Dr. Jan Grünert

X-ray Photon Diagnostics (XPD) group

EIROforum school on instrumentation (ESI) June 2021





Enlightening Science



Dr. Jan Grünert, X-ray Photon Diagnostics, European XFEL

European X F E L

European

X-ray

Free - Electron

Laser









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The machine

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General layout of the European XFEL



Beamline layout and experiment stations



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The people





~2010

<50 staff</p>
European XFEL

<100 staff

les

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~2014



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Jan Grünert **Group Leader**

Wolfgang Freund K-monochromator system

Andreas Koch

Imagers

Invasive Diagnostics



European XFEL

Naresh Kujala Spectroscopy and Wavefront Sensing

Jia Liu Temporal Photon Diagnostics





Florian Dietrich Mechanical Engineer



X-ray Photon Diagnostics Group (XPD) in 2021



Theophilos **Maltezopoulos** Gas-based online diagnostics (XGM)



Randeer Gautam Student









Welcome to the World of Diagnostics !





AMO-LCLS beamtime L675 (2/2013), PI R.Coffee

European XFEL

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Beam properties



Sketch from wikimedia.org: Gaussianbeam.png: en:User:DrBob / CC BY-SA (http://creativecommons.org/licenses/by-sa/3.0/)



European XFEL

Special requirements for diagnostics at EuXFEL



POWER



Photon beamlines

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- ~50 diagnostics installations in 3 undulator beamlines
 ✓ installed
 ✓ commissioned
- \checkmark in operation



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Reference: J.Grünert et al., J. Synchrotron Rad. 26 (5), 1422–1431 (2019)

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SASE1 tunnel XTD2





2017



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SASE1 tunnel (XTD2)

tunnel videos XPD_01 XPD_02

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EuXFEL Photon Diagnostics – examples

- K-monochromator and Imagers
- X-ray gas monitor (XGM)
- Photoelectron spectrometer (PES)
- Crystal-based spectrometer (HIREX)



K-Monochromator system (SASE1)



Filter chamber

- Alignment base plates
- Holds up to 5 filter foils

Material	Thickness	K-edge
Aluminum (light blocker)	3 µm	(1559.6eV)
Chromium	5 µm	5989 eV
Copper	10 µm	7709 eV
Nickel	5 µm	8333 eV
Molybdenum	20 µm	20 keV



N:\4all\intern\User data\wp74\Devices\31-2 K-Mono\production drawings\filter chamber

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Design: Wolfgang Freund, WP74

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K-Monochromator



One K-monochromator device per SASE beamline

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Design: Wolfgang Freund, WP74

K-Mono with spontaneous radiation

- K-Monochromator + SR-Imager
- Spontaneous radiation from last SASE1 undulator segment @ ~8.2keV
- Variation of K-Mono tuning



SASE3 K-mono measurements

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E_ph: 18.137 keV / Bragg: 6.257996 ° E_ph: 3.630 keV / Bragg: 33.002780 ° E_ph: 4.555 keV / Bragg: 25.723114 ° E_ph: 9.101 keV / Bragg: 12.546575 ° E_ph: 15.454 keV / Bragg: 7.350358 ° 200 400 exp. 1000 250 500 750 1000 1250 1500 1750 250 500 750 1000 1250 1500 1750 250 500 750 1000 1250 1500 1750 250 500 750 1000 1250 1500 1750 1000 1250 1500 750 1750 sim. 0 Horizontal Positio 0 Horizont-1 -10mm -10mm -10mm 0 Horizontal Position 0 Horizontal Positio -10mm 18.15 keV 3.62 keV 4.55 keV 9.1 keV 15.48 keV energy, 20th harmonic 4th 5th 10th 17th

Measurement and SRW simulation of SA3 cell 23
 e-beam: 14.1 GeV, 30 bunches

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Synchrotron Radiation Workshop (SRW): O. Chubar, P. Elleaume, "Accurate And Efficient Computation Of Synchrotron Radiation In The Near Field Region", proc. of the EPAC98 Conference, 22-26 June 1998, p.1177-1179.



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Design: Wolfgang Freund, WP74

Pop-in monitor under assembly



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Reference: Andreas Koch (XPD)

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FEL imager



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X-ray Gas Monitor (XGM)

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Gas-based Online Photon Beam Diagnostics

- Rare gases (Ar, Kr, Xe) at p < 10⁻⁴ mbar
- Indestructible + no beam perturbation
- Online, shot-to-shot operation:
 - reference data to user experiments
 - input for real-time steering of the electron beam



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XGMD



R. Klein et al., Synchrotron Radiation News 15 (2002) 23.
 K. Tiedtke et al., Gas detectors for x-ray lasers, J. Appl. Phys. 103, 094511 (2008)



<u>X</u>-ray <u>Gas Monitor</u> (XGM)

 Contributed by Tiedtke group @ DESY
 2 XGMDs and 2 HAMPs (one each for hor. and vert. beam position)



Design: FLASH / DESY

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Shot-to-shot pulse energy and average beam position



Facility implementation: European XFEL

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Multibunch-mode

(300 bunches)



300 pulses per train

~ 3.6 Watt at 9.3keV

1.3.2018

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Public Status Monitor

(ttfinfo.desy.de/status-displays/, www.xfel.eu/facility/operation/)

30.4.2019

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Photo-electron spectrometer

Photoionization of rare gases
Time-of-flight measurement of electrons
Automatization of target gas type and pressure, drift-tube voltages
Two-color operation





Reference: J.Laksman

Hard X-Ray PES prototype

Design objectives:

- 5 24 keV (E_kin up to 10keV)
- resolution 10⁻³ 10⁻⁴
- Non-invasive, pulse-resolved
- Online wavelength info to operators & users

Challenges:

- Cross-section is poor for hard x-rays
- Geometric constraints in tunnel
- Minimize maintenance (tunnel!)
- conductive, non-magnetic, light weight material
- Avoid sparking concern at high voltages



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Reference: J.Laksman

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Crystal-based hard X-ray spectrometer

High-resolution Transmissive Hard X-ray Single-shot Spectrometer



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Hard X-ray High Resolution Single Shot Spectrometer (HiREX)

Specifications

- Energy range: 5 15 keV
- Energy resolution: E/dE > 10'000 *
- Transmission > 90% *
- Full 4.5MHz rate (depends on Gotthard + grating durability)
- UHV compatible (p<10-8 mbar)



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Ref.: N. Kujala / W.Freund, XPD

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XILON

PAUL SCHERRER INSTITUT

HIREX diagnostic spectrometer for SASE1

- Grating + bent crystals (Silicon and Diamond)
 2D-camera (10Hz) + fast 1D-detector (MHz)
- Cross-calibration with FXE at 8980eV





Ref.: N. Kujala / W.Freund, XPD

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HIREX diagnostic spectrometer

Full range & high resolution

- hard x-ray range of 6 25 keV
- up to 1% bandwidth
- up to 40,000 resolving power (0.2 eV at 8 keV) .

Minimally-invasive measurement during user operation

full spectrum measurement with better than 1 eV resolution.

Detectors:

Ion Pump

Crystal manipulator

>95% transmission to experimental hutch.

Scope

- HIREX provides single-shot spectra to experiments which • depend on the knowledge of SASE FEL spectrum.
- It provides spectral information to accelerator physicists for machine optimization studies.



HIREX at SASE2 / XTD6

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Reference: N.Kujala

SASE spectrum using Si333 crystal





Two-Color studies at SASE2



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9240 eV and 9300 eV

2020-02-12T10_12_35

Seeding studies at SASE2 Without seeding x=9075.7, y=3070.9 XGM: 369.82 µJ HIREX: 18790028.38 µJ @ 9039.7 eV 1000 7000 / single 6000 average 800 5000 600 4000 N bunch A (au) With seeding 3000 400 2000 200 1000 8.9 9.0 9.1 9.02 9.04 9.0 9.06 9.08 9.1 (keV) (keV)

Spectrum by SA2_HIREX spectrometer at photon energy 9040 eV

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Reference: N.Kujala, M. Guetg, S. Serkez, G. Geloni, et al.



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... and there is also temporal diagnostics...

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European XFEL groups:

XPD, XRO, VAC, EEE, CTRL, ITDM, LAS, Experiments

DESY: L. Fröhlich, M. Guetg

Contributors to instrumentation:

- XGM: K.Tiedtke group (DESY)
- PES: J.Viefhaus group (DESY)
- MCP: E. Syresin, O.Brovko, A.Grebentsov (JINR, Russia)
- KMONO: A. Erko (HZB), J. Rehanek (PSI)
- HIREX: C.David, B.Schmitt (PSI), AXILON, TISNCM
- Imagers: JJ X-ray, Irelec, FMB-Berlin

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... or google-find us by "XPD diagnostics"

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Thank you for your attention.



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