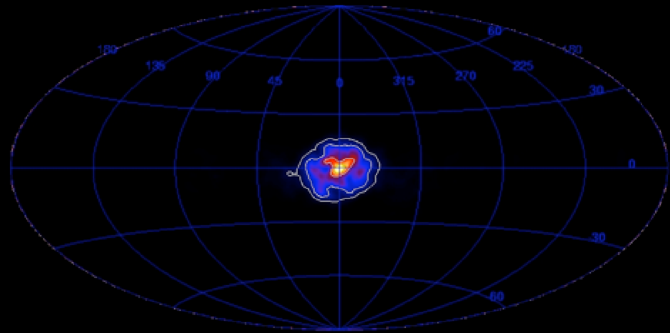
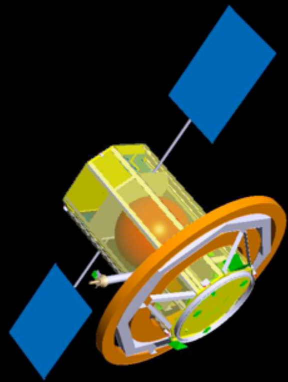
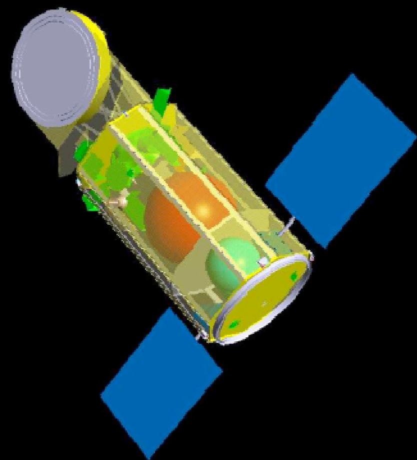




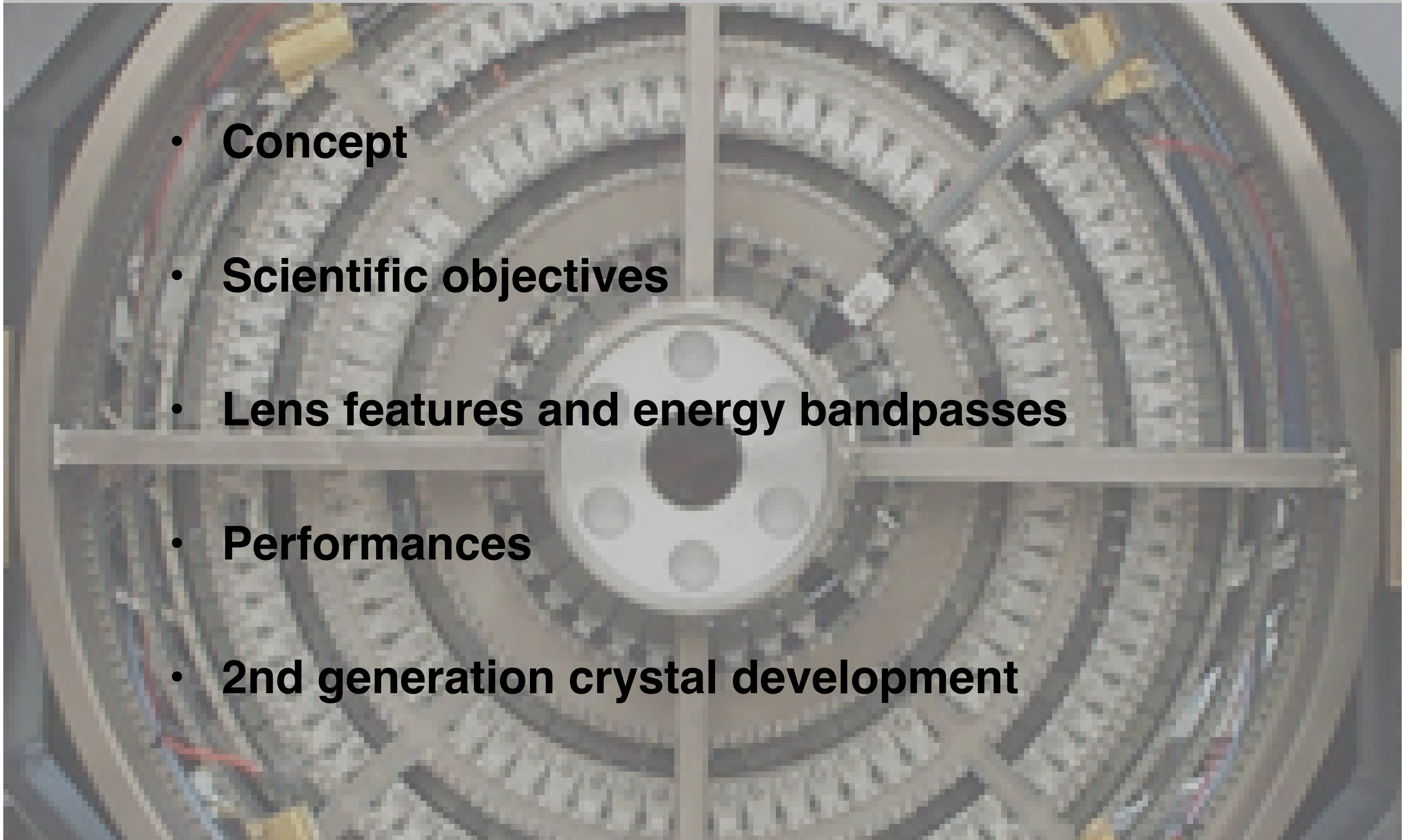
MAX, a Laue Diffraction Lens for nuclear astrophysics



Nicolas BARRIERE

CESR, Toulouse France

Outlines



- **Concept**
- **Scientific objectives**
- **Lens features and energy bandpasses**
- **Performances**
- **2nd generation crystal development**

MAX mission concept

CLAIRE : A successful R&D program

Achievement of a Laue diffraction lens based on Ge_x-Si_{1-x} crystals (von Ballmoos et al. 2003 ;Abrosimov et al. 2004)

Positive detection of the Crab Nebulae during the 2001 balloon borne flight (Halloin, PhD thesis 2004)

Technologies are now mature to build a gamma-ray space borne telescope focusing with a Laue lens

Aim of MAX: Achieving a sensitivity increase of a factor 30 - 100 over existent missions

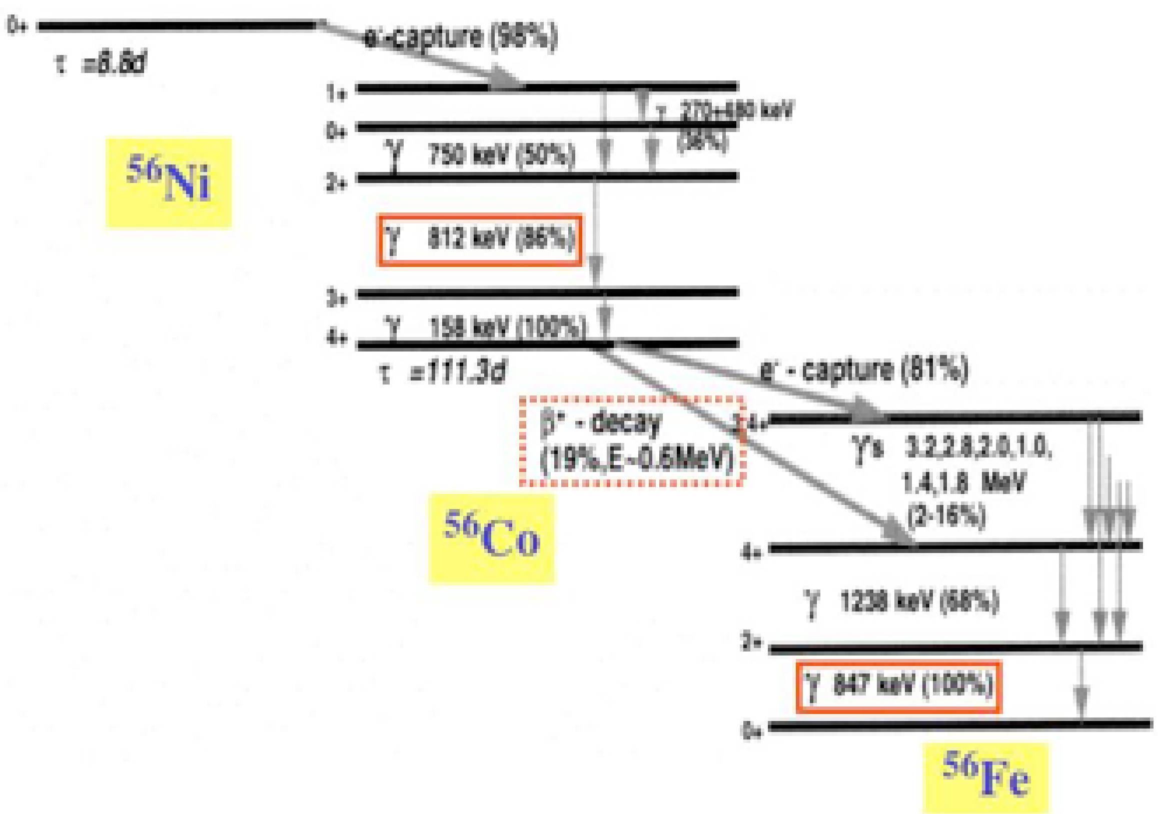
Angular resolution of ≈ 30 arcsec

Spectral resolution of 2 keV @ 511keV

Polarization measurement

Type 1 A supernovae

^{56}Ni decay scheme:



SN 1987 A

- ✔Constrain explosions models
- ✔Standard candle used by cosmologist to determine great scale shape of the universe
- ✔Understand mechanisms of explosive nucleosynthesis

Scientific objectives

electron-positron annihilation

511 keV line

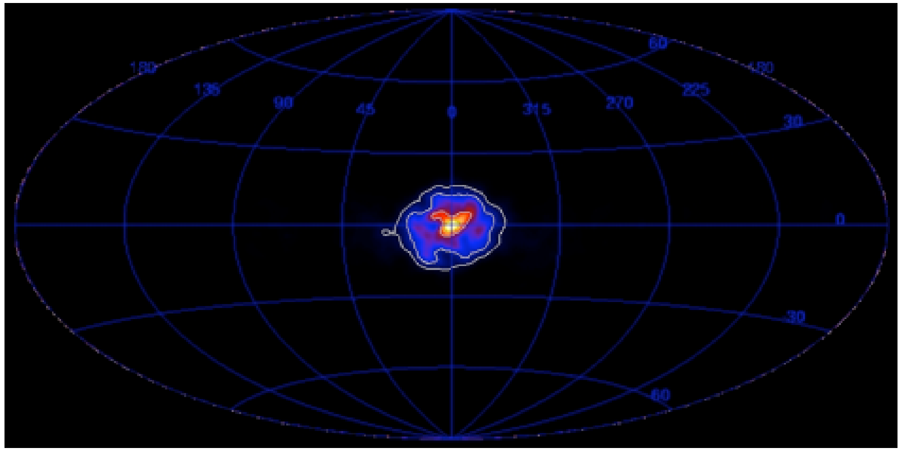
✓Sources of positrons in galactic center

✓AGN

✓Micro-quasars

✓SN 1A

✓Dark matter?

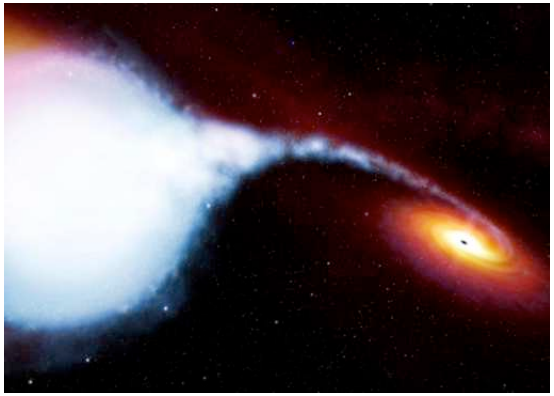


First all-sky map of 511keV e^- - e^+ annihilation (Knödlseder et al. 2005)

➡ Resolve 511 keV point sources

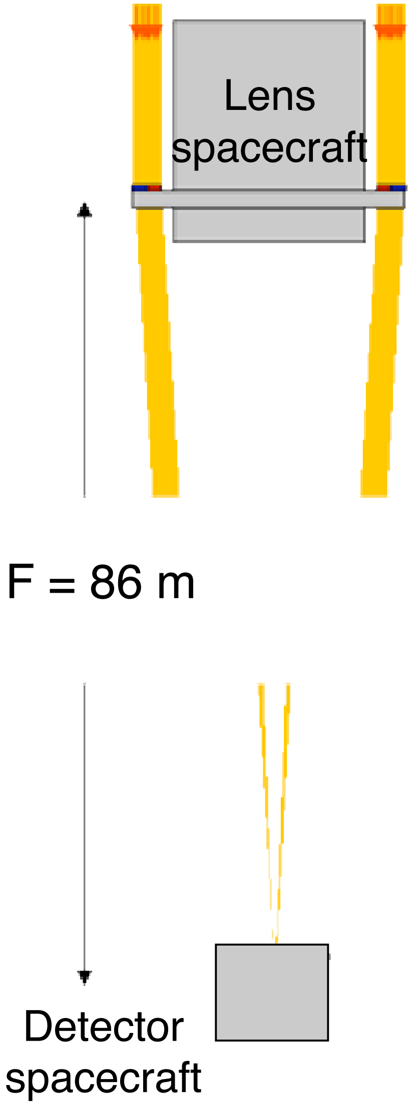
478 keV line from ^{7}Be decay

✓Constrain Novae models



Artist view of Binary system

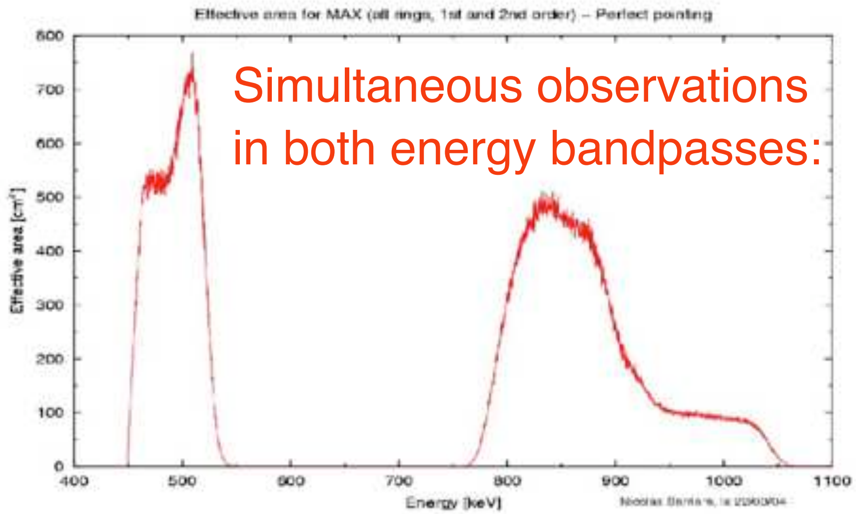
MAX features



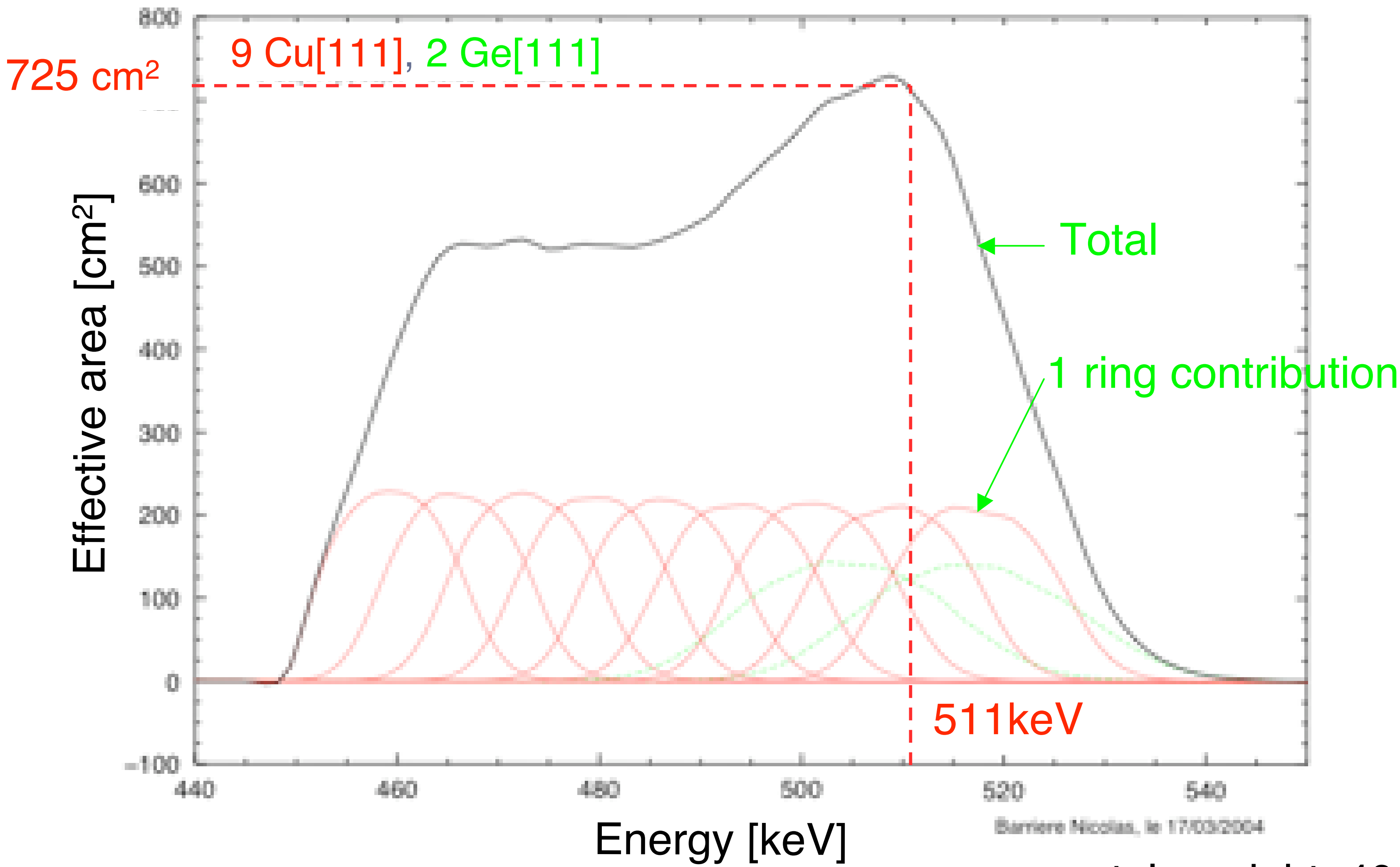
Laue diffraction lens based on mosaic crystals

- 7870 crystals tiles 15 x 15 mm^2, mosaic spread: 30''
  - Collecting area: 17700 cm^2
  - crystals weight: 115 kg

- 24 rings with radii between 57 cm and 111.25 cm
  - Low energy band 460 - 530 keV
  - High energy band 800 - 900 keV

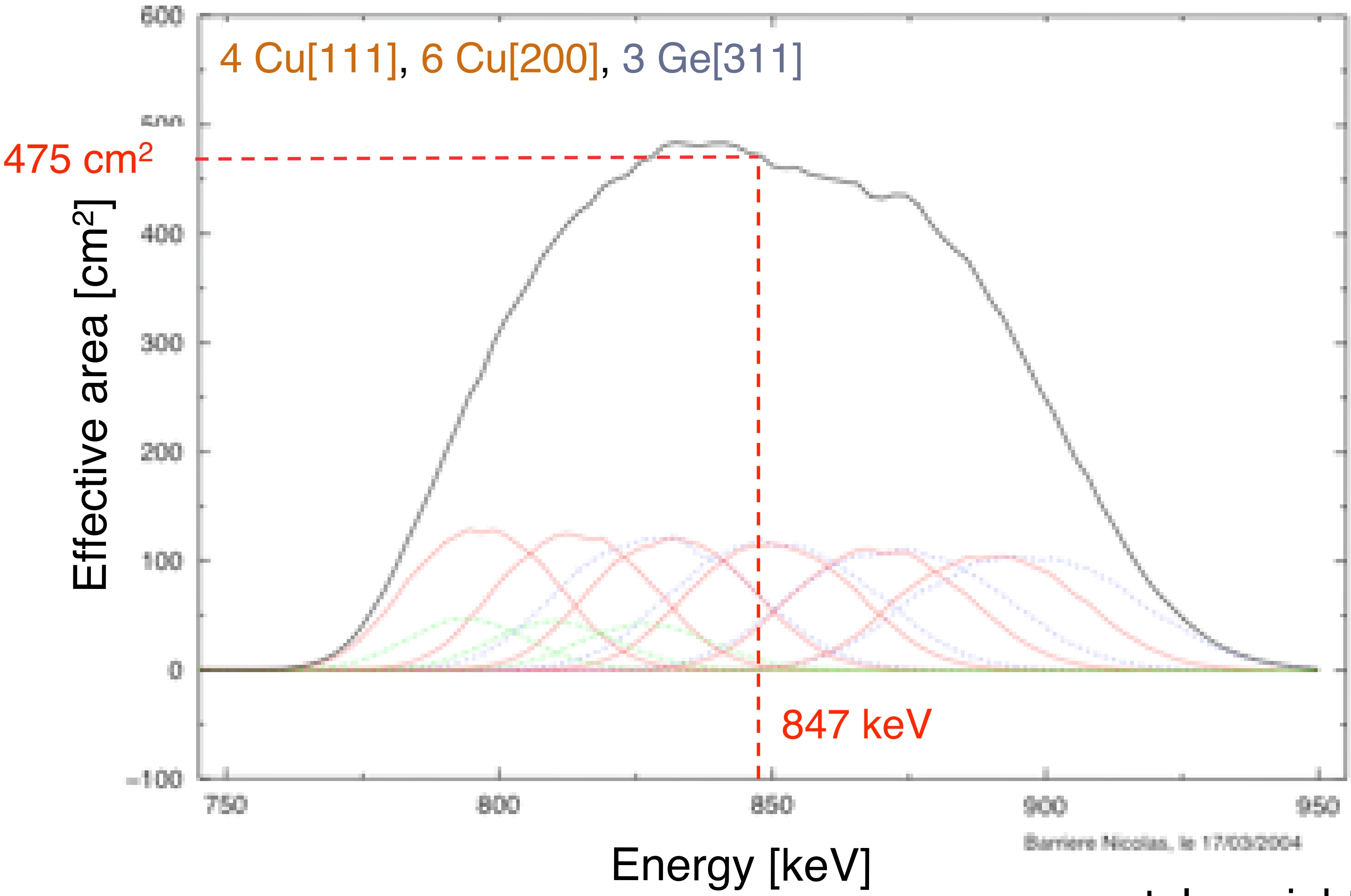


Low energy bandpass



⇒ crystals weight: 40 kg

High energy bandpass



⇒ crystals weight: 75 kg

Detector baseline

Compton stack

✔Events reconstruction ⇒ Allows efficient background rejection

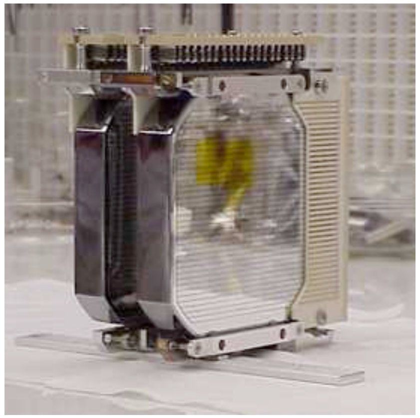
✔Polarization

Stripped germanium planars from ***Nuclear Compton Telescope***

(Boggs and Wunderer)

✔Spectral resolution

Detection efficiency



Cross Strip 3-D GeDs:

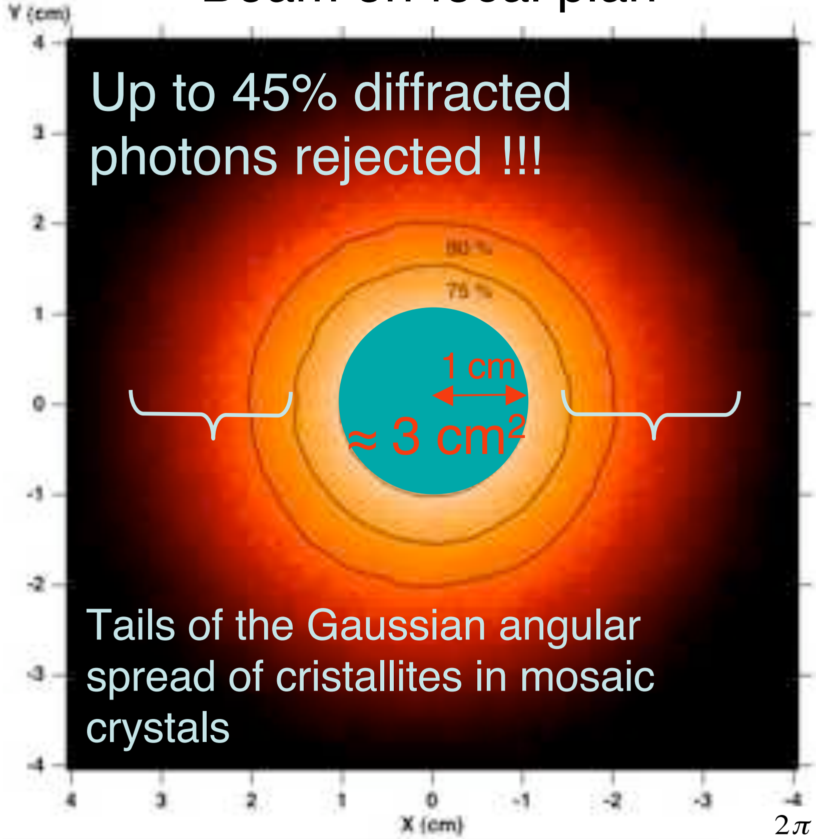
- 37x37 strips
- 2-mm pitch
- 15-mm thickness
- 81000 mm^3 volume
- 1 mm^3 localization
- 2 keV spectral resolution

First estimates based on a 4 3-D GeDs stack: Optimization of the geometry could dramatically enhance the detection efficiency

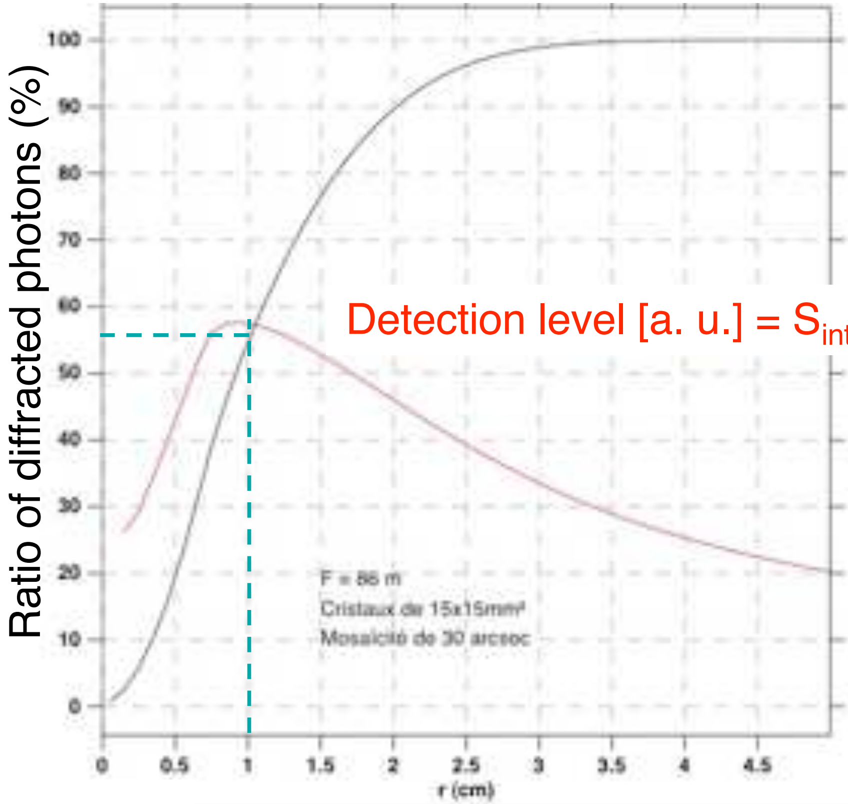
(P. von Ballmoos, S. Boggs, C. Wunderer, G. Weidenspointner, P. Jean)

Lens' Focus: features of the focal spot

Beam on focal plan



Integrated radial distribution



Detection significance: $n = \frac{S}{\sigma(S)}$

$$S \longrightarrow \int_0^{2\pi}\int_0^{R} I(r,\theta)\,dr\,d\theta$$

$$\sigma(S) \longrightarrow \sqrt{S+N} \approx \sqrt{N} \approx \sqrt{V_{Det}} \;\; \alpha \;\; r$$

⇒Wish for crystals with square "crystallites" distribution instead of gaussian

MAX performances

- **simultaneous observation in two broad energy bands**

- **E/dE ~ 500**
- **ang. res. ~ 1'**
- **timing**
- **polarization**

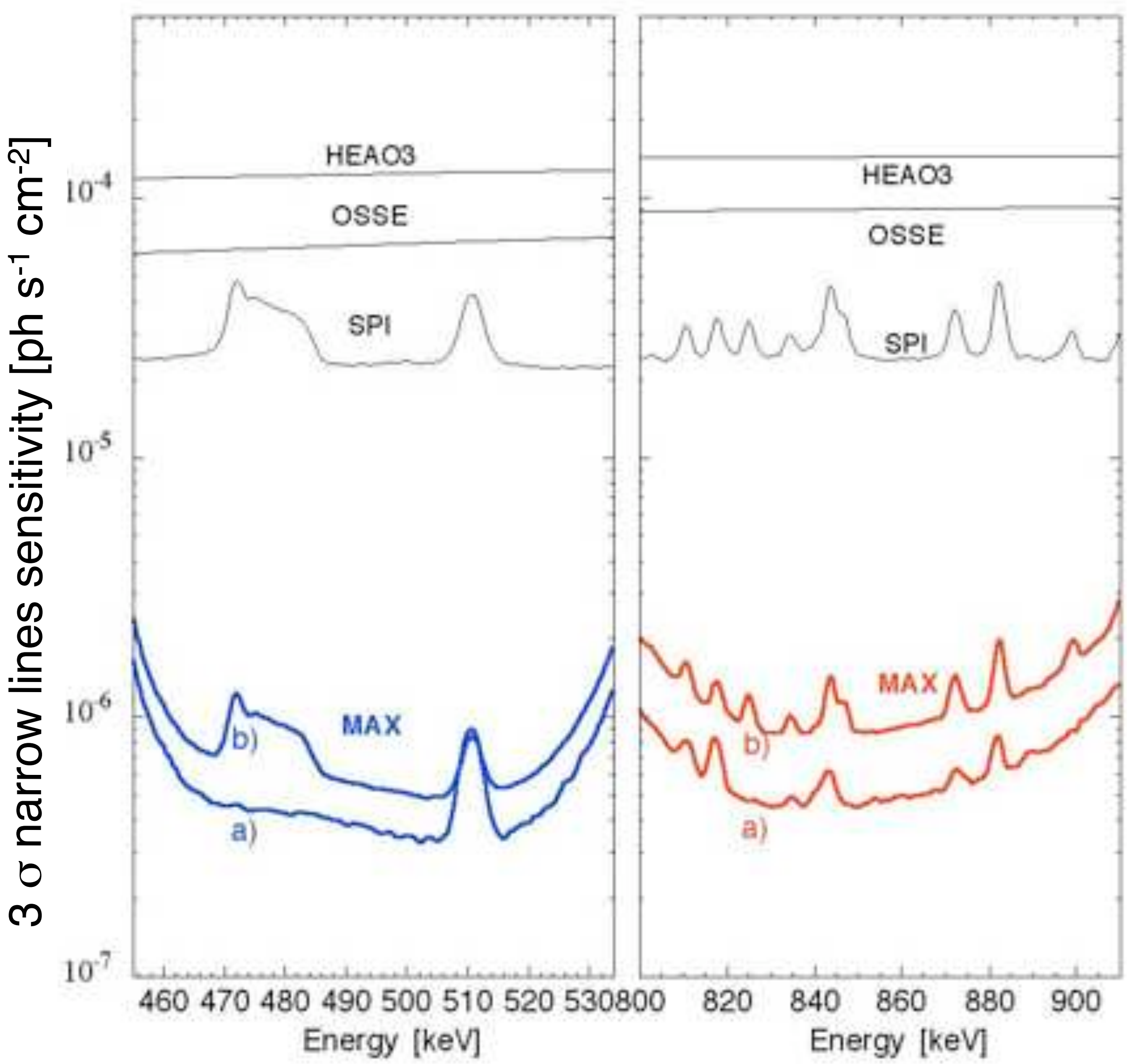
Options:

a) baseline detector

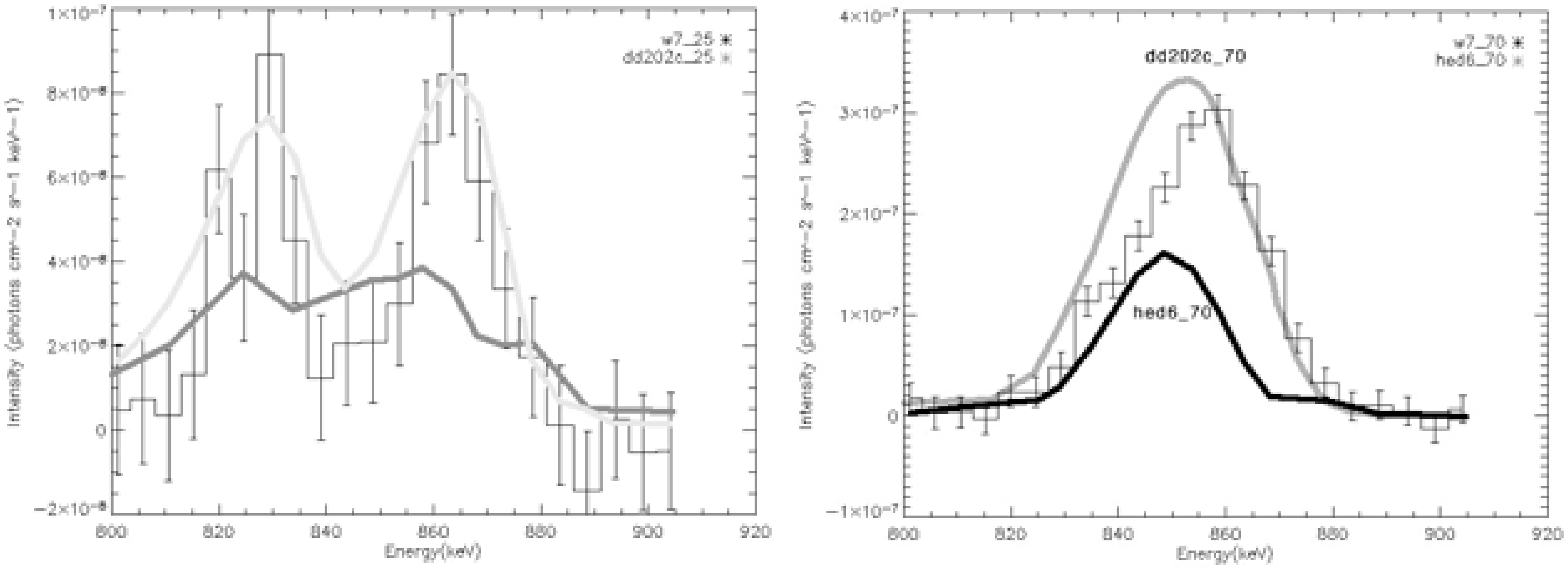
Ge Compton stack

b) single detector

SPI type GeD



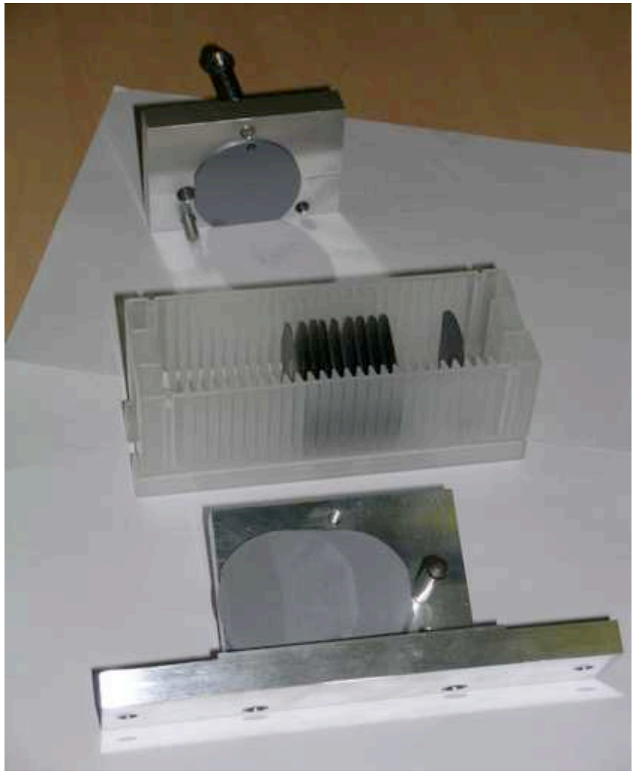
Simulated MAX observation of a SNIa (W7)



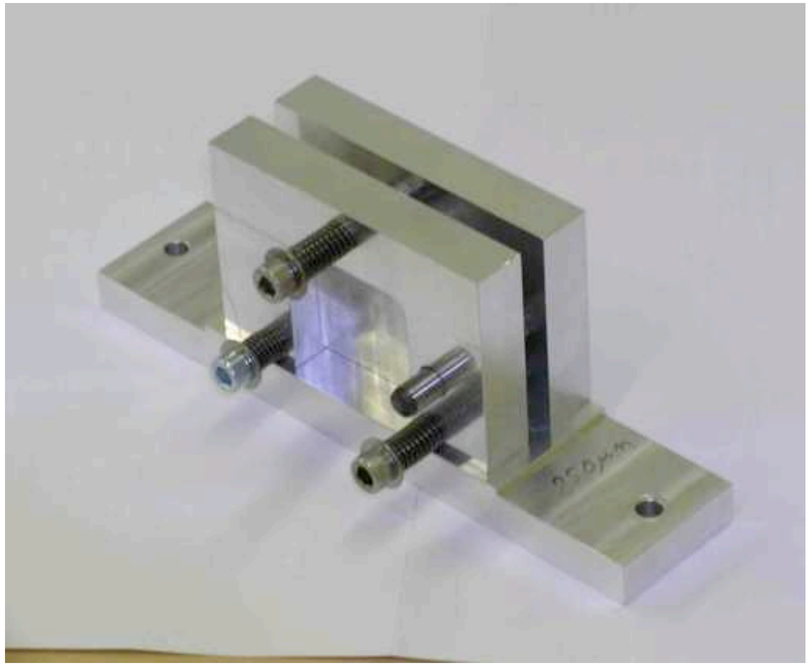
- SNIa at 20 MPc, observed after 25 days (a) and 70 days (b)
  "observed SN" : W7 (Chandrasekhar mass deflagration) Nomoto, Thielemann et Yokoi (1984)
- delayed détonation (DD202C, Höflich et al. 1998)
- Sub-Chandrasekhar mass star (HED6, Höflich & Khokhlov 1996)

Development of 2nd generation's crystals

Composite Crystals of silicon and germanium
with mosaic spread between 30’’ and 1’



Silicon wafers

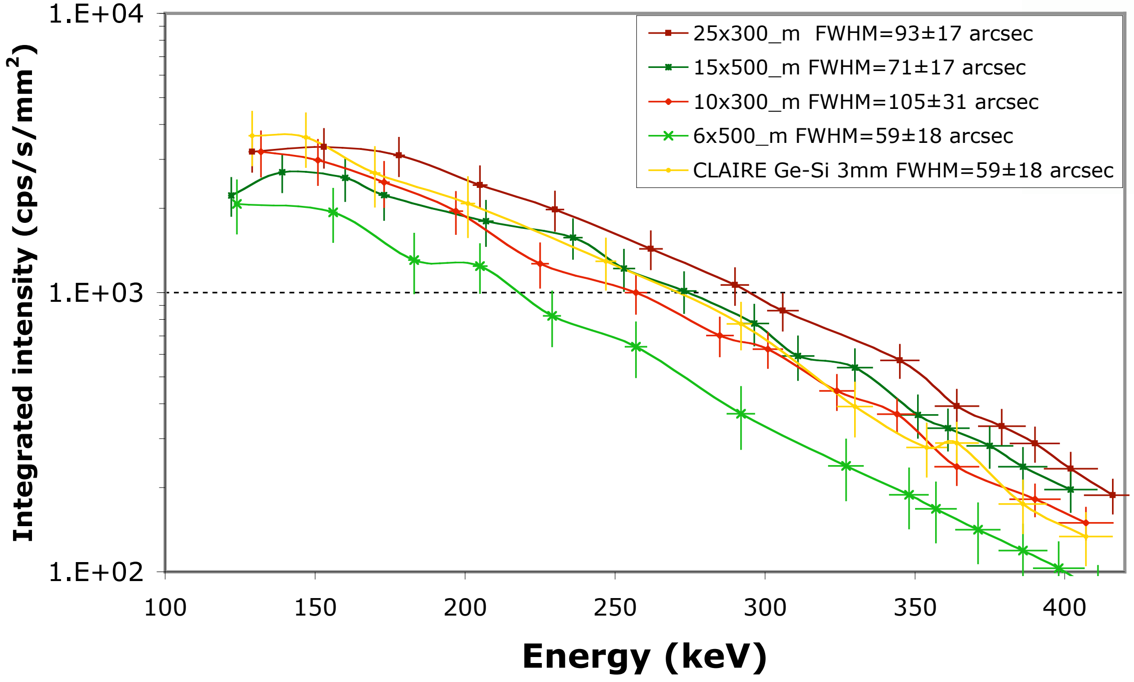


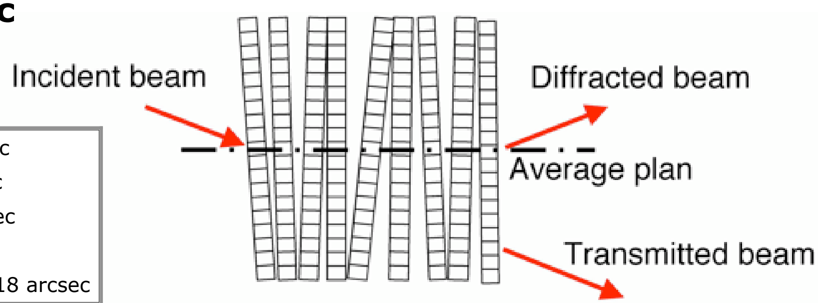
Aluminium frame with tightening screws

Development of 2nd generation's crystals

What we have got: Composite crystal with ≈ random angular spread of the wafers

Diffraction efficiency of CLAIRE's Ge_x-Si_{1-x} mosaic crystal VS stacks of Ge wafers



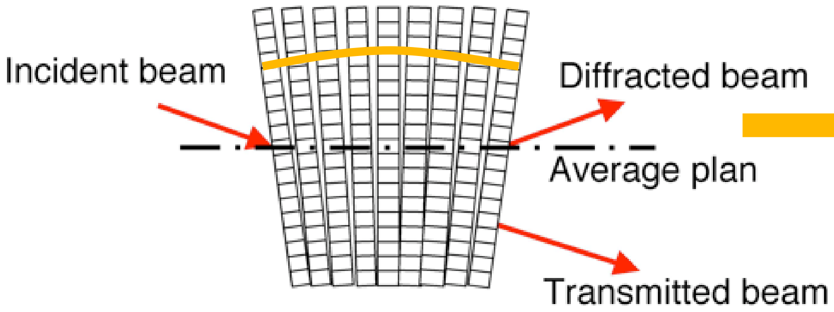


Measurements done in ILL, with a beam 100keV < E < 420keV, with an X-Ray camera pixelized of 10'' angular resolution

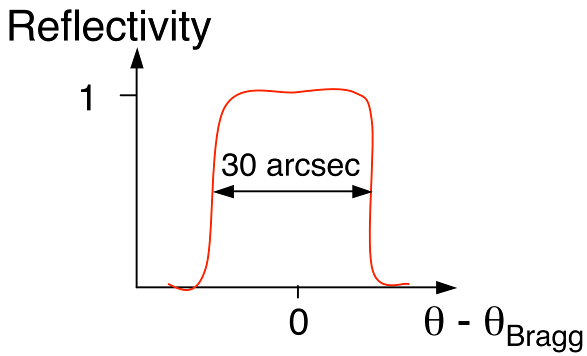
First measurement session: encouraging results !

Development of composite crystals

What we would like: Composite crystal with square angular spread of the wafers



Equivalent to curved diffracting plans



Optimized wafers thickness ≤ 1.2 T_{ext}
⇒ reach the maximum diffraction in each wafer:

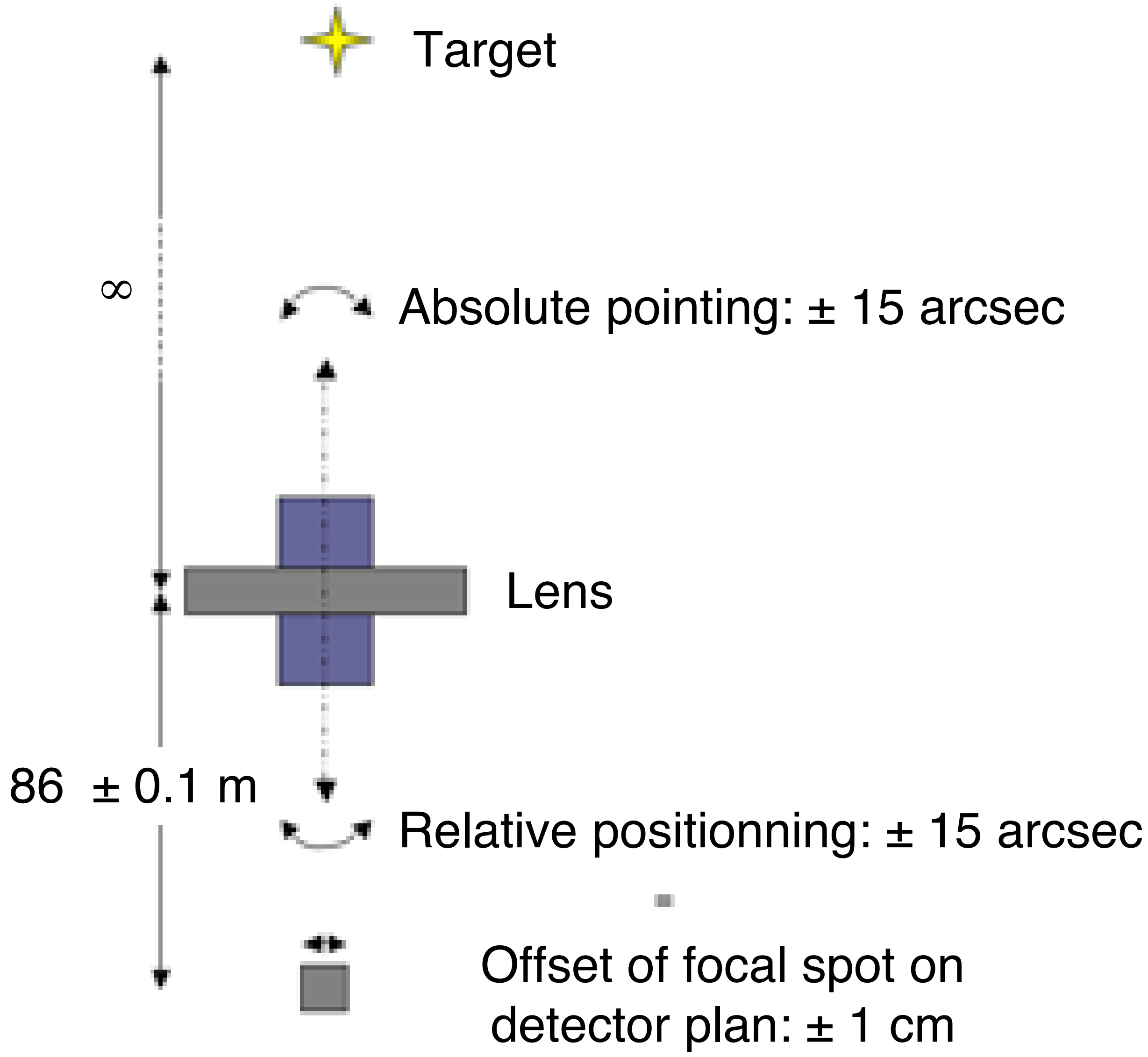
Energy (keV)	$T_{ext\ Ge(111)}$ (μm)
511	170
847	350

Presently: wafers of 350 and 500 μm

measurement session in ESRF in November 2005

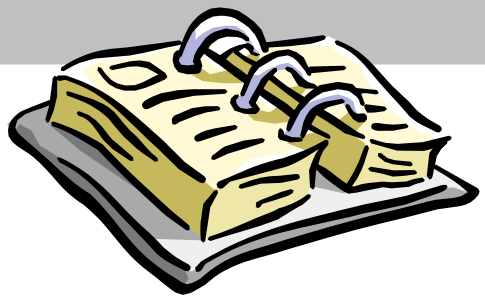
Formation flying specifications

Specifications for absolute and relative pointing



⇒ CNES' phase 0 study: no major problem…

MAX mission calendar



Januar 2004	CNES call for ideas for a formation flying demonstrator mission
March 2004	MAX mission proposal
December 2004	Beginning of MAX study in phase 0 by PASO group in CNES
May 2005	End of phase 0
September 2005	Issue of phase 0 report (science and technology)
October 2005	Selection of 2 formation flying missions for phase A study

Conclusion

Viable mission concept:

Formation flying realizable

Scientific objectives reachable with sensitivities around 10^{-6} ph/s/cm^2

Remains some work to do:

Optimize detection plan

Production and cutting of suitable copper crystals

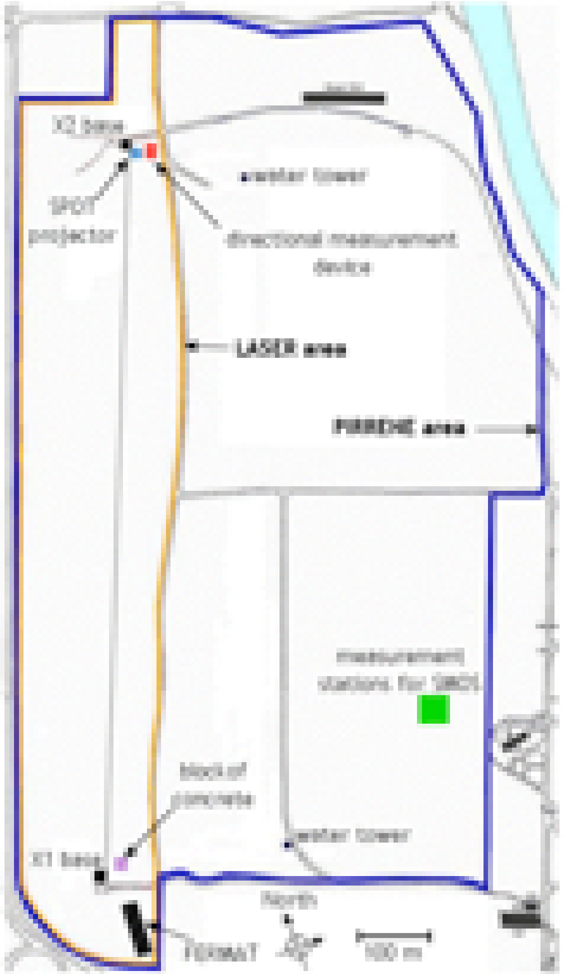
Alternative crystals: composite, gradient…

Confirm Imaging capabilities

Accurate mounting on the lens frame

⇒ **PASO Phase A study**

Tests and calibrations of the lens



Collaboration with the Département Environnement Spatial of ONERA

Very powerful industrial X-ray:

Betatron portable (2 or 6 MeV) (JME)

⇒Realization of a long distance optical bench (1km) for gamma ray lens + other applications

MAP of a1000m long laser base on a safe field of ONERA, near Toulouse (France)

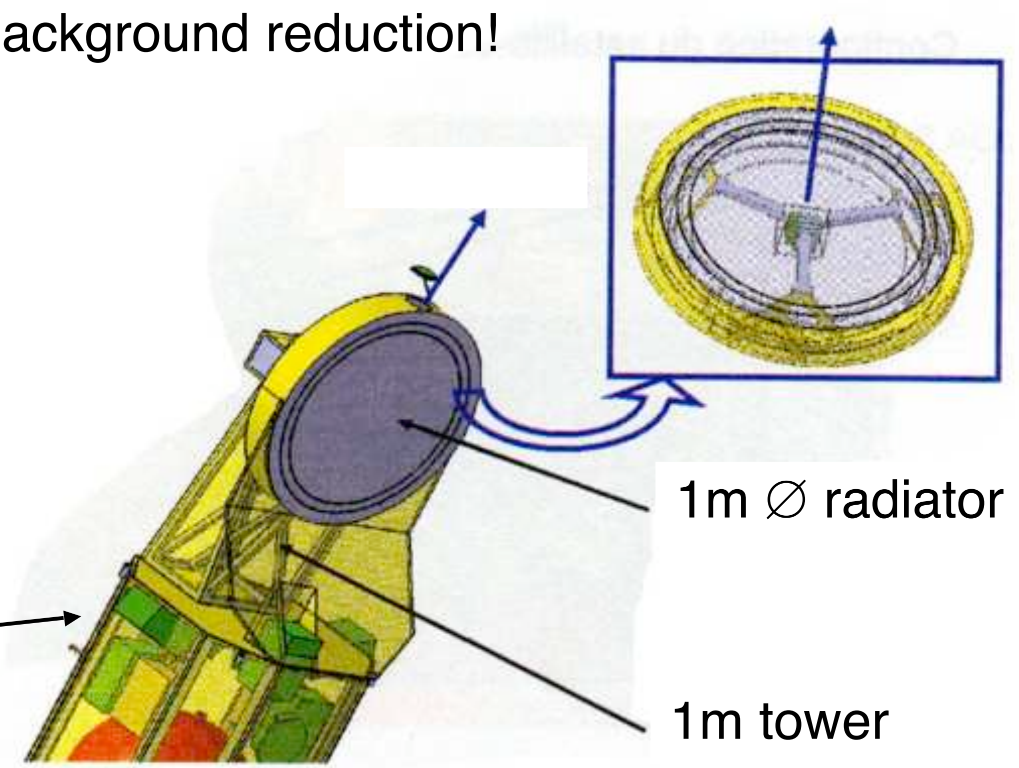
Detector baseline

4 NCT's 3-D GeDs:
- ≈ 300 readout lines
- Total power consumption ≈ 31W
- Total weight < 15 kg (without shield)

Detector on a 1m high tower ⇒ background reduction!

PASO's Phase 0 conclusion:

Feasible to cool down passively
with a ≈ 1m ∅ radiator



(B. Cornet, H. Hinglais, PASO)