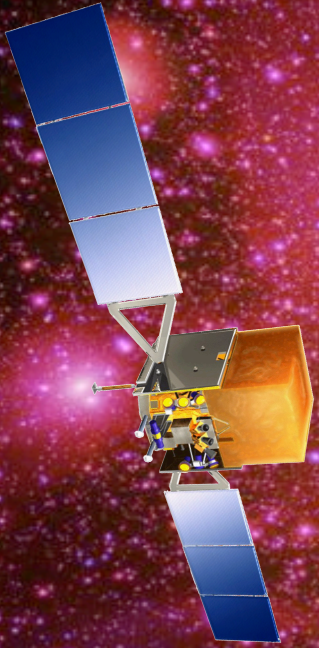
Experimental Astroparticle Physics



Aldo Morselli

INFN Roma Tor Vergata

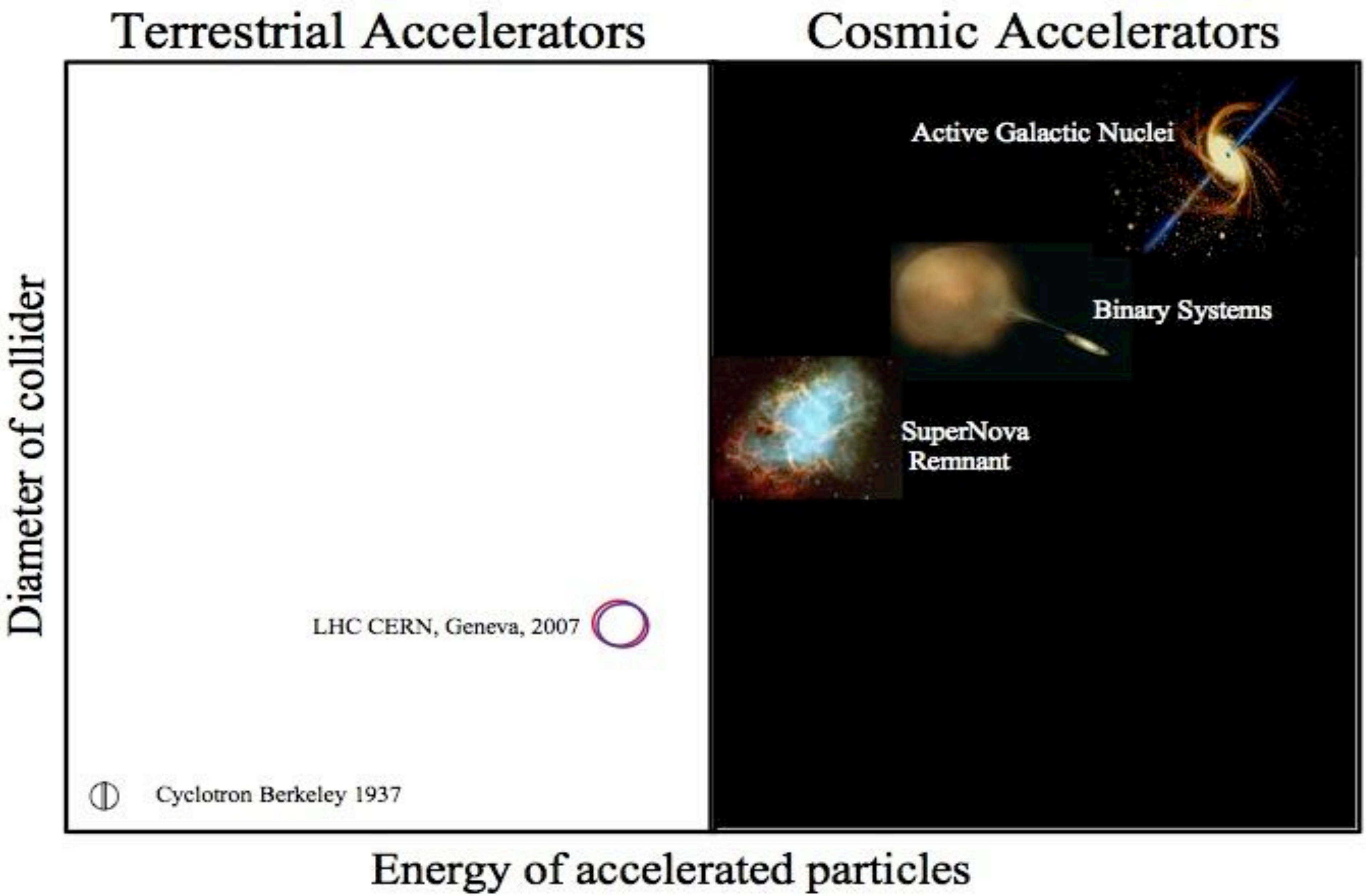
Summer School and Workshop on the Standard Model and Beyond

Corfu 11 September 2014

Astroparticle Physics

- Study of the Origin of Cosmic Rays
- Study of interactions at energies higher than LCH
- Search for signals from Dark Matter

Particle Physics => Particle Astrophysics

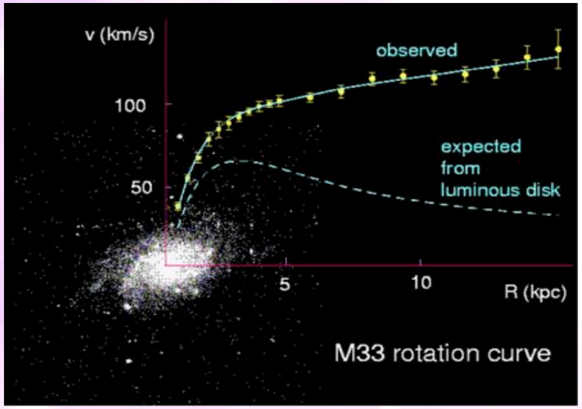


Dark Matter EVIDENCES

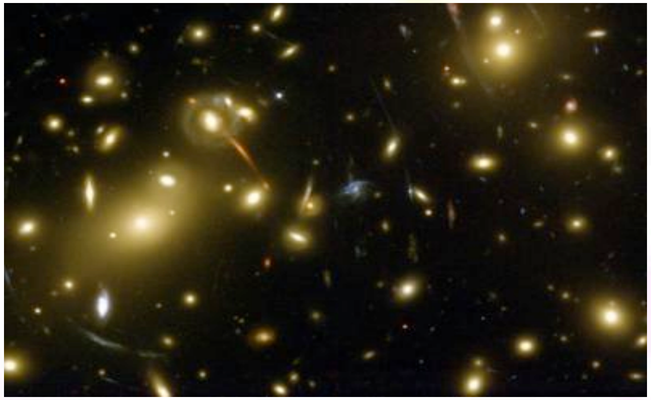
- In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies:

- Since then, many other evidences:

Rotation curves of galaxies

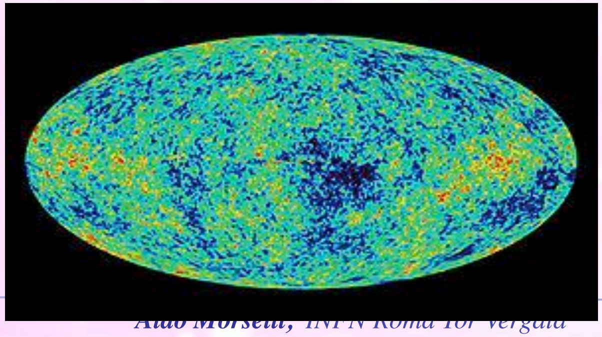


Gravitational lensing

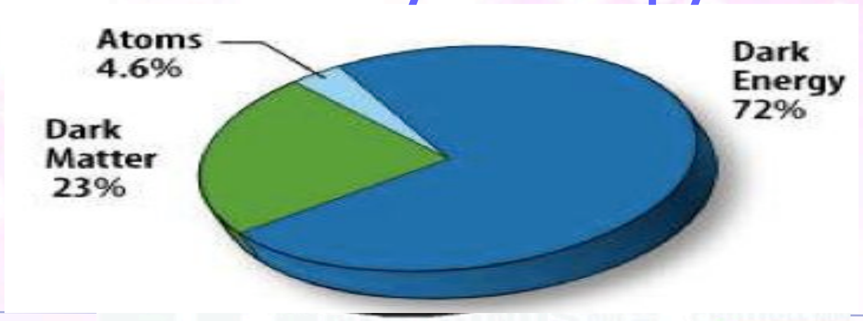


Bullet cluster

Structure formation as deduced from CMB



Data by WMAP imply:

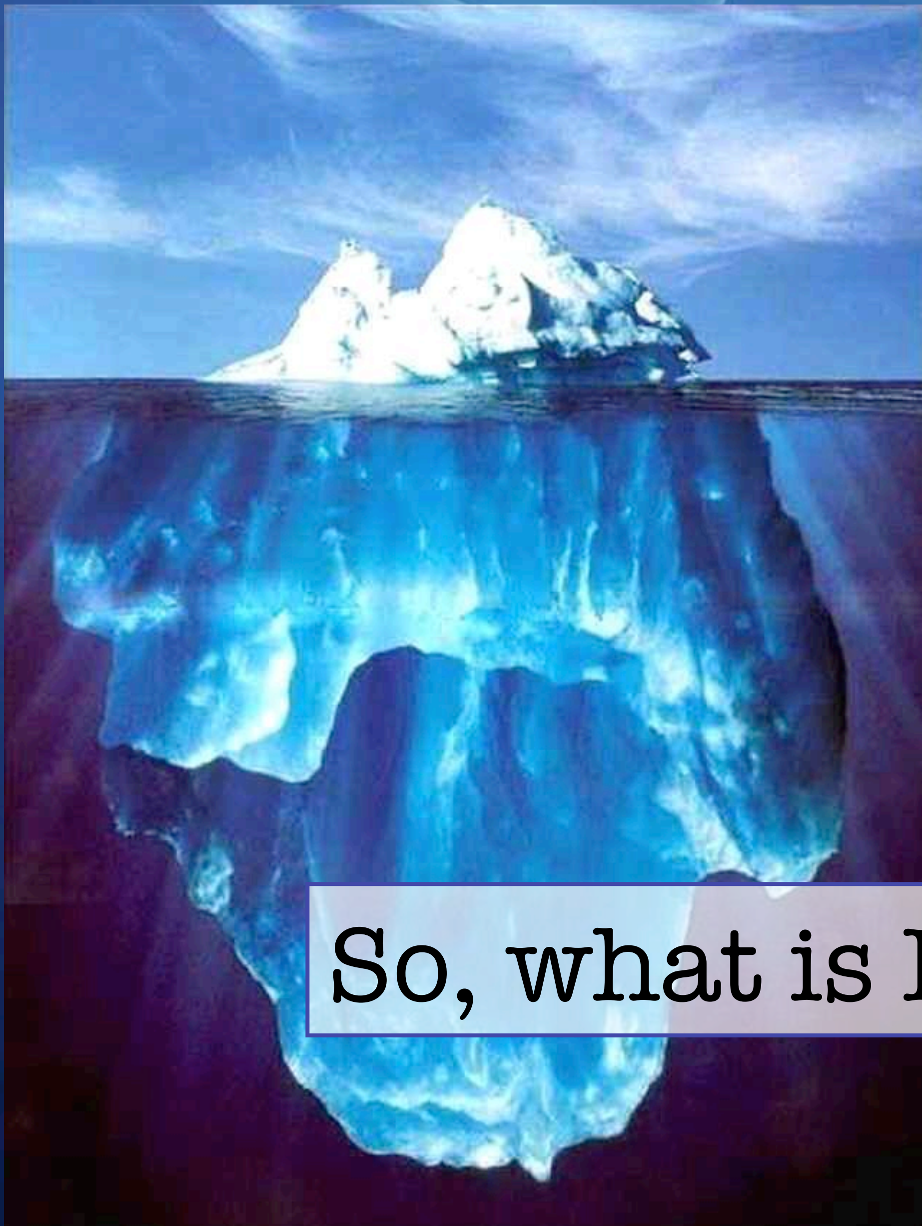


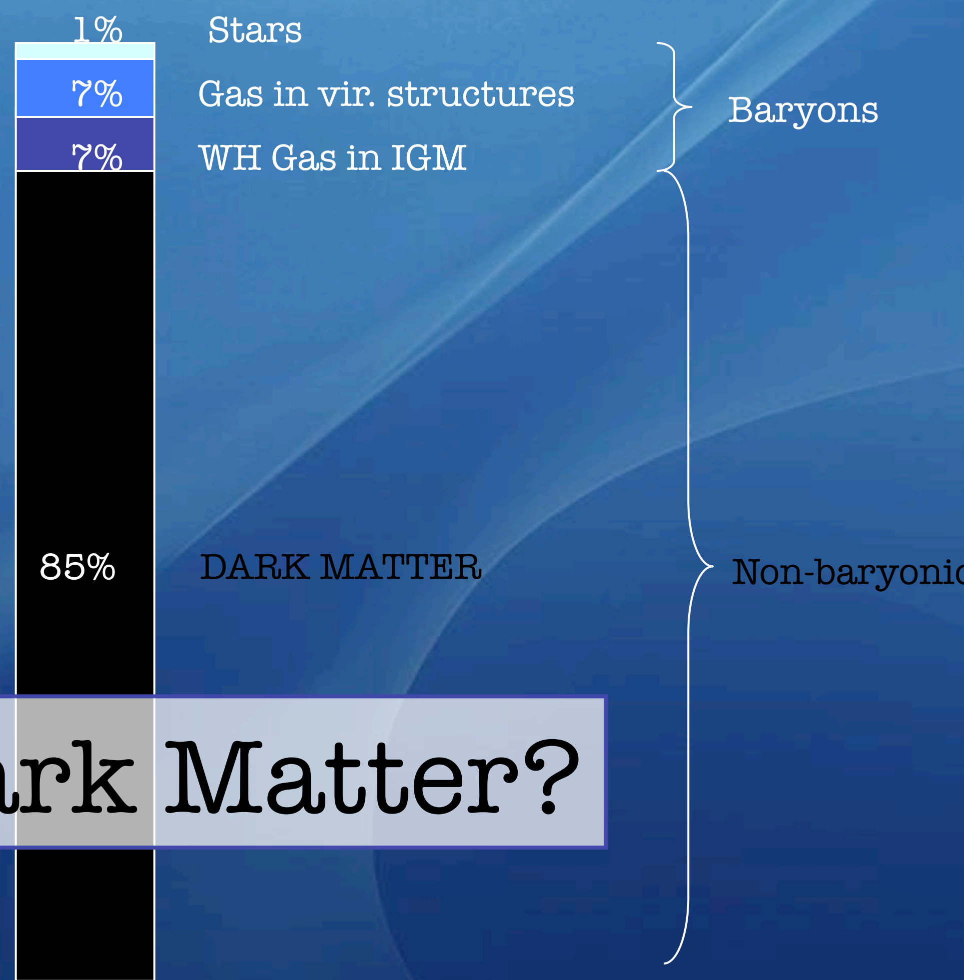
$\Omega_b h^2 \approx 0.02$

$\Omega_{DM} h^2 \approx 0.1$

Dark Matter

An Inventory of Matter in the Universe

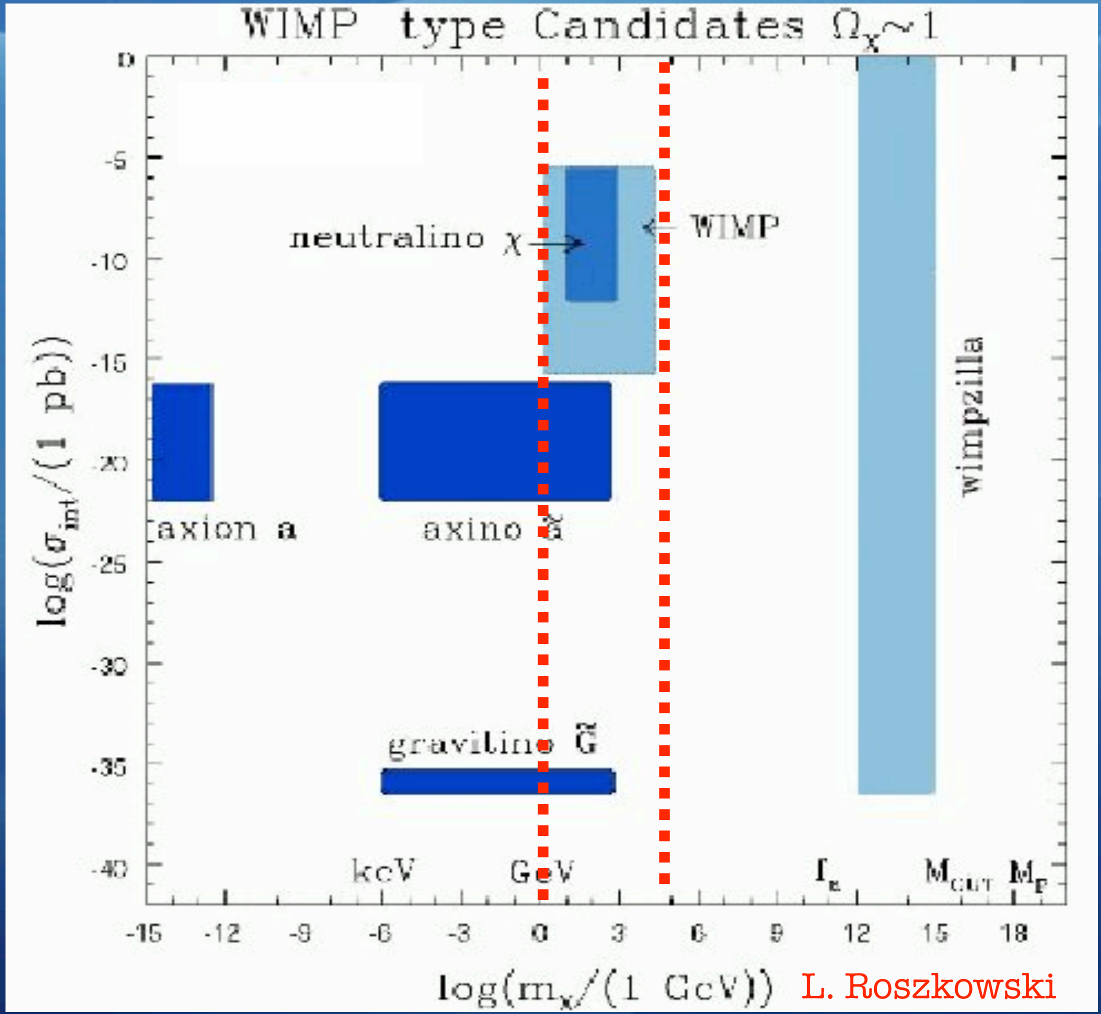




So, what is Dark Matter?

Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



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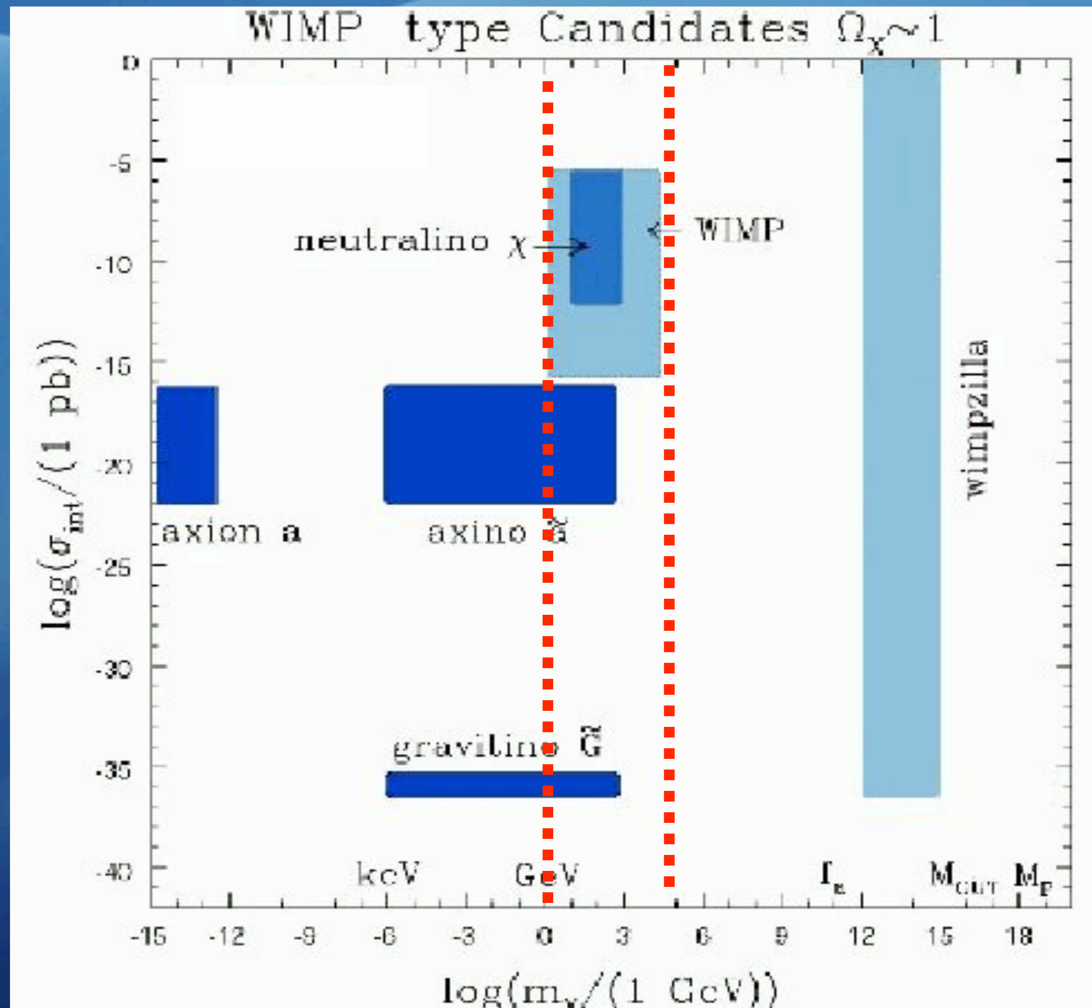
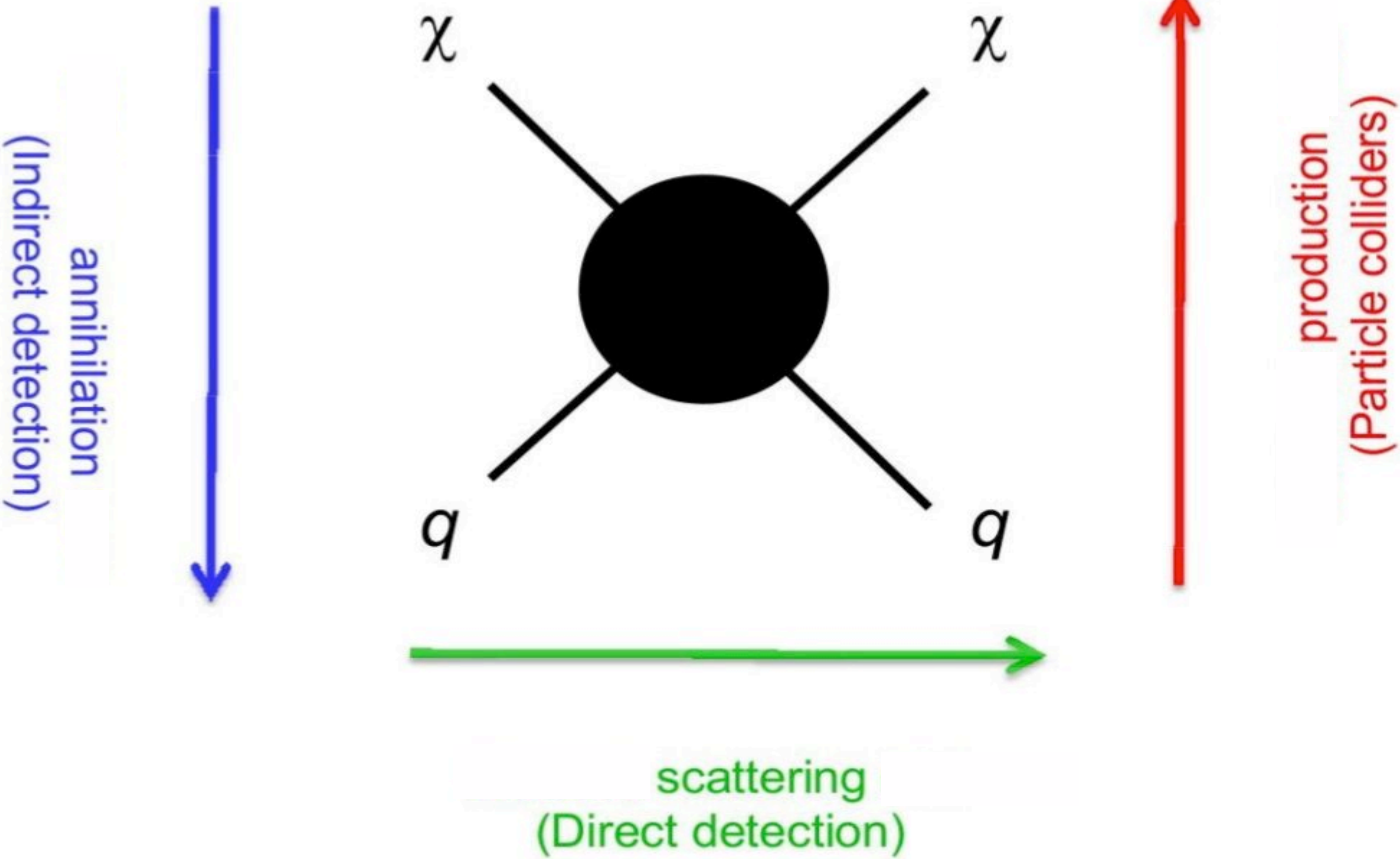
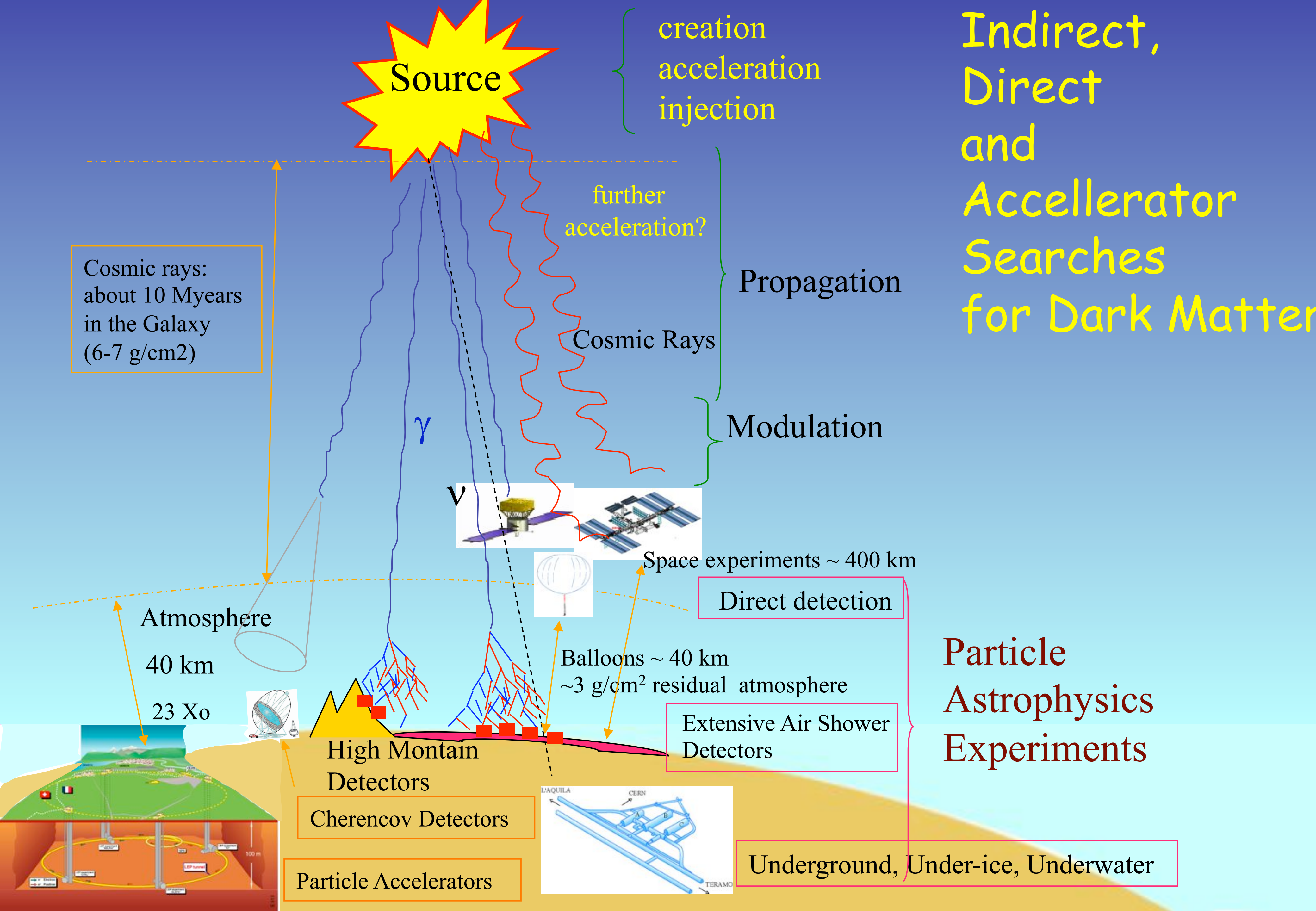
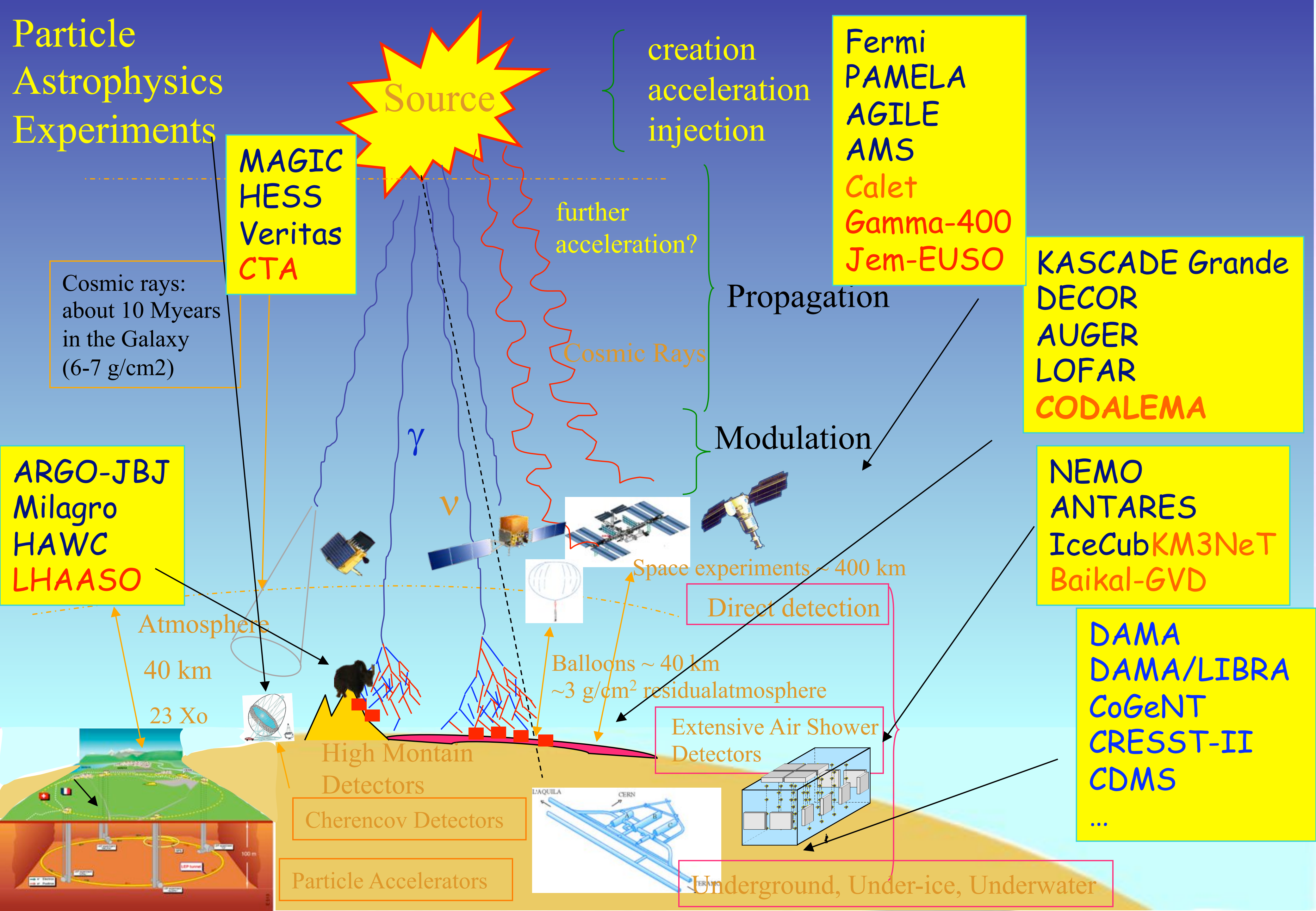



χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)


Indirect, Direct and Accellerator Searches for Dark Matter
Source
creation
acceleration
injection
further acceleration?
Propagation
Cosmic Rays
Modulation
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
γ
ν
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residual atmosphere
Extensive Air Shower Detectors
Particle Astrophysics Experiments
High Montain Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater



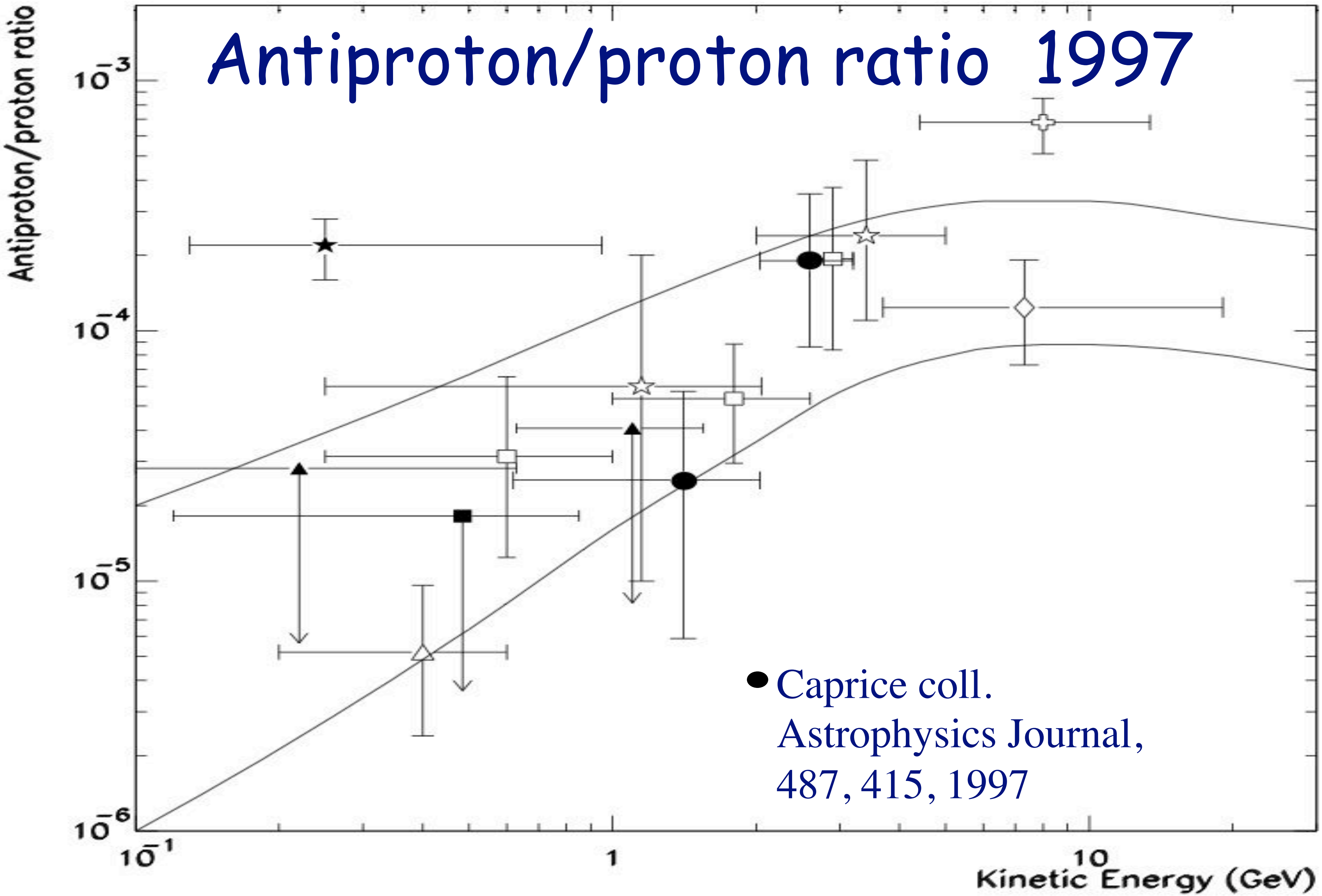
Particle Astrophysics Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
Calet
Gamma-400
Jem-EUSO
MAGIC
HESS
Veritas
CTA
further acceleration?
Propagation
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
γ
ν
Modulation
ARGO-JBJ
Milagro
HAWC
LHAASO
NEMO
ANTARES
IceCubKM3NeT
Baikal-GVD
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
DAMA
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
...
Extensive Air Shower Detectors
High Montain Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
Underground, Under-ice, Underwater

Neutralino WIMPs

Assume χ present in the galactic halo

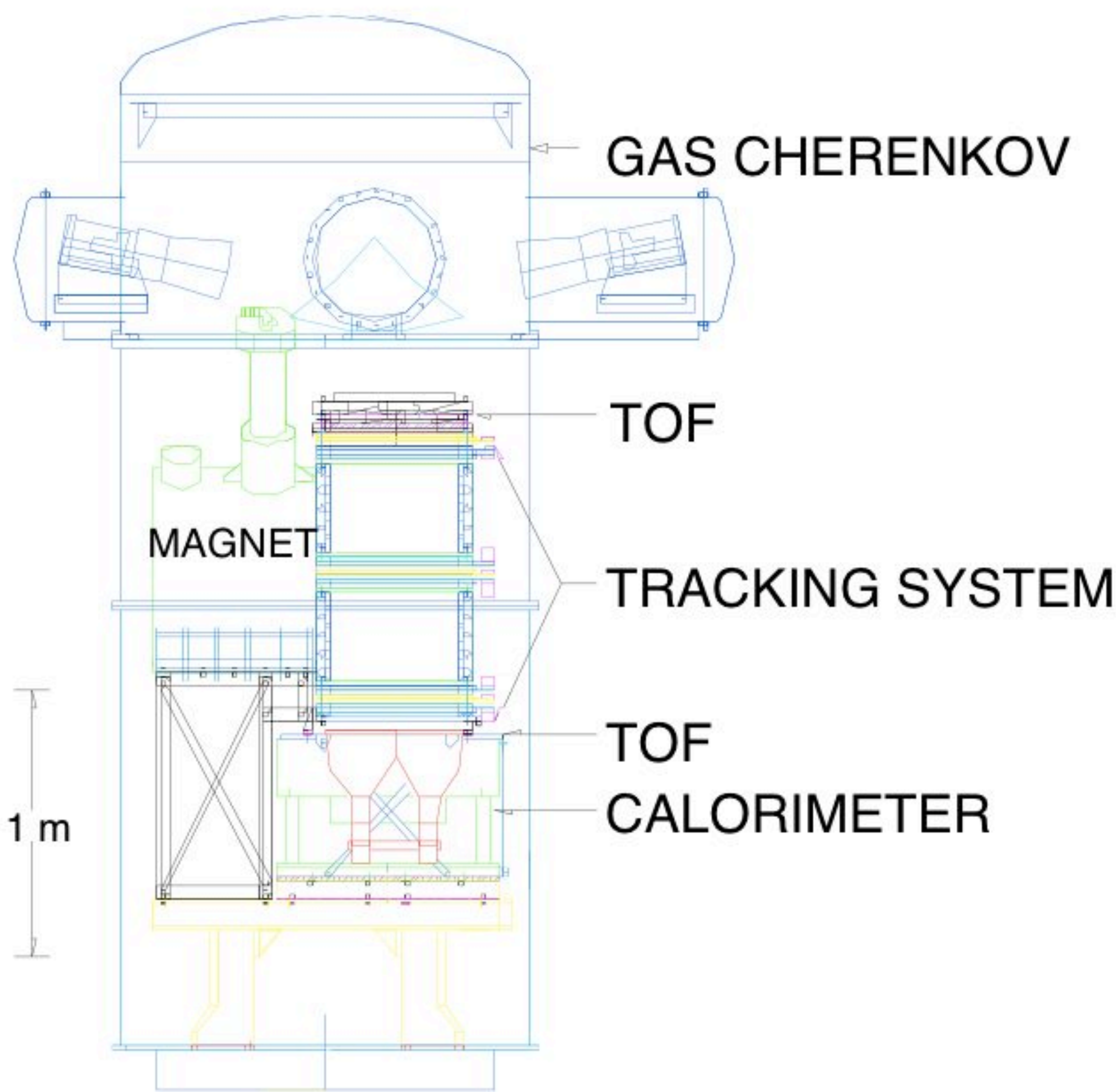
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) is an interesting signature
- ie: χ χ --> anti p + X
- Produced from (e. g.) χ χ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

Antiproton/proton ratio 1997



● Caprice coll.
Astrophysics Journal, 487, 415, 1997

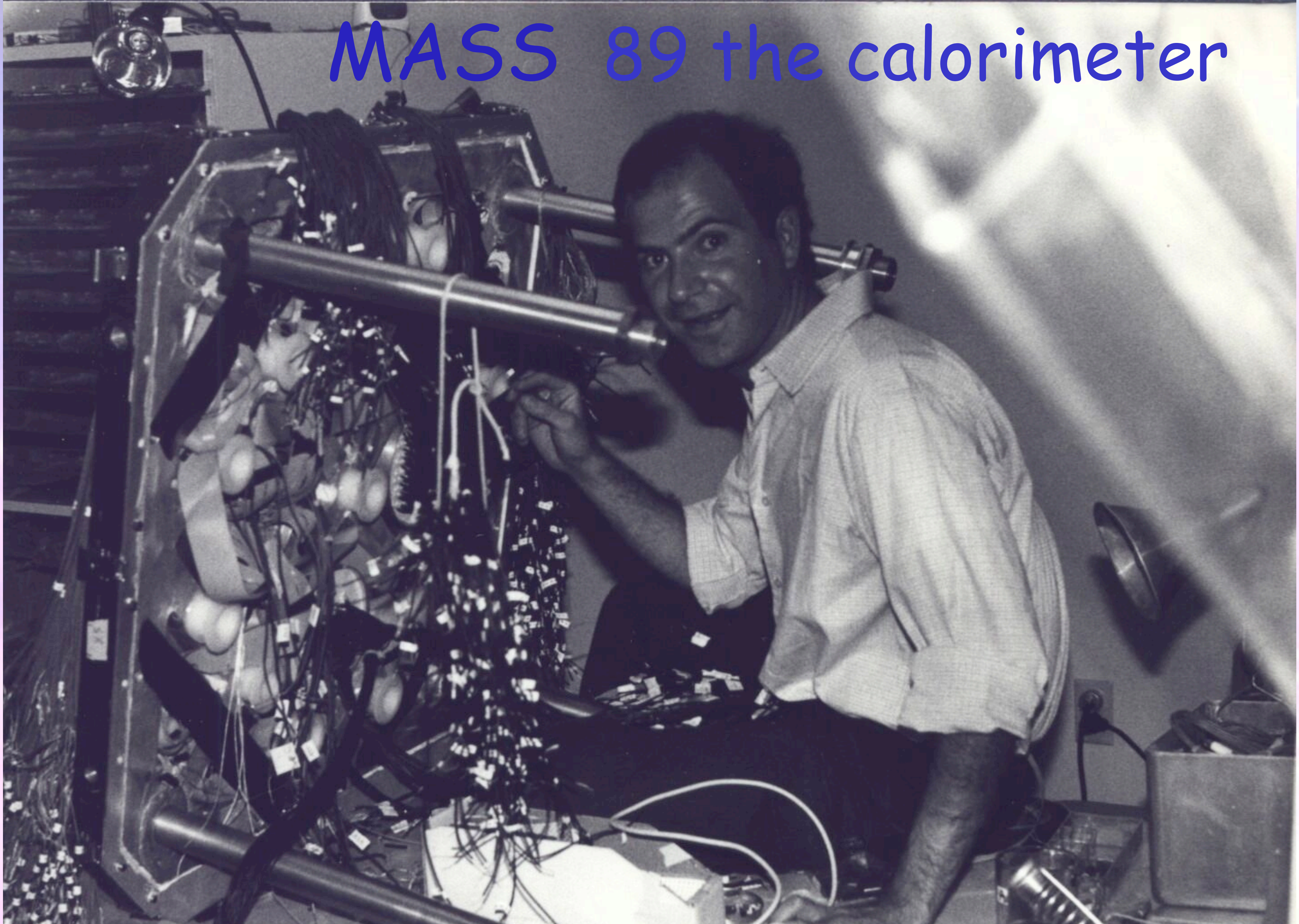
MASS Matter Antimatter Space Spectrometer



5 September 1989


HOLD

MASS 89 the calorimeter



MASS 89 flight

MASS 89 flight


MASS 89

PAMELA

Payload for **A**ntimatter **M**atter **E**xploration and **L**ight Nuclei **A**strophysics

In orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

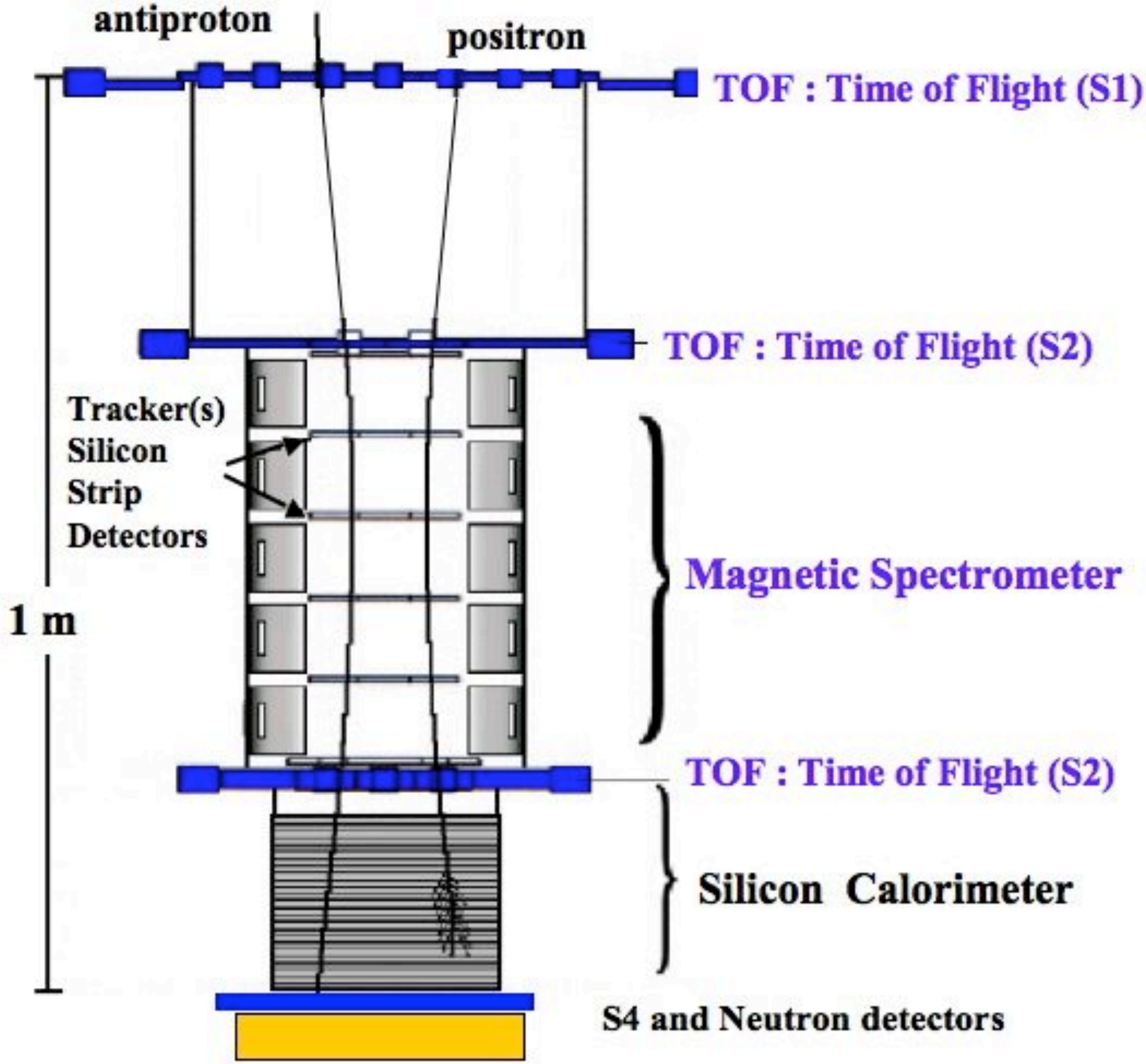
First switch-on on June 21 2006

From July 11 Pamela is in continuous data taking mode

- ~ 6 years from PAMELA launch

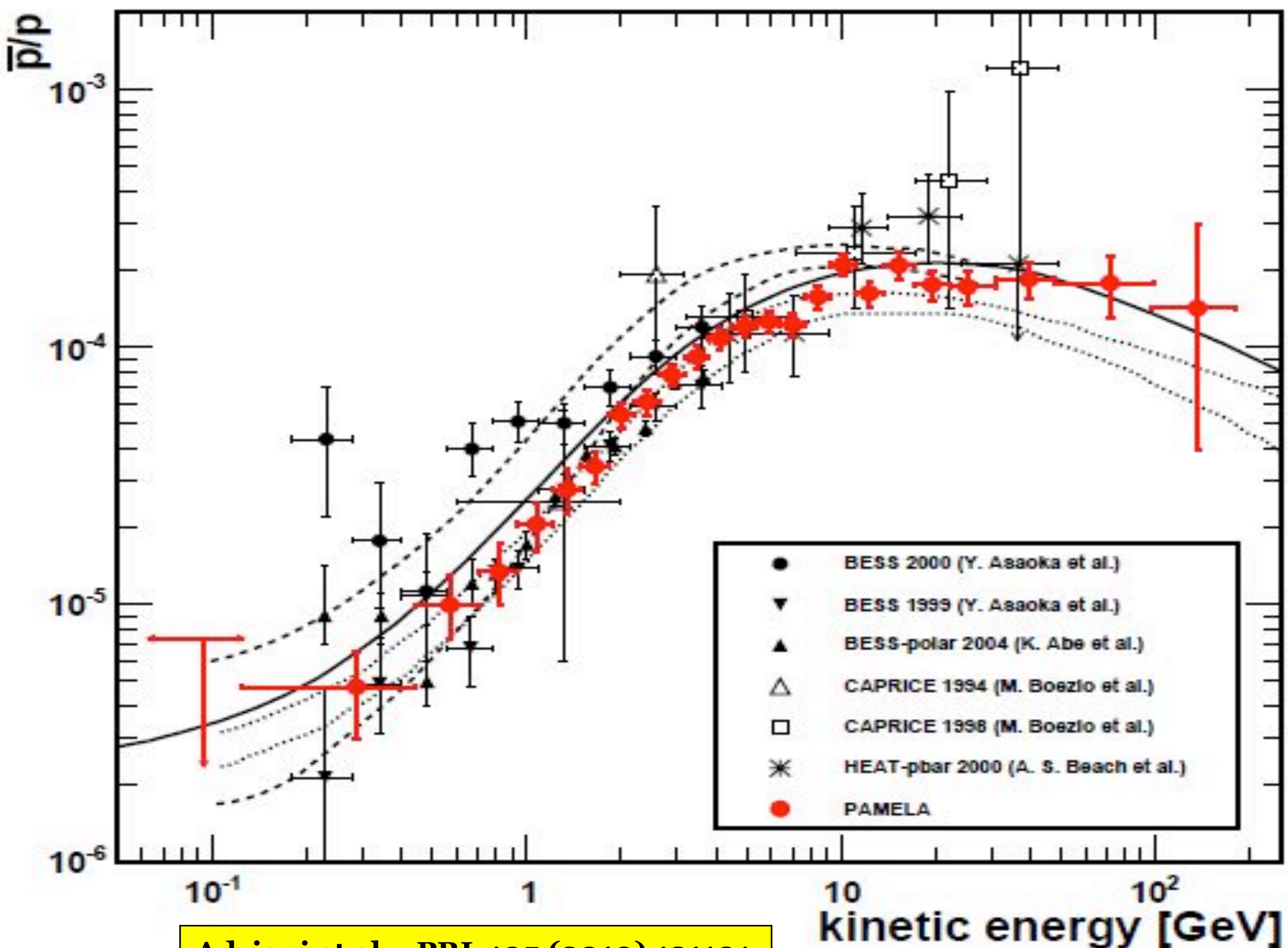
- Launched in orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour cosmodrom.

Pamela


antiproton
positron
TOF : Time of Flight (S1)
TOF : Time of Flight (S2)
Tracker(s)
Silicon
Strip
Detectors
1 m
Magnetic Spectrometer
TOF : Time of Flight (S2)
Silicon Calorimeter
S4 and Neutron detectors

Antiproton-to-proton ratio

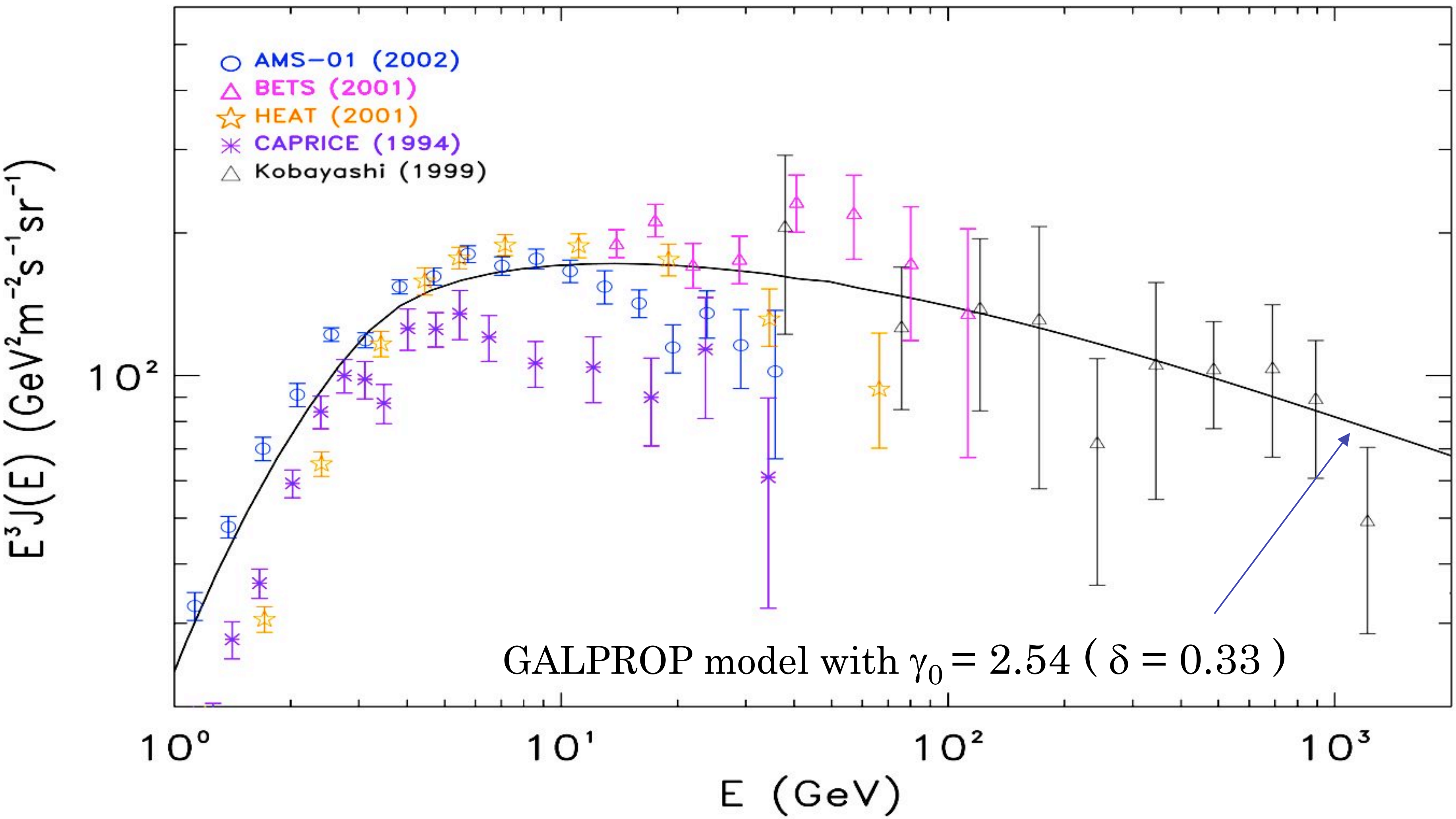
- Overall agreement with pure secondary calculation



Adriani et al. - PRL 105 (2010) 121101

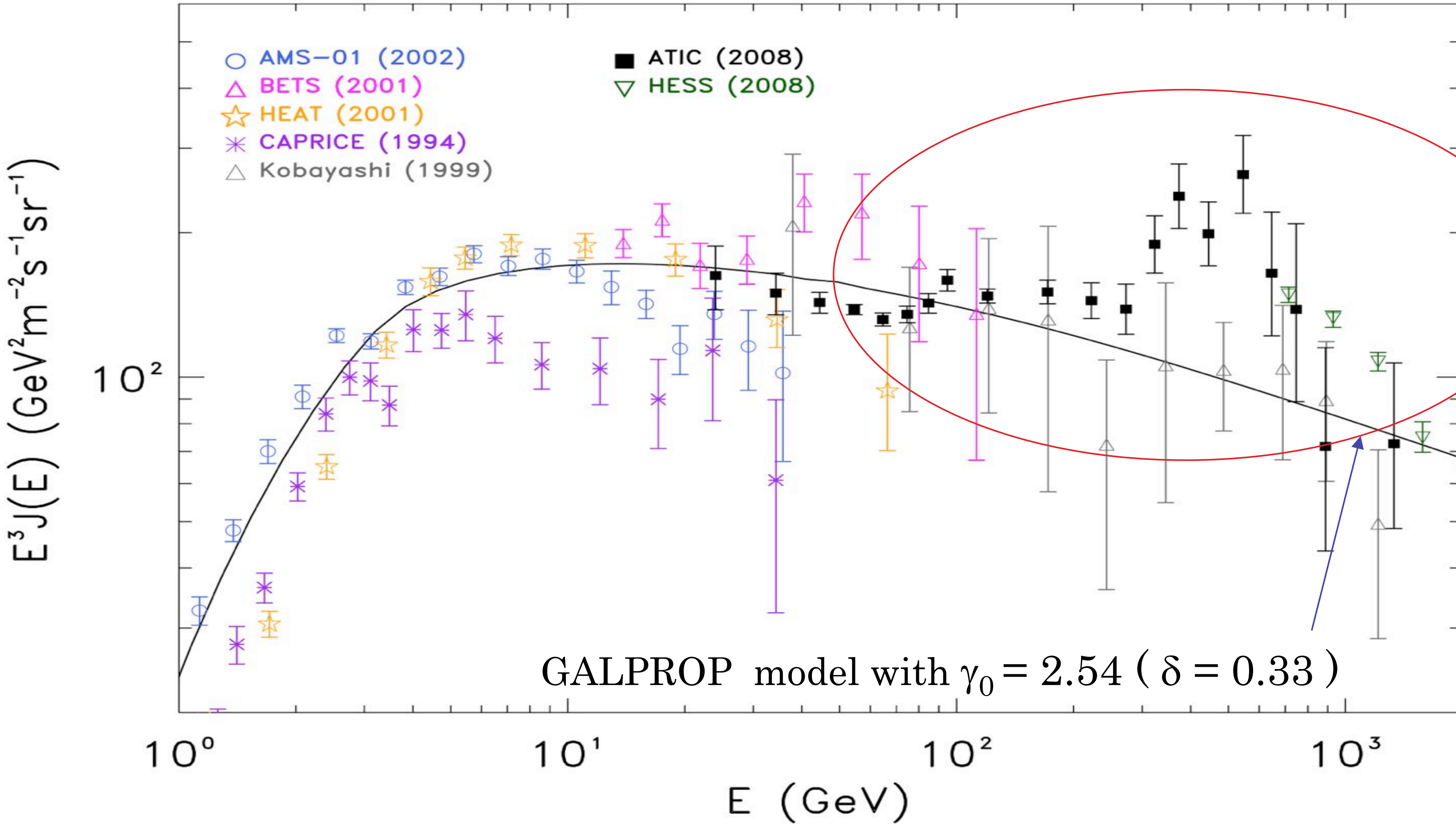
The situation before 2008

Electron + positron spectrum



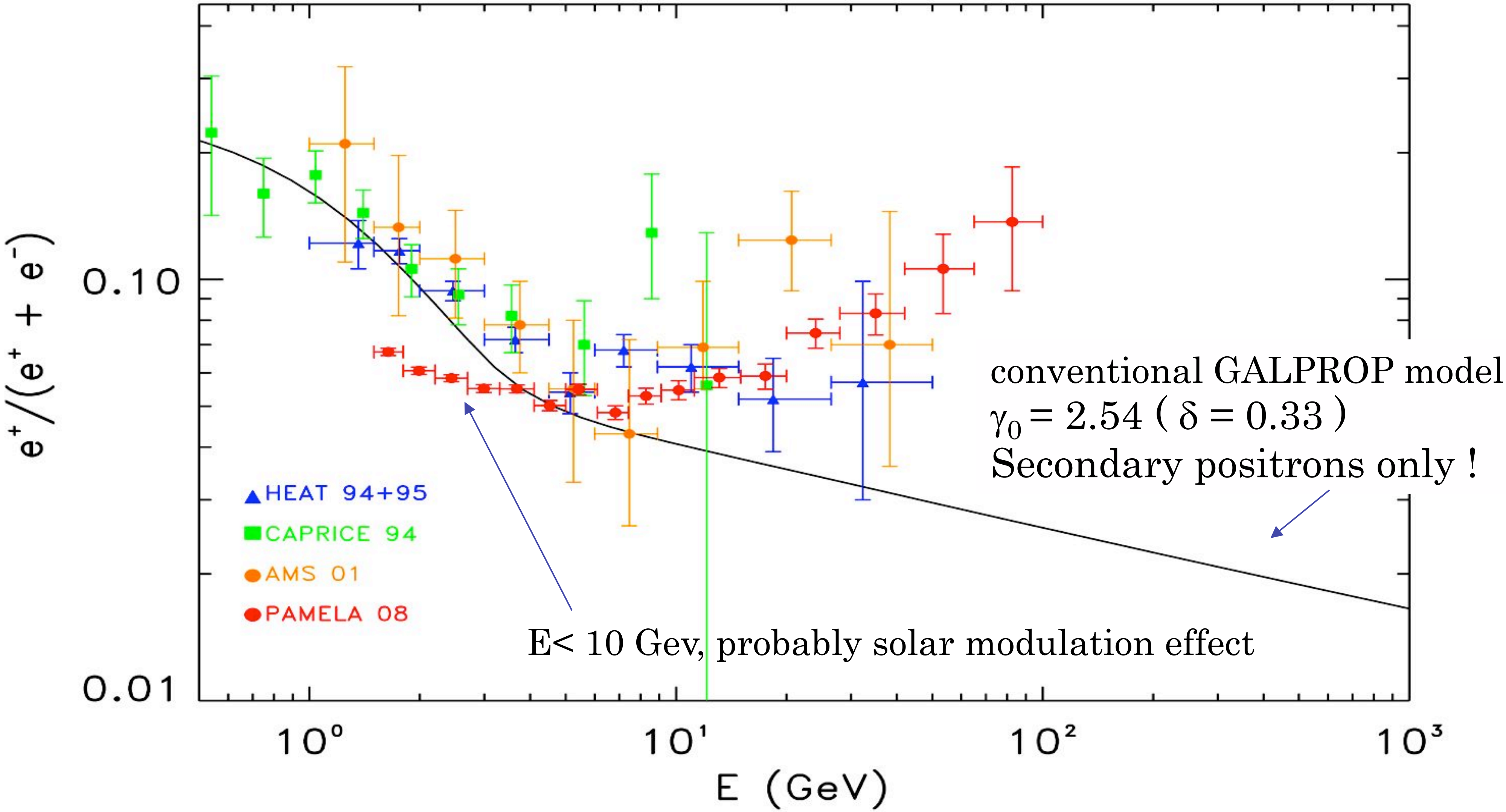
Data were compatible with conventional large-scale Galactic models of CRs tuned to fit gamma-ray data and other observables

2008: Results from ATIC and HESS



Data clearly call for major changes to the conventional model:
Nearby sources (e.g. pulsar) or dark matter annihilation/decay models have been proposed to explain those data

2009: PAMELA results



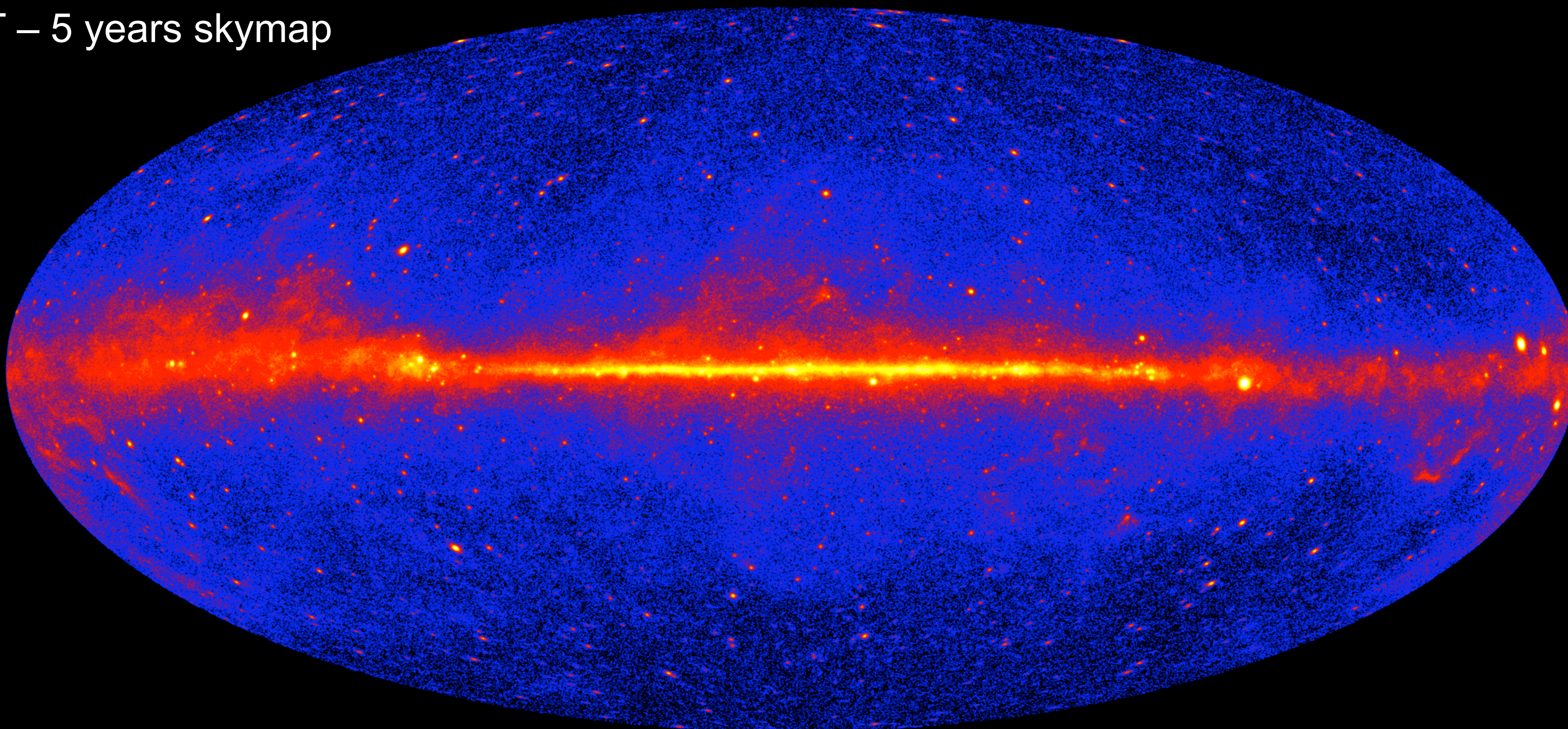
$e^+/(e^+ + e^-) \propto E^{-\gamma p + \gamma_0 - \delta}$ γp: proton source power-index

It improves only adopting very soft electron spectra (high γ_0)

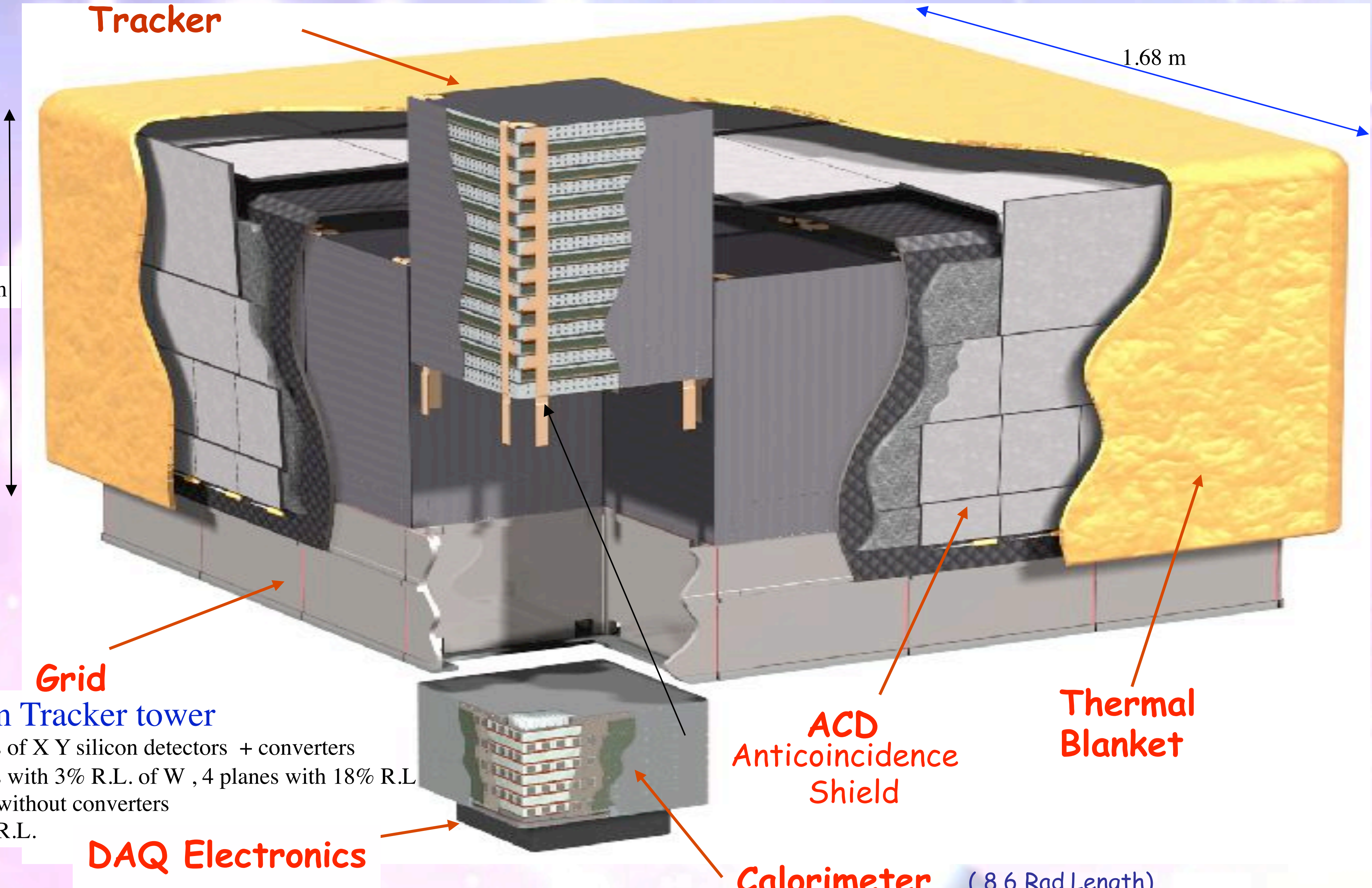

Fermi
Gamma-ray
Space Telescope
Happy 6th Birthday Fermi !!
11 June 2008

Discovering the gamma-ray sky

LAT – 5 years skymap



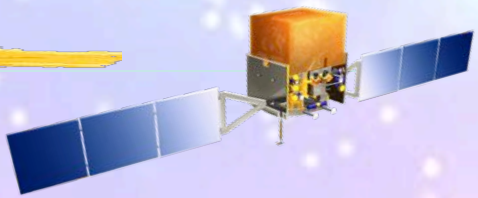
Fermi Gamma-Ray Large Area Space Telescope



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
total 1.5 R.L.

The Fermi LAT Participating Institutions



American Institutions

SU-HEPL Stanford University, Hanson Experimental Physics Laboratory , ,
SU-SLAC Stanford Linear Accelerator Center, Particle Astrophysics group
GSFC-NASA-LHEA Goddard Space Flight Center, Laboratory for High Energy Astrophysics
NRL - U. S. Naval Research Laboratory, E. O. Hulburt Center for Space Research, X-ray and gamma-ray branches
UCSC- SCIPP University of California at Santa Cruz, Santa Cruz Institute of Particle Physics
SSU- California State University at Sonoma, Department of Physics & Astronomy , WUStL-Washington University, St. Louis
UW- University of Washington , TAMUK- Texas A&M University-Kingsville, Ohio State University

Italian Institutions
INFN - Istituto Nazionale di Fisica Nucleare and Univ. of Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine
ASI - Italian Space Agency
IASF- Milano, Roma

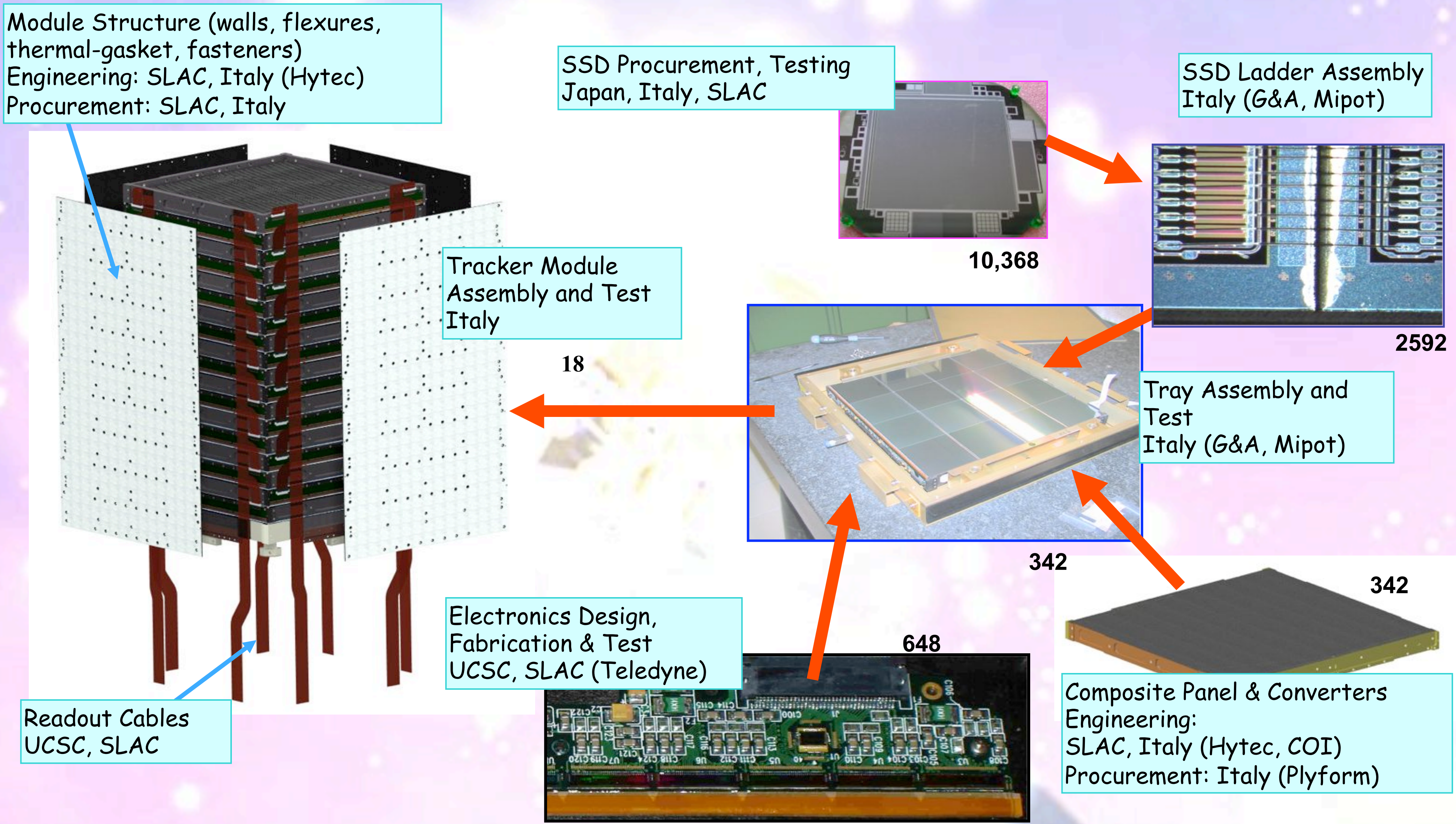
Japanese Institutions
University of Tokyo
ICRR - Institute for Cosmic-Ray Research
ISAS- Institute for Space and Astronautical Science
Hiroshima University

French Institutions
CEA/DAPNIA Commissariat à l'Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nucliaire et de l'Instrumentation Associée, CEA, Saclay
IN2P3 Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
IN2P3/LPNHE-X Laboratoire de Physique Nucléaire des Hautes Energies de l'École Polytechnique
IN2P3/PCC Laboratoire de Physique Corpusculaire et Cosmologie, Collège de France
IN2P3/CENBG Centre d'études nucléaires de Bordeaux Gradignan
IN2P3/LPTA Laboratoire de Physique Theorique et Astroparticules, Montpellier

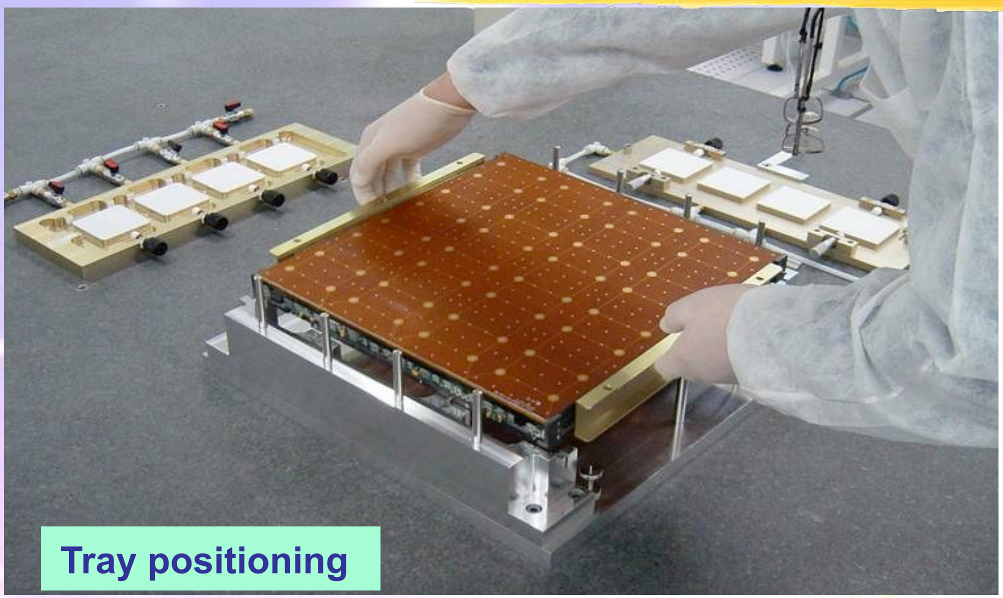
Swedish Institutions
KTHRoyal Institute of Technology
Stockholms Universitet

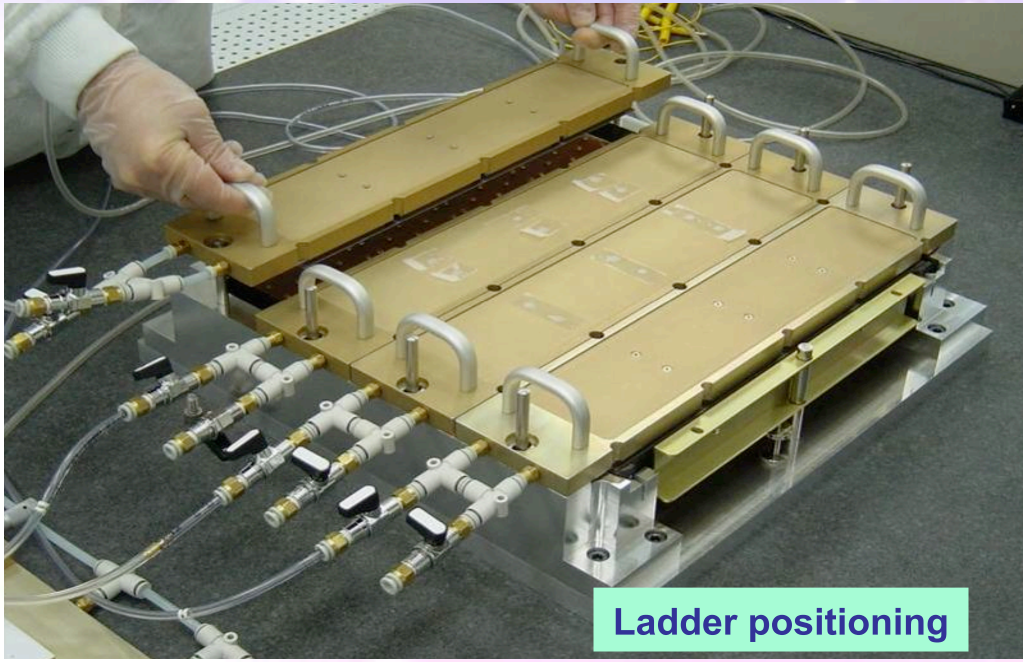
Collaboration members:	**~270**
Members:	**95**
Affiliated Scientists	~90
Postdocs:	37
Graduate Students	48

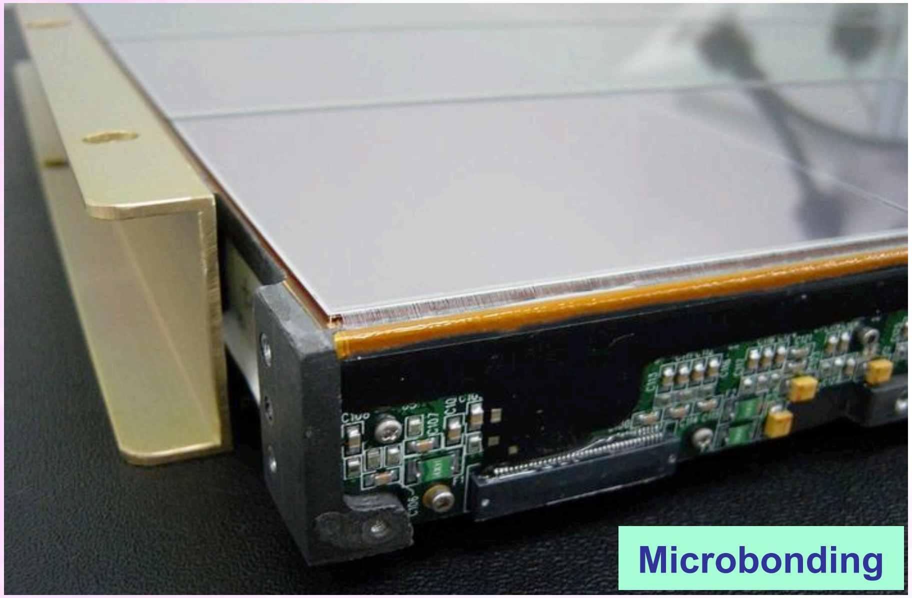
Tracker Production Overview



Tray assembly in G&A

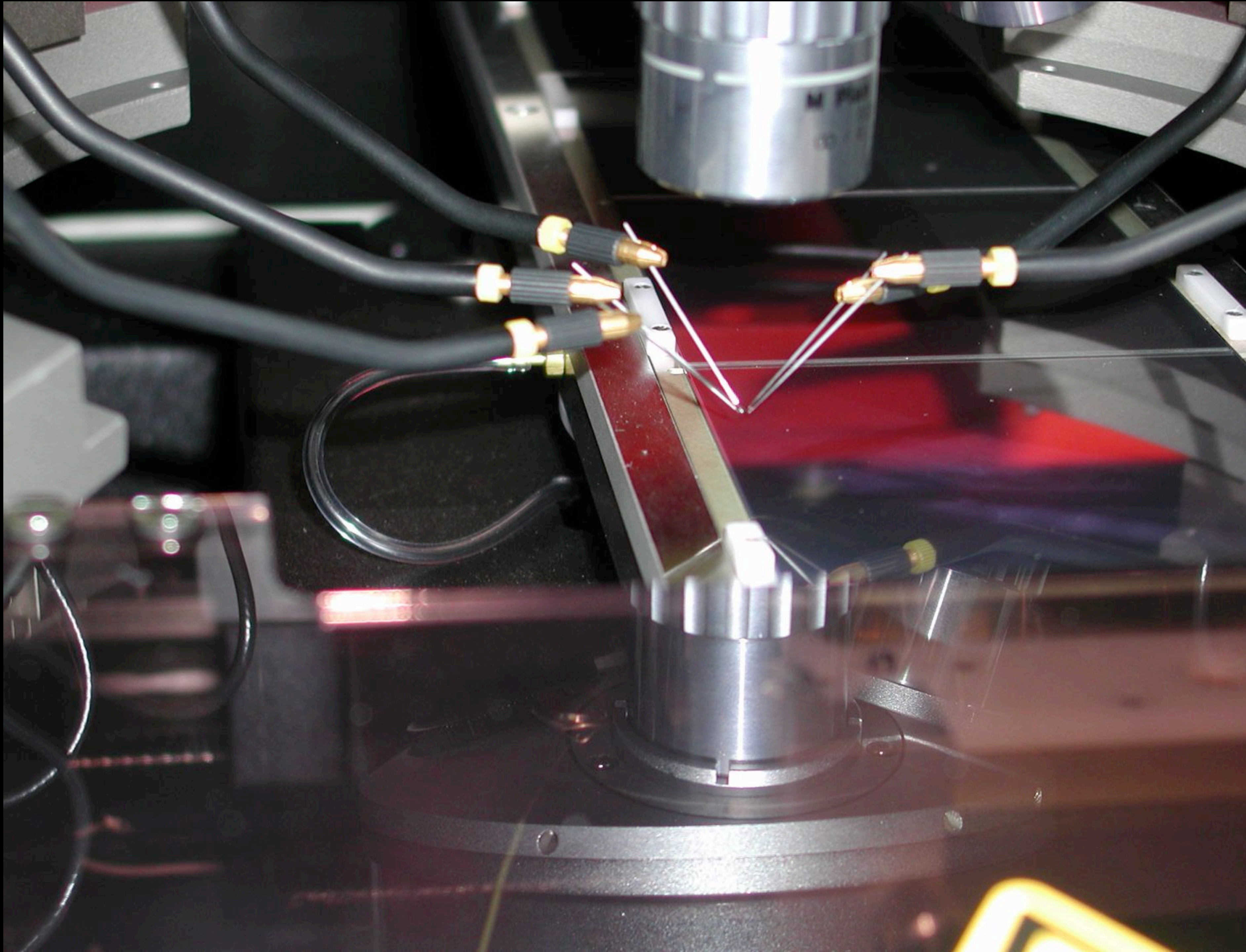


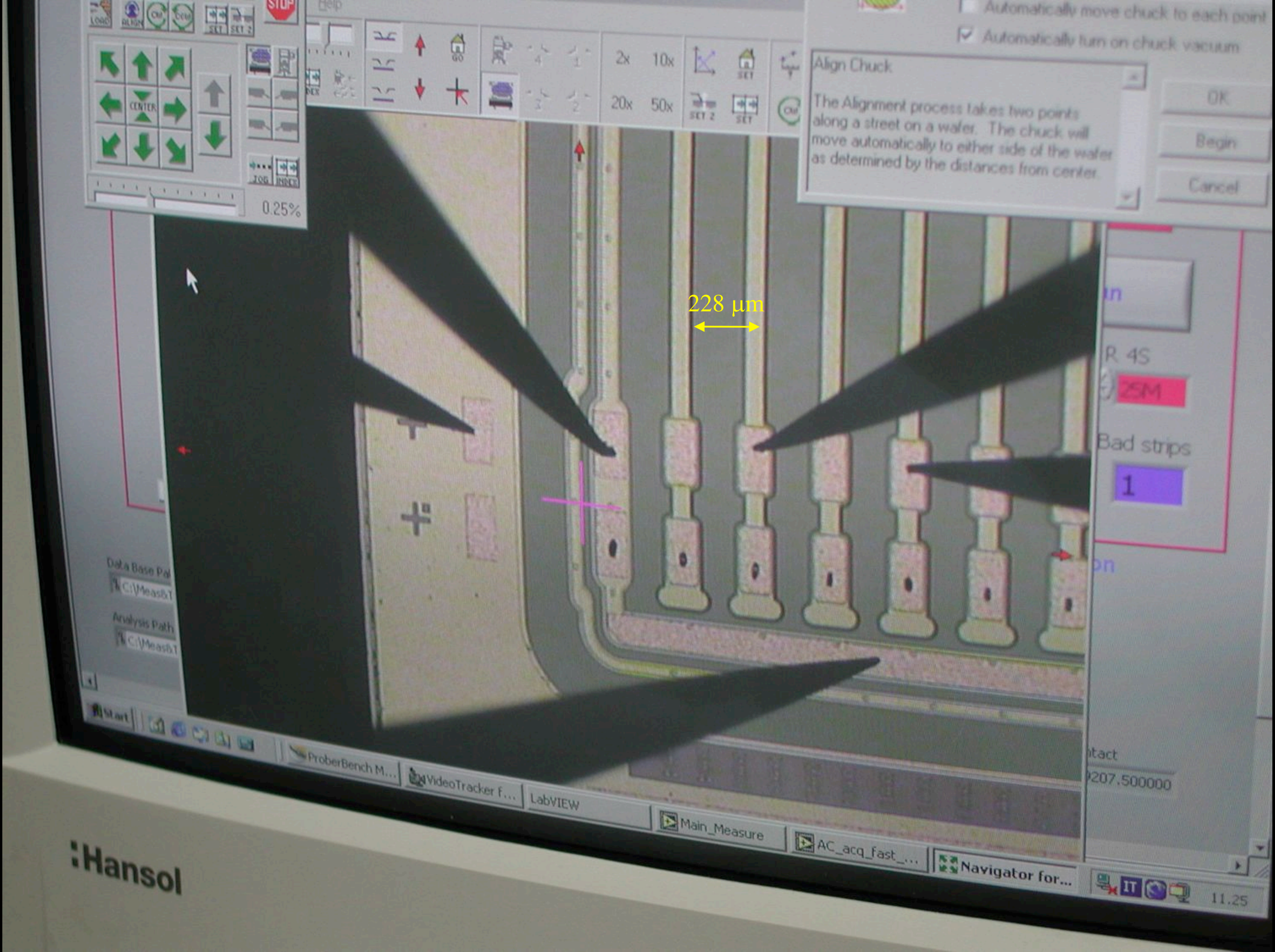




- 160 bare panels produced
- 100 tested and qualified for integration with ladders
- completed trays for 3.3 towers
- 6 assembly chain ready
- Max assembly rate : 3 trays/day/shift


EMERGENCY STOP




228 µm
Align Chuck
The Alignment process takes two points along a street on a wafer. The chuck will move automatically to either side of the wafer as determined by the distances from center.
Automatically move chuck to each point
Automatically turn on chuck vacuum
OK
Begin
Cancel
STOP
CENTER
2x
10x
20x
50x
0.25%
Bad strips
1
Data Base Pat
Analysis Path
ProberBench M...
VideoTracker f...
LabVIEW
Main_Measure
AC_acq_fast_...
Navigator for...
Hansol

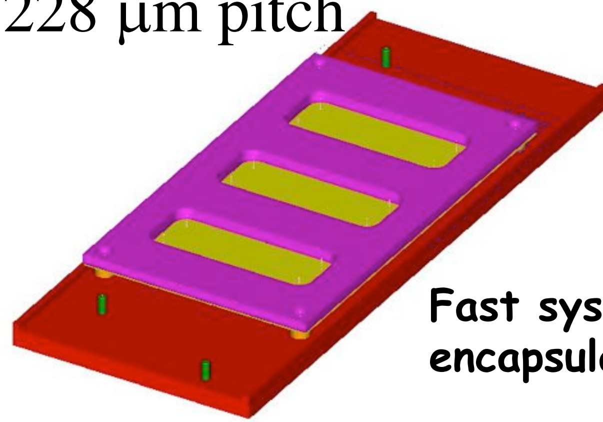
Encapsulation

Dam & Fill encapsulation

Dam Nusil 1142
Fill Nusil 15-2500

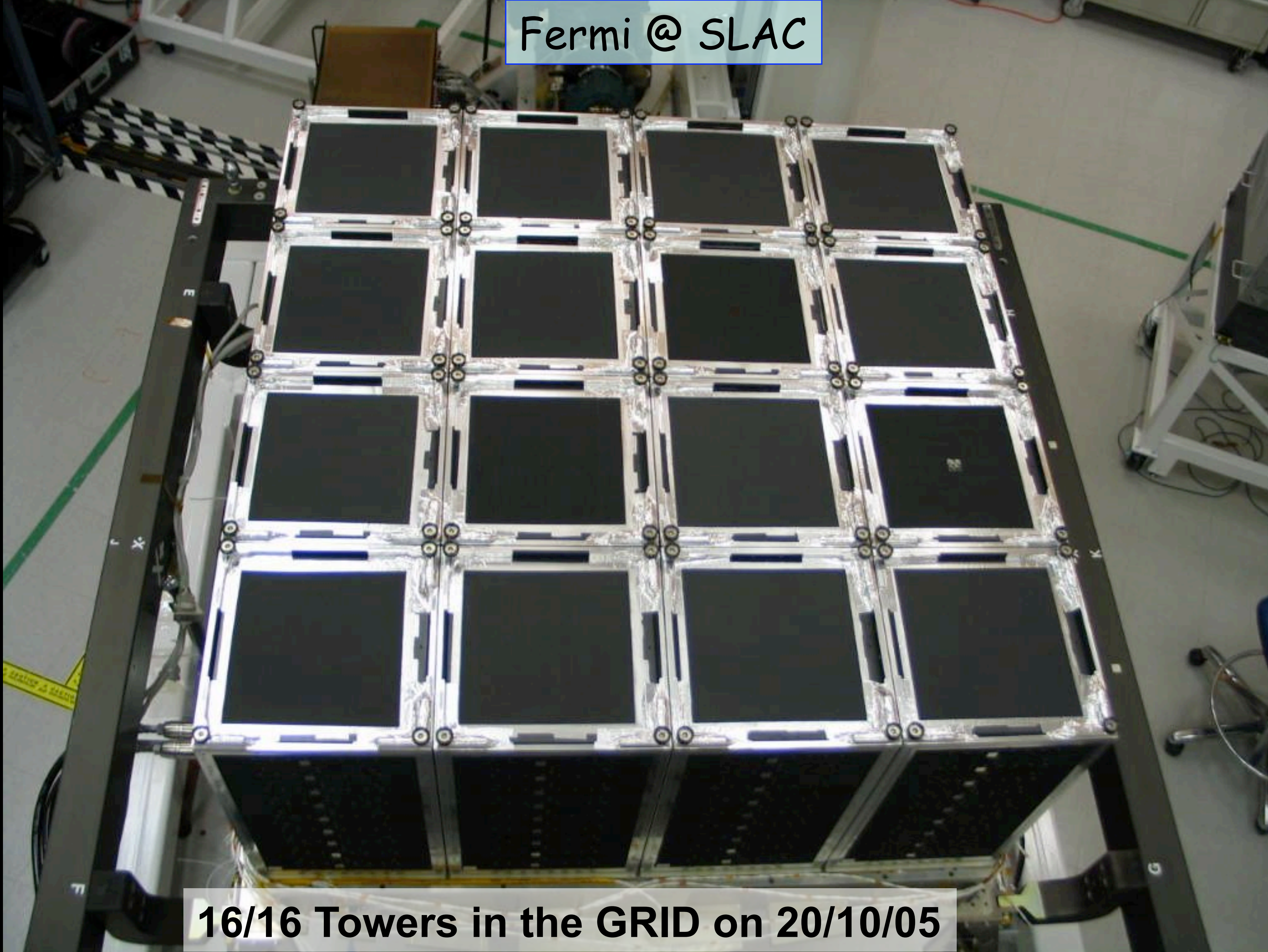
Requirements:
1. **Height <0.5mm**
2. **Lateral overflow <0.05mm**
3. **Coverage of all the bondings and pads**

228 μm pitch



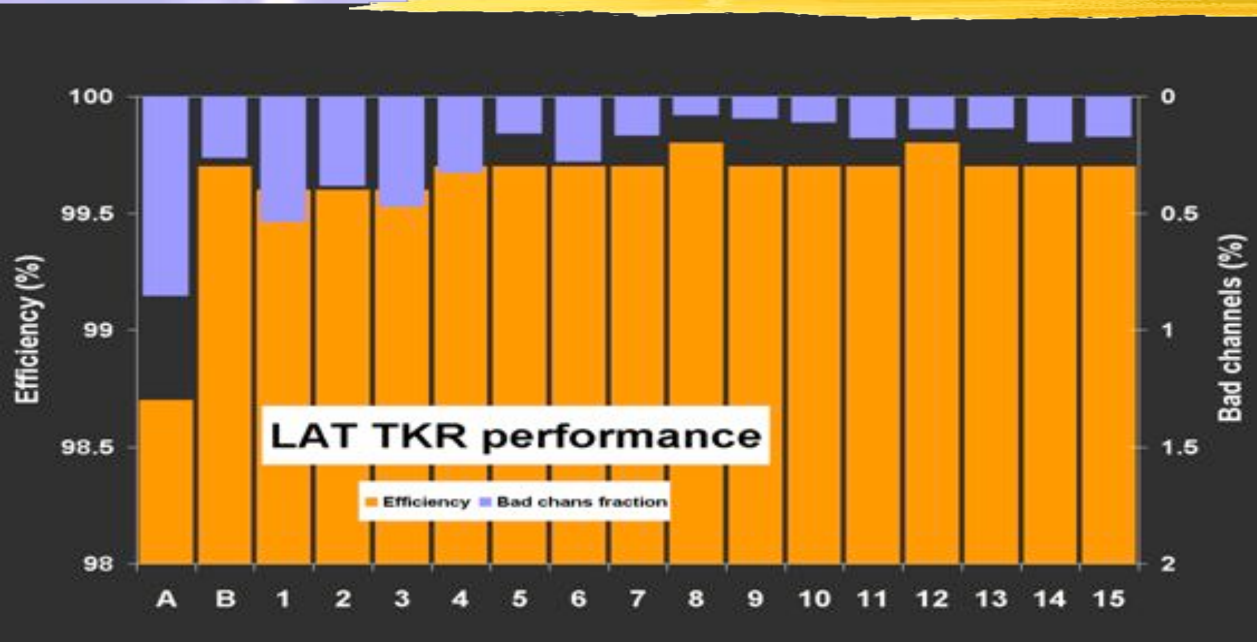
Fast system to check encapsulation height

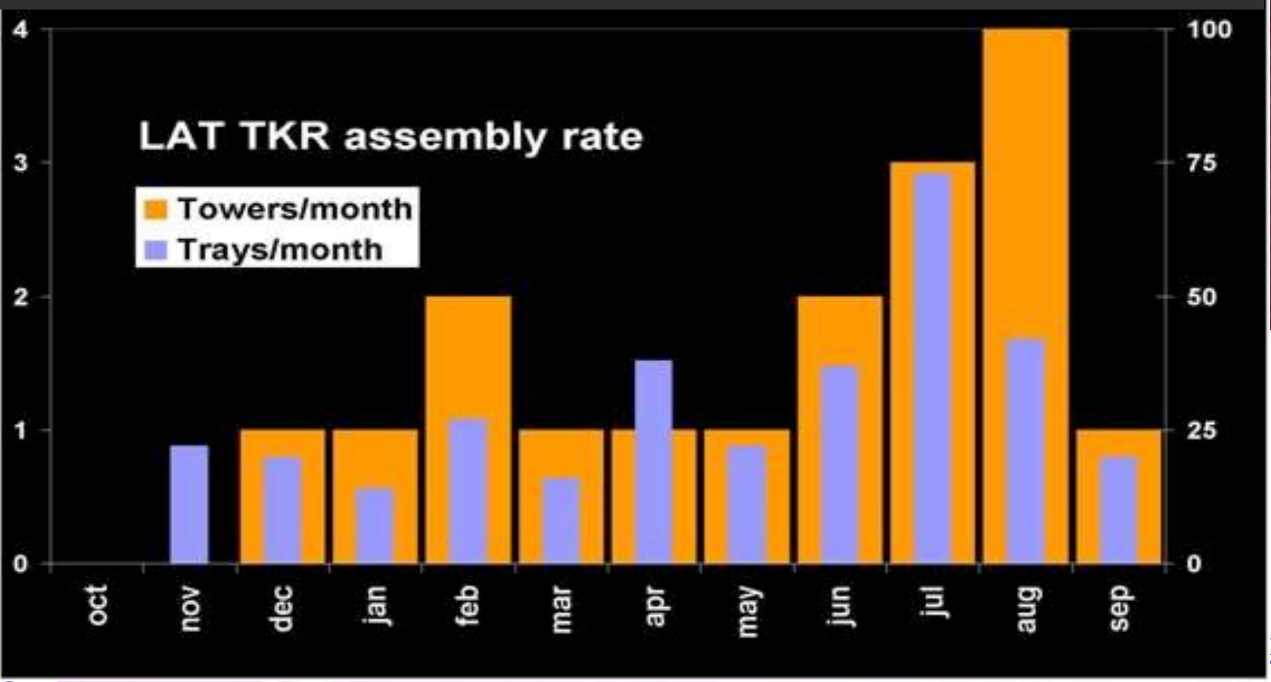
Fermi @ SLAC

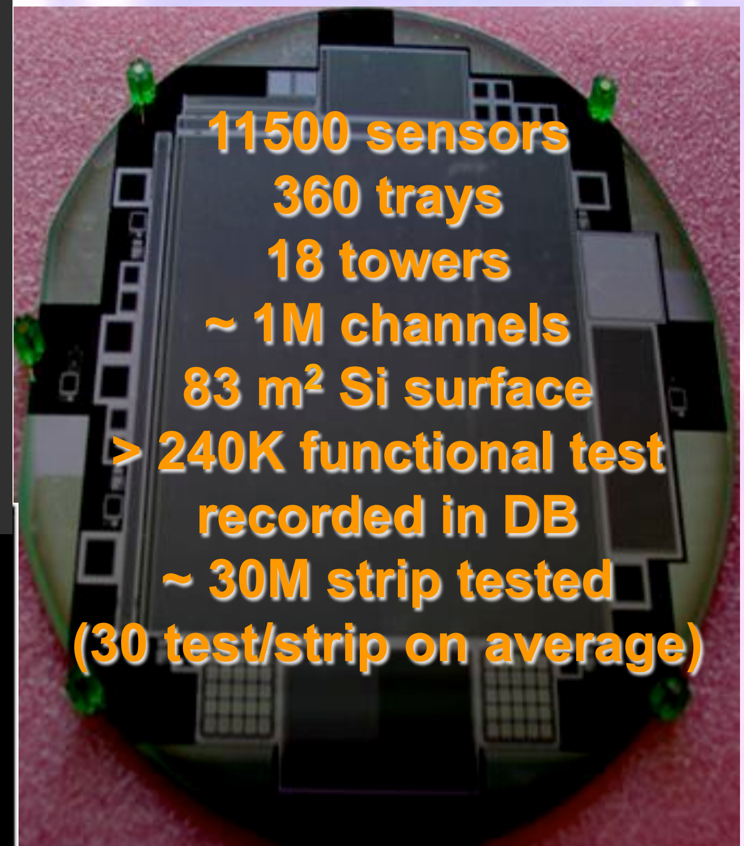


16/16 Towers in the GRID on 20/10/05

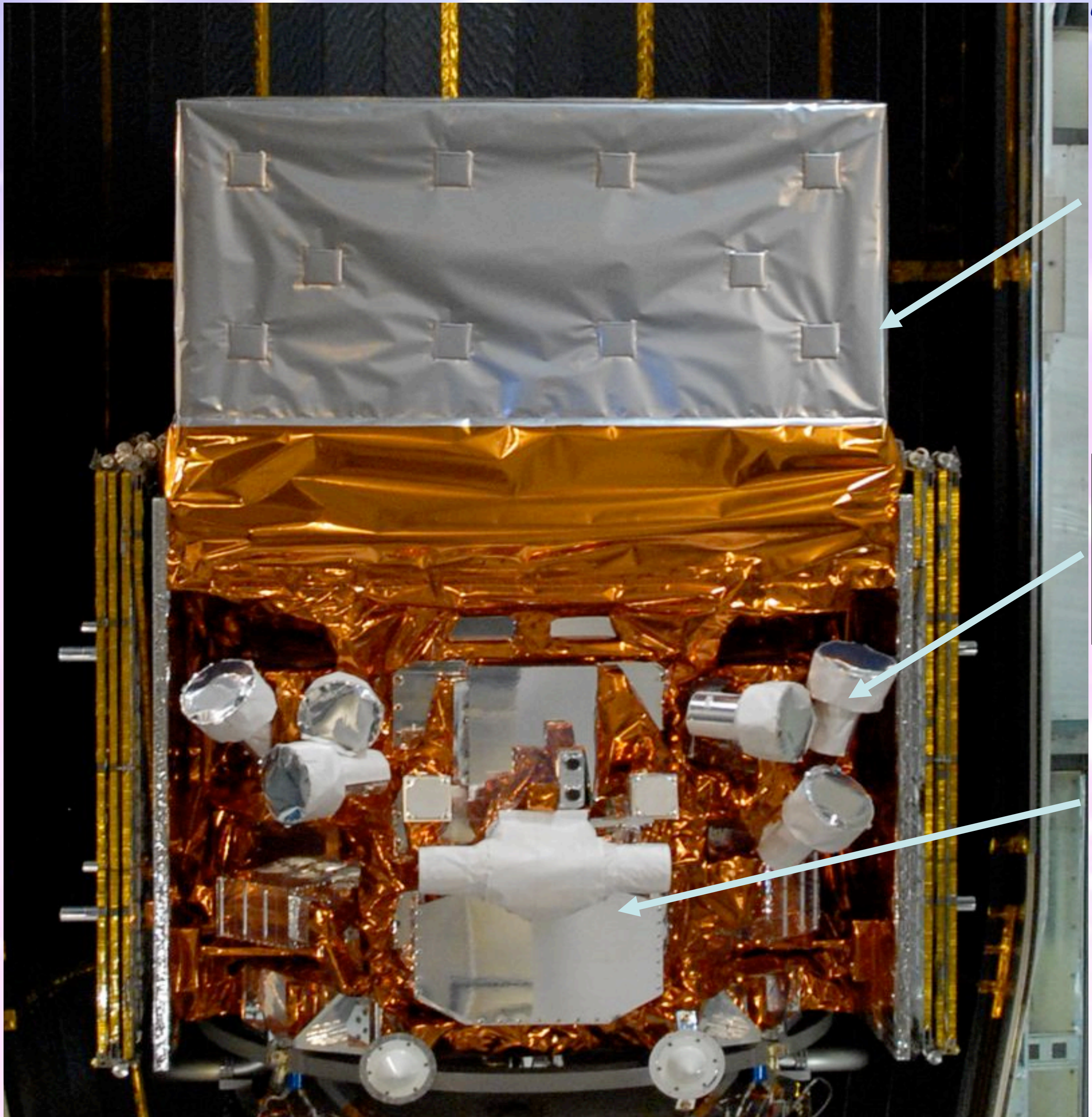
The LAT Tracker numbers







The Fermi Observatory



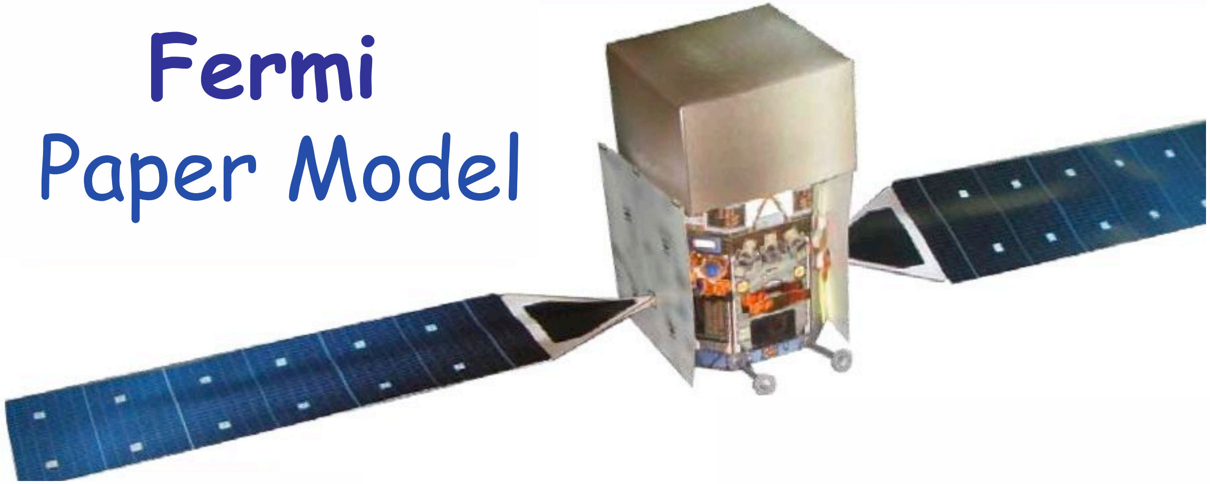
LAT
Large
Area
Telescope

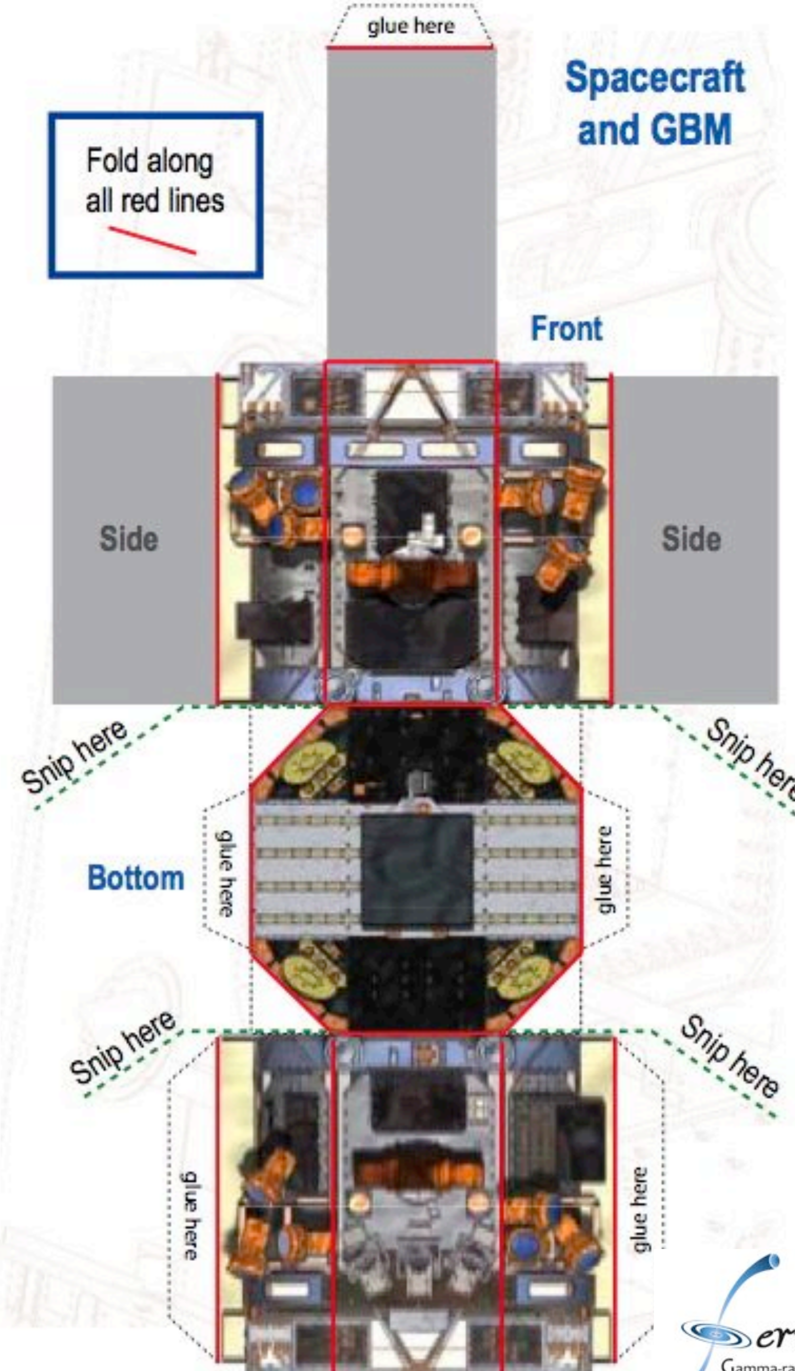
GBM
Sodium Iodide
Detector

GBM
Bismuth
Germanate
Detector

Fermi Prior to Fairing Installation

Fermi
Paper Model



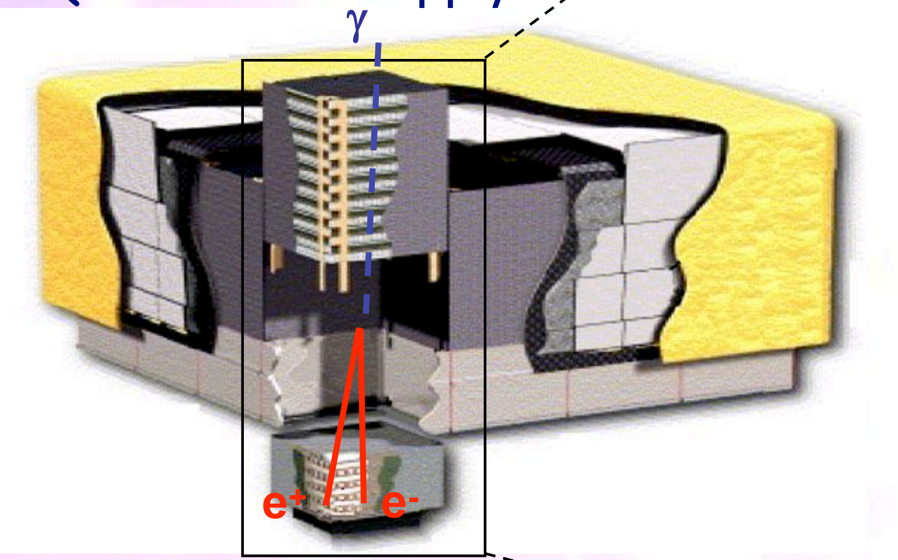


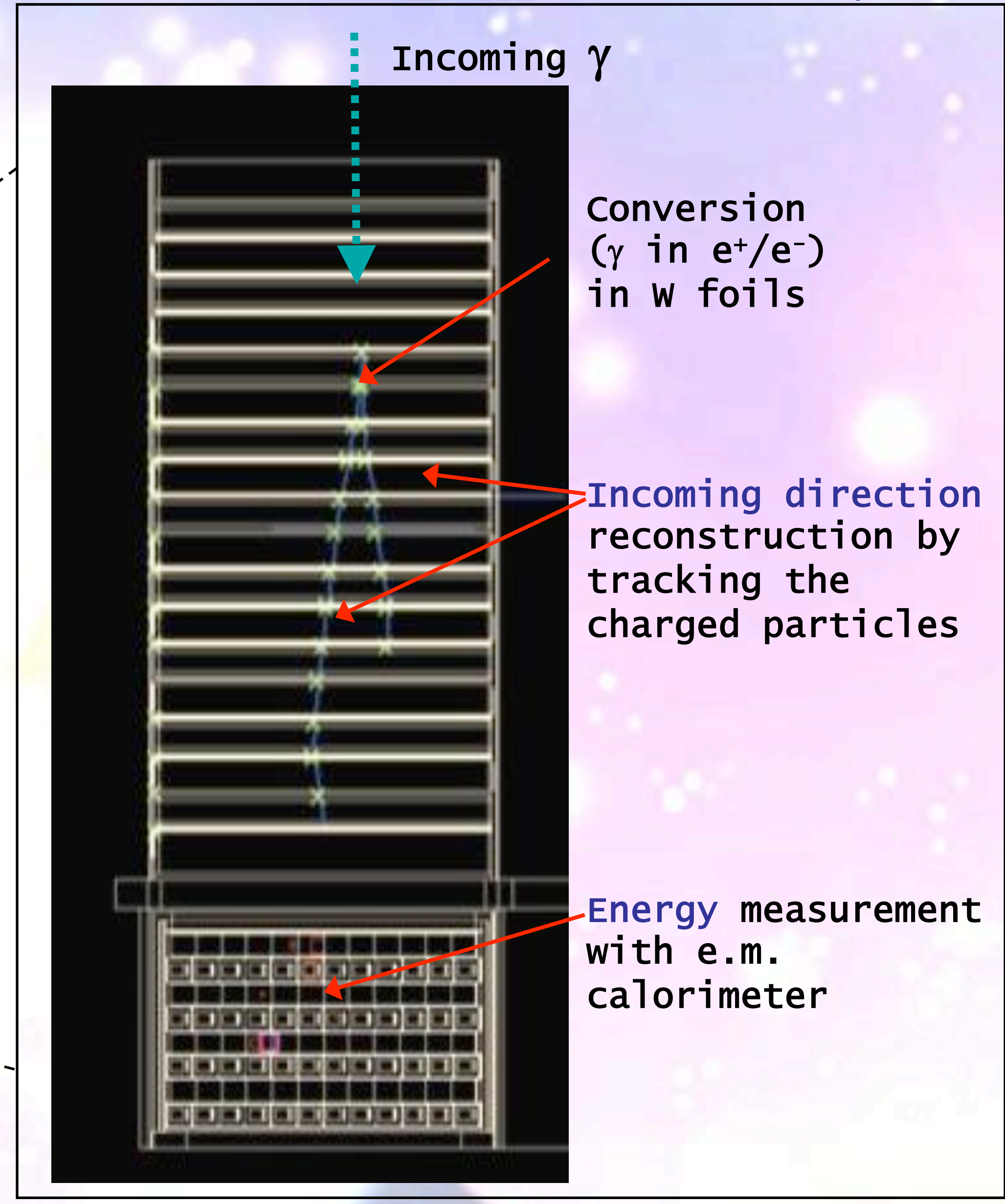
http://people.roma2.infn.it/~aldo/GLASTpaperModel.pdf

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

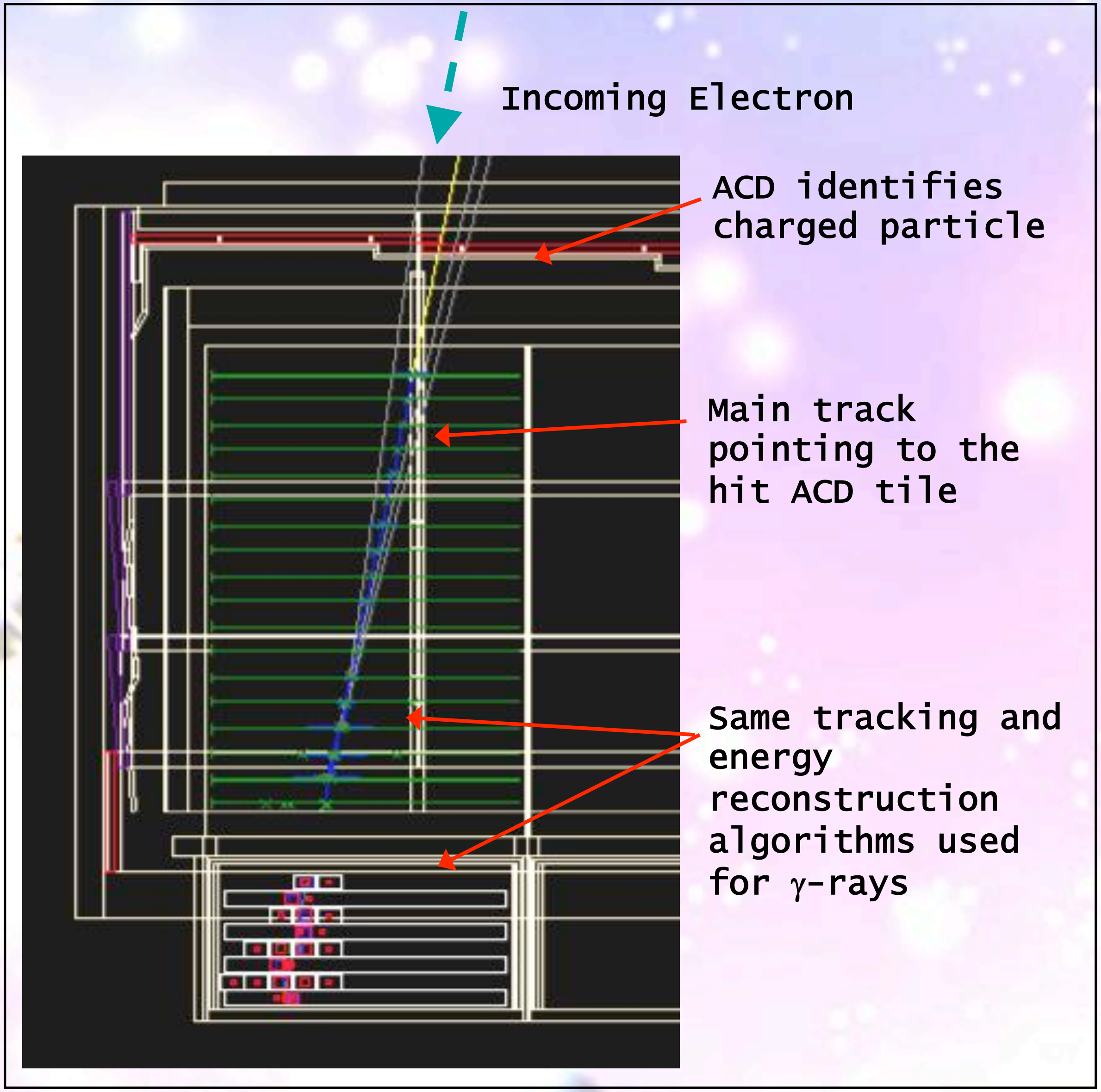
How Fermi LAT detects electrons

Trigger and downlink

- LAT triggers on (almost) every particle that crosses the LAT
  - ~ 2.2 kHz trigger rate
- On board processing removes many charged particles events
  - But keeps events with more that 20 GeV of deposited energy in the CAL
  - ~ 400 Hz downlink rate
- Only ~1 Hz are good γ-rays

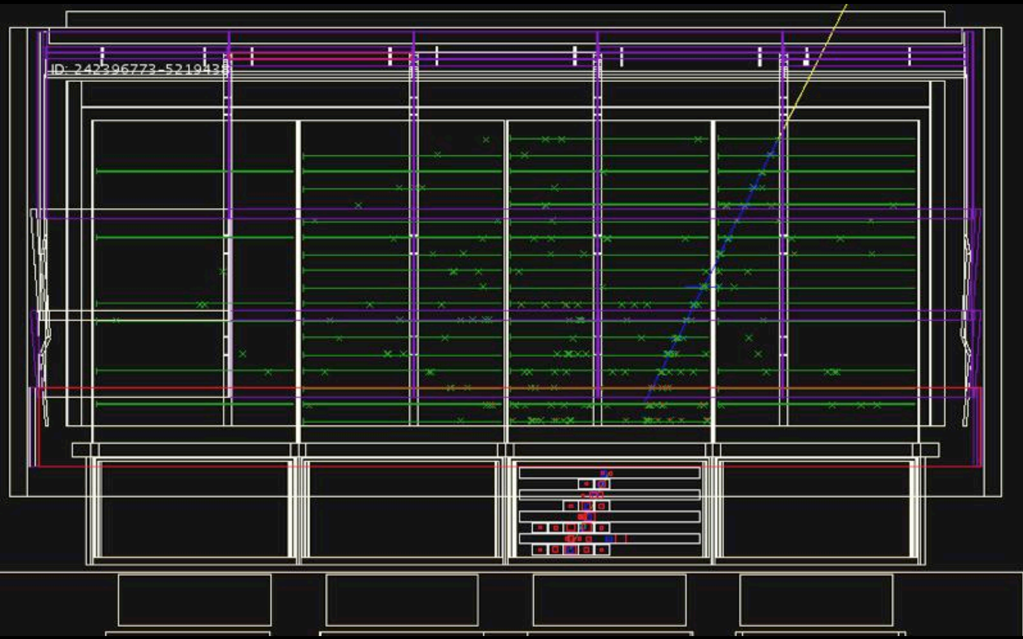
Electron identification

- The challenge is identifying the good electrons among the proton background
  - Rejection power of 10^3 – 10^4 required
  - Can not separate electrons from positrons



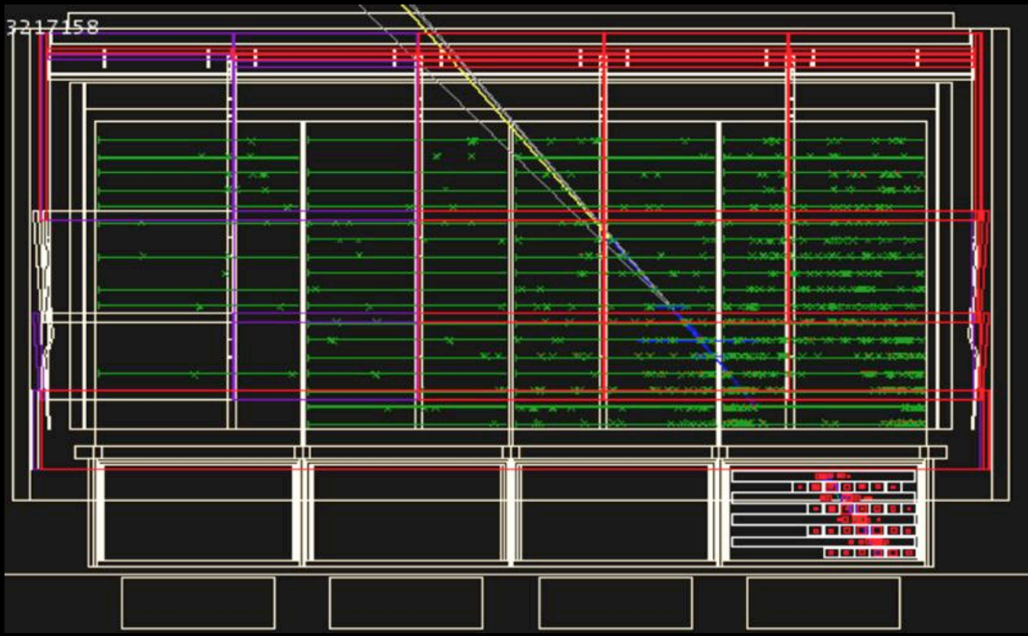
Event topology

A candidate electron
(recon energy 844 GeV)



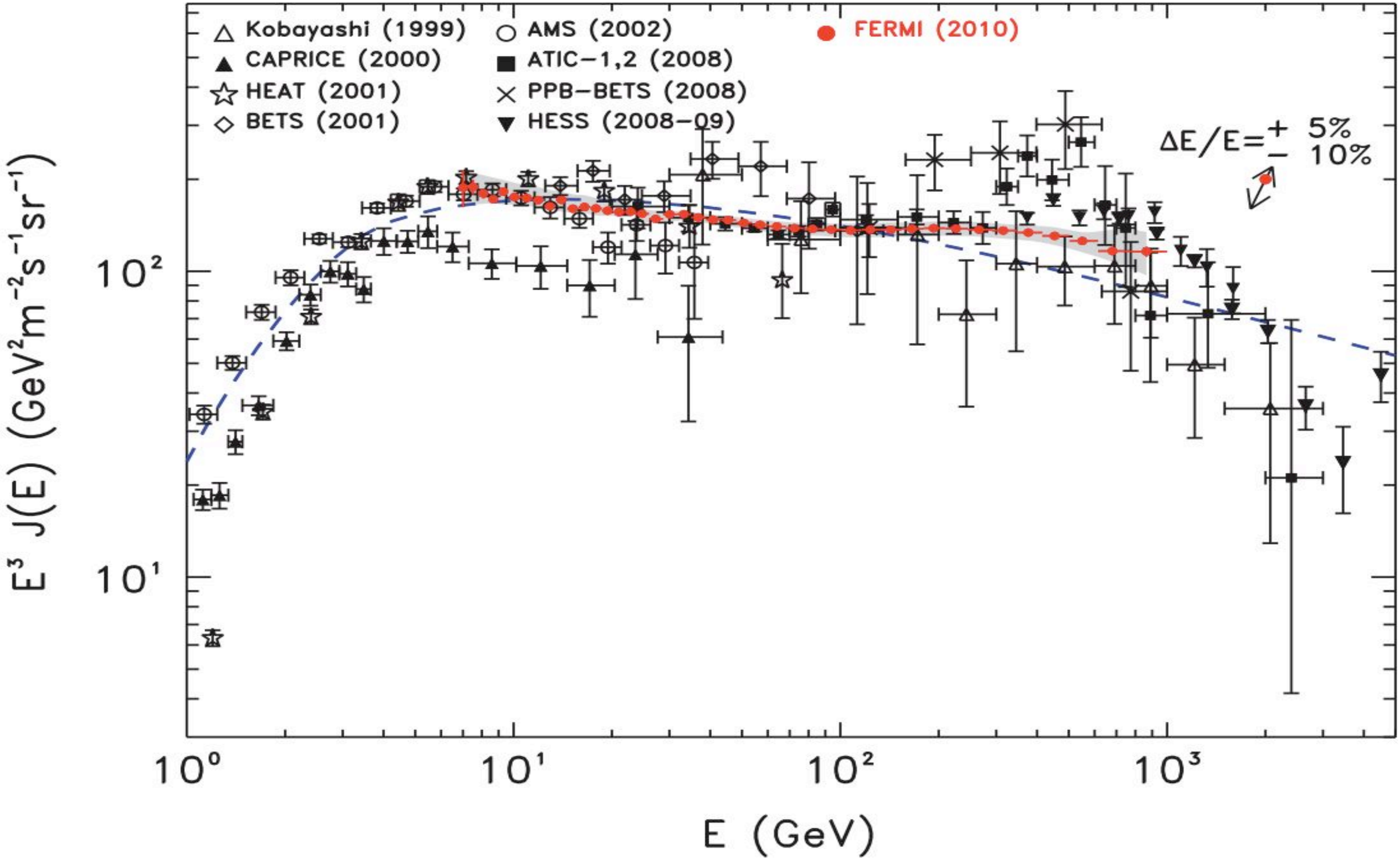
- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

A candidate hadron
(raw energy > 800 GeV)



- TKR: small number of extra clusters around main track
- CAL: large and asymmetric shower profile
- ACD: large energy deposit per tile

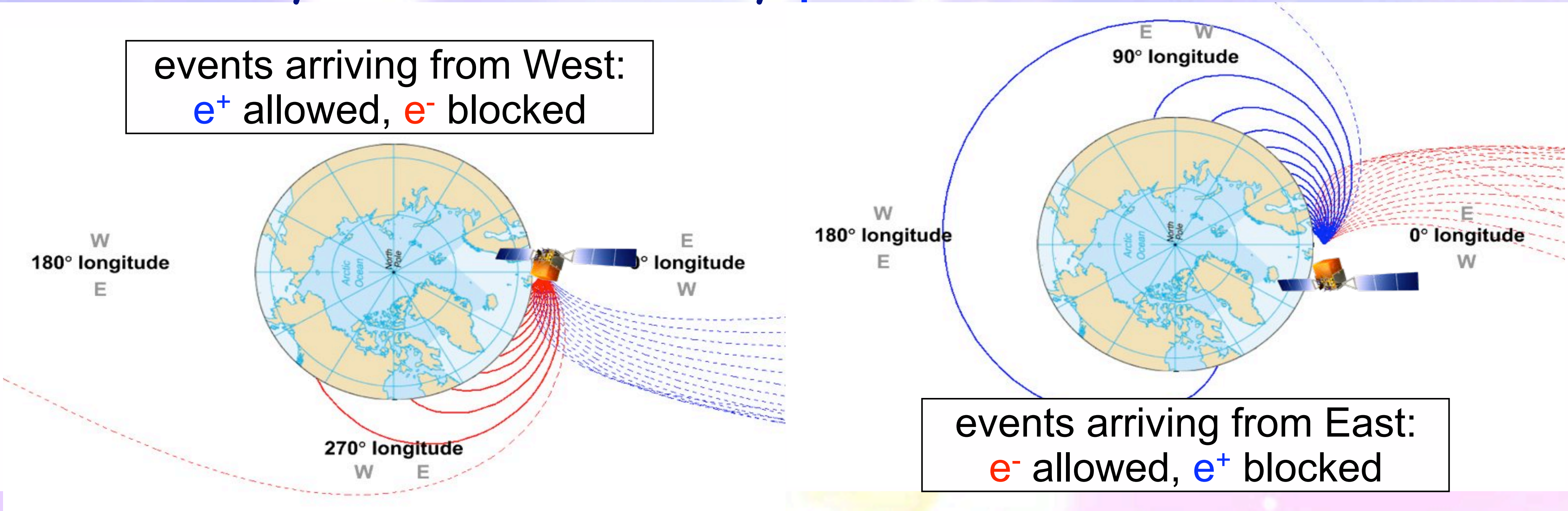
Fermi Electron + Positron spectrum



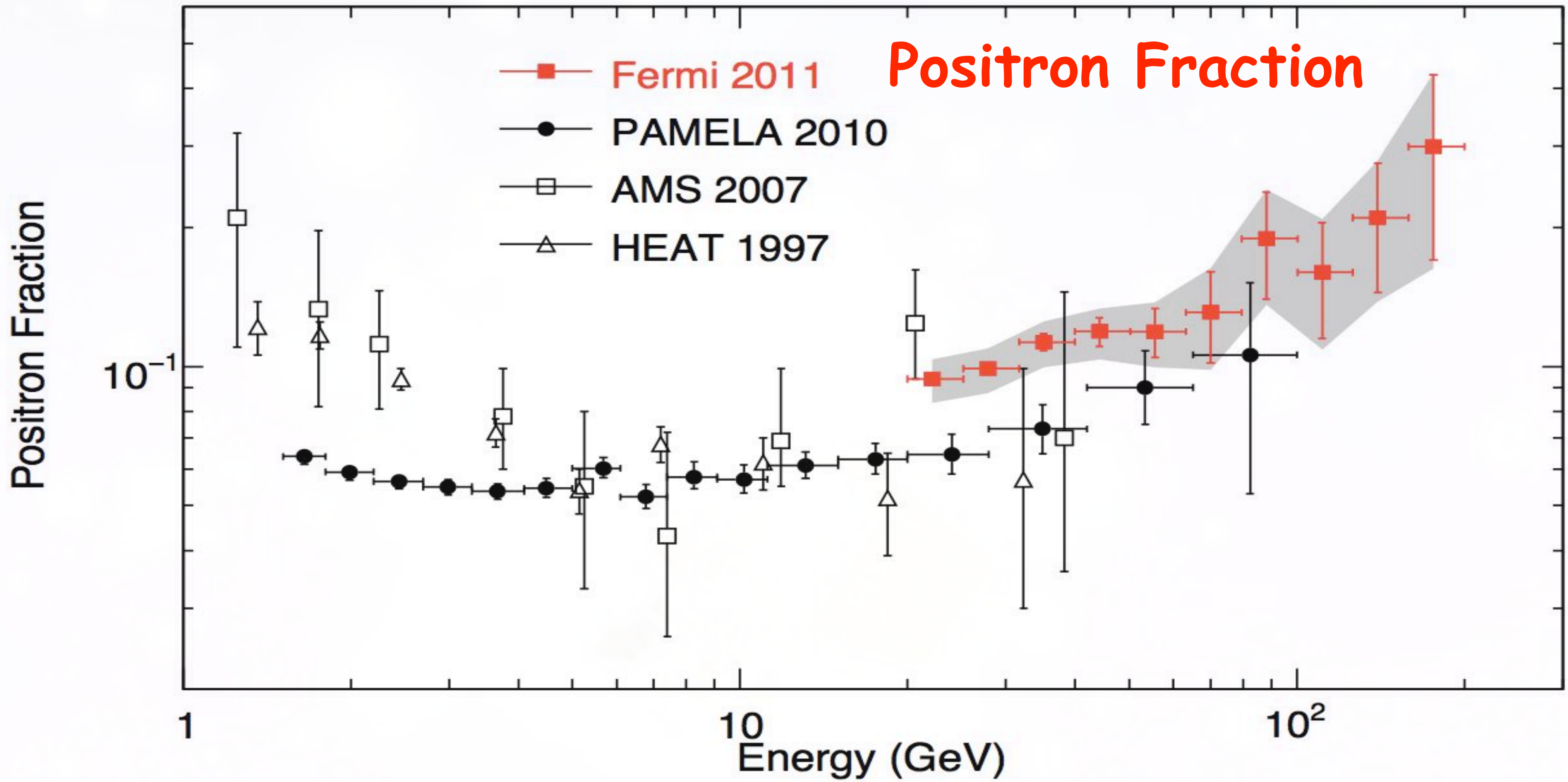
Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

Geomagnetic field + Earth shadow = directions from which only electrons or only positrons are allowed



- For some directions, e^- or e^+ forbidden
- Pure e^+ region looking West and pure e^- region looking East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Don Smart and Peggy Shea (numerically traces trajectory in geomagnetic field)
- Using International Geomagnetic Reference Field for the 2010 epoch



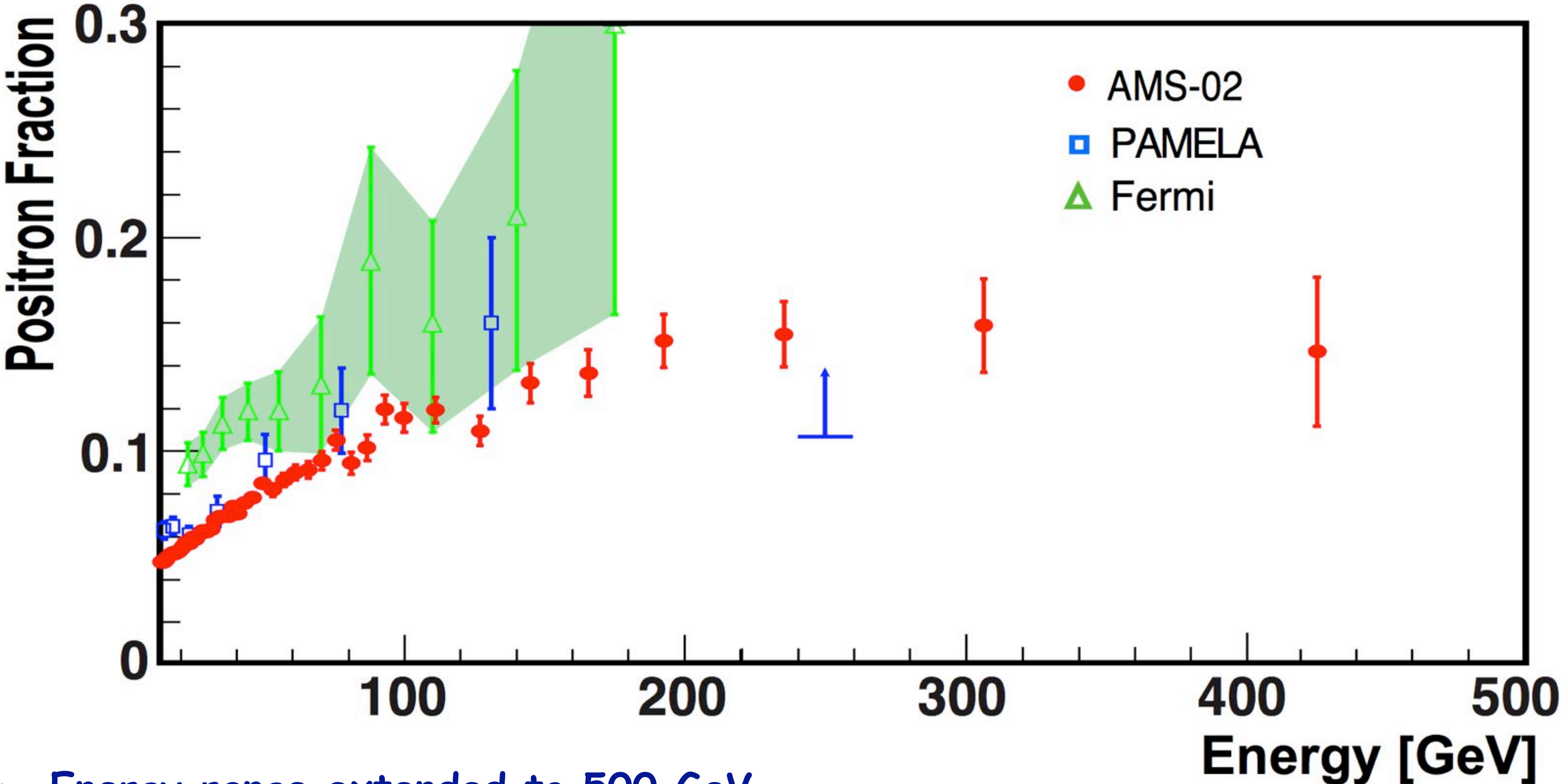
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth's magnetic field as a charge discriminator

- **Two independent methods of background subtraction produce consistent results**
- **The observed positron fraction is consistent with the one measured by PAMELA**

Differences between different experiments below few GeV's probably due to charge-sign-dependent modulation but still under study

Fermi Coll., PRL, 108 (2012) 011103 arXiv:1109.0521

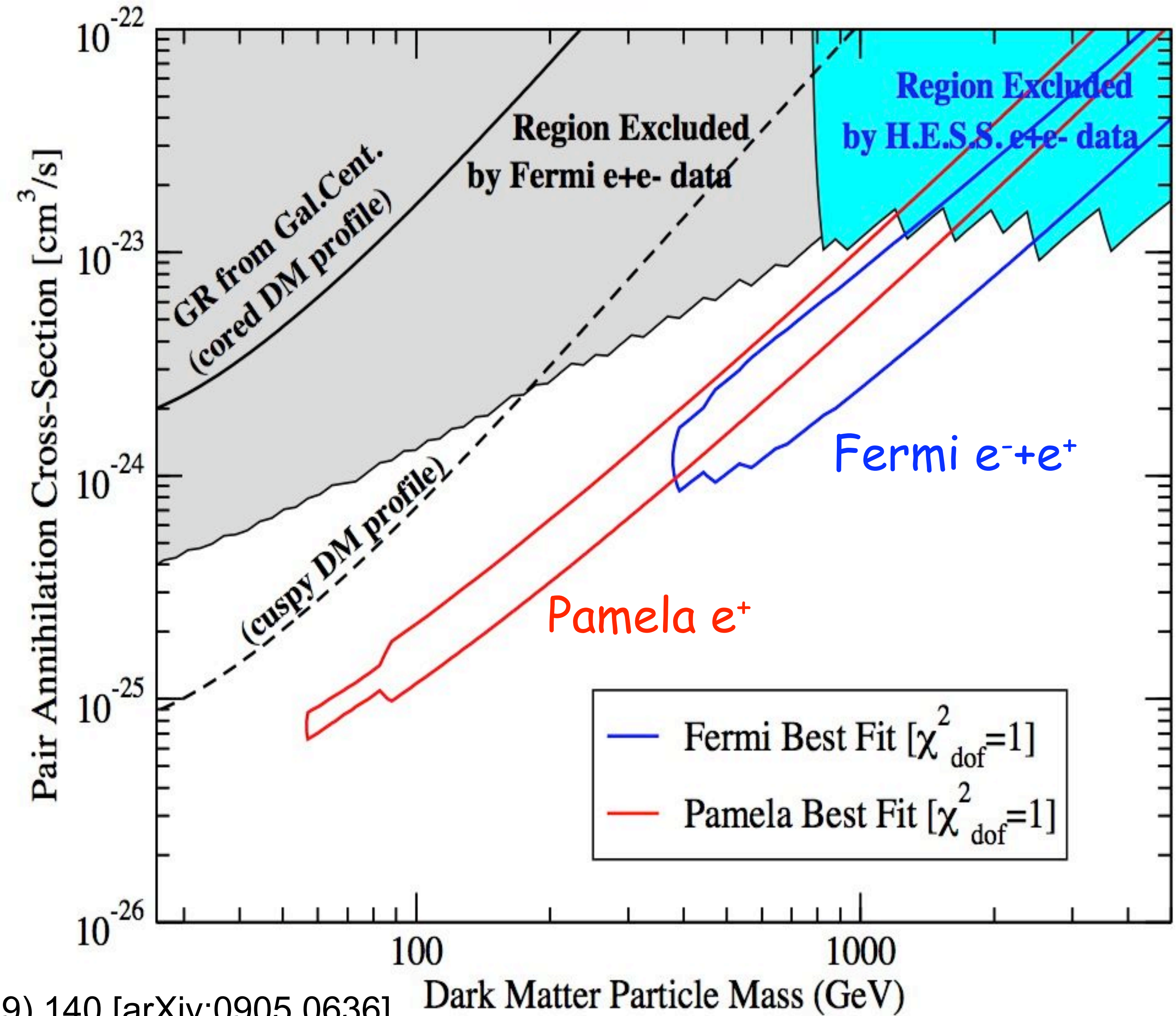
Positron Fraction @ ICHEP14



- Energy range extended to 500 GeV
- • Improved accuracy compared with previous AMS measurement
- • Positron fraction becomes energy independent above 206 GeV

Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+ τ- Here too antiprotons are not produced in dark matter pair annihilation.



Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

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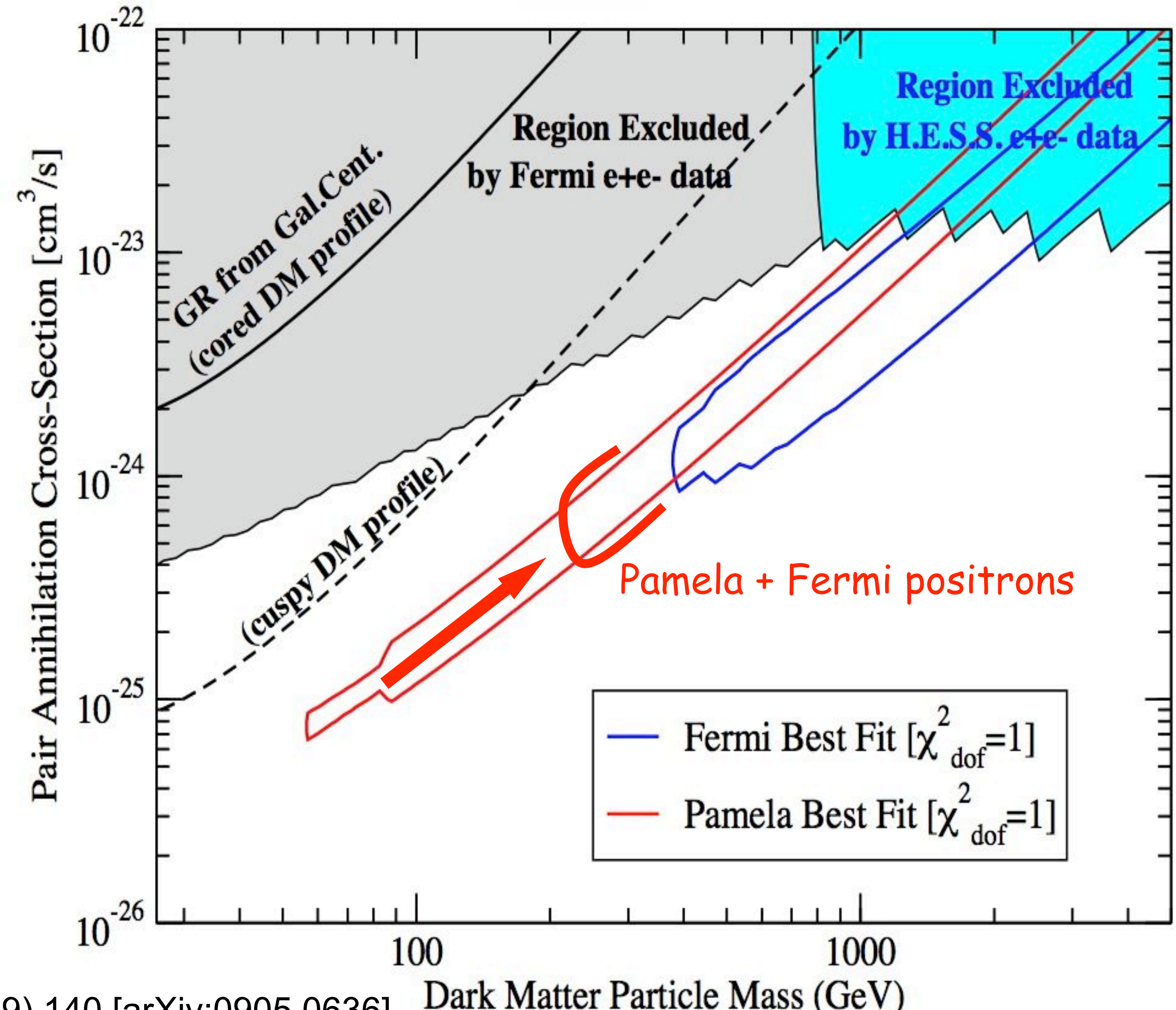
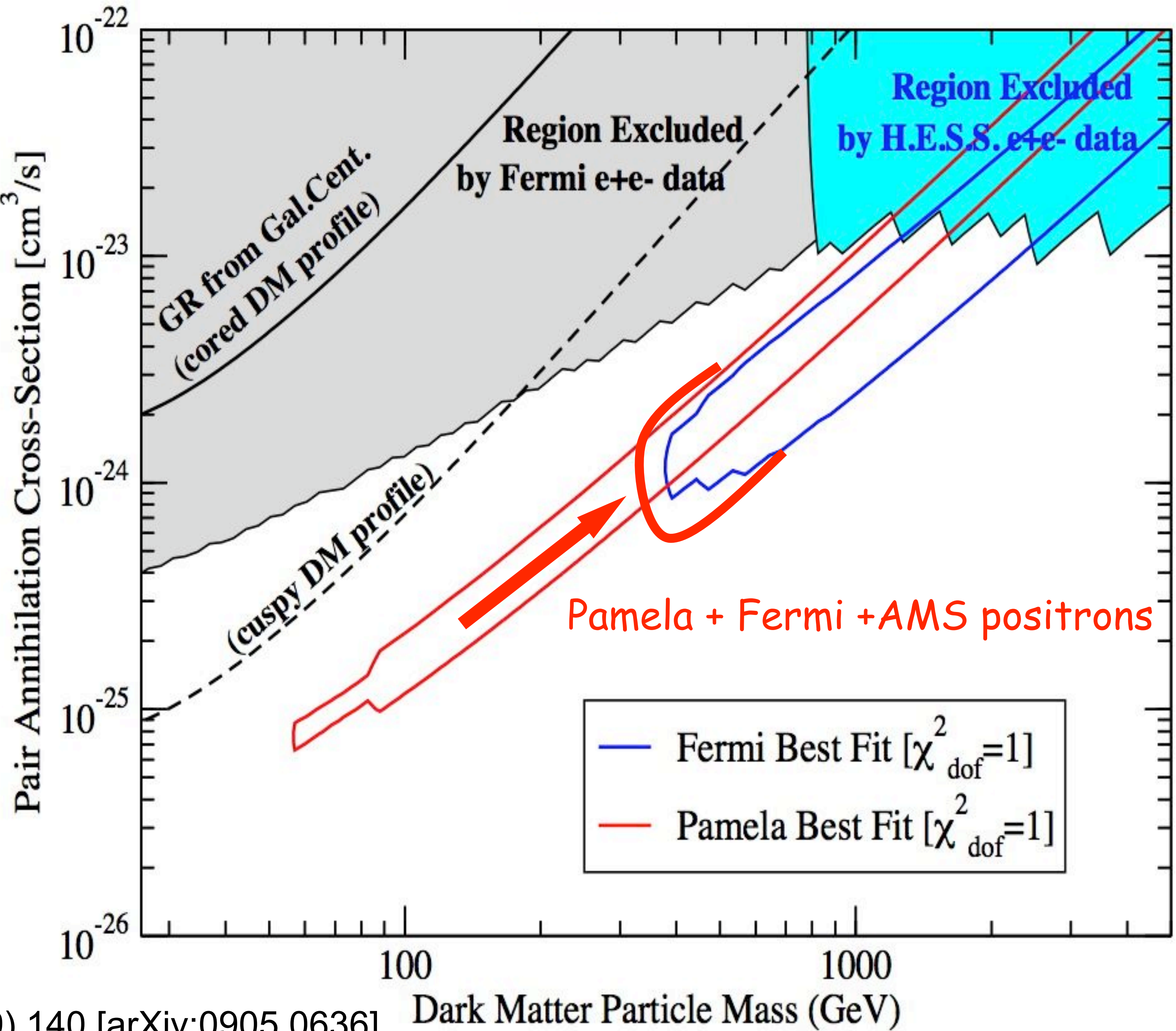


update of
Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into $\mu^+ \mu^-$ and 1/3 into $\tau^+ \tau^-$ Here too antiprotons are not produced in dark matter pair annihilation.



update of Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Pulsars

1. On purely energetic grounds they work (relatively large efficiency)

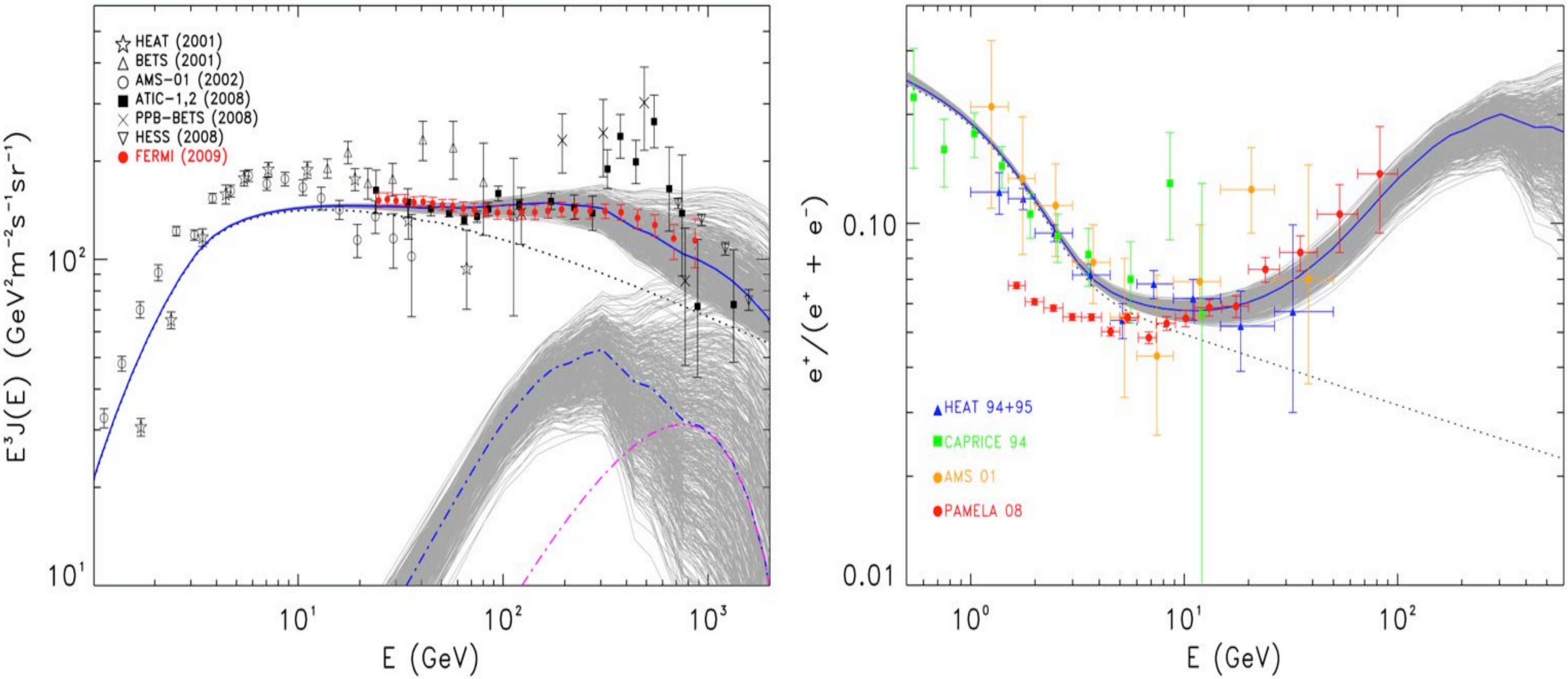
2. On the basis of the spectrum, it is not clear
   1. The spectra of PWN show relatively flat spectra of pairs at Low energies but we do not understand what it is
   2. The general spectra (acceleration at the termination shock) are too steep

The biggest problem is that of escape of particles from the pulsar
   1. Even if acceleration works, pairs have to survive losses
   2. And in order to escape they have to cross other two shocks

New Fermi data on pulsars will help to constrain the pulsar models

What if we randomly vary the pulsar parameters relevant for e+e- production?

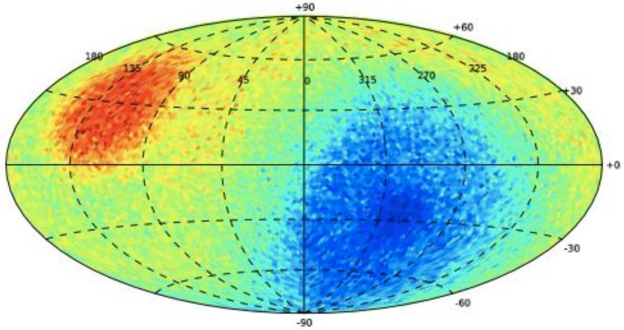
(injection spectrum, e+e- production efficiency, PWN "trapping" time)



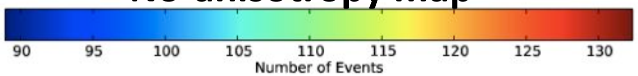
Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

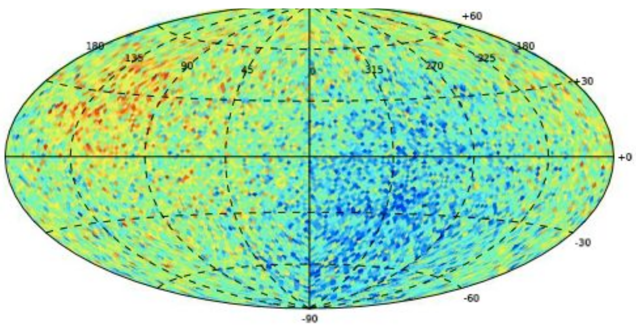
D.Grasso et al. Astropart. Phys. 32 (2009), pp.140 [arXiv:0905.0636]

Cosmic Ray Electrons Anisotropy

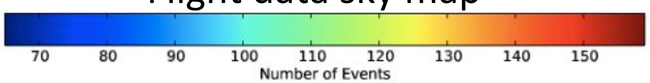


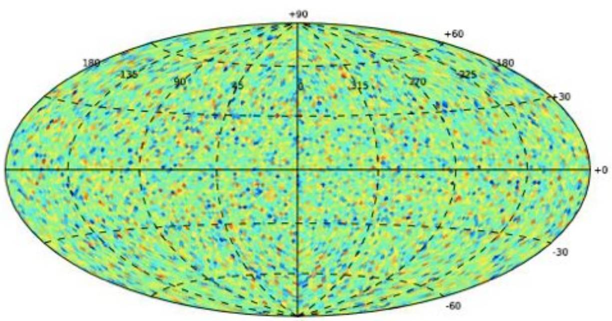
No-anisotropy map



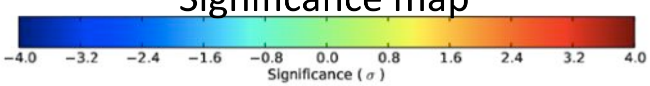


Flight data sky map



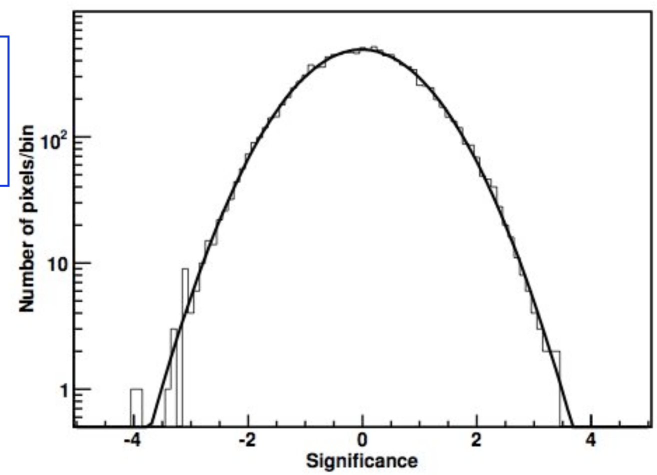


Significance map



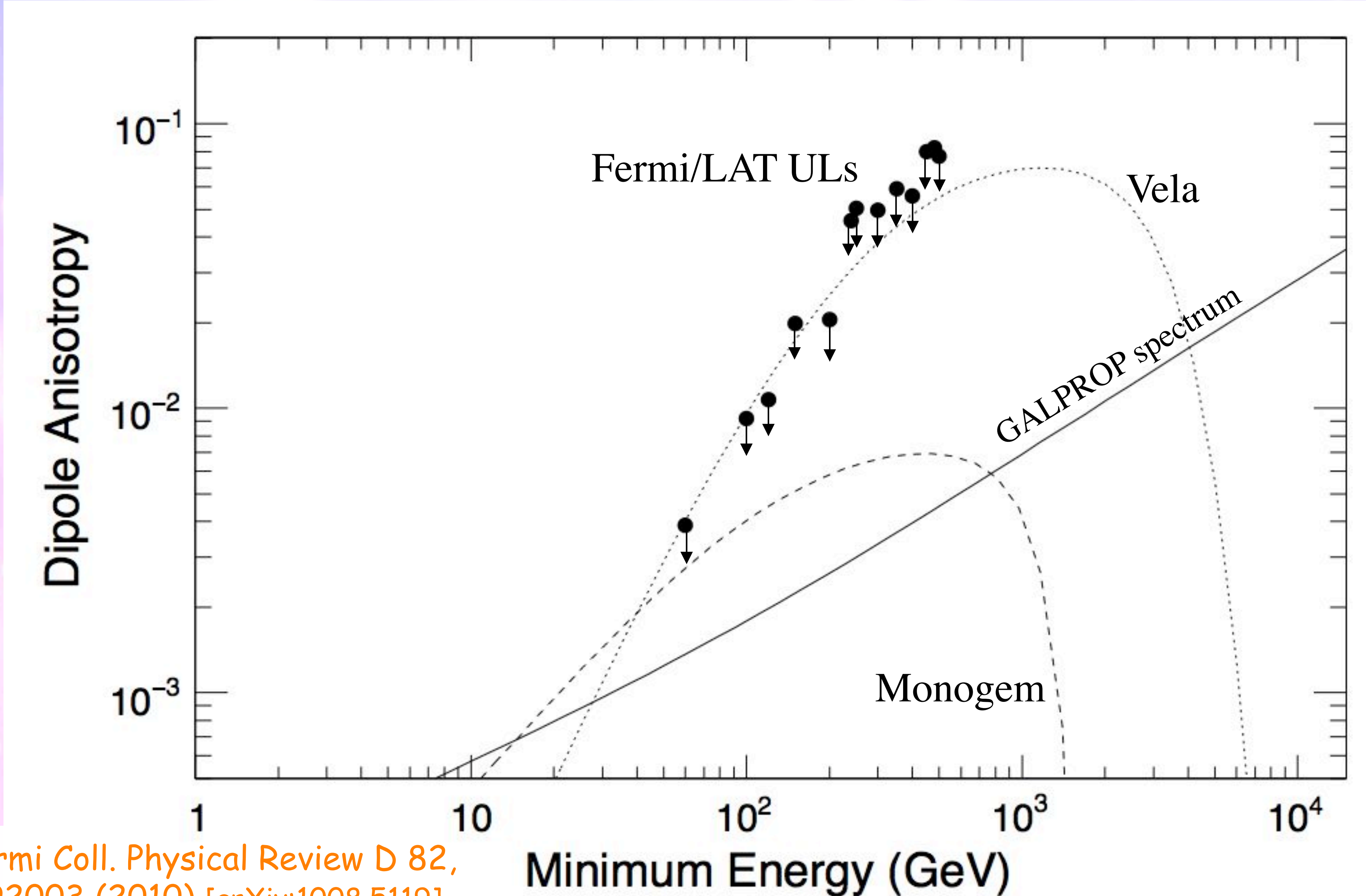
<u>the levels of anisotropy expected for Geminga-like and Monogem-like sources</u> (i.e. sources with similar distances and ages) <u>seem to be higher than the scale of anisotropies excluded by the results</u>
However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters

Distribution of significance, fitted by a Gaussian →



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

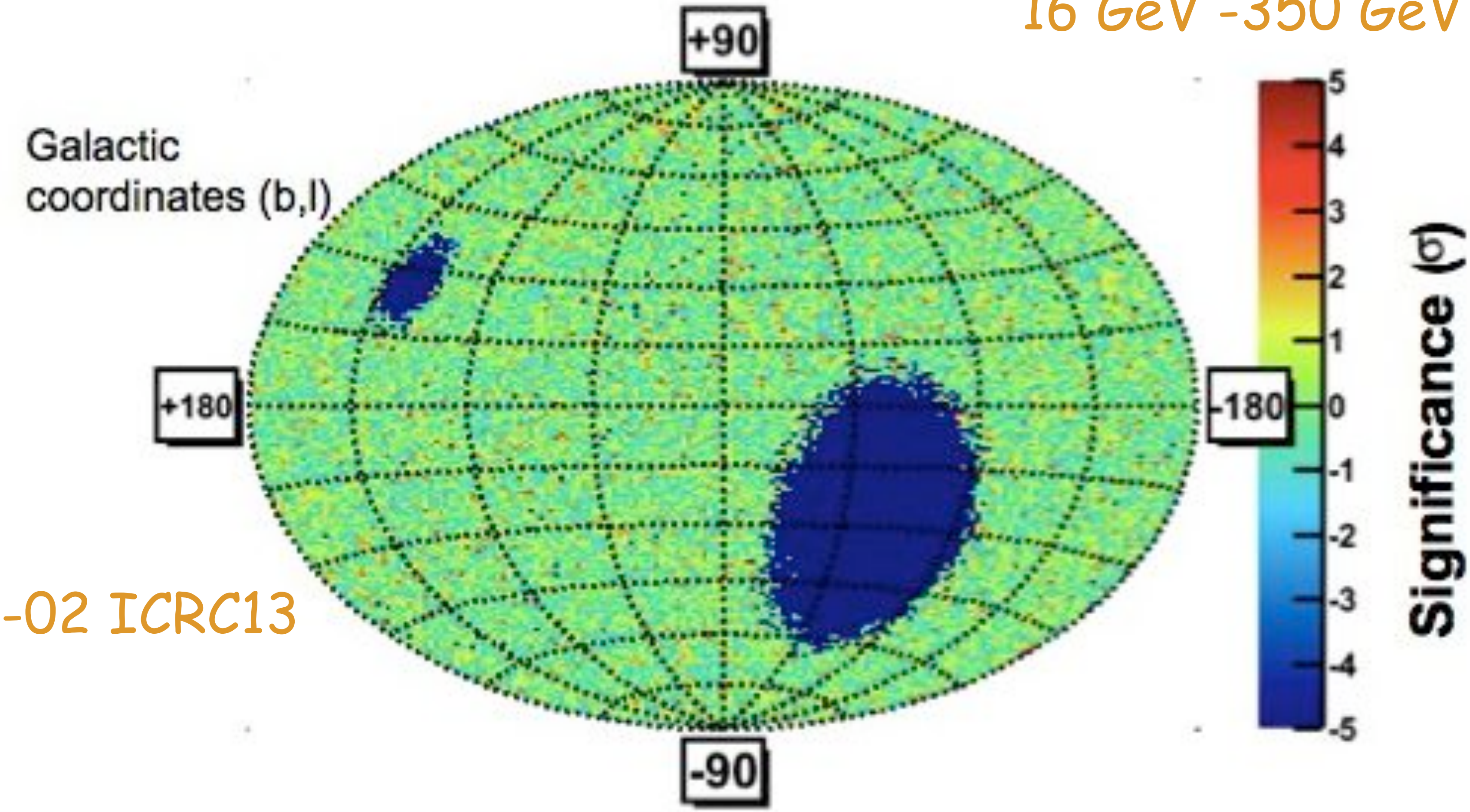
electron + positron expected anisotropy in the directions of Monogem and Vela



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

Dipole anisotropy in the positron ratio

16 GeV -350 GeV

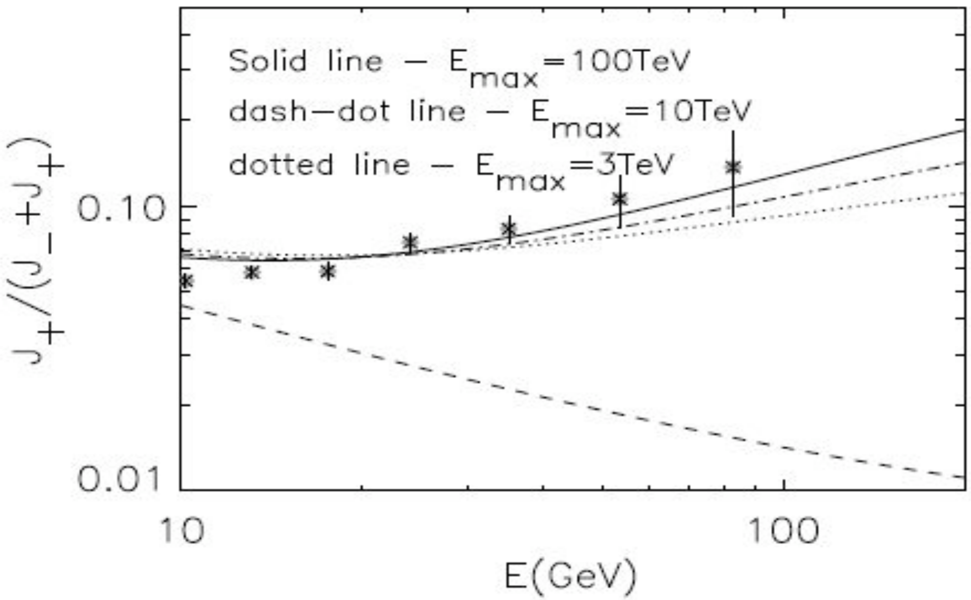


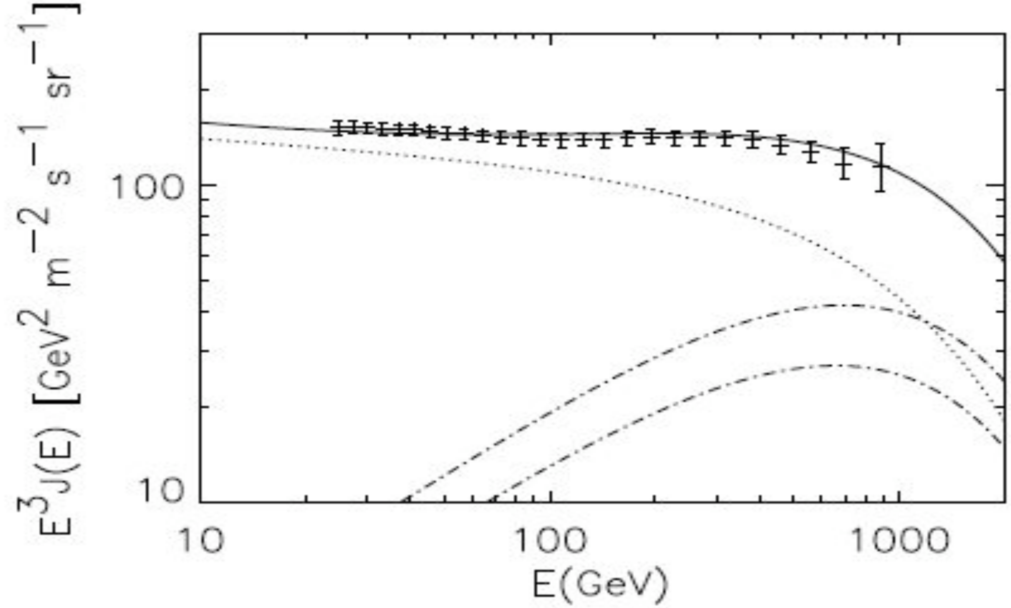
AMS-02 ICRC13

The fluctuations of the positron ratio e^+/e^- are isotropic

$\delta \leq 0.030$ at the 95% confidence level

other Astrophysical solution



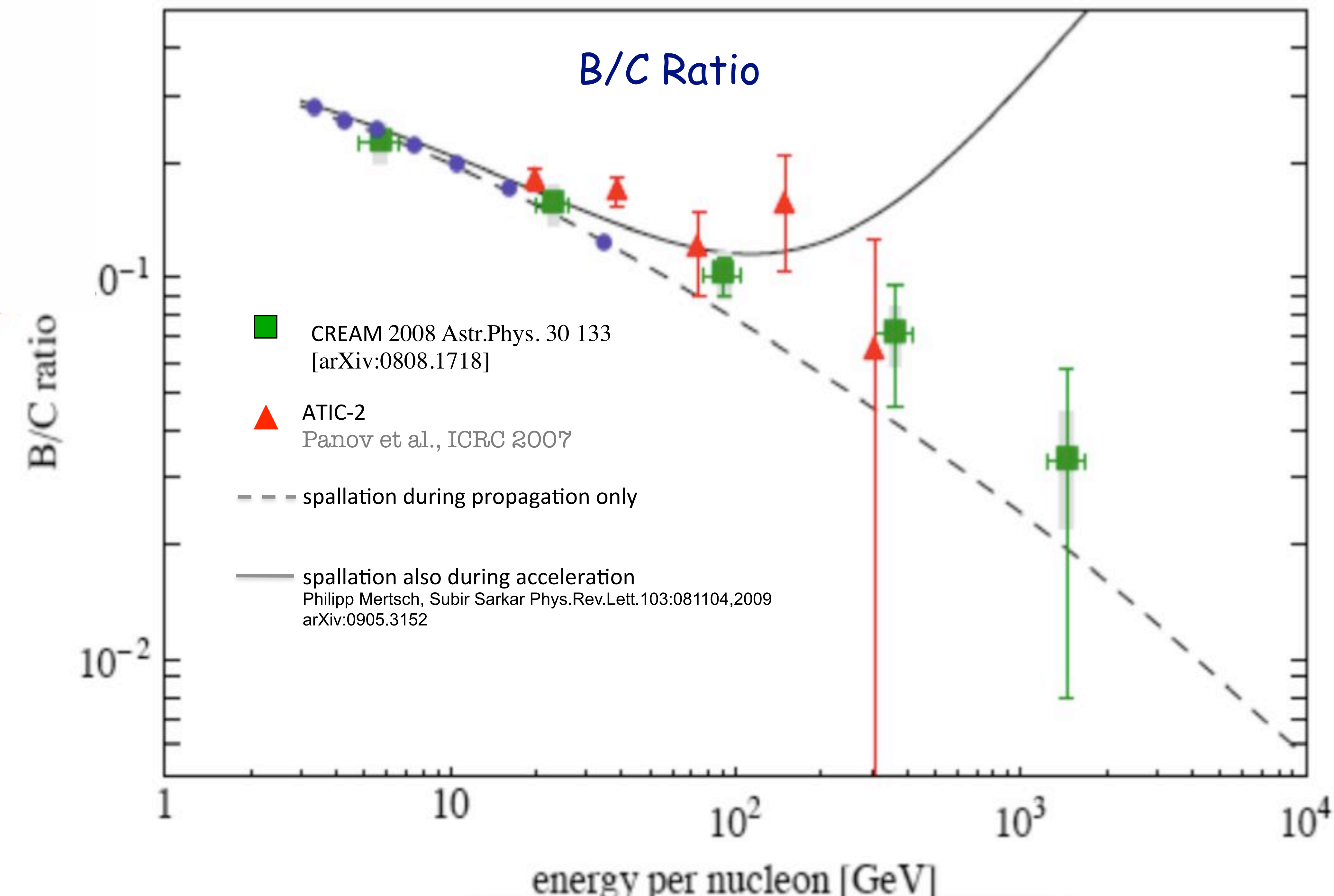


• Positrons created as secondary products of hadronic interactions inside the sources

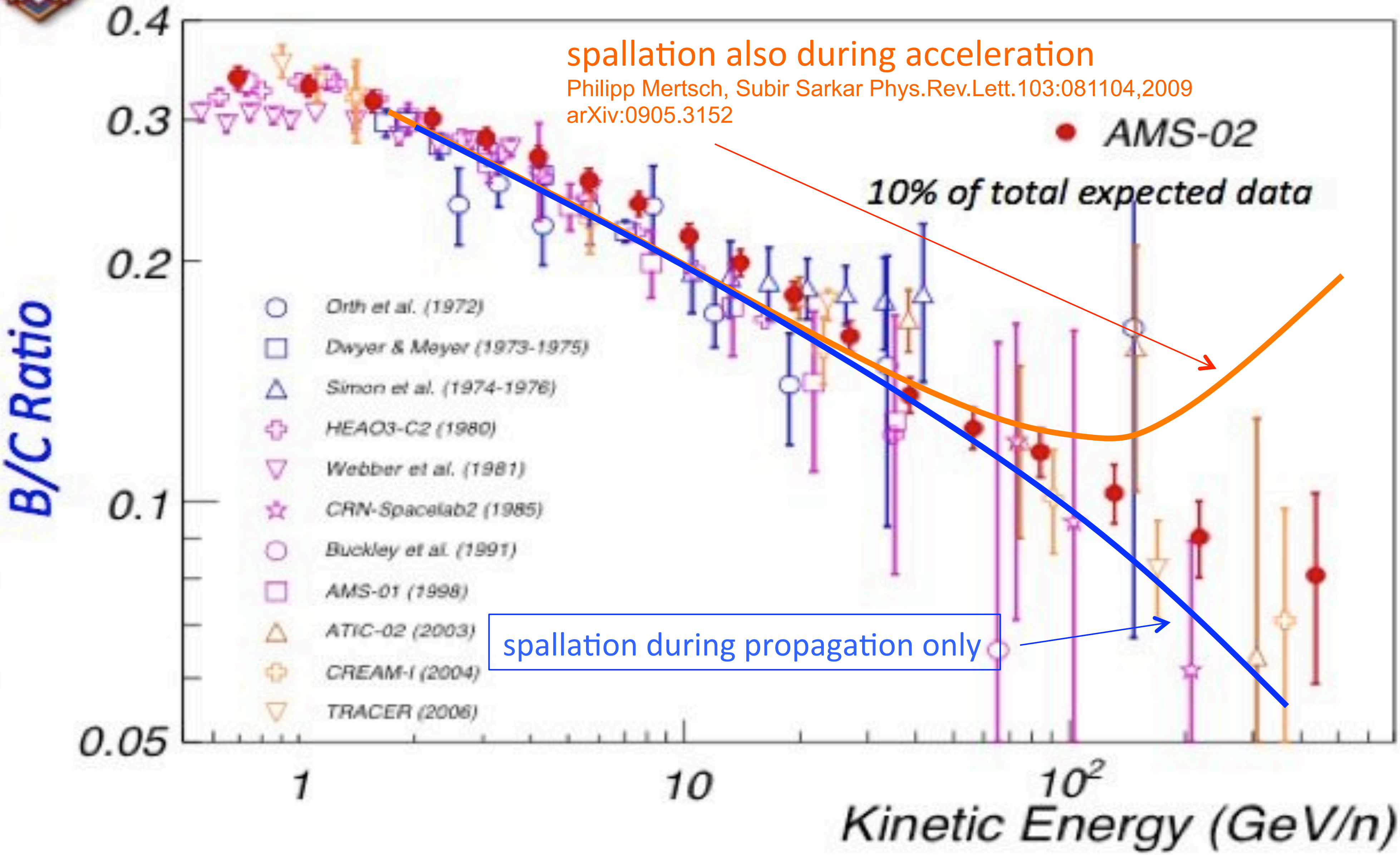
• Secondary production takes place in the same region where cosmic rays are being accelerated

-> Therefore secondary positron have a very flat spectrum, which is responsible, after propagation in the Galaxy, for the observed positron excess

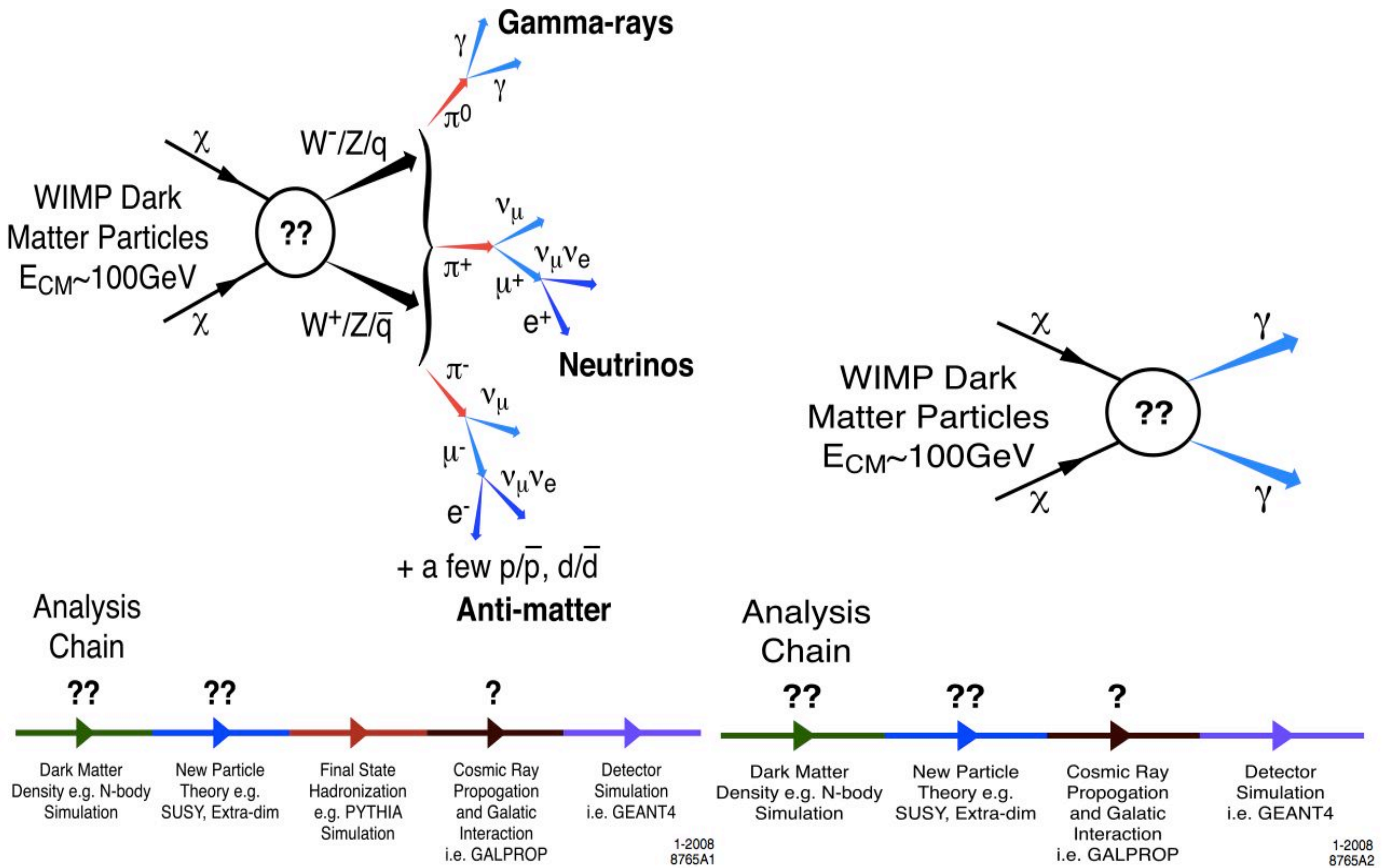
Blasi, arXiv:0903.2794


B/C Ratio
B/C ratio
10^{-1}
10^{-2}
1
10
10^2
10^3
10^4
energy per nucleon [GeV]
CREAM 2008 Astr.Phys. 30 133
[arXiv:0808.1718]
ATIC-2
Panov et al., ICRC 2007
spallation during propagation only
spallation also during acceleration
Philipp Mertsch, Subir Sarkar Phys.Rev.Lett.103:081104,2009
arXiv:0905.3152

Boron-to-Carbon ratio compared with previous data



Annihilation channels



Signal rate from Supersymmetry

gamma-ray flux from neutralino annihilation

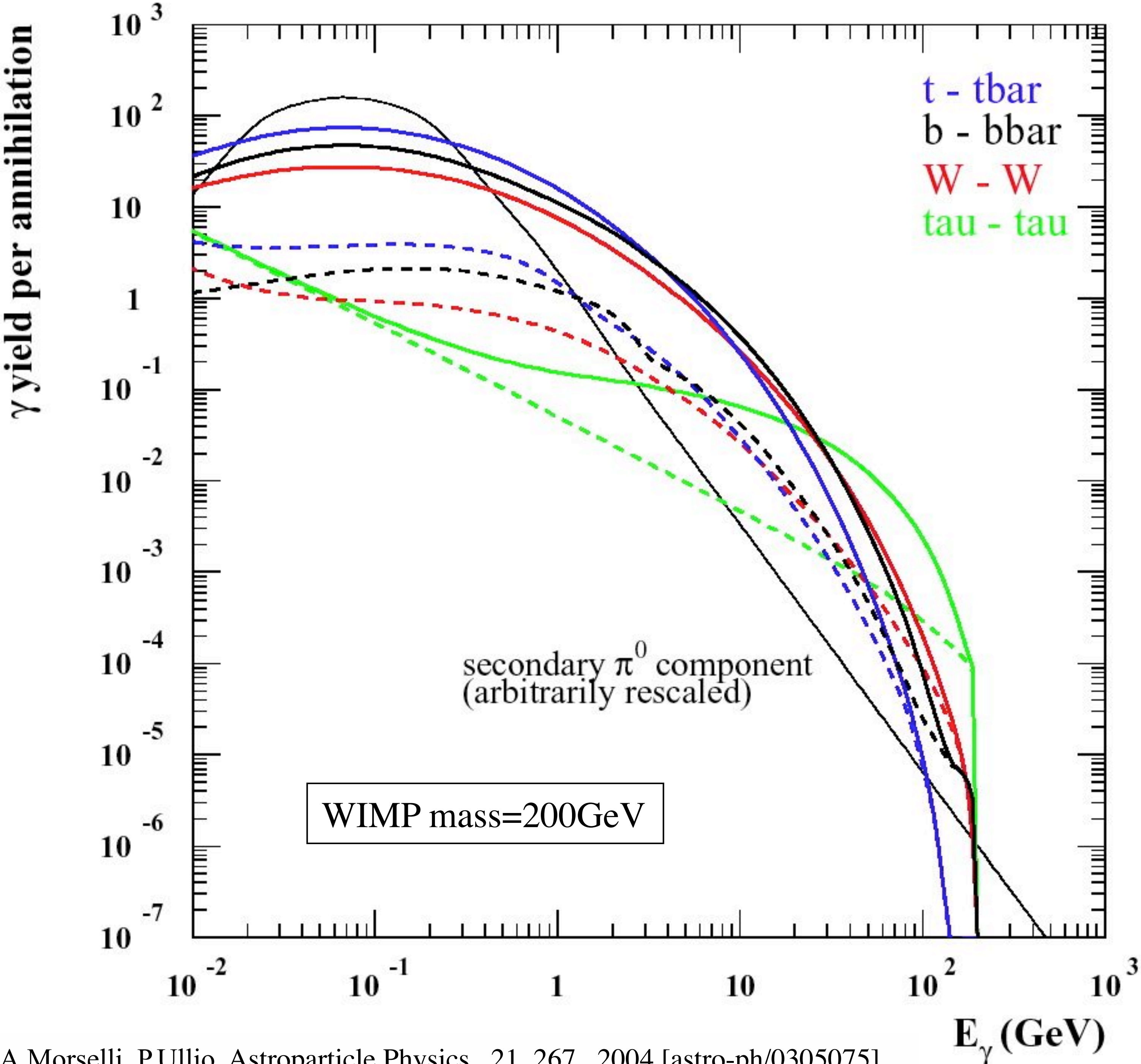
$$\phi(E,\Delta\Omega) \propto \left(\frac{\sigma v}{m_\chi^2}\right) \int_{l.o.s} \int_{\Delta\Omega} \rho^2(l)\, dl\, d\Omega)$$

governed by supersymmetric parameters

$J(\varphi)$:

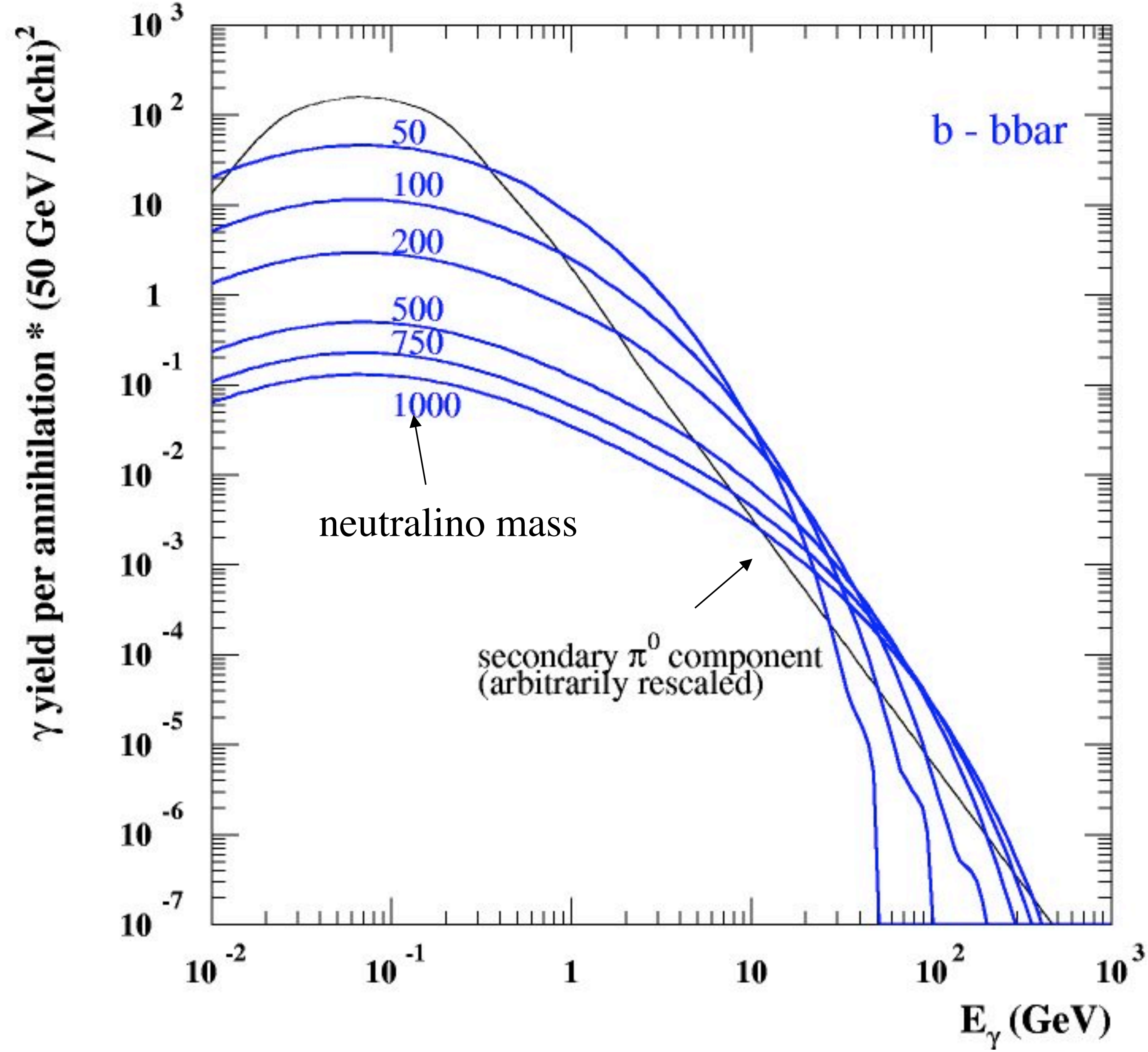
governed by halo distribution

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



The low energy window (<100 MeV) is important even for a 1 TeV DM Mass !!

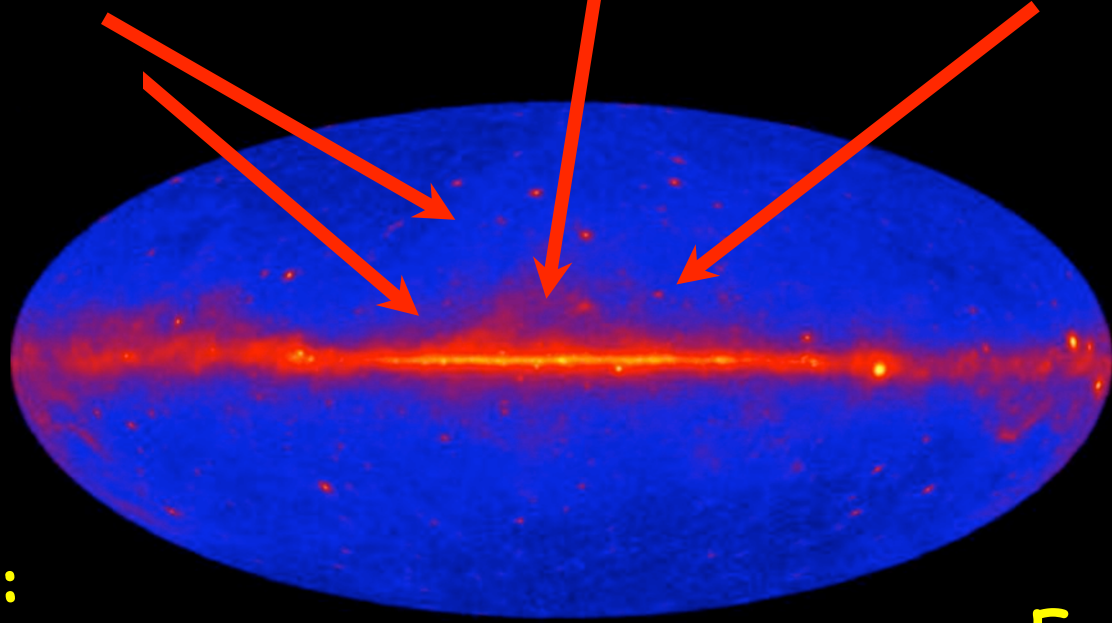
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Search Strategies

Satellites:
Low background and good source id, but low statistics

Galactic center:
Good statistics but source confusion/diffuse background

Milky Way halo:
Large statistics but diffuse background



And electrons!
and
Anisotropies

Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

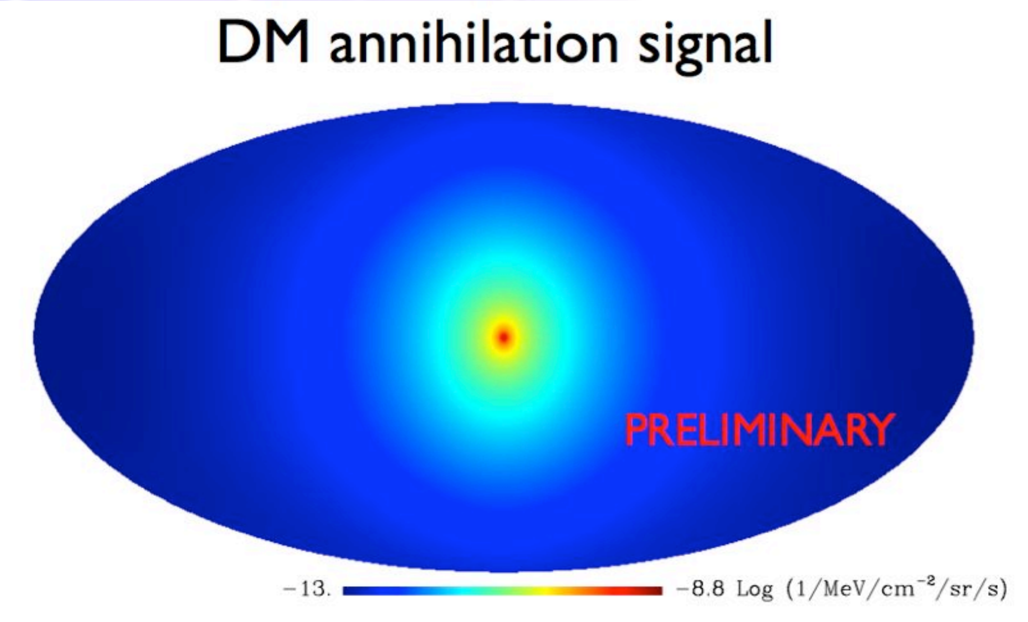
Galaxy clusters:
Low background but low statistics

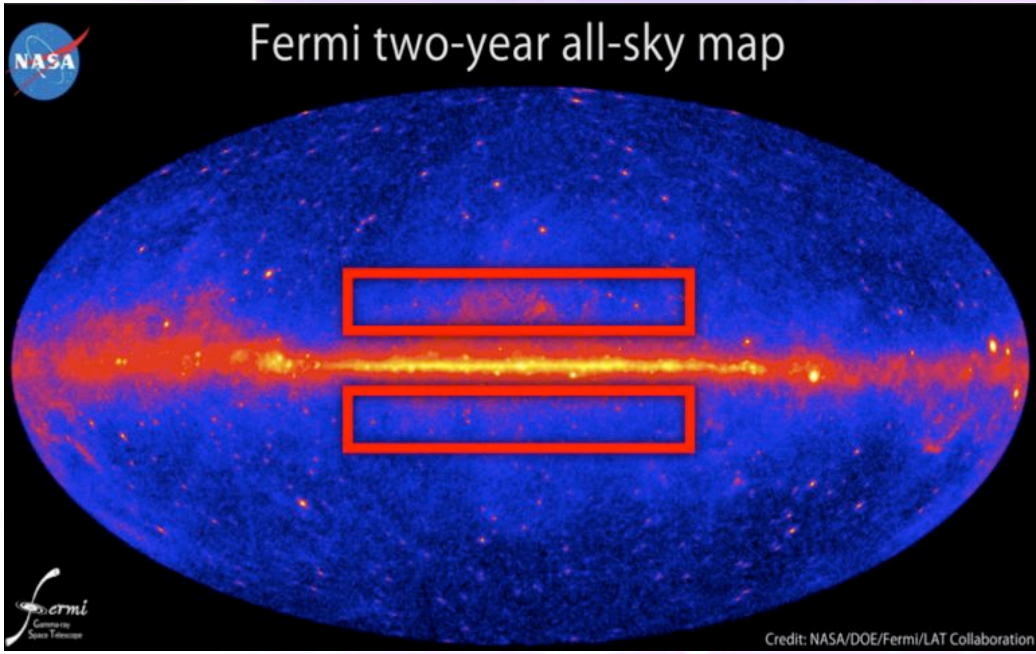
Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Constraints from the Milky Way halo

testing the LAT diffuse data for a contribution from a Milky Way DM annihilation/decay signal





2 years of data   1-100 GeV energy range

ROI: 5° <|b|<15° and |l|<80°, chosen to:

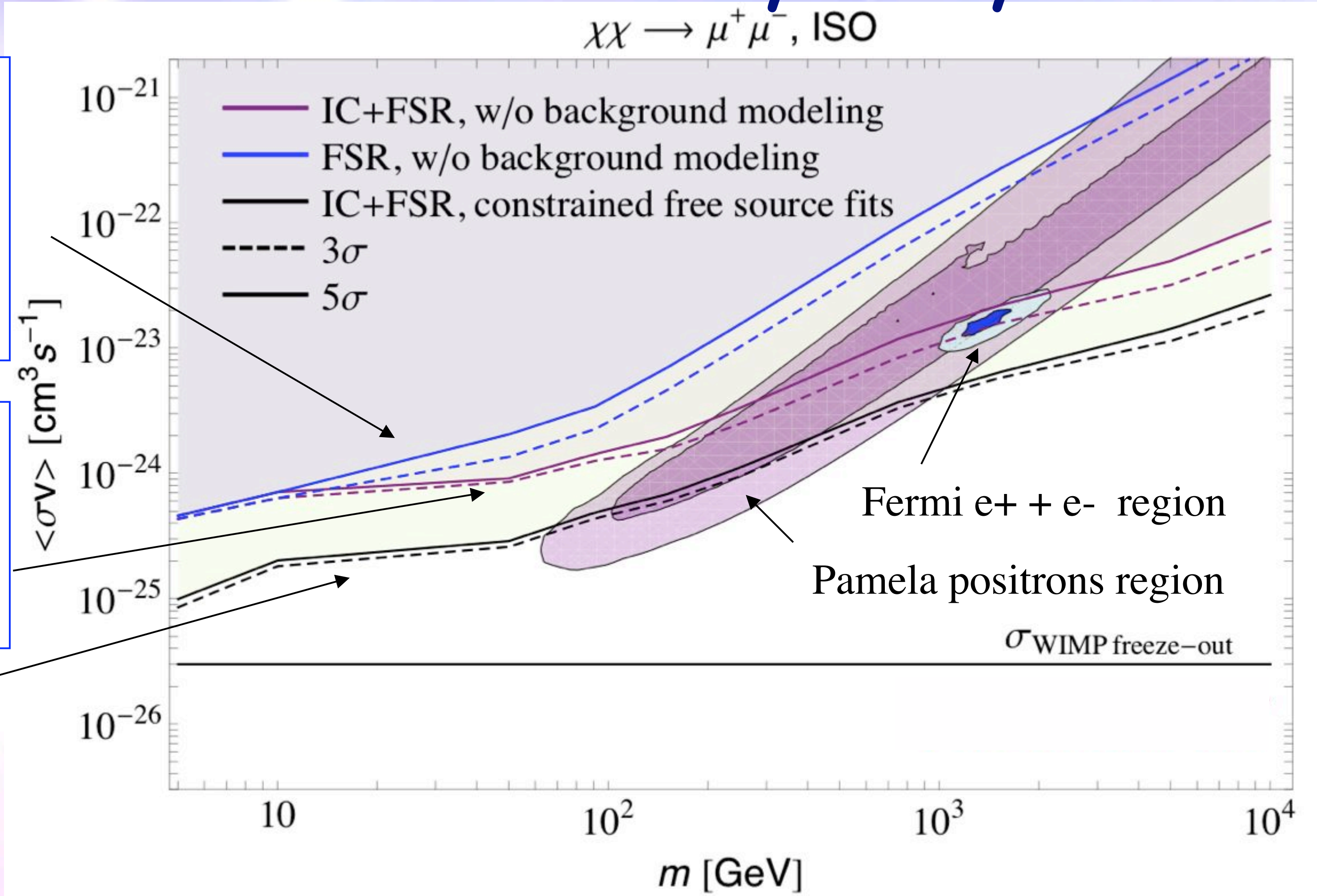
- minimize DM profile uncertainty (highest in the Galactic Center region)
- limit astrophysical uncertainty by masking out the Galactic plane and cutting-out high- latitude emission from the Fermi lobes and Loop I

Constraints from the Milky Way halo

only photons produced by muons (no electrons) to set "no-background limits"

"no-background limits" including FSR +IC from dark matter

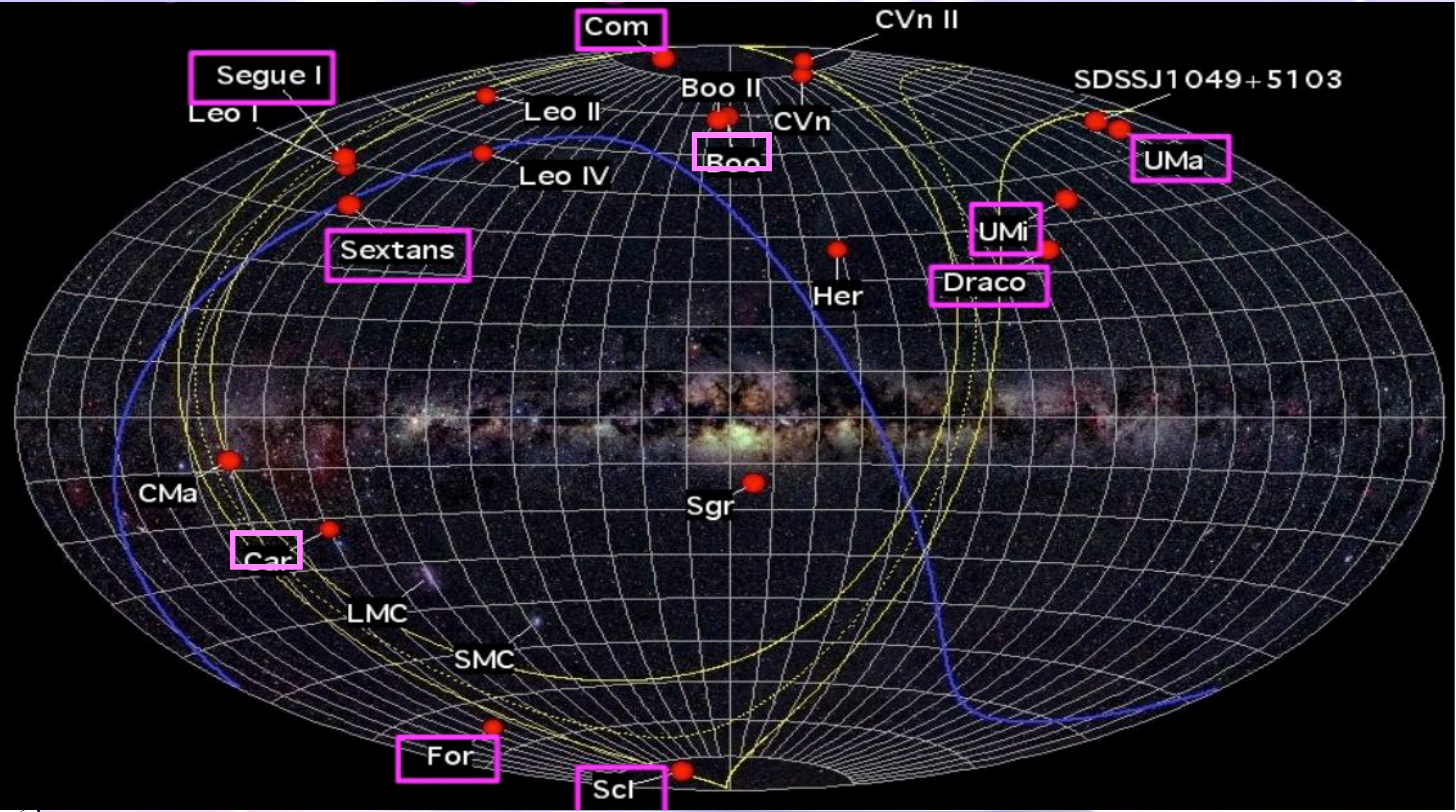
limits from profile likelihood and CR sources set to zero in the inner 3 kpc



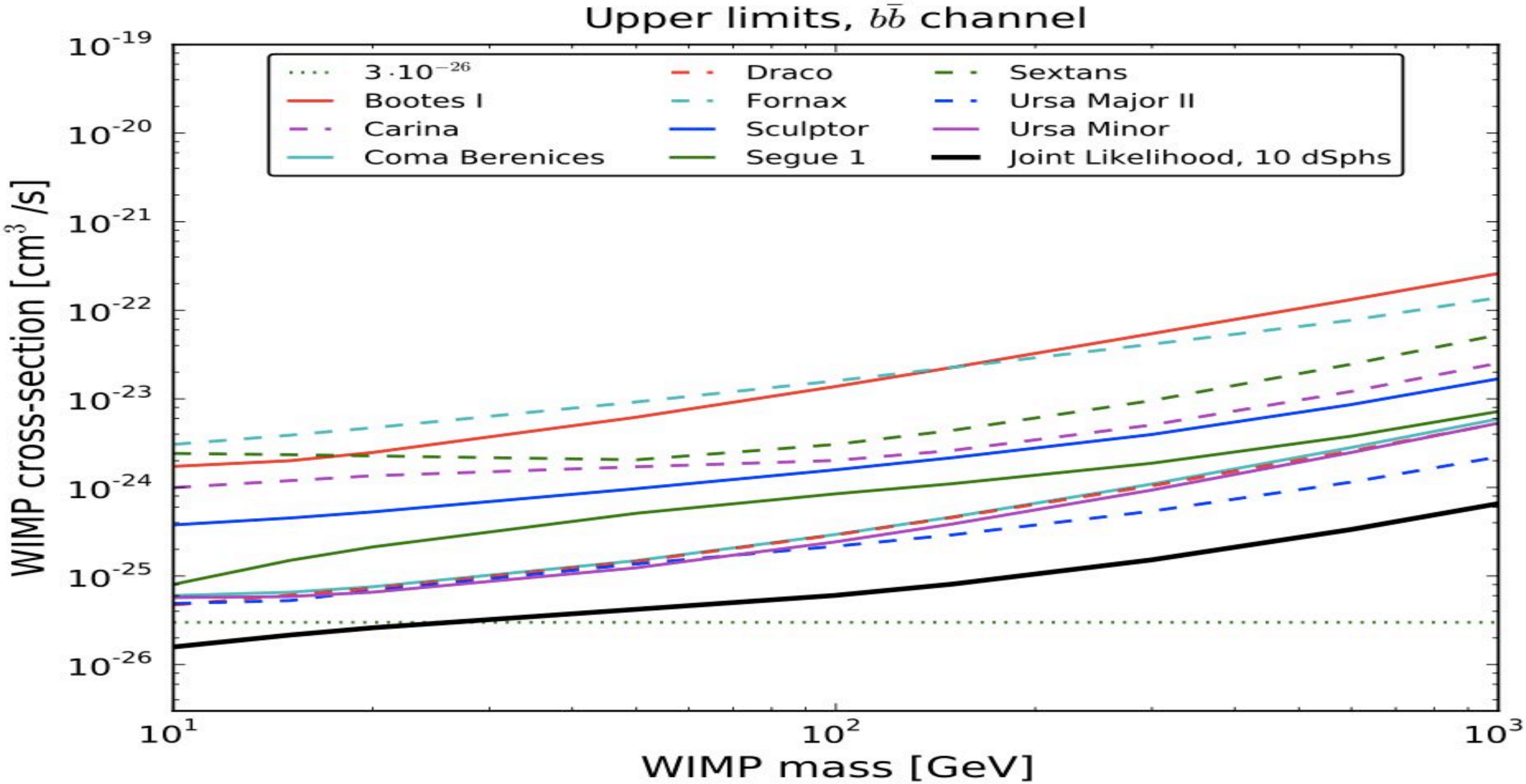
DM interpretation of PAMELA/Fermi CR anomalies disfavored

Fermi Coll.ApJ 761 (2012) 91 [arXiv:1205.6474]

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



Dwarf Spheroidal Galaxies combined analysis

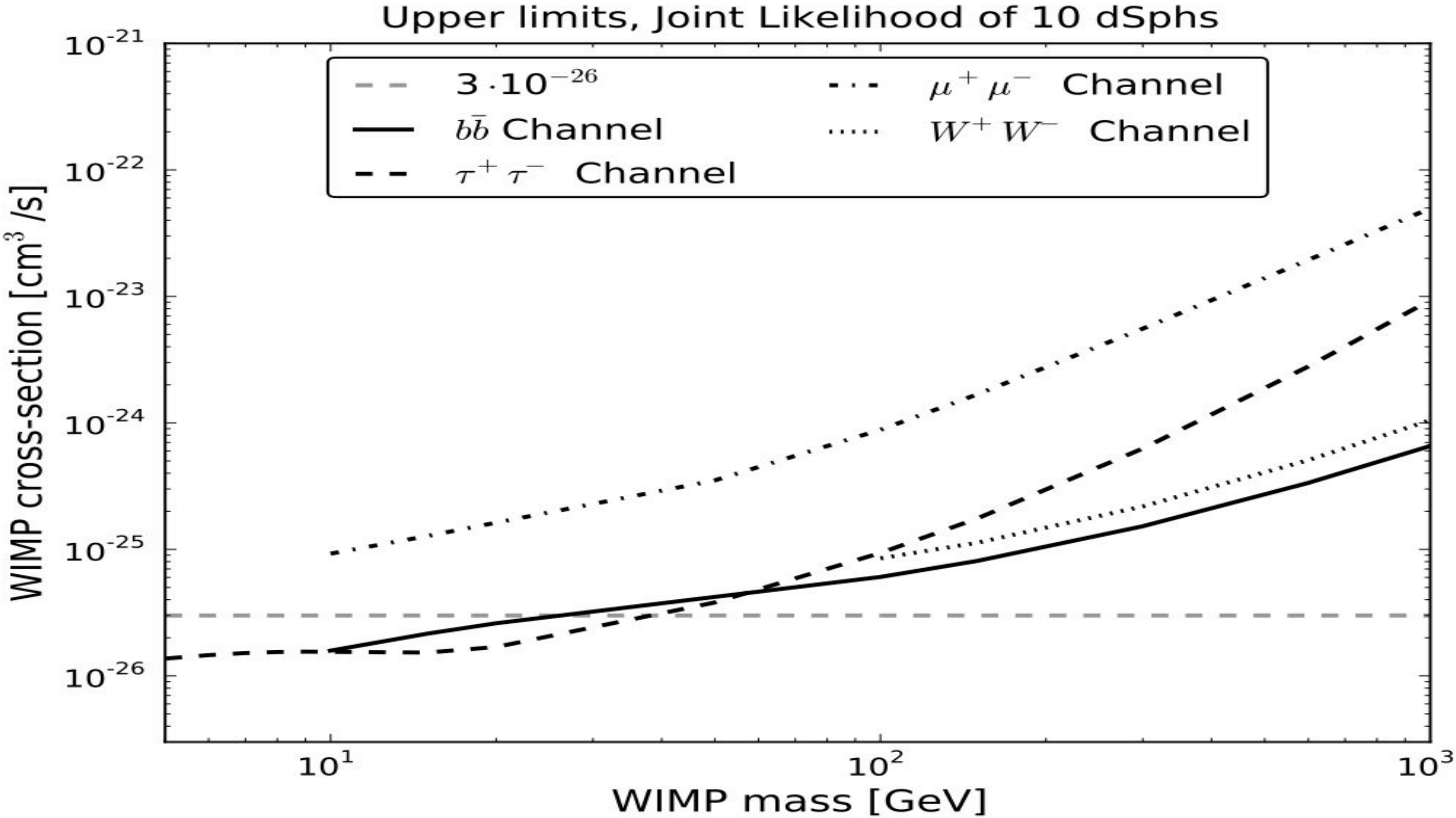


robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

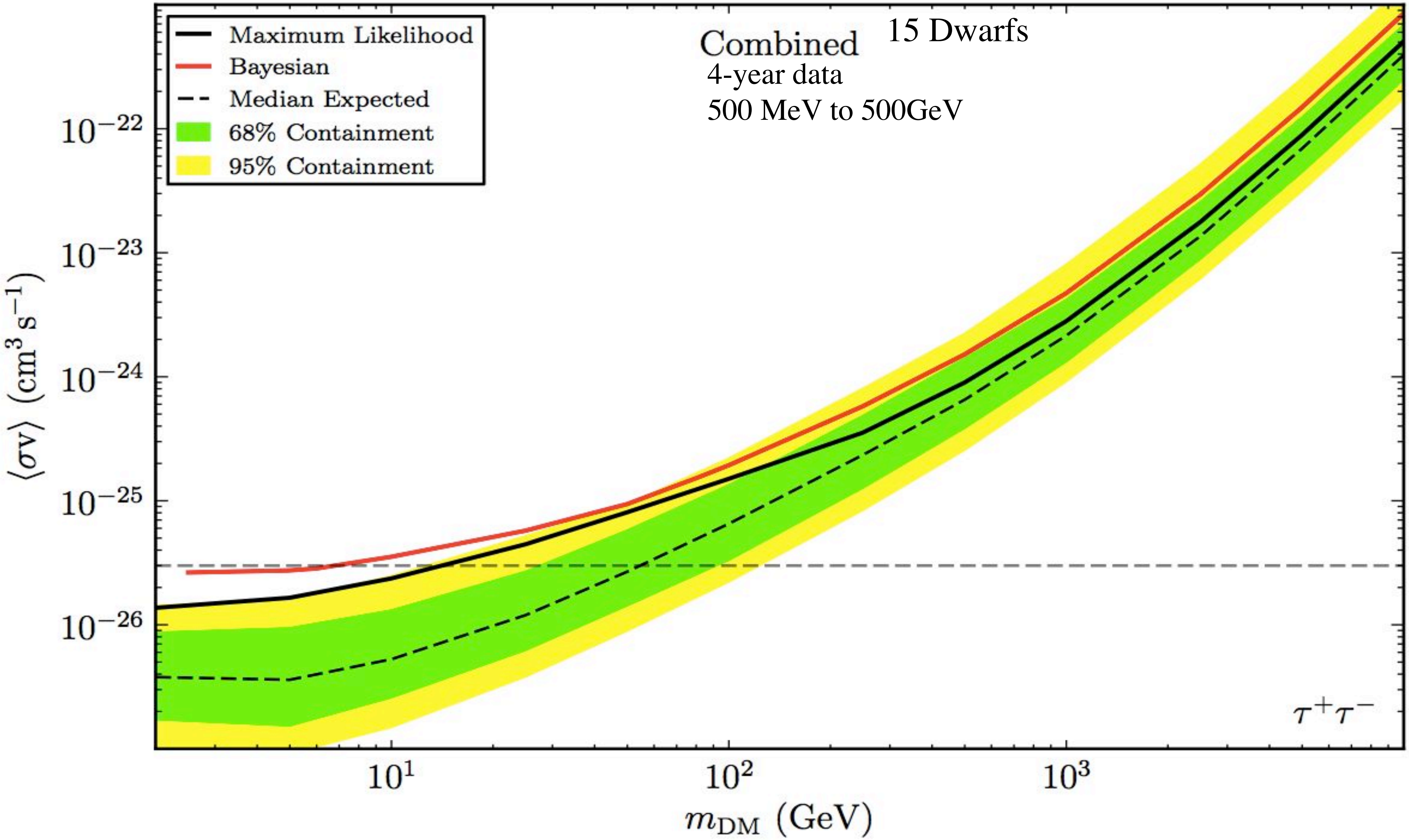
Dwarf Spheroidal Galaxies combined analysis



robust constraints including J-factor uncertainties from the stellar data statistical analysis

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

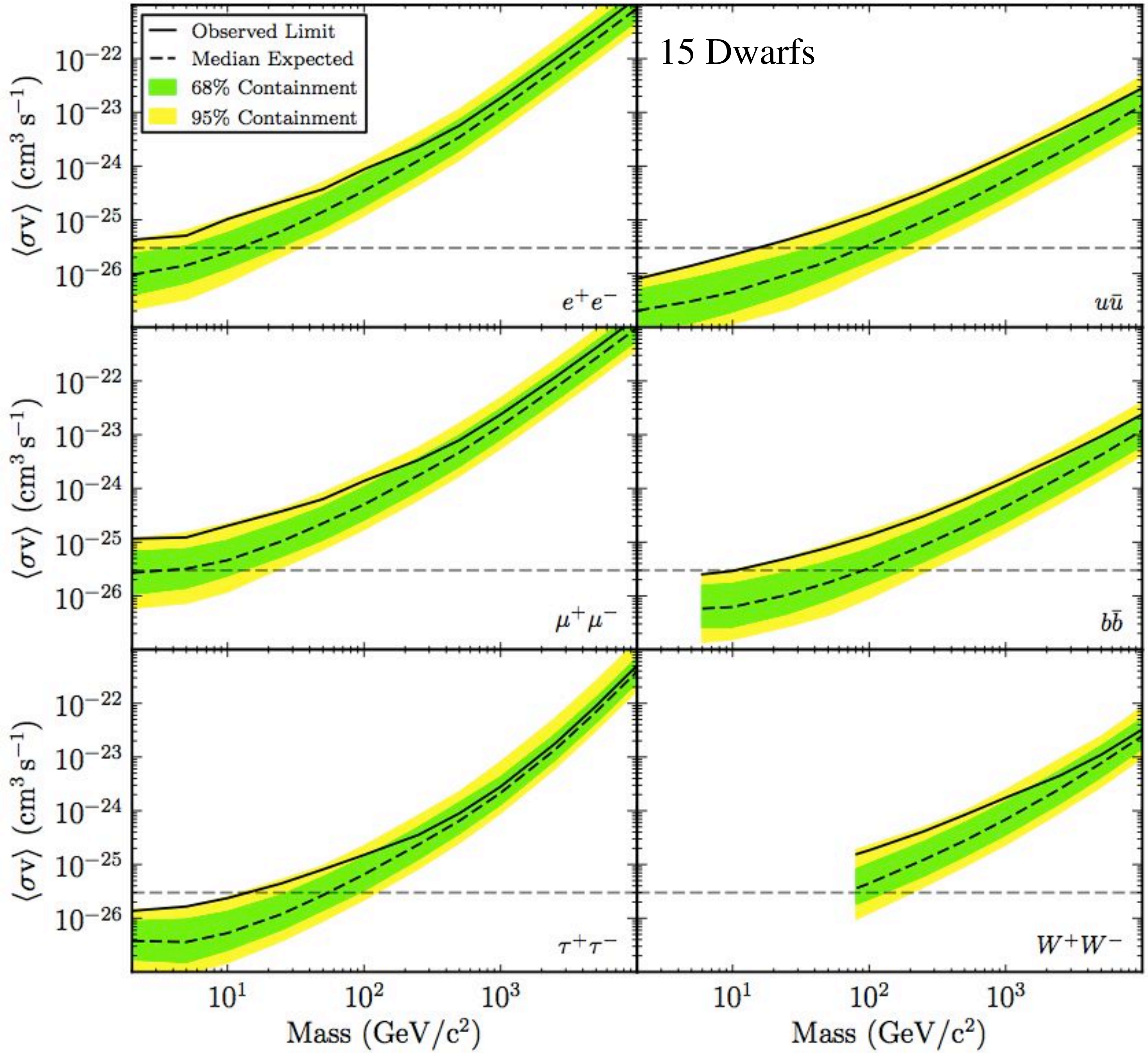
Dwarf Spheroidal Galaxies upper-limits



M.Ackermann et al., [Fermi Coll.] PRD sub.[arXiv:1310.0828]

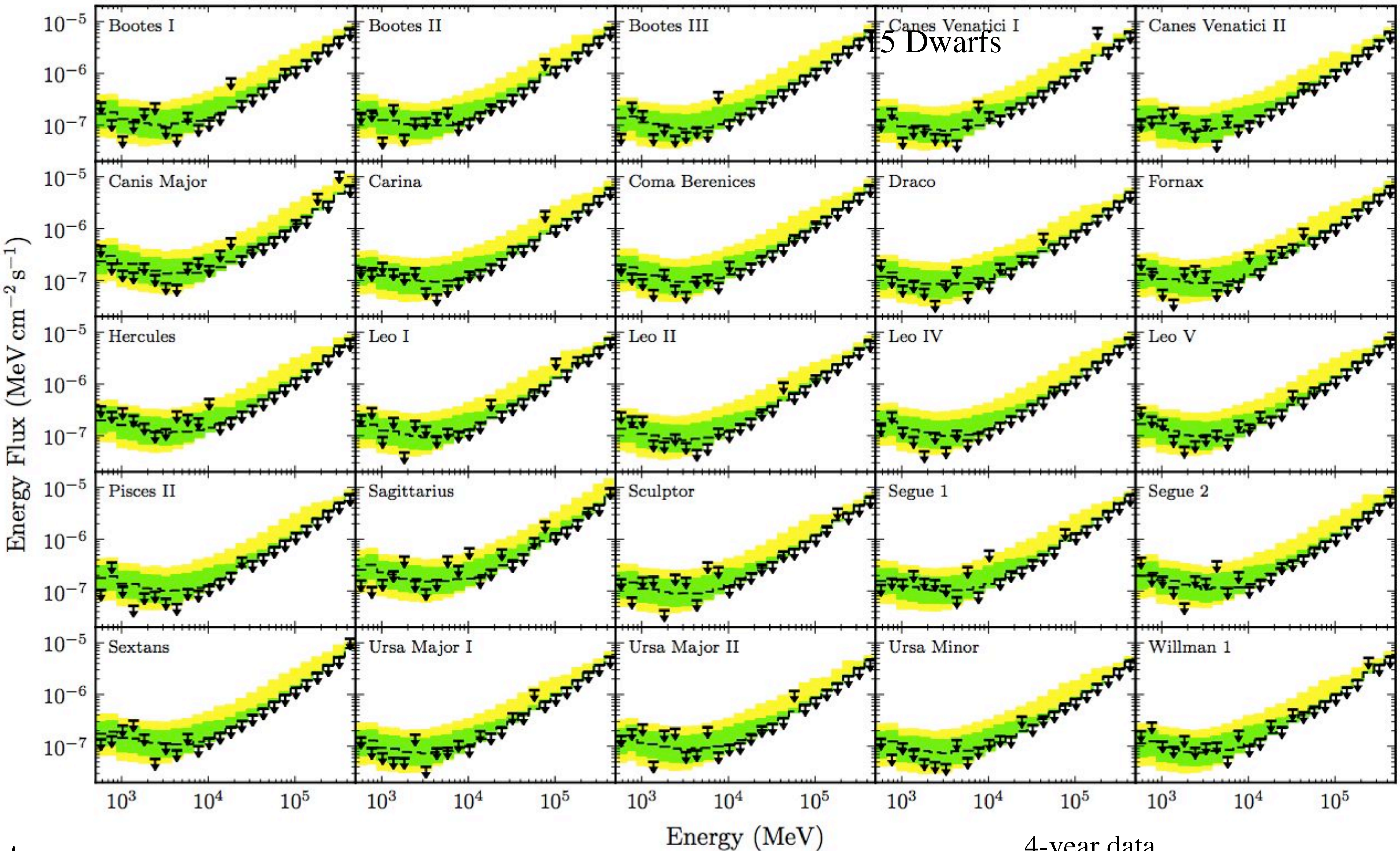
Dwarf Spheroidal Galaxies upper-limits

15 Dwarfs
4-year data
500 MeV to 500GeV



M.Ackermann et al., [Fermi Coll.] PRD sub. [arXiv:1310.0828]

25 Dwarf Spheroidal Galaxies upper-limits



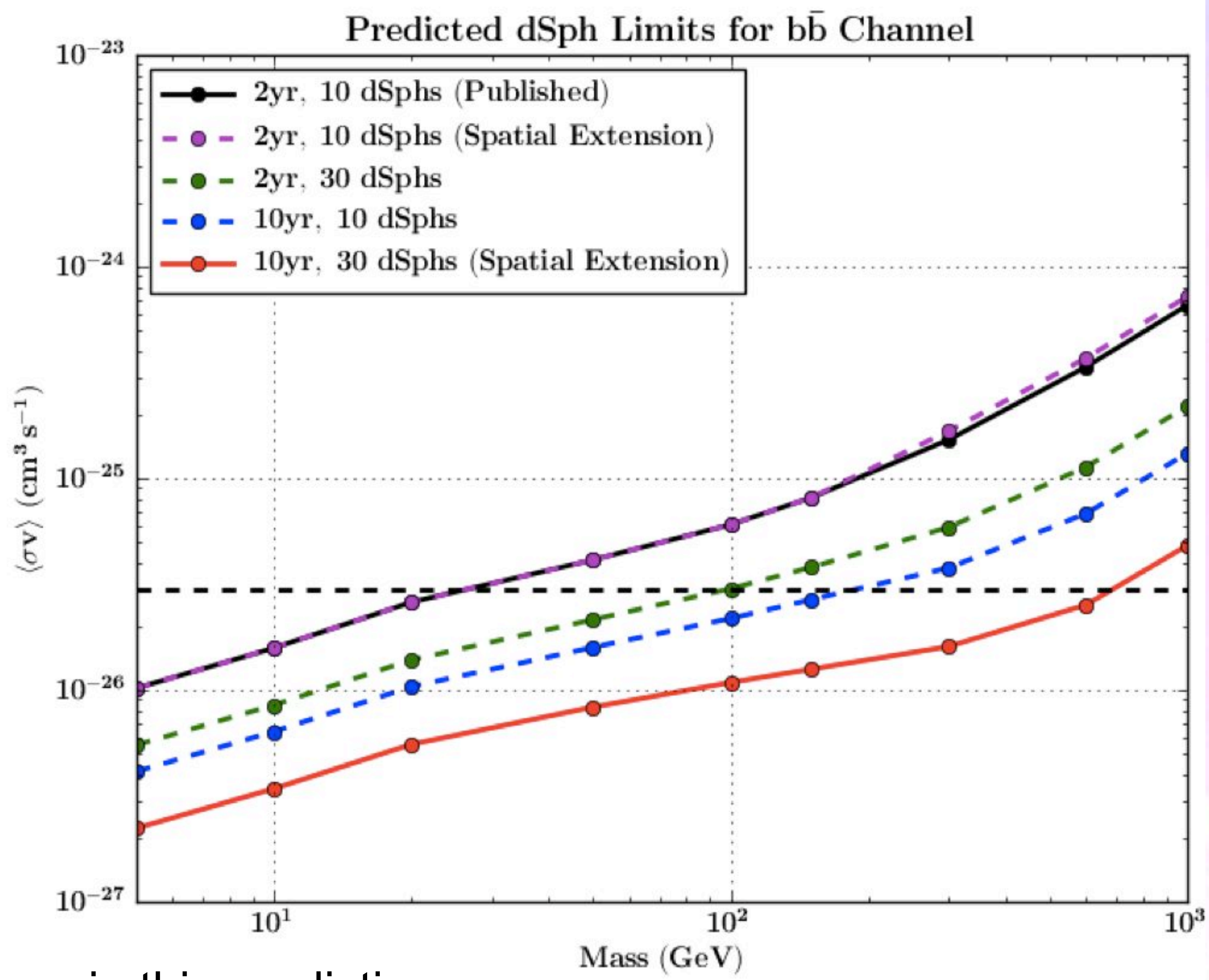
15 Dwarfs

4-year data
500 MeV to 500GeV

M.Ackermann et al., [Fermi Coll.] PRD sub.[arXiv:1310.0828]

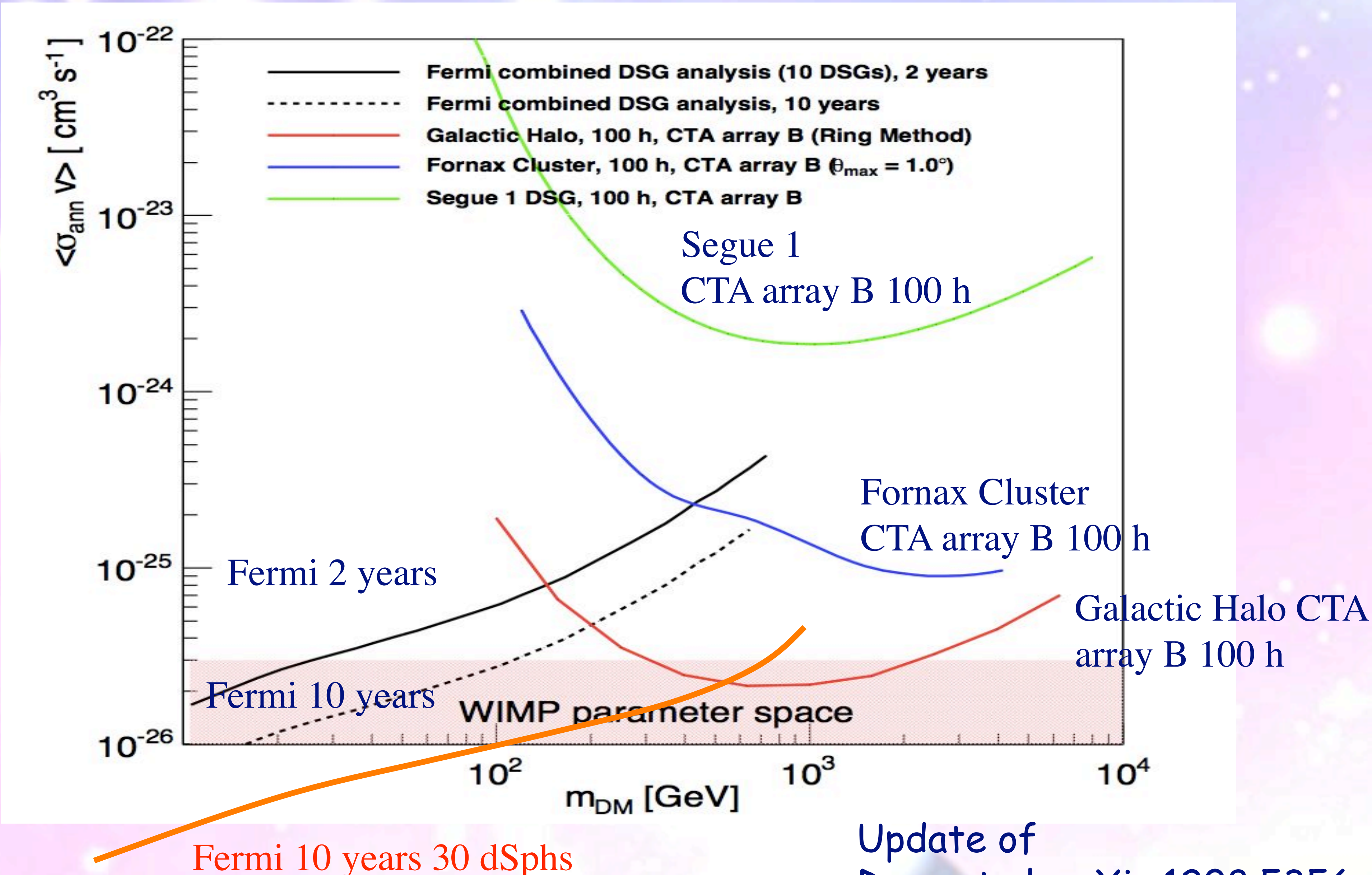
DM limit improvement estimate in 10 years with the composite likelihood approach (2008- 2018)

- 10 years of data instead of 2(5x)
- 30 dSphs (3x) (supposing that the new optical surveys will find new dSph)
- -10% from spatial extension (source extension increases the signal region at high energy E > 10 GeV, M > 200 GeV)



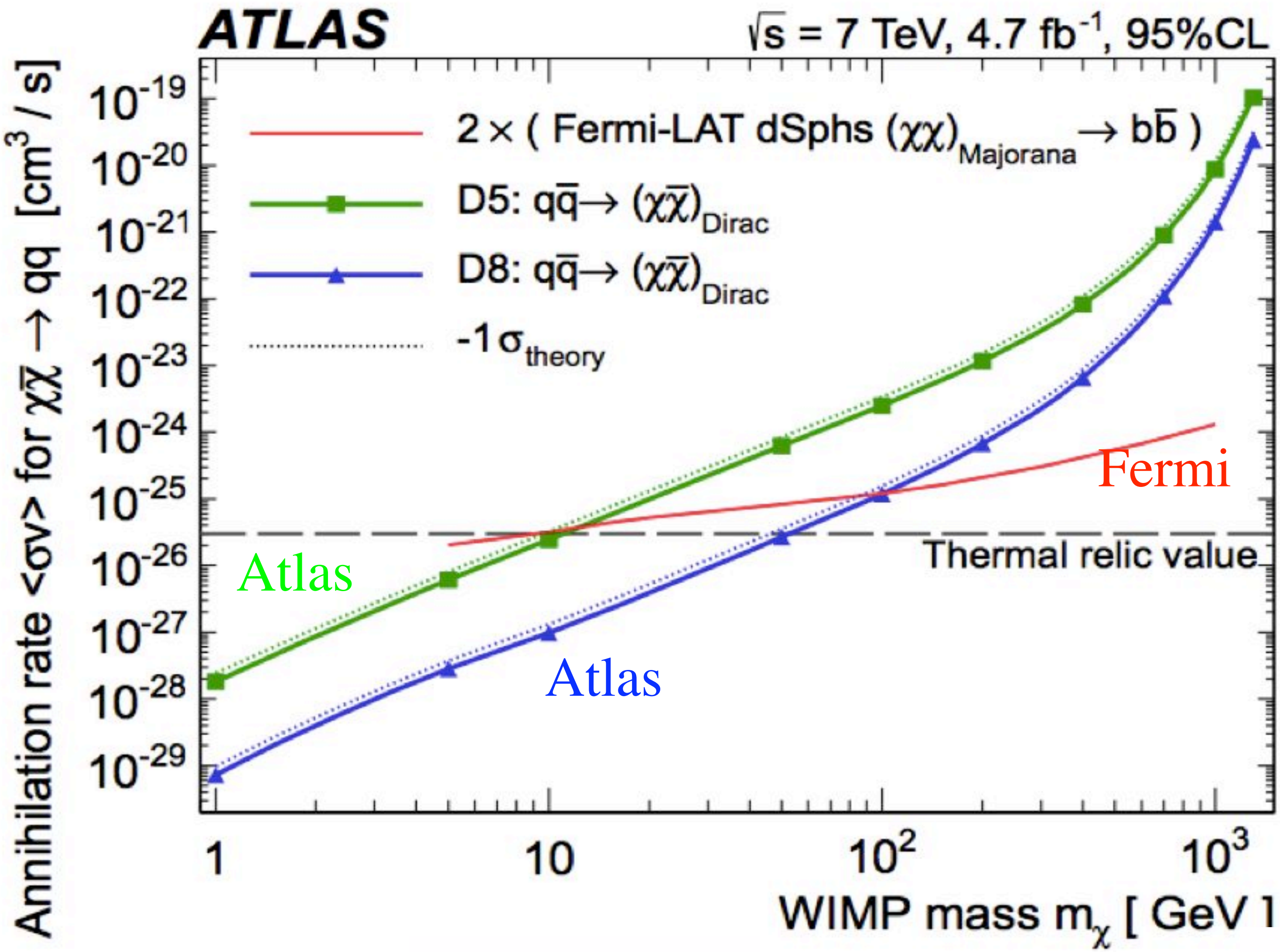
- There are many assumptions in this prediction
- Doesn’t deal with a possible detections.

Dwarf Spheroidal Galaxies upper-limits



Update of
Doro et al. arXiv:1208.5356

ATLAS-Fermi Results

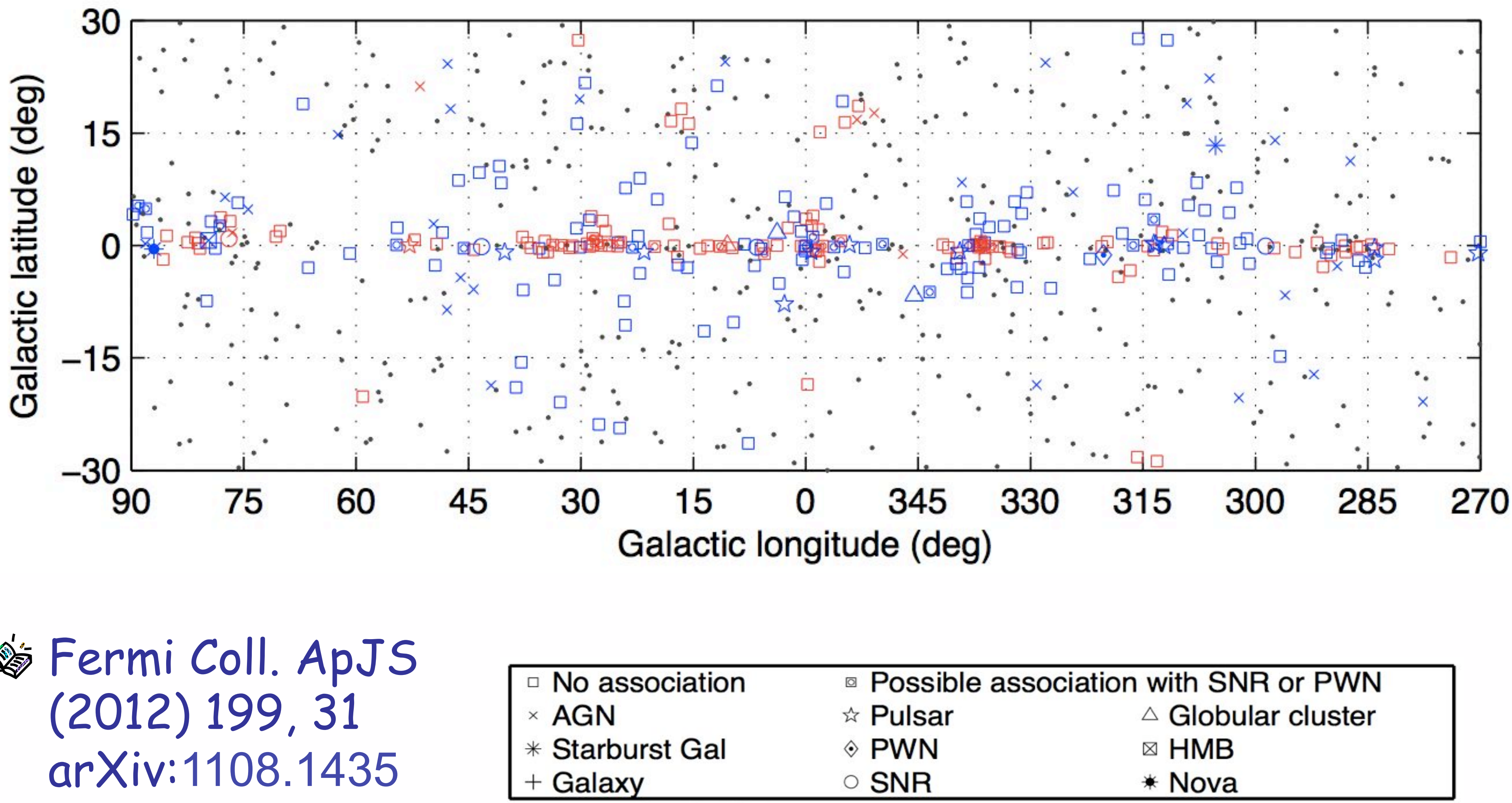


Atlas Coll. arXiv:1210.4491

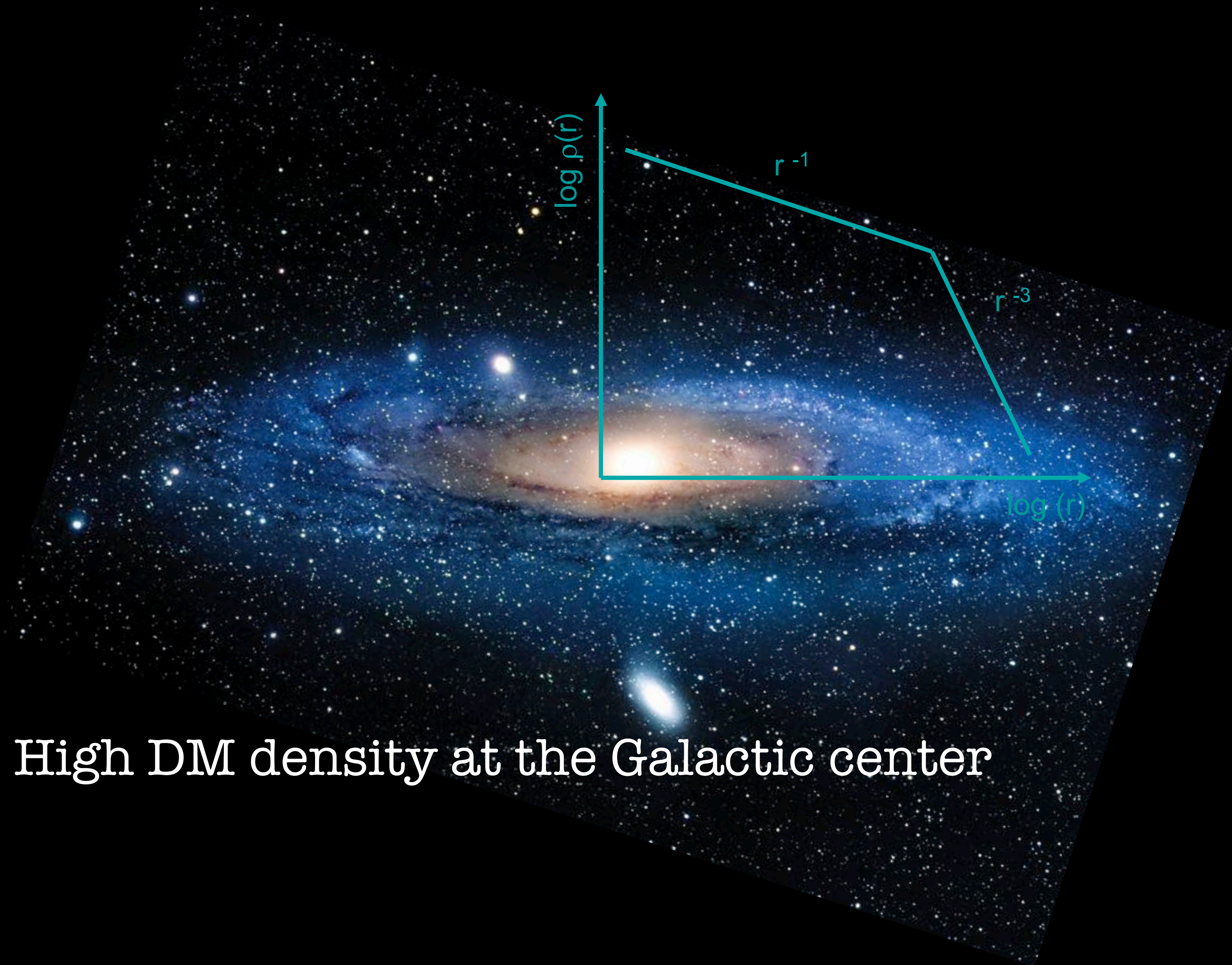
The Fermi LAT 2FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



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



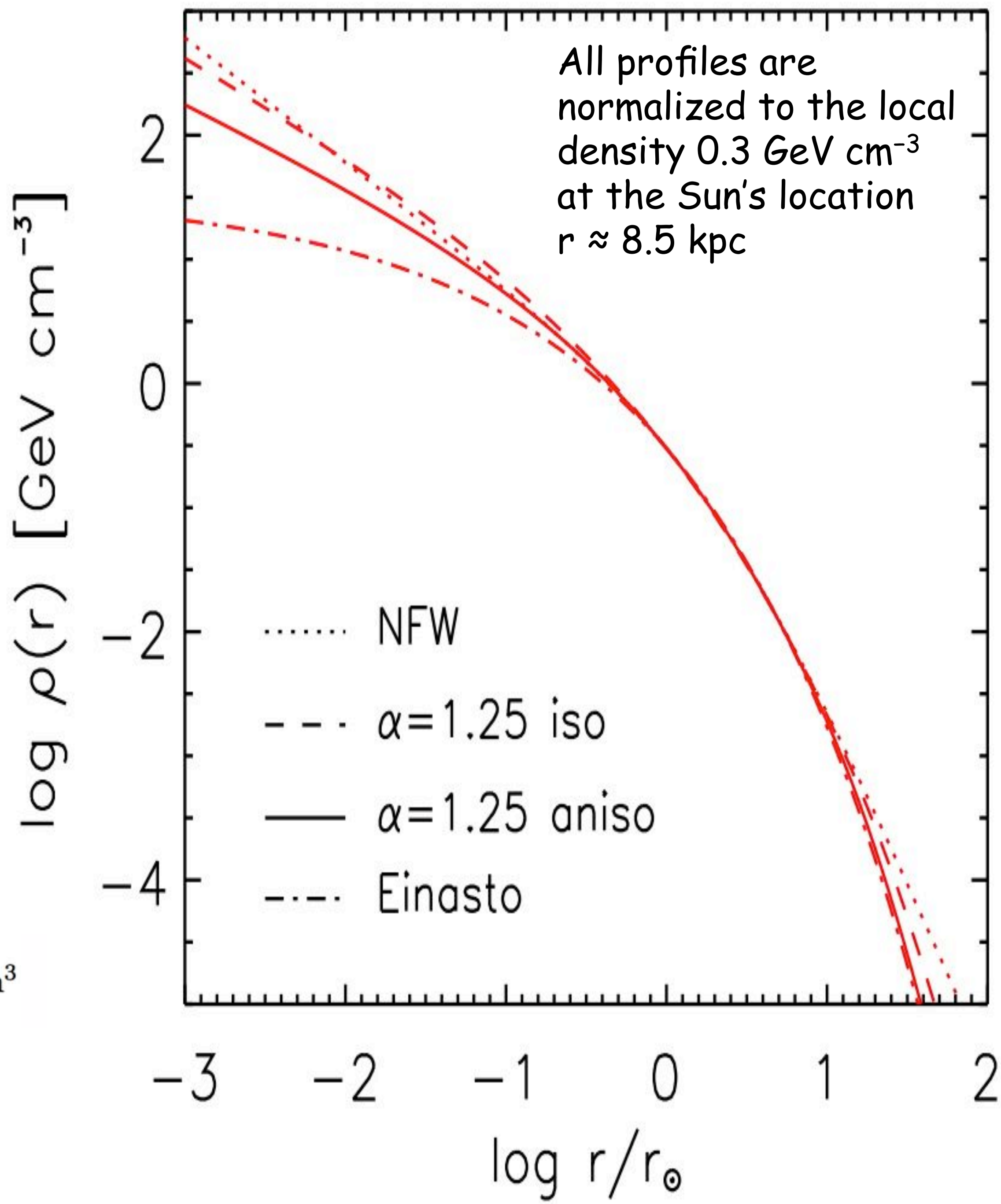
High DM density at the Galactic center

Milky Way Dark Matter Profiles

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

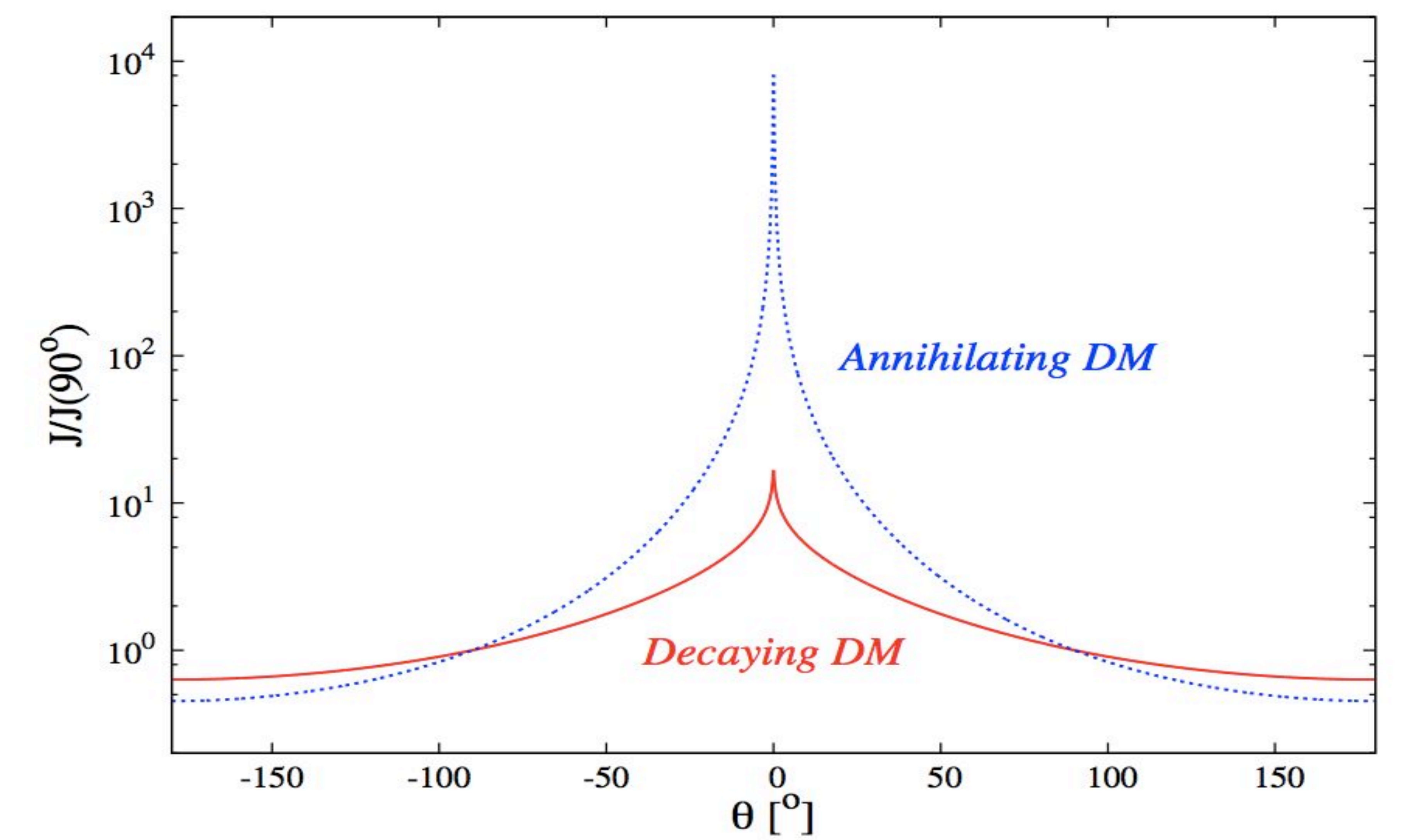
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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



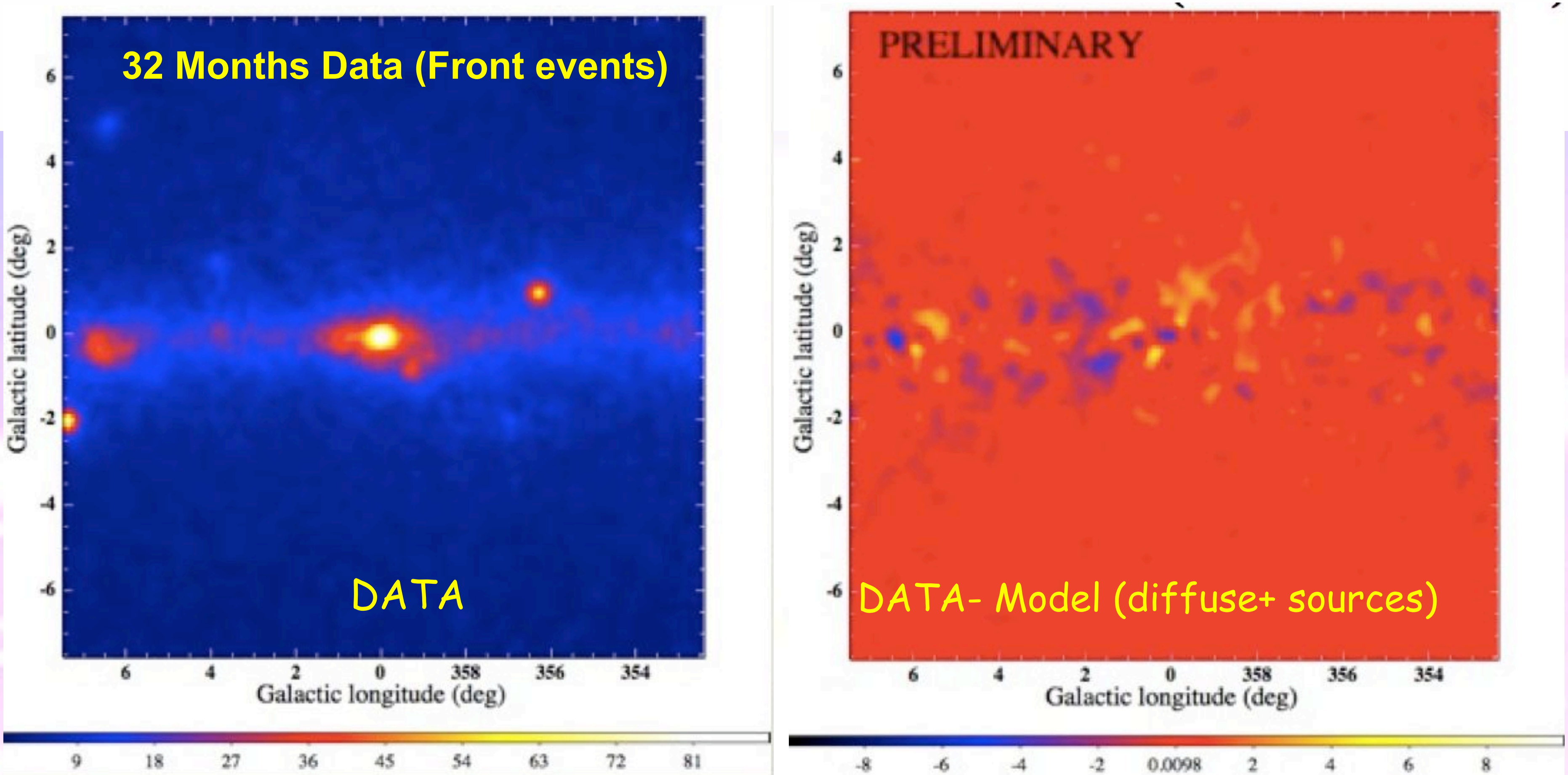
A.Lapi et al. arXiv:0912.1766

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

Residual Emission for 15 * 15 degrees around the Galactic center



Diffuse emission and point sources account for most of the emission observed in the region.

Low-level residuals remain, the interpretation of these is work in-progress

Papers are forthcoming and will include dark matter results.

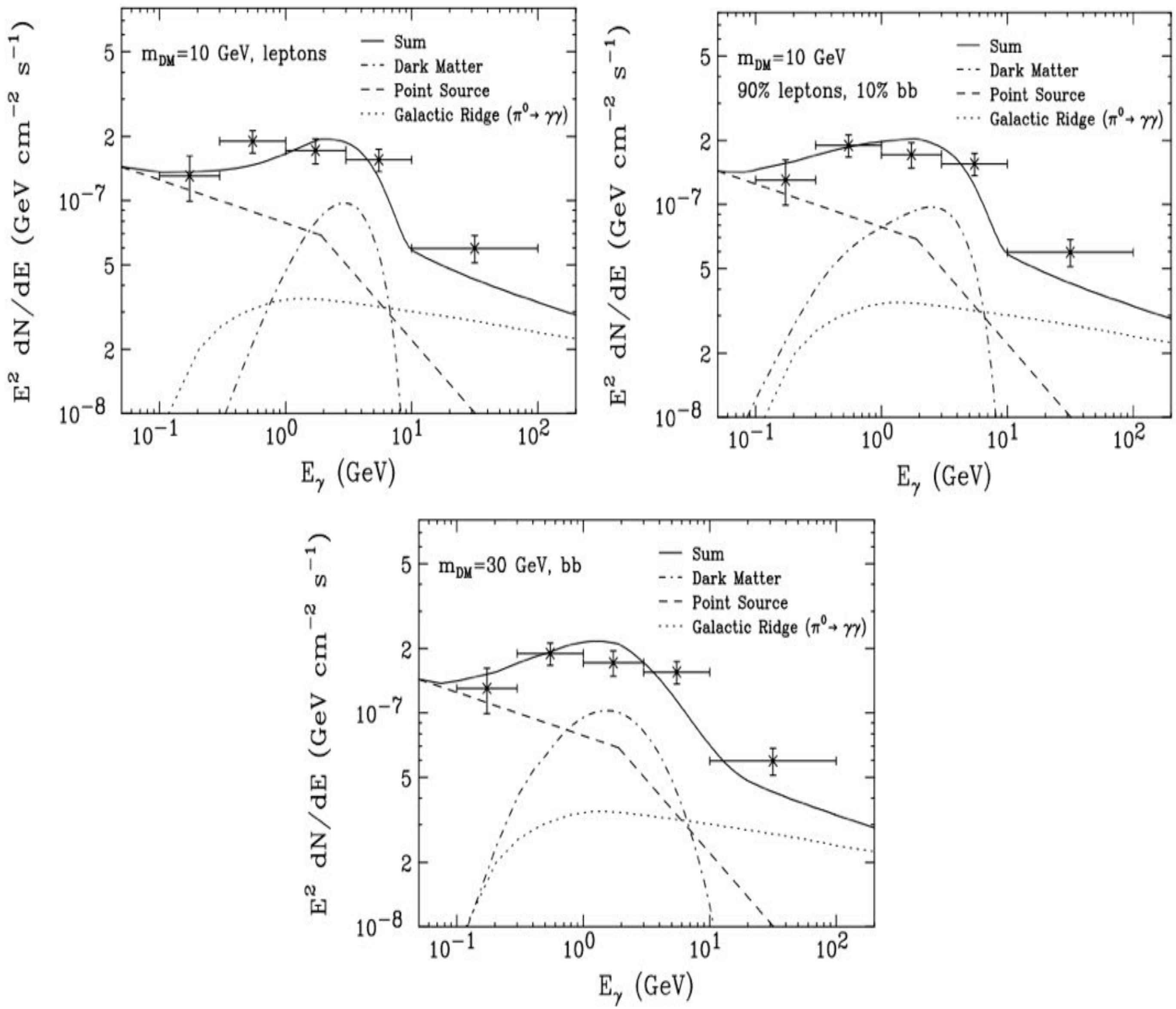
DM in the galactic center?

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

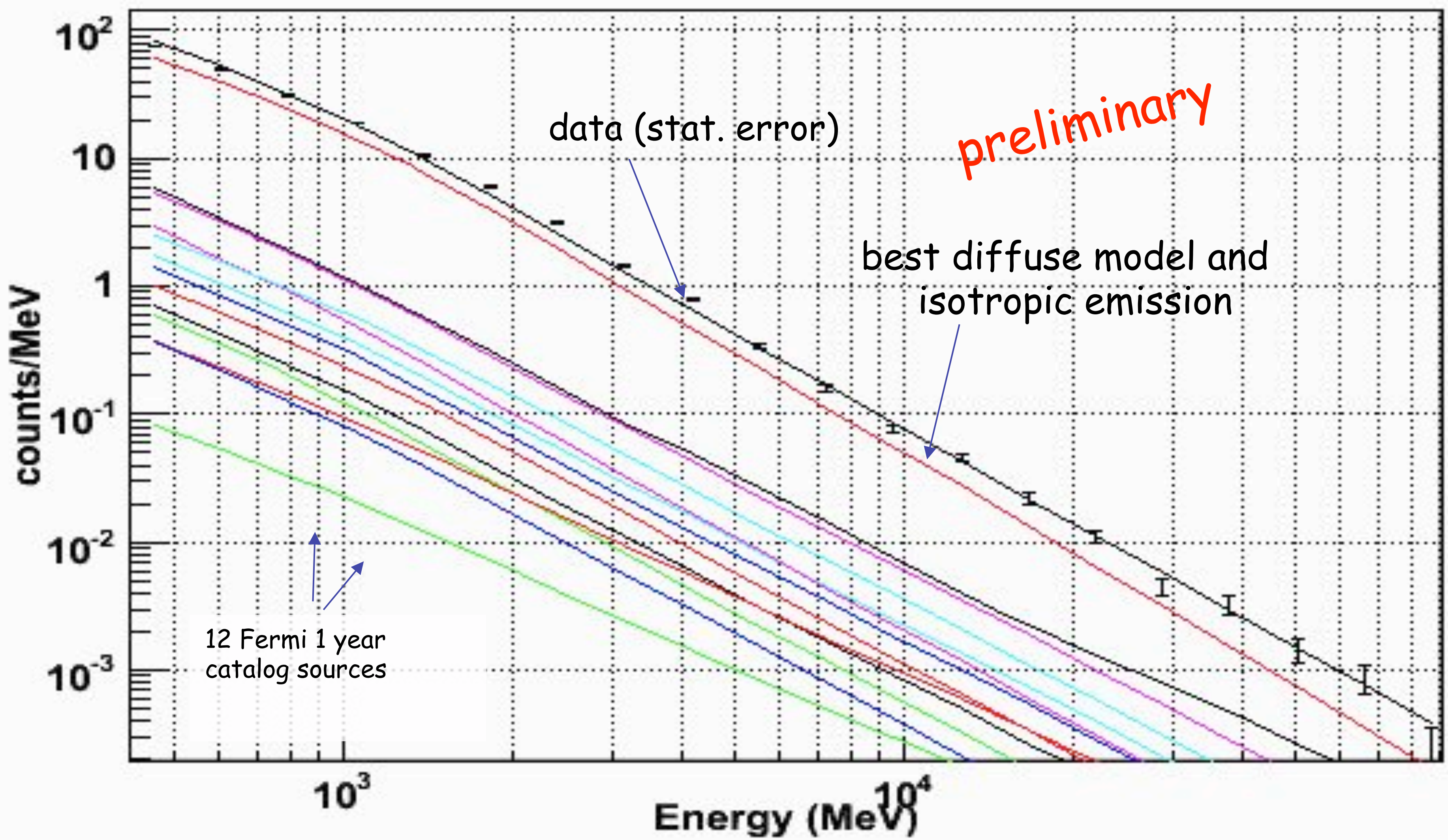
Using the remarkable source of public Fermi-LAT data!

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!



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

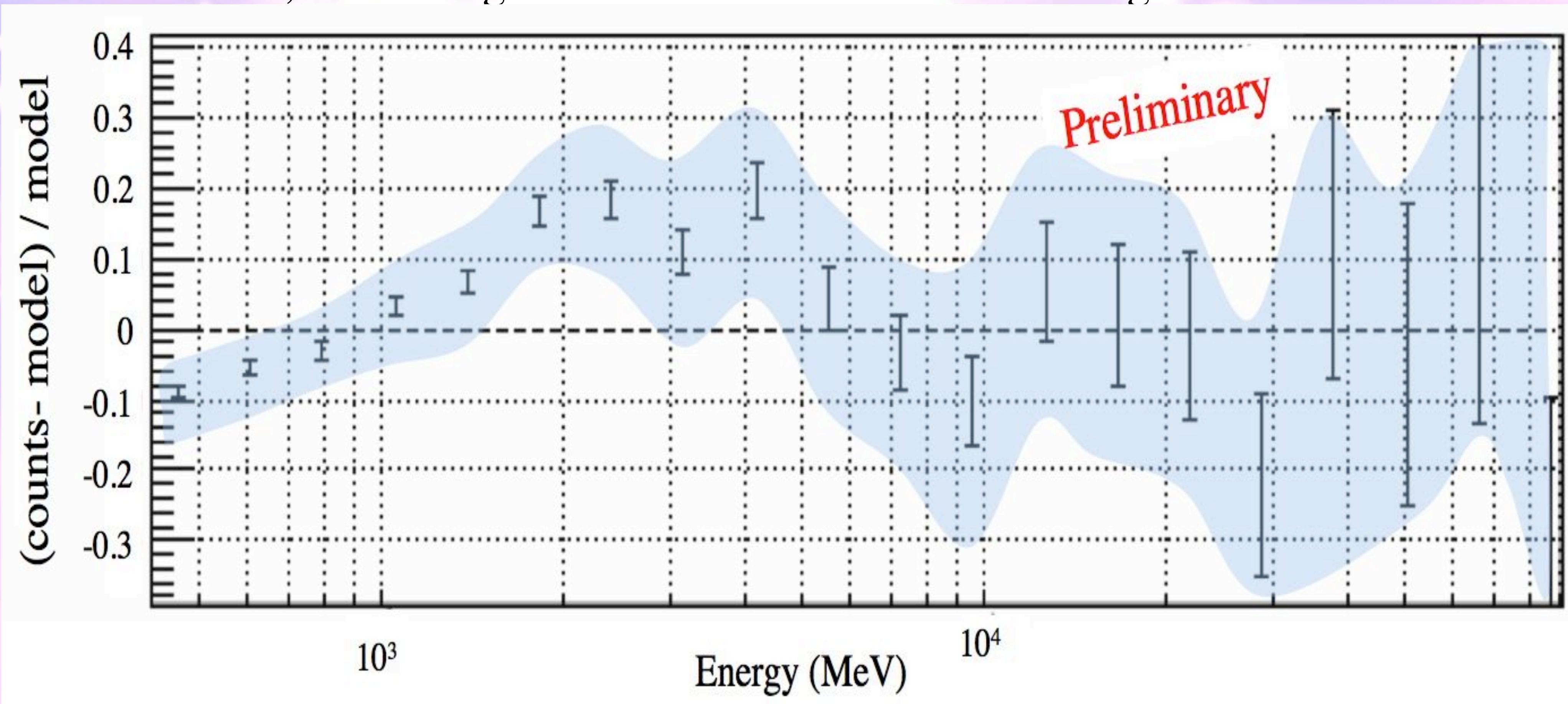


Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

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

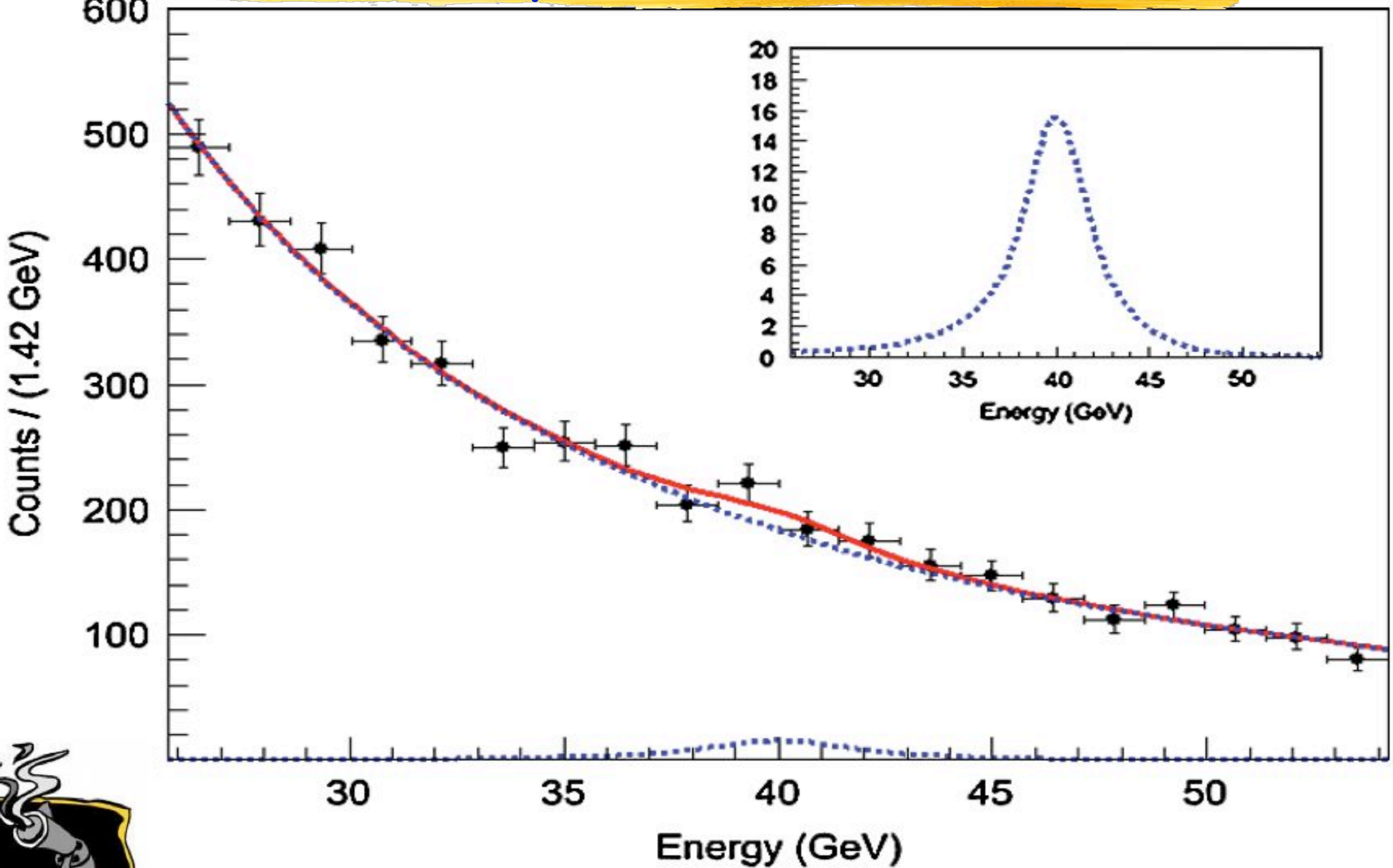


Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

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

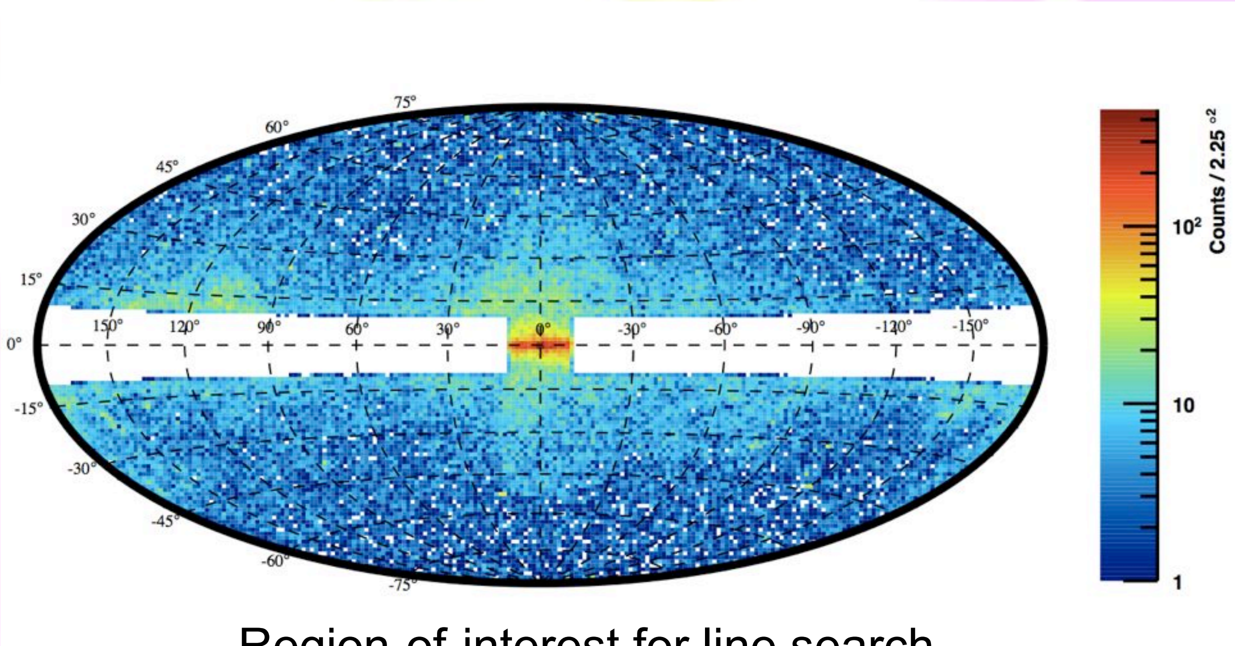
- Maybe yes, but we can't be sure as far as we don't understand the background at the level needed for disentangle a DM-induced γ-ray flux in this interesting region.
-
- New molecular and atomic gas, CR and γ-ray data is around the corner, keep tune!

Wimp lines search



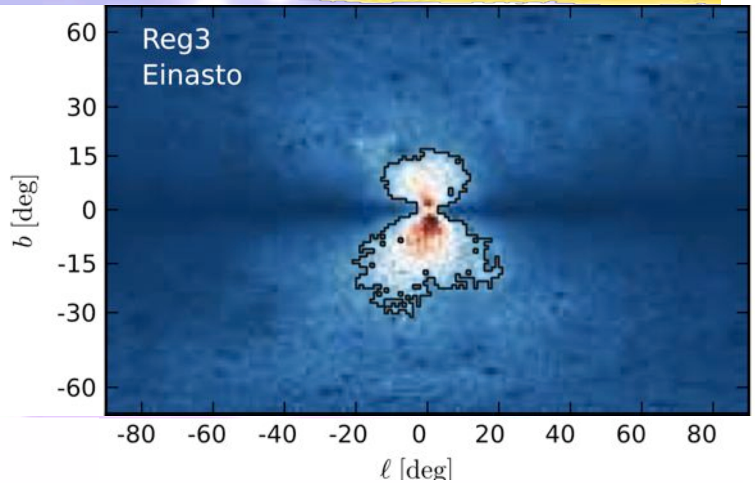
Search for Spectral Gamma Lines

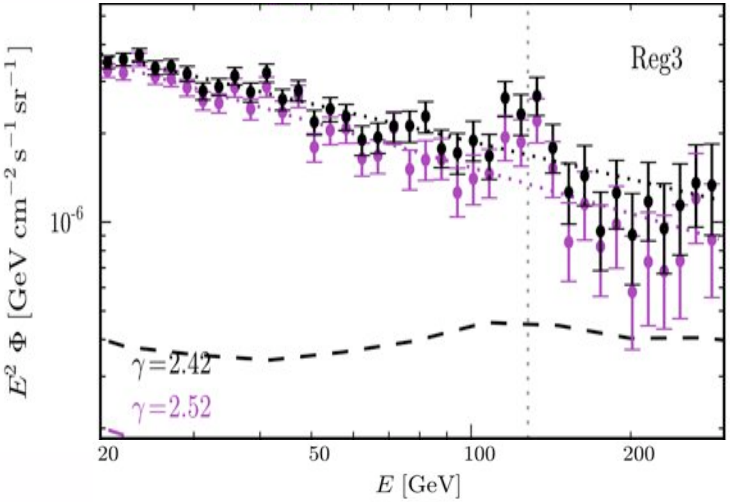
- Smoking gun signal of dark matter
- Search for lines in the first 23 months of Fermi data (7-200 GeV en.range)
- Search region |b|>10° plus a 20°x 20° square centered at the galactic center
- For the region within 1°of the GC, no point source removal was done as this would have removed the GC
- For the remaining part of the ROI, point sources were masked from the analysis using a circle of radius 0.2 deg
- The data selection includes additional cuts to remove residual charged particle contamination.

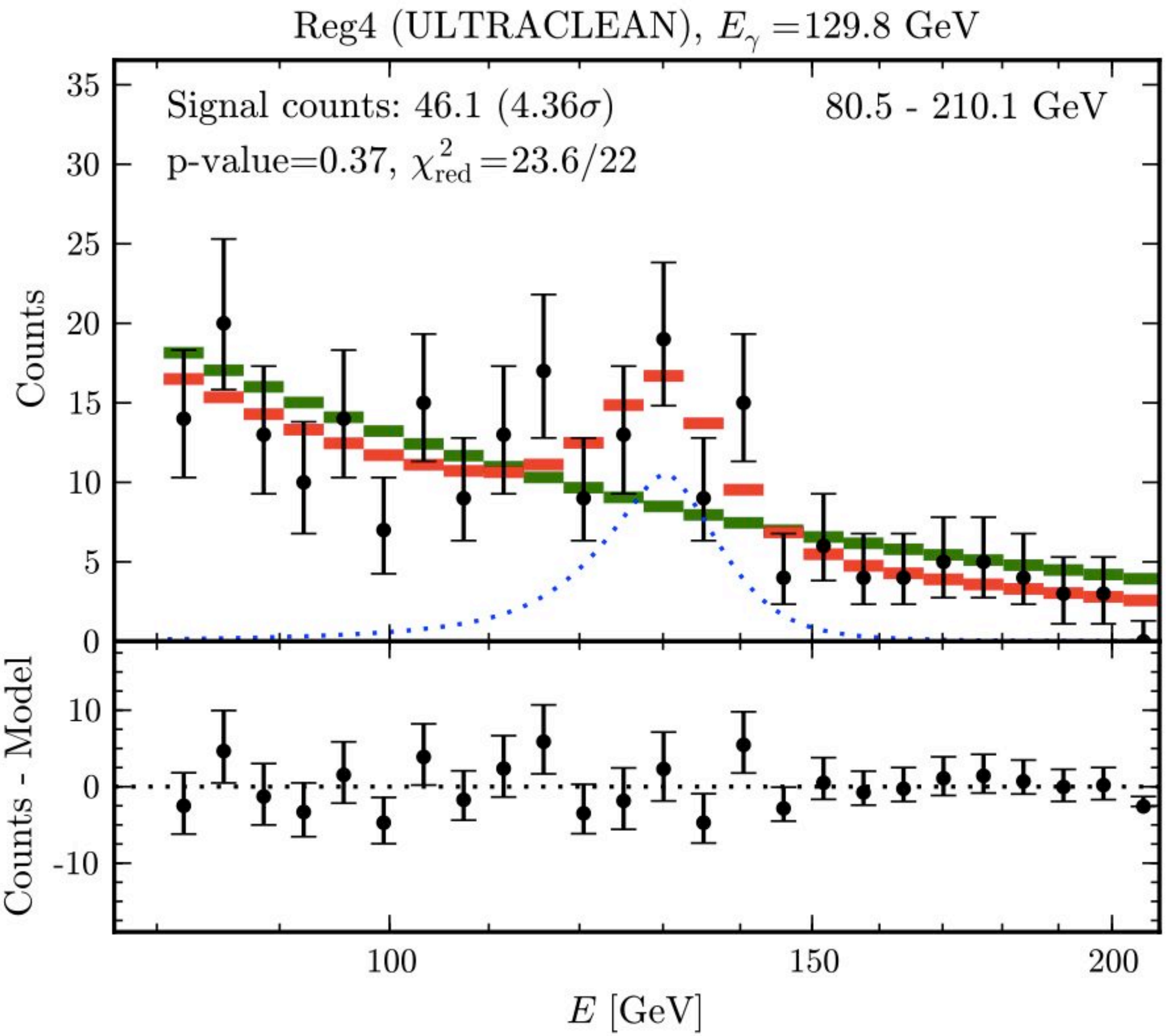


Region-of-interest for line search

A line at ~ 130 GeV ?

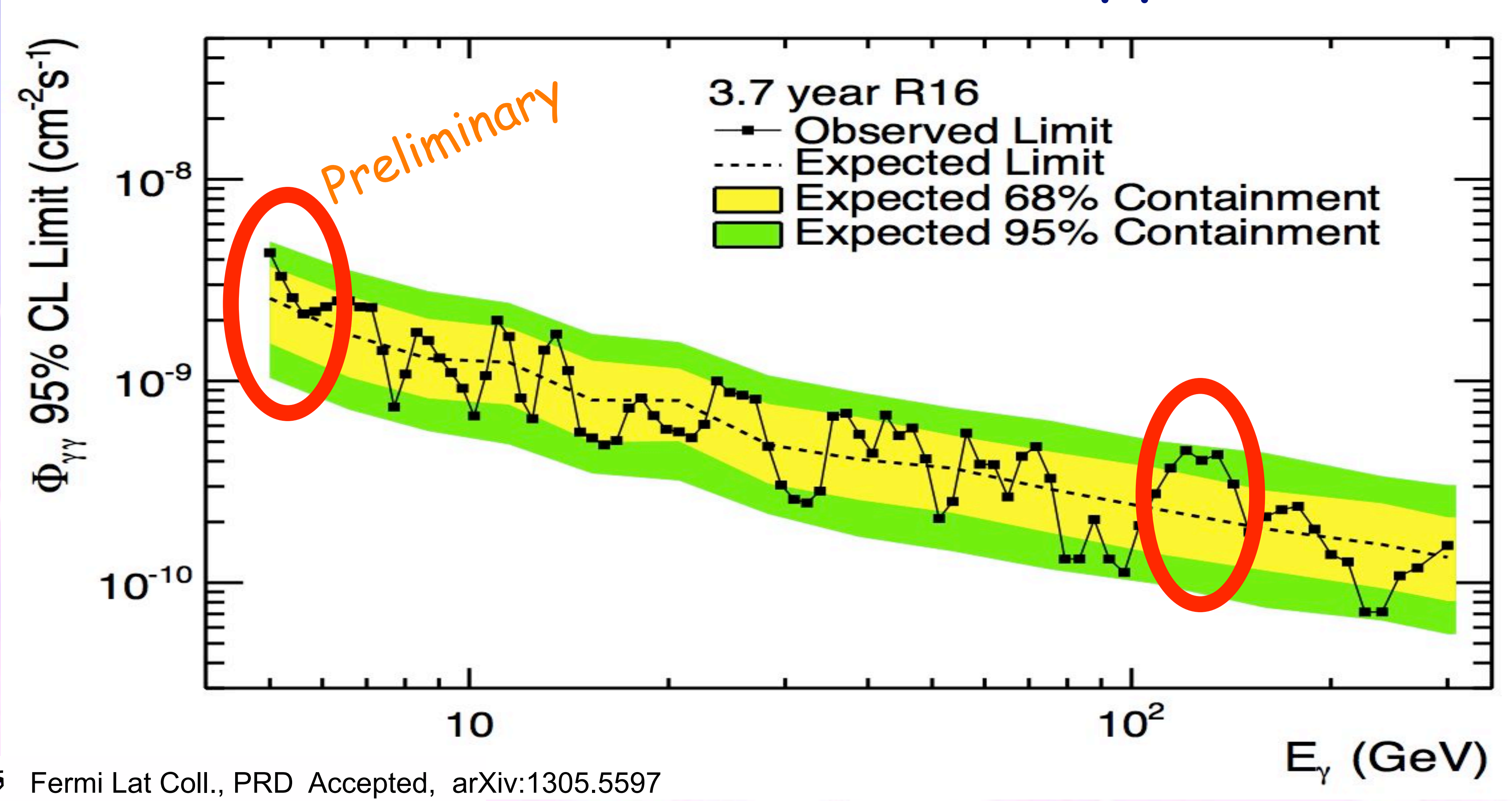






Weniger arXiv:1204.2797

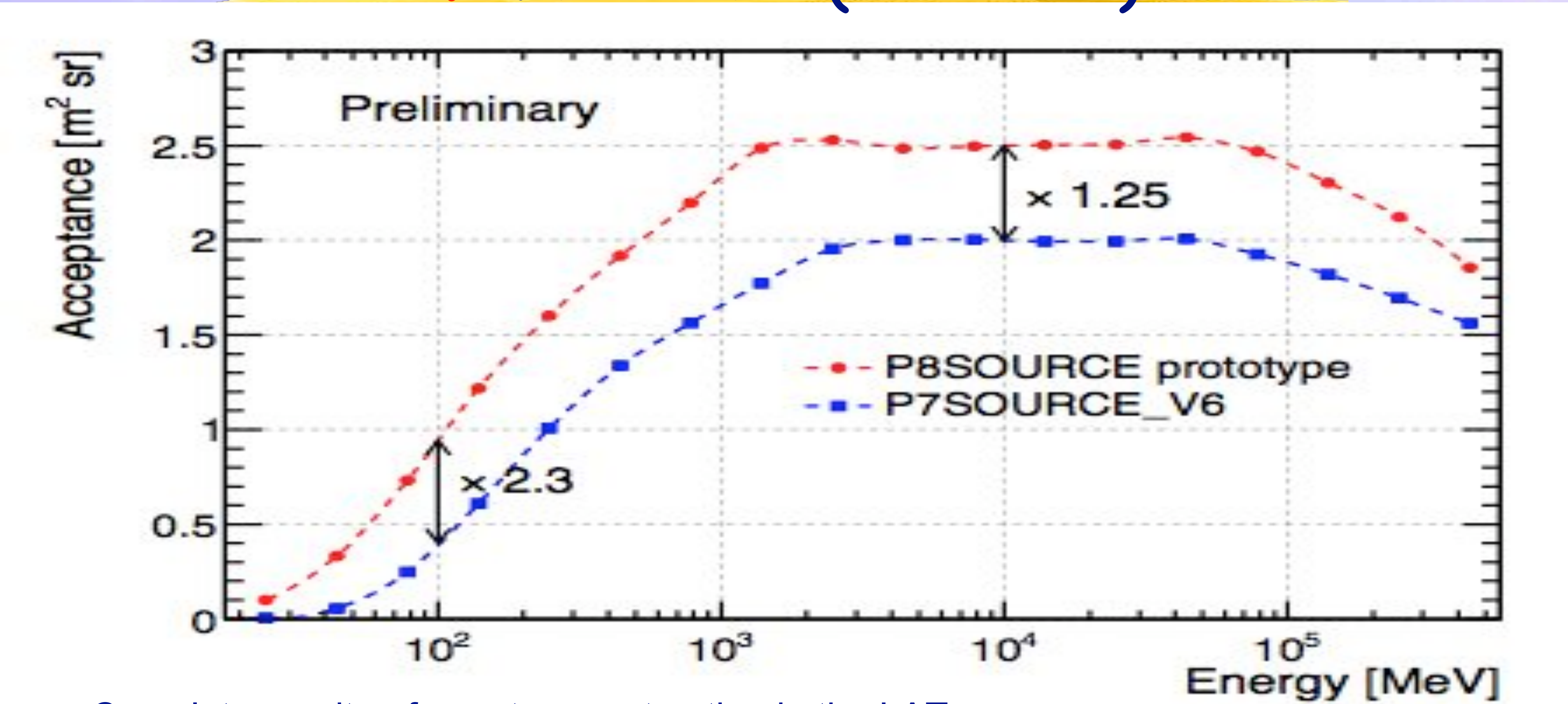
Fermi-LAT Line Search Flux Upper Limits



Fermi Lat Coll., PRD Accepted, arXiv:1305.5597

- Most of the limits fall within the expected bands.
- Near 135 GeV the limits are near the upper edge of the bands.
- The huge statistics at low energies mean small uncertainties in the collecting area can produce statistical significant spectral features.

Fermi-LAT New Instrument Response Functions (Pass 8)

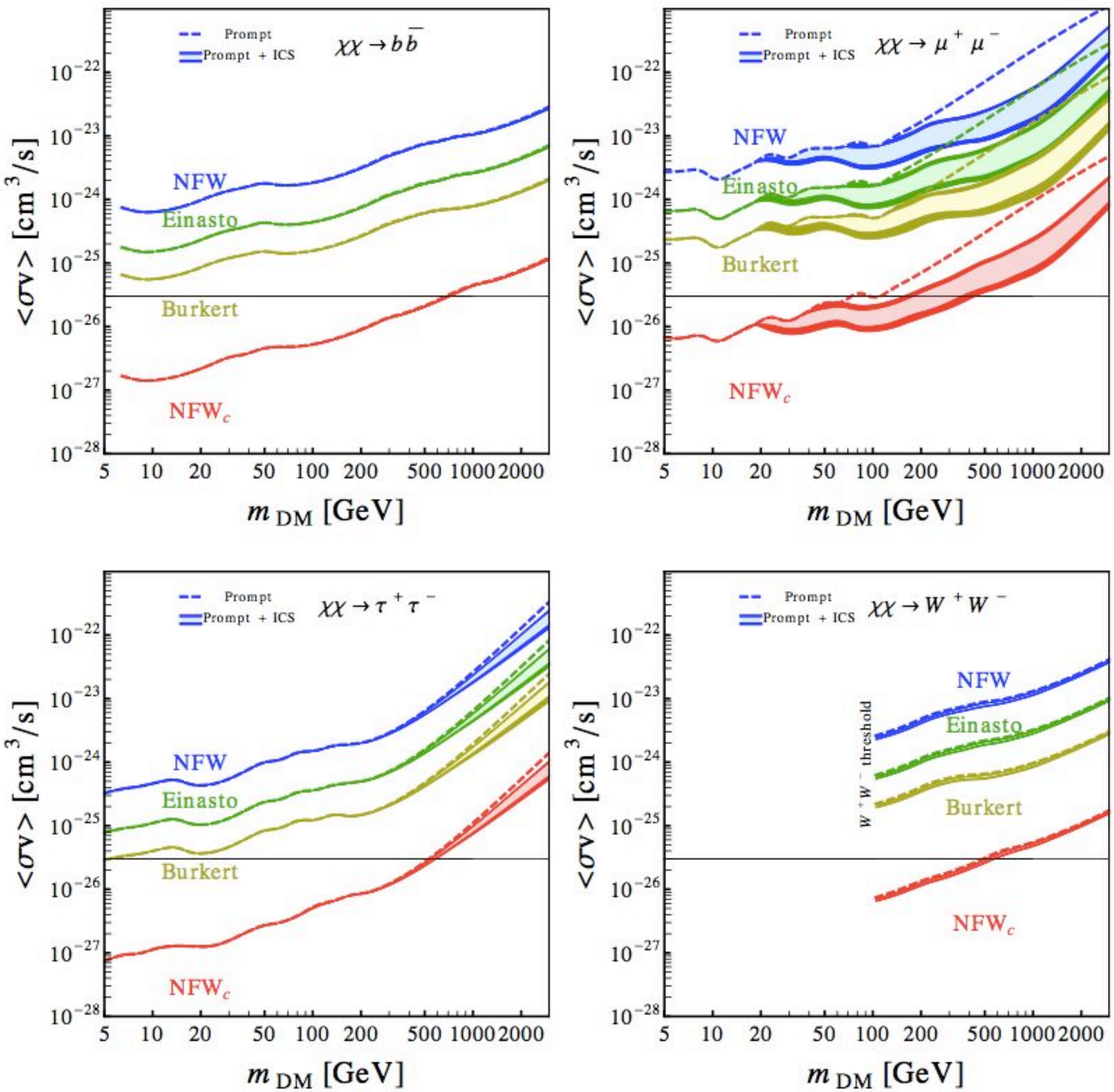


- Complete rewrite of event reconstruction in the LAT
  - Well beyond original motivation of suppressing cosmic-ray pileup
- Significant improvements wrt Pass7 performance
  - Larger acceptance, Increased energy range (low and high energy)
- Will be used for 5 year catalog and LAT analyses starting 2014

Arxiv 1303.3514

Constraints from the inner Galaxy

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

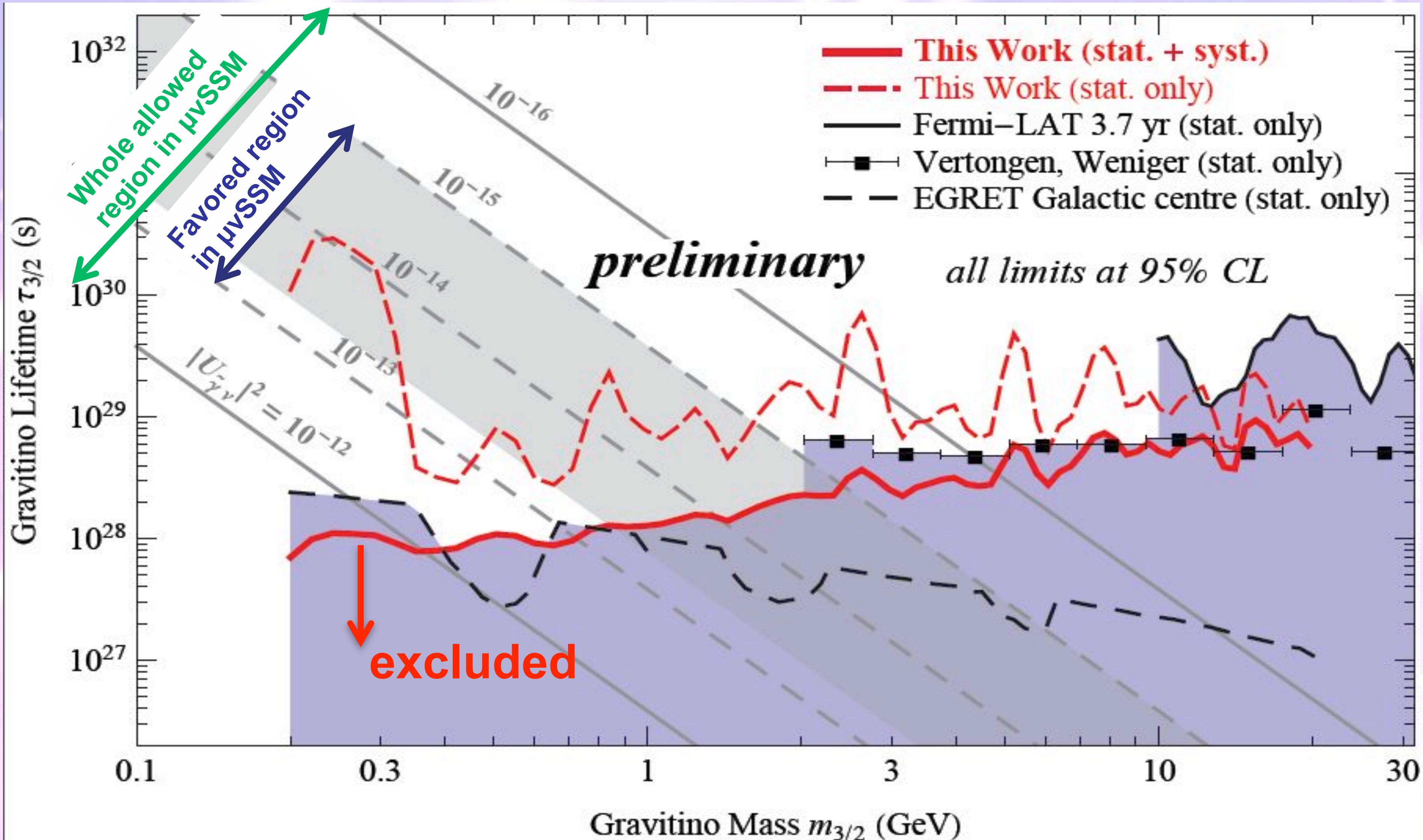


No assumption on background. Very robust result

Gomez-Vargas et al. JCAP 10 (2013) 029, (16 October) arXiv:1308.3515

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

JCAP accepted,[arXiv:1406.3430]



New projects in space

- ISS-Cream launch planned for 2014
- CALET CALorimetric Electron Telescope launch planned for 2014
- arXiv:1302.1257
- Gamma-light (Proposed to ESA but not approved)

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

- JEM EUSO launch tentatively planned for 2017

Dolores Rodriguez-Frias later

- Gamma-400 launch foreseen by end 2018

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

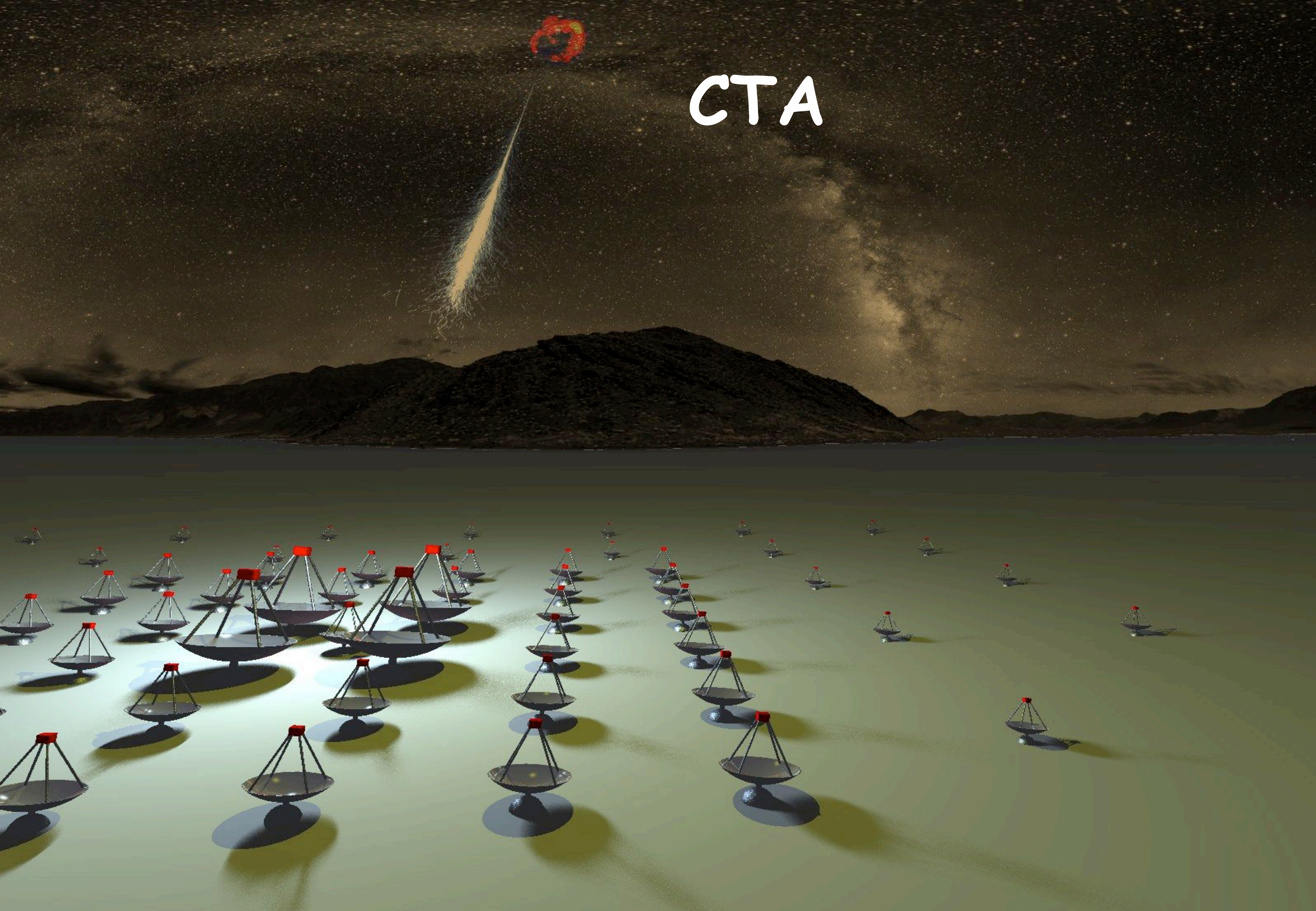
Science with Gamma-400 Workshop http://cdsagenda5.ictp.it/full_display.php?ida=a1311

- DAMPE: Satellite of similar performance as Gamma-400.

An approved Chinese γ-ray satellite. Planned launch 2015-16.

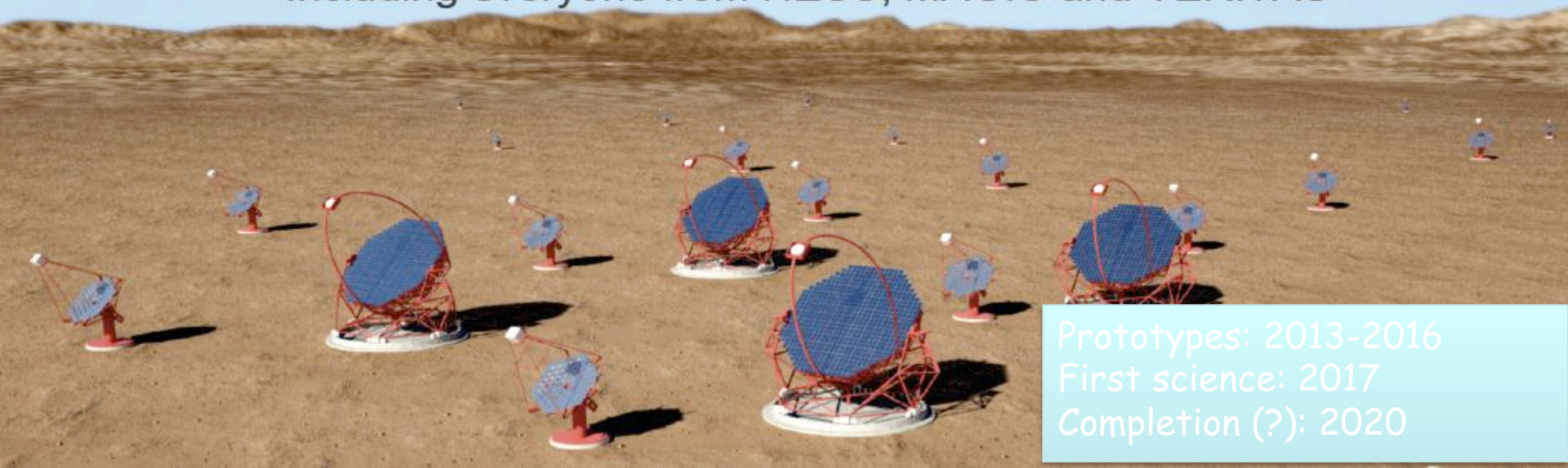
- HERD: Instrument on the planned Chinese Space Station.

Energy resolution (100 GeV) ~ 1 %. Effective area ~ 1 - 2 m2. Angular resolution (100 GeV) ~ 0.01°. Planned launch around 2020.


CTA

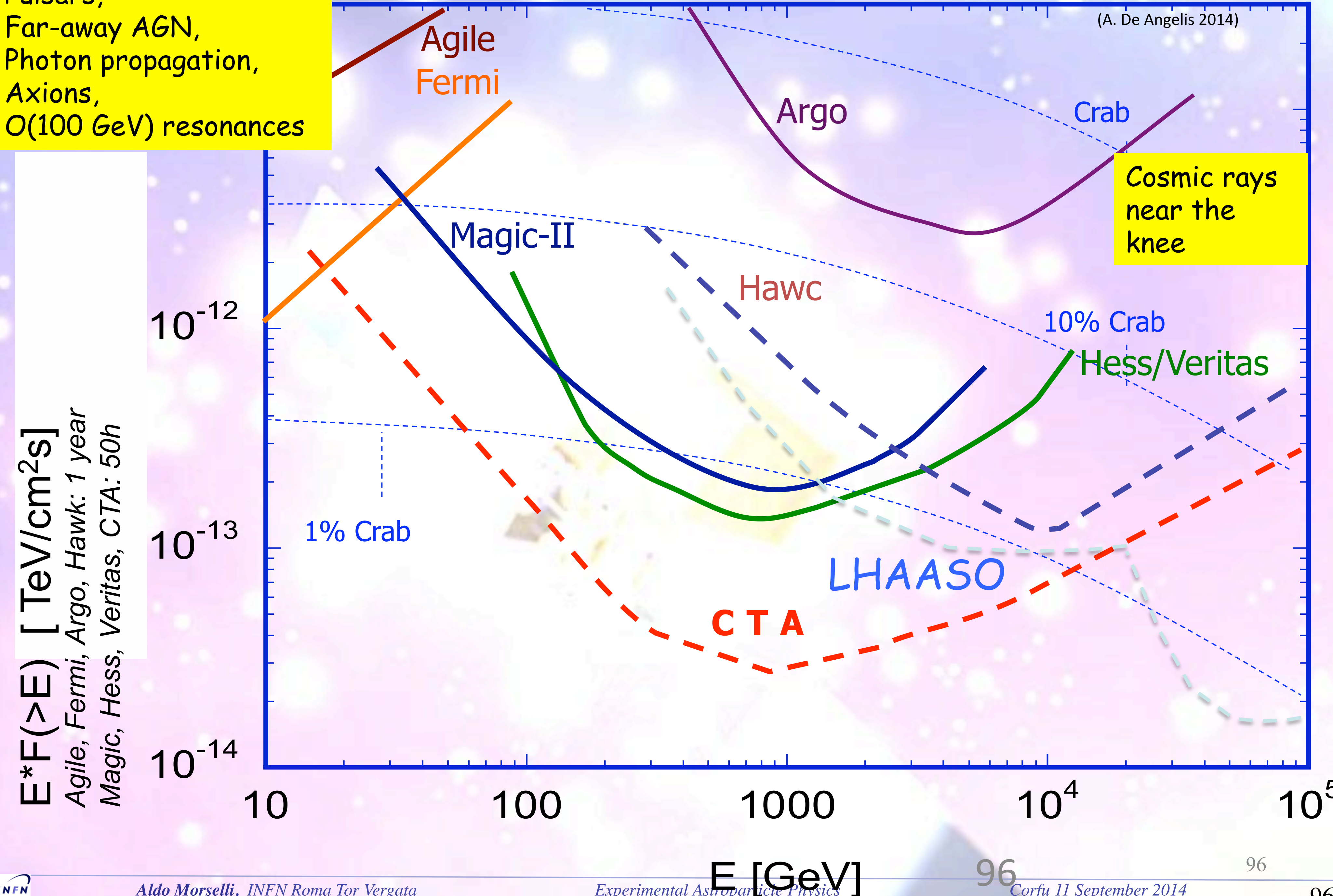
The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS



Prototypes: 2013-2016
First science: 2017
Completion (?): 2020

Pulsars,
Far-away AGN,
Photon propagation,
Axions,
O(100 GeV) resonances

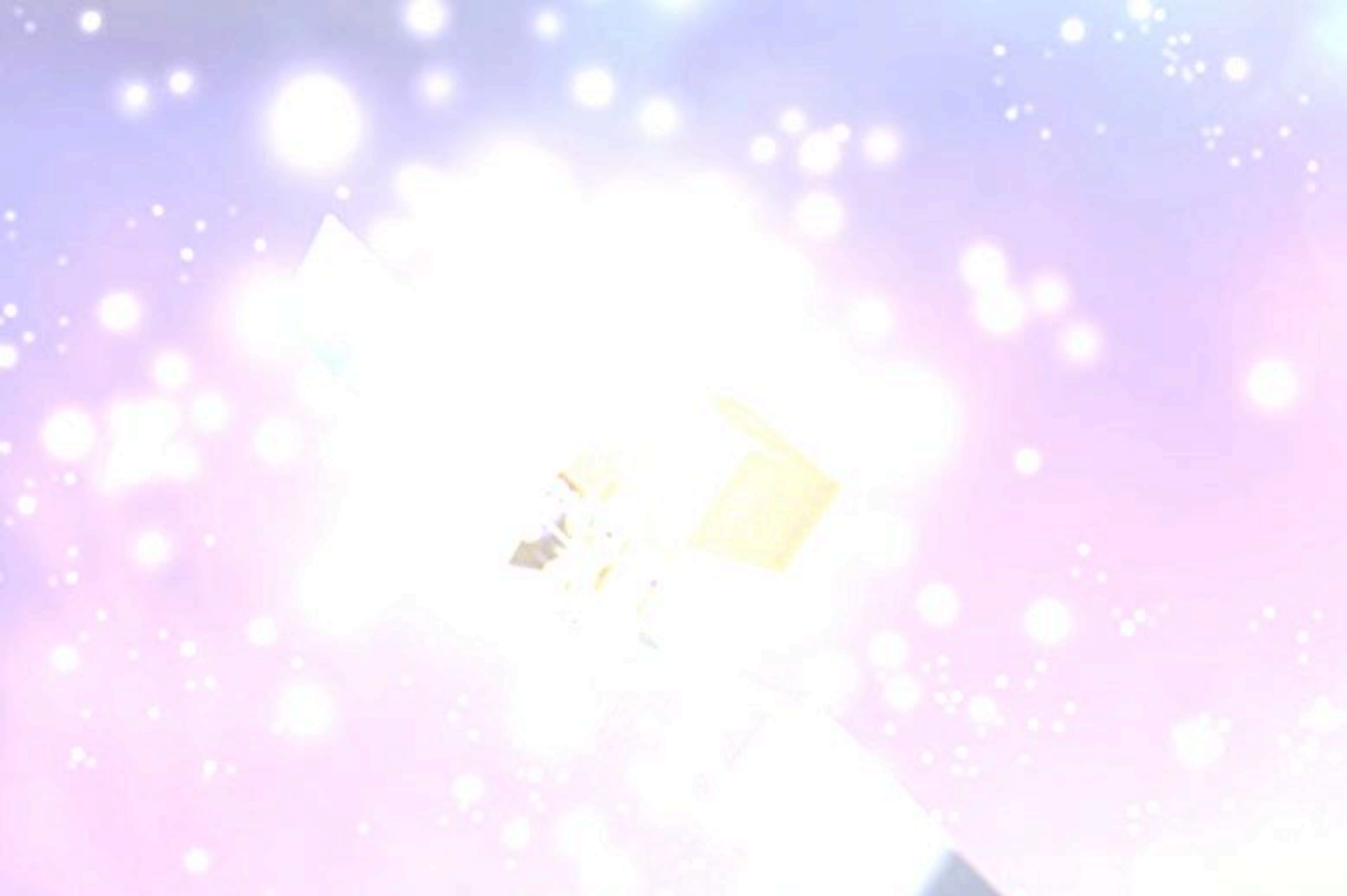


Conclusions

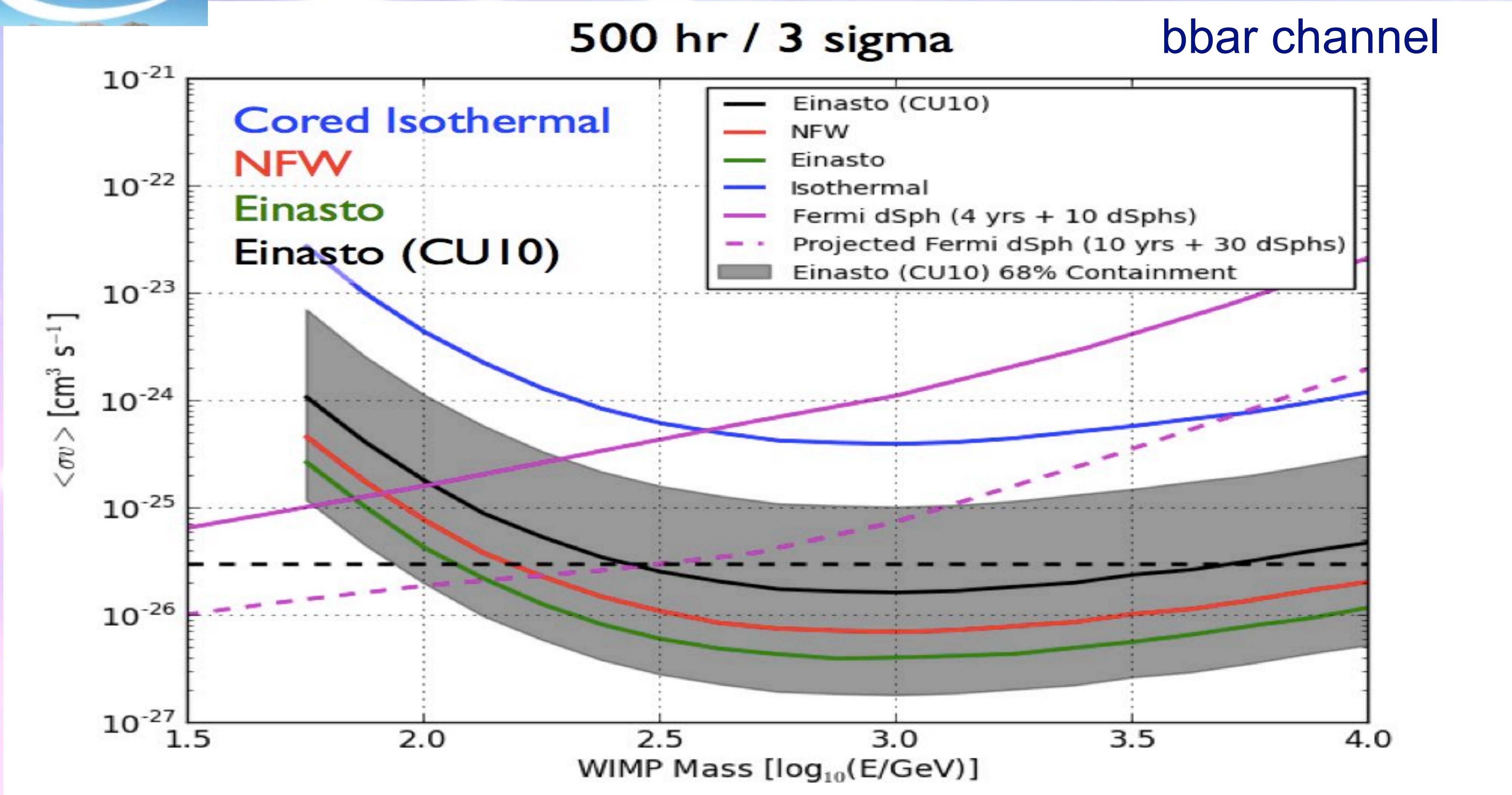
Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe (in synergy with the experiments at the LHC and in the underground laboratories).

In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies) (eg. Gamma-Light) and higher energies (HAWC, Dampe, HERD, Gamma-400, CTA, LHAASO)

Thank you !

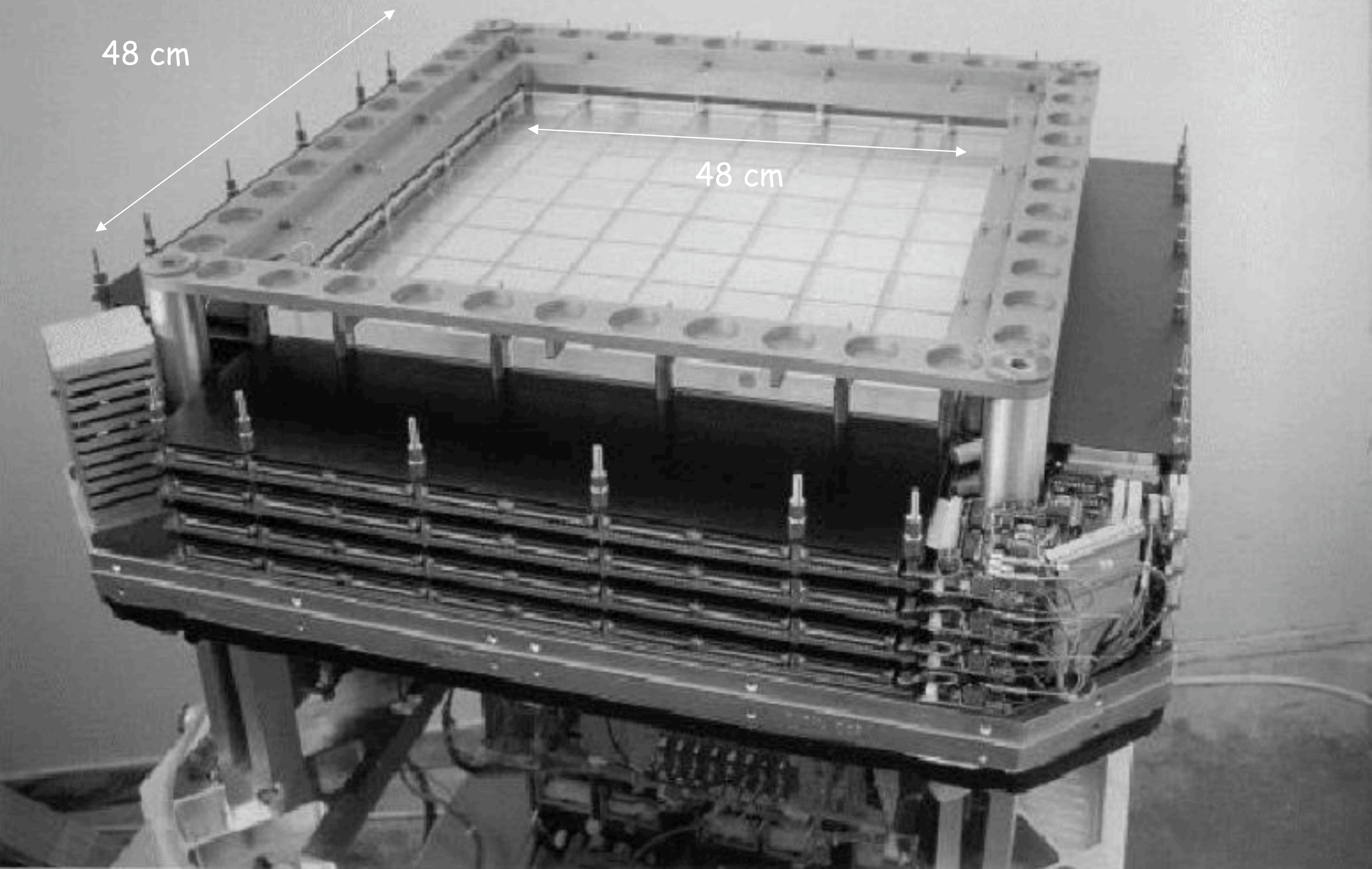


CTA and Galactic Center



Models with thermal relic cross section should be detectable assuming an extrapolation of the DM density profile consistent with CDM simulations

The TS93 and CAPRICE silicon-tungsten imaging calorimeter.



Galactic Center bump and LHC and direct detection results

- We revisit MSSM scenarios with light neutralino as a dark matter candidate in view of the latest LHC and dark matter direct and indirect detection experiments. We show that scenarios with a very light neutralino (~ 10 GeV) and a scalar bottom quark close in mass, can satisfy all the available constraints from LEP, Tevatron, LHC, flavour and low energy experiments and provide solutions in agreement with the bulk of dark matter direct detection experiments DAMA/LIBRA, CoGeNT and CRESST-II

Alexandre Arbey, Marco Battaglia, Farvah Mahmoudi, arxiv:1308.2153

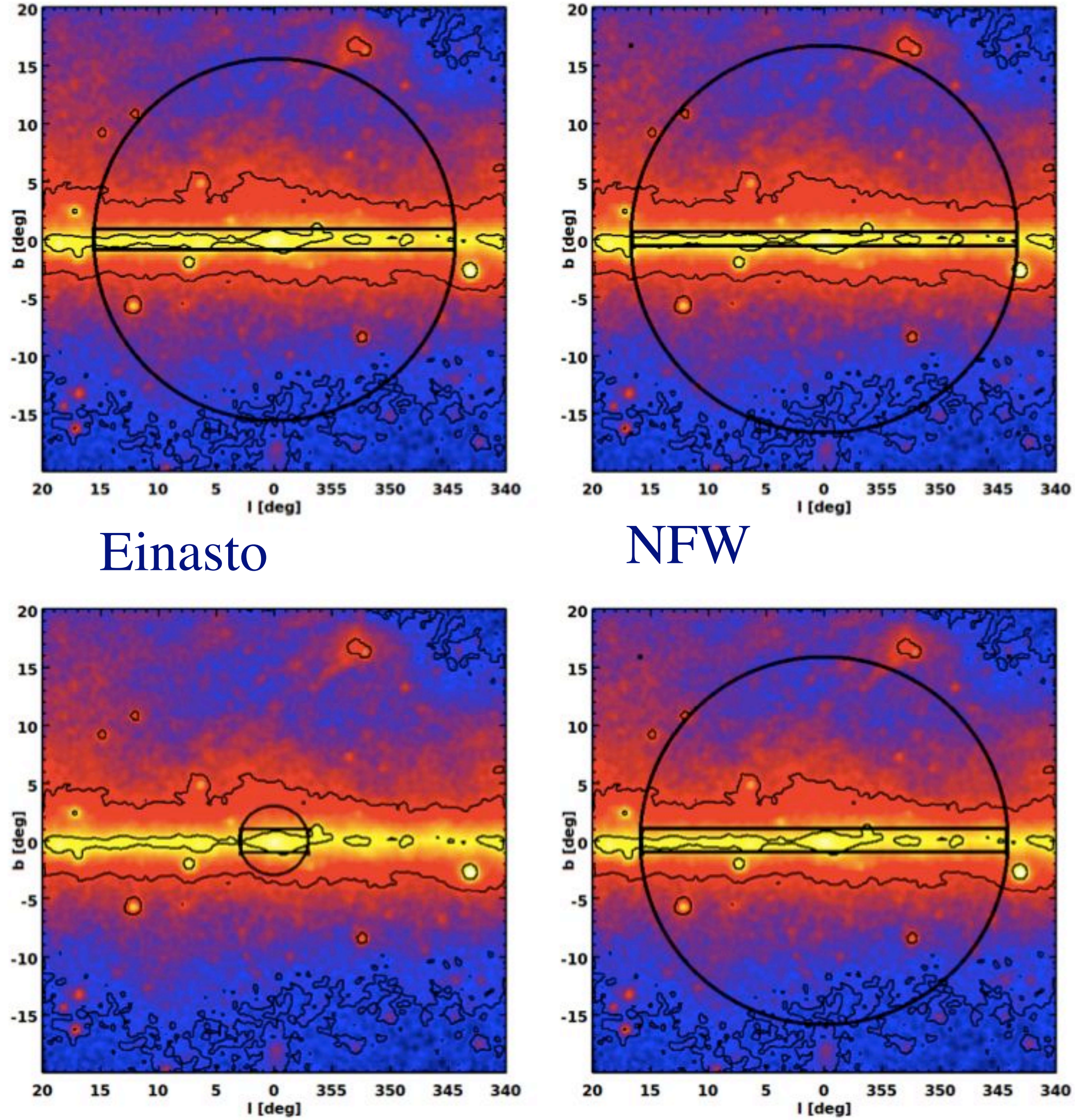
5-7 GeV bump produced by pulsar population ?

- we find that millisecond pulsars can account for no more than ~10% of the Inner Galaxy's GeV excess

Dan Hooper, Ilias Cholis, Tim Linden, Jennifer Siegal-Gaskins, Tracy Slatyer arXiv:1305.0830v1

Constraints from the inner Galaxy

Optimized ROI for each profile



Einasto NFW

NFWc Burkert

Gomez-Vargas et al. JCAP sub., arXiv:1308.3515

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 354 (1995) 547–552

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

The GILDA mission: a new technique for a gamma-ray telescope in the energy range 20 MeV–100 GeV

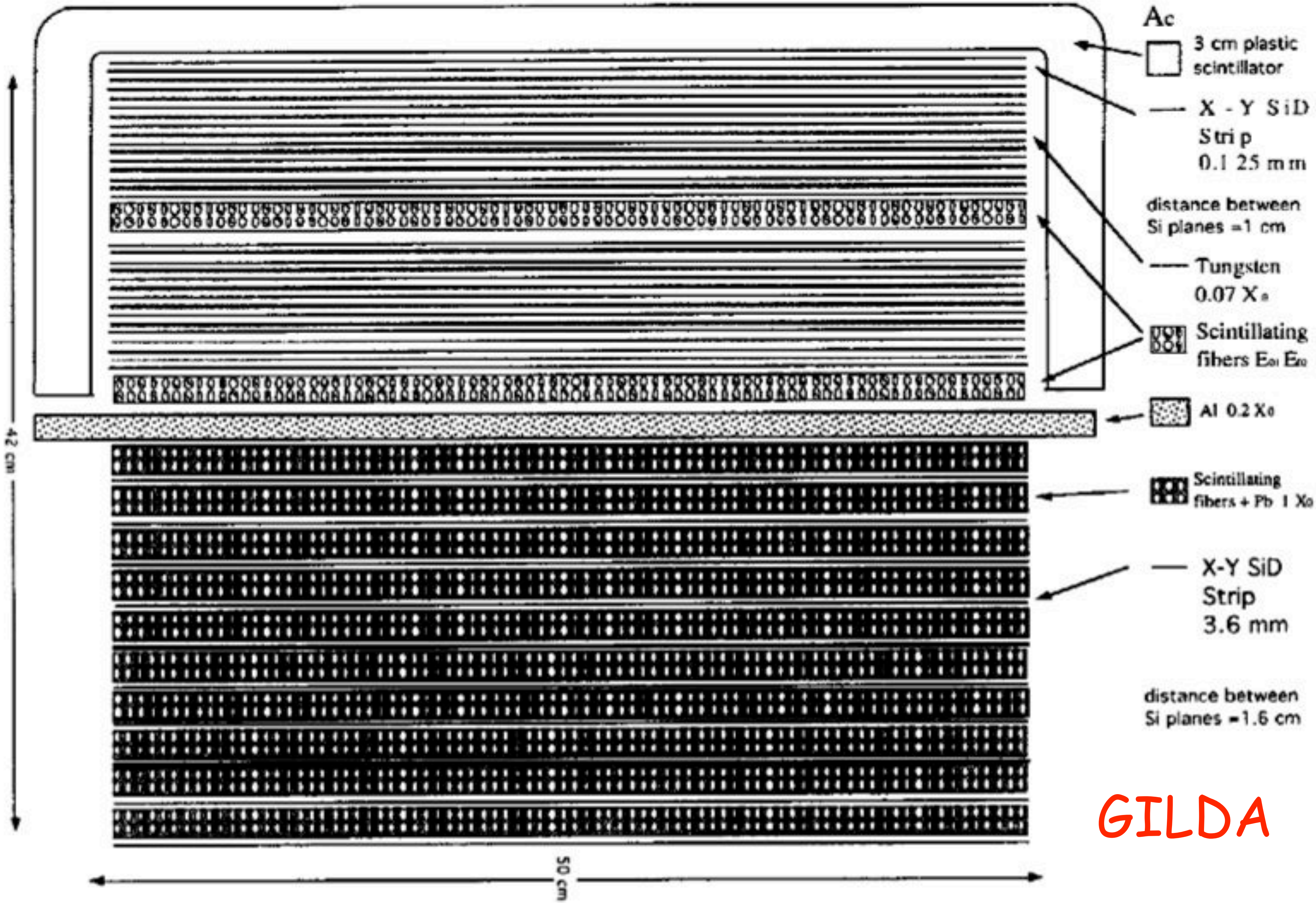
G. Barbiellini [a], M. Boezio [a], M. Casolino [b], M. Candusso [b], M.P. De Pascale [b], A. Morselli [b,*], P. Picozza [b], M. Ricci [d], R. Sparvoli [b], P. Spillantini [c], A. Vacchi [a]

[a] *Dept. of Physics, Univ. of Trieste and INFN, Italy*
[b] *Dept. of Physics, II Univ. of Rome "Tor Vergata" and INFN, Italy*
[c] *Dept. of Physics, Univ. of Firenze and INFN, Italy*
[d] *INFN Laboratori Nazionali di Frascati, Italy*

Received 5 August 1994

Abstract

In this article a new technique for the realization of a high energy gamma-ray telescope is presented, based on the adoption of silicon strip detectors and lead scintillating fibers. The simulated performances of such an instrument (GILDA) are significatively better than those of EGRET, the last successful experiment of a high energy gamma-ray telescope, launched on the CGRO satellite, though having less volume and weight.



Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
distance between Si planes =1 cm
Tungsten 0.07 X_0
Scintillating fibers E_{01} E_{02}
Al 0.2 X_0
Scintillating fibers + Pb 1 X_0
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm

GILDA

Quindi eravamo pronti per rispondere alla Call for Ideas ASI per Piccole Missioni (Scienze dell'Universo) 26 giugno 1997
e rispondemmo con due proposte:

- GILDA 40

e

- AGILE

Proposta per la *Call for Ideas* **ASI per Piccole Missioni (Scienze dell'Universo)**
26 giugno 1997

GILDA40: rivelatore di raggi gamma al Silicio

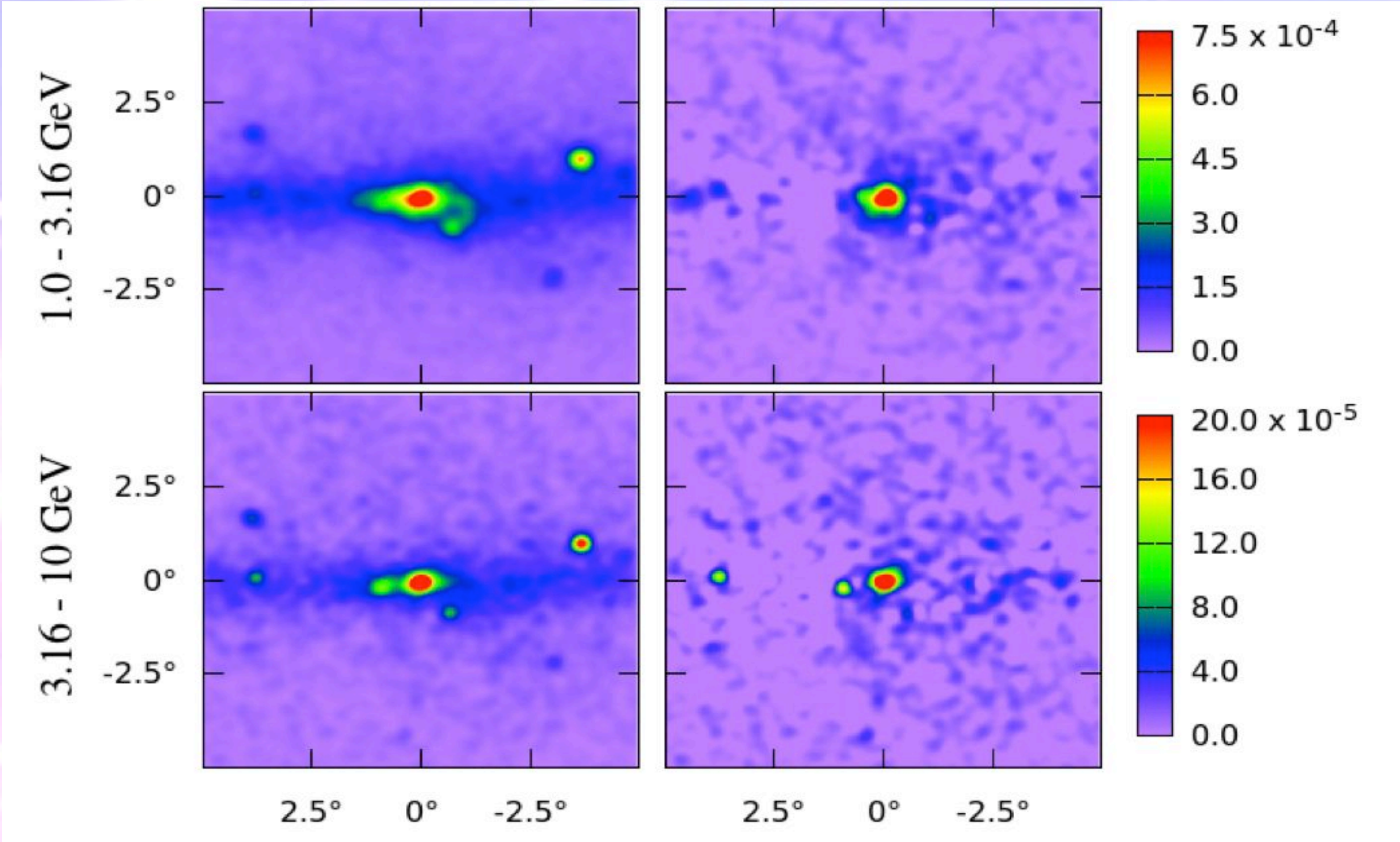
A. Morselli[1], G. Barbiellini[2], M. Boezio[2], P. Caraveo[3], M. Casolino[1], M. P. De Pascale[1], S. Mereghetti[3], A.Perrino[2], P. Picozza[1], P. Schiavon[2], R. Sparvoli[1], M. Tavani[3,4], A. Vacchi[2]

1. Dipartimento di Fisica, Universitá "Tor Vergata" e INFN.
2. Dipartimento di Fisica, Universitá di Trieste e INFN.
3. Istituto di Fisica Cosmica e Tecnologie Relative, CNR, Milano.
4. Columbia Astrophysics Laboratory, Columbia University, New York, USA.

Introduzione

La proposta del telescopio gamma GILDA40 nasce dall'attivita' consolidata della collaborazione internazionale denominata WiZard che prevede le missioni *Nina* (prevista volare per l'autunno 1997) e *Pamela* (programmata per la seconda meta' del 2000). Cio' significa che esiste un contesto scientifico in cui GILDA40 si inserisce naturalmente. Costi e tempi di sviluppo possono essere realisticamente e sensibilmente bassi visto che e' possibile attingere a tutto il lavoro di progettazione, realizzazione e test gia' esistente (vedi descrizione tecnica). Il telescopio GILDA40 fa infatti uso di rivelatori al silicio ad alta risoluzione spaziale. Questi offrono grandi vantaggi per la rivelazione astrofisica di radiazione gamma: non presentano problemi di rifornimento di gas, non necessitano di alti valori di tensione nè di fotomoltiplicatori per l'analisi del segnale, presentano un tempo morto breve (1μs) e un trigger dato esclusivamente dai piani di silicio. Lo strumento consiste in un tracciatore al silicio e di un calorimetro di dimensioni e peso opportunamente configurati in base all'orbita scelta. GILDA40 puo' volare sia su un satellite a puntamento con orbita equatoriale, che in *scanning mode* su un satellite elio-sincrono. GILDA40 puo' essere realizzata interamente in Italia entro tre anni con un costo dello strumento inferiore ai 10 miliardi di lire.

Galactic Center and Dark Matter

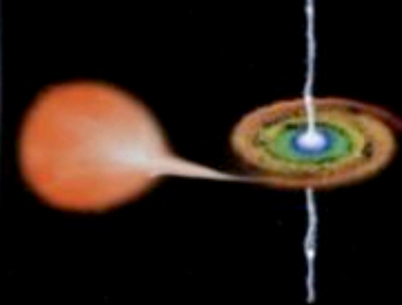
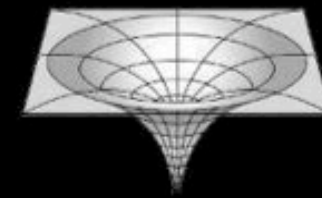


A raw image of the Galactic Center region

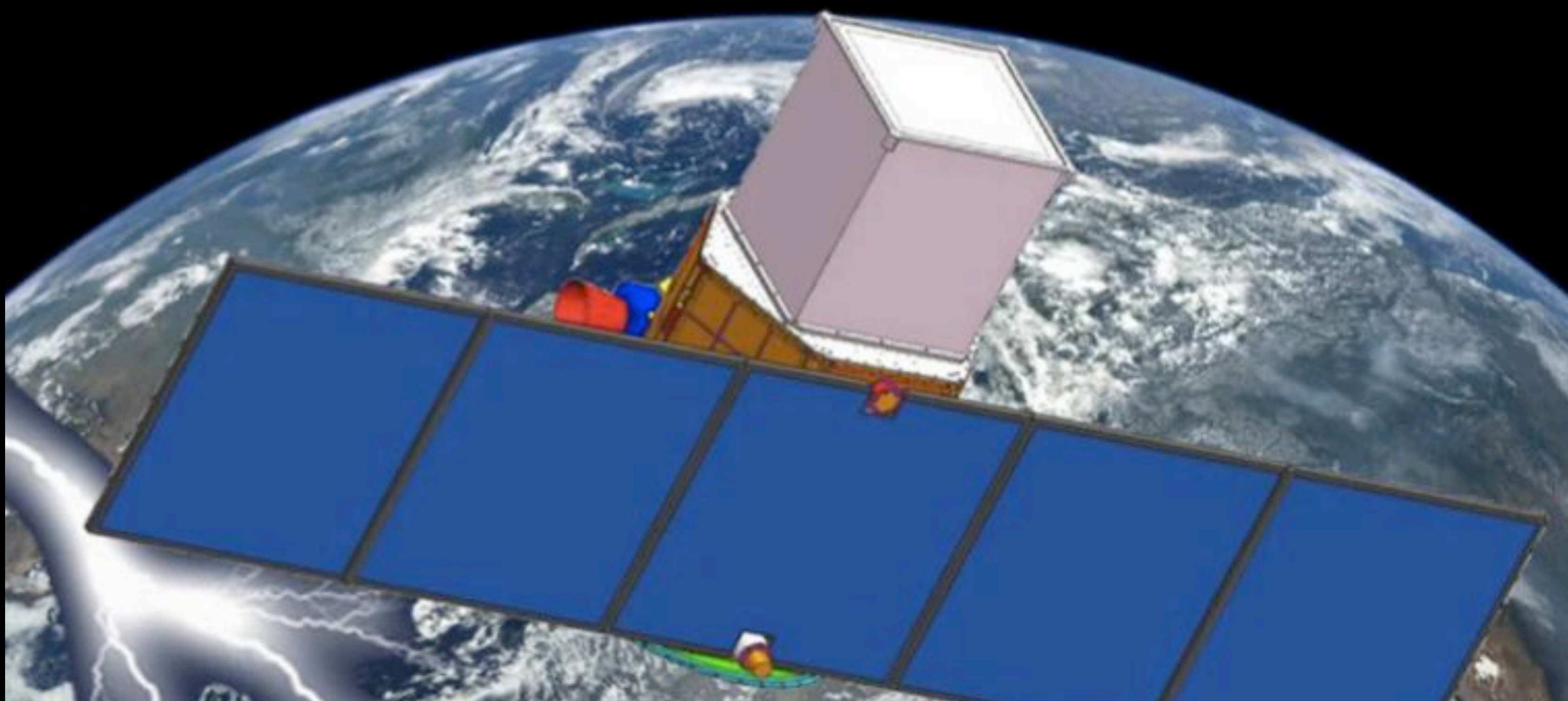
all known sources subtracted

- Spatially extended excess of 1-3 GeV γ rays with a spectrum, angular distribution, and overall normalization that is in good agreement with that predicted by simple annihilating dark matter models"
- Well fit by a 31-40 GeV WIMP with $\langle\sigma v\rangle = (1.4 - 2.0) \times 10^{-26}\ cm^3/s$
- approximately spherically symmetric and centered around the dynamical center of the Milky Way

A Compelling Case for Annihilating Dark Matter arXiv:1402.6

Gamma-Light



http://people.roma2.infn.it/~morselli/Morselli_Scineghe_rr2.pdf

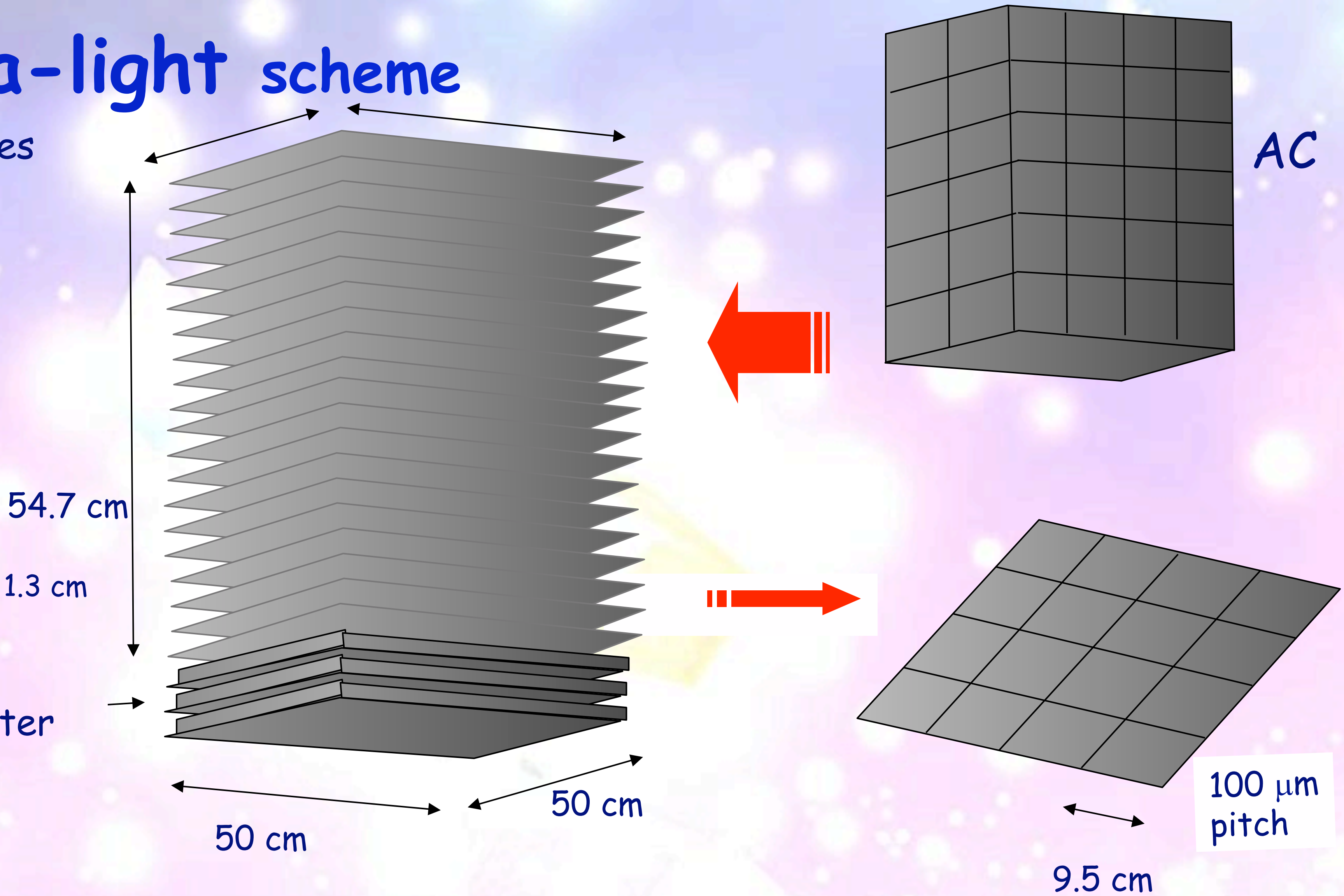
Gamma-light scheme

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

Tot~ 1 X_0

height of a plane 1.3 cm

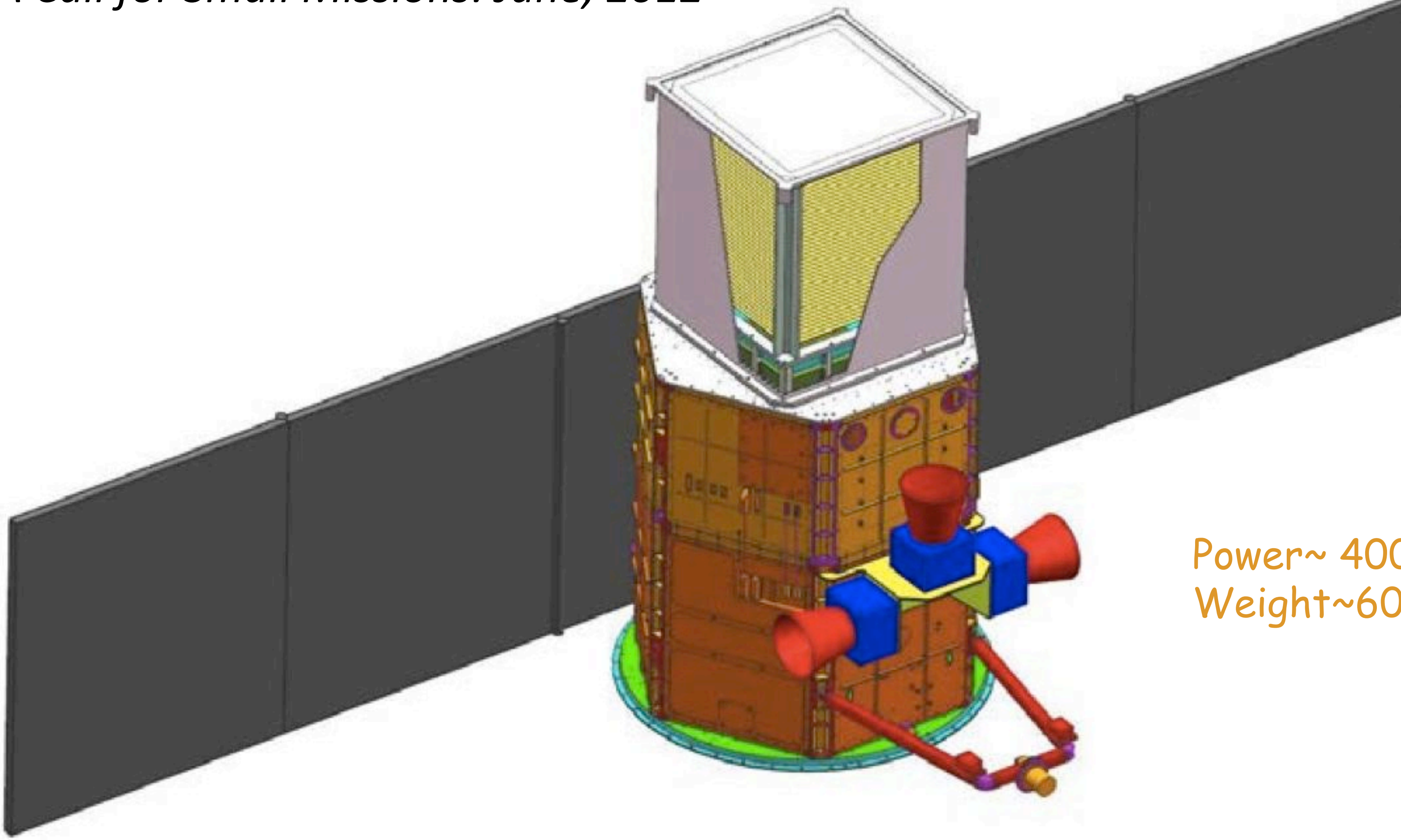
2 Xo Calorimiter



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

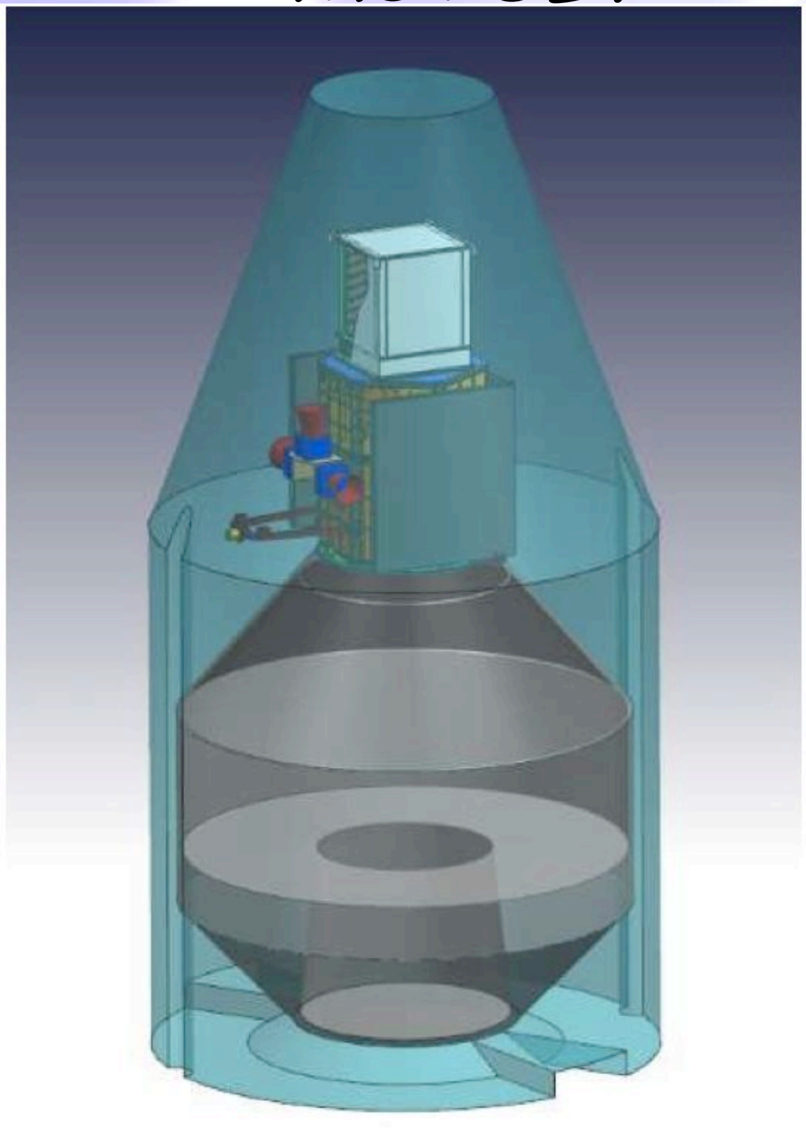
Gamma-light payload

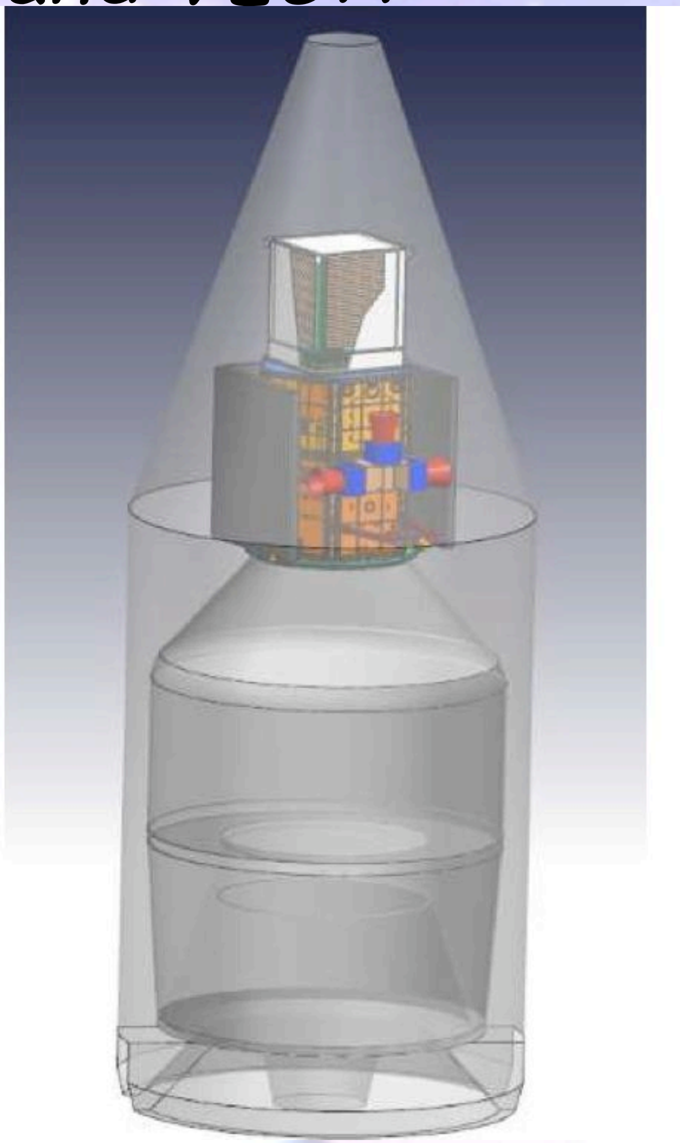
ESA Call for Small Missions: June, 2012



Power~ 400 W
Weight~600 Kg

GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA

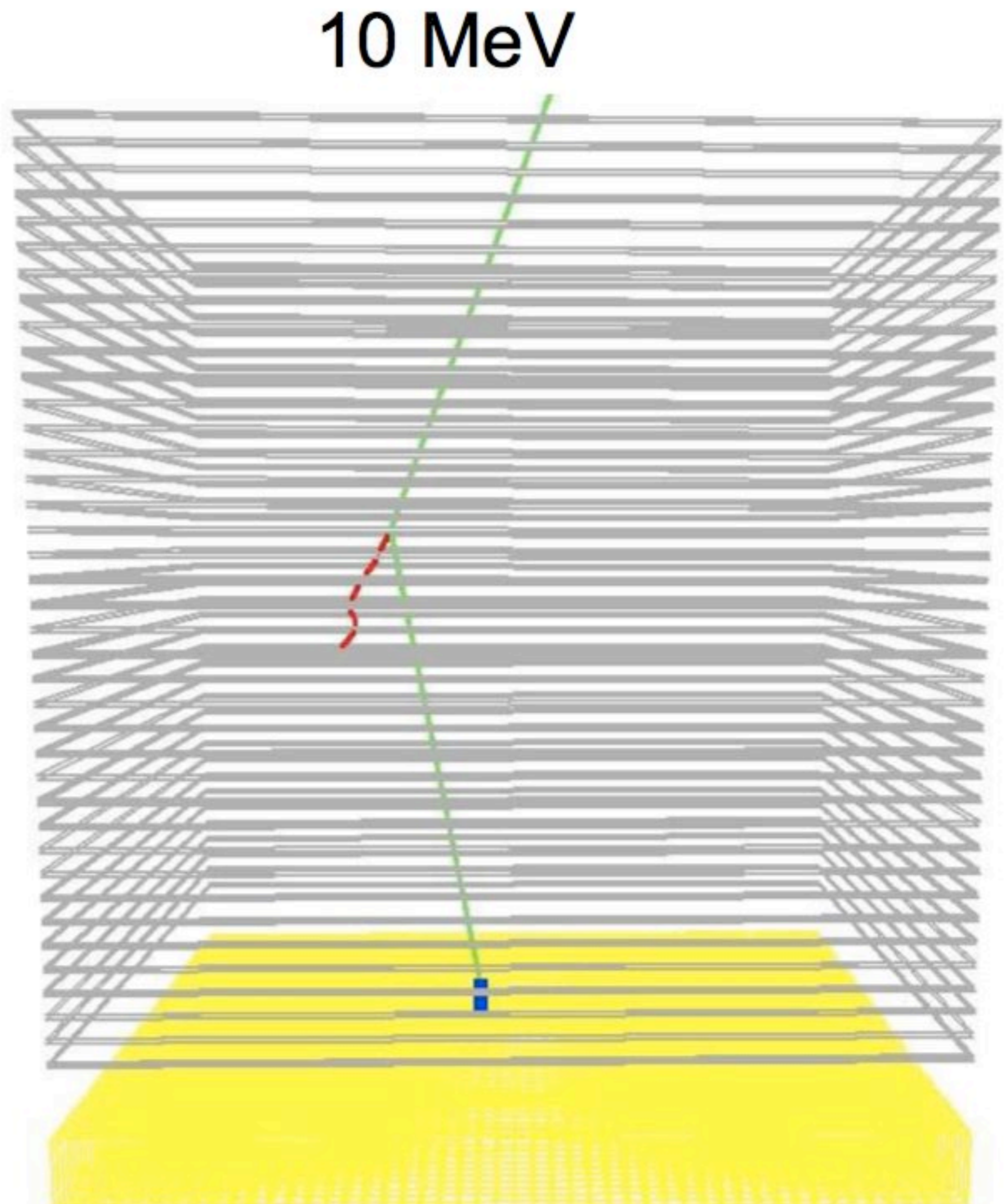




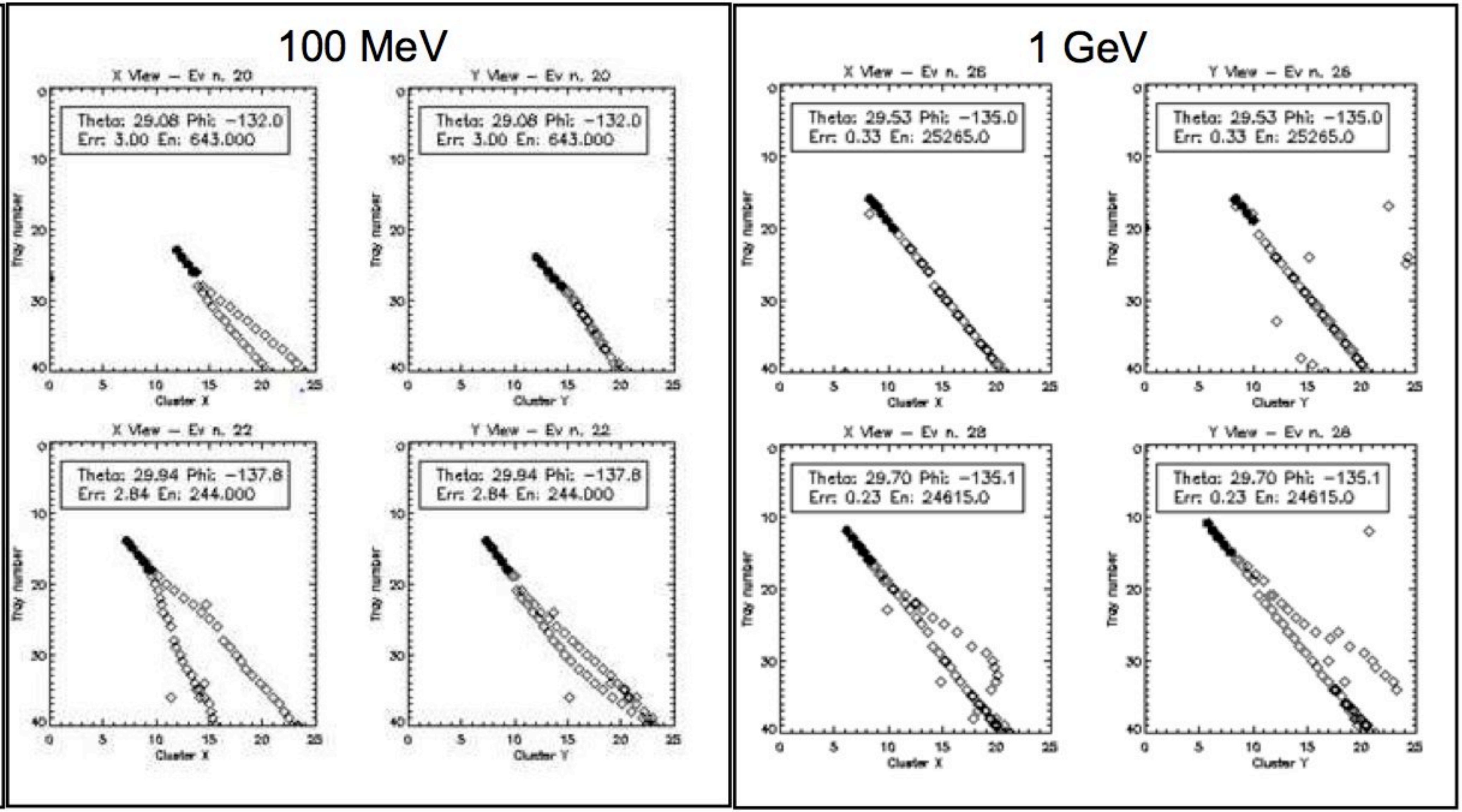
- a companion satellite similar to G-LIGHT can be accomodated.

G-LIGHT Simulation

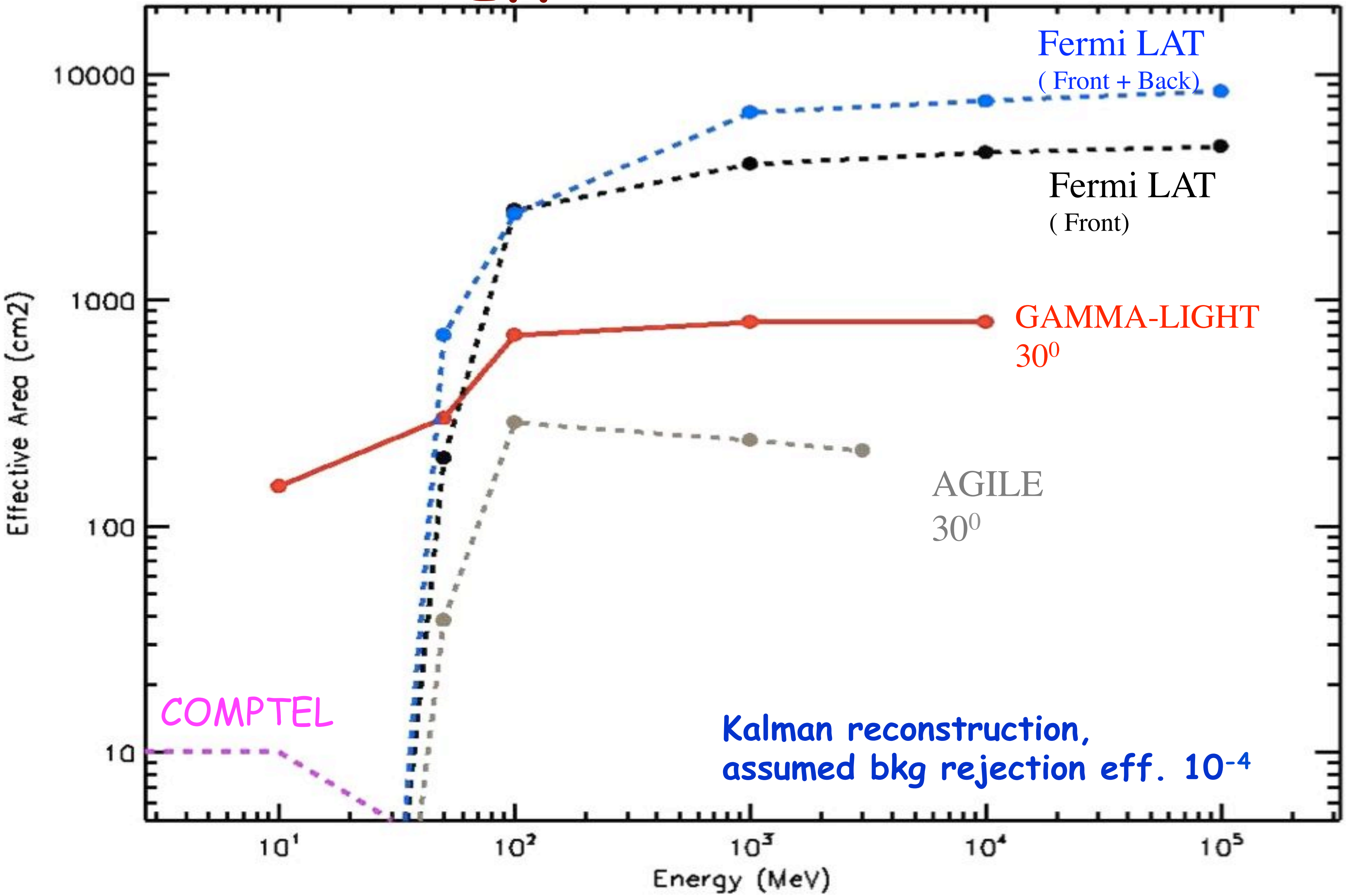
Compton interaction of a 10 MeV photon producing a low-energy single-track electron, and depositing energy in the Calorimeter for a 30^0 incidence



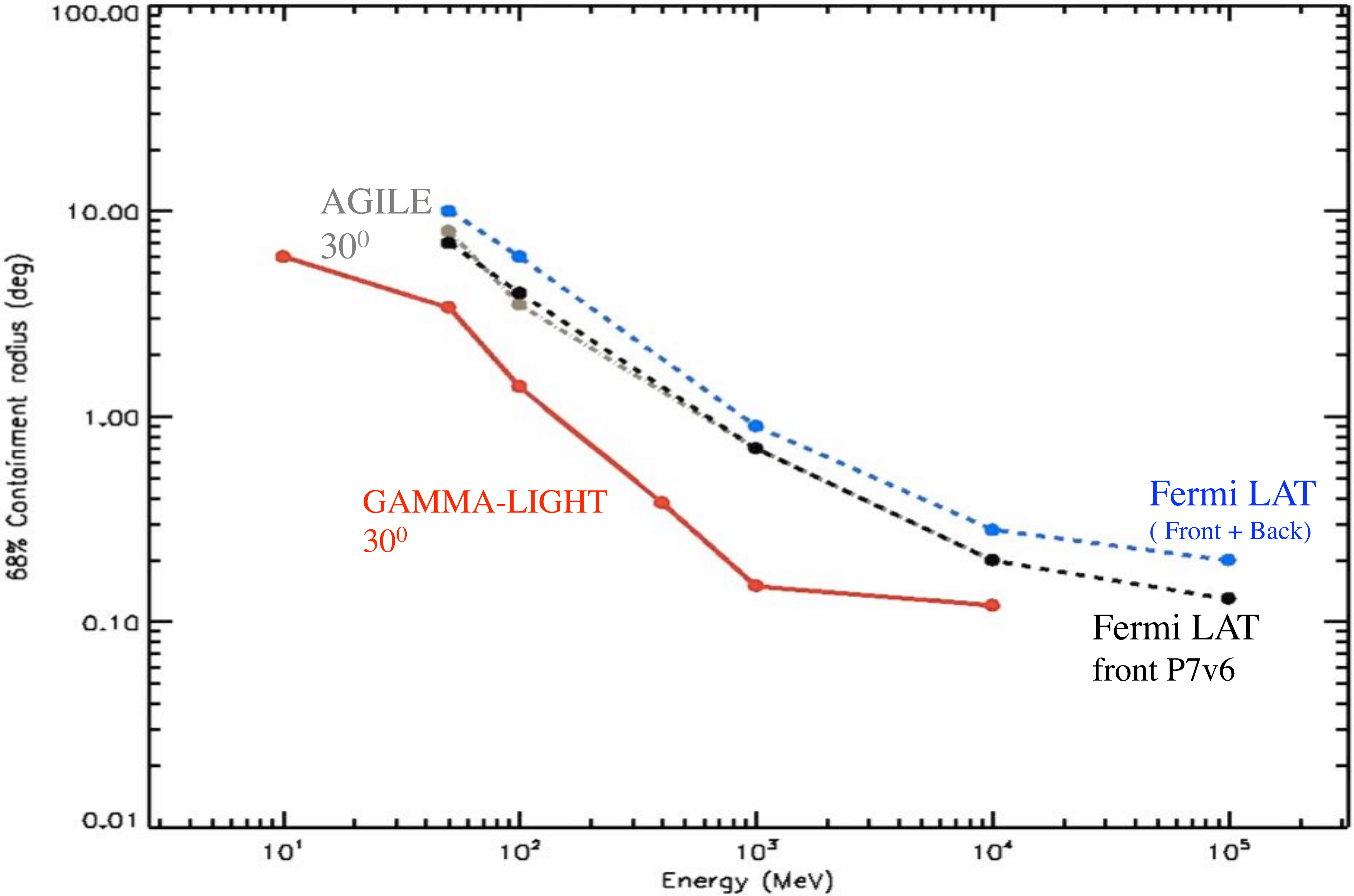
Gamma-light *Simulation*

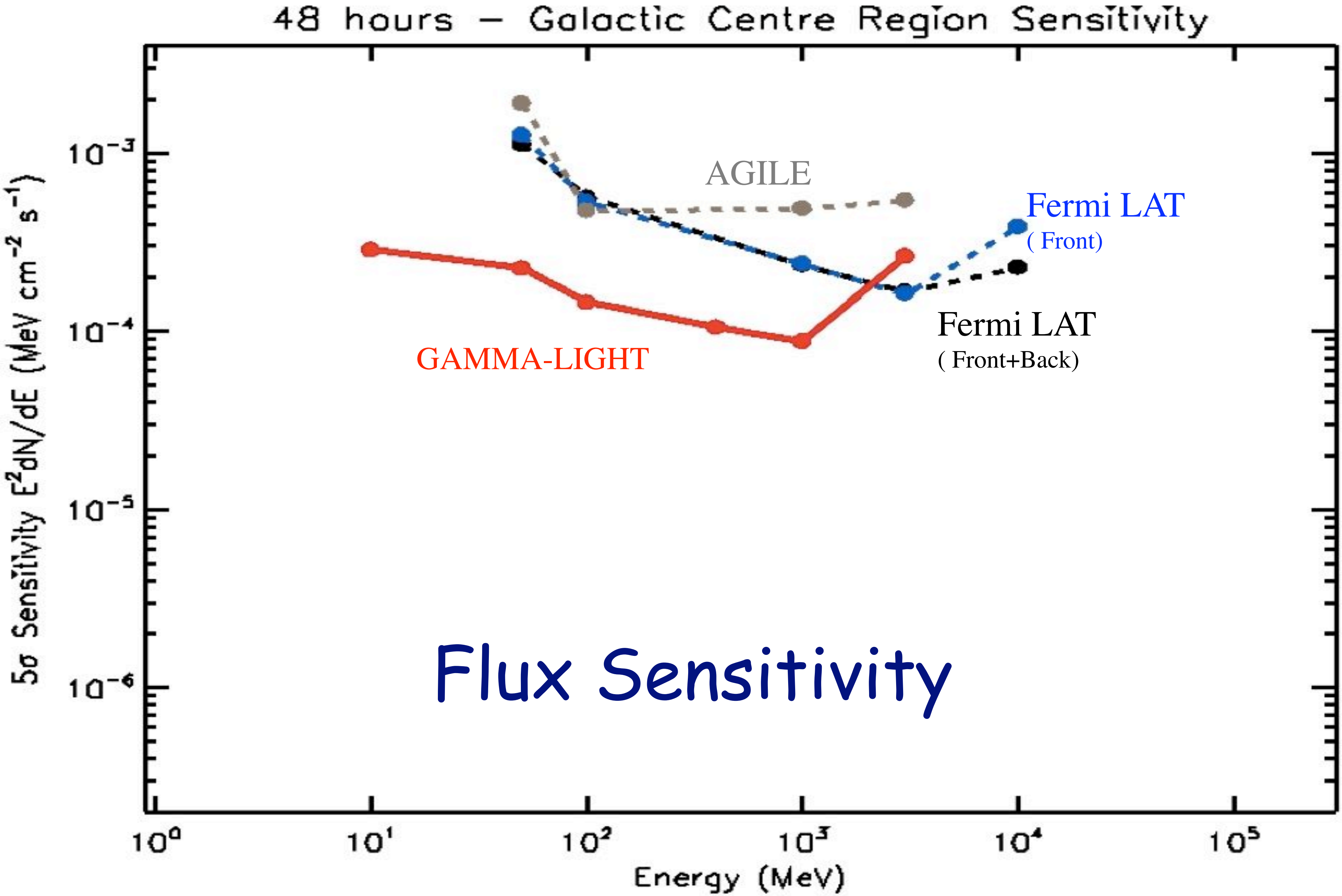


Effective area



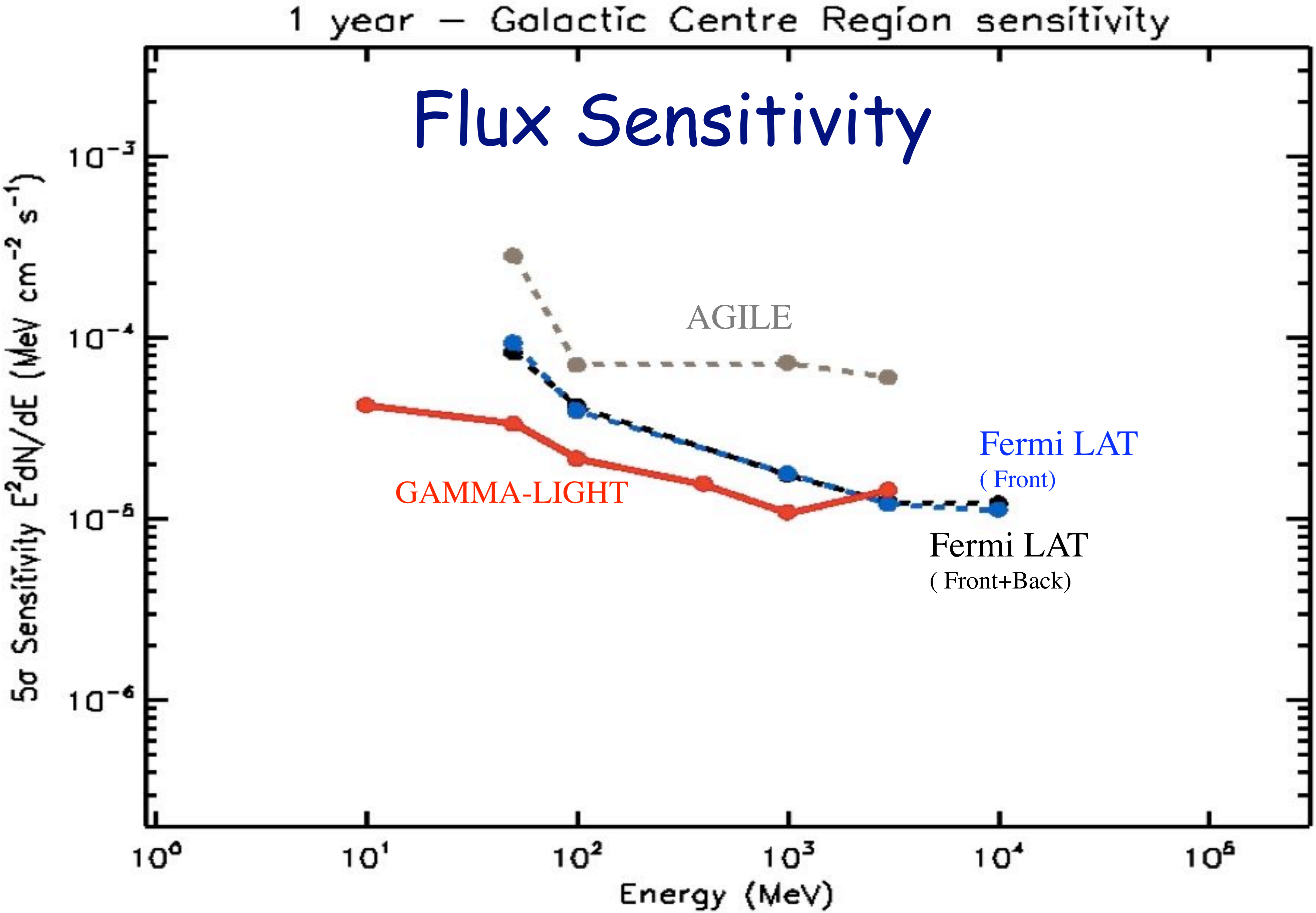
PSF (68% containment radius)





Flux Sensitivity

Flux Sensitivity



Astrophysics Objectives of GAMMA-LIGHT

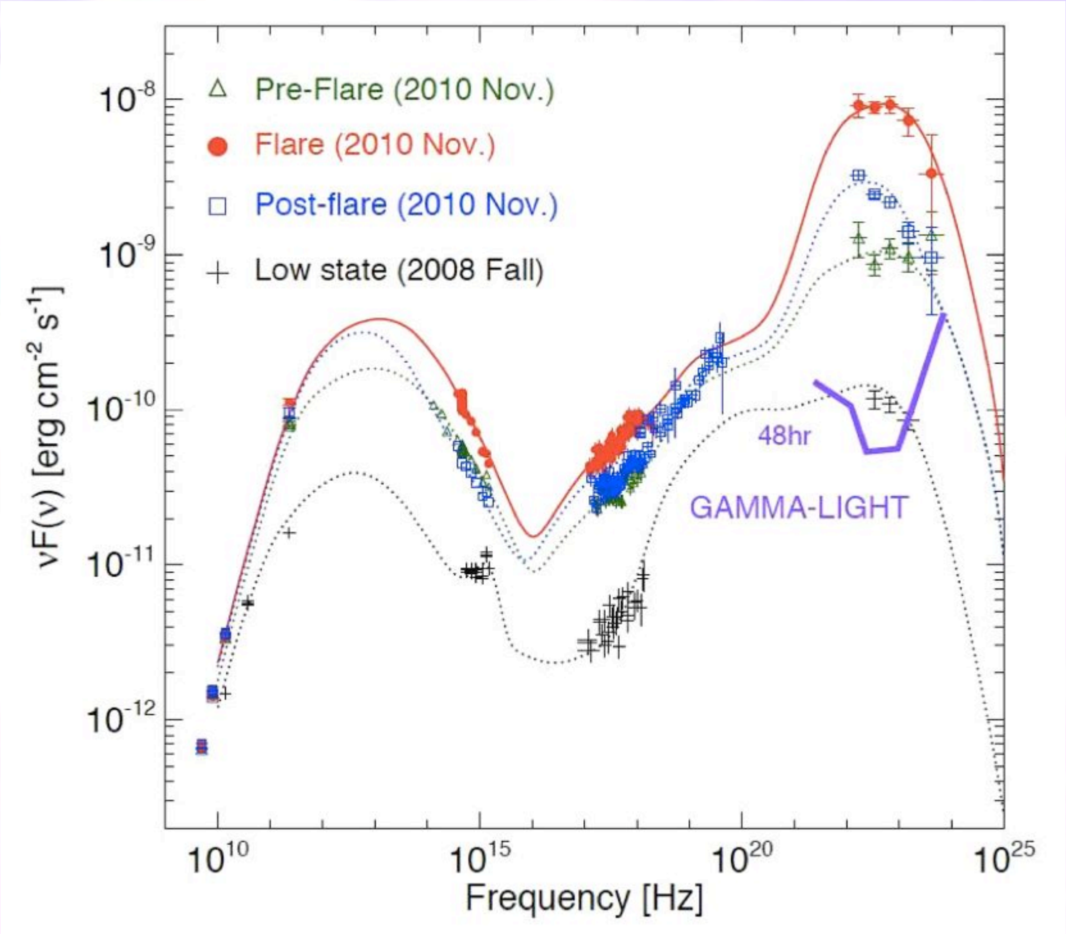
- 1. Search of Dark Matter gamma-ray signatures in the Galaxy and in particular in the Galactic Center region;
- 2. Resolving the Galactic Center region in gamma-rays: the central BH region, GeV and TeV sources, nebulae, compact sources, SNRs;
- 3. Resolving the diffuse emission in the Galactic plane, 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.

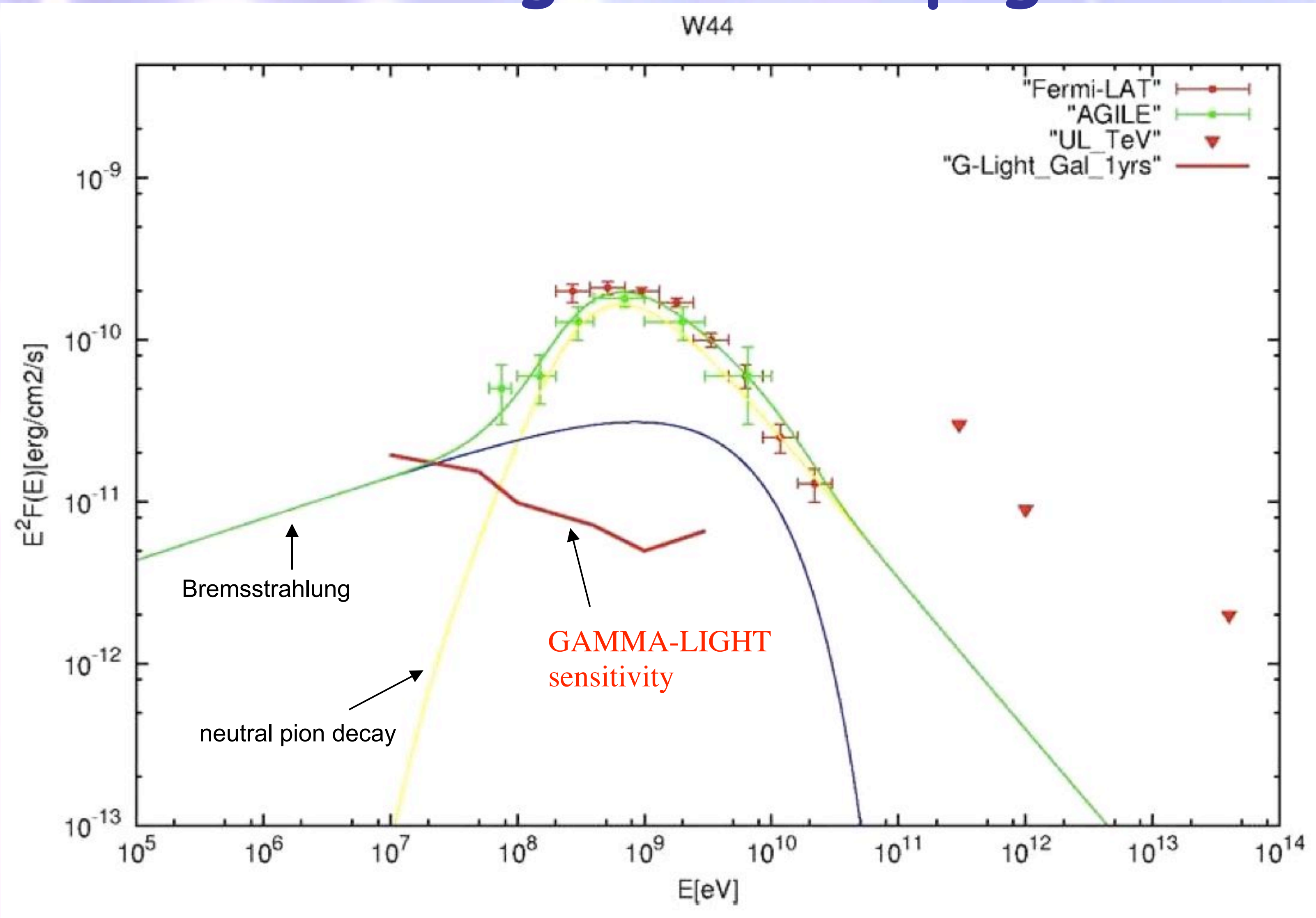
Extragalactic Sources, Blazars, MeV Blazars

Multi-epoch SEDs of the FSRQ 3C454.3

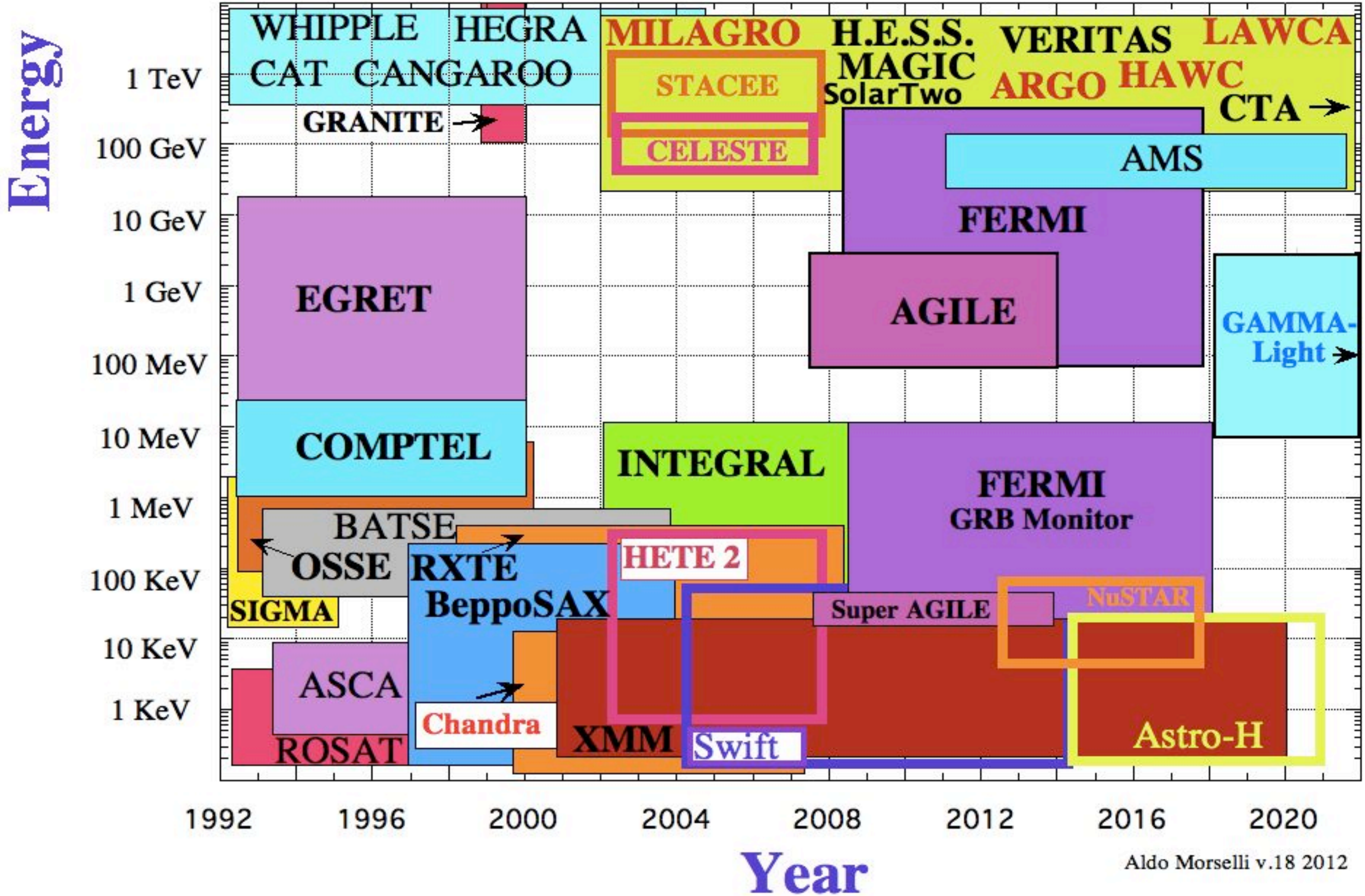


G-LIGHT will allow us to investigate daily (or sub-daily) SEDs during gamma-ray super- flares. The 5-sigma G-LIGHT differential sensitivity (purple line) is computed for an integration time of 48 hours

SNRs and the Origin and Propagation of CRs



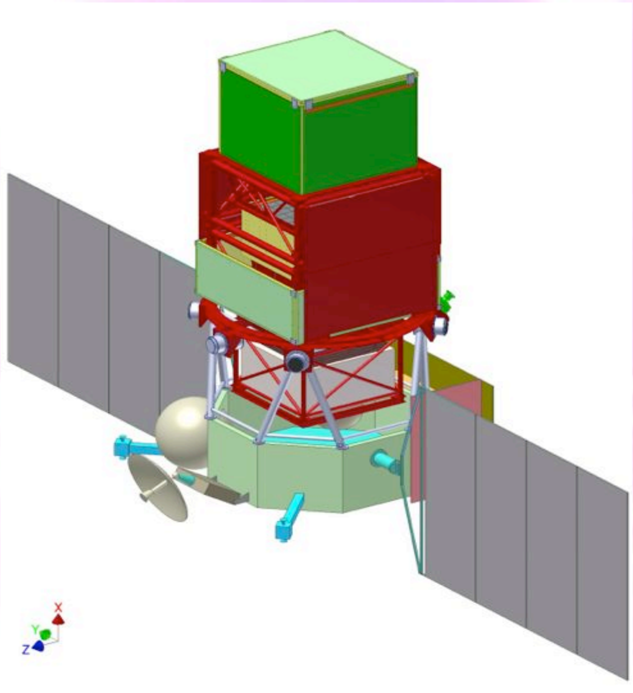
- *gamma-ray spectrum of SNRs W44. The red curve shows the expected GAMMA-LIGHT sensitivity for a 1-year effective time integration.*


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
LAWCA
HAWC
CTA
AMS
FERMI
EGRET
AGILE
GAMMA-Light
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
NuSTAR
ASCA
Chandra
XMM
Swift
Astro-H
ROSAT
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli v.18 2012

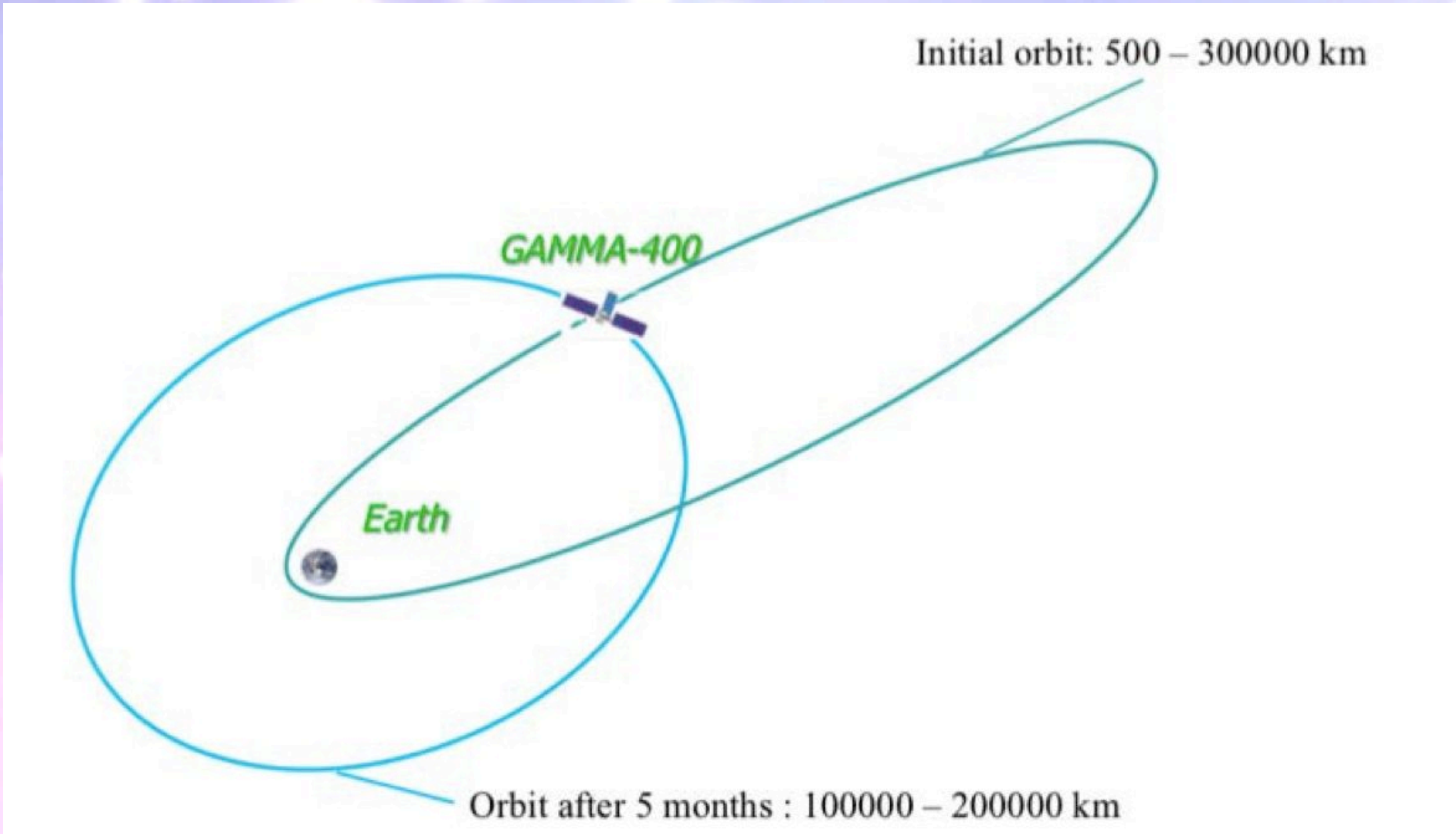
Gamma-400

Gamma-400 goals: follow and deepen the findings of Fermi LAT (similar energy range and instrument overall capabilities). Very suitable for the search for WIMPs. However much better performance at high energy (> 10 GeV): PSF and energy resolution. Search for dark matter is the main goal for Gamma-400

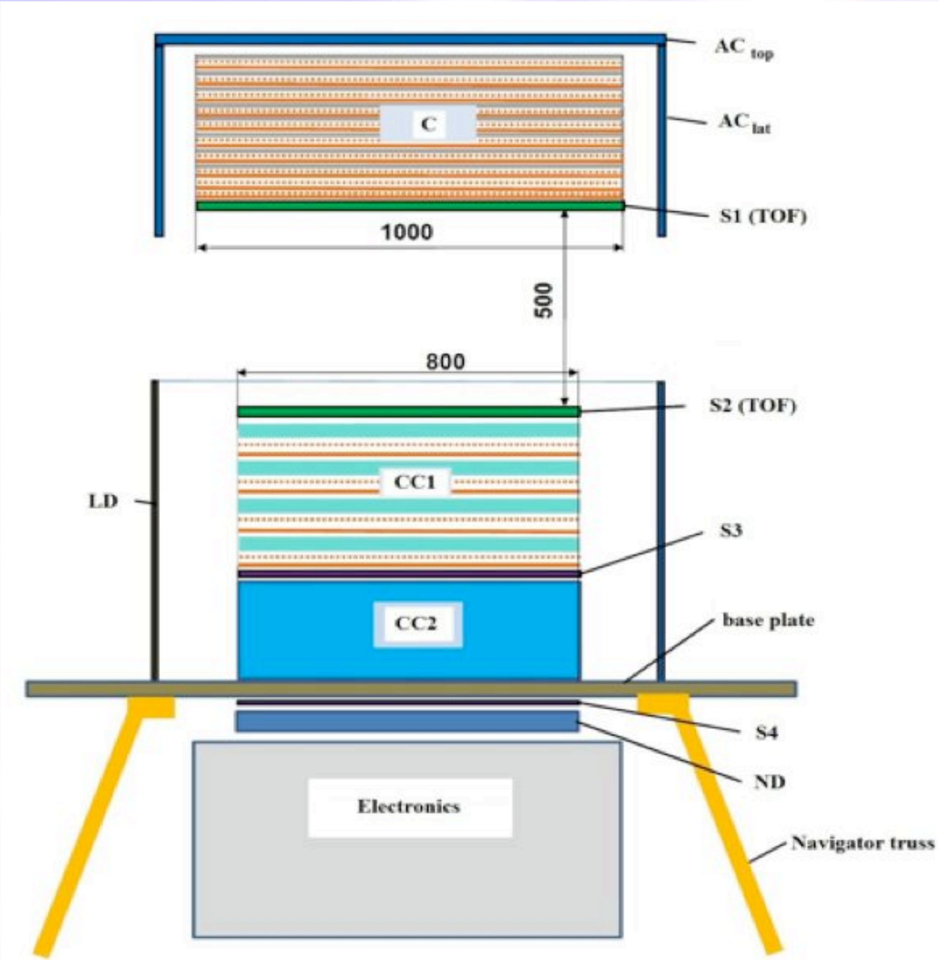
- A new high-energy space γ-ray telescope
- Approved and fully funded by Russian Space Agency Russian, included in Federal Space Program
- Uses the Navigator service module made by Lavochkin Association, recently used for the Radioastron mission, planned for other missions
- Uses technology similar to Fermi Large Area Telescope (tracker/converter, energy measurement system, anticoincidence detector), but with better angular and energy resolution
- Launch is planned for 2018-2019



Gamma-400 Orbit

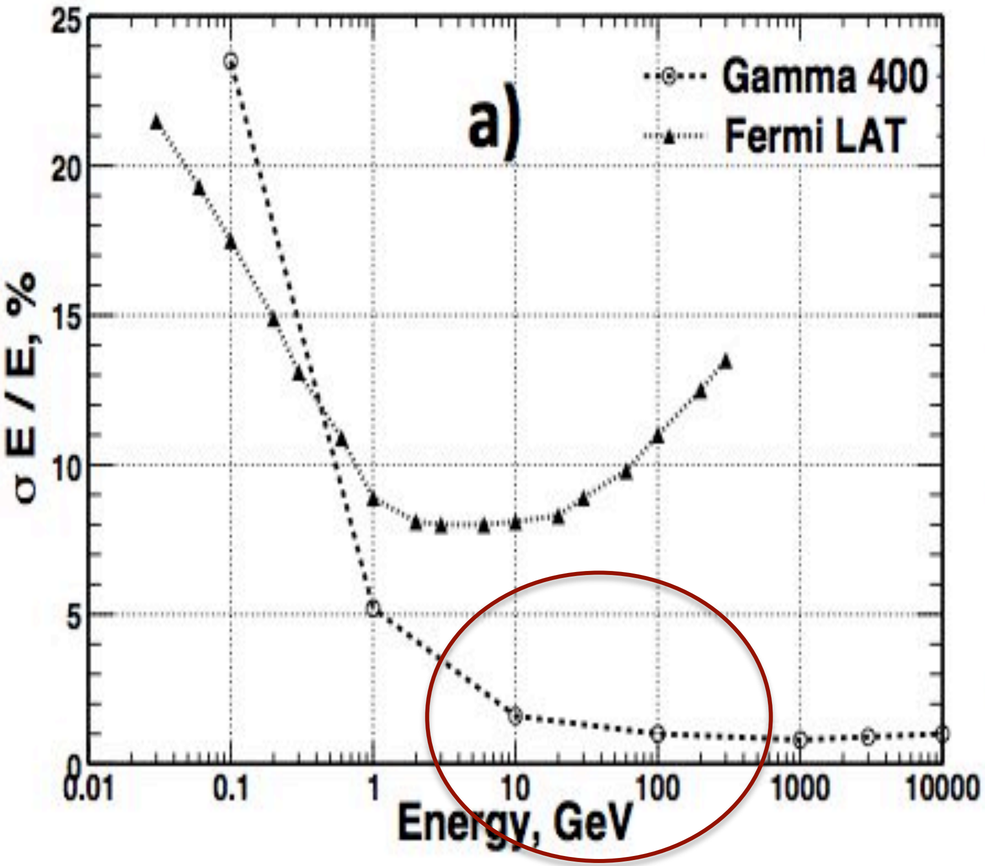


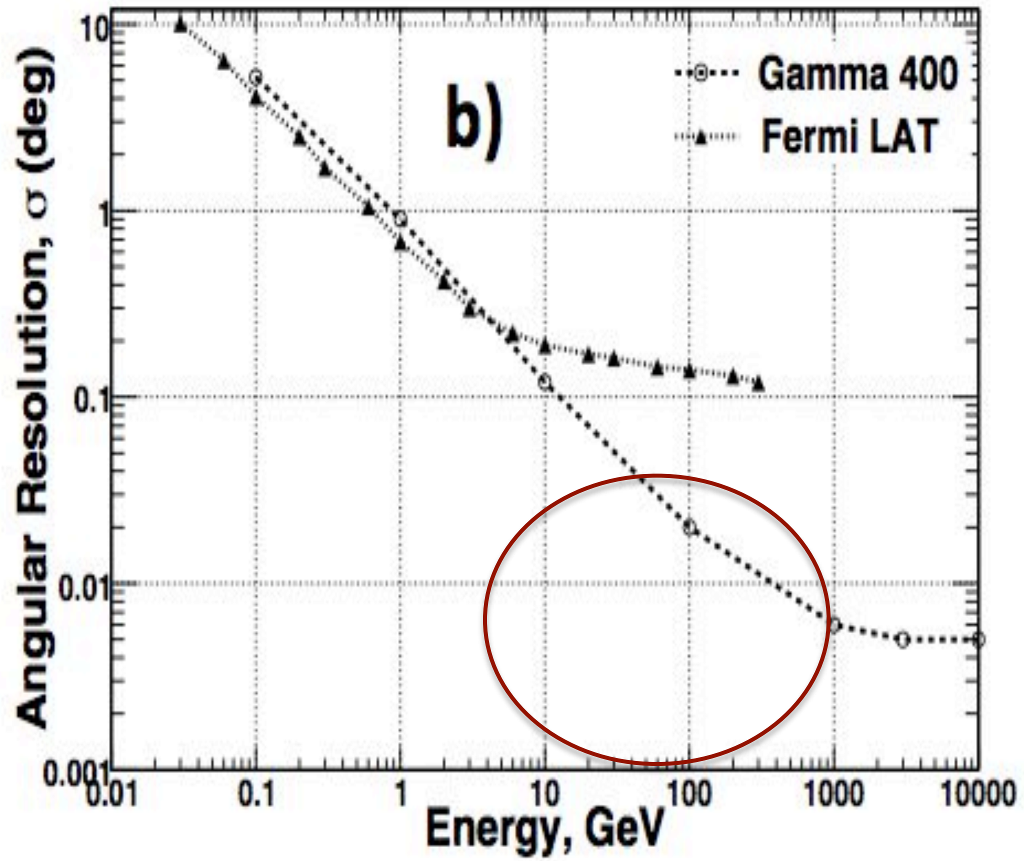
Gamma-400 Concept



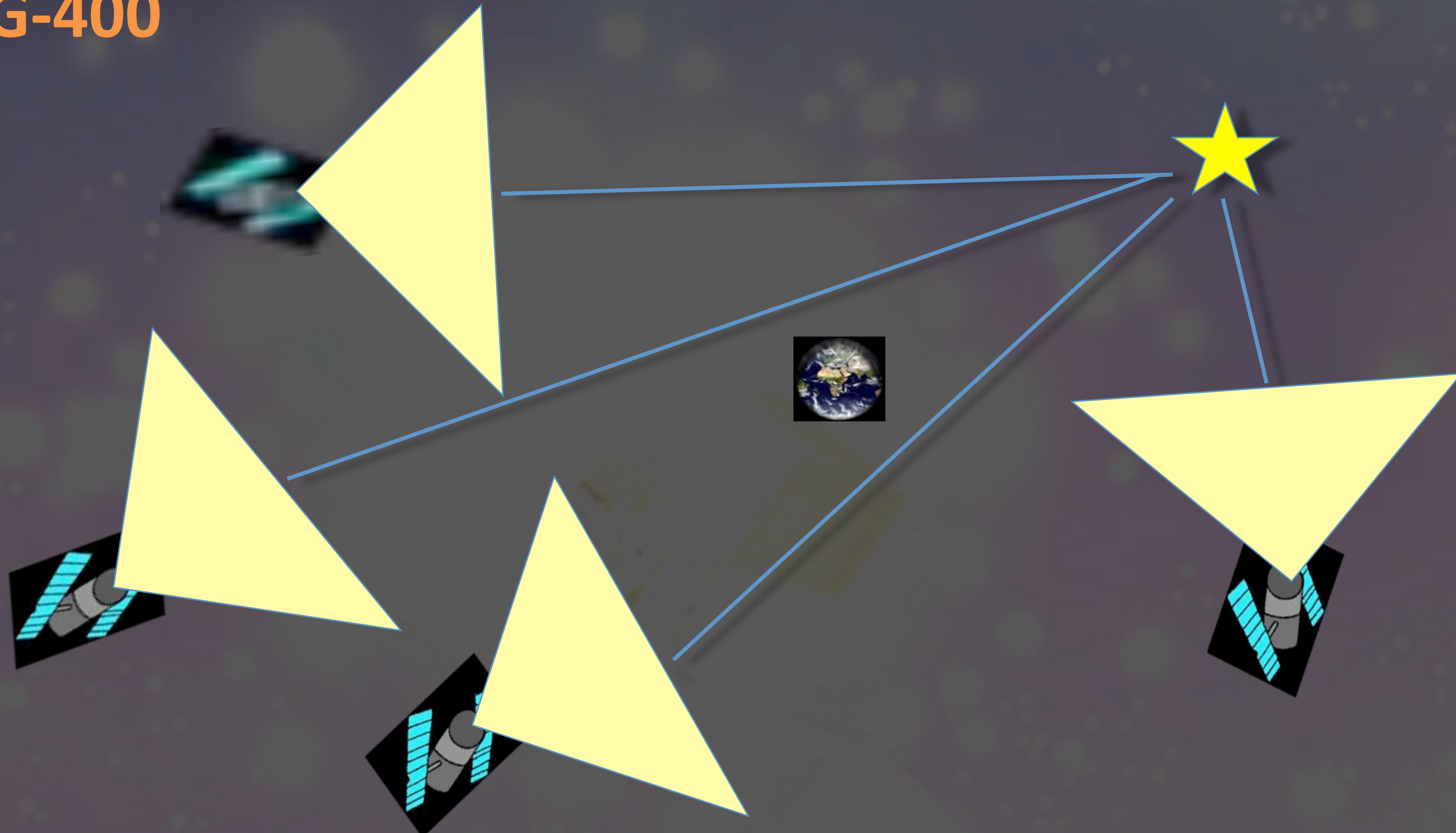
Energy range	100 MeV – 3000 GeV
Field-of-view, sr (E > 1 GeV)	~1.2
Effective area, cm^2 (E > 1 GeV)	~4,000
Energy resolution (E > 10 GeV)	~1%
Angular Resolution (E >100 GeV)	~0.01°
Converter-tracker thickness	~ $1X_0$
Calorimeter thickness	~ 25 X_0
Proton rejection factor	~ 10^6
Telemetry downlink volume, GB/day	100
Total mass, kg	2,600
Maximum dimensions, m	2.0 x 2.0 x 3.0
Power consumption, W	2,000

Gamma-400 Performance





G-400



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.

NEWS & ANALYSIS

***Science*, 20 May 2011**

SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing

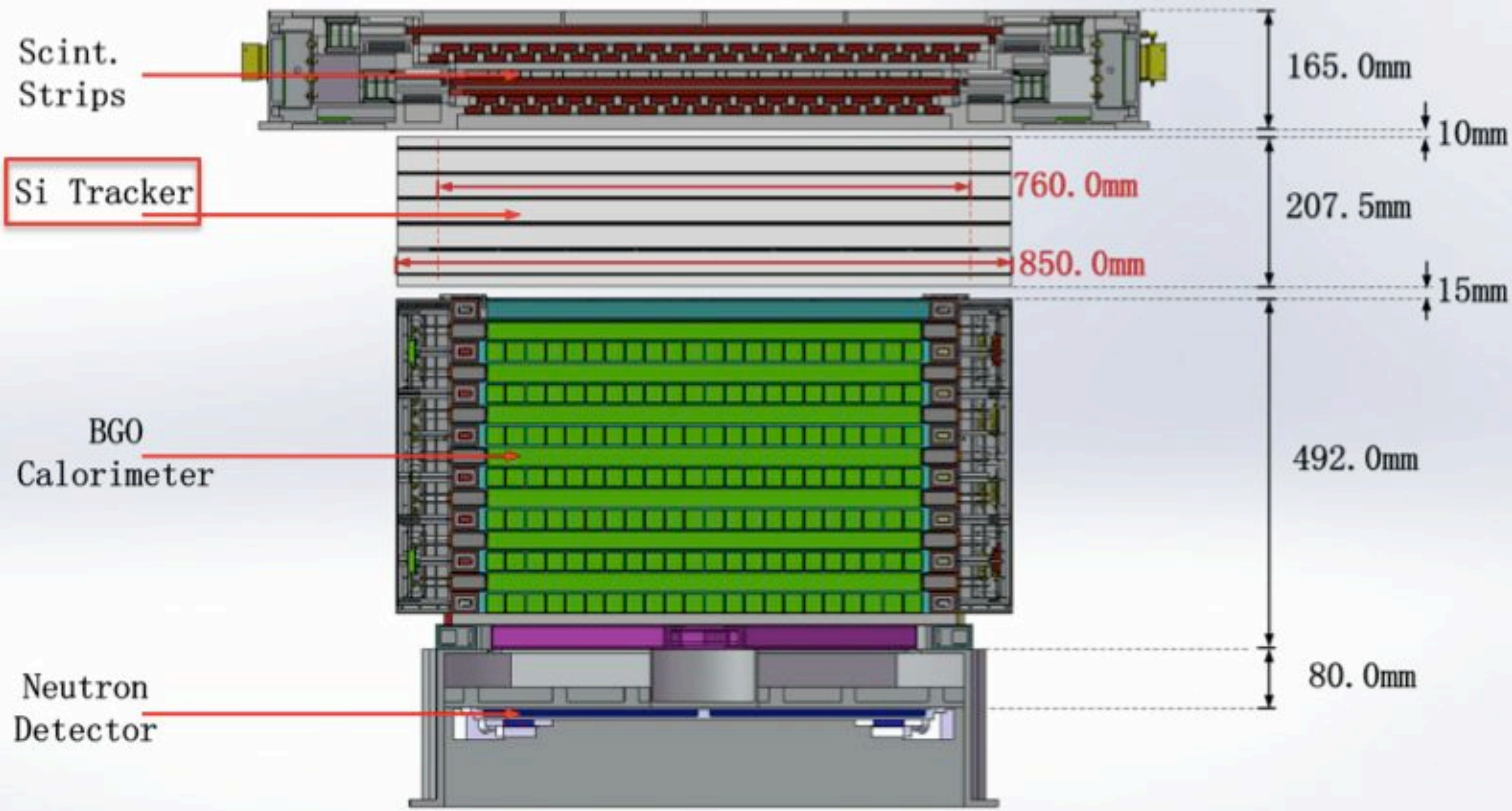
LOFTY AMBITIONS

Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
KuaFu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

Strategic Priority Research Program in Space Science

Dark Matter Particle Explorer Satellite

DAMPE Detector Layout



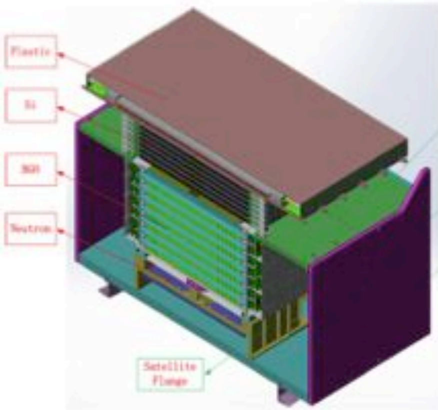
- Scintillator strips, Silicon tracker, BGO calorimeter, neutron detector
- Combine a γ-ray space telescope with a deep imaging calorimeter
  - Silicon tracker/converter + BGO imaging calorimeter
    - Total ~33 X_0 → deepest detector in space

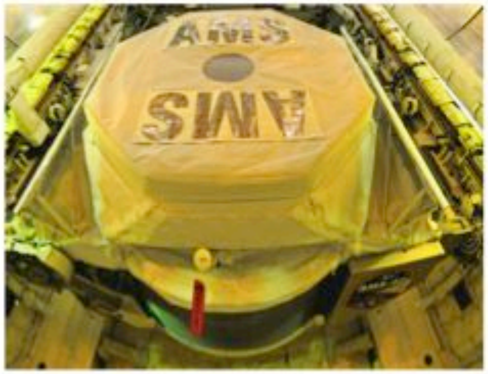
DAMPE Tracker Components

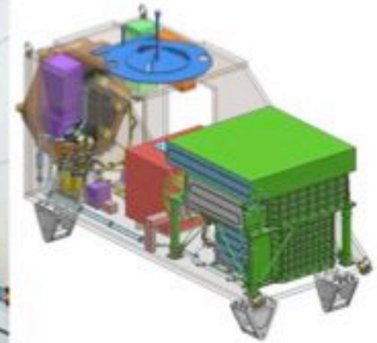
- Silicon sensor (Hamamatsu)
  - use AGILE specification
- FE ASIC (Gamma Medica-Ideas)
  - use updated version of the AMS-02 ASICs, already available thanks to INFN Perugia R&D
- Electronics (INFN Pg, DPNC for specs)
  - use updated version of the AMS readout and power electronics
- Silicon ladder (INFN Pg +DPNC)
  - similar to AMS-02
- Silicon plane and tracker assembly (DPNC + INFN Pg)
  - based on AMS-02 experience

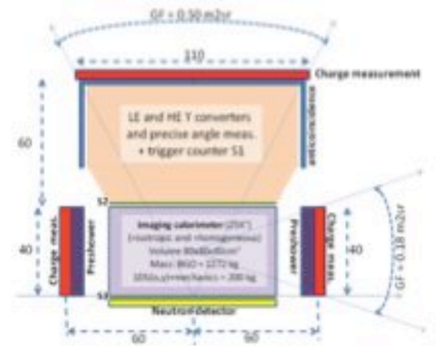
Proven technologies and profiting from previous experiences!

DAMPE and other detectors









	DAMPE	AMS-02	Fermi LAT	CALET	GAMMA-400
Energy range (GeV)	5 - 10^4	0.1 - 10^3	0.02 - 300	1 - 10^3	0.1 – 3 10^3
e/γ Energy res.@100 GeV (%)	1.5	3	10	2	1
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1	0.1	0.01
e/p discrimination	10^5	10^5 - 10^6	10^3	10^5	10^6
Calorimeter thickness (X_0)	31	17	8.6	30	25
Geometrical accep. ($m^2 sr$)	0.4	0.09	1	0.12	0.5