# High precision X-ray measurements

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Laboratori Nazionali di Frascati INFN

# Book of Abstracts

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**X-ray beam facilities / 9**

## DAFNE-Light DXR1 Soft X-ray Synchrotron Radiation Beamline: Characteristics and Applications.

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X-ray Absorption Fine Structure Spectroscopy (XAFS) is a powerful technique to investigate local atomic geometry and the chemical state of the atoms in different types of materials specially if lacking of long-range order like nanomaterials, liquids, amorphous and highly disordered systems, polymers containing metallic atoms, etc. The DAFNE-Light DXR1 beam line is mainly dedicated to soft X-ray absorption spectroscopy; it collects the radiation of a wiggler magnet and covers the energy range from 0.9 keV to 3.0 keV or the range going from the K-edge of Na through to the K-edge of Cl. From the end of 2018, using the SDD ARDESIA detector, it will also be possible to perform XAFS measurements in fluorescence mode. The performance of the beamline will be shown together with XAFS data obtained on several reference compounds and in different studies.

**X-ray beam facilities / 15**

## BM08-LISA: the new Italian CRG XAS spectroscopy beamline at ESRF

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LISA (Linea Italiana per la Spettroscopia di Assorbimento di raggi X) is the new italian CRG beamline at the European Synchrotron Radiation Facility (ESRF) dedicated to X-ray Absorption Spectroscopy (XAS).
The optical layout consists in one collimating mirror, a double crystal monochromator (DCM) and a double toroid focusing mirror. Si and Pt coatings ensure an efficient rejection of harmonics. The DCM is equipped with two different pairs of thick crystals Si(311) and Si(111) to cover a wide energy range of 4-70 keV, which offers the possibility to probe the K and L edges of the most of Metals and Rare Earth elements. The design is compatible with the new EBS ring that will be operative after

year 2020.
The beamline provides a high photon flux (1011 ph/s) with a focused beam size < 200 μm and together with the fluorescence detectors available (a 12-channels HP-Ge and a 4-channels SDD) allows the analysis of small-sized or highly diluted samples.
A liquid He/N2 cold finger cryostat and a compact furnace are available for measurements in a wide temperature range (10 - 1000 K), allowing in-situ chemical treatments and measurements under controlled atmosphere.
In this contribution we present the present status and the future perspectives of the beamline.

**X-ray beam facilities / 18**

## A Coherent Imaging XUV-FEL users end-station for the EuPRAXIA@SPARC_ FEL

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A proposal for building a Free Electron Laser, EuPRAXIA@SPARC_LAB, at the Laboratori Nazionali di Frascati, is at present under consideration. This FEL facility will exploit plasma acceleration to produce ultra-bright photon pulses with durations of few femtoseconds down to a wavelength between 2 and 4 nm, in the so called "water window". The project is now focused on machine development, but it will host a user end-station to allow performing photon experiments in different areas.
The main class of experiments will include coherent diffraction imaging, soft X-ray absorption spectroscopy, Raman and photofragemtnation measurements. These techniques will allow studying a variety of samples, both biological and inorganic, providing information about their structure and dynamical behavior. In this context, the possibility of inducing changes in samples via pump pulses leading to the stimulation of chemical reactions or the generation of coherent excitations would tremendously benefit from pulses in the soft X-ray region. High power synchronized optical lasers will also be made available for laser pump-FEL probe experiments. Moreover, a split-and-delay station will allow performing XUV-XUV pump-probe experiments.
In order to perform the widest possible class of experiments, from coherent imaging, to diffraction and spectroscopy, emission, absorption, a top class experimental end-station, including a dedicated section with beam diagnostics and focusing devices and a highly flexible experimental chamber will be built. In this talk an overview of the user end-station including details about sample delivery, data collection, analysis and data storage will be given.

**X-ray beam facilities / 21**

## Characterization of the Detector System for the XAFS beam-line of the synchrotron light source SESAME

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A Fluorescence Detector System for XAFS (X-ray Absorption Fine Structure) composed of 8 monolithic arrays of SDDs (Silicon Drift Detector), each having 8 cells of 9 mm2 area, is being realized within the INFN ReDSoX Collaboration. It will be used for X-ray absorption spectroscopy at the Jordan's synchrotron light source SESAME that provides a photon beam with an energy range between 3 and 30 keV. Detailed characterization tests at ELETTRA Sincrotrone Trieste have demonstrated an energy resolution at the Mn 5.9 keV Ka line, for the monolithic array, below 150 eV FWHM at 10 ℃.

**X-ray HAPG optics / 0**

## " Graphite optics - current opportunities, prospects and limits" Grigorieva I., Antonov A., Gudi G.

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Graphite optics consists of thin layers of Pyrolytic Graphite deposited on a substrate of focusing shape. Pyrolytic Graphite is a perfect artificial carbon obtained by annealing of carbon deposit at temperatures about 3000oC under deformation. Varying annealing procedure one could get Pyrolytic Graphite of different mosaic structure and mechanical properties. Graphite Optics made by Optigraph GmbH on the base of thin films of different type of PG (standard HOPG, HOPG-flex and HAPG) are discussed.
HOPG-flex and HAPG optics are of the main interest as they offer fast any required shape including full figure of revolution, wide range of possible sizes and radii from 1000 to few mm. HAPG optics has mosaic spread 0,1o and could provide in von Hamos scheme resolution comparable with ideal crystals and more than order of magnitude bigger reflectivity. Application of different materials as a substrate is discussed. The optics of both types is used for RFA and plasma analysis. Spectrometers of enhanced efficiency on the base of HAPG optics are used for discrimination of EXAFS, XANES and XES fine spectra at set-up on laboratory and SR X-ray source.

**X-ray HAPG optics / 5**

## Characterization and modeling of HAPG's diffraction properties

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With the advent of synchrotron radiation facilities, scientists became familiar with high end X-ray analytical methods, e.g. X-ray emissions spectroscopy (XES) and X-ray absorption spectroscopy (XAS). Many of these experiments are equipped with crystal monochromators based on diffraction to ensure highest resolving power.
To exploit new users and scientific fields for these methods, laboratory equipment has been developed in recent time. For laboratory X-ray sources usually have a lower brilliance, highly efficient detection concepts had and still have to be developed to ensure the necessary performance. Graphite based mosaic crystals, i.e. Highly Annealed Pyrolytic Graphite (HAPG), have proven to be a suitable component for wavelength dispersive X-ray spectrometers, for they show the highest integrated reflectivity among all known crystals [1]. For example, it can be larger by a factor of 30 compared to Si (111) reflection. This renders XES and XAS possible in laboratory environment with cost efficient setups based on low power X-ray sources while keeping good spectral resolving power ($E/\Delta E \sim 4000$) at moderate measurement times of a few minutes to several hours [2,3].
In contrast to ideal crystals, these mosaic crystals show a more complex diffraction behavior, i.e. penetration effects and focusing errors. Both are depending on the crystal's thickness and the mosaic spread and have to be modeled as they decrease the spectral resolving power. Hence, a good understanding of the diffraction processes in the crystal is of utmost importance not only to evaluate the accumulated spectra but also for the design of optimized optics.
In a collaboration between the HAPG's manufacturer Optigraph GmbH, the Physikalisch Technische Bundesanstalt and the Technische Universität Berlin which was funded in the frame of a Pro FIT project by the IBB, the crystal's properties were investigated by several means. The outcome of this project and further development will be shown. This includes the characterization of the so-called Q-factor, a measure for the reflectivity per crystal layer, the mosaic spread and the homogeneity in dependence of the optic's substrate material [4]. Additionally, a multi reflection-based model to describe and test the crystals behavior in various conficgurations was developed, implemented in a raytracing software and compared with measurements [5].

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**X-ray HAPG optics / 35**

## Characterization of HAPG mosaic crystals using synchrotron radiation

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While Highly Oriented Pyrolytic Graphite (HOPG), a mosaic crystal of high integral reflectivity, has been successfully used in different XRF concepts as an effective X-ray focusing monochromator its further development enables new XAFS and XES configurations: Highly annealed pyrolytic graphite (HAPG) is an advanced type of pyrolytic graphite that, as a mosaic crystal, combines high integral reflectivity with a very low mosaicity of typically less than 0.1°. When used as dispersive X-ray optics, a high resolving power has been observed, rendering HAPG very suitable for applications in high-resolution X-ray spectroscopy, which conventionally relies on ideal crystals. For the design and modelling of HAPG crystals in applications requiring high spectral resolution, the diffraction properties must be known very accurately. To close this gap, a comprehensive characterization of HAPG crystals was performed that allows for modelling of the diffraction properties in different diffraction orders over a broad spectral range. The crystal properties under investigation are the mosaic spread, the peak reflectivity and the intrinsic reflection width. The investigations were carried out for different thickness crystal films, which were mounted adhesively on a substrate. It is shown that the diffraction properties are strongly correlated to the grade of adhesion, which depends crucially on the substrate material and its surface properties. The investigations were performed using monochromated tunable synchrotron radiation of high spectral purity with a high-precision experimental setup and calibrated detection devices at the electron storage ring BESSY II.

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M. Gerlach, L. Anklamm, A. Antonov, I. Grigorieva, I. Holfelder, B. Kanngießer, H. Legall, W. Malzer, C. Schlesiger and B. Beckhoff, J. Appl. Cryst. 48, 1381-1390 (2015)

**Graphite Crystals Spectrometers / 19**

## Development of a graphite Von Hamos spectrometer for hard - Xray XAS applications

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On B18, the Core-XAS beamline at DLS we have developed an emission spectrometer for the collection of high resolution X-ray emission spectra using the Von Hamos configuration. Design considerations, performance and experimental results will be presented.

**Graphite Crystals Spectrometers / 3**

## High resolution X-ray spectroscopy with HAPG crystals

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Highly Annealed Pyrolytic Graphite (HAPG) was developed around 10 years ago by the Company Optigraph. Soon, first experiments demonstrated its potential for high resolution X-ray spectroscopy, namely X-ray Absorption Spectroscopy (XAS) and X-ray Emission Spectroscopy (XES). Meanwhile, spectrometer for XAS as well as for XES are in operation, which use X-ray tubes as sources and are suitable for the analysis of samples from chemical or materials research.
The contribution will begin with a general discussion of design fundamentals for HAPG based high resolution spectrometer. This includes considerations regarding resolving power, spectrometer dimension, optic alignment, etc. Setups for XES and XAS which are in operation are presented. The fields of applications are discussed and examples are shown.

**Graphite Crystals Spectrometers / 1**

## A compact and calibratable von Hamos X-Ray Spectrometer based on two full-cylinder HAPG mosaic crystals for high-resolution XES

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In high-resolution X-ray Emission Spectroscopy (XES) crystal-based Wavelength-Dispersive Spectrometers (WDS) are being applied for characterization of nano- and microscaled materials. Thereby the so called von Hamos geometry provides high detection efficiency due to sagittal focusing using cylindrically bent crystals. To maximize the detection efficiency a full-cylinder optic can be applied. A novel calibratable von Hamos X-ray spectrometer based on up to two full-cylinder optics was developed at the PTB. To realize the full-cylinder geometry Highly Annealed Pyrolytic Graphite (HAPG) [1] was used. Besides its good bending properties this mosaic crystal shows highly integrated reflectivity while offering low mosaicity ensuring high resolving power [2]. The spectrometer enables chemical speciation of elements in an energy range from 2.4 keV up to 18 keV. The design and commissioning of the spectrometer will be presented together with first results using synchrotron radiation as excitation source. The spectrometer combines high efficiency with high spectral resolution (ten times better than in commercial WDS systems) in a compact arrangement also suitable for laboratory arrangements.

**Summary**:

A calibratable wavelength-dispersive spectrometer that can detect X-ray radiation in the photon energy range between 2.3 keV and 18 keV will be presented. By using two dispersive full-cylindrical optics in the beam path, the sensitivity and efficiency of the spectrometer has been increased, and so access to high-resolution X-Ray Emission Spectrometry (XES) in nanoscaled materials, consisting of light elements and transition metals was enabled. Furthermore, due to both integrated optics, a compact design and four different operation modes have been realized.

**X-ray detectors - 1 / 2**

## Silicon Detectors for Real-Time Dosimetry in Radiation Therapy

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The evolution of silicon sensors for real-time radiation dosimetry is essential for new cancer treatments that incorporate small or mixed radiation fields. At the Centre for Medical Radiation Physics, University of Wollongong, Australia, such sensors are being designed, developed and tested in a wide variety of radiation oncology modalities including megavoltage radiotherapy, brachytherapy, proton therapy and heavy ion therapy at cancer treatment facilities around the world. This talk will provide an overview of the current status of developments.

**X-ray detectors - 1 / 12**

## Scintillator pixel detectors for measurements of gamma ray Compton scattering

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The Compton scattering of gamma rays has lately received a growing interest in developing medical physics applications such as Positron Emission Tomography and Compton camera based Single-photon Emission Computed Tomography, as well as in research involving tests of fundamental quantum mechanical laws, such as entanglement. A common method of detection and reconstruction of gamma Compton scattering is to use two detector layers, the first for detection of the scattered electron and the second for the scattered gamma. We have assembled modules of scintillation pixels, which are able to detect and reconstruct the Compton scattering with only one readout layer, thus minimizing the number of electronic channels. A module consists of a 4x4 matrix of Lutetium Fine Silicate scintillators with dimensions 3 mm x 3 mm x 20 mm. It is read out by a matching Silicon photomultiplier array, the signals are amplified and finally acquired by fast pulse digitizers. Two such modules have been tested with a 22Na source and the performance in the detection of 511 keV gamma rays has been evaluated. We have also successfully reconstructed Compton scattering of the 511 keV gammas and we will present the results obtained at the corresponding lower energy depositions approaching the X-ray region.

**X-ray detectors - 1 / 20**

## Development of Advanced Room Temperature Silicon Drift Detectors and Electronics for Synchrotron Radiation, X-ray Astronomy and Astrophysics

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The realization of a tracking system based on large area silicon drift detectors (SDD), within the frame of the ALICE-LHC experiment, has given rise to a coherent effort to adapt the whole technological framework of large area SDD to the field of low energy X-ray detection with high spectroscopy resolution. The scientific drive that have set the specifications for this effort, which is involving a

large collaboration, comes from the needs of synchrotron light beam lines and X-ray astrophysics projects. The results that will be presented have motivated a large community in using the versatility and performances of our detection systems in different directions.

**Summary**:

With the delivery and commissioning in 2007 of the ALICE tracking system which included two layers of silicon drift detectors for a total surface of more than one square meter we achieved two main results. The first is to demonstrate that such a refined device, requiring extreme care, can be mass-produced with high yield in a constructive and rewarding collaboration with industry. But also a proof that with an iterative work between user's detector modeling and a dedicated evolution of the photolithography technology high quality performances could be obtained. The consequences brought to the idea to step into applications requiring large area and low leakage currents hence, high performances low energy X-ray detection systems. Through a dedicated evolutionary development of the ALICE detectors new detection systems for X-ray astrophysics and advanced light sources have been proposed. At the same time the development of very low noise VLSI front-end has allowed valuable steps in the crucial field of tailor-made detection systems.

**Materials investigation techniques - 1 / 33**

## Nanoscale geometry and dynamics in complex matter as seen by synchrotron x-ray micron beam techniques

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Outstanding structure-function relationship of new complex materials are often due their dynamic heterogeneous structure and composition. Examples of complex materials include biomaterials, colloids, complex liquids and strongly correlated materials. These materials are characterized by weak interactions between structural units at nanoscale and mesoscale giving rise to different spatio-temporal configurations. The visualization of the fluctuations between these configurations require advanced methodologies based on high precision X ray measurements and statistical tools for data analysis. Here we present recent results on the connections between the dynamic nanoscale geometry and the macroscopic properties of complex matter in different fields, ranging from material science to biology.

**Materials investigation techniques - 1 / 16**

## A novel approach to a non-destructive depth profiling using soft x-ray spectroscopies

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While the chemical and structural analysis of a surface has become commonplace using a variety of techniques including Auger Electron Spectroscopy (AES) and x-ray photoemission spectroscopy, it is often advantageous to differentiate between the chemistry and structure of the surface and the near surface (e.g., interface). The method used to make this distinction depends on the thickness of the layers to be differentiated. If the combined thickness of the layers is greater than 100 Å, then the surface must be physically removed by ion bombardment before the subsurface components can be identified. However, the bombardment will consequently alter the structure and in many cases, particularly in soft matters, the surface structure and chemistry of the studied component [1]. This alteration makes these methods incapable of precise investigation of super sensitive structure such as the passivation superficial layers formed on the metal alloy oxides in contact with the electrolyte salts [2-3] and the interface formation between low dimensional superconductive layers and the substrate significantly, modifying their properties [4-5].
Here, we carry a novel approach to a non-destructive depth profiling using a combination of the soft x-ray absorption spectroscopy in total electron yield and total fluorescence yield mode with soft x-ray reflectivity measurement. This method allows to have a precise elemental and spatial map of the different layers based on the effective mean probing depth present in specific layers and allows an in depth studies of the super sensitive structures.

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**Materials investigation techniques - 1 / 17**

## X-ray characterization of thin conducting MoO3 films on copper. A new opportunity for technological applications

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The next generation of accelerators has to use cavities with higher RF fields in order to significantly reduce the length and the cost of particle accelerators and to make available these devices to a larger number of users. [1] In order to accomplish this goal is extremely important to minimize overheating effects due to the RF field and reduces the breakdown phenomena. The latter are highly destructive and induce permanent damages on the surface of any copper RF device. [1,2] The use of materials with improved thermo-mechanical properties or working at cryogenic temperature are possible alternatives. [3] Here we will present an alternative approach, which consists in the deposition of thin films on the inner copper surface of RF devices. We developed and built a dedicated evaporation setup to growth by vacuum sublimation molybdenum trioxide films on copper and we measured both the conductivity and the work function. [4]
We will present the x-ray characterization of thin molybdenum trioxide films deposited on thick metallic copper substrates manufactured with a low roughness. Actually, a thin layer of molybdenum trioxide, a hard transparent insulator deposited on copper tends to be conductive, while its

work function remains almost constant and higher than the original copper surface. [4]
By using X-ray Diffraction and X-ray absorption spectroscopy, we characterized the structural order and the electronic properties of these films. In particular the XANES spectroscopy probed the presence of insulating or metallic oxide phases and correlate the electronic properties with the conductivity properties of these coatings. Indeed these films are complex nanophase systems where molybdenum may exist in several oxidation states: Mo4+, Mo5+ and Mo6+ and whose properties can be tuned by changing the substrate and/or the treatment after the evaporation for different technological applications. The measure of a the edge shift at the Mo K-edge can be also correlated with the Fermi level, a parameter that is associated to the transport properties of these films. [4]

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**Materials investigation techniques - 2 / 30**

# Polycapillary Optics for precision measurements

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A novel x-ray source proposal based on radiations channeling in periodical structures will be presented. The state-of-the-art of polycapillary optics based systems applied for elemental analysis and x-ray imaging will be given paying main attention to μ-XRF and TXRF studies as well as to dedicated x-ray microscopy studies for advanced μ-tomography.
Many important medical imaging technologies require a high brightness and quasi-monochromatic x-ray source. They are well known as phase contrast imaging, coherent x-ray diffraction imaging, digital subtractive angiography, dichromography, time-of-flight imaging and mammography in part. Monochromatic radiation source results in better imaging, and, moreover, lower irradiation dose can be applied to patients, doctors or nurses. Another key solution of the idea relates to the selection of narrow band energy portion of radiation, mainly free from the hard X-ray radiation tail. It can be acquired by means of polycapillary optics (polyCO). For instance, X-ray channeling in polyCO can be used to deflect selectively defined portion of radiation emitted by the beam of electrons in a crystal (near 33 keV) through rather large angles (10÷15 degs) that would allow the radiation to be delivered to the patients. Hard tail of the radiation spectrum remains undeflected in such a way and the irradiation dose for a patient becomes much lower.
Based on the experience in the use of polyCO systems, recently the XLab Frascati collaborations have been strongly involved in studying the techniques for high resolution x-ray imaging and micro-tomography that intends in the development of a new imaging instrument to examine low contrast samples complicated by fast developing processes.
In order to get the reliable signal to noise ratio, typically available via SR dedicated x-ray optical devices, for the desktop solutions we have to increase the radiation fluxes from conventional sources. As known, manipulated through polyCO beams result in getting higher fluxes with respect to a pin-hole (with a gain factor of 102 ÷ 103). Moreover, polyCO semilenses can provide low divergent beams of mrad order. These features
make possible the realization of high resolution imaging of low contrast samples in the transmission mode without various algorithmic processes as typically done, for instance, for phase contrast imaging. This report presents the results on x-ray micro tomography

for both static biological and fast dynamic samples as well as a possible future development of a polyCO-based experimental layout for biomedical imaging diagnostics, for the studies in material and environmental sciences, for diagnostics of hi-tech samples, etc. The physics of polyCO-based imaging that substitutes the routine Math procedures of image filtering to improve the characteristics of image transfer will be discussed.

**Materials investigation techniques - 2 / 10**

## Radiation-induced photoluminescent point defects in lithium fluoride for versatile X-ray imaging detectors

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Microscopy imaging detectors play a crucial role in the field of X-ray technologies. The research and development of new advanced detectors is fundamental in order to overcome some of the limits of the standard ones. Solid-state X-ray imaging detectors based on visible photoluminescence from aggregated electronic defects, known as colour centres (CCs), locally produced in lithium fluoride (LiF) crystals and thin films will be discussed. Their peculiar features, such as a very high spatial resolution over a large field of view, wide dynamic range, versatility and simplicity of use combined with the sensitivity of the optical fluorescence reading technique, make LiF-based detectors very attractive for several X-ray imaging applications. In this work, we show the results of X-ray imaging experiments performed by using LiF detectors for (a) a laboratory X-ray source combined with polycapillary optics in contact mode configuration and (b) a synchrotron facility in diffraction-mode configuration. The achieved results confirm that LiF-based detectors are powerful and versatile tools for X-ray imaging.

**Materials investigation techniques - 2 / 25**

## PolyCO Tecniques Applied on X-ray Analysis

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X-ray analytical techniques are widely used in the world. By the way, due to the strong radiation–matter interaction, to design optical devices suitable for X-ray radiation remains still of wide interest. As a consequence of novel advanced material studies, in the last 30 years several typologies of X-ray lenses have been developed. Nowadays, polycapillary optics (polyCO) is a commonly utilized optical device for a wide variety of applications that operates by collecting X-rays and efficiently

propagating them down to the channels by total external reflection in order to form both focused and parallel beams. The development of a compact source-detector system with characteristics to match the requirements of polyCO allows substantial reduction in a size, weight, and power of complete units.

In this short overview presentation we are going to make a comparison of the results achieved by several groups through different X-ray optical elements, paying attention to important beam parameters such as its flux, focal spot-size and divergence.

**Materials investigation techniques - 2 / 26**

## XAS measurements of high-diluted Cu-Amylin complexes

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The amyloidogenic islet amyloid polypeptide (IAPP) and the associated pro-peptide ProIAPP1-48 are involved in cell death in type 2 diabetes mellitus. It has been observed that interactions of this peptide with metal ions are connected with both the cytotoxicity of the peptides and their deposition as amyloids fibrils associated. In particular, Cu(II) seems to inhibit amyloid fibril formation, thus suggesting that Cu homeostasis unbalance may be involved in the type 2 diabetes mellitus pathogenesis.

We performed X-ray Absorption Spectroscopy (XAS) measurements of Cu(II)-amylin complexes in physiological concentration conditions, namely at a very low concentration of absorbing atoms, i.e. 10 μM of Cu(II) ions.

Such low concentrations have been faced by exploiting the High Energy Resolved Fluorescence Detection (HERFD) XAS, as implemented at the ESRF beamline BM16 (FAME-UHD).

Our results demonstrated the feasibility of XAS measurements on ultra-diluted biological samples, thus making possible experiments very close to the physiological conditions.

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## Is there place for strangeness in the Universe? Kaonic atoms studies at the DAFNE collider with advanced X-ray detectors

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I shall present a series of experiments performed during the last two decades at the DAFNE collider in Frascati devoted to the measurement of kaonic atoms using advanced X-ray detectors. The detectors which were used for these studies range from Charged Coupled Devices to two versions of spectroscopic Silicon Detectors. Combining the excellent quality kaon beam delivered by the DA⊠NE collider with these X ray detectors we have performed unprecedented measurements in the low-energy strangeness sector in the framework of the DEAR and SIDDHARTA Collaborations.

The kaonic atoms, as kaonic hydrogen and kaonic deuterium, provide the isospin dependent kaon-nucleon scattering lengths from the measurement of X rays emitted in the de-excitation process to the fundamental 1s level of the initially excited formed atom; these scattering lengths are key-ingredients for understanding the strong interaction. The most precise kaonic hydrogen measurement was performed by DEAR, followed by the SIDDHARTA experiments. SIDDHARTA also realized the first exploratory measurement for kaonic deuterium ever. Presently, a major upgrade of the setup, SIDDHARTA-2 was done, aiming to perform in 2019 the first precision measurement of

kaonic deuterium. We plan to continue our adventure in the strangeness world by using new X-ray detectors and I hope new ideas and concepts will come from this Workshop.
Kaonic atoms studies represent an opportunity to, finally, unlock the secrets of the QCD in the strangeness sector and understand the role of strangeness in the Universe, from nuclei to the stars.

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## Past experiments and possible future experiments with high resolution X-ray detectors

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The application of Gamma and X-ray detectors in exotic atom research has already a quite long history.
On the one hand spectroscopy was used to study high Z kaonic atoms, low Z atoms recently by SIDDHARTA and last but not least to extract the up-to-now much precise masses of the charged kaon and the sigma, on the other hand the dynamics of processes in higher quantum states of exotic atoms were studied like muon transfer reactions. For these investigations different detector systems were used. New X-ray detectors are needed to attack still open issues in exotic atom research. Selected past experiments and possibilities for future investigations will be discussed.

**Summary**:

The field of high resolution X-ray spectroscopy will be discussed with selected past experiments and possible future experiments applying new detectors.

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## X-ray measurements at J-PARC –a general overview

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The antikaon-nucleon interaction close to threshold provides crucial information on the interplay between spontaneous and explicit chiral symmetry breaking in low-energy QCD. In this context, the importance of kaonic atom X-ray spectroscopy has been well recognized and were performed at KEK and J-PARC (Japan) and DAFNE (Italy) during the last 3 decades.
At J-PARC there are now two experiments ongoing to study strong interaction physics using X-rays: E57 –"Measurement of the strong interaction induced shift and width of the 1st state of kaonic deuterium at J-PARC"and E62 –"Precision Spectroscopy of Kaonic Helium 3 and 4 to study 3d->2p X-ray transitions". Both experiments are involving two different X-ray detection systems Silicon Drift Detectors and Transition Edge Sensors. In this talk, I will concentrate on the newly developed large area Silicon Drift Detector system for E57.

**X-ray applications in various fields - 1 / 22**

## Characterization of sub-ps hard X-ray pulses for pump-probe experiments

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Out-of-equilibrium states are obtained by irradiation with ultra-short laser pulses in the optical range, which induces electronic transitions on a timescale at which the lattice is considered to be frozen. Such phenomena are studied experimentally in the so-called 'pump-probe'scheme, in which the sample is excited (pumped) by a fs optical laser pulse and probed by a pulse of an eventually different wavelength such as X-rays.
Currently ultra-short hard X-rays pulses are produced by X-FELs (Free Electron Laser), table-top X-ray plasma sources, and femto-slicing sources at synchrotrons.
The femto-slicing scheme was proposed [1] and experimentally demonstrated for the first time at the Advanced Light Source (ALS) in Berkeley [2]. It is based on the interaction of a femtosecond laser with an electron bunch travelling through the magnetic field produced by an insertion device (usually a wiggler). This process is used to produce sub-picosecond hard X-ray tunable photons in synchrotrons.
Such a femto-slicing source has recently been implemented at SOLEIL [3] synchrotron providing an average photon flux of 10e6 ph/s at 7 keV in a 0.8% bandwidth, with a repetition rate of 1 kHz.
The commisioning of the source will be discussed. It was carried on the CRISTAL hard X-ray beamline, already used for time-resolved diffraction experiments [4], by using a Si(113) double crystal monochromator and a single photon-counting hybrid-pixel XPAD3.2 detector [5].

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## SPHINX: Structure Probing by Holographic Imaging at Nanometer scale with X-ray lasers

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The project aims creating ultrafast X-ray holographic cameras able to record 3D images of microscopic samples and of their internal parts with nanometer resolution. The proposal is based on a new implementation of phase-contrast holography. As practical solution, a combination of polycapillary lenses, X-Ray CCD arrays and XFEL sources enables focusing, magnification and phase contrast imaging, in the keV energy range. This reduces the diffraction limit and the characteristic angles, both crucial for the resolving power, while eliminating the shielding effect and giving access to full structure probing. The key parameters are defined by the focusing optics. The femtosecond exposure time allows holographic reconstruction of in vivo cell elements, viruses and nano-robotic devices also during ultrafast molecular processes, yet unexplored by imaging techniques.

**X-ray applications in various fields - 1 / 6**

## Imaging of X-rays from ortho-positronium decay with J-PET tomograph

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Standard Positron Emission Tomography (PET) allows to determine spatial and sometimes also temporal distribution of concentrations of selected substances in the body based on production of 2 gamma quanta from e+e- reaction, with energies of 511 keV.
Positron emitted inside the human body can either annihilate directly with one of the electrons or it creates the quasi-bound state of electron and positron called positronium atom.
Imaging of the properties of positronium inside the body may deliver new diagnostic information. J-PET group has developed a way of measuring one of such new parameters [1], but it is necessary to detect positronium decay into 3 photons, which constitutes to about 0.5% of all annihilations.
The energy of photons, due to three body decay, varies from 0 to 511 keV, which implies that J-PET detector needs to sensitive to hard X-ray region.
In the presentation the feasibility of imaging positronium with X-rays will be discussed as well as initial results from measurements performed during this summer.

[1] P. Moskal et al., "Feasibility study of the positronium imaging with the J-PET tomograph", submitted to PMB, HEP: arXiv:https://arxiv.org/pdf/1805.11696.pdf

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## Metal elemental organizations in natural Sphalerite : an X-ray absorption microscopy study

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Sphalerite is one of the most common natural zinc sulfide (ZnS) mineral commonly present at Santander, Spain. Here we present X-ray absorption and fluorescence spectroscopy and X-ray element distribution mapping aimed to characterize the inhomogeneous (zonal) distribution of Cu, Ni, Co, and Fe atoms and its effect on the Zn local environment in sphalerite. A linear combination fit of XANES spectra collected in several representative points of a natural mineral surface is employed to obtain the spatial distribution of the Zn containing mineral species. Apart from the majority ZnS fraction, Zn has been found as smithsonite (ZnCO3) and zincite (ZnO) stochiometries. Zn K-edge EXAFS analysis reveal that the presence of smithsonite impurities lead to structural order and shrinking of the Zinc local environment, while zincite contamination increases the level of structural disorder in the zinc local geometry.

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## High precision tests of the Pauli Exclusion Principle, status and future perspectives

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The VIP experiment aims to perform high precision tests of the Pauli Exclusion Principle (PEP) for electrons, and look for a possible small violation. The method consists in circulating a current in a copper strip, searching for the X radiation emission due to a prohibited transition (from the 2p level to the 1s level when this is already occupied by two electrons). The energy of the transition would differ from the standard Kα (2p → 1s) of about 300 eV. Two data taking periods were performed at the LNGS of INFN. The first VIP run used Charged Coupled Devices; the upgraded experiment VIP2, presently taking data, exploits the higher resolution triggerable Silicon Drift Detectors.

The results of the VIP measurements will be presented together with an exploratory study for the application of High Annealed Pyrolitic Graphite detectors to a VIP like measurement, motivated by the high gain in the energy resolution.

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## X-ray detector technologies for astrophysics on-board the enhanced X-ray Timing and Polarimetry (eXTP) mission

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High energy radiation from celestial objects is one of the most powerful diagnostic tools to access and understand the mechanisms underlying the most energetic and violent phenomena in our Universe. Spectral, timing and polarimetric radiation signatures in the X-ray energy range offer a direct access to plasma in environments hosting extreme conditions of gravity, density or magnetic field.
The enhanced X-ray Timing and Polarimetry (eXTP) is a science mission specifically designed to study the state of matter under extreme conditions. To this aim the mission carries an unprecedented suite of instruments enabling for the first time simultaneous spectral-timing-polarimetry studies in 0.5-30 keV energy range.

In this talk we will describe the intensive R&D programs carried out in the last years by the Italian National Institutes for Astrophysics (INAF) and Nuclear Physics (INFN), focused on the development of innovative imaging photoelectric polarimeters and fast, large-area Silicon Drift Detectors (SDDs) that have led to the design of the Large Area Detector (LAD), the Polarimetry Focusing Array (PFA) and the Wide Field Monitor (WFM) instruments on-board the eXTP mission.

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## The HERMES project

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HERMES (High Energy Rapid Modular Ensemble of Satellites) is a mission concept to probe the emission of bright high-energy transients based on a constellation of nano-satellites in low Earth

orbit, hosting fast, modular and broadband X and ?-ray detectors, composed of Silicon Drift Detectors coupled to scintillator crystals.
HERMES main scientific objective is the prompt localisation of bright hard X-ray/soft ?-ray transients such as Gamma-ray bursts (GRBs), that are also among the likely electromagnetic counterparts of the gravitational wave events (GW) discovered by LIGO/VIRGO. The signals detected by the different units can be combined together to largely increase the total collecting area and thus improving the statistics.
In this talk a brief overview of the scientific objectives of the project will be given, and the innovative technological solutions foreseen for the detector and its electronics will be discussed, having to face particular constraints in terms of sensitivity, power consumption, volume and mass.

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## Conclusion

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## Silicon Drift Detectors and low-noise readout ASICs for X-ray Spectroscopy

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This work reports about the development of Silicon Drift Detector (SDDs) arrays and readout electronics for the upgrade of the INFN- SIDDHARTA experiment. The SIDDHARTA experiment uses high resolution X-ray spectroscopy of kaonic atoms to determine the transition yields and the strong interaction induced shift and width of the lowest experimentally accessible level. A new detection system based on 200cm2 SDDs will be installed within 2018 to run kaonic-deuterium measurements in 2019.
The detector is a Silicon Drift Detector (SDDs) array composed by 8 independent elements, square shaped with 64 mm2 (8×8) area each. The detector is organized in a 4×2 format for a total area of 34×18 mm2. The upgrade of the SIDDHARTA experiment requires 48 detector arrays that are designed and manufactured by the Fondazione Bruno Kessler (FBK). The readout electronics is composed by CUBE (a low-noise CMOS preamplifier), individually connected to each SDD, and by SFERA (SDDs Front-End Readout ASIC), a 16 channels ASIC that perform analog shaping of the signals.
SFERA is designed in a 0.35 µm technology and the main elements of the single channel are a high order shaping amplifier (9th order Semi-Gaussian complex poles), a fast shaper amplifier, a peak detector, a baseline holder and a high efficiency pile-up rejection logic. The shaping amplifier is characterized by selectable gain and peaking times that can be selected with different configurations of an internal 256-bit register. The available gain settings are (corresponding energy of the shaper full scale): 10 keV, 16 keV, 36 keV, 50 keV and 20000 e-. This last setting is useful when SFERA chip is used to read an SDD array coupled to a scintillator crystal in gamma-ray applications. The main shaper has peaking times of 500 ns, 1 µs, 2 µs, 3 µs, 4 µs and 6 µs (selectable) while the fast shaper has a fixed one of 200 ns.
The outputs of the channels are connected to an analog multiplexer that can be connected to an external ADC card or to a 12-bit SAR on-chip ADC.
Measurements of the detectors arrays will be reported (coupled to the SFERA chip) in this work. Moreover, a study the effect of charge sharing on SDD channels upon absorption of X-rays and background particles on SDD is discussed. This study aims at investigating the performances of such devices when expected to be irradiated with X-rays signals and with a large background due to MIPs of the accelerator.

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## Large Format, Direct And Indirect Detection CCD Cameras For Soft X-Ray

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Since the invention of charge-coupled-device (CCD) technology in 1969, the possibility to use such devices in application starting from the NIR to the x-ray region of the electromagnetic spectrum has attracted the interest of scientist in a wide range of areas like astronomy, Bose-Einstein condensates, fluorescence imaging, photometry, plasma research, Raman spectroscopy and x-ray imaging.
The use of CCDs for VUV and X-ray imaging and spectroscopy however, suffers for the strong absorption of UV radiation by materials utilized in the layer above the CCD's epitaxial photon-absorption layer (depletion layer). Therefore it is very important to make sure that any layer above the depletion layer is as thin as practically possible.
In order to address the challenge of having imaging tools extremely stable and sensitive in the soft x-ray to VUV energy, special enhanced-process and other back-illuminated CCDs without AR coating now provide unprecedented sensitivity in the soft x-ray to VUV range.
Results of ultimately technological achievement it will be presented outlining mostly (1) standard-process, back-illuminated CCDs; (2) enhanced-process, back-illuminated CCDs; (3) deep- depletion, back-illuminated CCDs; and (4) deep-depletion, front-illuminated CCDs. Sensitivity differences within the soft x-ray to VUV energy range will be discussed and several models of large format CCDs will be described.

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## Silicon Drift Detectors for exotic atom precision measurements, SIDDHARTA 2 experiment

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SIDDHARTA 2 Collaboration aims to perform the first measurement of the kaonic Deuterium at DAFNE Collider of INFN-LNF.
In order to do this, new spectroscopic Silicon Dirft Detectors (SDDs) system has been developed. We present a detailed characterization of the SDDs system concerning stability, energy and time resolution in the range of the X Rays going from about 3 KeV to 20 KeV.

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## ARDESIA - a Fast SDD X-ray Spectrometer for Synchrotron Applications

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ARDESIA is an SDD-based, X-ray spectrometer, optimized for synchrotron experiments that require high count rates (>1Mcps/channel) and excellent energy resolution (<150 eV FWHM at shaping times faster than 200 ns). The main target applications are XRF and XAFS techniques. The detection module consists of 2 × 2-pixel monolithic SDD (5 mm pitch) coupled with a 4-channel version of the CUBE CMOS preamplifier. The mechanical structure of the instrument has been realized to fit inside a sample chamber with a finger-like structure. The system grants proper cooling (-40oC), static vacuum condition (10-2 mbar). ARDESIA is also equipped with two auxiliary electronics: for power and SDD biasing SDD and for closed-loop double Peltier TEC driving. The output signals of the instrument are then processed by digital pulse processors using short pulse processing times, to show good performances at high count rates (about 1 Mcps per channel). Two different campaigns of measurements in synchrotron beamlines have been performed to assess the performance of the instrument. At the LNF DA⊠NE-Light DXR1 soft X-ray beamline, XRF measurements on low atomic number elements (down to C-K line, 270 eV) have demonstrated good energy resolution and first XAFS spectrum of Silicon K-edge in a PyrexTM glass sample has been acquired. At the LISA beamline of ESRF, XAFS measurements on different samples, such as Kesterite and Photochabourneite, are performed. demonstrating high count rate capability and stability of the instrument over time.

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## Detectors for present and future light sources at Elettra

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This work reports on the recent activities carried out by the Detector and Instrumentation Laboratory of Elettra Sincrotrone Trieste. Since both the Elettra synchrotron and the Fermi free electron laser are generating photons in the low to medium x-ray energy range from some eV to tenths of keV the activities of the detector and instrumentation laboratory focuses on spectroscopic and imaging photon detectors, which feature high quantum efficiency from below the carbon edge and are operated also in UHV environments. Special focus will be drawn on custom made monolithic and multi element silicon drift detectors for the Twinmic and the XRF beam line at Elettra. Regarding low energy imaging detectors the PERCIVAL CMOS ('Pixelated Energy Resolving CMOS Imager, Versatile and Large') will be discussed which is currently being developed by a collaboration of DESY, RAL, Elettra, PAL and DLS to address the need for this type of detectors for free electron lasers in the soft X-ray regime. The majorities of Elettra's soft x-ray beam lines are employing fast and spatially resolving electron detectors and their associated readout electronics, which have been developed in-house and have been tailored to the specific needs of the respective beam line. In addition devices for in situ beam diagnostics and dose monitoring for synchrotron radiation and FEL beams have been developed and are operated on a daily basis. Moreover, some recent results in basic research on room temperature semiconductors will be discussed. In this presentation an overview of these devices and their application to specific scientific applications will be given and in view of upgrade programs future directions will be discussed.