XUV Seeding at sFLASH

Christoph Lechner for the sFLASH team

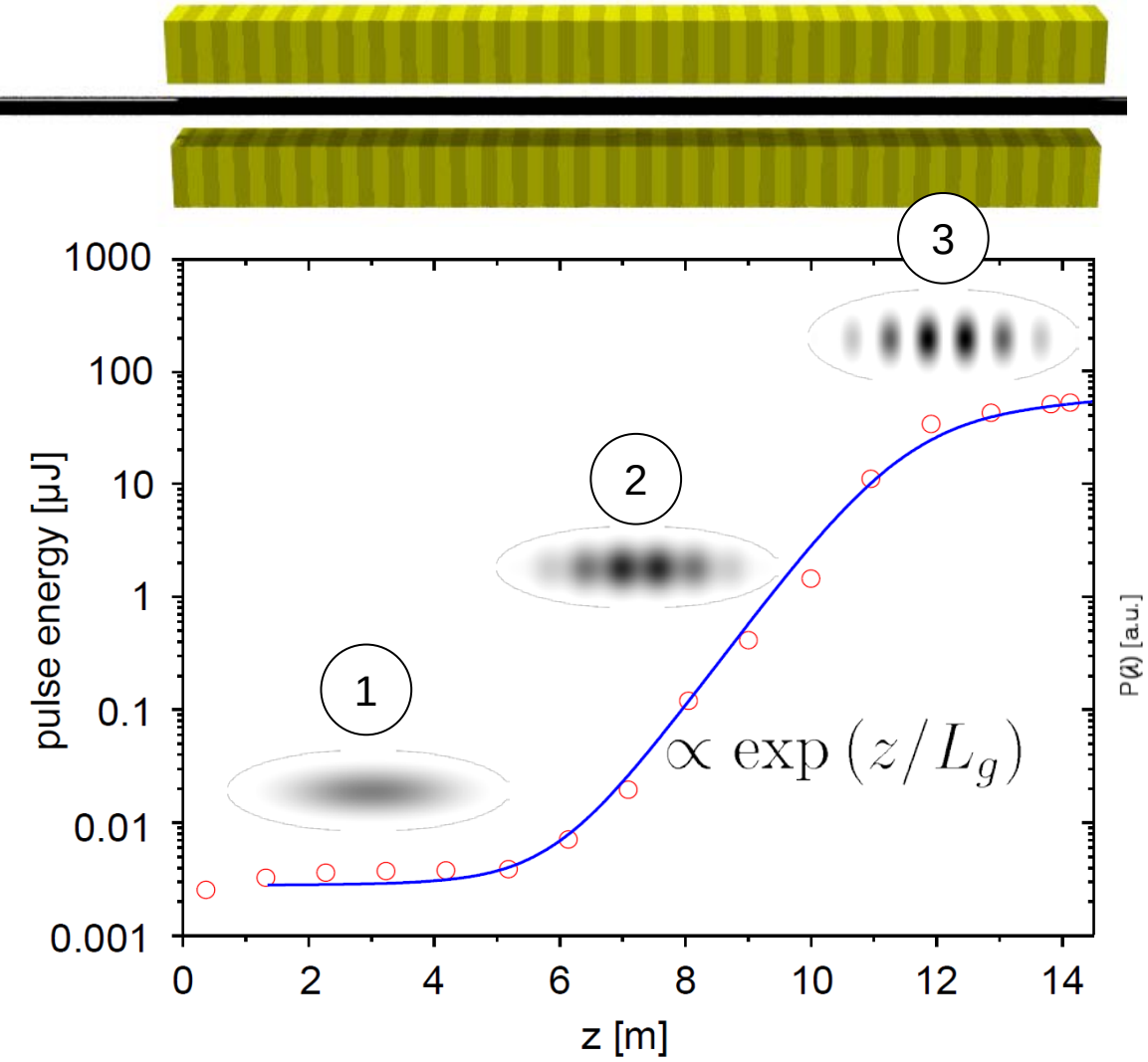
Hamburg Alliance New Beams and Accelerators, 07 September 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Introduction: Free-Electron Laser (FEL) & Seeding

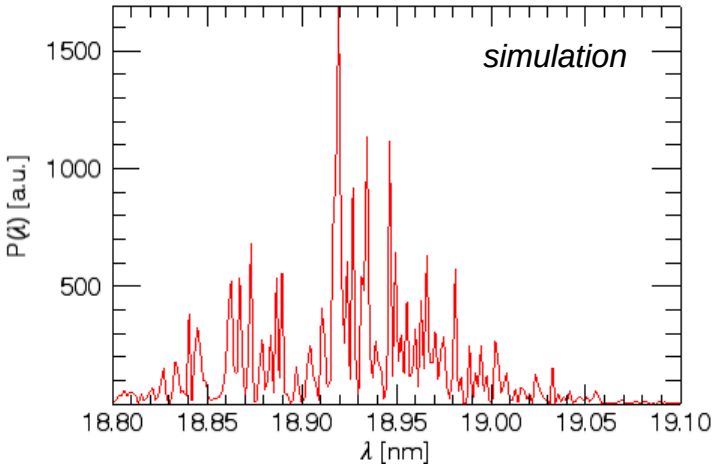
Controlling and manipulating the FEL light pulses



=> **ultra-short** photon pulses with **GW**-peak power

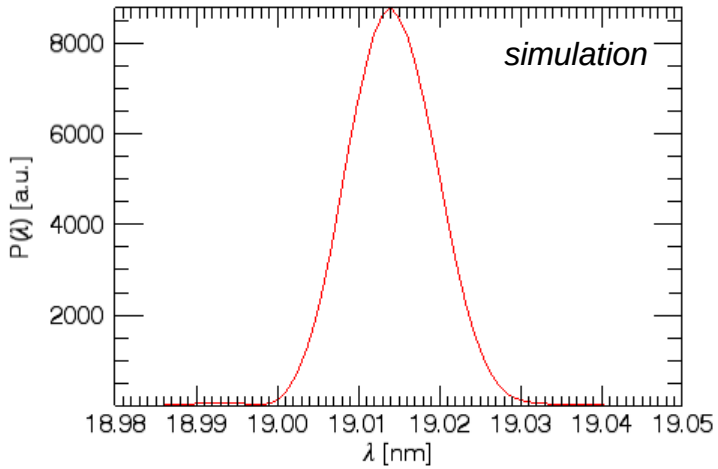
SASE operation

- Stochastic start-up
- Noisy spectrum



Seeded operation

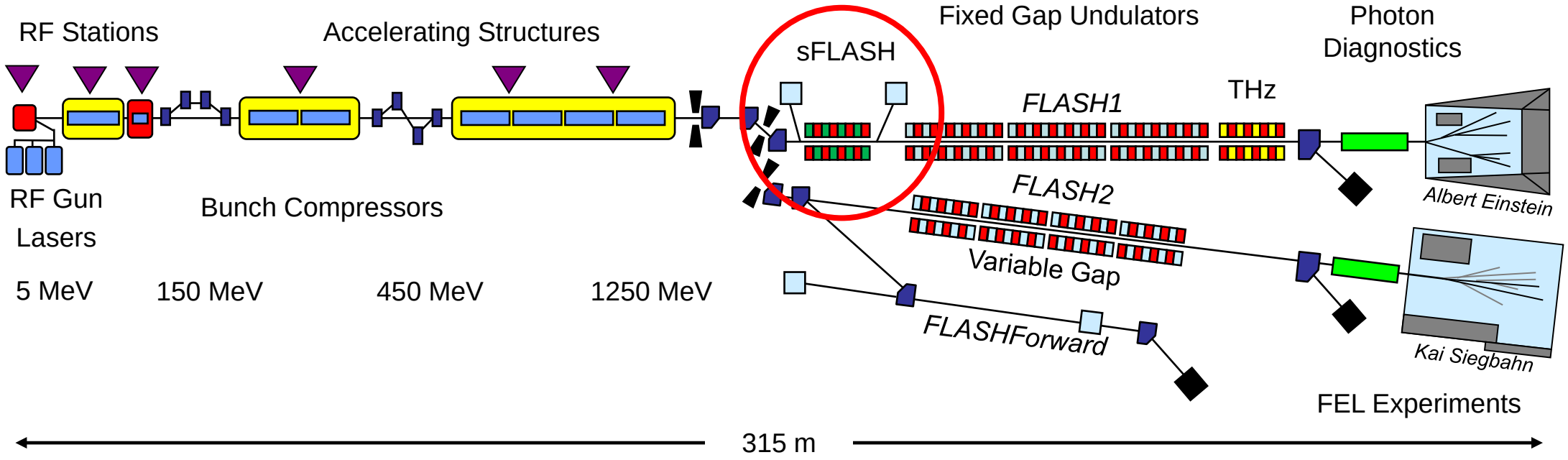
- **FEL controlled by external, coherent light pulse** → from laser

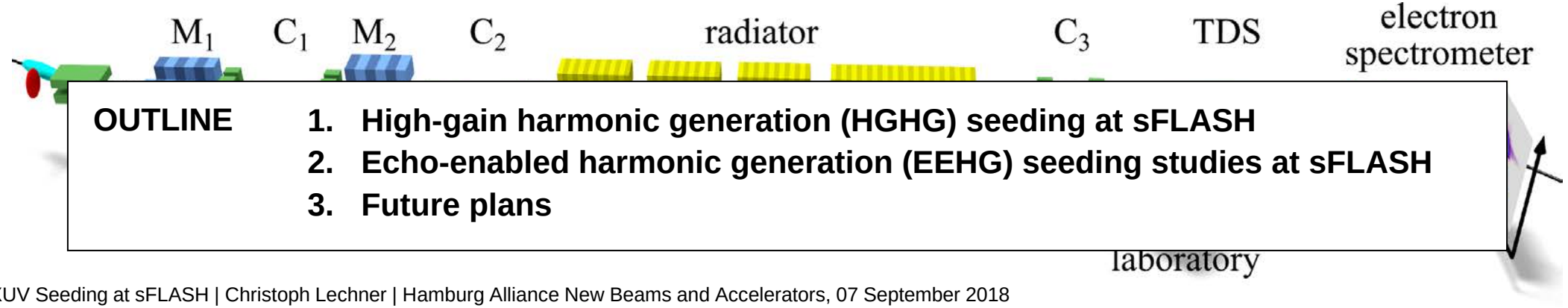


Seeding transforms the FEL into a fully coherent light source

sFLASH – The Seeding Test Facility at FLASH

sFLASH as R&D experiment integrated into the FLASH user facility

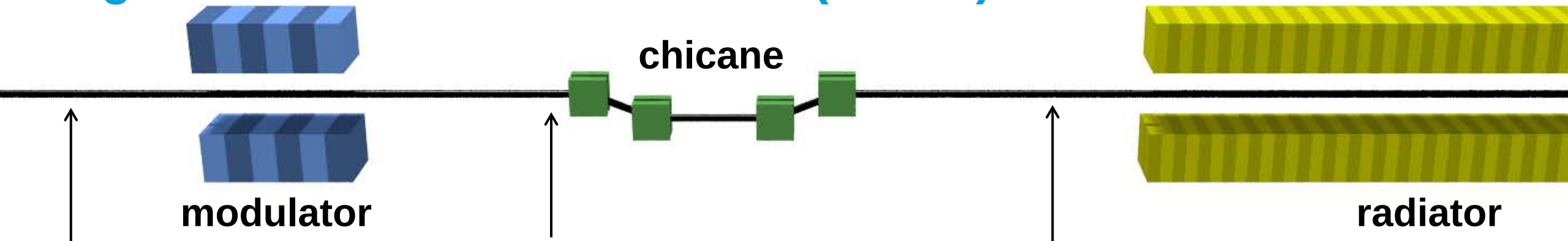


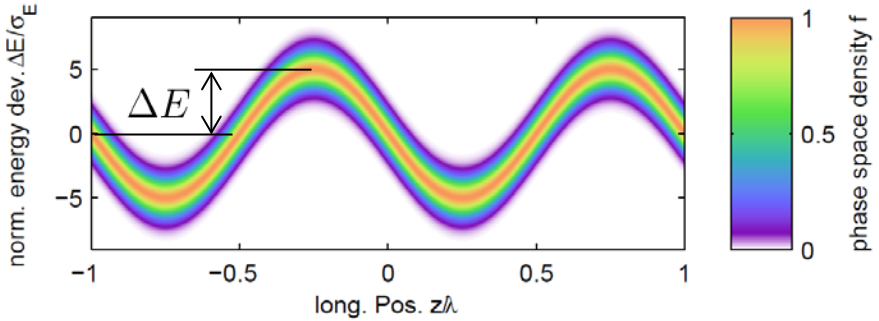


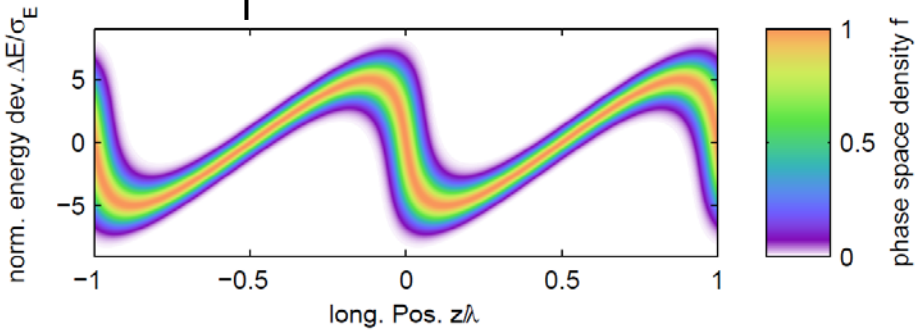
OUTLINE

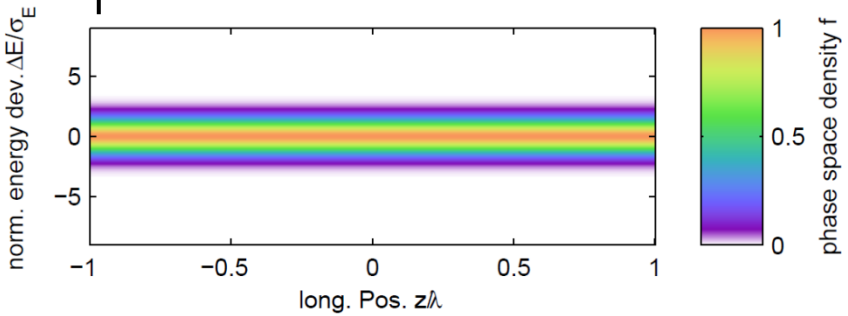
1. **High-gain harmonic generation (HGHG) seeding at sFLASH**
2. **Echo-enabled harmonic generation (EEHG) seeding studies at sFLASH**
3. **Future plans**

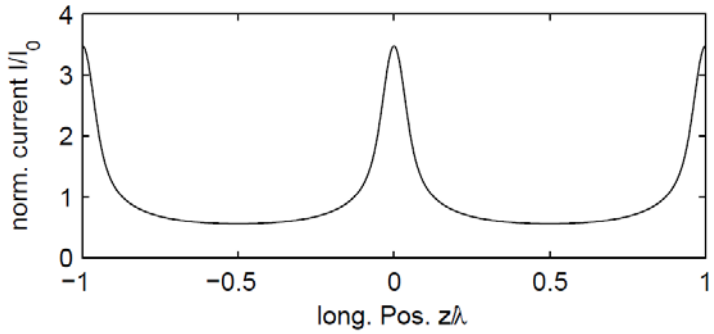
High-Gain Harmonic Generation (HGHG)











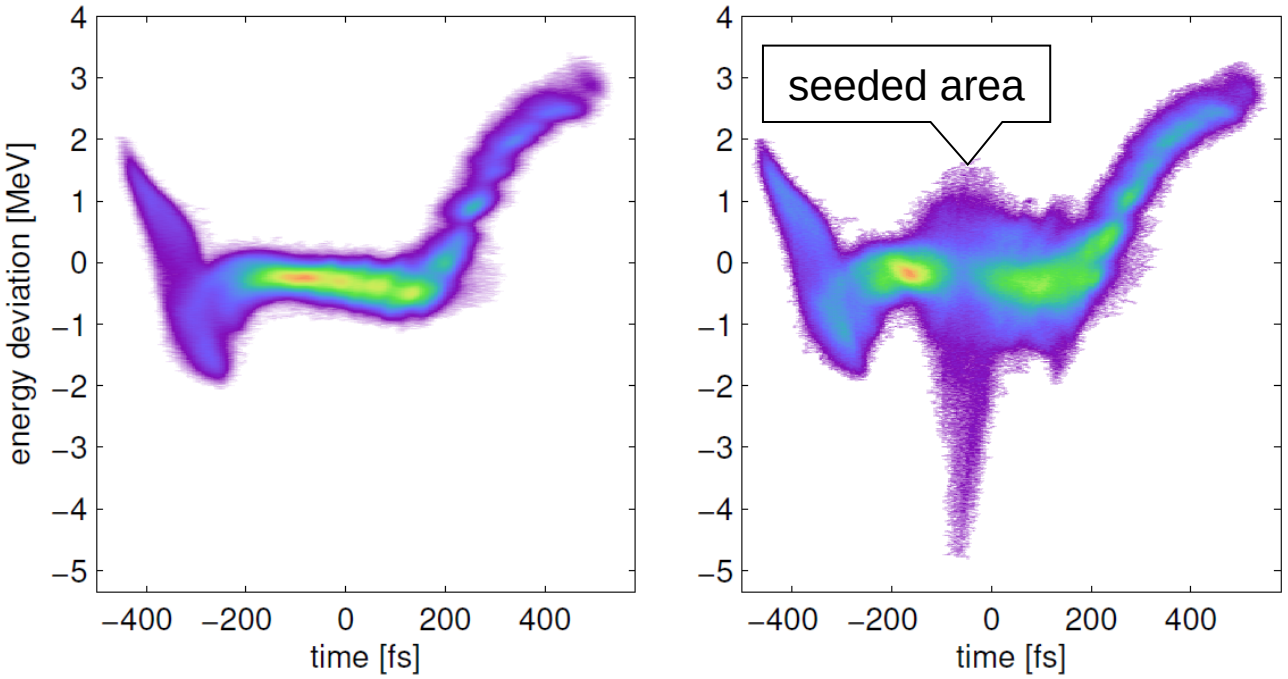
Proposed by Yu in 1991:
L.H. Yu, Phys. Rev. A 44, 5178 (1991)

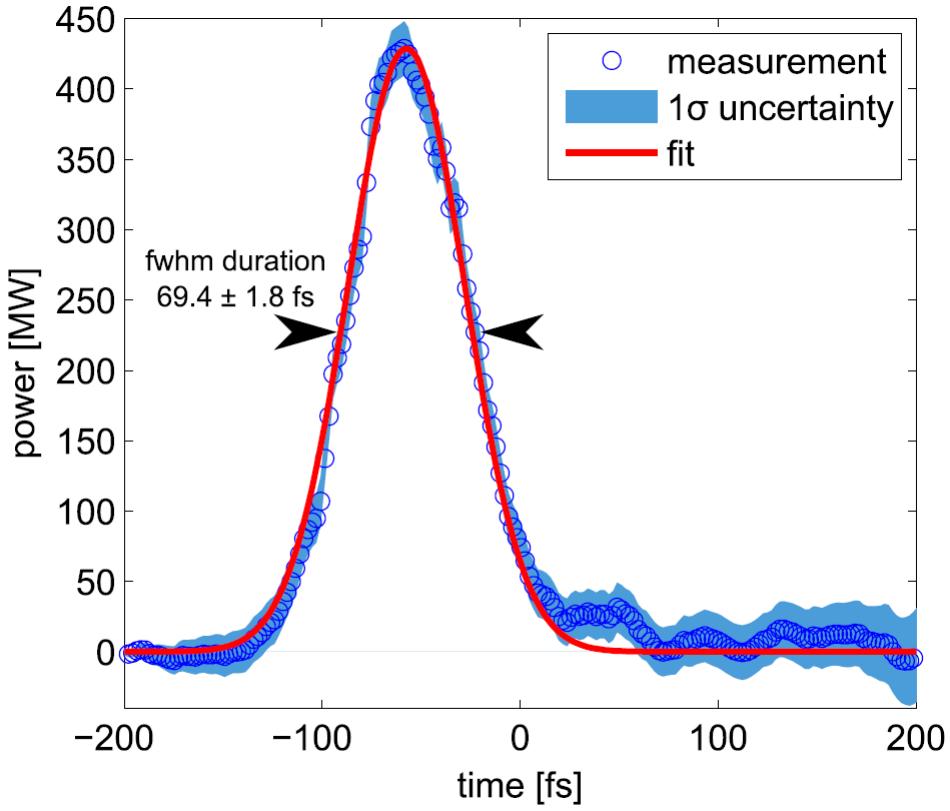
Bunching factor at harmonic *n*

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

Generation and Analysis of Seeded FEL Pulses at sFLASH

Extraction from electron bunches with RF deflector



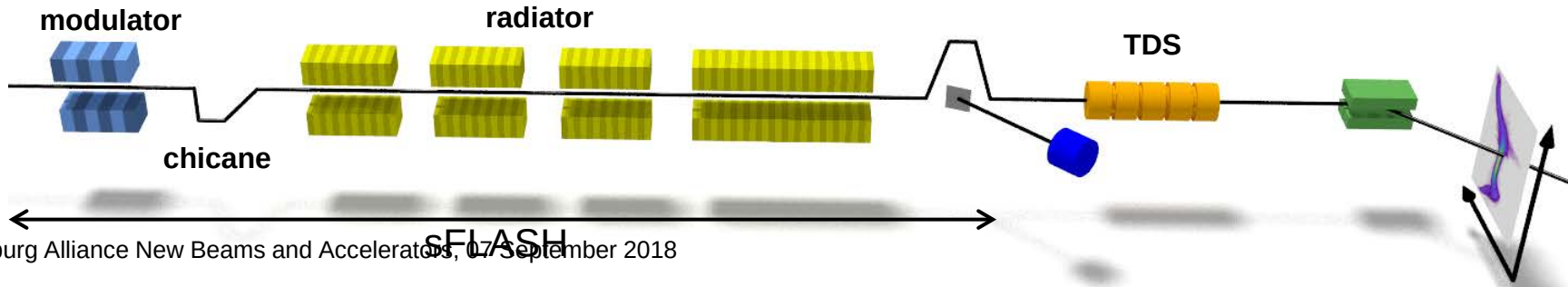


Electron beam energy	685 MeV
Peak current	0.62 kA
Seed laser wavelength	267 nm

Demonstrated for SASE FELs at LCLS (DESY as co-author): **C. Behrens, et al., Nat. Commun. 5, 4762 (2014)**

sFLASH: first achieved for seeded FEL

T. Plath, et al., Sci. Rep. 7, 2431 (2017)



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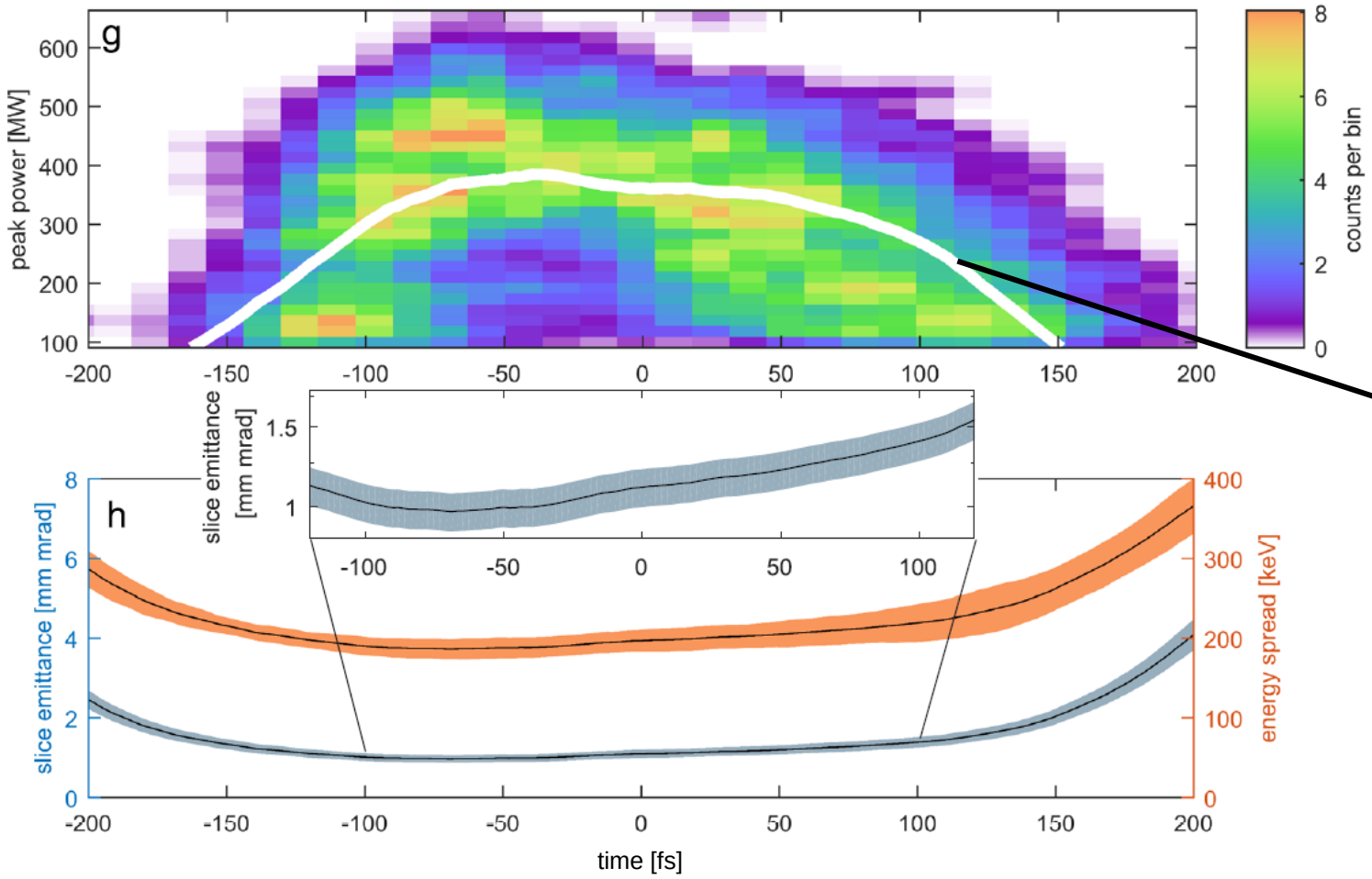


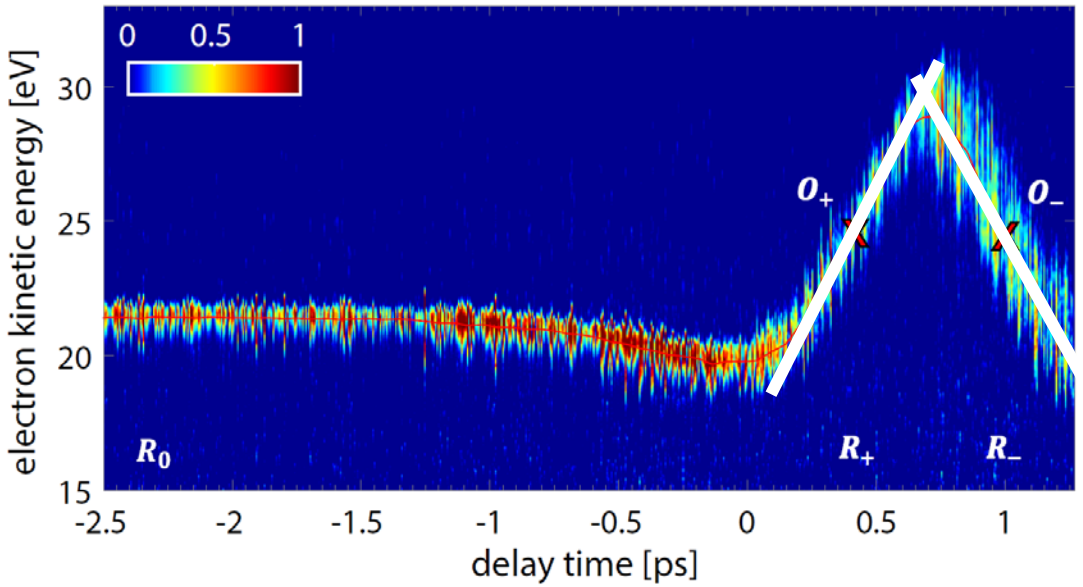
Measured emittance and current profiles and Ming Xie formalism very nicely model lasing in different regions of electron bunch

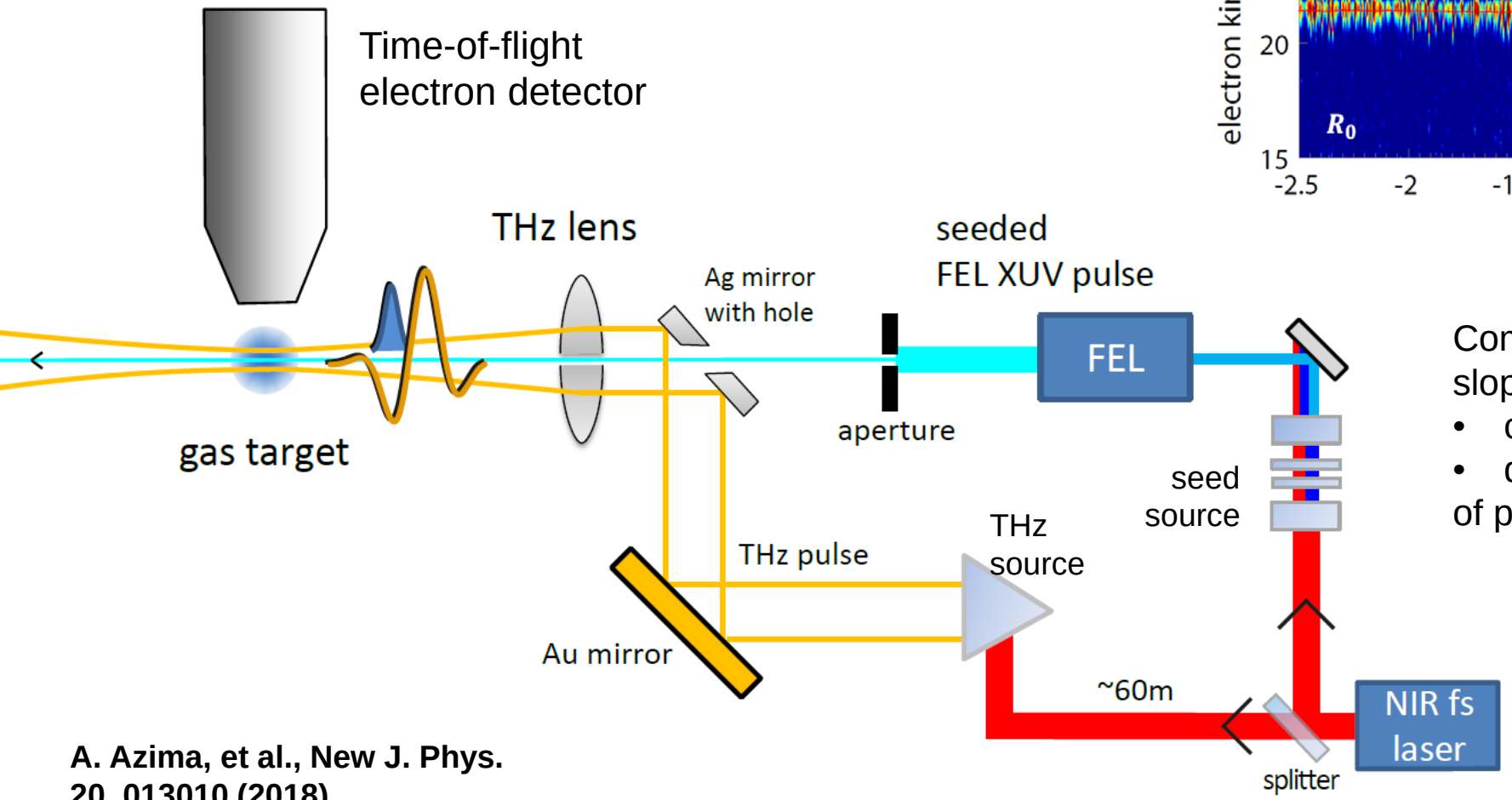
Unique hardware configuration (TDS setup at the exit of seeded FEL) enables detailed study of the seeded FEL

T. Plath, et al., Sci. Rep. 7, 2431 (2017)

THz Streaking of Photon Pulses

Newly applied at DESY for seeded pulses





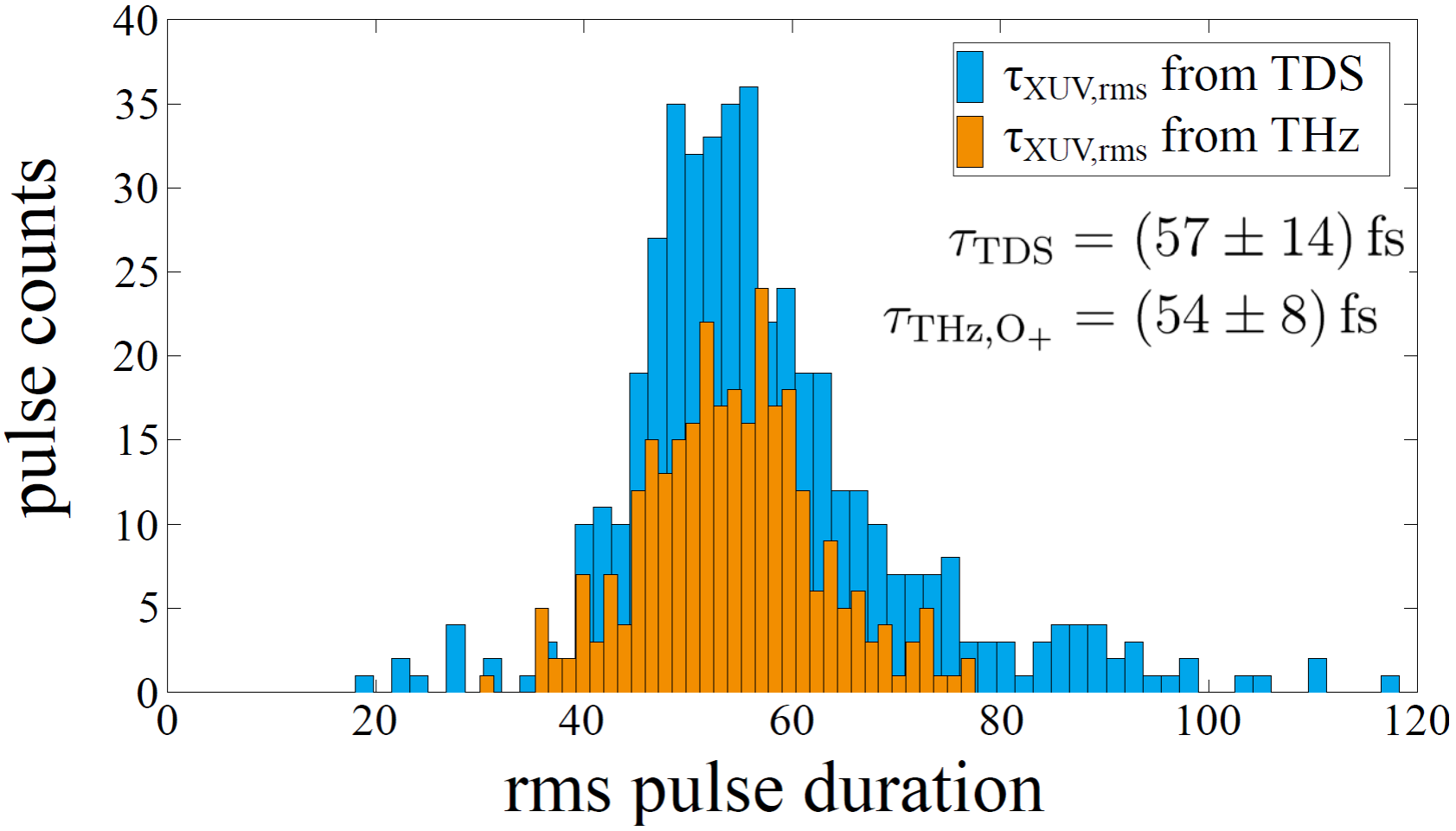
Combining measurements at both slopes gives access to

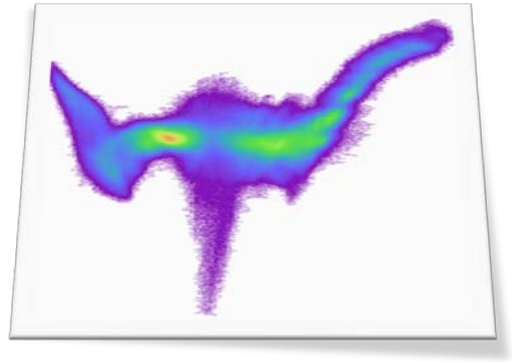
- chirp
- duration

of photon pulses

A. Azima, et al., New J. Phys. 20, 013010 (2018)

Measurement of FEL Pulse Duration





Using **transverse-deflecting structure (TDS)**:

- Extract duration of seeded FEL pulses

With THz streaking:

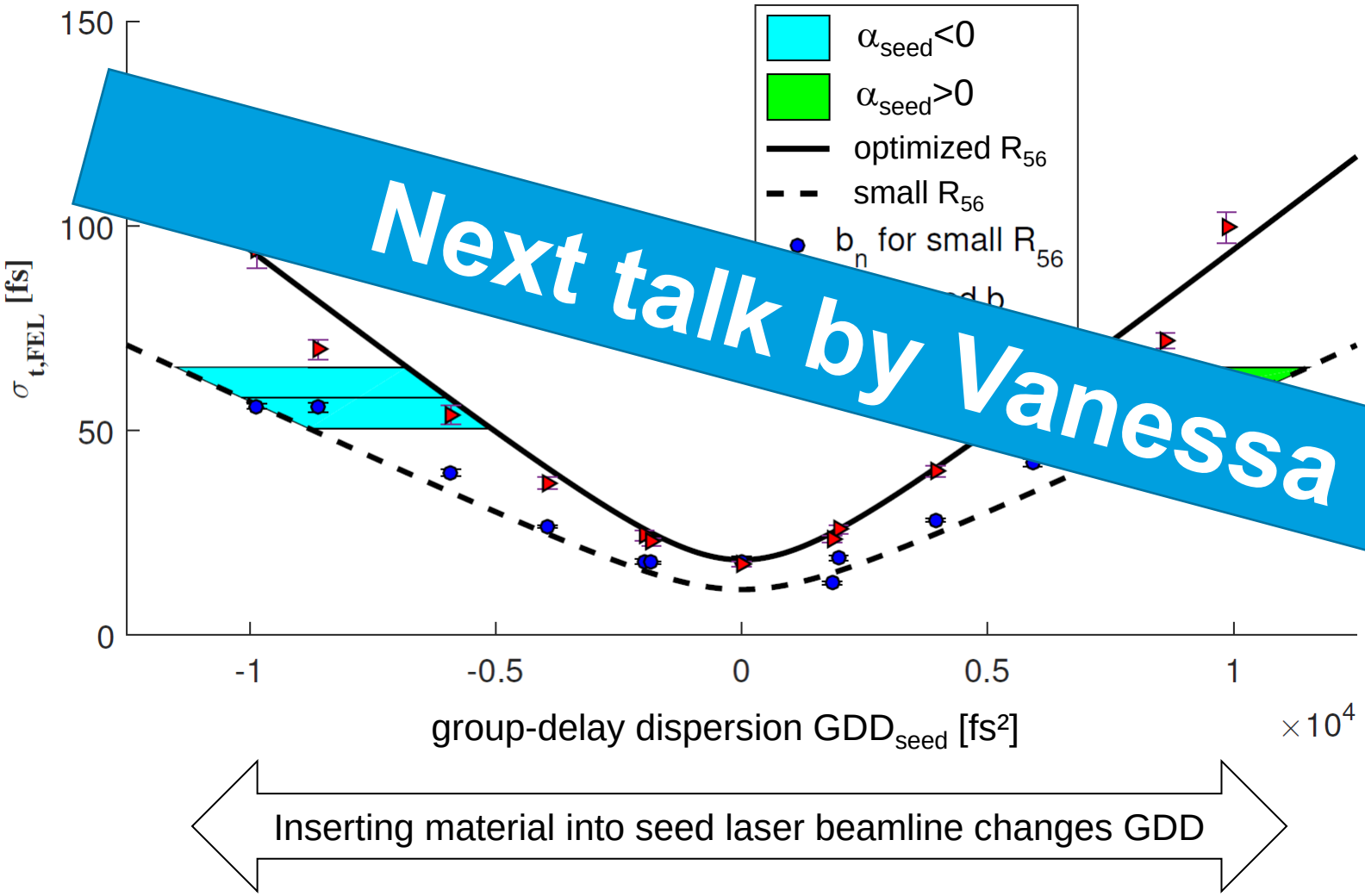
- **Access optical phase of FEL pulses**
- **Chirp of seeded FEL pulses** (only determined by THz streaking)

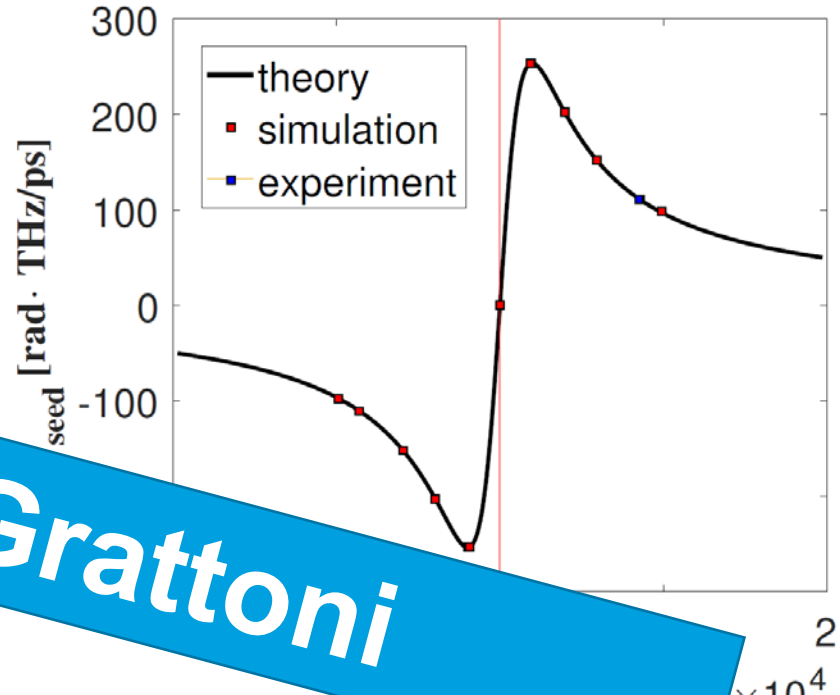
$$c = (-1940 \pm 800)\ \mathrm{THz/ps}$$

A. Azima, et al., New J. Phys. 20, 013010 (2018)

Next Step: Manipulation of UV Seed Laser Pulses

First step towards tailored seeded FEL pulses



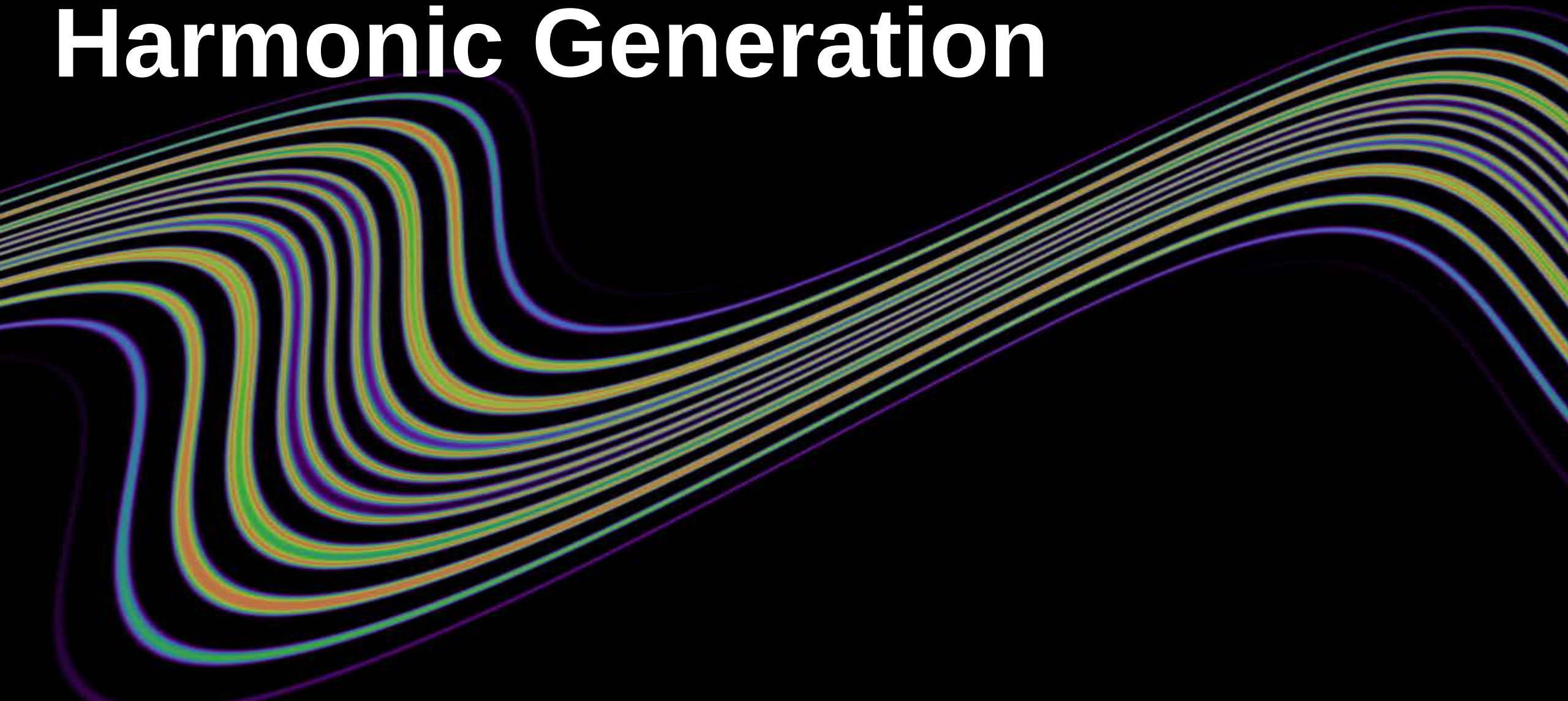


Next talk by Vanessa Grattoni

Inserting material into seed laser beamline changes GDD

GENESIS simulation

Echo-Enabled Harmonic Generation

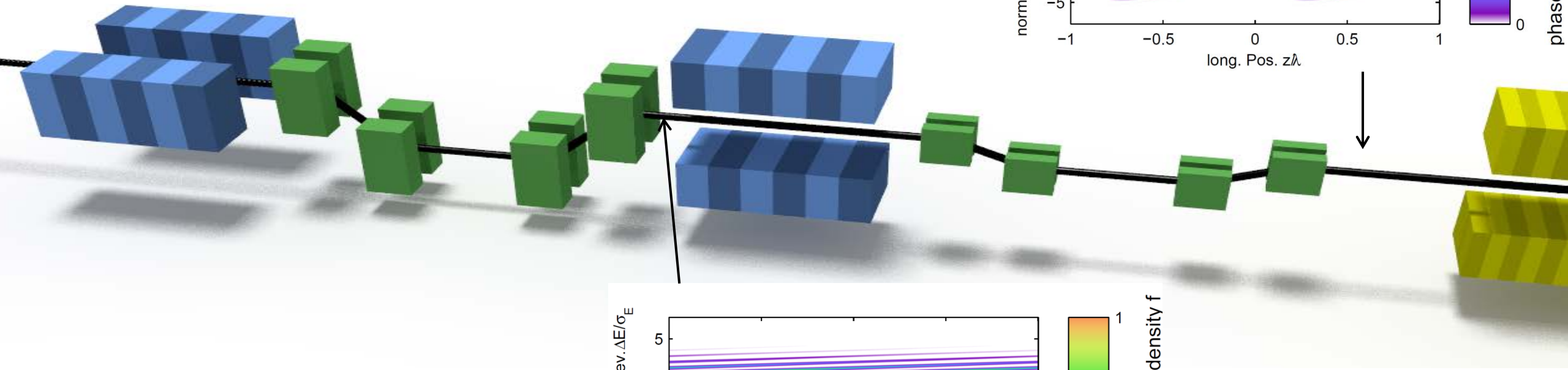


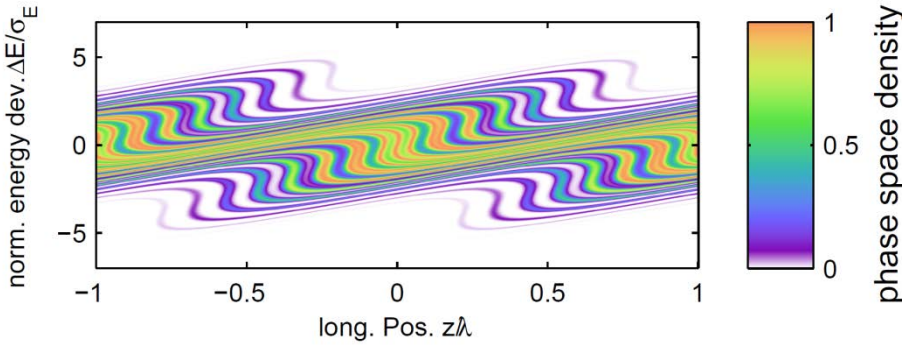
Echo-Enabled Harmonic Generation (EEHG)

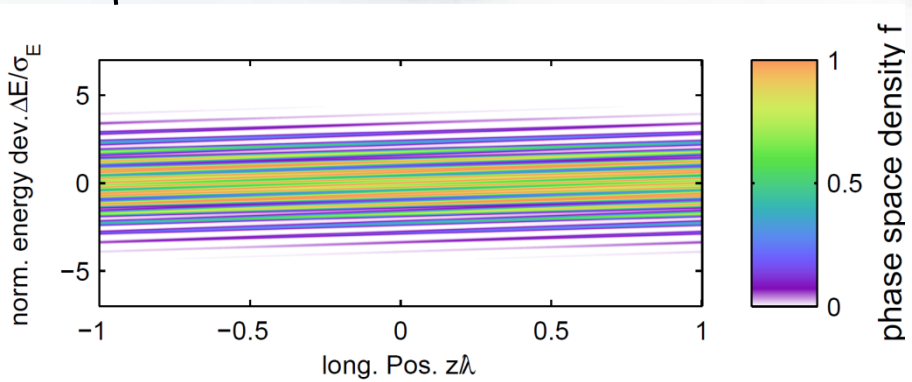
Echo-enabled harmonic generation (EEHG):

- Seeding adds less energy spread to electron beam
- Electron beam imperfections have smaller impact on generated photons
- Favorable bunching efficiency at high harmonics

FERMI@Elettra demonstrated EEHG seeding at h=45 (λ=5.9nm)

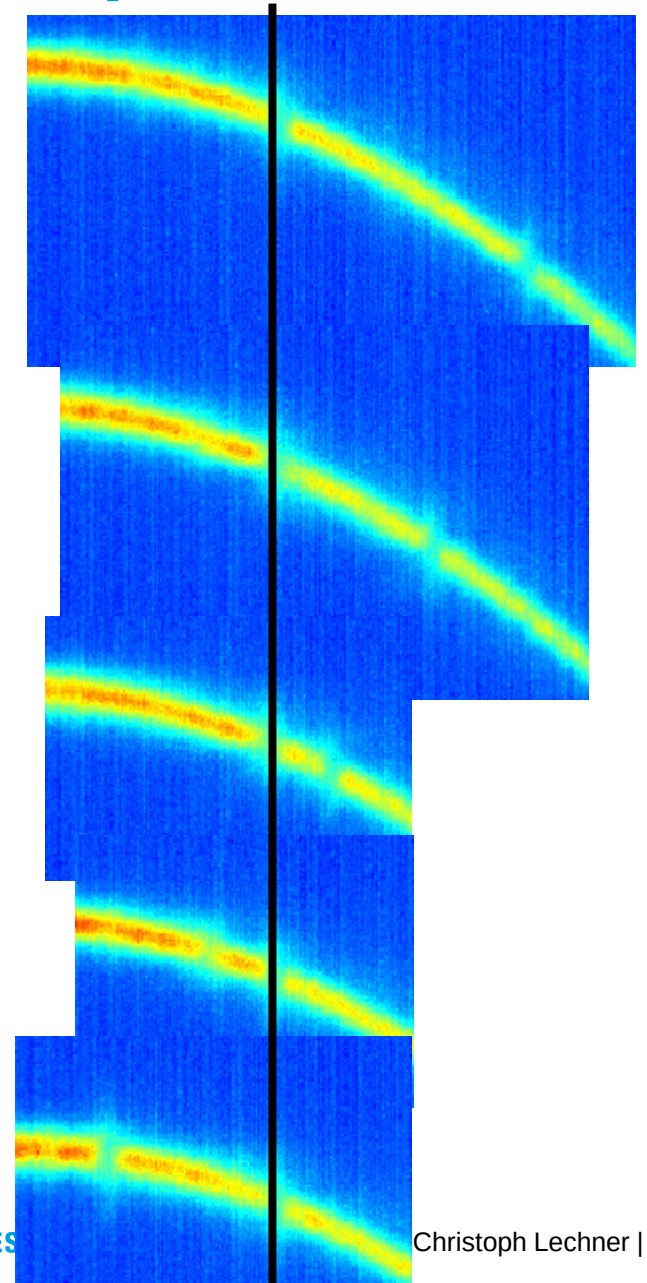


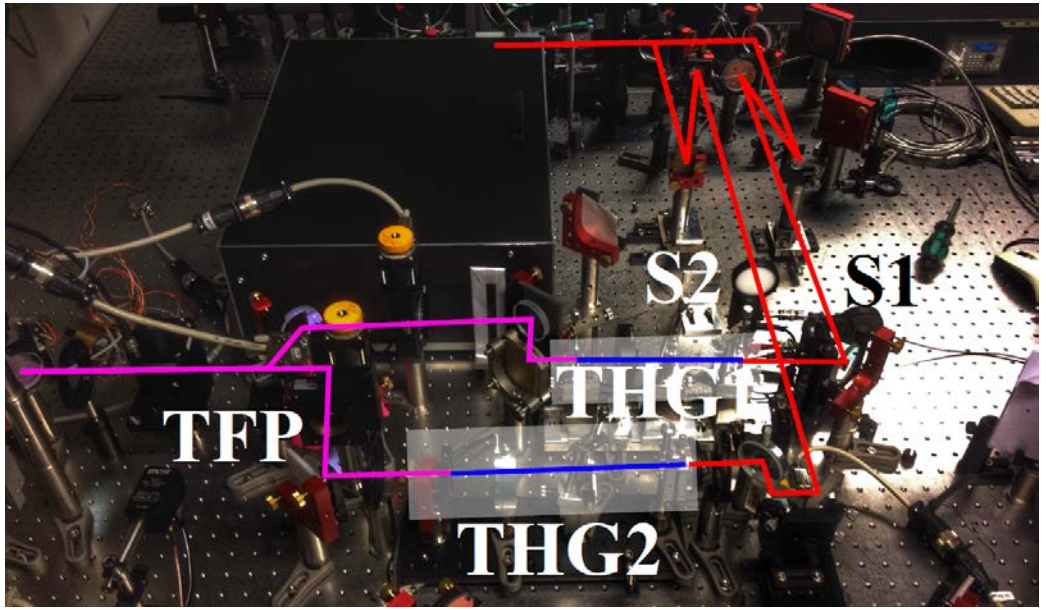




SLAC invention:
G. Stupakov, Phys. Rev. Lett.
102, 074801 (2009)

Preparations for EEHG Studies at sFLASH

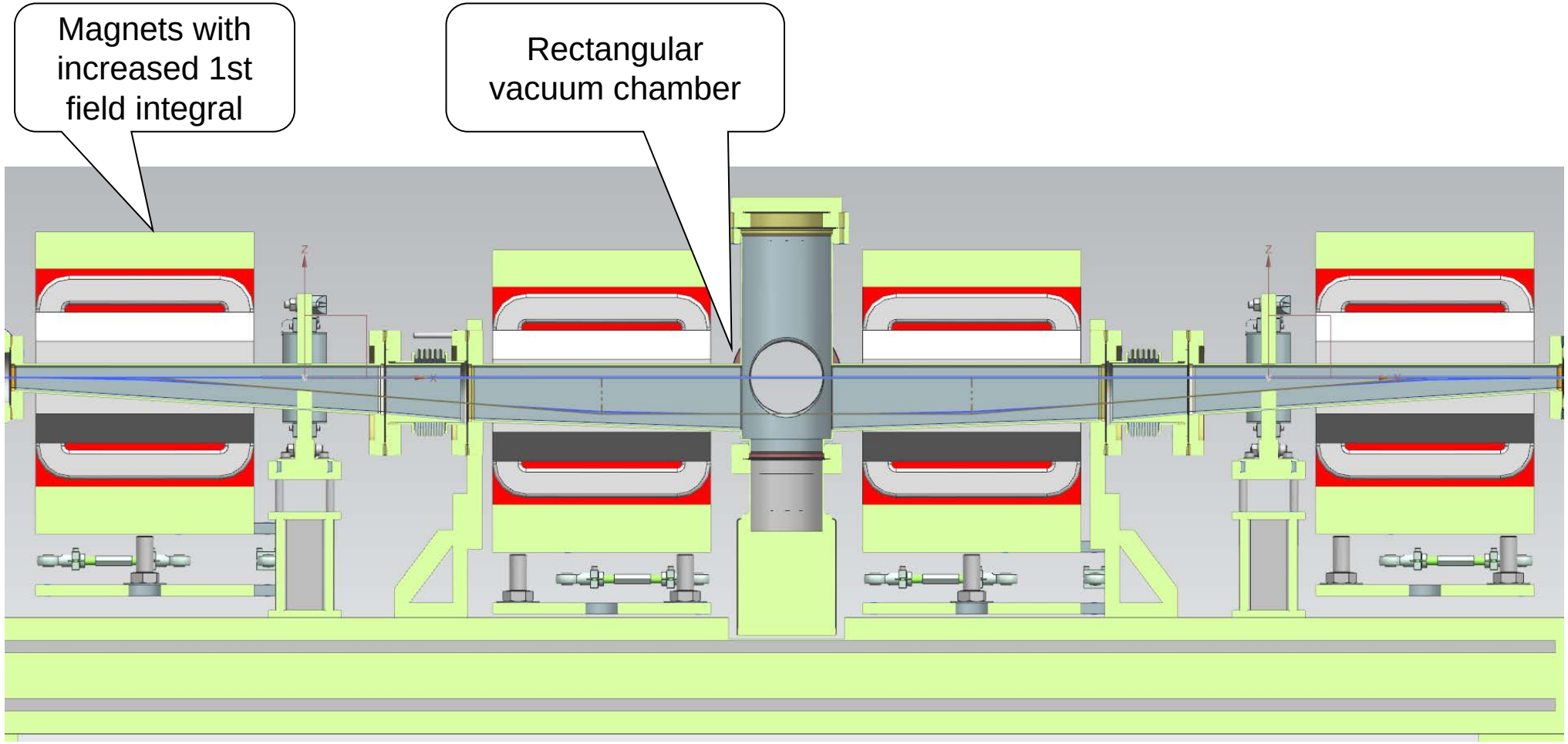




- Seed laser pulses have orthogonal polarization
  - Pulse 1 interacts with bunch in 1st modulator
  - Pulse 2 interacts with bunch in 2nd modulator
- Demonstrated independent control in timing, modulation amplitude
  - Global timing of seed laser pulses w.r.t. electron bunch controlled by vector modulator or OXC
  - Delay stage controls relative timing of the two seed pulses

Upgrade Plans: 1st sFLASH Chicane

Current 1st sFLASH chicane is limited by vacuum chamber (R_{56}<700µm) => Upgrade is being designed (4mm at 700MeV)

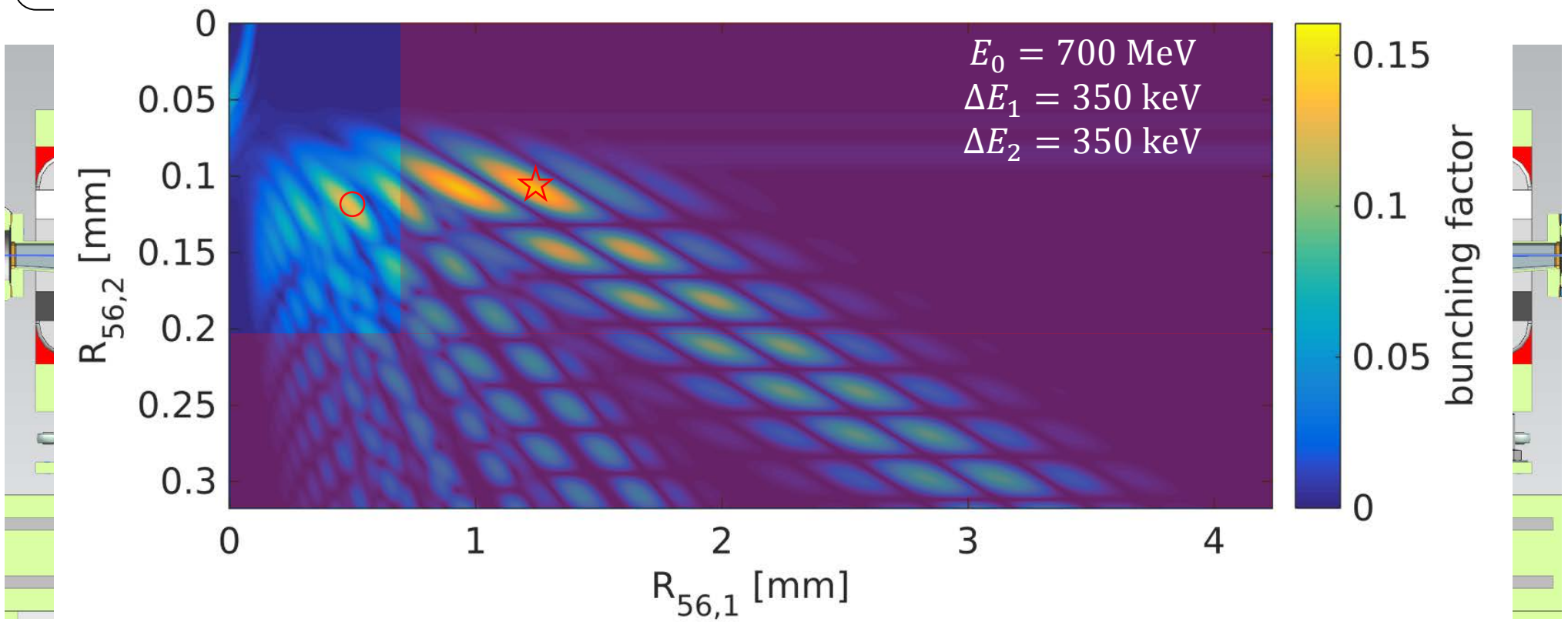


Upgrade Plans: 1st sFLASH Chicane

Current 1st sFLASH chicane is limited by vacuum chamber (R_{56}<700µm) => Upgrade is being designed (4mm at 700MeV)

Magnets with increased 1st

Rectangular vacuum chamber

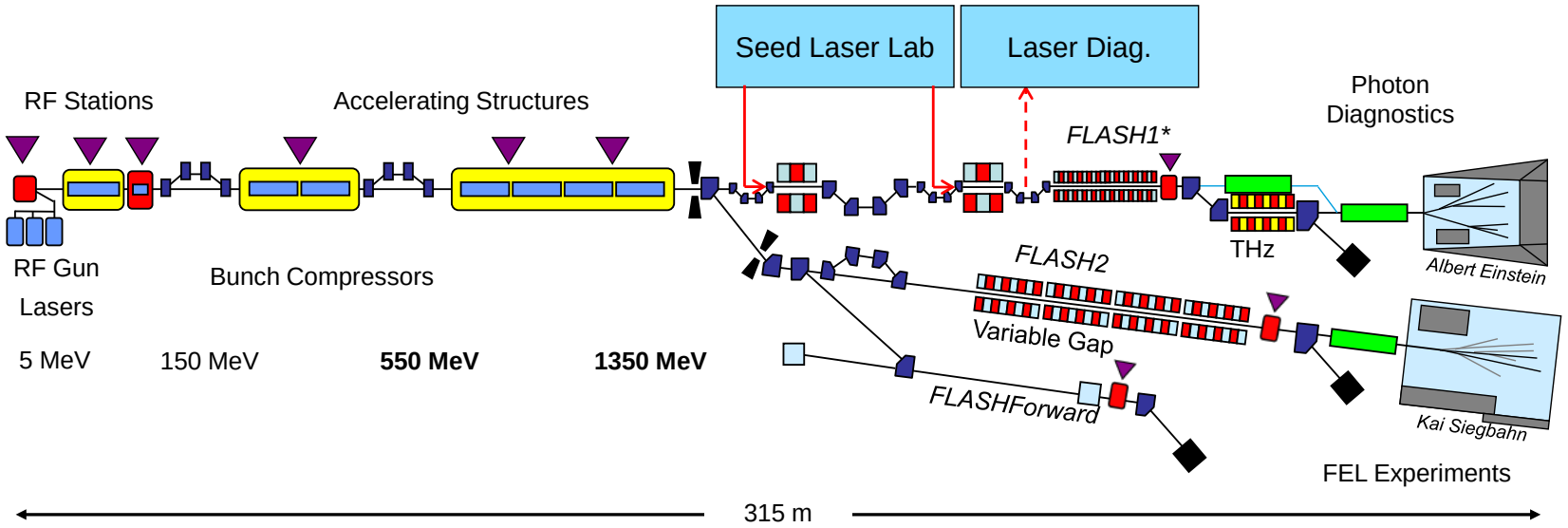


Seeding Design for FLASH2020+

Proposal for a seeded FEL beamline at FLASH

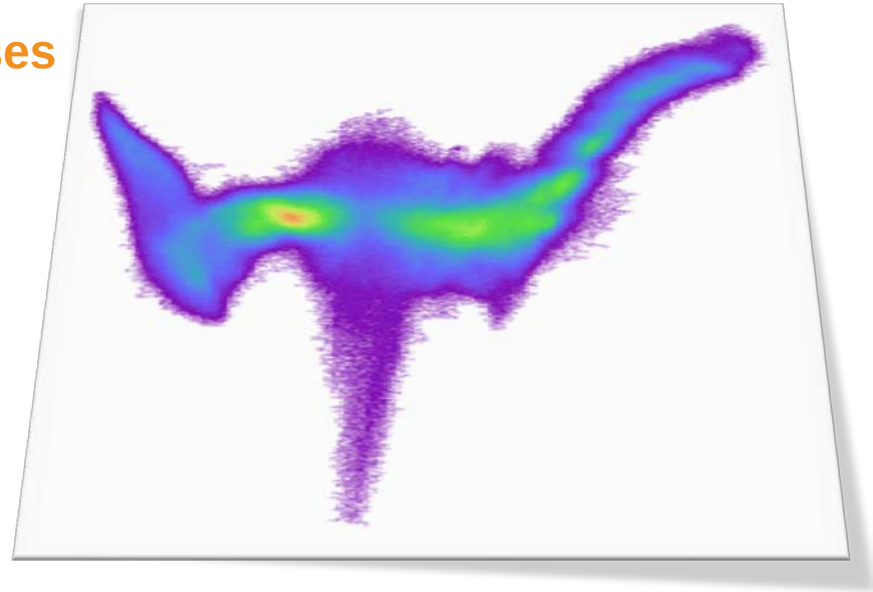
Key parameters:

- Target wavelength range 4 – 60 nm
- Variable FEL polarization (APPLE III undulators)
- Burst repetition rate 100 kHz, matching the bunch pattern of the superconducting machine
- EEHG seeding with two tunable UV seeds -> talk by Bastian Manschwetus (Thursday)



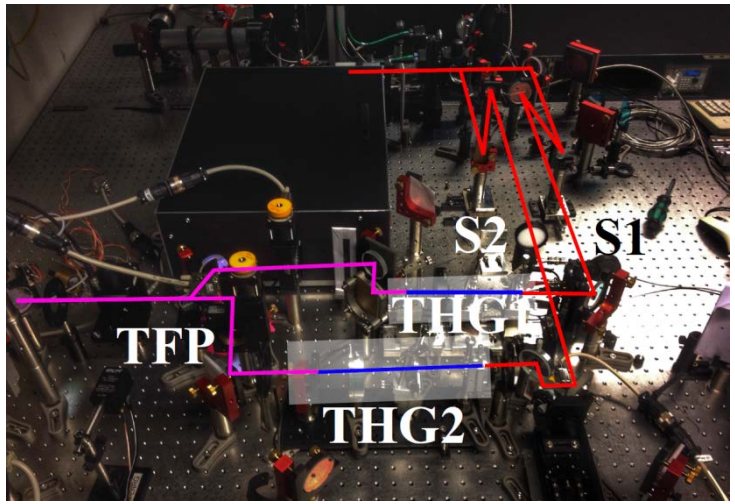
Summary

Seeding providing new insights and control for sFLASH FEL light pulses



- sFLASH developed important new analysis methods (with HGHG seeding)
  - **World-wide first TDS measurements of seeded FEL process,** providing insights into FEL light properties
  - **World-wide first THz streaking of seeded photon pulses**: allows determining optical phase of FEL pulses, a critical information for frontier photon science

- EEHG seeding
  - Prepared seed laser setup for the study of EEHG seeding
  - EEHG studies are on-going



- Next steps:
  - **Demonstration of EEHG seeding at sFLASH**
  - HGHG with manipulated seed laser pulses -> next talk
  - **Seeding design for FLASH2020+ upgrade plans**

Thank you for your attention

Sven Ackermann*, Armin Azima, Jörn Bödewadt*, Hauke Biss, Martin Dohlus,
Nagitha Ekanayake*, Vanessa Grattoni, Kirsten Hacker*, Mehdi Kazemi, Leslie L. Lazzarino,
Christoph Lechner, Hannah Limberg, Bastian Manschwetus, Theophilos Maltezopoulos*,
Velizar Miltchev, Georgia Paraskaki, Tim Plath*, Andreas Przystawik, Yannik Ristau,
Sergey Usenko, Mathias Vogt, Igor Zagorodnov, Johann Zemella,
Ralph Assmann, Markus Drescher, Bart Faatz, Ingmar Hartl, Wolfgang Hillert, Shaukat Khan,
Tim Laarmann, Jörg Rossbach, Wilfried Wurth

* former team member