New opportunities for FemtoXMCD and mSAXS with variable polarization

European XFEL

Dr. Loïc Le Guyader
Detector Instrument Scientist

Schenefeld, 2025-01-23

SCS Instrument: SAXS, but also XAS

N. Thielemann-Kühn *& al.* Sci. Adv.10,eadk9522 (2024)

FEL

Gas Monitor Detector

- Pulse energies >~ 100 nJ
- Rep rate up to 4.5 MHz

Laser Incoupling

- 800 nm, 15 -300 fs, 0.05 – 2 mJ
- 1030 nm, 400 fs or <1ps, 1 – 40 mJ

KB mirrors

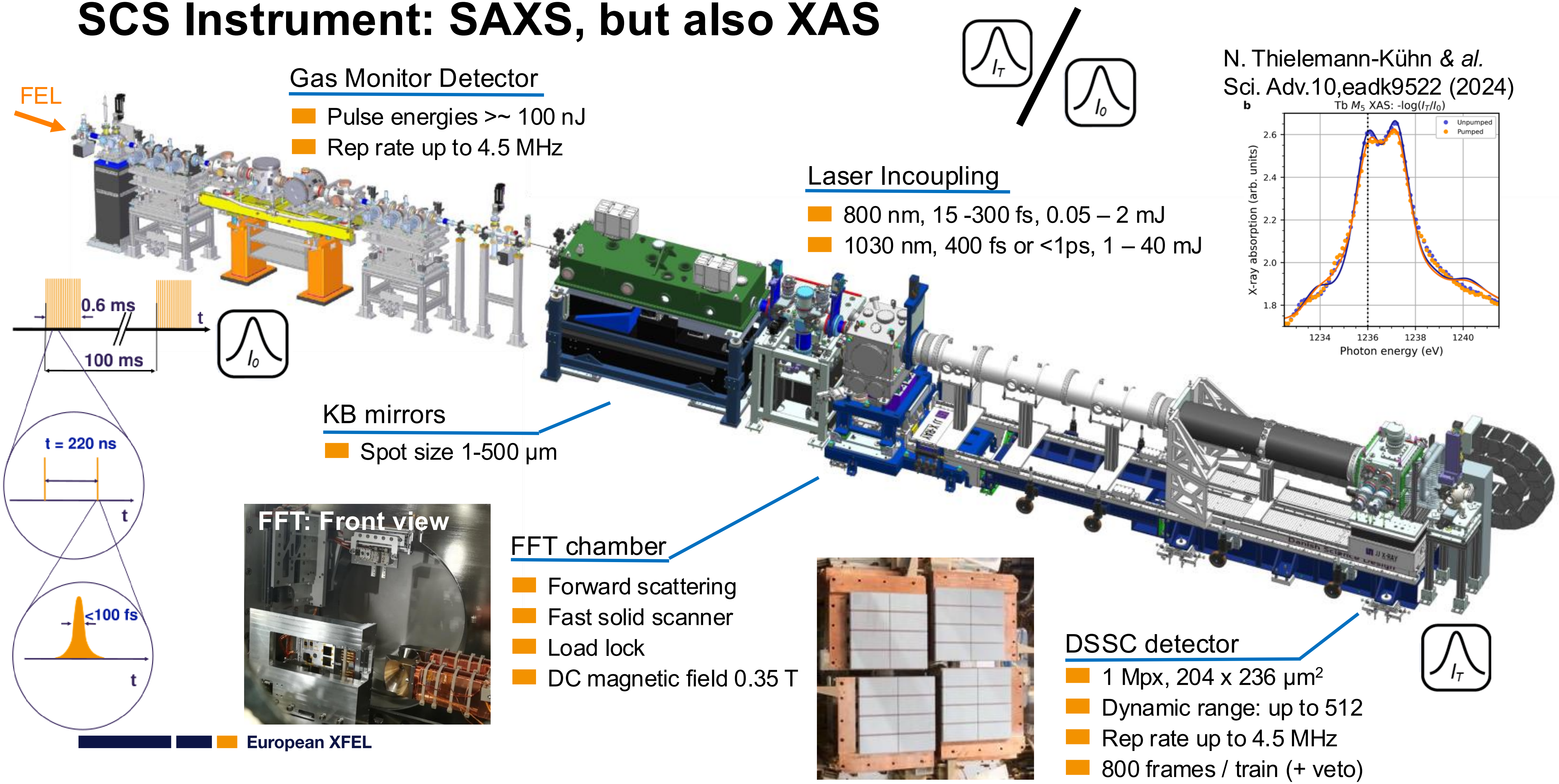
- Spot size 1-500 μm

FFT chamber

- Forward scattering
- Fast solid scanner
- Load lock
- DC magnetic field 0.35 T

DSSC detector

- 1 Mpx, 204 x 236 μm^2
- Dynamic range: up to 512
- Rep rate up to 4.5 MHz
- 800 frames / train (+ veto)



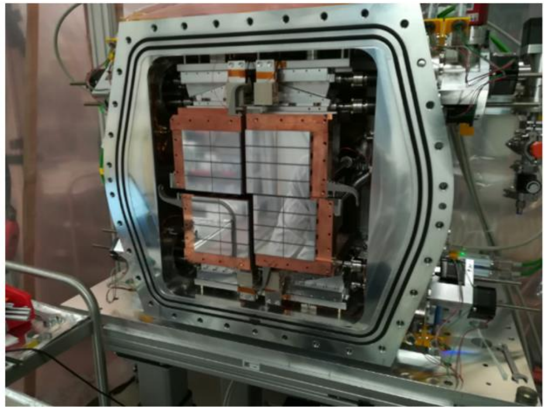
DSSC for CDI, SAXS, XPCS

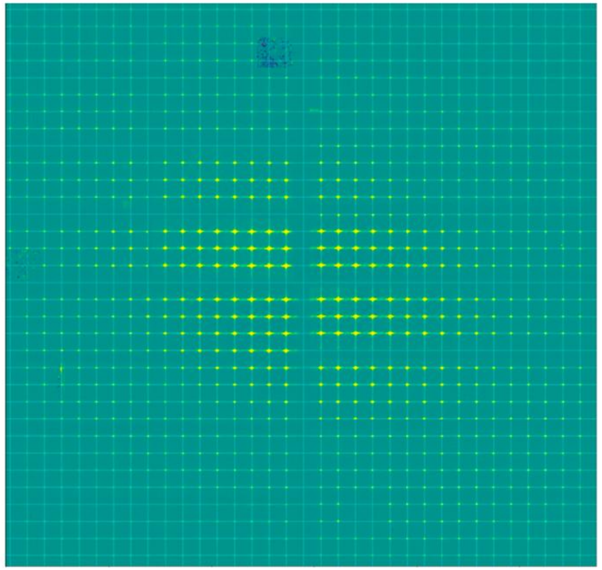
DEPFET Sensor with Signal Compression
DEpleted P-channel Field-Effect Transistor

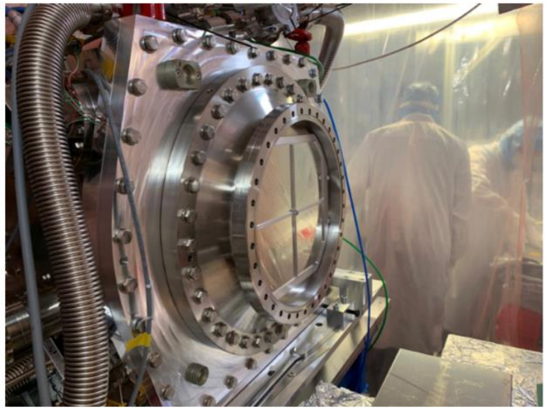
Miniaturized Silicon Drift Detector (MiniSDD)

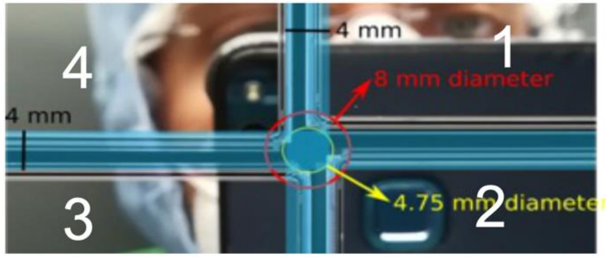
DSSC detector	SAXS, CDI, BOZ-XAS, XPCS	
Number of pixels	1024 x 1024	
Pixel coordinates	Hexagonal	Detector quadrants in windmill configuration
Pixel size	204 µm x 236 µm	
Max frame rate	4.5 MHz	
Beam hole size	Default: 4.75 mm (windmill)	The diameter of the central dead area is 8mm.
Standard detector-to-sample distance	Min: 1.02 m Max: 5.40 m Travel range: 1.5 m (under vacuum)	

Porro & al., IEEE Transactions on Nuclear Science, **68**, 1334 (2021)

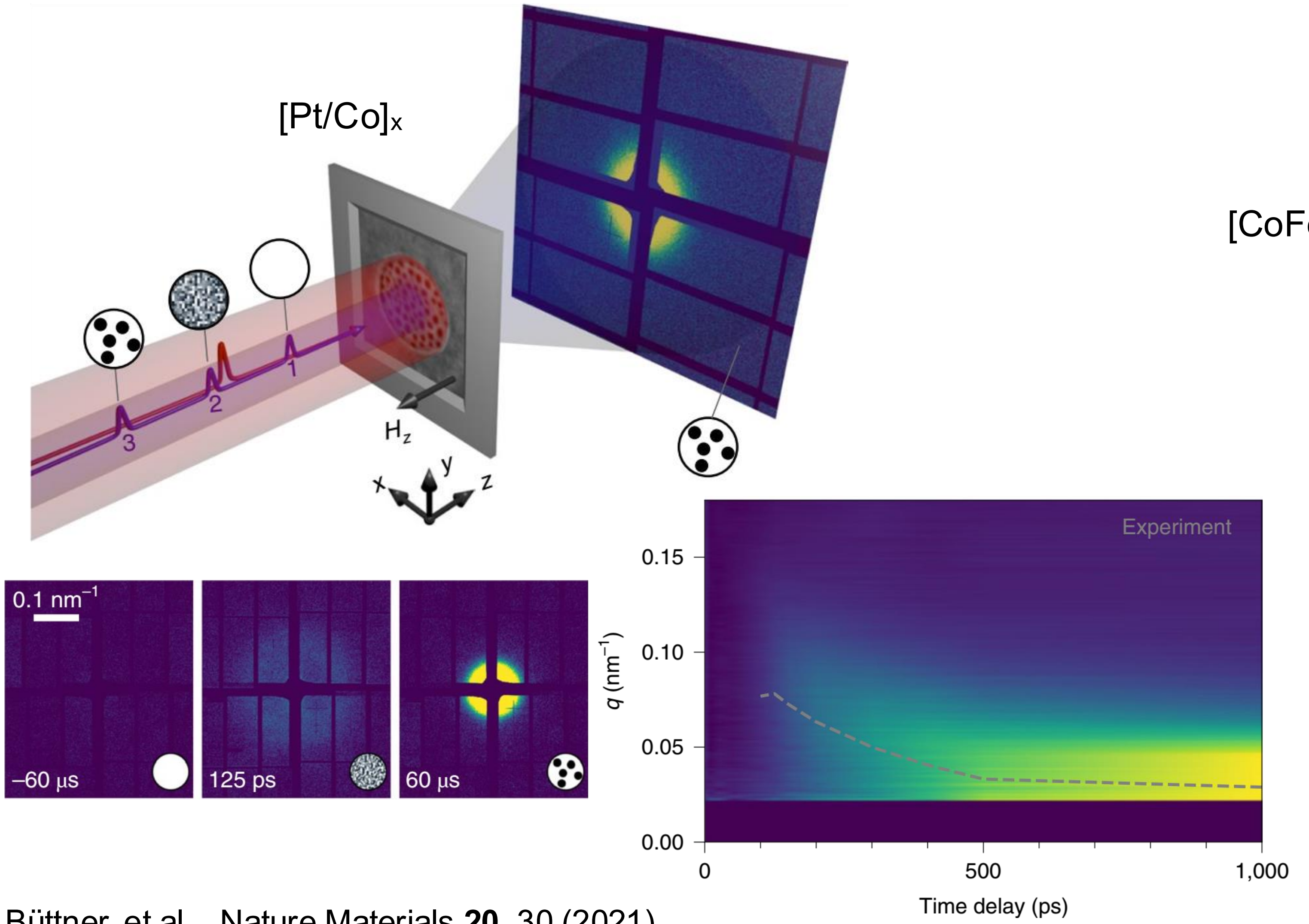




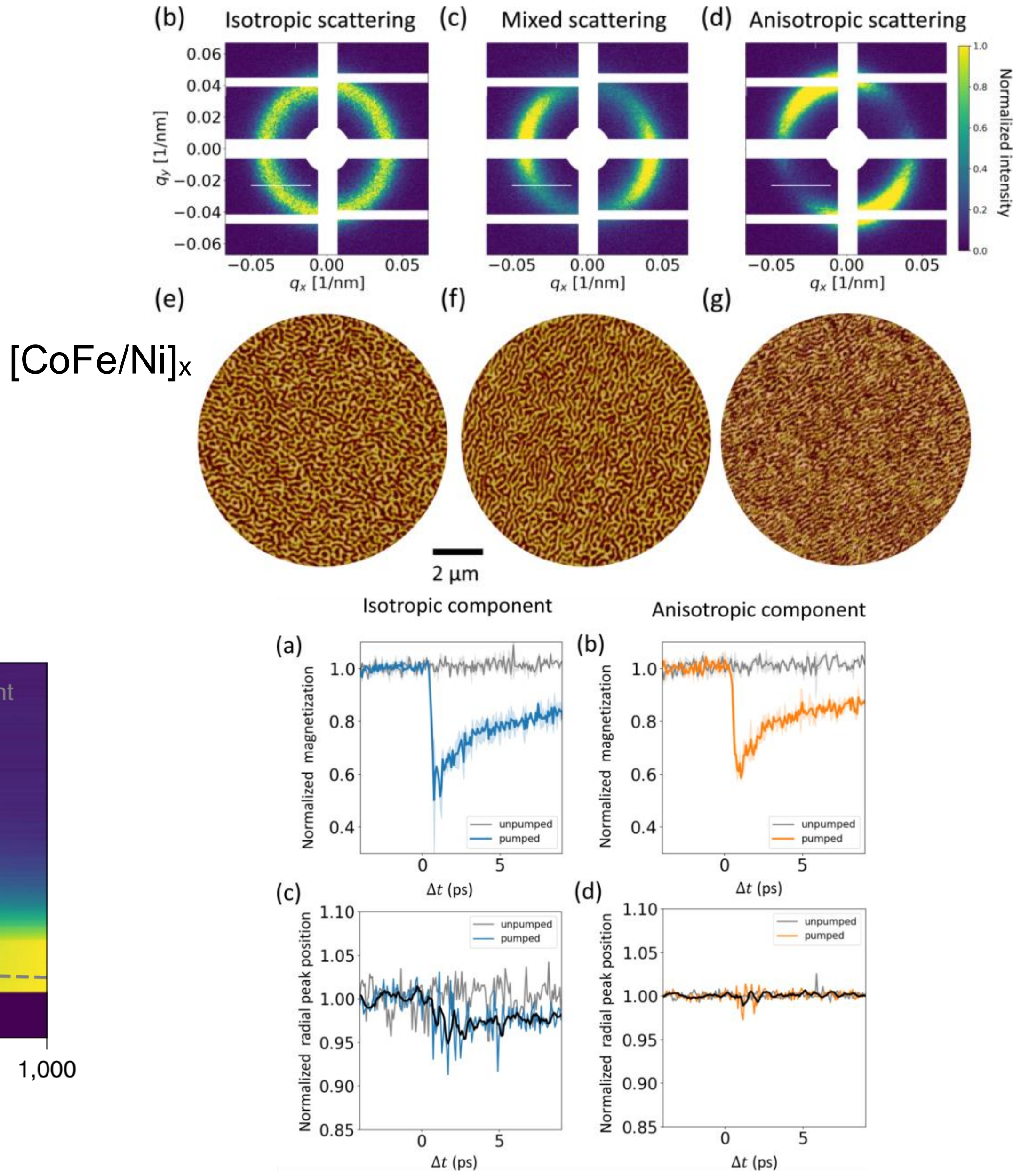




Small-Angle X-ray Scattering



Büttner, et al.., Nature Materials **20**, 30 (2021)

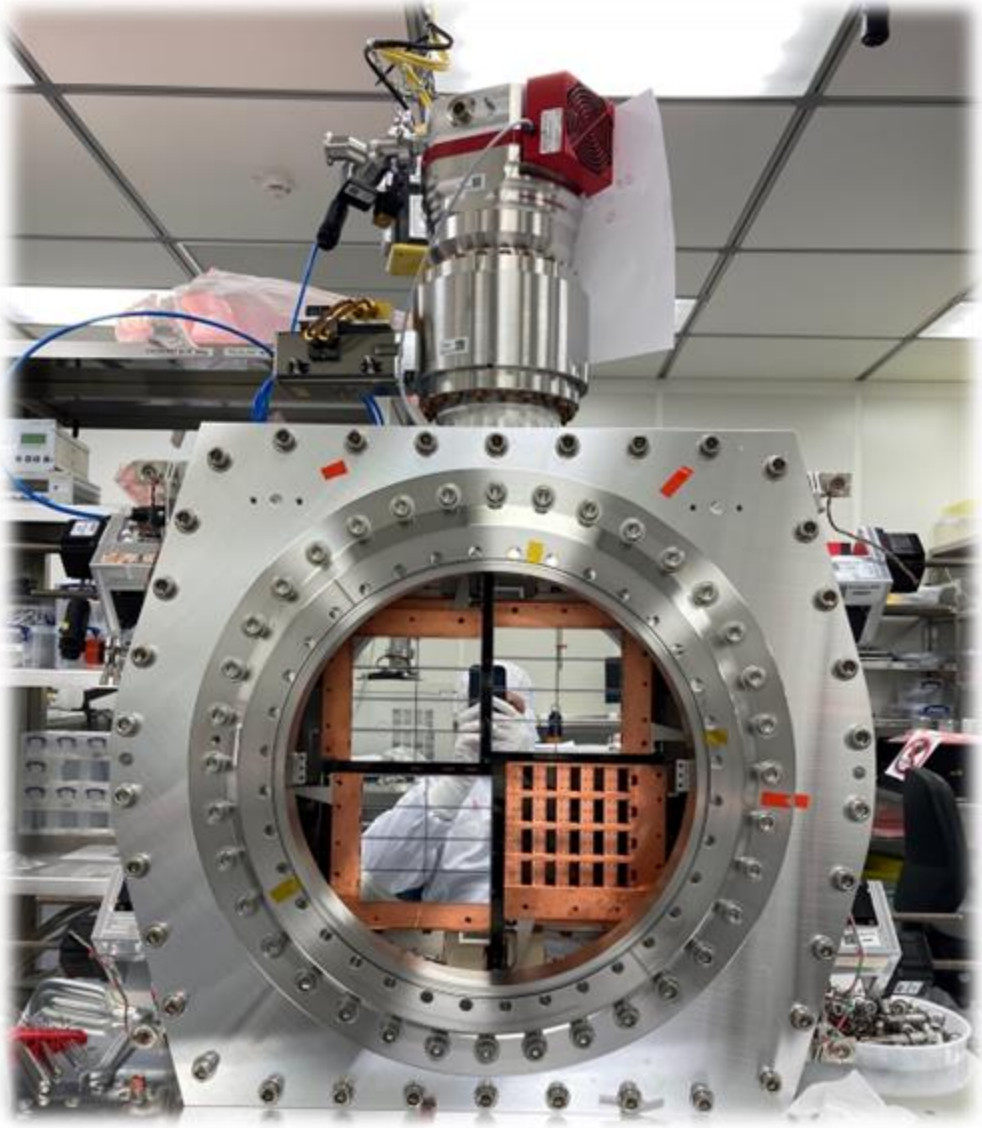


Hagström, et al. Phys. Rev. B, **106**, 224424 (2022).

DSSC2

- already 3 quadrants populated
- Low noise (SNR > 10 at 500eV)
- Gain compression
- calibration data collection Easter 2025
- First usage at SCS in 2nd half of 2026. Full camera
- DNL correction, ASIC baseline shift correction

Parameter		Value
Target energy range		0.25 keV – 6 keV
Pixel count		1024 × 1024
Pixel shape		hexagonal
Sensor pixel pitch		~204×236 µm
Input photon range / pixel / pulse (*)	MiniSDD	$2^n \times N - 1$
	DEPFET	**$>10^4$**
Achievable noise	MiniSDD	40 e- r.m.s.
	DEPFET	**10 e- r.m.s.**
Peak frame rate		1.1 - 4.5 MHz
Stored frames		800



- *Maffessanti, S., Hansen, K. et al., "A 64k pixel CMOS-DEPFET module for the soft X-rays DSSC imager operating at MHz-frame rates". Nature Sci Rep 13, 11799 (2023). https://doi.org/10.1038/s41598-023-38508-9*
- *A. Castoldi et al. "Qualification of the X-ray spectral performance of the DEPFET pixels of the DSSC imager", NIM A, 2023*

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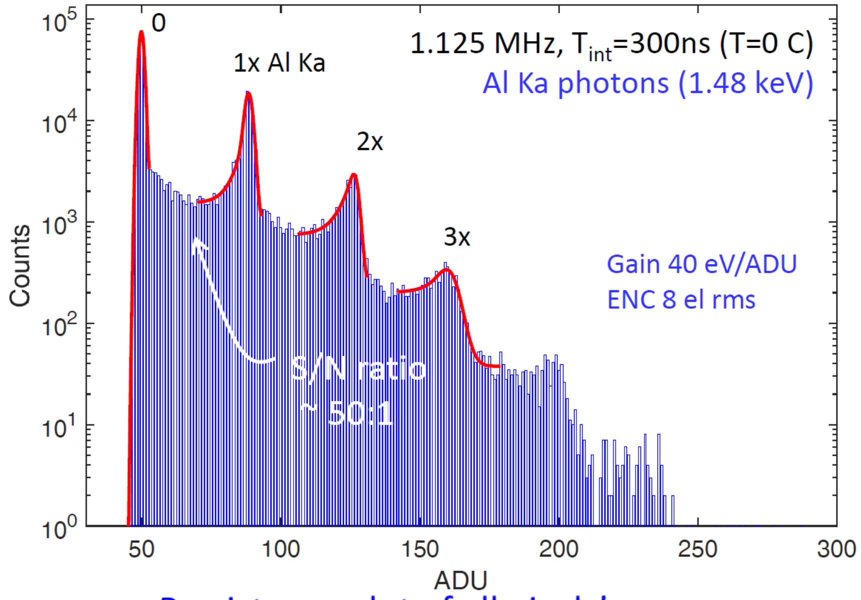
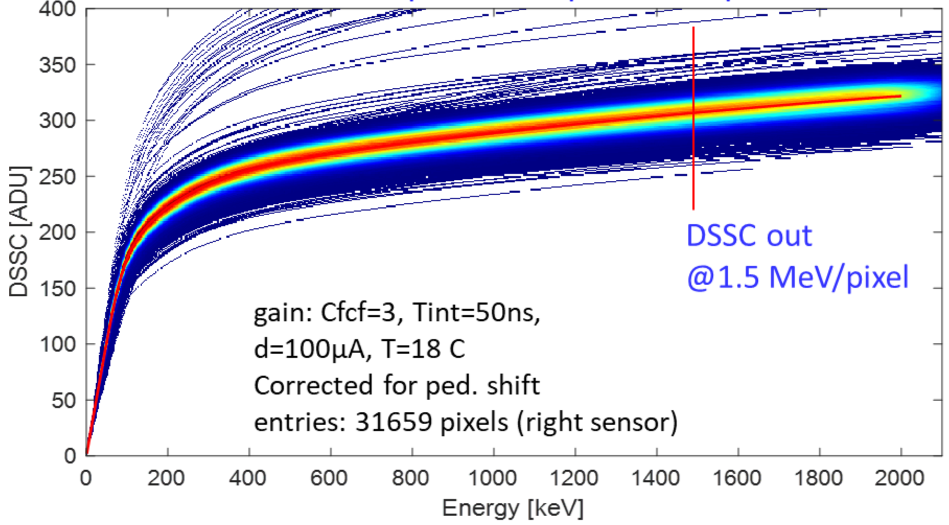


Persistence plot of all pixels' response



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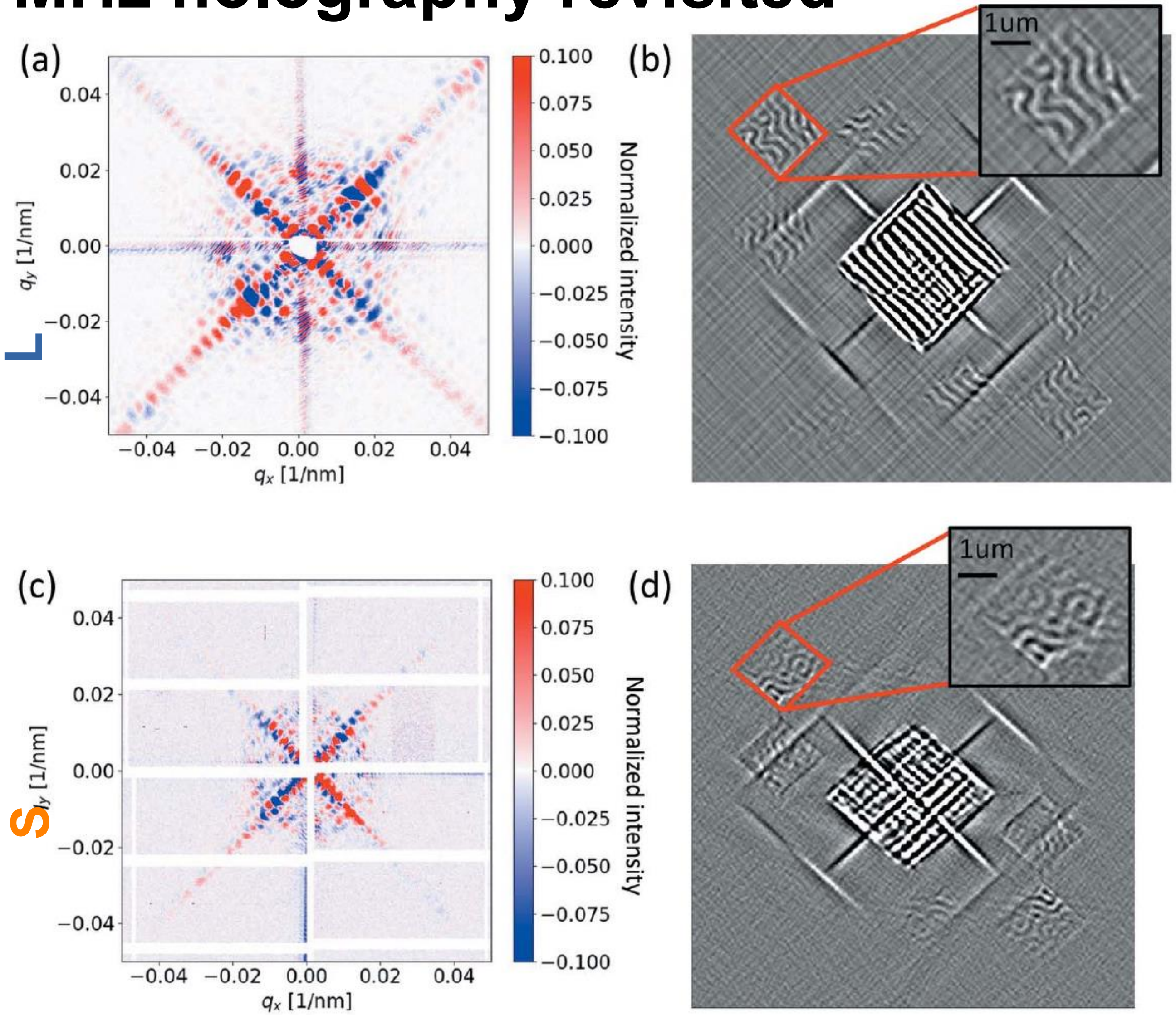
MHz holography revisited

SOLEIL

SCS

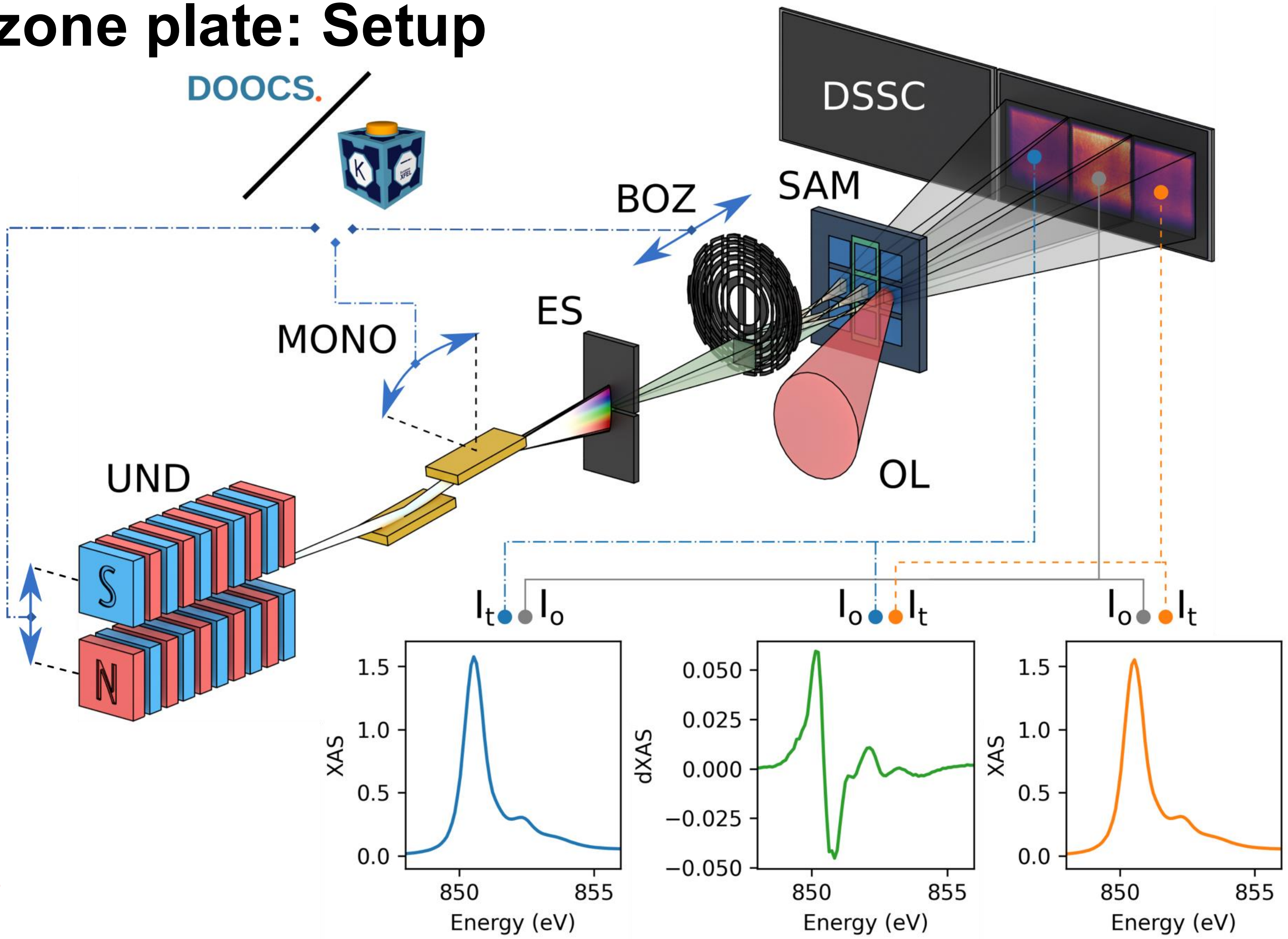


- polarizer *vs* afterburners
- geometry and hex2cart (extra-geom)
- DEPFET (lower noise)
- DSSC2 for *high-q* with second sensor for *low-q*

N. Zhou Hagström *& al.,* J. Synchrotron Rad. **29** 1454 (2022)

Beam-splitting off-axis zone plate: Setup

- MHz burst capabilities with DSSC
- extended spectra
- off-axis ZP to separate orders
- 3 beam geometry
- possibility for 10 Hz sample scanning
- single shot SNR of ~250



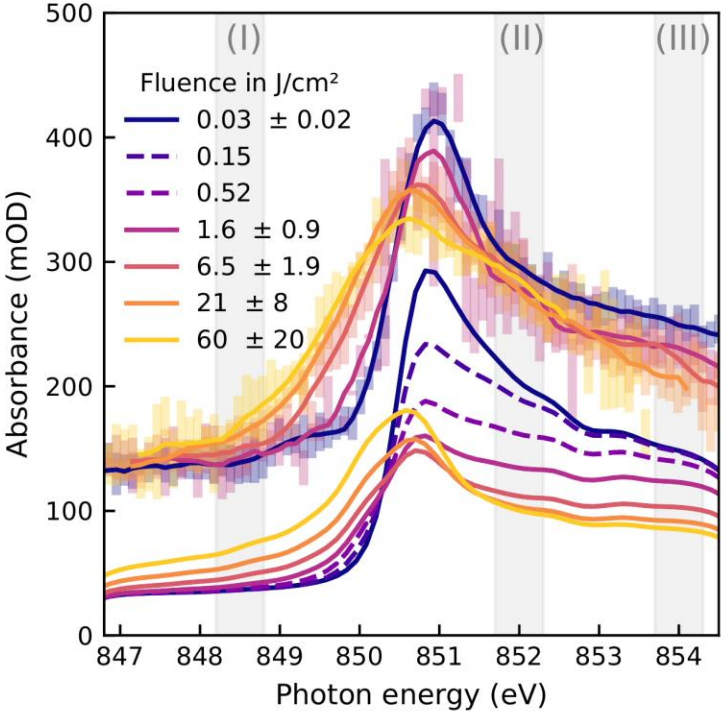
Optics from:

PAUL SCHERRER INSTITUT PSI

14 User Experiments

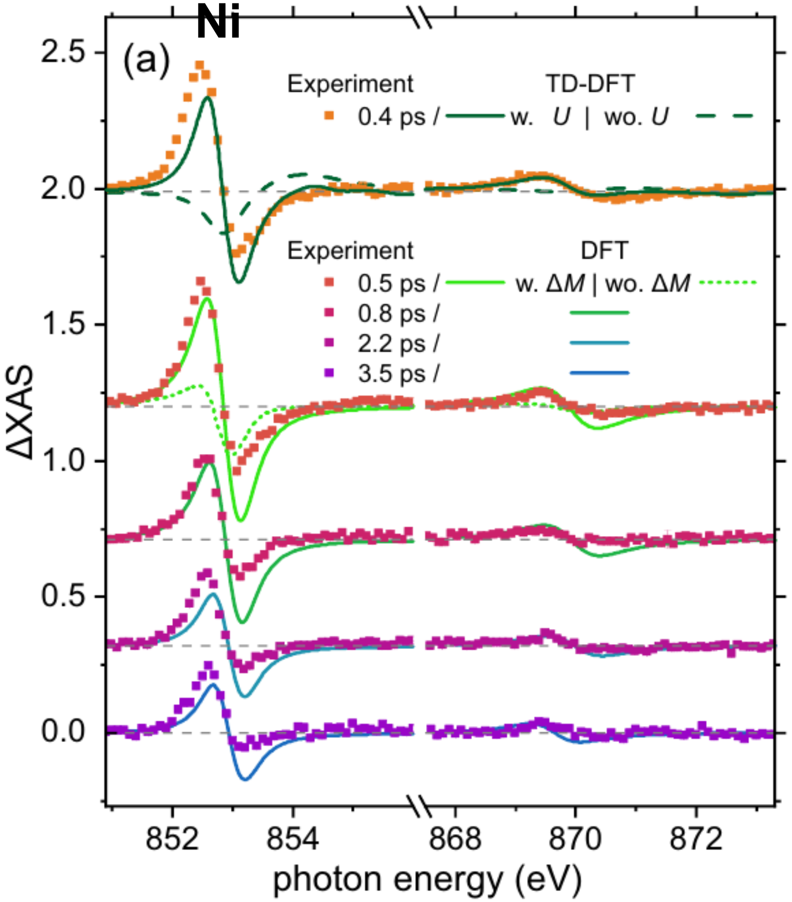
L. Le Guyader &. *al*, J. Synchrotron Rad. 30, 284 (2023)
https://youtu.be/R0wjD7J50is

Non-linear XAS in Ni



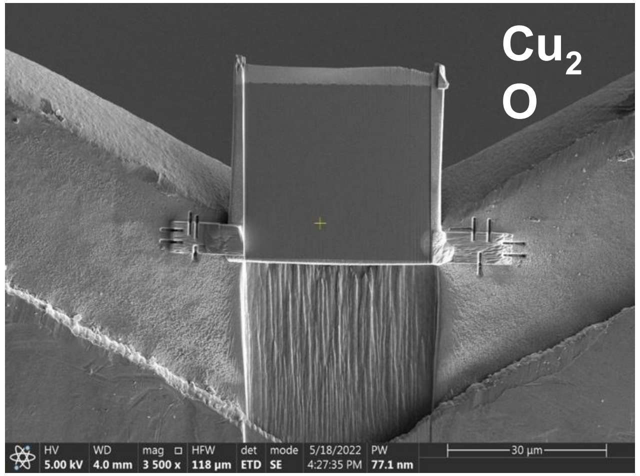
R. Engel & *al.*, Struct. Dyn. **10** 054501 (2023)

Transient XAS in Ni

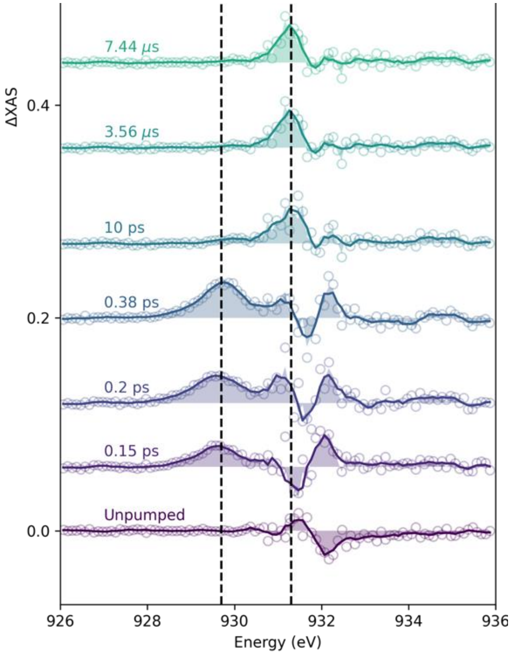


T. Lojewski, & al. Mat. Res. Lett., **11** 655 (2023)

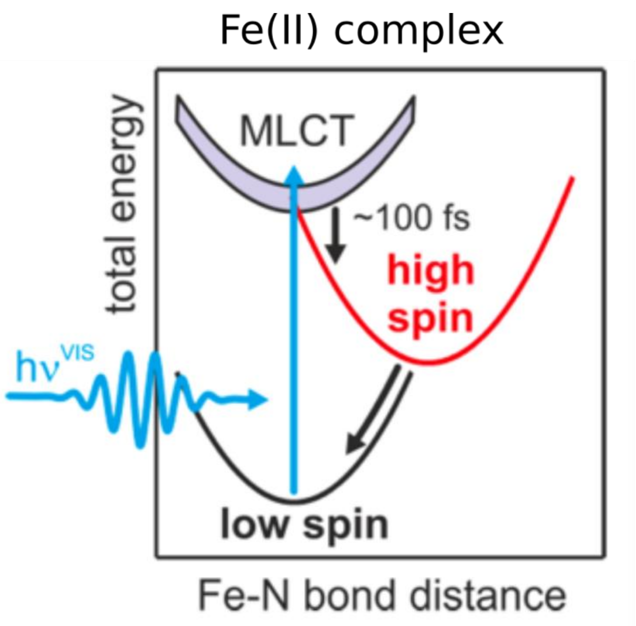
Transient XAS in single crystal

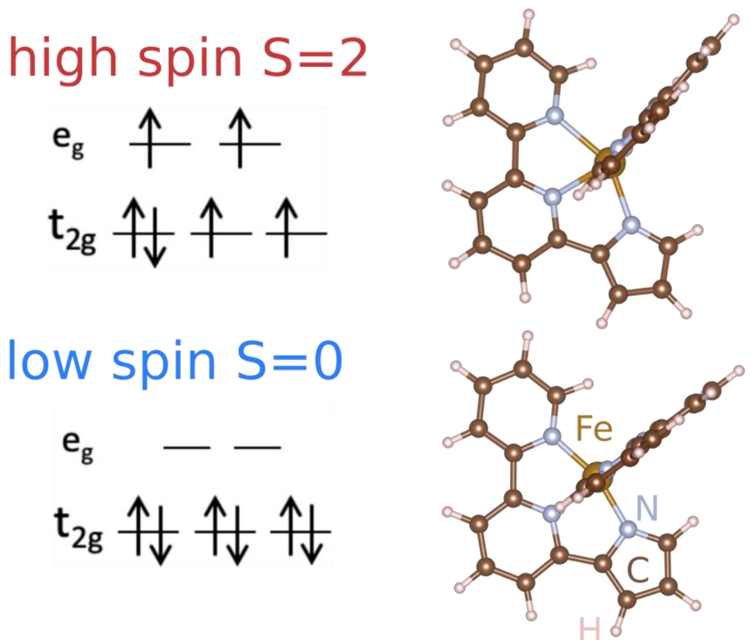


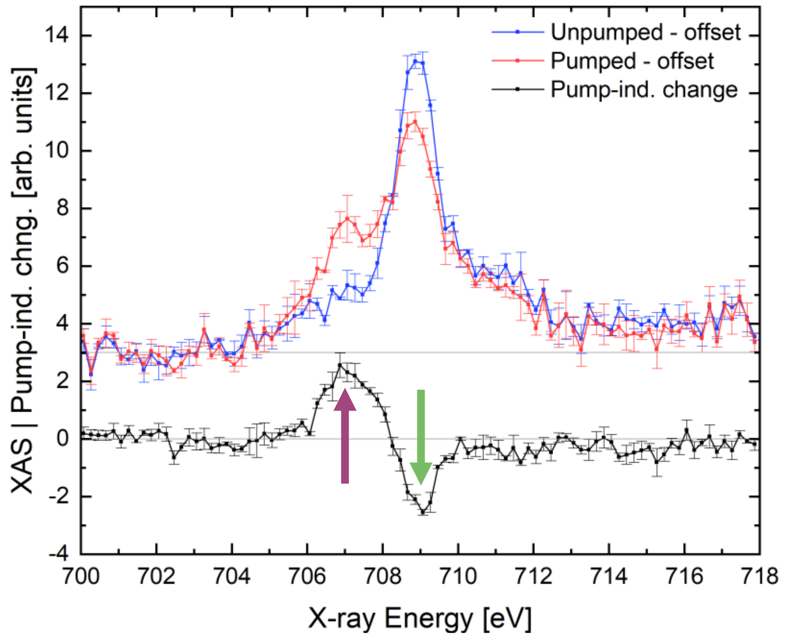
Mano Raj Dhanalakshmi Veeraraj
Master thesis

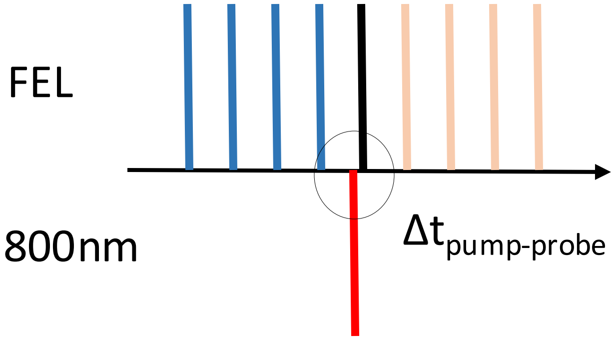


UP2783 Wende: spin crossover molecules

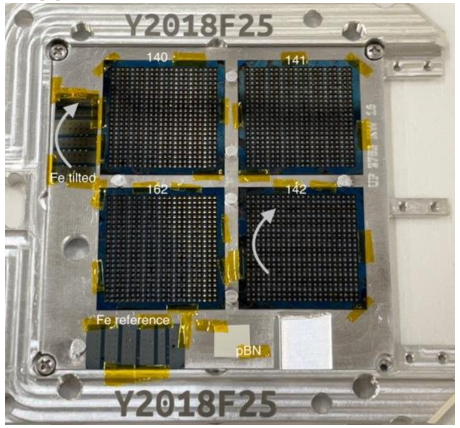


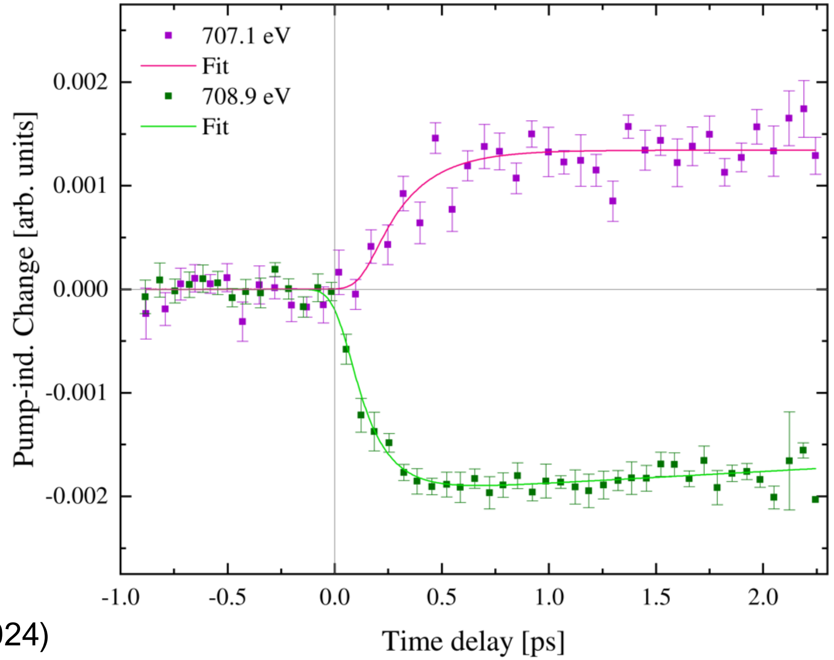






- radiation sensitive
- dilute system
- ~30 monolayers

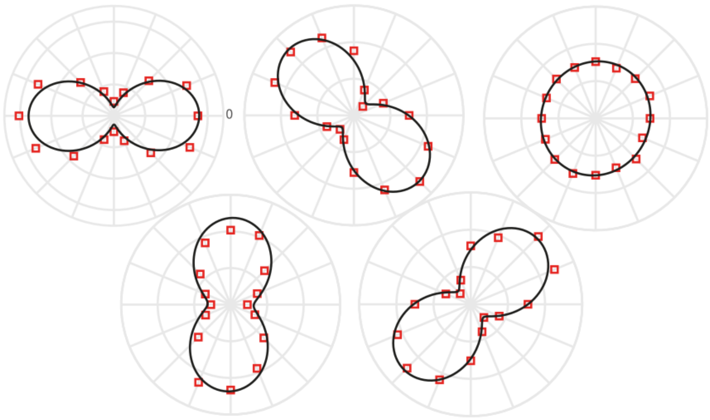




L. Kämmerer & *al.*, “Femtosecond Spin-State Switching Dynamics of Fe(II) Complexes Condensed in Thin Films” *ACS Nano* **18** 34596 (2024)

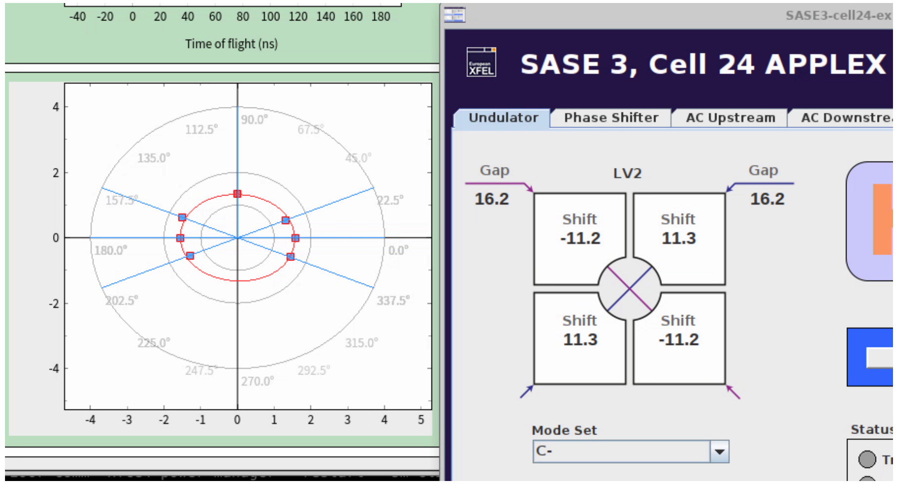
SA3 Afterburners

- Apple-X first lasing 2022
- Switching time: <1min
- Contrast: ~95%



1keV, average 20 pulses

Polarization mode	LH/LV/C+/C-	Linear 45°/135°
K-Range	**9.40 – 3.37**	**6.62 – 2.36**
Photon Energy Range [keV]		
@8.5 GeV	0.169 – 1.141	0.332 – 2.012
@11.5 GeV	0.309 – 2.088	0.608 – 3.684
@14 GeV	0.457 – 3.095	0.902 – 5.459
@16.5 GeV	0.635 – 4.299	1.252 – 7.583
@17.5 GeV	0.715 – 4.835	1.409 – 8.530



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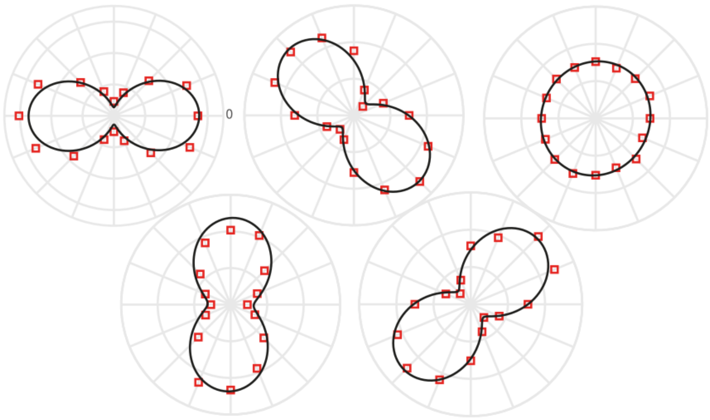
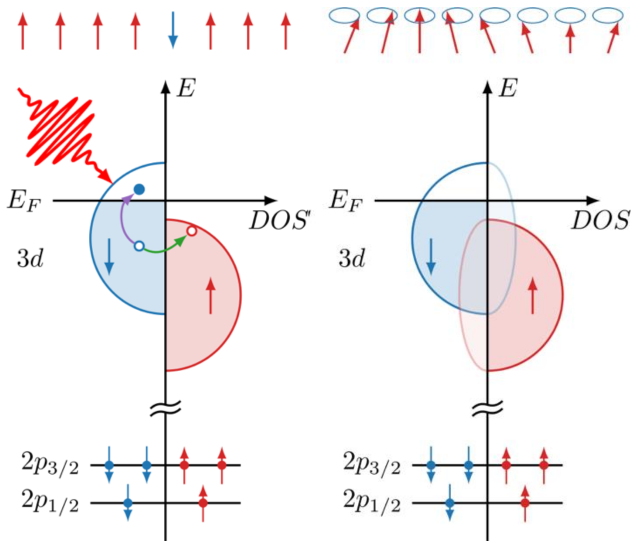


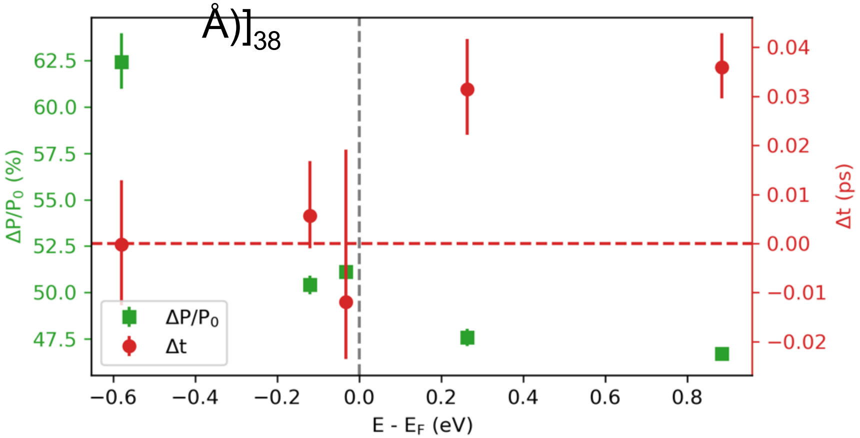
1keV, average 20 pulses

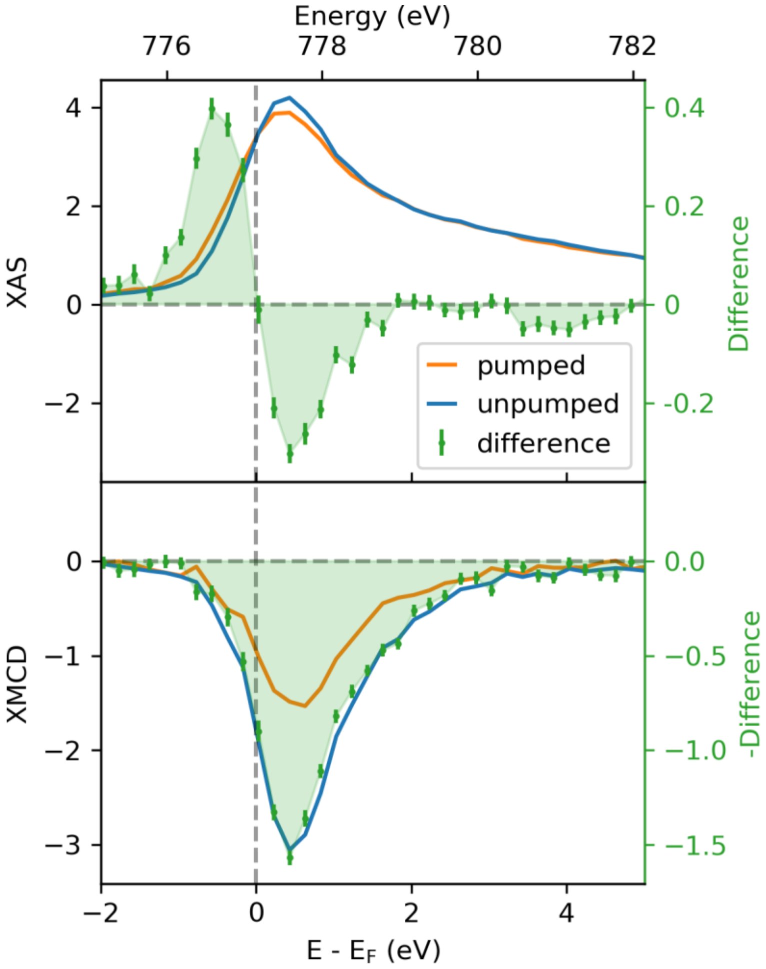
February							February							February							February					
					7							8							9							10
We 5	Th 6	Fr 7	Sa 8	Su 9	Mo 10	Tu 11	We 12	Th 13	Fr 14	Sa 15	Su 16	Mo 17	Tu 18	We 19	Th 20	Fr 21	Sa 22	Su 23	Mo 24	Tu 25	We 26	Th 27	Fr 28	Sa 1	Su 2	Mo 3
GeV 14.0							GeV 14.0							GeV 14.0							GeV 14.0					
SCS - IHR			SQS - Comm.				Comm		Set-up	SCS - 7956 BOZ-XAS				Set-up		SQS - IHR					Atto-second two-color setup		SCS - 8092			
Parchenko										Eschenlohr													LeGuyader			

Femto-XMCD

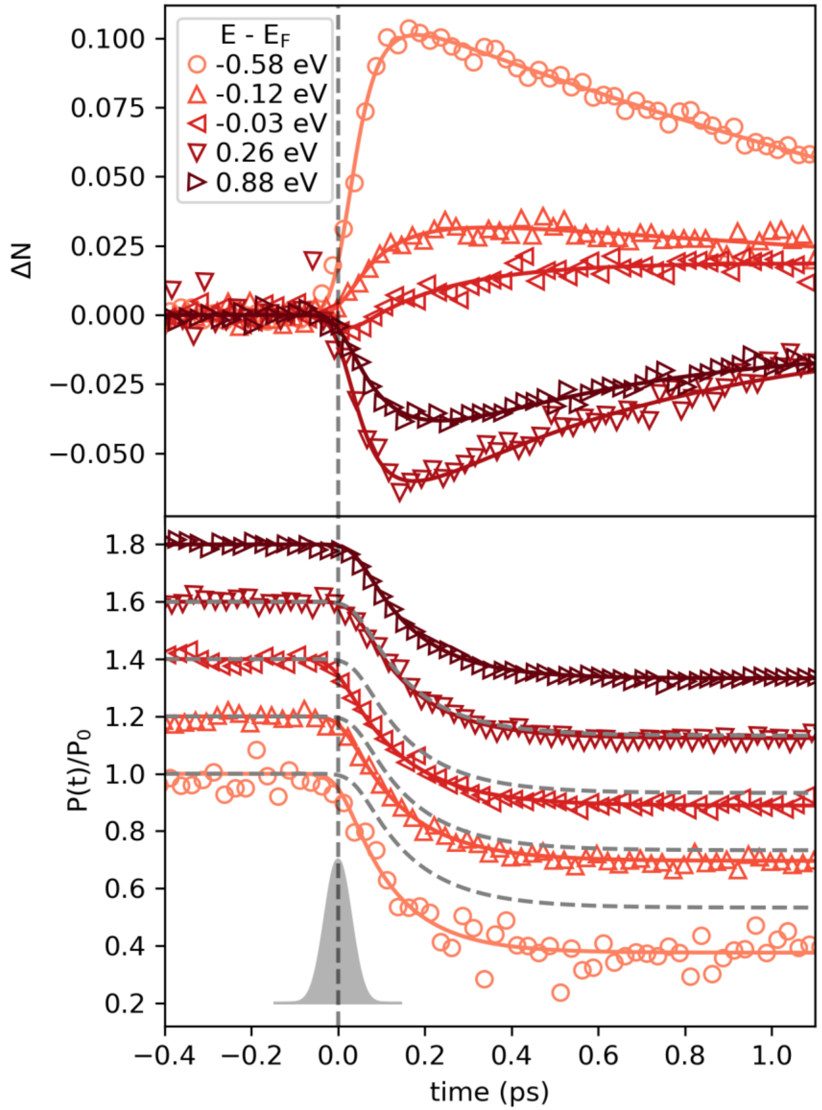


[Co(6 Å)/Pd(6 Å)]$_{38}$





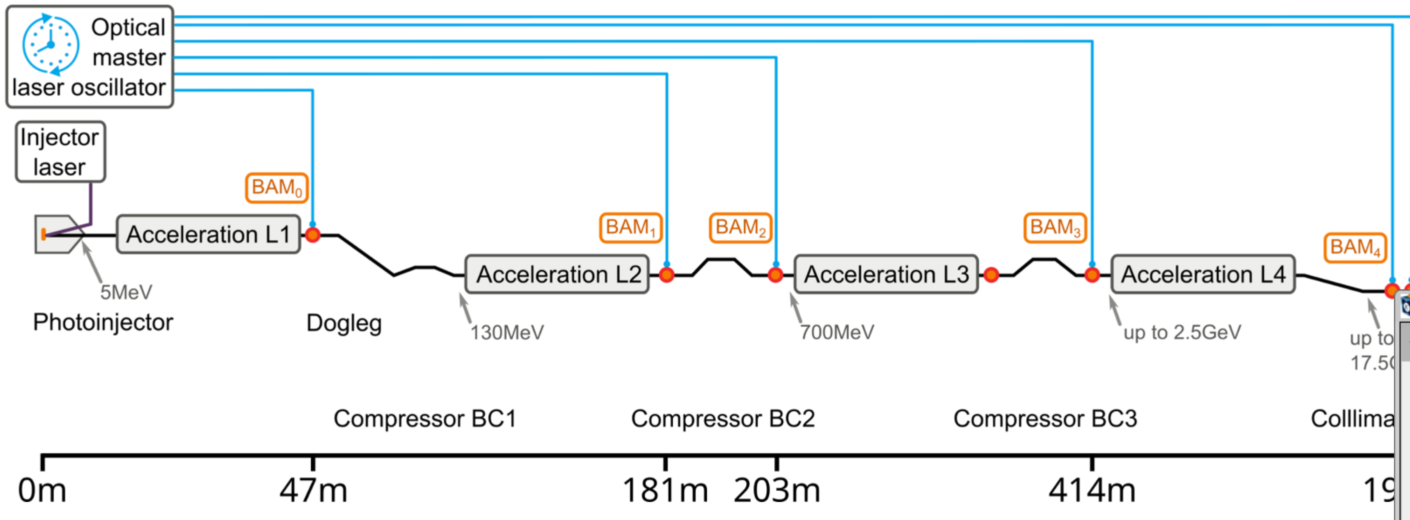
SNR ~ 15-30

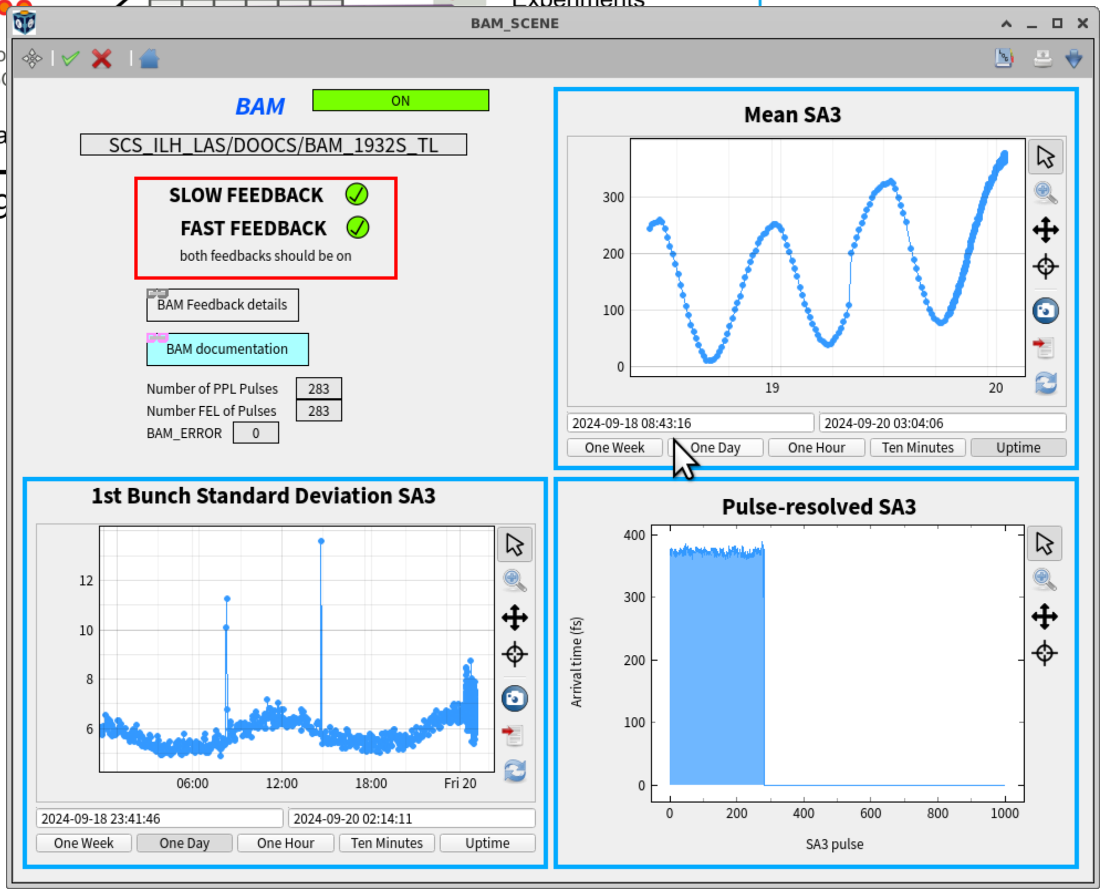


Le Guyader *& al.* APL **120** 032401 (2022)

below Fermi, instantaneous demagnetization
above Fermi, demagnetization delayed by 35+/-10 fs

EuXFEL synchronization

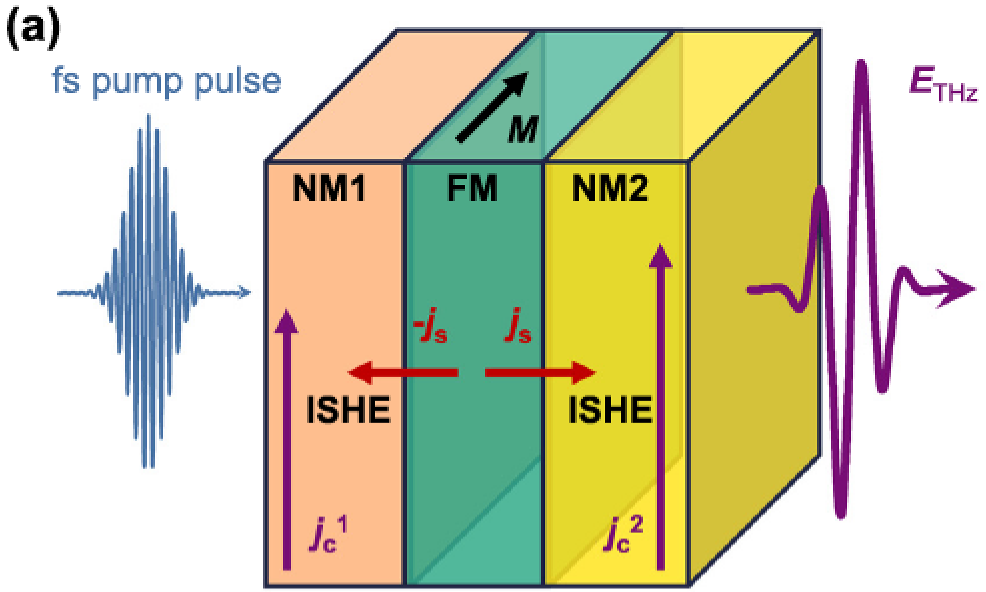




- Synchronization system linking photoinjector to all PP lasers
- Bunch arrival monitor (BAM)
- PPL has typically 5 fs RMS jitter

Timing tool

- Transient absorption/reflection requires about 20 mJ/cm^2 of x-rays on the sample
- With closed mono exit slit there is not enough pulse energy



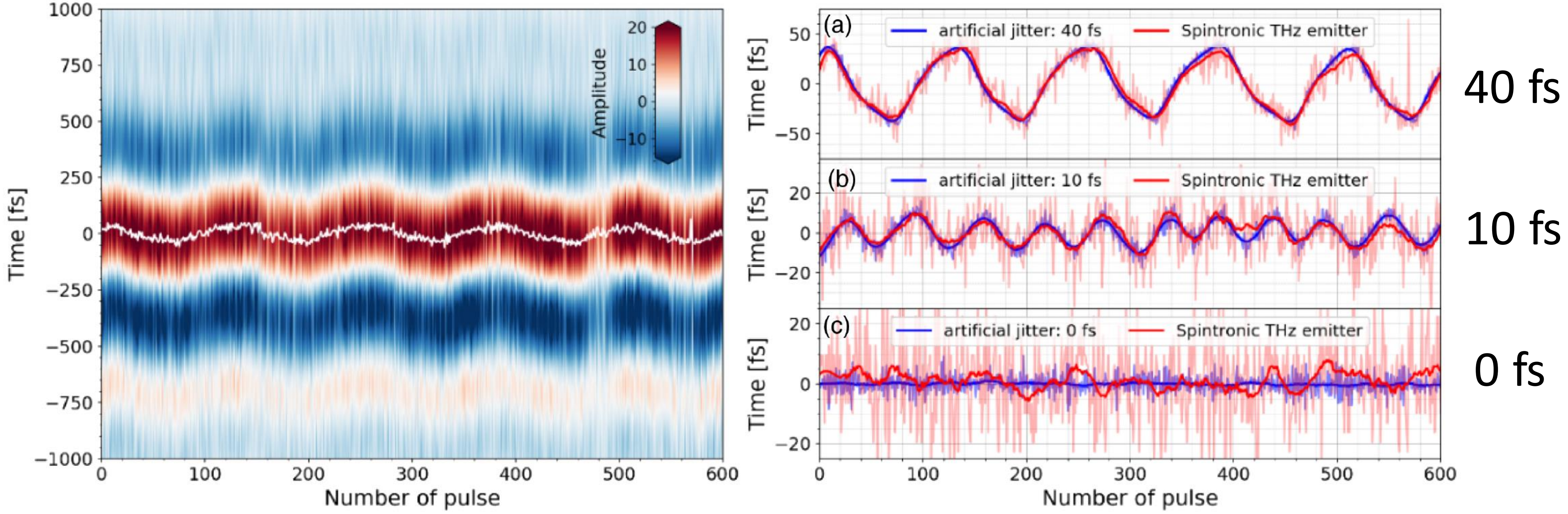
- Excitation of FM layer creates spin current, Js.
- Js flows into the adjacent NM materials.
- Inverse spin Hall effect: large SOE converts Js in real current, Jc.
- Moving charges emit EM radiation in the THz.
- The NM layer have opposite SOE so the emitted radiation adds coherently.

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)

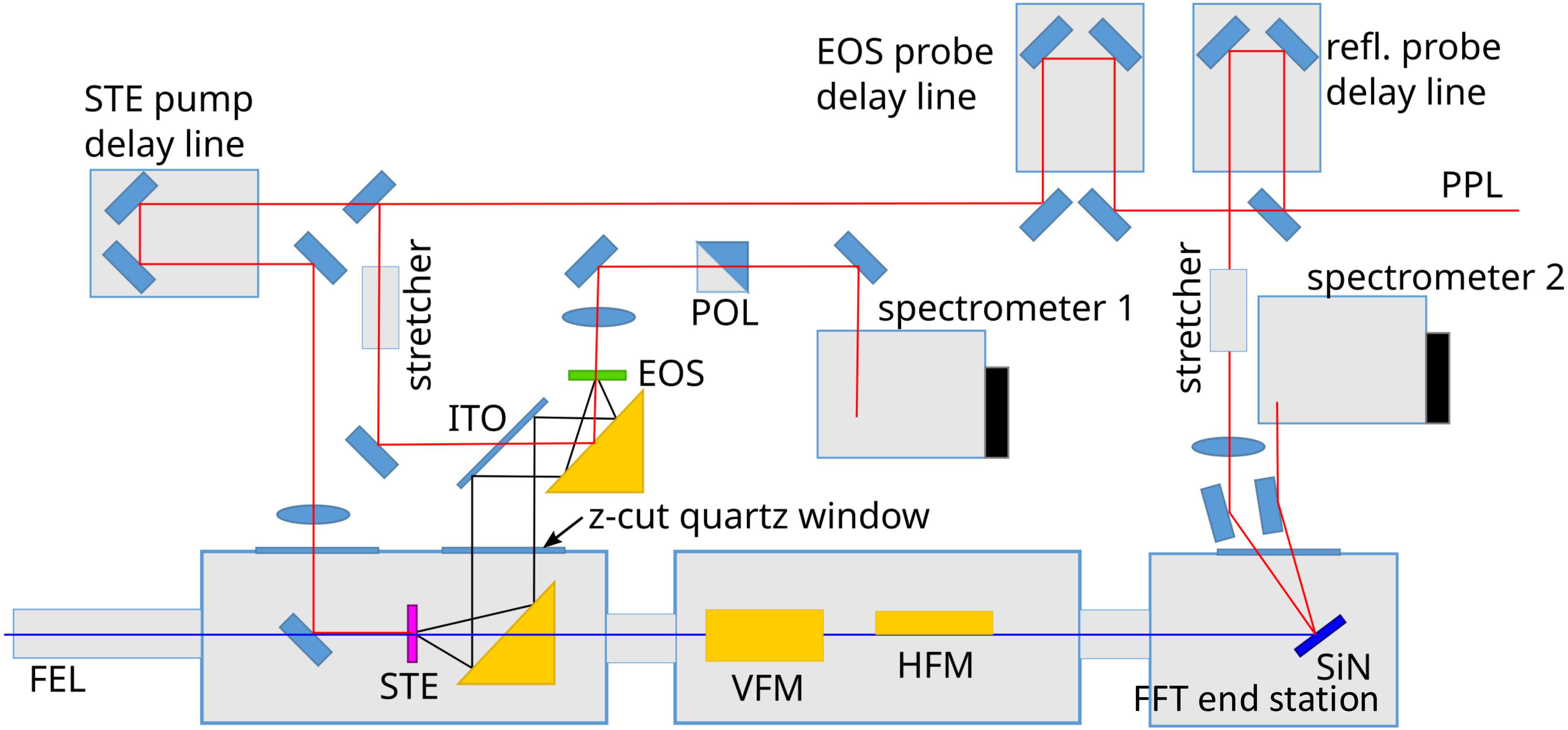
STE based timing tool

Experiment at FERMI:



Ilyakov *& al.*, Optica **9**, 545 (2022)

Test experiment at SCS: June 2023



SCS group: Robert Carley, Laurent Mercadier and Andreas Scherz

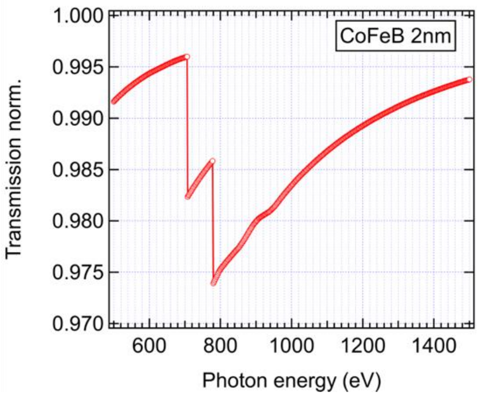
LAS group: Ilie Radu, Rosen Ivanov, XPD group: Jia Liu

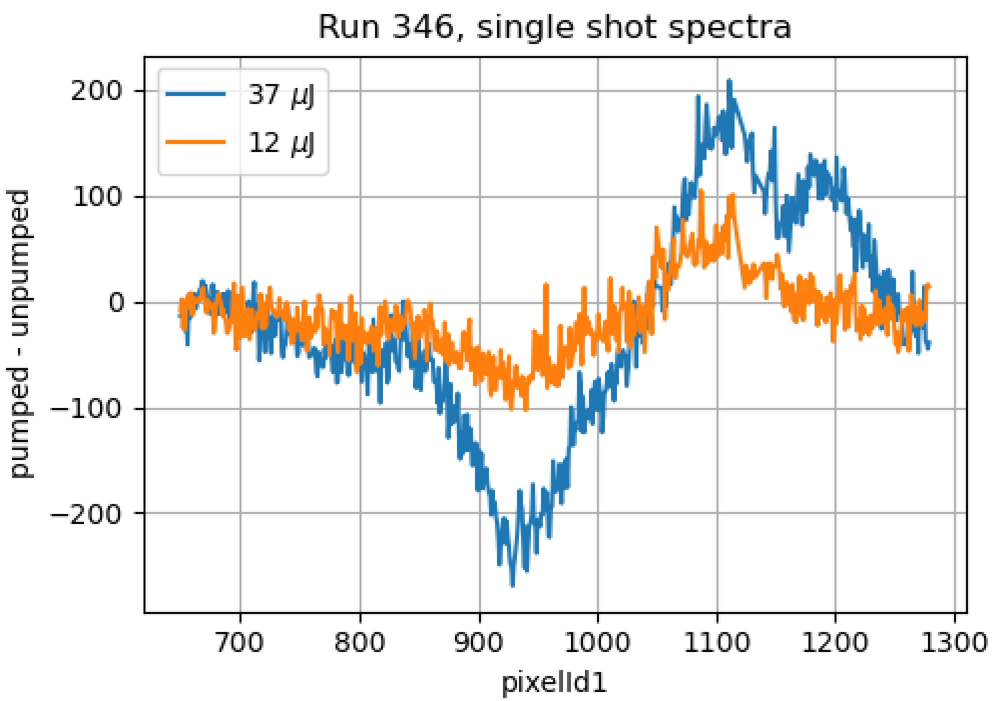
Tobias Kampfrath (FU Berlin), Tom Seifert (TeraSpin GmbH)

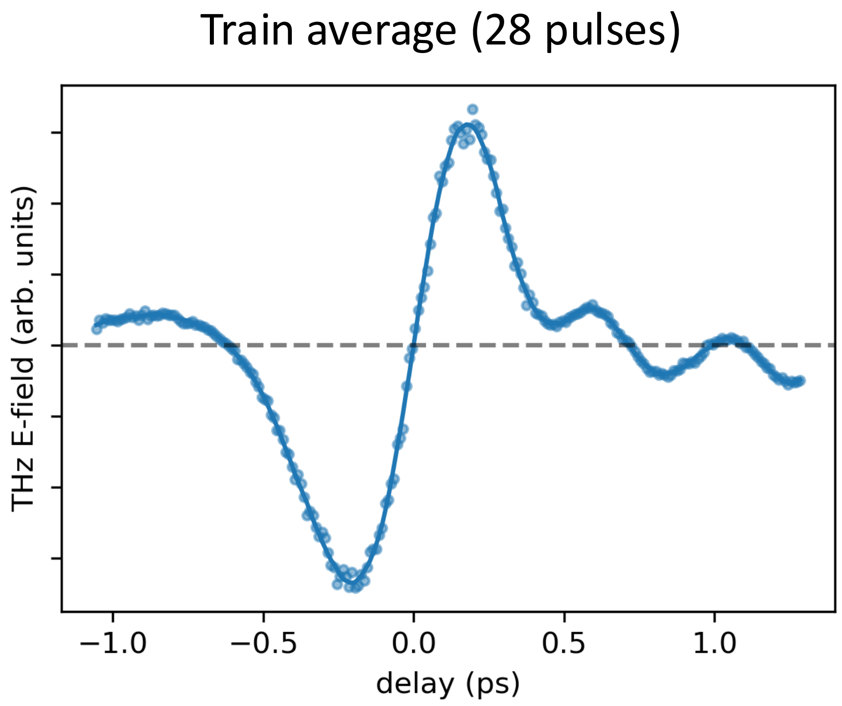
Michael Gensch (TU Berlin/DLR), Igor Ilyakov (HZDR Dresden)

Prototype experiment at SCS:

Photon energy: 935eV
Pulse energy: few 10uJ (simulating monochromatic condition)
Incident fluence: 6 to 19 mJ/cm^2
Absorption: ~2%

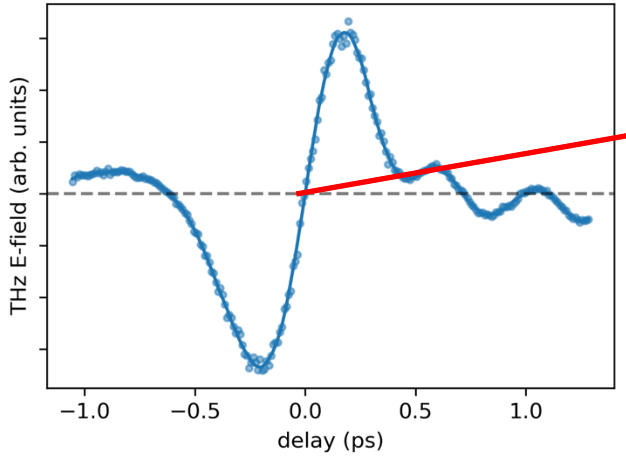


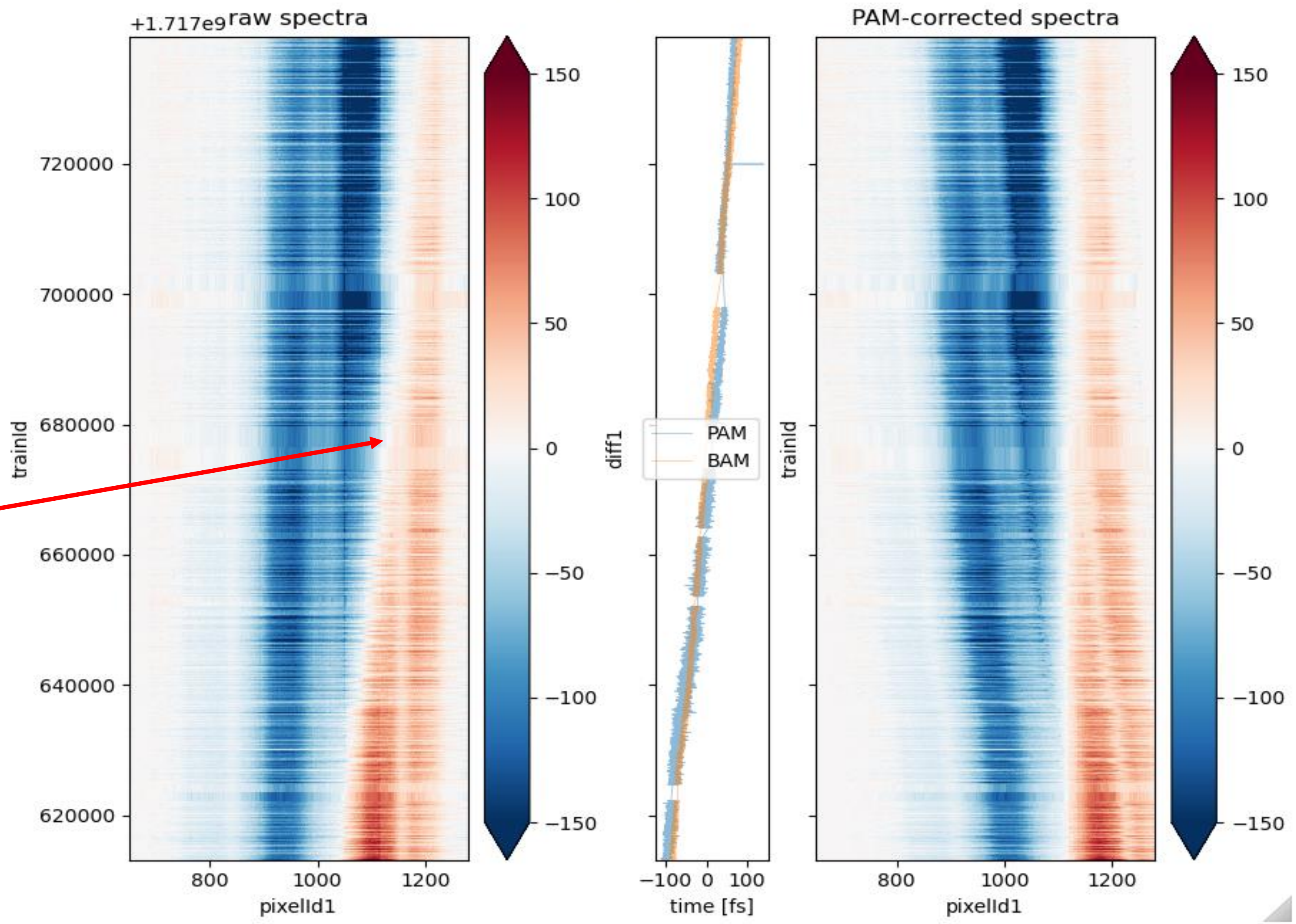




Prototype experiment at SCS: long term drift

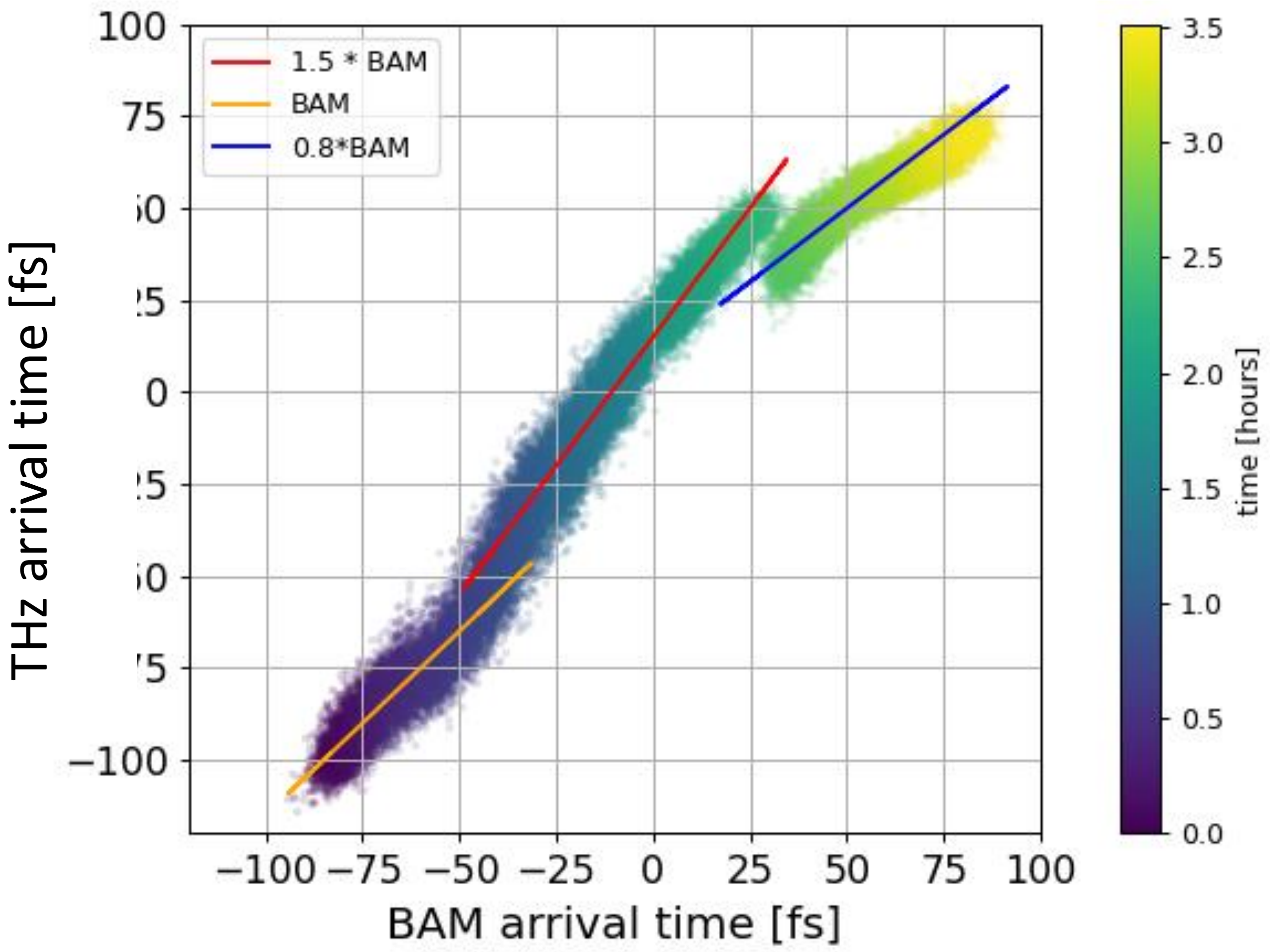
- 3.3 hours of data
- Each train is averaged over 28 pulses
- Captures the long term drift





THz-BAM correlation

- THz time resolution ~20fs
- Non-trivial evolution of THz versus BAM
- Origin is not currently understood.



Current status and what to expect?

- Limited progress since June 2023 due to STE supply issue (New STE end of January)
- New detector (GHII), improved setup
- Our goal: to provide a transparent timing tool to SCS users (Federal funding proposal submitted)
- We will do our best effort to provide THz emission to monitor FEL arrival time as early as possible
- To be a reliable tool, we have to handle different x-ray pulse energies, photon energies and edges,

different PP laser repetition rates, bandwidths and wavelenghts, and different path lengths for eg SHG, THG and Topas