11th call for proposals
- HED instrument -

…closes **May 11, 2023 at 16:00**

(German summer time)

Submit via web portal:

https://in.xfel.eu/upex

Never been at HED? No problem: look at our hutch using

the virtual tour (link)!

https://www.xfel.eu/facility/instruments/hed/

European XFEL

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Scientific Instrument HED

Take our virtual tour and look at the hutch!

Proposal preparation for the HED instrument

Call for Proposals - Frequently asked Questions and Answers +

What is HED?

The High Energy Density (HED) scientific instrument is a new, unique platform for experiments combining hard X-ray FEL radiation

Possible experiments at HED in this call:

Scientific drivers:

- Isochoric heating (using the focused intense XFEL pulse to create a plasma)
- Diamond anvil cells (incl. a standard configuration)
- Pump-probe laser (PP)
- 100 TW laser RE.LA.X (incl. a standard configuration)
- *DiPOLE+shock → please submit during next call 12 in 6 months*

Contact the instrument staff for detailed information.

We encourage to use our standard configurations
(see next slide – about 2x higher chance to get scheduled)

All proposals must be submitted through UPEX (https://in.xfel.eu/upex)

Standard configurations
(allows to schedule more experiments back-to-back)

Diamond Anvil Cell (DAC) standard configuration

- IC2 standard DAC setup, symmetric DAC cell support for users who need cells. user supplied BX90 with adapters.
- optical observation microscope, streaked pyrometry for x-ray heating.
- 18 keV SASE, max rep rate 4.5 MHz, > 0.5 mJ pulse energy from the undulators (not accounting for beamline transmission)
- 5-15 micrometer focal spot size (fixed at 5 µm, but effectively larger depending on beam pointing stability)
- Detectors: AGIPD mini-half detector and VAREX flatpanel
- Requirement to contact HED instrument team for feasibility check.

Standard configurations (allows to schedule more experiments back-to-back)

ReLaX standard configuration 1: ReLaX + SAXS + PCI + Spectroscopy

IC1 chamber, 100 TW ReLaX laser incident on target at 45° w. r. t. XFEL (no normal incidence of laser on target)

SAXS+PCI @ 8.15 keV SASE (tunable within reasonable range), ca. 1 mJ per pulse, 2.25 MHz maximum rep rate.

+ 5-50 µm spot size (both X-ray and ReLaX)
+ PCI resolution of about 1µm

Backward HAPG x-ray spectrometer. Forward spectrometer with restrictions due to SAXS setup

Laser diagnostics (upon request): EMP, electron, bremsstrahlung and proton diagnostics (contact HED staff for details before submission).

ReLaX standard configuration 2: ReLaX + Imaging + Spectroscopy

IC1 chamber, 100 TW ReLaX laser incident on target at 45° w. r. t. XFEL (no normal incidence of laser on target)

Imaging @ 8.15 keV SASE (tunable within reasonable range), ca. 1 mJ per pulse, 2.25 MHz maximum rep rate.

+ 1.5-50 µm spot size (X-ray), 5-50 um spot size ReLaX)
+ Imaging resolution <1µm

Not compatible with SAXS

Backward and forward HAPG x-ray spectrometer.

Laser diagnostics (upon request): EMP, electron, bremsstrahlung and proton diagnostics (contact HED staff for details before submission).

Platforms – Interaction Chamber 1

- 2 ePIX100 detectors for spectroscopy, imaging or XRD,
  50um pixel pitch, ~700x700 pixels, 10 Hz. Very low noise **– currently damaged!**
- 3x (vacuum) and 1 in-air JUNGFRAU detectors (gain switching 10^4) at 10 Hz
  (***no*** burst mode) and 1 JUNFGRAU module for in-air use.
  for XRD or spectroscopy (pixel pitch 75um, detector size ~ 3.5*7 cm)

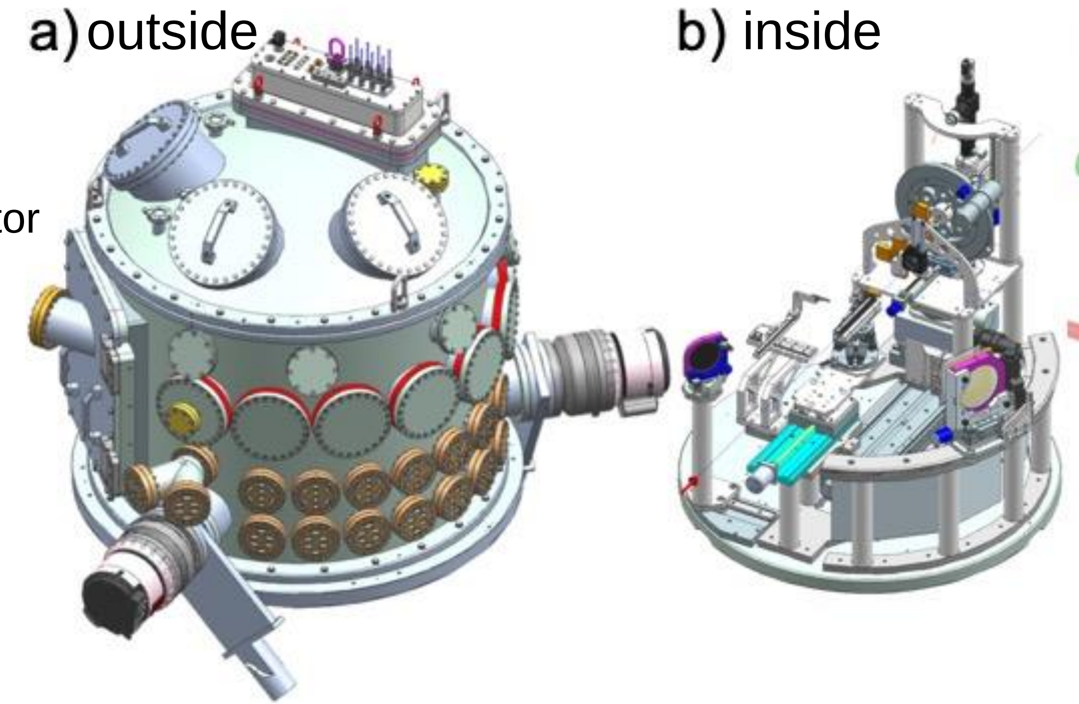
For details on detectors,
please contact Thomas Preston from EuXFEL detector group.

- Possibility to mount area detectors or spectrometers on curved rails in vacuum on vertical breadboard
- Von-Hamos HAPG spectrometers (RoC 50mm and 80mm, crystals available 40um HAPG, 100um HAPG, 200um HOPG)
- X-ray emission spectroscopy in Von-Hamos geometry
- High-resolution monochromator and diced analyzers (Si 533) for ~45meV spectroscopy at 7.490 eV
- stepper-motor target stage (10x10 cm area) on hexapod and precision rotation stage
- CRL4 for ~um foci with short focal length

Platforms – Interaction Chamber 2

- **IC2**
  - Diamond Anvil Cell (DAC) setup for precision XRD
  - 2 VAREX flatpanel detectors in IC2 (10 Hz)
  - AGIPD mini-half 4.5 MHz detector
  - Pulsed laser heating for DAC research
  - Dynamic DAC (dDAC)

IC2:



contact HED instrument scientists: *Zuzana Konopkova,*
or HiBEF UC members: *Cornelius Strohm, Rachel Husband*
for details of this platform

X-ray delivery from the faciliy to HED

The conditions expected for this allocation period are listed below. **Nevertheless, case-by-case verification of specific feasibility conditions with the instrument groups is required.**

	Photon energy range	Expected pulse energy**
SA2	5.8–9.3 keV	2 mJ
	>9.3–12 keV	1 mJ
	>12–24 keV	0.5 mJ

Bunch distribution: 350 X-ray pulses per instrument assuming the equal distribution at 2.25 MHz. Higher or smaller numbers for higher/smaller intra-train frequency.
Max. 2250 electron bunches within 500 µs at 4.5 MHz (only 1 week in the next run).

** Pulse energy depends on bunch charge, electron energy, and photon energy.

The above parameters correspond to the *standard* SASE operation mode.

The following *special* modes are available but require more tuning and are less reliable:

a. Hard X-ray self-seeding (SA2; 7 - 14 keV
b. Hard X-ray two-colour w. variable delay (SA2; 6–10 keV; 0–0.5 ps)
c. Short bunches (< 10 fs FWHM); requires coordinated scheduling as other instruments and available number of bunches might be affected; time-diagnostics is only partially available
d. Full trains at instruments with rep. rates much lower than 10 Hz (~ max. 2250 pulses)

Experiments requesting these *special* modes should address the development of new techniques and fields and are expected to involve large communities and facility staff. Since there is a vast range of detailed specifications for these special modes, proposers are requested to contact instrument staff in order to clarify requirements.

Details on Special mode d:
Full trains with low rep rates (up to ~2250 pulses)

- EuXFELs timing system is absolutely capable of this mode. However the various feed-backs and feed-forwards that are presently optimised for each beamline separately will have to work on a common setpoint.
- We would tune for a 'compromise' working point that works for all cases, but would not reconfigure the linac for a single pulse every minute or so. So every SASE would operate with a not optimal working point all the time.
- As a consequence we estimate a systematic **about 30% less intensity at compared to the standard modes.**
- The accelerator would run normally, where each train would deliver a portion of the RF window to each SASE. Then, every minute or so, a full train (full RF window) would go ONLY to SASE2 (HED). This means that SA1 and SA3 would “miss” one train every minute.

Some constraints

- The linac of EuXFEL has specific electron energy setpoints, 11.5, 14, and 16.5 GeV.
- At 11.5 GeV, the available photon energy range at SASE2 and HED is 5-9 keV, it can be extended to higher values but the intensity will drop significantly. Even at 8-9 keV, the pulse energies will probably not exceed 0.3 mJ. 14 GeV:~6 - ~ 15 keV, 16.5 GeV: 8.2 – 25 keV, respectively.
- It is **not possible to change between 5-6 keV and 12-24 keV** during one user experiment because the electron energy is fixed for the entire facility.
- We **strongly recommend to not change the photon energy during your experiment**, or at least not more than 1 keV. Larger changes need extensive tuning time of the LINAC and undulators and may lead to a low technical feasibility ranking. Also the x-ray focusing needs to be changed and aligned after each change.
- The „**special mode“ two-color** (see slide 3) has been successfully used at HED in 2022, however interested proposers should contact HED staff with their specific request and HED would catalyze a discussion with experts feeling comfortable to discuss these. We feel confident to offer up to 100 µJ per color and pulse.

X-ray parameters and diagnostics for the HED instrument

- 5-24 keV x-ray photon energy SASE spectrum (about 0.2% bandwidth), usually about 1-2 mJ pulse energy in ~20-40 eV bandwidth
- Seeded x-rays between 7-14 keV (~1 eV spectral width), few 100 µJ

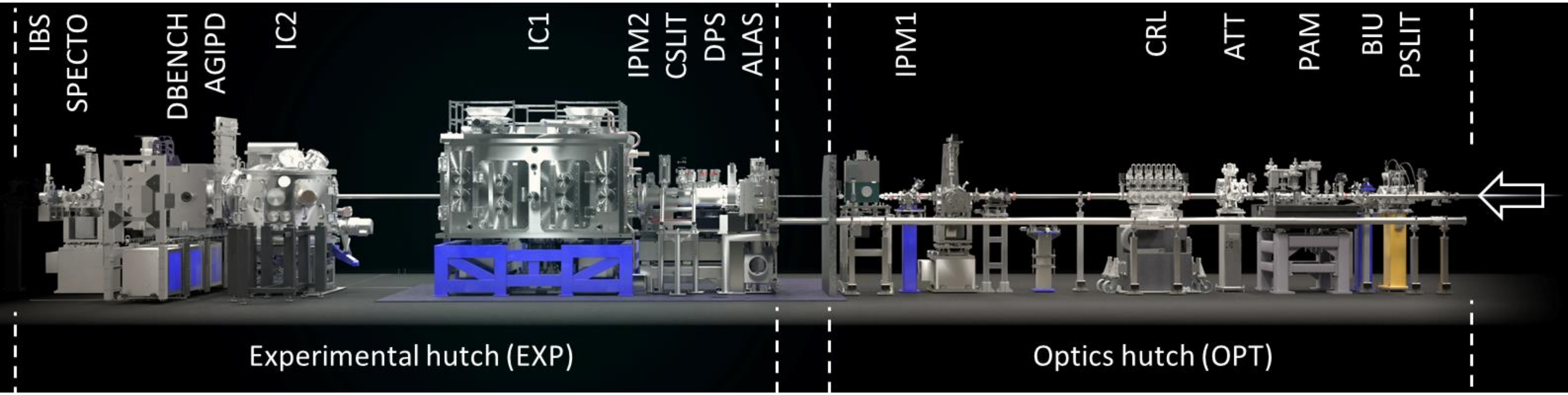
- Single pulses/trains on demand, or 10 Hz continuous
- pulse trains of 2.25 MHz (440 ns) or less (down to single pulse on demand)
- One week with 4.5 MHz rep. rate (222 ns pulse spacing)

- *Only experts:* 4-bounce monochromator (1 eV bandwidth) at max. 10 Hz between 5-18 keV *please contact Karen Appel before to talk about transmission and stability.*
- High resolution-mono@7.49 keV (about 40 meV bandwidth) at 10 Hz

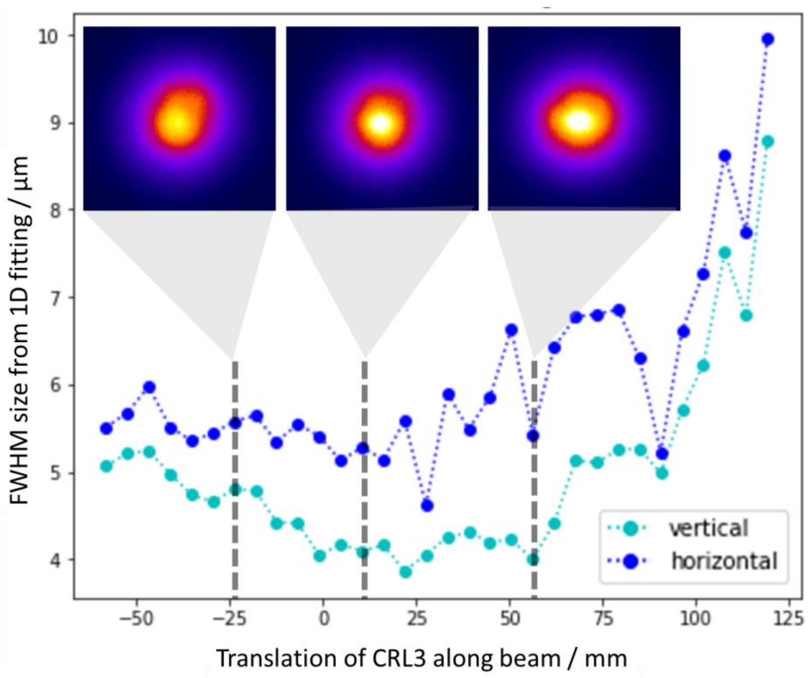
- full focusing capability CRL 1,2,3,4 any focus from parallel beam (few µrad divergence) down to slightly less than 1 µm foci, however with potentially significant absorption in the Be lenses. **The feasibility of sub-micron foci at any photon energy has to be discussed with the instrument scientists before submission.**

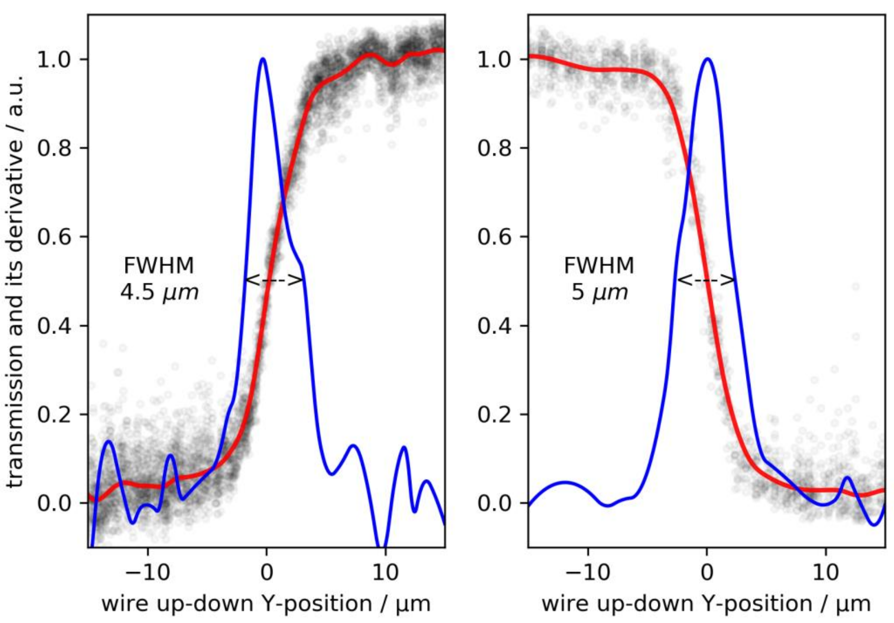
- “HIREX2” spectrometer in the SASE2 branch (before the separation into MID and HED) for monitoring the incident SASE / seeded spectrum.

HED beam transport



5x5 µm focus characterized

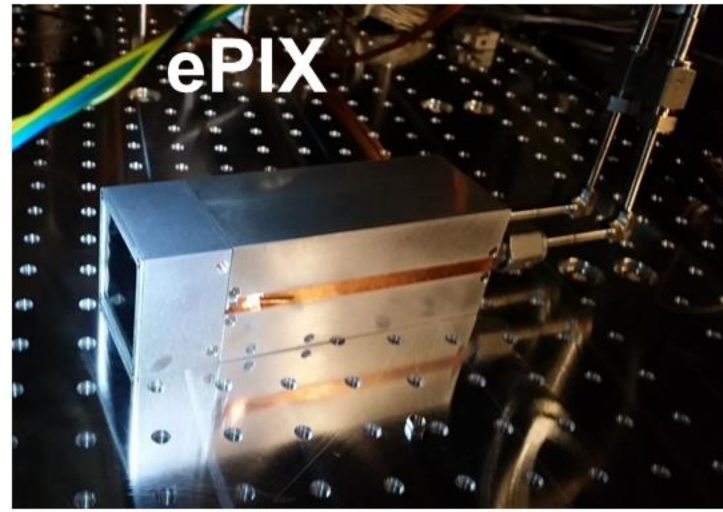




Focus in IC1 at 6.0 keV photon energy by LiF imprints and post analysis

Focus in IC2 at 17.8 keV photon energy by scanning with a 1 mm diam. W rod

ePIX and JUNGFRAU

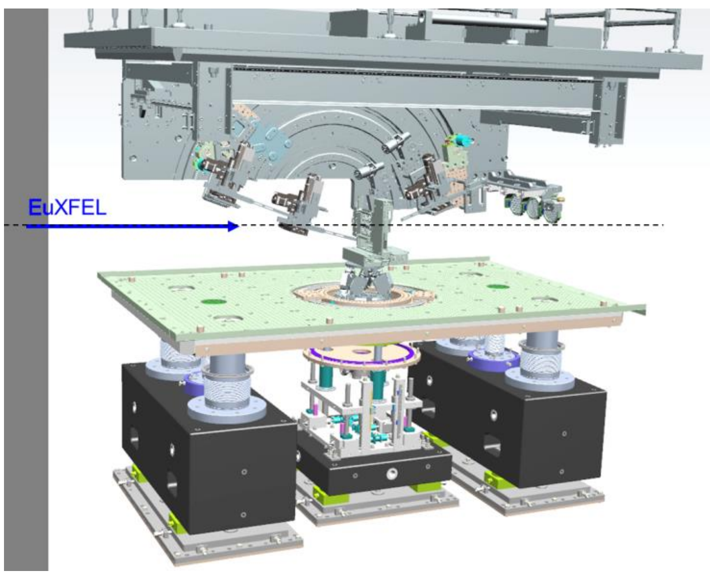


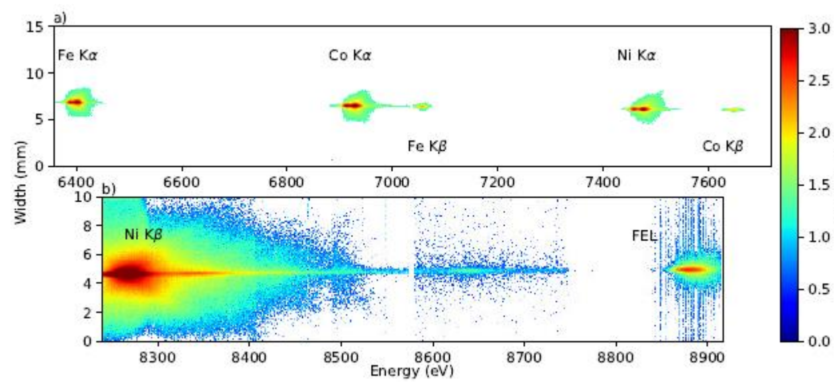
Name	Pixel size (μm)	No. of pixels (adim.)	Detection area (mm^2)	Noise (eV)	Frame rate (Hz)	Dynamic Range (photons per pixel)
ePix100	50	704×768	35×38	< 280	120	10^2 8 keV
Jungfrau	75	512×1024	38.55×77.25	< 450	2400	10^4 12 keV

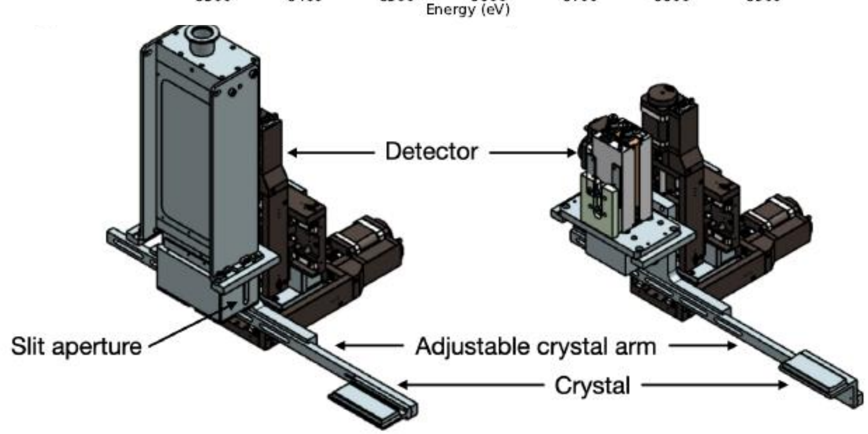
Mosaic graphite von-Hamos spectrometer

- Inside IC1, we offer von-Hamos HAPG spectrometers for emission or scattering experiments. Please contact us for further details. A JINST publication is available: https://doi.org/10.1088/1748-0221/15/11/P11033 .
  Contact Thomas Preston for details.

- The spectrometers, equipped with Jungfrau detectors and tungsten shielding, have been successfully used for K-line spectroscopy in combination with RELAX shots at I=10^{20} W/cm².

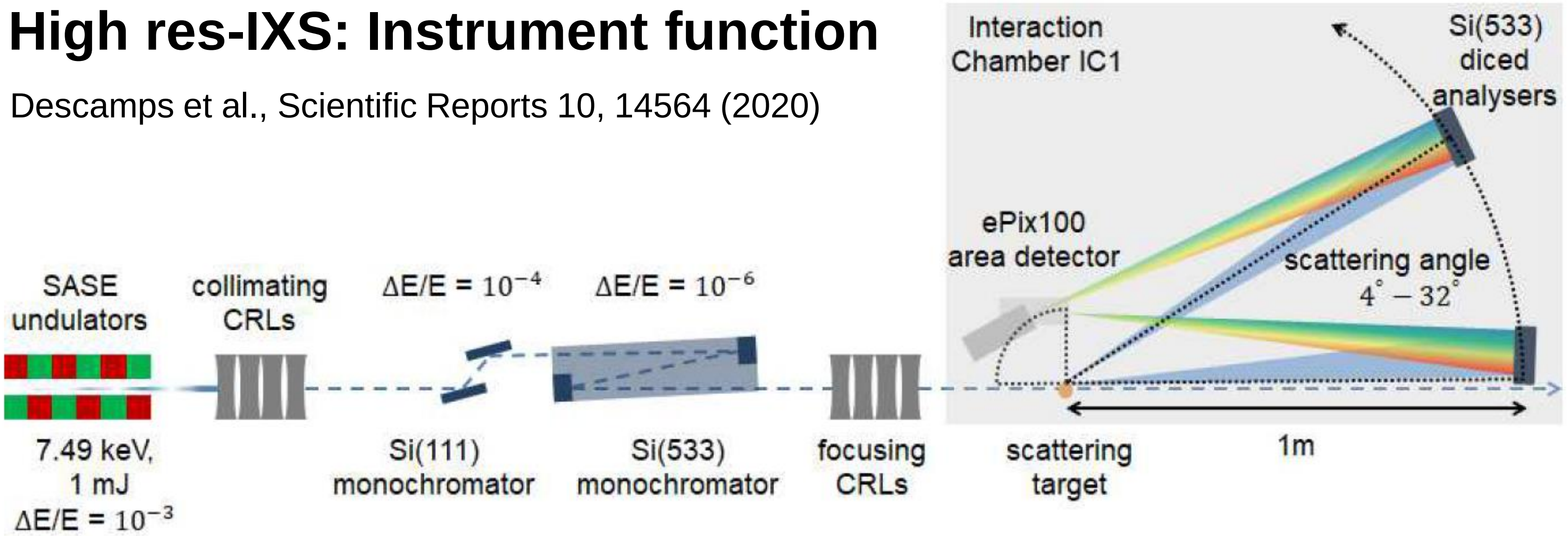




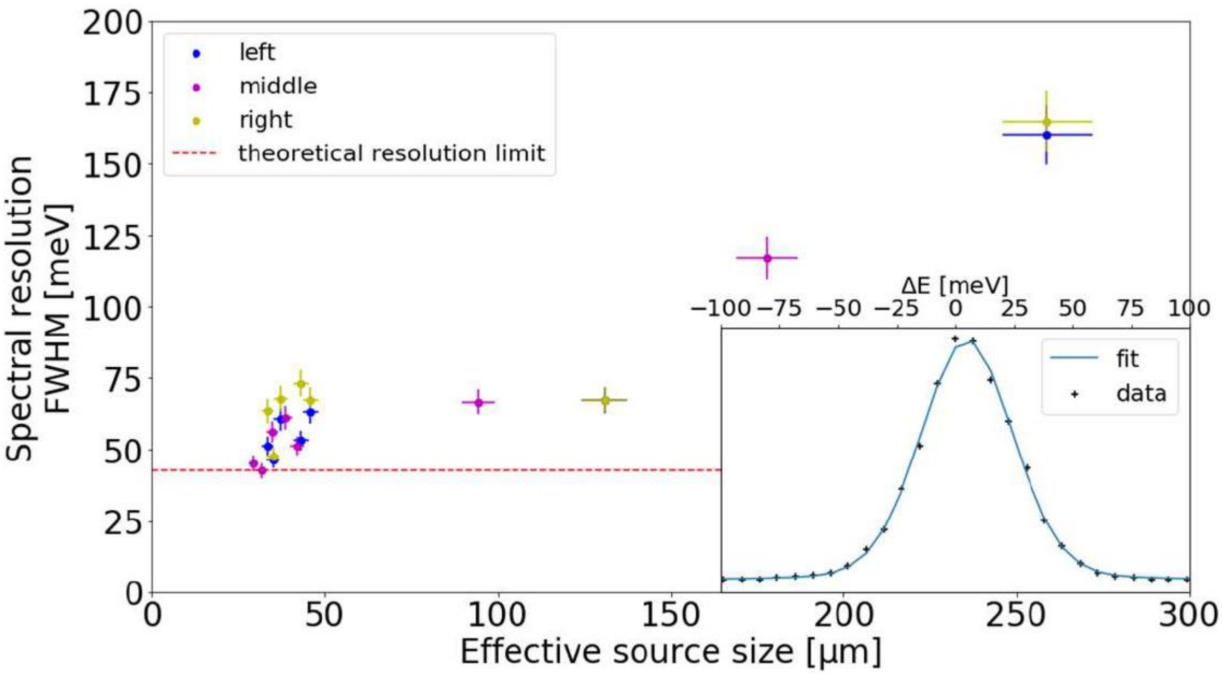


High res-IXS: Instrument function

Descamps et al., Scientific Reports 10, 14564 (2020)



Samples thickness ~ pixel size yield close-to design spectral resolution



Wollenweber et al., Review of Scientific Instruments 92, 013101 (2021)

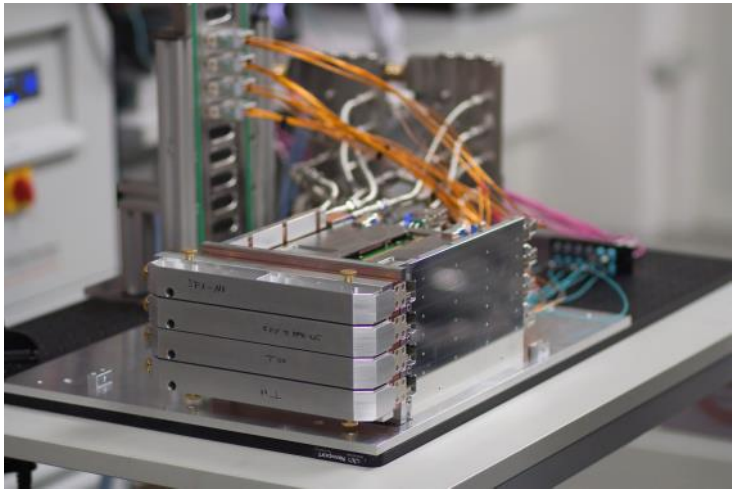
- Contact Karen Appel or Thomas Preston for details.

"direct"-beam spectrometer, AGIPD detector

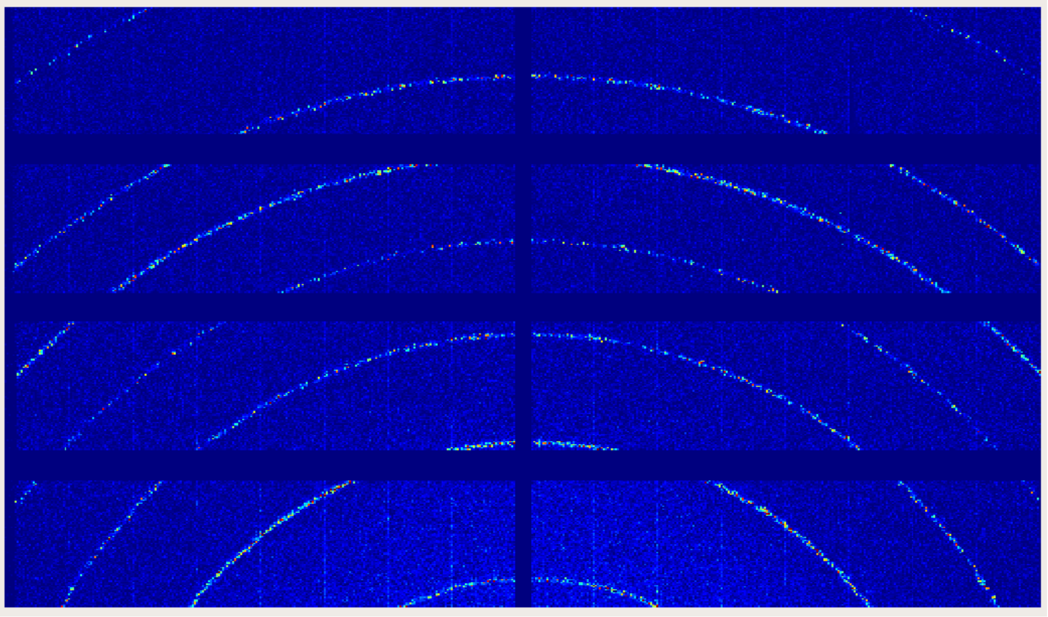
- bent diamond crystal spectrum analyzer downstream of the interaction.
  Contact Karen Appel for details if you plan to use it.

- AGIPD 500K detector (352 images at 3 gain stages with up to 4.5 MHz).
  Contact Cornelius Strohm for details. It is part of the DAC platform.

AGIPD 500K

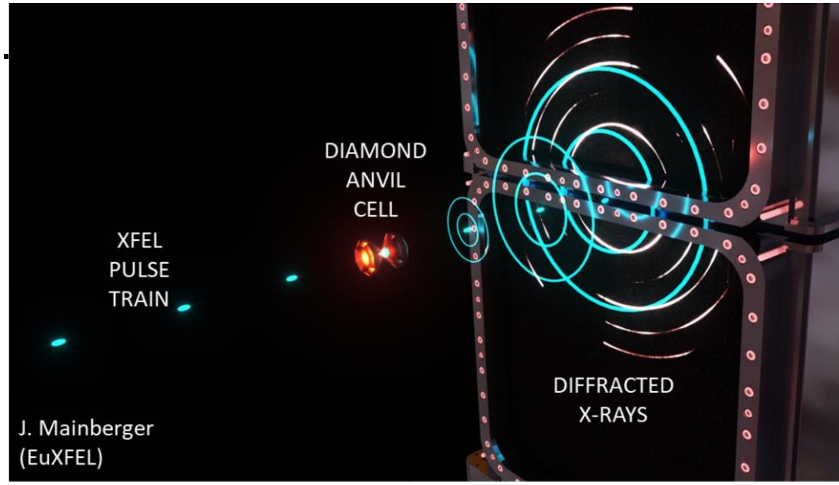


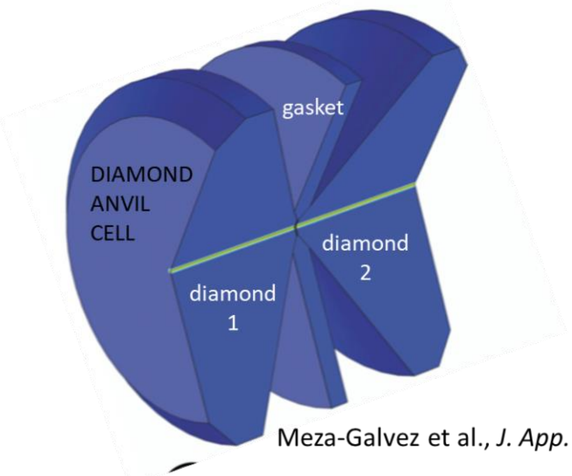
XRD standard on the AGIPD 500K at HED - LaB6 at 17.8 keV



Pulsed Laser heating for DAC research

- double side laser heating in DACs
- 2x 100 W NIR lasers in pulse mode or cw mode. Pulse duration 10-500 ns, and >1 µs possible
- temperature determination: time resolved spectral radiometry (SOP) using streak camera system

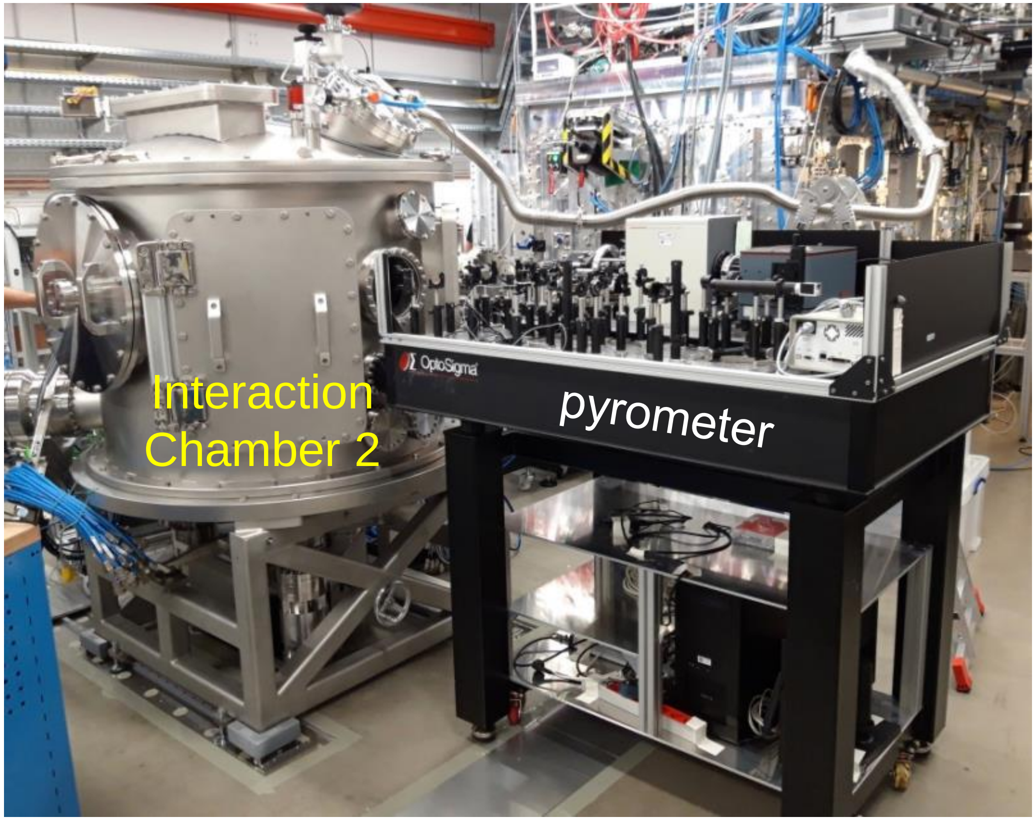




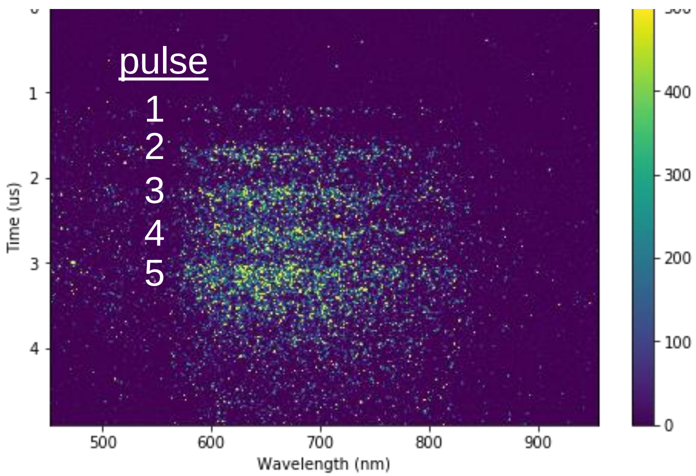
Meza-Galvez et al., *J. App. Phys.*, 2020

For further information, please contact Zuzana Konopkova from the HED team: zuzana.konopkova@xfel.eu

Streak Optical Pyrometry (SOP) to measure thermal emission

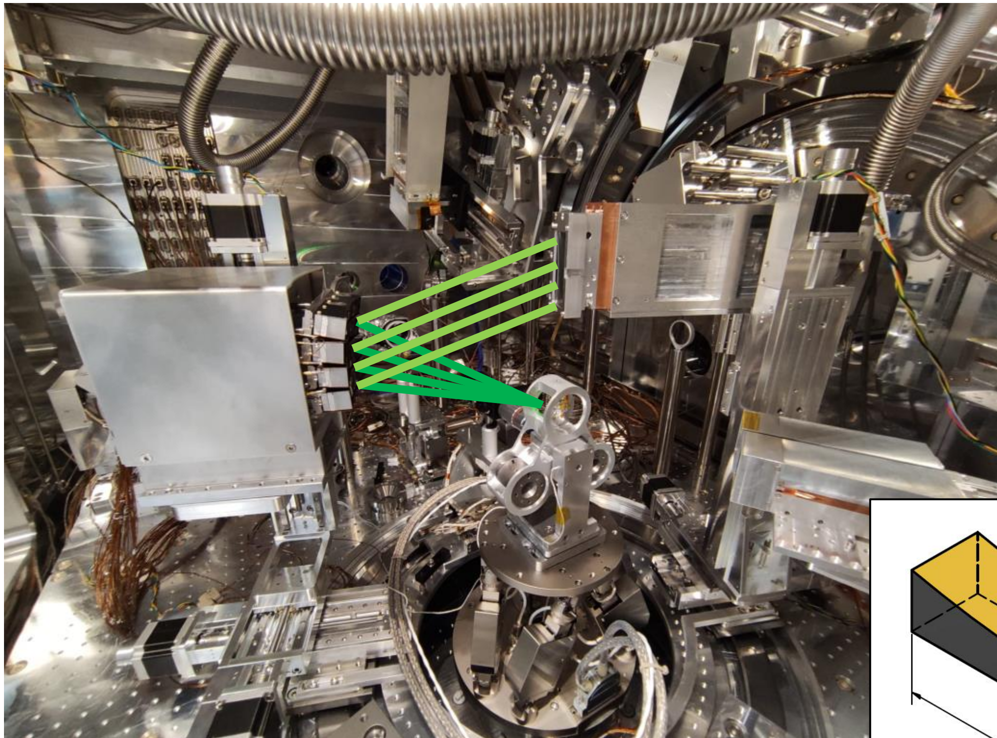


Streaked spectrogram

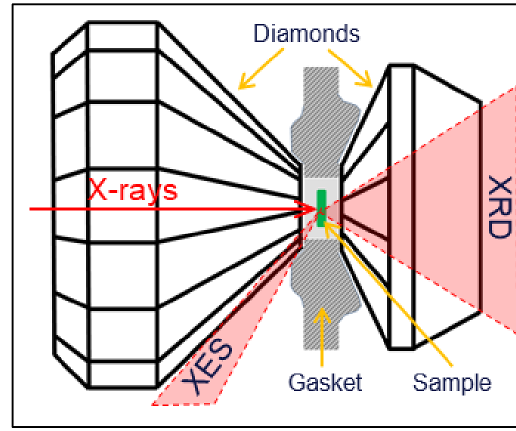


For further information, please contact Zuzana Konopkova from the HED team: zuzana.konopkova@xfel.eu

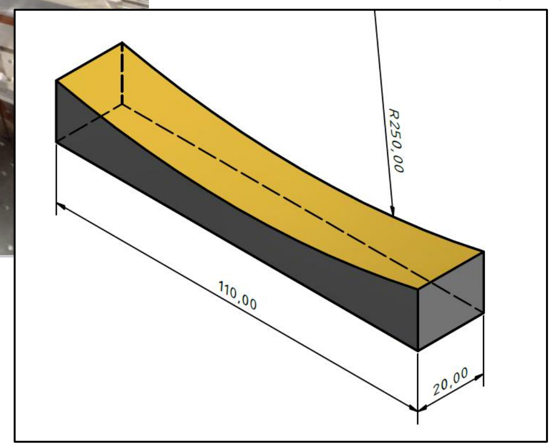
Von-Hamos spectrometer for measurements from DACs in IC1



Courtesy J. Kaa



Kaa et al. 2023, accepted



- range: 6 keV - 12 keV
  dispersion: ~0.4 eV/pixel (JF detector)
  instrumental broadening: ~0.5 - 1 eV

- Multi-fluorescence spectroscopy e.g.:
  - Si(531) for Fe K beta
  - Si(333) for Fe K alpha
  - Si(444) for Re L alpha (~12 keV)

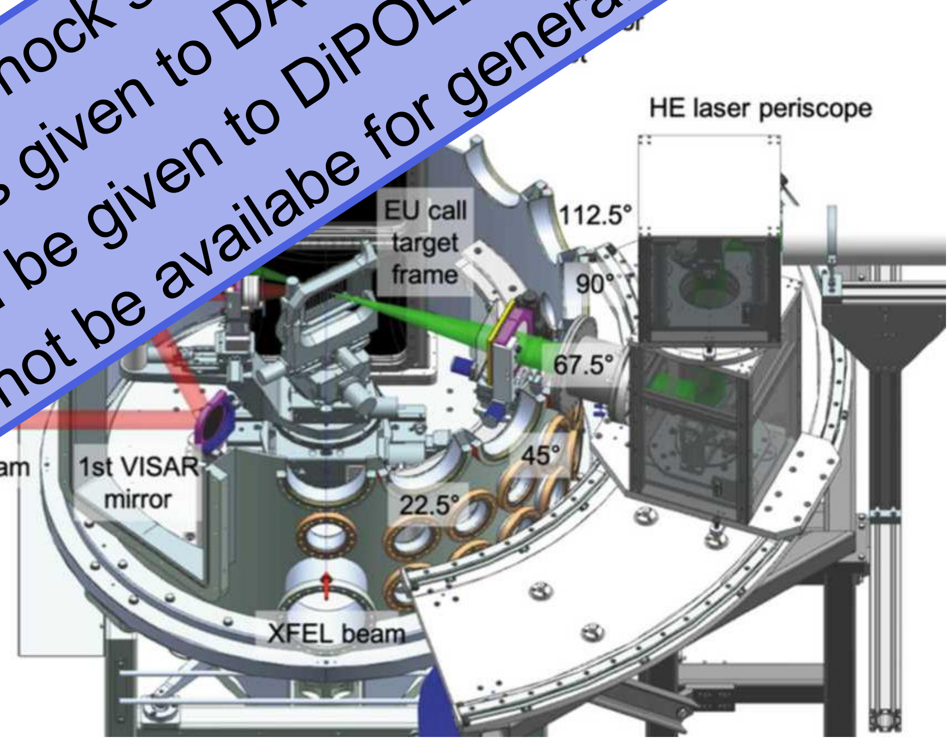
Crystal	Orientation (hkl)	d-spacing (Å)
Si	531	0.9179
Si	111	3.1355
Si	533	0.8281
Si	511	1.0451
Ge	220	2.0000
Ge	111	3.2660

Bundesministerium für Bildung und Forschung
#05K19PE2

Platforms – Interaction Chamber 2 + shock setup

- **IC2**
  - Shock-setup in IC2
  - Can be coupled with 1030 nm pp-laser with ~450 ps (see slide 19)
  - Other possibilitie… (other pump… need to… wit… …itive significant setup

IC2



NOTE: In Call 11, the DiPOLE and shock setup are **not offered** for regular user experiments. Priority is given to DAC proposals instead. In the next call 12, priority will be given to DiPOLE and shock experiments, and DAC will not be availabe for general users.

Pump-probe (PP) laser

- Anticipated parameters
  - **PP laser at 800 nm wavelength**
    - ▶ < 20 or 50 fs duration, close to Fourier-limited bandwidth (going for narrower bandwidth with longer pulse duration is an option)
    - ▶ max ~2 mJ at 100 kHz, or down to 10Hz or shot-on-demand
    - ▶ Higher repetition up to 4.5 MHz with lower pulse energy
    - ▶ Second harmonic (400 nm) is available. Conversion efficiency is however low (15-20%) due to the large bandwidth.
    - ▶ Chirped mode up to ~10 ps duration
  - **PP laser at 1030 nm wavelength**
    - ▶ Duration: ~ 1 ps compressed “or” ~450 ps uncompressed.
      - Duration between these two values are not possible.
    - ▶ max ~30 mJ at 100 kHz, or down to 10Hz or shot-on-demand
    - ▶ Higher repetition up to 4.5 MHz with lower pulse energy
    - ▶ Second/third harmonic (515/343 nm) are *potentially* available.

If you plan to use the PP laser, please contact Motoaki Nakatsutsumi from the HED team to discuss your requirements:

motoaki.nakatsutsumi@xfel.eu

HI-OL: HiBEF ReLaX TW laser

There is a publication about the performance of this laser:

High Power Laser Science and Engineering

A. Laso Garcia et al., High Power Laser Science and Engineering (2021) - https://doi.org/10.1017/hpl.2021.47

Further questions about the laser can be directed to Toma Toncian, t.toncian@hzdr.de

HI-OL Laser parameters:

- up to 100 TW laser beam available at IC1 target chamber.
- Laser pulse duration <30 fs (nominal).
- Energy up to 3 J on target.
- Irradiation geometry: 45 deg to X-ray axis and target normal.
- F/2 focusing optic.
- Laser wavelength 750-850 nm.
- Arrival jitter compared to x-rays at IC1 <30 fs RMS.
- a synchronized optical probe beam with mJ energy can be made available upon request.
- on shot diagnostic package with NF, FF, WF, pulse duration, arrival time at PAM.
- latest laser contrast trace can be measured upon request.
- Shot-on-demand experiments (other modes upon request).

Shot rate will be limited by alignment time, debris issues, and probationary radiological limits.

For further details, contact Toma Toncian: toma.toncian@xfel.eu

HI-OL: HiBEF ReLaX TW laser standard configuration 1: SAXS + PCI + Spectroscopy

X-ray diagnostics:

- X-ray XFEL photon energy: **SASE, 7.8…9 keV**
- X-ray spectrometers (HAPG)
- Small angle scattering (SAXS) setup
  angular range covered: 1.7-19 mrad
  indirect FOV imaged with Highly Oriented Pyrolytic Graphite Crystals
  with an accepted x-ray bandwidth optimized for 8.15 keV
- Focusing setup (CRL3)
  direct FOV: 10^2 µm^2 to 1000^2 µm^2

Non X-ray diagnostics can be provided if needed:

- Thomson Parabola with an energy range .5- 40 MeV for p+
- electron spectrometer
- Bremsstrahlung spectrometer with an energy range up to 20 MeV

"Other diagnostics (e.g. optical probe such as FDI) can be discussed and integrated in the proposal upon request if feasible."

HI-OL: HiBEF ReLaX TW laser standard configuration 2: Imaging + Spectroscopy

X-ray diagnostics:

- X-ray XFEL photon energy: **SASE, 7.8…9 keV**
- X-ray spectrometers (HAPG)
- Focusing setup CRL4a inside the chamber before target
  FOV: 1.5^2 µm^2 to 50^2 µm^2

- Imaging setup CRL4b inside the chamber after target
  FOV: 200^2 to 400^2 um^2

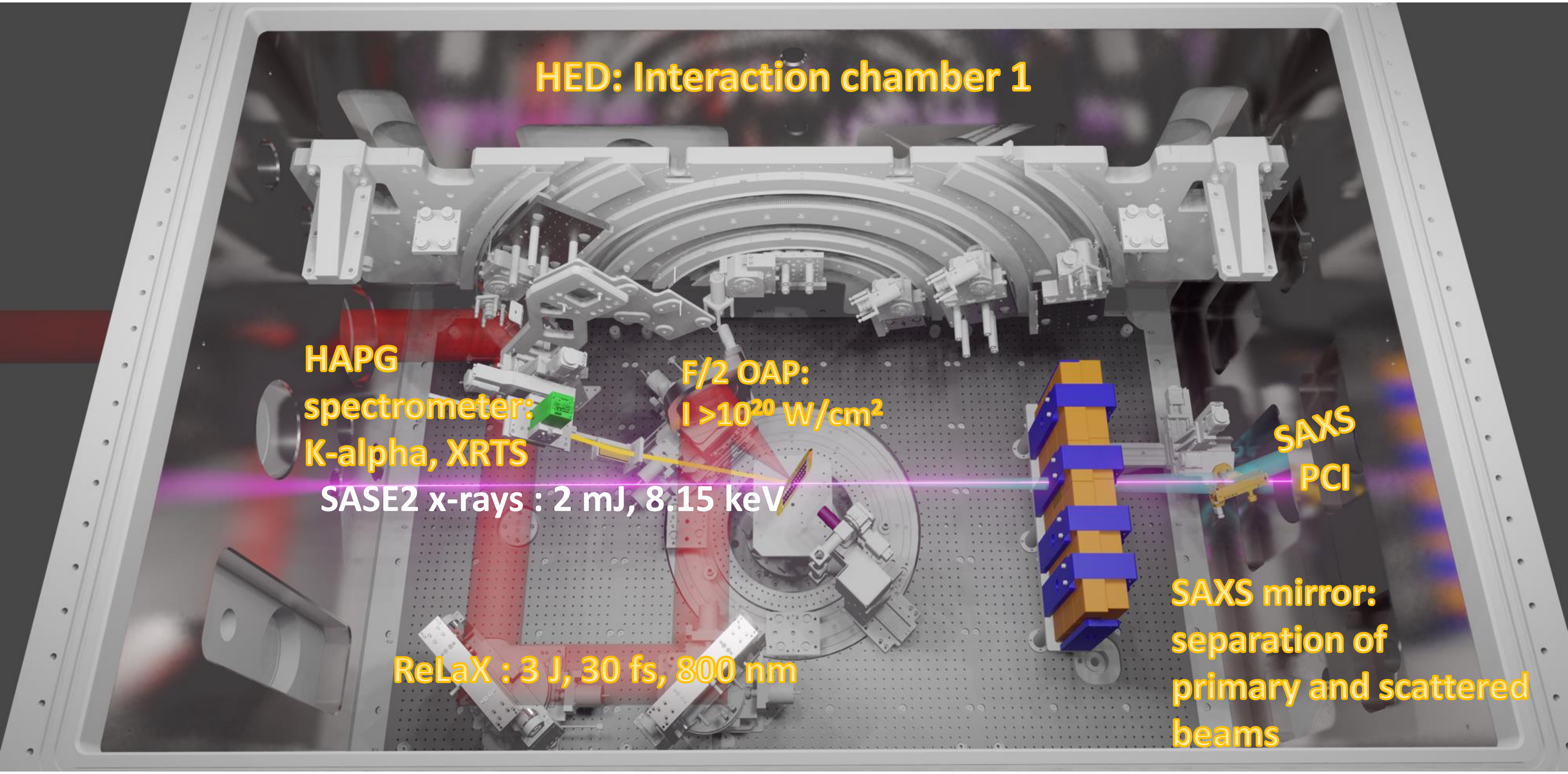
Non X-ray diagnostics can be provided if needed:

- Thomson Parabola with an energy range .5- 40 MeV for p+
- electron spectrometer
- Bremsstrahlung spectrometer with an energy range up to 20 MeV

"Other diagnostics (e.g. optical probe such as FDI) can be discussed and integrated in the proposal upon request if feasible."

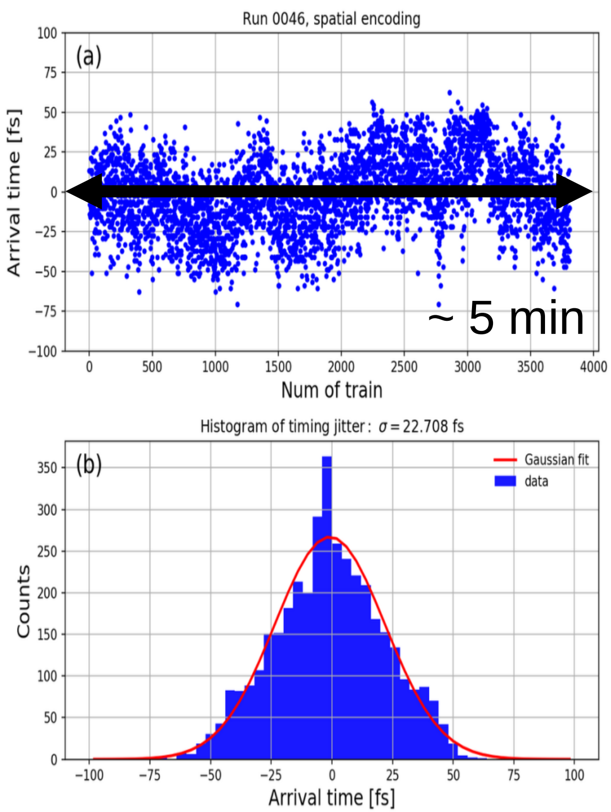
THIS CONFIGURATION IS NOT COMPATIBLE WITH STANDARD CONFIGURATION 1!

Typical setup at IC1 combining ReLaX with SAXS,PCI and spectroscopy

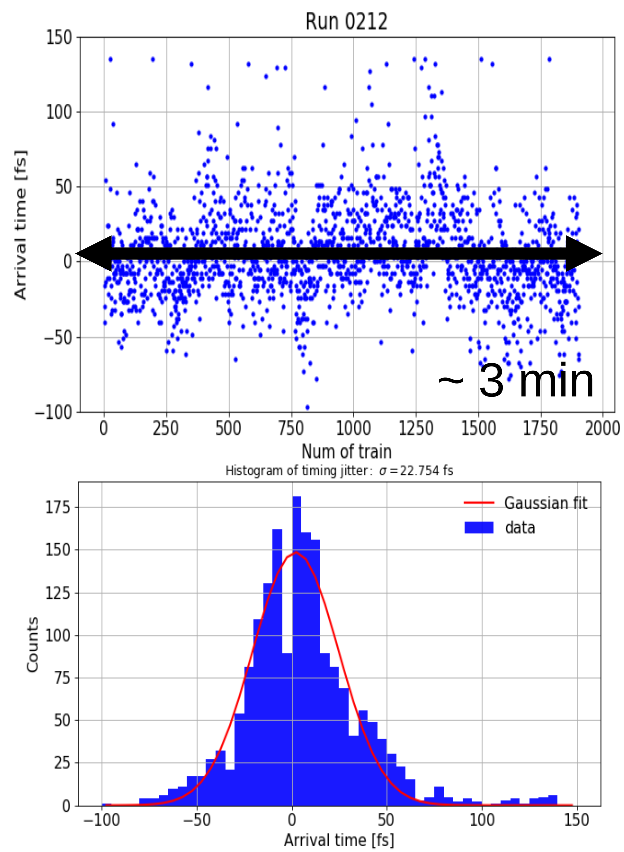


Pulse-to-pulse arrival jitter betweeen x-ray and optical lasers is 20-30 fs

Pump-probe laser



ReLaX TW laser



Awareness – beam jitter

Our facility is still suffering from spatial drifts (on the timescale of minutes) and jitter (pulse-to-pulse) of the x-ray beam. It is dominantly in the horizontal direction (left-right). This occurs only sometimes and at unforeseeable times (no correlations with external events). The issue is complex and the root cause(s) not yet fully understood. We are working on solving this issue.

!

However, from the current perspective, we cannot guarantee that we will have implemented a solution at the time of allocation of your beamtime. Therefore, if your experiment is critically depending on a stable beam pointing, please **address mitigation scenarios** in your proposal, take into account that **more statistics** on your data will be needed, and make your experiment design **robust against beam jitter (e.g. choice of x-ray focusing scheme)**.

This is work in progress - in case of specific questions, please inquire with the instrument scientists.

Instrument papers

- **General overview of the HED instrument**
  - Zastrau, Appel, Baehtz et al., J. Synchrotron Rad. (2021). 28, 1393–1416
- Diffraction from Diamond Anvil Cells - overview
  - Liermann et al., J. Synchrotron Rad. (2021). 28, 688-706
- ReLaX: the HiBEF high-intensity short-pulse laser driver
  - A. Laso Garcia et al., High Power Laser Science and Engineering (2021) - https://doi.org/10.1017/hpl.2021.47
- Design and performance of the HAPG von-Hamos spectrometers
  - Preston et al., Journal of Instrumentation, Volume 15 (2020)
- Design and performance of the meV high resolution setup
  - Wollenweber et al., Review of Scientific Instruments 92, 013101 (2021)
- Design and performance of the SAXS HAPG mirror
  - Smid et al., Review of Scientific Instruments 91, 123501 (2020)
- *Design and performance of Von-Hamos X-ray emission spectroscopy*
  - *Kaa et al., J. Synchrotron Rad. (2023). accepted*