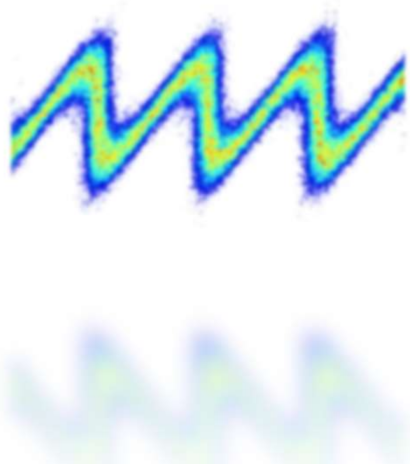
Seeding at FLASH

Jörn Bödewadt on behalf of the seeding team

FLASH Seminar 17.05.2016



- ***Introduction***
- ***Recent experimental results from sFLASH***

Supported by BMBF under contract 05K13GU4
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DFG GrK 1355
Joachim Herz Stiftung
Helmholz Accelerator R&D

Bundesministerium für Bildung und Forschung

Universität Hamburg
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technische universität dortmund

DFG Deutsche Forschungsgemeinschaft

JOACHIM HERZ STIFTUNG

HELMHOLTZ | ASSOCIATION

Accelerator Research and Development (ARD) HELMHOLTZ | GEMEINSCHAFT

DESY

Short history of seeding at FLASH

- 2007 – Design of sFLASH (direct seeding with HHG)
- 2009 – Installation of sFLASH infrastructure
- 2010 – Commissioning of sFLASH hardware
- 2012 – First direct seeding at 38nm (HHG)
- 2013 – Switch from direct seeding to HGHG (FLASH2 shutdown)
- 2014 – Commissioning of UV beamline
- 2015 – HGHG at 38nm
- 2016 – HGHG < 38 nm, FEL characterization, Laser upgrade

Seeding Team

Machine Operation

FLASH operators

Matthias Vogt & Johann Zemella

Laser Operation / Seed Source

Bastian Manschwetus

Core Team

Jörn Bödewadt

Nagitha Ekanayake (left 04/2016)

Tim Plath

Theo Maltezopoulos

Christoph Lechner

Leslie L. Lazzarino

Kirsten Hacker (left 01/2016)

Simulation

Guangyao Feng

Martin Dohlus

FEL characterization

Armin Azima

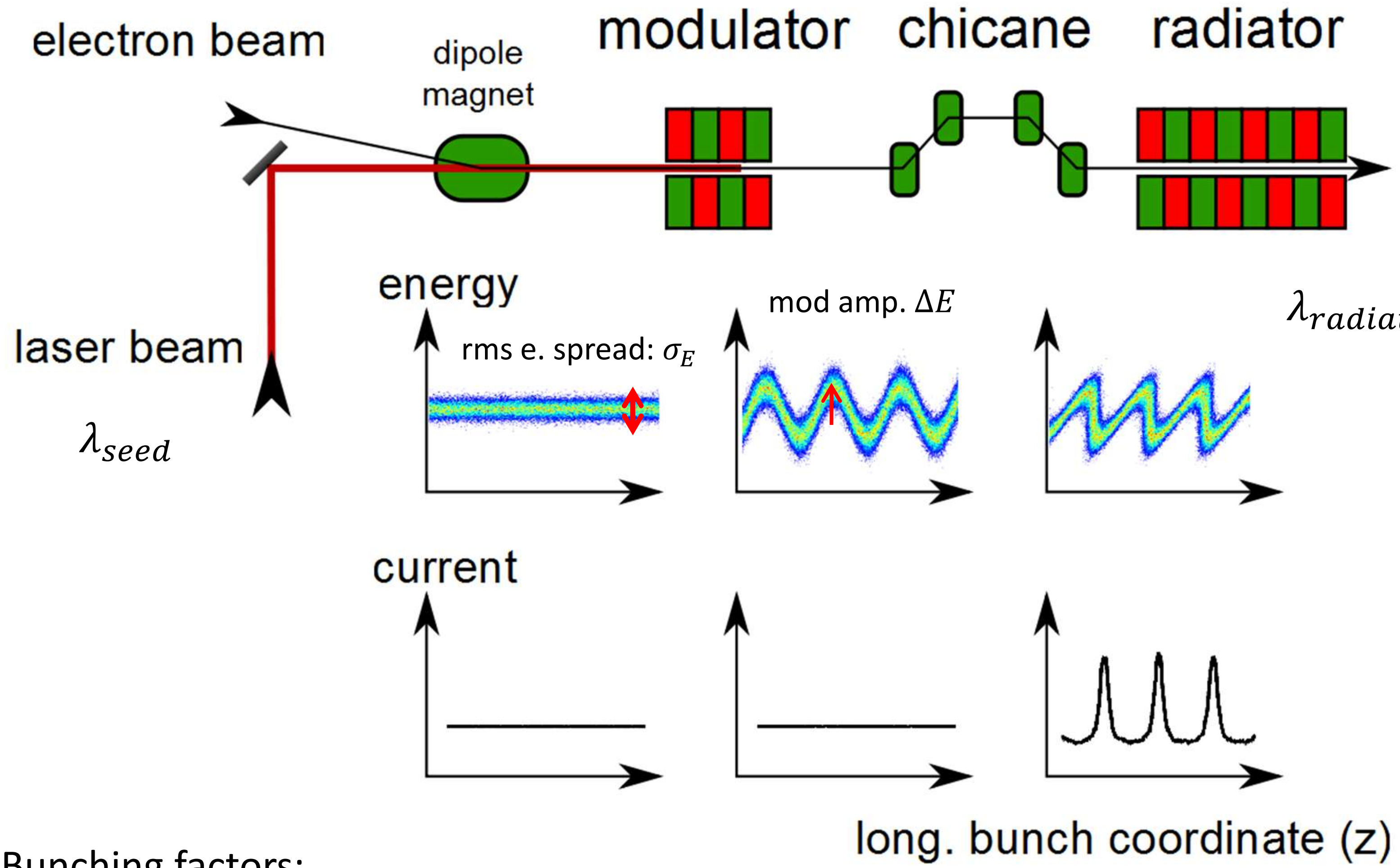
Andreas Przystawik

Sergey Usenko

UGRD students:
Philip Amstutz
Nils Lockmann
Florian Jacobs
Alexander Fröhlich

DESY
Uni HH
TU Dortmund

High-Gain Harmonic Generation



$$\lambda_{radiator} = \frac{\lambda_{seed}}{n}$$

$$\boldsymbol{n < \frac{\Delta E}{\sigma_E}}$$

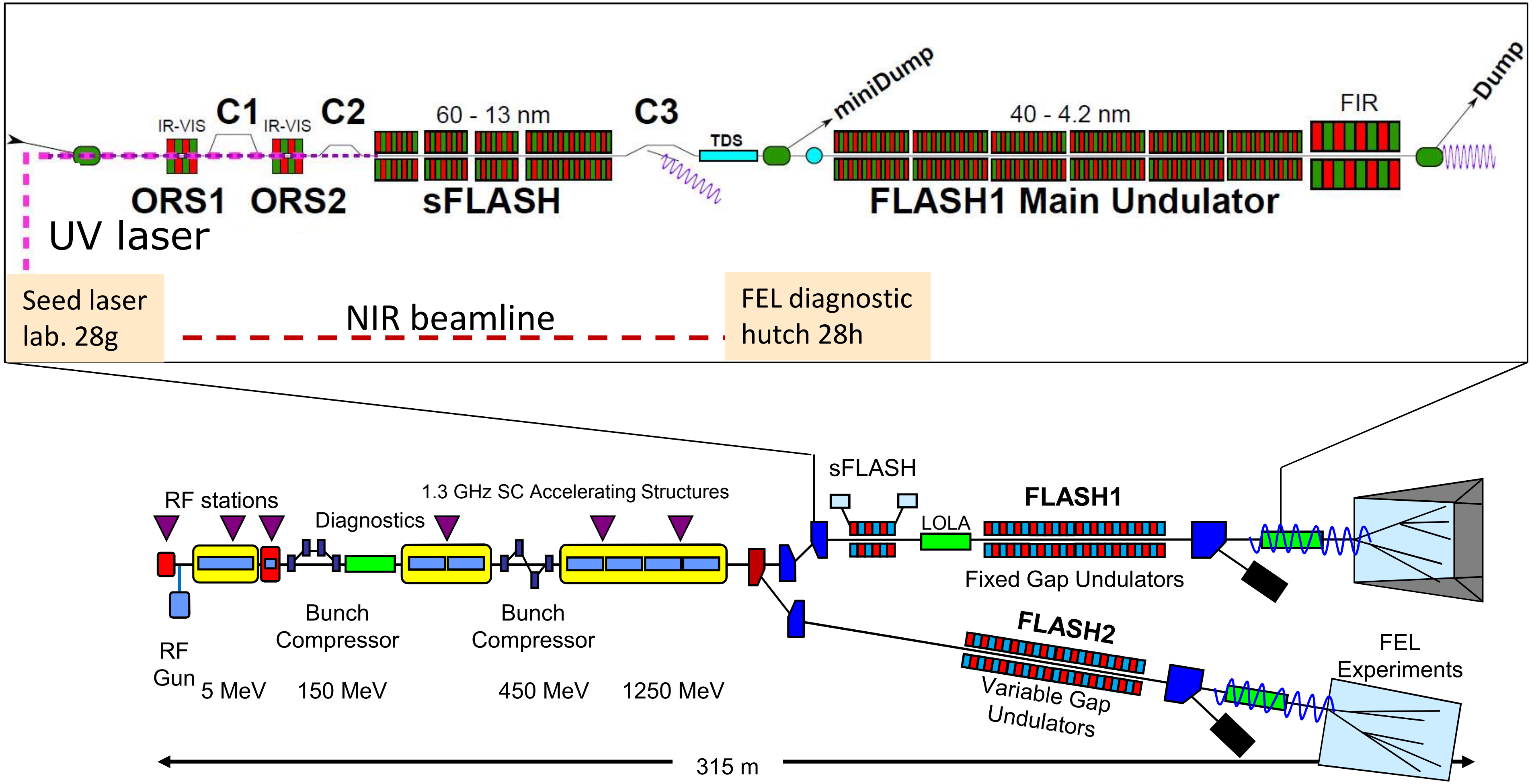
Bunching factors:

$$b_n = exp\left[-\frac{1}{2}\cdot\frac{(2\pi)^2 n^2 R_{56}^2 \sigma_E^2}{\lambda_{seed}{}^2 E_0^2}\right]\cdot J_n\left(\frac{2\pi\, n\, \Delta E\, R_{56}}{\lambda\, E_0}\right)$$

L.H. Yu, Phys.Rev. A 44, 5178 (2001)

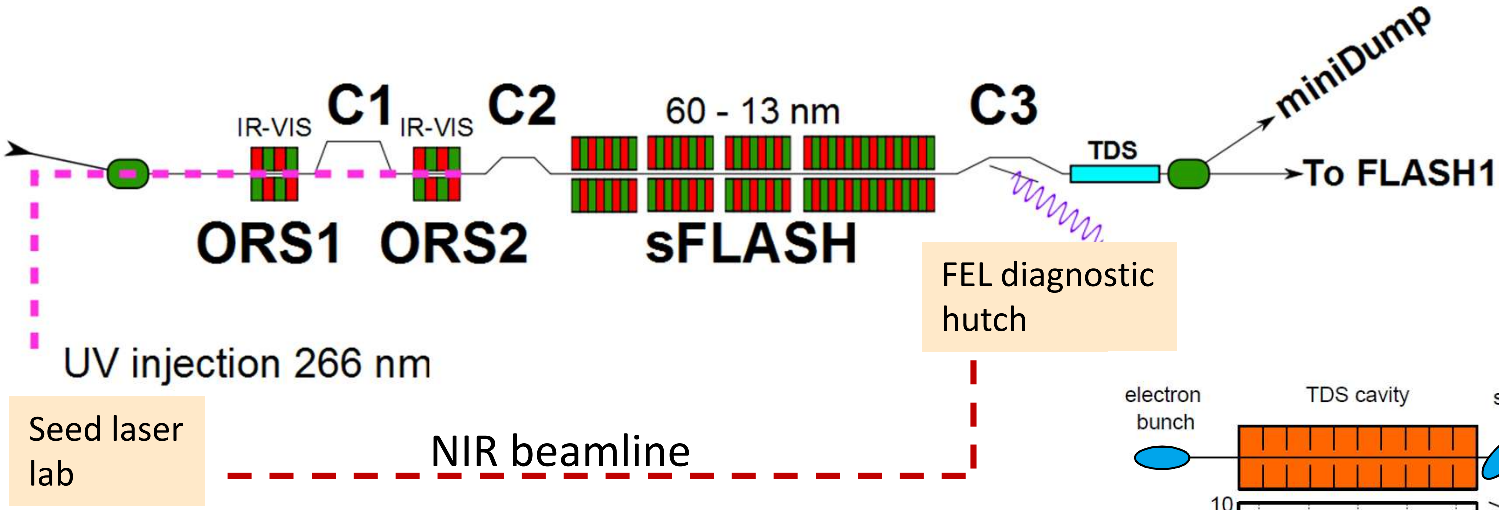
Seeding at FLASH

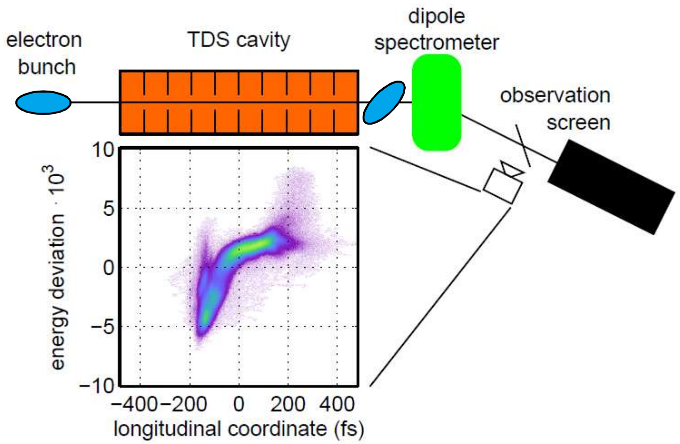
> Overview of FLASH1 beamline



Temporal diagnostics

- Transverse deflecting structure (TDS) and electron beam spectrometer is installed downstream of the sFLASH radiator
- Mapping of longitudinal phase space distribution into transverse coordinates





- THz streaking of seeded FEL pulses

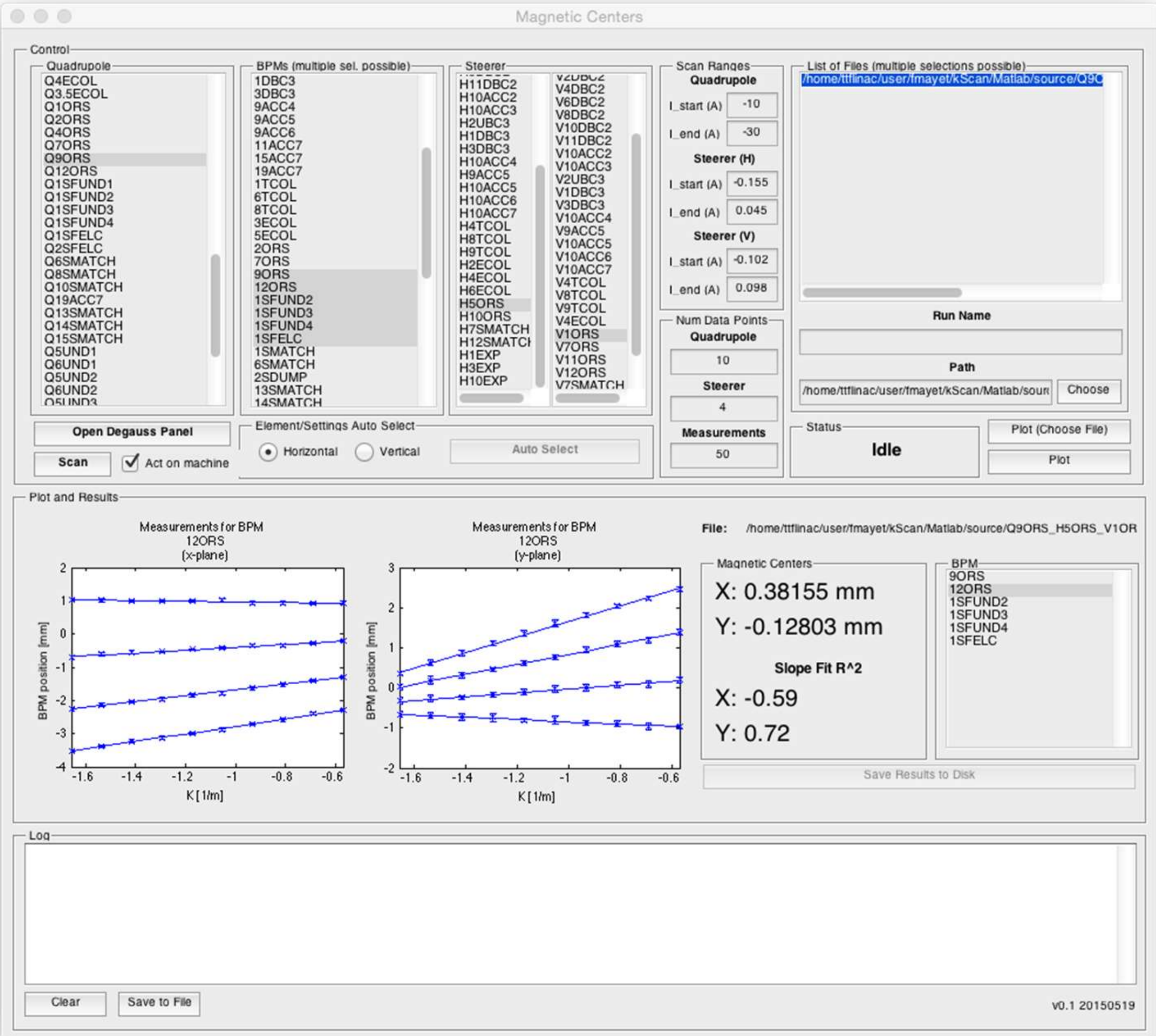
Outline

- Beam based alignment / Beam optics setup
  - Straight orbit in seed section
- Optics compensation
- Bunch compression studies
  - Simultaneous operation of FLASH2 and sFLASH
  - Microbunch instabilities
- 7th harmonic HGHG operation and characterization
  - LOLA studies
  - THz streaking
- Outlook

Beam based alignment / Beam optics setup

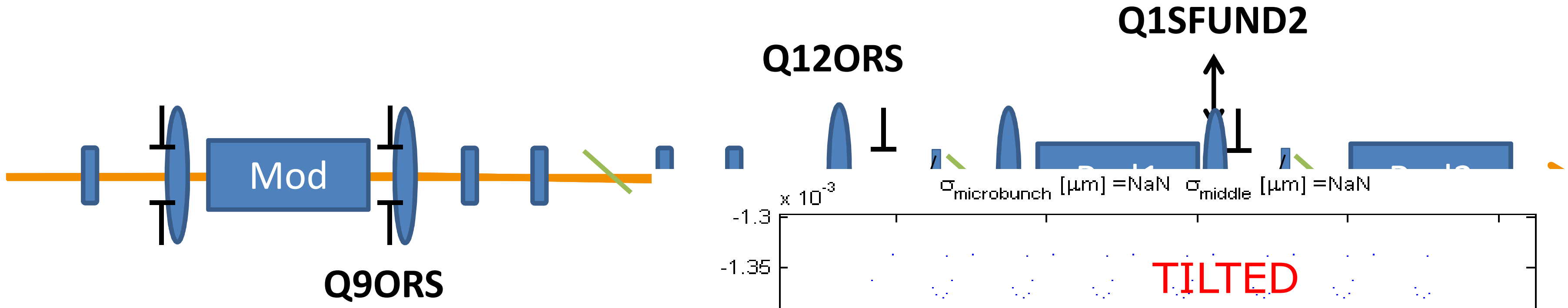
Beam based alignment

- Quad scan tool (by F. Mayet and T. Plath)

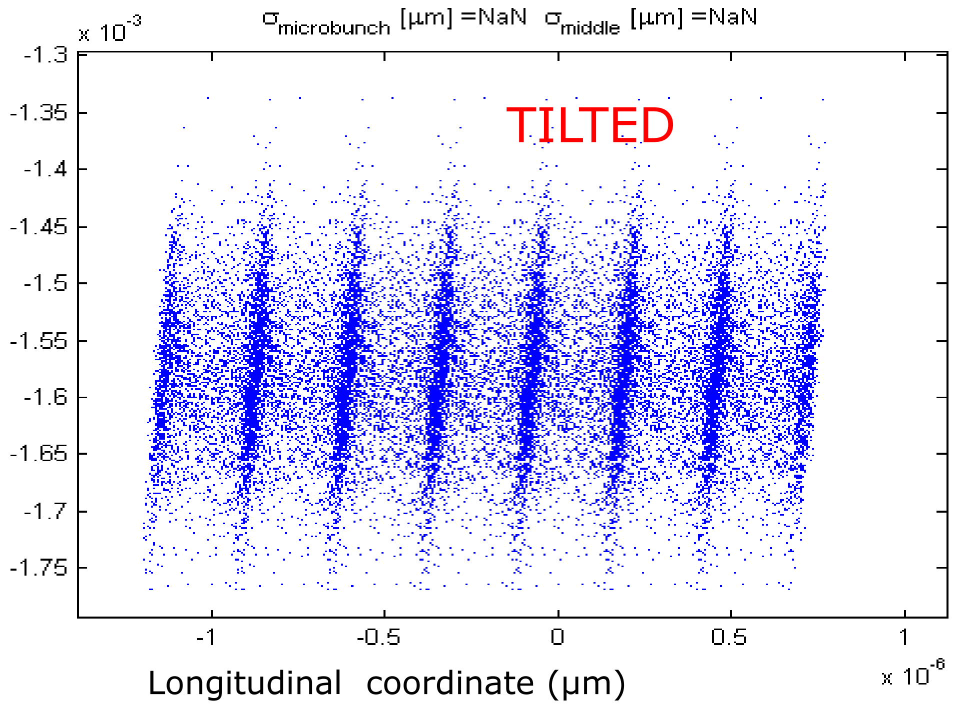


Beam based alignment of seed section

- Checking the quadrupole position using beam-based alignment we observed significant misalignment of quadrupoles between the modulator and radiator.



Quad	Offset ref. beam and magnetic centers	
	X (mm)	Y (mm)
Q2ORS	-0,26	0,15
Q7ORS	-0,02	0,28
Q9ORS	**0,77**	0,16
Q12ORS	-0,09	0,24
Q1SFUND1	0,12	0,35
Q1SFUND2	-0,02	0,12



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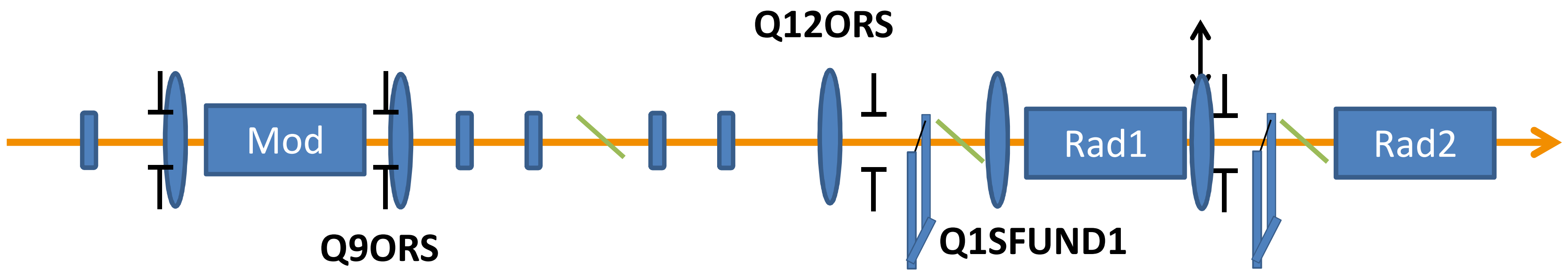
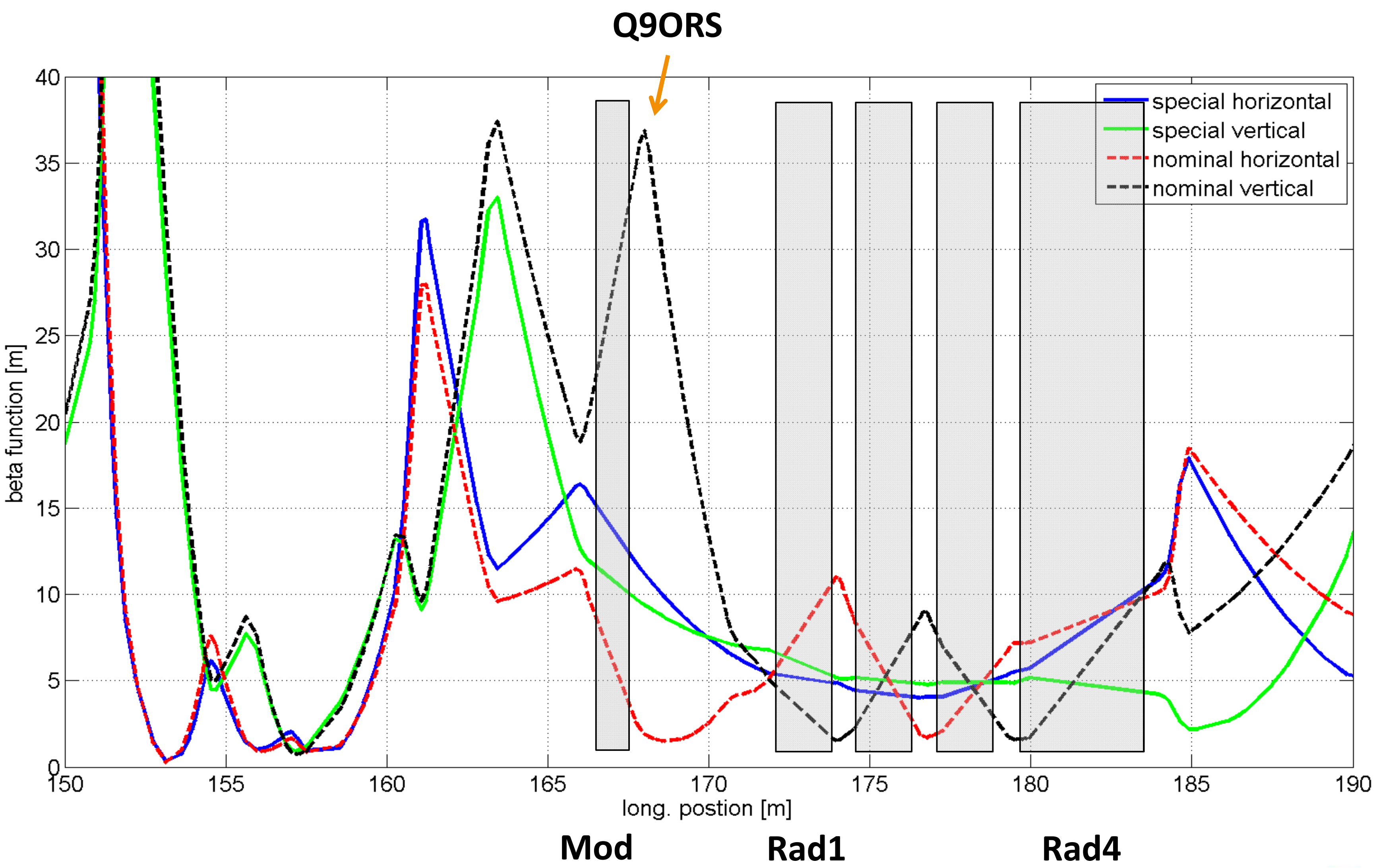
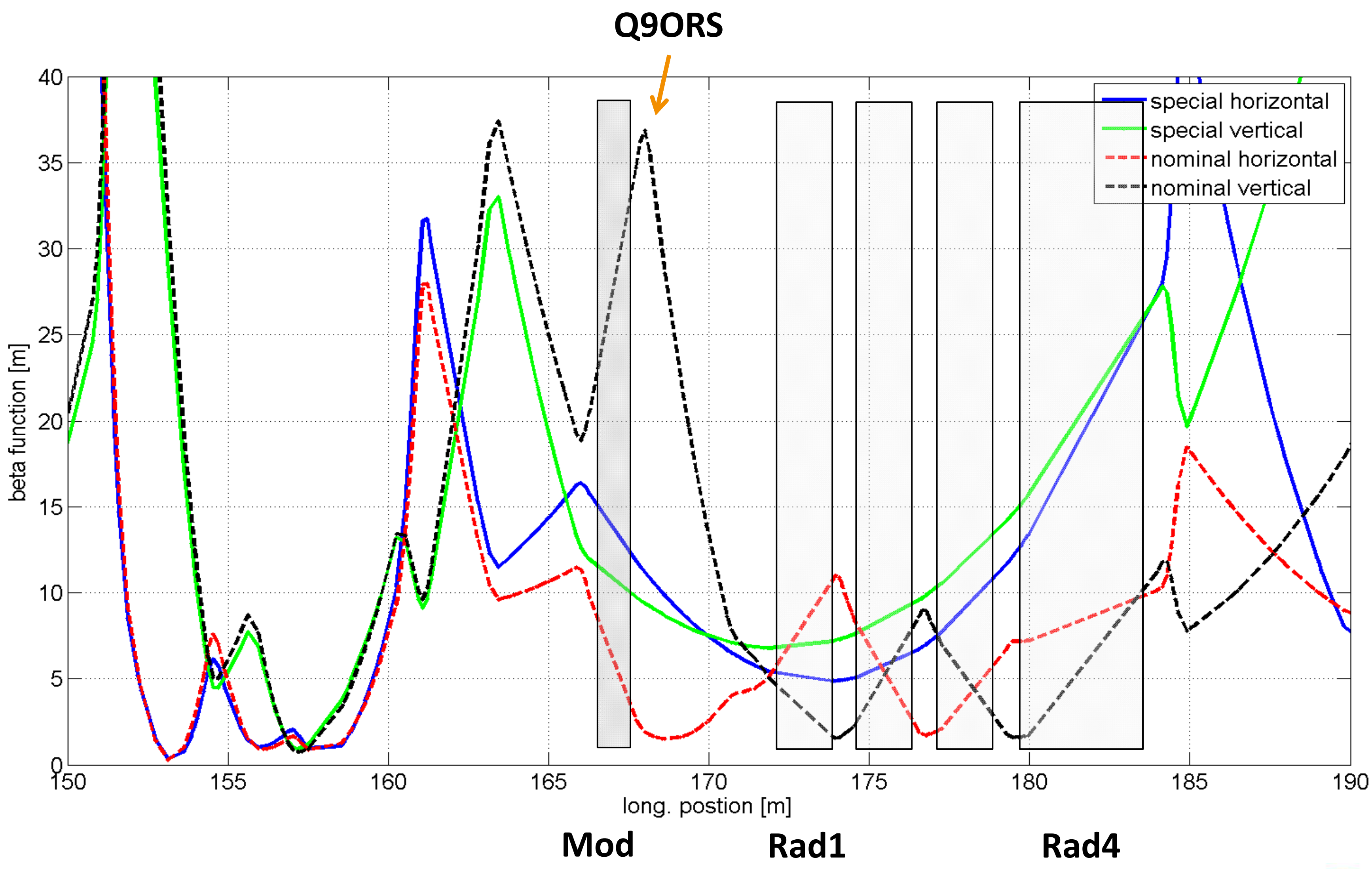


- Only quadrupoles in the radiator section are on movers as it was required for HHG seeding experiment.
- To avoid quadrupole kicks we switched off the quads between modulator and in the radiator

Changing beam optics in seed section



Changing beam optics in seed section (undulators open)



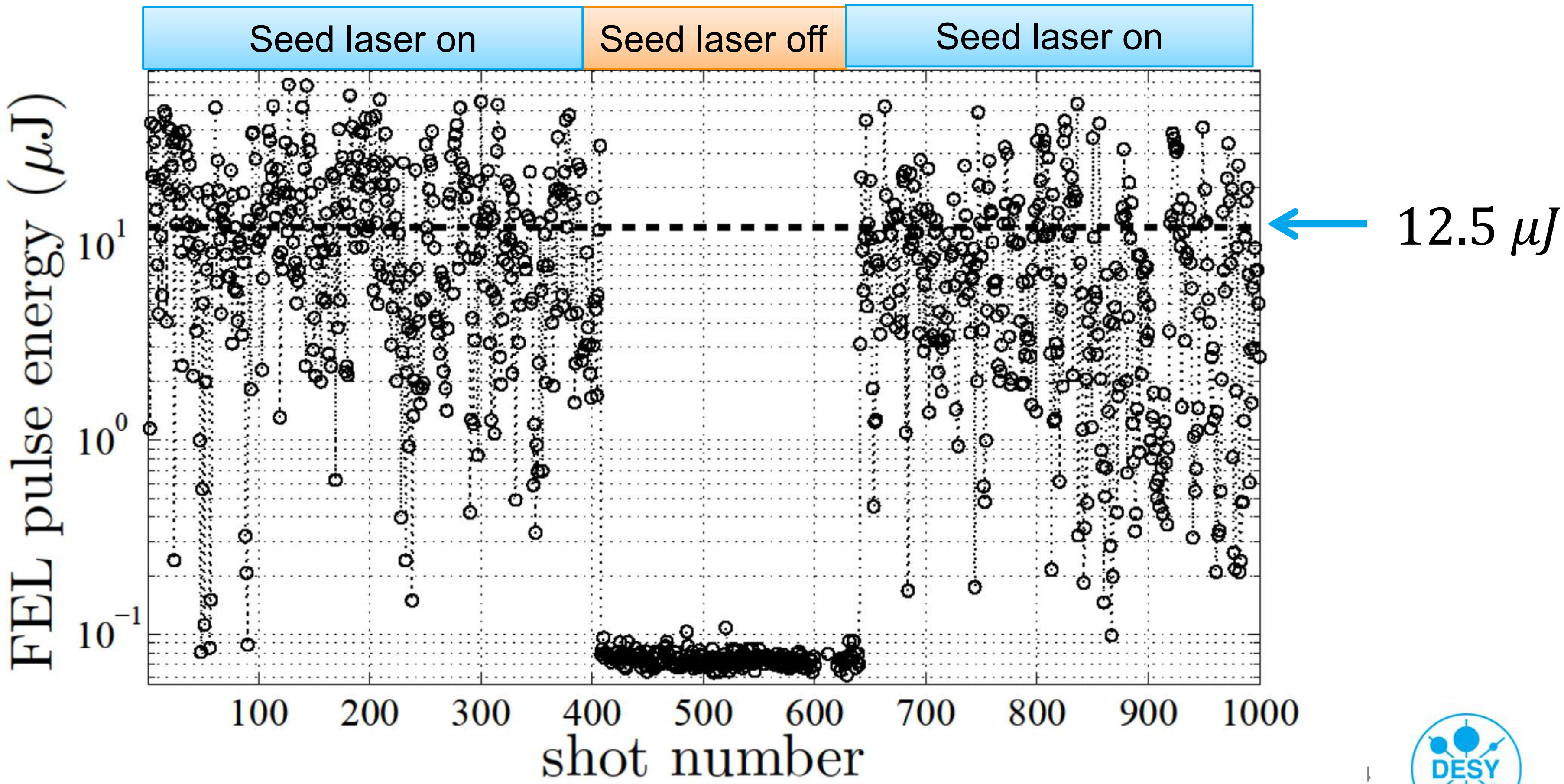
FEL gain 38nm (7th harmonic)

- FEL pulse energy

mean pulse energy: $(12.5 \pm 12)\ \mu J$

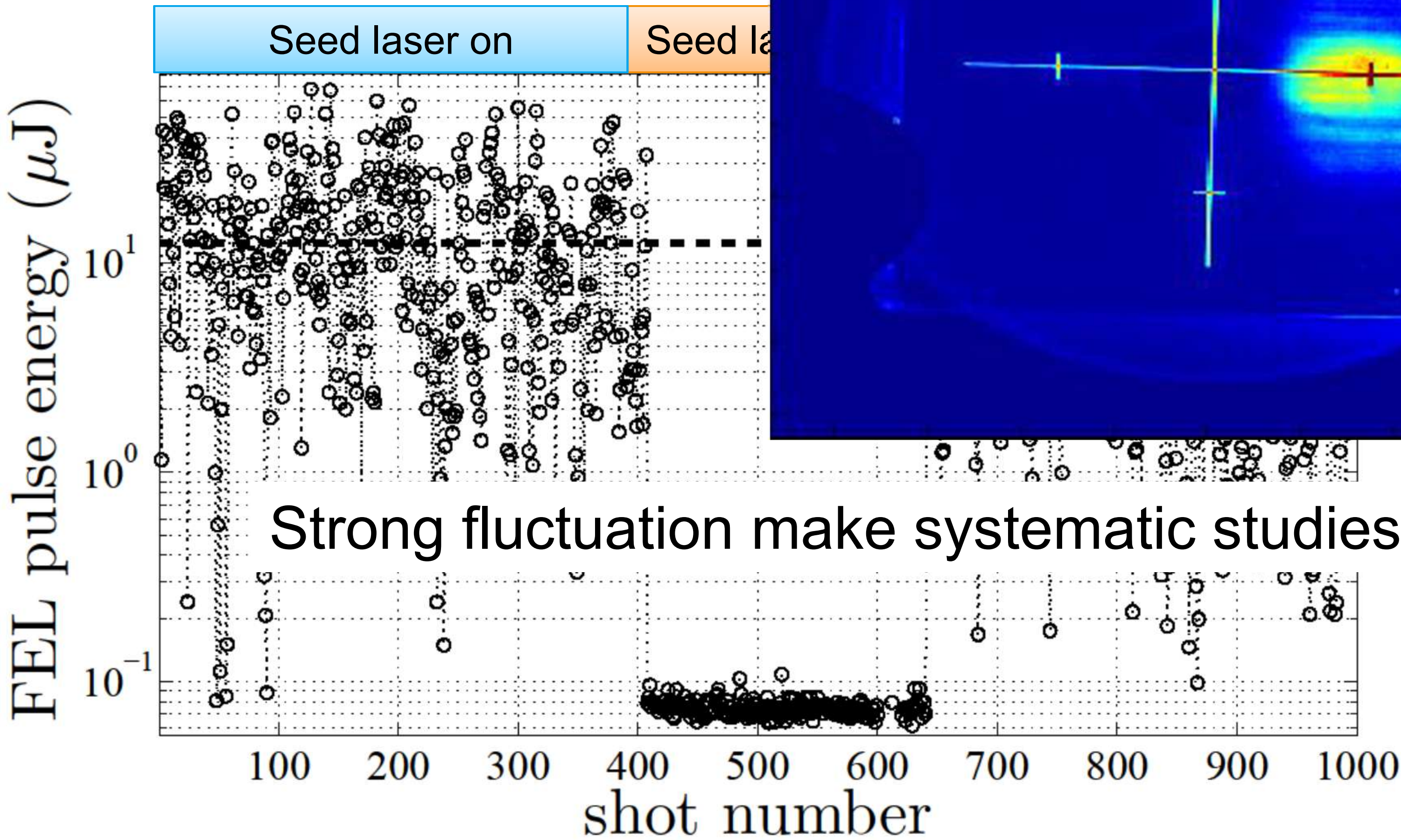
maximum pulse energy: $\mathbf{75\ \mu J}$

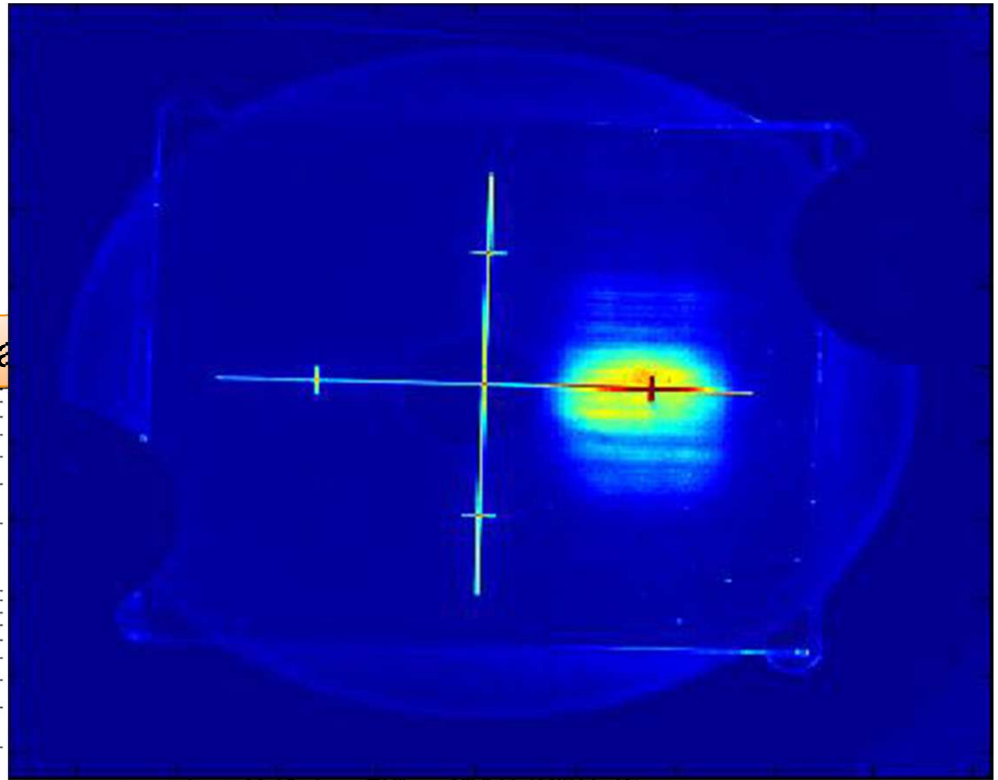
estimated gain length: $\sim 0.9\ m$



FEL gain 38nm (7th harmonic)

- FEL beam profile



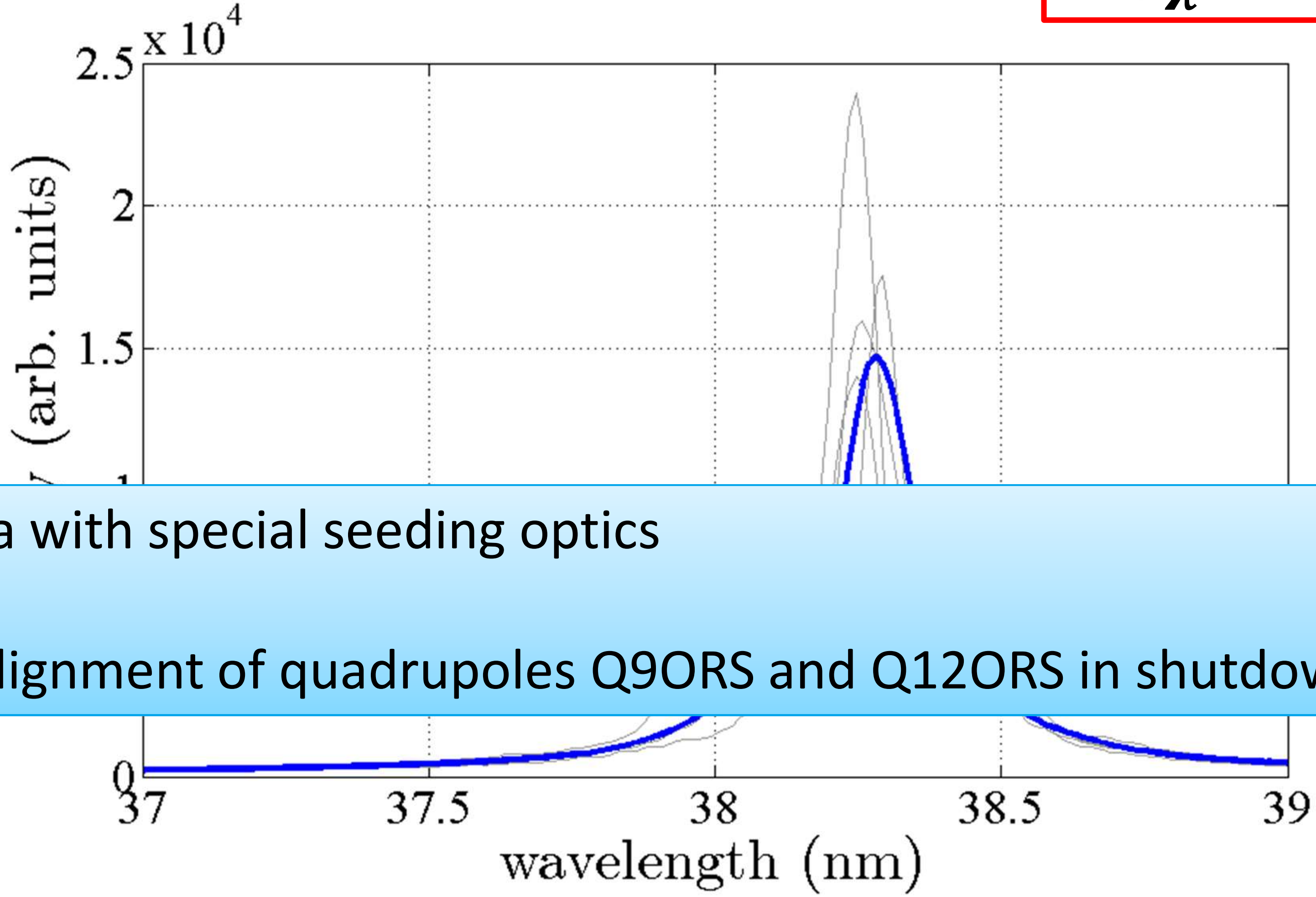


Strong fluctuation make systematic studies difficult

FEL gain 38nm (7th harmonic)

> Spectra of HGHG (second run **May, 1st 2015**)

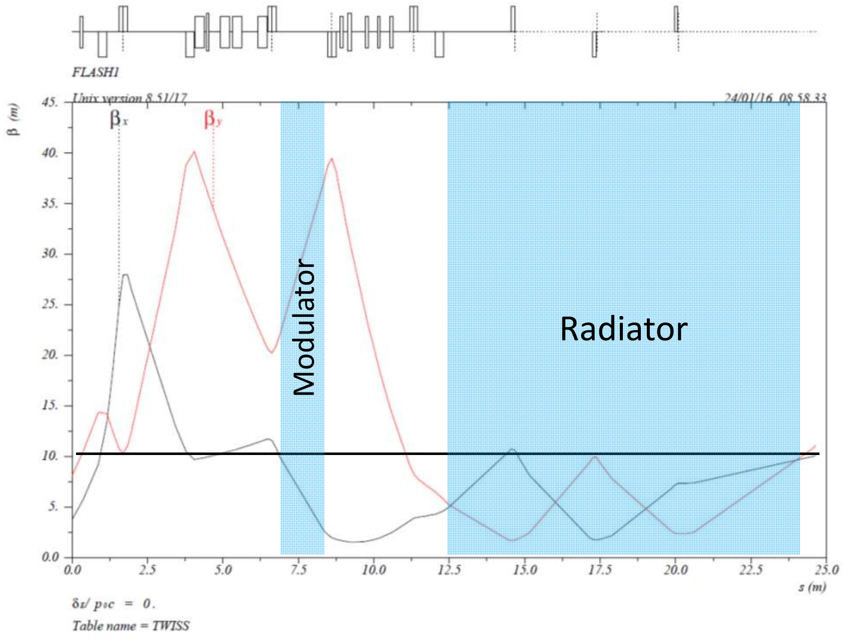
$$\Delta\lambda/\lambda \sim \mathbf{5.2 \cdot 10^{-3}}$$

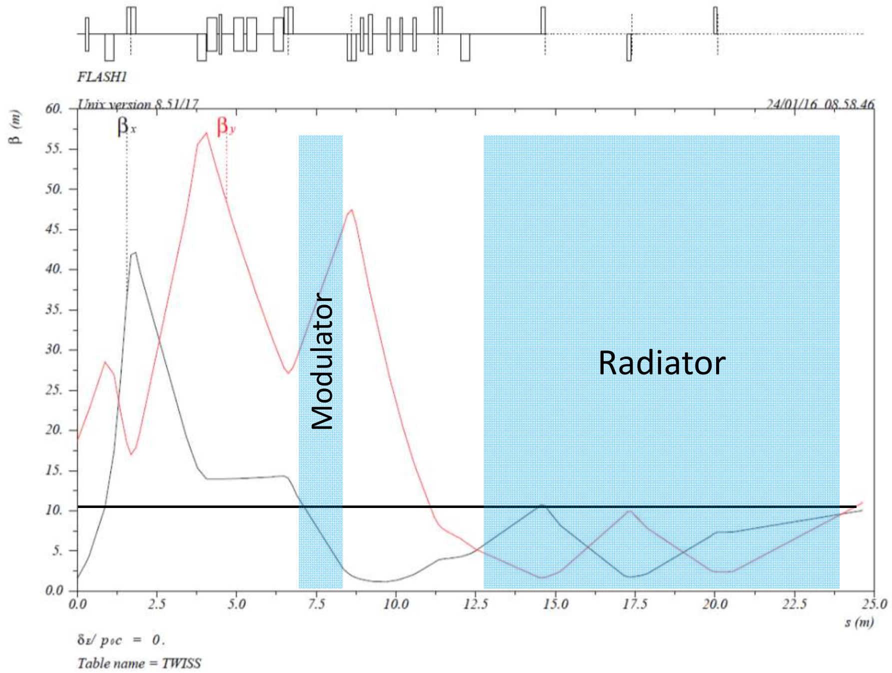


Data with special seeding optics

Realignment of quadrupoles Q9ORS and Q12ORS in shutdown 2015

Nominal FLASH1 optics (design vs. measured)





- Example of optics setup in seeding section
- Optics measurements are done with uncompressed e-beam (minimum e-spread)

Optics setup for seeding

April 2016, Friday, 29/30.04.2016

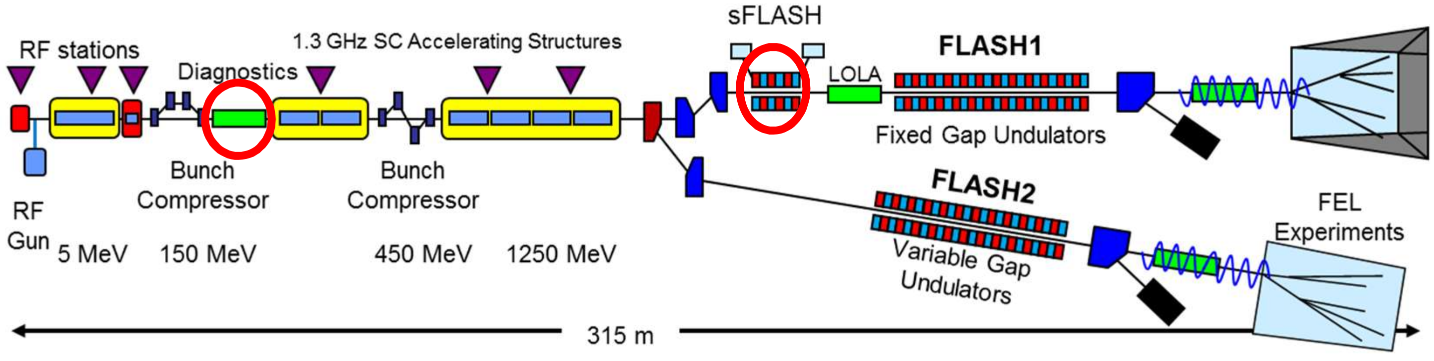
DBC2

Iteration	Mismatch parameter X / Y	Emittance X / Y [µm rad]
1	2.827 / 3.012	0.59 / 0.59
2	1.204 / 1.574	0.53 / 0.60
3	1.127 / 1.042	0.55 / 0.57

SFUND

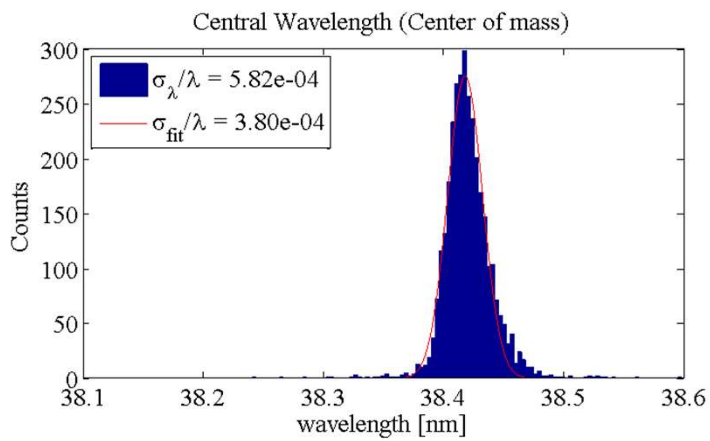
Iteration	Mismatch parameter X / Y	Emittance X / Y [µm rad]
1	1.047 / 1.197	2.00 / 1.24
2	1.000 / 1.001	2.12 / 1.92

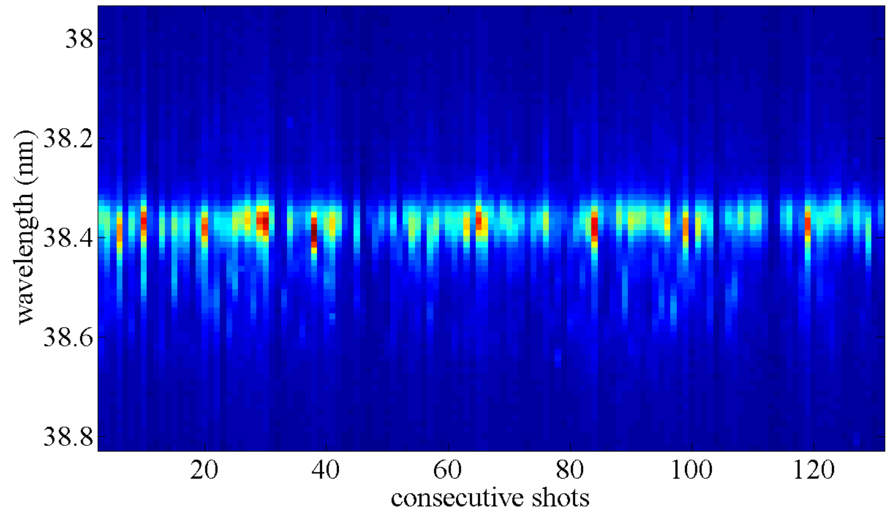
DBC2 **SFUND**

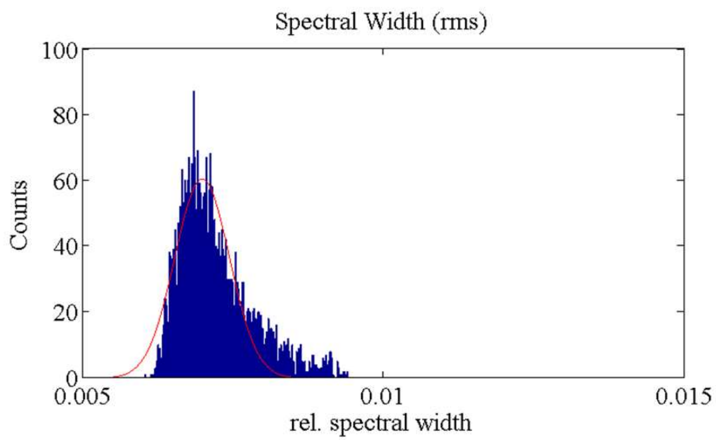


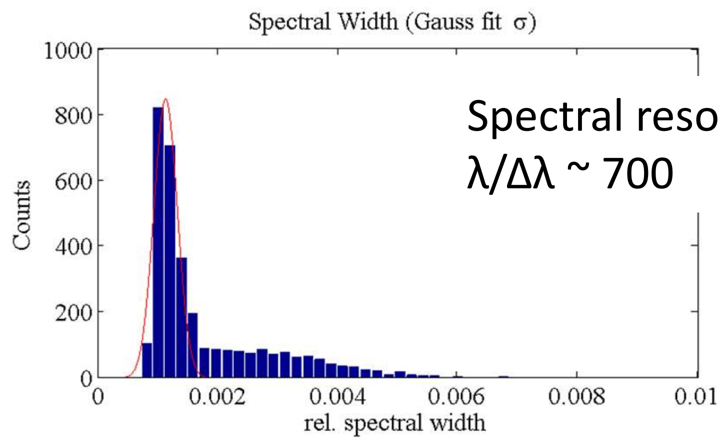
HGHG at 7th harmonic

> Analysis of FEL spectra





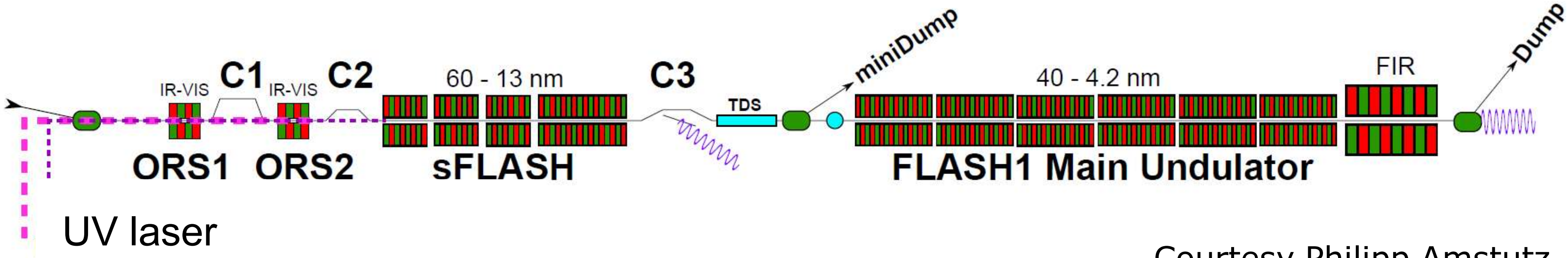




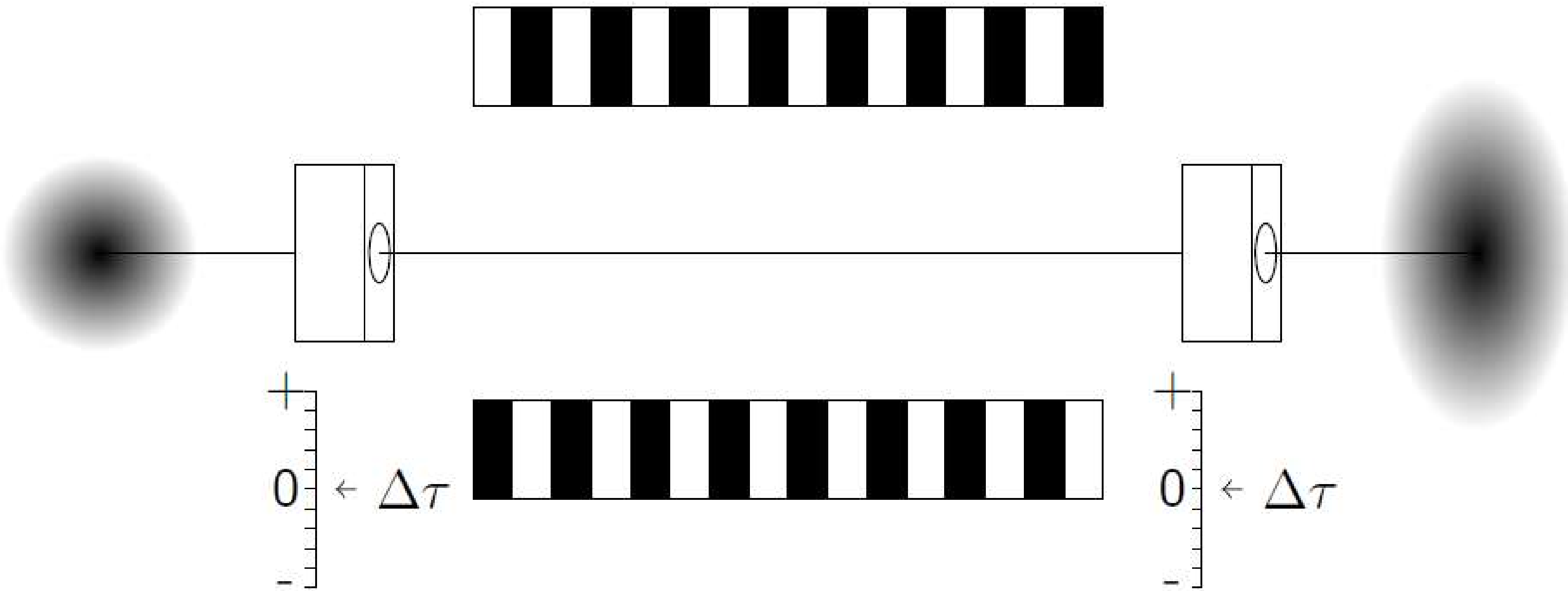
Spectral resolution
$\lambda/\Delta\lambda$ ~ 700

Optics compensation

Compensate effect of vertical undulator focusing for closed variable-gap undulators



Courtesy Philipp Amstutz



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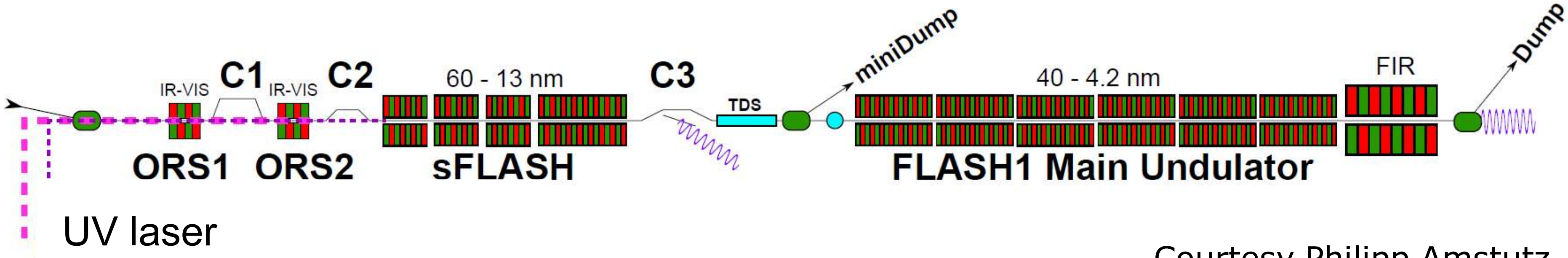

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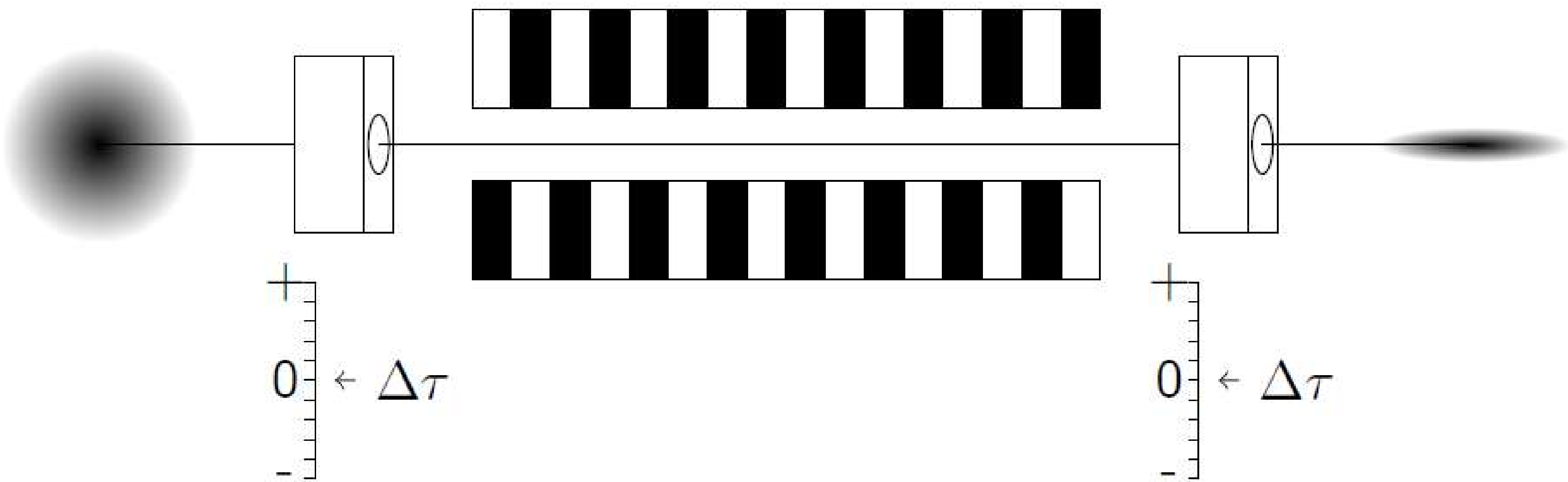

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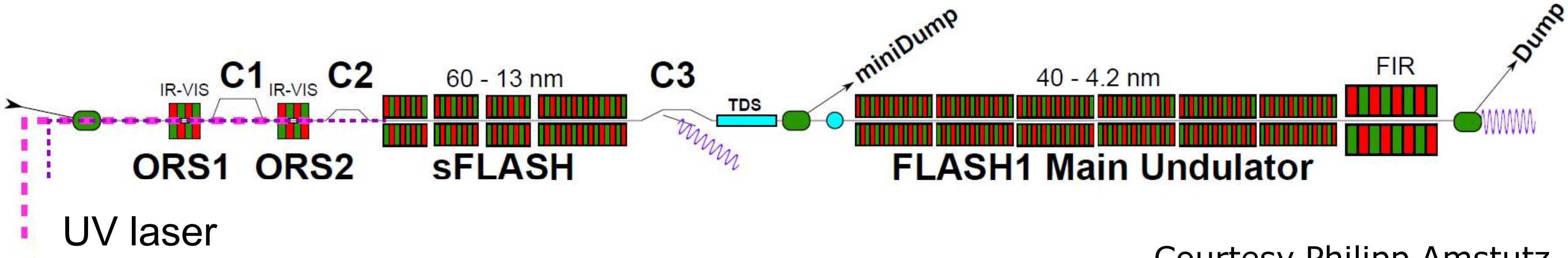

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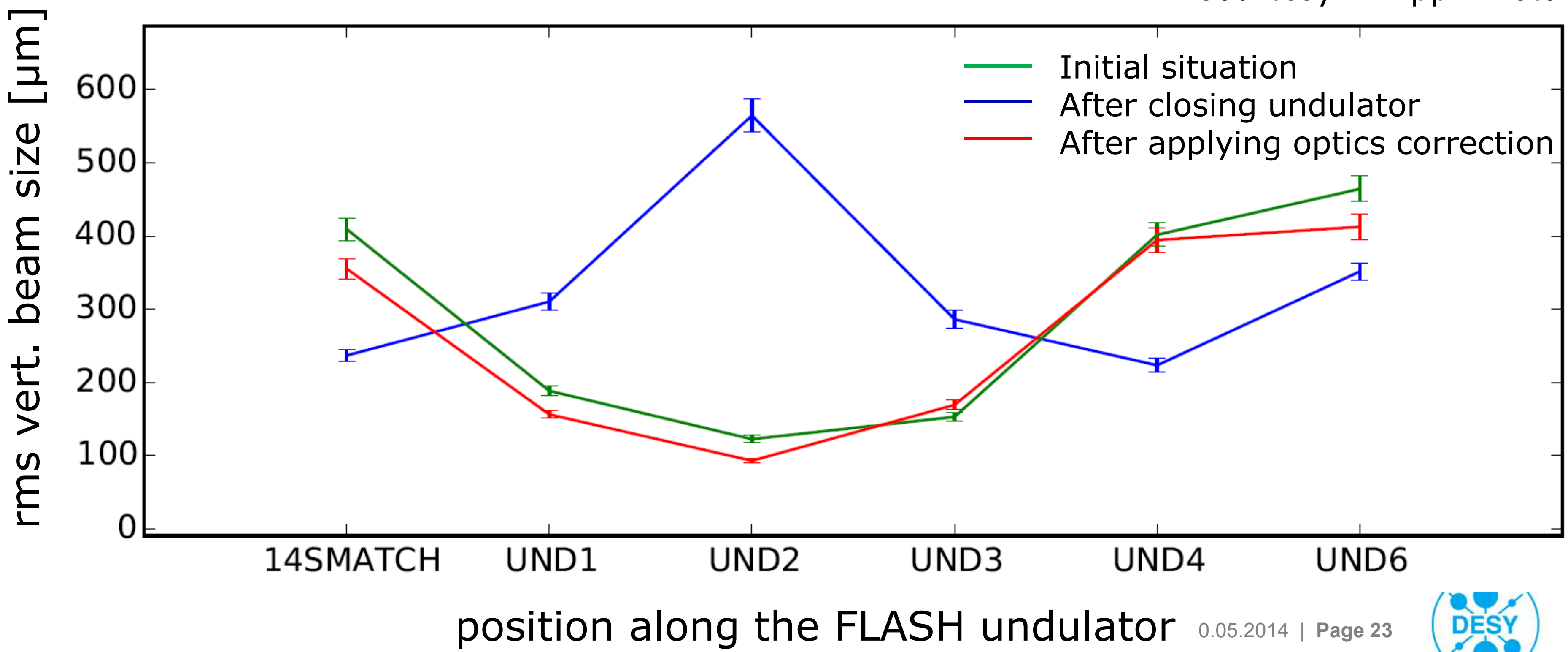
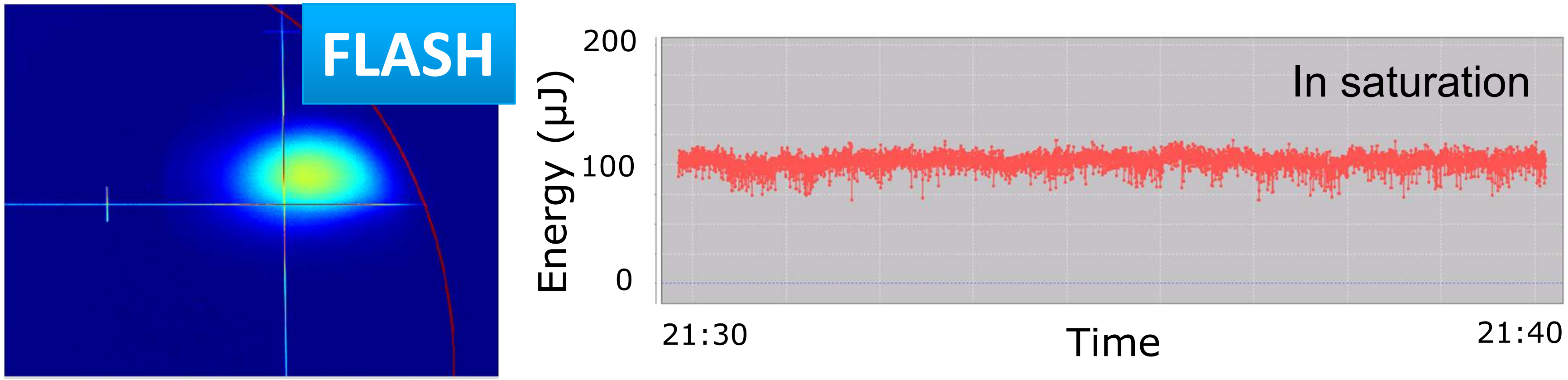
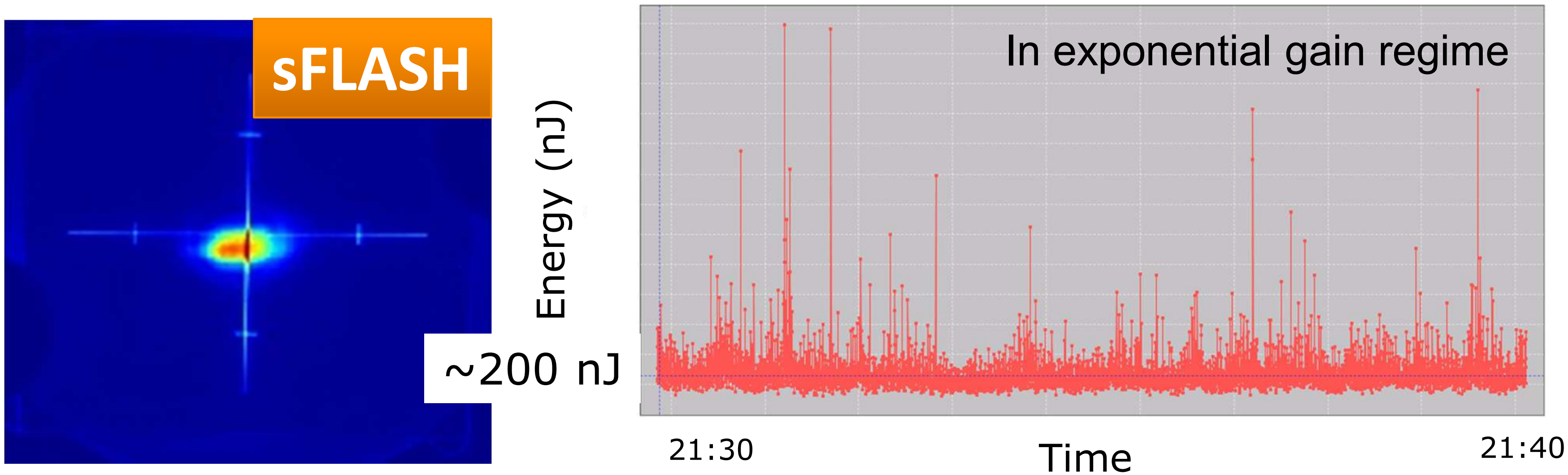


DESY

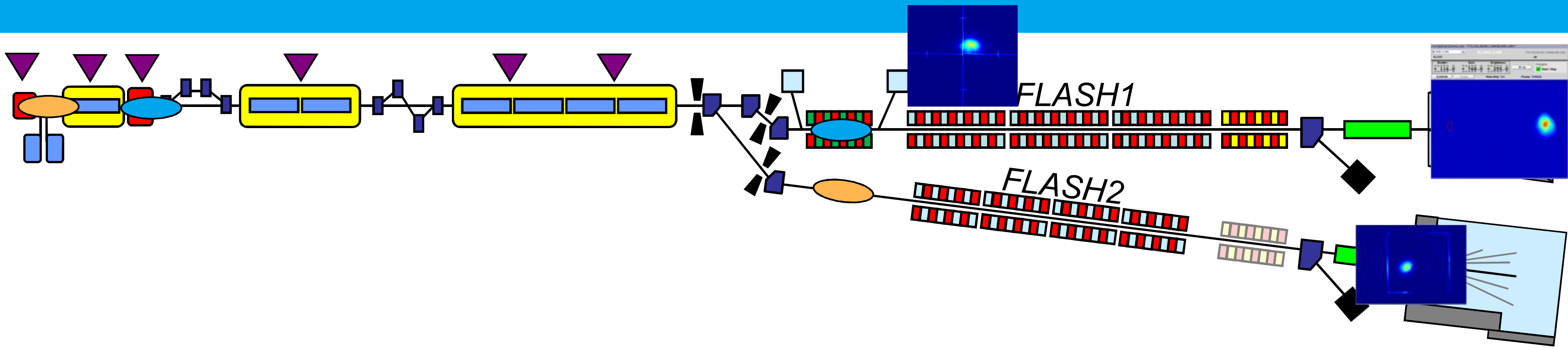
Simultaneous operation (January 2015)

- Parallel operation of sFLASH@24nm SASE and FLASH@9nm SASE





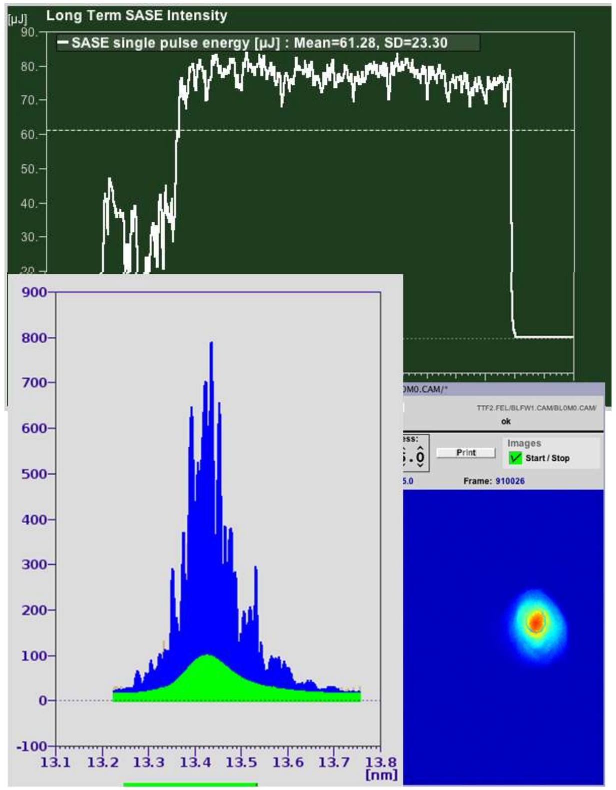
Simultaneous operation (August 2015)

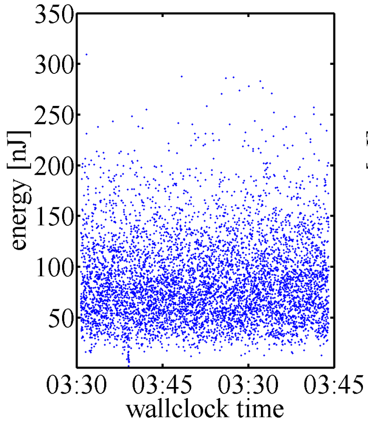


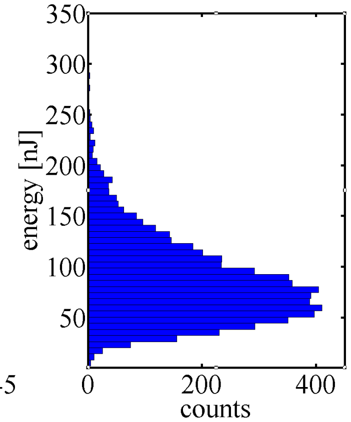
FLASH1 @ 13 nm

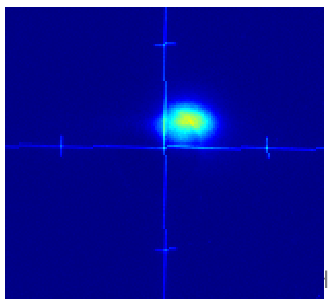
sFLASH @ 38 nm

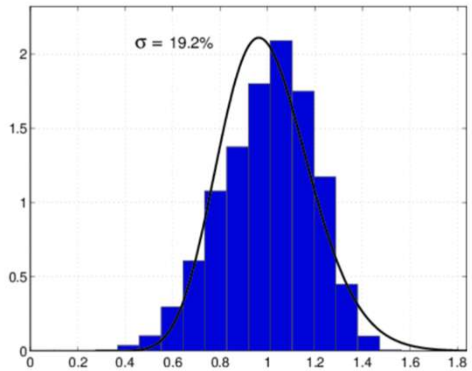
FLASH2 @ 20 nm

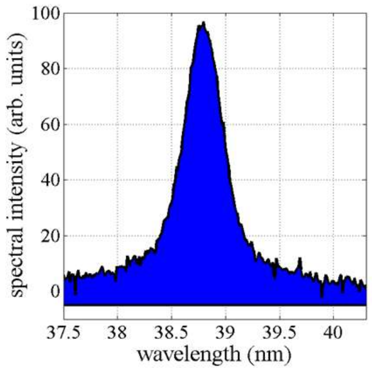


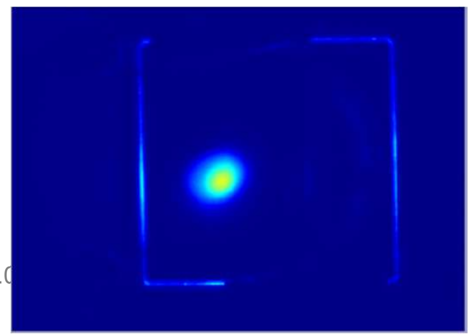










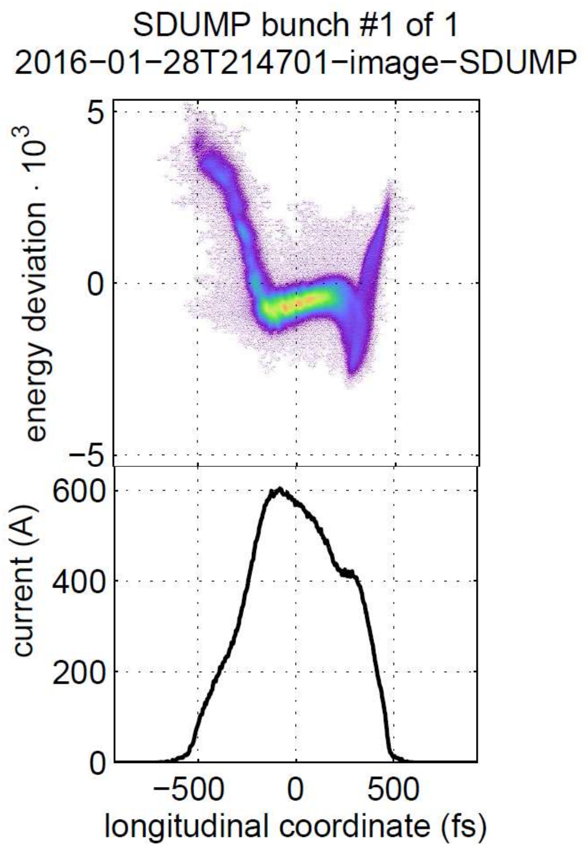


Bunch compression studies

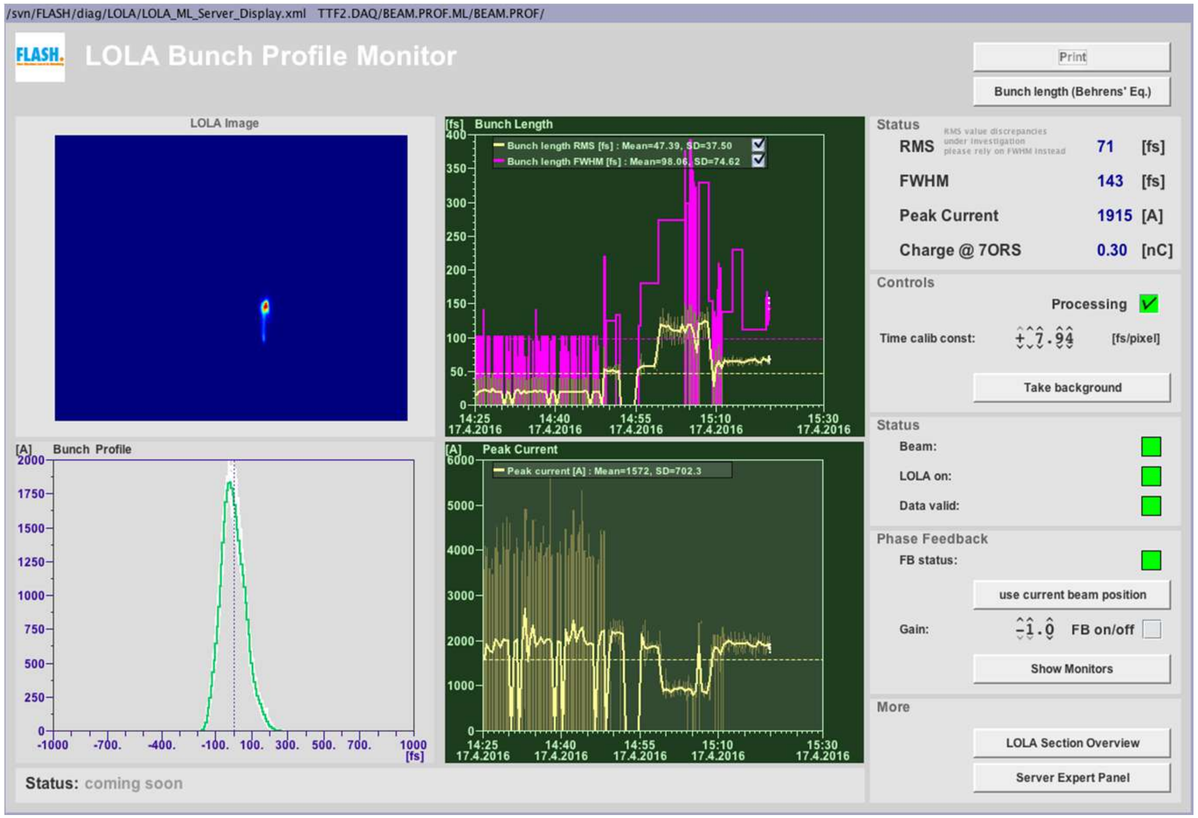
Bunch compression studies (SASE vs. SEEDING)

> Typical compression modes

Seeding (0.4 nC)



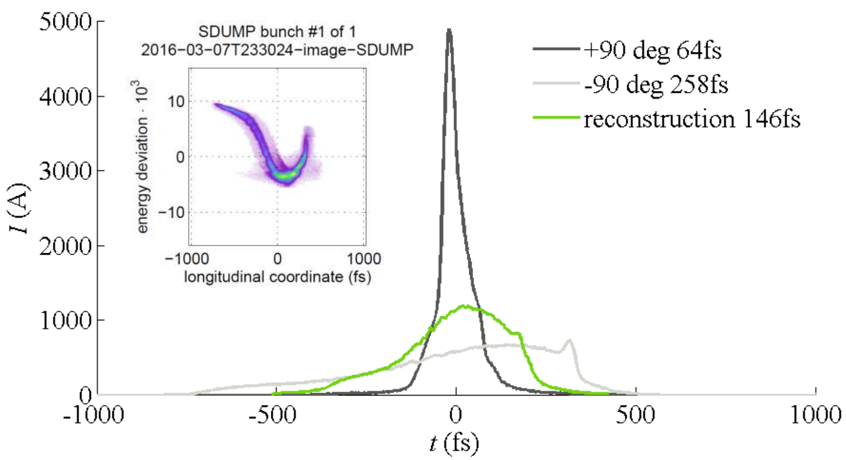
SASE (e.g. 0.3 nC)



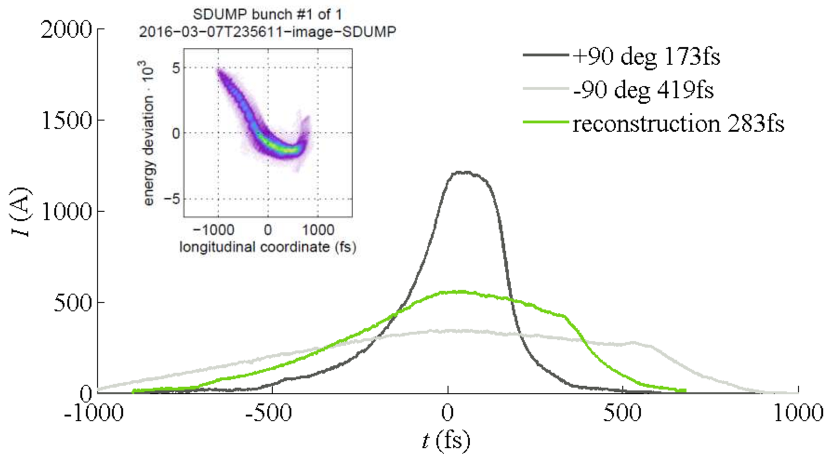
Bunch compression studies (SASE vs. SEEDING)

- In view of FLASH2 a compression setting needs to be established which allows SASE operation in FLASH1 and seeded operation in FLASH2
- Ansatz 1:
  - Setup SASE in FLASH1 and FLASH2 with same bunch compression settings (check TDS)
  - Keep FLASH2 under SASE and decompress for FLASH1 and setup seeding in sFLASH

SASE in FLASH1

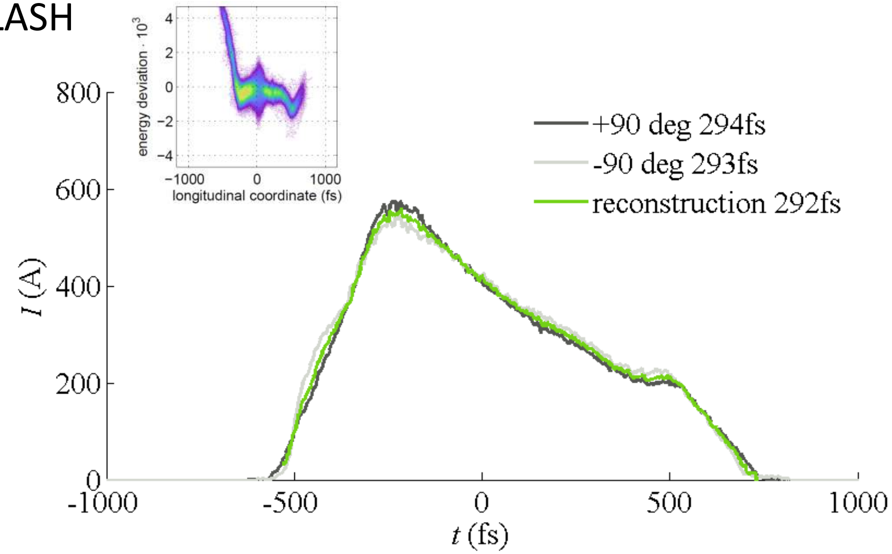


Seeding in sFLASH

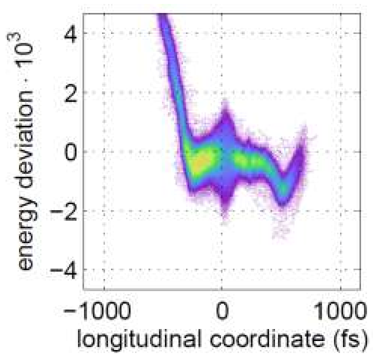


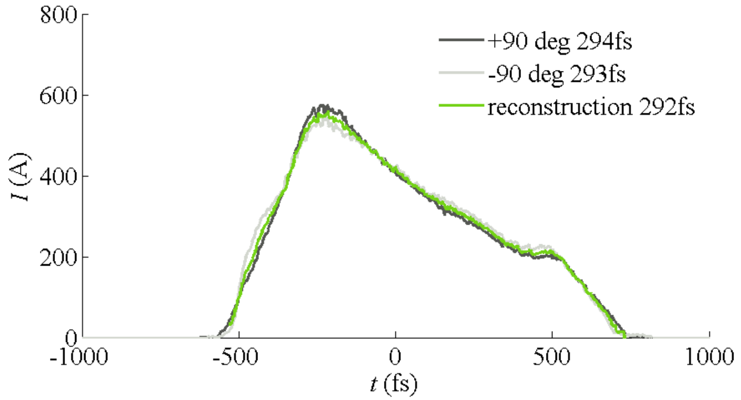
Bunch compression studies (SASE vs. SEEDING)

- In view of FLASH2 a compression setting needs to be established which allows SASE operation in FLASH1 and seeded operation in FLASH2
- Ansatz 1:
  - Setup SASE in FLASH1 and FLASH2 with same bunch compression settings (check TDS)
  - Keep FLASH2 under SASE and decompress for FLASH1 and setup seeding in sFLASH
- Ansatz 2 (MD last week 30.04.2016 and 13.05.2016):
  - Setup compression mode for seeding in sFLASH
  - Further compress e-bunch (TDS monitor)
  - Setup SASE in FLASH1 and FLASH2

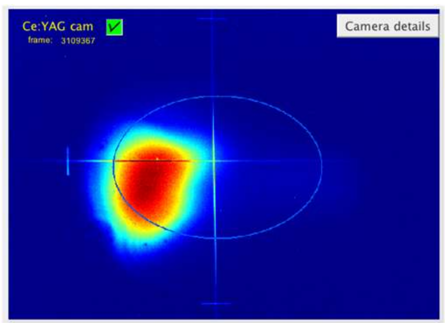


Bunch compression studies (SASE vs. SEEDING)



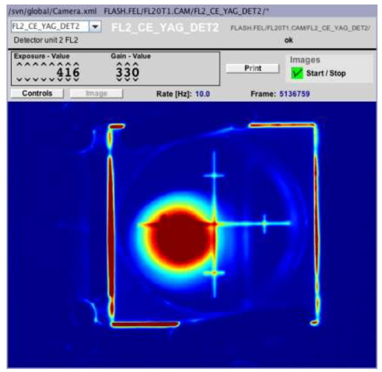


SASE in FLASH1



Single shot pulse energy
~ 10 µJ

SASE in FLASH2



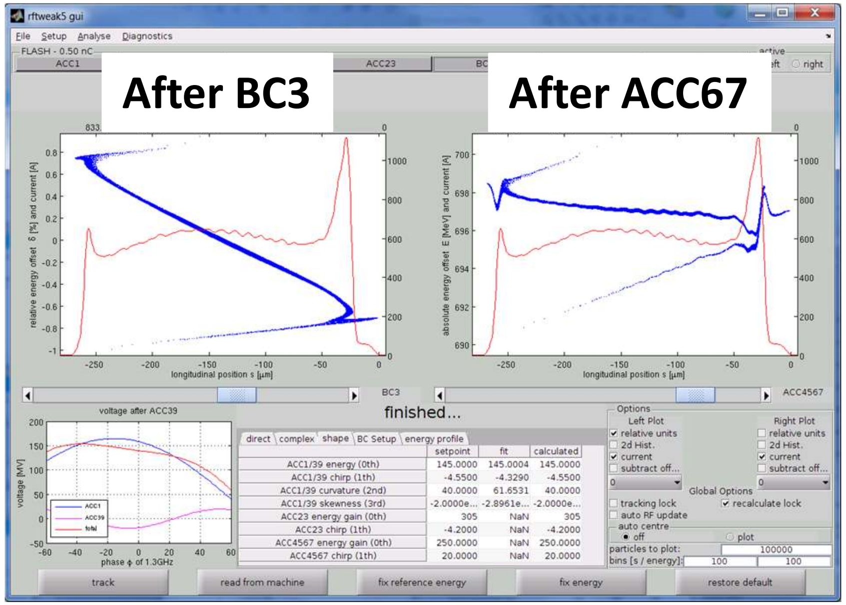
Single shot pulse energy
~ 220 µJ

DESY

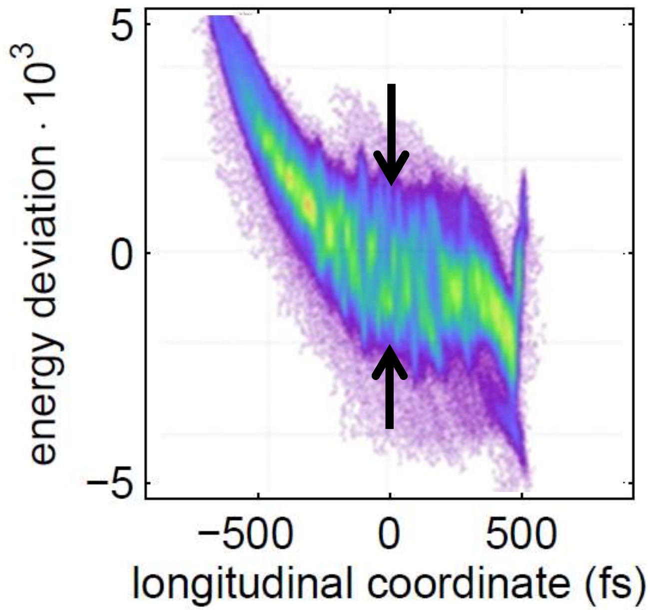
Impact of bunch compression on Microbunching Instability (MBI)

> Example for a flat-top current profile and low energy chirp

Modell



Reality



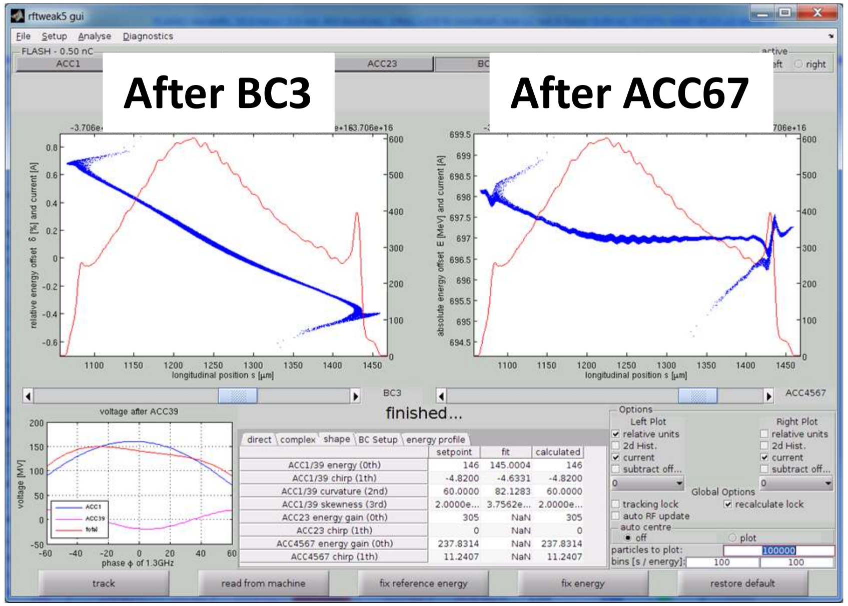
energy spread 1e-3 (rms)

- Very low HGHG signal observed
- Noisy spectrum

Impact of bunch compression on Microbunching Instability (MBI)

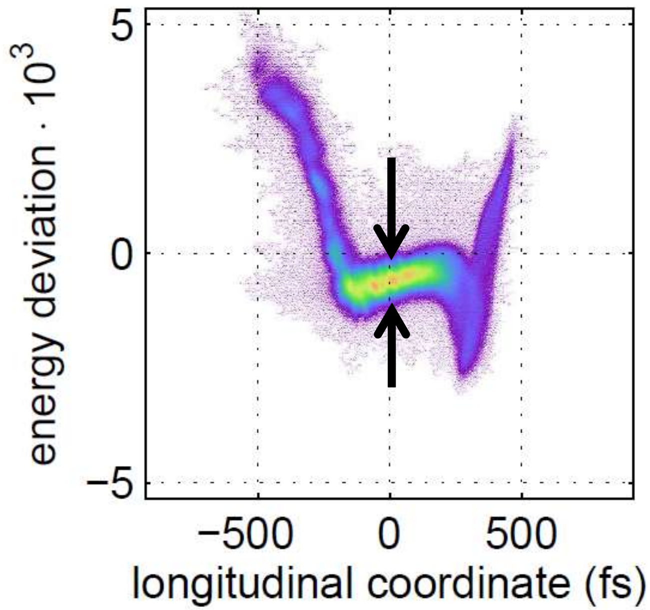
> Example for a current profile with low energy chirp

Modell



- Good HGHG output
- Clean spectrum

Reality

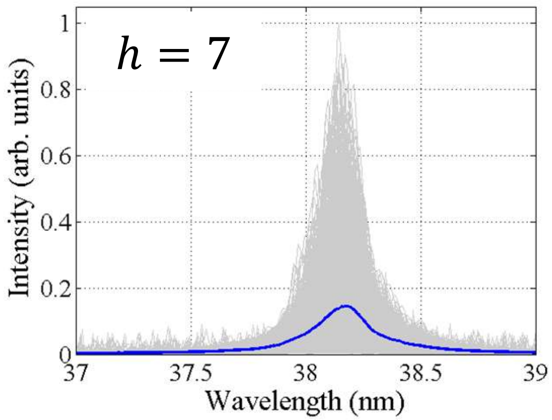


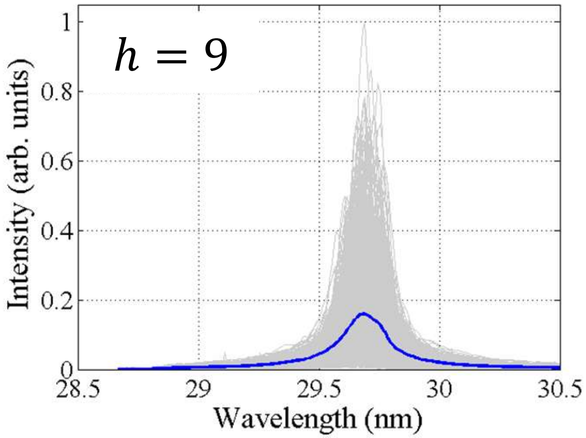
energy spread <0.4 e-3 (rms)

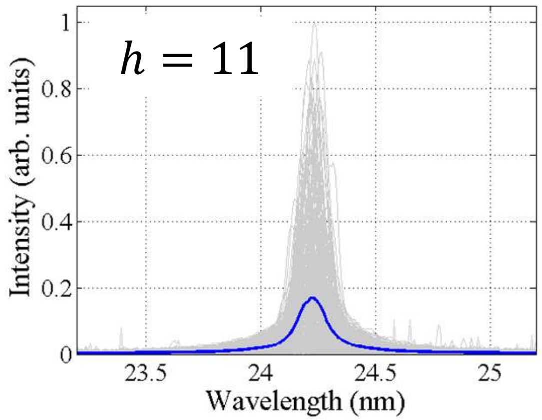
Bunching at 9th and 11th harmonic

- Electron bunch compression unchanged (I_{peak} = 600A)

$$\lambda_{seed} = 267\ nm$$

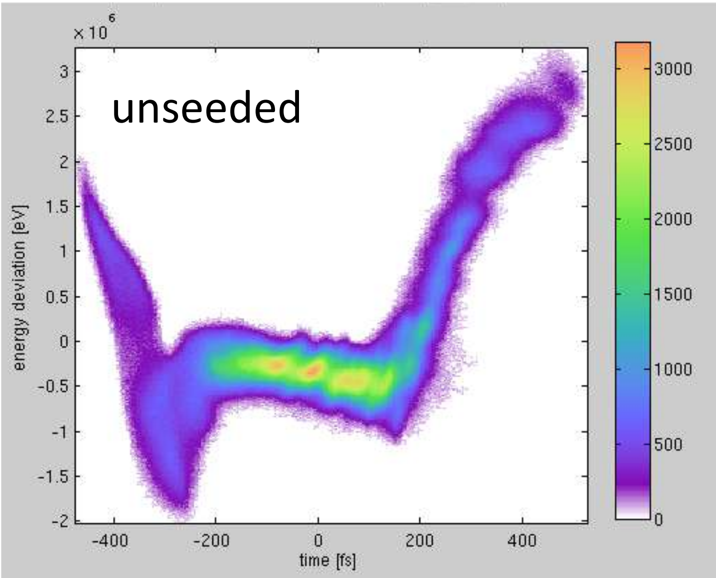


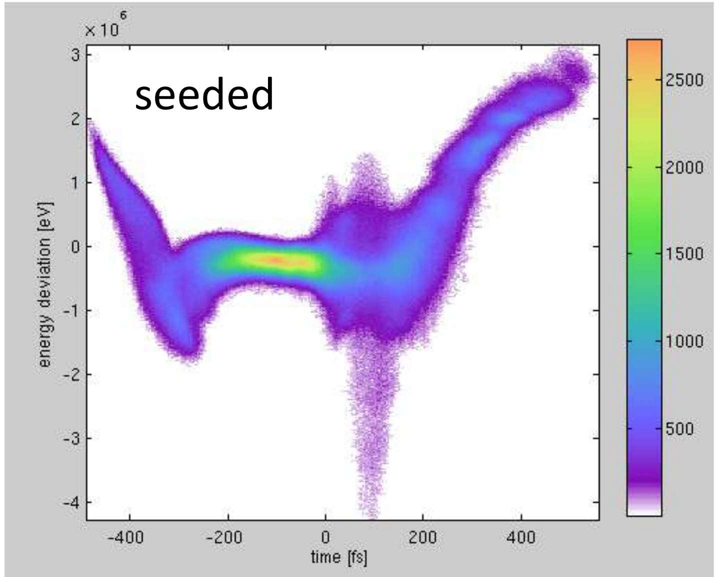




7th harm. HGHG characterization

Effect of seeding on long. phase space distribution





Changes in LPS distribution allow for characterization of photon pulse power profile:

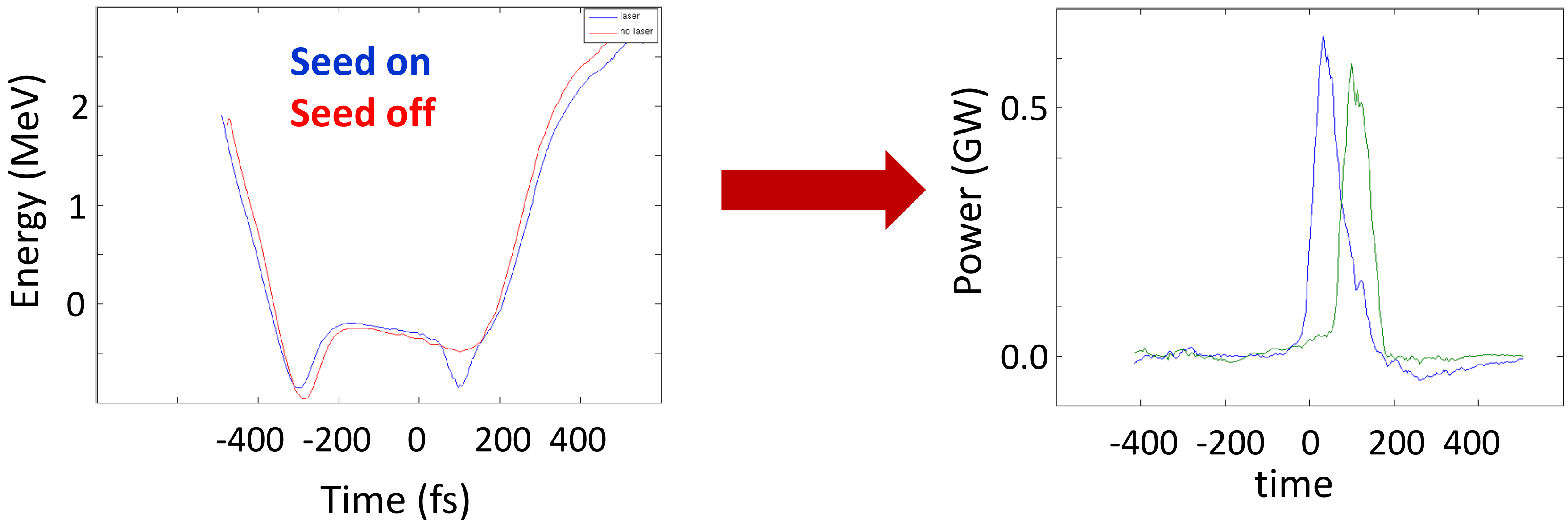
Energy drop method

$$P(t_i) = \Delta E(t_i) \cdot I(t_i)/e$$

Energy spread method

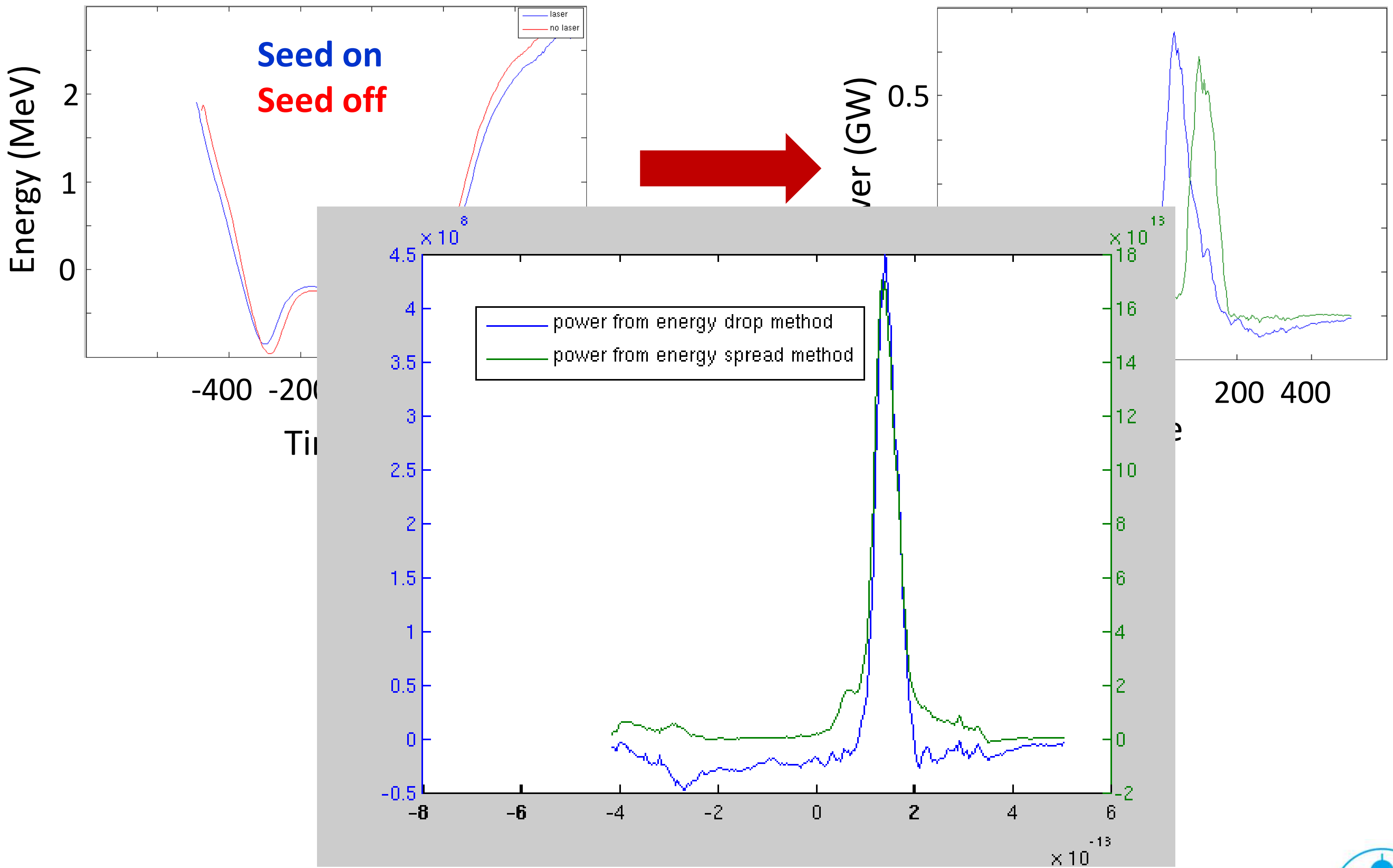
$$P(t_i) \propto [\sigma_{Eon}^2 - \sigma_{Eoff}^2] \cdot I(t_i)^{2/3}$$

Effect of seeding on long. phase space distribution

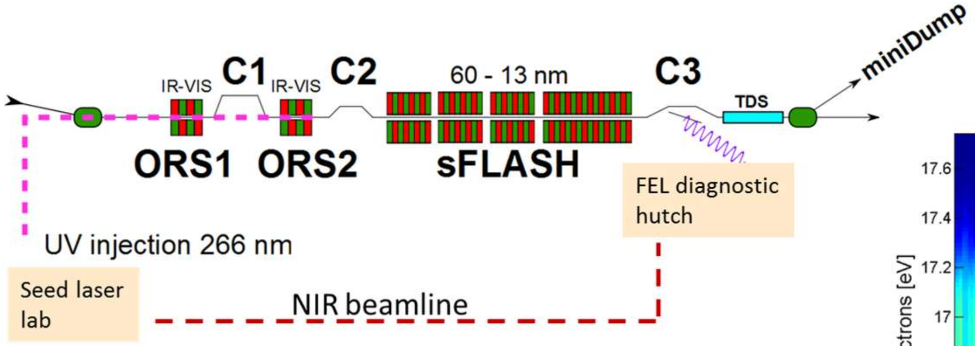


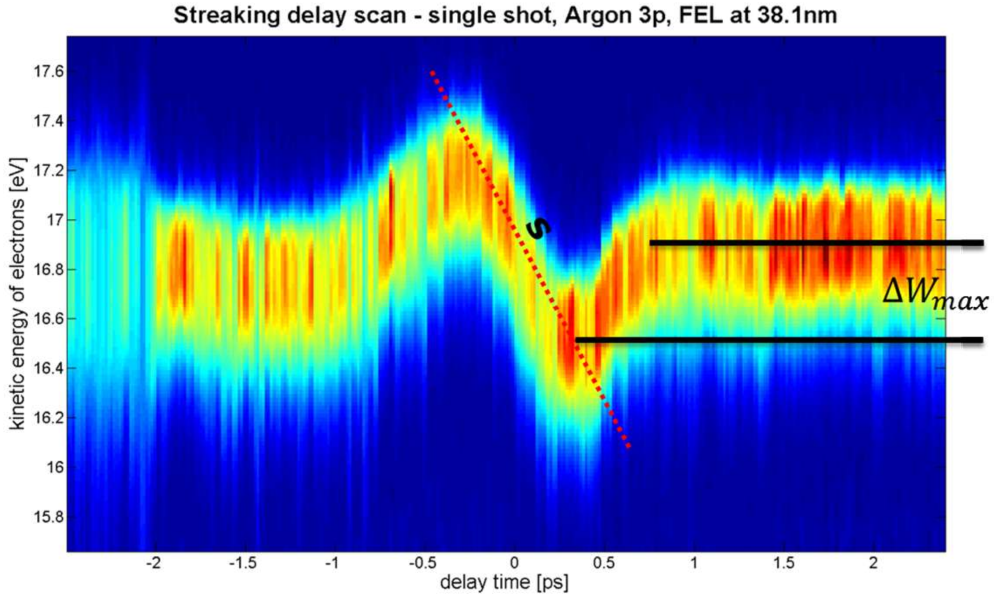
	Blue shot	Green shot
Approx. fwhm duration	84 fs	76 fs
Energy	57.6 uJ	48.2 uJ

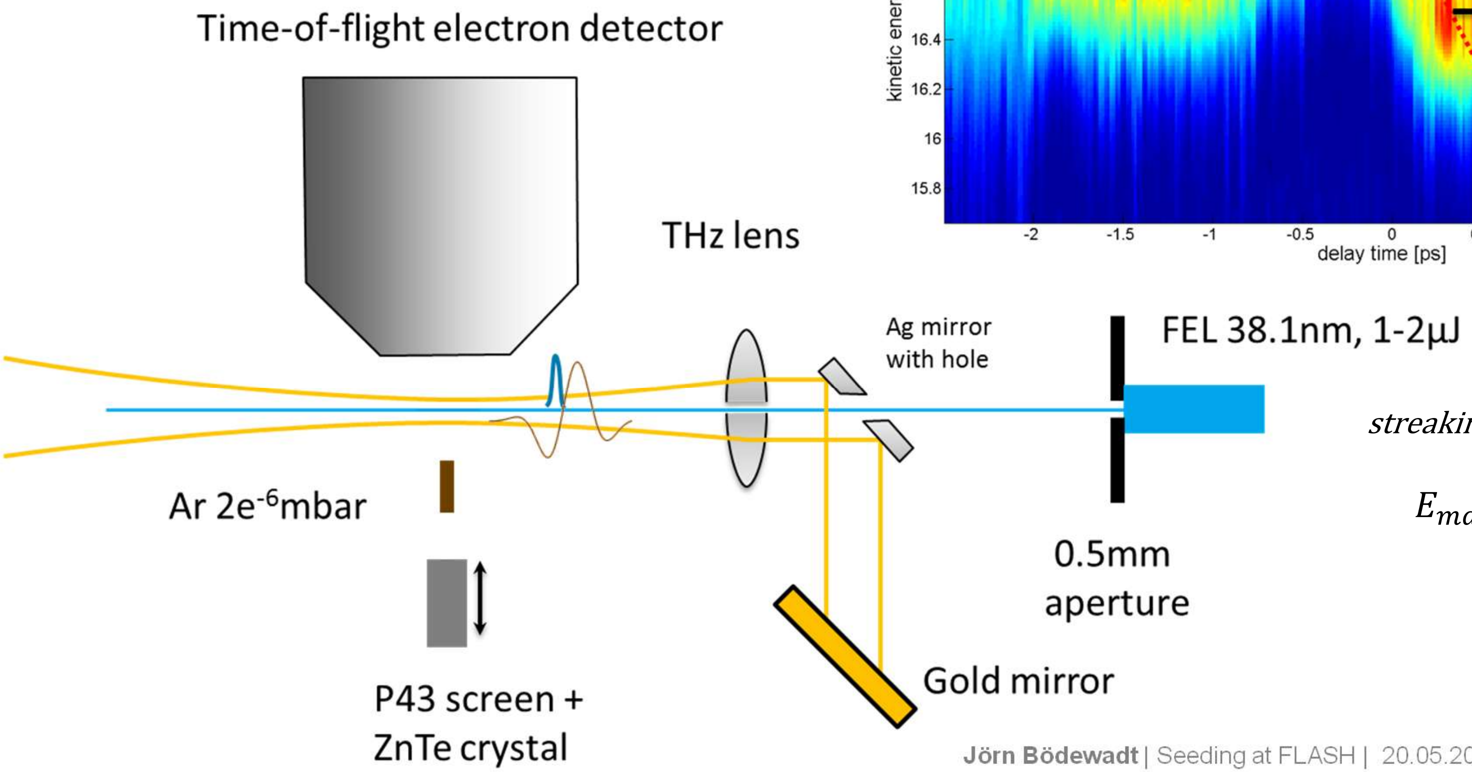
Comparison: energy drop vs. energy spread method



Scheme of THz streaking camera







streaking speed $|\mathbf{s}| \sim 1 meV/fs$

$$E_{max} = 0.6\ MV/m$$

Seeding at FLASH

- We established a standard procedure for the machine setup to guarantee reproducible operation conditions:
  - Control of electron beam optics (injector and seeding section)
  - Control of bunch compression
  - Setup and control of laser-electron overlap
  - FEL optimization
- 7^{th} harm. HGHG operation at 38 nm (saturation)
- Bunching up to 11^{th} harm. verified
- Temporal XUV characterization ongoing
- Simultaneous operation of sFLASH (seeded) and FLASH2 (SASE)
- Simultaneous operation of SASE in sFLASH, FLASH1, and FLASH2

Outlook

Upgrade is needed for injection beamline to eliminate…

- Access restrictions to tripler and critical diagnostics in controlled access area
  - More beamtime, longer operations -> increased probability of issues (e.g. tripler failure on 01.29)
  - Currently FLASH maintenance time is extremely limited: ~4hrs. per every 2 -3 weeks!

- Lack of real-time diagnostics & space constraints in tunnel for further development
  - Having a in-lab tripler does not provide any real-time (non-invasive) measurements

- Inability to meet future double-pulse (EEHG) seeding requirement
  - A single tripler can not provide 10 GW peak power in the interaction regions

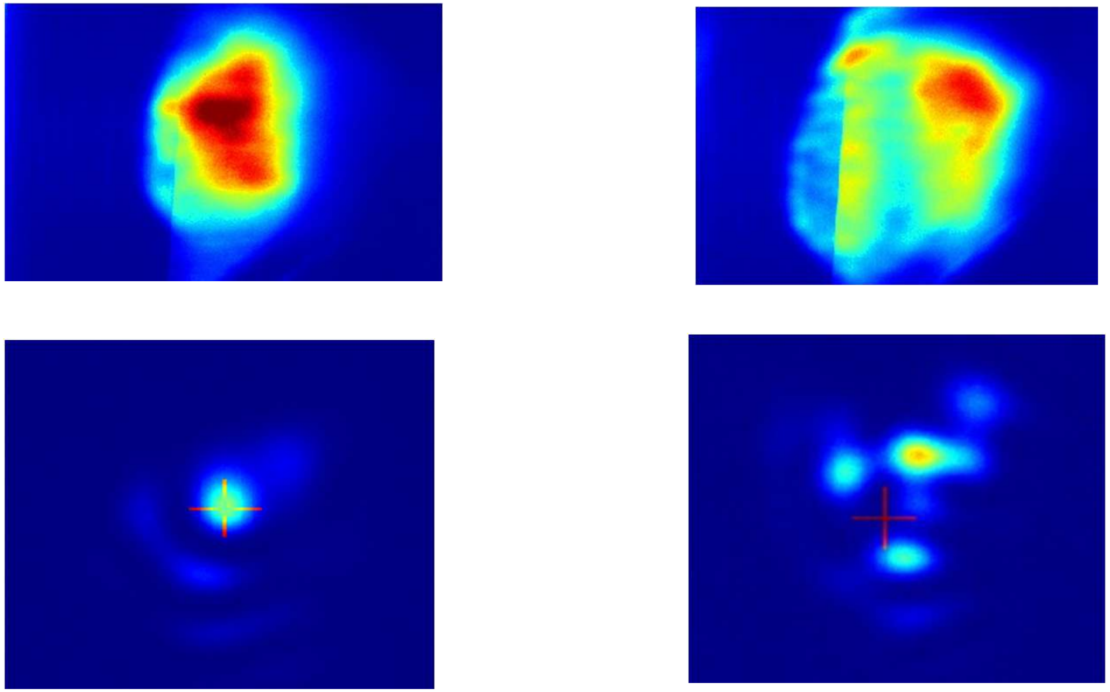
Upgrade of UV injection

- Degradation of UV source

After fresh setup | After several 10s hours of operation

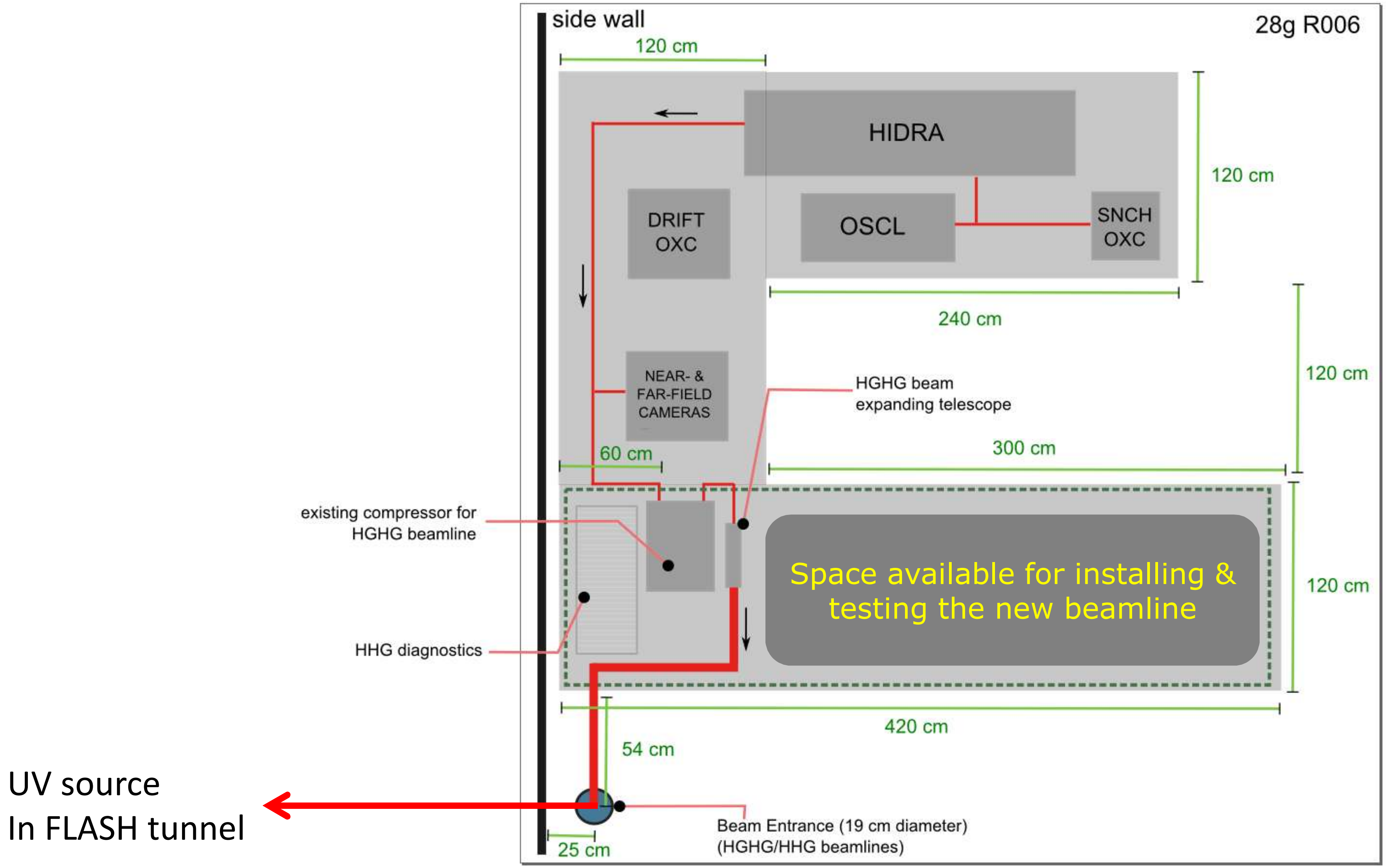
UV near-field

UV focus

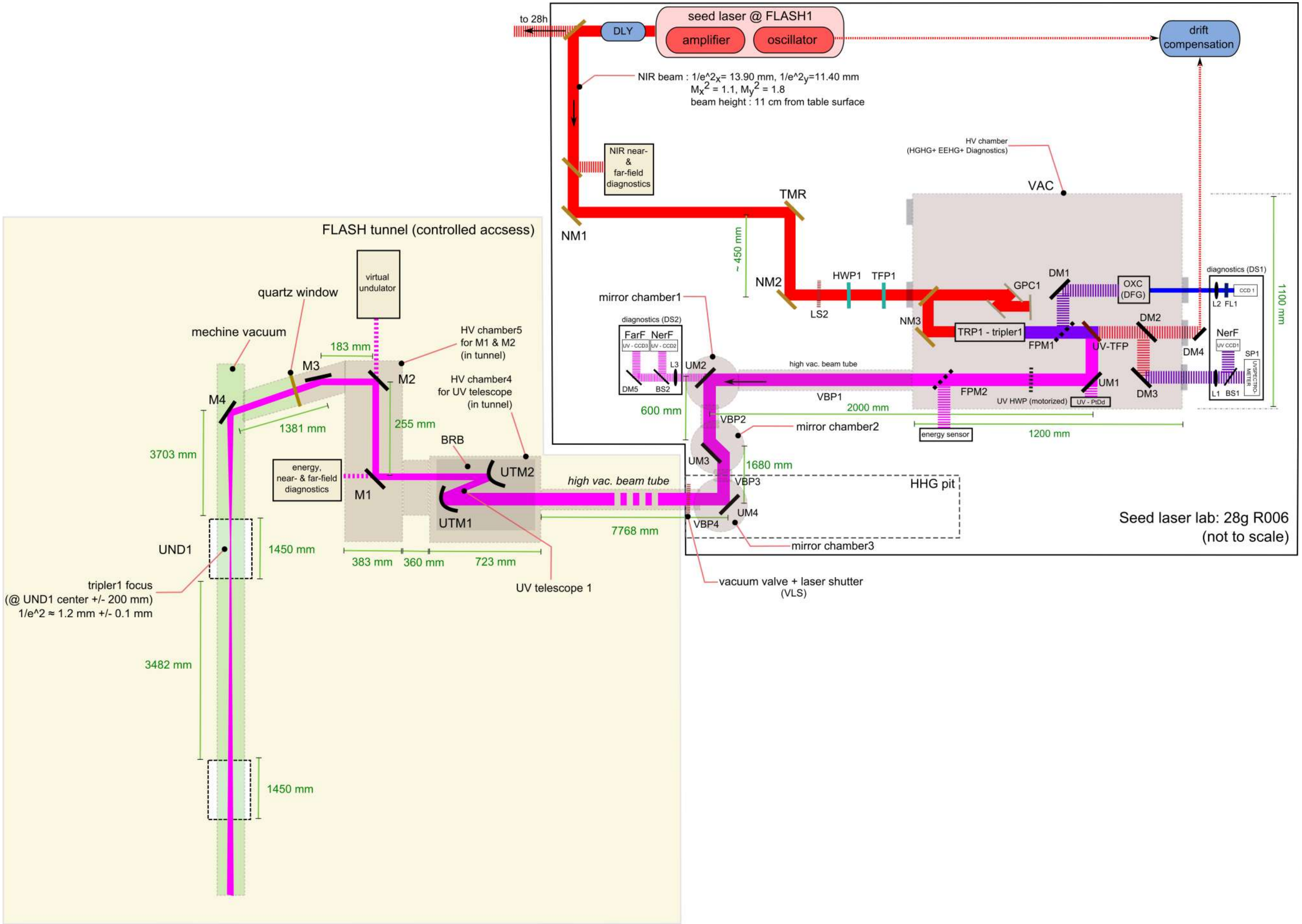


- UV source currently installed in FLASH tunnel

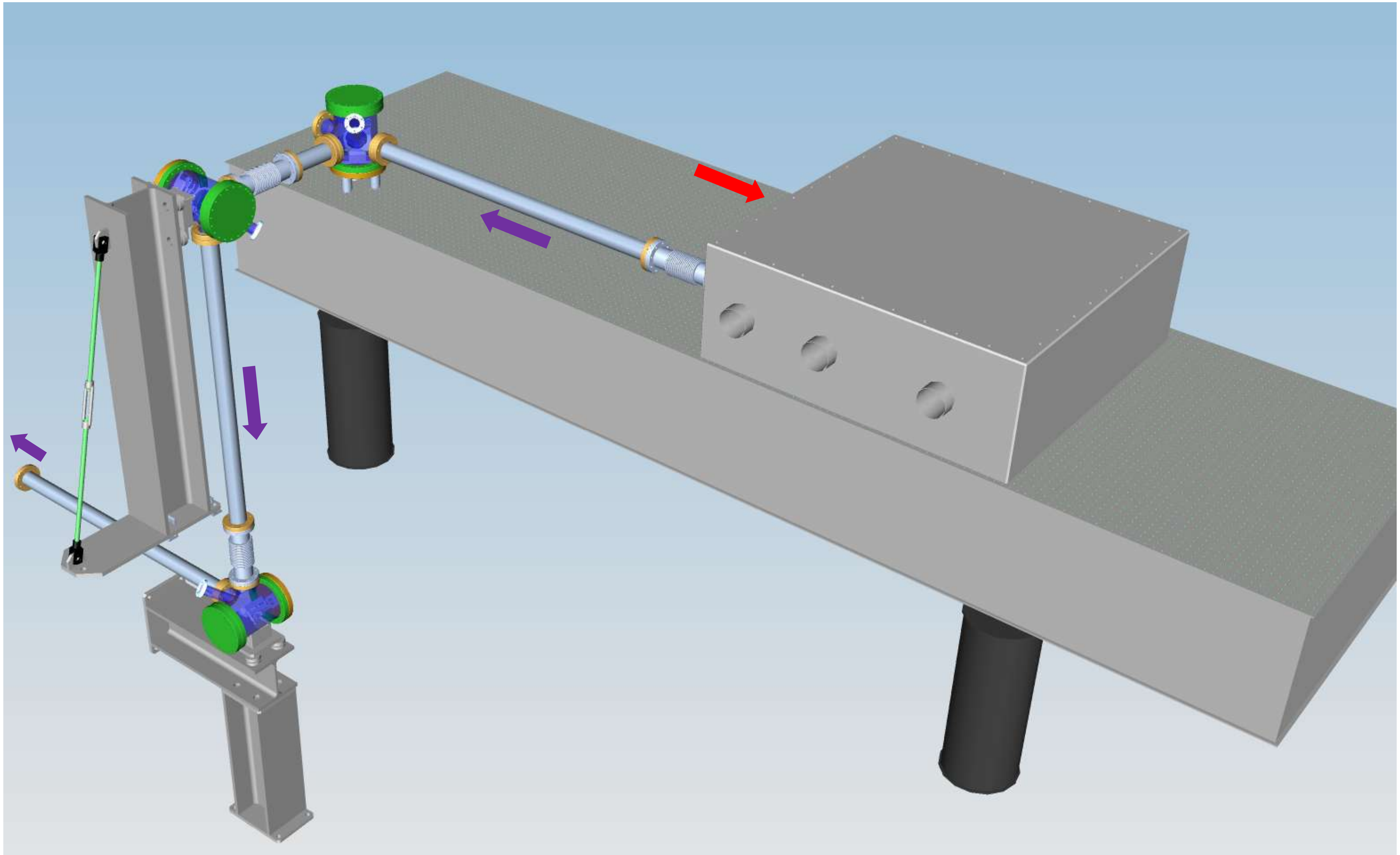
Seed Laser Lab: Current Layout



New Seed Injection Beamline Design : Phase 01 (2015-2016)



Vacuum Beamline Design



- On behalf of the seeding team

Thank you for your attention