The Small Quantum Systems - SQS Instrument at the European X-Ray Free Electron Laser

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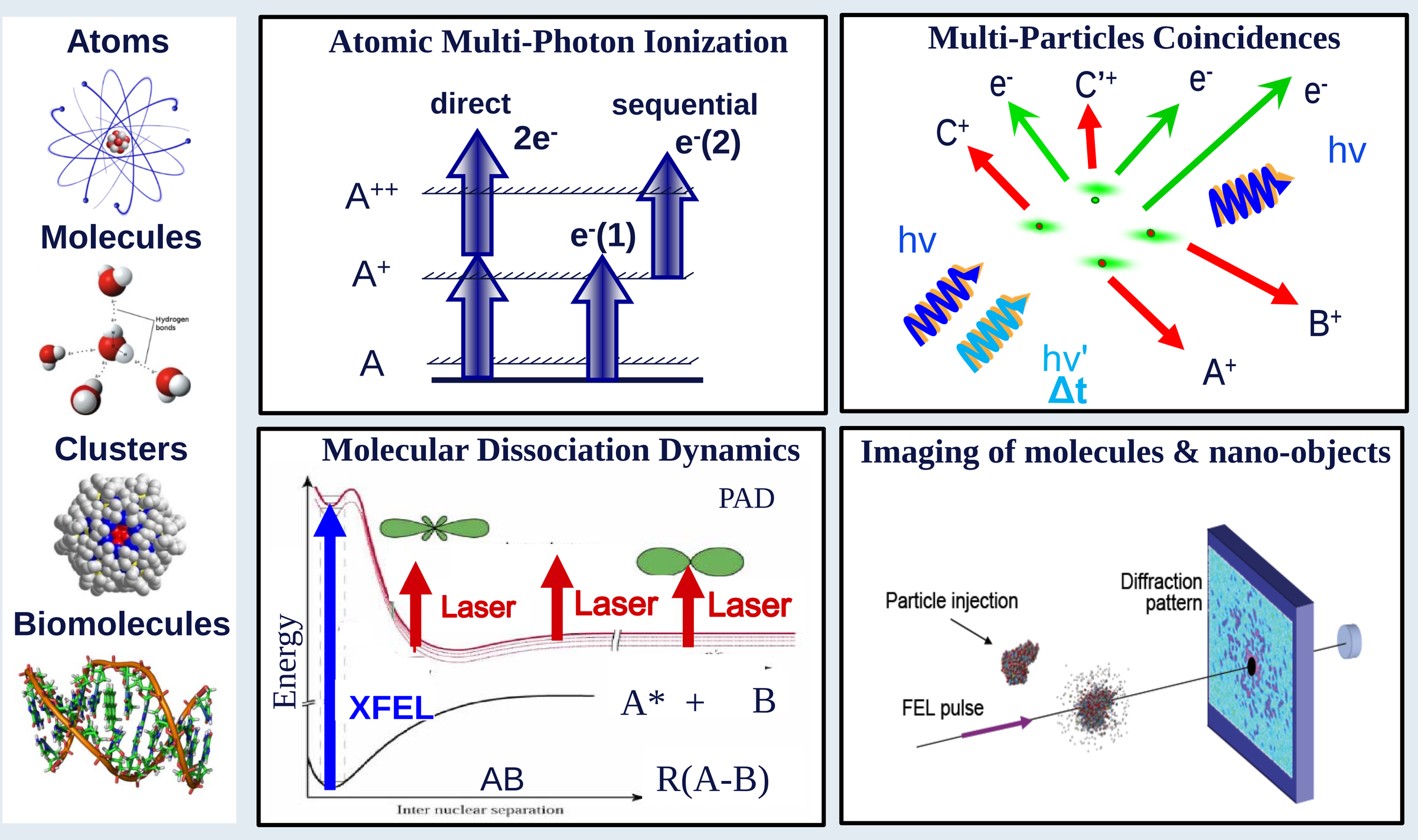
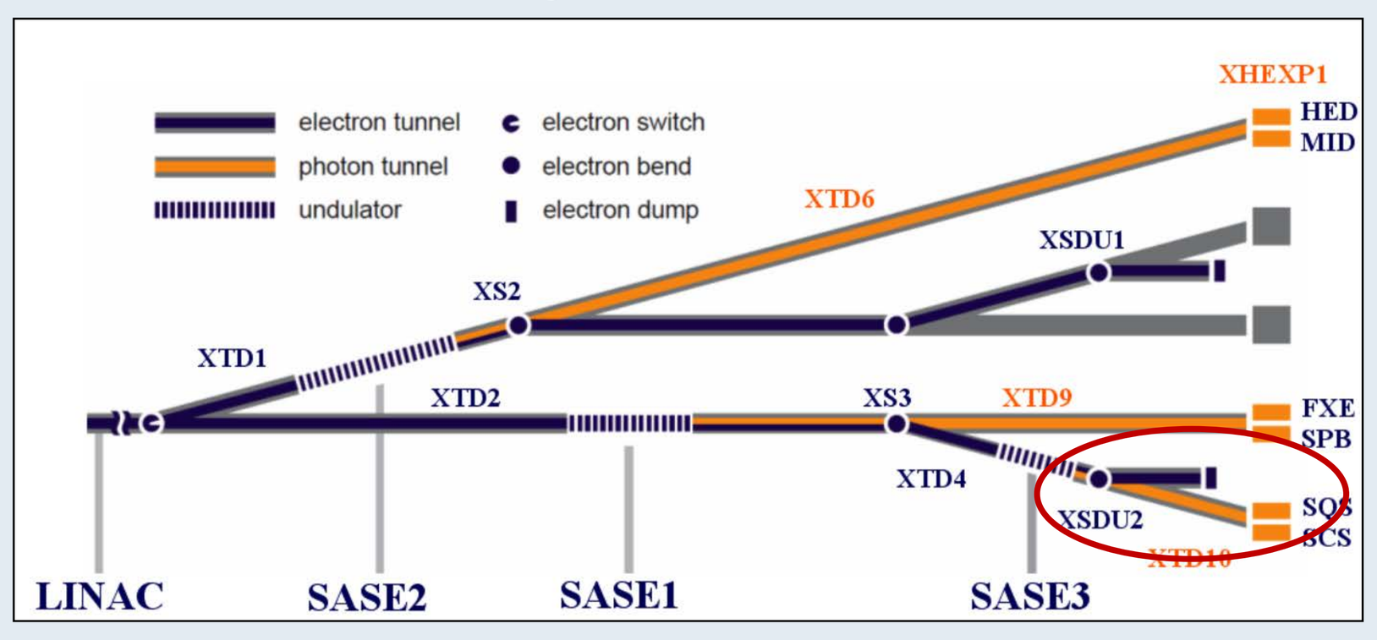
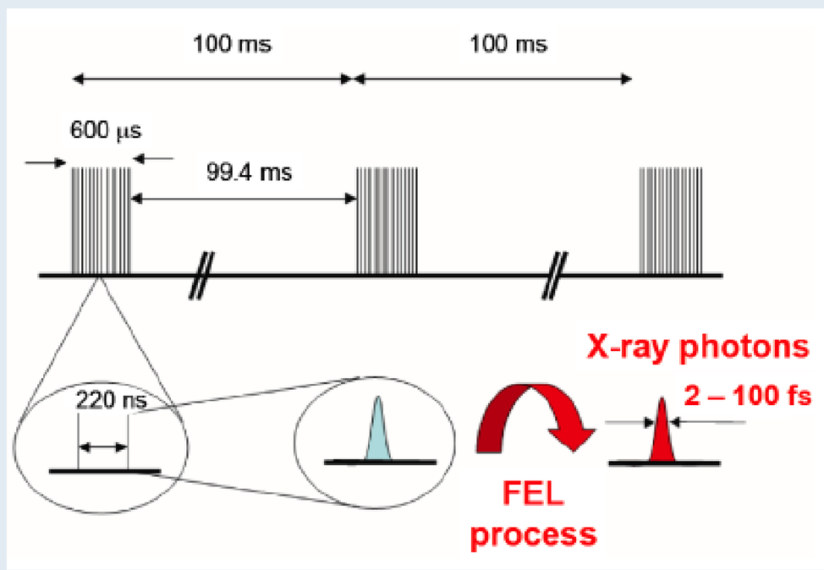
European XFEL

Scientific Scope: Small Quantum Systems (SQS)



SASE3 Soft X-Ray Beamline

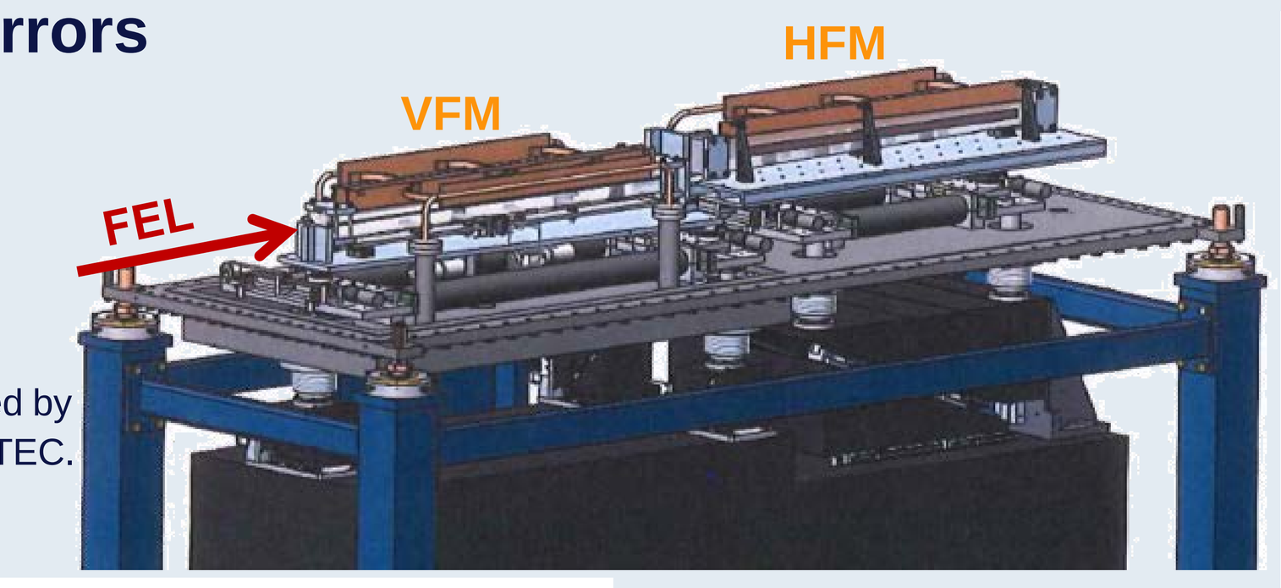




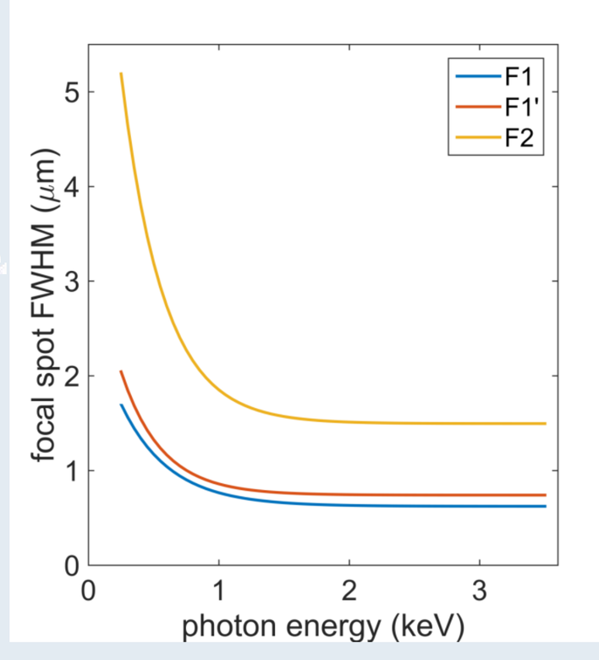
Photon energy	250 – 3000 eV
Wavelength	4.8 – 0.4 nm
Pulse energy	0.2 – 11.0 mJ
Peak power	50 – 120 GW
Average power	3 – 300 W
Pulse width	2 – 100 fs
Coherence time	0.3 – 1.8 fs
Photons / pulse	0.1 – 2 x 10^{14}
Repetition rate	10 Hz
Pulses per train	2700

Beam Transport and KB mirrors

- Two source positions
  - Monochromator.
  - Pink beam from undulator.
- Three focal points in SQS (F1, F1', F2)
- Bendable mirrors.
- < 1 µm focus in F1.
- Contractor: FMB Oxford, substrates polished by JTEC.

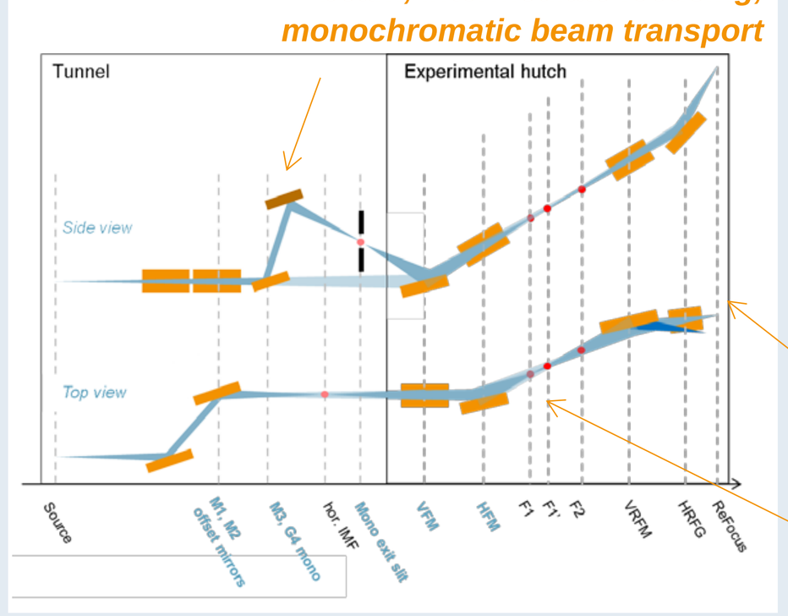


Parameter	VFM	HFM
Mirror profile	Elliptical bendable	
Clear aperture	800 x 20 mm	
Mirror length	1000 mm	1000 mm
Max. mirror width	58.77 mm	52.71 mm
Mirror thickness	45 mm	42 mm
Substrate material	Si single crystal	
Roughness	< 0.3 nm rms	
Tangential height error	< 2 nm PV	
Tangential slope error	< 0.1 µrad rms	
Slope error (focus F1)	50 nrad	
Slope error (focus F2)	250 nrad	
Incidence angle	9.0 mrad	
Focal length	3 m	1.8 m
Sagittal radius	> 10 km	
Mirror orientation	Facing up	Facing South



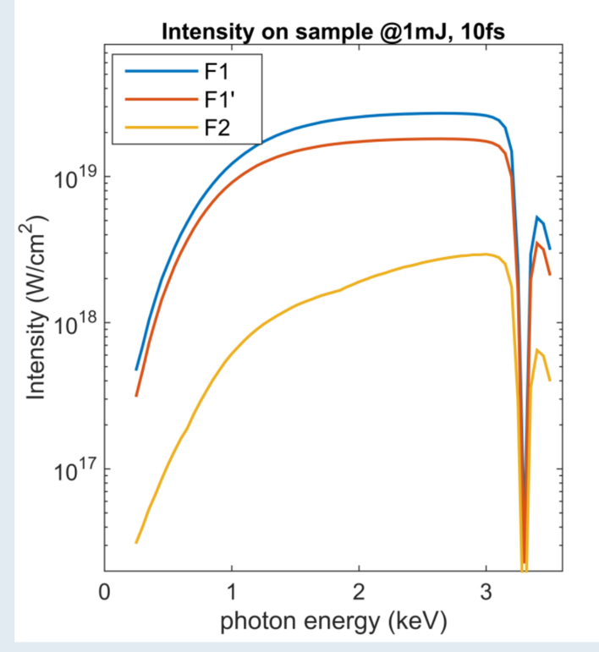
SASE3 and SQS X-Ray Beam Transport Layout

SASE3 Beamline tuned for direct pink beam, intermediate focusing, monochromatic beam transport

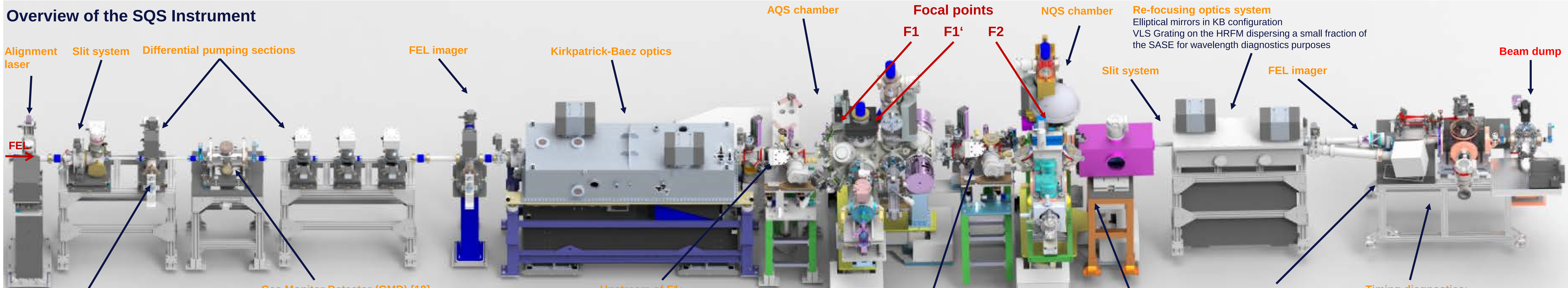


Refocusing optics with VLS grating for timing and wavelength diagnostics

Multiple focal positions enable by mechanical bending



Overview of the SQS Instrument



FEL imager [11]
Developed with A. Koch, *et al.* (XFEL WP-74)

Gas Monitor Detector (GMD) [10]
FEL total pulse energy measurement.
Developed by K. Tiedtke, *et al.* (DESY)

Upstream of F1:
- Differential pumping.
- Optical laser In-coupling.
- Clean-up slits.
- 2 FEL Imagers.

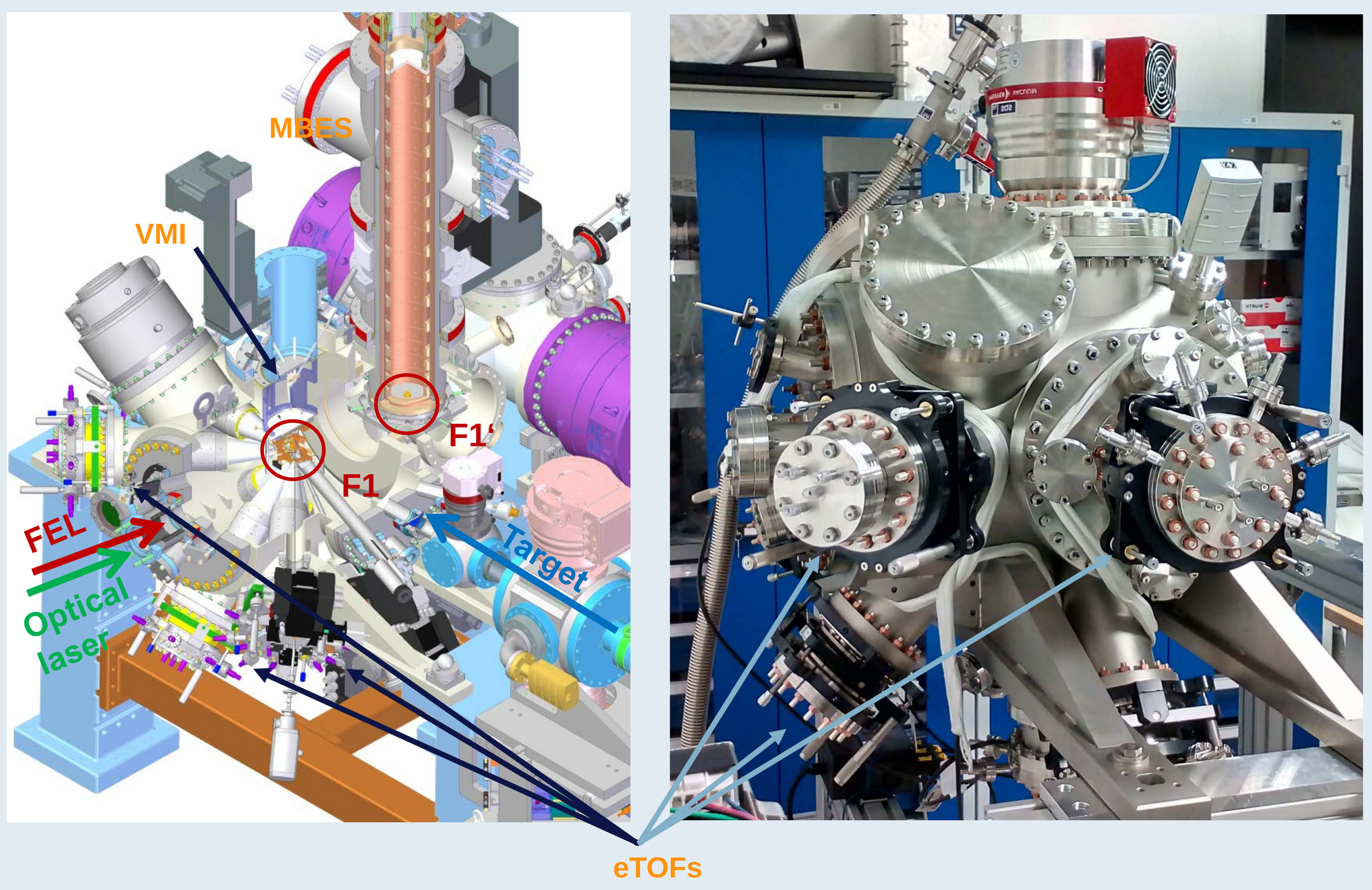
Between F1' and F2:
- Differential pumping.
- Clean-up slits.
- 2 FEL imagers.
- Optical laser In/Out-coupling.

Scattering detector

Wavelength spectrometer
Imaging the spatial dispersion of the SASE spectrum
- Optical imaging of a scintillator
- X-ray streak camera

Timing diagnostics:
- Spectral encoding.
- THz streaking.
- Developed with J. Liu, *et al.* (XFEL WP-74).

Atomic-like Quantum Systems (AQS)

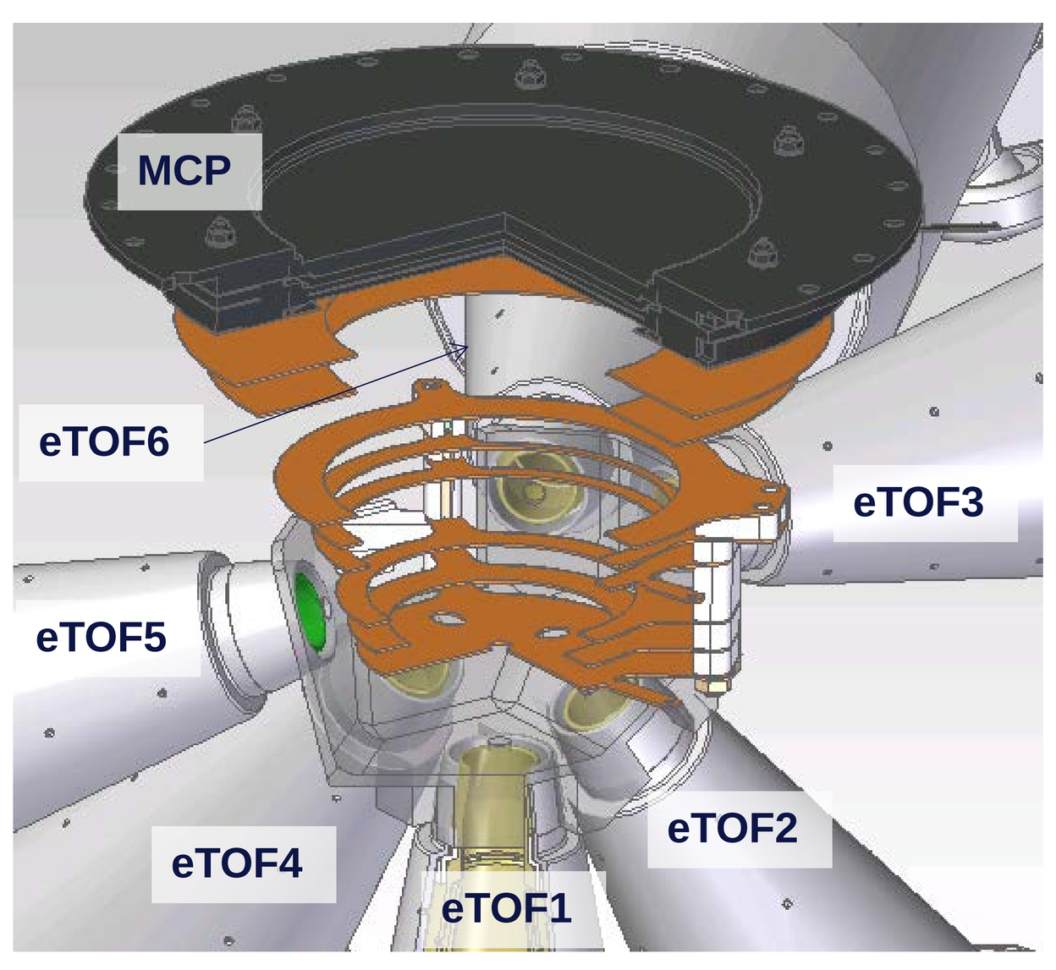


F1 Spectrometers

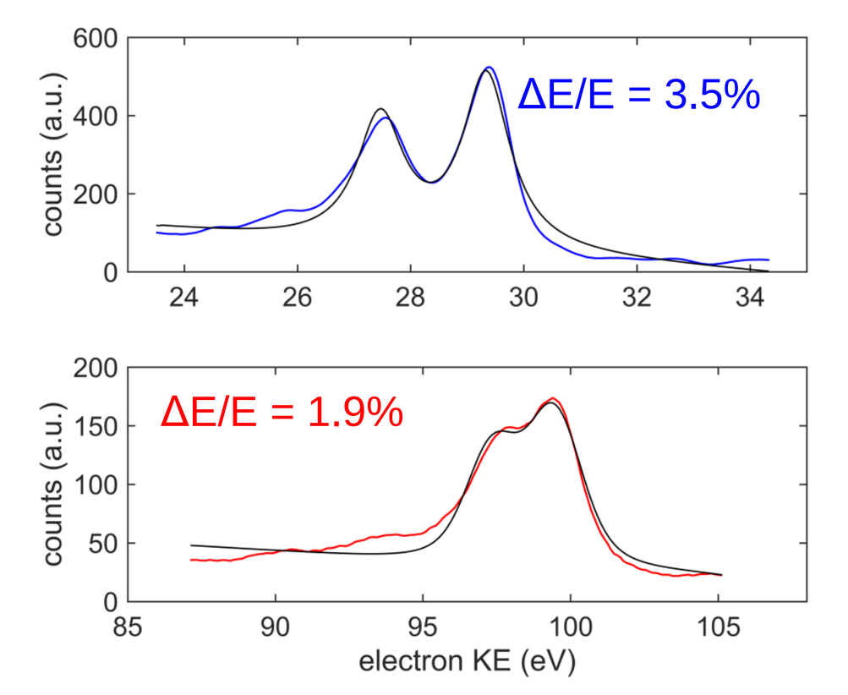
- VMI spectrometer with angular resolution
  - Electron and ion spectrometer.
  - Energy resolution E/ΔE = 100.
  - High energy (E ≤ 1200 eV).
  - 4 π sr acceptance.
  - Operation with fast phosphor screen + camera
- Electron TOF spectrometers (6x)
  - Electron energy 5 eV to 5 keV.
  - Energy resolution E/ΔE up to 10000.
  - Acceptance angle 0.14% of 4 π.

F1' Spectrometers

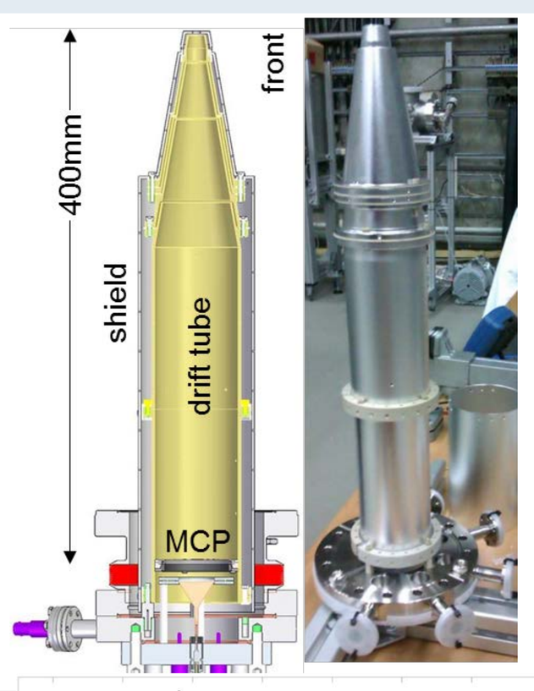
- Magnetic bottle electron spectrometer
  - Electron energy up to 3keV;
  - E/ΔE = 500 @(transmission=50% of 4π);
  - Single pulse sensitivity.
  - Possible operation with iTOF for coincidences, M/ΔM=50
- 1d imaging XUV spectrometer [3]
  - Photon energy 250-1000 eV
  - Energy resolution E/ΔE up to 10000.
  - Spatial resolution along the beam 10um = 1fs
  - transmission=$5 \cdot 10^{-6}$ of 4π
  - Surface Concept multi delay line anode.

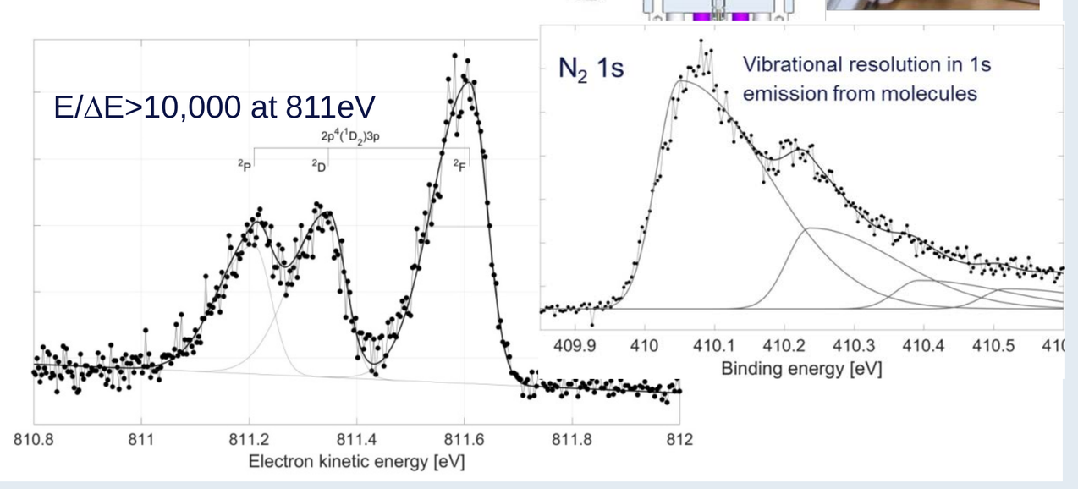


VMI performance test (P04@Petra III) [2]
- Ar 2p photoelectrons, KE up to 400eV
- Different voltage configurations tested
- Energy resolution down to 2% possible

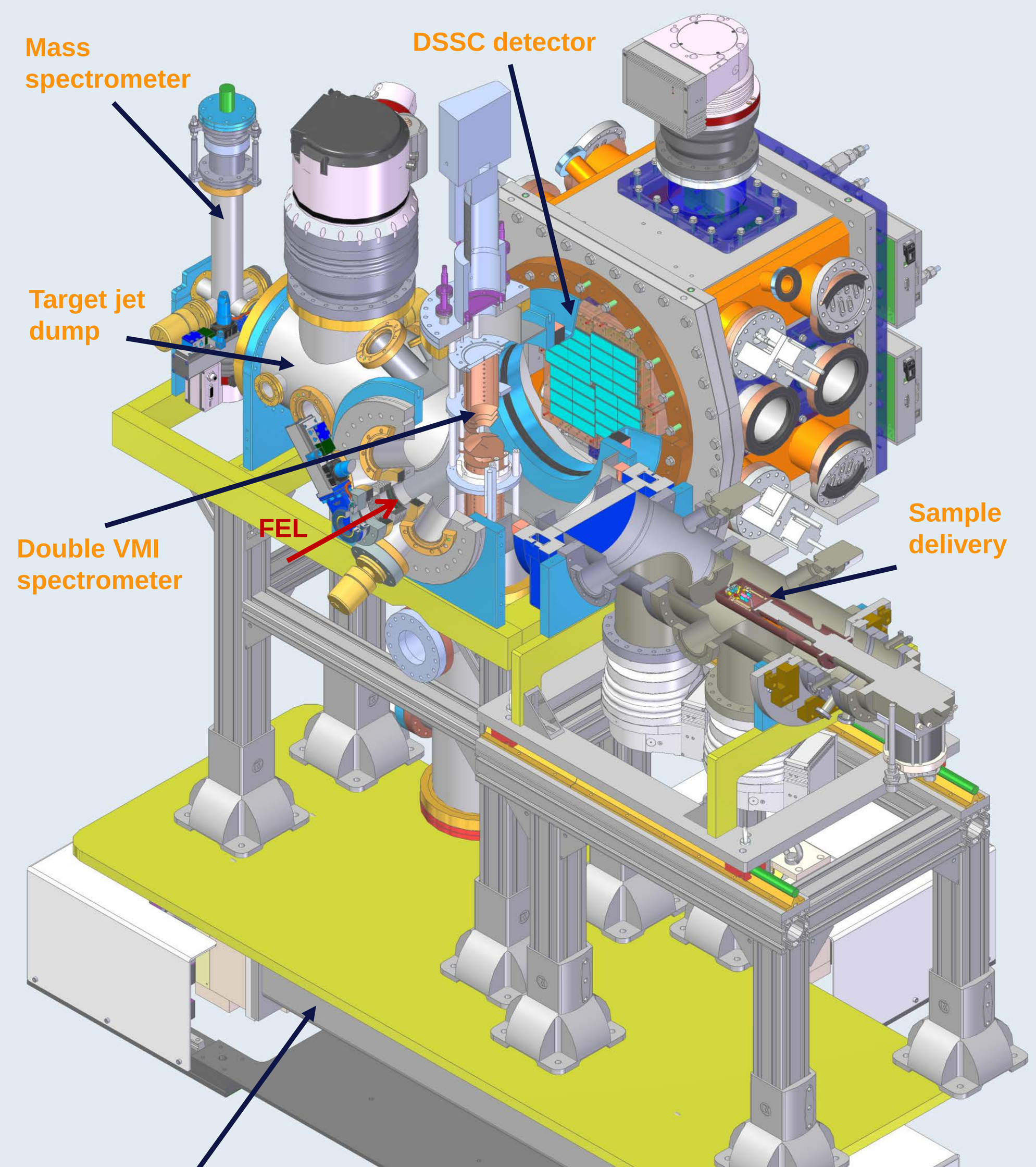


eTOF performance test (P04@Petra III) [2]
- World record eTOF resolution achieved
- Good transmission at low energy





Nano-sized Quantum Systems (NQS)



Alignment support
- Motorized.
- 5 degrees of freedom.

Electron and Ion Spectroscopy

- Double VMI spectrometer with conical electrodes
  - Electron kinetic energy up to 150 eV.
  - 4 π sr acceptance.
  - Full view angle for the scattering detector is max. 60°.
  - Operation with MCP and phosphor screen or delay-line anode.
- Options: Magnetic bottle spectrometer, Scienta analyzer [7].

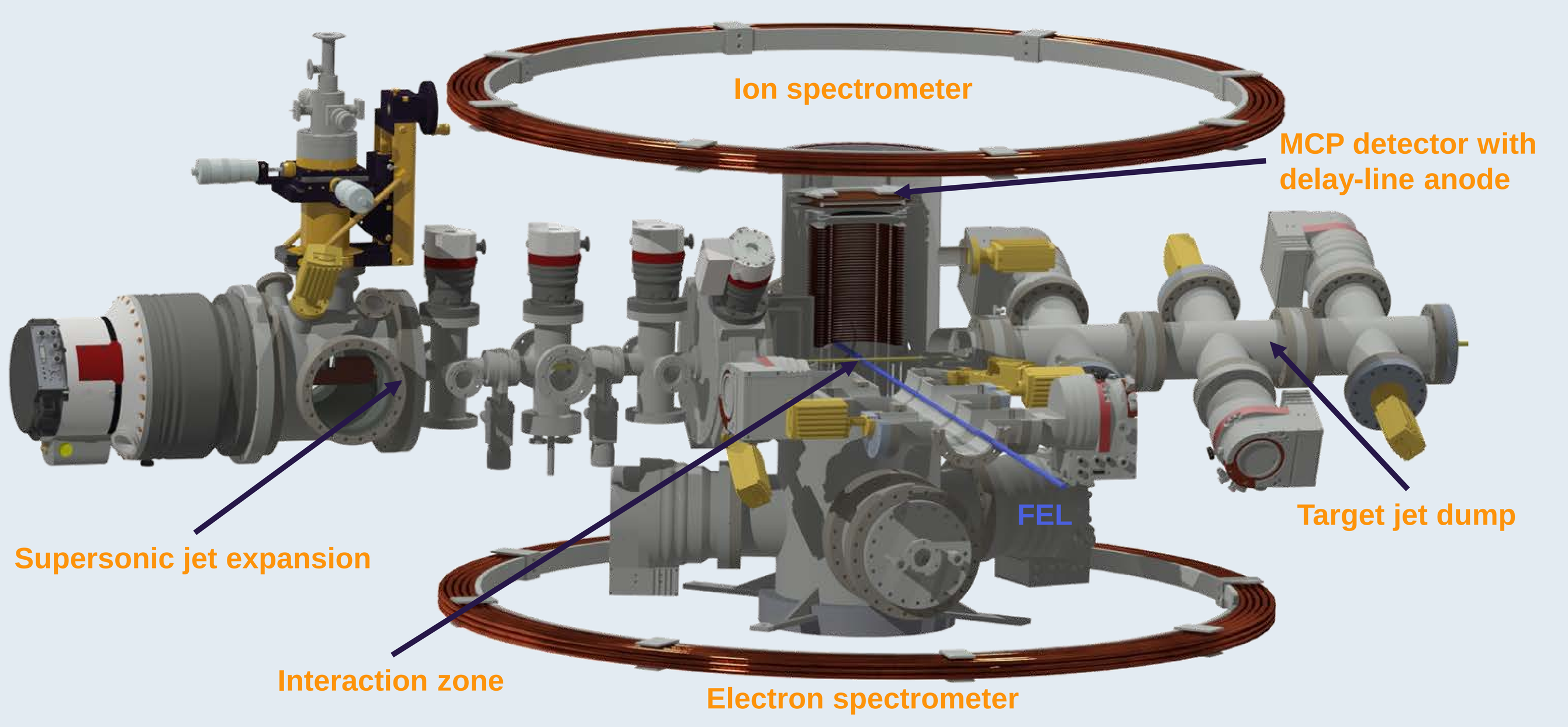
Single Shot Scattering Imaging

- DSSC-DEPFET sensor [9]
  - Single photon resolution for 0.5 keV at 2.5 MHz and 1 keV at 4.5 MHz.
  - Detection efficiency 100% from 0.5 keV to 10 keV.
  - Detector size 210x210 mm² composed of 1024x1024 pixels.
  - Pixel size (hexagonal) 236x272 µm².
  - Dynamic range >6000 photons/pixel/pulse @ 1 keV.
  - 800 frames / bunch train, 10 Hz read out frequency.
- Fast CCD detector [8]
  - Single photon resolution for 0.5 keV to 1.5 keV.
  - Detection efficiency 70% from 0.25 keV to 0.6 keV and 90% from 1 keV to 6 keV.
  - Detector size 57.8x22.8 mm² composed of 1920x960 pixels.
  - Pixel size (hexagonal) 30x30 µm².
  - Dynamic range 1000 photons/pixel/pulse @ 1 keV.
  - 200 Hz readout frequency.
- MCP-based scattering detector
  - Detection efficiency 15% from 0.5 keV to 1.5 keV.
  - Detector size 75 mm in diameter.
  - Spatial resolution 30x30 µm².
  - Dynamic range 1000 photons/pixel/pulse @ 1 keV.
  - 50 Hz readout frequency.

Sample Delivery at SQS (AQS, NQS, REMI)

- Cluster sources
  - He droplet cluster source [6].
  - Metal cluster microplasma source [4].
- Controlled molecules (COMO) [5].
- Moderate temperature oven for metallic vapors.
- Atomic or molecular supersonic jet.
- Liquid jet (with XFEL WP-79).
- Sublimation oven for metal vapour production

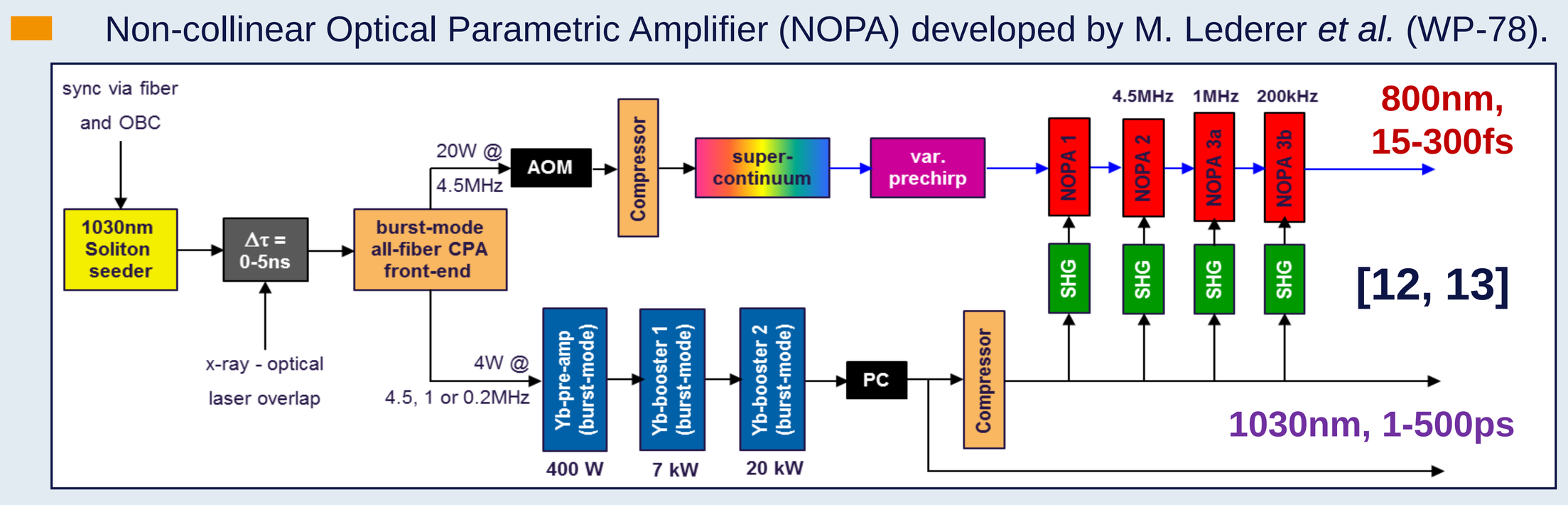
Reaction Microscope (REMI) [1]



- Electron-Ion coincidence measurement.
- Complete 3d momentum reconstruction of all charge reaction fragments.
- Fragment energies of few eV.
- Ion momentum resolution of 0.05 a.u.
- Will be used in F1 focal position.

Optical Pump-Probe Laser

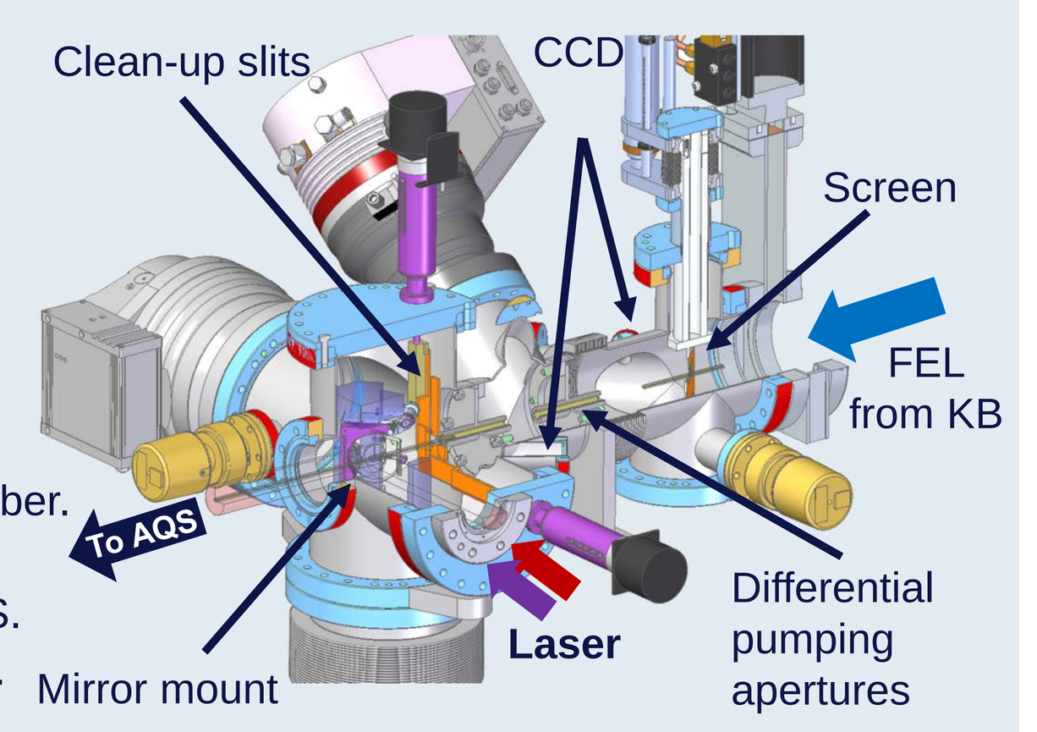
- Non-collinear Optical Parametric Amplifier (NOPA) developed by M. Lederer *et al.* (WP-78).



Set Points	f_{rep} (MHz) (within 600 µs burst)	E_{pulse} (mJ) at 800 nm	E_{pulse} [mJ] at 1030 nm
1	4.5	0.05	1
2	1	0.2	4
3	0.2	1	20
4	0.1	2	40

Laser in-coupling

- Motorized laser in-coupling mirrors.
- Mirrors vibrationally decoupled from chamber.
- Two screens to monitor FEL beam.
- Differential pumping between KB and AQS.
- Breadboard installed within AQS chamber.



Status of the Instrument

- Assembly and test of individual components is ongoing at Hera South labs.
- Experiment hutch ready in early 2018.
- Instrument installation in the hutch from spring 2018.
- First FEL beam possible from summer 2018.
- Beamline and instrument commissioning in the third quarter of 2018.
- User operation starts in autumn 2018.
- Pump-probe laser scheduled to operate second half of 2019.

References

[1] REMI: R. Dörner, G. Kastirke, M. Schöffler, L. Schmidt, *et al.*, *(Goethe-Universität Frankfurt).*
[2] beamtime at P04 @ Petra III. contact people: J. Viefhaus, *et al., (DESY)*.
[3] XUV spectrometer: J.E. Rubensson, J. Nordgren, *et al.*, *(University of Uppsala)*.
[4] Metal Cluster Source: P. Piseri, *et al.*, *(Universita' di Milano).*
[5] Controlled Molecules (COMO): J. Küpper, *et al.*, *(CFEL).*
[6] Rare gas cluster source: T. Möller, *et al., (TU-Berlin)*.
[7] Scienta detector: K.-H. Meiwes-Broer, *et al., (Universität Rostock).*
[8] Fast CCD: Doering, *et al.,* Rev. Sci. Instrum. **82**, 73303 (2011).
[9] DSSC detector: M. Porro, *et al.,* Nucl. Inst. Meth. B, **624**, 509 (2010).
[10] GMD: K. Tiedtke, *et al.*, J. Appl. Phys. **103**, 094511 (2008).
[11] FEL Imager: A. Koch, *et al.*, Proc. SPIE 9512, 95121R (2015).
[12] Pergament *et al.*, Optics Express **22**, 22202 (2014) .
[13] Pergament *et al.*, Optics Express **24**, 29349 (2016).