LARIX-T Facility

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The LARIX (LARge Italian X-ray facility) laboratory is located inside the Scientific-Technological Pole of the University of Ferrara, in an underground building that includes a 100 m long tunnel with two large experimental rooms on each side. It hosts two hard X-ray installations: the 12 m long LARIX-A located in the experimental room A, and the 50 m long gamma-ray facility, LARIX-T, installed in the tunnel.

In this document, we present a description of the LARIX-T facility. The LARIX-T facility provides polychromatic gamma-ray beams from 20 keV up to 300 keV with high brightness, and polychromatic gamma-ray beams from 50 keV up to 1 MeV with low brightness. The facility is suitable for testing gamma-ray reflectors and low-weight gamma-ray detector prototypes when low-divergence beam and/or very long beamlines are needed.

The X–ray facility is controlled by a remote console room, by means of a well equipped Personal Computers. We provide below a description of the hardware and software in the facility which is available for the national and international community, via collaborations or transnational access programs, such as AHEAD.

1 LARIX-T Overview

The facility spans all the 100 m tunnel connecting LARIX-A to the smaller LARIX-B and can be operated to get polychromatic beams (see below) from 20 keV up to 800 keV. LARIX-T features a 26.5 m long beamline, of which 21 m are inside a vacuum tube. The facility provides a gamma-ray beam obtained either by a high power X-ray generator or a low power portable betatron. The gamma-ray beam size is regulated by a fully motorized, adjustable collimator. The collimated beam reaches a 6D hexapod, where the examined sample can be positioned. In the case the sample is a focusing material, like a bent crystal, a flat-panel scintillator imager and an HPGe spectrometer can be positioned at the required distance. The collimator and the sample positioning system are contained inside a class 10^5 clean room, temperature controlled. Figure 1 shows a schematic of the beamline. Each component is described in detail in its own section.

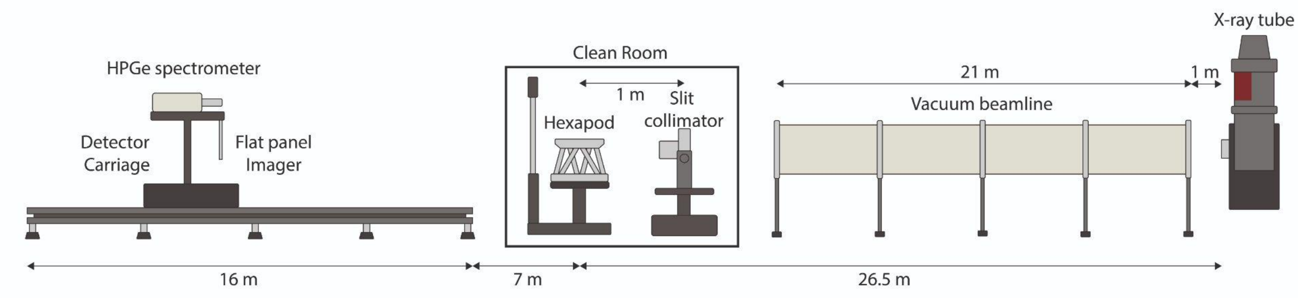

Figure 1: Schematic of the beamline

2 Equipment

2.1 X/Gamma-ray generators

The X-ray tube (main features in Fig. 1) is mounted at the end of the tunnel, in an opportunely shielded area. The tube is equipped with a Tungsten anode and operates from 60 to 320 kV. The tube has two possible focal spot modes: a fine mode, with a focal spot of 0.4 mm diameter, and a broad mode, with focal spot of 1.0 mm diameter. The divergence of the beam is reduced by a 20 mm thick tungsten plate with a 3 mm diameter hole and a 50 mm thick Lead shield with a 1 mm diameter hole. The spectrum of the tube is shown in Fig. 2. The tube can operate in continuum mode.
The X-ray tube is fully motorized: it can be moved up/down and left/right with a minimum step of 10 µm and it can be rotated along two different axes, with a minimum step of 0.01 deg.

LARIX-T X-ray Tube	
Nominal Tube Voltage	320 kV
Maximum Power (fine/broad)	800 W / 1800 W
Focal Spot (fine/broad)	0.4 mm / 1.0 mm
Anode Material	Tungsten
Radiation Coverage	40° x 30°

Fig. 1: Left, main features of the X-ray tube at LARIX-T. Right, picture of the X-ray tube.

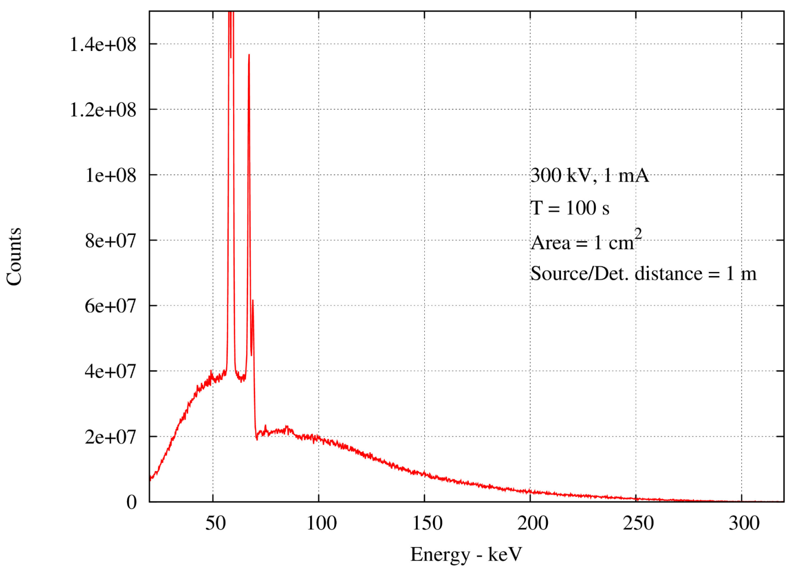

Fig. 2: Normalized energy spectrum of the tube emitted with an anodic voltage of 300 kV and a current of 1 mA on a collecting area of 1 cm^2, source-detector distance of 1 m and 100 s exposure time.

A portable betatron (main features in Fig. 3) is also available. The betraton has a maximum voltage of 2.5 MV, a power of 310 W and a maximal focal spot dimension of 0.2 x 3 mm^2. The emission spectrum of the betatron after 1 m of air is shown in Fig. 4.

Portable Betatron	
Peak accelerated electron energy	2.5 MeV
Maximal focal spot size	0.2 x 3 mm^2
Maximum Power	310 W
Maximum operation time	10 h/day in cicles of 45 min of operations and 15 of cooling
Storage Battery	48 V, 45 min of duration
Fluence after 1 m of air @200 keV	15000 photons/keV/cm^2/s
Fluence after 30 m of air @200 keV	16.7 photons/keV/cm^2/s

Fig. 3: Main features of the portable betatron at LARIX-T.

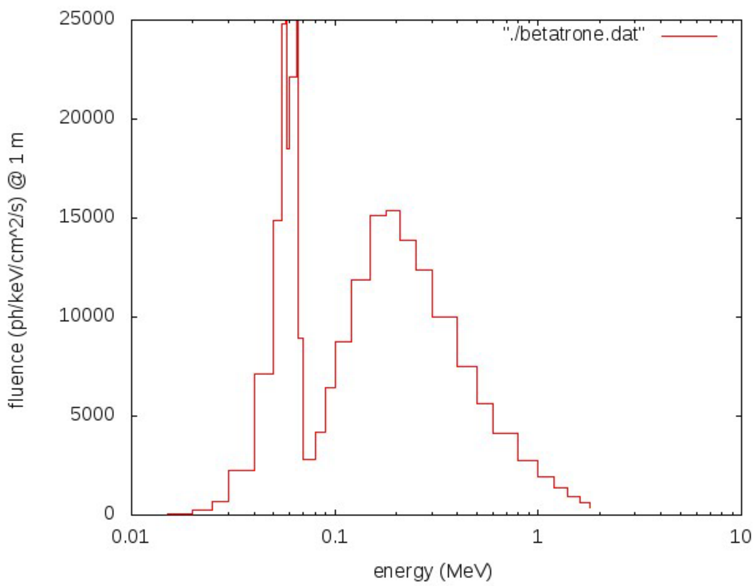

Fig. 4: Normalized energy spectrum of the betatron after 1 m of air.

Different filters are available for selecting a specific band of interest and the related fluorescence lines. The available filters and their thickness are listed in Table 2 and are the same used for the LARIX-A X-ray tube.

Available X-ray Filters	
Material	***Thickness***
High Purity Aluminium	5 mm
Brass	5 mm
High Purity Copper	3 mm
Tin	1 mm
Lead	1 mm

Table 2: X-ray filters available

2.2 Vacuum Beamline and collimator

The X-ray beamline passes inside a 21 m long vacuum tube of 60 cm of diameter (pressure ≤ 1 mbar), with entrance and exit window in 3 mm thick carbon fiber.

A motorized, adjustable collimator is placed inside a clean room, after the vacuum tube. The collimator is fully motorized: it can be moved in 2-dimensions on the plane perpendicular (minimum step = 10 µm) to the beam and it can be rotated along three different axys (minimum step = 0.01 deg).

Each one of its 20 mm thick tungsten blades can be remotely adjusted from a minimum opening of 0 x 0 mm^2 to a maximum of 30 x 30 mm^2. Thanks to this collimation system, the **divergence** of the beam after the collimator is of the order of **100 arcsec**

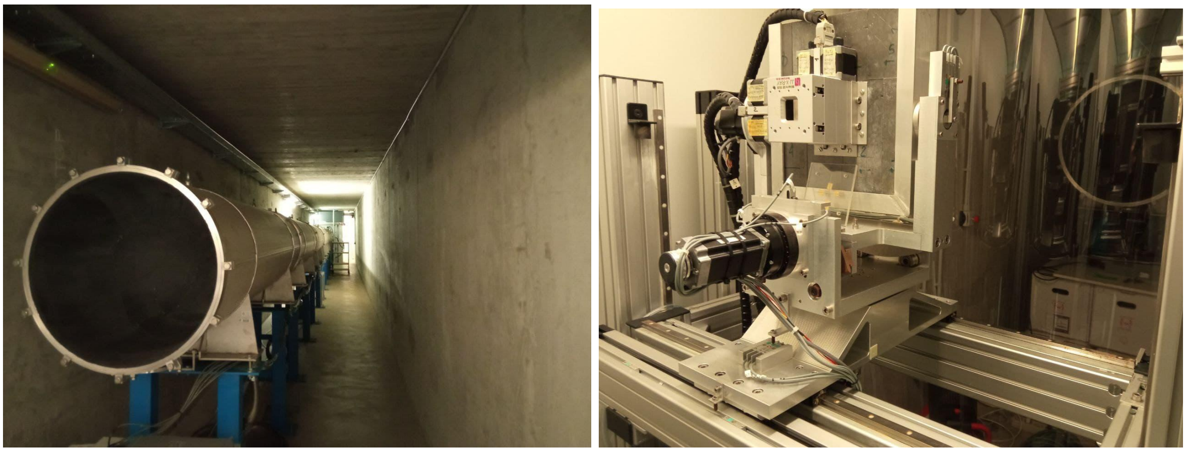

Figure 3: Left -The exit of the 21 m vacuum tube enclosing the X-ray beam. The carbon fiber exit window is visible. Right - The slit collimator inside the clean room.

2.3 High Precision Sample Holder

The sample holder is placed inside the clean room. The sample holder consists of a movable bench which can be moved in the plane perpendicular to the beam, and a high precision hexapod positioner (model: Newport HPX-100), with 6 degrees of freedom (3 translations and 3 rotations) and maximum load of 20 kg. The main features of the hexapod are shown in table 2.

HPX-100 Positioning Hexapod	
Flat platform diameter	200 mm
Travel Range X, Y, Z	±27.5, ±25, ±14 mm
Travel Range ΘX, ΘY, ΘZ	±11.5, ±10.5, ±19 °
Minimum Incremental Motion X, Y, Z	0.5, 0.5, 0.25 µm
Minimum Incremental Motion ΘX, ΘY, ΘZ	0.25, 0.25, 0.5 mdeg
Bi-directional Repeatability (X,Y,Z)	±2.0,±2.0 , ±1.0 µm
Bi-directional Repeatability (ΘX, ΘY, ΘZ)	±1.0, ±1.0, ±2.0 mdeg

Table 2: Main features of the hexapod sample holder

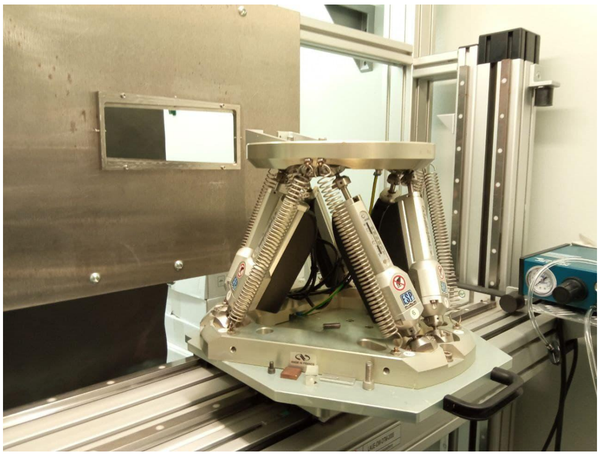

Figure 4: The hexapod sample holder on its motorized carriage.

2.4 Detectors

Both an imager and a spectrometer are available. The detector holder carriage is mounted on a rail and it can be moved from a minimum distance from the sample holder of 7 m to a maximum distance of 23 m. The carriage is motorized and the detectors can be moved in the plane perpendicular to the beam and along two different rotation axes.

2.4.1 Imager

The available imager is a Perkin Elmer flat panel image, which consists of CsI(Tl) scintillators directly deposited on Si photodiodes. The main characteristics of the imager are shown in table 3:

LARIX-T Flat Panel Imager Detector	
Producer and Model	Perkin Elmer XRD 0822
Detector Area	204.8 x 204.8 mm^2
Pixel Pitch	200 µm
Pixel Number	1024 x 1024
Minimum Integration Time	66.6 msec
Radiation Energy	40 keV - 15 MeV

Table 3: Characteristics of the imager detector available at LARIX-T

2.4.2 Spectrometer

The available spectrometer is a Nitrogen-cooled HPGe spectrometer, with a carbon fiber entrance window. The characteristics of the spectrometer are summarized in Table 4.

LARIX-T HPGe Spectrometer	
Producer and Model	AMETEK-ORTEC GEM-SP5020P
Detector Diameter	50 mm
Detector thickness	20 mm
Energy Resolution (FWHM) @5.9 keV	300 eV
Energy Resolution (FWHM) @122 keV	585 eV
Energy Resolution (FWHM) @1.33 MeV	1.8 keV
Nitrogen Tank Volume	5 litre

Table 4: Characteristics of the HPGe detector available at LARIX-T

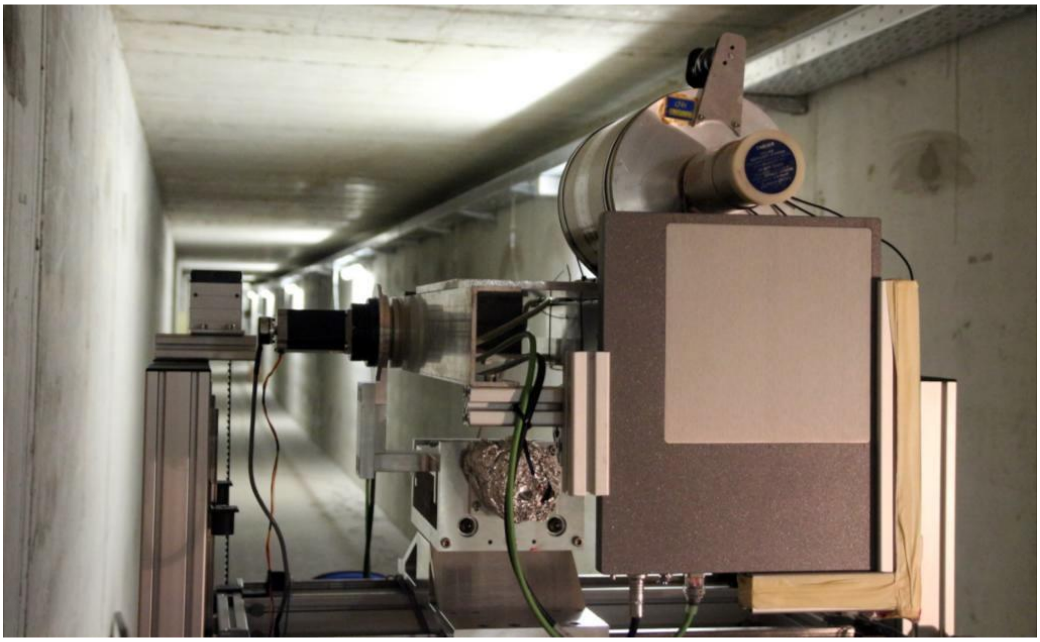

Fig. 5: The flat panel imager (on bottom) and the HPGe detector (on top) available at LARIX-T.

2.5 Other Features

2.5.1 Control Room

The entrance of the tunnel and the control room are separated by a motorized blast door made by a 65 mm lead shield. Safety cameras, motion sensors and emergency shut-down buttons are installed in all the length of the tunnel, to ensure the safety of the operators. From the control room, it is possible to operate all the instrumentation of the beamline thanks to a LabView based interface (Fig. 6). Several BNC, RS-232, USB and Ethernet cables of different lengths are available for the users.

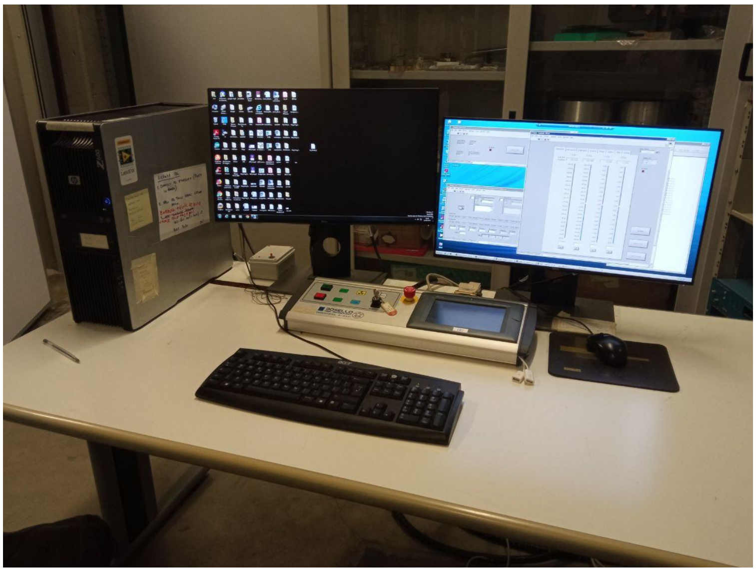

Fig. 6: The computer from which all the instrumentation inside the tunnel can be controlled.

2.5.2 Clean Room

A clean room class 10^5 hosts the sample holder carriage and the slit collimator. The room is equipped with a thermal control system with a stability of ±1° and an hygrometric control which can keep the relative humidity fixed to 60% within 10%.

2.5.3 UPS

The laboratory is equipped with an UPS system. Its technical features are summarized in Table 5.

UPS System	
Output nominal Power	15 kWA - 12 kW
Output Voltage	400 V ± 20%
Output Frequency	50 Hz
Battery Voltage	216 V
Battery Capacity	9.5 Ah

Table 5: Characteristics of the UPS system available at LARIX-A

2.5.4 Radioactive sources available at LARIX

The following radioactive sources are available: **^{241}Am, ^{137}Cs, ^{60}Co, ^{57}Co, ^{22}Na, ^{55}Fe, ^{90}Sr, ^{133}Ba**. The sources are shared among all the Department of Physics and Earth Science. It is suggested to let us know in advance if any source is needed, so we can book them for the time slot necessary for the tests.

3 Examples of experiments done at LARIX-T

The facility is used to perform a variety of experiments and in this section we will present some examples of the kind of measurements which can be performed at LARIX-T.

3.1 Diffraction tests of bent Germanium (220) crystals

At LARIX-T, we are advancing the technology of Laue lenses, a type of hard X/soft Gamma-ray optics based on Bragg's diffraction in crystals. In our past studies, we understood that bent crystals are the best candidates to build a broad-band Laue lens with radiation concentration capabilities: bent crystals act as 1D X-ray concentrators and can be used to build a focussing able to focus X-rays from tens of keV up to hundreds of keV in an image of the size of arcmin or some arcseconds (for reference, see *F. Frontera and P. Von Balmoos, Laue gamma-ray lenses for space astrophysics: status and prospects, 2011*) . At our facility, we performed plenty of tests at our facility on those kinds of crystals. Thanks to its low-divergence beamline and its high precision hexapod, the facility allows us to position the crystals in a very accurate way and perform diffraction measurements with ease.

In Fig. 7 it is possible to see the image produced by a 30 x 10 mm^2 Ge(220) crystal, while in Fig. 8 a diffraction spectrum of the same crystal is shown.

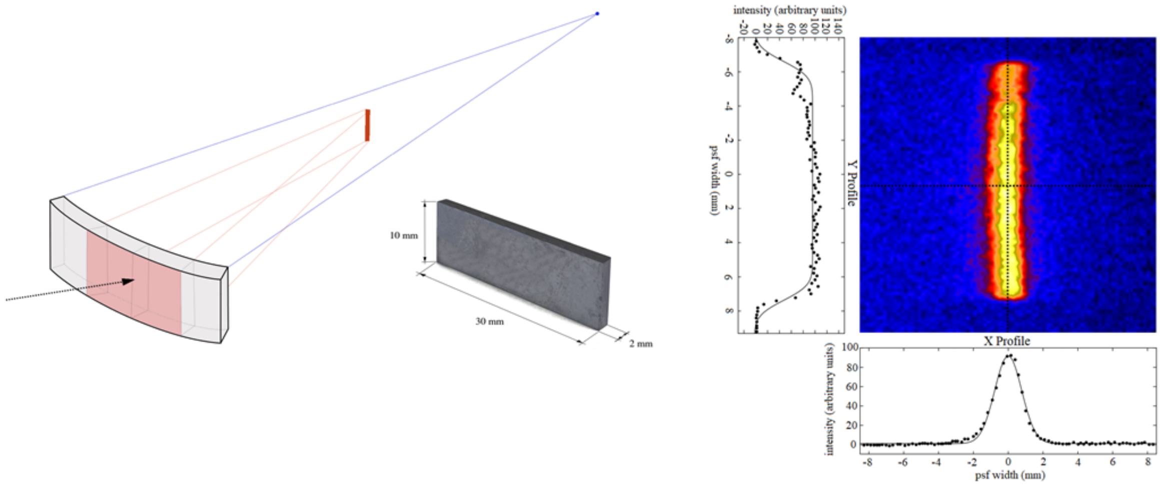

Fig 7:Left, schematic picture of an X-ray beam (red square) focalized by a 30 x 10 mm^2 *crystal. The bent crystal concentrates the beam along the major direction at a distance equal to half the curvature radius of the crystal itself (red line). Right, experimental image of a polychromatic beam diffracted by a Ge(220) crystal oriented in such a way to diffract a narrow energy band centered on 131 keV. The image was collected at LARIX-T, with the LARIX-T scintillator imager.*

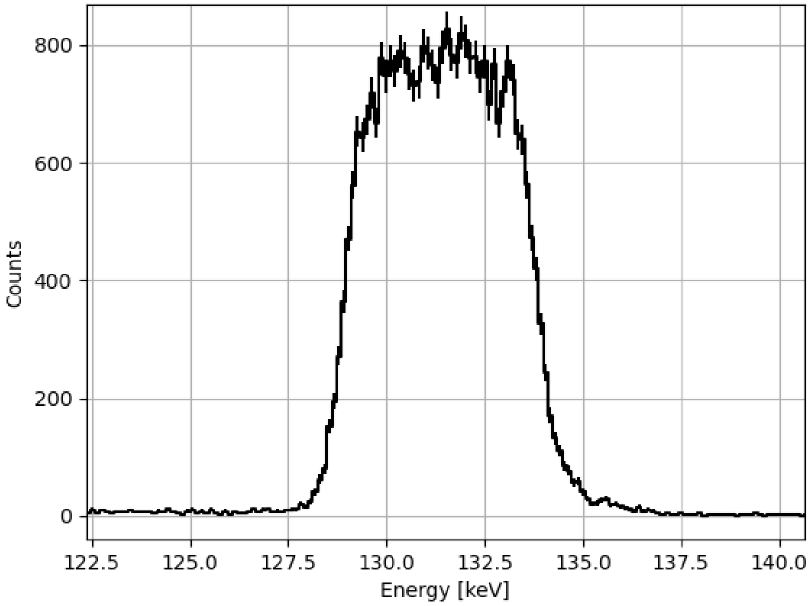

Fig 8: Diffraction spectrum of a Ge(220) crystal positioned to obtain a diffraction peak centered on 131 keV. The spectrum was collected with the LARIX-T HPGe spectrometer.

3.2 Test of a double-Laue diffraction Laue lens configuration

Another example of tests performed at the facility was the proof-of-concept of a double-Laue diffraction configuration, in which two Gallium Arsenide (GaAs) crystals were paired to perform a double diffraction on two independent directions of an X-ray beam, obtaining a 2D concentrator. Again, the possibility to have a long beam-line and fine positioning systems were necessary for the success of the experiment.

The image produced by the double-diffraction pairs is shown in Fig. 9.

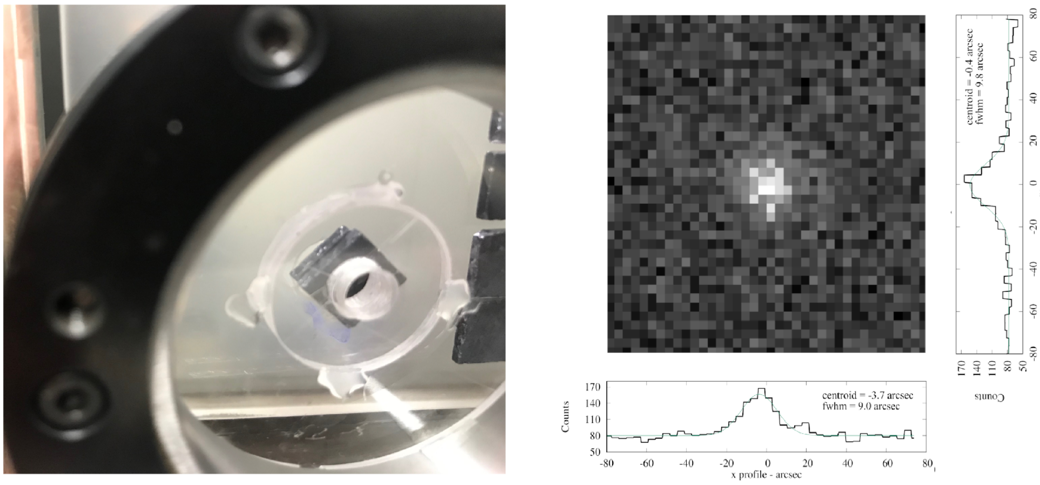

Fig 9:Left, the two square crystals of GaAs(220) of size 10 x 10 mm^2 *paired together. Right, the image produced by the double-diffracting pair. The X-ray spot in the image has size of about 1 x 1* mm^2

3.3 Performance test of the Compton - POLCA detector

Within the framework of the AHEAD project, the LARIX-T was used to test the Compton-POLCA detector, a multilayer, pixelated CdTe spectraimager detector developed by the University of Coimbra (Fig. 10). At the LARIX-T facility, we tested how the Compton - POLCA detector performed in detecting the beam diffracted by a section of Laue lens made by opportunely oriented crystals. The image of a crystal diffracted beam seen from different off-axis positions is shown in Fig. 11 and the energy passband of 6 different crystal tiles measured with the instrument are shown in Fig. 12.

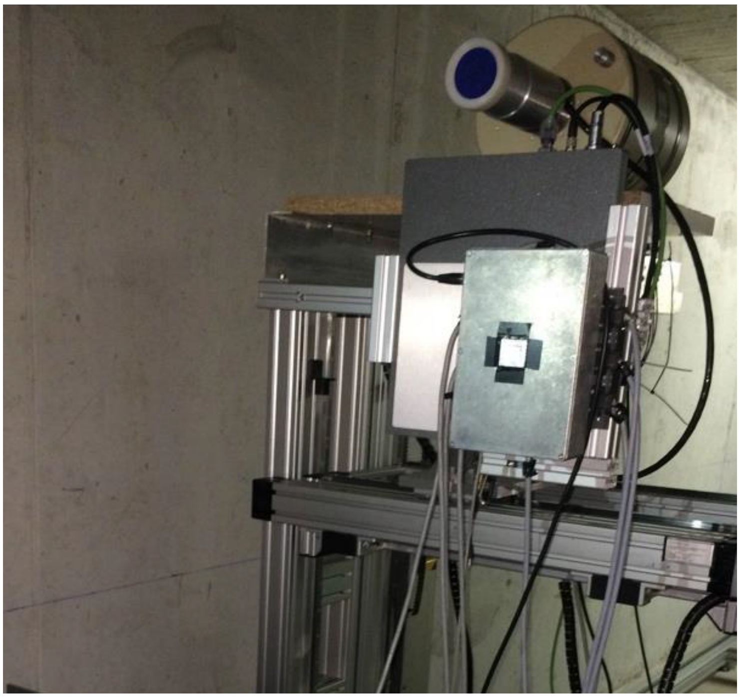

Fig 10: The Compton-POLCA detector, mounted in place of the LARIX-T imager (gray box).

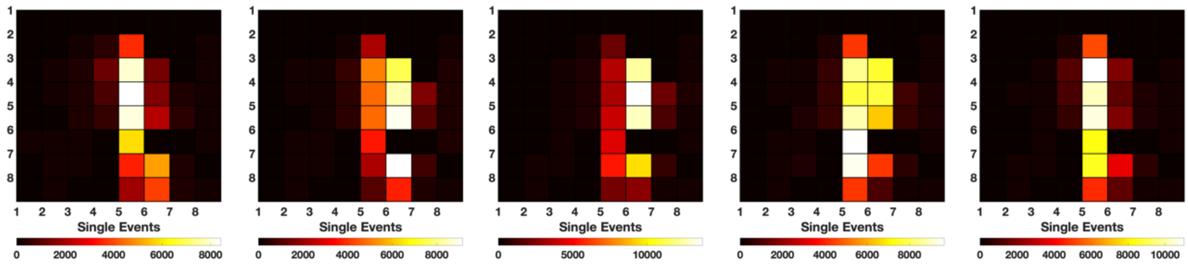

Fig 11: Intensity maps obtained by irradiating crystal a GaAs(220) crystal from 5 different positions.

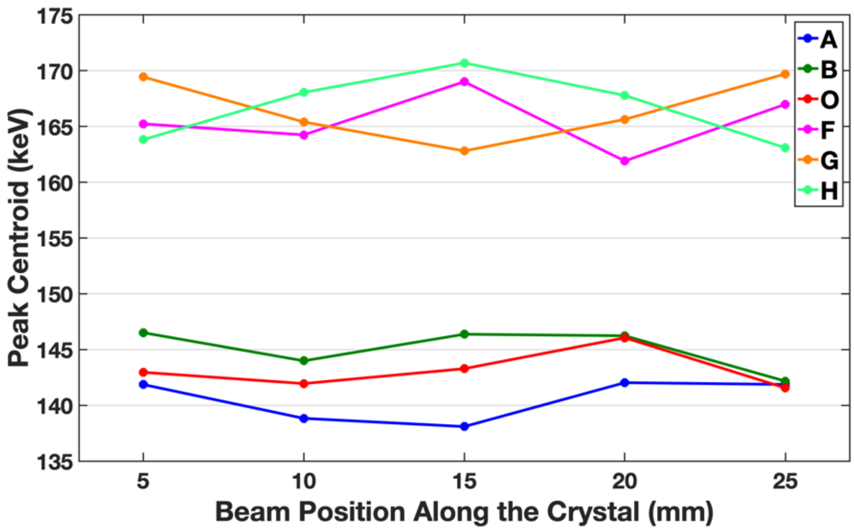

Fig 12: Energy passband for the 6 crystal tiles of two different Laue rings.