Commissioning and First Results of the Materials Imaging and Dynamics (MID) Station at the European XFEL

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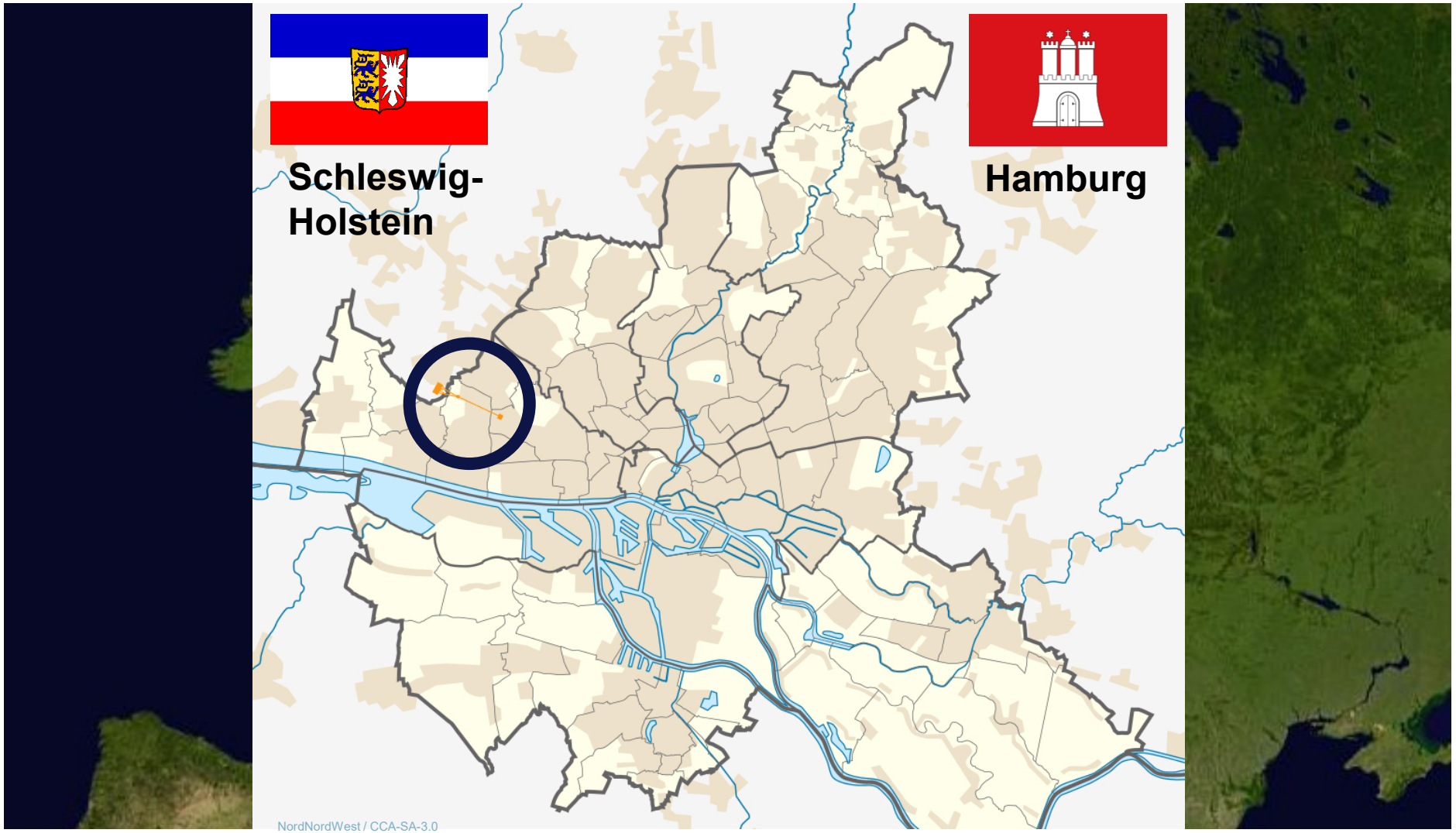
European XFEL
Schenefeld
Germany

ILL - ESRF Colloquium, Nov 15, 2019

European XFEL – a new unique research facility



European XFEL – an overview of the underground

10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from winter 2011

Tunnel drilling machine
coming out at Osdorfer Born

10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from spring 2012

Looking down into the
future experimental hall

10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from spring 2012

Tunnel drilling machine almost out of the SASE-2 tunnel (MID)

10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from summer 2012

Aerial view of the construction site

10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from Nov 2012

Experimental hall

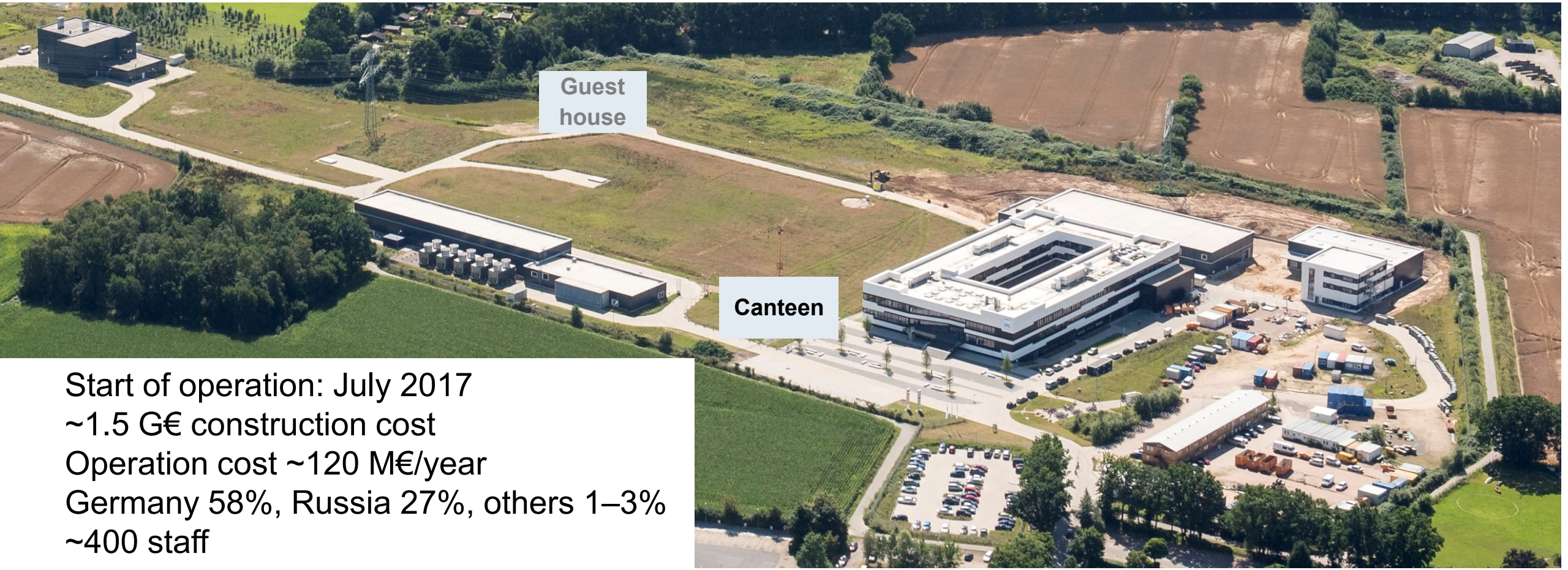
10 year anniversary of European XFEL

Nov 2009: Start of construction work

Picture from Nov 2019

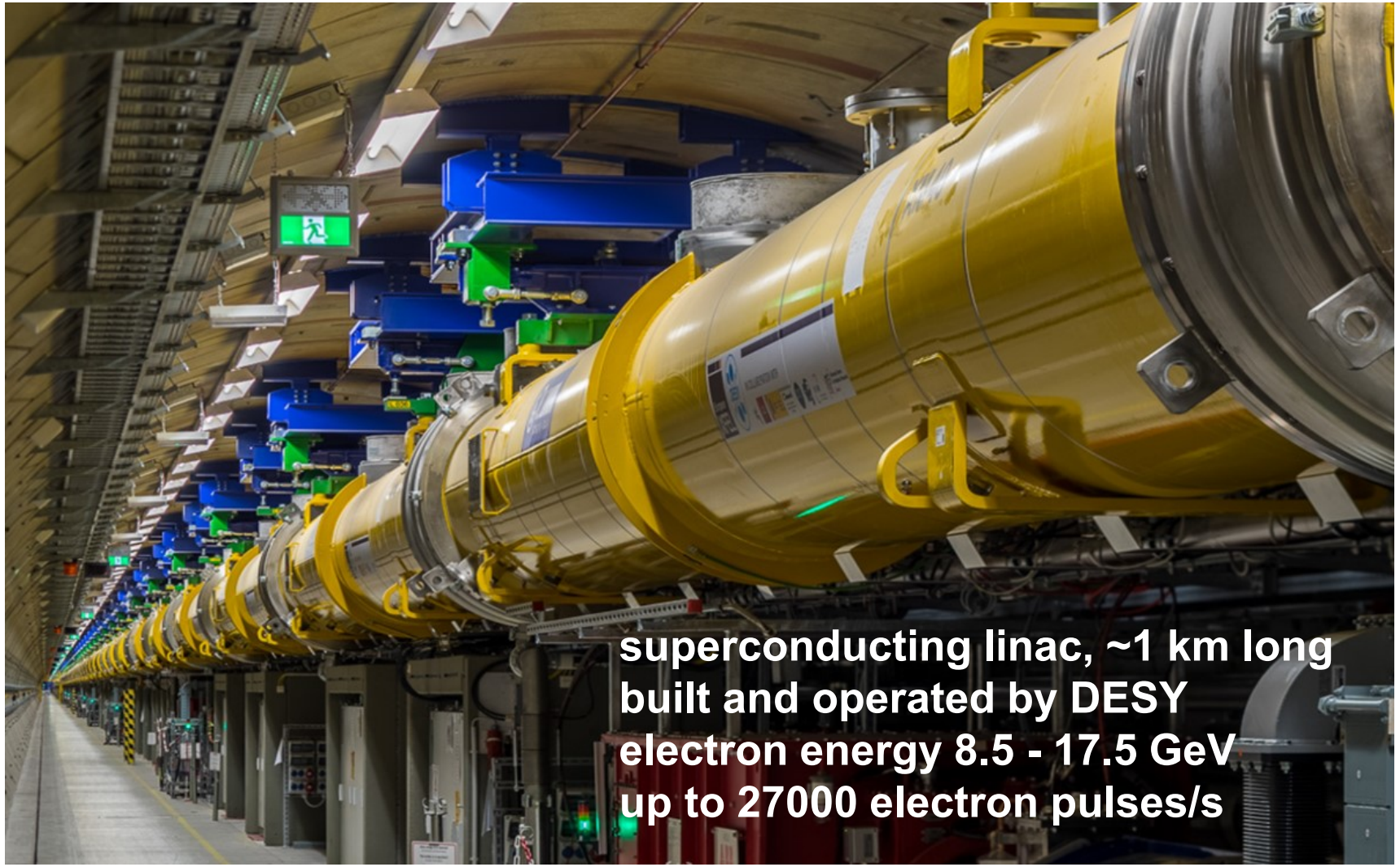
Experimental hall

The facility

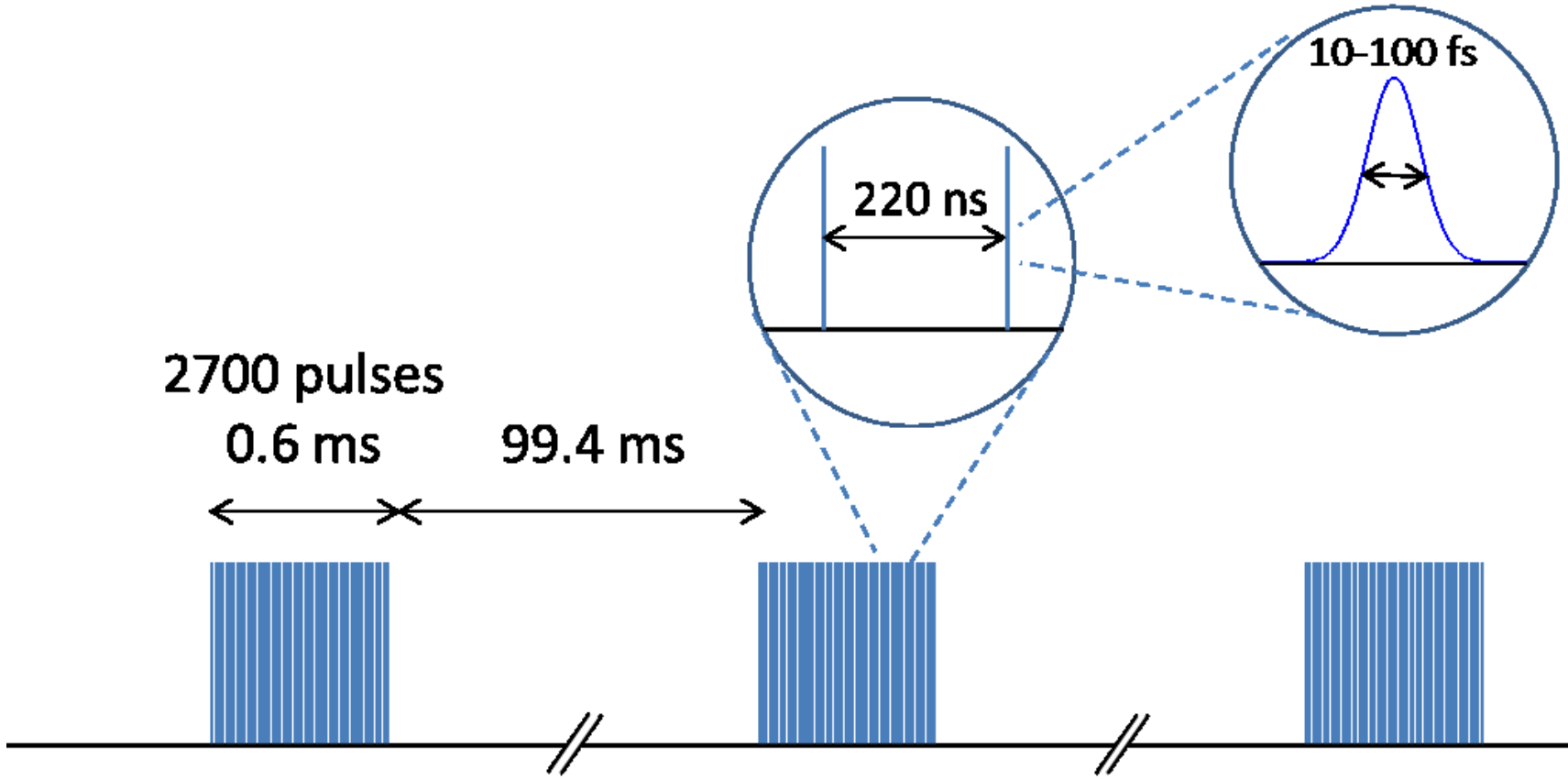


Start of operation: July 2017
~1.5 G€ construction cost
Operation cost ~120 M€/year
Germany 58%, Russia 27%, others 1–3%
~400 staff

The accelerator



Pulse pattern of European XFEL

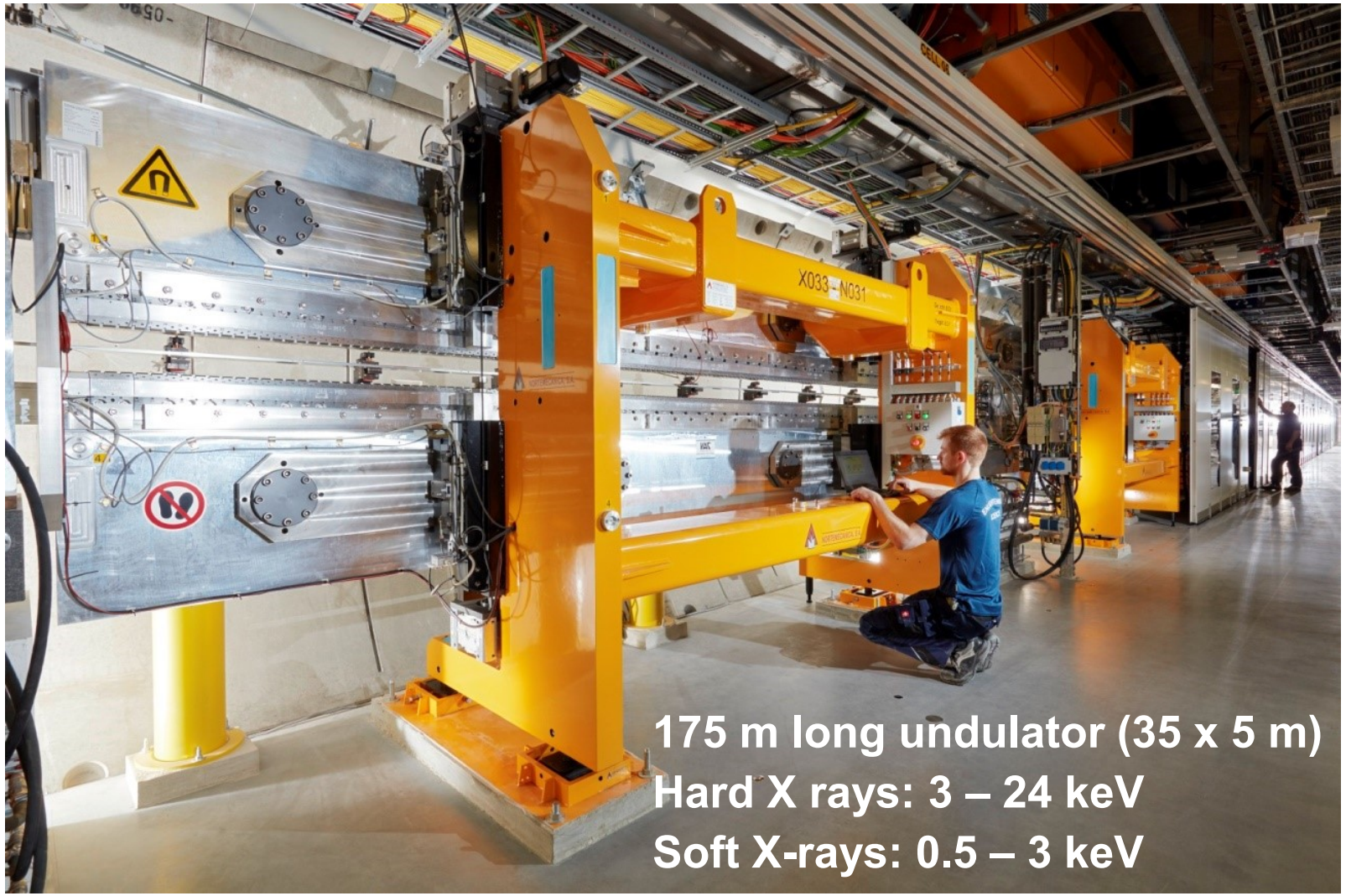


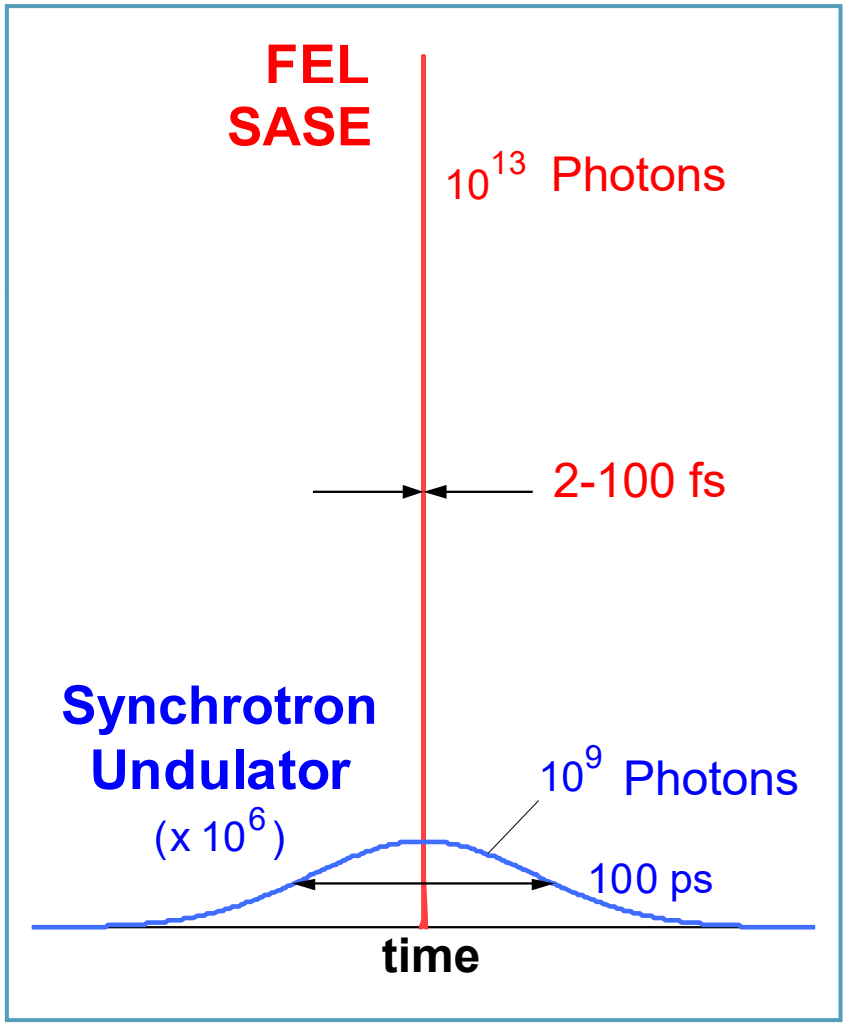
10^{12} X-ray photons (~1 mJ) per pulse (<100 fs)

10 trains/s
Until 27000 pulses/s

Pulses within train distributed to all beamlines in a predefined pattern

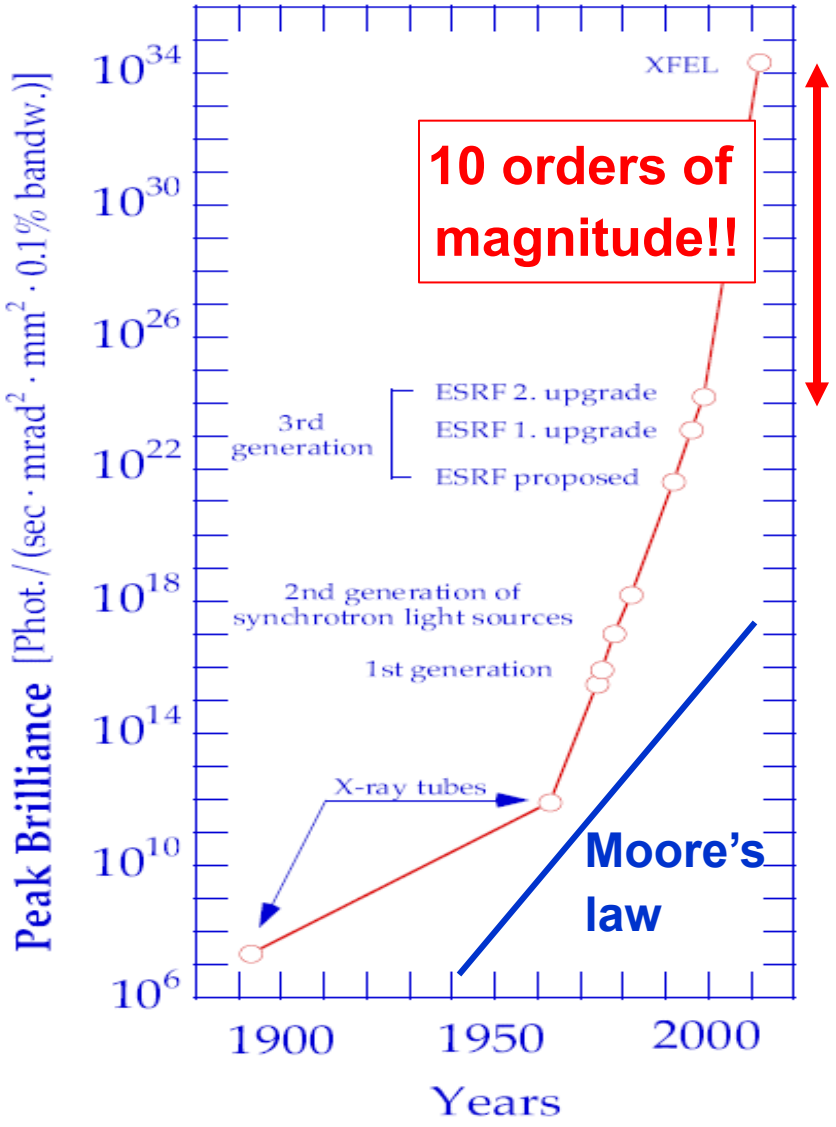
X-ray lasing





Coherence and brilliance!

X-ray lasing



Average Brightness is huge but **Peak Brightness (~10^{34})** is gigantic due to the short (<100 fs) pulse duration

Combination of the three:

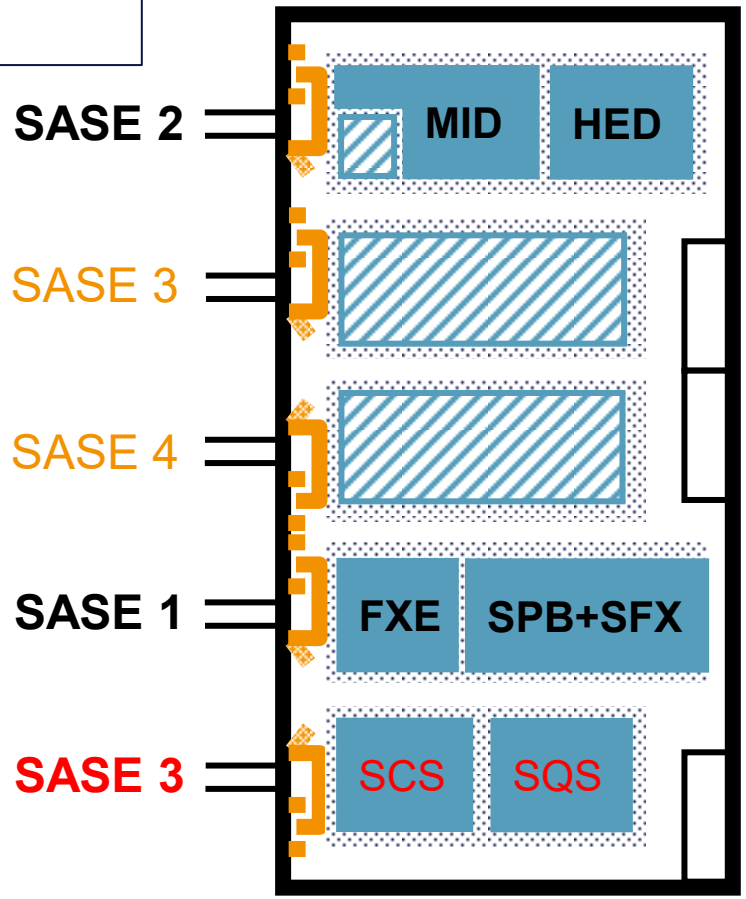
- **Coherence**
- **Ultra-fast pulses**
- **Gigantic peak brilliance**

is particularly interesting

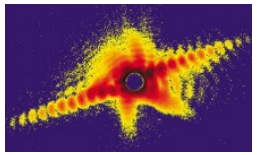
→ Important part of XFEL mission

1st Batch of Instruments at European XFEL

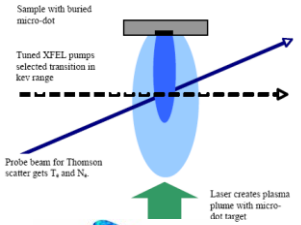
Experimental hall
~ 90 x 50 m



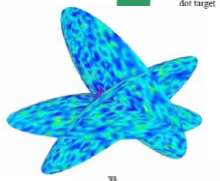
MID Materials Imaging & Dynamics



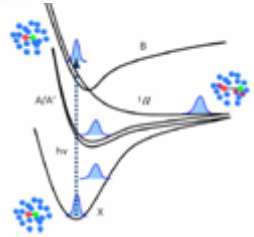
HED High Energy Density Science



SPB Single Particles & Biomolecules

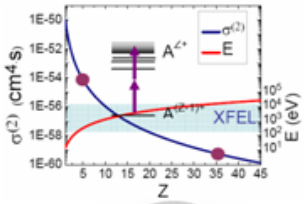


FXE Femtosecond X-ray Experiments



3 - 24 keV

SQS Small Quantum Systems



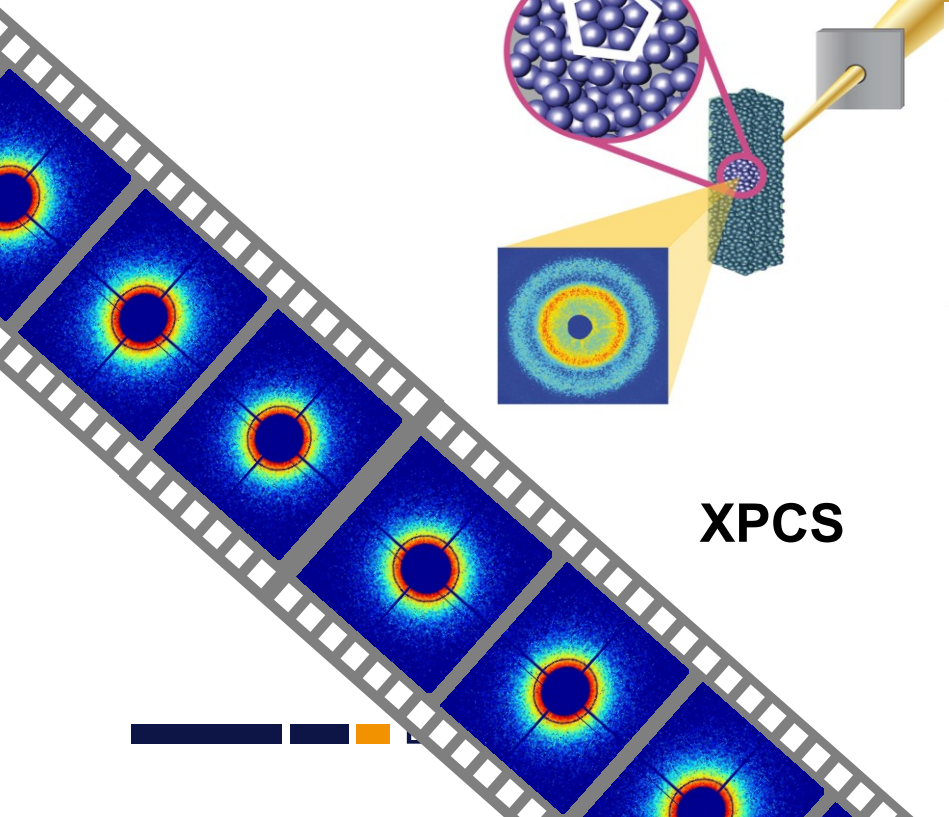
SCS Spectroscopy & Coherent Scattering

0.5 - 3 keV

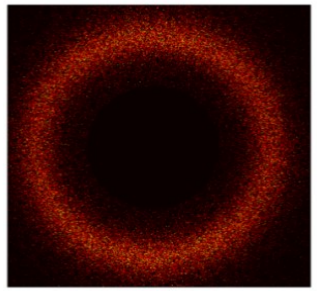
Materials Imaging and Dynamics Instrument

The Materials Imaging and Dynamics (MID) station aims at the investigation of nanosized **structure** and nanoscale **dynamics** using **coherent hard X-rays**. Applications to a **wide range of materials** from hard to soft condensed matter and biological structures are envisaged

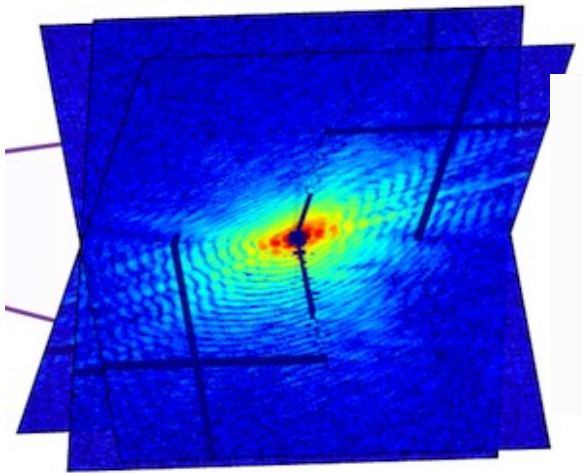
(1st MID workshop, Oct 2009 @ ESRF, Grenoble)

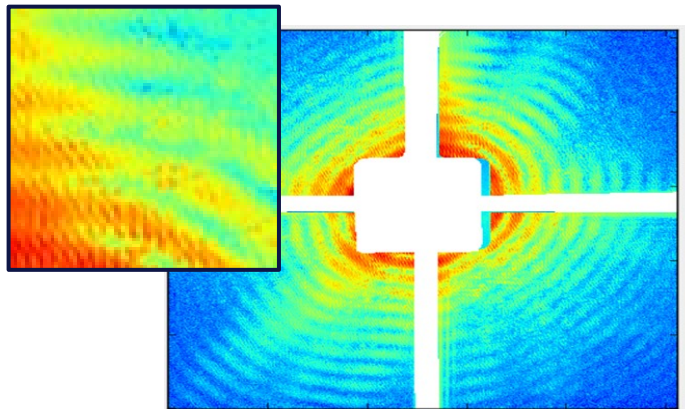


XCCA



CDI





Holography

XPCS

in combination with:
- External pump
- Spectroscopy
- Nano-focusing
- Split-delay techniques

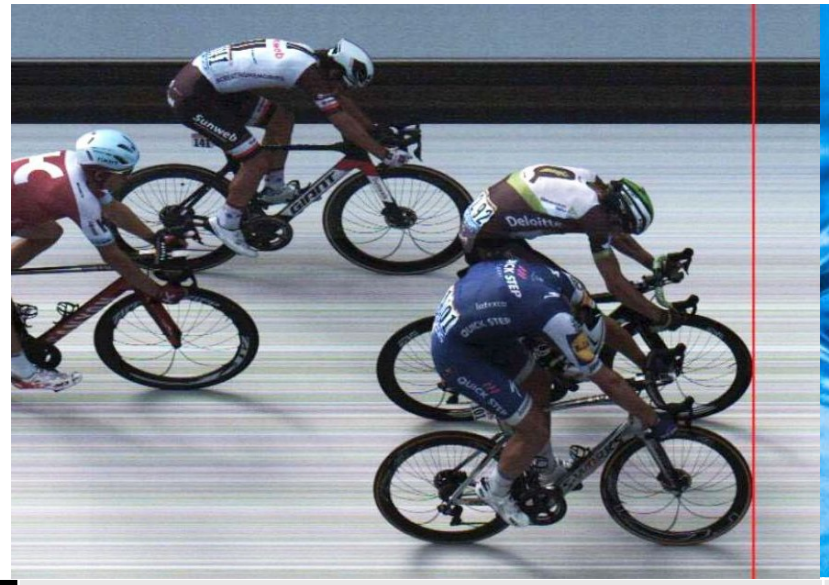
Materials Imaging and Dynamics Instrument

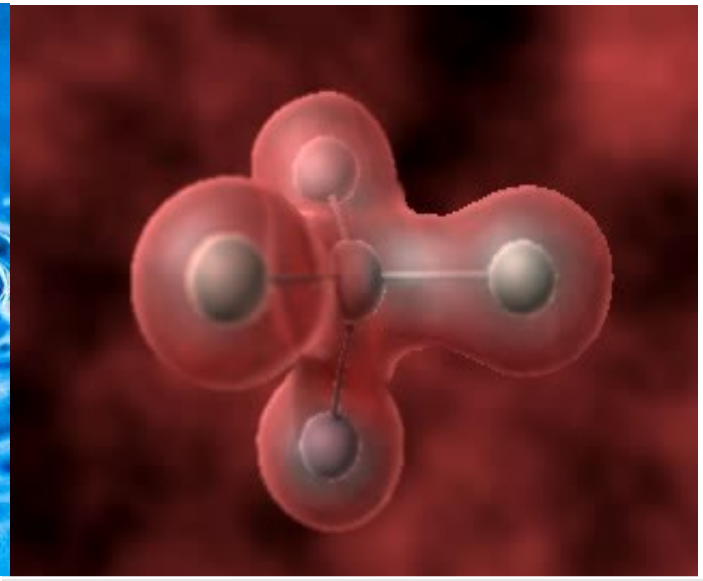
Materials MID focuses on structural studies of materials including liquid, glassy, amorphous and crystalline states. Connecting the nanoscale behavior to the macroscopic properties of materials is at the heart of our investigations

Imaging Imaging of materials with X-rays is the technique used at MID. X-ray imaging can be done in many ways, e.g. using absorption, phase or scattering contrast. The coherence of the beam offers new opportunities to achieve higher spatial resolution in X-ray microscopy

Dynamics With sufficiently high time resolution in imaging experiments it will be possible to capture phenomena like phonon dynamics or atomic diffusion. The pulsed structure of European XFEL with MHz repetition rate of fs pulses is a unique feature with benefit for time-domain investigations like XPCS

Materials Imaging and Dynamics Instrument: An ultrafast camera

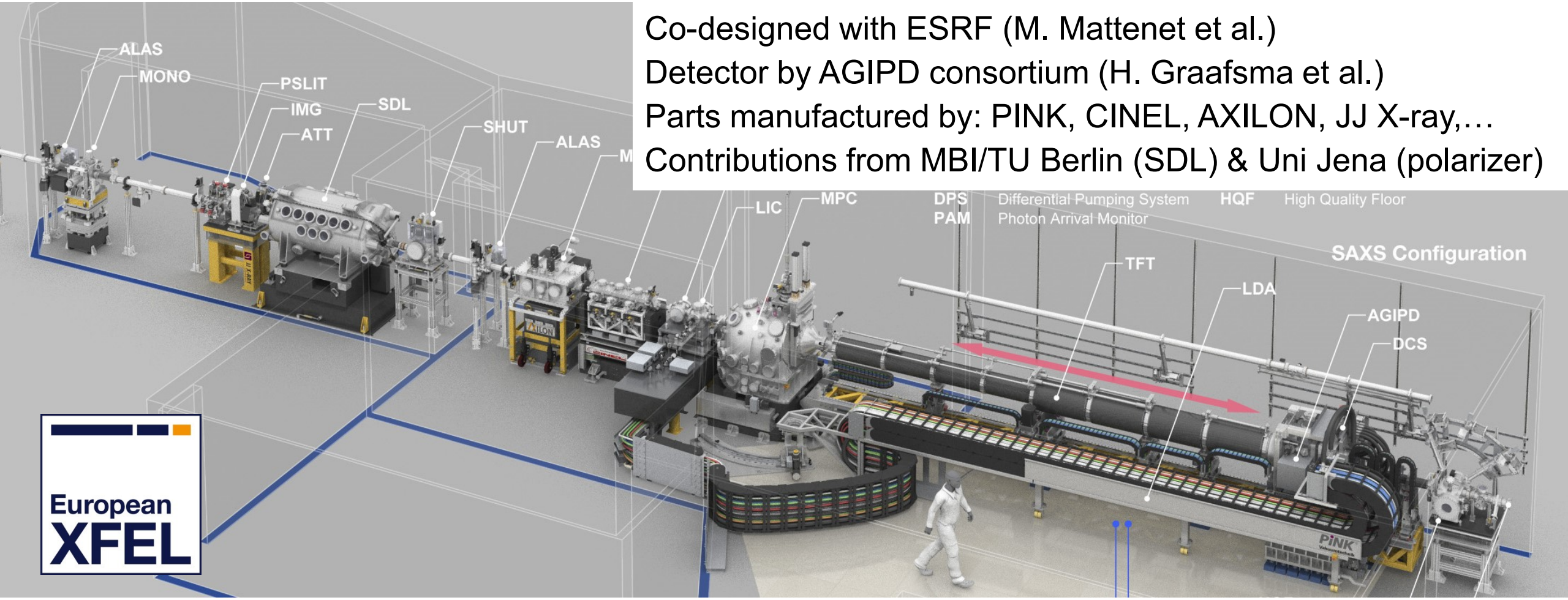




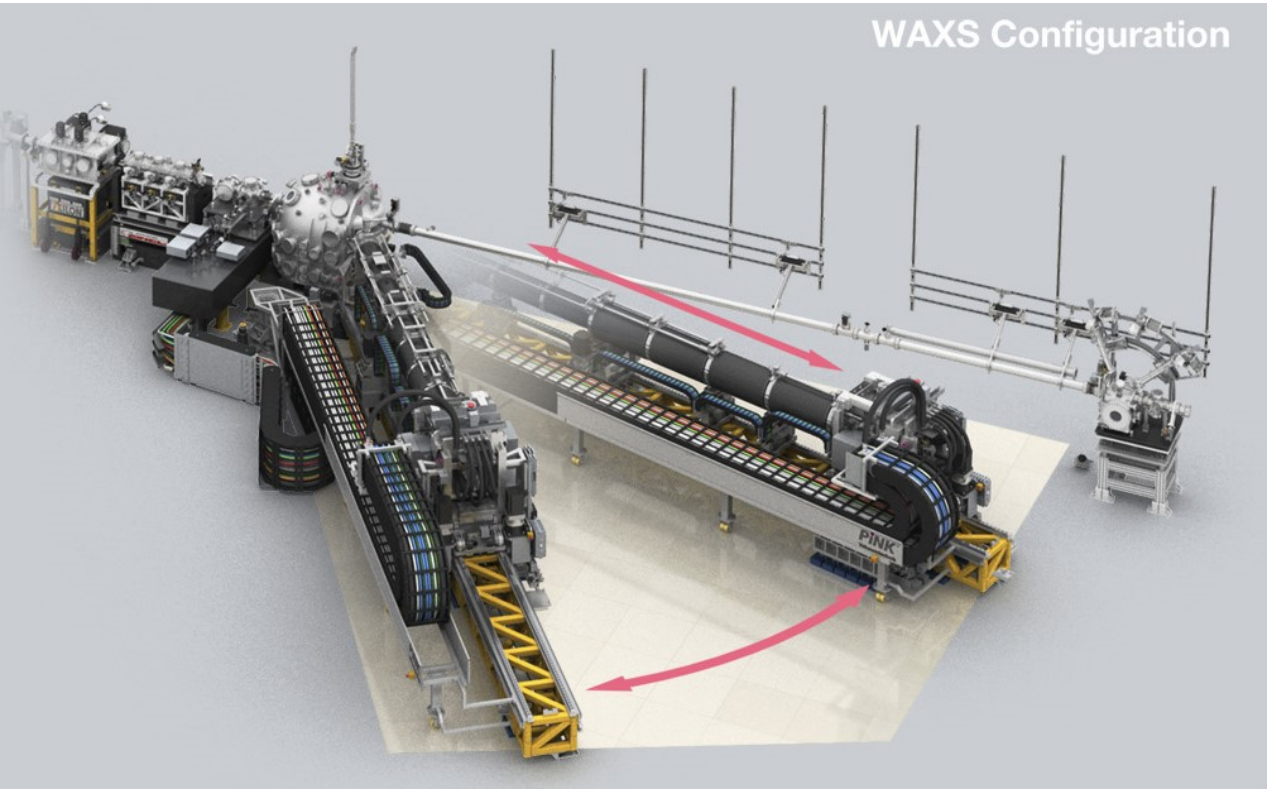
Length	10 mm	1 mm	0.1 nm
Velocity	10 m/s	100 m/s	1000 m/s (acoustic phonon in matter)
Time	1/1000 s	1/100.000 s	**1/10.000.000.000.000 s (100 femto-seconds)**

Materials Imaging and Dynamics Instrument

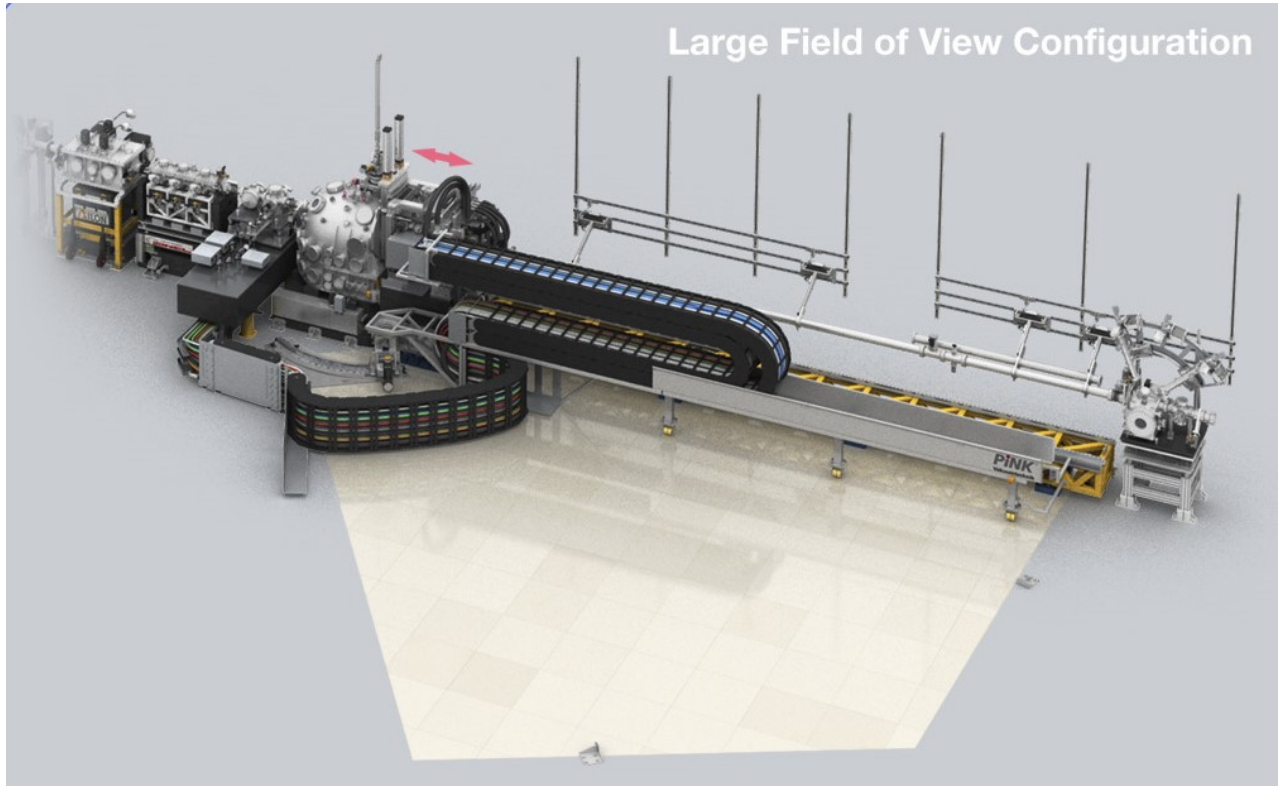
Co-designed with ESRF (M. Mattenet et al.)
Detector by AGIPD consortium (H. Graafsma et al.)
Parts manufactured by: PINK, CINEL, AXILON, JJ X-ray,…
Contributions from MBI/TU Berlin (SDL) & Uni Jena (polarizer)



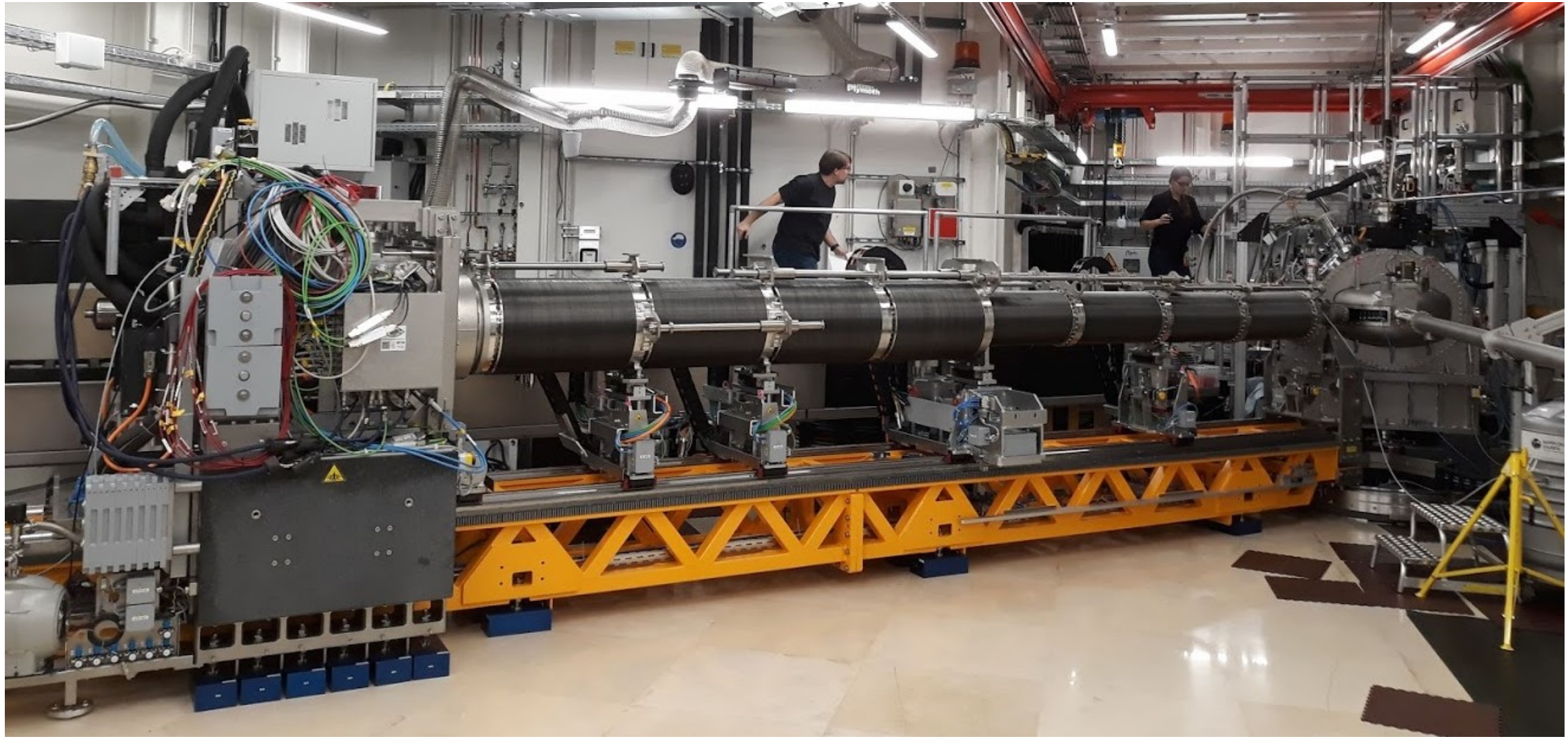
Materials Imaging and Dynamics Instrument



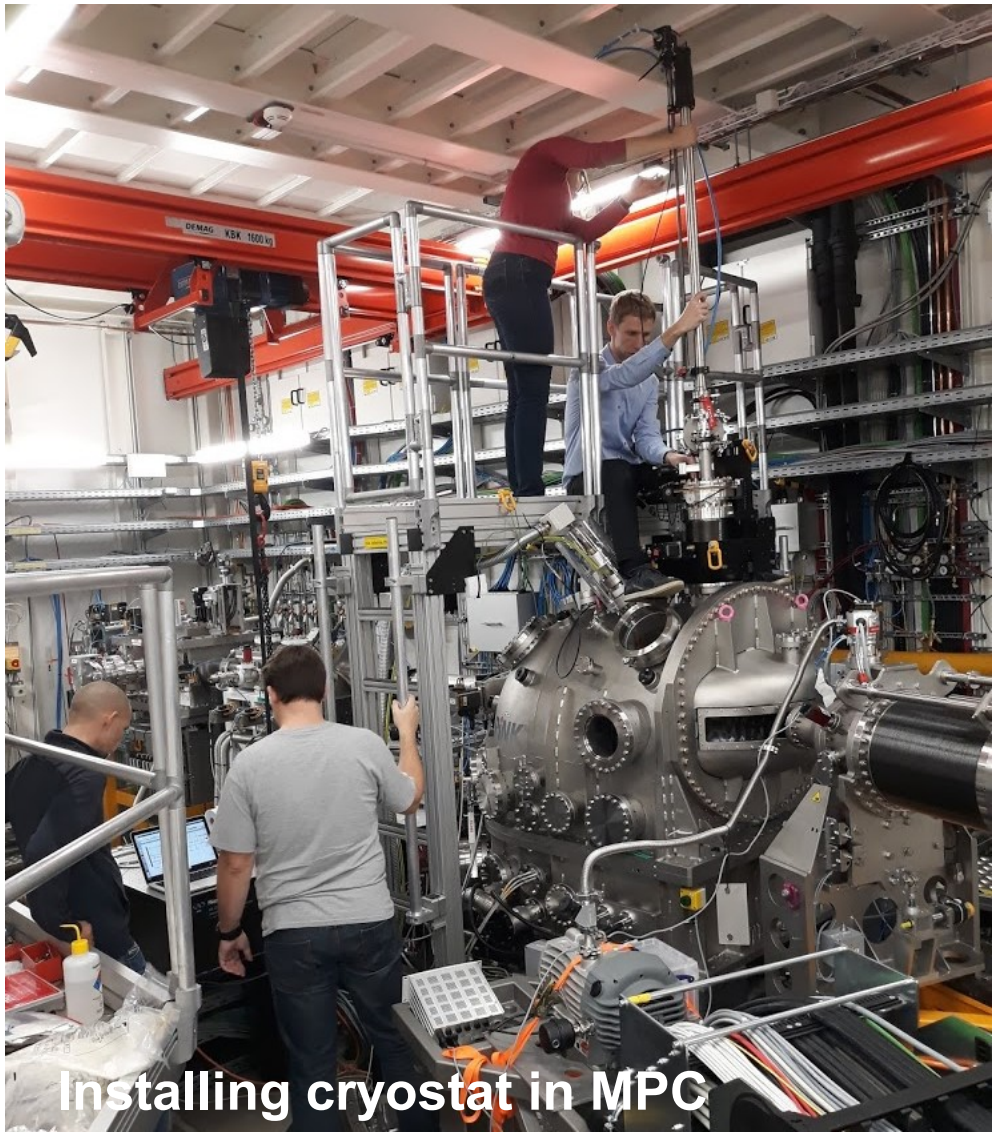
MHz area detector, 1M pixels (AGIPD)
Windowless, all in-vacuum setup or sample in air
Sample - detector distance 0.2 – 8 m
2θ up to ~50^{o} , 5-24 keV



Materials Imaging and Dynamics Instrument



Materials Imaging and Dynamics Instrument

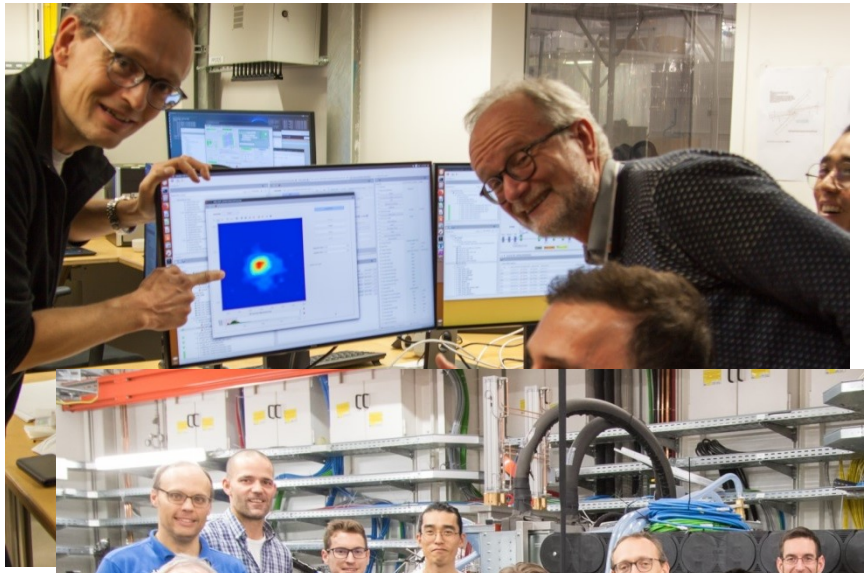


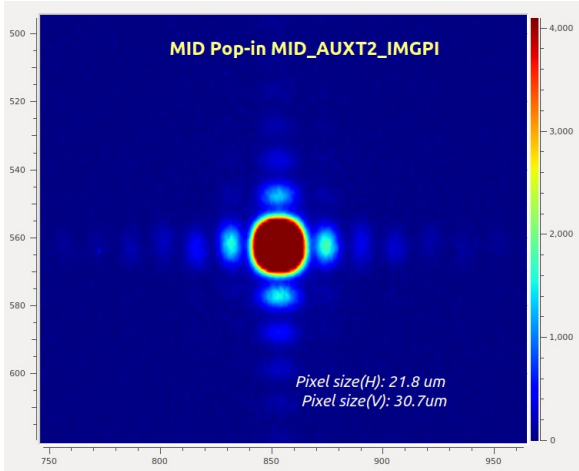
MID commissioning

First lasing at SASE-1
May 2017

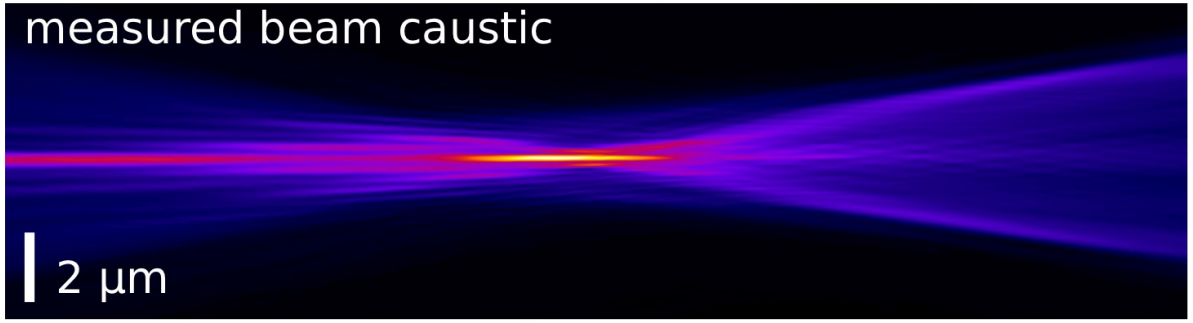
First users at SASE-1
Sept 2017

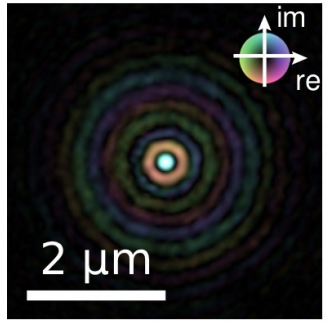
First beam at MID, Dec 2018

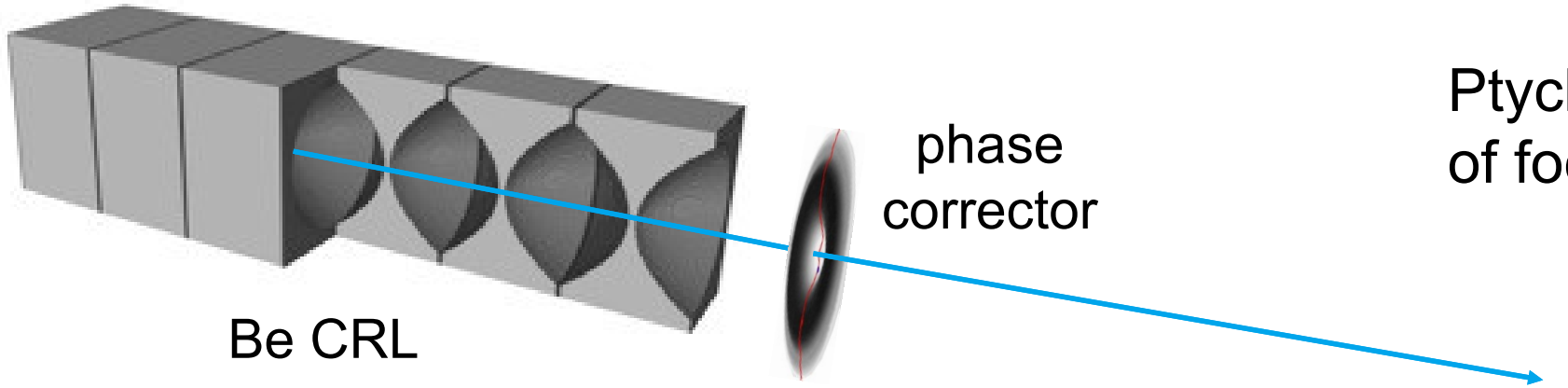




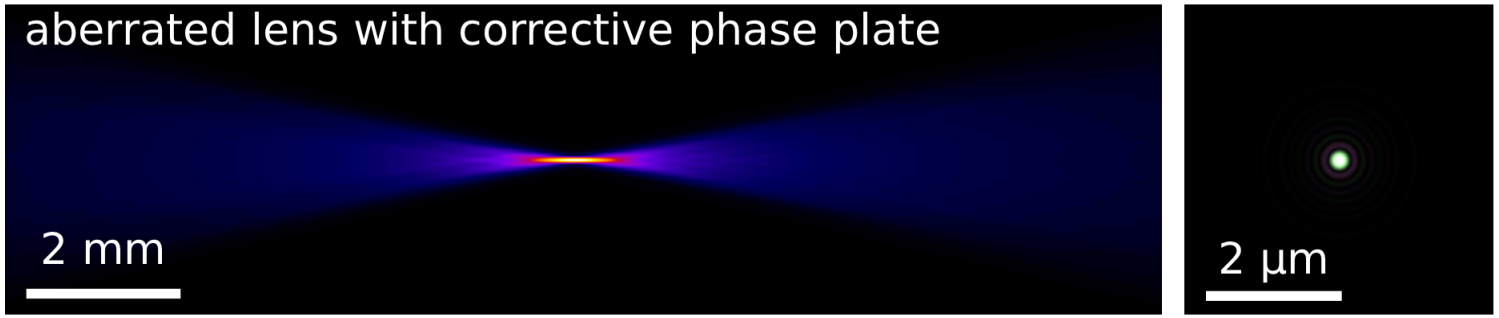
MID commissioning: nano-focusing







Ptychographic verification of focusing properties

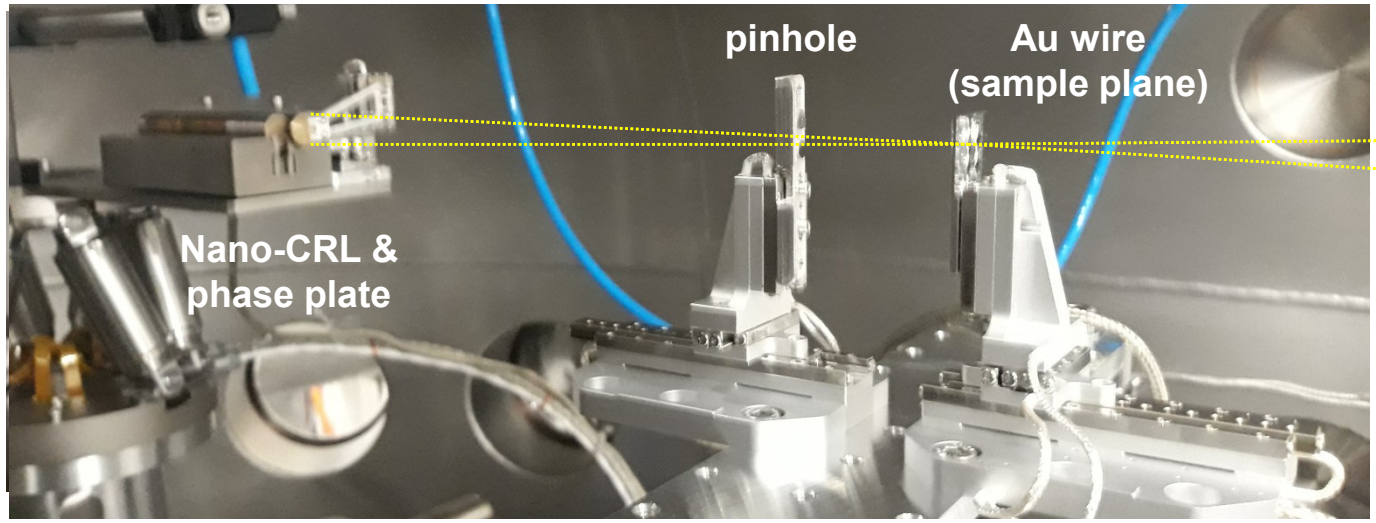


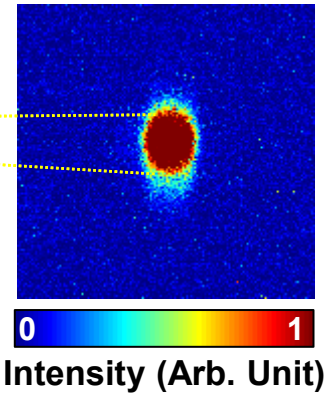
Seiboth *et al*,
Nature Comm. **8**:14623 (2017)

MID commissioning: nano-focusing

- Be is a good material for XFEL optics due to the high ablation threshold
- Ablation limits (~1eV energy absorbed per atom per pulse) are typically not reached for Be in the unfocused FEL beam

nano-CRL & phase plate





20 Be lenses
f=30 cm @ 9 keV

MID commissioning: nano-focusing

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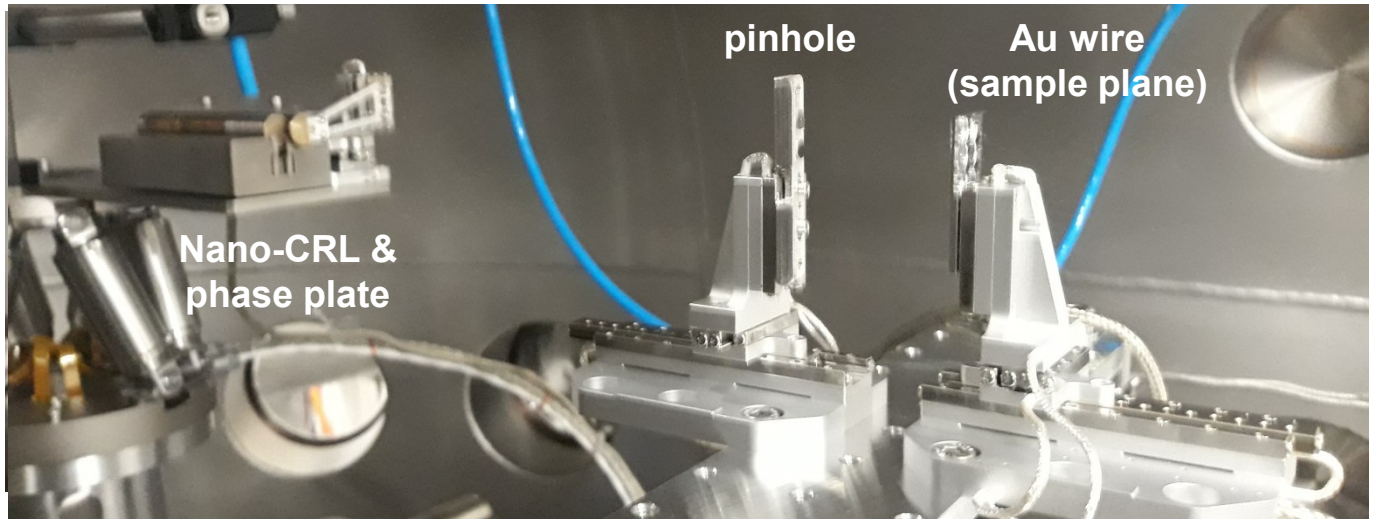
nano-CRL & phase plate



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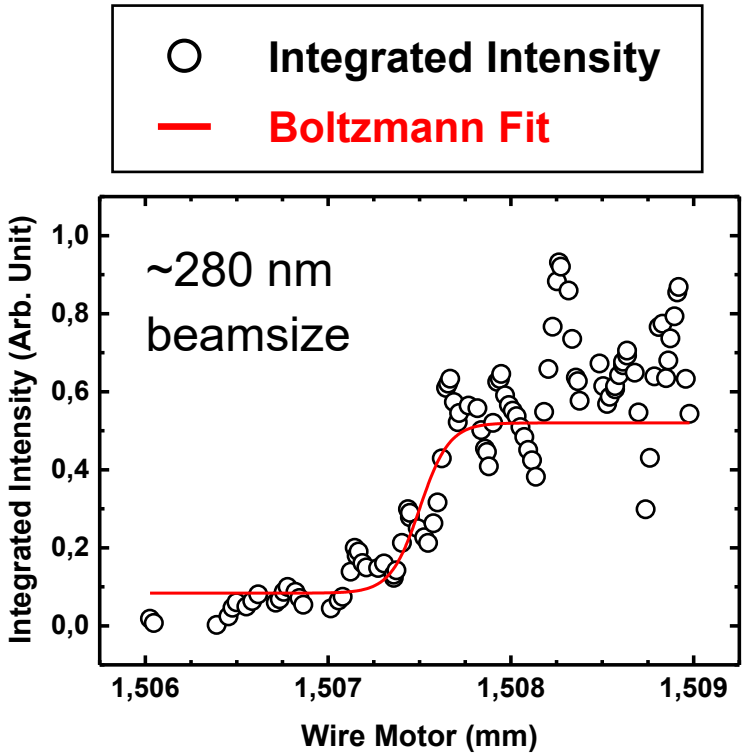
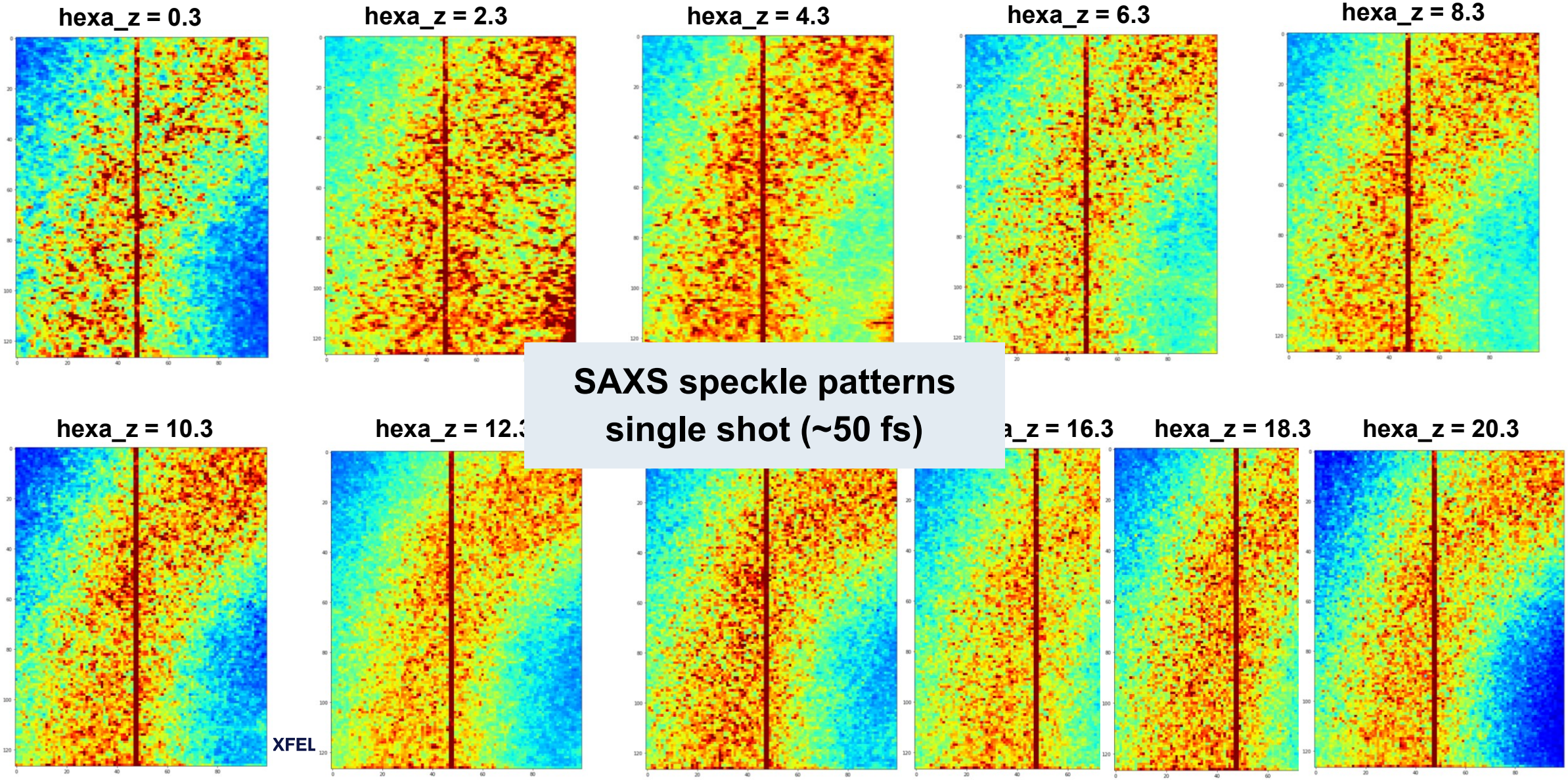
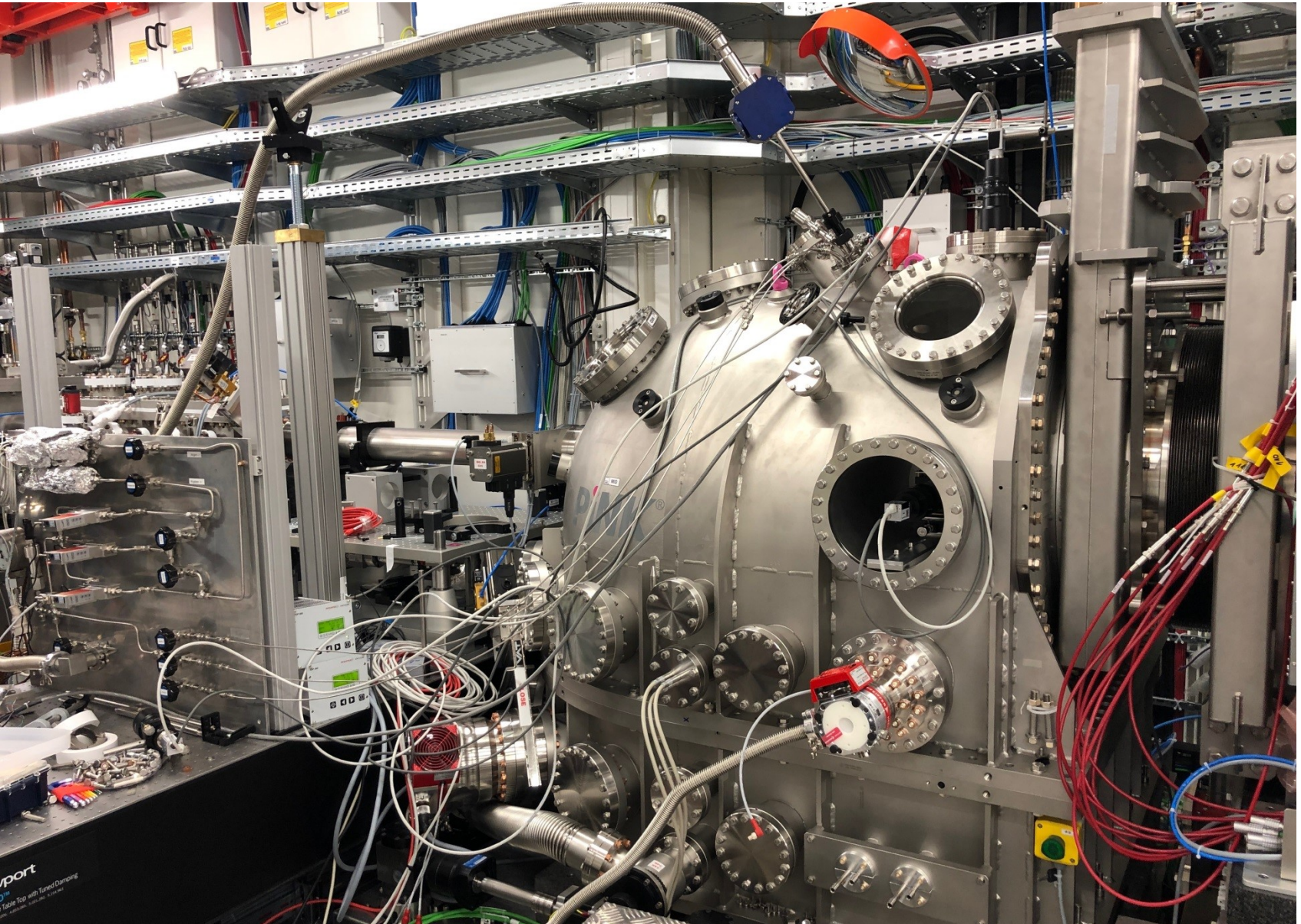


Au wire scans, 50 nm step size
Integrated over 1000 pulses

MID commissioning: nano-focusing



Jets of Ar and Kr in MID's vacuum chamber (#2272 and 2542)



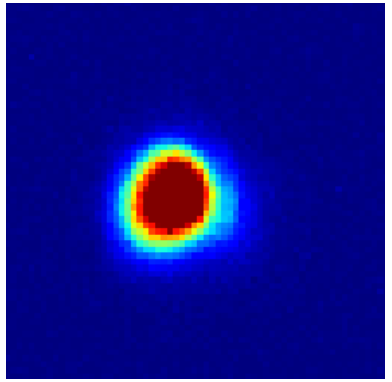
1st users at MID (#2272)
20-24 March 2019

Alexander Schottelius,
Robert Grisenti,
Anton Kalinin, et al.
Uni. Frankfurt and GSI

MID commissioning

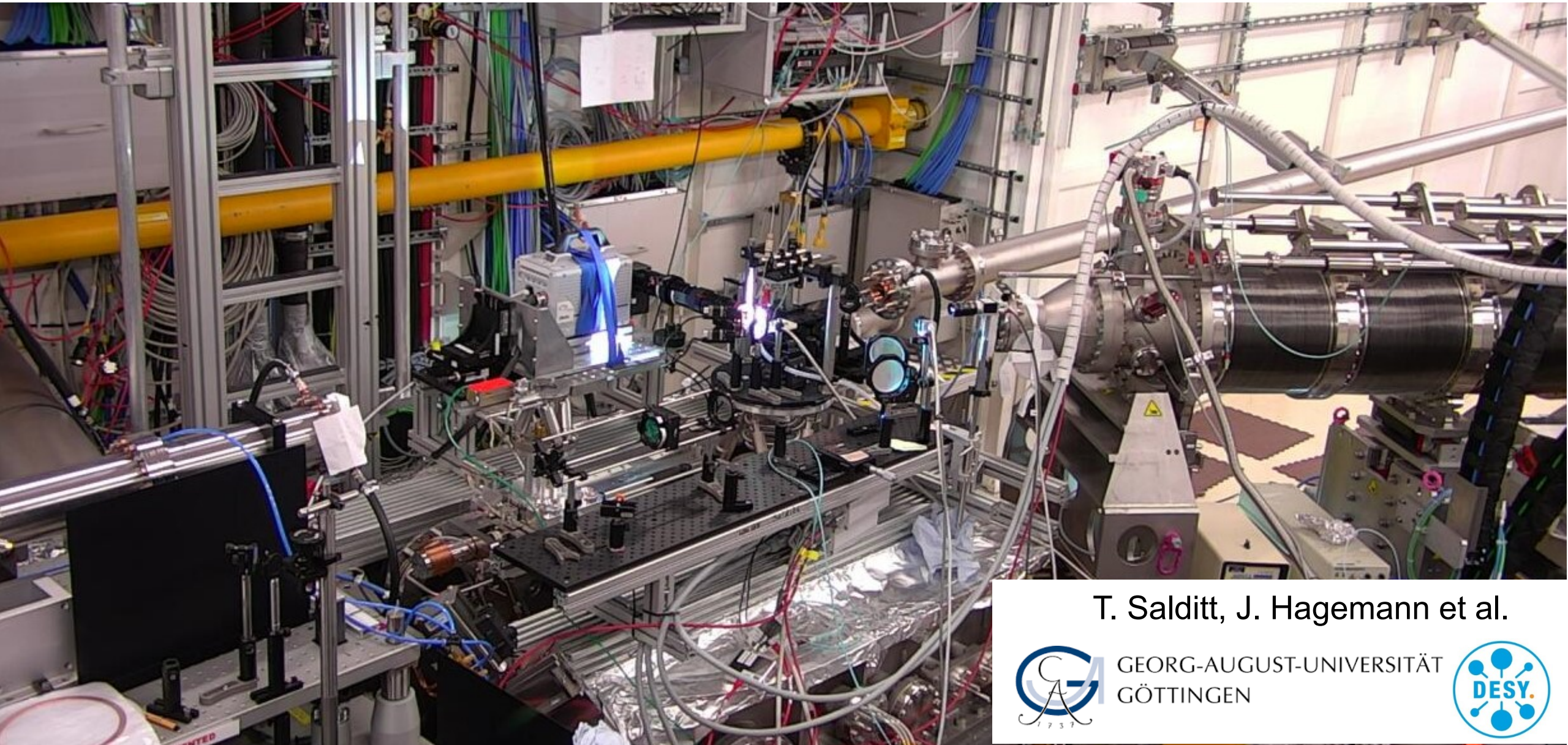
- Towards lasing at larger photon energy
  - 1st run with 16.5 GeV electron energy → 18 keV with good flux at MID (Oct 2019)

18 keV beam at MID
960 m from source,
730 m from collimating optics



~ 500 x 500 µm²

Time-resolved in-line holography of cavitation dynamics (#2207 & 2544)

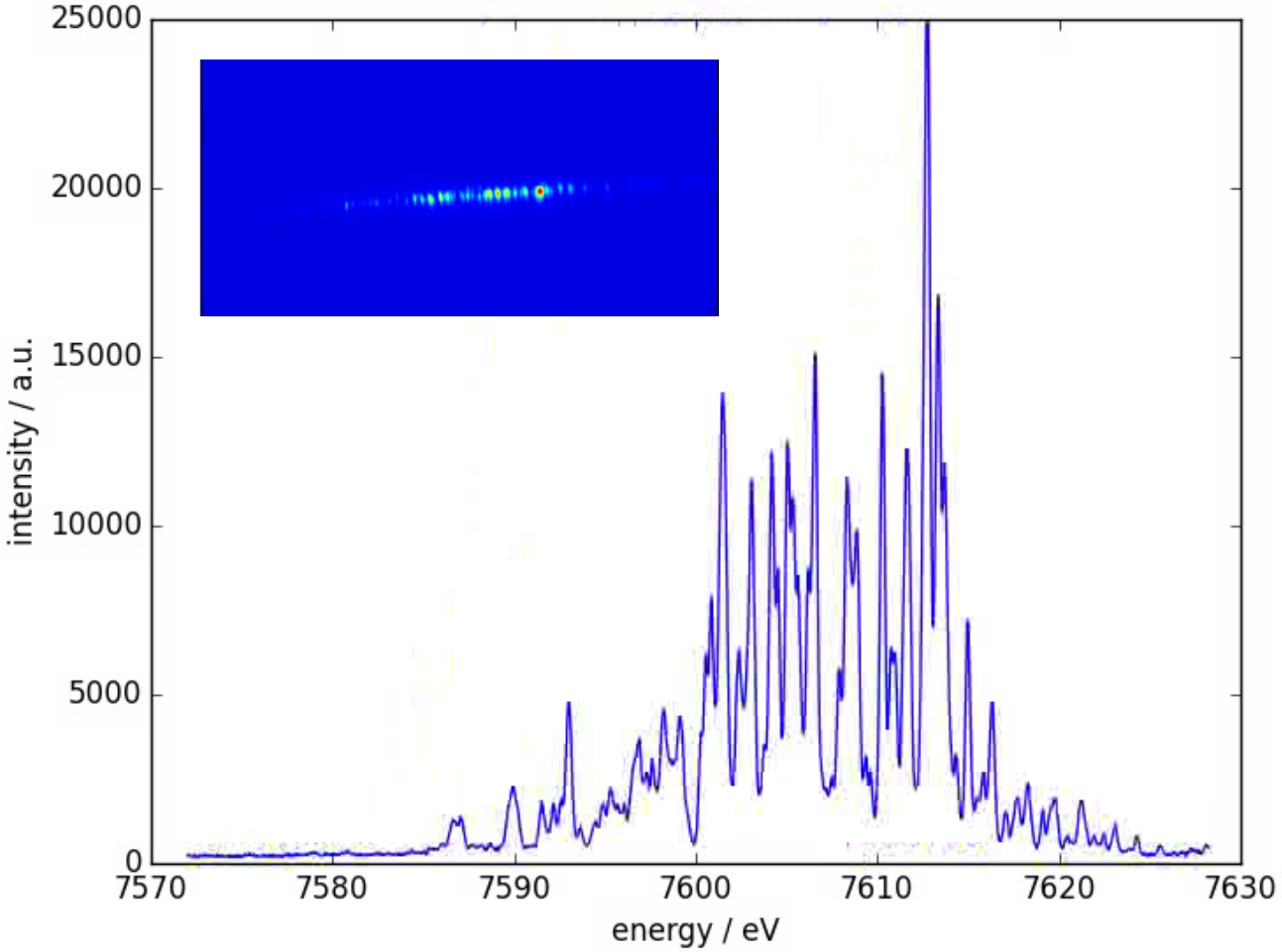


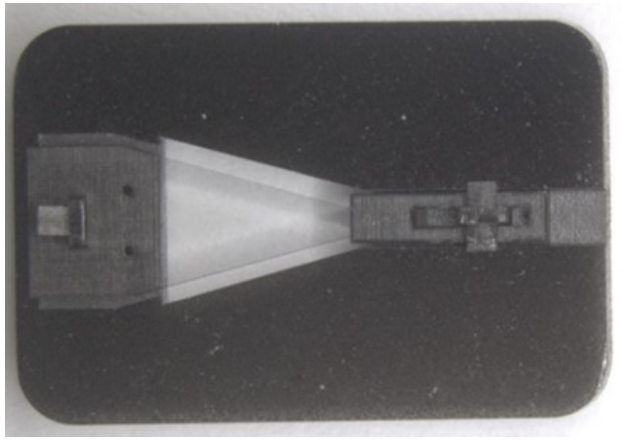
T. Salditt, J. Hagemann et al.

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

DESY.

Commissioning of single-pulse spectrometer (this week)





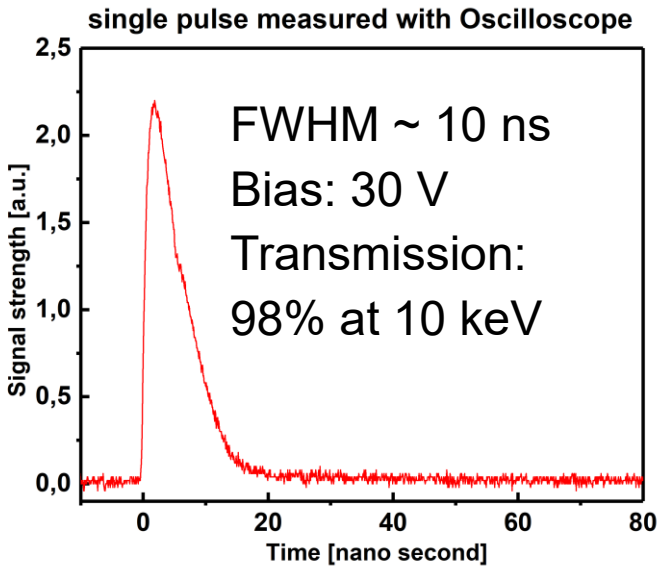
Diamond crystal bender C*(220)

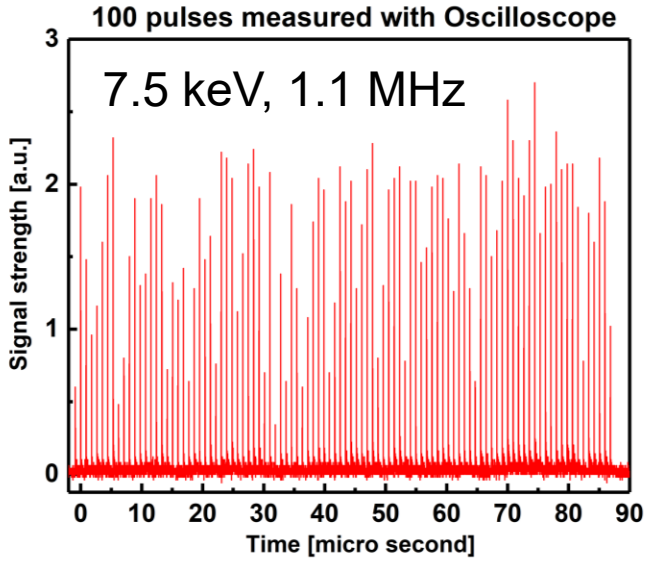
Pulse resolved spectra recorded at LCLS (120 Hz)

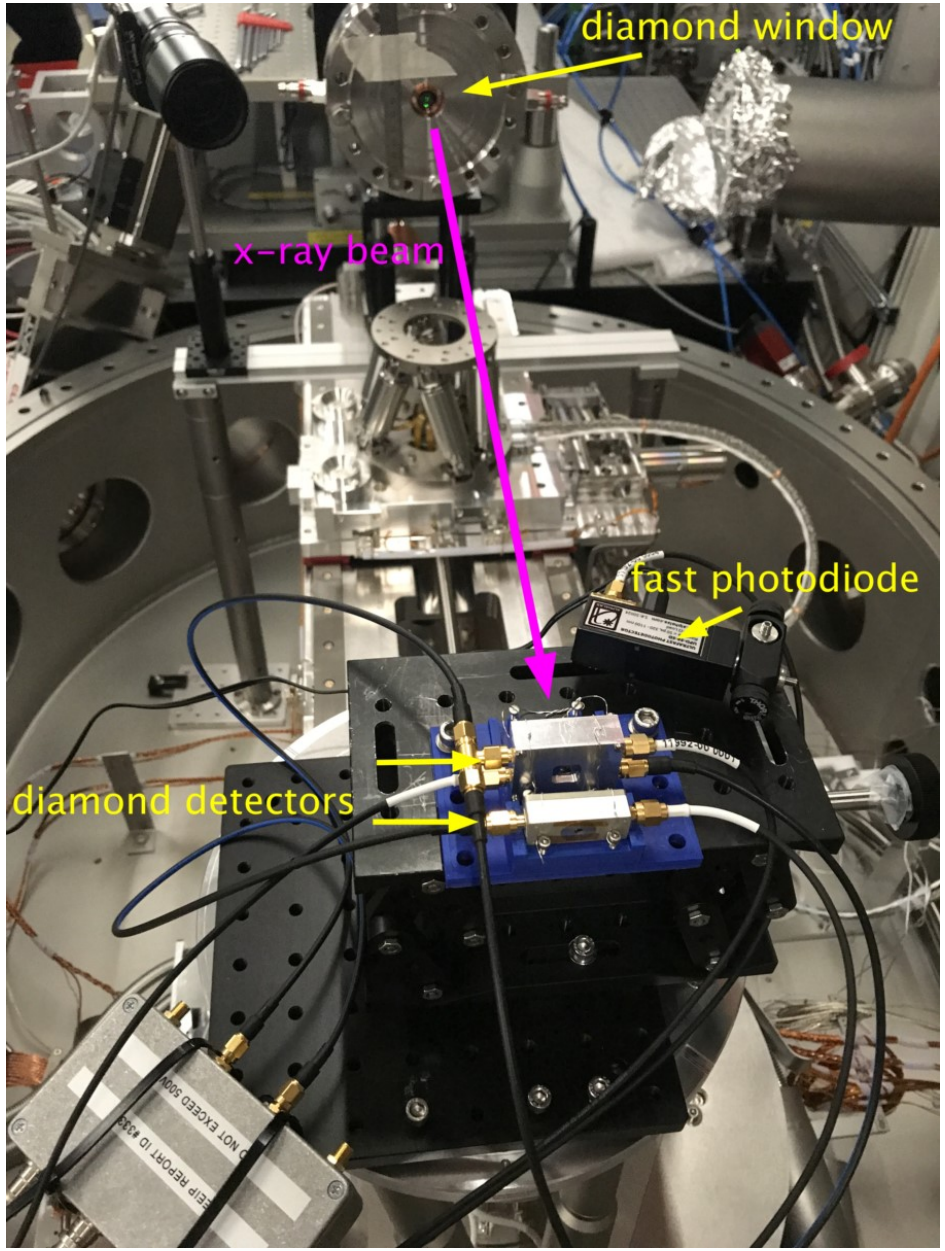
U. Boesenberg *et al.*, Optics Express **25**, 2852 (2017)

Diamond detectors and fast photodiode

- test with 9 keV, 120 uJ / 7.5 keV , 40 uJ
- In-air setup with 200 um SC-diamond window upstream
- Be and graphite-coated diamond detectors (I_0 monitor)
- Using oscilloscope and fast ADC digitizer boards

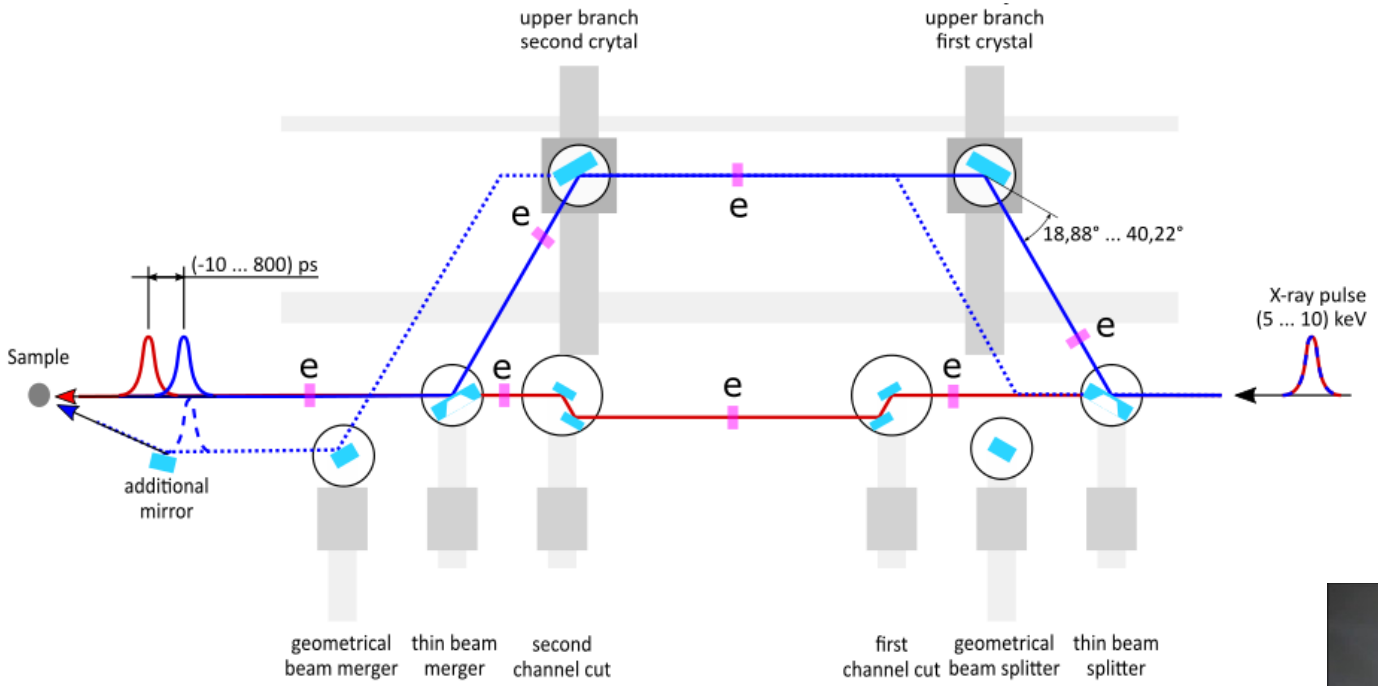




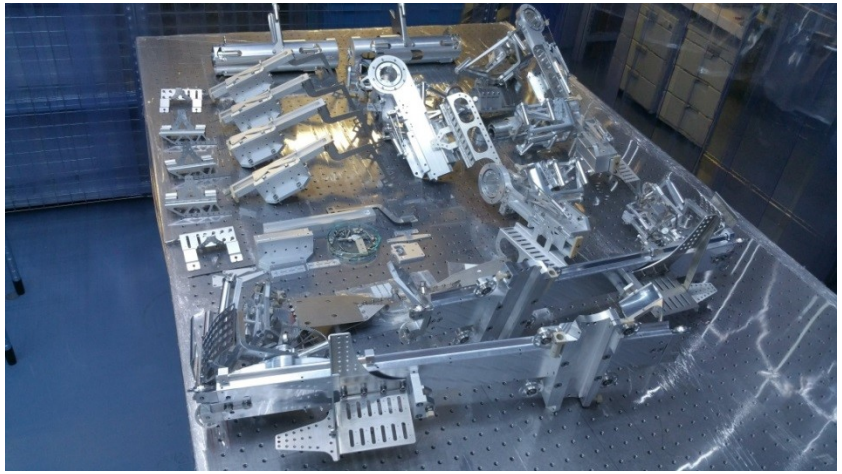


T. Roth *et al.*, J. Synchrotron Rad. **25**, 177 (2018)

Split-Delay line at MID (installation start: Dec 2019)

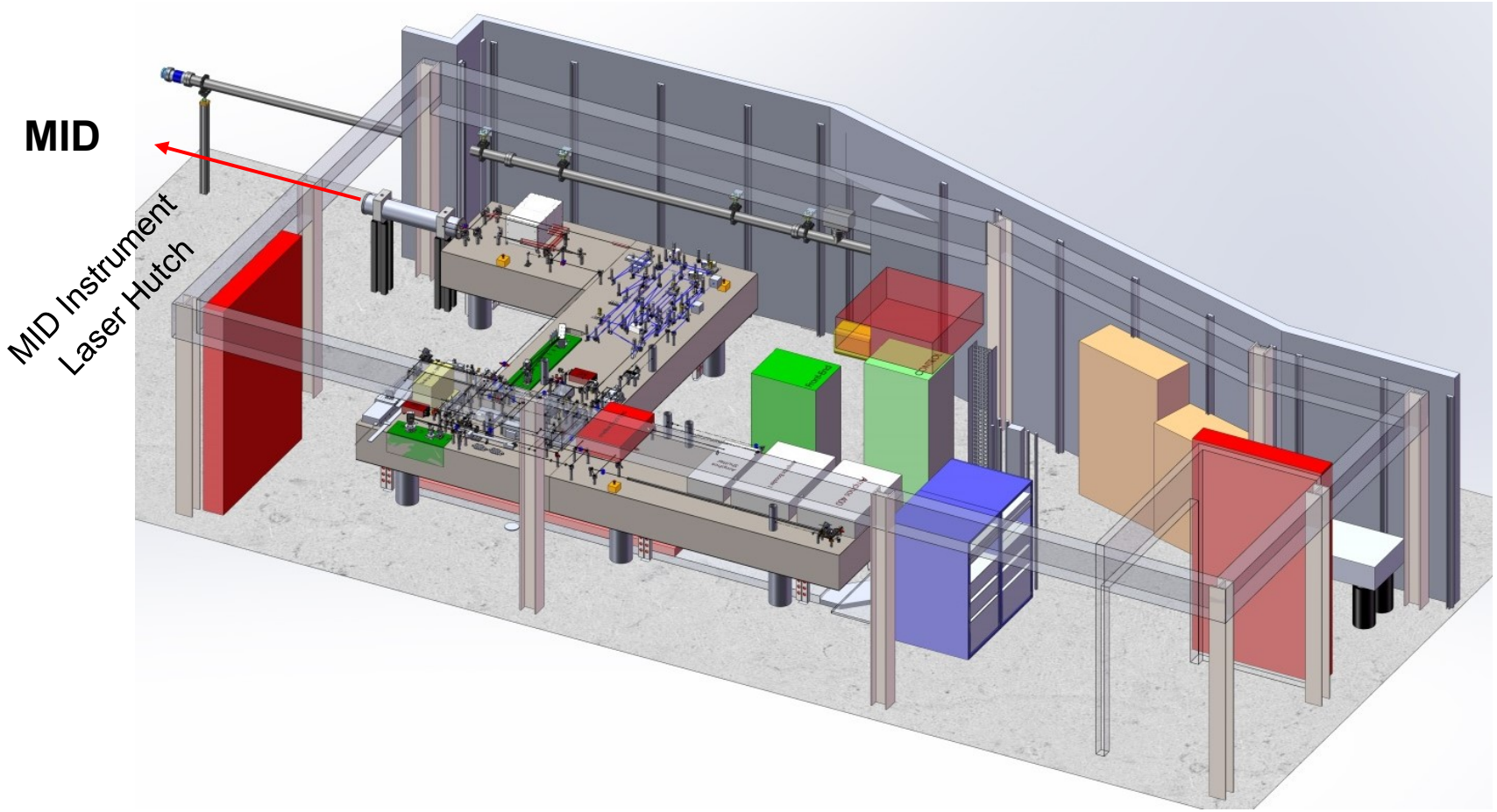


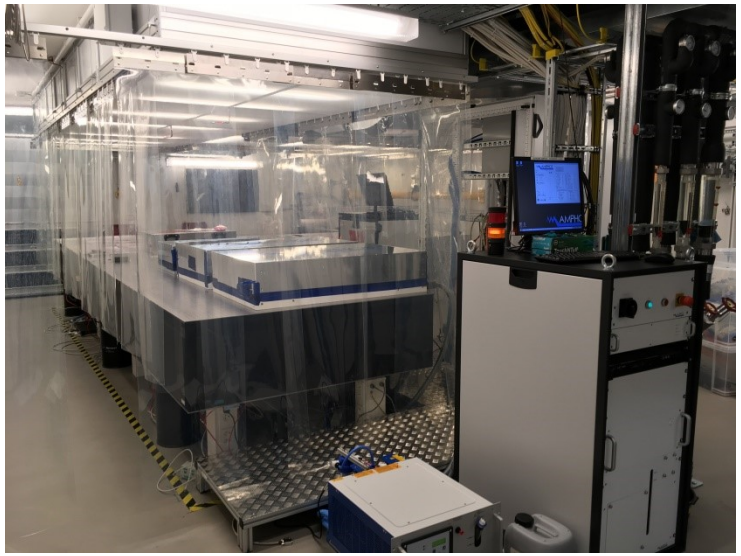
Inner mechanics

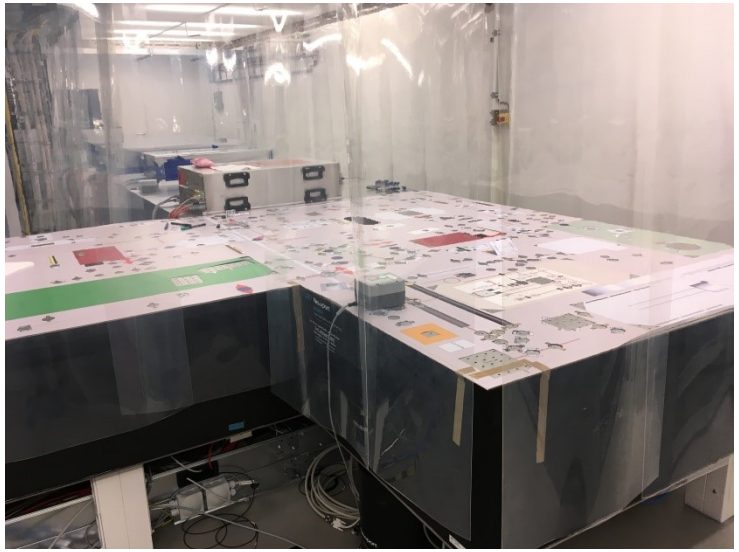


Max Born Institute
Eisebitt group

Femtosecond Pump laser for MID (commissioning start: Feb 2020)



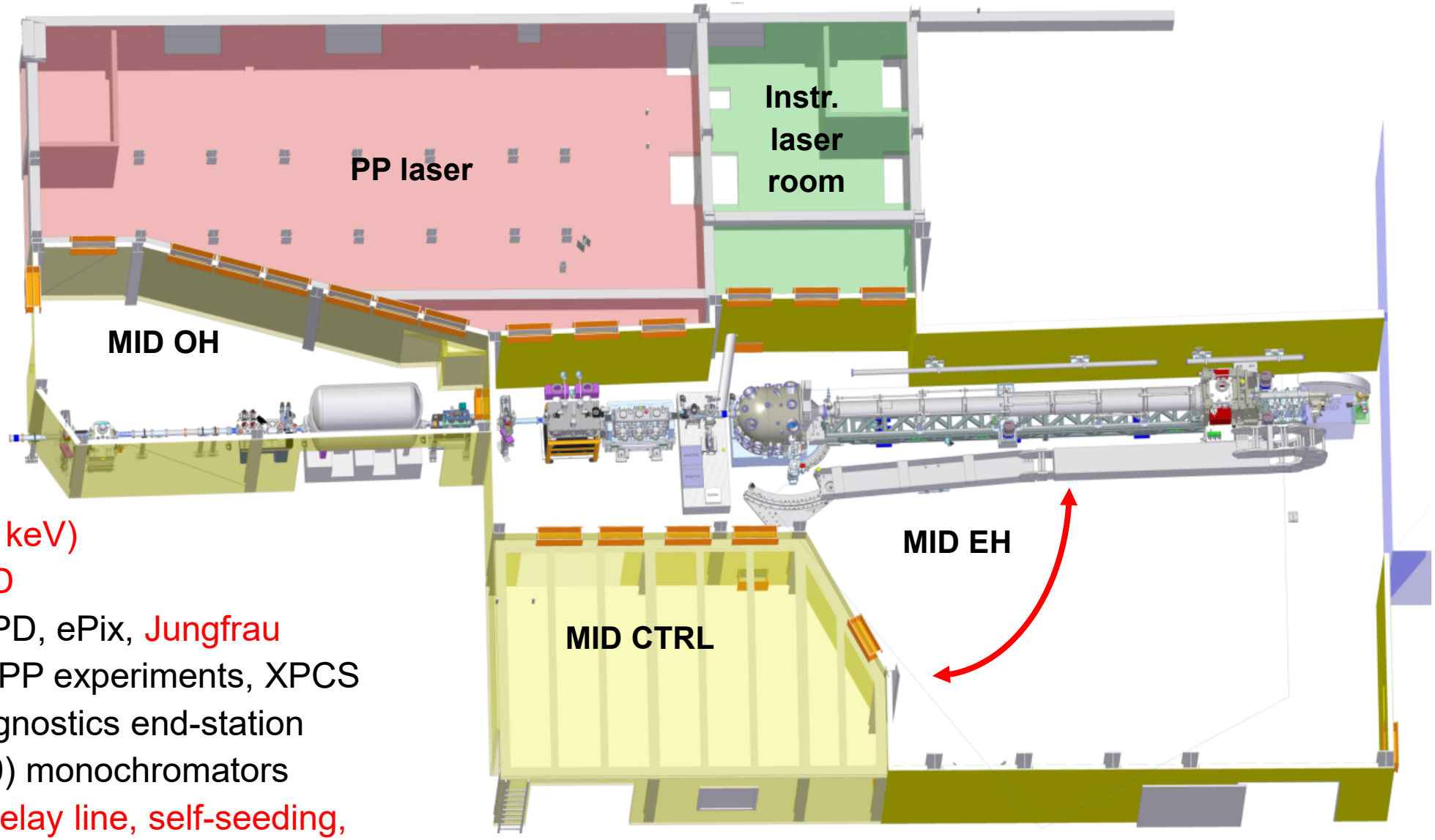




Hutches and infrastructure ready (AC, interlock, cooling, safety)
Laser tables and major sub-systems installed, laser installation ongoing

Courtesy Max Lederer (EuXFEL laser group)

MID overview



7 - 18 keV (5 – 25 keV)
SAXS, WAXS, GID
MHz rep rate AGIPD, ePix, Jungfrau
speckle, imaging, PP experiments, XPCS
nanofocusing, diagnostics end-station
Si(111) and Si(220) monochromators
fs PP-laser, split-delay line, self-seeding,

MID

Materials Imaging and Dynamics

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https://www.xfel.eu/facility/instruments/mid/index_eng.html

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