XLab Frascati (XlabF)

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The XLab Frascati Laboratory (XlabF) is a multidisciplinary X-ray facility. As a huge experience of X-ray manipulation technologies based on polycapillary optics, the XlabF activities are mainly based on XRD, μXRF and μCT, in various fields, such as cultural heritage, innovative materials, medical diagnostics, pharmacology, radiation diagnostics, detector characterization, etc. Furthermore, having possibility of designing, producing and characterising polycapillary optics, XlabF is strongly involved in the activity on the realisation of various experimental schemes for different spectroscopic and imaging applications.

Having recognised experience in research related to interaction of charged beams and radiations in various media, XlabF takes part in several projects dedicated to theoretical studies on channeling the beams and radiations in crystal-based solids as well as in plasma- and laser-based structured fields, and capillary-based photonic units, in ...

1 Facilities @XlabF

Presently, four facility stations (RXR, XENA, PXRDS, CTS) are open to users: their combined work allows optimising and matching the various analysis, while one more stations is actually in realisation and in commissioning (Soft-XRF).

- **XENA** - X-ray Experimental station for Non-destructive Analysis. It is equipped with three X-ray Oxford Apogee tubes (W, Mo and Cu anodes), a set of mechanical components and motors for lens alignment and scanning, and an optical table providing many geometrical setup possibilities. At first thought to be a multi-technique station, actually XENA is a facility dedicated exclusively to imaging, tomography and characterisation of X-ray devices such as novel sources, optics - diffractive crystals and vibrating optics - and detectors. Status: *Operative*.

- **RXR** - Rainbow X-Ray. Designed, realised and optimised system for 2D/3D XRF micro-imaging and TXRF, RXR is equipped with a MoKα X-ray source coupled with a polycapillary optics in order to generate a micro beam with beam less than 80 μm, and with two detectors of different energy efficiency, in order to measure a full spectrum ranging from 1000 eV to 30 keV. RXR can also work in confocal mode: the source is coupled with a full-lens, and both the detectors are combined with dedicated half-lenses. Status: *Operative*.

- **CTS** - Computed Tomography Station. This is a measuring station for high precision tomography, equipped with a micro-focusing source (4 μm on the anode), high precision mechanics and high-resolution CCD detector (10.4 μm per pixel). Through the phase retrieval technique CTS resolution is estimated in 600-700 nm per voxel. CTS is currently in the installation and commissioning step. Status: *Operative*.

- **PXRDS** - Powder X-ray Diffractometer Station. This is a $\Theta/2\Theta$ "Seifert - XRD 3003" diffractometer, with a remarkable mechanical stability, high precision and a variety of possible configurations. The diffractometer is a 2200W Power System with a CuKα anode target, 1x12 mm beam, while the goniometer, placed in a vertical position, has a high precision thanks to the use of stepper motors with microstep movement which ensures an angular resolution greater than 0.001°. Status: *Operative*.

- **SoX** - Soft-XRF. This station is the new fluorescence station for the study of organic materials. The main characteristics of this instrument is the high vacuum chamber, the 6-axis manipulator for positioning and a windowless detector necessary for detection of low atomic number elements, such as Carbon, Oxygen, Nitrogen and Fluorine. Actually we are implementing the station, with a dedicated detector for low energies. Status: *Commissioning*.

2 Activity in 2024

2.1 User Facilities

During the 2024, the XlabF team were involved in several fields. In particular, in collaboration with University of Sao Paulo and ICPT Trieste, though the ICPT-TRIL program, we have the possibility to host Dr.ssa Perez for several months. During this period, we characterized the potentiality of CTS by μCT and phase analysis techniques, and studied several biological samples, insects entrapped in amber matrix.

Fig. 1 shows CTS experimental setup, composed of a microfocus source (S), a rotation stage (R) and a CCD detector (D). To obtain partial spatial coherence, an X-ray microfocus source (L9421-02, Hamamatsu) with a 5 μm focal spot was used. This source employs a tungsten anode and was operated at a low power tube of 4 W.

Figure 1: (a) CTS experimental setup and (b) its components: S - microfocus source Hamamatsu (5 μm spot size), R - Rotation stage (set for 0.2° step movement), and D - CCD detector (10.4 μm pixel size).

X-rays were recorded using a charge-coupled device (CCD) detector (CCD FDI 1.61:1, Photonic Science) that was fiber-optics coupled to a Gadox (10 mg/cm^2) scintillator with an input active area of 14.4x10.7 mm^2 and image pixel matrix of 1384x1302 with a pixel pitch of 10.4 μm. The pixel size is related to slice thickness in tomographic reconstruction. The readout speed ranges from 10 MHz to 20 MHz pixel rate, therefore the readout of each projection image was performed in less than 0.2 s, enabling fast tomographic acquisitions. A precision rotation stage (L-611.90SD, PI) was used for optimised xyzθ positioning. It employs a 2-phase stepper motor, 360° rotational angle, 100 N load capacity, 50°/s maximum angular velocity and 35 mm diameter aperture.

The first μCT imaging results from CTS were obtained using attenuation-based approach and are shown in Figs. 2. Fig. 2a shows a projection image of a 3.0 mm thread diameter screw, with inner diameter of 2.57 mm and pitch between threads of 0.35 mm. The yellow line in Fig. 2a refers to the region from which the slice in Fig. 2b was obtained. In the slice image it is possible to identify screw helical thread as a lower attenuation region in its boundary. 3D rendering image from Fig. 2c allowed to reconstruct volumetric information on screw structure as well as to identify its helical thread. By varying tube potential from 30 kV to 70 kV different sample features became visible.

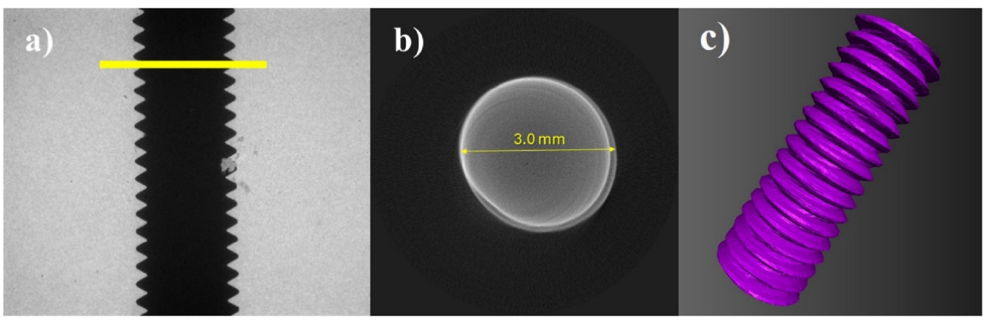

Figure 2: (a) Projection image of a 3.0 mm thread diameter screw, with inner diameter of 2.57 mm and pitch between threads of 0.35 mm. The yellow line indicates the region from which (b) slice image was reconstructed. (c) Rendered image of a screw after reconstruction. Helical thread is depicted. Acquisition parameters used were 70 kV and 30 μA, with time exposure per projection of 100 ms and 0.2° step movement.

An insect, entrapped in amber matrix, with dimension nearly 0.5 mm long, was analyzed. Figs. 3a and b show original phase contrast and phase retrieved projection images, respectively. Fig. 3c presents a subtracted image, showing that subtracted projection image combines both edge-enhancing features and area contrast.

Insect phase contrast images were used for tomographic reconstruction. Figs. 4 presents the first phase contrast tomography results from CTS. Fig. 4a shows the segmentation of a slice image, while 3D rendering of the insect is seen in Fig. 4b. The slice images exhibit sharp transitions within the insect and reveals details about its morphology. However, the gray levels differences are small, which makes it more difficult to distinguish different regions within the sample. After segmentation, volume rendering shown in Fig. 4b enabled to identify six paws, pair of antennae and mouthparts of a 0.5 mm long insect (see smaller image in Fig. 4b). Volume data of this kind allow biologists to study morphological features in three dimensions.

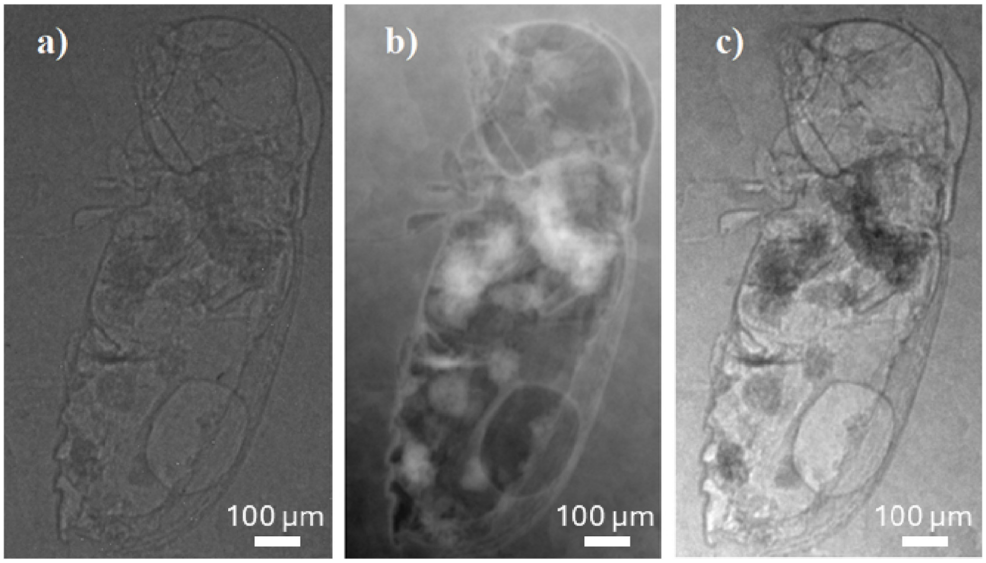

Figure 3: (a) Original phase contrast, (b) phase retrieved and (c) subtracted projection images of an insect embedded in amber. Acquisition parameters used were 40 kV and 100 μA, with time exposure per projection of 10 s and 0.2° step movement.

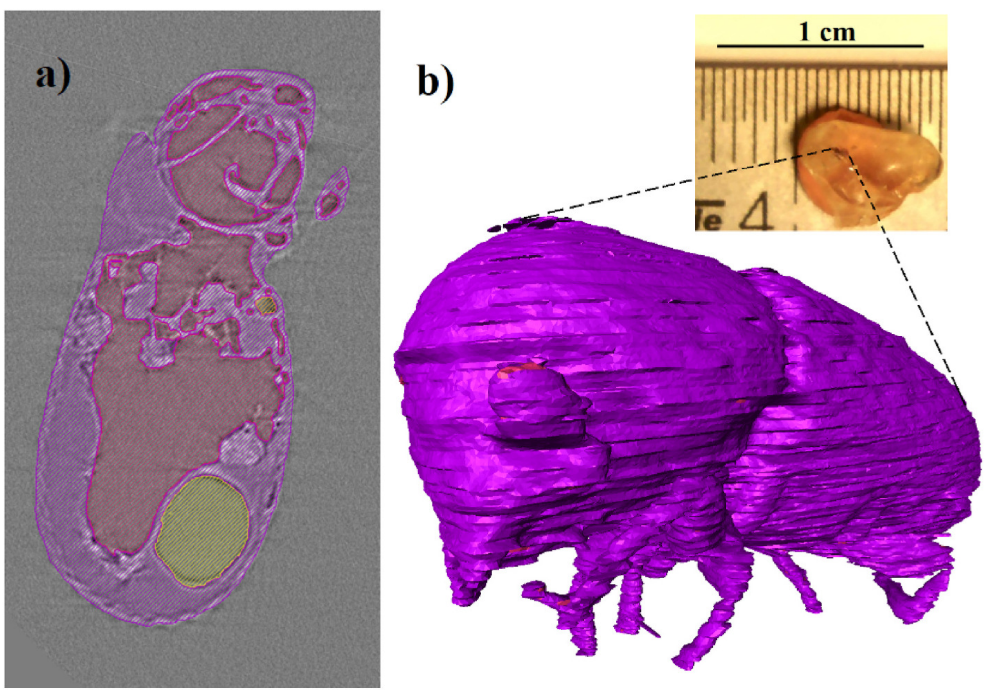

Figure 4: (a) Slice segmentation and (b) rendered image of a nearly 0.5 mm long insect embedded in amber. Dashed lines indicate the insect in the smaller image.

2.2 Projects

@ G-2. During 2024, the collaboration with the g-2 experiment at FNAL was in progress. As members of the project, we continued participation in general discussions related to elaboration of numerical analysis of complete collected data as well as in the discussions on the future concepts for muon beams dynamics and crystal detectors. For latter we have performed calculations for Cherenkov radiation in aligned crystals. We demonstrated that shaping individual radiators can

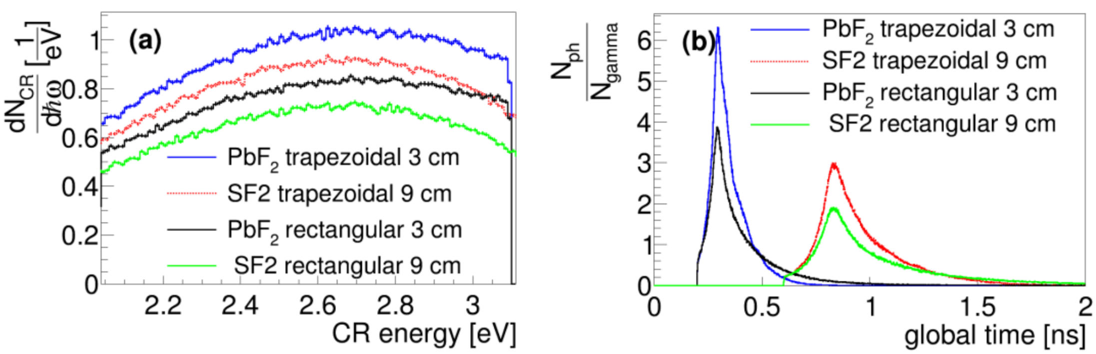

Figure 5: *Spectral (a) and time (b) distributions of Cherenkov photons detected by SiPM attached to the rear surface of PbF2 and SF2 radiators hit by 511 keV primary electrons.*

be an effective way to improve the efficiency of Cherenkov radiation-based calorimeters. Namely, the use of the lead glasses (PbF2 and SF2 show closed results) of trapezoidal shape leads to 25% increase in the output of CR photons. Such calorimeter type can be used for increasing the quality of the upcoming muon experiments or as a potential detection system for medical applications such as positron emission tomography.

@ CROWN (see related report in this collection).

@ Mu2e (see related report in this collection).

@ LiteBIRD (see related report in this collection).

3 Conferences & Meetings & Seminars for 2024

During 2024 we have participated in a number of international meetings contributing as organisers, committees' members and speakers. Below there is a list of the main meetings names and the titles of contributions:

- S.B. Dabagov. Advanced Channeling Technologies: Strong External Electromagnetic Fields to Guide Charged & Neutral Beams. *Invited lectures at the National Academy of Sciences of Republic of Armenia (3-5 April 2024, Yerevan)*

  - Ordered Structures to Handle Relativistic Charged Beams. Crystal and Amorphous Body: Advantages for the Ordered Systems (*2 lectures*).

  - Laser-plasma based Channeling Phenomena (*1 lecture*).

  - Capillary Structures for X-Ray Optics: how the Curvature Helps to Control X-Rays Polycapillary X-Ray Microscopy and Tomography: the Instrument to Solve the Math Tasks (*2 lectures*).

- A. Perez. From Medical Physics to Phase Analysis for High Resolution X-ray Imaging and Tomography. *Seminar at LNF INFN from May 14, 2024, Aula Conversi*
- S.B. Dabagov. Advanced Channeling for Novel Accelerator Concepts *Invited talk at the Ultrafast Beams and Applications (UBA 24) International Conference: Collaborate, Innovate, Accelerate (17-23 June 2024, CANDLE, Armenia)*
- *Channeling 2024 - the 10th International conference "Charged & Neutral Particles Channeling Phenomena" (Riccione, 8-13 September 2024).*

  - S. Dabagov, chairman; co-author of 13 presentations

  - D. Hampai, member of LOC, session chairman, resp. for Book of Abstract and technical support; invited speaker and co-author of 3 presentation

  - F. Galdenzi, member of LOC, technical support; speaker of 1 and co-author of 1 presentations

  - A. Perez, speaker of 1 presentation
- S.B. Dabagov. State-of-the-Art of Channeling of Charged Particles in Crystals and Nanostructures. Advanced Channeling for Novel Accelerator and Radiation Source Concepts. *Plenary lecture at the 2nd workshop on Applications of Nanostructures in the field of Accelerator Physics - NanoAc (17-18 September 2024, Valencia)*
- S.B. Dabagov. Channeling as Novel Optical Solution for Beams and Radiations. *Invited talk at the 12th International Symposium "Optics & its Applications" - OPTICS-12 (15-19 October 2024, Yerevan)*

4 Publications for 2024

1. D. Hampai, V. Guglielmotti and E. Capitolo, CTS - A new X-ray facility for imaging and tomography @ XlabF, *Nucl. Instr. Meth. A* 1060, 169041 (2024).
2. D.P. Aguillard et al., Detailed report on the measurement of the positive muon anomalous magnetic moment to 0.20 ppm, Phys. Rev. D 110(3), 032009 (2024).
3. N. Atanov, et al. R.Y. Zhu, The Mu2e Digitizer ReAdout Controller (DiRAC): Characterization and radiation hardness, *Nucl. Instr. Meth. A* 1068, 169688 (2024).
4. N. Atanov, et al. The Mu2e crystal and SiPM calorimeter, *Nucl. Instr. Meth. A* 1069, 169959 (2024).
5. F. Galdenzi, et al. The EuAPS Betatron Radiation Source: Status Update and Photon Science Perspectives, *Condens. Matter* 9(3) (2024) 30 doi: 10.3390/condmat9030030 .
6. H.R. Drmeyan, S.B. Dabagov, H.G. Margaryan, S.A. Mkhiraryan. Influence of mechanical damage to an interferometer block on its x-ray diffraction pattern. *Journal of Surface Investigation: X-ray, Synchrotron and Neutron Technique* 18(5) (2024) 1281. ISSN 1027-4510.
7. L. Porcelli, S. Dabagov, G. Delle Monache, D. Hampai, G. Modestino, and S. Savaglio. The INFN LNF astrophysics and cosmology integrated test facility startup. *NDT* 2(3) (2024) 249 doi: 10.3390/ndt2030015
8. A. Saharian, S. Dabagov, H. Khachatryan, and L. Grigoryan. Quasidiscrete spectrum Cherenkov radiation by a charge moving inside a dielectric waveguide. *Journal of Instrumentation* 19(06):C06017, Jun 2024.

9. D. P. Aguillard, et al. Detailed report on the measurement of the positive muon anomalous magnetic moment to 0.20 ppm. *arXiv: 2402.15410[hep-ex]* 2024.

10. L. Grigoryan, et al. Observation of coherent Cherenkov radiation of electron bunches from a partially dielectric loaded waveguide. *Nucl. Instr. Meth. A* , 1062 (2024) 169177 doi: 10.1016/j.nima.2024.169177

11. A. Dik and S. Dabagov. On grazing scattering of a charged particle by a flat solid surface. *Nucl. Instr. Meth. A* 1060 (2024) 169082 doi: 10.1016/j.nima.2024.169082

12. A. Curcio, S. Dabagov, G. Dattoli, and D. Giulietti. Phase-matching in high-energy photon sources by relativistic laser-plasma interactions. *Nucl. Instr. Meth. A* 1061 (2024) 169106 doi: 10.1016/j.nima.2024.169106

13. M. Mazuritskiy et al. Propagation of synchrotron radiation through double microchannel plate device: Comparison of experimental data and wave-approach simulation. *Nucl. Instr. Meth. A* 1059 (2024) 168953 doi: 10.1016/j.nima.2023.168953

14. S.B. Dabagov, Ed., Channeling 2023, Proc. of the 9th International Conference "Charged and Neutral Particles Channeling Phenomena" (Riccione, June 4-9, 2023), *Nuclear Instruments and Methods in Physics Research A* 1056 (2024).