High Precision X-Ray Measurements 2023

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Laboratori Nazionali di Frascati INFN

Book of Abstracts

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XRD spectra of Algerian porcelain

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Porcelains represent the basis of the ceramic discipline. The compositions for the different types of industrial porcelain are presented graphically as part of the K_2O-Al_2O_3-SiO_2 phase diagram. This work presents a study conducted on four porcelain formulations. Compositions made by mixing materials such as kaolin, quartz, potassium feldspar and talc were studied. Results of a study are presented to determine how the type and proportion of each raw material in the starting mixture affects the porcelain phase. The extent of the above physicochemical transformations can vary considerably depending on the properties of the starting materials. These can cause significant changes in the properties of the fired product.

The crystalline phases of formulated porcelain are the same as found in certain porcelains. Many reactions observed with the individual raw materials were also observed in the mixture. The main variations relate to (i) crystallization of cristobalite is observed only in the kaolin and not in the mixture, where the silica precipitated from the reaction to form mullite from metakaolinite is readily incorporated into the alkaline amorphous phase; (ii) quartz is only temperature stable but tends to partially decompose on contact with the alkaline melt in the mixture; and (iii) in illite-rich clay, the melting of the system and subsequent expansion caused by pyroplastic deformation of the K-rich melt begins at a relatively low temperature.

Quartz is a residual mineral from the original raw materials, and mullite, formed during firing. Porcelain fired bodies generally contain a single mullite phase, $3Al_2O_3.2SiO_2$, evolution pathway: the dehydroxylated kaolin, metakaolin, transforms into a nonequilibrium unstable spinel type structure, which converts to mullite above 1075 ℃. In aluminous porcelain, corundum is observed in addition to quartz. Furthermore, X-ray analysis indicated that no significant effect on mullitisation was observed in talc formulation. Addition of talc had little effect on the mullite content of the fired body. However, talc contributes greatly to the increased formation of a glassy matrix.

Summary:

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Application Specific Integrated Circuits in large format hyperspectral imaging radiation detectors for space-borne instrumentation

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The observation of X- and γ-ray emissions coming from the deep space is fundamental for the study of matter under extreme conditions of gravity and for the understanding of the early Universe. Due to the absorption of X-/γ-rays in the atmosphere, the realization of high spectroscopic-resolution and high-granularity radiation detectors with large format focal planes is made even more challenging by the strict constraints that characterize the design of space-borne instrumentation. In this context, the integration of the scientific payload cannot overlook the delicate interplay between the sensors and the readout electronics, making vital the use of Application Specific Integrated Circuits (ASICs). Moving through the common ground of large format high-resolution silicon drift detectors (SDDs), the design and experimental results of mixed-signal ASICs — with ENC levels of few tens of electrons r.m.s. and with input energy range extending from 500 eV to 5 MeV — realized for different space

mission concepts, are reviewed highlighting challenges and goals of a long-standing research activity of Politecnico di Milano within the ReDSoX collaboration.

Summary:

X-ray beam facilities / 40

The EuAPS betatron photon beam: ultra-bright light pulses for imaging and spectroscopy

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The EuPRAXIA Advanced Photon Sources (EuAPS) project, led by INFN in collaboration with CNR and the University of Rome Tor Vergata, foresees the construction of a laser-driven "betatron"X-ray user facility at the LNF SPARC_LAB laboratory [1]. EuAPS has received financial support from the Italian PNRR plan for the creation of a new research infrastructure.
While the EuPRAXIA@SPARC_LAB facility [2] will provide the Laboratori Nazionali di Frascati (LNF) with a unique combination of a high-brightness GeV-range electron beam accelerated by a state-of-the-art X-band RF linac, a 0.5 PW class laser system and an ultimate soft X-ray FEL light source [3] driven by a plasma accelerator, the EuAPS project, still using the plasma acceleration, will move in the direction of a pulsed X-ray beam having a continuous energy spectral range from soft to hard X-rays [4,5].
The foreseen applications of the betatron photon source [6], which include ultrafast, time-resolved imaging and spectroscopy measurements on a variety of samples, both biological and inorganic, providing information about their structure and dynamics will be described.

[1] https://euaps.infn.it/
[2] M. Ferrario et al. Nucl. Instrum. Methods Phys. Res. Sect. A 909, 134-138 (2018).
[3] A. Balerna et al. Condensed Matter 4: 30 (2019).
[4] A. Curcio et al. Phys. Rev. Accel. Beams 20 012801 (2017).
[5] A. Curcio, et al., Nucl. Instrum. Methods Phys. Res. Sect. B 388 (2017).
[6] F. Stellato et al. Condensed Matter, 7, 23 (2022).

Summary:

X-ray applications in various fields / 41

Influence of solution parameters on the XRD studies and optical constant of CeO2 films

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Cerium Oxide (CeO_2) is an n type semiconductor with a high bandgap (3.2eV) , the material is highly transparent in visible region (400-700nm). Although CeO_2 is diamagnetic, it shows ferromagnetic properties when it is reduced to a nano level. CeO_2 has used widely applications such as gas sensors, energy storage devices, fuell cells, solar cells and optoelectronic devices. CeO_2 can be fabricated by various production methods such as spray pyrolysis, pulsed laser deposition, sputtering and sol-gel spin coating. The sol–gel spin coating method has distinct advantages such as cost effectiveness, transparent, multicomponent oxide layers of many compositions on various substrates, simplicity,

excellent compositional control and lower crystallization temperature.
In this study, CeO2 films using solutions prepared in different solution parameters [(citric acid molarity and Ce concentration (0,05; 0,1; 0,15; 0,2)], were prepared by sol–gel process using a spin coating technique onto glass substrates. The precursor solution was prepared by dissolving cerium chloride and citric acid in methanol. The coating solution was dropped into glass substrate, which was rotated at 2000 rpm for 30 s using a LAURELL WS-400B-6NPP/ LITE spin coater. After the deposition, the film was dried at 90 oC for 10 min into a furnace to evaporate the solvent and remove organic residuals. The procedures from coating to drying were repeated nine times. The film was then inserted into a tube furnace and annealed in air at 500oC for 1 h.
X-ray diffraction pattern was obtained with a RIGAKU RINT 2200 Series X-Ray Automat-ic Diffractometer using the CuKa radiations (⊠⊠= 1.54059 Å) in the range of 2⊠ between 20 and 80. The diffractometer reflection was taken at room temperature. The crystal structure and orientation of CeO2 nanostructured thin films have been investigated by X-ray diffraction (XRD) method. The XRD result suggests that the film has the cubic CeO2 crystal structure having polycrystalline structure. The films was crystallized with the hexagonal wurtzite structure. The lattice constants, crystalline size and preferred orientation of the films were calculated from X-ray data.
The optical measurement of the film was carried out at room temperature using a SHIMADZU 2450 spectrophotometer in the wavelength range from 200 to 900 nm including an integrating sphere attachment with using barium sulfonate (BaSO4) as reference. The optical band gap, Urbach energy and optical constants (refractive index, extinction coefficient, real and imaginary parts of the dielectric constant) of the film were determined.
Acknowledgements:
This work was supported by Eskisehir Technical University Commission of Scientific Research Projects under Grant No. 22ADP0278.

Summary:

X-rays in nuclear physics / 42

The KAMEO proposal: Nuclear resosnance effects in kaonic atoms

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The nuclear E2 resonance effect occurs when atomic de-excitation energy is closely matched by nuclear excitation energy. It produces an attenuation of some of the atomic x-ray lines from resonant versus normal isotope target. The investigation of the nuclear E2 resonance effect in kaonic ticklish atoms could provide important information about strong kaon nucleus interaction. In the past, only $K^- - ^{98}_{42}Mo$ nuclear resonance effect was measured by G. L. Goldfrey, G- K. Lum and C. E. Wiegand at Lawrence Berkeley Laboratory, in 1975. The nuclear E2 resonance effect was observed, but 25 hours of data taking resulted not enough for a conclusive result.
The E2 nuclear resonance effect is expected to occur in four kaonic Molybdenum isotopes ($^{94}_{42}$Mo, $^{96}_{42}$Mo, $^{98}_{42}$Mo, and $^{100}_{42}$Mo) with similar energy values. The KAMEO (Kaonic Atoms Measuring Nuclear Resonance Effects Observables) proposal plans to study this effect in these isotopes at the DAΦNE Φ factory during the SIDDHARTA-2 experiment. KAMEO will use four solid strip targets, each enriched with a different Molybdenum isotope, and expose them to negatively charged kaons produced by Φ meson decays. The X-ray transition measurements will be performed using a high-purity germanium detector, and an additional solid strip target of non-resonant $^{92}_{42}$Mo isotope will be exposed and used as a reference for standard non-resonant transitions. This experiment would provide the first measurements of nuclear resonance effects in 4 isotopes of kaonic molybdenum, with needed precision for conclusive results, and a unique opportunity to study kaon-nucleus strong interaction in kaonic ticklish nuclei.

Summary:

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characterization and quantification of clay minerals by x-ray diffraction

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The work carried out is part of a global study carried out on the marly-clay formations of Tizi-Ouzou. Indeed, marls known as "evolving materials" exhibit very specific behaviors which evolve differently over time, particularly in the presence of water.
this work tends to the mineralogical characterization of these marly formations of the Tizi Ouzou basin, the typology and the quantification of clay minerals based on X-ray spectroscopy.
it is a non-destructive technique and allows us to recognize the symmetry of the crystal, to determine its structure, the parameters of its lattice and to identify the crystal. The results obtained following the processing of the samples by the XRD made it possible to characterize and identify the nature and the mineralogical composition. And classified them according to the content of calcite and clay minerals based on Jung's classification. Most of the samples are classified as much as clay limestones, marls and clay-limestone. So we conclude that the marls of the region of study are formed mainly of carbonates.

Summary:

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High frame-rate detectors for hard X-ray applications

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Two new ASICs have been developed for the readout of CdZnTe and similar detectors materials used for hard X-ray measurement. Although the two ASICs are targeted at different applications and use different CMOS process nodes, they implement the same concept of utilising in pixel digitisation and Gbps scale serialisers to operate at high frame rates. A common DAQ design is employed to aggregate the high data bandwidths and convert raw data into manageable, processed data formats in FPGAs. The design, performance and applications will be presented.

HEXITEC-MHz is a hyperspectral X-ray detector that measures the energy of each individual X-ray photon up to 300keV with a <1keV FWHM energy resolution. Each detector has 80x80 pixels on a 250µm pitch with an integrating amplifier with correlated double sampling. Each 2x8 pixels

share a ramp-based TDC with 12-bit resolution. Every 4 columns are readout on independently controlled 4.1 Gbps serialisers with Aurora encoded 64b66b data. The 180nm CMOS process ASIC operates with a 1MHz frame rate and in conventional operating modes, measuring 1 photon per 3x3 pixels to be able to reconstruct charge sharing events, provides a count rate of ~10⁶ photons/mm²/s. Results from CdZnTe and p-type Si detectors will demonstrate the <1keV FHWM energy resolution and the ability to integrate multiple monochromatic photons in a frame and measure ~10⁸ photons/mm²/s.

DynamiX is an to measure the large intensity signals from 4th generation synchrotron facilities such as the proposed, Diamond II. A first test structure ASIC has been manufactured with 16x16 pixels on 110µm pitch with a view to scaling to 192x192 pixels in the future. The ASIC uses a two-stage charge cancellation design. The first "coarse stage"is optimised to cancel 25 photons at 25 keV at rates >100MHz with an 8bit counter. The second "fine stage"is designed to subtract charge at 0.2 photon segments with a 7bit counter. An "out of range"bit is included to give a 16bit value per pixel. The final operating mode will use the synchrotron RF clock (499.96 MHz) to drive and synchronise the ASIC with an integration time of 1.82µs, matching the rate of 1 turn of Diamond. At this 533kHz frame rate, the counting capability is ~10¹¹⁻¹²photons/mm²/s. The data is output on similar serilaisers to HEXITEC-MHz, with 64b66b aurora encoded which can reach 14Gbps in the 65nm process. The ASIC is programmable so that other energy X-rays, charge cancellation magnitudes and frame rates can be selected. The first test ASIC will be used to continuously readout CdZnTe detectors at up to ~10¹² photons/mm²/s and verify that the detector material is stable and suitable for these extreme applications in photon science.

Summary:

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The EuPRAXIA@SPARC_LAB project: a plasma-based accelerator user facility for the next decade

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The EuPRAXIA@SPARC_LAB facility is the beam driven pillar of the EuPRAXIA project which is expected to provide by the end of 2028 the first European Research Infrastructure dedicated to demonstrating usability of plasma accelerators delivering high brightness beams up to 1-5 GeV for users.
Among the possible EuPRAXIA@SPARC_LAB applications the realization of a short wavelength Free Electron Laser (FEL) able to provide radiation in the "water window"of the e.m. spectrum for bio-physical investigations is one of its main goals. Another interesting X-ray radiation source based on betatron radiation will be implemented by the end of 2025 in the framework of the PNRR initiatives. In addition the production of high-quality electron beam as the one required to drive an FEL is expected to be also a fundamental milestone towards the realization of a plasma driven future Linear Collider (LC).
In this talk we report about the recent progress in the context of the EuPRAXIA collaboration with reference to the recent breakthrough results obtained at the test facility SPARC_LAB at INFN-LNF and the new perspectives offered by the Italian Next Generation Eu program (PNRR).

Summary:

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Characterisation and optimisation of laser-wakefield betatron emission for imaging applications - Part I

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A unique aspect of high intensity laser plasma interactions (LPI) is the ability to generate broad ranges of energetic radiation by tuning the target and laser conditions. The different radiation types share a common set of characteristics, they are short pulse (sub-ps), emanate from a small source (100nm-100um), and can be tuned by altering the laser parameters or target conditions. For laser-wakefield betatron emission we expect the x-ray energies to be ~10-100 keV and emanate from a sub-micron source size with narrow collimation. This bright, directional, and energetic source of x-rays is highly applicable to radiography and has been demonstrated to be capable of both X-ray CT and phase contrast imaging. New facilities, such as the Extreme Photonics Applications Centre (EPAC) at the CLF, are looking to utilise these sources for industrial applications, combining the increased repetition rate of the new laser facilities with the penetrative imaging of laser-driven sources.

With laser-wakefield interactions we are able to tune the x-ray energies and flux by altering the gas channel (length and density) [1], or the laser conditions (focus and temporal profile) [2]. Recent work has also demonstrated the ability to maximise the emission using a Bayesian optimisation processes on all parameters simultaneously [3]. We can apply this flexibility to secondary applications instead and determine the optimum spectra required for different samples and detectors, and therefore look to tune the source as required.

[1] J. Wood. Betatron radiation from laser wakefield accelerators and its applications. Diss. Imperial College London, 2016.
[2] SJD. Dann, et al. Physical Review Accelerators and Beams 22, 041303 (2019)
[3] RJ. Shalloo, et al. Nat Commun 11, 6355 (2020).

Summary:

X-ray detectors / **47**

Hard X-ray applications of the HEXITEC hyperspectral detector

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HEXITEC is a hard X-ray detector that measures the energy of every X-ray interaction and presents the accumulated data over many frames as a spectrum per pixel. This full spectral information has become known as "colour"or "hyperspectral"X-ray imaging.

HEXITEC is based upon an ASIC manufactured in a 0.35µm CMOS process. It has 80 x 80 pixels on 0.25mm pitch with each pixel containing a charge sensitive amplifier, shaping amplifiers and peak hold circuit. The held voltage on the pixel is directly proportional to the energy measured on that pixel. The ASIC employs a rolling row readout to readout each pixel in turn with a frame rate of up to 9kHz. The ASIC is typically operated with fewer than 1 in 3x3 pixels measuring an X-ray per frame so that charge sharing events can be identified and corrected. The ASIC is gold stud and silver epoxy bonded to detector material including CdTe, CdZnTe and p-type Si with a matching array of 80x80 pixels and mounted on a mechanical block to form a detector module. The module is wire bonded to a PCB on one edge so that it can be tiled with a dead space of two pixels on three sides. The module PCB connects to readout electronics that digitise the signal, corrects for dark levels and provides the clock to operate the ASIC. The readout electronics are available as a single detector, 2x2 or 2x6 camera system. HEXITEC achieves <1 keV FWHM at 60 keV when operated in the range of 3 to 200 keV and can be used in a lower gain modality that will go to 600keV with a slight reduction in energy resolution.

HEXITEC has many applications where the hyperspectral X-ray measurements can provide additional information. In transmission X-ray imaging the energy spectra can be used to identify elements from their absorption edges or to distinguish between different tissue types in mammographic imaging. Full field of view X-ray fluorescence imaging has been demonstrated with a pinhole camera configuration with the aim of observing the elemental distribution during metal alloy solidification. Simultaneous energy and angular dispersive measurements have been made which show the ability to identify materials using standard X-ray tubes with applications in security screening. HEXITEC has been used in Compton scattering imaging, a synchrotron technique to infer the charge density of a material and has been used for in-situ imaging of battery charging and discharging. The fine energy resolution of HEXITEC is finding use as a prototype SPECT imaging camera for new theragnostic imaging modalities. The combination of many energy resolving pixels operating independently has found uses in characterising new laser driven radiation sources and some of their potential applications.
The detector operation and a selection of applications, developed with many collaborators from around the world, will be presented.

Summary:

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Measuring the temperature of X-rays with superconducting detectors

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Low Temperature Detectors (LTDs) are thermal detectors that are operated at cryogenic temperatures and measure the energy deposition via conversion to heat. Unlike HPGe, their spectral resolution is not limited by the statistics of charge creation and collection, and they can thus achieve exceptional energy resolutions.
This performance comes at a price. The cryogenic environment (the working temperature of LTDs can be as low as few tens of mK) alongside their small collection area dictate a tradeoff between dead-time and the complexity of readout.
Among all the types of LTDs, superconducting Transition Edge Sensors (TES) combine the superior resolving power of wavelength dispersive techniques (the energy of single photons can be measured with resolving powers E/ΔE > 10^3 in the case of x-rays) with a large collection capability, a relatively high speed and established multiplexing schemes.
In this contribution I will introduce the working principles of a TES and their applications in the field of X-rays spectroscopy. In particular, I will present the design and performance of fast TESs, designed for neutrino mass measurement, but fully characterized by an external soft X-rays source.

Summary:

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Science and technology of laser-driven X-ray sources at ELI Beamlines

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X-ray sources driven by femtosecond lasers with high peak power provide compact alternatives to large-scale facilities such as synchrotrons and X-ray Free electron lasers. ELI Beamlines facility is devoted to providing various beamlines of laser-driven X-rays and accelerated particles to the user community [1]. While the X-rays sources driven by kHz lasers such as high-order harmonic beamline [2] and plasma X-ray sources [3] have entered the operation phase with regular experiments performed together with external users, the sources driven by PW-class L3 laser [4] are about to be commissioned soon.
In this contribution, I will provide a review of the technical implementation of the laser-driven X-ray sources and present selected results from recent application experiments.

1. B. Rus et al. "Outline of the ELI-Beamlines facility", Proc. SPIE 8080, 808010 (2011).

2. O. Hort et al., "High-flux source of coherent XUV pulses for user applications", Opt. Exp. **27**, 8871 (2019).

3. J. Nejdl et al, "Progress on laser-driven X-ray sources at ELI Beamlines", Proc. SPIE 11111, 111110I (2019).

4. U. Chaulagain et al. ELI Gammatron Beamline: A Dawn of Ultrafast Hard X-ray Science, Photonics **9** (11), 853 (2022)

Summary:

X-ray applications in various fields / 50

X-ray imaging using compact light sources - Part II

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From liquid metal jet to laser driven x-ray sources, a variety of new, compact x-ray sources are emerging in between the gold standard of synchrotron facilities and the widely used standard laboratory x-ray sources.
Translating, adapting, or redesigning x-ray imaging techniques specifically for these novel sources is paramount to achieve the best performance and serve the society by providing new tools for science, industry, security, and education.
We present here some preliminary results of application of different x-ray techniques at these novel sources, and we describe the challenges, possible solutions and future perspectives.

Summary:

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Controlling protein orientation in gas phase using strong electric fields

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Single particle imaging is a set of emerging techniques that utilize ultrashort and ultraintense X-ray pulses to generate diffraction from single isolated particles in the gas phase to determine their structures. However, one of the main challenges of this approach is the unknown orientation of the individual sample molecules at the time of exposure, which makes structure determination computationally demanding and, in some cases, impossible.
Proteins often have nonzero electric dipole moments, making them interact with external electric fields and offering a means for controlling their orientation. Through classical and ab initio molecular dynamics simulations, we identify a range of electric field strengths that allow for successful orientation of proteins without altering their structure. Additionally, we demonstrate that orientation information is crucial for successful structure determination in various experimentally relevant cases. Our findings suggest that non-destructive field orientation of intact proteins is a viable method that opens up new avenues for structural investigations using single particle imaging.

Summary:

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Claims of Priority - The scientific path to the discovery of X-rays

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Shortly after Röntgen's publication about a new kind of rays, a dispute about priority claims began. Röntgen was not the first researcher to produce X-rays nor the first to take X-ray images. An analysis of the history of cathode ray research in the 19th century reveals ample evidence that researchers before Röntgen had already produced X-rays, albeit without knowing this. Most of them, for their part, did not claim any priority, some did so rather casually. The German-Hungarian physicist Philip Lenard, a co-founder of German Physics, considered himself a "true discoverer". It remains to be said, however, that he, like many others before him, failed to recognize the character of the new radiation. It was Wilhelm Conrad Röntgen, with his three scientific publications on X-rays, who laid the foundations for their physical clarification and paved the way for the success story of their application in a variety of fields that continues to this day.

Summary:

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Wilhelm Conrad Roentgen - The discovery of X-rays and the creation of a new medical profession

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February 10, 2023, marked the 100th anniversary of the death of Wilhelm Conrad Röntgen. Reason enough to remember the scientist who discovered a "new kind of rays" on November 8, 1895, and wrote his first scientific paper on X-rays in just six weeks of research. Two more publications were to follow, and Röntgen laid the foundation for the physical clarification of X-rays and paved the way for the success story of their application in a wide variety of fields that continues to this day. In the first year after the discovery of X-rays, a total of 49 books and brochures and 1044 scientific papers were written on scientific aspects as well as on the possible applications of the newly discovered rays. Many of these publications already dealt specifically with possible medical applications. Thus, the year 1896 plays a special role in the history of radiology due to its groundbreaking discoveries and inventions in X-ray diagnostics and also in radiation therapy.

Summary:

X-rays in nuclear physics / 54

High precision kaonic atoms X-ray spectroscopy with the SIDDHARTA-2 experiment at the DAFNE collider

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Kaonic atoms represent a unique laboratory for the study of the antikaon-nucleus interaction at threshold and investigate the low-energy quantum chromodynamics (QCD) in the strangeness sector. State-of-the-art X-ray detectors and modern experimental techniques allow to perform high-precision X-ray kaonic atoms spectroscopy, leading to fundamental input for nuclear, particle, and astrophysics research.
The SIDDHARTA-2 experiment at the INFN-LNF DAΦNE collider is currently performing a data taking campaign to carry out high-precision X-ray spectroscopy of various kaonic atoms, with a particular focus on the first measurement ever of the kaonic deuterium X-ray transitions to the fundamental level. This measurement aims to allow to determine the isospin-dependent antikaon-nucleon scattering length and contribute to our understanding of the strong interaction in the strangeness sector.
In this talk, I will present the SIDDHARTA-2 experiment, the recent results obtained during the first phase of the experiment, in particular the most precise measurement of kaonic helium X-ray Lα transition in gas and the first measurement ever of the M-type transition, as well as the first measurement of several high-n transitions in other kaonic atoms.
Finally, I will outline the prospects for the ongoing kaonic deuterium measurement and our future plans.

Summary:

X-ray in astrophysics / 55

The Italian Space Agency: X-ray technologies for astrophysics missions

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The Italian Space Agency (ASI) plays a key role in the filfilment of space missions, contributing to the scientific, technological and economic progress of our country. The agency accomplishes space experiments by collaborating with scientific and industrial entities, supporting them to the realization of new products able to achieve unprecedeted results as the fundamental information on the birth and evolution of the universe collected during the last two decades. The presentation describes the X-ray technologies developed by the synergy between the Italian Space Agency and its principal collaborators, which brought to the main scientific results achieved over the years toghether with the last advances addressed to the next astrophysic missions.

Summary:

X-rays in nuclear physics / 56

Studying fine structure in exotic atoms

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Hadronic atoms offer two main advantages for nuclear and low energy particle physics: first - studies of level shifts and widths due to strong interactions allow us to test hadron-nucleon scattering amplitudes at or below the thresholds as both particles are bound. In this way one could test properties of exotic quasi-bound-states in the two body systems, second - the atomic decay modes of these systems are a method to study the structure of nuclear surfaces. For both of these aims the studies of atomic X-rays constitute an essential part of the research.
The content of this talk is devoted to two experimental lines of research. Studies of level shifts in light K-mesic atoms performed in INFN Frascati [1] and extension of these to study the K- proton quasi-bound state. The other line is a study of (hyper) fine structure in light anti-protonic atoms . Here, the purpose is to complete the partial wave analysis and establish expected quasi-bound states in antiproton –proton and antiproton-neutron systems. This knowledge, will serve PUMA experiment proposed to study neutron haloes in unstable nuclei [2].
[1] H. Bazzi et al: Phys. Lett B 704, 103(2011) , B 714,40(2012) Nucl.Phys. A 907,69(2013)
[2] A. Obertelli , PUMA proposal at CERN

Summary:

X-ray beam facilities / 57

Activities using X-rays at DAFNE-Light

Author: Antonella Balerna[1]

Co-authors: Giacomo Viviani [2]; Lucilla Pronti [2]; Marco Angelucci [2]; Marco Pietropaoli [3]; Mariangela Cestelli Guidi [2]; Martina Romani [2]; Vittorio Sciarra [3]

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DAΦNE-Light is the INFN-Frascati National Laboratories (LNF) synchrotron radiation facility. The LNF have a longstanding tradition of using synchrotron radiation for interdisciplinary studies that started with the ADONE accelerator and is now continuing with DAΦNE. Because of its low energy (510 Mev) and high electron current (higher than 1 A) DAΦNE provides a high photon flux also in the X-ray low energy region. Together with the experiments using X-ray absorption spectroscopy (XAS) and the DAΦNE-Light soft X-ray beamline other projects are being developed using X-ray fluorescence and conventional sources. Some information on very recent activities will be given together with an overview of the facility.

Summary:

X-ray detectors / 58

Improving the time resolution of large area LaBr3:Ce detectors with SiPM array readout

Authors: Maurizio Giorgio Bonesini[1]; Roberto Bertoni[2]; Andrea Abba[3]; Francesco Caponio[3]; Marco Prata[4]; Massimo Rossella[2]

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LaBr3:Ce crystals have been introduced for radiation imaging in medical physics, with photomultiplier or single SiPM readout. An R&D was pursued with 1" LaBr3:Ce to realize compact large area detectors with SiPM array readout, aiming at high light yields, good energy resolution, good detector linearity and fast time response for low-energy X-rays.
A natural application was found inside the FAMU project at RIKEN-RAL muon facility, that aims at a precise measure of the proton Zemach radius to solve the so-called "proton radius puzzle", triggered by the recent measure of the proton charge radius at PSI. The goal is the detection of characteristic X-rays around 130 KeV. Other applications may be foreseen in medical physics, such as PET, and gamma-ray astronomy. A limiting factor, as compared to a photomultiplier (PMT) readout, is the poor timing characteristics of the detectors (especially falltime) due to the large capacity of the used SiPM arrays. With a standard parallel ganging typical risetime (falltime) of the order of 50 (300-400) ns are obtained. Long falltime are a problem in experiments as FAMU, where a "prompt" component must be separated from a "delayed" one in the signal X-rays to be detected. A dedicated R&D was pursued to settle this problem starting from hybrid ganging of SiPM cells, to development of a suitable zero pole circuit with increased overvoltage and to development of an ad-hoc electronics to split the 1" SiPM array in 4 quadrants, thus reducing the detectors' capacitance. The aim was to improve the timing characteristics, while keeping a good FWHM energy resolution. Reductions in falltime (risetime) up to a factor 3X were obtained with no deterioration of the energy resolution. A FWHM energy resolution better than 3% (8%) at the Cs137 (Co57) peak was obtained. These results compare well with the best results obtained with a PMT readout.

Summary:

X-ray detectors / 59

Potentialities of Quasi-Hemispherical CdZnTe Detectors for Hard X-ray Spectroscopy of Kaonic Atoms

Authors: Antonino Buttacavoli[1]; Fabio Principato[1]; Manuele Bettelli[2]; Andrea Zappettini[2]; Johann Zmeskal[3]; Alessandro Scordo[4]; Catalina Curceanu[4]; Florin Sirghi[4]; Leonardo Abbene[1]

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In this work, we will present the potentialities of new quasi-hemispherical CZT detectors, recently developed at IMEM- CNR Parma (Italy), for high-resolution X-ray spectroscopy of kaonic atoms. Kaonic atoms are formed when a K- is moderated inside a target until it reaches a low enough kinetic energy to be stopped, replacing one of the outer electrons and forming an exotic atom in a highly excited state. Precise and accurate measurements of the radiative X-ray transitions can provide information about the kaon nucleus interaction. In the framework of SIDDHARTA-2 and WP26 JRA8-ASTRA collaborations, we developed new quasi-hemispherical CZT detectors for measurements of hard X rays from kaonic atoms (> 20 keV). The detectors are characterized by good room temperature performance, with energy resolution FWHM of 3 % (3.7 keV) and 1.4 % (9.3 keV) at 122.1 keV and 662 keV, respectively. Preliminary tests at the DA�NE collider in Frascati (Italy) will be also presented

Summary:

X-ray detectors / 60

Development of energy-resolved X-ray scanners for contaminant detection: results from the AVATAR X project

Authors: Antonino Buttacavoli[1]; Fabio Principato[1]; Manuele Bettelli[2]; Andrea Zappettini[2]; Donato Cascio[1]; Giuseppe Raso[1]; Vincenzo Taormina[1]; Giuseppe Bertuccio[3]; Filippo Mele[3]; Jacopo Quercia[3]; Leonardo Abbene[None]

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The importance of energy-resolved photon counting (ERPC) systems for quality enhancements in X-ray images is now widely recognized. Due to the energy-dependence of the X-ray attenuation processes, spectral X-ray imaging represents a key tool for high resolution material detection and quantitative analysis, especially for medical diagnosis and non-destructive testing (NDT) in security and food industry. Recently, in the framework of the AVATAR X project (funded by the Italian Ministry for University and Research), we developed ERPC systems based on sub-millimetre CZT linear array detectors for contaminant detection in food industry. In this work, we will present the main results obtained from the developed ERPC prototypes, in terms of both detector and X-ray imaging performance.

Summary:

X-ray in astrophysics / 61

The Cryogenic Anticoincidence detector for the new Athena X-IFU instrument: a program overview.

Author: Claudio Macculi[1]

Co-authors: Andrea Argan [2]; Matteo D'Andrea [1]; Simone Lotti [1]; Gabriele Minervini [2]; Luigi Piro [1]; Lorenzo Ferrari Barusso [3]; Edvige Celasco [3]; Giovanni Gallucci [3]; Flavio Gatti [3]; Daniele Grosso [3]; Manuela Rigano [3]; Fabio Chiarello

[4]; Guido Torrioli [4]; Mauro Fiorini [5]; Michela Uslenghi [5]; Daniele Brienza [6]; Elisabetta Cavazzuti [6]; Simonetta Puccetti [6]; Angela Volpe [6]; Paolo Bastia [7]

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Athena (Advanced Telescope for High Energy Astrophysics) is an ESA Large Class mission, at present under a re-defnition "design-to-cost"phase, planned to a prospective launch at L1 orbit on 2nd half of 2030s.
It will be an observatory alternatively focusing in its focal plane 2 complementary instruments: the X-IFU, a TES-based kilo-pixel array able to perform simultaneous high-grade energy spectroscopy (~ 3eV@7keV) and imaging over 4' FoV, and the WFI, having good energy spectral resolution (~ 170eV@7keV) and imaging on wide 40'x40' FoV.
Athena will be a truly transformational observatory, operating in conjunction with other large observatories across the electromagnetic spectrum available in the 2030s like ALMA, ELT, JWST, SKA, CTA, etc…, and in multi-messenger synergies with facilities like LIGO A+, Advanced Virgo+, LISA, IceCube and KM3NeT.
The italian team is involved in both the instrument, having in particular the co-PIship of the cryogenic instrument for which has to deliver the TES-based Cryogenic AntiCoincidence detector (CryoAC) necessary to guarantee the X-IFU sensitivity which is degraded by primary particle background of both solar and galactic cosmic ray (GCR) origins, and by secondary electrons produced by primaries interacting with the materials surrounding the main detector. Indeed, Geant4 studies outcome the necessity to adopt both active and passive techniques to guarantee the residual particle background at 5E-3 cts/cm^2/s/keV level in 2-10 keV scientific bandwidth. The CryoAC is a four-pixel detector made of Si-suspended absorbers sensed by IrAu TESes placed at < 1 mm below the main detector.
After a brief overview of the Athena mission, we will report on the particle background reduction tecniques highlighting the impact of the Geant4 simulation on the X-IFU focal plane assembly design, then a broader discussion on the CryoAC program in terms of detection chain system requirements, production, test and programmatics.

Summary:

X-ray detectors / 62

Energy-resolved X-ray imaging and contrast enhancements in CZT detectors for contaminant detection.

Authors: Vincenzo Taormina[1]; Antonino Buttacavoli[2]; Donato Cascio[1]; Fabio Principato[1]; Giuseppe Raso[1]; Manuele Bettelli[3]; Andrea Zappettini[3]; Leonardo Abbene[None]

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Recently, in the framework of the AVATAR X project (funded by the Italian Ministry for University and Research), we developed energy-resolved photon counting (ERPC) X-ray scanners based on CZT detectors for contaminant detection in food industry. In this work, we will present the results from the analysis of energy-resolved X-ray images from CZT linear array detectors. The key steps of image processing and energy-resolved analysis in contrast-to-noise ratio (CNR) enhancements will be discussed. The benefits of a new energy-resolved X-ray imaging approach, termed window-based energy selecting, in the detection of low and high density contaminants are also shown.

Summary:

X-ray applications in various fields / 63

Design and use of portable X-ray fluorescence devices for the analysis of heritage materials

Authors: Adolfo Esposito[None]; Astrik Gorghinian[1]; Daniele Chiti[2]; Federico Chiarelli[2]; Marco Ferretti[3]; Maurizio Chiti[4]; Raffaella Donghia[2]

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X-ray fluorescence (XRF) is a successful technique frequently used for the elemental analysis of cultural heritage materials. It is non-invasive, equipment can be miniaturized and made portable and it allows addressing crucial issues such as fabrication technology, authenticity and provenance of the artefacts.
Depending on components'selection (i.e. the primary source, the detector and the focusing optics, if present), the analytical performance and the consequent suitability to investigate a given class of materials may vary considerably. The present paper discusses the analytical performance - with special regard for the limits of detection and the quantification uncertainty - of two portable XRF spectrometers developed within a collaboration between INFN-LNF-FISMEL and CNR-ISPC. The devices are expressly designed for heritage materials. In particular, one is equipped with focusing optics and is intended to analyse small details on glasses and pigmented surfaces, whereas the other has a 70 kV X-ray tube, which highly improves sensitivity for medium-Z elements, important in copper-based artefacts.
Finally, the paper discusses two case studies, significant to highlight the features of the instruments: one is about Etruscan glass beads and the other about pre-historical copper-based artefacts from Tyrrhenian Central Italy. Thanks to the small size of equipment, both investigations could be easily carried out in situ that is, the Museo Nazionale Etrusco at Villa Giulia in Rome and the Museo della Preistoria della Tuscia e della Rocca Farnese at Valentano.

Summary:

X-ray beam facilities / 64

X-ray detectors at the European XFEL: user operation and optimization

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The European XFEL facility started operation in 2017 and provides 10 Hz trains of unpreceded high brilliance X-ray pulses at MHz repetition rate to seven different experimental end stations. Such unique beam delivery capabilities provide new research opportunities in numerous fields and namely Biology, Chemistry, Material Science but also Physics and Astrophysics. The megahertz operation combined with the high photon intensity required the development of specific X-ray detectors to complete the detectors already available on the market. Those specific detectors show namely low noise, high dynamic range and the capability to store hundreds of frames in the front-end electronics. Using those new detectors in the framework of a user research facility that requires high quality experimental data, multiple operation modes and long run reliability is challenging and needs a strong commitment of detector experts to ensure successful user experiments.
We organized the detector expert teams'effort around three main axes: before the beamtime, according to the experiments' specifications, they calibrate the detectors and set up the required operating scenarios. During the beamtime they provide support to ensure the success of the user experiment data taking. After the beamtime, based on the Instruments Scientists feedback, they propose and conduct improvements. The presentation describes the state-of-the-art X-ray detectors at the European XFEL, namely the implemented technologies, their scientific usage and how reliable detector operation and high-quality scientific data production for our users is ensured.
Pre-beamtime overall tests sessions are implemented after the European XFEL maintenance periods. Those sessions, combined with our Data Operation Center - providing direct expert support during the user experiments - increased the reliability of the detector experimental setups. In addition, the analysis of the user experiments feedback permitted to implement new detector features and operating modes.
The effective work on the support to experiments and the instruments scientists feedback improves the detector data quality we provide to our users and is therefore a major priority. To answer the new research challenges, our detectors are also in constant evolution and new development projects are starting to move towards higher photons energies and continuous beam delivery at MHz repetition rates.

Summary:

X-ray applications in various fields / 65

Investigating Metals'Content and Oxidation States in Edible Liquids using XRF Analysis with VOXES X-ray Spectrometer

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X-Ray Fluorescence (XRF) is a valuable analytical technique for investigating the properties of metals. The MITIQO project is focused on using XRF to identify the metals' content and oxidation states in various edible products, with a particular emphasis on liquids such as wine and oil. In this study, we showcase the MITIQO experimental apparatus at the INFN laboratory of Frascati, based on the VOXES X-ray spectrometer, with a focus on the identification of the oxidation state of Iron. As a first outcome of the project, we demonstrated the capability of MITIQO to establish the correct oxidation state of the Iron present in a liquid sample. This research opens up new possibilities like using XRF to analyze the concentration and oxidation state of metals in edible liquids, which has important implications for food safety and quality control.

Summary:

X-ray detectors / 66

Investigation of Platinum contacts on High-Flux CdZnTe

Authors: Manuele Bettelli[1]; Oriane Baussens[2]; Silvia Zanettini[3]; Francesca Casoli[1]; Lucia Nasi[1]; Giovanna Trevisi[1]; Cyril Ponchut[2]; Marie Ruat[2]; Antonino Buttacavoli[4]; Fabio Principato[5]; Leonardo Abbene[5]; Andrea Zappettini[1]

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With the rise of 4^{th} Generation Synchrotron Light Sources such as the Extremely Brilliant Source (EBS) of the ESRF, the need for direct X-ray detection under high photon flux with moderate to high energies ($30 - 100\ keV$ range) has increased. Moreover, multiple medical imaging companies that build prototypal Computed Tomography (CT) scanners need to innovative material able to withstand to extremely high photon fluxes. One of the candidate materials for these applications is Cadmium Zinc Telluride (CdZnTe or CZT). Thanks to its high atomic number ($Z = 50$) and its bandgap value ($1.57\ eV$), the CZT allows to realize spectroscopic detector able to operate at room temperature and with high stopping power also with high energy radiation (5 mm of CZT can absorb $> 99\ \%$ of $100\ keV$ photons). Furthermore, the novel CZT material developed by Redlen for high-flux applications (HF-CZT) seems promising as it limits the polarizing phenomena observed in standard CZT under high photon flux.
However, the novel high-flux CdZnTe showed a different behavior with respect to the standard grade when combined with gold electroless contacts. While they typically resulted in blocking contacts with very low dark leakage current on standard low-flux CZT, they led instead to high leakage current even at low biasing on high-flux material.
In this work, a detailed study on the behavior of platinum and gold contacts is shown. The behavior of several HF-CZT sensors with different contact configuration (Au/Au, Au/Pt, Pt/Au, Pt/Pt) has been investigated using current-voltage characteristics in dark and under X-ray irradiation, as well as gamma-ray spectroscopy. The linearity of Au/HF-CZT/Pt sensors under high X-ray fluxes up to $10^{11}\ photons/mm^2/s$ has been demonstrated. In addition, the morphology of the Pt/CZT contact has been investigated by means of Transmission Electron Microscopy (TEM) in order to reveal the microscopic peculiarity of this contact with respect to the standard Au/CZT contact. Results of these characterizations will be presented in this work.

Summary:

X-ray detectors / 67

Silicon Drift Detector technologies for high-throughput spectral-timing X-ray space astronomy

Author: Francesco Ceraudo[1]

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Thanks to the large photon-collecting area and small anode capacitance, combined with state-of-the-art techniques to reduce the impact of leakage current on the overall electronic noise, Silicon Drift Detector (SDD) technology enables the development of sensors which are particularly suited for high-throughput space-based spectral-timing X-ray astronomy. In this talk, we will present the

latest activities on SDDs carried out by a large collaboration involving INAF, INFN, FBK and several Universities. In particular, we will focus on three applications for space astronomy: the Large Area Detector (LAD) on board the eXTP mission, for the study of matter under extreme conditions; the High Energy Rapid Modular Ensemble of Satellites (HERMES) CubeSat constellation, for the localization of high-energy transient sources via triangulation; and the Pixelated Drift Detector (PixDD) integrated system, to be used as a focal-plane detector for X-ray concentrators and large field-of-view optics.

Summary:

X-ray applications in various fields / 68

Fluorescence and Raman micro-spectroscopy of LiF films containing radiation-induced defects for X-ray detection

Authors: Francesca Bonfigli[1]; Sabina Botti[1]; Maria Aurora Vincenti[1]; Rosa Maria Montereali[1]; Pasquale Gaudio[2]; Riccardo Rossi[2]

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Radiation-induced point defects, known as color centers (CCs), in lithium fluoride (LiF) thin films are successfully used in passive X-ray imaging detectors [1]. LiF film detectors for extreme ultraviolet radiation, soft and hard X-rays, based on photoluminescence of stable, laser-active electronic defects, have been proposed [2, 3, 4] and are currently under further development and investigation. LiF can be grown in the form of polycrystalline thin films and it is compatible with several substrates. These LiF film detectors are versatile and can be integrated in different experimental apparatus and imaging configurations. Moreover, the CCs photoluminescence response, which is directly related to the material radiation sensitivity, can be enhanced through the appropriate choice of substrates and multi-layer designs [5], and by tailoring the micro-structural properties of polycrystalline LiF films through the control of the growth conditions [6].
In this work we present the characterization, through fluorescence and Raman micro-spectroscopy of LiF films, thermally evaporated on different substrates with thicknesses up to 1 µm, irradiated with soft X-rays produced by a laser plasma source. After irradiation, the imaging of the visible photoluminescent of radiation-induced CCs in LiF films were obtained by a confocal laser scanning microscope operating in fluorescence mode. The 2D Raman maps of the X-ray irradiated LiF films were measured by a Raman spectrometer combined with a confocal microscope that acquires a complete Raman spectrum in each point of the maps. In LiF, due to high symmetry of its fcc (face centered cubic) lattice, the Raman modes are not active at first order. The presence of defects, such as CCs, destroy this symmetry, allowing the observation of Raman spectra also at first order. The combination of these micro-spectroscopy techniques could represent an advanced method to investigate the role of the polycrystalline film structures in the CC formation efficiency at microscopic level, a fundamental aspect for the development of LiF films radiation imaging detectors.

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Summary:

X-rays in nuclear physics / 69

Tests of QED by precision spectroscopy of highly-charged ions and exotic atoms

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Quantum electrodynamics (QED) is the best understood quantum field theory. High-precision tests are being performed using free particles (e.g., the electron anomalous magnetic moment [1]). Many bound electron systems are being studied and compared to the most advanced calculations. One can cite hydrogen, positronium, muonium, highly charged, few electron ions[2] and exotic atoms (atoms in which the electron is replaced by a heavier particle like a muon, a pion or an antiproton).
In this talk I will present a few cases of highly charged ions high-precision results (few ppm accuracy) obtained with our Double Crystal Spectrometer in Paris[3-5] for medium-Z elements, and preliminary results obtained at GSI/FAIR on few-electron uranium. I will then present new ideas [6] and first demonstration results on QED tests using muonic atoms and transition-edge sensor micro-calorimeter at JPARC [7, 8], and their extension to antiprotonic atoms at ELENA in the future. Detailed comparison with QED and relativistic many-body calculations when relevant will be made. I will also describe the new project QUARTET intended to use micro-calorimeters for precision spectroscopy in light (Li to B) muonic atoms to measure the nuclear radii more accurately.

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Summary:

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Calibration of Silicon Drift Detectors for High Precision Spectroscopy in SIDDHARTA-2 Experiment

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The SIDDHARTA-2 experiment at the DAΦNE collider aims to perform the first high-precision measurement of kaonic deuterium x-ray transitions to the fundamental level with low systematic uncertainty. To achieve this goal, the experimental apparatus is equipped with 384 Silicon Drift Detectors (SDDs) distributed around its cryogenic gaseous target. The SDDs developed by the SIDDHARTA-2 collaboration are suitable for high precision kaonic atoms spectroscopy, thanks to their high energy and time resolutions combined with their radiation hardness. Calibration and monitoring of the energy response of each SDD is critical to keeping the systematic error at a minimum level. This presentation will discuss the SIDDHARTA-2 calibration method optimised in the real background conditions of the DAΦNE collider. The method includes energy calibration using x-rays tubes and multielement target. The optimised calibration method is a fundamental tool to guarantee the high precision spectroscopic performances of the system over long period of data taking, as that required for the kaonic deuterium measurement. The results of the calibration process and their impact on the achieved precision will also be presented.

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Semiconducting Polymer X-ray Detectors: Towards Printable, Flexible, and Tissue Equivalent Devices

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Ionizing radiation is the foundation of modern society with rapid growth in medical diagnostics and treatment, space exploration, nuclear energy, and border security. However, increased use in recent decades has correlated to higher radiation exposures, with harmful effects to the health of workers and patients. Active monitoring has now become compulsory in many countries to instantaneously detect, evaluate, and correct for any deviations from the planned exposure. Ideal sensors for active monitoring must be positioned on the body and operated at low voltages to record the total biologically relevant radiation dose absorbed across a wide range of spectra and radiation sources, termed tissue equivalence. These devices should also be relatively transparent to ionizing radiation to minimize impact on protocols [1].

Printed organic semiconductors are to date the only flexible technology capable of active monitoring as a wearable, tissue equivalent sensor [2]. However, they have long been thought of as poor materials to sense ionizing radiation due to low sensitivity and poor tolerance towards high energy radiation. Here we develop a new system to solve these issues, reporting the optoelectronic, x-ray

response, and radiation tolerance of an organic photodetector fabricated with solution-based inks prepared with polymer donor P3HT and non-fullerene acceptor o-IDTBR. The optoelectronic properties facilitated a high operating efficiency under x-rays without requiring any external bias when coupled with a plastic scintillator as a safe alternative to high voltage devices [3]. The thin, 500 nm, active layer was demonstrated to be ideal for high spatial resolution reconstruction of 50 µm FWHM radiation beams for novel modalities of Microbeam Radiation Therapy at the Australian Synchrotron, measuring a FWHM of (51 ± 1.4) µm across all 50 microbeams [4]. However, challenges with background luminescence from the polyethylene substrates commonly used for printed electronics were observed. Therefore, an alternative flexible substrate, polyamide (Kapton), was required. P3HT:o-IDTBR performance was found to be both higher and more stable on the Kapton substrates than P3HT:PCBM[5]. The tissue equivalence was determined by measuring the energy dependence of the detector responses across low and high x-ray energies. The response of devices coupled with the plastic scintillator matched the theoretical output of the plastic scintillator, validating the energy independence and tissue equivalence of the materials whilst commercial silicon detectors exhibited a 7-fold over-response compared to human tissue at low energies [6].

The devices also exhibited temporal responses approaching sub-microsecond time scales, the fastest ever observed for organic semiconductors as radiation detectors. High energy x-rays were produced from a Varian Clinac 2liX linear accelerator at 6 MV (<E>=1.2 MeV) with a pulse width of 3.6 µs, with individual pulses able to be resolved with temporal resolution directly comparable to state-of-the-art silicon radiation detectors. This result established organic semiconductors as the first ever ultrafast flexible devices for ionizing radiation with a tissue equivalent response.

The radiolucency was experimentally verified to be 99.8%, enabling operation as a transparent dosimeter with negligible perturbance of radiation beams. Device stability as a function of cumulative ionizing radiation dose past 5 kGy demonstrated P3HT:o-IDTBR was significantly more radiation tolerant than expected. P3HT:PCBM devices exhibited a 98.5% decrease in short circuit current density compared to just an 18.4% for P3HT:o-IDTBR under a radiation exposure equivalent to 10 years in a typical medical clinic. Mechanistic studies employing electrochemical impedance spectroscopy revealed photocurrent degradation occurred primarily in the P3HT polymer via formation of deep trapping sites in the P3HT:PCBM blends however, blends with o-IDTBR were more effective at preventing radiation induced damage. The reported devices provided a successful demonstration of the first fully organic ionizing radiation detectors, with further optimization of the scintillator required to enhance the sensitivity and tissue equivalence.

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Summary:

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The IXPE calibration, from ground to space

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IXPE (Imaging X-ray Polarimetry Explorer) is the Small Explorer space mission developed in a partnership between NASA and ASI that is unveiling the polarized X-ray sky in the 2-8 kev energy band. IXPE was launched on December 9th 2021 and it is performing X-ray spectro-polarimetry of astrophysical sources, including imaging-polarimetry for extended ones and timing-polarimetry for X-ray pulsar.
The IXPE telescopes comprise three grazing incidence mirror modules coupled to three Detector Units (DUs) hosting each one a Gas Pixel Detector (GPD) polarimeter. The GPD, developed by the INFN and INAF-IAPS Italian research institutes, exploits the photoelectric effect to measure the linear polarization of the X-ray emission from astrophysical sources. Its spectroscopic (energy resolution < 20% at 6keV), timing and imaging capabilities allow IXPE to perform unprecedented polarimetric measurements with high significance.
A wide and accurate on ground calibration was carried out on the IXPE DUs at INAF-IAPS in Rome. A dedicated facility was set-up to calibrate the DUs with polarized and unpolarized X-rays at different energies in the operating energy band.
The spare DU was also calibrated with polarized and unpolarized X-ray sources at the Stray Light Test Facility of NASA Marshall Space Flight Center (MSFC) at the focus of the spare Mirror Module Assembly, designed and manufactured by MSFC itself.
Currently, the 3 IXPE DUs are up and running in space and they are periodically monitored and gain calibrated in flight by means of polarized and unpolarized radioactive sources hosted in the DU's filter and calibration wheels. We will present an overview on the IXPE calibraitons from ground to space.

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An X-ray survey of wave function collapse signal

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One of the main conundrums of physics is the quantum-to-classical transition. Models of Dynamical wave function Collapse (DCMs) explain it by a progressive reduction of the quantum superposition, proportional to the increase in mass of the system under consideration. Gravity-related collapse models, like the one developed by Diosi and Penrose (DP), aroused growing interest in the last decades, for the privileged role that gravity may play to solve the measurement conundrum.

`The VIP-2 experiment, operated at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN, is p`

`The strong bounds set by VIP-2 on the DP, and other models like the Continuous Spontaneous Lo`

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Advancing Plasma Analysis: An Integrated X-ray Spectroscopy System Utilizing GEM and Timepix3 Technology for Soft and Hard X-Rays, and Gamma Radiation Detection

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X-ray emission measurements offer profound insights into plasma behavior in both spatial and temporal contexts. These findings are critical in understanding various plasma parameters, including ion and electron temperatures, electron density, impurity concentration, and more. We propose an innovative X-ray spectroscopy diagnostic system that integrates a robust, noise-free Gas Electron Multiplier (GEM) detector for sensitive Soft X-ray detection and a compact, solid-state silicon Timepix3 (TPX3) detector for Hard X-ray and gamma radiation detection. The GEM detector readout has been equipped with a PCB layout having four rows with 64 pads, each one having an area of 1.5×20 mm^2. In this configuration, it offers not only a wide active area (10×10 cm^2) for 2D measurements on Soft-X rays (2-20 keV) through a cathode Mylar window but also 1-D measurements on higher X-ray energies (2-50 keV) through two symmetric side Kapton windows on the opposite ends of the active gas region. It features high sensitivity, a wide dynamic range, excellent energy resolution, high temporal resolution, significant resistance to electromagnetic disturbances and high neutron and gamma background, despite its limited pixel count. The TPX3 detector's silicon-based, pixelated sensor (pixel dimensions 55 µm × 55 µm; active area 14 mm $\times$ 14 mm) enables ionizing particle or radiation identification through morphological particle track analysis. We used the GEM detector in a 1-D configuration leveraging the full depth of the gas (10 cm) with an energy resolution of about 25%. The more energetic part of the radiation beam is not absorbed in GEM gas volume and exits through the downstream side window. Consequently, the TPX3 detector is situated side-on at the GEM detector's exit, harnessing the full size of the silicon sensor (14 mm), in contrast to the mere 300 µm front face. This positioning allows the TPX3 detector to identify Hard X-rays (50-500 keV) through a suitable morphological analysis and gamma rays in the 0.5-10 MeV range with a different trace treatment inside the detector. The tandem operation of the GEM and TPX3 detectors facilitates a spectroscopic analysis of radiation along the same line of sight. Both detectors have been also tested in the Frascati Neutron Generator (FNG) with 14 MeV neutrons up to 10^7 n/s·cm^2, suggesting potential use in experiments or facilities with high radiative (n, gamma) background. For such scenarios, we propose including a diamond TPX3 in the diagnostic system for fast neutron background monitoring.

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Innovative X-ray detection systems based on monolithic arrays of Silicon Drift Detector

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This work reports on the development of innovative energy-dispersive X-ray detection systems based on monolithic arrays of Silicon Drift Detector (SDD). We present the adoption of SDDs in different configurations to enhance properties like detection efficiency, throughput capability, and compactness, in addition to high-energy resolution.
Regarding detection efficiency, we propose a solution to reach an effective thickness of 2 mm by the realization of a stacked structure involving two 1 mm thick 2×4 monolithic arrays of SDD, with 64 mm^2 area per pixel, placed atop each other. The goal is to increase the detection efficiency in the hard X-ray range, in particular for the SIDDHARTA experiment.
Another system configuration, ARDESIA-16, involves the use of a 1 mm monolithic 16-element

SDD array, of 25 mm^2 area each, obtaining a multichannel X-ray spectrometer, optimized for synchrotron applications that require a high-count rate (> 1 Mcps per channel) and good energy resolution (e.g. below 150 eV at peaking times faster than 200 ns) for X-ray fluorescence detection (XRF) spectroscopy, X-ray absorption fine structure (XAFS) techniques and X-ray fluorescence microscopy (XFM) imaging.
The success of ARDESIA-16 has led to the study of ARDESIA-64, a 64-channel detector based on a monolithic 64-element SDD matrix, with 4 mm^2 area per pixel, with a potential total count-rate of 64 Mcps, using 1 Mcps/channel electronics. To be highlighted that the size of the detector remains unchanged.
An alternative solution to increase throughput capability with respect to ARDESIA-16 is being exploited in ASCANIO, which adopts an annular SDD configuration, with a central hole, meant to be used in a backscattering geometry configuration to optimize solid angle, resulting in an increase of the total output count rate.
The SCARLET project represents another contribution in the development of X-ray detection systems based on SDDs, with the goal of implementing a novel readout ASIC for integration with monolithic arrays of SDD by means of bump-bonding, resulting in a compact X-ray spectrometer with high-rate and high-energy resolution.
At the conference, we look forward to presenting the current state of these developments.

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Soft X-ray detection with single photon resolution using LGAD sensors

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Hybrid X-ray single photon-counting and charge integrating detectors developed at the Paul Scherrer Institute perform outstandingly in many hard X-ray experiments, both at synchrotrons and XFELs, but they show limitations in the soft X-ray energy region. The main factors that limit the detection of soft X-rays are the poor quantum efficiency, due to the short attenuation length of soft X-rays, which are absorbed in the inefficient region of the sensor, and the low signal-to-noise ratio (SNR), due to the small charge created by low energy photons.
In the present work, we present the developments carried out at PSI in collaboration with Foundazione Bruno Kessler to optimize the quantum efficiency and improve the SNR adapting the Low Gain Avalanche Diode (LGAD) technology to soft X-ray detection. We report an improvement on the quantum efficiency to above 60 % for 250 eV X-rays and the measurement of single photons with energies down to 400 eV.

Summary:

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The multi-detectors system of the PANDORA facility for β-decay investigation in astrophysical conditions: focus on the full-field pin-hole CCD system for X-ray imaging and space-resolved spectroscopy

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PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) is an INFN project aiming at measuring, for the first time, possible variations of in-plasma β-decay lifetimes in isotopes of astrophysical interest, as a function of thermodynamical conditions of the in-laboratory controlled plasma environment. Theoretical predictions say that the ionization state can dramatically modify the β-decay lifetime (several orders of magnitude). The PANDORA experimental approach consists of confining a plasma able to mimic specific stellar-like conditions, thus measuring the evolution of the nuclear lifetime as a function of plasma parameters. The density and temperature of radionuclides can be maintained in dynamical equilibrium even for weeks when diffused in a buffer plasma confined by a B-minimum superconducting magnetic trap, now under construction. The β-decay events will be tagged by detecting the γ-ray emitted by the daughter nuclei by an array of 14 HPGe detectors placed around the magnetic trap. In this frame, plasma parameters have to be continuously monitored online: in PANDORA they will be measured through an innovative, non-invasive multi-diagnostic system, including high resolution time- and space-resolved X-ray analysis, which will work synergically with a γ-rays detection system. In this contribution we will describe this multi-diagnostics system with a focus on the powerful technique based on spatially resolved high resolution X-ray spectroscopy using a pin-hole X-ray camera setup operating in the 0.5 - 20 keV domain. The achieved spatial and energy resolutions are 500 μm and 230 eV at 8 keV, respectively. An analysis algorithm has been specifically developed to obtain SPhC (Single Photon-Counted) images and local plasma emission spectrum in High-Dynamic-Range (HDR) mode. Thus, investigations of image regions where the emissivity can change by even orders of magnitude are now possible. Post-processing analysis is also able to remove readout noise, which is often observable and dominant at very low exposure times (ms). Several measurements were made in compact magnetic plasma traps, allowing quantitative and absolute evaluation of local emissivity, and the elemental analysis was carried out. Recently new models have been developed to obtain spatially resolved plasma parameters from the experimental spectra, and the first local measurements of the electron density and temperatures have been provided. In addition, fast X-ray shutters and trigger systems have been tested and will be routinely implemented to simultaneously carry out space- and time-resolved spectroscopy during transients, stable and turbulent plasma regimes (in the ms timescale), useful to study kinetic plasma turbulences in laboratory plasmas, such as the cyclotron maser instability causing radio and X-ray bursts emission in astrophysical objects.

Summary:

X-ray applications in various fields / 79

Muonic X-rays for cultural heritage: technique overview and developments

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Muonic X-ray Emission Spectroscopy (μXES) is a novel technique in the broad field of non-destructive methods for cultural heritage analysis [1]. It relies on the interaction of a probe of negative muons with matter and the following emission of x-ray radiation. Since the muon mass is about 200 times bigger than the electron, the emitted X-rays are highly energetic and are characteristic of the emitting atom, making it possible to cover a wide part of the periodic table (from Lithium to Uranium). Thanks to the multi-elemental range, a negligible self-absorption effect of the x-rays and very low residual activity left in the sample after irradiation, μXES is a very powerful probe for material characterization, especially for historical samples [2,3]. In addition, by varying the muon beam energy, the muon stops at different sites inside the sample (in metals, up the centimeter scale), thus providing information both from the surface and from the bulk in the form of a depth profile. Given the novelty of the technique, there is a lot of room for improvements, especially for data processing and data interpretation. On this topic, Monte Carlo (MC) simulation software can provide a new way to approach the data analysis process. Among MC software, SRIM-TRIM is an established method for simulation of the interaction of particles within matter [4]. In this work, the results of simulations performed with SRIM will be presented, along with the results obtained with a Geant4 based simulation tool developed at the university of Milano Bicocca called "Arby"[5]. With Arby, it is possible to exploit all the tool provided by Geant4 in a more user-friendly approach. The simulation environment is defined by a configuration file and the simulation is run via command line. With both software, the information provided regards the number of muons topped in any given layer, that is then compared to the data collected during the real measurement. Here, results on the analysis of gilded metals will be presented. Moreover, Arby can be used not only to give an information of the number of muons stopped in each layer, but it can provide the X-ray spectra generated after the interaction of the muon with matter. However, the process is not yet reliable, since a lot of information are missing for high energy transition of high Z atoms. A solution to this issue could be provided by using another simulation software called "MuDirac"[6]. MuDirac is a Dirac equation solver that calculates the frequencies and probabilities of the transitions between levels of the muonic atoms. This software could be used to provide a database of transitions to be implemented in Arby. Here, preliminary results will be presented.

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Summary:

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eXTP (enhanced X-ray Timing and Polarimetry mission): scientific objectives and sensors

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The Enhanced X-ray Timing and Polarimetry (eXTP) mission is a collaboration between Chinese and European research institutes and is designed to study the state of matter under extreme conditions of gravity, density and magnetic field. The primary objectives are to determine the equation of state of matter at densities higher than nuclear, measure QED effects in very high magnetic fields and study accretion discs in the strong gravity regime. To do this, the mission will study neutron stars in binary and isolated systems, magnetars and black holes.
The observations will be carried out thanks to the satellite's instrumentation, which will allow spectroscopy, timing and polarimetry of X-ray sources in the 0.5-30 keV energy range to be analysed simultaneously. The instrumentation includes the Spectroscopic Focusing Array (SFA), the Large Area Detector (LAD), the Polarimetry Focusing Array (PFA) and the Wide Field Monitor (WFM).
The Trieste section of INFN and TIFPA, in particular, are involved in this mission through the design and testing of Silicon Drift Detectors (SDD) for LAD and WFM, large area sensors for collimator X-ray spectroscopy and imaging respectively.
In order to achieve the scientific objectives of the mission, the sensors must meet very stringent specifications. Design techniques and verification measures were devised to assess their characteristics in order to carry out a careful selection process before integration.

Summary:

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Comparison of characteristics and performance between the new detection system based on Silicon Drift Detectors of XAFS beamline of Elettra and SESAME

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The collaboration between INFN-Trieste, TIFPA, FBK, the Politecnico di Milano and Elettra-Sincrotrone Trieste over the past few years has led to the design, production and deployment of two state-of-the-art instruments that now equip the XRF/XAFS beamline of the SESAME synchrotron and the XAFS

beamline of Elettra.
Both these instruments are 64-channels modular detection systems based on monolithic array of Silicon Drift Detectors (SDD). Detection systems have large total collection area, capable of operating with low dead time and high count rate. They present excellent performance already at room temperature: an energy resolution at the Mn 5.9 keV Kα line below 170 eV FWHM. These instruments are similar but have their own unique and different characteristics due to the construction experience and the particular requirements of the beamline scientists who collaborated in the development of the detector systems, such as the new collimation system installed on the Elettra's instrument. In addition, they are optimised and seamlessly integrated with the beamlines for which they were designed.

Summary:

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Photon science detector development at PSI

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Single photon counting detectors developed at PSI, like MYTHEN and EIGER, are the detector of choice of many imaging ad diffraction experiments at synchrotrons and the JUNGFRAU charge integrating detector is widely used at Free Electron Lasers thanks to its reliability and large dynamic range.
In this presentation we will discuss the new developments carried out at PSI to improve the performance for next generation light sources.
Our R&D efforts focus mainly on single photon counters with higher count rate capability, charge integrating detectors with higher frame rates and optimized sensors for the whole energy spectrum (200 eV to 80 keV).

Summary:

X-ray detectors / **83**

Tests at INFN on X-ray photon counting hybrid pixel detectors based on the Timepix4 ASIC

Authors: Paolo Cardarelli[1]; Nicolò Vladi Biesuz[2]; Riccardo Bolzonella[1]; Viola Cavallini[1]; Pasquale Delogu[1]; Alessandro Feruglio[3]; Massimiliano Fiorini[1]; Edoardo Franzoso[1]; Renata Longo[1]; Giovanni Mettivier[1]; Gabriele Romolini[3]; Valeria Rosso[1]; Angelo Taibi[1]; Salvatore Tudisco[1]

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Timepix4 is the readout chip produced by the Medipix4 international Collaboration for hybrid pixel detector assemblies, developed to provide particle identification and tracking with high spatial and timing resolution. The chip is composed of 448 x 512 pixels with a size of 55 μm x 55 μm, which can be coupled to a sensor with a matching pixel structure, for a total active area of about 7 cm^2. For the first time, these chips are fully prepared for Through-Silicon-Via (TSV) processing, so that they could be tiled on four sides to cover large areas with negligible dead regions.
Timepix4 can operate in two different modes: frame-based, where each event generating a signal above a programmable threshold increments a counter, and data-driven, in which time-of-arrival and time-over-threshold are measured for each signal over threshold in a pixel.
INFN joined the Medipix4 collaboration in 2020 with the aim of studying and testing the possible applications of the read-out chips in a wide range of fields, from X-ray spectral imaging to nuclear medicine and dosimetry. The characterization of the first available assemblies of Timepix4 bump-bonded to silicon sensors are currently ongoing at INFN. In this contribution we will present an overview of this innovative technology and the first results of the characterization activities at INFN.

Summary:

X-rays in nuclear physics / 84

Measurements of the Pauli's Exclusion Principle violation with X-Rays detectors: the VIP group

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Pauli's Exclusion Principle (PEP) is the basis of the stability of matter and many other phenomena relevant to physics, astrophysics, cosmology, and even biology. It is related to the spin-statistics theorem, and possible violations of this relation have been searched for since its inception. Violations of the PEP may come from various Beyond Standard Model descriptions, including Quantum Gravity models, which are being recently developed.
I shall present the VIP group's efforts in searching for possible small PEP violations using open and close systems. The former will focus on the VIP-2 experiment, suited for models that respect the Messiah-Greenberg Super-Selection rule; the latter will focus on BEGe and VIP-Lead experiments, befitted for Non-Commutative Quantum Gravity models.

Summary:

X-ray in astrophysics / 85

Updates about the multi-detectors system of the PANDORA facility aiming at the measurement of β-decay in astrophysical conditions

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PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) is an INFN project aiming at measuring, for the first time, possible variations of in-plasma β-decay lifetimes in selected isotopes of astrophysical interest, as a function of thermodynamical conditions of the in-laboratory controlled plasma environment. Theoretical predictions say that the ionization state can dramatically modify the β-decay lifetime (several orders of magnitude) due to the opening of a new decay channel as the bound state β-decay [1,2]. The PANDORA experimental approach consists of creating and confining a plasma whose main features can mimic specific stellar-like conditions, thus measuring the evolution of the nuclear lifetime as a function of plasma parameters [3]. The density and temperature of radionuclides can be maintained in dynamical equilibrium even for weeks when diffused in a buffer plasma confined by a B-minimum superconducting magnetic trap, now under construction. The β-decay events will be tagged by detecting the γ-ray emitted by the daughter nuclei by an array of 14 HPGe detectors placed around the magnetic trap. In this frame, plasma parameters have to be continuously monitored online: in PANDORA they will be measured through an innovative, non-invasive multi-diagnostic system which will work synergically with a γ-rays detection system [3]. In this contribution we will describe this multi-diagnostics system and advanced analysis methods that have been already developed, and which allow unprecedented investigations of magnetoplasma properties (in terms of plasma density, temperature, charge state distribution), including high resolution time- and space-resolved X-ray analysis. The developed setup includes an interfero-polarimeter for total plasma density measurements, a multi-X-ray detectors system for volumetric X-ray spectroscopy (including time resolved spectroscopy), a X-ray pin-hole camera for high-resolution 2D space-resolved spectroscopy and imaging, and optical spectrometers for the plasma-emitted visible light characterization. A description of recent results about plasma parameters characterization in quiescent and turbulent Electron Cyclotron Resonance-heated plasmas will be given. This synergic operation of the diagnostics will be crucial also for the additional case-studies of PANDORA: a) the determination of metallic ECR plasma opacities resembling thermodynamical conditions of post neutron-star-merging ejecta [4]; b) the study of kinetic plasma turbulence in laboratory plasmas, such as the cyclotron maser instability causing radio and X-ray bursts emission in astrophysical objects.

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Summary:

X-ray applications in various fields / 86

Comparison of different methods for evaluating quantitative XRF data in copper-based artefacts

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X-ray Fluorescence (XRF) analysis with energy dispersive spectrometers (ED-XRF) is a versatile, multi-elemental analytical technique able to determine the major, minor and trace elements of a broad range of different materials in a non-invasive way and in short measuring times. The non-destructive capabilities of XRF are indeed particularly suited to research in the field of cultural her-

itage where the sample is unique, or its integrity has significant technical or esthetic value [1]. In the last decades, technological developments in X-ray generation and detection have led to the production and commercialization of different types of portable instruments [2], such as the so-called hand-held XRF devices, which allow both qualitative and quantitative analysis of samples in situ. In the cultural heritage field, the opportunity to avoid sampling by on-site field analyses through a non-destructive and non-invasive method is significant, and for this reason, different hand-held XRF devices are employed and performed ad hoc also for this sector.
Quantitative XRF analysis requires the conversion of measured intensities of the characteristic radiation to the concentrations of the elements to be determined [3]. Numerous methods, both empirical and theoretical, have been proposed for quantitative X-ray fluorescence analysis [4] and all hand-held analyzers are equipped with programs providing quantitative results using one of them. Usually, the results of measurements are derived from the X-ray spectra of the sample using either an empirical calibration or one based on the Fundamental Parameter approach [5].
In this study, we compare the quantitative XRF results, obtained by a commercial hand-held XRF device "Bruker Tracer 5g", using these two different approaches methods.
In detail, the XRF data were achieved by the analysis of twenty-six (26) certified standards, compositionally significant of heritage copper-based artefacts. The measured elemental concentrations were derived using three different calibrations. Two of them are based on empirical coefficients: one was loaded into the device by Bruker when instruments were purchased, whereas the other is a customized calibration from us through the "Bruker EasyCal software"; while the third one was performed with the fundamental parameter-based PyMCA software [6], which was used properly configured to account for all the required set-up and spectrometer characteristics.
The results of this study will be very useful for future in situ measurements of copper-based manufact in order to select the most suitable quantitative method.

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Summary:

X-ray detectors / 87

Recent trends of X-ray dosimetry with thermoluminescent detectors

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X-ray dosimetry is an area of increasing importance in diagnostic radiology, due to the potential for radiation-induced cancer and acute organ damage to body organs such as skin and eyes. There are three aspects to dosimetry in diagnostic radiology: measurement of performance of X-ray equipment, assessment of doses to patients, and assessment of doses to workers. One type of radiation detectors used in this field is the thermoluminescent dosimeters (TLDs), which consists of a luminescent crystalline material, that when exposed to ionizing radiation, it absorbs and traps some of the energy of the radiation in its crystal lattice. When heated, the crystal releases the trapped energy in the form of visible light, the intensity of which is proportional to the intensity of the ionizing radiation the crystal was exposed to. Some advantages of using TLDs for x-ray dosimetry compared to typical detectors include their ability to measure a greater range of doses, their ease of obtaining doses, and reusability. However, none of the commercially available TLDs fully satisfies all the needs for X-ray dosimetry, which generates a large area of opportunity for the investigation of new materials for this application.

Summary:

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Enhancing SDD Energy response with ML and differential programming

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We show a novel ML and differentiable programming calibration technique and the gains it yields on the energy response of the Silicon Drift Detectors used in the VIP-2 underground experiment. This technique shows an improvement of 10 eV on the previous state-of-the-art in the VIP collaboration, in terms of Full Width at Half Maximum at 8 keV. The SDD energy resolution is a key observable in the VIP-2 experiment, searching for violations of the Pauli Exclusion Principle in atomic transitions in copper. Finally, we show that this method additionally corrects for miss-calibrations, and requires less fine-tuning with respect to standard methods.

Summary:

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Reverse X-ray Photoemission Spectroscopy with LIXS

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Laser ablation (LA) is a spatially resolved technique enabling fast sampling of any kind of matrix without sample preparation. The ability to measure important elements such as H, C, N, O or Li, Be, B, F, P, Cl, makes laser-induced breakdown spectroscopy (LIBS) complementary to established laboratory techniques such as X-ray Fluorescence spectroscopy (XRF). While poorer on the target analysis, LIBS offers a substantial potential for non-target qualitative analysis, if precision and specificity would improve consistency. Furthermore, although LIBS has the unique advantage to be operable in situ, i.e. in the field and/or in a low-pressure environment for space exploration, its susceptibility to the conditions limits its impact for heterogeneous materials.
Laser-Induced XUV Spectroscopy (LIXS) is similar to LIBS, but at a much shorter wavelength domain, the soft X-ray (10-100 nm). LIXS happens when the early laser-plasma is extremely hot and dense, giving selective prevalence to ion lines. These make the spectrum cleaner, stable and intense, with modest noise. The generation of a LIXS spectrum requires a high-fluence laser pulse, and a vacuum spectrometer for the short wavelength. The degraded resolving power at shorter wavelengths makes it generally difficult to collect a non-distorted (stigmatic) spectrum below 100 nm. We have addressed this technical challenge. The application of LIXS to characterize the heterogeneity of energy

and valuable materials is discussed. The signal produced by radiative electron recombination may be used to obtain chemical information, similarly as done in X-ray photoelectron spectroscopy.

Summary:

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3D CZT spectro-imagers for hard X- and Soft γ-ray astronomy: development status and preliminary results from a stratospheric balloon flight

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New instruments require detectors exploiting high dynamics to cover a large energy band and very high performance in terms of efficiency, spectroscopy, imaging, and, in particular after the launch of IXPE, high polarimetric capabilities. Recently, ASI funded a project ("3D-CZT Module for spectroscopic imaging, timing and polarimetry in hard X-/soft γ-rays satellite mission - 3DCaTM") dedicated to develop a prototype demonstrator based on an innovative CZT drift strip sensor unit (3DCZT) and implementing a digital readout of signals to obtain unprecedented
performance with three-dimensional spatial resolution (<0.5 mm), fine spectroscopy (1% FWHM at 511 keV), and high response uniformity (few %'s) with a limited number of electronics channels.
Furthermore, in the framework of the European HEMERA program for stratospheric balloon flights we launched in September 2022 the BADGER (BAlloon Detector for Gamma ray with three-dimensional Resolution) payload consisting of a detection system based on one of the 3DCZT developed sensor.
Herein, we present the principles on which the 3DCZT sensors are based, the state of their development and the prospects for use in future satellite missions for high energy astrophysics. We conclude by describing the stratospheric balloon payload BADG3R developed from this type of detector and the preliminary results obtained from a performed flight.

Summary:

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PEROV project: perovskite devices for visible light and potential for X-ray detection

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Since several years, the organometal halide perovskites (OMHP) semiconductors have been proved to be promising material for fast, sensitive large-area photodetectors, and, more recently, also for

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.
In this talk I will show the results from the PEROV INFN project where several OHMP based devices have been developed and tested with visible light. I will focus on a novel technique wich enables the deposition of OHMP micro-wires directly on patterned conductive substrate with precise positions and dimensions. This novel techniques is attractive for X-ray pixelated detectors and further opens the possibility to integrate OHMPs with CMOS technology.

Summary:

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Best Talks Contest Winners announcement and Conclusions

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Welcome

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Registration Opening

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A New Scatterer Detection System for a Compton CubeSat telescope aboard the ComPol project

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In the last decades, the use of Compton telescopes has greatly increased in astronomy. Compton telescopes are designed to perform X-ray and γ-ray polarimetry of celestial bodies like neutron stars, quasars, supernova remnants and binary black holes. In this context, the ComPol project involves the implementation of a Compton telescope in a 1U CubeSat nanosatellite to perform polarimetric analysis of the Binary Black Hole (BBH) system known as Cygnus X-1. The payload consists of two detection systems arranged in a stacked fashion: 1) the scatterer based on Silicon Drift Detector (SDD) arrays and 2) the absorber based on a scintillating crystal integrated with matrices of Silicon Photomultiplier (SiPM). This paper presents the first layer design of the Compton telescope for photons experiencing Compton scattering. The analog readout chain consists of two 7-pixel SDD arrays, four CUBE preamplifiers and SFERA ASIC Analog Pulse Processor (APP). At the end of the chain, FPGA technology is employed to handle data signal flow between SFERA and PC. This paper presents the prototype system consisting of three boards: ICARO, intended to house detectors and preamplifiers, SFERA L-like carrier, which houses the APP chip, and ENOS, which implements the FPGA module and BIAS section of ICARO. At the conference, the results of tests performed with the final flight module will be presented.

Summary:

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Detectors for beam monitoring and dosimetry at ultra-high dose rates for FLASH Radiotherapy

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FLASH radiotherapy (RT) is attracting a significant interest since the first investigations carried out in 2014 [1]. Several preclinical studies worldwide have demonstrated that ultra-high dose rate (UHDR) beams produce an improvement of normal tissue sparing, compared to conventional dose-rate RT, while maintaining same tumor control probability (FLASH effect). However, to fully understand the mechanisms behind the effect and to support the future clinical translation of FLASH radiotherapy, novel beam monitoring and dosimetry technologies must be developed, and new approaches studied [2]. Currently used detectors for reference dosimetry for conventional radiotherapy, such as ionization chambers, saturate at these extreme regimes, therefore the optimization of already established technologies as well as the investigation of new instrumentation for dosimetry are required [3]. Alternative approaches, such as calorimetry or the use of solid state detectors are currently being studied and their usage at UHDRs is under assessment. The challenges characterizing dosimetry for FLASH radiotherapy vary considerably depending on the accelerator type and technique used to produce the relevant UHDR radiation environment. Different beam pulse structures can be used for the acceleration of the radiation beams, depending on the specific accelerator, and the related dose and dose-rate per pulse can affect the detector response. A reliable measurement also of the instantaneous dose rate, beyond an accurate measurement of the dose, are relevant at these extreme regimes. The main challenges coming from the peculiar beam parameters characterizing UHDR beams for FLASH RT will be discussed. A status of the current technology will be provided, including recent developments for established detectors and novel approaches currently under investigation with a view to predict future directions in terms of dosimetric approaches and practical procedures for the clinical translation of FLASH RT.

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Summary:

X-ray applications in various fields / 97

An advanced X-ray spectromicroscopy of Bi2Se3 ultrathin films on SiO2/Si substrates

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Here, our aim is to study through an advanced X-ray spectromicroscopy (SPEM) analysis the first stages of growth of ultrathin Bi2Se3 films on the same substrate with particular attention to the film stoichiometry and interaction with the substrate underneath. To this end, Bi2Se3 films have been grown on n-doped silicon (001) wafers with native oxide. The X-ray photoelectron spectromicroscopy (SPEM) was conducted at ESCA microscopy beamline of Elettra Sincrotrone Trieste research center. Two samples (obtained by positioning the two substrates in two different locations along the bottom of the furnace quartz tube) were been analyzed through SPEM. Using the data obtained, the ability of this two-step PVD growth technique to produce stoichiometric Bi2Se3 films is confirmed. Moreover, SPEM images taken at Bi4f, Se3d, Si2p XPS peaks show for the two samples a completely different behavior. While in one of the samples, Bi and Se are almost homogeneously distributed on the Si oxide substrate; for the other one, Bi atoms are present only in certain areas corresponding to the protruding regions in the optical micrograph, while Se atoms are distributed quite homogeneously on the Si oxide surface. This means that at the first stages of this PVD growth, Se atoms are the first sticking on the Si oxide surface. Interestingly, the Bi4f and the Se3d binding energies are found to be comparable with those reported in literature for the Bi2Se3 films, suggesting that no charge transfer occurs at the interface with Si oxide surface, which should have been clearly detected for such an ultrathin Bi2Se3 film. In addition, the analysis of the high resolved XPS O1s peaks confirms the presence of Bi-O bindings. All these findings confirm the SPEM images results, indicating that in the first stages of PVD growth, Se atoms are the first to distribute on the Si oxide substrate and followed by the formation of a stoichiometric Bi2Se3 film. Furthermore, no charge transfer has been detected between the substrate surface and the Bi or Se atoms, which we detect after about more than a month from the growth, a small fraction of the bismuth oxide formation due to the interaction of the Bi2Se3 film with environment.

Summary:

X-ray detectors / 98

Use of Hydrogenated Amorphous Silicon to precisely measure X-ray fluxes

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Hydrogenated amorphous silicon has been used since many years in the fabrication of devices related to optoelectronics, such as solar cells, thin-film transistors and other applications. To obtain a detector grade device it is necessary to reduce the number of dangling bonds inside the material by

introducing hydrogen into the material to passivate them. 10-14% is the typical value of hydrogen content to obtain a detector grade device that is highly resistant to ionizing radiation damage due to its intrinsic disordered nature.
The research program of the INFN HASPIDE project aim to develop a-Si:H devices for ionizing beam characterization, space radiation measurements and neutron detection.

This talk will describe the fabrication details of the a-Si:H devices, the characterization methods and some results obtained so far for X-ray beam measurement, for different sources: clinical LINACs, laboratory X-ray beams, synchrotron radiation.
The linearity of the response with respect to dose-rate is about 1-2 %, sensitivity and noise are comparable to diamond devices, variability of samples from the same production batch is smaller than 10%.
The PECVD techniques (temperature in 150-300 ℃) allow the deposition of thin layers of material (few micrometers) on a variety of substrates, among which also thin layers of plastic materials. Hence it will be discussed also the possibility of transmission detectors for different
applications: instrumented flange at the vacuum/air separation of charged particle accelerators, transmission detectors for dosimetry of real dose delivered to patients by clinical beams in radiotherapy.

Summary:

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X-ray imaging using compact light sources - Part I

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From liquid metal jet to laser driven x-ray sources, a variety of new, compact x-ray sources are emerging in between the gold standard of synchrotron facilities and the widely used standard laboratory x-ray sources.
Translating, adapting, or redesigning x-ray imaging techniques specifically for these novel sources is paramount to achieve the best performance and serve the society by providing new tools for science, industry, security, and education.
We present here some preliminary results of application of different x-ray techniques at these novel sources, and we describe the challenges, possible solutions and future perspectives.

Summary:

X-ray beam facilities / 100

Characterisation and optimisation of laser-wakefield betatron emission for imaging applications - Part II

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A unique aspect of high intensity laser plasma interactions (LPI) is the ability to generate broad ranges of energetic radiation by tuning the target and laser conditions. The different radiation types share a common set of characteristics, they are short pulse (sub-ps), emanate from a small source (100nm-100um), and can be tuned by altering the laser parameters or target conditions. For laser-wakefield betatron emission we expect the x-ray energies to be ~10-100 keV and emanate from a sub-micron source size with narrow collimation. This bright, directional, and energetic source of x-rays is highly applicable to radiography and has been demonstrated to be capable of both X-ray CT and phase contrast imaging. New facilities, such as the Extreme Photonics Applications Centre (EPAC) at the CLF, are looking to utilise these sources for industrial applications, combining the increased repetition rate of the new laser facilities with the penetrative imaging of laser-driven sources.

With laser-wakefield interactions we are able to tune the x-ray energies and flux by altering the gas channel (length and density) [1], or the laser conditions (focus and temporal profile) [2]. Recent work has also demonstrated the ability to maximise the emission using a Bayesian optimisation processes on all parameters simultaneously [3]. We can apply this flexibility to secondary applications instead and determine the optimum spectra required for different samples and detectors, and therefore look to tune the source as required.

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Summary: