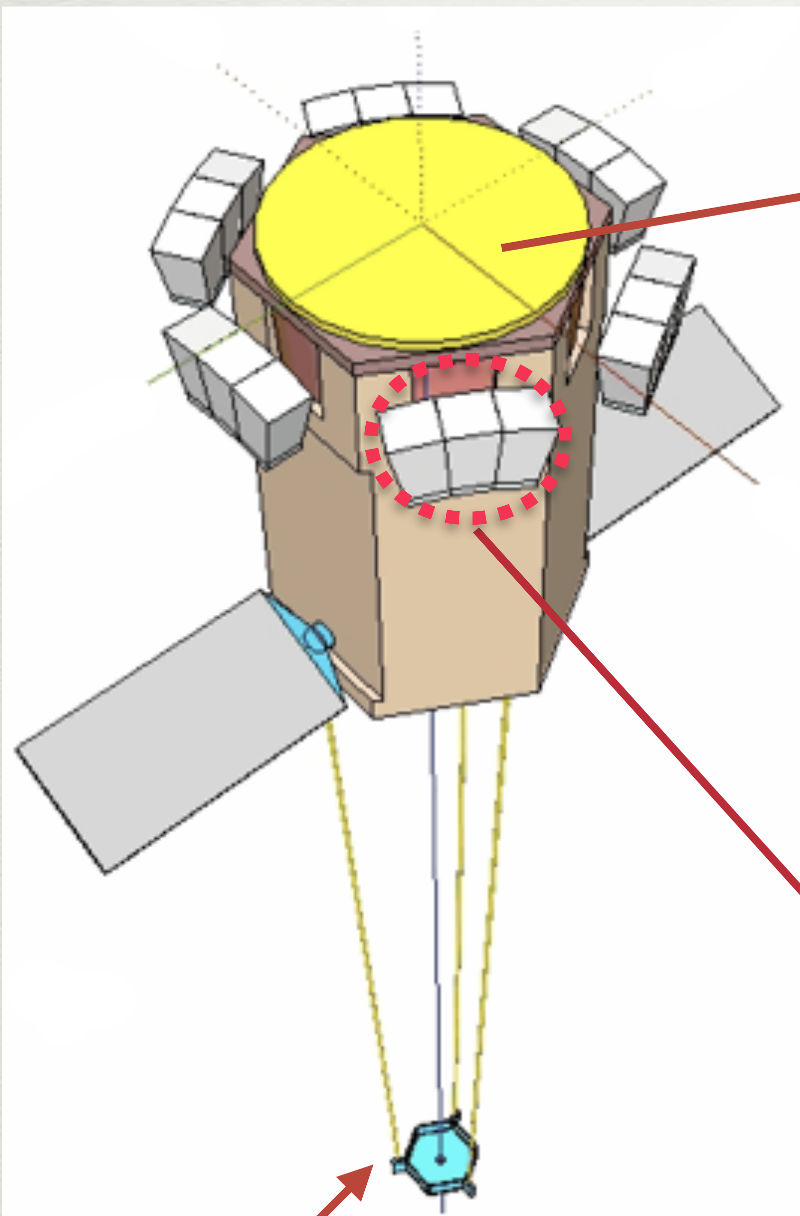
SIMULATION UPDATE ON THE ASTENA INSTRUMENTS

Enrico Virgilli
on behalf of the AHEAD/ASTENA collaboration

University of Ferrara - Italy
INAF-IASF - Bologna

AHEAD SWG meeting - Roma - University Tor Vergata - November, 14-15

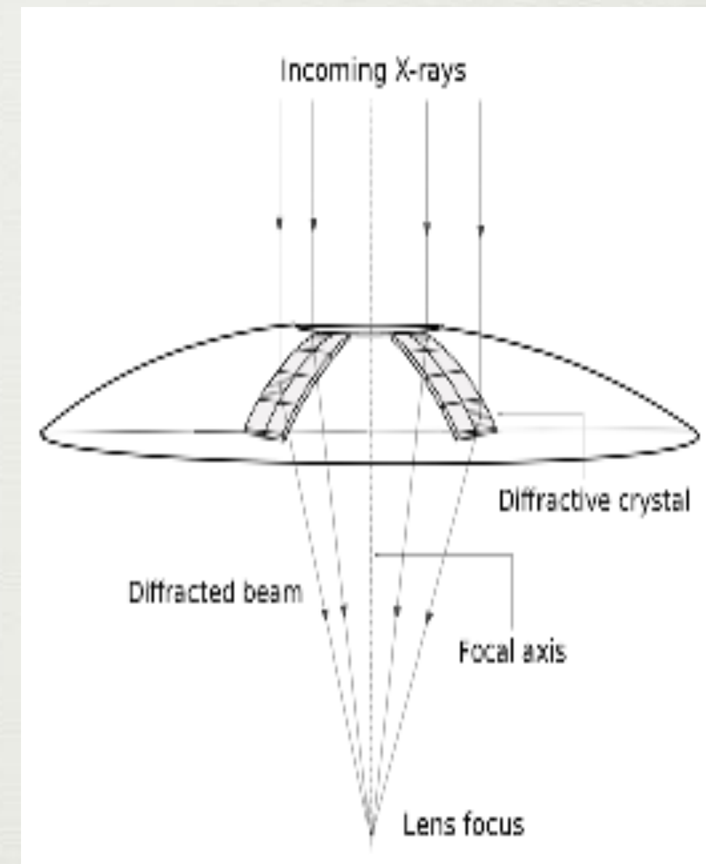
Advanced Surveyor of Transient Events and Nuclear Astrophysics (ASTENA)



Narrow Field Telescope (NFT)

broad band
large collection area

LAUE lens



Wide Field Monitor Spectrometer (WFM/S)

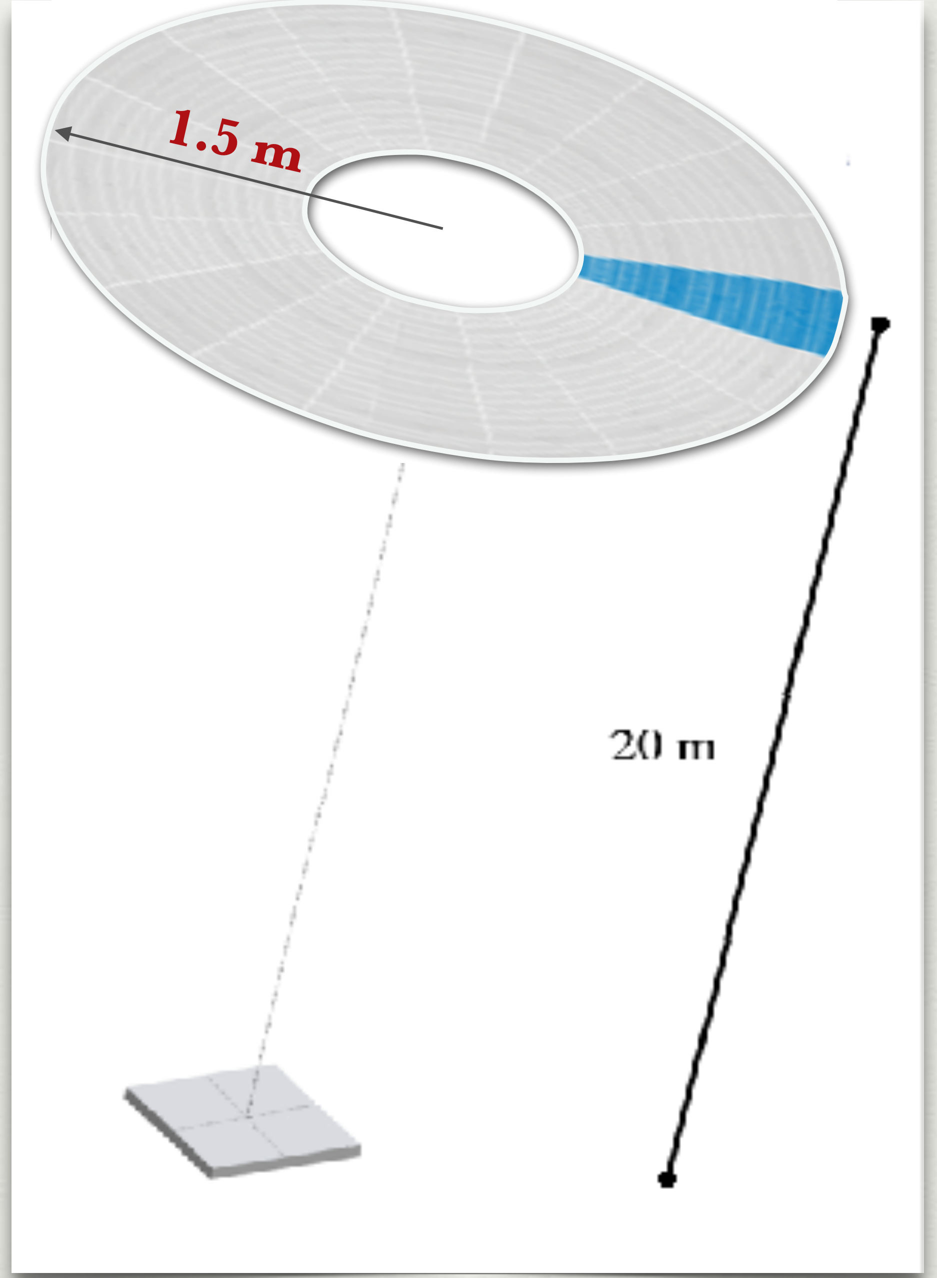
3 x 6 = 18 modules
total detector area ~ 18000 cm^2
1 keV - 20 MeV
>1 sr FoV

focal plane detector
3D CZT

ASTENA Narrow Field Telescope (NFT)

optics configuration

pass-band 50 - 700 keV
20 m focal length
Si 111 + Ge 220
crystal dimensions: 30 x 10 x (optimized thickness) mm^3
43 rings
Rin/out= 18 cm / 149 cm
Filling Factor 93%
Total Geometric Area 69800 cm^2 ~ 7 m^2 !!



focal plane detector requirements

detection efficiency > 80% @ 700 keV
3D imaging capability = 400 µm (x, y, z direction)
fine spectroscopy response 1 % @ 511 keV

Narrow Field Telescope (NFT) outline

- Software development-upgrade for performance evaluation
- Simulation results:
    - optics
    - focal plane detector

the NFI on board ASTENA is the only instrument in this working group that requires 2 tools to be optimized.
one is the LLL that was developed for Laue lens optics, and the other is the megalib.

optimization and performance evaluati[c] ASTENA/NFI

Two step process is **required**

- Ray tracing to define the Laue lens photons flow over the detector
- PSF and FoV optimization

→

Development of a model of spectro-imager focal plane detector

Laue Lens Library

MEGAlib

through the LLL we define the crystals with their material, dimensions, geometry. The crystals are assembled in the lens that is defined by its FL, radius and mounting accuracy.

To get the output results, i.e. the lens performances, is required to define a source, therefore its spectrum, intensity, dimension must be given.

Laue Lens Libr

definition of the basic crystals

- material
- diffraction planes
- crystal geometry
- crystal dimensions
- crystal mosaicity distribution
- uncertainty on $R_{curvature}$

definition of the lens parameters

- lens profile
- filling factor
- focal length
- lens dimension (radius)
- mounting accuracy

definition of the source

- source dimension
- source-target distance
- number of photons
- photons energy distribution

interaction process

- $\mathbf{k}_{diff} = \mathbf{k}_{in} + \mathbf{g}$
- $I_d = I \quad R(E)$

output parameters

- Point Spread Function
- Field of View
- Effective Area
- Sensitivity

Laue Lens

definition of the basic crystals

- material
- diffraction planes
- crystal geometry
- crystal dimensions
- **crystal mosaicity distribution**
- **uncertainty on Rcurvature**

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- lens profile
- filling factor
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- **mounting accuracy**

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- Field of View
- Effective Area
- Sensitivity

link with MEGAlib

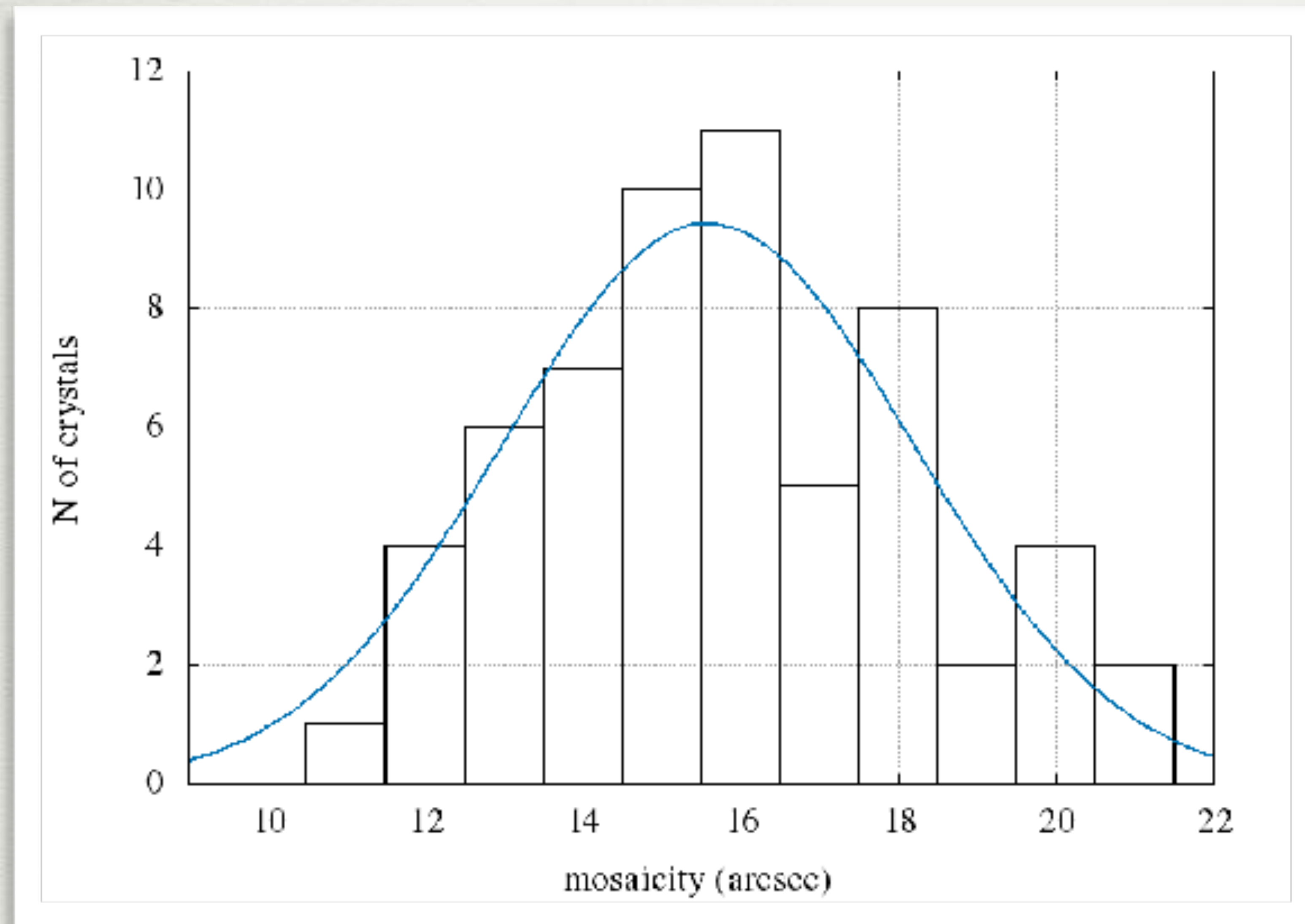
recently the LLL has been upgrded with new features and I want to describe here few of them. Some of them are very important for the ASTENA performances evaluation.

1. in case of mosaic crystals (not the case of NFT-ASTENA) the mosaicity distribution can be different, we can have a distribution.
2. curvature radius distribution
3. mounting accuracy

In a focusing instrument that needs to be coupled with a focal plane detector the source component has two meanings.

In LLL the meaning is the original astropysical source. Later we have to use the output of LLL as input source for the detector simulation.

Mosaicity distribution example: GaAs crystals sample for the LAUE project



sample of 60 **GaAs** crystals provided by IMEM-CNR Parma C.Ferrari, A.Zappettini

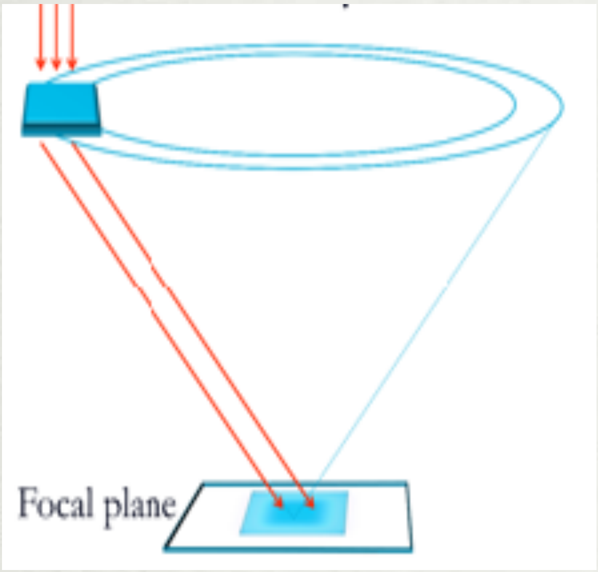
foe instance, this is an example of mosaicity distribution of a sample of 60 mosaic crystals made of GaAs measured at LARIX. We can use this distribution in our code, to get the real PSF or the Effective Area or the sensitivity affected by this crystal production inaccuracy

For STENA we are not going to use mosaic crystal but perfect bent crystals. For some crystallographic orientatons a quasi mocaicity occur that can have a less evident effect.

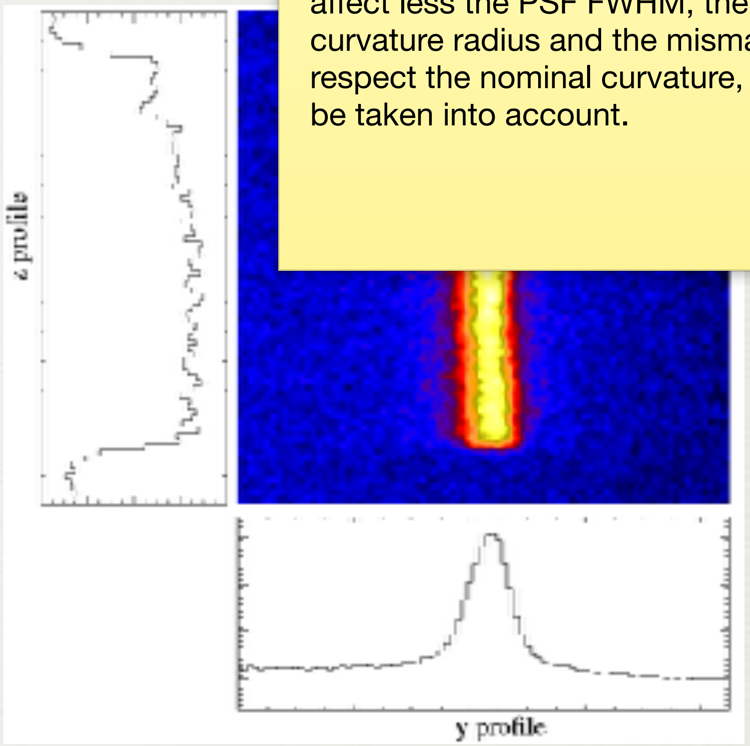
the main property that we can exploit with bent crystals is their capability to focus the radiation in an area smalle than their cross section itself

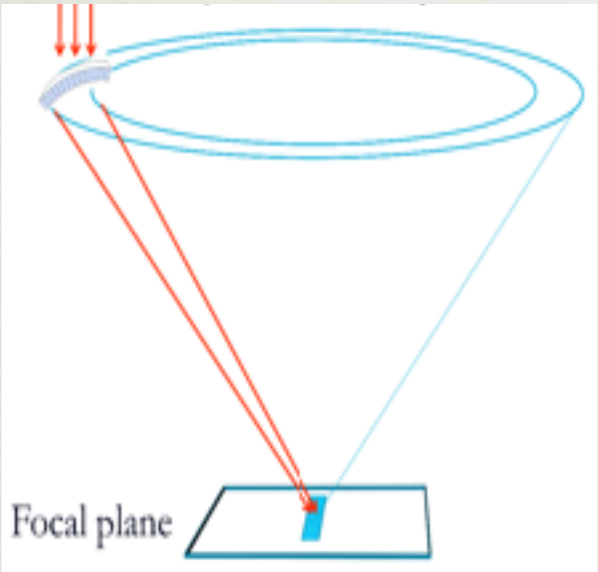
Even if for perfect crystals the mosaicity affect less the PSF FWHM, their curvature radius and the mismatch with respect the nominal curvature, has to be taken into account.

Flat vs. bent crystals



flat crystal





bent crystal

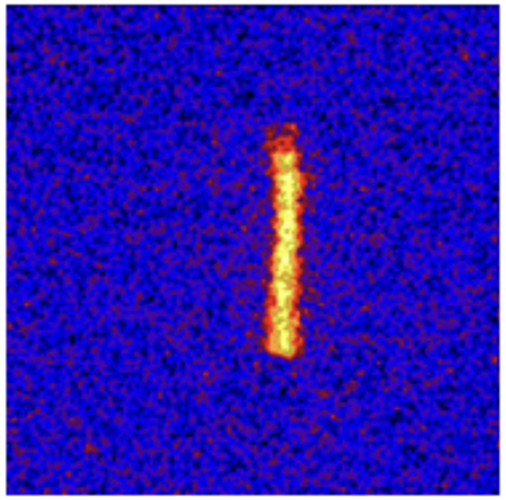
PSF FWHM = 1.1 ÷ 1.7 mm depending on:

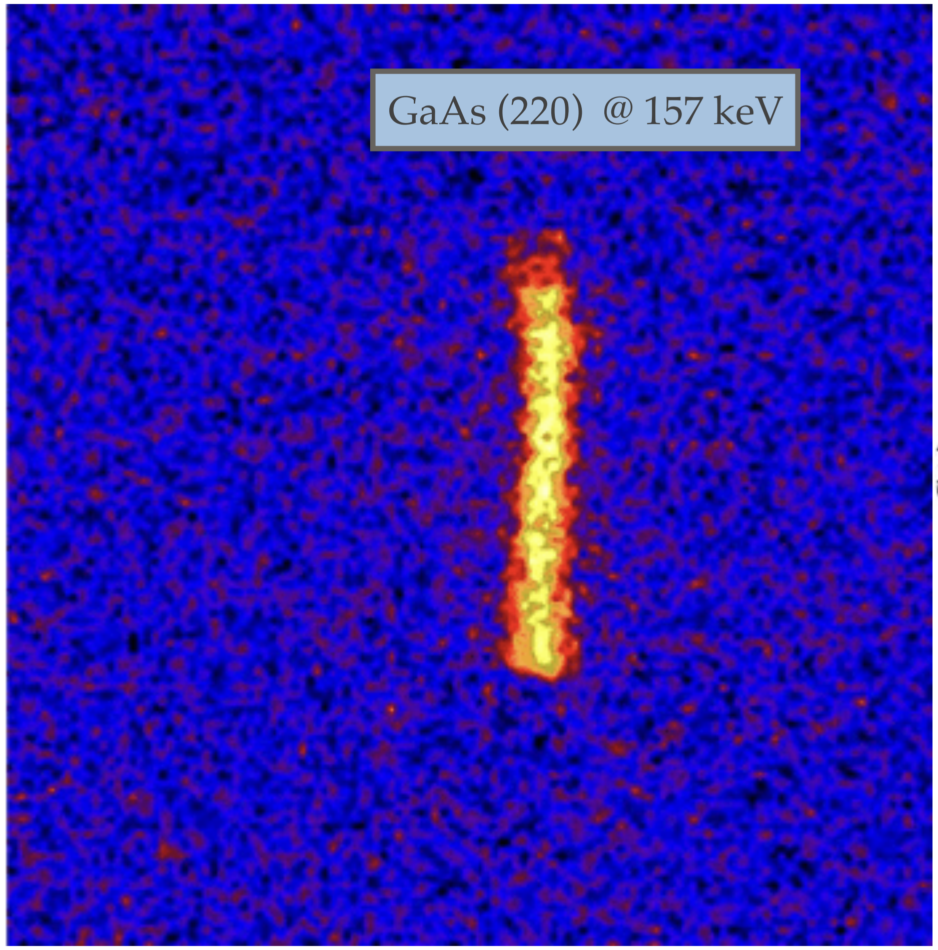
- mosaicity
- curvature radius

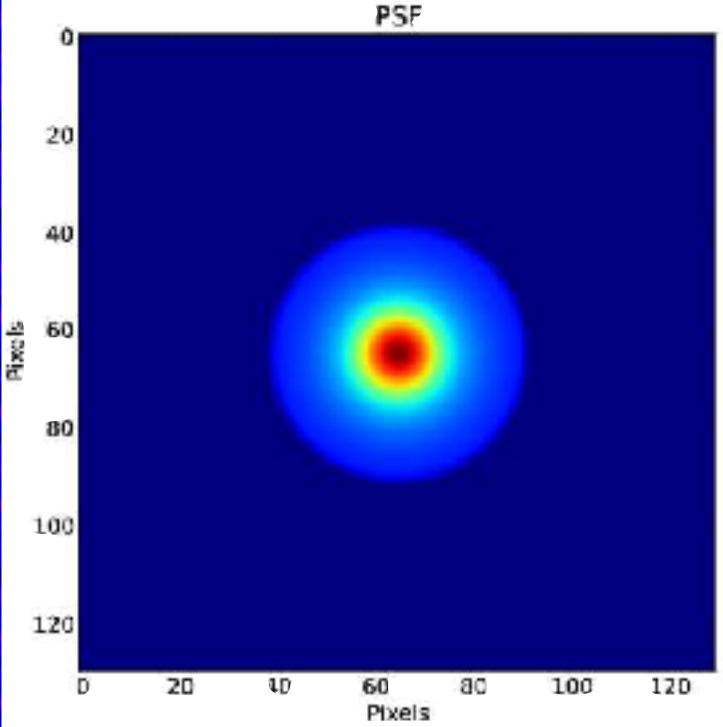
ASTENA-NFT is based on **bent perfect crystals** for which the PSF FWHM is < 1 mm (curvature uncertainty still present)

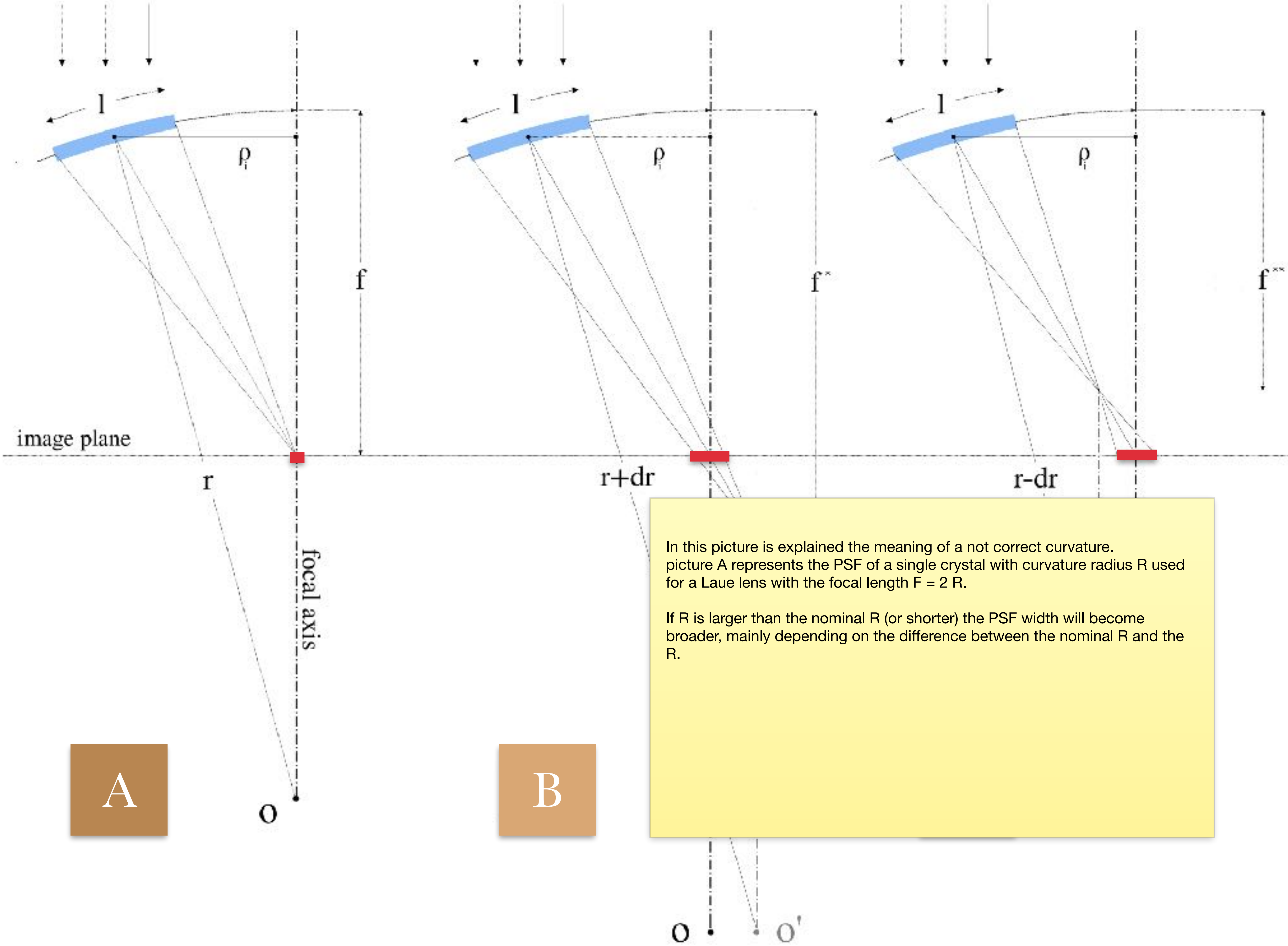
Combined PSF from a ring of 20 **perfectly aligned** and **perfectly bent** GaAs bent crystals

simulation









In this picture is explained the meaning of a not correct curvature.
picture A represents the PSF of a single crystal with curvature radius R used for a Laue lens with the focal length F = 2 R.

If R is larger than the nominal R (or shorter) the PSF width will become broader, mainly depending on the difference between the nominal R and the R.

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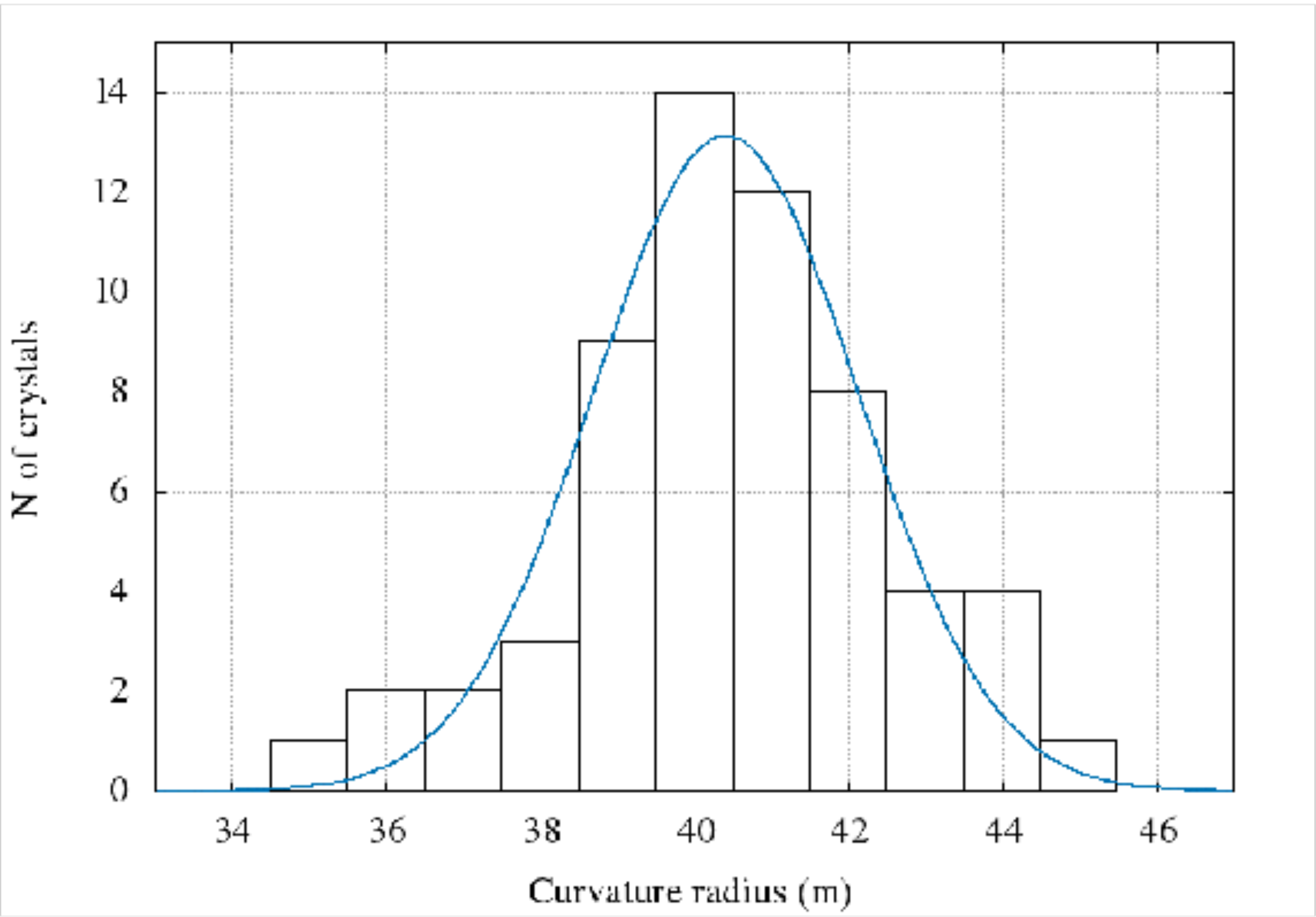
Curvature radii distribution of GaAs for the LAUE

even if small this radial mismatch occur for each crystal therefore a distributon of mismatch must be considered



in the L

- Gaus

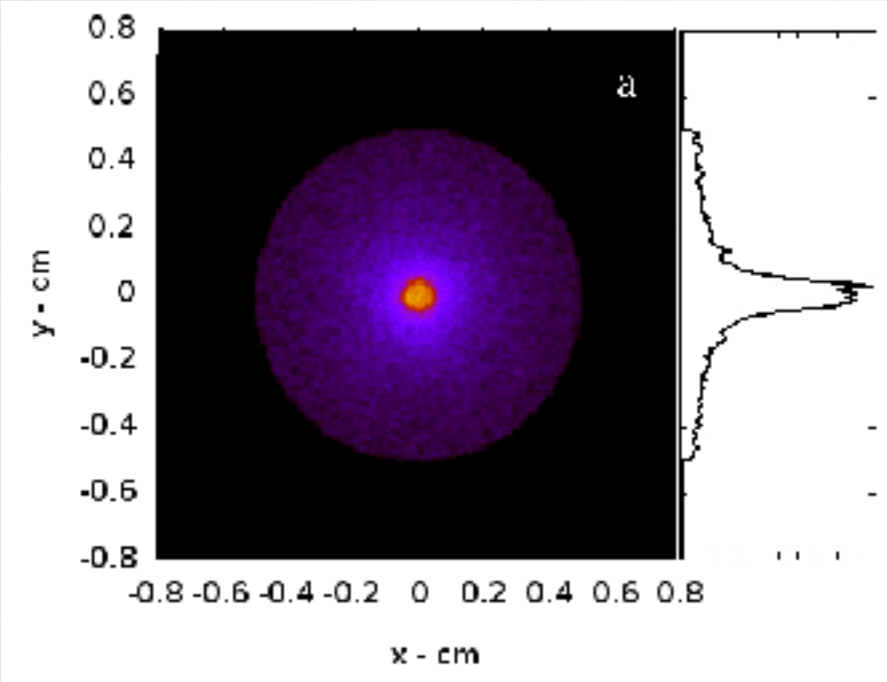
- uniformly distributed
- affected by systematic uncertainty (radial shift)

LAPPING process for bending the crystlals adopted by IMEM-CNR, Parma
C. Ferrari, A. Zappettini

sample of the 60 bent **GaAs** crystals

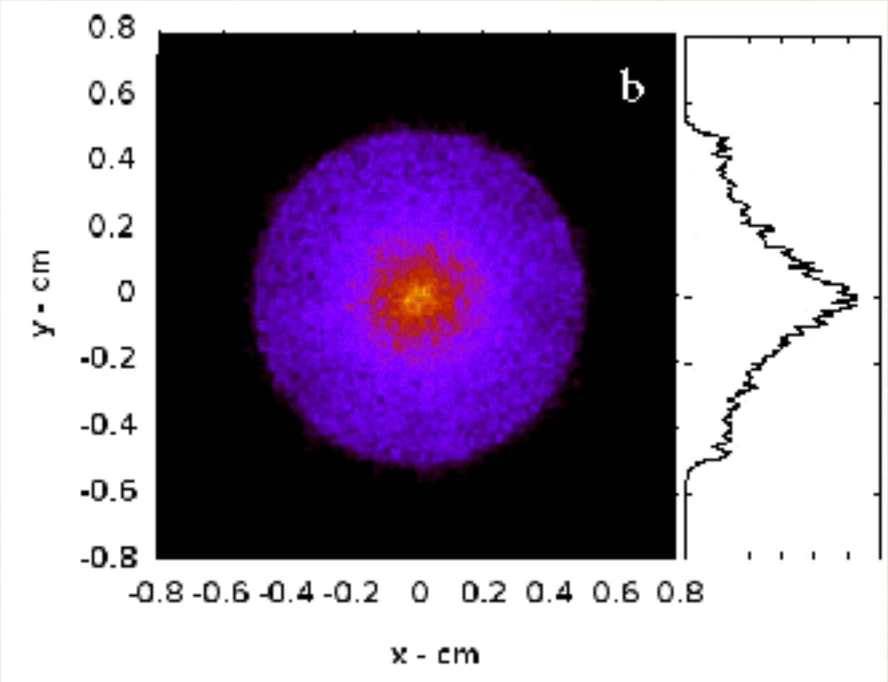
Curvature radii distribution (II)

nominal PSF with crystals R_c = 40 m



HPD ~ 1.1 mm

PSF with Gaussian distribution of the curvature (**FWHM = 6 m**)



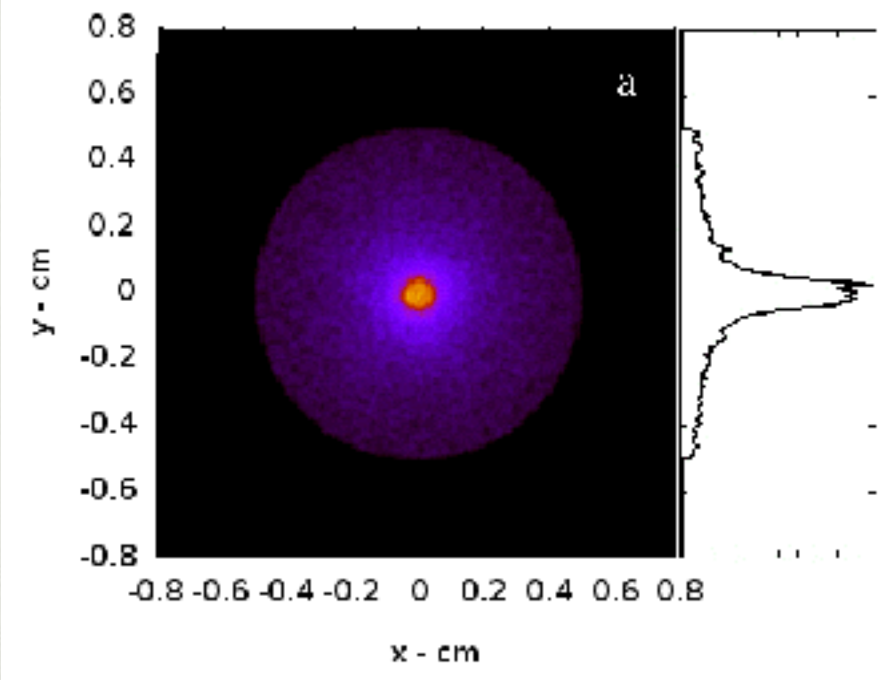
HPD ~ 4.5 mm

worsening factor ~ 4

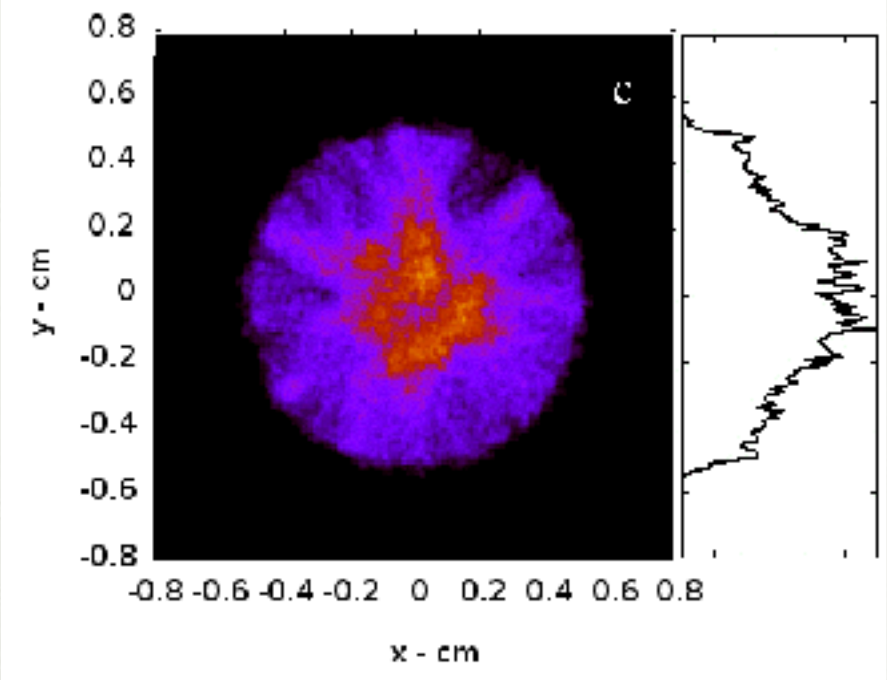
recent results have shown a bending accuracy of ~ 5 % R_c (~ 2 m)

Crystals mounting uncertainties

nominal mounting accuracy



15″ mounting accuracy



our experimental monting capability is better than 10 arcsec

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Expected performances of a Laue lens made with bent crystals

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[d]ITA-Instituto Tecnológico de Aeronáutica, São José dos Campos, Brasil

Abstract. In the context of the LAUE project devoted to build a Laue lens prototype for focusing celestial hard X-/soft gamma-rays, a Laue lens made of bent crystal tiles, with 20 m focal length, is simulated. The focusing energy passband is assumed to be 90–600 keV. The distortion of the image produced by the lens on the focal plane, due to effects of crystal tile misalignment and radial distortion of the crystal curvature, is investigated. The corresponding effective area of the lens, its point spread function and sensitivity are calculated and compared with those exhibited by a nominal Laue lens with no misalignment and/or distortion. Such analysis is crucial to estimate the optical properties of a real lens, in which the investigated shortcomings could be present.

Keywords: Focusing telescopes; X-ray diffraction; Laue lenses; Experimental astronomy; High energy instrumentation.

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Ge bent perfect crystals

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University of Ferrara - Physics and Earth Science Department

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Laue lenses made with bent mosaic crystals: comparison between simulations and experimental results

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ABSTRACT

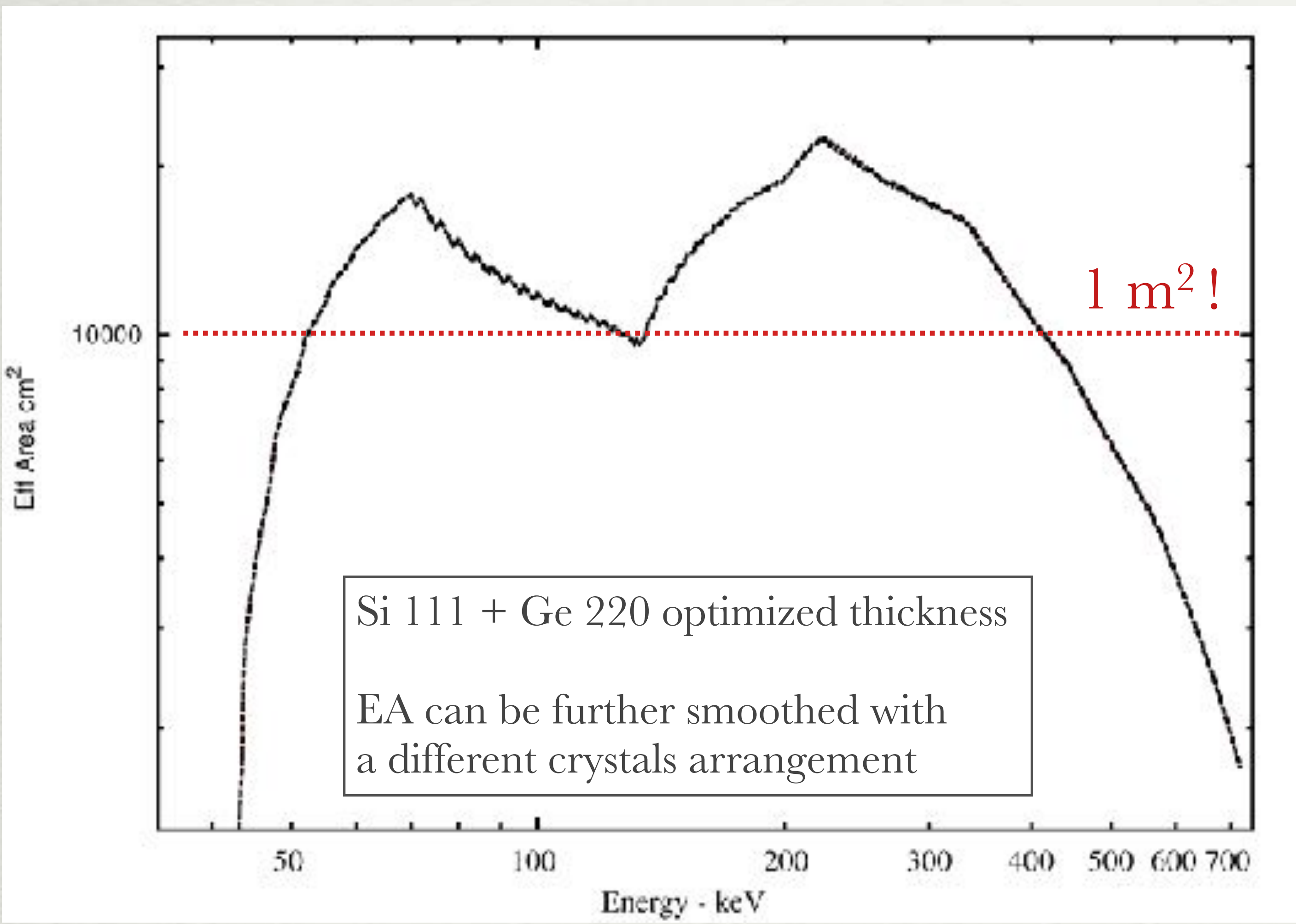
Context. Laue lenses made with bent crystals represents a challenging way to focus the radiation from the Gama ray sky. Investigate the possibility of using bent crystals represents a new window that only recently started to be a real possibility.
Aims. It is shown that the crystals curvature radii represent a very important parameter to be carefully investigated, given that is capable to minimize the PSF. The distortion of the photon distribution on the focal plane detector due to the effects of crystal misalignment and radial distortion with respect to the nominal curvature are dicussed.
Methods. A software named laue lens library LLL has been developed for the purposes. In the Monte Carlo code, all the main parameters have been takein into account. The ray tracer
Results. We have found that a radial distortion of 5-10% with respect to the nominal curvature radius can be accepted to turn into a worsening of the on-axis PSF of about 10%. In this paper we have shown our method to realize a prototype with an unprecedent accuracy and stability in long time monitoring.
Conclusions.

Key words. Focusing telescopes; X-ray diffraction; Laue lens; Experimental astronomy; High energy instrumentation

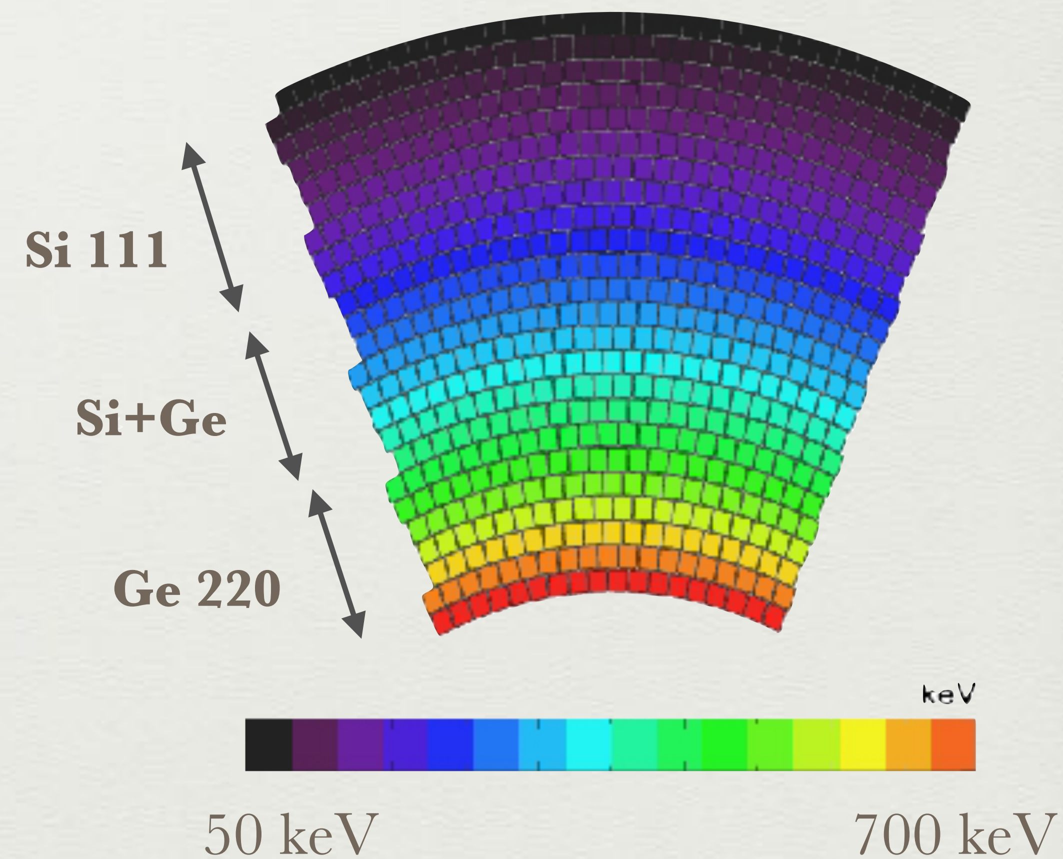
GaAs bent mosaic crystals

In preparation

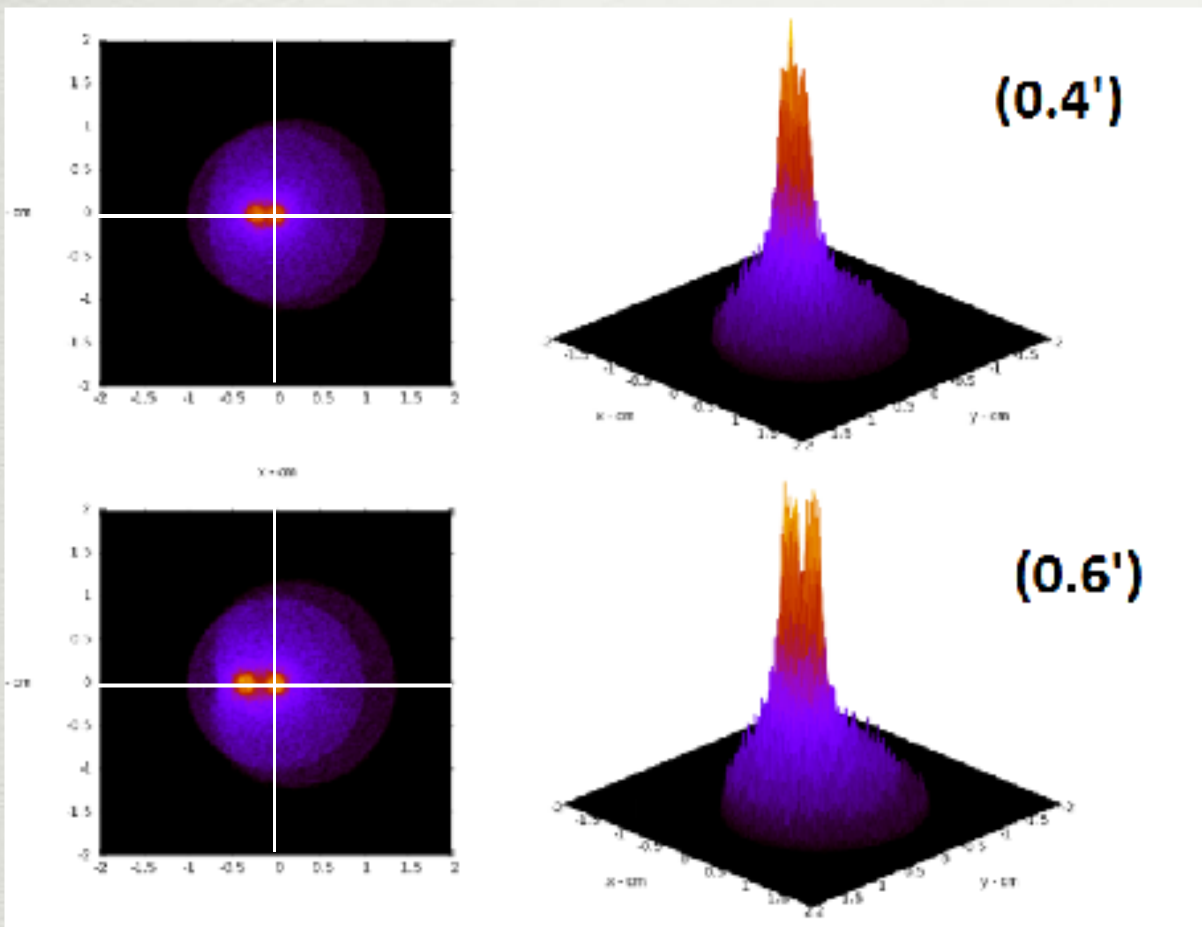
ASTENA-NFI Effective Area

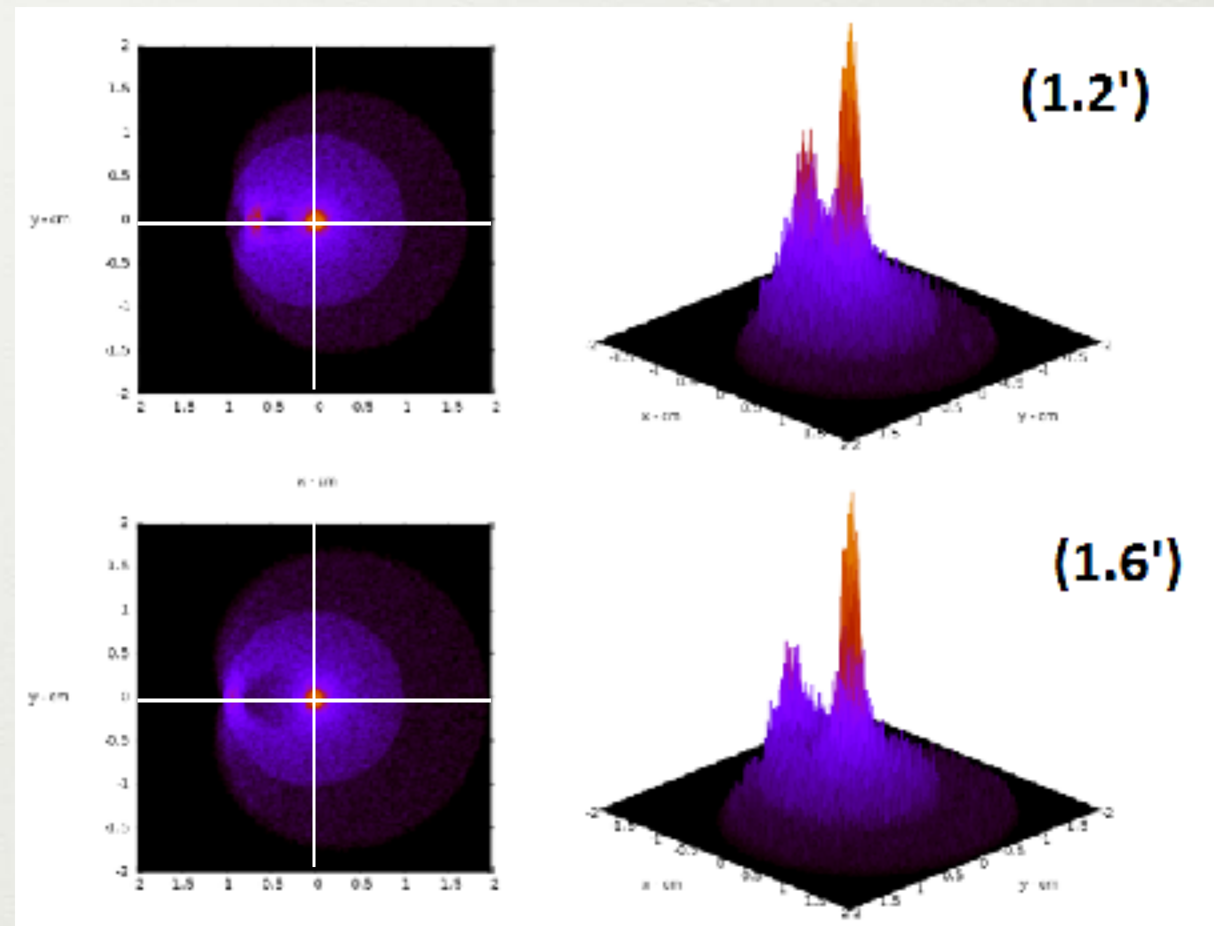


- pass-band 50 - 700 keV
- 20 m focal length
- Si 111 + Ge 220
- crystal dimensions: 30 x 10 x (optimized thickness) mm^3
- 43 rings
- Rin/out= 18 cm / 149 cm
- Filling Factor 93%
- **Total Geometric Area 69800 cm^2 ~ 7 m^2 !!**



Detector dimensions and FoV





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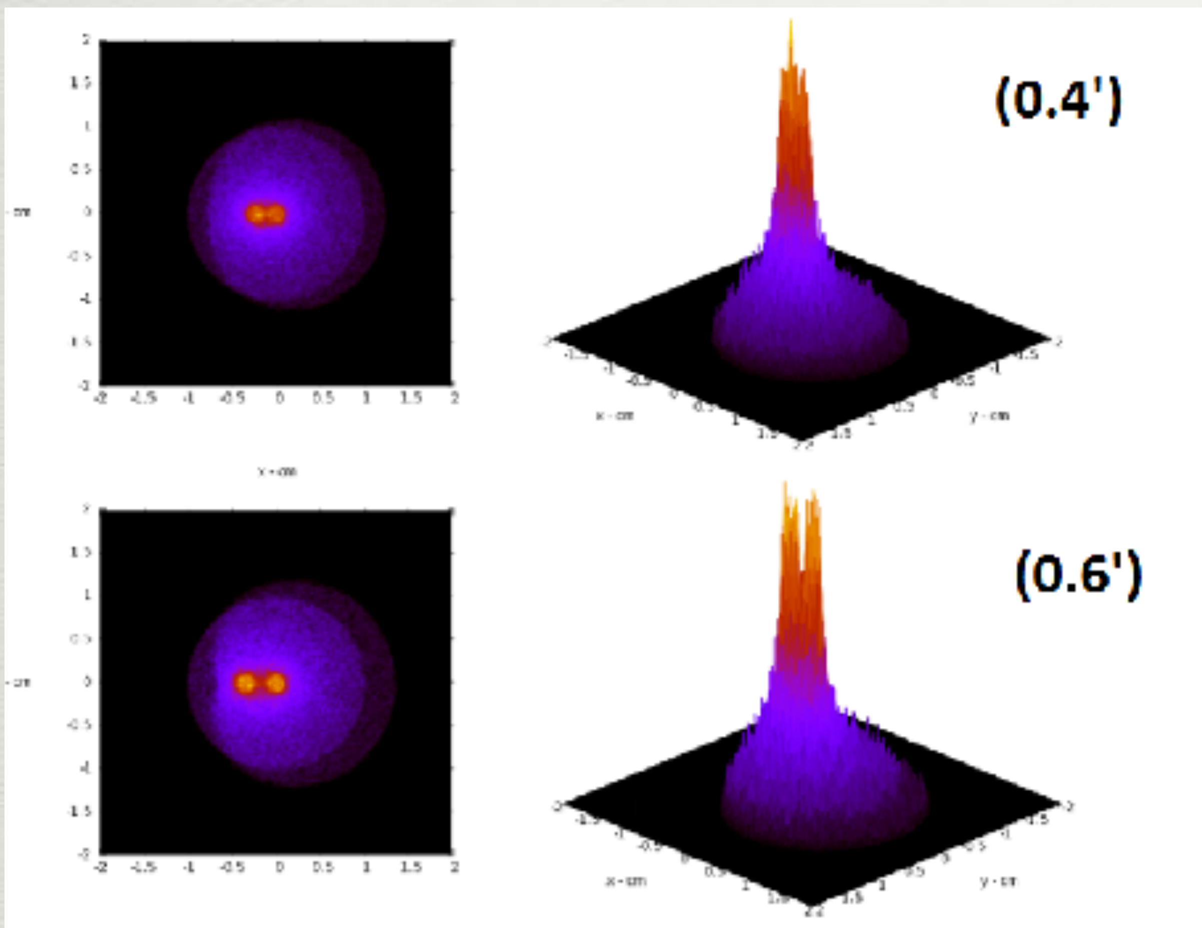
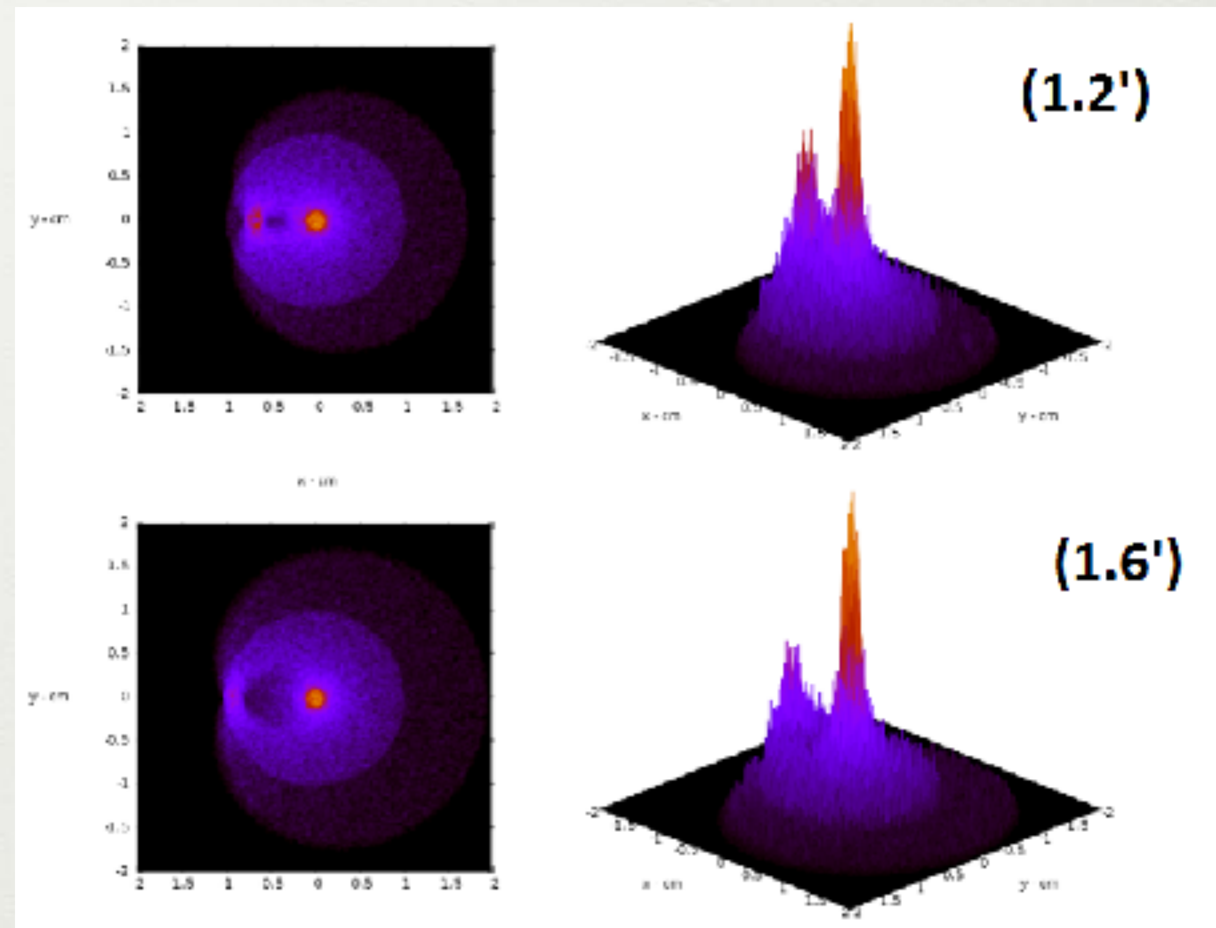




Detector optimization activity @ DTU - Copenhagen

Detector geometry definition:

- 3D CZT detector (DTU - I. Kuvvetli, C. Butz-Jorgensen):

    - (3D position sensitive) 400 μm spatial resolution (x, y, z directions)
    - spectral resolution

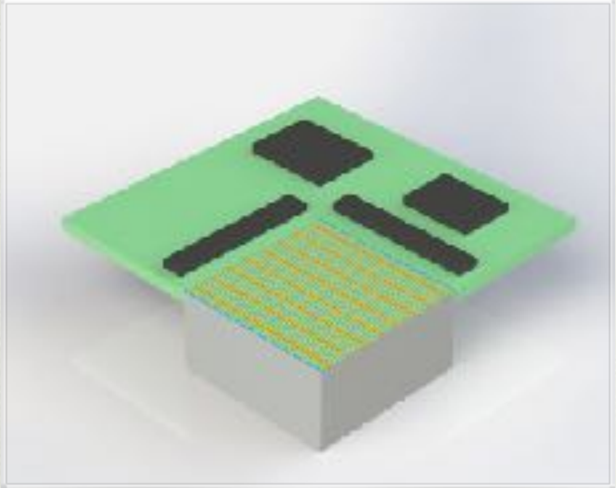
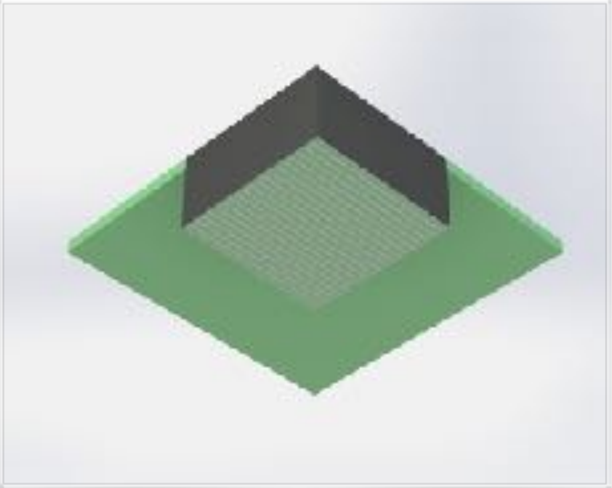
- required ≥ 80% efficiency @ upper energies i.e. @ inner LL ring radius for Ge 220 (612 - 700 keV)

Source definition

- 10^5 photons interact with the focal plane detector
- > 10^5 photons are generated
- two generation methods of the source of radiation are being investigated

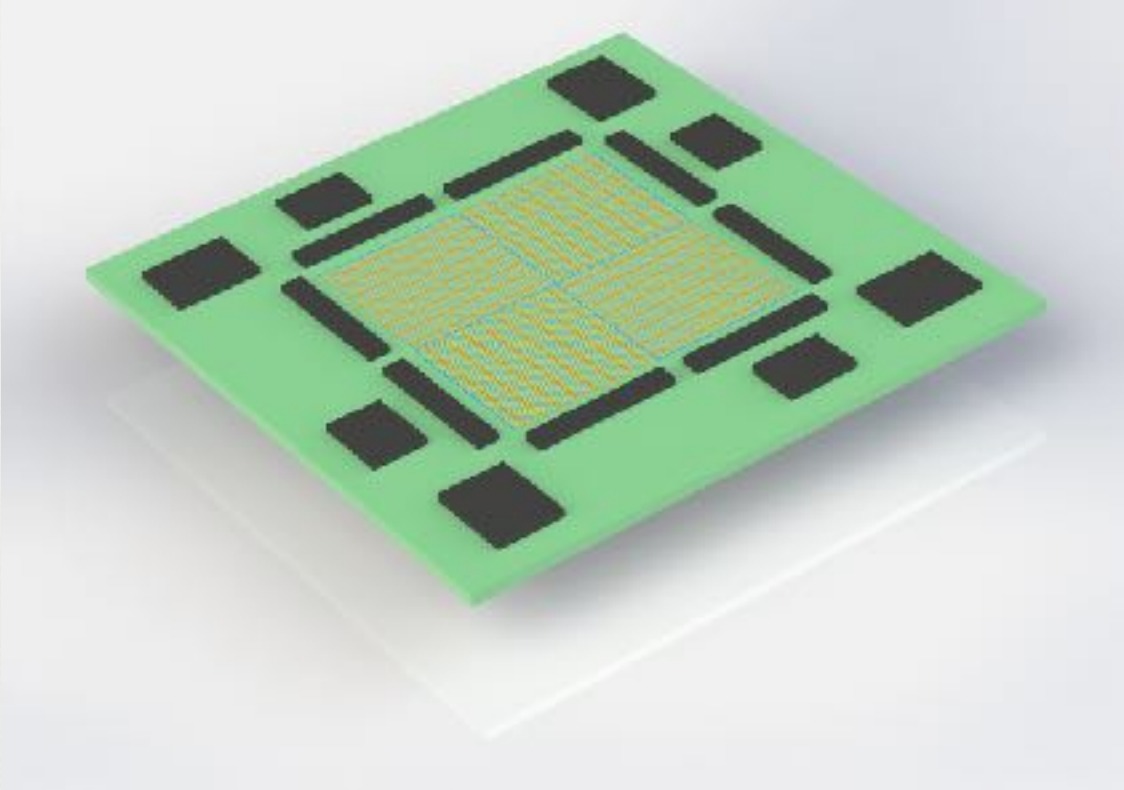
Detector optimization activity @ DTU - Copenhagen

I. Detector geometry definition

Single CZT unit 20 x 20 x 5 mm + read out electronics

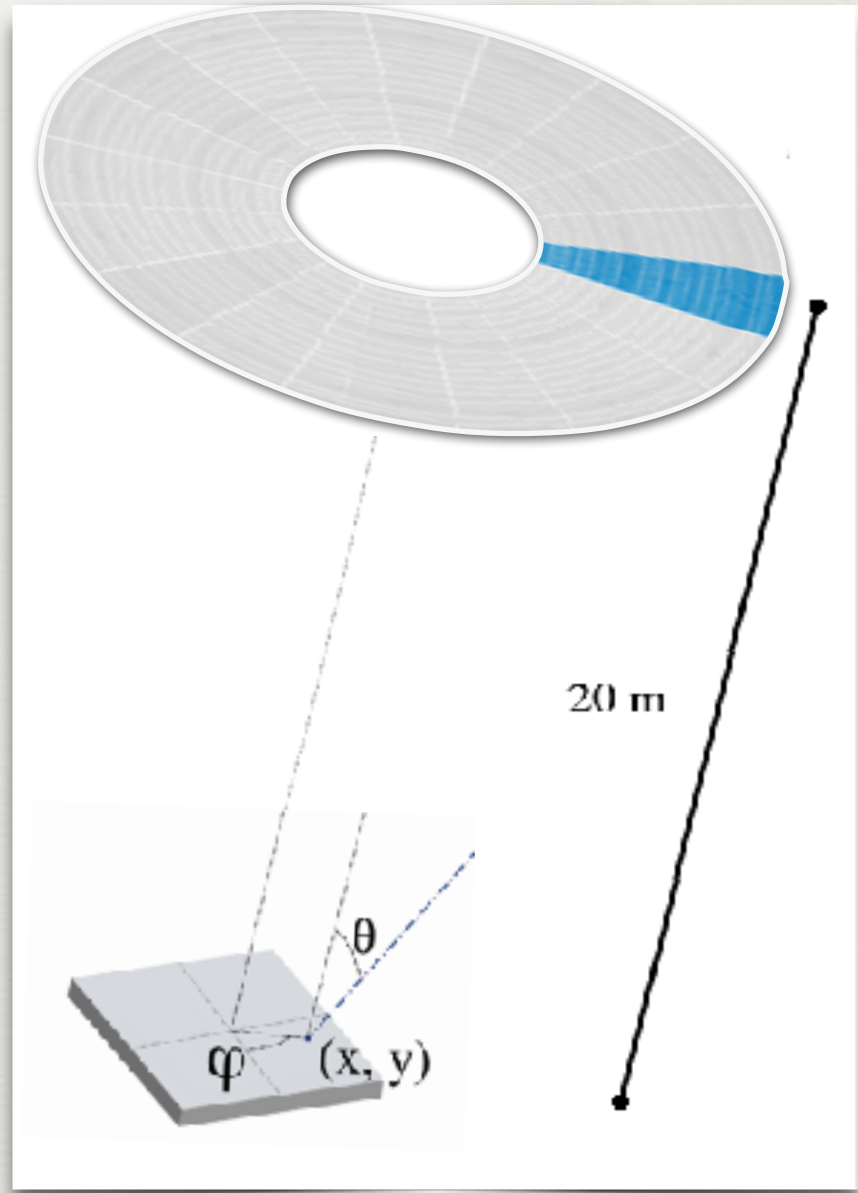
4 CZT packed units



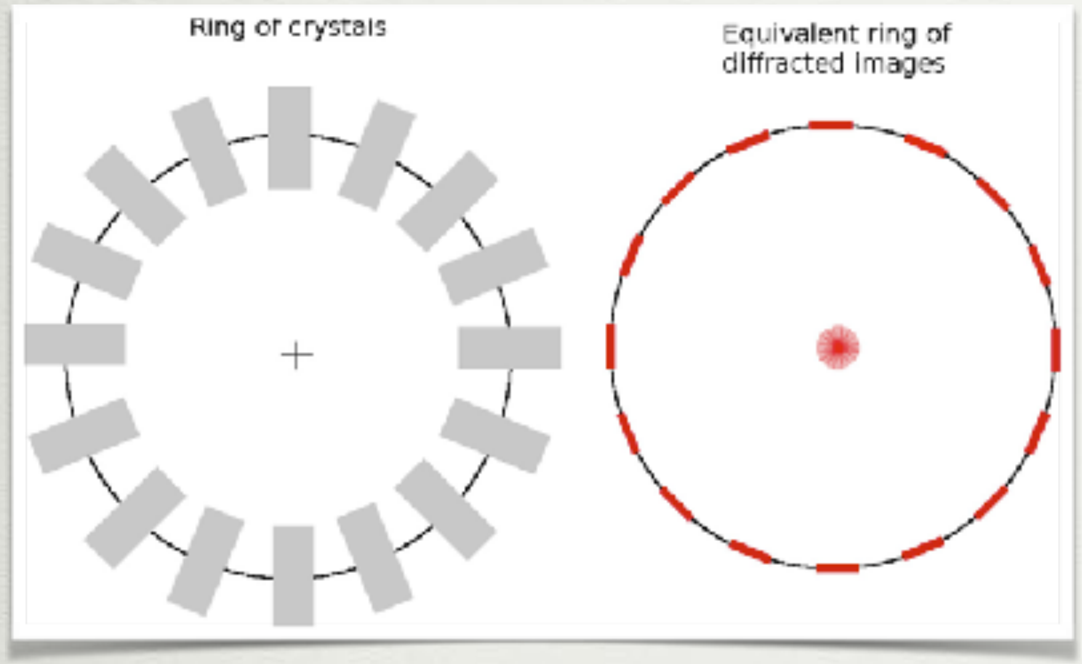
II. Source definition

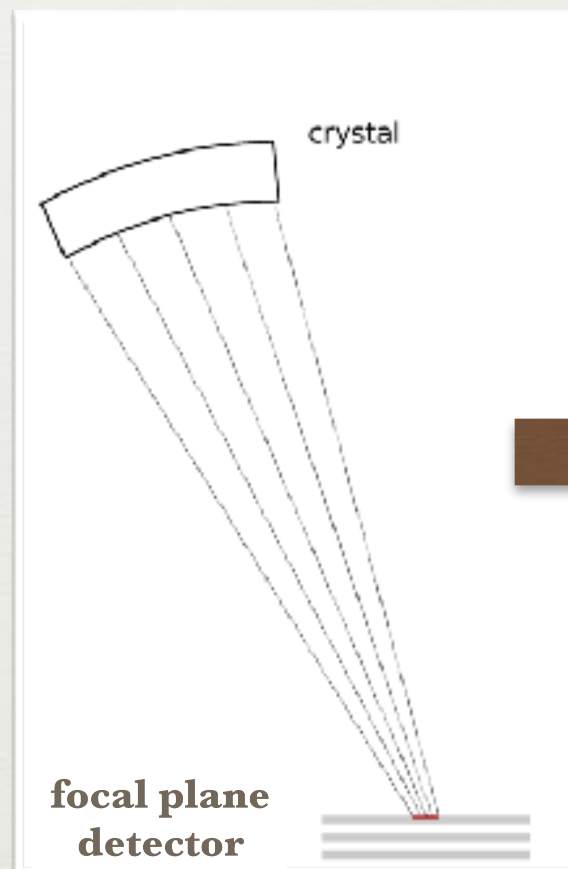
Energy	X, Y position	θ	ϕ

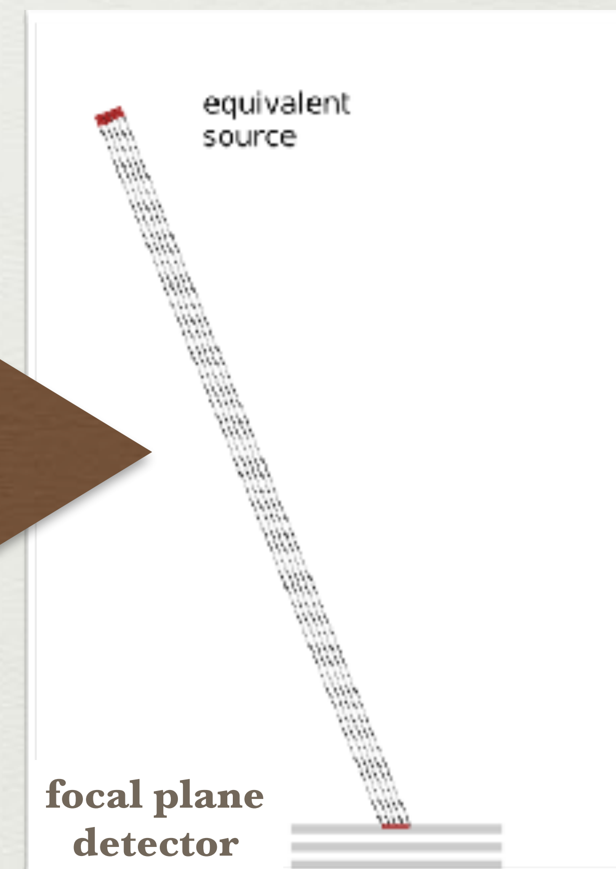
Output flux from the LLL can be used as input source for MEGAlib (photon list available)



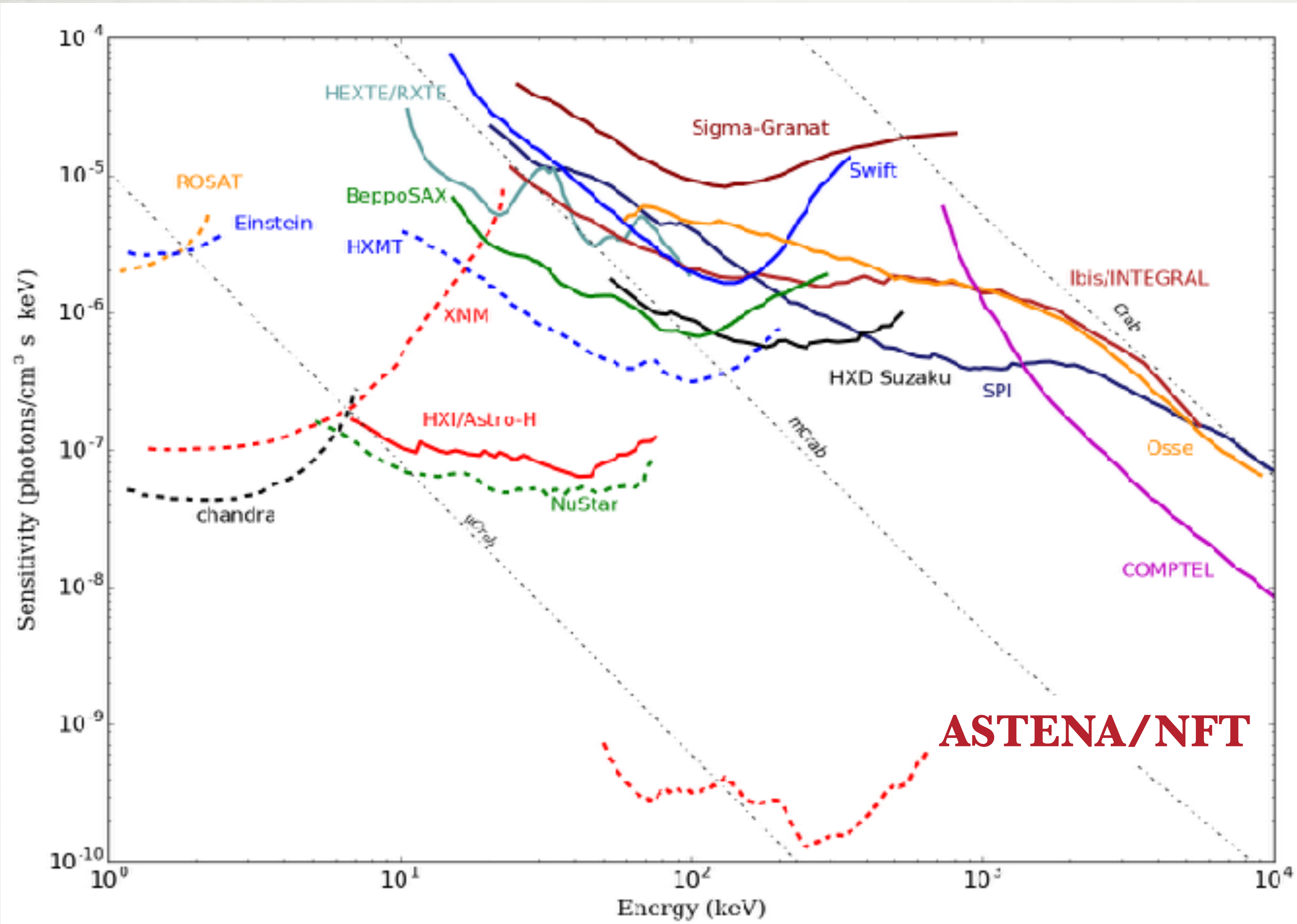
II. Source definition for MEGAlib







Broad band continuum sensitivity



$3\sigma \quad 10^5$ s $\quad \Delta E = E/2$

Virgilli et al. (2017)

Line sensitivity will also benefit from the Laue lens large EA:

Improvement over INTEGRAL/SPI:

350 x @ 100 keV

100 x @ 200 keV

Conclusions and next steps

- LLL is fully implemented and capable to describe ideal and real operative conditions of the NFT optics;
- Detector material and geometry already defined: 3D-CZT;
- Focal plane detector requirements have been defined (spectral and imaging capabilities);
- Source localization method for MEGAlib is being investigated;
- With this lens-detector system, FoV and sensitivity have been preminary investivated;
- Nuclear line sensitivity is being evaluated (e.g. e^+/e^- 511 keV line)