# Laser Infrastructure and Timing Diagnostics for the SQS Scientific Instrument

Patrik Grychtol
Scientific Instrument SQS
Instrument Scientist
SQS Early User Workshop

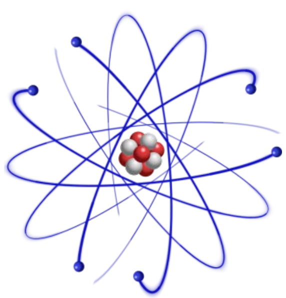
Schenefeld, 12.02.2018

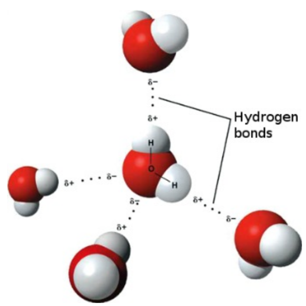
# Content

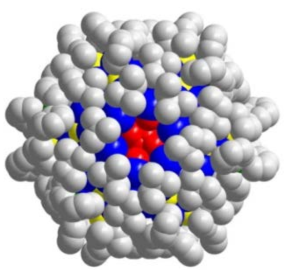
# Scientific Scope of the SQS Scientific Instrument

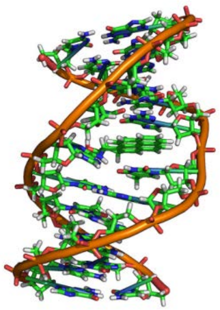
**Dynamic investigations of light-matter interactions in atoms, molecules and clusters, such as**

- Non-linear phenomena
- Atomic multi-photon ionization
- Molecular dissociation dynamics
- Multi-particle coincidence spectroscopy
- Imaging of complex molecules and nano-scale objects

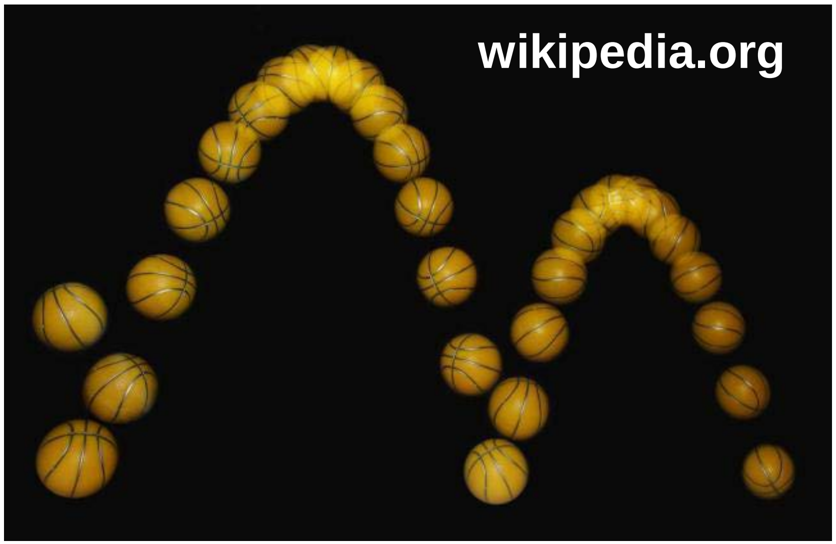


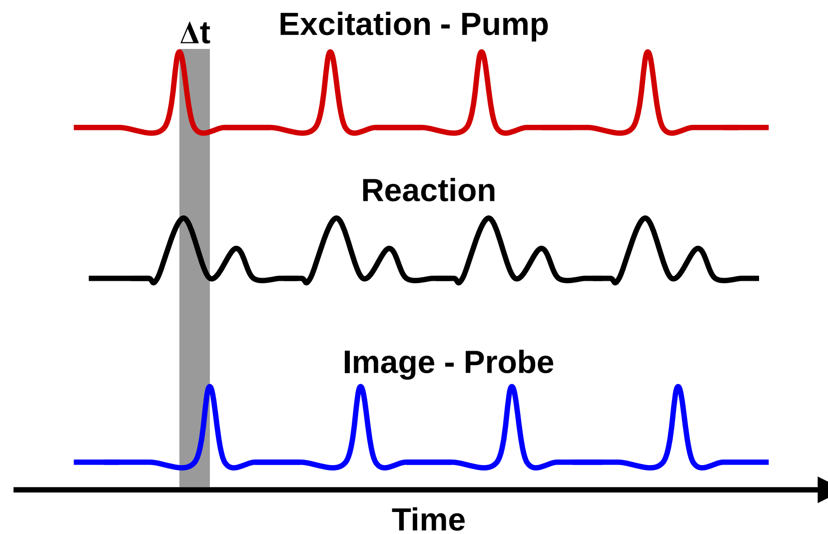


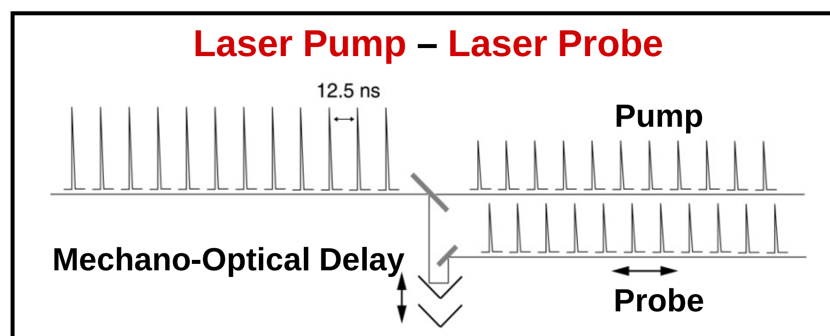


# Time-Resolved “Pump-Probe” Experiments: Capturing reversible processes stroboscopically



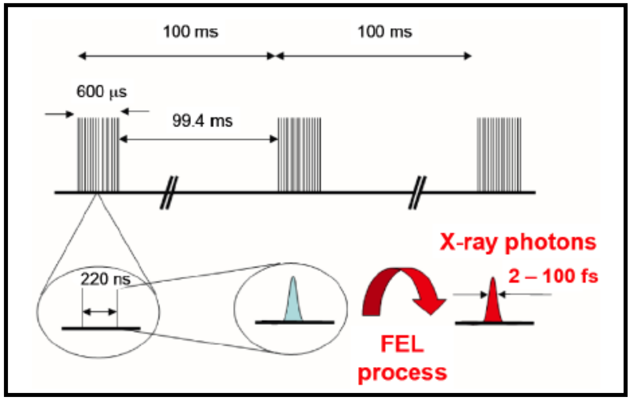




**Accessing ultrafast, electronic time scales with pulsed femtosecond laser sources in the visible and near infrared spectral range**



# Pump-Probe Laser Requirements

**XFEL Pulse Train: Up to 2700 electron bunches every 0.1s → effective repetition rate 27 kHz**




- Match XFEL pulse train: 10Hz burst mode & 0 - 4.5 MHz
- Ultrafast 800nm laser (down to fs range with few mJ's energy)
- Arbitrary pulse pattern selection
- Frequency/wavelength conversion from THz to UV

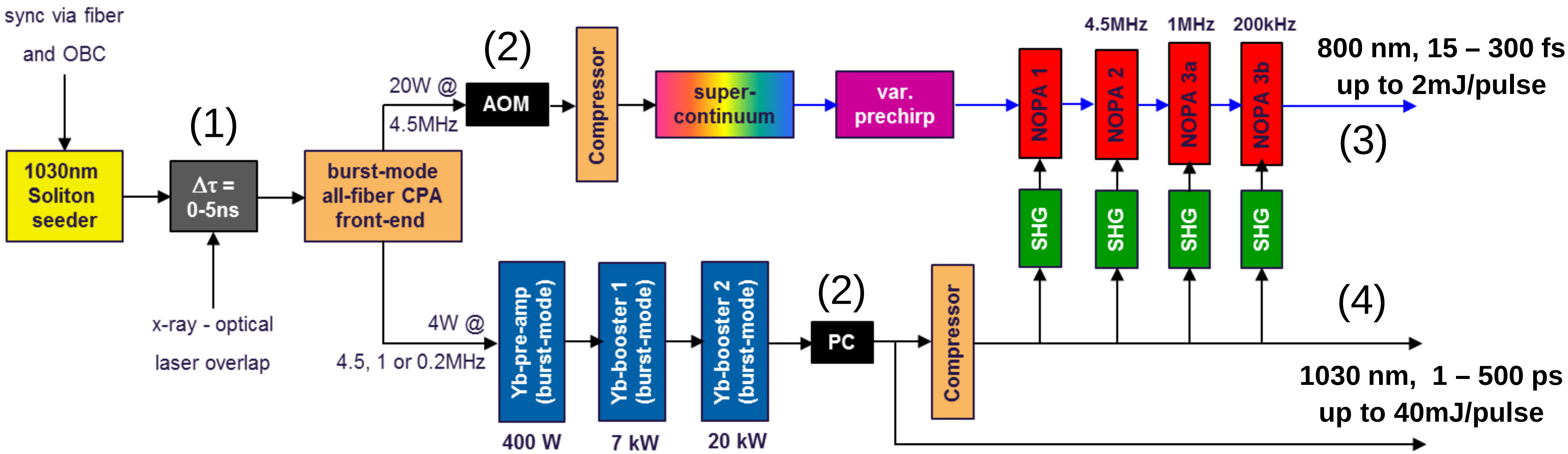
**Development of a versatile laser system by XFEL laser group – from left to right:**

Guido Palmer, Laurens Wissmann, Martin Kellert, Moritz Emons, Max Lederer (PI),
Kai Kruse, Gerd Priebe, Jinxiong Wang, Ulrike Wegner, Mikhail Pergament



Pergament *et al.*, Optics Express **22**, 22202 (2014) & **24**, 29349 (2016).

# Non-collinear Optical Parametric Amplifier (NOPA)




- Time zero overlap of XFEL and optical laser (1)
- Pulse on demand with Acousto-Optical-Modulator (AOM) and Pockels Cell (PC) (2)
- Ultrafast fs excitation: Output of 800 nm, 15 - 300 fs and up to 2mJ/pulse (3)
- Intense ps excitations: Output of 1030 nm, 1 - 500 ps and up to 40mJ/pulse (4)
- Laser commissioning scheduled to begin **Q2-2019**



Pergament *et al.*, Optics Express **22**, 22202 (2014) & **24**, 29349 (2016).

# INTERIM SOLUTION: Fiber-based pump probe laser for day 1

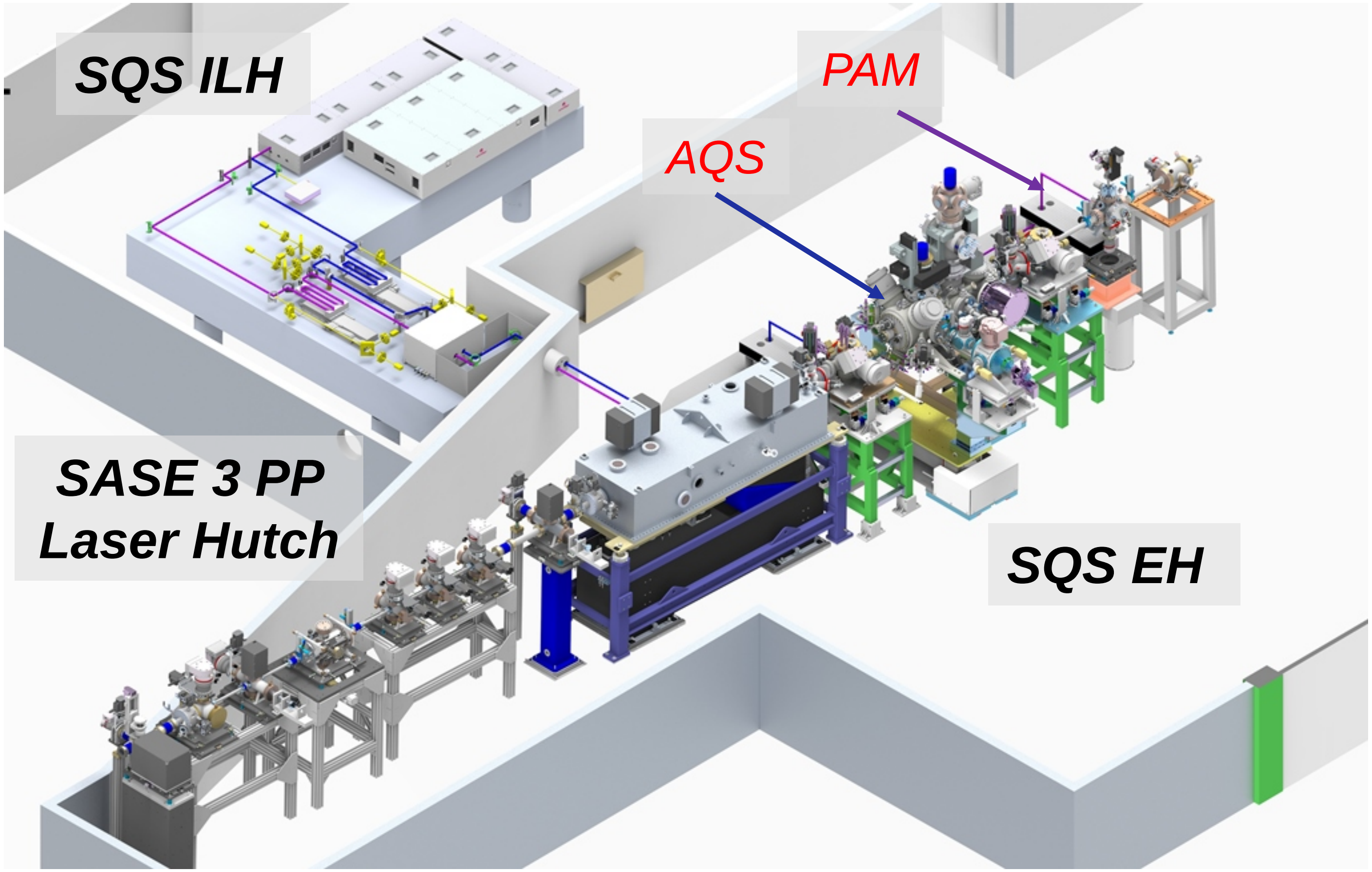

**Active Fiber Systems 200W laser amplifier:**

- Delivering 1030nm, 300fs, 2mJ pulses @ 100kHz!
- Continuously adjustable repetition rate up to 20MHz.
- Same seed oscillator as NOPA, thus synchronizable.
- Installation planned for **Q3-2018**.

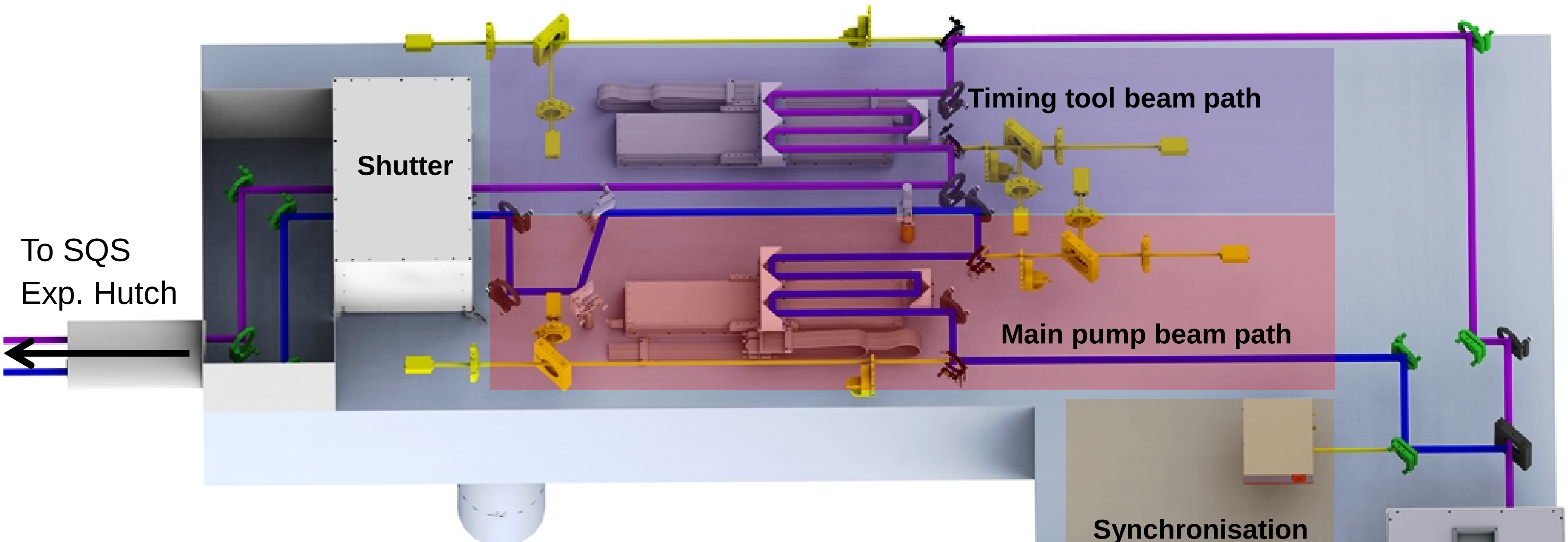
**http://www.afs-jena.de/**

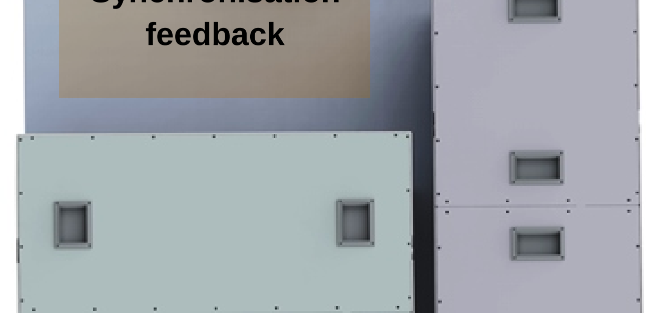
# PP laser infrastructure at SASE 3 for the SQS instrument

- **Overview of the laser beam propagation from the instrument laser hutch (ILH) to the experimental hutch (EH) for day 1 operation.**



# Laser beam in the SQS instrument laser hutch



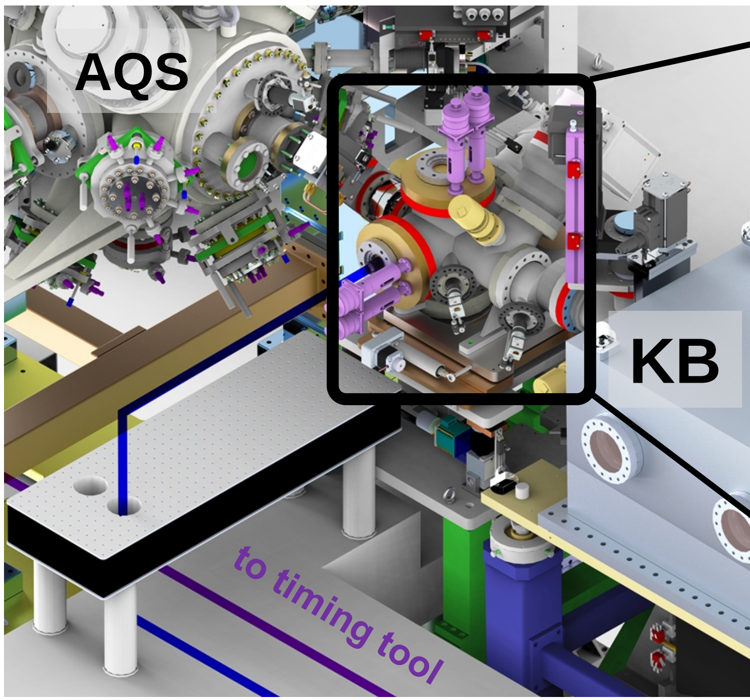



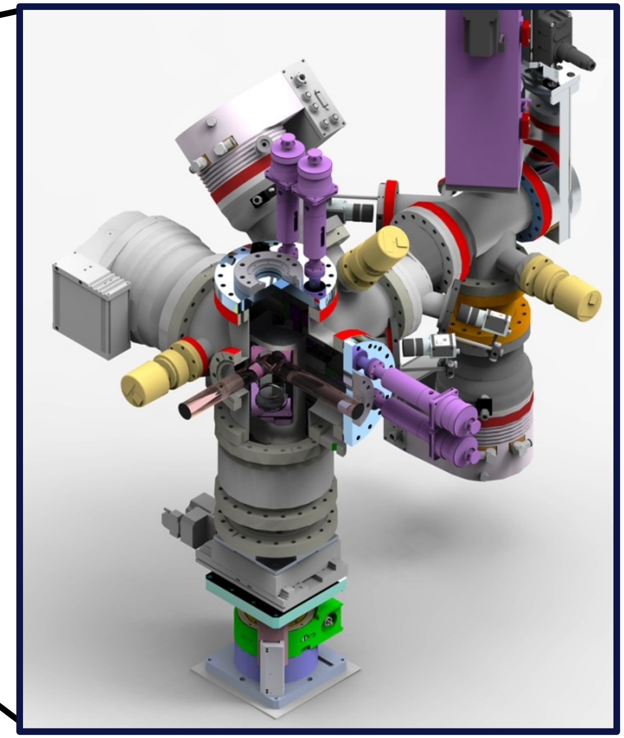
## Active Fiber Systems 200W laser amplifier:

- Delivering 1030nm, 300fs, 2mJ pulses @ 100kHz!
- Continuously adjustable repetition rate up to 20MHz.
- Same seed oscillator as NOPA, thus synchronizable.
- Installation planned for **Q3-2018**.

http://www.afs-jena.de/

# Laser beam in the SQS experimental hutch

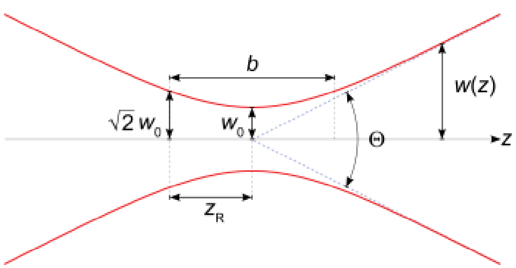


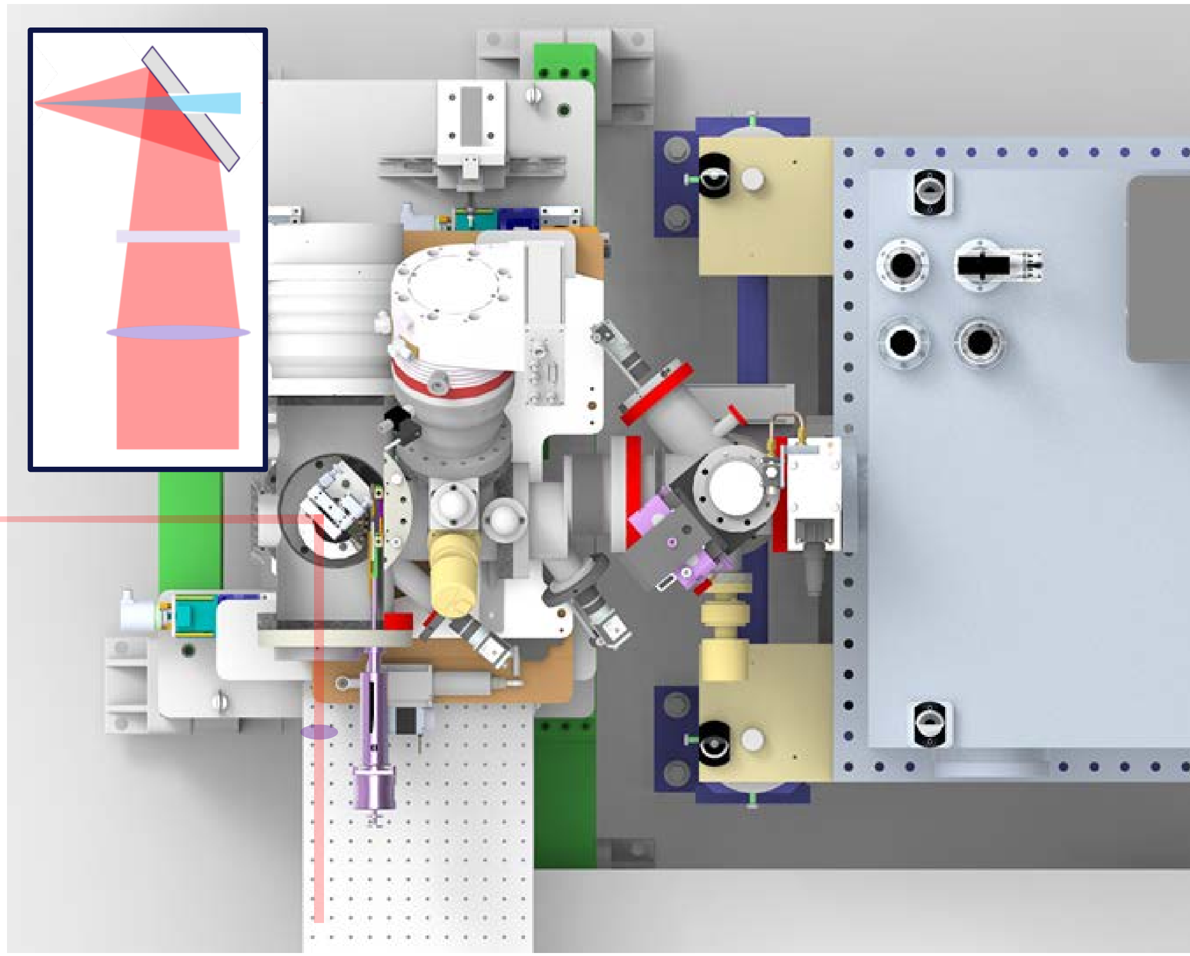



**Laser in-coupling vacuum vessel**

- UHV compatible mirror mounts with piezo actuators
- Stiff mirror mount holder
- Mechanical decoupling bellow
- XY out-of-vacuum precision positioning coupled to optical table

# Laser In-Coupling (LIC) unit for the SQS instrument



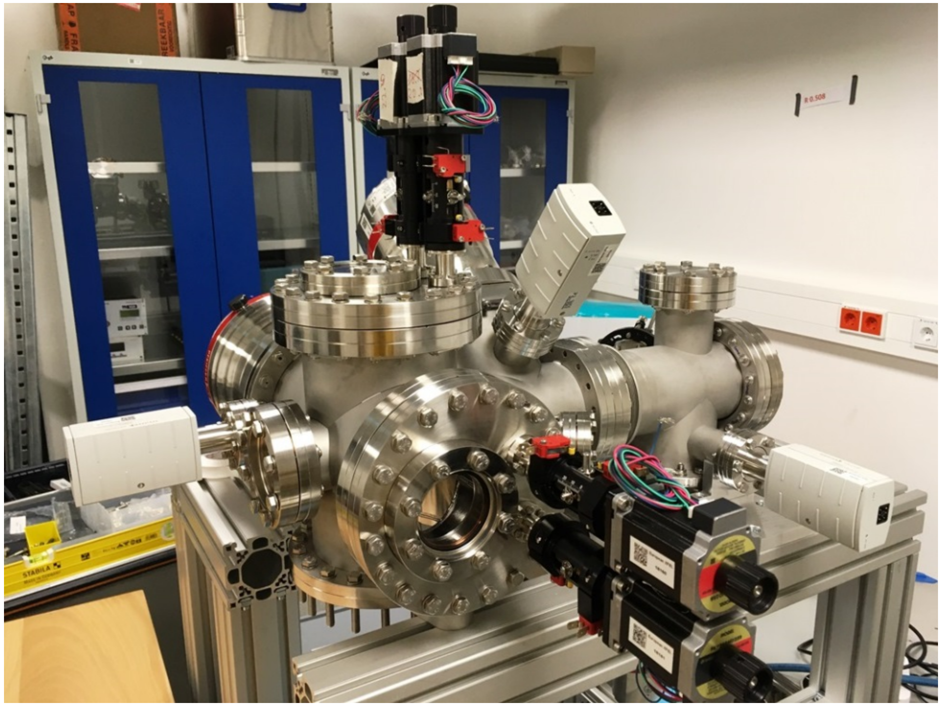
$f_l$

**Focusing with external lens**
**f = 1.4m**
**$w_0$ = 30 µm ($1/e^2$)**
**$I_{peak}$ = $3.5 \times 10^{14}$ W/cm²/mJ**

# Status of the Laser In-Coupling Unit

**Status of the LIC for the AQS instrument:**
- Assembly of core components.
- Electric test of motors.

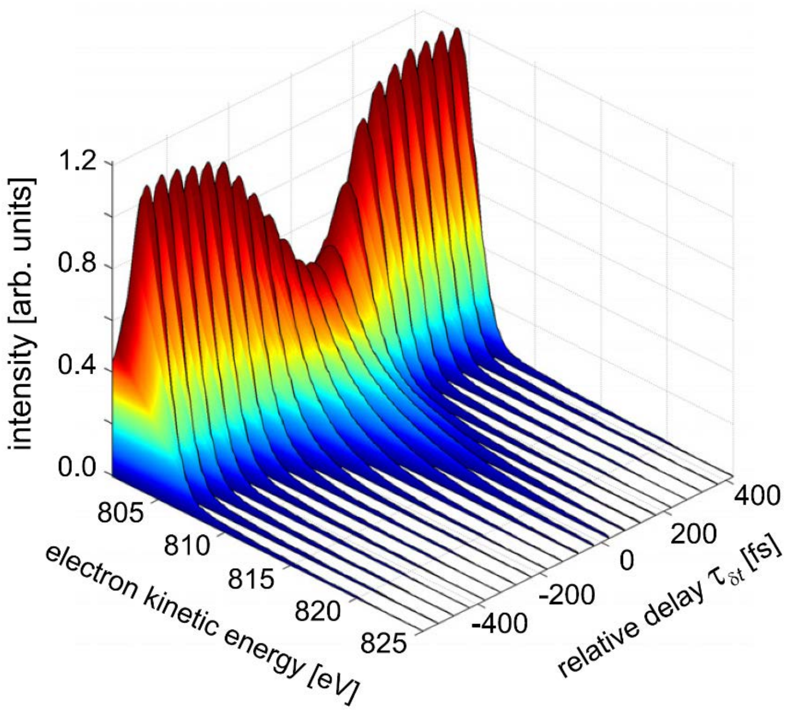
**Next steps:**
- Test of vacuum.
- Assembly of intermediate positioning stage.



# Timing Diagnostics: PP Laser and XFEL Synchronisation

**Laser & X-ray Jitter:**

- Current Jitter with RF Synchronization at PP laser position is approx. 50-70 fs.
- Quantifying *relative* jitter at sample position by laser assisted Auger decay.
- Quantifying *absolute* jitter with timing diagnostics employing spectral encoding.



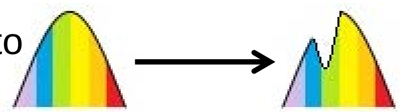

**Laser Assisted Auger Decay (LAAD) in Neon @ LCLS**

Düsterer *et al.*, New Journal of Physics **13**, 093024 (2011).

# Timing Diagnostics: Spectral/Spatial Encoding

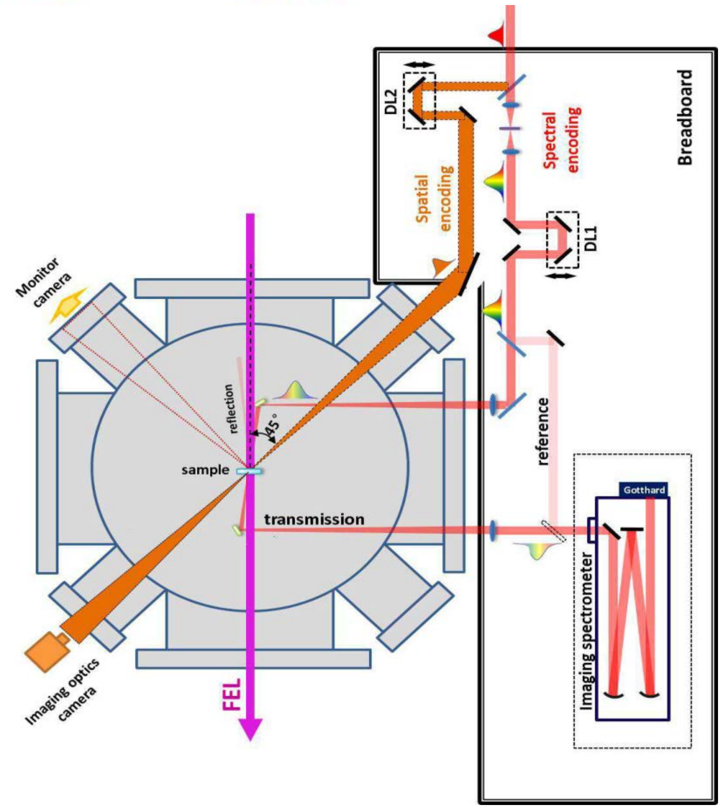
**Measuring the arrival time of the XFEL pulse with respect to the synchronized PP laser**

- X-ray induce changes in the transmission of a membrane to map the relative delay onto a spectral coordinate



- About 25fs RMS resolution within a 3ps window
- High intra-burst rep rate will cause high thermal load on sample membrane at the damage threshold
- Single-shot measurements require high speed CCD camera working at MHz repetition rate
- Well established technique!
- Timing diagnostics is going to be installed in **Q4 2018** to be ready in **Q1 2019**.

Bionta *et al.*, Optics Express **19**, 21855 (2011).



# Status of the pulse arrival time monitor (PAM)

## Status of the PAM:

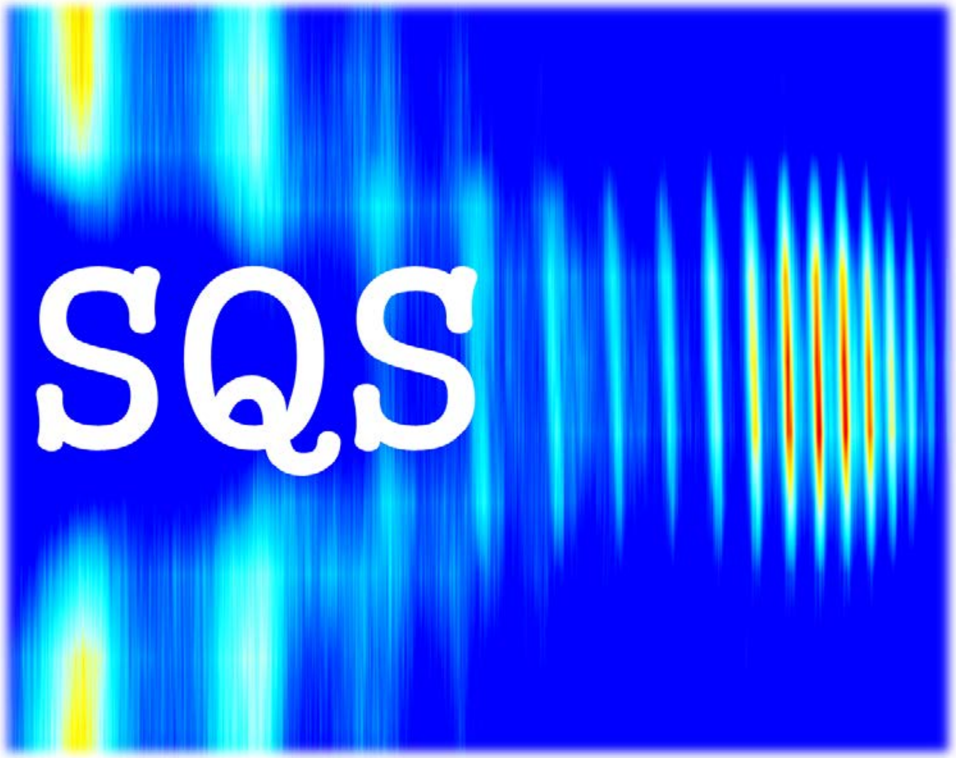
- Core components assembled.
- Electric test of motors.
- Test of vacuum.

# Summary

- Final:NOPA commissioning to begin in **Q2 2019** (800nm, 15fs, 2mJ & 1030nm, 1ps, 40mJ, @ 100kHz ).
- Day 1: INTERIM fiber-baser PP laser is going to be installed in **Q3 2018** (1030nm, 300fs, 2mJ @ 100kHz ).
  - Commissioning planned for **Q4 2018**.
  - Ready for user operation planned for **Q1 2019**.
- Focusing conditions allow for tight focusing, *i.e.* $w_{focus}$ = 30 µm resulting in $I_{peak}$ = 3.5x10$^{14}$ W/cm$^2$ **per mJ**.
- Timing diagnostics (LAAD / PAM) is going to be installed in **Q4 2018** to be ready in **Q1 2019**.

| Set point | $f_{rep}$ [MHz] | $E_{pulse}$ [mJ] | Focus Intensity [W/cm$^2$] | Estimated Jitter |
|---|---|---|---|---|
| 1 | 1 | 0.2 | 7 x 10$^{13}$ | > 50 fs |
| 2 | 0.5 | 0.4 | 1.4 x 10$^{14}$ | |
| 3 | 0.1 | 2 | 7 x 10$^{14}$ | |

# Acknowledgments: Thank you!




**The SQS Team:**

- Alexander Achner
- Alberto De Fanis
- Thomas Baumann
- Rebecca Boll
- Sascha Deinert
- Patrik Grychtol
- Markus Ilchen
- Tommaso Mazza
- Michael Meyer
- Jacobo Montaño
- Yevheniy Ovcharenko
- Nils Rennhack
- Rene Wagner
- Haiou Zhang (Alumni)
- Pawel Ziołkowski

**Diagnostics:**

- Jia Liu
- Jan Grünert