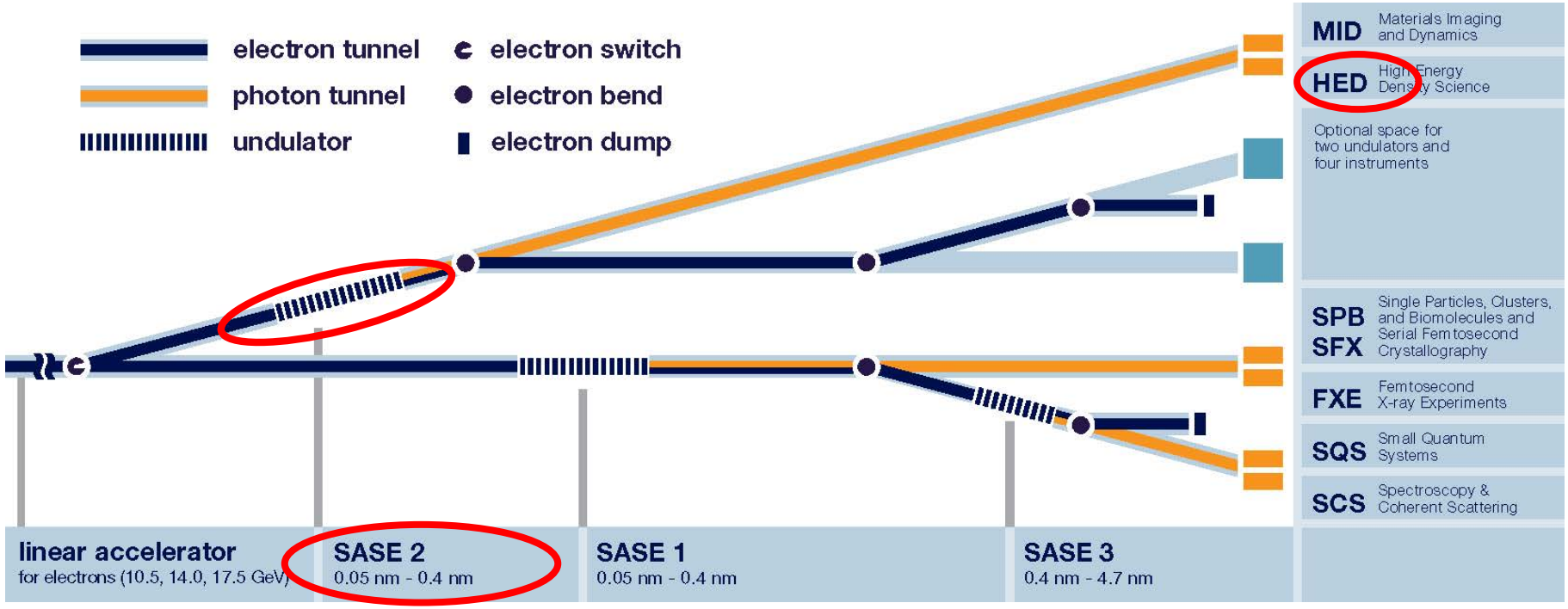
The HED Instrument at the European XFEL
Status in 2020

Karen Appel for the HED/HIBEF team
Scientist
HED scientific instrument at the European XFEL

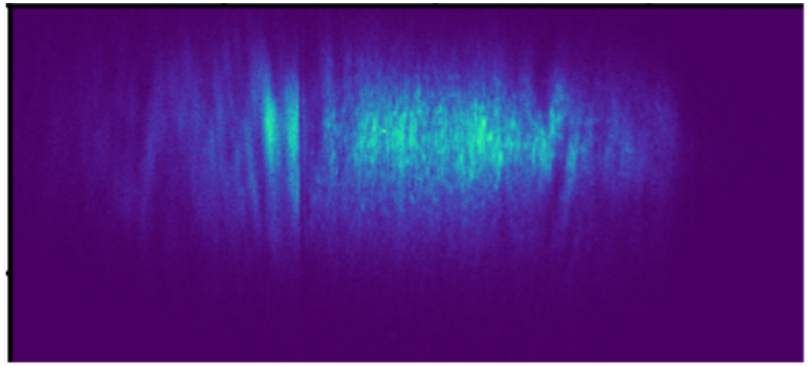
HED-HiBEF satellite meeting to the EuXFEL/DESY UM 2021,
20th January 2021, European XFEL, Germany

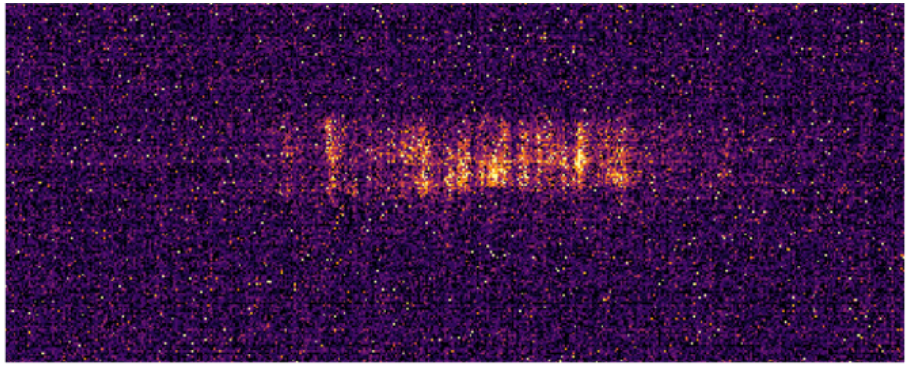
European XFEL: beamlines and instruments

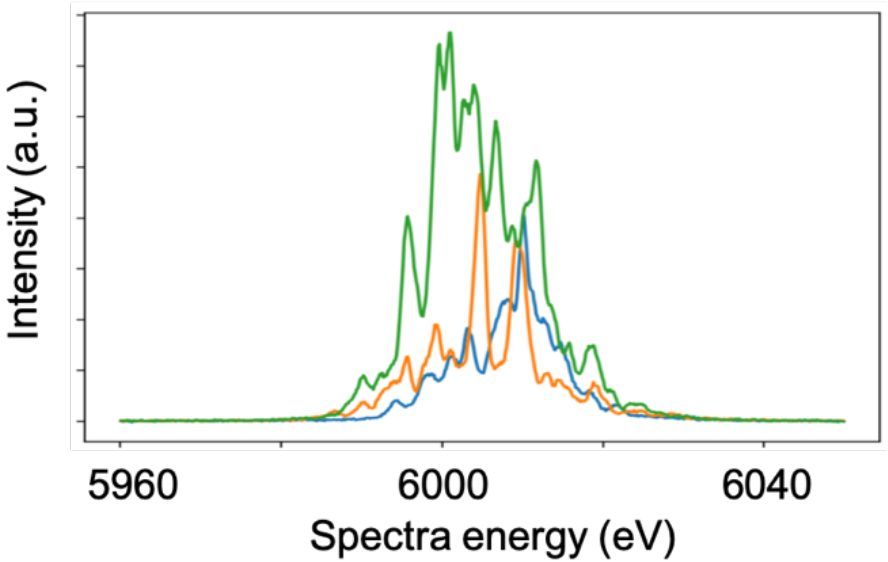


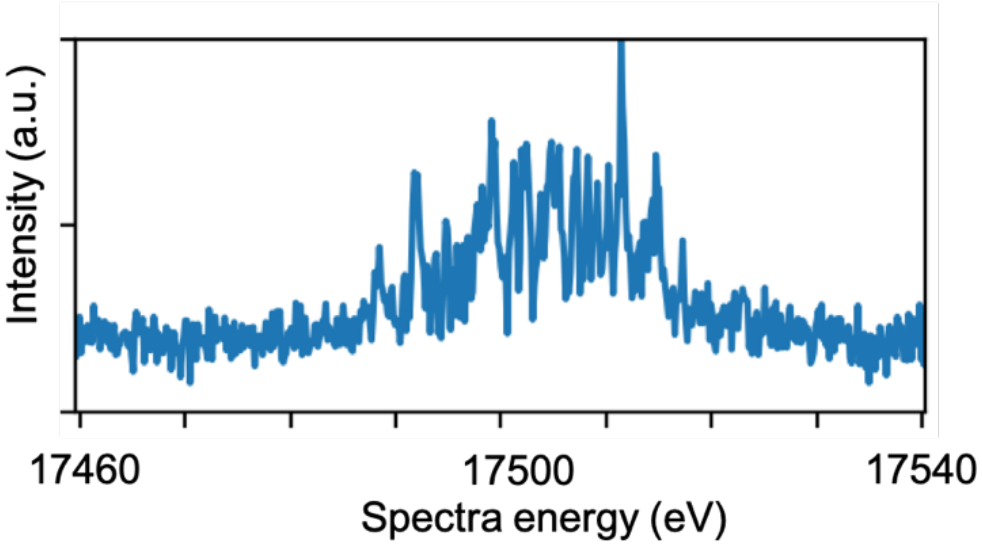
- 8 keV lasing in SASE1 with up to 1 mJ — May 2017
- First experiments at SASE1 — Sept. 2017
- First experiments at HED — May 2019

SASE beam at HED at 6 keV and 17.8 keV







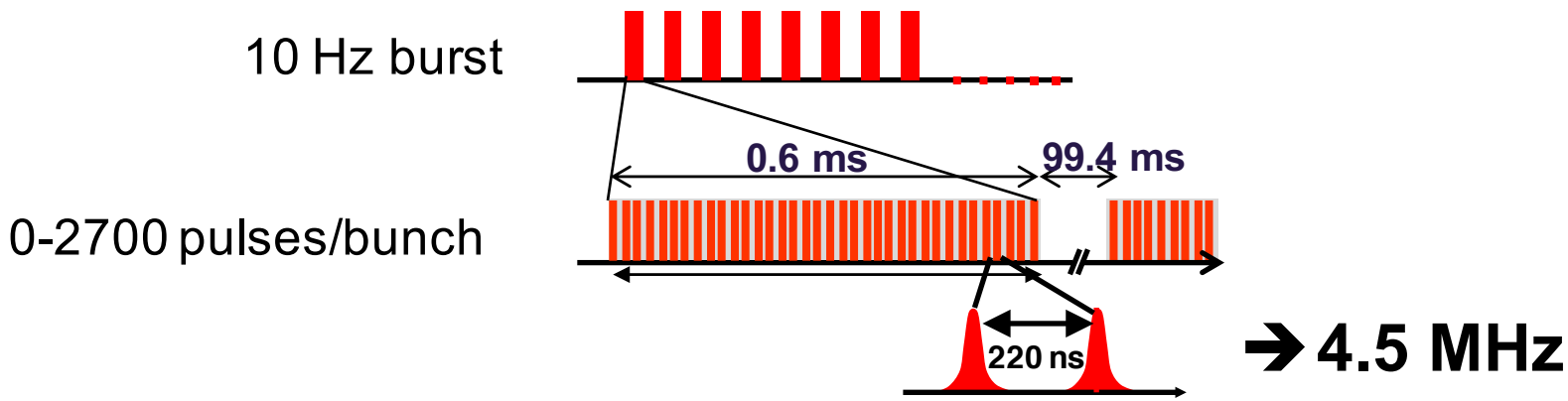


Zastrau et al., Journal of Synchrotron Radiation, in preparation

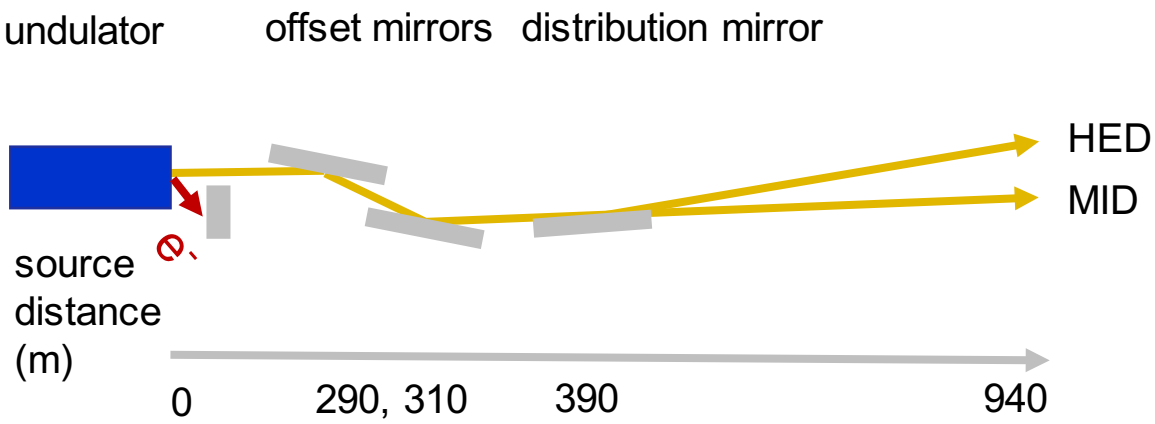
XFEL properties at the HED instrument in 2019 & 2020

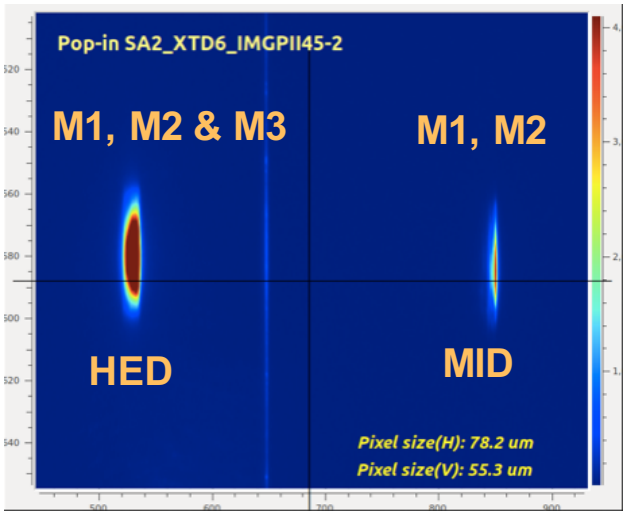
cw 41, 2019: up to 780 µJ @ 17.8 keV/ cw 42, 2020: 3 mJ @ 9 keV

Fully tunable between	3 – 25 keV → 6 – 18 keV (3 – 5 keV with limited performance)
Pulse duration	2 – 100 fs → 25 fs at 250 nC
Photons per pulse	~10^{11} (25 keV), ~10^{12} (5 keV) → reached
Spot size on sample	sub-µm (HIBEF), few µm, 20 – 30 µm, 200 – 300 µm, few mm
Seeded beam	5 – 14.4 keV → 02/2020 (9 keV)
Repetition rate	shot on demand, 1, 5, 10 Hz – 3000 pulses/s



Mirrors at HED: offset and distribution

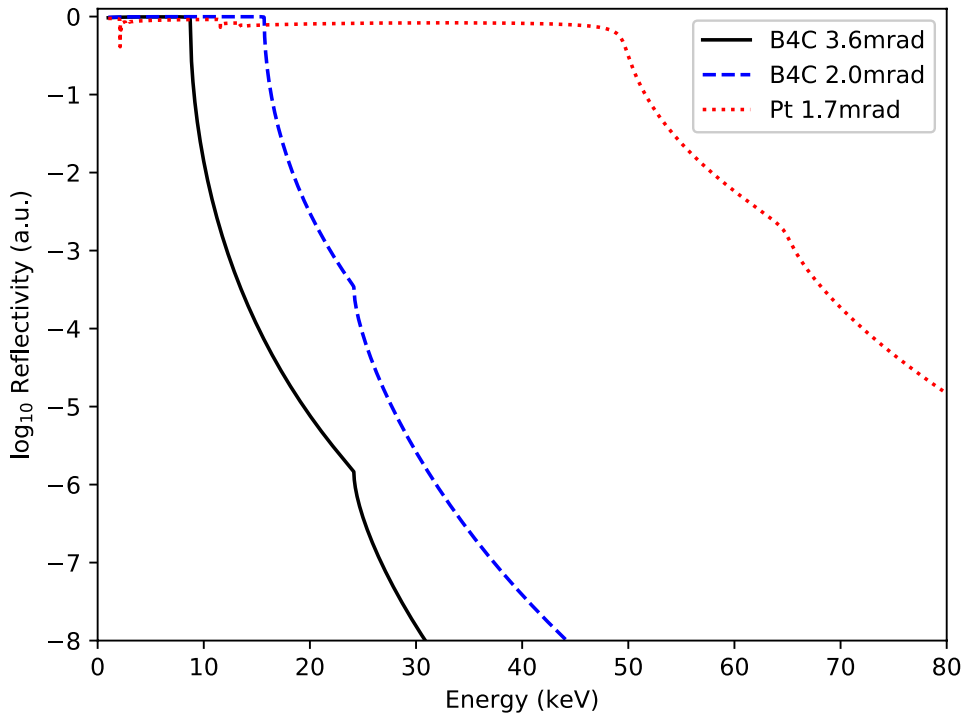




- Offset mirrors: 1.7 (1.1) – 3.6 mrad, Pt & B_4C coating
- Bender on M2
- Distribution mirror: 1.3 mrad; B_4C (21.4 keV); Pt (60.7 keV)

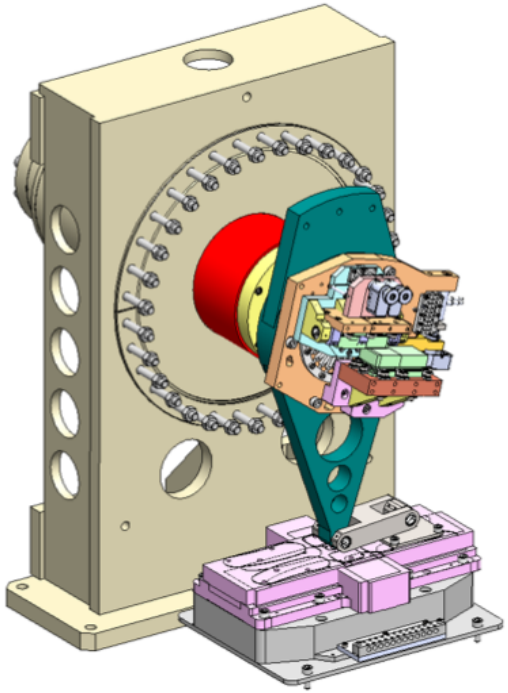
- All mirrors have a useable length > 80 cm
- Intermediate focusing optics scheme reduces cutting effects on edges

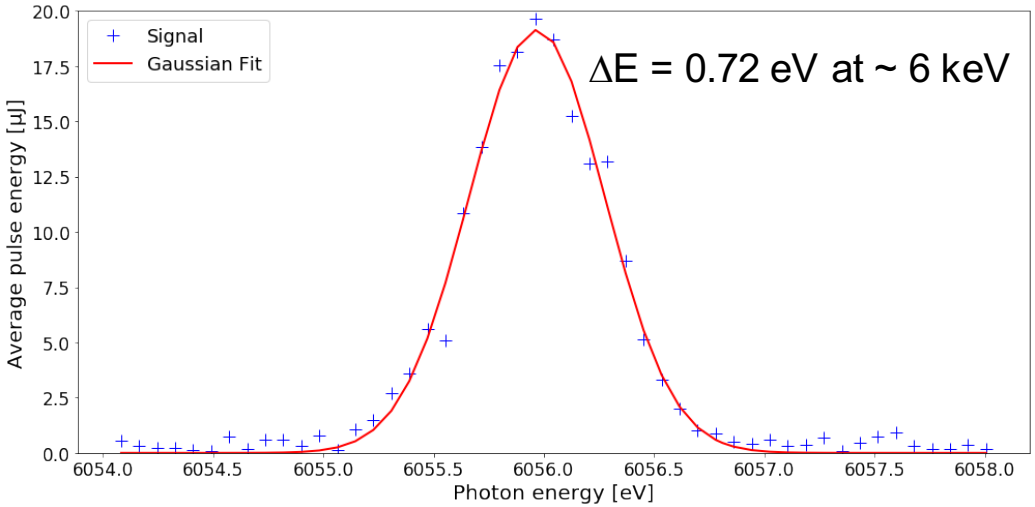
Reflectivity of 2x offset mirror + 1x distribution mirror

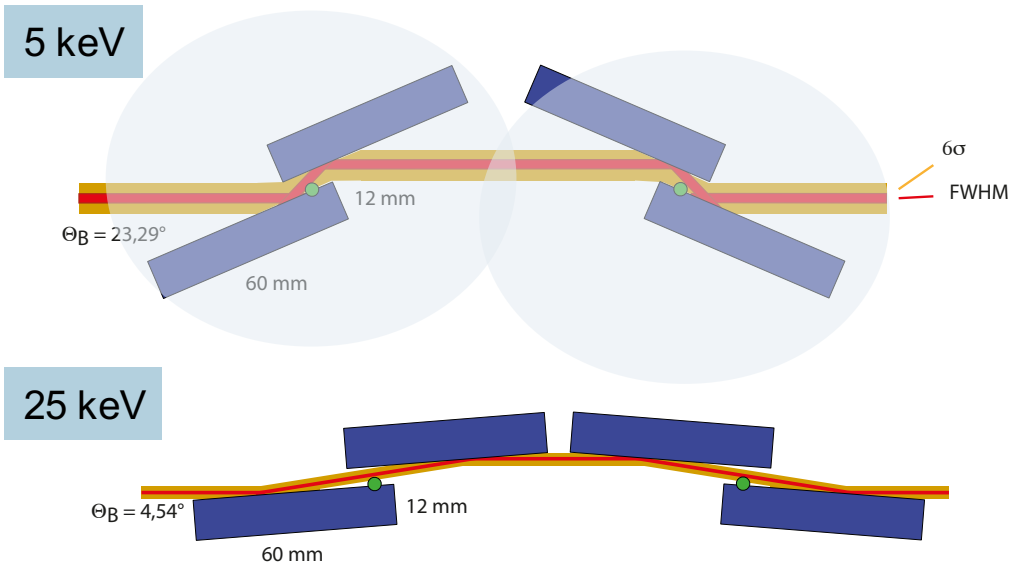


Monochromator

- 4-bounce, Si_{111} crystals
- Beam size: 6σ
- Energy range: 5 - 25 keV (24.5° - 4.5°)
- Working range up to now: 6 - 9 keV
- Cryogenically cooled
- $\Delta E/E = 10^{-4}$



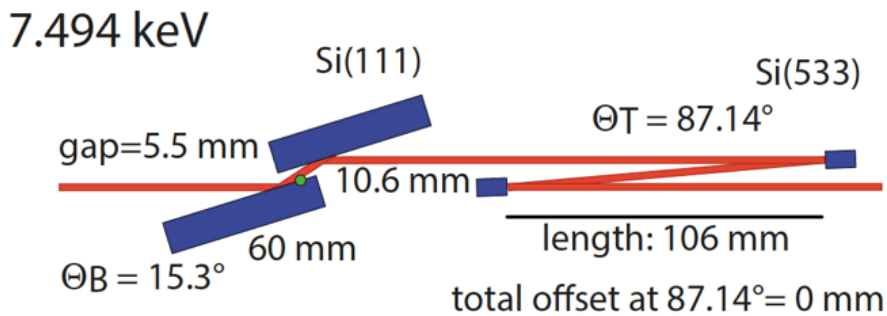


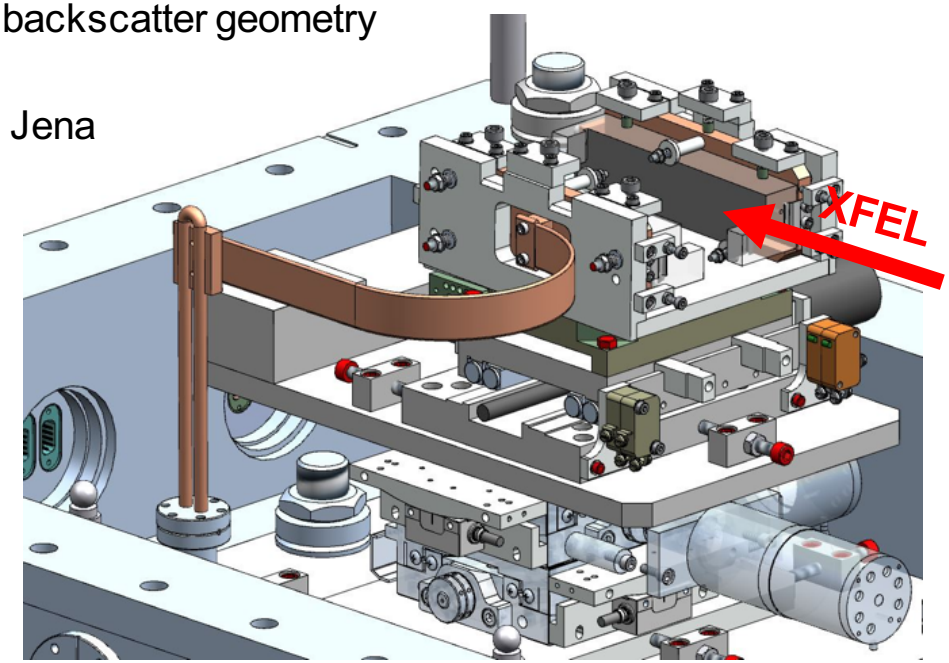


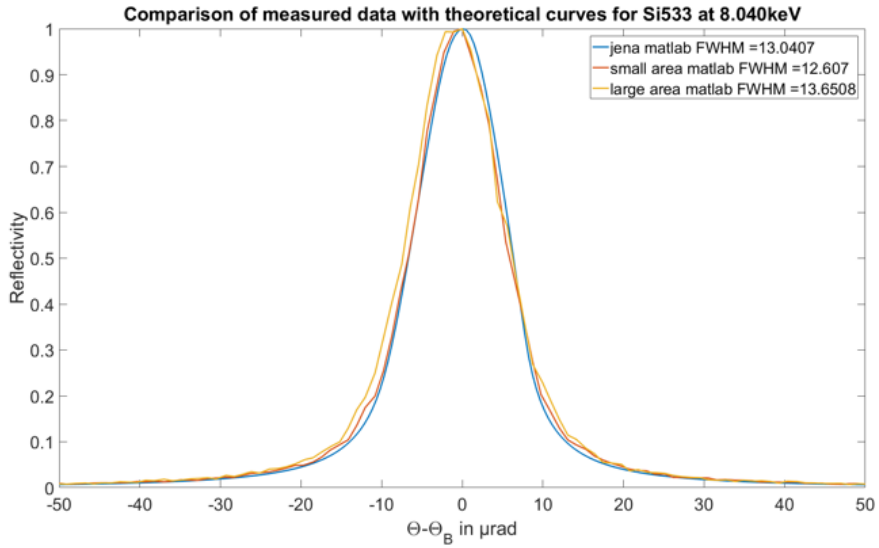
Zastrau et al., Journal of Synchrotron Radiation, in preparation

High-resolution monochromator

- First 2 crystal of standard mono + Si_{533} crystals in backscatter geometry
- Design being finalized by FMB Oxford
- Crystal was cut, prepared by X-ray optics group in Jena





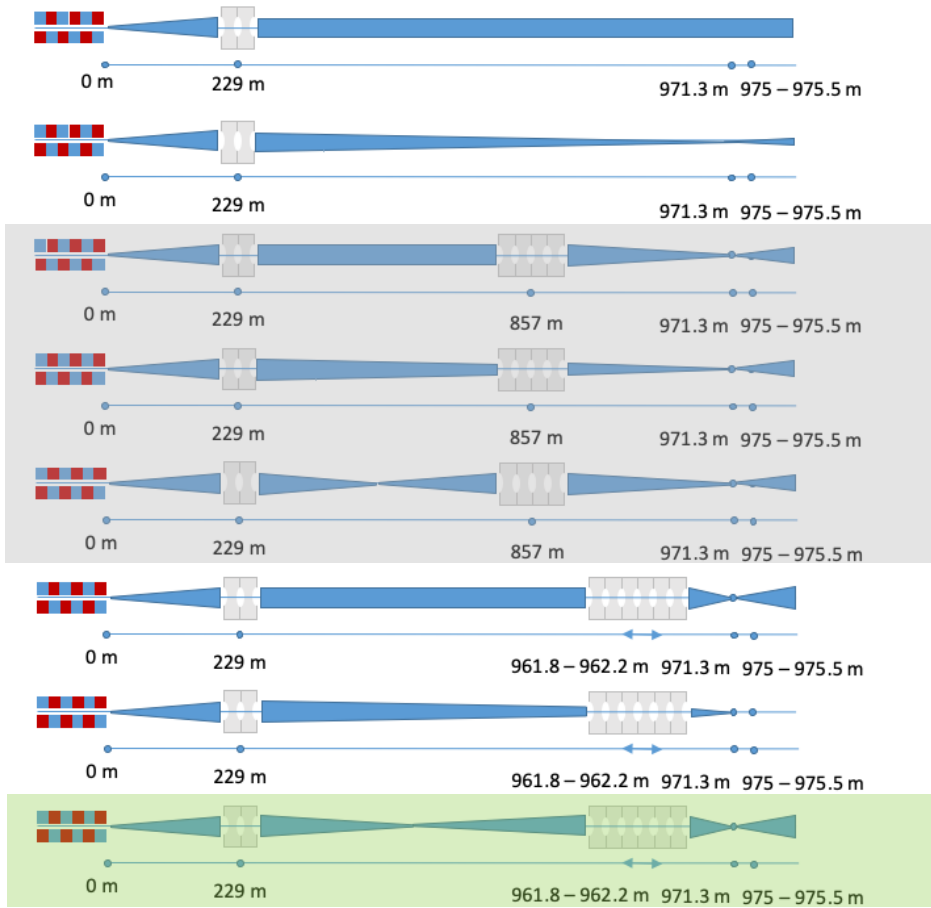


Four different bandwidths:

- $\Delta E/E = 10^{-3}$: SASE
- $\Delta E/E = 10^{-4}$: Si_{111} monochromator
- $\Delta E/E = 10^{-4} - 10^{-5}$: seeded (E: 5 - 14 keV)
- $\Delta E/E = 10^{-6}$: Si_{533} ➔ 7.494 keV

Focussing scheme at HED

- 4 CRL systems placed at various distances from the source
- Foci ranging from ~1 mm down to *sub-micron (using nanofocus setup - framework HIBEF DESY, A. Schropp, position few 10s cm upstream of sample)*
- CRL2 still not operational for safety constraints
- Energy range 5 - 25 keV
- Chromatic (different set of lenses for different X-ray energies) → change in photon energy causes significant shift in focus position
- Optimized for transmission (>95%) → actual transmission lower atm
- Use of intermediate focussing scheme improves beam stability



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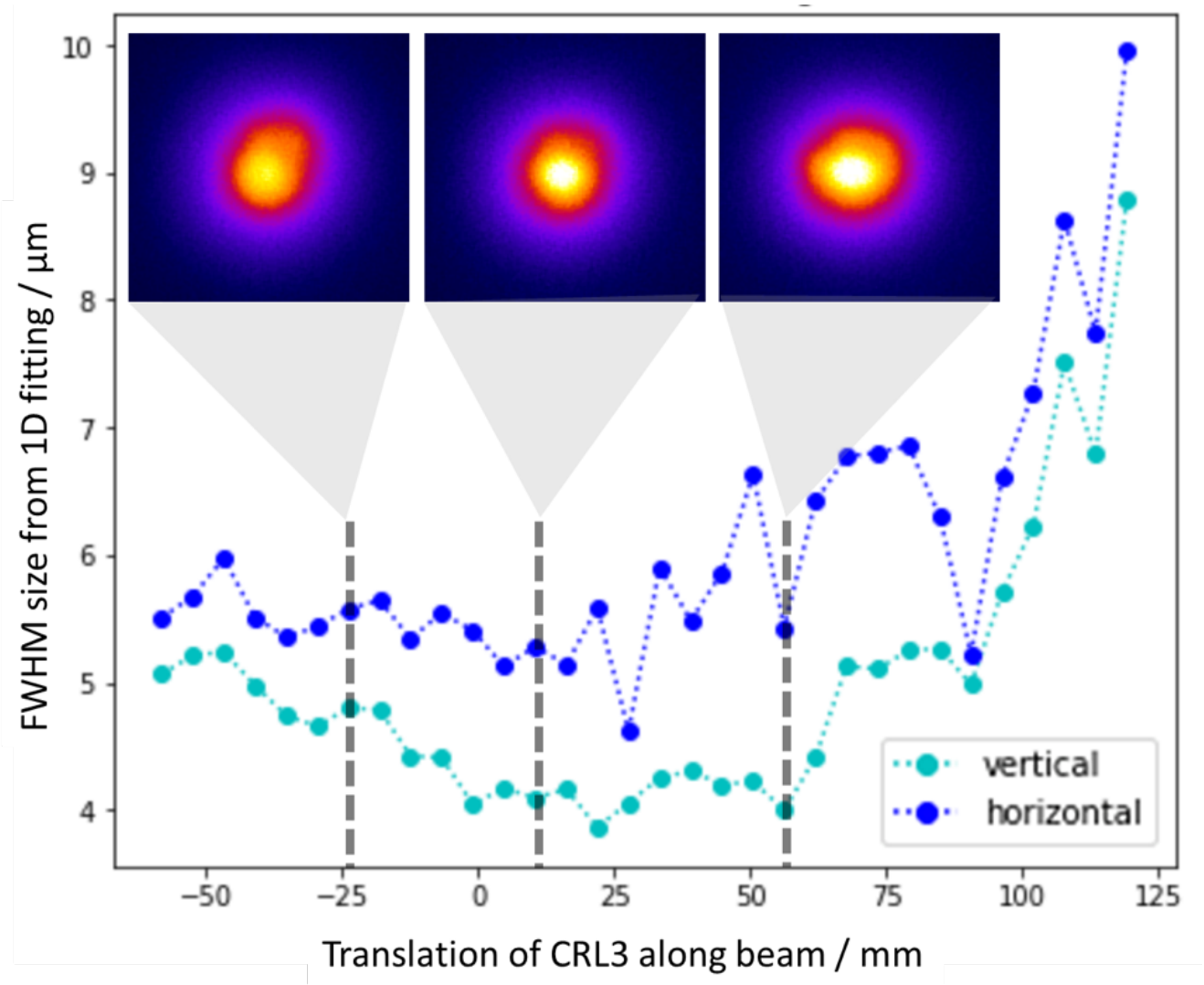
LiF imprint focus characterisation at 6 keV in IC1



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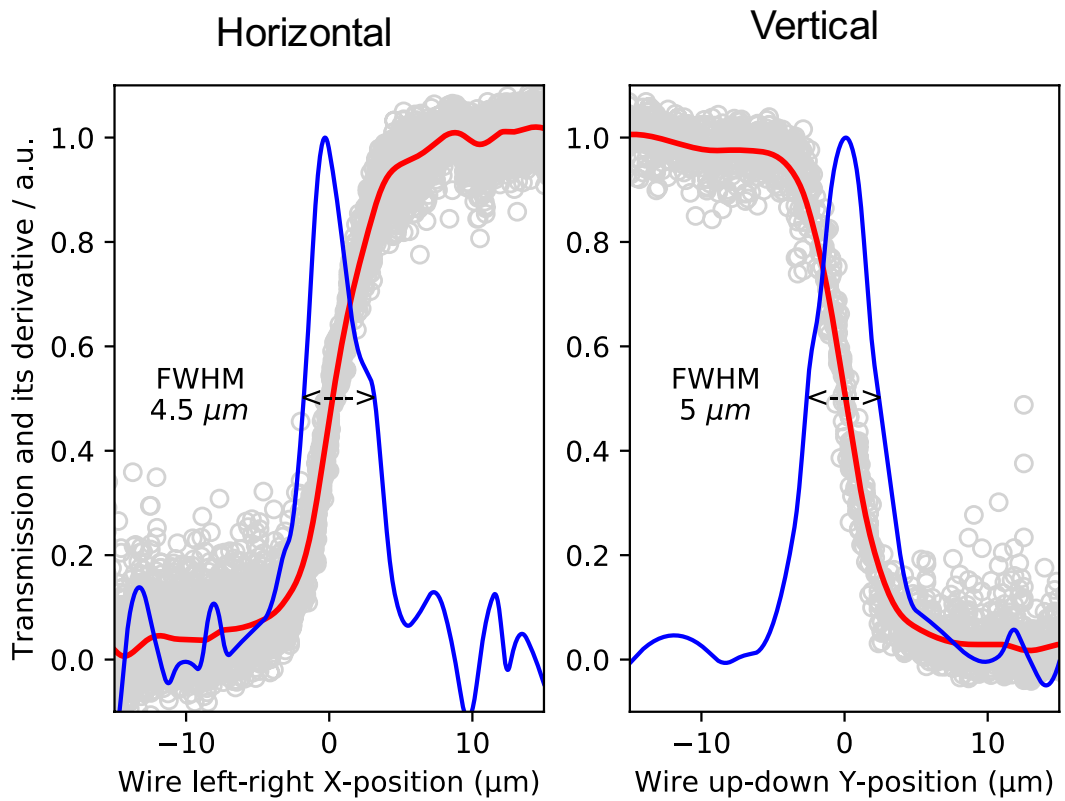
Wire scan focus characterisation at 17.8 keV in IC2



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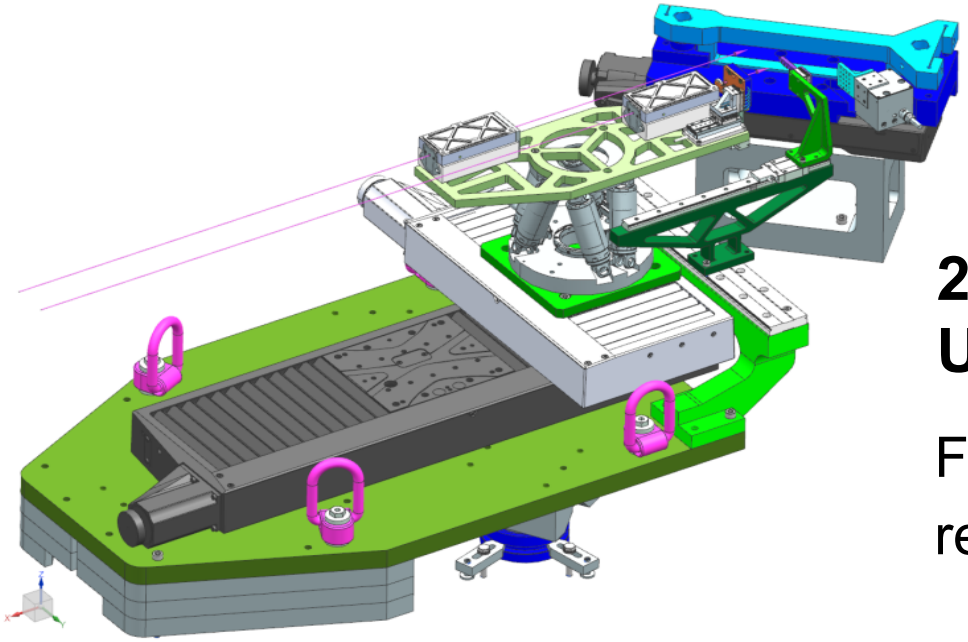
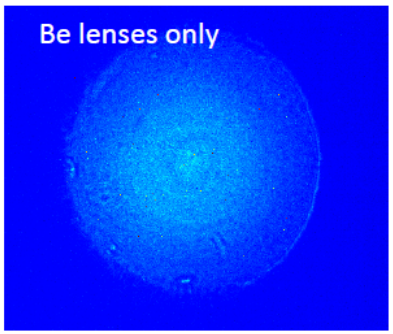
Nano-focused beam (CRL 4) - HIBEF contribution (WPL A. Schropp, DESY)

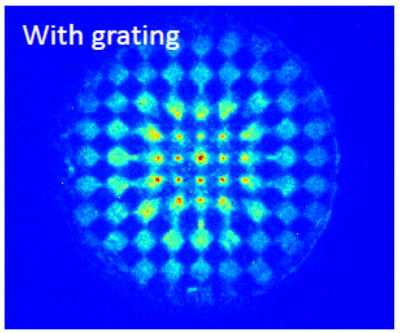


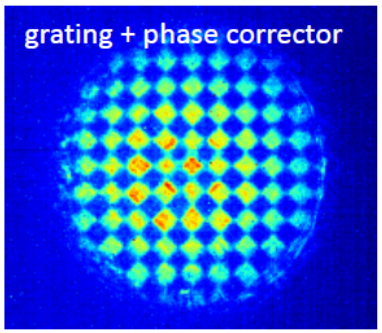
220 nm focus at 9 keV
User experiment M. Makita

First tests in August 2019 at 9 keV, rescheduled for March 2020

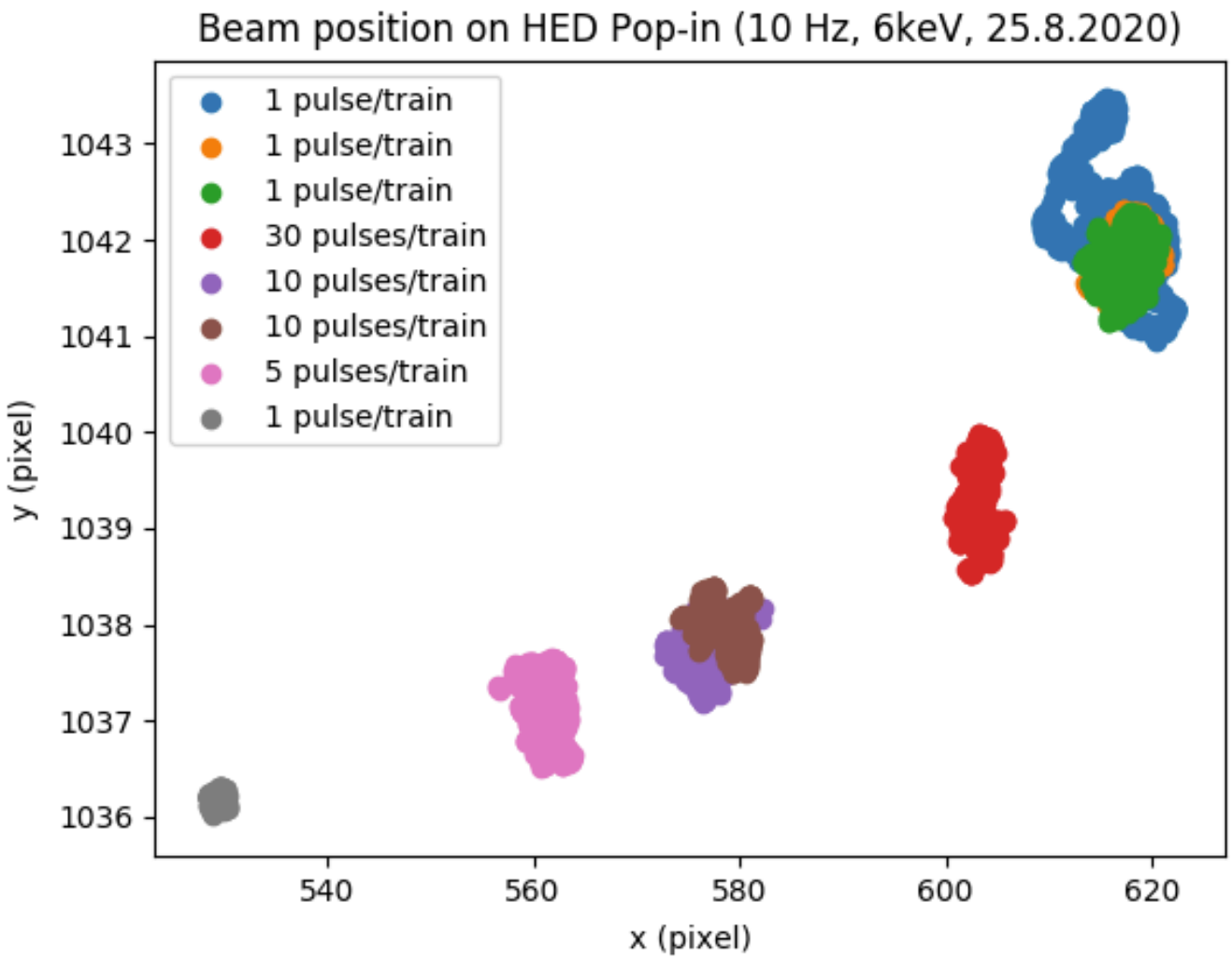
Be CRL4 and phase corrector aligned for nano-focused beam





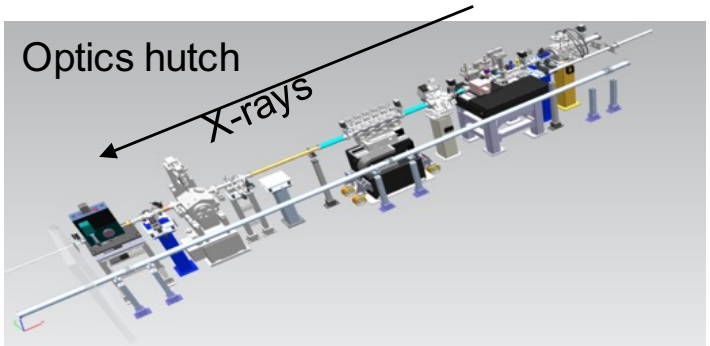


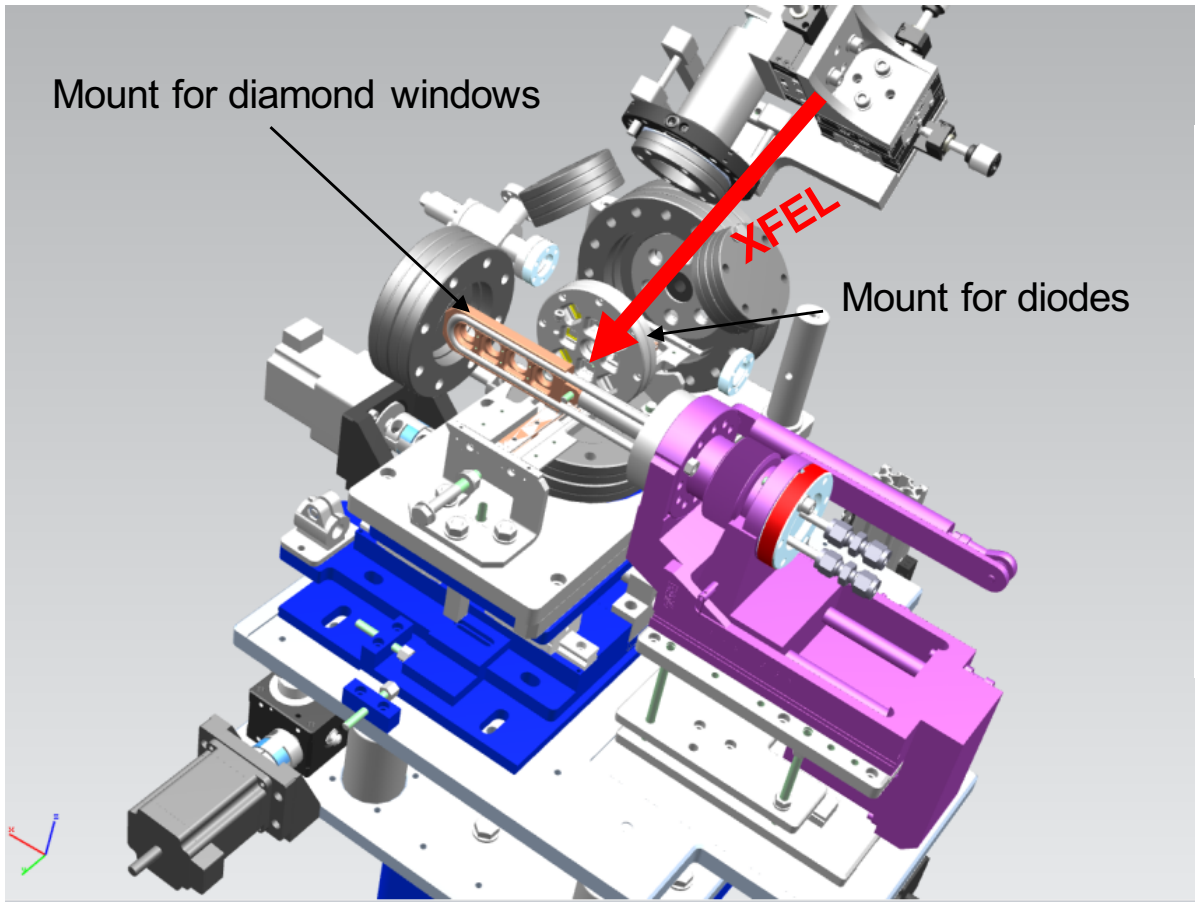
Beam stability – heat load effect and drifts



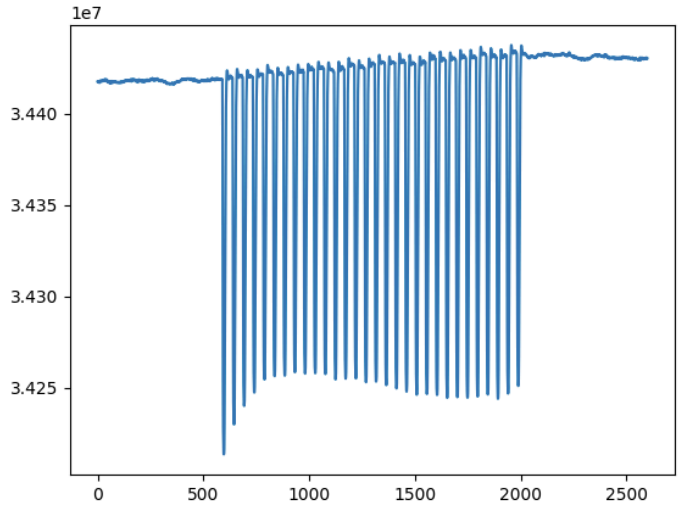
- Beam stabilisation compensates for these drifts (it was deactivated for these measurements)
- Change in attenuation level upstream of the beam stabilisation will also cause drifts

I_{zero1} and positioning monitor





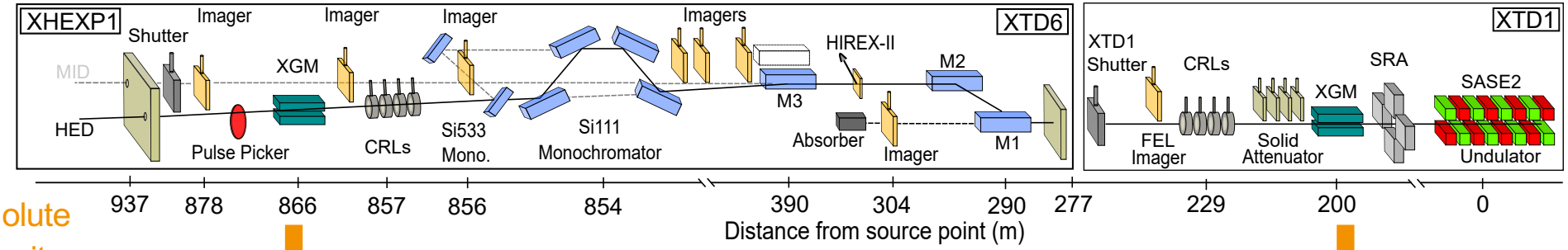
30 pulses recorded in 1 diode, raw data



- I0 (20-100 um diamonds, <10% attenuation)
- Backscattering signal is recorded in 4 fast diodes

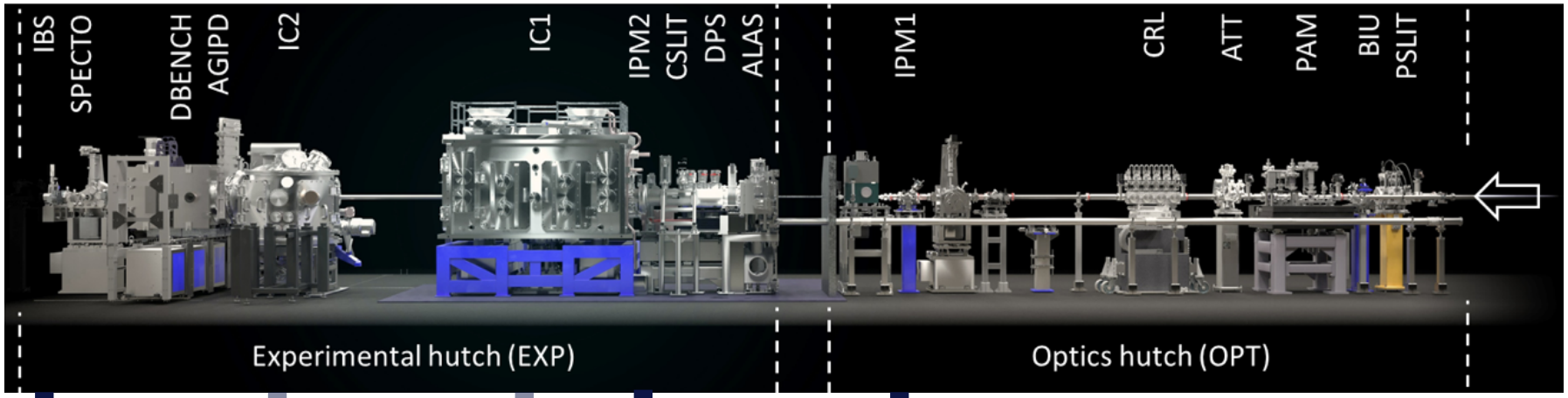
Same principle for IBS, I_{zero2}, diodes in IC1 and IC2

Beamline transmission measurements



Absolute intensity monitors:

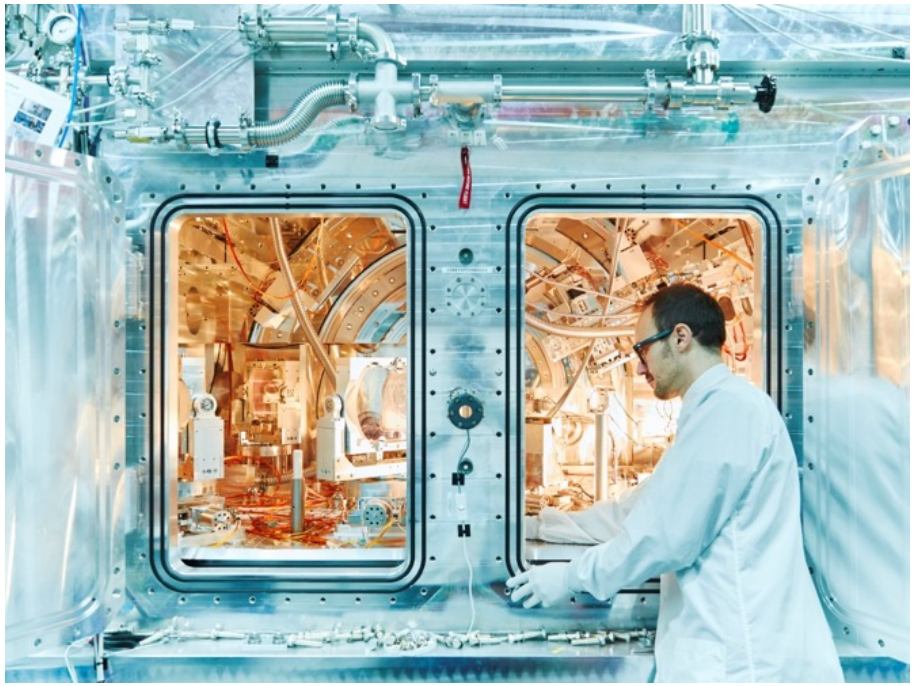
XGM_HED Beamline transmission through mirrors and CRL < 0.8 XGM_SA2



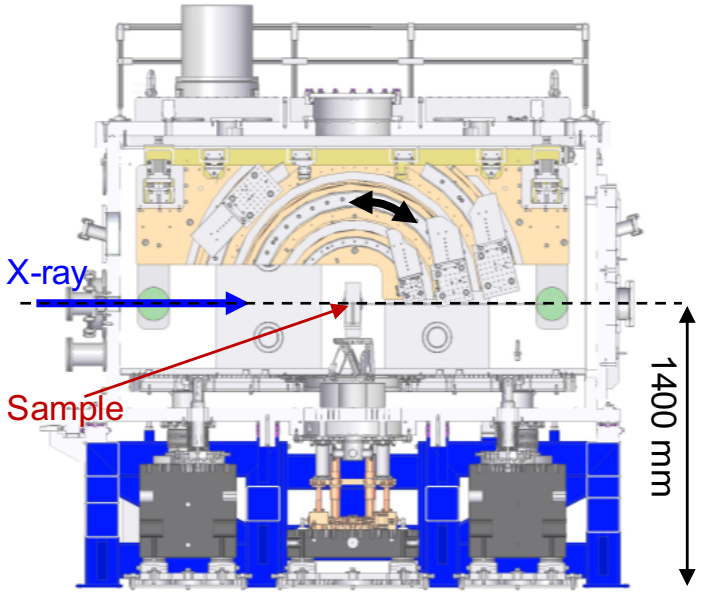
Relative intensity monitors: Pulse resolved intensity and position monitors (permanent) and flexible intensity monitors. Cross correlation to XGM needed depending on experimental set-up.

Zastrau et al., Journal of Synchrotron Radiation, in preparation

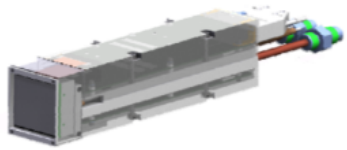
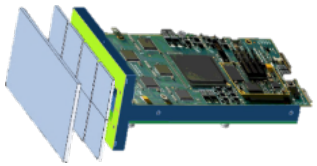
IC1 – flexible large chamber



- Motorized carriages
- Arc R = 306, 517, 750mm
- Breadboard moveable in x-axis
- Mounting of X-ray detectors
- Mounting of spectrometers



HED vacuum compatible and compact X-ray detectors


Parameters	ePix100	ePix10k	Jungfrau	Gotthard-II
	SLAC	SLAC	PSI	PSI
Sensor	300 µm Si	300 µm Si	320 µm Si (upgrade 450 µm Si)	320 µm Si
Sensor size (pixel)	704x768 (35x38 mm^2)	352x384 (35x38 mm^2)	512x1024 (40x80 mm^2)	1x1280 (8x64 mm^2)
Pixel size (µm)	50	100	75	25
Dynamic range	10^2 (@ 8 keV)	10^4 (@ 8 keV)	10^4 (@ 12 keV)	10^4 (@ 12 keV)
Noise (eV)	< 280	< 560	< 450	< 900
Repetition (Hz)	120	120	2000 (200 tested) 0.5MHz in burst mode, 16 images on-chip memory	40,000 0.8MHz in burst mode, 128 images digital memory
# of modules	**2**	**3**	**4**	**2**

Platforms – Interaction Chamber 1

- 2 ePIX100 detectors for spectroscopy, imaging or XRD, 50um pixel pitch, ~700x700 pixels, 10 Hz. Very low noise
- 2-3 ePIX10k (gain switching, 10^4 dynamic range) for XRD or spectroscopy, 100um pixel pitch, ~350*350 pixels, 10 Hz
- 2-3 JUNGFRAU detectors (gain switching 10^4) at 10 Hz (no burst mode) for XRD or spectroscopy (pixel pitch 75um, detector size ~ 3.5*7 cm)

- Possibility to mount area detectors or spectrometers on curved rails in vacuum on vertical breadboard
- Von-Hámos HAPG spectrometers (RoC 50mm and 80mm, crystals available 40um HAPG, 100um HAPG, 200um HOPG), single crystal van Hámos (Si 111 and Si 531)
- High-resolution monochromator and diced analyzers (Si 533) for ~50meV spectroscopy at 7.490 eV
- Stepper-motor target stage on hexapod and precision rotation stage
- CRL4 for sub-µm foci and PCI set-up
- SAXS set-up (see talk of Allejandro Garcia Lajo later today)

In-line spectrometer specifications for beam characterisation

HIREX-II (XPD group, XFEL)

- Energy range (5 - 20 keV)
- 0.2 eV/300 eV
- C(110), R=100 mm, Si(110), R=50 or 100, Si(111), R=75 mm
- Pulse to pulse information with Gotthard detector
- 2D with PhotonicsScience

Bending Radius (mm)	Bragg angle	Energy (keV)	Crystal	Crystal reflection
YAG screen/Flat crystal				
125	50° -- 20°	6,5 - 16	C(110)	220
100	40,22° -- 23,80°	5,1 – 8	Si(110)	220
75	47,85° -- 21,75°	8,1 – 16	Si(111)	333
50	37,25° -- 28,96°	16,1 – 20	Si(110)	660

HED-flex (outside IC1)

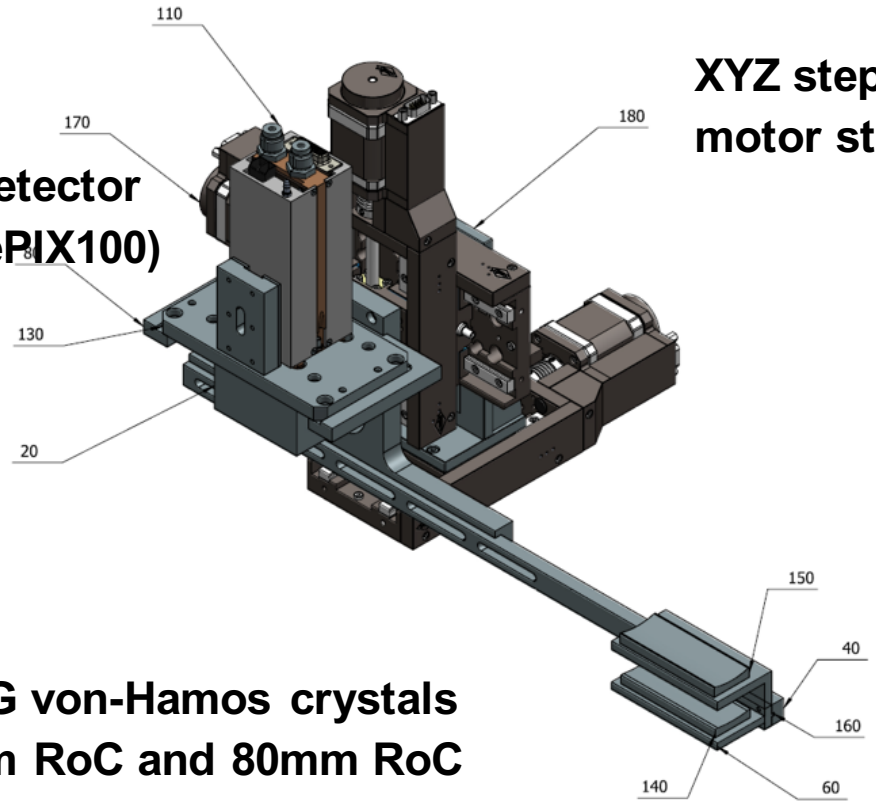
- Energy range (5 - 20 keV)
- 0.13 eV/100 – 200 eV
- C(110), R=100 mm, C(111), R=100; Si(110), R=50 - 150, Si(111), R=50 - 150 mm
- Pulse to pulse information with Gotthard detector
- 2D with Zyla 4.2 Plus or Zyla 5.5

CNRS spectrometer (comm with beam planned 2021)

- Energy range (5 - 20 keV)
- 0.3 eV/100 – 200 eV
- C(110), R=100 mm, C(111), R=100; Si(110), R=50 - 150, Si(111), R= 75 mm
- Pulse to pulse information with Gotthard detector
- 2D with Zyla 4.2 Plus or Zyla 5.5
- PI-MTE:2048B (in vacuum in IC1)

Collaboration with M. Harmand

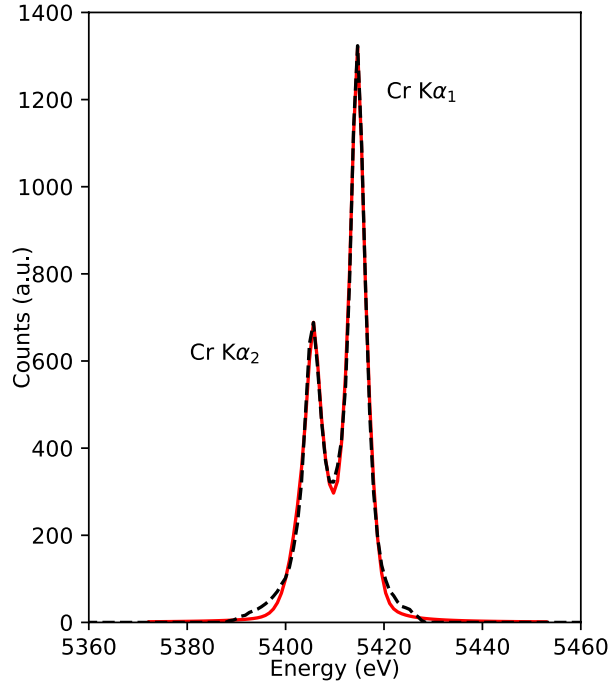
Emission spectrometer for resolutions down to 2 eV



X-ray detector (here: ePIX100)

XYZ stepper motor stages

HAPG von-Hamos crystals 50mm RoC and 80mm RoC

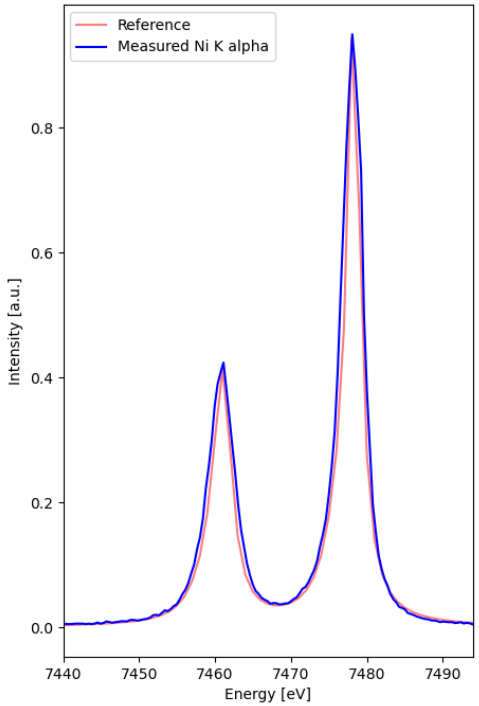


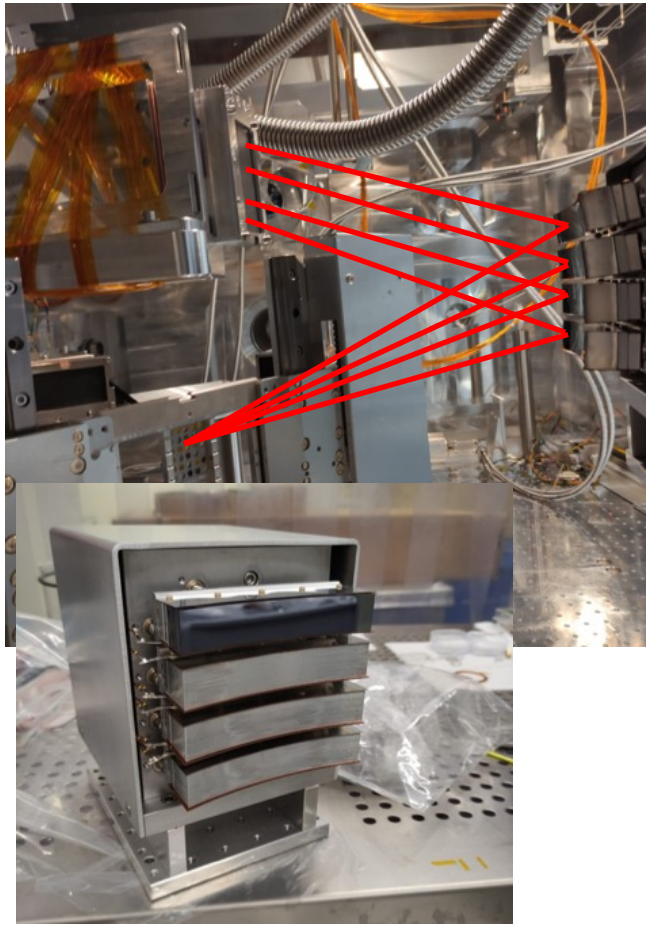
R (mm)	t (μm)	E_C (eV)	ΔE (eV)	dE/dx (eV/pixel)	IF (eV)	RP (adim.)
80	40	5650	839	0.58	2	2.8×10^3
80	100	6050	448	0.82	5	1.2×10^3
50	40	7000	1359	1.33	5–8	$0.9–1.4 \times 10^3$
50	100	8575	677	0.88	17	0.5×10^3

T. Preston et al., JINST, 2020

Single crystal van Hámos spectrometer for higher energy resolution

- Dedicated von Hámos spectrometer
  - 4 vertical analyzer crystals to compensate for lower signal
  - Si (5,3,1) and Si (1,1,1)
  - Calculated energy resolution ~ 0.3 – 0.4 eV
  - First test on Ni foil performed 10 2020





BMBF funding
(# 05K19PE2)

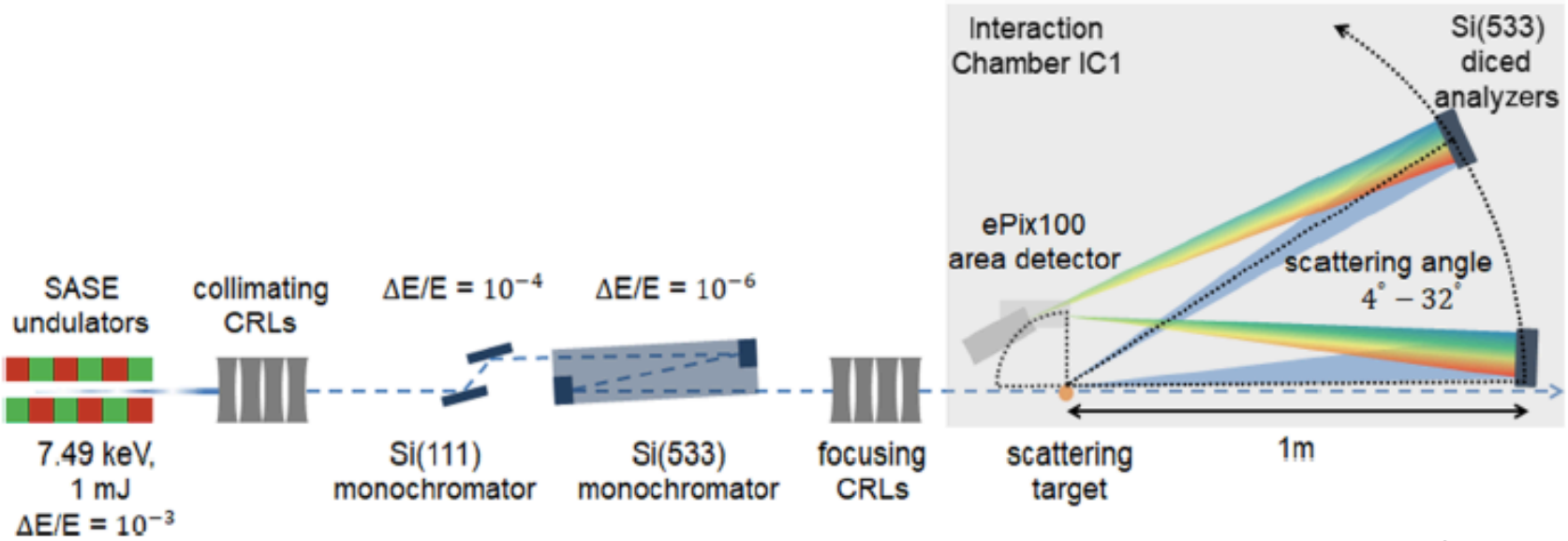
Bundesministerium für Bildung und Forschung

technische universität dortmund

European XFEL

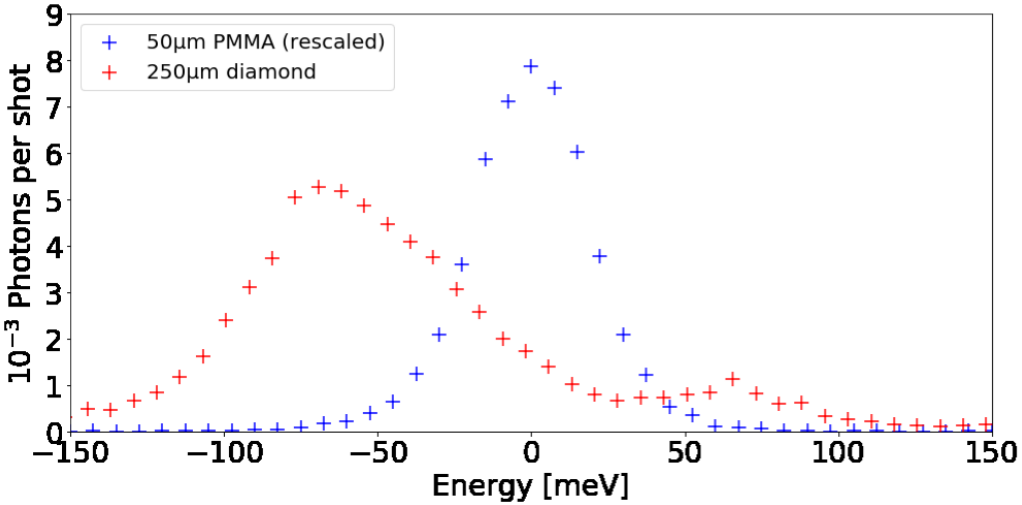
Collaboration with J. Kaa (PhD student) and C. Sternemann

HRIXS set-up with 40 meV resolution



Wollenweber et al., RSI, 2021

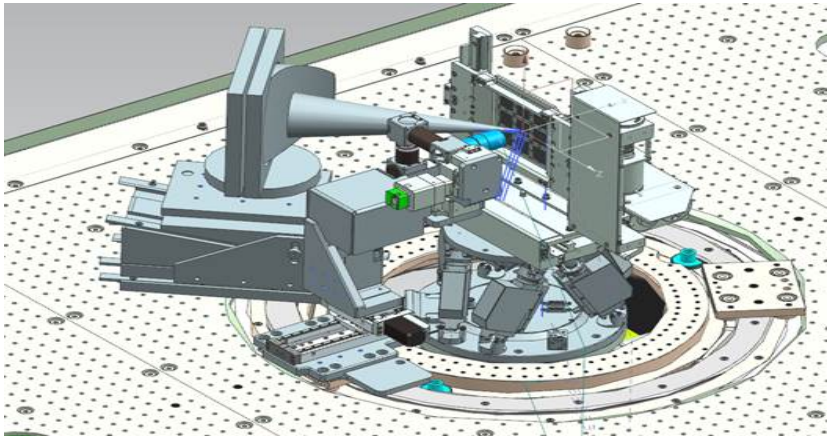
Set-up was also used in
Descamps et al., Sci. Rep., 2020

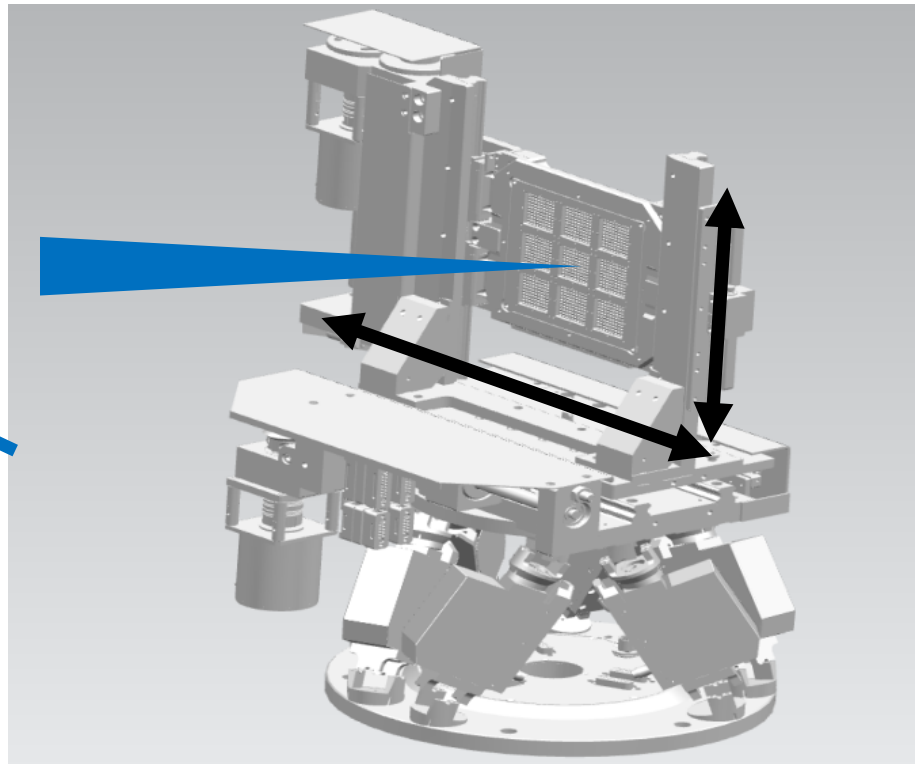


Zastrau et al., Journal of Synchrotron Radiation, in preparation

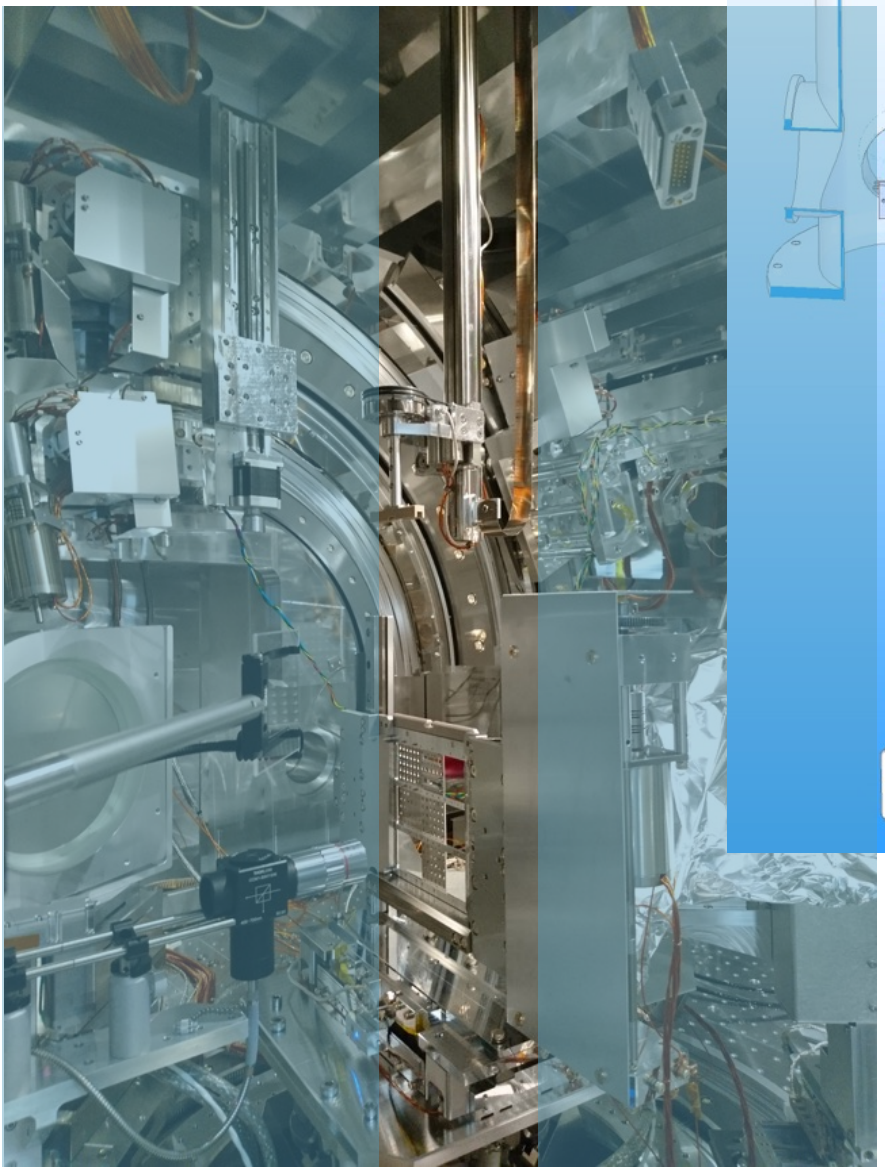
FSS (Fast sample scanner)

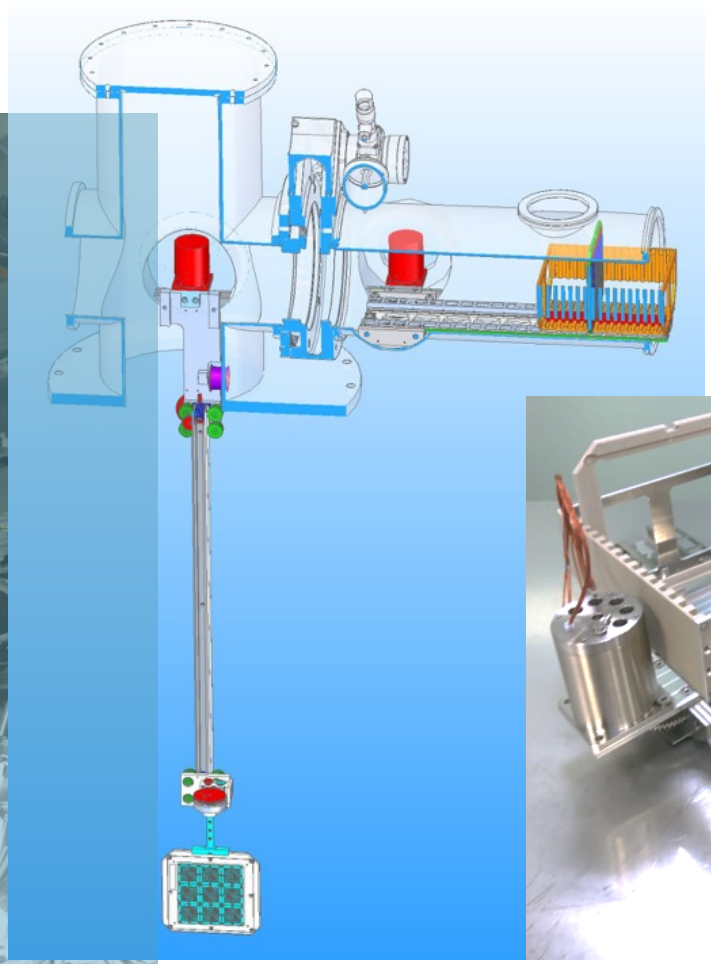
- Stepper motor-driven (2 axis) ~2um resolution
- Mounted on PI hexapod
- HUBER rotation stage below

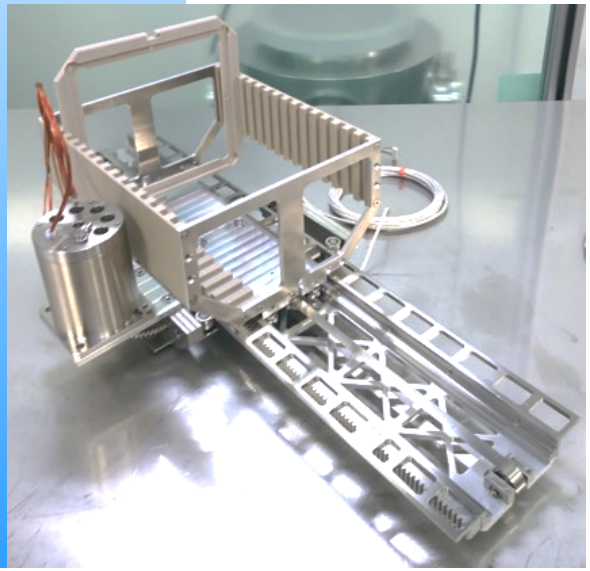




Sample exchanger







- Installed to IC1 in Sep 2020
- 1st in-hutch motion test: Nov-Dec 2020
- Next commission ~ mid-late 2021
- User operation ~ 2022
- Design C. Deiter SEC, XFEL

The joint HED and HIBEF team at European XFEL

Great thanks to

European XFEL support groups

DESY-HIBEF

HZDR-HIBEF

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