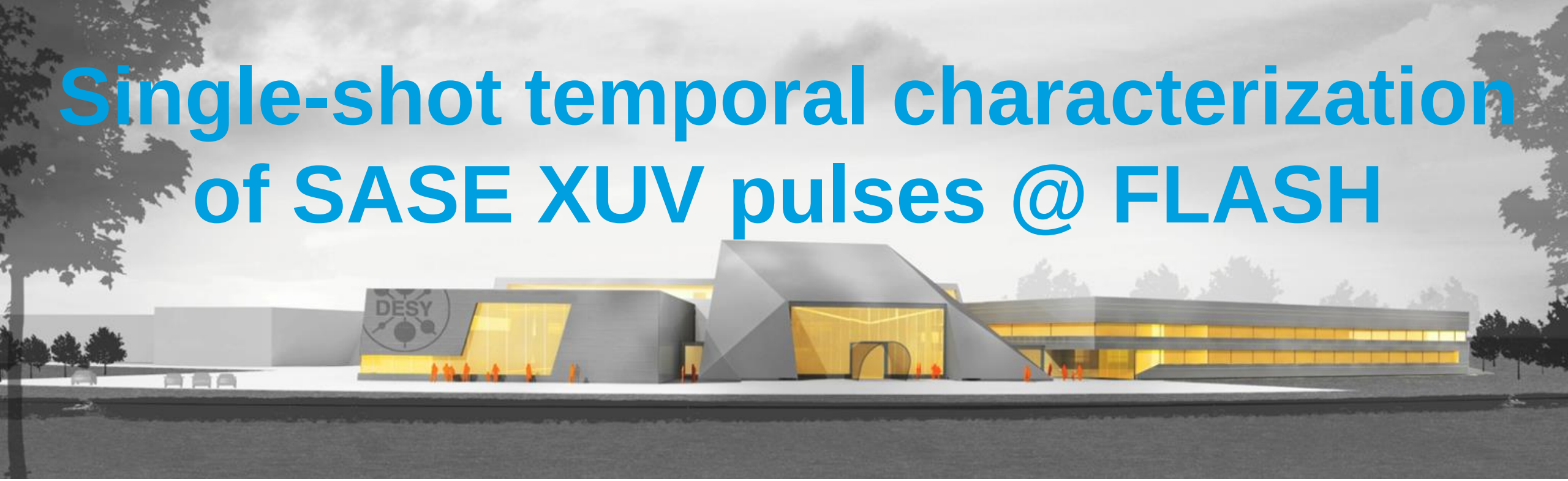
# Single-shot temporal characterization of SASE XUV pulses @ FLASH




**Mahdi Bidhendi**

**R. Ivanov, I. J. Bermudez, M. V. Yurkov, S. Düsterer and the FLASH team**

**Trieste, 14.09.2023**

HELMHOLTZ

PhotonMEADOW 2023

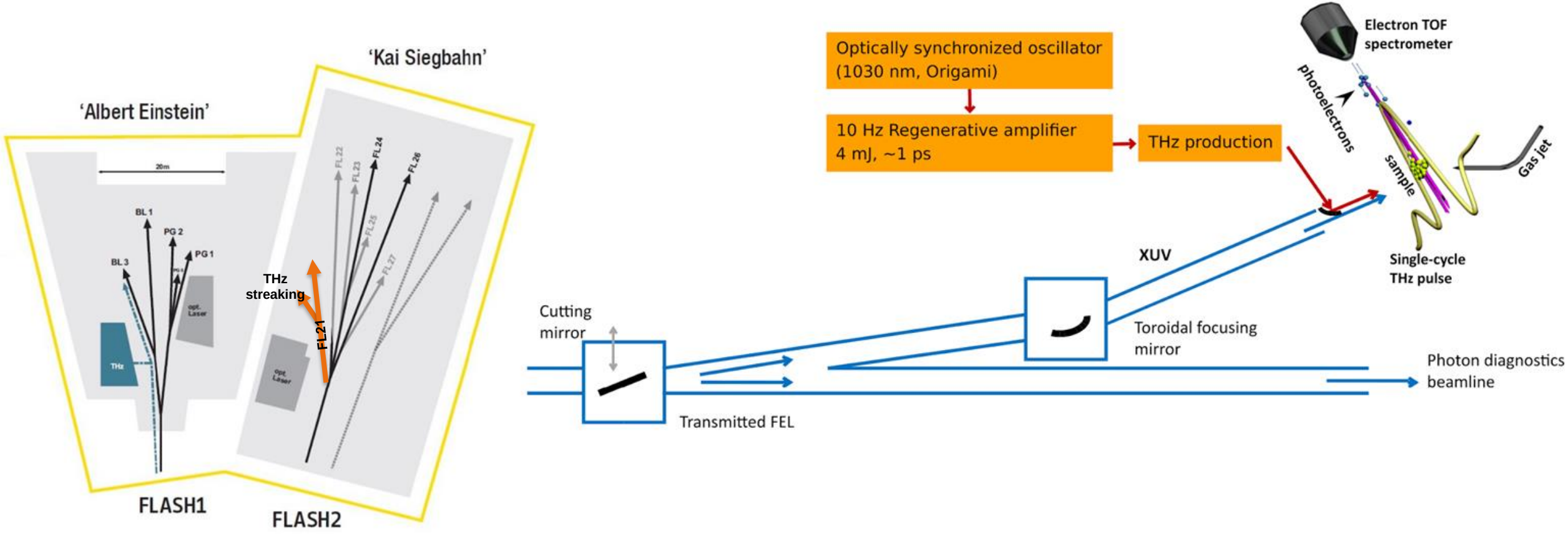
DESY.

# Outline

1. THz streaking setup at FLASH2
2. THz streaking principle
3. THz streaking applications
4. Comparison with Polarix TDS
5. XUV chirp measurement of FEL
6. Gain curve measurement
7. Special operation modes
8. Scheme for parasitic measurement

# THz streaking setup at FL21

## FL21 beamline is dedicated to FLASH2 diagnostics

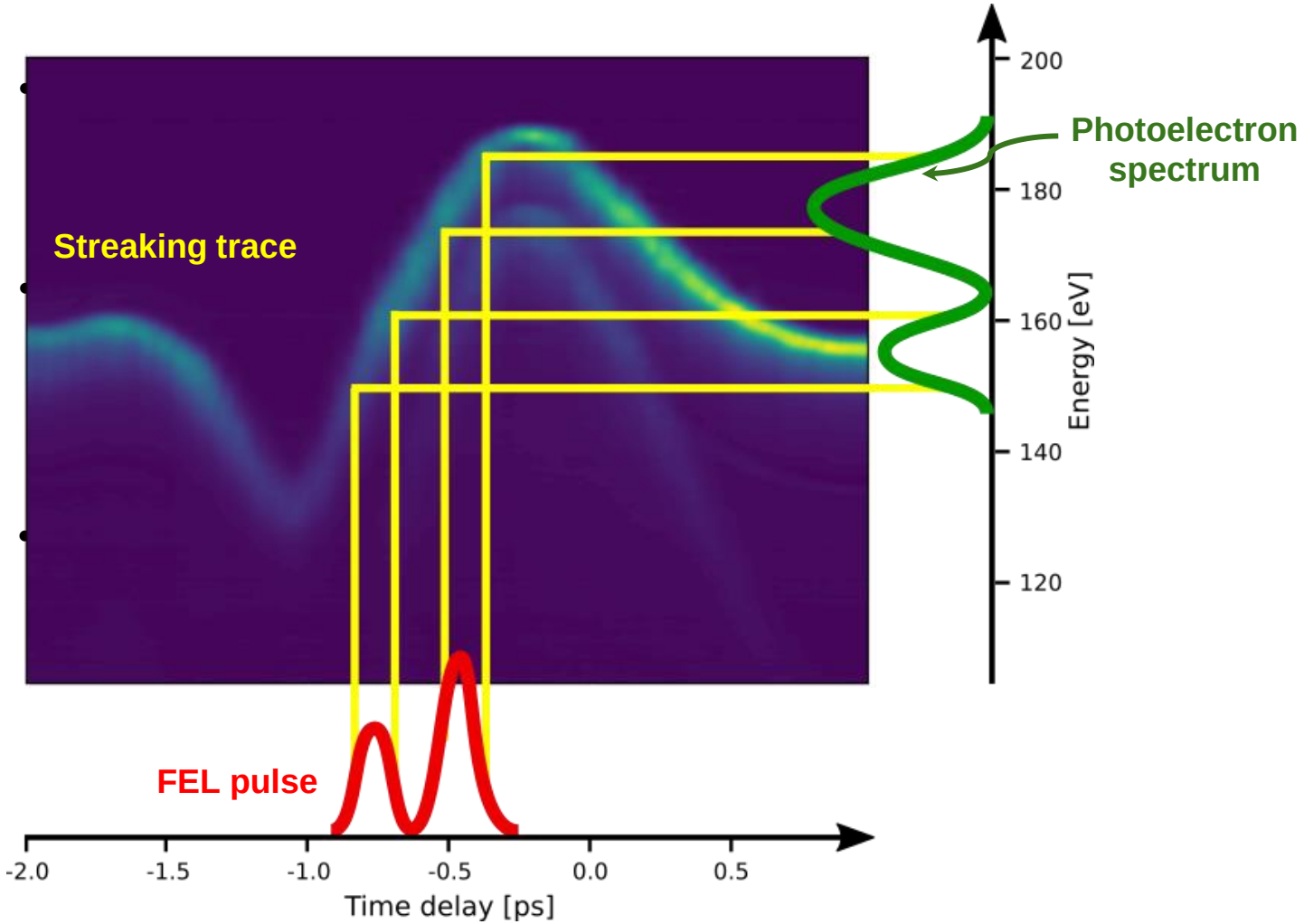


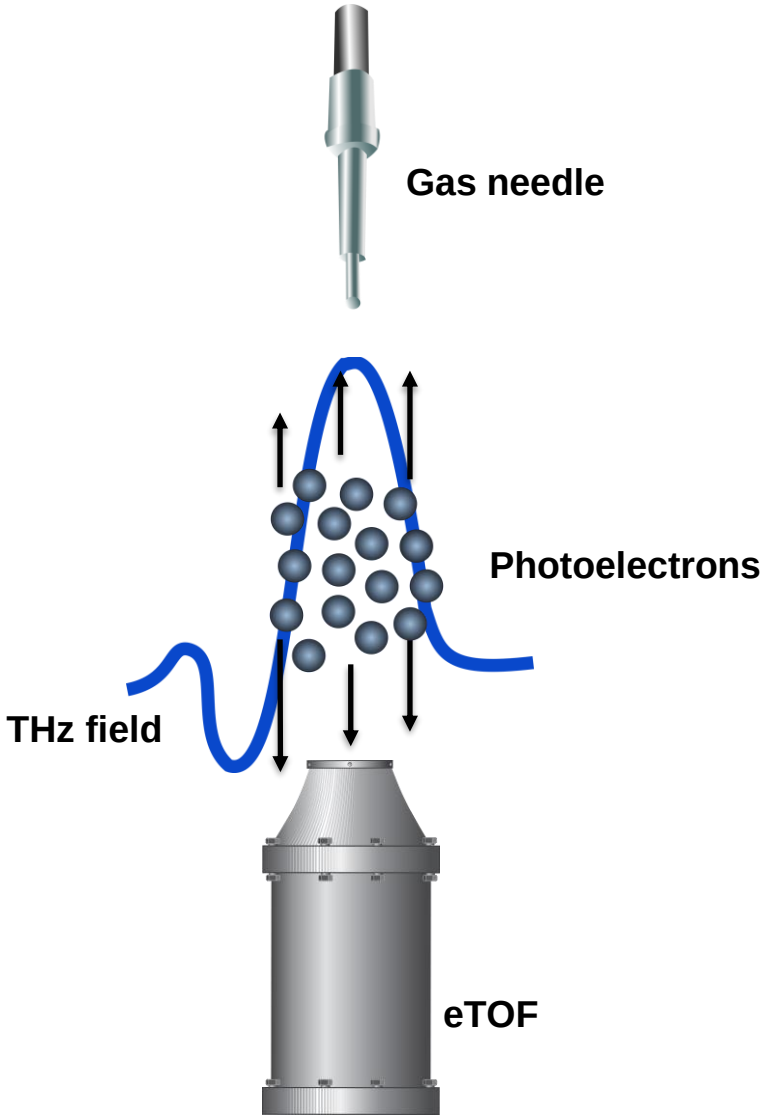



R. Ivanov et al. Opt. Express 31, 19146-19158 (2023)

# THz streaking principle

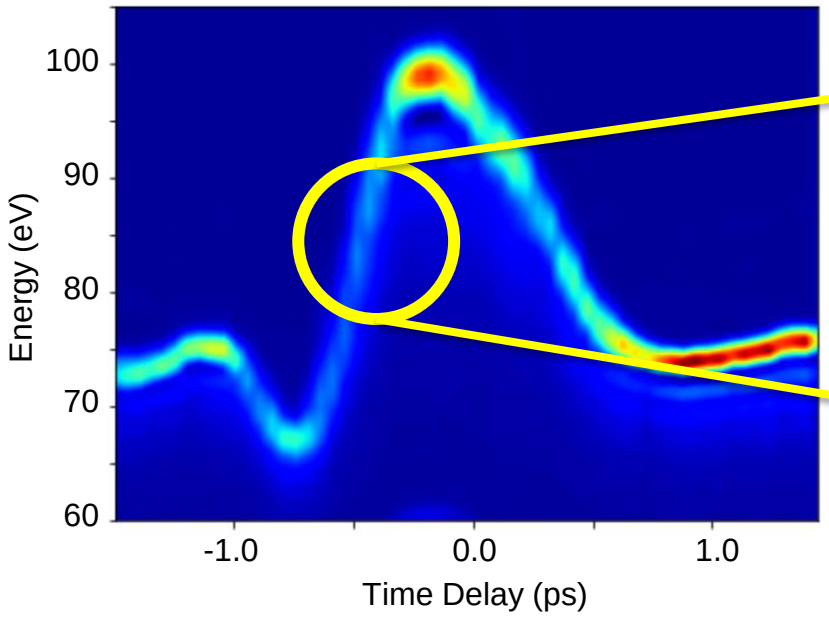
## How does it work?

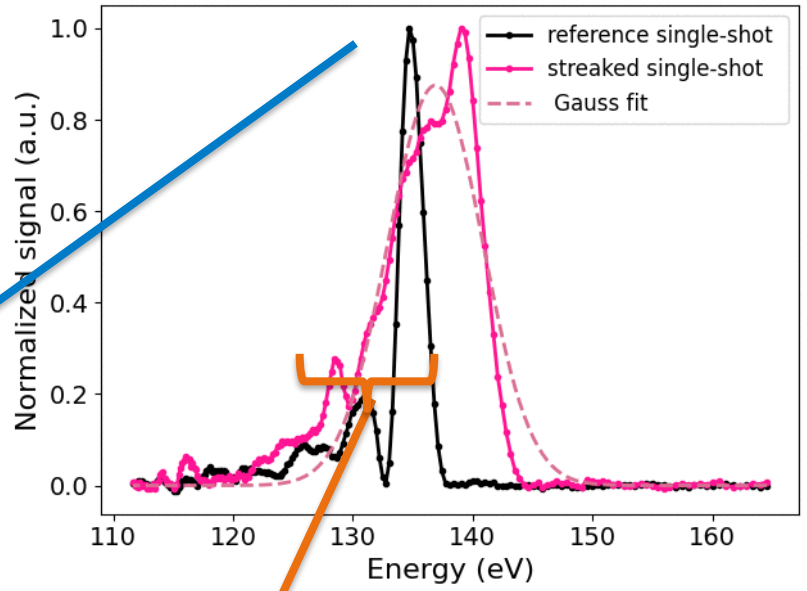


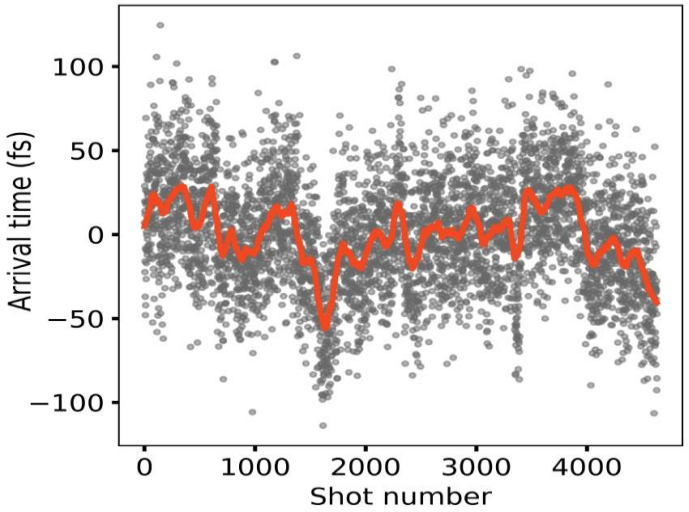

U. Frühling et al. Nat. Photonics 3, 523 (2009)
I. Grguraš et al. Nat. Photonics 6, 852 (2012)

# What can we measure with THz Streaking

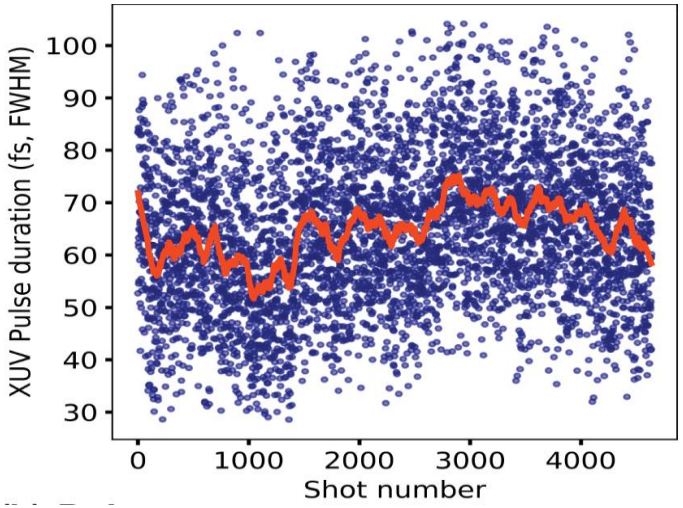



- **Single shot XUV arrival time**



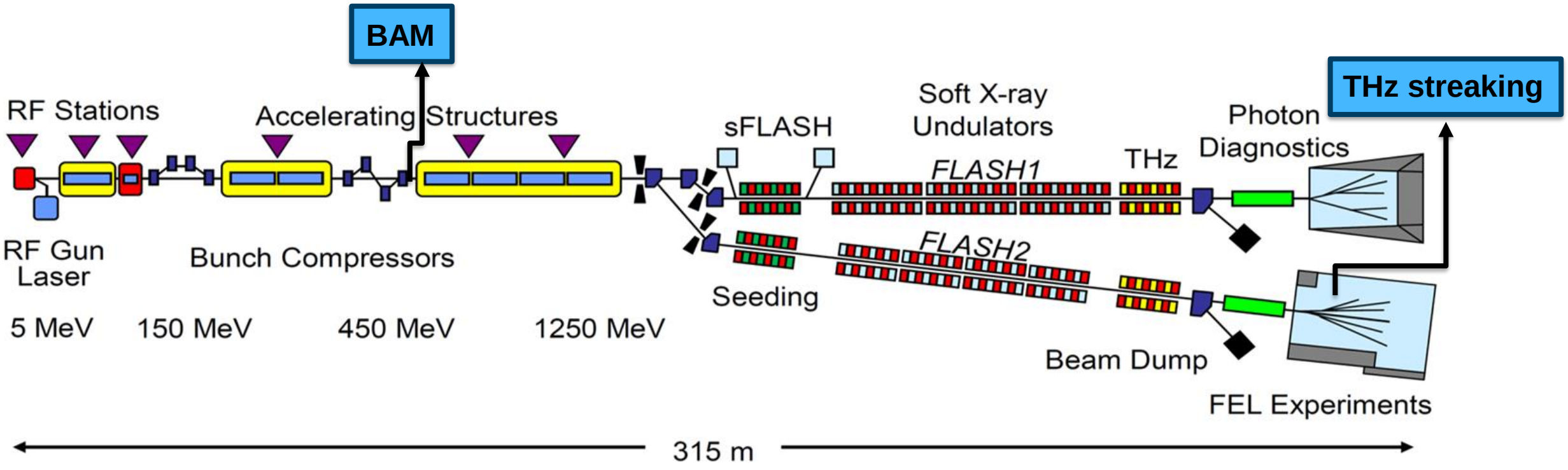

- **Single shot XUV pulse duration**




Courtesy: Ivette J Bermudez

# Arrival time measurement

## And comparison with BAM



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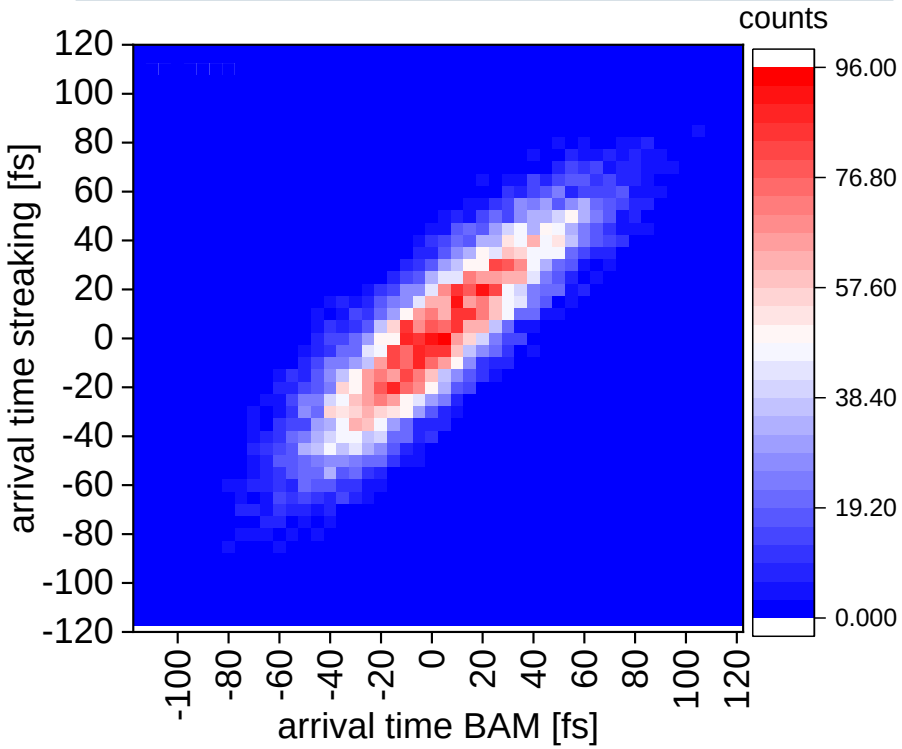
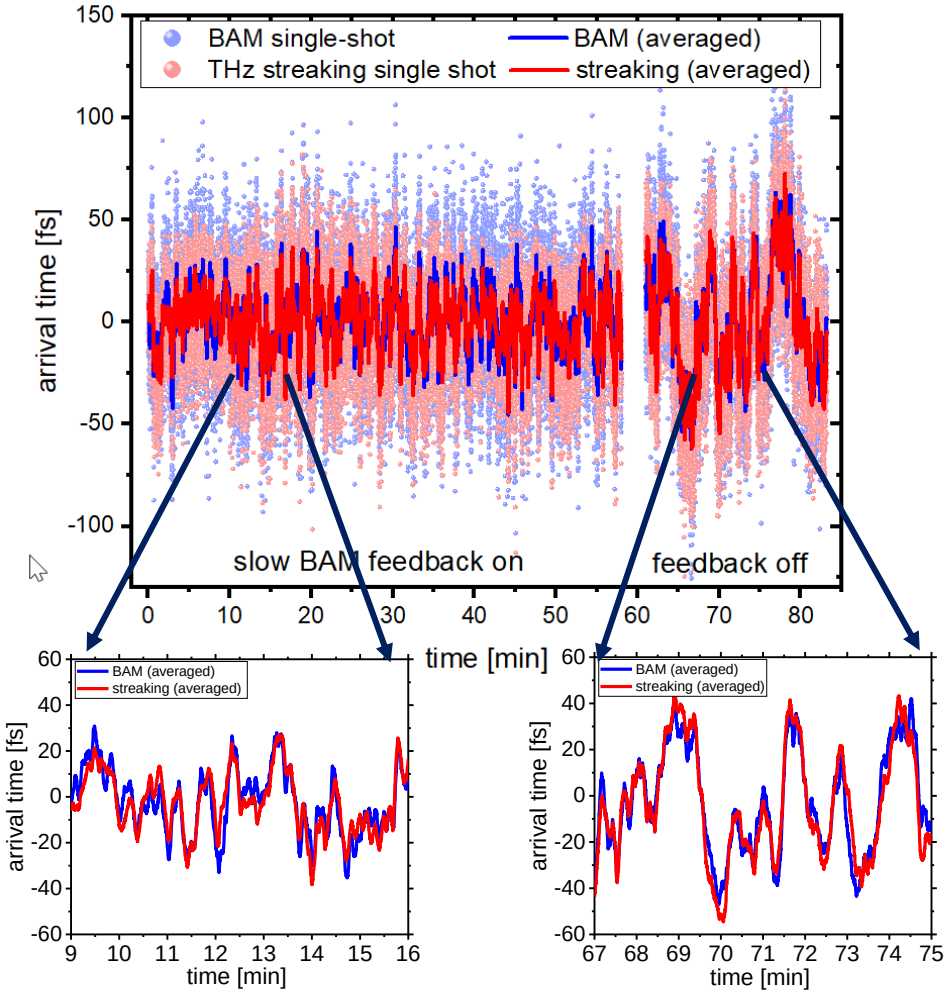
# Arrival time measurement

## And comparison with BAM

**Correlation width of 12 fs rms!**



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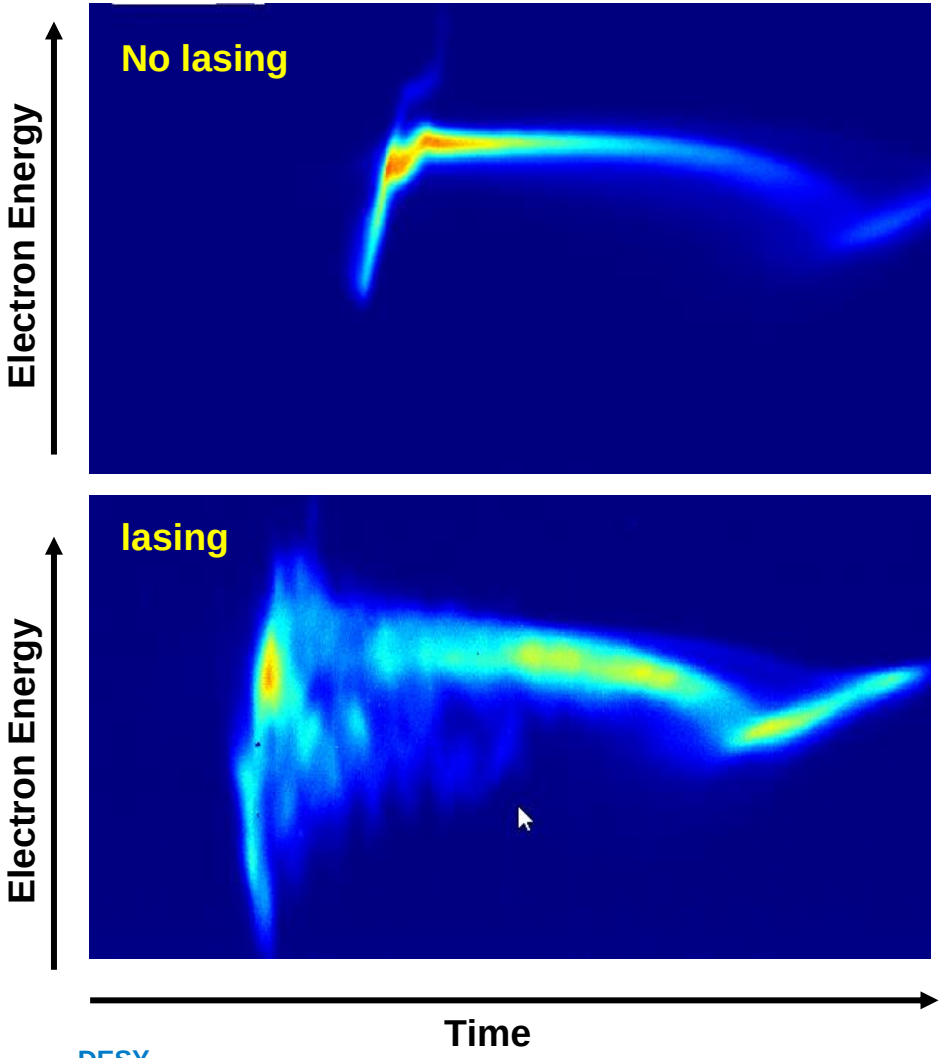
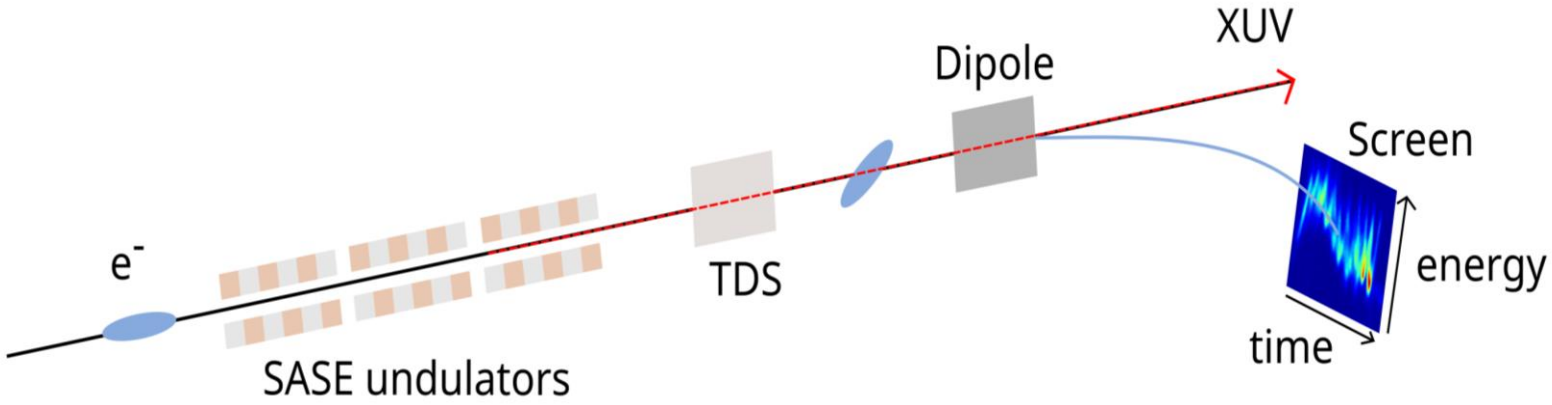
# Polarix TDS

## Use electron diagnostics to measure XUV pulse duration / shape

Courtesy: G. Goetzke



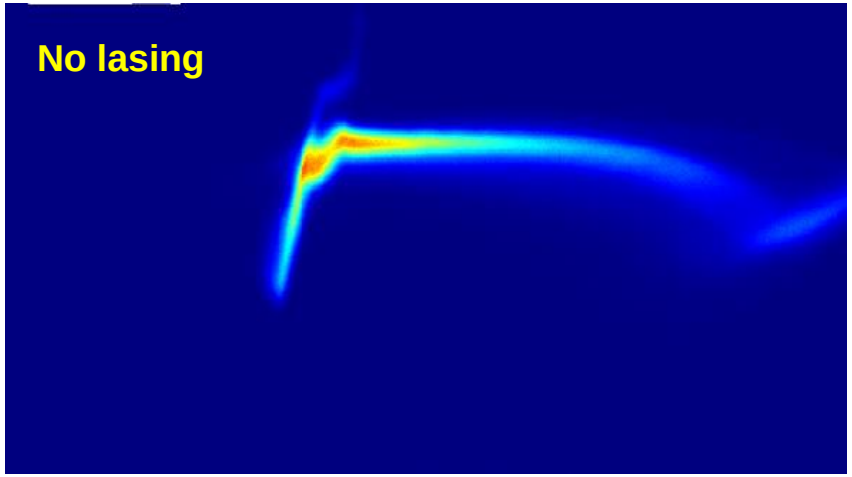

*Method C. Behrens at al, Nature Communications* **5**, 3762 (2014)

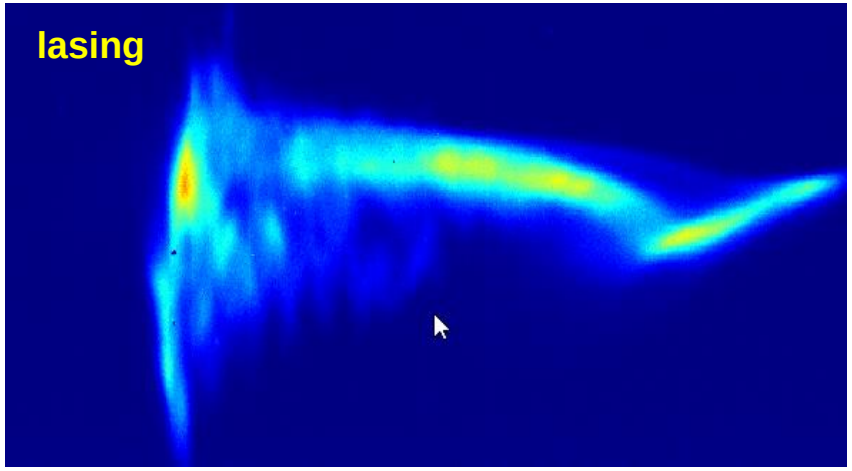
# Comparison TDS vs THz streaking

More info in poster 27

## Recent data … work in progress …

Courtesy: G. Goetzke

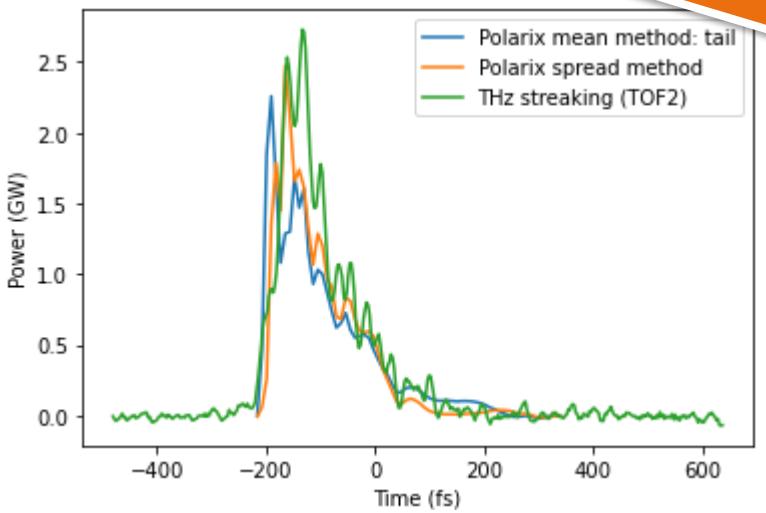


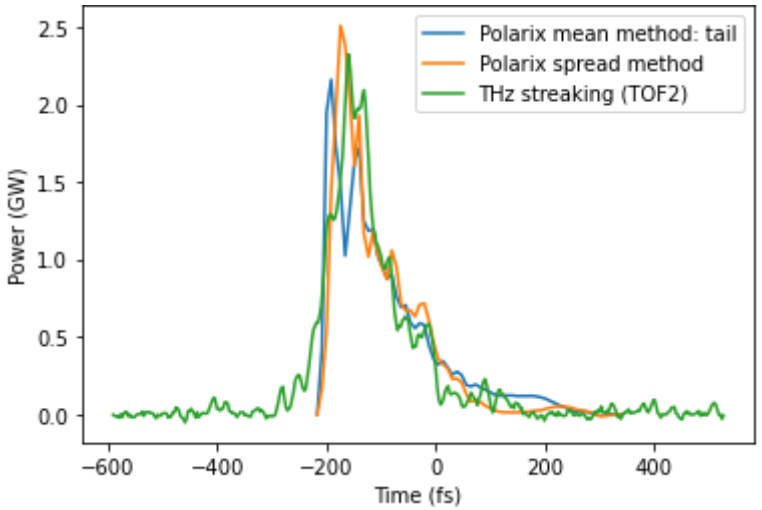



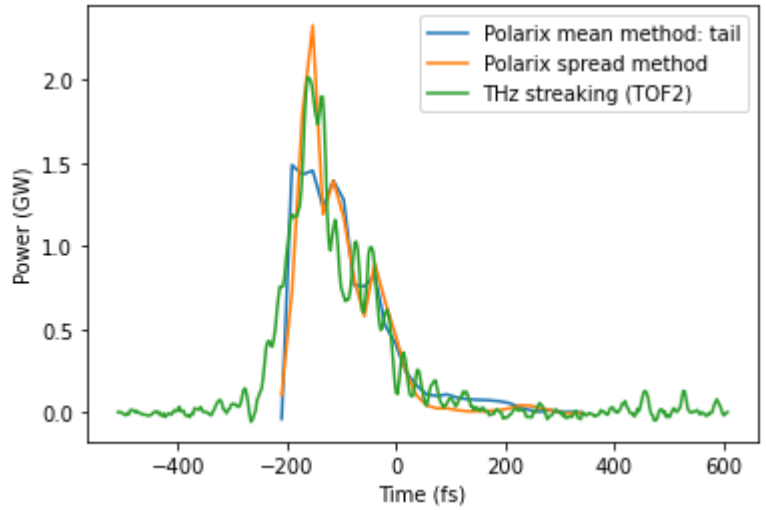

Electron Energy

Electron Energy

Time



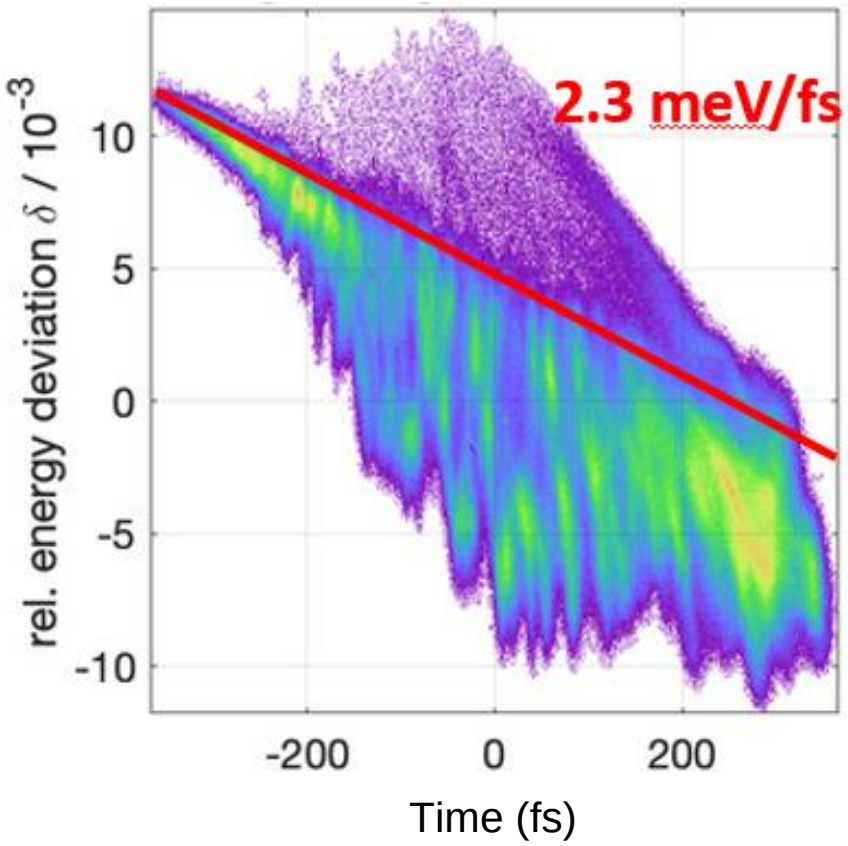




Courtesy: Ch. Behrens and G. Goetzke

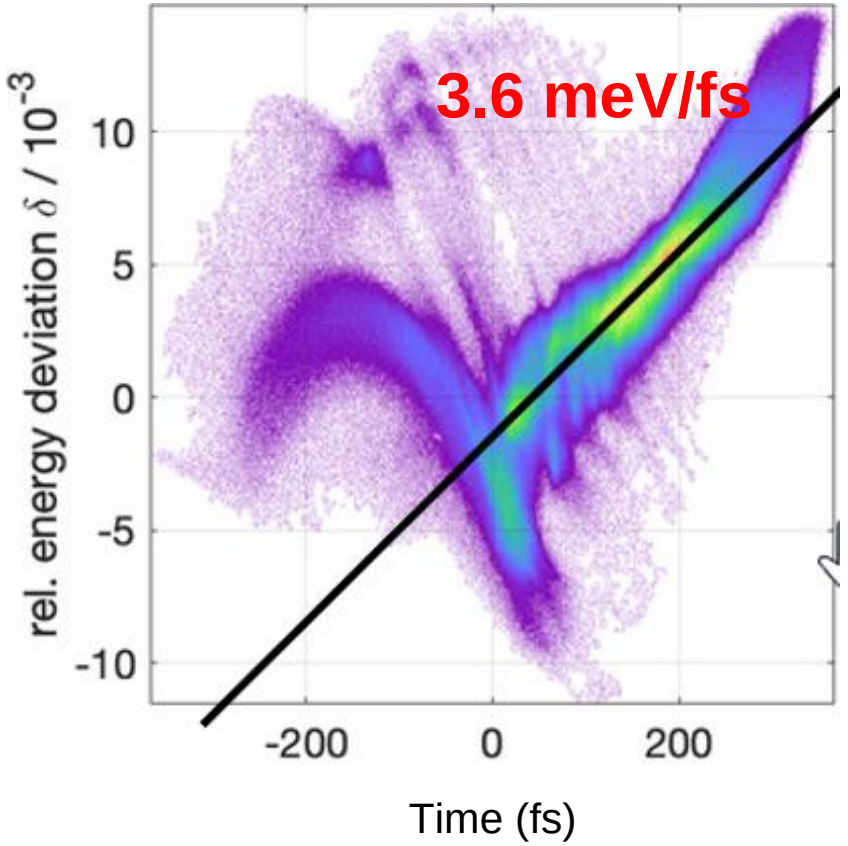
# Polarix TDS

## Predicted XUV chirp from Polarix

### Negative chirp setting

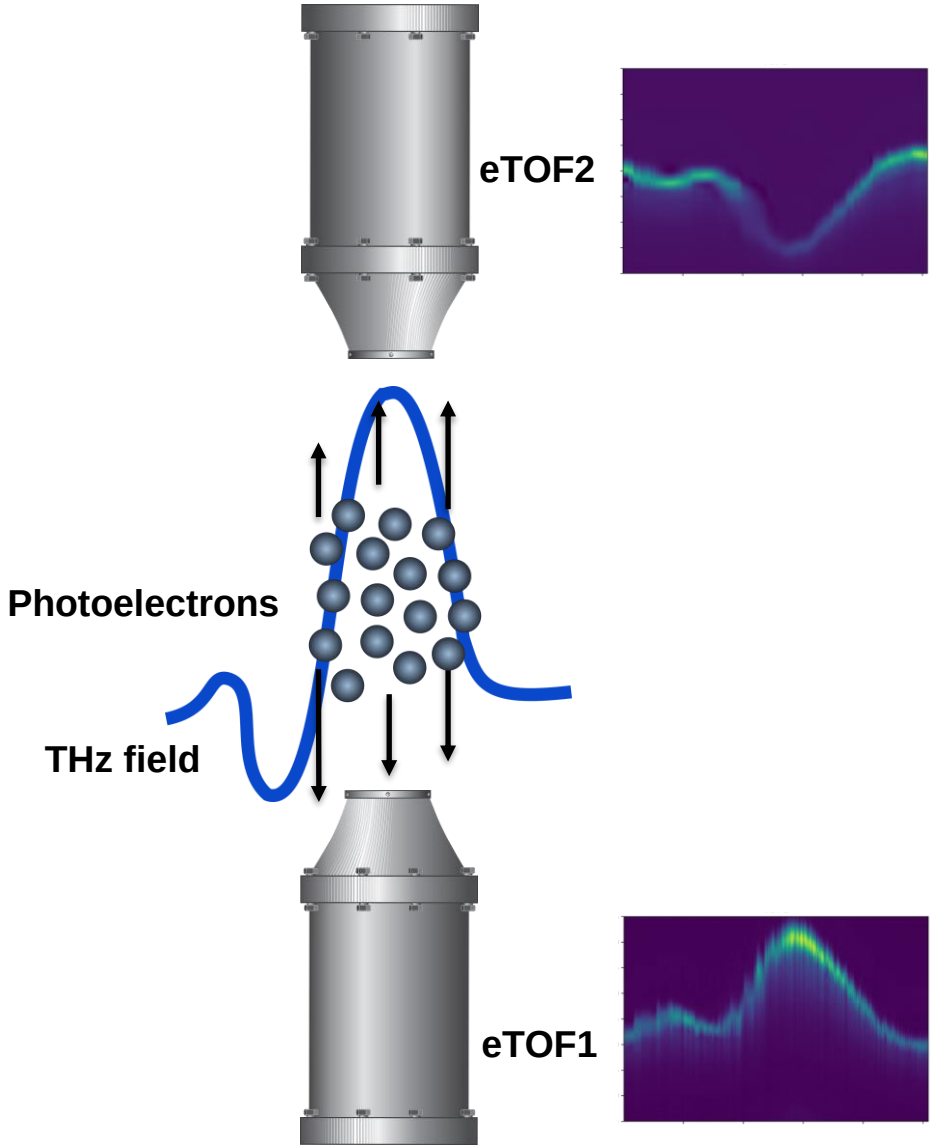



### Positive chirp setting

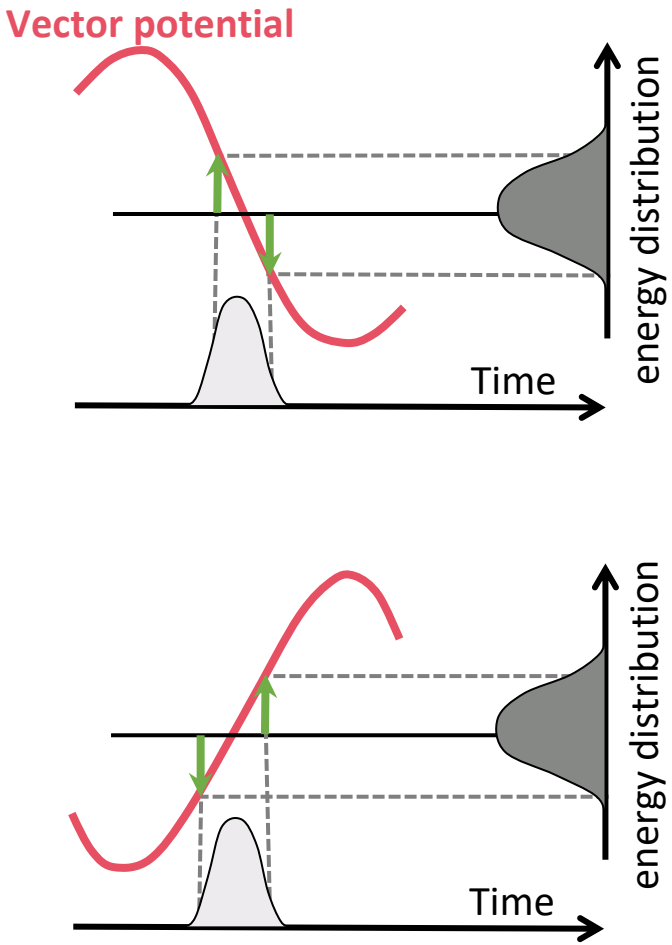



Thanks to Evgeny Schneidmiller for tuning the machine

# Linearly chirped FEL

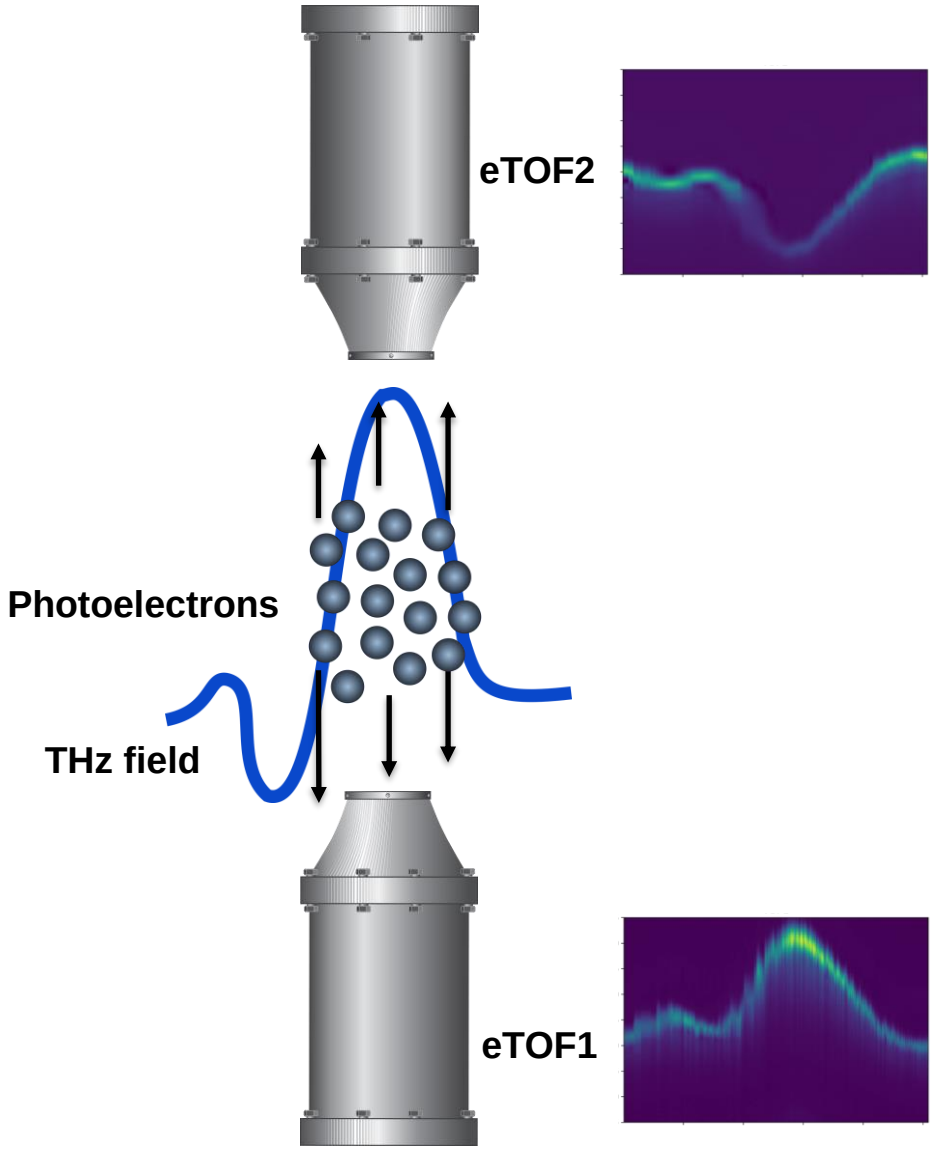



## 1) No XUV chirp

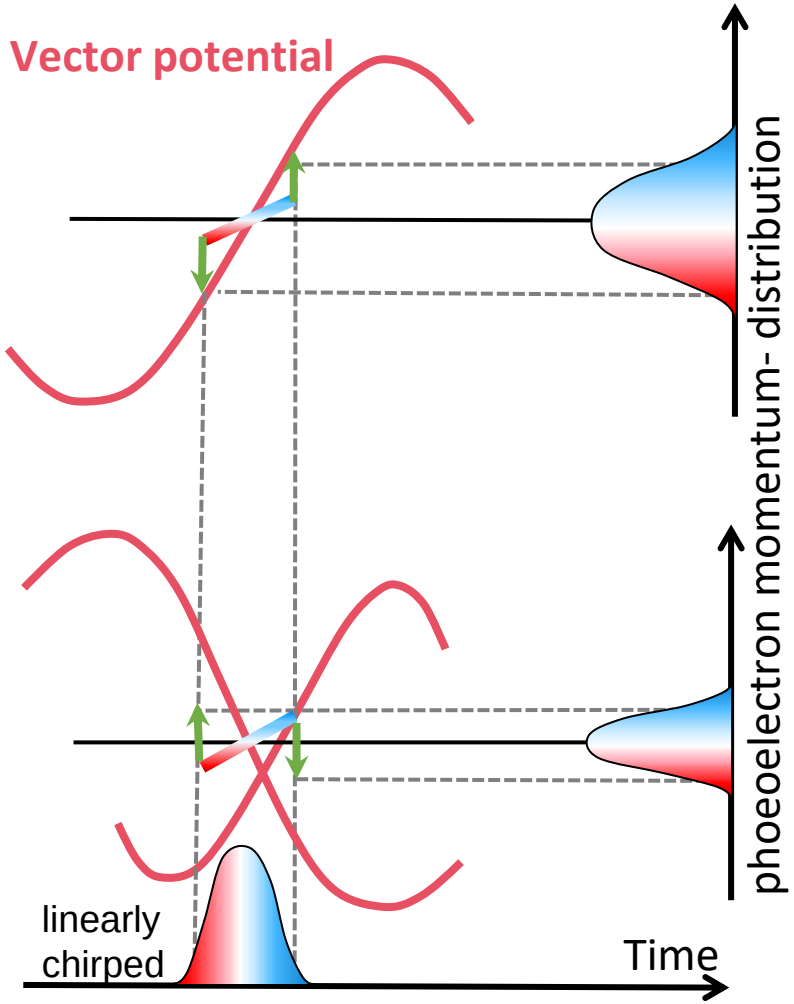



Courtesy: Ivette J Bermudez

# Linearly chirped FEL




## 2) Linearly chirped

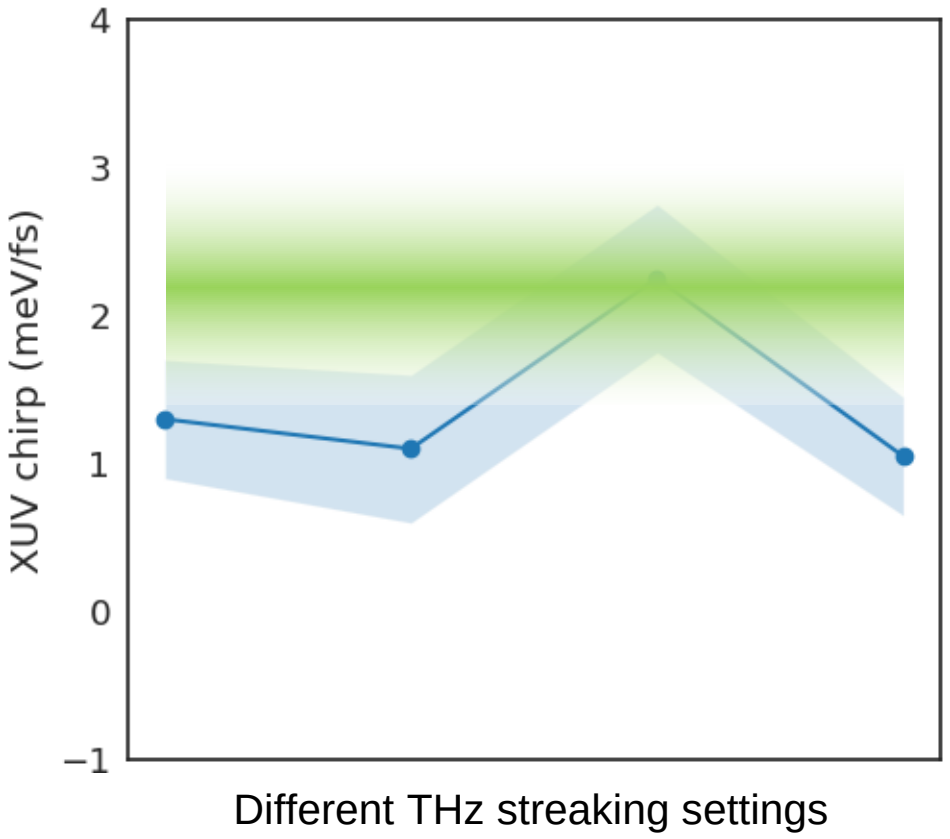



Courtesy: Ivette J Bermudez

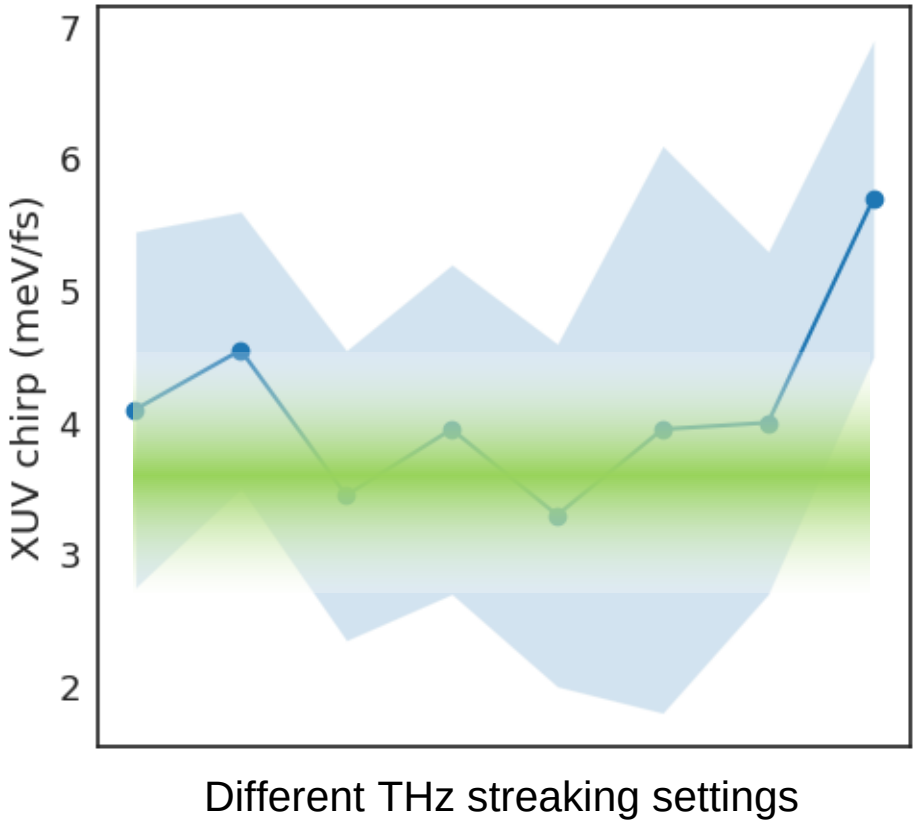
# Comparison TDS vs THz streaking

## Analysis in progress

### Negative chirp setting




### Positive chirp setting




THz streaking measurements

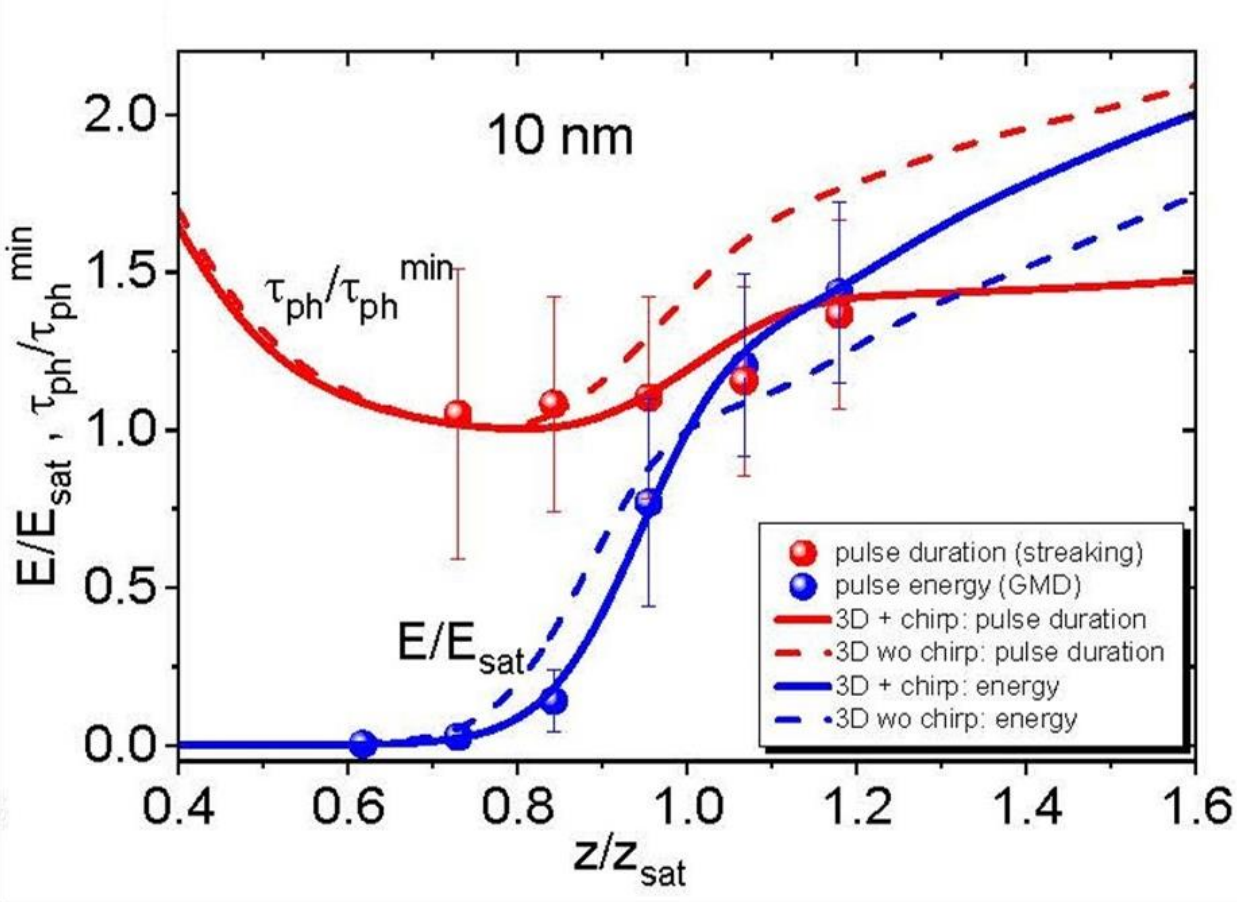
Polarix measurements

# Evolution of pulse energy and pulse duration

## The so-called gain curve measurement

- Evolution of the pulse duration and pulse energy along the undulators.
- Experimental result is compared with time-dependent FEL simulation (FAST code) with and without chirp.
- Energy chirp in the simulation was set such that the bandwidth was 1 percent.

Electron energy = 1 GeV (energy spread of 0.2 MeV rms)
Radiation wavelength = 13.5 nm
Lasing fraction of electron bunch = 16 fs rms




Energy chirp along the lasing fraction is mainly formed by the longitudinal space charge field
In this case, electrons in the head of the bunch have higher energies with respect to the tail.
(This is equivalent to the positive undulator tapering)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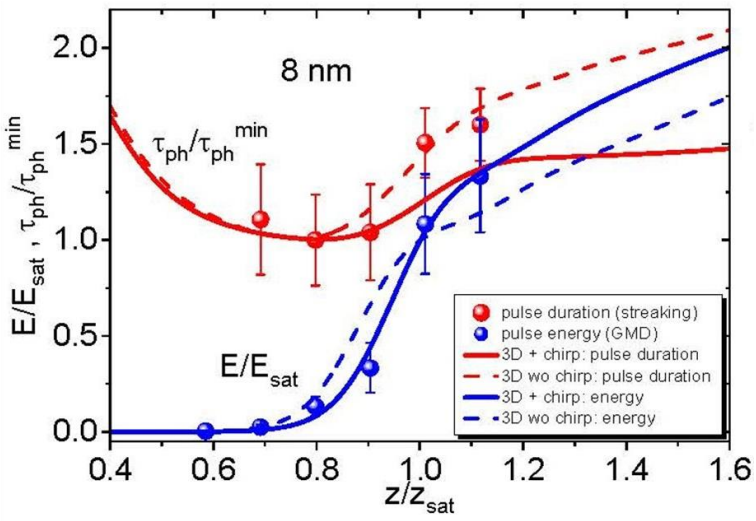
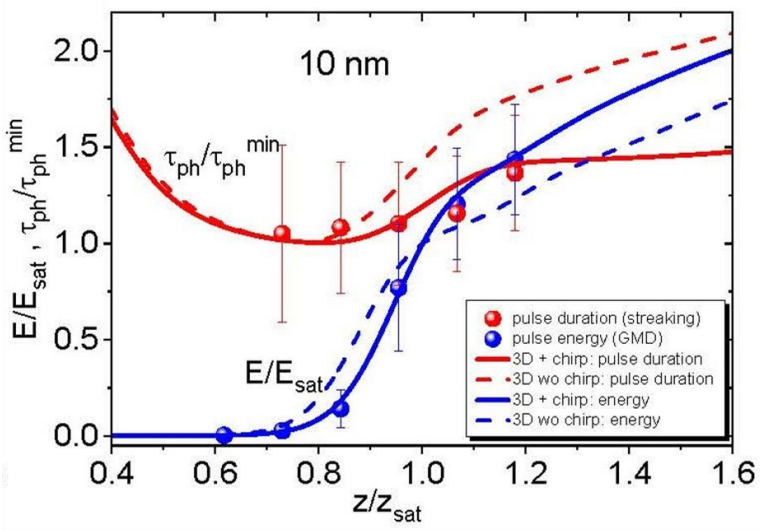
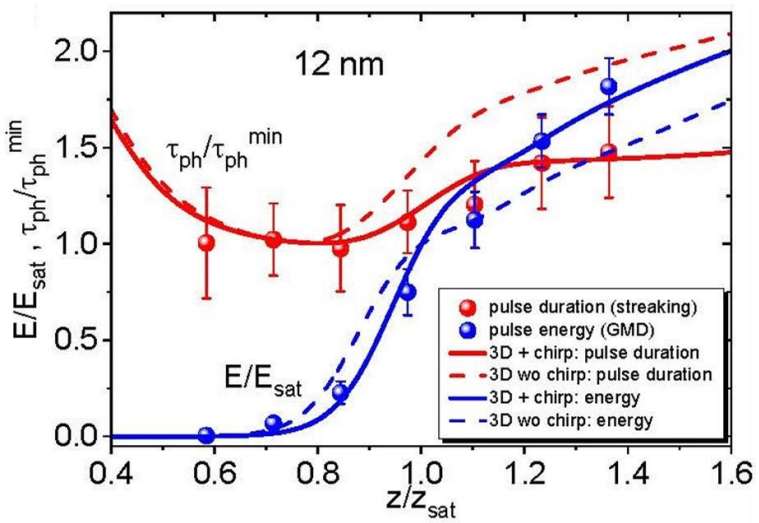
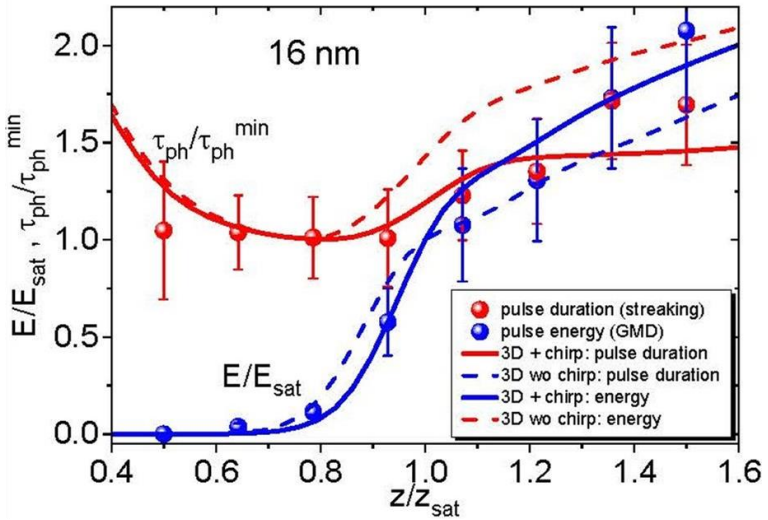
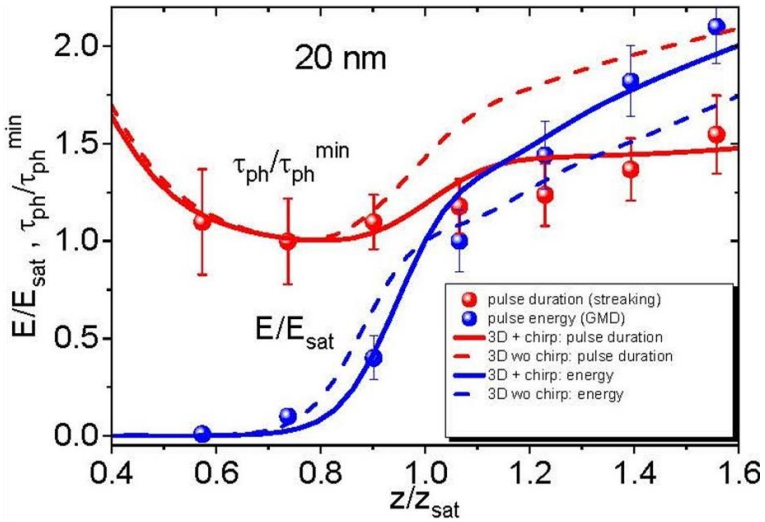
# Evolution of pulse energy and pulse duration

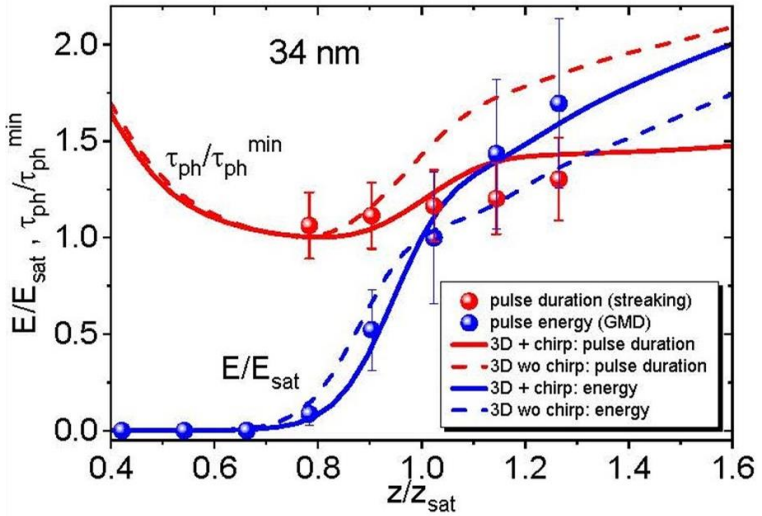
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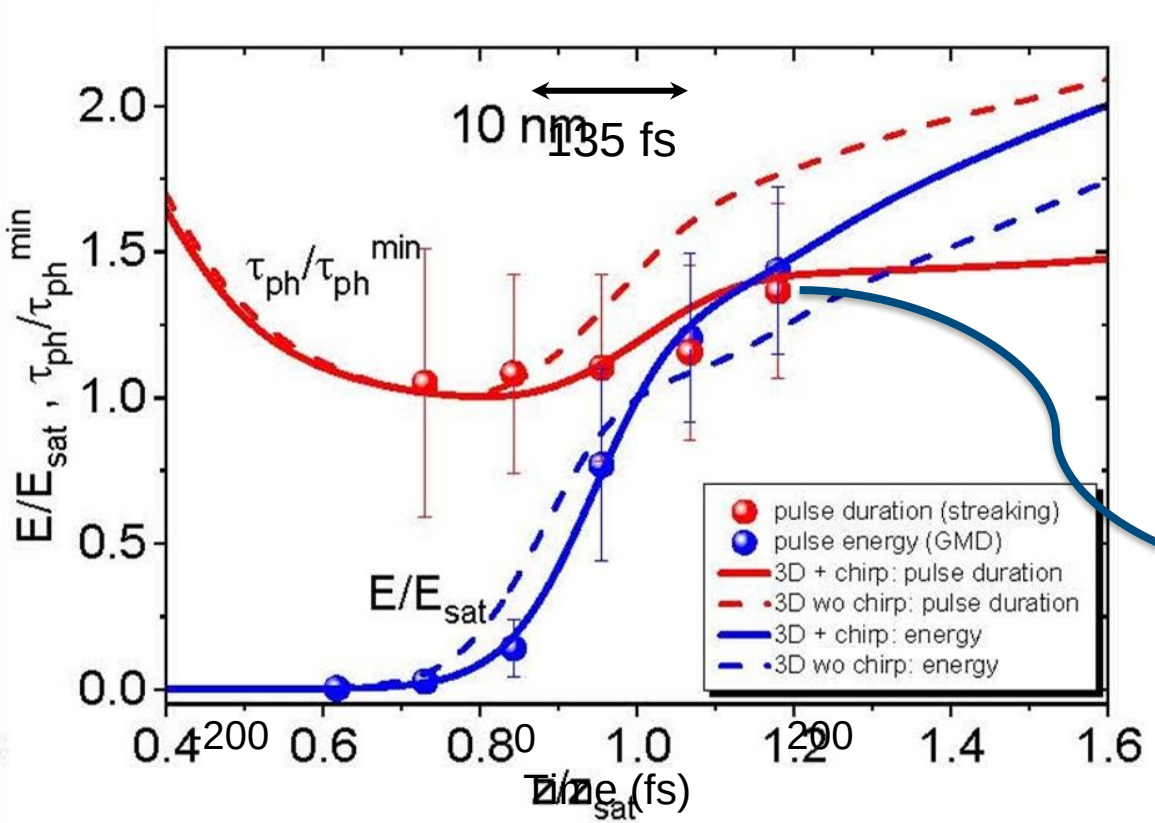
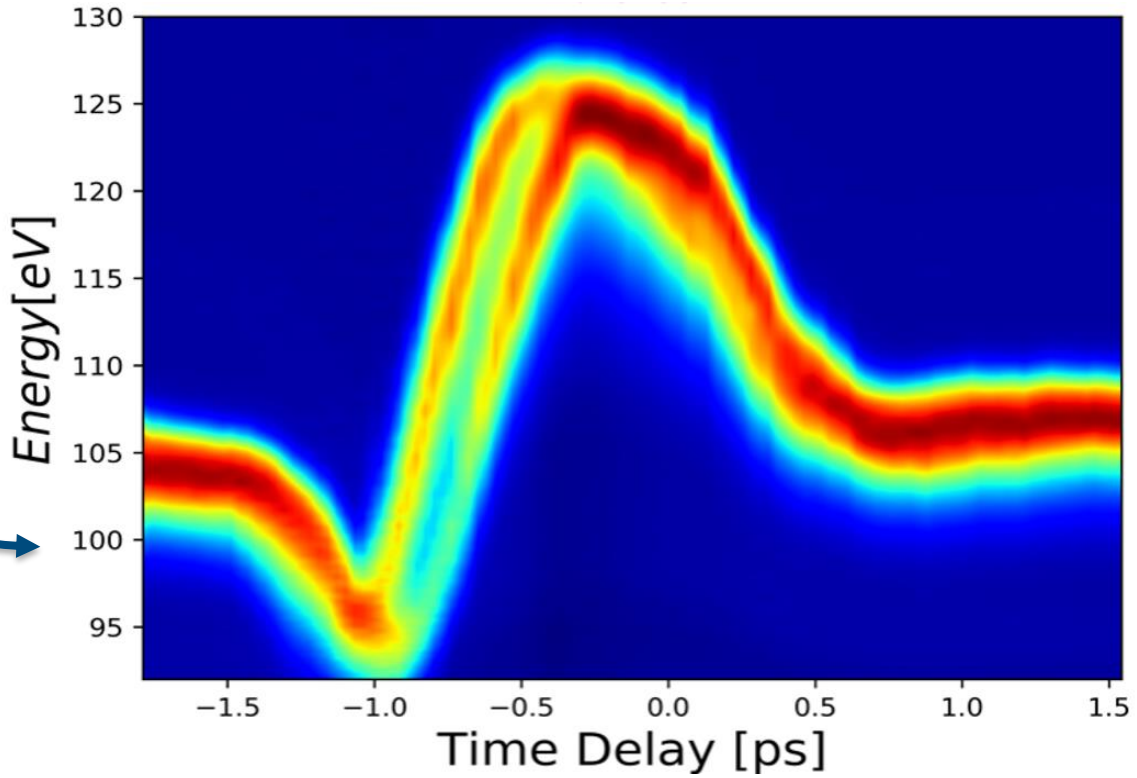
# Special operation modes

## What can happen in deep saturation

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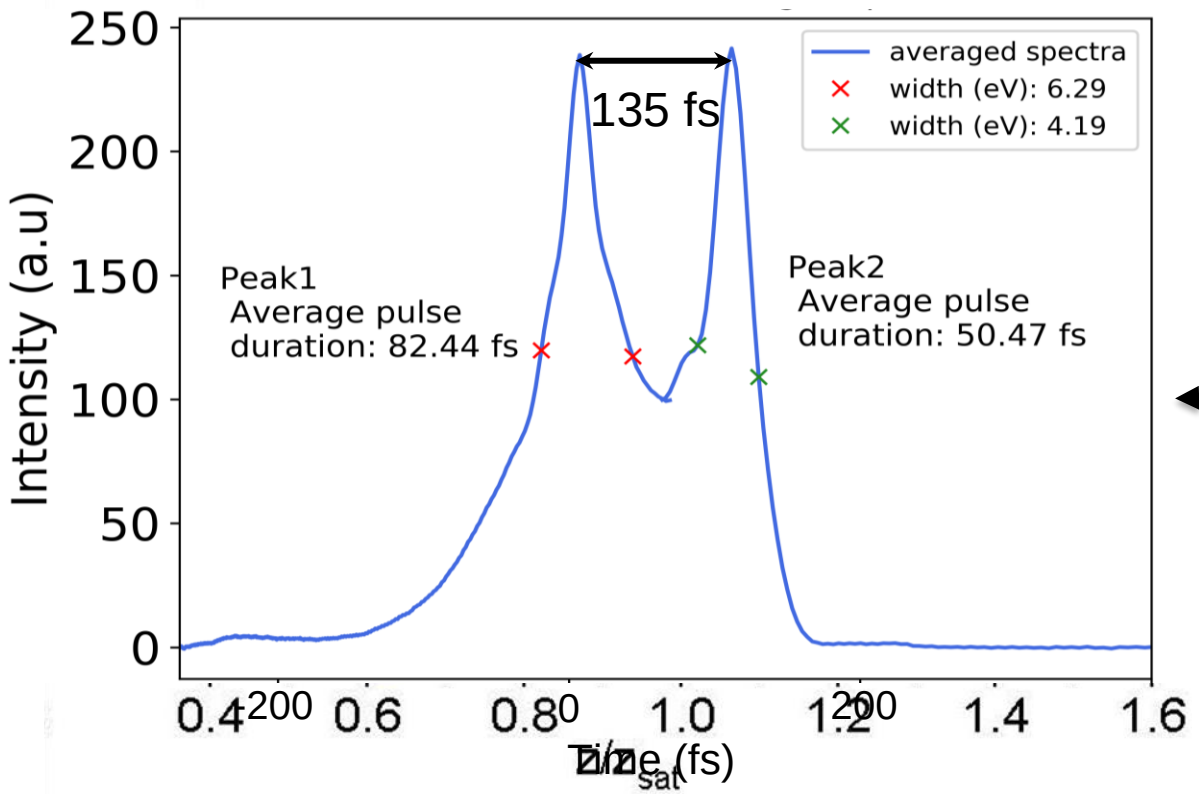
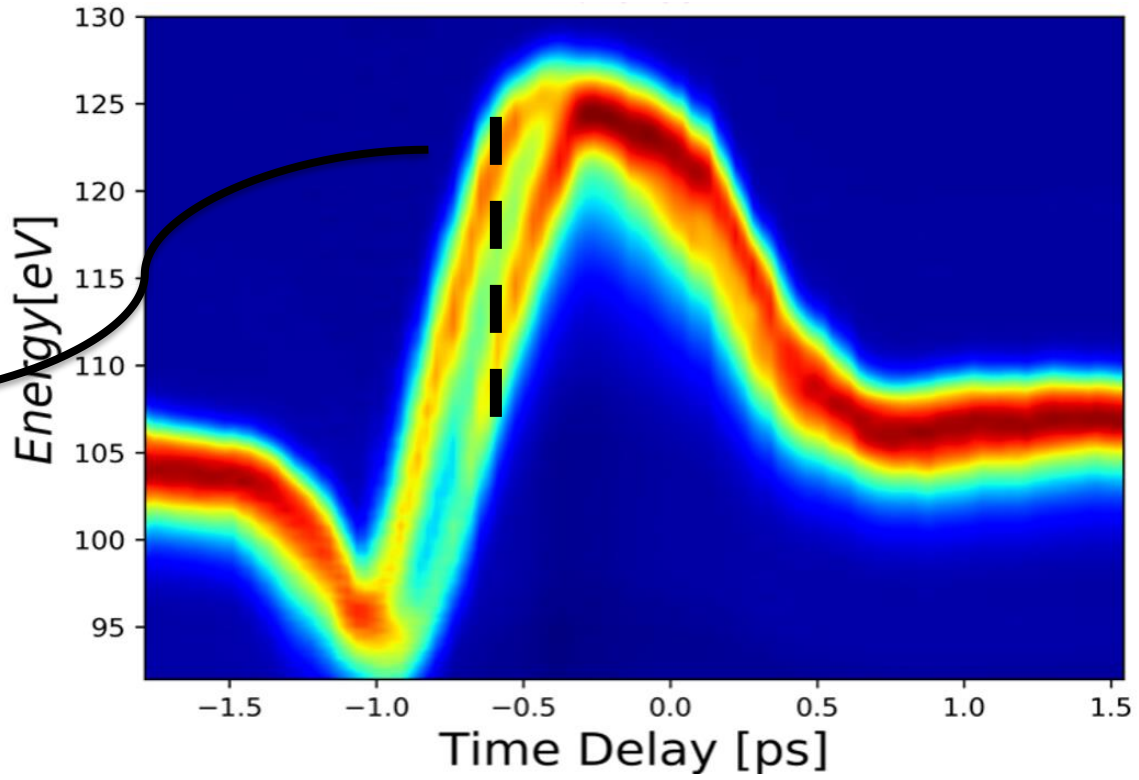
# Special operation modes

## What can happen in deep saturation

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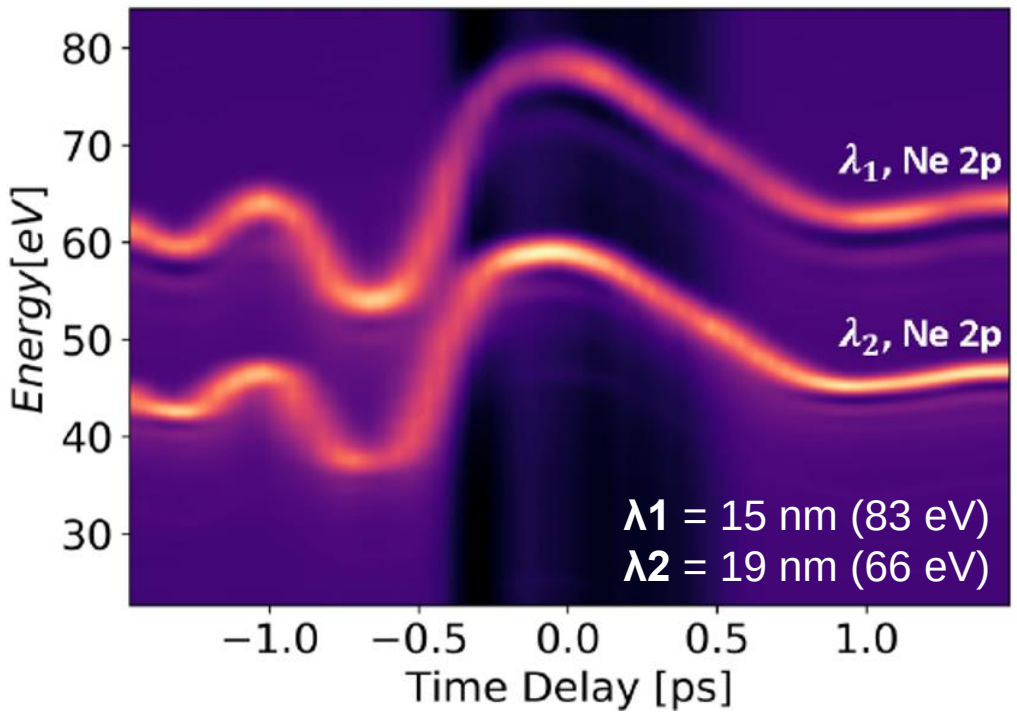
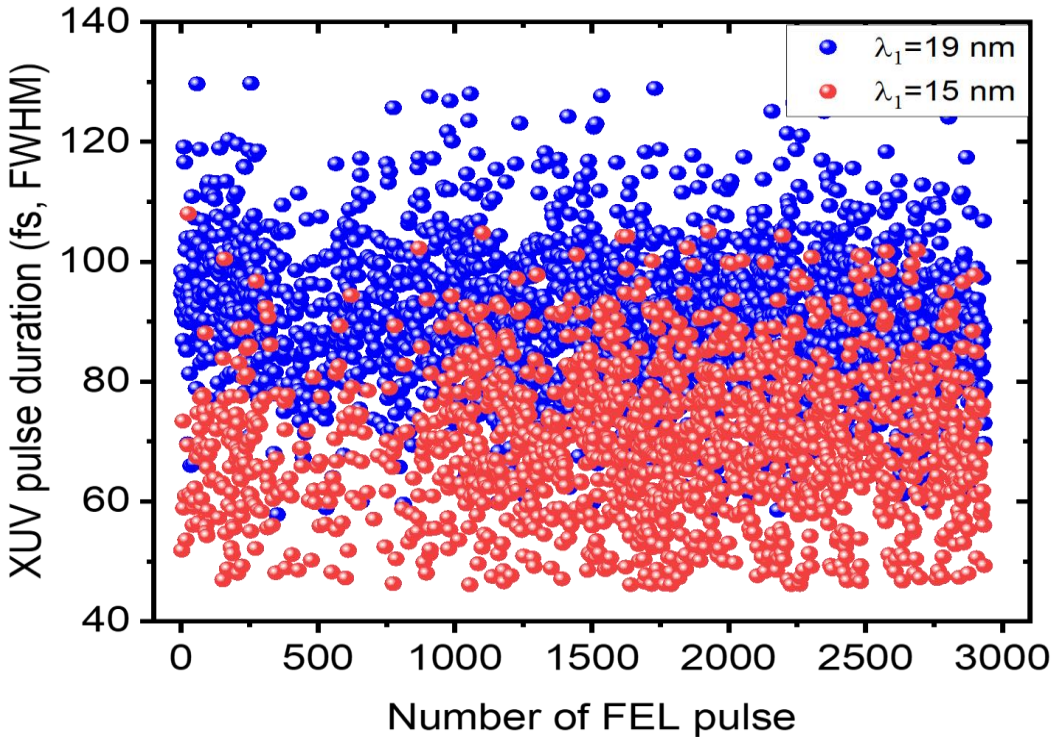
# Special operation modes

## Two-color operation mode




## Pulse duration measurement

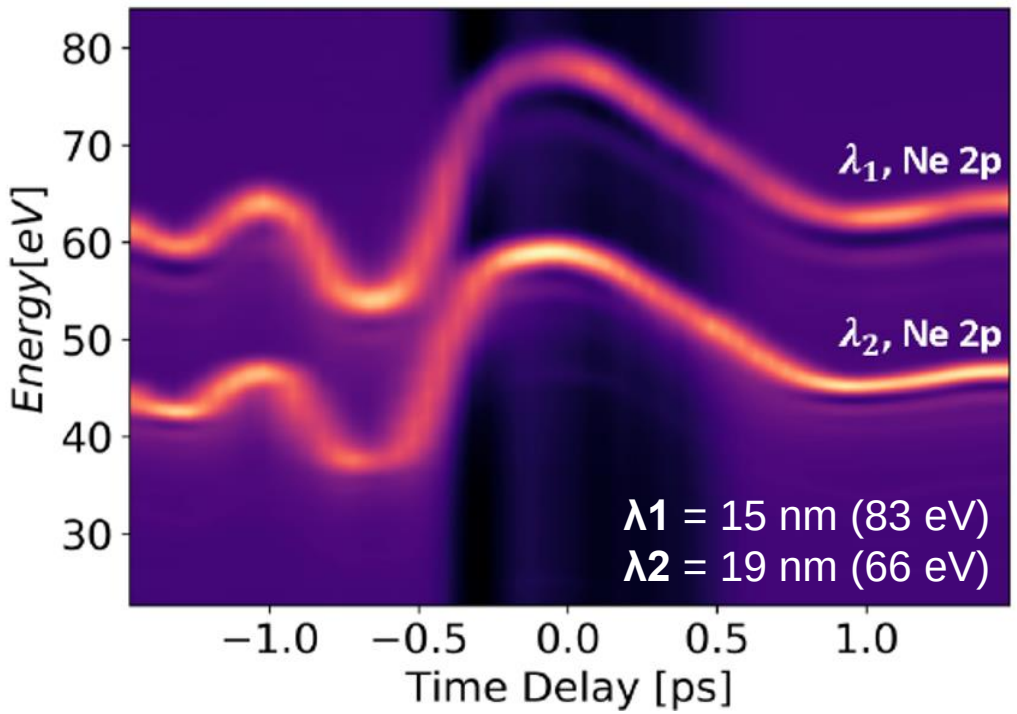



**The single-shot measurements show that the duration of the pulses with shorter wavelength is less than those with longer wavelength**

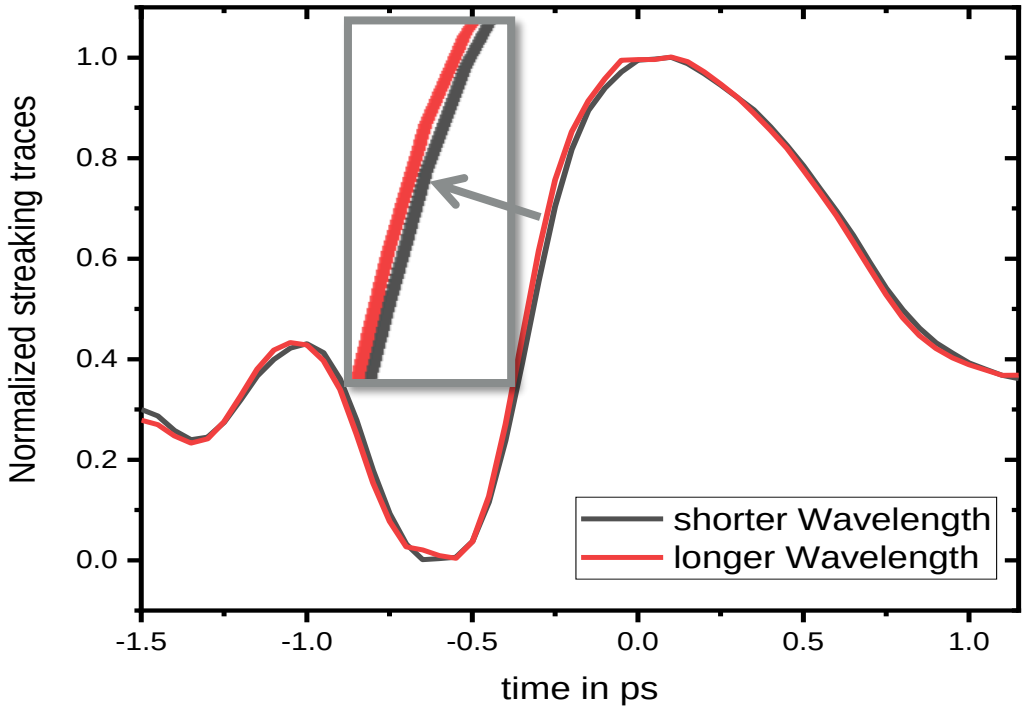
 E. Schneidmiller et al., Appl. Sci. **13,** 67 (2023)

# Special operation modes

## Two-color operation mode




## Arrival time measurement




**Longer wavelength pulses arrive on average ~ 15 fs later**

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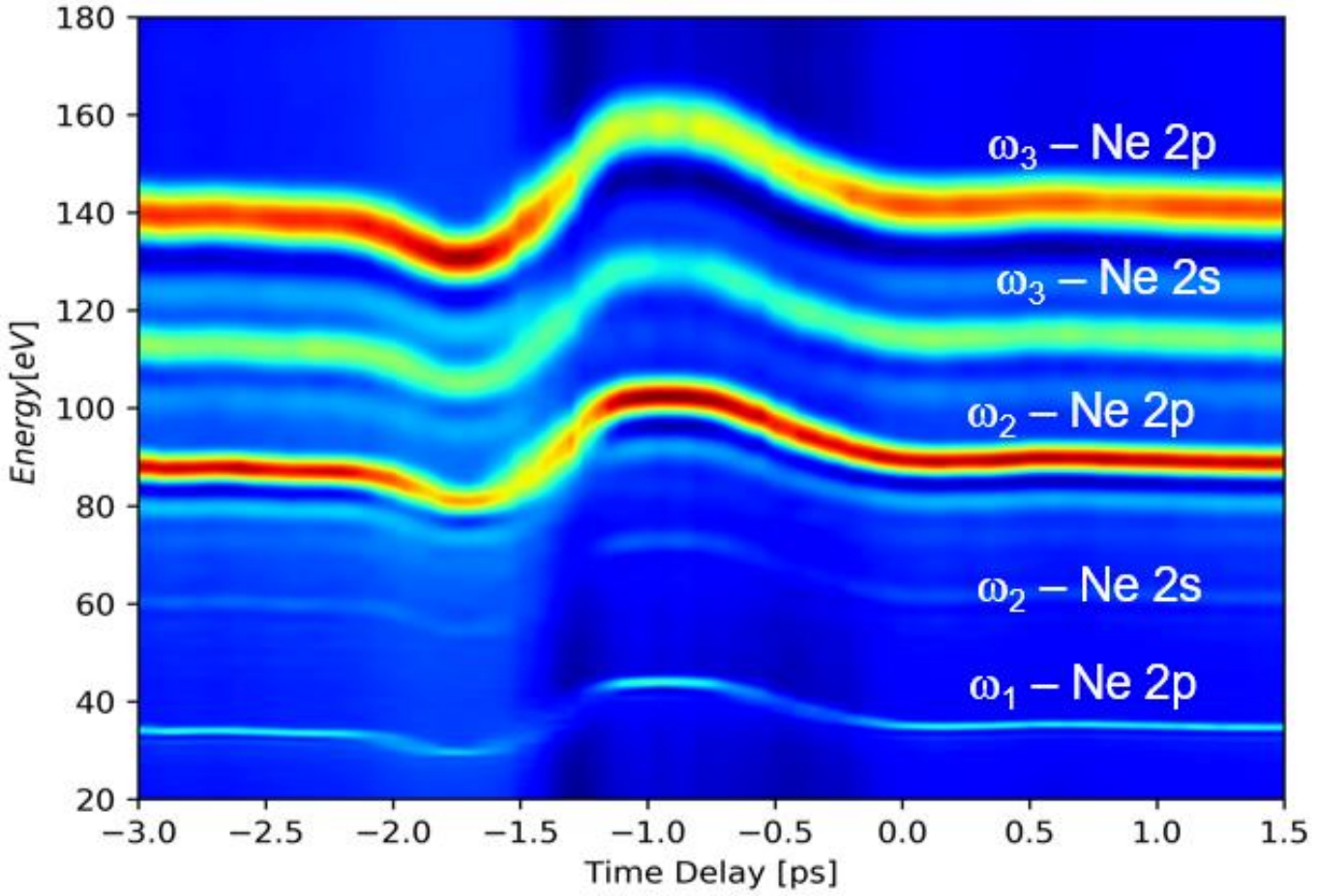
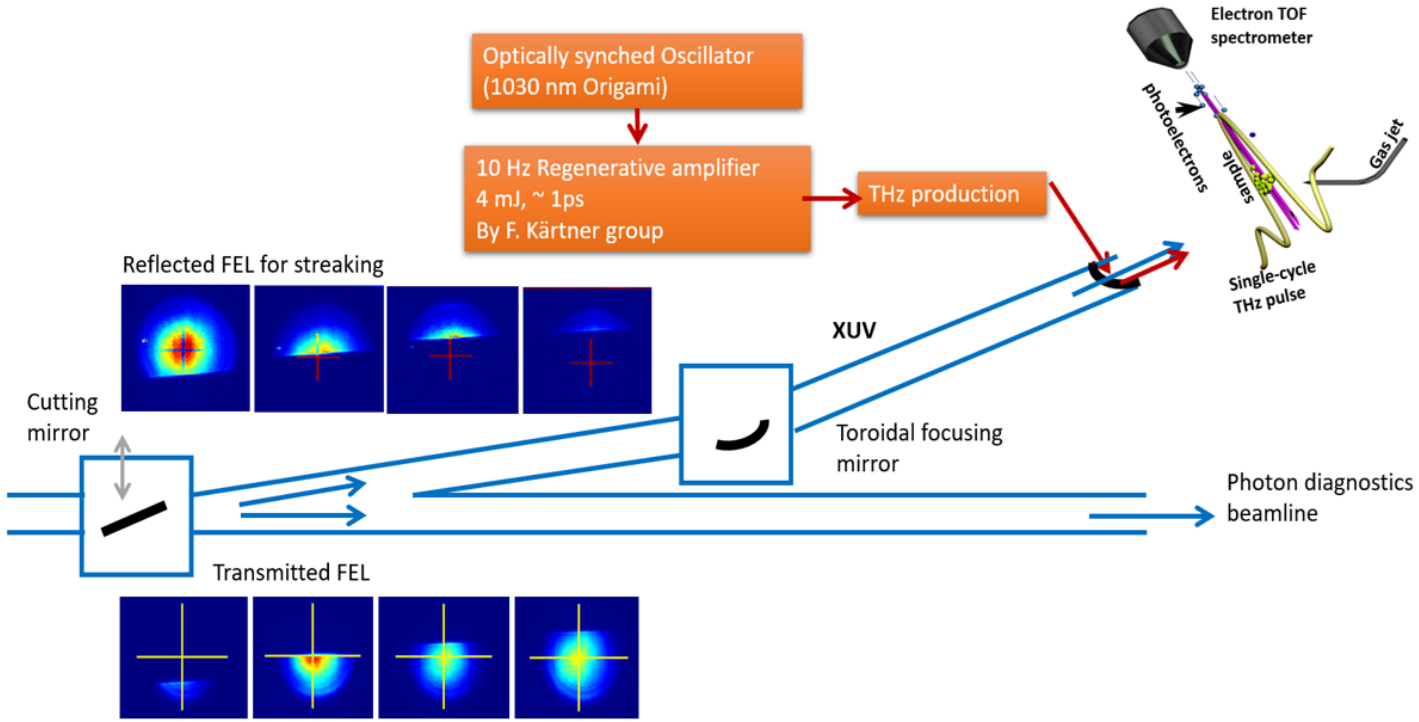
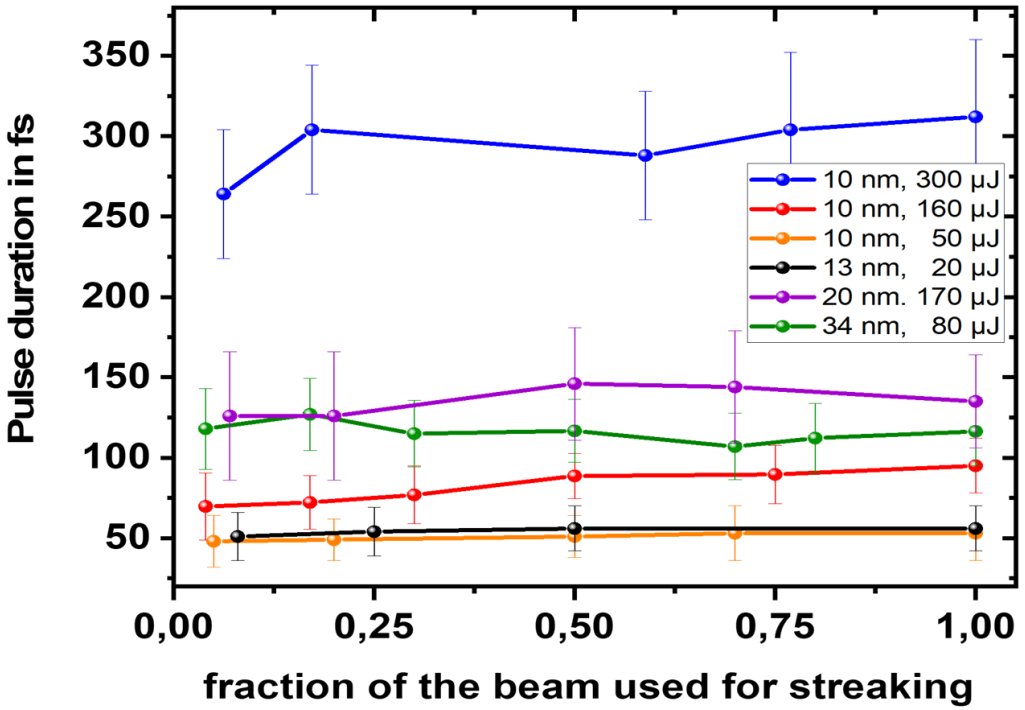
# Pulse duration of FEL higher harmonics

## Work in progress



# Plan for parasitic measurement

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# FLASH upgrade

## Extension of easurement range + parasitic measurement for FLASH2

### Current setup:

20 fs < $\tau_{FEL}$ < 300 fs (FWHM)

7 nm < $\lambda_{FEL}$ < 50 nm

### After upgrade

### (FLASH 2020+ upgrade):

1 fs < $\tau_{FEL}$ < 20 fs (FWHM) **Using angular streaking**

20 fs < $\tau_{FEL}$ < 300 fs (FWHM)

Sub-4 nm < $\lambda_{FEL}$ < 50 nm

- **THz streaking setup will be moved to the main FLASH2 beamline branch**
- **Parasitic measurement in combination with Angular streaking**

# Summary

- **Having a dedicated beamline for FEL diagnostics**
- **Single shot characterization (pulse duration, arrival time and XUV chirp) of SASE FEL pulses**
- **Comparison with BAM and Polarix TDS**
- **Good agreement with with 3D FEL simulation**
- **Parasitic measurement**

## Future plans

- **Move to main FLASH2 beamline branch for parasitic measurement (in combination with angular streaking)**

# Thank you for your attention!


## Acknowledgments

S. Düsterer, R. Ivanov, I. Bermudez, M. Yurkov, E. Schneidmiller, G. Brenner, J. Roensch-Schulenburg , M. Kuhlmann, U. Frühling,  M. K. Czwalinna, M. Vogt, E. Schneidmiller, M. Brachmanski, S. Kreis, J. Müller, S. Schulz, A. L. Calendron, K. Tiedtke, M. Braune, G. Goetzke, Ch. Behrens …


J. Liu


F. Kärtner, M. Pergament, M. Kellert, S. Reuter