

Diagnostics and instrumentation at SQS



Thomas Baumann
Small Quantum Systems (SQS) Instrument

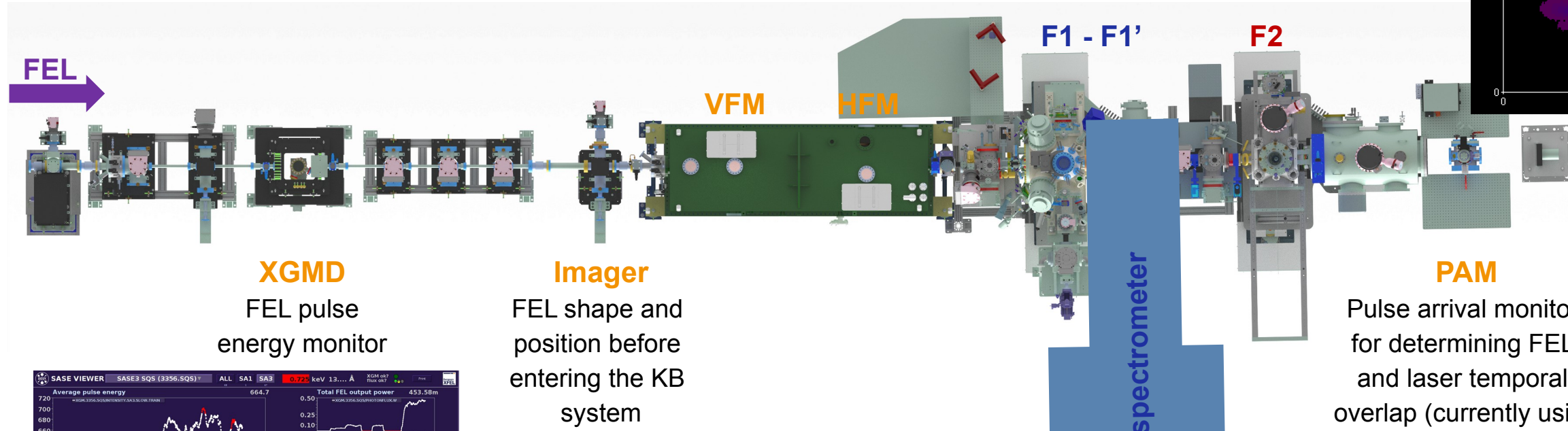
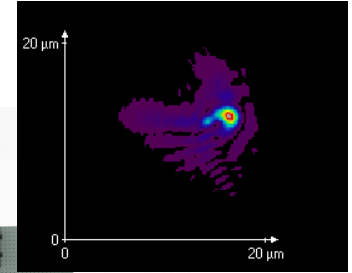
Schenefeld, 21.10.2021

Outline

- Overview on FEL diagnostics at SQS
 - Pulse energy
 - Wavefront analysis
 - Timing diagnostics
 - Spectral distribution
- Additional instrumentation
 - Photo-electron spectrometer (PES)
 - AQS electron spectrometers

Diagnostics overview – what we have today

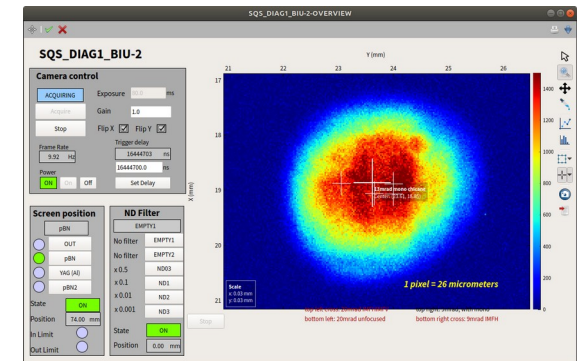
Wavefront sensor
FEL focus characterization



XGMD
FEL pulse energy monitor

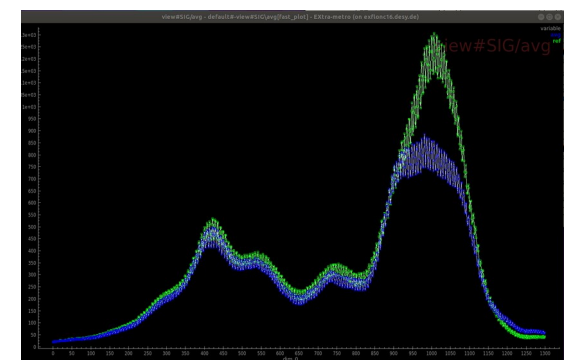


Imager
FEL shape and position before entering the KB system

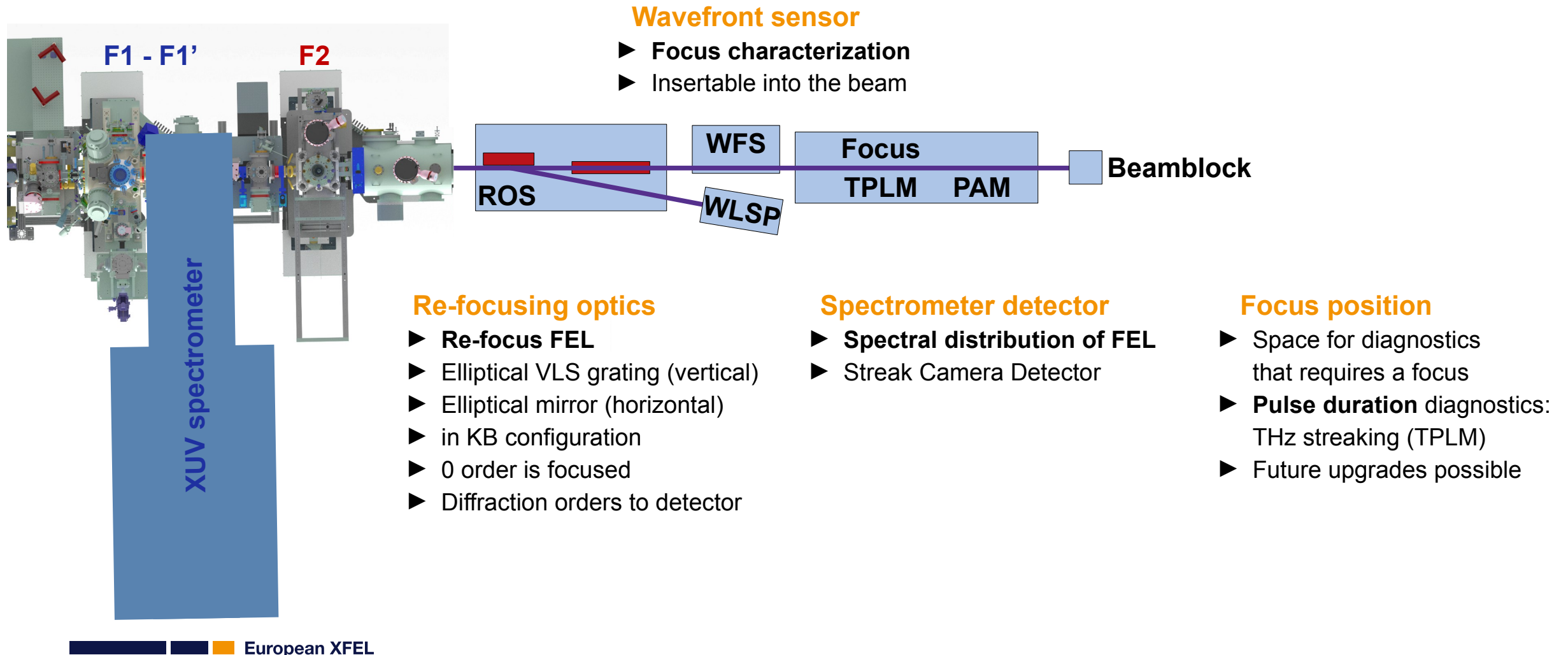


XUV spectrometer

PAM
Pulse arrival monitor for determining FEL and laser temporal overlap (currently using spectral encoding)

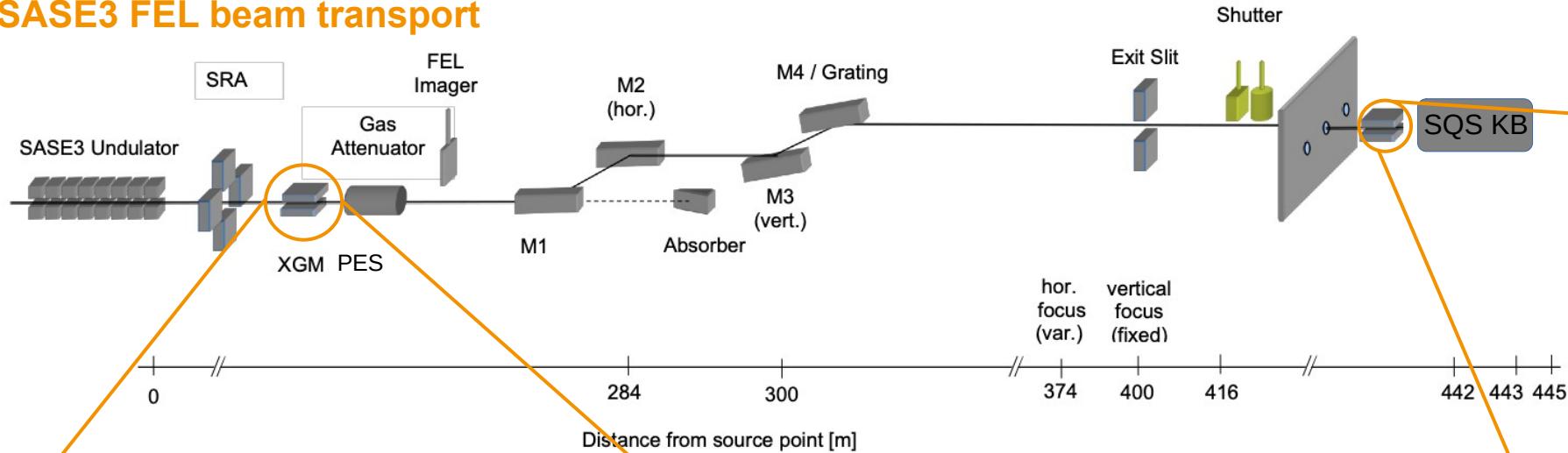


Diagnostics overview – DIAG3 upgrade in 2022

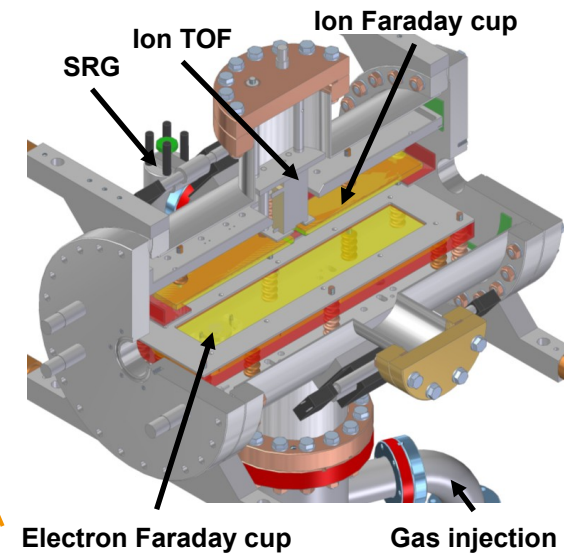


Pulse energy measurement

SASE3 FEL beam transport



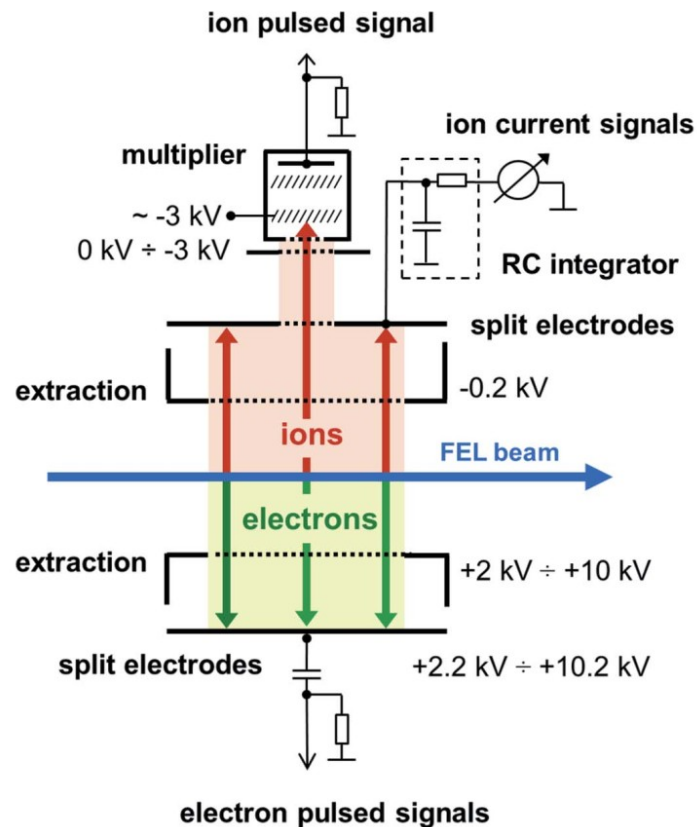
XGMD upstream of SQS KB mirrors



XGM upstream of beam transport



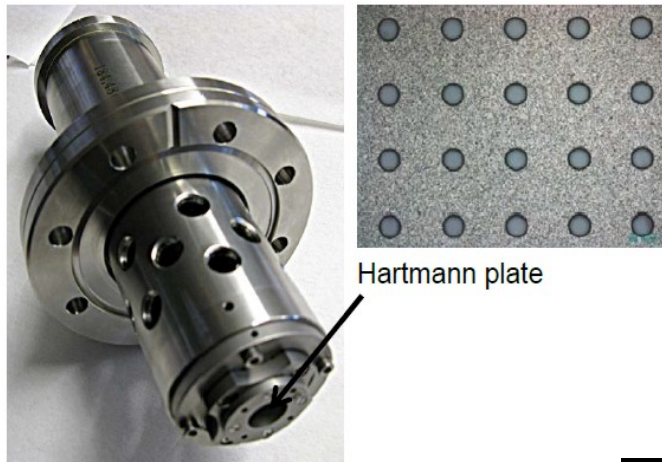
Pulse energy measurement



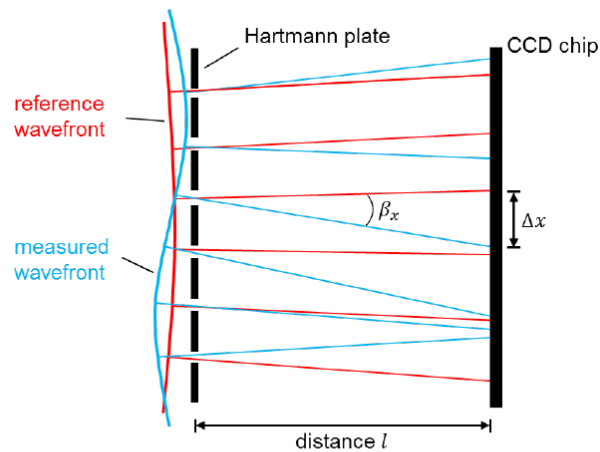
- Absolute determination of pulse energy from photo-ion current (**slow**):
 - Photo-ionization of target gas (usually Krypton or Xenon).
 - Measurement of photo-ion current.
 - Measurement of gas pressure and temperature.
 - Number of incoming photons can be calculated using photo-ionization cross section and average photo-ion charge state.
 - Uncertainty < 5%.
- Pulse-resolved measurement using photo-electrons (**fast**):
 - Measurement of photo-electrons for each FEL pulse.
 - Signal recorded on digitizers after amplification.
 - Calibrated on slow pulse energy measurement.
 - Uncertainty < 10%.
- XGM allows for beam position measurement using split electrodes.

In collaboration with K. Tiedtke, *et al.*, DESY
 and T. Maltezopoulos, J. Grünert, *et al.*, EuXFEL XPD
 A.A. Sorokin, *et al.*, *J. Synchrotron Rad.*, **26**, 1092-1100 (2019)

Wavefront measurement

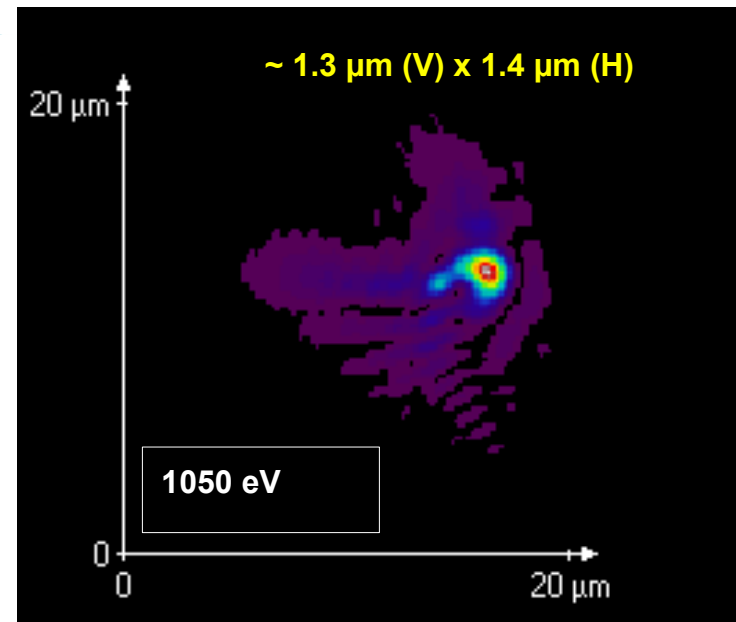


Hartmann plate



The **actual beam** is compared to a **reference wave** (spherical wave).

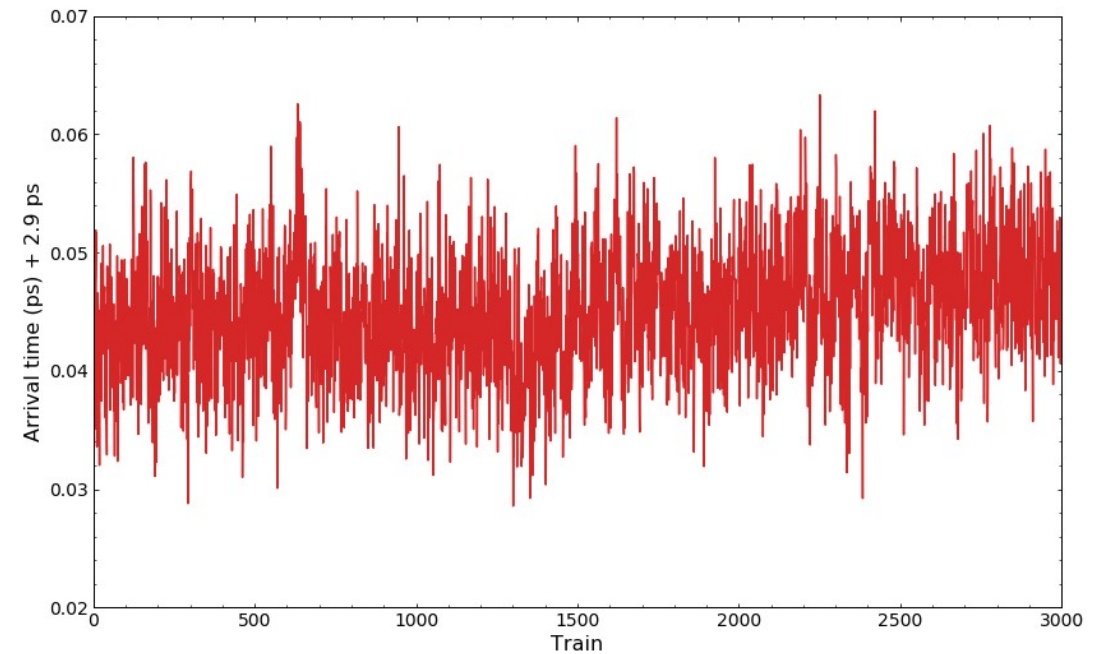
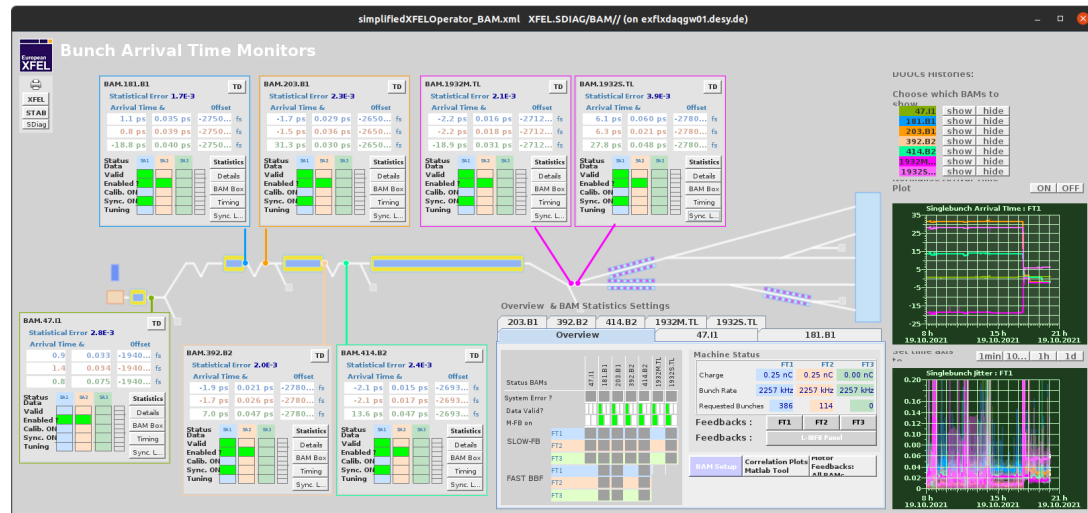
- Measures FEL wavefront compared to reference spherical wave.
- Pinhole array (Hartmann plate) and x-ray sensitive CCD camera.
- Back propagation of wavefront to determine focus properties.
- Software for online analysis.
- Current wavefront sensor is installed at the end of the beamline.



- Upgrade in 2022:
 - Sensor specifically developed for SQS.
 - Entire set-up can be moved into the beam when needed.

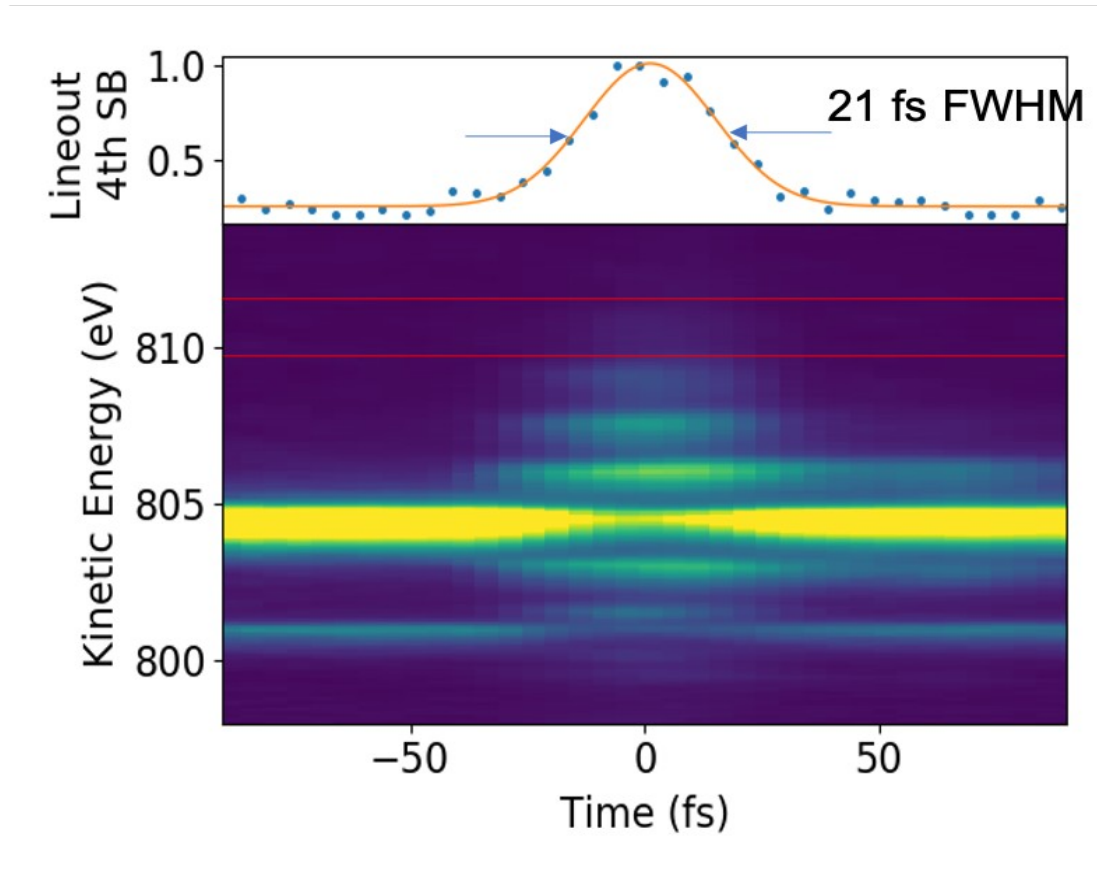
In collaboration with B. Keitel, E. Pjönjes-Palm, *et al.*, DESY and K. Mann, *et al.*, IFNANO Göttingen
B. Keitel, *et al.*, *J. Synchrotron. Rad.* **23**, 43-49 (2016)

FEL / laser timing diagnostics: BAM (Bunch Arrival Monitor)



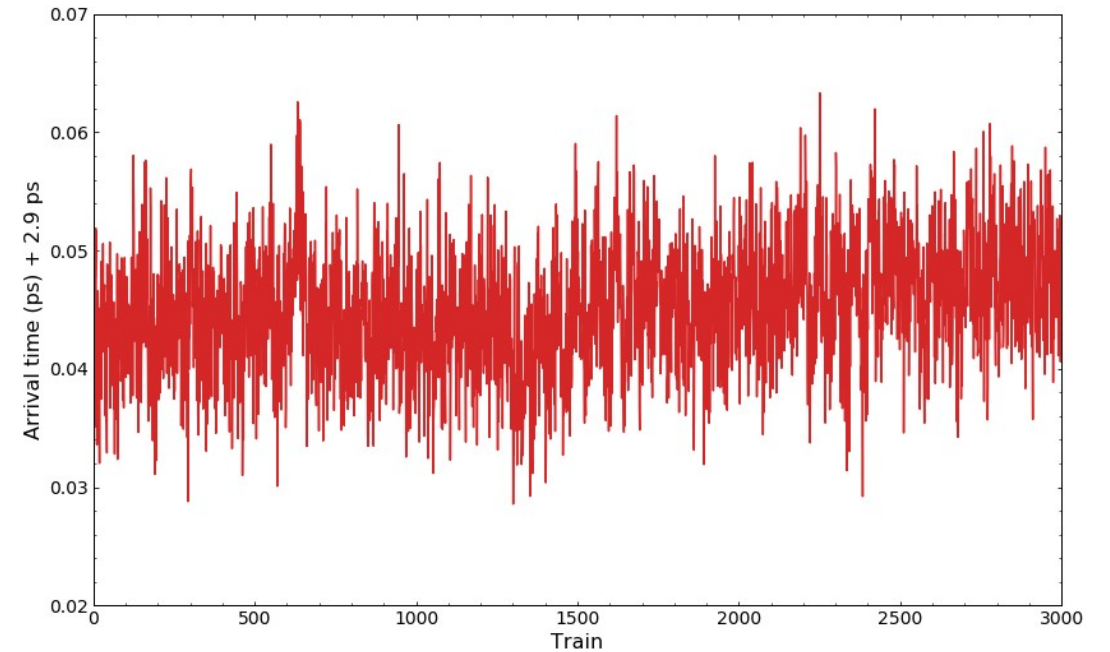
- Measures relative arrival time of the electron bunch.
- RF pick-ups detect electron bunch in the accelerator.
- RF signal is compared to master oscillator by electro optical modulator.
- Used for feedback system to stabilize arrival time.

FEL / laser timing diagnostics: BAM (Bunch Arrival Monitor)

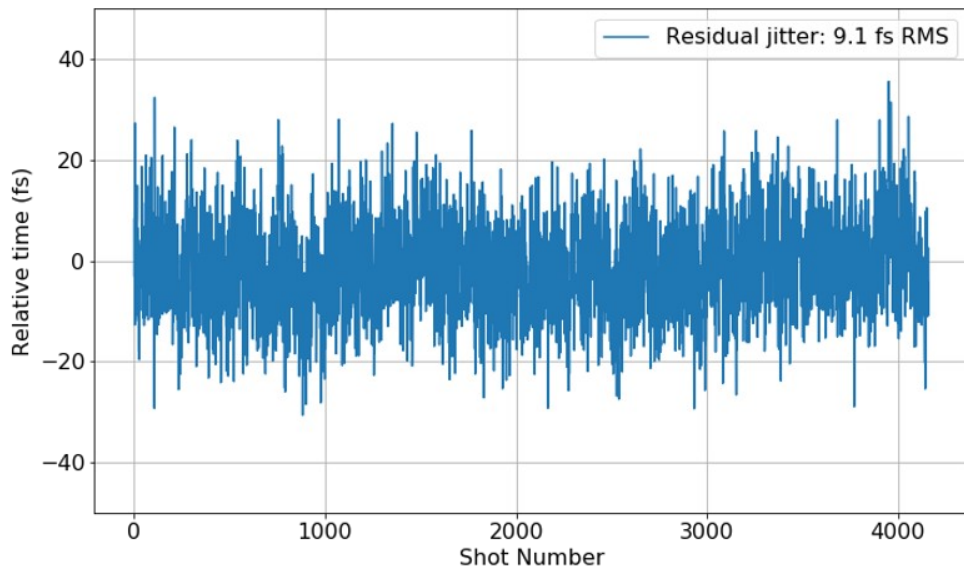
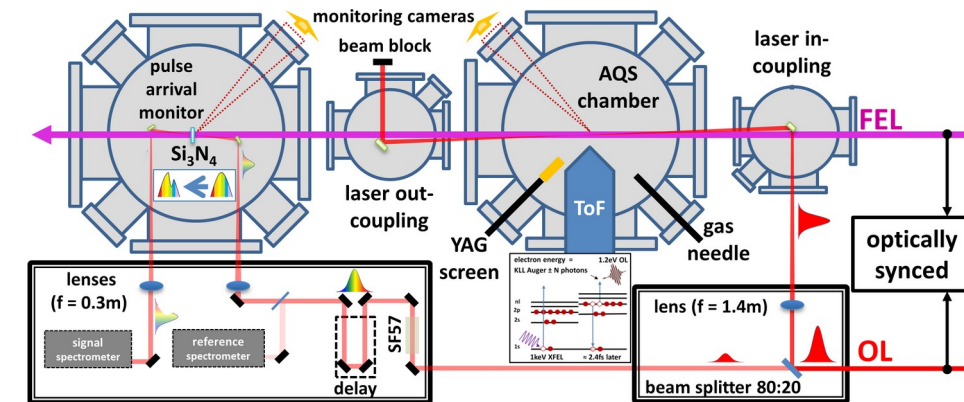


Sidebands on Neon Auger electrons

Courtesy of D. Rivas

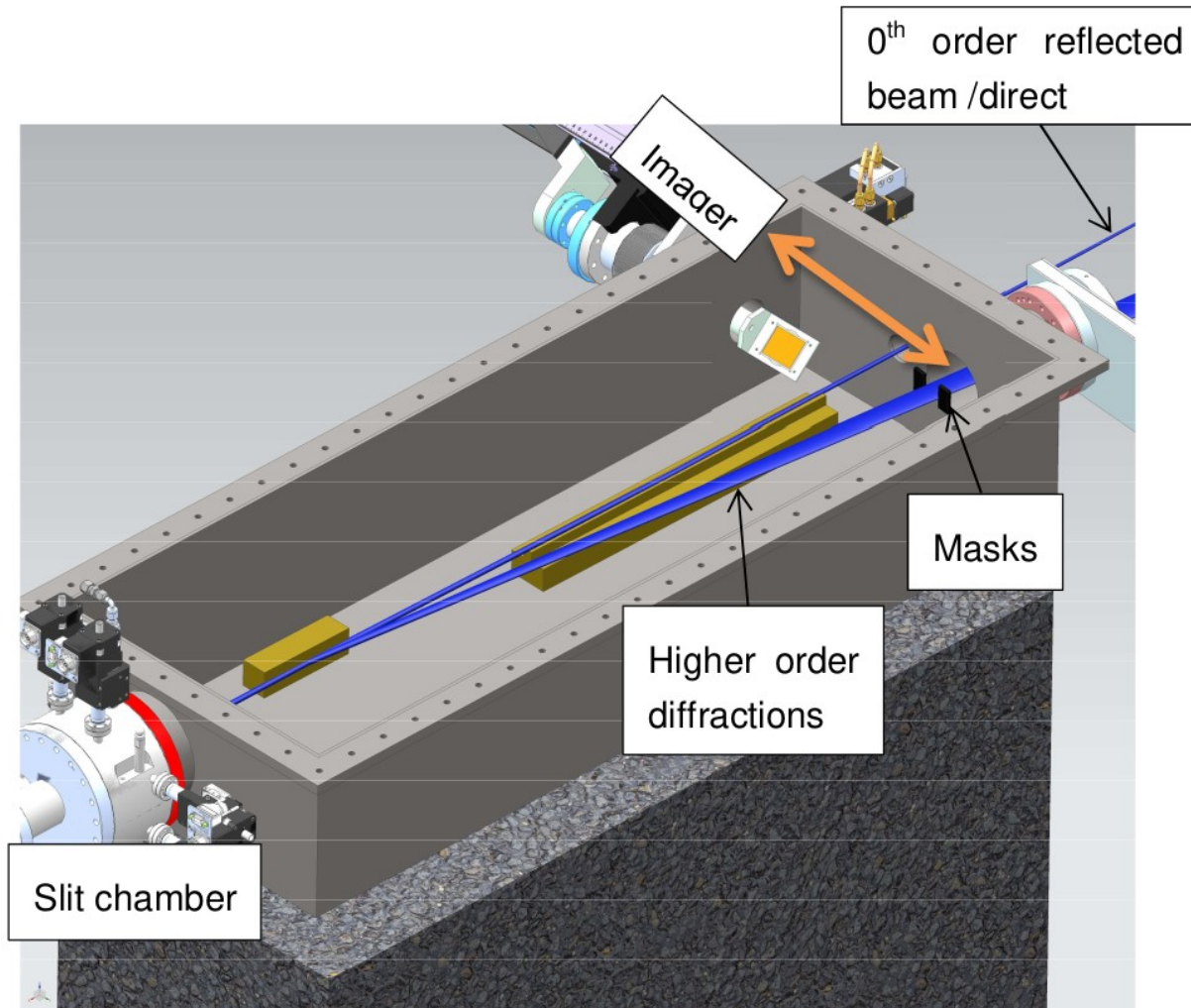


FEL / laser timing diagnostics: PAM (Pulse Arrival Monitor)



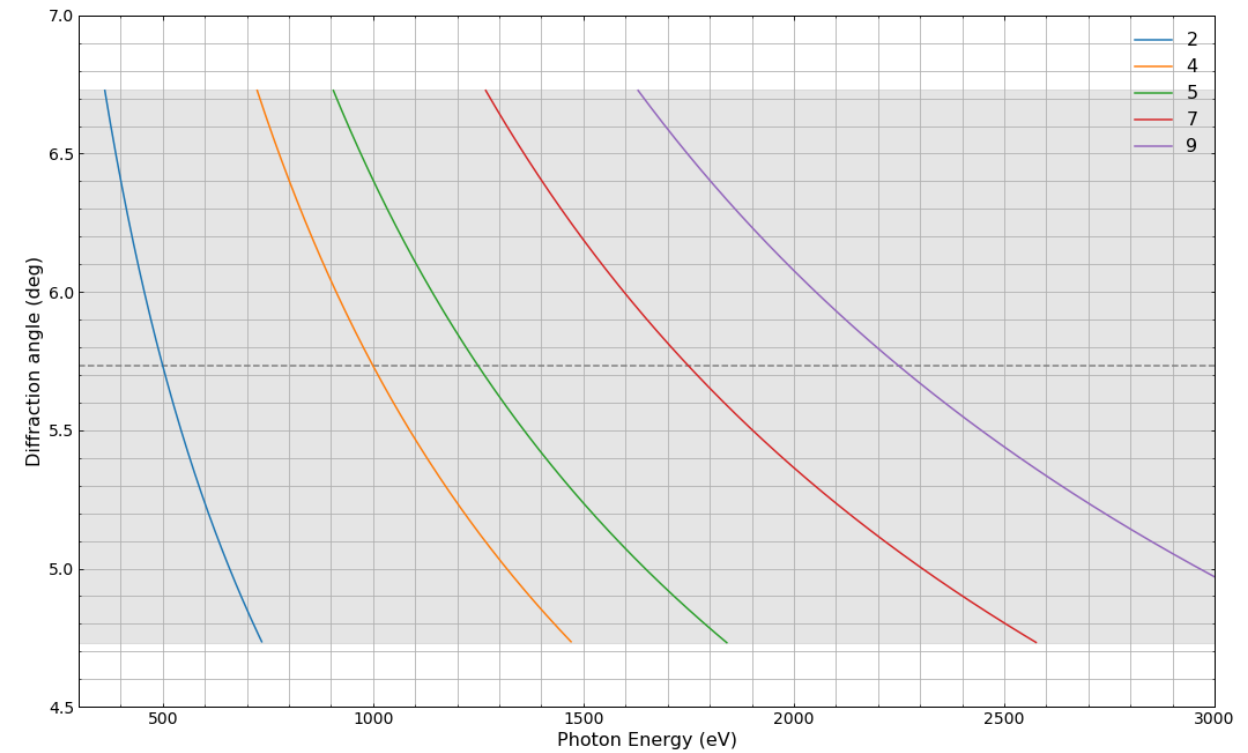
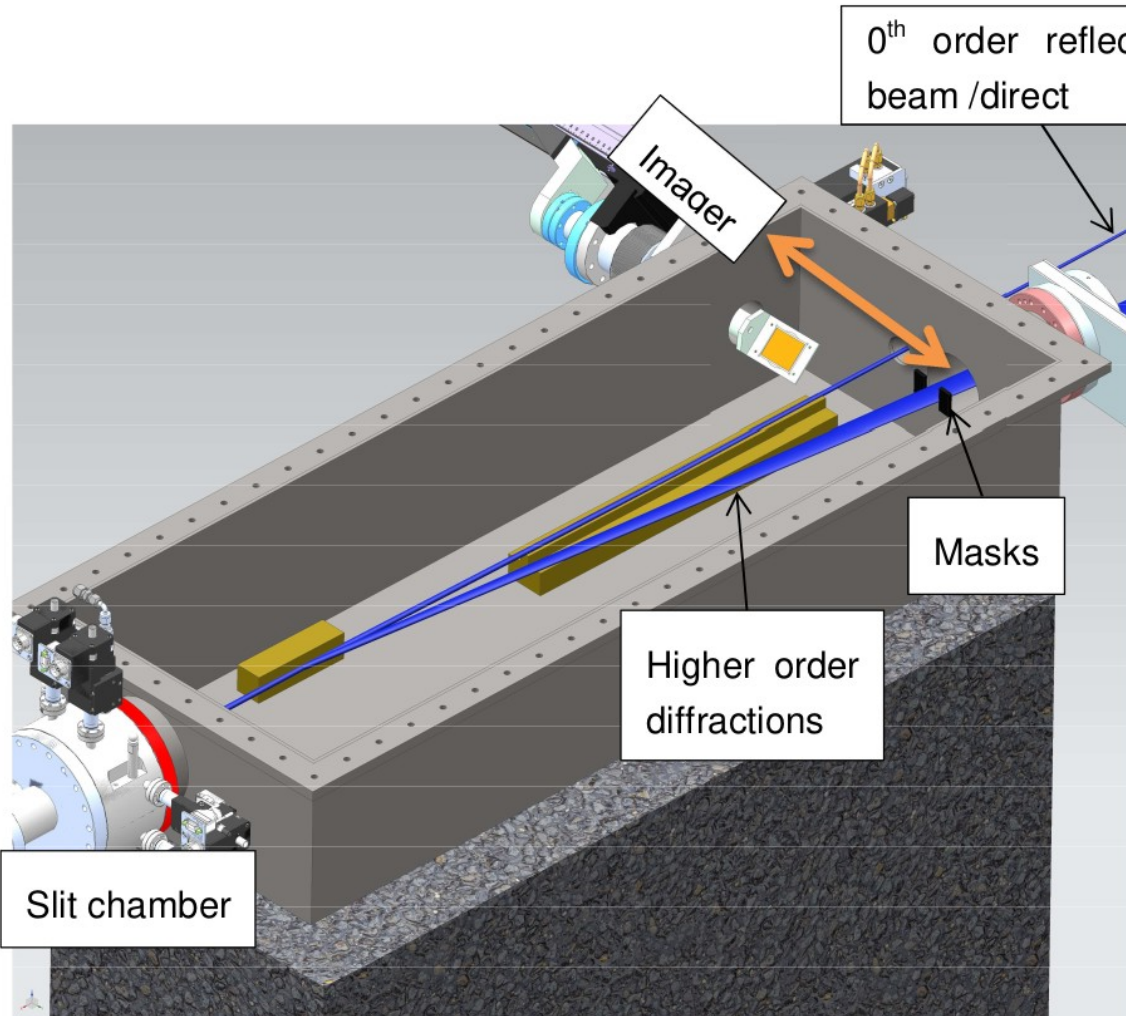
- Pulse arrival monitor to measure temporal overlap of FEL and laser.
- Based on spectral encoding.
- Target: Si_3N_4 or YAG.
- Measured arrival jitter < 10 fs (RMS) (convolution of FEL jitter and PAM accuracy).
- Uses second laser arm split from main laser beam.
- Cannot measure long term drifts of FEL arrival time.
- Only usable in limited parameter space (FEL energy and pulse energy, laser power, repetition rate).
- We are looking into alternatives and further improvements.

FEL spectrum: re-focusing optics and spectrometer



- Currently we have to use the SASE3 monochromator for analyzing the SASE spectrum.
- Upgrade in 2022: spectrometer for online monitoring
- VLS grating properties:
 - Elliptical surface.
 - Clear aperture of 140 mm x 15 mm.
 - Later upgrade to 500 mm long grating possible.
 - Incidence angle of 9 mrad.
 - Groove density 1000 l/mm
- 0 Order to re-focusing, higher orders to spectrometer detector.

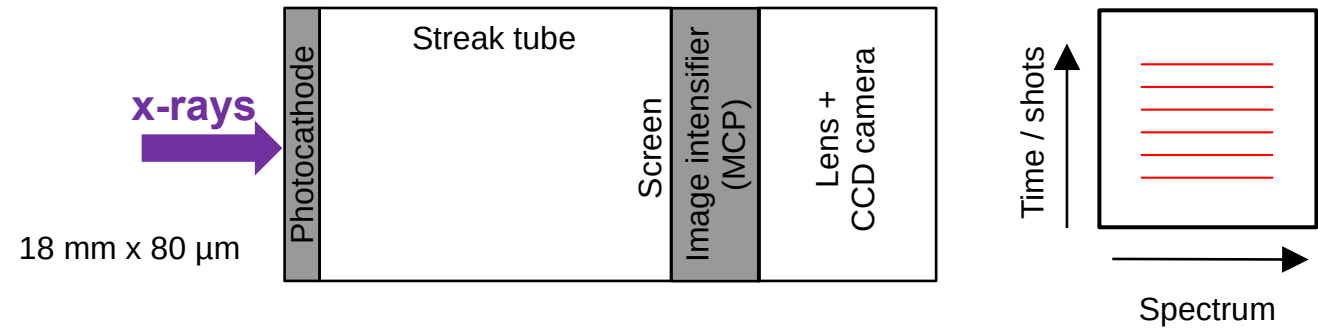
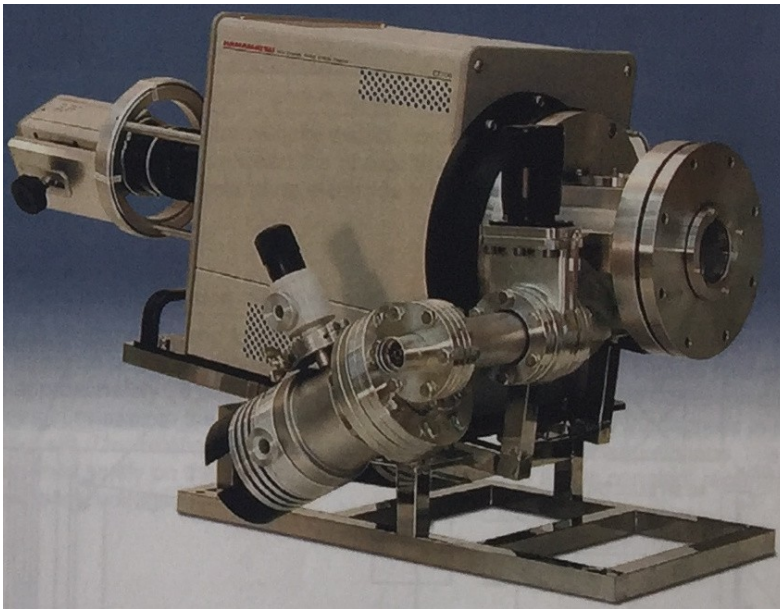
FEL spectrum: re-focusing optics and spectrometer



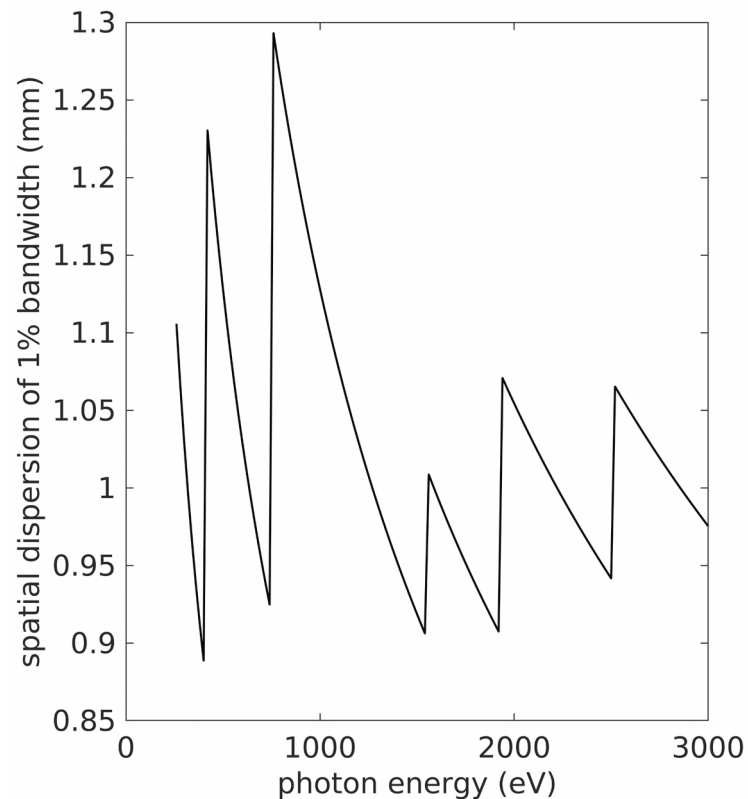
FEL spectrum: streak camera

Hamamatsu X-ray Streak Camera (C7700)

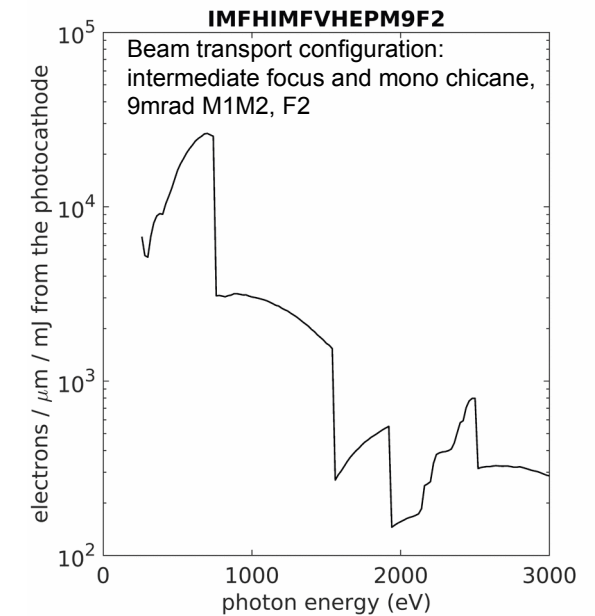
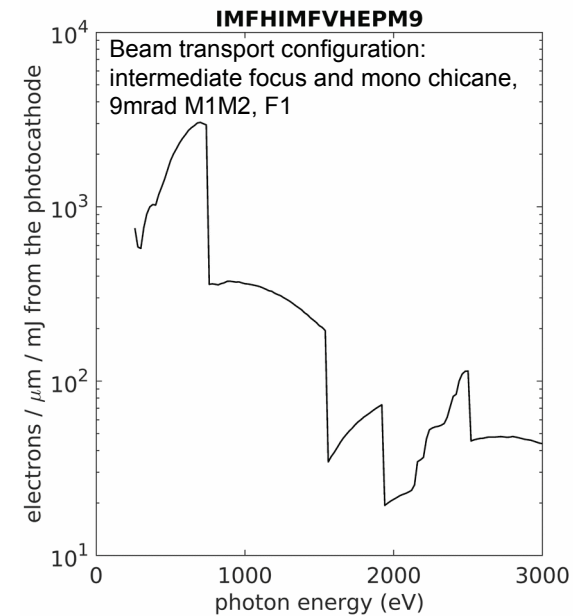
- Enables pulse-resolved measurements.
- Spatial resolution about 25 μm .



FEL spectrum: expected performance



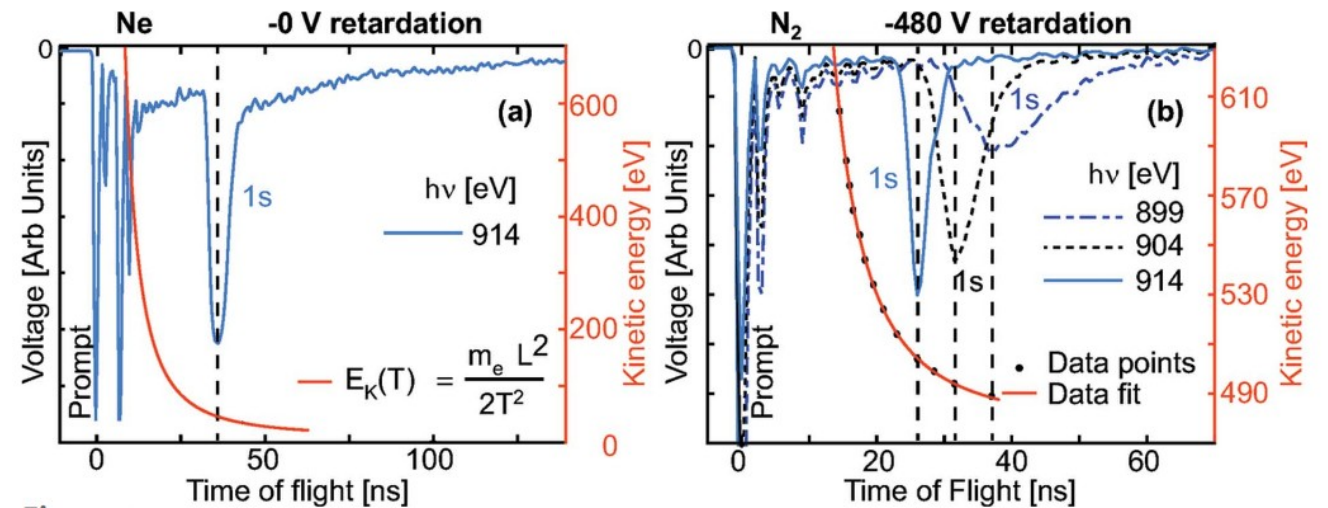
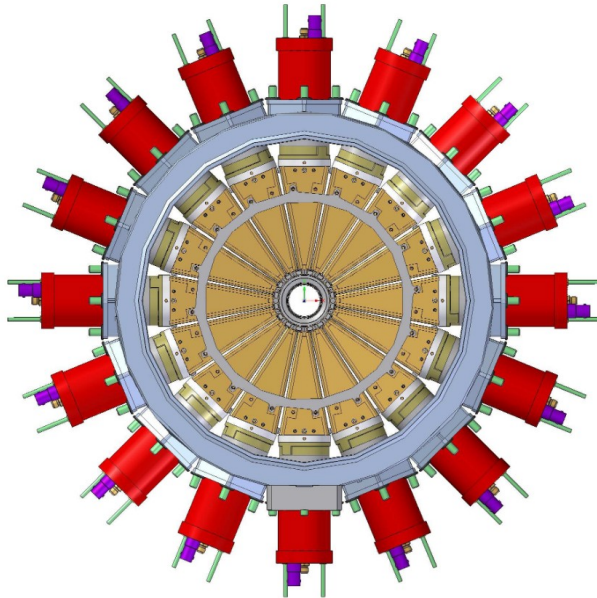
Spectral **resolution of $E/\Delta E \sim 2000$** ,
using an effective pixel size of $25 \mu\text{m}$.



Includes beamtransport transmission, photocathode size and efficiency, grating efficiency. The streak camera has a gain factor of ~ 1000 on top of these numbers.

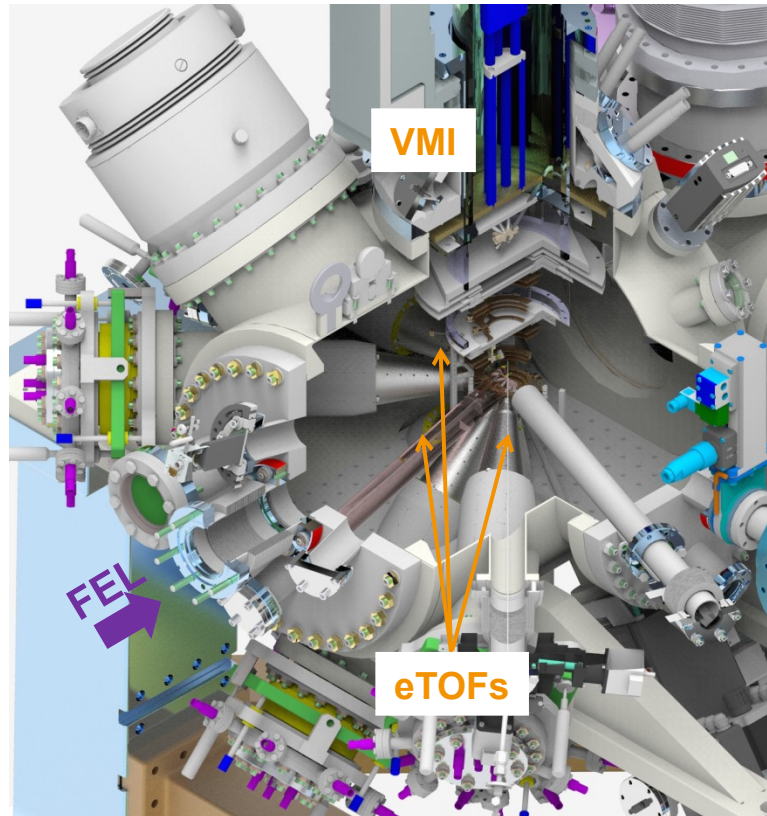
→ **single shot capability**

Photo Electron Spectrometer (PES) at SASE3



- Array of 16 electron time-of-flight spectrometers.
- Located in the SASE3 tunnel upstream of mirrors.
- Can be used to record pulse-resolved FEL spectrum measuring photo-electron spectra.
- Resolution about 0.1%

AQS spectrometers



- Electron Time-of-Flight spectrometers (also for ions)
 - Angle resolved: 6 ToFs at different angles
 - Acceptance of 0.14% of 4pi
 - Electron energy range: 5 eV – 5000 eV
 - Electron energy resolution $E/\Delta E > 10000$ at 811 eV
- Velocity Map Imaging Spectrometer (VMI)
 - For electrons or ions
 - 4pi acceptance
 - Energy resolution of few percent
- FEL size about 1 mm in F1 when focusing in F1'

Thanks to everybody

SQS Instrument team

Michael Meyer

Thomas Baumann

Rebecca Boll

Alberto De Fanis

Simon Dold

Till Jahnke (Uni Frankfurt)

Michael Lüdeke

Tommaso Mazza

Terry Mullins

Jacobo Montaña

Yevheniy Ovcharenko

Nils Rennhack

Daniel Rivas

Sergey Usenko

Aljoscha Rörig (PhD student)

Aswan Kishore Das Alangattuthodi (PhD student)

Sharath Sasikumar (PhD student)

Moto Togawa (PhD student)

Rene Wagner (PhD student)

Maria Peter

Markus Ilchen (now DESY)

Valerija Music (now DESY)

Philipp Schmidt (now DA)

Patrik Grychtol (now SXP)

European XFEL

Jan Grünert

Andreas Koch

Joakim Laksman

Jia Liu

Theophilos Maltezopoulos

and many more...

DESY

Kai Tiedtke

Fini Jastrow

Susanne Bonfigt

Yilmaz Bican

Barbara Keitel

Elke Pjönjes-Palm

and many more...

IFNANO Göttingen

Klaus Mann

Bernd Schäfer

Jens-Oliver Dette

