A NEW GENERATION OF GAMMA-RAY TELESCOPE

Aleksandar GOSTOJIĆ

CSNSM, Orsay, France

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Introduction: Gamma-ray instruments

GROUND BASED:

- ENERGY HIGHER THEN **100 GeV**
- INTERACTION IN ATMOSPHERE
- ELECTROMAGNETIC CASCADES
- FLASHES OF CHERENKOV LIGHT
- WIDE AREA OF DETECTION

H.E.S.S. - High **E**nergy **S**tereoscopic **S**ystem

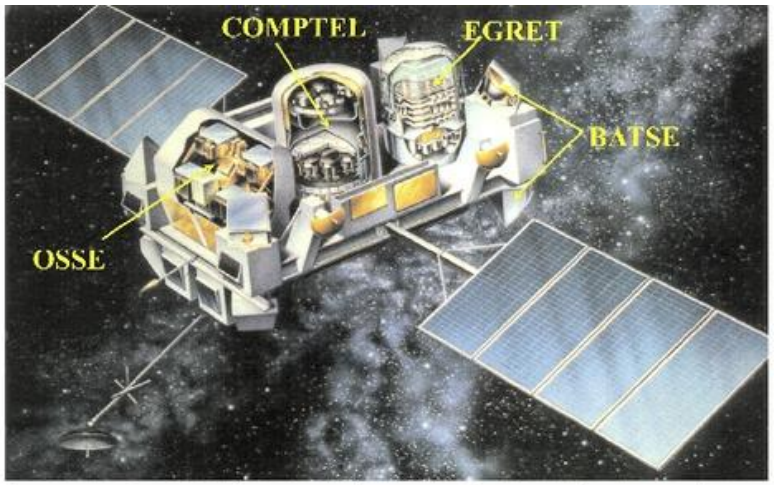
INTEGRAL - INTErnational **G**amma-**R**ay **A**strophysics **L**aboratory

SPACEBORNE:

- ENERGY: **100 keV – 100 GeV**
- DETECTION ABOVE THE ATMOSPHERE
- BALLOONS AND SATELLITES
- **PAIR PRODUCTION TELESCOPES, COMPTON, CODED MASK, GAMMA-RAY LENSES**

Previous missions 1: CGRO - COMPTEL

Compton **G**amma-**R**ay **O**bservatory (5th of Apr 1991. – 4th of June 2000.)
30 keV up to 30 GeV / 4 Instruments

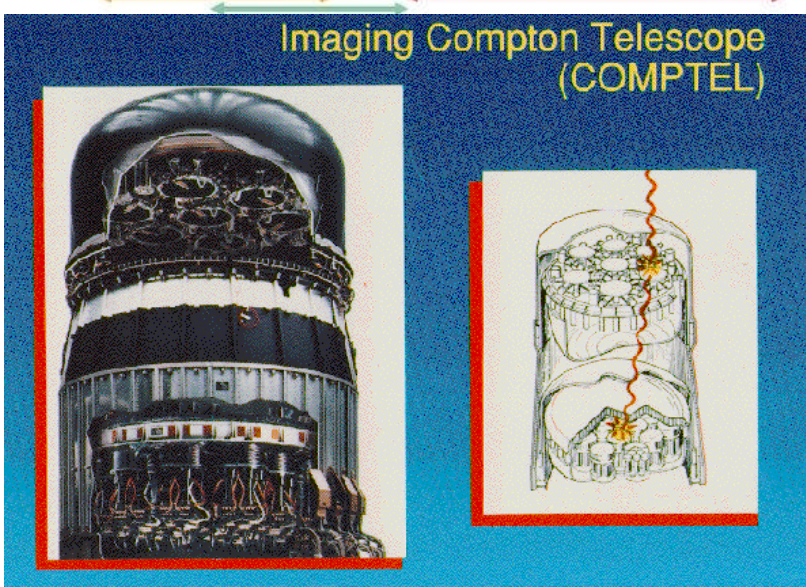


Imaging Gamma-Ray Telescope – COMPTEL

- ✓ 0.8 – 30 MeV
- ✓ upper detector: NE 213A liquid scintillator
- ✓ 4 lower: clusters of NaI scintillators
- ✓ Anti-Coincidence (AC) shielding
- ✓ electronics

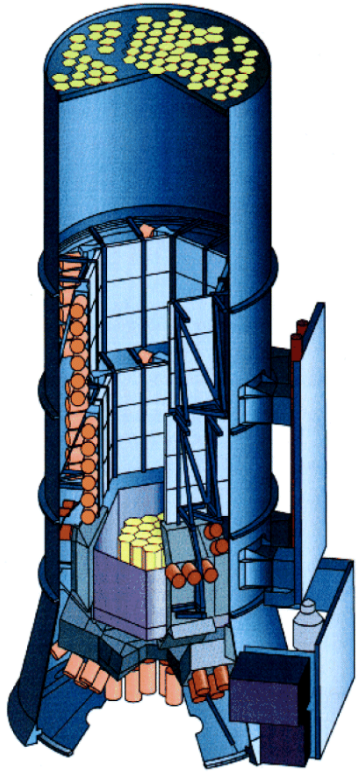
ALL-SKY MAPPING AND GAMMA LINE SPECTROSCOPY

- ^{44}Ti and ^{26}Al lines: on-going nucleosynthesis in massive stars and supernovae
- GRBs, SNR, pulsars (X-ray), blazars, black holes
- all-sky maps in MeV range: 63 γ-ray sources pulsars and active galactic nuclei (AGN)
- Solar gamma rays, diffuse emission



Previous missions 2: INTEGRAL – SPI/IBIS

INTErnational **G**amma-**R**ay **A**strophysics **L**aboratory (17 of Oct. 2002 -)



The imager on-board INTEGRAL – **IBIS**

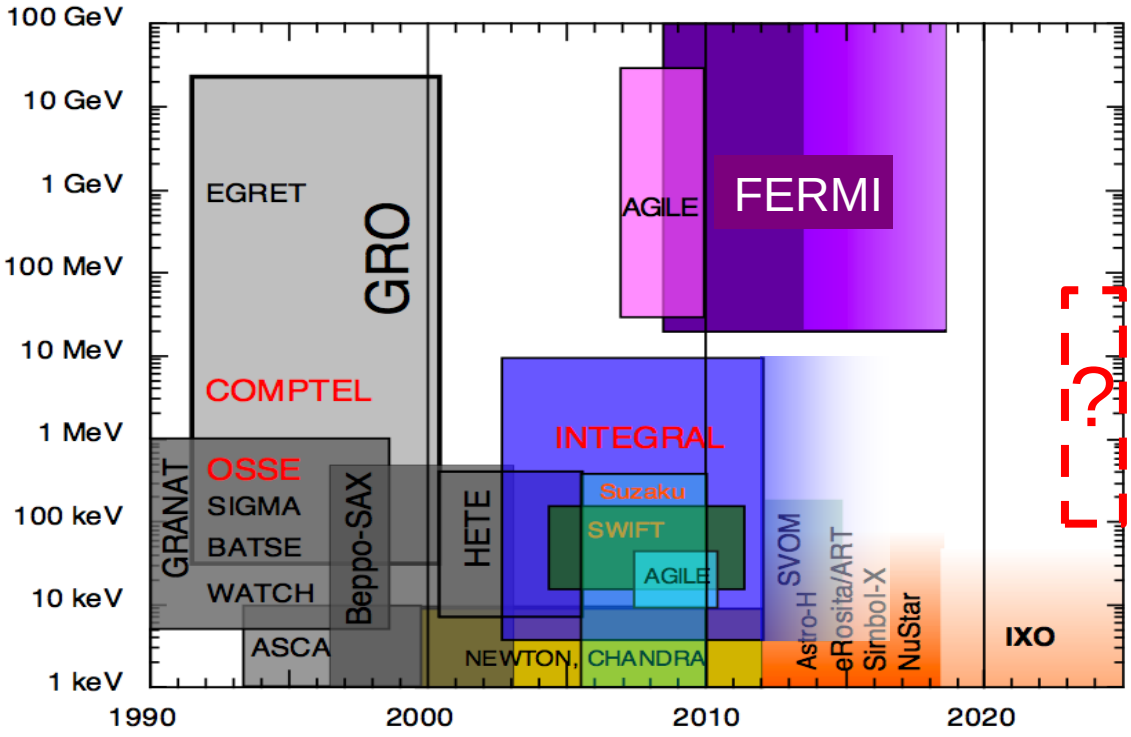
- Angular resol: 12 arcmin FWHM
- 15 keV – 10 MeV
- coded mask + 2 planes of pixels
- 1st 16384 CdTe pixels: low E γ-rays
- 2nd 4096 CsI pixels: high E
- Shielding: lead + BGO

Spectrometer on-board INTEGRAL – **SPI**

- 18 keV – 8 MeV
- E: 2.2 keV (FWHM) @ 1.33 MeV
- array of cooled HPGe
- Tungsten hexagonal coded aperture mask
- AC shielding: BGO+plastic scintillator.

galaxy map of 511 keV annihilation emission, gamma line emissions from ^{44}Ti, ^{60}Fe and ^{26}Al, catalogued over 400 γ-ray objects (neutron stars, active galactic nuclei or black holes), powerful X-rays and γ-rays (pulsars with an extremely powerful magnetic field, magnetars), weak GRBs (nearby GRB 031203), captured giant GRB (SGR 1806-20), X-ray binaries

Motivation: Gamma-ray astronomy and ESA's Cosmic Vision



- Prepare a new γ-ray space telescope operating in the MeV range

⇒ nucleosynthesis (γ-ray radioactivities), low-energy cosmic-ray physics, high-energy solar physics
+ active galactic nuclei, physics of neutron stars and stellar black holes…

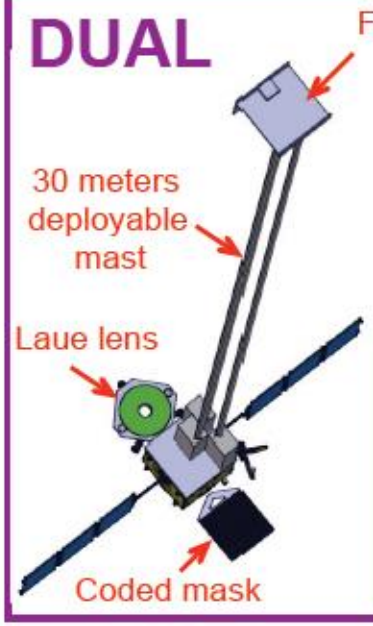
- European proposals in response of ESA's call (2010) for a third Medium-size mission (program "Cosmic Vision 2015-2025"):

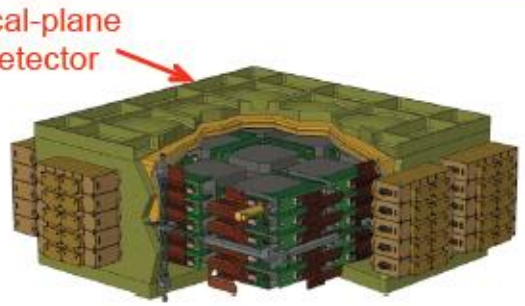
– DUAL (PI: CESR Toulouse): a Laue lens + a Compton telescope in Germanium
– GRIPS (PI: MPE Garching): a Compton telescope in Si (tracker) and $LaBr_3$
– CAPSiTT (PI: APC Paris): a Compton telescope in Si (no calorimeter)

A single proposal for ESA's next call (M4 in 2014) !

M3 Mission proposals for the Cosmic Vision 2015 - 2025

DUAL

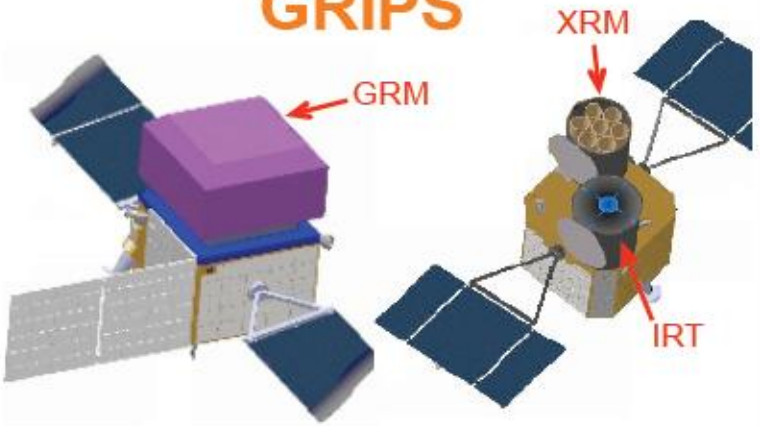




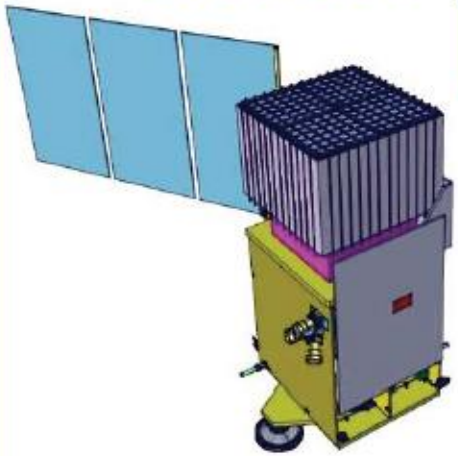
- **Compton telescope** made of **cross-strip Ge detectors** (0.1 – 10 MeV)
- 2 optical modules on the main satellite: a **Laue lens** and a **coded mask**
- Soyuz launcher to an **L2 orbit**

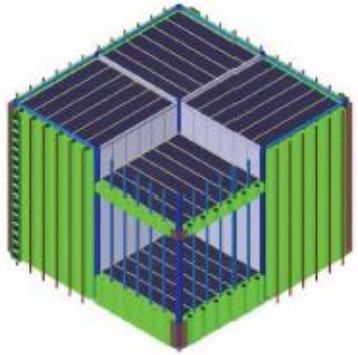
GRIPS

- Main instrument is a **Compton and pair telescope** (0.2 – 80 MeV) with a tracker in **Si DSSDs** and a calorimeter in **$LaBr_3$**
- Soyuz launcher to an **equatorial low Earth orbit**



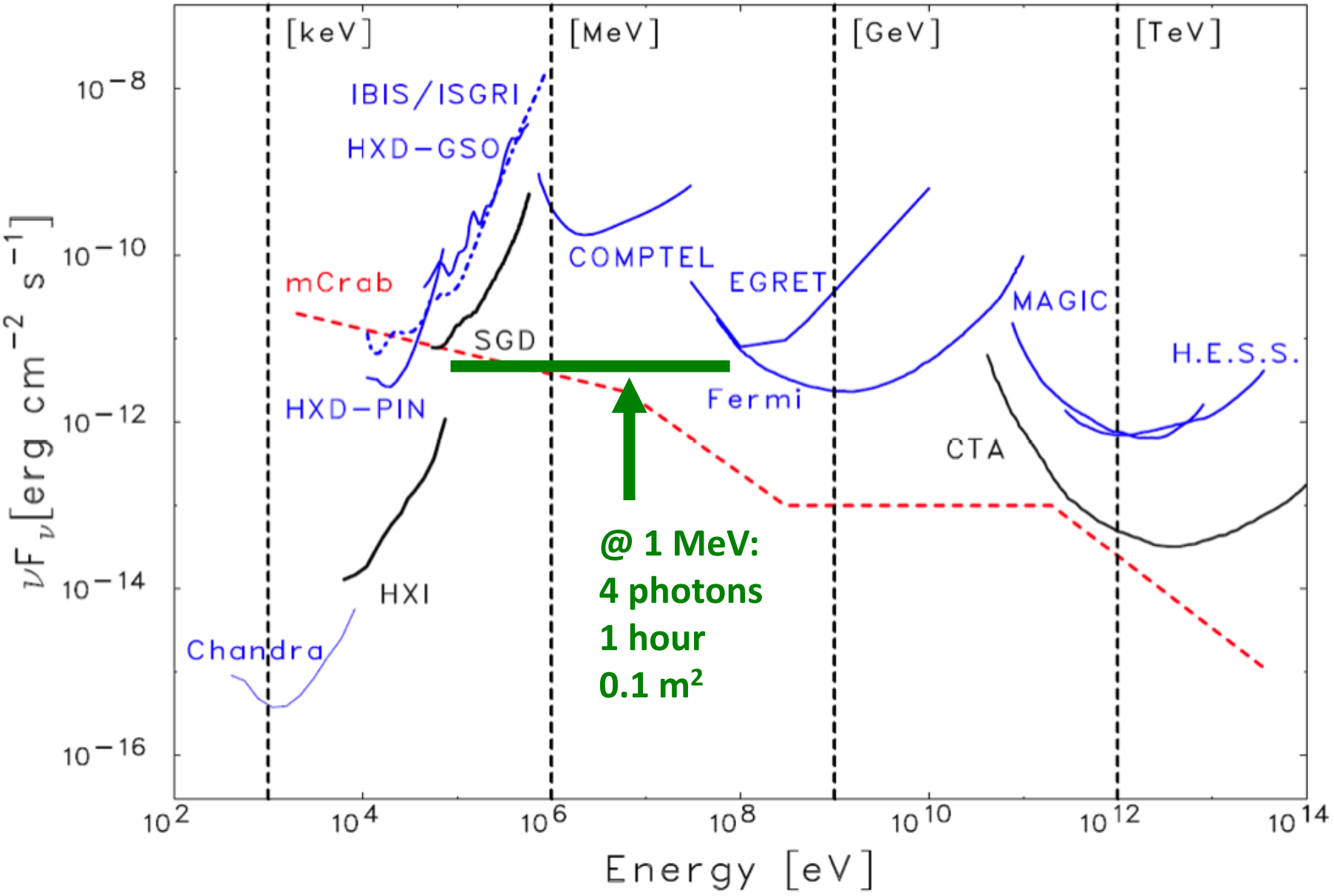
CAPSiTT



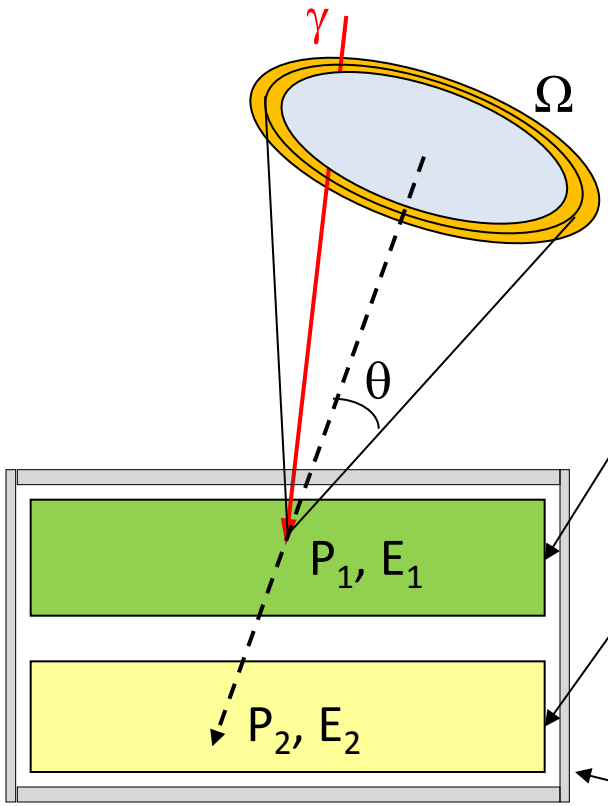


- **Compton and pair telescope** with a tracker in **Si DSSDs** (0.1 – 100 MeV)
- **No calorimeter** (3-Compton technique)
- VEGA launcher to an **equatorial low Earth orbit**

Motivation: Sensitivity of current and previous instruments



Conceptual design of an Advanced Compton Telescope



$$E_\gamma = E_1 + E_2$$
$$\cos\theta = 1 + m_e c^2[1/(E_1+E_2)-1/E_2]$$

Tracker. Low-Z material for Compton scattering and minimum Doppler broadening ⇒ Si

Calorimeter. High-Z material for an efficient absorption of the scattered photon

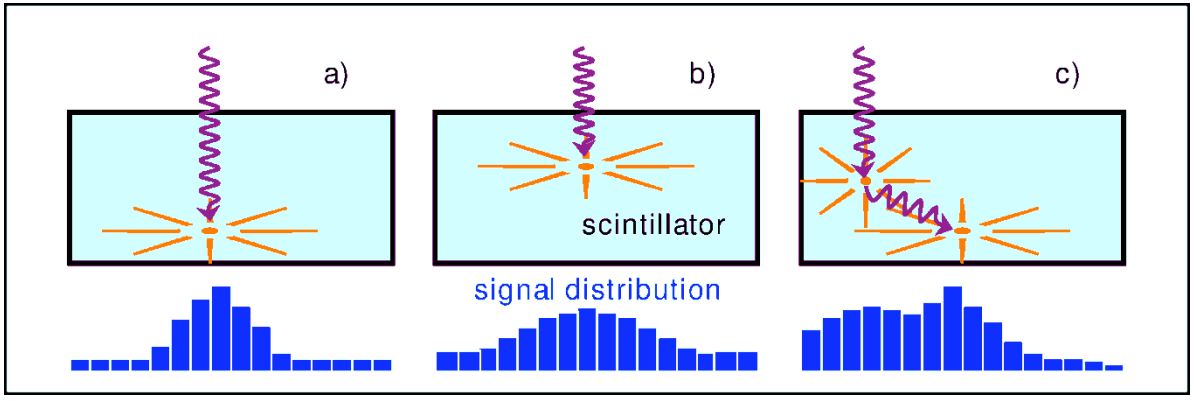
Anticoincidence detector to veto charged-particle induced background

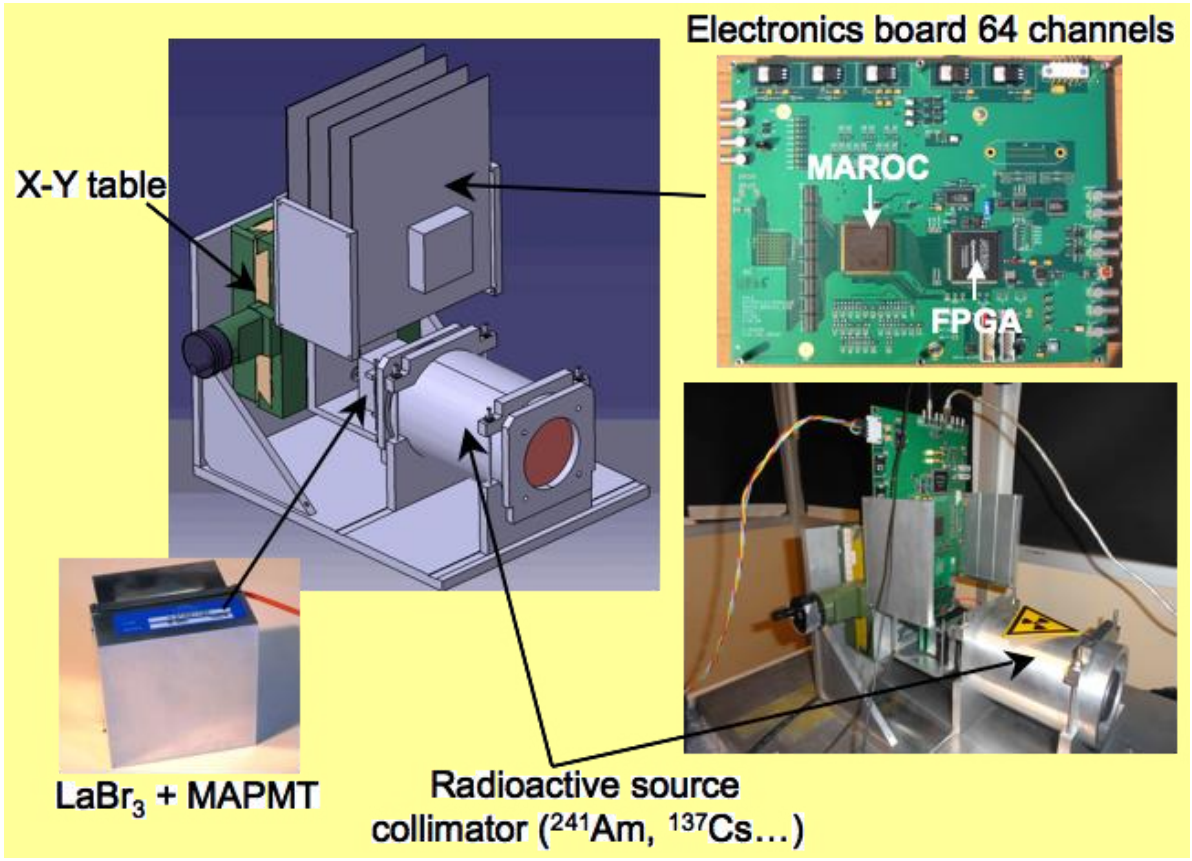
Optimize background rejection (sensitivity), perform Compton imaging and **polarization** studies:

- ✓ Fine **3-D position resolution** (~1 mm^3) ➔ **Si DSSD** (tracker)
- ✓ Good **energy resolution** ➔ **$LaBr_3$:Ce scintillator** (calorimeter)

3D - Imaging calorimeter in $LaBr_3$:Ce

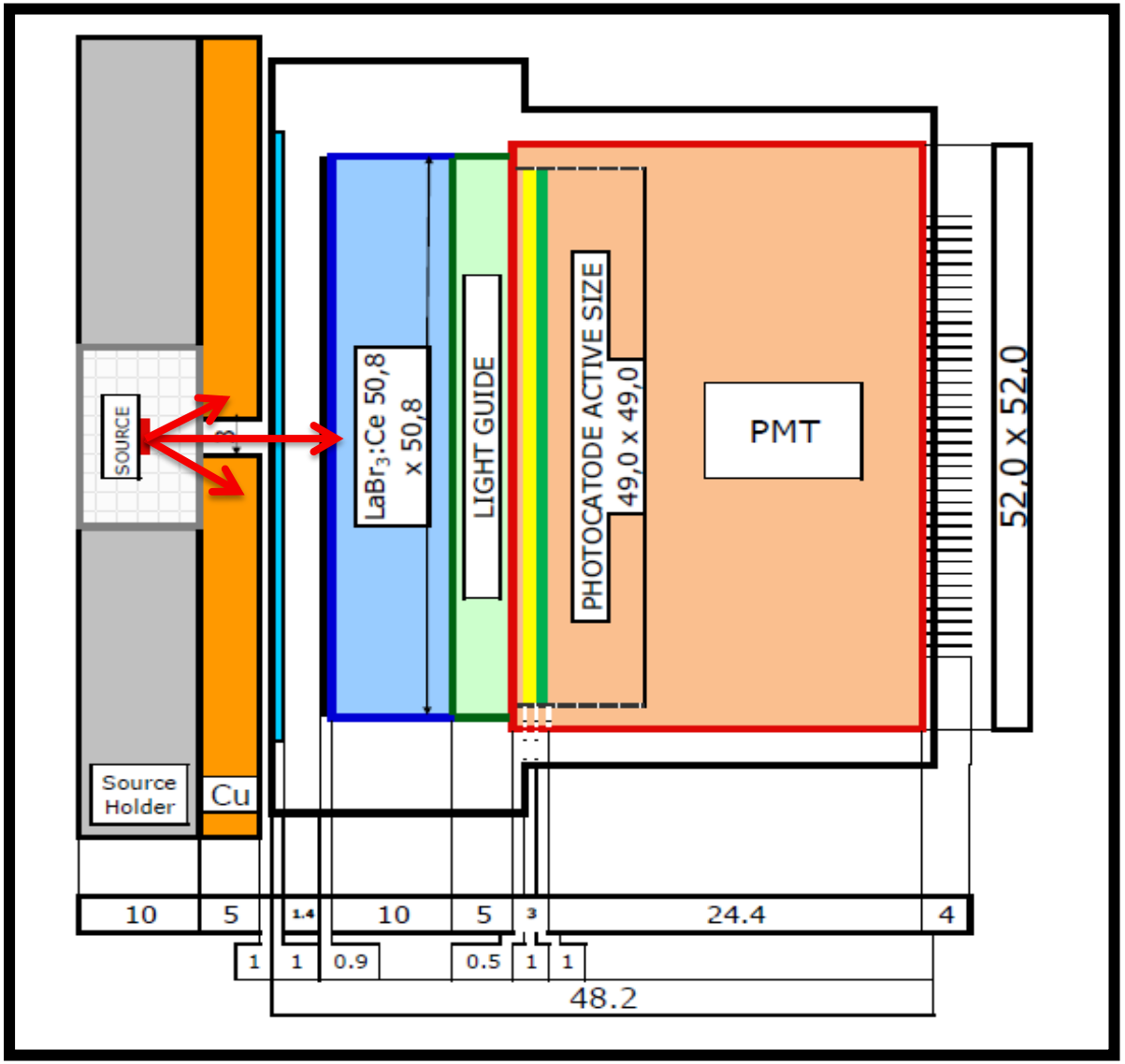
- **$LaBr_3$:Ce** scintillator : good energy resolution, high stopping power, very fast response
- **3D position** resolution Anger-camera-like module
- **Coupling** of $LaBr_3$:Ce crystals (St Gobain) to a multianode PMTs (Hamamatsu)
- Dedicated **test bench** (mechanics, electronics)

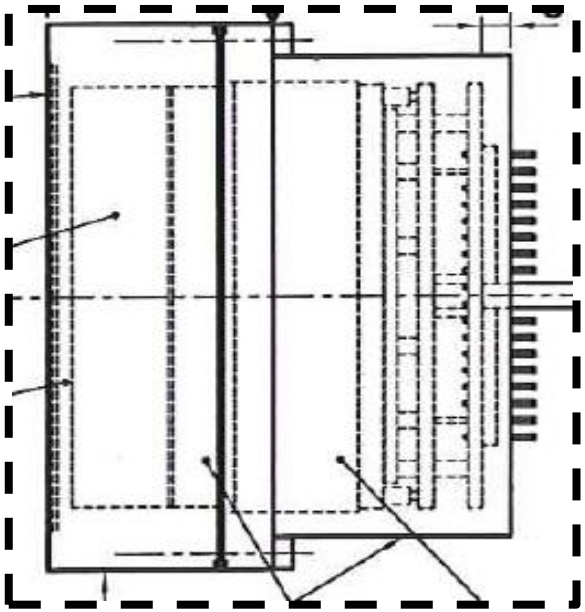


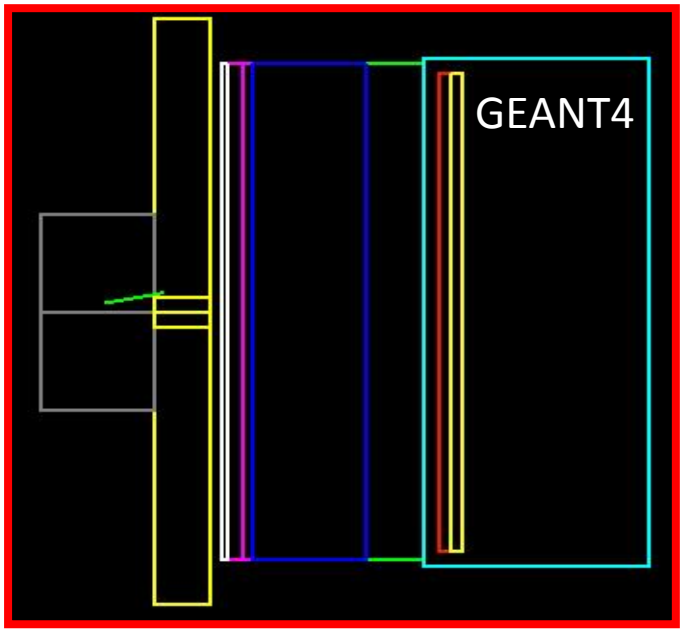


Detector module in detail

4 Volumes: SHIELD – CRYSTAL - GUIDE – PMT

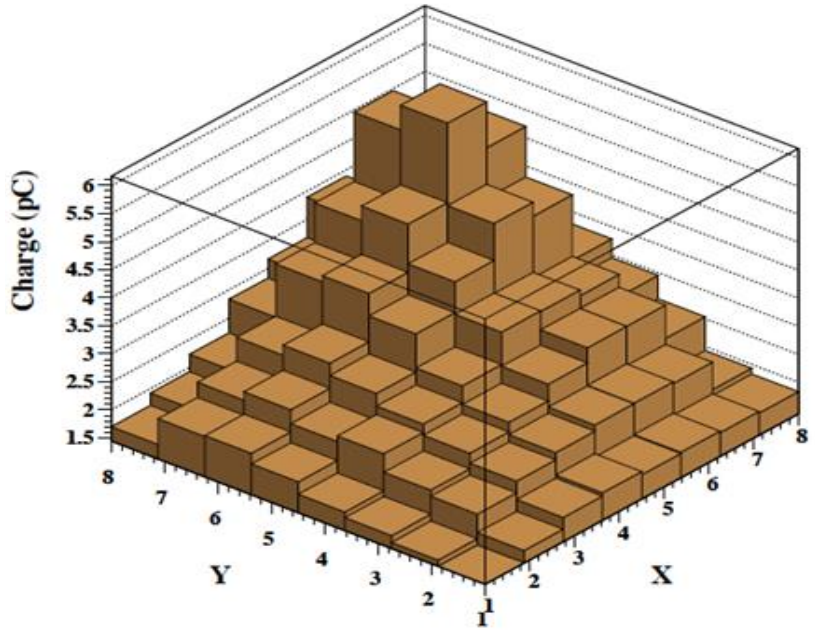


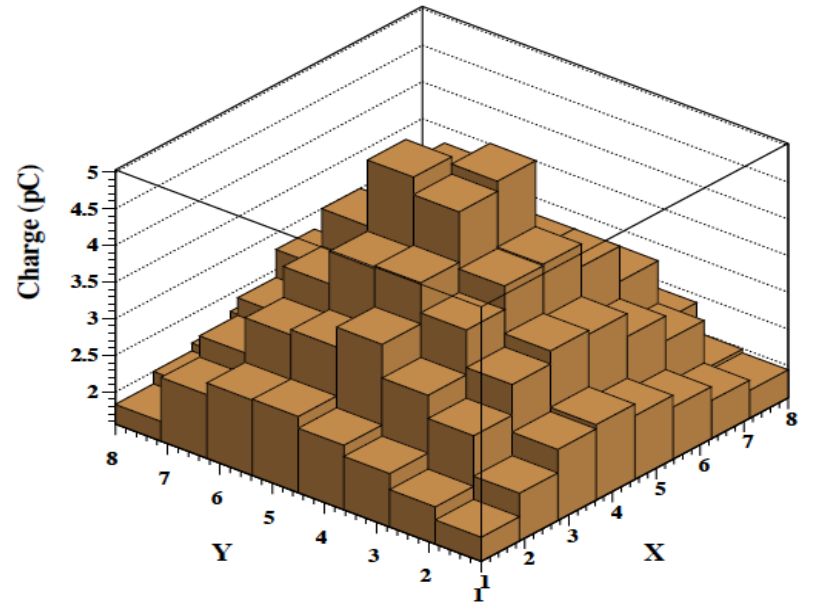




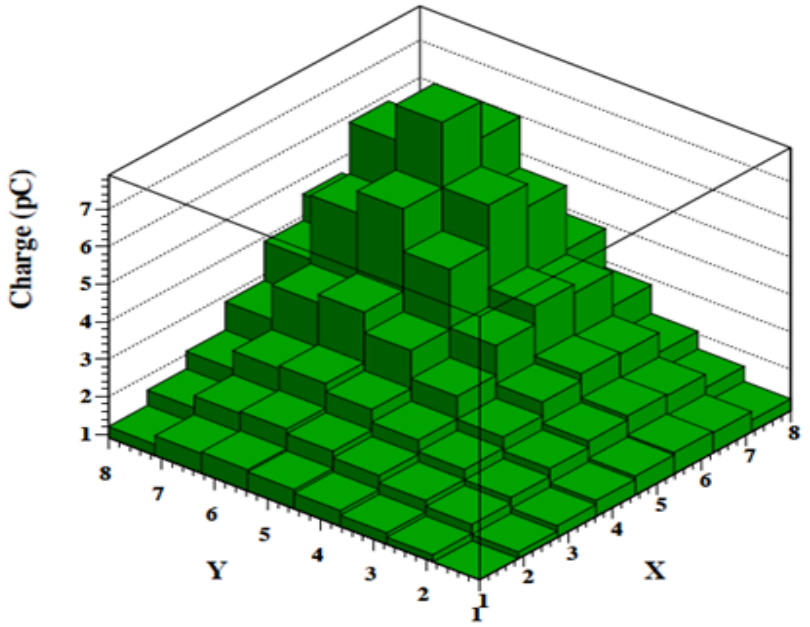
Results: measurements and simulation

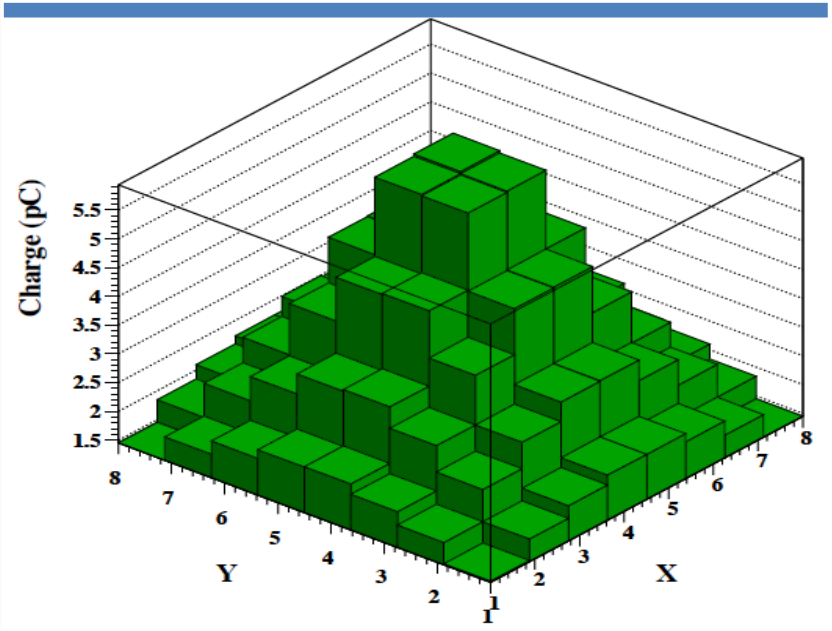
EXPERIMENTAL DATA



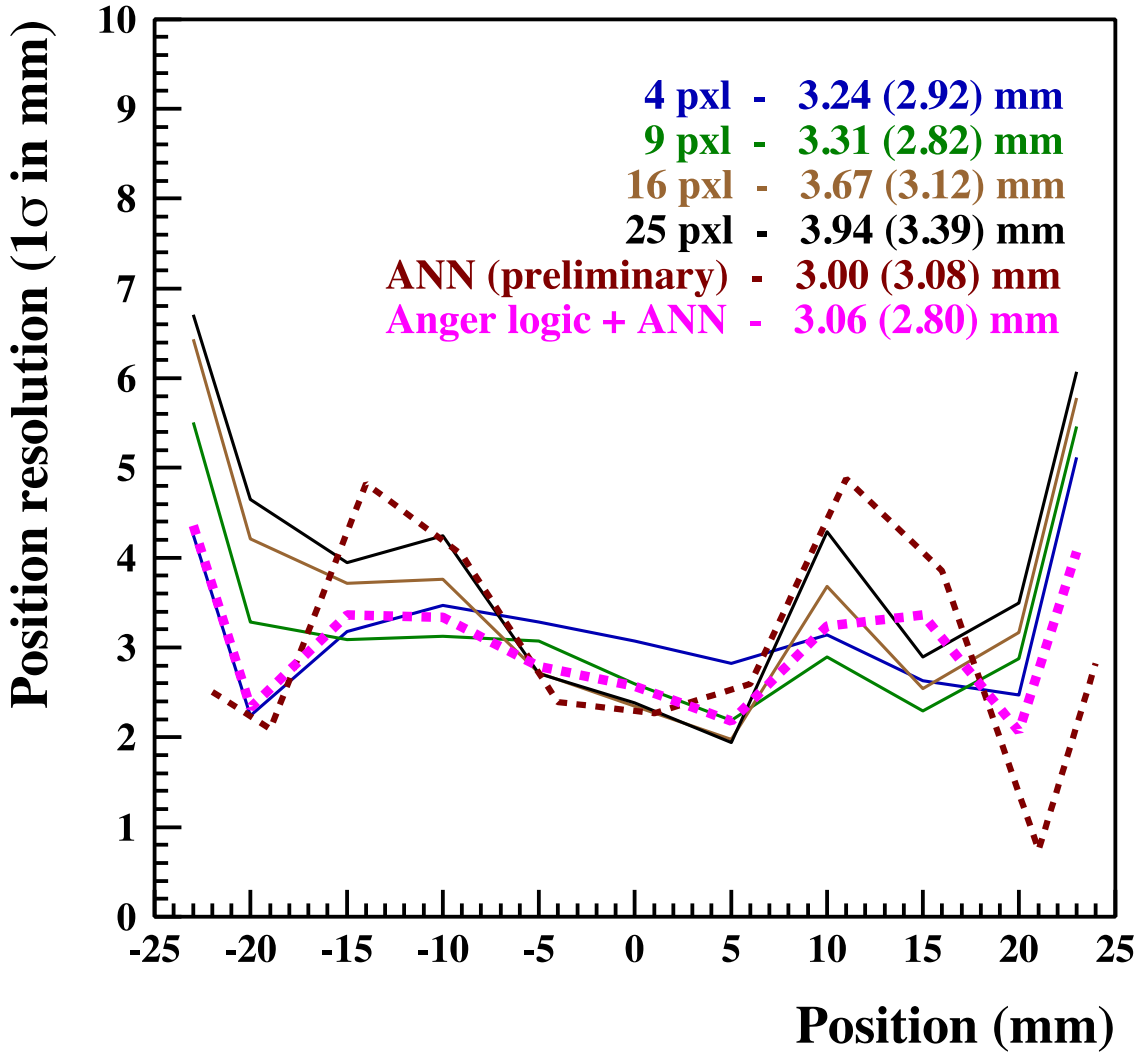


SIMULATION GENERATED





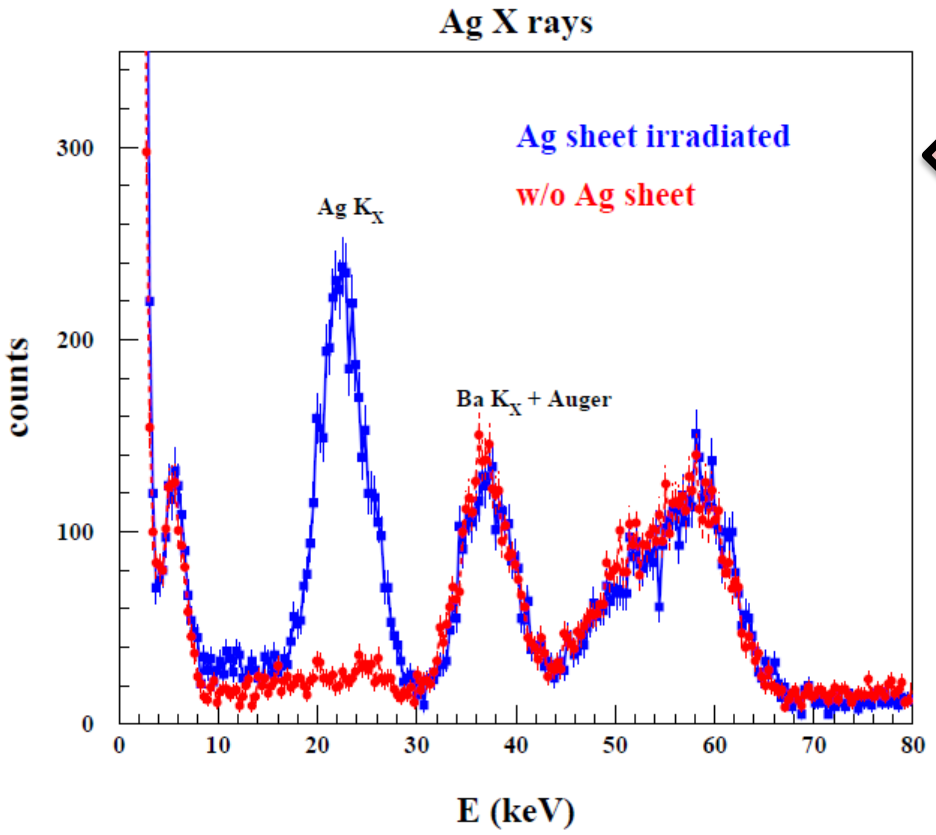
Detector characterization (1): Position resolution



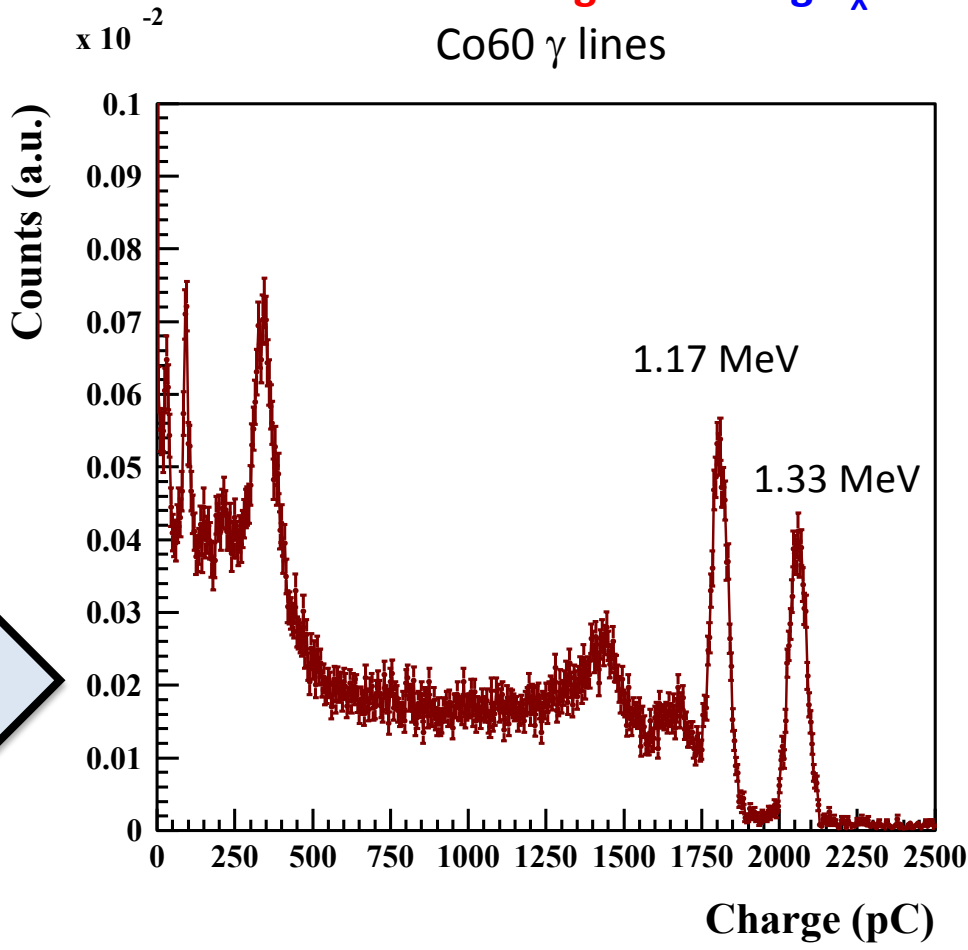
- Center of gravity - Anger logic
- 11 diagonal points with ^{241}Am source
- 4,9,16,25,36 channels (pixels) for different precision
- Artificial Neural Network (ANN)
- 10 Inputs: center of gravity values for X and Y
- 2 Outputs: X and Y positions of the 1st γ-ray hit

Final error on 2D position resolution: standard deviation corrected for beam spot size: $\sigma \approx 1.7$ mm (from GEANT4 simulation)

Detector characterization (2): E dynamic range

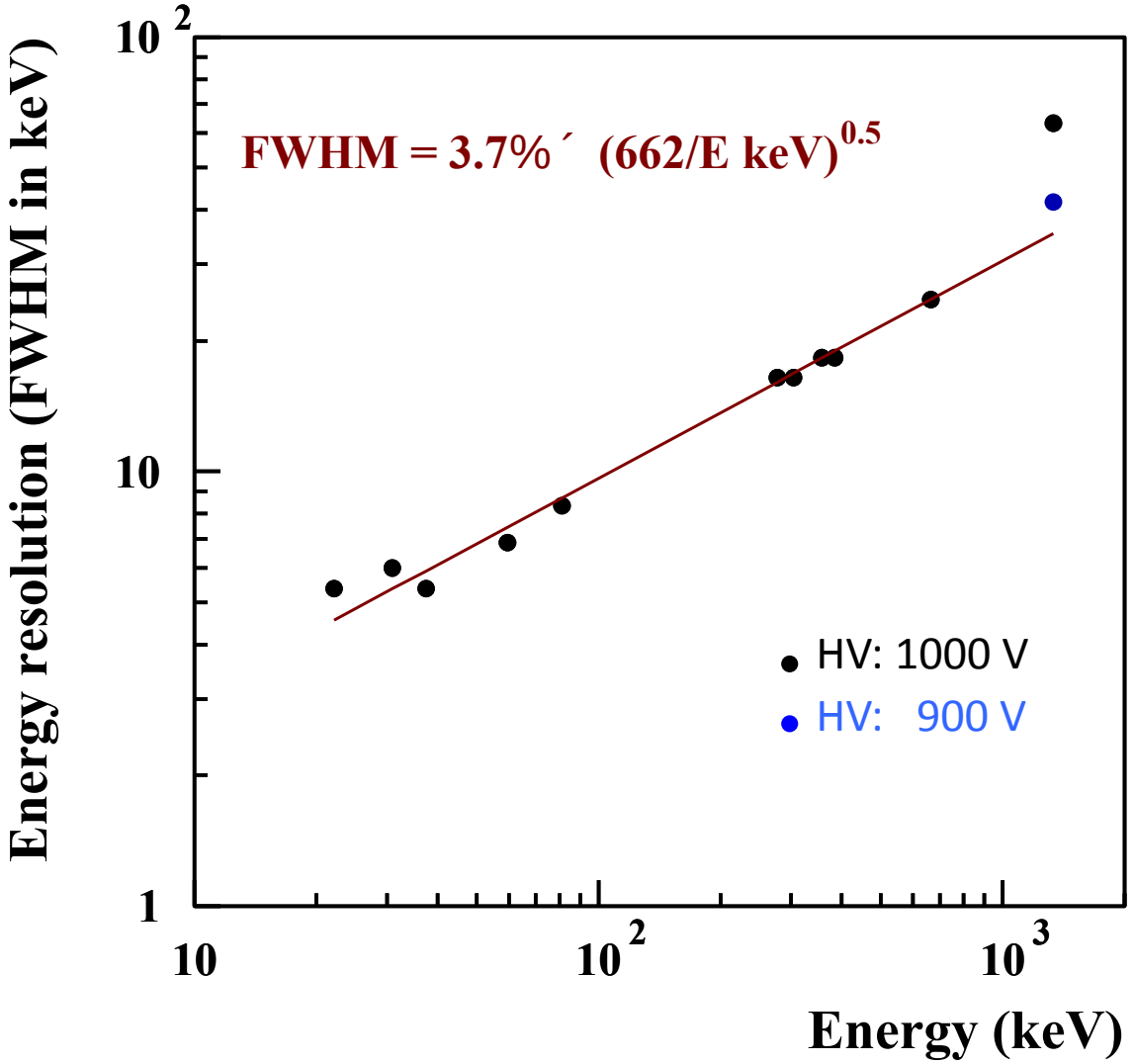


LOW-END: - X rays
- MIN energy: **22 keV**
- background + Ag K_X



HIGH-END: - gamma-rays
- MAX energy: **1.3 MeV**

Detector characterization (3): Energy resolution



LINES	E (keV)
Ag K_α X	22.1
Cs K_α X	30.85
Ba K X + Auger	37.44
γ ^{241}Am	59.5
γ ^{133}Ba	80.9
γ ^{133}Ba	276.4
γ ^{133}Ba	302.9
γ ^{133}Ba	356.0
γ ^{133}Ba	383.8
γ ^{137}Cs	661.7
γ ^{60}Co	1332.5

Compensated for different interaction locations (less charge detected closer to the detector border) => **4.9 % -> 3.7 %** at **662 keV**

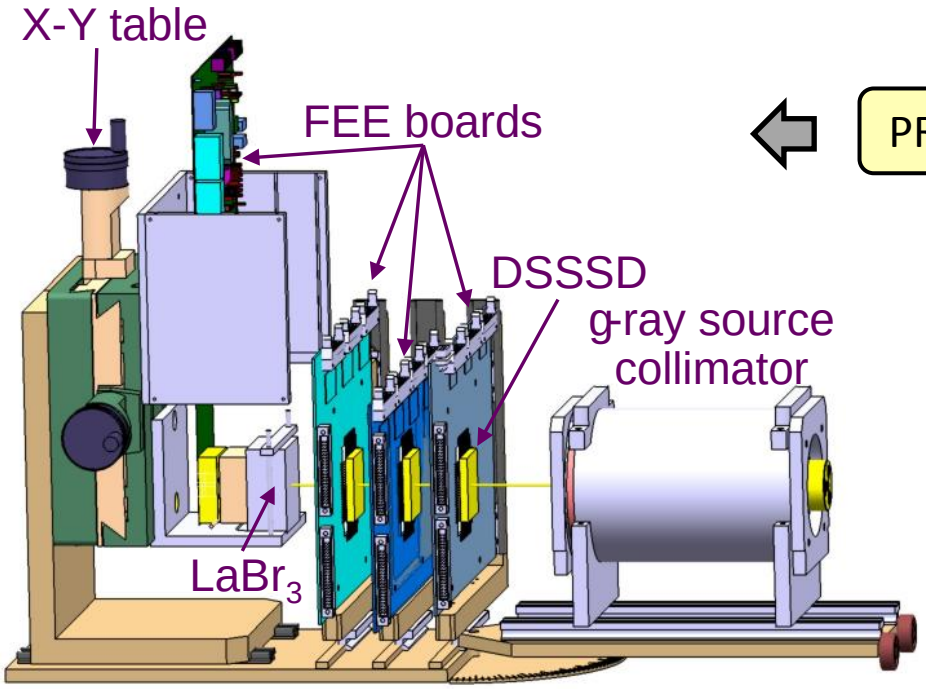
Overview

POSITION RESOLUTION

- Successful 2D interaction reconstruction
- $1\sigma \approx$ **3.0 mm** (< bin size)

DYNAMIC RANGE and E RESOLUTION

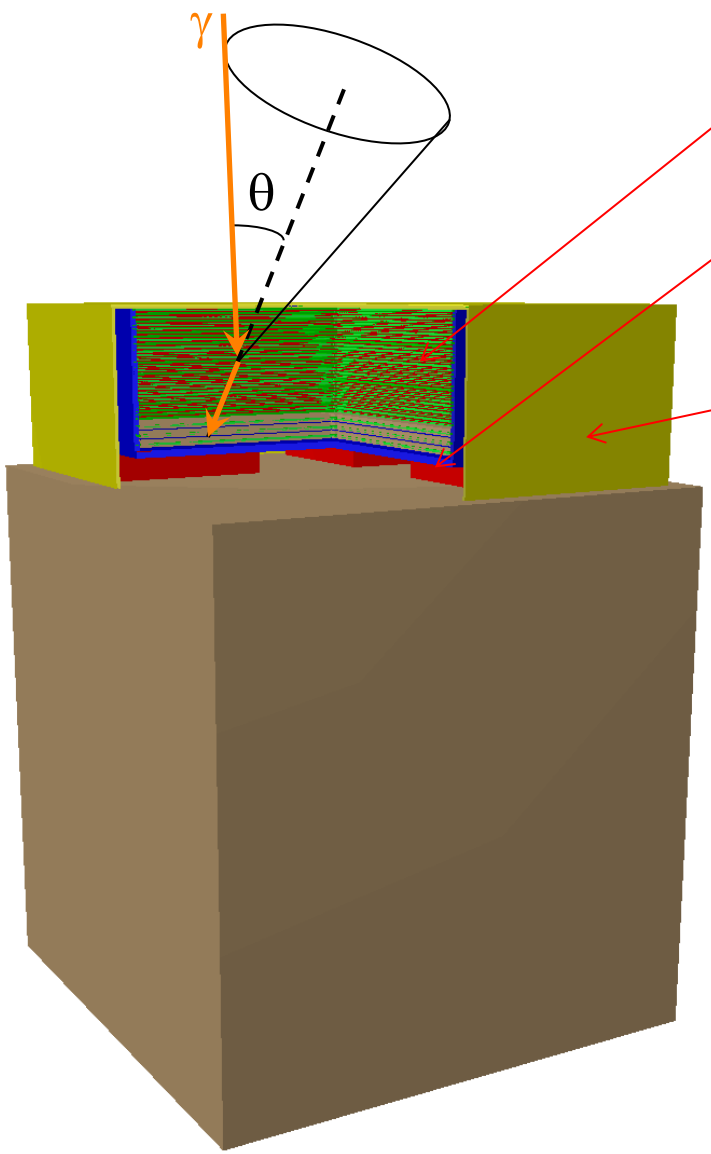
- Good range: covering **X** and **γ-rays**
- **10 keV – 1.3 MeV** (good for a Compton telescope)
- Good E resolution: only 20% above cylindrical crystal



PROTOTYPE & TESTING

- $LaBr_3$:Ce + 3 Si DSSD layers
- Coincidence mode
- Aiming for the 2017./18. balloon mission
- Polarization of the Crab Nebula and the Crab Pulsar, in the range of 100–300 keV

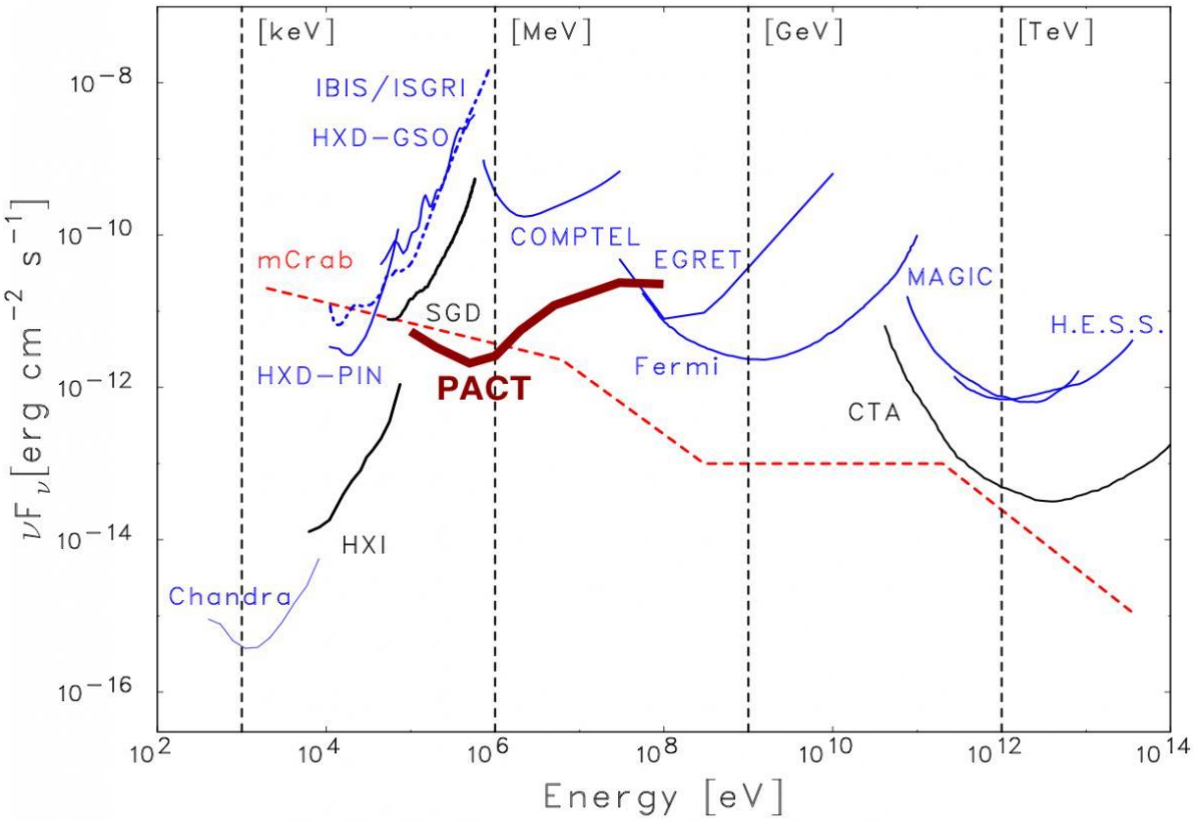
PACT: Pair And Compton Telescope



Tracker: Si DSSDs e.g. 30 layers of 12x12

Calorimeter: several layers of inorganic scintillator, crystal e.g. $CeBr_3$ or ceramics, coupled to an array of SiPMs

Plastic anticoincidence detector e.g. NE-110 ~ 1 cm thickness



More information at:

astromev.eu