First Direct Seeding at 38 nm

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FEL 2012
Nara, 08/28/2012

on behalf of the sFLASH team

Supported by BMBF under contract No. 05K10GU1 and by DFG GRK 1355.

Outline

- Introduction / Motivation
- The experiment
  - Layout
  - Procedures
- Seeding results at $\lambda = 38\ \mathrm{nm}$

Motivation for Seeding

SASE Free-electron lasers

- pulsed radiation with wavelengths down to sub-Å
- transverse coherence
- typically limited longitudinal coherence: multiple uncorrelated longitudinal modes present

with seeding:

- amplify external coherent optical field
- longitudinal coherence of the FEL pulse determined by the external field

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with seeding:

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Goals:

→ high peak power (GW level)

→ stable pulse spectrum and energy

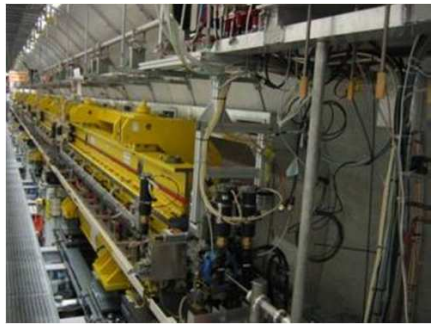
→ high longitudinal coherence

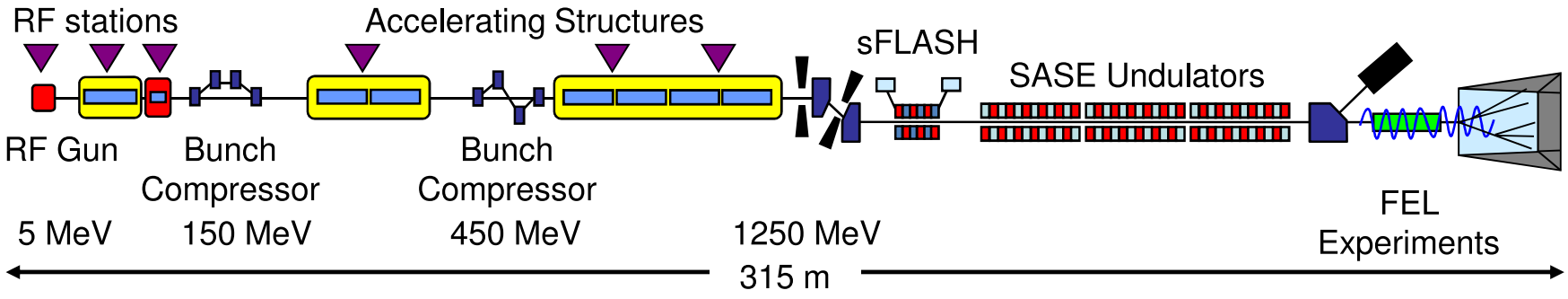
FLASH at DESY (Hamburg)

Normal conducting 1.3 GHz RF gun

TESLA type superconducting accelerating modules (1.3 GHz)

Fixed gap SASE undulators

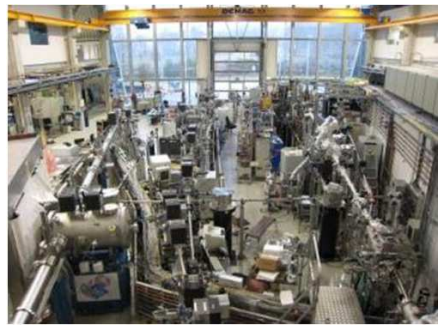




3rd harmonic module (3.9 GHz)

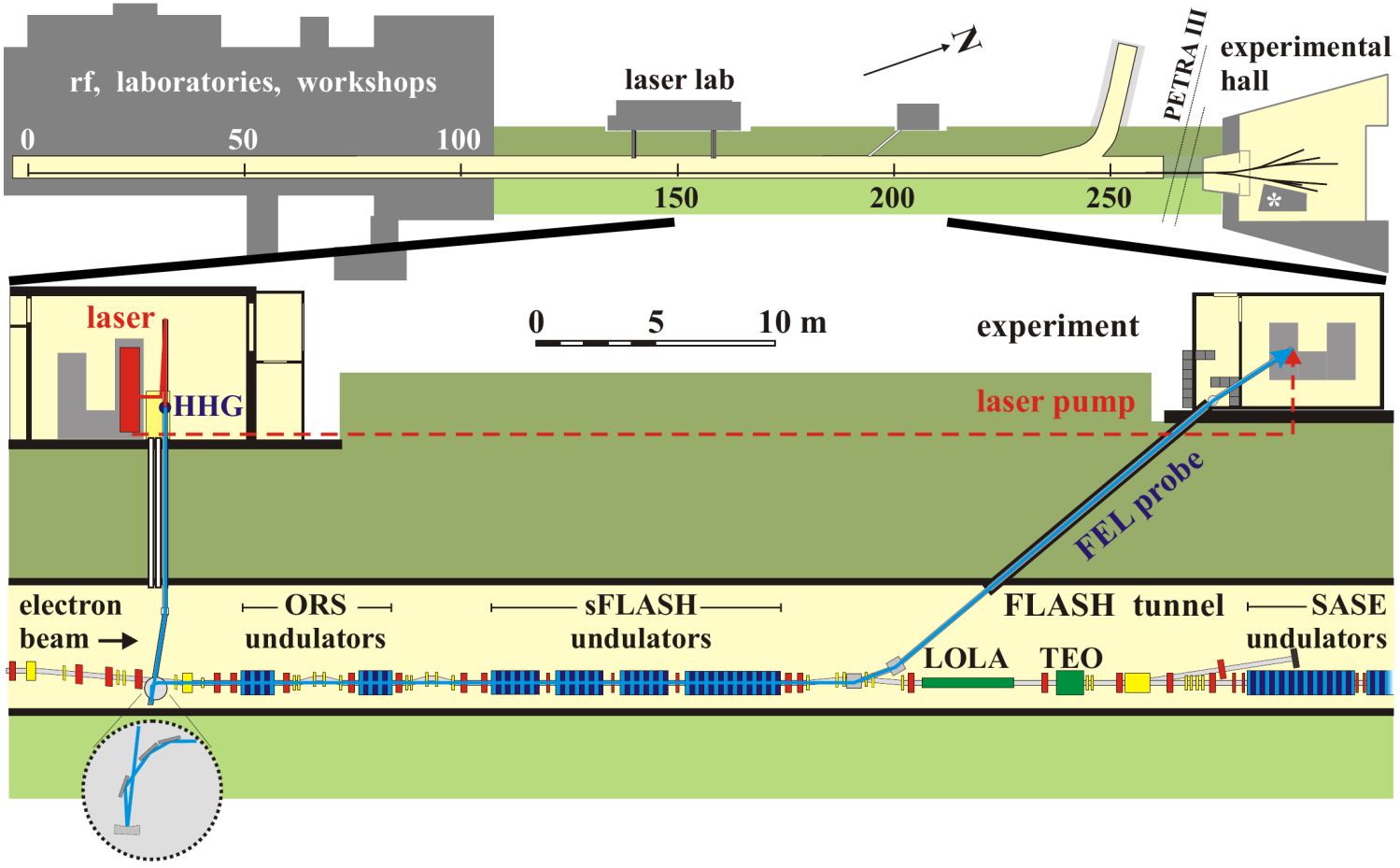
Diagnostics and matching

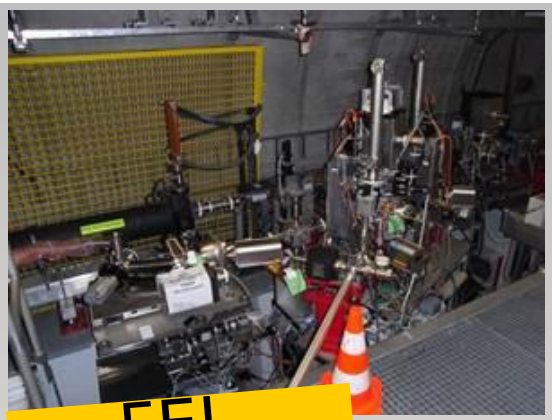
Variable gap sFLASH undulators

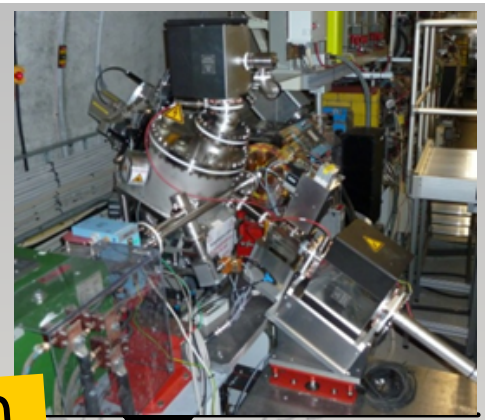


FEL Experimental Hall

Layout of the sFLASH Experiment







FEL extraction

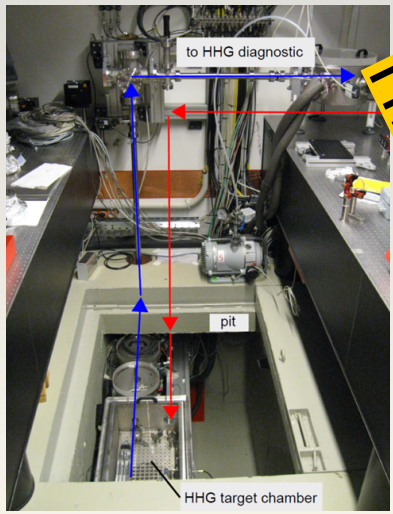
Undulator section

ORS section

Seed injection

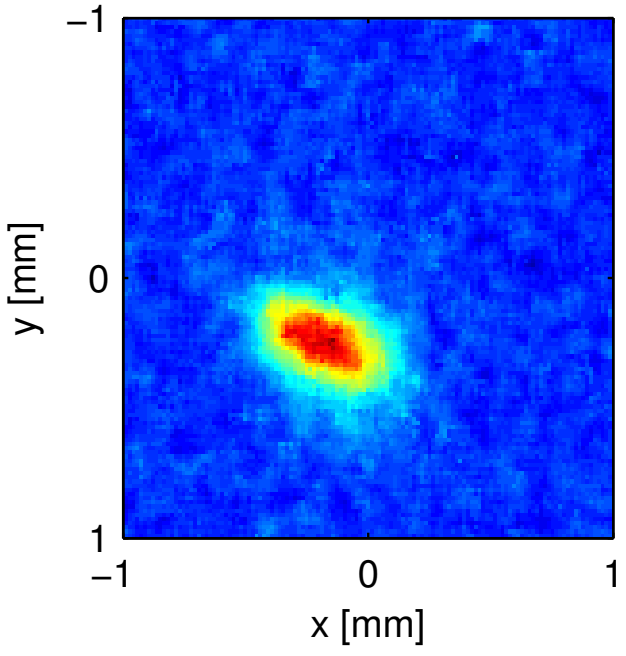
HHG source

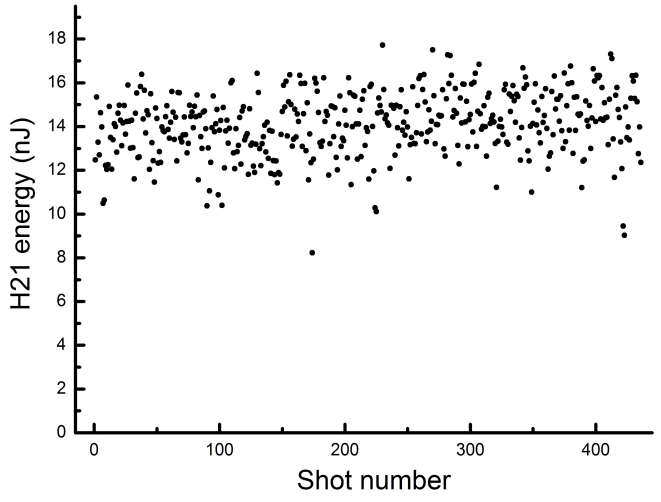
variable-gap undulators with gap setting reproducibility better than 1µm



HHG Source Performance

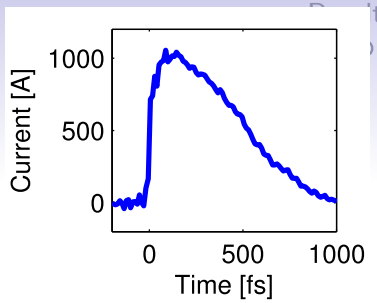
Typical HHG seed beam profile at the entrance of the first undulator:





✓ At the source: energy in 21st harmonic 14 nJ (10% rms stability)

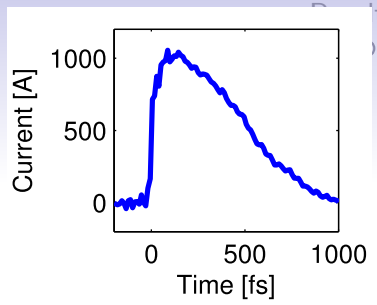
Experimental Procedure



Current profile reconstructed from a THz single-shot spectrum

- setup accelerator for 700 MeV
  - bunch charge 0.5 nC
  - feedback systems for compression and energy
- establish high FEL gain at correct wavelength
  - tuning sFLASH to SASE
  - spectral overlap of 21st harmonic ($\lambda = 38.1\ \mathrm{nm}$) and sFLASH SASE

Experimental Procedure



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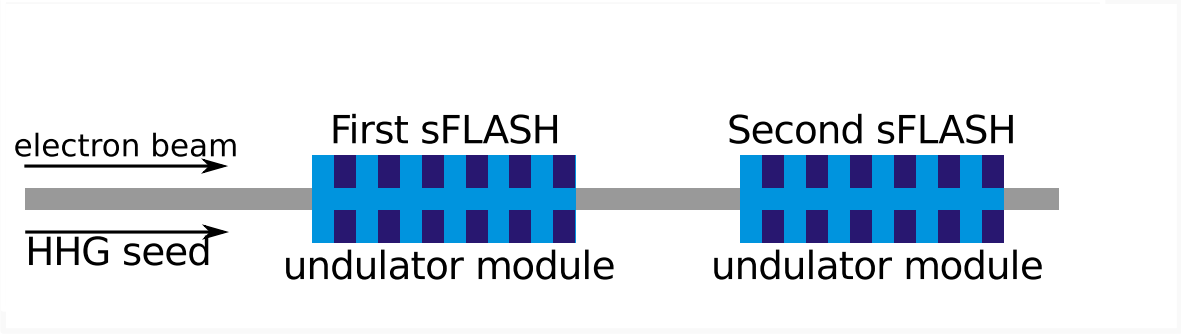
- transverse overlap (tolerances 50 $\mu\mathrm{m}$, 50 $\mu\mathrm{rad}$)



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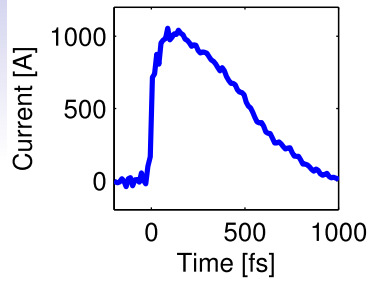

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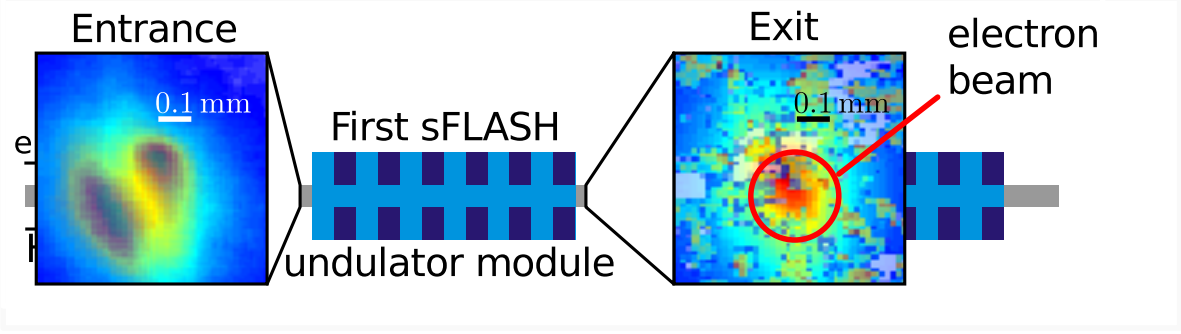
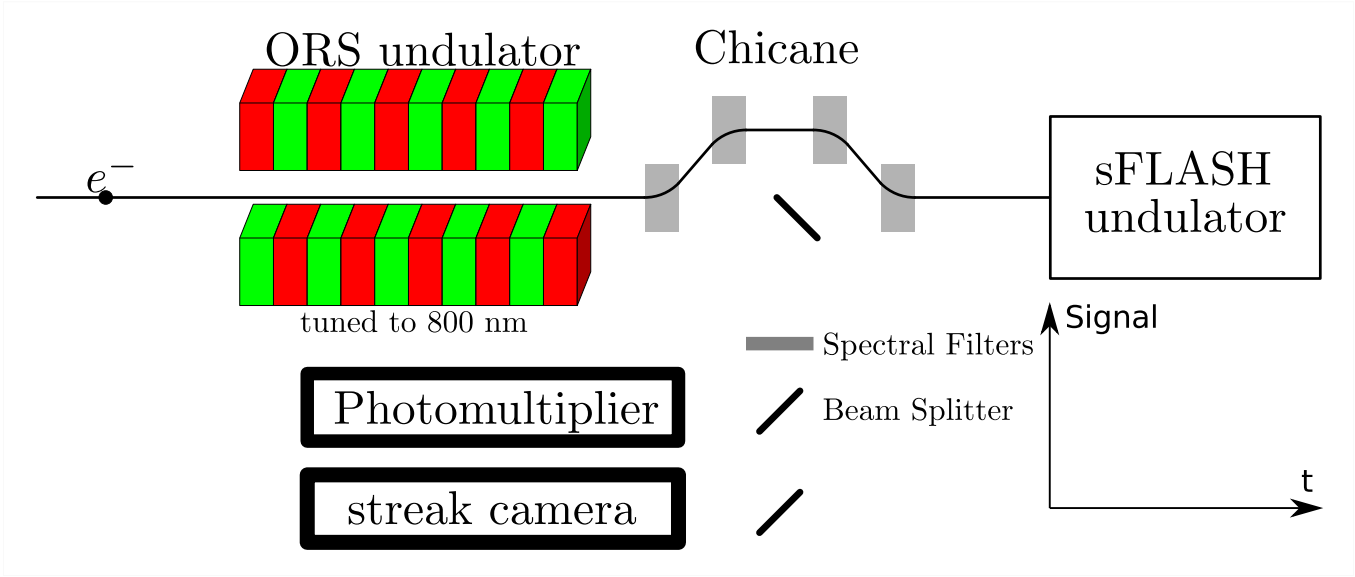


typical transverse profiles (electrons and HHG) at the first sFLASH undulator

Experimental Procedure

- temporal overlap
  - down to 1 ns: photomultiplier + oscilloscope
  - down to 10 ps: streak camera
  - finally: time scan (100 fs steps)



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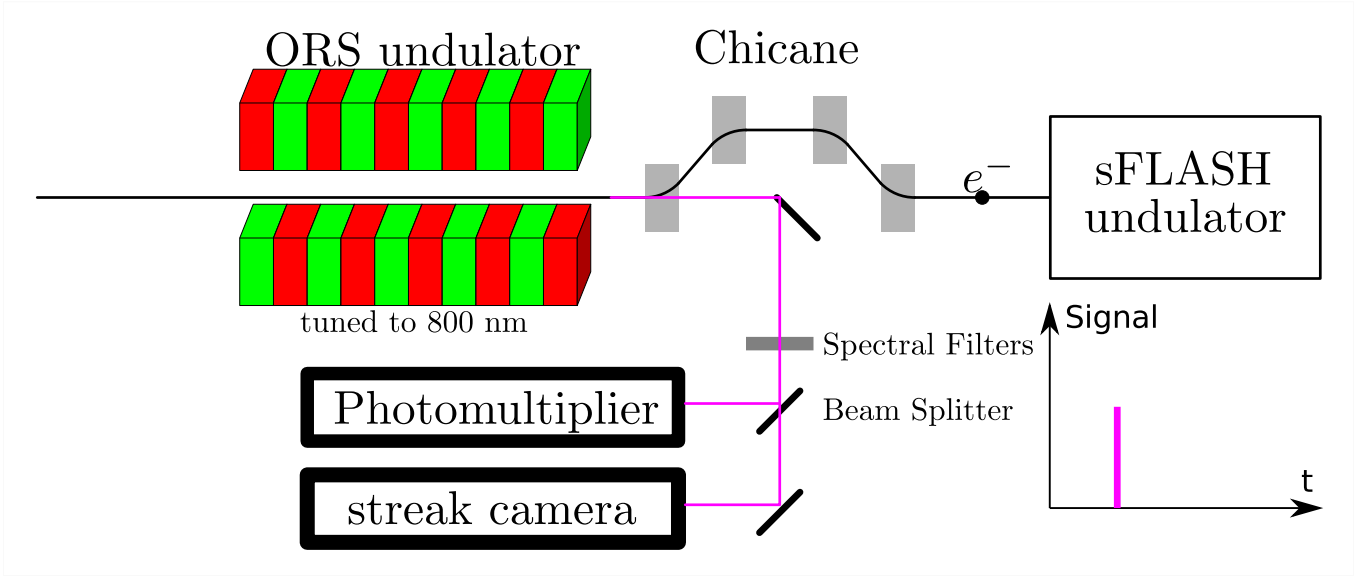

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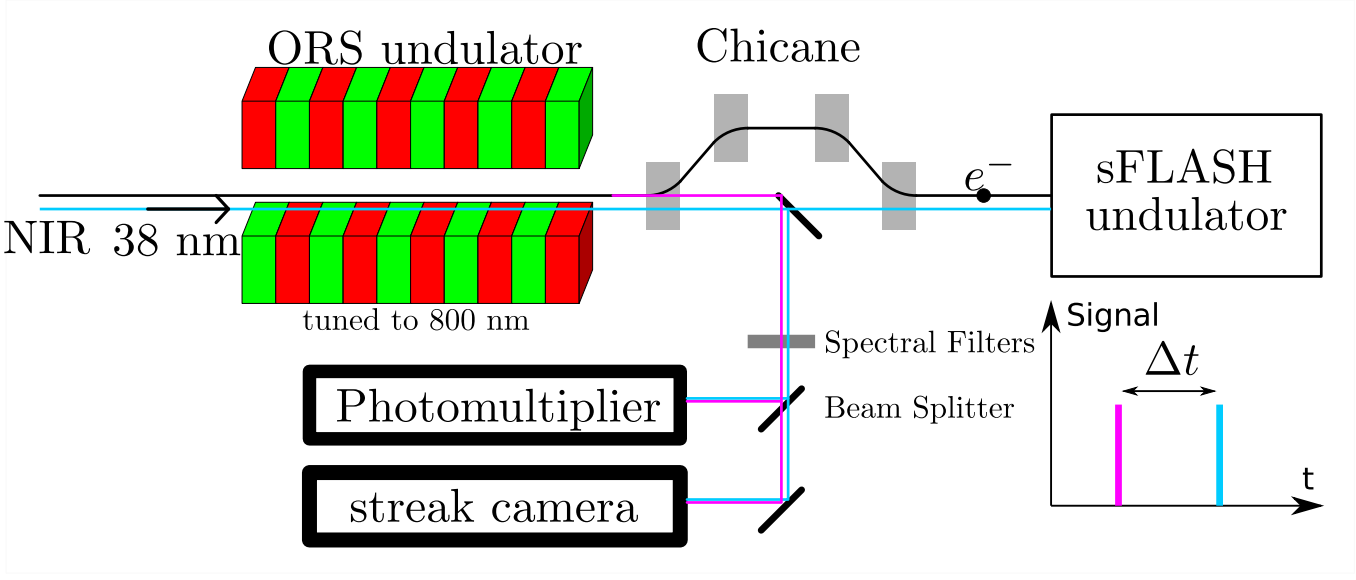

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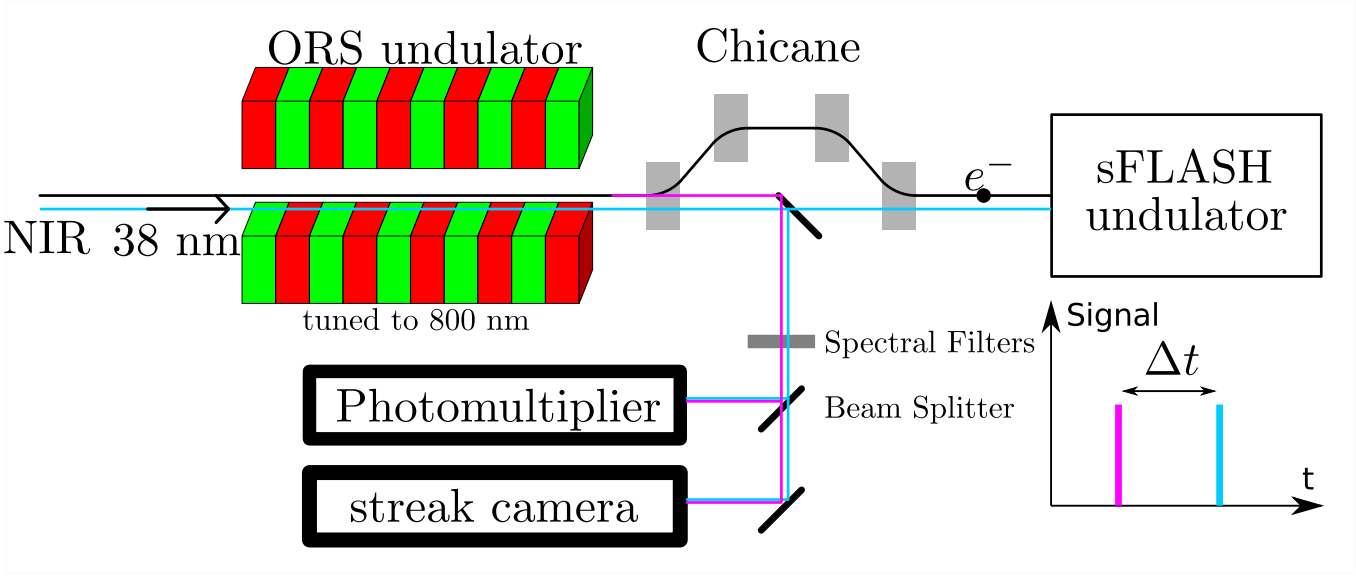
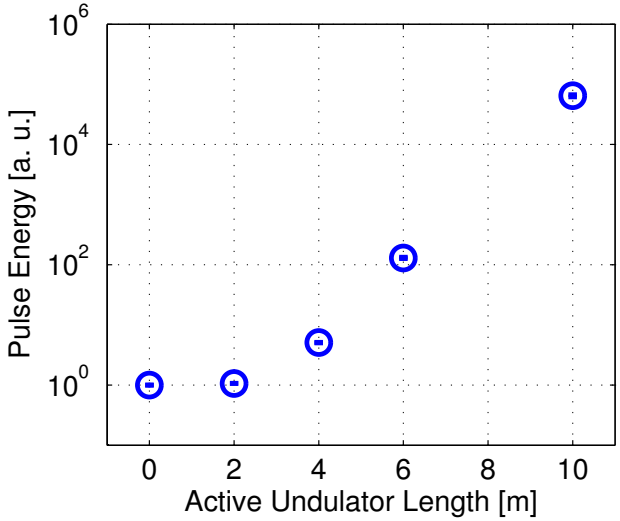


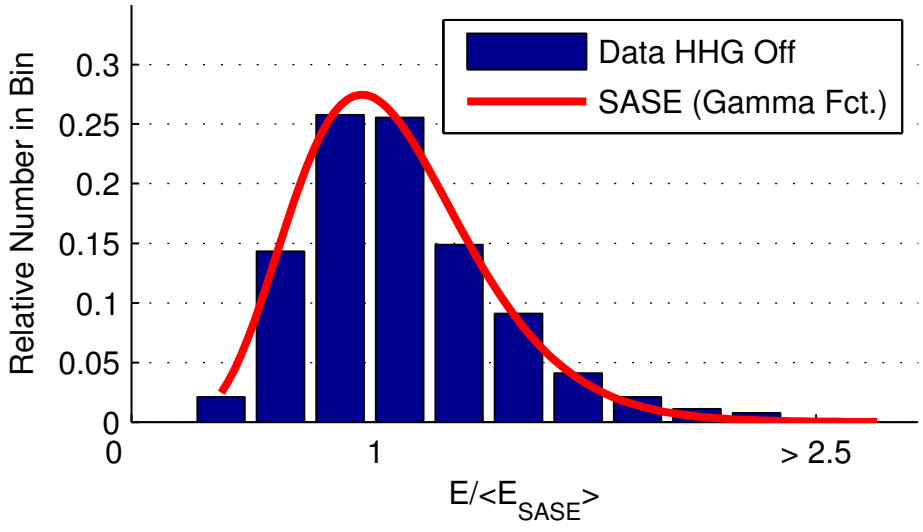
Durations (FWHM): electron bunch 300-400 fs, HHG seed pulse 20 fs

Tolerance 100 fs

FEL Amplifier Characterization

SASE mode





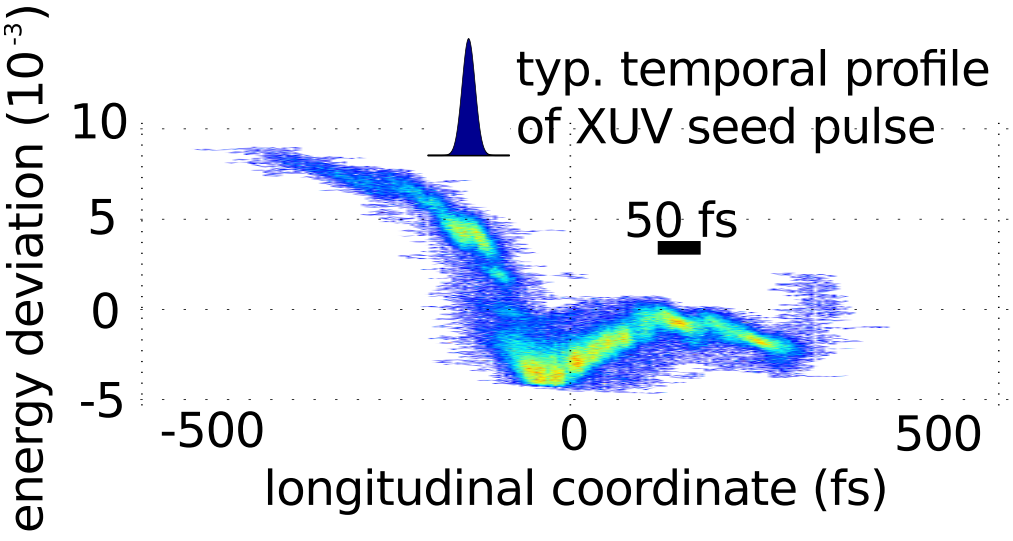
Power gain length about
0.65 m

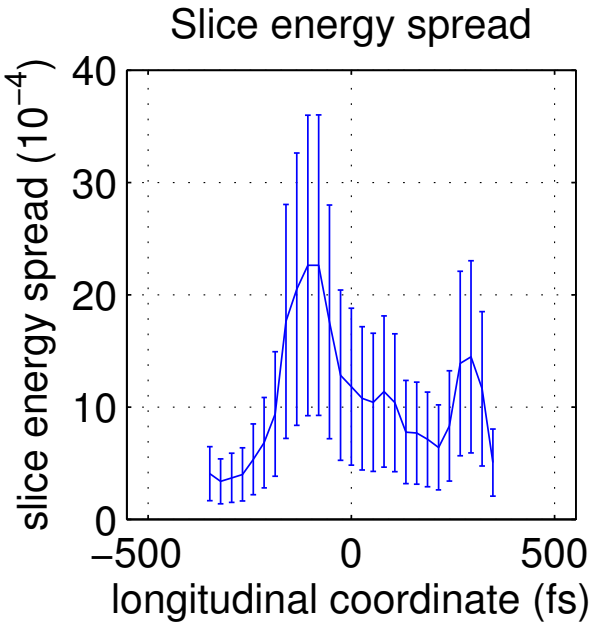
Number of longitudinal modes:
$M = 8.3 \pm 1.2$

$\Rightarrow$ Coherence time 6 fs, radiation pulse length $\sim$ 50 fs

LOLA TDS

With the LOLA transverse deflecting structure (TDS) one can measure the longitudinal phase space after sFLASH undulators ...





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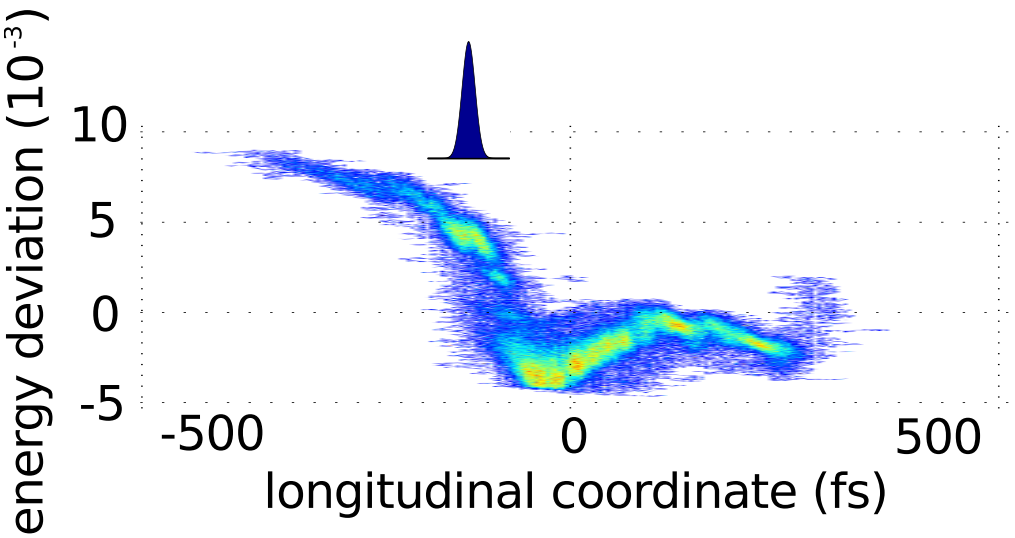
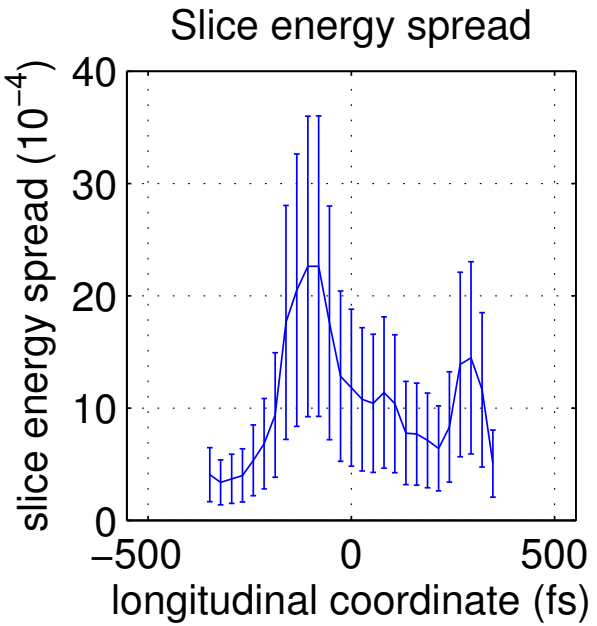
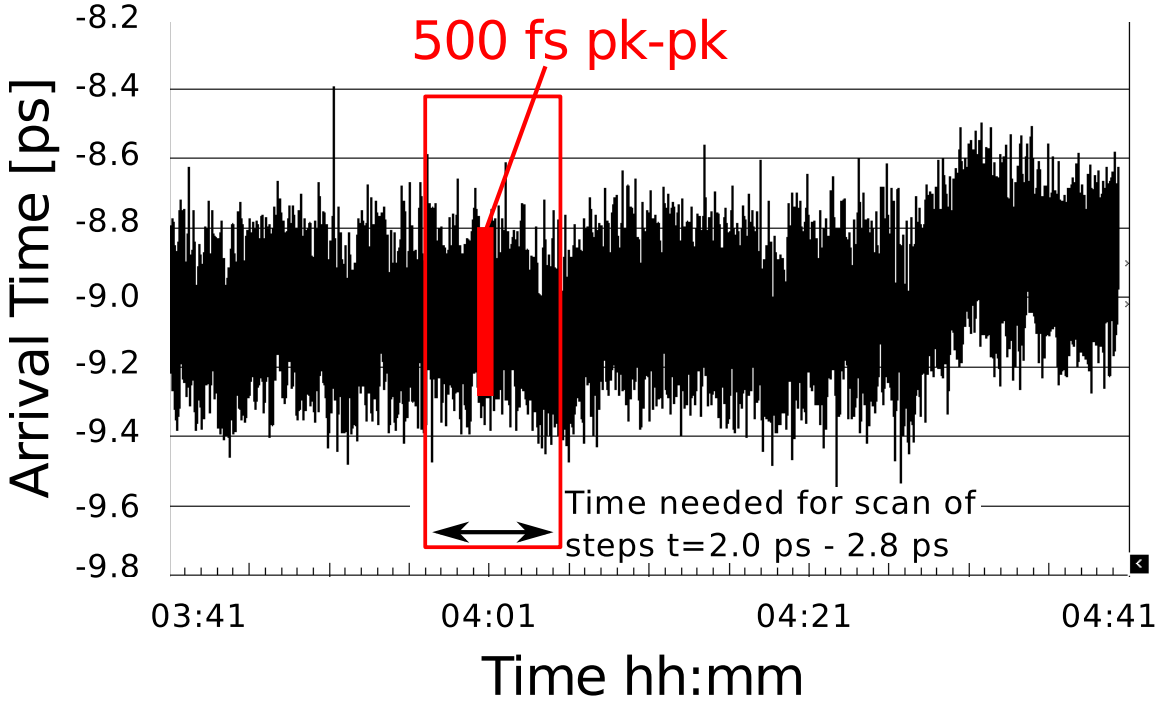




Electron Bunch Arrival Time During Measurements

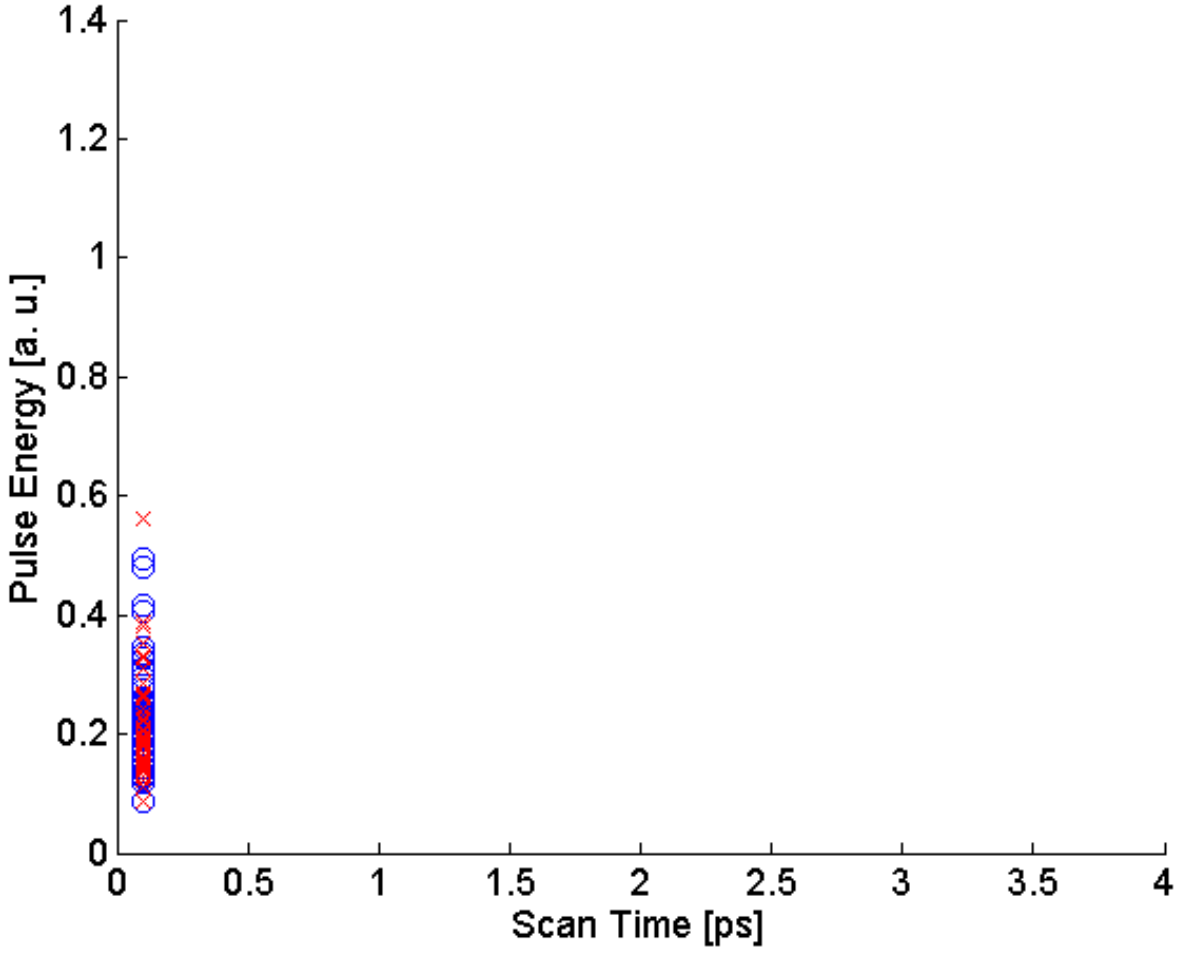
- arrival time feedback off due to single bunch operation
- future sFLASH scenario: make use of existing arrival time feedbacks in multibunch operation mode



SASE pulse duration estimated to 50 fs
500 fs pk-pk electron arrival jitter
$\Rightarrow$ limits probability for temporal overlap

Temporal Fine Scan

Transverse, wavelength overlap and coarse temporal overlap established.
Scan time to establish overlap.



HHG source on

HHG source off

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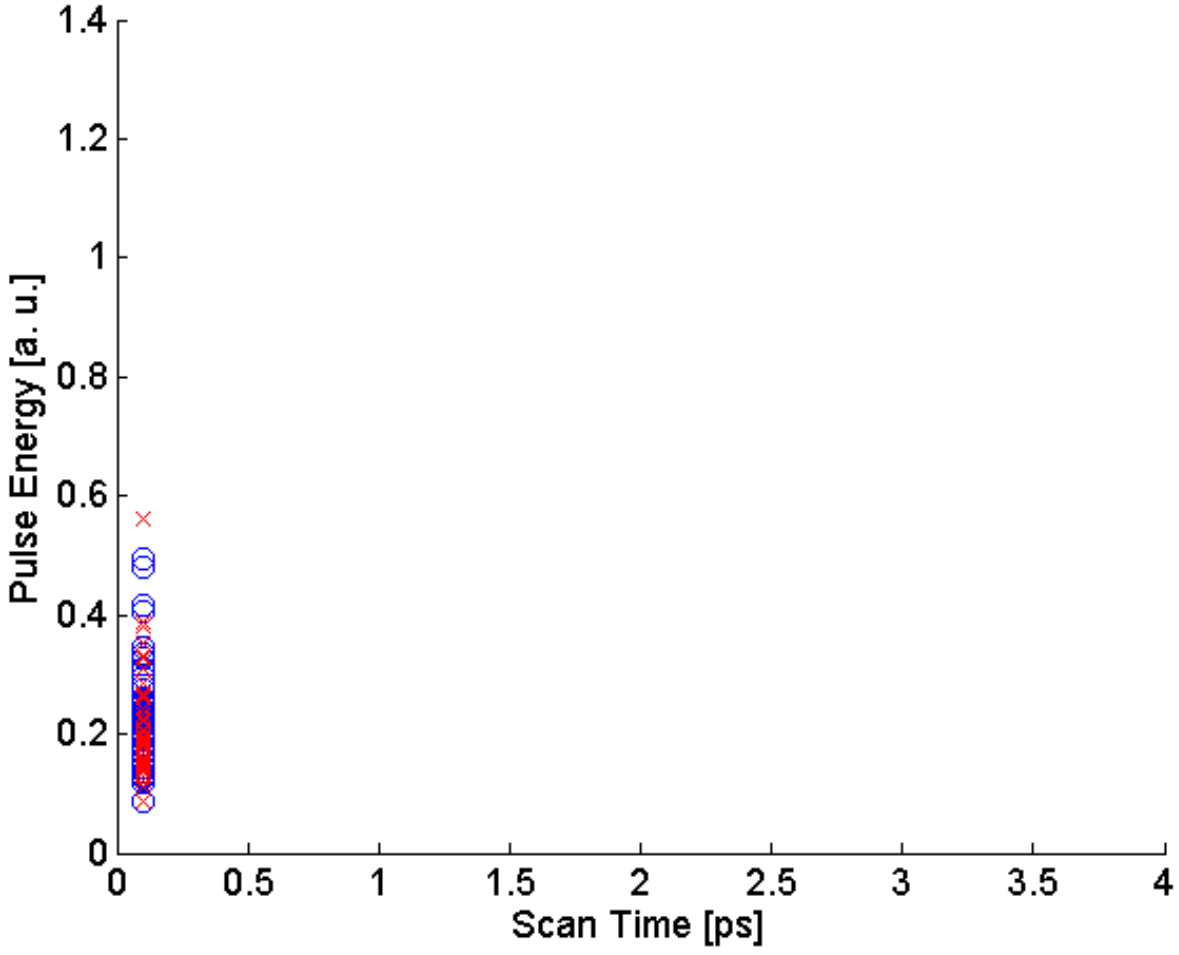
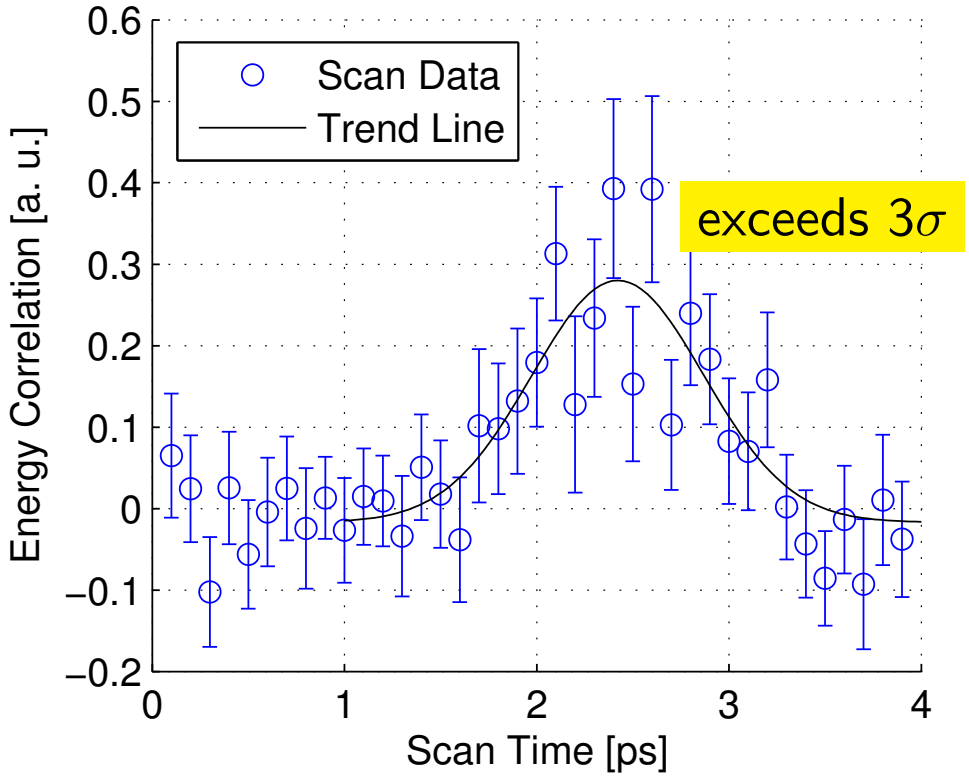


HHG source on

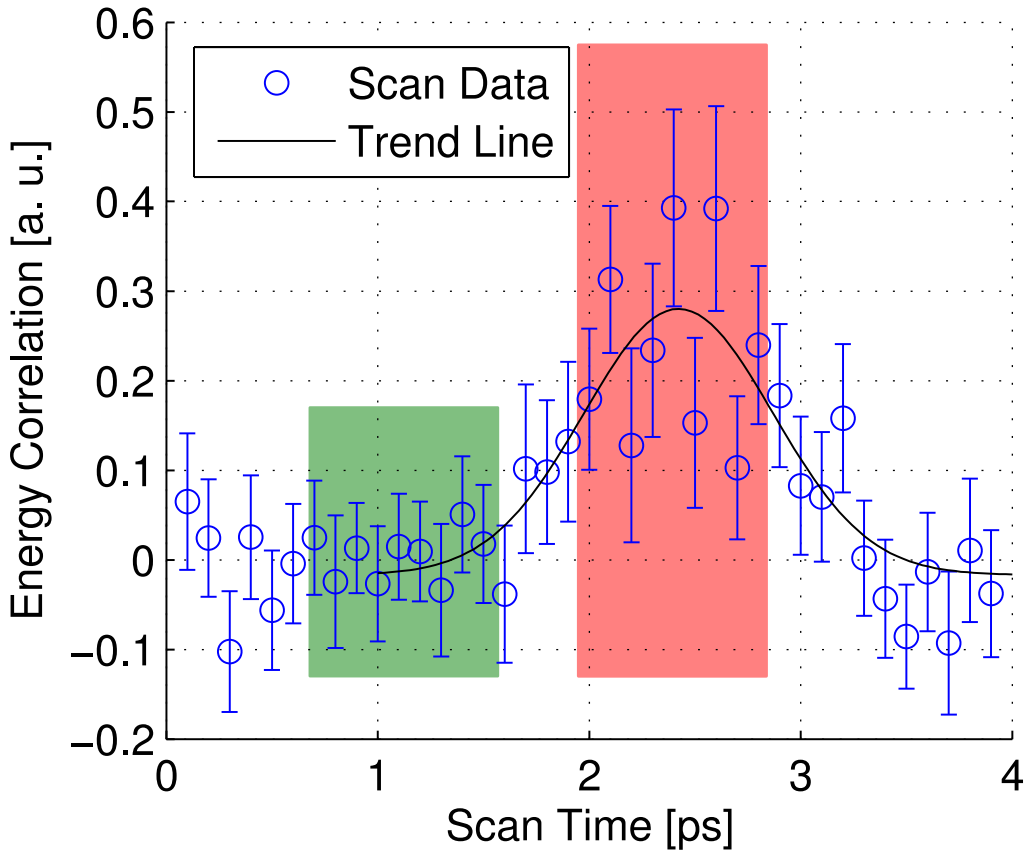
HHG source off

FEL Pulse Energy vs. Time Offset



For each scan step: Correlation of XUV seed pulse energy at the source and pulse energy in the FEL pulse

Alternative Data Analysis



Alternative Data Analysis

Histograms removed for copyright reasons (paper submitted).

Electron Bunch Arrival Time During Measurements

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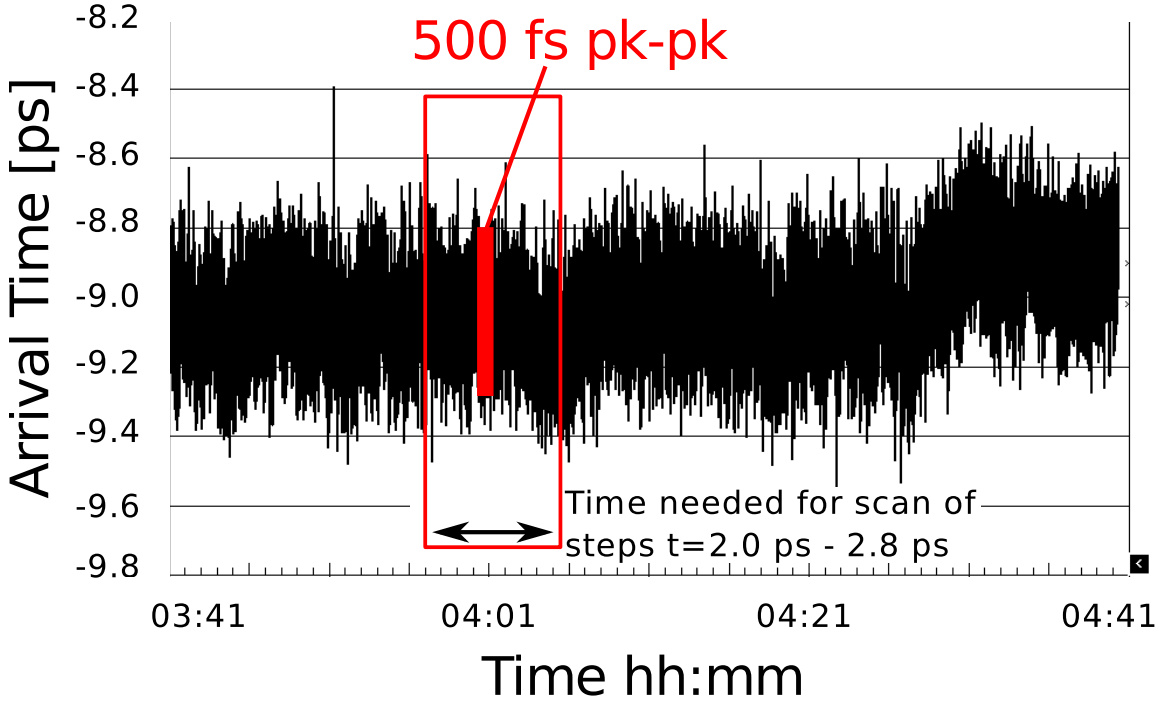

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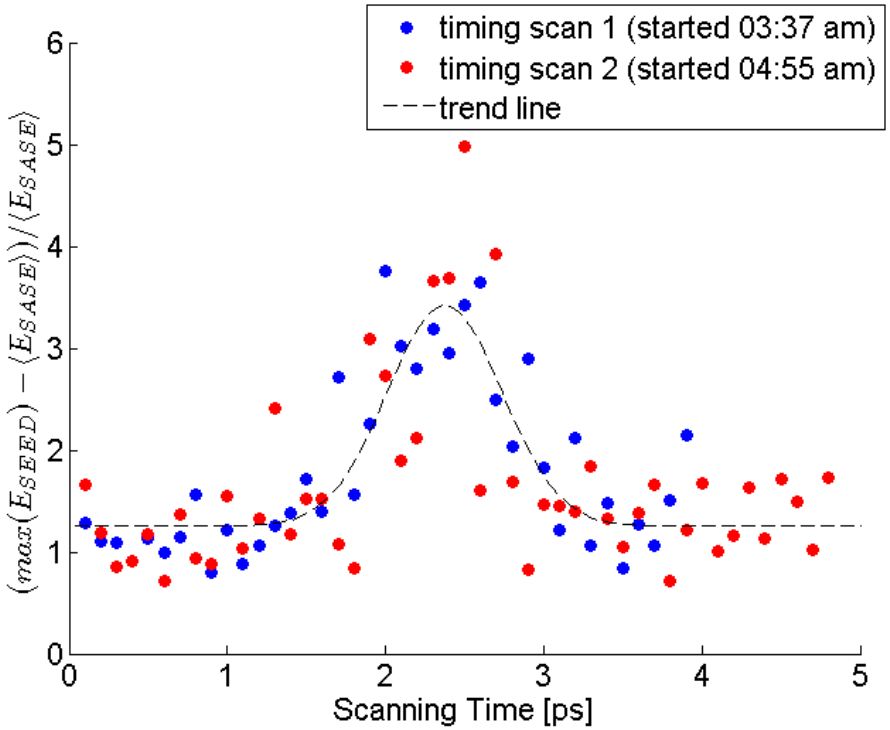
Energy Contrast Measurement



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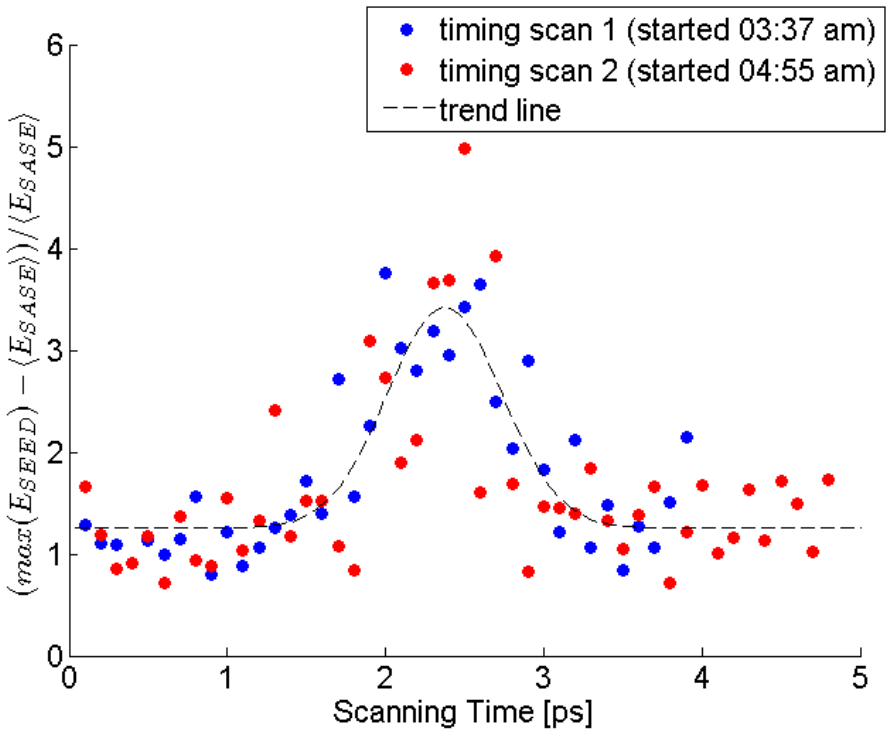
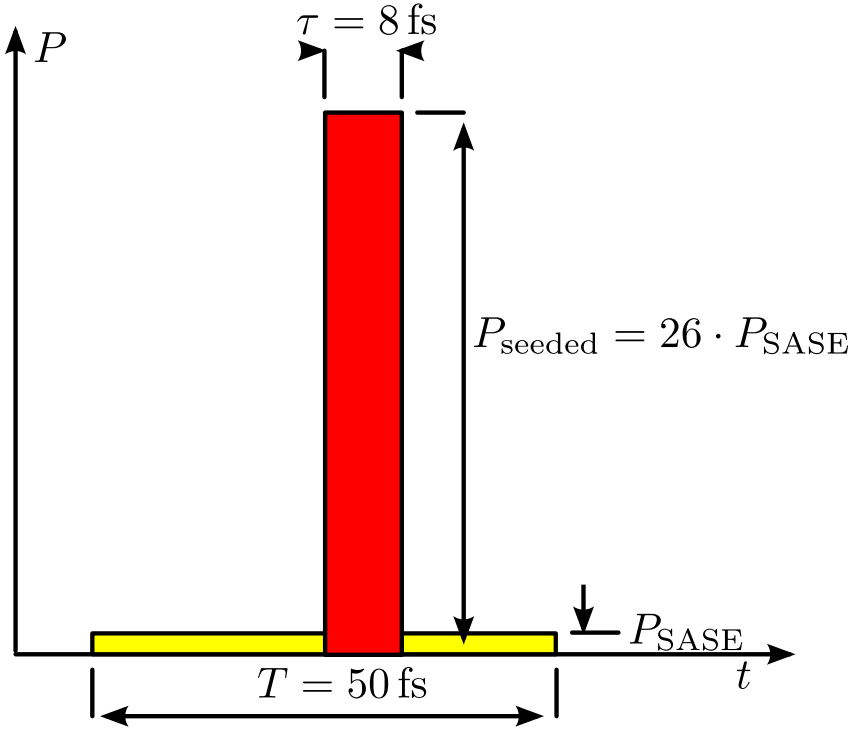


What can we conclude from $\frac{\max(E_{\text{seed}}) - \langle E_{\text{SASE}}\rangle}{\langle E_{\text{SASE}}\rangle} = 4$ for excess of instantaneous power in the seeded part of the pulse?

From Energy Contrast to Power Increase

Model for expected time profile of the photon pulse



Assumptions:

- energy contrast of 4
- SASE pulse length $T = 50$ fs
- HHG pulse length $\tau = 8$ fs

Linear FEL amplifier

$$\frac{E_{\mathrm{tot}}}{E_{\mathrm{SASE}}} = \frac{T \cdot P_{\mathrm{SASE}} + \tau(P_{\mathrm{seeded}} - P_{\mathrm{SASE}})}{T \cdot P_{\mathrm{SASE}}}$$

$$\Rightarrow P_{\mathrm{seeded}} = 26 \cdot P_{\mathrm{SASE}}$$

Summary and Outlook

- first seeding at wavelength $\lambda = 38\ \mathrm{nm}$ demonstrated
  - power contrast approx. 30
- lessons learned:
  - need for HHG pulse characterization at the entrance of the undulator
  - stability of temporal overlap limits fraction of seeded bunches
  - feedbacks have to be applied to electron beam and photon beam parameters

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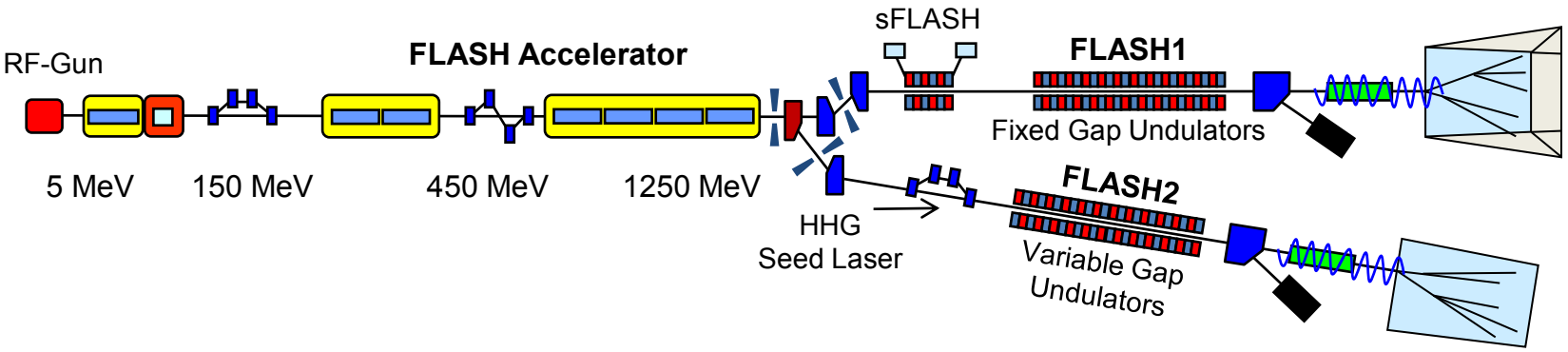
Outlook:

- spectral phase control
- temporal characterization of seeded FEL radiation
- towards shorter wavelengths
- run sFLASH parallel to FLASH SASE

FLASH2 Beamline

Seeding will be a key asset of FLASH2.



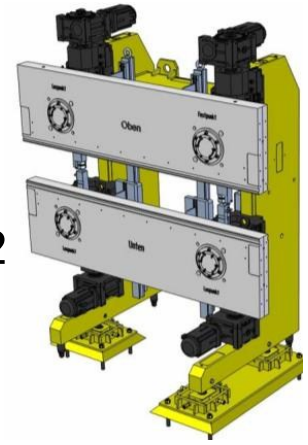
Posters:

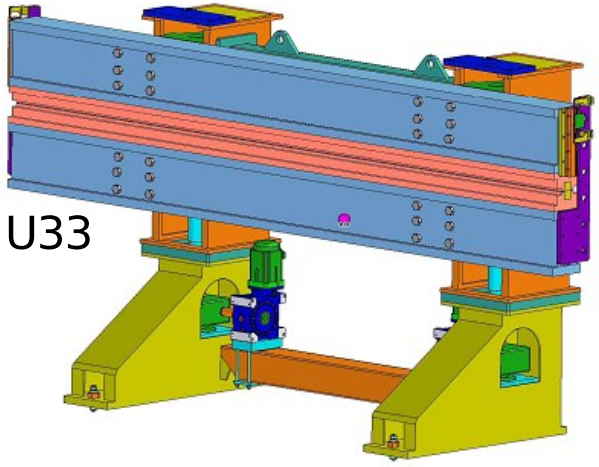
- Sven Ackermann et al: "Optimization of HHG Seeding between 10 nm to 40 nm", TUPD11
- Katja Honkavaara: "Status of the FLASH II Project", WEPD07

Thank you for your attention

S. Ackermann, A. Azima, S. Bajt, J. Bödewadt, F. Curbis, H. Dachraoui, H. Delsim-Hashemi, M. Drescher, S. Düsterer, B. Faatz, E. Hass, U. Hipp, K. Honkavaara, R. Ischebeck, S. Khan, T. Laarmann, C. Lechner, T. Maltezopoulos, V. Miltchev, M. Mittenzwey, M. Rehders, J. Rönsch-Schulenburg, J. Roßbach, H. Schlarb, S. Schreiber, L. Schroedter, R. Tarkeshian, M. Tischer, V. Wacker, M. Wieland

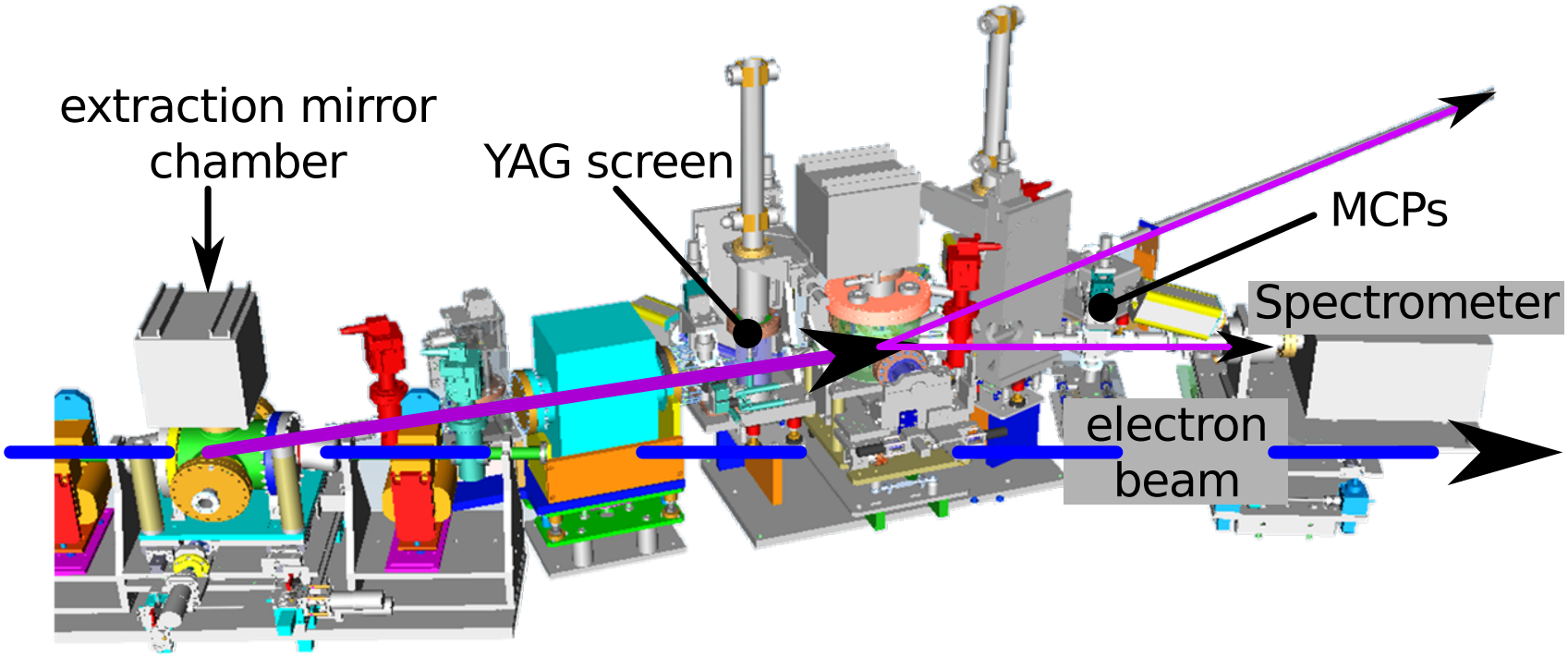
sFLASH Undulator Modules

3x U32 

+ 1x U33 

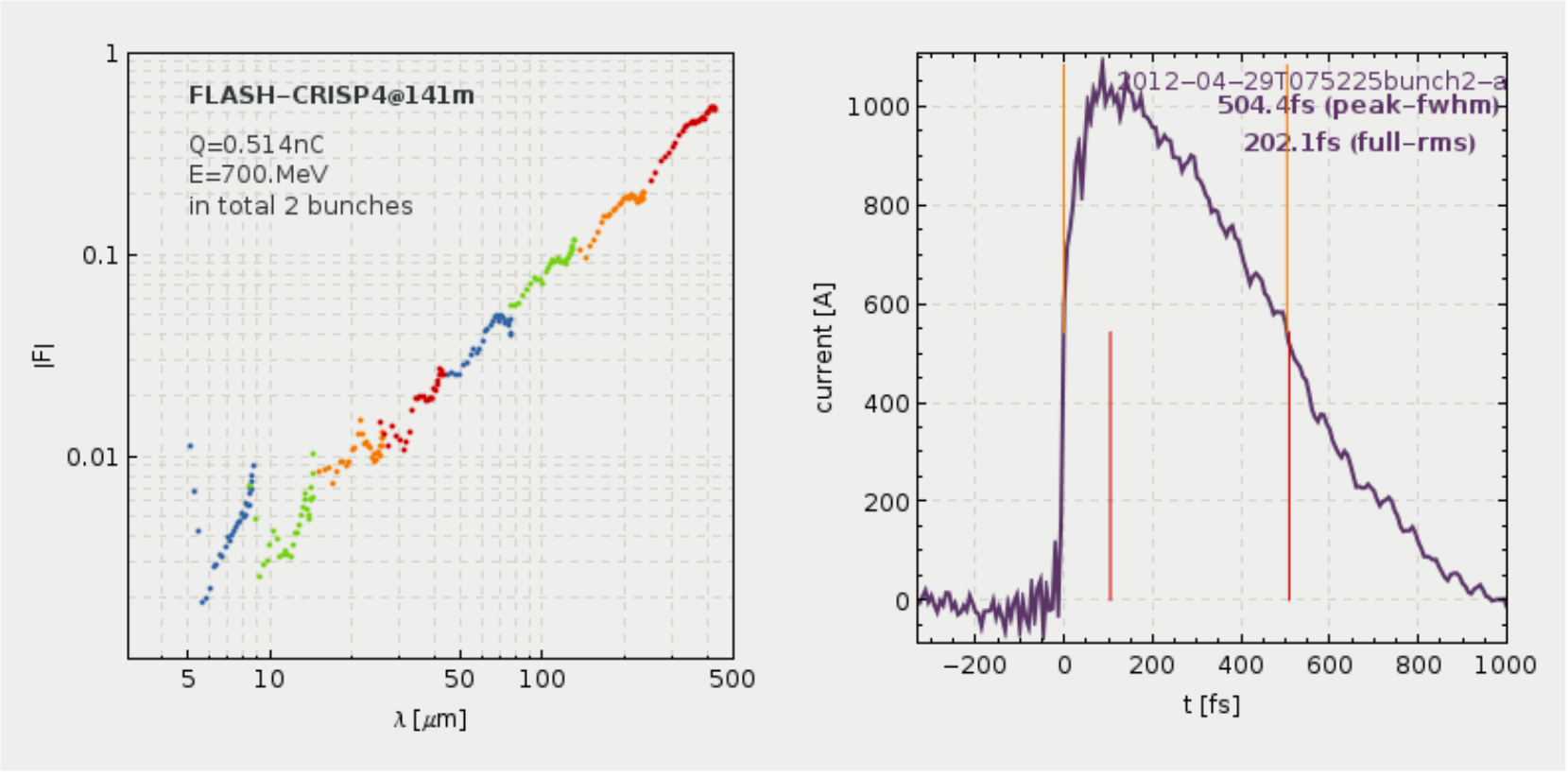
	U32	**U33**
Minimum gap [mm]	9.0	9.8
Period length [mm]	31.4	33
No. of poles	120	240
Length [m]	2	4
maximum K value	2.72	3.03

Photon Extraction and Diagnostics



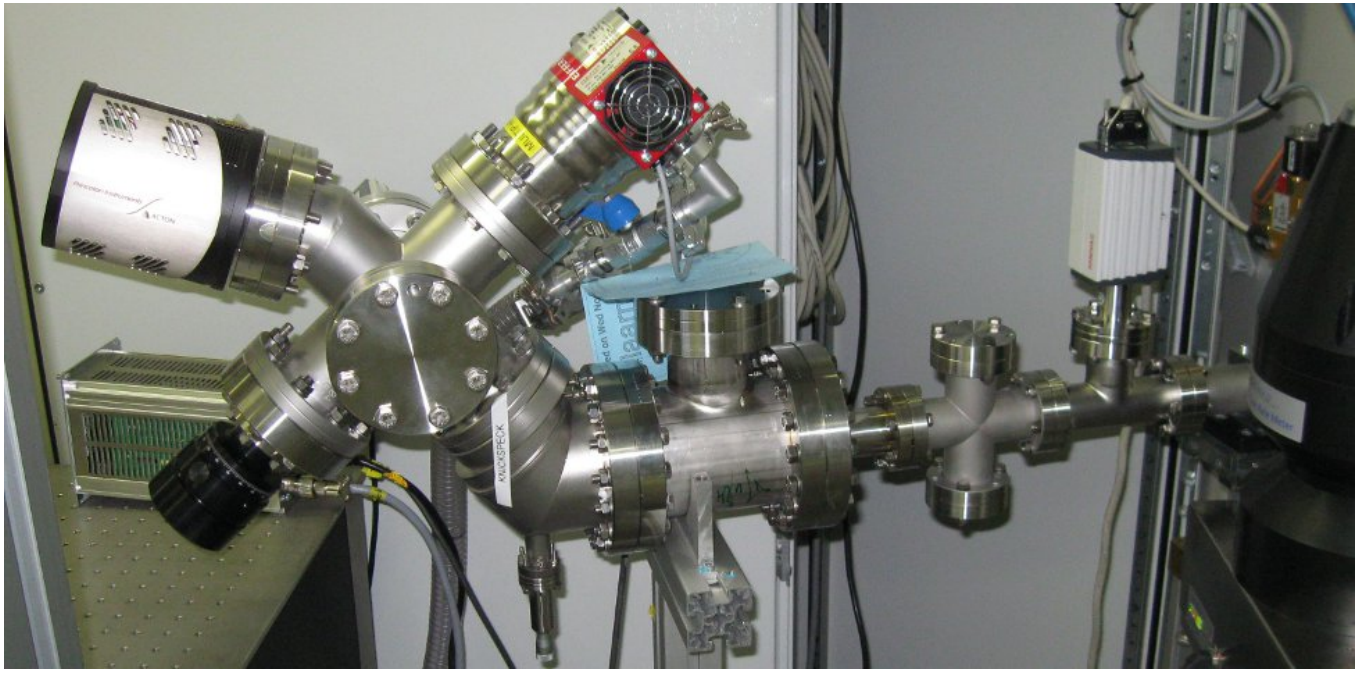
- Located after the sFLASH undulators
- Micro-channel plates (MCPs) used to detect FEL radiation pulse energy

CRISP4



Left: single-shot THz spectrum
Right: Reconstructed current profile

Spectral Overlap



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