# PhotonMEADOW23

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# Book of Abstracts

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## Welcome

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## Correction of X-ray wavefront errors using adaptable refractive correctors

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Imperfection in X-ray focusing optical elements result in phase errors which when propagated to the focal plane cause broadening of the focused beam profile. A useful concept is the X-ray wavefront which is a surface of constant phase and for ideal focusing this is a spherical surface centred on the focal point. Aberrations in optical elements cause a deviation of the wavefront from this ideal surface and give rise to loss of spatial resolution at the focus.
For 4th generation X-ray sources emitting X-rays with high spatial coherence, the requirement for achieving close to diffraction limited focusing is that the rms wavefront error should be a small fraction of the X-ray wavelength. This implies rms wavefront errors at the picometre level, which is highly demanding, and often this is beyond the limits of fabrication.

X-ray wavefront correction is a developing field in which special optical elements are inserted into the optical path to compensate the X-ray wavefront errors introduced by imperfect optics. I will describe design, fabrication and testing of wavefront correcting optical elements that use the weak refraction of X-rays to advance the X-ray phase with a variation in refractor thickness along one transverse direction giving a position dependent phase correction. Using a pair of refractors, the correction can be made adaptable to dynamically match the optical element allowing compensation for time dependent changes and for an X-ray energy independent correction. A pair of correctors can be used to separately correct the wavelength along two orthogonal directions.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**X-ray optics design, realization and metrology / 54**

## Blazed Soft X-Ray Gratings Fabricated by Grey-Tone Electron-Beam Lithography and Thermal Oxidation of Silicon

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Blazed gratings are an essential element for instruments used at free electron laser and synchrotron facilities in soft and tender X-ray ranges. Their application ranges from beamline monochromators and spectrometer analyzers to self-seeding and pulse compression elements. These gratings are commonly made by mechanical ruling, however, the production time of high-quality blazed gratings has become a major bottleneck due to technological challenges in their fabrication and few suppliers only.
In this presentation, we report on a novel method for the production of next-generation X-ray diffraction gratings based on grey-tone electron-beam lithography (EBL) and thermal oxidation of silicon. This new technology gives advantage of high flexibility regarding the grating design, allowing for enhanced optical performance as well as novel optical functionalities. This EBL technique with its high resolution allows for the fabrication of several gratings with different pitches and/or blazed angles on the same substrate.
We will also present the at-wavelength characterization of manufactured blazed gratings. The measurements were done at the Optics beamline at BESSY II. The diffraction efficiency over the soft X-ray energy range, as well as the dispersion of the gratings, was investigated. The results show that the measured gratings match the required surface roughness, high diffraction efficiency, and very low diffuse scattering noise.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

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## Synchrotron- and substrate-induced structural modifications in adventitious carbon layer on beamline optical elements

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The XRD2 and XPRESS beamlines of Elettra, the Italian synchrotron facility, share a multipole semiconducting wiggler as photon source. XRD2 receives light from the central portion of the photon beam while a Si(111) beam splitter, at an incident angle of 4.5°, reflects a side portion of the radiation cone towards XPRESS. Upon dismounting, the crystal showed an unexpected, longitudinal, 4 mm-wide stripe on the optical element surface, clearly correlated with the beam footprint.

We will show the structural and chemical characterization performed in trying to understand what occurred to the crystal surface. Fizeau Interferometry revealed that the stripe was a relatively bulky bump, roughly 500 nm high at the initial incident point of the beam, and gradually decreasing along the crystal. Interestingly, X-ray Diffraction did not show any local variation of the Si crystal lattice parameter, ruling out any possible thermally-induced deformation. Finally, Infrared and Raman Spectroscopy allowed us ascertaining the adventitious carbon composition of the bump, also suggesting a non-amorphous layer and its hybridization states.

This study highlights the role played by carbon, as a common and diffuse contaminant, on affecting the performances of X-ray optical elements. Moreover, it confirms the occurrence of significant structural changes in the carbon layer, as the result of complex interactions with the substrate, *i.e.* the optical element surface, and the synchrotron radiation.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

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# Diamond-VeNOM: a high-speed slope profiler for characterising X-ray mirrors

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We present the Diamond-VeNOM (velocity-NOM): a high-speed slope profiler of X-ray optics. With recent improvements in the fabrication quality of X-ray mirrors, the systematic errors of optical profilers are no longer negligible. For optics with slope errors « 100 nrad rms, repeated scans with the mirror oriented in a range of configurations are required to null experimental errors and improve measurement accuracy. This process is effective, but time consuming. To solve this problem, we have developed a dynamic profilometer system, whereby the optical surface is pitched in synchronization with translation of the scan head. Multiple autocollimators are used to simultaneously monitor the optical surface, parasitic angular errors of the air-bearing scan head, and angular rotation of the optic under test. A significant increase in measurement speed is achieved using new Elcomat5000 autocollimators with a 250 Hz acquisition rate. Based on 1 kHz feedback from motion encoders, a PandA input/output box triggers mechanical shutters to simultaneously block the beam path of each autocollimator when the motion stages reach a series of user-defined positions or angles. This enables synchronization of variable-speed translation and pitch trajectories with data acquisition from multiple autocollimators. This new innovation reduces the burden of post-processing data alignment and enables more sophisticated motion trajectories, including on-the-fly, automated nulling of the optical surface to reduce systematic errors. We demonstrate that fly-scanning, combined with the speed enhancement of the new autocollimators, leads to a 20X time efficiency of the Diamond-VeNOM compared to the Diamond-NOM's traditional step-scans, without loss of data quality.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**X-ray optics design, realization and metrology / 45**

## Experiences and Challenges with X-ray Optics for the LCLS

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In the past 5 years, the LCLS Optics Metrology Laboratory has measured and encountered numerous types of extreme x-ray optics in various phases, i.e. from prototyping to qualifying the bare optics to the fully assembled optics systems. In this presentation, selected examples of optic work will be shared for illustrating the interesting experience working with optics for the LCLS, and the lessons learned. The hope is to create awareness in the community on what may be expected from such scale and magnitude of facility upgrade.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

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## Characterization of silicon pore optics for the ATHENA observatory in the PTB laboratory at BESSY II

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For new astrophysics X-ray observatories like the Advanced Telescope for High ENergy Astrophysics (ATHENA), mirror surfaces of several hundred m² are required. As such an area is not achievable with a single mirror in space, the silicon pore optics (SPO) technology will be utilized. In the PTB laboratory at BESSY II, two dedicated beamlines are in use for their characterization with monochromatic radiation at 1 keV and a low divergence well below 2 arc sec: the X-ray Pencil Beam Facility (XPBF 1), providing a pencil beam of about 100 µm x 100 µm since 2005, and the X-ray Parallel Beam Facility (XPBF 2.0) where since 2016 beam sizes up to 7.5 mm x 7.5 mm are available while maintaining the low beam divergence. The SPOs are aligned and scanned with in-vacuum hexapods, and two electronic autocollimators are used to guaranty a hexapod positioning accuracy of 0.7 arc sec. A movable CCD-based camera system at a distance of 5 m or 12m to the SPO registers the direct and the reflected beam. The positioning of the detector can by verified by a laser tracker. XPBF 2.0 is not only used to characterize mirror stacks, but also to control the focusing properties of mirror modules (MM) - consisting of 4 mirror stacks - during their assembly at the beamline. The energy-dependent reflectance of a MM with Ir coating has been measured at two other beamlines in the entire photon energy range from 0.2 to 10 keV.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

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## Updates on optical metrology for synchrotron mirrors at NSLS-II

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In most synchrotron applications, X-ray mirror slope specification is an important parameter for applications using a partially coherent X-ray beam. The slope error is typically specified at the sub 100 nrad RMS for mirrors up to 1000 mm long by 50 mm wide. For applications using diffraction-limited X-ray beams, height specification is a more relevant parameter to maintain and focus the beam at the diffraction limit. The typical specification is at 1 nm or even sub-nm RMS level.
These requirements, whether specified in slope or height, bring enormous challenges to synchrotron mirror metrology. This task requires dedicated metrology instruments to accurately characterize these high-precision mirrors when typical surface shapes can be flat, circular cylinders, off-axis elliptical cylinders, or even two-dimensional curved shapes. Several metrology instruments have been developed at NSLS-II to tackle these challenges to characterize these high-precision synchrotron mirrors.
With several years of research and development, our group at the NSLS-II has established a procedure for optical metrology and mirror fabrication using ion beam figuring. In our workflow, a stitching interferometer prototype based on a Fizeau interferometer is used as an in-process inspection tool to provide feedback to an ion beam figuring instrument for synchrotron optics fabrication. When the mirror is under specification, it will be inspected by other metrology instruments to make cross-validation. Various metrology instruments, including the stitching shack-Hartmann instrument, the nano-accuracy surface profiler, and the micro-stitching white light interferometer, are used as final inspection tools to characterize the optics fabricated in-house or supplied by vendors.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

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## Highly efficient multilayer-coated blazed and laminar gratings for tender X-ray energy range

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Multilayer coating on top of high line density blazed gratings can increase its diffraction efficiency up to one order of magnitude for a selected diffraction order. In combination with multilayer coated pre-mirror in plane grating monochromator (PGM) the total instrument transmission can be increased in hundreds of times. In our developments on multilayer-coated blazed gratings (MLBG) we have reached experimentally efficiency up to 60% [1,2] in tender energy range where single coated grating would demonstrate only few percent. After several successful prototypes the real MLBG were designed and installed in c-PGM at u41-TXM-beamline at BESSY-II [3].
The key factor of high performance MLBG is in correct optimization of both multilayer and grating profile parameters to each other [4]. Our current developments are focused on extension of operating energy range, employing ML coating on laminar profile (MLLG) and tuning the optimization in order to significantly increase grating angular dispersion (i.e. an instrument energy resolution) with minimal losses in the grating efficiency. In our contribution, we are presenting our latest successful experiments with broad energy range MLBG, high efficiency MLLG and MLBG optimized for higher diffraction orders. Together with this, we are going to discuss possibilities to reach highest of possible resolving power with MLBG and challenges connected with that.
[1] A. Sokolov et al., Opt. Express 27(12), 16833 (2019)
[2] F. Senf et al., Optics Express 24(12), 13220 (2016)
[3] S. Werner et al., Small Methods 7(1), 2201382 (2023)
[4] Q. Huang et al., Opt. Express 28, 821 (2020)

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**X-ray optics design, realization and metrology / 32**

## Development of stitching interferometry and ion beam figuring methods for high precision X-ray mirrors

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Driven by the fast development of the new generation storage ring and free-electron laser facilities, X-ray mirrors with nanometer figure accuracy, complex shape and large size are widely demanded. These optics are being developed in Tongji University using stitching interferometry and ion beam figuring technique. Stitching interferometry is commonly used for the 2-D figure metrology of X-ray mirrors, while the accumulated angular error among neighboring subapertures and the systematic error within each subaperture are affecting the stitching accuracy. A method to correct the angular error using low-frequency profiles measured by other instruments is studied, called 'mixed stitching' . It directly obtains the stitching angles from the 1-D profile along one direction of the entire tested mirror which further correct the relative angles fitted from algorithm. The stitching accuracy can be both improved either by a commercial contact profiler or a high-precision slope measurement system and the minimum figure error of below 1 nm RMS can be achieved. The shape error of a single subaperture is studied and reduced by calibration of the reference mirror and lateral resolution of the Fizeau interferometer. Based on these improvements, the measured figure accuracy of elliptical mirror using simple global stitching algorithm was improved to 1.5 nm RMS. Based on the high-precision stitching interferometry, mirrors with maximum length of 500mm and figure height error of 1nm RMS were manufactured and some of them have been applied in the synchrotron radiation facility. These results will be presented and discussed.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**X-ray optics design, realization and metrology / 28**

## Next Generation of Mirror Benders at LCLS

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The ongoing upgrades of the Linac Coherent Light Source (LCLS) at SLAC aim to further expand the capabilities of X-ray free electron lasers by delivering photon energies up to 20 keV at 1 MHz repetition rates. To support these advancements, significant improvements are being made to the beamlines, particularly through the implementation of new bendable mirror systems capable of operating under these extreme conditions. The design of these upgraded benders builds upon the success of previous generation systems at LCLS, improving aspects such as cooling, mounting and kinematics, twist correction, stability, and overall performance. This talk will provide an overview of the upgrade efforts and highlight the key features and advancements of the new mirror bender systems.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Beamline design and simulation / 3**

## The Optics of the Athos Soft X-ray Beamlines at SwissFEL

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SwissFEL is a free electron laser, comprising of two undulator lines with three endstations each: covering 2 –12.7 keV (up to 1.5 mJ) and 0.25 –2 keV (up to 5.0 mJ), respectively.
We present the design and commissioning of the ATHOS soft x-ray optics, starting with the overall beamline-layout and the optical components inside the front-end: a gas attenuator, a thin foil based solid-state attenuator, slits and a photon-beam diffusor, dispersing the x-ray beam and protecting the beam-stopper.
Inside the optics hutch a horizontal deflection mirror separates the bremsstrahlung and the x-rays. To ensure a common beam-path behind the monochromator, for mono- and pink-beam operation, two vertical offset mirrors can move into the beam instead of the monochromator. We discuss the design and performance of these in-house build mirror-systems. The monochromator has an upward deflecting grating, accommodating different beam-heights at the endstations. We present commissioning results for the monochromator using an ionisation chamber, a scintillation screen based 2D-detector and a 1D-detector with improved resolution for also characterising the spectrum of attosecond pulses.
There are horizontal deflection mirrors between the monochromator (common to all three endstations) and the exit slits (specific to the endstations) to steer the beam towards the corresponding experiment.
Each endstation has a KB-mirror system to focus the beam onto the sample. We use slit scanning to

optimise its focal spot size. A laser-based pointing system (upstream of the KB) coincides with the x-ray beam, enabling sample alignment ahead of the beamtime.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 10**

## BEaTriX, the new facility to measure the modular X-ray optics of the ATHENA telescope with an expanded and parallel X-ray beam

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BEaTriX (Beam Expander Testing X-ray) is a unique facility developed at the INAF-Osservatorio Astronomico Brera (Merate, Italy) to test ATHENA's X-ray mirror. The commissioning has been successfully completed, and the facility is now open to users.
The unique BEaTriX X-ray beam approximates the one created by an astronomical source (collimated and large), and it is re-created in a small lab (about 9 m × 18 m) thanks to an innovative design. A microfocus X-ray source produces a divergent beam which is conditioned by a parabolic mirror and a set of silicon crystals, one of which is asymmetrically cut with respect to the lattice planes. The first beam line, at the energy of 4.51 keV, is operative. The beam is collimated to < 3 arcsec, with a flux of 60 photons/s/cm2. Its size (170 mm × 60 mm) is sufficiently large to cover the entrance pupil of the ATHENA Silicon Pore Optics Mirror Modules (MM), generating an image at its focal length of 12 m. Its small size and vacuum modular compartments ensure a fast test rate, enabling the X-ray acceptance tests (PSF and Effective Area) of the ATHENA Silicon Pore Optics Mirror Modules (MM) at their production rate (2 MM/day), at 4.51 and 1.49 keV.
Giving the excellent results of the 4.51 keV beam-line, we have started the development of the second 1.49 keV beam line to be implemented in Merate, and a feasibility study to replicate the facility at the cosine premises, with beamlines at 1.49 and 6.4 keV

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Beamline design and simulation / 22**

## Closing the gap - towards tender X-rays by means of multi-layer coated gratings as monochromator optics

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State-of-the-art soft X-ray beamlines use collimated plan-grating monochromators (cPGM) as monochromatizing devices. Multi-Layer (ML) coated plane gratings and mirrors allow to extend the available photon energy range of cPGM's towards the so-called tender X-ray photon energy range (up to 5 keV) providing a significantly higher photon flux. This X-ray energy regime covers L- and M-absorption edges of most of the transition and rare-earth metals as well as K-edges of lighter elements such as silicon, sulfur and phosphorus. Recently such a ML based monochromator setup became operational at the U41-PGM1-XM beamline at the BESSY-II storage ring in Berlin. This beamline upgrade enabled for the first-time high resolution spectro-microscopic applications using photon energies up to 3keV. And extend its possibilities to support research e.g. on the field of life-science, semiconductor development and battery research. We will report on the design, commissioning and performance of this beamline and discuss possible options for new developments on the field of beamlines and end-stations in the tender-X-ray energy range (up to 5keV) at existing and future new accelerator-based photon sources.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 48**

## Scattering effect from mirror surface defects: analytical and simulation approach

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The scattering properties of mirror surfaces are strongly dependent on the surface structure and radiation incidence angle, for a given photon energy. In particular, in Free Electron Laser and Synchrotron X-ray photon transport beamlines, the perturbation of the scattering effect is often dominant in the Point Spread Function (PSF) degradation. The perturbation theory explains the surface Power Spectral Density (PSD) - scattering link, its main result being a simple linear relationship between the scattered intensity distribution and the PSD, expressed as a function of the surface spatial wavelength. The PSD can be assembled from various surface profile measurements, such as optical interferometry, profilometry, and Atomic Force Microscopy. Mathematically, the PSD is the square of the surface profile's Fourier transform, or, equivalently, the Fourier transform of the auto-covariance function of the surface profile. Given the PSD of a non-ideal mirror surface, the mathematical form of the observed scattering is provided by the well-consolidated first-order perturbation theory.

The present work discusses the degradation of the PSF due to the scattering in grazing incidence geometry, from Extreme Ultra Violet to Hard X-ray photon energies. We analyzed a simple optical system constituted by a plane mirror and a set of Kirkpatrick-Baez plane-elliptical mirrors, taking into account the complete PSD of the mirrors.
The issue is discussed by comparing a first-order scattering theoretical approach and simulations performed with SHADOW (raytracing), Synchrotron Radiation Workshop (SRW, wave optics based), WISEr (wave optics based), and SHADOW's Hybrid extension. The results obtained should be useful in facing this issue.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 15**

## Design plane varied-line-spacing grating in complex optical layout using step-by-step ray tracing method

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Varied-line-spacing grating is a key optical element in the light facilities, concerning lithography, holography, tomography, as well as spatially resolved monochromator/spectrometer. In the last decades, the grooves parameters of varied-line-spacing gratings are necessary to be strictly deduced through the light path function and the Fermat's principle. This method is of great importance to analytically solve the spot focusing, correcting aberrations and compressing the pulse stretching. However, one needs to develop sophisticated light path function with Taylor expansion, and even with the efforts, coma and aberrations in high order cannot be totally corrected. In this article, we report a visual and universal method to analytically calculate the groove parameters for plane varied-line-spacing grating in a Hettrick-Underwood type spectrometer using step-by-step ray tracing, and have a great agreement with the Fermat's principle with Maclaurin series. Additionally, we use a semi-analytic approach to fast find out the focus point for a whole energy range based on the ray-tracing method. This framework provides new insights into optical design, manufacture, and metrology.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 46**

# X-ray photon transport simulators comparison: which will win?

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The race toward completing several next-generation X-ray light source facilities around the world has been running hot since a few years. This has created the need to accurately simulate the performances of the beamlines before they are built, so as to make sure the optimal layout has been chosen. To this end, the optical community has at its disposal several simulation tools, most of them incorporated into a single framework, Oasys.
The aim of this work is to highlight the strengths and weaknesses of three among the most commonly used software tools, namely SHADOW, Synchrotron Radiation Workshop (SRW), and WISEr, the first being a raytracer, while the last two are concerned with wave optics. For completeness, we included in our analysis also SHADOW's Hybrid extension.
In order to compare the different codes, we propagate a photon beam at different energies through a simple optical system, constituted by a plane mirror and a set of Kirkpatrick-Baez plane-elliptical mirrors.
We compare different diffraction effects, as well as the effects of the mirrors'figure errors.
The results obtained should be useful in choosing a specific simulation tool for a specific task in beamline design, while at the same time clarifying to new users the strengths and limits of each of the codes.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 65**

# Active grating for monochromatization in the extreme-ultraviolet spectral region

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The monochromatization of radiation in the extreme ultraviolet spectral region is accomplished by using diffraction gratings at grazing incidence. In the most general case, the grating is roto-translated to perform the wavelength scanning. Different optical configurations have been proposed until now, both using plane and concave gratings and with uniform or variable line spacing.
In this work we propose the use of a bendable grating as dispersing element. The control of the curvature radius of this optical element permits to perform at the same time the spectral selection and the focalization of the selected spectral component. As a consequence, the number of the optical elements is reduced from three to two: the grating and a focusing mirror.
We will present a low-cost mechanical implementation of this optical concept in which a thin plane diffraction grating, with a flat at rest optical surface, is bended by the use of a mechanical device to an almost cylindrical shape.
The device has been tested in the 13-50 eV energy region, showing very good focal properties with

very low residual aberrations. To quantify these aberrations, the shape of the bended surface has been measured using a wavefront sensor.
Possible applications of the proposed solution are both in large-scale facilities such as FELs or synchrotrons, but also in table-top setups, such as those exploiting high-order harmonic generation.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Beamline design and simulation / 36**

# The new Pulse-Length Preserving Double Monochromator Beamline at FLASH

**Authors:** Guenter Brenner[None]; Luca Poletto[1]; Mabel Ruiz Lopez[2]; Maciej Brachmanski[2]; Holger Weigelt[2]; Siarhei Dziarzhytski[3]; Mangalika Sinha[2]; Pragya Chopra[2]; Kai Tiedtke[2]; Stefan Düsterer[4]; Elke Plönjes[5]; Hilmar Bienert[2]; Thorsten Hans[None]; Boris Steffen[None]; Rolf Treusch[2]; Soeren Grunewald[2]; Markus Degenhardt[2]; Mathias Hesse[2]; Horst Schulte-Schrepping[2]

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FLASH, the soft X-ray free-electron laser (FEL) in Hamburg provides high-brilliance ultrashort femtosecond pulses at MHz repetition rate for user experiments. For high resolution spectroscopic and dynamical studies in various research fields a small FEL energy bandwidth and ultrashort pulses are a prerequisite. While single grating monochromators provide high-energy resolution they introduce a pulse-front tilt which effectively elongates the longitudinal pulse profile, thus decreasing the time resolution. In order to preserve a short pulse duration and still monochromatize the FEL radiation, the new pulse-length preserving monochromator beamline FL23 at FLASH2 uses a double-grating design. A first grating disperses the radiation and an intermediate slit reduces the spectral bandwidth, a second grating operating in compensating configuration turns back pulse front tilt, thereby preserving the ultrashort photon pulses.
The open port beamline covers the spectral range between 1.3 nm and 20 nm with a spectral resolving power of approximately 2000. The beamline can also be operated in a single grating configuration in order to maximize the transmission at the high energy end. The bendable Kirkpatrick-Baez mirror system provides flexible microfocusing at the experiment. A femtosecond optical laser synchronized to the FEL will be provided for pump-probe experiments. The beamline concept and design has been developed using ray tracing simulations and confirmed by wavefront propagation simulations.
Here, the pulse-length preserving double monochromator beamline concept will be introduced, the different operation modes and expected photon parameters at the experimental station will be discussed and the first commissioning results will also be shown.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**73**

# OASYS and DABAM: Two important projects born after MEADOW-2013. Status and Perspectives

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We present two significant projects, namely OASYS (OrAnge SYnchrotron Suite) and DABAM (DAta BAse for mirror Metrology), which emerged as notable outcomes from MEADOW2013. Both projects have had a considerable impact on the field of X-ray science and have provided valuable resources for researchers and scientists.

OASYS [1], an open-source software suite developed for the simulation and analysis of X-ray beamlines, has been instrumental in enhancing the design and optimization of beamlines in upgraded storage rings. Through its comprehensive toolset (add-ons), OASYS facilitates ray tracing, wavefront propagation, source modeling, and data analysis, thereby enabling researchers to study X-ray optics and simulate beamline performance. OASYS continues to evolve, incorporating new features and functionalities to meet the challenges of the X-ray science community.

DABAM [2] is a collaborative project aimed at creating a comprehensive database for mirror profiles measured in the metrology laboratories of synchrotron facilities and research institutions worldwide. DABAM serves as a centralized repository of information on the error profile characteristics of mirrors used in X-ray beamlines. DABAM facilitates the simulation of real mirrors in ray tracing and wavefront propagation simulations and is completely integrated into the OASYS environment.

This talk discusses the status and ongoing developments of both projects. It highlights the impact of OASYS and DABAM in adapting and upgrading many beamlines to the new low-emittance storage rings in operation (EBS-ESRF), being implemented (APS-U), or in project (ALS-U, etc).

[1] http://dx.doi.org/10.1117/12.2274263
[2] http://dx.doi.org/10.1107/S1600577516005014

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Wavefront sensing / 43**

# Developing high numerical aperture EUV Lithography at FELs

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Extreme ultraviolet lithography (EUVL) is considered to be the future method of mass production of integrated circuits on chips. For long time, Free-Electron Lasers (FELs) have been proposed to accomplish the challenges of EUVL, i.e., a suitable power optical light source and the scanning speed of the wafer. According to this, we developed a two-steps EUVL experiment at FLASH using a Schwarzschild objective:
First, the Schwarzschild objective (SO) is aligned using at-wavelength wavefront sensor optimized for beams with a high numerical aperture. The phase measurements acquired with the wavefront sensor were analyzed using Fourier Demodulation (FD), an approach based on Fourier transformation analysis of repeating patterns. FD can recover the phase and the intensity and overcomes the measurement challenges of a SO pattern: 1) a huge magnification downstream the focus with attendant spherical aberration; 2) an obscuration of the central area; and 3) a discontinuous annular pattern divided into three lobes.
Secondly, the micrometer-sized focus of the Schwarzschild is used to demonstrate imaging. The Schwarzschild objective is used here in an on-axis geometry to image transparent samples on photosensitive material. Based on ray tracing, it is expected that the imprinted structures will have a resolution of approximately 100 nm (RMS focus-size). We will investigate state-of-the-art EUV components related to EUVL such as multilayer mirrors and photoresists submitted to intense EUV radiations.
Here the methods used in the first and the second step of this experiment will be presented and the results of the measurements will be discussed.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Wavefront sensing / 59**

## Wavefront sensing : Investigating FEL sources and Optics tuning

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For the past 10 years, wavefront sensing has been a crucial component of Free Electron Laser (FEL) facilities. Not only does it help evaluate the quality of the wavefront delivered on the sample and optimize optical systems, but it also opens the door to the new, intriguing field of source metrology. Because of the complexity of the emission process, important parameters such as the effective source position and dimension may be a-priori not known and depend on the required machine optimization. Therby, the idea of aiming wavefront sensing at source characterization is captivating because of its shot-to-shot operability and accuracy, making it suitable as feedback for machine-tuning operations.In such a scenario, the interplay of both source and optics is determinant for the quality of the delivered spot. Here, we will report on the recent advances in both fields at the FERMI XEUV seeded-FEL facility.
On the optics side, we will discuss the application of Hartmann wavefront sensing for pushing to the limit the capabilities of the KAOS active focusing system when operated far away from its ordinary working range. This is necessary to deliver a near collimated beam, and it is becoming increasingly common with the use of auxiliary diffractive optics used to deliver OAM beams.
On the source metrology side, we will show how distinct machine configurations may affect the emitted wavefront, inspect subtle parameters, such as phase shifter, dispersive section currents and the seed delay.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Wavefront sensing / 93**

## Wavefront metrology and beam propagation in the EUV/X-ray spectral range

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Proper in-situ fine-adjustment of the optical elements is crucial for an optimal performance of beam lines at synchrotron or free-electron laser facilities, considering that even slight misalignments of the grazing incidence mirrors can already deteriorate the focal spot. Real-time wavefront monitoring represents a valuable tool for reduction of these aberrations. In particular, wavefront sensors based on the Hartmann technique are well suited for this purpose as they afford rather compact setups and can be employed for both coherent and partially coherent radiation.
A Hartmann-type wavefront sensor was developed for the EUV and soft X-ray range in cooperation with DESY / Hamburg. From the simultaneous recording of wavefront and beam profile, prediction of the propagation behaviour of the beam is possible. In particular, focal intensity distributions can be computed, considering also the spatial coherence properties of the FEL beam. The latter were accessed experimentally for FLASH, using caustic scans and a subsequent evaluation of the Wigner distribution function. The improved Hartmann sensors are now routinely applied for fine-tuning of grazing incidence focusing mirrors of the free electron lasers FLASH and European XFEL / Hamburg. Nevertheless, due to the many non-orthogonal degrees of freedom of these focusing optics, an optimal adjustment using wavefront metrology can be still very time-consuming. Within the new project "FEL Focus"fast machine learning algorithms based on wavefront data are developed in order to automate the fine-adjustment of FEL optics. Such an automated system control will greatly reduce the workload of the measuring station staff.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Wavefront sensing / 12**

## Hard X-ray Hartmann wavefront sensor for focus optimization of Compound Refractive Lenses at the European X-ray Free Electron Laser

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The intense X-ray FEL beam delivered by European X-ray Free Electron Laser (EuXFEL) facility gives rise to strong challenges for the optics and their diagnostic. It is important to have an accurate knowledge of the single pulse X-ray wavefront, which affects focal plane intensity and profile, spot size, and spatial resolution, as well as centroid location within the focal plane. Wavefront sensing is important for quantitatively understanding the aligning of X-ray optical components and for conducting scientific experimental analysis. The Hartmann hard X-ray Wavefront sensor (HXWFS) enables measurements over a wide range of energies, as is common on X-ray instruments, with simplified mechanical requirements and is compatible with the high average power pulses delivered by EuXFEL. Hartmann sensor is composed of a grid of holes and a 2D detector that is tightly bound together with mechanics as a single device. Furthermore, the use of a hole array makes the sensor achromatic; wavefront measurement can be performed over a broad energy range. We will present recent preliminary results of the characterization of the focus scheme of SPB/SFX hutch compound refractive lenses (CRLs) at 9.3 keV photon energy using HXWFS (from the Imagine Optic, France) and Talbot wavefront sensor (diamond phase grating + scintillator-based camera) device. It is used to provide real-time measurement of the focal spot by CRLs of a beamline at strategic positions such as at the interaction of sample position.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Wavefront sensing / 40**

# High-resolution hard X-ray Hartmann wavefront sensor

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Wavefront sensing is a powerful tool enabling a variety of applications ranging from characterization and alignment of passive or active optical systems to non-destructive testing and phase imaging. Indeed, in the recent past, high-resolution Hartmann sensors have facilitated translating the applications of wavefront sensing to the extreme ultraviolet and X-ray spectral range.

In this work, we report on the performances of a high-resolution hard X-ray Hartmann wavefront sensor (HASO HXR) compatible with a broad photon energy range (5 - 25 KeV). The given sensor exhibits a spatial sampling of 20 μm, offering 100×100 sampling points over a field of view of 2×2 mm^2. To assess the performance of the hard X-ray wavefront sensor, we utilize Instrumentation Facility BM05 at European Synchrotron Radiation Facility (ESRF), Grenoble, France. The calibration performed at 14 KeV (88.57 pm) indicates at-energy root-mean-square (RMS) wavefront measurement accuracy and repeatability of 112 pm and 6 pm, respectively. Moreover, post-calibration, we utilize the HASO HXR to perform phase imaging of different polymeric wires at 14 KeV. Through relative wavefront measurement, i.e., detecting the wavefront with and without the sample, the Hartmann-based approach offers the possibility of extracting absorption, deflection, and phase images in X-ray spectral range.

On the one hand, the high-resolution hard X-ray Hartmann wavefront sensor can be a critical tool for easing the characterization and alignment of optical systems in the stated energy range. On

the other hand, as a potential application, the presented results demonstrate HASO-HXR-enabled wavefront sensing for hard X-ray phase imaging.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Wavefront sensing / 64**

## Recent developments in X-ray speckle-based techniques at Diamond Light Source

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Over the last decade, X-ray speckle-based techniques have been extensively developed for advanced imaging and high precision metrology of X-ray optics. The speckle-based techniques have gained popularity due to their relatively simple experimental requirements and ease of use. At Diamond, we have worked extensively since 2012 to enhance the technique and to apply it to a range of X-ray imaging and metrology applications[1-3]. In this presentation, we are going to present our recent developments of these techniques and their latest applications. First, we show that the omnidirectional differential phase and dark-field images can be simultaneously extracted from a single speckle data set[4] . Further, we demonstrate the link between the irregular patterns in the far-field intensity image and the local wavefront curvature through beamline measurements and optics theory [5]. Finally, we have extended our techniques to the temporal applications [6] and have shown that it is possible to achieve very fast temporal measurements using conventional hardware. This new technique has great potential for time-resolved or real-time applications for X-ray instrumentation.

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**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Scientific computing, machine learning and large data management / 70**

## Advancements in X-ray Wavefront Sensing and At-wavelength Metrology at the Advanced Photon Source

**Author:** Xianbo Shi[1]

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The Advanced Photon Source (APS) has achieved significant advancements in X-ray wavefront sensing and at-wavelength metrology, which are essential for optimizing the performance of X-ray optics and synchrotron beamlines. A notable breakthrough is the development of the coded-mask-based wavefront sensing technique, which merges the advantages of grating interferometry and speckle tracking. Capitalizing on this technique, two wavefront sensor prototypes have been engineered: one featuring adjustable zoom capabilities catering to varying beam conditions and resolutions and a second, more compact and cost-effective model adaptable for different beamline configurations. In terms of at-wavelength metrology, the technique has been used to evaluate the quality and performance of hundreds of lenses of different materials and types, mirrors, crystals, and windows for APS and the APS upgrade projects. The characterization results are critical to ensure optimal performance of the beamline instrument and, ultimately, the scientific experiments. For wavefront sensing, the applications are diverse, concentrating particularly on beamline diagnostics and wavefront control, which are vital for the precise adjustment and preservation of X-ray beam quality. Plans are underway to design and fabricate wavefront sensors customized for each APS upgrade beamline, promising further performance enhancements. Furthermore, a specialized application of these advancements is their integration into adaptive optics systems as feedback mechanisms for real-time wavefront control.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Scientific computing, machine learning and large data management / 49**

## A new user-friendly tool for simulating the efficiency of multilayer gratings

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In recent years, several x-ray facilities have begun to use multilayer gratings (MLGs) in plane-grating monochromators thanks to their vastly superior efficiencies in the tender x-ray range compared to traditional single-layer gratings (SLGs). However, most of the software tools normally used for simulating the efficiencies of SLGs are not able to simulate MLGs. As a result several x-ray beamline designers have resorted to purchasing stand-alone proprietary software to calculate the efficiencies of MLGs. However this approach can lead to other complications, especially since many proprietary software packages have been designed with rather different scientific applications in mind.

Here we present a new MATLAB-based software tool being developed at Diamond Light Source (DLS) for simulating the efficiencies of both SLGs and MLGs for x-ray beamlines. At its core our software uses a freely-available program (GD-Calc from KJ Innovation) which calculates grating efficiencies via the Rigorous Coupled Wave Analysis method. Our aim is to provide a user-friendly software tool for simulating grating efficiencies which only requires a MATLAB license. Moreover, as the code is fully-integrated into MATLAB, we believe that our software will help streamline the design optimisation of future SLGs and MLGs. We will present our latest grating efficiency simulations and validate them against complementary simulations using established software such as REFLEC. The existing user interface for the software will be described and we will outline our plans for future software developments. Finally, we will summarise our plans for multilayer gratings at DLS in the context of the Diamond-II upgrade.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Scientific computing, machine learning and large data management / 21**

## Efficient simulation and AI surrogate models for real-time optimisation

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In order to aid the design and development of optical elements, such as Reflection Zone Plates, and automate the process of aligning optics in both spectrometers and beamlines, we have developed new simulation software as well as deep learning AI methods.

RAY-X, our open-source state-of-the-art physics-based ray tracing software is designed to utilise modern GPUs to reduce trace time of simulated beamlines and allow for easier multi-processing of tasks. RAY-X fundamentally restructures the architecture of the well-known RAY and RAY-UI software [1, 2] and uses the Vulkan framework [3], an industry leading graphics and computing API, to provide high efficiency, cross-platform access to modern GPUs.

The capabilities of RAY-X have afforded us the capacity to generate large datasets in order to train complex neural networks as surrogate models for both beamlines and Spectrometers. These surrogate models have inference times of milliseconds and can therefore be deployed in situ at beamlines for the purpose of automated real-time alignment of optical elements.

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**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Scientific computing, machine learning and large data management / 25**

## A New Ray Trace Computer Program For Radiation Safety

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A new computer program has been created to assist in radiation safety ray trace operation for Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory. In contrast to historical method which has been performed manually using drafting tools on CAD softwares, the computer-based calculation propagate the illumination boundaries automatically and accurately using phase space method. This method differs from ray-based sampling method available in most commercial ray tracing packages and avoids the risk of under-sampling.
With a native graphical user interface, the program is easy to operate and allows for near real-time feedback on placements and motional ranges of components with regard to beam containment. By replacing manual construction of ray trace drawings, significant time saving is achieved (from week to second) and potential human errors avoided. Such reduction in overhead also allows beam line safety considerations to enter early in the design iterations and potentially avoid engineering effort for costly modifications later on.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Photon diagnostics for FELs and synchrotrons / 39**

## XFEL sub-10 nm focusing with 10^22 W/cm^2 intensity: wavefront corrected mirror and focus characterization

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We have developed a sub-10 nm focusing system to achieve an ultraintense X-ray laser field with 10^22 W/cm^2 intensity at SACLA. For the sub-10 nm focusing optics, an advanced KB (AKB) mirror system based on Wolter-type III geometry has been adopted. One of the remarkable challenges was the fabrication of steeply curved mirrors with radii of curvature of ~3 m with a shape accuracy of 1 nm. We applied an X-ray wavefront correction scheme using a single-grating interferometer and a differential deposition technique. The horizontal mirror pair was corrected twice and the vertical pair once, resulting in the wavefront error of λ/15 rms which satisfies Maréchal's criterion. The focus characterization was performed by single-grating interferometry and ptychography. Both methods consistently indicated a focusing spot size of 7 × 7 nm^2, while the 2nd-order aberration term, i.e. astigmatism, contained slight uncertainty. To accurately measure astigmatism, we employed speckle interferometry that directly measures the on-focus beam size. From the speckle measurements, remained 3 μm astigmatism was identified and corrected faithfully. Consequently, XFEL 7 nm focusing spot with 1.45 × 10^22 W/cm^2 intensity has been achieved.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Photon diagnostics for FELs and synchrotrons / 1**

## X-ray Gas Monitor operation at European XFEL above 25 keV

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X-ray Gas Monitors (XGMs) are operated at European XFEL for non-invasive single-shot pulse energy measurements and average beam position monitoring. The basic mechanism is photo-ionization of rare gas atoms. They are used for machine SASE tuning and for sorting single-shot experimental data according to the pulse energy. The XGMs were developed at DESY based on the specific requirements of European XFEL. In this contribution we will present the XGM operation at photon energies above 25 keV. We will discuss how we extrapolated the cross-sections and ion-mean-charges with an increased uncertainty into these high photon energies and how we want to improve the precision of these values in the future. For the XGM single-shot signal we use the Huge Aperture MultiPlier (HAMP), because the standard X-ray Gas Monitor Detectors (XGMDs) do not give reliable signal-to-noise above 18 keV even at highest operating gas pressures. We will present single-shot correlations between consecutive XGMs operated with HAMP. We discovered an intra-train non-linearity of the HAMP signal and studied operation parameters to mitigate this effect. Additionally, we will report the limit of the single-shot resolution which we found at 4.5 MHz where the HAMP peaks are overlapping.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Photon diagnostics for FELs and synchrotrons / 24**

## Development of X-ray Ionization Beam Position Monitor for PAL-XFEL Soft X-ray

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The Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) operates hard X-ray and soft X-ray beamlines for scientific experiments with providing intense ultrashort X-ray pulses based on the self-amplified spontaneous emission (SASE) process. X-ray Free-Electron Laser is characterized by strong pulse-to-pulse fluctuations due to the SASE process. Thus, online photon diagnostics are very important for the rigorous measurements. The photo-absorption and emission concept using solid materials is very limited in the soft X-ray beamline diagnostics. Instead, the gas monitoring detectors (GMDs) that utilize the photo-ionization of the gas are installed at the optics hutch and the experimental hall of the soft X-ray beamline, and employed for monitoring the beam intensity status and for normalizing the experimental data. To track the beam position at the soft X-ray beamline in addition to those intensity monitors, we developed a X-ray ionization beam position monitor (XIBPM). The XIBPM uses ionization of either residual gas in the vacuum or Kr gas injected, and microchannel plate with phosphor. The XIBPM was installed at the experimental hall, and it was

tested separately for horizontal and vertical beam position monitoring. Electrostatic field-map of the XIBPM is analyzed using the CST (Computer Simulation Technology) Studio Suite, and multiparticle tracking studies on the field-maps obtained from the CST Studio Suite are in progress to quantitatively analyze and identify error components. Here, we introduce the newly developed XIBPM about a basic structure and test results and a design optimization considering beam-gas interaction and particle tracking on a realistic field-map.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Photon diagnostics for FELs and synchrotrons / 20**

## Silicon Carbide ultra-thin membranes for X-ray beam position and intensity monitoring

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In this work, the performances of thin (0.5um-10um) Silicon Carbide (SiC) membranes as in-line X-ray Beam Position Monitors (XBPM) for synchrotron beams presented and compared with commercial single- and poly-crystalline diamond ones. Results show that SiC devices can reach superior transparencies with respect to diamond, thanks to the realisation of <2um thick sensors, while allowing for much larger active areas and zero-voltage operating conditions.
Given the obtained experimental and theoretical results and availability of electronic-grade epitaxies on up to 8inch wafers, we expected that SiC will substitute diamond in most X-ray beam monitoring applications, even in the cases of extreme X-ray power densities, such as pink and white beams. This is because, in such conditions, although the material properties of diamond are superior, SiC, thanks to the larger sensors sizes, allows for better heat dissipations and -overall- device reliability.
At the conference an overview of the different SiC XBPM products realised by SenSiC GmbH (including beam and center stops: intensity and position sensors), as well as preliminary results on XFEL beam monitoring, will be presented.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**69**

## AI-driven real-time optics control system to achieve aberration-free coherent wavefronts at 4th-generation synchrotron radiation and free electron laser beamlines

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When dealing with experiments conducted at 4th-generation synchrotron radiation and free electron laser beamlines, the primary challenge for X-ray optical elements lies in achieving and maintaining focused X-ray beams of high intensity, possessing near-perfect wavefront quality and exceptional stability. Optical elements necessitate more stringent specifications compared to other applications due to the shorter wavelength and ultra-small emittance of the radiation generated by these sources. In the case of diffraction-limited light sources producing coherent photons, it is crucial to preserve well-controlled wavefronts. The degradation of the wavefront proves detrimental to phase-sensitive imaging techniques such as Tomography. For coherent X-ray scattering experiments employing techniques like X-ray Photon Correlation Spectroscopy, Coherent Surface Scattering Imaging, and Coherent X-ray Diffraction Imaging, wavefront uniformity holds particular significance. X-ray optics must be manufactured with a near-perfect shape, and automatically and consistently align and focus the beam according to experimental requirements. Furthermore, they should be capable of providing real-time correction in response to wavefront deformations. At the APS, we have successfully demonstrated the practical application of two methods: i) utilizing a Neural Network (NN) model to autonomously control deformable mirrors with remarkable precision and control. The NN is trained to establish a time-dependent relationship between the hardware setup and the wavefront properties during experiments. ii) Employing Bayesian optimization with Gaussian processes to automatically align and stabilize the focusing optical systems of hard X-ray synchrotron radiation beamlines. This approach utilizes ultra-realistic digital twins constructed using the OASYS simulation framework and enables effective steering of the optical assembly.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Time-related beam properties - temporal characterisation of electron, FEL, and laser beams / 82**

## A New Electro-Optic Detection Scheme for Recording Electron Bunch Shapes With High Resolution and Record Recording Length

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Non-destructive, single-shot recording of longitudinal bunch profiles is a prerequisite for accelerator commissioning and operation. A common strategy for the measurement of ultra-short electron bunches is to sample the Coulomb field with femtosecond laser pulses. However, recording electric field evolution in single-shot with THz bandwidth is a largely open problem and has been recognized as a fundamental bottleneck.

We present here a novel electro-optic sampling strategy that is theoretically capable to overcome this limit, and achieve femtosecond resolution for any recording length. This new conceptual approach is based on mathematical concepts from photonic time stretch theory and information diversity in radio-frequency communication. We show numerically and experimentally that this approach enables recording of THz electric field and electron bunch shapes in single-shot with high bandwidth than previous spectral decoding single shot techniques.

This technique opens the way to ultrafast electric field shape characterization with femtosecond resolution in new situations, including longitudinal bunch profile monitoring, studies of microbunching instabilities, and THz pulses generated at free-electron lasers.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Time-related beam properties - temporal characterisation of electron, FEL, and laser beams / 44**

## X-ray pulse shortening via nonlinear absorption and diffraction

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Controlling optical properties with nonlinear light-matter interactions, which has been the justification of optical lasers, remains largely unexplored in the hard X-ray region. By combining nanofocusing optics and stable X-ray pulses from SACLA, we are testing various concepts of nonlinear devices to control the temporal and spectral properties of XFEL pulses. In this talk, I will discuss our recent experimental studies on X-ray pulse shortening through nonlinear absorption processes [1] and the reduction of atomic scattering factors at high intensity [2,3].

[1] I. Inoue et al., Phys. Rev. Lett. 127, 163903 (2021).
[2] I. Inoue et al., Phys. Rev. Lett. 126, 117403 (2021).
[3] I. Inoue et al., arXiv:2304.05948.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Time-related beam properties - temporal characterisation of electron, FEL, and laser beams / 7**

## Single-shot temporal characterization of fundamental and harmonic ultra-short FEL Pulses

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FLASH, the free-electron laser in Hamburg, operates in the self-amplified spontaneous emission (SASE) regime, leading to a unique combination of energy, spectrum, arrival time and pulse duration. So it is critical to be able to determine the pulse duration and arrival time of each pulse. THz field-driven streaking has the potential to deliver single-shot pulse duration information basically wavelength-independent and over a large dynamic range (in pulse duration and FEL energy)[1,2].

In addition, using THz streaking, the single-shot pulse duration has been measured over a wide range from 10fs to 350fs (FWHM) [2] and correlations with other photon beam parameters have been investigated [3]. Furthermore, the study included an examination of the impact of the number of undulators on the pulse duration contributing to lasing, which was compared to results from 1D

and 3D FEL simulations [4]. Furthermore, we will show the excellent agreement of the XUV pulse arrival time measured by streaking with the electron arrival time.

In SASE FELs, nonlinear energy modulation of the electron bunch gives rise to natural harmonics of the fundamental wavelength. The pulse duration of these harmonics can be determined as well using THz streaking, which employs the same scheme used for the fundamental pulse duration. In this regard, we have conducted measurements and simulations to determine the pulse duration of the third harmonic and to observe its evolution along the undulators.

1-I.Grguraš et al.,Nat. Photon. 6(2012)
2-R.Ivanov et al.,J. Phys. B 53(2020)
3-I.Bermúdez et al.,Opt. Exp. 29(2021)
4-M.Bidhendi et al.,Appl. Sci. 12(2022)

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Time-related beam properties - temporal characterisation of electron, FEL, and laser beams / 63**

## Photon arrival time monitoring with few fs measurement uncertainty at MHz rate

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Pump and probe technique with X-ray free electron lasers (XFEL) is a powerful tool to study ultrafast X-ray matter interactions and subsequent ultrafast dynamics. It requires precise characterization of X-ray temporal properties, i.e. relative X-ray arrival time with respect to external optical laser pulses, X-ray pulse duration, and structure, preferably on a shot-to-shot basis.
In this contribution, we will give an overview of the X-ray temporal diagnostics techniques and present our X-ray/optical cross-correlation-based timing tools that can work at up to 1.13 MHz repetition rates with an ultrahigh measurement accuracy of down a few fs at the European XFEL.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Science instruments and detectors / 13**

## A Diamond Sensor for Position Resolving Measurements at the European XFEL

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The European X-ray Free Electron Laser (XFEL) facility produces extremely intense and short X-ray pulses, where the diagnostics of the X-ray beam properties is of critical importance. Besides existing diagnostic components, utilization of a diamond sensor was proposed to achieve radiation hard, non-invasive beam position and pulse energy measurements for hard X-rays. In particular, at very hard X-rays diamond-based sensors become a useful complement to gas-based devices which lose sen-
sitivity due to significantly reduced gas cross-sections. The measurements performed with a diamond sensor consisting of a 40 µm thick electronic grade single crystal chemical-vapour-deposition diamond with position-sensitive resistive electrodes in a duo-lateral configuration are presented in this work. The results show, for the first time to the best of our knowledge, that the diamond sensor delivers pulse-resolved beam position within less than 1% uncertainty at 2.25 MHz, and can be a valuable tool
for X-ray Free Electron Lasers, especially for the coming high repetition rate machines, enabling applications such as beam based alignment and intra-pulse-train position feedback.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Science instruments and detectors** / **27**

# Detector developments at PSI

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Developments of cutting-edge X-ray detectors are largely driven by experiments at large photon science facilities, i.e. the synchrotron radiation sources and free-electron lasers (FELs) which enable a wealth of investigations in different subjects. At PSI, we develop hybrid X-ray detectors for these facilities as well as for the next-generation radiation sources, namely diffraction-limited storage-rings and high repetition rate FELs. Their applications include but are not limited to scattering and diffraction imaging experiments for pixel detectors and XES, XRD, ED-XAS and XPD for strip detectors. Using different sensors, i.e. the Low Gain Avalanche Diodes (LGADs) and high-Z sensors, the hybrid X-ray detectors are able to cover a large energy range from hundreds of eV to hundreds of keV.

In this talk, I will introduce the detector developments at PSI and their broad applications in various scenarios. In particular, I will present Gotthard-II, a silicon microstrip detector capable of imaging up to 2720 frames at 4.5 MHz frame rate and 400 kHz continuously in beam diagnostic applications. Examples include their usage in the HIgh REsolution hard X-ray single-shot spectrometer (HIREX) for temporal energy resolution diagnostic and in the Photon Arrival time Monitor (PAM) for X-ray pulses arrival time jitter measurement. Finally, the new possibilities of Gotthard-II and the other hybrid detectors in combination with LGAD sensors for measurements in the soft and tender X-ray energy range, as well as the prospects for the next generation high-speed continuous imaging Gotthard-III with a frame rate greater than 1 MHz will be discussed.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Science instruments and detectors / 41**

# High-NA hard X-ray in-line holography with advanced KB optics based on Wolter type-III geometry

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Hard X-ray imaging techniques employing bright-field images, such as bright-field microscopy and in-line holography, offer the benefit of capturing a wide field of view without the need to scan the sample. However, the spatial resolution of these techniques has been limited by the numerical aperture (NA) of hard X-ray optics.

Advanced KB optics based on Wolter type-III geometry is highly efficient and stable, with dramatically higher NA than conventional KB mirrors. This optical system uses multilayer mirrors to increase the NA and employs a Wolter type-III configuration to ensure robustness. By using this technology, the sub-10 nm focusing system at SACLA can attain a high NA of 0.01 and 40% efficiency while maintaining the sub-10 nm focusing for half a day.

Our research aims to develop a phase-contrast imaging technique with high spatial resolution and a wide field of view by combining in-line holography with the Advanced KB optics based on Wolter type-III geometry. To verify the efficacy of this approach, we conducted a proof-of-concept experiment employing the SACLA sub-10 nm focusing system. We used nanoparticles as test samples to evaluate the performance. The reconstructed data from this experiment confirmed a spatial resolution of 100nm. In this presentation, we will discuss findings from the simulation and demonstration experiments, and address the challenges identified for future work.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Science instruments and detectors / 57**

# Correcting for the loss in degree of polarization caused by beamline optics

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The impact from optics on circular, elliptical, and inclined linear polarized light at synchrotron beamlines is known and understood but perhaps not always addressed. This impact is of particular interest for beamlines operating below ~150 eV and it becomes severe for energies below 40-60 eV, depending on the beamline's optical layout. The Bloch beamline at MAXIV Laboratory is designed for angular and spin resolved photoemission spectroscopy, generally operating in the 15-200 eV energy range. It is sourced by a quasi-periodic elliptically polarizing undulator that delivers circular polarization and linear polarization at any inclination.

We have designed a compact 4-reflections polarimeter that can be inserted into the focus of the synchrotron beam in the experimental station's analysis chamber and determine the actual polarization of the light at the sample. Based on this information we can set the undulator gap, helical phase, and inclined phase in an unconventional configuration to compensate the impact from the beamline optics on the polarization and deliver a high degree of circular or linear inclined polarized light to the users.

At present the polarimeter has been commissioned and is in operation while the undulator compensation procedure is still in its commissioning phase. Here we report the design and the design considerations of the polarimeter, the undulator compensation procedure, and first experimental results.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

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## Closing remarks

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**Poster Session** - Board: 18 / **51**

## Single-shot spectrometer usage for I-zero normalization for Bragg-diffraction investigations with pink beam

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At FELs, Bragg diffraction experiments are usually performed with monochromatic beam, whose bandwidth is smaller than the acceptance of the Bragg peak under investigation. This enables straightforward normalization of the measured Bragg peak intensity by detecting the FEL pulse intensity with a "scalar"detector (e.g. a diode measuring the scattering from a thin foil). In certain FEL applications, however, the bandwidth markedly exceeds the acceptance of the Bragg peak under investigation. In this case, the normalization can be achieved by integrating the spectrum measured by a "vector detector", typically named single-shot spectrometer, after multiplication with a suitable windowing function.

We have performed experiments at the SwissFEL ARAMIS hard x-ray beamline exploiting the "broad-band mode"(bandwidth > 0.005), characterized by a substantial temporal/photon energy chirp, and the "sub-fs mode"(bw ~ 0.002), characterized by one to few FEL temporal spikes. In both cases, the bandwidth markedly exceeded the acceptance of the Bragg peak under investigation. Here, we report on our work assessing the windowing function from the measured per-pulse spectra and Bragg peak intensities, focusing on the emerged problems and discussing possible improvements on the spectrometer.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 5 / **16**

## Fast shaping control of X-ray beams using a closed-loop adaptive bimorph deformable mirror

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Recent technological advances at synchrotron and free electron laser facilities, including brighter X-ray sources, faster detectors, and automated sample handling, have led to an increasing demand to tailor the X-ray beam profile to the size and shape of the sample. For beamlines which routinely measure hundreds of samples per day, such changes need to be made rapidly and autonomously. Bimorph piezo-electric deformable mirrors are widely used to control the profile of the reflected X-ray beam. However, when operated in open-loop, such optics suffer from curvature drift when large and frequent changes are made. To resolve these issues, we have successfully demonstrated a high-resolution, real-time, closed-loop "adaptive"optical system capable of rapidly changing and stabilizing the shape of the X-ray beam. The bimorph's optical surface is continuously monitored by an array of Zygo ZPS absolute distance measuring sensors operating at 20 kHz. Surface corrections are autonomously applied to each piezo, with sub-500 picometre resolution, at a refresh rate of ~ 1 Hz, using a programable high-voltage power supply. After calibration of the X-ray wavefront at the B16 Test beamline using speckle scanning, the wavefront diagnostic was removed from the X-ray beam path. Non-invasive control of the reflected X-ray beam was then demonstrated, including variable beam size, or non-Gaussian profiles, such as flat-top intensity or multiple split-peaks with controllable separation and relative amplitude. Such changes can be applied in any order and in rapid succession without the need for invasive wavefront diagnostic sensors which block the X-ray beam for scientific usage.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 3 / **11**

## Micropore Optics for the SMILE SXI Instrument

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Micropore optics (MPOs) have become the optic of choice in recent years for low mass and wide-angle field of view x-ray missions, such as SVOM and Einstein Probe. The Soft X-ray Imager (SXI) instrument for ESA's SMILE mission aims to spectrally map the location, shape and motion of the Earth's magnetosphere as it interacts with high energy particles excited by the Sun's solar wind. To meet this aim, an array of 8 by 4 Photonis MPOs will provide angular coverage of 15.5° x 26.5° over the energy range 0.2 to 2.5 keV. One of the key requirements of the mission is for low optical straylight to reach the detector, so the transmission of visible light through the optic is a key parameter. In this paper the x-ray performance of the individual MPOs, both qualification and flight MPOs, will be presented as well as investigation into their straylight performance and the quality of the optical blocking filter.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 10 / **31**

## TRIXS end-station at FLASH for ultrafast high-resolution soft X-ray spectroscopy

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We present the upgraded TRIXS (Time-Resolved Inelastic soft X-ray Scattering Spectrometer) end station at the PG1 monochromator beamline at the soft X-ray free-electron laser FLASH [1]. TRIXS was developed for studies of ultrafast processes in condensed matter, e. g. various types of interactions in strongly correlated electronic systems, by means of femtosecond pump-probe IXS technique with the energy resolution of about 50 - 100 meV. The spectral range of TRIXS spans from 40 eV to 250 eV and covers M-edges of the 3d transition metals and N-edges of rare earth elements. High brilliance and high repetion rate photon source as FLASH and high spectrometer collecting efficiency are mandatory for such type of experiments. A recent upgrade of the sample allows now to explore dynamics also in XAS in transmission as well as in reflectivity regimes with 0.01-degree angular resolution. FLASH synchronized femtosecond facility laser PIGLET provides 80 fs fwhm long pulses to pump samples with 1030 nm photons as well as with higher harmonics down to 257 nm. The overall time-resolution is in the range between 180 and 250 fs fwhm. First time-resolved RIXS measurements were already carried out with the new TRIXS chamber and further experiments are envisioned. New control system and machine-learning-based alignment and stabilization algorithms will provide a better user interface and even more stable operation, and cover new FLASH features that will become available after the FLASH2020+ upgrade.
[1] S. Dziarzhytski et al. Structural Dynamics 7, 054301 (2020), https://doi.org/10.1063/4.0000029

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 33 / **76**

## An X-ray beam property analyzer based on dispersive crystal diffraction for next-generation light sources

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The advent of low-emittance X-ray sources necessitates the development of new beam diagnostic methods. Existing systems tend to provide limited information or inadequate spatial resolution. A newly-developed spatial beam property analyzer has been introduced, which comprises a double-crystal monochromator followed by a Laue crystal arranged in a dispersive diffraction configuration. Through the analysis of the beam pattern transmitted via this multi-crystal arrangement, the device is capable of concurrently measuring various spatial source attributes - including size, divergence, position, and angle - with high sensitivity. This presentation details the experimental validation performed at two bending magnet beamlines at the Swiss Light Source. Additionally, simulations are conducted to explore the feasibility of employing this analyzer for characterizing source properties of synchrotron undulator beamlines and X-ray free electron lasers.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 37 / **80**

## Study on UV FEL single shot damage threshold of an Au thin film

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We evaluate the damage threshold of an Au coated flat mirror, which is one of the reflective optics installed on FEL-1 beamline of Dalian Coherent Light Source (DCLS), upon far UV free electron laser (FEL) irradiation. The surface of the coating is characterized by profilometer and optical microscope. We present also theoretical approach of the phenomenon by applying conventional single-pulse damage threshold calculation as well as one-dimensional thermal diffusion model to the case.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 29 / **71**

## X-Ray mirror carbon contamination removal test at ESRF

**Author:** Amparo VIVO[1]

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The performance of reflective optics such as X-ray mirrors or diffraction gratings generally degrades following exposure to high intensity X-ray or EUV beams. The most common degradation phenomenon is beam-induced contamination with the formation of inhomogeneous carbonaceous films on the optical surface.
Most X-ray light sources suffer from these effects which progressively reduce the optical reflectivity of the optic but can also introduce spurious signals into spectroscopic data. For tender and hard X-ray energies, phase-shifts of the X-rays after transmission though in the irregular thickness contamination film create perturbations in the reflected wavefront which can degrade focus quality. For diffractive crystal optics, contamination can cause strains in the crystal lattice which may give rise to spurious structure in the intensity profile of the diffracted beam. In time, performance degradation can become so severe that the optic becomes unusable with obvious impact to the performance of the analytical instrument.
Various light sources have investigated strategies to mitigate or remediate such contamination using in- or ex- situ techniques but, given the diversity of optical devices, either the methods are not generally applicable or the potential deleterious impact on the performance of the highest performance optics may not be well studied.
In order to build in-house expertise for the refurbishment of contaminated mirrors we have performed tests on several cleaning and remediation methods: UV-Ozone exposure, oxygen plasma treatment and stripping of various different coating materials. The impact of such treatments on micro-roughness and X-ray reflectivity measurements is presented.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 4 / **14**

## Development of Precision, Variable Slits for Dynamic X-Ray Scattering Instrument

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The LCLS-II-HE beamline at SLAC (Menlo Park, USA) is planned to come online in 2027. With FEL photon energies ranging from 0.25 keV to more than 18 keV at up to 1 MHz repetition rate, the upgraded beam calls for new science endstations to be developed. The Dynamic X-ray Scattering (DXS) instrument will employ experimentation methods such as X-Ray Photon Correlation Spectroscopy (XPCS) and High Resolution Inelastic X-Ray Scattering (IXS) to investigate quantum materials and condensed matter chemistry among other topics. To realize its science goals, DXS requires an energy resolution of less than 3 meV for energies ranging from 6-18 keV, with a tunable energy bandwidth. A key component of DXS is a 4f-High Resolution Monochromator (4f-HRM), featuring a Wavelength Defining Slit (WDS) mechanism. A novel slit blade design absorbs 10 W direct beam heat load, while preventing transmission of relevant photon energies. To achieve less than 3 meV energy resolution

with tunable bandwidth, the WDS mechanism features an adjustable slit gap size down to 1.0 micron with 0.1 micron motion resolution and stability. This presentation discusses the goals, design challenges, and solutions for the WDS.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 27 / **67**

## Characterizing SASE X-ray Pulses Using Machine Learning

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Accurate online characterization of the intensity, spectral distribution, and temporal structure of X-ray pulses is crucial for free-electron lasers. We propose a novel approach for characterizing temporal profiles of X-ray pulses at the free-electron laser FLASH in Hamburg, using β-Variational Autoencoder (β-VAE) [1] networks in conjunction with a Transverse Deflecting Structure (TDS).

The TDS in combination with a dipole spectrometer allows the measurement of time and energy variations of electrons with femtosecond resolution after they pass through the undulator, providing valuable insights into the temporal structure of the electron bunches influenced by the lasing process. [2]. To obtain a XUV power profile, a lasing off reference is required. However finding a suitable lasing off reference may prove challenging due to stability issues and drifts. For highly fluctuating electron beam properties, this matching may not be possible at all.

To address this challenge, we demonstrate the effectiveness of β-VAE networks in identifying key principles within the dataset. By training artificial neural networks on datasets comprising both lasing on and lasing off shots, we can artificially create matching lasing off images for each shot. The β-VAE networks exhibit noise reduction capabilities, uncovering hidden data artifacts and enabling enhanced analysis of the temporal structure of the electron bunches, thereby helping to obtain temporal characteristics of SASE X-ray pulses in a non-invasive manner.

References:

[1] Higgins, I. et al. B-VAE, conference paper at ICLR 2017
[2] Behrens, C. et al. Nat Commun 5, 3762 (2014)

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 31 / **74**

## Power management, coherence and photon propagation for ESRF-EBS beamlines

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Synchrotron facilities worldwide, including the ESRF, are adopting the fourth-generation storage ring, Extremely Brilliant Source (EBS). The EBS utilizes long undulators (~2 m) with short magnetic periods (< 20 mm) of in-vacuum cryogenic permanent magnets (CPUM) to enhance brilliance and coherence. However, this leads to high power deposition on beamline components, necessitating an evaluation of heat-induced deformations' impact on photon beam properties. This study introduces simulations and tools developed by the ESRF Mechanical Engineering Group to tackle EBS beamline challenges.

OASYS (Orange Synchrotron Suite), an open-source and user-friendly platform introduced in 2013, facilitates x-ray optics modeling [1]. Power transport calculations in OASYS combine XOPPY and ray-tracing algorithms for various optical components. Finite element simulations in ANSYS model heat-load-induced deformations, which are then integrated into OASYS using a dedicated widget. Photon transport simulations employing SHADOWOUI or WOFRY analyze the effects on beam properties. For example to investigate heat-load effects on crystal and multilayer monochromators.

ESRF has developed customized, open-source OASYS widgets (some are included in the official release). These widgets cater to EBS beamlines, allowing fast power transport calculations for tasks such as obtaining power density peaks based on undulator gaps and modeling beamline attenuators.

[1] https://oasys-kit.github.io/

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 38 / **81**

## New Achievements in OAM beam characterization using Hartmann wavefront sensor and KAOS

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Light beams carrying Orbital Angular Momentum (OAM) are sparking new developments in several fields like the excitation of chiral magnetic phenomena, both in the static and dynamic regime, enhanced imaging and novel light-matter interaction. The creation and characterization of OAM beams is by itself a challenging task and thus a separate field of study.

At FERMI we can create an OAM beam either by tailoring the emission process on the undulator side, or, in most cases, by coupling a spiral zone plate in tandem with the KAOS active optic system. To provide a robust and reproducible workflow to our users we leverage on the use of a Hartmann

wfs both for optics tuning and beam characterization. In particular, to operate KAOS in the so-called near-collimation mode and to provide an independent characterization of beam helicity and topological charge characterization after the creation of a structured beam. In this poster, we will present our latest achievements in operating the KAOS system out of nominal configuration and in the beam characterization workflow while powering up the OAM research community.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 9 / **30**

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

**Authors:** Andrey Sokolov[1]; Frank Eggenstein[2]; Peter Bischoff[2]; Peter Baumgärtel[3]; Matthias Mast[2]; Marcel Mertin[2]; Ingo Packe[2]; Franz Schäfers[2]; Frank Siewert[3]; Jens Viefhaus[3]

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An accurate characterization of the real performance sophisticated reflective or diffractive optics including such cases as XUV reflective zone plates (RZP) or multilayer coated gratings is extremely demanding task to experimental conditions. An At-Wavelength Metrology facility for EUV and XUV optics is under operation since many years at the BESSY-II storage ring. As the main instrument a versatile 11-axis UHV-reflectometer is 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 flexible sample stage support system based on an UHV-tripod. It is possible to care out measurements with beam incident angle from 0 to 88.9 degrees and scan outgoing radiation in almost complete in-plane circle as well to continuously rotate whole system from s- to p- polarization geometry. High spectral purity beam in energy range from 13.5 eV ato 1800 eV is provided by 4-mirorrs High-Order Suppressor System. In additional 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.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 20 / **53**

## Addressing slow drift effects in the SASE3 Soft X-ray Beamline at the European XFEL: performance of an autocollimator-based correction method

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The SASE3 soft X-ray beamline at the European XFEL is equipped with a 100-meter-long-arm monochromator, which delivers to the experiments (SQS, SCS, SXP) pink or monochromatic beam in the photon energy range of 250 eV - 3000 eV. Due to the considerable length of the arm, ensuring stability becomes crucial in the short and long timescale. Currently, the system does not have cooling installed, primarily due to the complexity of that installation and the challenges associated with fabricating the long grating.
The absence of cooling is triggering a slow drift of the system, which is not entirely captured by the encoders and therefore cannot be corrected. Consequently, this drift results in an undesired drift of the photon energy of the delivered monochromatic beam, causing challenges for high-precision experiments. The effect becomes more pronounced when using multiple pulses and high pulse energies, due to the higher heat load.
To address this issue, we have installed an autocollimator that directly observes the grating position from outside the chamber, providing an independent measurement of the drift. In this presentation, we will discuss the performance of this system, present the results obtained from experiments, and outline potential future improvements. While the proposed method offers a straightforward solution for on-site correction of these drifts, it is important to acknowledge certain limitations that need to be taken into account.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 14 / **37**

## Ultrafast Pump-probed Resonant Elastic X-ray Scattering Station Based on Soft X-ray Free Electron Laser in Shanghai

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X-ray Free Electron Laser (XFEL) represents the cutting-edge advancements in light sources, characterized by their exceptional features of ultra-short pulse durations, extraordinarily high pulse peak brightness, and remarkable coherence. These intrinsic properties establish a development for practical implementations in ultrafast X-ray diffraction and scattering techniques. With the successful construction of the Soft X-ray Free Electron Laser facility in Shanghai, we have enabled the establishment of the XFEL-based Resonant Elastic X-ray Scattering (REXS) experimental station, which offers a remarkable platform for investigating and exploring long-range states, such as charge, orbital, and spin states, in strongly correlated systems. Notable examples of such states encompass superconducting phases, microscopic magnetic structures, and charge density waves, among others. Moreover, The REXS station facilitates selective excitation of electronic states within correlated systems by employing infrared pump lasers. Subsequently, the ultra-short pulse duration of the XFEL, reaching the remarkable timescale of 100 femtoseconds, enables precise detection and comprehensive exploration of the ultrafast dynamic processes associated with these states. Thus, this platform provides an ideal opportunity to investigate transient superconductivity, magnetization dynamics, and various other phenomena of scientific interest.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 23 / **58**

## Determination of astigmatism in XFEL sub-10 nm focusing system using speckle patterns from random nanoparticles

**Author:** Atsuki Ito[1]

**Co-authors:** Jumpei Yamada [2]; Yuto Tanaka [1]; Kota Shioi [1]; Ichiro Inoue [3]; Taito Osaka [3]; Gota Yamaguchi [3]; Yuichi Inubushi [4]; Makina Yabashi [3]; Kazuto Yamauchi [1]

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The intense X-ray free-electron laser (XFEL) focused on a single-nanometer scale has facilitated the exploration of new frontiers in X-ray nonlinear physics. We have developed an XFEL sub-10 nm focusing mirror system, based on Wolter III-advanced KB mirror optics, for achieving 10^22 W/cm^2 intensity at SACLA. The focus size has been characterized by ptychography and reached 6.8 × 6.9 nm. However, in the ptychography, the sample has required to be placed at defocus position to avoid radiation damage, making a determination of the low-order wavefront errors difficult. This lead to subtle remaining astigmatism that significantly affects the intensity reduction of the focus.
In this study, we applied speckle interferometry to determine the low-order wavefront errors. When sufficiently small nanoparticles are illuminated by coherent X-ray, distinctive scattering patterns are observed, referred to as the speckle. The randomly distributed nanoparticles provide an inversely proportional relationship between the sizes of the speckle and the focused beam. The experiment was performed at SACLA BL3 with a photon energy of 9.124 keV. As a scattering media, 2-5 nm diameter Pt particles were randomly spread on a 50-μm-thick polyimide film. The nanoparticles were placed near the focus of the sub-10 nm XFEL and speckle patterns were acquired by MPCCD placed 0.7 m downstream from the focus. As a result, we identified remained astigmatism from the difference of the center of speckle size envelopes. By correcting the 3 μm astigmatism, a finely focused sub-10 nm spot corresponding to the intensity of 1.45×10^22 W/cm^2 was achieved.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 7 / **19**

## Wavefront analysis by Shadow raytracing program

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X-ray wavefront provides precise information about optics misalignments, optics figure errors, and beam caustics. The knife edge wavefront sensing method is developed recently at Diamond Light Source and used in the wavefront profile reconstruction of focusing elements such as X-ray mirrors

and lenses [1]. The wavefront profile is reconstructed from the intensity drop in each pixel of an area detector as the knife edge obscures the rays. We have developed a modelling tool for the knife-edge wavefront sensing method in Shadow [2] under the OASYS interface to simulate and analyse the X-ray wavefront and determine its polynomial compositions. The simulation tool was employed in understanding and interpreting the wavefront data obtained from combined optics consisting of the Alvarez X-ray lens [3] and an elliptical mirror. Unique coordination between the adaptive radius of the Alvarez lens and the incident angle of the elliptical mirror was proposed for reducing the defocus and the lowest-order coma aberrations of combined optics and simulated data were verified with measured data. This paper presents the performance of the wavefront analysis tool in Shadow and its further use in designing the wavefront compensation optics and overcoming the optics misalignments.

References:
[1] Adaptable refractive correctors for x-ray optics; D.Laundy, V.Dhamgaye, T.Moxham, & K.Sawhney, Optica 6, 1484 (2019)
[2] OASYS: A software for beamline simulations and synchrotron virtual experiments; M.Sanchez-del Rio, L.Rebuffi, AIP Conf. Proc. 2054, 060081 (2019).
[3] An Alvarez varifocal X-ray lens; V.Dhamgaye, D.Laundy, H.Khosroabadi, T.Moxham, S.Baldock, O.Fox, & K.Sawhney (Submitted for publication).

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 25 / **62**

## How not to become a ghost writer

**Authors:** Analía Fernández Herrero[1]; Nazanin Samadi[2]; Andrey Sokolov[3]; Grzegorz Gwalt[4]; Jana Buchheim[5]; Stefan Rehbein[1]; Anke Teichert[6]; Thomas Krist[6]; Christian David[2]; Frank Siewert[1]

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Accelerator-based photon sources have improved in brilliance, stability, and coherence over the last decades. To transfer those properties to photon-hungry and high-resolution-demanding users and experiments in the VUV-, soft- and tender X-ray photon energy range, high-quality blazed profile gratings are mandatory. In addition, such gratings are of interest e.g. for spectroscopic applications at laboratory sources or as master gratings for the production of replica gratings. Currently, their availability is critical due to technological challenges and limited manufacturing resources. To counterbalance this bottleneck, grey-tone e-beam lithography is been investigated for the production of blazed profile gratings. E-beam lithography (EBL) allows patterning of arbitrary shapes over relatively large areas in a short time. However, in order to achieve a high-quality grating and a stable manufacturing process and precise metrology is essential. We report on the ongoing investigation of blazed profile gratings to track the lithography process and on challenges that EBL poses to structure characterization. Measurements performed by atomic force microscopy as well as at-wavelengths at the Optics Beamline at BESY II will be presented. We focus on the investigation of the imperfections and their causes. Ghosts are additional peaks that appear on the dispersion plane, which ultimately reduce the resolution and performance of the grating. At EBL they are caused by stitching of the fields while writing and reducing its impact on the scattering plane is sought.

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**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 16 / **42**

## MINERVA, a new X-ray facility in operation for the characterization of the NewATHENA Mirror Modules at the ALBA Synchrotron

**Authors:** Dominique Heinis[1]; Antonio Carballedo[1]; Carles Colldelram[1]; Guifré Cuní[1]; Núria Valls Vidal[1]; Alejandro Sánchez[1]; Joan Casas[1]; Josep Nicolàs Roman[1]; Nicolas Barriere[2]; Max Collon[2]; Giuseppe Vacanti[2]; Dieter Skroblin[3]; Levent Cibik[3]; Michael Krumrey[3]; Ivo Ferreira[4]; Marcos Bavdaz[4]

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The ALBA Synchrotron (Barcelona, Spain) is commissioning MINERVA a new X-ray beamline designed to support the development of the NewATHENA mission (Advanced Telescope for High Energy Astrophysics), which mission is to observe and study energetic objects in space (accretion disk around black holes, large-scale structure, etc…). MINERVA is dedicated to assemble stacks manufactured by cosine into mirror modules (MM), building blocks of the NewATHENA optics. The new beamline is originally based on the monochromatic pencil beam XPBF 2.0 at the Physikalisch-Technische Bundesanstalt (PTB at BESSY II) but also includes additional features on the scanning scheme to improve the characterization time of each MM produced. Interoperability between MINERVA and XPBF 2.0 is nonetheless preserved to strengthen the mass production of the MMs and characterize their performance. MINERVA is funded by the European Space Agency (ESA) and the Spanish Ministry of Science and Innovation and will enter in operation by autumn 2023.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 32 / **75**

## X-ray lens aberrations retrieved by deep learning from several beam intensity images

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In this study, we explore the capability of a Convolutional Neural Network (CNN) trained on synthetic data to accurately estimate the profile error in an x-ray lens. The CNN is able to retrieve the profile expresses as a list of Zernike coefficients from a series of intensity distributions simulated (or measured) at several positions. This approach offers a promising method for profile error assessment in x-ray lenses without wave-front sensor measurements, potentially reducing the need for time-consuming and costly characterization techniques. The results highlight the potential of using machine learning algorithms trained on synthetic data as a valuable tool in the field of x-ray optics for efficient and accurate error analysis.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 21 / **55**

## Optical metrology for bender and adaptive optics optimization and characterization

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We present some of the methods, procedures and analysis tools used at ALBA to characterize mirror benders, and other adaptive optics mirror systems. The tests we describe combine measurements of different instruments, including our NOM and our stitching interferometry platform, with a number of optimization routines based on the deformation model of the mirror within the bender.
The characterization of an adaptive optics system has three distinct purposes: Checking that the system meets the optical requirements, Optimizing some mechanical adjustments, and providing information for the operation of the bender at the beamline. Besides this, metrology often reveal features of the opto-mechanical system which are useful information for continuous improvements.
The characterization of an adaptive optics system is very time consuming, since one must explore the configuration space of the system under test with sufficient surface measurements. At the same time, the continuously-improving quality of optical surfaces requires that the measurements are taken with sufficient averaging, redundancy and stabilization. To be effective in this aspect, we have optimized our metrology instruments to be fast and still accurate.
A feature of the presented procedures is the analysis of the obtained surface measurements using the deformation model of the system. This analysis allows minimizing the number of required measurements for a complete characterization, and allow identifying the nature of some of the observed deviations.
We describe the procedures and provide results based on measurements on more than 50 systems, with a wide range of optical lengths, figures and surface qualities.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 40 / **95**

## Wavefront sensing using Talbot effect for Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE)

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The SHINE aims at generating X-rays between 0.4 and 25 keV at rates up to 1MHz for 10 experimental stations. Wavefront sensing is important for aligning X-ray instruments, reconstructing the field at the plane of interest and conducting scientific experimental analysis. Based on the a Talbot interferometer at hard x-rays using a π-phase shift checkerboard grating, the wavefront accuracy sensitivity for WFS is better than λ/50 at the wavelength of 0.177nm. The soft X-ray WFS covers energy from 200 eV to 2500 eV by changing the grating plane position with different grating periods. The grating plane motion region is approximately 0.5 m. The accuracy sensitivity in the soft X-rays region using a dot array grating is better than λ/50.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 39 / **94**

## Photon diagnosis for Shanghai high repetition rate XFEL and extreme light facility (SHINE)

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SHINE is China's first Hard X-ray FEL and now is under construction. This facility has an 8-GeV CW superconducting linac accelerator. Using 3 phase-I undulator lines, the SHINE aims at generating X-rays between 0.4 and 25 keV at rates up to 1MHz for 10 experimental stations. We have finished the design concepts of photon diagnosis for different diagnosis purposes, including Photon Arrival Time Monitor (PAM), THz Streaking Pulse Length Monitor (PLM), X-ray pulse Energy and Position Monitor (EPM), Beam Position and Intensity Monitor (BPIM), Beam Loss Monitor (BLM), Soft X-ray Energy Resolution Measurement (SERM), Photoelectron Spectrometer (PES), Single Pulse Spectrometer (SPS), Hard X-ray Energy Resolution Measurement (HERM), Wavefront Sensor (WFS) and X-ray Imager (IMAGER). The major parameters as follows: the PAM sensitivity is better than 15 fs (rms), the PLM sensitivity is better than 20 fs (rms) when the pulse jitter is less than 40 fs (rms), the pulse energy and position measurement precisions for the EPM both approaches are better than 10%, the BPIM sensitivity is better than the 10% of beam size. The BLM response time is better than 10 us. The energy resolving power of SERM is better than 10-4, the SPS is 0.1 eV and the HERM is 1e-4 (⊠E/E), respectively. The wavefront accuracy sensitivity for WFS is better than λ/50 at the wavelength of 0.177nm, and the sensitivity is better than λ/50 at the wavelengths of 0.6nm and 3nm.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 17 / **47**

## X-ray Optical Delay Line at European XFEL

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Free-electron lasers (FELs) are the most advanced class of light sources, enabling a wide range of innovative experiments such as two-color pump-probe spectroscopy. For this experiment, it is required to control the temporal delay between two X-ray pulses. For this purpose, the soft X-ray Self-Amplified Spontaneous Emission (SASE3) beamline at the European XFEL was equipped with a magnetic chicane (MC) that delays the electron beam and therefore the corresponding photon sources. Using an optical delay line (ODL) would allow the implementation of two pulses crossed with zero-time as well as negative delay. The ODL consists of a double optics chicane using 4 flat silicon mirrors coated with 50 nm B4C that delays the x-ray beam.
We present a brief description of ODL and review its specification. The mirror surface was measured and wavefront propagation software was used to examine the effects of the mirror surface on the beam spot. The study of the damage threshold was also an important challenge that we examined.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 22 / **56**

## Updates on the optical design and initial characterization activity of the MOST beamline in view of Elettra 2.0

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We report on the latest developments regarding the design and initial operations of the Molecular and Optical Science Technology beamline (MOST), the new beamline specifically devoted to serve the atomic and molecular physics community at Elettra 2.0.
Two new insertion devices (IDs) have recently been installed, adopting an in-line configuration; one covers the low-to-intermediate photon energy range (8-300 eV), a second one the intermediate-to-high photon energy range (80-3000 eV). Both undulators provide full polarization control of the emitted radiation.
The optical layout will be presented, as well as future prospects for the beamline. A central main line will allow for the intermediate-to-high energy range, and it will be complemented by two branches, one for low-energy equipped with a normal incidence monochromator (NIM, currently at the Circular Polarization beamline of Elettra) and a second for the intermediate XUV range equipped with the spherical grating monochromator (SGM, currently at the GasPhase beamline at Elettra). The main line will use five optical elements implementing a spherical mirror and a novel variable line spacing grating monochromator, to deliver a beam parallel to the orbital plane.
We are currently carrying out preliminary measurement of the performances of the two new undulators exploiting the old CiPo beamline layout. Later this year we plan to undertake polarimetric characterisation of the radiation, too.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 34 / **77**

## Stitching Interferometer at PAPS

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We have established a new optical metrology laboratory belonging to the Platform of Advanced Photon Source (PAPS) technology R&D project located in Beijing. PAPS provides strong support for construction, testing and technology R&D for the High Energy Photon Source (HEPS). The optical metrology laboratory has proposed and developed a variety of optical metrology technologies with high accuracy to support the construction of beamlines in HEPS. In this optical metrology laboratory, we have independently developed the scanning and stitching interferometer platform system with high stability and high-accuracy metrology performance. We proposed and verified two methods based on angular measurement 7 years ago. Recently, based on this new stitching system at PAPS, another novel stitching method has been proposed and verified. The accuracy of two-dimensional surface profile measurement is as high as 0.1~0.3nm RMS.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 15 / **38**

## Linear Error Elimination Procedure for 2D stitching metrology

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We present a new 2D stitching method that effectively removes the systematic errors introduced by the reference flat, as well as any other additive measurement error constant across the sub-aperture measurements. This method, referred to as Linear Error Elimination Procedure (LEEP), can provide the two-dimensional error map for a wide range of X-Ray mirror lengths and figures, with sub-nanometer accuracy and lateral resolution well below the millimeter. We discuss the main features of LEEP, including the conditions required for the measurement routine. A main condition is that the scan trajectory along the surface under test must be two-dimensional, i.e. not a straight line, in order to allow for 2D reconstruction. In addition, it must have a non-constant stitching step, to avoid periodic errors in the reconstructed surface. We will prove that, in order to determine the curvature and twist of the surface under test, one can track the orientation of the interferometer at every step. We provide experimental results that show the effective error suppression by means of the proposed method, applied to several mirrors, and that allow estimating the systematic errors with a repeatability of 40 picometers.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 30 / **72**

## LEAPS and LEAPS-INNOV - a status report

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Established in 2017, LEAPS is the League of European Accelerator-based Photon Sources, a strategic consortium initiated by the Directors of the Synchrotron Radiation and Free Electron Laser (FEL) user facilities in Europe. Its primary goal is to actively and constructively ensure and promote the quality and impact of the fundamental, applied and industrial research carried out at their respective facility to the greater benefit of European science and society.
The LEAPS-INNOV pilot project contributes to solving key technological challenges for the light sources, over 50 facilities in Europe and worldwide. It is kick-starting the implementation of the LEAPS Technology Roadmap and, at the same time, enhances partnership with industry through open innovation by offering joint technological developments and advanced research capabilities for industry as collaborators, suppliers and users.
Six technology work packages (WP) form the heart of LEAPS-INNOV, based on their potential for co-innovation and their ability to enhance European leadership. They integrate 50-some companies, are supported by an industry networking WP and complemented by pilot activities towards co-creation with the Horizon Europe clusters. In the context of open innovation, LEAPS-INNOV focusses on new approaches for partnership between industry and the photon science community, with the goal of accumulating a strategy for long-term industry engagement for LEAPS in Europe.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 2 / **6**

## Soft X-ray wavefront sensing at an ellipsoidal mirror in the lab

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We report on a fast and reliable method for wavefront sensing in the soft X-ray domain, developed for the characterization of rotationally symmetric optical elements, like an ellipsoidal mirror shell. In our laboratory setup, the mirror sample is irradiated by an electron-excited (4.4 keV), micron-sized ($\approx 2\,\mu$m) fluorescence source (Carbon $K_\alpha$, 277 eV). The near-focal, 3-D intensity distribution $I(\vec{r})$ is recorded by a CCD camera ($512 \times 512$ pixels à $13.5\,\mu$m) at multiple positions along the optical axis, displaced by $(20-25)\,\%$ from the focus. The transport-of-intensity equation is interpreted in a geometrical sense from plane to plane and implemented as a ray tracing code in Mathematica$^{TM}$ / Optica$^{TM}$, to retrieve the phase $\phi(\vec{r})$ from the radial intensity gradient on a sub-pixel scale. 15

intra-focal CCD image pairs are evaluated in this way and averaged to an annular 2-D map of the wavefront error. In units of the test wavelength (C $K_\alpha$), we find $\sigma = \pm 47\,\lambda$ (rms) and a P-V of $\pm 118\,\lambda$. The wavefront can be used in a threefold purpose: First, the focus is predicted with a result of $48.3\,\mu$m (rms), in reasonable agreement with the direct experimental observation of $55.3\,\mu$m (FWHM). Secondly, the combined figure and alignment error of the ellipsoid is reconstructed – and again, the statistical mean of $\pm 9.4$ arcsec (rms) roughly coincides with independent estimations from the measured focal intensity distribution ($\pm 11.8$ arcsec). At last, a diffractive wavefront corrector may be computed and fabricated, for wavelength-dispersive spectroscopy with high efficiency and optimized resolution.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 36 / **79**

## The Development of Wavefront Metrology Technique at Beijing Synchrotron Radiation Facility (BSRF)

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In this work, we describe an innovative wavefront metrology technique at the first-generation synchrotron radiation source BSRF named Double Edges Scan (DES) wavefront metrology technique. It can achieve high precision measurement of the optical elements used in the fourth-generation synchrotron radiation source. The approach we proposed can resolve several vital problems of the first-generation synchrotron radiation source, including inferior lateral coherence, poor stability, and distortion of incident wavefront. As the lateral coherence has been improved by an order of magnitude, the monochromator crystals used in the fourth-generation synchrotron radiation source need to maintain the wavefront over a large range. By means of the DES wavefront metrology technique, we successfully measured diffraction surface slop error with a precision better than 22.5 nrad (rms). The lateral resolution was 50 microns on the crystal surface. The result proved that we have already realized diffraction limit level wavefront metrology. Currently, the DES measurement has been regarded as an important feedback in the next generation crystal fabrication process.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 6 / **18**

## MooNpics –European metrology round-robin collaboration observing different aspects on high-quality X-Ray mirrors

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**Co-authors:** Idoia Freijo Martin [1]; Maurizio Vannoni [1]; Elke Ploenjes [2]; Harald Sinn [1]

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We present here a summary of the European metrology round-robin project MooNpics - Metrology On One-Nanometre-Precise Optics. Established in 2017, this collaboration between ten European light sources and two X-ray optic manufacturers aimed to improve the quality and availability of high-precision X-ray mirrors. Several work packages were created to focus on the metrology and analysis methods used in the European light sources'metrology labs as well as on software and methods for focal spot reconstruction and fast mirror alignment. Different aspects of X-ray mirror production and metrology were observed. For this purpose, three high-quality X-Ray mirrors with different shapes and surface structures were investigated in a European-wide round-robin experiment over four years. Mirrors with very different parameters were chosen to meet the large variety of metrology instruments used in the facilities and to explore different aspects of height and slope error measurements. One of the round-robin mirrors, a 950 mm long plane mirror could be used to calibrate instruments and to identify errors due to its very high flatness and extremely good surface quality. One strongly curved spherical and one elliptical mirror served these purposes with their strong shapes and imprinted structures. Results of the plane mirror will be presented here.
With the large amount of metrology data collected, a cross-calibration of instruments and methods used in the facilities was made possible. In addition, it enabled the metrology labs to develop new methods, to create standards and to improve deterministic polishing methods in close collaboration with our industrial partners.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 28 / **68**

## Single shot tender X-ray spectral measurements via the 3rd harmonic using bent crystals

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The tender X-ray region provides access to various absorption edges, such as sulfur, chlorine, and silicon, which are of particular interest for developing organic semiconductors. Direct measurement of the X-ray spectrum in the energy region between 2.5 –4.0 keV is challenging and typically suffers from poorer energy resolution from ruled gratings or lower efficiency from scattering-based approaches. Presented here is the modification of a beamline spectrometer at SwissFEL[1], using bent silicon crystals, to measure the single shot spectrum of the 3rd harmonic FEL emission produced in operation at 2.5 keV.
Using a 2D CMOS detector, the transverse mode structure of the 3rd harmonic emission is discussed. The measured spectral bandwidth with the 3rd harmonic is compared to the bandwidth of the fundamental of 2.5 keV when measured via monochromator scanning.

[1] J. Rehanek et al 2017 JINST 12 P05024

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 13 / **35**

## New wavefront sensor for renewed differential pumping unit at FLASH2 beamlines

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In the past years, DESY developed in collaboration with the Institut für Nanophotonik Göttingen e.V. several Hartmann wavefront sensors (WFS) for FEL focus characterization and optics alignment in the soft x-ray spectral range, approx. 5 - 40 nm. In principle, a WFS is used in the direct beam at an appropriate position behind the focusing system which is to be characterized. Practically, at FLASH this straight direction is often blocked by an experimental setup, thus prohibiting fast focal spot characterization and in-situ adjustment during the experiments. For this reason and as a first improvement, the FEL beam at beamline FL24 can be deflected at 90° just before the experiment and guided to a WFS located in a distance of about 3 m behind the focus position.
As this concept is very space consuming, a new differential pumping unit with a permanently integrated WFS located directly after the K-B focusing optics system, was developed. This newly designed WFS is located in front of the nominal beamline focus position under an angle of 45° to the beam. The beam is directed to the WFS by means of a Ni mirror, which is adjustable in 6 degrees of freedom. This deflecting mirror can be moved in very fast for optics alignment and focus optimization. Although not in-situ this allows one to efficiently prepare the beamline focus for user experiments.

This fast and space-saving method will be presented and first results will be shown. A new and compact WFS under development will be presented.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 11 / **33**

## Development of Ion beam figuring (IBF) system at Diamond Light Source

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Modern synchrotron and free-electron laser sources demand ultra-high-quality x-ray mirrors for many challenging x-ray applications, including nano focusing, preserving coherence, and extreme energy resolution. As a deterministic polishing technique, Ion Beam Figuring (IBF) is often used to produce these mirrors with the required precision. Recently, an in-house IBF system has been developed and commissioned at Diamond Light Source [1]. It has a large diameter DC gridded ion source, 4-axis motion stages, and an imaging system for alignment. In addition, a laser Speckle Angular Metrology (SAM) instrument [2] has been incorporated to monitor progress during each IBF iteration, thereby reducing the overall time required. We describe developmental details of our position–velocity–time (PVT) algorithm, including the fiducialization procedure for precise alignment with ex-situ metrology data [3]. Preliminary figuring results will be presented for 1D and 2D corrections, with accuracy on the sub-nanometres level.

Reference:
1. M. Hand, S. G. Alcock, M. Hillman, R. Littlewood, S. Moriconi, H. Wang, K. Sawhney, Advances in Metrology for X-Ray and EUV Optics VIII. Vol. 11109. SPIE, 2019.
2. H. Wang, S. Moriconi, and K. Sawhney, Light: Science & Applications, 10, 195 (2021).
3. M. B. Da Silva, S. G. Alcock, I. T. Nistea, and K. Sawhney, Optics and Lasers in Engineering 161, 107192 (2023).

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 12 / **34**

## Recent developments in Speckle Angular Metrology (SAM) for X-ray mirrors at Diamond Light Source

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High precision and accurate metrology plays a pivotal role in the characterization and improvement of X-ray mirrors for synchrotron and X-ray Free Electron Laser (FEL) sources. To meet the stringent requirements of nano-precision metrology for demanding X-ray mirrors, a novel metrology instrument called Speckle Angular Metrology (SAM) has been recently developed at Diamond Light Source [1]. We present the latest experimental results in the form of comparison between measurements performed using SAM, the Diamond- Nanometre Optical Metrology instrument (NOM) [2], and a Fizeau Interferometer [3]. The results are given for three challenging X-ray Mirrors: a 9.3m spherical mirror (also measured by various facilities around Europe as part of the MOONPICS collaboration); a flat grating blank with a radius of curvature > 16 km, and a super-polished JTEC cylindrical, low-reflectivity glass substrate mirror with a radius of ~ 116 m. The study considers systematic errors and assesses the advantages and limitations of SAM. The SAM will extend the capability of the existing metrology instruments and provide an alternative and complementary metrology means for future X-ray mirrors.

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2. Alcock,S.G.et al. The Diamond-NOM: A non-contact profiler capable of characterizing optical figure error with sub-nanometre repeatability. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. 616, 224–228 (2010).

3. da Silva,M.B.,Alcock,S.G.,Nistea,I.T.& Sawhney,K. A Fizeau interferometry stitching system to characterize X-ray mirrors with sub-nanometre errors. Opt. Lasers Eng. 161, 107192 (2023).

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 1 / **5**

## An efficient polycapillary beam collimator for soft X-rays

**Authors:** Christoph Braig[1]; Heike Löchel[2]; Jürgen Probst[2]; Semfira Bjeoumikhova[3]; Christian Seifert[1]

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A halved polycapillary lens (PCL) may be used as an efficient collimator in the soft X-ray domain. We present recent results of laboratory-based experiments with a micron-sized fluorescence source (Carbon $K_\alpha$ line, 277 eV). Its emission is collected by the PCL and converted into an almost parallel beam, with a residual angular divergence less than 7 mrad. As evaluated by a CCD camera at six positions along the maximal propagation distance of 0.9 m, the beam diameter spreads to no more than $(5.6 \pm 0.2)$ mm (FWHM). The measured 3-D beam profile is reproduced by simulations approximately, applying a newly developed ray tracing code witten in the Mathematica$^{TM}$ / Optica$^{TM}$ language. It turns out that both the experimental and the theoretical intensity distribution can be well described by the same, universal fit model. We guess that our findings may open the door to compact and versatile, table-top metrology of optical components in the soft X-ray range — with high efficiency: to verify the gain provided by the PCL, the photon flux through a narrow slit ($\sim$ 1 mm) is recorded in a variable distance of several $10^{-1}$ m from the collimator's exit aperture. In comparison to unconfined radiation, the PCL yields an up to $90\times$ enhanced count rate on the detector. In this way, relatively weak laboratory X-ray sources, equipped with customized polycapillary lenses, might enable quick and flexible in-house testing of the reflectivity of mirrors, or the diffraction efficieny of transmission and reflection zone plates in the future, for instance.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 35 / **78**

## Zooming optics in HEPS beamline design

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With the reduction of the emittance of electron bunches in new generation synchrotron radiation sources, the generated X-ray beam is beneficial for applications with high spatial resolution, coherence, and flux, bringing opportunities for the design of multifunctional beamlines. Considering the partial coherent characteristics of the light field, the achievement of experiments requiring flux and coherence on the same beamline is important research. This paper studies the ZOOMing, or two-stage focusing configuration, aiming to control the coherence and the spatial resolution. The high-coherent field is obtained by limiting the field through a slit, The relationship between the coherence or flux and the range of the field is investigated to meet experimental requirements. We also present the zoom beamline design method based on geometric optics, including cascade focusing and secondary focusing. Taking into account the change in coherence, cases of both diffraction-limited and system-limited focusing are considered separately. Finally, the numerical experiments by wave propagation are also carried out to verify the design.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 26 / **66**

## PyLOSt –a software package for sub-aperture stitching and data analysis of surface metrology data of reflective X-ray optics

**Authors:** Amparo Vivo[1]; Bharath Reddy Adapa[2]; Francois Perrin[2]; Ray Barrett[2]

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The apertures of X-ray mirrors are often larger than the measurement apertures of common optical metrology instruments. To overcome this limitation, sub-aperture stitching is an increasingly used technique for X-ray mirror surface metrology. In this approach, the full surface is measured in a series of highly overlapped sub-apertures which are subsequently recombined numerically to recover the overall surface topography. The fidelity of the stitched data to the measured surface can be strongly influenced by the stitching algorithms which are employed. Although some commercial software is available to perform the numerical reconstruction of such surfaces, the algorithms employed are rarely documented and are inflexible for the implementation of new calculation strategies. PyLOSt (Python Large-Optic Stitching) is an open-source software tool designed to perform stitching and data analysis of surface metrology data. The standard software release includes several algorithms for stitching and performing routine operations such as surface fitting and extraction of statistical parameters. The code framework is also designed to allow the straightforward integration of new calculation tools for surface reconstruction and analysis. PyLOSt has been extended to run in the Orange data analysis suite which provides an intuitive interface to the data pre-processing, stitching and analysis tools. In this presentation we will showcase the current code features including global optimisation algorithms permitting the reduction of stitching errors.
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**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 24 / **61**

## Testing some limits of long trace profilers using Zemax simulations.

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Acquiring direct images of distant exoplanets or focusing X-rays requires high performance optics. Laboratories and optics suppliers are therefore actively seeking to improve polishing methods and metrology. For slope-error evaluation, many accelerator-based light sources use Long Trace Profilers (LTP) whose measurement accuracy can reach 80 nrad in a relatively short period of 6 hours, and which typically have a better reproducibility in radius determination for highly curved mirrors than interferometers with stitching. The ESRF implementation of this measuring device, the result of over 35 years of development, has been modelled using Zemax from Optic Studio. This ray-tracing code offers the possibility to configure the simulations using Python code. This provides a convenient means to explore the potential influence of multiple parameters of the LTP (e.g. alignment, optical aberrations) upon the measurement accuracy. This can guide and complement experiments with the instrument itself. This study is the beginning of a theoretical approach, which aims to improve LTPs, and identify the key parameters in slope profiler accuracy and repeatability. For example, in the ESRF LTP design, errors in positioning the sensor from the Fourier Transform (FT) lens focal plane have been predicted to induce repeatable errors. However, slight misorientation of this sensor, or the (FT) lens, has no impact compared with the lowest measurement noise. Field curvature can also be neglected, but pixel size can have an importance depending on interpolation algorithms. The impact of calibration in different configurations is also discussed.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no

**Poster Session** - Board: 19 / **52**

## A wavefront propagation study of the effect of apertures in laser transports on the beam profile achieved with relay imaging illuminated circular masks

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Relay imaging an illuminated circular mask is a common way of projecting a laser beam onto the photocathode in an RF photo-injector whilst generating a round laser beam spot with a sharp-edged profile. The mask is illuminated with the laser beam and an optical system images the mask onto the cathode. Geometrical optics predicts the beam on the cathode will be an exact replica of the intensity profile at the aperture. However, in physical optics, generating a sharp-edged profile requires an infinite Fourier series of spatial harmonics. The Gibb's phenomenon shows that truncating the Fourier series at any point, for example with the finite aperture of the transport system, results in a peak at the edge and ripples over the beam profile.

This work explores this effect using a wavefront propagation code. We show that the finite aperture of the transport can have a marked effect on the final image even when an aperture truncates the

beam at very low intensity. Small beams at the cathode require correspondingly larger apertures in the transport. This has significant implications when a small beam size is required at the cathode because the apertures in RF photo-injector guns can be very restrictive and asymmetric with respect to the laser beam centre. Furthermore, when a 'virtual cathode' is used to monitor the laser beam profile, the beam profile at the actual cathode may be significantly different to that at the virtual cathode unless the path to the virtual cathode has identical apertures.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

yes

**Poster Session** - Board: 8 / **26**

## On the design of monochromators for high-resolution inelestic x-ray scattering

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Traditional back-scattering high resolution monochromators for synchrotron light sources can't inadequately address the unique thermal problems of XFEL beam, especially seeded X-rays. Alternatively, LCLS-II-HE will support a novel in-line instrumentation design for ultra-high-resolution inelastic x-ray scattering based on perfect silicon crystals. The initial design of the monochromators applies zig-zag 4-bounce optical traces, before evolving into double-crystal monochromators (DCM). However, even DCMs can't meet the stability requirement of the system. In order to meet the stability and minimize thermal induced distortions, the final design has been settled to double channel-cut crystal monochromators (DCCM). Asymmetrically cut crystals are intentional designed to reduce the thermal intensity by spreading the beam over a larger surface areas. In this article, the reasoning processes of the design evolution and the final implementation of the monochromator designs will also be presented.

**Journal of Synchrotron Radiation Special Issue: will you submit your contribution?**:

no