DSSD detectors development for a space Compton telescope

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High Energy Astrophysics in a few words …

High Energy astrophysical sites

Sites where extreme physical conditions prevail: intense gravity fields, very high temperatures, strong magnetic and electric fields

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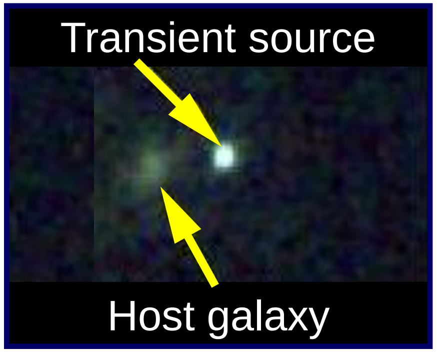

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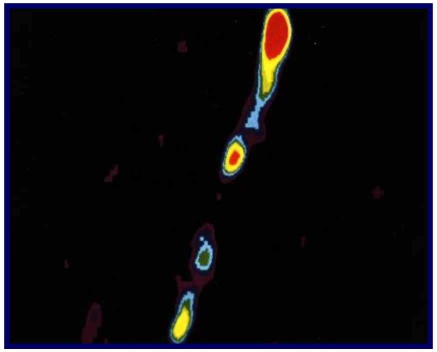

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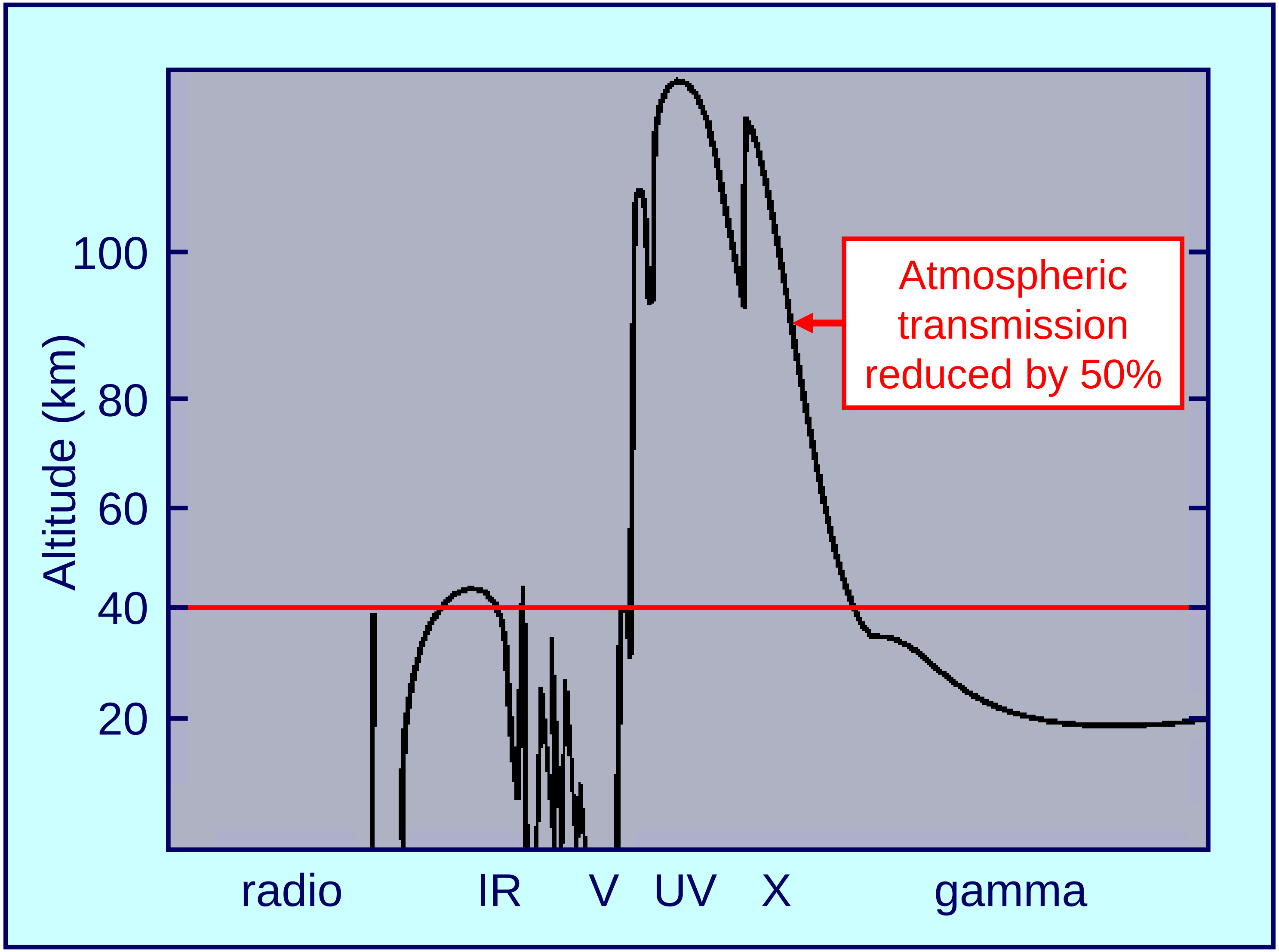
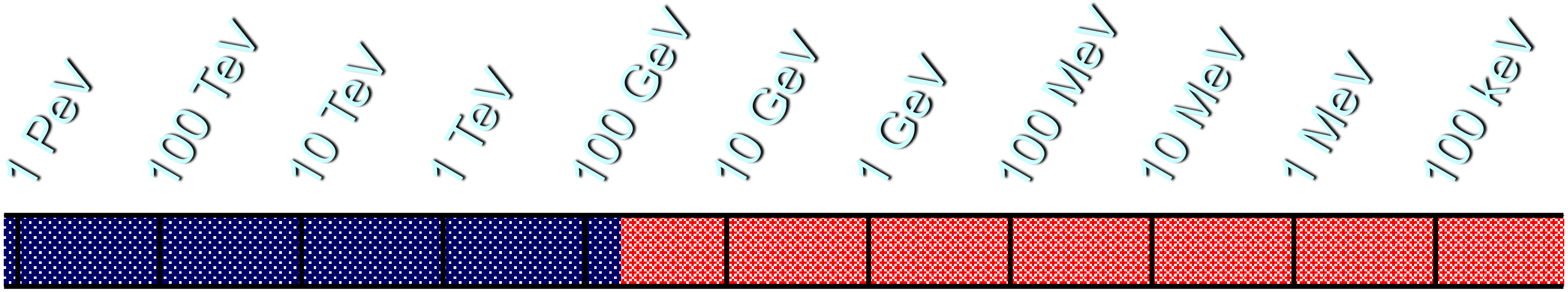
An apparently ill-assorted gallery of cosmic sites, but ...

- All sites give way to the fatal attraction of gravity
- Many sites produce copious outflows of relativistic matter
- Privileged messengers: gamma-ray photons, neutrinos, cosmic rays, gravitational waves

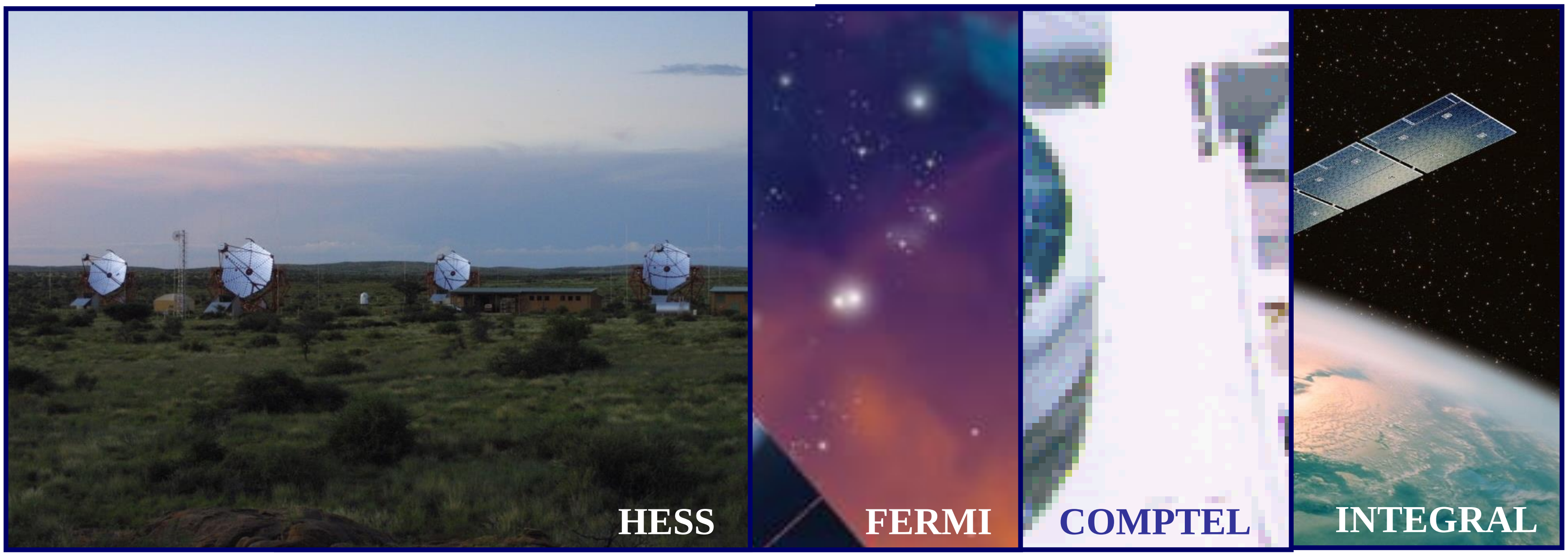
The atmospheric screen



High Energy telescopes



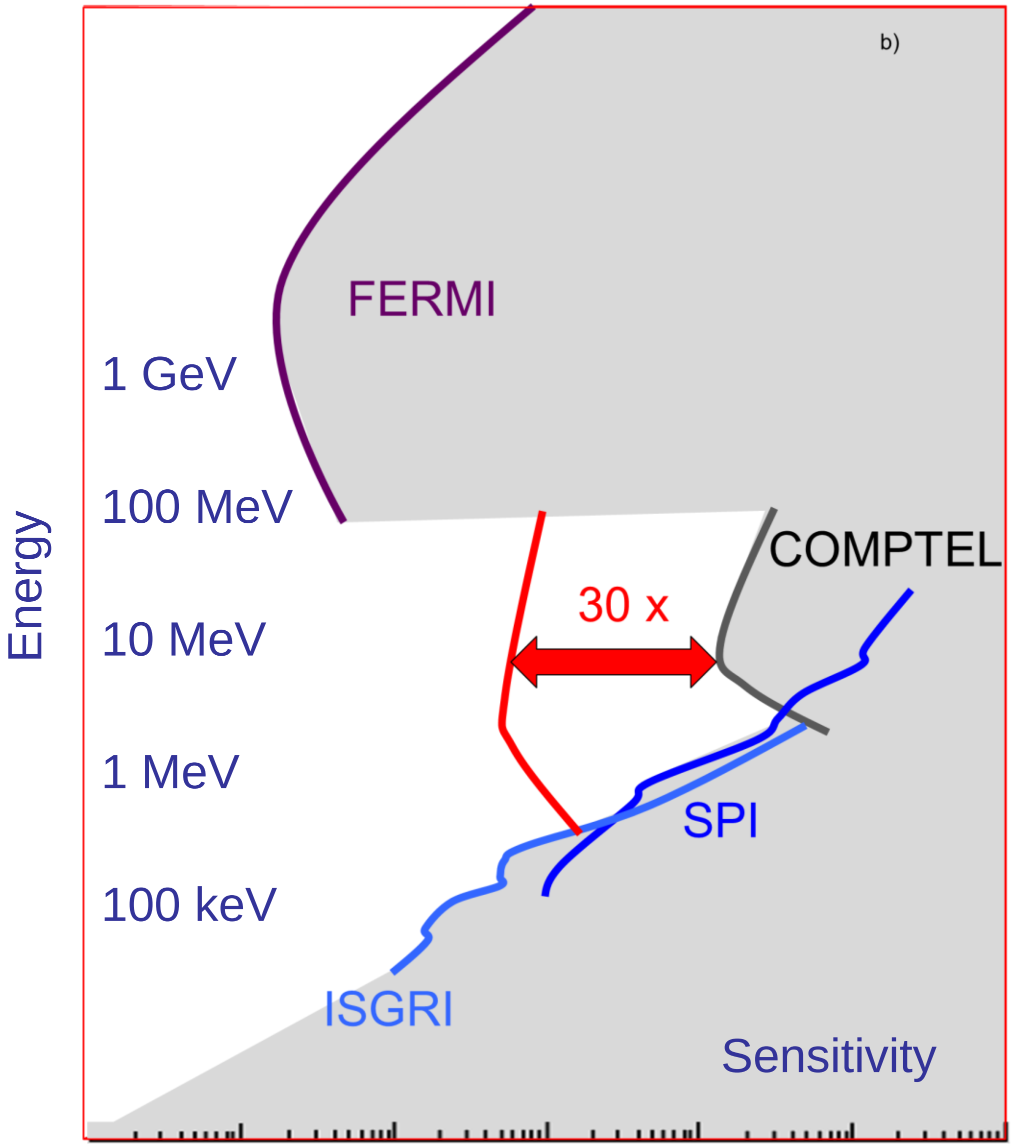
Ground



MeV range sensitivity gap

The MeV range suffers from a high sensitivity gap as this is the domain for:

- ✓ Inelastic Compton scattering ⇒ minimal cross section of interaction.
- ✓ Nuclear lines ⇒ sky observations are polluted by a strong induced background.



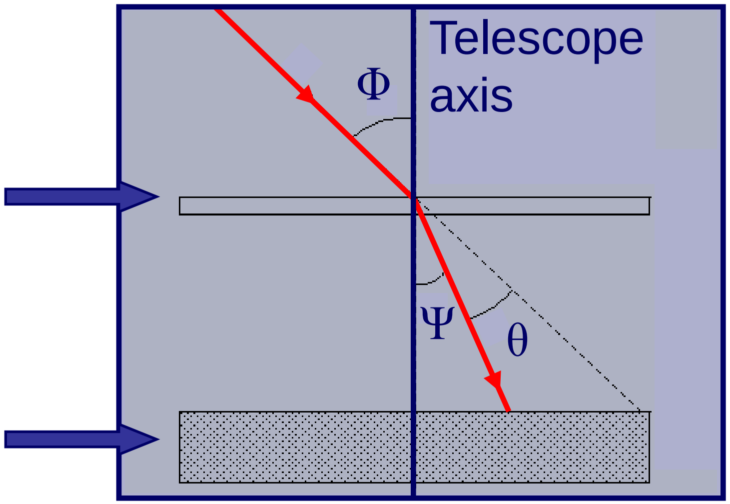
Telescopes in the MeV range: Compton telescope principles

Compton telescope principles

A basic Compton telescope features two layer of position sensitive detectors

Layer 1: made of diffusive material to scatter the incident gamma ray

Layer 2: made of absorbing material to absorb the scattered photon



Both incoming photon incidence angle Φ and energy E_0 can be derived from the energy deposits E_1 in layer 1 and E_2 in layer 2 and from the angle Ψ of the scattered photon

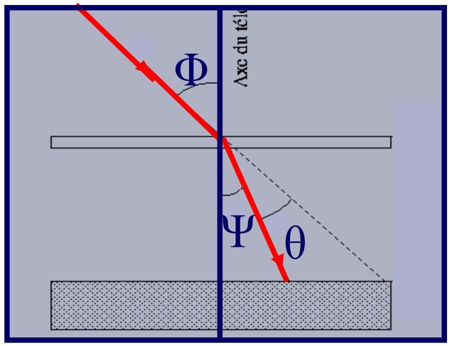
$$E_0 = E_1 + E_2$$

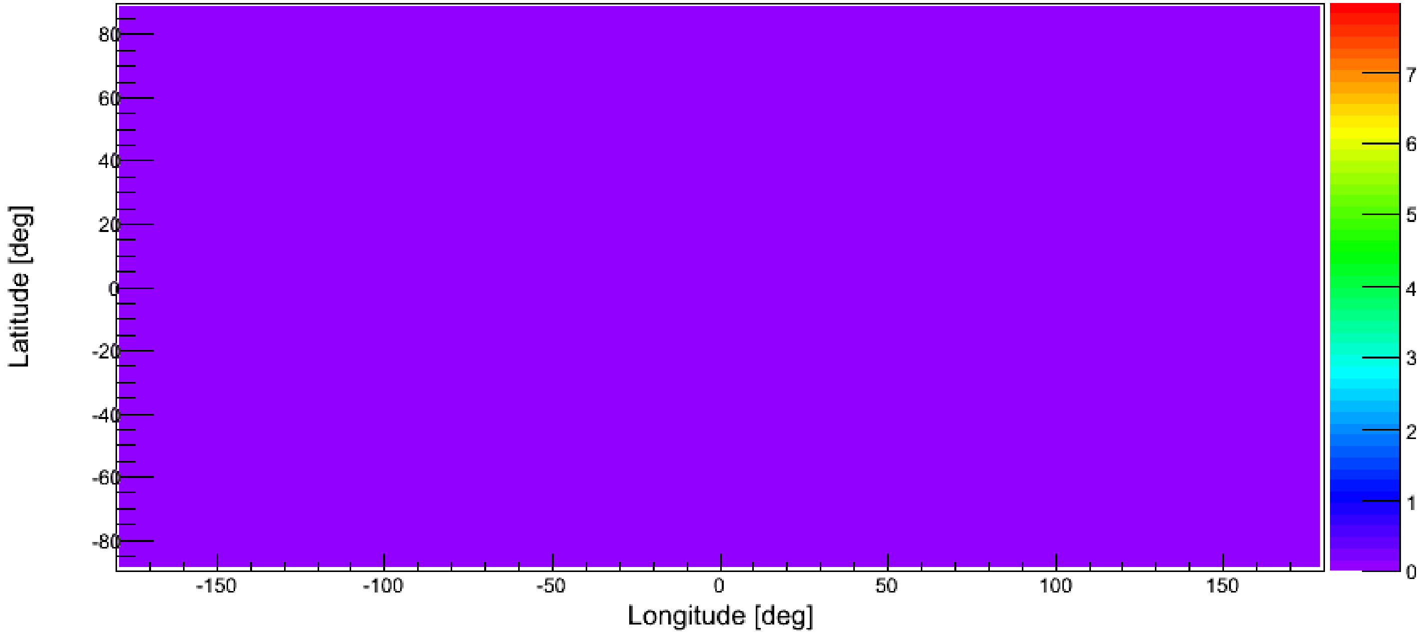
$$\Phi = \psi + \theta$$

$$\cos\theta = 1 - \frac{E_1 m_e c^2}{E_0 E_2}$$

Compton telescope principles

- Thus the direction of the incident photon is on a cone of semi-angle θ and axis along the scattered photon direction. The intersection of this cone with the celestial sphere is a circle.



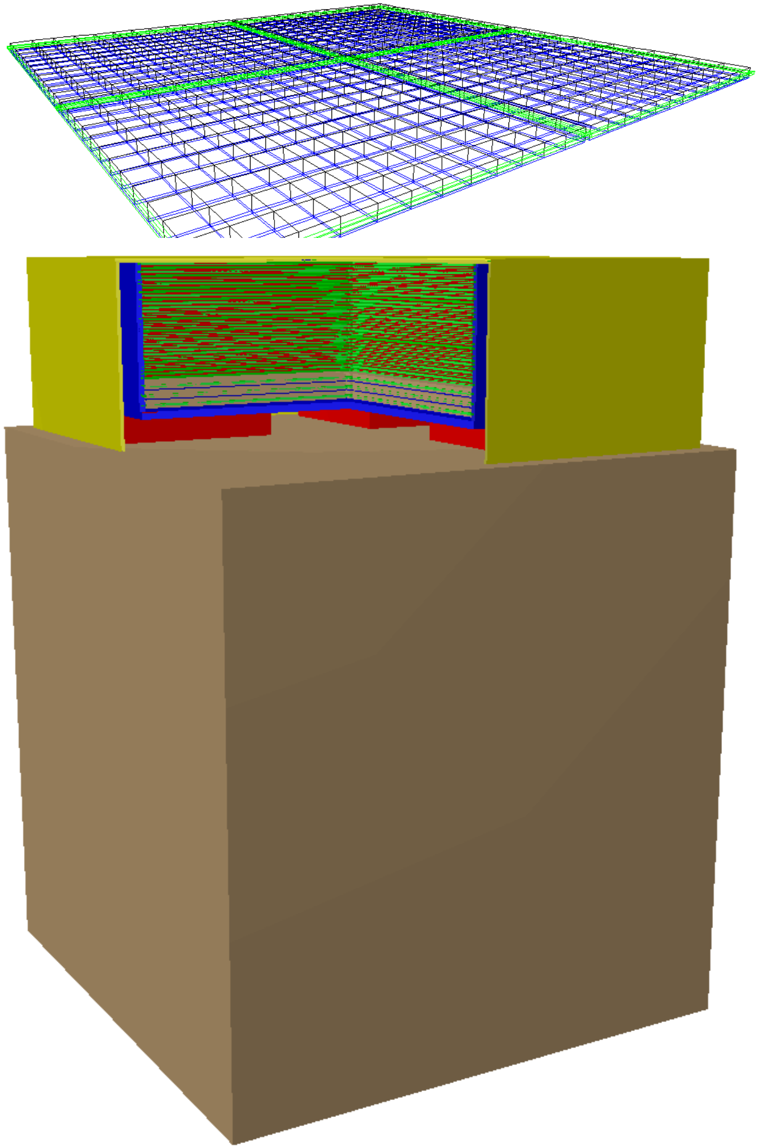


Cones projection

simulation done by gamma-ray astronomy group @ SSL (UC Berkeley)

PACT Compton telescope short description

GEANT 4 mass model of the PACT telescope



30 layers of 12 x 12 Si DSSDs = 4320 DSSDs

3 layers of 24 x 24 LaBr3 ($CeBr_3$:Sr) detectors
Each crystal is 5x5x2 cm^3, coupled to a
3-mm thick SiPM (matrix 8x8) at the bottom

Number of electronics channels:
92160 (DSSDs) + 110592 ($CeBr_3$) = 202752

Plastic anticoincidence detector

Overall instrument size: 136.6 x 136.6 x 49.3 cm^3

Summary of PACT Performances

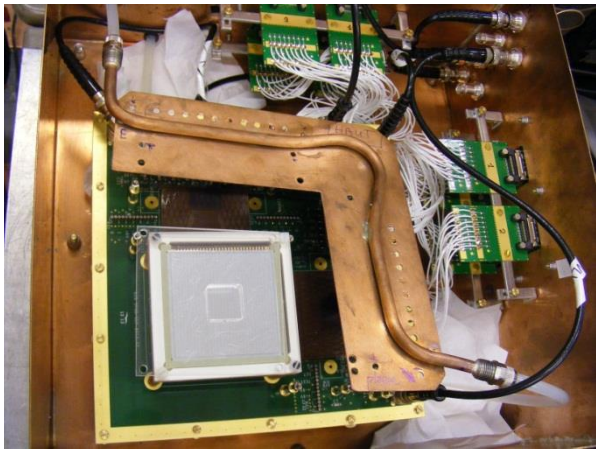
Energy resolution (FWHM)	14.0 keV at 1 MeV	33 keV at 5 MeV	3.0 MeV at 30 MeV
Field of view (deg. HWHM)	65° at 1 MeV	63° at 5 MeV	55° at 30 MeV
Angular resolution (deg. FWHM)	1.4° at 1 MeV	0.9° at 5 MeV	8.3° at 30 MeV
Effective area (cm^2)	1110 at 1 MeV	231 at 5 MeV	726 at 30 MeV
Narrow line sensitivity γ/s/cm2 (3σ in 10^6 s)	2.7×10^{-6} at 0.511 MeV	1.5×10^{-6} at 1.157 MeV	1.4×10^{-6} at 2.223 MeV
Continuum sensitivity γ/s/cm2/MeV (3σ in 10^6s, ΔE = E/2)	9.9×10^{-6} at 1 MeV	1.6×10^{-6} at 5 MeV	7.6×10^{-8} at 30 MeV

On-going R&T programs; DSSD chain @ APC

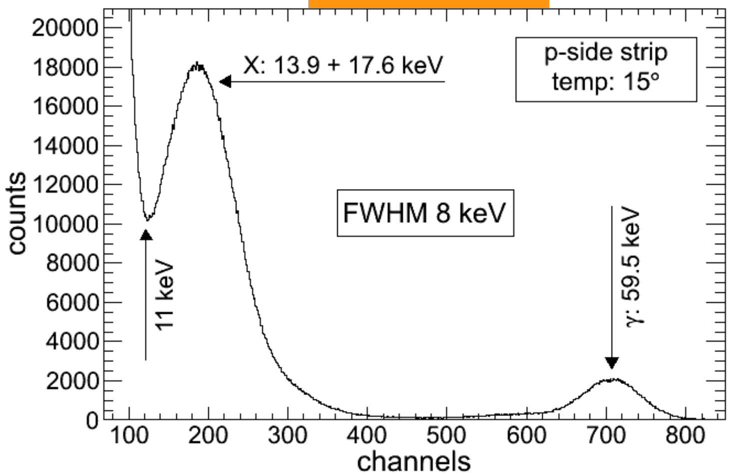
R&D DSSDs @ IPNO

BB7 detector (Micron Semiconductor):
- 1.5 mm thickness
- 64 x 64 mm^2
- 32 + 32 channels
- Pitch 2mm

Test bench with standard electronic



^{241}Am source



Energy resolution @ 60 keV → 8 keV (FWHM)
Energy threshold: ~ 11 keV

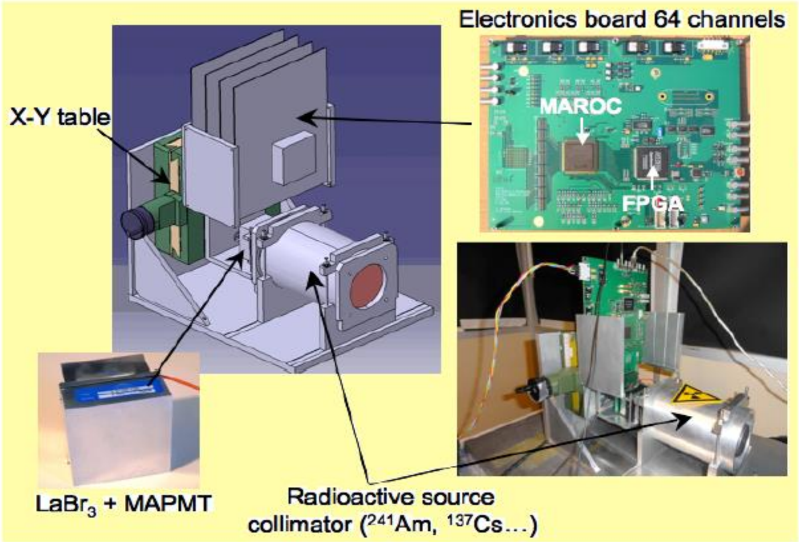
Ongoing: charge sharing study,
temperature study,

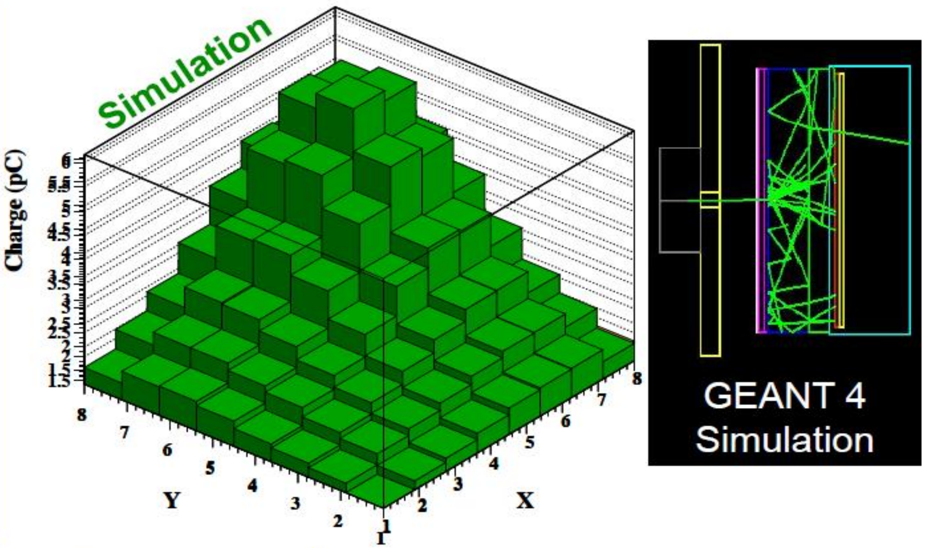
ASIC based solution: → VA32TA7 from IDEAS
- DNR = +/- 72 fC (= 1.6 MeV)
- ENC: 160 e- + 16 e-/pF → ~ 5 keV

Ongoing:
- FEE board design almost finished
- New BB7 detector ordered

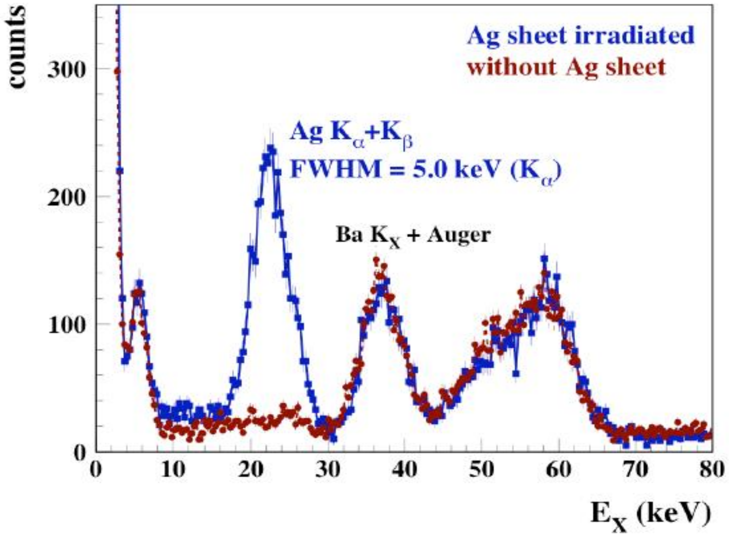
First tests with BB7 beginning of 2014

Calorimeter developments at CSNSM





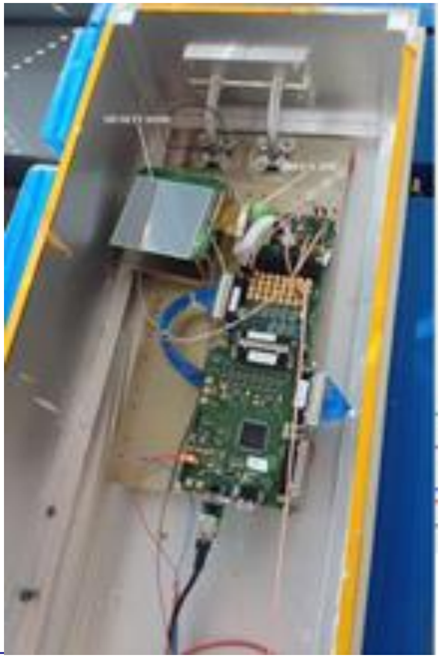
- Test of 2 $LaBr_3$:5%Ce crystals of 5x5x2 cm^3 and 5x5x1 cm^3 coupled to 8×8 multi-anode PMTs
- Readout of the signals with the ASIC MAROC developed (at LAL Orsay) for ATLAS/LHC
- Energy threshold: <15 keV
- Energy resolution: 3.5% FWHM at 662 keV
- 3D localization of γ-ray hits from the scintillation light distributions using Anger logic + an Artificial Neural Network trained by GEANT4 simulated data (Tatischeff et al. 2010; Gostojic et al. 2014)



DSSD development at CEA and APC

	junction side	ohmic side
Active area	10 cm x 10 cm	10 cm x 10 cm
Thickness	1500 µm	
Pitch width	1500 µm	1500 µm
Strip width	600 µm	600 µm
Number of strips	64	64
Max. Capacitance per strip	20 pF	20pF
Leakage current (0˚ C)	<1nA	<1nA
Depletion bias	<500 V	

- We made in APC DSSD simulations with the Silvaco software in order to determine our detector parameters (see above).
- This has led to the order of DSSD to the Micron company. They will be delivered in Fall 2014.
- In parallel, we are mounting a test bench using a MUSETT DSSD with the IdefX chain, conceived at CEA (see right).



Laboratory program

- ✓ Initiation to High Energy Astrophysics; specificity of the MeV range.
- ✓ Compton telescope principles.
- ✓ Description of the PACT telescope and its performance. GEANT 4 simulations.
- ✓ Silicon stack and DSSDs.
- ✓ Presentation of the readout chain with the IdeFX ASIC.
- ✓ Implementation and first light of the DSSD + readout chain.