Dynamic laser compression at XFELs

pushing boundaries and identifying challenges

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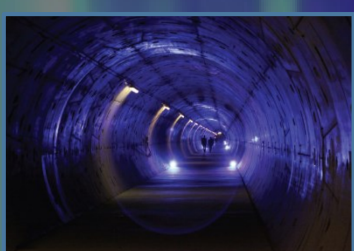
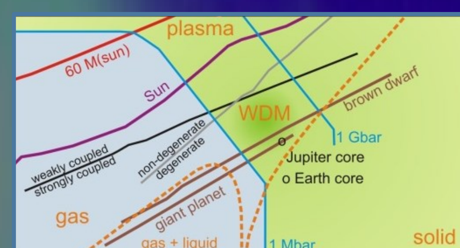
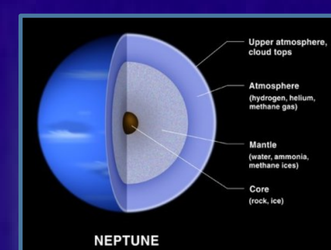
ESRF, 29-30 March 2017

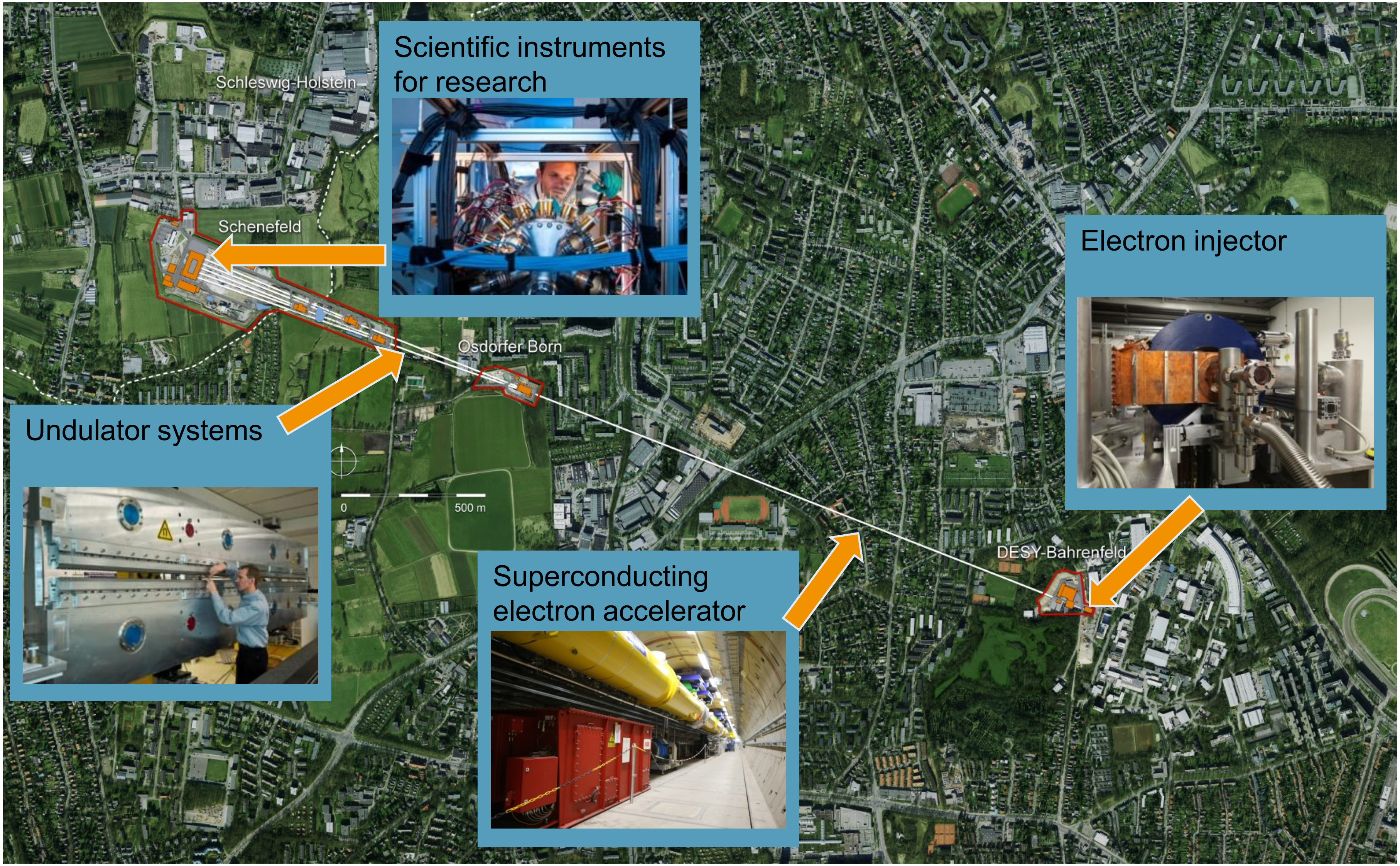






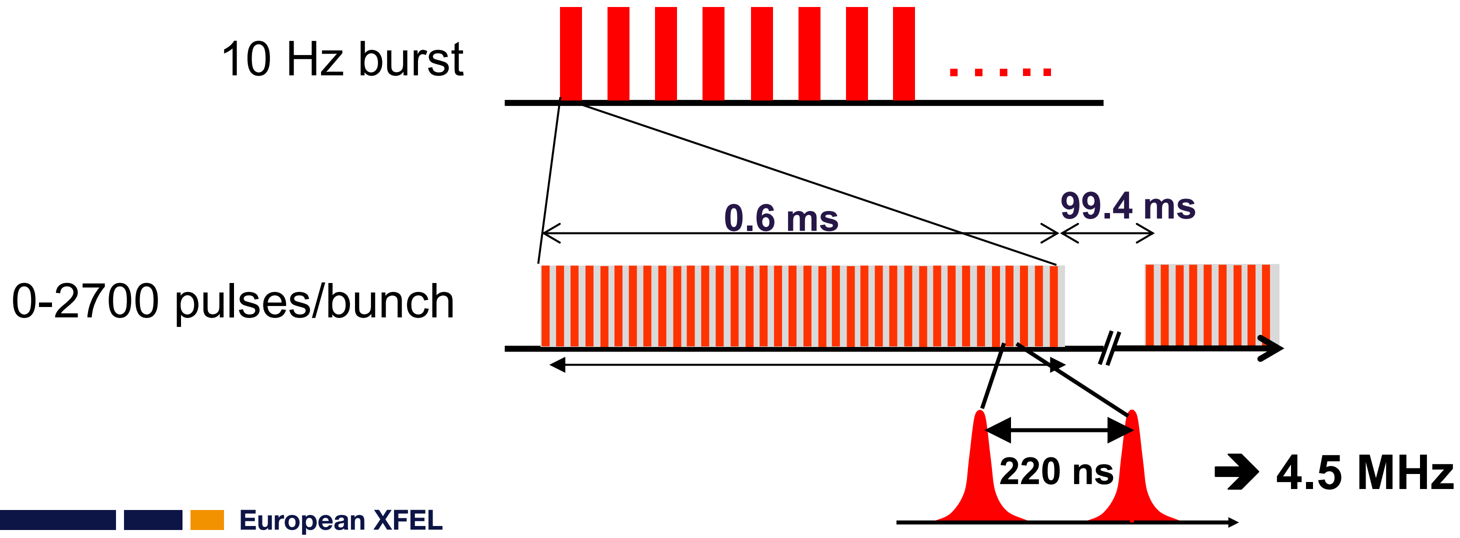
European XFEL—a leading new research facility

How it works: a closer look at the facility



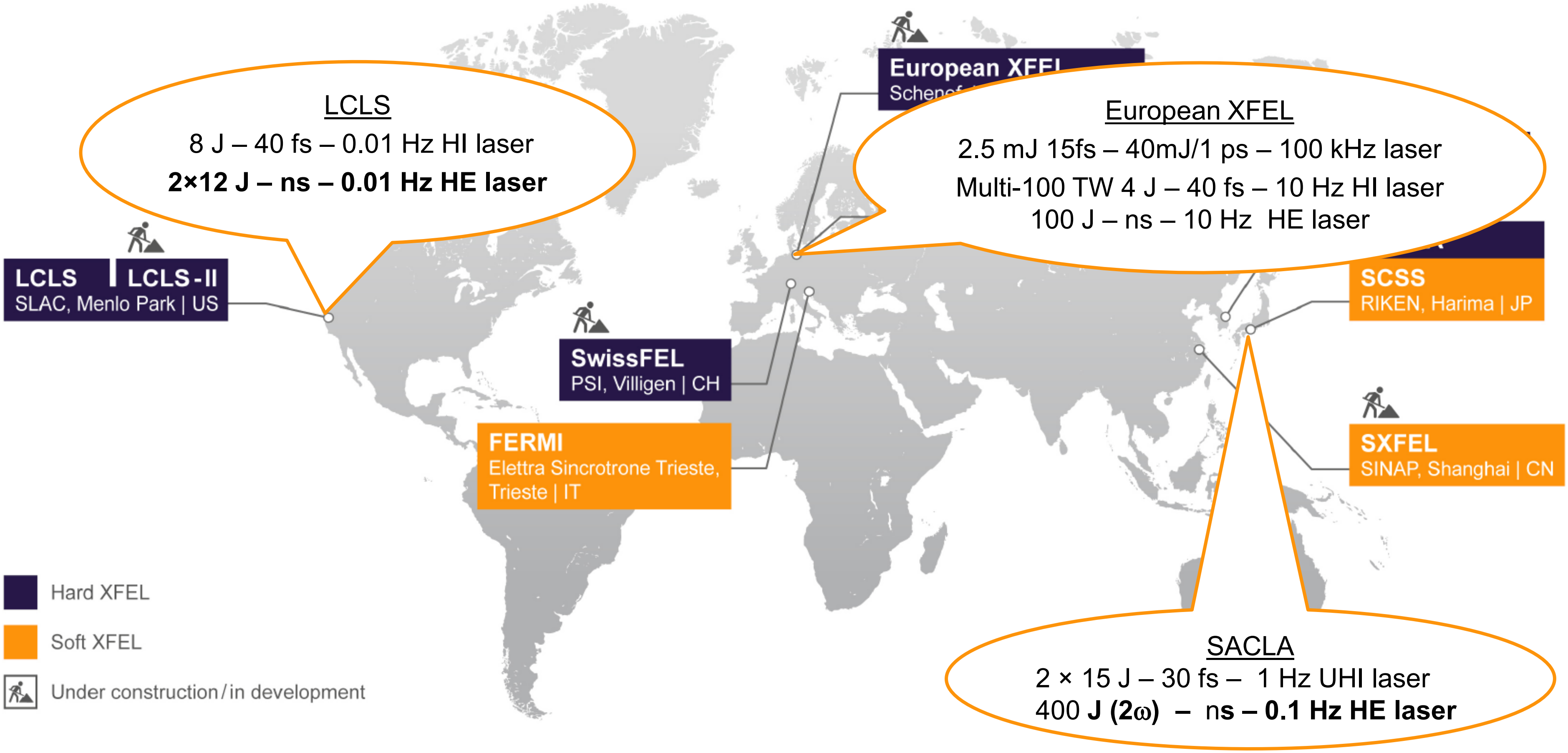
XFEL properties at the HED instrument (SASE2)

Fully tunable between	3 – 25 keV (3 – 5 keV with limited performance)
Pulse duration	2 – 100 fs
Number of photons per pulse	~10^{12} (25 keV), ~10^{13} (5 keV)
Spot size on sample	sub-μm (HIBEF), few μm, 20 – 30 μm, 200 – 300 μm, few mm
Seeded beam	First SASE beamline to be seeded; available soon after initial commissioning
Repetition rate	shot on demand (pulse picker), 10 Hz – 27000 pulses/sec

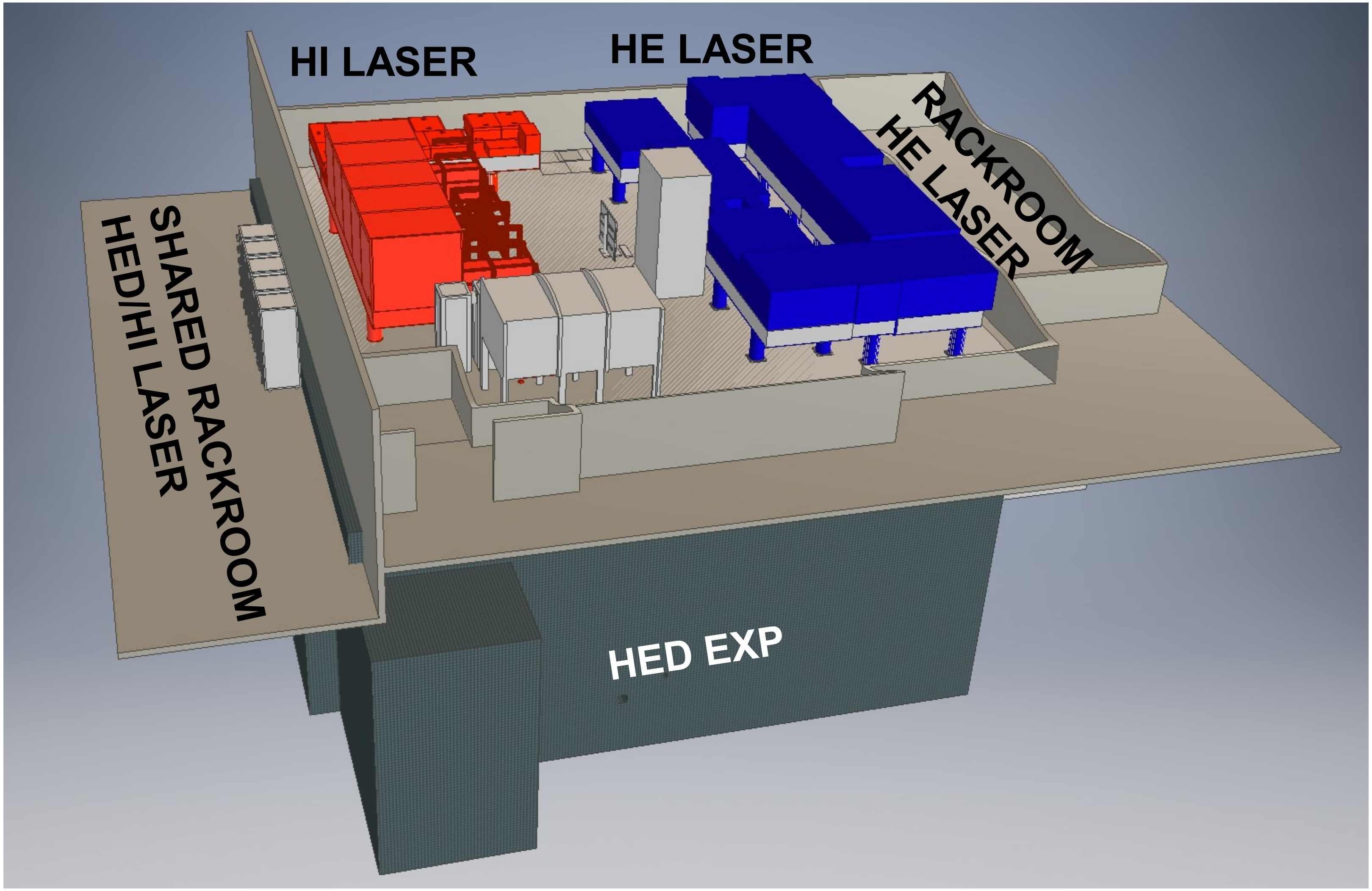


X-ray free-electron lasers worldwide

with big OLs



laser locactions – on the roof of concrete enclosure!

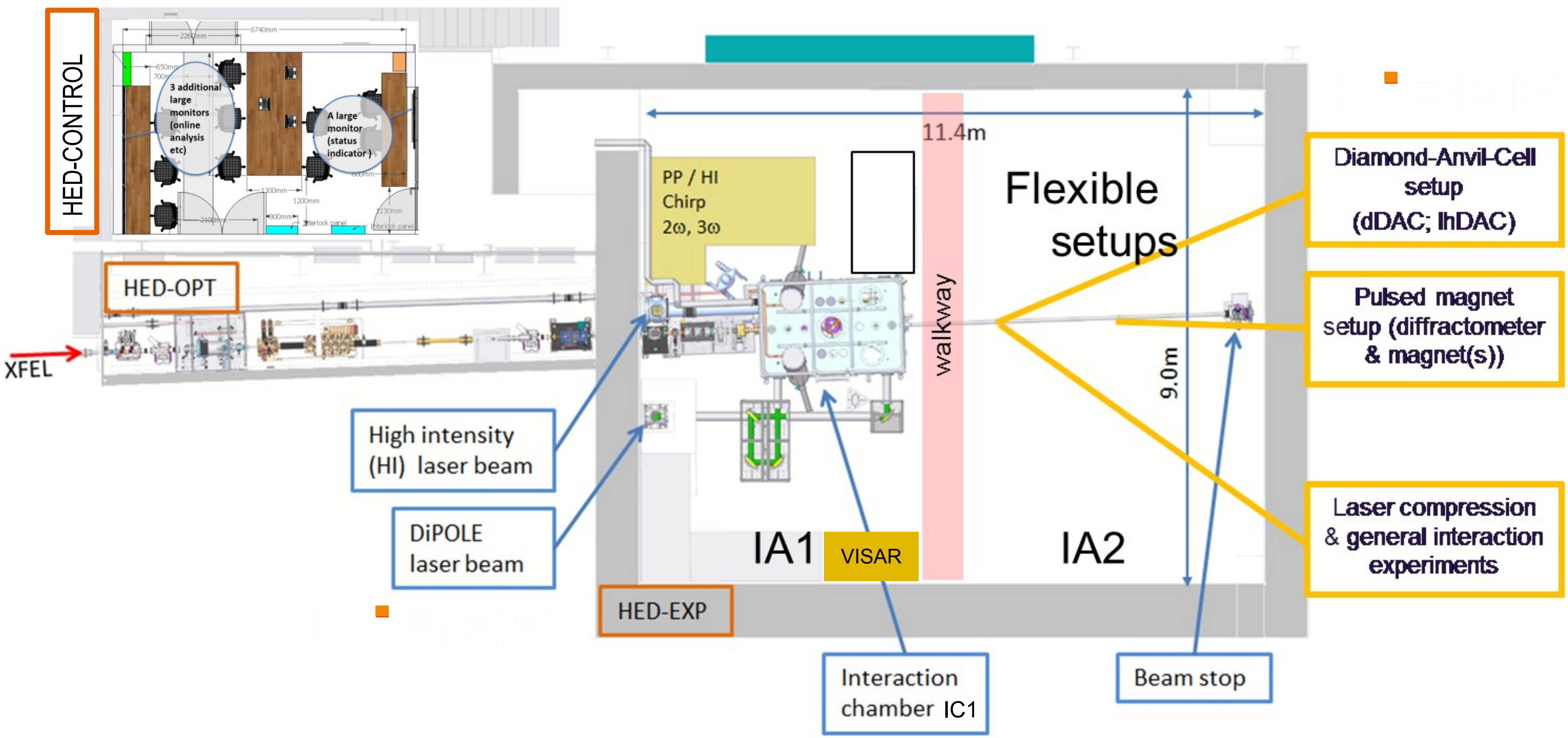


DiPOLE 100-X properties

- >100 J @ 10 Hz
- 2-15 ns pulse
- pulse shaping
- 2ω conversion
- delivery mid 2018
- User operation in 2019

- UK contribution in kind
- EPSRC – Oxford University
- STFC – Central Laser Facility
- Designed, built and commissioned at CLF, Rutherford Appleton Laboratory, UK
- Decommissioned, packaged & shipped to European XFEL

HED hutch overview



Conceptual Design Report: Dynamic lasesr compression at European XFEL

HED
High-Energy Density science

Workshop: Dynamic Laser Compression Experiments at the HED instrument at European XFEL

12-14 September 2016 *European XFEL Schenefeld*
Europe/Berlin timezone

Search

Overview

The workshop is over.

This site serves now as repository for the pdf files of the given presentations as well as the Draft of the Conceptual Design Report. Please find the material as link at the end of this page. Except the workshop programme, these are password protected and only visible for active participants. If you would like to get access, please contact the local organizers.

Local Organizing Committee

- H.-P. Liermann (DESY) - hanns-peter.liermann@desy.de
- U. Zastrau (European XFEL) - ulf.zastrau@xfel.eu

Dates: from 12 September 2016 12:30 to 14 September 2016 11:30
Timezone: Europe/Berlin
Location: *European XFEL Schenefeld*
Material: CDR Draft
Talks
Workshop program

XFEL.EU TR-2017-001

CONCEPTUAL DESIGN REPORT

Dynamic Laser Compression Experiments at the HED Instrument of European XFEL

February 2017

Malcolm McMahon and Ulf Zastrau (Editors)
for HIBEF and European XFEL

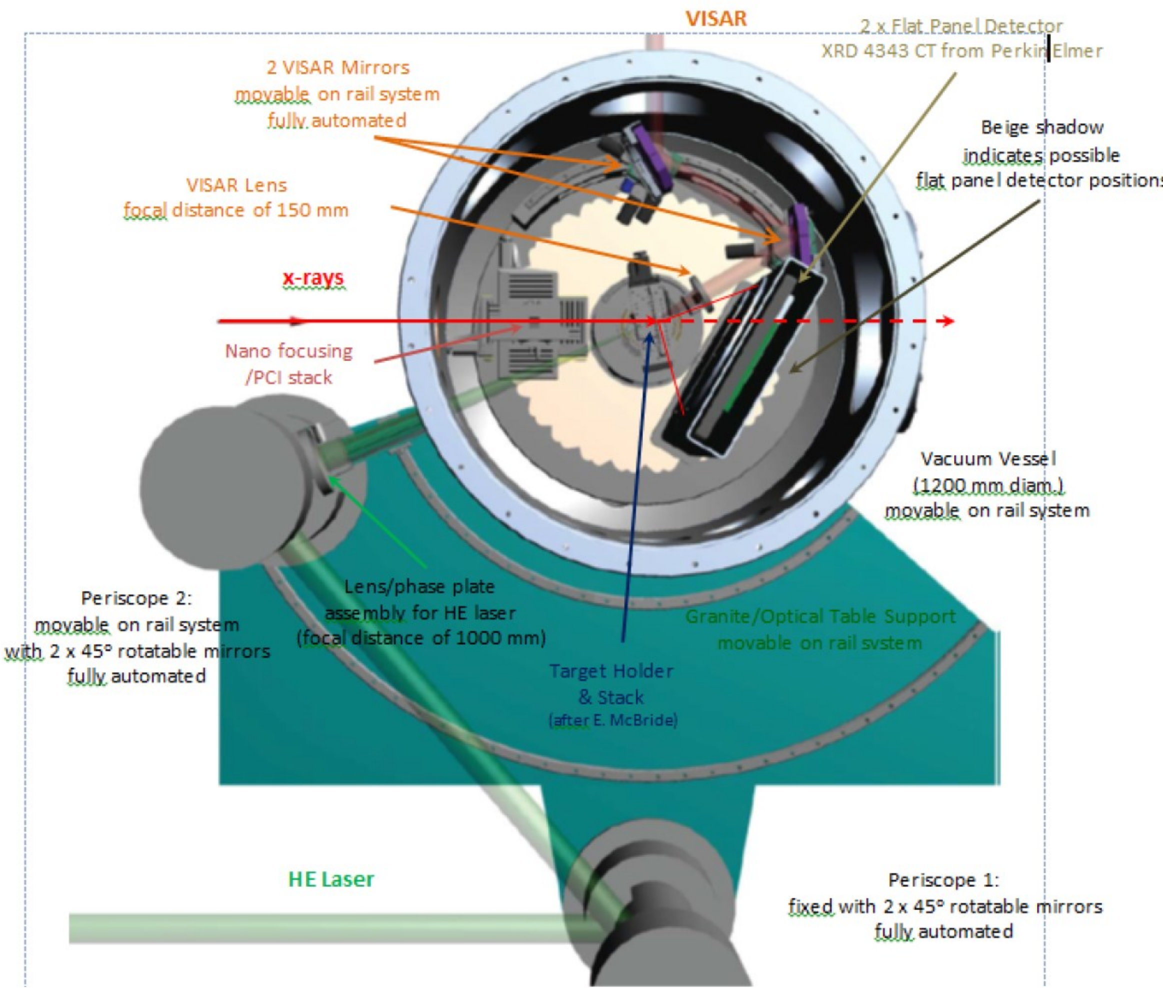
HiBEF European XFEL

- CDR published: go to XFEL HED website, under „documentation“ http://www.xfel.eu/research/instruments/HED
- http://dx.doi.org/10.22003/XFEL.EU-TR-2017-001

XRD Perspectives at HED, European XFEL

- DiPOLE 100-X laser (HIBEF / STFC) with 100 J at 10 Hz, 2ω
  → go beyond current repetition rates of one shot every few minutes
- Photon energies up to 25 keV
  → collapse *q*-space forward
- DiPOLE focus >100µm
- Pulse shaping with few-% accuracy
- Large area detector
  → Increase *q*-range
  → texture analysis
- Proposal by HIBEF UC for a dedicated chamber:

courtesy HP Liermann, J Eggert et al., Draft CDR on Dynamic Compression



Call for proposals

- Timeline not entirely fixed, best estimate currently:
  - First call for SASE1 instruments (FXE and SPB/SFX)
    - ► published 23 Jan 2017
    - ► Experiments in second half 2017
  - Second call + 6 months
    - ► published June-August 2017
    - ► Experiments in first half 2018
    - ► SASE1 + SASE3 instruments
    - ► SASE2 (HED, MID) depends on performance
  - Third call + 6 months
    - ► Published in Dec 2018 if possible
    - ► For second half of 2018 → all instruments
  - Fourth call + 6 months most likely with all HIBEF lasers (depending on perfomance)
- XFEL may ask for feedback by SAC for the first intervals for calls

3rd and 4th generation light sources - Competitive or complementary?

	European XFEL, HED	ESRF, HPLF
Pulse length	< 100 fs	100 ps
Energy range	5 - 25 keV	5 keV - 25 keV - > 60 keV
# of photons/pulse	10^{13} - 10^{12} on target, focused	10^{10} -10^{9}-10^{8} from source, w/o optics
bandwidth	SASE and seeded (~0.1% bw)	~3% bw - ~1% bw

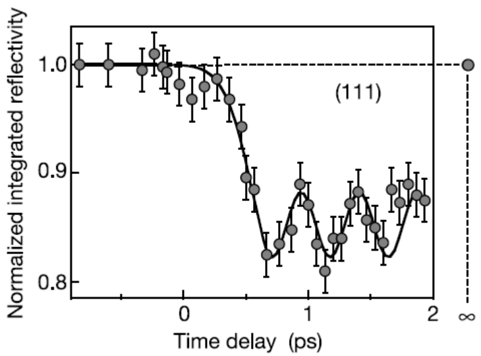
XFEL: observing ultrafast phase transitions

- how fast is a phase transition?
  - magnetic phase transitions may occur on the order of 100 ps or quicker
    (only electronic response, spin state changes)
  - Crystallographic twinning may occur of order < 100 ps
    (work by Sebastien Merkel et al.)

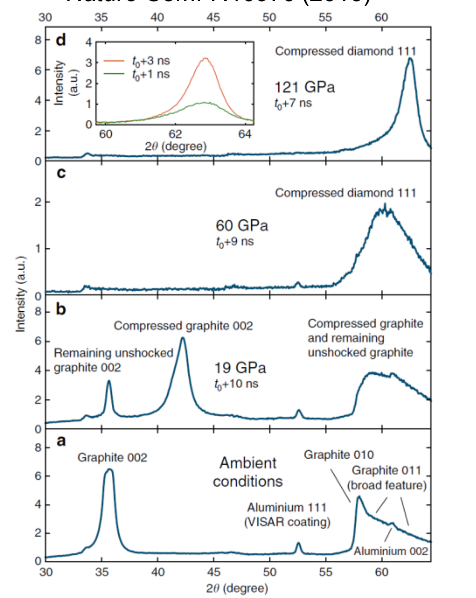
  - structural changes might also be as fast as 100 ps (of order phonon dynamics)
    - ► Fastest phase transition = typical phonon period
      example Bi (467 fs, electronic) XRD oscillations
    - ► References:
      - Work by Norimasa Osaki & Marion Harmand
      - proton heating results in fast phase transition
        work by Pelka et al., PRL **105** (2010): melting < 18 ps
        Y. Sentoku et al., Physics of Plasmas 14, 122701 (2007)
        P. K. Patel et al., Phys. Rev. Lett. 91, 125004 (2003)

  - if a (transient) phase lives for less than 100 ps, measurements are blurred due averaging over different states when done at synchrotron

Sokolowski-Tinten *et al.*,
Nature **422**, 287-289 (2003)

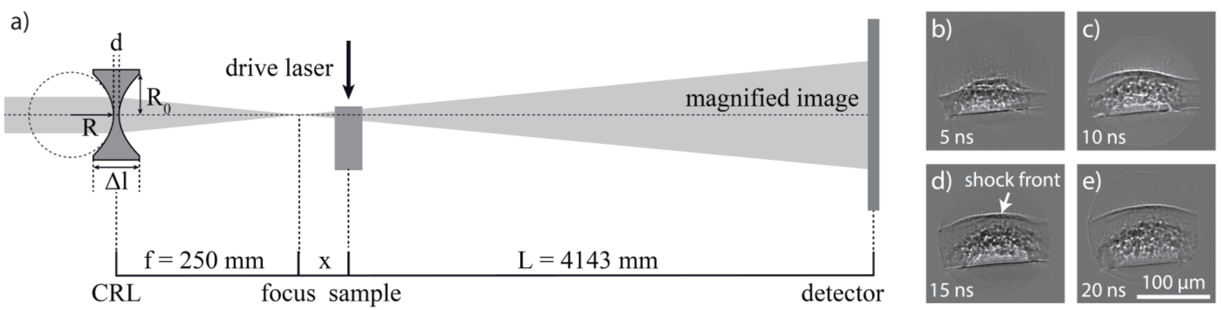


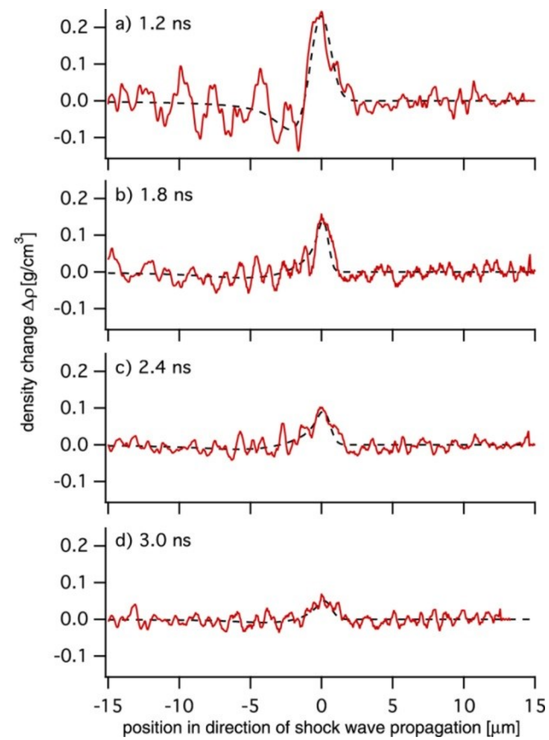
Kraus *et al.*,
Nature Com. 7:10970 (2016)



XFEL: transient phases, 90° geometry XRD, PCI

- For strong (fast) shocks, 100 ps could be on the (long) edge for hydrodynamic evolution in strong shocks (ramps might be safe).





Schropp et al., *Sci. Rep 2015*, **5**, *11089*

-

- 90° geometry (90° between shock propagation and x-rays)
  - Diagnostics could be phase contrast imaging (PCI) and/or diffraction (XRD) - *Nagler, Schropp et al., RSI 87, 103701 (2016)*
  - Shock speed 10 km/s = 1 nm/ 100 fs = 1 µm/ 100 ps
  - sharpness and fringes in shock front may be blurred
  - Fine structure in shock front (denting, instability growth, ...) might be washed out

- Additionally, PCI might need the higher photon number and coherence of an XFEL → talk by A. Schropp

Synchrotron: XRD, XANES

- XRD → generally better done at synchrotrons
  - Higher photon energy than 25 keV (current limit at XFEL.EU)
  - large detectors that are already available.

  - However, XFELs have advantages for:
    - ► Combine XRD with collective (plasmon) IXS
      → need < 10 keV photon energy
    - ► Transient and/or ultrafast phase transitions, high strain rates (strong shocks)

  - Do we benefit from „snapshots“ in shorter than a phonon period?

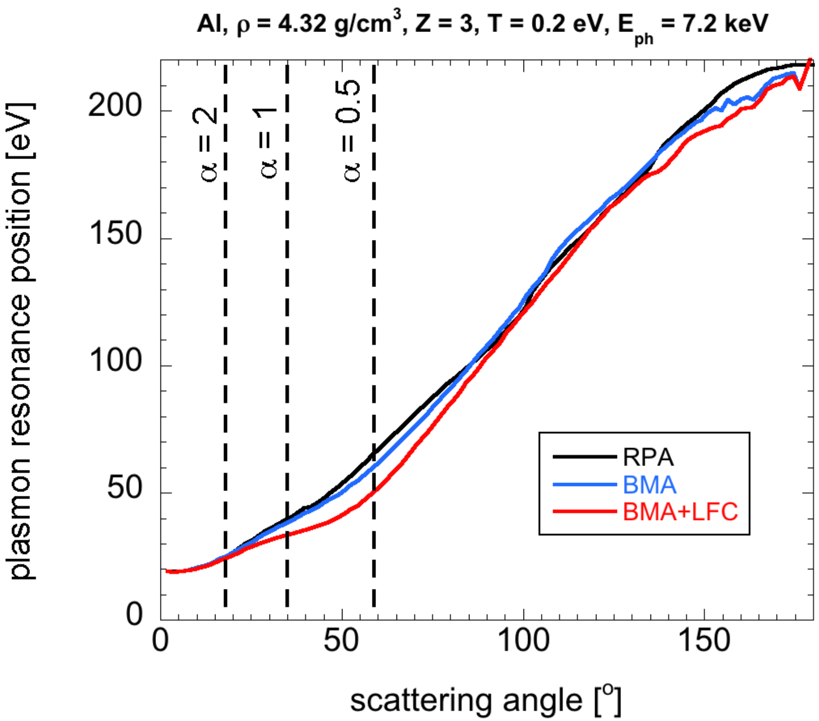
- XANES → generally better done at synchrotrons
  - wider bandwidth 1-3% b.w. (after upgrade)
  - Shot-to-shot reproducibility
    no SASE spikes, XFELs lack good incident spectrum monitor
  - Expert for XANES at XFELs → talk by Marion Harmand

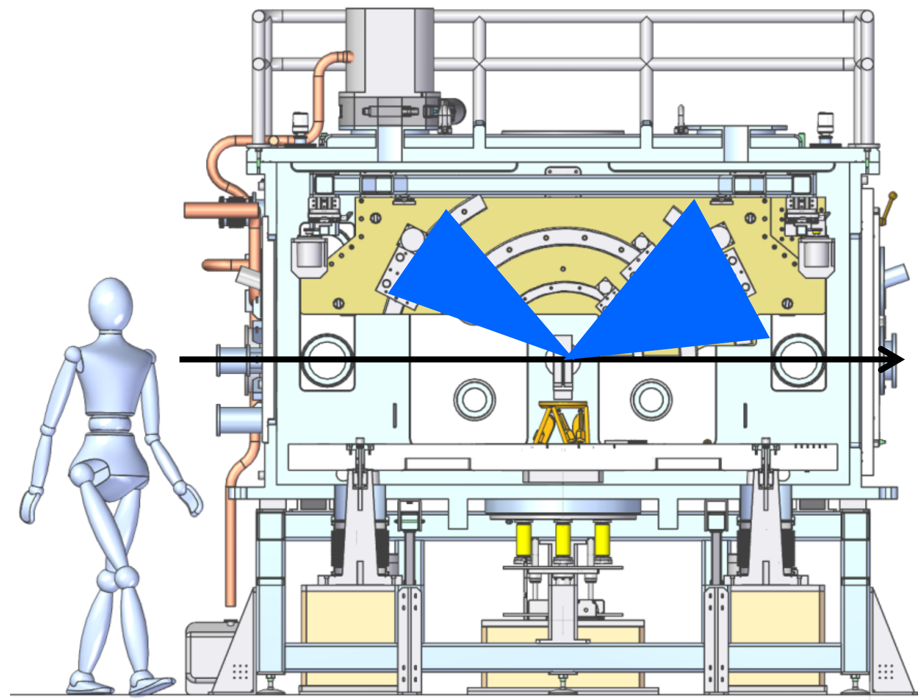
Emission spectroscopy

- Typically, the X-ray Kβ line shapes are analyzed
- x-ray emission scan of K-edges (pumping, IPD)
  - Narrow bandwidth → XFEL
- x-ray resonant / two-photon (DCH, beat the Auger clock)
  - high intensity & short pulses → XFEL
- Potential challenge for both facilities:
  - fluorescence/IXS from plasma might be stronger than X-ray emission
    → More photons at XFEL might be an advantage

IXS Plasmon Perspectives at HED

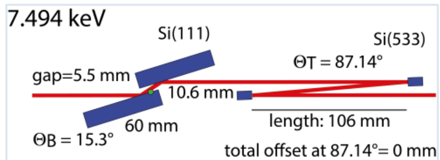
- Seeding availble, 4-bounce monochromator available, ΔE ~ 1eV
- HAPG spectrometers on curved rails to scan scattering angles
- Measure plasmon dispersion in compressed matter ~ 1Mbar
- Distinguish between collision models and local field corrections

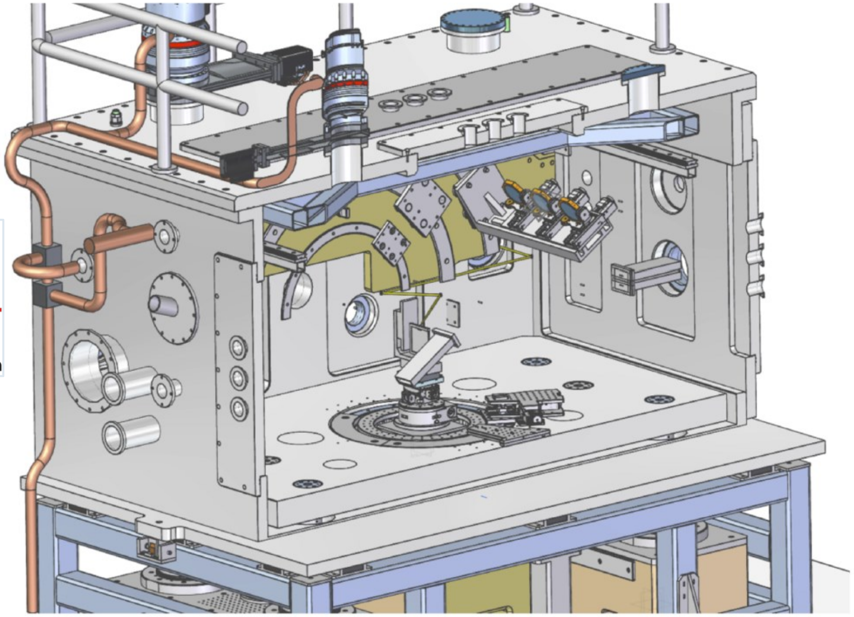




hrIXS perspectives at HED, European XFEL

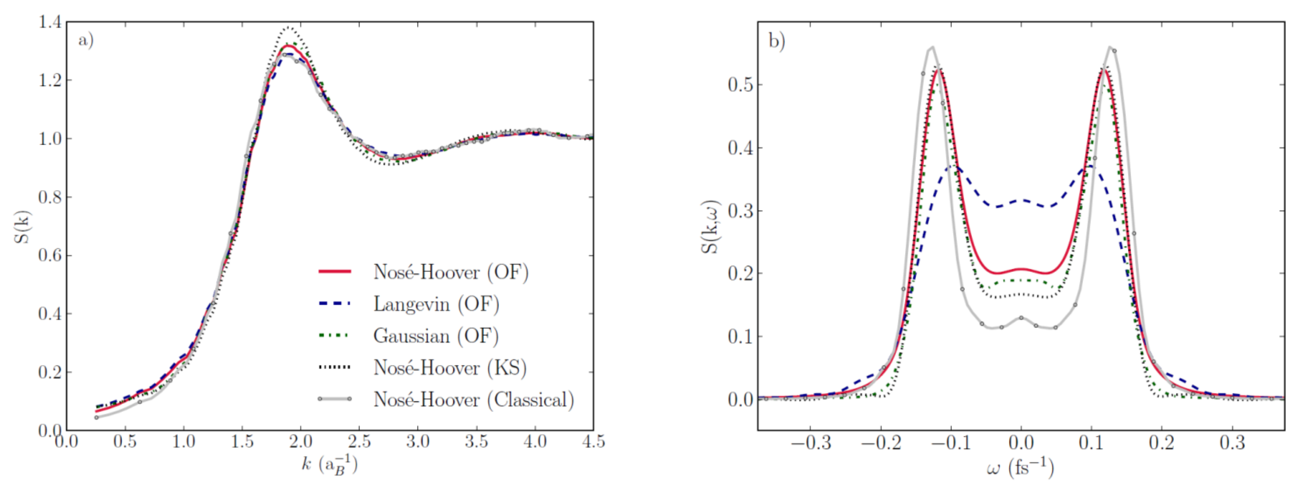
- Monochromator with different bandwidths:
  - $\Delta E/E = 10^{-3}$: SASE
  - $\Delta E/E = 10^{-4}$: Si_{111} monochromator
  - $\Delta E/E = 10^{-5}$: seeded
  - $\Delta E/E = 10^{-6}$: Si_{533} at 7.5 keV





- 4 diced analyzer crystals from Si533
  - 3 in forward direction, →collective modes
  - 1 in backward scattering →Doppler broadening, ion temperature

- Dynamic ion structure factor allows accessing
  - disipative processes
  - viscosity
  - thermal conductivity
  - diffusive modes at Δk=0

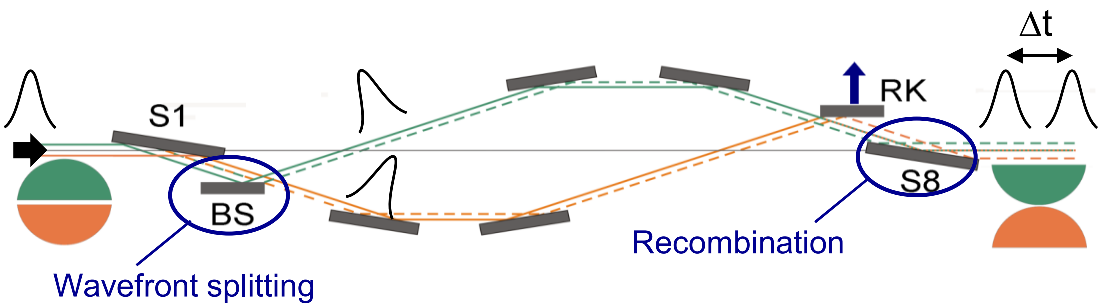


Courtesy P. Mabey et al., under review

x-ray pump-probe – fs dynamic response

HED x-ray beam split & delay line (SDL) – wavefront division

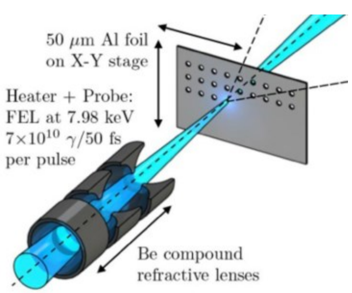
Multi-layer mirrors --- Variable delay up to ~23 ps (5 keV), ~4 ps (15 keV), 2 ps (20 keV)



S. Roling, H. Zacharias, et al., SPIE conf 8504, 850407 (2012)
BMBF project 05K10PM2
University of Münster

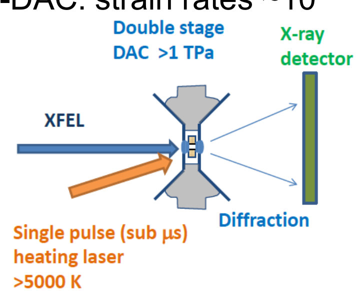
- → measure ultrafast dynamic response (electron-electron, electron-ion equilibration)
- → with 2 subsequent fs x-ray pulses launched into sample
- → reach astrophysically relevant states at $\rho > \rho_0$ with pre-compressed samples
- → conductivity of deeper layers of Jupiter, conductivity of eath core-mantle boundary

Targets at initial density



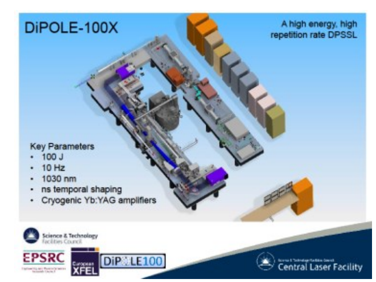
Solid foils

(quasi-) Statically compressed targets, dynamic-DAC: strain rates ~10³



DAC, Double stage, or laser heated DAC

Dynamically compressed targets



DiPOLE 100X laser

Summary

- European XFEL, HED instrument:
  - IC1 for very flexible setups, IXS, 90° etc
  - HIBEF IC2 as standard high quality XRD platform
    ► concept similar in scope the XRD part of the HPLF proposal.

- Synchrotron cases:
  - XRD
  - XANES

- XFEL cases:
  - Collective IXS: plasmons, ion acoustic waves (hrIXS)
  - Emission spectroscopy
  - Repetition rate (need: refreshing targets & ablator concept)
  - Ultrafast X-ray pump-probe
  - XRD in 90°, phase contrast imaging

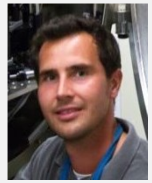
The current HED group at European XFEL

Group Leader HED Scientists Laser Group


Ulf Zastrau


Motoaki Nakatsutsumi


Karen Appel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Zuzana Konôpková


Mikako Makita


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Gerd Priebe

Engineers Technicians/Mech's


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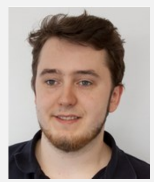
Eike Martens

Externally funded PostDocs / Ph.D.s / Guest Scientists


Emma McBride
Volkswagen Foundation


Philipp Sperling
Humboldt Foundation


Wolfgang Morgenroth
BMBF


Nicole Biedermann
DFG


Bolun Chen
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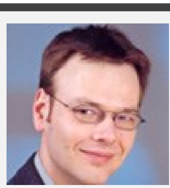
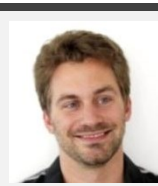
Coordinator HIBEF UC staff at European XFEL


Carsten Bähtz


Alexander Pelka

N.N.

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Toma Toncian (HIBEF lasers)

Monika Toncian

HIBEF at HZDR:

Klaus Knöfel

Wolfgang Seidel

Jörn Dreyer, …

SASE2 milestones II/II

- Early 2018 Commission the tunnel and optics hutch devices with X-rays
  - up to the beam stop between optics and experiments hutch
  - HED tunnel devices: CRLs, monochromator, split-and-delay line
  - HED optics hutch: slits, attenuators, CRLs, spectrometer, monitors

- Spring 2018 mechanical setups around the IC1 commissioning in full swing
  - Slits, differential pumping stages from IC1, laser beam transport
  - step-by-step commissioning with x-rays, starting from the optics hutch up to beam stop
  - rooms will be interlocked frequently and access is limited

- Delivery of multi-100-TW class laser and DiPOLE laser to HED laser room
  - Unpacking, setup and full-scale commissioning will take a minimum of 6-9 months.

- Summer 2018: start of early user operation
  - Experiments in IC1, x-ray only (plus split-and-delay unit).

- End-2018: as soon as the pump-probe (PP) laser (up to 2.5 mJ short pulse at 800 nm / up to 40 mJ at 1030 nm @ 1 ps) is available, this laser can be commissioned at HED and thereafter provided for user experiments.

- 2019: Tentatively, we do not expect availability of the large HIBEF laser systems before 2019.
  - HED instrument fully operational spring 2019.