Laser Infrastructure and Timing Diagnostics at the SXP Scientific Instrument

Patrik Grychtol
Scientific Instrument SXP
Instrument Laser Engineer

European XFEL Users‘ Meeting 2022
Satellite Meeting „The SXP Instrument at European XFEL: Status and perspective”

Schenefeld, 24.01.2022

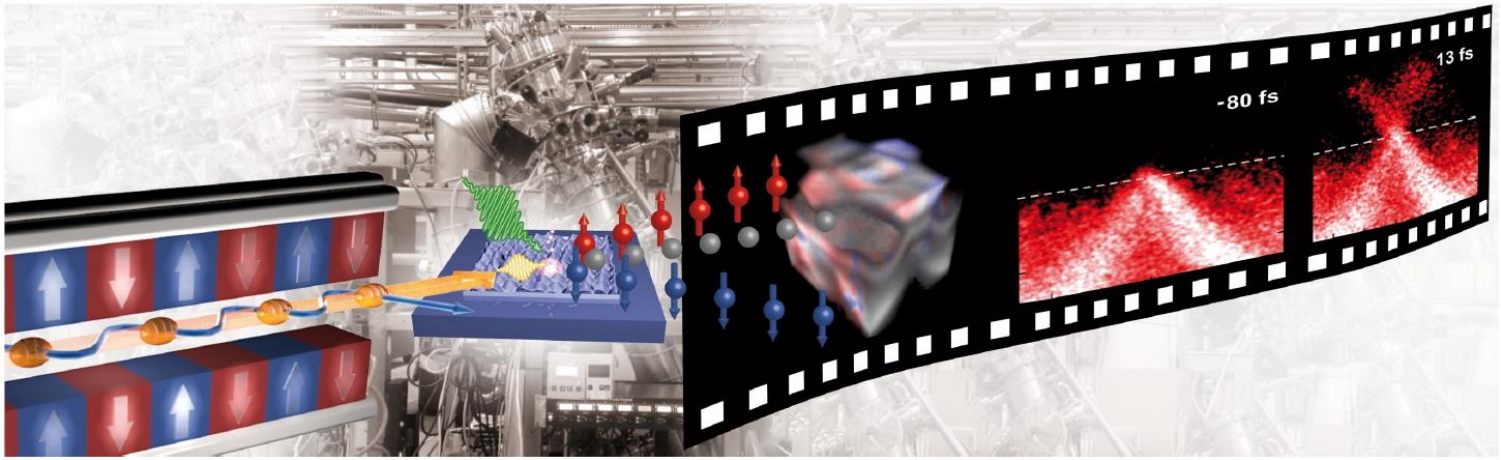
Content

Scope of the SXP Scientific Instrument

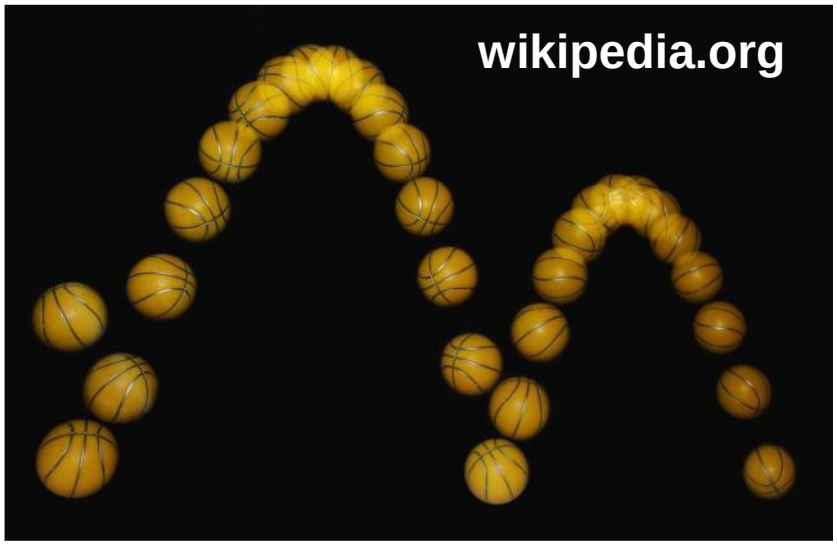
Extending the portfolio of techniques available at the baseline instruments SQS and SCS:

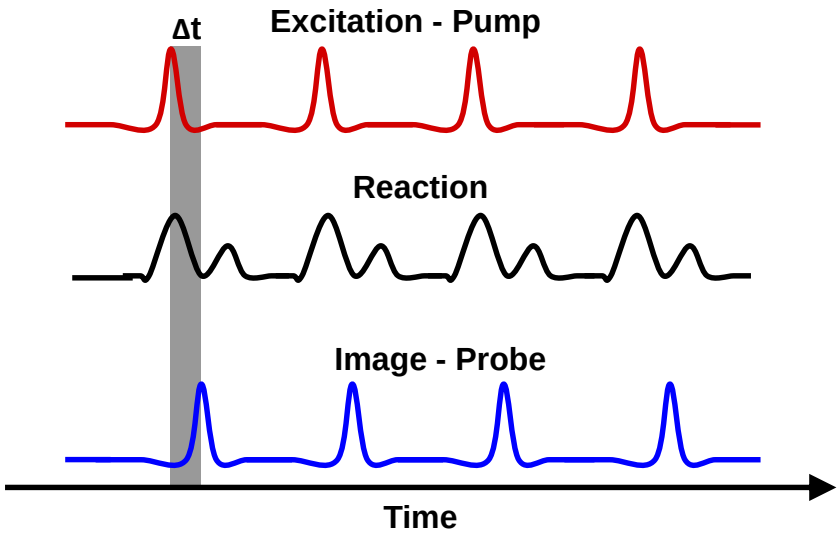
SCS	SQS	SCS	SQS	SXP	20%
SQS	SCS	SXP	SCS	SQS	

- Complete spin- and time-resolved photoelectron spectroscopy
- Spectroscopy of biological and inorganic catalysts
- Fundamental research on highly charged ions
- Development of experimental techniques

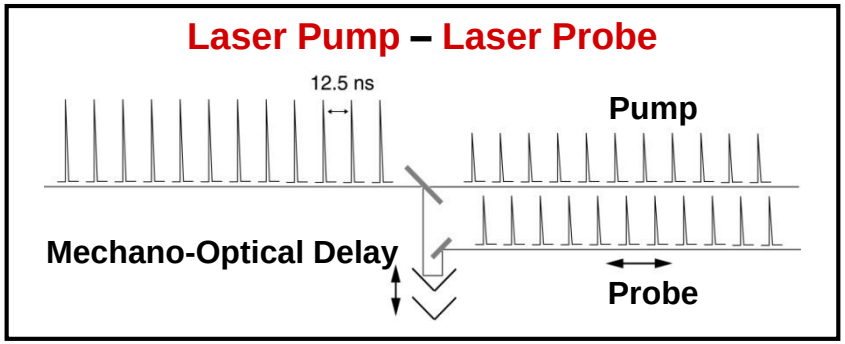


Pump-Probe Laser Requirements



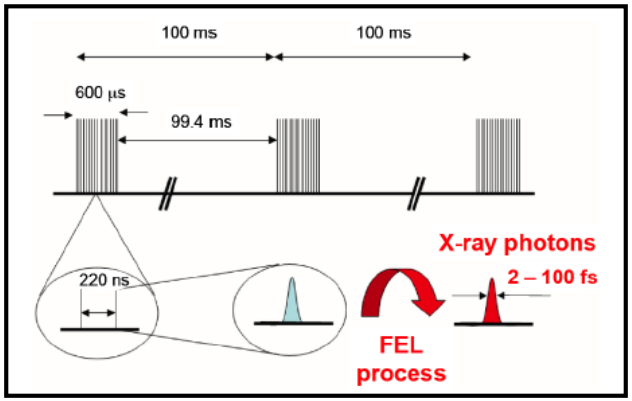


- Time-resolved “pump-probe” experiments: Capturing reversible processes stroboscopically
- Accessing ultrafast, electronic time scales with pulsed femtosecond laser sources



Pump-Probe Laser Requirements

XFEL Pulse Train: Up to 2700 electron bunches every 0.1s → effective repetition rate 27 kHz

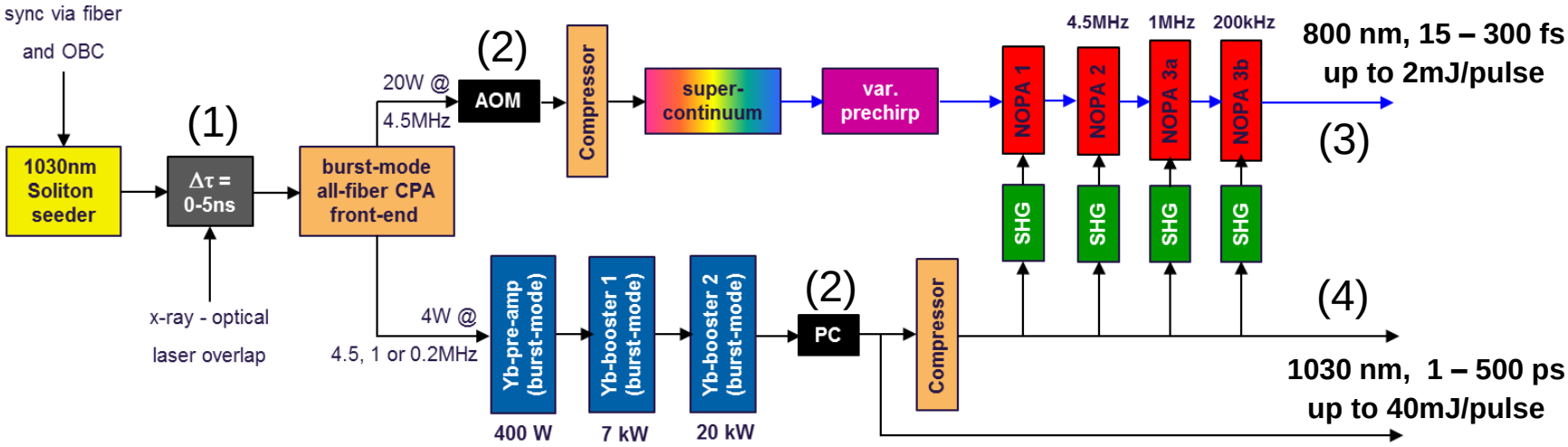


- Match XFEL pulse train: 10Hz burst mode & 0 - 4.5 MHz
- Ultrafast laser (down to fs range with few mJ's energy)
- Arbitrary pulse pattern selection
- Frequency/wavelength conversion from THz to XUV

Development of a versatile laser system by XFEL laser group – from left to right:
Guido Palmer, Laurens Wissmann, Martin Kellert, Moritz Emons, Max Lederer (PI),
Kai Kruse, Gerd Priebe, Jinxiong Wang, Ulrike Wegner, Mikhail Pergament

Pergament *et al.*, Optics Express **22**, 22202 (2014) & **24**, 29349 (2016).

Non-collinear Optical Parametric (NOPA) laser amplifier

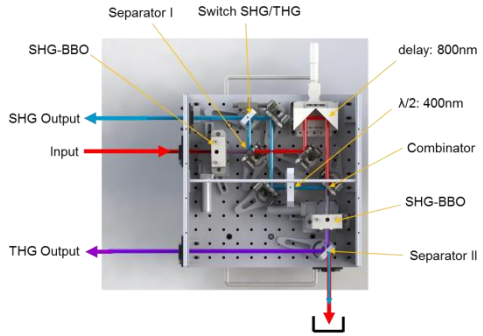


- Time zero overlap of XFEL and optical laser (1)
- Pulse on demand with Acousto-Optical-Modulator (AOM) and Pockels Cell (PC) (2)
- Ultrafast fs excitation: Output of 800 nm, 15 - 300 fs and up to 2mJ/pulse (3)
- Intense ps excitations: Output of 1030 nm, 1 - 500 ps and up to 40mJ/pulse (4)

Pergament *et al.*, Optics Express **22**, 22202 (2014) & **24**, 29349 (2016).

Wavelength conversion

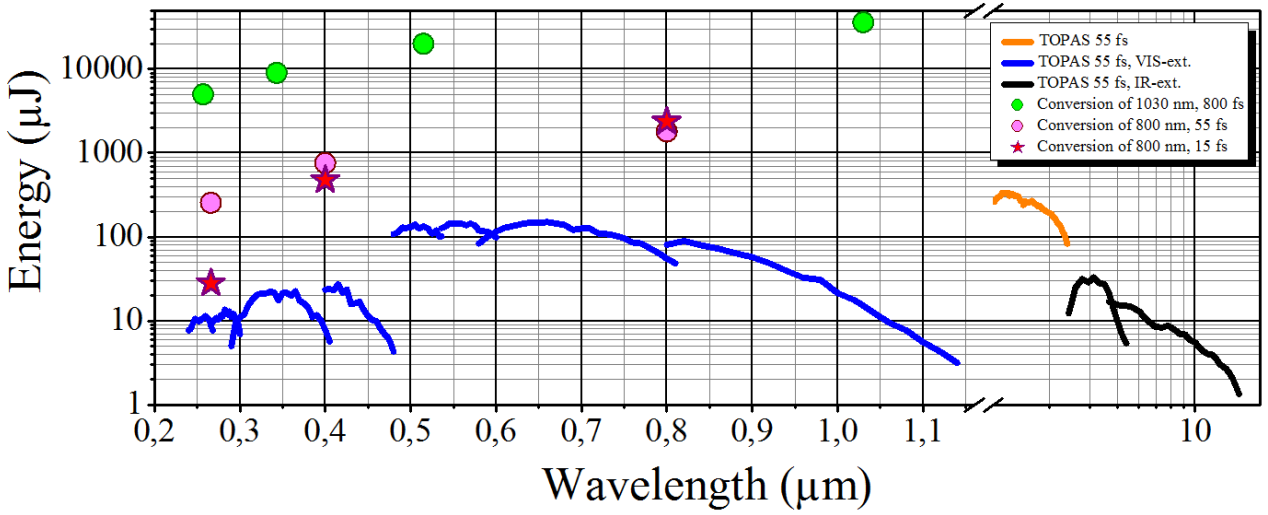
High Harmonic Generation (HHG)



Optical Parametric Amplifier (OPA)

TOPAS prime
Light Conversion
http://lightcon.com/

HHG and OPA at 100 kHz mode



Laser Input Parameters:

- OPA
  - 800 nm = 1.8 mJ @ 55 fs
- HHG
  - 800 nm = 1.8 mJ @ 55 fs
  - 2.4 mJ @ 15 fs
  - 1030 nm = 40 mJ @ 1 ps

Pergament *et al.*, Optics Express **22**, 22202 (2014) & **24**, 29349 (2016).

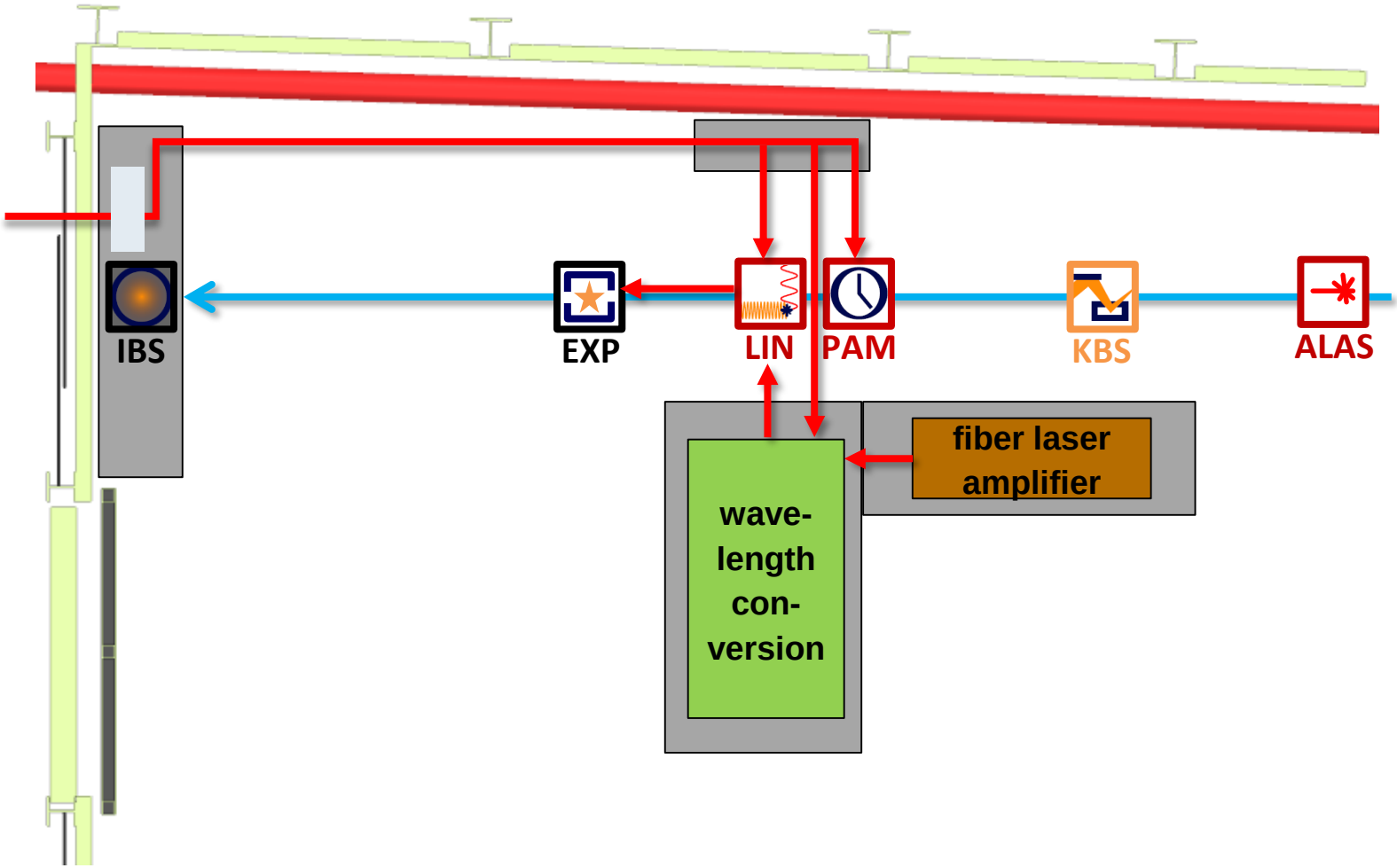
Commercial fiber laser amplifier for commissioning

http://www.afs-jena.de/

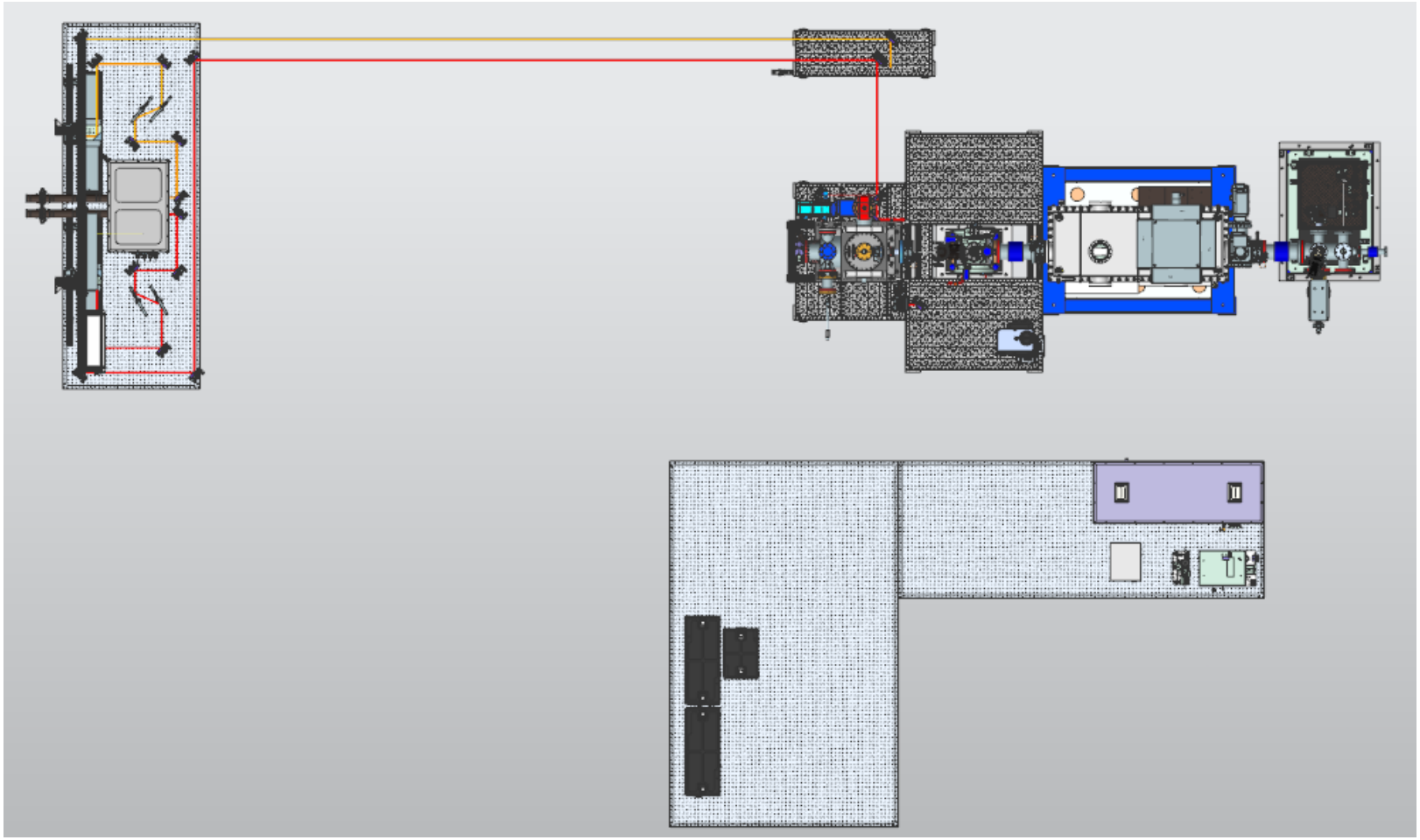
Active Fiber Systems 60W laser amplifier:

- Delivering 1030nm, 250fs, 200µJ pulses @ 300kHz!
- Pulse compression to sub-40fs planned
- Continuously adjustable repetition rate up to 20MHz.
- Same seed oscillator as NOPA, thus synchronizable.
- Installation planned for **Q2-2022**.

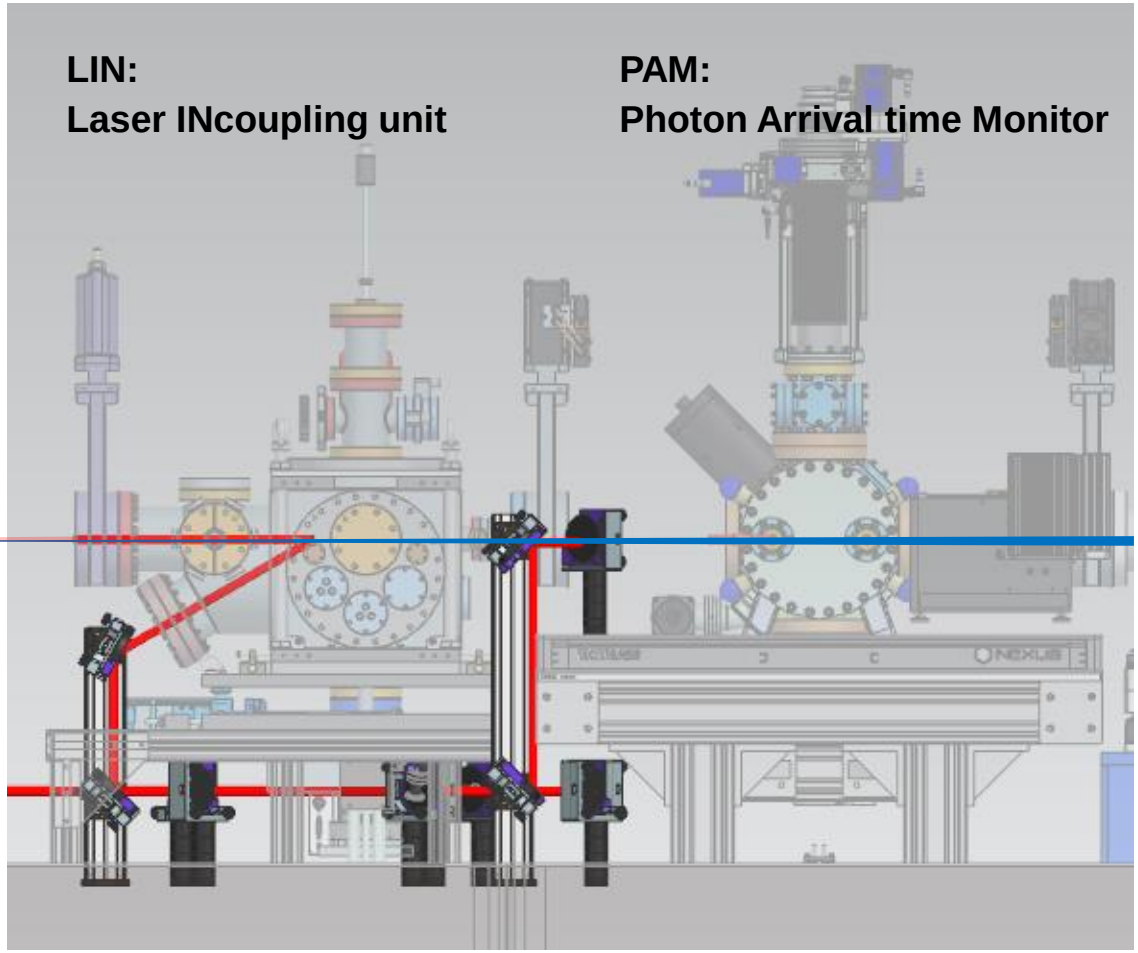
Overview of the SXP experiment hutch at SASE3



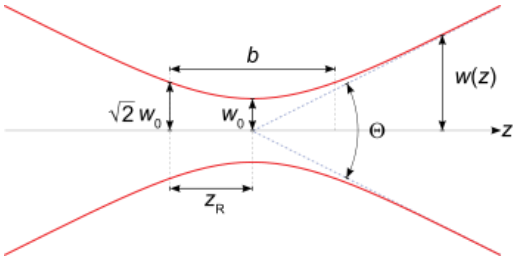
Laser beam in the SXP instrument laser hutch



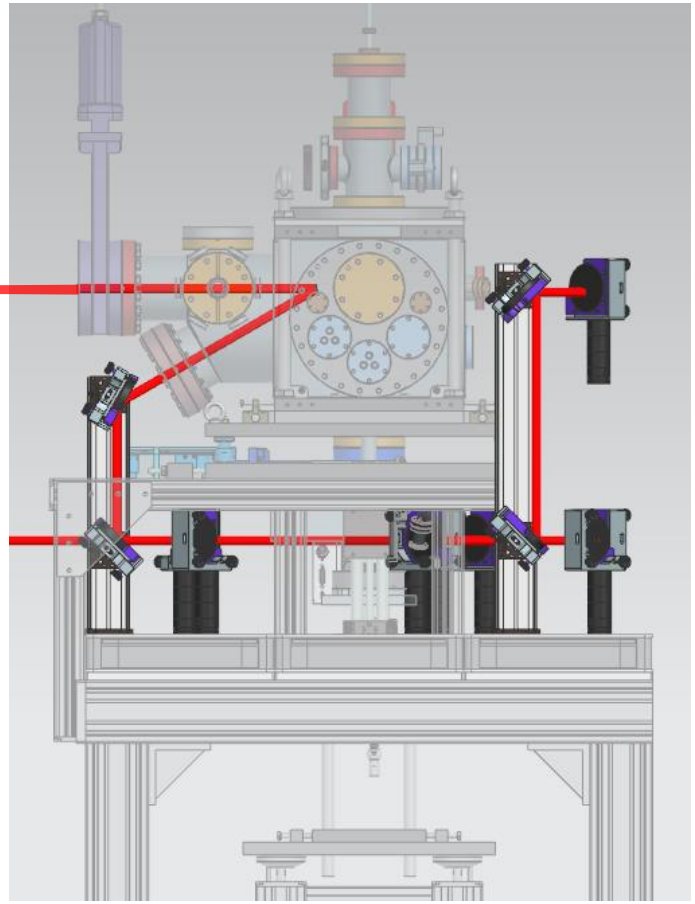
LIN and PAM for the SXP instrument



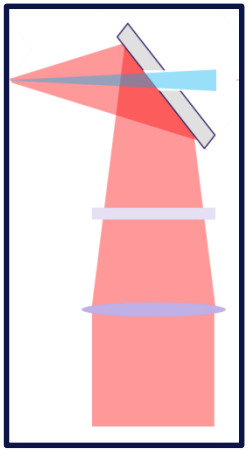
Laser In-Coupling for the SXP instrument



f_l



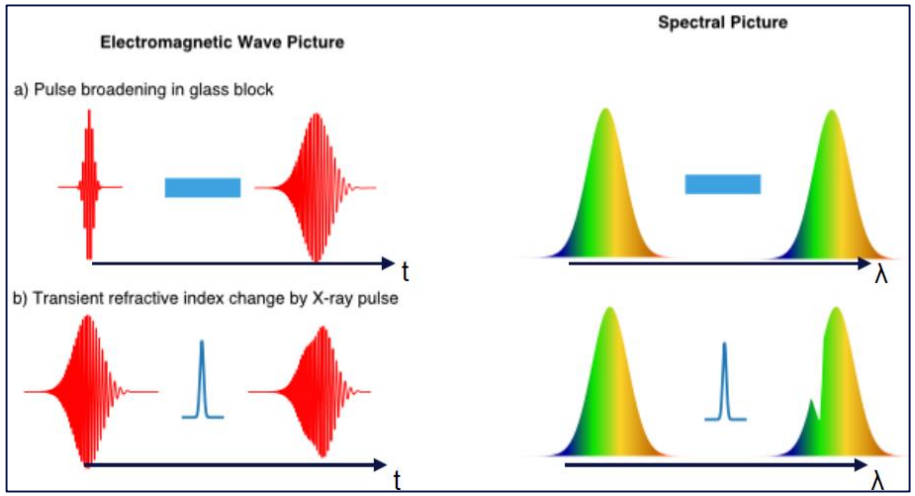
Focusing with external lens
800nm, 15fs laser pulse
f = 2m
w_0 = 50 µm ($1/e^2$)
$I_{peak} \approx 1x10^{15}$ W/cm²/mJ



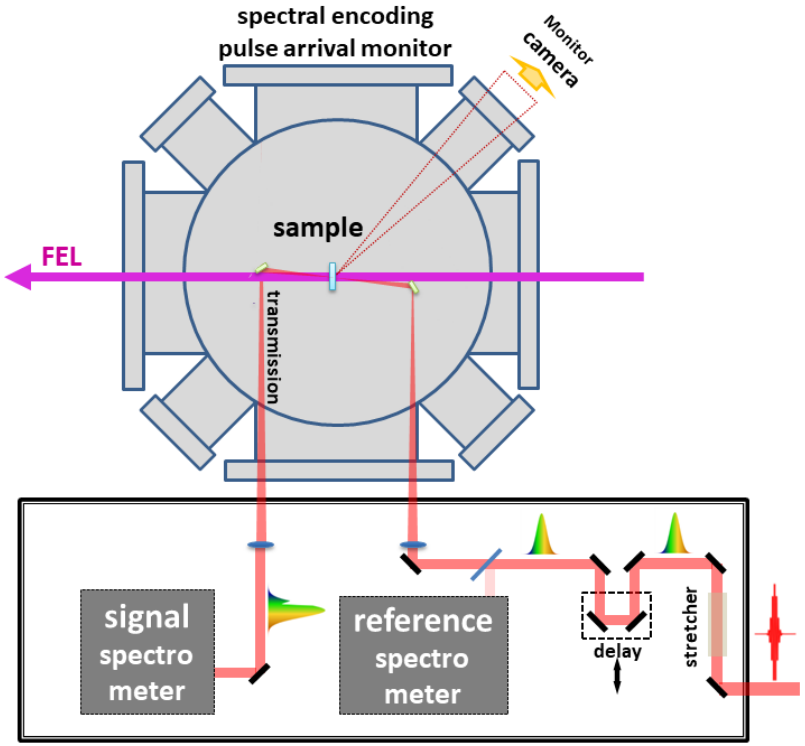
Timing Diagnostics: Spectral Encoding

Measuring the arrival time of the FEL pulse with respect to the synchronized optical laser (OL)

- Soft X-ray pulses induce changes in the transmission of a 1µm thin Si_3N_4 membrane to map the relative delay onto a spectral coordinate.
- Design of the photon arrival time monitor (PAM) by X-ray Photon Diagnostics group.



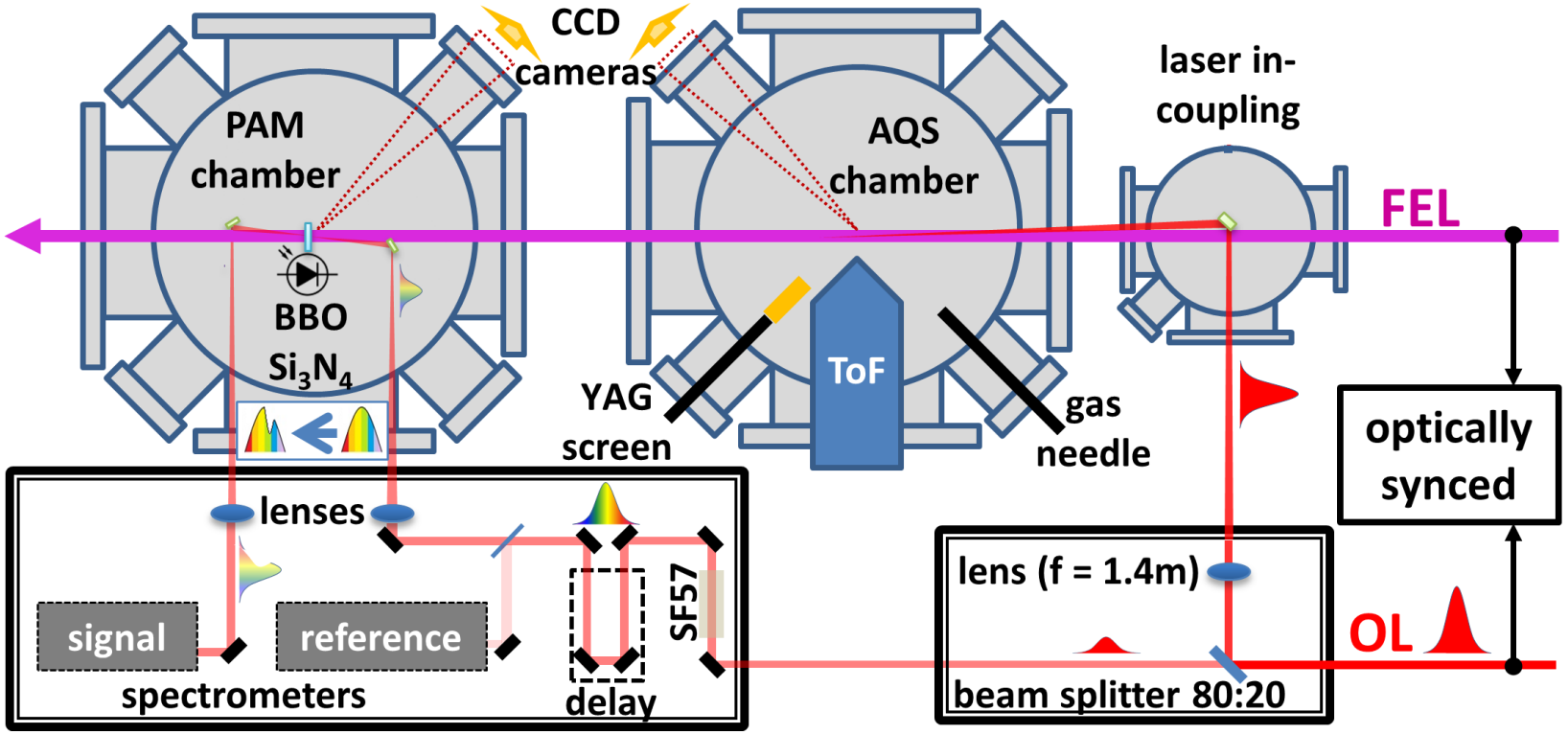
Bionta *et al.*, Optics Express **19**, 21855 (2011).



with courtesy of M. Diez and J. Liu

First benchmark pump-probe experiment at SASE3

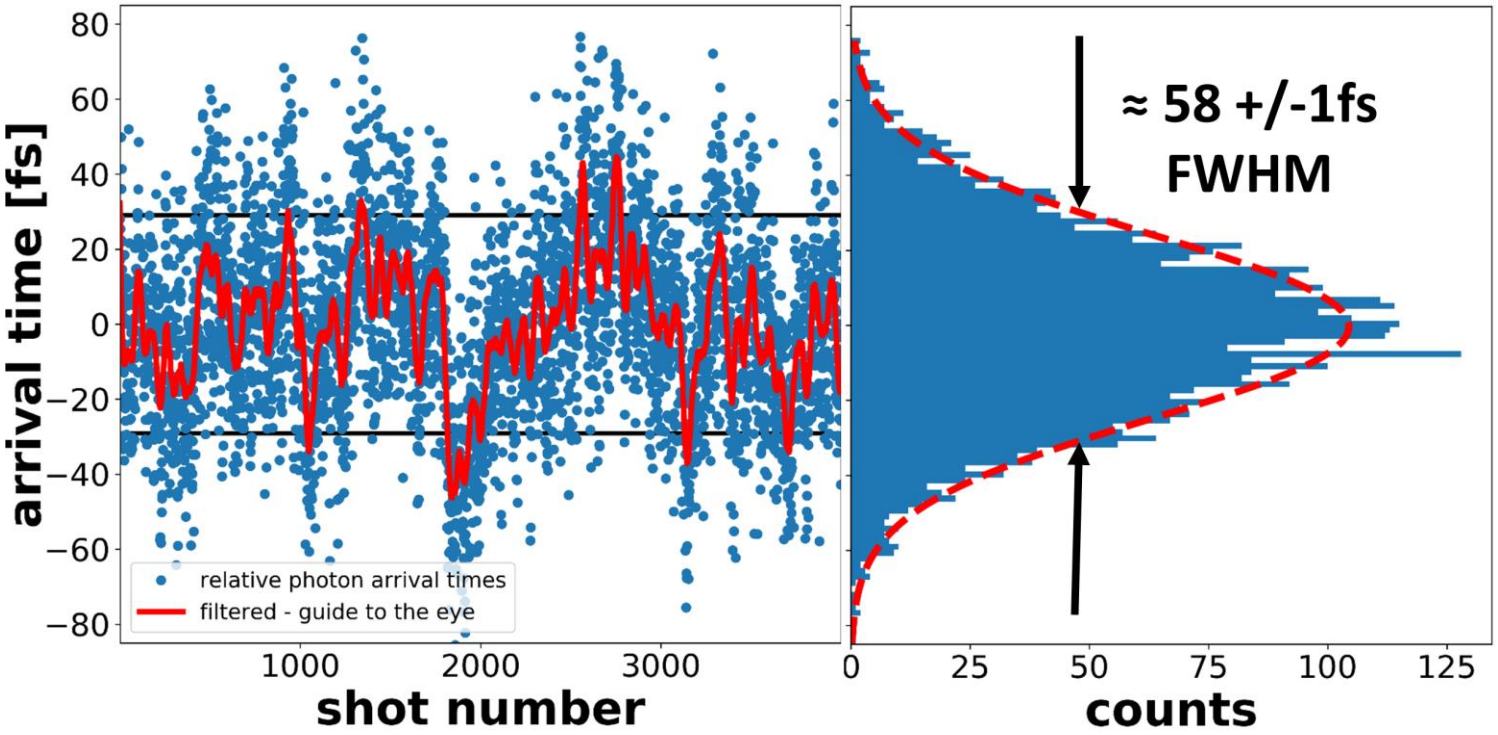
Characterize timing performance at SASE3: Can PAM be used to sort experimental data?



Grychtol *et al.*, Optics Express **29**, 37429 (2021).

Single shot timing jitter between OL and FEL pulses

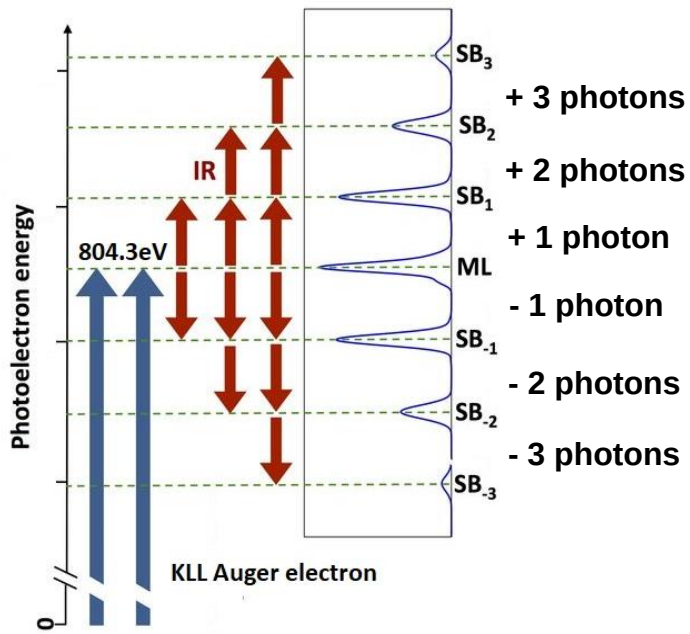
Characterize timing performance at SASE3: Consistent with measurements at SASE1!

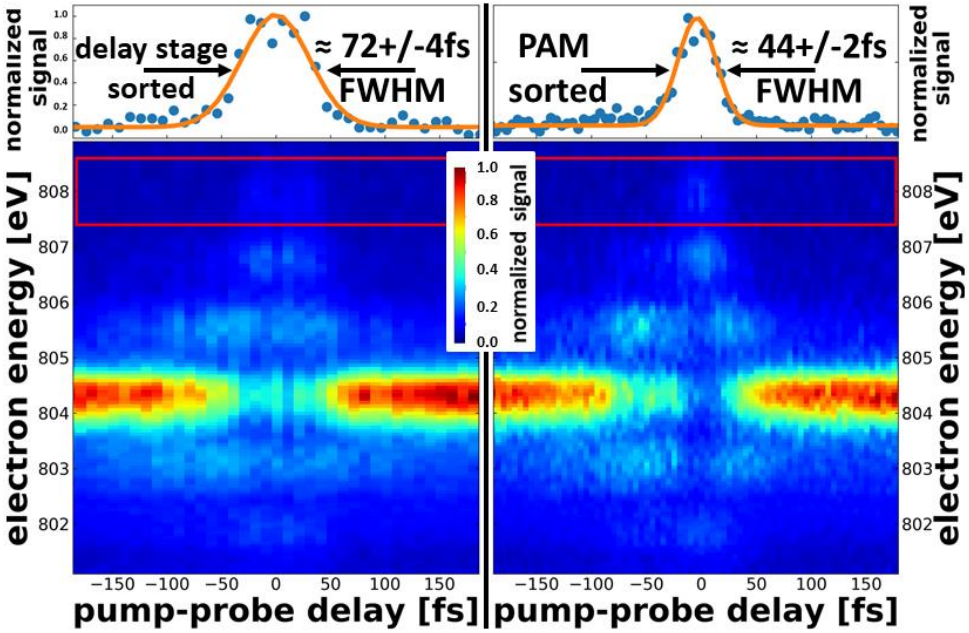


Grychtol *et al.*, Optics Express **29**, 37429 (2021).

Sideband measurements – OL/FEL cross-correlation

- Demonstrating the feasibility of time-resolved experiments with time-of-arrival sorting
  - 1keV XFEL photons generate an angularly isotropic Auger electron spectrum.
  - In the presence of a laser field, the Auger electrons absorb/emit OL photon giving rise to sidebands.





Grychtol *et al.*, Optics Express **29**, 37429 (2021).

Summary

- NOPA pump probe laser: 800nm, 15fs, 2mJ & 1030nm, 1ps, 40mJ, @ 100kHz
- TOPAS for wavelength tunability in the range of approx. 0.25µm – 15µm with a pulse length of ≈ 50fs
- Fiber-based pump-probe laser for commissioning**:** 1030nm, 250fs, 200µJ @ 300kHz.
- Focusing conditions allow for tight focusing*, i.e.* w_{focus} ≈ 50 µm resulting in I_{peak} ≈ 1 x10^{15} W/cm^2 **per mJ**.
- Timing diagnostics is going to be available for active time-of-arrival sorting.

Set point	f_{rep} [MHz]	E_{pulse} [mJ]	Focus Intensity [W/cm^2]	Estimated Jitter
1	1	0.2	2 x 10^{14}	> 50 fs
2	0.5	0.4	5 x 10^{14}	
3	0.1	2	2 x 10^{15}	

Acknowledgments: Thank you!

The SXP group:
- David Doblas-Jimenez
- Patrik Grychtol
- Vahagn Vardanyan
- Manuel Izquierdo

X-ray Photon Diagnostics:
- Jia Liu
- Jan Grünert

X-ray optics group:
- Maurizio Vannoni

Vacuum group:
- Joshua Ohnesorge
- Martin Dommach

Mechanical engineering:
- Nicole Kohlstruck
- Daniele La Civita

SXQM group:
- Sebastian Thiess
- Jens Buck
- Kai Rossnagel

KOMET 4:
- Gerd Schönhense