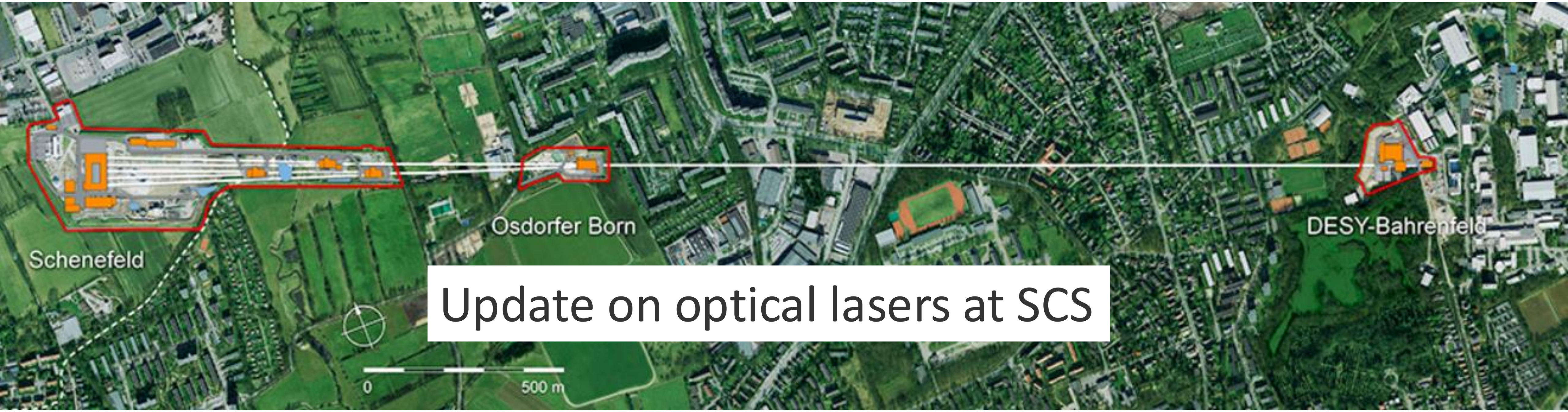


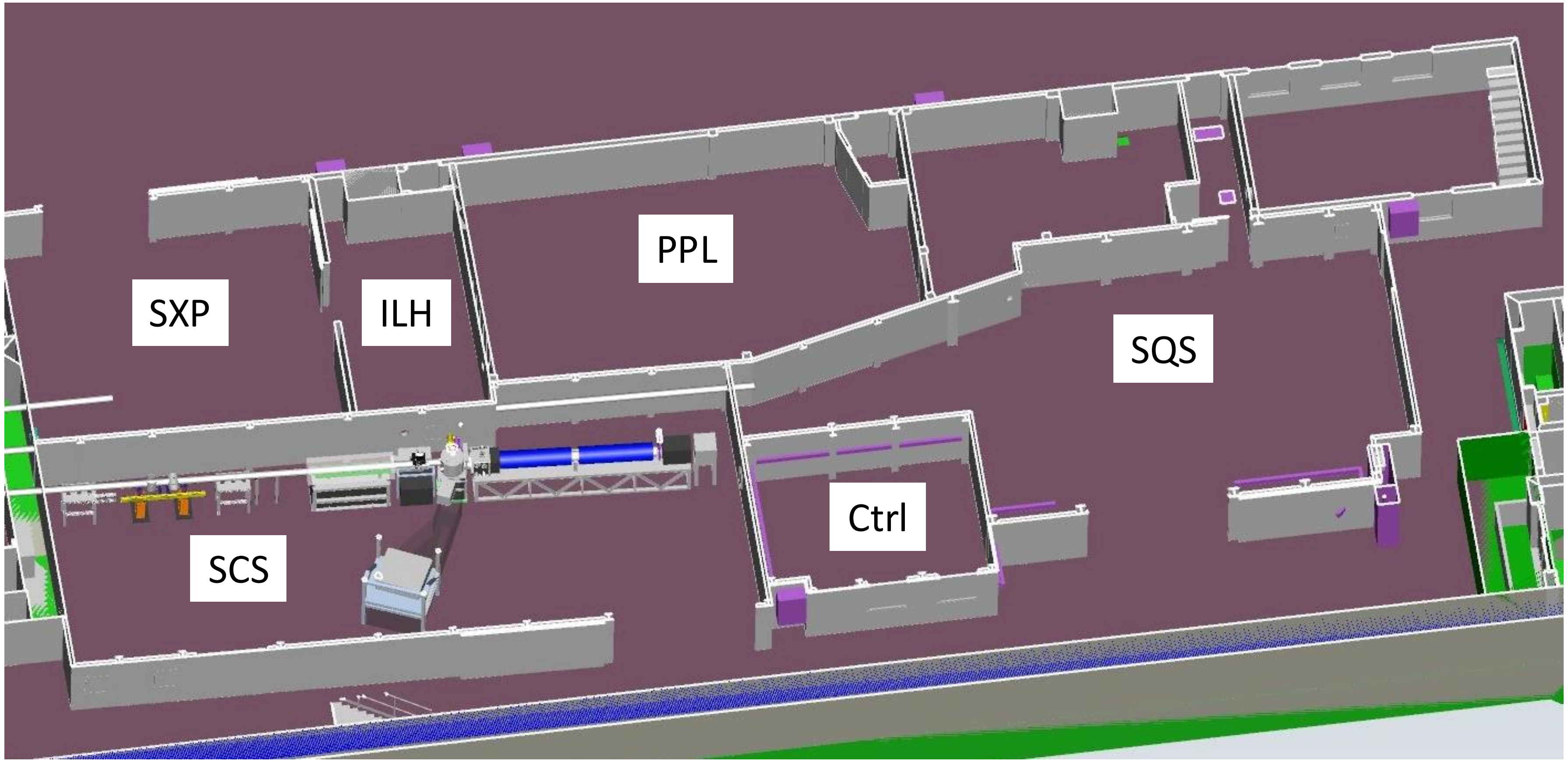
Update on optical lasers at SCS

Robert Carley

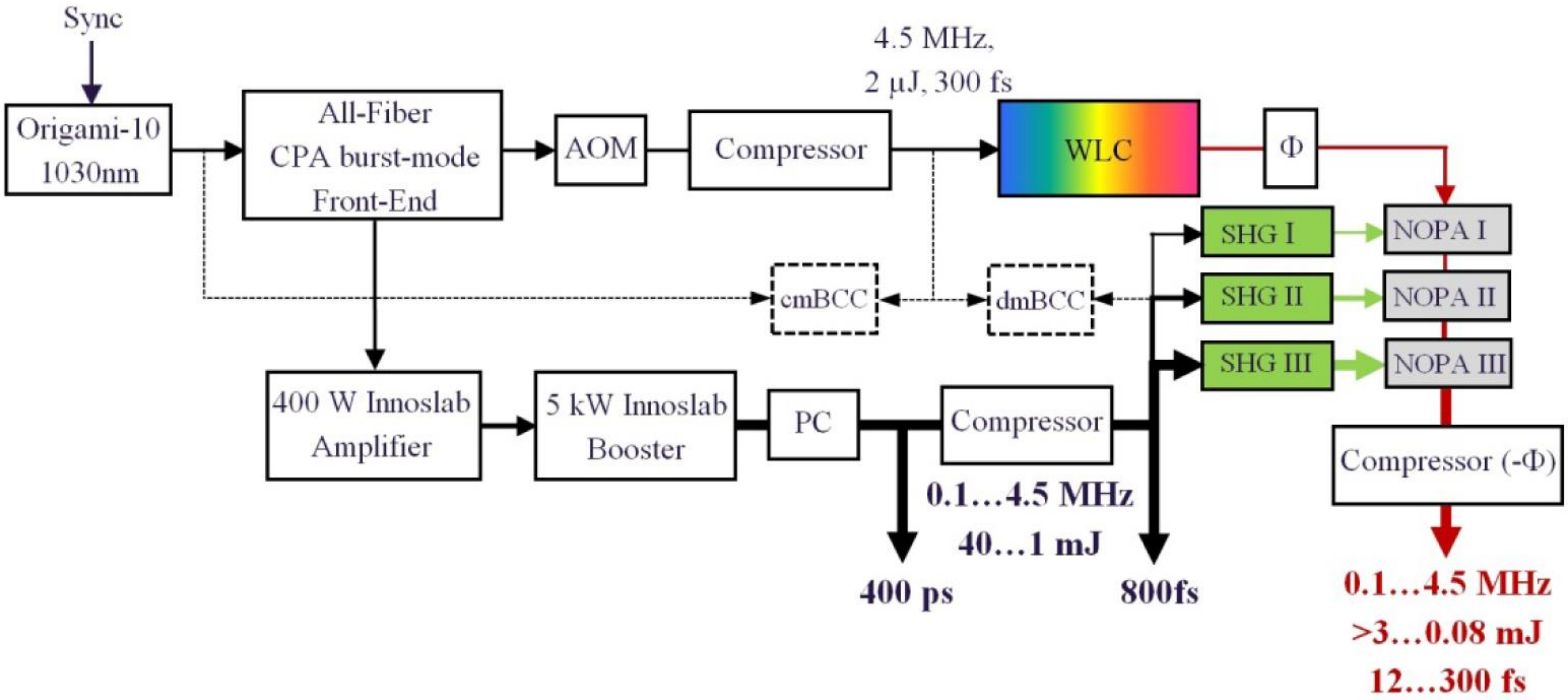
Spectroscopy and Coherent Scattering (SCS) Instrument

European XFEL

The pump-probe (PP) laser in SASE 3



Pump-probe laser at EuXFEL



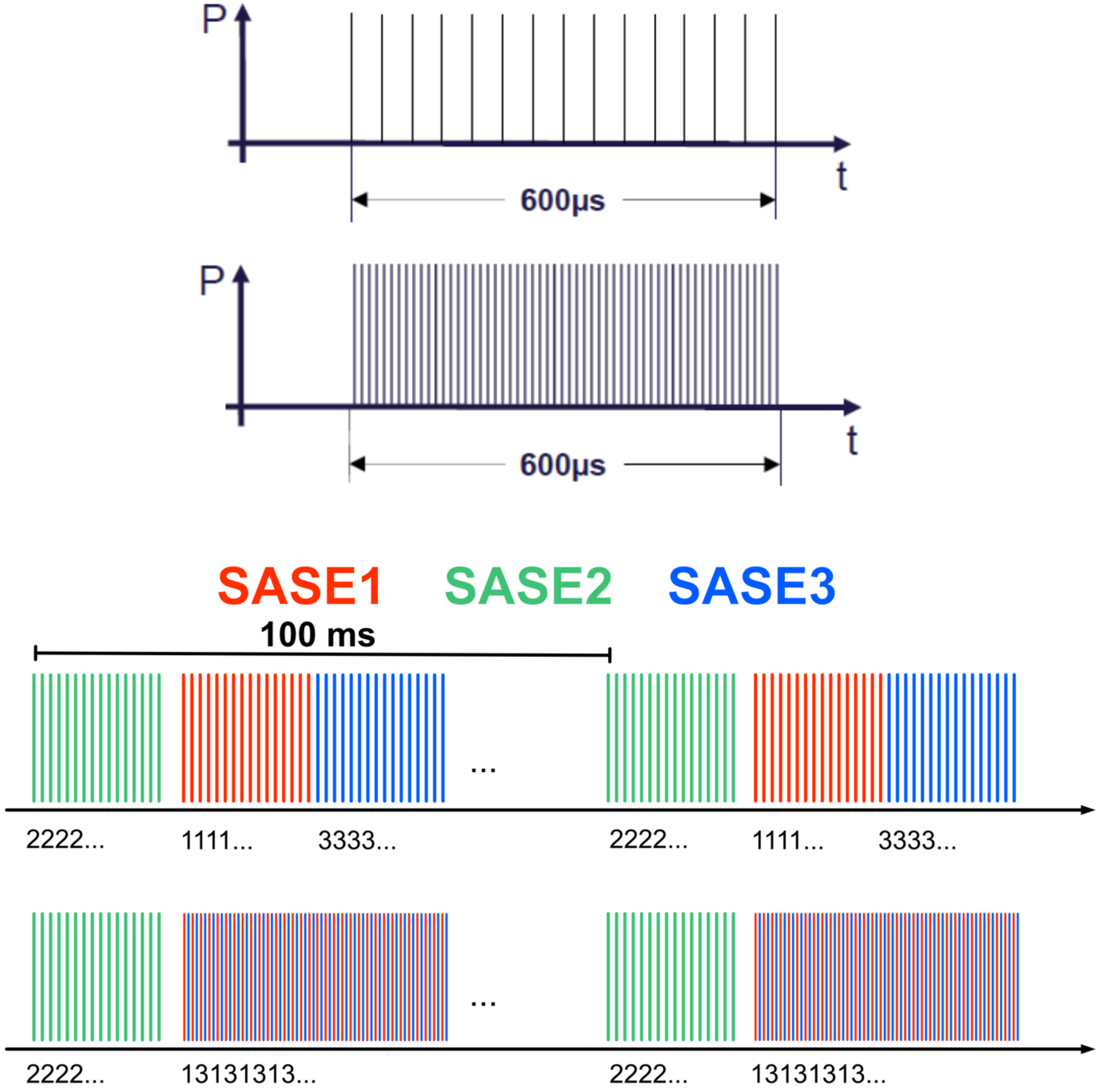
M. Pergament et al. Optics Express 22 (18) 22202 (2014) DOI:10.1364/OE.22.022202
M. Pergament et al. Optics Express 24 (26), 29349 (2016) DOI: 10.1364/OE.24.029349

Pulse Patterns

Train and pulse patterns

- 600 μs burst
- 10 Hz
- 1 – 2700 pulses
- Up to 4.5 MHz pulse repetition frequency
- Arbitrary patterns possible

- PP laser pattern matches X-ray pattern



PP Laser Operating Points

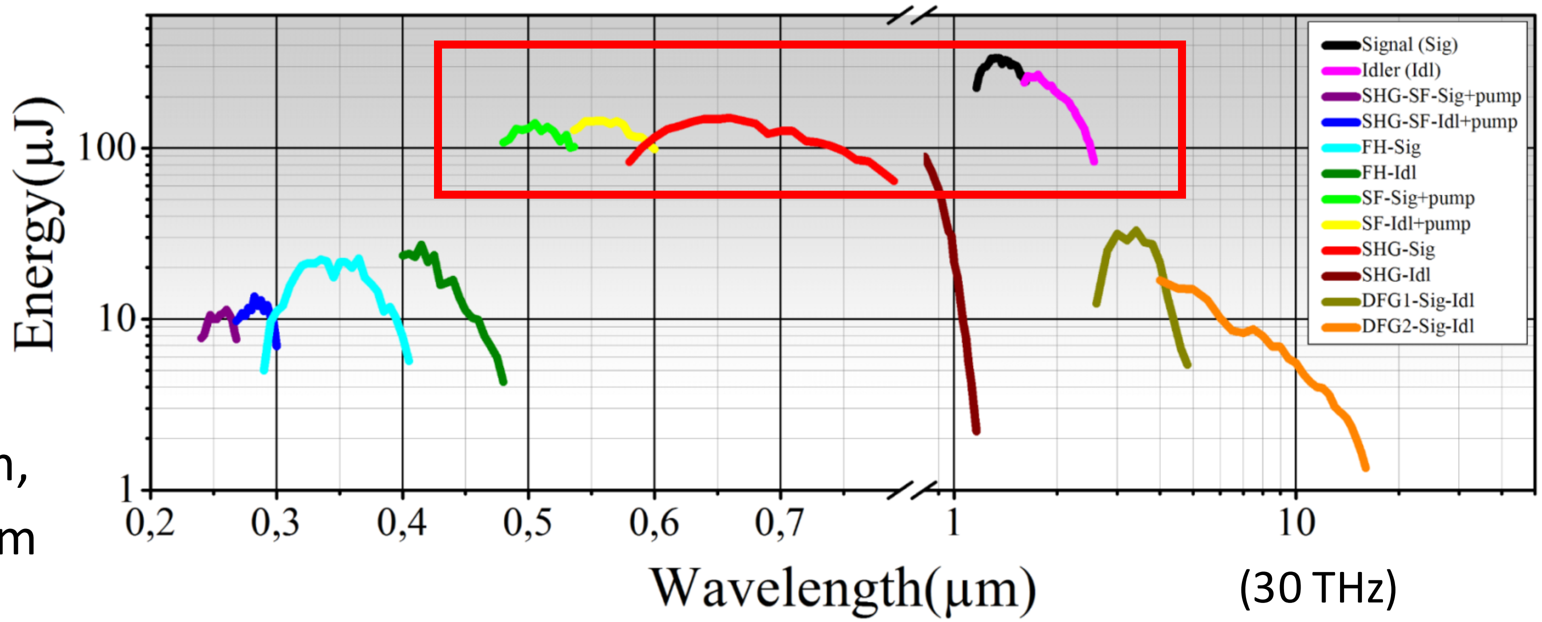
				800 nm	1030 nm
Mode	**F_rep / MHz**	**Δt / ns**	**F_eff / kHz**	**E_pulse / mJ**	**E_pulse / mJ**
1	4.5	222	27	0.05	1
2	**1.1**	**1000**	**6**	**0.2**	**4**
4	**0.564**	**2000**	**3**	**0.4**	**10**
5	**0.113**	**10000**	**0.6**	**2**	**40**
		Pulse duration		15 fs or 50 fs	<1ps or 800 fs

- Wide flexibility in repetition rate and pulse duration

Frequency conversion

- Harmonic generation
  - 800 nm (50 fs) → 400 nm (60 fs) and 266nm (90 fs)
- Optical parametric amplifier (TOPAS from Light Conversion)
  - 800 nm, 50 fs
    - ▶ 2 mJ pump at 113 kHz
    - ▶ 400 uJ pump at 564 kHz
  - Tuneable between UV and mid IR
  - Safer to use the strongest outputs
  - User experiments with 550 nm, 630nm, 1300 nm, and 2500 nm

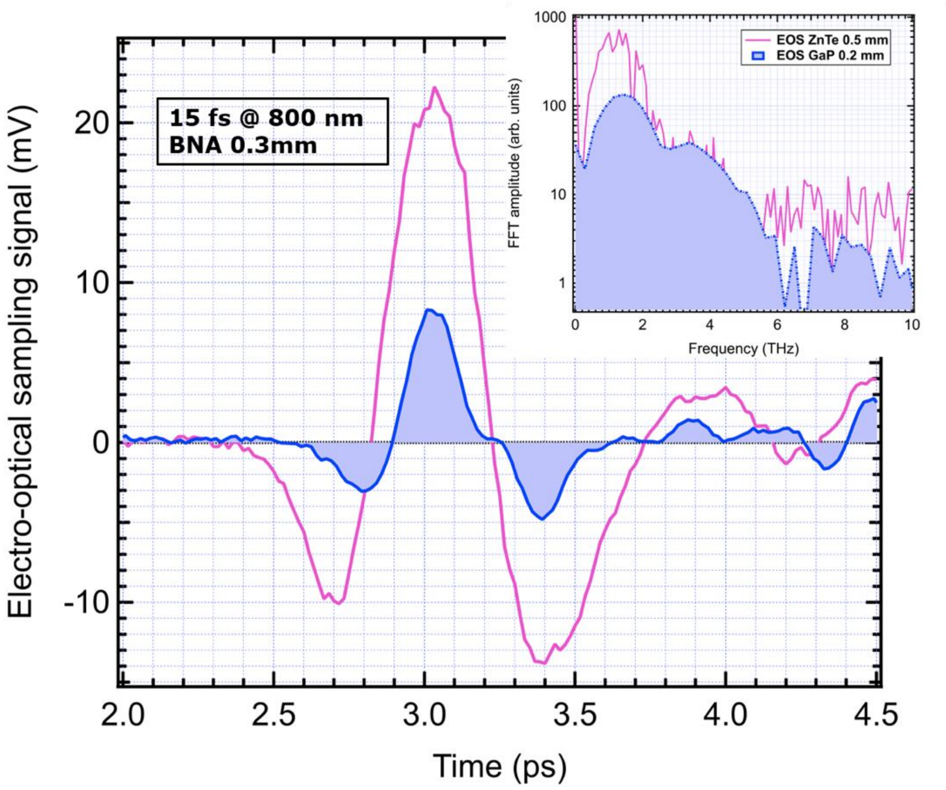
TOPAS outputs at 113 kHz



(30 THz)

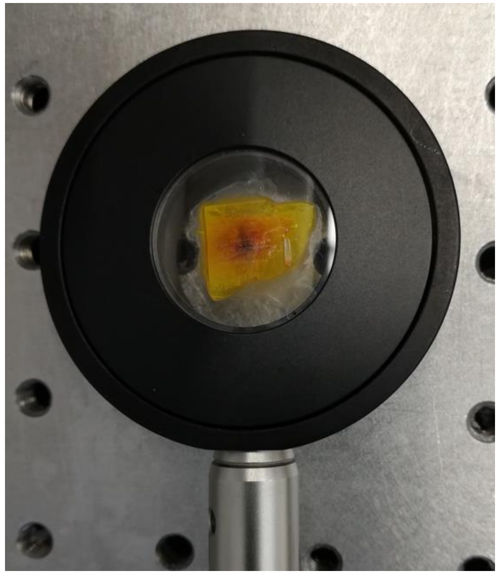
Frequency converion: THz

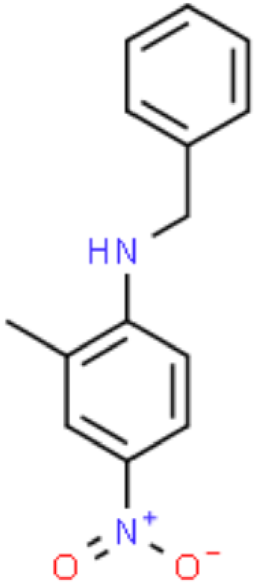
- BNA pumped with 15 fs, 2 mJ, 113 kHz



Ilie Radu, European XFEL

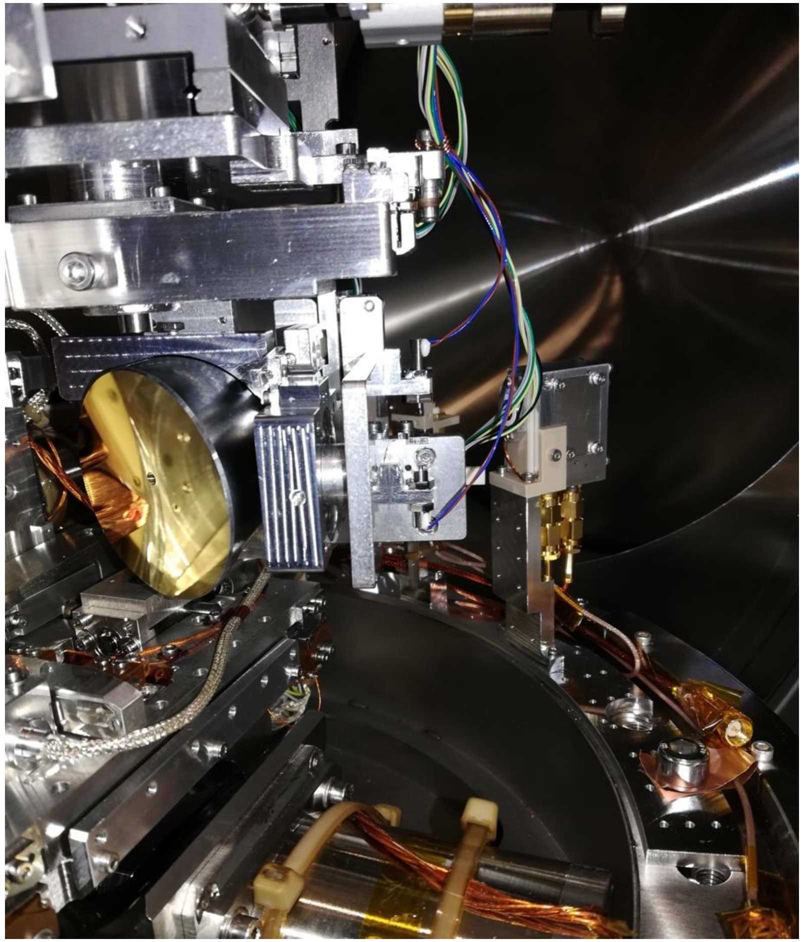
N-Benzyl-2-methyl-4-nitroaniline

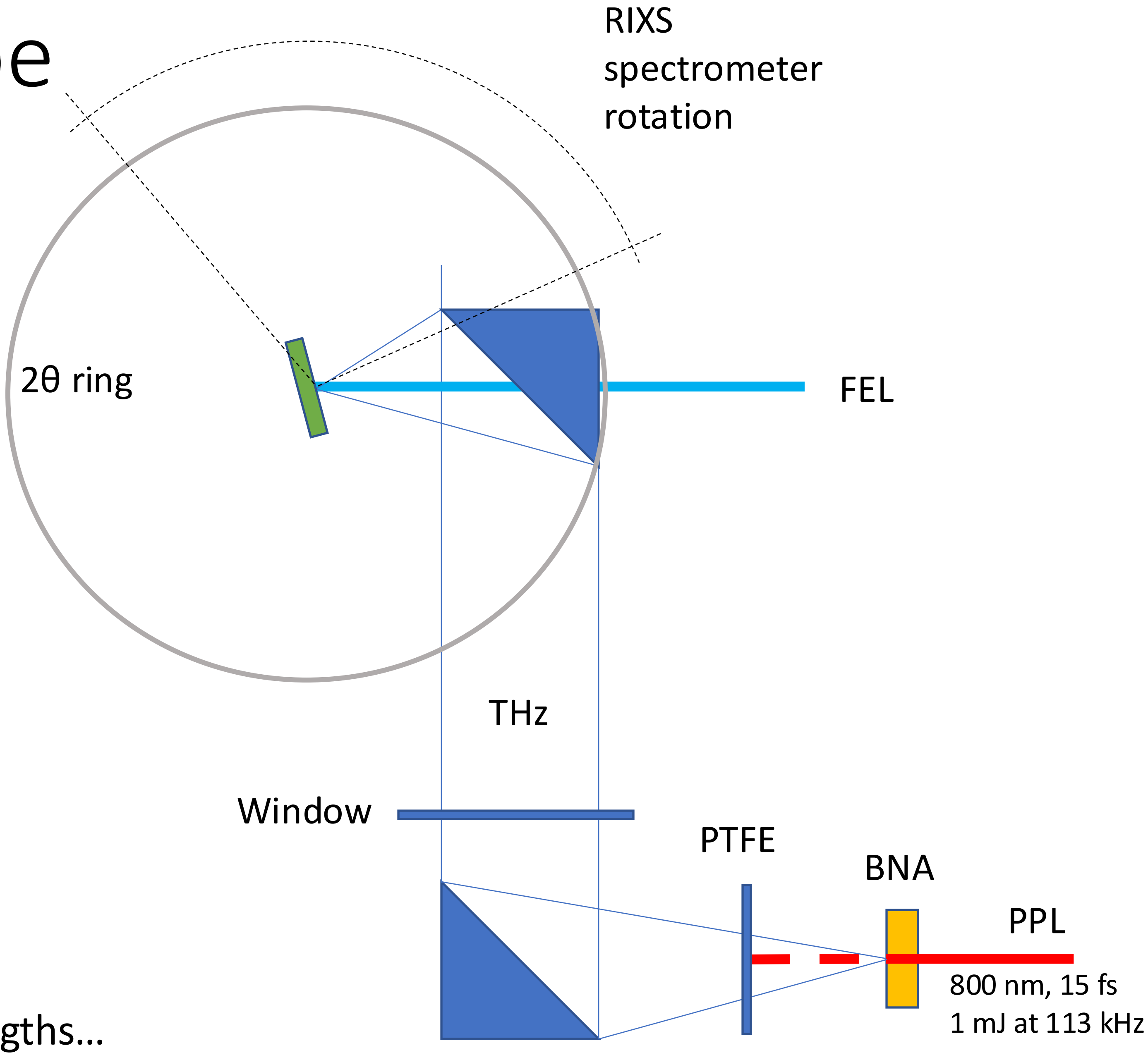




https://www.chemspider.com/Chemical-Structure.2127659.html

THz pump – RIXS probe

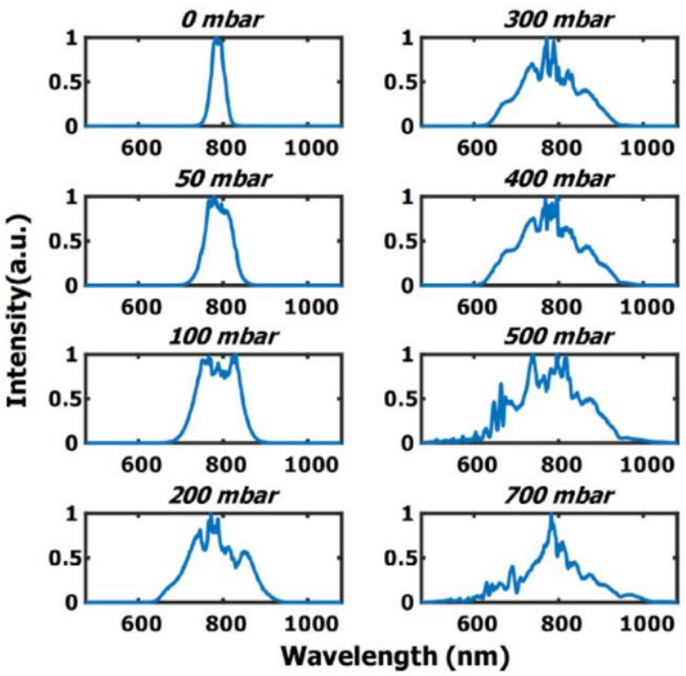


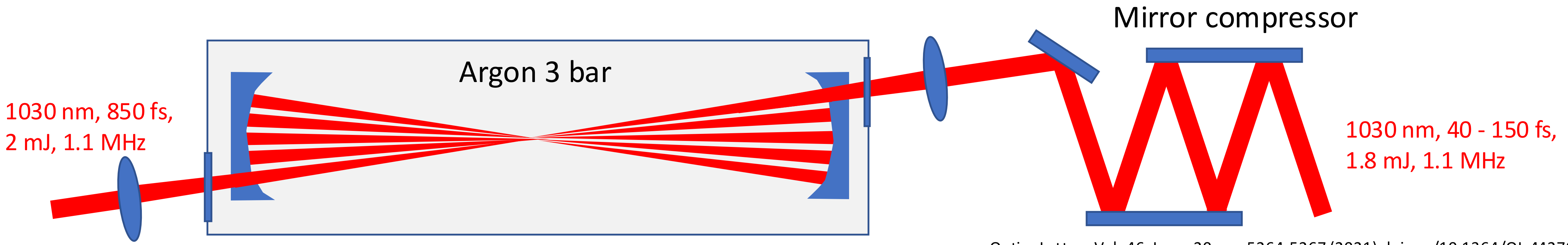


In-coupling can be used for other wavelengths…

Upcoming: Herriott multi-pass cell (HMPC)

- Input: 1030 nm, 850 fs, 2 mJ at 1.1 MHz
- Output: 1030 nm, 40 fs to 150 fs, 1.8 mJ at 1.1 MHz
  - SHG at 515 nm
  - THG at 345 nm
- 10 times higher pulse energy than at 800 nm at 1.1 MHz

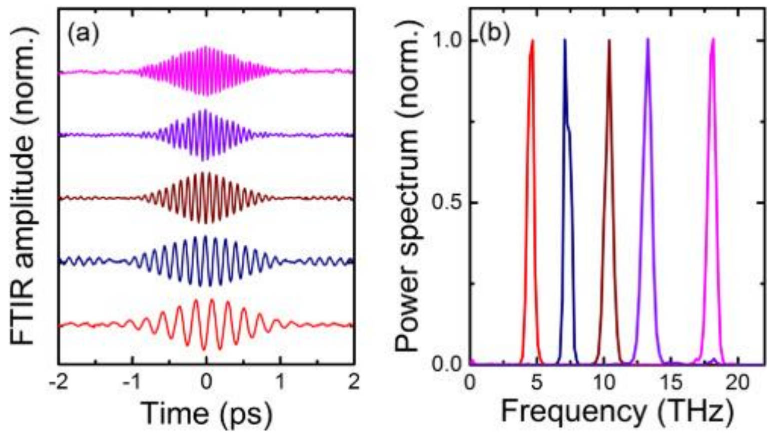




Optics Letters Vol. 46, Issue 20, pp. 5264-5267 (2021) doi.org/10.1364/OL.442707

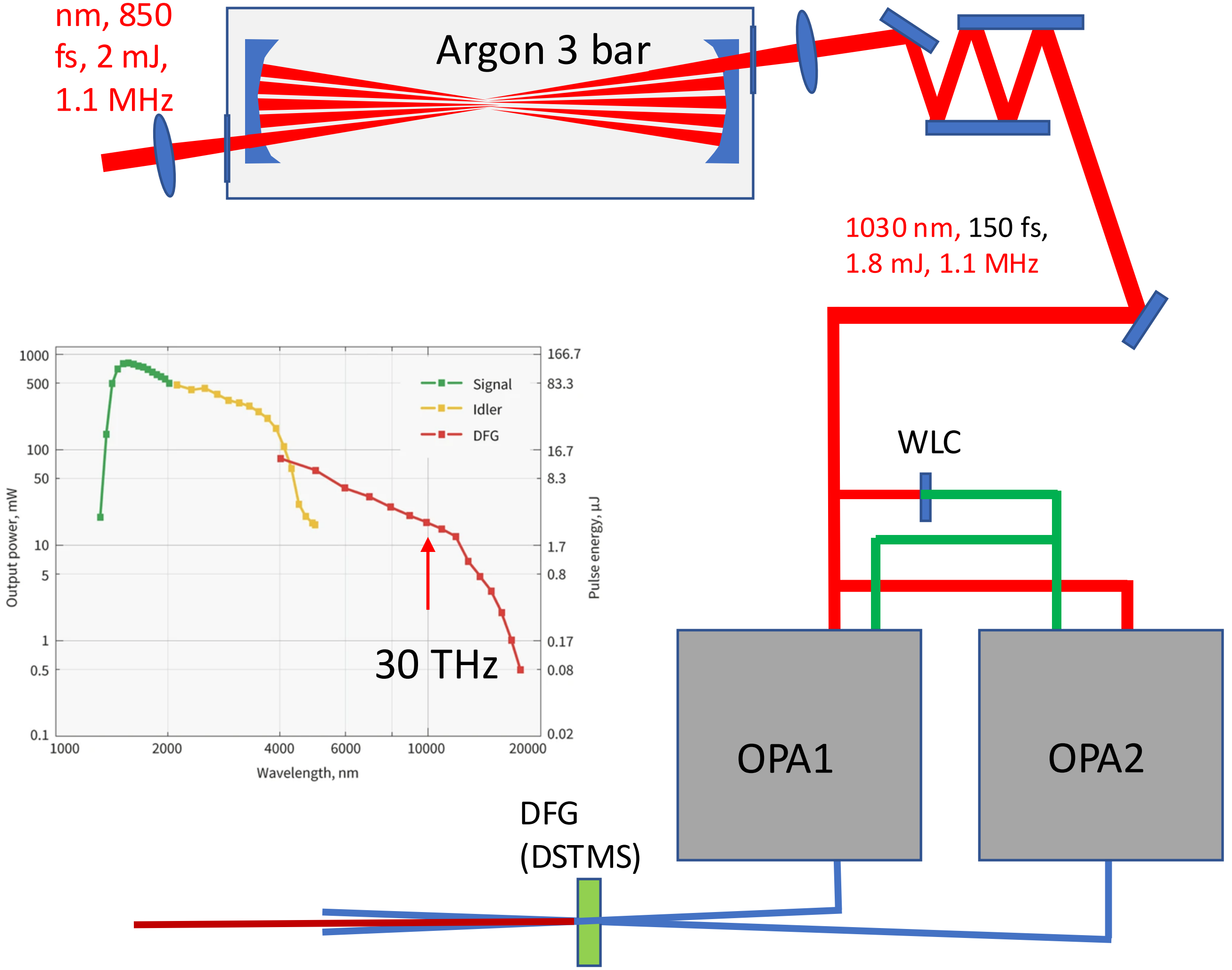
Upcoming: Tunable THz and mid-IR

- Herriott multi-pass cell output pumps two OPAs
  - 150 fs, 1 mJ, 1.1 MHz
- Orpheus OPAs with common white light source
  - Carrier phase stable mid-IR and THz
- DFG between two OPA signals for tunable THz
  - Relaxes signal-idler DFG contraints



10 THz = 30 µm

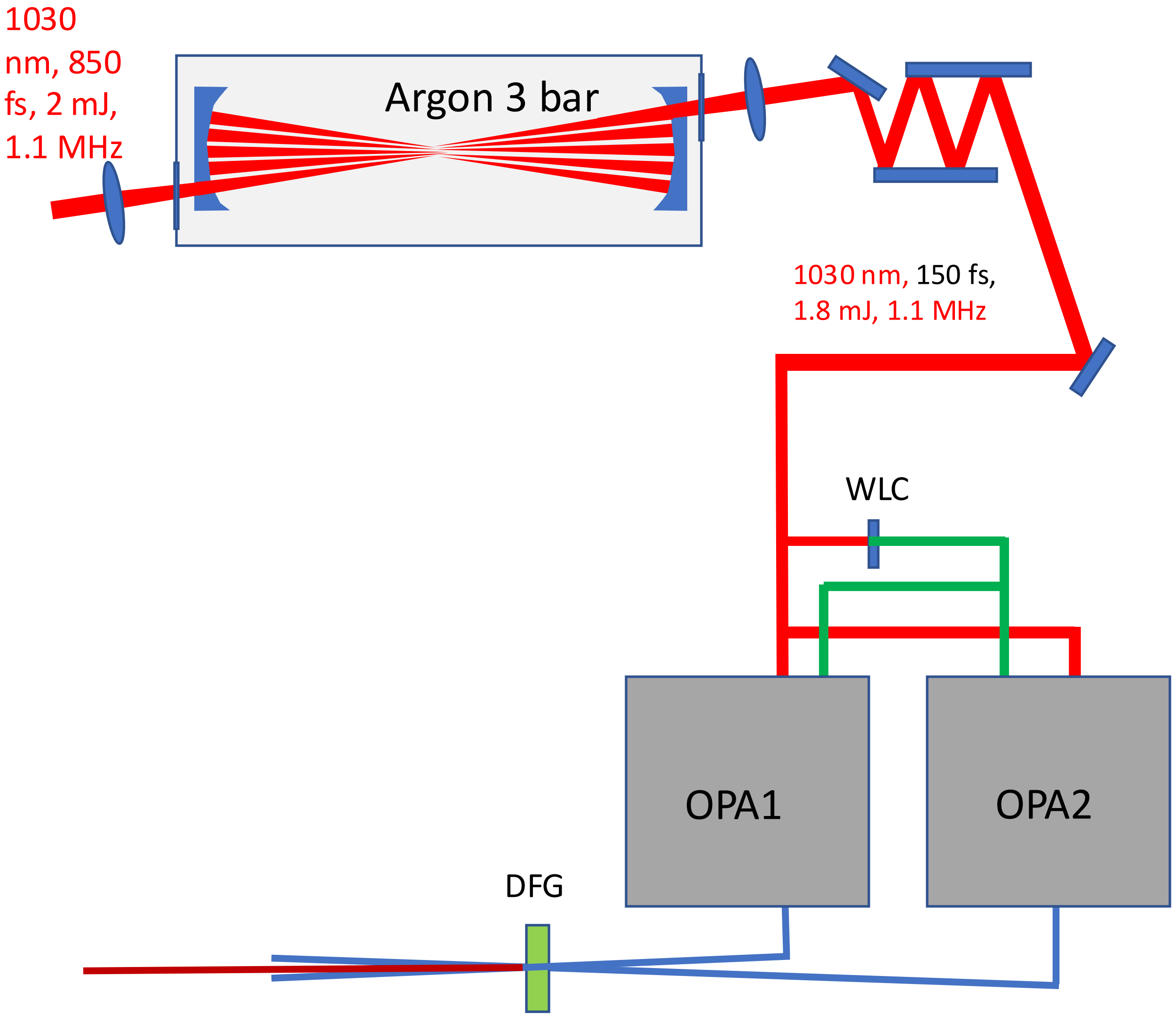
B. Liu et al., Optics Letters 42 (1) 129 (2017) doi.org/10.1364/OL.42.000129



https://lightcon.com/product/orpheus-mid-ir-opa/

Tunable THz and mid-IR - Timeline

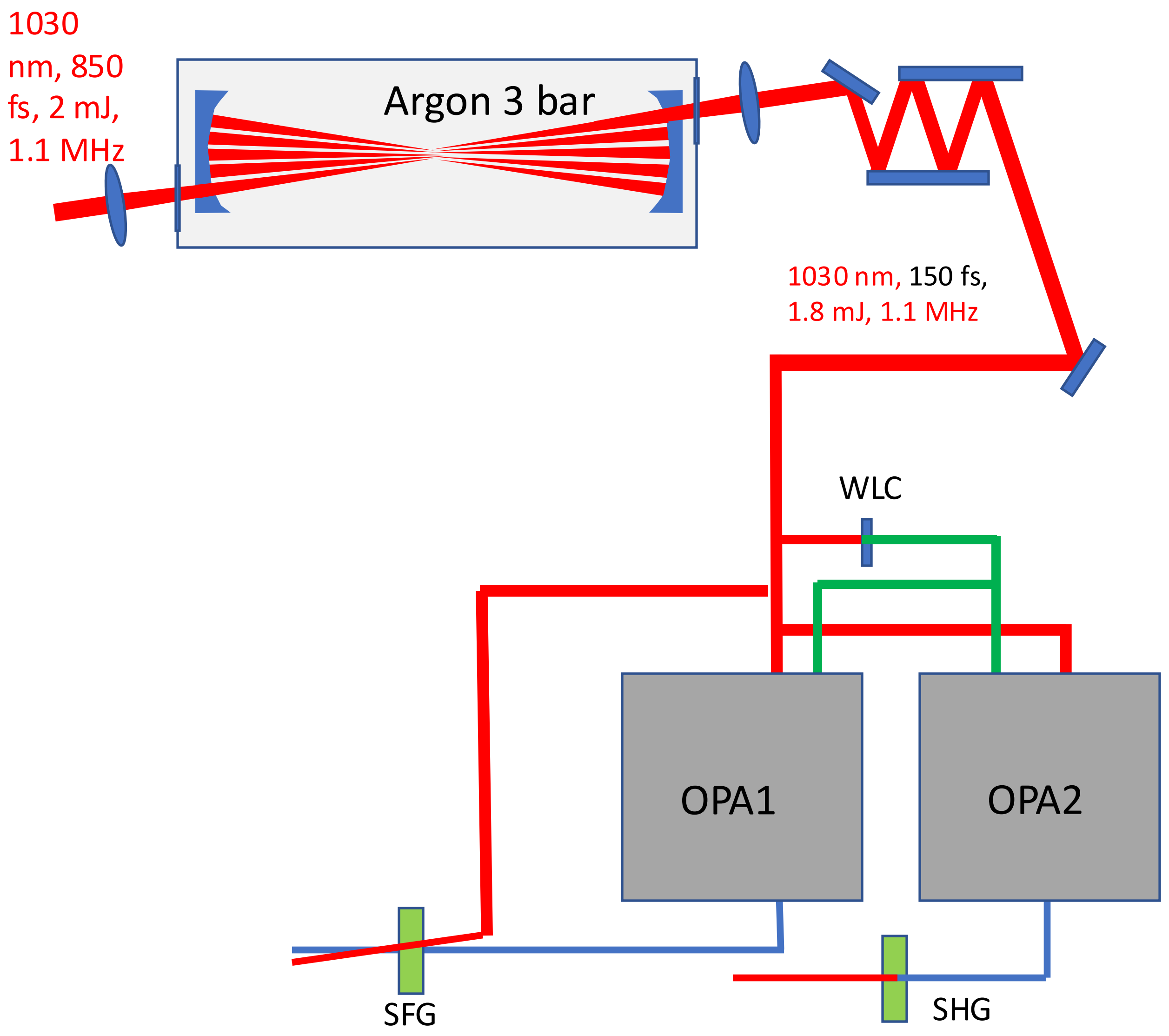
- LAS currently have an operational HMPC compressor and one OPA for testing
- Second OPA arrives in March
- Set up in LAS R&D lab
- White light testing
- Installation at SCS Summer 2025
- Commissioning with PPL Autumn 2025
- Commissioning with FEL at XRD+RIXS early 2026



Upcoming: OPA output at 1.1 MHz

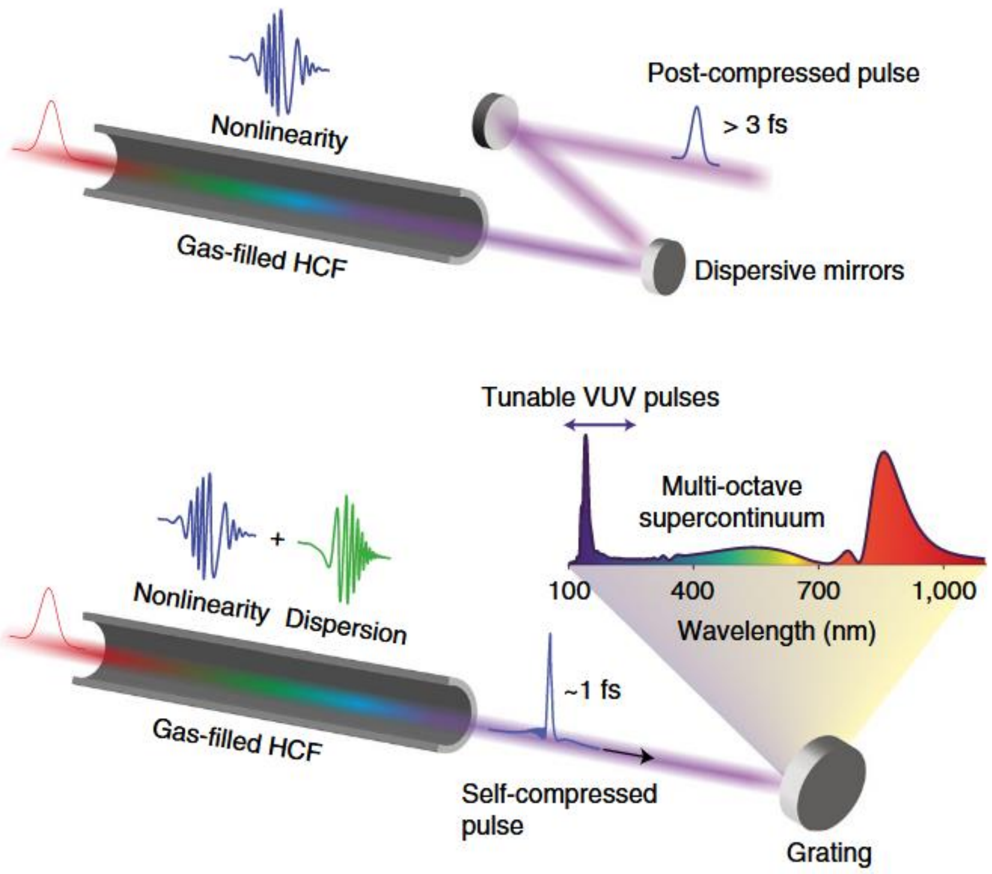
- OPA output similar to TOPAS but 10 times higher repetition rate
  - ca. 100 uJ at 1.1 MHz

- SHG, SFG, …
- Tunable two-color excitation
- Post compression
  - 150 fs to few fs in Heriott cell or hollow-core fiber



Upcoming: tunable visible and UV

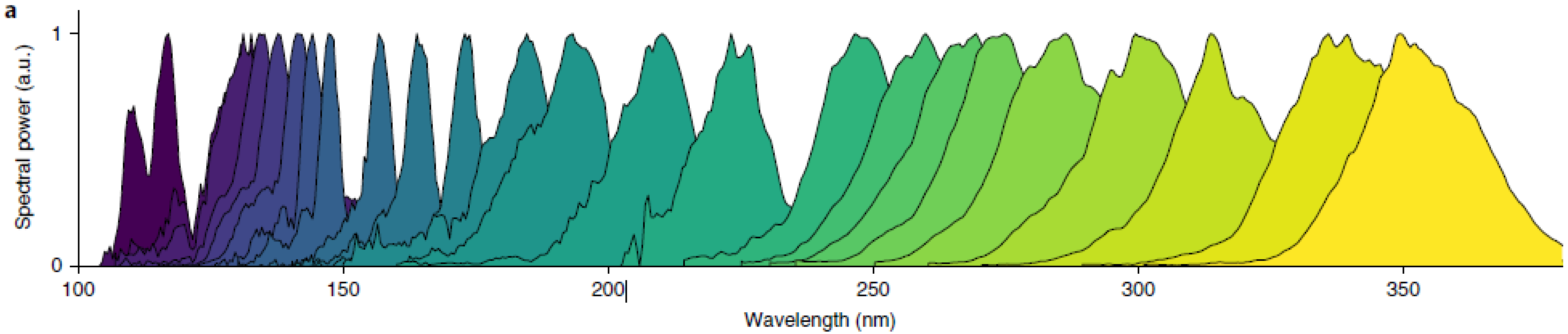
- Gas-filled hollow-core fibers
  - Resonant dispersive wave - NIR → tunable visible to UV pulses, self compressed to few femtoseconds
- SQS has tested this with the PP laser
  - Fiber 1: HMPC output compressed to <10 fs
  - Fiber 2: Resonant dispersive wave - NIR → tunable visible to UV pulses, self compressed to few femtoseconds
  - High repetition rate performance may be problematic
- Tunable UV with high pulse energy and very short pulses
  - CHEM
  - Attosecond science



J. Travers et al., Nature Photonics 13, 547, 2019. https://doi.org/10.1038/s41566-019-0416-4

Upcoming: tunable visible and UV

- Space is a challenge
- In-coupling to experiments is a challenge
  - Limited optics
  - Windows stretch pulses
- Getting longer pulses (e.g. 15 fs) is an area of active research



J. Travers et al., Nature Photonics 13, 547, 2019. https://doi.org/10.1038/s41566-019-0416-4

Summary

- Standard operation: 800nm, 15fs – 50 fs,
  - SHG and THG at 50 fs
  - SHG at 15 fs needs optimization
  - THG does not yield useable pulse energy
  - OPA for tunability
  - Limited by pulse energy at high repetition rate
  - THz with organic crystals: few THz, single cycle.
- Outlook
  - THz pumping at CHEM and FFT
  - Heriott multipass cell – mJ at MHz (10 times current repetition rate)
  - MHz OPA operation
  - Tunable THz and mid-IR
  - Hollow-core fiber and RDW for tunable visible and UV few-fs pulses

Thank you for your attention!

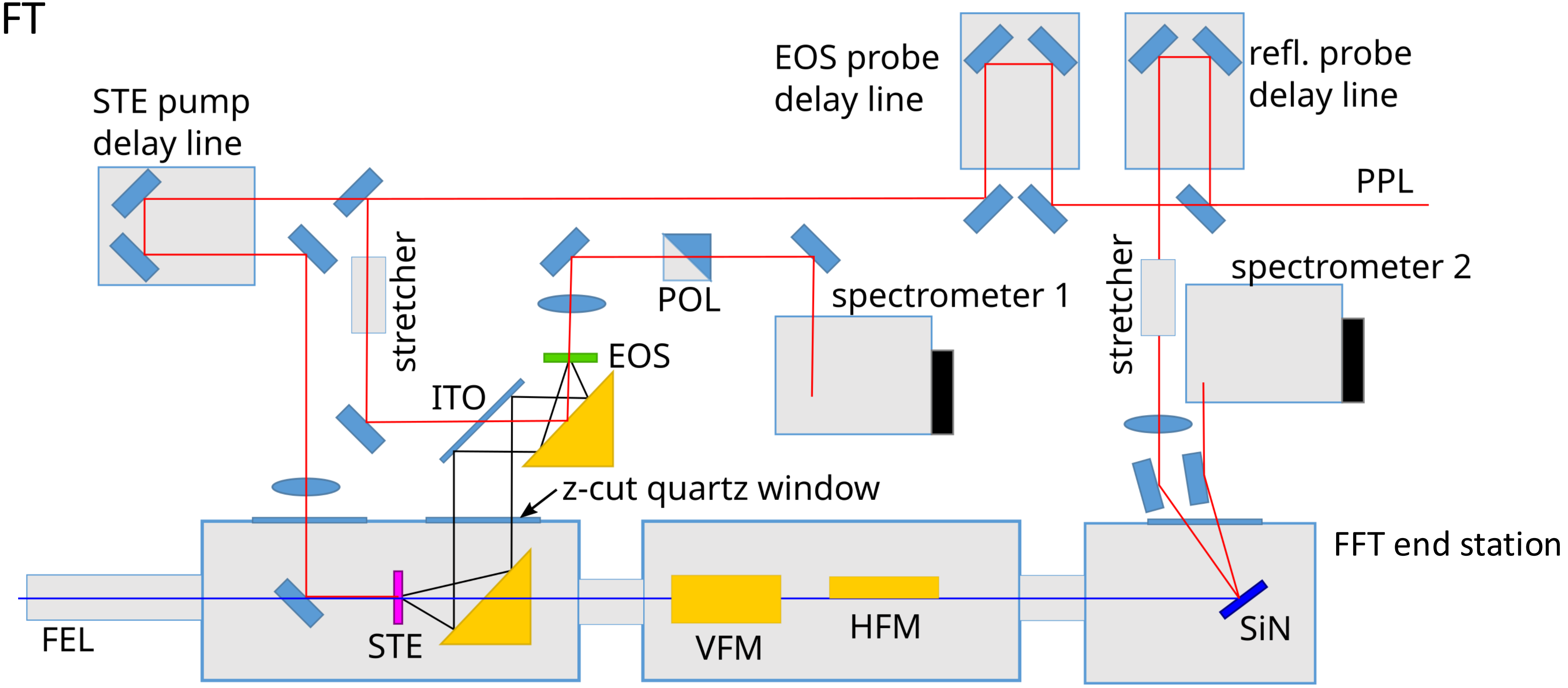
X-ray optical pulse arrival monitor based on spintronic THz emitters

Or

keV to meV extreme non-linear frequency down-conversion

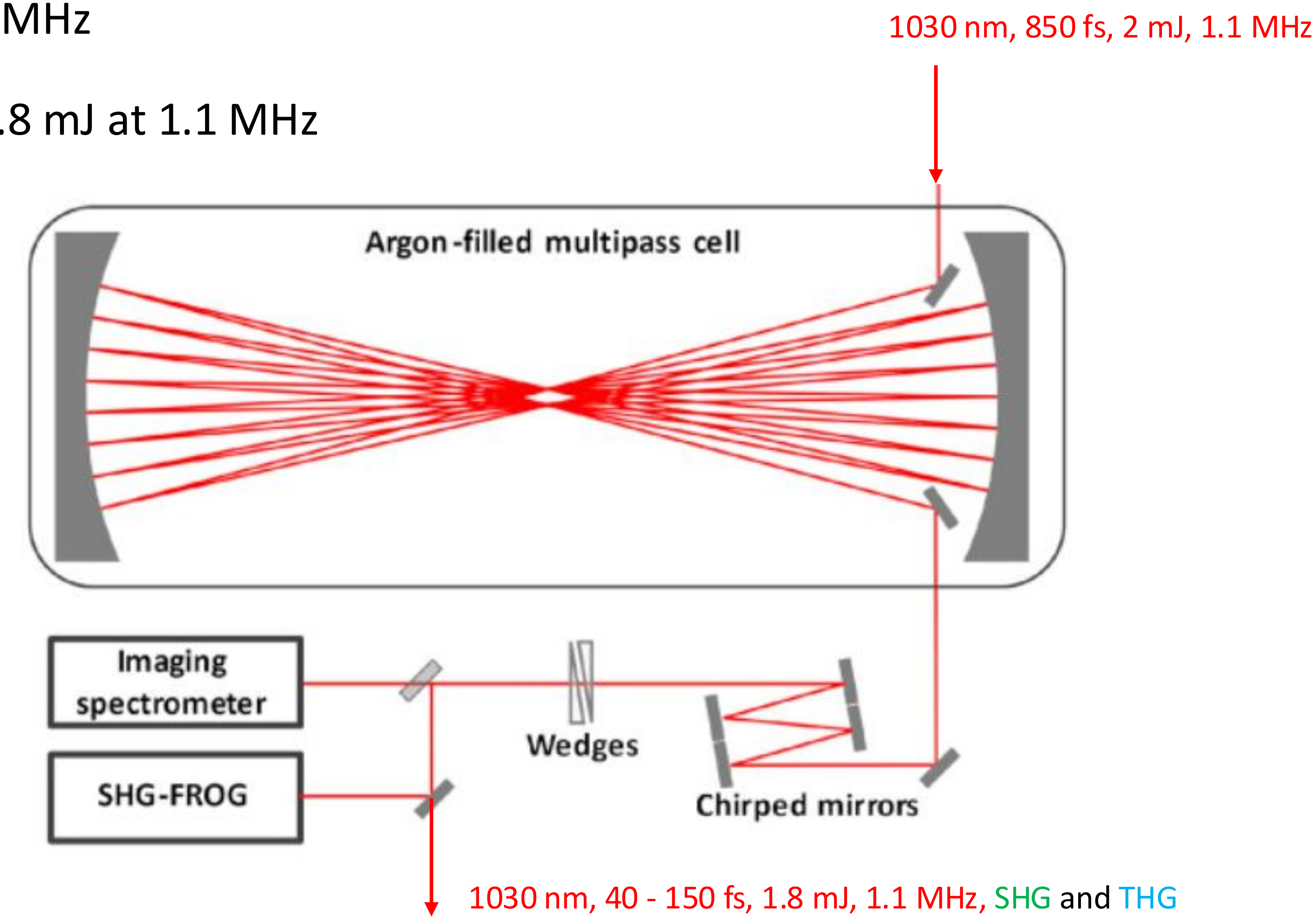
THz emission and PAM experiment at SCS

- Put setup upstream of KBS
- Perform simultaneous transient reflectivity at FFT



Upcoming: Herriot multi-pass cell (HMPC)

- Input: 1030 nm, 850 fs, 2 mJ at 1.1 MHz
- Output: 1030 nm, 40 fs to 150 fs, 1.8 mJ at 1.1 MHz
  - SHG at 515 nm
  - THG at 345 nm
- Ca. 10 x increase in pulse energy at 1.1 MHz
  - Essential for CHEM and RIXS



Optics Letters Vol. 46, Issue 20,
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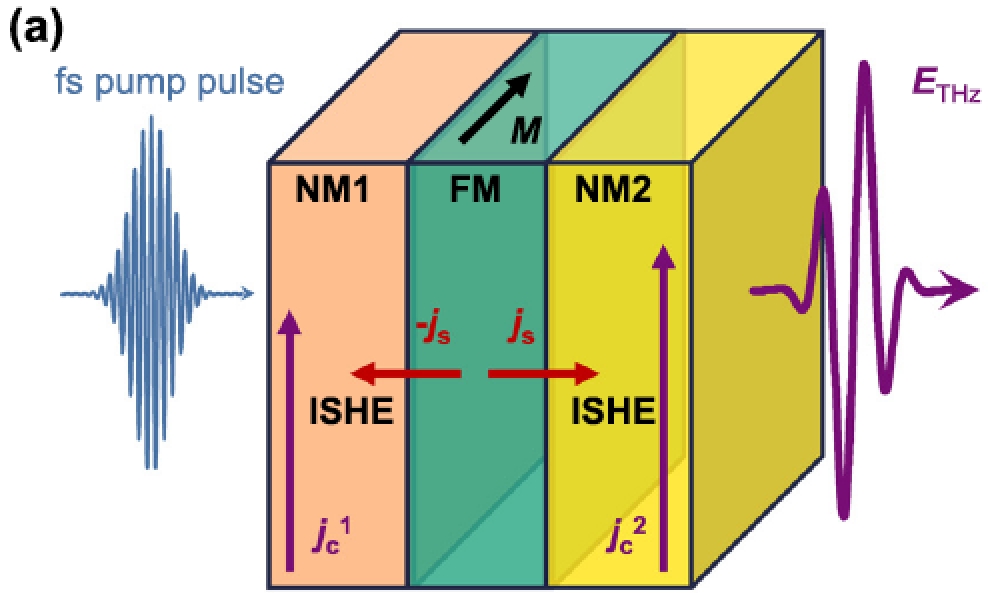
doi.org/10.1364/OL.442707

Spintronic THz emitters (STE)

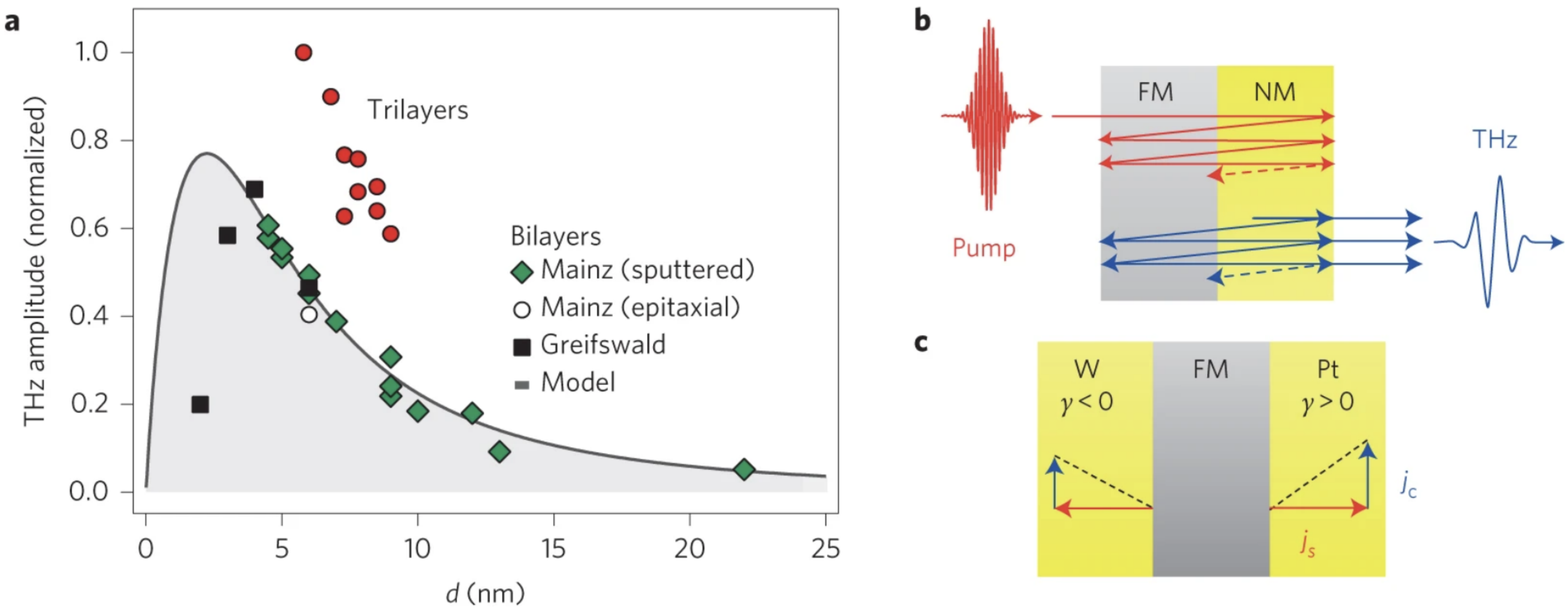


- Excitation of FM layer creates spin current, Js.
- Js flows into the adjacent NM materials.
- Inverse spin Hall effect: large SOE converts Js in real current, Jc.
- Moving charges emit EM radiation in the THz.
- The NM layer have opposite SOE so the emitted radiation adds coherently.

W (1.8nm) / $Co_{20}Fe_{60}B_{20}$ (2 nm) / Pt (1.8 nm)

T. Seifert, et al., "Ultrabroadband single-cycle terahertz pulses with peak fields of 300 kV cm^{-1} from a metallic spintronic emitter," Appl. Phys. Lett. 110, 252402 (2017)

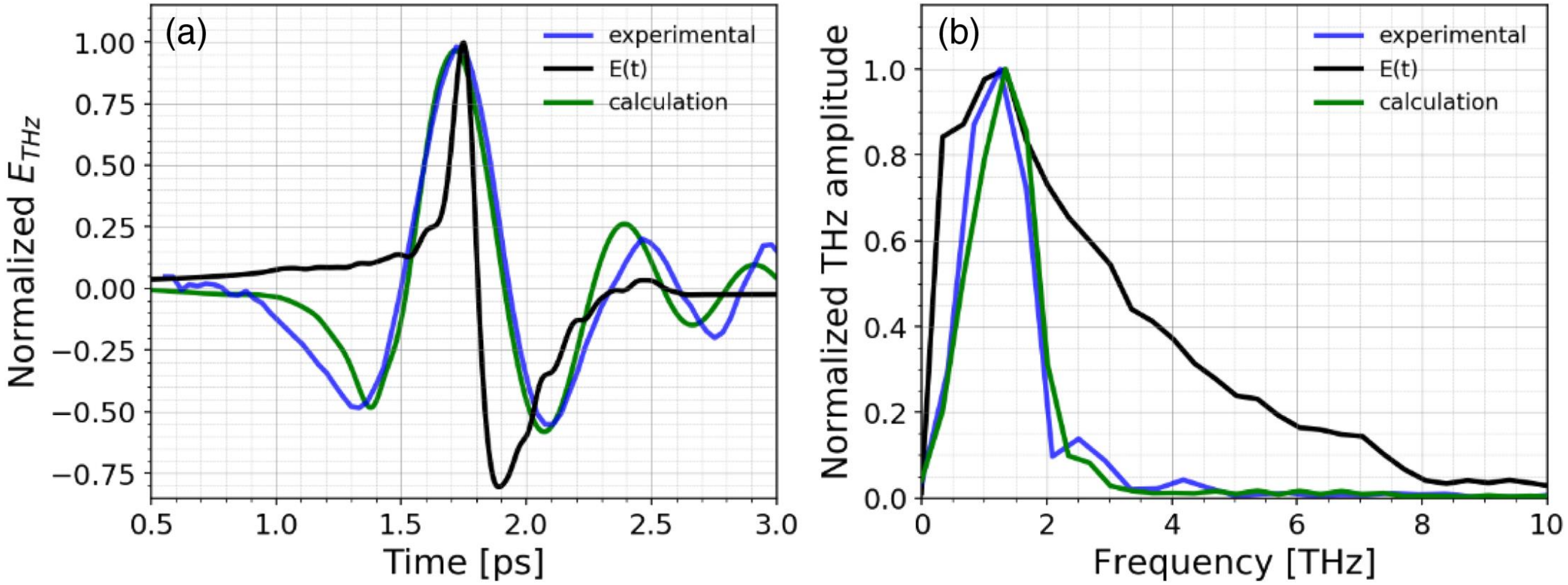
Multilayer STEs



Seifert, T et al., Nature Photon 10, 483 (2016) DOI:10.1038/nphoton.2016.91

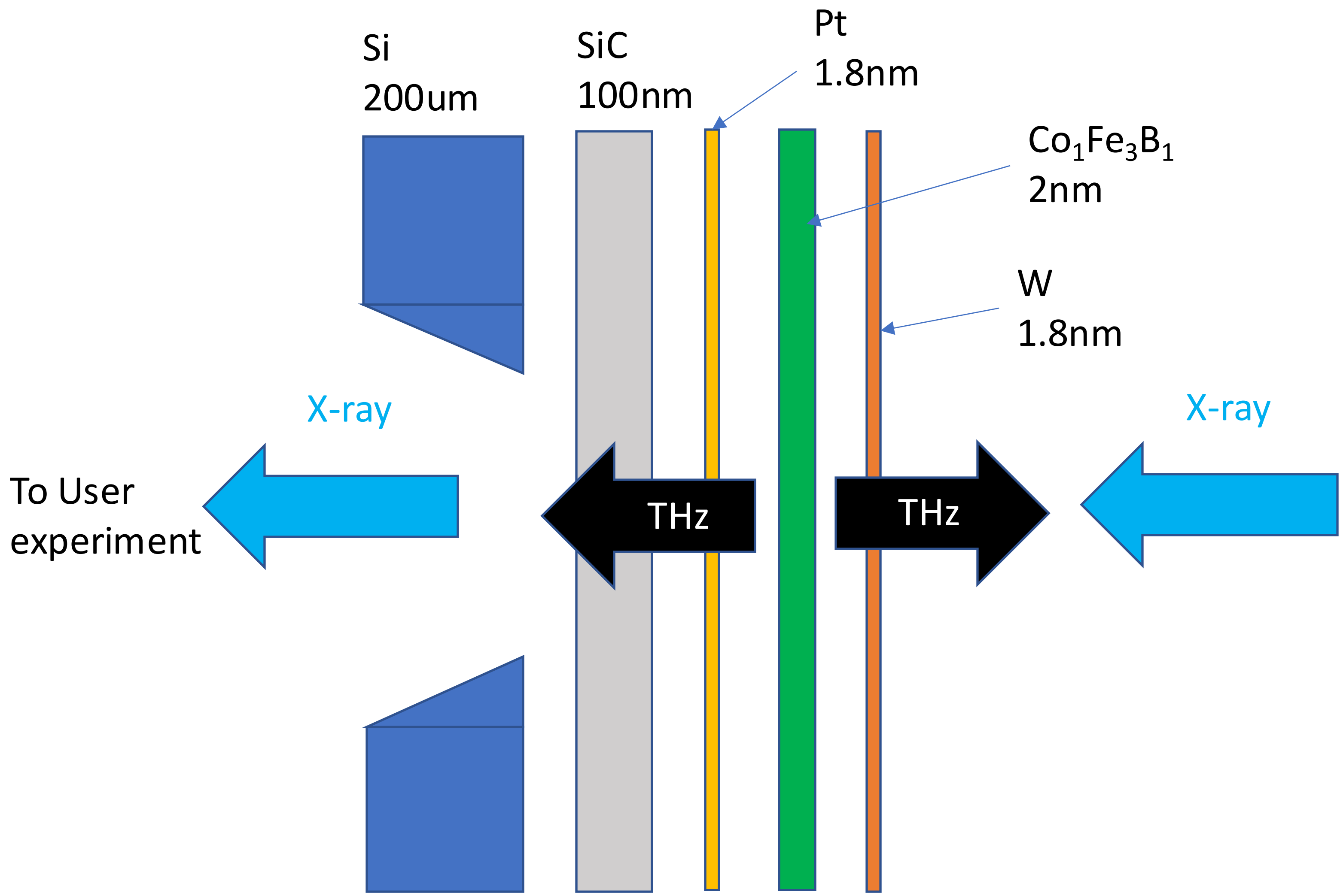
Spintronic THz emitters (STE)

- Excitation with 30 fs, 20 nm pulses at Fermi
- 1 THz: 300 µm wavelength or 4 meV photon energy



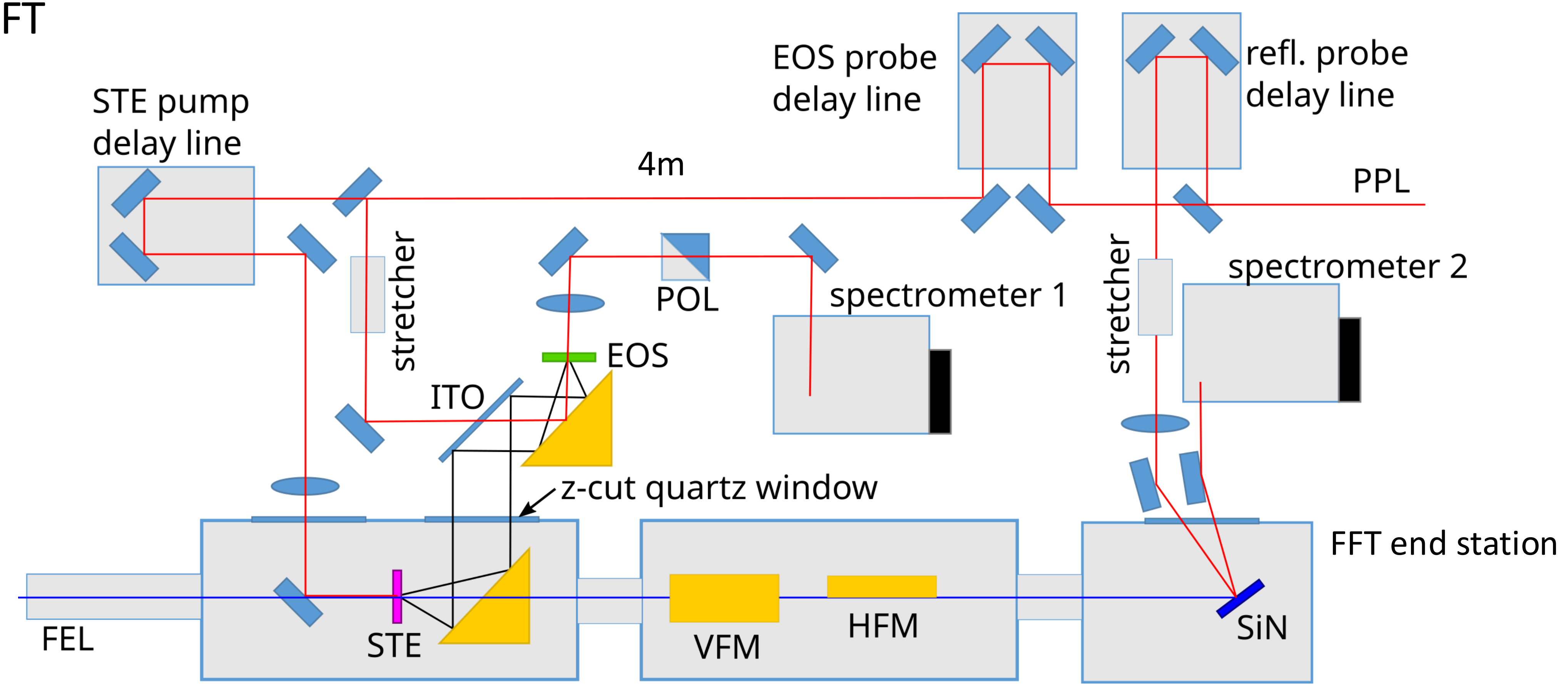
Sample composition

- SiC on Si with STE
- SiC transparent to x-rays
- STE absorbs a few percent
- Suitable for parasitic operation



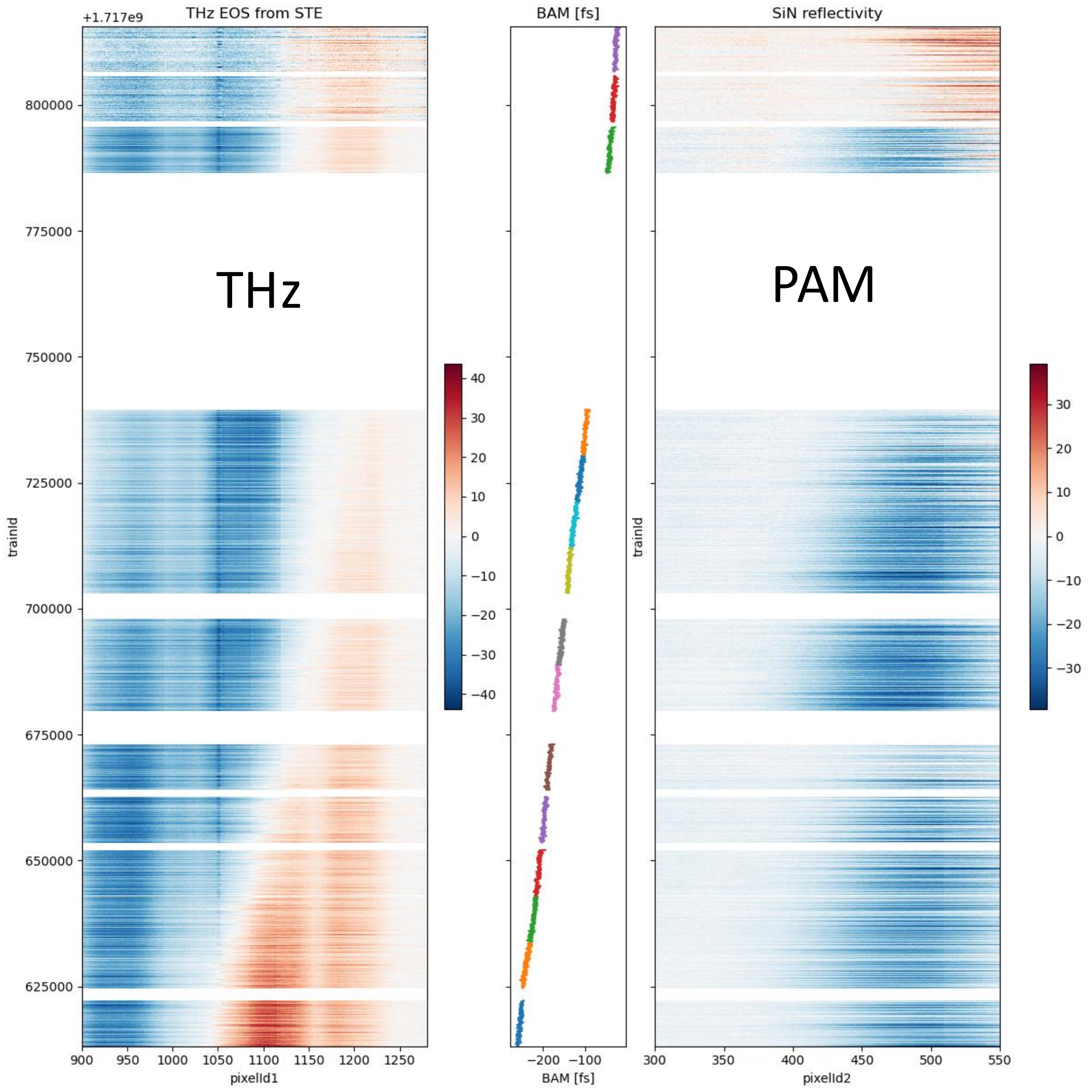
THz emission and PAM experiment at SCS

- Put setup upstream of KBS
- Perform simultaneous transient reflectivity at FFT



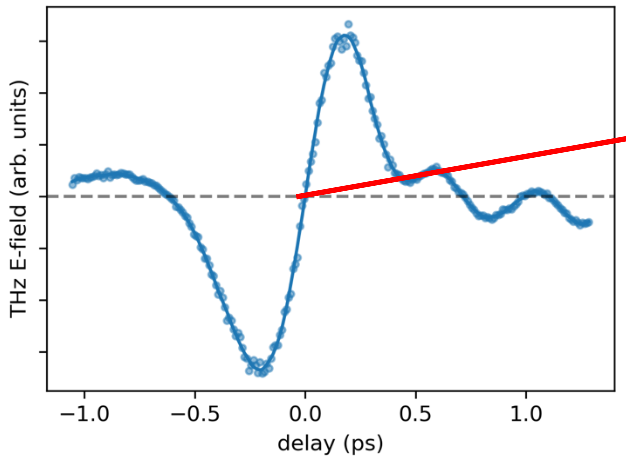
Overnight data acquisition

- About 5 hours measured
  - FEL: 28pulses @ 282 kHz, 905 eV, PPL 15 fs
  - PPL: 56 PPL @ 564 kHz, 800 nm, 15 fs, chirped with some glass (FS, SF57, SF11)
  - difference between pumped and unpumped, average over all pulses in a train
  - GOTTHARD I detectors not fully gain calibrated giving vertical stripes.
- Simultaneous measurement of arrival time at THz EOS and PAM
- Both show shifts that qualitatively matches the BAM trend
- Spectra show a shifts that qualitatively matches the BAM trend

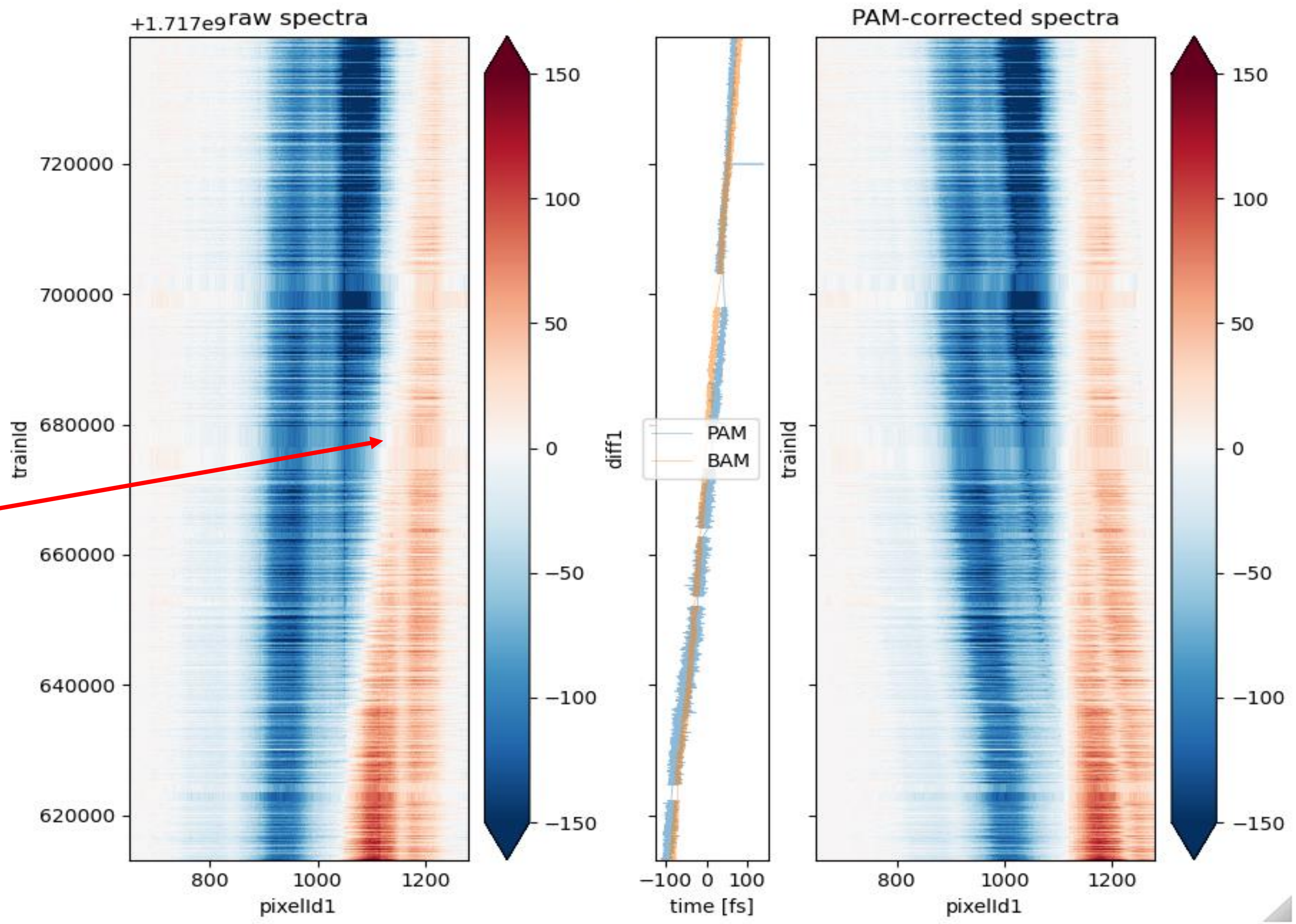


Improved Woody's algorithm to extract time arrival

- 3.3 hours of data
- Each train is averaged over 28 pulses
- Captures the long term drift



A. Cabasson & al., IEEE Signal Process. Lett. 15, 573 (2008)

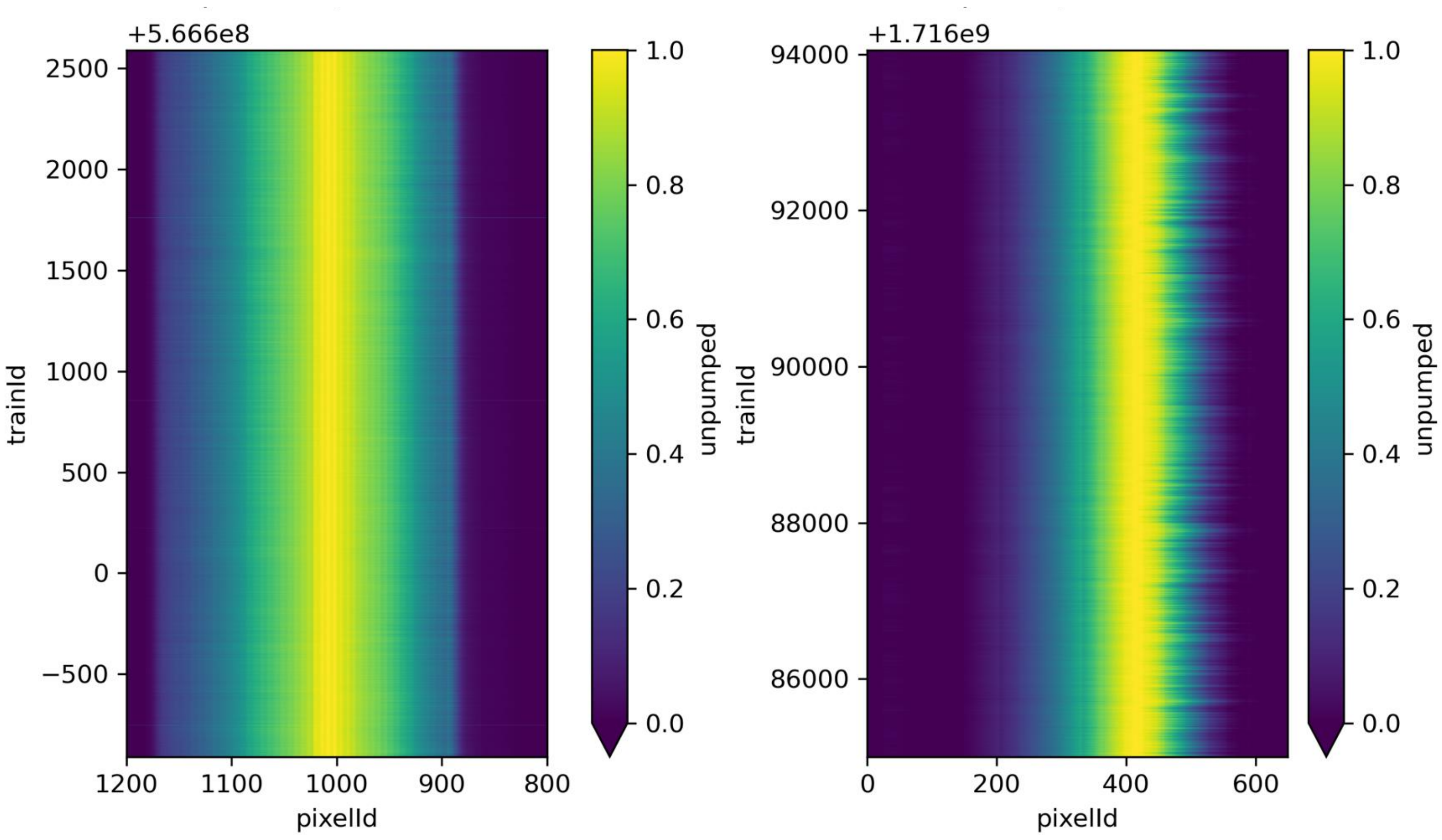


PAM-PAM correlation

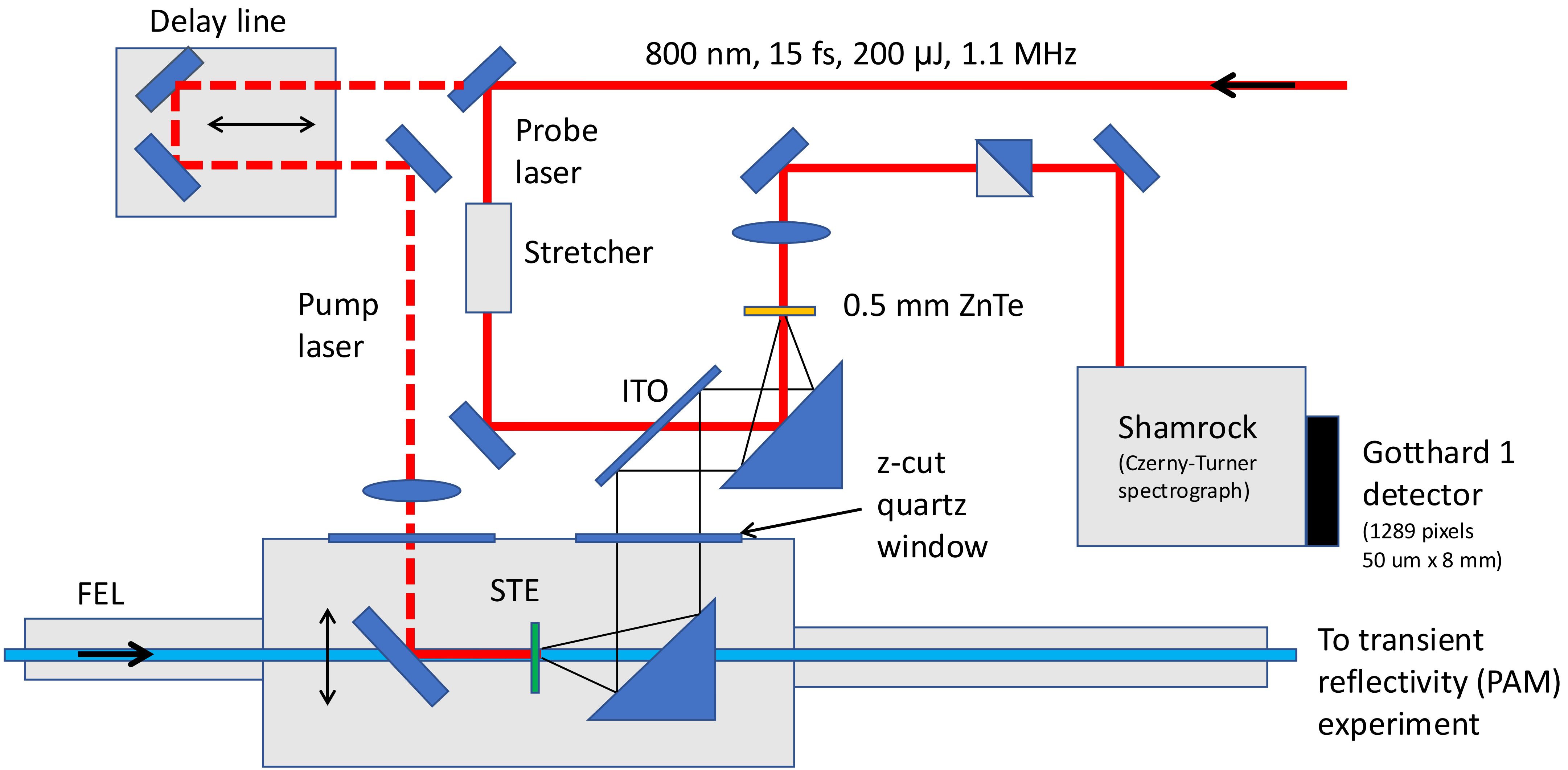
- Cannot extract meaningful pulse arrival data from the reflectivity data
- Probably due to instability of PPL spectrum during this run (since corrected).

PPL spectrum

2019 2023

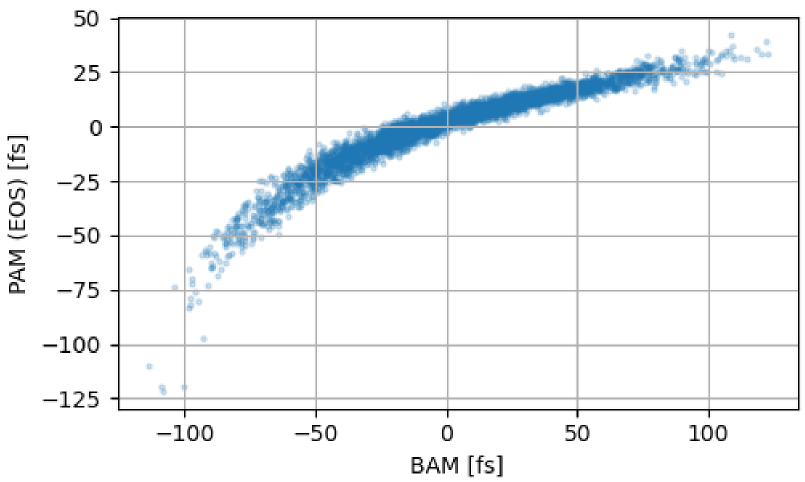


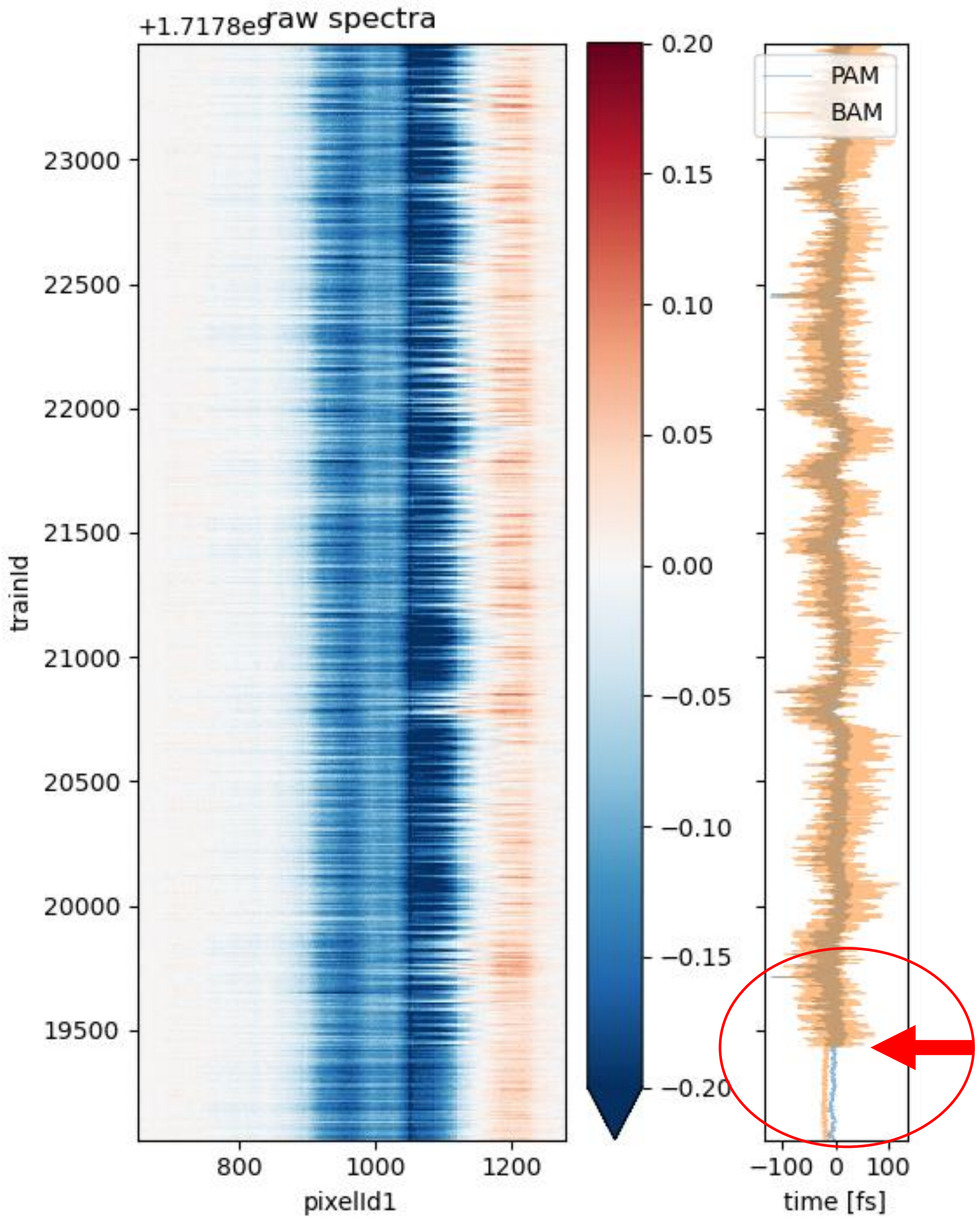
Spectrally encoded electro-optic sampling



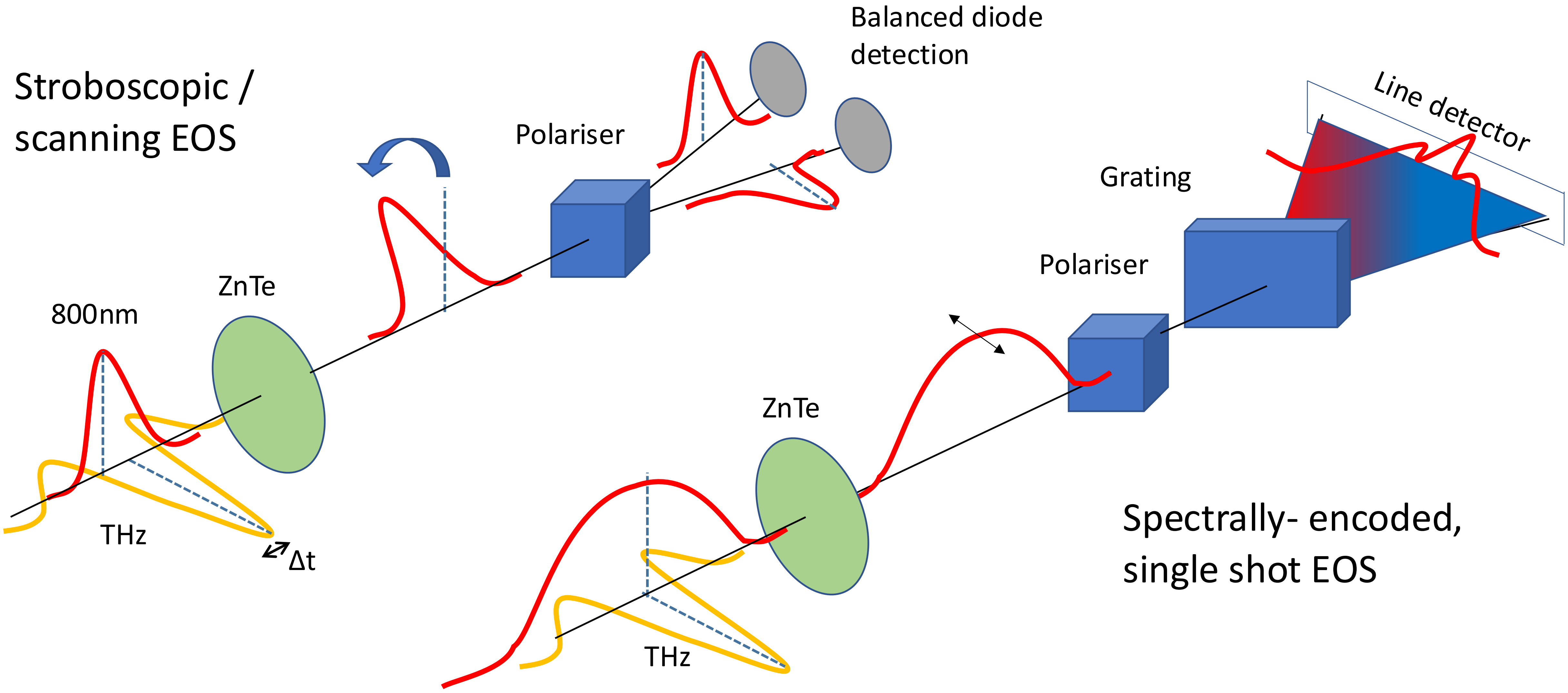
PAM-BAM correlation

- THz deviates for positive jitter. Cause unknown.
- Efficacy of BAM feedback is clear on short term.





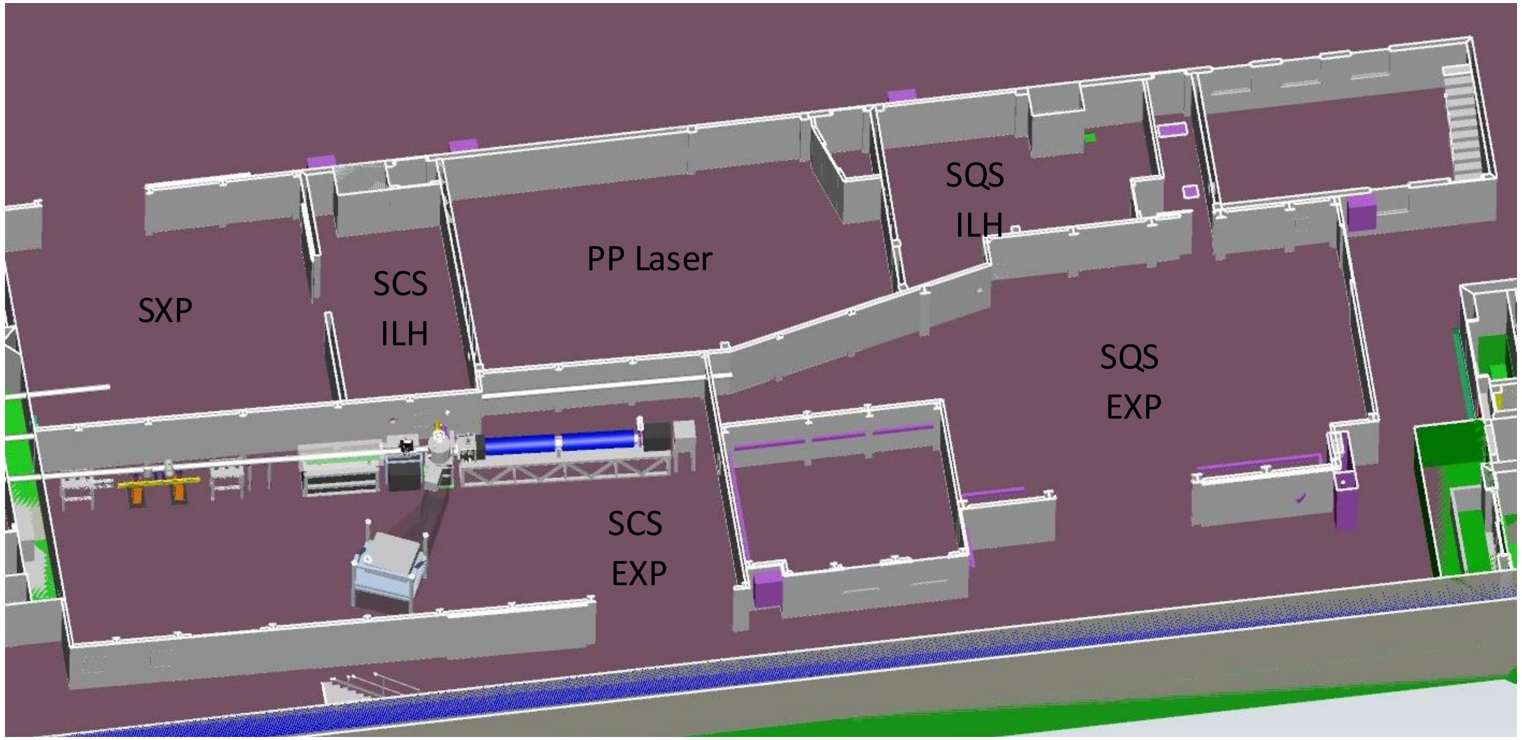
Electro-optic sampling



Pump-probe laser at EuXFEL

- Three SASEs
  - Each with two Instruments and a PP laser run by dedicated group
  - Fiber front end
  - Yb:YAG Innoslab amplifer producing 1030 nm, 800 fs
  - NOPA for each instrument generating 800 nm at 15 fs or < 50 fs
  - Repetition operating points
    - 113 kHz (2 mJ) , 563 kHz (400 µJ), 1.1 MHz (200 µJ), 4.5 MHz (50 µJ)

SASE 3 Experimental Area



- 80% of user proposals call for optical laser

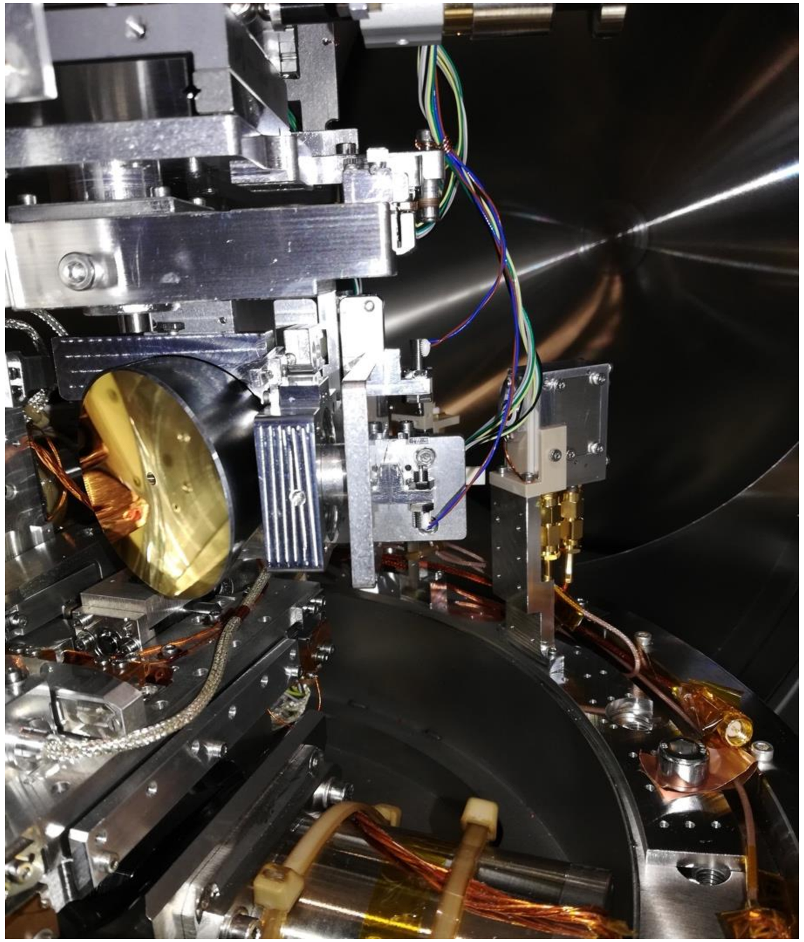
- Large, high power system
- Matches FEL burst pattern
- Burst mode adds complexity
- Reduced stability compared to CW, e.g. 100 kHz

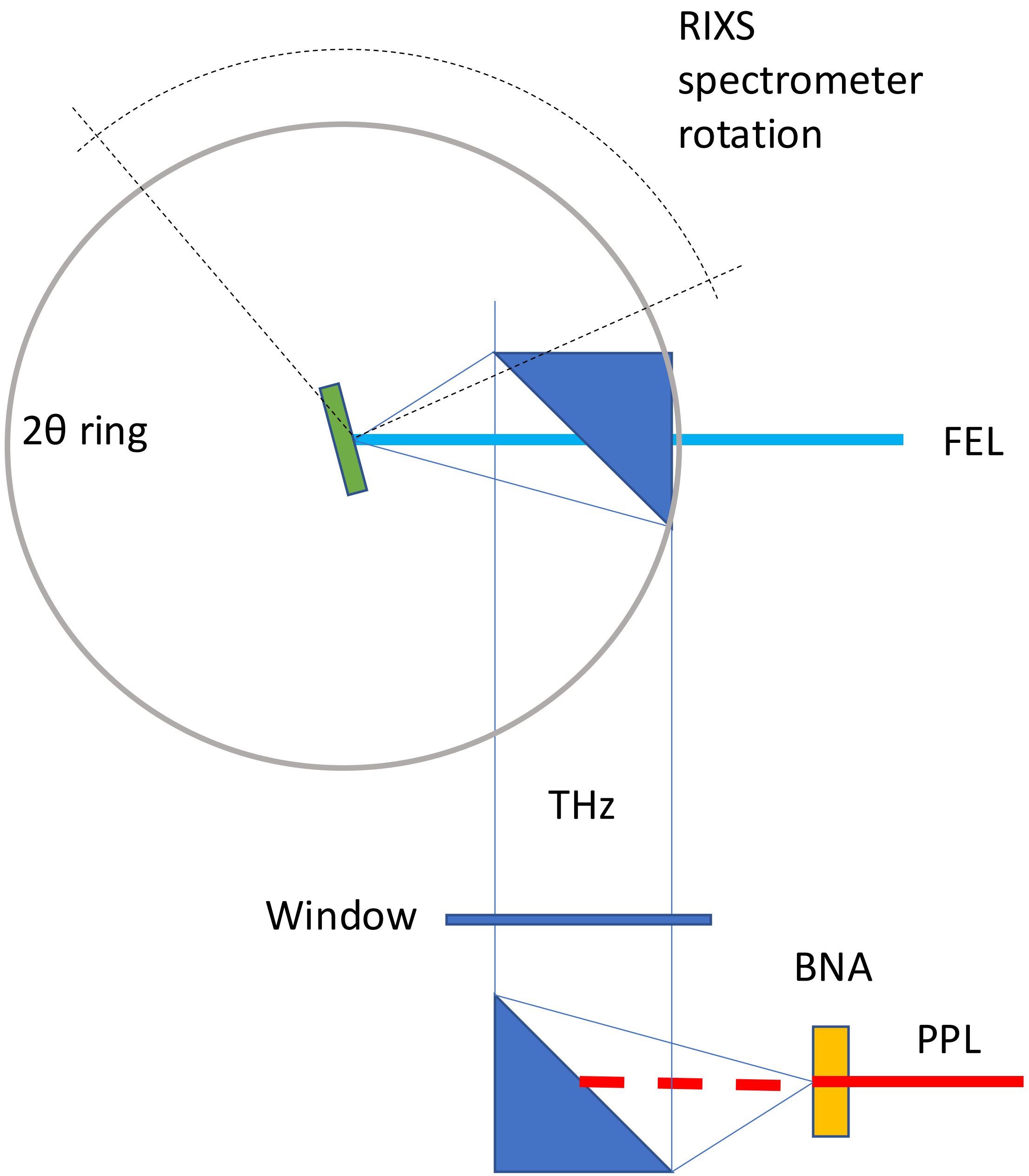
- Run by separate group

- Requires maintenance
- Limited beam availability for testing and setup

- Long beam path

Outlook: THz pump – RIXS probe

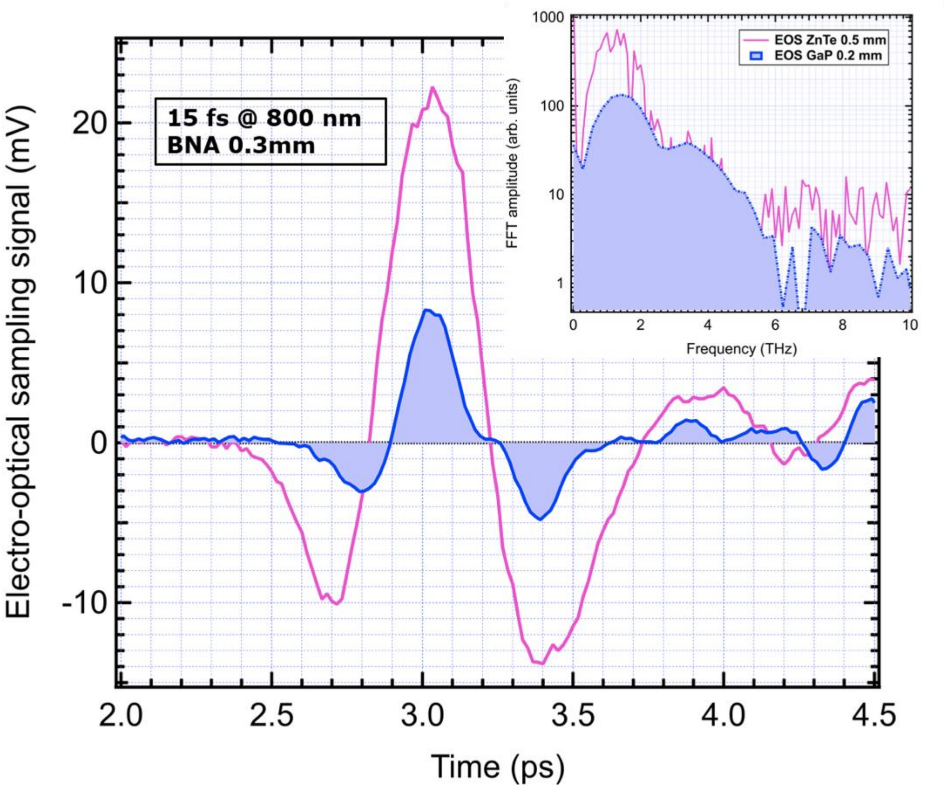


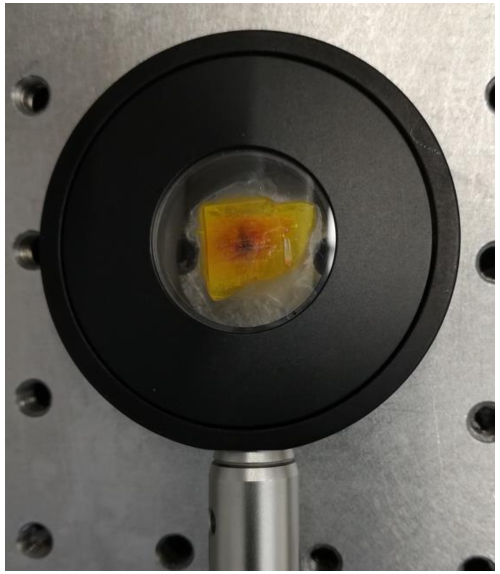


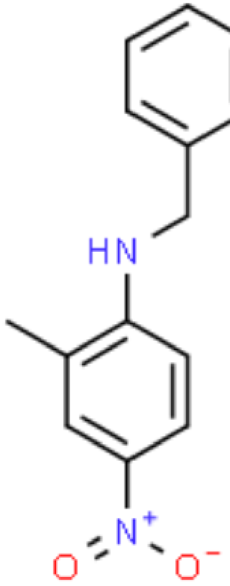
Outlook: THz pump – RIXS probe

- BNA pumped with 15fs, 2mJ, 113kHz

N-Benzyl-2-methyl-4-nitroaniline





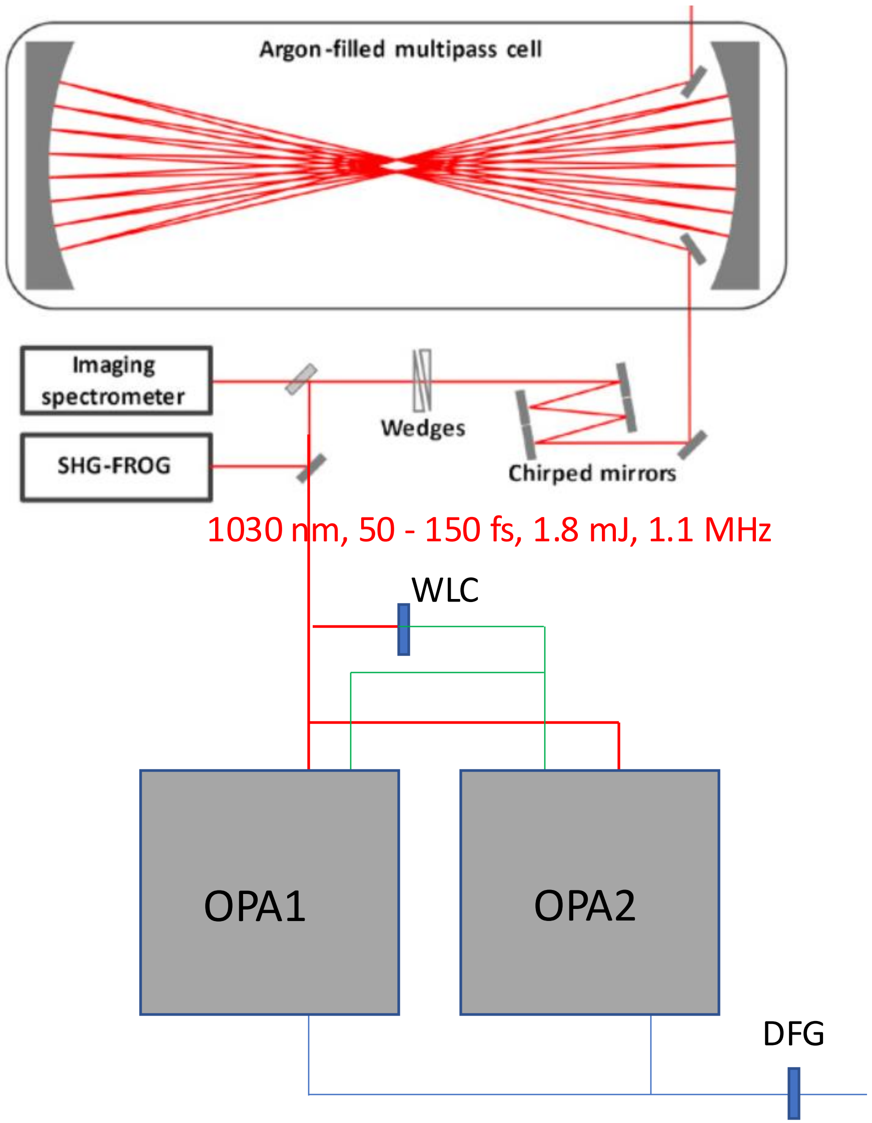


Ilie Radu, EuXFEL

https://www.chemspider.com/Chemical-Structure.2127659.html

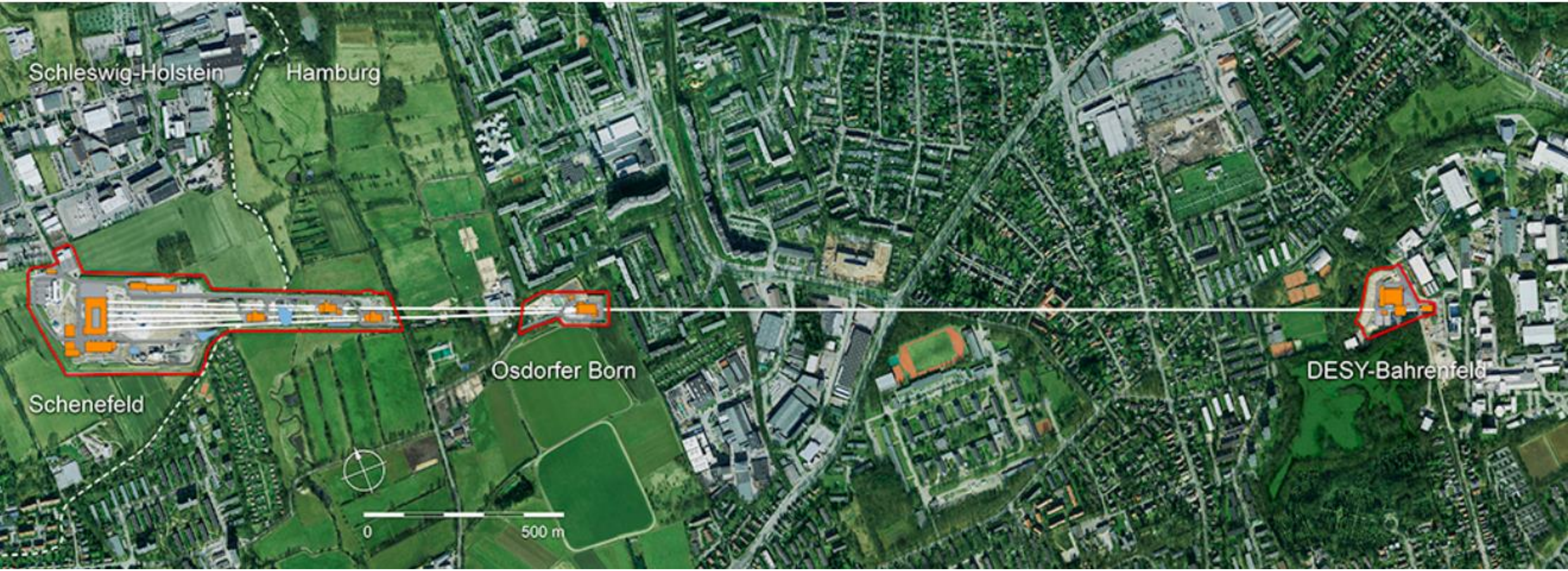
Outlook: THz at SCS

- Further THz source development
  - Heriott cell post compression at 1030nm, 1.1MHz
    - 50 - 150 fs, 2 mJ, 1.1 MHz
    - SHG and THG
  - Pump two Orpheus OPAs with common white light source
  - DFG between two OPA signals for tunable THz
- Visible and UV sources ...



Optics Letters Vol. 46, Issue 20, pp. 5264-5267 (2021) doi.org/10.1364/OL.442707

European XFEL

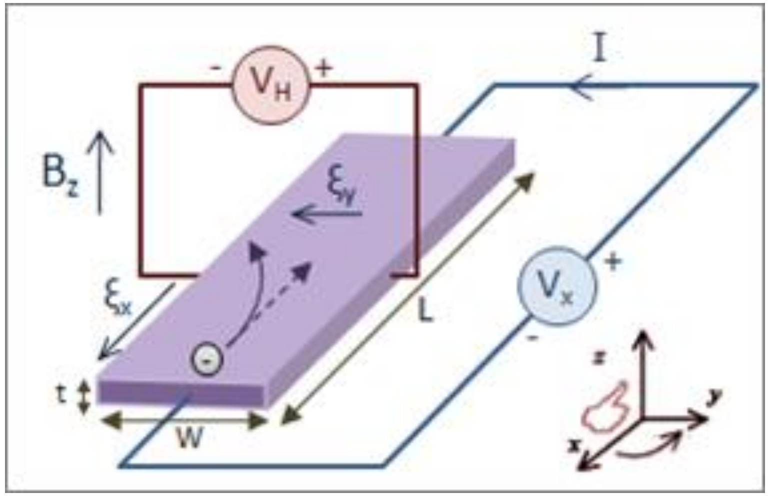


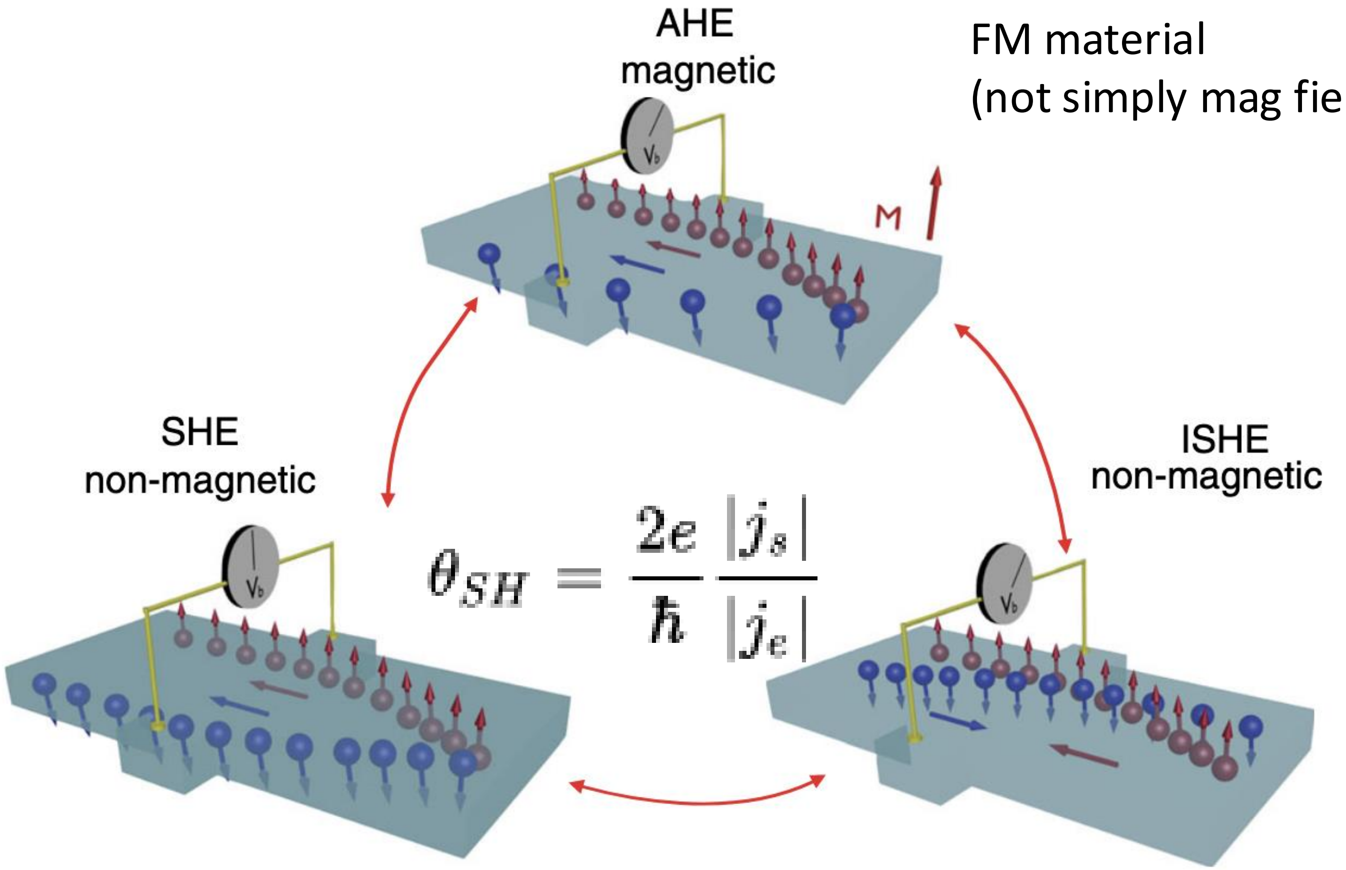
https://www.xfel.eu/facility/overview/index_eng.html

Hall effects

Hall effect

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$



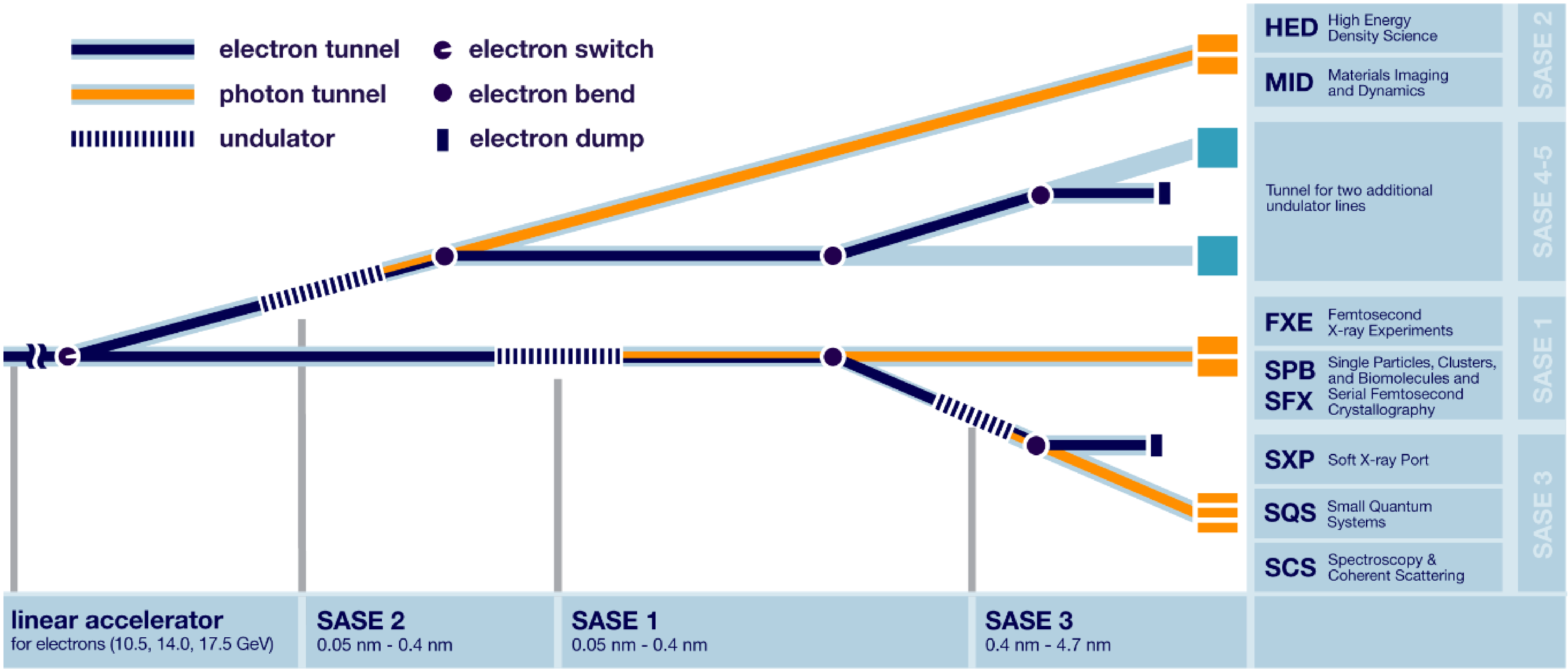


FM material
(not simply mag field)

https://commons.wikimedia.org/wiki/File:Hall_Effect_Measurement_Setup_for_Electrons.png

Sinova et al. Rev. Mod. Phys. 87,1213, (2015) DOI: 10.1103/RevModPhys.87.1213

European XFEL



https://www.xfel.eu/facility/beamlines/index_eng.html

Conversion results with 800 nm at 113 kHz

TOPAS output with pump

E = 1.8 mJ, Ø = 8 mm (1/e²)