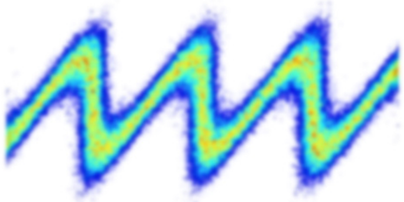
Recent Results of Seeding at FLASH

Jörn Bödewadt

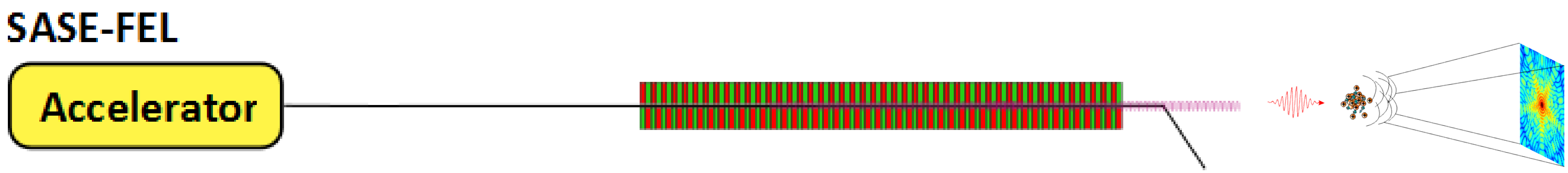
- **FEL Seeding**
- **Experimental setup at FLASH**
- **Recent results**



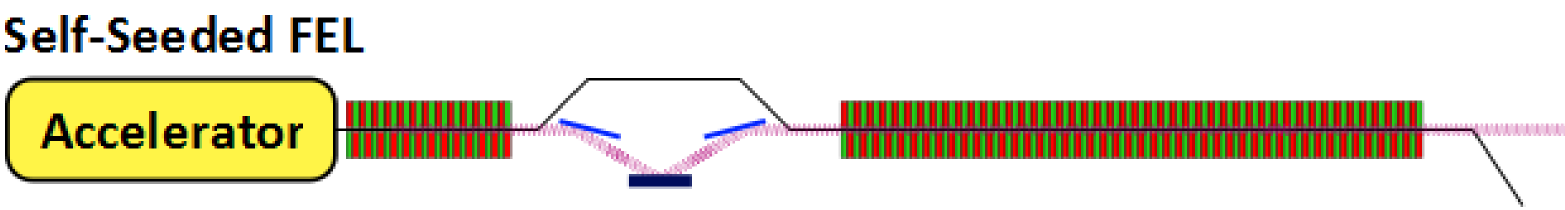
6th International Particle Accelerator Conference, 2015, Richmond VA

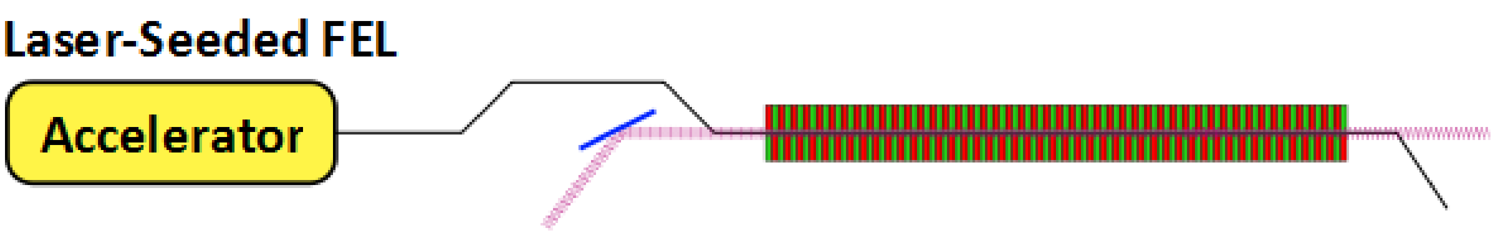
Supported by BMBF under contract 05K13GU4 and 05K13PE3
DFG GrK 1355
Joachim Herz Stiftung
Helmholtz Acclererator R&D

Free-electron lasers



- Electron LINAC:
  - relativistic e-beam, high peak-current, small emittance and energy spread
- Undulator: FEL process creates ultra-intense X-ray beams
  - ultra-short pulses, high degree of coherence
- FEL seeding:

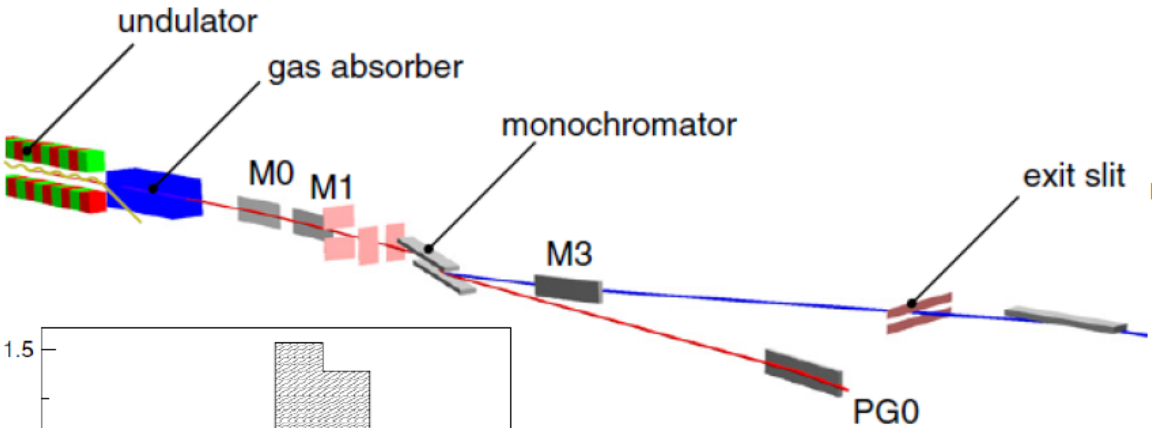


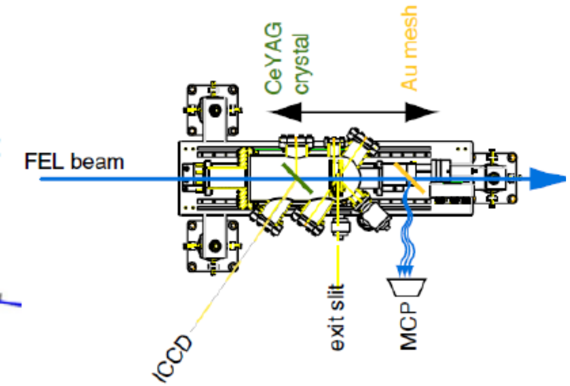


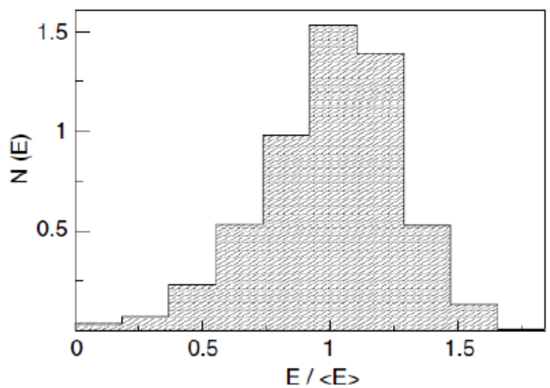
Why would FEL users want seeding?

Properties	Beneficial for:
○ Fully synchronized with optical laser	▪ All pump-probe experiments using second laser
○ Close to Fourier limited pulses	▪ All pump-probe experiment ▪ Nonlinear light-matter interaction
○ Small bandwidth with high pulse energy	▪ Resonant excitation ▪ High resolution spectroscopy
○ Less fluctuations in	
➢ Photon energy	▪ Resonant excitation ▪ All spectroscope experiments
➢ Spectral shape	▪ Resonant excitation ▪ All spectroscope experiments
➢ Pulse energy	▪ Nonlinear light-matter interaction ▪ All spectroscopy experiments
○ Full coherence	▪ Nonlinear spectroscopy

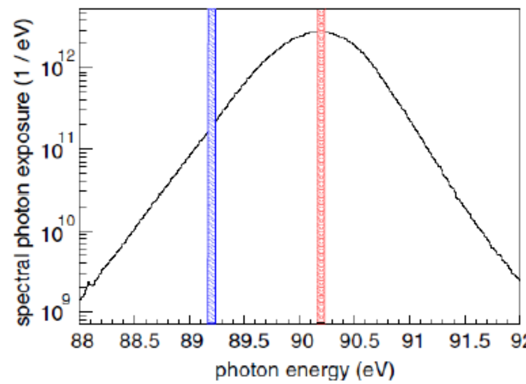
Statistical fluctuations of spectrum with SASE



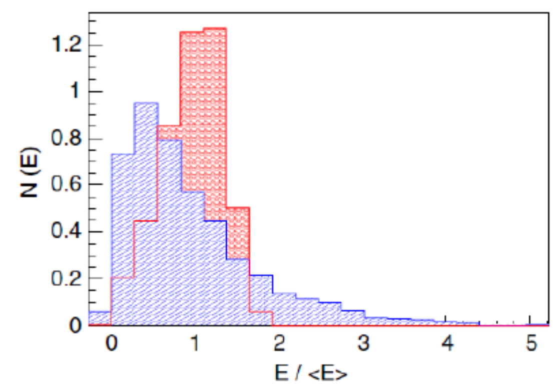




SASE distribution



Average spectrum



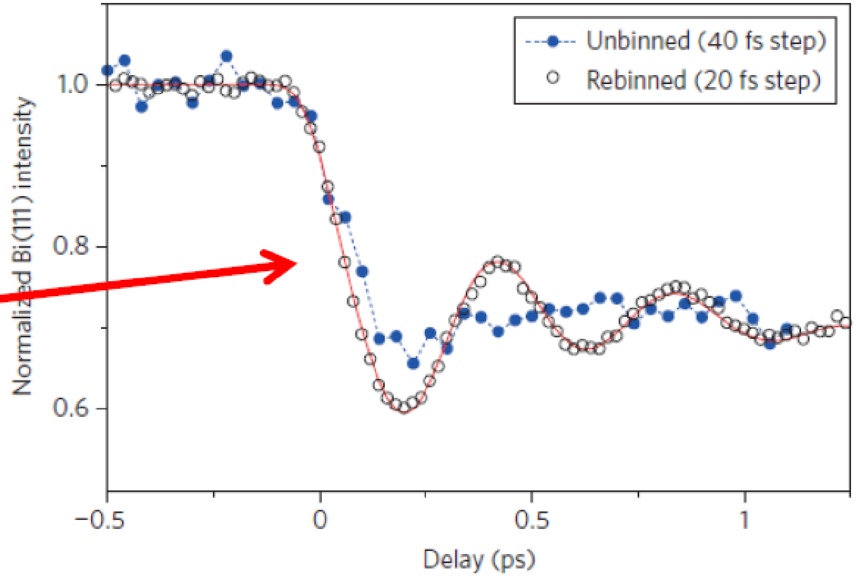
Distribution behind mono

M. Wellhöfer et al., Performance of the monochromator beamline at FLASH
J. Opt. A: Pure Appl. Opt. **9** (2007) 749–756

Timing fluctuations with two lasers

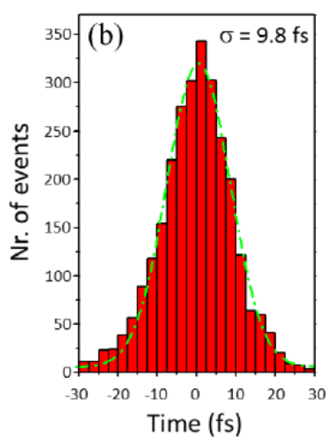
Problem: timing jitter between external lasers and FEL's

Solution:
a) perfect synchronisation
or b) shot-to-shot timing diagnostics

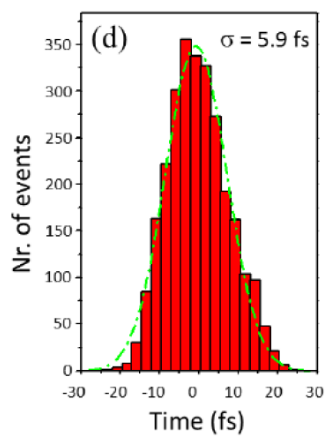


M. Harmand et al., Nat. Phot. 7, 215 (2013)

DiProI



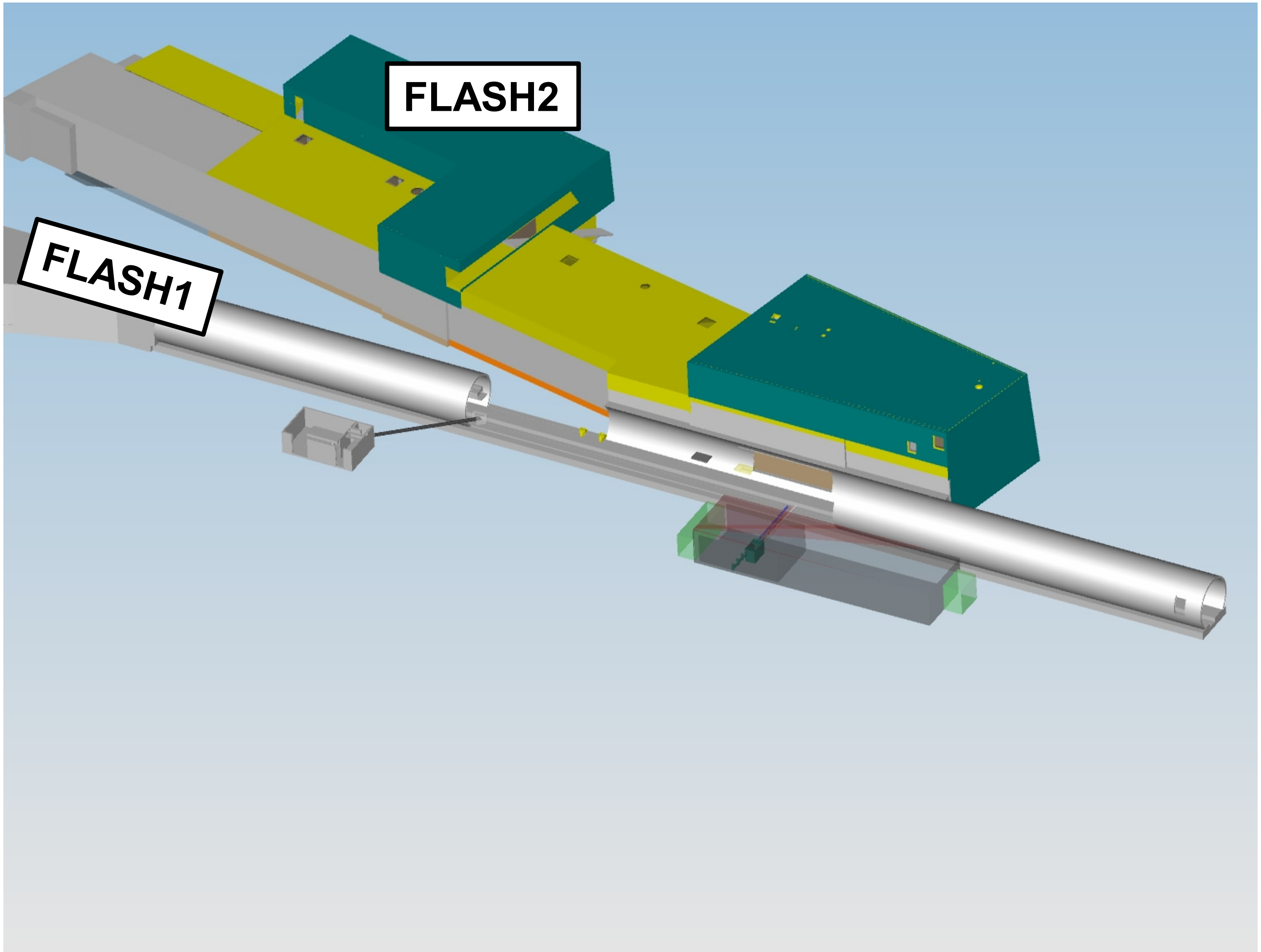
TIMEX



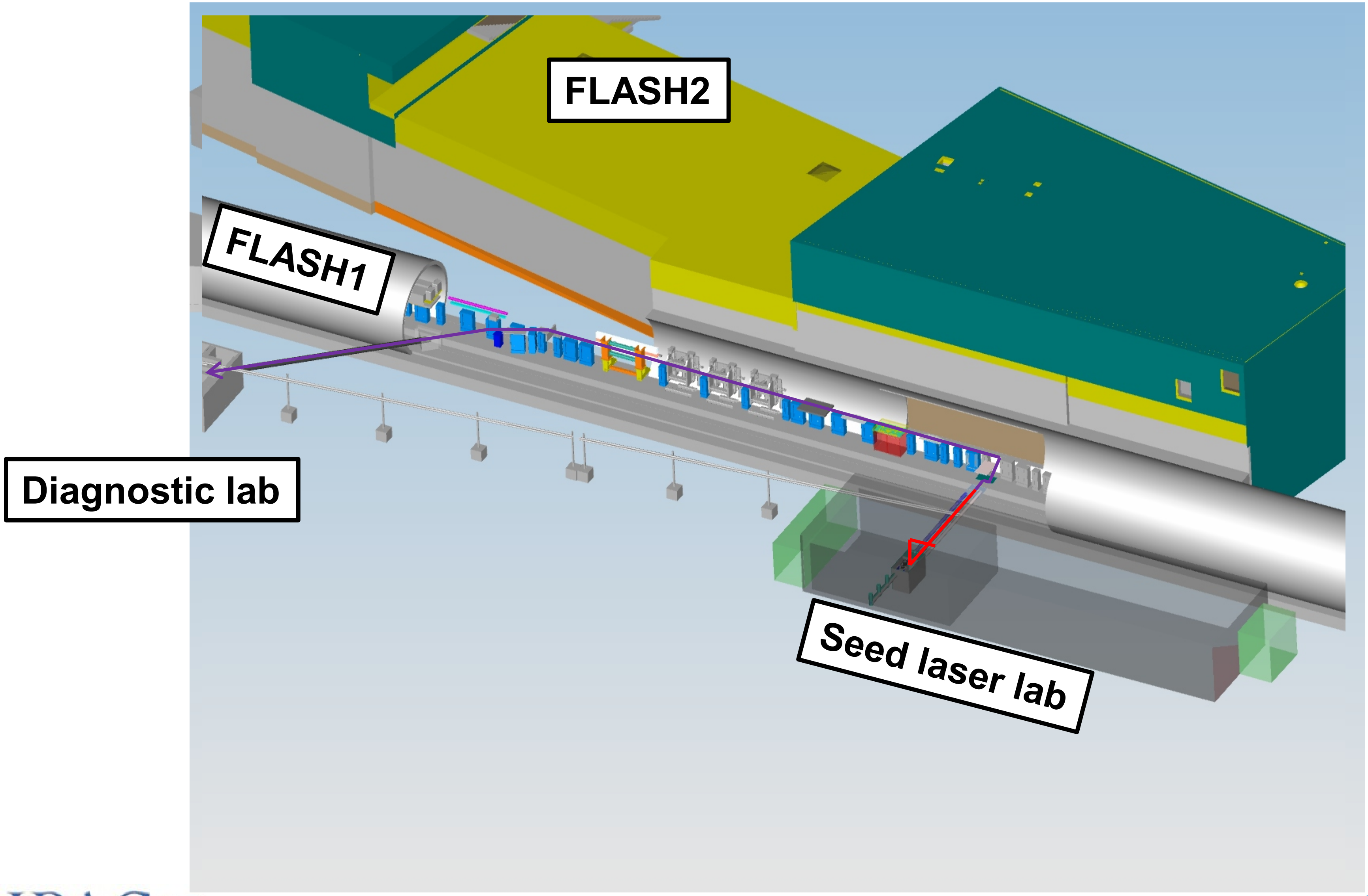
FERMI@Elettra
Seeded Soft X-ray FEL facility

M. Danailov et al., Optics Express 22, 12869 (2014)

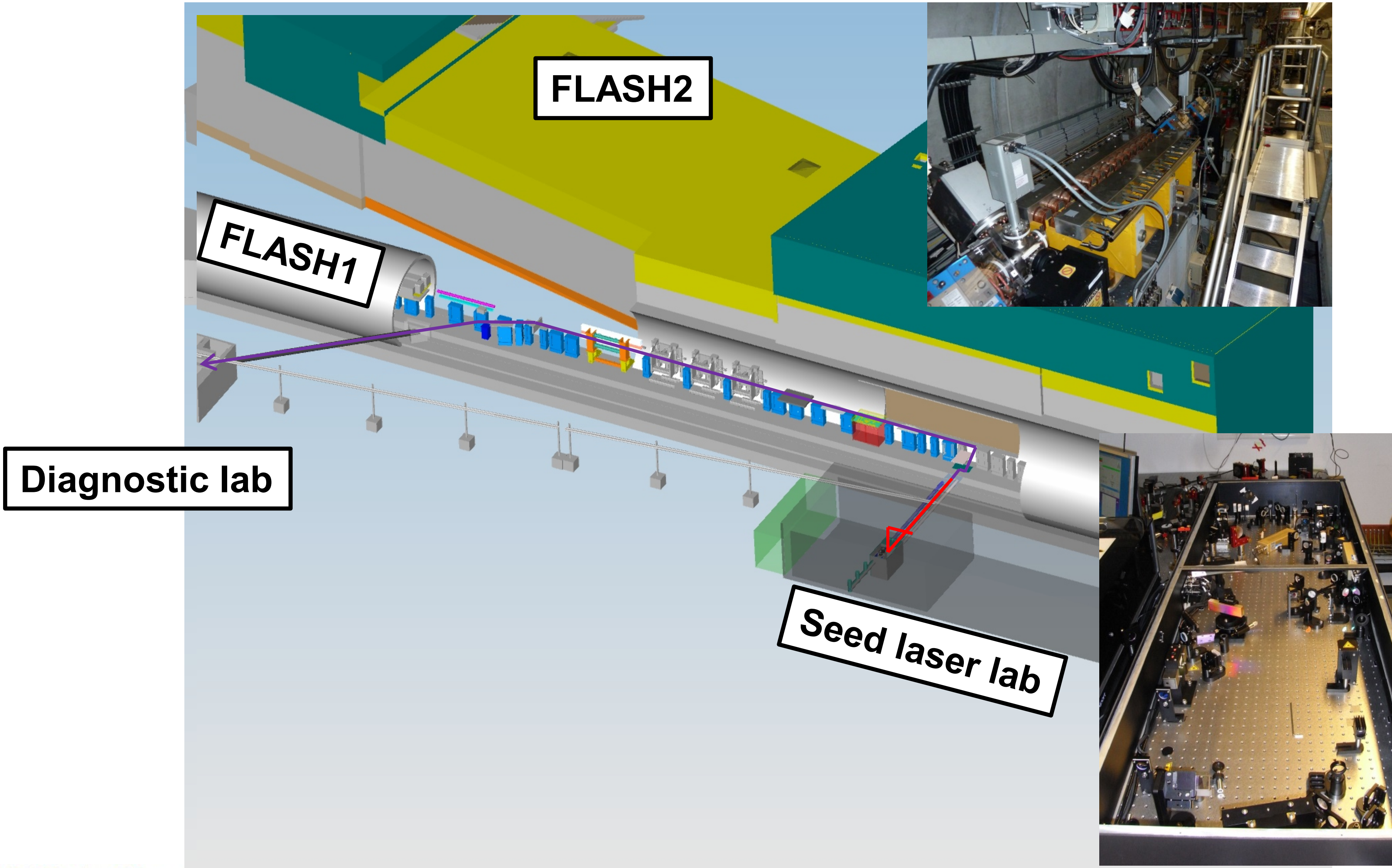
Seeding experiment at FLASH



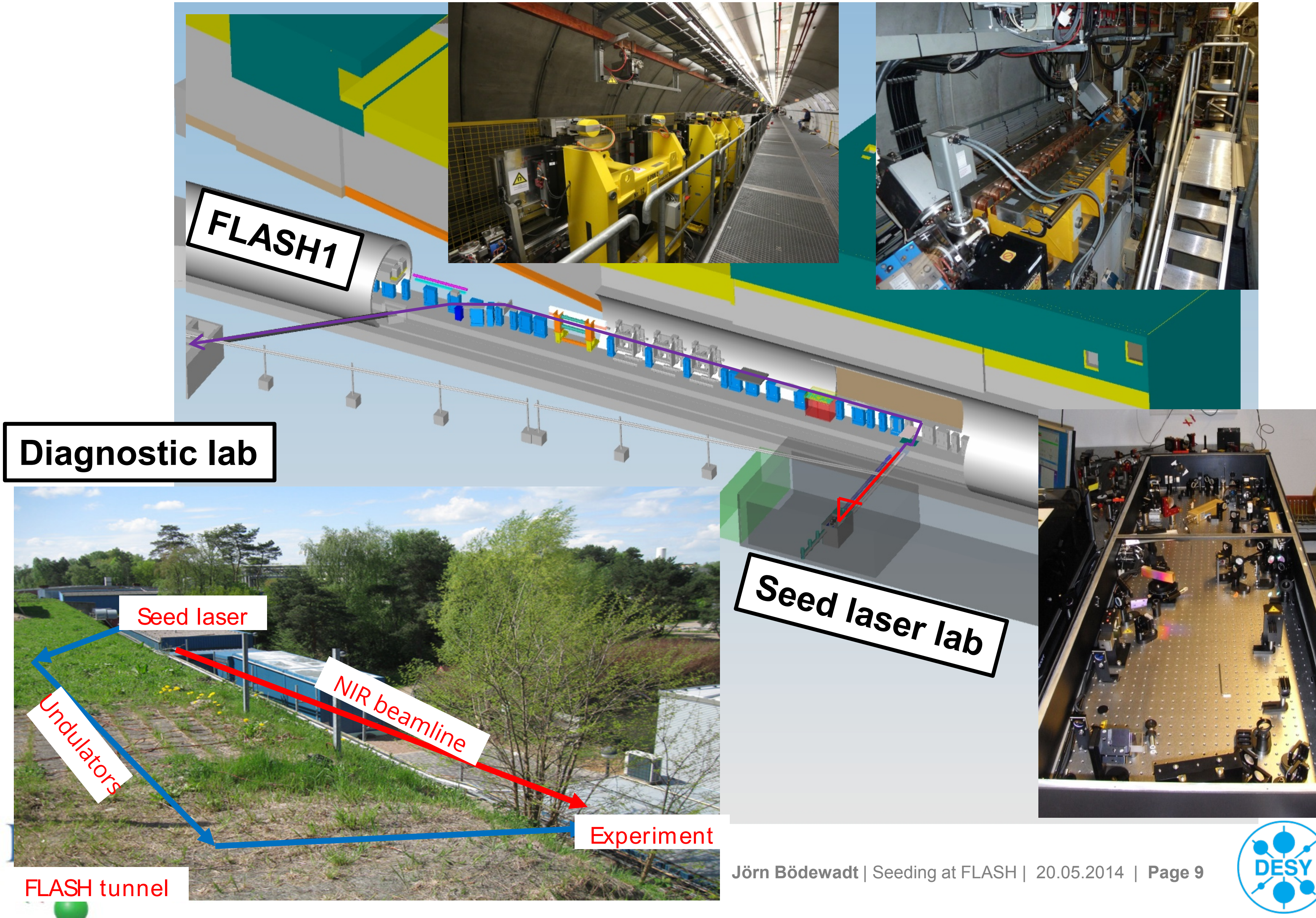
Seeding experiment at FLASH



Seeding experiment at FLASH

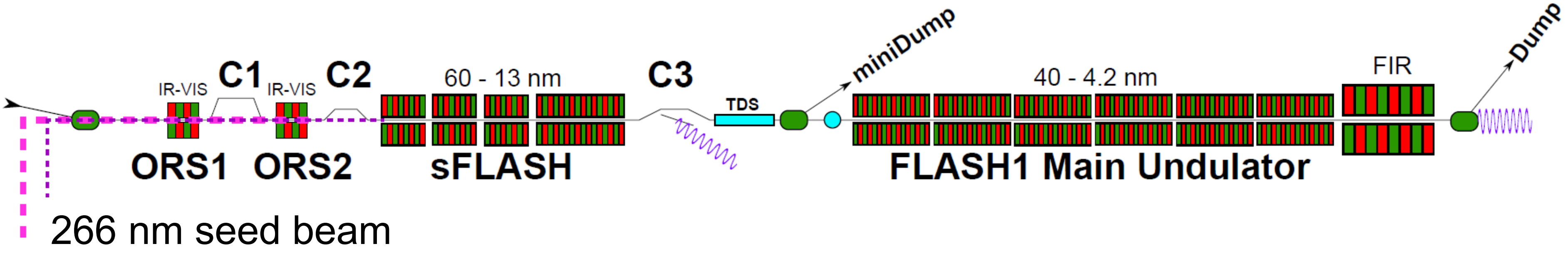


Seeding experiment at FLASH



Seeding experiment at FLASH - *sFLASH*

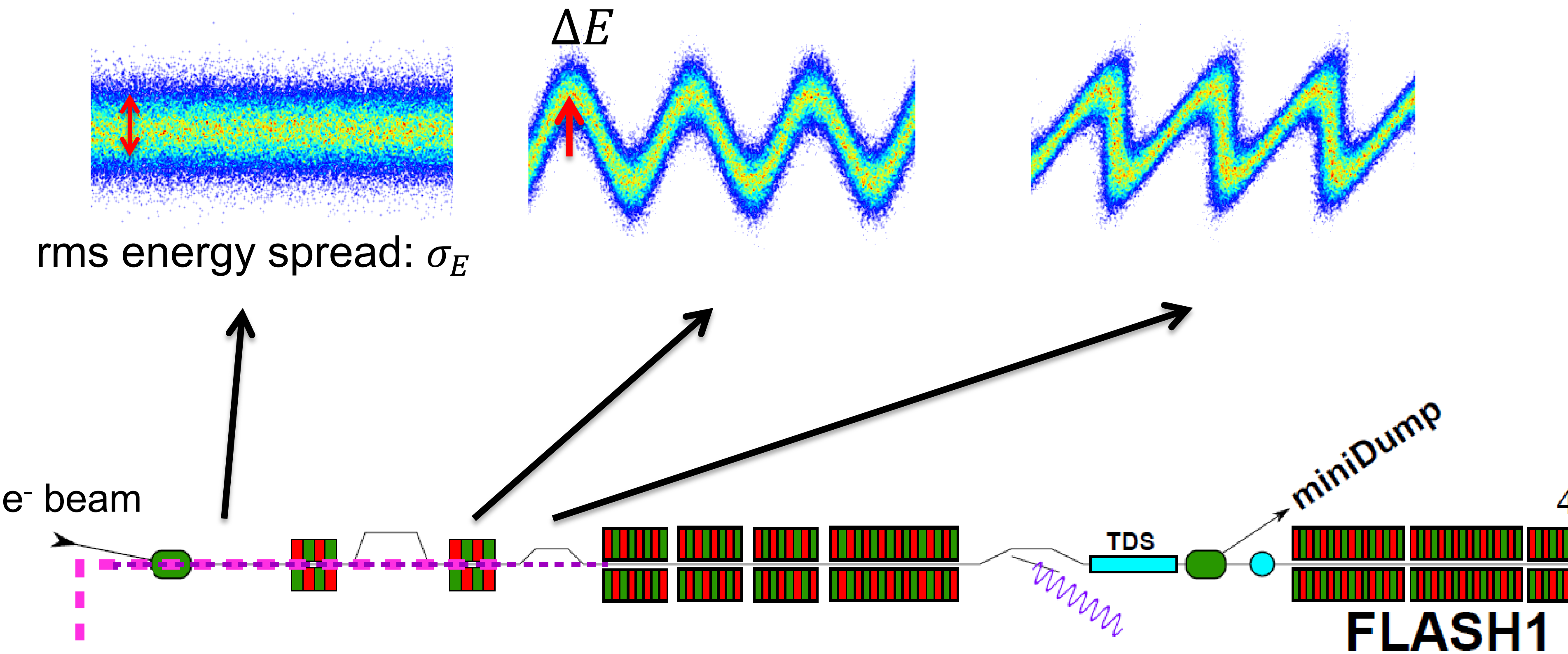
FLASH1 beamline



- Installed during FLASH upgrade in 2010
- First demonstration of direct HHG seeding at 38 nm (2012)
- No operation in 2013 (FLASH2 upgrade)
- Since 2014 preparation of HGHG

S. Ackermann et al., PRL **111**, 114801 (2013)

High-Gain Harmonic Generation

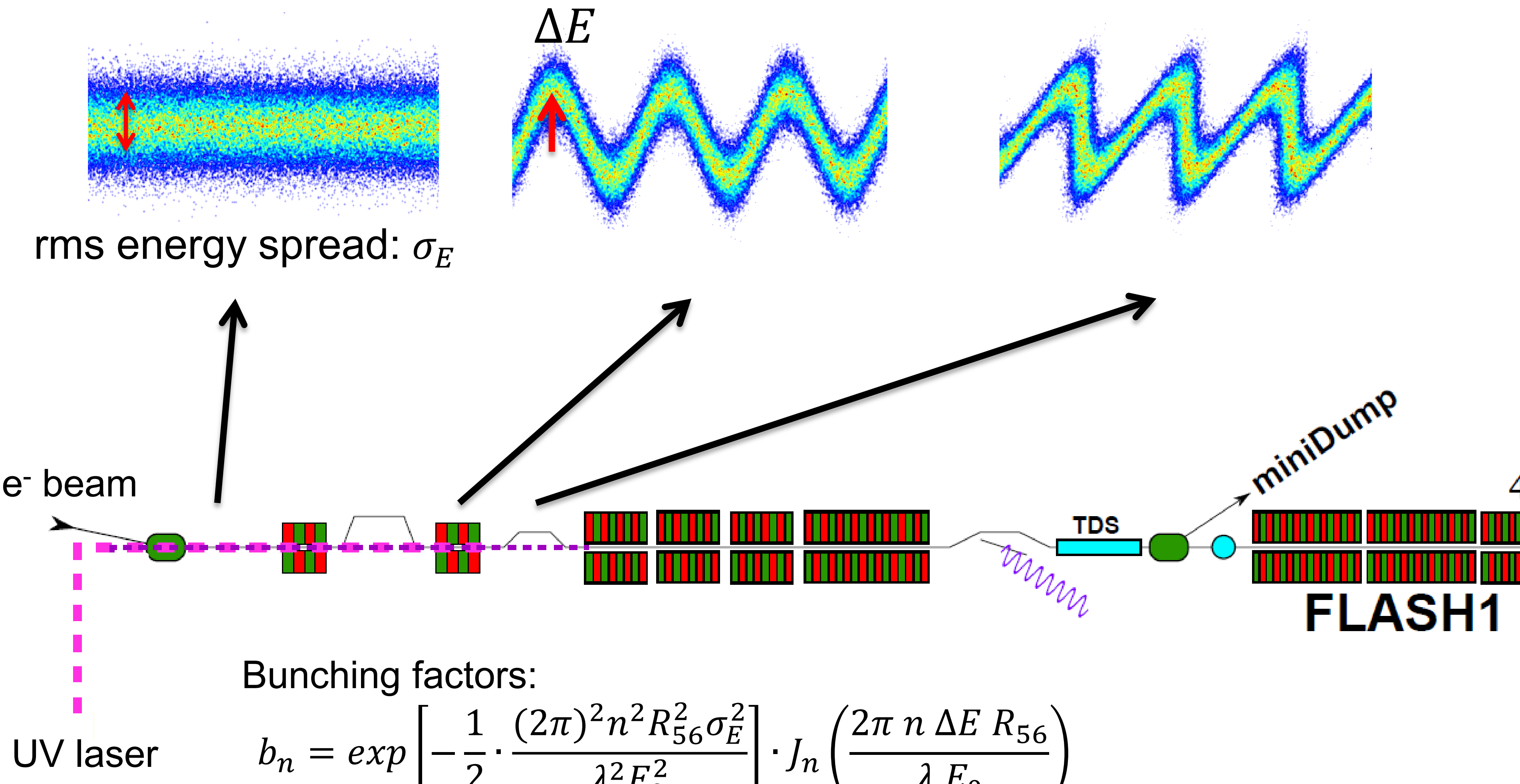


Modulation amplitude:

$$\Delta E = \sqrt{\frac{P_L[GW]}{8.7\ GW} \cdot \frac{K_p L_u}{\gamma_0 \sigma_r} \cdot \frac{m_0}{c^2}} \left(J_0\left(\frac{K_p^2}{4+2K_p}\right) - J_1\left(\frac{K_p^2}{4+2K_p}\right) \right)$$

D. Xiang et al., PR-STAB 16, 110701 (2013)

High-Gain Harmonic Generation



Bunching factors:

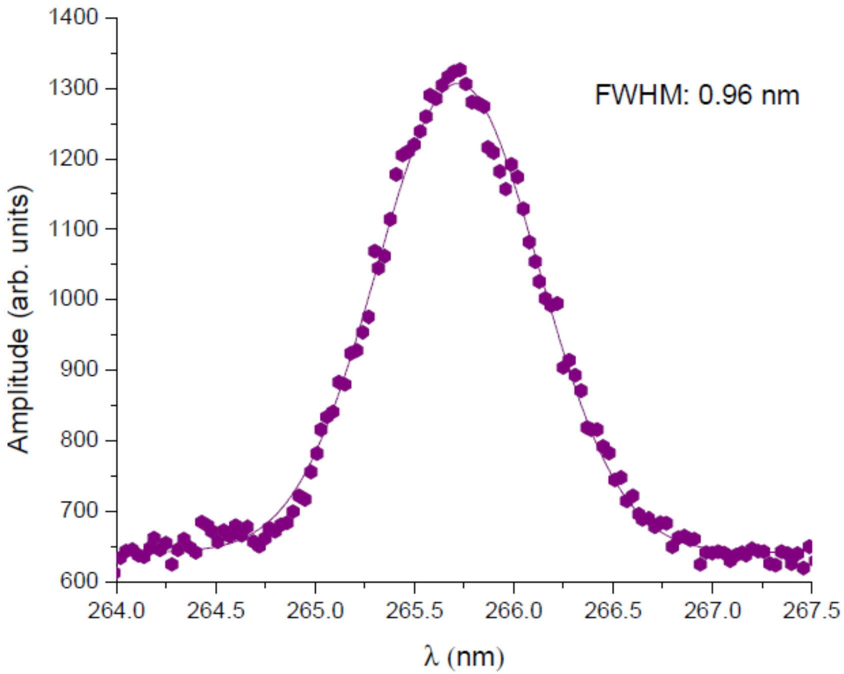
$$b_n = exp\left[-\frac{1}{2}\cdot\frac{(2\pi)^2 n^2 R_{56}^2 \sigma_E^2}{\lambda^2 E_0^2}\right]\cdot J_n\left(\frac{2\pi\ n\ \Delta E\ R_{56}}{\lambda\ E_0}\right)$$

D. Xiang et al., PR-STAB 16, 110701 (2013)

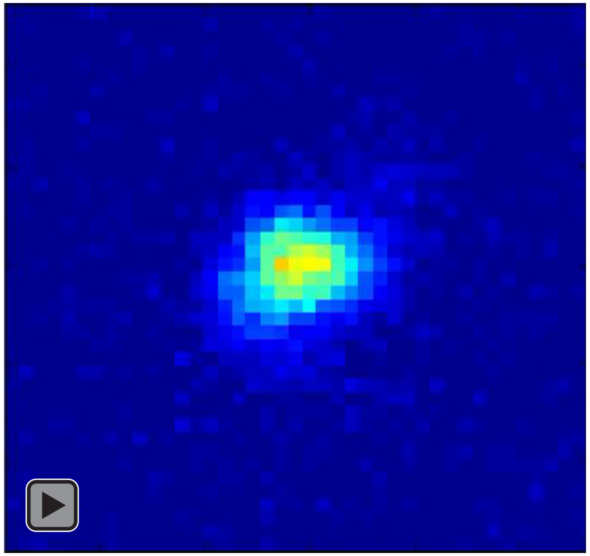
Seed laser system

- Driver system:
  - Ti:sapphire 800 nm, 10 Hz, 60 fs (FWHM), <50 mJ max pulse energy
- Third harmonic generation in crystals

Measured Spectrum of the 3rd harmonic

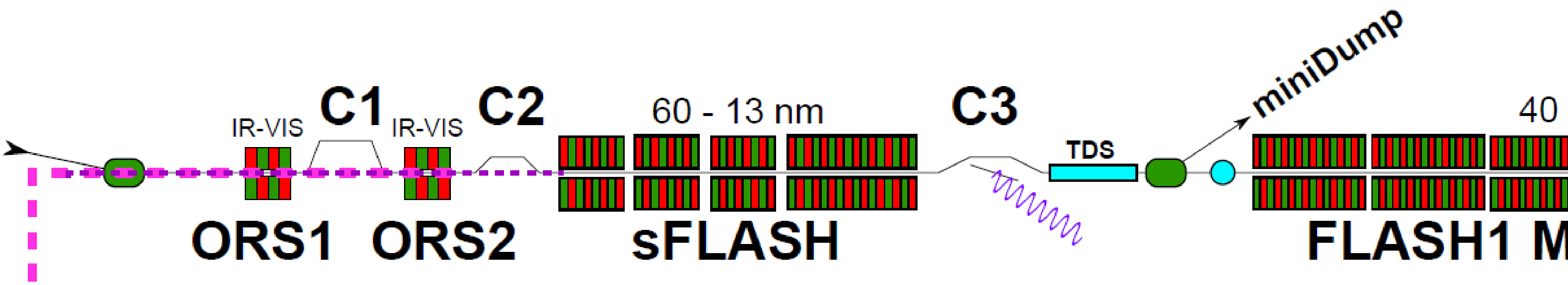


UV beam on YAG screen at the focus



Max. available pulse energy in the UV ~ 280 μJ

Laser-electron overlap



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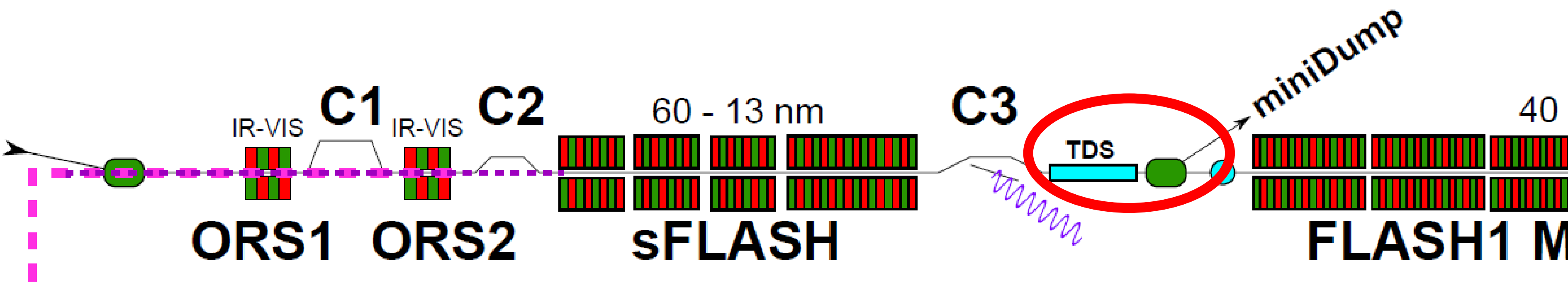
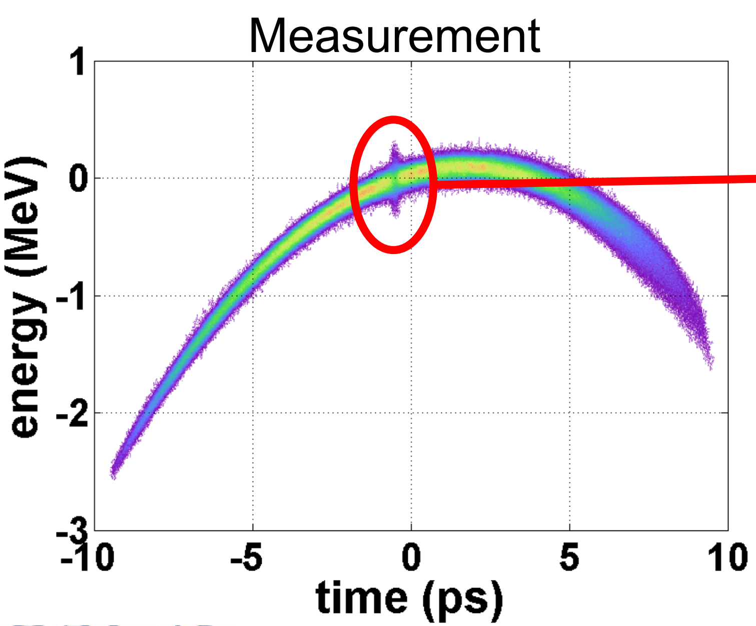


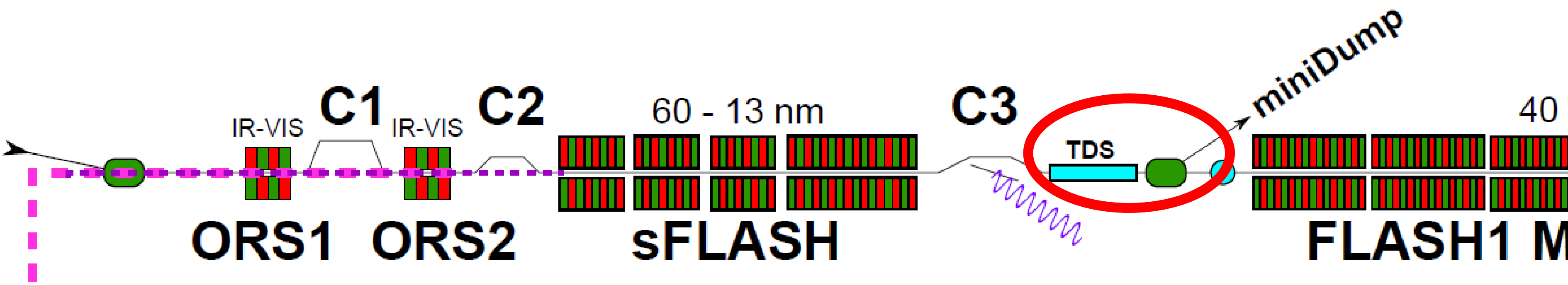


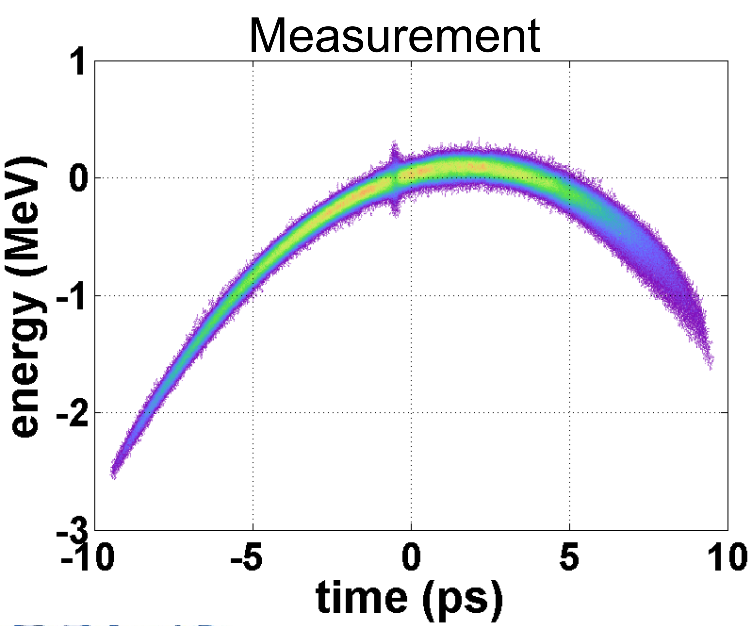
energy modulation observed with LOLA

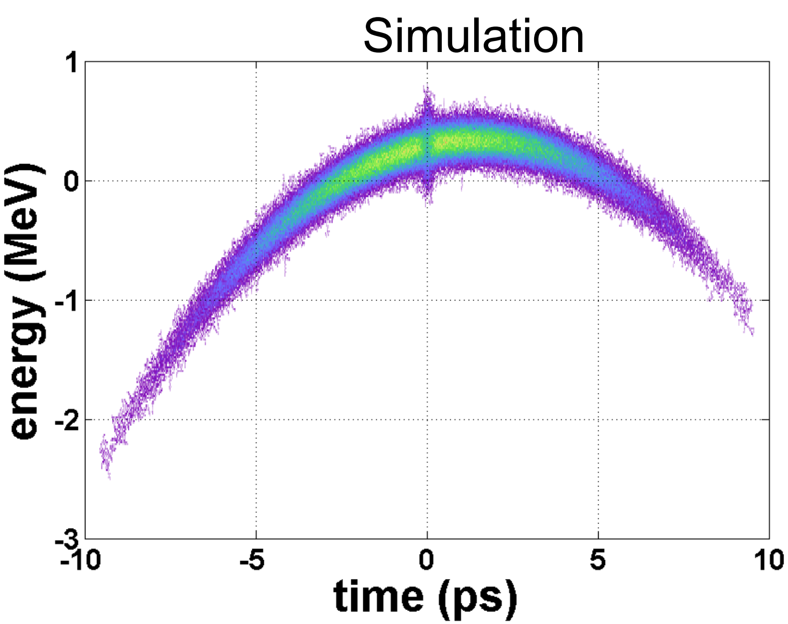
modulation by UV laser

Comparison with simulation allows a characterization of the modulation amplitude (thanks to C. Behrens)

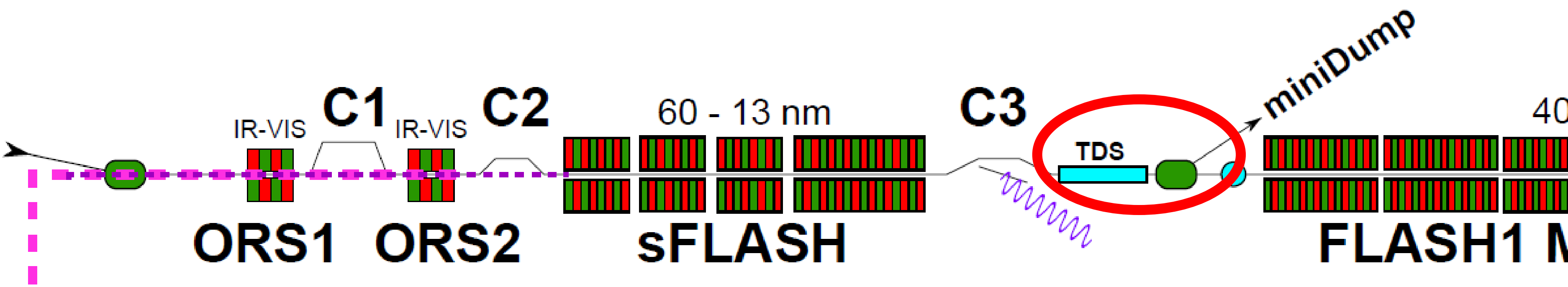
Characterization of induced energy modulation

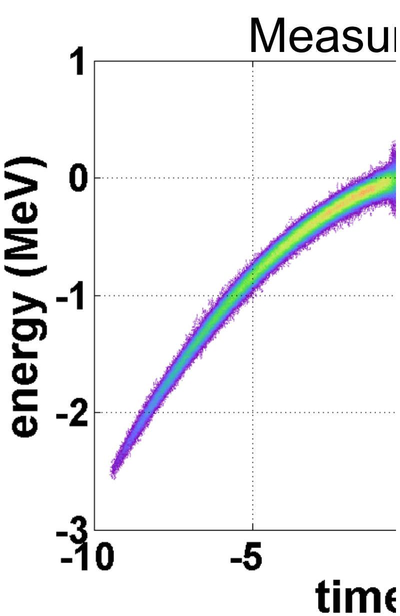


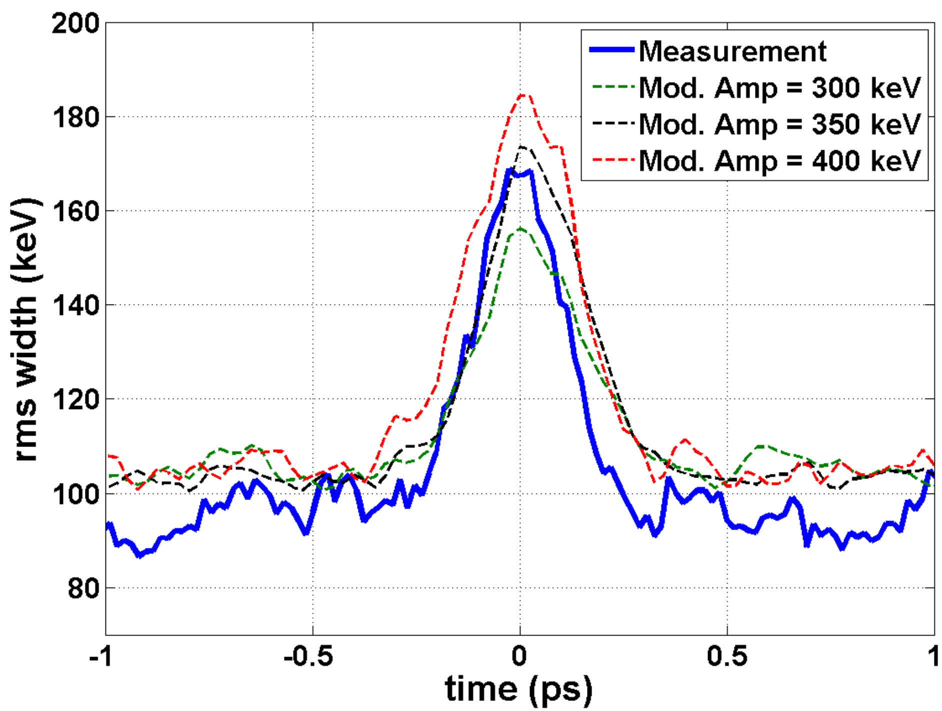


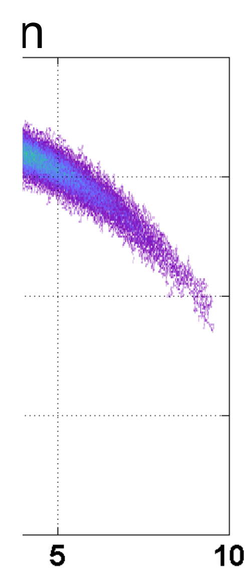


Characterization of induced energy modulation









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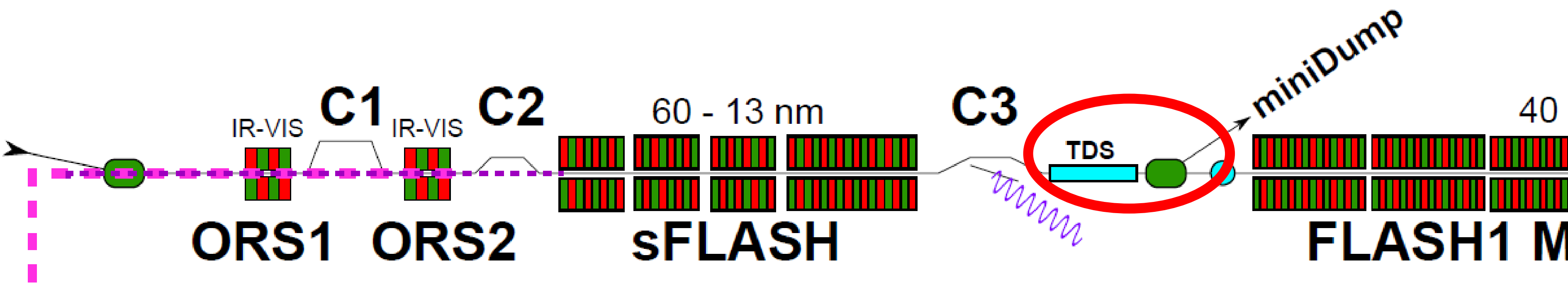
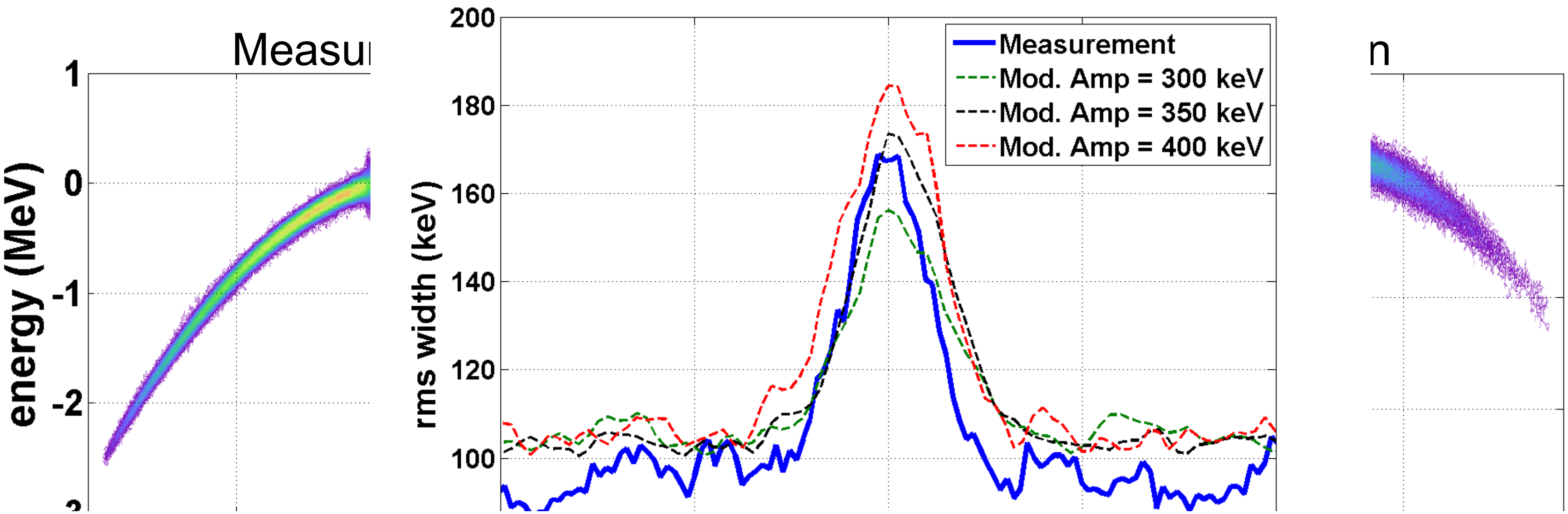


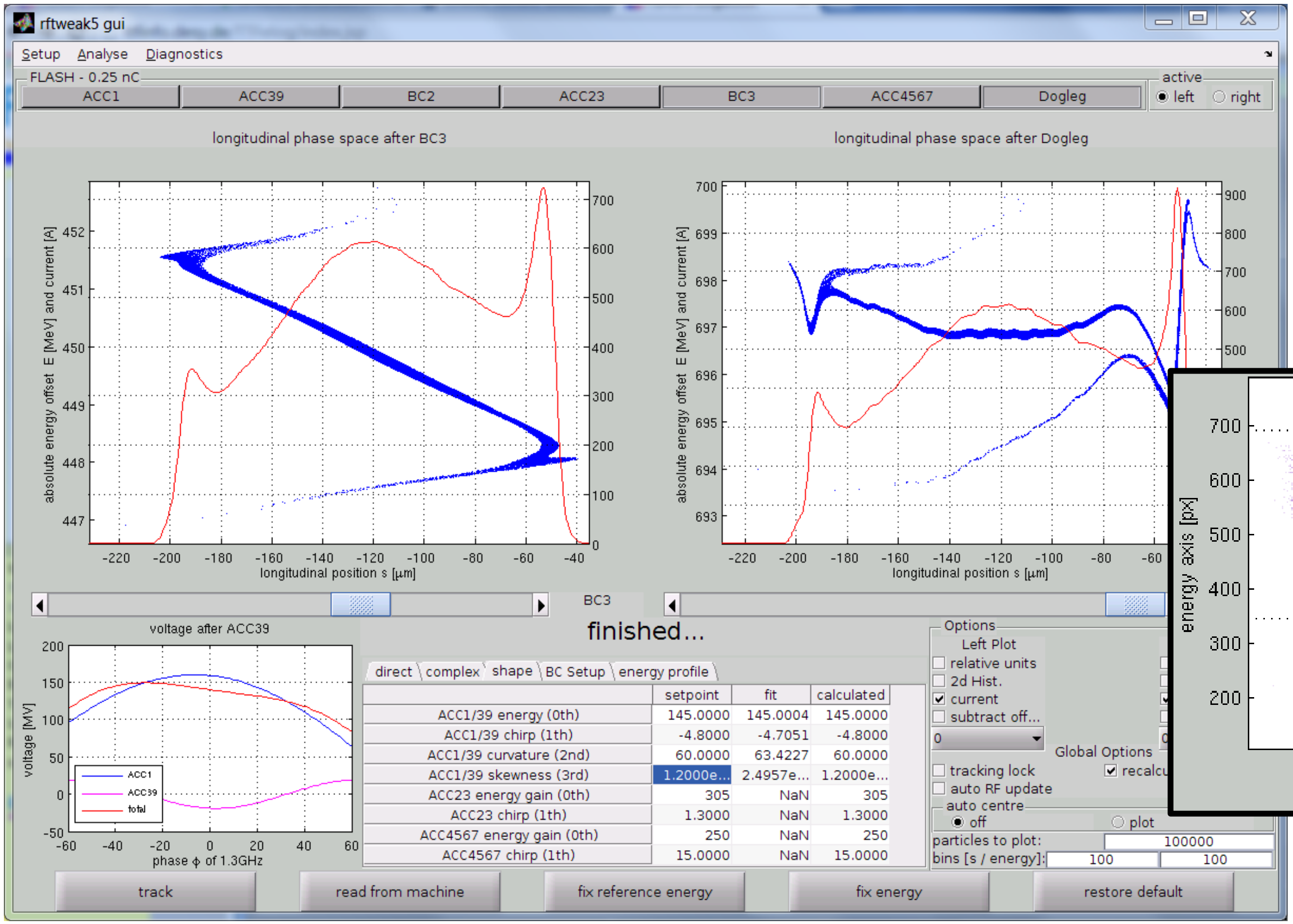


ATTENTION!

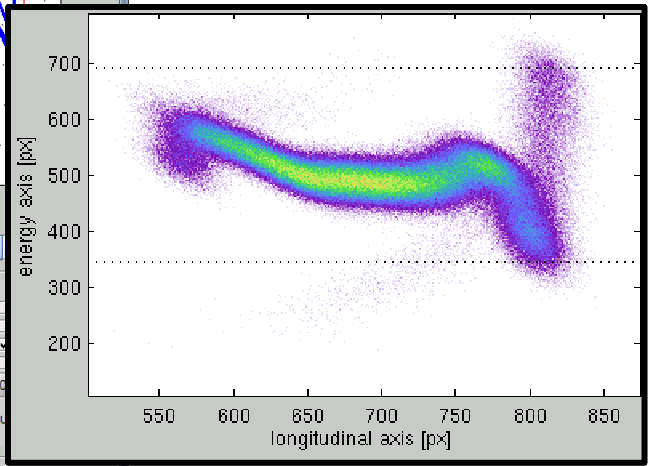
Effects of longitudinal space charge (LSC) will change the modulation along the drift and needs to be taken into account!

Electron parameters

> Operation of LINAC for moderate compression



Simulated long. phase-space



Electron parameters

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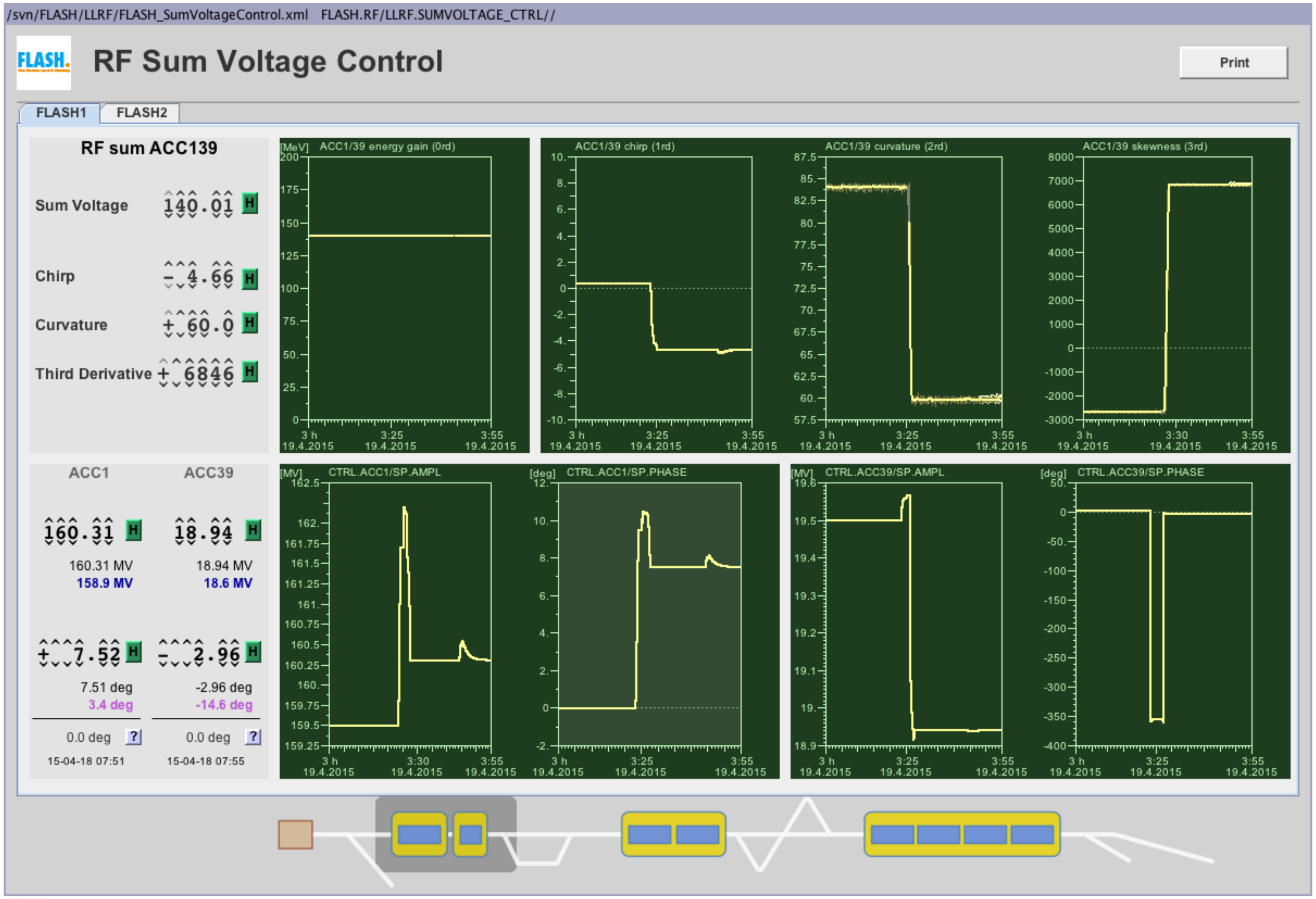
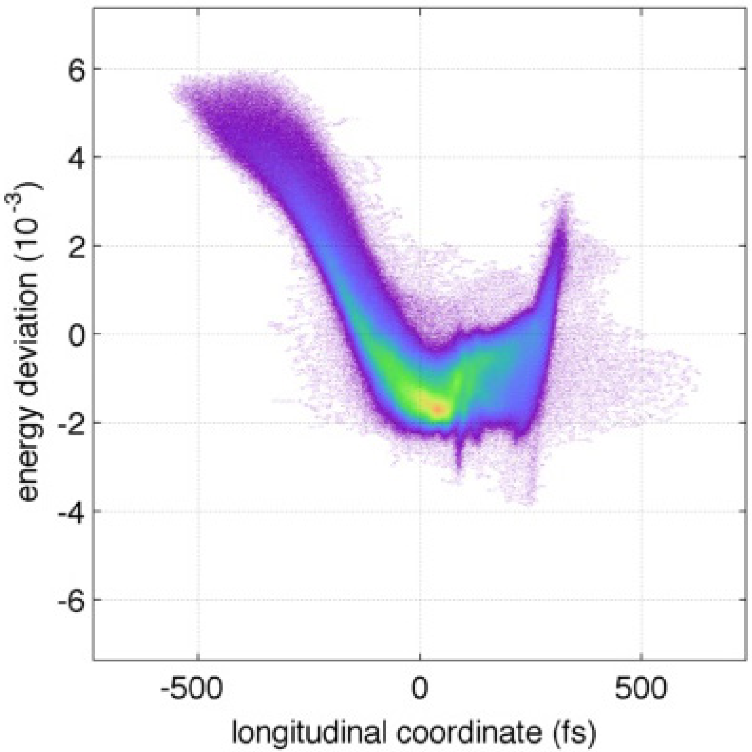


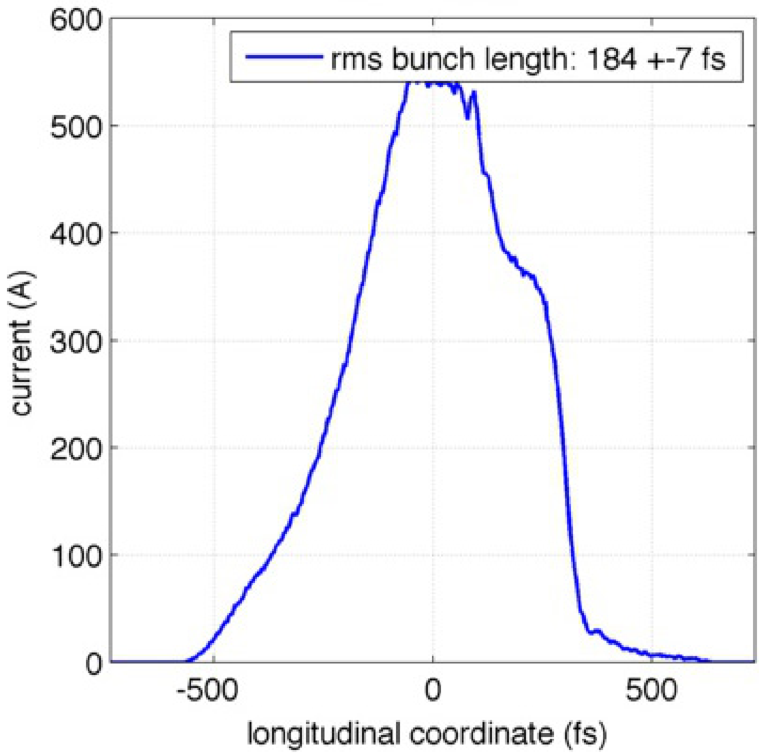
Electron parameters

> Operation of LINAC for moderate compression

Measurement of longitudinal
 phase-space distribution



Current profile



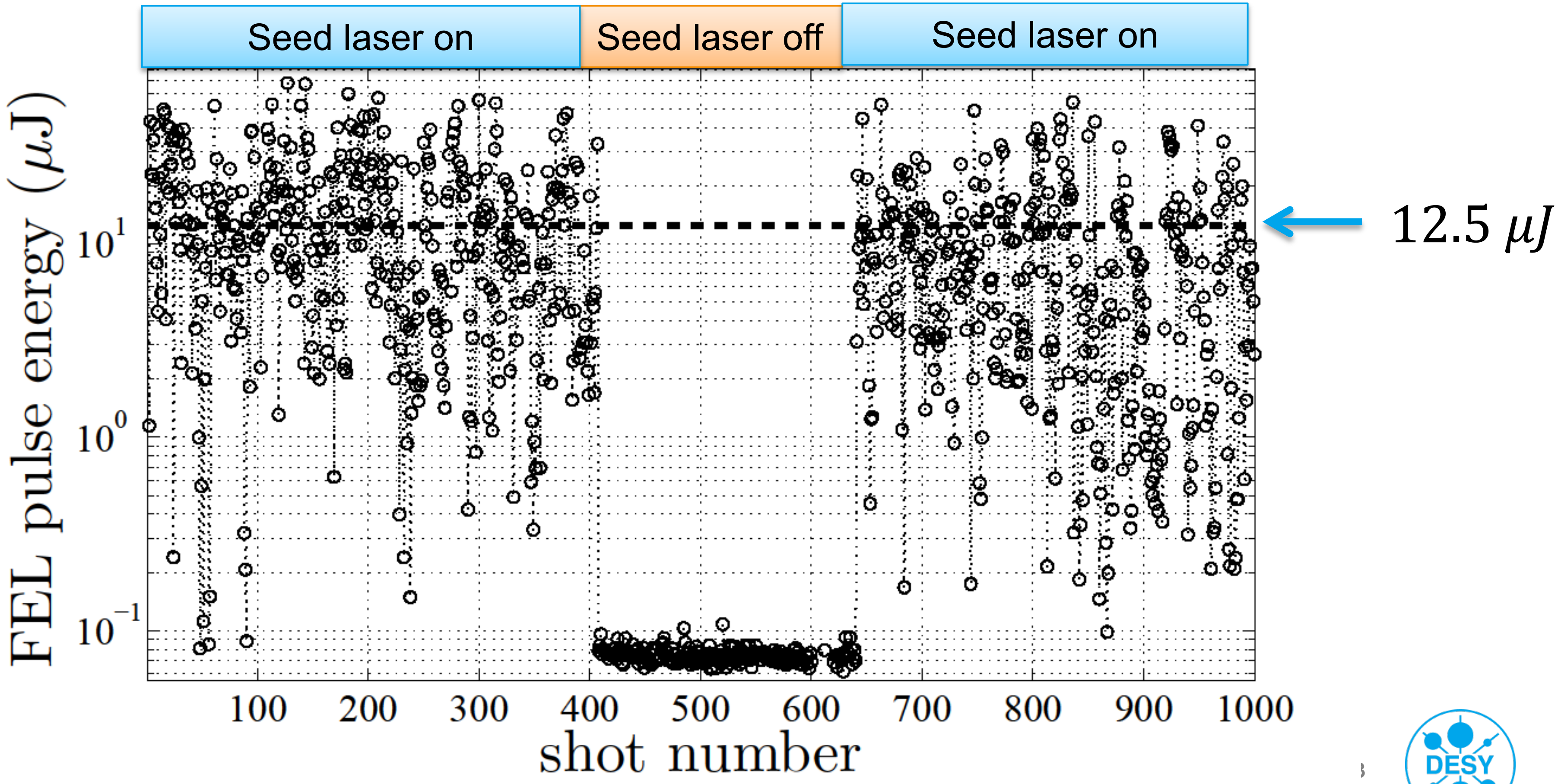
FEL gain 38nm (7th harmonic)

- FEL pulse energy

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

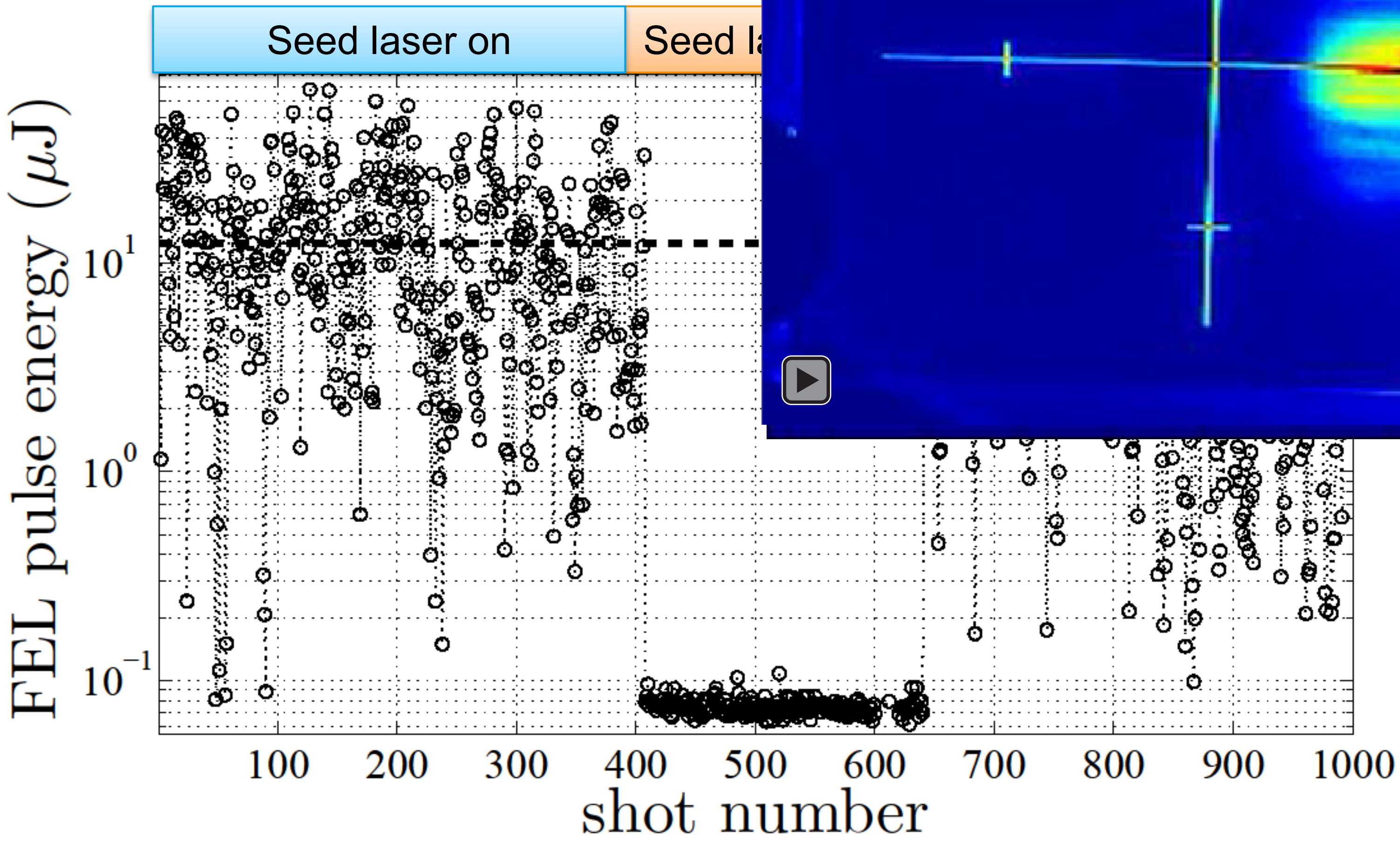
maximum pulse energy: $\mathbf{75\ \mu J}$

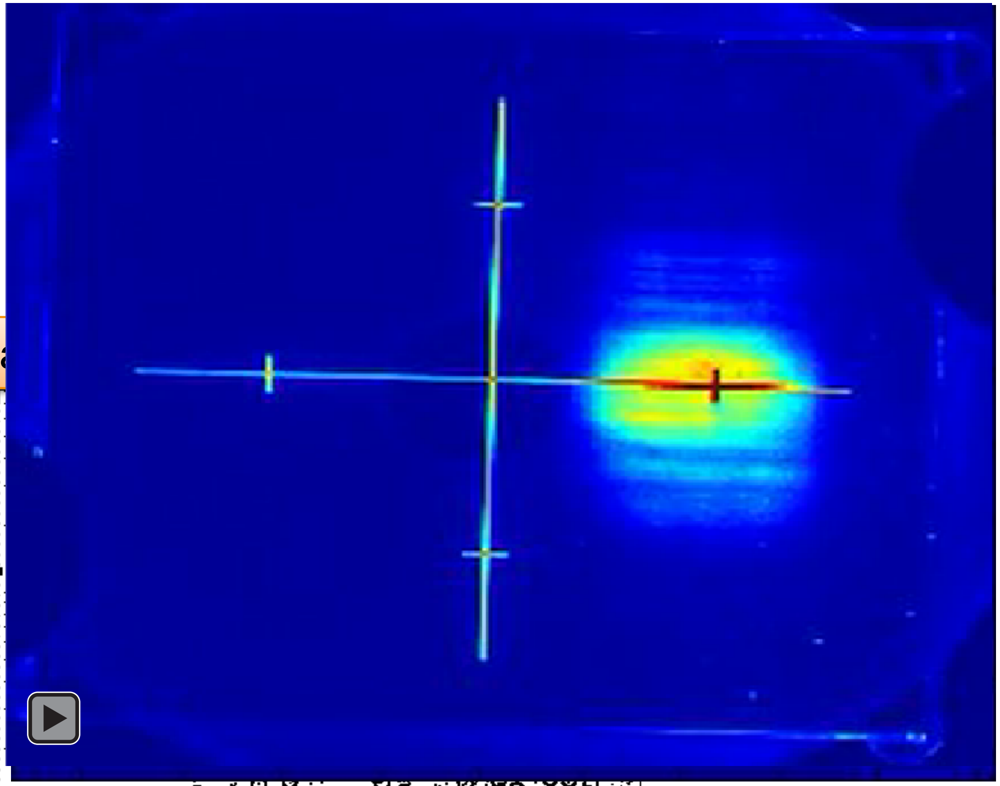
estimated gain length: $\sim 0.9\ m$



FEL gain 38nm (7th harmonic)

- FEL beam profile

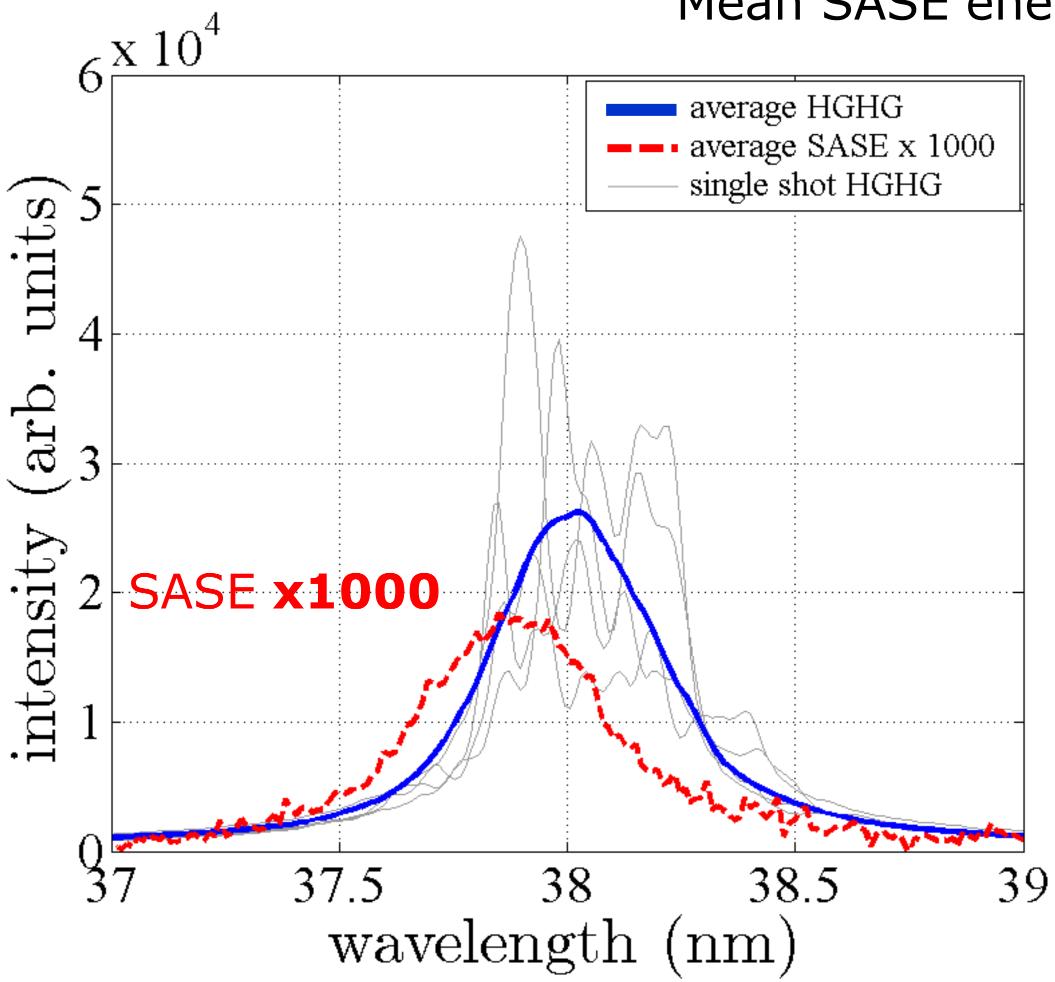




FEL gain 38nm (7th harmonic)

- Spectra of HGHG and SASE (April, 19th 2015)

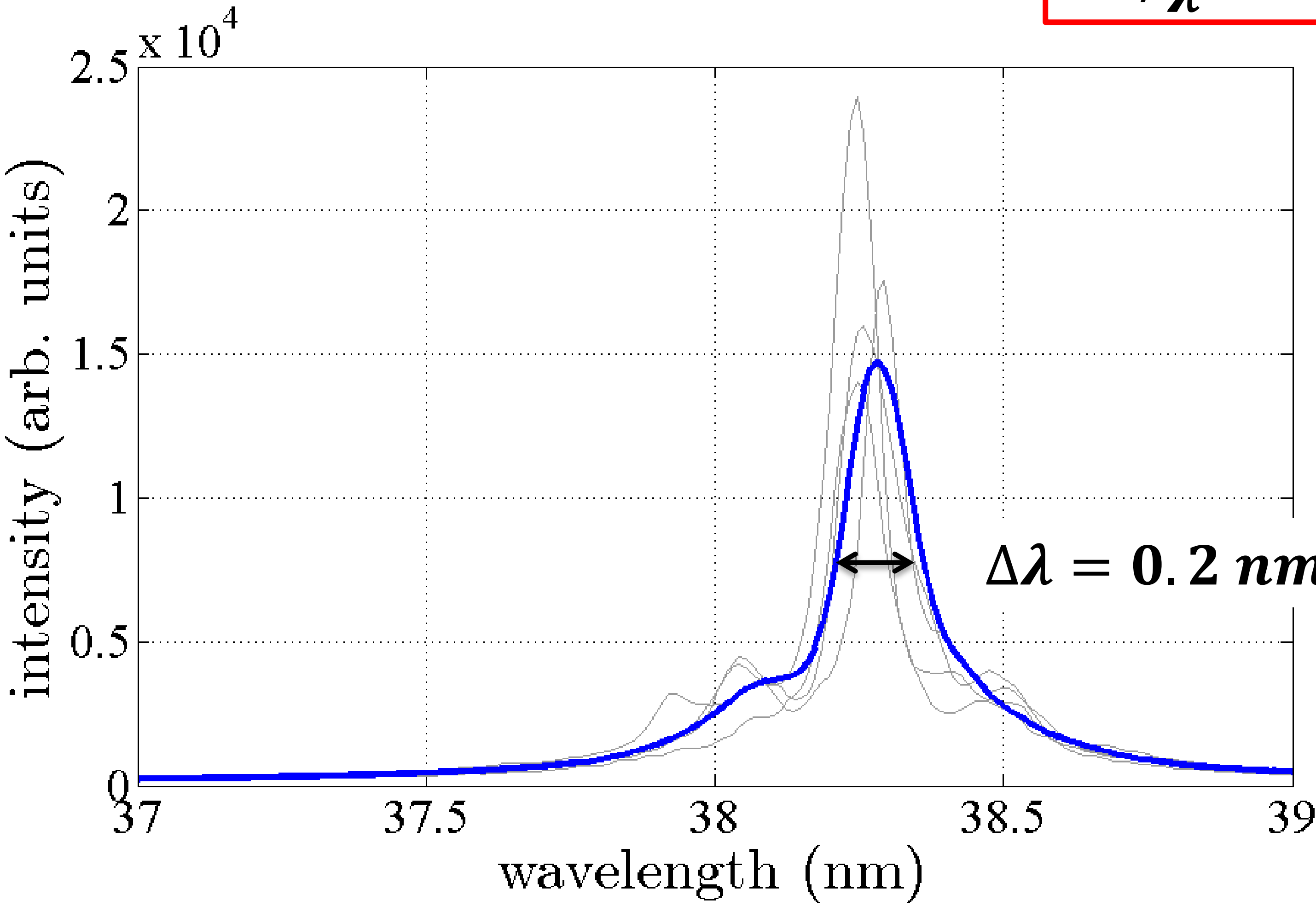
Mean SASE energy: $2.6 \pm 0.2\ nJ$



FEL gain 38nm (7th harmonic)

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

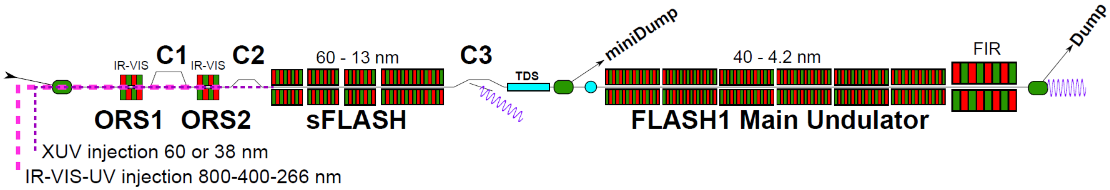
$$\Delta\lambda/_{\lambda} \sim 5.2 \cdot 10^{-3}$$



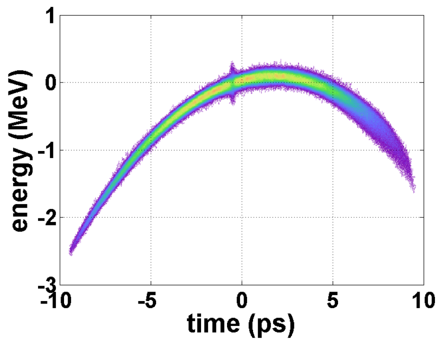
$$\Delta\lambda = 0.2\ nm$$

Summary

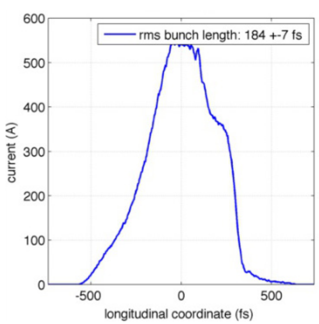
> Prepared seeding experiment at FLASH for HGHG operation

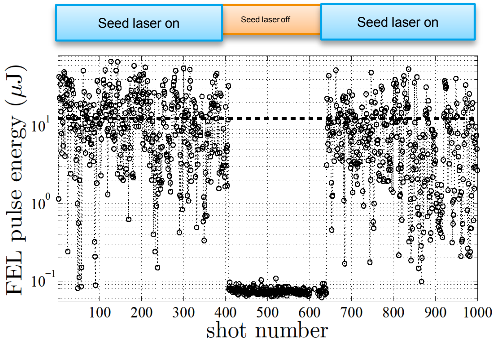


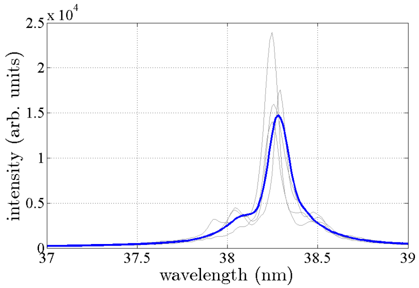
> Laser-electron overlap commissioned and characterized with TDS



> Recently first operation of HGHG with peak current of 600 A







Outlook

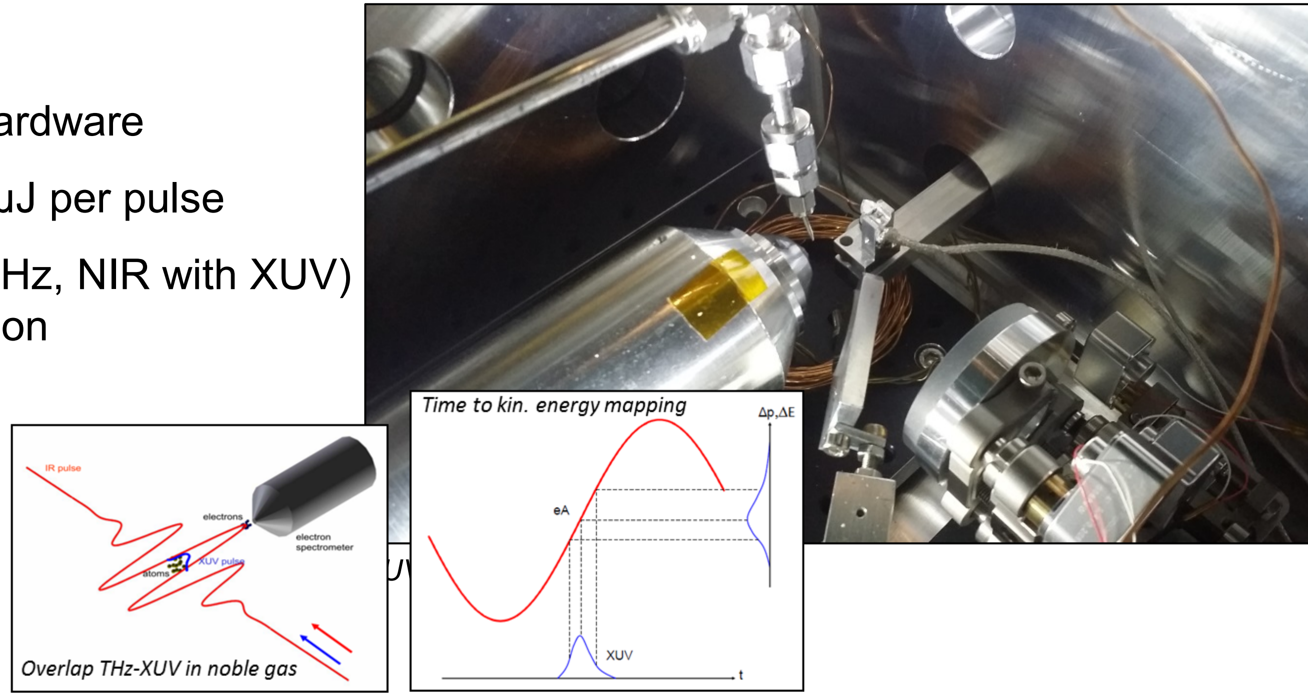
- Proceed with HGHG operation and characterization till end of 2015
  - Improve stability
  - Investigate dependence of microbunch instability
  - Investigate higher harmonics (> 7th)
  - Stronger e-bunch compression (> 1 kA)

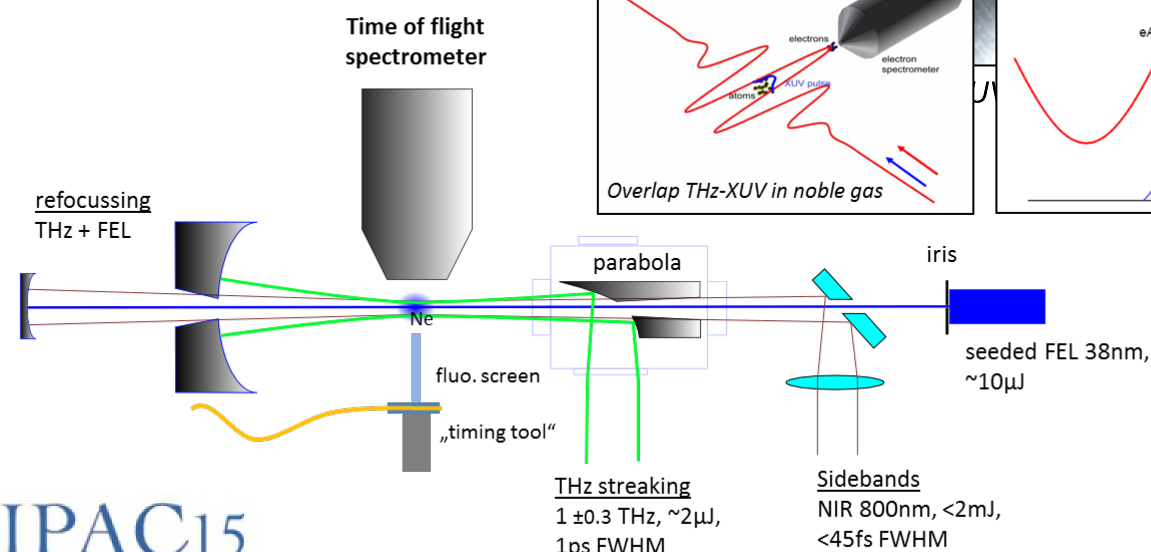
- Upgrade of seed laser system to improve stability and prepare for Echo-Enabled Harmonic Generation operation

- Temporal characterization of seeded FEL pulses

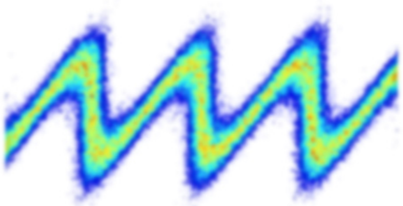
Single shot temporal diagnostic of seeded FEL pulses

- Mapping time to energy by the "THz streaking" method
- Achievements:
  - Commissioning of hardware
  - THz generation: 2.5µJ per pulse
  - Temporal overlap (THz, NIR with XUV) set with 50ps precision





> On behalf of the FLASH seeding team



Thank you for your attention

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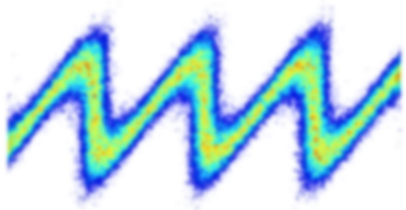
technische universität dortmund

K. Hacker
S. Khan
R. Molo

Lots of thanks to the FLASH operation team

> On behalf of the FLASH seeding team



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Posters during IPAC 2015:

T. Plath et al., “Optics Compensation for Variable-Gap Undulator Systems at FLASH”, **TUPWA038**

J. Boedewadt et al., “Simulation of optical transport beamlines for high-quality optical beams for accelerator applications”, **TUPWA026**

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