Small Quantum Systems (SQS)

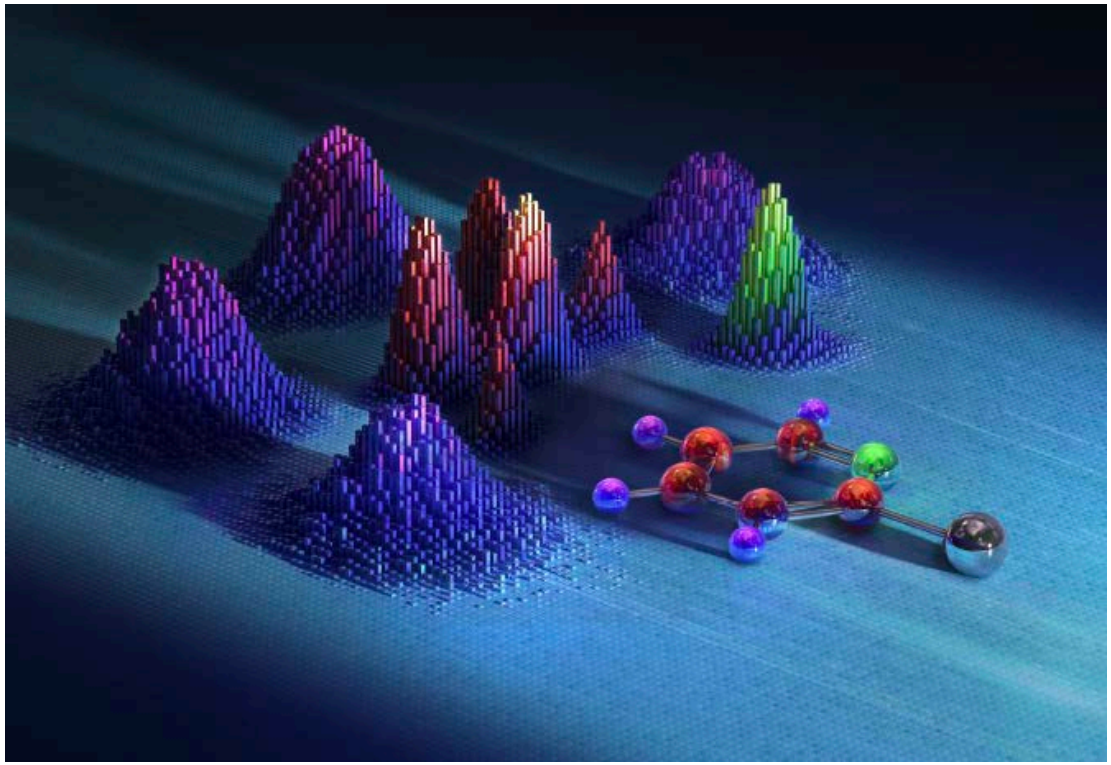
M. Meyer
SQS Scientific Instrument

Townhall meeting, October 10, 2023

Gas Phase Samples

Soft X-Rays (250 – 3000 eV)

- **Study of non-linear phenomena**
- **Time-resolved investigations**
- **Coherent Diffraction Imaging**

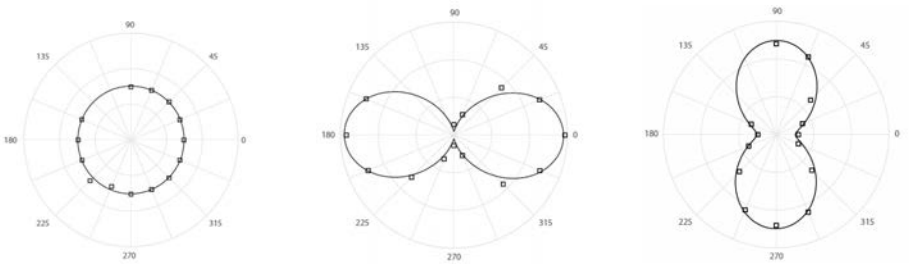


SASE3 Soft X-Ray radiation parameters

Photon Beam Parameter	Unit	Operation 2024_2 (August – November 2024) RUN 12
Photon energy	eV	400 – 1400 (@ 10.5 GeV) 500 – 1500 (@ 11.5 GeV) 660 – 2500 (@ 14.0 GeV) 920 – 3000 (@ 16.5 GeV) fully tunable!!
Spectral Bandwidth	%	~1% in SASE mode or monochromatized (resolution: 3000 @ 870 eV)
Pulse duration (calc.)	fs	10 – 25 (FWHM) in standard operation mode
Pulse energy	mJ	up to 10 (depending on photon energy)
Number of pulses		up to 400 per train (@ 1.1 MHZ)
Polarization		linear (and circular)
Focus size	µm	1 – 2 (@ F1 / F1') 2 – 3 (@ F2)
"Special" modes		Two-color operation (delay < 1ps) Short (<10fs) pulses

Variable Polarization at SASE3

EuXFEL Undulator Group & DESY
(S. Karabekyan et al.)



An 8 m long system consisting of four 2 m long APPLE X Helical Undulators developed at PSI

- **Installation of APPLE X undulator in the upcoming winter shutdown 2023/2024**
- **Commissioning of APPLE X undulator in 1st semester 2024**
- **Available of APPLE X undulator for user experiments earliest in 2nd semester 2024**

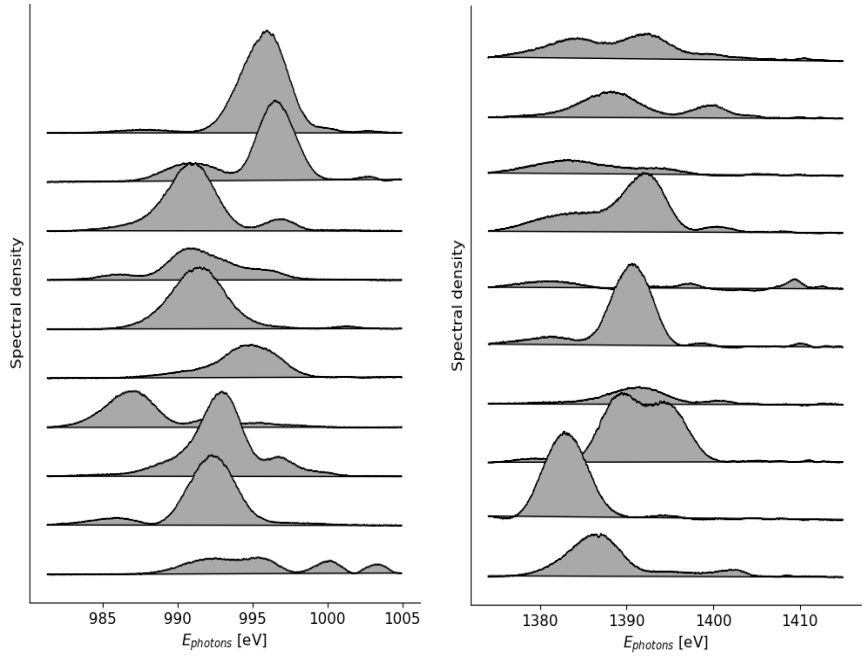
Polarization mode	LH/LV/C+/C-	Linear 45°
K-Range	9.59 – 3.38	6.76 – 2.39
Photon Energy Range [keV]		
@8.5 GeV	0.163 – 1.137	00.320 – 1.981
@11.5 GeV	0.299 – 2.082	0.585 – 3.626
@14 GeV	0.443 – 3.085	0.868 – 5.373
@16.5 GeV	0.615 – 4.286	1.205 – 7.464
@17.5 GeV	0.692 – 4.821	1.356 – 8.396

First tests (2022):
1 mJ @ 880 eV was demonstrated

Two-color short pulse operation

Single-spike lasing at SASE3

Demonstration at 16.5 GeV with dedicated (strong compression combined with electron beam orbit dispersion) operation mode

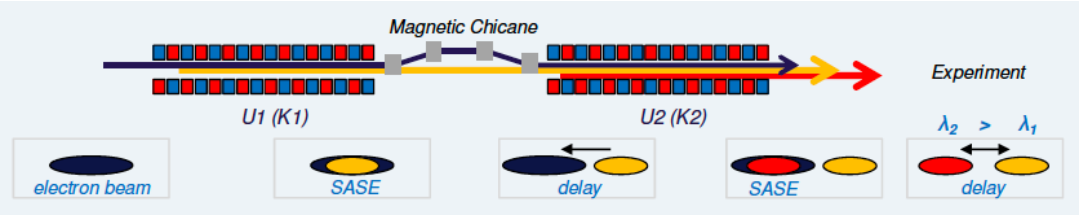


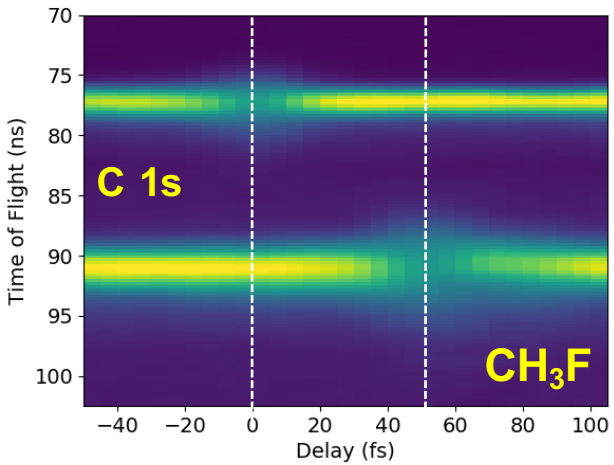
S. Serkez, M. Guetg et al. (FEL R&D)

2-Color Pump Probe (2CPP)

X-ray – X-ray Pump-Probe

Magnetic chicane in SASE3 undulator





Electron spectra

C1s photolines

660eV and 698 eV

Delay 50 fs

(D. Rivas et al.)

Photon energy range: **500 – 1500 eV (→ 3000 eV)**

Pulse energy: **up to 1 mJ**

Pulse duration: **< 30 fs**

Temporal delay: **up to 1 ps**

Operation in close collaboration with S. Serkez & G. Geloni

Two-color short pulse operation

Two-color operation mode

20-30 fs **standard operation**

Special modes:

≤ 10 fs **„short pulse mode“**
→ requires tuning
→ spectral diagnostics

2 – 5 fs **„few fs mode“**
→ requires special tuning
→ spectral diagnostics
→ large instabilities

< 1 fs **„attosecond mode“**
→ requires special tuning
→ under development
→ no standard diagnostics
→ large instabilities

2-Color Pump Probe (2CPP)

X-ray – X-ray Pump-Probe

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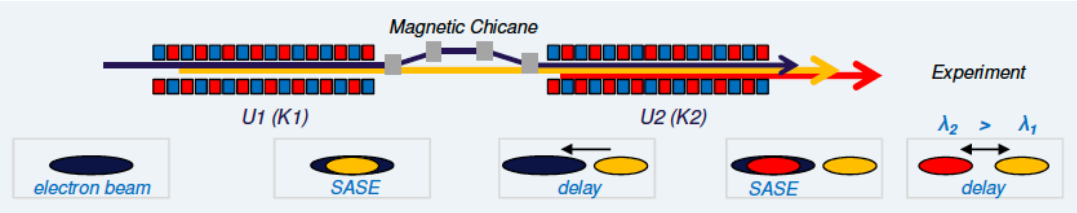

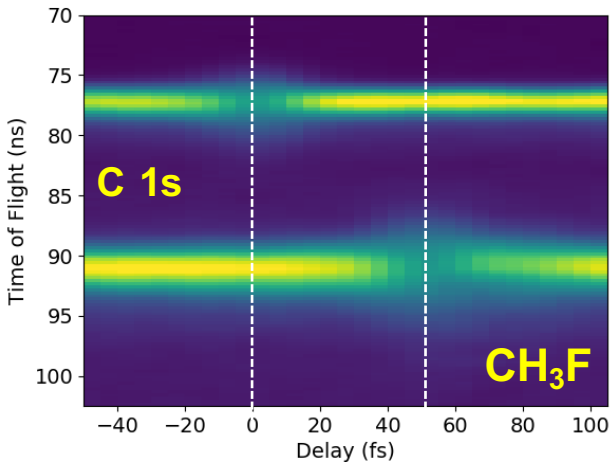

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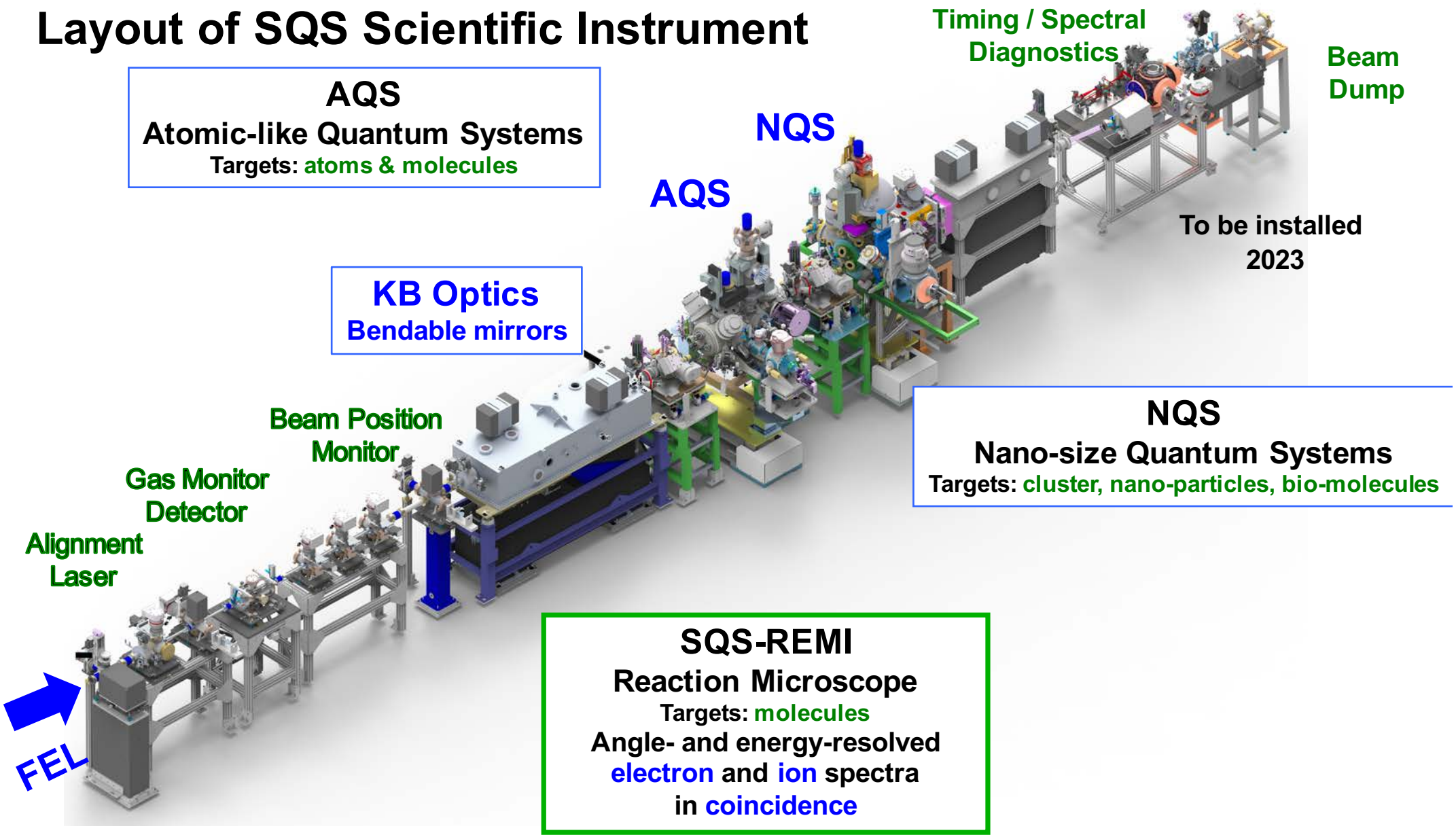
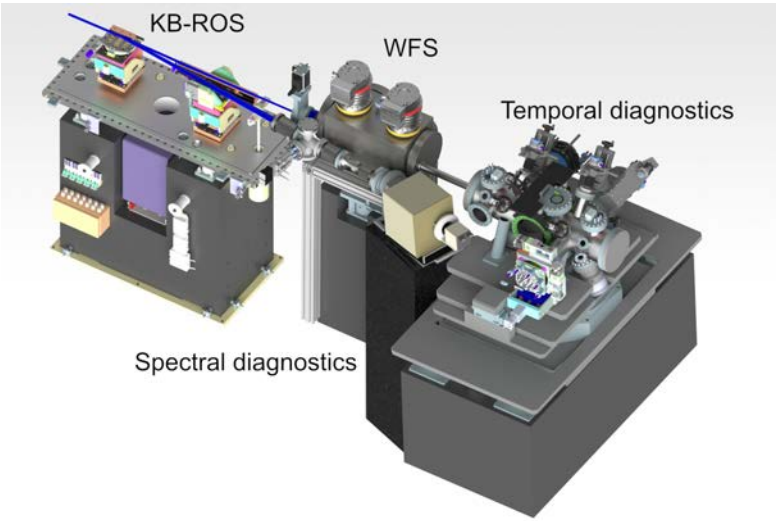
Layout of SQS Scientific Instrument



X-ray diagnostics at SQS

Single shot diagnostics of X-ray pulses

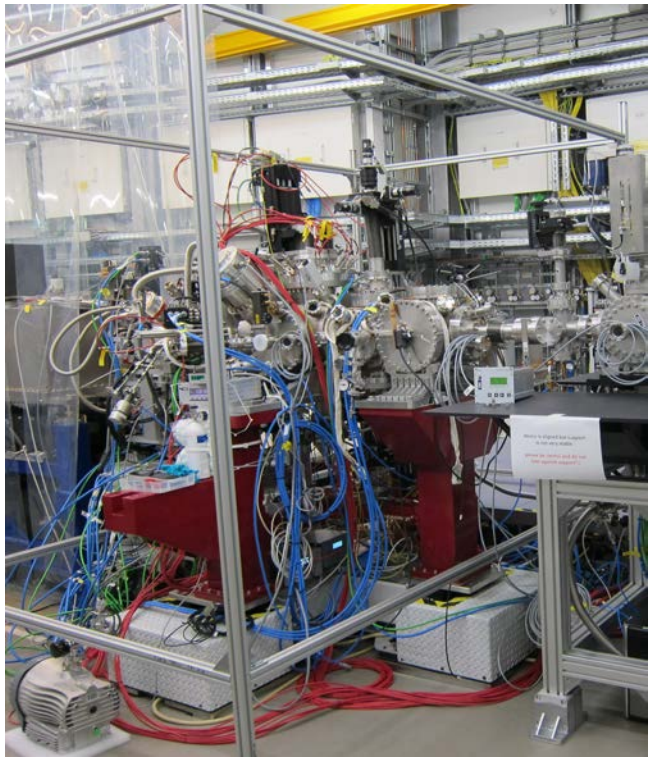
Spectrum: 300-3000eV, E/ΔE ~ 2000,
Single photon sensitivity
Arrival time: 5 fs resolution
Temporal structure:
THz streaking: 20fs resolution, 500fs range
Angular streaking: sub-fs resolution, 10fs range
Beam profile: WFS for F1, F1', F2



- **Installation of refocusing mirrors in the upcoming winter shutdown 2023/2024**
- **Commissioning of spectral diagnostics in first semester 2024**
- **Exploratory use of spectral diagnostics in second semester 2024**
- **Installation of angular streaking set-up in the summer shutdown 2024**
- **Commissioning of angular streaking set-up in the second semester 2024**

AQS experimental chamber

Targets: atoms & molecules
Detection: electrons, ions, photons



Sample delivery:

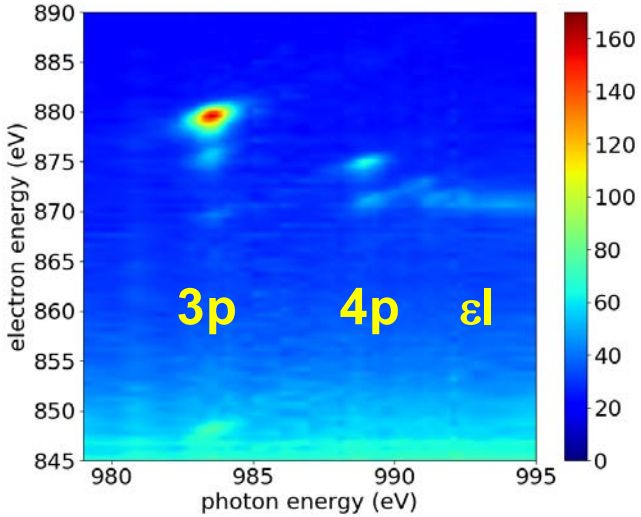
- **Supersonic molecular beam**
- **Effusive gas jet (capillary)**

AQS: Atomic-like Quantum Systems

- **6 eTOFs** — **High energy resolution**, **Non-dipole studies**
- **ionTOF** — **High mass resolution**
- **VMI** — **Angular distribution**, **e / ion – coincidences**
- **MBES** — **High electron acceptance**, **e-e, e-ion coincidences**

Example: Non-linear Spectroscopy
Double Core Hole Resonances in Neon

Ne^{+} $1s^{0}$ $2s^{2}$ $2p^{6}$ np



T. Mazza et al.
PRX **10**, 041056
(2020)

SASE: ΔE = 8.5 eV

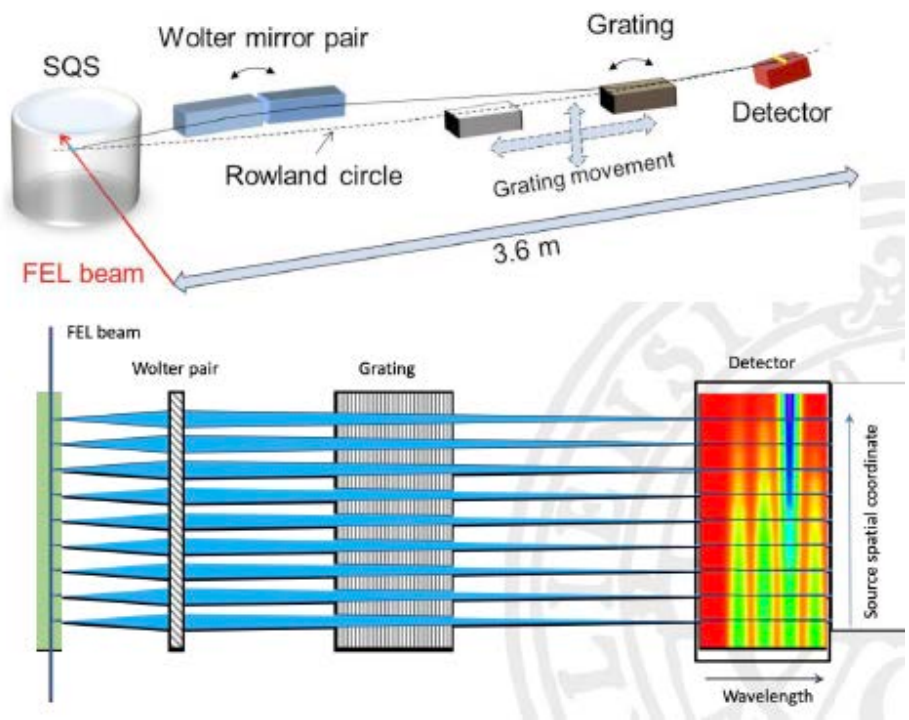
Mono: ΔE = 0.5 eV

AQS experimental chamber

1D-Imaging XUV Spectrometer

In-kind contribution:

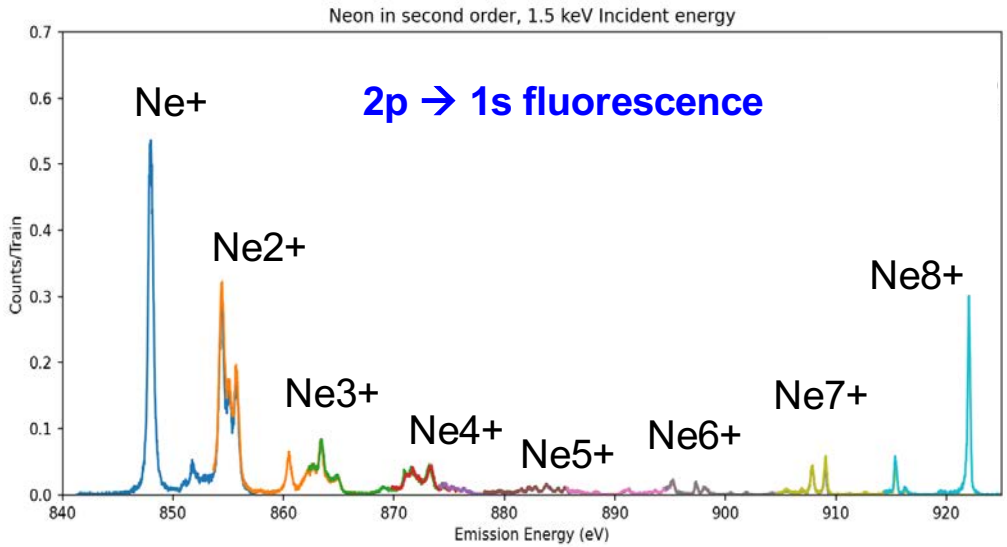
J. Nordgren, J.E. Rubensson (U Uppsala)

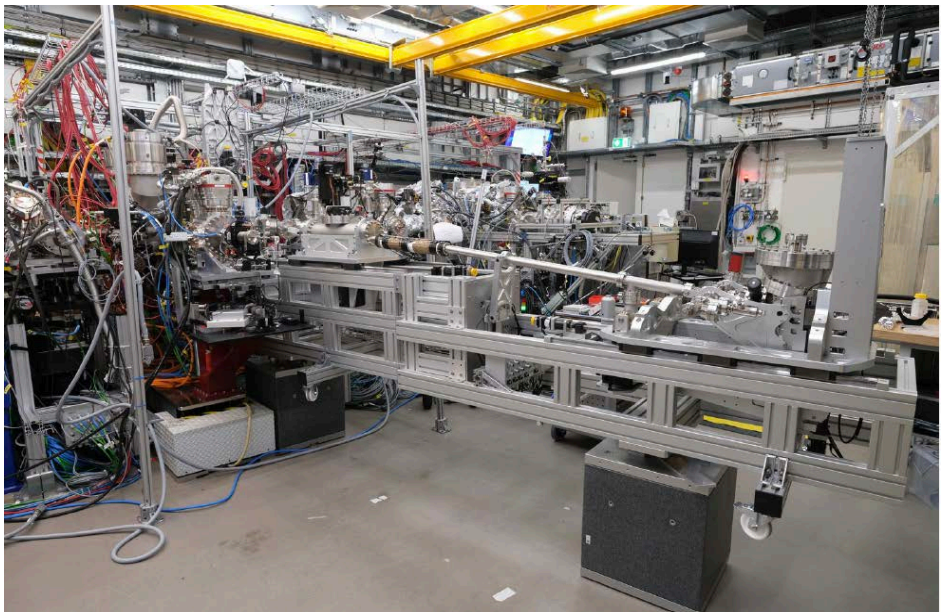


Energy range: 140 – 1150 eV, res. 100meV @ 540 eV

Source size : 2 mm, resolution: 15 μm

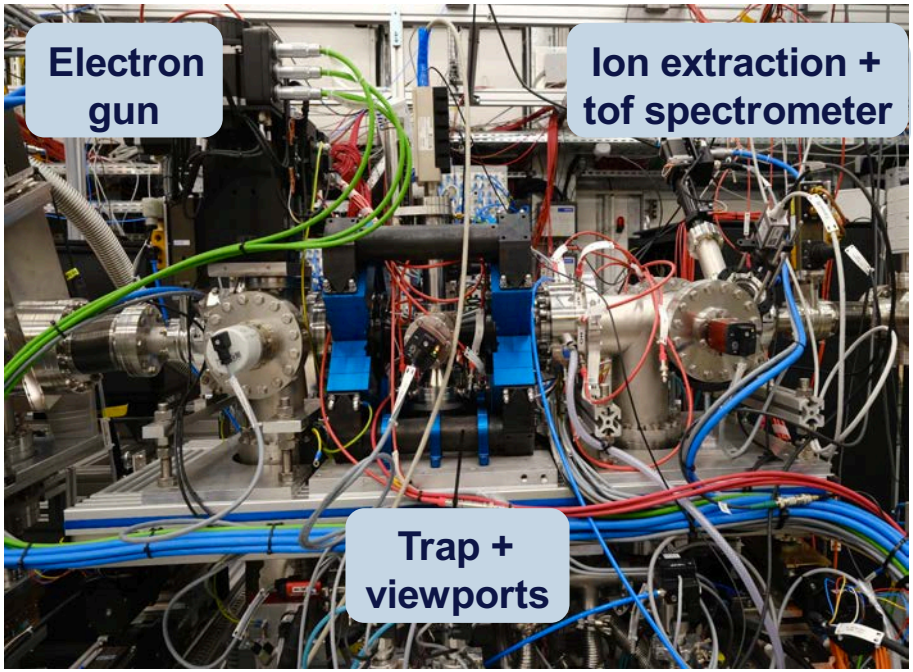
First user experiment in Nov. 2022





EBIT (Electron Beam Ion Trap)

SQS R&D project:
collaboration J. Crespo, MPIK Heidelberg



Compact EBIT source

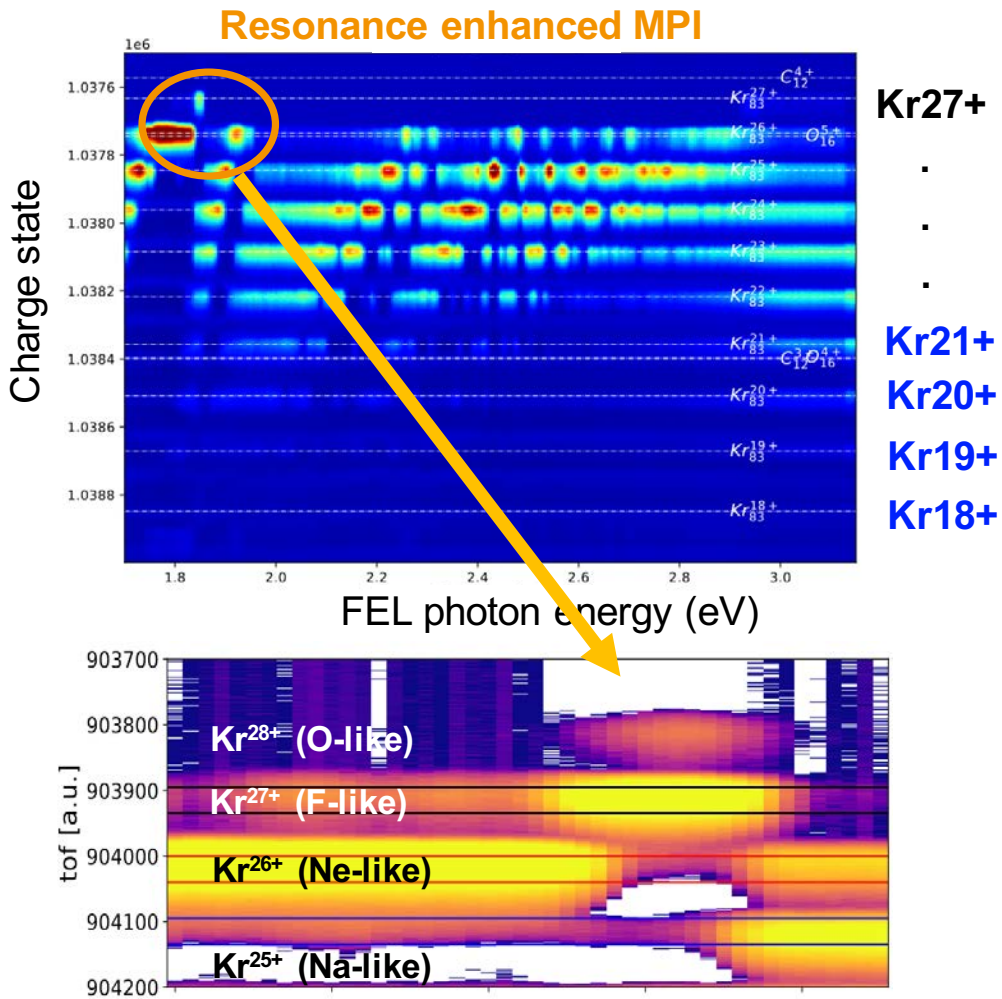
Production of highly charged ions

→ H-like up to Fe, He-like up to Xe

Fluorescence or ion time-of-flight detection

Also available at SXP!!

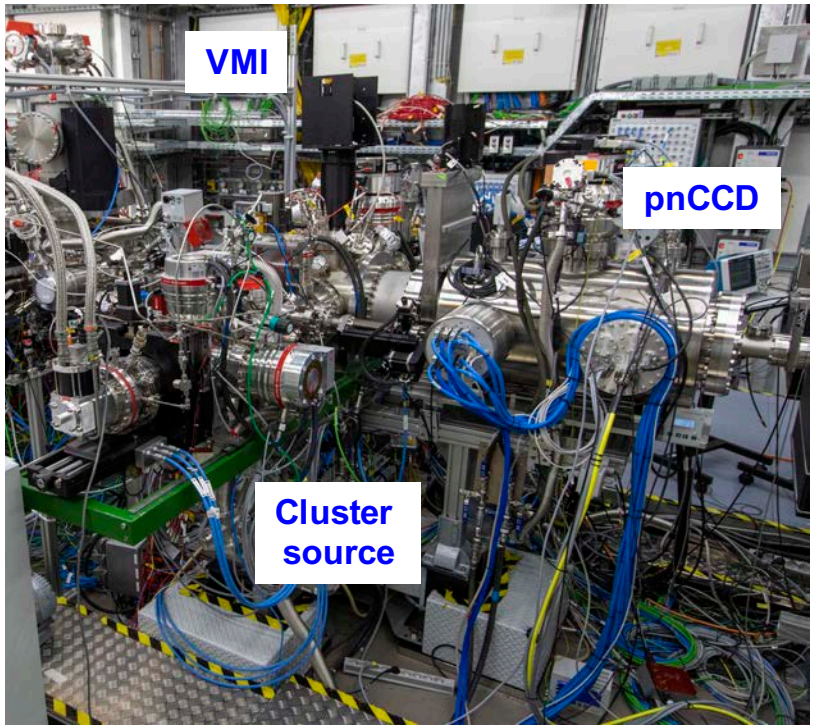
First user experiment in May 2023



NQS experimental chamber

Targets: Cluster, Nano-particles, bio-molecules

Detection: electrons, ions, photons

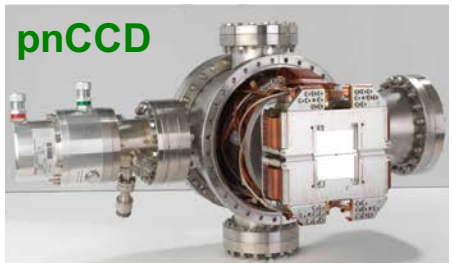


Sample delivery:

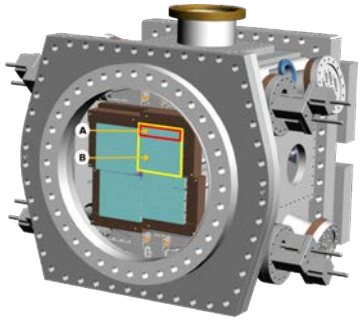
- **Rare gas cluster / He-droplet source**
- **Aerosol source**
- **COMO set-up (J. Küpper / CFEL)**

NQS: Nano-sized Quantum Systems

- **ionTOF** — **Fragmentation products**
- **VMI** — **Angular distribution**
- **Large area pixel detectors**
  Coherent diffraction imaging



DSSC



Parameter	pnCCD	Mini-SDD
Energy range	0.03 – 25 keV	0.5 – 6 keV
Detector size	78 x 78 mm^2	210 x 210 mm^2
Number of pixels	1024 x 1024	1024 x 1024
Sensor pixel size	~ 75 x 75 μm^2	~ 236 x 236 μm^2
Dynamic range	>6000 ph @ 1 keV	256 ph @ 1 keV
Frame rate	**Up to 150 Hz**	**0.9 – 4.5 MHz**
Read-out of frames	**1 @ 10Hz**	**800 @ 10Hz**
Vacuum conditions	< 10^{-8} mbar	10^{-7} mbar

3 quadrants !!

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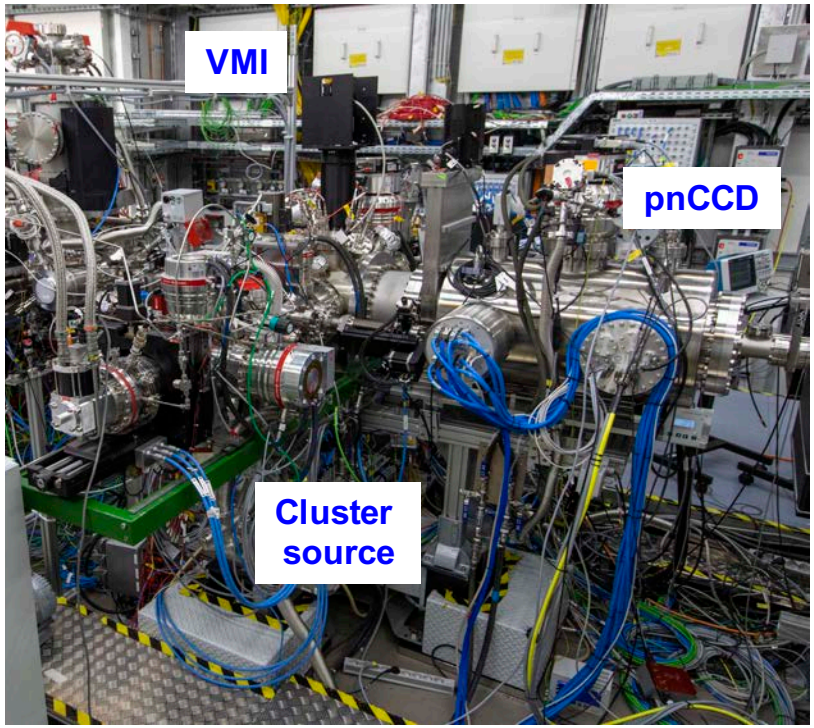
Detection: electrons, ions, photons



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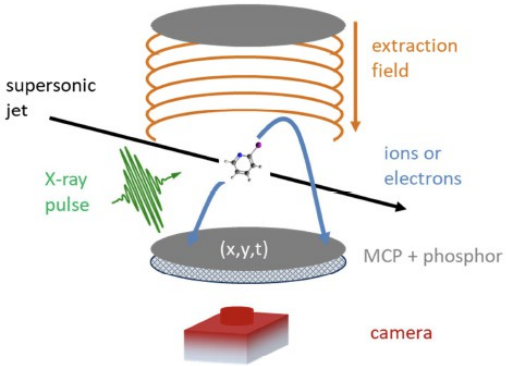
NQS: Nano-size Quantum Systems

- **VMI** **Angular distribution**



Timepix3 camera

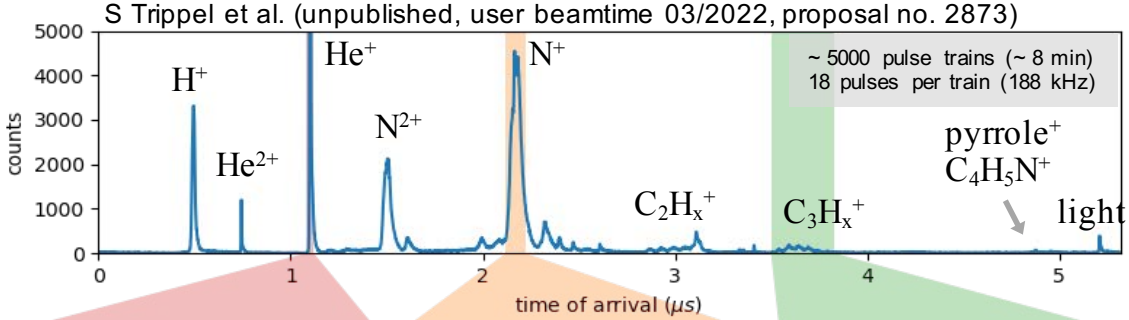
Pulse-resolved VMI images

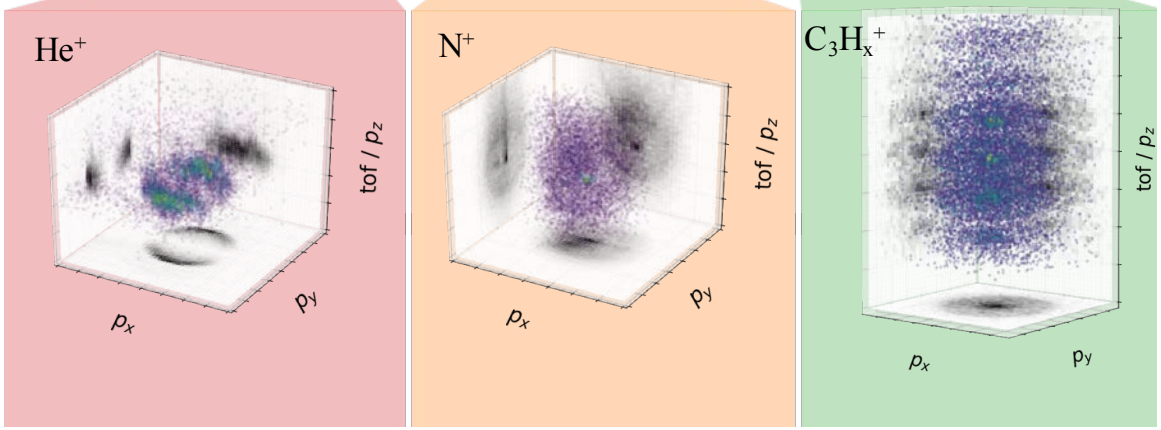
electrons and ions

256 x 256 pixel

200 kHz for ions
2 MHz for electrons

S Trippel et al. (unpublished, user beamtime 03/2022, proposal no. 2873)

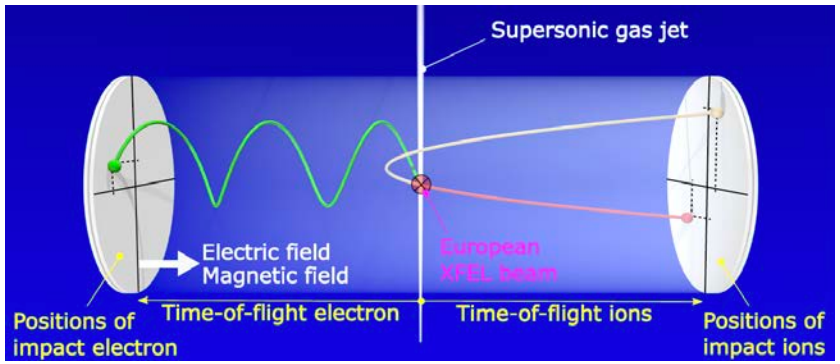




SQS-REMI experimental chamber

Targets: molecules
Detection: electrons, ions

User contribution
U. Frankfurt (R. Dörner et al.)



European XFEL

SQS-REMI Reaction Microscope

COLTRIMS set-up
(Cold Target Recoil Ion Momentum Spectroscopy)

Electron & Ion Momentum Imaging

Coincidence Spectroscopy

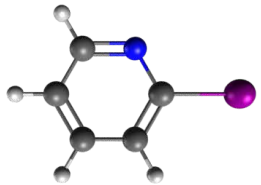
Coulomb Explosion Imaging

Coulomb explosion imaging (CEI)

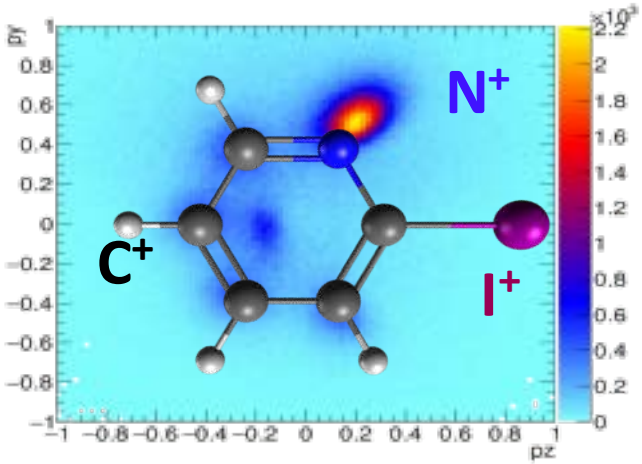
→ **Time-resolved experiments**

R. Boll et al., Nat. Phys. 18, 423 (2022)

Iodopyridine



Coincidences I+ / N+ / C+



Time-resolved experiments

X-Ray - Optical Pump-Probe

Pump-Probe Laser (M. Lederer et al.)

800 nm, 0.2 mJ at 1.1MHz, < 20 fs

800 nm, 1 mJ at 188 kHz, < 20 fs

1030 nm, 3 mJ at 1.1 MHz, 900 fs

1030 nm, 3 mJ at 1.1 MHz, 400 ps

SQS extension (T. Mullins et al.)

SHG: 400 nm, ~0.1 mJ, (30 fs)
THG: 266 nm, <10 μJ, 30 fs

Other wavelength (UV and IR) in preparation.
Contact SQS for further Information!!!

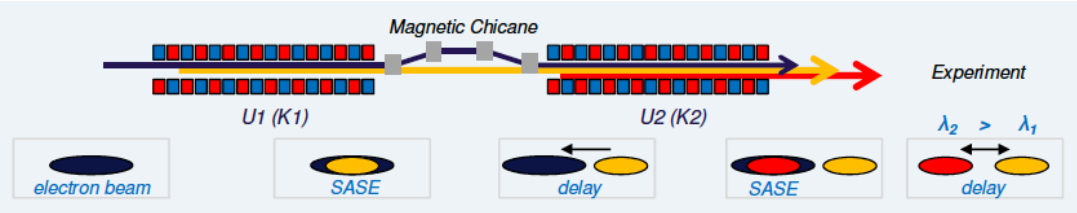
Pulse Arrival Time Monitor

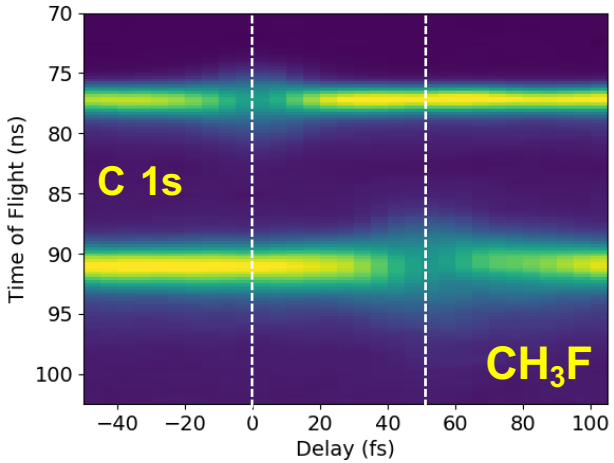
Synchronization < 20 fs

2-Color Pump Probe (2CPP)

X-ray – X-ray Pump-Probe

Magnetic chicane in SASE3 undulator





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Operation in close collaboration with S. Serkez & G. Geloni

RUN 12: August – November 2024

https://www.xfel.eu/facility/instruments/sqs

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NQS: Yevheniy.Ovcharenko@xfel.eu

REMI: Rebecca.Boll@xfel.eu

Laser: Terry.Mullins@xfel.eu

Timepix3: Bjoern.Senfftleben@xfel.eu

X-ray beam transport: Tommaso.Mazza@xfel.eu

or simply sqs@xfel.eu

RUN 12: August – November 2024

https://www.xfel.eu/facility/instruments/sqs