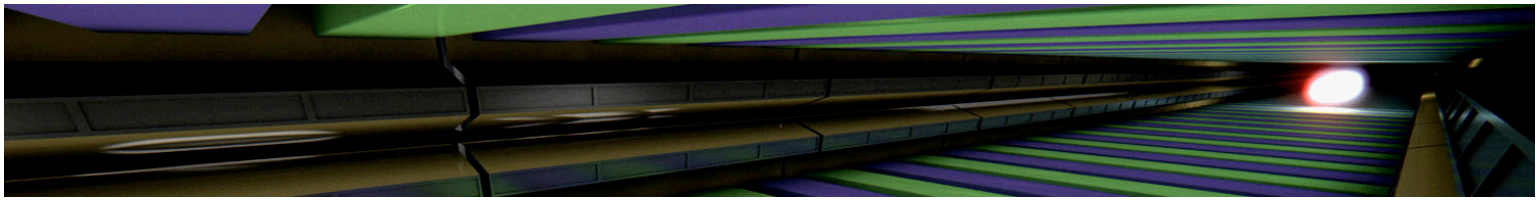


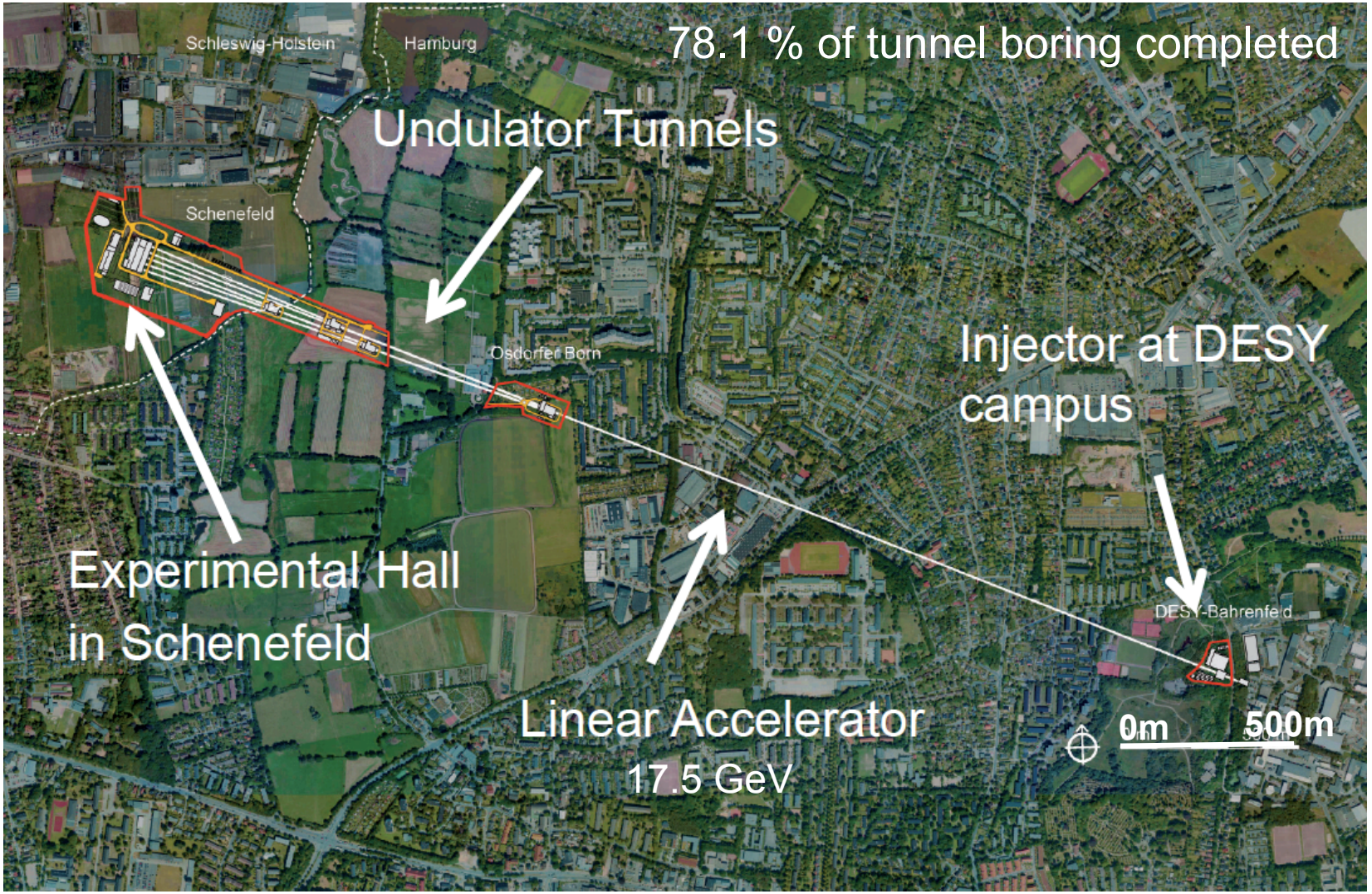
Soft X-Ray Instrumentation at the European XFEL

M. Meyer & S. Molodtsov
European XFEL GmbH

- **Soft X-rays at the European XFEL**
- **Scientific Instruments in the Soft X-ray regime**
  - SQS Scientific Instruments
  - SCS Scientific Instruments
- **Infra-structure**
  - optical laser, diagnostics, add-on equipment, time line

European XFEL

European X-ray Free Electron Laser



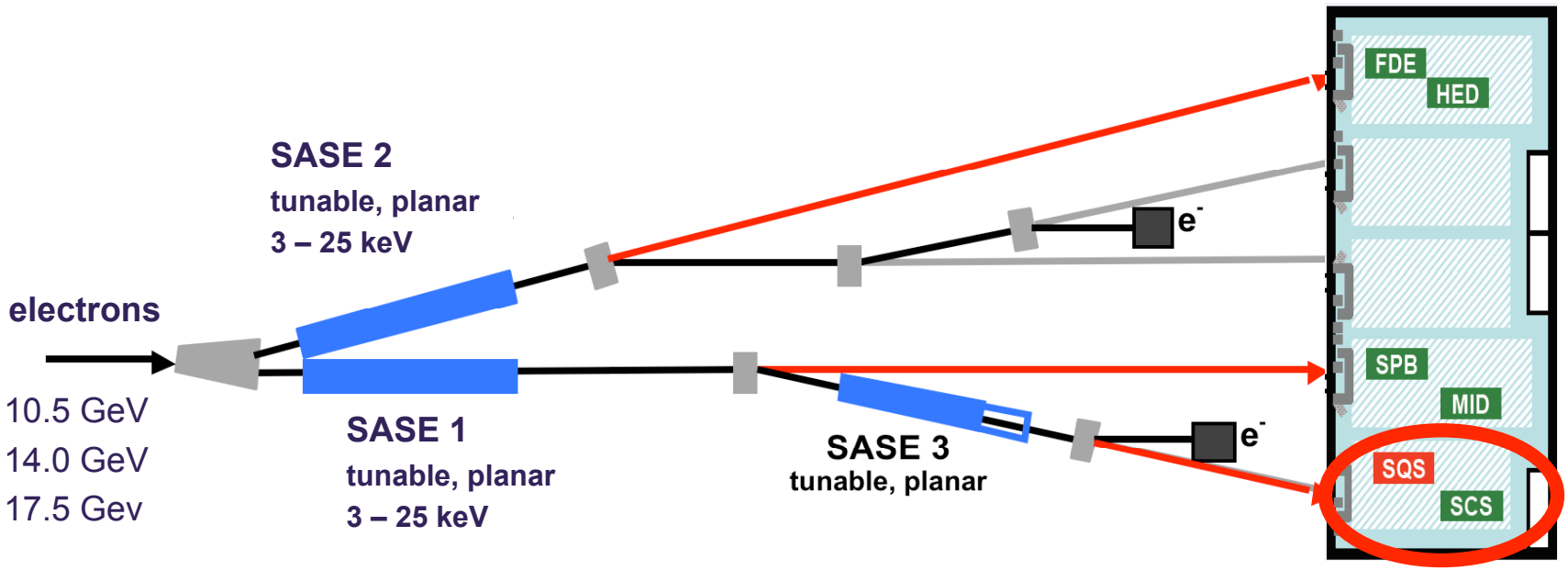
European XFEL

European X-ray Free Electron Laser

European XFEL

Electron and Photon beam transport systems

Undulators at the European XFEL



SASE 3 : 730 – 3000 eV (17.5 GeV)
470 – 2600 eV (14 GeV)
260 – 2000 eV (10.5 GeV)

European XFEL

Les Instruments Scientifiques

SASE 1 / SASE 2

Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules (SPB)

- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.

Materials Imaging & Dynamics (MID)

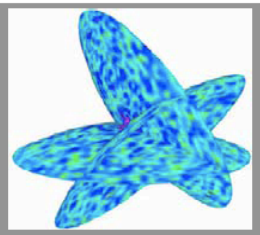
- Structure determination of nano- devices and dynamics at the nanoscale.

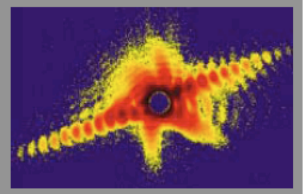
Femtosecond X-ray Experiments (FXE)

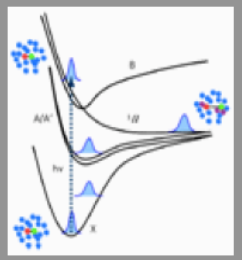
- Time-resolved investigations of the dynamics of solids, liquids, gases

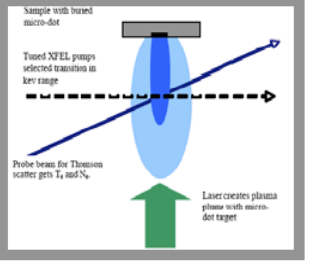
High Energy Density Matter (HED)

- Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas









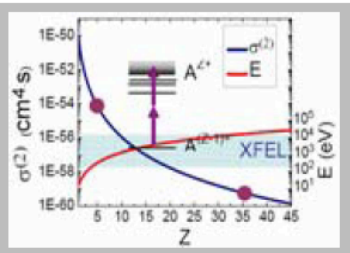
SASE 3

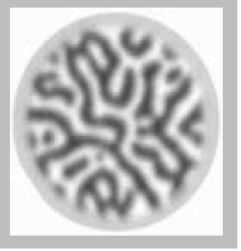
Small Quantum Systems (SQS)

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

Spectroscopy and Coherent Scattering (SCS)

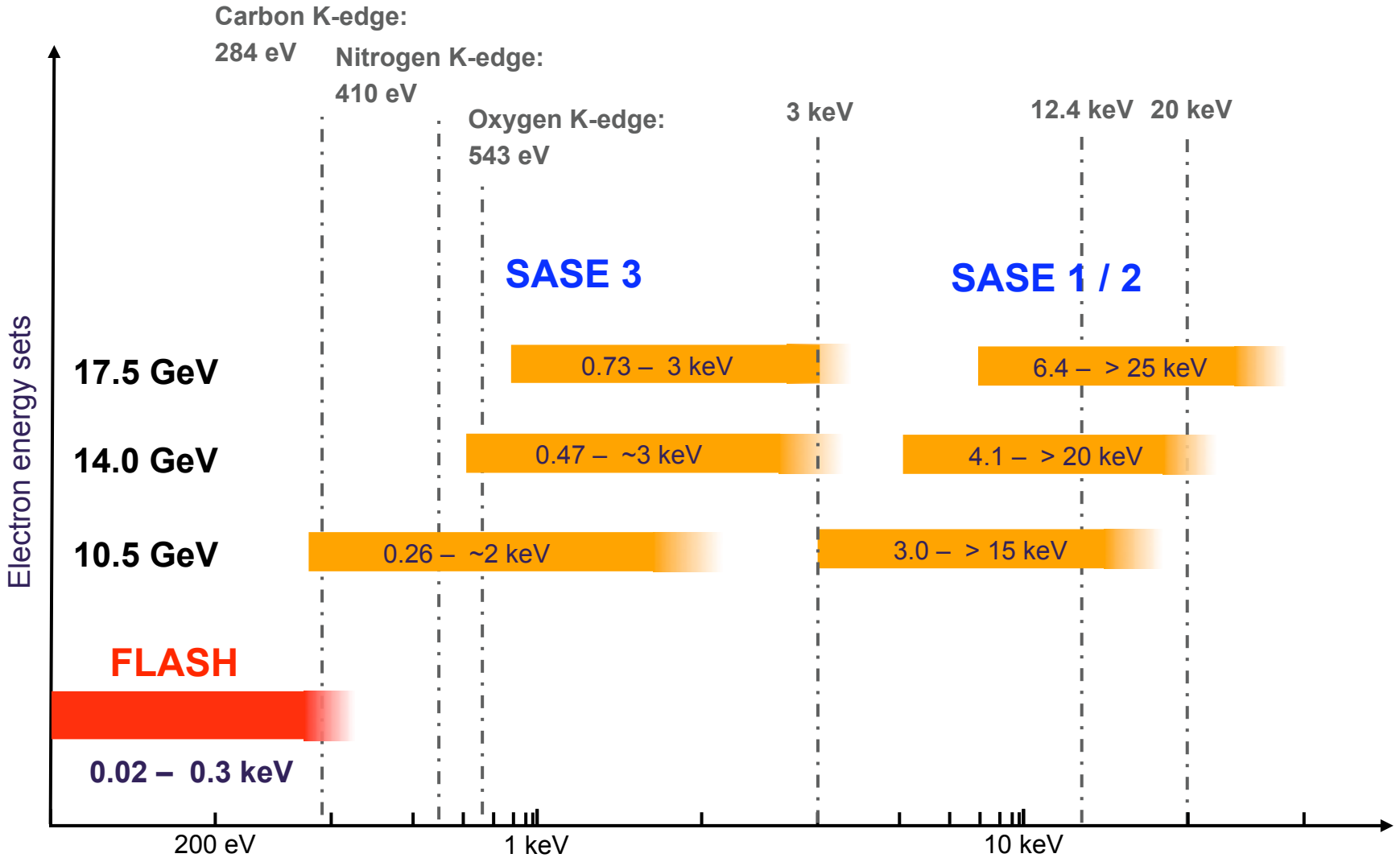
- Structure and dynamics of nano-systems and of non-reproducible biological objects





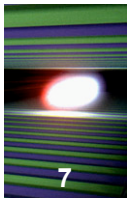
European XFEL

Photon energy ranges



European XFEL

SASE 3 Undulator



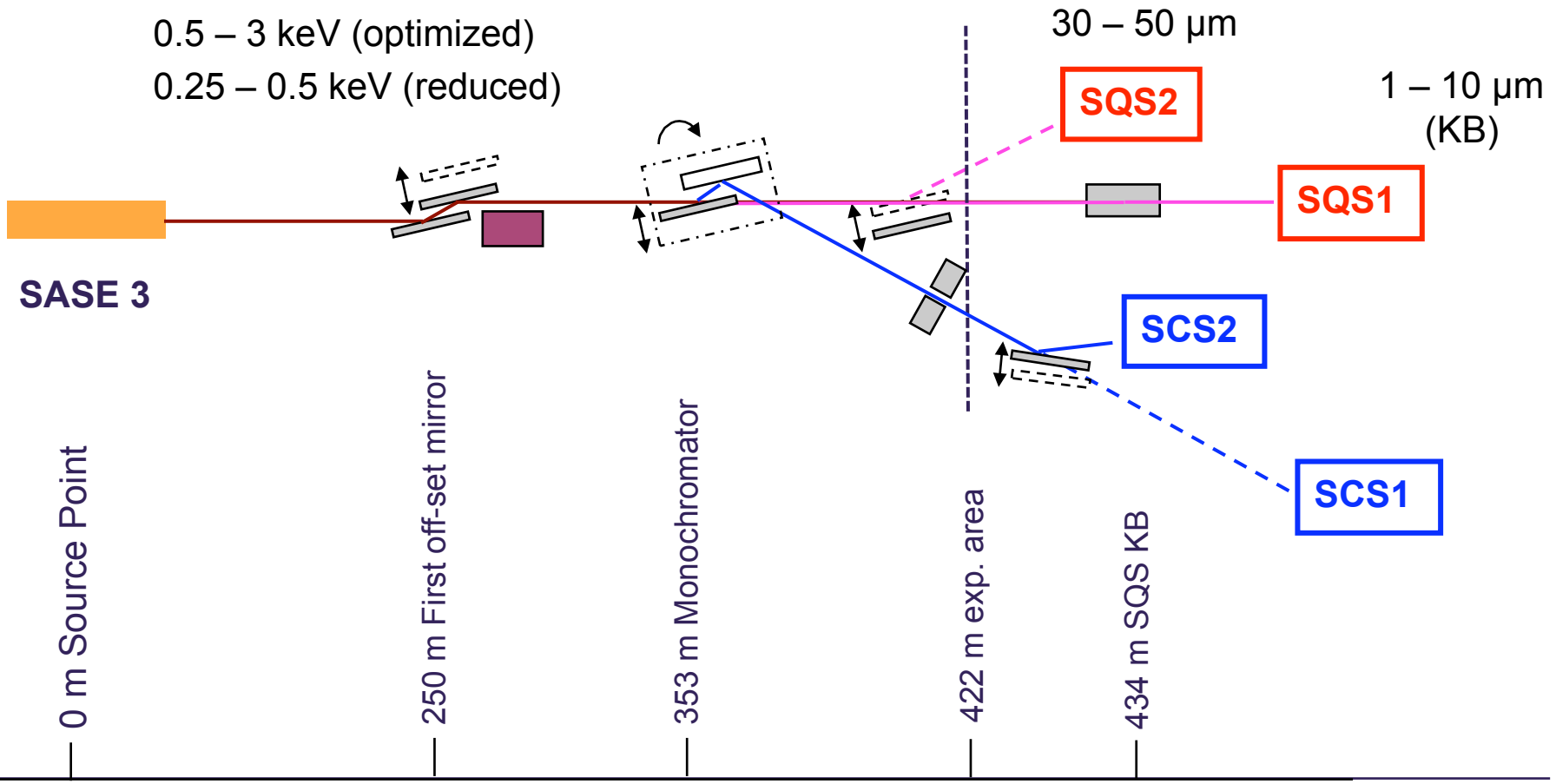
General Soft X-Ray radiation parameters

Pulse widths	**2 – 100 fs**	**Coherence time**	0.3 – 1.8 fs
Pulse energy	**0.2 – 11.0 mJ**	**Bandwidth**	0.25 – 0.7 %
Peak power	50 – 120 GW	**Number of photons**	**0.1 – 2 x 10^{14}**
Average power	3 – 300 W	**Average flux of photons**	0.3 – 5.4 x 10^{18}
Beam size	40 – 80 μm	**Average brilliance**	0.03 – 2.6 x 10^{24}
Rep. rate	**10 Hz (2700 pulses in bunch train)**		

Parameter	Unit					
Bunch charge	pC	20	100	250	500	1000
Pulse duration (FWHM)	fs	2	9	23	43	107

Optical layout of the beam transport system (H. Sinn)

- direct beam → Small Quantum System (SQS)
- monochromatized → Spectroscopy @ Coherent Scattering (SCS)



SQS
"Small Quantum Systems"
Scientific Instrument

SQS – Small Quantum Systems –

Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

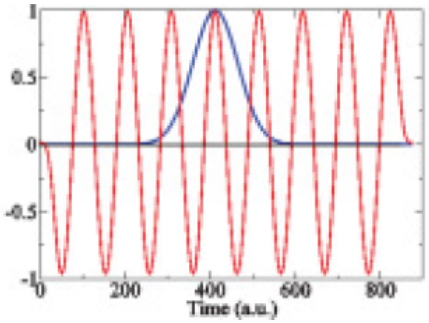
High intensities: $>10^{15}$ W/cm^2	⇨	**Non-linear phenomena, multi-photon**
Short pulses: 2 - 100 fs	⇨	**Ultra-fast dynamics, pump-probe**
High flux $>10^{12}$ photons / pulse $>10^{15}$ photons / sec	⇨	**Extremely dilute targets,** **Processes with small cross section**
Spatial coherence	⇨	**Coherent Diffraction Imaging**
Soft X-Ray photon energies	⇨	**Threshold phenomena** C(1s)=290 eV, N(1s)=410eV, O(1s)=560eV

International Workshop: Aarhus, Denmark, October 29 - 31, 2008
Trieste, Italy, December 16 - 17, 2010

Example: Two-color Pump-Probe

Optically induced electron interferences in the angular distribution

Auger lifetime similar to optical cycle

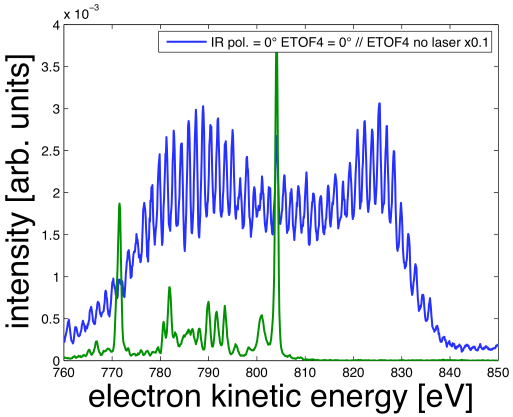


Core hole lifetime **LCLS: 1 keV, 2-5 fs**

τ (Ne 1s) = 2.4fs

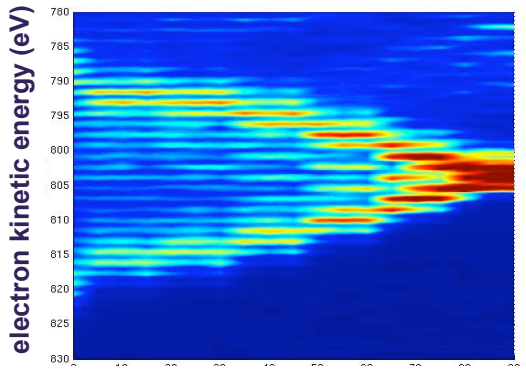
Optical cylce

T (800nm) = 2.6fs



HR - Electron spectroscopy

Ne



Angular distribution

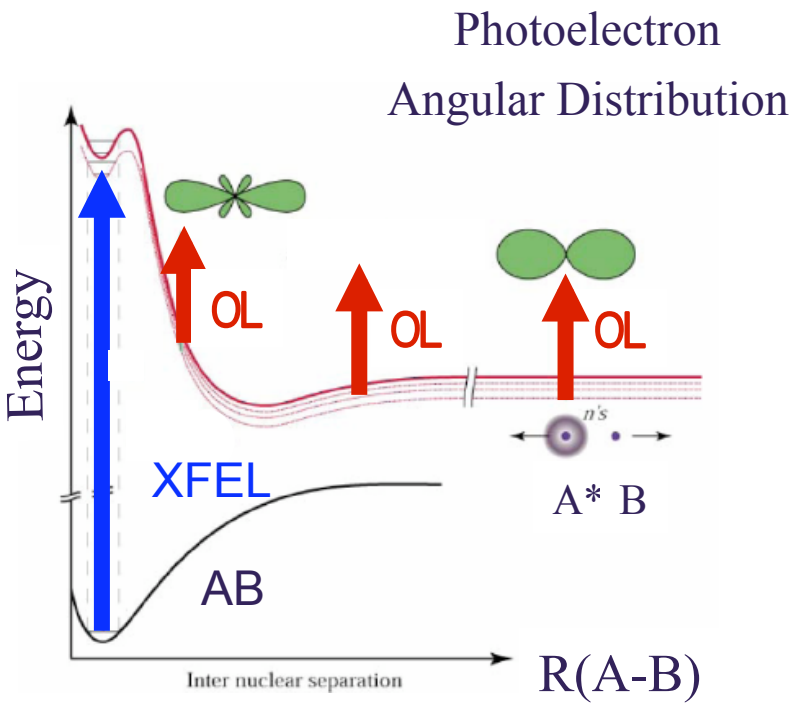
Meyer et al., LCLS_Nov/2010

A.K. Kazansky, N.M. Kabachnik, JPB 43, 035601 (2010)

European XFEL

Ultra-fast processes

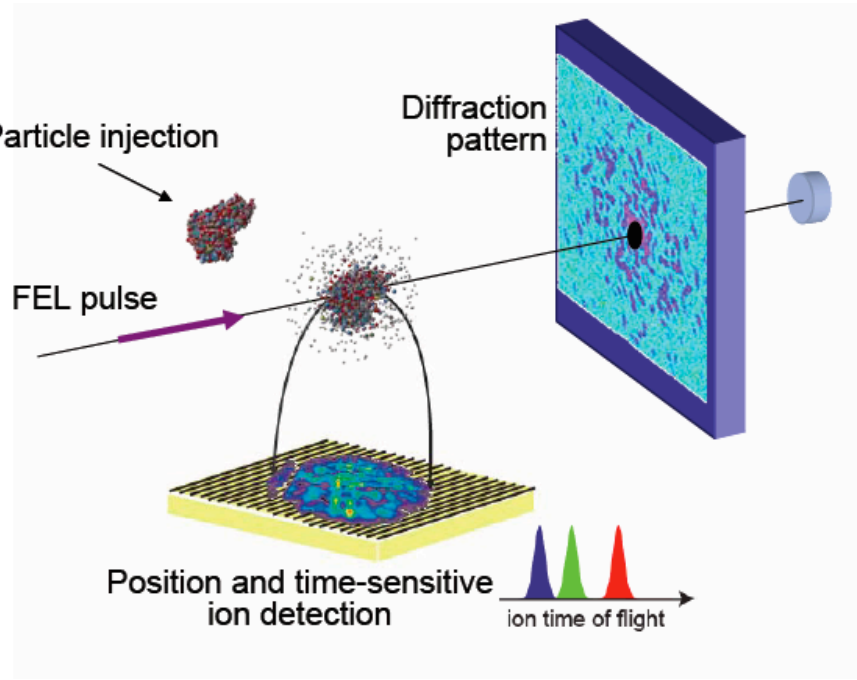
Diatomic molecules



molecules "fixed-in-space"

Complex Molecules

Ullrich et al. , ASG MPI Heidelberg



complete characterization = multiple coincidences

coincidences: ➡ high (> kHz) repetition rate

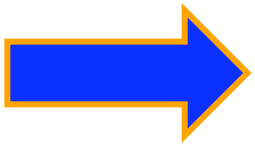
SQS end-station

Gas phase targets:

- Molecular beam (atoms & molecules)
  supersonic jet, effusive jet, cells
- Cluster beam (mass-selected)
- Nano-particles, Nano-crystals,
  bio-molecules
  (aerosols, liquid jet)

Particle analyzers:

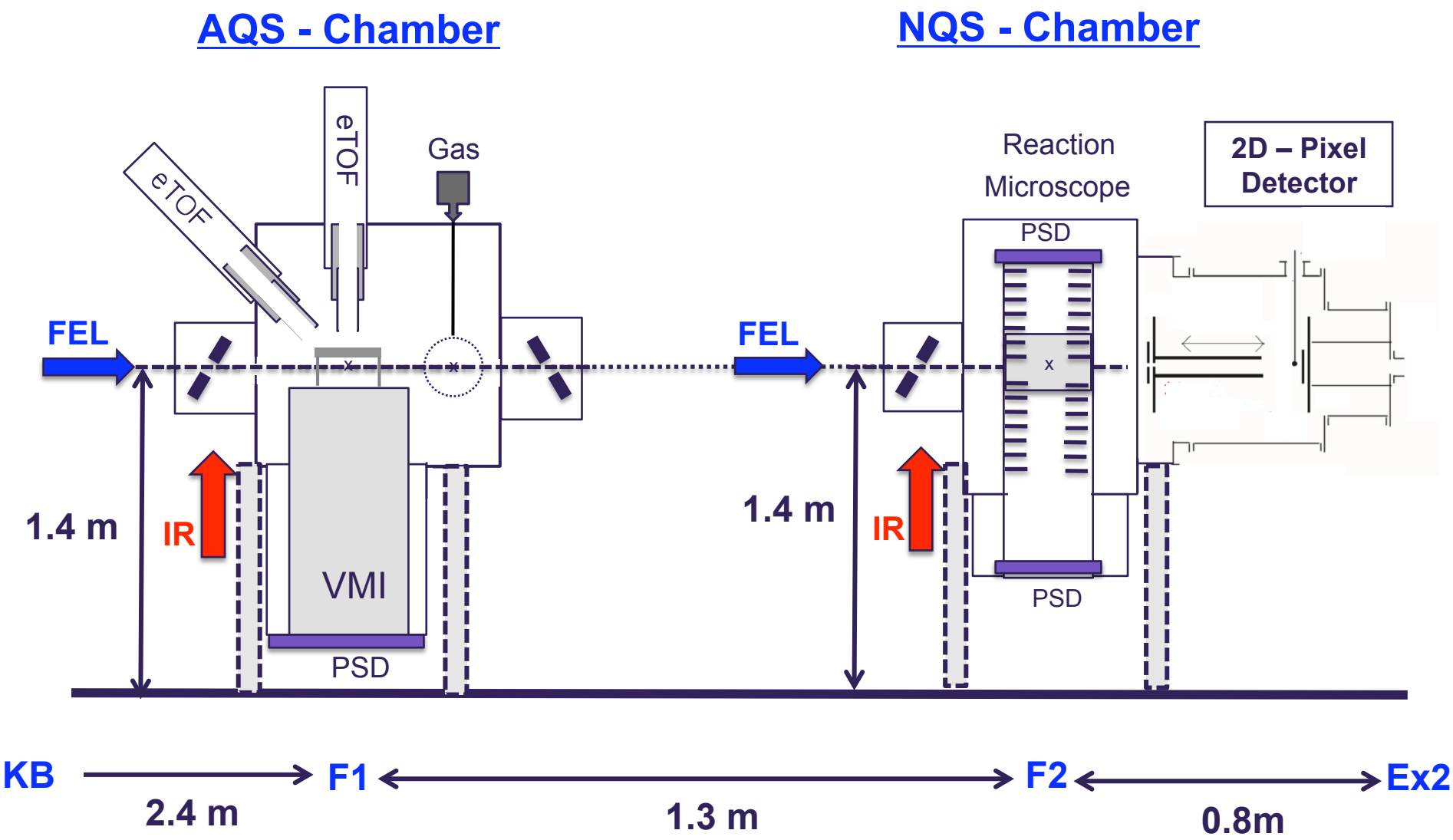
- High-resolution TOFs
- High resolution X-ray spectrometer
- Magnetic Bottle Electron Spectrometer
- Velocity-Map-Imaging
- Reaction Microscope
- Thomson Parabola



- **AQS** (Atomic-like Quantum Systems) Chamber
- **NQS** (Nano-size Quantum Systems) Chamber

European XFEL

SQS end-station

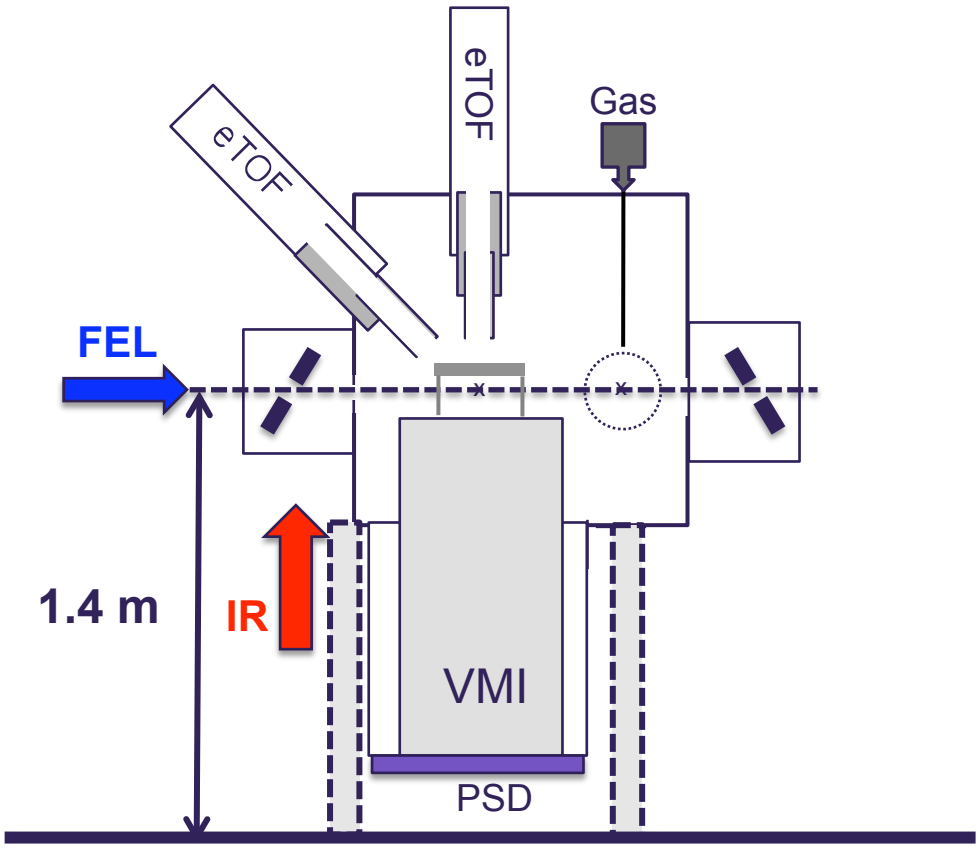


European XFEL

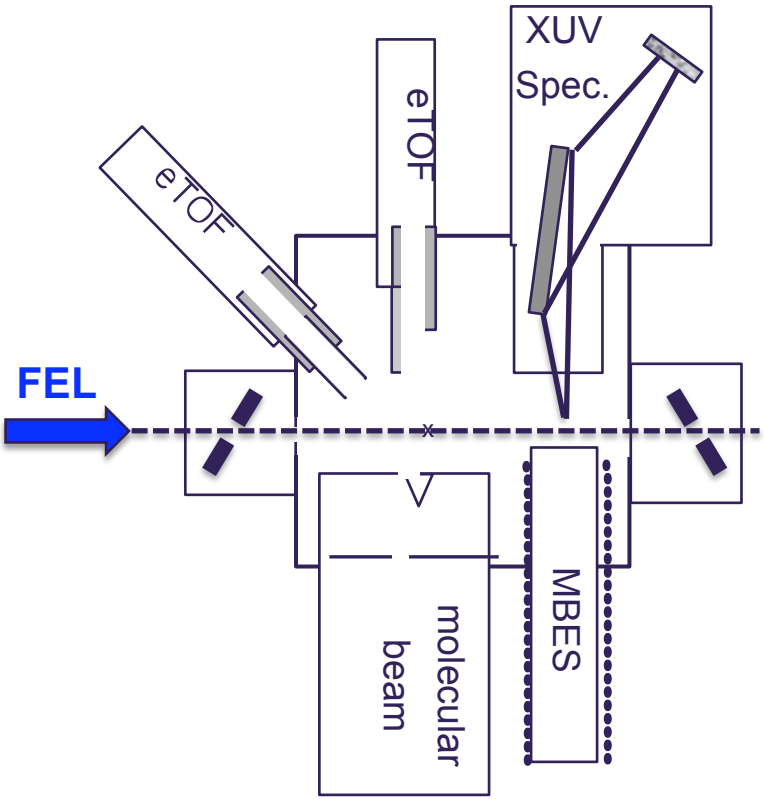
SQS end-station

AQS - Chamber

(side view)



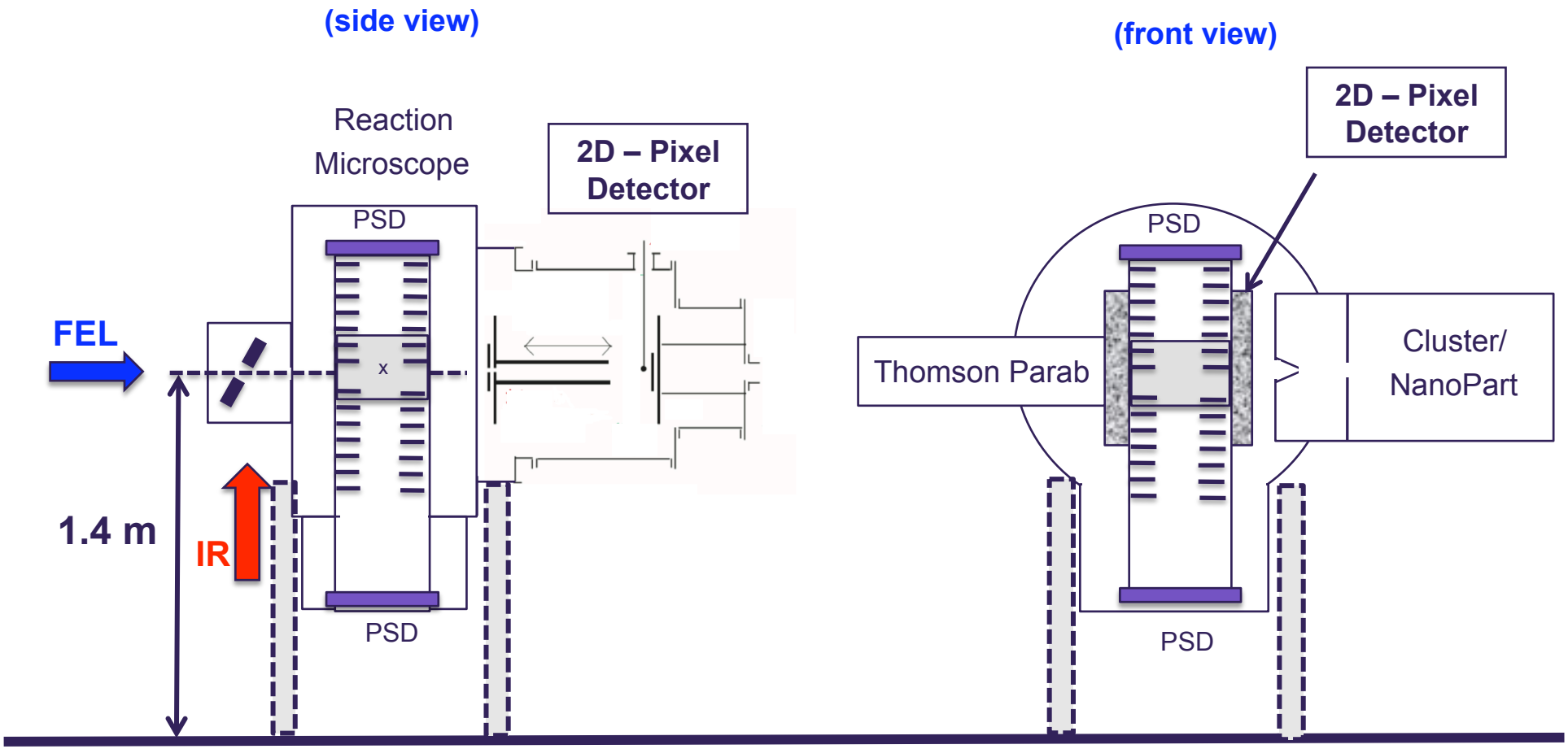
(top view)



European XFEL

SQS end-station

NQS - Chamber



European XFEL

Floor plan

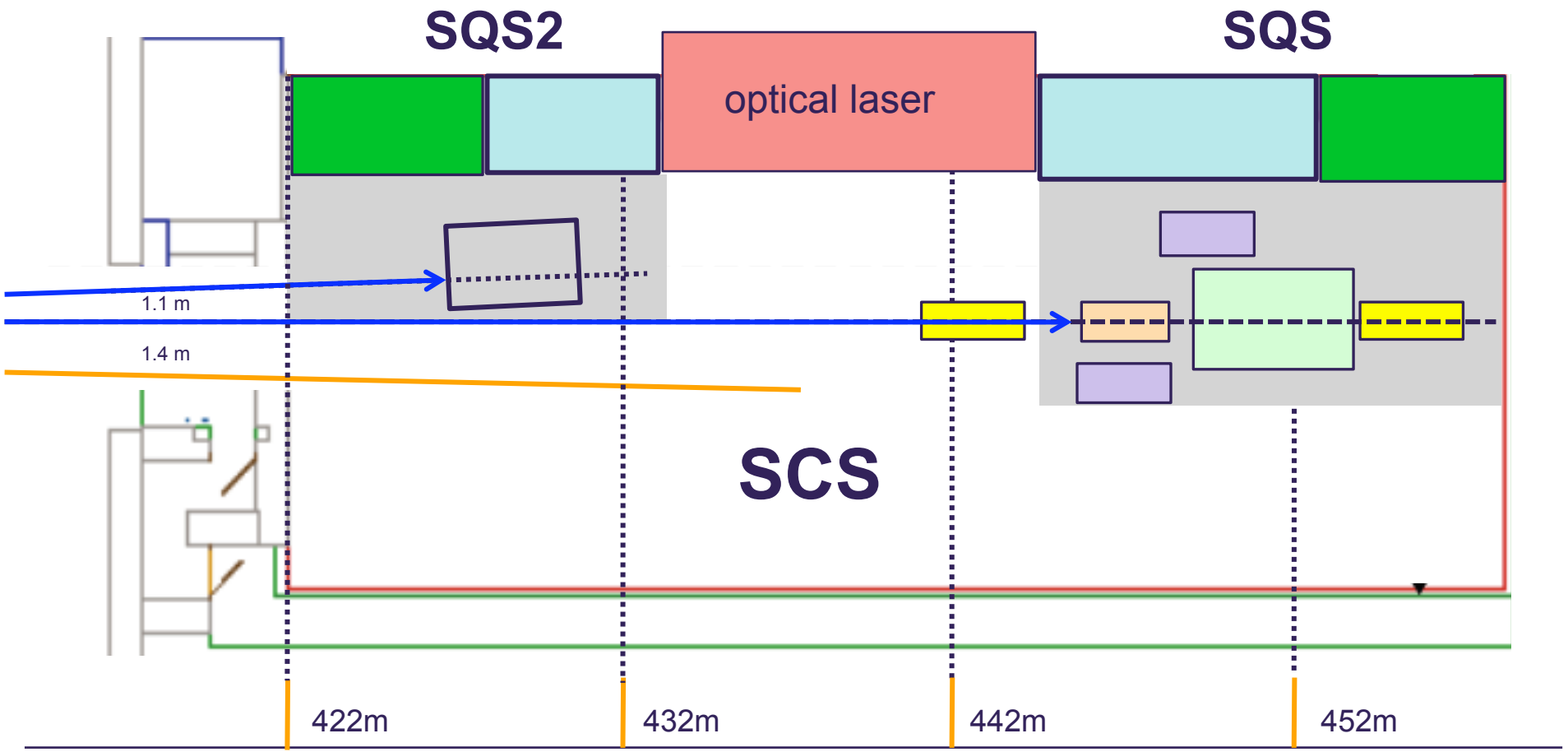
experimental chamber
5 x 3 m²

KB chamber
2.5 x 1.2 m²

Laser table
2.5 x 1.3 m²

rack room

diagnostics



Optical Laser (M. Lederer)

Collaboration DESY, European XFEL, CFEL

Intra-Burst:

- 2700 pulses
- $f_{intra\text{-}burst}$ = 0.1…4.5 MHz
- **1mJ per pulse at 1MHz**
- τ_{FWHM} = 10 … 100fs
- ≈ 10 fs jitter (rms)

„Burst Energy“: ... 1J
„Burst-Power“: … 1kW
„Average Power“: … 10W

Pump-Probe Laser	Alignment Laser
1 - 4.5 MHz rep. rate	100 kHz rep. rate
0.2 – 1 mJ pulse energy	1 – 250 mJ pulse energy
10 - 100 fs pulse duration	30 fs / 1 ns pulse duration
< 10 fs synchronization	< 10 fs synchronization

SQS Specific

- OPA (200 – 3000 nm)
- variable polarization
- THz radiation
- beam characterization
- pulse stretcher

Option: 800 nm, 100 kHz, 20 – 100fs, 10mJ
1030 nm, 100 kHz, 1 ns, 250 mJ

FEL beam parameters for experiments

single shot / "on-line"

1. pulse energy: ± 1% (rel.)

   Gas Monitor Detector (GMD)

2. arrival time: < 10fs

   Reflectivity change (10 Hz),

   THz – electron streaking

3. wavelength: $\Delta\lambda / \lambda = 10^{-3}$

   Photoelectron Spectrometer

4. spectral profile: $\Delta\lambda / \lambda = 10^{-4}$

   VLS-grating monochromator

single shot / "off-line"

5. pulse duration: ΔT = < 10 fs

   auto-correlator

   cross-correlation

6. spatial profile

   extended beam on CCD

7. temporal profile

   N.N., THz electron streaking ?

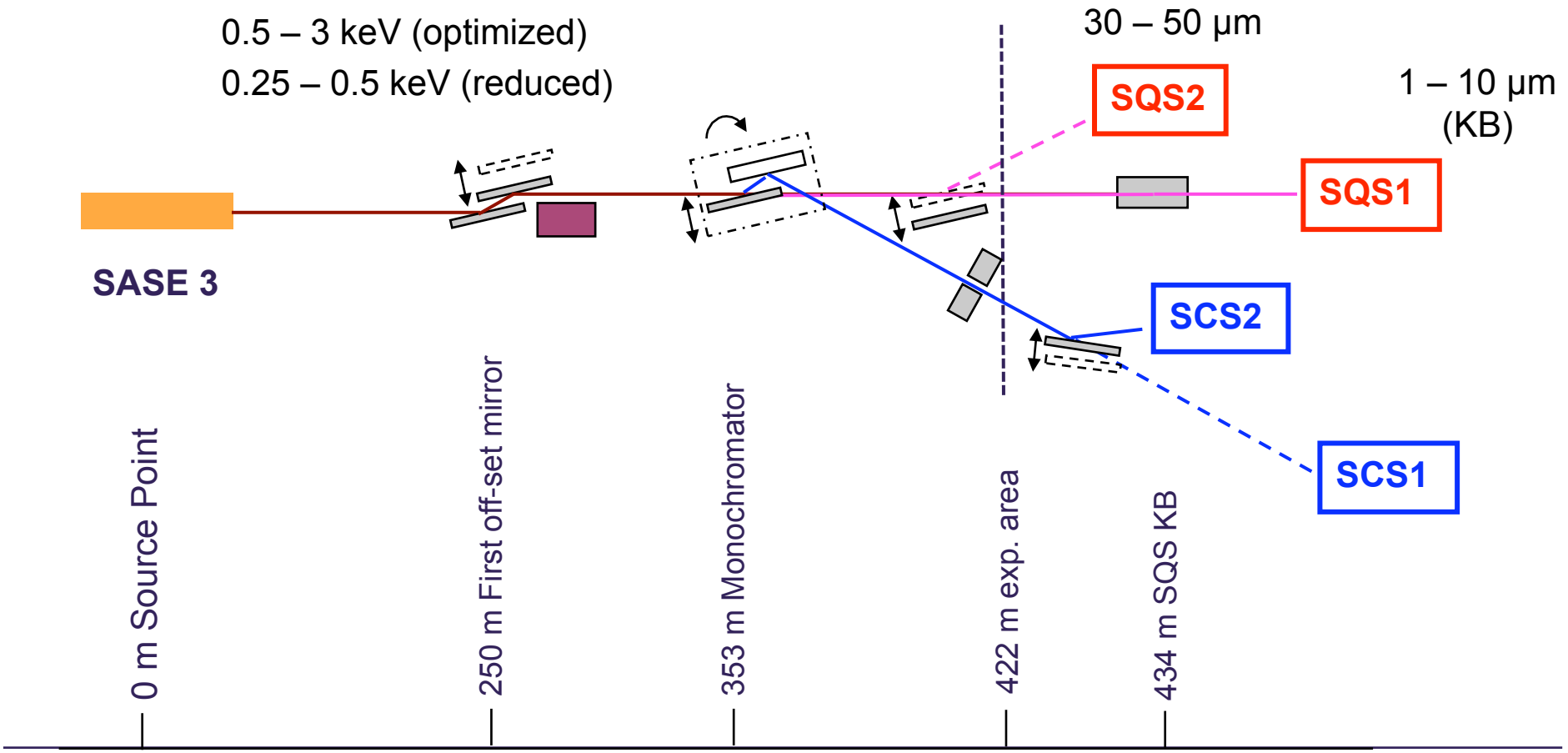
8. beam position: 1 μm

   YAG screens

SCS
"Spectroscopy & Coherent Scattering"
Scientific Instrument

Optical layout of the beam transport system (H. Sinn)

- direct beam → Small Quantum System (SQS)
- monochromatized → Spectroscopy @ Coherent Scattering (SCS)

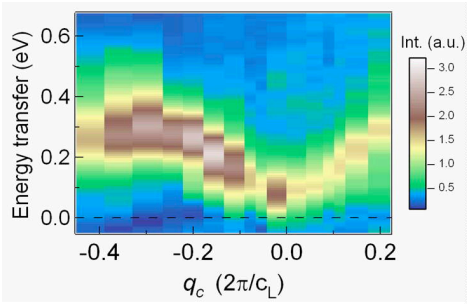


Spectroscopy & Coherent Scattering (SCS)

International Workshop:

Villingen, Switzerland, June 2 - 4, 2009

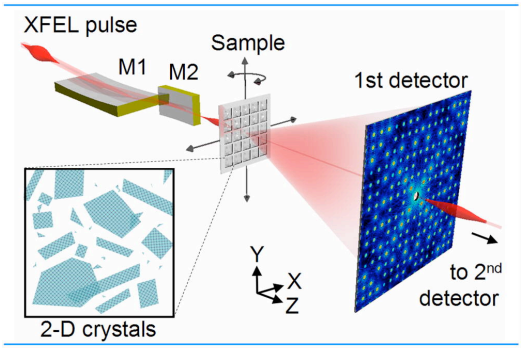
Trieste, Italy, December 16 - 17, 2010



Spectroscopies (electron, photon)

Imaging, Dynamics & PCS: Bio & Nano Objects

Imaging, Dynamics & PCS: Magn. Systems



Scientific applications & experimental techniques:

- Electronic and atomic structure and dynamics solids, surfaces, nano-systems, biological objects

- X-ray spectroscopy (XAS, XES, IXS, RIXS, XPS), imaging (holography, CDI, XPCS); Pump-probe experiments

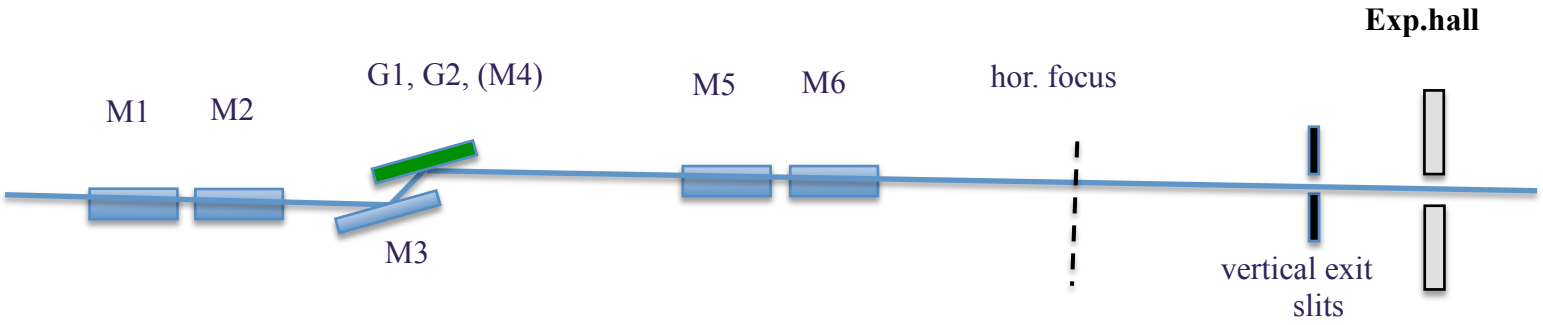
Variable polarization !!

European XFEL

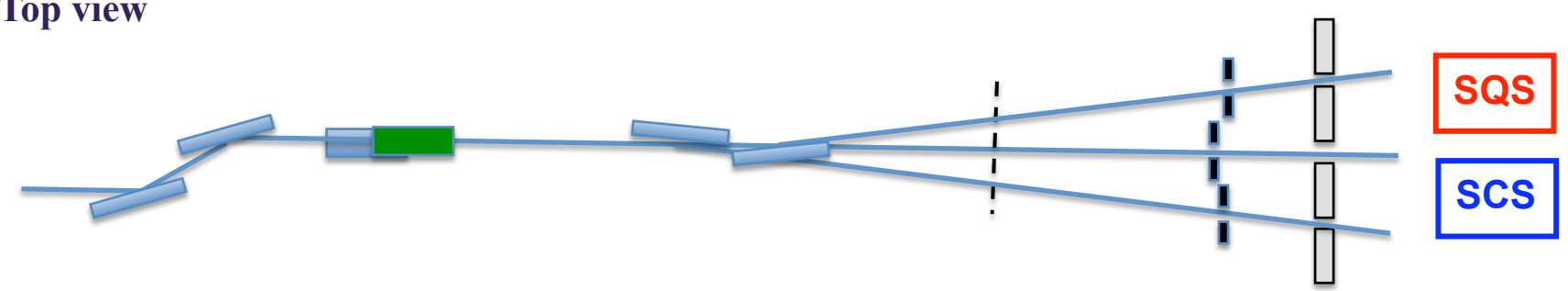
Soft X-Ray Monochromator (H. Sinn)

VLS (Variable Line Spacing) Grating

Side view



Top view



Wavelength regime:
0.5 – 3 keV (optimized)
0.25 – 0.5 keV (reduced)

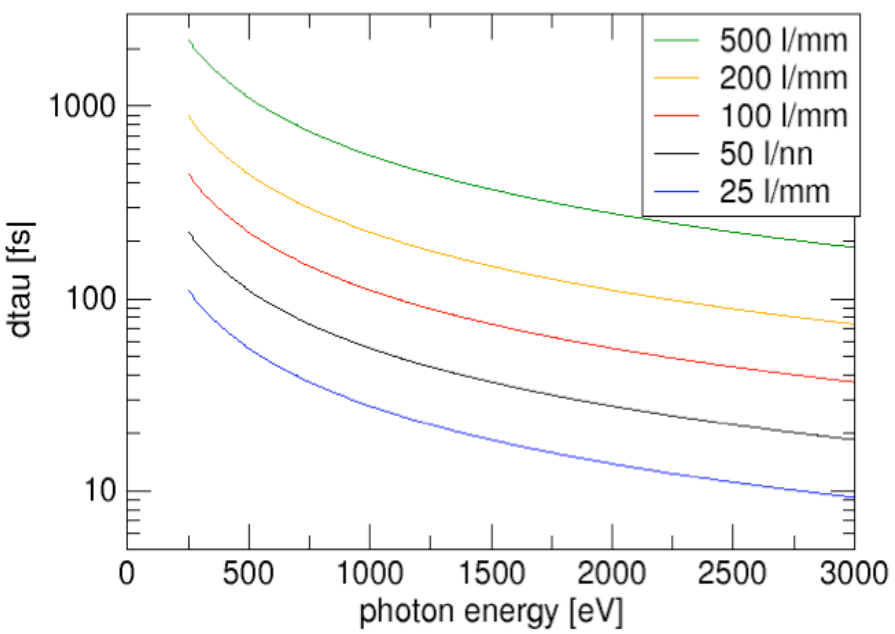
Spectral resolution:
$\lambda / \Delta\lambda \geq 10\,000$
(>30 000)

Temporal resolution:
$\Delta T \leq 100$ fs

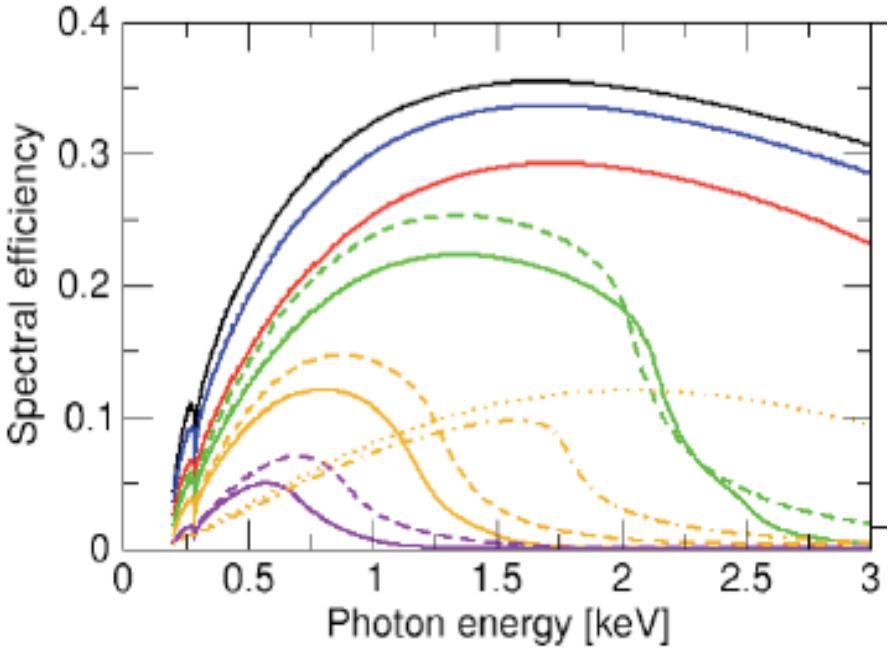
European XFEL

Soft X-Ray Monochromator (H. Sinn)

Temporal Resolution



Transmission

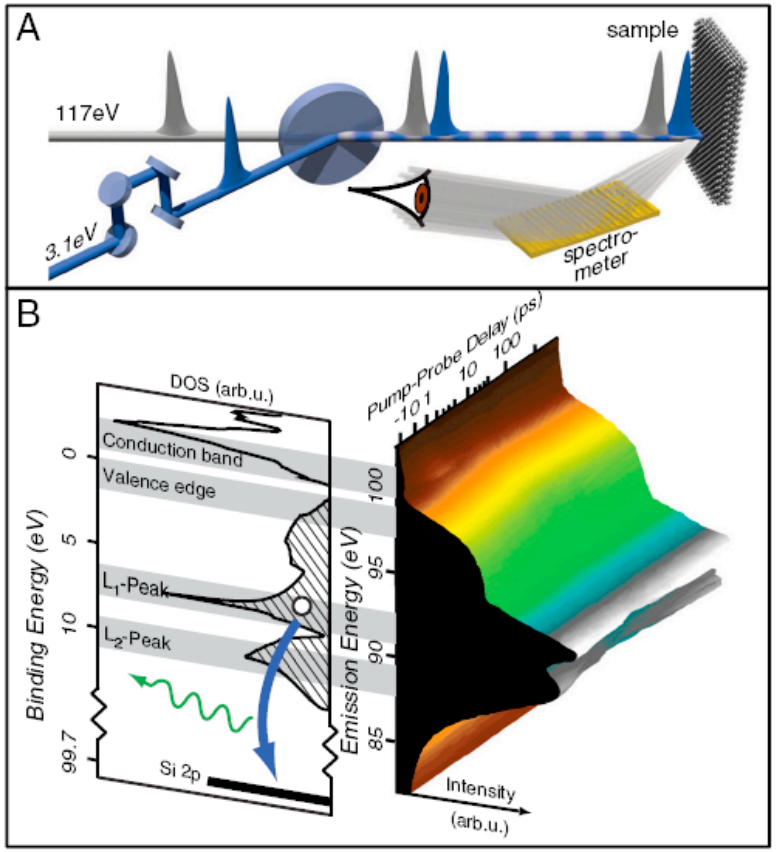


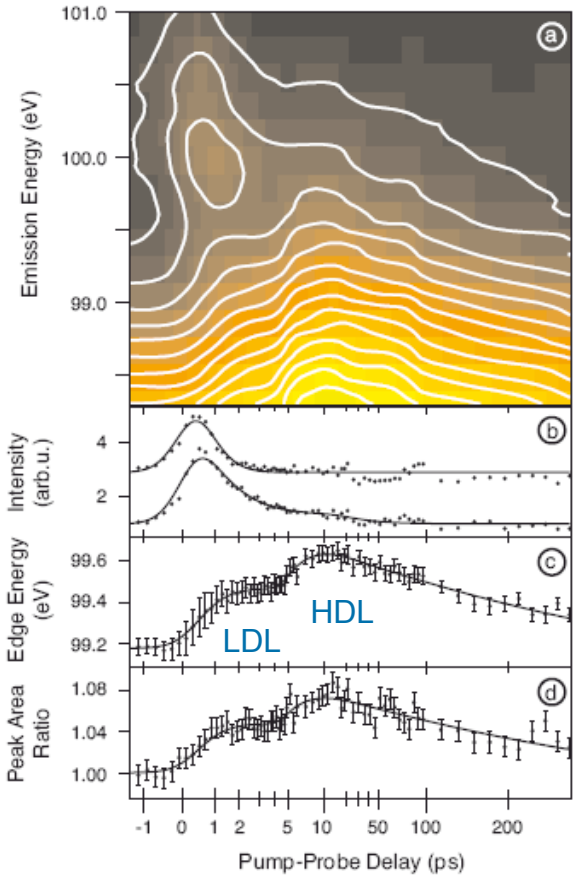
Final defintion of parameters and layout (in progress):
H. Sinn, R. Follath, M. Izquierdo, J. Gaudin, S. Molodtsov,

European XFEL

Time-resolved RIXS

The liquid-liquid phase transition in silicon revealed by snapshots of valence electrons
M. Beye, F. Sorgenfrei, W. F. Schlotter, W. Wurth, A. Föhlisch,
PNAS 2010 107 (39) 16772-16776



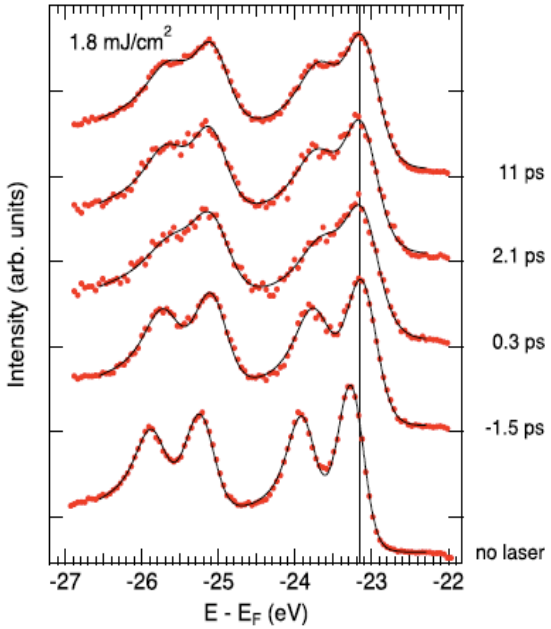


European XFEL

Electron Phonon Interactions

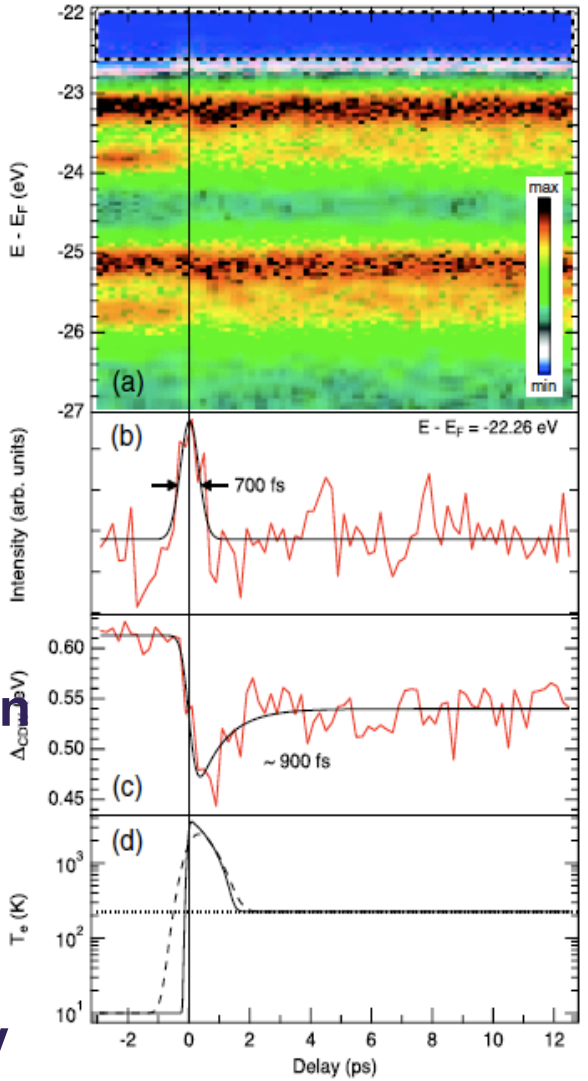
Ultrafast melting of a charge density wave in the Mott Insulator 1T-TaS_2

S. Hellmann et al. PRL 105, 187401 (2010)



Ta 4f photoemission

hν = 156 eV

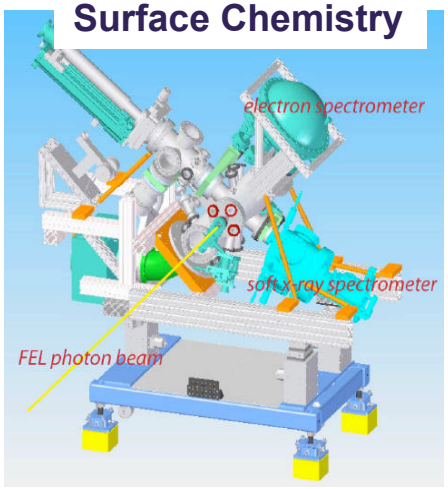


Femtosecond time-resolved core-level photoemission spectrosccopy

European XFEL

Spectroscopy at LCLS

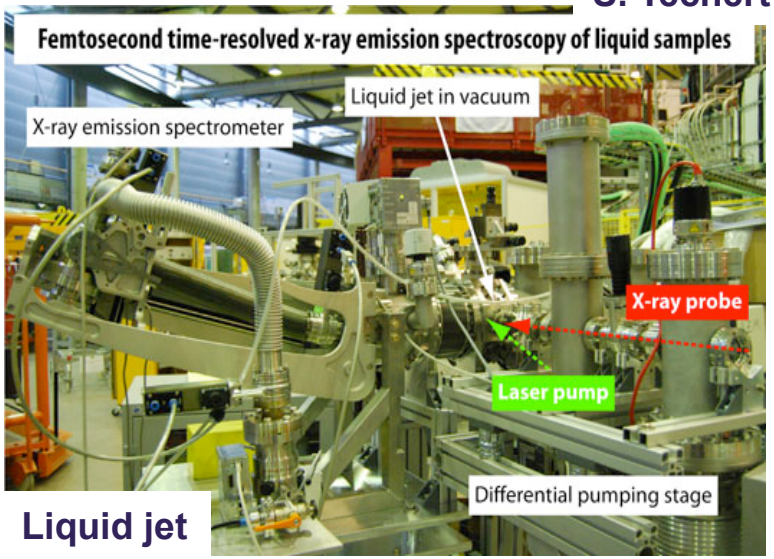
Surface Chemistry



A. Nilsson
D. Nordlund
H. Ogasawara

Roll on – Roll off

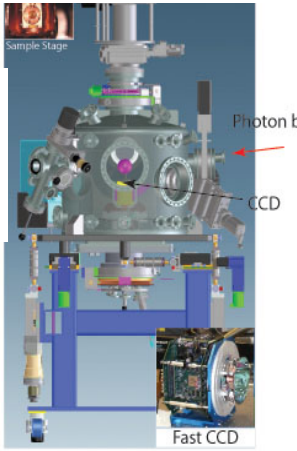
Ph. Wernet
A. Föhlisch
S. Techert



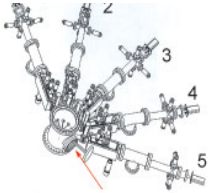
Liquid jet

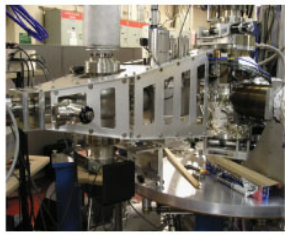
Momentum-resolved X-ray Scattering

Z.X.Shen
Z. Hussain
W-S. Lee



Resonant X-ray Scattering Endstation





q-resolved RIXS Endstation

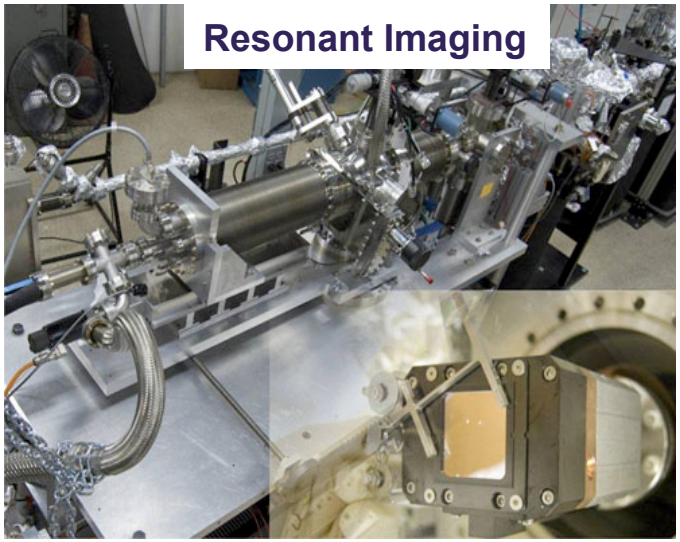
J. Stöhr
A. Scherz

\+

CAMP

EBIT

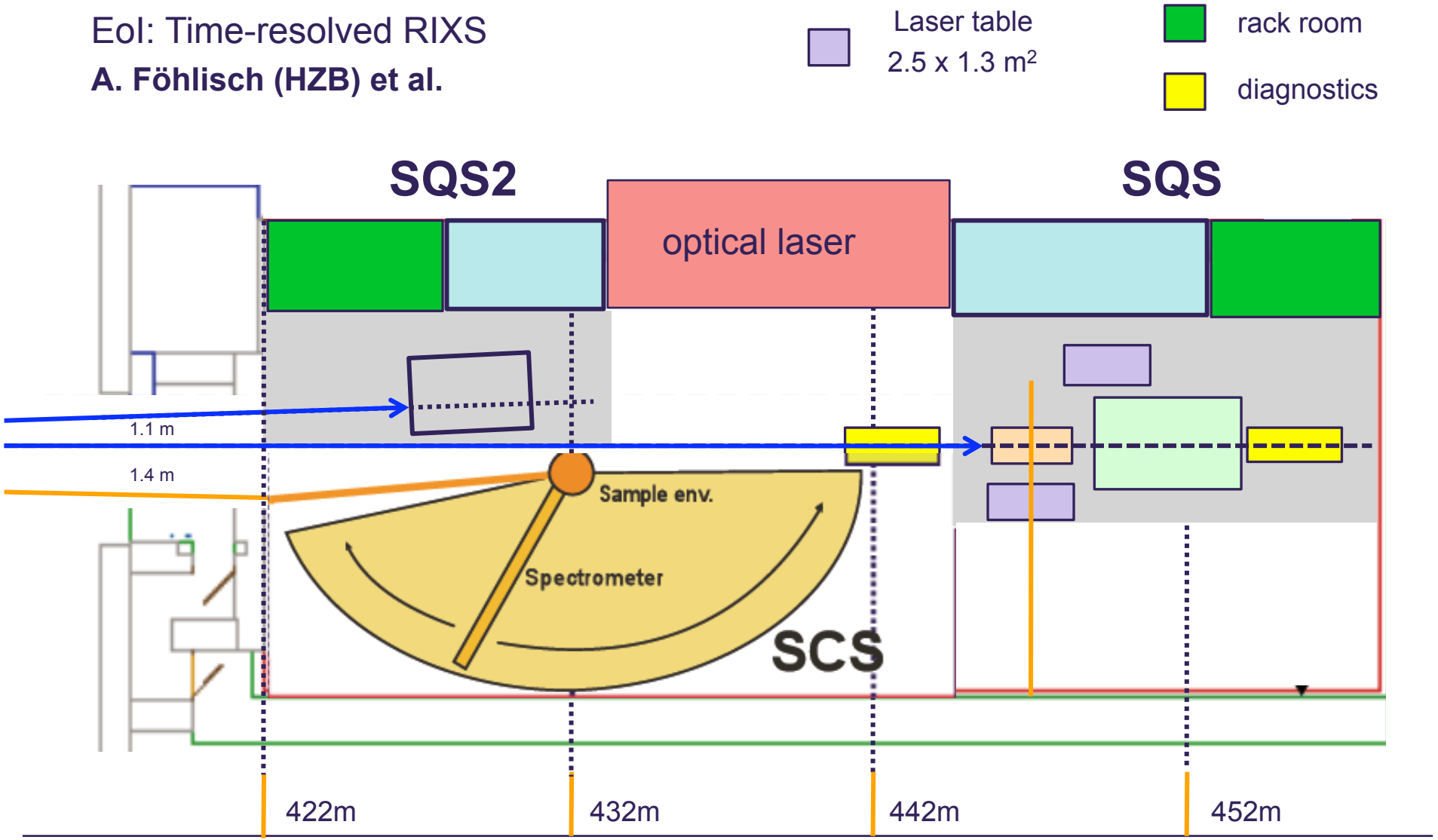
Resonant Imaging



Floor plan

EoI: Time-resolved RIXS

A. Föhlisch (HZB) et al.



European XFEL

Floor plan

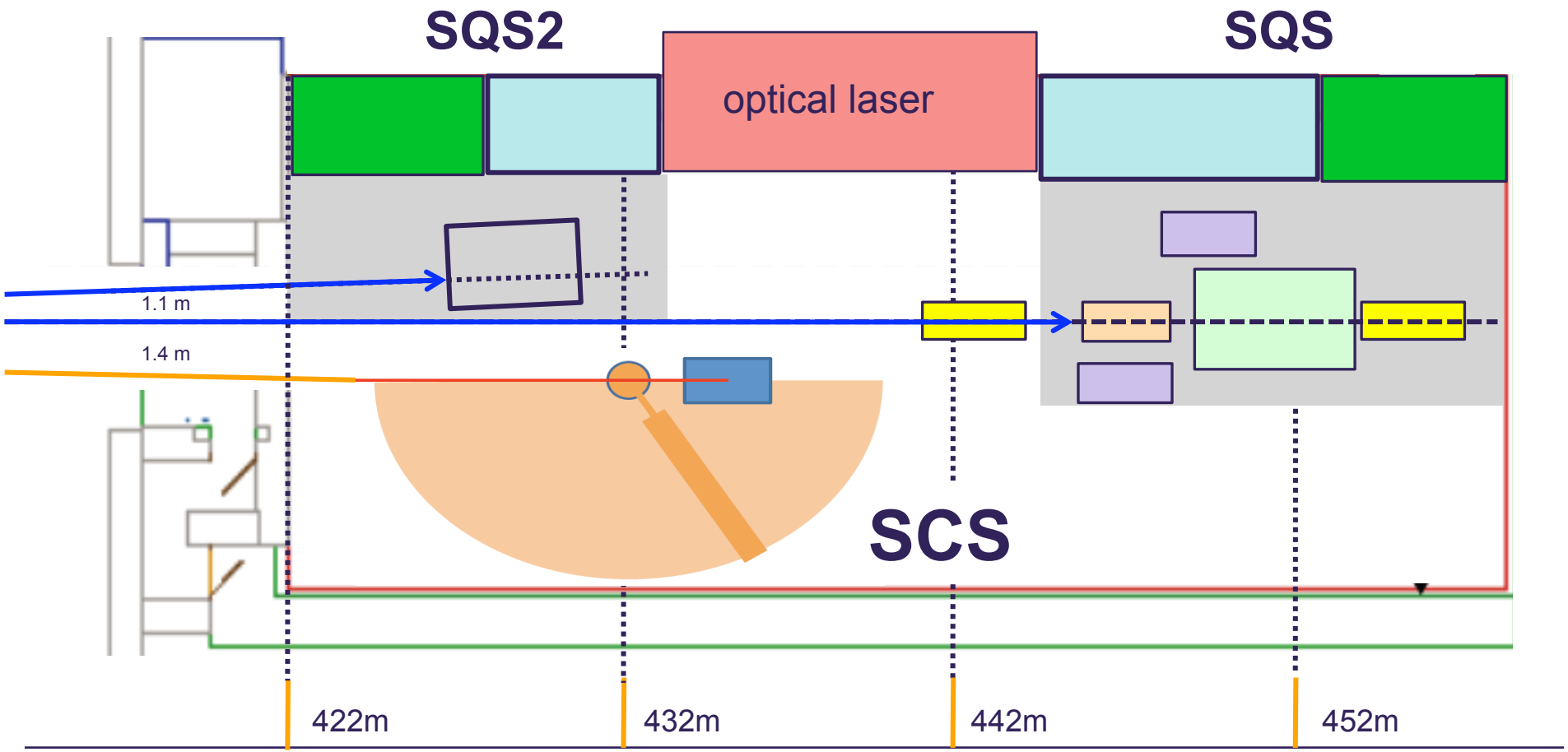
experimental chamber
5 x 3 m²

KB chamber
2.5 x 1.2 m²

Laser table
2.5 x 1.3 m²

rack room

diagnostics



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Floor plan

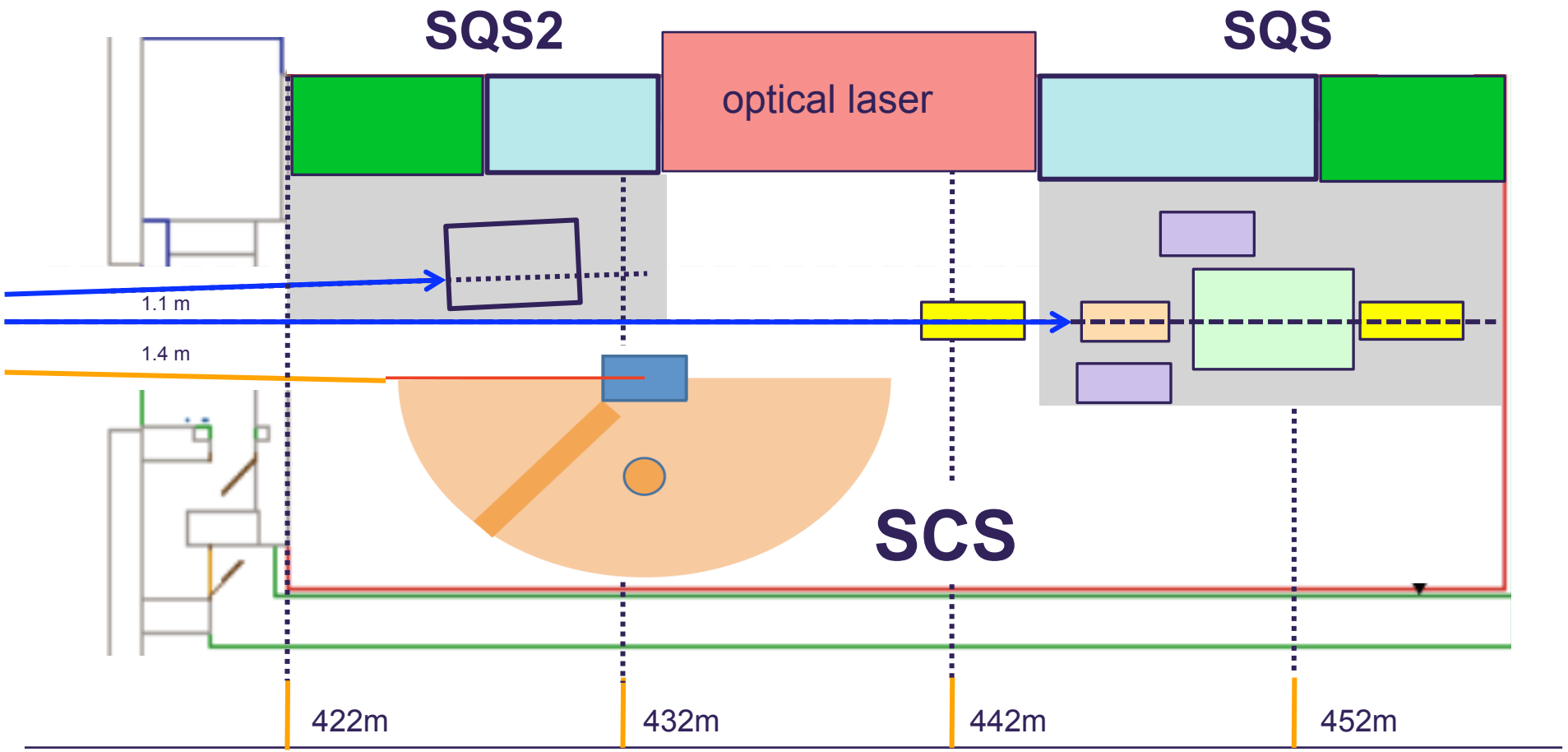
experimental chamber
5 x 3 m²

KB chamber
2.5 x 1.2 m²

Laser table
2.5 x 1.3 m²

rack room

diagnostics



Timeline

SQS Instrument

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

Conceptual Design Report	April 2011
Technical Design Report	October 2012

SCS Instrument

Conceptual Design Report	Spring 2012
Technical Design Report	Spring 2013

Installation in experimental hall	mid 2014
Ready for beam	mid 2015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Thank you
for your attention!