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ORAL: INVITED

Optics Designs for Diamond-II upgrade

Alianelli, Lucia

Diamond Light Source Ltd

Following two decades of operation, the Diamond Light Source accelerator will be upgraded to a higher energy, lower emittance ring, based on a Double Triple Bend Achromats lattice, with user operation resuming in January 2030. The increased capacity of the new Diamond-II machine will allow construction of new beamlines. Increased photon source brightness and flux density will enable higher flux experiments on hard x-ray beamlines. The upgrade includes renewal of beamline optics to match evolving needs and emerging opportunities in areas such as nano probe, high spatial resolution, higher x-ray energy, maximum transverse coherence or combinations of any of these. To take advantage of the new source and for the experiments to stay at the forefront of research, every beamline has been reassessed from the source to the detector. The presentation will include highlights of work on source modelling, impact of increased power on primary optics and estimation of increased performance for existing beamlines.

ORAL: INVITED

Profile Diagnostics for Spatial Overlap between X-ray and Electron Beams in an X-ray laser cavity*

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(Dated: July 4, 2025)

We present a profile diagnostic developed to measure and optimize spatial overlap between X-ray and electron beams in an advanced X-ray laser cavity. Using fast-gated imaging, <10 ns nanosecond resolution, and interchangeable luminescent targets—a diamond screen for electron beam profiles and a YAP:Ce scintillator for X-ray detection. Depending on target in use the system is aimed to achieve overlap up to <10 μm in precision and simultaneous measurement of beam position and size. While originally implemented for the CBXFEL project at LCLS, this diagnostic approach is broadly applicable to other XFEL and synchrotron settings where simultaneous spatial and temporal measurement is critical. We highlight recent results from commissioning experiments and discuss broader applications in ultrafast beam diagnostics and XFEL optimization.

ORAL: INVITED

Pico-metrology: pushing the limits of optical metrology to characterize ultra-quality X-ray optical systems for 4th generation light sources

Bazan Da Silva, Murilo

Diamond Light Source

Diamond Light Source is the UK's national synchrotron, supporting research in various scientific and technological fields. With the advent of a new 4th generation X-ray source, Diamond is poised for a transformative upgrade to its particle accelerators, enhancing data quality and speed. The Diamond-II upgrade will include next-generation X-ray optical systems to efficiently transport and focus the intense, coherent, photon beams. Diffraction-limited beamline performance relies on high-quality optical metrology to guide the correction tools of deterministic polishing machines, and provide accurate feedback for assembly and tuning of optical systems. The Optics and Metrology Group plays a critical role in delivering optimal performance for the X-ray optical systems. In recent years, this includes advanced metrology capabilities to guide optic fabrication. We present an overview of our activities, with a particular emphasis on dimensional metrology in the Optical Metrology Lab (OML) & Precision Metrology Lab (PML). Key topics include: the implementation of new metrology hardware; the integration of cutting-edge technologies; and a continuous effort to improve our methodologies to achieve the required accuracy and data quality. R&D examples and practical applications of pico-metrology will be presented for real-world scenarios. These include: the characterization and optimisation of optics; the validation of instrument performance; and the generation and measurement of sub-nanoradian angles and sub-100 picometre displacements. Through these examples, we hope to demonstrate how our work benefits the ultimate performance of X-ray optical systems and, on a grander scale, supports groundbreaking scientific research and technological innovation.

ORAL: INVITED

Beamline Automation, Optimization, and Control Activities at the European XFEL

Bishara, Fady

European XFEL

The European XFEL is an extremely complex machine with many subsystems that must work in concert in order to enable user experiments and maximize their scientific output. Some of these subsystems require frequent tuning and alignment, while others could be susceptible to damage if not carefully monitored by an operator. Therefore, automating repetitive and time-consuming manual tasks can lead to stable and reproducible experimental setups and free up time for user operation. In addition, detecting adverse conditions via continuous monitoring can prevent equipment damage, minimize the risk of lost beamtime, and save the cost of repair.

This talk will give an overview of selected automation, optimization, and feedback control activities of subsystems at the European XFEL. In particular, it will cover automation tasks including alignment of the optical laser for pump-probe experiments, the setup of a high-resolution spectrometer, alignment and focusing of X-ray beam, and automation of geometry tuning in multi-module detectors. In addition, the talk will cover the automatic calibration of the photoelectron spectrometer. Moreover, the use of computer vision techniques to mitigate damage to X-ray imagers from unwanted scattering on ice, which can buildup on sample injection nozzles, will also be discussed. Finally, the talk will conclude with a discussion of a more ambitious program to build data-driven surrogate models of facility subsystems for use in optimization, feedback control, and modelling.

ORAL: CONTRIBUTED

X-ray beam diagnostics at the Materials Imaging and Dynamics Instrument at EuXFEL

Boesenberg, Ulrike

European XFEL

The Materials Imaging and Dynamics Instrument (MID) at the European X-ray Free-Electron Laser Facility (EuXFEL) is a very versatile instrument where properties of hard and soft condensed matter are investigated with a variation of X-ray scattering techniques utilizing the unique X-ray properties of EuXFEL. Hence, depending on the experiment, different beam properties play a defining role and accordingly different diagnostic tools have priority. The high repetition rate up to 4.5MHz and the high brilliance of about 10^{12} photons per pulse challenge the materials used for detection and data readout schemes. Among the most important parameters are the measurement of absolute intensity, intra- and inter-train pointing stability, spectral distribution, beam size and wavefront characterization. Due to the long photon transport path between the source and the sample (approx. 1km) and intermediate optics the ability to measure these properties close to the sample is mandatory. A dedicated diagnostic device equipped with a bent-diamond spectrometer, high- and low-resolution imager and diamond-based intensity detector is available, but due to its location at the end of the instrument it is not feasible to combine with all experiments, therefore also flexible installed devices are utilized for characterization. In this presentation we will give an overview of applied techniques available at MID.

POSTER

Fe L-edge spectroscopy on the meV scale by diffractive wavefront correction

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Institute of Applied Photonics e.V.

We propose a wavelength dispersive instrument for high-resolution soft X-ray spectroscopy at large-scale facilities like synchrotron radiation sources or free-electron lasers. Demonstrated by simulations at the Fe L-edge in the range from 700 eV to 730 eV, an energy resolution of (12 – 15) meV is enabled by a wavefront corrected reflection zone plate (RZP) with an aperture of 40 mm x 190 mm on a spherical Si substrate (radius 69 m). Its deformation and tangential slope error are measured to ± 6.1 nm (rms) and ± 0.1 arcsec (rms), respectively, along the RZP and compensated at the design energy of 715 eV by a two-dimensional (2-D), adapted grating groove distribution. As an additional benefit, the diffracted beam is collimated to a 1-D focal line whose length of 40 mm nearly equals the sagittal detector size (50 mm). In this way, no photons of the first diffraction order with an efficiency around 4.9 % (Ni-coated laminar profile, etch depth 8 nm) are lost, and the acceptance solid angle of 16 mrad x 1.6 mrad provides a high transmission of the signal from the source. Compared to an analogue 1-D varied line space (VLS) grating [1] without diffractive wavefront correction (DWC) and collimation, the energy resolving power is enhanced by a factor of 2.3, whereas the photon flux is 2.5 times higher. In our contribution, we define the phase function and derive the vector field for the RZP on a curved and wavy substrate. We sketch the formalism for computing the groove structure, which can be regarded as a computer-generated hologram on an irregular 3-D surface [2]: at a central line density around 2150 / mm, position and shape of the grooves differ from those of a regular RZP or VLS on the scale of a half to one period, i.e., up to a few 100 nm. With a total optical path length of 7.55 m [1] and a fixed-focus constant of 2.28, a dispersion between -0.64 eV / mm and -0.70 eV / mm is achieved in the flat but tilted focal plane. We simulate the performance for an incoherent source of 13.5 μm x 2.5 μm (H x V) and use a strongly inclined detector (-79.3°), moderately oversampling the focal line width of (14 – 20) μm (FWHM) with the pixel size of 10 μm . Applications include, e.g., soft X-ray emission (XES) and absorption (XAS) spectroscopy. Polarization is preserved under grazing incidence, which makes the customized DWC conception also suitable for resonant elastic (REXS) and inelastic (RIXS) X-ray scattering.

[1] A. Pietzsch, A. Sokolov, T. Blume, S. Neppl, F. Senf, F. Siewert, and A. Föhlisch, “Inverted VLS Spectrometer at BESSY for Molecular Potential Energy Surfaces and Excitations,” *Synchrotron Radiation News* 31, 20 – 25 (2018).

[2] J. Probst, C. Braig, E. Langlotz, I. Rahneberg, M. Kühnel, T. Zeschke, F. Siewert, T. Krist, and A. Erko, “Conception of diffractive wavefront correction for XUV and soft x-ray spectroscopy,” *Appl. Opt.* 59, 2580 – 2590 (2020).

ORAL: INVITED

New online polarization diagnostics for 3rd harmonic afterburner radiation

Braune, Markus

Deutsches Elektronen-Synchrotron (DESY)

Measurements of the photoionization of rare gases have been an essential method for photon diagnostics at FLASH since the start of operation in 2005. Particularly at FLASH2, photoelectron TOF spectroscopy has been used for non-destructive monitoring of the FEL wavelength. With the online-photo-ionization spectrometer OPIS – a 4-channel eTOF spectrometer device – information about beam properties can be provided to the FLASH users as well as machine operators. In particular for the special two-color mode of FLASH2, we could demonstrate its ability for efficient monitoring of both wavelengths. Recently, an APPLE-III type undulator has been added to the radiator beamline in FLASH2 to enable variable polarization of the FELs 3rd harmonic. With an afterburner scheme FLASH2 can now generate increased output power in a high photon energy range up to 860 eV with selectable polarization between the two linear and two circular modes. Here again photoelectron spectroscopy has been applied for polarization diagnostics with a 16-channel eTOF spectrometer instrument by measuring the angular distribution of photoemission. Results from the experimental studies of the afterburner undulator commissioning will be presented.

ORAL: CONTRIBUTED & POSTER

Temporal characterization of the new time-delay-compensating monochromator beamline at FLASH and first user experiments

Brenner, Günter

DESY Hamburg

The new pulse-length preserving double monochromator beamline FL23 at FLASH went into user operation beginning of 2024. The double grating design guarantees an ultrafast beamline response, thereby maximizing the time-resolution for dynamical studies. The beamline is designed to work in the soft X-ray regime covering the spectral range between 1.3 nm and 20 nm with a spectral resolving power of approximately 2000 [1]. A bendable Kirkpatrick-Baez mirror system provides a flexible microfocus at the experimental station while a femtosecond optical laser synchronized to the FEL enables experiments in a pump-probe scheme. Here, we present spectral encoding measurements that validate the ultrafast beamline response and also show results from first user experiments on 1) a liquid jet sample using time-resolved X-ray absorption spectroscopy at the Nitrogen K-edge and 2) the demonstration of soft X-ray magnetic circular dichroism measurements [2,3] at the L-edges of the important transition metals Fe, Co, and Ni, employing for the first time the new variable polarization afterburner undulator [4] at FLASH2.

[1] L. Poletto, F. Frassetto, G. Brenner, M. Kuhlmann and E. Plönjes, Double-grating monochromatic beamline with ultrafast response for FLASH2 at DESY, Special Issue (PhotonDiag2017), J. Synchrotron Rad. 25, 131-137 (2018); <https://doi.org/10.1107/S1600577517013777>

2] N. Pontius et al., First experiments with ultrashort, circularly polarized soft X-ray pulses at FLASH2, Struct. Dyn., accepted

[3] M. Pavelka, et al, Femtosecond charge and spin dynamics in a Co₅₀Pt₅₀ alloy, Struct. Dyn. 12, 024303 (2025); <https://doi.org/10.1063/4.0000297>

[4] M. Tischer et al., Development of an APPLE-III undulator for FLASH-2. J. Phys.: Conf. Ser. 2380, 012017 (2022).

ORAL: CONTRIBUTED & POSTER

Status and prospects of Silicon Carbide-based in-line sensors for X-ray realtime monitoring

Camarda, Massimo

SenSiC GmbH

In modern synchrotron and free-electron laser (FEL) facilities, the demand for compact, radiation-hard, and high-resolution X-ray diagnostics continues to rise. Silicon Carbide (SiC)-based in-line sensors represent a transformative technology in this field, offering superior performance over conventional blade-based or metal photoemission monitors. This abstract outlines the current development status and future prospects of such sensors, focusing on their integration into beam diagnostics systems for real-time X-ray intensity and position monitoring. SiC-based sensors leverage the intrinsic advantages of wide-bandgap semiconductors, such as high radiation hardness, thermal stability, and insensitivity to visible light, which makes them ideal for high-brilliance beamlines. Recent innovations have demonstrated how SiC devices can fulfil the roles of beamstoppers, intensity monitors, and position-sensitive detectors in ultra-compact formats. These different devices The Beamstopper Integrated Sensors (BIS) can incorporate from one up to four-quadrant diode geometries for beam centering and live intensity feedback in footprints below 1 mm, and have been successfully validated at major European light sources such as SLS and MAX IV.

Another key innovation in the deployment of these sensors lies in the concept of harmonic tuning, where the spectral sensitivity of the devices is tailored using filtering strategies to isolate specific harmonics from insertion devices. This approach yields enhanced signal-to-noise ratios and up to tenfold improvements in spatial resolution compared to legacy systems. Further, the successful functionalization of SiC diodes for center-stop integration within order sorting apertures (OSA) has enabled new designs for scanning transmission X-ray microscopy (STXM), where in-situ beam monitoring within sub-millimeter working distances is essential. The current status of SiC-based in-line sensors demonstrates their readiness for widespread deployment in both new and upgraded beamlines.

To fully exploit the capabilities of these sensors, robust and high-speed electronics are essential. STLab srl has developed dedicated readout and control electronics tailored to the unique requirements of SiC-based devices. These systems enable low-noise, high-bandwidth signal acquisition and facilitate seamless integration into beamline control architectures. The synergy between SenSiC's sensor technology and STLab's electronics platforms allows for real-time data processing and closed-loop feedback applications, thereby enhancing beam stability and reducing measurement artefacts. This contribution presents a comprehensive review of performance benchmarks, deployment case studies, and integration strategies, highlighting the collaboration between SenSiC GmbH and STLab srl. Together, these developments mark a significant step forward in achieving compact, reliable, and high-fidelity X-ray monitoring for the next generation of photon science.

ORAL: CONTRIBUTED

Wavefront control approach for X-ray optics alignment

Vishal Dhamgaye, David Laundry, Hossein Khosroabadi and Kawal Sawhney

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The ultimate focusing of the X-ray focusing optical element not only depends on its optical quality but is also influenced by the misalignment of its own or any upstream optical elements, if present. Wavefront measurement of such an optical element provides both information on the optical quality and its alignment error. Diamond has developed a knife-edge wavefront sensing method for characterising the focusing optical components, such as X-ray mirrors and lenses [1, 2]. The measured wavefront is fitted to a series of polynomials to determine the aberrations present in the focusing element. The coefficients of the polynomials, particularly second and third order, provide a direct measure of the magnitude of misalignment error in image distance and incidence angle for an X-ray mirror. By minimising these coefficients, we can achieve better alignment of a focusing element [3].

Several factors such as thermal load on optics, source instability and temperature drift in the experimental hutch, lead to beam drift in the nano or micro-focus experimental stations [4, 5]. This beam drift can be corrected as desired by changing the incidence angle of the optics or moving the sample in the focal plane. Small changes are required in the optics, which may not be feasible due to motion resolution or repeatability. This paper reports the concept of a wavefront-based alignment procedure and the precise control of second and third order components to the wavefront of the focusing element using refractive phase correctors. The refractive correctors can control the focal planes to a few microns to a few millimetres and incidence angles within a few microradians without disturbing a focusing X-ray mirror. Further, the correctors provide adaptive focusing performance of X-ray optics by controlling the latter's wavefront.

[1] David Laundry et. al., Adaptable refractive correctors for x-ray optics, *Optica* 6, no. 12 (2019): 1484-1490.

[2] Hossein Khosroabadi et. al., Wavefront analysis and phase correctors design using SHADOW, *Synchrotron Radiation*, 31(3), 438-446 (2024).

[3] Vishal Dhamgaye et. al., Automatic alignment of KB mirror systems with the knife-edge imaging wavefront sensing technique, *SRI-2024, Hamburg* (2024)

[4] Dina Carbone et. al., Design and performance of a dedicated coherent X-ray scanning diffraction instrument at beamline NanoMAX of MAX IV, *J. Synchrotron Rad.* 29, 876–887 (2022).

[5] R. Tucoulou et. al., High-resolution angular beam stability monitoring at a nanofocusing beamline, *J. Synchrotron Rad.* 15, 392–398 (2008).

ORAL: CONTRIBUTED

Nanofabrication Solutions for Advanced Photon Diagnostics

Döring, Florian

XRnanotech

State-of-the-art photon diagnostics at free-electron laser (FEL) and synchrotron facilities demand unprecedented precision in spatial, spectral, and temporal characterization of intense and ultra-short photon pulses. High-performance optics and diagnostic tools are critical to enable accurate beam delivery and real-time feedback for both beamline tuning and experimental science. In this talk, we present recent advances in nanofabrication technologies that unlock new capabilities for photon diagnostics and beamline instrumentation. XRnanotech specializes in high-precision nanostructures and x-ray optics, including ultra-high-resolution transmission gratings, zone plates, and wavefront sensors tailored for high photon energies and repetition rates. Leveraging electron-beam lithography and cutting-edge pattern transfer techniques, we fabricate nanostructures with ultra-high precision in different materials e.g. diamond, silicon, gold and iridium. We will highlight application examples ranging from transmission gratings for high-resolution diagnostics, to Hartmann sensors for wavefront characterization at FELs. Furthermore, we will outline XRnanotech's ongoing development of customized optics solutions that address the specific needs of beamlines operating under demanding conditions such as high photon flux, coherence, and pulse-to-pulse variability. These nanofabrication-enabled tools not only improve photon diagnostics but also pave the way for new measurement methods, combining precision nanostructures with advanced detection approaches.

ORAL: CONTRIBUTED

5 years of experience with the THz streaking beamline FL21 at FLASH

Duesterer, Stefan

DESY

The intense ultra-short XUV pulses of the free-electron laser FLASH@DESY fluctuate from pulse to pulse due to the underlying SASE-FEL operating principle and thus demand single-shot diagnostics. To cope with this, a beamline (FL21) for temporal diagnostics was designed, built and put into operation at FLASH2 in 2019. The beamline has been equipped with a permanently installed terahertz field-driven streaking setup that enables the determination of single shot pulse duration and arrival time. In numerous beamtimes we had the chance to collect a large number of THz streaking measurements. Here we present some lessons learned and the variety of different options offered by the streaking setup. Looking at gain curve measurements, two-color FEL operation, harmonic content of the FEL radiation, frequency chirp of the XUV pulse as well as on correlations between the pulse duration and other parameters like pulse energy or spectral distribution, we can learn more about the performance of FLASH. Having all the experimental data at hand, we also used it to compare to different theoretical models and to find/verify scaling laws. Finally, an outlook will be given on the plans for pulse duration measurements at FLASH2 in the next years.

ORAL: INVITED

Advanced & Intelligent Beam Diagnostics at KIT

Presented by Andreas Ebersoldt

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Advanced high-speed beam diagnostics are essential for the next generation of particle accelerator facilities. This contribution presents recent developments in ultra-fast silicon detector technologies, with a particular emphasis on Low-Gain Avalanche Detectors (LGADs). A novel trench-isolated TI-LGAD approach will be highlighted, offering exceptional timing resolution at the level of tens of picoseconds, sub-25 μm granularity, and unprecedented frame rates of several hundred frames per second in continuous acquisition mode.

These TI-LGADs, recently produced by FBK (Fondazione Bruno Kessler), leverage state-of-the-art fabrication processes to deliver groundbreaking performance. Preliminary test results and characterization data will be discussed, demonstrating their potential for ultra-precise beam diagnostics and underscoring their key role in advancing instrumentation for future accelerator machines.

In addition, results on the application of reinforcement learning technologies for autonomous accelerator operation will be presented, illustrating how intelligent control strategies can further enhance beam control capabilities and pave the way toward next-generation of accelerator machines.

ORAL: CONTRIBUTED & POSTER

Blazed profile gratings produced by EBL for spectroscopic applications

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In order to transfer properties of new accelerator-based photon sources in the soft X-ray energy range, high quality reflective optics are needed. In spectroscopy, blazed profile gratings are used when high efficiency is sought. However, their availability is critical due to technological challenges and limited manufacturing resources using classical methods, such as ruling. To balance this bottleneck, grey-tone e-beam lithography (EBL) has been investigated for the production of blazed profile gratings with a moderate line density showing very nice results and an overall good agreement with ruled gratings. Here, we expand the capabilities of the developed method for constant and moderate line density, for the production of variable line space (VLS) gratings. A spectrometer consisting of 11 VLS gratings is planned for achieving high-spectral resolution at the femtoslicing HR beamline at BESSY II. The 11 apertures, on a single substrate, have central line densities from 550 lines/mm to 1360 lines/mm and optical apertures up to 4 mm x 90 mm.

We report on the ongoing work on the manufacturing and metrology control of the blazed profile gratings to track the lithography process, and show the capabilities of blazed gratings by EBL.

Acknowledgments

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ORAL: CONTRIBUTED

Calibration and analysis of the wide-band compact spectrometer COSP

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The COmpact SPectrometer – COSP is a grating spectrometer designed to provide medium resolution in a wide spectral range. Such instrument can be used either to measure the intensity of the interacting electromagnetic fields in a multi-color experiment or to quantify the amount of spurious harmonics. In both cases it plays an important role as a real-time monitor for the FEL operation, and the information gathered can be used to validate data in a multi messenger (electrons / photons) approach. In particular, a wide-band spectrometer will have a key role in ensuring the monitoring of several different harmonics on a single-shot basis in multi-color experiments, both to validate the acquired data and to monitor and adjust the working parameters.

COSP consists of a flat-field concave replica grating (Shimadzu) having a groove density of 300/mm. The detector is a 40-mm-diameter micro channel plate (MCP) with a MgF₂ photocathode and phosphor screen provided by PHOTEK (PHOTEK VID140). The system is read by a commercial CMOS camera (Basler acA1300-75gm, 1280×1024 px) on a single-shot basis with a repetition rate of 50 Hz. The use of a large-area MCP detector allows to acquire in a single shot a spectrum spanning the entire 10-100 nm region (120-12 eV). Moreover, the detector is mounted on a movable stage and can be displaced manually along the flat focal curve, thus covering wavelengths down to 5 nm (250 eV) or up to 124 nm (10 eV).

In this work, we present the calibration activities performed at Elettra Sincrotrone Trieste. We measure the optical performance of the spectrometer, obtaining a polynomial curve fitting the energy positions measured in order to ensure the identification of unknown spectral energies. Then, we evaluate the linearity of the detector response, using both the CiPo – Circular Polarization beamline of Elettra Sincrotrone Trieste and the LDM – Low Density Matter beamline of the FEL FERMI, highlighting the spectrometer performance over a wide spectral range and with different types of input. We present also the analysis of a depletion phenomenon observed after prolonged use of COSP at the FEL FERMI; this suggests that the instrument shall be operated with low flux, to reduce depletion effects on the MCP detector.

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POSTER

Recent developments on fast 0D detectors at European XFEL

Freund, Wolfgang

European XFEL GmbH

In the photon diagnostics group (XPD) at European XFEL we have developed an APD detection system with diamond grating for the intensity readout of the weak circulating photon pulses inside the XFEL [1] cavity. Another device, our diamond sensor system [2], is designed for the pulse resolved MHz-rate detection of position and intensity of the X-ray pulses. This presentation will give a short overview over the system designs and the special fast electronics for the readout of weak signals from the APD, as well as the pulse resolved strong signals from the diamond sensor.[1] Cavity based x-ray free electron laser demonstrator at the European X-ray Free Electron Laser facility, Patrick Rauer et.al., Phys. Rev. Accel. Beams 26, 020701 (2023) [2] Diamond sensors for hard X-ray energy and position resolving measurements at the European XFEL, Tuba Conka-Yildiz et.al., J. Synchrotron Rad. (2024). 31, 1029–1036

ORAL: INVITED

Detector Developments at PSI for SwissFEL and SLS2.0

D. Greiffenberg, A. Bergamaschi, M. Brückner, M. Carulla, R. Dinapoli, S. Ebner, K. Ferjaoui, E. Fröjd, V. Gautam, S. Hasanaj, A. Haugdal, J. Heymes, V. Hinger, V. Kedych, T. King, S. Li, C. Lopez-Cuenca, A. Mazzoleni, D. Mezza, K. Moustakas, A. Mozzanica, J. Mulvey, M. Müller, K.A. Paton, C. Posada Soto, C. Ruder, B. Schmitt, B. Schmitt, P. Sieberer, S. Silletta, D. Thattil, X. Xie, J. Zhang

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Abstract: The Paul Scherrer Institut (PSI) is hosting Switzerland's large-scale research infrastructure like the fourth-generation synchrotron source SLS2.0 and the free electron laser SwissFEL. The CPS detector group pioneered detector technologies like single-photon counting detectors for synchrotrons and dynamic gain switching detectors for diffraction-limited light sources and FELs. Fourth-generation light sources pose challenges to current detector systems as in case of SLS2.0 the photon flux is expected to be up to a factor 100 higher with much higher photon fluxes at higher photon energies (<80 keV).

The CPS detector group seeks to tackle these challenges by developing a new single-photon counting readout chip called MATTERHORN with an increased count-rate capability of up to 20 MHz per pixel and to extend the usable energy range of our detector systems by using (i) LGADs for lower photon energies (>200 eV) and high-Z sensors for photon energies above 15 keV.

The presentation will give an overview of the current detector portfolio of the CPS detector group and will describe the challenges in developing detectors for fourth-generation synchrotrons.

ORAL: CONTRIBUTED & POSTER

Diagnostics for XFEL

Grünert, Jan

European X-ray Free Electron Laser Facility GmbH

The established hard x-ray beam generation schemes at the European XFEL are self-amplified spontaneous emission (SASE) and hard x-ray self-seeding (HXRSS) [1].

The X-ray photon diagnostics (XPD) group contributed to a facility-internal project to demonstrate the operation of a cavity-based XFEL (CB-XFEL) or XFEL oscillator (XFEL), see [2], which offers the potential of further improved spectral purity and brightness.

This presentation will describe the diagnostic elements designed and implemented for this project, explain details about the required diagnostic hardware and software, and present the results and performance of these elements and their contribution to the project success.

References:

- [1] Gianluca A. Geloni, "High repetition rate hard x-ray self-seeding at the European XFEL," Proc. SPIE PC13536, X-Ray Free-Electron Lasers: Advances in Source Development and Instrumentation VII, PC1353604 (6 June 2025)
- [2] Patrick Rauer et.al., "Cavity based x-ray free electron laser demonstrator at the European X-ray Free Electron Laser facility", Phys. Rev. Accel. Beams 26, 020701 (2023).

POSTER

Novel atomic force microscope at the BESSY Optics Lab for large sample inspection

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The common characterization technique for coatings, surfaces, microroughness or microstructures of synchrotron mirrors, gratings or other large samples is usually realised by instruments like white light interferometry (WLI) or atomic force microscopy (AFM). WLI offers a robust ex-situ method to measure polished surfaces and coatings on e.g. synchrotron mirrors but have limitations in the spatial resolution and characterizing of nanostructures if it comes to higher spatial frequencies.

AFM systems are mainly designed to meet the requirements of semiconductor industry to inspect samples of low thickness or diameter of about 6 inches, which is a common wafer size. Thus AFM metrology is mostly done on small samples like witness probes or smaller mirrors or gratings.

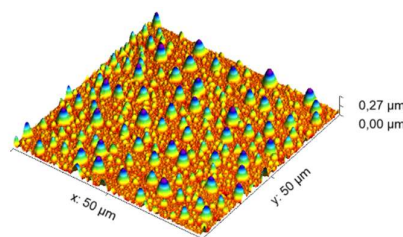


Fig. 1: left: a view inside the metrology box of the BESSY large volume AFM, right: AFM-measurement result taken at a highly contaminated synchrotron mirror

In our contribution, we will present a novel AFM System in use at the BESSY Optics Lab. which allows the inspection of large sized samples up to a volume of $150 \times 100 \times 1000 \text{ mm}^3$.

Such instruments allow the characterization of large sized synchrotron mirrors as well as large gratings as required for future applications at Free Electron Lasers (FEL). Investigations can be performed regarding roughness or pattern quality as well as optics damage or contamination by e.g. carbon before and after refurbishing.

Keywords: AFM, Optics Metrology, X-Ray Optics, Synchrotron Optics

ORAL: CONTRIBUTED

EUV-FEL nanofocusing mirror optics: two-dimensional aberrations of KB and AKB optics.

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The 7-nm focusing of hard X-ray free-electron laser (XFEL) pulses has been successfully achieved at SPring-8 Angstrom Compact free-electron Laser (SACLA) [1]. This was accomplished by developing an optical system based on Wolter-III advanced Kirkpatrick-Baez (AKB) optics, utilizing ultraprecise mirror fabrication techniques known as OsakaMirror technology [2–4] and X-ray wavefront correction techniques [5]. As a next step, we plan to extend these technologies into a longer wavelength regime such as Extreme Ultraviolet (EUV). We are developing AKB optics with a numerical aperture (NA) of 0.082, designed to achieve EUV-FEL focusing spot size of ~80 nm. This system can produce an intensity of ~1019 W/cm² at SACLA and is also intended to serve, in the future, as a diffraction-limited reference spherical wave for the development of large-NA optical systems.

The AKB optics comprises one-dimensional Wolter mirrors arranged perpendicularly in the horizontal and vertical directions. While rotationally symmetric Wolter optics provides an analytical solution for focusing based on Fermat's principle, AKB optics does not constitute such an analytical solution and therefore inherently introduces two-dimensional geometric aberrations. These aberrations become more pronounced in EUV mirrors with a large NA of 0.082, corresponding to a convergence angle of 9.4°. In this study, we investigated the impact of such aberrations and optimized optical design to enhance EUV-FEL focusing performance. Comprehensive evaluations of the AKB optics were conducted using ray tracing and wave propagation simulations. In particular, the relationship between geometric aberrations and mirror alignments was thoroughly analyzed. As a result, AKB optical systems modeled after hard-X-ray sub-10 nm focusing system [1] were found to induce significant two-dimensional aberrations at a large NA of 0.082, with a spot size of 4.0 µm and a wavefront error of 4.2λ (λ = 13.56 nm). Nevertheless, the AKB system, which consists of a tandem arrangement of one-dimensional Wolter mirrors, was shown to be capable of diffraction-limited focusing for the EUV-FEL at the same NA of 0.082, yielding a spot size of 4.6 nm and a wavefront error of λ/69. We will discuss the nature of two-dimensional aberrations in KB and AKB optical system, the optimized AKB configuration, and the expected EUV-FEL focusing performance. This work was supported by JST K Program Grant Number JPMJKP24M1, Japan.

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ORAL: INVITED

ePix Detector Family and Future Detector Development Plans at LCLS

Hansson, Conny

SLAC National Accelerator Laboratory/Stanford University

At SLAC National Laboratory, the Detector R&D and Applied Microelectronics program has been developing the next generation X-ray detectors towards megahertz operation. This talk will present the family of detectors that the program develops starting with existing detectors that are deployed at LCLS and other light sources, called ePix. Then we will discuss the strategies for faster detectors, from 120 frames per second (fps) to 100,000fps, by introducing the Ultra-High-Rate family. Beyond 100,000 fps the program approach to data collection shifts from reading out the content of all pixels available in the focal plane to performing information extraction in the detector itself. This last strategy is developed within the SparkPix family. These detectors explore experiments where data is sparse in time, space or otherwise to dynamically extract information and compress the data before it is transmitted to a host computer. At the end, we will share some thoughts on opportunities that Machine Learning presents for future X-ray detector developments.

ORAL: CONTRIBUTED

Upgrading Front-End XBPMs for Diamond-II: Design, Testing, and Validation

Houghton, Claire

Diamond Light Source Ltd

The transition to a 4th generation light source, Diamond-II, introduces substantial changes in white photon beam characteristics. As a result, modifications to the front-end X-ray Beam Position Monitors (XBPMs) are necessary. This study outlines the practical implementation and verification of these upgraded XBPMs, which are designed to cope with the increased beam power while maintaining high sensitivity in position measurements. Initial simulations conducted with the Synchrotron Radiation Workshop (SRW) identified optimal blade positions. These simulations took into account factors such as beam power damage thresholds, potential shadowing from upstream components, and the overall sensitivity to beam position. The objective was to determine blade positions that maximize sensitivity while keeping the absorbed power within safe limits. Following the theoretical design phase, the upgraded XBPMs were installed on the Diamond front ends. Validation tests were carried out to assess their performance under beam conditions, focusing on position sensitivity, linearity, and comparing actual blade current to simulation results.

ORAL: CONTRIBUTED

Enhancement of an X-ray Ionization Beam Position Monitor for PAL-XFEL Soft X-rays through Internal Structure Redesign

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The Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) operates hard and soft X-ray beamlines that deliver intense ultrashort pulses generated via the self-amplified spontaneous emission (SASE) process. Due to the inherent pulse-to-pulse fluctuations of SASE, online photon diagnostics are essential for accurate experimental measurements. While photo-absorption and emission-based diagnostics are limited in the soft X-ray regime, gas-based diagnostics such as gas monitoring detectors (GMDs) utilizing photoionization are widely used to monitor beam intensity and normalize experimental data.

To complement these intensity monitors and enable position tracking of the soft X-ray beam, we previously developed an X-ray ionization beam position monitor (XIBPM) based on krypton gas ionization and detection via a microchannel plate (MCP) and phosphor screen. The initial system, installed at the experimental hall, demonstrated the feasibility of both horizontal and vertical beam position monitoring.

In this work, we present an upgraded version of the XIBPM with a redesigned internal structure aimed at enhancing its spatial resolution and detection sensitivity. CST Studio Suite simulations and multiparticle tracking studies have been conducted to evaluate the impact of the structural changes. Experimental tests confirm improved performance in beam profile monitoring and position accuracy. This presentation will detail the design modifications, simulation results, and comparative performance evaluation of the original and enhanced XIBPM systems.

POSTER

Status of THz Streaking Setup Development for Soft X-ray Pulse Characterization at PAL-XFEL

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The characterization of ultrashort X-ray pulses - such as their temporal duration and arrival time - is critical for time-resolved experiments using free-electron lasers. At PAL-XFEL, we are developing a THz streaking setup for soft X-ray pulse diagnostics. The system is based on photoelectron streaking in a THz field generated via a tilted pulse front scheme using a lithium niobate (LiNbO_3) crystal and probed by an electron time-of-flight (e-TOF) spectrometer.

The e-TOF spectrometer (ETF11-1200) and gas-jet nozzle system were first assembled and tested in an existing test chamber at the soft X-ray beamline. Based on the results, the system is now being prepared for final integration into the dedicated THz streaking chamber, with full installation scheduled by the first week of June 2025. A second round of performance tests - using krypton gas and soft X-rays in the 500–900 eV range - is planned for late June 2025 after the setup is completed.

In this presentation, we describe the current status of the THz streaking setup, including system configuration, chamber integration, and performance evaluation of the e-TOF and gas-jet systems.

ORAL: INVITED

Temporal characterization of attosecond hard X-ray pulses via nonlinear fluorescence

Inoue, Ichiro

The University of Tokyo / RIKEN SPring-8 Center

Attosecond science with ultrafast optical pulses has revolutionized our understanding of electron dynamics, enabling direct observation of charge migration, electron correlation effects, and field-driven phenomena on their intrinsic timescales. Recent advances in electron accelerator technologies at XFEL facilities have extended attosecond techniques into the hard X-ray regime, allowing matter to be probed with both attosecond temporal and sub-angstrom spatial resolution. A key challenge in the generation and application of attosecond hard X-ray pulses is their temporal characterization. While angular streaking techniques have enabled direct time-domain measurements in the soft X-ray regime, no such measurement has yet been realized at hard X-ray energies. Current estimates of pulse duration rely on comparisons between measured spectra and theoretical simulations of the FEL process. However, such estimates are inherently uncertain, as the spectral width is strongly affected by the energy chirp of the lasing electron bunch and provides only a lower bound on the pulse duration. In this talk, I will present the first direct experimental evidence of attosecond hard X-ray pulses, enabled by a novel temporal diagnostics method. Our approach leverages amplified spontaneous emission (ASE), a collective spontaneous emission process observable when tightly focused X-ray pulses irradiate 3d transition metal targets. By analyzing the yield of collective X-ray fluorescence induced by ultrashort pulses, we can retrieve shot-to-shot pulse duration. I will discuss the underlying principles of this nonlinear diagnostic technique and its application to attosecond pulse characterization at LCLS, European XFEL, and SACLA [1].

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POSTER

On the way to automatized focus adjustment at FLASH

Keitel, Barbara

DESY

In recent years, DESY has successfully developed several Hartmann wavefront sensors in collaboration with the Institut für Nanophotonik Göttingen e.V. (formerly the Laser-Laboratorium Göttingen e.V.). These sensors have been designed for the precise FEL focus characterization and the alignment of optics in the soft X-ray spectral range, with a wavelength of approximately 5 - 40 nm. Even when using those wavefront sensors, the optimal adjustment of optics is very time-consuming and can only be successfully carried out by experienced beamline scientists. This is especially true for the often-used so-called Kirkpatrick-Baez (KB) optics with up to 14 strongly coupled degrees of freedom. Furthermore, the optics adjustment process must be repeated frequently due to changing beam requirements of the users and occasionally varying beam characteristics of the SASE FELs during user experiments. Consequently, there is a high level of interest in the automation of fine-tuning of the focusing optics using rapid "machine learning" algorithms. In order to test the automation, the focus of the KB-optics system was optimized by bending the two KB mirrors with initially 4 actuators, whereby the wavefront sensor measures the wavefront and the intensity distribution in real time at the location of the sensor. Using Fresnel-Kirchhoff integration of these data, the focus size and the intensity distribution at the focus position are calculated. Both the wavefront shape (Zernike coefficients) and the computed focal characteristics are used for an automated control of the actuators of the motorized KB optics, employing a conventional minimization algorithm. In a next step, advanced machine learning methods will be integrated into the algorithm to speed up the focus alignment. We will present results of first automated focus alignments using the KB-optics system at FL23/FLASH2.

POSTER

Statistical analysis of hard X-ray radiation at PAL-XFEL facility performed by Hanbury Brown and Twiss interferometry

Kim, Young Yong

Pohang Accelerator Laboratory

A Hanbury Brown and Twiss interferometry experiment based on second-order correlations was performed at the PAL-XFEL. With this experiment, the spatial and temporal properties were studied. Measurements were performed at NCI-CXI beamline at 10 keV photon energy in various operation conditions: Self-Amplified Spontaneous Emission (SASE), SASE with the monochromator, and self-seeding regimes at 180 pC bunch charge, respectively. Statistical analysis showed short average pulse duration from 6 fs to 9 fs depending on operation conditions. A high spatial degree of coherence of about 70-80% was determined in the spatial domain for the SASE beams with the monochromator and self-seeding regime of operation. The obtained values describe the statistical properties of the beams generated at PAL-XFEL facility.

ORAL: CONTRIBUTED & POSTER

Development and integration of a PID Control System in a Multichannel High-Current Ammeter for XBPM Applications

La Rosa, Niccolò

University of Catania

This work presents the development and experimental validation of an integrated control system for synchrotron X-ray beam stabilization, with the novel feature of embedding the control loop directly within a high-performance readout unit—the PCR4 picoammeter. The approach combines high-speed current measurement and control in a compact, unified platform, targeting future needs in fourth-generation synchrotron beamlines where beam stability and feedback responsiveness are critical. A laboratory-scale test bench was developed to emulate beamline conditions. Beam dynamics were simulated using an analog oscilloscope, while an electromagnet introduced disturbances. Beam position was monitored by a 2×2 photodiode matrix, replicating the function of standard X-ray Beam Position Monitors (XBPMs). The photocurrents generated by the matrix were read and processed in real time using the PCR4 unit—jointly developed by STLab srl and SenSiC GmbH—which is a pico-to-milliammeter specifically designed for high-dynamic-range X-ray beam applications. It features four independent acquisition channels with 24-bit resolution, a sampling rate of 10 kHz, and a dynamic range spanning nine decades (1 pA to 50 mA). In addition to precise current measurement, PCR4 integrates a bipolar voltage bias generator (-20 V to +20 V), enabling sensor pre-characterization (e.g., for Silicon Carbide detectors) through dark current measurements prior to installation.

A key innovation of this work is the integration of a proportional–integral (PI) feedback controller directly into the PCR4’s data acquisition and processing architecture. The embedded controller operates on real-time current signals to compute correction voltages for beam steering elements (e.g., focusing mirrors). System identification procedures, including steady-state and transient analysis, yielded a first-order dynamic model used to tune the controller. Experimental tests under simulated X-ray Absorption Spectroscopy (XAS) conditions demonstrated that the system effectively stabilized beam position with sub-0.2% steady-state error at a 1 kHz control rate.

The PCR4’s dual function—as both high-precision readout and control unit—represents a step forward in compact, scalable solutions for beam stabilization. Its ability to handle large signal ranges, combined with low-latency feedback capabilities, makes it a promising candidate for implementation of real-time beam diagnostics. Further developments aim to extend its control bandwidth to 10 kHz and enhance integration into distributed beamline environments.

ORAL: CONTRIBUTED

Operation of Photo Electron Spectrometers for Photon Diagnostics at the European X-Ray Free Electron Laser

Laksman, Joakim

European X-Ray Free-Electron Laser Facility GmbH

Angle-resolved photoelectron spectrometers with fast digitizer electronics are versatile devices for providing non-invasive single-shot photon diagnostics at MHz repetition rate X-ray free-electron lasers. In this contribution, we demonstrate and characterize the performance of our two operational photoelectron spectrometers for the application of hard X-rays and soft X-rays as well as new automation tools and online data analysis that enable continuous support for machine operators and instrument scientists. Customized software has been developed for the real-time monitoring of photon beam polarization and spectral distribution both in single-color and two-color operation. Hard X-ray operation imposes specific design challenges due to poor photoionization cross-sections and very high photoelectron velocities. Furthermore, recent advancements in machine learning enable resolution enhancement by training the photoelectron spectrometer together with an invasive high-resolution spectrometer, which generates a response function model.

POSTER

Photon Diagnostics Design of Shenzhen Superconducting Soft-X-ray Free Electron Laser (S³FEL)

Qinming Li,^a Bingbing Zhang,^a Xueqian Sun,^a Long Huang,^a Zequn Wang,^{b,c} Mingchang Wang,^{c,d} Qinghao Zhu,^a Siyuan Tan,^c Haoyu Wei,^a Xuan Liu^a and Weiqing Zhang^{a*}

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Abstract

This poster introduces the design of the photon diagnostics system for the Shenzhen Superconducting Soft-X-ray Free Electron Laser (S³FEL) facility, covering the layout and design of core instruments and key diagnostic equipment. The comprehensive photon diagnostics system includes a wide array of instruments, which can be categorized based on the physical properties of the FEL they measure: diagnostics for pulse energy, wavelength, polarization, temporal and spatial coherence, beam position, spot size, wavefront and arrival time.

Operating within a wavelength range of 2.3–30 nm, S³FEL is characterized by a larger beam spot and shorter beamlines compared to many other XFEL facilities worldwide, particularly those in the hard X-ray regime. These unique features present significant challenges for the design of the photon diagnostics system, especially for gas-based instruments such as the Online Photoionization Spectrometer (OPIS) and the Gas Monitor Detector (GMD). These constraints demand novel solutions for achieving large-area detection uniformity, extreme compactness, and robust thermal management under high photon flux.

Keywords: FEL, Beamline, Optical diagnostic

ORAL: INVITED

Temporal diagnostics at various time scales

Liu, Jia

European X-Ray Free-Electron Laser Facility GmbH

X-ray free-electron lasers have attracted a great amount of scientific attention due to their unprecedented peak brightness, transverse coherence, and ultrashort pulse durations. Studies of nonlinear physical and chemical phenomena, as well as structural biology, benefit from these unique properties, where X-ray pulses are often used as an excitation or a probe to investigate the time-resolved evolution of the process. Due to the stochastic nature of the SASE FEL pulses, temporal diagnostics have been developed to monitor the shot-by-shot timing jitter, inter- and intra-pulse timing instabilities, and long-term drifts at the European XFEL. In this talk, we will present an overview of temporal photon diagnostics at the European XFEL in recent years, including pump-probe experiments that have been used to benchmark measurement results, and give an outlook on short- and long-term development plans related to the recent demonstration of attosecond capabilities at the European XFEL.

ORAL: CONTRIBUTED

Maintaining Pulse Integrity: Diagnosing MHz Modulations in High-keV X-ray Regimes

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Ultra-high intensity and a high degree of spatial coherence are hallmark features of X-ray pulses produced at X-ray Free Electron Laser (XFEL) facilities. In addition, a key feature of the European XFEL is its MHz-class pulse repetition rate, enabling the delivery of up to approximately 400 X-ray pulses at 220 ns intervals within a 10 Hz pulse ‘train’ structure [1-2]. Such operation modes have enabled breakthroughs such as ultrafast MHz “video” imaging [3], paving ways to capture ns to μ s stochastic phenomena. Consequently it has since become a standard particularly for these single-shot and high repetition measurements to rely, as well as to strive, on individual pulse refinements. Accurate diagnosis and attribution of changes in the pulse wavefront (WF) to their contributors are therefore essential – for both data analysis and for machine learning/optimising applications. Meanwhile, unprecedented intensity and repetition rates also accelerated incidents of radiation damages, particularly on X-ray optical components, degrading the WF quality. The ability to optimise the machine performance while safeguarding optical components thus directly determines the quality of X-ray delivery and the calibre of scientific output.

In this work, we present results from the MID instrument at the European XFEL, where the Talbot Interferometry method [5] was used to resolve WF modulations on a single-pulse basis, at-wavelength spatial resolution, and at MHz repetition rates using the Shimadzu-MHz camera. We examine the contributions arising from direct mechanical perturbations — such as low-frequency vibrations of X-ray distribution mirrors [4] — and differentiate them from indirect forces acting on electron bunches within the accelerator and undulator systems. This analysis can be further correlated with other pulse diagnostics [6] for comprehensive study. We also demonstrated this WF measurement to higher (30 keV) FEL energies in 10 Hz mode, where many conventional optics become ineffective or require re-adaptations, including the Talbot method. Finally, we introduce our current optics protection system (“Watchdog”), in which the control logic is set to ensure the requested number of X-ray pulse delivery to each endstation/user. At the same time, it monitors real-time energy and photon parameters to ensure the radiation dose for the inserted optics to remain below the in-situ estimated damage threshold—thereby, hopefully, extending the lifetime of the optical components.

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POSTER

Characterization and Diagnostic of Coherence of Next-Generation Beamlines

Sebastian Malerz, Iain Wilkinson, Frank Siewert, Florian Gores, Simone Vadilonga, Jan Lüning, and Jens Viefhaus

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As a fourth-generation synchrotron light source, BESSY III will deliver synchrotron radiation of exceptional brightness and coherence in the soft to tender X-ray range. The high degree of coherence will enable detailed imaging and enhance higher contrast at the nanometer length scale of methods such as X-ray microscopy, holography, and phase-contrast imaging. This will allow for advanced investigations of material interfaces and magnetic field distributions.^[1]

To fully exploit these capabilities, it is critical to manage the beam coherence along the entire beam transport and manipulation system. The goal of this work is to identify and mitigate factors that influence and degrade coherence, and to develop targeted strategies for its stabilization and control.

We will present the MetrokX-project, which is being realized in the Liquid and Interfacial Dynamics with Ultrafast X-rays (LIDUX) laboratory at HZB and around a near fully coherent, laser-based beamline that delivers photon energies up to 600 eV.^[2] A dedicated coherent X-ray beamline is being constructed within the project, which will incorporate exchangeable test reflective and diffractive optics, a spectrometer, and a prototype wavefront sensor system. Together with an adaptive mirror, this setup will enable comprehensive diagnostics of the absolute photon flux, spectral flux density, spatial and temporal coherence, and wavefront properties – including correction and shaping after diffraction or reflection on optical components. This new beamline will allow us to develop innovative measurement techniques and instrumentation, ready for seamless integration into future BESSY III beamlines.

In combination with advanced beamline control systems and machine learning algorithms, the MetrokX-project developments are expected to contribute to the next generation of beamlines, where experimental conditions can be autonomously monitored and optimized in real time, ensuring optimal performance for a broad range of scientific applications.

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ORAL: CONTRIBUTED

The Good, the Bad and the Broad spot. Doing Science at FERMI with KAOS. Old Tricks and New Challenges

Manfreda, Michele

ELETTRA Synchrotron

In this contribution, we provide an overview of the performance and application range of KAOS, the active Kirkpatrick–Baez optical system at FERMI. Originally designed to deliver micrometre-scale focal spots across a wide spectral range (70–4 nm), KAOS has evolved to support a broader set of experimental needs. We revisit its main operation modes, starting from the classical tight-focus configuration—typically optimised using wavefront sensing—to more recent uses requiring broad or even collimated beams. These relaxed focusing conditions have become increasingly relevant in experiments involving structured light and orbital angular momentum (OAM) beams, where control over the phase structure is often more important than achieving the smallest possible spot. By tracing this shift, we illustrate how KAOS has adapted to the changing landscape of FEL science, and we discuss its current capabilities, limitations, and prospects for further development.

POSTER

In situ small-angle X-ray Scattering Technique for Materials Characterization

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Aqueous zinc-ion batteries (AZIBs) are promising candidates for next-generation energy storage systems owing to their intrinsic safety, cost-effectiveness, and environmental compatibility. However, ensuring long-term structural stability of cathode materials during repeated charge–discharge cycles remains a key challenge. In this study, we employed in situ small-angle X-ray scattering (SAXS) to monitor the real-time structural evolution of a newly developed cathode material during electrochemical cycling. The SAXS analysis revealed that the nanoscale architecture of the cathode remains largely intact throughout extended cycling, indicating high structural resilience. This structural stability is directly correlated with the improved cycling performance observed in electrochemical tests. This result demonstrates the critical role of in situ SAXS in uncovering dynamic structural responses of electrode materials, providing valuable insights for the rational design of stable and high-performance AZIB cathodes.

ORAL: INVITED

Development of 20.2 Mpixel CITIUS detector and prospects for 5 kHz operation

Nishino, Haruki

JASRI/RIKEN

A new X-ray imaging detector, CITIUS, is capable of operating at 5 kHz in XFEL mode. At SACLA, we have recently constructed a 20.2 Mpixel CITIUS system for Serial Femtosecond Crystallography (SFX). In this setup, where SACLA operates at a maximum of 60 Hz, CITIUS is configured in a 16-sampling mode, running at 960 Hz, with each exposure sampled by 16 frames. This results in a noise floor of 25 e⁻ rms (equivalent to 0.015 photons rms at 6 keV), while the detector achieves a peak signal of 17,000 photons. CITIUS achieves both low noise and high dynamic range, exhibiting no detectable artifacts caused by gain switching or global crosstalk. Instead of adopting a dynamic gain-switching scheme, CITIUS employs a gain-selecting architecture, where the detector operates in fixed gain modes. To manage the data, we developed a dedicated pipeline to record, calibrate, transfer, and compress the output. Each pixel has three gain settings, and the data-handling process automatically selects the appropriate gain for each pixel. Global crosstalk is also corrected within this pipeline. In the summer of 2024, we conducted the first beamtime with XFEL beams and demonstrated the detector's capability for protein crystal structure analysis using standard protein samples.

ORAL: CONTRIBUTED

Reminisce - Refurbishment of Mirrors to Increase Sustainability at Light Sources

Schmidtchen, Silja

European X-Ray Free Electron Laser Facility

Carbon contamination of X-ray optics is a well-known problem that has been detrimental to beamline performance for several decades. Consequences of such contamination include loss of flux, distortion of the wavefront, and reduction in focusing power and resolution. For new and upgraded light sources, that have much higher photon intensity and repetition rates, more rapid accumulation of contamination and damage will occur. Those faster rates of contamination, more beamlines affected, and more noticeable effects combine to become rate-limiting for optical performance. However, replacing damaged optics is a time-consuming, risky, and expensive task. Production times can exceed 1 year with cost per optic typically tens of thousands of Euro and even exceeding 100k Euro. The option of refurbishing and cleaning mirrors to overcome this problem has been discussed within the community for a long time and on several occasions in metrology and X-ray optics meetings, emphasizing the need to find suitable methods. Most facilities have independently investigated optical contamination and cleaning methods over several years. A variety of methods were tried, including: adding a partial pressure of oxygen into the vacuum vessel; illumination with UV light or plasma treatment; chemical stripping of contaminated optical coatings; or repolishing the substrate. Research has progressed slowly, on an ad-hoc basis, with minimal funding. Due to a lack of time and samples, extending those single tests to systematic studies is difficult. In addition, cleaning techniques that work for one mirror aren't effective for a nearby optic, pointing to hidden complexities, such as temperature, X-ray flux and wavelength spectra, and proximity to nearby sources of carbon (such as motors or cables). Results are often not well understood and seldom published. These issues clearly show that coordinated action is now required. For that purpose, a workshop dedicated to "Cleaning and Refurbishment of Optics" was held at Trieste in February 2025. It was attended by many experts representing most synchrotron and XFEL labs in Europe and the collaboration project REMINISCE (Refurbishment of Mirrors to Increase Sustainability at Light Sources) has been created by that community. The aims of the project are two-fold. Firstly, to understand the dynamical formation of carbon contamination on X-ray optics. Secondly, based on this knowledge, develop simple and reliable methods to slow or remove contamination and return the optic to a pristine condition to achieve optimal beamline performance. The project and first results of preliminary studies will be presented here.

ORAL: INVITED

XUV-XUV time-resolved experiments at FERMI: the AC/DC optical layout, open problems and future perspectives within the FERMI2.0 project

Simoncig, Alberto

Elettra Sincrotrone Trieste

The ultrafast X-ray science community is looking for new spectroscopical techniques capable of triggering out of equilibrium states of matter by stimulating transitions at specific core resonances while monitoring in real-time its subsequent response. The final goal is fully committed to a deeper knowledge of the microscopic mechanics responsible for driving some of the most intriguing, and still not fully understood, phases of materials. The advent of free-electron lasers (FELs) allows us to achieve the implementation of XUV-XUV spectroscopies by virtue of their unique capability to lase high-brightness pulses marked by wavelengths spanning the extreme-ultraviolet, the soft and hard X-ray spectral domains, as well as by temporal lengths lying in the femtosecond (fs) timescale. In specific circumstances, as in the case of the seeded FERMI FEL (Italy), it is possible to lase in a multi-color way and offer full polarization control of light, too. At FERMI the possibility to perform XUV-XUV time-resolved experiments is committed to the optical device known as AC/DC (auto correlator/delay creator), which is designed to transform the incoming FEL pulses into a couple of pulses acting as a pump and a probe ones, once focused on the sample under study. This can be done by splitting the XUV beam (in the simpler FERMI configuration), or to properly separating its multi-color emission (in the FERMI state-of-the-art configuration), along two different optical paths, while preserving the spectral and temporal properties, and introducing the desired time delay. Strong emphasis will be dedicated to the AC/DC opto-mechanical design and to the custom laser-based feedback system implemented to compensate in real-time for any mismatch affecting the beams optical trajectory. These are ascribable to both mechanical imperfections and paraxial errors rising during a time delay scan and may particularly affect it when the incoming beams are focused in the few microns focal spot regimes. Attention will be dedicated to discussing the open problems affecting the capability to achieve the perfect time delay scan when using the AC/DC, and to the future upgrades planned to be implemented soon.

ORAL: CONTRIBUTED

Double Multilayer Monochromators for Beamline Upgrades at Diamond Light Source: Insights into Optical and Multilayer Design

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Over the past year, the newly commissioned Multilayer Deposition System (MDS) at Diamond Light Source (DLS)¹ has succeeded in the fabrication of several periodic and laterally graded multilayers. They have contributed to the Diamond-II upgraded program, serving as multilayer gratings, multilayer polarisers, and Double Multilayer Monochromators (DMMs). DMMs are critical elements for synchrotron and high-intensity X-ray facilities, as they deliver a few percent bandwidth and thereby enhance photon flux by around two orders of magnitude compared to conventional double crystal monochromators², essential for the high flux applications such as imaging, ptychography, and small-angle X-ray scattering. Achieving high-performance DMMs requires not only optimisation of multilayer parameters but also precision in substrate manufacturing and deposition control to maximise reflectivity and eliminate stripe artefacts. This study presents the optical and material design, as well as the fabrication process development of a DMM for the KMX I24 beamline. The DMM comprises of two stripes of Ru/B4C and NiV/B4C operating at 14.0 keV and 22.4 keV, respectively. Multilayer coatings are deposited using the MDS system via dynamic deposition with an optimised shadow mask to achieve uniformity better than 0.3% in both horizontal and vertical directions³. A sample mask scheme is used to maximise the usable active area for each stripe. The DMM performance was subsequently characterised at the B16 test beamline demonstrating high reflectivity of 88.7% at 14.0 keV and 85.6% at 22.4 keV. White beam imaging horizontal double-reflection geometry reveals stripe-free images confirming the excellent quality of the substrates manufactured by the in-house Ion Beam Figuring machine⁴. These results establish a framework for optical and multilayer design and underscore the capabilities of the MDS system in producing high performance DMMs for synchrotron applications.

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ORAL: INVITED

The new online single-shot photon spectrometer for the soft x-ray beamline of SwissFEL

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I will describe the new spectrometer for the Athos (soft x-ray branch) of SwissFEL - the “SASE spectrometer”. This spectrometer provides single-shot diagnostics in a non-destructive manner, and the new design of the instrument allows versatile high-resolution to high-bandwidth operation modes across a large range of photon energies (400 – 1000 eV).

In this talk, I will present the initial commissioning and performance of the Athos SASE spectrometer to demonstrate the overall capabilities, lessons learned, and future goals. I will provide a comparison with the pre-existing photon diagnostics at Athos/SwissFEL and outline the new diagnostic capabilities offered. Finally, I will show the first results of uses of the Athos SASE spectrometer combined with the Furka and Maloja endstations that open opportunities to carry out soft x-ray spectroscopic measurements without a monochromator.

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ORAL: CONTRIBUTED & POSTER

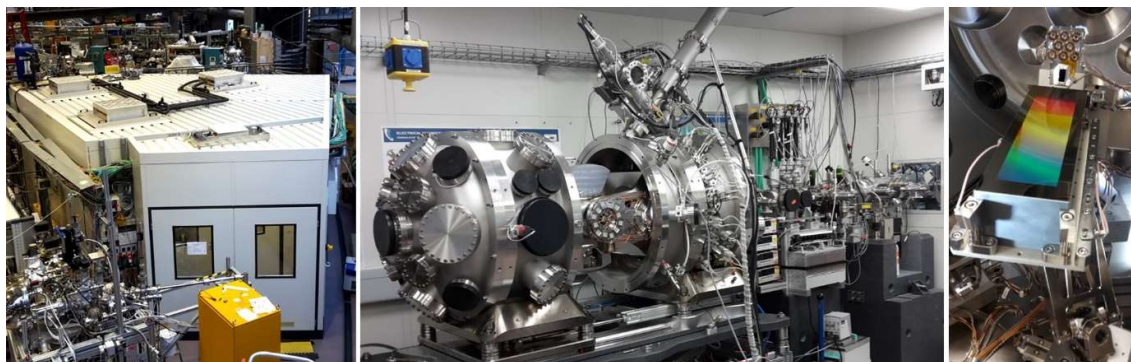
At-Wavelength Metrology facility for EUV, XUV and tender X-ray energy range optics

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An accurate characterization of the real performance of sophisticated reflective or diffractive optics including such cases as XUV diffraction gratings, reflective zone plates (RZP) or multilayer coated gratings is an extremely demanding task to experimental conditions. An At-Wavelength Metrology facility for EUV and XUV optics is successfully under operation since many years at the permanently connected to a dedicated Optics beamline. The setup is suitable for measurements on both small test samples and real size optics up to 360 x 60 x 60 mm³. 6-degrees of freedom in alignment and surface mapping of tested optical elements are possible due to a flexible sample stage support system based on an UHV-tripod. It is possible to carry out measurements with beam incident angles from 0 to 88.9 degrees and scan outgoing radiation in an almost complete in-plane circle as well as to continuously rotate whole system from s- to p- polarization geometry. A high spectral purity beam in the energy range from 13.5 eV to 1800 eV is provided by a 4-mirror High-Order Suppressor System. In addition to that a small Reflectometer as a portable end-station is used to get access to UV-EUV or X-ray energy ranges by setting it up at U125-2_NIM (4eV – 30eV) and KMC-1 (2keV – 10keV) beamlines at BESSY-II. The present status of the metrology facility, their latest upgrade projects and most challenging results will be presented in our contribution.



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ORAL: INVITED

From Data Deluge to Discovery Engine: How AI-Augmented Instruments Revolutionize Science

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Light sources like LCLS-II and LCLS-II-HE, a MHz-repetition-rate X-ray free-electron laser, generate torrents of data that overwhelm traditional analysis. This talk presents a transformative framework where edge-to-exascale computing and AI-driven experiment steering converge to unlock new capabilities in diagnostics, beamline control, and detector systems. By embedding lightweight AI/ML models at the experiment edge – directly into detectors and beamline hardware – we enable real-time feature extraction and adaptive decision-making. These edge systems feed processed data into local computing and remote exascale HPC resources which refine models, perform simulations, and optimize experimental parameters. This bidirectional pipeline closes the loop on experiment steering, converting data avalanches into precision scientific insights. We will describe the LCLS-II Data System which exemplifies edge-to-exascale: streaming feature-extracted data to distributed HPC enables large-scale datasets to yield actionable feedback in seconds to minutes, slashing time-to-science. By aligning detector design, real-time analytics, and shared infrastructure, we are building a future where every photon, pixel, and processor collaborates to push scientific frontiers. The future of big-data science lies not in bigger hardware, but in smarter integration where instruments evolve from passive sensors to active partners in discovery.

ORAL: CONTRIBUTED & POSTER

A diamond scintillator-based beam position and pulse energy monitor for SHINE

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A diamond scintillator-based beam position and pulse energy monitor has been designed for SHINE, which is a high-repetition-rate hard X-ray free-electron laser. The system employs a water-cooled boron-doped diamond scintillator and two linear array detectors equipped with lenses. The linear array detectors can operate at an exceptionally high frame rate, enabling high-repetition-rate beam position detection. With appropriate data processing and calibration, the system is also capable of measuring the pulse energy. Simulations have been conducted using the real imager data. This paper presents the design and simulation results based on the SXFEL imager data.

ORAL: CONTRIBUTED

Evaluation of SiC-Based X-ray Beam Position Monitors (XBPMs) for Application in XFEL Environments

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Silicon carbide (SiC) is a wide-bandgap semiconductor combining high thermal conductivity, high radiation hardness, and mechanical robustness, making it an increasingly attractive candidate for advanced X-ray beam monitoring in synchrotron and free-electron laser applications [1]. Compared to materials such as single-crystal diamond, SiC enables larger-scale fabrication due to its commercial availability in 6" wafers and offers better uniformity and signal stability when used as a thin membrane. Recent advances in electrochemical substrate etching have enabled the fabrication of free-standing SiC membranes with transmission exceeding 97%, collection efficiencies above 85% at zero bias, and responsivities comparable to or exceeding state-of-the-art detectors, while also maintaining high signal-to-noise ratio and fast response in the sub-microsecond range [2]. These features, along with the mature SiC semiconductor processing and improved quantum yield (thanks to the lower ionization energy compared to diamond), allow SiC-based detectors to operate reliably even under extreme conditions. This includes exposure to high-brilliance, short-pulsed beams of X-ray Free-Electron Lasers (XFELs), where both radiation tolerance and thermal resilience are crucial. The proposed study aims to assess the performance of SiC detectors under XFEL conditions. In the planned beamtime at SwissFEL, two SiC detectors with thicknesses of 2 μm and 10 μm , respectively, positioned in series at the interaction point downstream of the KB mirrors, will be studied using 10 ns pulses of 7 keV photons (~ 1 mJ pulse energy, 100 Hz repetition rate). The primary objectives are to assess linearity, saturation behavior, and position sensitivity of the SiC detectors under single-shot conditions, benchmarked against the beamline's online I_0 monitor. Additional measurements of signal stability, shot-to-shot noise, and comparison with a diamond detector will also be evaluated. This campaign will further investigate optimal biasing and amplification strategies, compatibility with fast digitizers, and signal conditioning requirements to adapt synchrotron-grade XBPMs to XFEL-specific pulse structures and fluences.

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POSTER

RAYX - An optics simulation software for synchrotron applications

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Many synchrotron facilities around the world are upgrading to fourth-generation sources, which promise significantly enhanced brightness and coherence. In this context, and in view of a future upgrade toward BESSY III, there is a growing need for advanced simulation tools that can keep pace with the increasing complexity and performance requirements of modern beamlines. We present **RAYX** [1], a next-generation simulation framework for synchrotron optics and the successor to RAY/RAY-UI [2]. RAYX is designed to support the full workflow of beamline design, optimization, and data analysis. It combines a high-performance ray tracing engine with GPU acceleration, an interactive graphical interface, and a tightly integrated Python interface. The Python API provides full access to RAYX's capabilities, enabling scripting of complex optical systems, seamless integration into scientific workflows, and machine learning-based optimization. This contribution outlines the current status of RAYX and highlights its role as a flexible, modular platform for simulating synchrotron beamlines across a broad spectral range and variety of optical components.

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ORAL: CONTRIBUTED

Optical Delay Line (ODL) with fixed time delay for 2-color applications at European XFEL: from metrology of the mirrors to early commissioning results to tunnel installation

Vannoni, Maurizio

European XFEL

The European XFEL is implementing an Optical Delay Line (ODL) to allow a major improvement in producing two-color pulses at the SASE3 soft X-ray beamline with a controlled time delay. The technique is based on a magnetic chicane (MC) placed among the undulators, already installed and operational, and a ODL to displace the delay in time by a fixed amount. Operating the ODL together with the MC will allow crossing of the zero-delay point between the two colors. The ODL was engineered and produced by FMB Berlin under European XFEL specifications and also the strong collaboration with DESY Vacuum Group (MVS). All the different steps were followed from the authors and included simulations, production details, factory based commissioning and on-site commissioning. The system was delivered at European XFEL last June, where it was commissioned, prepared for installation and eventually installed. We present here specifically the last tests and characterization, the metrology of installed optics and the installation details. The results are defining the base performances that will be transferred to the next activity that will be the beam-based commissioning, when European XFEL will be operational again (March-April 2026).

ORAL: CONTRIBUTED

EuPRAXIA@SPARC_LAB AQUA beamline: a FEL beamline in the water window from plasma accelerated electrons

Villa, Fabio

INFN-LNF

Plasma acceleration is paving the way for new compact accelerators aiming at reducing the scale of the facilities needed by free electron laser (FEL) or high energy physics by employing accelerating gradients much larger than conventional RF structures. The EuPRAXIA Design Study [1] is dedicated to realizing a distributed FEL facility powered by plasma acceleration in the European framework (it is included in the ESFRI roadmap). As part of the EuPRAXIA project, Frascati National Laboratories propose hosting a cutting-edge facility named EuPRAXIA@SPARC_LAB [2], tailored to meet these specific requirements with a unique combination of a high-brightness X-band RF linac driving a plasma-accelerator-based FEL. We plan to realize a FEL beamline in the XUV (3-10 nm) called “AQUA”, and we are studying the possibility of another beamline in the VUV (50-150 nm), called “ARIA”. We are completing a Technical Design Report, while the building has just finished executive drawing phase. In this contribution, we will present the status of the EuPRAXIA@SPARC_LAB project, focusing on the characteristics and opportunities of the AQUA FEL beamline in the water window, driven by plasma accelerated electrons.

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POSTER

Offline Flat-Field Spectrometer Design for S3FEL Spectral Diagnostics

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This report introduces a novel spectrometer design method aimed at providing spectral diagnostic information for the initial commissioning of Shenzhen Superconducting Soft-X-Ray Free Electron Laser(S3FEL). This diagnostic capability specifically requires analyzing and diagnosing photon flux within a 0.1% bandwidth in the 2.3-30 nm wavelength range, in order to provide feedback on undulator electron beam alignment. Utilizing ZEMAX optical design software, we successfully designed a flat-field off-line spectrometer with a resolving power exceeding 3000 across the entire spectral range, achieved through ray tracing calculations of its resolving power and iterative tolerance analysis (this performance considers the combined effects of assembly, alignment, and manufacturing tolerances). In the field of advanced light sources, this design method offers two main advantages compared to traditional approaches: First, it directly calculates the spectrometer's resolving power using ray tracing (instead of traditional theoretical formulas), with the calculated results comprehensively incorporating the influences of light source size, grating surface errors, exit slit, higher-order and lower-order aberrations, and diffraction limits; more importantly, leveraging the accuracy of this ray tracing method, the spectrometer design can be completed conveniently and efficiently using ZEMAX software's built-in optimization algorithms. Second, owing to the speed and accuracy of the aforementioned ray tracing, we are able to use the spectrometer's resolving power as an evaluation criterion to perform Monte Carlo analysis and calculations for spectrometer assembly and alignment, as well as grating groove density and manufacturing tolerances, and the results from this tolerance analysis provide feedback for iterative optimization of the design, thereby significantly enhancing the engineering feasibility of the spectrometer design.

POSTER

The research and calibration experiments of the room-temperature calorimeter for VUV FEL

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Accurate and reliable measurement of photon flux is crucial for the scientific experiments and stable operation of free-electron laser (FEL) facilities. The Dalian Coherent Light Source (DCLS), which delivers high-intensity, pulsed radiation in the challenging vacuum ultraviolet (VUV) to extreme ultraviolet (EUV) spectral range of 50–150 nm, presents a significant metrological demand. To address this need, we have developed a dedicated room-temperature radiometer. This instrument is engineered to serve as a primary standard for absolute radiometric measurements, establishing a traceable reference for photon intensity within the facility. Its principal role is the in-situ calibration of other online diagnostic instruments, such as the shot-to-shot intensity monitors (IMs), thereby ensuring the quantitative accuracy of data provided to users. In preparation for its deployment, the radiometer has undergone a comprehensive series of offline calibration experiments. The results confirm its excellent performance, characterized by high accuracy, good linearity, and robust stability, validating its readiness as a metrological cornerstone for the DCLS.

ORAL: CONTRIBUTED

Development and calibration of a novel EUV reflectometer and its first polarimetry-dependent measurements

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The investigation of optical properties in the extreme ultraviolet (EUV) spectrum is essential for the development of materials used in space optics and synchrotron facilities; however, strong technological and physical constraints exist on this task, hence the need to develop new instrument and techniques to probe these wavelengths. Within this context, we have developed a novel EUV reflectometer, integrated into the broader I-PHOQS infrastructure, Italy's largest research network dedicated to the optical and physical characterization of materials across a wide spectral range from the XUV to the FIR.

Our instrument enables the measurement of material reflectivity at various incidence angles and allows for polarization-resolved studies. The facility supports multiple light sources, including deuterium arc lamps, mercury lamps, and hollow cathode lamps. A monochromator equipped with two interchangeable gratings (mounted on a rotatable turret) provides flexibility between high-resolution and broad-range spectral scanning. The selected spectral component is collimated by a toroidal mirror into a rotating vacuum sample chamber, which permits angular adjustment of the sample with respect to the incident beam, changing the polarization state of the incident light in the sample reference frame. A high-precision digital multimeter ensures accuracy and repeatability in all measurements.

In the initial phase of the project, we focused on constructing and aligning the facility. After the initial calibrations, we refined the analysis protocol to extract the optical properties of the material by combining multiple measurements with different polarization states. The measurement protocol has furthermore been completed by performing a comprehensive study of both random and systematic errors affecting measurement accuracy.

In the second phase, we validated the system using various material samples relevant to space and synchrotron applications, including SiO₂ and MoS₂. The instrument's capability to analyze polarization-dependent reflectivity allowed us to precisely determine the Brewster angle for these materials.

Acknowledgement: the authors acknowledge support from PNRR I-PHOQS Research Infrastructure

POSTER

Extreme ultraviolet photon diagnostic technology based on photoelectron spectroscopy

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As the core probe for exploring the microscopic world, the interaction between laser and matter can selectively excite or regulate molecules through its anisotropic characteristics. This provides a key excitation method for cutting-edge research such as the identification of chiral molecular conformations and the analysis of the spin polarization state of magnetic materials. S3FEL relies on its unique elliptically polarized undulator (EPU) to generate lasers with adjustable polarization states. The accuracy of polarization state diagnosis directly affects the data analysis results. In response to the needs of large-scale devices, this report mainly introduces the coaxial electron velocity imaging (C-VMI) laser polarization state detection equipment independently designed and developed. The physical design, mechanical design, assembly and debugging of the C-VMI equipment have been completed, and the offline performance test of the equipment has been carried out using a desktop laser.

The polarization diagnosis accuracy is as high as $\pm 0.5\%$, leading the current international level. In addition, the C-VMI equipment can also be used for the diagnosis of many properties such as FEL pulse length, multi-harmonic phase relationship, vortex, etc., and has the ability to characterize photons in multiple dimensions.