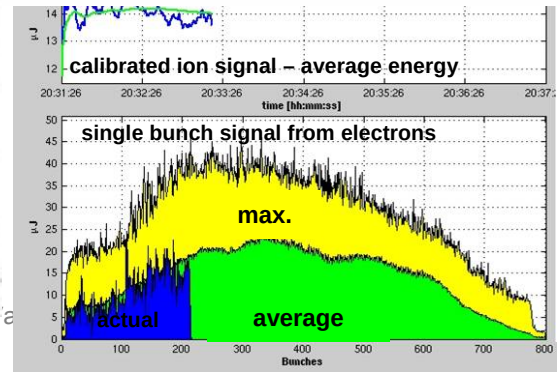
Plot und Zahlen für Experten:
Das Wellenlängenspektrum bei 6,5 nm. Zahl der

Two weeks after the maximum beam energy of 1 gigaelectronvolt was reached, the control room announced another milestone: "On the evening of October 4, we observed lasing at a wavelength of 7 nanometers (nm) at FLASH for the first time." Only 24 hours later, the FLASH team achieved the facility's design value of 6.5 nm. In FLASH, the electrons are accelerated to an energy of 986 megaelectronvolts in six superconducting modules. On their flight through the undulator, the electrons now demonstrated the desired behavior also at this high energy: the spontaneous radiation they emit

Lasing with a complete bunch train of 800 bunches @ 13.4 nm

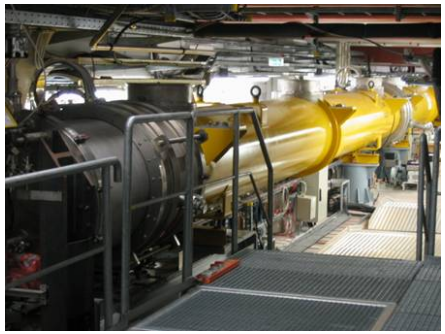
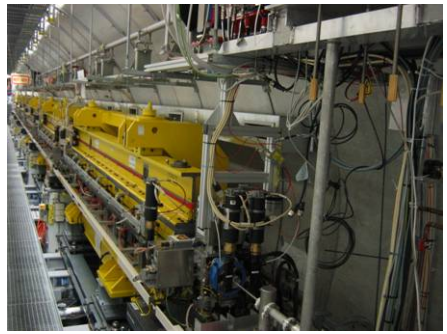
abgegebene Strahlung
verstärkt sich selbst zu der gepulsten Freie-Elektronen-Laserstrahlung (SASE-FEL).

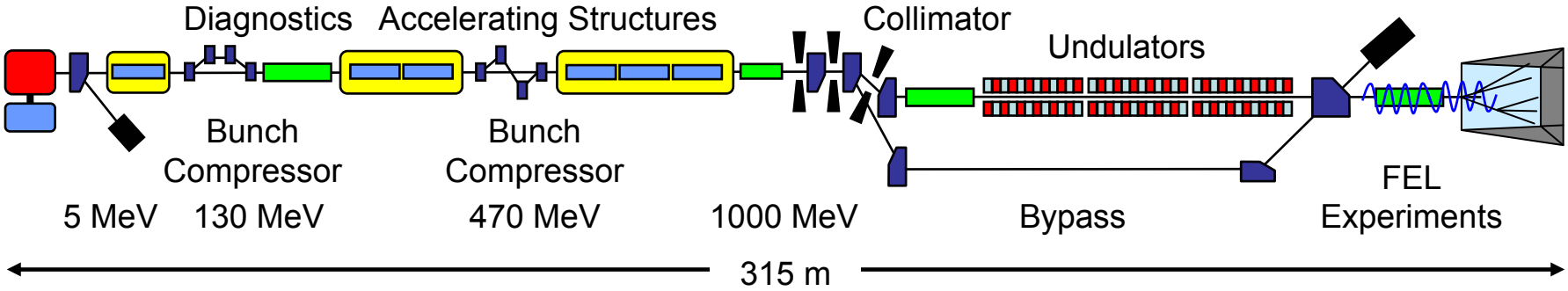




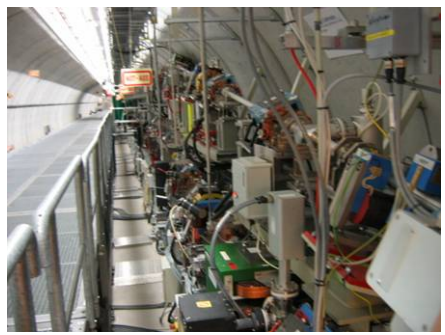
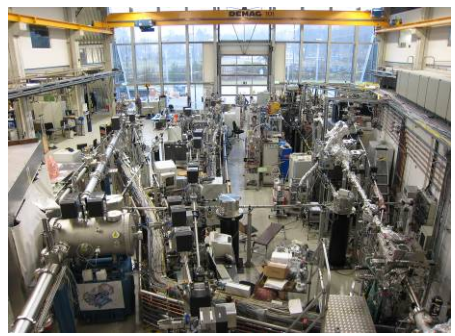
FLASH overview

FLASH
Free-Electron Laser in Hamburg



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Accelerating modules

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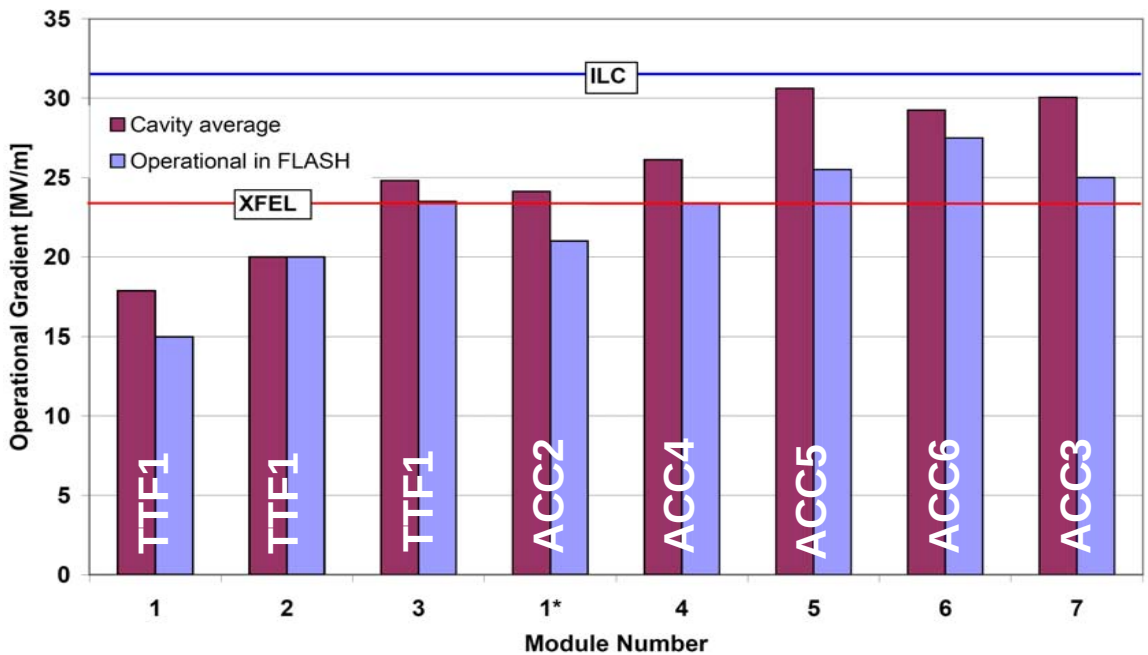
Free-Electron Laser in Hamburg

- Six TESLA type accelerating modules
  - each having eight 9-cell superconducting niobium cavities operated at 1.3 GHz
- Energy upgrade to 1 GeV in 2007
  - 6th module installed, 3rd module replaced
  - Both new modules ≥ 25 MV/m in average
- Upgrade autumn 2009:
  - 7th module (XFEL type) → energy 1.2 GeV
  - 3rd harmonic module with 4 sc cavities @ 3.9 GHz



Undulators

FLASH
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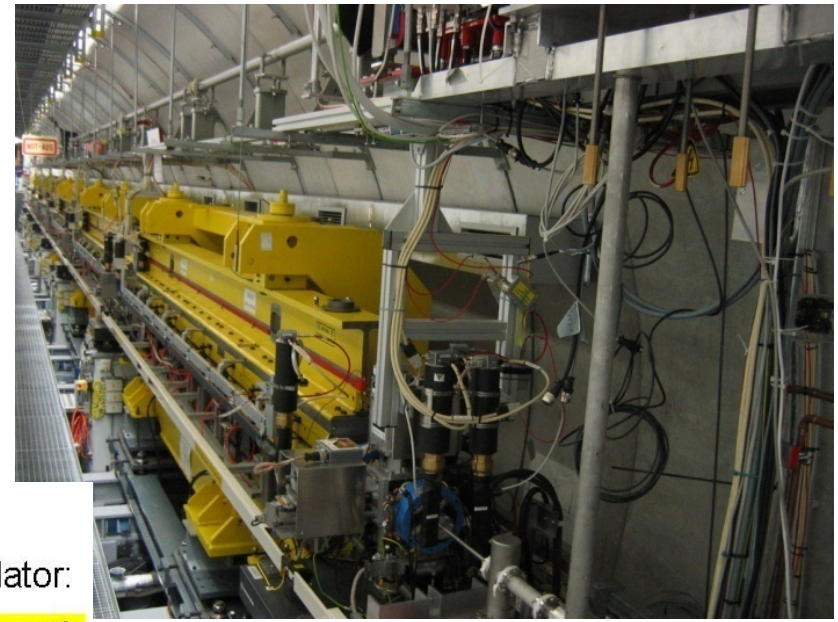
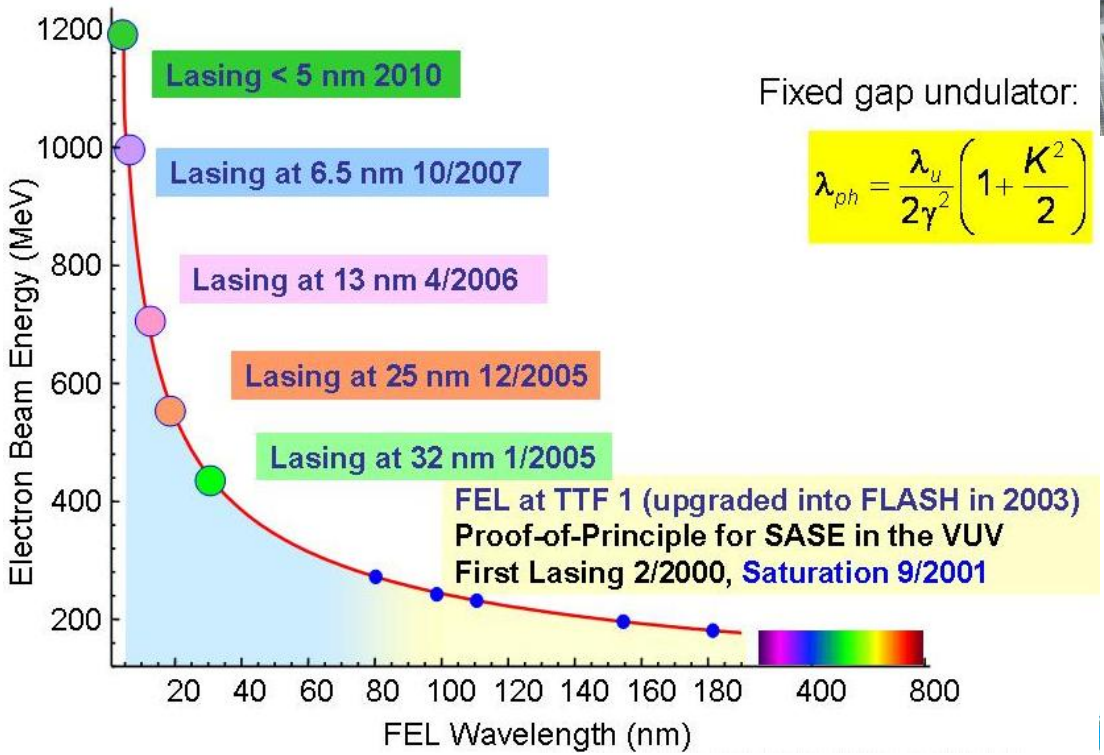
- High-gain single-pass FEL requires a long undulator system
  - 6 modules with a total length 27.3 m
  - permanent NdFeB magnets
  - fixed gap of 12 mm





Fixed gap undulator:

$$\lambda_{ph} = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

- Changing photon wavelength requires a change of the electron beam energy

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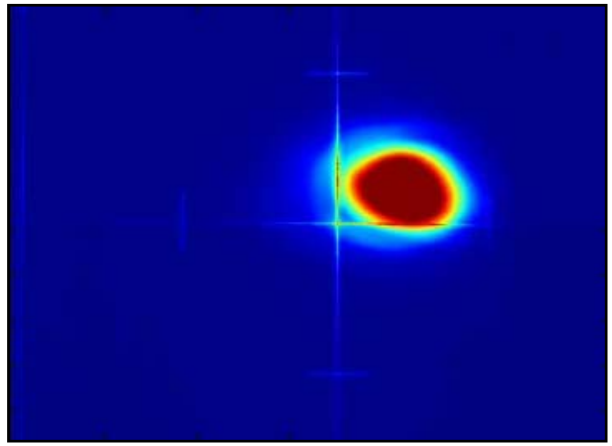
SASE performance

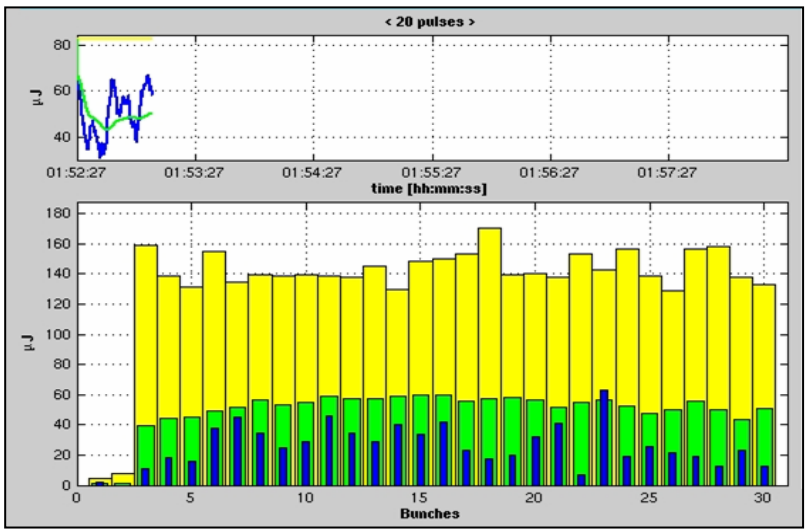
FLASH
Free-Electron Laser in Hamburg

Typical user operation parameters:

Wavelength range (fundamental)	7 – 47 nm
Average single pulse energy	10 – 100 µJ
Pulse duration (FWHM)	10 – 50 fs
Peak power (from av.)	1 – 5 GW
Average power (example for 500 pulses/sec)	~ 15 mW
Spectral width (FWHM)	~ 1 %
Peak Brilliance	10^{29} - 10^{30} B



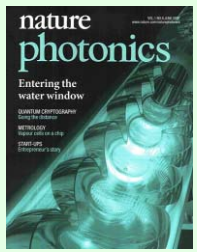
B = photons/s/mrad^2/mm^2/0.1%bw



Multibunch SASE signal (µJ) recorded with MCP detector

max
single
average

Top performance at 13.7 nm:



Average energy	70 µJ
Peak energy	170 µJ
Pulse duration	10 fs
Peak power	>10 GW
Peak brilliance	(6 ± 3) 10^{29} B

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Organization of beam time

FLASH
Free-Electron Laser in Hamburg

- Beam time overbooked – by a factor of ~3
- The current 2nd user period started in November 2007 and continues until August 2009
  - ~ 300 days scheduled for user operation
  - distributed in 4-week blocks
- FLASH runs 24/7
  – what else would you expect?
  - users do 12 h shifts, typically 2 experiments interleaved for 1 or 2 weeks
- Between user blocks: study weeks
  - FEL physics studies
  - improvements of the FLASH facility
  - preparation of the next user block
  - general accelerator studies

    2-3 weeks three times per year
    related to e.g. XFEL and ILC

	52	24.Dec - 30.Dec	5	Maintenance
January	1	31.Dec - 6.Jan	5	
2008	2	7.Jan - 13.Jan	4	Accelerator studies
	3	14.Jan - 20.Jan	4	
	4	21.Jan - 27.Jan	2	FEL studies
February	5	28.Jan - 3.Feb	2	
	6	4.Feb - 10.Feb	3	
	7	11.Feb - 17.Feb	1	User Run
	8	18.Feb - 24.Feb	1	
	9	25.Feb - 2.Mar	1	
March	10	3.Mar - 9.Mar	1	
	11	10.Mar - 16.Mar	2	FEL studies
	12	17.Mar - 23.Mar	2	
	13	24.Mar - 3.Jan	3	
April	14	31.Mar - 6.Apr	1	User Run
	15	7.Apr - 13.Apr	1	
	16	14.Apr - 20.Apr	1	
	17	21.Apr - 27.Apr	1	

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Time distribution during 2nd user run

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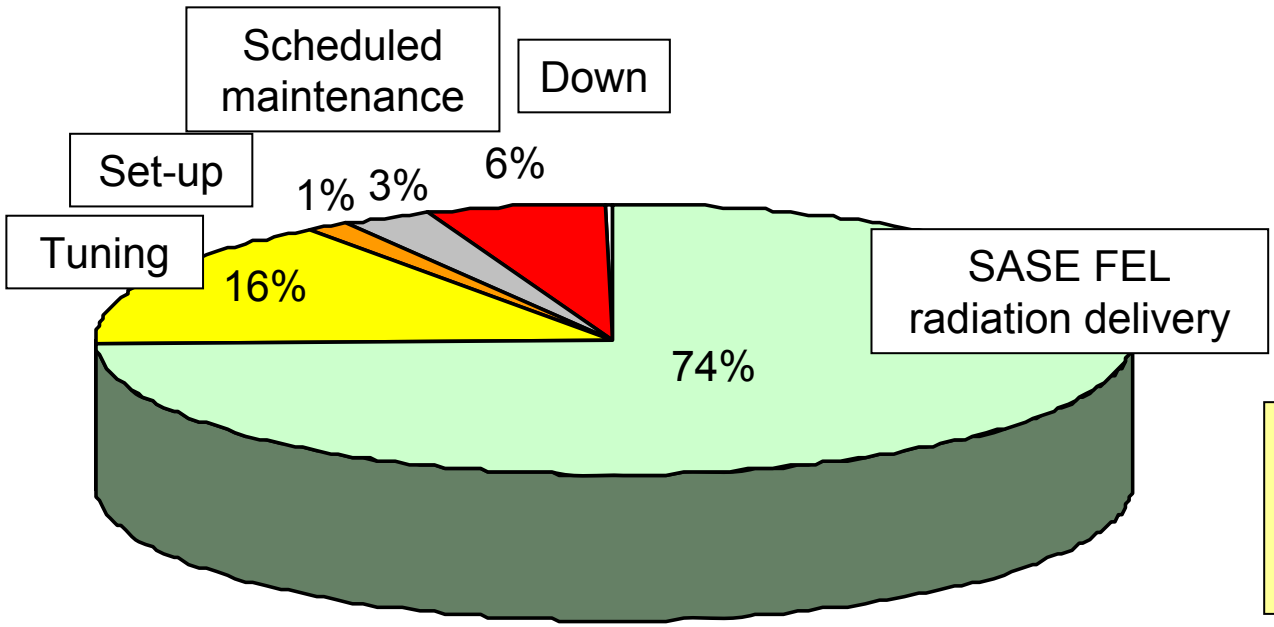
data from 2nd user run

9 blocks of 4 weeks each,
Nov-2007 to April-2009



in 2009:

SASE delivery 78 %

uptime 95 %

- **FLASH uptime 94 %**
- Tuning time: mainly when changing wavelength
- Wavelength has been changed more than 120 times
- More than 30 different wavelengths between 6.8 nm and 40.5 nm

Experiments

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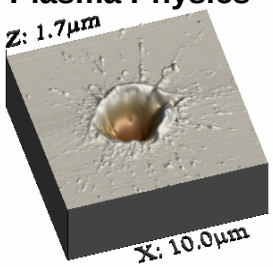
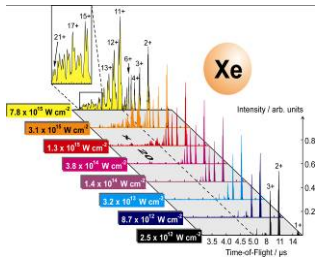
Free-Electron Laser in Hamburg

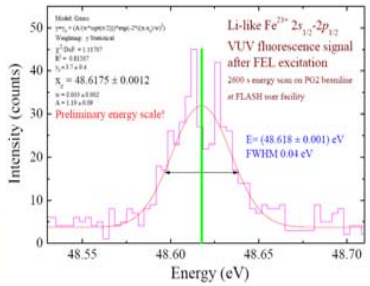
Plasma Physics



Multi-Photon Processes

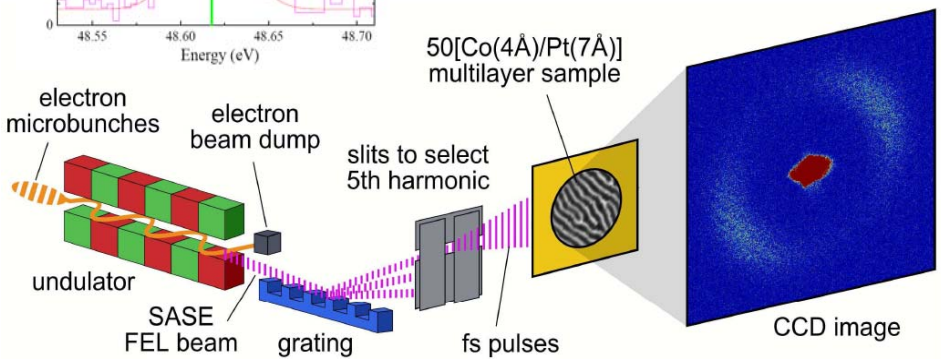


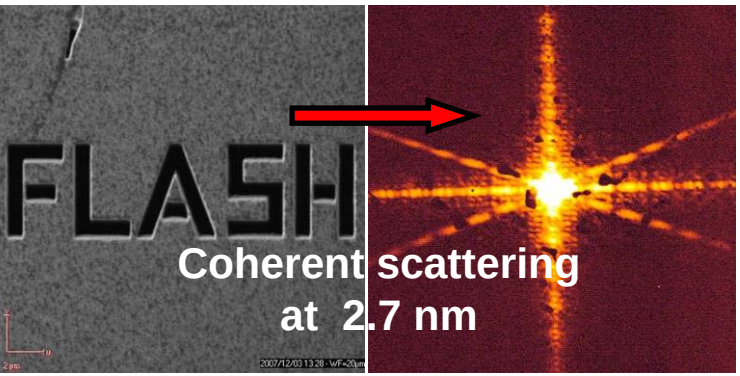
Spectroscopy on Highly Charged Ions

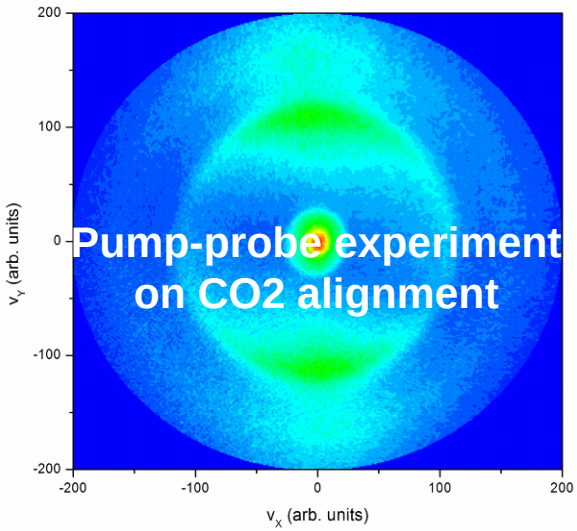


→ talk M. Bogan Fr 14 h

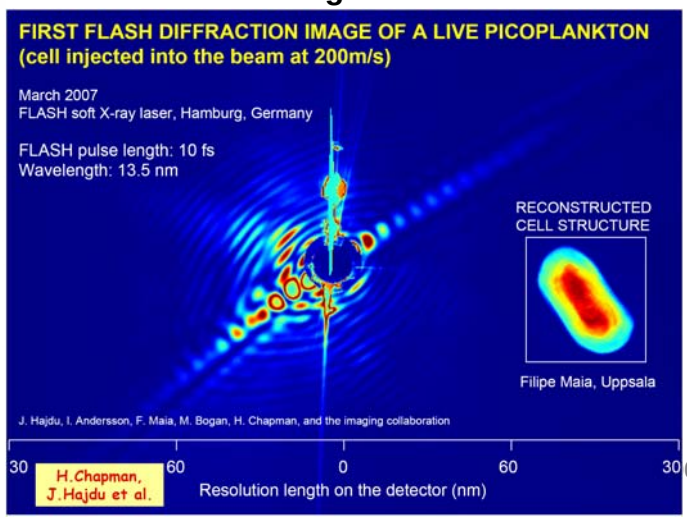
Resonant magnetic scattering with fs-pulses at 1.59 nm

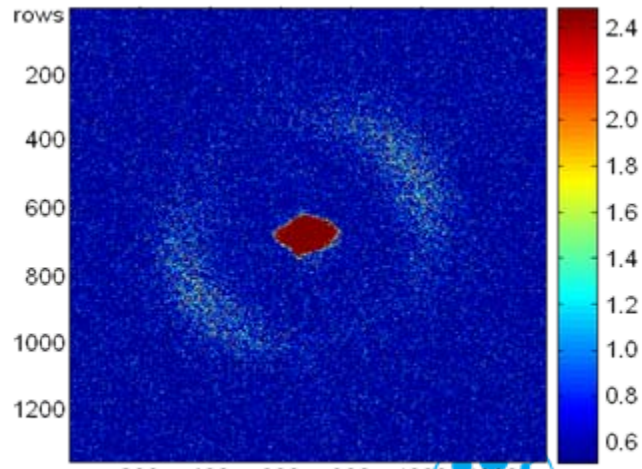






Single Particle Diffraction





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Experiments

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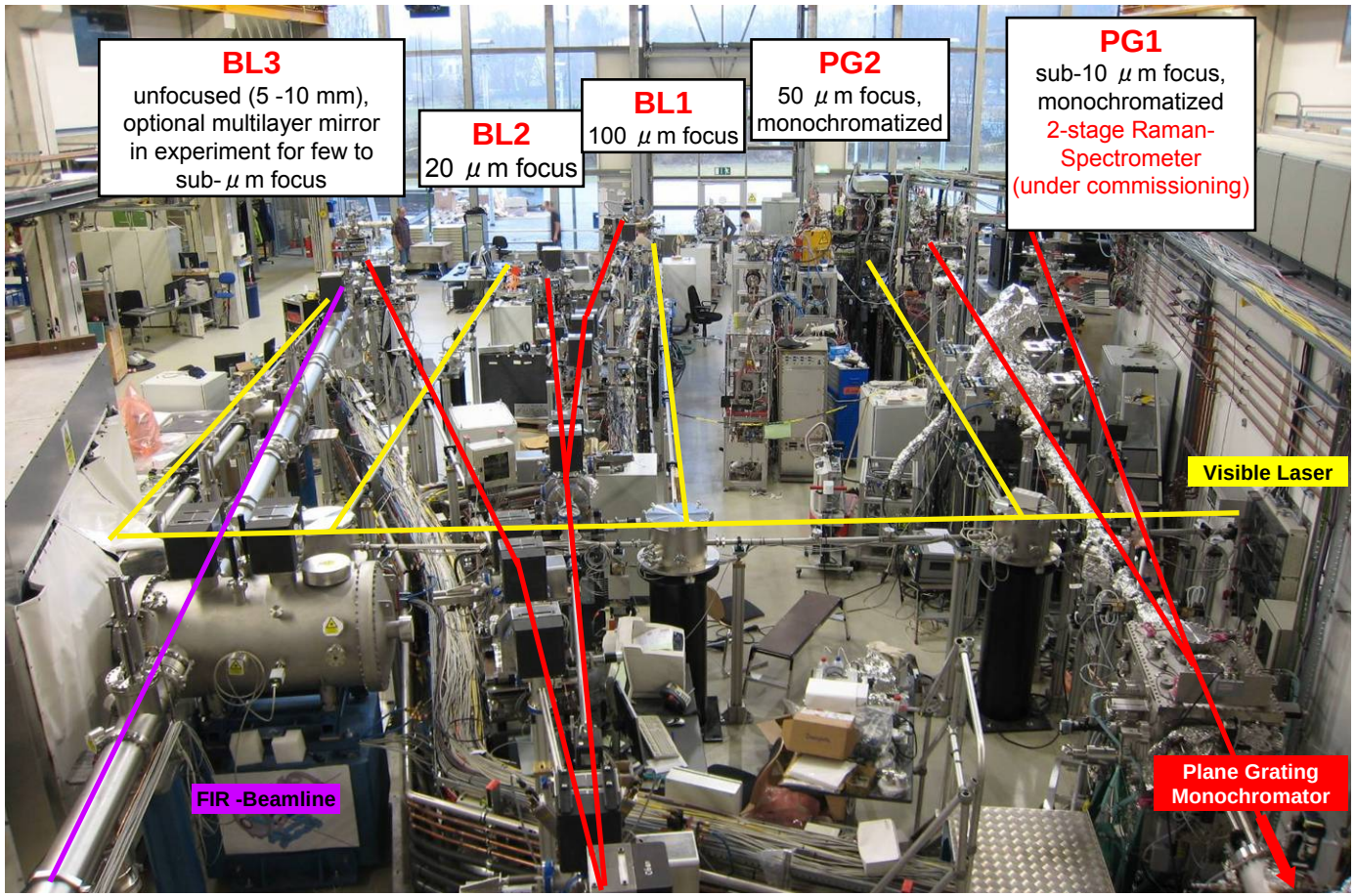
> ~50 publications (plus ~20 submitted) on photon science at FLASH:
1 Nature, 1 Nature Physics, 4 Nature Photonics, 12 PRL, 5 PRA/E, 5 APL, 3 Optics Express, 1 Opt. Lett., 2 JPB …



http://hasylab.desy.de/facilities/flash/publications/selected_publications/

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Upgrade Plans

FLASH
Free-Electron Laser in Hamburg

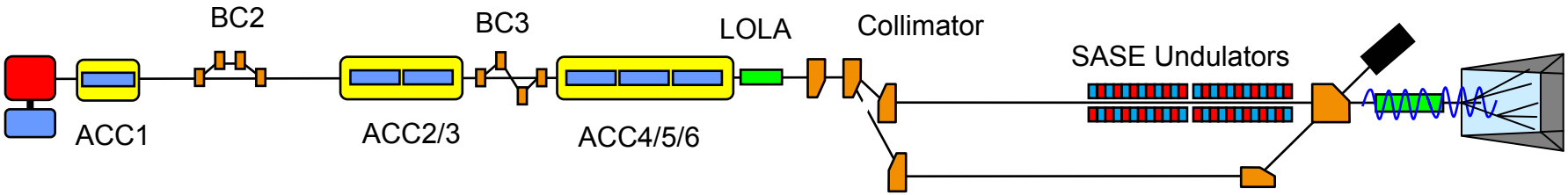
- Continuous beam operation until August 2009
- Upgrade in 2009: major modifications
  - installation the 3rd harmonic (3.9 GHz) module – *arrived from FNAL last week*
  - installation of the 7th accelerating module → energy up to ~ 1.2 GeV ↔ 5 nm
  - installation of an experiment for seeded VUV radiation "sFLASH"

  → replacement of complete electron beam line between collimators and SASE undulators (~ 40 meters)
  - exchange of the RF gun
  - upgrades of RF stations and waveguide distribution
- Commissioning spring 2010
- The 3rd FEL user period is foreseen to start summer 2010
- Beyond this upgrade: proposal for a 2nd undulator beamline (FLASH II) together with Helmholtz Zentrum Berlin (HZB)

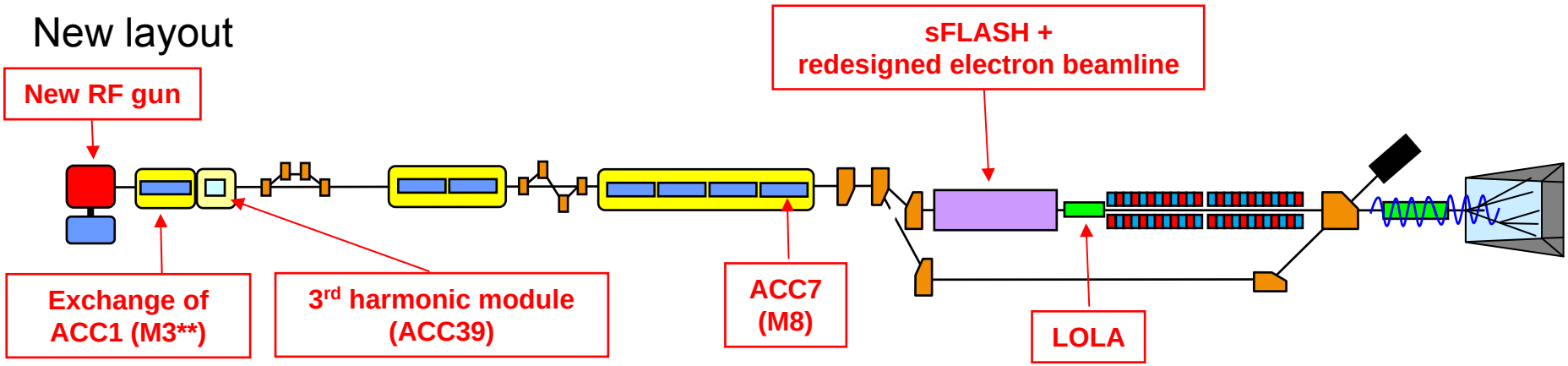
Upgrade: Linac layout

FLASH
Free-Electron Laser in Hamburg

Present layout



New layout



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sFLASH

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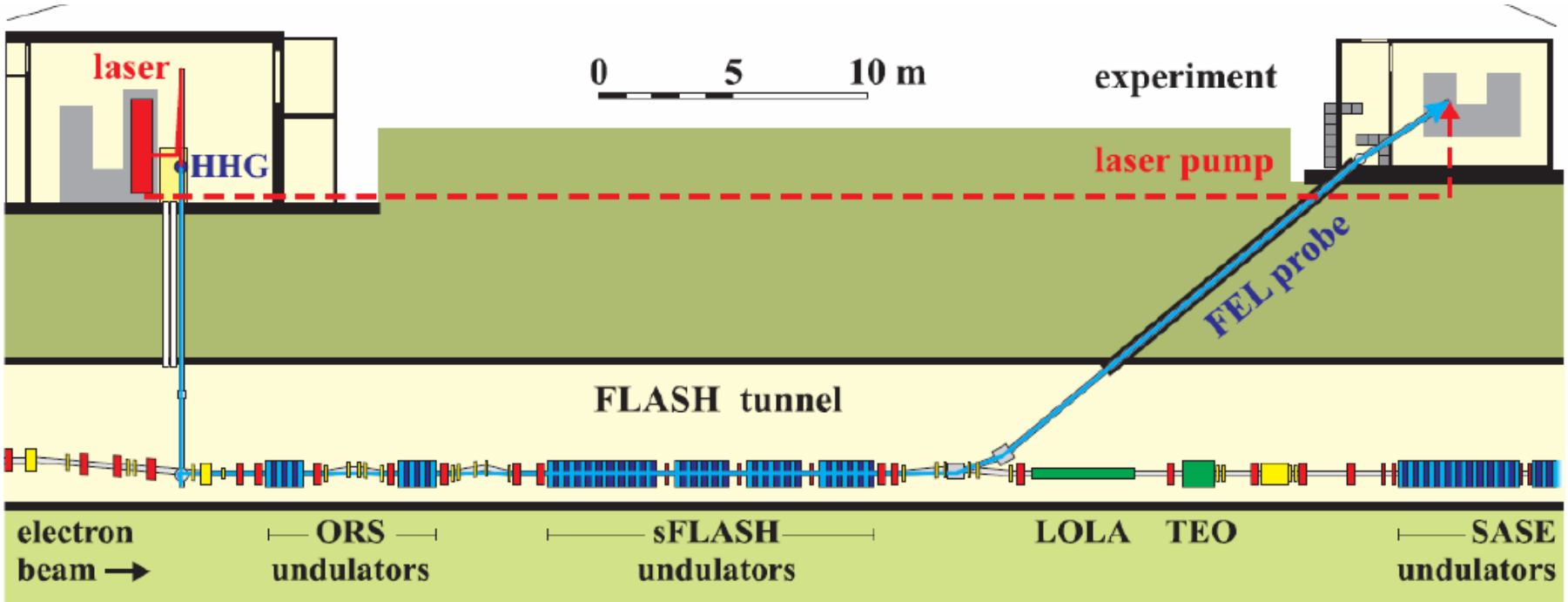
- High Harmonic Laser Seeding at 30nm
- To be installed between the linac and the FLASH undulators



top view

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Summary

FLASH
Free-Electron Laser in Hamburg

- FLASH is a world-wide unique light source
  - in the wavelength range of 47 nm to 6.8 nm
  - ultra-short FEL pulses (10 to 50 fs)
  - unprecedented brilliance
- Since summer 2005, user FEL experiments in different fields have been performed successfully
- Upgrade shutdown 21-Sep-2009 to 1-March 2010
  - increase beam energy to 1.2 GeV (5 nm)
  - 3rd harmonic cavity
  - seeding experiment sFLASH
- 3rd user period will start summer 2010
- Proposal pending for a 2nd beamline (FLASH II) together with HZB
- FLASH is also a world-wide unique test facility for SCRF technology