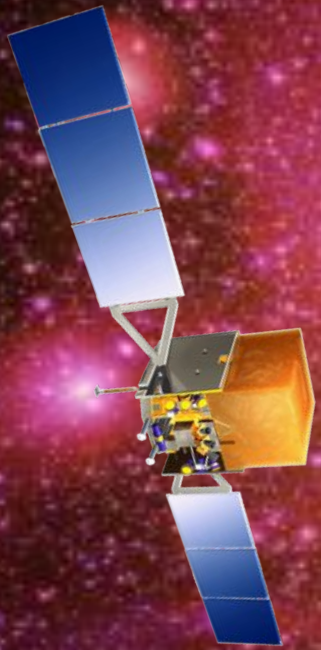
The Quest for Dark Matter Signals and the gamma-ray sky: the low energy window



Aldo Morselli
INFN Roma Tor Vergata

2 Feb 2013

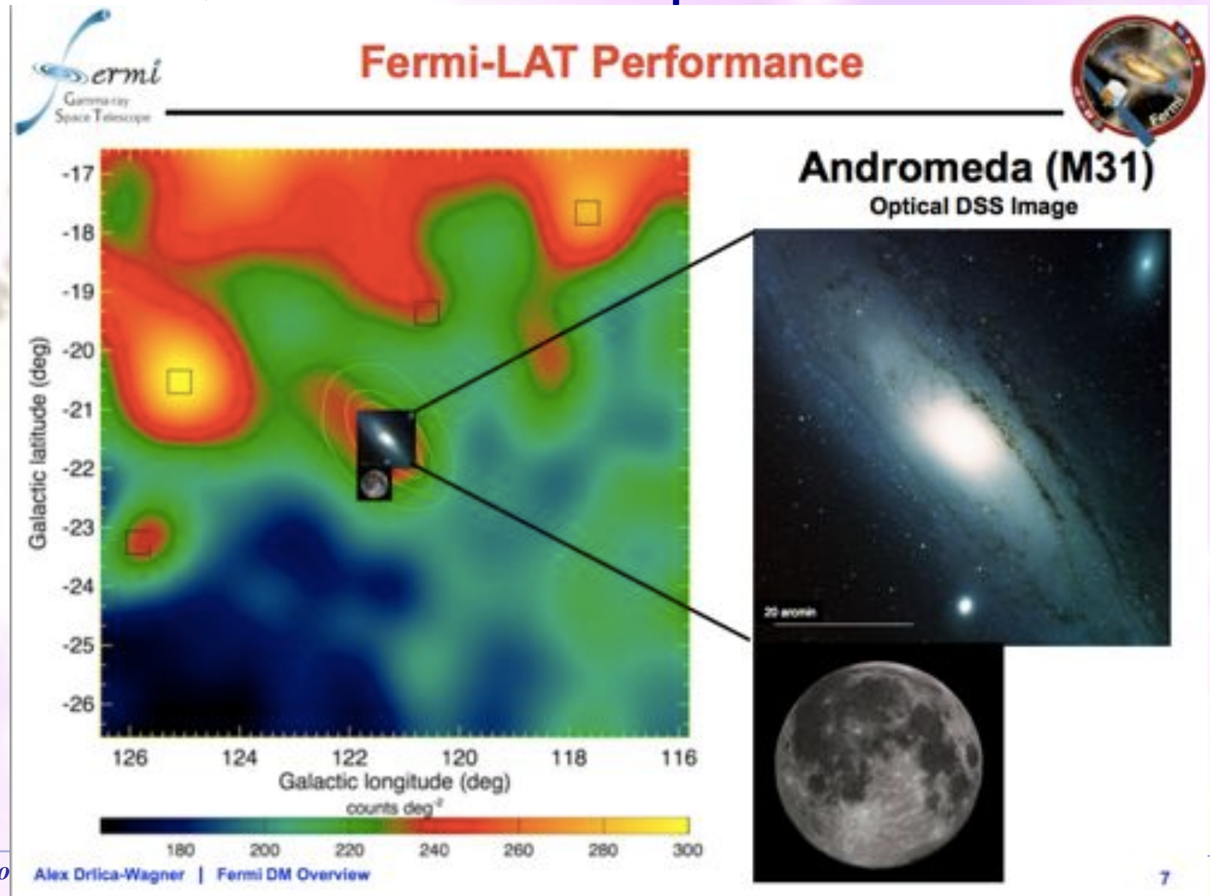
Aspen 2013 Closing on Dark Matter

many talks during this conferences:

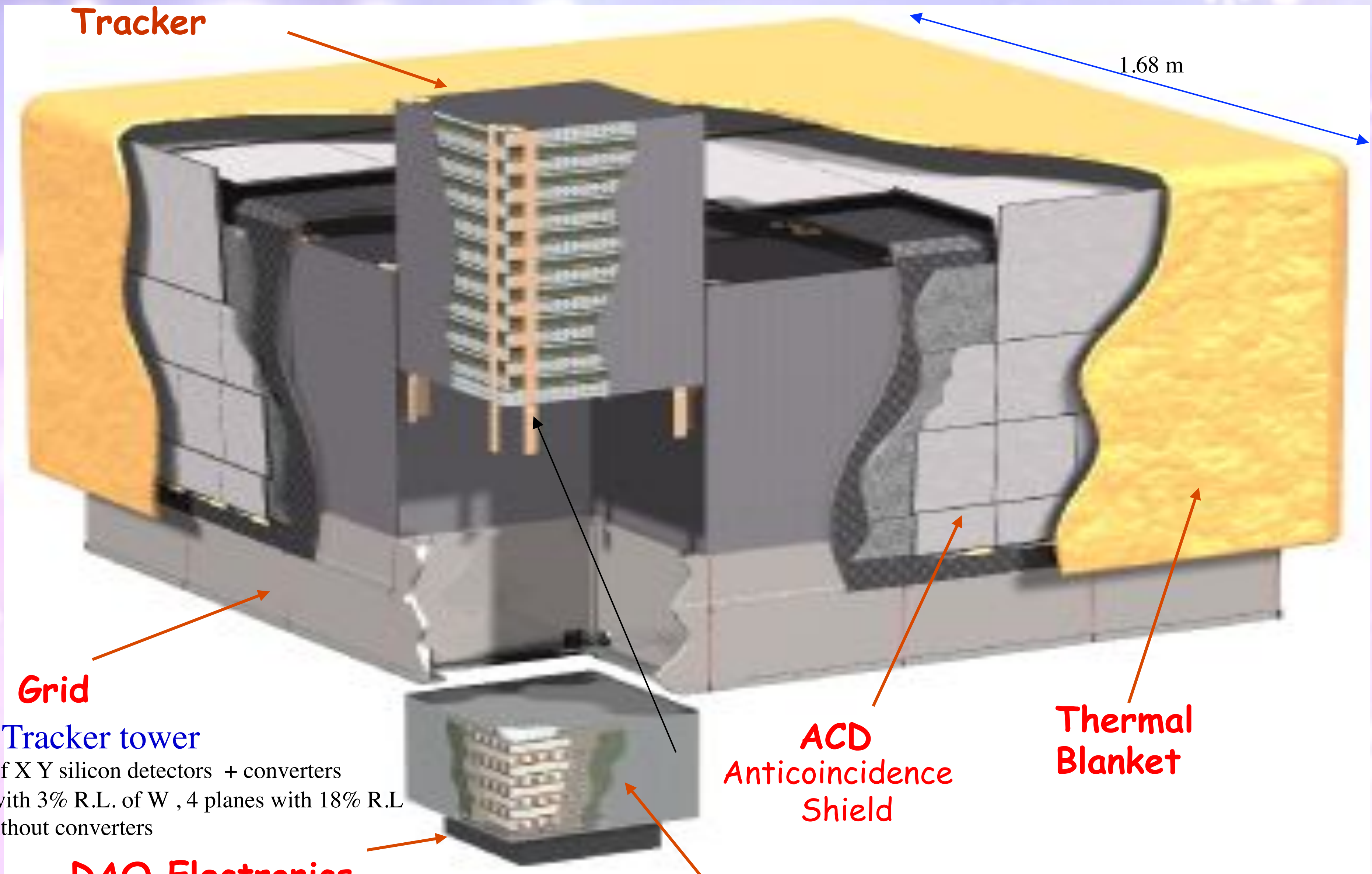
- Dan Hooper: In my opinion, no single indirect detection experiment has more potential to constrain or discover dark matter than the Fermi Gamma Ray Space Telescope (FGST)

- Tim Linden: the importance of the galactic center
 But we need more data to discriminate between pulsar and Dark Matter

- *Alex Drlica-Wagner* ⇨
Angular resolution of Fermi Lat
Compared with optical telescopes



Fermi Gamma-Ray Large Area Space Telescope



(8.5 Rad.Length)

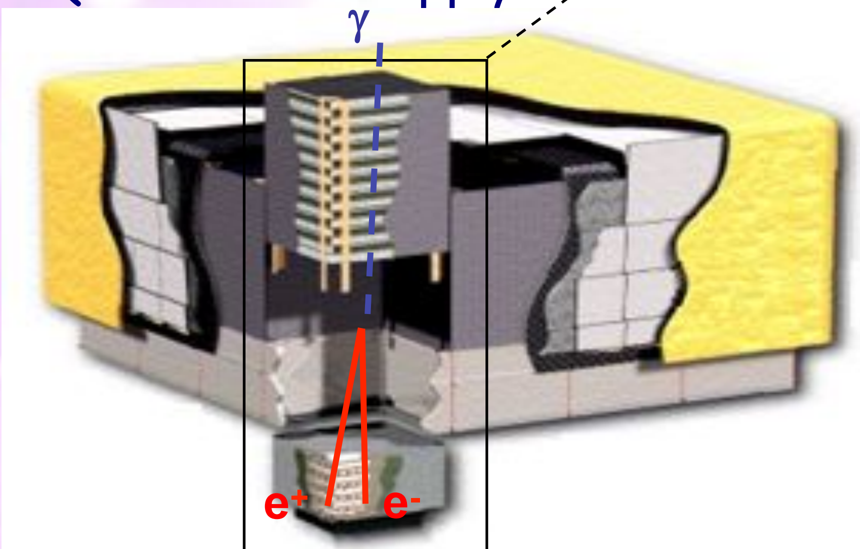
Silicon Tracker tower

18 planes of X Y silicon detectors + converters
12 planes with 3% R.L. of W , 4 planes with 18% R.L
2 planes without converters

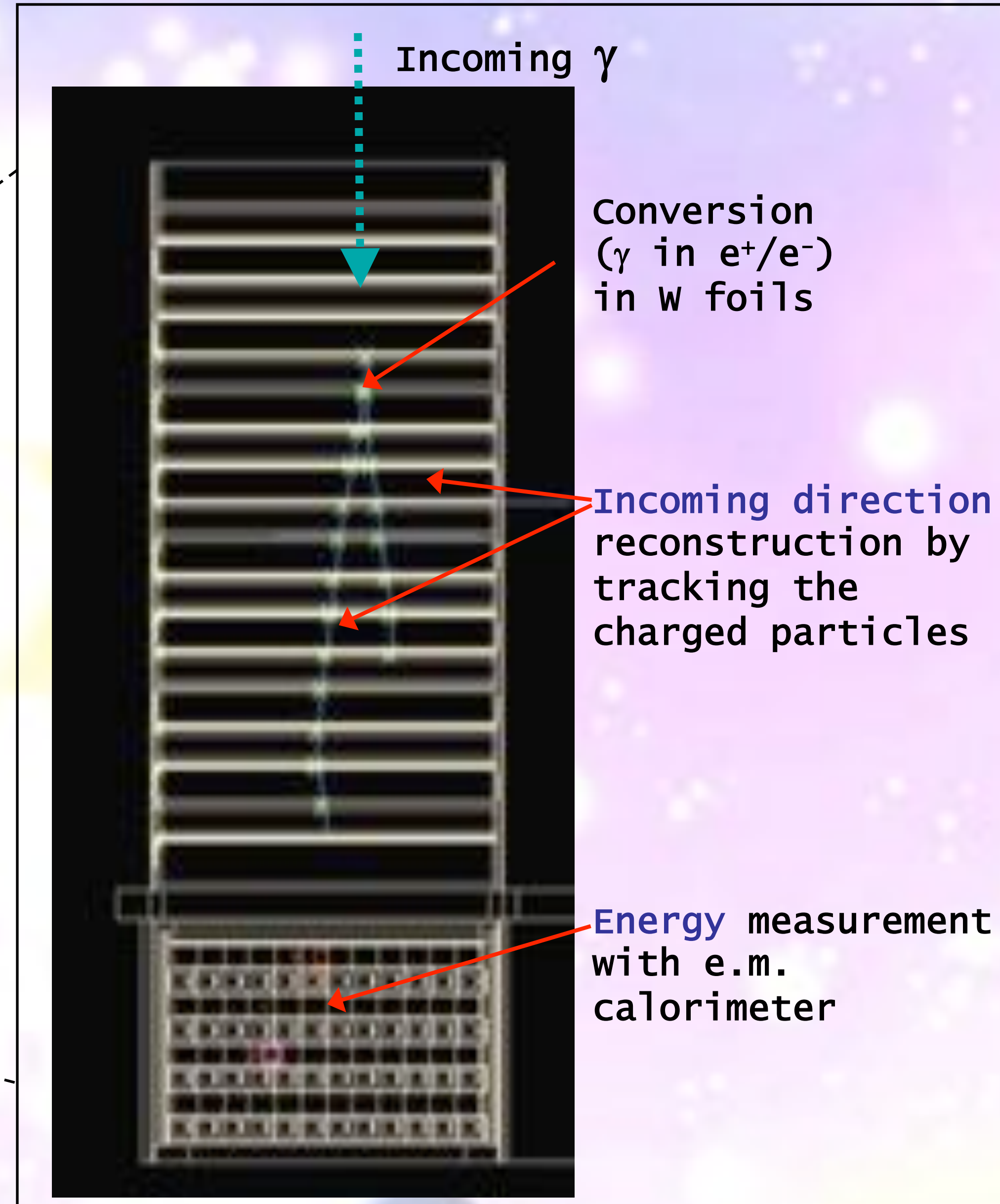
How Fermi LAT detects gamma rays

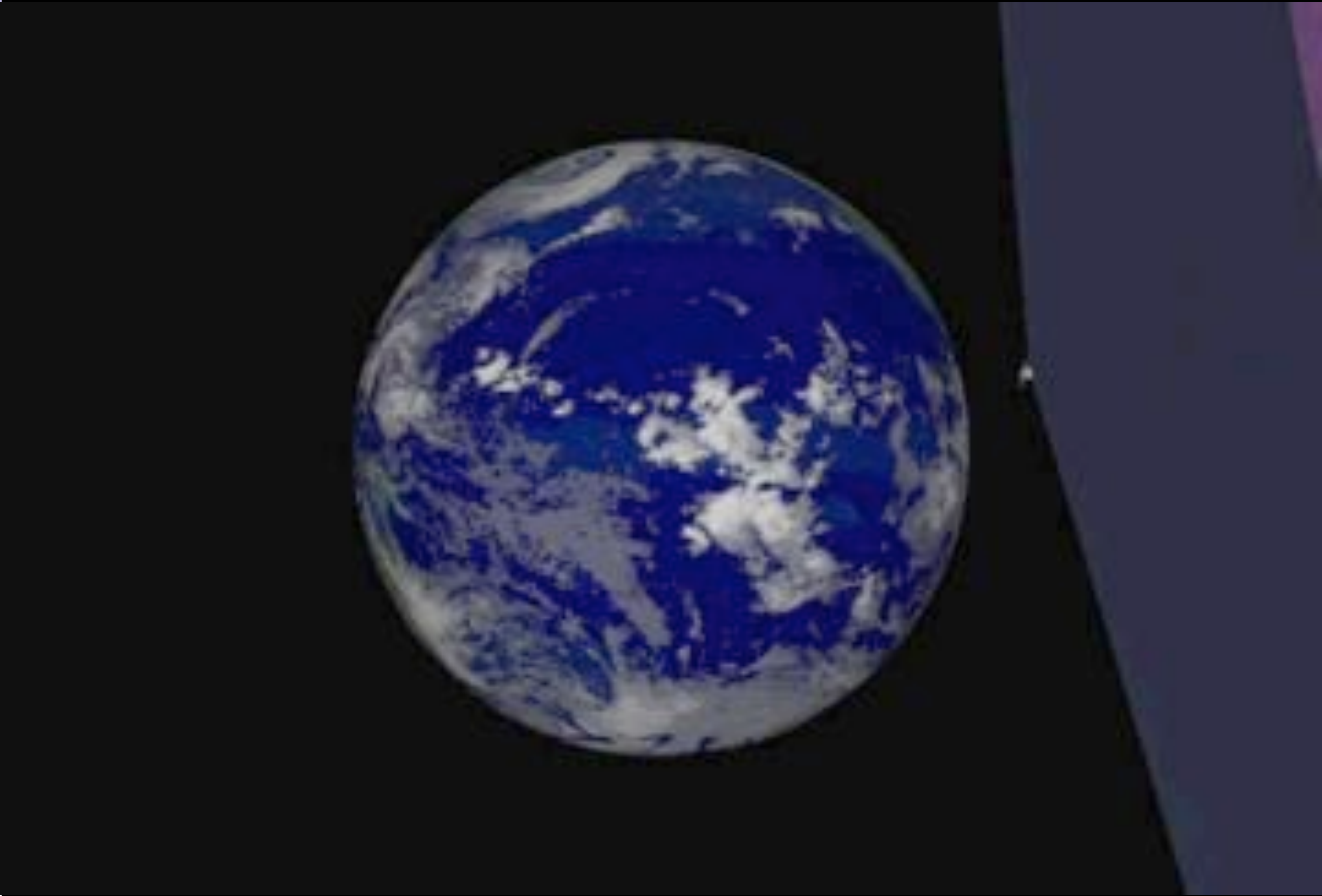
4 x 4 array of identical towers with:

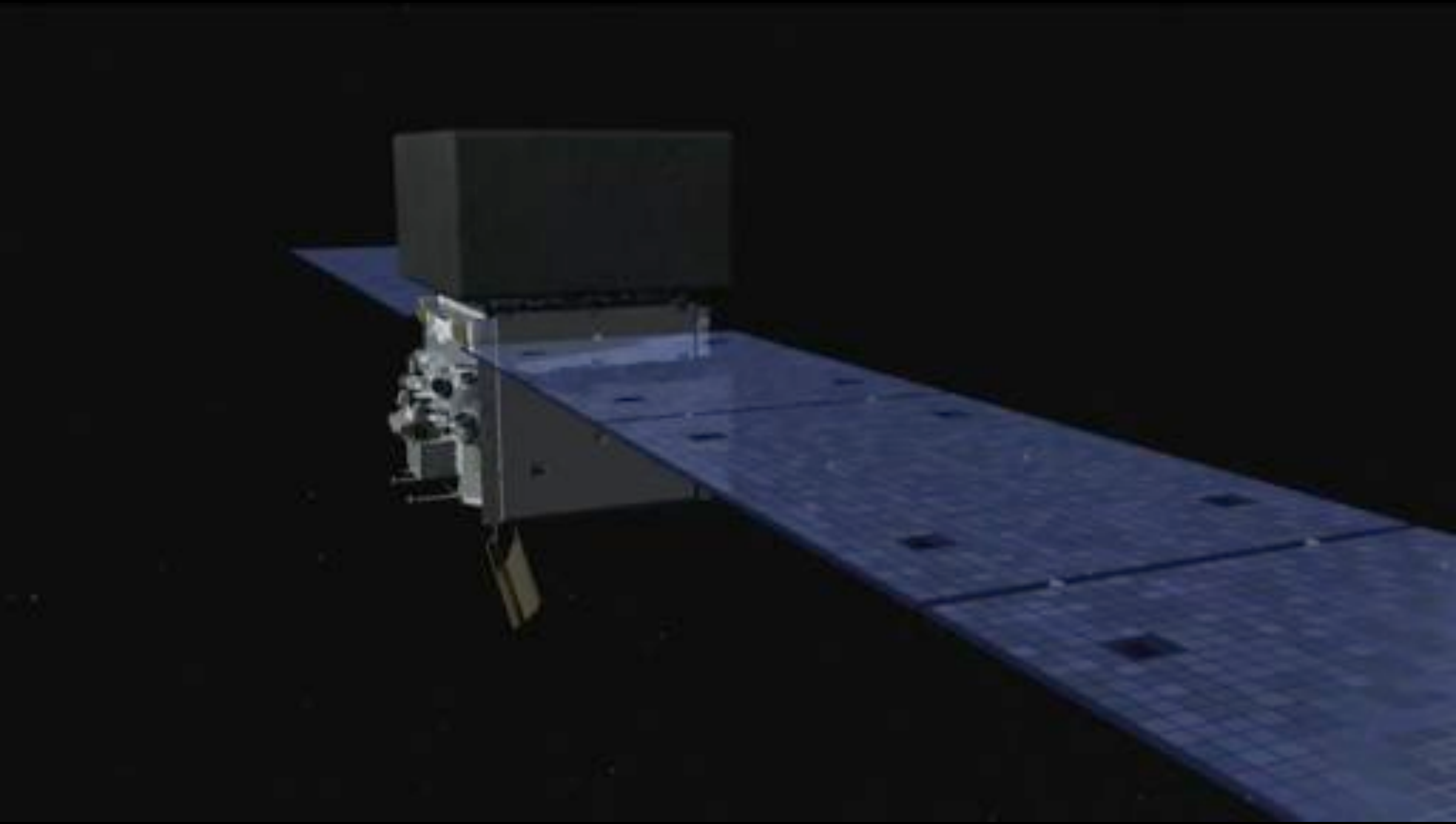
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box



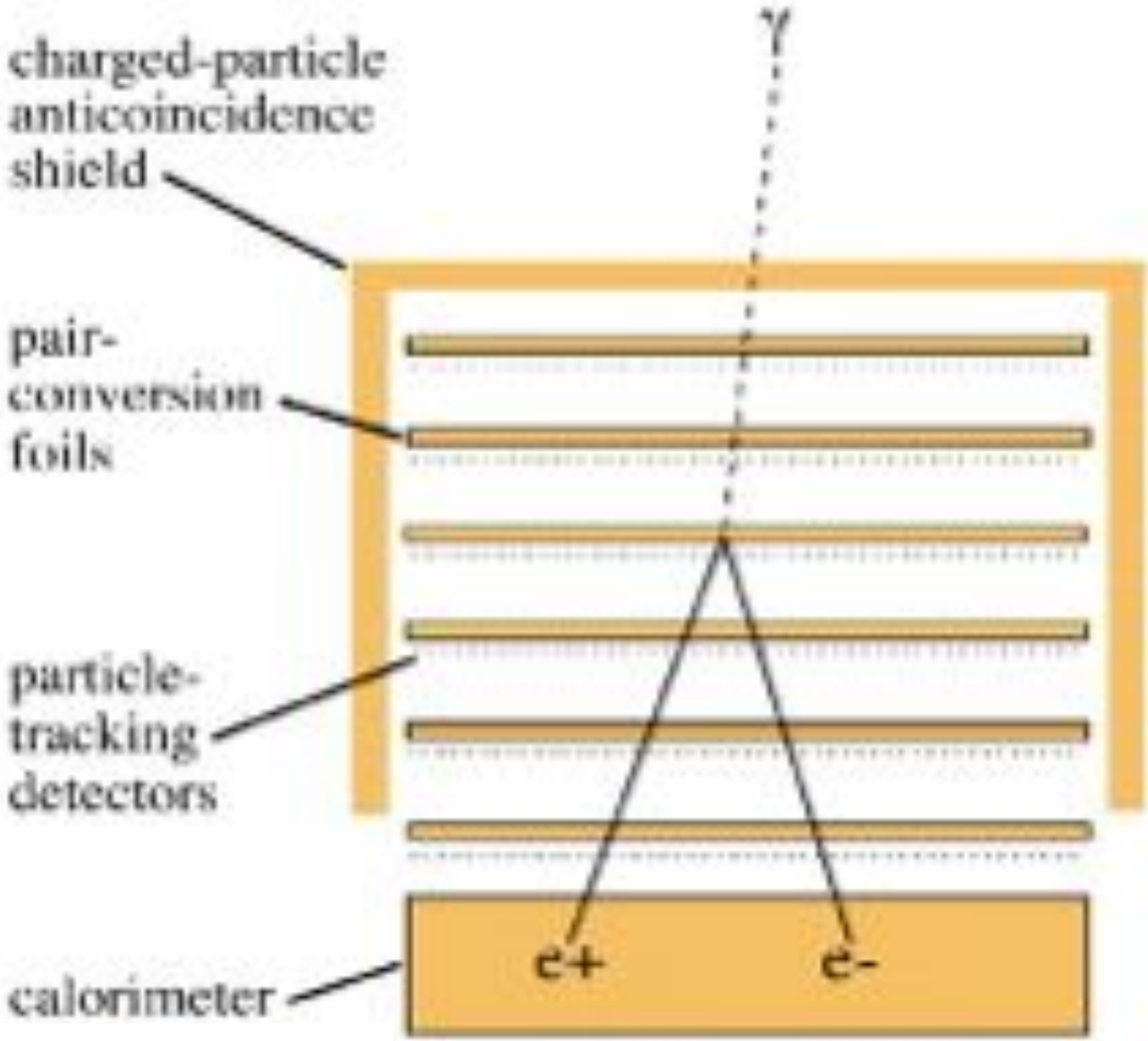
An anticoincidence detector around the telescope distinguishes gamma-rays from charged particles







Elements of a pair-conversion telescope

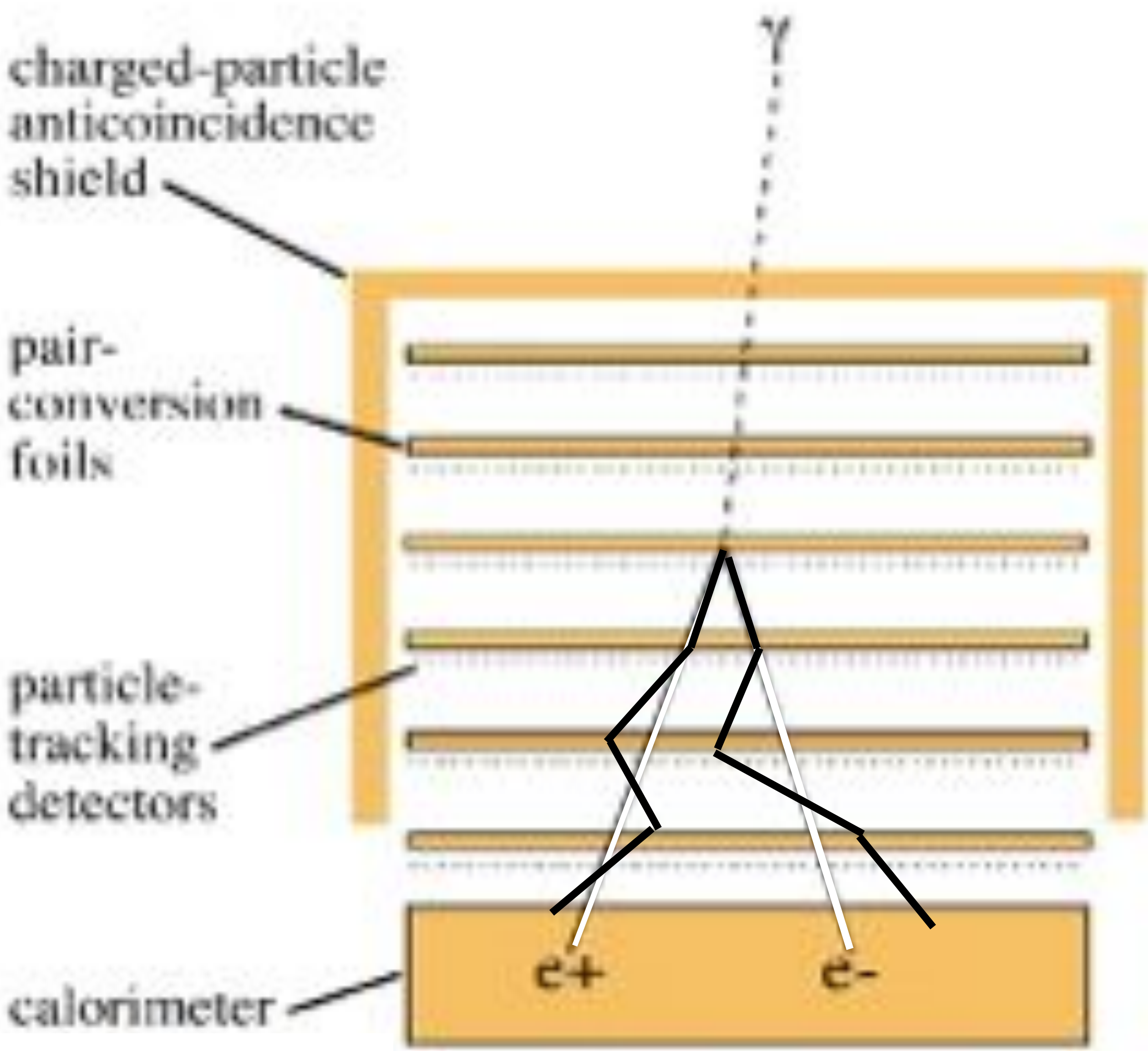


(energy measurement)

- 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

Elements of a pair-conversion telescope

(more realistic scheme)



(energy measurement)

- photons materialize into matter-antimatter pairs:

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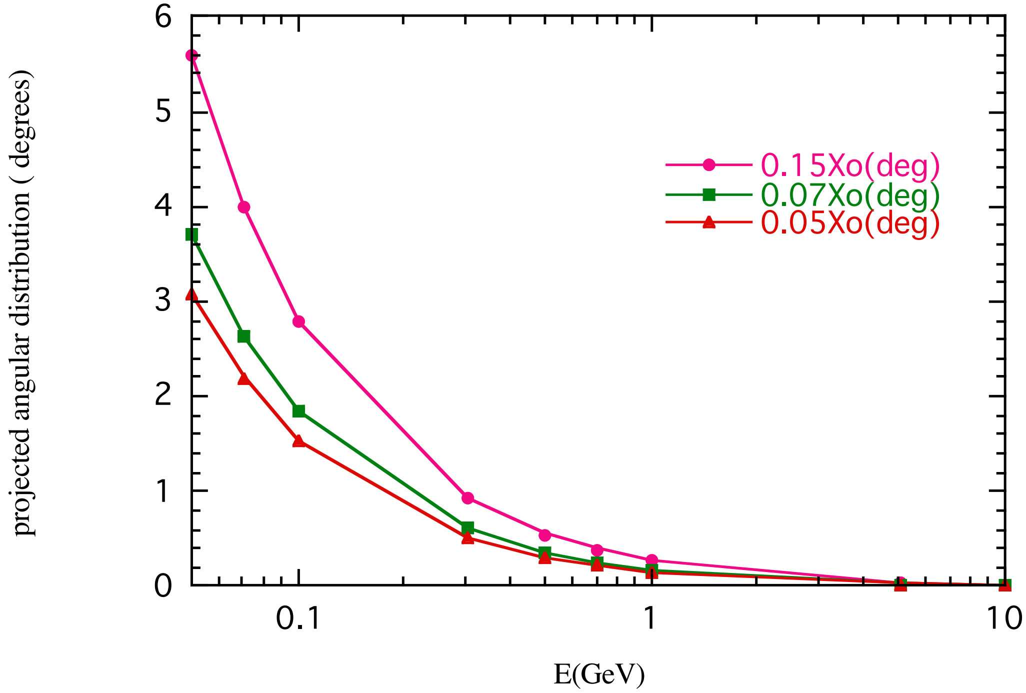
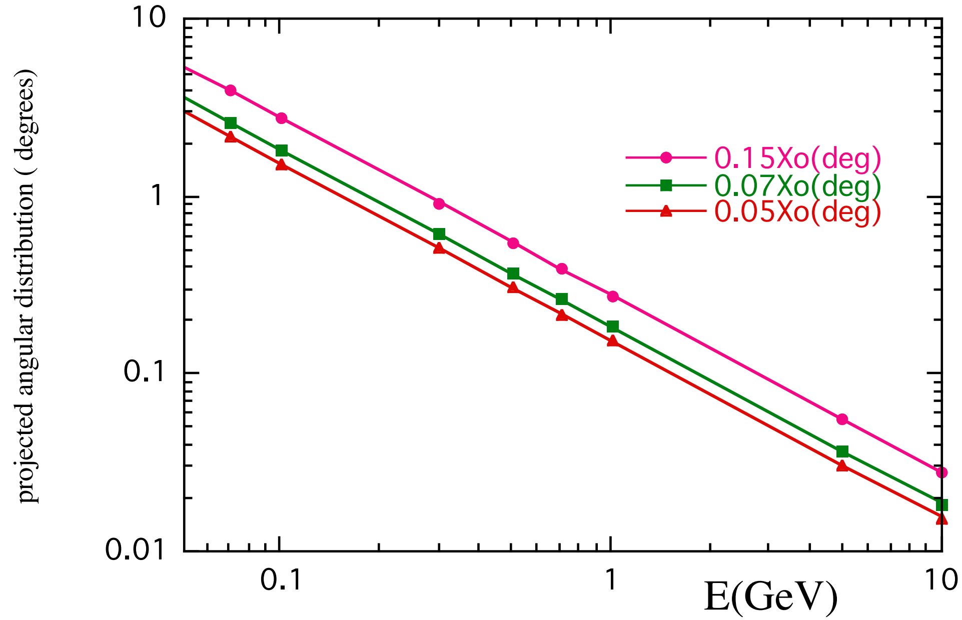
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering

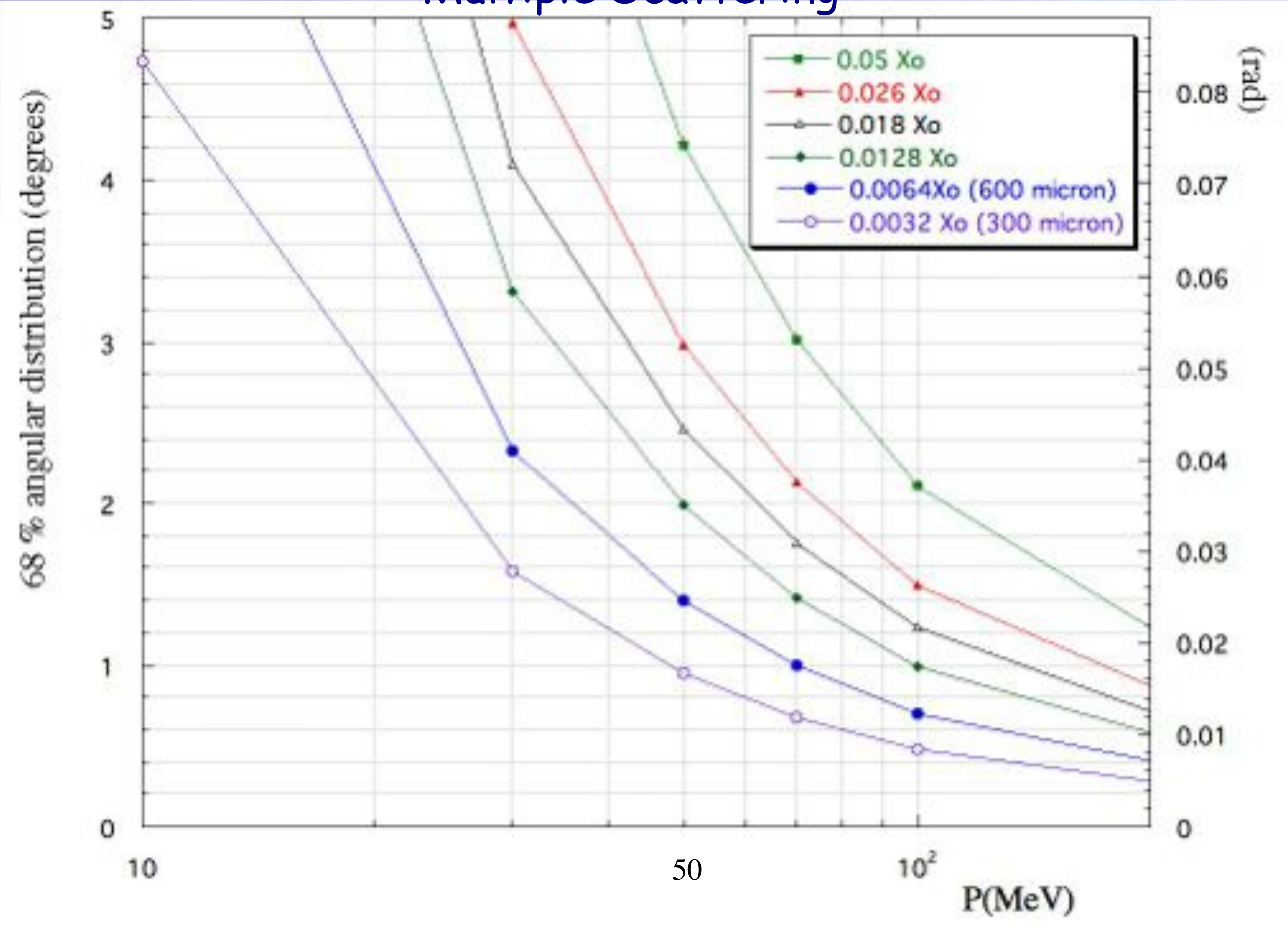




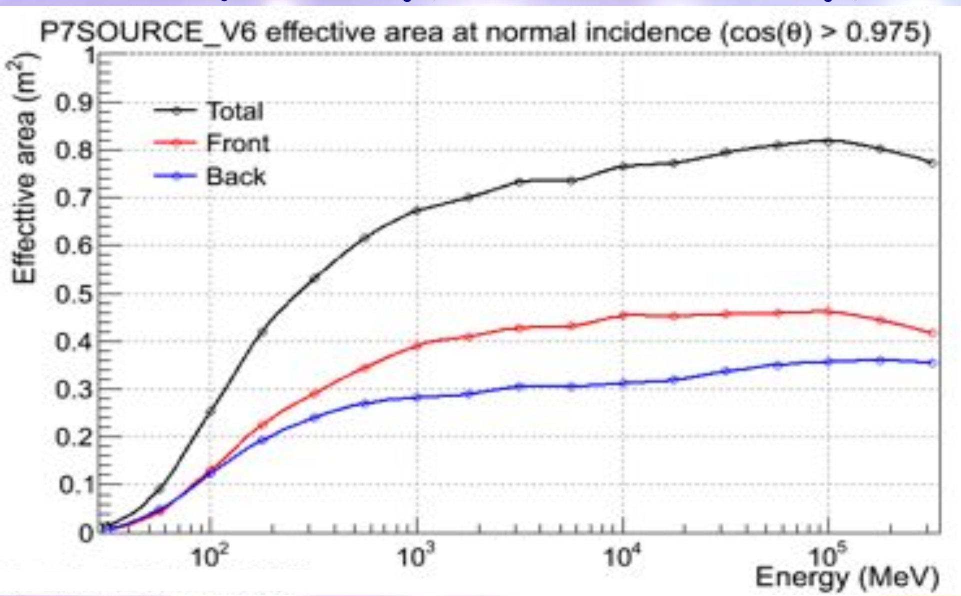
$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

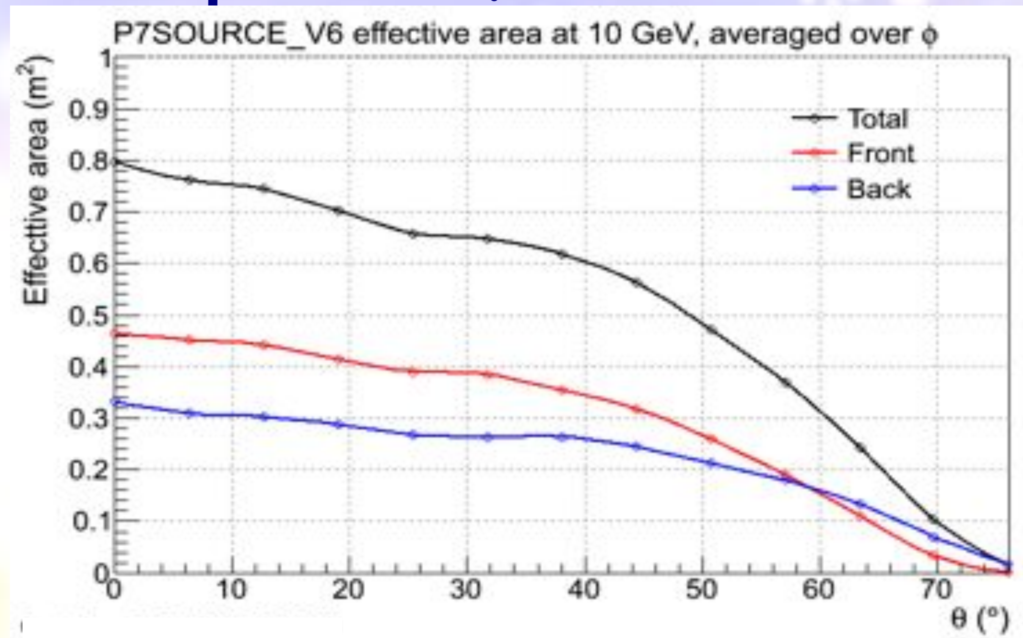
$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\,\left[1 + 0.038\ln\left(x/X_0\right)\right]$$

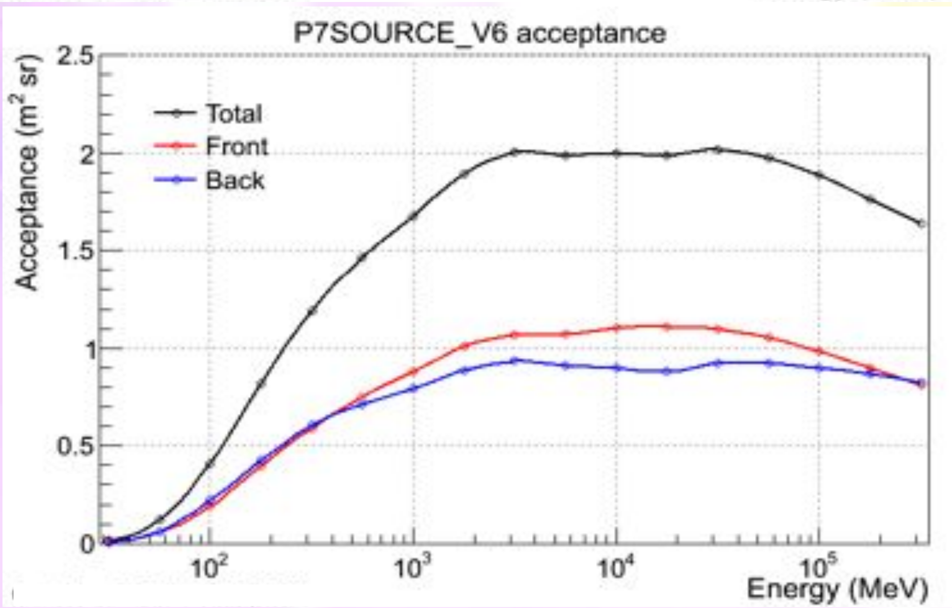
Multiple Scattering

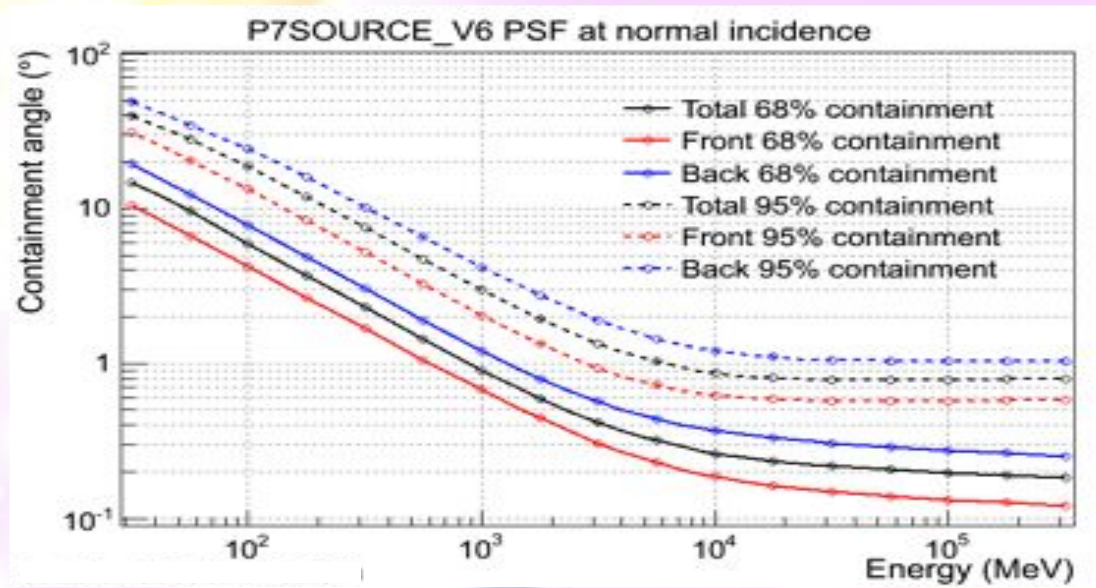


Fermi Instrument Response Function



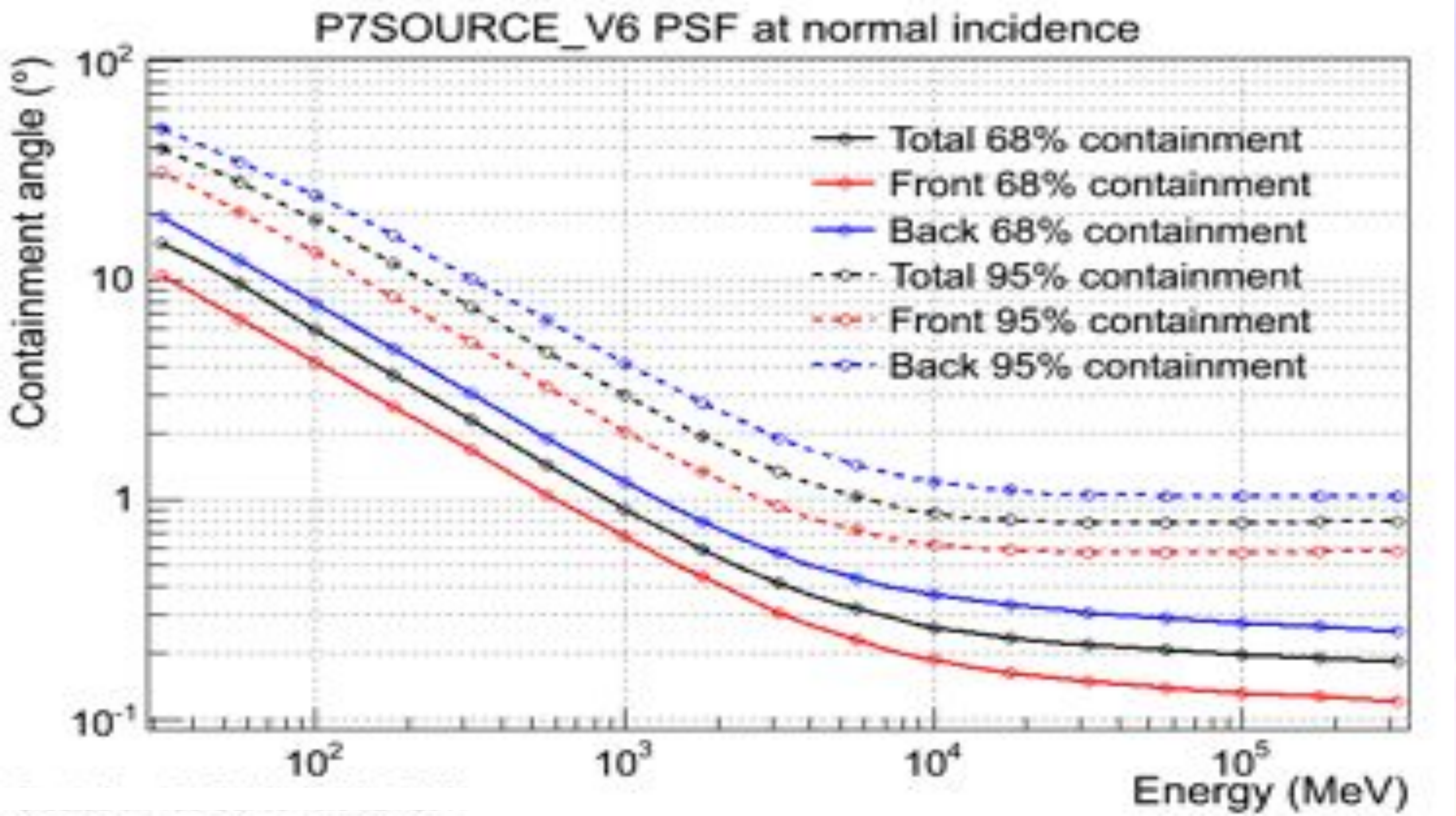






http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Fermi Instrument Response Function



http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

$N\gamma_s$= number of photons from source
$N\gamma_B$= number of photons from background
$\Delta\Omega$ = solid angle around dth source
A_{eff} = Effective area (Area* efficiency)
x = converter plane in radiation lengh

Sensitivity

depends on field of view

$$N_{\gamma s} = \Phi_s(cm^{-2}) * A_{eff} * \Delta T$$

$$N_{\gamma B} = \Phi_B(cm^{-2} sr^{-1}) * \Delta\Omega * A_{eff} * \Delta T$$

Sensitivity

number of σ

depends on angular resolution

$$N_{\gamma s} \geq 5(N_{\gamma B})^{-\frac{1}{2}}$$

$$\Delta\Omega \sim \pi\theta^2 \sim \pi E^{-2} x$$

$$\Phi_s \geq \frac{5}{E}\left(\frac{\Phi_B * x}{A_{eff} * \Delta T}\right)^{-\frac{1}{2}}$$

good detector

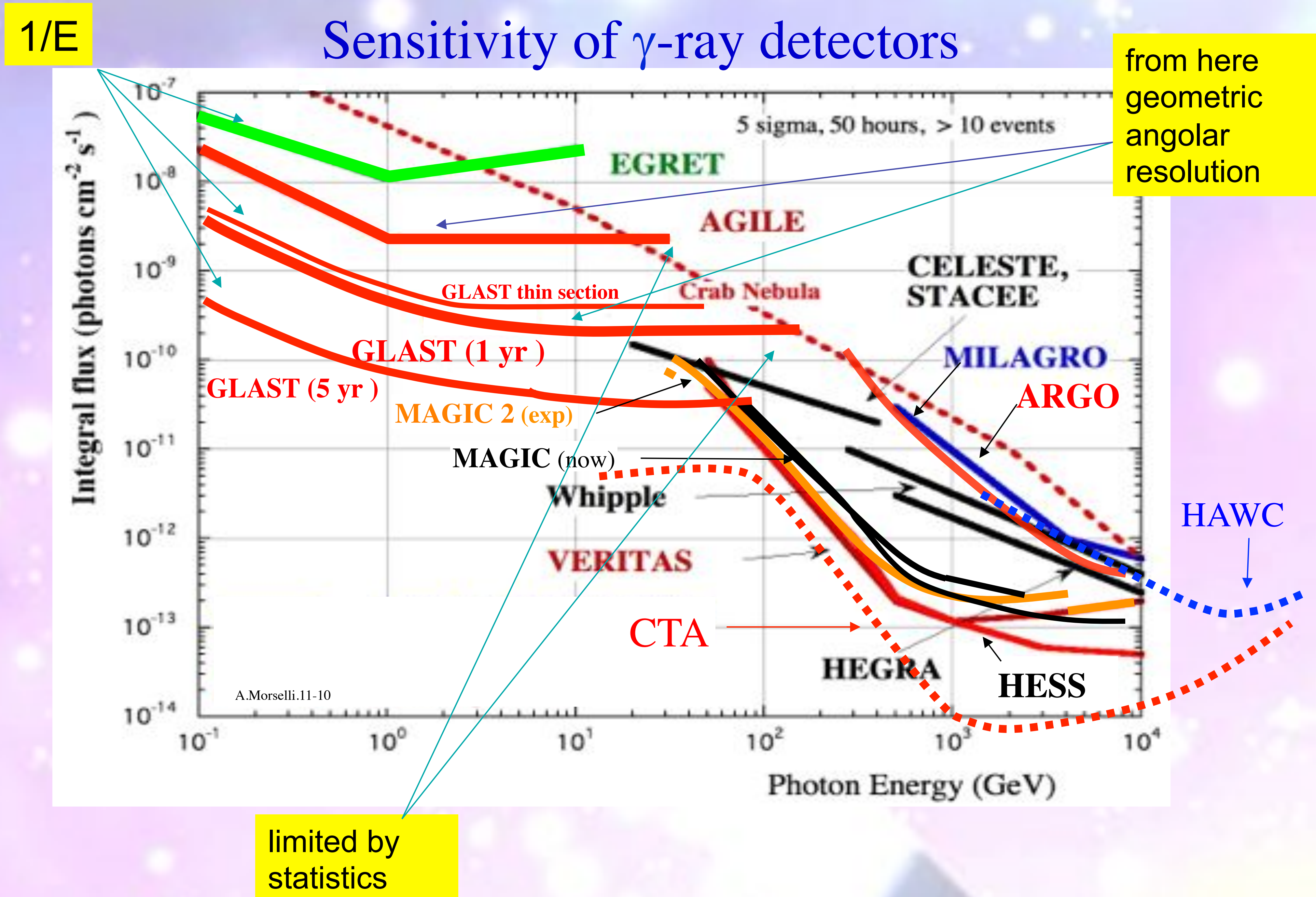
small converter plane

$$\Phi_s \geq \frac{5}{E}\left(\frac{\Phi_B * x}{A_{eff} * \Delta T}\right)^{-\frac{1}{2}}$$

large effective area
(large geometric area and large total conversion efficiency)

large field of view

Sensitivity of γ-ray detectors

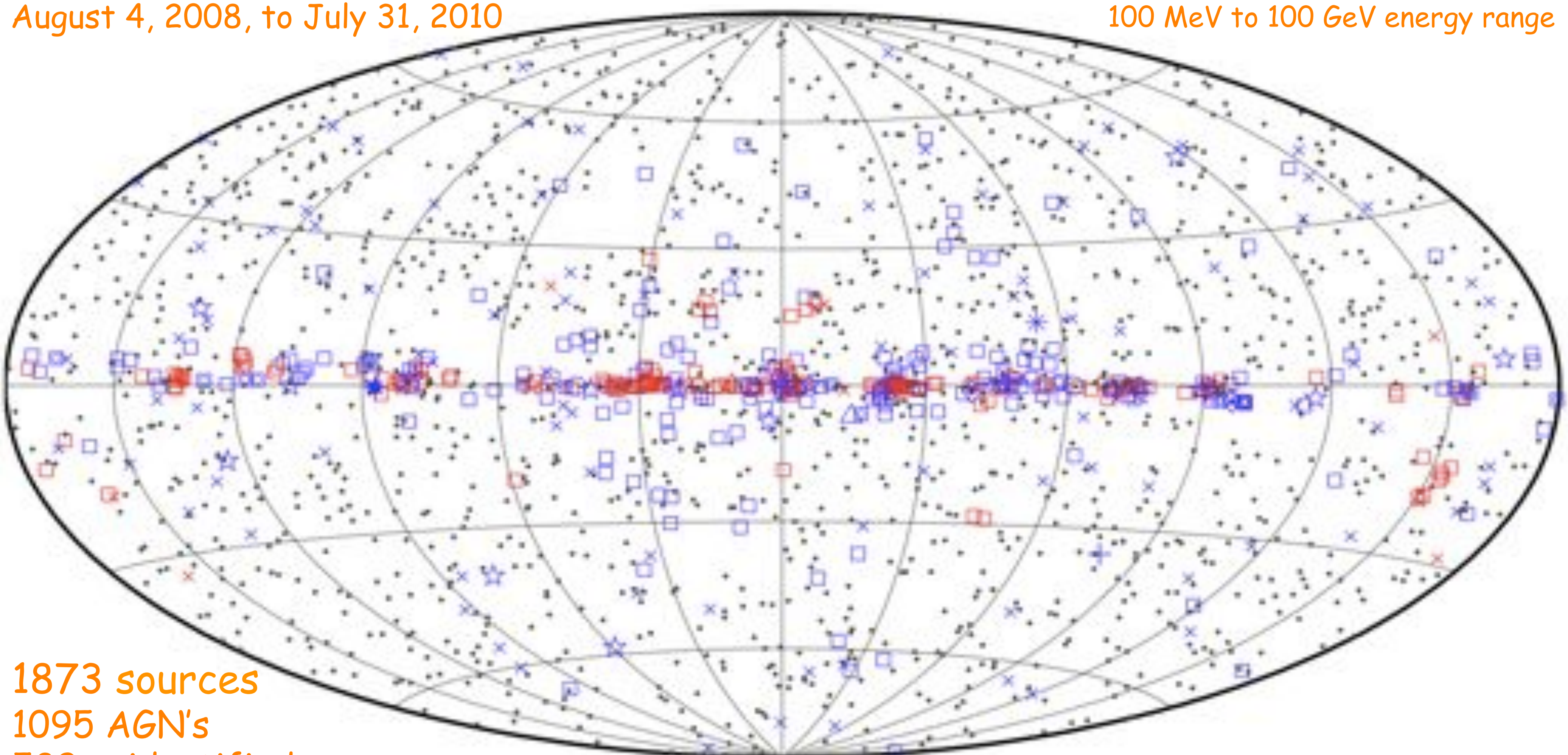


The Fermi LAT 2FGL Source Catalog

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



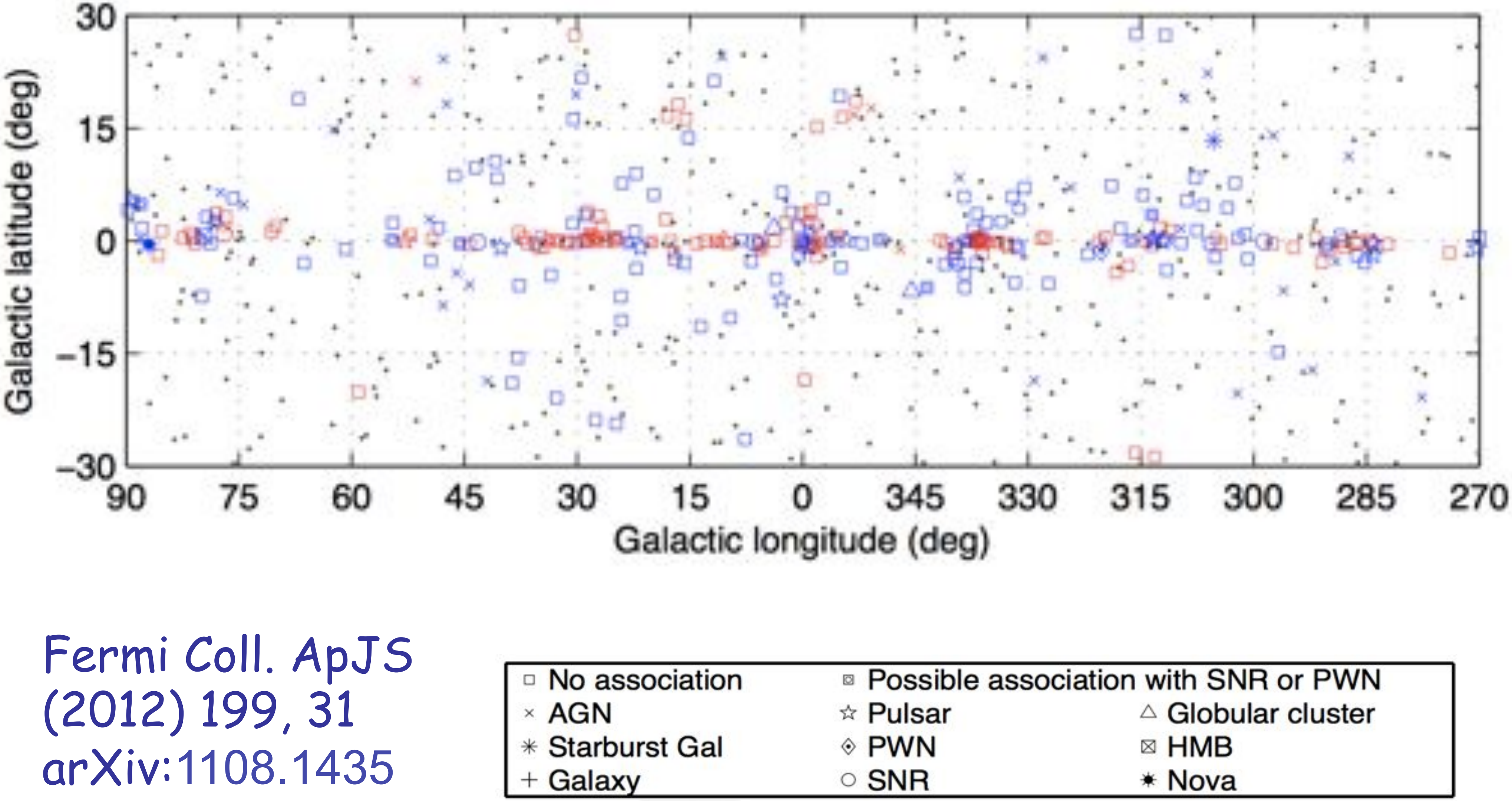
1873 sources
1095 AGN's
589 unidentified

Fermi Coll.
arXiv:1108.1435

The Fermi LAT 2FGL Inner Galactic Region

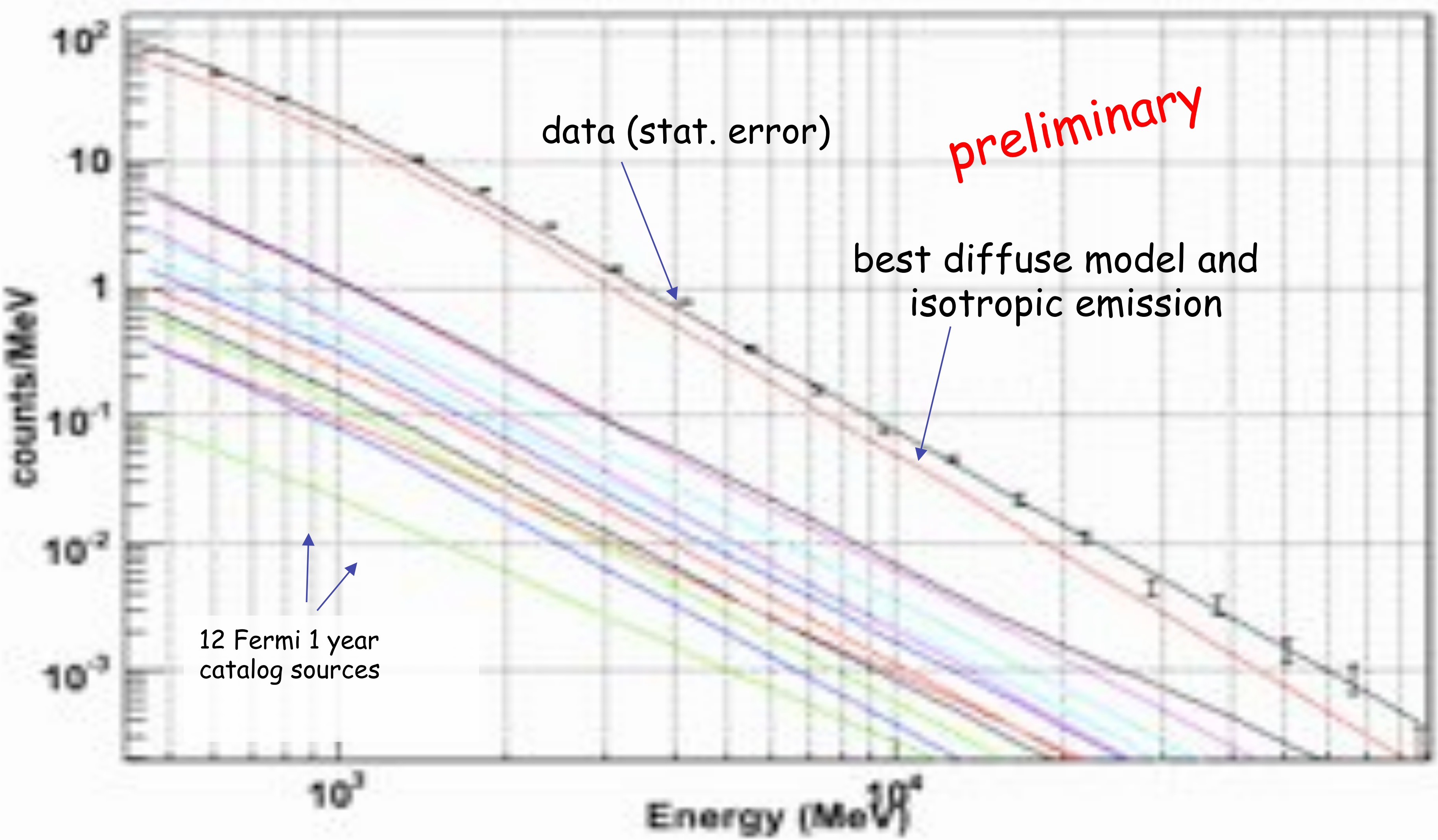
August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



Fermi Coll. ApJS (2012) 199, 31
arXiv:1108.1435

Spectrum (E> 400 MeV, 7°x7° region centered on the Galactic Center analyzed with binned likelihood analysis)

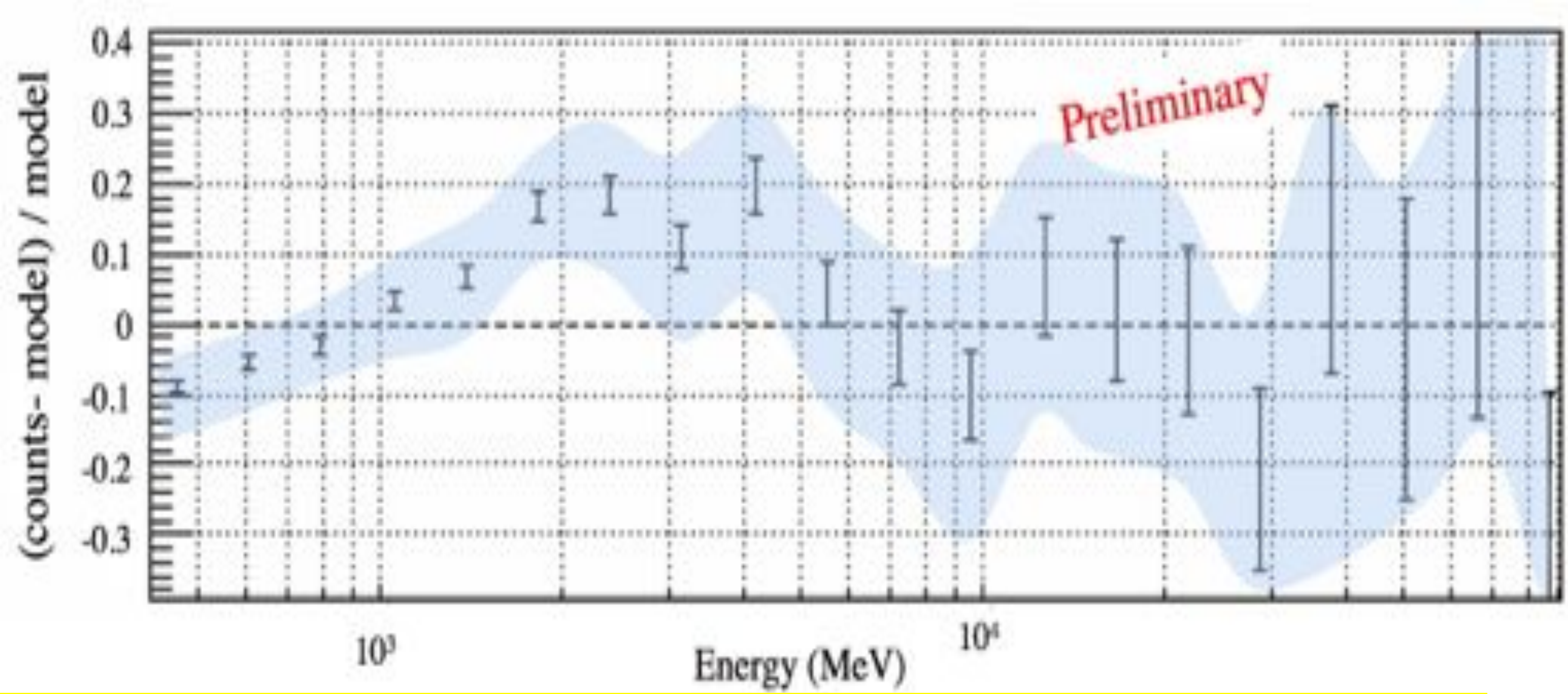


V.Vitale, A.M. for the Fermi Coll. NIM A630 (2011) 147–150

GC Residuals 7°x7° region centered on the Galactic Center

11 months of data, E >400 MeV, front-converting events
analyzed with binned likelihood analysis)

- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



V.Vitale, A.M. for the Fermi Coll. NIM A630 (2011) 147–150

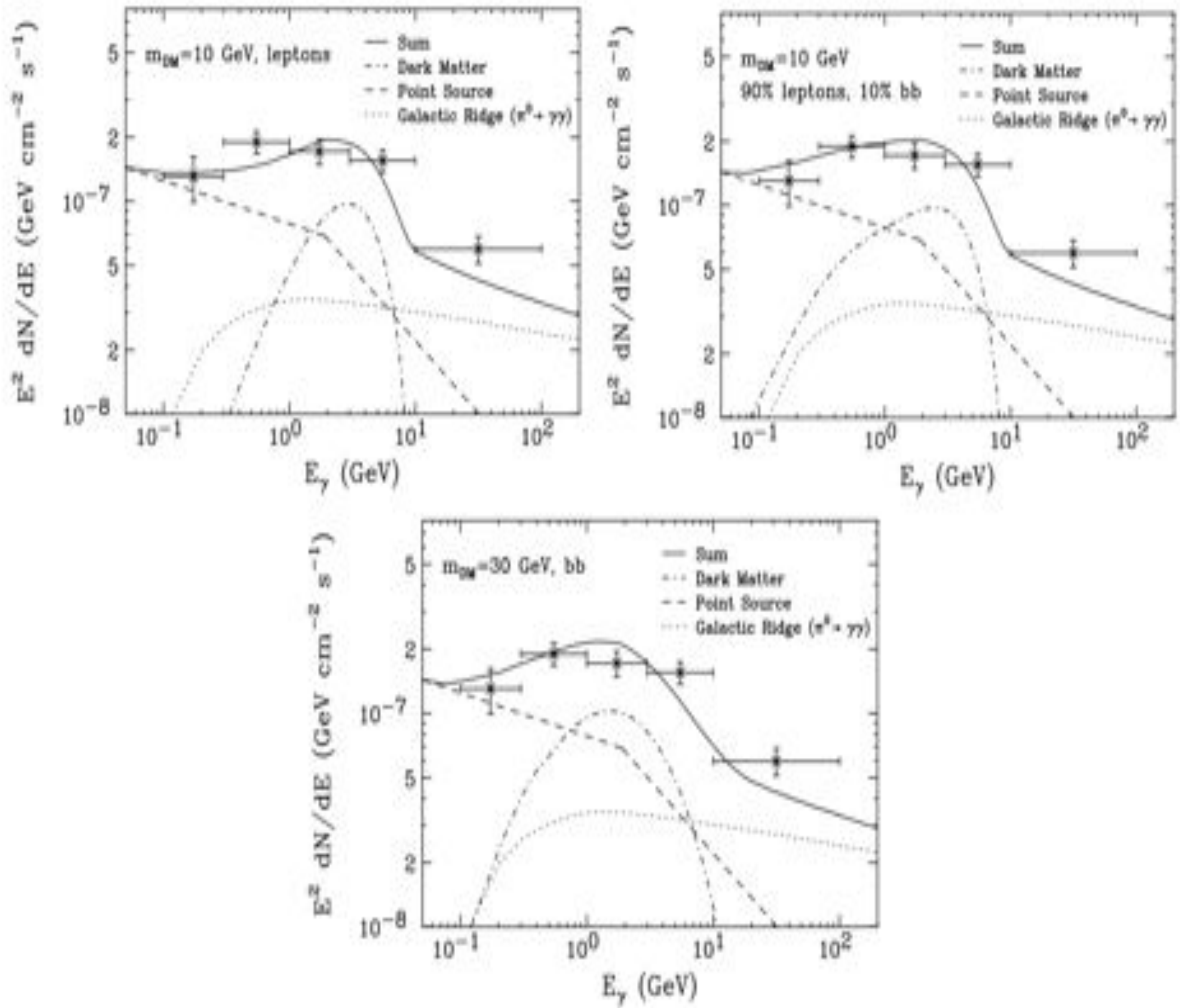
DM in the galactic center?

D. Hooper and T.Linden, 2011.
arXiv:1110.000

Using the remarkable source of public Fermi-LAT data!

To improve, need better angular and energy resolution in the 1 – 20 GeV range.

Eventually, a gamma-ray line at the DM mass could be seen – would be very convincing!

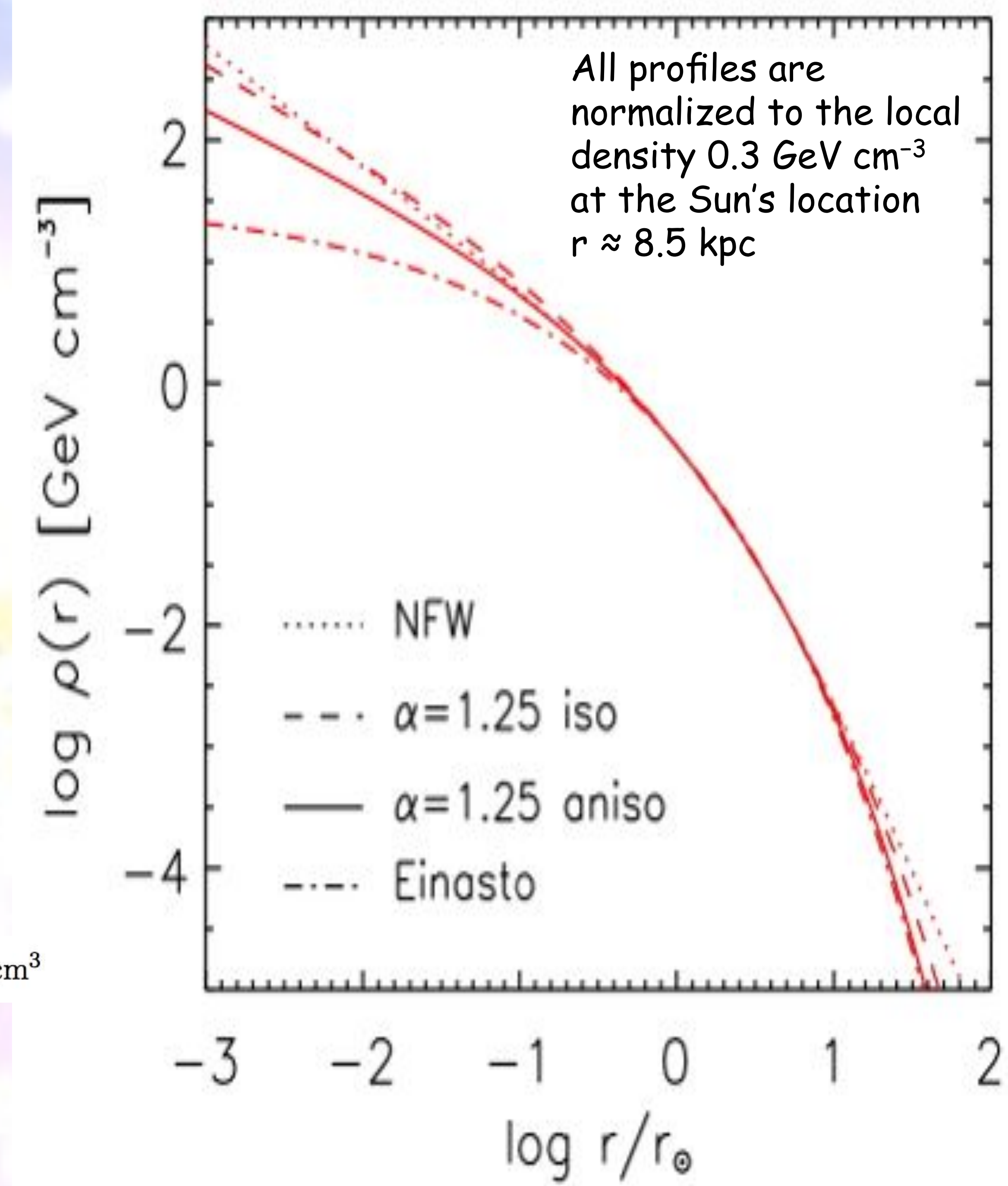


Milky Way Dark Matter Profiles

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/r_s)^\alpha}{1+(r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

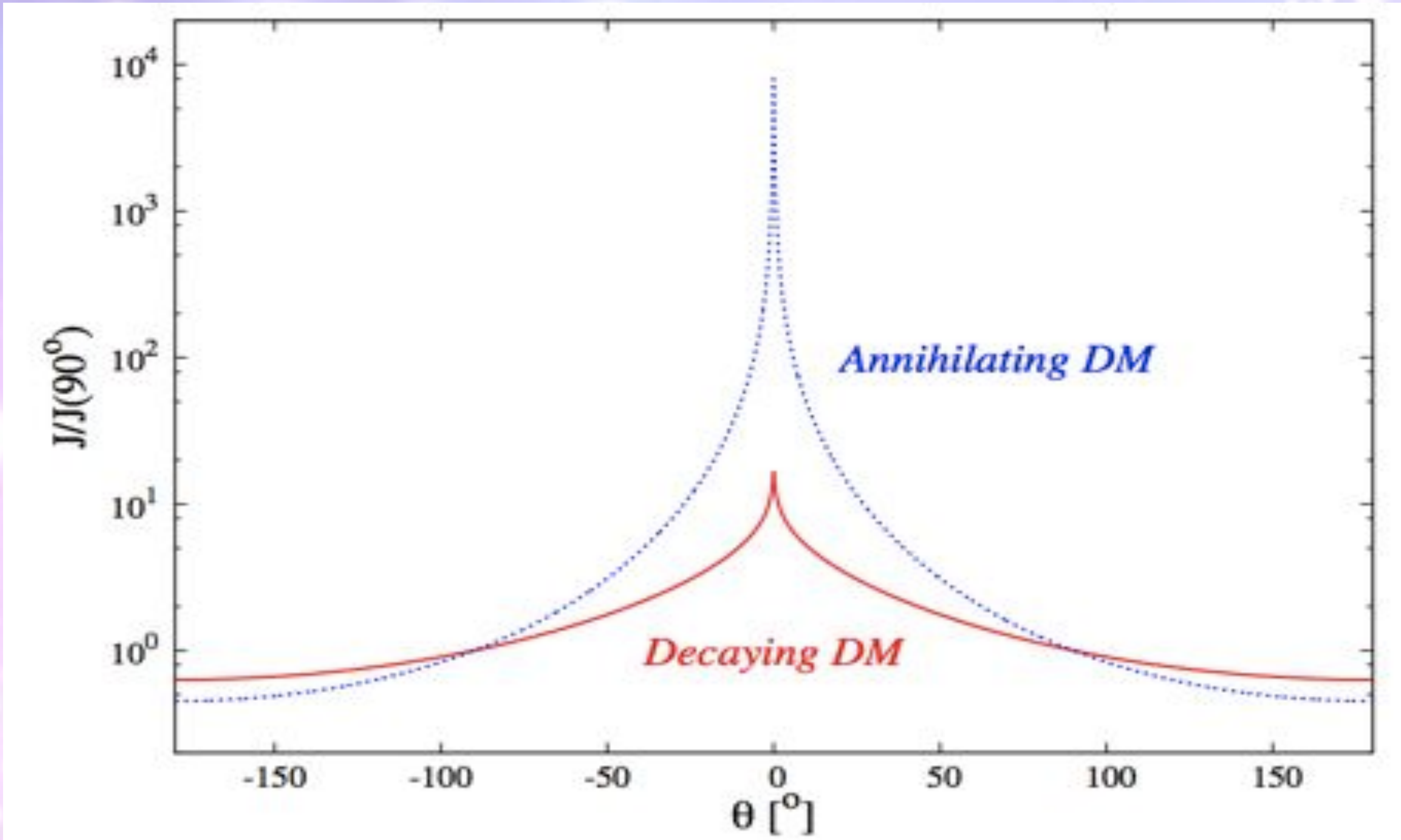
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\text{kpc}$ $\rho_s = 0.06\,\text{GeV/cm}^3$



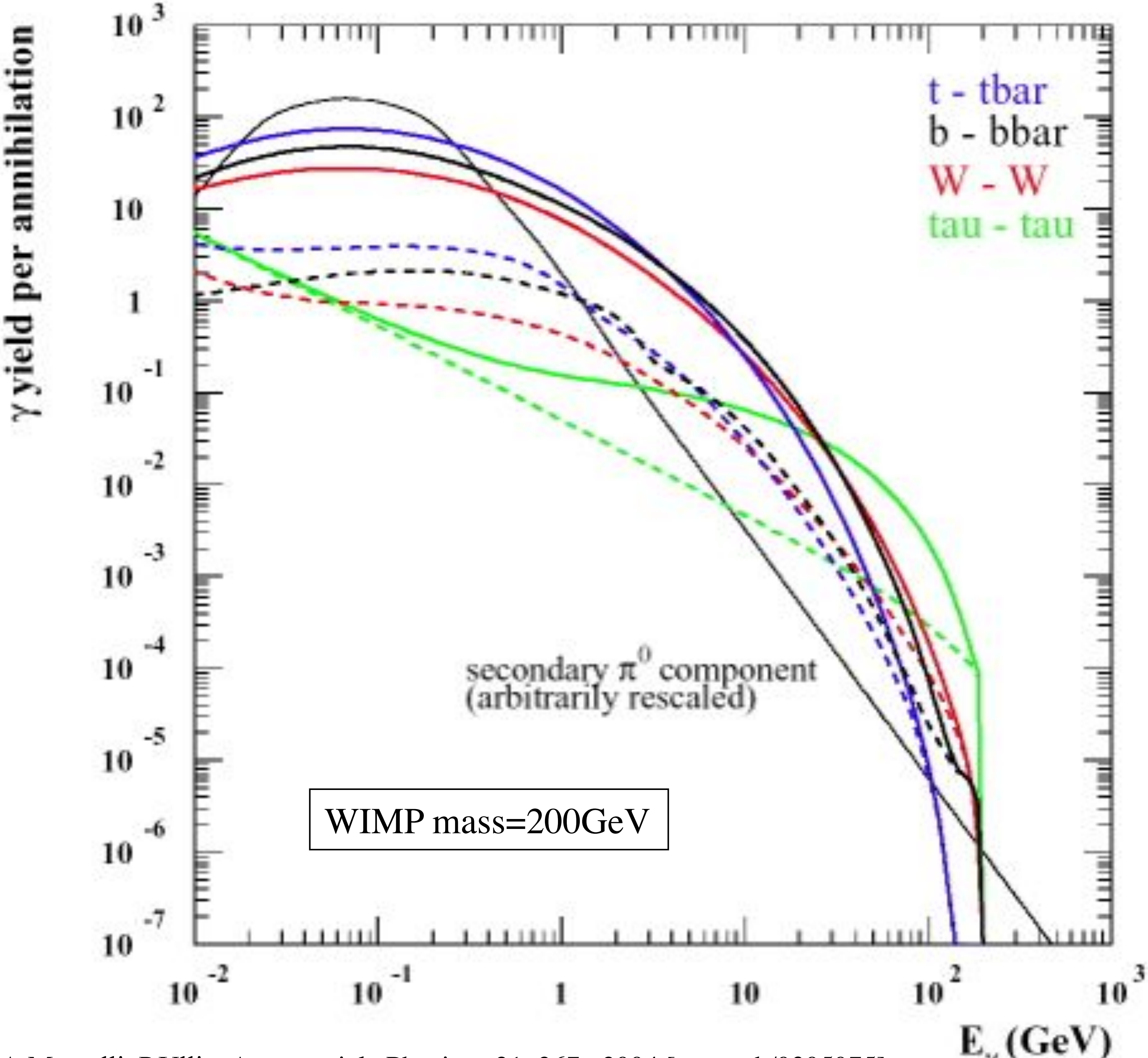
A.Lapi et al. arXiv:0912.1766

Different spatial behaviour for decaying or annihilating dark matter



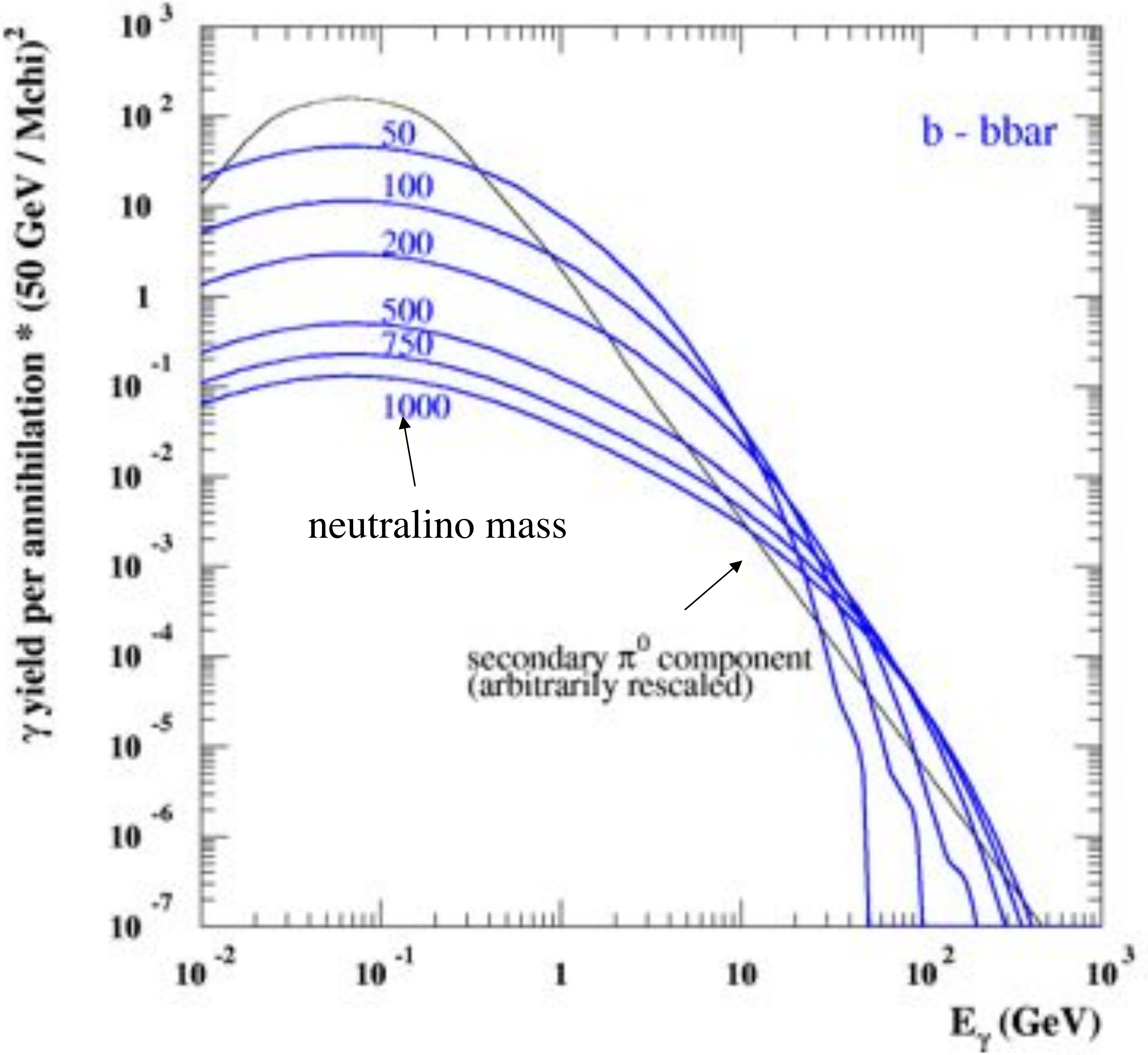
The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

Differential yield for each annihilation channel



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

Differential yield for b bar



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Gamma-light scheme

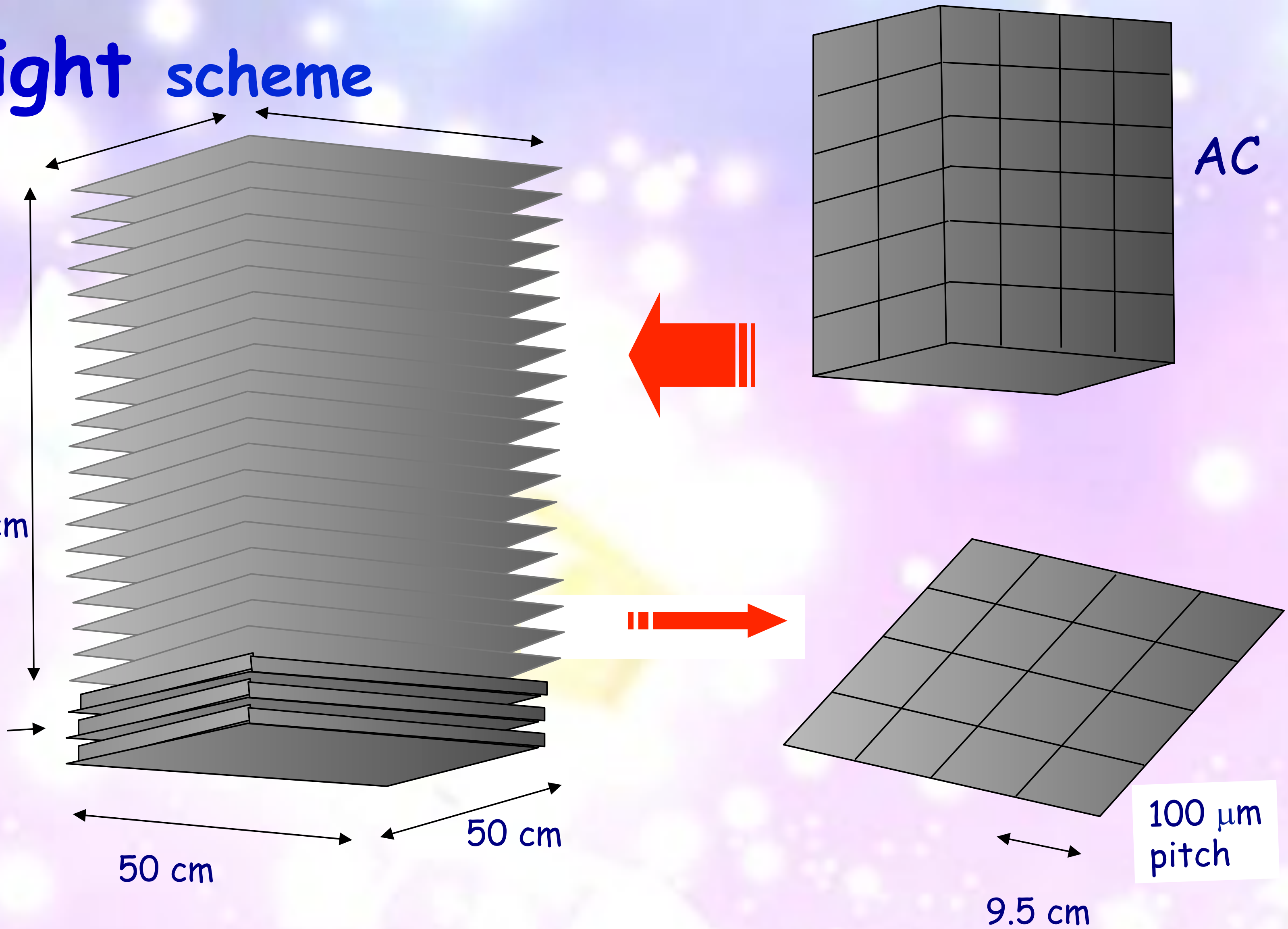
40+1 x-y planes
100 μm pitch
each
~0.025 X_0

Tot~ 1 X_0

54.7 cm

height of a plane 1.3 cm

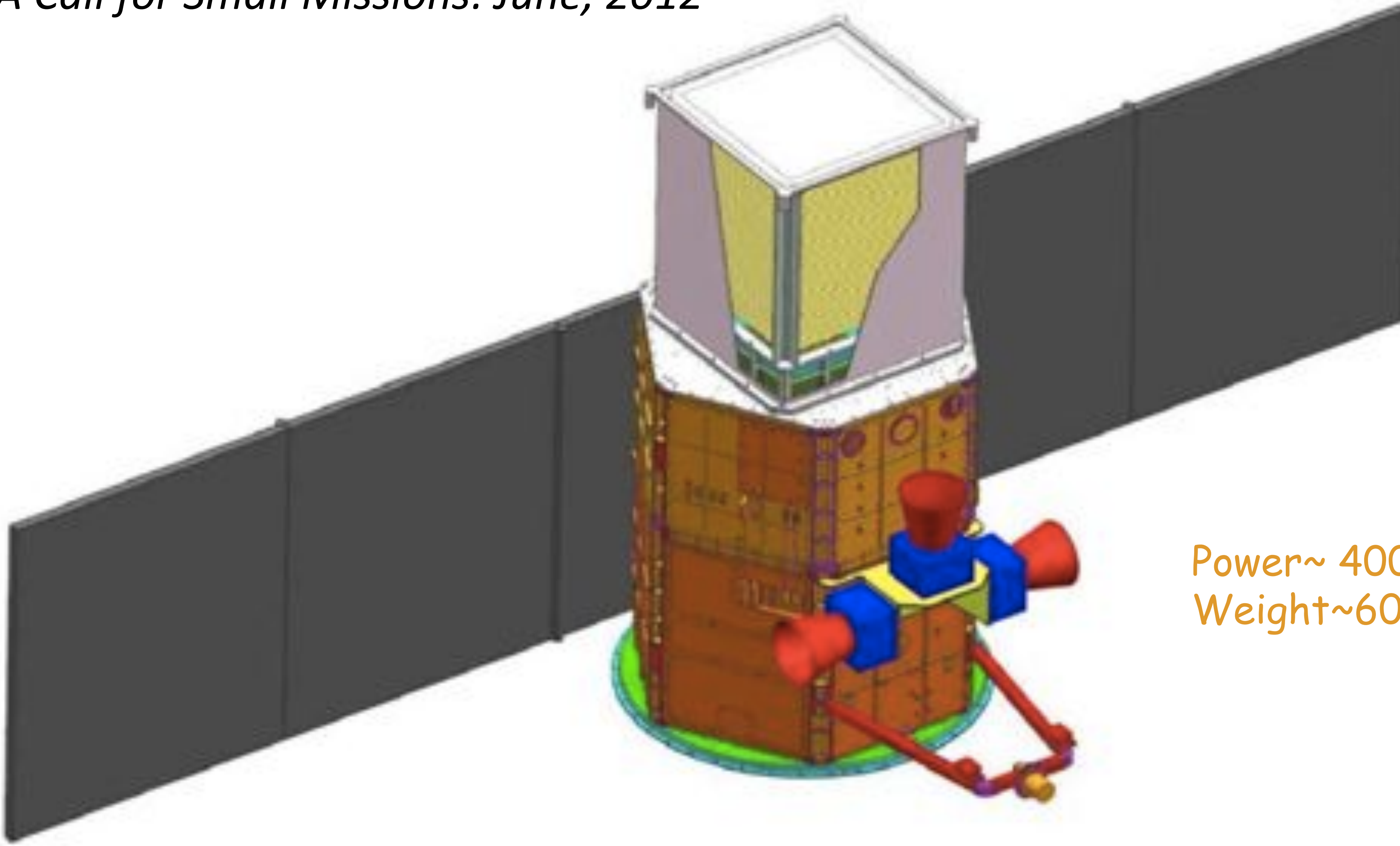
2 Xo Calorimiter



*Compton scattering **and** pair production telescope*

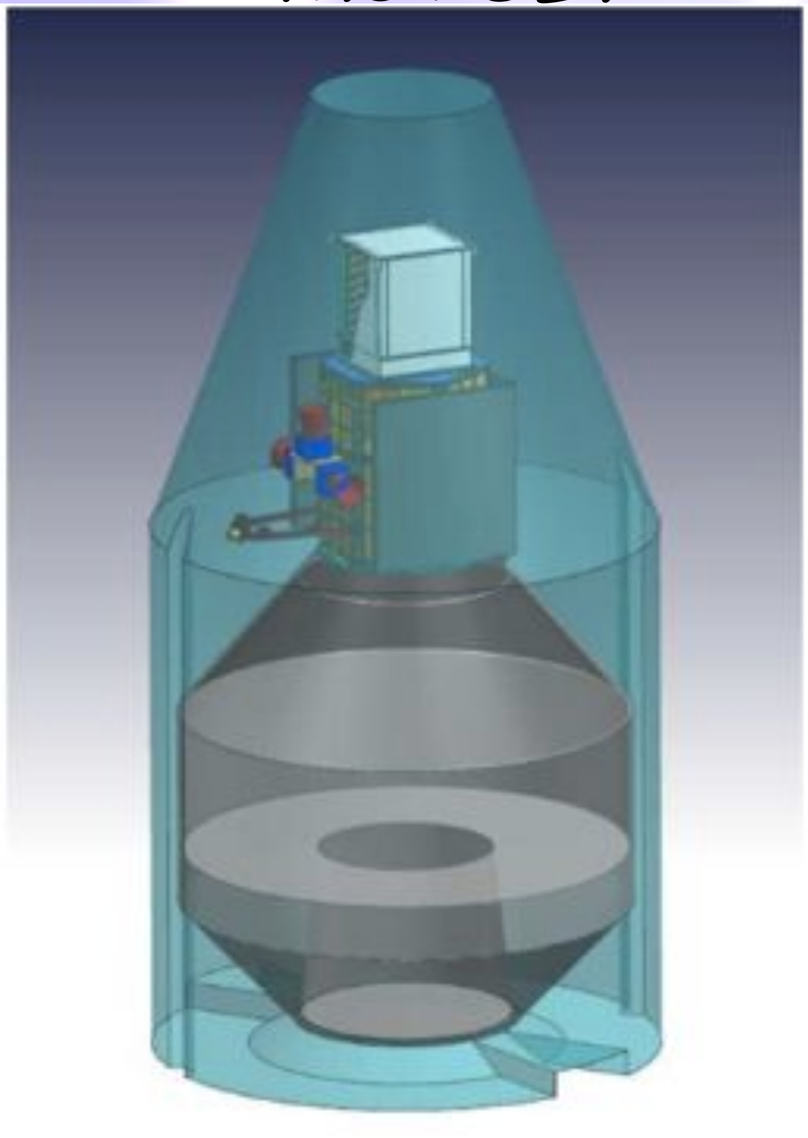
Gamma-light payload

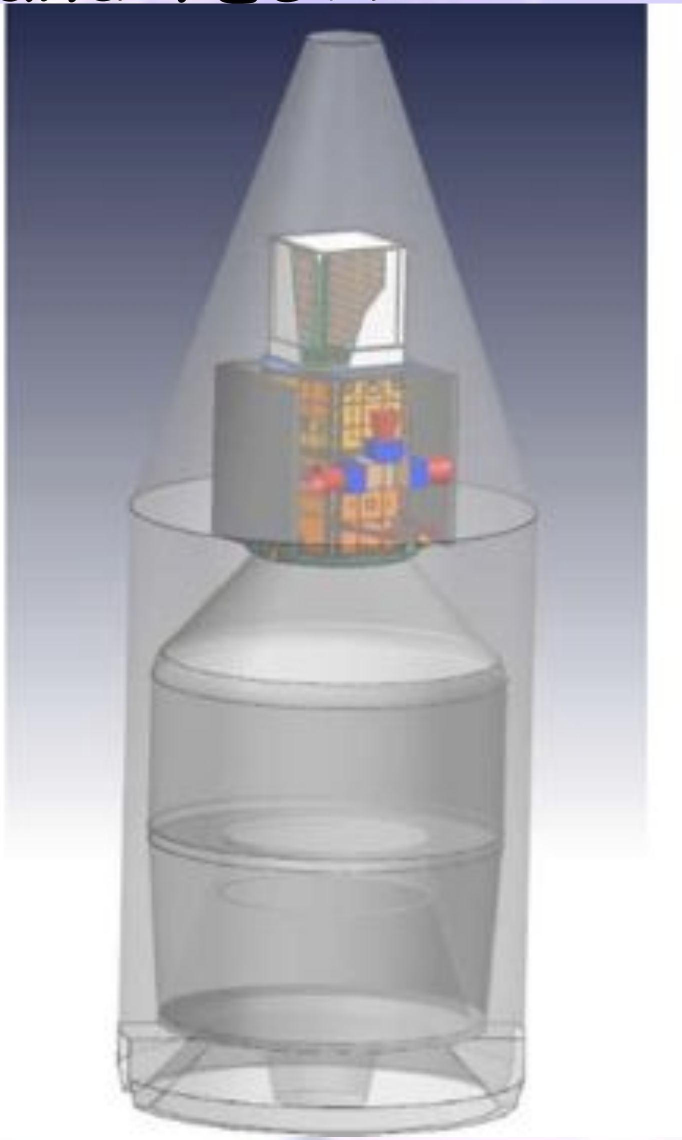
ESA Call for Small Missions: June, 2012



Power~ 400 W
Weight~600 Kg

GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA





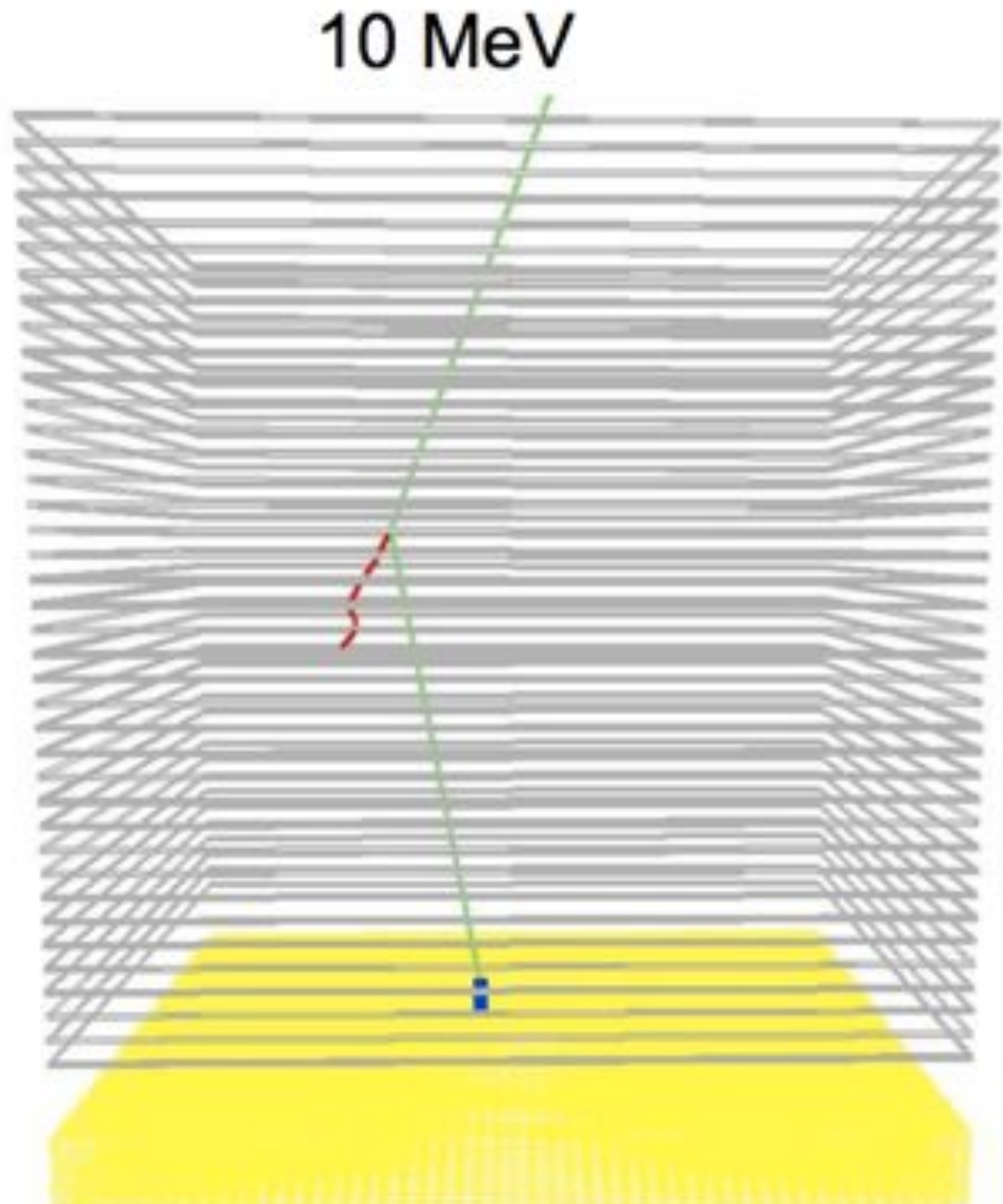
- a companion satellite similar to G-LIGHT can be accomodated.

Gamma-light Participants

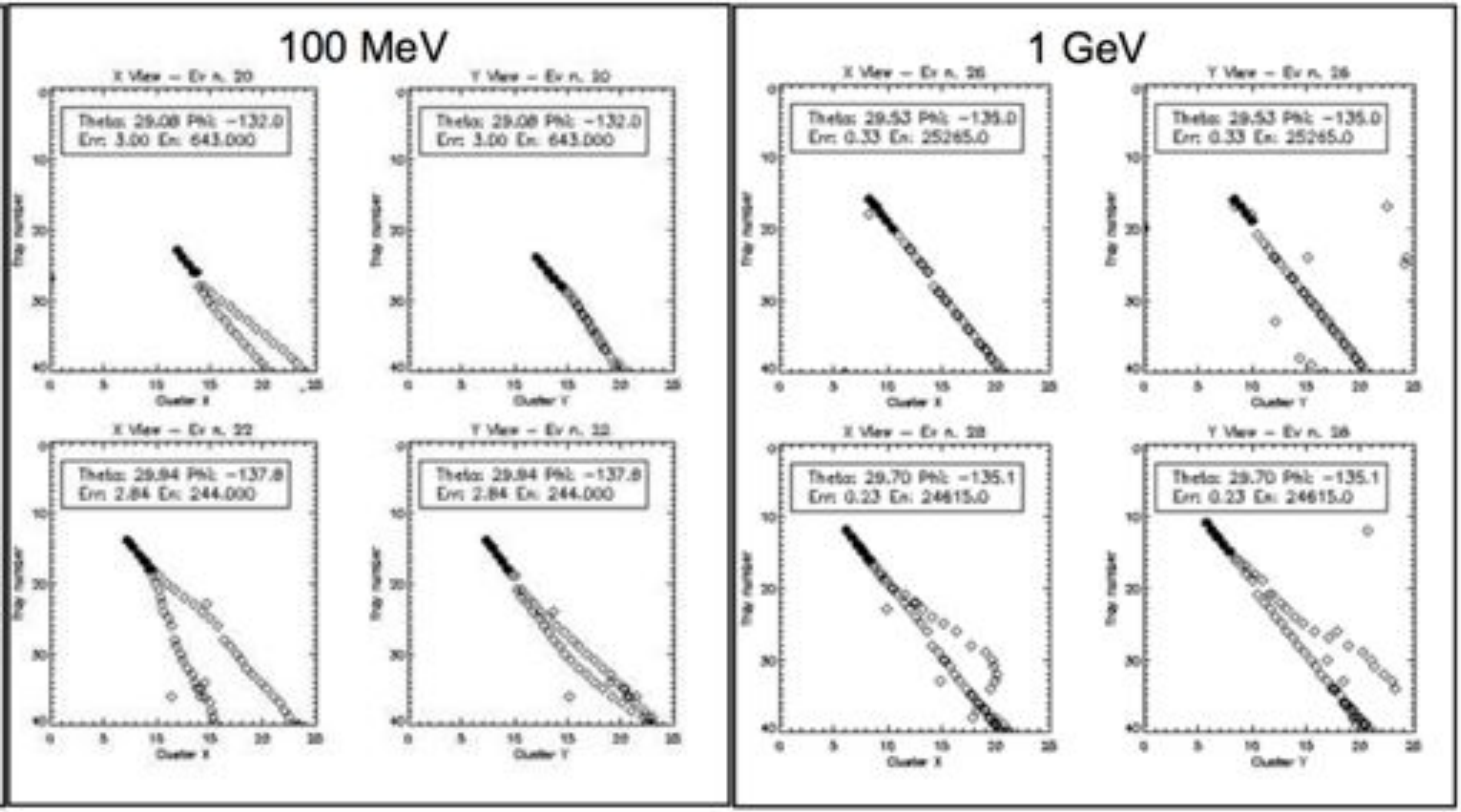
- INAF Italian Institute of Astrophysics (INAF), Italy
- INFN Italian Institute of Nuclear Physics, Italy
- ASDC ASI Science Data Center, Italy
- SRC PAS Space Research Center of Polish Academy of Sciences, Poland
- NCAC Nicolaus Copernicus Astronomical Center, Warsaw, Poland
- UBA University of Barcelona, Spain
- DTU Space, Denmark
- UIB University of Bergen, Norway
- TOV University of Rome Tor Vergata, Italy
- TUR University of Turin, Italy
- YAL Yale University, USA
- SAP University of Rome "La Sapienza", Italy
- IFT-UAM Universidad Autonoma de Madrid, Spain
- USAL University of Salamanca, Spain
- TRI University of Trieste, Italy
- ENEA, Italy

G-LIGHT Simulation

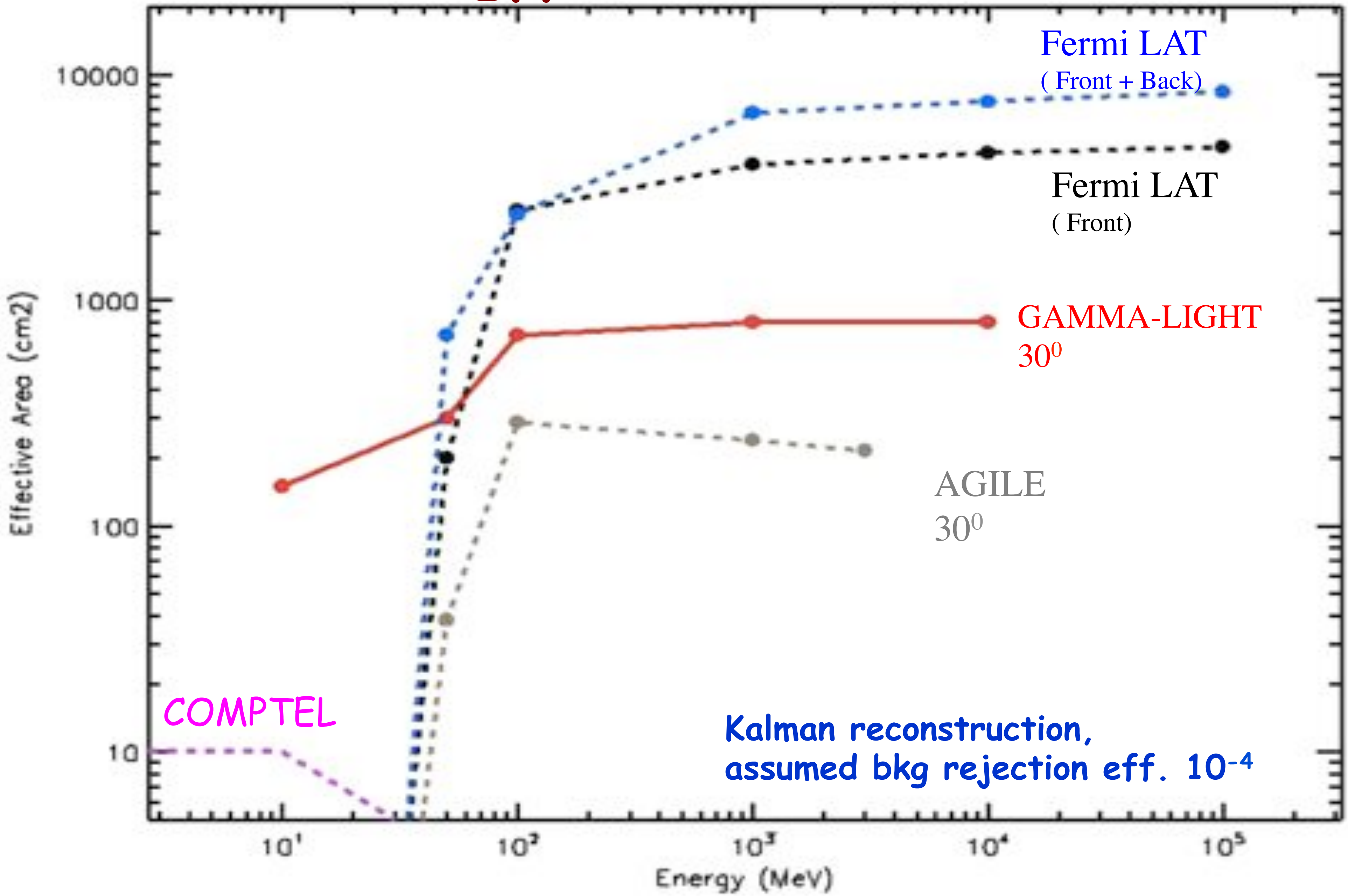
Compton interaction of a 10 MeV photon producing a low-energy single-track electron, and depositing energy in the Calorimeter for a 30^0 incidence



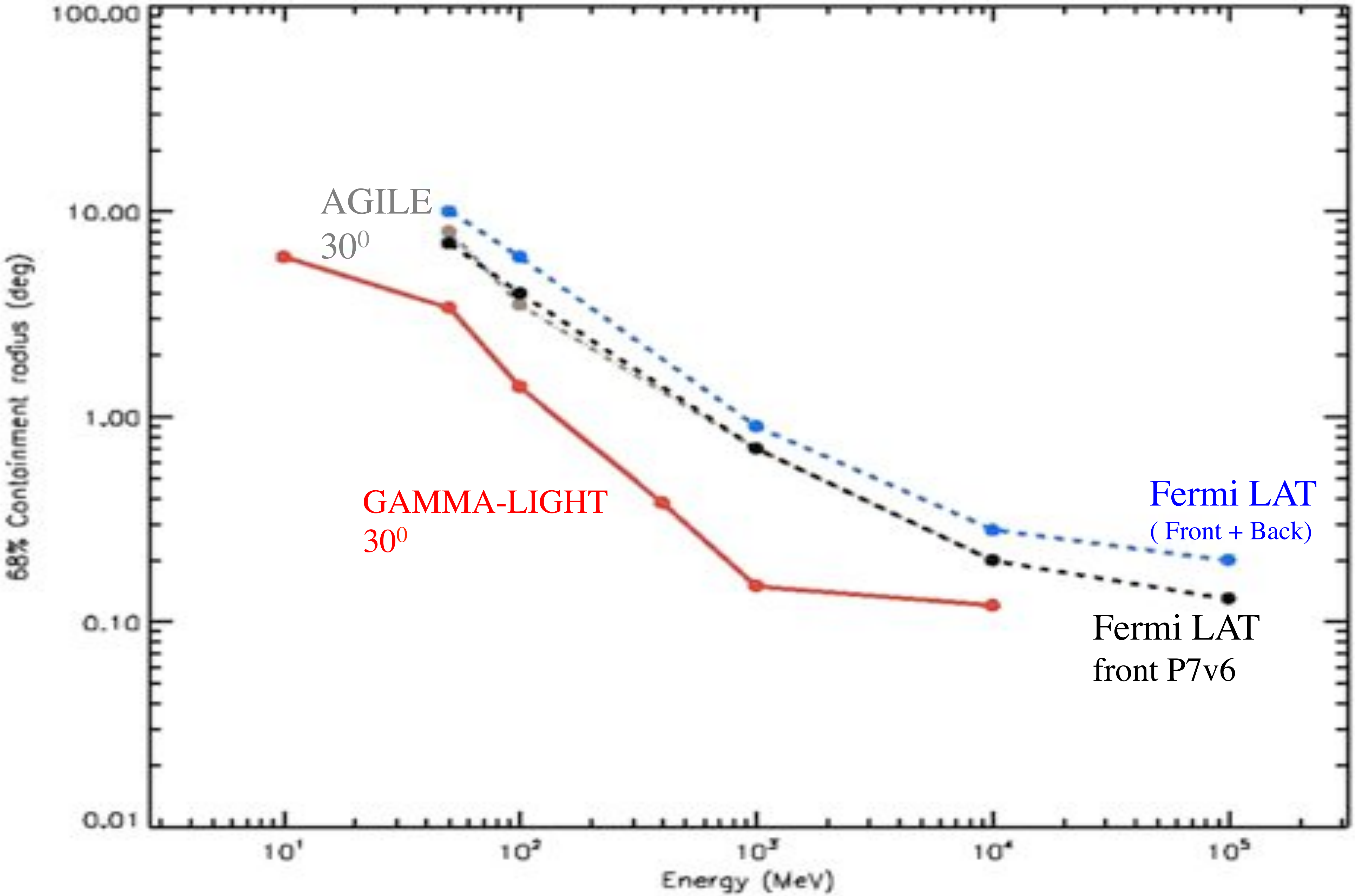
Gamma-light *Simulation*

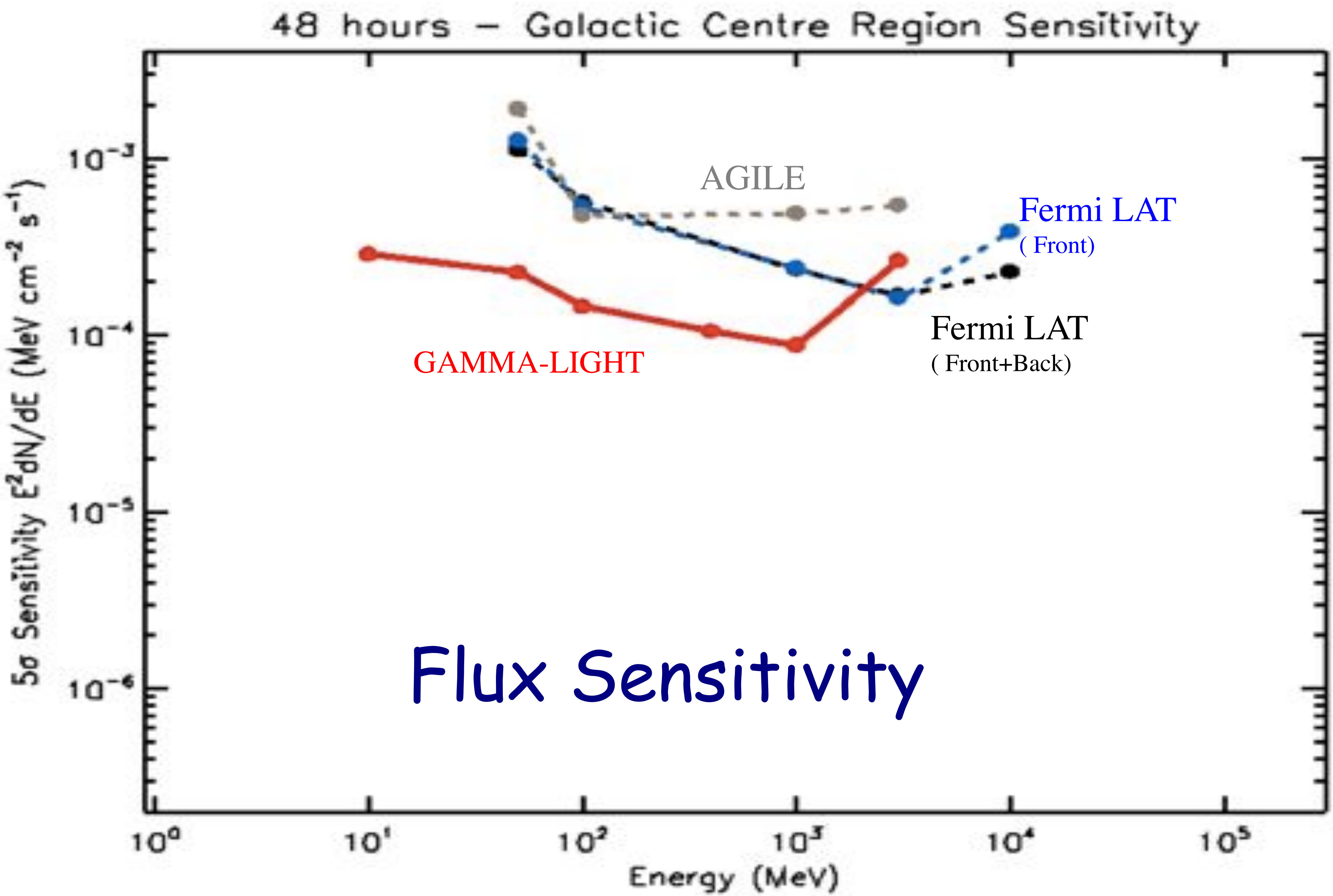


Effective area

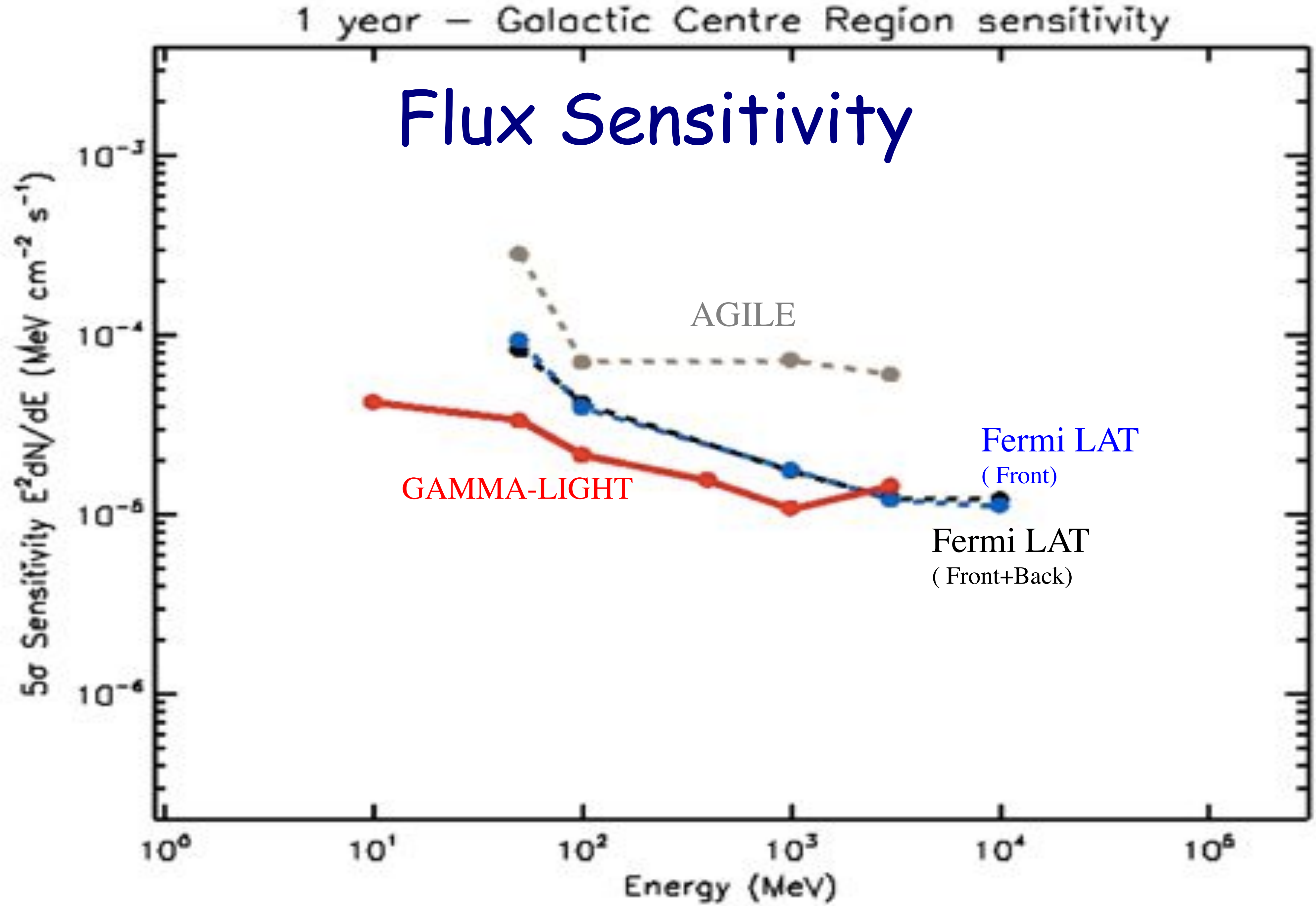


PSF (68% containment radius)




48 hours - Galactic Centre Region Sensitivity
AGILE
Fermi LAT
(Front)
Fermi LAT
(Front+Back)
GAMMA-LIGHT
Flux Sensitivity
5σ Sensitivity E²dN/dE (MeV cm⁻² s⁻¹)
Energy (MeV)

Flux Sensitivity



Astrophysics Objectives of GAMMA-LIGHT

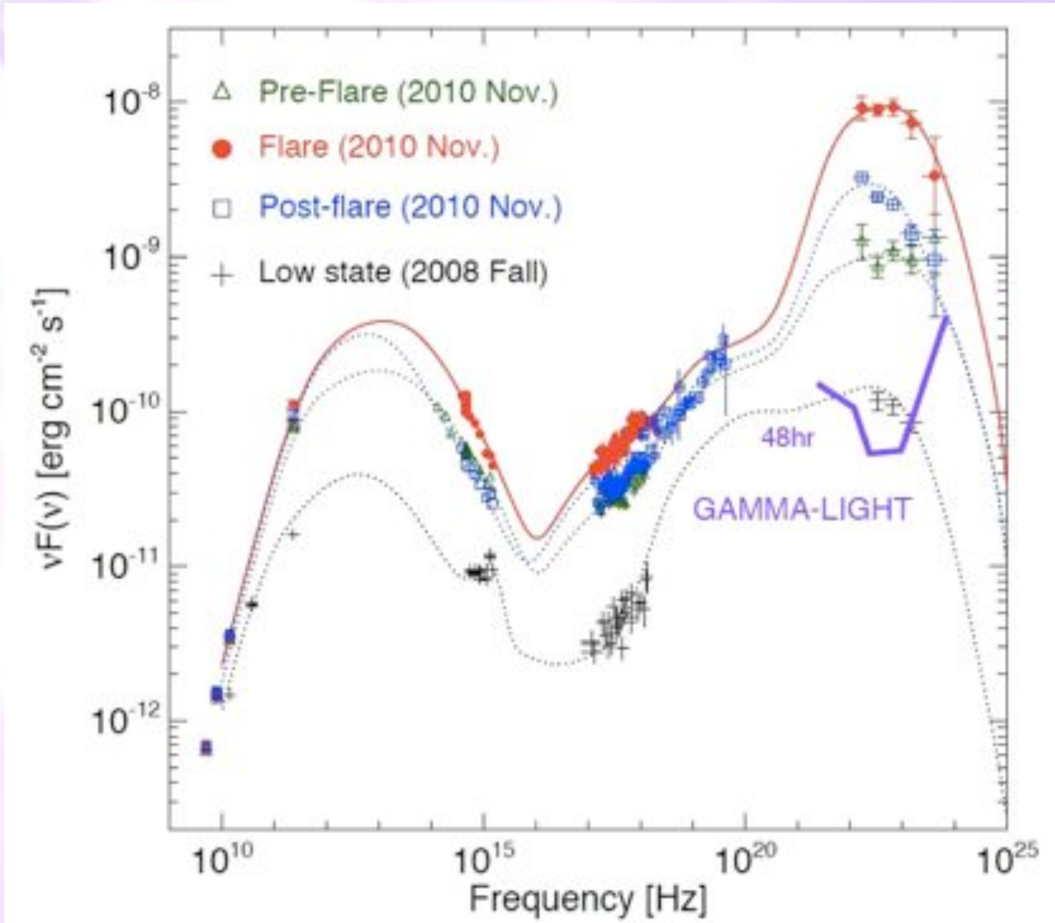
- 1. Search of Dark Matter gamma-ray signatures in the Galaxy and in particular in the Galactic Center region;
- 2. Resolving the Galactic Center region in gamma-rays: the central BH region, GeV and TeV sources, nebulae, compact sources, SNRs;
- 3. Resolving the diffuse emission in the Galactic plane, relation with cosmic-ray propagation, star forming regions in the Galactic plane; extending the cosmic-ray propagation and emission properties of the "Fermi bubbles" to the lowest energies below 100 MeV;
- 4. Resolving spatially and spectrally SNRs and addressing the origin and propagation of cosmic- rays;
- 5. Polarization studies of gamma-ray sources;

Astrophysics Objectives of GAMMA-LIGHT (cont.)

- 6. Detection of soft gamma-ray pulsars in the range 10-100 MeV, and pulsar wind nebulae studies;
- 7. Detection of compact objects, microquasars, relativistic jets in the range 10 MeV - 1 GeV resolving the issue of hadronic vs. leptonic jets for a variety of sources (e.g., Cyg X-3);
- 8. Detection and localization of transients and exotic sources with much improved sensitivity;detection of Crab Nebula gamma-ray flares with excellent sensitivity down to 10 MeV;
- 9. Blazar studies down to 10 MeV, excellent positioning resolving source confusion;
- 10. GRB excellent capability in the range 10 MeV - 5 GeV; sub-millisecond timing capability in the range 0.3-100 MeV.

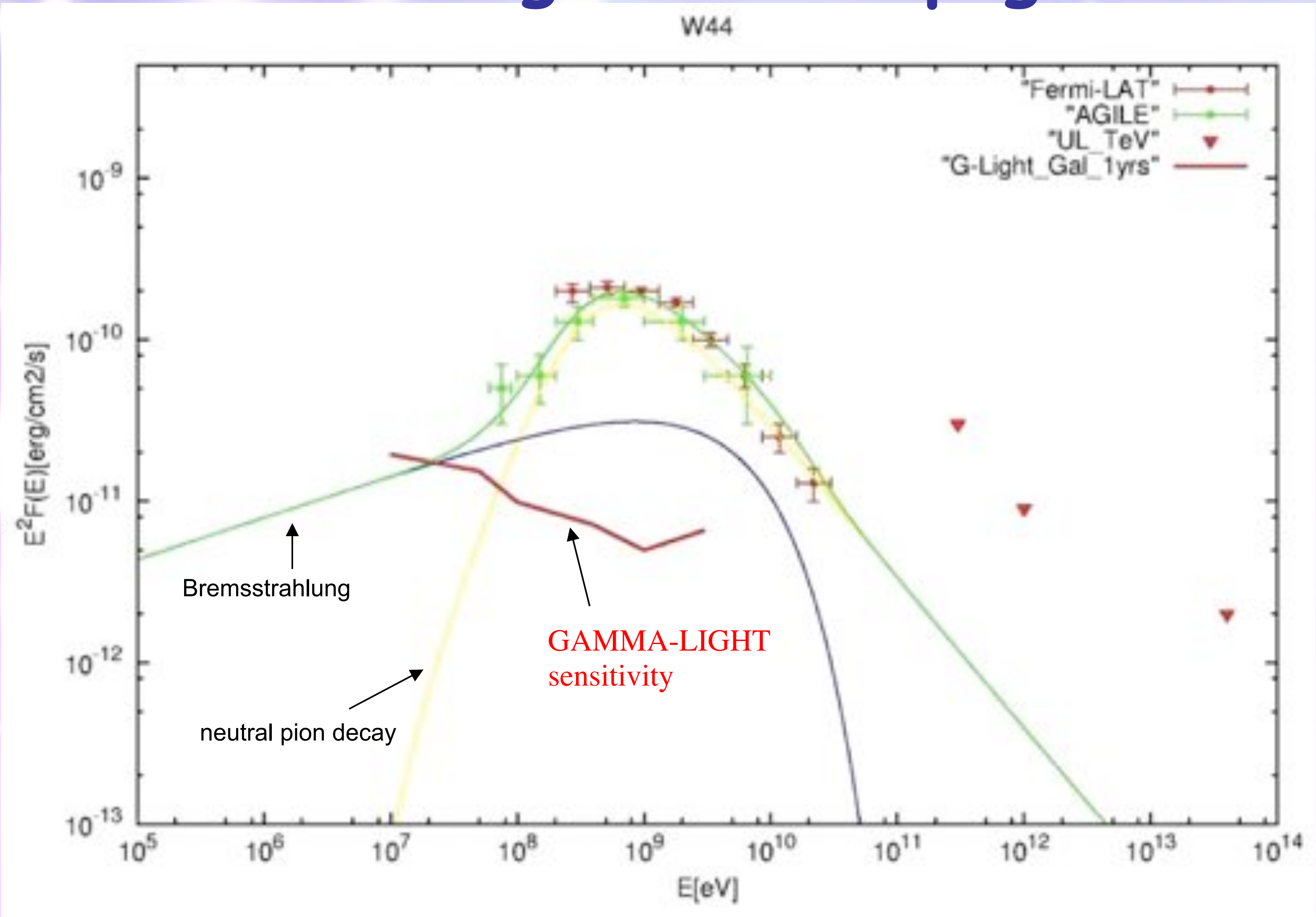
Extragalactic Sources, Blazars, MeV Blazars

Multi-epoch SEDs of the FSRQ 3C454.3



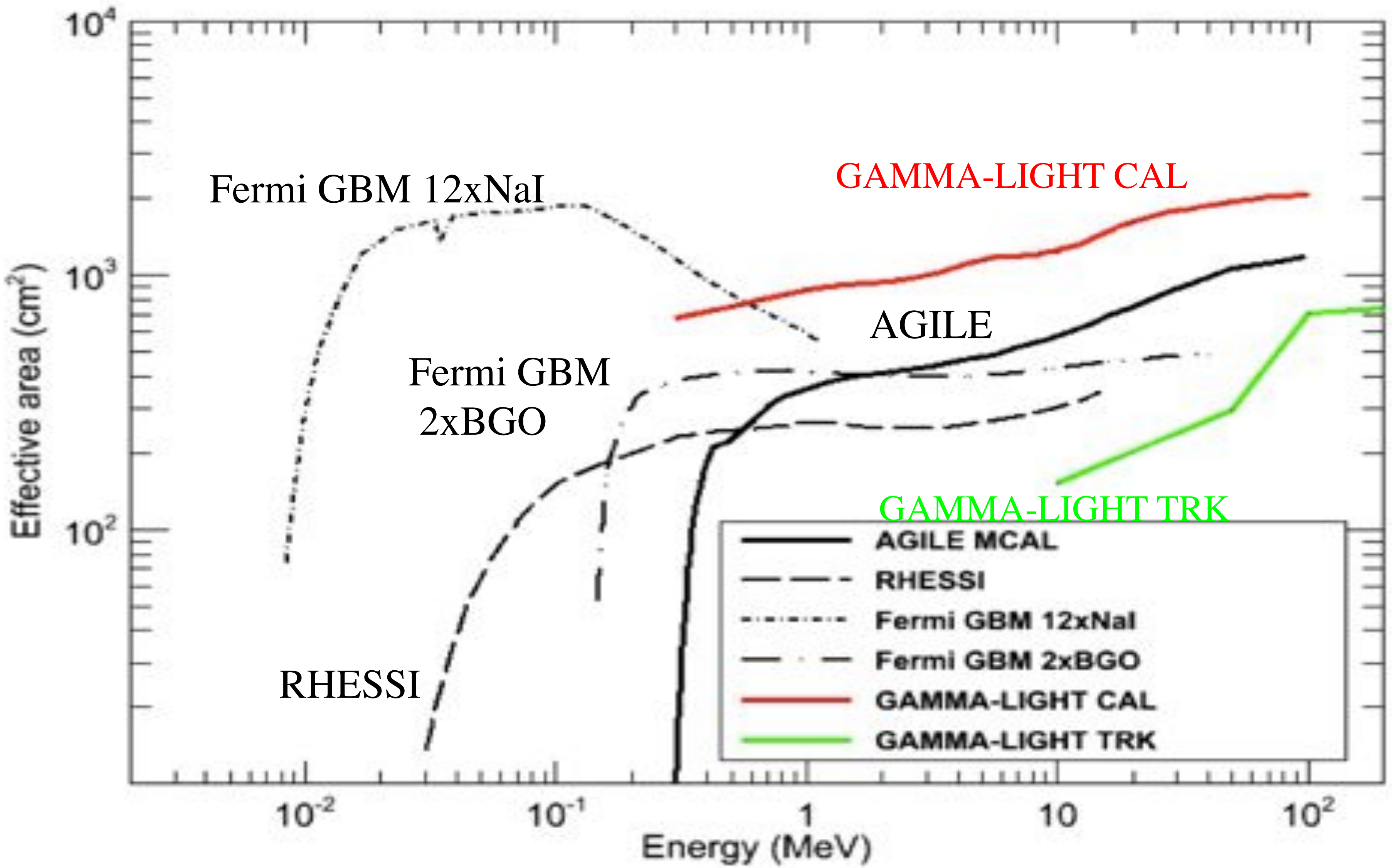
G-LIGHT will allow us to investigate daily (or sub-daily) SEDs during gamma-ray super- flares. The 5-sigma G-LIGHT differential sensitivity (purple line) is computed for an integration time of 48 hours

SNRs and the Origin and Propagation of CRs



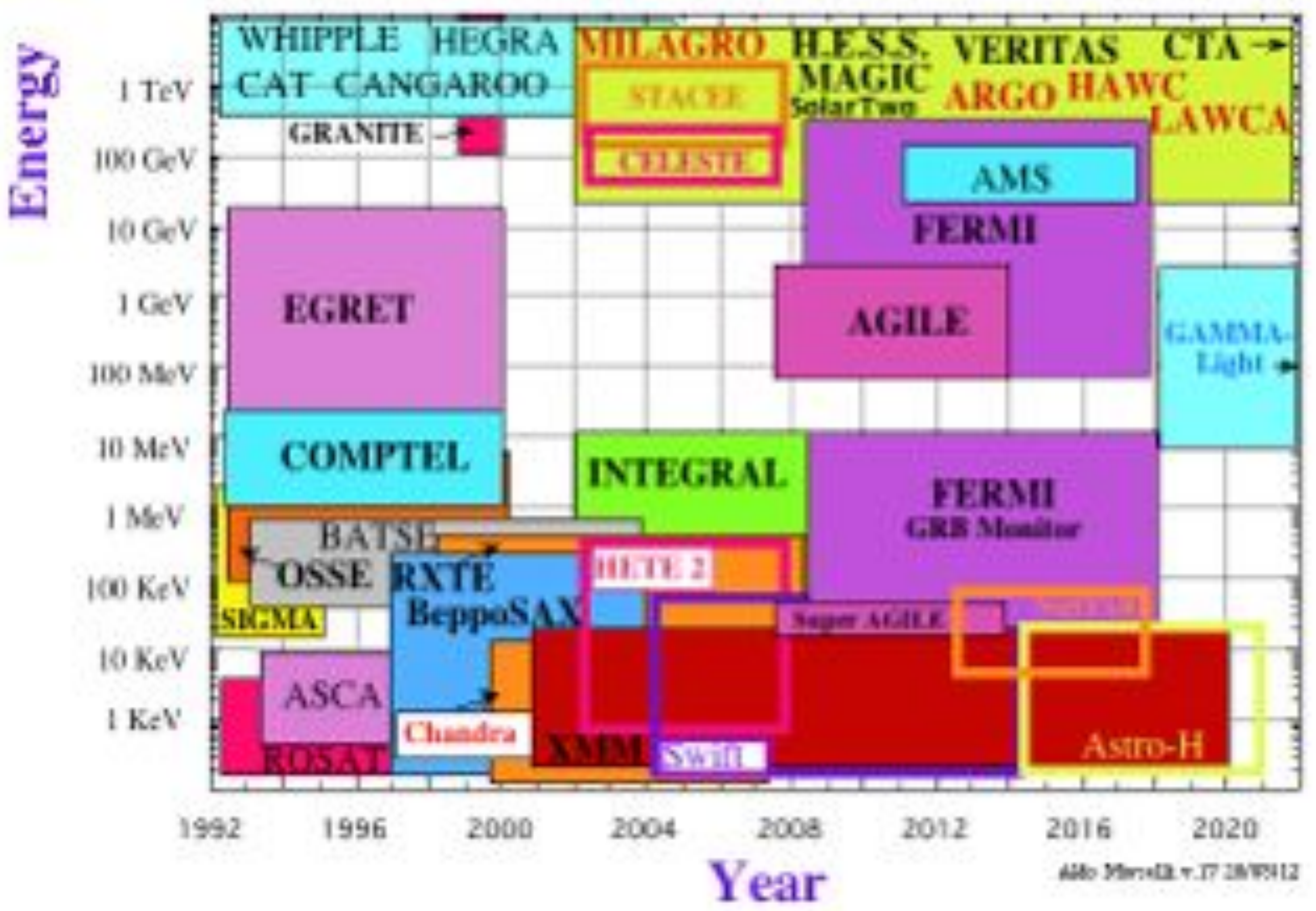
- *gamma-ray spectrum of SNRs W44. The red curve shows the expected GAMMA-LIGHT sensitivity for a 1-year effective time integration.*

Earth Studies Objectives of GAMMA-LIGHT: Terrestrial Gamma-Ray Flashes



Earth Studies Objectives of GAMMA-LIGHT: Terrestrial Gamma-Ray Flashes

- G-LIGHT will fill this observational gap and contribute to TGF science with the following points:
- 1) detection of Terrestrial Gamma-Ray Flashes (TGFs) with extended energy range and imaging capability obtained by a new strategy for Earth albedo background rejection;
- 2) correlating high-energy TGFs with local and global meteorological data, addressing local climate and Climate Change issues;
- 3) studying the impact of TGFs and "high-energy"-TGFs for the atmospheric chemistry and particle transport including gamma-ray and neutron generation and atmospheric propagation to the ground;
- 4) maintaining an updated TGF archive, available to ESA and meteorological institutions.



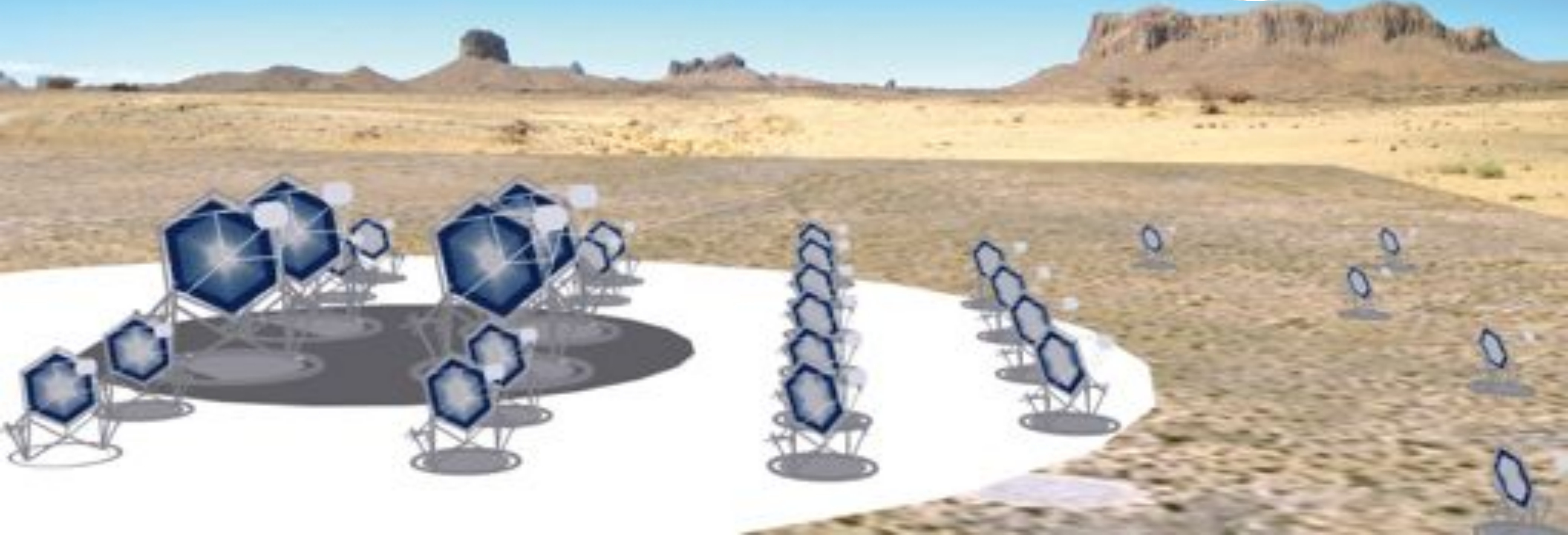
Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
HEGRA
CAT
CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
CTA
ARGO
HAWC
LAWCA
AMS
FERMI
EGRET
AGILE
GAMMA-Light
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
ASCA
Chandra
XMM
Swift
ROSAT
Astro-H
1992
1996
2000
2004
2008
2012
2016
2020
Year

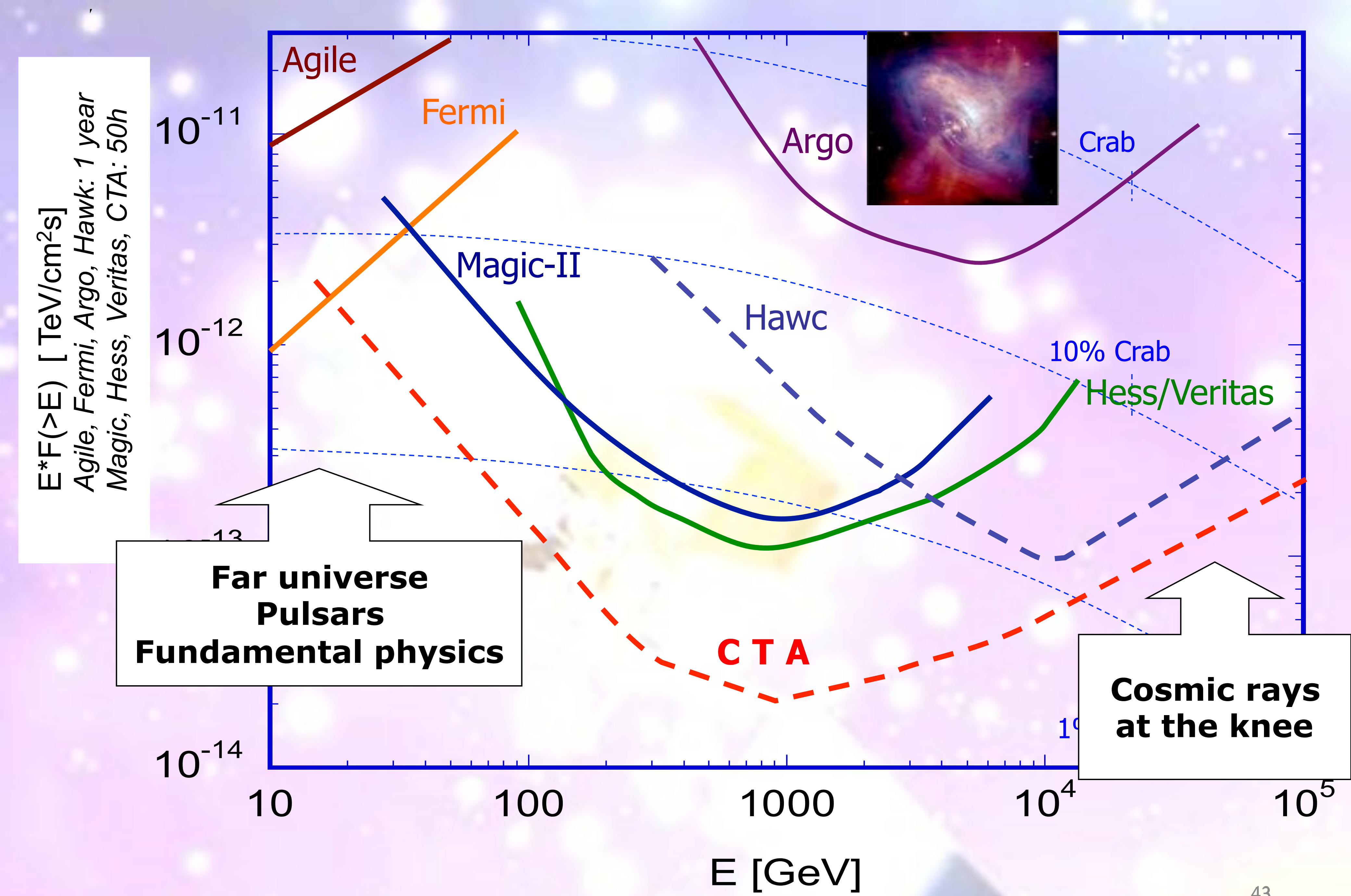
INFN and the Cherenkov Telescope Array

The future in VHE gamma ray astrophysics:

cta

cherenkov telescope array




Agile
Fermi
Argo
Crab
Magic-II
Hawc
10% Crab
Hess/Veritas
C T A
E*F(>E) [TeV/cm²s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10
100
1000
10⁴
10⁵
E [GeV]
Far universe
Pulsars
Fundamental physics
Cosmic rays
at the knee
43

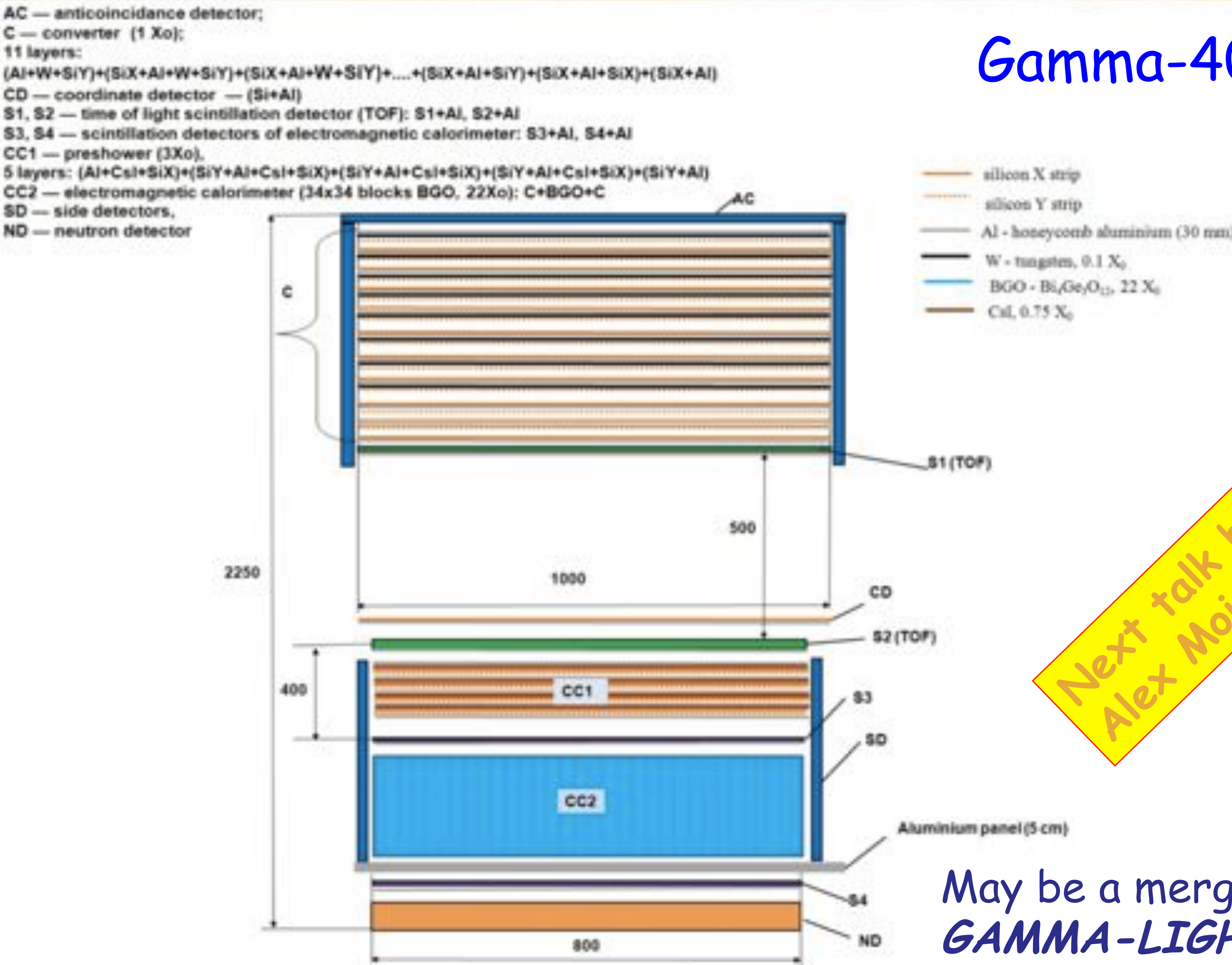
Future Experiments

- **GAMMA-400**, 100 MeV – 3 TeV, an approved Russian γ-ray satellite. Planned launch 2017-18.
Energy resolution (100 GeV) ~ 1 %. Effective area ~ 0.4 m2.
Angular resolution (100 GeV) ~ 0.01°.

- **DAMPE**: Satellite of similar performance.
An approved Chinese γ-ray satellite. Planned launch 2015-16.

- **HERD**: Instrument on the planned Chinese Space Station. Energy resolution (100 GeV) ~ 1 %. Effective area ~ 1 - 2 m2. Angular resolution (100 GeV) ~ 0.01°.
Planned launch around 2020.

Gamma-400



Next talk by Alex Moiseev

May be a merging with ***GAMMA-LIGHT*** ?

thank you for the attention