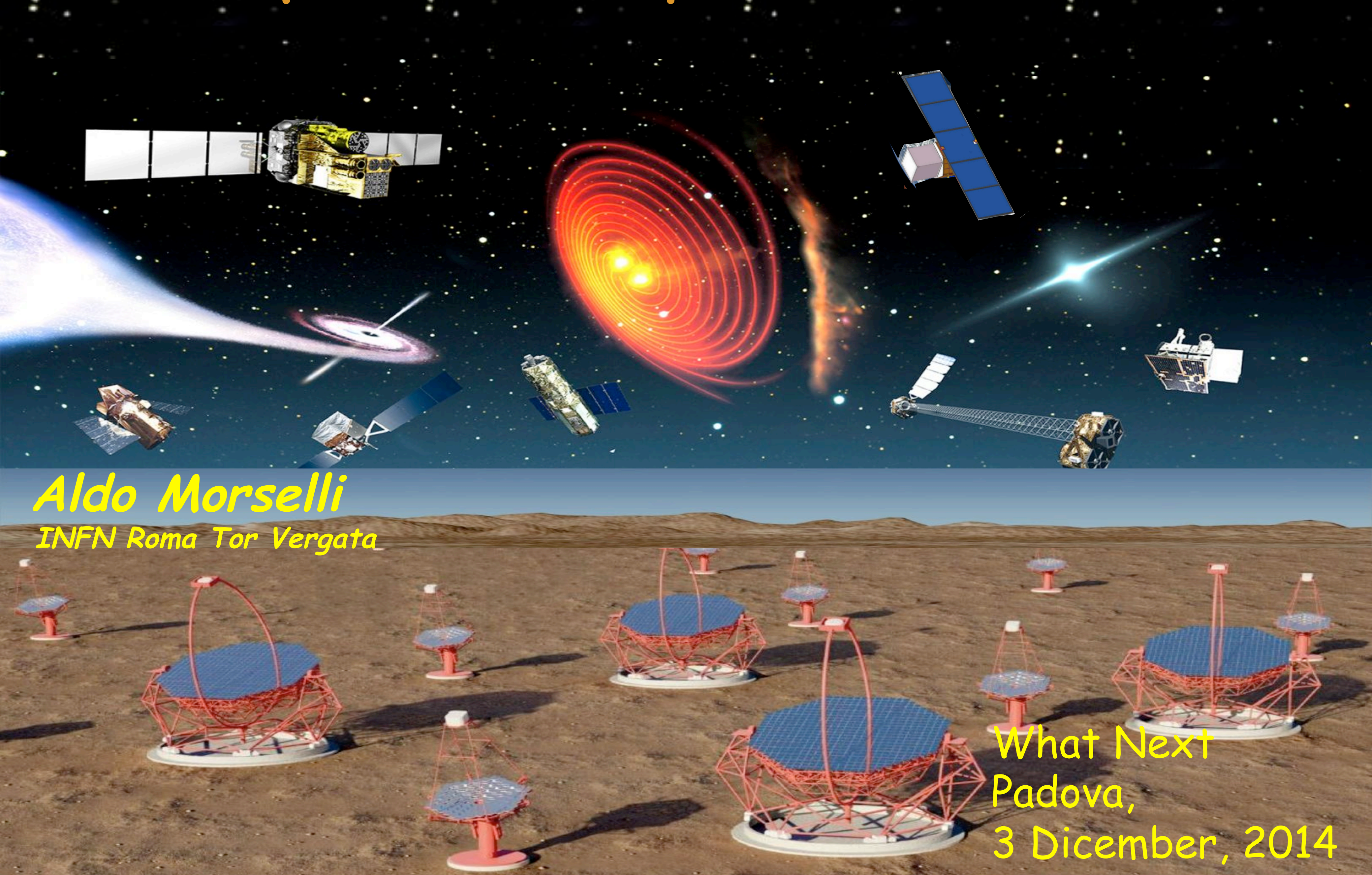
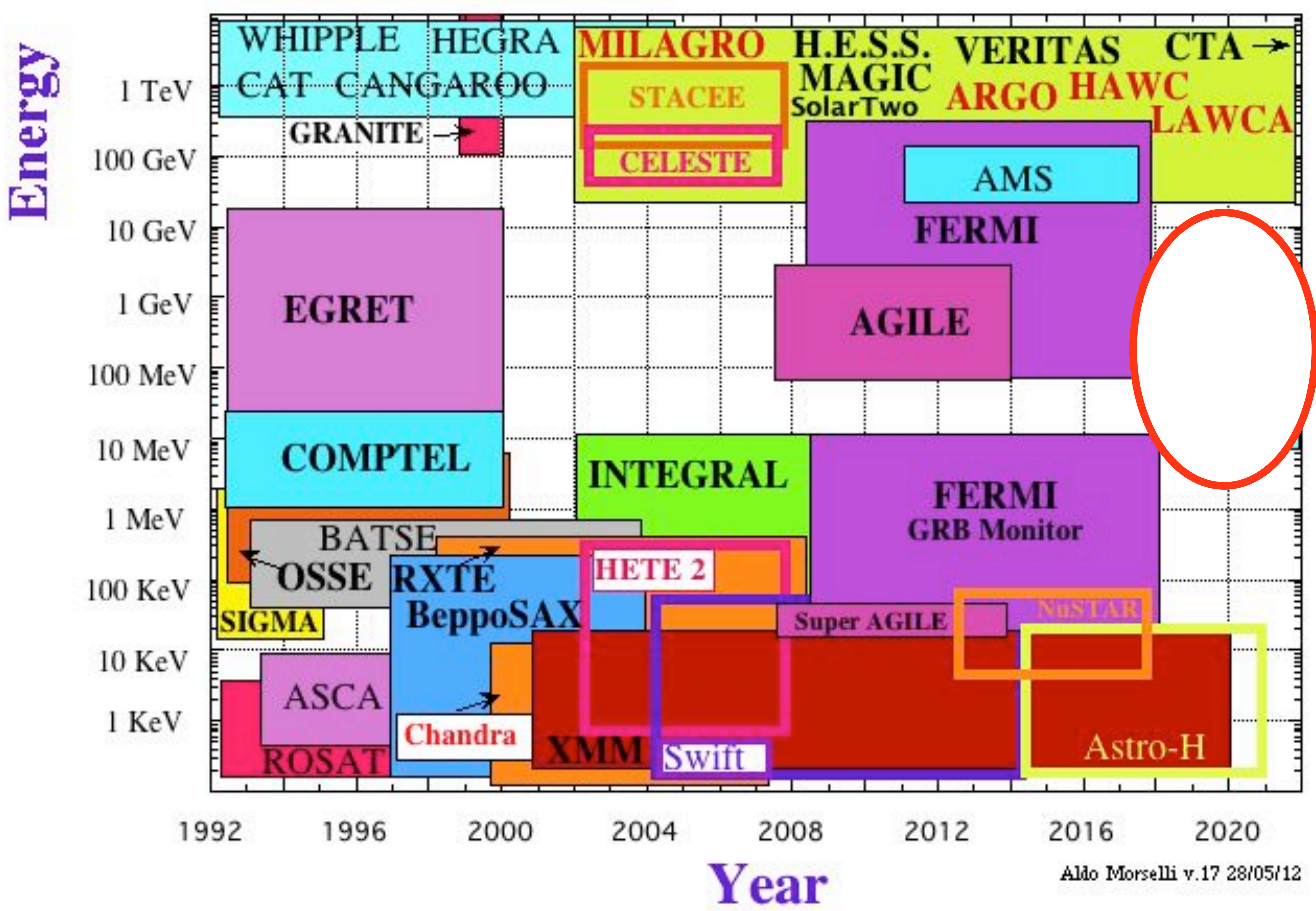
Future experiments in space : From KeV to TeV



Aldo Morselli
INFN Roma Tor Vergata

What Next
Padova,
3 Dicember, 2014

The Low Energy frontier


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
ARGO
HAWC
CTA
LAWCA
AMS
FERMI
AGILE
EGRET
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
NuSTAR
ASCA
ROSAT
Chandra
XMM
Swift
Astro-H
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli v.17 28/05/12

- the 1-100 MeV energy range: the last frontier

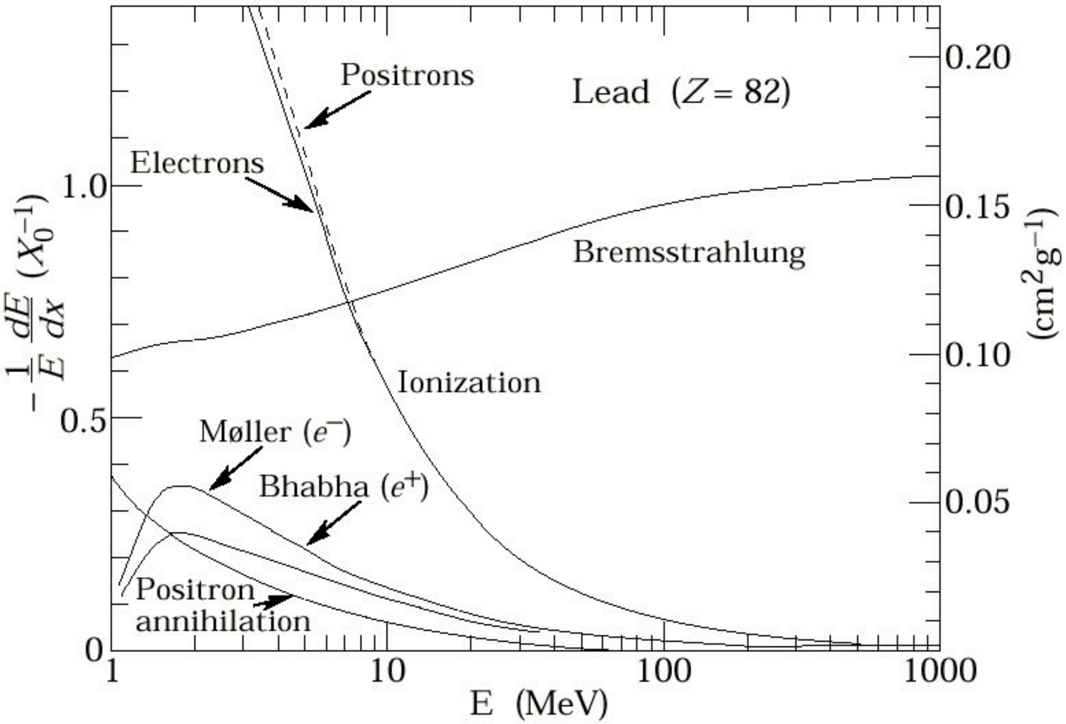
- mostly unexplored

- crucial energy range: transition from quasi-thermal (Comptonized) to non-thermal processes.

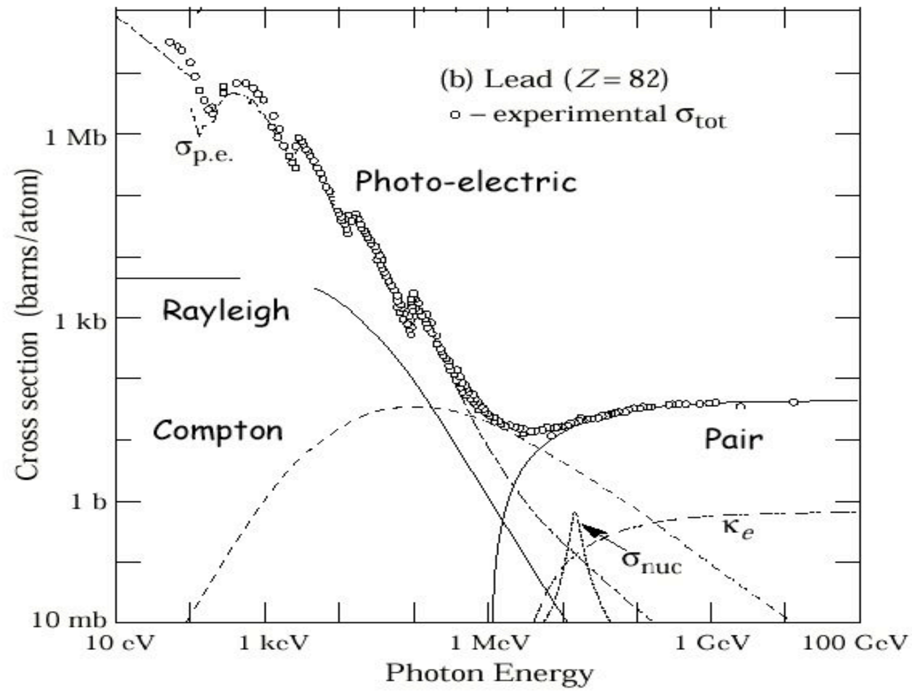
- 1-100 MeV unexplored domain with good sensitivity at GeV energies for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Interaction of photons with matter

Fractional energy loss for e^+ and e^- in lead



Photon total cross sections

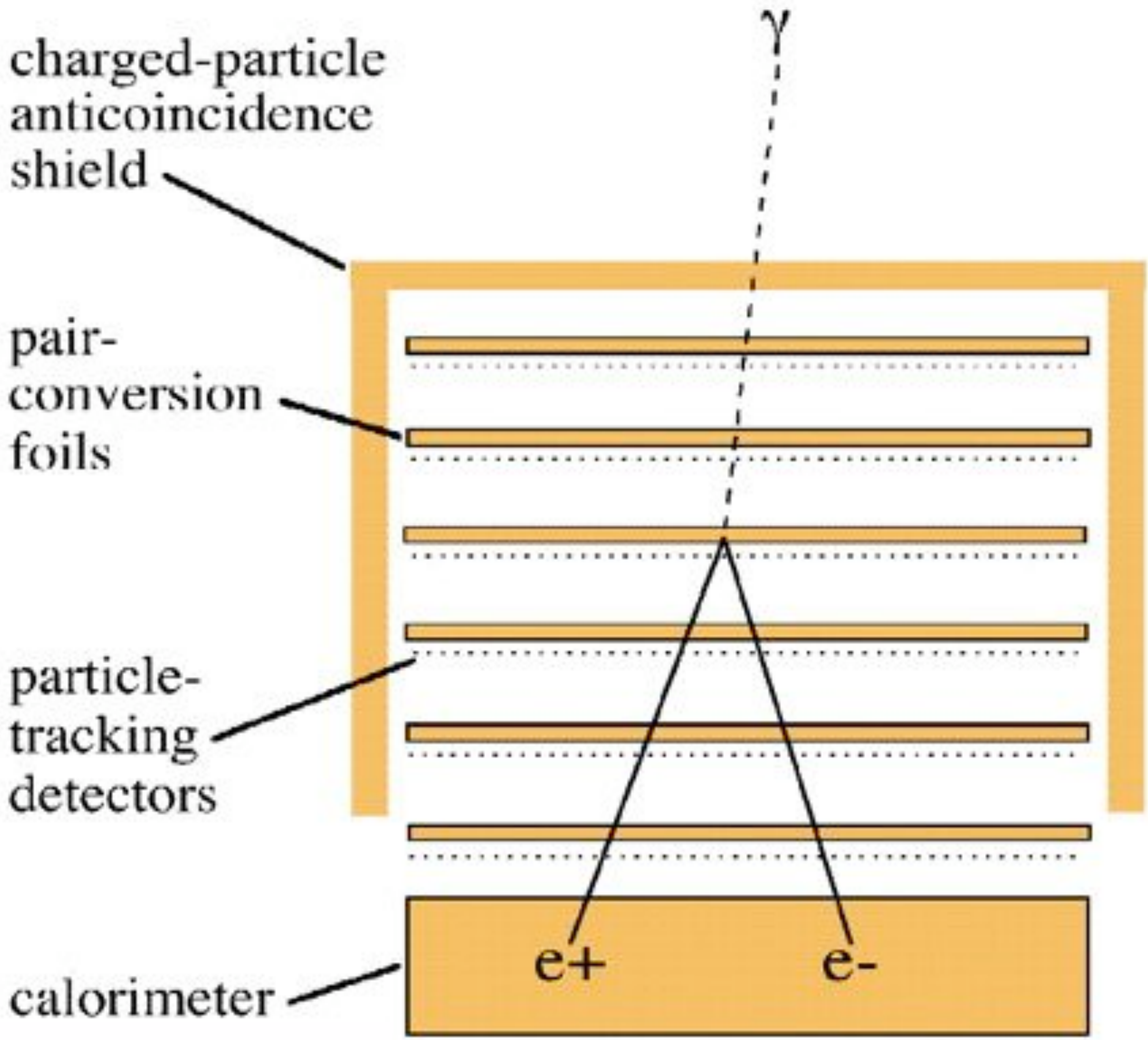


$$\left.\frac{dE}{dx}\right|_{Brems} = -\frac{E}{X_0} \Rightarrow E(x) = e^{-\frac{x}{X_0}}$$

$$\text{Prob. of Int.} = 1 - \exp^{-\frac{7}{9}\frac{x}{X_0}}$$

x/X_0	Prob Int.
0.5	0.40
1	0.54
2	0.79
7	0.995

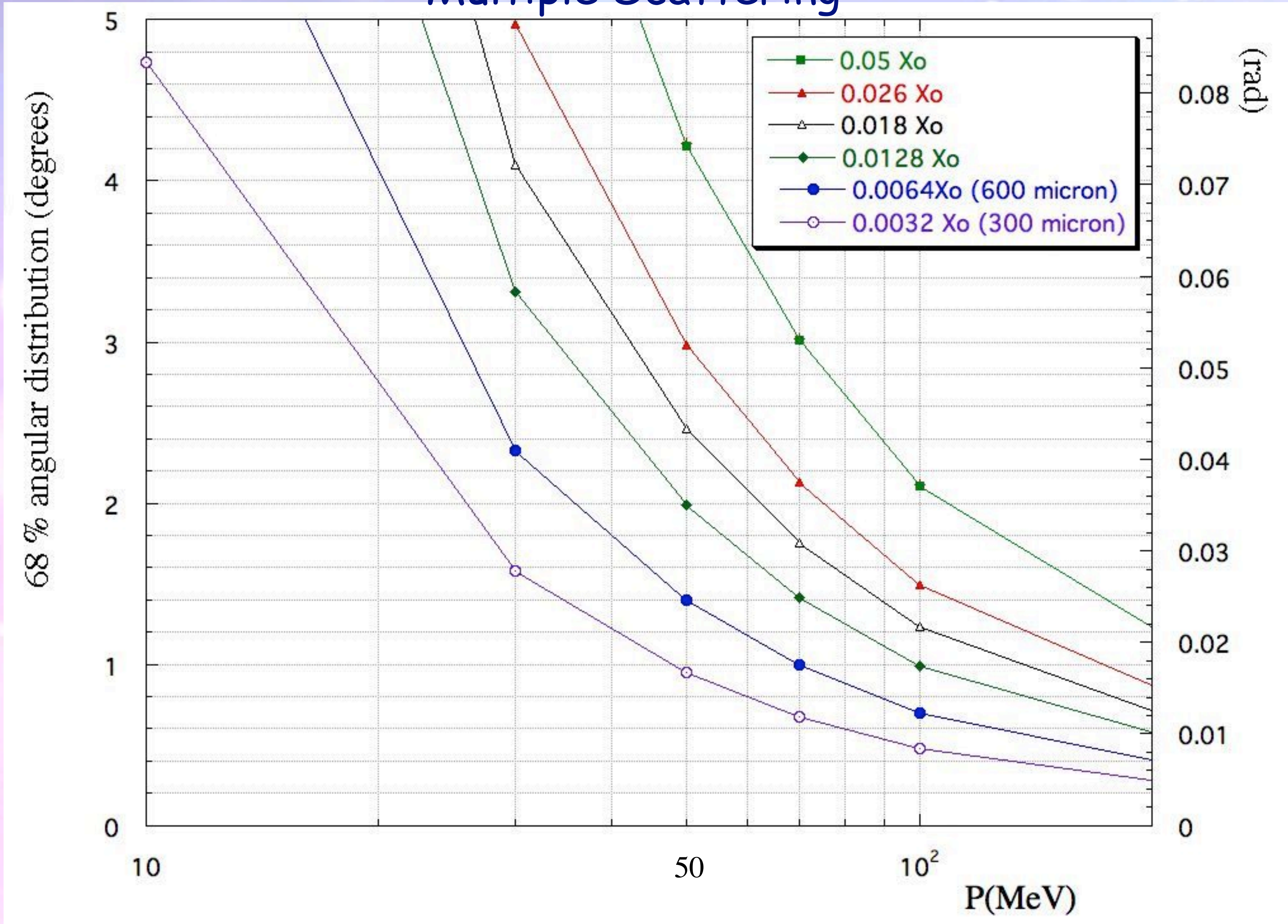
Elements of a pair-conversion telescope



(energy measurement)

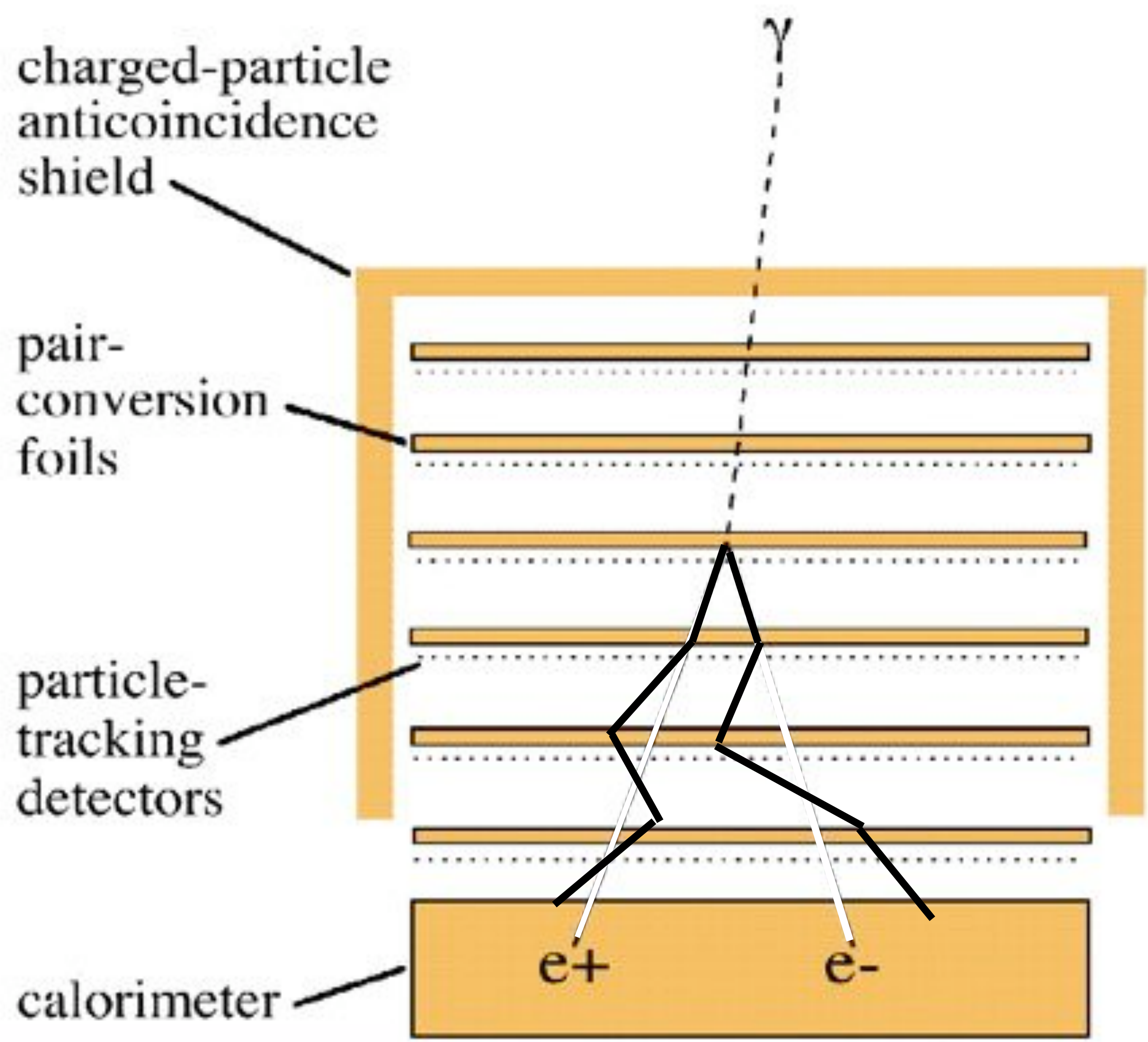
- photons materialize into matter-antimatter pairs:
  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering



Elements of a pair-conversion telescope

(more realistic scheme)



(energy measurement)

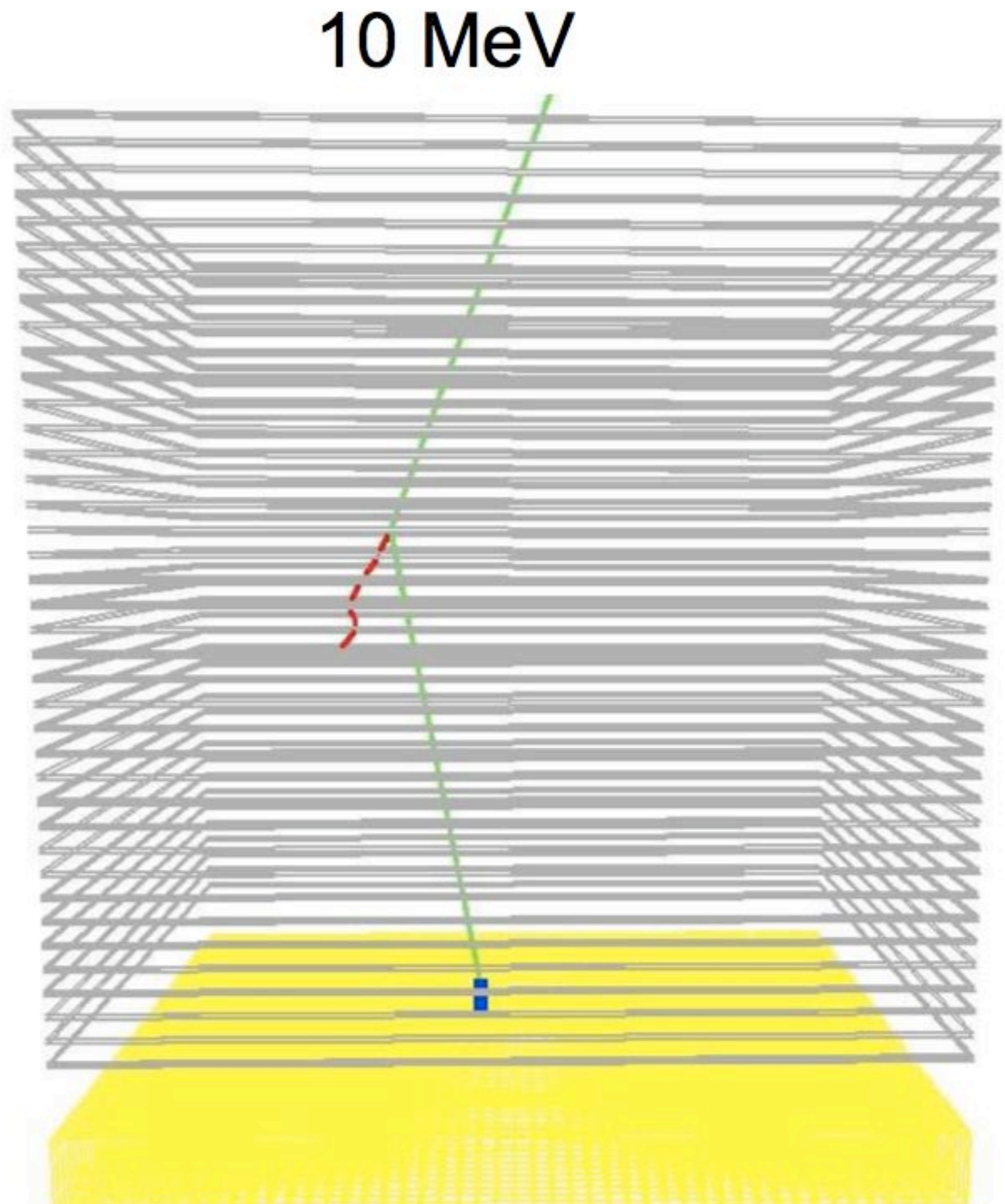
- photons materialize into matter-antimatter pairs:

  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

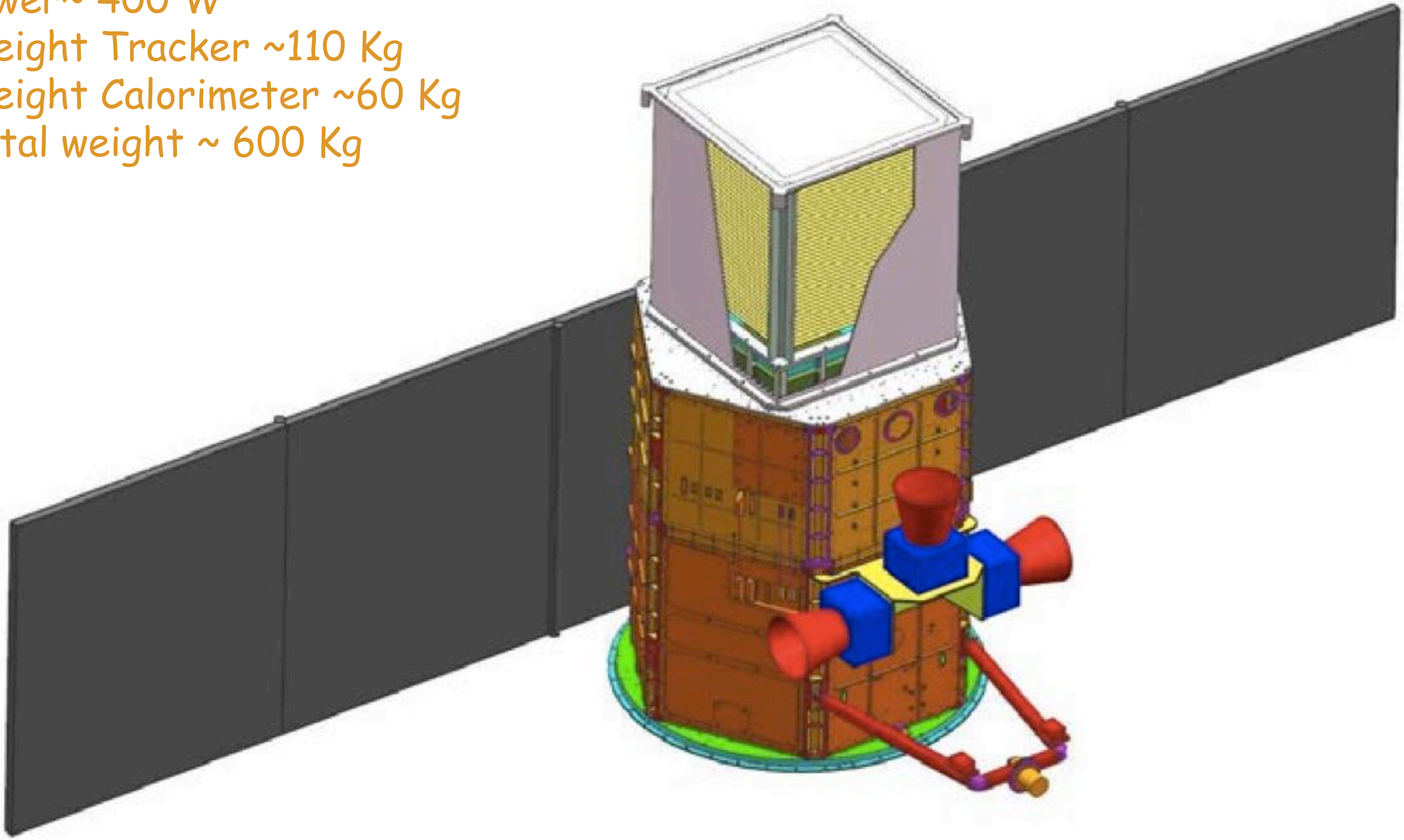
Compton Simulation

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 project

Power~ 400 W
Weight Tracker ~110 Kg
Weight Calorimeter ~60 Kg
Total weight ~ 600 Kg



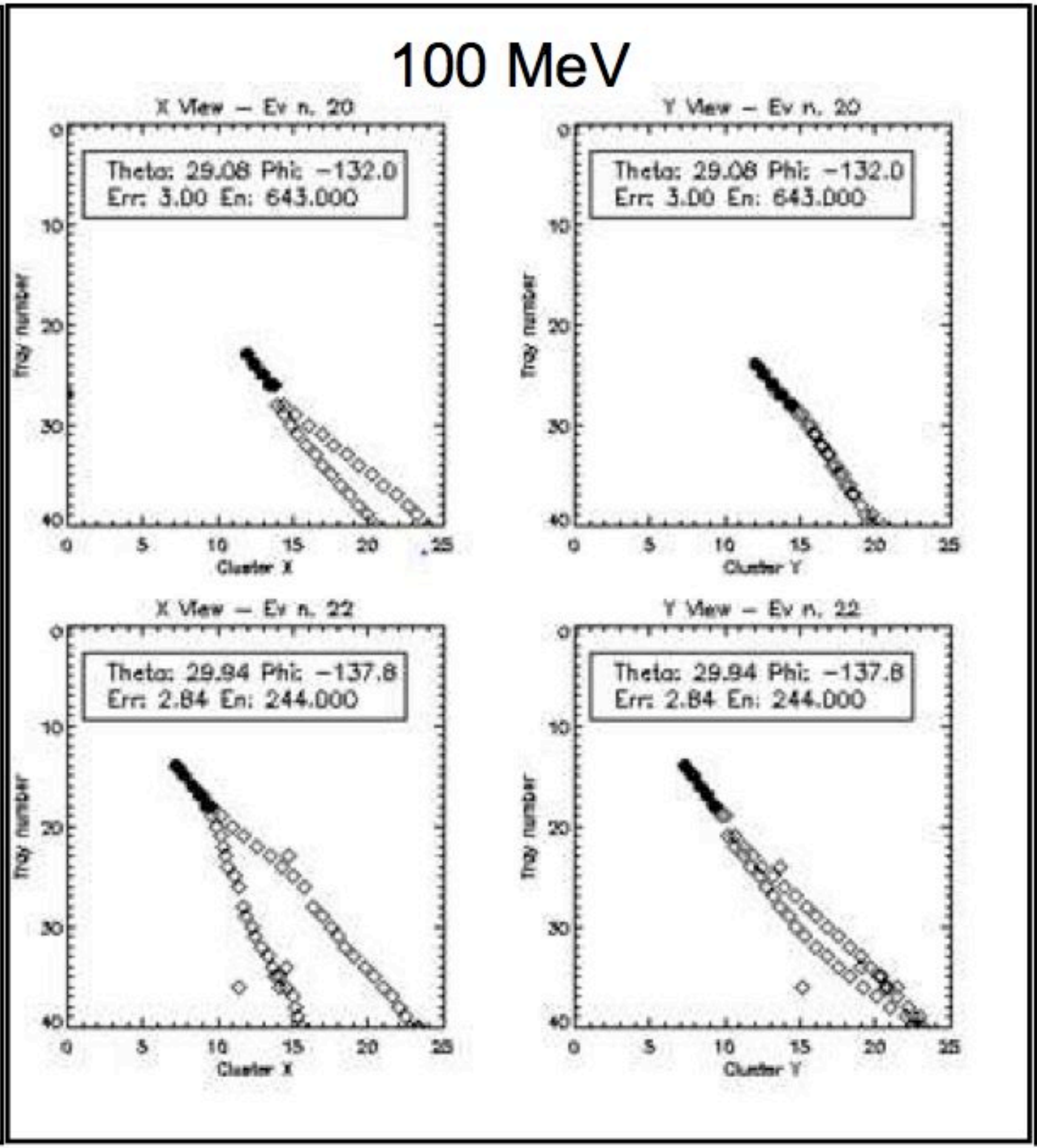
GAMMA-LIGHT

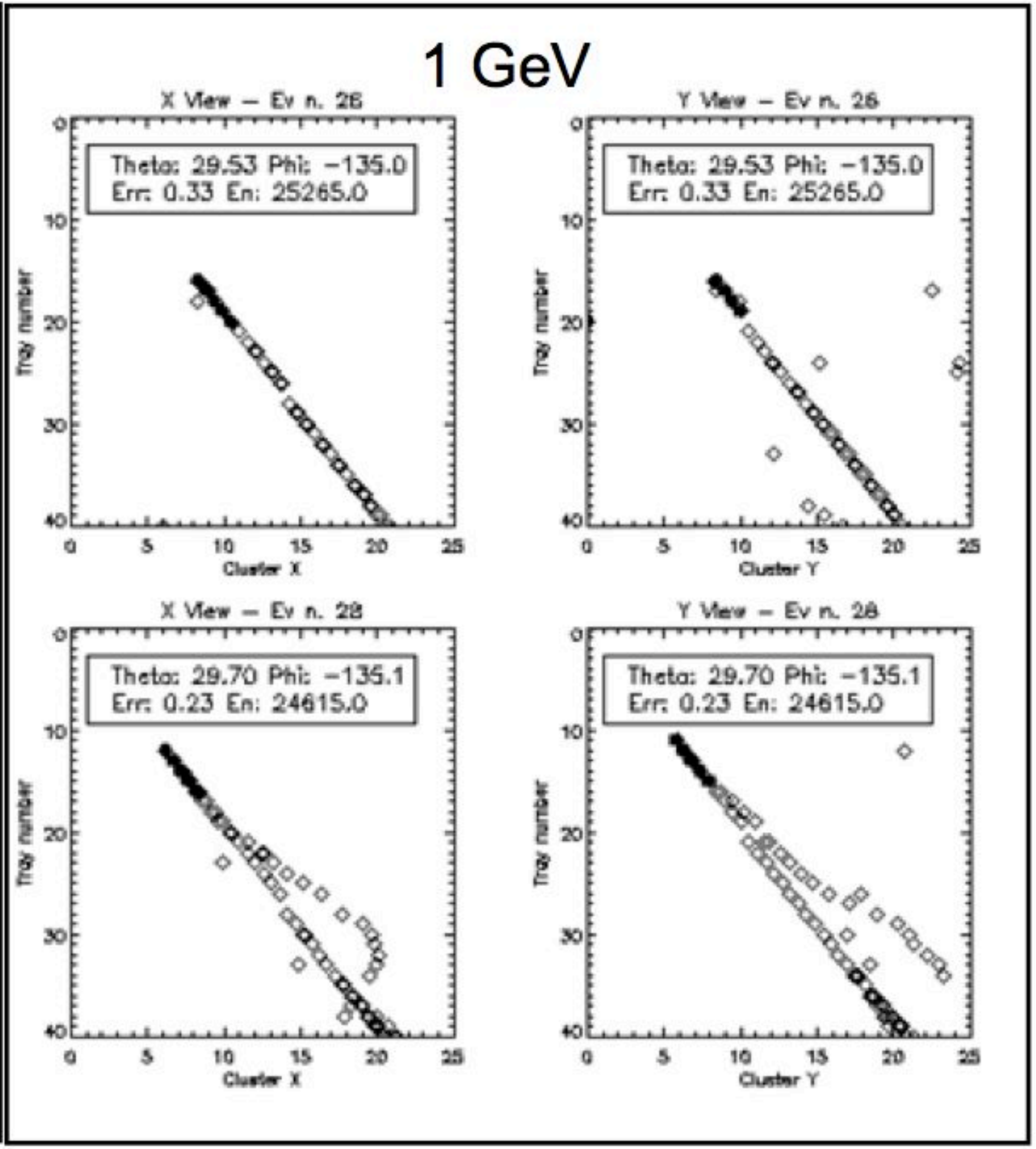
- First proposed in 2012 for the ESA Call of Small Scientific Missions.
- Focused on gamma-ray detection with much improved sensitivity in the range **10-100 MeV**.
- **Very high level of readiness (AGILE, Fermi heritage)**.
- **New astrophysics** in the range below 100 MeV for both Galactic and extragalactic sources

GAMMA-LIGHT: the instrument (total weight: 260 kg)

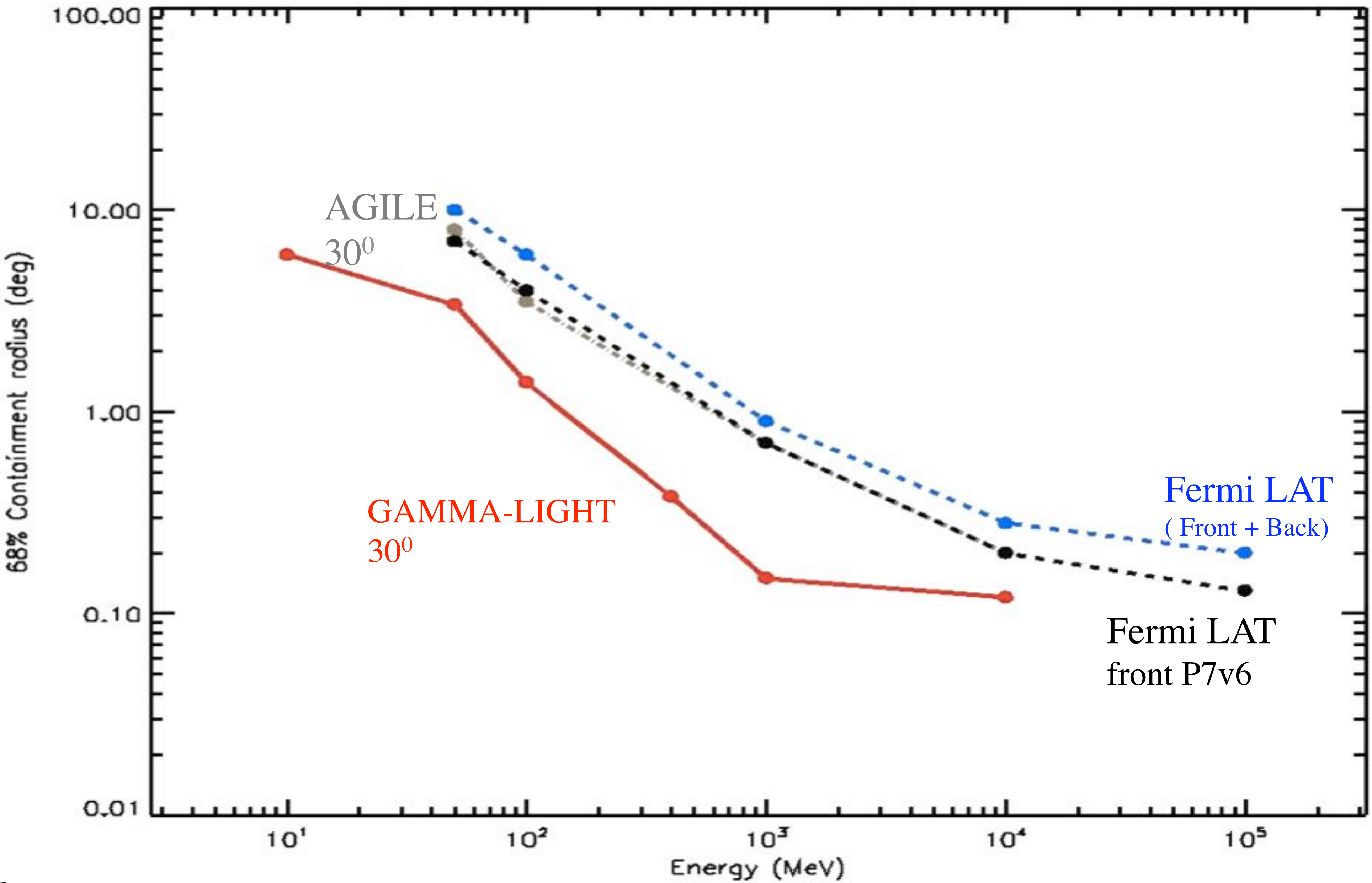
- Silicon Tracker with **analog readout** and **no heavy absorber** (10 MeV – 1 GeV)
- CsI Calorimeter (200 keV – 200 MeV)
- Anticoincidence
- Data Handling

Gamma-light *Simulation*



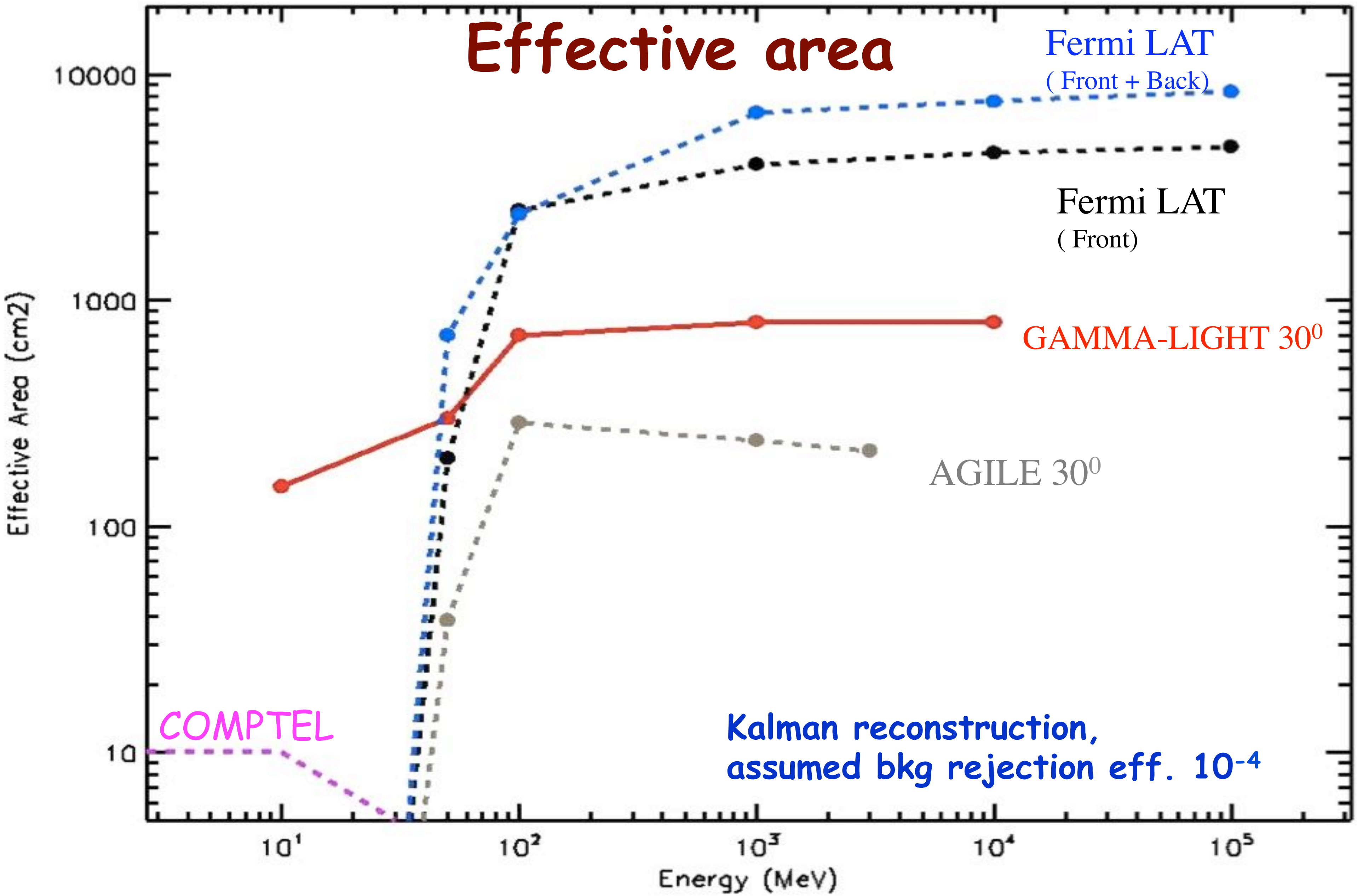


Gamma-Light Point Spread Function (angular resolution)

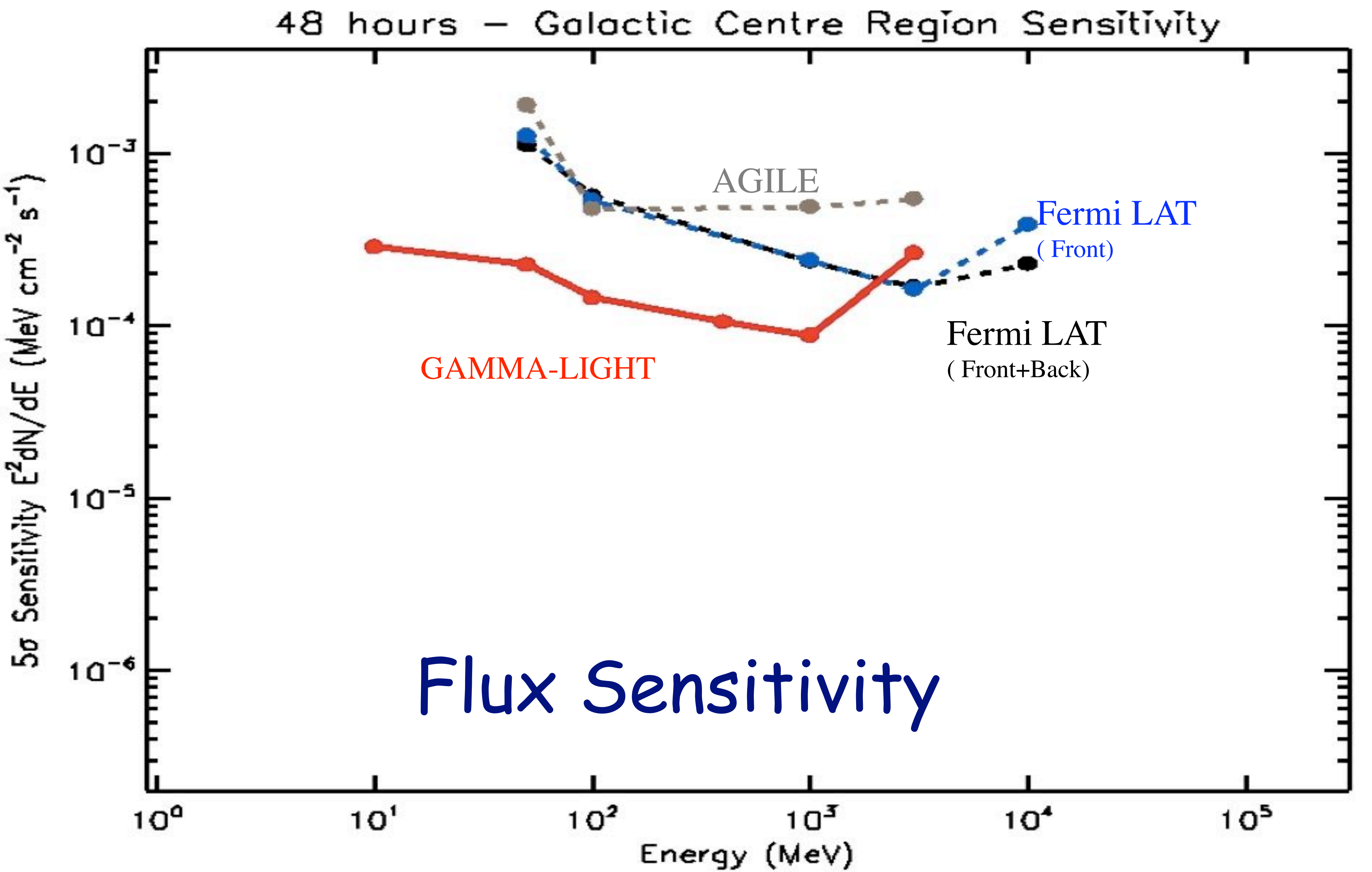


A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

Effective area

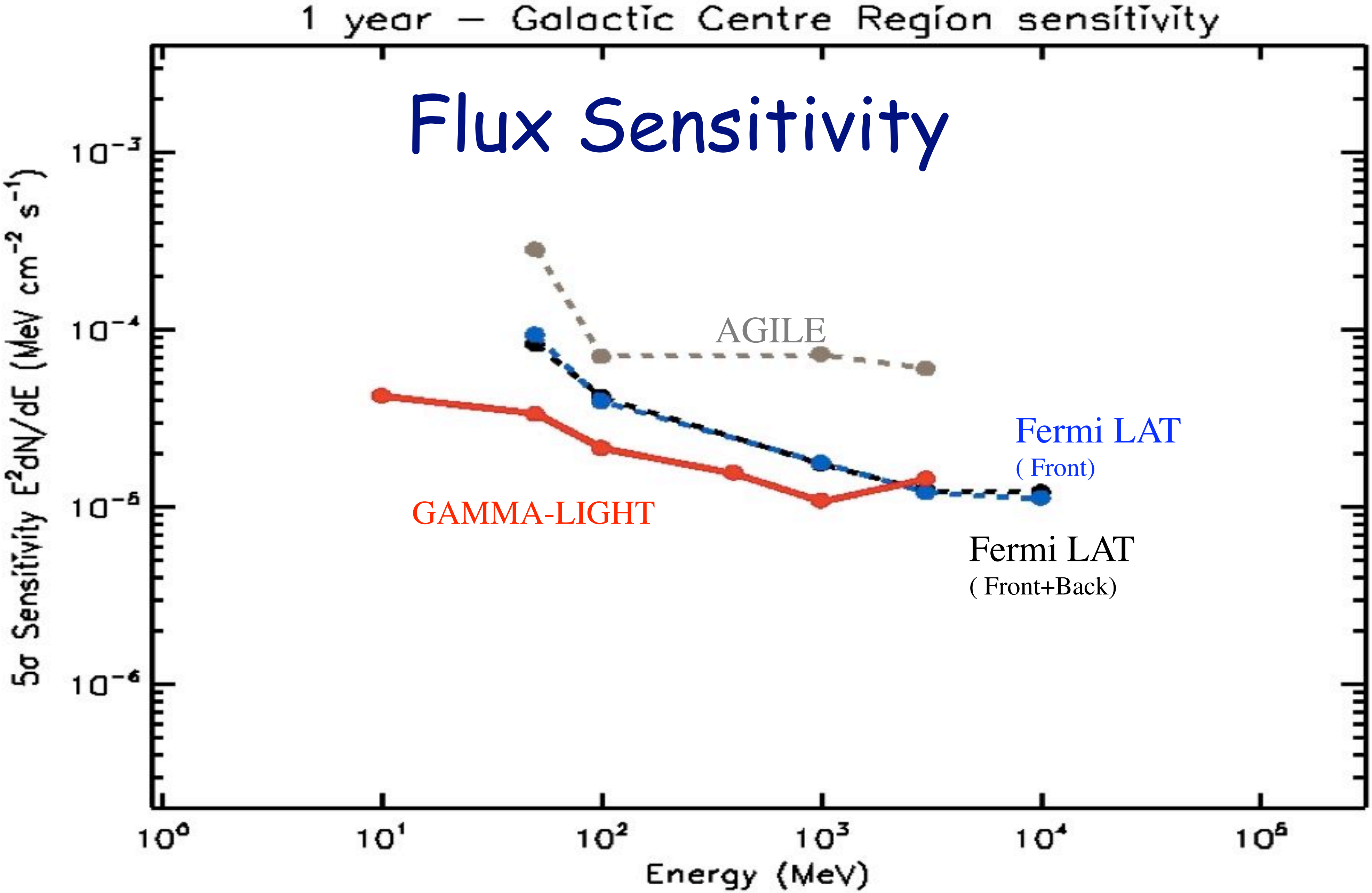


A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

Flux Sensitivity



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

ESA M-4 Call

- quite different from previous Medium-sized Mission Calls (Solar Orbiter, EUCLID, PLATO);
- total ESA budget: 450 Meuro.
- guidelines for an ‘‘ESA-only’’ mission:
  - Payload mass: 300 kg;
  - total spacecraft mass: 800 kg.

ESA M-4 Call

- idea of ‘’ marriage’’ with a Compton telescope sensitive in the range 200 keV – 10 MeV.

- possible merging with the Astro-MeV group.

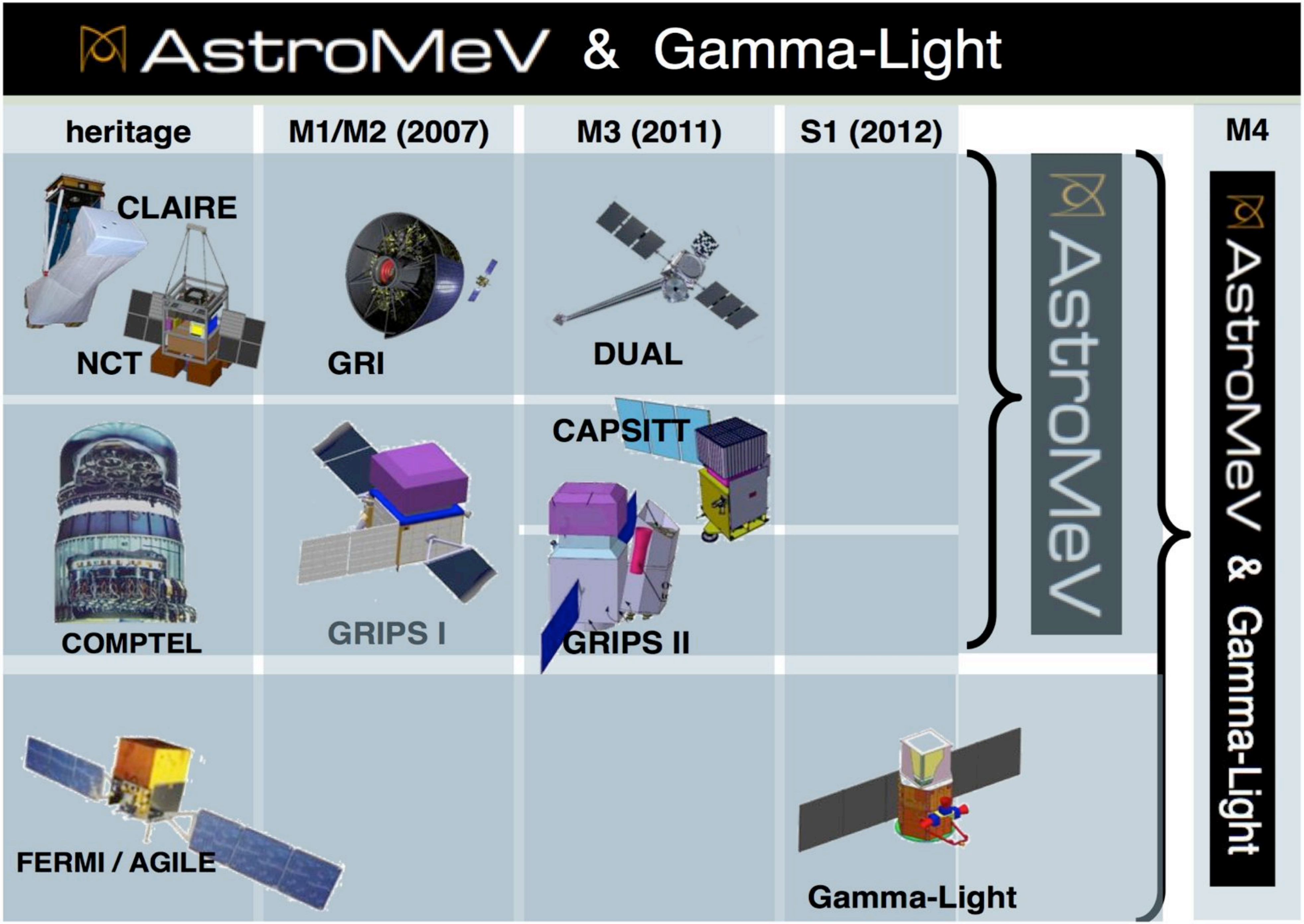
- Science, Instrument, Community.

the ‘‘MeV-GeV’’ concept

- range 200 KeV – 100 MeV: new window.

- sensitivity (continuum and lines) better than INTEGRAL, COMPTEL, AGILE and FERMI by a factor 10-20.

- Two options under considerations:
  - One single instrument for Compton and pair
  - Two instruments on board the same spacecraft



AstroMeV & Gamma-Light
heritage
M1/M2 (2007)
M3 (2011)
S1 (2012)
M4
CLAIRE
NCT
GRI
DUAL
CAPSITT
COMPTEL
GRIPS I
GRIPS II
FERMI / AGILE
Gamma-Light
AstroMeV
AstroMeV & Gamma-Light

ASTROGAM Consortium organization

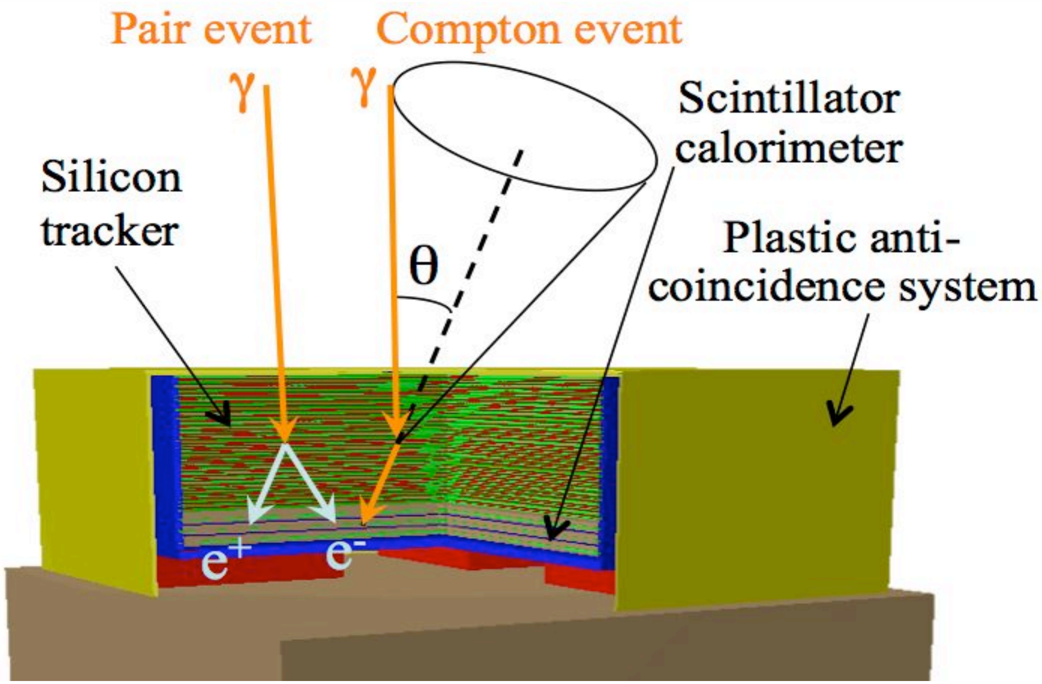
- Consortium members: 230 scientists from 18 countries
- Executive board (representatives of key nations/labs):
  - INAF- Istituto di Astrofisica e Planetologia Spaziali, Rome, **Italy**: Andrea Argan
  - INFN Roma Tor Vergata, Rome, **Italy**: Aldo Morselli
  - INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, Milano, **Italy**: Sandro Mereghetti
  - IRAP, Toulouse, **France**: Peter von Ballmoos
  - Institut de Ciències de l'Espai, CSIC-IEEC, Bellaterra, Barcelona, **Spain**: Margarita Hernanz
  - University College Dublin, School of Physics, Belfield Dublin, **Ireland**: Lorraine Hanlon
  - MPI für Extraterrestrial Physics, Garching, **Germany**: Gottfried Kanbach
  - Johannes Gutenberg Universität Mainz, Institut für Physik, Mainz, **Germany**: Uwe Oberlack
  - DTU SPACE, Lyngby, **Denmark**: Carl Budtz-Jørgensen, Niels Lund
  - University of Geneva, **Switzerland**: Roland Walter
  - KTH Royal Institute of Technology, Stockholm, **Sweden**: M.Pearce, J. Larsson, F. Ryde
  - The University of Tokyo, Department of Physics, Tokyo, **Japan**: Kazuhiro Nakazawa
  - Ioffe Physico-Technical Institute, St.Petersburg, **Russia**: Bykov Andrei
  - Clemson University, Clemson, SC, **USA**: Dieter Hartmann, Marco Ajello, Mark Leising
  - NRL, Washington, DC, **USA**: Eric Grove

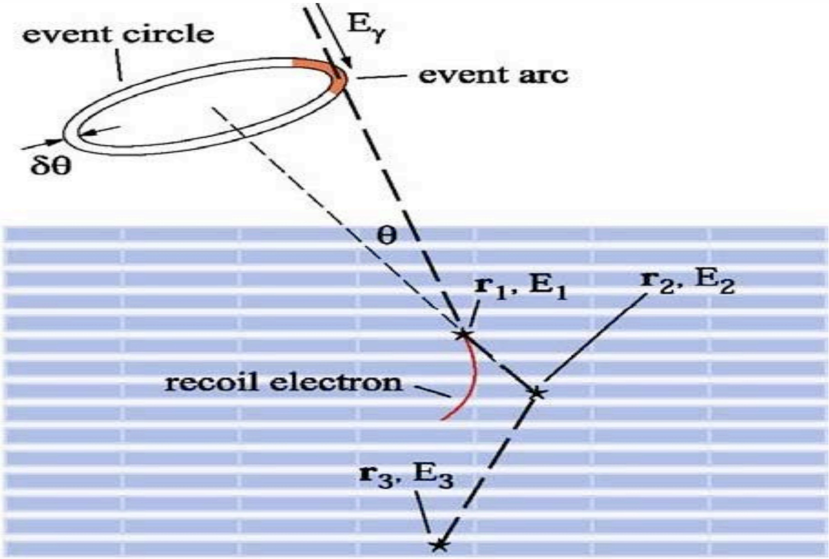
ASTROGAM Programmatic interests

- Scheme of national involvements in the ASTROGAM payload currently discussed within the Consortium

Item	programmatic interest	Italian labs involved
Tracker Si detector procurement*	Japan, **Italy**	**FBK**
Tracker ASIC and FEE	France, Spain, **Italy**	**INFN**
Tracker mechanical structure	Spain	
Tracker back-end electronics	**Italy**	**INFN**
Tracker assembly, verification & testing	**Italy,** France	**INAF, INFN, Univ. Roma-2**
Calorimeter crystal procurement*	France	
Calorimeter SDDs* and FEE	**Italy**	**INAF-IASF-Bo**
Calorimeter module assembly	Ireland, France	
Calorimeter back-end electronics	Germany	
Cal. assembly, verification & testing	**Italy**	**INAF-IASF-Bo**
Anticoincidence detector	France, Germany	
Data Handling	**Italy**, Germany, France	**INAF**

* ***Procurement examples****: Si DSSD – FBK; CsI(Tl) – Saint Gobain; SDDs – FBK-SRS*



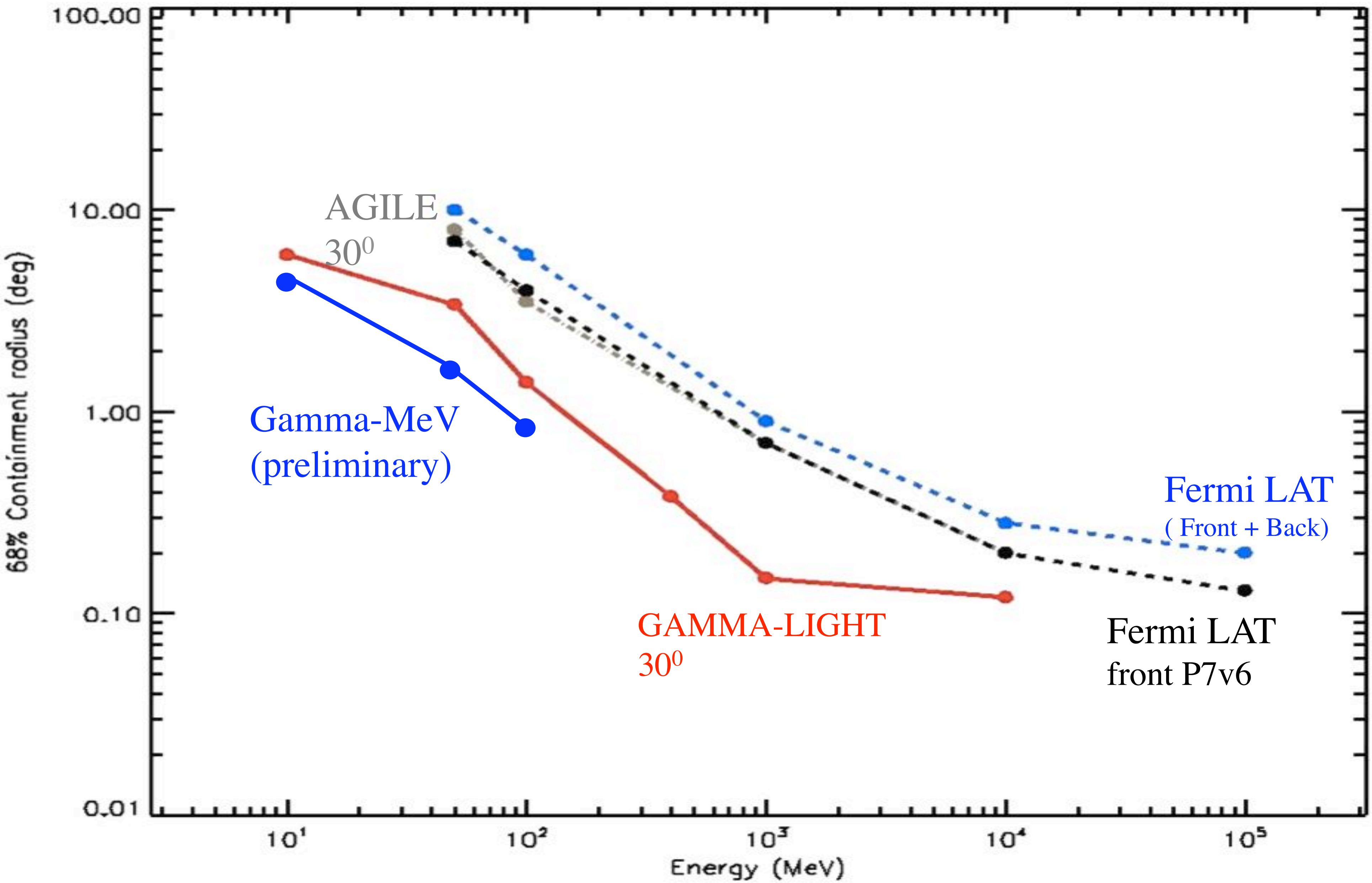


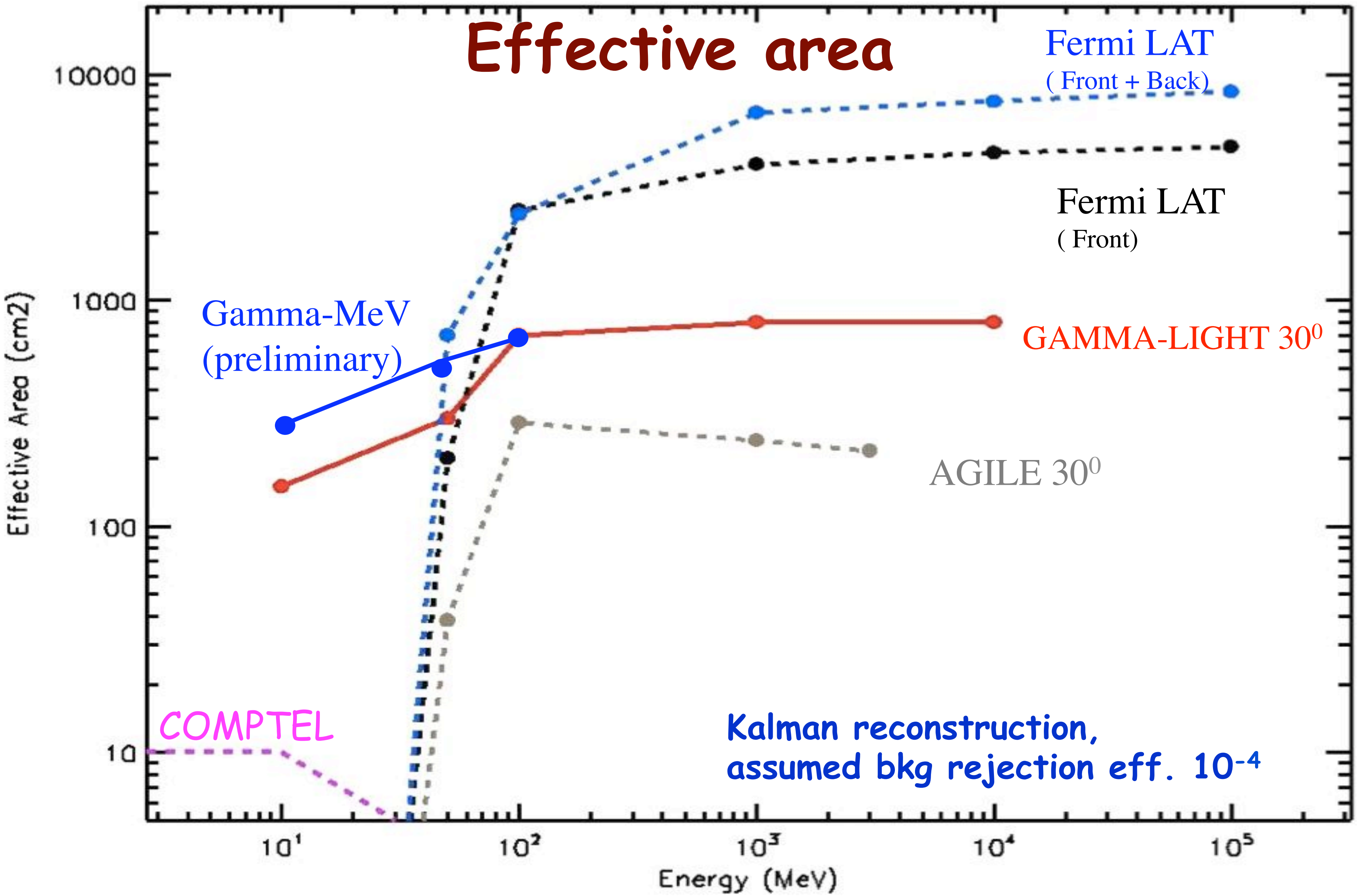
Measuring the direction of the recoil electron can constraint the event to an arc of the Compton annulus

Compton telescope - Incident γ-ray energy and angle from the hit 3D-positions and energy deposits (Compton equation: $\cos\theta = 1 + m_e c^2[1/(E_1+E_2) - 1/E_2]$)

Pair telescope - Tracking of the electrons and positrons produced by pair conversion of the incident γ-rays, as in Fermi/LAT, but without tungsten converter and with analog readout to optimize angular resolution

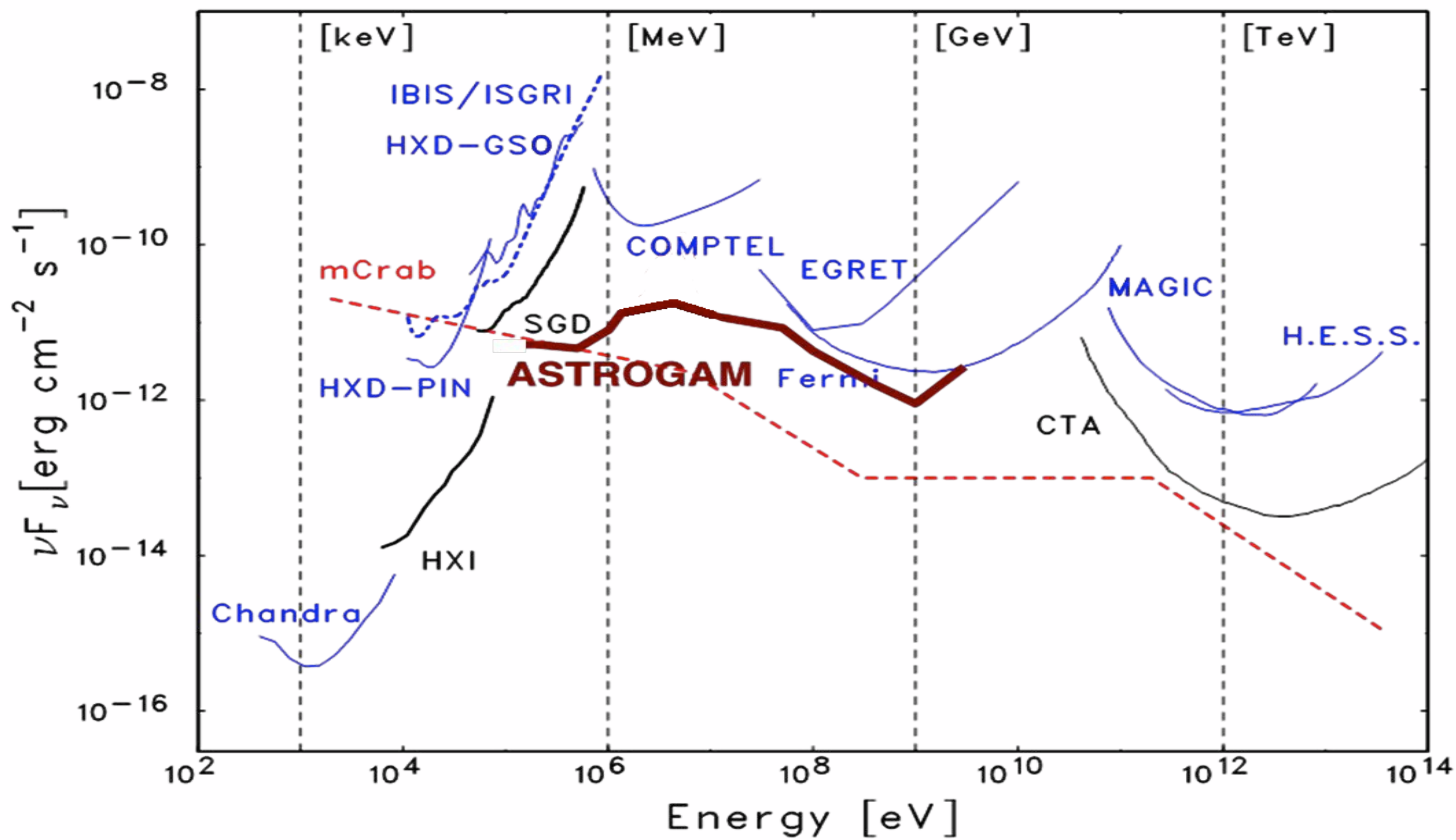
Point Spread Function (angular resolution) Comparison





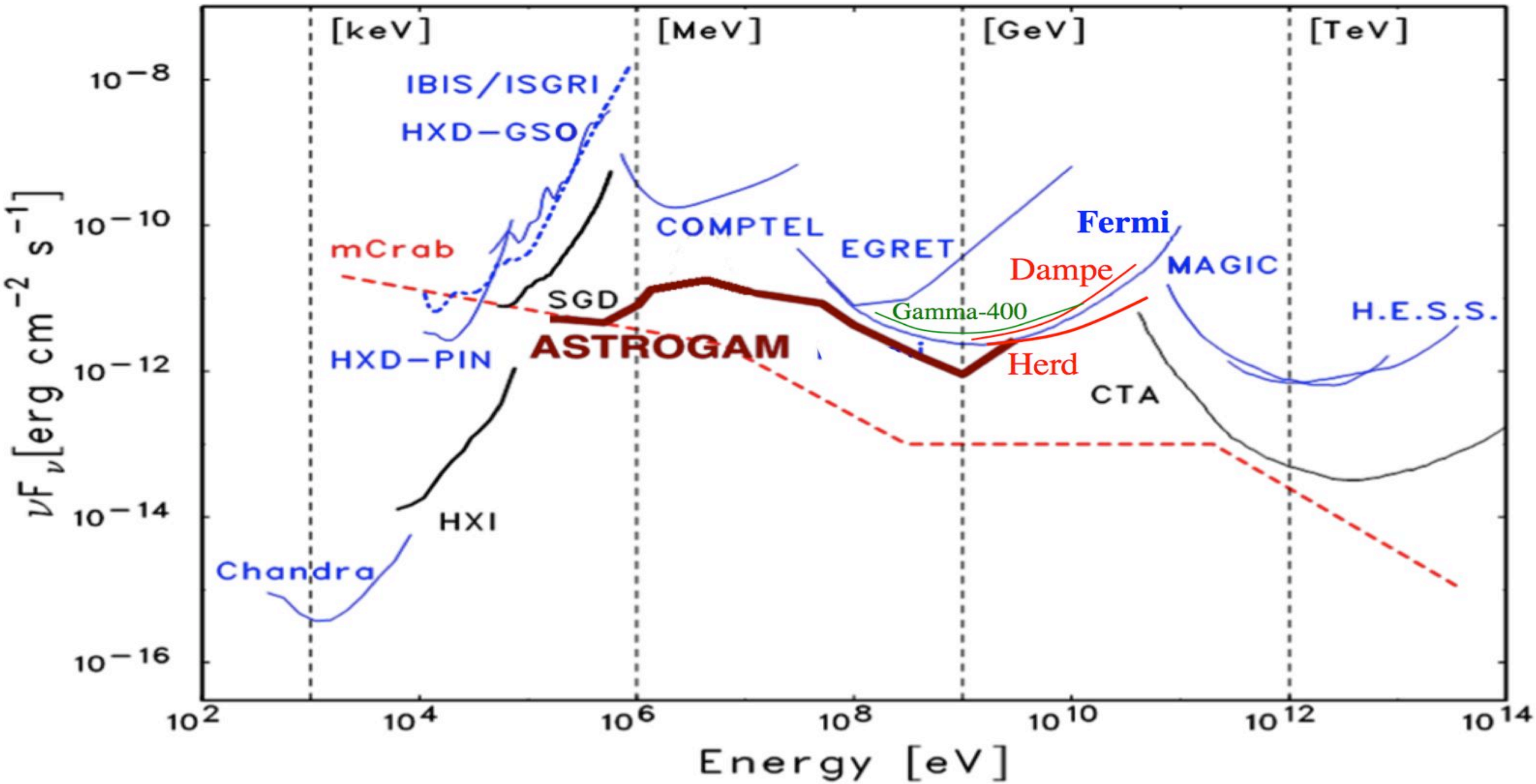
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

ASTROGAM 3.5 yr survey sensitivity



- **ASTRO-H/SGD** – 3σ sensitivity for 100 ks exposure of an isolated point source
- **COMPTEL** and **EGRET** – sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT** – 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
- **ASTROGAM** – 5σ sensitivity for a high Galactic latitude source after 3.5 years in survey mode

ASTROGAM 3.5 yr survey sensitivity



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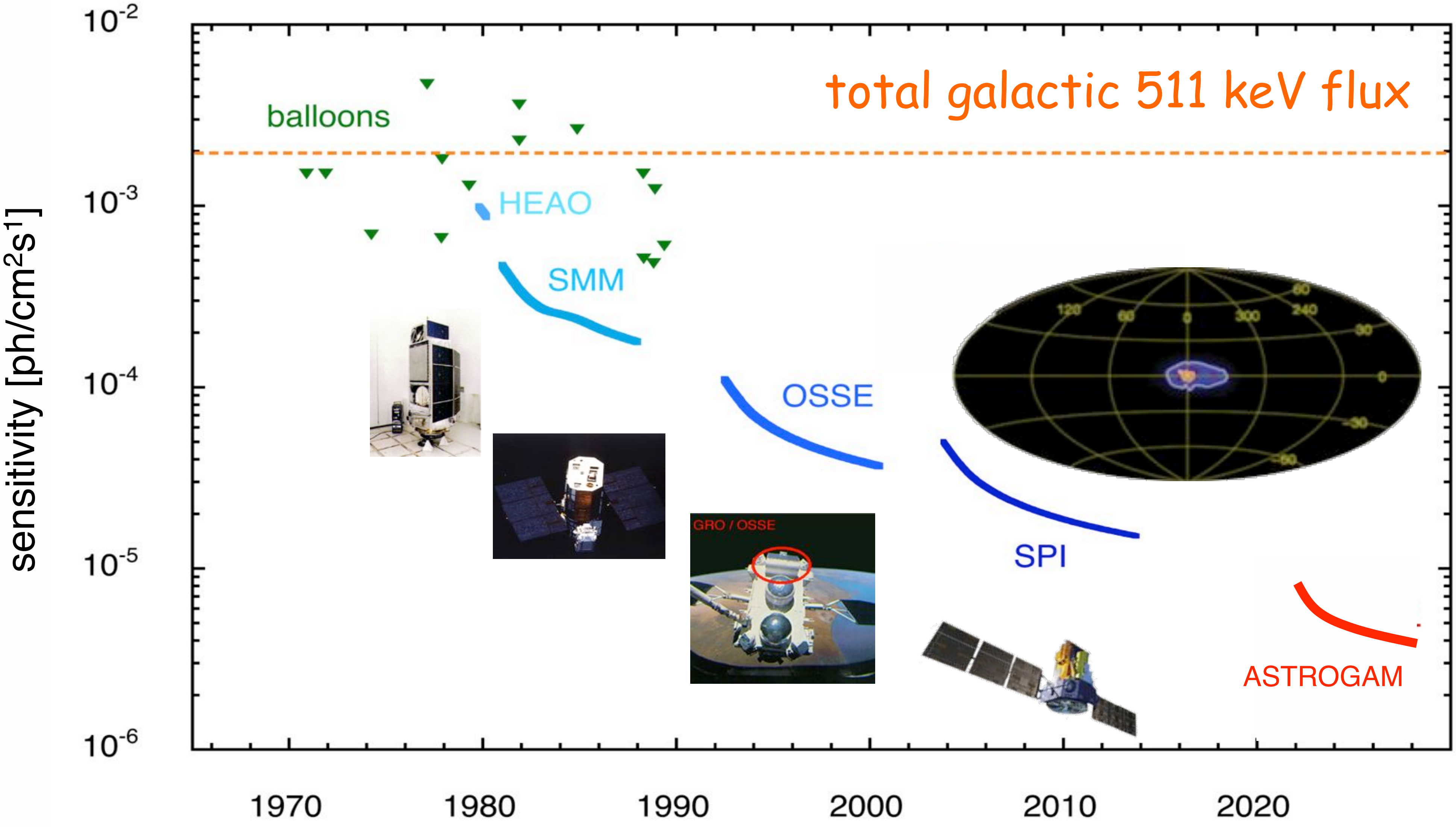
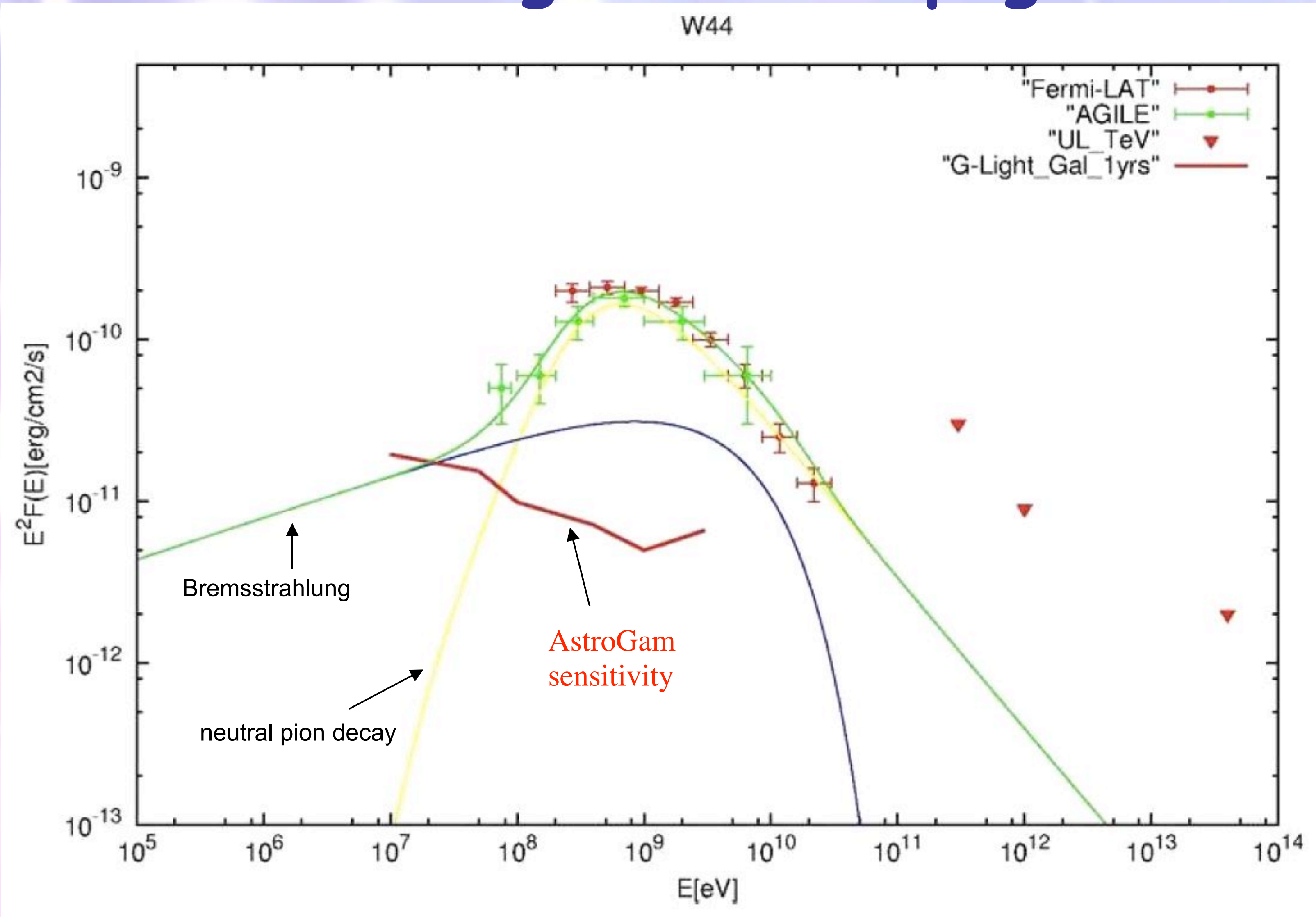
ASTROGAM positron annihilation

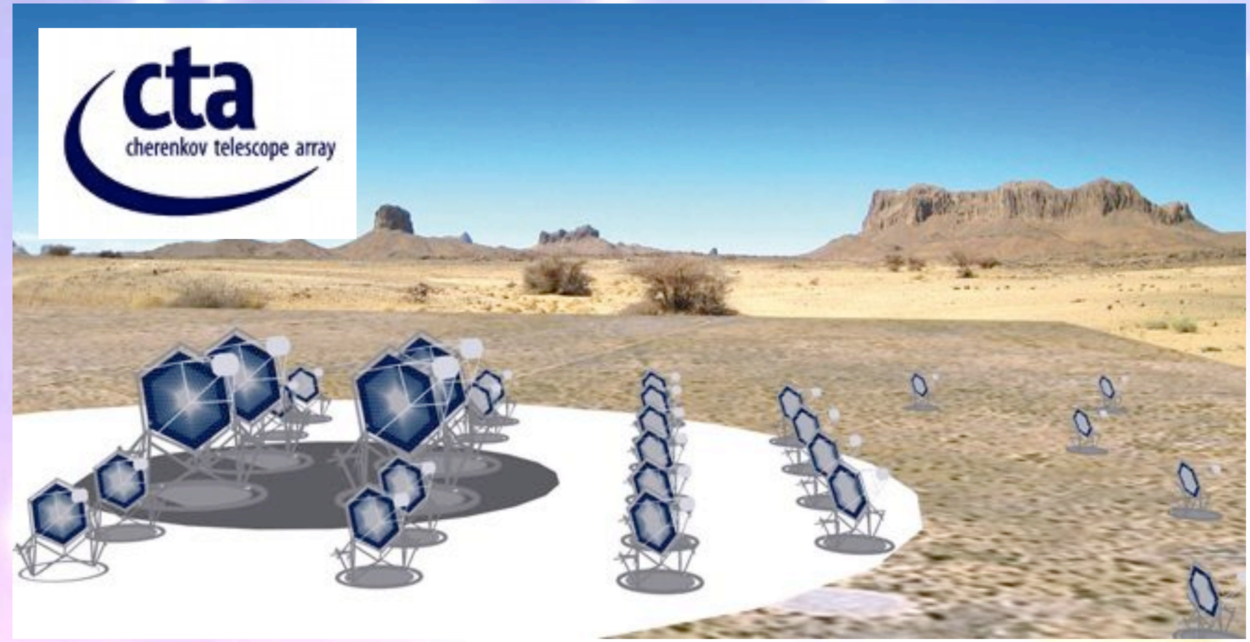


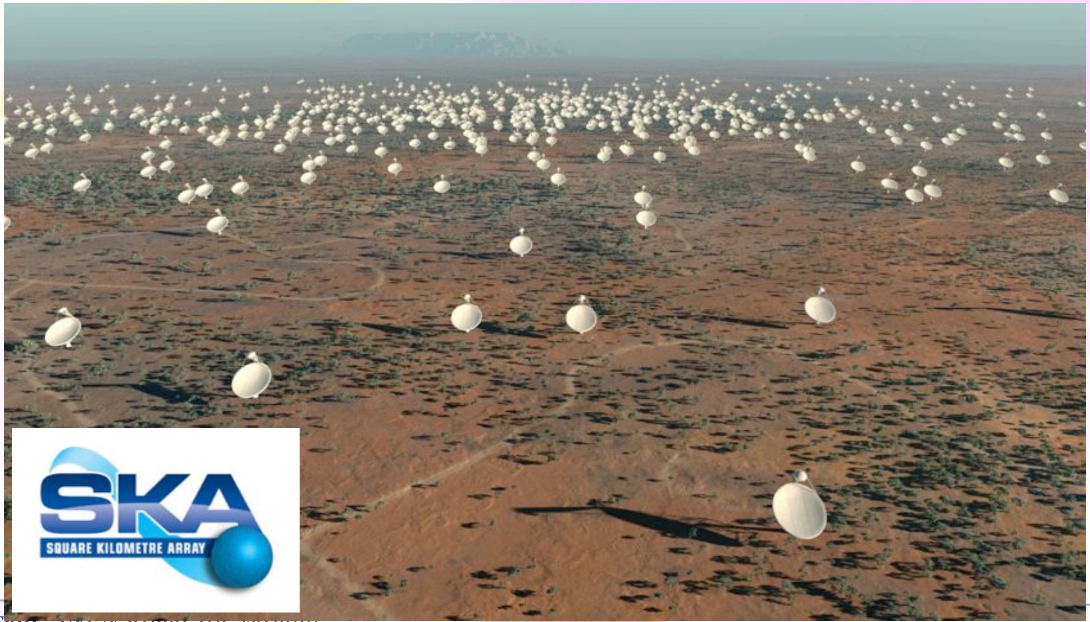
SNRs and the Origin and Propagation of CRs



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

ASTROGAM Complementary to CTA and SKA !





the GALACTIC CENTER : any hints of Dark Matter?

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope
Vincenzo Vitale, Aldo Morselli, the Fermi/LAT Collaboration
Proceedings of the 2009 Fermi Symposium, 6 pages, eConf Proceedings C091122 **arXiv:0912.3828**

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi/LAT Collaboration
Nuclear Instruments and Methods in Physics Research A 630 (2011) 147–150 (Available online 23 June 2010)

Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. Published in **Phys.Lett. B697 (2011) 412-428**

On The Origin Of The Gamma Rays From The Galactic Center
Dan Hooper , Tim Linden. Oct 2011. 13 pp. Published in **Phys.Rev. D84 (2011) 123005**

Detection of a Gamma-Ray Source in the Galactic Center Consistent with Extended Emission from Dark Matter Annihilation and Concentrated Astrophysical Emission
Kevork N. Abazajian, Manoj Kaplinghat (UC, Irvine). Jul 2012. 13 pp. Published in **Phys.Rev. D86 (2012) 083511**

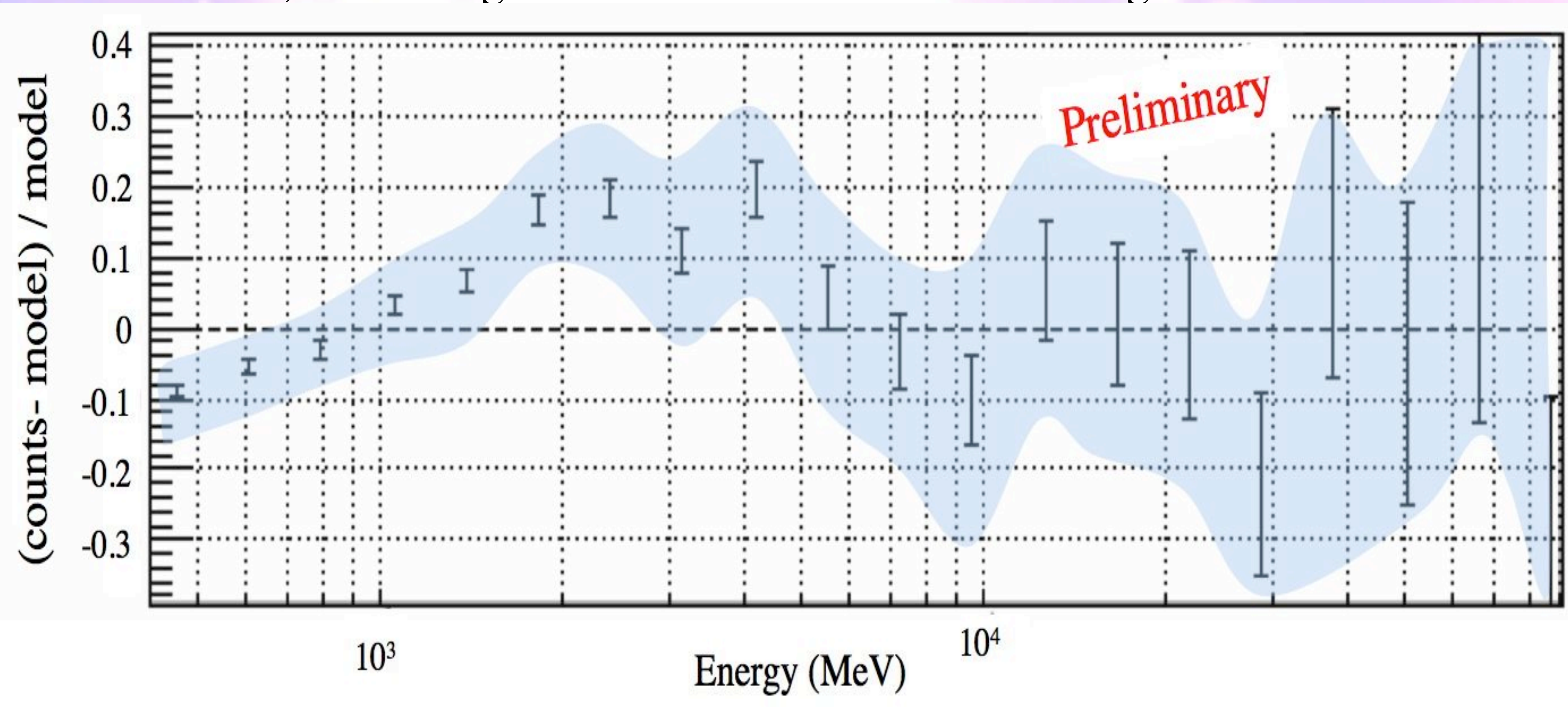
Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations
Chris Gordon, Oscar Macías (Canterbury U.). Jun 24, 2013. 20 pp.
Published in **Phys.Rev. D88 (2013) 083521**

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
Tansu Daylan, Douglas P. Finkbeiner, Dan Hooper, Tim Linden, Stephen K. N. Portillo, Nicholas L. Rodd , Tracy R. Slatyer . Feb 26, 2014. 26 pp. e-Print: **arXiv:1402.6703 [astro-ph.HE]**

The GeV excess

7°x7° region centered on the Galactic Center
11 months of data, E >400 MeV, front-converting events
analyzed with binned likelihood analysis)

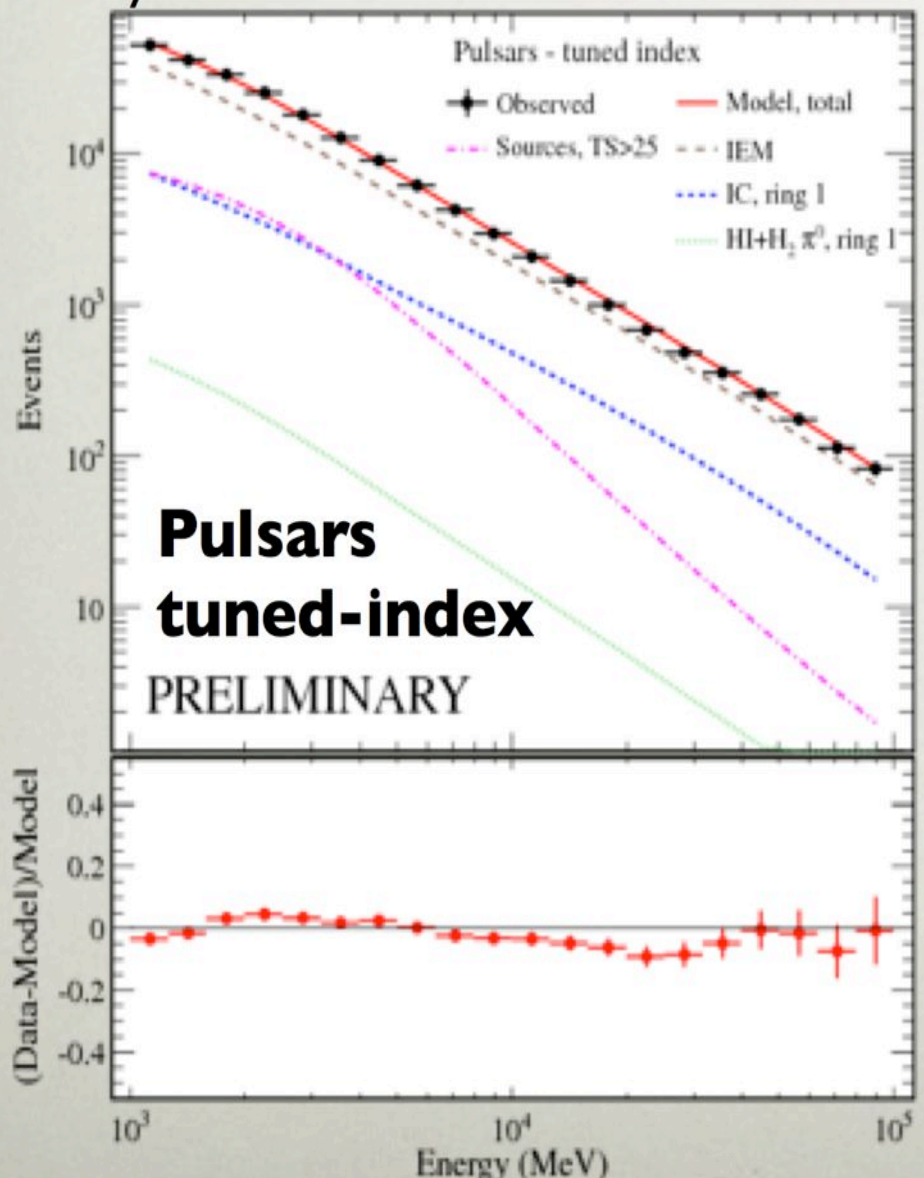
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV

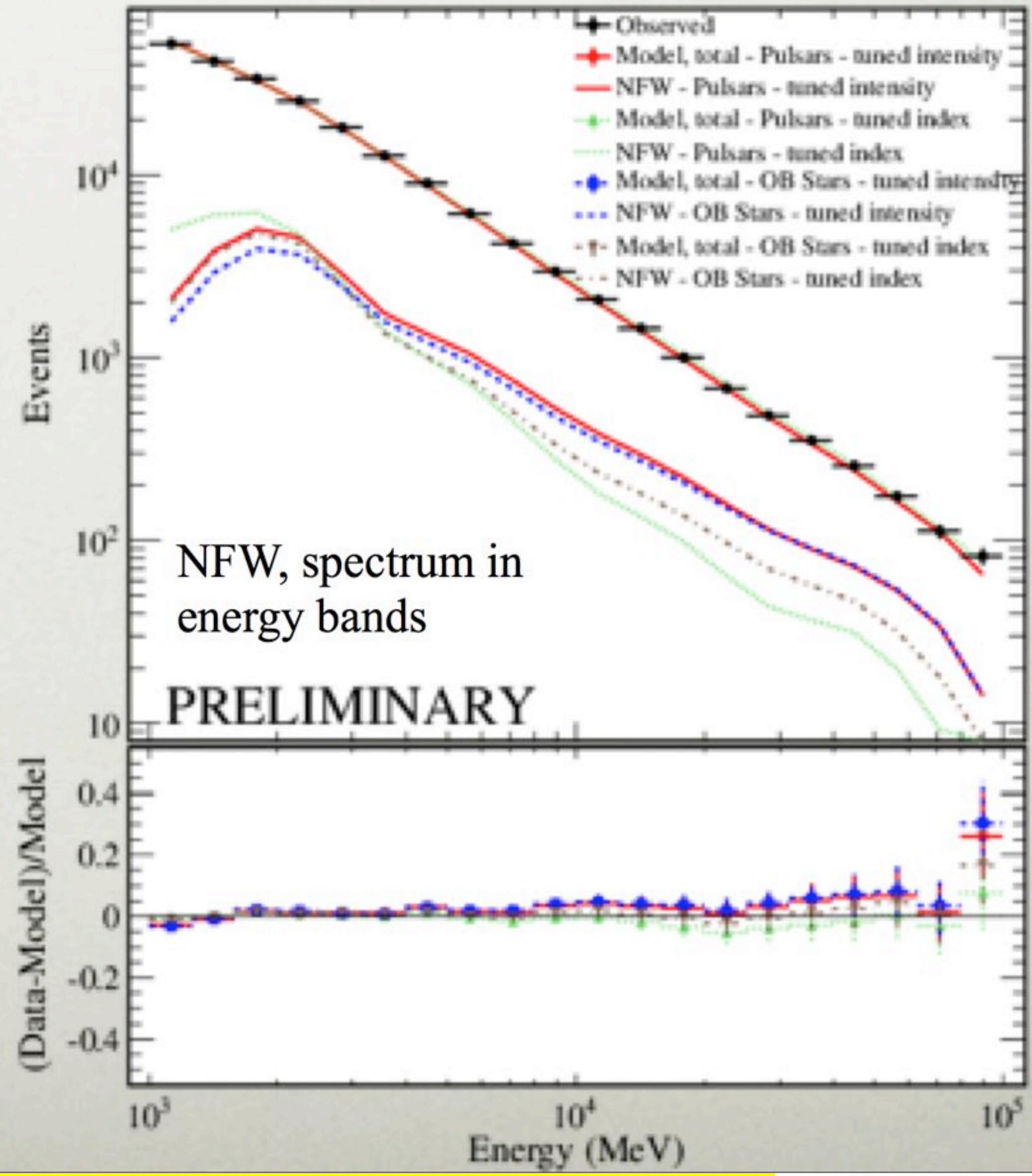


V.Vitale, A.Morselli, Fermi Coll. NIM A630 (2011) 147, arXiv:0912.3828

The GeV excess

Integrated counts in 15°x15° ROI





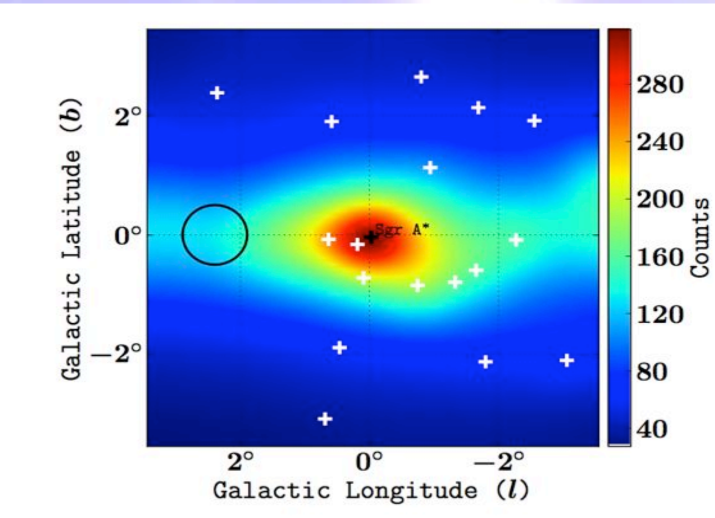
S. Murgia on behalf of Fermi Coll. Fermi Symposium 2014

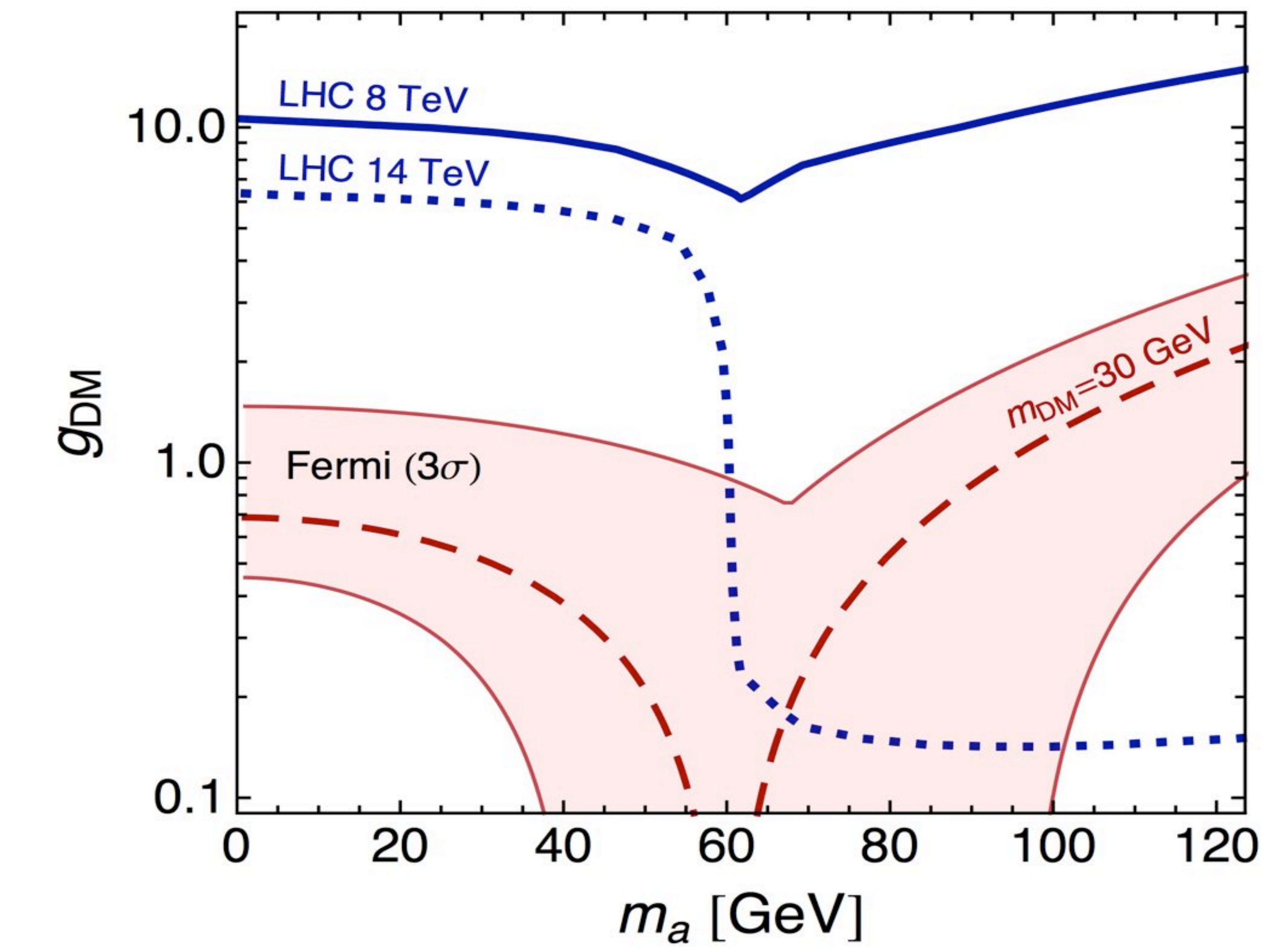
ARE WE SEEING DARK MATTER WITH THE FERMI-LAT IN A REGION AROUND THE MILKY WAY CENTER?

- Maybe yes, but we can't be sure as far as we don't understand the background at the level needed for disentangle a DM-induced γ-ray flux in this interesting region.

It would be really very nice to have a new experiment with better angular resolution at energies below 100 MeV

Galactic Center and Dark Matter





arXiv:1306.5725

arXiv:1401.6458

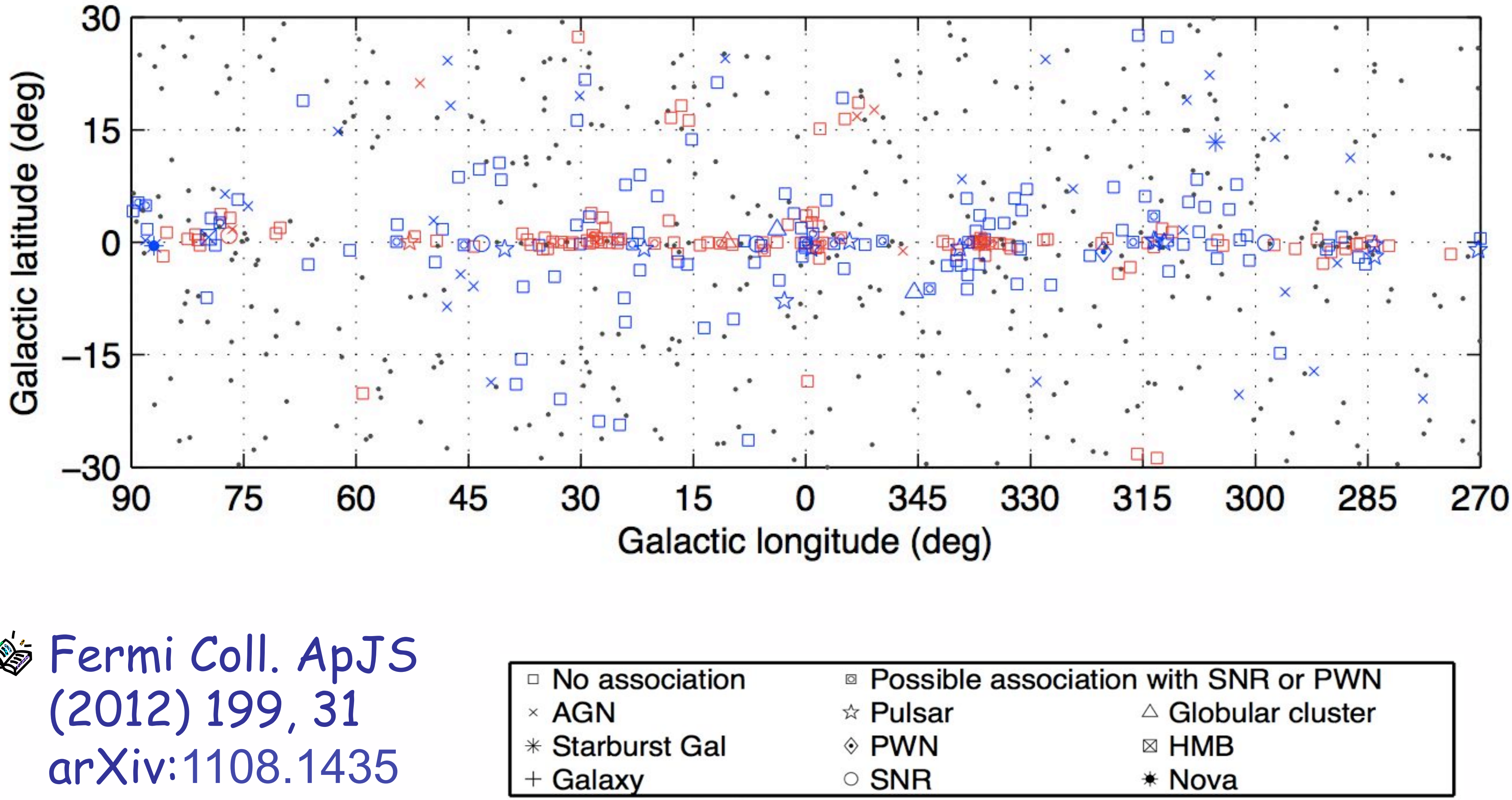
Se non è vero è ben trovato

(If it is not true, it is well conceived)

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

New gamma projects in space

- **AstroGam** 300 KeV- GeV (Proposal to ESA for M4)
- **Gamma-light** (Proposed to ESA but not approved)

http://agenda.infn.it/getFile.py/access?contribId=67&resId=0&materialId=slides&confId=4267

- **Gamma-400** launch foreseen by 2020

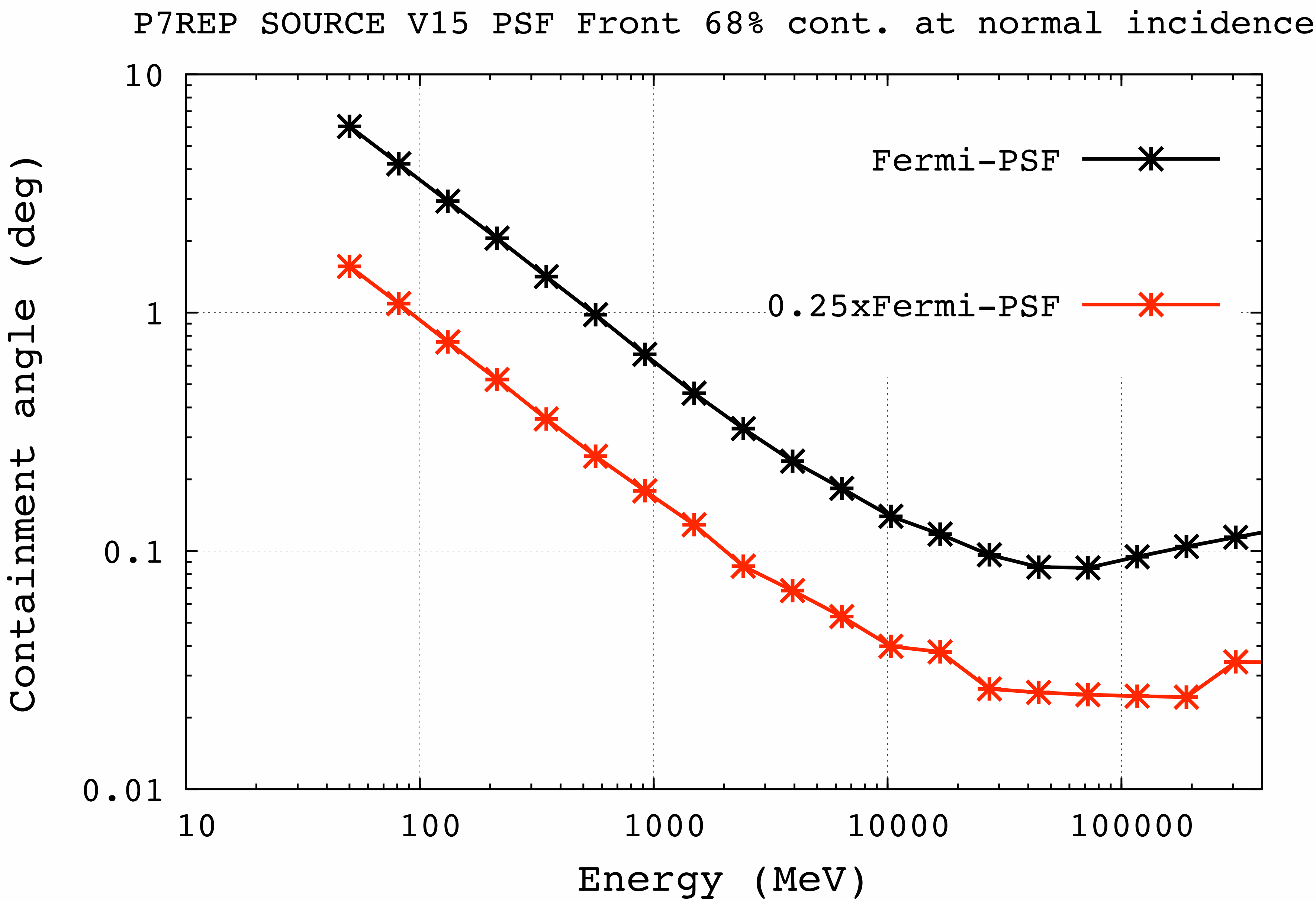
100 MeV – 3 TeV, an approved Russian γ-ray satellite. Energy resolution (100 GeV) ~ 1 %. Effective area ~ 0.4 m^2. Angular resolution (100 GeV) ~ 0.01°.

Science with Gamma-400 Workshop http://cdsagenda5.ictp.it/full_display.php?ida=a1311

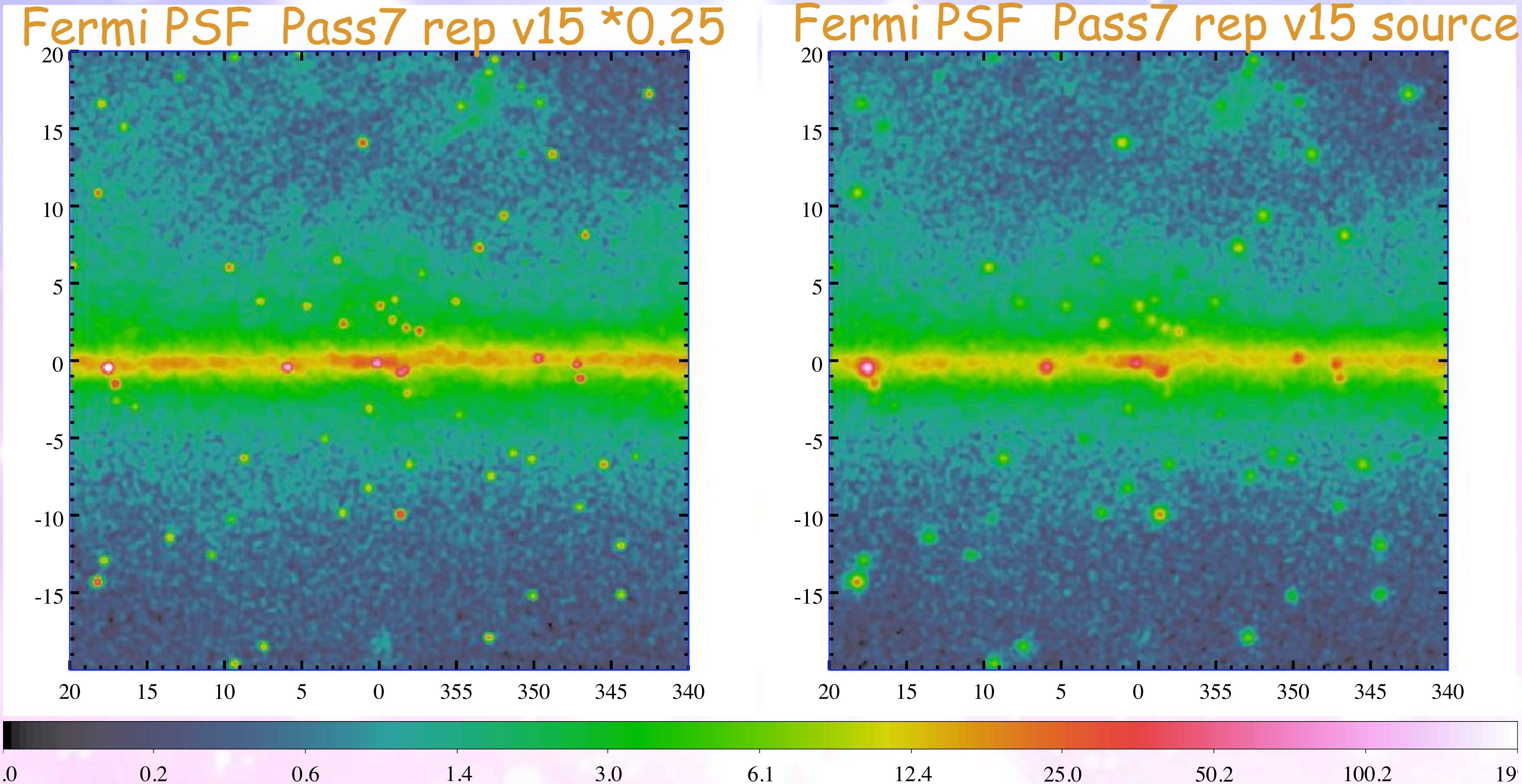
- **DAMPE**: Satellite of similar performance as Gamma-400. An approved Chinese γ-ray satellite. Planned launch 2015-16.

- **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.

- **PANGU**: suggested as a candidate for the joint small mission between the European Space Agency (ESA) and the Chinese Academy of Science (CAS) arXiv:1407.0710 (performances similar to Gamma-Light)


P7REP SOURCE V15 PSF Front 68% cont. at normal incidence
Containment angle (deg)
10
1
0.1
0.01
10
100
1000
10000
100000
Energy (MeV)
Fermi-PSF
0.25xFermi-PSF

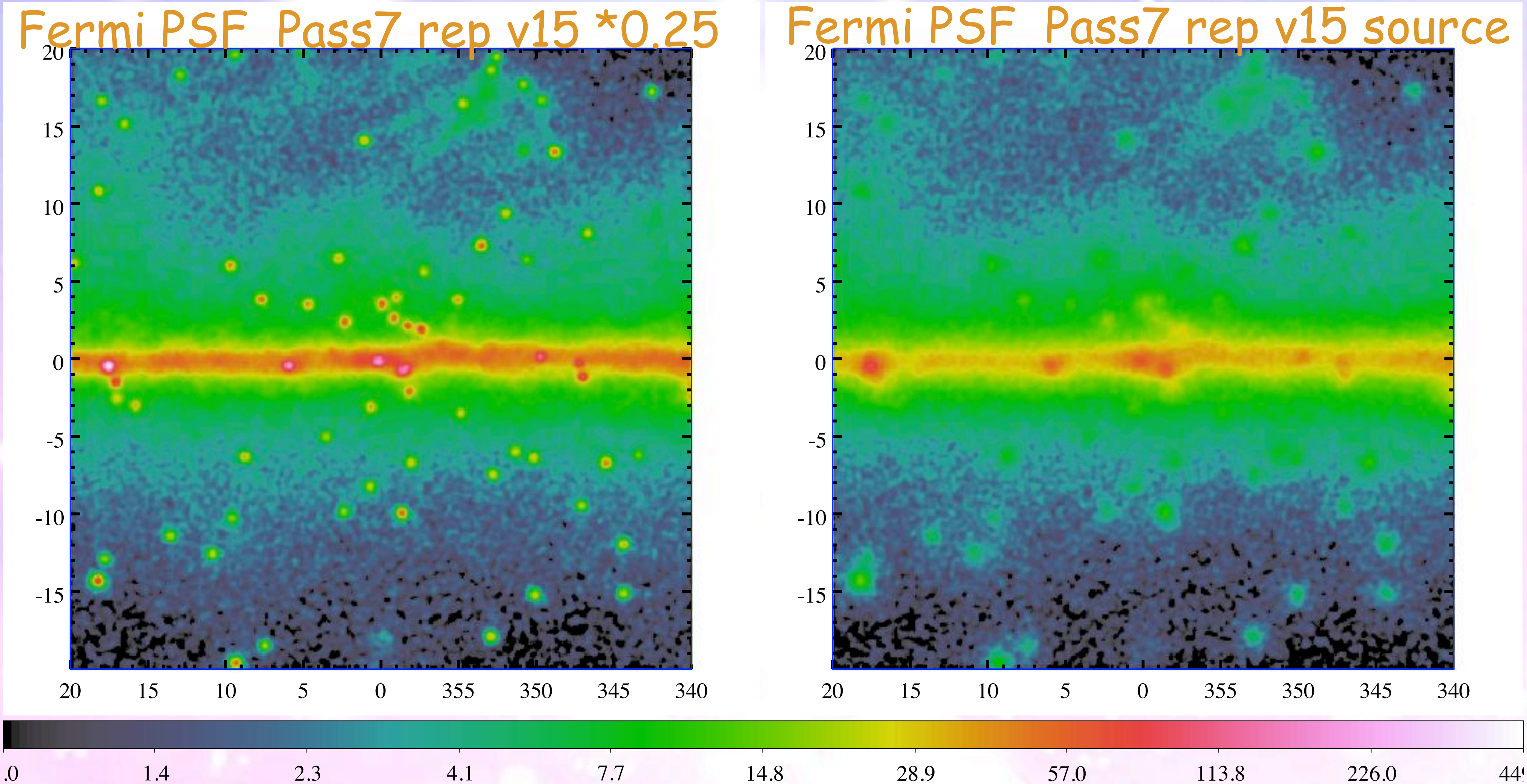
Galactic Center Region 1-5 GeV



Sources from two years Fermi catalog , template ring model for diffuse

ApJ S 2012 199,31 [arXiv:1108.1435]

Galactic Center Region 0.2-1 GeV

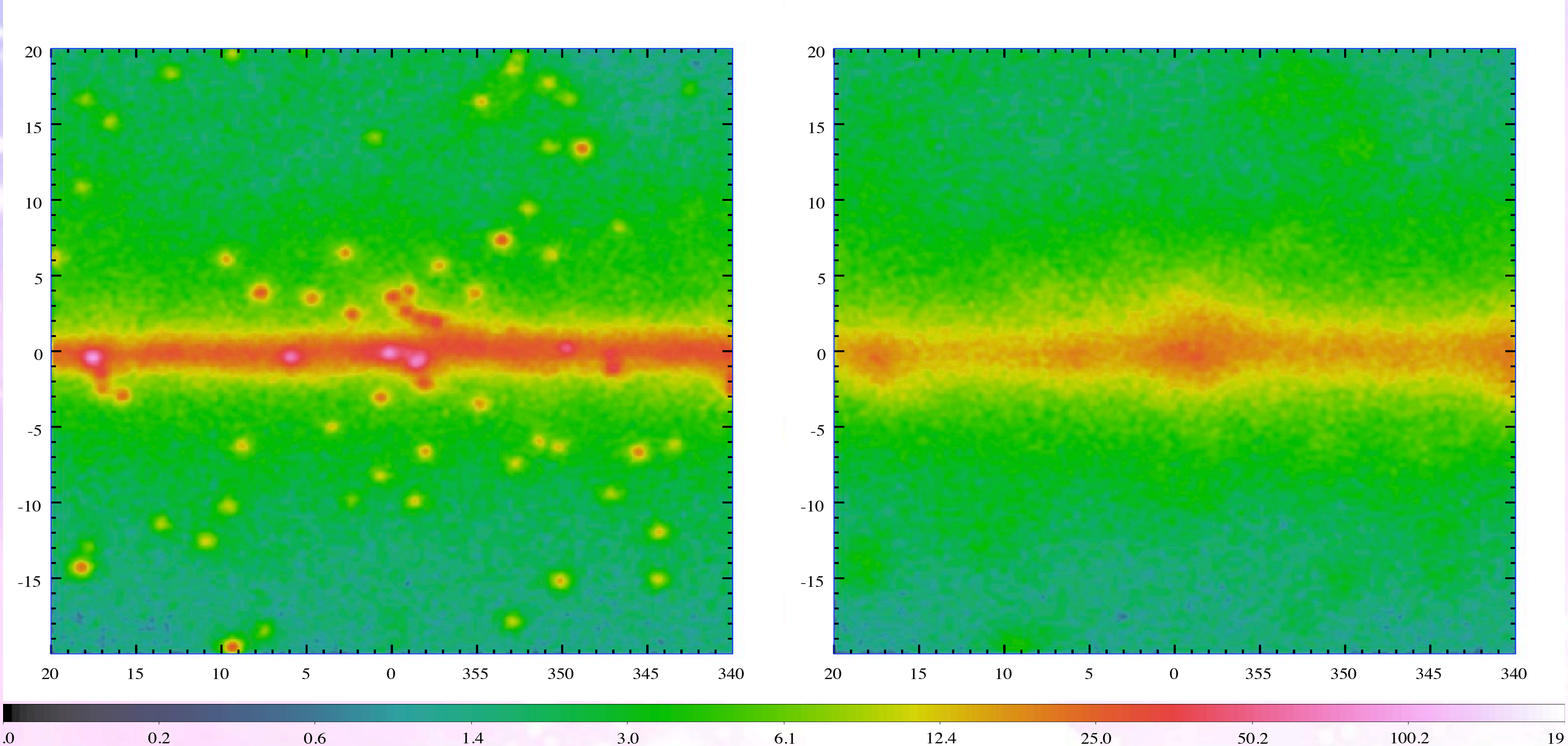


Sources from two years Fermi catalog , template ring model for diffuse,

ApJ S 2012 199,31 [arXiv:1108.1435]

Galactic Center Region 50-200 MeV

Fermi PSF Pass7 rep v15 *0.25   Fermi PSF Pass7 rep v15 source



Sources from two years Fermi catalog ApJ S 2012 199,31 [arXiv:1108.1435], template ring model for diffuse

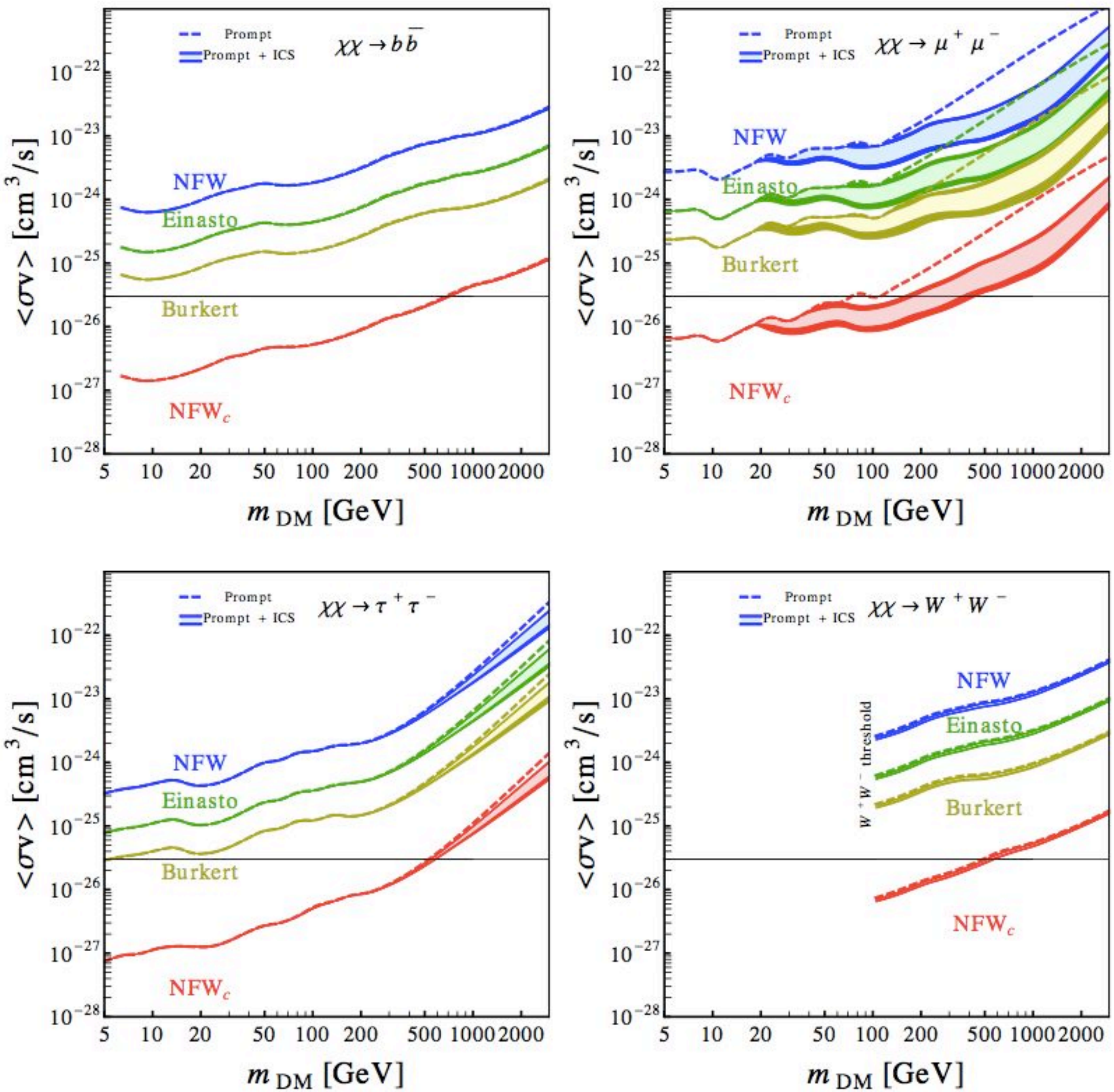
Constraints from the inner Galaxy

3 σ upper limits on the annihilation cross-section for different channels and halo profiles

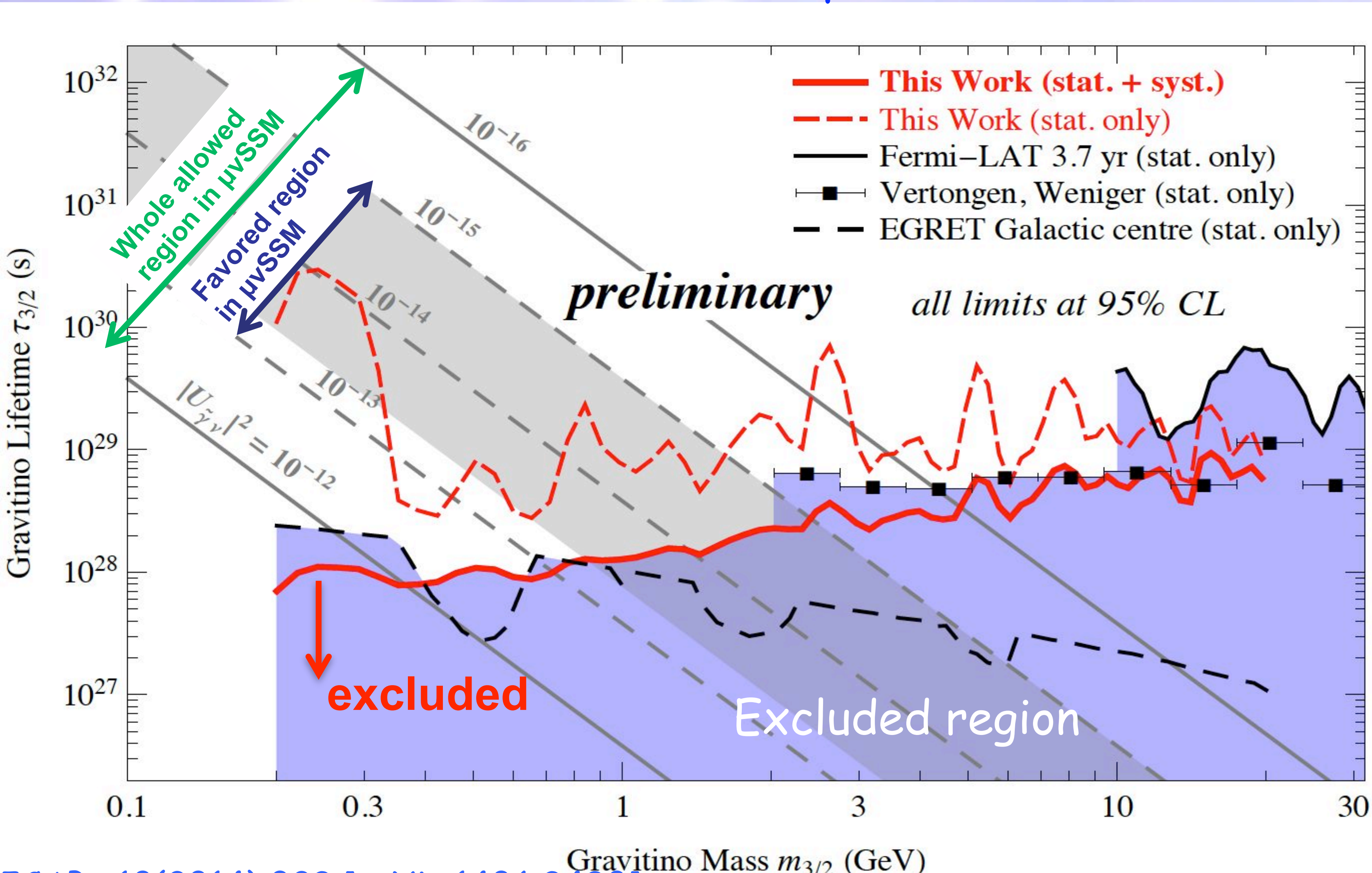
No assumption on background

very robust result

Gomez-Vargas et al.
JCAP 10 (2013) 029
arXiv:1308.3515



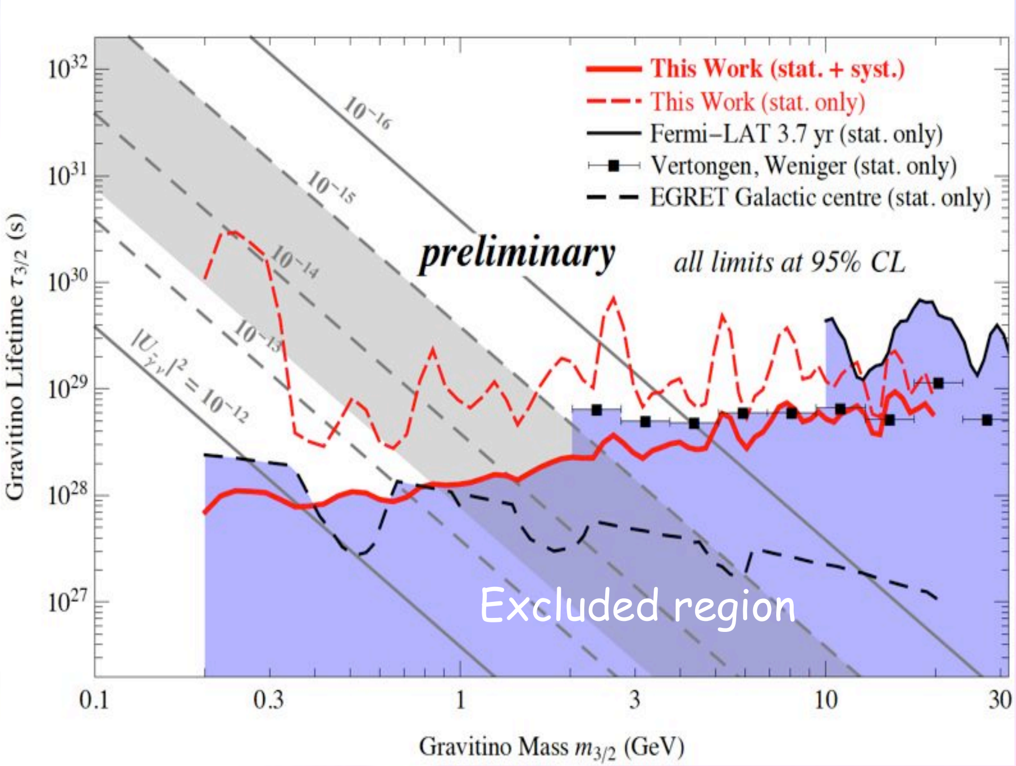
Low energy lines limits and implications for gravitino dark matter in the μνSSM



JCAP 10(2014) 023,[arXiv:1406.3430]

New Low Energy Line Search

But this Analysis is Systematics Limited



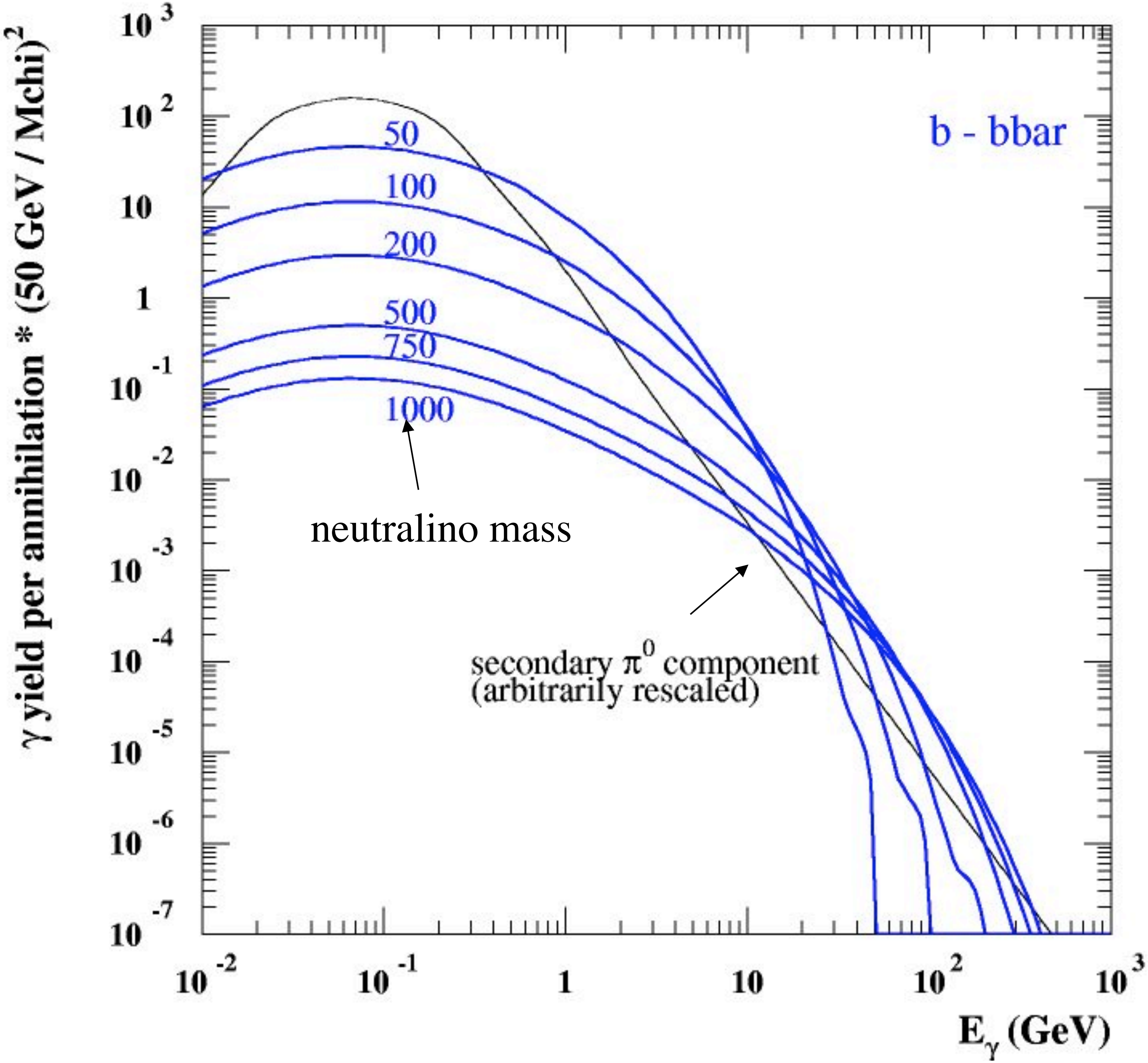
- *Modeling effective area*
- *background emission*
- *not masking known point sources*: because the broad PSF of the LAT at low energies.

JCAP 10(2014) 023,[arXiv:1406.3430]

To improve the search a better energy and angular resolution at low energies is needed

Differential yield for b bar for different neutralino mass

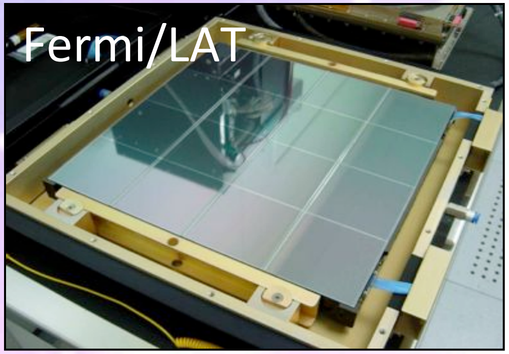
Low energy range is very important also for high mass neutralino search

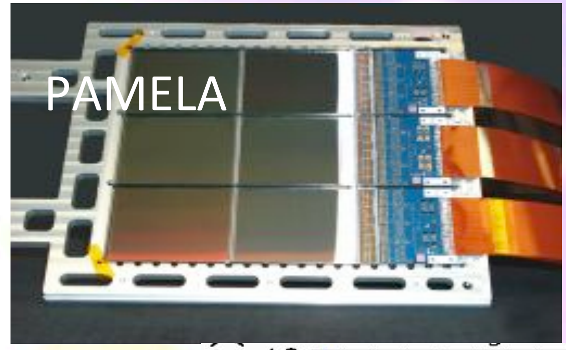


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

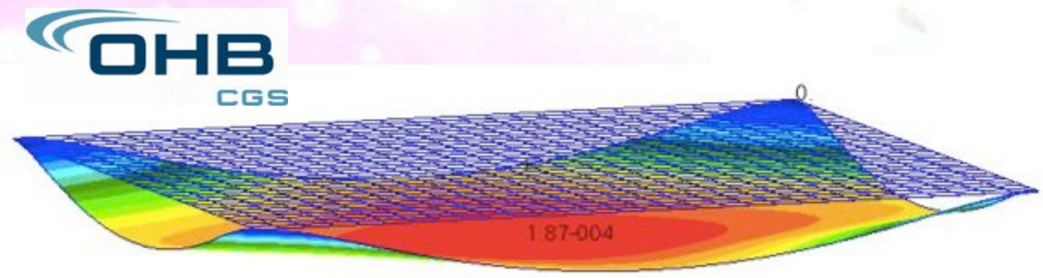
Tracker heritage - Technology challenges

- DSSDs are widely used in particle physics experiments, e.g. LHC/Atlas
- Ladders of wire-bonded SSSDs in Fermi/LAT and AGILE, and of wire-bonded DSSDs in PAMELA and AMS-02 + ASTRO-H/HXI do be launched in 2015

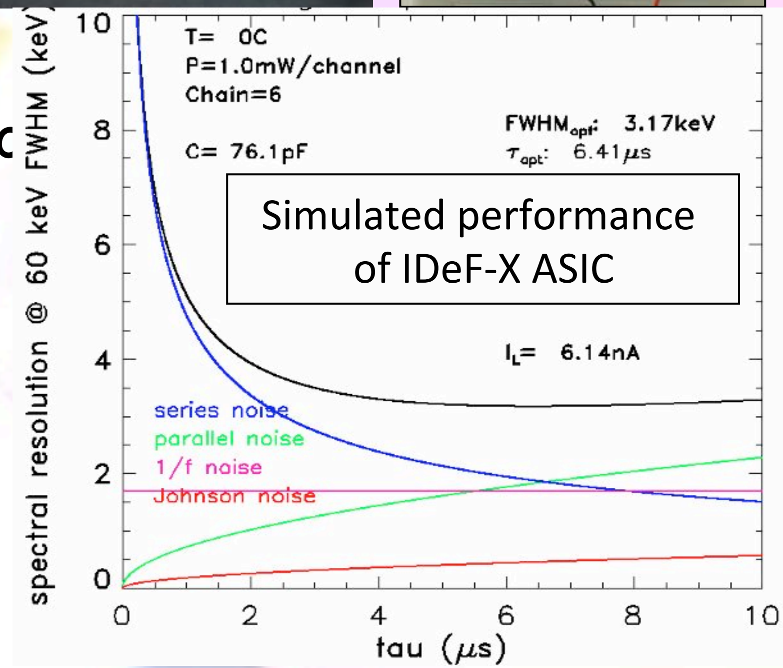




- **Main technology challenges:**
  (i) Mechanical structure and thermal contro
  (ii) Front-end electronics



Tracker layer - preliminary structural analysis

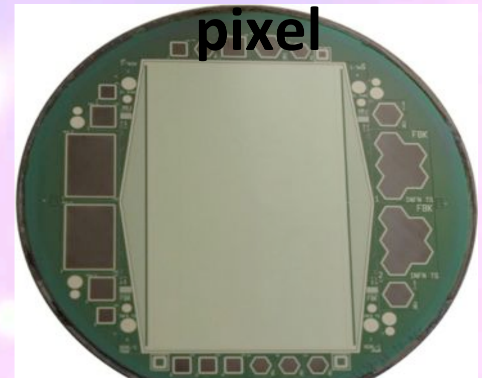


Simulated performance of IDeF-X ASIC

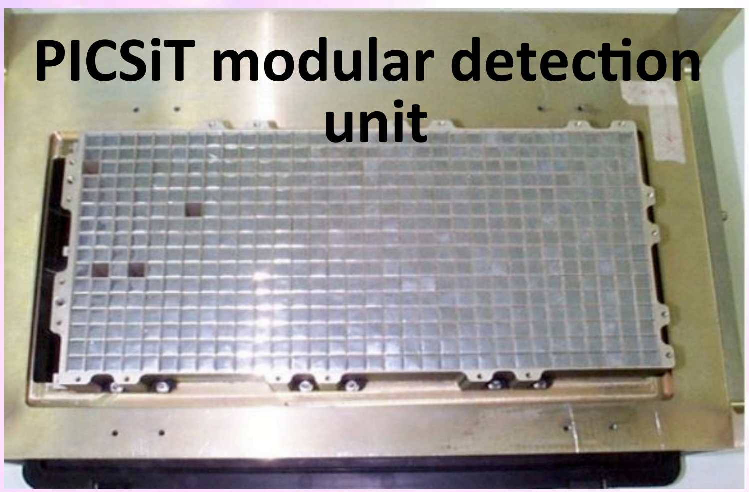
ASTROGAM Calorimeter

- Pixelated detector made of CsI(Tl) scintillator bars of 4.5 cm length and 5×5 mm^2 cross section, glued at both ends to Silicon Drift Diodes (SDDs). Calorimeter formed by the assembly of 196 (14×14) individual modules
- Each module comprises 64 CsI(Tl) bars wrapped with light diffusive material, two arrays of 8×8 SDDs, the associated front-end electronics, within a carbon-fiber structure
- Total of 25088 electronic channels
- **Heritage**: INTEGRAL/PICsIT, AGILE, Fermi/LAT, LHC/ALICE

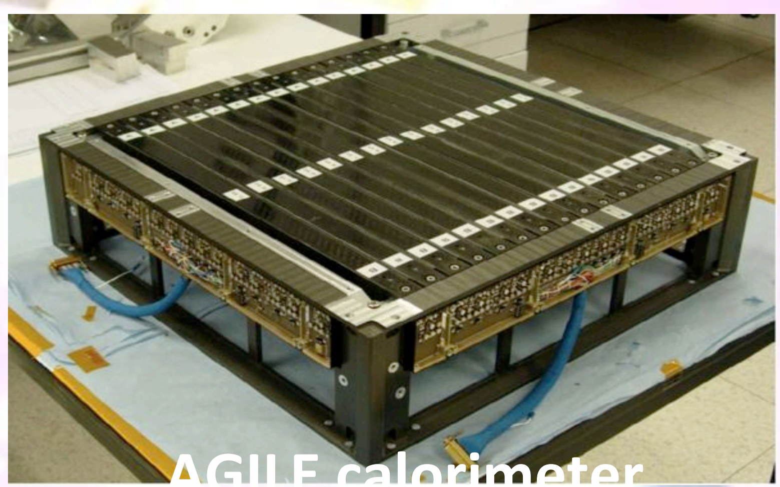
PICSiT CsI(Tl) pixel



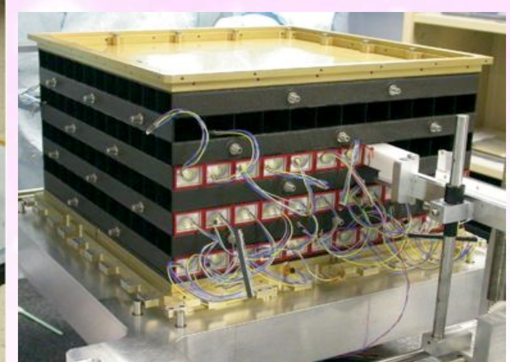
Samples of SDDs from FBK-SRS



PICSiT modular detection unit



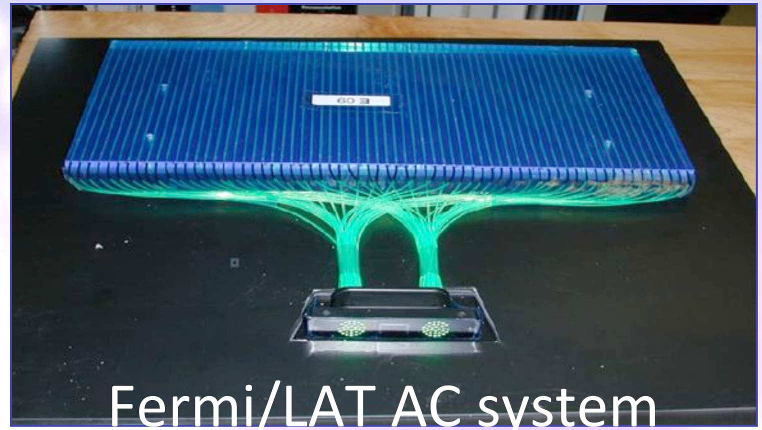
AGILE calorimeter

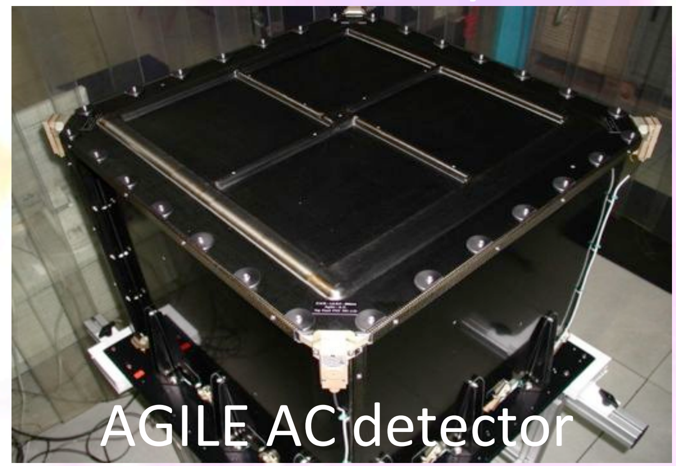


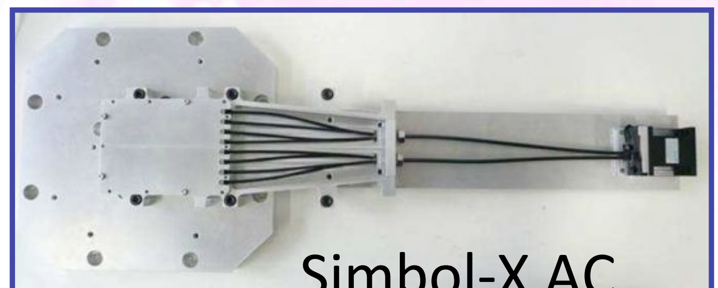
Fermi cal. module

Anticoincidence

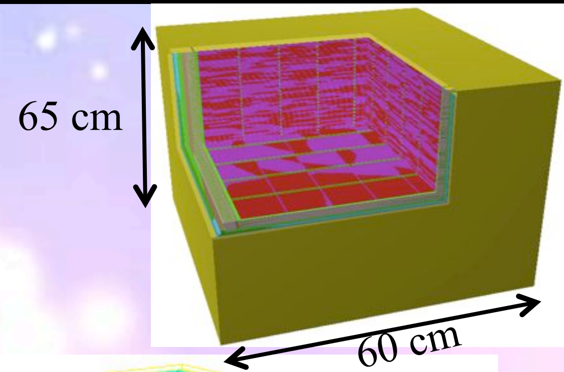
- AC system formed with large 1 cm thick plastic BC408 panels covering 5 faces of the instrument. In each panel, small clear fibers buried in trenches convey the scintillation light to silicon photomultipliers (SiPMs) glued at the end of the fibers.
- With 72 fibers (70 cm long) for the top panel and 288 fibers (55 cm long) for the side panels, there are in total 360 SiPMs (= # of electronic channels)
- The SiPM signals are readout by 10 ASICs of 36 channels each
- **Heritage**: FERMI/LAT, AGILE, Simbol-X AC prototype


Fermi/LAT AC system


AGILE AC detector

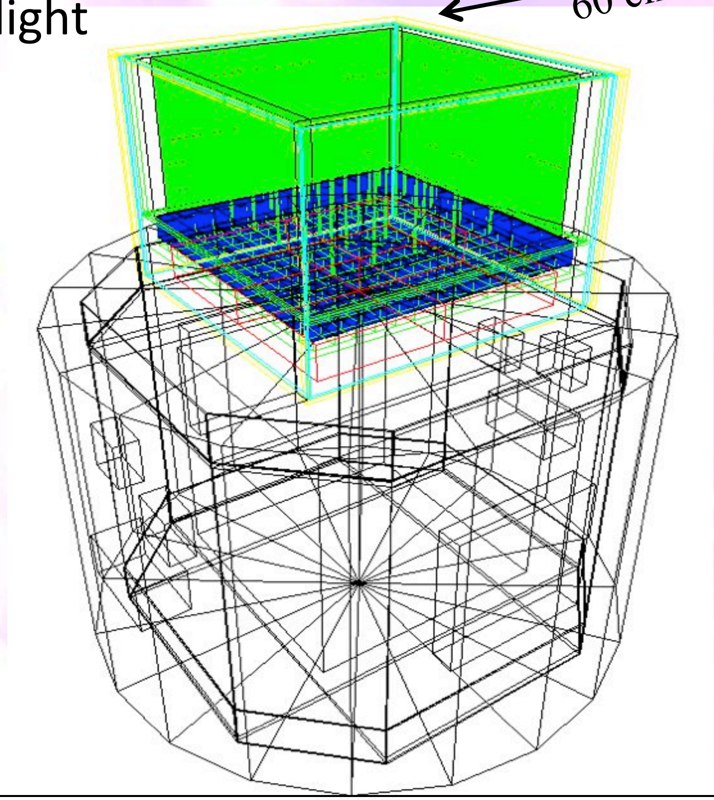

Simbol-X AC prototype

- **Tracker** – 70 layers of 6x6 double sided Si strip detectors (2520 detectors, 268 800 electronics channels)
- **Calorimeter** – CsI(Tl) scintillation bars readout by Si Drift Diodes at both ends (12 544 crystals, 25 088 channels)
- **Anticoincidence system** – Plastic scintillator panels with light collection by embedded wavelength-shifting fibers



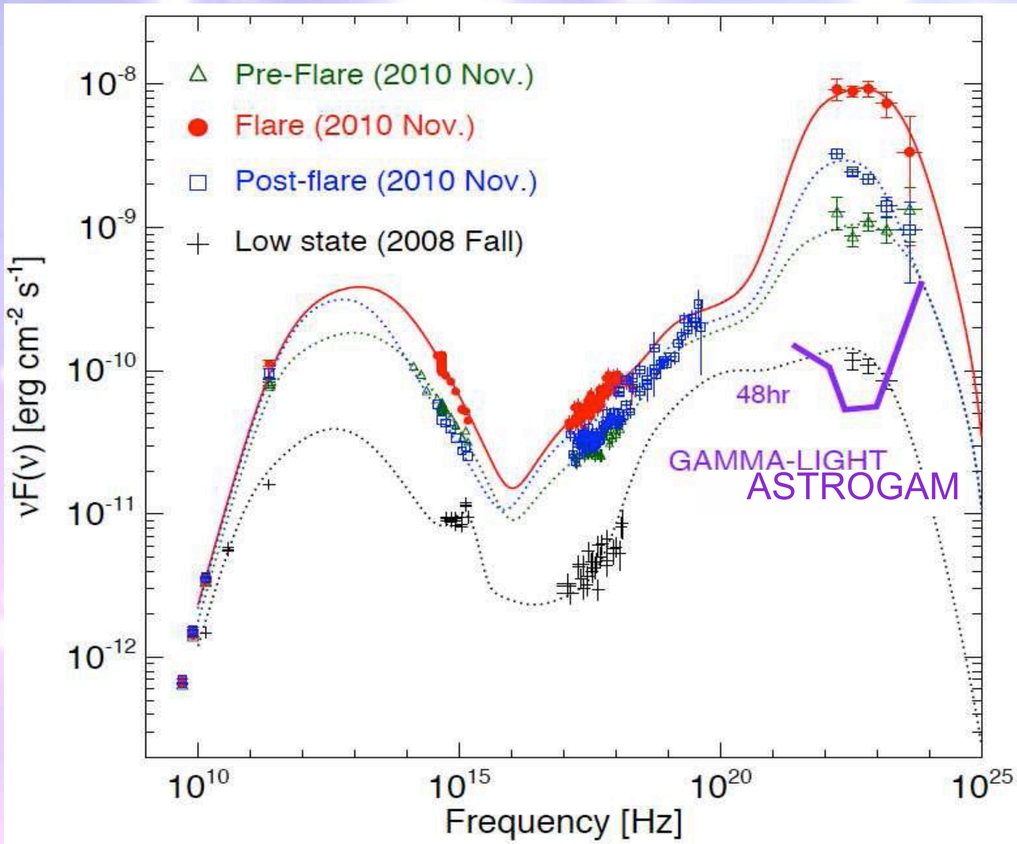
Instrument mass budget

Detection unit		Mass + margin [kg]
Tracker	Si DSSD	26 + 1.3
	Structure	40 + 8.0
Calorimeter	CsI(Tl)	71 + 3.6
	Structure	15 + 3.0
ACS	Plastic	20 + 1.0
	Structure	20 + 4.0
Electronics		70 + 20
Total instrument		**260 + 40**



GEANT4/MEGAlib mass model

ASTROGAM Active Galactic Nuclei



Multi-epoch SEDs of the Flat Spectrum Radio Quasar 3C454.3. ASTROGAM will allow us to investigate daily (or sub-daily) SEDs during gamma-ray superflares.
5-σ differential sensitivity for an integration time of 48 hours.

The SEDs of many blazars (FSRQs) and non-blazar AGNs detected in γ-rays peak in the "MeV range"

Total energy output ⇒ feedback

Obs. below 100 MeV are useful to distinguish leptonic and hadronic models

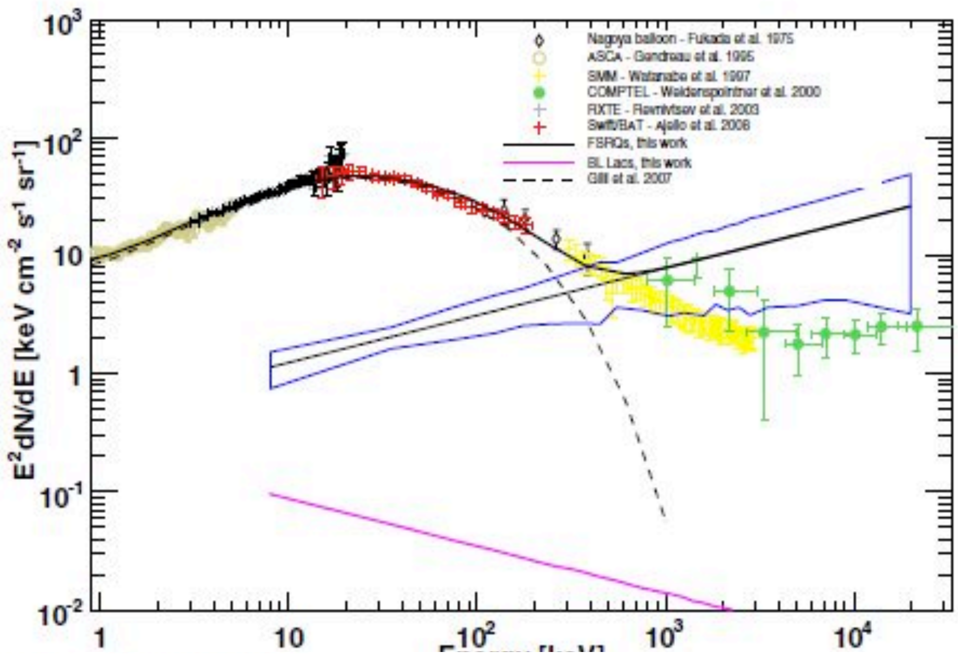
AstroMeV will detect more than 1000 AGNs (mostly FSRQs)

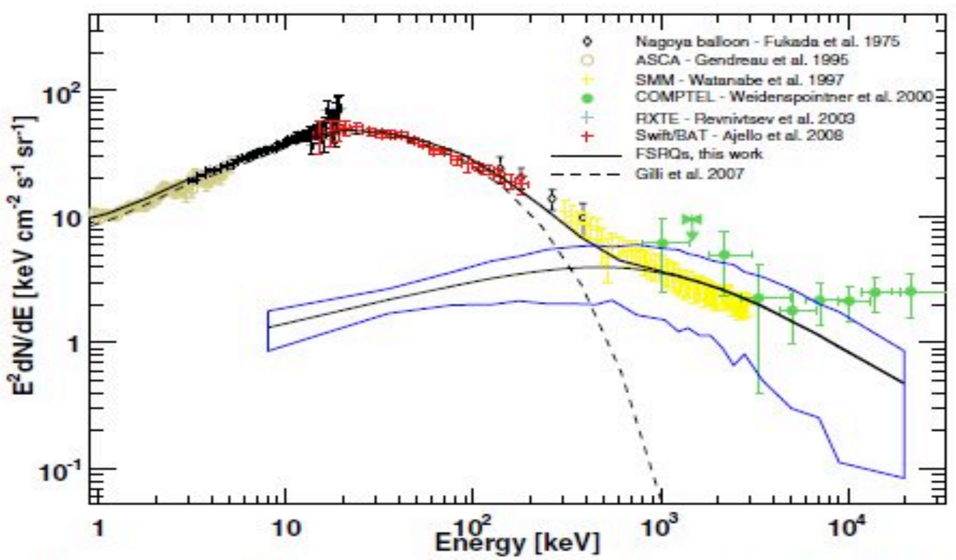
- Evolution ("Blazar sequence")

- Origin of UHECRs and HE neutrinos

- MeV gamma-ray background

Contribution to CXB





The origin of MeV background:
more likely associated with
- dark matter annihilation
- nuclear decays from SNe Ia
- nonthermal emission from Seyfert galaxies
- blazars

Ajello et al. 2009, by integrating the X-ray LF (hard X-ray selected sample) derived from Swift/BAT data, found that:
a) the blazar population accounts for 10%–20% CXB in the 15–55 keV band.
b) FSRQs account for most of the diffuse background e mission for *energies>500 keV.*
Both results agree with previous findings by Giommi et al. 2006 in 2-10 keV and E> 500 keV

In order not to overproduce the MeV background, most FSRQs are required to "peak" at MeV energies for a large fraction of their time (Γ_gamma=2.2-2.5)

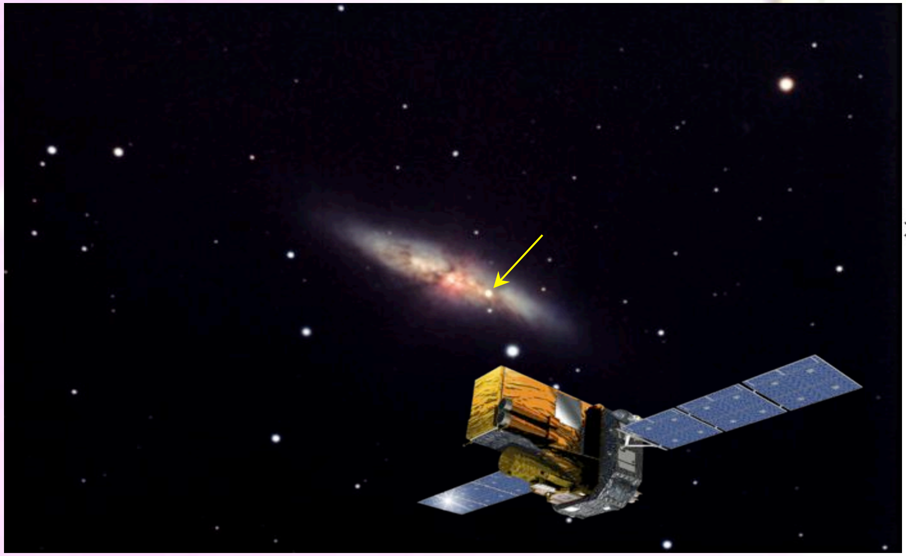
Issues:
-**Variability level and duty cycle**
-**Sensitivity at lower gamma-ray energies**

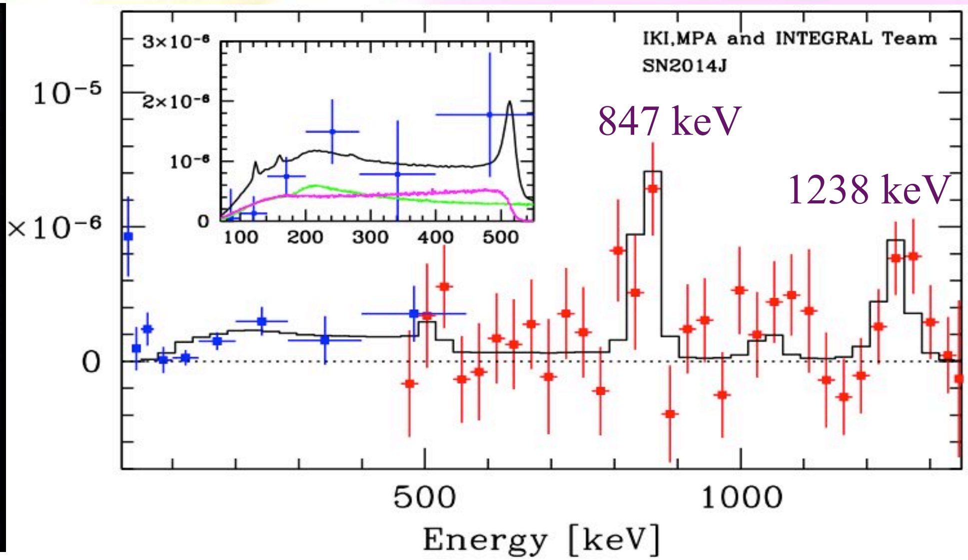
SN 2014J

Type Ia supernova exploded on 2014 Jan 14 in the starburst galaxy M82 at $D \approx$ 3.5 Mpc ⇒ nearest SN Ia in more than 40 years

Detection with INTEGRAL of gamma-ray lines from ^{56}Co decay ($T_{1/2}$=77 d) ⇒ synthesis of 0.6 ± 0.1 $M_\odot$ of ^{56}Ni (Churazov et al. 2014, *Nature, 28 Aug*) and from ^{56}Ni decay ($T_{1/2}$=6,1 d) ~20 d after explosion (Diehl et al. 2014, *Science, 5 Sep*); ^{56}Ni lines are broad and redshifted (!) (Isern et al., in prep.)

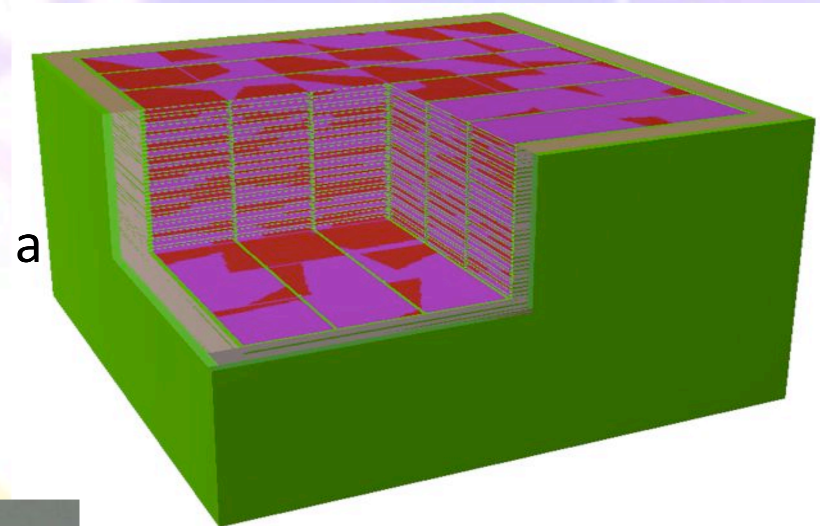
INTEGRAL and NuSTAR observations can not be explained by current SN Ia explosion models (Burrows et al., in prep.)





Silicon Tracker

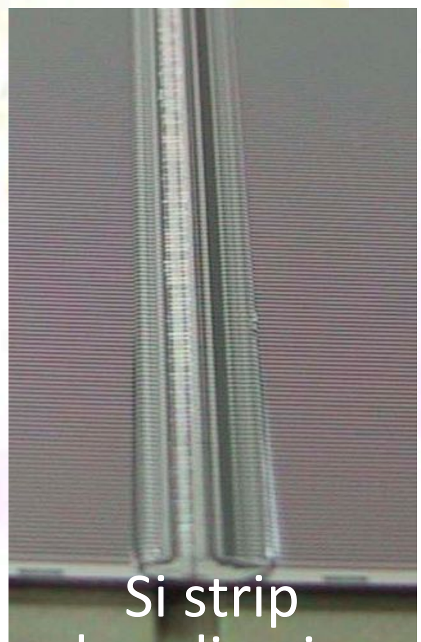
- 70 layers of 6×6 double-sided Si strip detectors = 2520 DSSDs
- Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 400 μm, a guard ring of 1.5 mm, and a pitch of 240 μm.
- The DSSDs are wire bonded strip to strip to form ladders



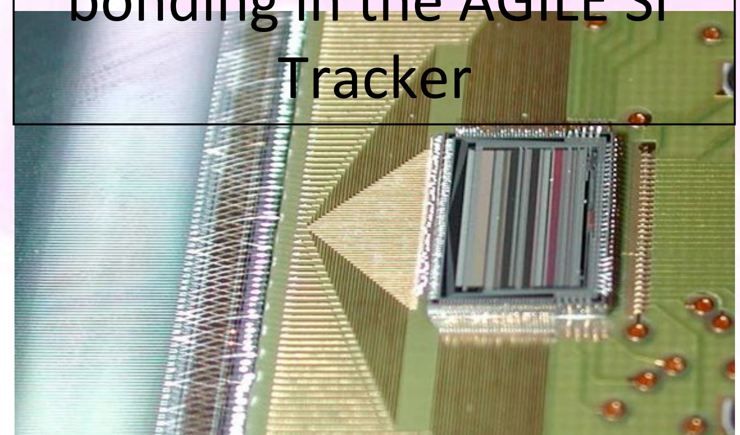
⇒ 330 000 electronic channels

- DSSD strips connected to ASICs (64 channels each) through a pitch adapter (DC coupling)
- 60 ASICs per layer (30 per DSSD side)

⇒ 4200 ASICs total

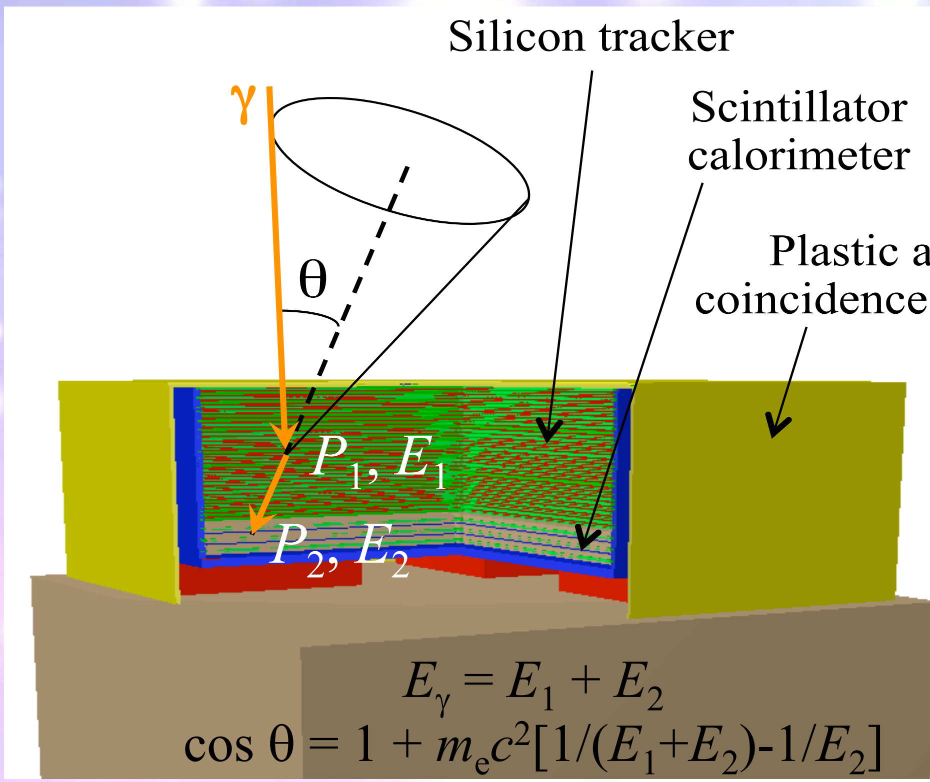


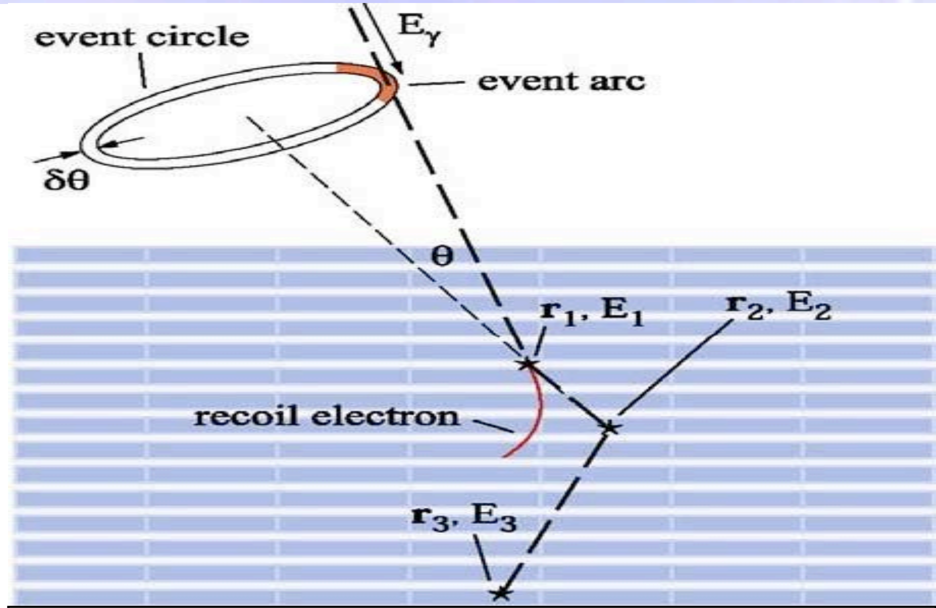
Si strip bonding in



Detail of the Si tile-ASIC bonding in the AGILE Si Tracker

Principle of a Compton telescope





Measuring the direction of the recoil electron can constraint the event to an arc of the Compton annulus.

- **Tracker** – Double sided Si strip detectors (DSSDs) for fine 3-D position resolution
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillator

ASTROGAM Science summary

- **Galactic Radioactivities**
- ^{26}Al, ^{60}Fe, ^{44}Ti, activation lines

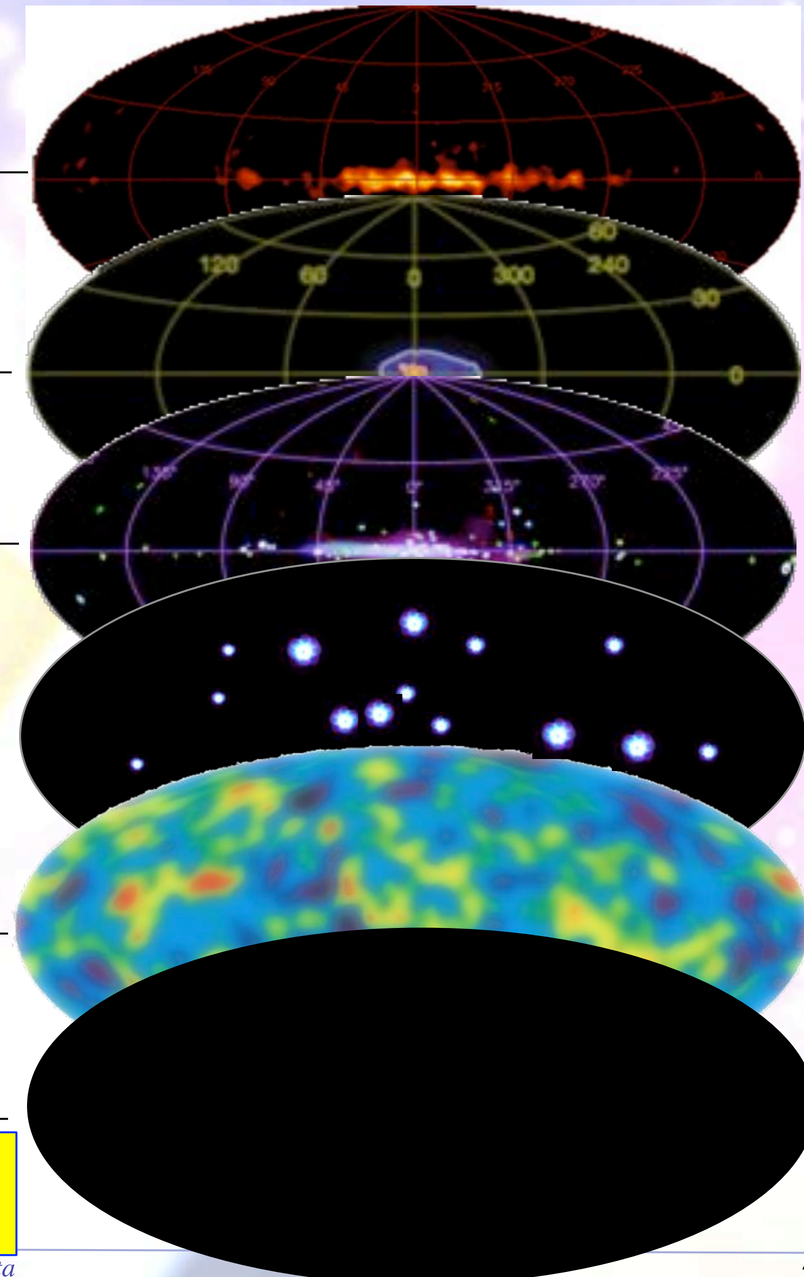
e^-e^+ Annihilation Radiation
sensitive all sky spectro-imaging

Compact Sources
AGN, XRBs, μ-quasars, magnetars …

Gamma-ray bursts
localization, spectroscopy, polarization !

Cosmic gamma background
multipole analysis, search/constrain AM

Dark Matter Search
DM signatures, fundamental physics



Meeting in Roma 8-9 Dic open to all the interested people
Proposal deadline Jan 15 2015