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The Wide Field Monitor and Narrow Field Telescope on board the ASTENA mission

E. Virgilli

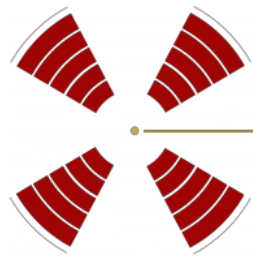
ASTENA collaboration

University of Ferrara - Italy

INAF-IASF - Bologna - Italy

DTU - Technical University of Denmark - Copenhagen

University of Coimbra/LIP, Portugal



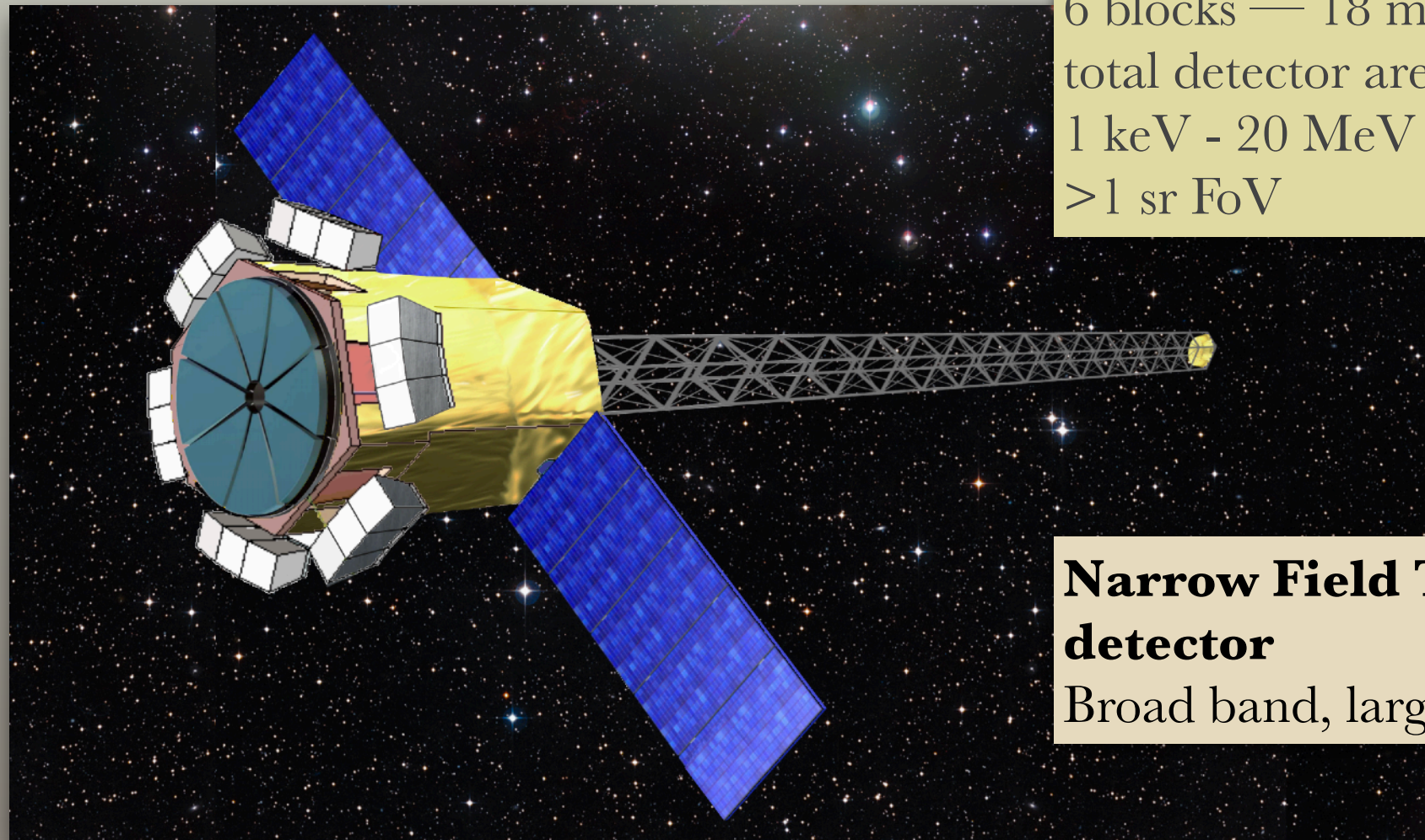
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Advanced Surveyor of Transient Events and Nuclear Astrophysics (ASTENA)

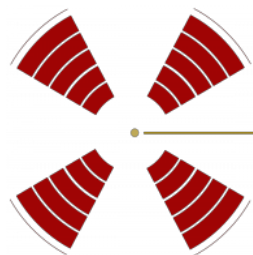


Wide Field Monitor Spectrometer (WFM/S)

6 blocks — 18 modules
total detector area $\sim 18000 \text{ cm}^2$
1 keV - 20 MeV
 $>1 \text{ sr FoV}$

Narrow Field Telescope (NFT) + focal plane detector

Broad band, large collection area LAUE lens



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ASTENA Narrow Field Telescope (NFT)

OPTICS

pass-band 50 - 600/700 keV

20 m focal length

Si 111 + Ge 220 bent crystals

crystal dimensions: 30 x 10 x 2 mm³ (optimized thickness if possible)

43 rings

Rin/out= 18 cm / 149 cm

Filling Factor 83%

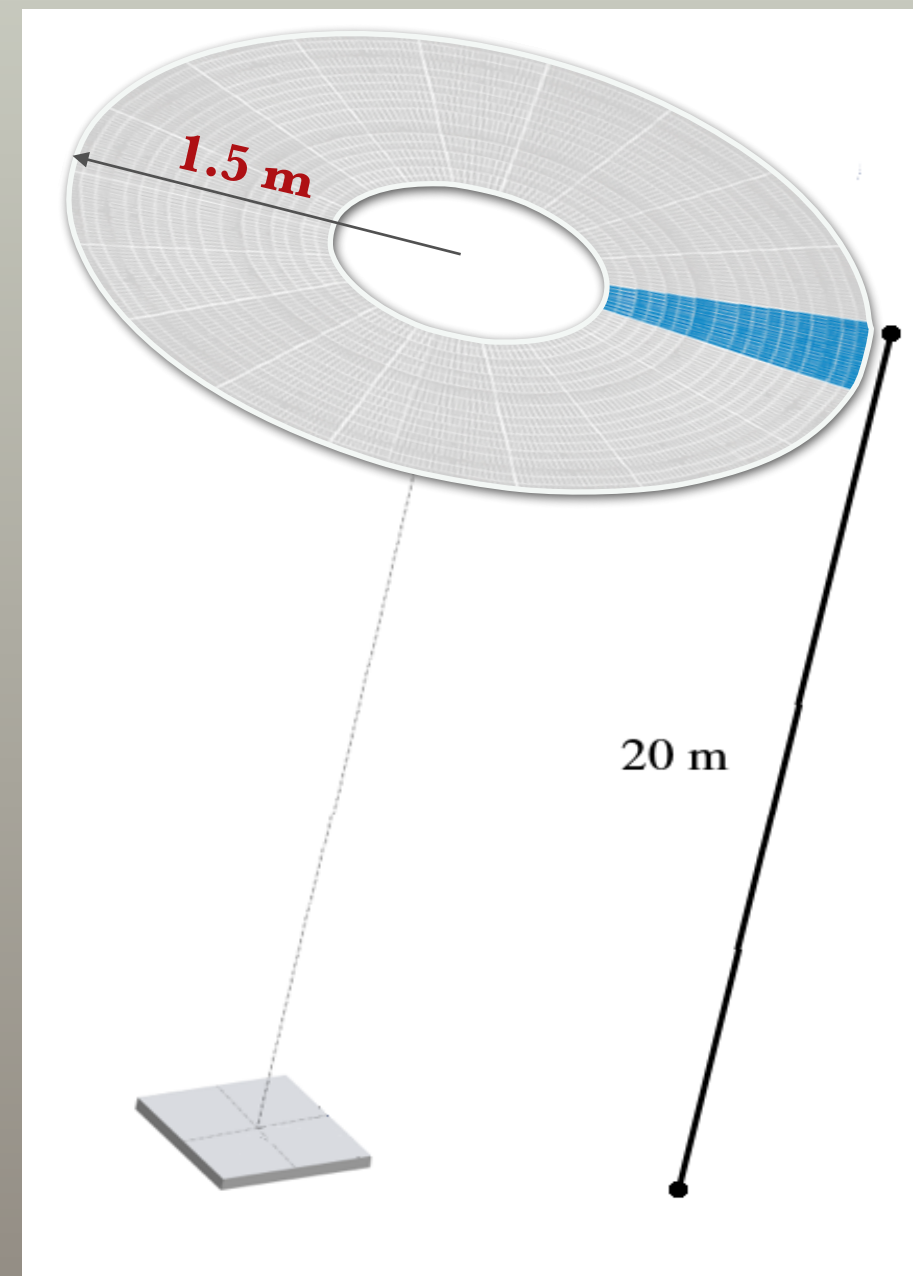
Total Geometric Area 69800 cm² ~ 7 m² !!

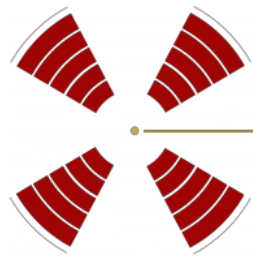
FOCAL PLANE DETECTOR

detection efficiency > 80% @ 600 keV

3D imaging capability = 300 μm (x, y, z direction)

fine spectroscopy response 1 % @ 511 keV





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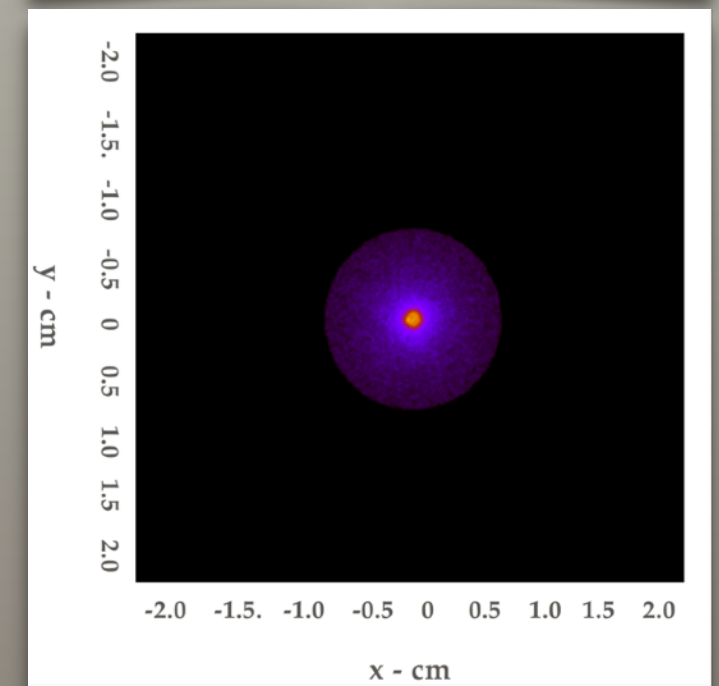
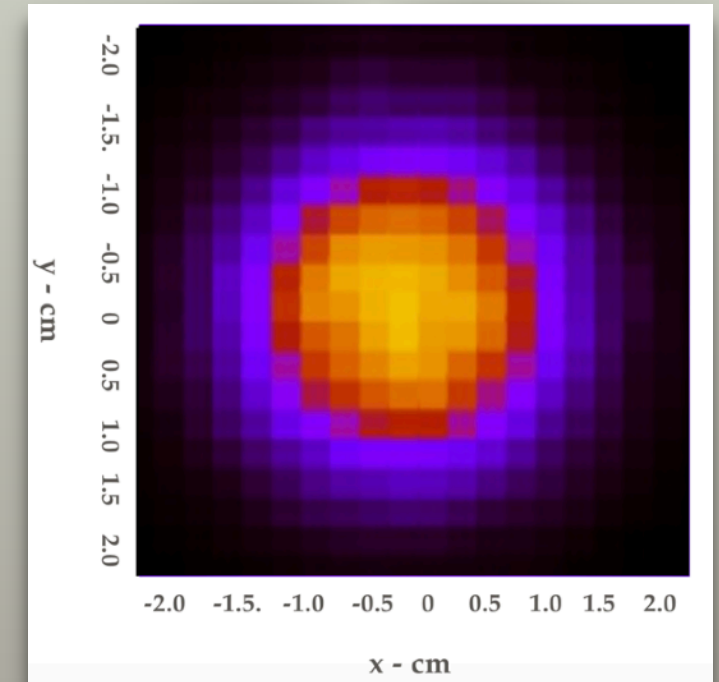
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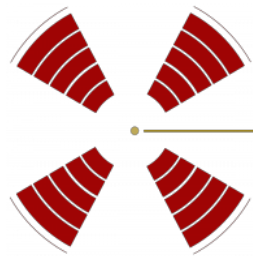
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PSF: flat vs bent crystals





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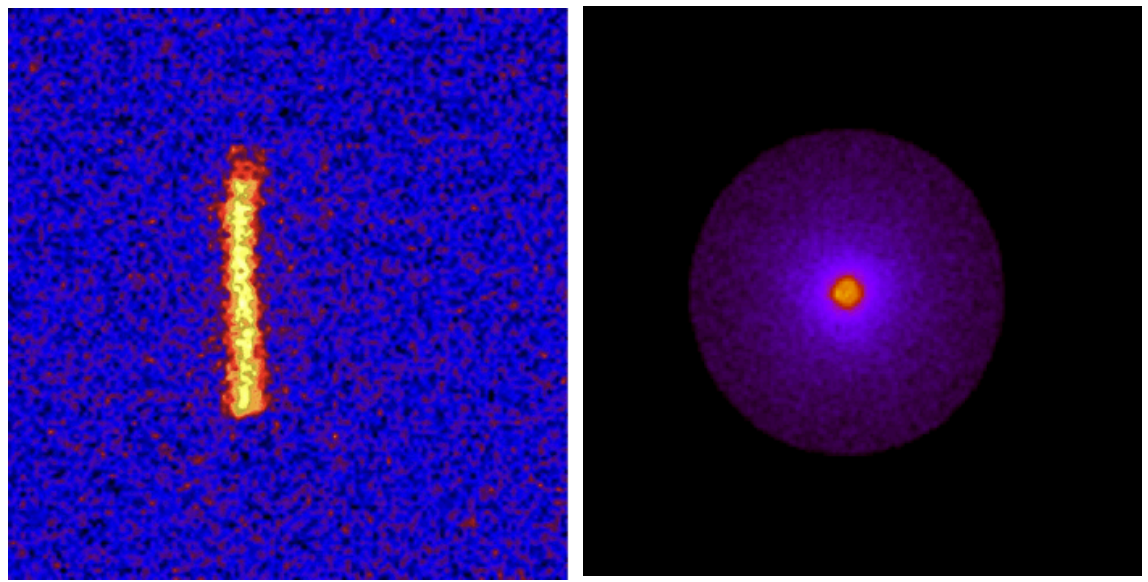


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REAL PSF $\neq$ NOMINAL PSF

Optimization of the NFT optics: critical aspects



Hybrid simulated-measured PSF
produced with 20 ring-oriented crystals

Crystals **manufacturing**

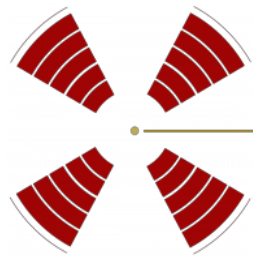
Crystals **assembly**



1. Accuracy of the imprinted curvature
2. Uniformity of the curvature

1. Accuracy of the crystal positioning
2. Long term stability

Inaccuracies affect the overall Point Spread Function (PSF)



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CRYSTAL

- material
- diffraction planes
- crystal geometry
- crystal dimensions
- **curvature**

LAUE LENS PARAMETERS

- filling factor
- focal length
- lens radius
- **mounting accuracy**

SOURCE

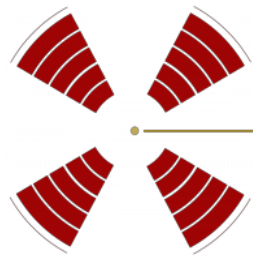
- source dimension/extension
- source-target distance
- number of photons
- photons energy distribution

interaction process

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

output

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



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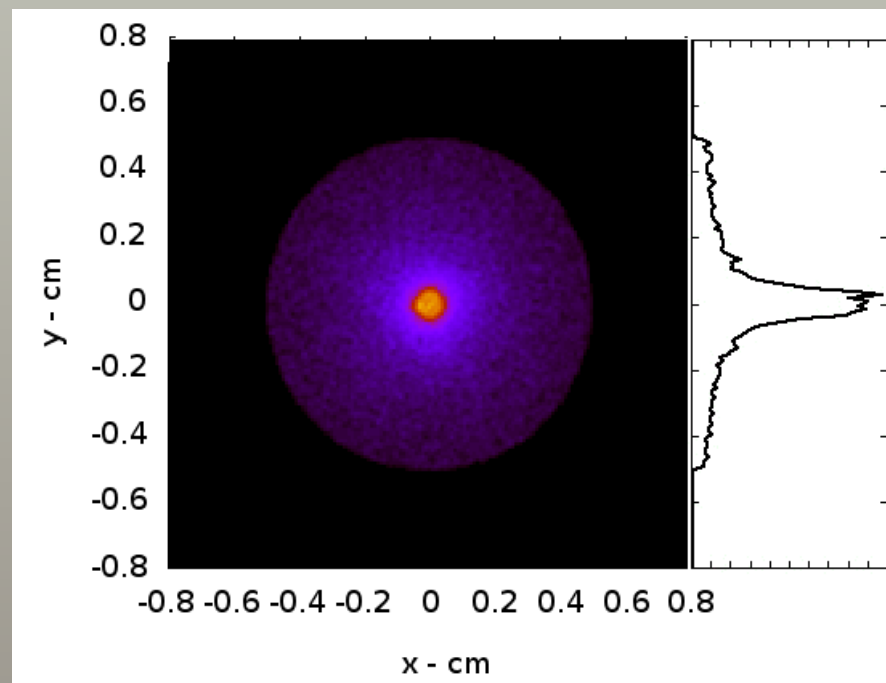


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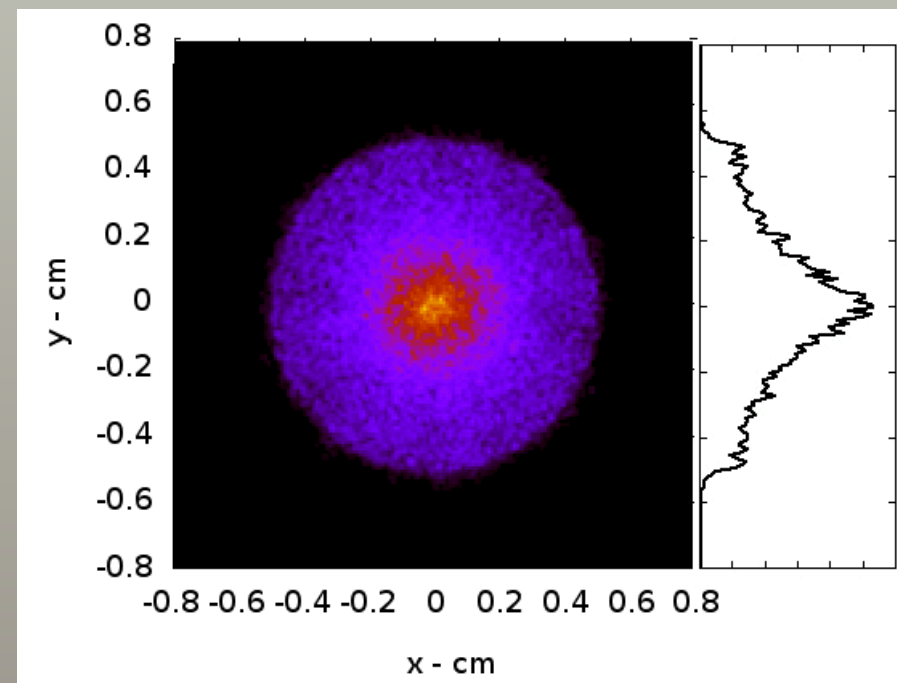
Crystals manufacturing accuracy

nominal PSF with crystals $R_c = 40$ m



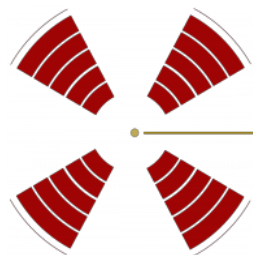
HEW ~ 2 mm

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



HEW ~ 4.5 mm

Goal N. 1: $R = 40 \text{ m} \pm 5\%$ $\rightarrow$ HEW $< \sim 30''$



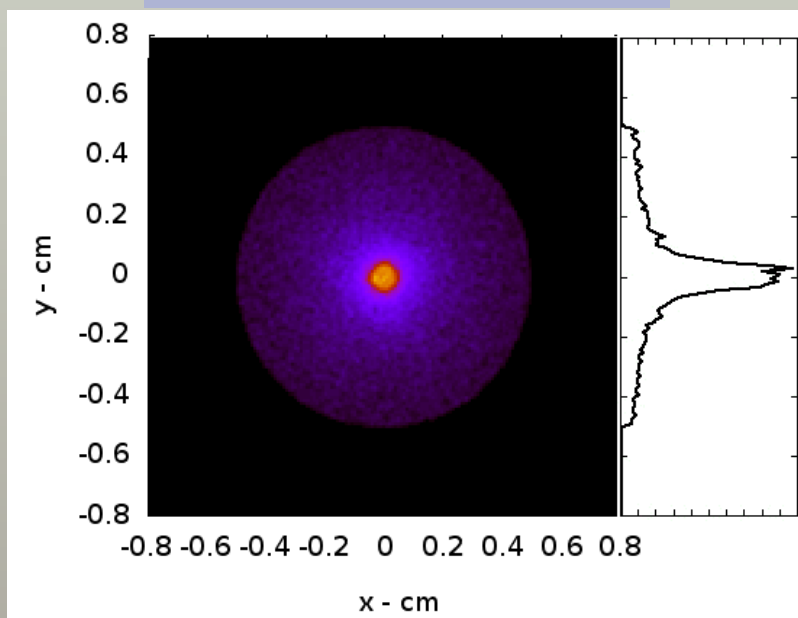
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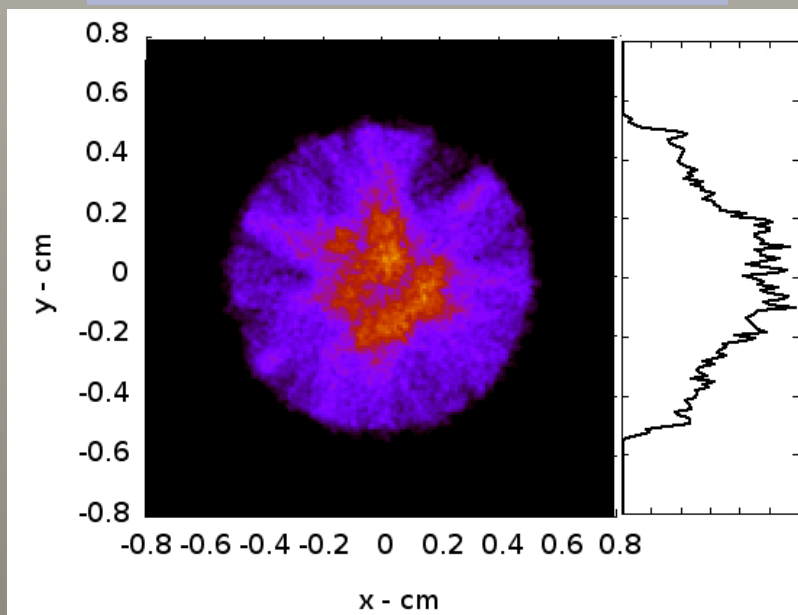
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nominal mounting

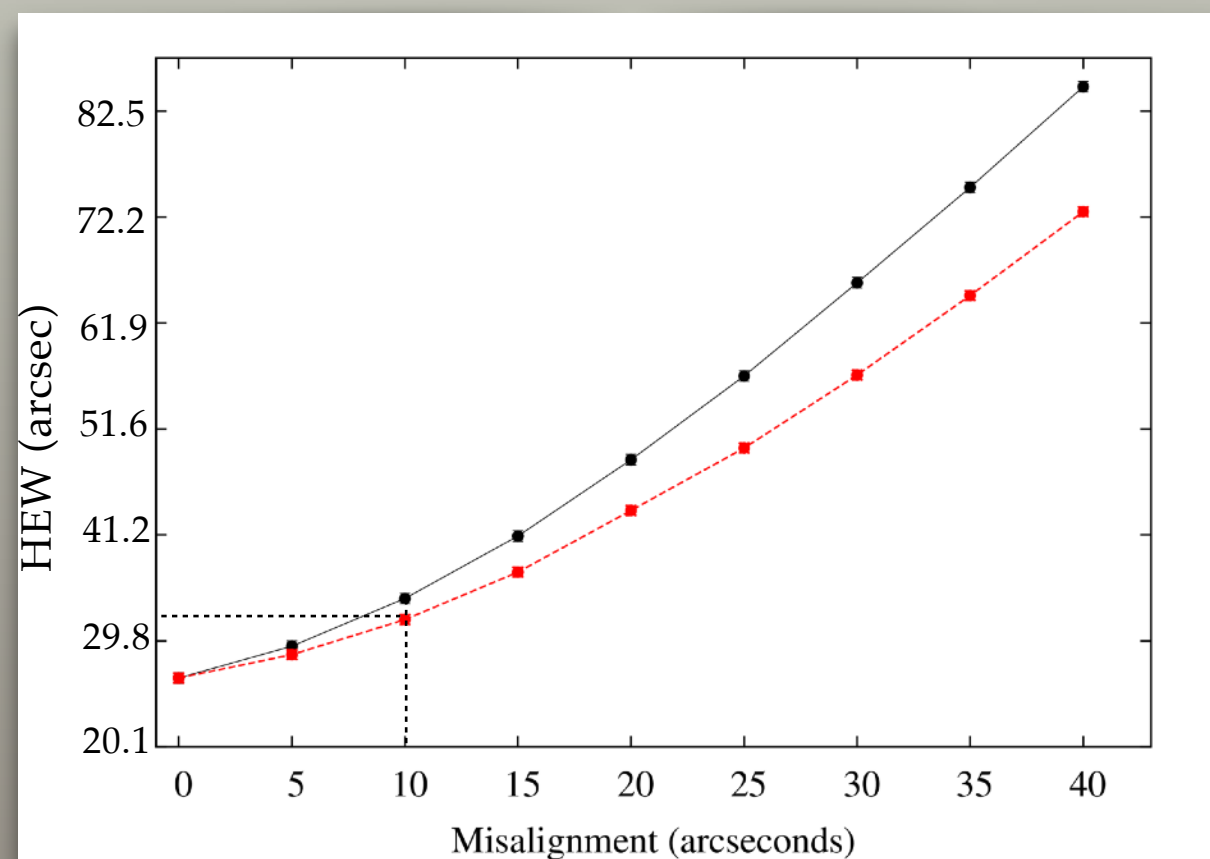


25'' mounting accuracy

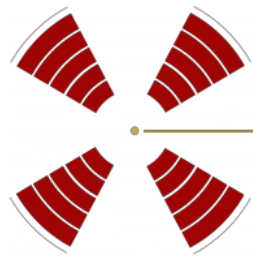


Crystals mounting accuracy

Ferro et al. (2019) in prep.



Goal N. 2: = 10'' accuracy ($\rightarrow$ HEW $\sim$ 30'')



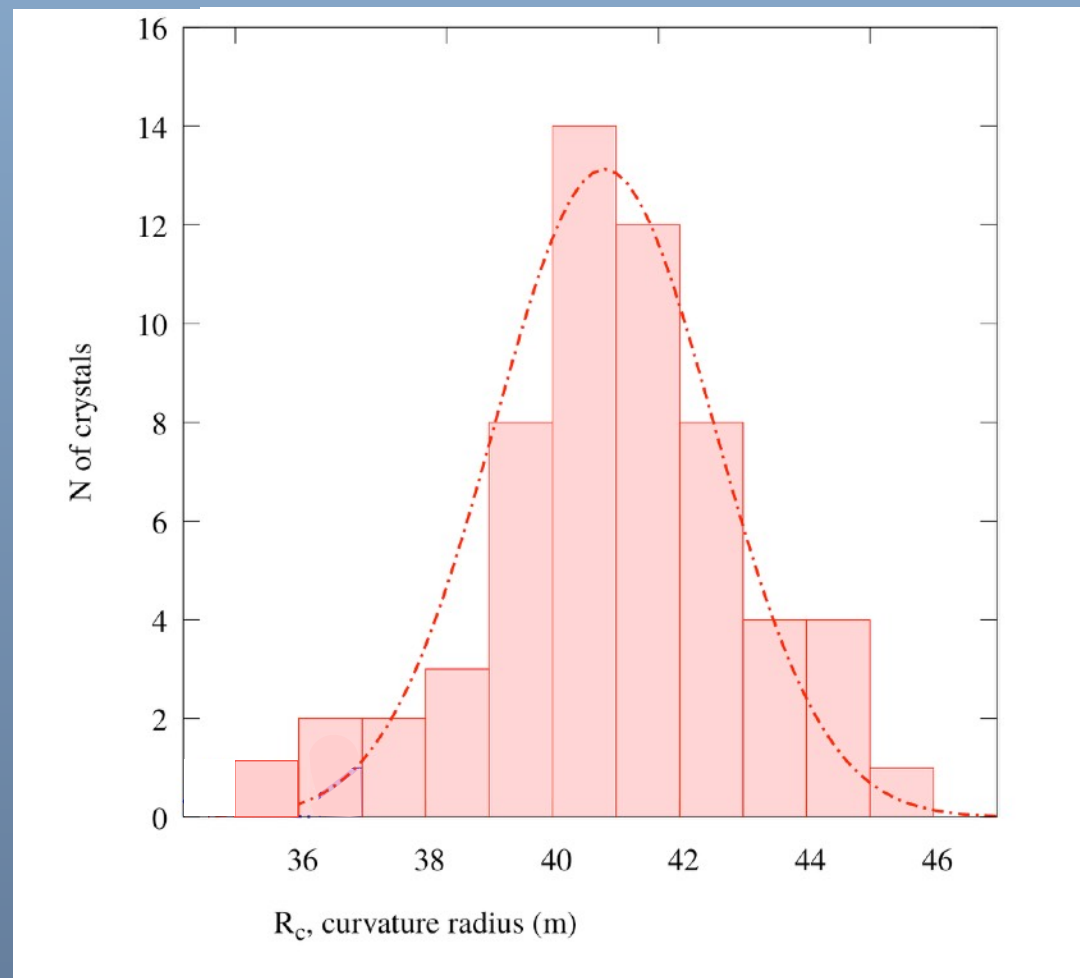
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Crystals curvature distribution

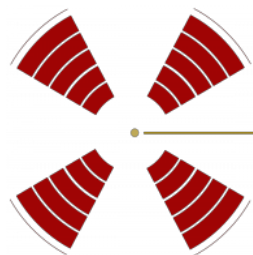


Gallium Arsenide provided by IMEM/CNR
Parma (Italy)
C. Ferrari, A. Zappettini

Latest bunch of 60 GaAs crystals curvature radius

$\langle R \rangle \sim 40.9 \text{ m}$
 $\pm 5\% \text{ (fwhm)}$

We expect a narrower distribution with Ge and Si crystals



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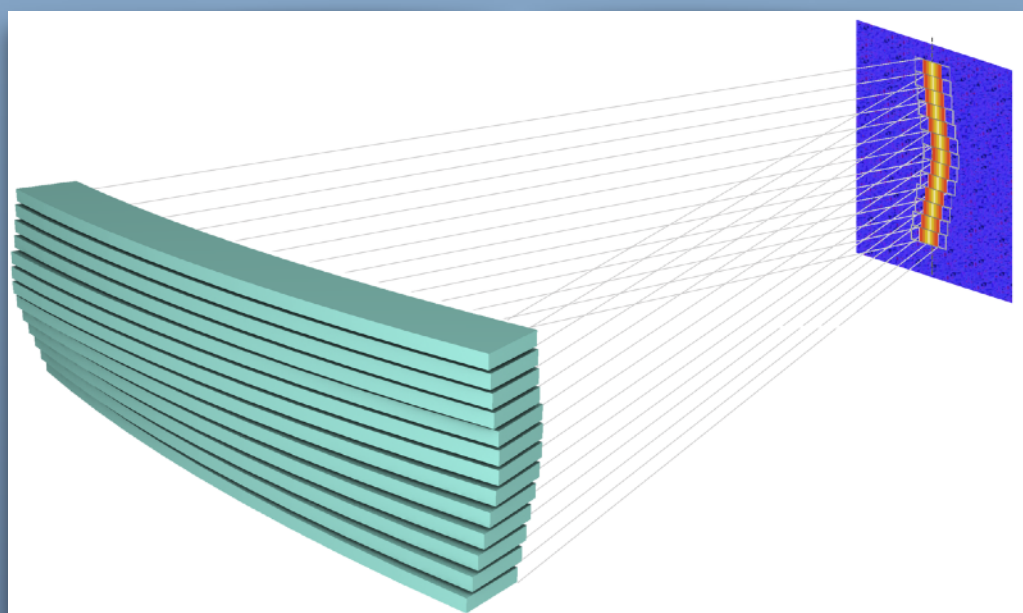


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Crystals distortion

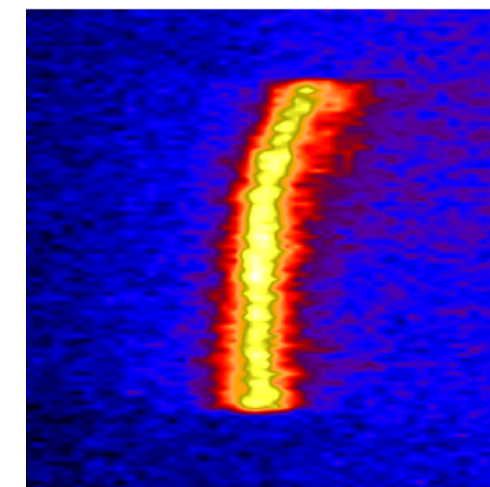
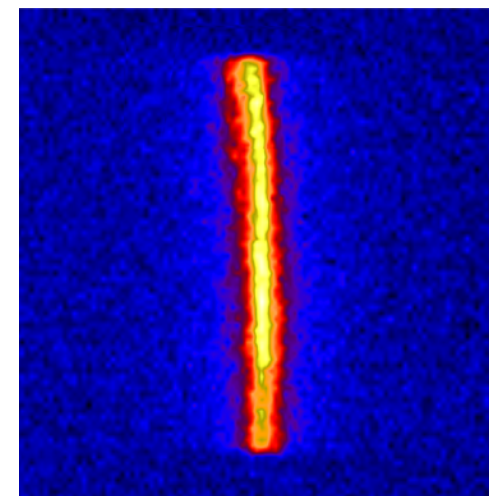
selection criteria of the crystal tiles



Diffraction profile **discretization**
and calculation of the deformation
parameter D

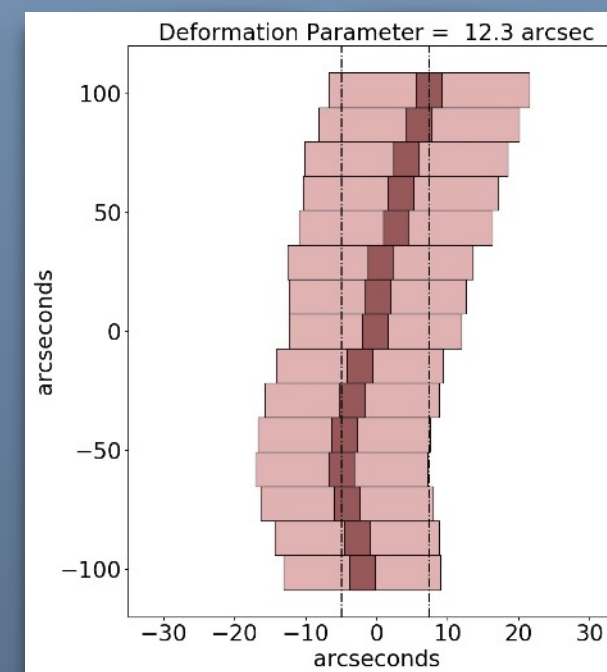
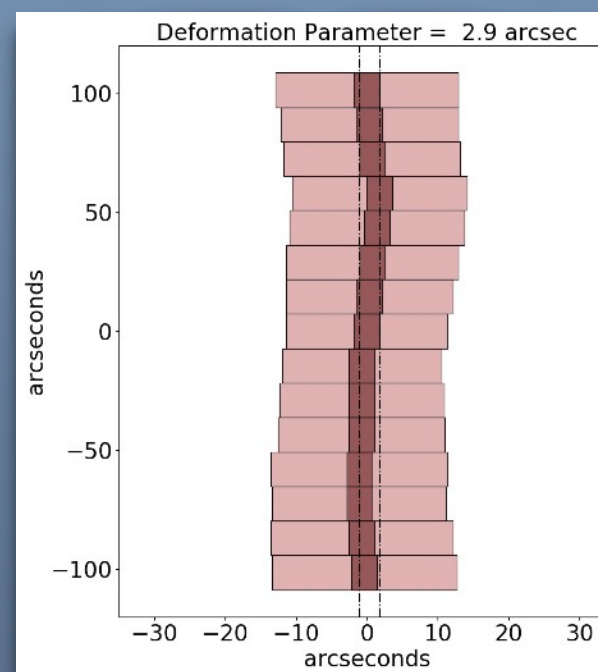
Crystals **discarded** if $D > 10$ arcsec

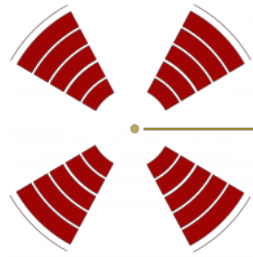
Experimental data for GaAs



$D = 2.9$ arcsec

$D = 12.3$ arcsec





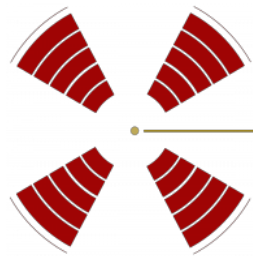
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Experimental activity in support to NFT / ASTENA



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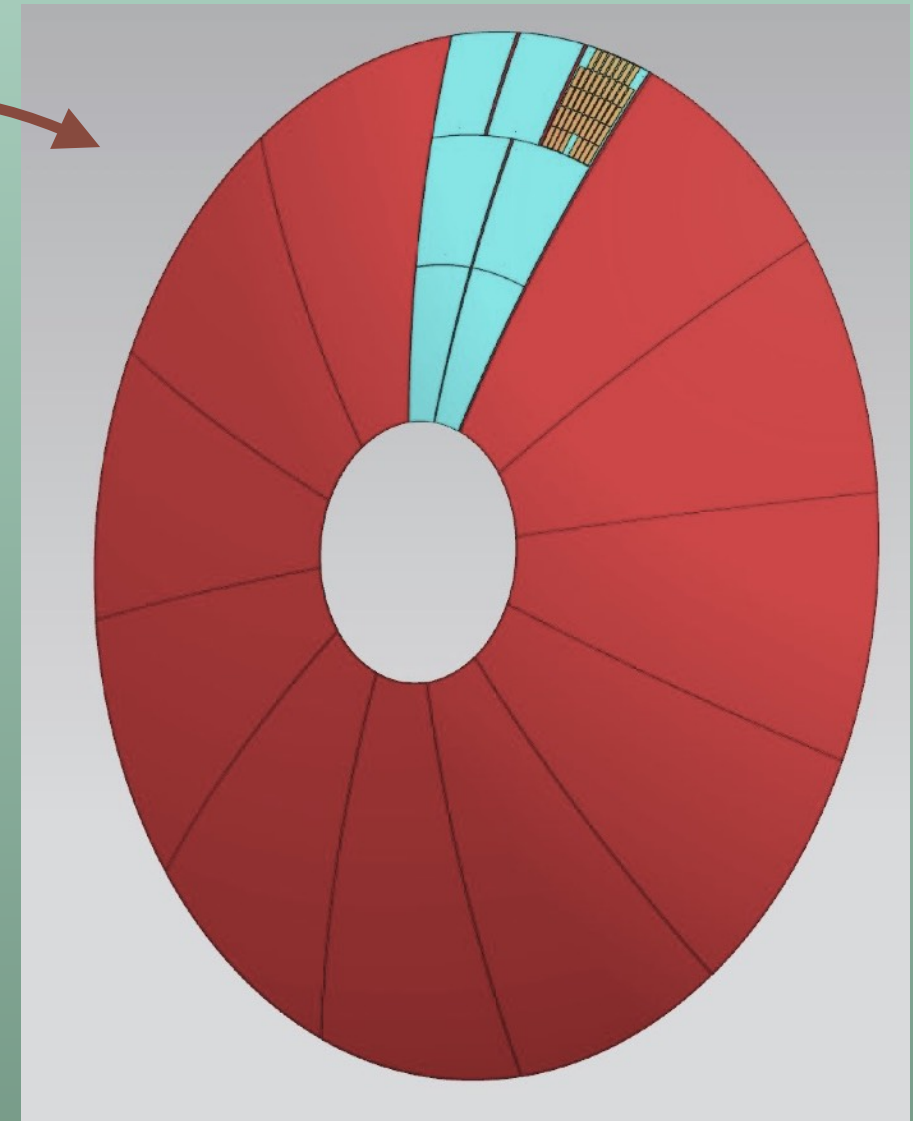
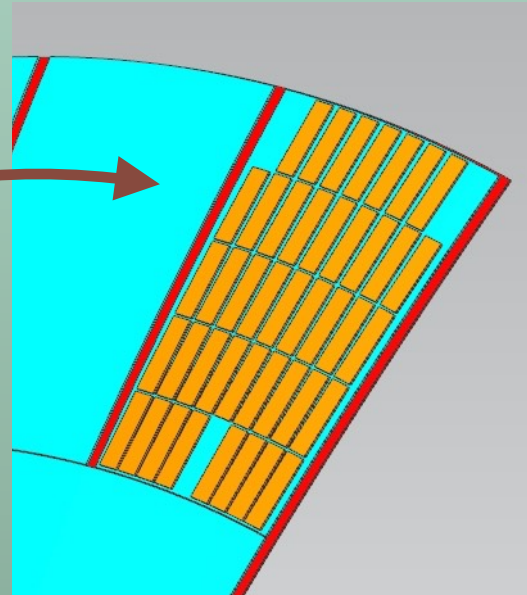
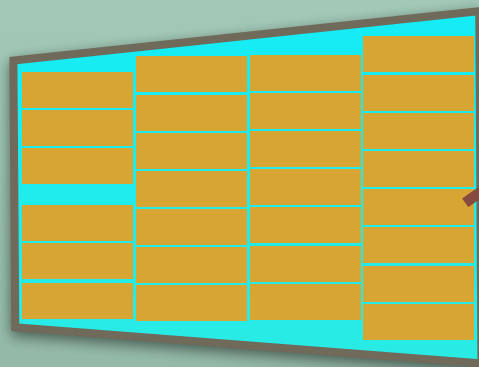


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Modular solution proposed (ASI approved project) for increasing the Laue lens TRL to 4-5

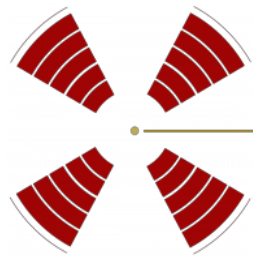
Sub-petal



Facing 2 main tasks:

Set 20/30 crystals per sub-petal with the required accuracy (better than 10").

Define a method to properly orient and keep stable the sub-petals.



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Preliminary tests on one module



prepared a proper substrates in
collaboration with:



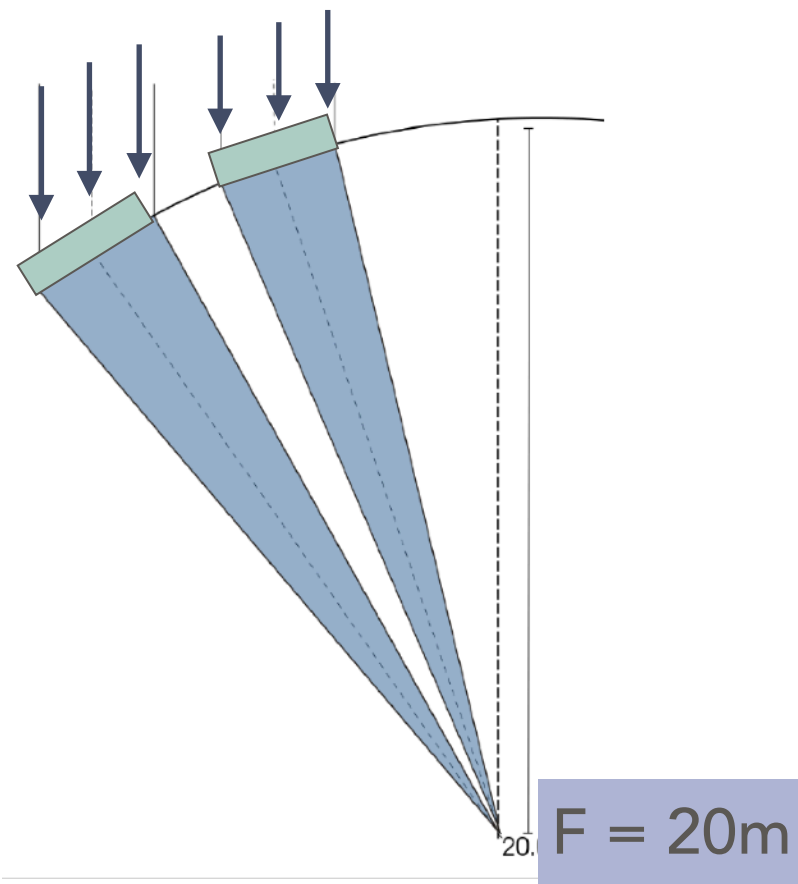


ASSEMBLY STRATEGY

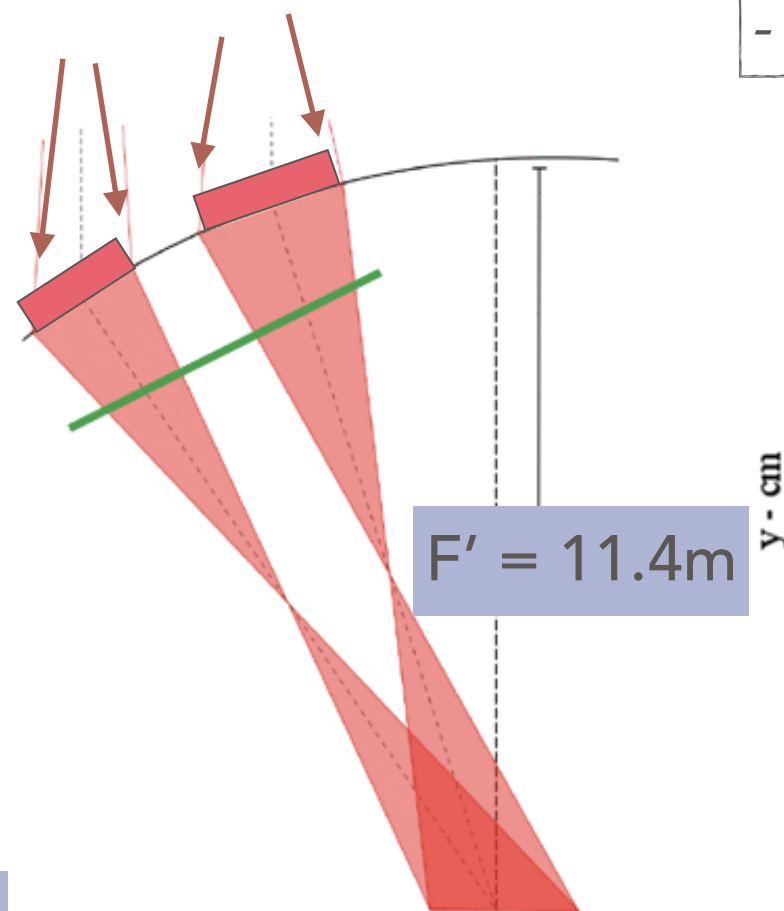
Alignment with gamma-rays both for:

- crystals within each module;
- modules from one another.

non diverging
source

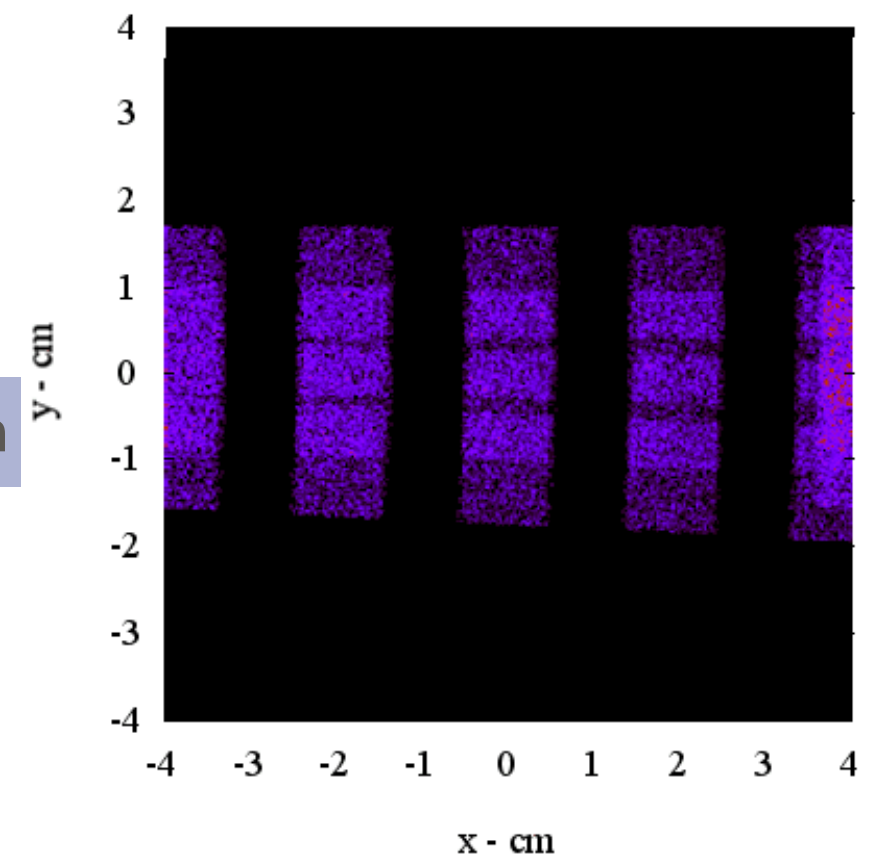


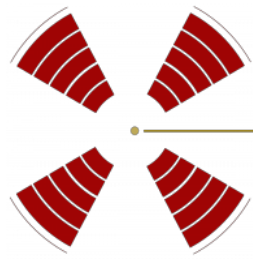
diverging source
(@LARIX)



The shift of F in F' depends on:

- Focal length F
- Crystals curvature radius R_C
- Source-target distance D_{ST}





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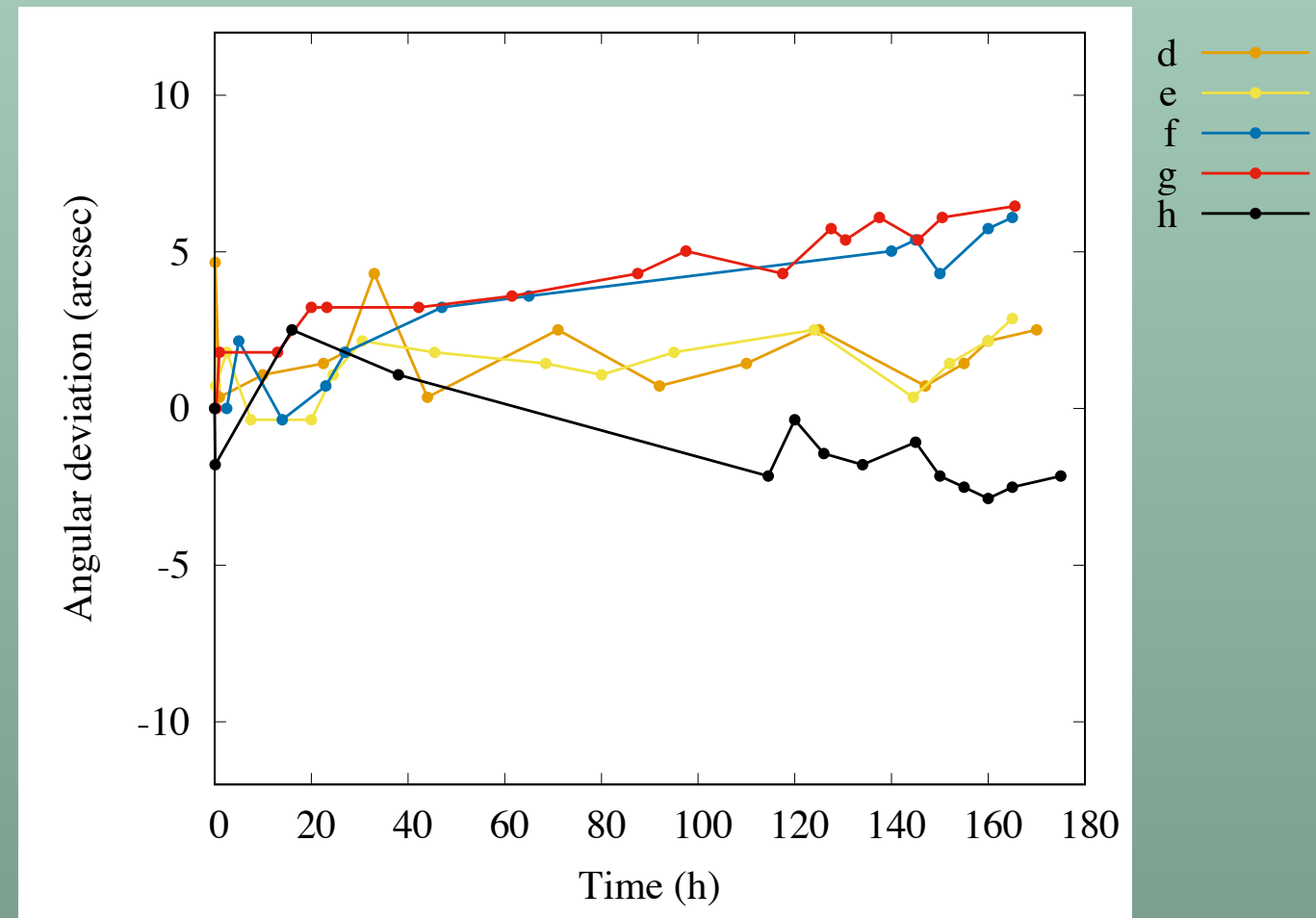
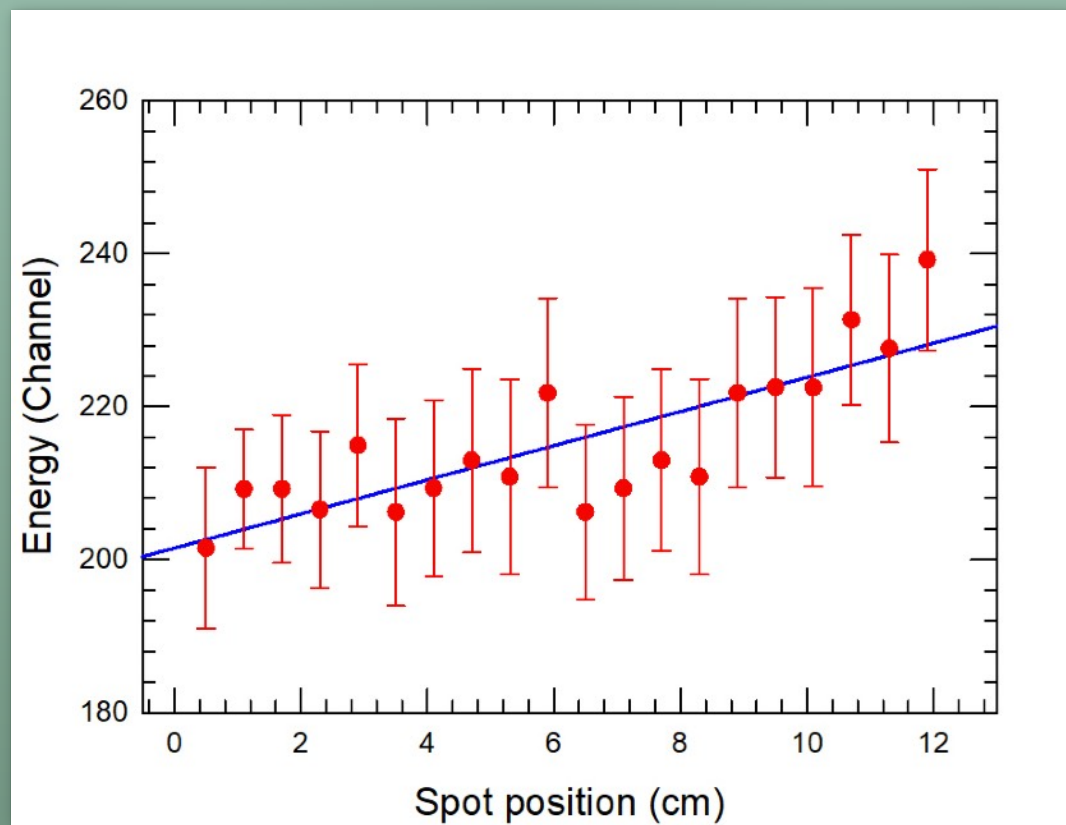
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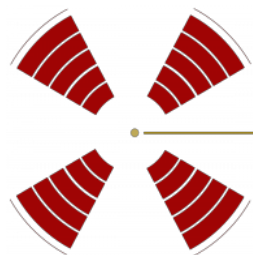
POSITIONING ACCURACY (ON SHORT TIME-SCALE)

PRELIMINARY

But promising accuracy within ~ 10 arcsec



Measured 4 crystals pass-band with spectra/imager detector



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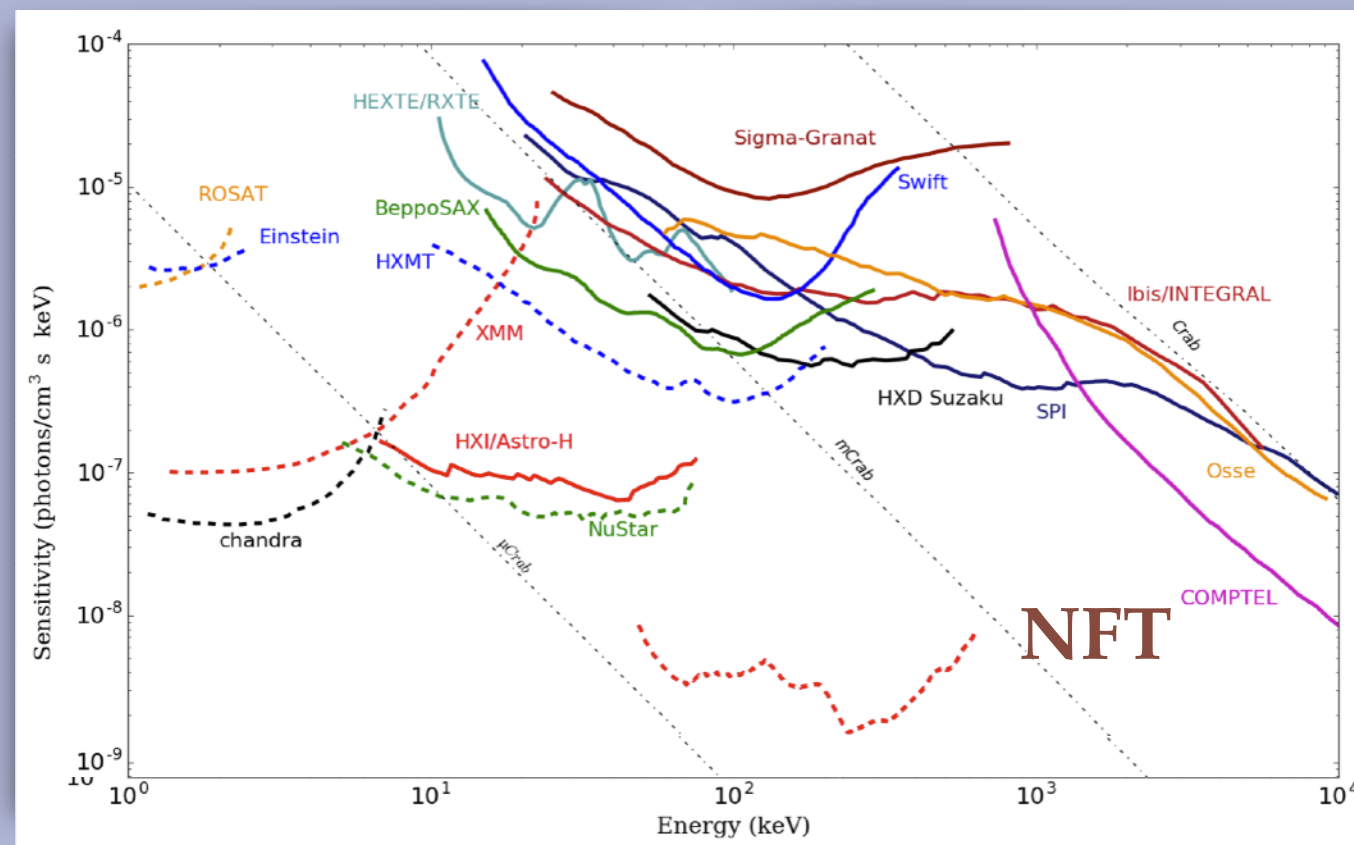


Summary

Within AHEAD we have presented an innovative mission concept based on a Wide Field Monitor and on a Narrow Field Telescope NFT both with unprecedented effective area.

The NFT exploits **bent crystals** that narrows the PSF ($\sim 30''$ HEW) and also thanks to the large effective area significantly **improve the sensitivity** with respect to a non focusing instrument in the same energy band.

Our efforts are now focused on the TRL improvement (supported by ASI).

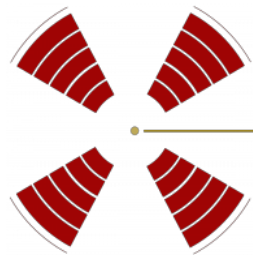


All mission compared:

$$\Delta E = \frac{E}{2}$$

$$T = 10^5 s$$

$$3 \sigma$$



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