Astrofisica e particelle elementari

aa 2009-10

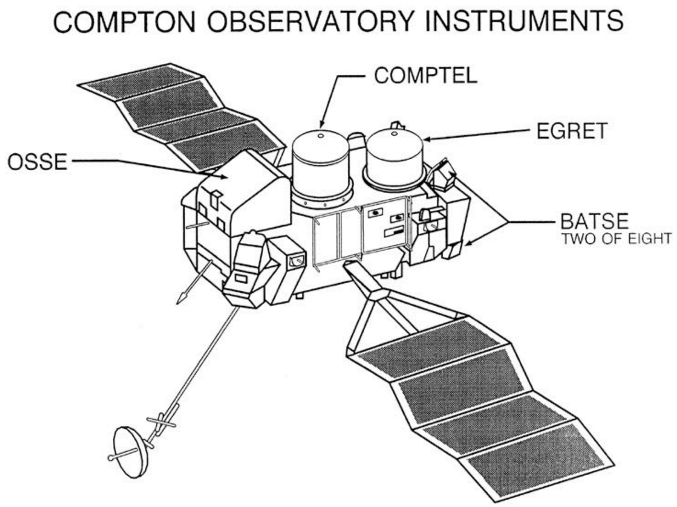
Lezione 10

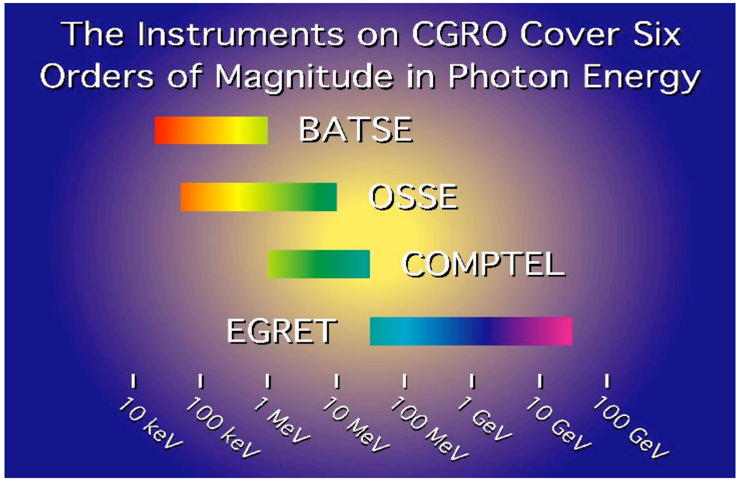
- Esperimenti su satellite per radiazione gamma
- Esperimenti Cerenkov in atmosfera

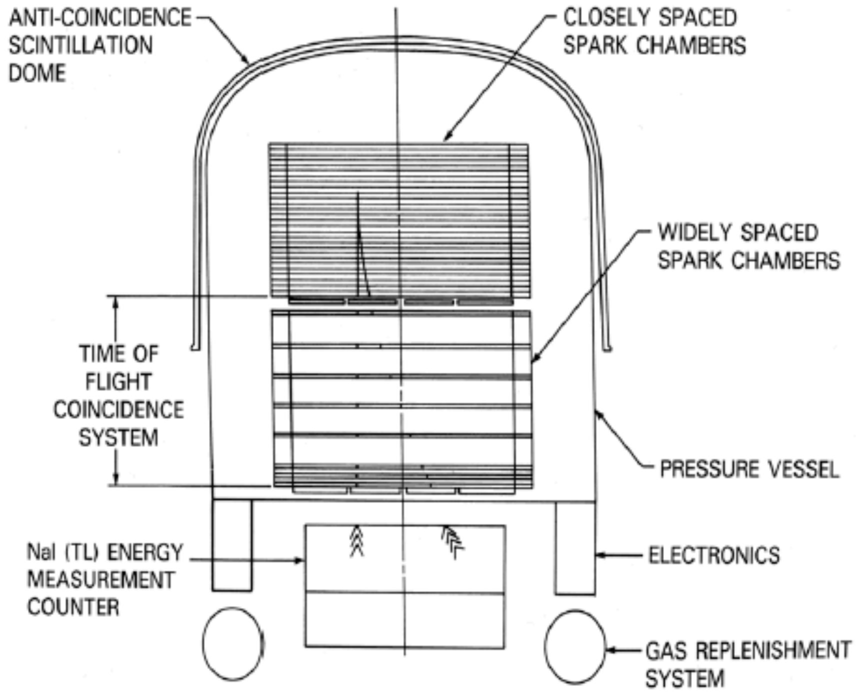
Bruno Borgia

Esperimenti nello spazio

EGRET







EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

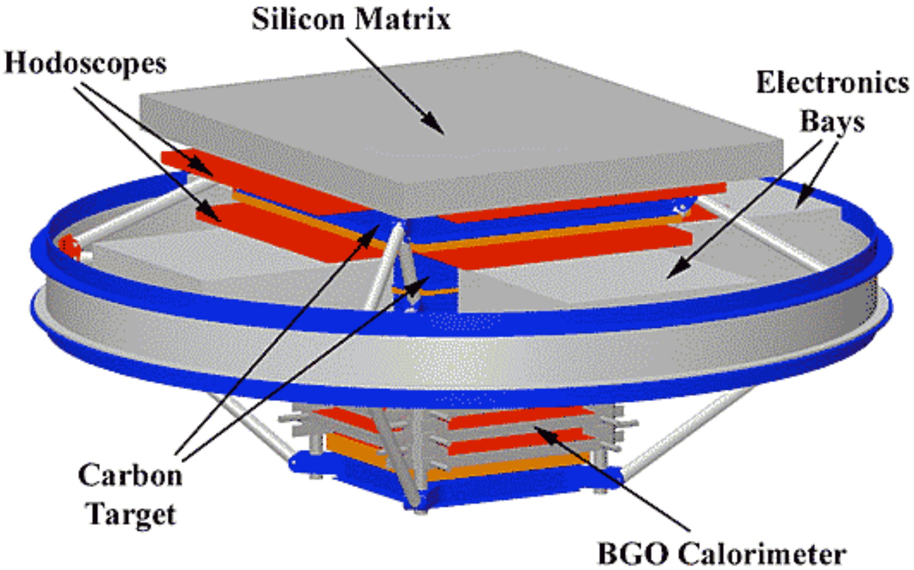
ATIC

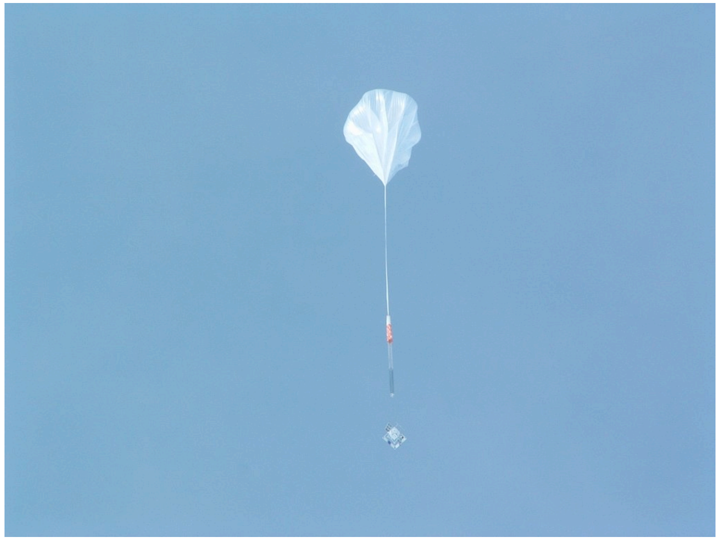
4 lanci dal 2000

ATIC must be capable of measuring the incident cosmic ray charge and energy over an energy range of 50 GeV to >100 TeV.

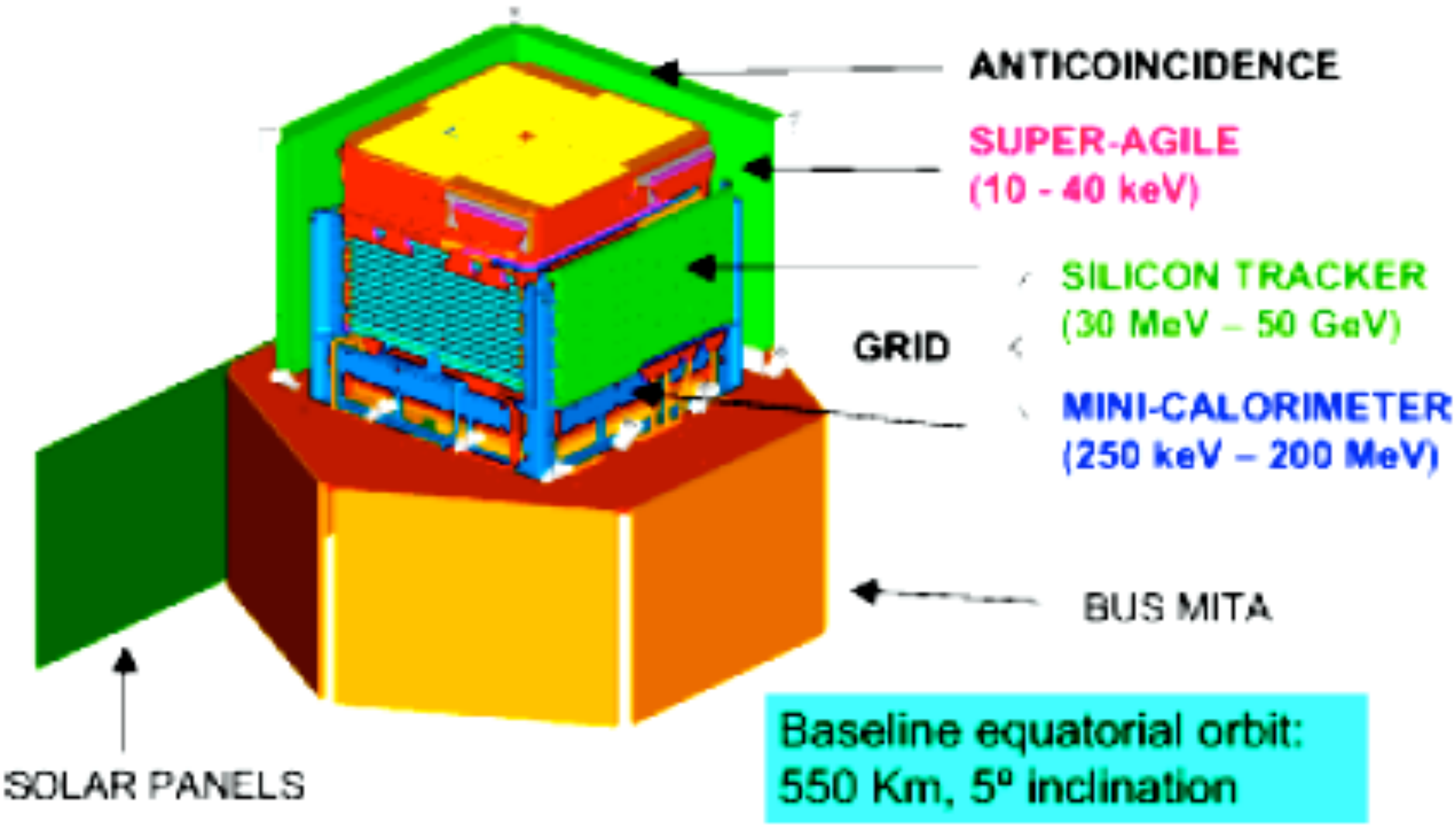
The fully active ATIC calorimeter is composed of 10 layers of Bismuth Germanate (BGO) scintillating crystals and is located on the bottom of the instrument. Above the calorimeter is the target section consisting of three plastic scintillator strip hodoscopes to define the instrument aperture and provide redundant charge and trajectory measurements, as well as layers of inert carbon (between hodoscopes) to provide a volume for the incident particles to interact.

On the top of the detector stack is the highly segmented silicon matrix detector that provides an accurate measure of the incident particle charge. Surrounding the detector stack, electronics bays hold the flight computers, readout electronics, power system boards and other instrument electronics. The total weight of ATIC is about 1,500 kg (3,300 lbs), the total power consumed is less than 350 Watts.

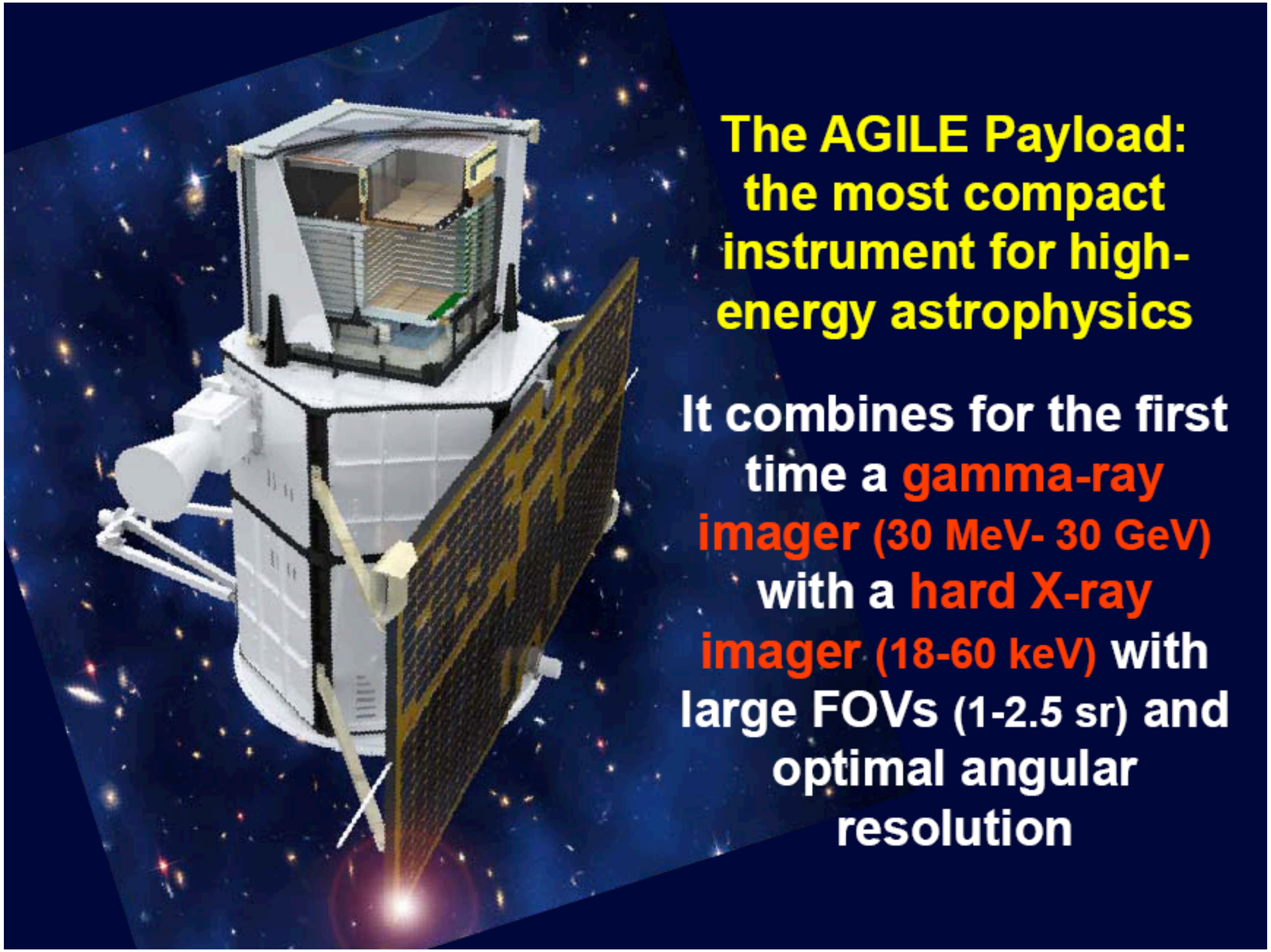




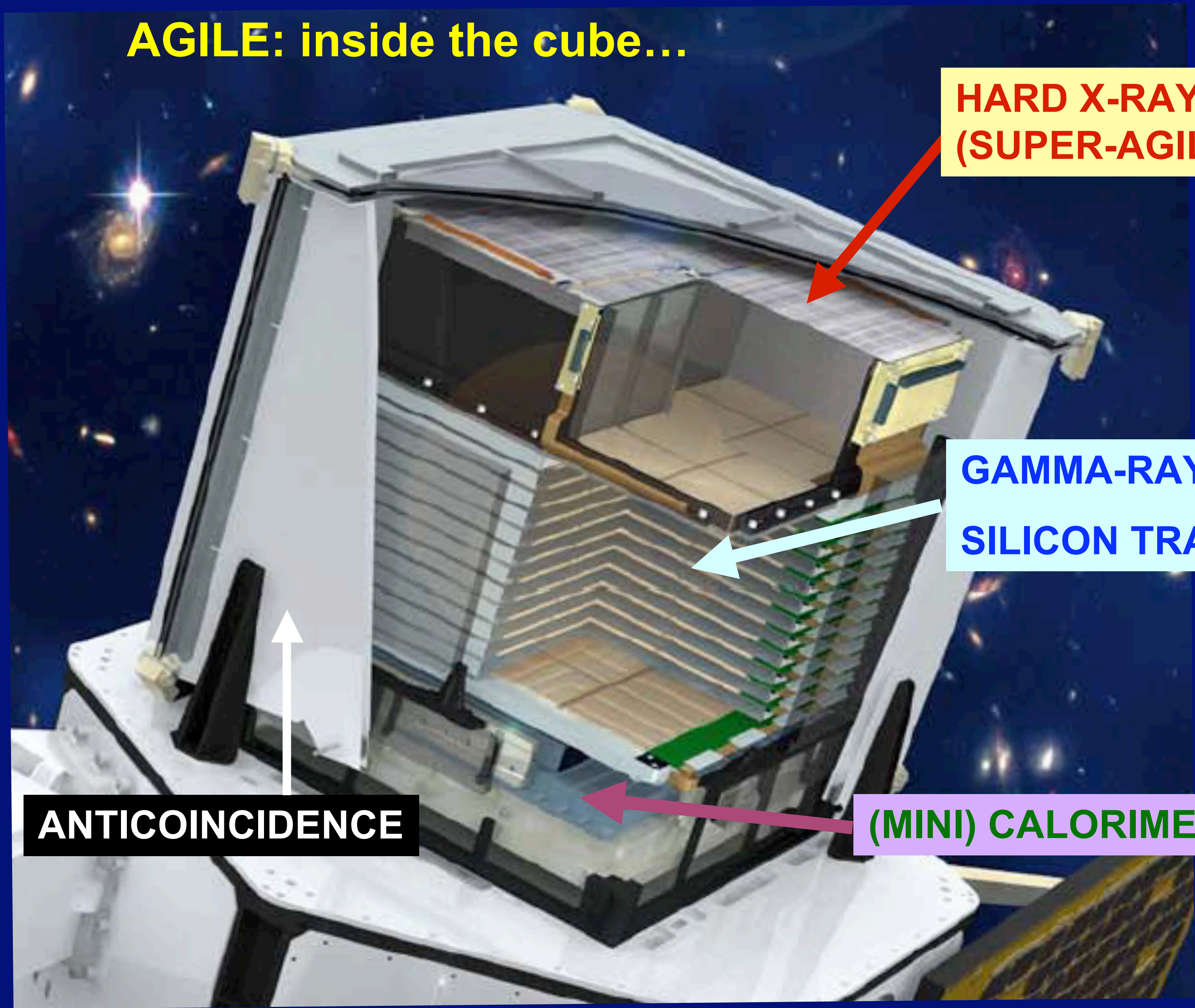
AGILE


ANTICOINCIDENCE
SUPER-AGILE
(10 - 40 keV)
SILICON TRACKER
(30 MeV – 50 GeV)
GRID
MINI-CALORIMETER
(250 keV – 200 MeV)
BUS MITA
SOLAR PANELS
Baseline equatorial orbit:
550 Km, 5° inclination

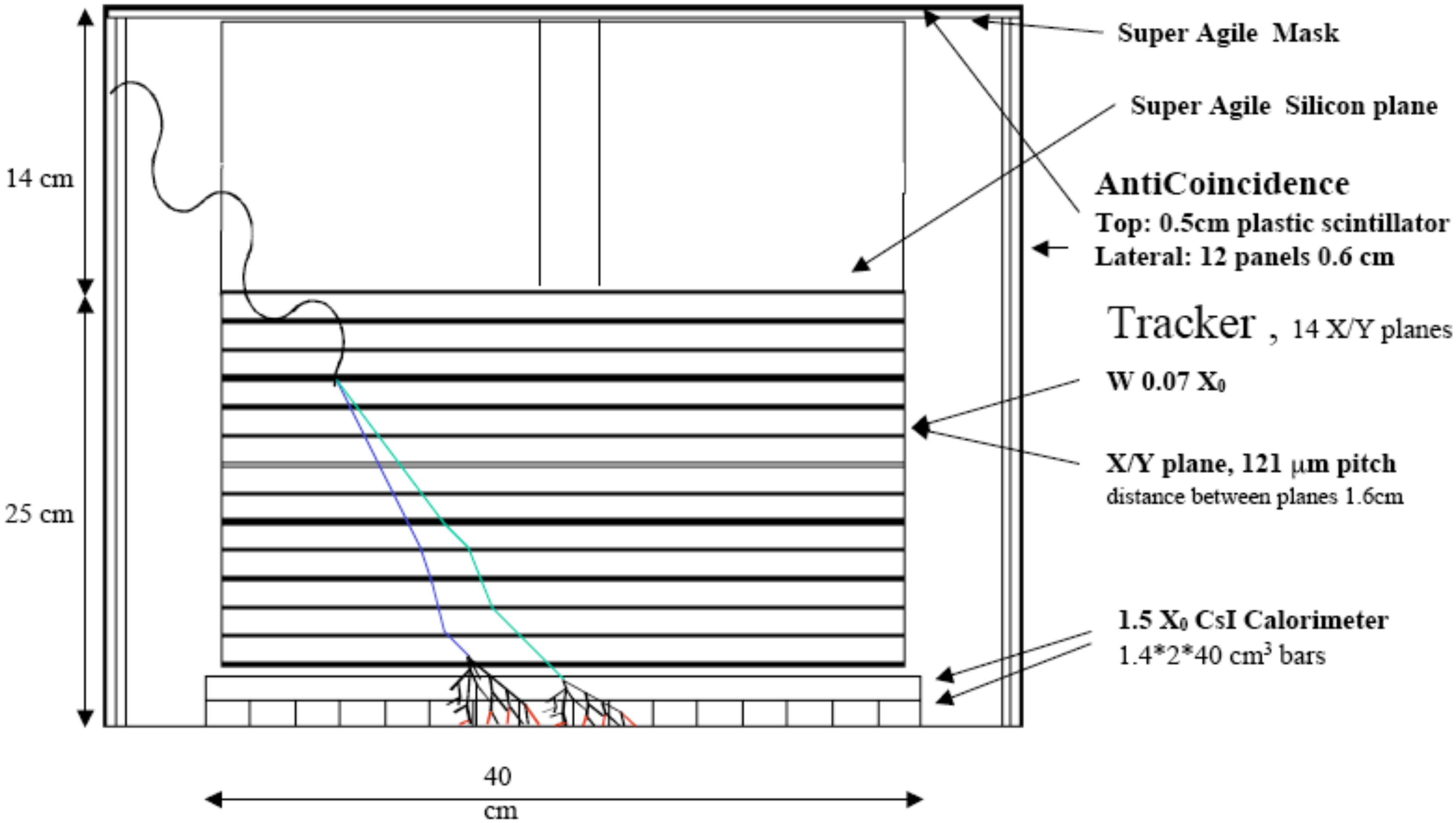
AGILE
lancio 23.04.2007



AGILE: inside the cube…

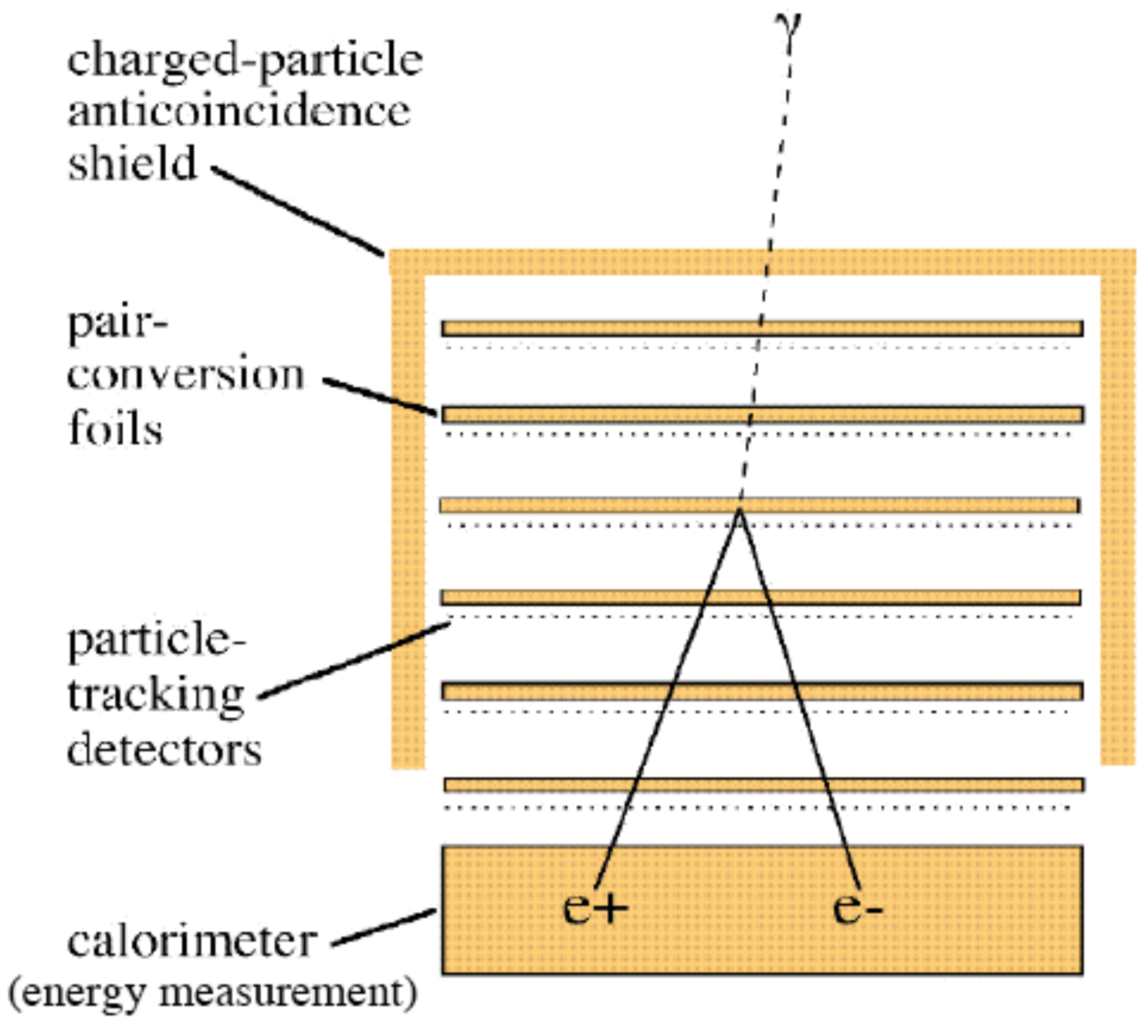


AGILE



Super Agile Mask
Super Agile Silicon plane
AntiCoincidence
Top: 0.5cm plastic scintillator
Lateral: 12 panels 0.6 cm
Tracker , 14 X/Y planes
W 0.07 X_0
X/Y plane, 121 μm pitch
distance between planes 1.6cm
1.5 X_0 CsI Calorimeter
1.4*2*40 cm^3 bars
14 cm
25 cm
40
cm

CONVERSIONE $\gamma \rightarrow e^+ e^-$



- photons materialize into matter-antimatter pairs:
  E_γ --> $m_{e+}c^2 + m_{e-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

$\gamma \rightarrow e^+ + e^-$

High-energy γ-ray telescopes work on the principle of pair production. A photon passing through matter may convert into an electron-positron pair.

$$\gamma + nucleus \rightarrow e^+ + e^- + nucleus$$

The probability of such a conversion taking place is roughly independent of the energy of the incident photon above 1 GeV, and falls off at lower energies. While the full pair-production differential cross section is a complex function of incident γ-ray energy, electron and positron energy, nuclear recoil energy, opening angle, azimuthal angle, and recoil angle [1], several simplifying assumptions give simple estimates of bulk behavior [2]. For a homogeneous material the intensity of the incident γ-ray beam falls off like

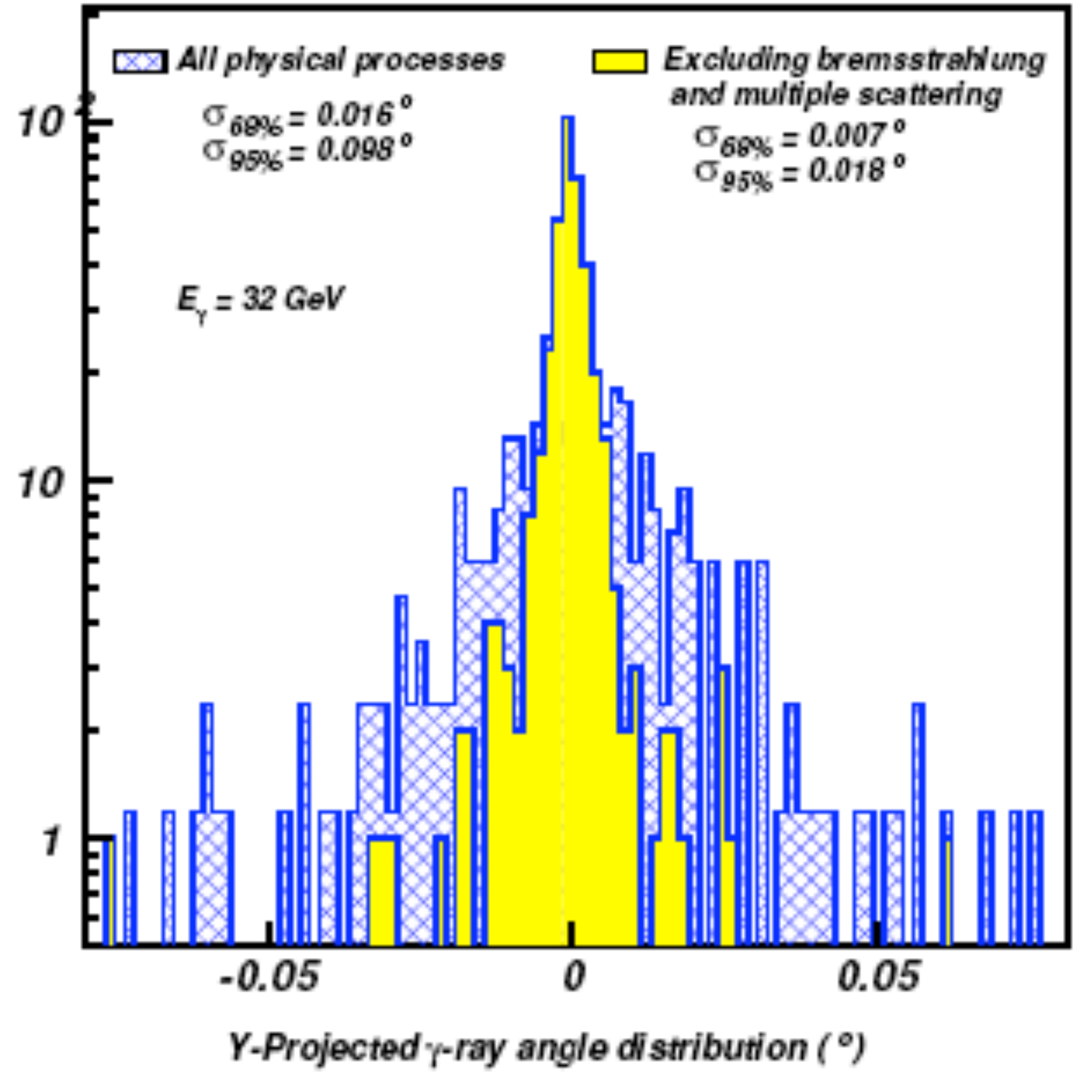
$$I = I_0 exp(-\frac{7}{9} t/X_0), \tag{1}$$

due to all interactions, where t is the thickness of material and X_0 is the radiation length of the material. Therefore, the probability of a particular γ-ray to interact in the material is

$$P(t) = 1 - exp(-\frac{7}{9} t/X_0). \tag{2}$$

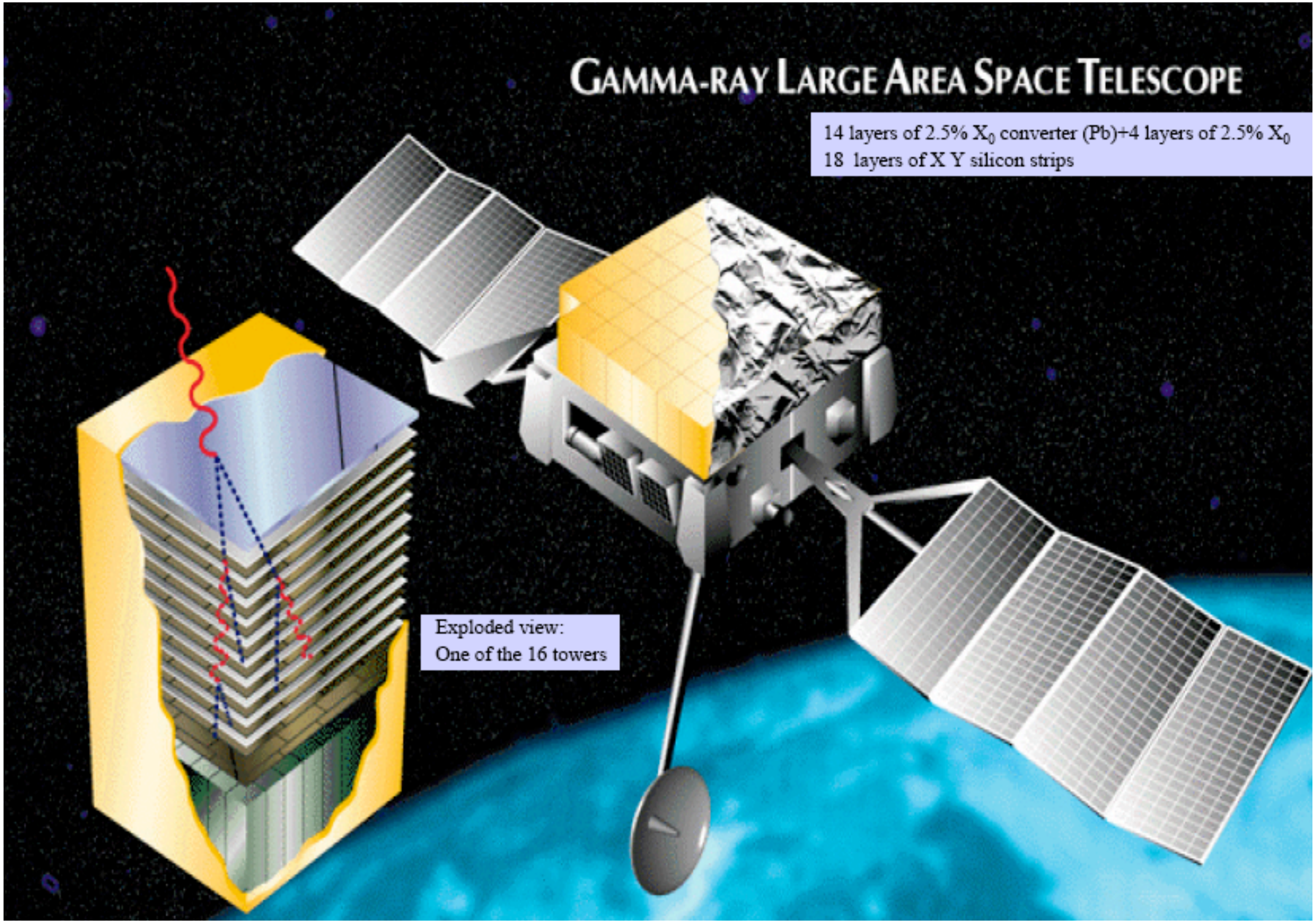
Pair production offers an opportunity for photons detection. In fact we can estimate the incident γ-ray energy and direction by tracking the resulting e^+e^- pair. The reconstructed energy will be the sum of the e^+ and e^- energies, corrected for energy loss in the instrument, and the incident direction of the γ-ray can be obtained by the momentum-weighted average of the e^+ and e^- directions.

DISTRIBUZIONE θ_P

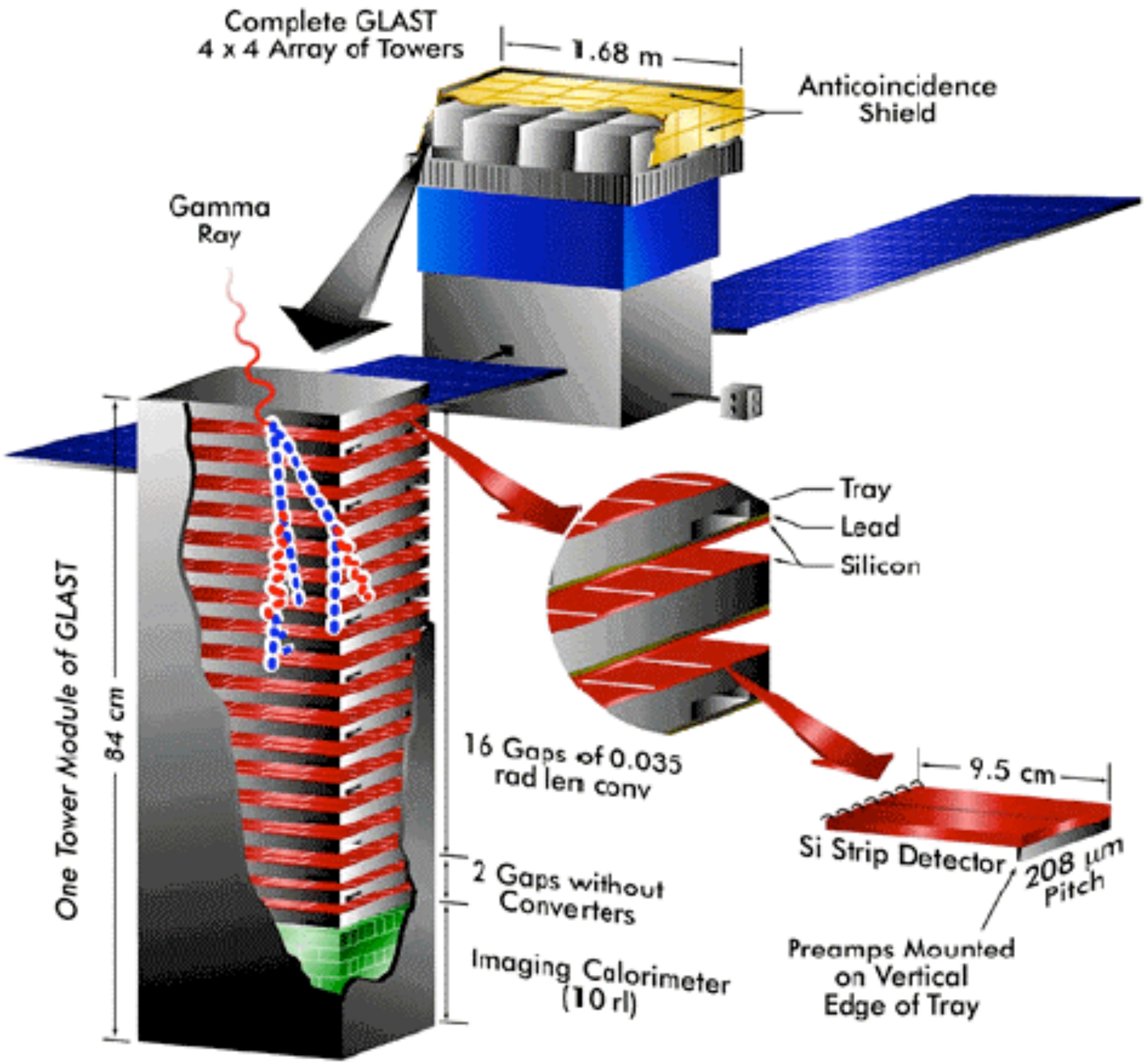


GLAST/FERMI

lancio 11.06.2008



GLAST



Complete GLAST
4 x 4 Array of Towers
1.68 m
Anticoincidence
Shield
Gamma
Ray
Tray
Lead
Silicon
One Tower Module of GLAST
84 cm
16 Gaps of 0.035
rad len conv
9.5 cm
Si Strip Detector
208 μm
Pitch
2 Gaps without
Converters
Imaging Calorimeter
(10 rl)
Preamps Mounted
on Vertical
Edge of Tray

GLAST Large Area Telescope

Mechanical Prototype of
Carbon Cell Design

Instrument

Pair-conversion telescope

16 towers ⇒ modularity

height/width = 0.4 ⇒ large field-of-view

Calorimeter Modules

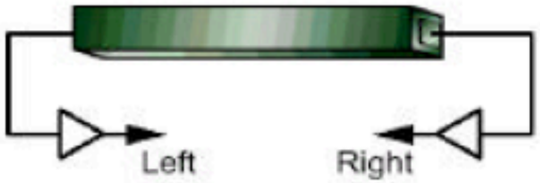
Hodoscopic Imaging Array of CsI crystals:

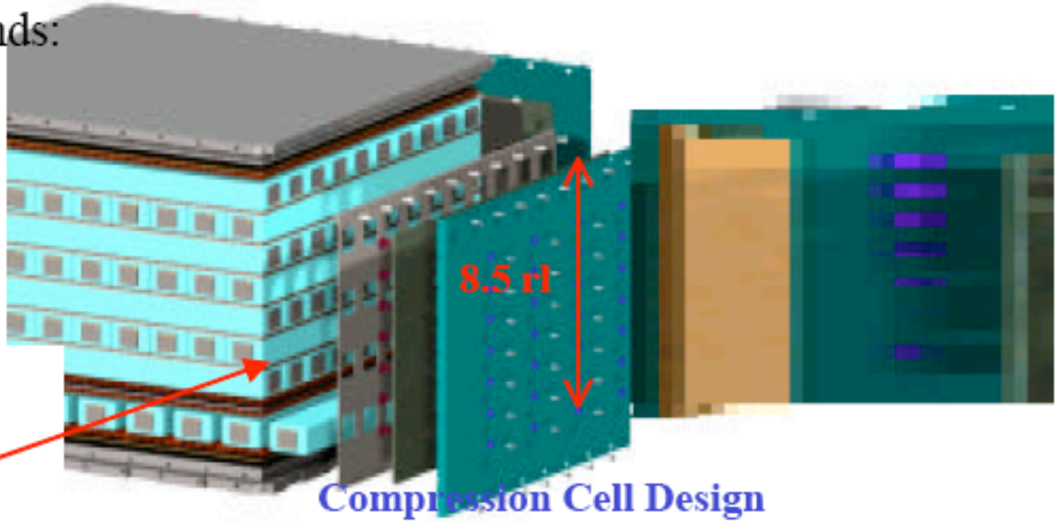
~ 8.5 rl depth

PIN photodiode readout from both ends:

2 ch/xtal x 80 xtals/mod = 2,560 ch

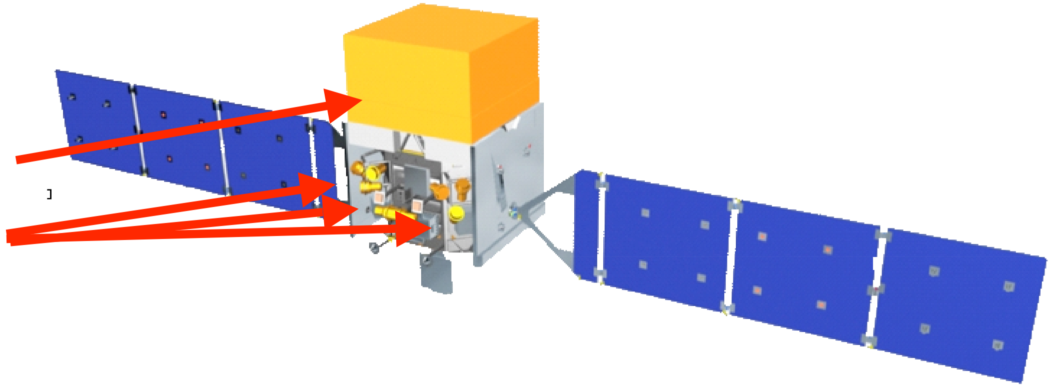
segmentation allows pattern recognition (“imaging”) and leakage correction





Compression Cell Design

GLAST Key-Features



- Two GLAST instruments:
  - LAT: 20 MeV - >300 GeV
  - GBM: 10 keV - 25 MeV
  - Launch: 11 June 2008.
  - 565 km, circular orbit
  - 5-year mission (10-year goal)
  - International Collaboration
- Huge field of view:
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours.
  - GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV- 100 GeV
- *LAT: Large Area Telescope*
- *GBM: Gamma ray Burst Monitor*

The GLAST Large Area Telescope

- **Precision Si-strip Tracker (TKR)**

  18 XY tracking planes. 228 mm pitch). High efficiency. Good position resolution (ang. resolution at high energy) 12 x 0.03 X_0 front end => reduce multiple scattering. 4 x 0.18 X_0 back-end => increase sensitivity >1GeV . Tot t ≈ 1X_0

- **CsI Calorimeter(CAL)**

  Array of 1536 CsI(Tl) crystals in 8 layers.
  Hodoscopic => Cosmic ray rejection.

  => shower leakage correction.

  8.5 X0 => Shower max contained <100 GeV

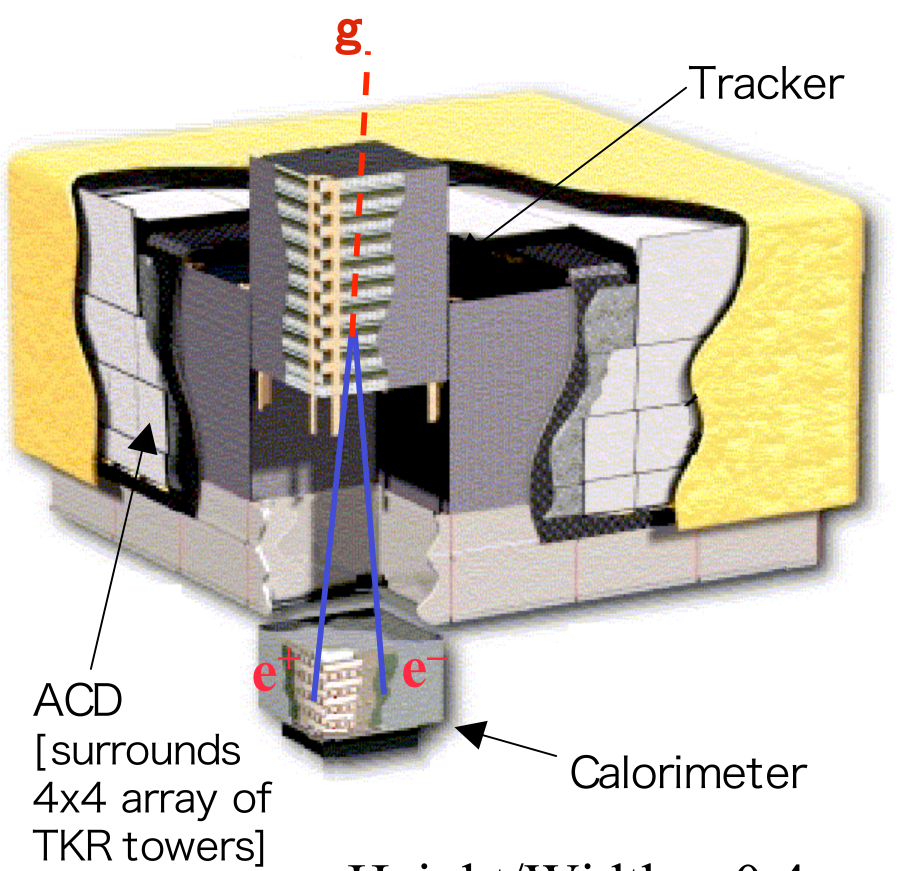
- **Anticoincidence Detector (ACD)**

  Segmented (89 plastic scintillator tiles)

  => minimize self veto,

  Reject background of charged cosmic rays;

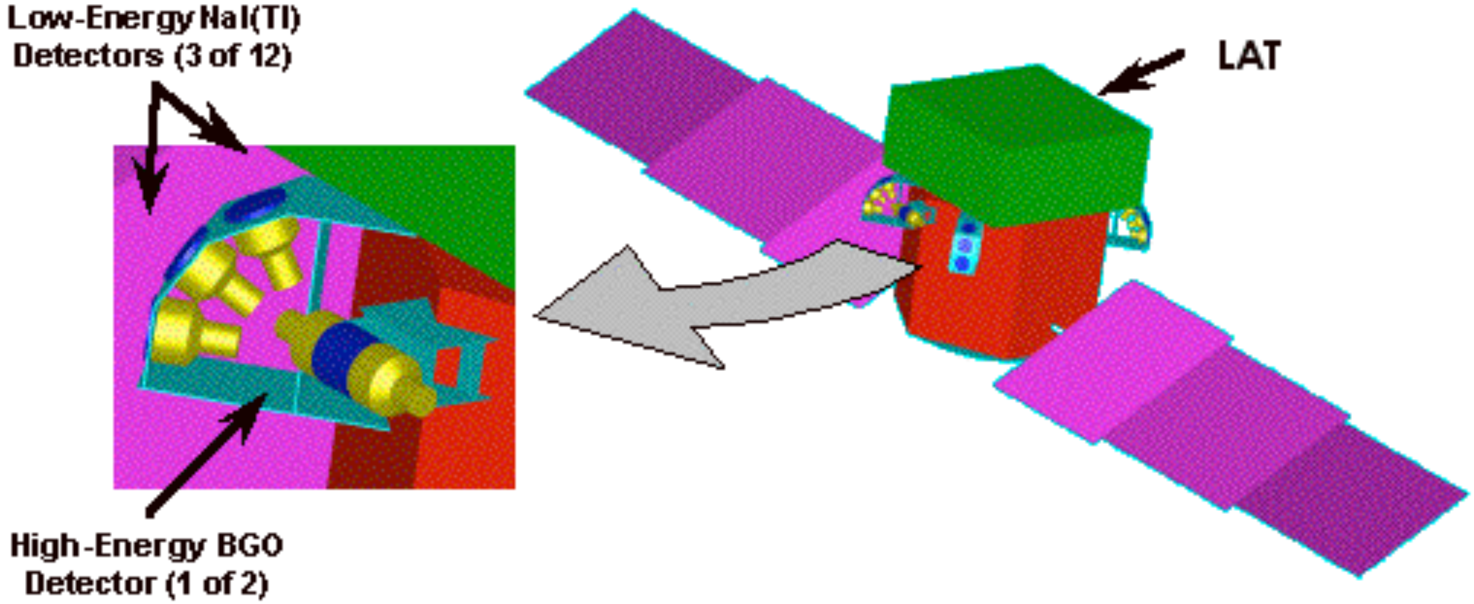
- **Electronics System** Includes flexible, robust hardware trigger and software filters.



Height/Width = 0.4
=> Large field of view

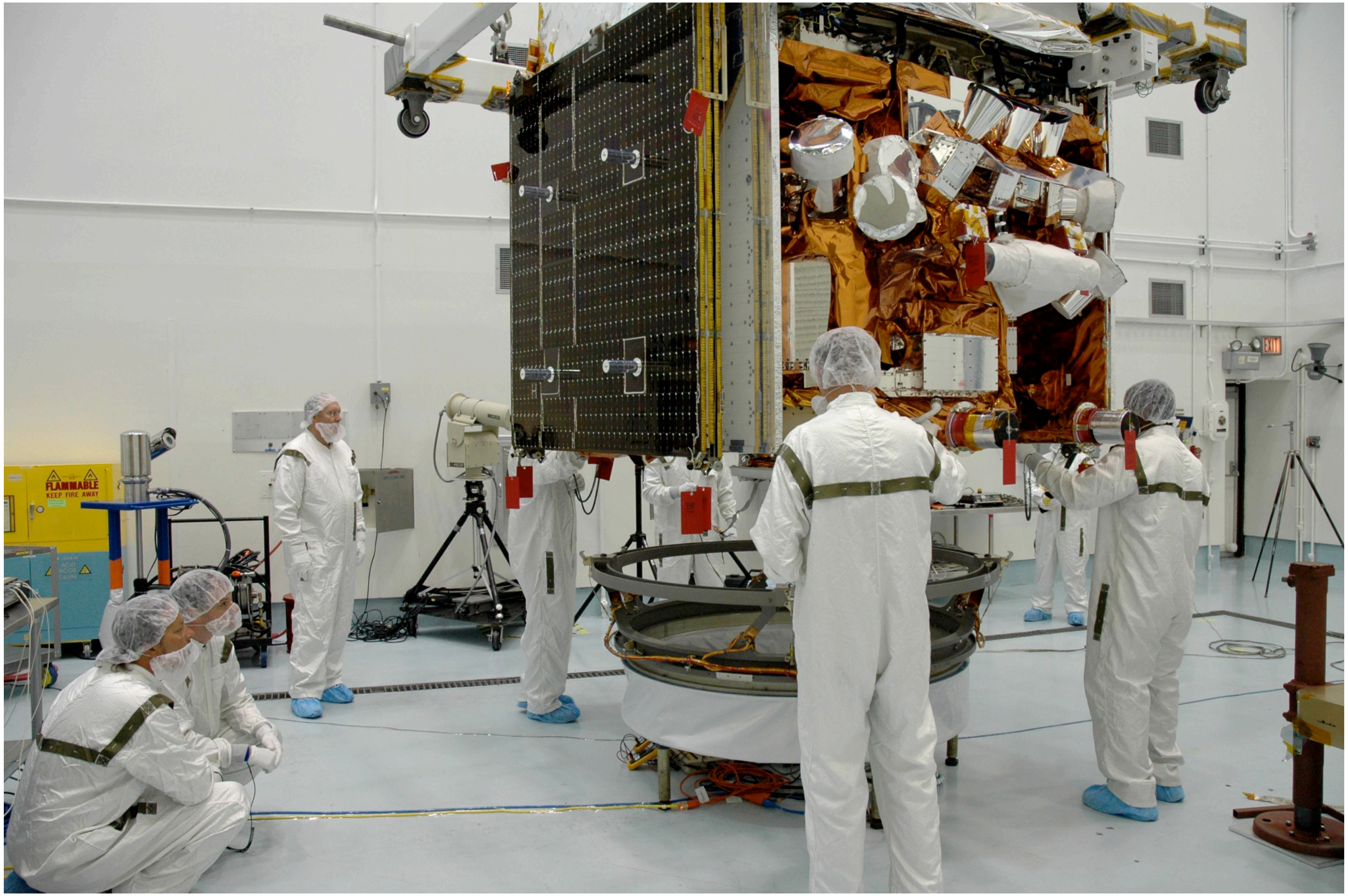
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

GBM

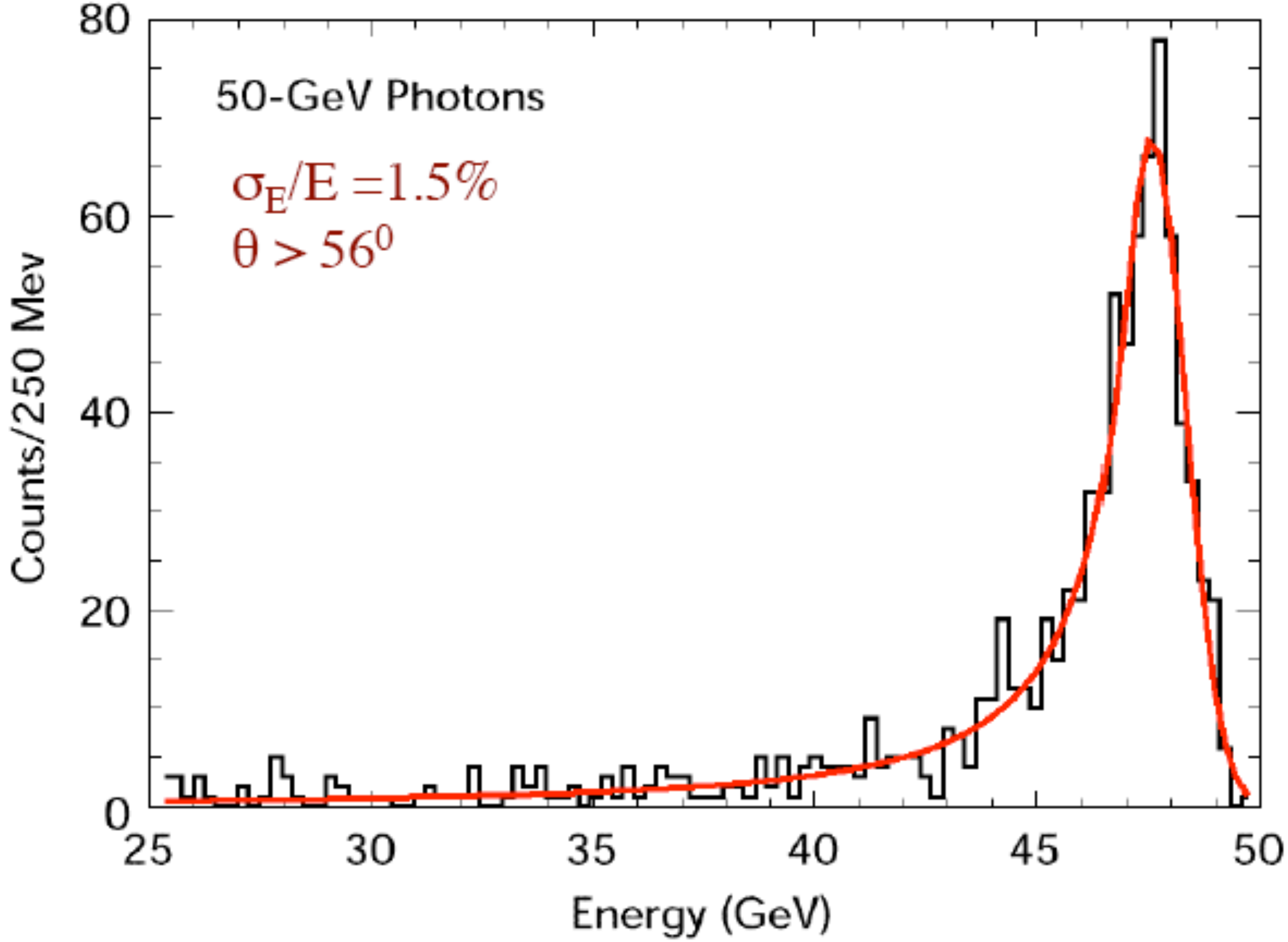


Low-Energy NaI(Tl)
Detectors (3 of 12)
LAT
High-Energy BGO
Detector (1 of 2)

GLAST/FERMI

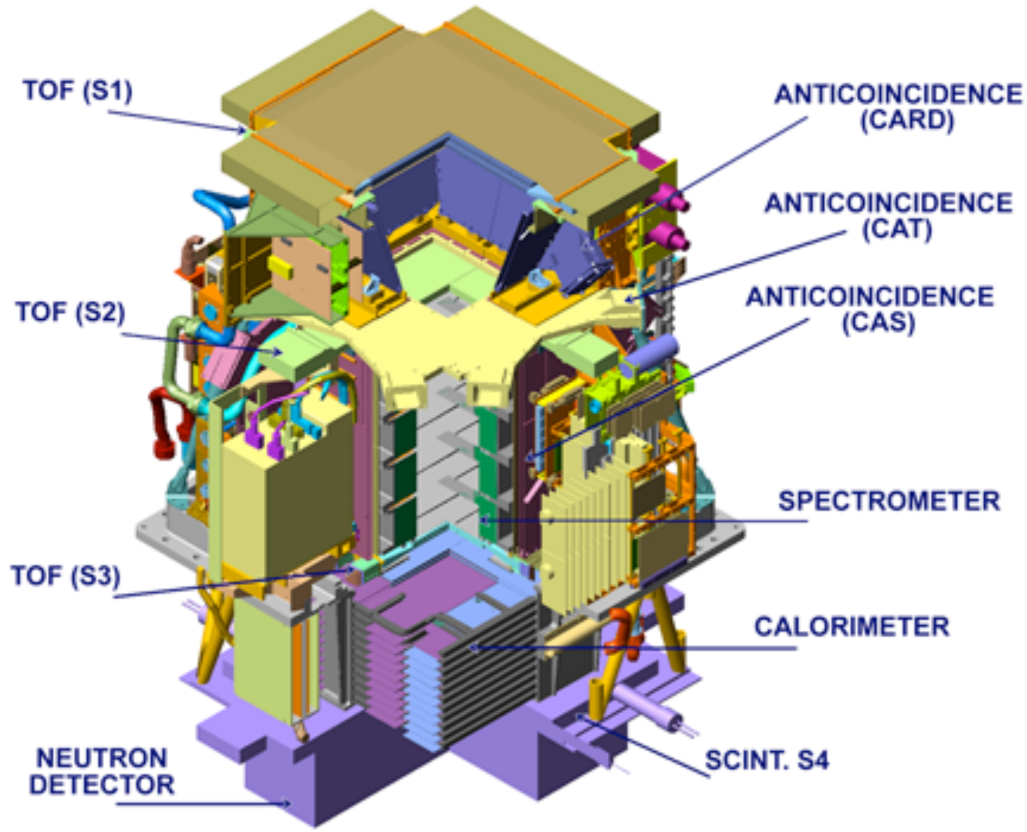


GLAST: RISOLUZIONE E

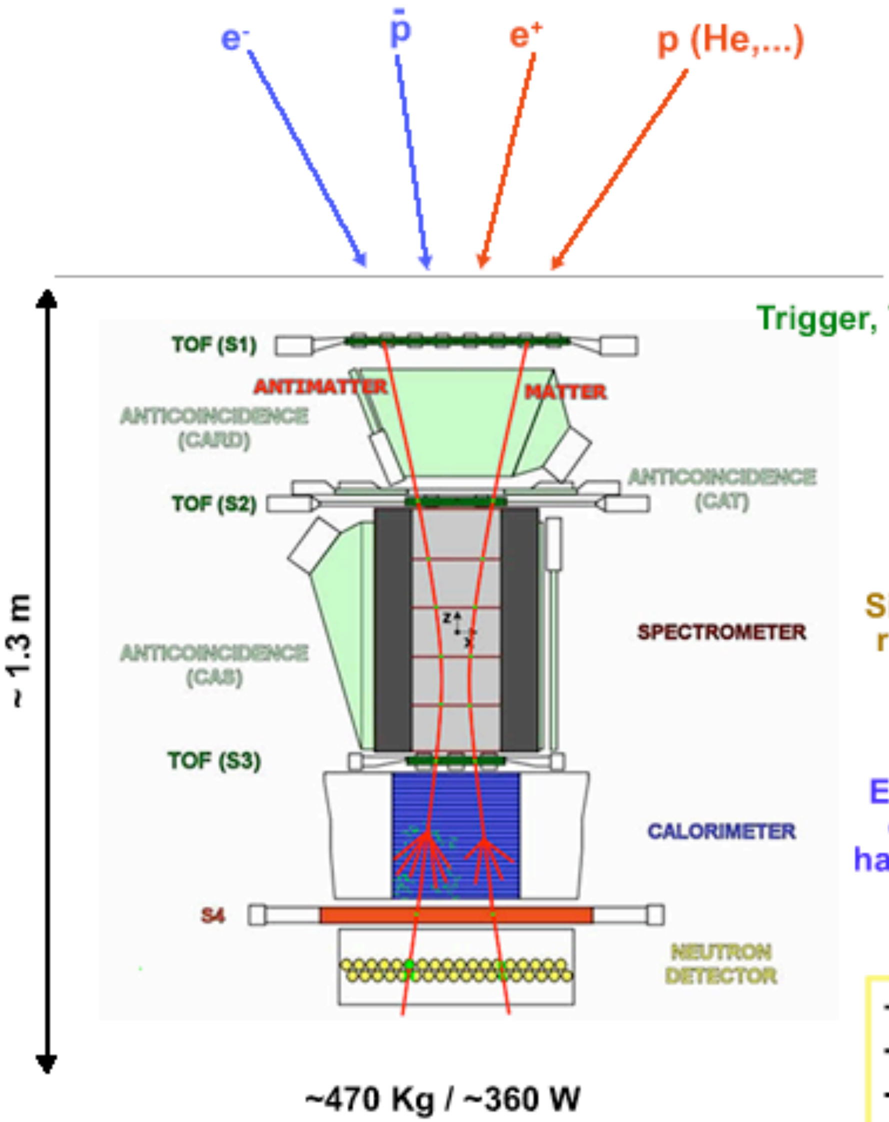


PAMELA
lancio 15.06.2006

- Costruito in gran parte in Italia
- Lanciato nel 2006 con un razzo russo



PAMELA



Trigger, ToF, dE/dx

- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

Sign of charge, rigidity, dE/dx

- Permanent magnet, 0.43 T
- 21.5 cm^2 sr
- 6 planes double-sided silicon strip detectors (300 μm)
- 3 μm resolution in bending view → MDR ~800 GV (6 plane) ~500 GV (5 plane)

Electron energy, dE/dx, lepton-hadron separation

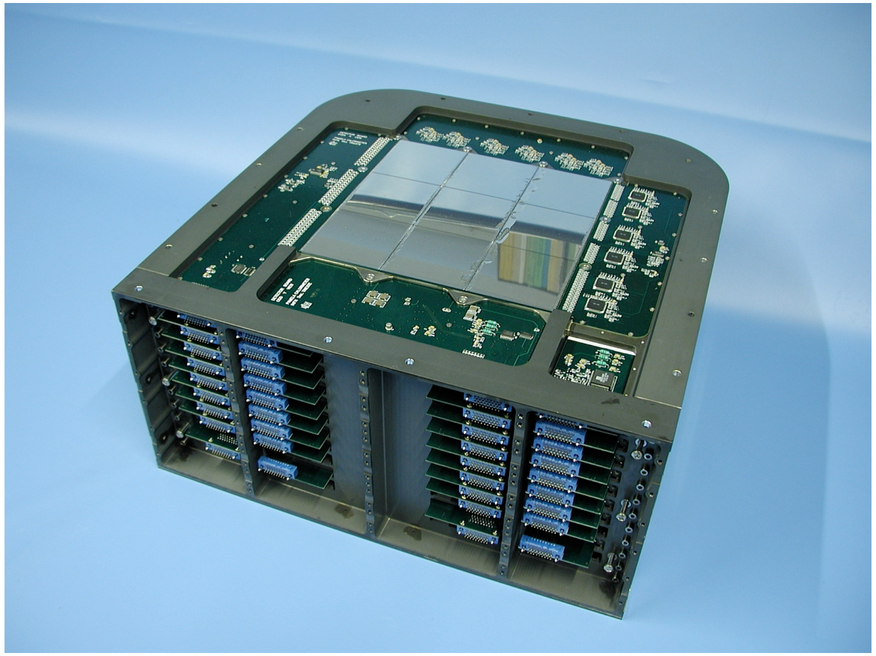
- 44 Si-x / W / Si-y planes (380)
- 16.3 X0 / 0.6 L
- dE/E ~5.5 % (10 - 300 GeV)
- Self trigger > 300 GeV / 600 cm^2 sr

- 36 ^{3}He counters
- ^{3}He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

PAMELA-MAGNETE

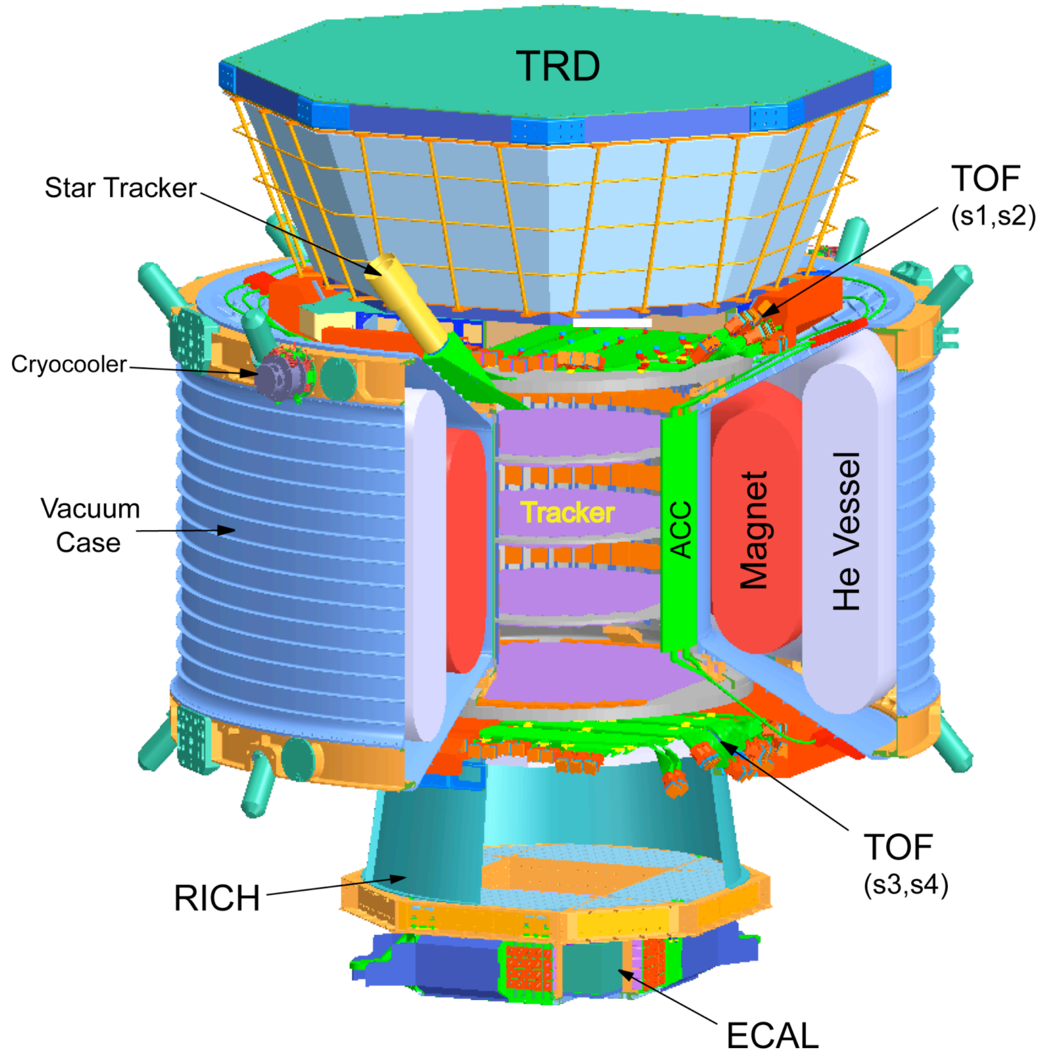
- The magnetic material used is the sintered Nd-Fe-B with a large residual magnetic induction (1.3T). The average field inside the magnet is 0.4 T, with a good homogeneity.
- The combined characteristics of the magnet and of the Si tracker will allow a Maximum Detectable Rigidity (MDR) greater than 740 GV/c.

PAMELA- CALORIMETRO EM

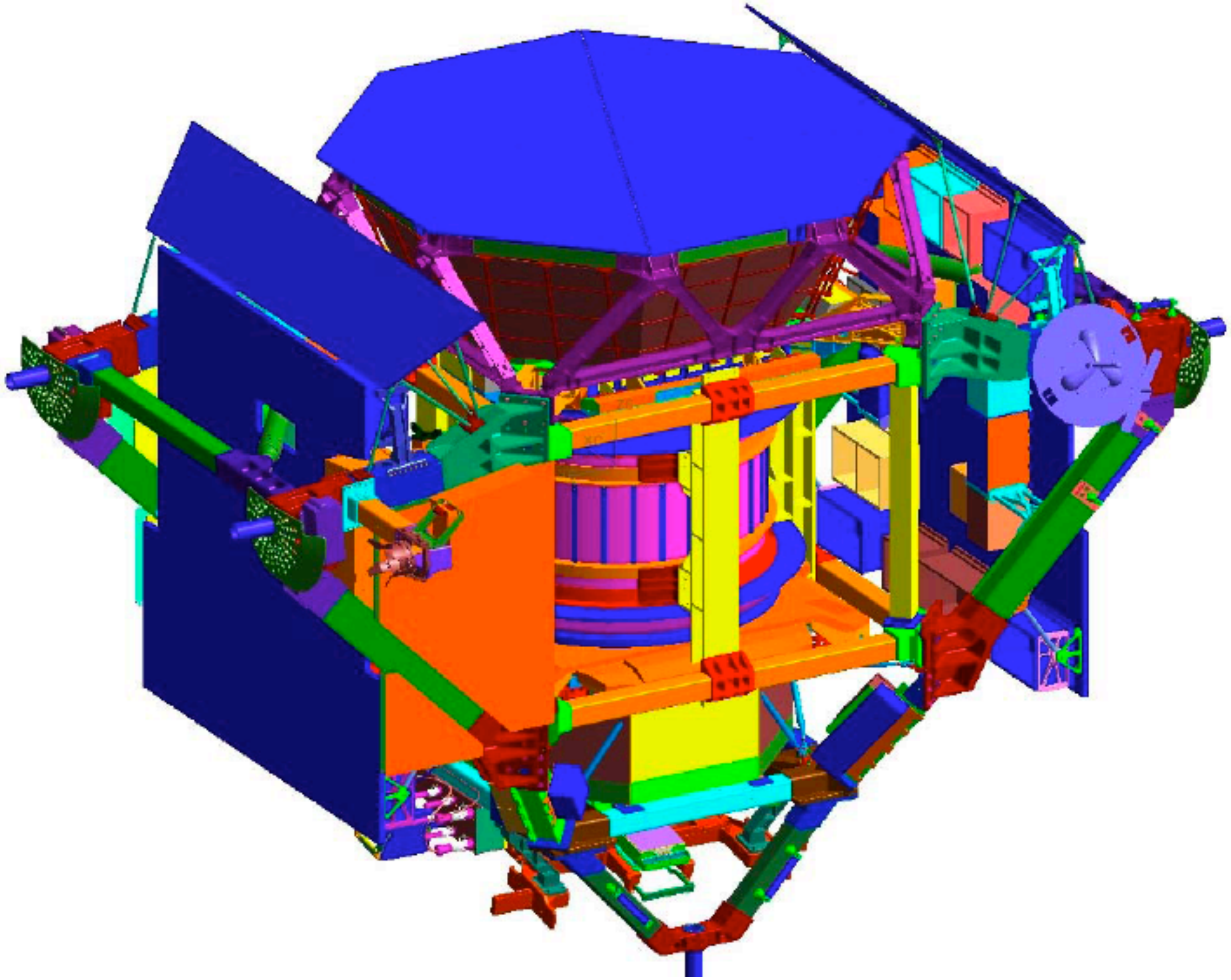


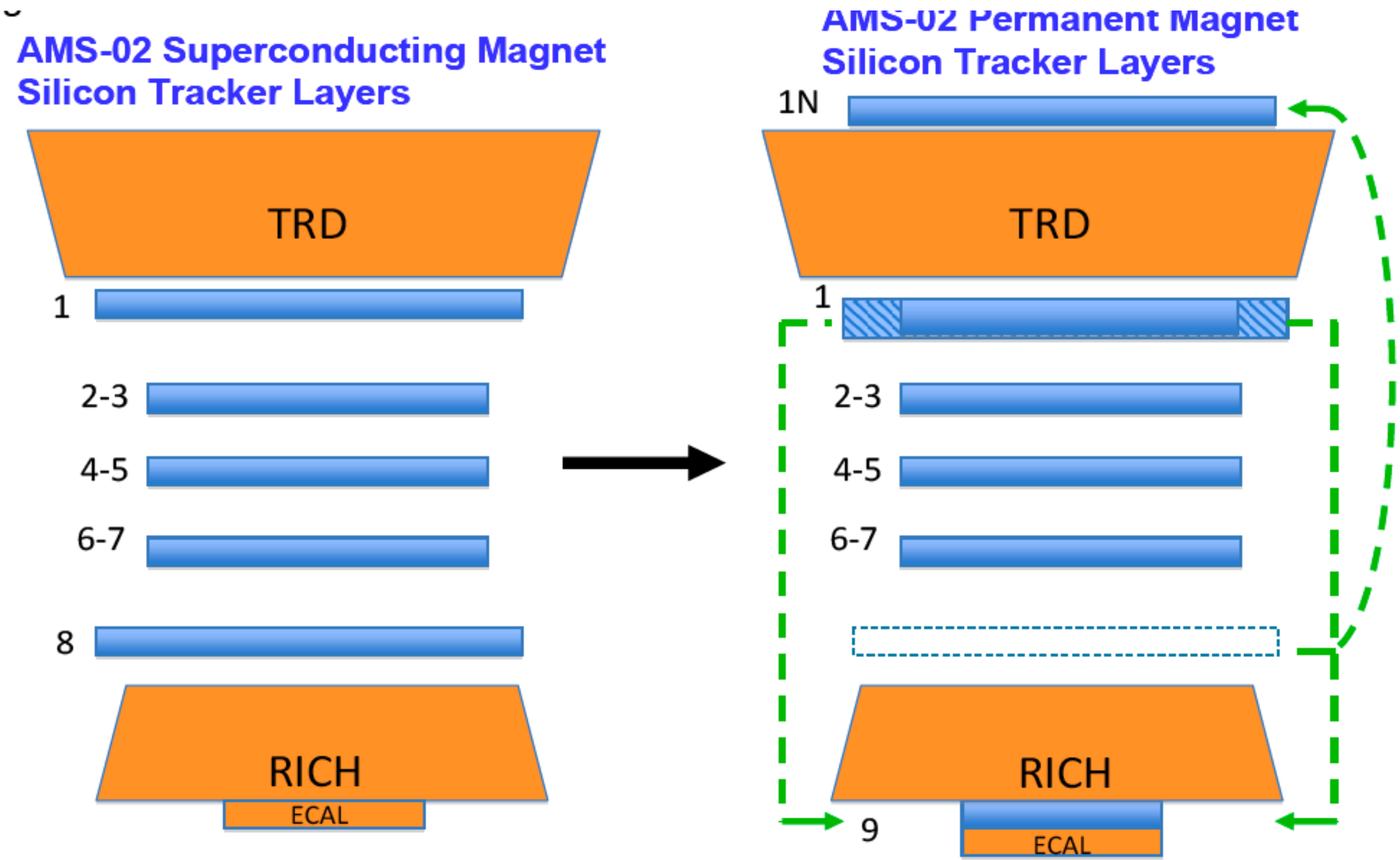
- The total thickness corresponds to 0.9 interaction lengths and 16 radiation lengths.
- The energy resolution for high energy electrons is better than 10% .

AMS con magnete superconduttore
BL^2=0.8 Tm^2



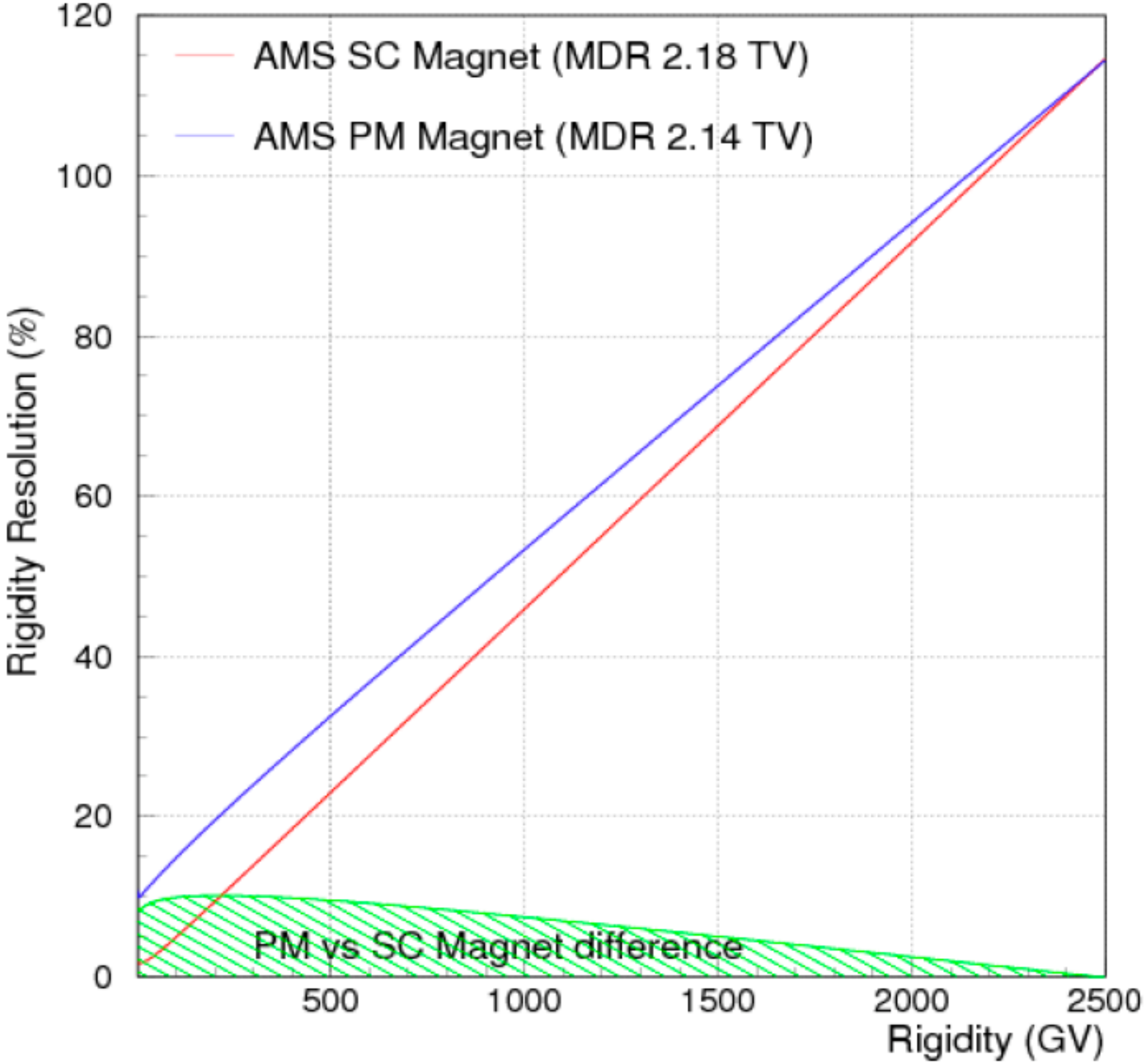
AMS con magnete permanente
BL^2=0.14 Tm^2



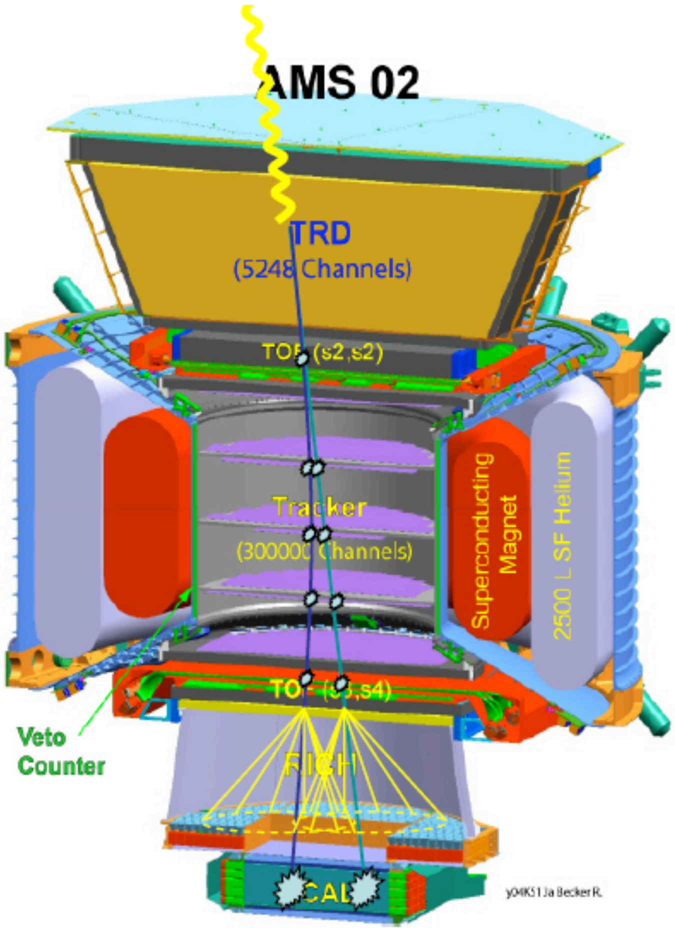


Layer 9 comes from moving the ladders at the edge of the acceptance from layer 1. The layer 8 is moved on top of the TRD to become 1N.

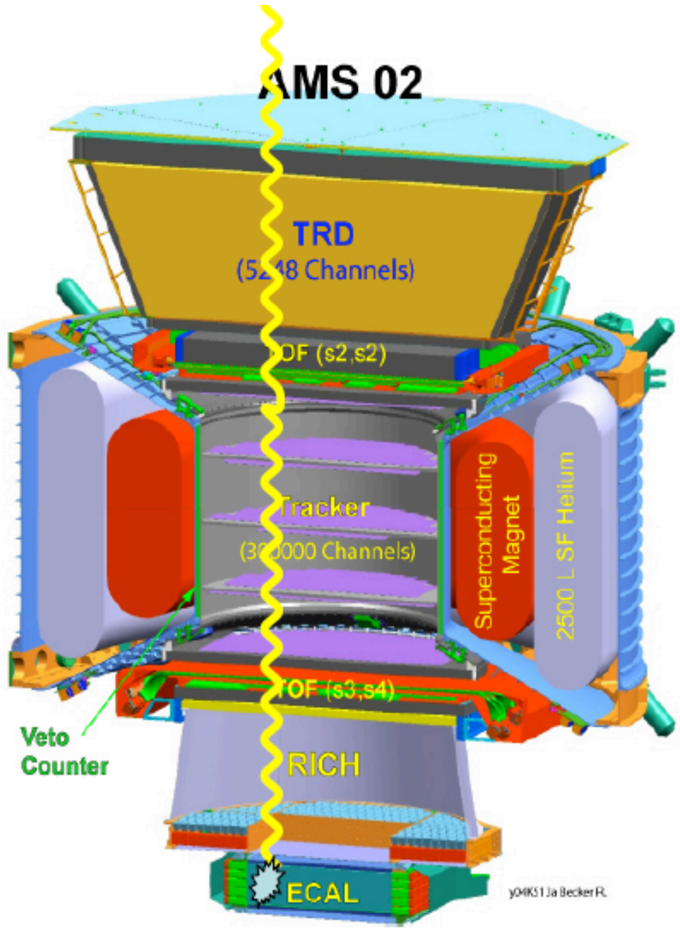
Risoluzione dello spettrometro



AMS2

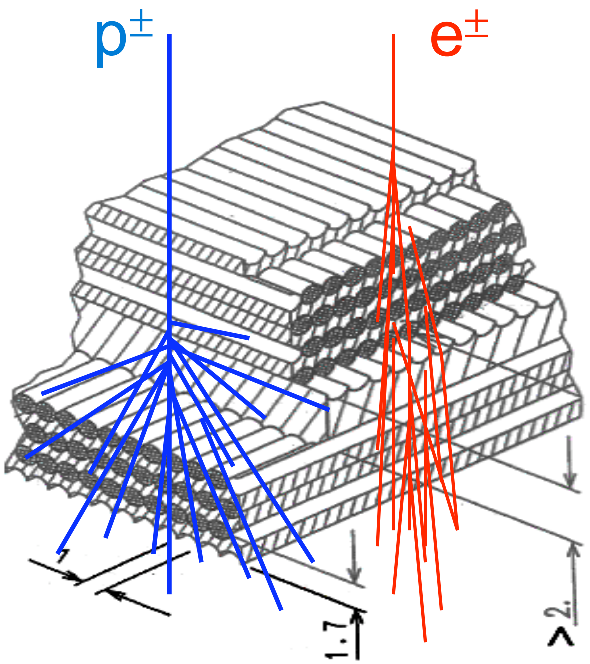


Photon conversion



Direct Photon detection

EM sampling calorimeter

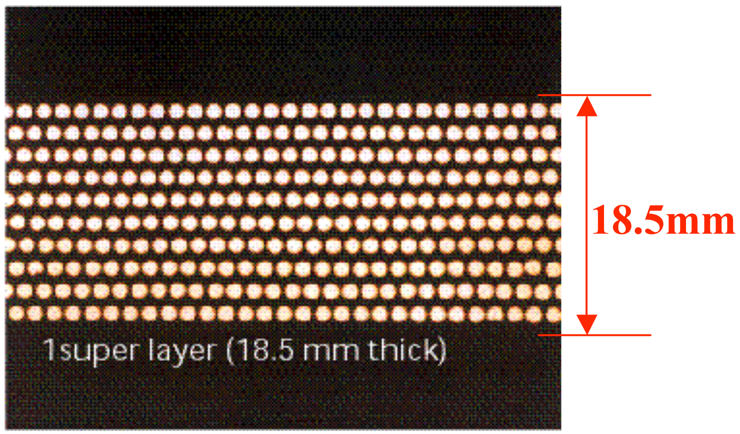


⇒ High granularity :
-0.5 Molière radius in X-Y
-18 samplings, 0.9 X_0 in depth

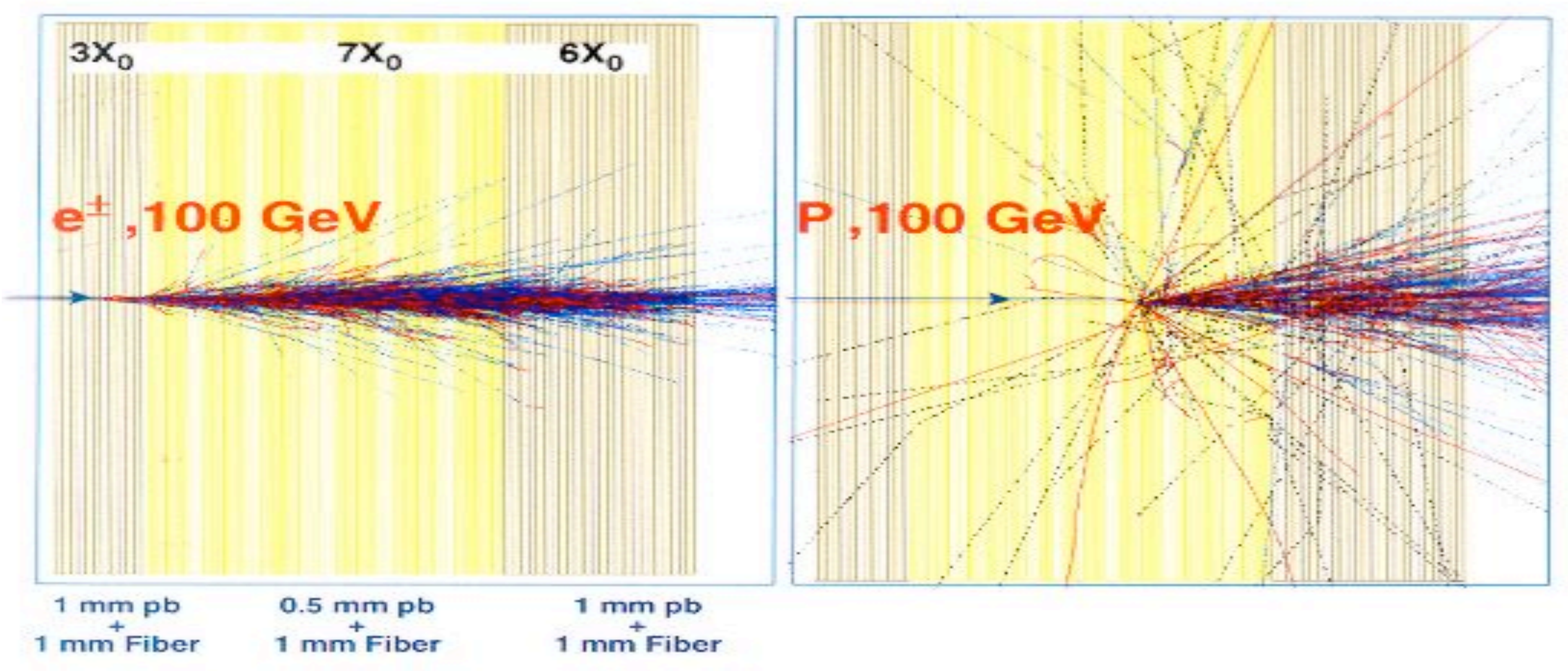
why *spaghetti*?

⇒ best longitudinal & lateral shower reconstruction
- ⇒ energy correction
- ⇒ p/e separation

⇒ best γ angular resolution



Calorimetro Elettromagnetico



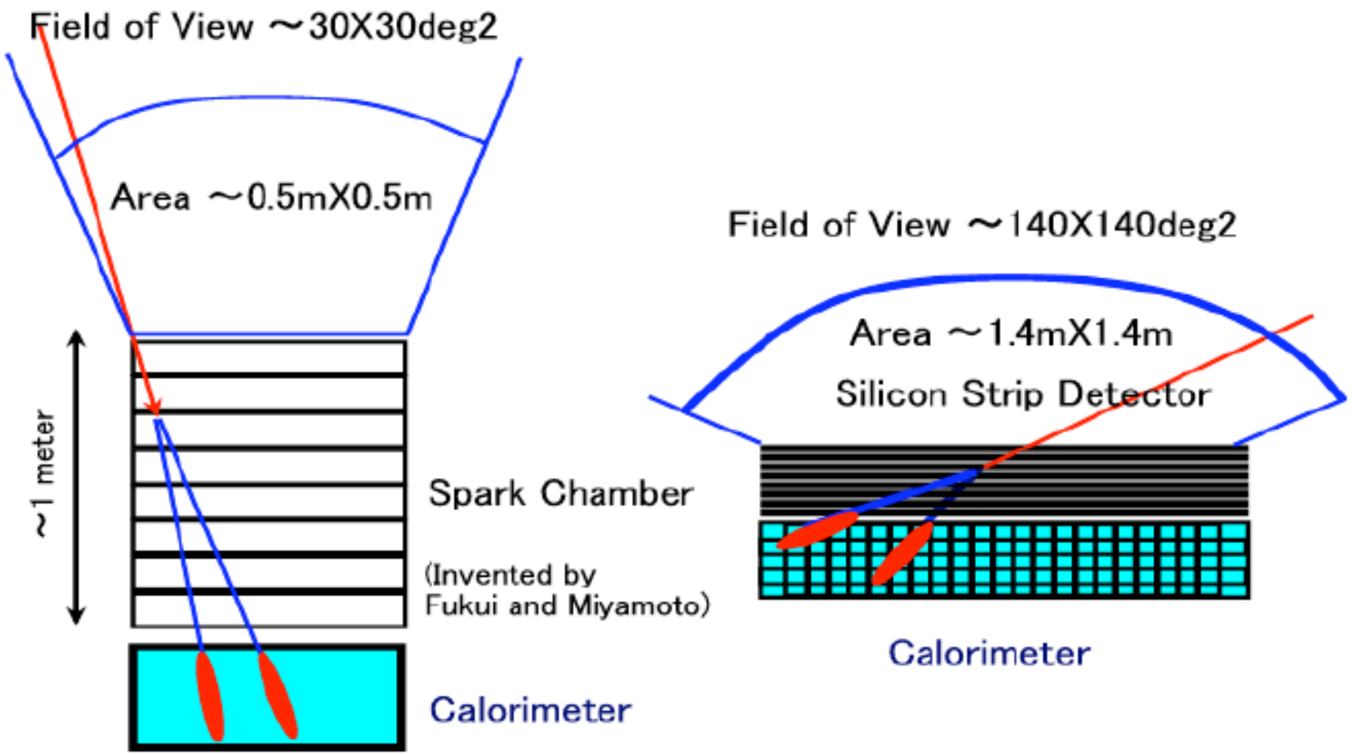
$1X_0$: probabilità 1/e di emettere 1γ o e^+e^-

\# fotoni $\propto$ E $\quad\quad$ $\Delta E/E = (a/\sqrt{E}) + b$

Alcune prestazioni degli esperimenti

SENSIBILITA`

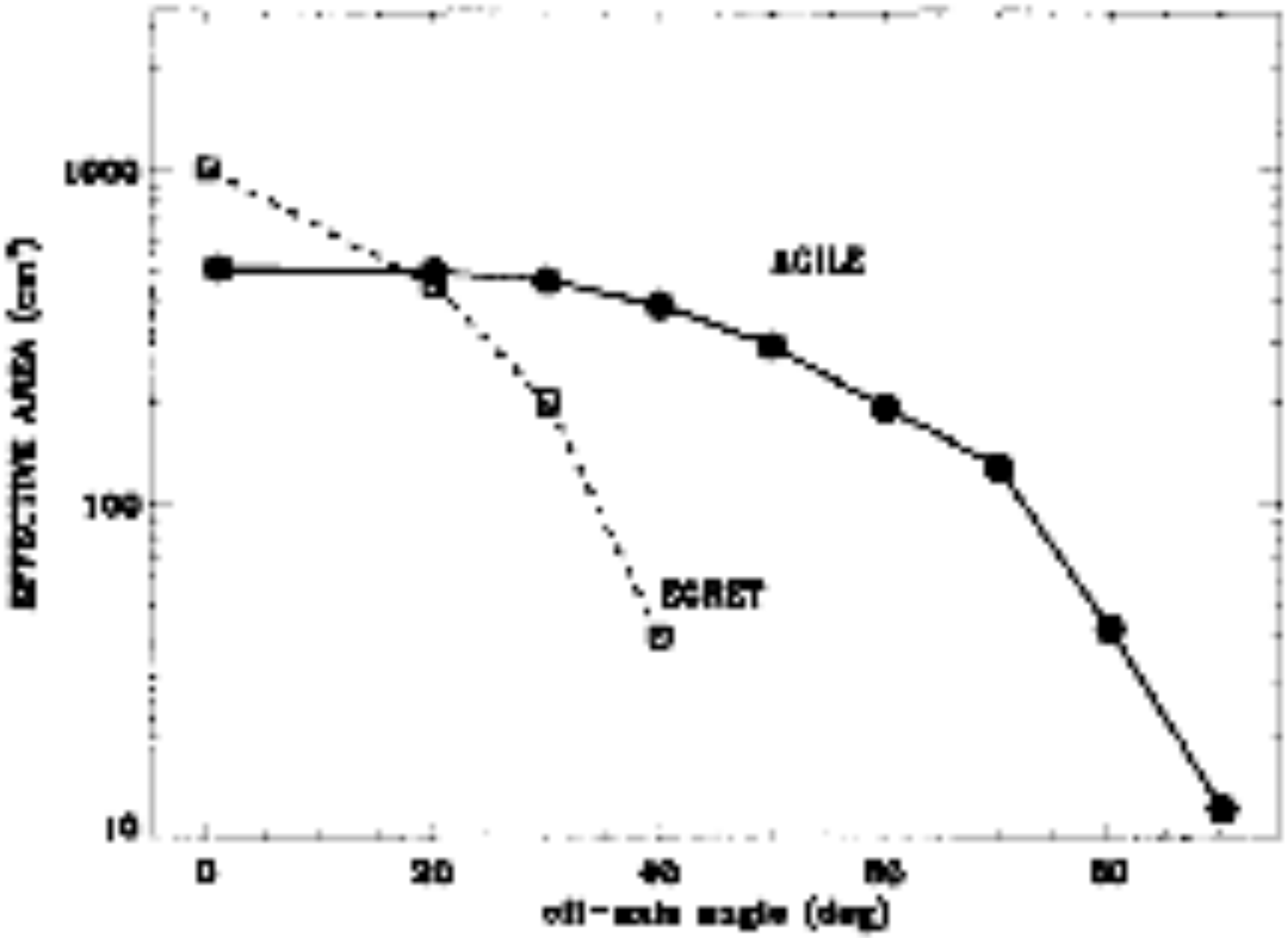
EGRET(Spark Chamber) VS. GLAST(Silicon Strip Detector)



EGRET on Compton GRO
(1991–2000)

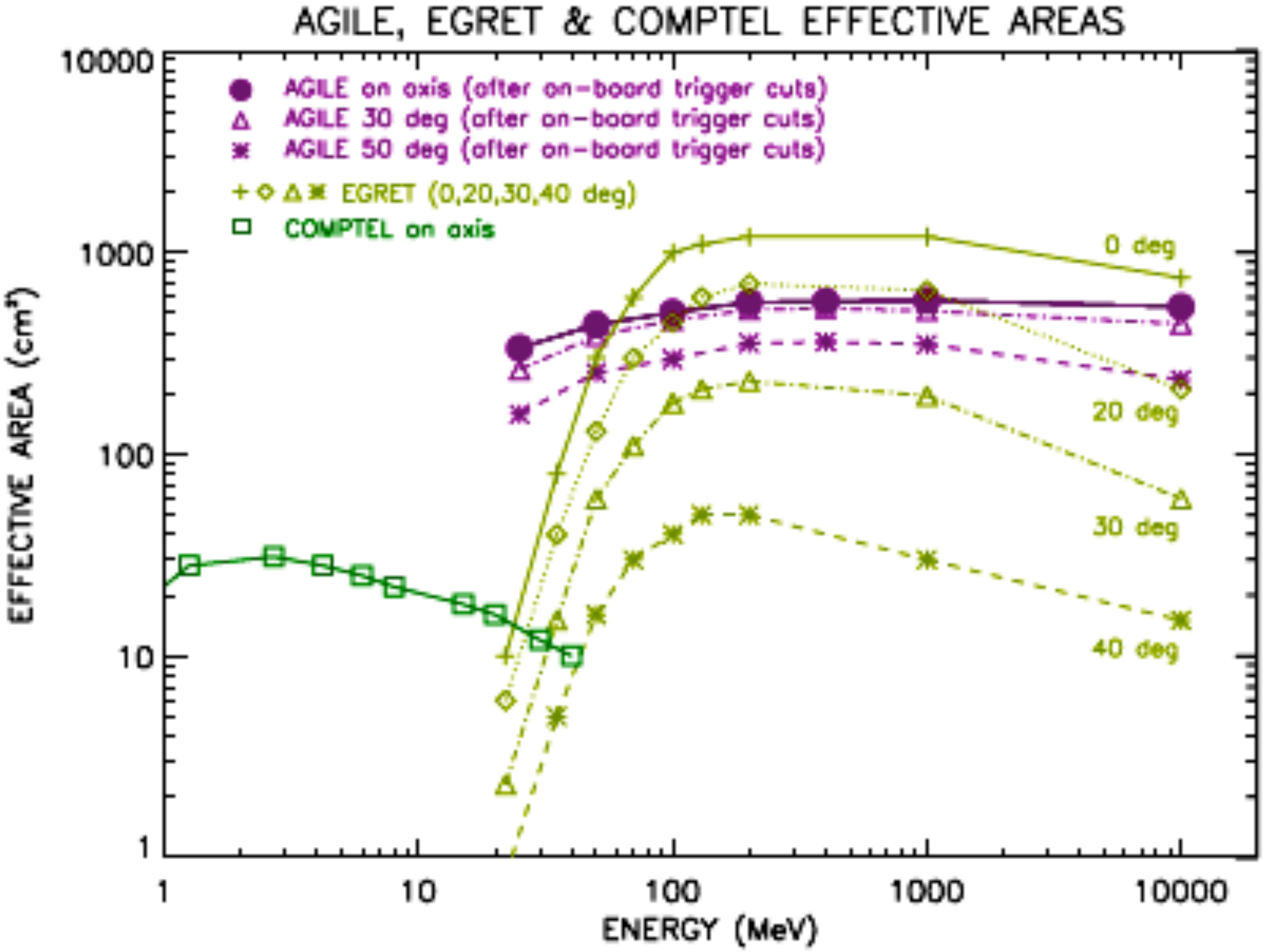
GLAST Large Area Telescope
(2006–2015)

AGILE



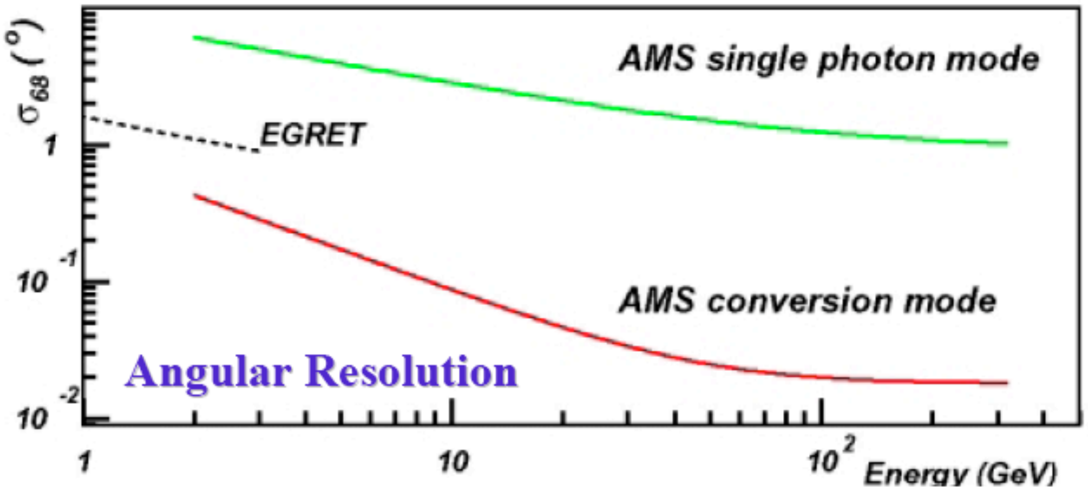
Area effettiva di AGILE a 100 MeV confrontata con EGRET in funzione della direzione di incidenza del fotone.

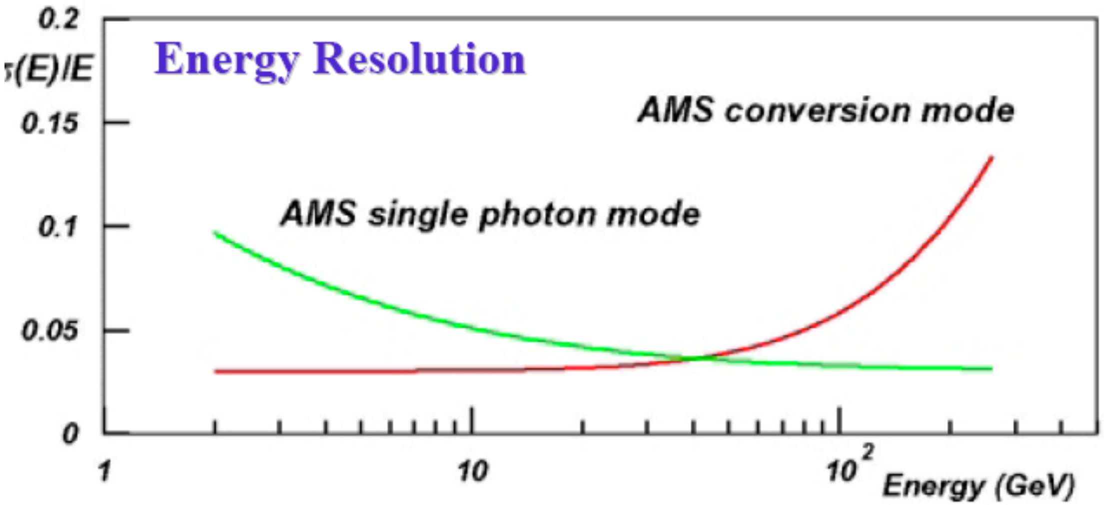
AGILE



Area effettiva in funzione dell'energia del fotone per diversi angoli di incidenza

AMS risoluzione γ





AMS02 Gamma

Unidentified Sources with AMS

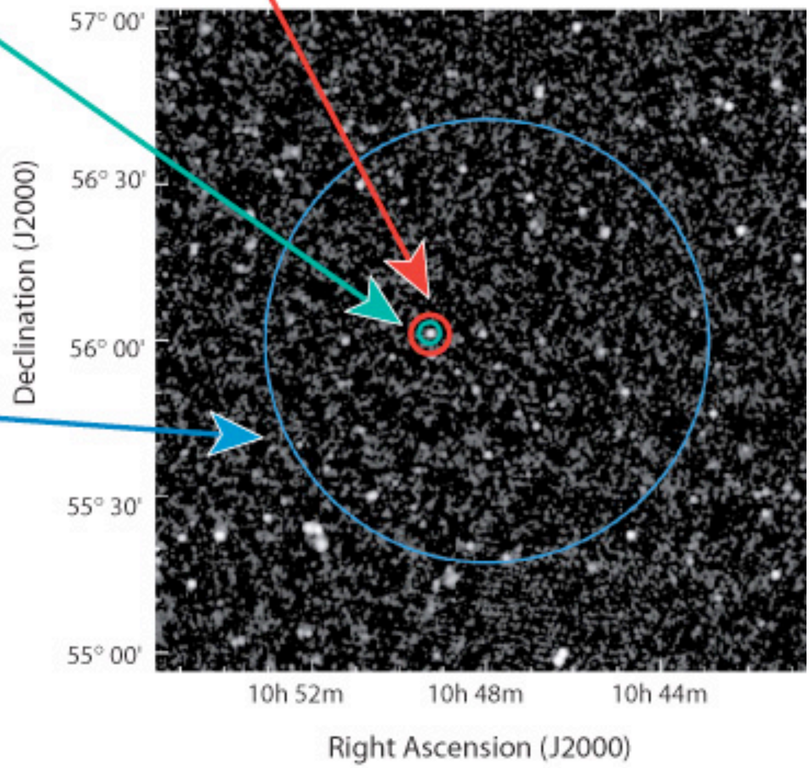
AMS

- **Source localization:**
  (E >10 GeV) < 2'

In 1 Year and for source of strength:
5.x 10^{-8} ph cm^{-2} s^{-1} (E = 1 GeV)

GLAST

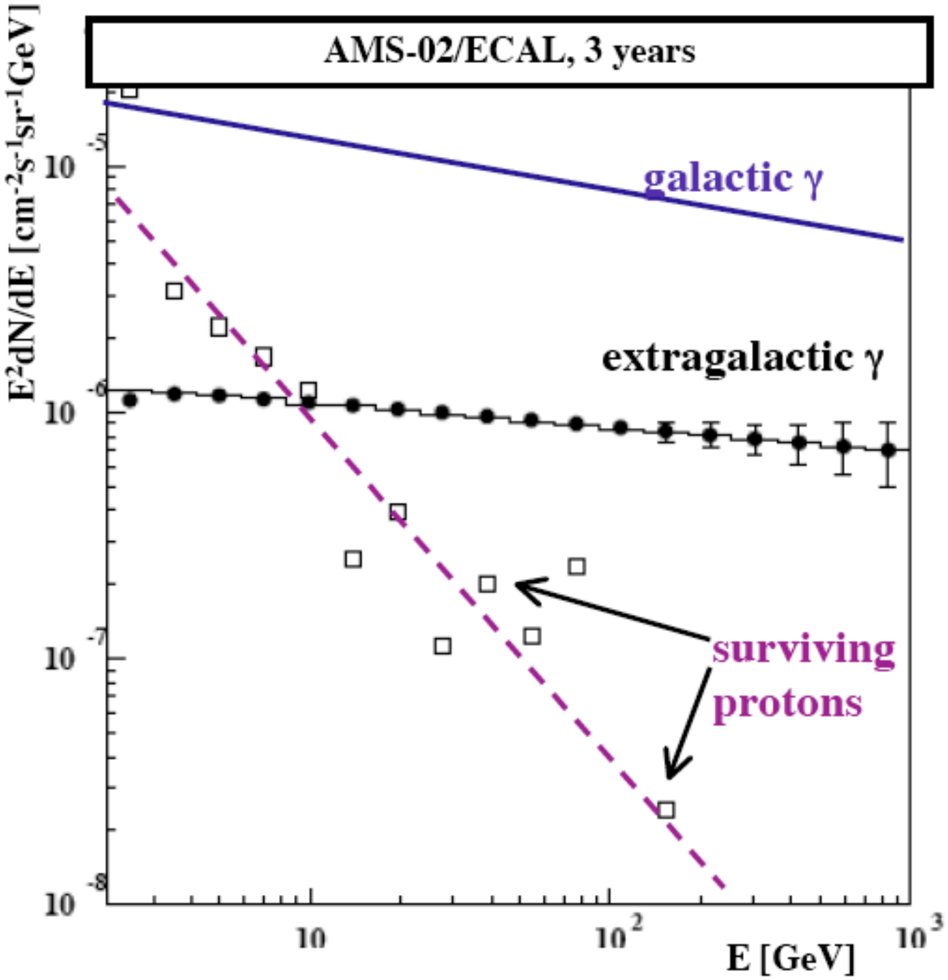
Source localization:
< 5' and high sensitivity

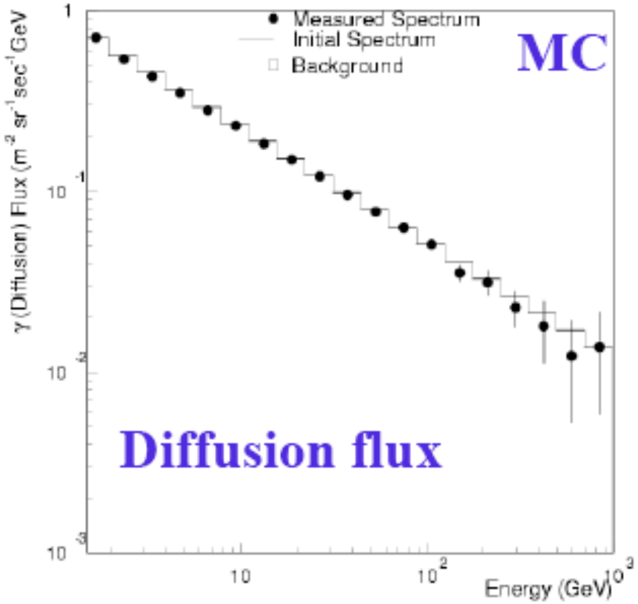


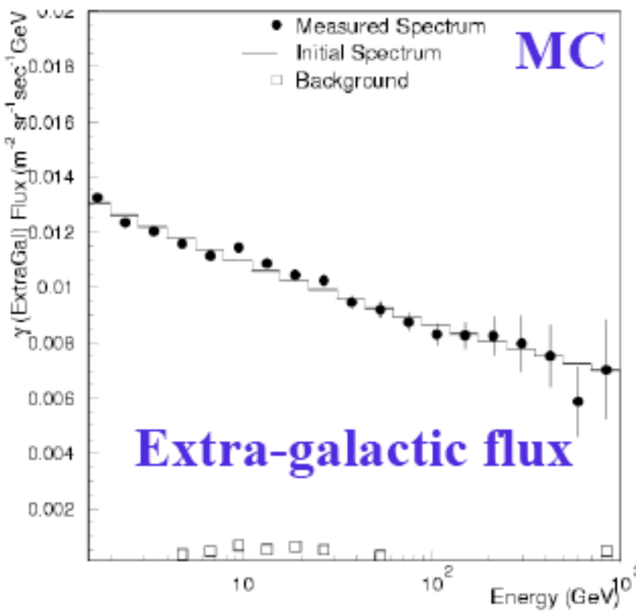
EGRET

- **Source localization:**
  < 30'
  for source of strength
  10^{-8} ph cm^{-2} s^{-1}
- **Limited sensitivity above 1 GeV**

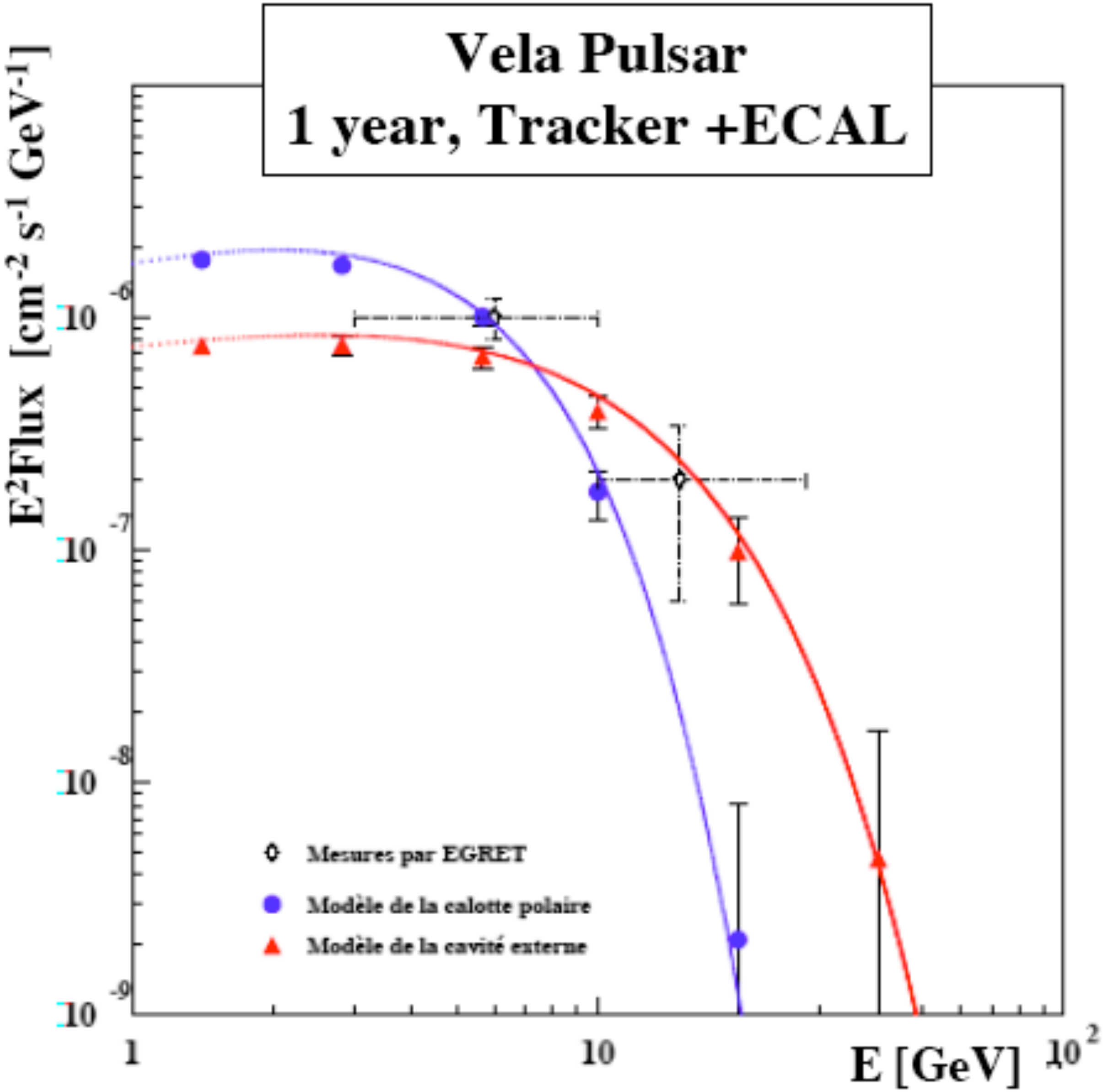
AMS: GAMMA G, EG



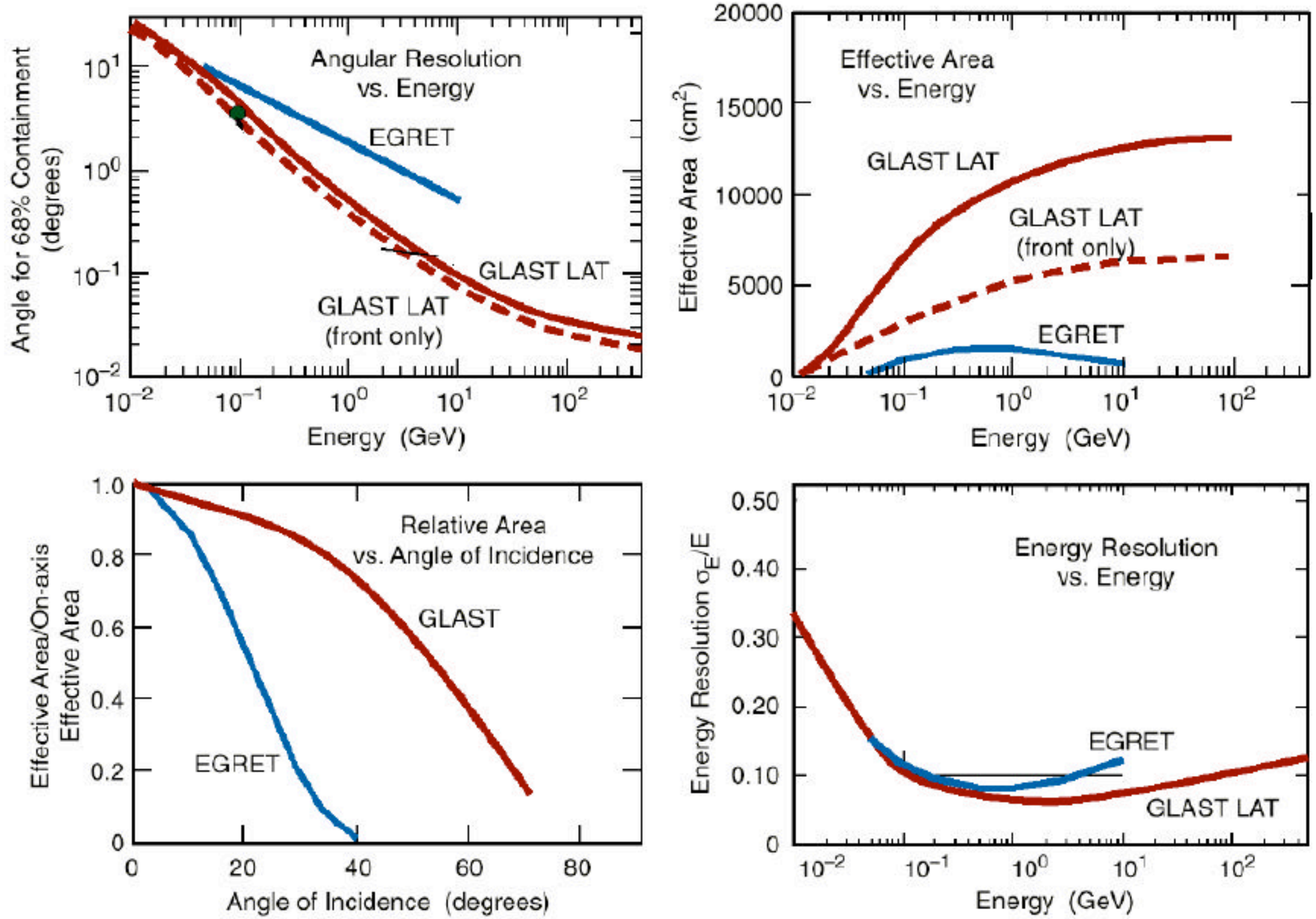




AMS: MODELLI PULSAR

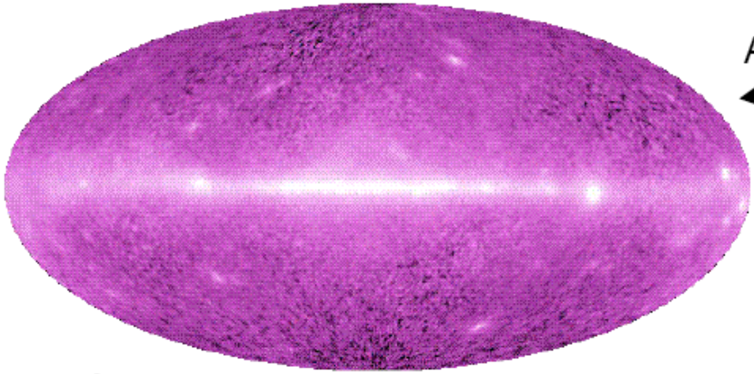


GLAST: PRESTAZIONI

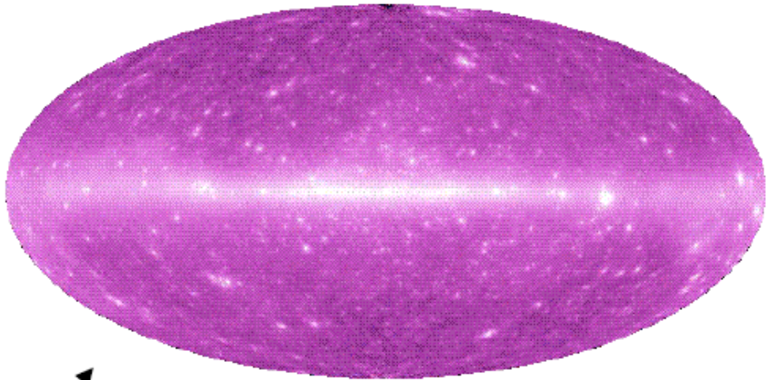


GLAST

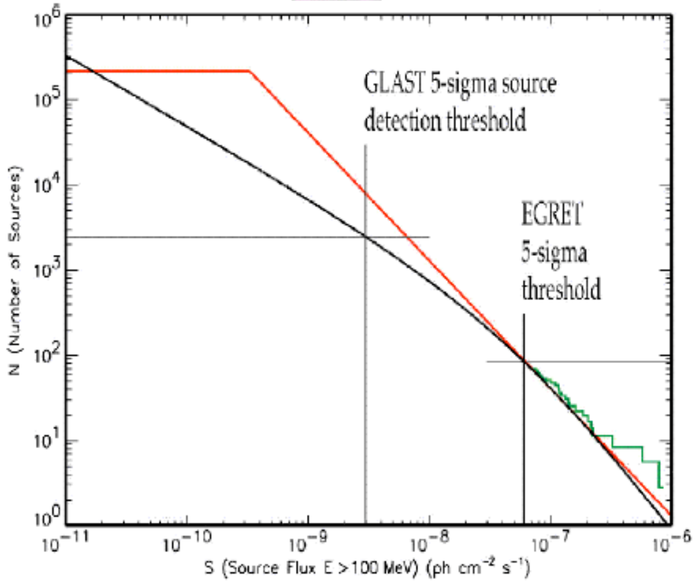
One year All-Sky Survey Simulation, Eγ > 100 MeV



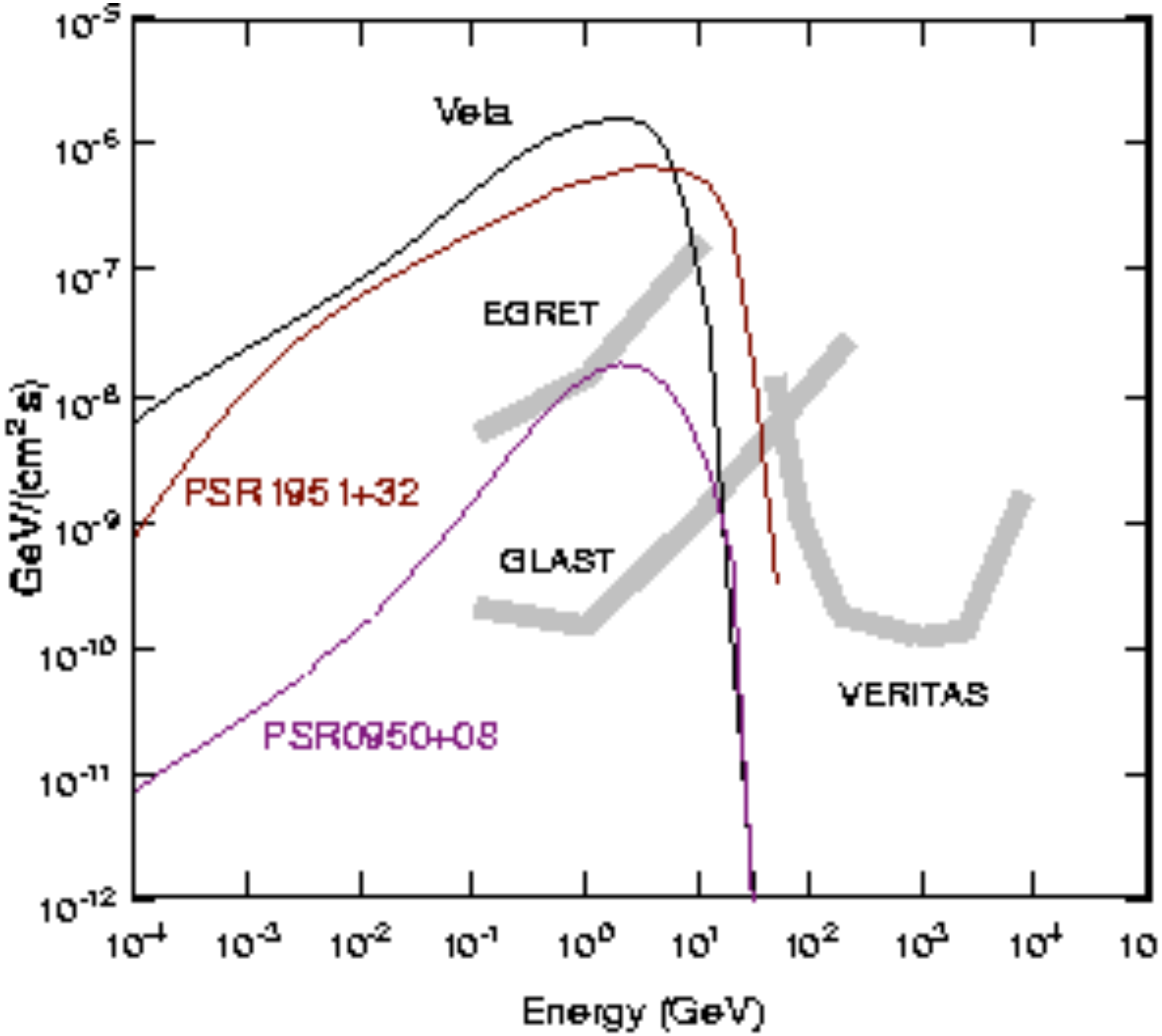
All-sky intensity map based on five years EGRET data.



All-sky intensity map from a GLAST one year survey, based on the extrapolation of the number of sources versus sensitivity of EGRET

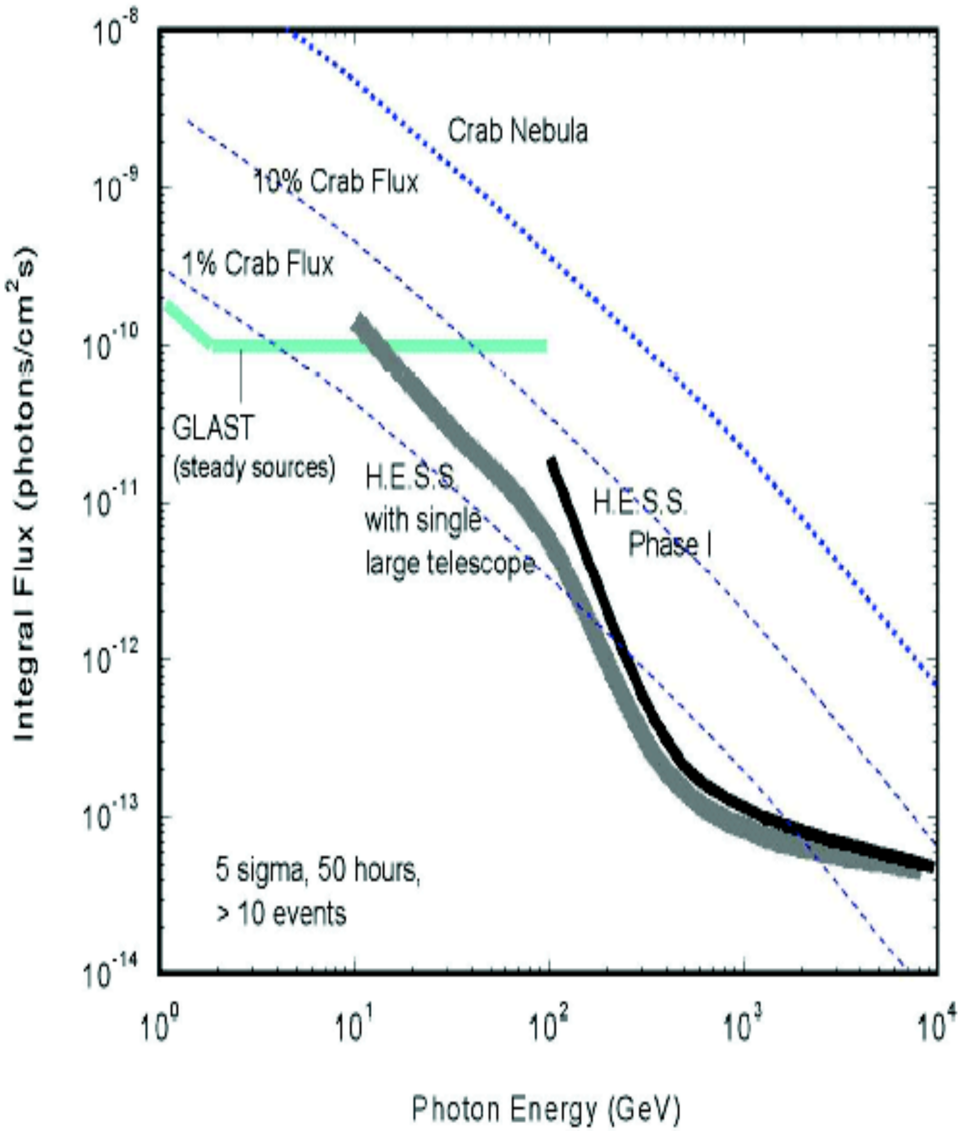


PULSAR: POLAR CAP

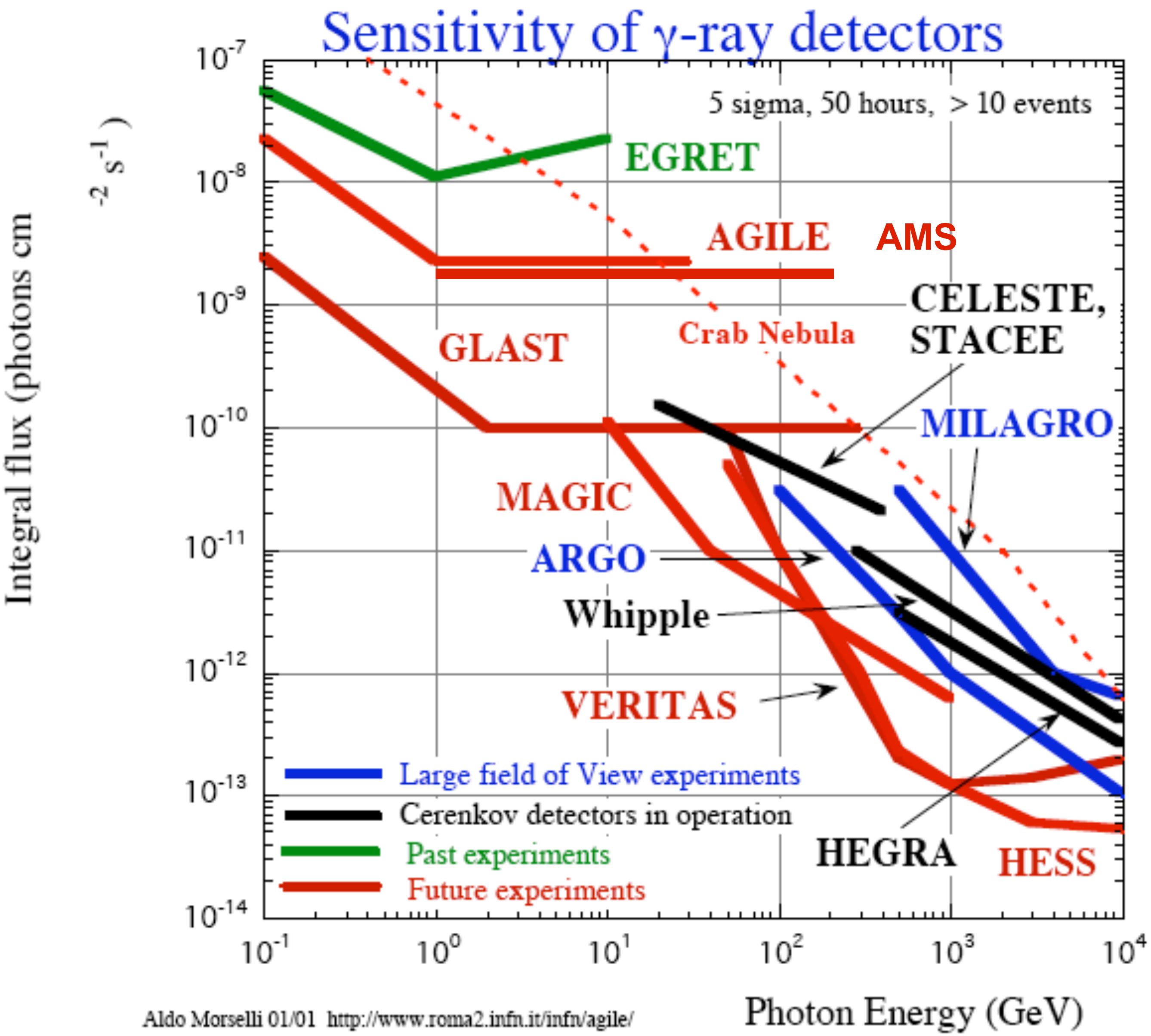


OSSERVAZIONE SPAZIO-TERRA

- Gli esperimenti nello spazio e a Terra sono complemetari fra di loro. Nella figura è mostrata la sensibilità al flusso di gamma vs l’energia di GLAST e di HESS. Le linee blu rappresentano rispettivamente il flusso di fotoni dalla Crab Nebula e lo stesso flusso ridotto per un fattore 10 e 100.



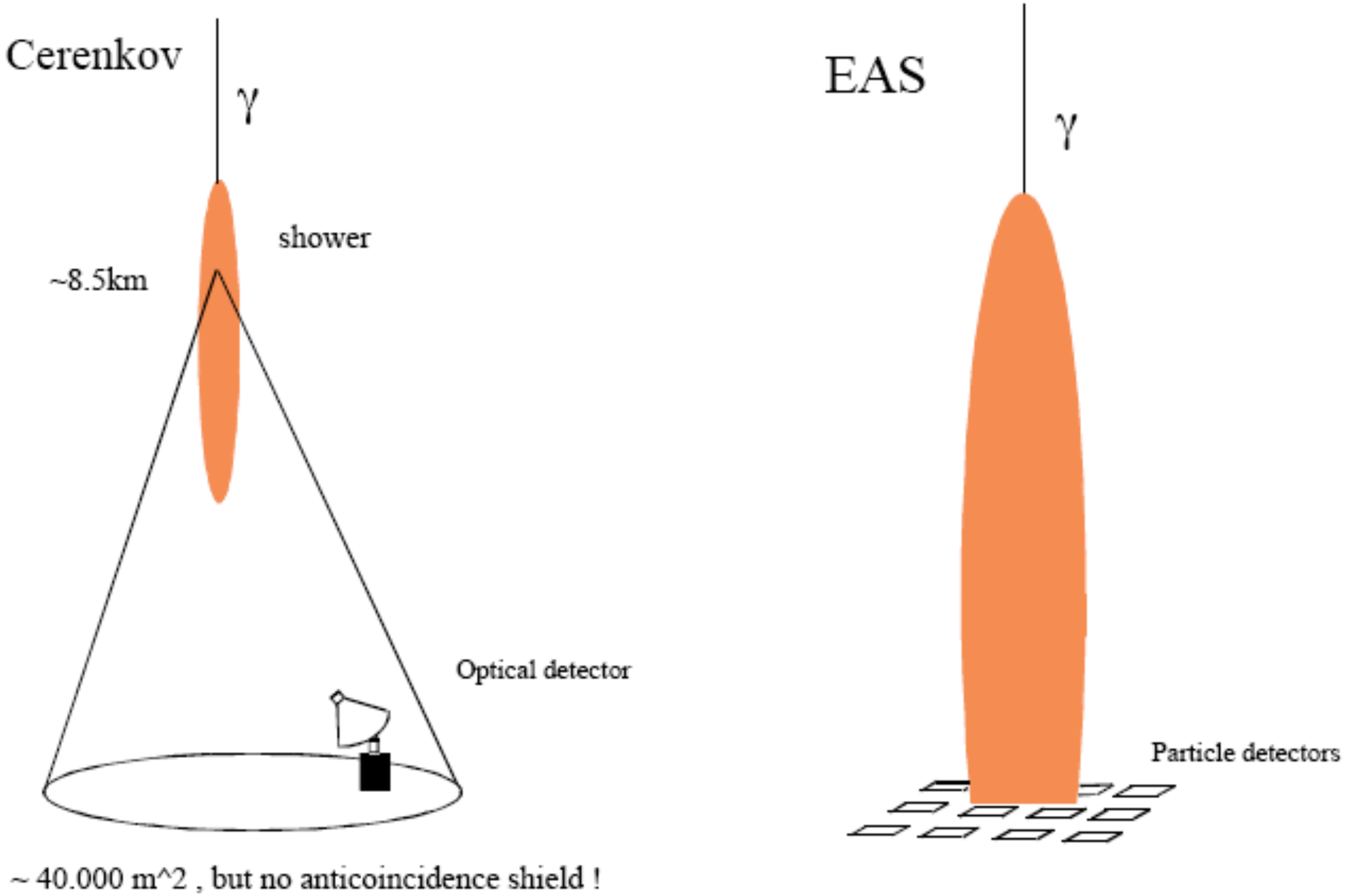
RIVELATORI GAMMA



Esperimenti
Telescopi Cerenkov

SCIAMI IN ATMOSFERA

Cerenkov and Extensive air shower (EAS) gamma ray telescope concepts



CERENKOV IN ATMOSFERA

- A livello del mare $(n - 1) = \varepsilon \approx 3\ 10^{-4}$.
- Per $v \approx c$, $\cos\theta = 1/\beta n \approx 23$ mrad $\approx 1.3°$
- Energia di soglia per l'effetto Cerenkov: $\cos\theta = 1 = 1/\beta n$; $\beta > 1/n$

$E = \gamma mc^2 = mc^2/(1-\beta^2)^{1/2}$; $(1-\beta^2)^{1/2} = (1-1/n^2)^{1/2} = [(n^2-1)/n^2]^{1/2}$

$E = mc^2/\sqrt{(2\varepsilon)}$ $1/\sqrt{2\varepsilon} \approx 41$

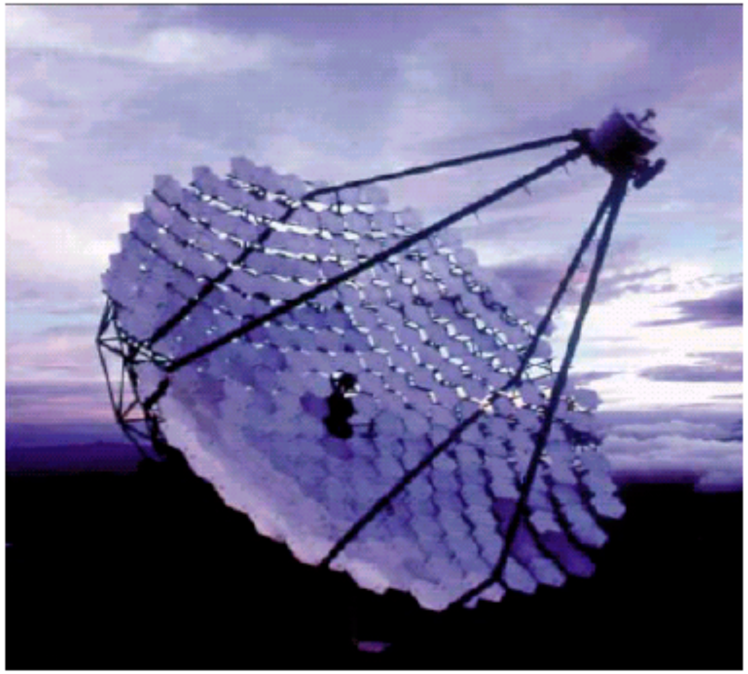
- La soglia per elettroni: $E \approx 21$ MeV

  muoni: $E \approx 4.4$ GeV
- Il massimo di produzione di particelle si ha a 10 km di quota (massimo di produzione Cerenkov).
- L'area illuminata a terra è un ellisse, o un cerchio di raggio $r = h \cdot \theta = 10^4\ 23\ 10^{-3} = 230$ m con una superficie di $1.6\ 10^5\ m^2$.
- Il numero di fotoni prodotti nel visibile, 350—500 nm, da un gamma di 1 TeV è

$$N\gamma \approx 8.2\ 10^3 \text{ fotoni}/\lambda$$

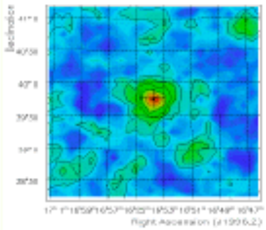
pari a circa 30—50 fotoni/m^2in un'area entro ≈100m dall'asse dello sciame.

CERENKOV

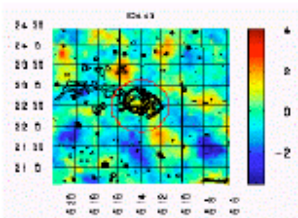


Whipple: diametro=10m, E > 350 GeV

The Whipple collaboration, which pioneered the Imaging Atmospheric Cherenkov Technique for the detection of very high energy (VHE) gamma rays, is based at the Fred Lawrence Whipple Observatory in Southern Arizona, in the United States. **The primary emphasis of the collaboration's research effort is the search for and study of celestial sources of gamma-rays in the energy range of 100 GeV - 10 TeV.**



MHK501



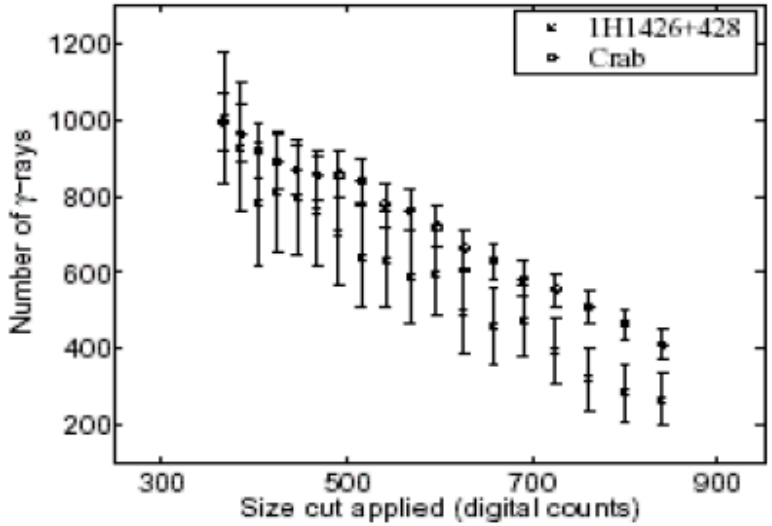
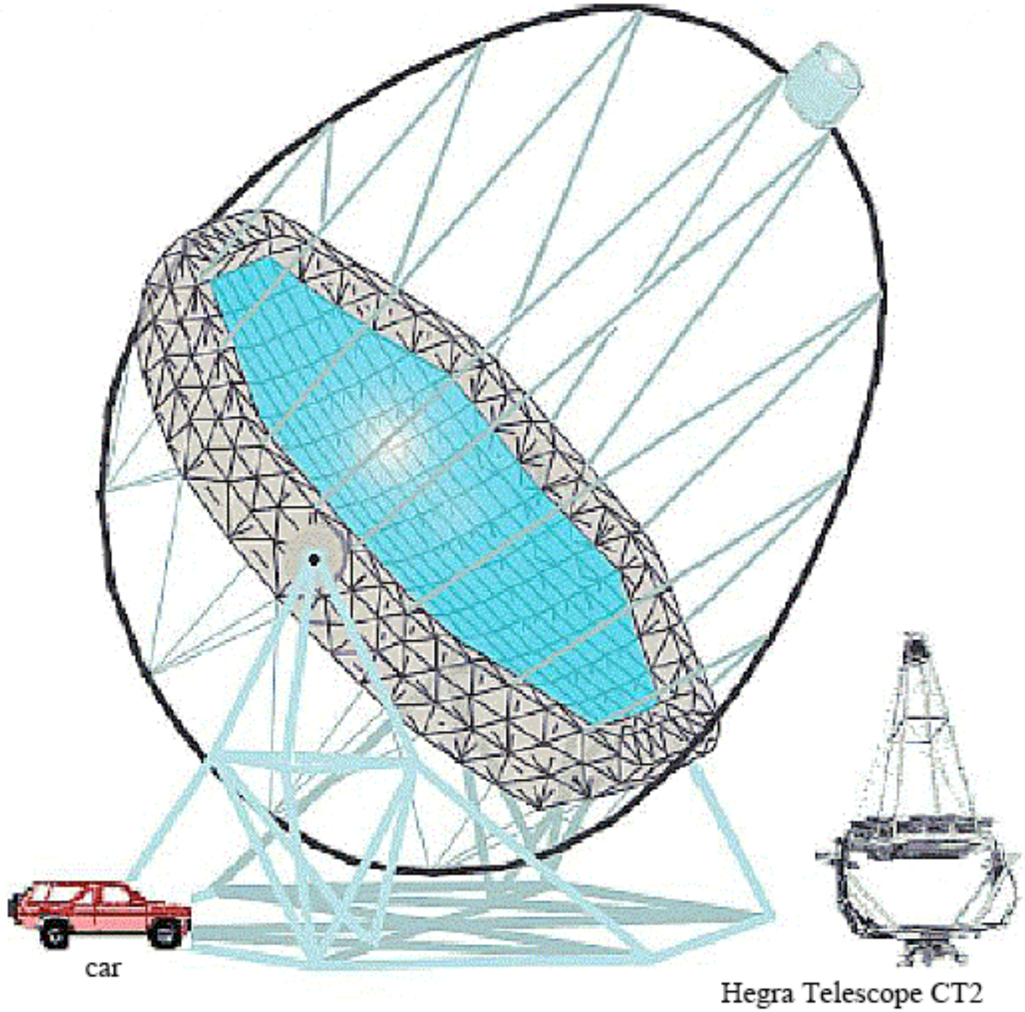


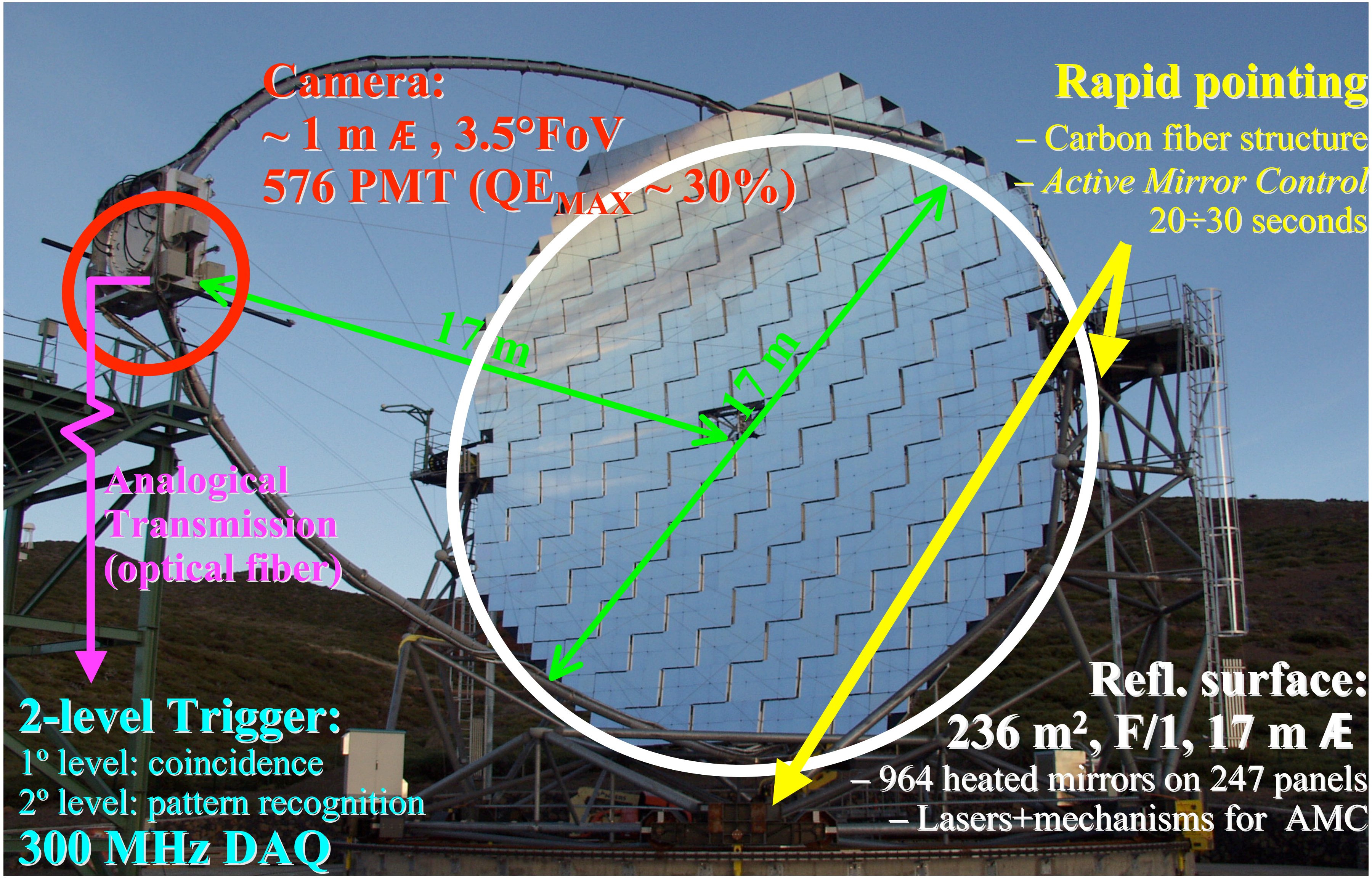
Fig. 4.— Integral excess events observed by the Whipple telescope from the directions of 1H1426+428 (crosses) and the Crab Nebula (open circles) during 2001 as a function of integrated Cerenkov light in the shower image. Exposure on the Crab Nebula was adjusted to match the total excess of 1H1426+428 at the lowest size cut applied, 366 digital counts. One photoelectron corresponds to ∼ 3.6 digital counts.

MAGIC

220 m^2
E: 10-300 GeV
La Palma



MAGIC



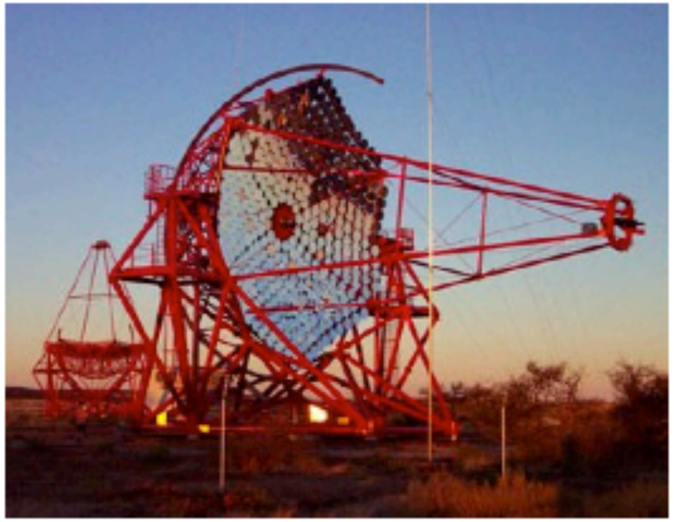
Camera:
~ 1 m Æ , 3.5°FoV
576 PMT (QE_MAX ~ 30%)
Rapid pointing
– Carbon fiber structure
– Active Mirror Control
20÷30 seconds
17 m
17 m
Analogical
Transmission
(optical fiber)
2-level Trigger:
1º level: coincidence
2º level: pattern recognition
300 MHz DAQ
Refl. surface:
236 m², F/1, 17 m Æ
– 964 heated mirrors on 247 panels
– Lasers+mechanisms for AMC


MAGIC 24 APRILE 2009

CERENKOV

HESS

H.E.S.S. is a next-generation system of Imaging Atmospheric Cherenkov Telescopes for the investigation of cosmic gamma rays in the 100 GeV energy range. The name H.E.S.S. stands for **High Energy Stereoscopic System**, and should also remind of **Victor Hess , who received in 1936 the Nobel Prize in Physics for his discovery of cosmic radiation**. The acronym also emphasizes two main features of the proposed installation, namely the **simultaneous observation of air showers with several (3 to 4) telescopes, under different viewing angles**, and the **combination of multiple (up to 16) telescopes to a large system to increase the effective detection area for gamma rays**. With telescopes of over 100 m^2 mirror area, the proposed system provides a



- **detection threshold of about 40 GeV,**
- **full spectroscopic capability above 100 GeV, an**
- **angular resolution for individual showers of 0.1 degrees**
- **energy resolution of about 20%.**

It will allow to explore gamma-ray sources with intensities at a level of a few thousandth parts of the flux of the Crab nebula. H.E.S.S. is located in Namibia, near the Gamsberg, an area well known for its excellent optical quality. The first four H.E.S.S. telescopes (Phase I of the H.E.S.S. project) are under construction and are expected to successively go into operation between early 2002 and 2003

I quattro telescopi della Fase I sono stati completati nel dicembre 2003

The H.E.S.S. technology

Christopher van Eldik from Germany and Eben Tjingaete from Namibia checking mirror facets

Just like big optical telescopes, the H.E.S.S. Cherenkov telescopes consist of a mirror which focuses the incident light, and a light detector (the 'camera') to record the images. A mount allows the telescope to rotate and to track celestial objects as they move across the sky.

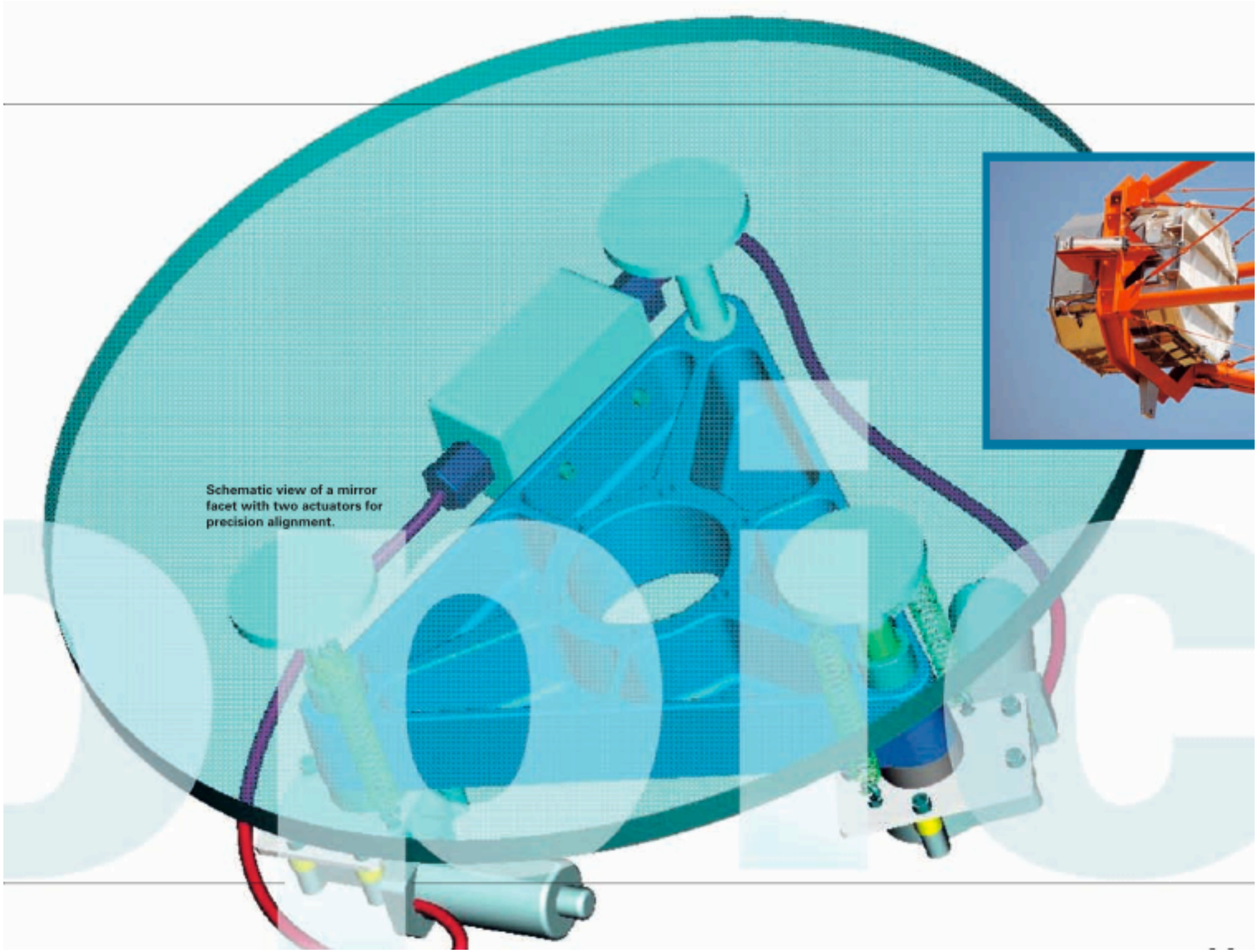
Mount and mirror dish

Mount and dish are sturdy steel structures, designed for high rigidity. The steel structure weighs 60 tons; it was designed in Germany and fabricated in Namibia. Computer-controlled drive systems steer the telescopes with high precision.

Mirrors

The diameter of the dish is more than 12 m, and the mirror area 107 m^2. Mainly for cost reasons, the mirror is composed of 380 individual facets, made of ground glass and aluminised for best reflectivity. Each facet can be aligned under remote control using two motor-driven actuators, with a precision of a few thousandth of a millimeter.

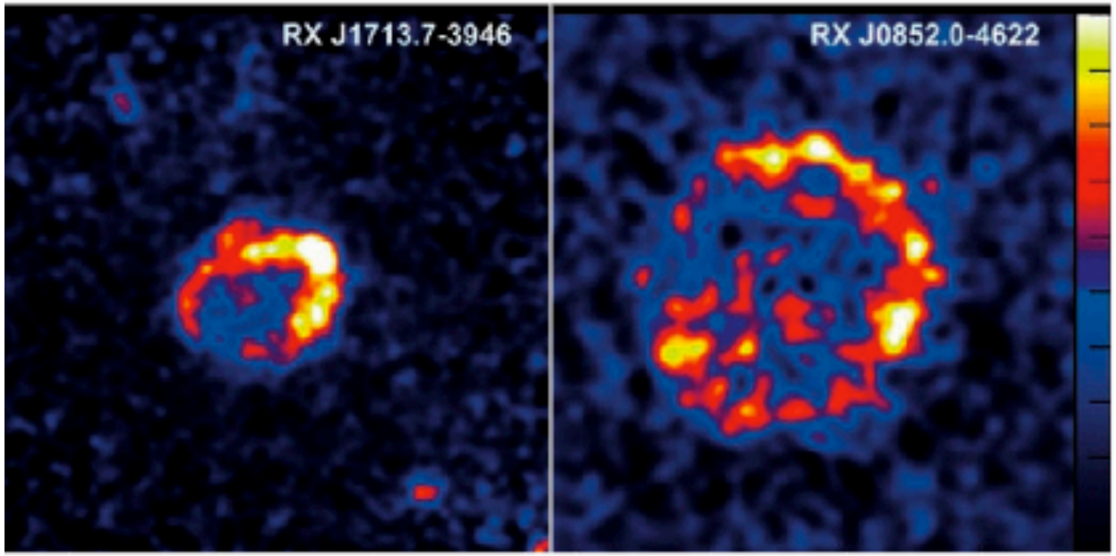
HESS



Schematic view of a mirror facet with two actuators for precision alignment.

HESS

Supernova explosions ...



Le immagini di HESS mostrano chiaramente la shell delle supernove dove hanno origine i gamma

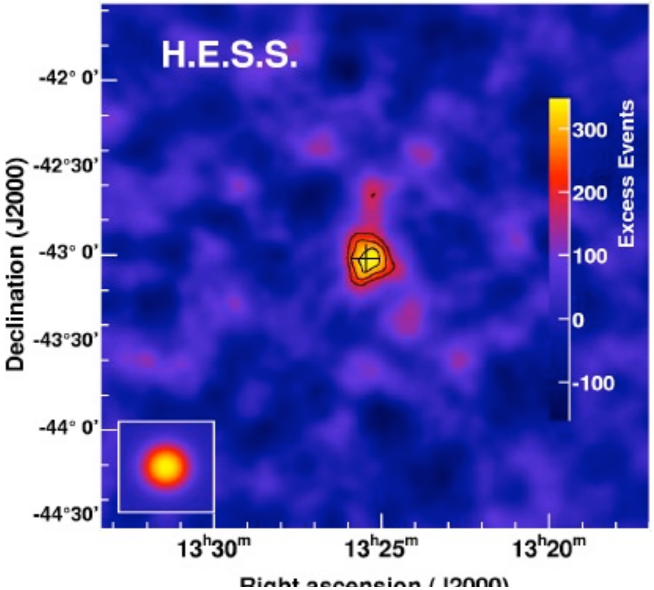
If supernova explosion waves are cosmic accelerators - as long suspected by scientists - they should be clearly visible in gamma rays. Indeed, H.E.S.S. images resolve the ring-like shock fronts for the first time and show them glowing in high-energy gamma rays.

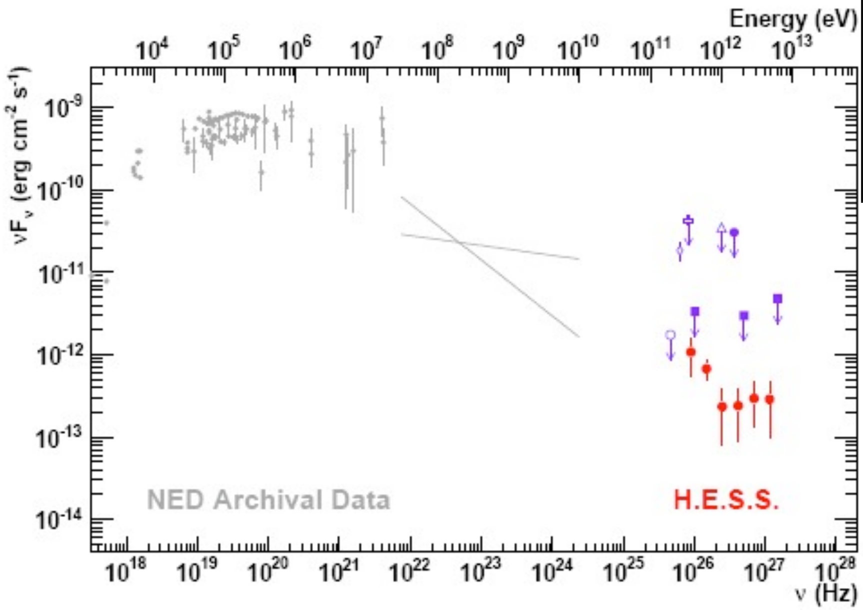
One of the first highlights of the H.E.S.S. observations was the discovery of high-energy gamma rays from two supernova explosion shells, whose 'names' RX J1713.7-3946 and RX J0852.0-4622 refer to their celestial coordinates and the fact that they were first seen as X-ray sources. The H.E.S.S. telescopes were able to resolve the spatial structure of the gamma-ray source; as predicted, gamma rays were found to exactly trace the supernova shell. This discovery proves conclusively that supernova explosion waves work as cosmic accelerators, at least up to energies of 100 million million electrons volts ('electron volt' is a unit characterising the energies of particles and radiation; visible light has 2 to 4 electron volts).

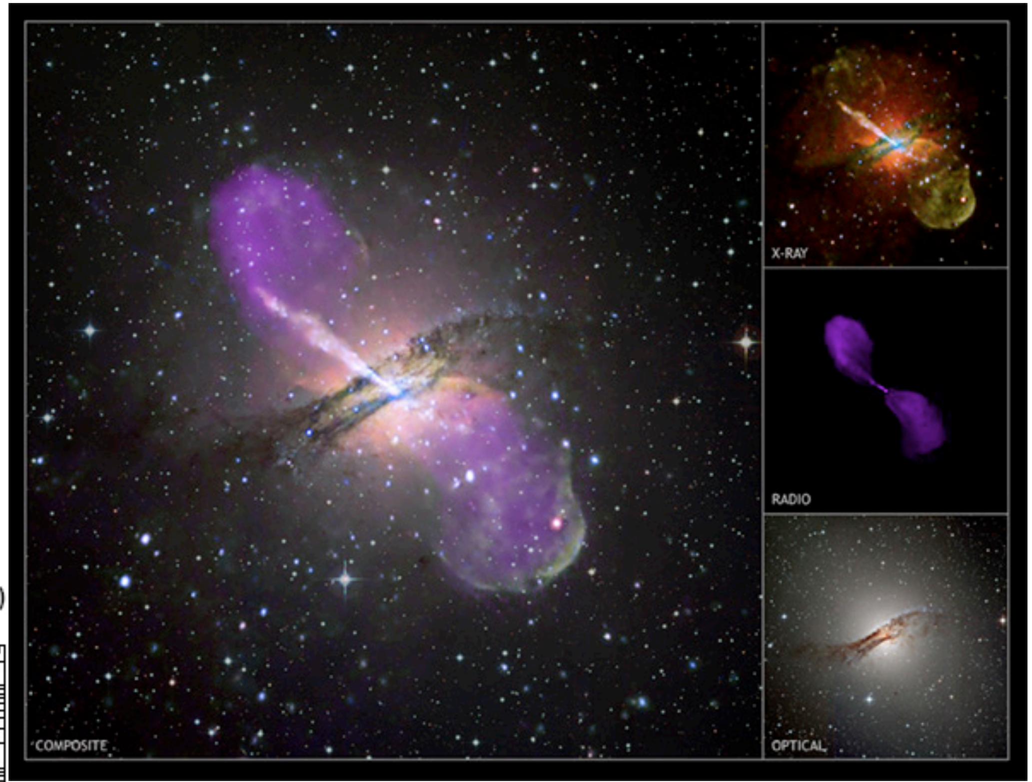
Background

Our entire Galaxy is permeated by cosmic rays – atomic nuclei accelerated to very high energies. The existence of cosmic rays was discovered by Victor Hess in 1912, almost 100 years ago. Throughout this time, the origin of cosmic rays was heavily debated: Somewhere in our Galaxy must be cosmic particle accelerators capable of creating particle energies many orders of magnitude beyond the biggest man-made accelerators on Earth.

HESS: CENTAUROS A







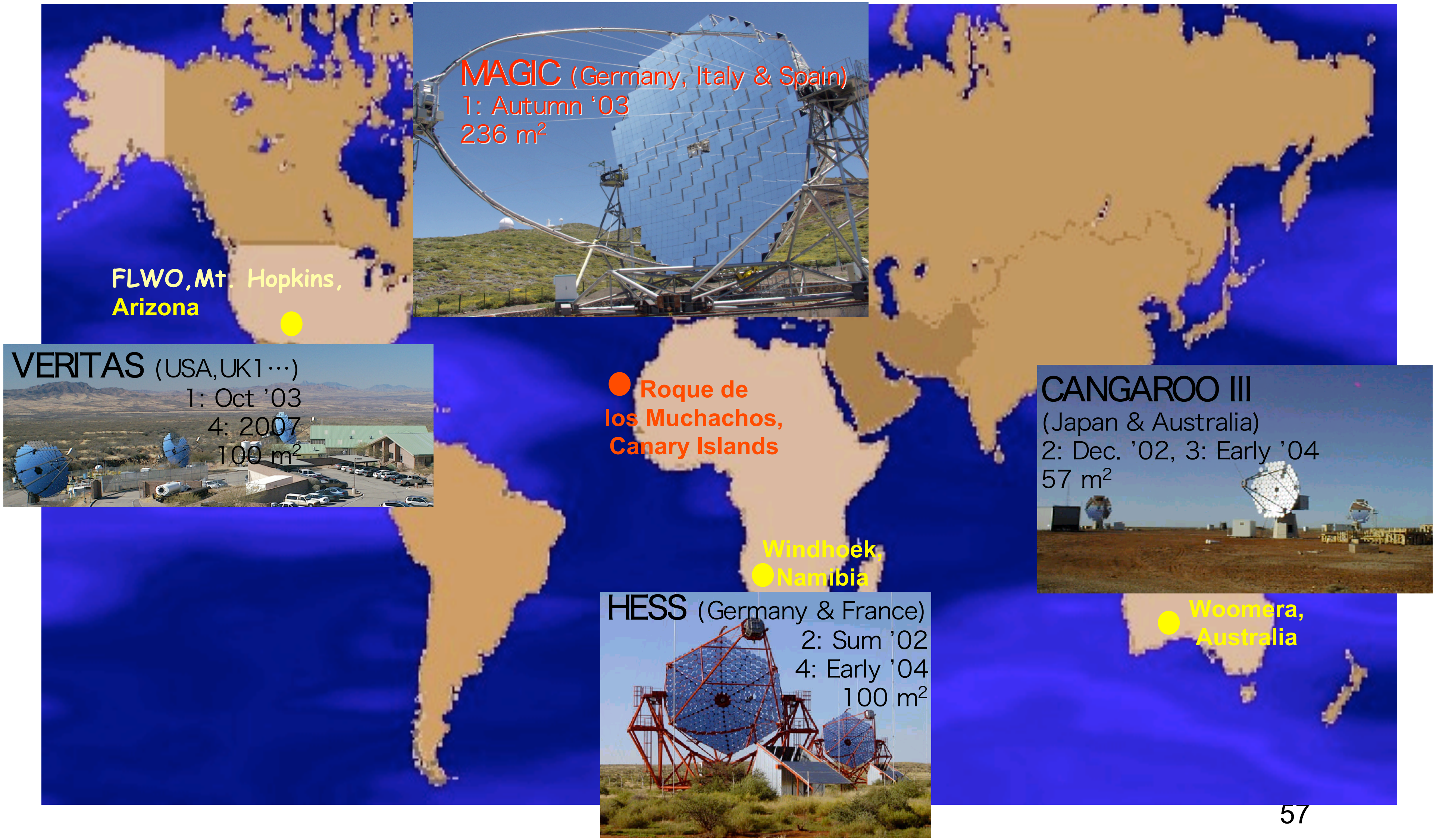
Spectral distribution of the emission from Centaurus A, from X-rays to the VHE gamma-ray energy band. Archival X-ray and EGRET gamma-ray data are shown in grey, previous VHE upper limits and the tentative early detection in purple.


VERITAS


The High Energy Stereoscopic System (H.E.S.S.)


CANGAROO

The “Big Four”


MAGIC (Germany, Italy & Spain)
1: Autumn ‘03
236 m2
FLWO, Mt. Hopkins,
Arizona
VERITAS (USA, UK1…)
1: Oct ’03
4: 2007
100 m2
Roque de
los Muchachos,
Canary Islands
CANGAROO III
(Japan & Australia)
2: Dec. ’02, 3: Early ’04
57 m2
Windhoek,
Namibia
HESS (Germany & France)
2: Sum ’02
4: Early ’04
100 m2
Woomera,
Australia

TELESCOPI CERENKOV

Group/ Instrument	Location	Reflector(s) Number × Aperture	Camera Pixels	Threshold (GeV)	Epoch Beginning
Operating Telescopes[a]					
Whipple	Arizona, USA	10 m	331	250	1984
Crimea	Crimea, Ukraine	6×2.4 m	6×37	1000	1985
SHALON	Tien Shen, Russia	4 m	244	1000	1994
CANGAROO	Woomera, Aust.	3.8 m	256	500	1994
HEGRA	La Palma, Sp.	5 × 3 m	5 × 271	500	1994
CAT	Pyrenées	3m	600	250	1996
Durham/ Mark 6	Narrabri, Aust.	3× 7 m	1× 109	250	1996
TACTIC	Mt. Abu, India	4× 3.5 m	1×225	300	1997
Seven TA	Utah, USA	7×2 m	7×256	500	1998
STACEE	Sandia, New Mexico	32 ×7 m	32× 1	75	1998
CELESTE	Pyrenées, France	40×7 m	40×1	50	1998
Future Telescopes					
CANGAROO II	Woomera, Aust.	7 m	1×512	250	1999
GRAAL/CESA-1	Almeria, Sp.	63×7.1 m	4	100	1999
Solar II	Barstow, CA	96×7.1 m	96× 1	20	2002
MAGIC	La Palma, Sp.	17 m	1×800	30	2001
HESS	Namibia	4×10 m	4×700	50	2002
CANGAROO III	Woomera, Aust.	4× 10 m	4×512	75??	2003
VERITAS	Arizona, USA	7×10 m	7×499	75	2004

[a] From Catanese & Weekes 1999

Cerenkov Telescope Array (CTA)

CTA stands for an initiative to build the next generation ground-based gamma-ray instrument, which is supposed to serve as an open observatory to a wide astrophysics community and which will provide the deepest ever insight into the non-thermal high-energy universe. It foresees a factor of 5-10 improvement in sensitivity in the current energy domain of about 100 GeV to some 10 TeV and an extension of the accessible energy range well below 100 GeV and to above 100 TeV. The observatory will consist of two arrays: a southern hemisphere array, which covers the full energy range from some 10 GeV to about 100 TeV to allow for a deep investigation of galactic sources, and of the central part of our Galaxy, but also for the observation of extragalactic objects. A northern hemisphere array, consisting of the low energy instrumentation (from some 10 GeV to ~1 TeV) complements the observatory and is dedicated mainly to northern extragalactic objects. The design of CTA is based on currently available technology, and therefore allows for reliable predictions of the performance parameters of the observatory. At the same time, the option for future upgrades with new technology is kept open. Implementation of first prototype telescope(s) of the system could start in 2010 after a period of a detailed design study and optimization, site evaluation and production of industrial prototypes of components.