Seeding developments at FLASH

Jörn Bödewadt and Christoph Lechner on behalf of the seeding team

FLASH Seminar 18.04.2017

- *Introduction*
- *Latest results*
- *Outlook (Christoph)*

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

Bundesministerium für Bildung und Forschung

Universität Hamburg
DIE FORSCHUNG | DIE LEHRE | DIE BILDUNG

DFG Deutsche Forschungsgemeinschaft

JOACHIM HERZ STIFTUNG

technische universität dortmund

HELMHOLTZ ASSOCIATION

Accelerator Research and Development (ARD)
HELMHOLTZ GEMEINSCHAFT

DESY

Seeding Operations Team

Machine Operation

FLASH operators
Matthias Vogt
Johann Zemella

Laser Operation / Seed Source

Nils Lockmann
Bastian Manschwetus

Core Team

Velizar Miltchev
Jörn Bödewadt
Mehdi Kazemi
Christoph Lechner
Tim Plath
(on leave to TUD)
Theo Maltezopoulos (left 01/17)
Armin Azima
Leslie L. Lazzarino
Andreas Przystawik

Simulation

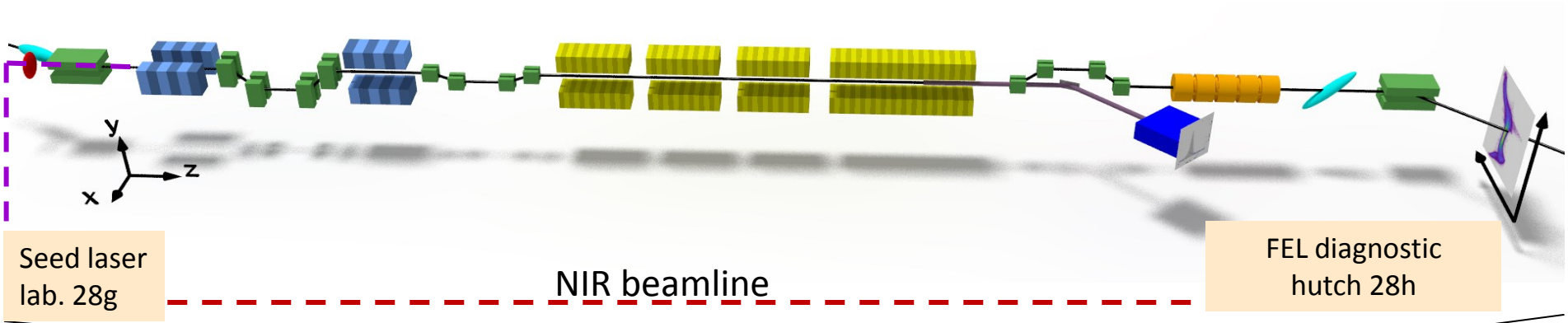
Guangyao Feng
Martin Dohlus

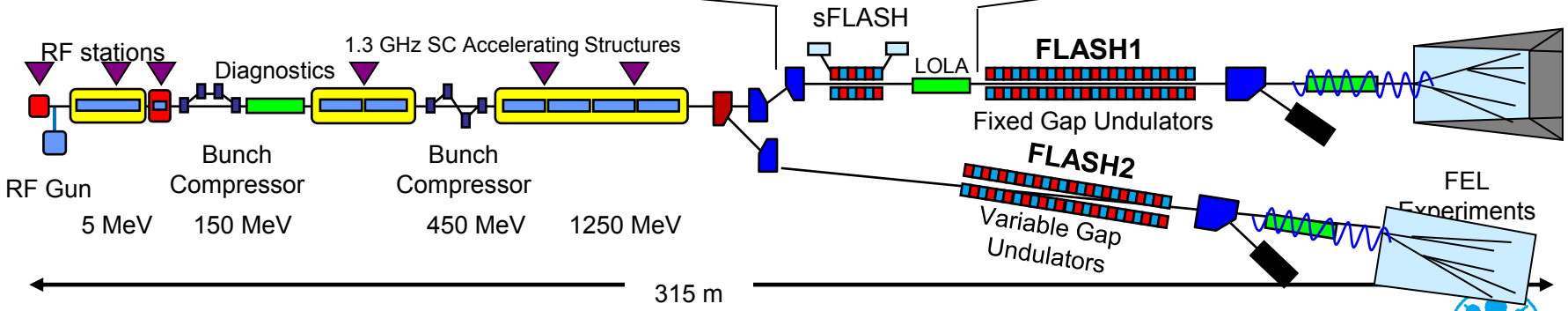
FEL characterization

Sergey Usenko

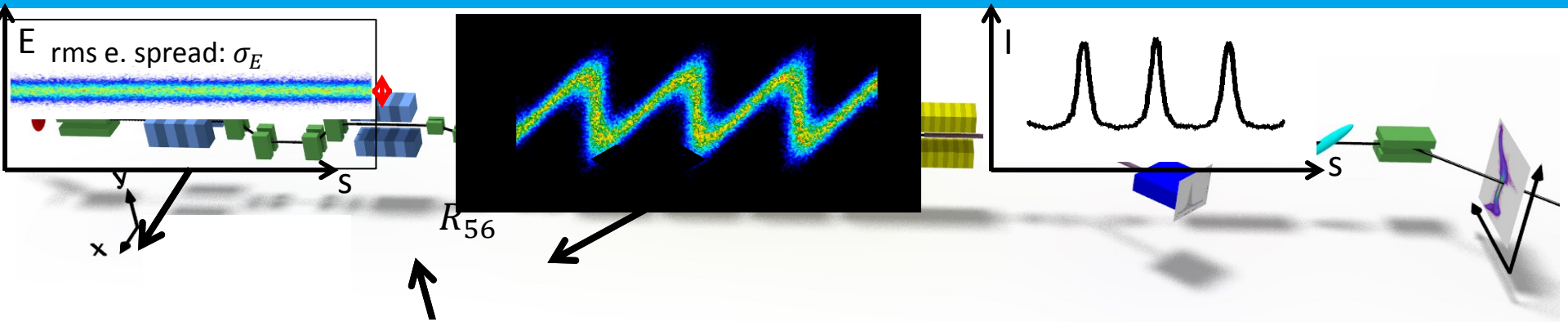
DESY
Uni HH
TU Dortmund

sFLASH layout and operation

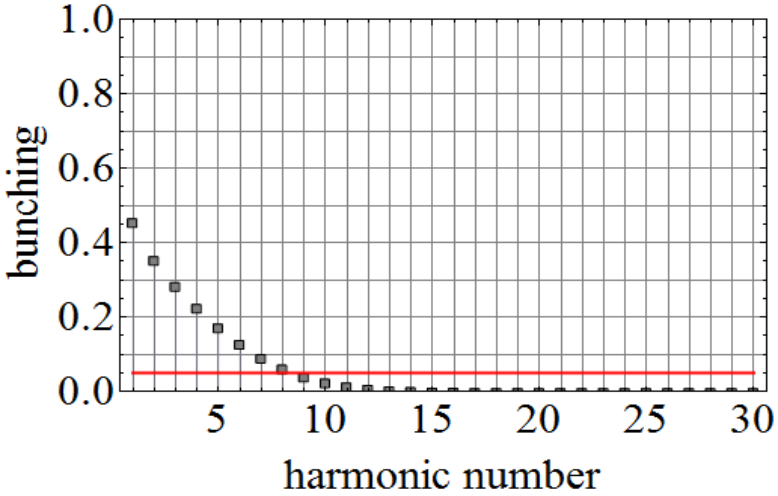




sFLASH layout and operation



$\{\sigma_E$: 70 keV, ΔE: 350 keV R_{56}:, 90 μm$\}$



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

amp. ΔE

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

hing factors:

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

hys.Rev. A 44, 5178 (2001)

Coherent Harmonic Generation & High-Gain Harmonic Generation

CHG (quadratic)

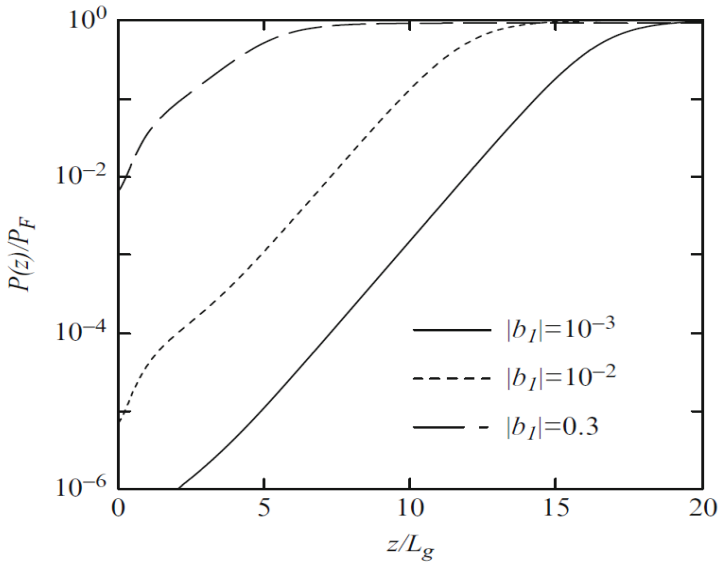
$$P_{\mathrm{coh}}(z) = \frac{1}{3}\rho_{\mathrm{fel}}|b_1|^2 P_{\mathrm{beam}}\left(\frac{z}{L_g}\right)^2$$

$$P_{\mathrm{th}} = \rho_{\mathrm{fel}}|b_1|^2 P_{\mathrm{beam}}$$

$$P_{\mathrm{beam}} = m_0 c^2 \gamma\, I_{\mathrm{peak}}/e_0$$

HGHG (exponential)

$$P_{\mathrm{exp}}(z) = \frac{P_0}{9}\exp\left(\tau/\tilde{L}_g\right)$$

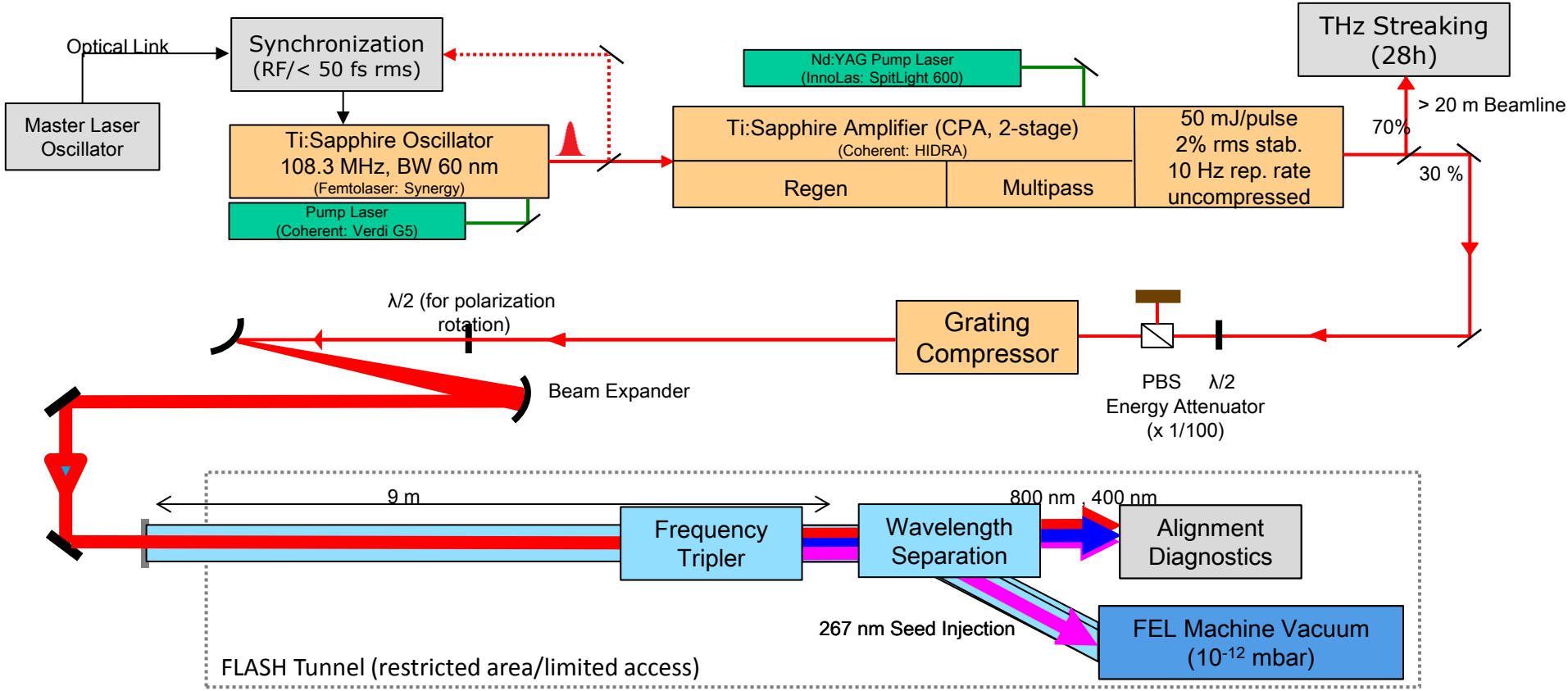


Eberhard J. Jaeschke et al.
Synchrotron Light Sources and Free-Electron Lasers, Springer International Publishing, 2016.

Improvement of UV seed beam quality (November 2016)

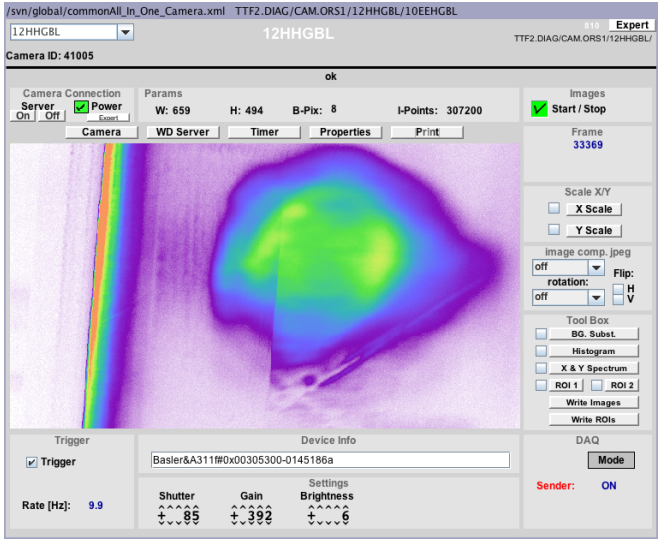
and characterization of the laser-induced energy modulation

FLASH1 Seed Laser System, UV Generation, & Transport (2016)

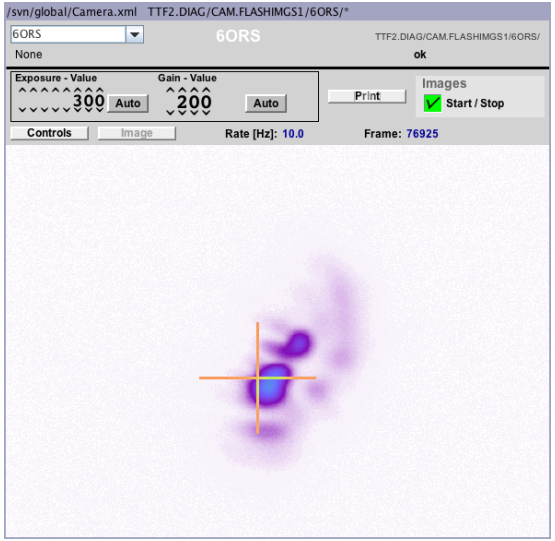


High Vacuum (10^{-6} mbar)

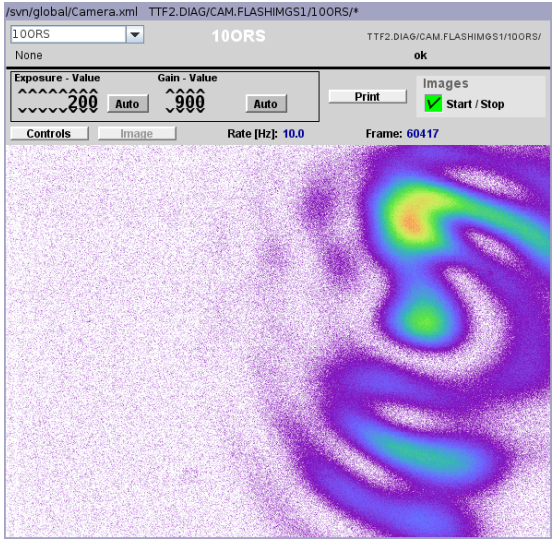
UV beam (before changing tripler)



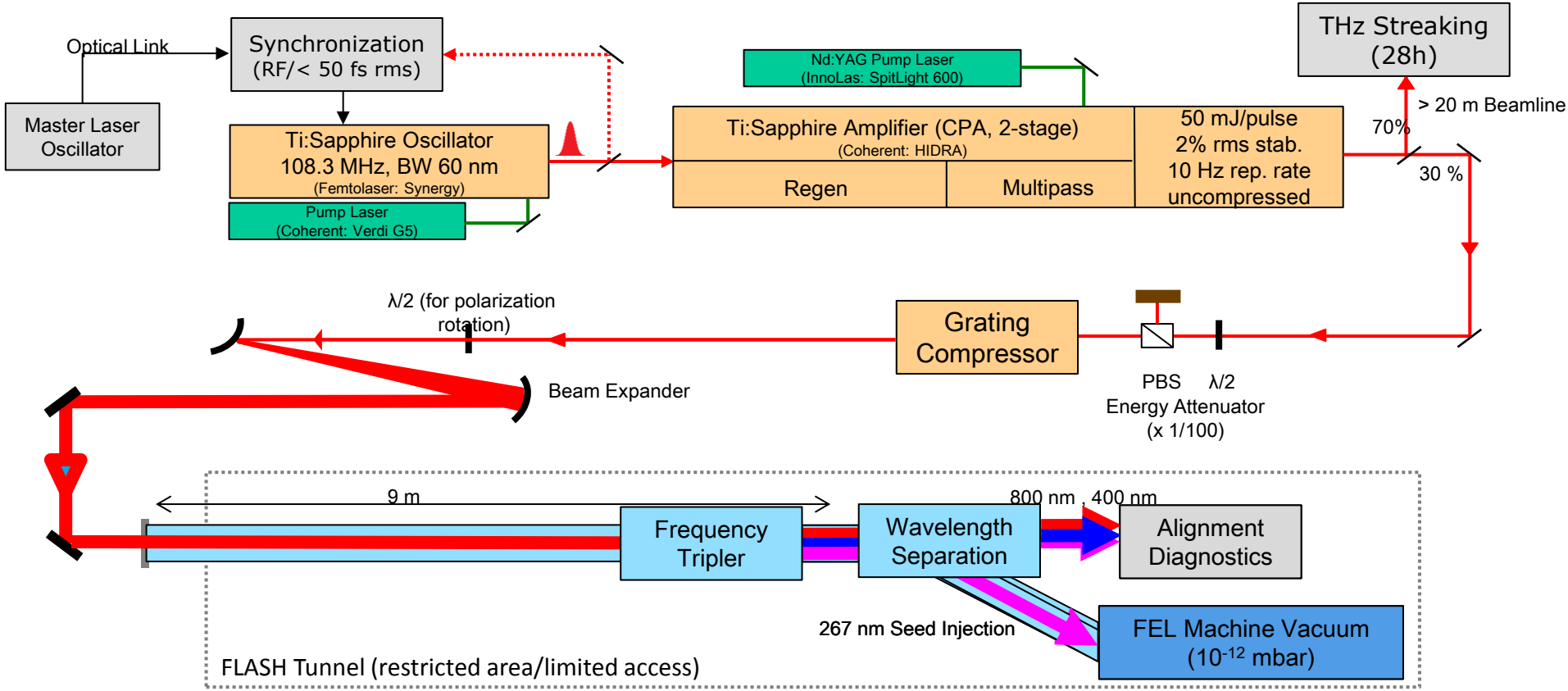
before
modulator undulator



after
modulator undulator

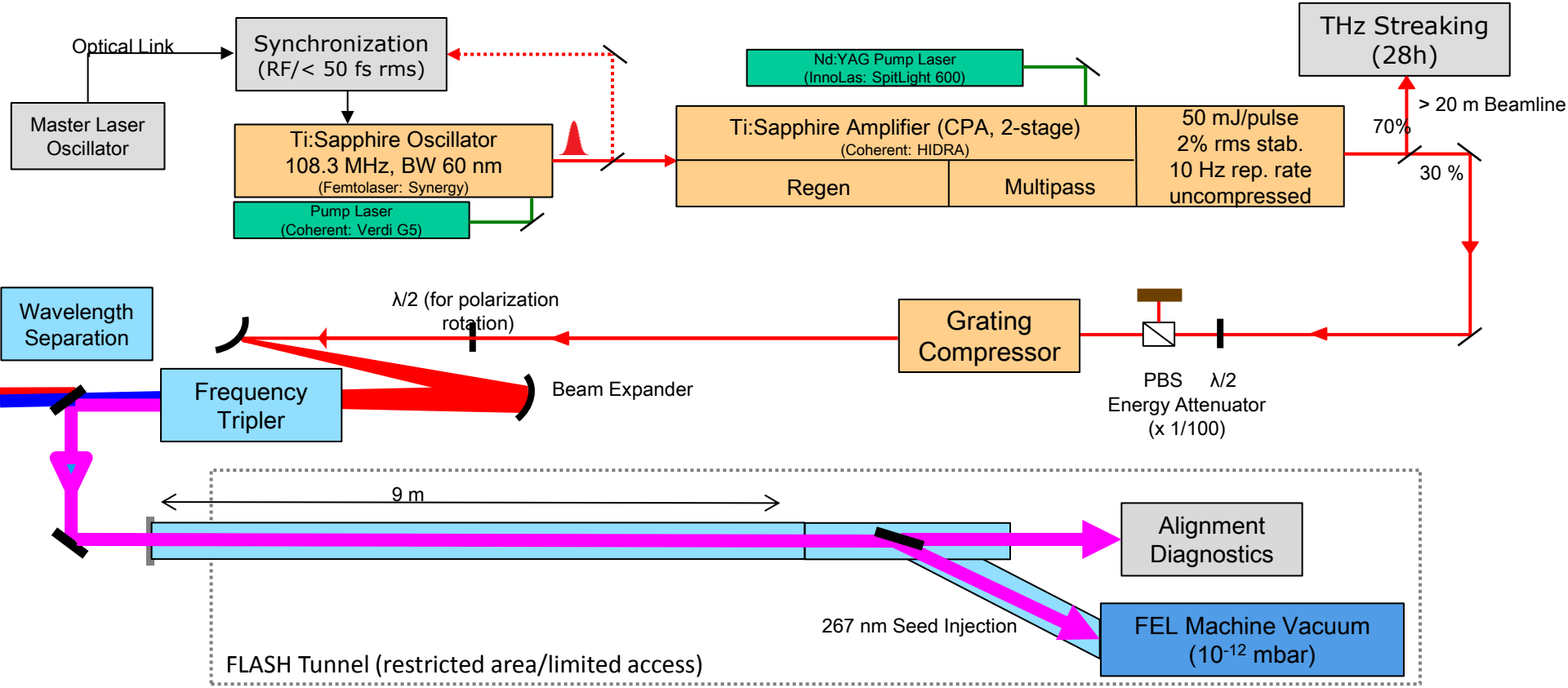


FLASH1 Seed Laser System, UV Generation, & Transport (2016)



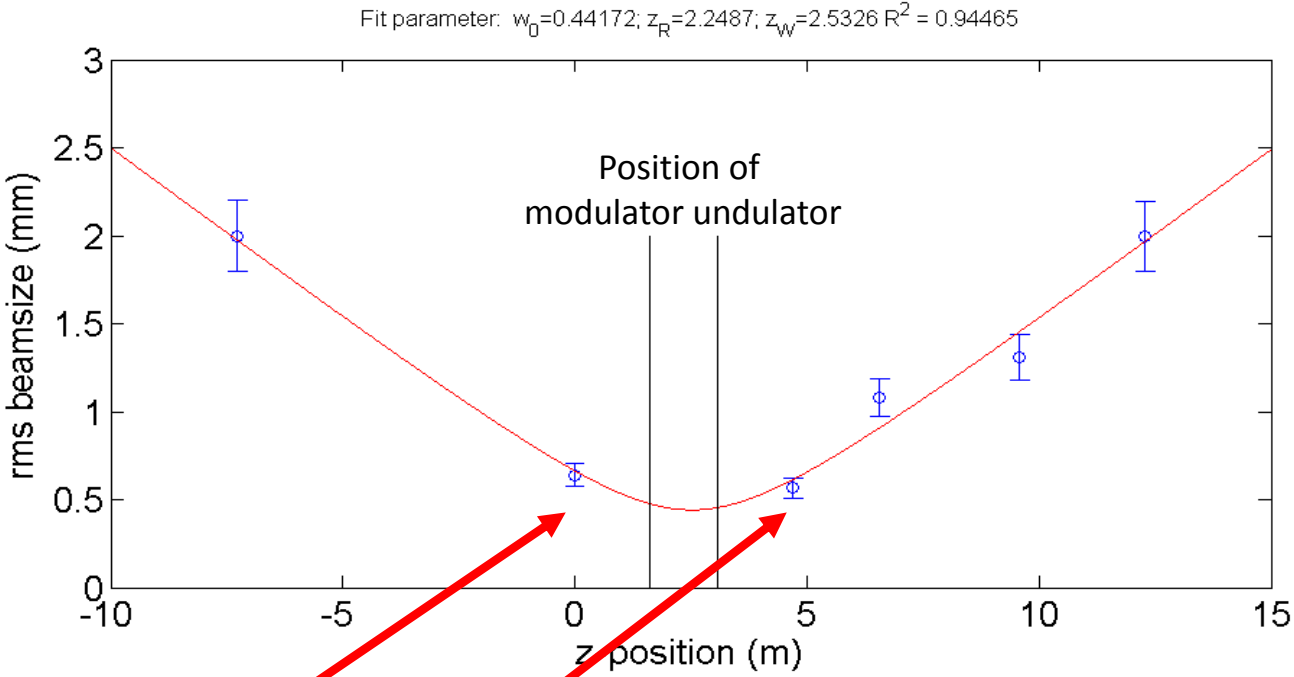
High Vacuum (10^{-6} mbar)

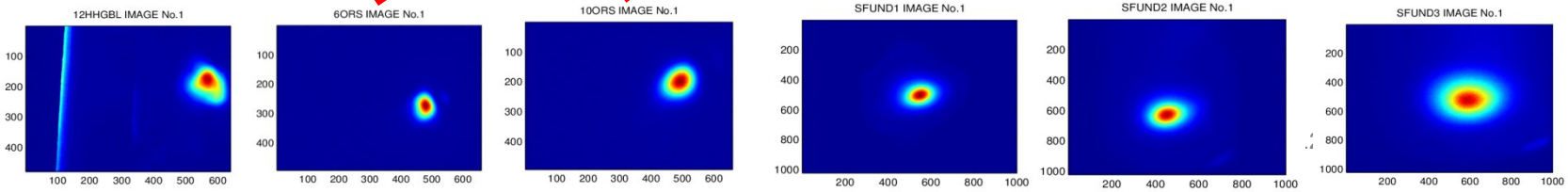
FLASH1 Seed Laser System, UV Generation, & Transport (2017)



High Vacuum (10^{-6} mbar)

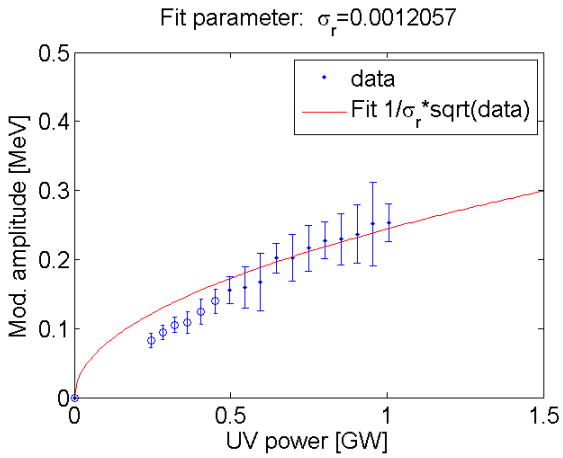
UV beam (after changing tripler)

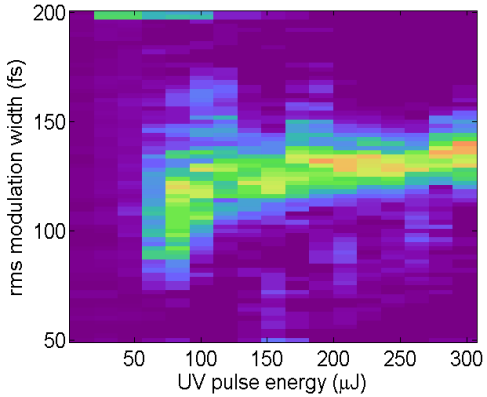


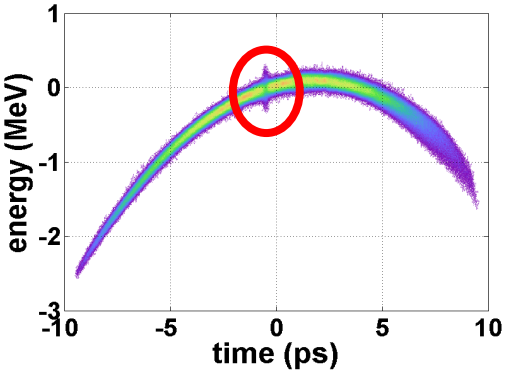


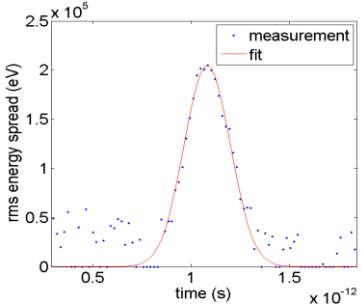
Characterization of laser-induced energy modulation ΔE

- Use TDS to measure the induced energy modulation









Modulation amplitude (simplified model):

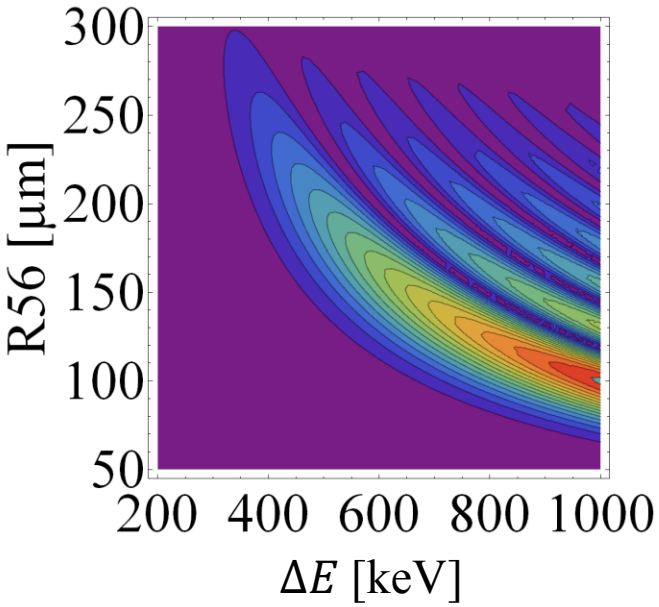
$$\Delta E = \sqrt{\frac{P_L[GW]}{8.7\ GW}} \cdot \frac{K_p L_u}{\gamma_0 \sigma_r} \cdot \frac{m_0}{c^2} \left(J_0\left(\frac{K_p^2}{4+2K_p}\right) - J_1\left(\frac{K_p^2}{4+2K_p}\right) \right)$$

CHG Studies

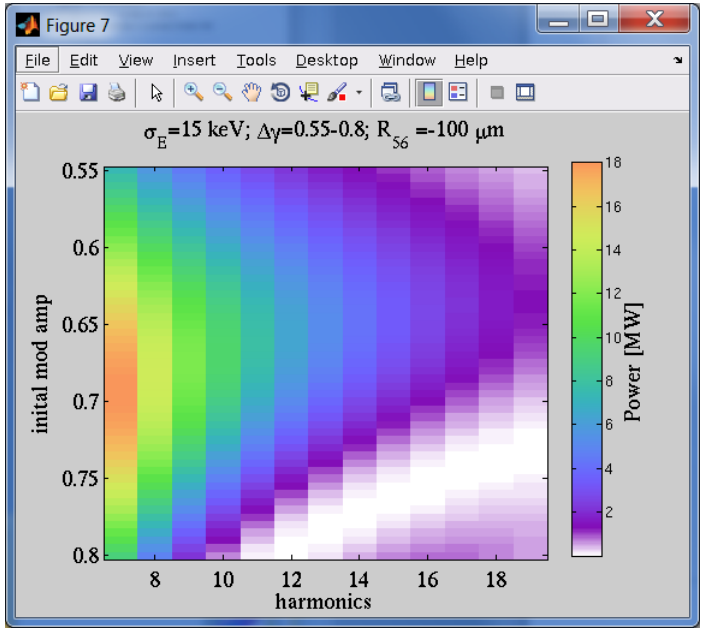
CHG experiments

- Idea: use CHG to retrieve the electron beam's energy spread

1st possibility:

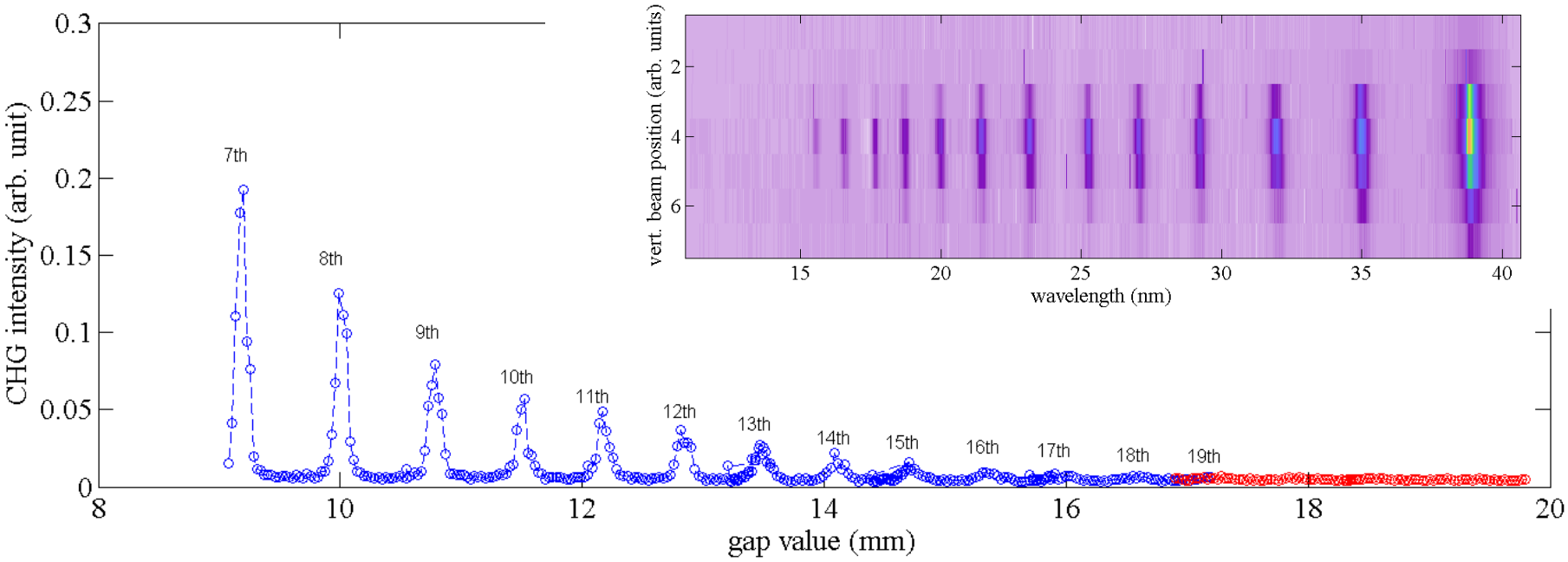


2nd possibility:



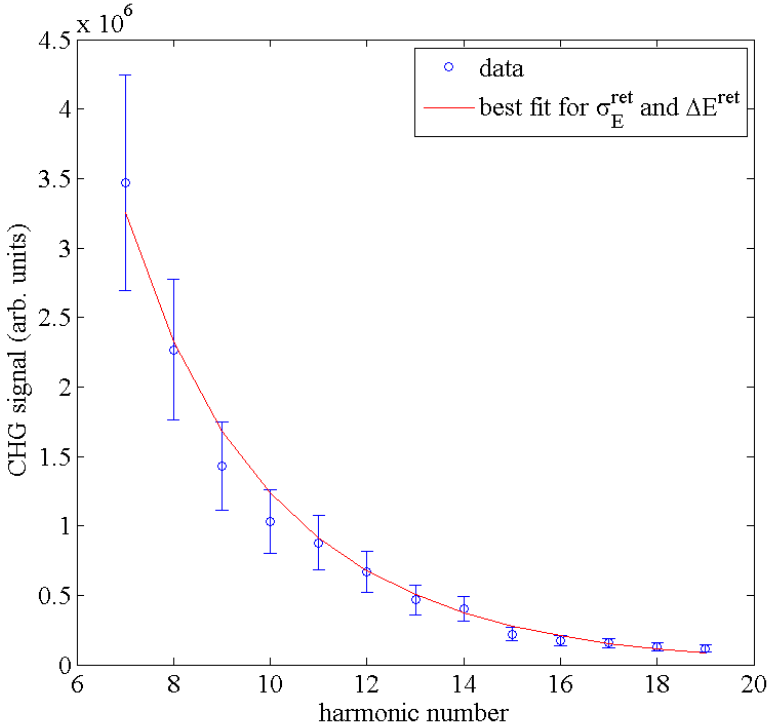
CHG experiments

> January 2017: Scan of undulator gap of first radiator module



CHG experiments

- Simulate CHG output power for varying initial energy spread and modulation amplitude and fit the results to the measurements



$$\sigma_E^{ret} = 9\,keV$$

$$\Delta E^{ret} = 250\,keV$$

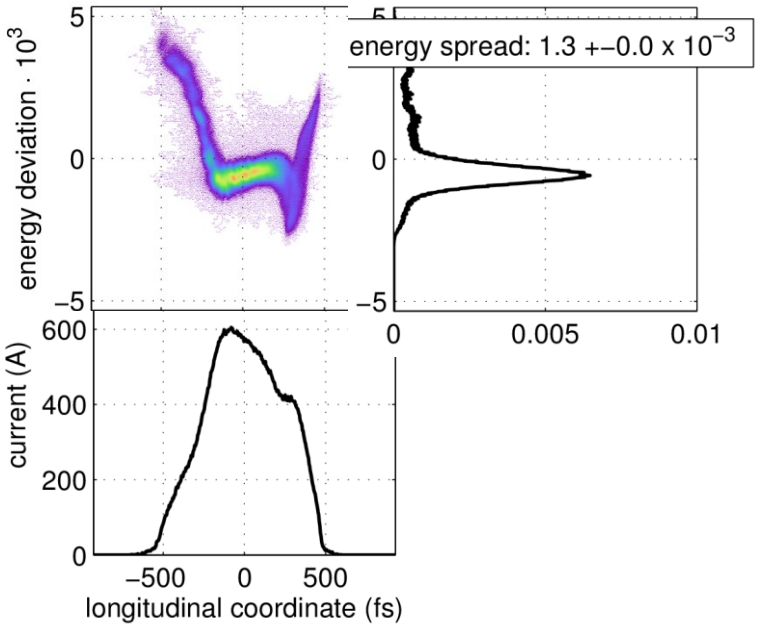
HGHG operation

HGHG operation

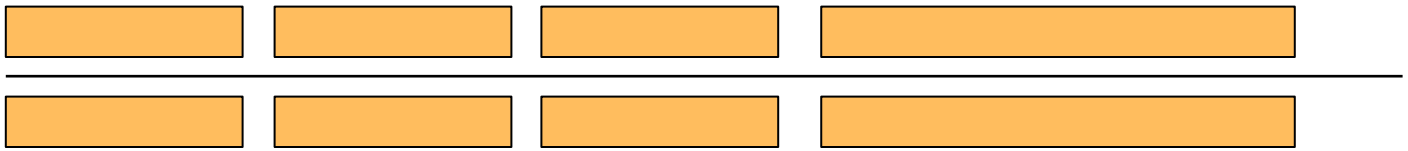
- Machine parameters:

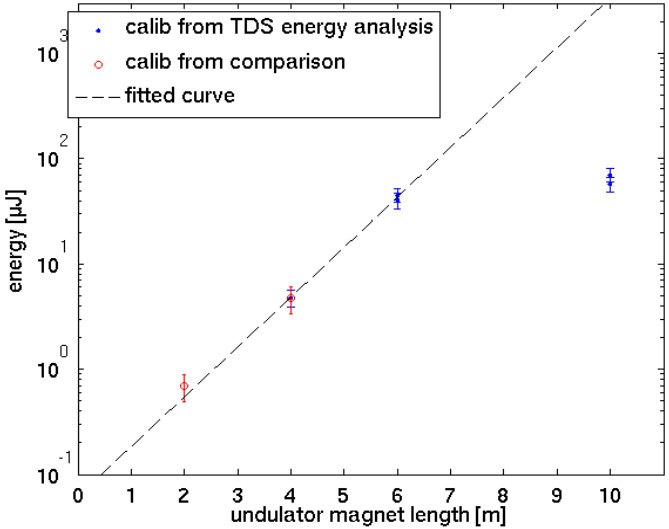
$$E \approx 680\,\mathrm{MeV} \qquad Q = 0.4\,\mathrm{nC}$$
$$\sigma_E \approx 70\,\mathrm{keV} \qquad \epsilon_n \approx 1\,\mathrm{mm\ mrad}$$

$$\Delta E : 250 - 350\,\mathrm{keV}$$
$$R_{56} : 50 - 100\,\mu\mathrm{m}$$



Gain Curve (maximum bunching)



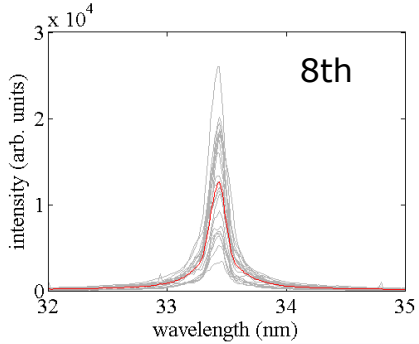


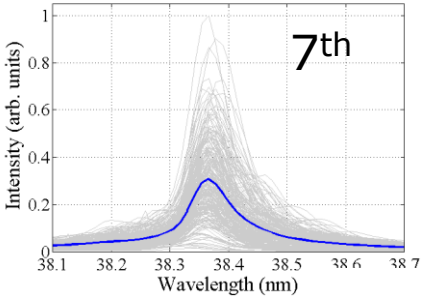
Only taken best 50% of the shots.

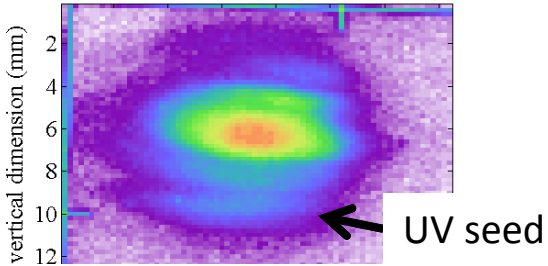
$$L_{g,fit} = (0.916 \pm 0.054)\, m$$

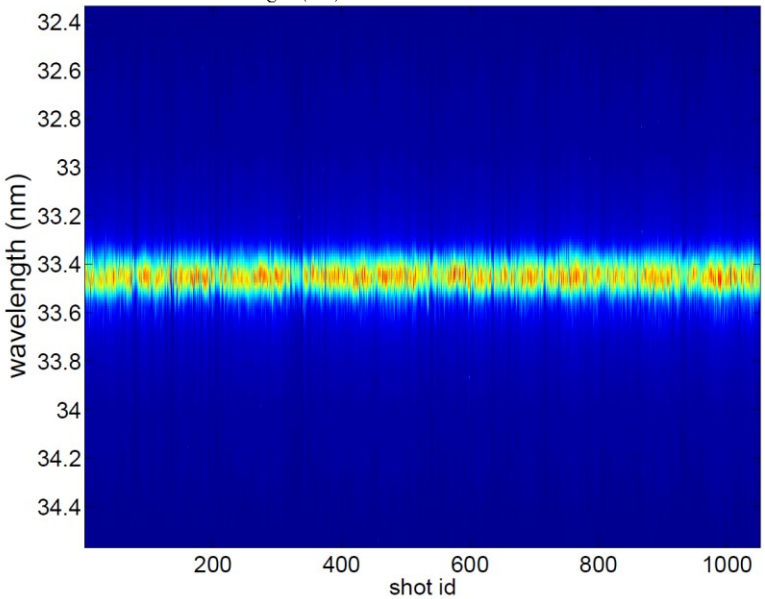
$$\rho = (1.56 \pm 0.09) \cdot 10^{-3}$$

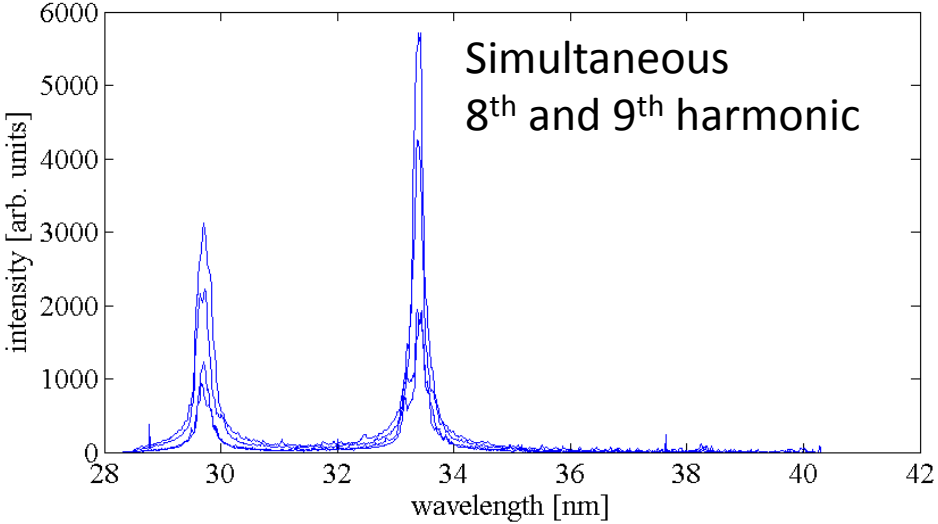
HGHG operation





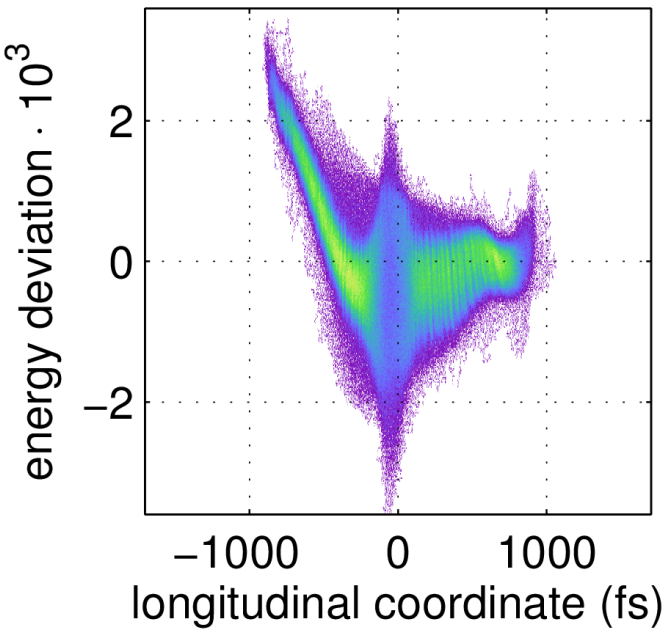


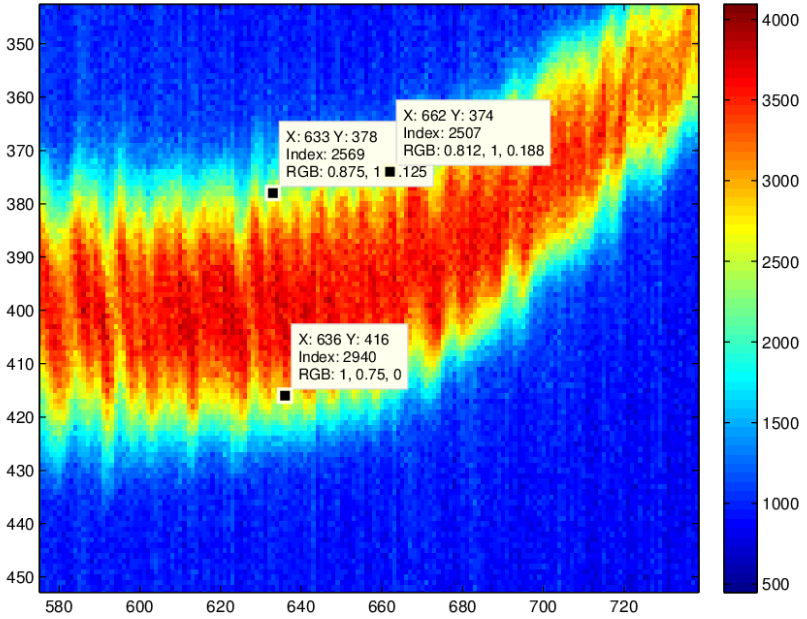




Microbunch instability

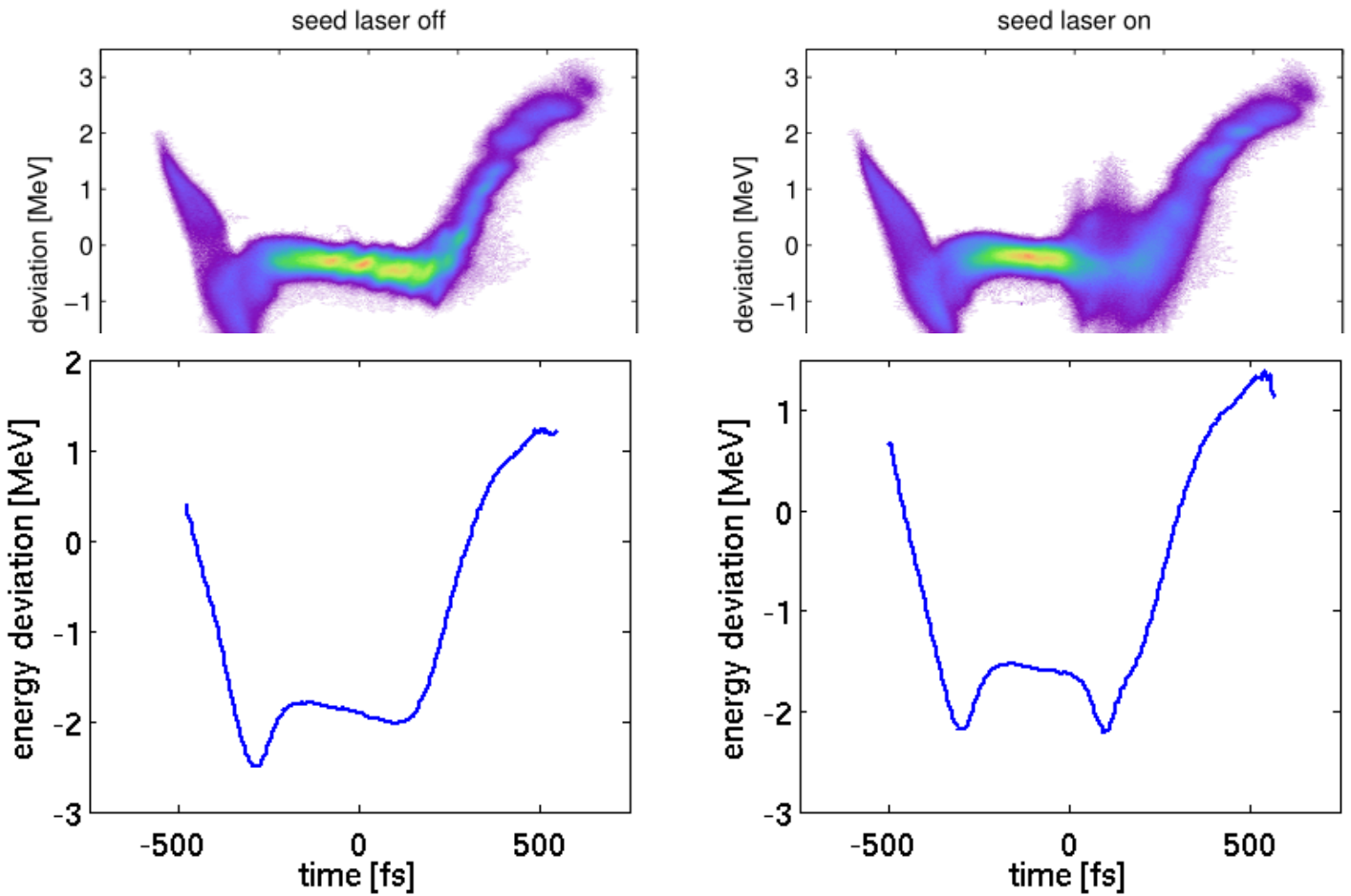
- Very poor and instable HGHG operation (< 1µJ)





Temporal diagnostics

Transverse Deflecting Structure

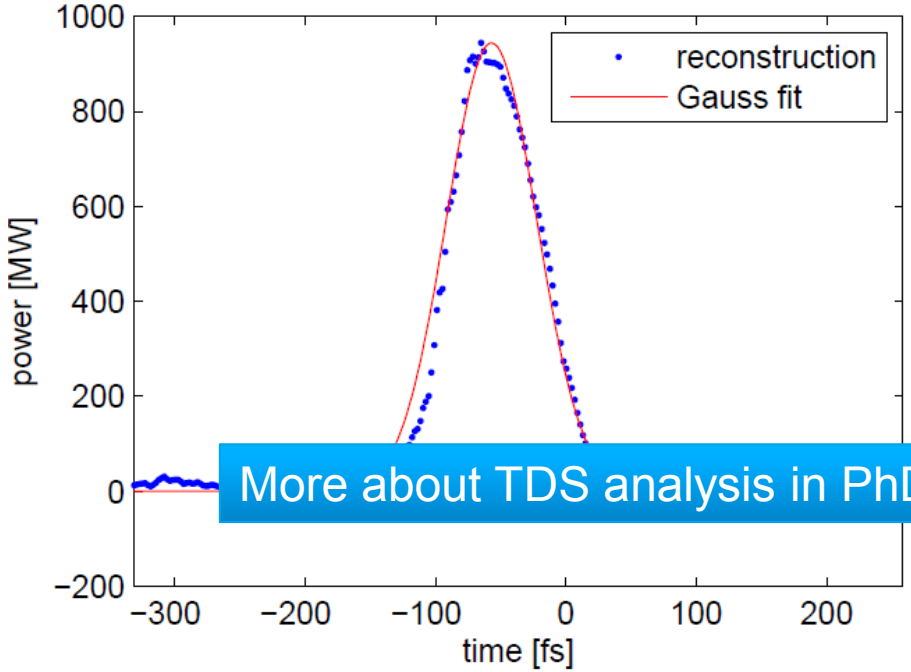


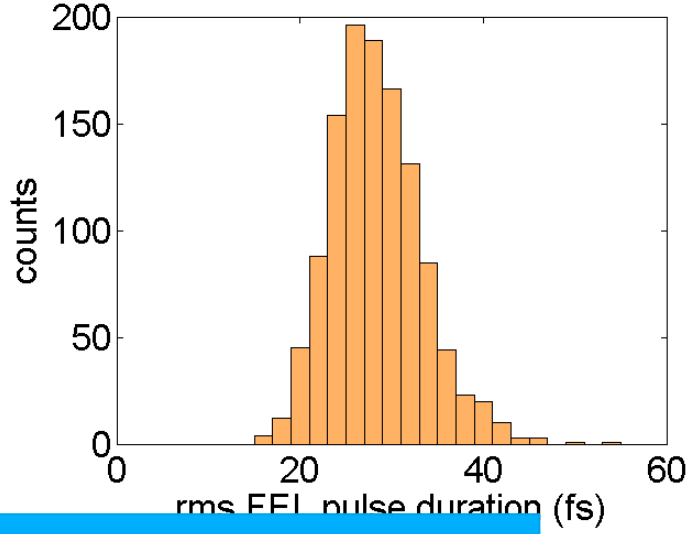
C

ile:

Transverse Deflecting Structure

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





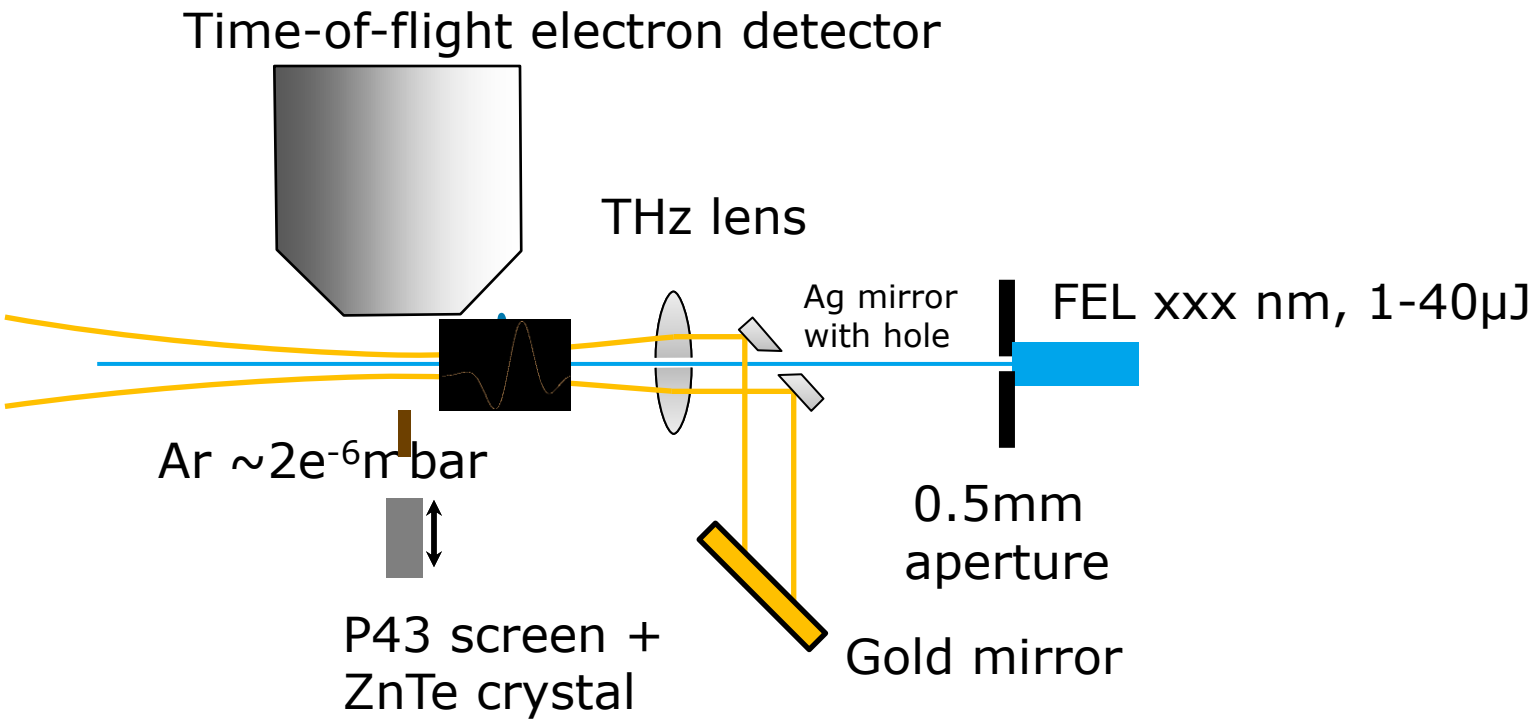
More about TDS analysis in PhD defense by Tim Plath

$$\langle \tau_{\mathrm{FEL}} \rangle = 28.4 \pm 5.6\,\mathrm{fs}$$

T. Plath et al. accepted at Scientific Reports

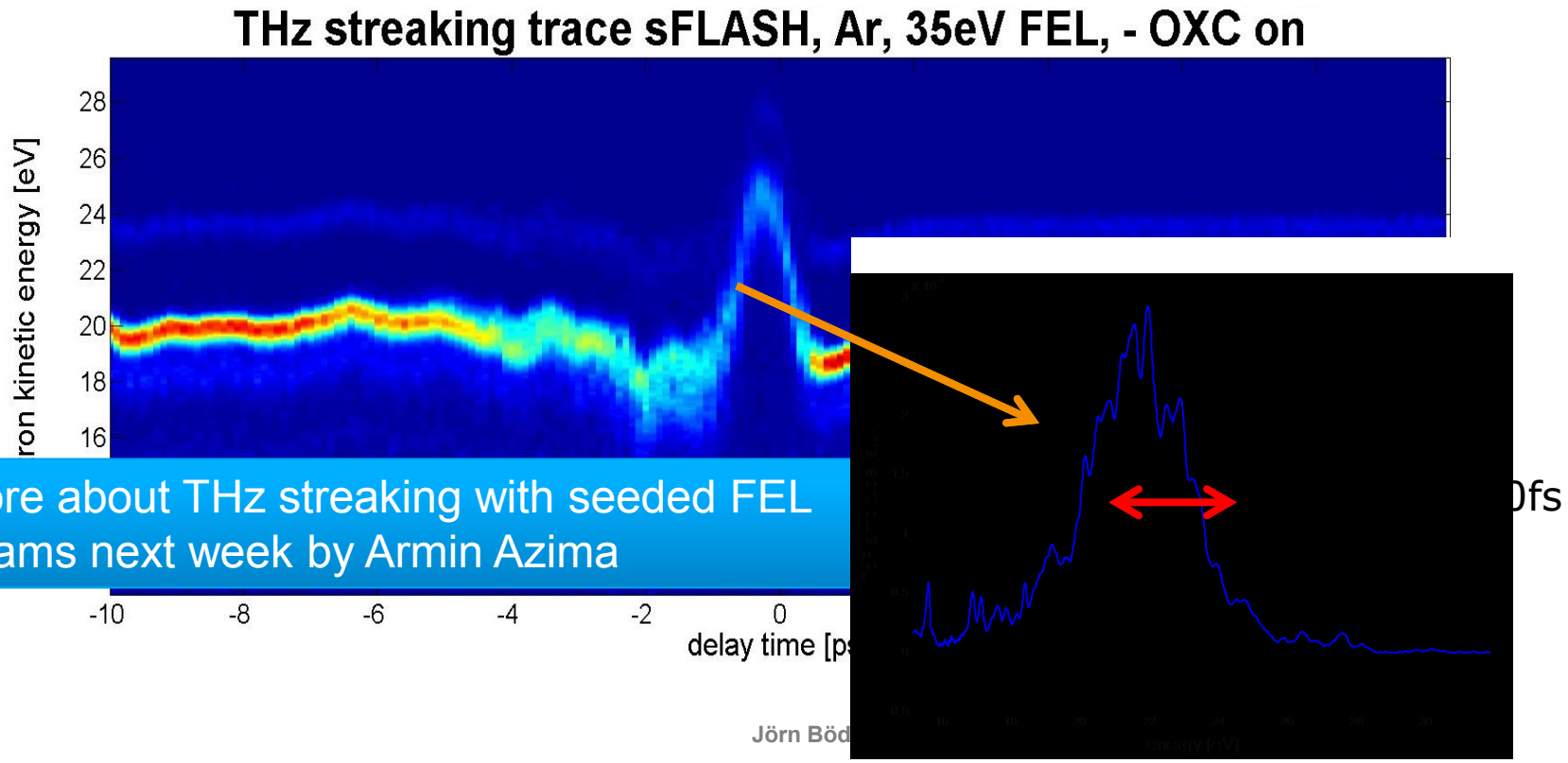
From this calculate: Pulse duration, peak power and energy.

THz streaking



THz Streaking

sFLASH SASE operation



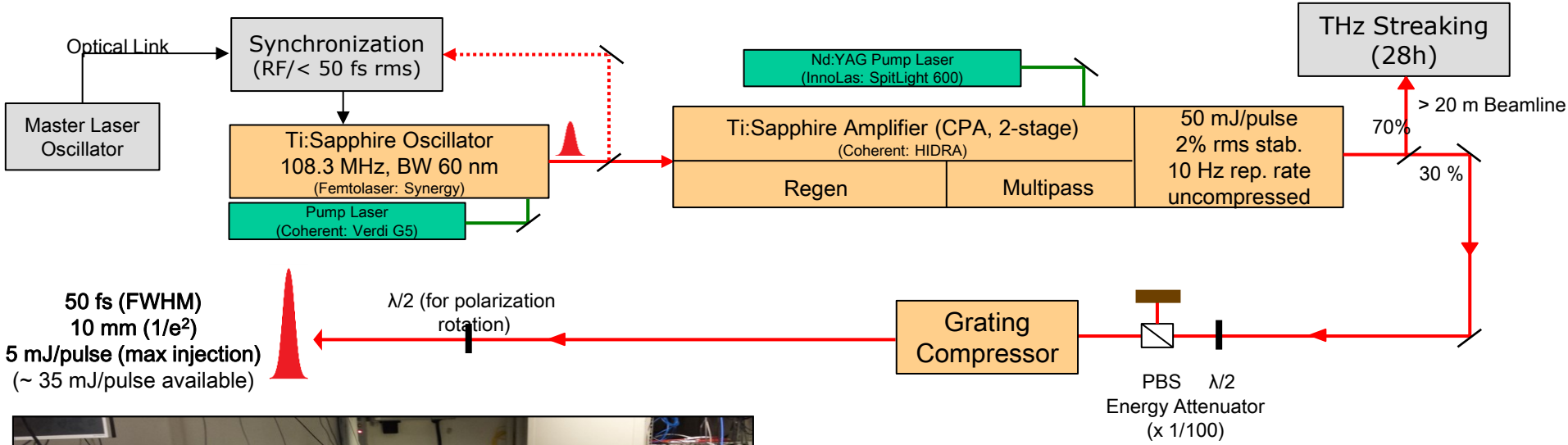
More about THz streaking with seeded FEL beams next week by Armin Azima

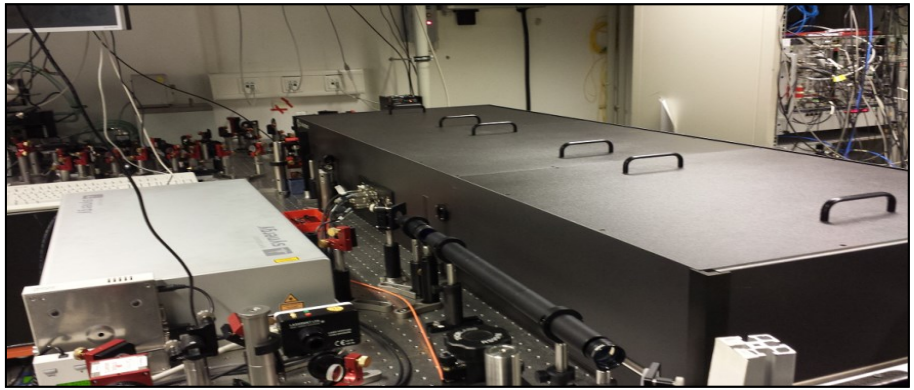
Outlook: next steps towards EEHG operation (Christoph)

> On behalf of the seeding team

Thank you for your attention

FLASH1 Seed Laser System





- Purchased by Uni. of Hamburg
- Now a shared property of DESY + Uni. of Hamburg
- Used for HHG seeding experiment
- Serves as HGHG seed laser