The Ferrara hard X-ray facility for testing/calibrating hard X-ray focusing telescopes

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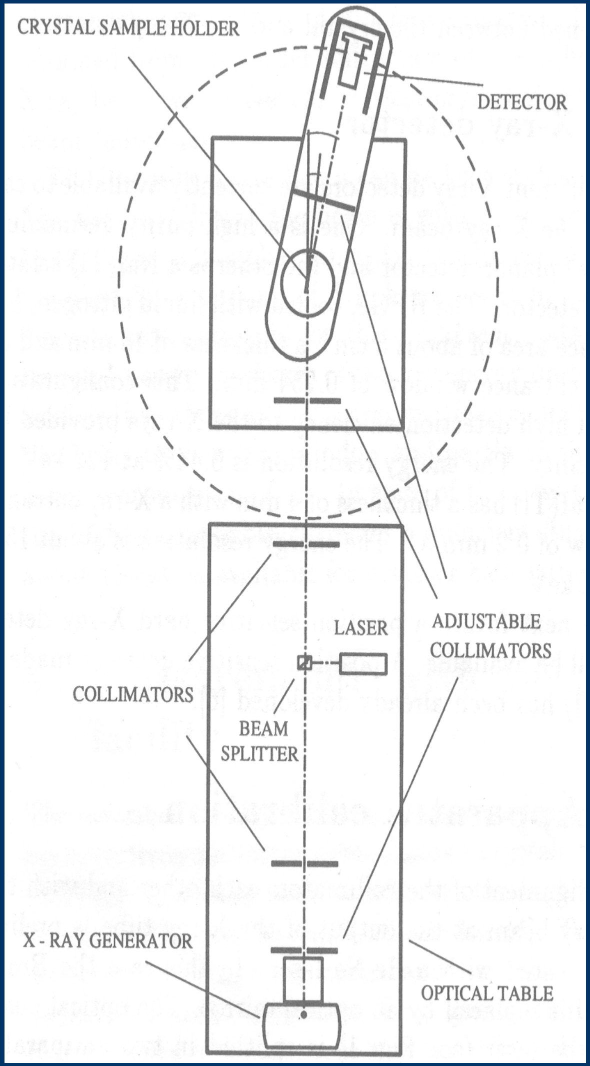
Historical introduction

- The X-ray facility of the Ferrara University initially motivated by the testing the PDS aboard BeppoSAX (Frontera et al. 1994, IEEE TNS);
- Simple apparatus with an X-ray generator, a set of collimators and an X-ray goniometer.
- The facility could provide monochromatic and collimated photons in the range from 15 to 140 keV by rotating the goniometer



Goals we want achieve with the Ferrara X-ray facility

- Detailed calibration of hard X-ray detectors (impossible with radioactive sources) for an accurate determination of their response function;
- For position sensitive detectors, unbiased knowledge of the instrument gain in each point of the detector surface;
- Study of linearity discontinuities in X-ray detectors (e.g. Zavattini et al. 1997 for Xe filled microstrip detectors);
- Hard X-ray reflectivity measurements of material samples (mosaic crystals, multilayers, etc);
- Calibration of hard X-ray optics;
- Transparency measurements of complex materials (e.g. mask support of IBIS).

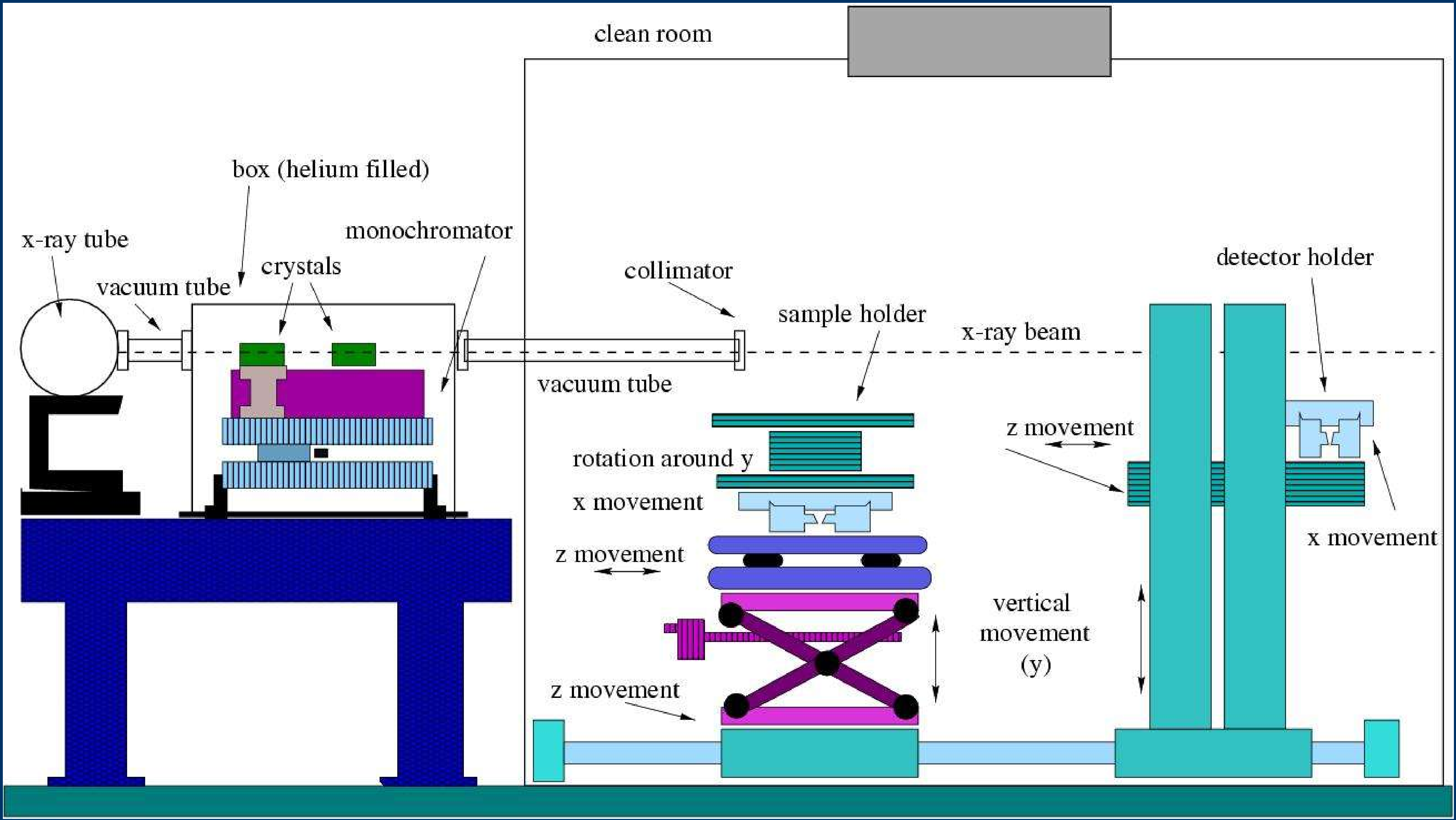
Current capabilities of the X-ray facility

- Availability of a monochromatic pencil beam with fixed exit;
- Photon energy selectable in a broad hard X-ray band (now in the 15-140 keV; in the future expected to be in the range 15-300 keV);
- Possibility of a uniform scanning of an energy band;
- Possibility of a uniform scanning of a surface area;
- Possibility of offset direction of photon incidence.

Main Measurements/Calibrations performed with the X-ray facility

- Ground calibration of the JEM-X detectors for INTEGRAL (Loffredo et al. 2003);
- Measurement of linearity discontinuities in Xenon filled X-ray microstrip detectors (Zavattini et al. 1997);
- Reflectivity measurements of mosaic crystals (e.g., Frontera et al. 1991);
- Reflectivity measurements of Cu (111) mosaic crystal samples in Laue geometry (Pellicciotta et al. 2005)

Configuration of the X-ray facility used for the most recent measurements/calibrations

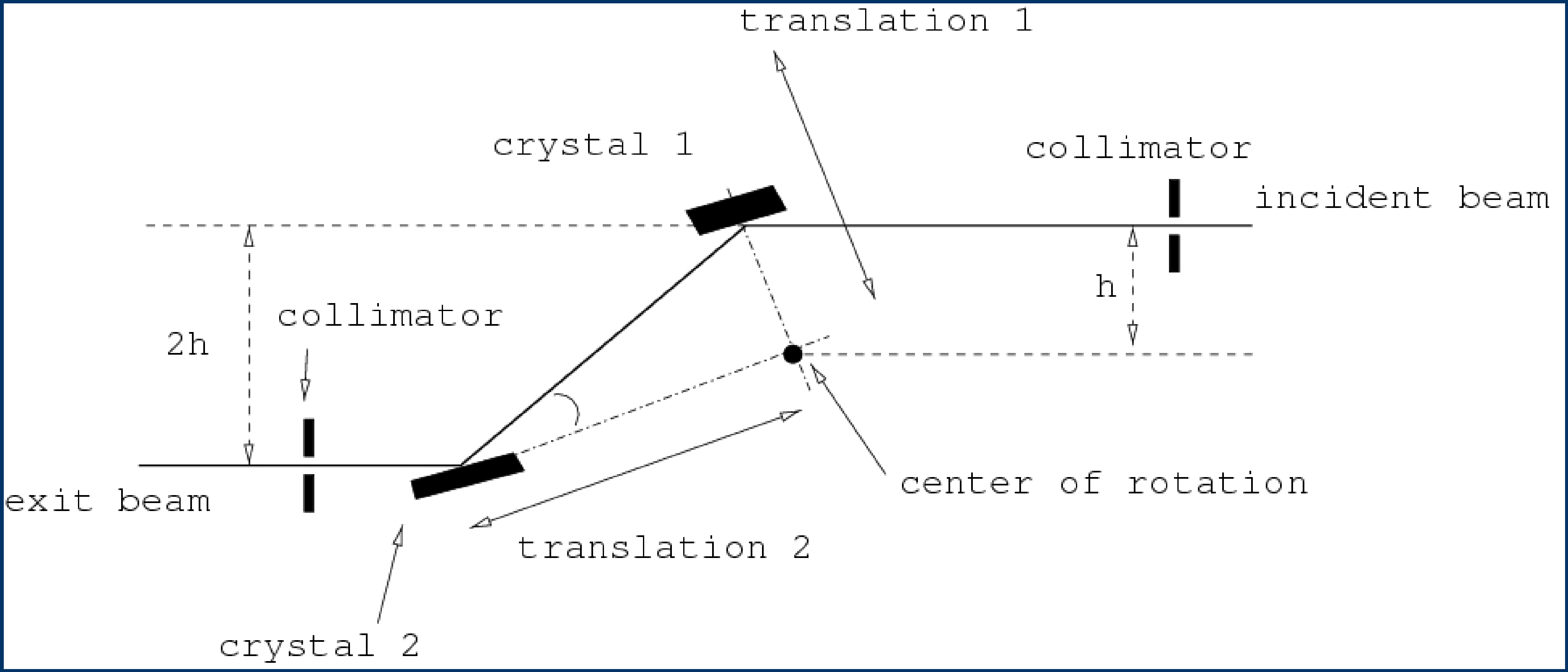


X-ray source

- Two alternatives
  1. Philips X-ray tube (PW2215/20, Mo anode):
     a. Voltage: 20-60 kV;
     b. Current: 20-60 mA;
     c. Maximum continuous power: 3 kW;
     d. Cooling system: water flow.
  2. Polymat 50 X-ray tube supplied by Siemens (Optitop 150/40/80 HC, W anode):
     a. Voltage: 40-150 kV;
     b. Current: 0.1-5 mA;
     c. Maximum continuous power: 300 W;
     d. Cooling system: rotating anode.

"Fixed exit" monochromator

- Crystal 1 [Si (111)] selects the energy from the incident polychromatic beam;
- Crystal 2 [Si (111)] re-directs the diffracted beam along a direction parallel to the incident beam;
- Proper translations of the two crystals allow the beam to be fixed in direction.

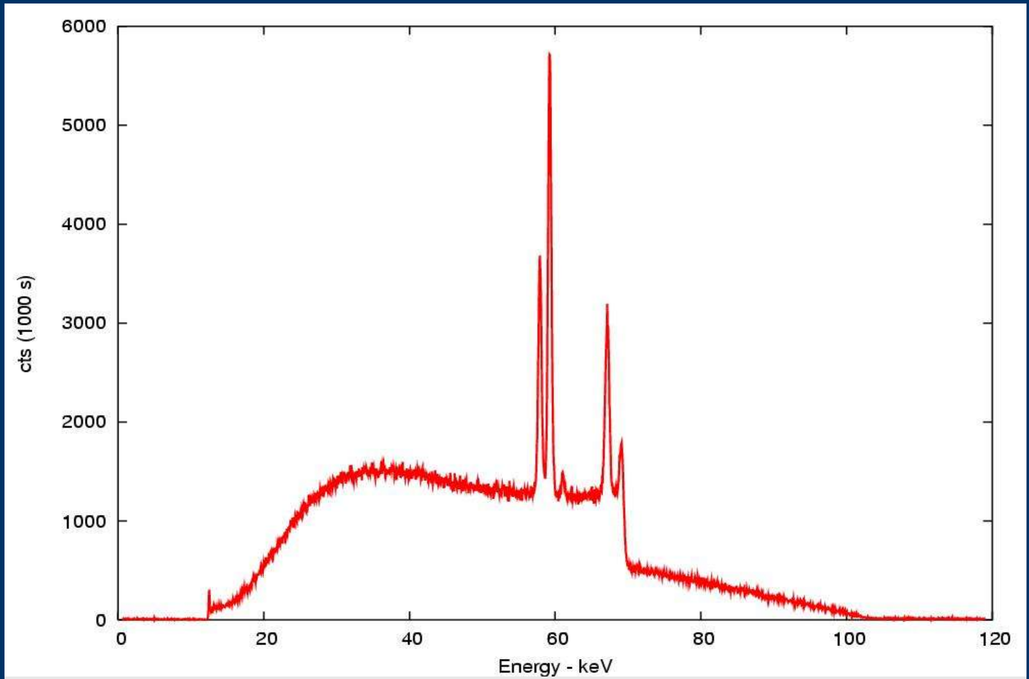


Monochromator Features

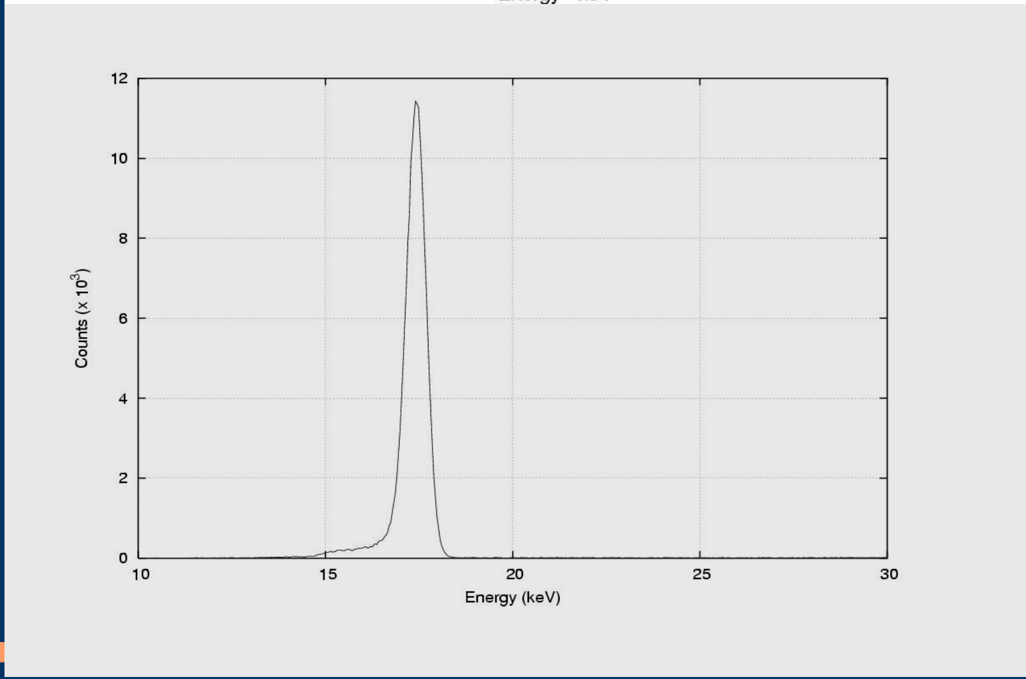
- Energy range: 10-120 keV;
- Capability of working either in air or in helium environment;
- Quick interchange of optical elements: crystals, synthetic structures, crystal bending, cooling devices, etc.;
- Use of mosaic crystals of Si (111) in order to maximize the brightness of the monochromatized beam.

Example of monochromatized X-ray beam

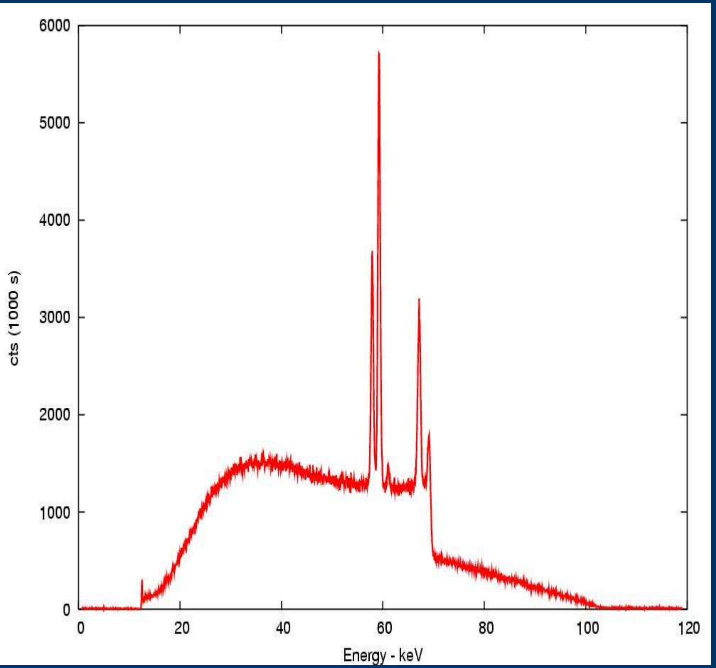
Incident spectrum on the monochromator from Polymat 50 X-ray tube (102 kV-0.5 mA) measured with a HPGe detector.



Monochromatized X-ray beam (17.4 keV; FWHM=0.3 keV) stored with a CZT detector.



Available X-ray detectors for spectroscopy



1. Peltier cooled CdZnTe:
   a. crystal size: 5 x 5 x 2(h) mm^3;
   b. X-ray window: 0.25 mm beryllium thick;
   c. Energy resolution ($\Delta E/E$ = 1.5%@60 keV).

2. Portable LN_2 HPGe:
   a. crystal size: 20 x 20 x 13(h) mm^3;
   b. X-ray window: 0.254 mm beryllium thick;
   c. Energy resolution ($\Delta E/E$ = 0.4 % @ 122 keV).

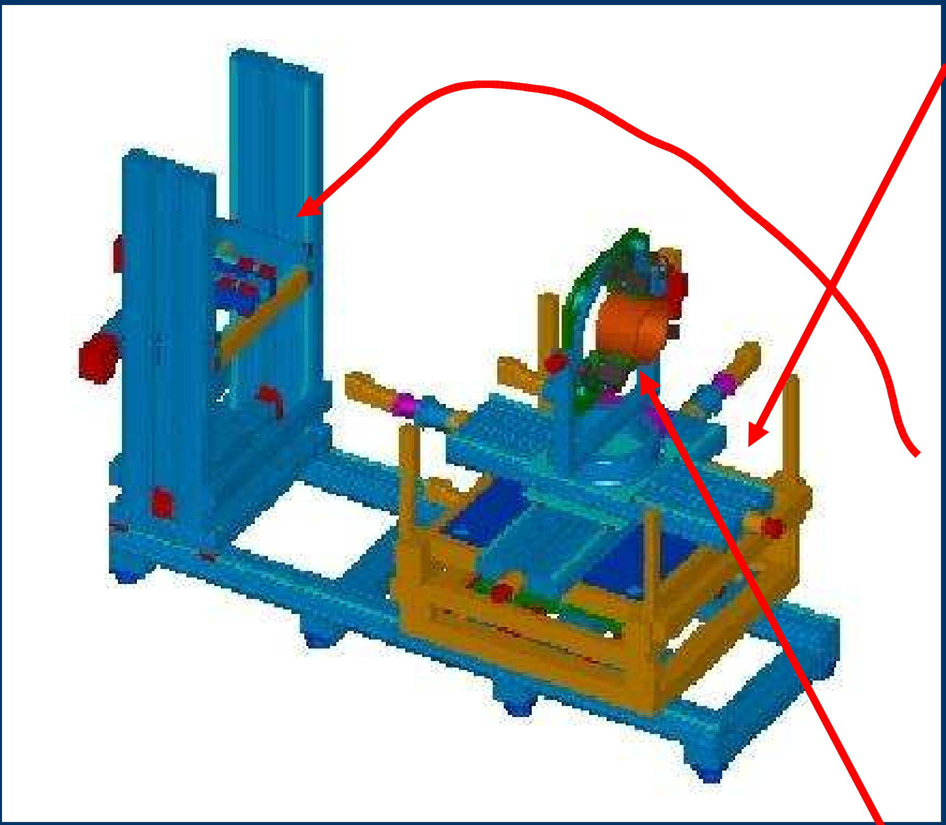
Available X-ray detectors for imaging

X-ray Imaging intensifier of THALES ELECTRON DEVICES

Main features:

- Useful entrance field size of 215 mm diameter;
- X-ray detection efficiency of about 65 % at 59.5 keV;
- Position resolution of 0.2 mm;
- High-Resolution CCD camera 1024x1024 pixels;
- Compact Optical System.

Sample/Detector Holders



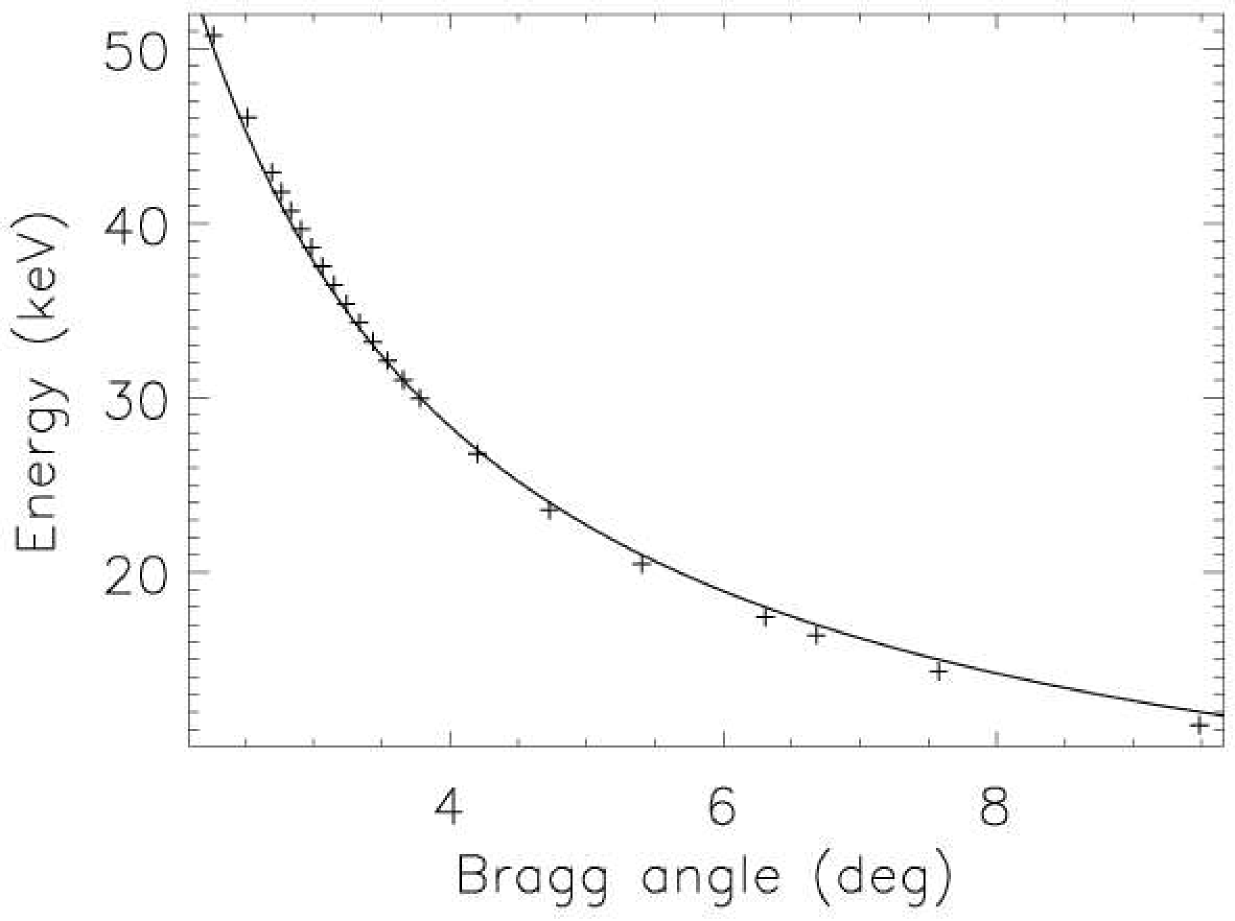
Sample holder: 6 degree of freedom:

- 3 linear stages: minimum step size 1 μm
- 3 rotation stages: 1 around vertical axis (0.001 degree) and two high precision motorized goniometers for the rotation around the horizontal axes (3 arcsec).

Detector holder: 4 degree of freedom:

- 3 linear stage: minimum step size 1 μm;
- 1 rotation stage with 0.001 degree resolution;
- Optical encoder system to read the thre translations of the sample holder;
- System capable to rotate X-ray mirror around the horizontal directions.

X-ray facility calibration



Centroid energy of the monochromatized photons as measured with a CZT detector as a function of the diffraction angle.

For comparison, the nominal photon energy expected from the Bragg law (continuous curve).

Some results of the JEM-X calibrations

Position scans: @ 5.9, 17 and 25 keV.
Energy scans: 6÷50 keV in four different positions of the detector surface.
Position scans: @ 0°, 3° and 6°.

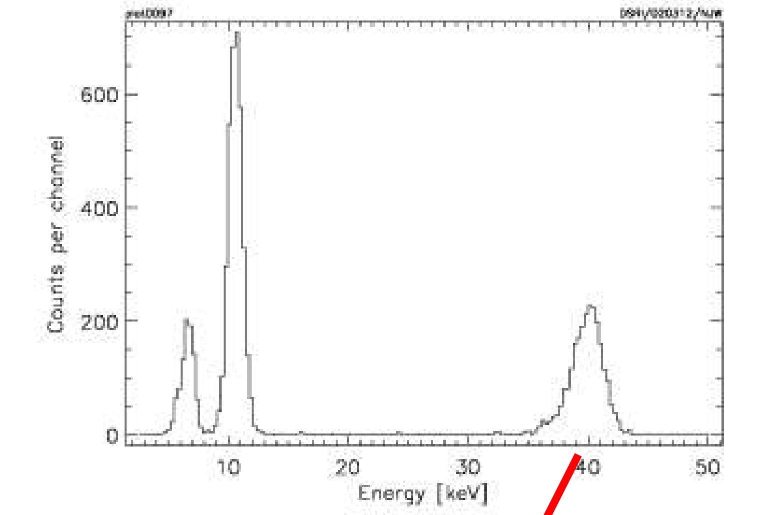


Fig. 5. A spectrum recorded with the FM1 detector for a beam energy of 40.15 keV. The K_α and K_β escape lines are clearly visible.

The monochromatic beam from the facility impinging on the FM1 JEM-X detector.

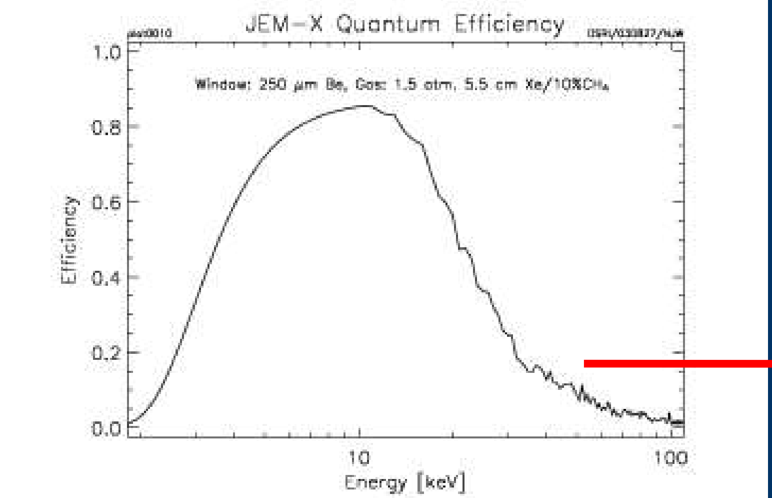
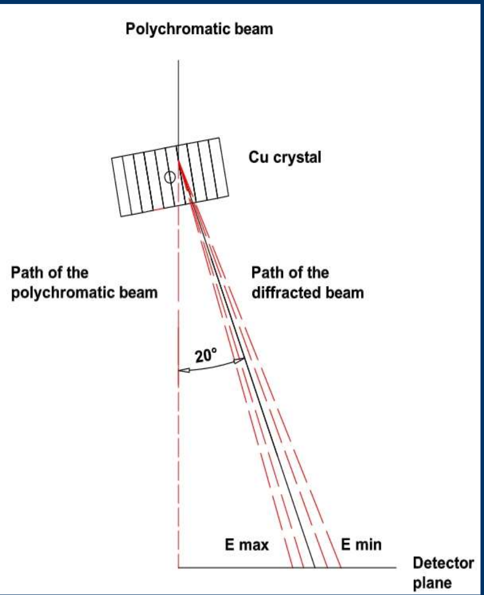
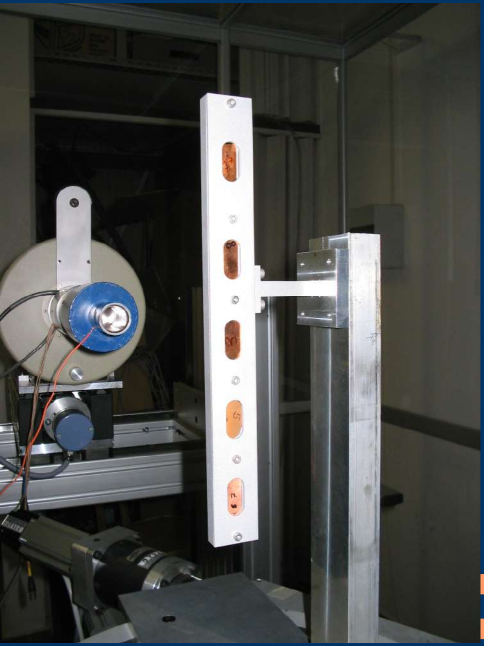


Fig. 6. JEM–X detector quantum effiency (including the 85% transmission of the on-axis collimator).

The JEM-X quantum efficiency derived during the energy scan.

X-ray reflectivity measurements (Laue configuration) of Cu (111) crystal samples



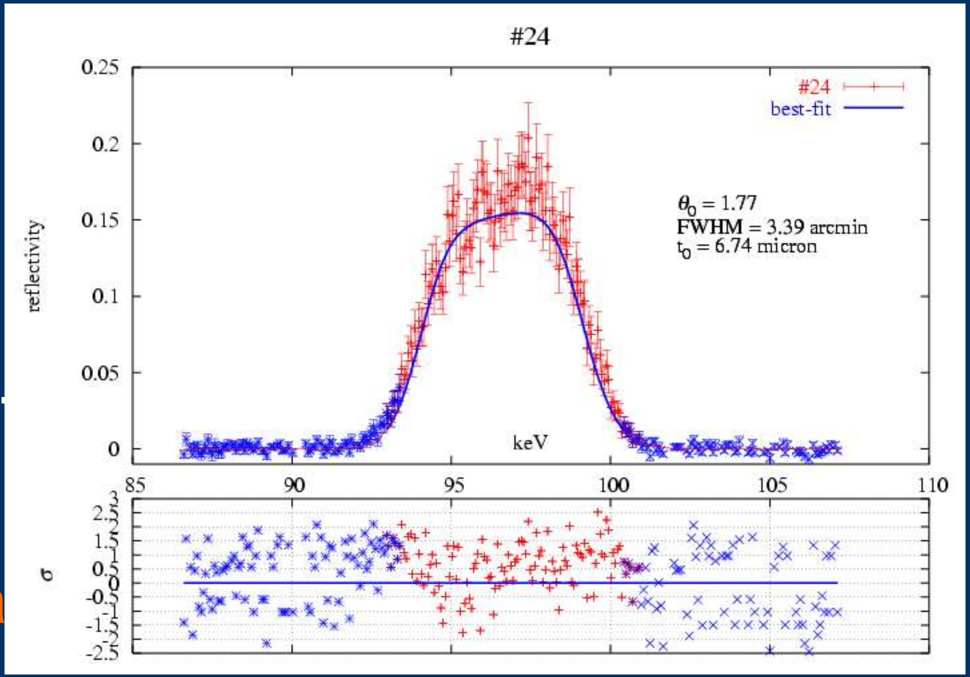


Set up:

- Polychromatic beam;
- X-ray beam size: 0.6 x 1.5 mm^2;
- Detector: Germanium.

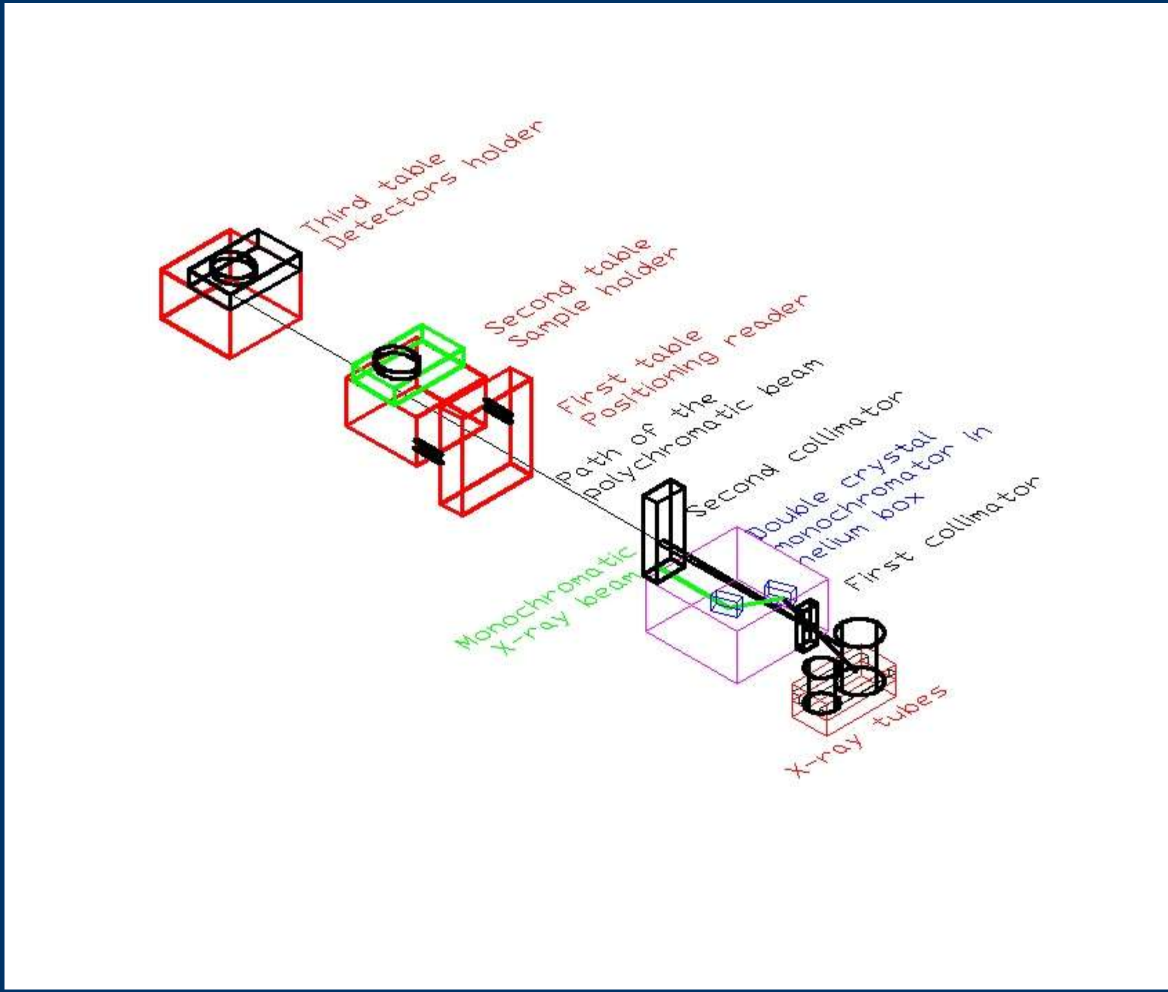
Result Example.

See talk by Frontera

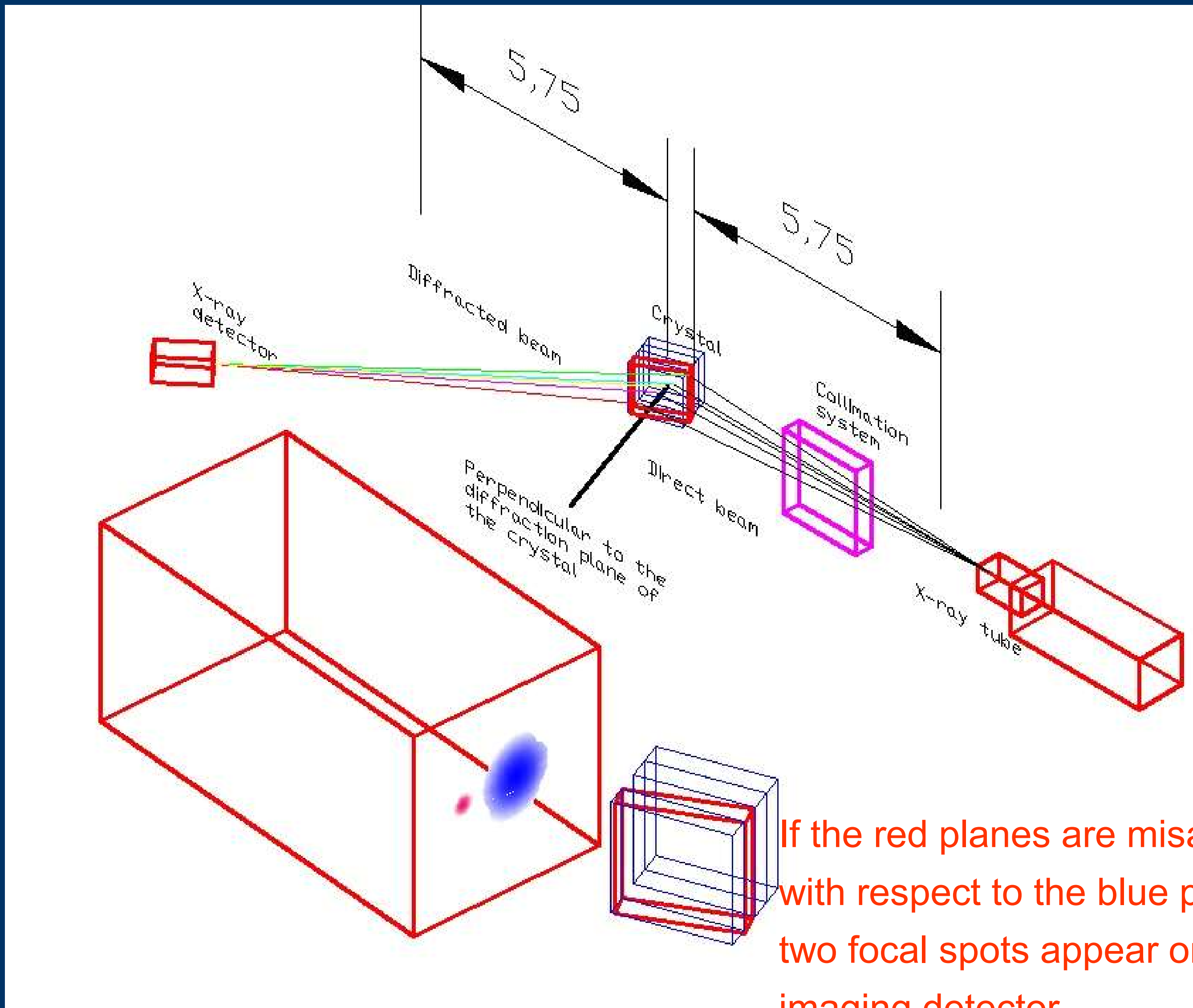


Current status of the facility

- The facility is now moved in a new building, where it is being re-assembled and extended (16 m).



Next application of the X-ray facility: determination of the crystal axis of Cu(111)

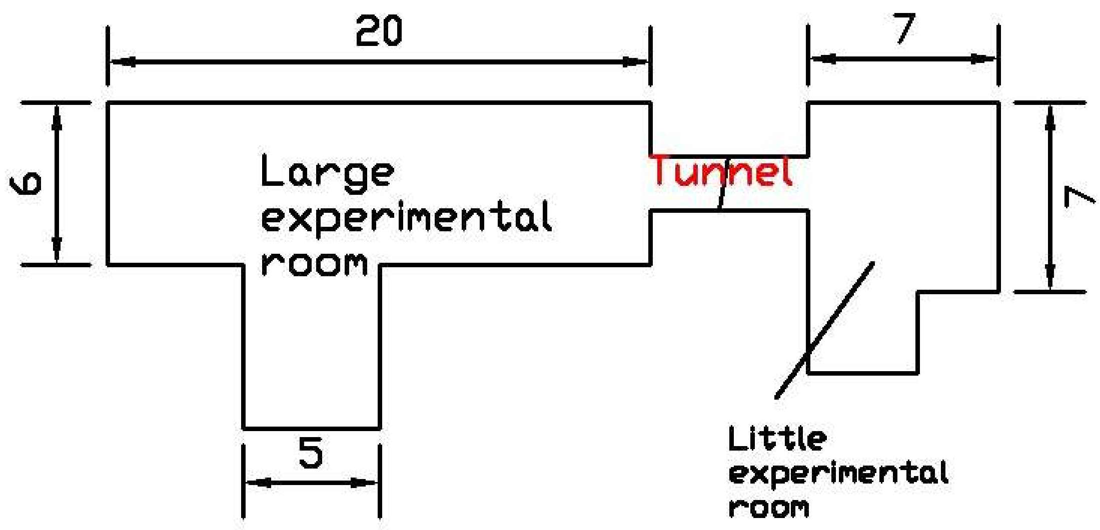


If the red planes are misaligned with respect to the blue planes, two focal spots appear on the imaging detector.

- Apparatus:
  - X-ray tube;
  - Collimation system;
  - Crystal sample in Laue configuration;
  - X-Ray Imaging Intensifier.

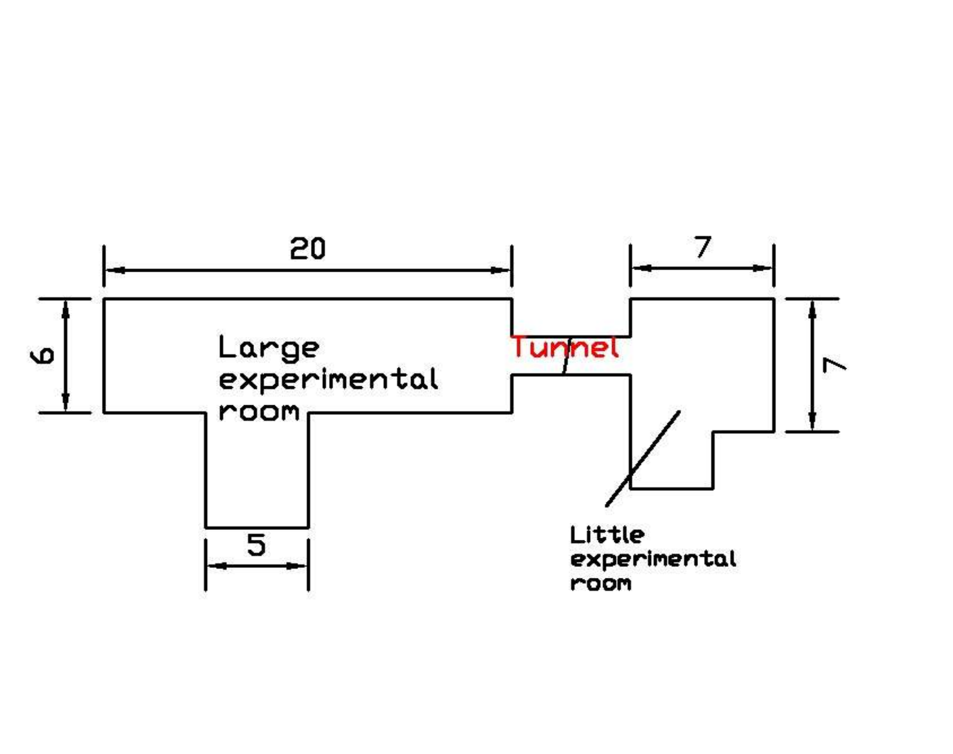
- Distances X-ray tube-sample and sample-detector have to be equal.

New location of the X-ray facility



- 20 long experimental room
- **100 m long tunnel**
- 7 m long experimental room

Next future: a LARge International X-ray (LARIX) facility



Other possible applications:
fundamental physics,
material science,
medical
physics, etc..

- MAIN GOAL:
test and calibration of hard X-/ gamma--ray focusing optics.
CONFIGURATION:
- X-ray sources: in the smaller room;
- Focusing optics in the larger room (in a large chamber);
- A 100 m beam line to allow a small divergence of the X--ray beam;
- Focal lengths up to 20-30 m (further extension possible);
- Detector plane clean room.

Thank you