High Precision X-Ray Measurements 2025

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Book of Abstracts

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Instrumentation / 2

Direct pre-amplifier sampling ADC for high- count rate and high-resolution X-ray spectroscopy

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Direct pre-amplifier sampling ADC for high- count rate and high resolution X-ray spectroscopy
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3 CAEN SpA, Viareggio, Italy Abstract**
This study introduces a novel technique for digital signal processing from X-ray detectors, such as silicon drift detectors, aimed at supporting high rates while maintaining excellent resolution.
Traditional high-rate detectors for X-ray or gamma applications, connected to transistor reset preamplifiers, face challenges in signal acquisition due to the large voltage ramp produced, which greatly exceeds the amplitude of the signal of interest. To address this, we utilized a 20-bit SAR ADC capable of sampling the signal directly from the preamplifier with a dynamic range of 1 to 1 million, allowing effective capture even with the presence of a voltage ramp.
We designed a system using four ADCs in interleaving mode to achieve a combined sampling rate of 160 Msps. The readout and control logic were managed by a Zynq SoC, interfacing with the ADCs. The firmware developed includes phase and gain correction for interleaving ADC, trapezoidal filter and readout PC interface logic.
Preliminary measurements were conducted with the Ardesia detector at the Polytechnic University of Milan. The tests, although initial, have shown that the resolution achieved surpasses that of traditional methods using analog reshaping. We performed measurements at both low and medium rates, achieving an optimal resolution (FWHM) of 128 eV at a peaking time of 2µs. A faster peaking time configuration tested for reduced dead time yielded a resolution of 140 eV at 1 Mcps.
These findings highlight the potential of our digital processing approach, which could offer improved resolution and efficiency in X-ray detection systems, especially beneficial for high-count rate applications in scientific environments such as synchrotron facilities.

References

[1] Evaluation of the Maximum Throughput of ARDESIA-16 with Different Digital Pulse Processors, B.
Pedretti, Conference paper NSS-MIC 2023
[2] Digital synthesis of pulse shapes in real time for high resolution radiation spectroscopy. 1.Jordanov, V. T.
& Knoll, G. F. Nucl Instruments Methods Phys Res Sect Accel Spectrometers Detect Assoc Equip 345, 337–345
[3] G. Utica, et al. "ARDESIA-16: a 16-channel SDD-based spectrometer for energy dispersive X-ray fluorescence spectroscopy,"Journal of Instrumentation, vol. 16, no. 07, p. P07057, 2021.

X-ray Applications / 3

Modeling x-ray spectrometers employing curved crystal optics

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Rowland circle-based and von Hamos spectrometers are the two most popular types of x-ray emission spectrometers. From the application point of view, there are two main categories of acquisition: (i) high energy resolution fluorescence detected x-ray absorption spectroscopy (HERFD XAS) at a constant emission energy and (ii) x-ray emission spectroscopy (XES) at a constant excitation energy, and a 2D cross product of the two categories, usually called RIXS or RXES. In this talk, I present the two spectrometer types and consider their suitability for the two acquisition categories.

Next, I present our x-ray modelling tool *xrt*, capable of modelling synchrotron sources, complete beamlines and particular x-ray instruments. *xrt* also includes a GUI for building a beamline, defining output plots and setting calculation job parameters. *xrt* also has another GUI that renders optical elements and rays in colorful 3D scenes. We have recently added to *xrt* quick and accurate calculations of bent crystals, making the modelling of x-ray emission spectrometers more realistic in energy resolution and flux.

I demonstrate the modelling capabilities of *xrt* applied to a few spectrometer designs. I discuss in greater detail the example of our Johansson spectrometer (a Rowland circle type) built at the Balder beamline at MAX IV that uses a 2D pixelated detector. I compare the measured acceptance band with the calculated one at various angles and diffraction orders. The measured emission maps exhibit a few surprising features that I explain by the Borrmann effect –anomalous transmission through thin crystals. Finally, I demonstrate our analysis pipeline of XES data with partial on-the-fly data reduction.

Beamlines and Facilities / **4**

Photon Science at EuPRAXIA@SPARC LAB: Free Electron Laser Biological Applications

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The EuPRAXIA project is a European initiative focused on developing groundbreaking, ultra-compact accelerator research infrastructures based on innovative plasma acceleration concepts. The EuPRAXIA@SPARC LAB facility, hosted by the Italian National Institute for Nuclear Physics at the Frascati National Laboratory, will be the first operating Free Electron Laser (FEL) facility within the EuPRAXIA framework. It will utilize an accelerator module driven by an electron bunch to generate ultra-short photon pulses in the soft X-ray region.
These photons will be delivered to the AQUA endstation, whose wavelength falls within the "water window", making it ideally suited for coherent imaging and ion spectroscopy on biological samples at room temperature in a fully hydrated environment. This talk describes the AQUA endstation and demonstrates its potential for coherent diffraction imaging and Coulomb explosion imaging experiments on biological samples.

X-ray Applications / **5**

Experimental study of PET with polarimetric capability

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We have developed, assembled and tested a novel device for Positron Emission Tomography (PET) capable of measuring polarization correlations of annihilation quanta. PET is know as an important medical imaging modality with applications in oncology, neurology and cardiology diagnostics. PET relies on detection of a pair of gamma rays created after positron annihilation in tissue. These annihilation quanta have opposite momenta, energies of 511 keV and orthogonal polarizations. The conventional PET systems have not been utilizing this last property so far, mostly due to lack of cost-efficient polarimeters compatible with PET technology. We developed and tested single-layer Compton polarimeters comprising scintillator matrices read out on one end by the matching silicon photomultipliers and we demonstrated that the polarization correlation can be measured with such devices. In this work we present the experimental study of the PET system based on such polarimeters and its performance with sources of clinically relevant activities.

Detectors and Detection Techniques / 6

Characterisation of MÖNCH 0.5, a 25 µm pitch prototype charge-integrating hybrid pixel detector

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MÖNCH is a charge-integrating hybrid pixel detector readout ASIC with 25 µm pitch, currently in the advanced prototyping phase.The small pixel pitch offers excellent native spatial resolution performance which has been demonstrated with several applications such as, full-field fluorescence imaging, computed tomography, and ptychography. With the combination of low noise and charge sharing effects, interpolation algorithms allow spatial resolution enhancements by assigning the signal into virtual subpixels. This improvement can be of prime importance for several applications such as X-ray emission spectroscopy, full-field transmission X-ray microscopy, and resonant inelastic X-ray scattering. The interpolation technique has not only been demonstrated with standard silicon sensors but also with low-gain avalanche diodes (LGADs) and high-Z sensors, making interpolation with MÖNCH suitable for photon energies ranging from 500 eV to 60 keV.

Current developments are oriented towards providing a full-scale detector system which requires the design of a fast (2 kHz), large-area (2.56 × 1.92 cm^2; 1024 × 768 pixels), at least one-side buttable, and low-noise (< 80 e^- at 500 µs exposure time at room temperature) readout ASIC. The most recent prototype, MÖNCH 0.5, has been designed to explore the feasibility of satisfying all of these aspects. The readout ASIC features an active area of 160 × 150 pixels split into 6 different designs, with one specifically focusing on reducing static power dissipation. A newly designed analogue readout

chain has also been implemented to confirm the ability to read out the full-scale chip at the expected rates.

The first results of MÖNCH 0.5 show that the implemented changes should satisfy the requirements. Noise levels of 53 e^- at 500 µs exposure time have been achieved in the low-power pixel variant. Also, a pixel design with maximised gain demonstrated under 20 e^- noise at 10 µs exposure time. The results of the pixel and analogue chain characterisations will inform the design of the full-scale readout chip with the ultimate goal of providing detector modules by 2027.

X-ray Applications / **7**

SHADOW4: Advanced Ray-Tracing for the Design and Simulation of X-Ray Optical Systems

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"SHADOW" is a ray-tracing program originally developed by Franco Cerrina, widely adopted for the simulation of synchrotron radiation beamlines. Over more than four decades and across three generations of synchrotron sources, SHADOW has played a key role in the design and upgrade of numerous beamlines.

This work presents a comprehensive overhaul of SHADOW, resulting in the development of SHADOW4: a modern, object-oriented implementation written entirely in Python. The core package, shadow4, is integrated into the OASYS environment, providing a performant, intuitive, and workflow-based graphical interface.

Several application examples in X-ray optics are presented, including systems employing mirrors, multilayers, and crystals. In addition, the architecture of the software and its main dependencies are briefly described.

SHADOW4 is built upon modern, standard software engineering principles, facilitating collaboration and contributions from a broader community of developers. This foundation supports the creation of new features, tutorials, and documentation. Thanks to Python's cross-platform compatibility, SHADOW4 can be seamlessly deployed on Windows, macOS, and Linux systems.

Using the OASYS interface, SHADOW4 scripts are automatically generated, offering users a high degree of customization and control over their simulations. Advanced functionalities such as parameter scans and the development of digital twins enable integration with AI-driven workflows and optimization tools.

This project is presented with a dual aim: to engage potential users who can benefit from SHADOW4's powerful simulation capabilities, and to invite contributors to extend the platform by developing tools tailored to their specific applications. Such contributions have the potential to enrich the ecosystem and benefit the broader scientific community.

Beamlines and Facilities / **8**

New opportunities and challenges of a micro-XRF/XAS beamline in Elettra 2.0

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After over thirty years of serving the international research community, the Elettra synchrotron light source is undergoing a major upgrade. Its successor, Elettra 2.0, will feature a cutting-edge, diffraction-limited storage ring, designed to significantly enhance spatial, energy, and temporal resolution across imaging, scattering, and spectroscopic applications. As part of the upgrade, a new hard X-ray micro-X-ray fluorescence (μ-XRF) beamline—equipped with an in-vacuum undulator—will replace the existing XRF beamline.
This presentation outlines the current development status of the new μ-XRF beamline and its end-station design, highlighting expected capabilities and anticipated challenges. Positioned downstream of the undulator, the beamline will employ Kirkpatrick–Baez mirrors in a secondary source configuration to achieve a tunable micrometric probe, ranging from 50 μm × 50 μm to 1 μm × 1 μm (H × V). This capability will enable high-resolution studies of material heterogeneity.
The μ-XRF beamline is conceived as a versatile micro-analytical platform, combining 2D/3D XRF mapping with micro-X-ray absorption spectroscopy (μ-XAS). Its flexible geometry—departing from the standard 45°/45° configuration—will support additional XRF-based techniques. Leveraging the high photon flux from the in-vacuum undulator, the beamline will enable fast, continuous ("on-the-fly") acquisition for both XRF mapping and XAS energy scans, with synchronized undulator gap adjustments. To manage the resulting data volume, new analysis pipelines will be essential to accommodate the significantly increased acquisition rates.

Detectors and Detection Techniques / 9

Development and application of flexible a-Si:H detectors for advanced X-ray beam characterization

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The HASPIDE project, funded by INFN, focuses on the development of hydrogenated amorphous silicon (a-Si:H) detectors for applications in X-ray dosimetry. These devices are fabricated on thin Kapton substrates, combining good mechanical flexibility with promising dosimetric performance. The control over the deposition process and the integration on flexible supports make this technology particularly suitable for in vivo and superficial dose measurements.
In this contribution, I will present an overview of the detector design and the latest results obtained from characterization campaigns carried out with different X-ray sources —including clinical beams, laboratory setups, and synchrotron radiation. Measurements have focused on evaluating dose linearity, sensitivity, and response stability under various irradiation conditions, with particular attention to applications such as microbeam radiation therapy (MRT) and standard radiotherapy settings.
The preliminary results confirm the potential of a-Si:H technology as a flexible and versatile solution for precise X-ray beam characterization, both in clinical and research contexts, opening up interesting perspectives for future developments.

Detectors and Detection Techniques / 10

X-ray imaging detectors based on optical active defects induced in lithium fluoride crystals and films

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The study and the development of innovative imaging detectors represent a crucial element in the field of X-ray imaging, mainly to overcome some of the limits of the standard ones. In this work an overview of the main results obtained during the study and the development of imaging detectors based on optically active point defects produced by X radiation in lithium fluoride (LiF) crystals and films will be presented. The LiF detectors are based on optical reading of visible photoluminescence produced by aggregated colour centres (CCs), locally produced by X radiation, and among their peculiarities, noteworthy ones are their very high intrinsic spatial resolution across a large field of view, wide dynamic range and versatility.
LiF-based detectors for extreme ultraviolet radiation, soft and hard X-rays are currently under investigation for imaging applications with laboratory radiation sources, e.g. laser-driven plasma sources and conventional X-ray tubes, as well as large-scale facilities, e.g. synchrotrons and free-electron lasers. The achieved results confirm that LiF-based detectors are powerful and versatile tools for X-ray imaging.

Fundamental Physics / 11

Elusive quark state studied by X-rays

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The Λ(1405) state is a basic element used to affect K-mesic atoms and built K-mesic nuclear states. The common understanding is that this state is predominantly a quasi-bound state of anti- K meson and a proton. Scattering data in Kp channel and Σπ channel allow to built interaction models. However, these models differ strongly if extrapolated to energies below the Kp threshold where Λ(1405) is located.
Upper levels of K-mesic atoms offer studies of quasi-free K –nucleon interactions , below the threshold as both particles are bound. From level widths of such atoms w extract the absorptive subthreshold K-N amplitude which disagrees with all potential models. It indicates that Λ(1405) has a 3-quark component. That is an old idea of simple quark models that was discarded as inconsistent with data. However, we extended the old formalism and show that such an interpretation is possible. It may dramatically change K- nuclear physics. As uncertainties are high, a new X-ray experiments are necessary. Suggestions will be presented.

X-ray Applications / 12

Development of a direct-reading dosimeter for eye-lens dose estimation in medical radiology

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Interventional radiology procedures are becoming increasingly common in modern clinical practice, often replacing invasive surgical interventions, despite increasing exposure of medical personnel to X-rays.
New epidemiological data correlating occupational exposure of interventional radiologists to radiation induced cataracts led ICRP to reduce the occupational dose limit for workers from 150 mSv/year to 20 mSv/year.
The EYEDOS project aims at developing a direct-reading eye-lens dosemeter to improve operational radiation protection of interventional radiology operators.
The EYEDOS system is based on a solid-state detector, whose dosimetric performance is in line with relevant international recommendations.
This communication describes the EYEDOS system and the results of the dosimetry qualification tests.

X-ray Applications / 13

The J-PET tomograph as an advanced, multifunctional detection system for applications in medical imaging and fundamental research

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The Jagiellonian Positron Emission Tomograph (J-PET) is the first modular and portable multi-photon PET scanner, which is a multidisciplinary detection system used in medical imaging as well as in fundamental research including discrete symmetry tests in positronium decays [1,2]. In addition to standard PET imaging, the J-PET scanner allows the positronium lifetime imaging in the human body [3,4,5]. The first ever in-vivo image of positronium in the human brain recently obtained using a J-PET scanner [5] shows the huge potential of this new diagnostic method in the future.

I am going to present research performed with the J-PET facility regarding both fundamental studies and medical imaging.

1 P. Moskal et al., Nature Communication 12, 5658 (2021).
2 P. Moskal et al., Nature Communication 15, 79 (2024).
3 P. Moskal et al., Nature Reviews Physics 1, 527 (2019).
[4] P. Moskal et al., Science Advances 7, eabh4394 (2021).
[5] P. Moskal et al., Science Advances 10, eadp2890 (2024).

Detectors and Detection Techniques / 14

3D Cadmium-Zinc-Telluride Drift Strip Detectors for Room Temperature X-ray and Gamma Ray Spectroscopic Imaging

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Intense research activities have been made in the development of room temperature spectroscopic imagers working in the X-ray and gamma ray energy band. Cadmium-zinc-telluride (CZT) detectors equipped with custom electrode structures have shown interesting performance up to 1 MeV, competing with the superb energy resolutions of high-purity germanium (HPGe) detectors (0.3 % FWHM at 662 keV), obtained after cryogenic cooling. In this context, we will present the spectroscopic and spatial performance of new high-resolution CZT drift strip detectors for room temperature X-ray and gamma ray spectroscopic imaging. The detectors, equipped with cross-strip electrode patterns on the cathode/anode electrodes, allow excellent room temperature energy resolution (0.8 % FWHM at 662 keV) and sub-millimetre 3-D spatial resolution. These activities are in the framework of an Italian collaboration on the development of spectroscopic gamma ray imagers (10 keV-1 MeV) for medical and astrophysical applications.

Detectors and Detection Techniques / 15

Perovskite for X-ray detection: preliminary results from Micro-Perov and HyPoSiCX projects

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The organometal halide perovskites (OMHP) semiconductors have been proven in the recent years to be promising material to detect ionization radiation, beside the well known success as photovoltaic devices.
In particular, OHMPs show large potential for X-rays detection due to their high stopping power, especially for energy above 30 keV where the Silicon absorption coefficient starts to decrease.
In this talk I will show preliminary results from the Micro-Perov and HyPoSiCX (Hybrid Perovskite on Silicon CMOS X-ray Detectors) projects.
I will focus on novel techniques which enable the deposition and growth of OHMPs crystals of micrometer dimensions directly on patterned conductive substrate with precise positions and dimensions.These techniques are attractive for X-ray pixelated detectors and opens the possibility to integrate OHMPs with CMOS technology.

Fundamental Physics / 16

Studies of the absorption parameter 3γ/2γ in positronium decays

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During Positron Emission Tomography (PET), as much as 40% of annihilations happen through the formation of positronium inside the patient's body. Its properties, such as the fraction of positronium annihilations into three photons (3γ/2γ), are highly influenced by the tissue's submolecular architecture. This has led to the development of a novel PET imaging techniques - positronium imaging - which provide additional insights into the imaged tissue. Conventional PET devices record only two annihilation photons and cannot assess the properties of positronium. However, the Jagiellonian PET (J-PET) scanner, capable of multi-photon detection, enables three-gamma imaging necessary

for determining 3γ/2γ ratio. The aim of this work is to study the absorption of gamma quanta in simplified models approximating the human body, as well as in the XCAT human phantom. For this purpose, toy Monte Carlo (MC) simulations of positronium decays into 2γ and 3γ and photon absorption in the models were performed and compared with the results obtained with GATE MC simulation tool. Based on the simulations, the dependence of absorption probability of photons in the phantoms on the location of the decay point is determined. As a result of this research, we present absorption maps of para- and ortho-positronium decays, required for data correction.

Beamlines and Facilities / **17**

The INFN Frascati facility for X-Ray dosimetry

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X-ray dosimetry is a relevant topic in medicine, industry and research. With the purpose of providing a facility for the characterisation of devices to be used in these fields, a 40-110 kV C-Arm-type medical X-ray unit was adapted to produce X-ray fields with known dose rate and energy distribution, following the recommendations of ISO. It operates with constant kV and continuous or pulsed emission with current from 0.1 up to 3 mA. Owing to an Image Intensifier unit with field of view 20 cm (diameter), it allows non-destructive inspection of the devices in addition to their irradiation in a known field. This communication describes the facility, the monitor instruments and the characteristics of the available X-ray fields.

Detectors and Detection Techniques / **19**

CdZnTe radiation detector applications

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CNowadays, ionizing radiation detectors are widely employed across several application fields. These include medical imaging (such as CT and SPECT), environmental monitoring (e.g., background radiation control and detection of contaminated areas), homeland security (cargo and luggage inspection), synchrotron science, particle physics, and astrophysics (for the study of X- and γ-ray emissions from celestial sources). Over the past decades, the use of semiconductor-based detectors has become increasingly important, progressively replacing classical scintillator-based systems in many of these fields. Semiconductor detectors offer significant advantages, such as superior energy resolution

due to the direct conversion of ionizing radiation into electrical signals. Furthermore, they enable higher spatial resolution in imaging systems compared to scintillators, making them the most advanced technology currently available for detecting X- and γ-photons in the energy range of 1 keV to 10 MeV.
Among compound semiconductors, Cadmium Zinc Telluride (CdZnTe or CZT) stands out as one of the most promising materials for radiation detection. It offers an excellent balance between key performance parameters such as high atomic number, large resistivity, energy resolution, and the ability to operate at room temperature. Thanks to these properties, high-performance CZT-based detectors can be fabricated with excellent energy resolution, high detection efficiency, and without the need for cryogenic cooling.
In this work, we present several applications where CZT detectors are used, highlighting their versatility and performance across different radiation detection scenarios. Particular attention is given to the results obtained using custom-fabricated CZT detectors, designed and optimized for specific measurement conditions. We discuss their performance when coupled with state-of-the-art readout electronics and advanced digital pulse shape analysis techniques, which further enhance their spectroscopic capabilities. The combination of high-quality CZT material, optimized detector geometry, and advanced signal processing enables impressive precision in energy measurement, timing, and event classification. These results confirm CZT detectors as a powerful tool for both scientific research and practical applications in radiation detection.

X-ray Applications / 21

Wearable, Lightweight, and Flexible Ionizing Radiation Dosimeters for Real-Time Monitoring

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The development of detectors for high-energy photons, protons, and heavy particles has long been a key research topic, not only for fundamental studies but also for radiation monitoring in harsh environments –such as in hospitals during medical treatments and in outer space exploration. In this context, there is a rapidly growing interest in novels, high-performance, thin, and flexible sensors capable of real-time ionizing radiation detection at affordable costs. This is driven by the limitations of current technologies, which still lack in meeting requirements such as large-area coverage, conformability, portability, low weight, and low-power operation 1.
Recent significant progresses in the field of perovskites have demonstrated their great potential for direct X-ray detection, coupled to unique advantages including solution-processability, cost-effective fabrication and scalability to large area systems. However, they are limited by low bulk resistivity, high trap states density and significant ion migration effects leading to large dark current drift. Among the lead-halide perovskite, X-ray detectors based on polycrystalline low-dimensional (2D layered) lead-halide perovskites have emerged as promising semiconducting materials thanks to their high atomic number, excellent optoelectronic properties, combined with high resistivity, reduced ion migration, and enhanced environmental stability 2.
We present recent developments in X-ray detectors based on low dimensional perovskite films directly deposited onto pixelated flexible substrate. We also report on two devices: one specifically designed for in-situ dose monitor in medical radiotherapy [3, 4], and another developed for space applications within the IRIS project –founded by Italian Space Agency - for real-time radiation monitoring of crew members on the International Space Station.

References
1 L. Basiricò, A. Ciavatti, B. Fraboni, Solution-Grown Organic and Perovskite X-Ray Detectors: A New Paradigm for the Direct Detection of Ionizing Radiation, Adv. Mater. Technol. 2021, 6, 2000475.
2 F. Lédée, A. Ciavatti, M. Verdi, L. Basiricò, B. Fraboni, Ultra-Stable and Robust Response to X-Rays in 2D Layered Perovskite Micro-Crystalline Films Directly Deposited on Flexible Substrate, Adv. Optical Mater. 2022, 10, 2101145.
3 I. Fratelli, L. Basiricò, A. Ciavatti et al., Real-Time Radiation Beam Monitoring by Flexible Perovskite Thin Film Arrays. Adv. Sci. 2024, 2401124.

[4] L. Basiricò, M. Verdi, A. Ciavatti et al., Wearable Perovskite Films for On-Line Monitoring of Radiotracers in Nuclear Medicine, Adv. Mater. Technol. 2024, 2401111.

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X-ray Polarimetry with Optical Time projection chamber within HypeX project

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X-ray polarimetry is an observational technique with the potential to enrich our understanding of high-energy astrophysics via the measurement of the polarization of X-rays emitted by exotic cosmic phenomena such as black holes, neutron stars, Gamma-Ray Bursts and Solar flares, enabling to unveil new insights on fundamental physics and geometry of Galactic and extragalactic sources. We will present a novel large-volume, extended field-of-view Time Projection Chamber (TPC) tailored for hard X ray polarimetry in the range between 8 and 40 keV. Originally developed for directional Dark Matter searches, the system has been adapted to measure the polarization of X-rays by means of photoelectric effect. The technology, a TPC with triple-GEM amplification stage and optical readout exploiting the sensitivity and granularity of sCMOS cameras and PMTs, aims to achieve 3D reconstruction of photoelectrons and an active volume significantly larger—about 100 times—than the current state of the art. The prototype TPC, with a cylindrical active volume of radius of 3.7 cm and height of 6 cm, achieves full reconstruction of photoelectron tracks in the 10–50 keV range, with angular resolutions reaching 15°. Calibration tests using a collimated ^{90}Sr source and a fully polarized 17 keV X ray beam have yielded promising results, including modulation factors above 0.4 at 17 keV. We will also discuss future developments in order to optimize the detector structure and amplification structure, paving the way for innovative X-ray polarimetry missions.

Instrumentation / **23**

The hidden becomes apparent: Measurements of Carbon Layer Thickness in Air

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Homogeneity and thickness of a graphite film affect the performance of dispersive optical elements made by depositing of thin HOPG and HAPG crystals on a substrate of custom shape (Graphite Optics produced by Optigraph GmbH, Germany).

Standard techniques for analysis of carbon layers and compounds require expensive measuring equipment with a vacuum chamber. A new method for fast and accurate controlling of the carbon coating thickness, based on the X-ray measurements in air and normal pressure was developed for M1 MISTRAL (Bruker Nano GmbH, Germany).

Simple raster measurements in air provide the accurate and reliable information about thickness and homogeneity of carbon films on different substrates in the thickness range from 0.5 µm up to 100 µm. The method was validated with reference samples measured in M4 TORNADO plus (Bruker Nano GmbH, Germany) and in a synchrotron X-Ray source (BESSY II, Germany).

The newly developed method has been implemented at Optigraph GmbH for quality control of Graphite Optics, as well as freestanding films for novel applications, such as special X-ray windows and electrons stripping films.

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Space and time-resolved X-ray spectroscopy technique by CCD pinhole camera

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The X-ray diagnostics is an insightful technique to monitor the emission of magnetically confined plasmas. In the PANDORA (Plasmas for Astrophysics, Nuclear decay Observation and Radiation for Archaeometry) INFN project 1 framework, we here present the newly developed energy-space-time resolved diagnostic tool, consisting of a 400 µm lead pinhole coupled with a 4 MP X-ray CCD camera (sensitive in ~0.6–30 keV energy range) and a Pt-Ir X-ray shutter allowing exposure times of few ms. The use of CCD devices in single photon counting (SPhC) mode requires the application of imaging reconstruction algorithms to identify each single photon event from a raw image 2. Despite being the sequential data readout relatively slow and noisy, the CCD features the advantage of high space resolution (square pixel size: 13.5 µm) and high X-ray sensitivity (95% at 8 keV).
Monte Carlo simulations and a test-bench characterization of the CCD camera were performed at LNS to enhance the energy-resolved SPhC technique, providing the data-processed quantum efficiency and energy calibration on several configurations, with an energy resolution of 300 eV FWHM at 8 keV.

Preliminary results will be shown from a recent experimental campaign, performed at the ATOMKI ECR plasma facility 3 on X-ray space- and time-resolved spectroscopy measurements, to reconstruct plasma dynamics in the compact B-minimum magnetic plasma trap.
The X-ray fluorescence filtered imaging technique [2,4] has been applied to spatially investigate the plasma confinement structure in gas mixing configurations, combining Ne, Kr, Ar, Xe.
Time-resolved plasma imaging has been performed to study plasma transients, such as ignition and afterglow plasma decay, observing for the first time the evolution of such phenomena on ms time windows.
Such promising results obtained by the adopted X-ray technique could be of a wide and interdisciplinary interest, spanning from operations of ECR plasma systems such as ion sources, to plasmas for thermonuclear fusion and fundamental research.

References
1. D. Mascali et al., Universe, 2022, 8(2), 80.
2. E. Naselli et al., JINST, 2022, 17, C01009.
3. S. Biri et al., Rev. Sci. Instrum, 2012, 83.
4. G. Finocchiaro et al., Phys. Plasmas, 2024, 062506.

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AI Tools for Plasma Diagnostics by X-ray Imaging and Spectroscopy in the PANDORA Project Frame

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PANDORA (Plasmas for Astrophysics, Nuclear decay Observation and Radiation for Archaeometry) is a multidisciplinary project aimed at investigating β decays in stellar-like ECR plasmas, representing a breakthrough for fundamental studies on weak interactions in astrophysical contexts. The facility will rely on an extended diagnostic system. Among which, the X-rays diagnostic and spectroscopy will be one of the most relevant to measure and to monitor the emission of magnetically confined plasmas, their thermodynamic parameters, the confinement dynamics and its overall structure. The same techniques apply for plasma-based ion sources, such as ECR devices.

The diagnostics setup consists in an X-ray pin-hole camera, sensitive in the soft X-ray energy domain (0.5-30 keV). An innovative algorithm for X-ray imaging in Single-Photon Counting (SPhC) mode was developed by a sophisticated suite of post-processing routines which enabled this technique to reach 500 μm and 240 eV of spatial and energy resolution respectively, in HDR mode. Preliminary results will be hereby shown about the AI-based machine learning algorithm development and optimization.

Data have been acquired from several datasets, under different plasma conditions in two magnetic traps: the B-minimum ion source at ATOMKI Laboratories (Debrecen) and the simple mirror Flexible Plasma Trap (FPT) at INFN-LNS. The detected photons were labelled in terms of geometrical and intensity-related features. Through the AI tool encoded in MATLab, clusters of data exhibiting similar features were identified, highlighting parameters that allow the characterization of single-photon events. Then a feed forward neural network is used to discriminate and exclude spurious pile-up events, via a labelling procedure of the dataset. This approach aims to retrieve, in a much shorter time, plasma emission spectra with higher energy and spatial resolutions, maximize the signal-to-noise ratio, and provide unprecedented rapidity and accuracy in characterizing soft X-ray fluorescence and bremsstrahlung emissions from such plasmas.

The AI tools, including the ongoing stage of neural-network implementation, and the first results, obtained through systematic measurements, will be presented in this contribution.

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VOXES, a graphite mosaic crystal based Von Hamos spectrometer for extended and diffused sources

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Bragg spectroscopy is a consolidated experimental method for high-energy resolution X-ray measurements. However, this technique is limited to the detection of photons produced from point-like or well collimated sources and becomes quite inefficient for photons generated in extended and diffused ones. Also, the possibility to perform simultaneous measurements of several X-ray lines is of great benefit when low-rate signals are expected and individual angular scans require long exposure times.
We present a prototype of a high-resolution X-ray spectrometer based on Highly Annealed Pyrolytic Graphite (HAPG) mosaic crystals, developed by the VOXES (high resolution VOn hamos X-ray spectrometer using HAPG for extended sources) collaboration at INFN Laboratories of Frascati, able to work with extended (millimetric) and isotropic sources. The spectrometer has been tested in the energy range 6–19 keV, to deliver a cost-effective system having an energy resolution (FWHM) at the level of a few eV, able to perform sub-eV precision measurements of single and multielement targets in a broad energy range.
In this talk, the working principle of the VOXES spectrometer is presented, including a detailed description of the geometry, the calibration methods and the spectral fitting functions. Results of X-ray tracing simulations are compared to the experiment.
The proposed spectrometer has possible applications in several fields, going from fundamental physics, synchrotron radiation and X-FEL a applications, medicine and industry to hadronic physics experiments, where its performances make it a fundamental tool for a series of measurements like the energies of kaonic atoms transitions, allowing to extract fundamental parameters in the low energy QCD in the strangeness sector.

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Single-mask X-ray multimodal imaging for the investigation of dynamic processes

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X-ray multimodal imaging is based on the retrieval of phase changes and ultra-small angle scattering (or dark-field) in addition to conventional transmission. The availability of these additional contrast channels has already proven to be valuable in many research fields, including medicine and materials sciences, thanks to the ability to provide superior contrast for soft tissues as well as to highlight the internal microscopic structures of objects below the system's resolution. The availability of high flux synchrotron radiation beamlines has recently opened the way to dynamic X-ray imaging with impressive time resolution allowing the investigation of rapidly changing processes. However, dynamic imaging has mainly been limited to conventional absorption or free-space propagation phase imaging. Free-space propagation is not quantitative in single-shot mode unless the sample is homogeneous, which is often a condition not satisfied when investigating the dynamics of a process. On

the other hand, the use of quantitative imaging approaches based on gratings or masks poses challenges to a dynamic implementation. This is mainly due to the requirement acquiring frames while displacing one or more optical elements, which may not be compatible with the speed requirements of dynamic imaging. While single-shot methods exist, they typically impose a compromise between time and spatial resolution. To overcome these limitations, we propose a dynamic implementation of the beam tracking imaging method. BT uses a single absorption mask that shapes the beam into a series of beamlets, which are then individually resolved by a detector with a sufficiently small pixel. When a sample is introduced into the beam path, the profile of each beamlet modified by the sample is compared to that obtained without the sample in place to retrieve transmission, refraction and dark-field. The main advantage of BT over other grating and mask-based techniques is the requirement of a single absorption mask, which greatly simplifies the experimental setup. However, when BT is used as a single-shot method, the spatial resolution will be limited by the period of the mask in use, since the separation between adjacent beamlets determines the sampling rate. The way to overcome this limitation is the acquisition of images where the sample is translated by sub-period steps which are subsequently recombined into an image with spatial resolution determined by the mask aperture size. Since only a single movement is required, a dynamic implementation of this method is relatively straightforward and does not pose any demanding hardware requirement. Dynamic BT is based on the continuous translation of the mask in front of the sample, while the detector acquires a sequence of images. The speed of the mask has to be adjusted to match the final required time resolution, considering that to achieve an aperture-limited spatial resolution, the recombination of a number of images equal to ratio between mask period and aperture is required. To investigate the capabilities, the experimental challenges and limitations of this approach, we targeted additive manufacturing and fluid dynamics in two different experiments performed at synchrotron facilities, where we obtained multi-modal images with micrometric spatial resolution and a time resolution of milliseconds

Fundamental Physics / **29**

High-precision muonic atom x-ray spectroscopy with a metallic magnetic calorimeter

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Muonic atom spectroscopy is a well-established method to accurately determine the root-mean-square (RMS) radii of nuclear charge density distributions and has already delivered the most accurate results for very light ($Z < 3$) as well as heavier nuclei ($Z > 10$). However, a gap remains for muonic atoms from lithium to neon due to technological limitations in the relevant energy range (~20–200 keV) based on the lack of resolving power of conventional solid-state detectors.

To address this gap, the QUARTET collaboration employs cryogenic metallic magnetic calorimeters (MMCs) that combine broadband spectral coverage with record resolving power. In October 2024, the first experimental campaign at the Paul Scherrer Institute demonstrated the feasibility of this approach and showed the first high-resolution spectra of muonic lithium, beryllium, and boron, resolving the 2p-1s transitions of the individual stable isotopes. These results mark a significant step forward in bridging the low-Z charge radius gap and offer promising prospects for future precision measurements.

X-ray Applications / **30**

Characterizing Cerium Redistribution in PEM Fuel Cells Using an In-House X-ray Fluorescence System

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This study investigates cerium migration in polymer electrolyte membrane fuel cells (PEMFCs) using a custom in-house X-ray fluorescence (XRF) spectroscopy system. Cerium serves as a crucial chemical stabilizer in fuel cells, scavenging destructive free radicals through Ce(III)/Ce(IV) redox reactions. However, prolonged operational conditions can induce complex cation migration across the active area (such as electrolyte or electrode-electrolyte interface) driven by water, potential, and concentration gradients [1,2].
The RETINA facility, developed at Politecnico di Milano, employs a customized XRF system for electrochemical devices featuring a high-power W-anode X-ray tube (40-150 kVp) and a Peltier-cooled CdZnTe detector with 400 eV resolution at 5.9 keV Fe K-shell (see Figure 1a). The system enables 1-mm resolution elemental mapping through an adjustable collimator. Quantitative elemental analysis using the fundamental parameters method is facilitated via Pymca 3.
Our investigation focused on a 140-mm commercial PEMFC, systematically examining cerium distribution in pristine and post-degradation states. Scan results demonstrated a significant transformation in cerium spatial distribution from a uniform initial profile to a pronounced concentration gradient concentrated near both electrodes after 1100h of degradation (Figure 1b and c). This non-uniform redistribution suggests active cerium migration in response to electrochemical stress, potentially accumulating at interfaces with high free radical formation and chemical instability.

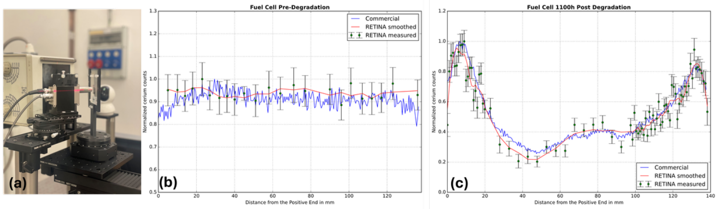

Figure 1: Figure 1. (a) Experimental setup; fuel cell normalized cerium concentration profiles in (b) pristine condition and (c) 1100-h post degradation

Validation was performed by comparing our results with a commercial micro-XRF Analyzer with a 500-um scan resolution, confirming RETINA's reliability through coherent cerium concentration profiles. Comparative analysis underscores RETINA's capability to provide quantitative XRF analysis with an accessible and effective approach. The obtained concentration profiles offer valuable insights into ion transport coefficients, enabling more comprehensive modeling of mobility and diffusivity within fuel cells.

References
(1) Y.H. Lai et al., J. Electrochem. Soc. 165 F3217, 2018.
(2) A. Baker et al., J. Electrochem. Soc. 164 F1272, 2017.
(3) V.A. Sole, et al., Spectrochim. Acta B 62, 2007, 63-68

Instrumentation / 31

Activity presentation TEES

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TEES srl, established in 2018, designs and manufactures mechanical equipments for Scientific Researches.
Born to follow 30 years of experience in the High Technologies Solutions, TEES inherits know how and technologies
from noted company of this market established in 1986.
In the 2019 TEES upgraded to EN ISO 9001:2015 his Quality Management System.
Most part of the activities of TEES has been devoted in
satisfying research laboratories needs.
TEES collaborates with industry R&D department designing and
manufacturing prototipes and custom applications.
Major areas can be distinctly identified:
- design and realization of High precision movement stage;
- design and realization of Ultra High Vacuum technologies
- design and realization of Geophysics technologies;
-design and realization of Space technologies;
-design and realization of Neutron technologies;
-design and realization of Art and cultural heritage technologies;
-design and realization of Industry technologies.

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First fluorescence spectra with LEAPS-INNOV HPGe detector using synchrotron radiation

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Detector performance often hinders the efficiency of advanced synchrotron-based techniques such as X-ray Absorption Fine Structure (XAFS) spectroscopy measured in fluorescence mode, which is essential for probing the electronic structure and elemental composition. To overcome these limitations, the XAFS-DET WP of the European LEAPS-INNOV project has developed a monolithic multielement high-purity germanium (HPGe)
detector that will offer a high energy resolution and detection efficiency in the hard X-ray regime compared to conventional silicon drift detectors (SDDs).
This detector incorporates a thermally optimized mechanical design, an electronics chain featuring TETRA low-noise preamplifiers capable of handling high count rates (20–250 kcps/mm^2) with low dead time, and a digital pulse processing stage for enhancing the performance by effectively rejecting charge-shared events.
In a recent characterization campaign conducted at the ESRF facility, the detector response was evaluated using 2D scans with a direct X-ray beam across the 20–50 keV energy range. These scans assessed spatial uniformity, count rate performance, and energy resolution under varying flux conditions. Following this, the first fluorescence spectra were successfully acquired using samples including elemental foils (Sb, Ag), a CsI glass, a GdTb scintillator, and an EnviroMAT soil sample.
The campaign also identified the need for further optimization, specifically in reducing system noise and enhancing electronic stability to support long-duration, high-count-rate experiments.

X-ray Applications / 33

Three-dimensional visualisation and quantification of cellular components in mm-sized unstained tissue cores using high-content

phase-based x-ray microscopy

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Volumetric imaging of mm-sized soft tissue samples with micron resolution opens new possibilities both in clinical and research settings, driven by the growing need for studying micro and nanoscale structures in a three-dimensional context at the mesoscale.

In this talk I will report the first proof of concept for three-dimensional soft tissue imaging with a laboratory-based x-ray microscope based on intensity-modulation masks, allowing for multi-modal retrieval of transmission, refraction, and scattering. The microscope allows for micron resolution in the resolved channels (transmission and refraction), while it can reach the nanoscale in the scattering channel. The combination of micron-level spatial resolution, set by the use of intensity modulation masks, and the enhanced contrast, arising from phase-based imaging, allows for the. Additionally, the high-content nature of this technique allows for the correlation of the scattering signal with nanoscale structures found in tissue, namely cellular nuclei and extra-cellular matrix.

This talk will address the challenges of correlating microscale cellular visualisation with the broader context of tissue architecture at the mesoscale, using a multi-scale imaging approach. Finally, I will discuss the potential of integrating X-ray microscopy with in-operando mesoscale imaging to investigate fluid dynamics processes within tissue.

Beamlines and Facilities / 34

Betatron X-ray Radiation in the EuPRAXIA Advanced Photon Source Project

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Betatron radiation is X-ray radiation generated by electrons oscillating within a plasma during the Laser WakeField Acceleration (LWFA) process. The relativistic laser-plasma interaction replicates the principle of wiggler emission on a millimeter scale.
Betatron sources stand between Free Electron Lasers (FELs) and synchrotron radiation sources. Due to the small transverse size of the source—on the order of a few microns—the emitted radiation is spatially coherent. Like a synchrotron, the spectrum is broadband and ranges from soft to hard X-rays while maintaining comparable peak brilliance. Additionally, the pulse duration can be as short as a few femtoseconds.

As part of the EuPRAXIA project, EuAPS (EuPRAXIA Advanced Photon Source) will be the first user dedicated betatron radiation source developed at INFN Frascati. The facility is designed to produce 1-10 keV photons using a compact laser-driven plasma accelerator, operating at 1 Hz and generating about $10^6 - 10^9$ photons per shot.
The beamline will be operational by the end of 2025 and will enable a variety of experiments, including time-resolved spectroscopy, phase-contrast imaging of biological samples, and pump–probe experiments.

X-ray Applications / 35

XRF Spectroscopy with VOXES: Techniques, Optimization and Applications

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X-rays are a standard tool for investigating the properties of metals, from determining their concentrations to probing their specific electronic states. At the National Laboratory of Frascati (LNF), the VOXES apparatus pursues this approach by implementing an X-ray fluorescence (XRF) spectrometer for extended sources. In this talk, I will present the capabilities of VOXES, highlighting its versatility across different XRF techniques. I will begin with energy-dispersive XRF (ED-XRF), focusing on its application within the MITIQO project at LNF, for measuring metal concentrations in wine, which enables geographical origin identification. Then, I will discuss wavelength-dispersive XRF (WD-XRF) applications, including ongoing optimizations aimed at improving the limit of detection and the development of lab-based spin-selective X-ray emission spectroscopy (XES).

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Macro X-ray fluorescence scanning (MA-XRF) as tool in the authentication of paintings and revealing hidden details

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X-ray fluorescence (XRF) analysis is a non-destructive technique widely employed in the examination of cultural heritage artifacts. Its capacity to rapidly identify the elemental composition of materials without causing damage makes it an essential tool for analyzing paintings, frescos, manuscripts, pottery, metalwork, glass, and various other artifacts. The advent of portable XRF devices has further enhanced on-site analyses in museums and archaeological sites, offering rapid, in situ assessments. Moreover, integrating the XRF devices with a scanning system (namely Macro-XRF) enables the analysis of extensive areas, allowing the detection of inhomogeneities that are challenging to identify with single-point measurements.
Meanwhile, XRF can identify the elemental composition of pigments, it proves extremely valuable for authenticating painting. Many pigments are attributed to specific historical periods or artists, and their presence (or absence) can provide critical evidence about the age and creative process of a painting. For instance, the detection of modern synthetic pigments in a work claimed to be from the Renaissance period would raise significant doubts about its authenticity. Conversely, the presence of historically appropriate materials, such as lead-tin yellow or natural ultramarine, can support the attribution to a specific time frame or school.
Moreover, since artists often reused canvases, XRF analysis proves highly valuable for revealing underlying paintings. This analysis can detect hidden layers of pigment and materials beneath the visible surface, offering insights into earlier compositions that have been painted over. By uncovering these hidden layers, researchers can reconstruct the evolution of a painting and gain a deeper appreciation of the artist's methods, intentions, and material choices throughout different stages of their work.
The presentation focuses on some preliminary studies conducted at the Dafne-Light Laboratory (INFN-LNF), involving the analysis of both modern and ancient paintings within the framework of the INFN-CHNet.

Fundamental Physics / 37

Probing Fundamental Interactions with Kaonic Atom X-ray Spectroscopy: From strong-field QED to low-energy QCD

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X-ray spectroscopy of kaonic atoms provides a unique tool for fundamental physics, enabling precision tests of quantum electrodynamics (QED) in strong electromagnetic fields and the exploration of the strong interaction at low energies with strangeness. In these exotic systems, the electromagnetic cascade of the kaon reveals both QED and strong-interaction effects in the innermost atomic levels. Thanks to the low-energy kaon beam from the DAΦNE collider at the National Laboratories of Frascati - INFN (Italy) and state-of-the-art Silicon Drift Detectors, the SIDDHARTA-2 collaboration has achieved high-precision X-ray spectroscopy of kaonic atoms, including helium-4 and neon, and the first measurement of kaonic deuterium.
In this contribution, I will present the scientific motivation, experimental approach, and recent results of the SIDDHARTA-2 experiment, highlighting how X-ray spectroscopy of kaonic atoms is advancing our understanding of fundamental forces, from the strong-field QED to the strong interaction in the non perturbative regime.

Detectors and Detection Techniques / 38

Precision X-ray Measurements with Silicon Drift Detectors in the SIDDHARTA-2 Experiment

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The SIDDHARTA-2 experiment at the DAΦNE collider aims to perform high-precision X-ray spectroscopy of exotic atoms to study the low-energy strong interaction in the strangeness sector. The experiment employs large-area Silicon Drift Detectors (SDDs) with a thickness of 450 µm, optimised for detecting soft X-rays. To extend the accessible energy range and enable precision measurements of higher-energy transitions (up to several tens of keV), the development of new 1 mm thick SDDs is currently underway.

In this contribution, we present the ongoing characterisation of the 1 mm SDD prototypes in a dedicated laboratory setup. The detectors are tested at various bias voltages to evaluate their response, energy resolution, and overall performance for high-energy X-ray detection. Understanding the optimal working conditions for these thicker sensors is essential for their future integration into the experimental apparatus.

Additionally, we report on an exploratory measurement carried out with the current 450 µm SDDs using a C2F4 solid target to measure, for the first time, transition lines of Kaonic Fluorine. The results demonstrate the feasibility of high-energy X-ray detection with the existing setup and provide a benchmark for comparison with the new detector generation.

Fundamental Physics / 39

Searching for signal of Quantum Collapse and Quantum Gravity in the cosmic silence of the Gran Sasso Underground Laboratories

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The VIP experiment is pursuing experimental studies of Quantum Mechanics (QM) foundations, investigating models of dynamical wave function collapse and performing high sensitivity tests of the Pauli Exclusion Principle (PEP) for electrons.
Unification of QM and General Relativity is probably the main ambition of modern physics. Motivated by the awareness that space-time fluctuations would induce decoherence in quantum systems, the idea to "gravitize"the QM aroused growing interest in the last decades, especially for the privileged role that gravity may play to solve the measurement conundrum. We will report on the strong experimental constrains on the gravity-related collapse models, obtained by searching for an unavoidable side-effect of the collapse mechanism known as "spontaneous radiation emission".
It was recently shown that violation of the PEP may be induced by Quantum Gravity (QG). X-ray surveys, searching for atomic transitions prohibited by the PEP, represent stunning candidates to test QG models, at unexpectedly high energy scales. The extreme sensitivity bounds obtained by VIP will be presented.

Instrumentation / **40**

HOPG and Graphite optics as high efficient "Bragg filter"and dispersive element in X-ray spectroscopy

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Highly Oriented Pyrolytic Graphite (HOPG) is a crystal of particularly high reflectivity. Being a mosaic crystal, it reflects a relatively wide energy window, since it provides crystallites located at the Bragg angle for a relatively wide range of wavelengths. Further efficiency gains can be achieved through mosaic focusing (parafocusing) in the image plane and focusing geometry of graphite optics based on flexible thin HOPG and HAPG (Highly Annealed Pyrolytic Graphite) crystals. The optics was developed and are offered on the market exclusively by Optigraph GmbH, Germany.
Graphite optics is particularly useful for detecting weak spectral lines of interest in the presents of intense matrix lines or background. Graphite optics can act as a filter to extract the required energy widow in front of another energy or wavelength dispersive detector, as well as it can serve as a wavelength dispersive element itself.
Resolution of Graphite Optics can be enhanced by using a crystal in von Hamos geometry. Availability of the optics made as of full figure of revolution significantly increase the acceptance angle in von Hamos geometry and make it possible to transfer methods that traditionally require a synchrotron radiation source to a laboratory setup with an X-ray tube as a source
Reducing of the crystal thickness and mosaicity also improves noticeably the optics resolution. HAPG optics with mosaic spread of 0.1 degree can provide resolution of $E/\Delta E$ up to 4000. The trade-off between efficiency loss and resolution improvement requires optimizing the optics parameters to each specific task and setup.
The unique radiation stability and thermal conductivity of graphite crystal allow it to be used under increased thermal and radiation loads where characteristics of other crystals crucially degrade.
Some examples of graphite optics applications developed by our customers for X-rays fluorescent analysis (XFA), X-rays emission and absorption spectroscopy (XES and XAS) , extended X-ray absorption fine structure spectroscopy (EXAFS) and plasma analysis are given.

X-ray Applications / 41

Fiber Diffraction of Amyloid Aggregates Using High brilliance X-ray sources: Opportunities and Challenges

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Protein misfolding and aggregation are central to numerous neurodegenerative diseases [Selkoe, Nature, 2003]. In particular, amyloid-β (Aβ) and α-synuclein are key pathological proteins in Alzheimer's and Parkinson's diseases, respectively. Brain regions where these aggregates accumulate often exhibit high concentrations of metal ions, making it critically important to understand how metal ions influence Aβ and α-synuclein aggregation and fibrillization [Minicozzi, JBC, 2008; Viles, Coord Chem Rev, 2012; De Santis, J Phys Chem B, 2015].

Conventional structural biology methods, such as X-ray crystallography performed at synchrotrons, typically require crystallization steps that can alter native oligomeric or fibrillar states. In contrast, high-brilliance X-ray sources, such as Free Electron Lasers (FELs), generate ultra-intense, femtosecond X-ray pulses, enabling high-resolution imaging of isolated biological samples. This feature makes FELs uniquely suited for investigating structurally heterogeneous systems, including amyloid fibrils and aggregates. Several studies [Laganowsky, Science, 2012; Popp, Cytoskeleton, 2017; Seuring, Nat Commun, 2018] have demonstrated the feasibility of FEL-based diffraction on fiber-like assemblies.

Fiber diffraction provides atomic-level insights into fibril periodicity, while coherent diffraction imaging (CDI) offers complementary information about the size and shape of individual, often non-crystalline aggregates. However, such experiments are technically demanding, with challenges including the intrinsic heterogeneity of the samples, variability in aggregate morphology, and complexities related to hit-finding in serial femtosecond crystallography-type setups. In this presentation, I will discuss both the opportunities and limitations of FELs for the structural characterization of amyloid aggregates.

Detectors and Detection Techniques / 42

Study of the excess noise and optimum operating conditions for LGAD detectors in high precision X-γ ray spectroscopy

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Radiation and particle detection systems based on low-gain avalanche diodes (LGAD) are promising technologies for a broad range of applications spanning from timing detectors of minimum ionizing particles in High-Energy Physics (HEP) experiments to soft X-ray detectors in synchrotron, FEL and X-ray fluorescence analysis instruments. LGADs are expected to improve the performance of the detection systems with respect to the standard Diode detector's structures due to the charge signal multiplication gain (Ms) originating from the impact ionization process in the narrow high electric field region near the output electrode. However, the advantage of the increase in the charge signal amplitude is hindered by the concurrent rise of the excess noise associated with the charge multiplication statistics itself, which negatively affects the energy resolution in spectroscopic acquisitions.

In this study, all the noise components of LGAD-based X-γ ray detection systems are precisely determined for a broad range of multiplication gain values and different shaper peaking times. The dependence of the electronic noise associated with the LGAD dark current is studied as a function of Ms and temperature. The white and 1/f series noise contributions decrease as Ms increase, reducing the optimum peaking time, reaching 0.1 us at Ms = 13 with the equivalent noise charge of 11 el. measured at room temperature. An expression for the equivalent noise charge at the optimum peaking time is proposed. The conditions, in terms of multiplication gain and shaping time to achieve the maximum energy resolution with LGAD-based X-γ ray detection system, are experimentally and theoretically determined.

Beamlines and Facilities / 43

BEaTriX: an innovative compact calibration facility enabling wide, collimated, and monochromatic low energy X-ray beam

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BEaTriX, the Beam Expander Testing X-ray facility, is the X-ray calibration facility at INAF-Brera Astronomical Observatory able to create a wide, monochromatic, and collimated X-ray beam in a compact laboratory (9 x 18 m2). This is possible thanks to an innovative optical design that includes a grazing-incidence paraboloidal mirror, in whose focus the micro-focus source is placed, for collimation and vertical expansion, a monochromatization stage and an expansion stage for the horizontal expansion, both exploiting the diffraction from crystals.
BEaTriX was built specifically for the New Athena mission, the future ESA X-ray space observatory to be launched in 2037. It will be the reference calibration facility for testing the about 500 optical modules that will compose the NewAthena telescope. A project, named BEaTriX+, has started in 2024 to enable X-ray measurements for other missions, giving the possibility to vary the focal length from 1.5 m to 12 m.
The facility hosts two beamlines at 4.51 keV and 1.49 keV energies; the first one is already operative, and the second one will be operational in the Q1-2026. The optical path and component slightly change based on the energy. For the 4.51 keV beamline, a source with Titanium anode is used, two Channel Cut Crystals in Silicon (220) are used as monochromator, and an asymmetrically-cut Si (220) crystal for the expansion stage, obtaining a 17 cm x 6 cm beam (divergence < 2 arcsec). The 1.49 keV beamline instead exploits a source with Aluminum anode, two asymmetrically-cut Quartz (100) crystals for the monochromation stage, and two asymmetrically-cut ADP (101) crystals for the expansion.
The crystal expander constitutes the key element of this design. It is a highly dispersive component, and as consequence, it requires a strong monochromatization, which, in turn, requires a very brilliant source. In the 1.49 keV beamline, all these aspects are more challenging than in the other beamline from several points of view especially, the crystals as the well-known Silicon crystal could not be selected due to its d-spacing not large enough.
The ADP and Quartz crystals characterization highlighted curvatures of the crystalline planes about one order of magnitude smaller of the 22 km requirement, a requirement extremely challenging for any application. The impact of this curvature on the final BEaTriX beam collimation was investigated through simulations performed with both the reference IDL code and the OASYS-SHADOW4. The results of these simulations report an impact on the beam collimation, that will be addressed with a dedicated actuation system for bending the ADP crystals.

Instrumentation / 44

DECTRIS Innovations: Shaping the Future of X-ray Detection Technologies

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DECTRIS's innovations strive to set new standards in detector technology, driving groundbreaking advancements in scientific research on both X-ray photon and electron science.

Our work addresses the evolving requirements of next-generation synchrotron light sources and high-precision laboratory systems used in diffraction scattering, and spectroscopy.
In parallel, we are expanding the reach of our innovations into electron microscopy, medical and industrial applications, including computed tomography (CT) imaging and electronics inspection.

Our success relies on delivering application-optimized detectors and software that meet these new scientific frontiers and on achieving detection excellence across various parameters, including high frame rates, exceptional count rates exceeding 10 MHz per pixel, pushing energy resolution limits down to 600eV (FWHM), and providing a broad energy coverage from few keV to 100 keV by the use of both silicon and cadmium telluride sensor materials for direct detection.

In this presentation, we will highlight our latest research and development efforts in X-ray detector technologies.

Some examples of our ongoing R&D have yielded the SELUN detector, engineered for high-frame-rate applications exceeding 100 kHz, which is crucial for techniques such as ptychography, BCDI, and XPCS. The SELUN features a 192 x 192-pixel array, each 100 µm in size, which creates a 19.2 mm x 19.2 mm active area. With advanced front-end electronics
and an instant retrigger capability, it supports non-paralyzable counting at rates over
20 Mcts/pixel/s. Moreover, when configured to a 2x2 digital binning mode, and a novel floating point compression, SELUN can achieve frame rates surpassing 100 kHz.
Simultaneously, we have developed the PILATUS4 detector to accommodate applications requiring larger active areas. Ideal for scanning powder XRD, XRD-CT, time-resolved XRD, scanning XRD, and SAXS, these detectors offer up to 4 million pixels with a 150 µm pixel size covering an active area of 311×327 mm^2. They can operate up to 2 kHz in 16-bit mode and 4 kHz in 8-bit mode, with minimal dead-time of 100 ns, ensuring an effective duty cycle of over
99.9%.
Such a high frame rate and the high detection efficiency at high energies are also a critical specification for imaging systems used in industrial applications such as battery inspection, where the performance of the imaging device must sustain the high throughput of modern gigafactories. PILATUS4 features four energy discriminating thresholds, which can also be employed for spectral imaging and tomography. Successful examples of this include the simultaneous discrimination of multiple contrast agents in preclinical settings.

Beamlines and Facilities / 45

Beamlines of the EuPRAXIA@SPARC_LAB X-ray FEL facility

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The Free-Electron Laser facility of the EuPRAXIA@SPARC_LAB infrastructure is driven by an electron beam with 1 GeV energy, produced by an X-band normal conducting LINAC followed by a

plasma wakefield acceleration stage, and consists of two beamlines.
The AQUA beamline aims at delivering selectable polarization photons in the 3-4 nm, water window wavelength range, by means of APPLE-X permanent magnet undulators.
The second beamline, called ARIA, is going to operate in a High Gain Harmonic Generation seeded configuration, able to produce coherent and tunable pulses with applications in the 50-180 nm wavelength range.
Performance associated to both beamlines is investigated and discussed.

Detectors and Detection Techniques / 46

Development of hybrid pixel detectors for photon science at the Paul Scherrer Institut

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Hybrid pixel detectors (HPDs) consist in a sensor absorbing the X-ray radiation, usually silicon, connected to the CMOS readout electronics, that processes the signal generated by the sensor signal on a pixel by pixel basis. They were spinned-off from high energy physics tracking applications to photon science at the beginning of the millennium, and they managed to be disruptive in both fields. PSI was one of the first research institutes to develop big size detectors for synchrotron and, successively, for X-Ray free electron lasers (XFELs) applications, which are now present in many facilities around the world. Single photon counting (SPC) HPDs, where every incoming photon is discriminated and counted, are well established at synchrotrons for diffraction applications. However, new needs are appearing at present, in particular with the increasing number of 4th generation synchrotrons, which challenge the state-of-the-art of present SPC detectors: detect low energy photons (<2keV),increase spatial resolution, allow for a higher flux of incoming photons. Additionally, SPCs cannot be used at FELs, where all the photons arrive simultaneously and cannot be counted individually.
In Charge integrating (CI) HPDs,the charge produced by all impinging photons is accumulated per pixel and successively digitized in number of photons. They solve already several of the problems connected with SPCs and, in low illumination conditions, can also provide information on the X-ray energy of the photons. Additionally, this analog information provided by CIs in low illumination can also be used to increase position resolution exploiting charge diffusion to interpolate the photon position at the level of a few microns.
However, they must be equipped with circuitry able to dynamically trade off noise versus dynamic range as the signal builds up in the pixel. Additional challenges come from their high data throughput and their complex calibration.
HPDs can profit from advances in the readout electronics, but this would not be enough to face all the modern challenges of photon science. However, they have the big advantage that the same frontend chip can be bump-bonded to different sensor materials. This way, the huge advancement in sensor research can contribute to the development of detectors that meet the required specs.In particular, sensors with improved quantum efficiency are under development, optimizing a shallow entrance window for soft X-rays or exploiting heavier material than silicon for higher energies (e.g, GaAs, CdTe or CdZnTe). Additionally, sensors with internal amplification (LGADs) can improve the signal-to-noise ratio of low energy photons and allow HPDs to be operated also in the soft X-ray energy range.
This talk presents the challenges of detector development for photon science, and how they have been addressed by PSI. Special emphasis will be given to the detector generations in development at present, to be deployed at the new X-ray sources.

Fundamental Physics / 47

Novel CZT Detectors for kaonic atoms spectroscopy

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Kaonic atoms spectroscopy provides essential observables for investigating low-energy strong interactions in systems with strangeness. I shall present an overview of the SIDDHARTA-2 collaboration's efforts in this field, with a particular focus on the development and first use of a novel Cadmium-Zinc-Telluride (CZT) detector system for studying intermediate-mass kaonic atoms.
This innovative detection system, applied for the first time in fundamental physics research at a collider, extends the accessible energy range of kaonic atoms spectroscopy to the hundreds of keV. Initial tests have demonstrated that its excellent energy resolution, efficient background rejection, and precise timing capabilities make it highly suitable for exotic atom measurements.
During the first data-taking campaign at the DAΦNE collider in Italy, the collaboration successfully measured kaonic fluorine and kaonic aluminium transitions, highlighting the detector's potential for advancing kaonic atom studies. These results pave the way for further applications at DAΦNE and J-PARC in Japan.
Ultimately, these developments aim to refine our understanding of kaon-multinucleon low-energy strong interactions by enabling high-precision measurements of intermediate-mass kaonic atoms.

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NI Platforms in High Precision X-Rays Measurements

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Short introduction of NI (National Instruments) hardware and software platforms for X-Rays measurements. Short overview of case studies within this specific application area

Detectors and Detection Techniques / 49

X-ray spectroscopy of exotic atoms using TES microcalorimeters

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Multi-pixel arrays of TES microcalorimeters have significant potential for various scientific applications, taking advantage of their excellent energy resolution and relatively large collecting area. We are exploring a TES application at the charged-particle beamline, with a focus on X-ray spectroscopy of exotic atoms.
Exotic atoms refer to Coulomb-bound systems of a positively charged atomic nucleus and a negatively charged particle other than electrons. They can be produced by stopping negative particles in a target sample. Because of their heavier mass than an electron, ~200 times and 1000 times in the case of muons and kaons, respectively, the negative particle has a smaller orbital radius. In the innermost states, they are close to the atomic nucleus so as to feel quite a strong electric field, the nuclear size effect, and the strong force in the case of hadrons such as kaons. One difficulty in the exotic-atom experiments is the beam's limited quality, which results in a low X-ray counting rate. Thus, a TES microcalorimeter array is a good option for precision X-ray measurement.

So far, we have performed the X-ray spectroscopy of pionic, kaonic, and muonic atoms using NIST-developed TES spectrometers equipped with 20 keV, 50 keV, and 100 keV arrays. The obtained science

results range from nuclear physics to fundamental physics, atomic and molecular physics.
In this contribution, I aim to provide an overview of our project and discuss the challenges and future directions for these microcalorimeter applications in accelerator facilities.

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Development of a Next-Generation Focal Plane Photoelectron Track X-ray Polarimeter with Timepix3 Readout

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Astrophysical X-ray polarimetry is a powerful technique for probing the physical conditions and emission mechanisms of cosmic X-ray sources. At energies below 50 keV, photoelectron track imaging is the leading method for measuring X-ray polarization. In this approach, the track of a photoelectron, produced when an X-ray photon is absorbed, is imaged to reconstruct its initial emission direction. Since photoelectrons are preferentially emitted along the direction of the X-ray's linear polarization, this allows direct determination of the polarization state. These detectors are hybrid systems that integrate a gas cell for photon absorption, a gas amplification stage, and a pixelated readout for detailed track imaging. Gas detectors are preferred over semiconductor-based detectors, as photoelectron tracks in semiconductors are typically too short to resolve with standard pixel sizes.
We present the development of a new generation of photoelectron track imaging detectors utilizing the Timepix3 pixel readout chip. This advanced technology enables three-dimensional track imaging and reconstruction by exploiting the relative timing between pixel hits, significantly improving the accuracy of polarization measurements. In addition, the sparse readout and low deadtime capabilities of Timepix3 allow the detector to operate under high count rate conditions, enabling potential integration with high-throughput X-ray optics. The gas amplification stage is implemented using a Micromegas structure. Two gas mixtures are used to span different energy ranges: dimethyl ether (DME) for 2–8 keV and argon-based mixtures for 6-35 keV.

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Low power , small spot X Ray sources for elemental and chemical analysis

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Oxford Instruments X-Ray Technology is a global leader in the design and manufacture

of integrated X-ray solutions. Their low power X-ray tubes feature high stability, high X-ray flux

and small spot sizes and are used for elemental and chemical analysis, particle analysis, Inspection, both XRD and XRF and radiography.

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Welcome from the INFN Director and the organizers

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Young Researcher Contest Award

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Arrays of cryogenic microcalorimeters for high precision x-ray and gamma-ray measurements

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Outgassing and surface contamination studies for XH - a HPGe microstrip sensor

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