Pulse duration measurement: Photon based techniques

Alaa Al-Shemmary and Nikola Stojanovic

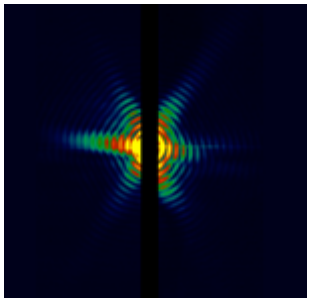
1st ARD Workshop ST3
ps-fs Electron and Photon Beams
22.08.2012

HELMHOLTZ
ASSOCIATION

DESY

Importance of the pulse duration

> **FEL characterization**



> **non-linear physics**

- **Short** (< 50 fs) pulses
- **Monitor** the pulse duration
  (average for now – substructure for future)
- Constant pulse duration over **pulse train**
- Constant over **all shifts** of the experiment

Outline

- Direct methods
  - Autocorrelation
  - Optical Cross-correlation
  - XUV reflectivity
  - THz streaking
- Indirect methods
  - Electron beam diagnostics
  - Spectral characteristics
  - Pulse energy fluctuations
  - Optical “afterburner”
- Summary and future

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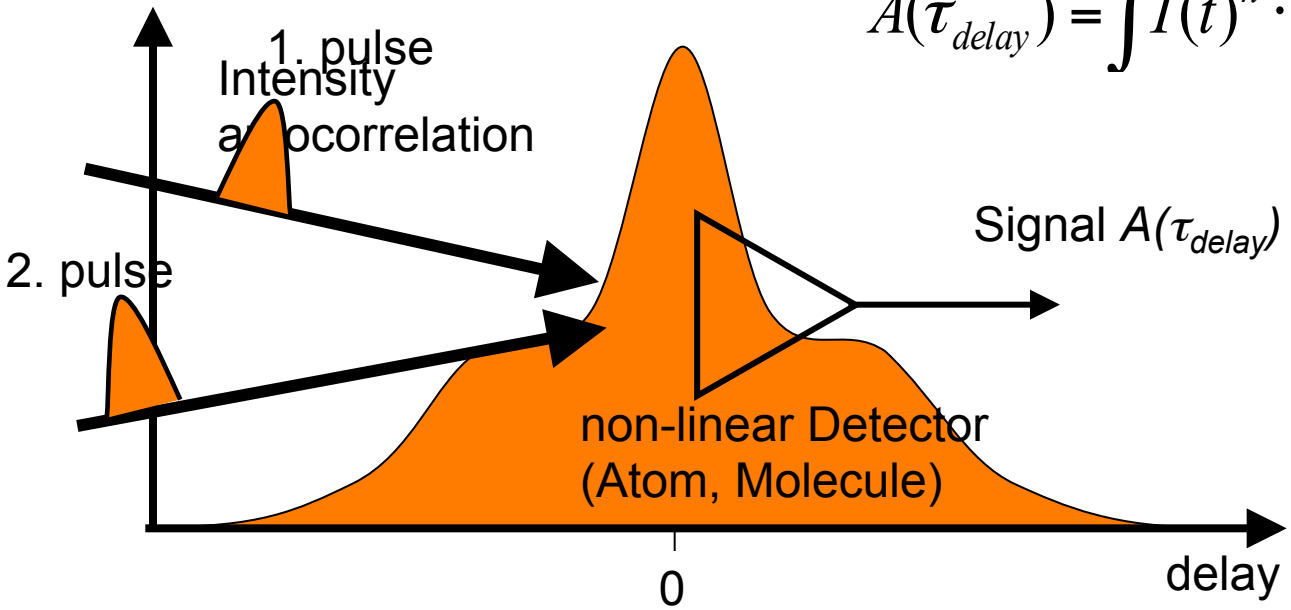
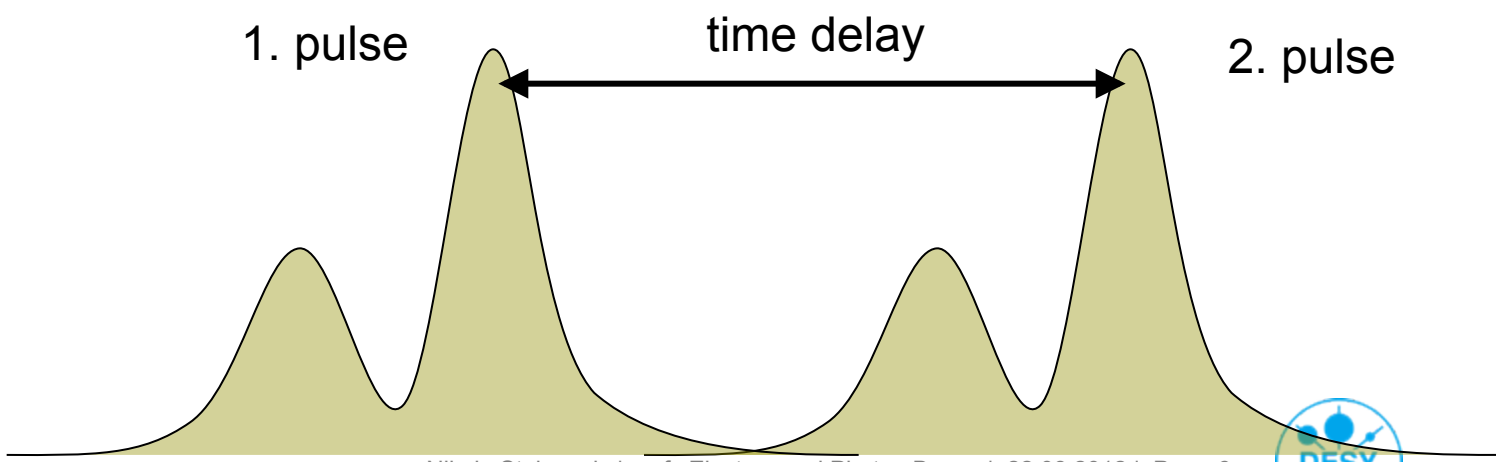
Direct methods

Direct PHOTON methods: auto correlation

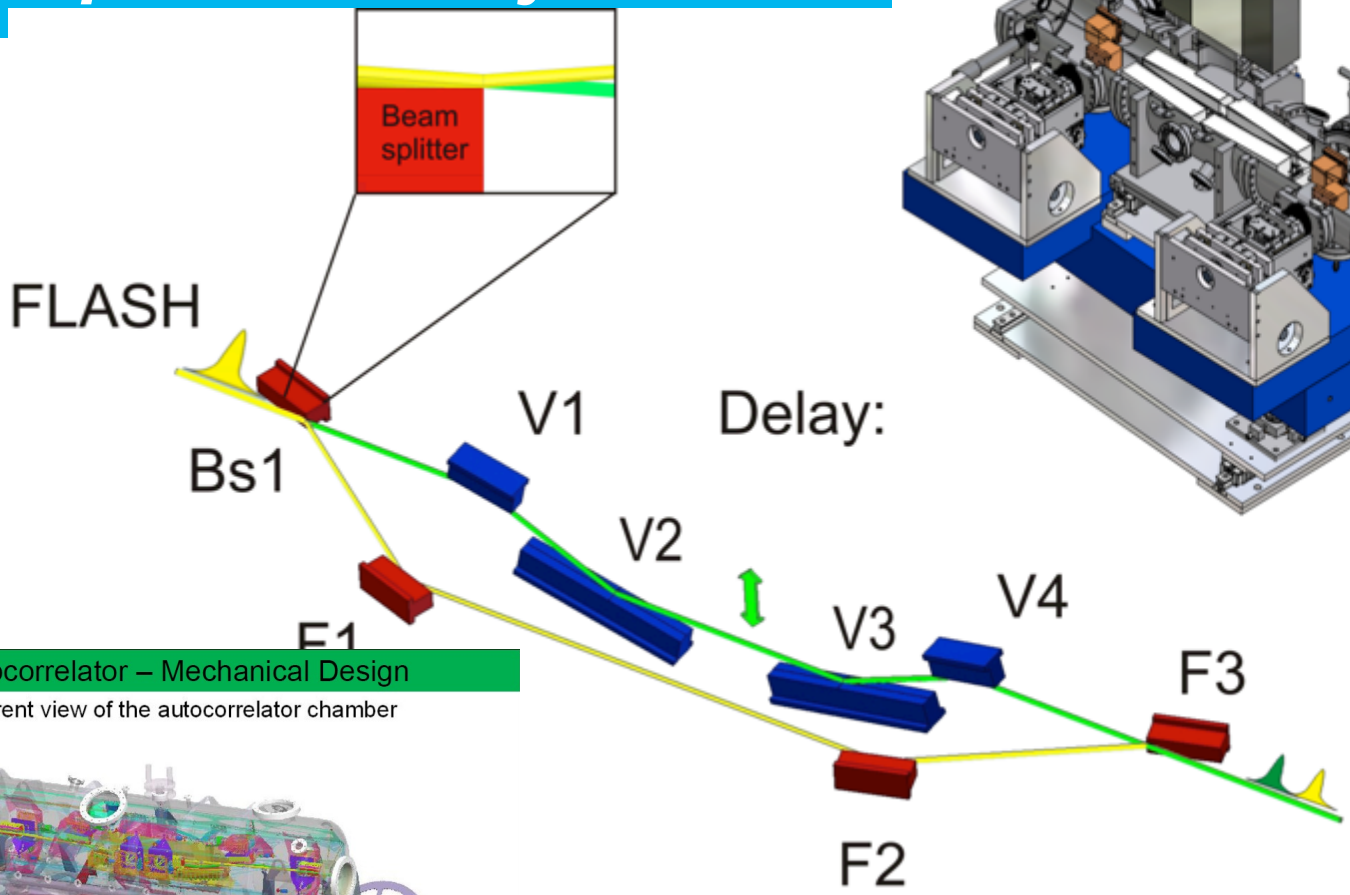
$$A(\tau_{delay}) = \int I(t)^n \cdot I^n(t - \tau_{delay})dt$$

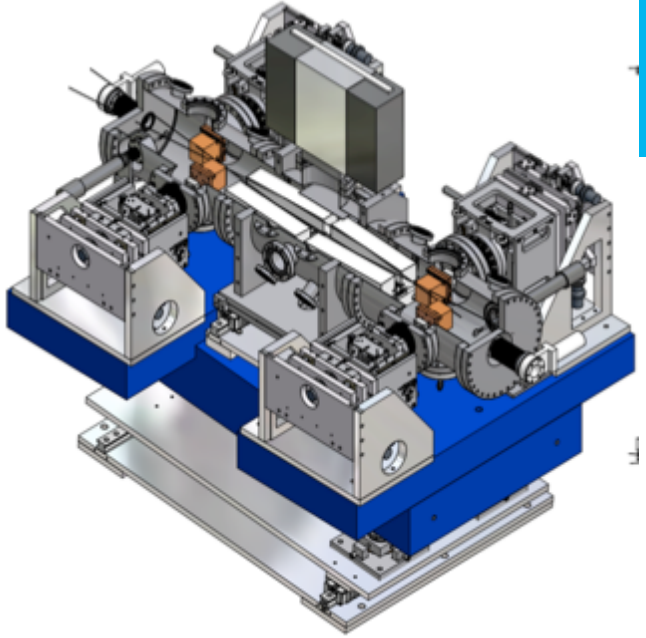




Courtesy R. Moshammer

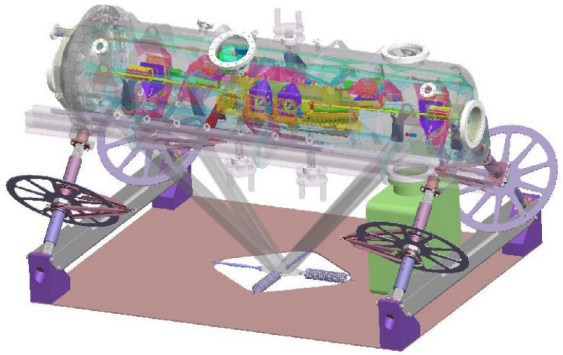
FEL split and delay





XUV-Autocorrelator – Mechanical Design

Transparent view of the autocorrelator chamber



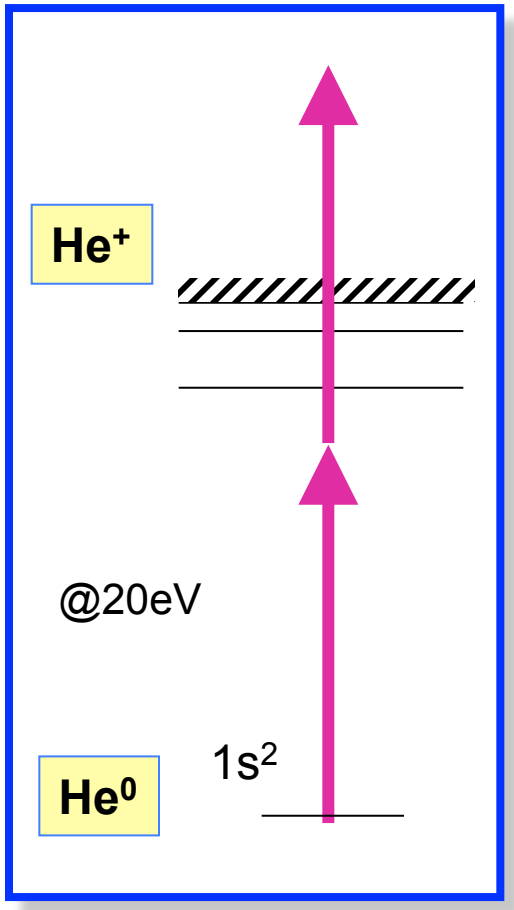
Courtesy of Tino Noll

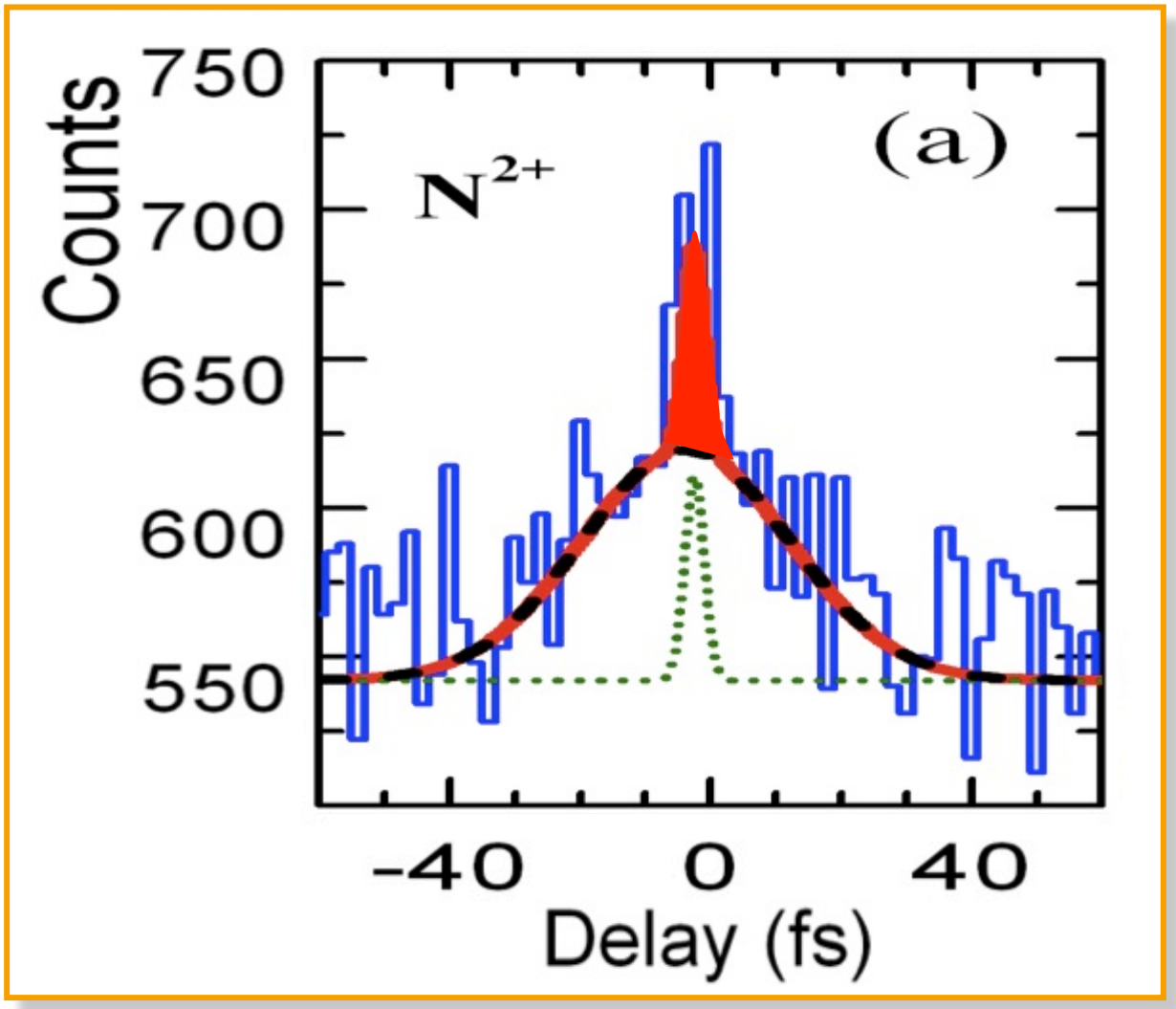
Uni Münster, BESSY, PTB, DESY

R. Mitzner, et al. Optics Express 16, 19909 (2008);

Direct PHOTON methods: auto correlation

Two-photon single ionization, Multiphoton molecule fragmentation …





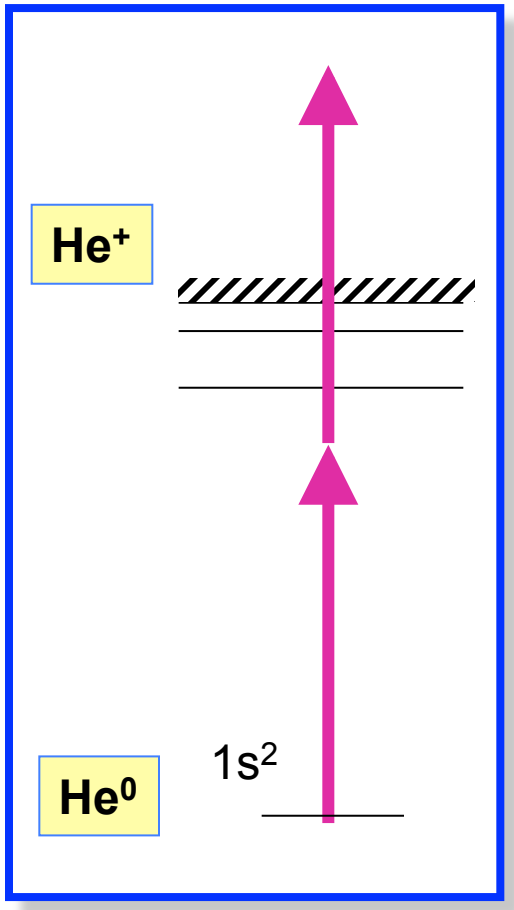
T. Pfeifer at al., Optics Lett. (2010)

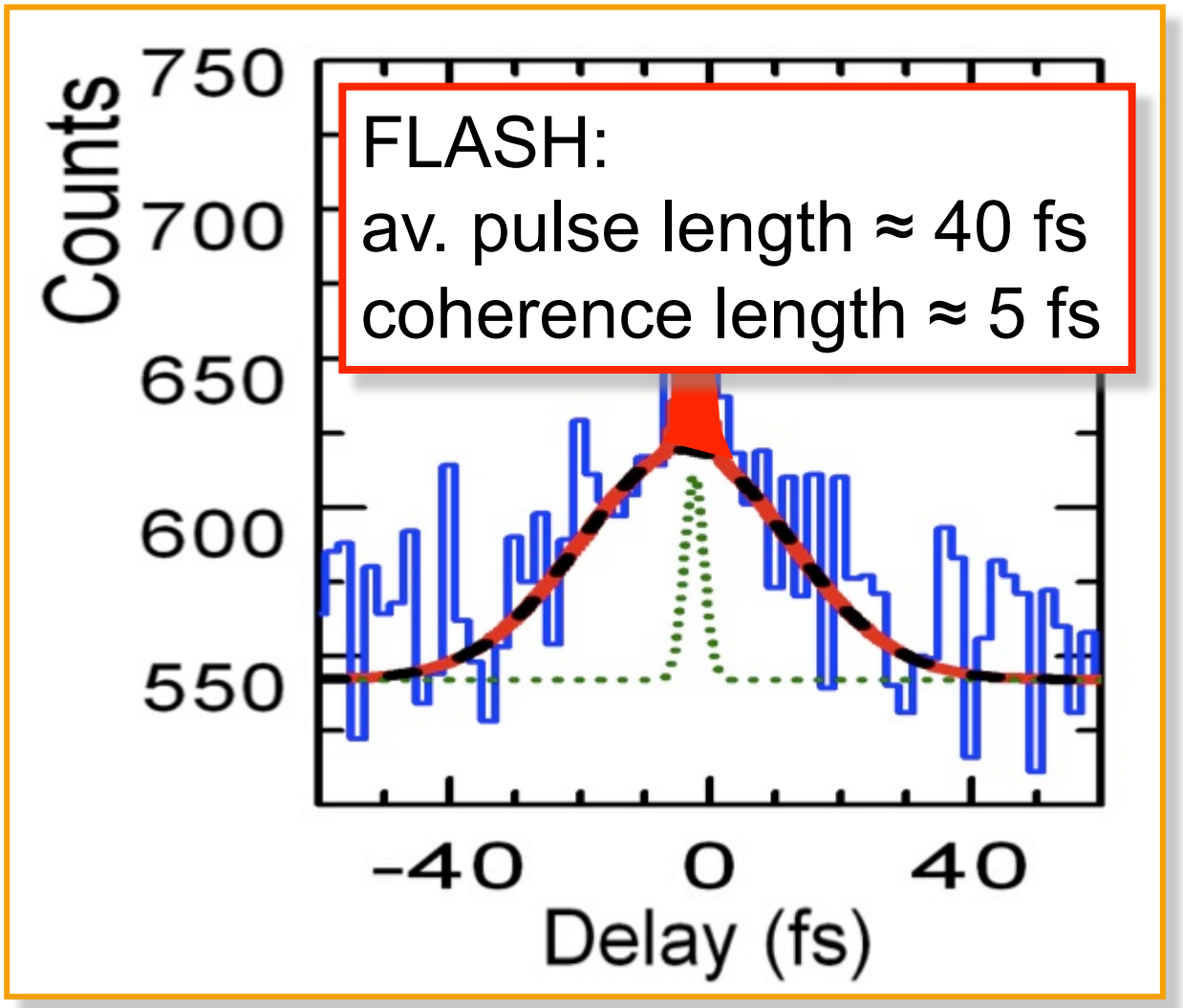
Y. Jiang et al., PRA (2010)

Courtesy R. Moshammer

Direct PHOTON methods: auto correlation

Two-photon single ionization
@ 20 eV



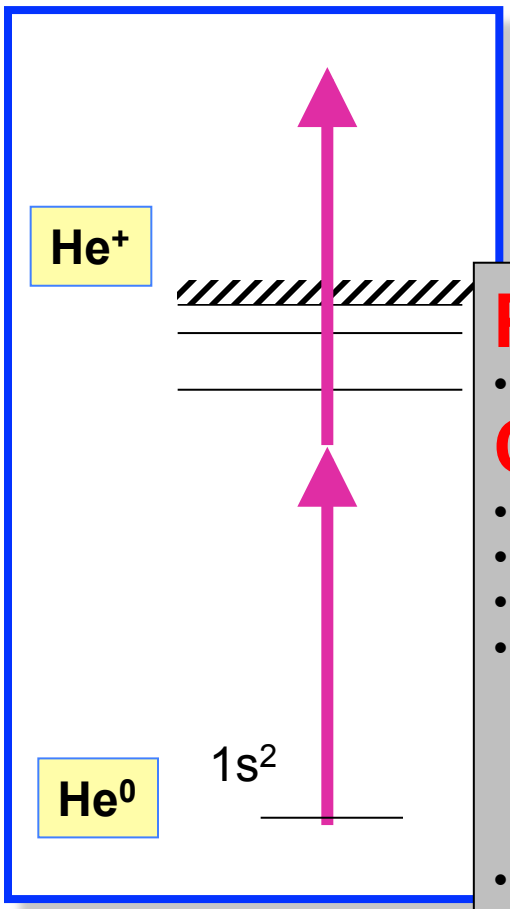


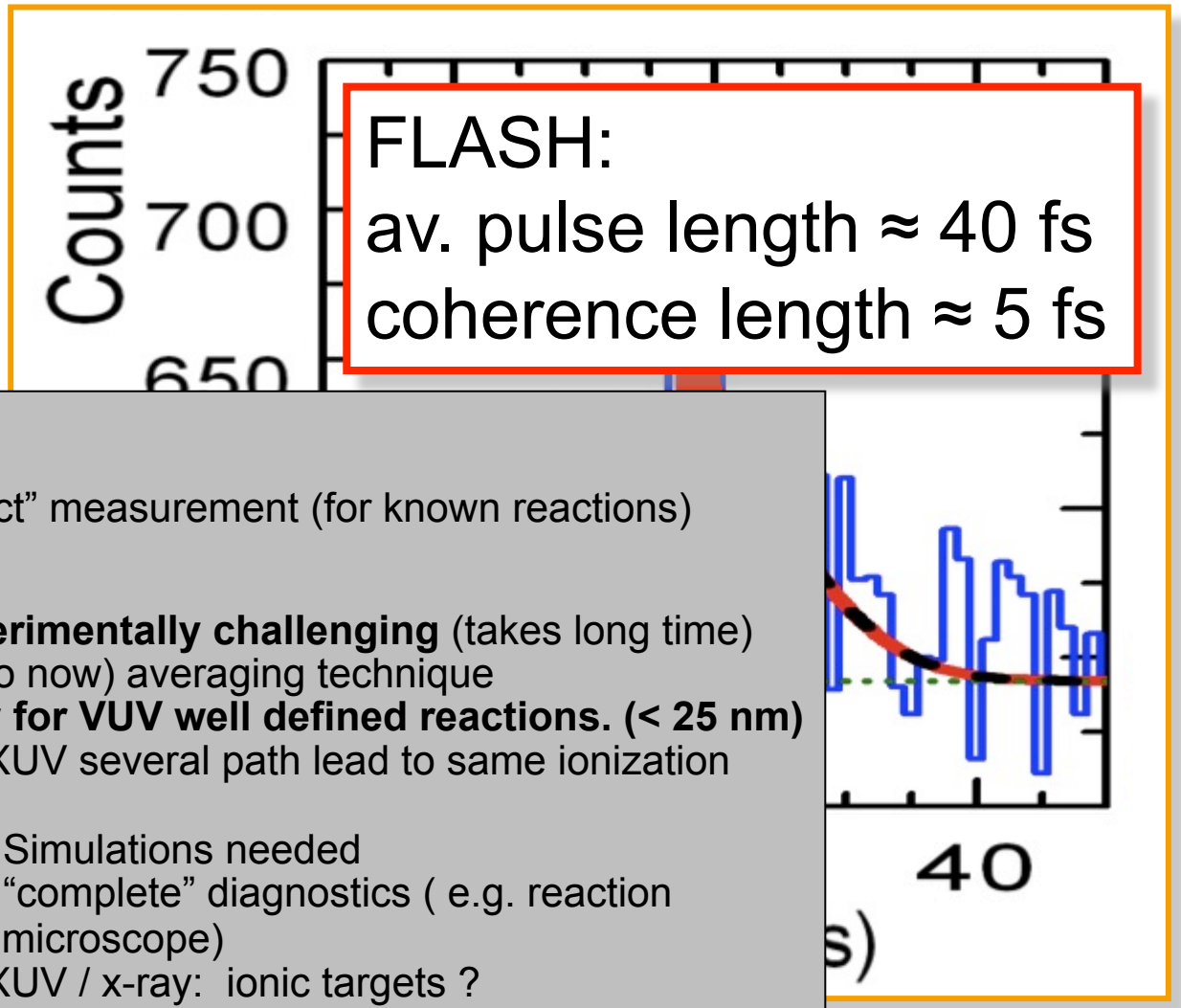
Y. Jiang et al., PRA (2010)
Courtesy R. Moshammer

T. Pfeifer at al., Optics Lett. (2010)

Direct PHOTON methods: auto correlation

Two-photon single ionization
@ 20 eV





FLASH:
av. pulse length ≈ 40 fs
coherence length ≈ 5 fs

Pro

- "direct" measurement (for known reactions)

Con

- **Experimentally challenging** (takes long time)
- (up to now) averaging technique
- **Only for VUV well defined reactions. (< 25 nm)**
- For XUV several path lead to same ionization state
  - Simulations needed
  - "complete" diagnostics (e.g. reaction microscope)
- For XUV / x-ray: ionic targets ?

Y. Jiang et al., PRA (2010)
Courtesy R. Moshammer

T. Pfeifer at al., Optics Lett. (2010)

Outline

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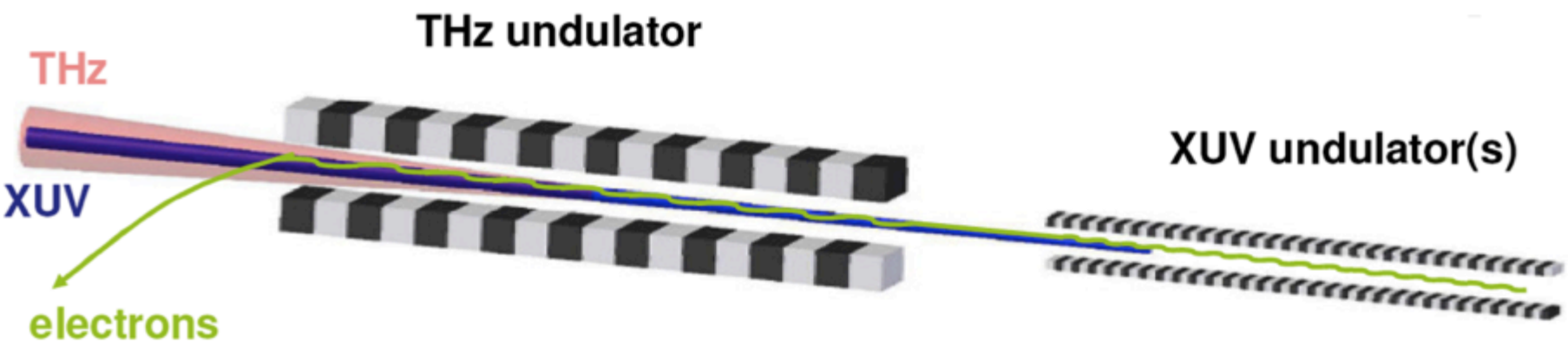
THz at FLASH – Source



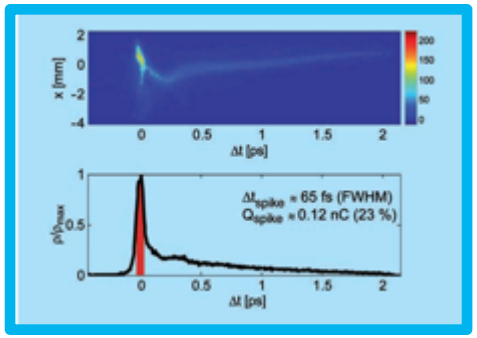
Cascaded design:

- Parasitic operation
- Synchronized to XUV pulse

Short electron bunch:

- Intensity ~ **N_e^2 (up to 70uJ)**
- Coherent and CPE stable

Tunable: (10 – 230 um)

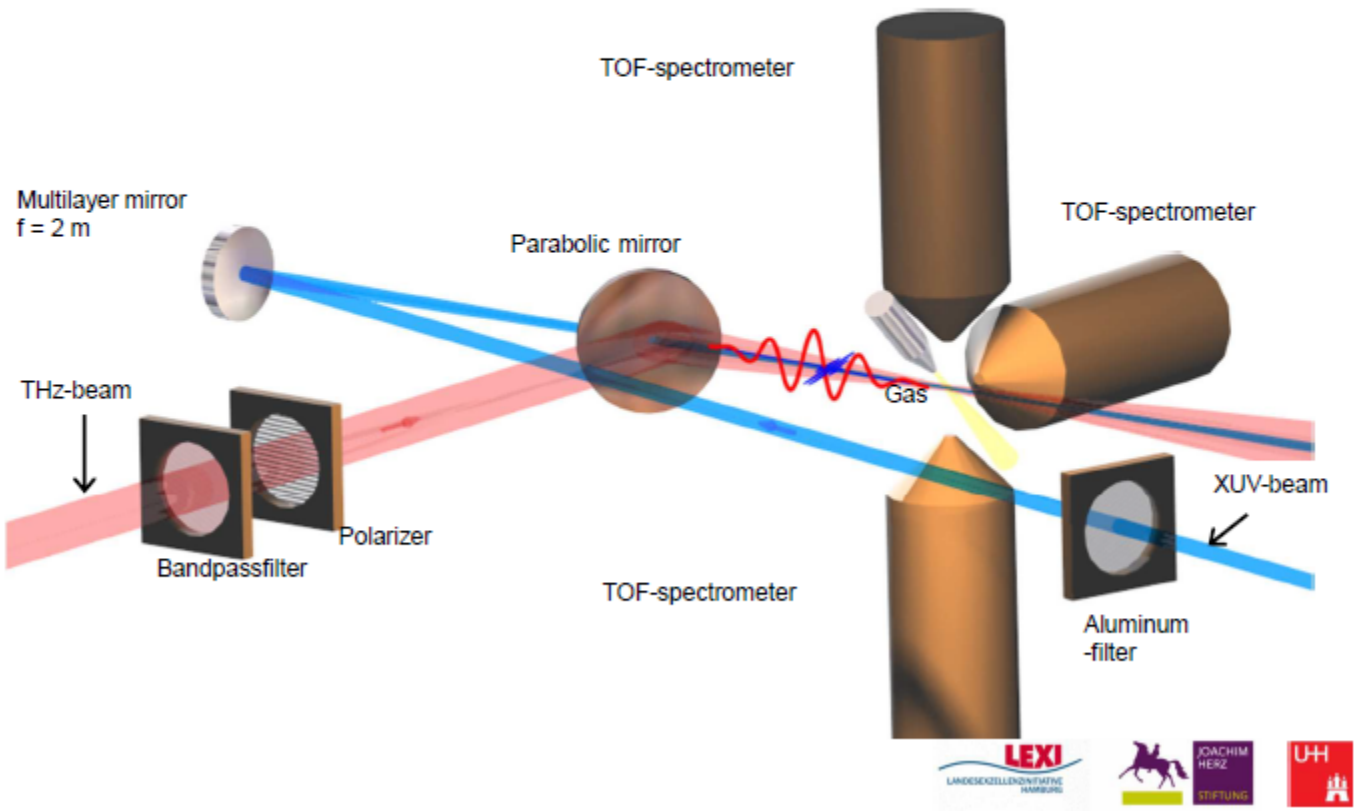


- B. Faatz et al., NIM A 475 (2001) 363.
- G. Geloni, E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov, Nucl. Instr. Method A 528 (2004) 184–188.
- Gensch, M. et al. New infrared undulator beamline at FLASH. Infrared Phys. Technol. 51, 423–425 (2008).

Direct PHOTON methods: THz streaking

THz streak camera for femtosecond XUV pulse length measurement

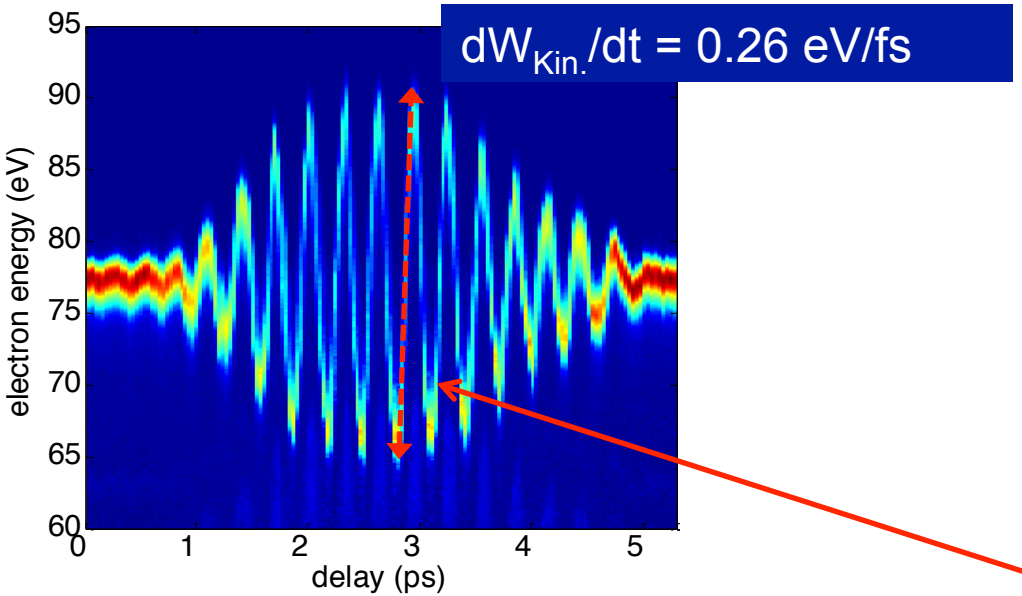
Experimental setup



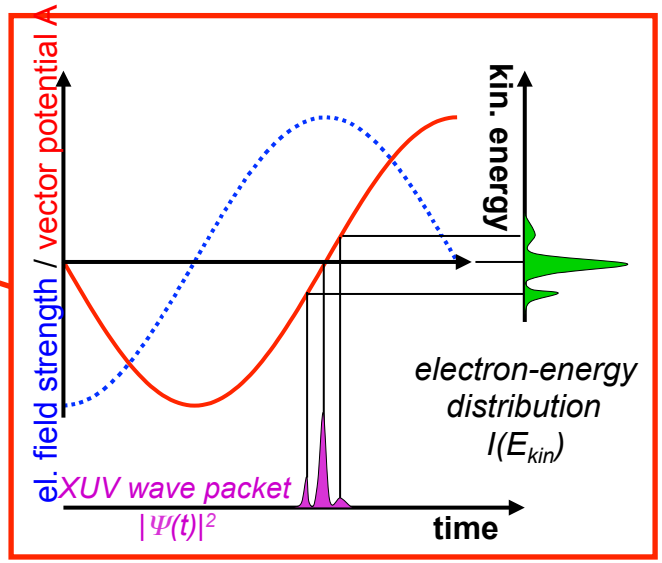
U. Frühling et al., Nature Photonics 3, 523 (2009).

Streaking with THz

with bandpass filter



FLASH @ 13.5 nm
Gas: krypton (4p)

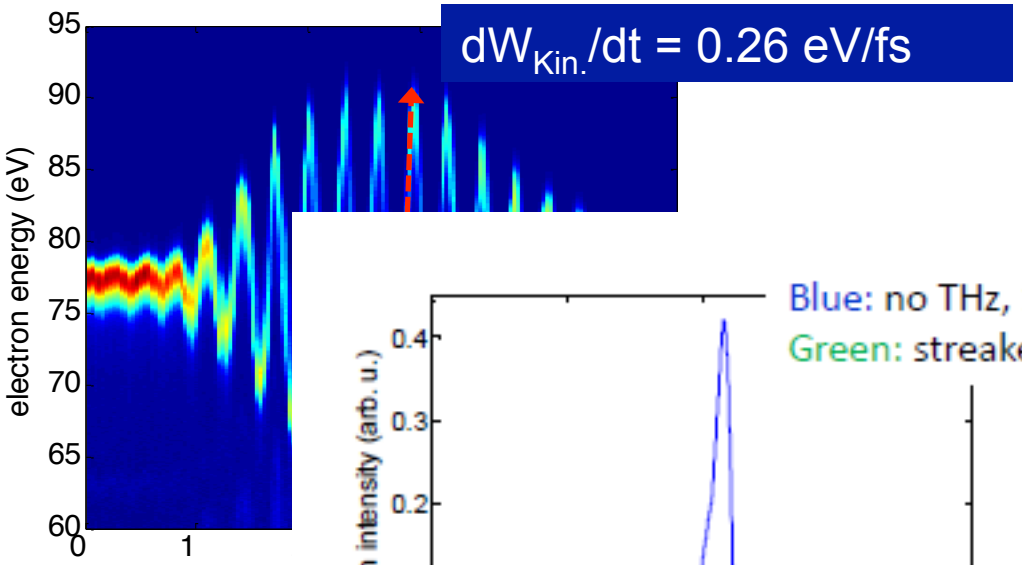


λ_{THz} = 91.7 μm
FWHM = 2.27 ps
$E_{max} \approx$ 50 MV/m
U_p = 0.26 eV

U. Frühling et al., Nature Photonics 3, 523 (2009).

Streaking with THz

with bandpass filter



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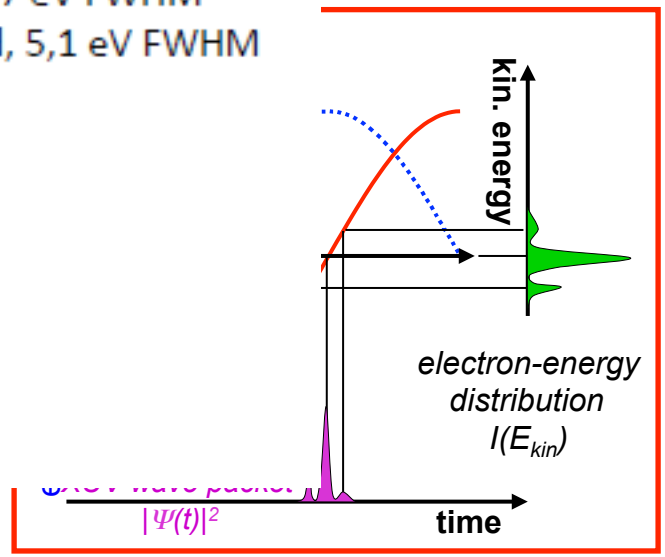
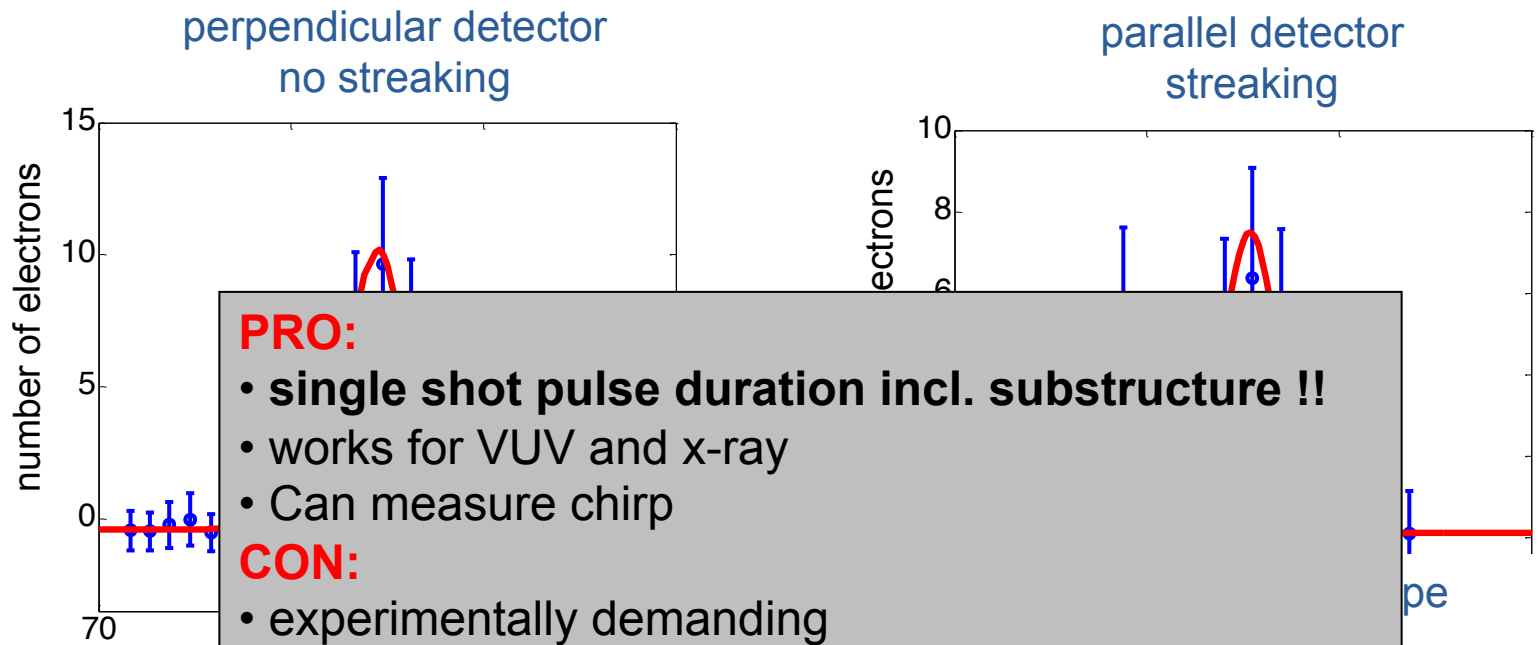


λ_{THz} = 9
FWHM :
$E_{max} \approx 50$ MV/m
U_p = 0.26 eV

U. Frühling et al., Nature Photonics 3, 523 (2009).

Pulse-shape reconstruction

B3



PRO:

- **single shot pulse duration incl. substructure !!**
- works for VUV and x-ray
- Can measure chirp

CON:

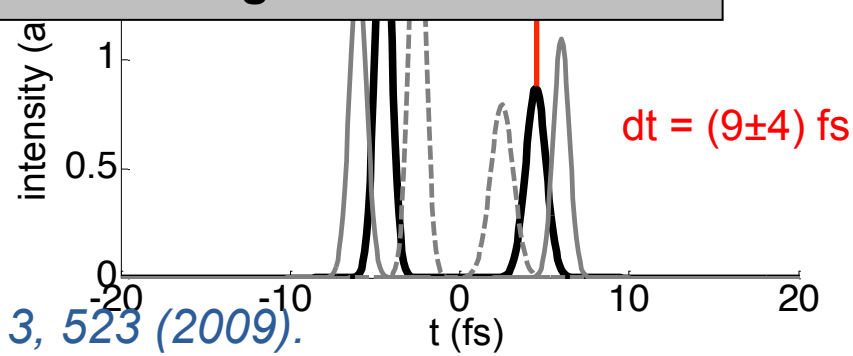
- experimentally demanding
- needs multilayer focusing - only for specific wavelength
- Problems with very low charge
- **for future: needs tailored diagnostic / sources**

Assump

2 gauss

: best fit

90% confidence



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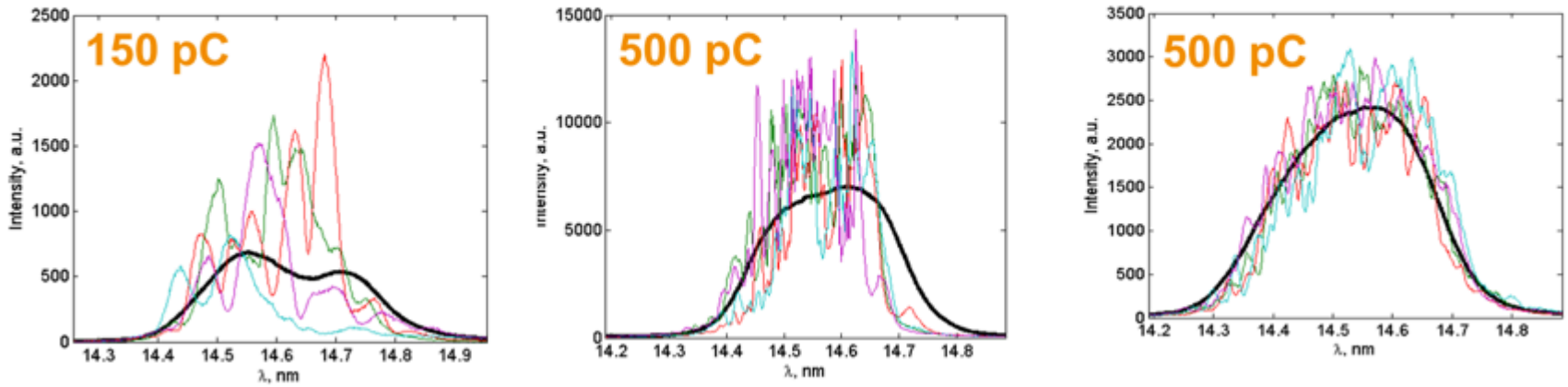
Analysis of statistical properties of FLASH radiation in spectral domain to characterize pulse duration

High resolution spectrometer at the PG2 beamline, FLASH

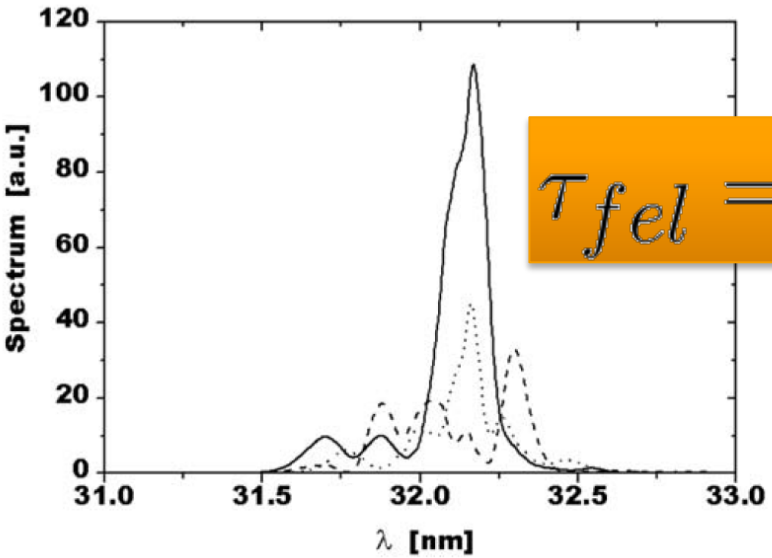
(Resolving Power > 10.000)



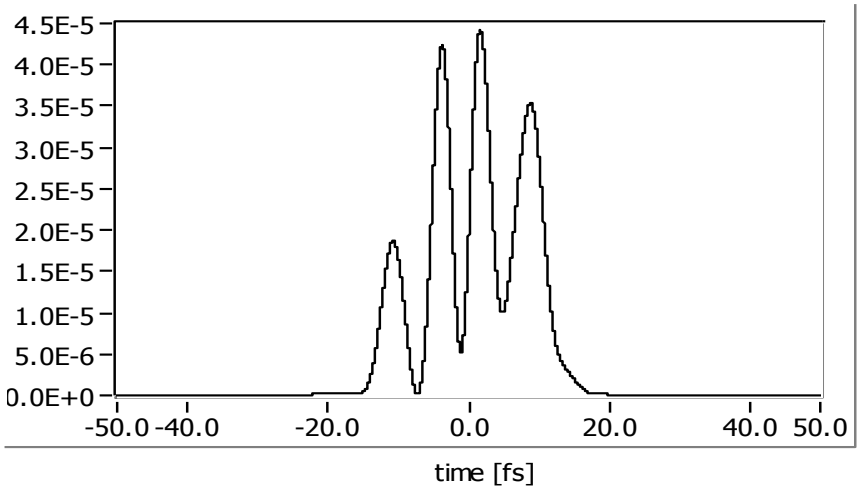
To be published!

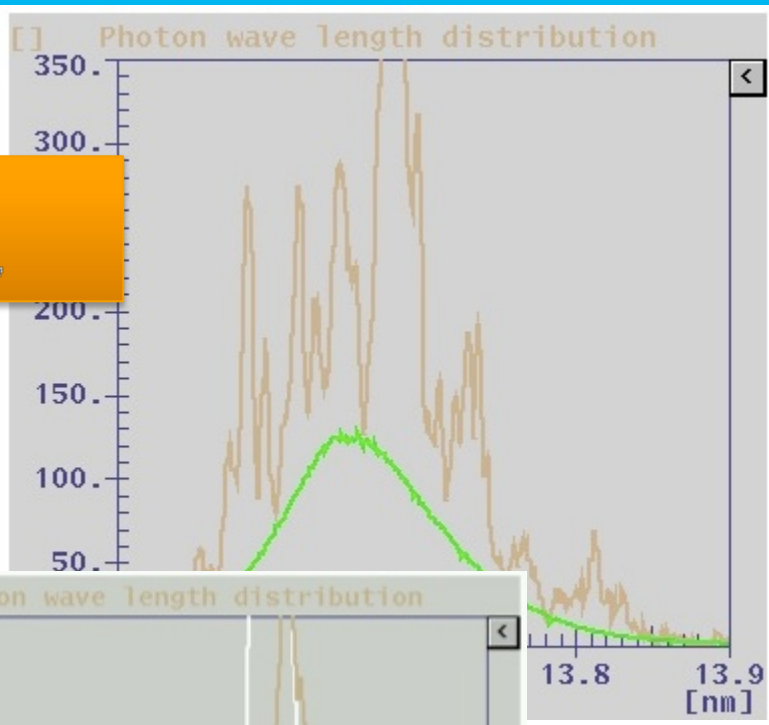
N. Gerasimova, S. Serkez

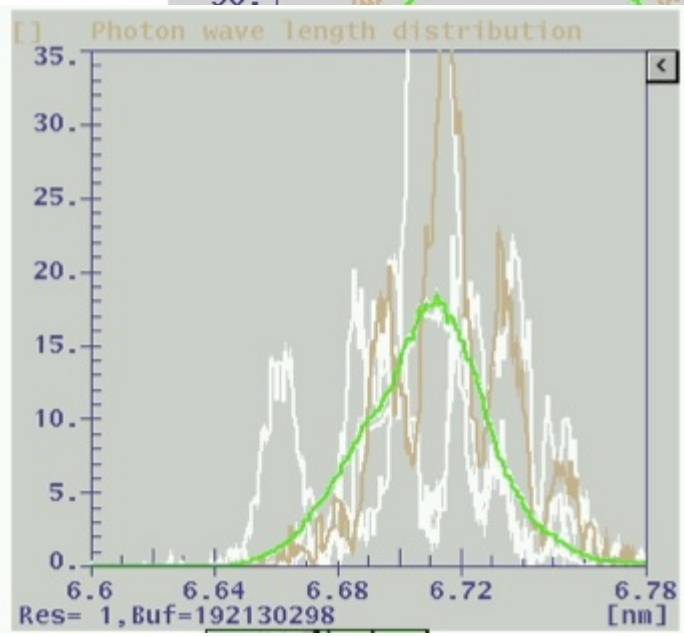
Indirect PHOTON methods: spectral spikes - correlations



$$\tau_{fel} = M\tau_{coh}$$

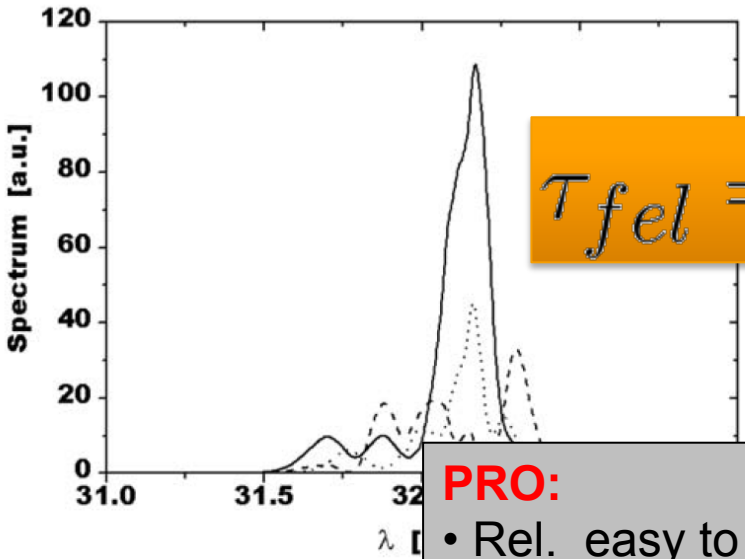






Courtesy N. Gerasimova

Indirect PHOTON methods: spectral spikes - correlations



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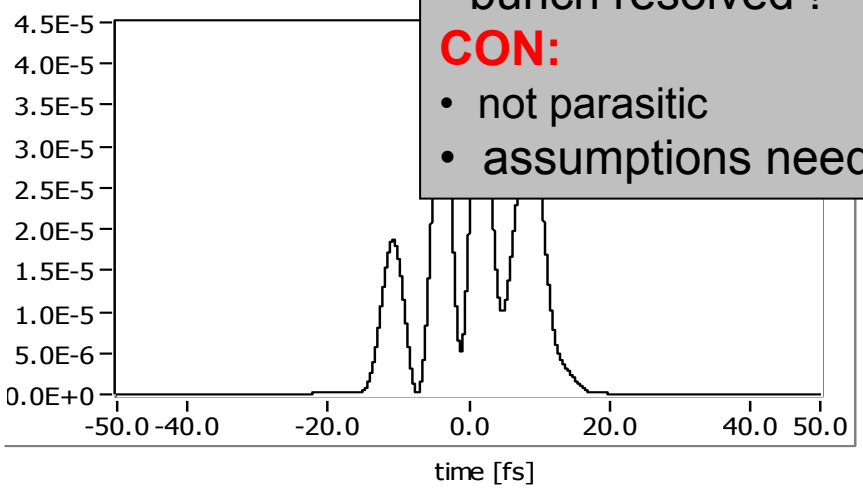

PRO:
- Rel. easy to use / analysis tools exist
- bunch resolved !

CON:
- not parasitic
- assumptions needed for reconstruction

Courtesy N. Gerasimova

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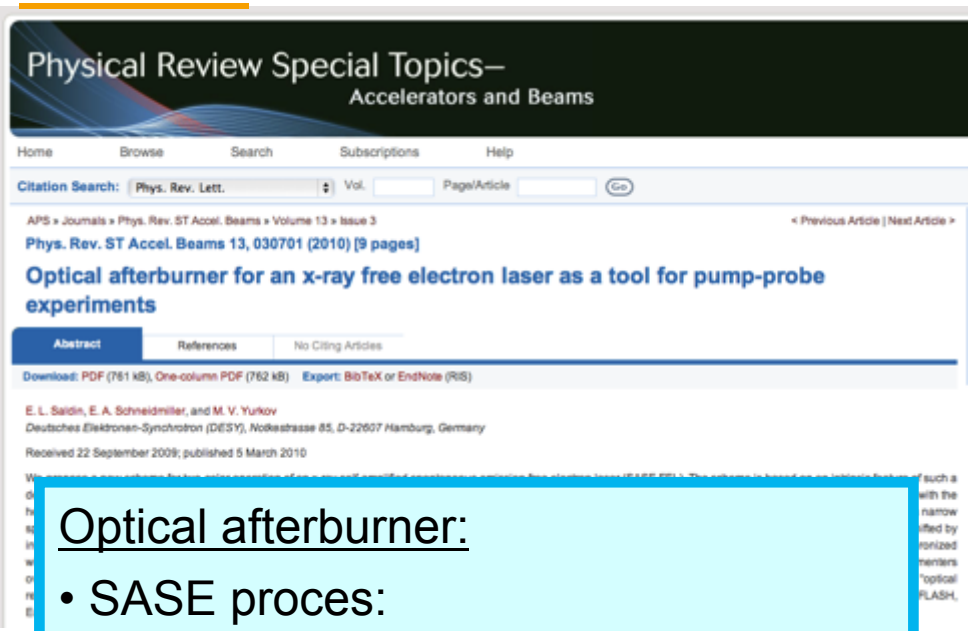
Indirect PHOTON methods: Optical AfterBurner

An idea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Phys. Rev. ST Accel. Beams 13, 030701 (2010) [9 pages]

Optical afterburner for an x-ray free electron laser as a tool for pump-probe experiments

Abstract References No Citing Articles

Download: PDF (761 kB), One-column PDF (762 kB) Export: BibTeX or EndNote (RIS)

E. L. Saldin, E. A. Schneidmiller, and M. V. Yurkov
Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, D-22607 Hamburg, Germany

Received 22 September 2009; published 5 March 2010

Optical afterburner:

- SASE proces:
  - modulations of the electron bunch energy (VIS/NIR scale)
- Dispersion section:
  - energy ➔ density modulations
- Radiator:

E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, *Phys. Rev. ST Accel. Beams 13, 030701 (2010)*

FIG. 1. (Color) Scheme of the afterburner for pump-probe experiments at an x-ray FEL.

Modulated density profile

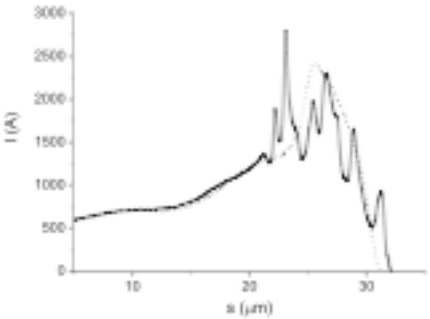
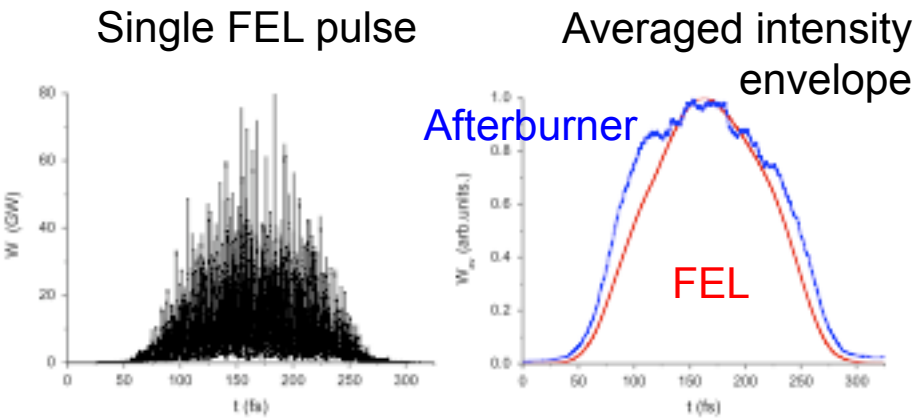


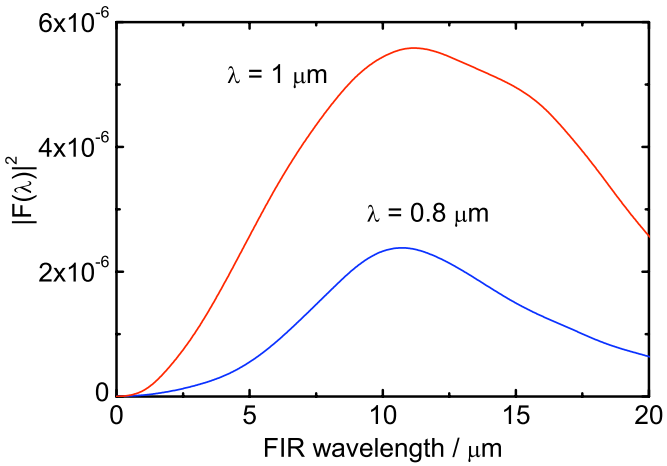
FIG. 8. Modulation of current in the head of electron bunch lasing at 7 nm in the VUV undulator of FLASH and passing FIR undulator with R_{56} equal to 250 μm (solid), and with $R_{56} = 0$ (dots). Only the small part of the bunch is shown; the bunch head is on the right.

Indirect PHOTON methods: Optical AfterBurner

Optical Afterburner: Optical replica of SASE pulse



Power distribution in a single x-ray pulse from the SASE1 undulator [12]. This shot was us
Right: Averaged power distribution (red) and its reconstruction (blue), see the text for d

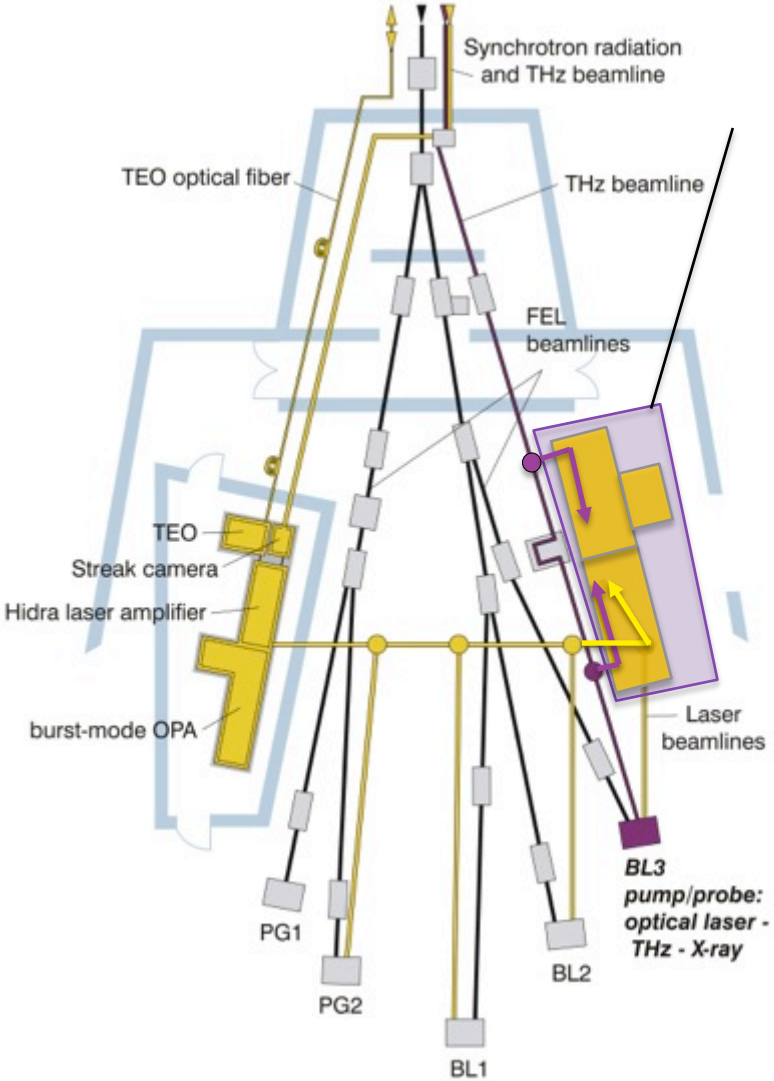


Optical afterburner - optical replica of SASE pulses:

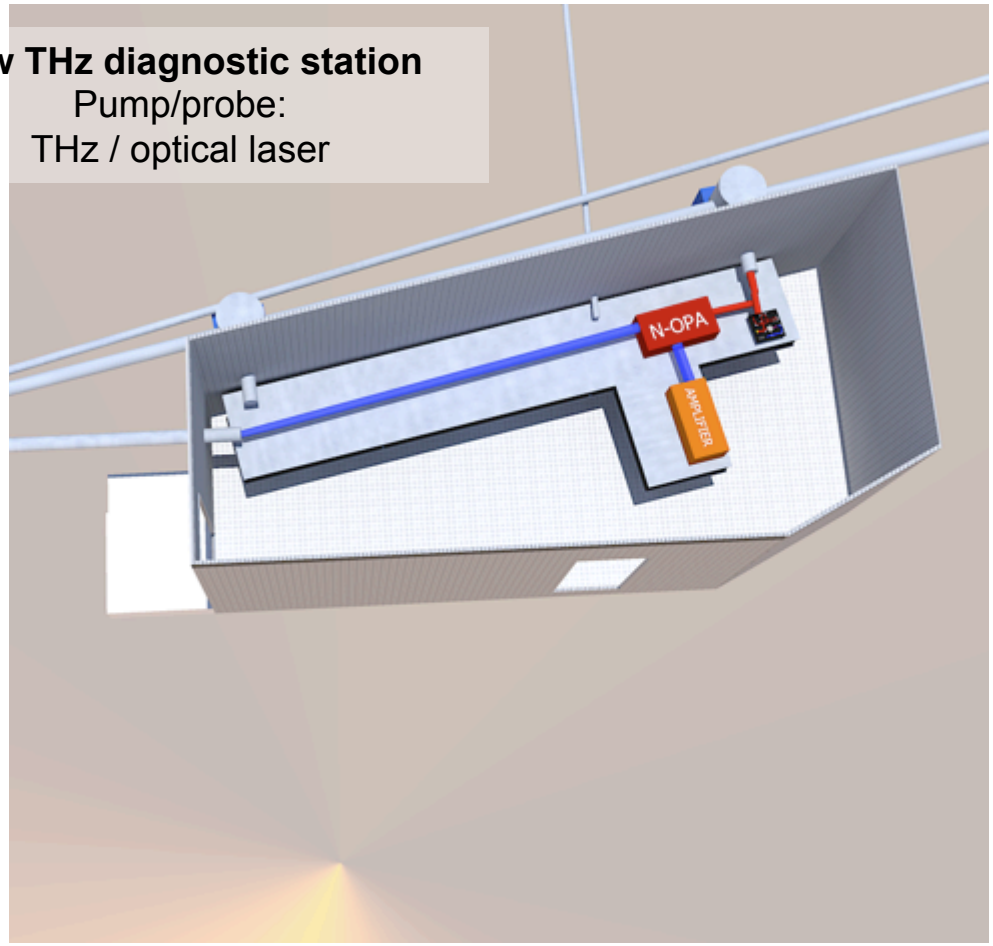
- **Pulse duration**
- Time marker (for sync. with ext. sources)
- Synchronized VIS/NIR source
  - covers the gap from 0.6 - 30um

E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, *Phys. Rev. ST Accel. Beams 13, 030701 (2010)*

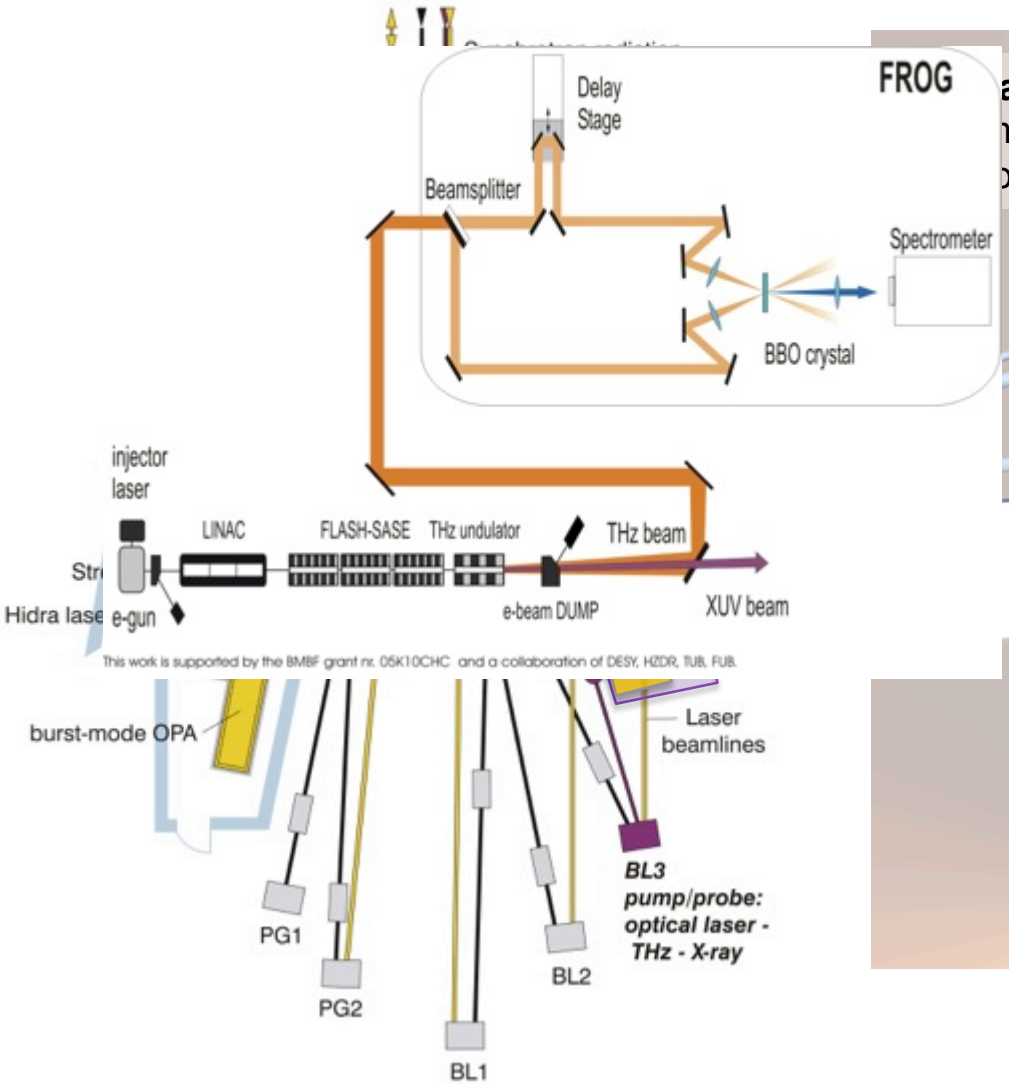
Indirect PHOTON methods: Optical AfterBurner

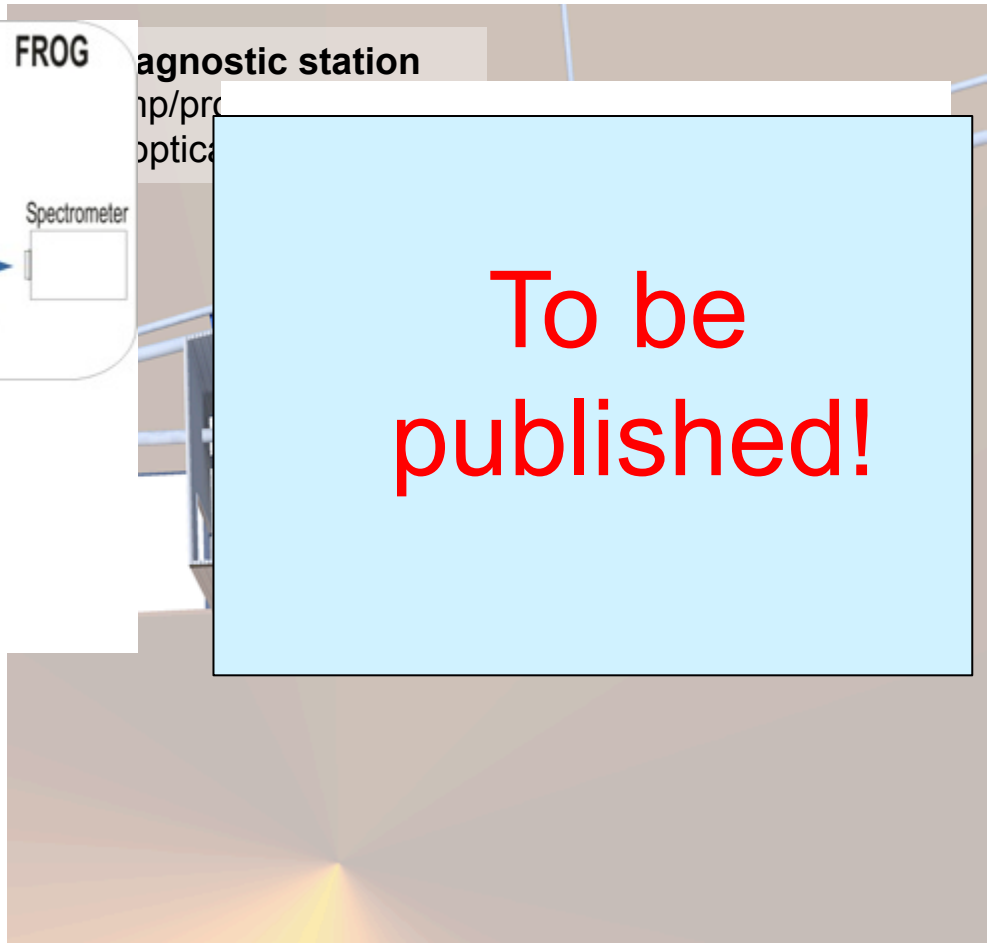


New THz diagnostic station
Pump/probe:
THz / optical laser



Indirect PHOTON methods: Optical AfterBurner





To be published!

Indirect PHOTON methods: Optical AfterBurner

XUV pulse duration…

To be published!

…double pulses

To be published!

- Electrons:
  - Charge 150 - 500pC
  - Energy 690 MeV
- SASE ~ 30 - 200μJ
- THz tuned to 800nm

Indirect PHOTON methods: Optical AfterBurner

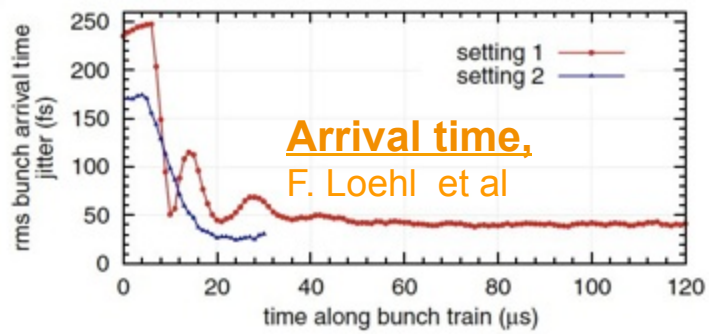
Pulse duration along bunch train

To be published!

Pulse duration

To be published!

PRL **104,** 144801 (2010) PHYSICAL REV



Arrival time,
F. Loehl et al

FIG. 4 (color online). Effect of the bunch arrival-time feedback on the arrival-time jitter along bunch train for two different machine settings. A stability of 25 fs could be achieved in the best case (setting 2).

Indirect PHOTON methods: Optical AfterBurner

Pulse duration along bunch train

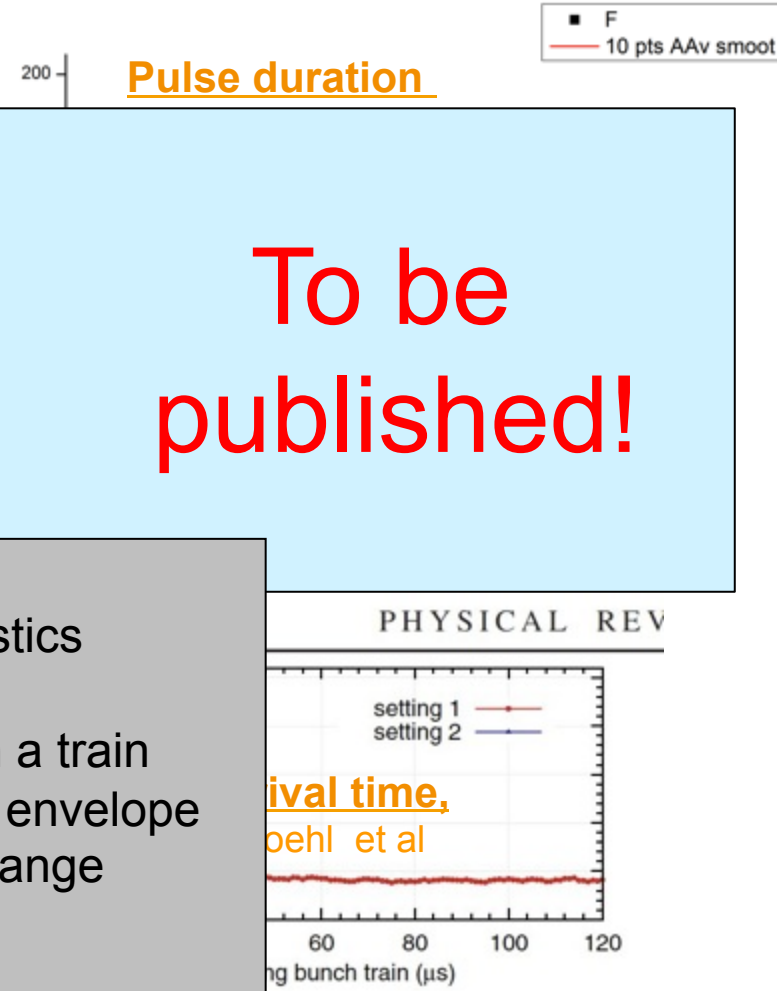
To be published!

Pulse duration

To be published!

PRO:
- “simple to use”: optics diagnostics
- parasitic to XUV operation
- resolved individual bunches in a train
- **in principle** single-shot pulse envelope
- covers complete wavelength range

CON:
- not direct



of the bunch arrival-time feed-
long bunch train for two different
machine settings. A stability of 25 fs could be achieved in the
best case (setting 2).

Thanks!