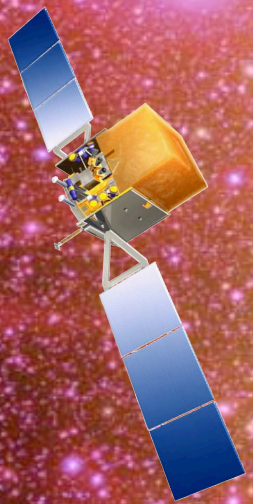
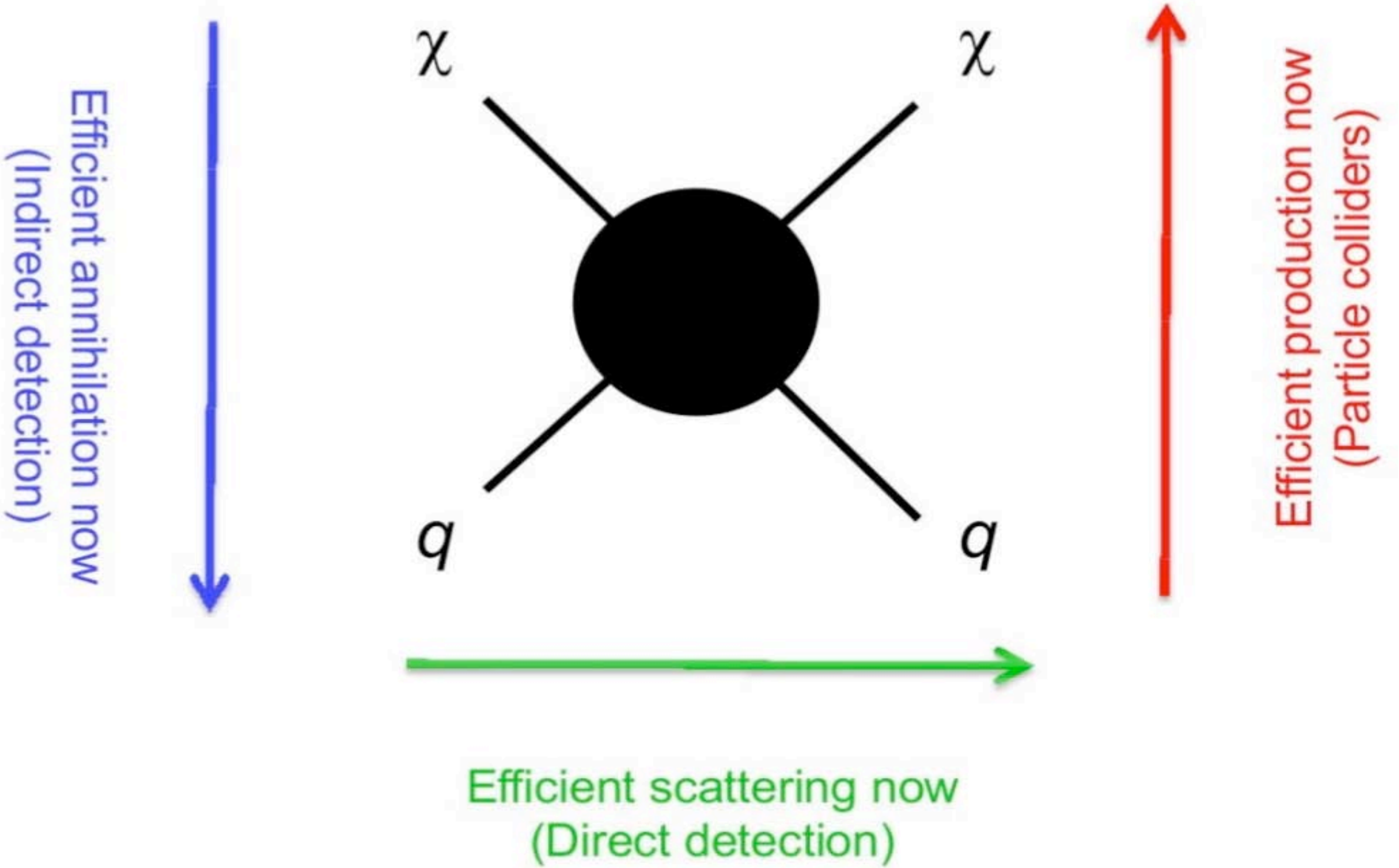
Status of the Cosmic Ray Universe



Aldo Morselli

INFN Roma Tor Vergata

GGI, 9 /09/ 2009

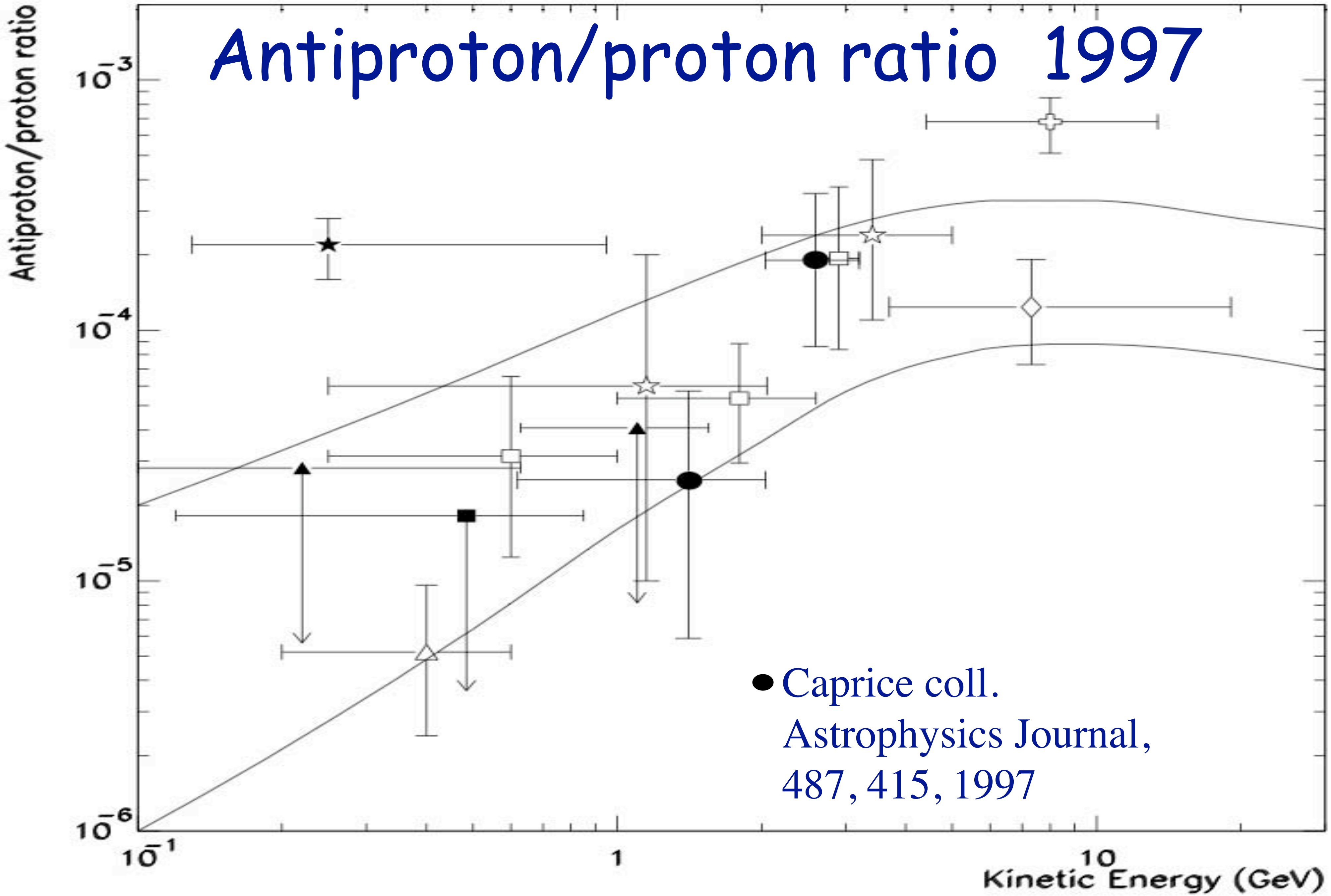

χ
χ
q
q
Efficient annihilation now
(Indirect detection)
Efficient production now
(Particle colliders)
Efficient scattering now
(Direct detection)

Neutralino WIMPs

Assume χ present in the galactic halo

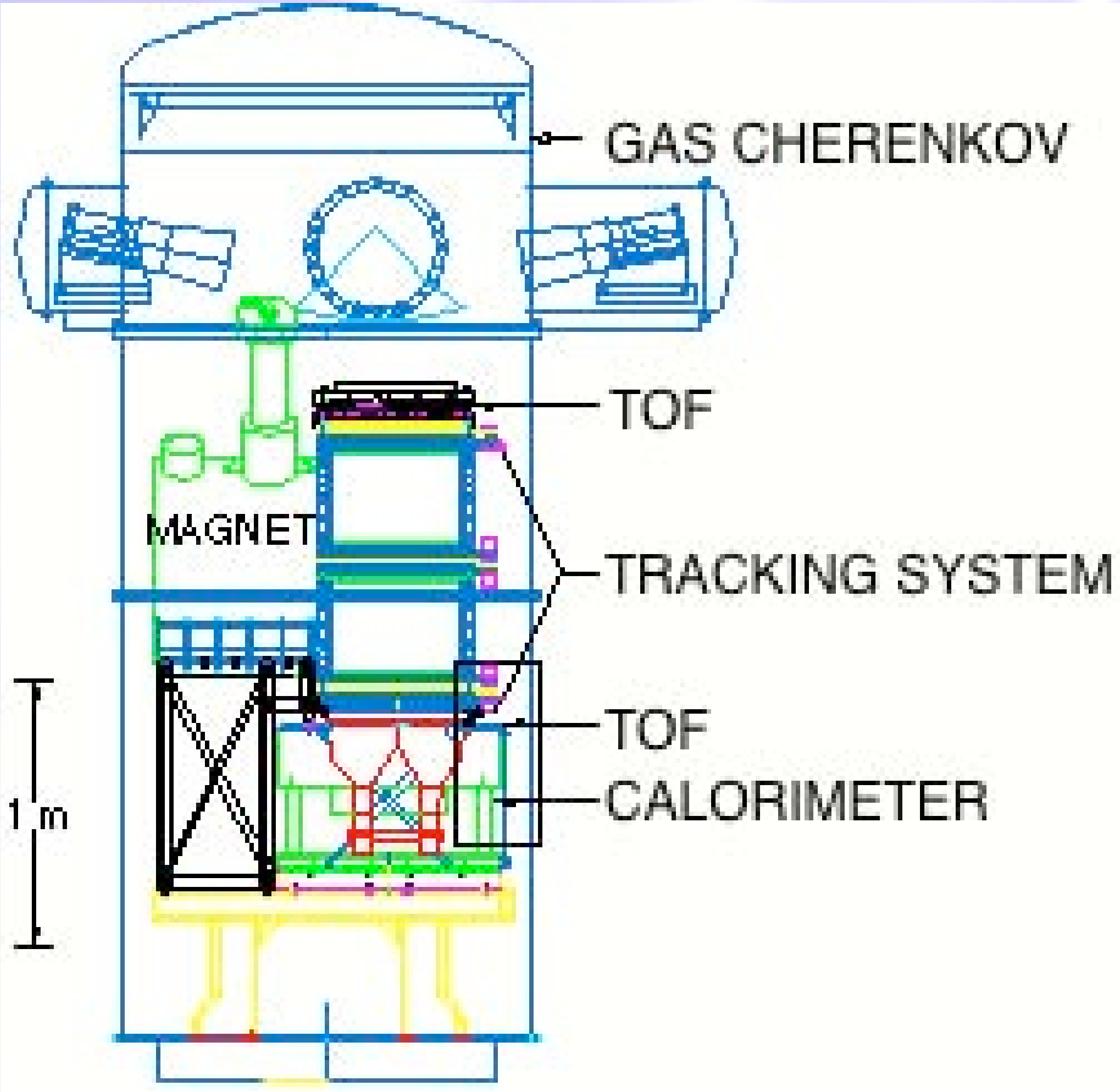
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources ($\chi\,\chi$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

Antiproton/proton ratio 1997

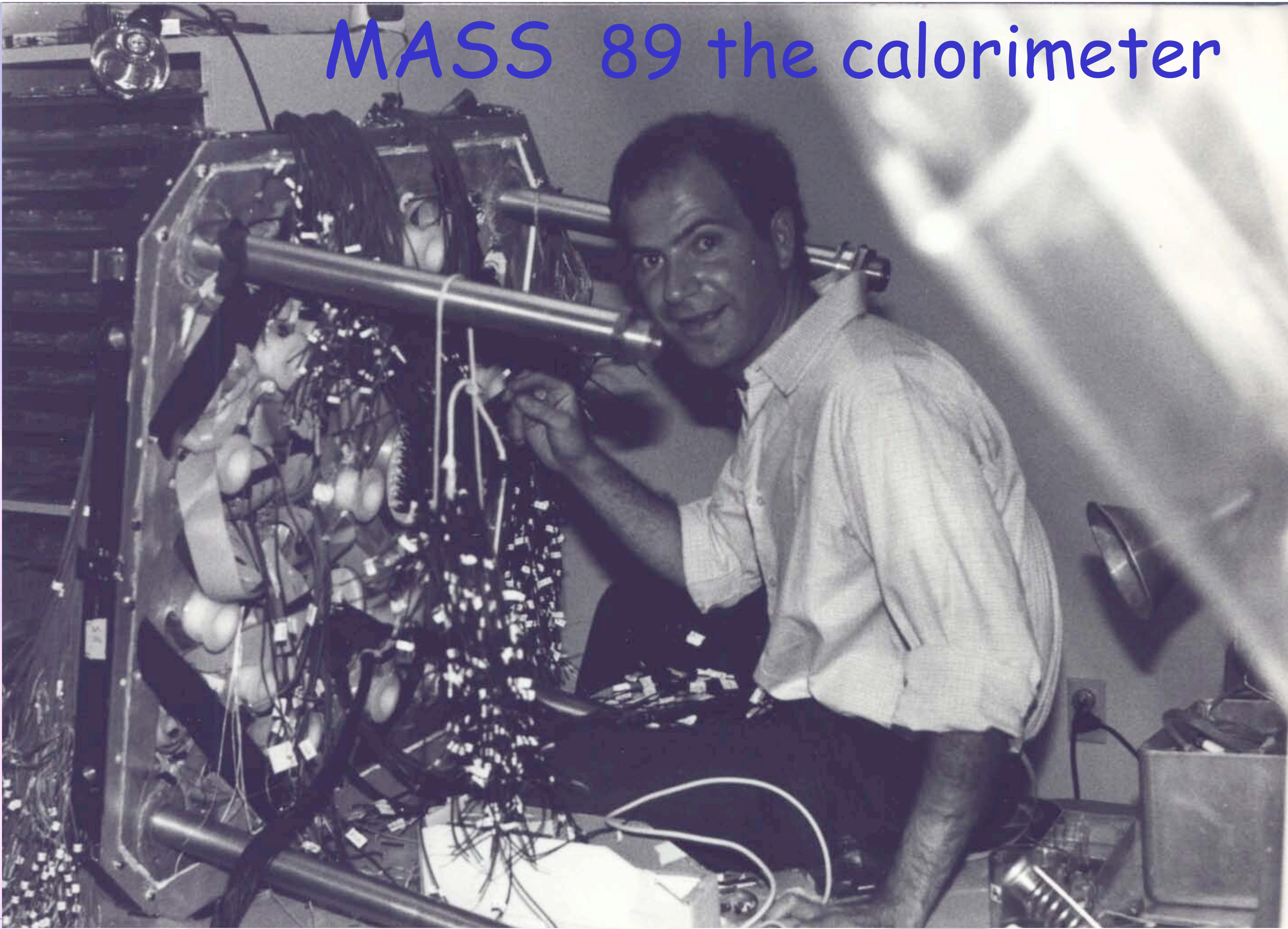


- Caprice coll. Astrophysics Journal, 487, 415, 1997

MASS Matter Antimatter Space Spectrometer



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

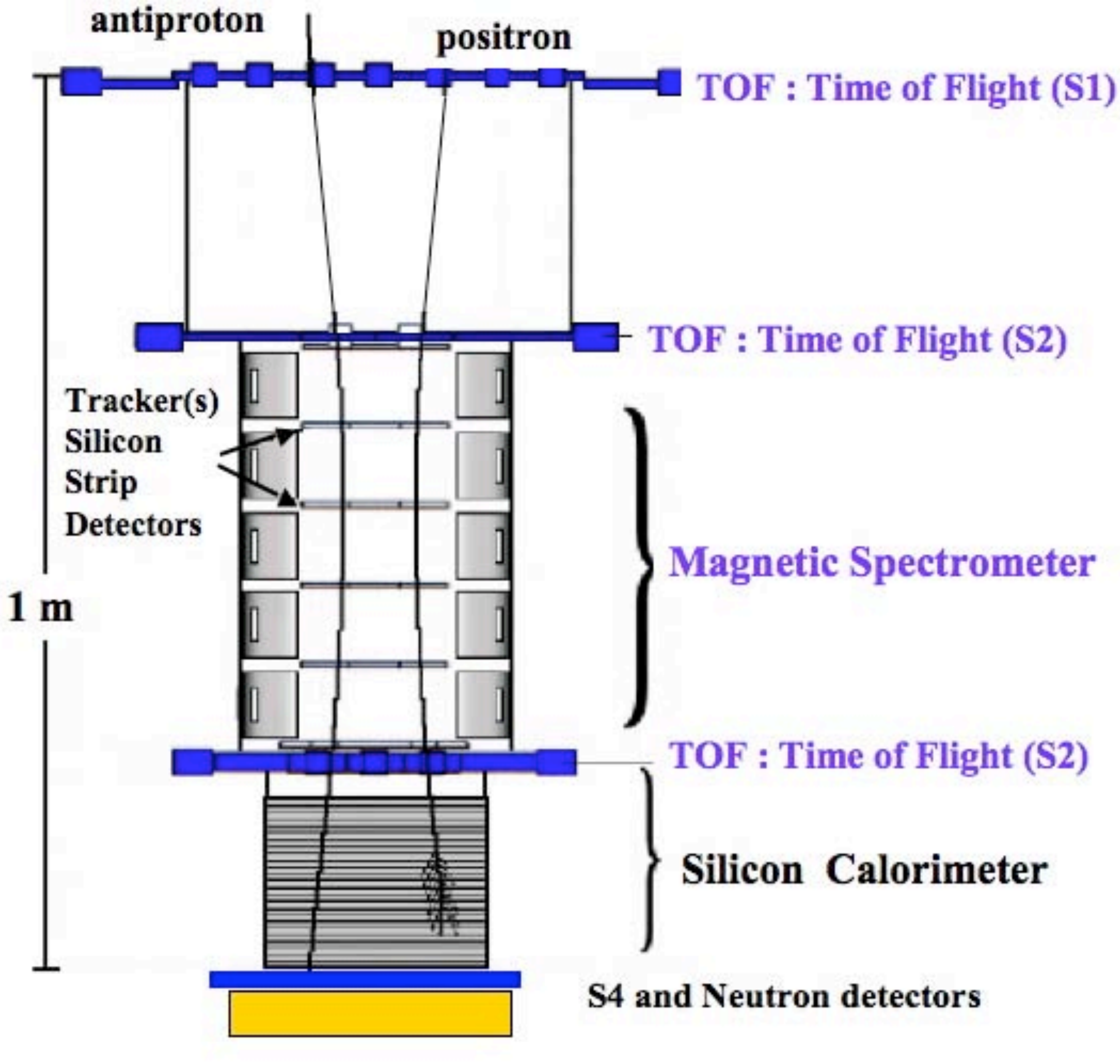
In orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

First switch-on on June 21 2006

From July 11 Pamela is in continuous data taking mode

Pamela

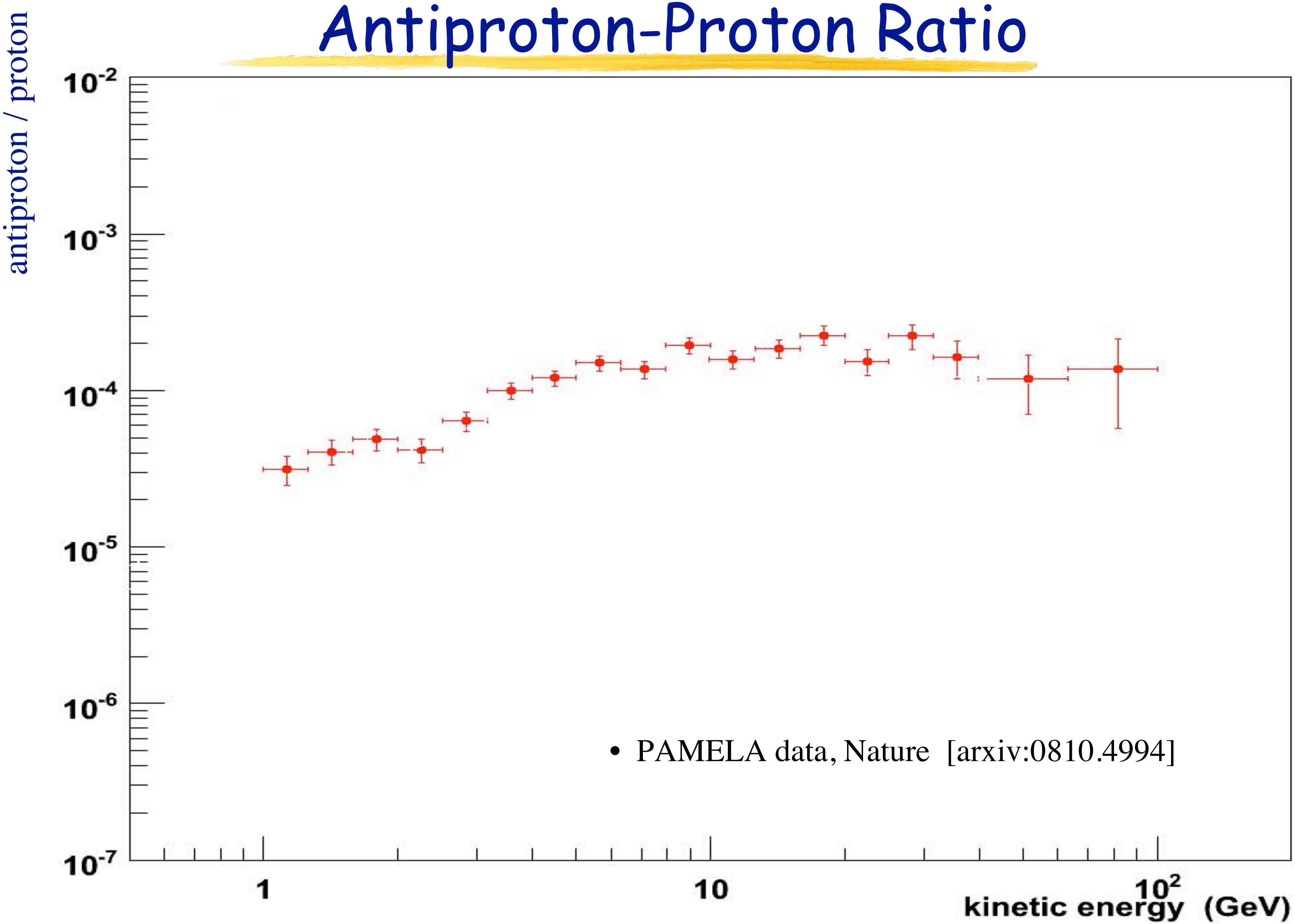
Separating p from e$^-$



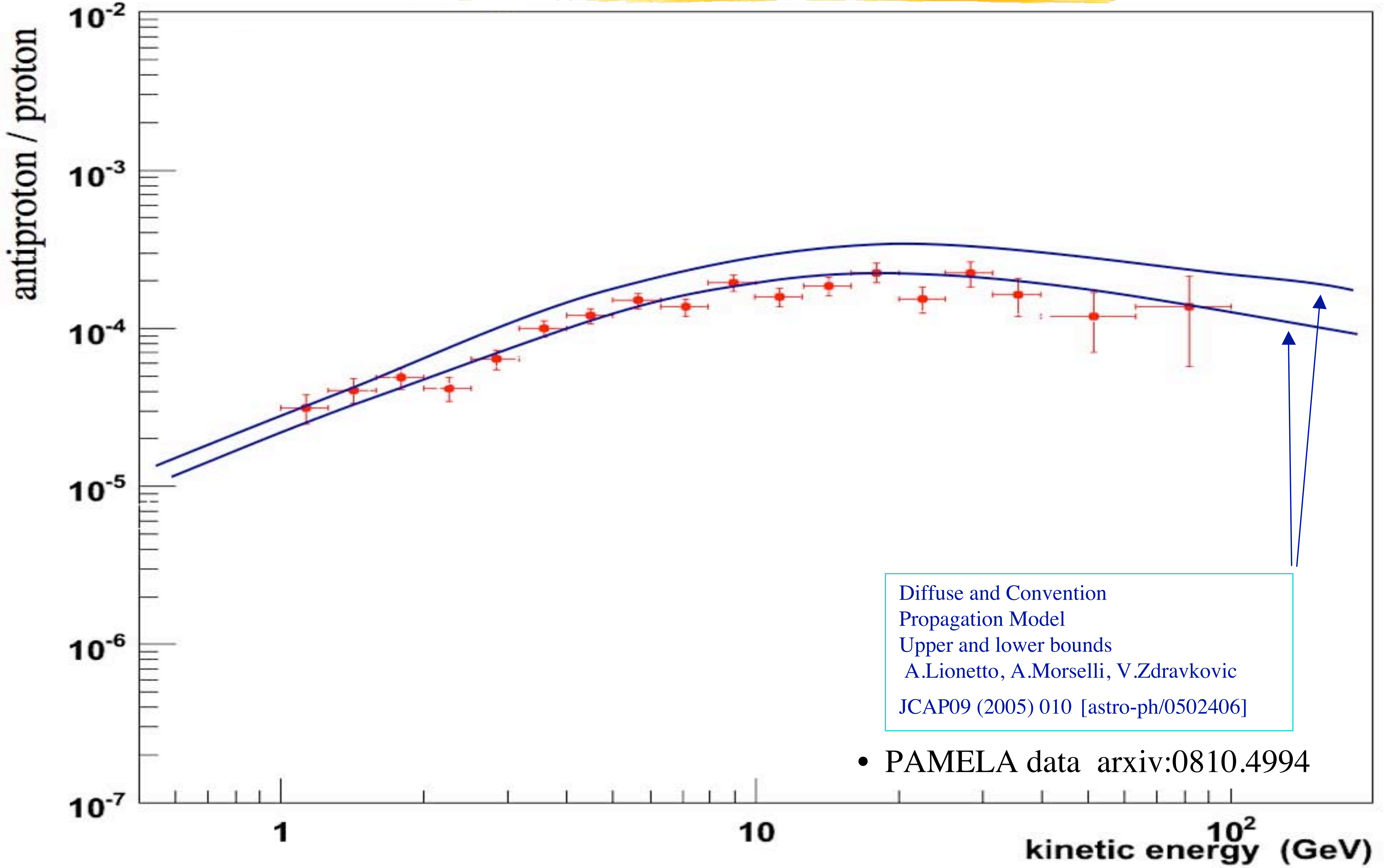
- ~ 3 years from PAMELA launch

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

Antiproton-Proton Ratio

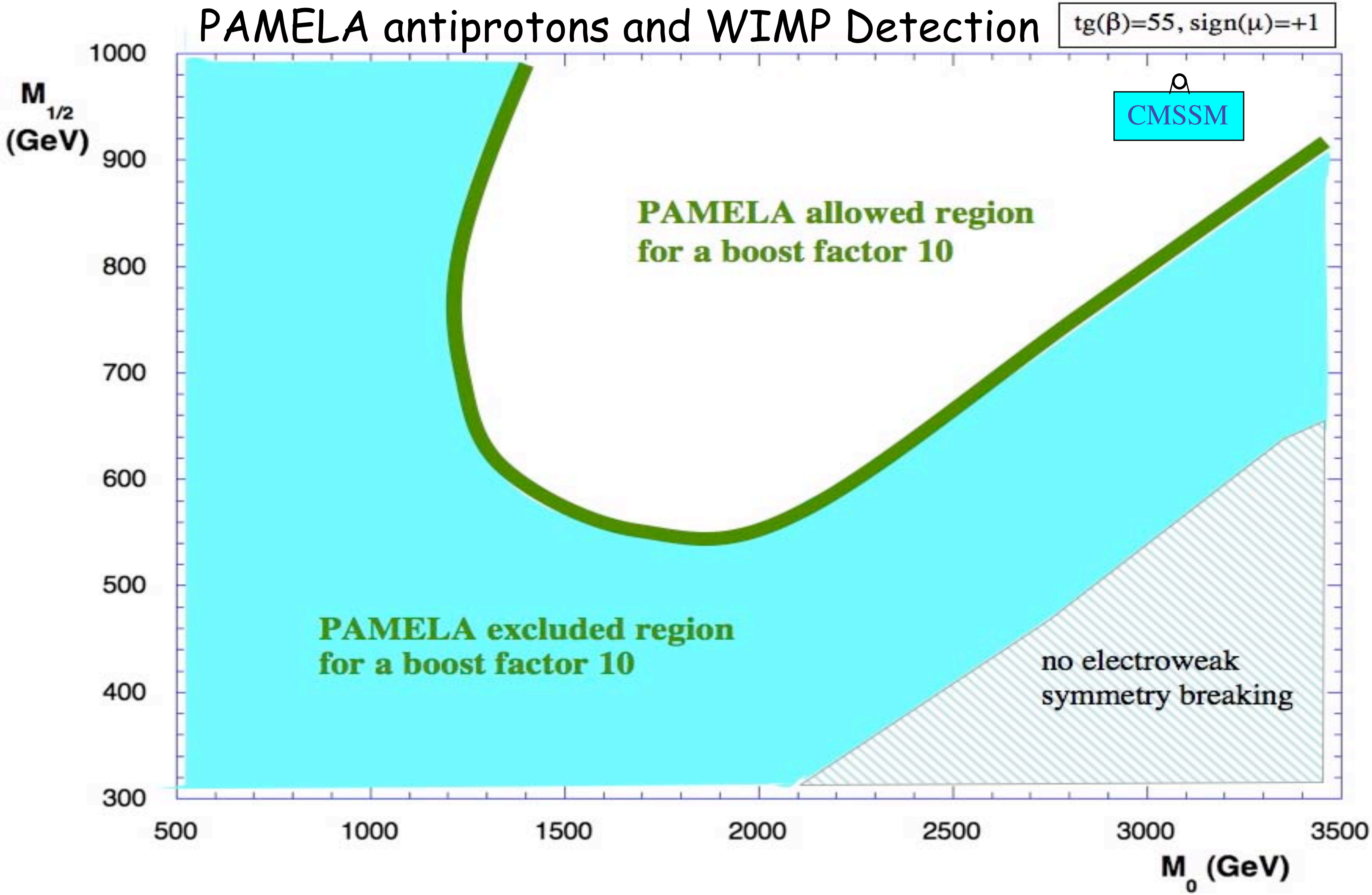


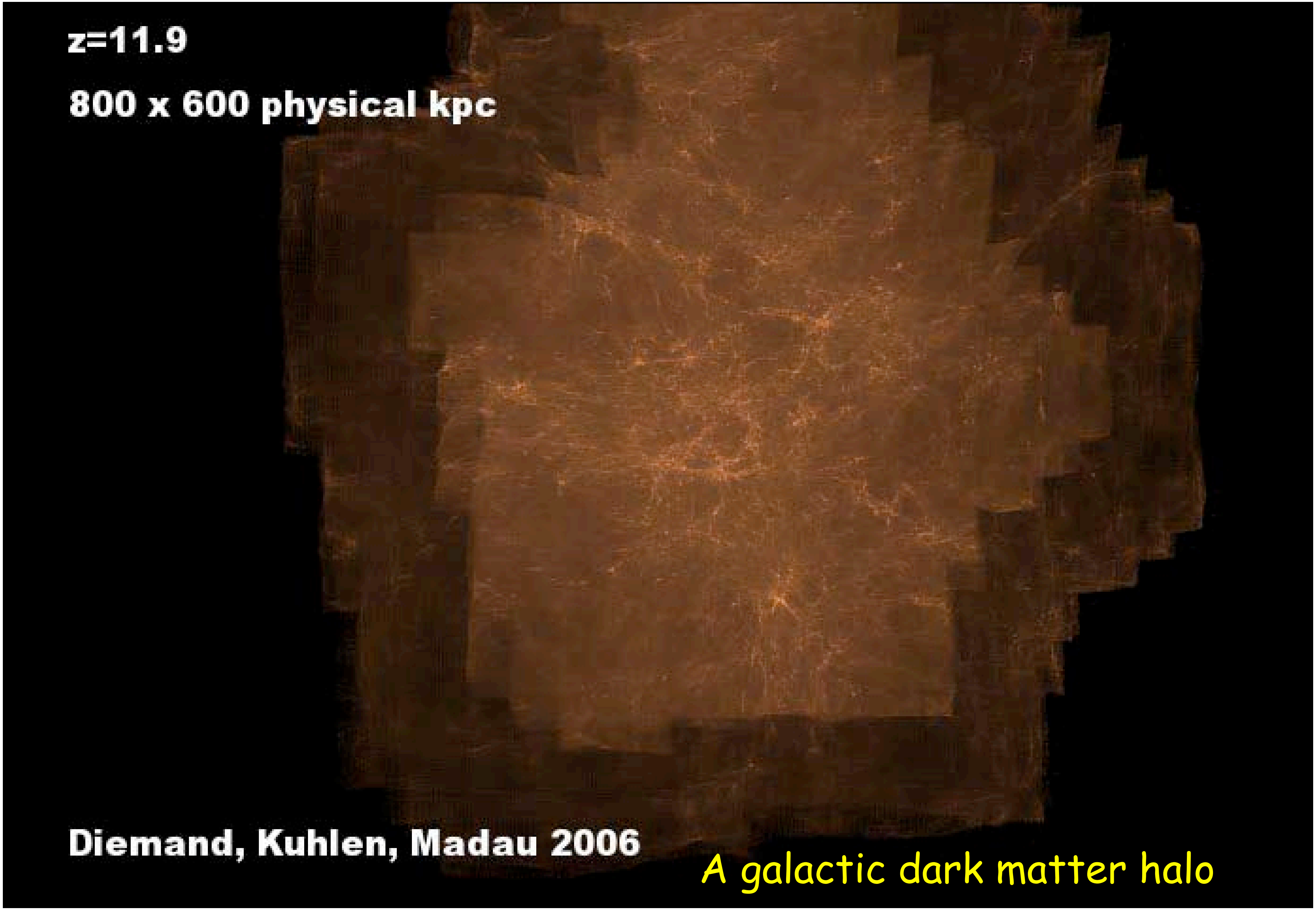
Antiproton-Proton Ratio



- PAMELA data arxiv:0810.4994

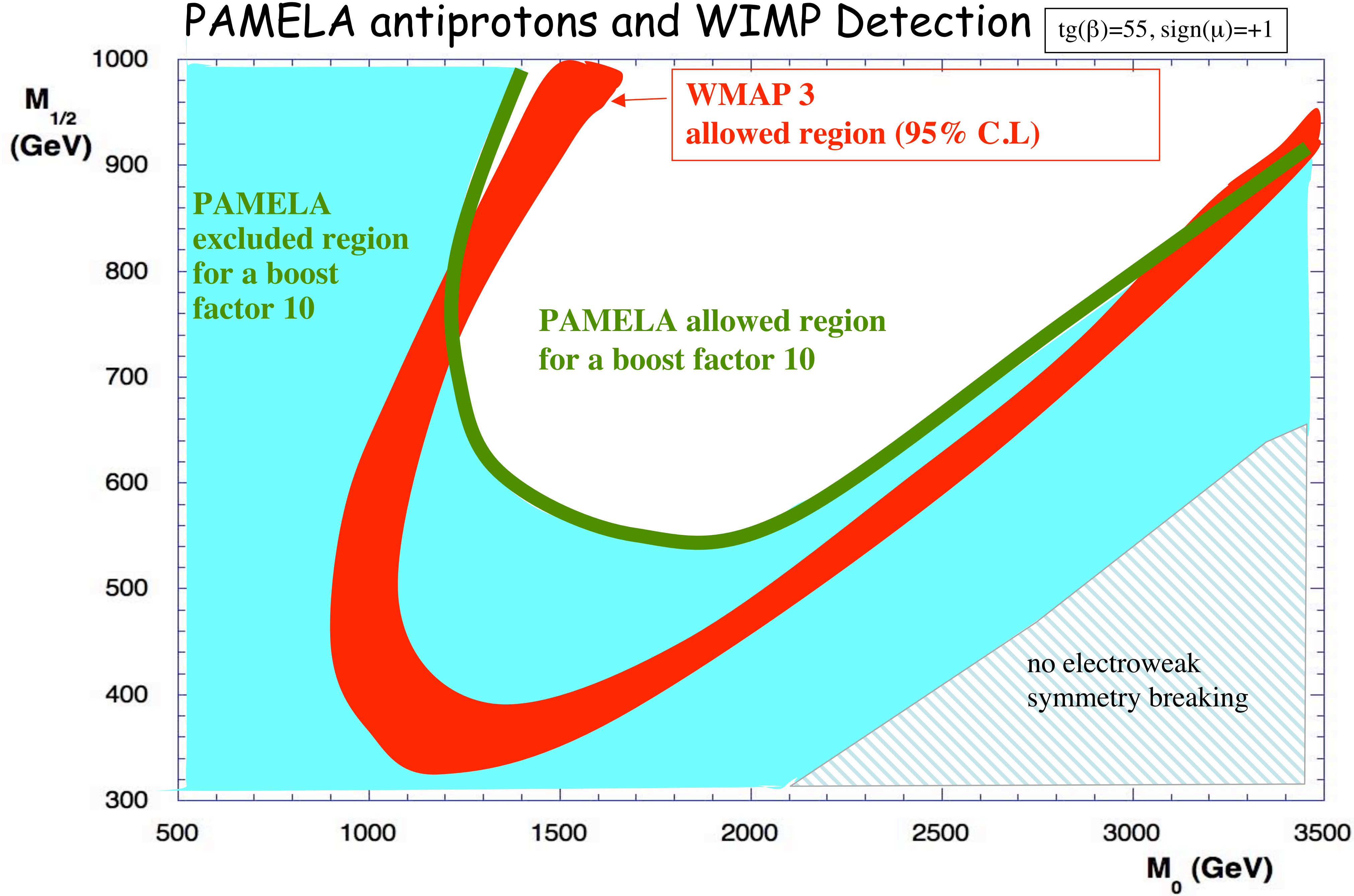
PAMELA antiprotons and WIMP Detection





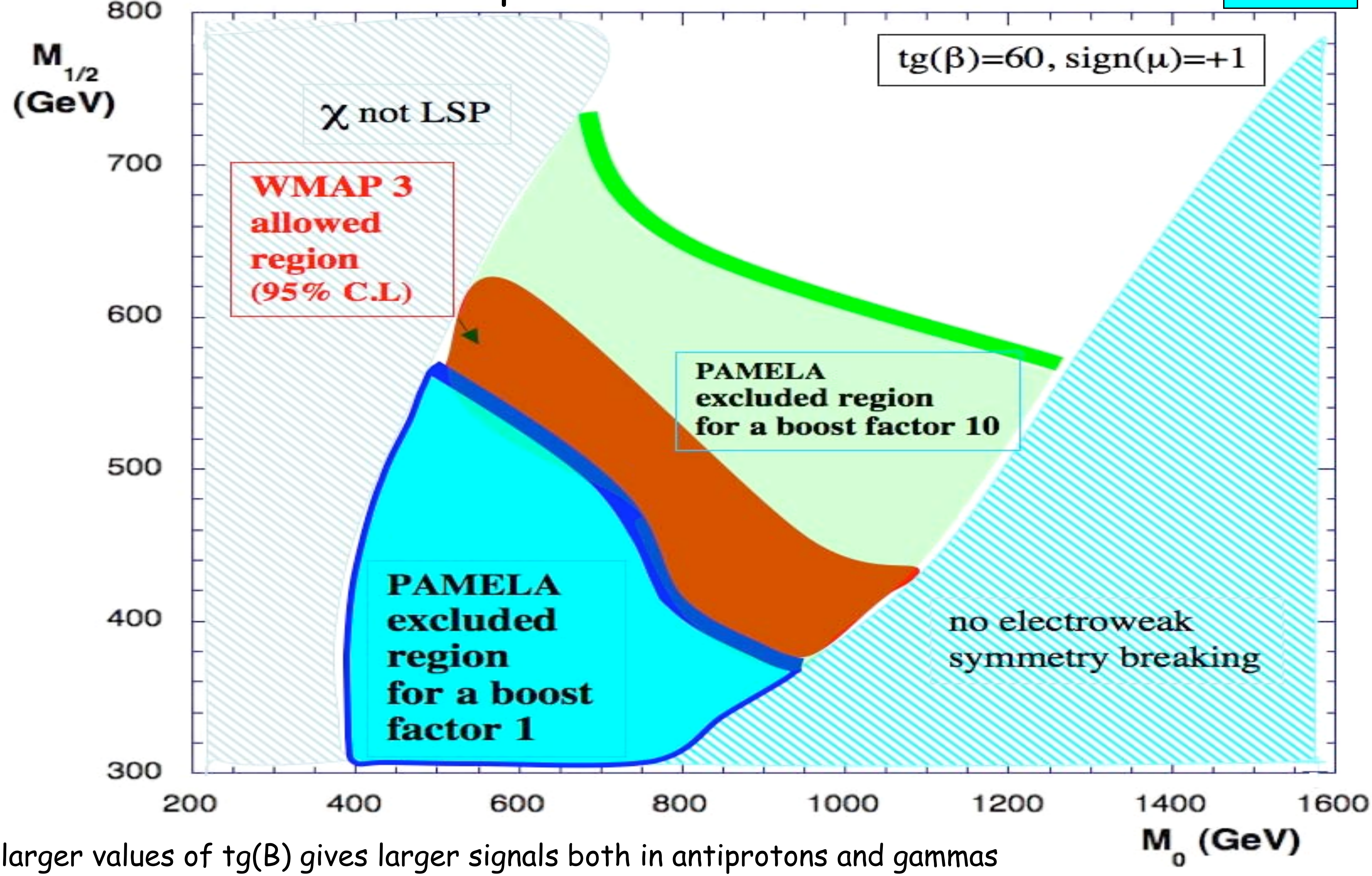
A galactic dark matter halo

PAMELA antiprotons and WIMP Detection



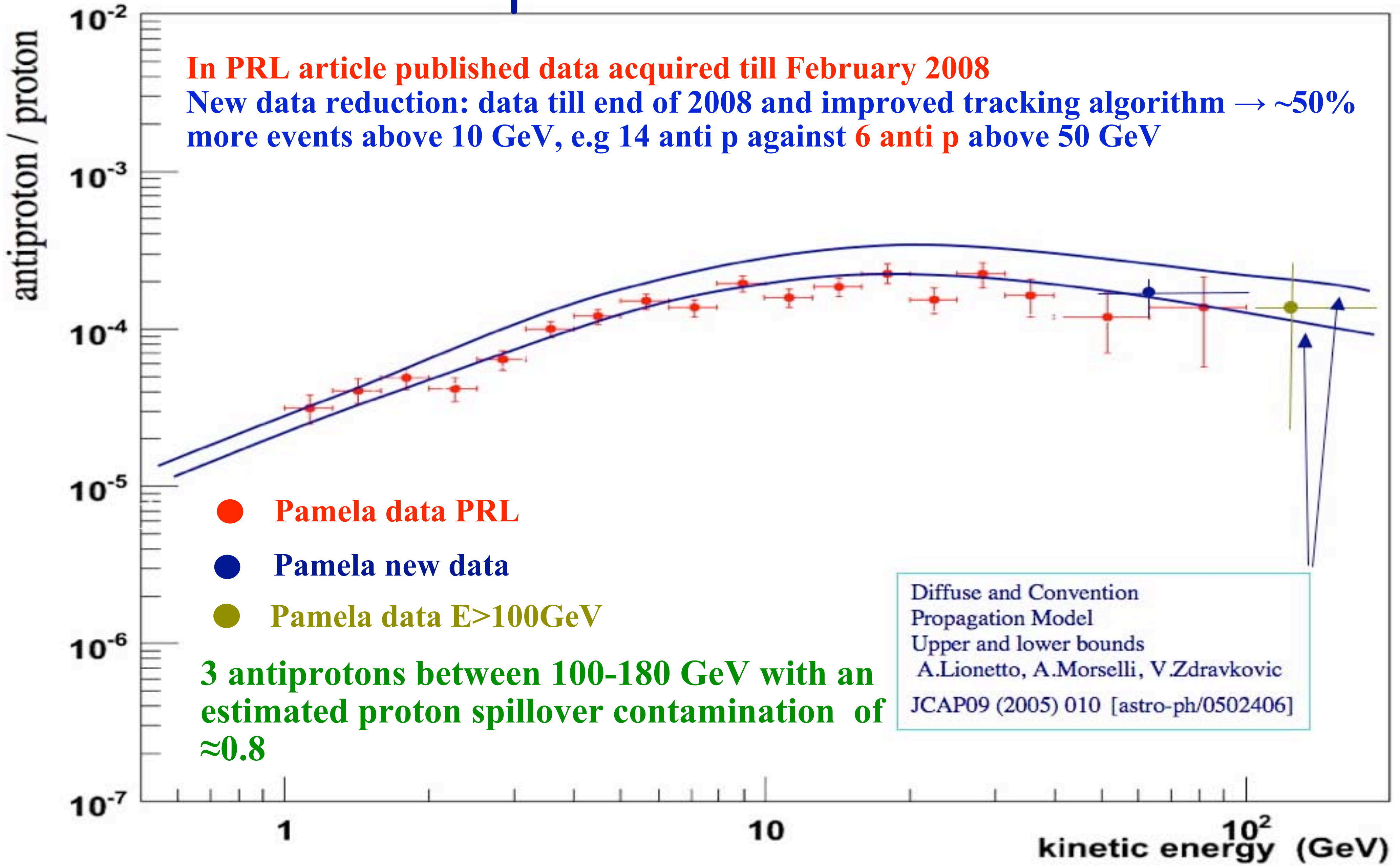
PAMELA antiprotons and WIMP Detection

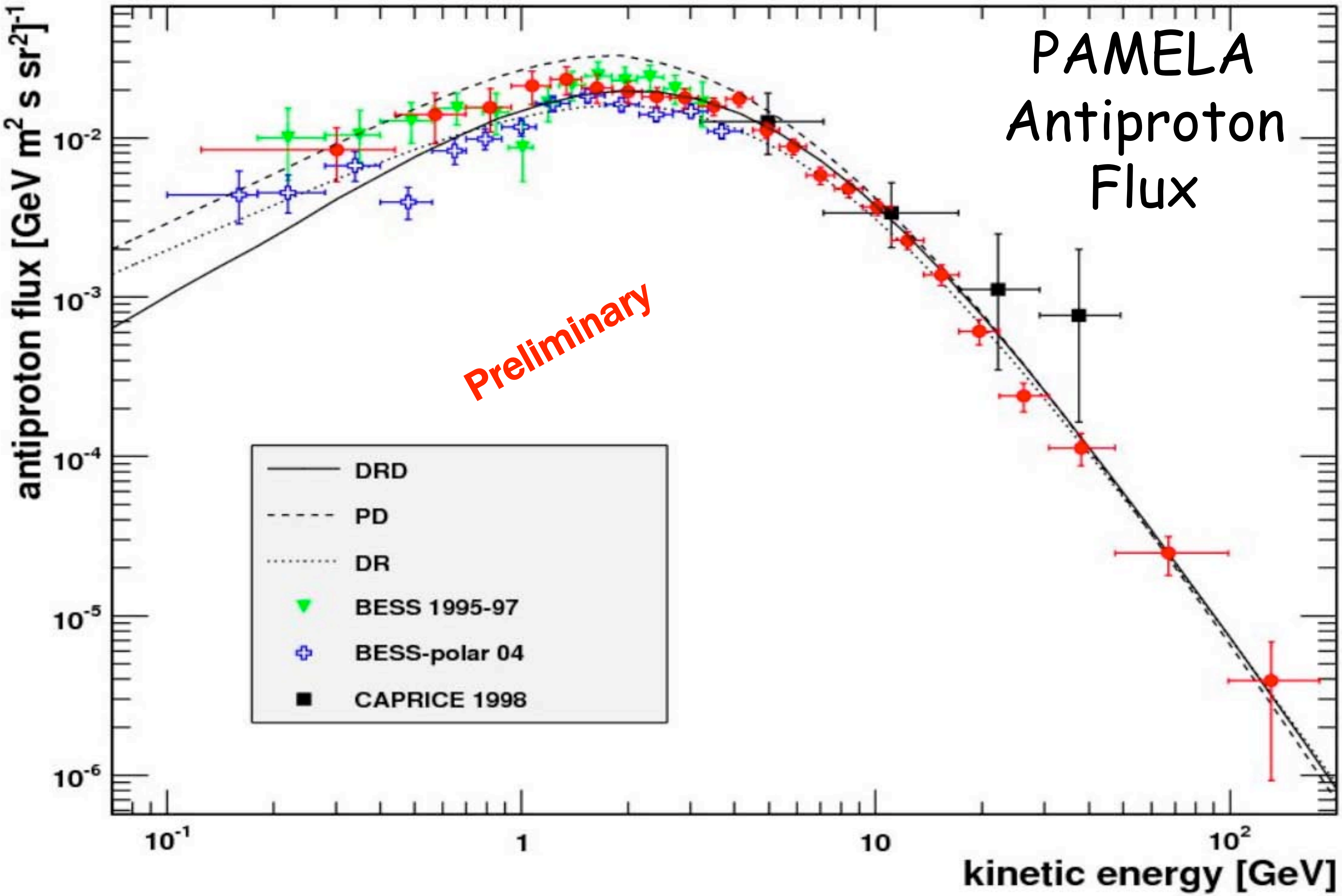
CMSSM



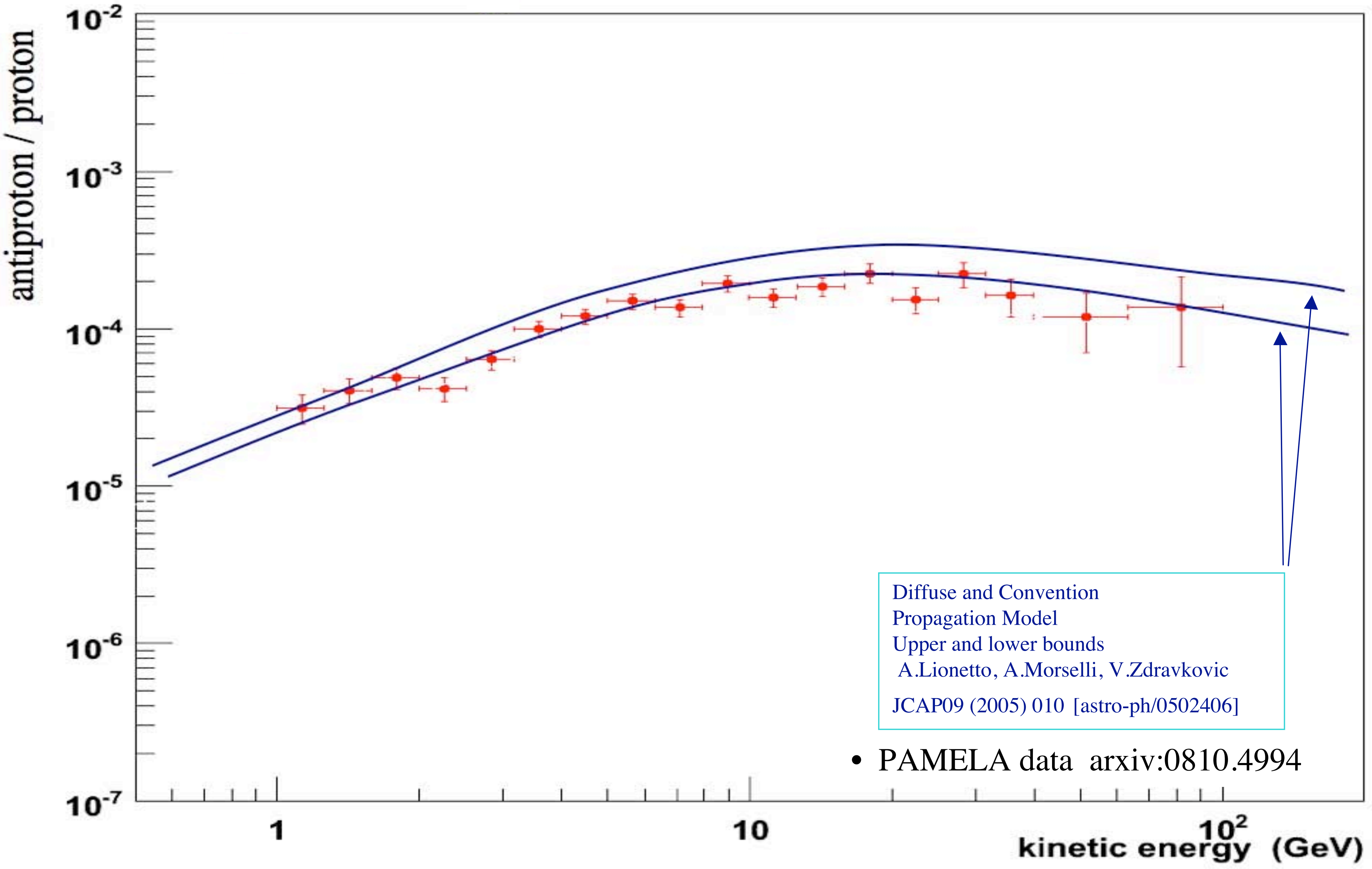
larger values of tg(B) gives larger signals both in antiprotons and gammas

Antiproton-Proton Ratio




PAMELA
Antiproton
Flux
Preliminary
antiproton flux [GeV m^2 s sr^2]$^{-1}$
kinetic energy [GeV]
DRD
PD
DR
BESS 1995-97
BESS-polar 04
CAPRICE 1998
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-1}
1
10
10^2

Antiproton-Proton Ratio



Propagation Equation for Cosmic Rays

$$\frac{\partial \psi(\mathbf{r},p,t)}{\partial t} = q(\mathbf{r},p) + \nabla \cdot (D_{xx}\nabla\psi - \mathbf{V}\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi$$
$$- \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\nabla \cdot \mathbf{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

diffusion coefficient in the impulse space, quasi-linear MHD: $D_{pp}(D_{xx}, v_A)$

convection velocity field that corresponds to galactic wind and it has a cylindrical symmetry, as the geometry of the galaxy. It's z-component is the only one different from zero and increases linearly with the distance from the galactic plane

loss term: fragmentation

loss term: radioactive decay

diffusion coefficient is function of rigidity

$$D_{xx} = \beta D_0 (\rho/\rho_0)^\delta$$

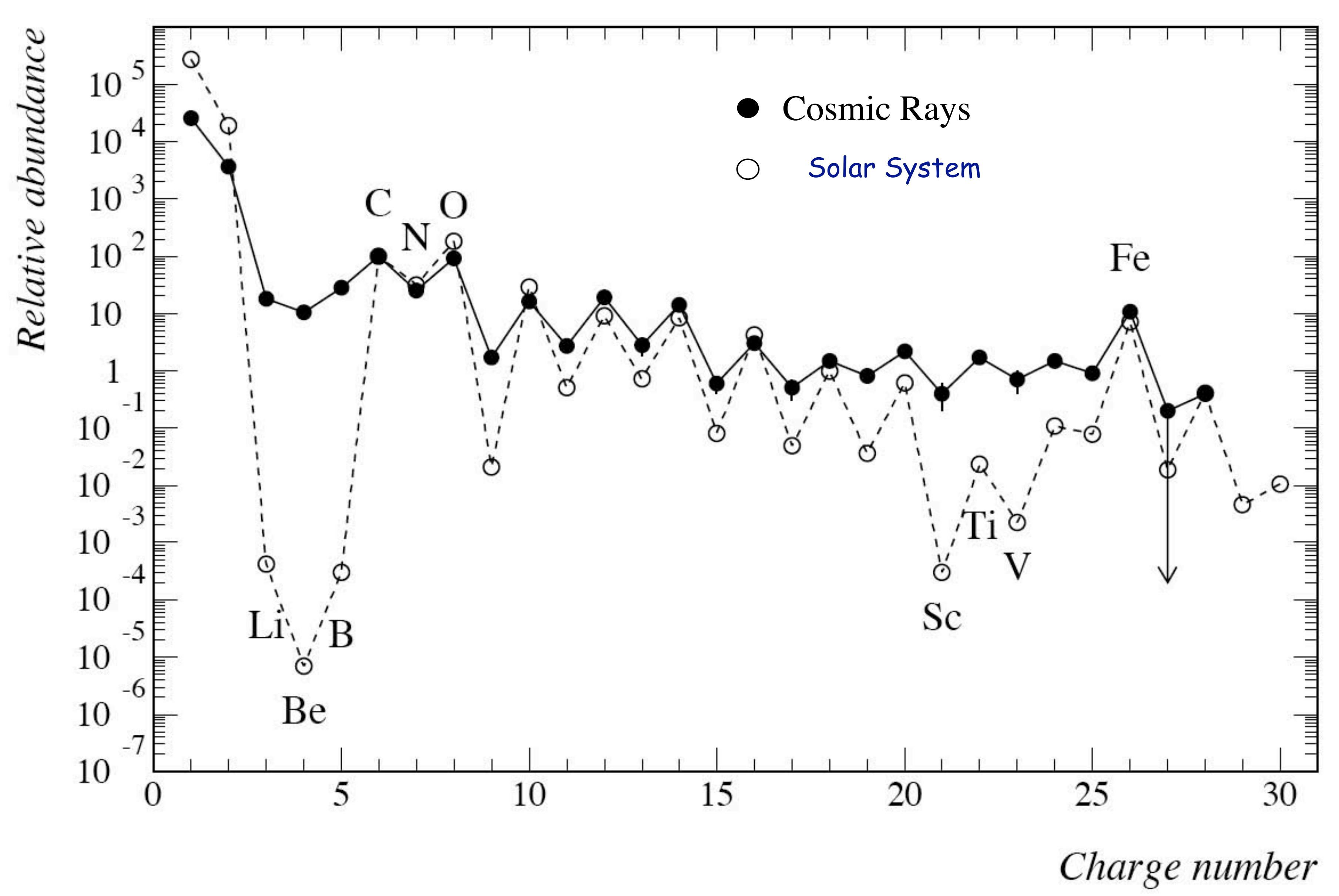
primary spectra injection index

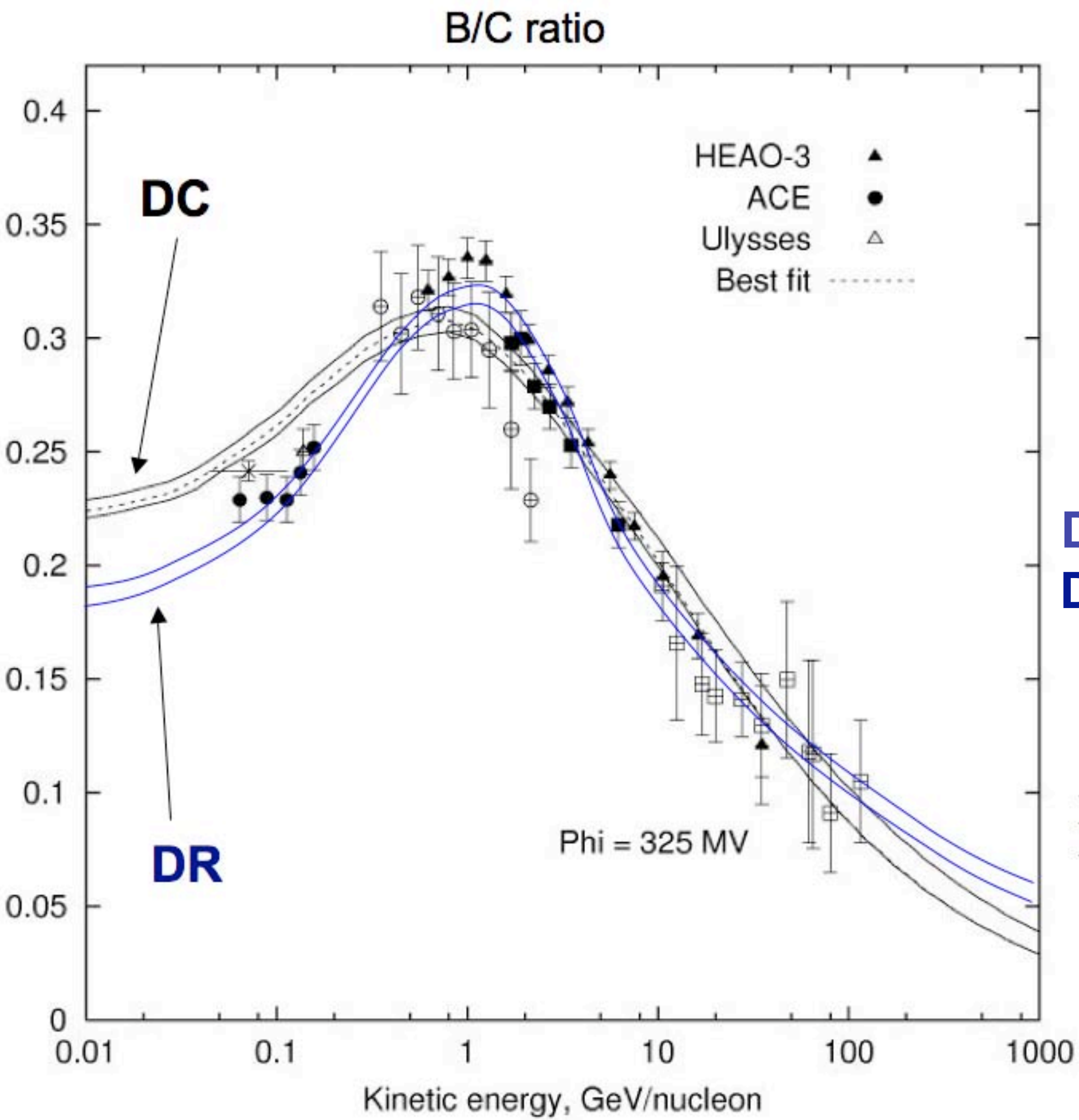
$$dq(p)/dp \propto p^{-\gamma}$$

implemented in Galprop (Strong & Moskalenko, available on the Web)

[astro-ph/0502406]

Comparison between the cosmic rays and the Solar System element composition, both relative to Carbon





Enveloping curves of all the good fits of the experimental B/C data

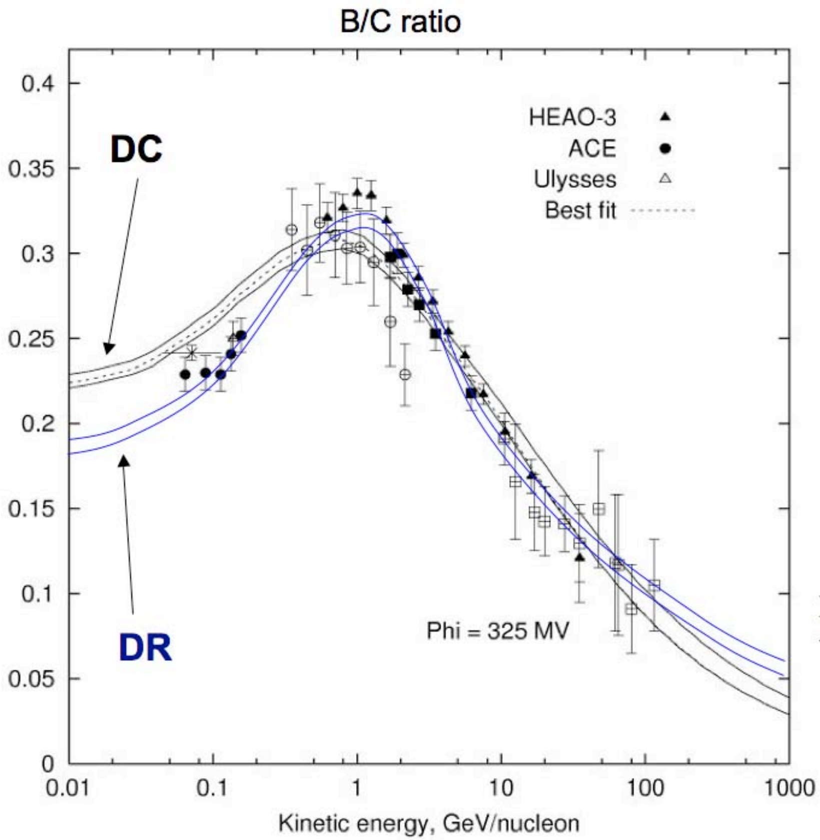
Dashed line: Best fit

DR: diffusion+ reacceleration

DC: diffusion+convection

In DC model problem with the ACE data at low energy

A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 astro-ph/0502406



Enveloping curves of all the good fits of the experimental B/C data

Dashed line: Best fit

DR: diffusion+ reacceleration

DC: diffusion+convection

$$\chi^2 = \frac{1}{N-1}\sum_n \frac{1}{(\sigma_n^{B/C})^2}(\Phi_{n,exp}^{B/C} - \Phi_{n,teo}^{B/C})^2$$

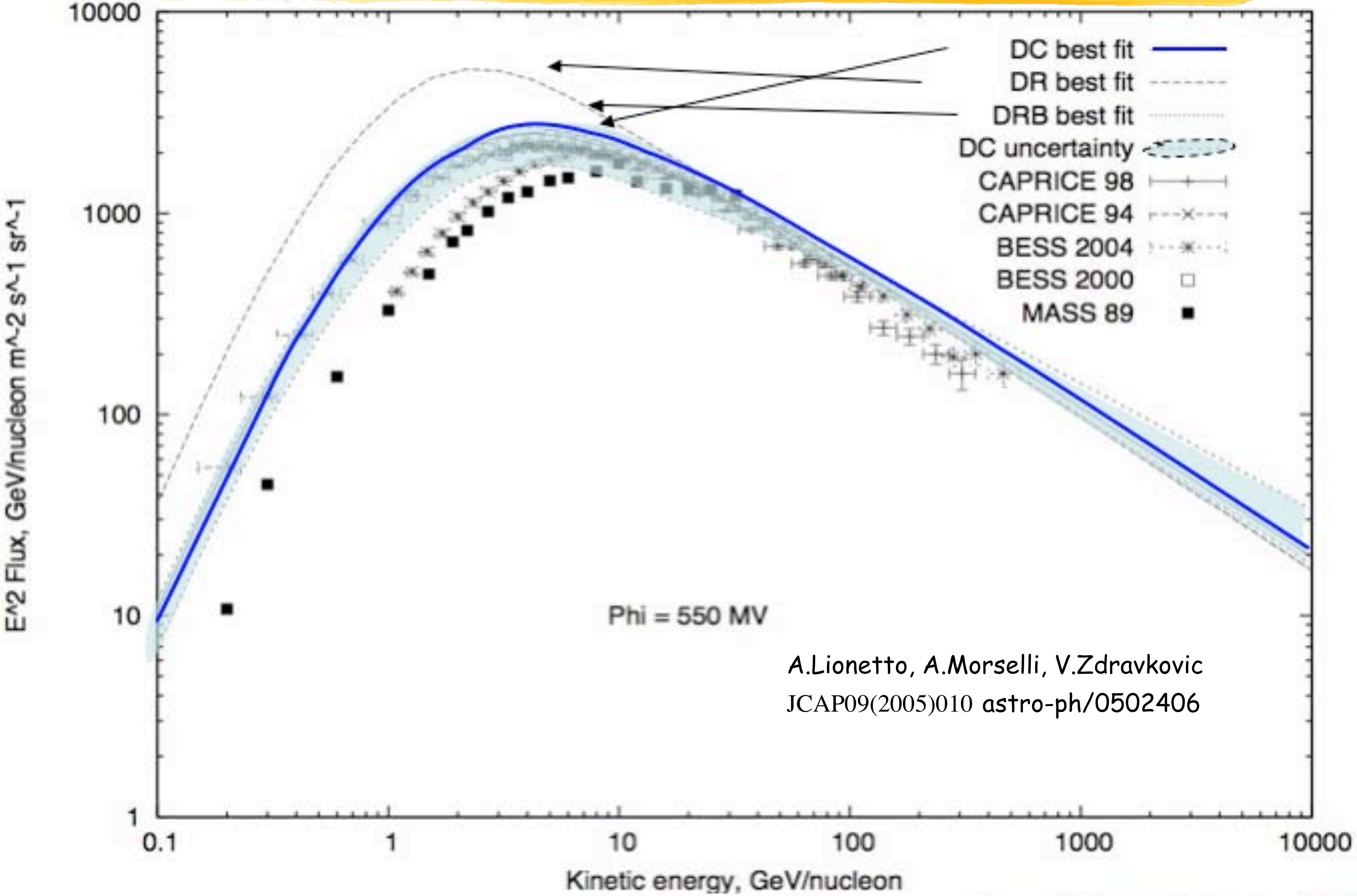
$\sigma_n^{B/C}$ = statistical errors for

N = 46 experimental points

A.Lionetto, A.Morselli, V.Zdravkovic

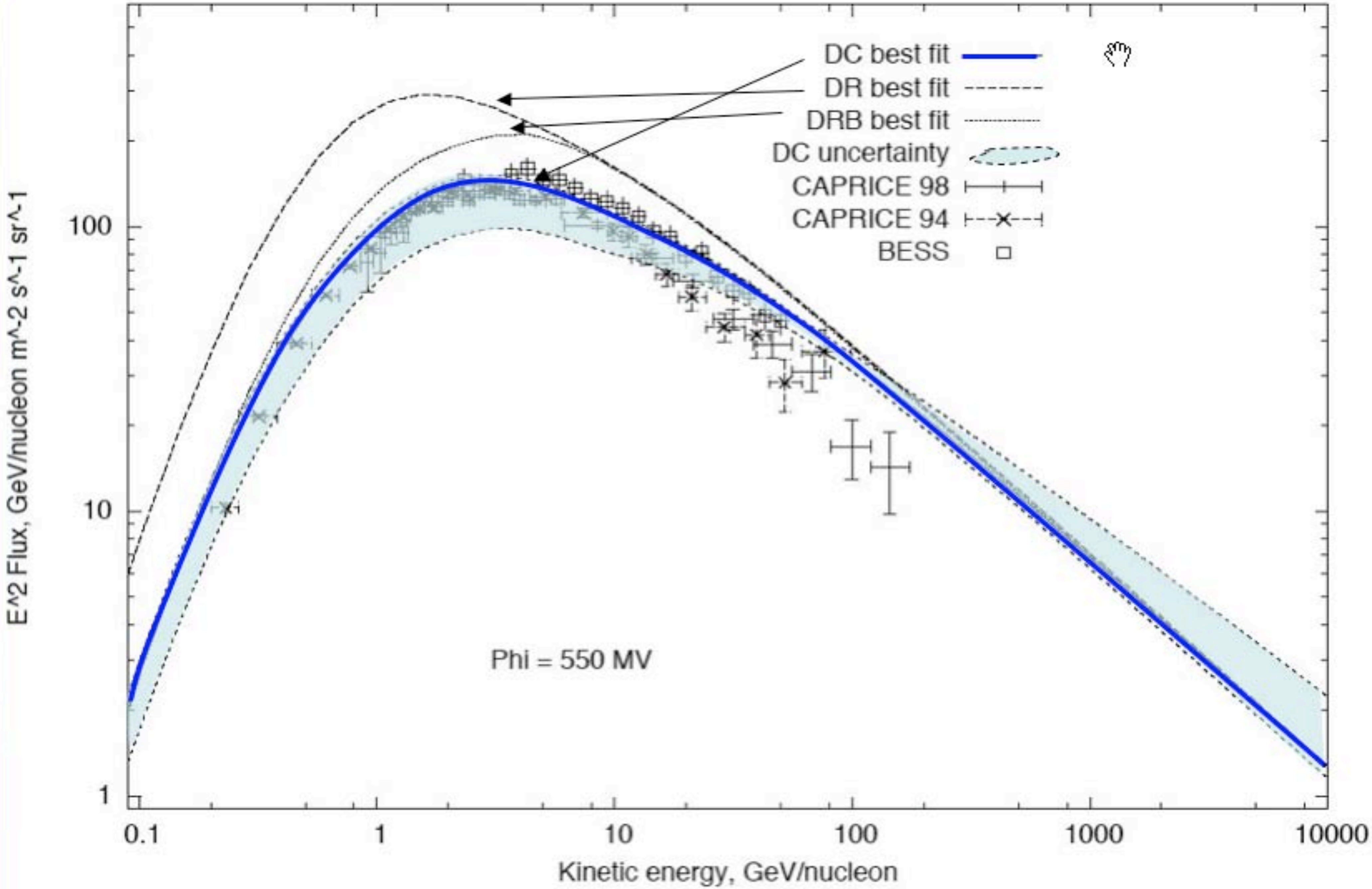
JCAP09(2005)010 astro-ph/0502406

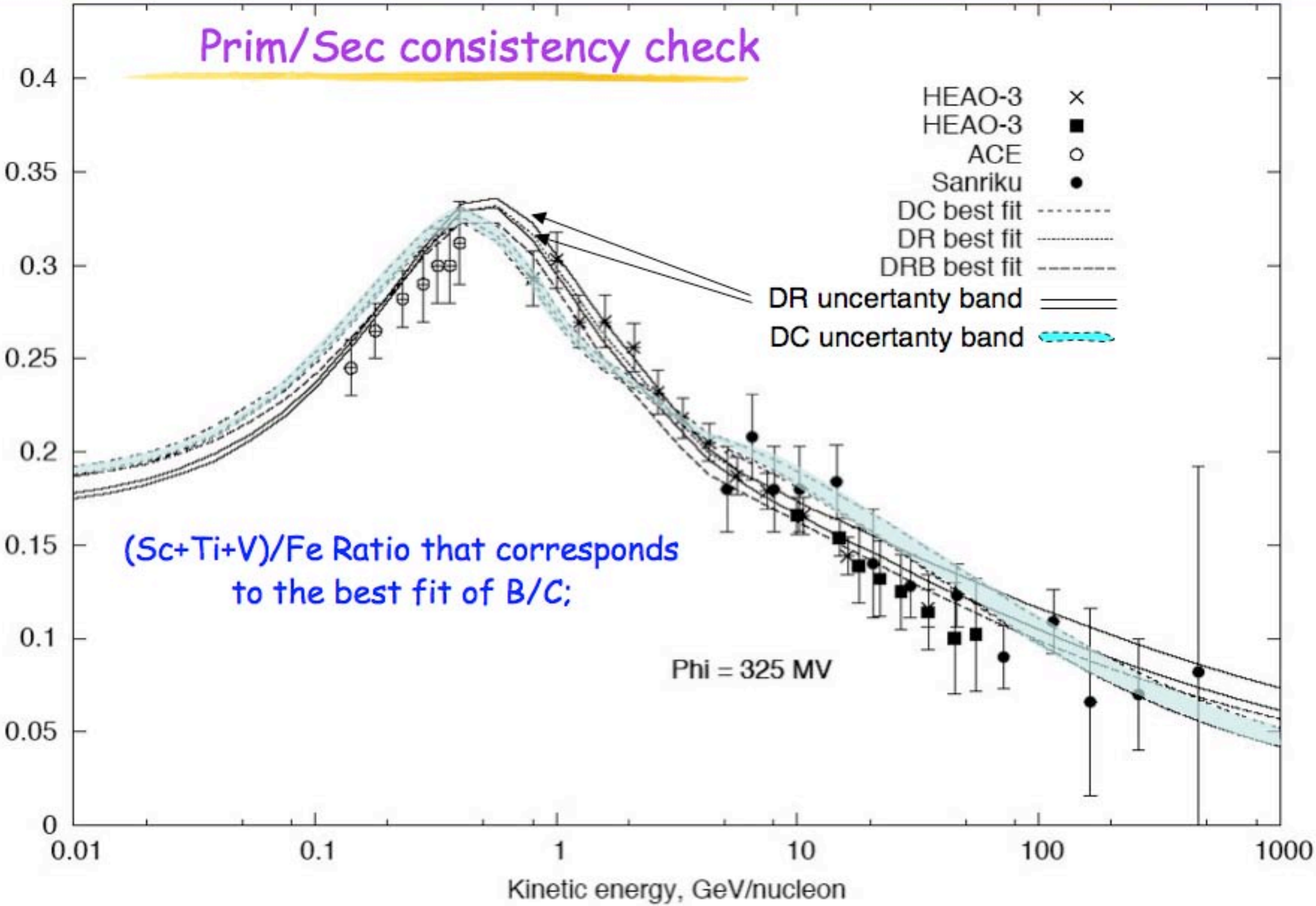
Proton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters



A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 astro-ph/0502406

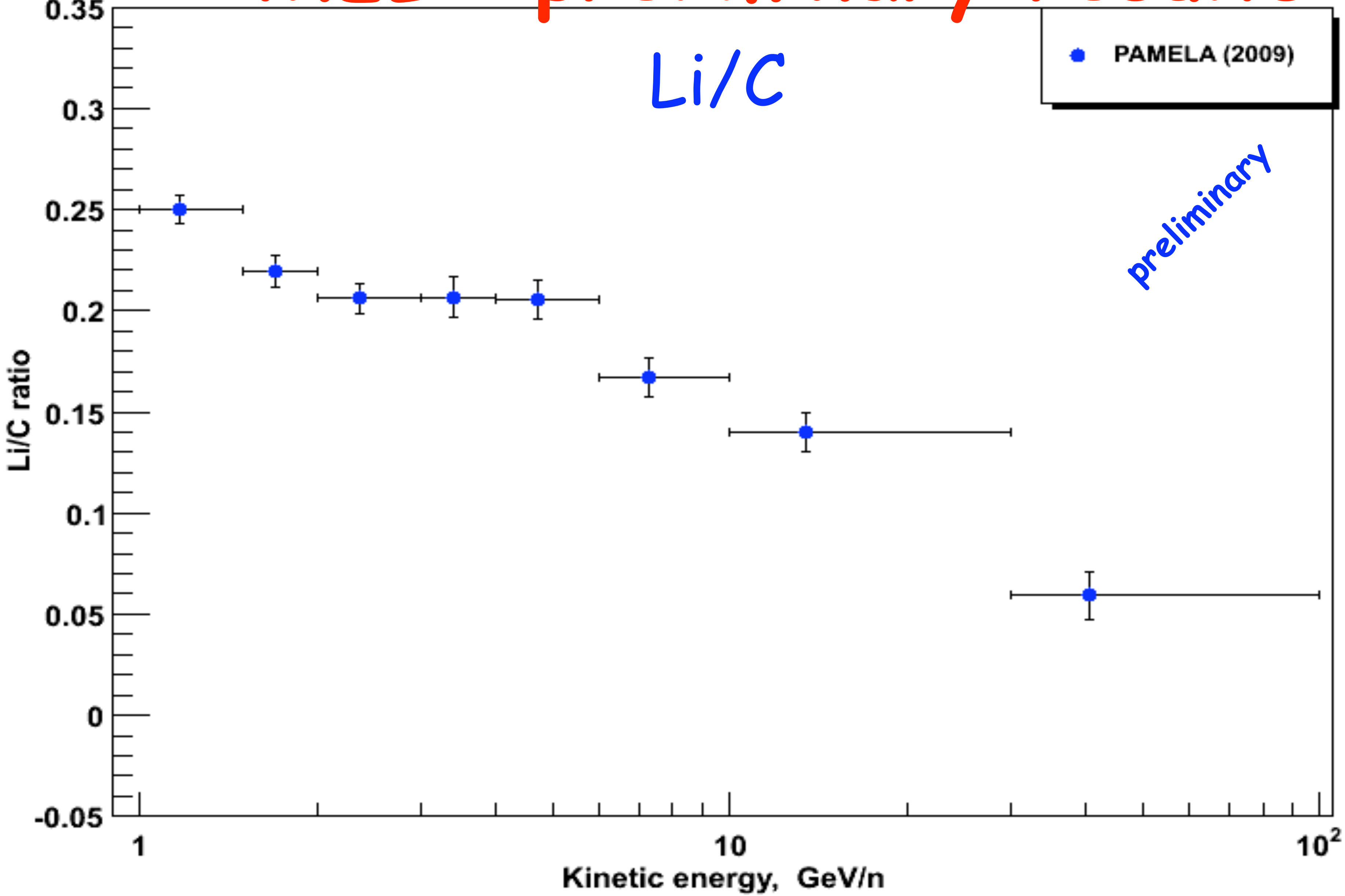
Helium spectra: Upper and lower bounds of due to the uncertainties of propagation parameters

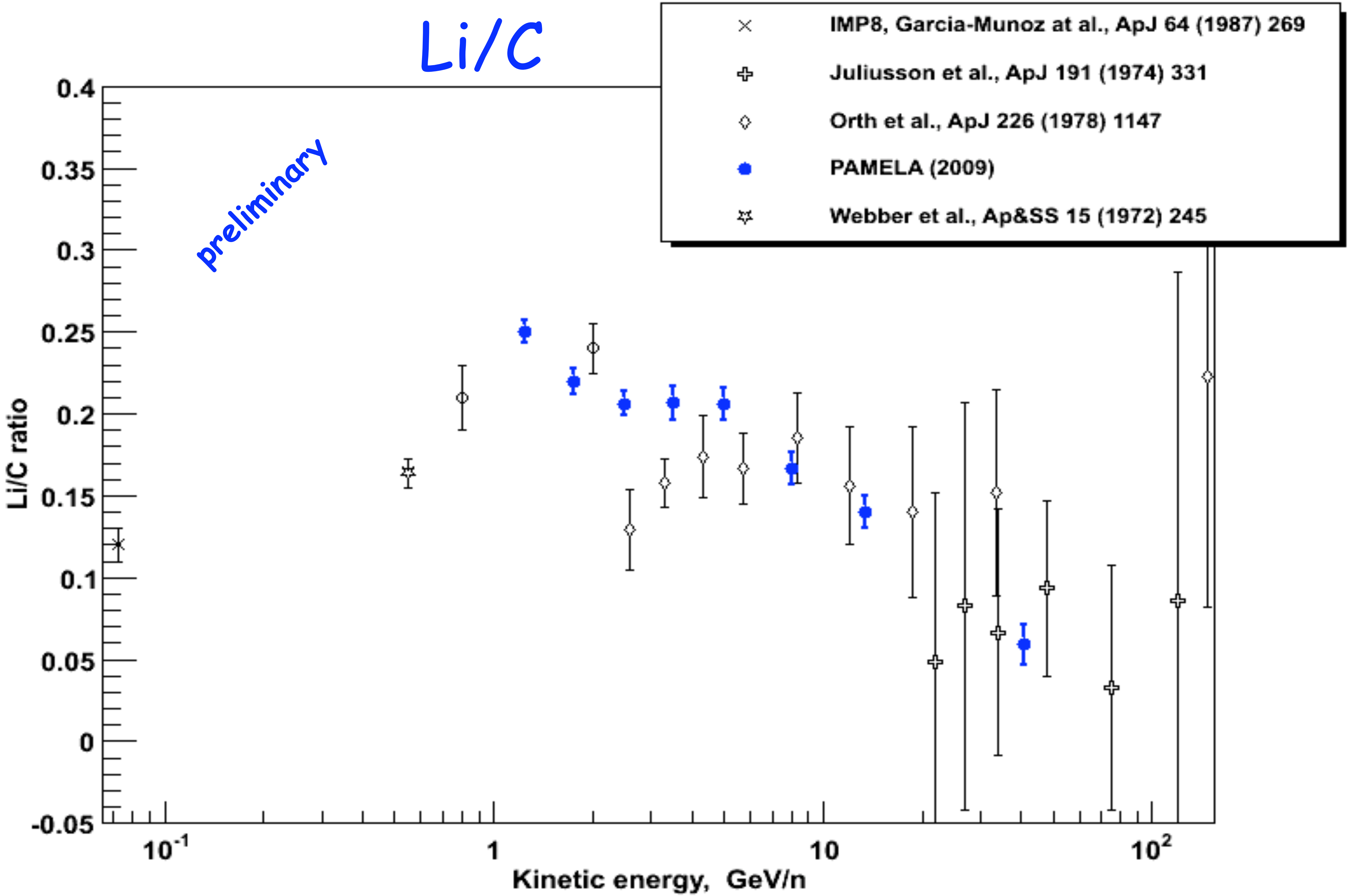




Prim/Sec consistency check
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.01
0.1
1
10
100
1000
Kinetic energy, GeV/nucleon
HEAO-3
HEAO-3
ACE
Sanriku
DC best fit
DR best fit
DRB best fit
DR uncertanty band
DC uncertanty band
(Sc+Ti+V)/Fe Ratio that corresponds
to the best fit of B/C;
Phi = 325 MV

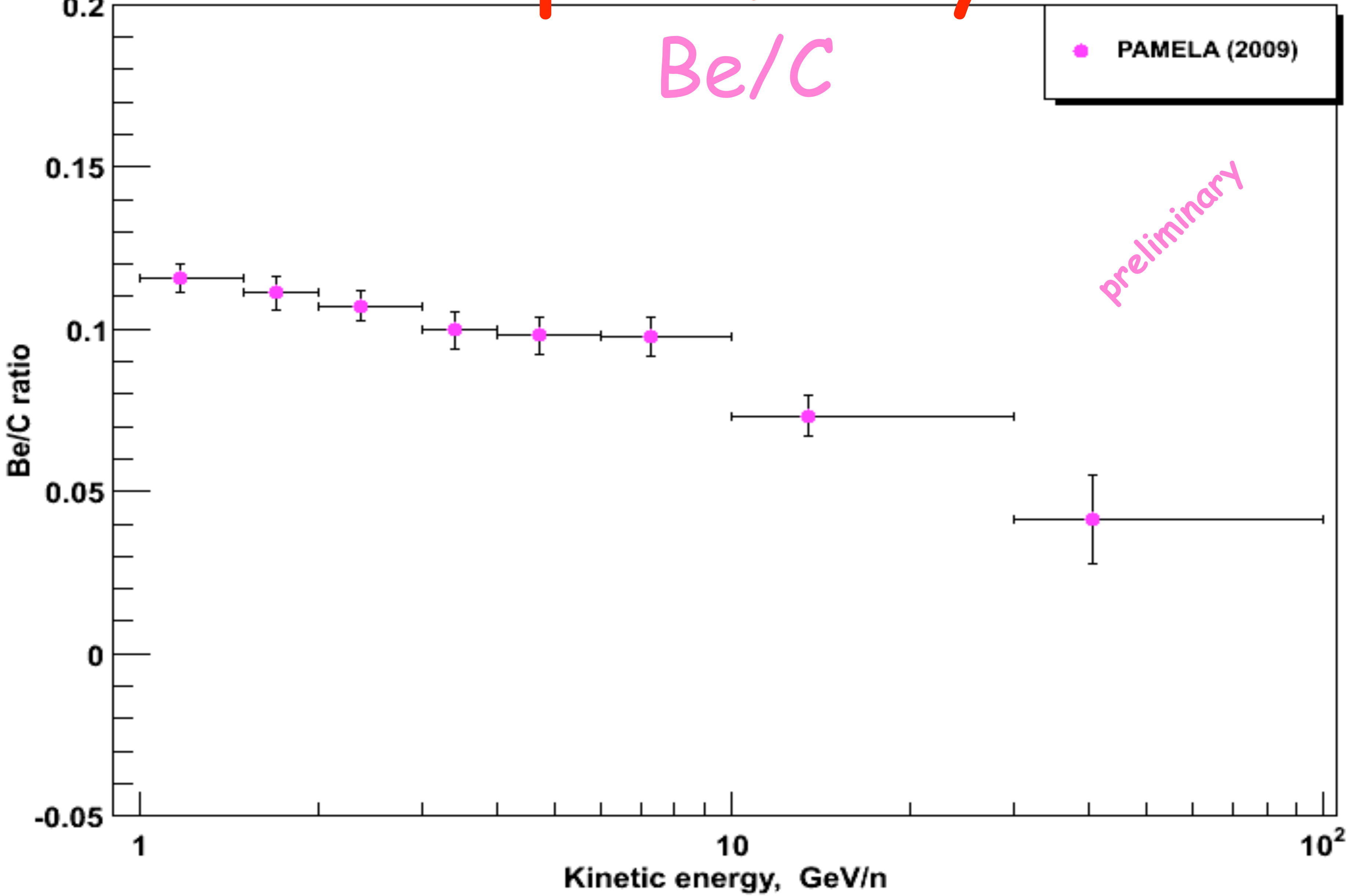
PAMELA preliminary results

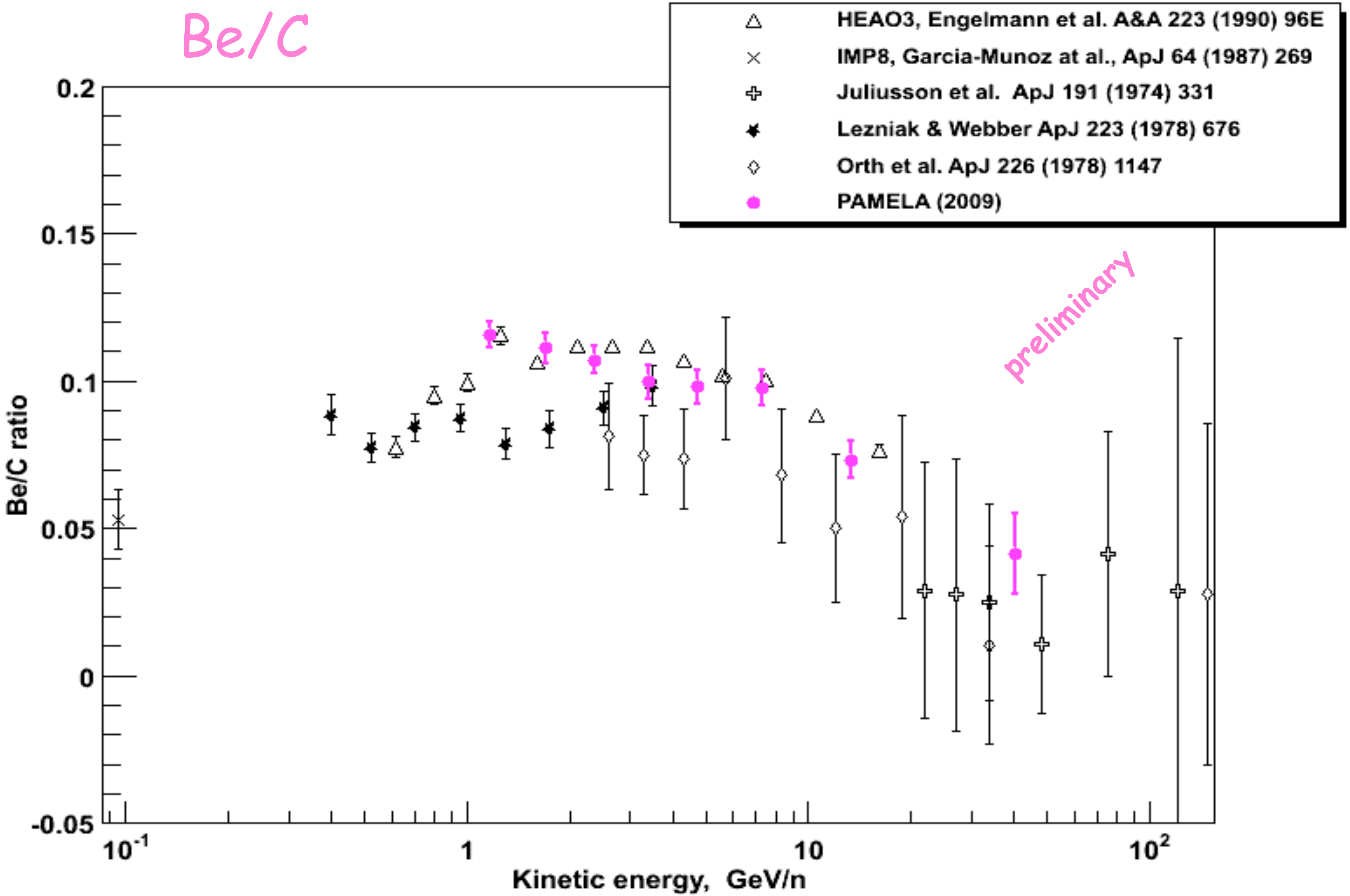




Li/C
preliminary
IMP8, Garcia-Munoz at al., ApJ 64 (1987) 269
Juliusson et al., ApJ 191 (1974) 331
Orth et al., ApJ 226 (1978) 1147
PAMELA (2009)
Webber et al., Ap&SS 15 (1972) 245
Li/C ratio
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
10^-1
1
10
10^2
Kinetic energy, GeV/n

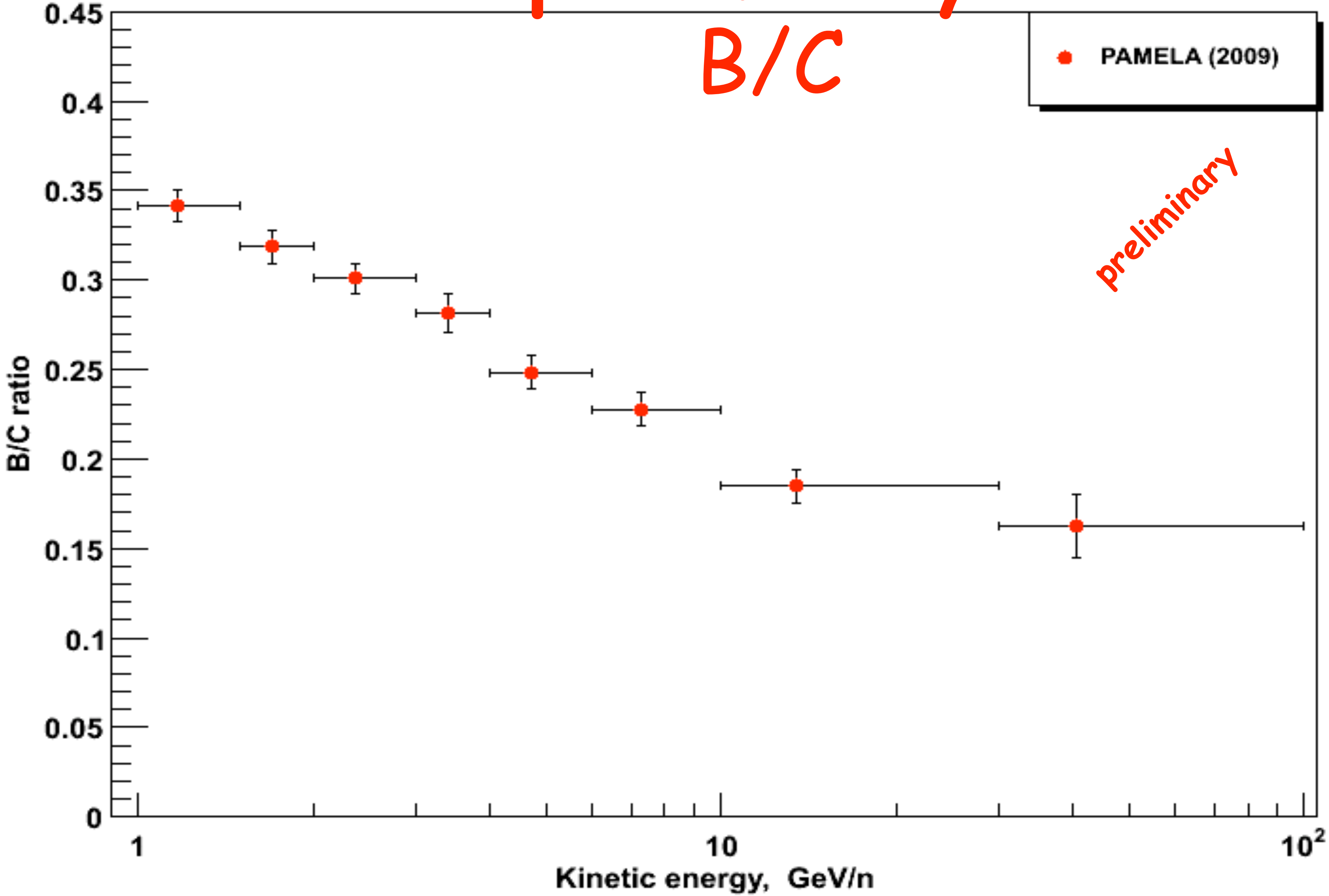
PAMELA preliminary results



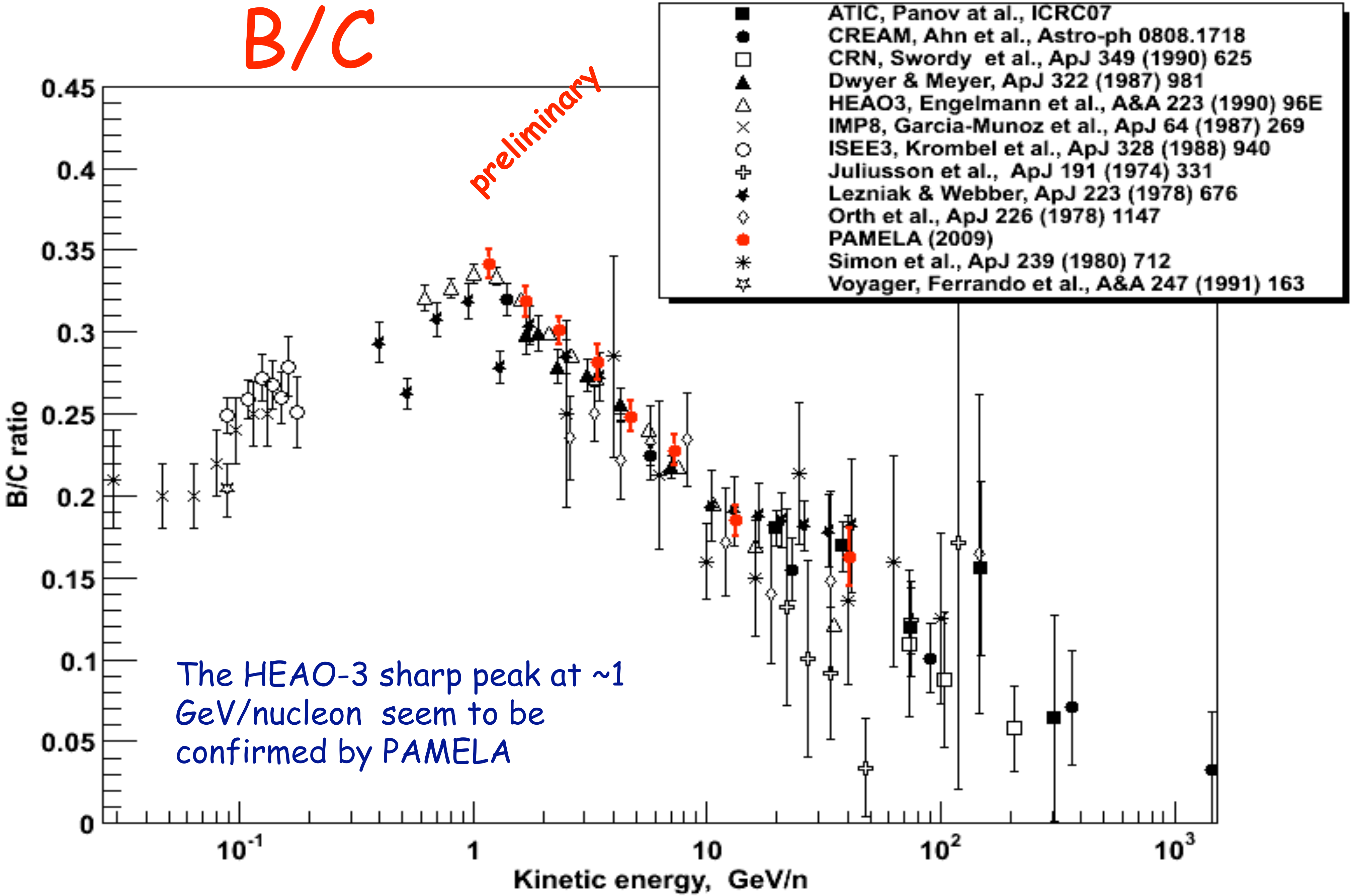

Be/C
HEAO3, Engelmann et al. A&A 223 (1990) 96E
IMP8, Garcia-Munoz at al., ApJ 64 (1987) 269
Juliusson et al. ApJ 191 (1974) 331
Lezniak & Webber ApJ 223 (1978) 676
Orth et al. ApJ 226 (1978) 1147
PAMELA (2009)
preliminary
Be/C ratio
0.2
0.15
0.1
0.05
0
-0.05
10^{-1}
1
10
10^2
Kinetic energy, GeV/n

PAMELA preliminary results

B/C



B/C



The HEAO-3 sharp peak at ~1 GeV/nucleon seem to be confirmed by PAMELA

Cosmic Ray Electron propagation models

They generally assume: $N_e(E) \propto E^{-\gamma_0}$

- Power-law source spectrum
- Power-law diffusion coefficient $D = D_0 \left(\frac{E}{E_0}\right)^{-\delta}$
  (normalised to match CR nuclear data)
- Continuos source distribution in the Galactic Disk

For E > 10 GeV solar modulation, re-acceleration, convection have negligible effects. Only synchrotron and IC energy losses matter.

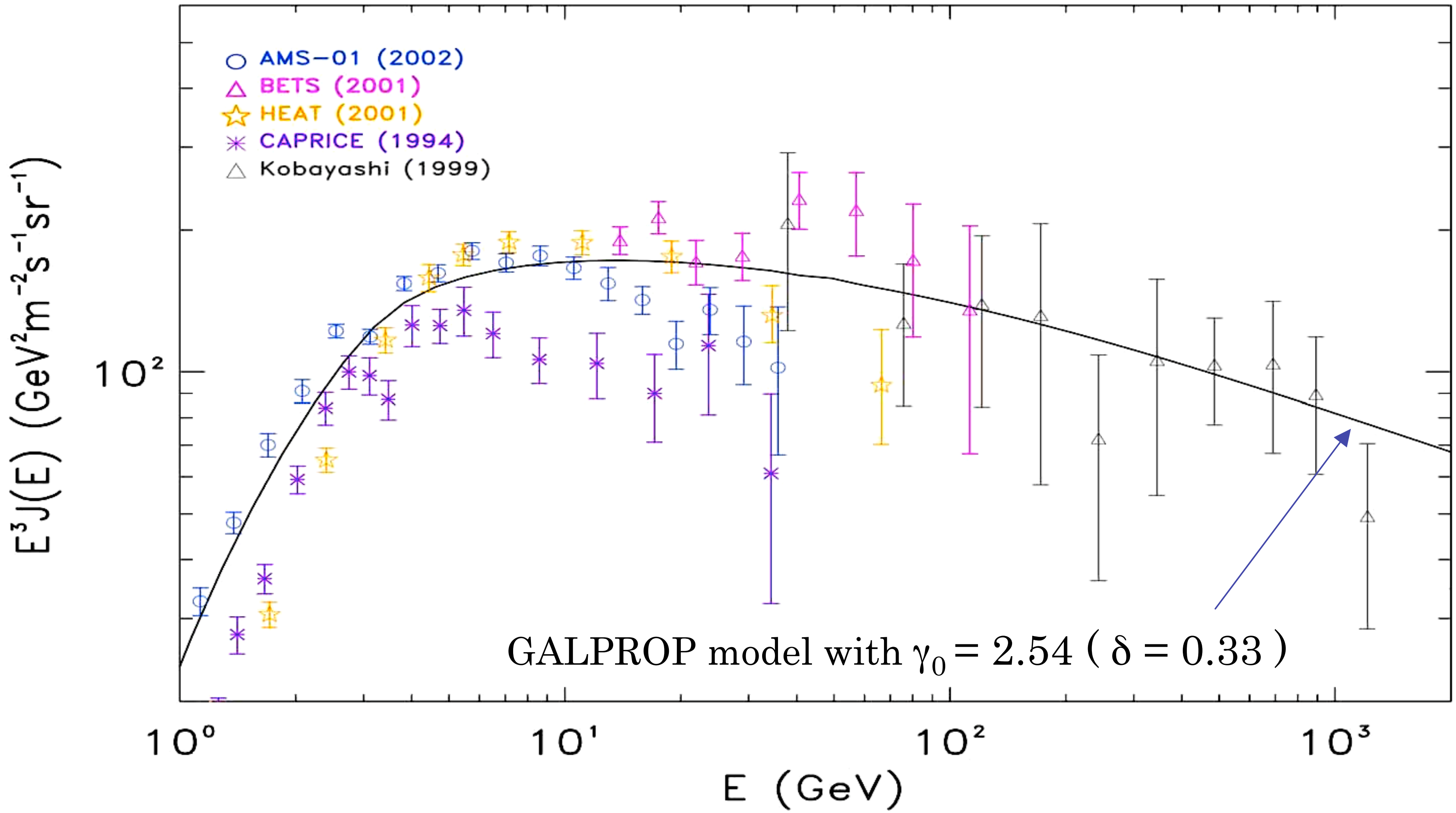
Under those conditions:

$$N_e(E) \propto E^{-(\gamma_0 + \frac{\delta}{2} + \frac{1}{2})}$$

This is only for illustrative purposes. All models here have been computed with GALPROP accounting for all effects !!

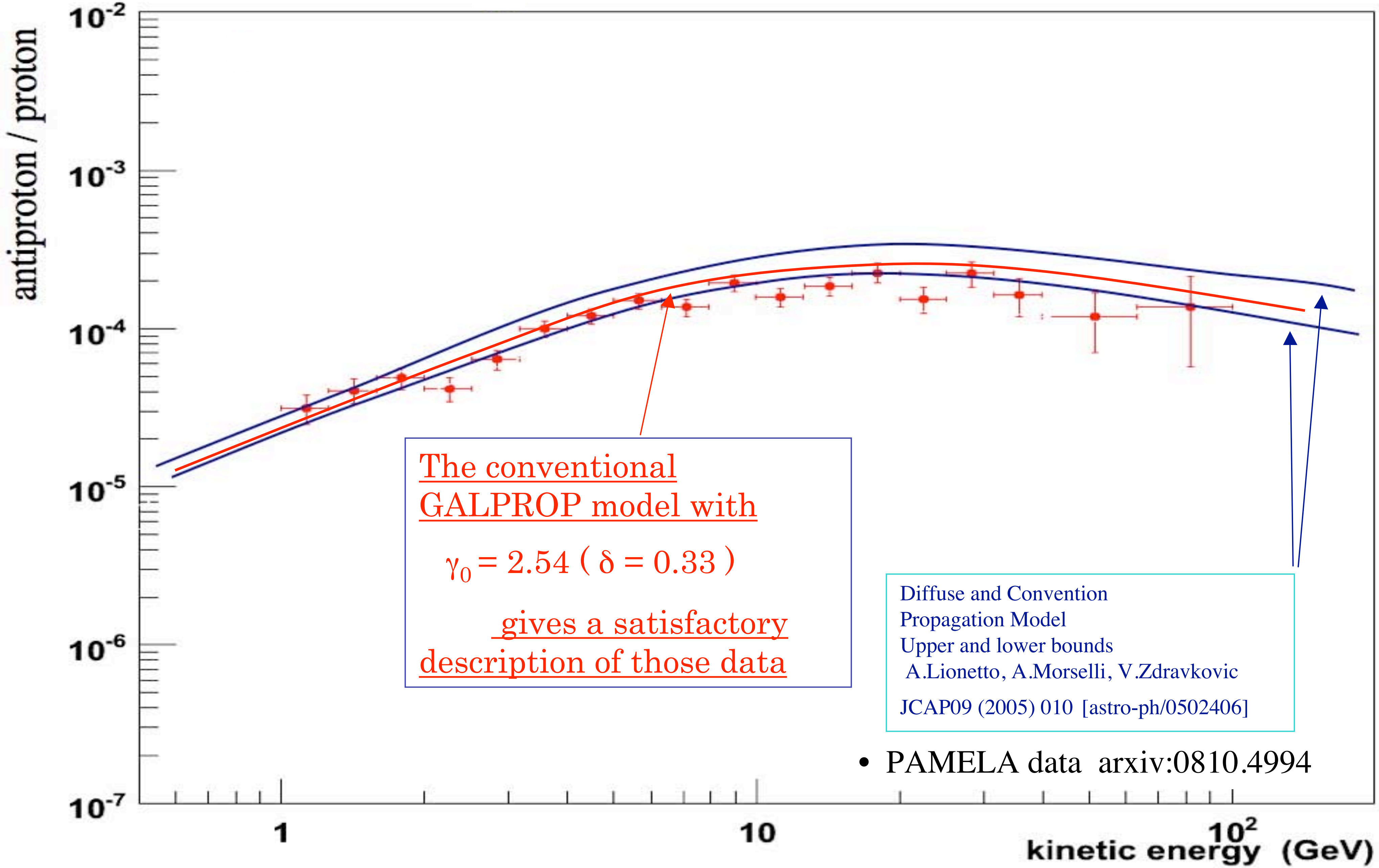
See http://galprop.stanford.edu/web_galprop/galprop_home.html

The situation before 2008
Electron + positron spectrum

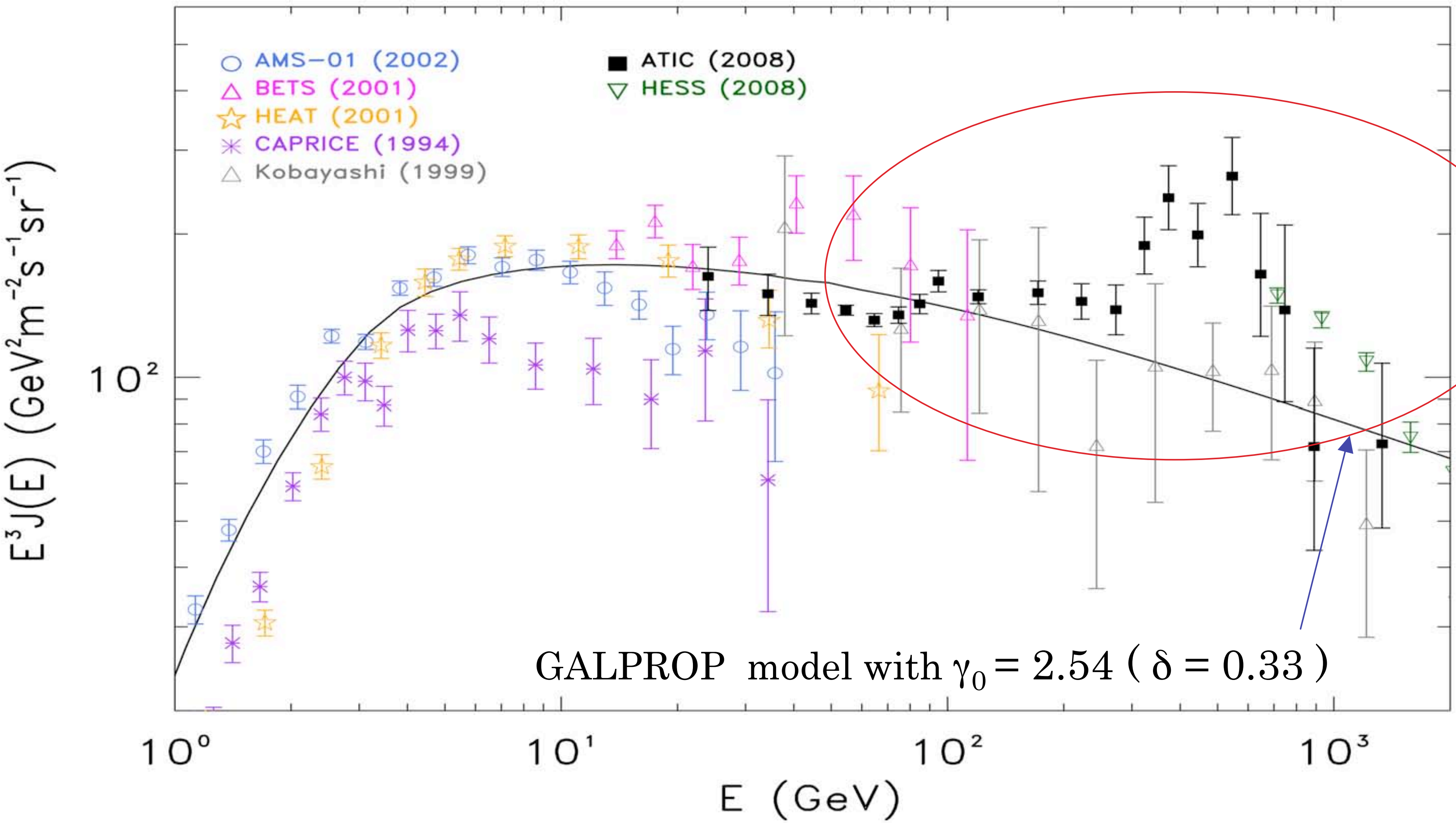


Data were compatible with conventional large-scale Galactic models of CRs tuned to fit gamma-ray data and other observables

Antiproton-Proton Ratio

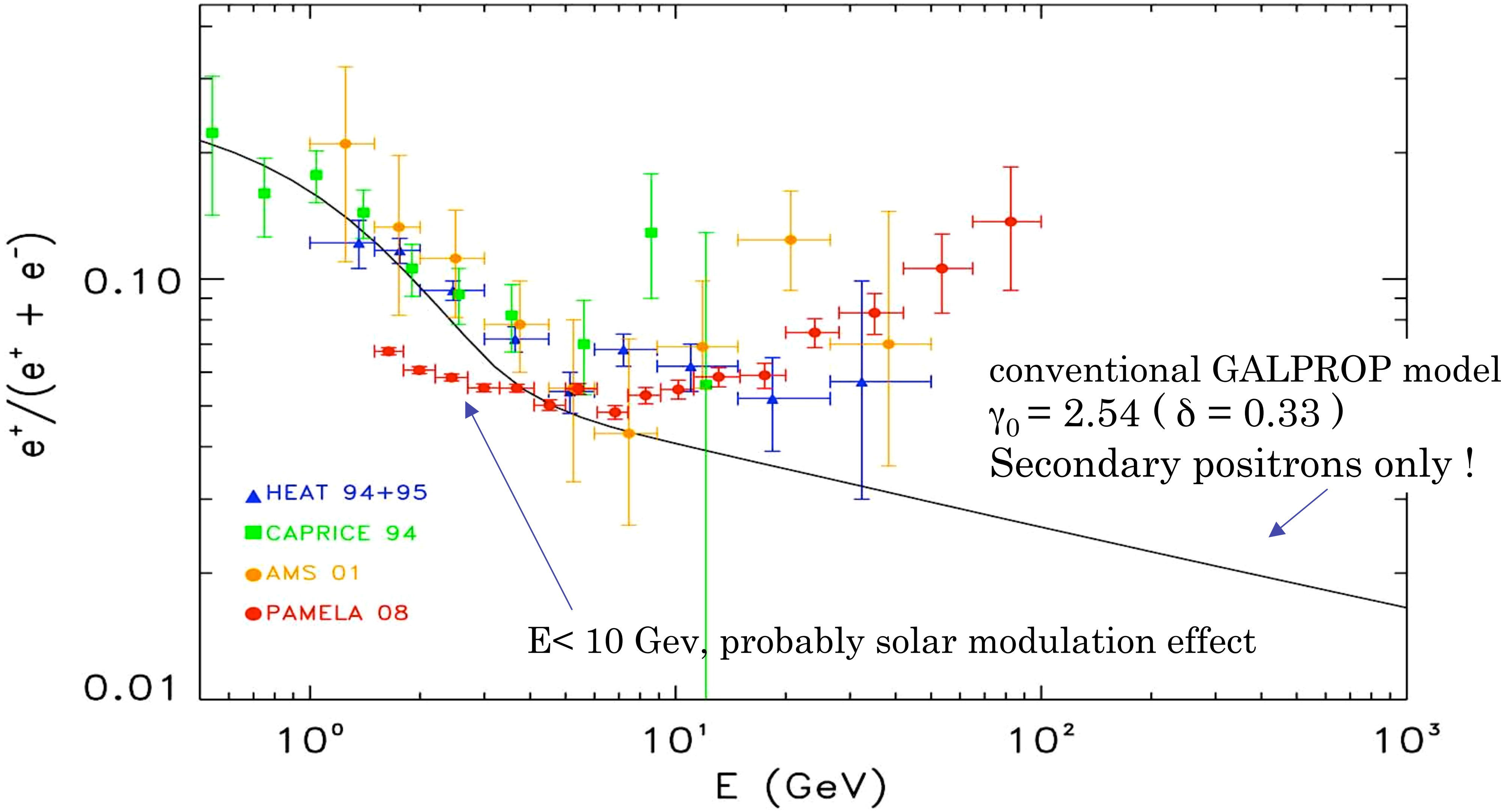


2008: Results from ATIC and HESS



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)

some articles about the positron excess

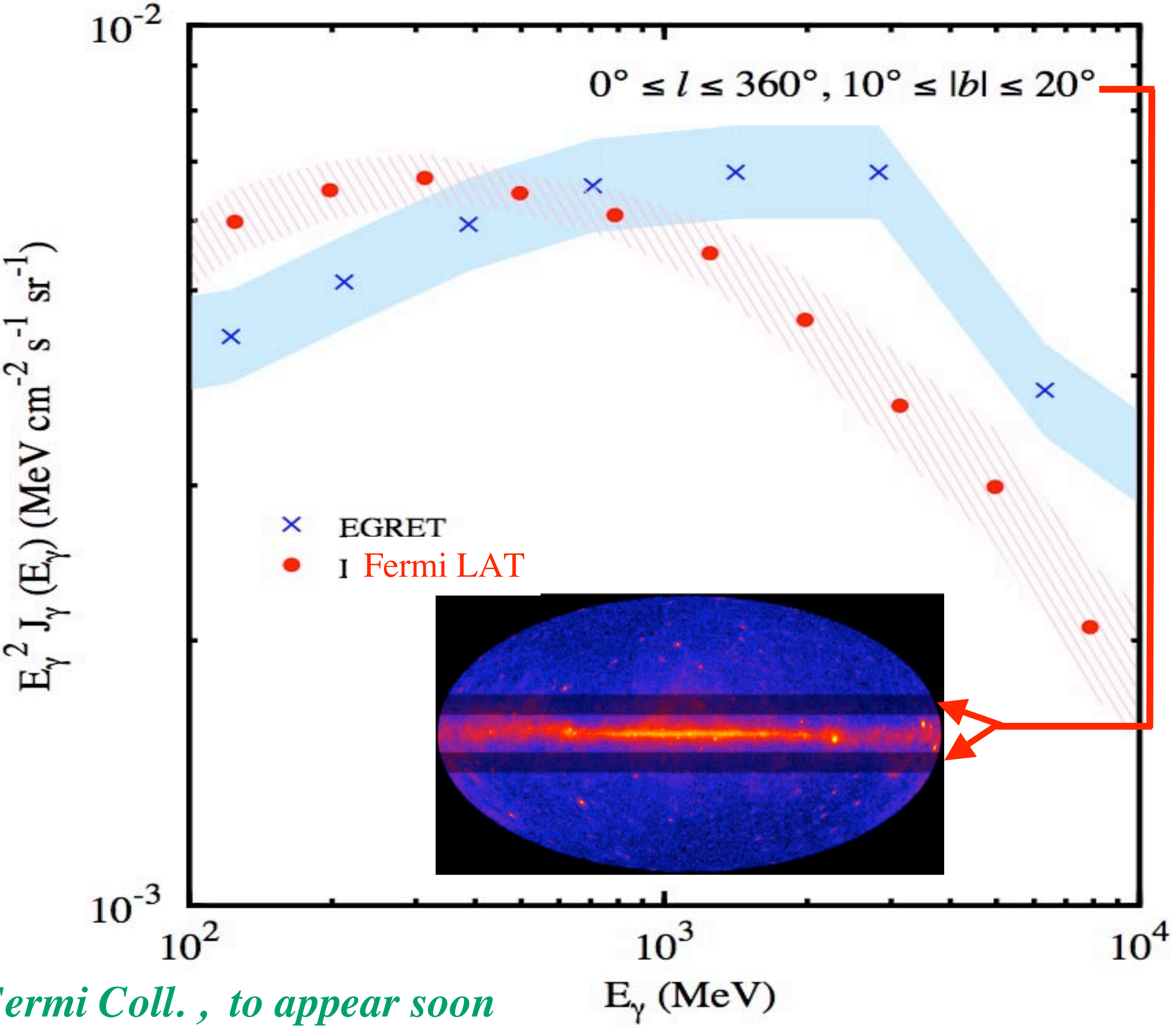
1. **arXiv:0901.3474** **Cosmic Ray Positrons from Cosmic Strings** Robert Brandenberger, Yi-Fu Cai, Wei Xue, Xinmin Zhang
2. **arXiv:0901.2556** **Positrons and antiprotons from inert doublet model dark matter** Emmanuel Nezri, Michel H.G. Tytgat, Gilles Vertongen
3. **arXiv:0901.1520** **On the cosmic electron/positron excesses and the knee of the cosmic rays - a key to the 50 years' puzzle?** Hong-Bo Hu, Qiang Yuan, Bo Wang, Chao Fan , Jian-Li Zhang , Xiao-Jun Bi
4. **arXiv:0812.4851** **A Gamma-Ray Burst for Cosmic-Ray Positrons with a Spectral Cutoff and Line**Kunihito Ioka
5. **arXiv:0812.4555** **Is the PAMELA Positron Excess Winos?** Phill Grajek, Gordon Kane, Dan Phalen, Aaron Pierce, Scott Watson
6. **arXiv:0812.4457** **Dissecting Pamela (and ATIC) with Occam's Razor: existing, well-known Pulsars naturally account for the "anomalous" Cosmic-Ray Electron and Positron Data** Stefano Profumo
7. **arXiv:0812.4272** **Study of positrons from cosmic rays interactions and cold dark matter annihilations in the galactic environment** Roberto A. Lineros thesis
8. **arXiv:0812.3895** **Gamma-ray and Radio Constraints of High Positron Rate Dark Matter Models Annihilating into New Light Particles** Lars Bergstrom, Gianfranco Bertone, Torsten Bringmann, Joakim Edsjo, Marco Taoso
9. **arXiv:0812.2102** **A Relativistic Electron-Positron Outflow from a Tepid Fireball**Katsuaki Asano, Fumio Takahara
10. **arXiv:0812.0219** **Neutrino Signals from Annihilating/Decaying Dark Matter in the Light of Recent Measurements of Cosmic Ray Electron/Positron Fluxes** Junji Hisano, Masahiro Kawasaki, Kazunori Kohri, Kazunori Nakayama
11. **arXiv:0811.0477** **High-energy Cosmic-Ray Positrons from Hidden-Gauge-Boson Dark Matter** Chuan-Ren Chen, Fuminobu Takahashi, T. T. Yanagida

11\. **arXiv:0811.3526** **Status of indirect searches in the PAMELA and Fermi era** Aldo Morselli, Igor Moskalenko

12. arXiv:0811.0250 **Cosmic-Ray Positron from Superparticle Dark Matter and the PAMELA Anomaly** Koji Ishiwata, Shigeki Matsumoto, Takeo Moroi
13. arXiv:0810.5344 **The PAMELA Positron Excess from Annihilations into a Light Boson** Ilias Cholis, Douglas P. Finkbeiner, Lisa Goodenough, Neal Weiner
14. arXiv:0810.4846 **Possible causes of a rise with energy of the cosmic ray positron fraction** Pasquale Dario Serpico
15. arXiv:0810.2784 **TeV Gamma Rays from Geminga and the Origin of the GeV Positron Excess** Hasan Yuksel , Matthew D. Kistler Todor Stanev
16. arXiv:0810.1892 **Positron/Gamma-Ray Signatures of Dark Matter Annihilation and Big-Bang Nucleosynthesis** Junji Hisano, Masahiro Kawasaki, Kazunori Kohri, Kazunori Nakayama
17. arXiv:0810.1527 **Pulsars as the Sources of High Energy Cosmic Ray Positrons** Dan Hooper, Pasquale Blasi, Pasquale Dario Serpico
18. arXiv:0809.5268 **Galactic secondary positron flux at the Earth** T. Delahaye, F. Donato , N. Fornengo , J. Lavalle , R. Lineros , P. Salati , R. Taillet ,
19. arXiv:0809.2601 **Two dark matter components in N_{DM}MSSM and dark matter extension of the minimal supersymmetric standard model and the high energy positron spectrum in PAMELA/HEAT data** Ji-Haeng Huh, Jihn E. Kim, Bumseok Kyae
20. arXiv:0809.2491 **On the 511 keV emission line of positron annihilation in the Milky Way** N. Prantzos
22. arXiv:0809.0792 **Gamma rays and positrons from a decaying hidden gauge boson** Chuan-Ren Chen, Fuminobu Takahashi, T. T. Yanagida
23. arXiv:0808.3867 **Minimal Dark Matter predictions and the PAMELA positron excess**Marco Cirelli, Alessandro Strumia
24. arXiv:0808.3725 **New Positron Spectral Features from Supersymmetric Dark Matter - a Way to Explain the PAMELA Data?**Lars Bergstrom, Torsten Bringmann, Joakim Edsjo


~ 1 year from Fermi launch
11 June 2008

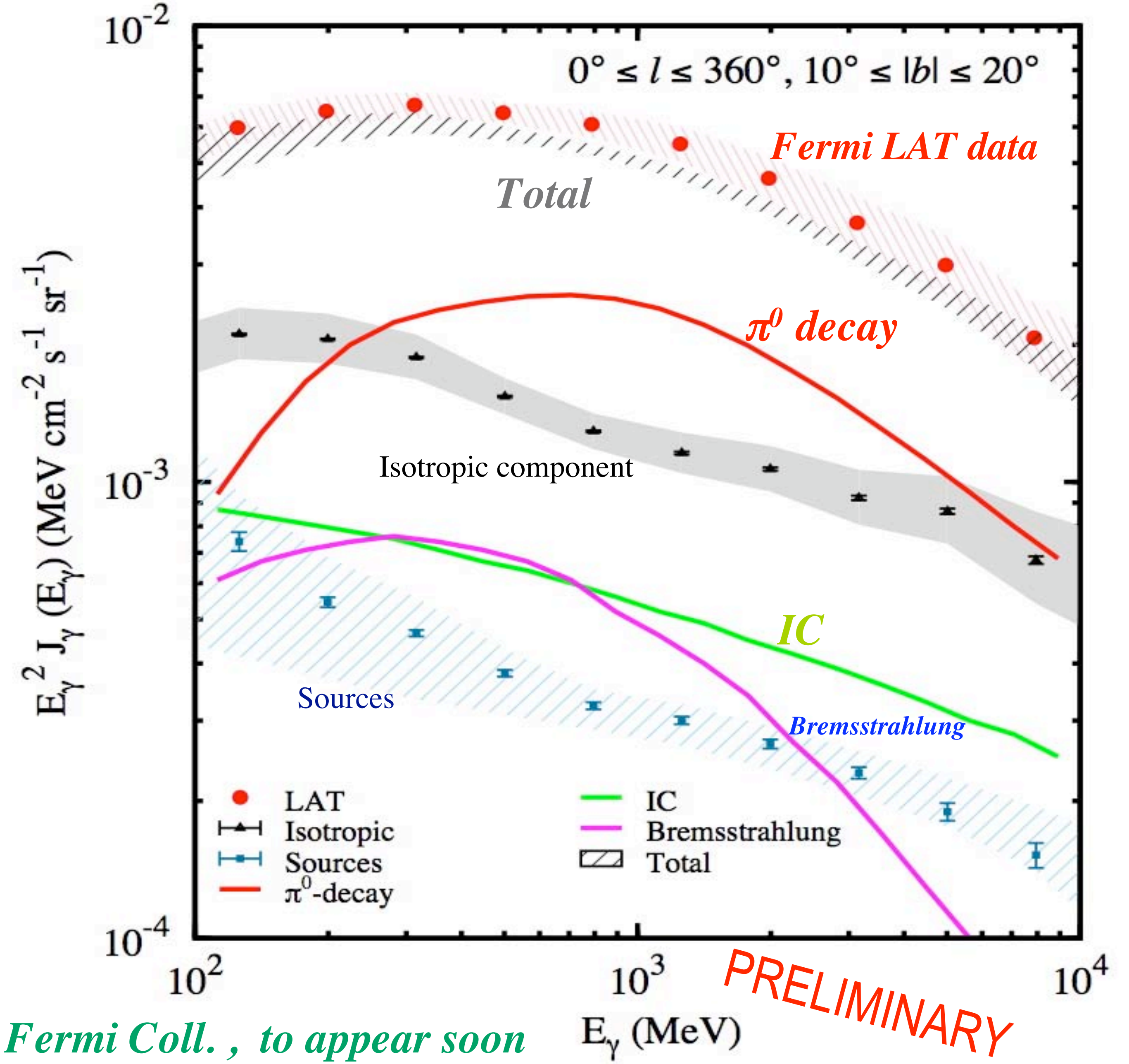
The Galactic Diffuse Emission



Fermi Coll. , to appear soon

- Spectra shown for mid-latitude range → GeV excess in this region of the sky is not confirmed.
- Sources are not subtracted but are a minor component.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% → this is preliminary.

2009: Fermi-LAT diffuse gamma-ray spectrum first measurements



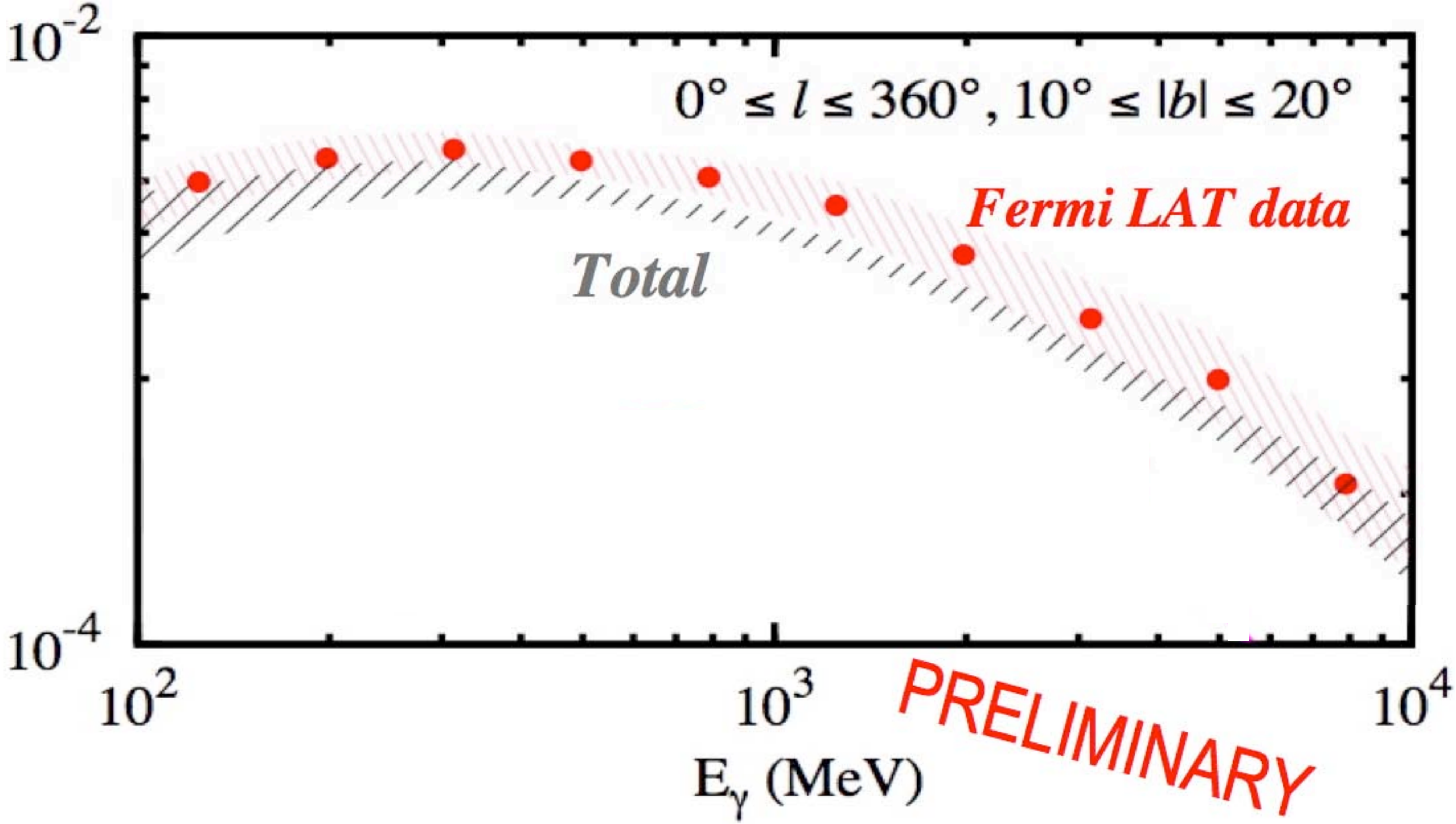
Fermi Coll. , to appear soon

EGRET GeV excess was not observed ⇒ Conventional models (based on the locally measured CR fluxes) can be used

The conventional model with $\gamma_0 = 2.54$ ($\delta = 0.33$) gives a satisfactory description of Fermi-LAT gamma-ray data

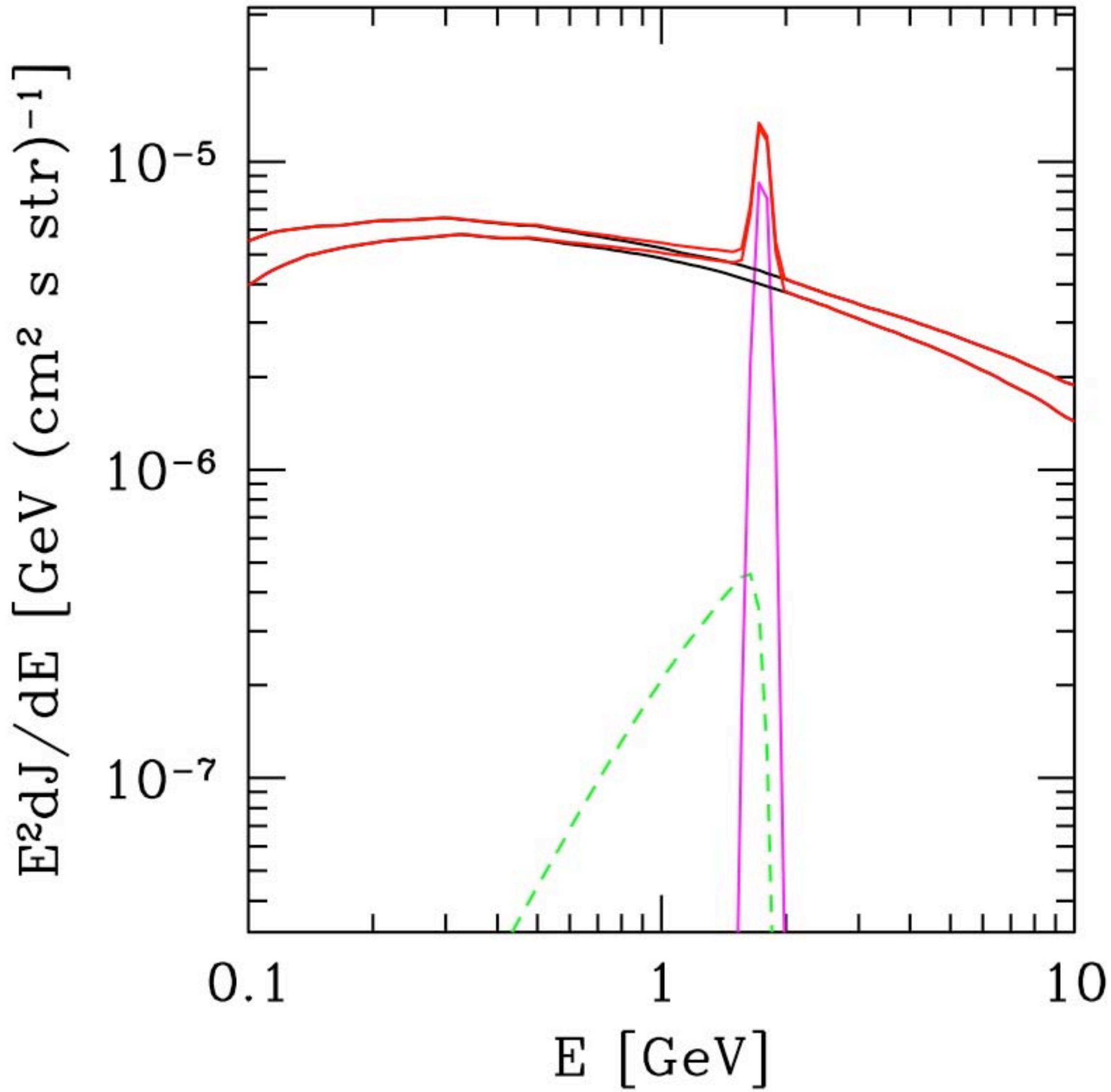
Conventional model are weakly affected by small changes in the electron spectrum.

2009: Fermi-LAT diffuse gamma-ray spectrum first measurements



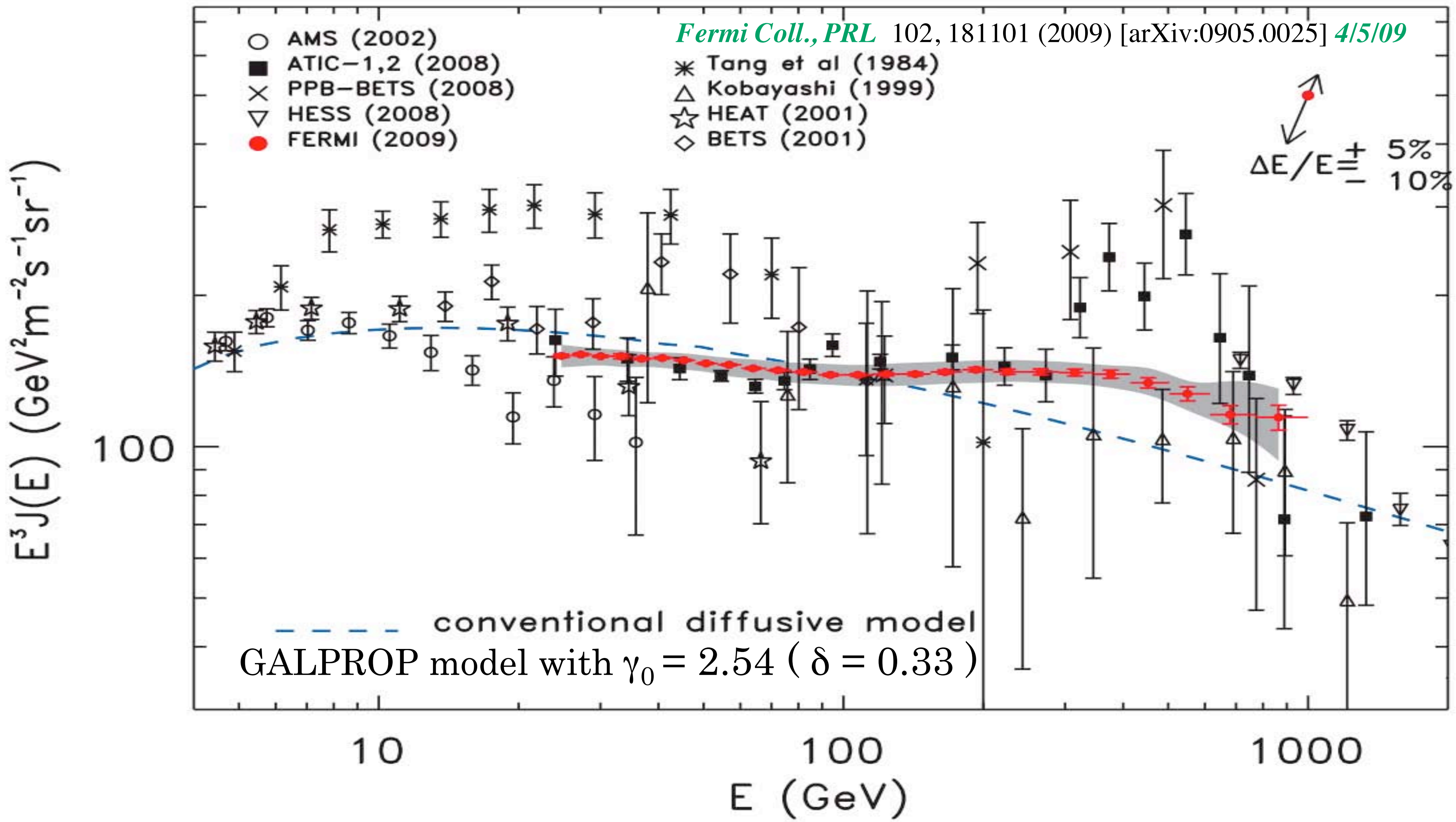
gamma-ray spectrum for an example of gravitino dark matter decay in the mid-latitude range

- $10^0 \leq |b| \leq 20^0$



Gamma-ray detection from gravitino dark matter decay in the μνSSM arXiv:0906.368

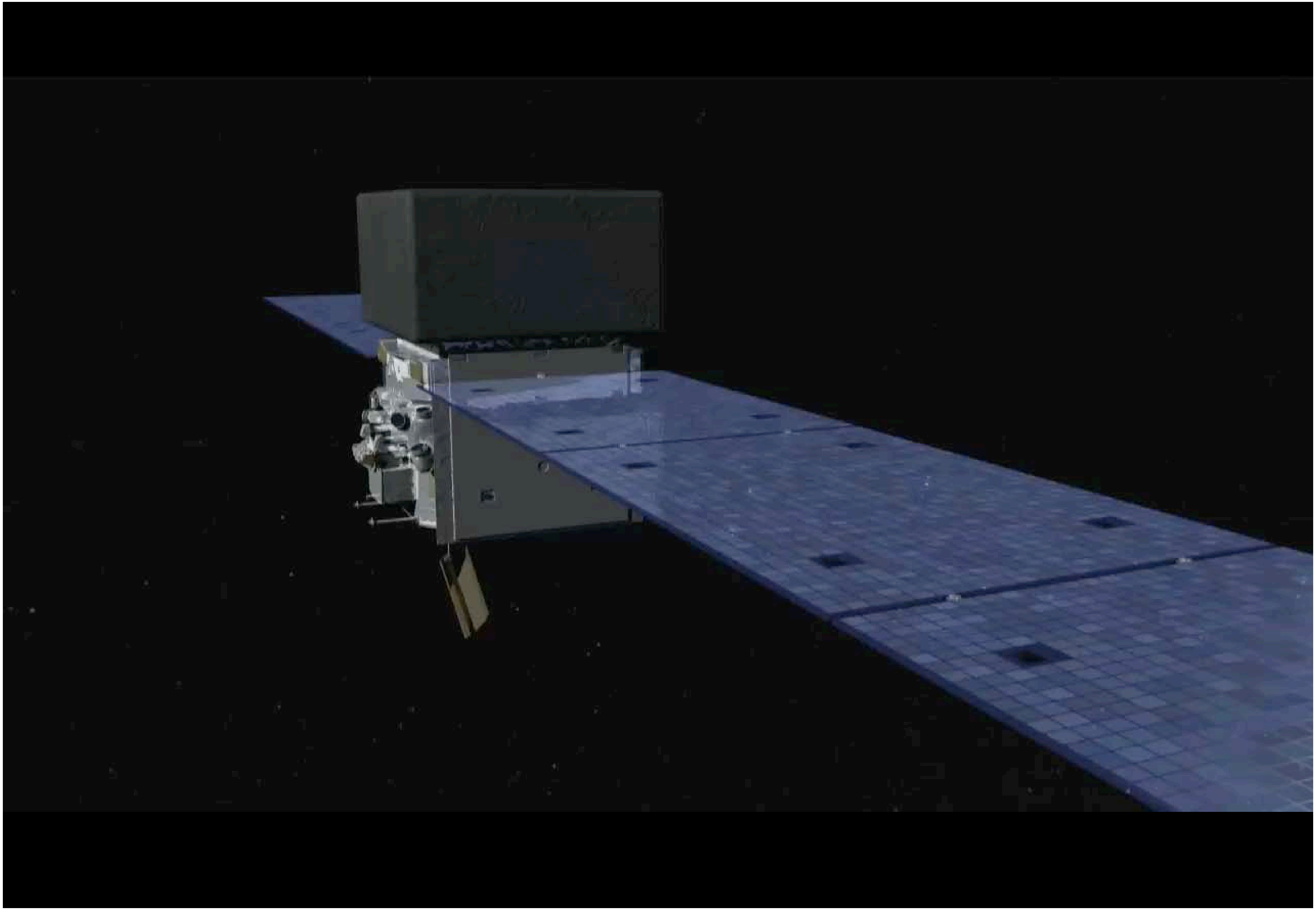
Fermi-LAT CRE data vs the conventional *pre-Fermi* model



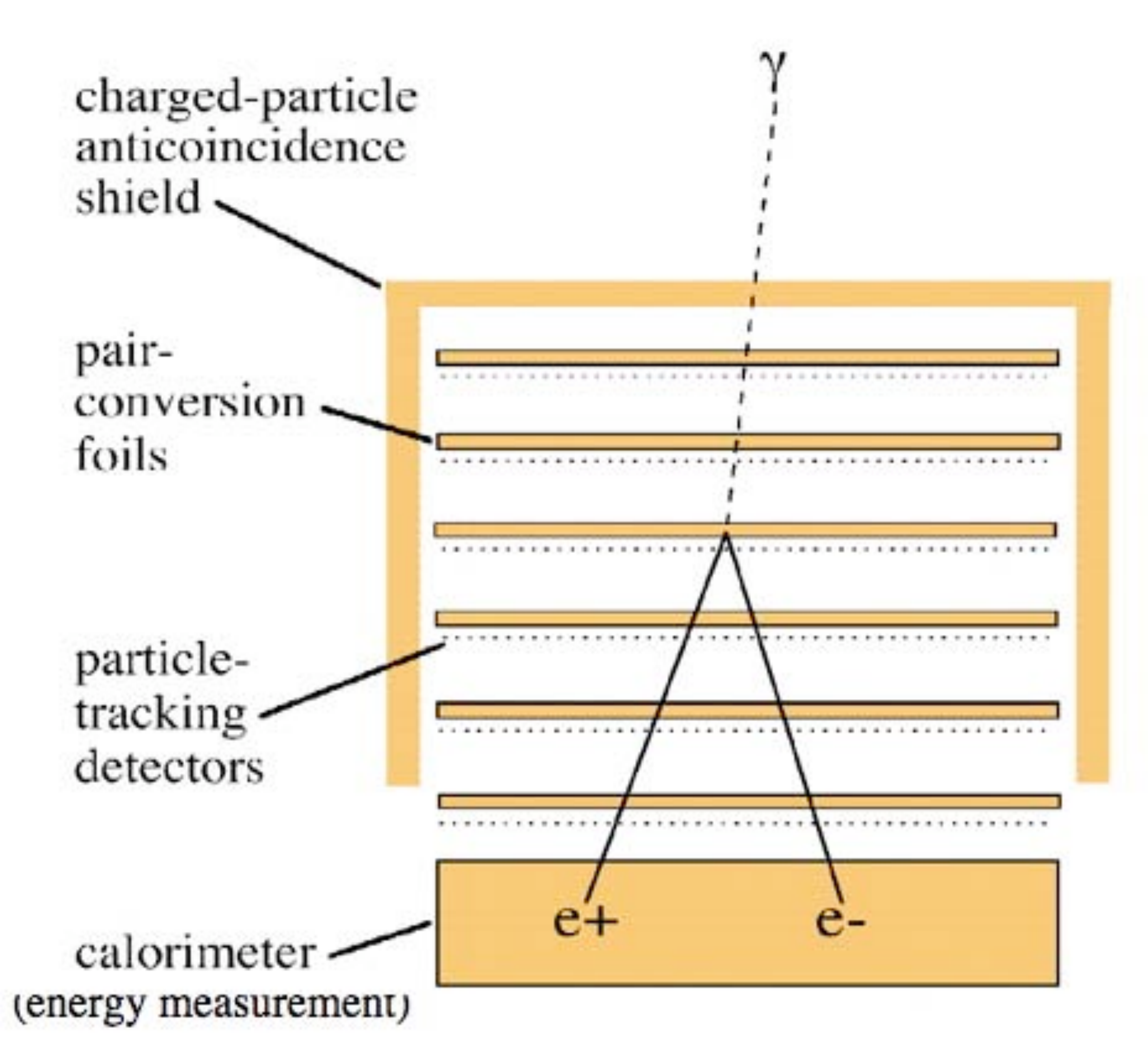
Although the feature @~600 GeV measured by ATIC is not confirmed

Some changes are still needed respect to the *pre-Fermi conventional model*

(



Elements of a pair-conversion telescope

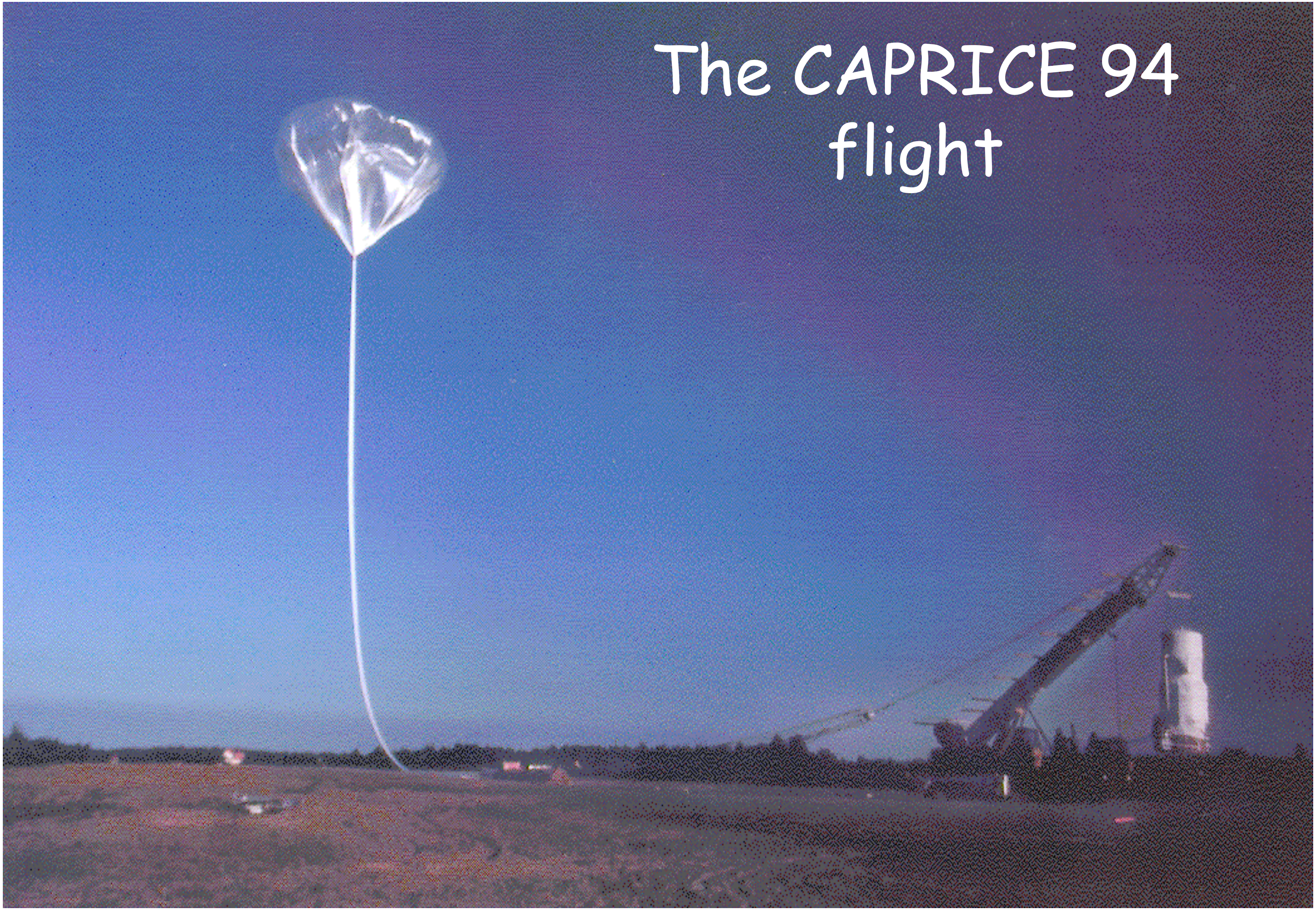


- photons materialize into matter-antimatter pairs:

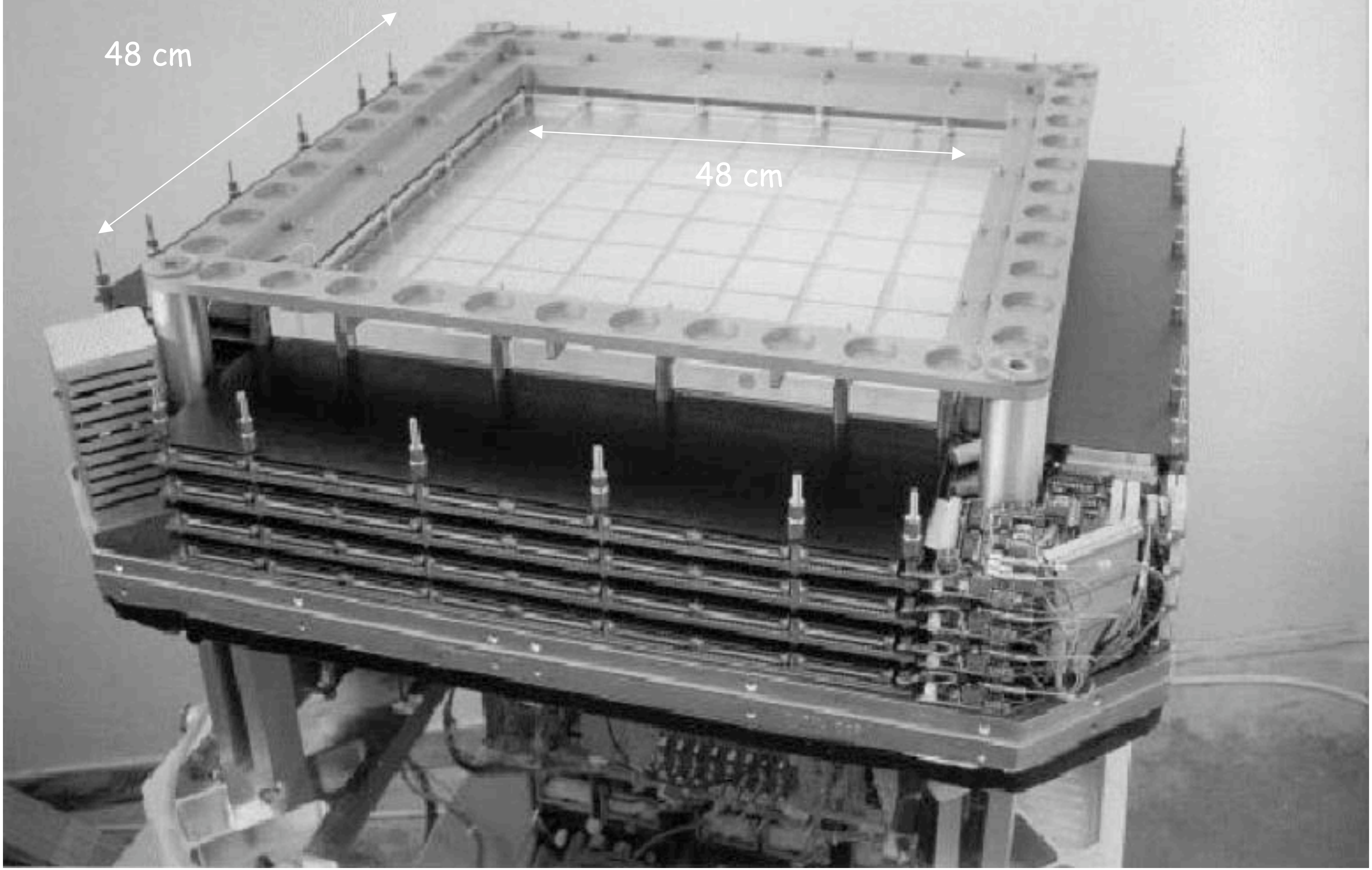
  $E_\gamma \; \text{-->} \; m_{e^+}c^2 + m_{e^-}c^2$

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

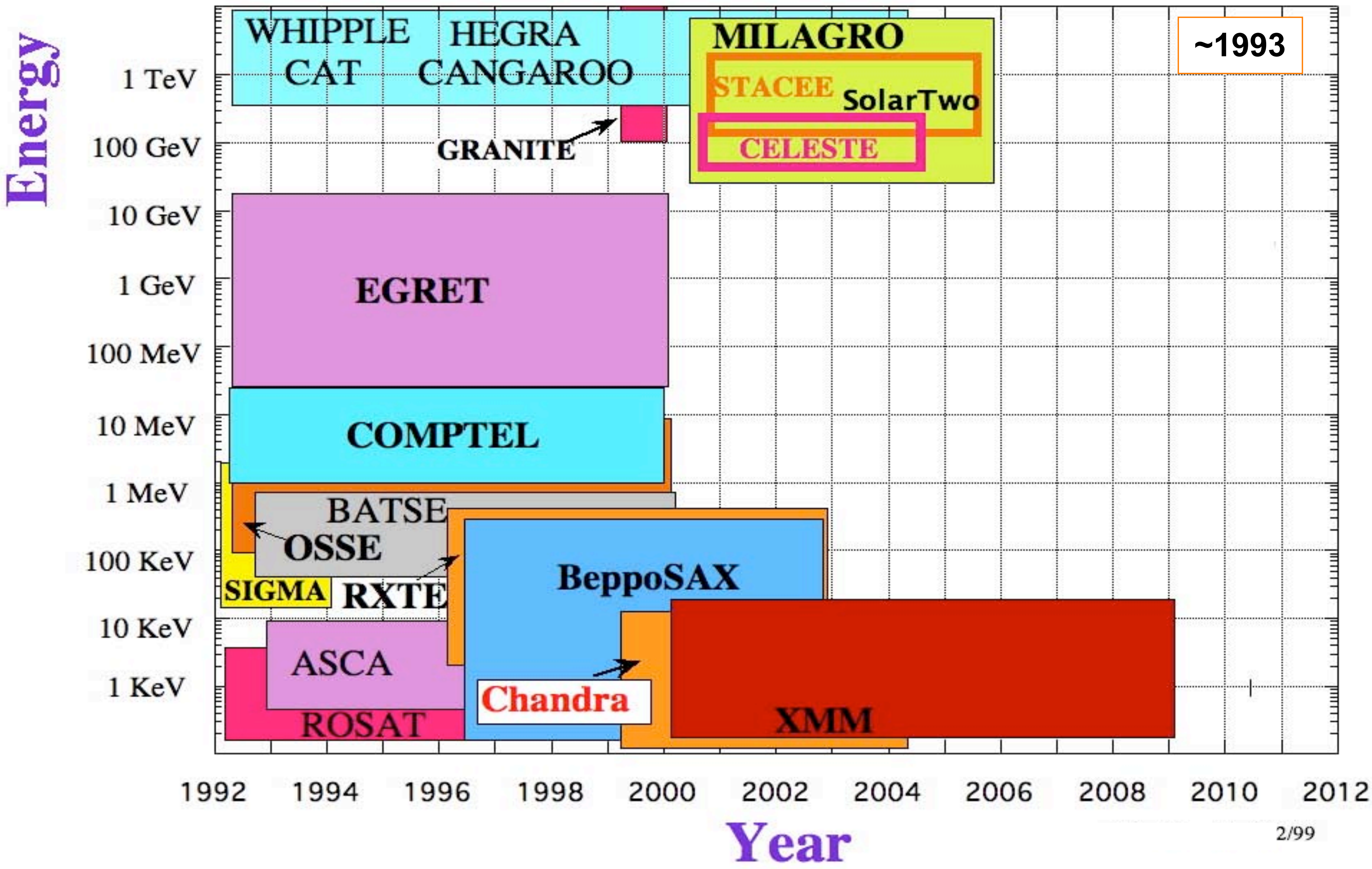
51


The CAPRICE 94
flight

The TS93 and CAPRICE silicon-tungsten imaging calorimeter.



High Energy Gamma Experiments Experiments



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]

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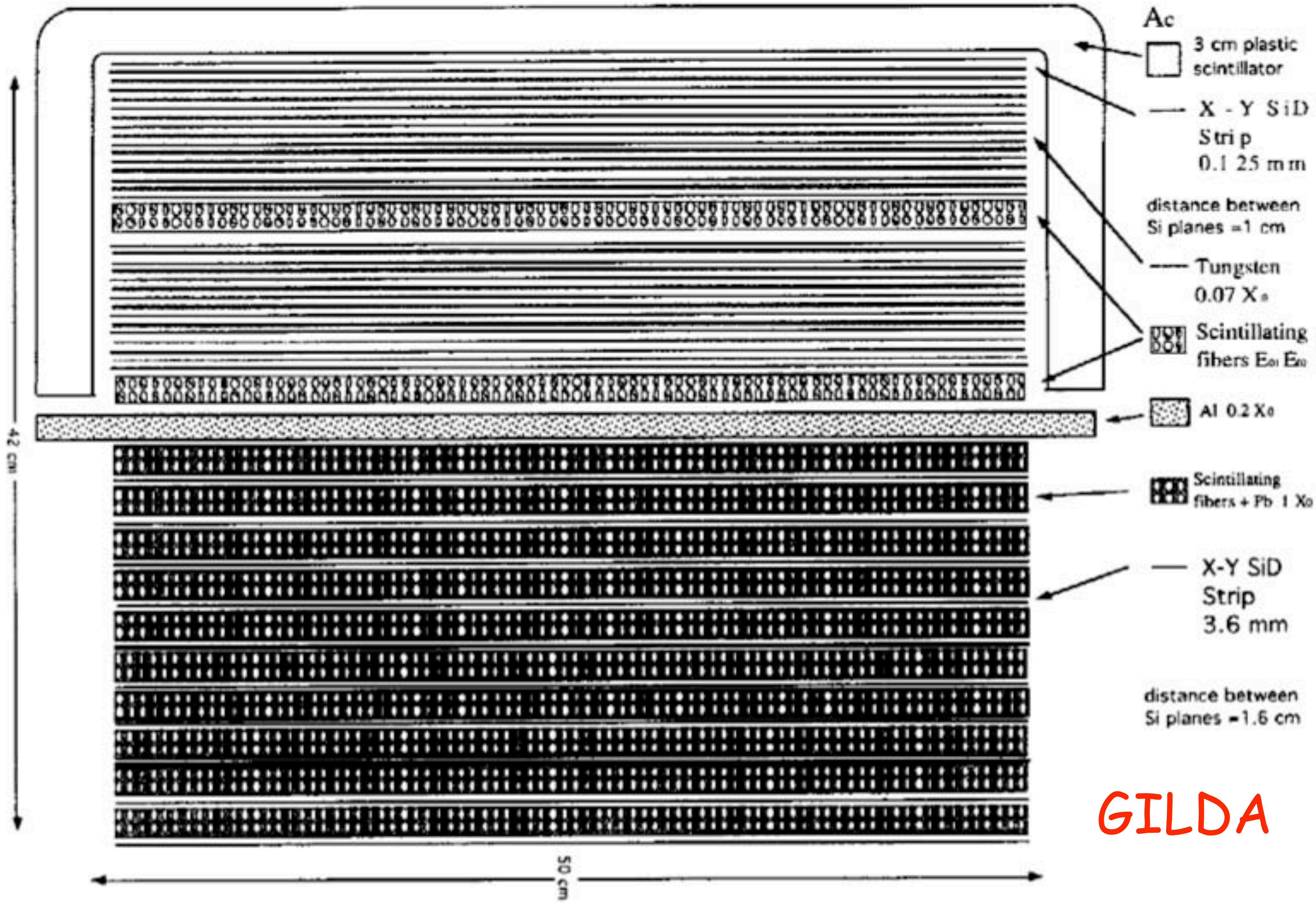
Received 5 August 1994

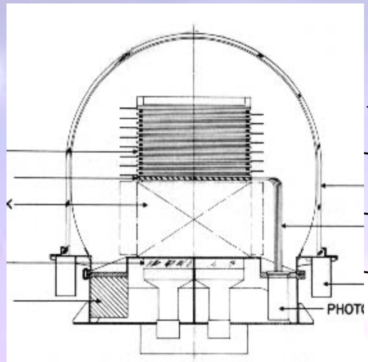
Abstract

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.



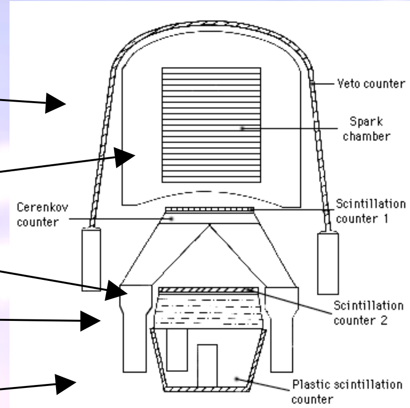
Ac
3 cm plastic scintillator
X - Y SiD Strip 0.1 25 mm
distance between Si planes =1 cm
Tungsten 0.07 X0
Scintillating fibers E01 E0
Al 0.2 X0
Scintillating fibers + Pb 1 X0
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm

GILDA



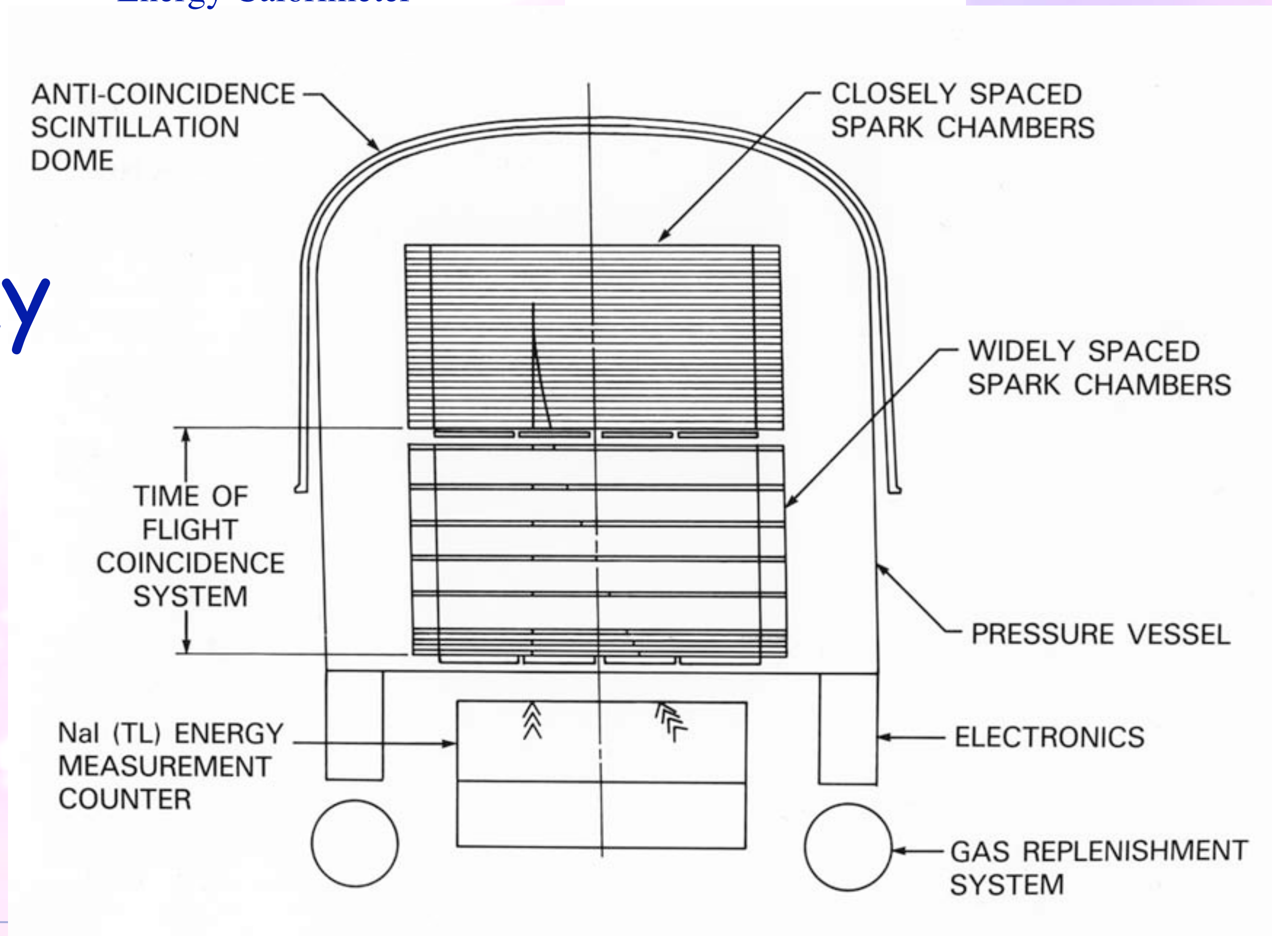
SAS-2
11/1972-7/1973

Anti-Coincidence Dome
Spark Chamber
Trigger Telescope
Cerenkov Counter
Energy Calorimeter



Cos-B
8/1975-4/1982

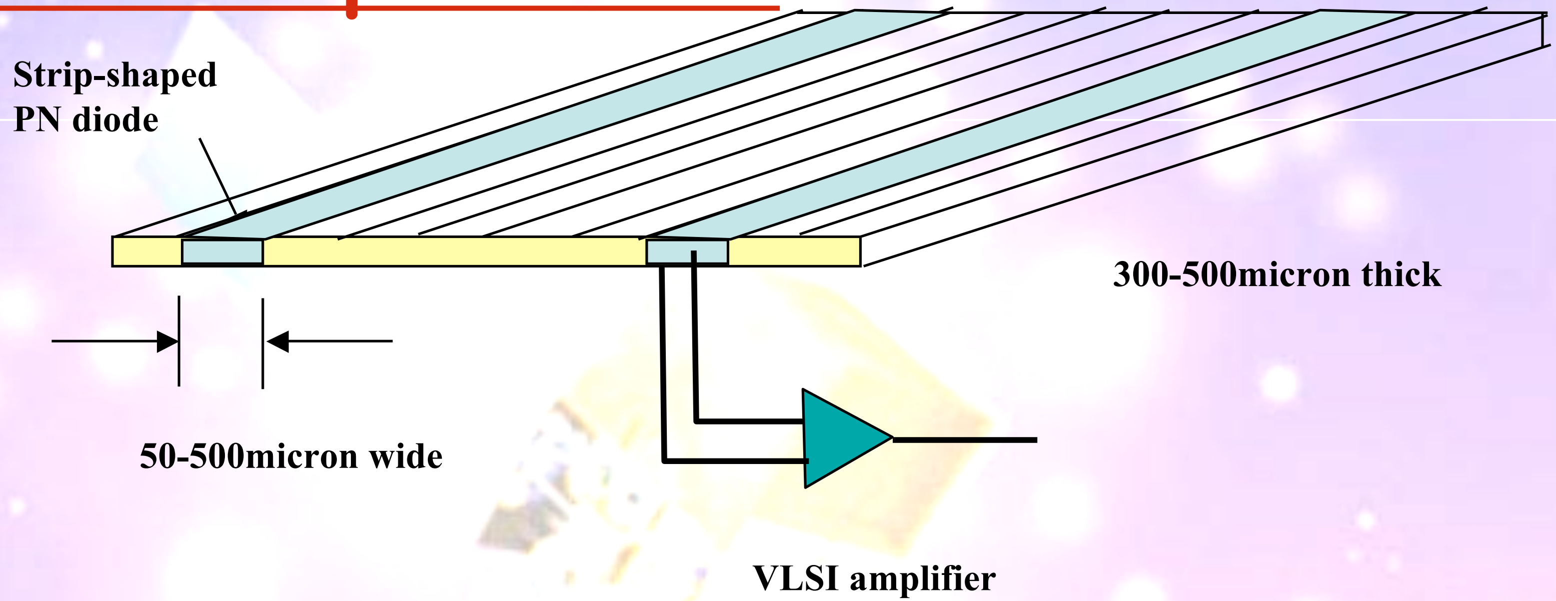
The gamma-ray missions



EGRET
4/1991-1999

New Detector Technology

- <u>Silicon strip detector</u>



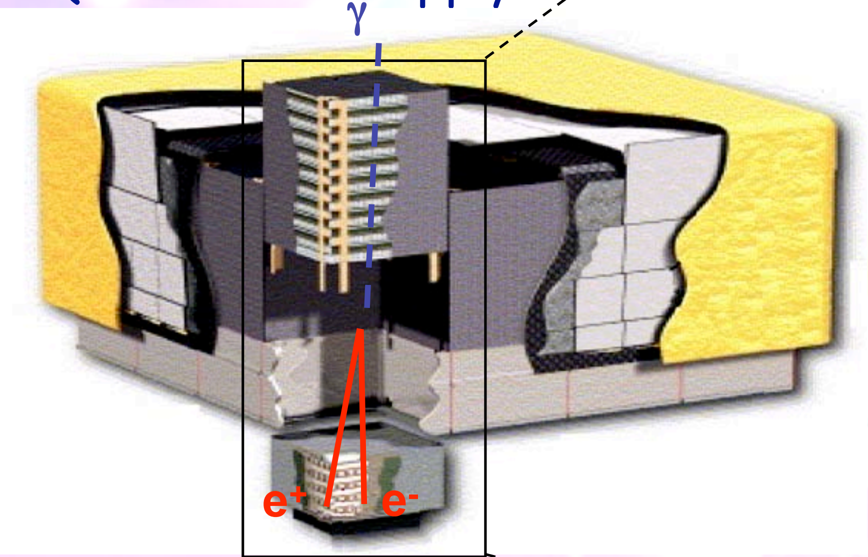
Stable particle tracker that allows micron-level tracking of gamma-rays

Well known technology in Particle Physics experiments.
Used by our collaboration in balloon experiments (MASS, TS93, CAPRICE), on MIR Space Station (SilEye) and on satellite (NINA)

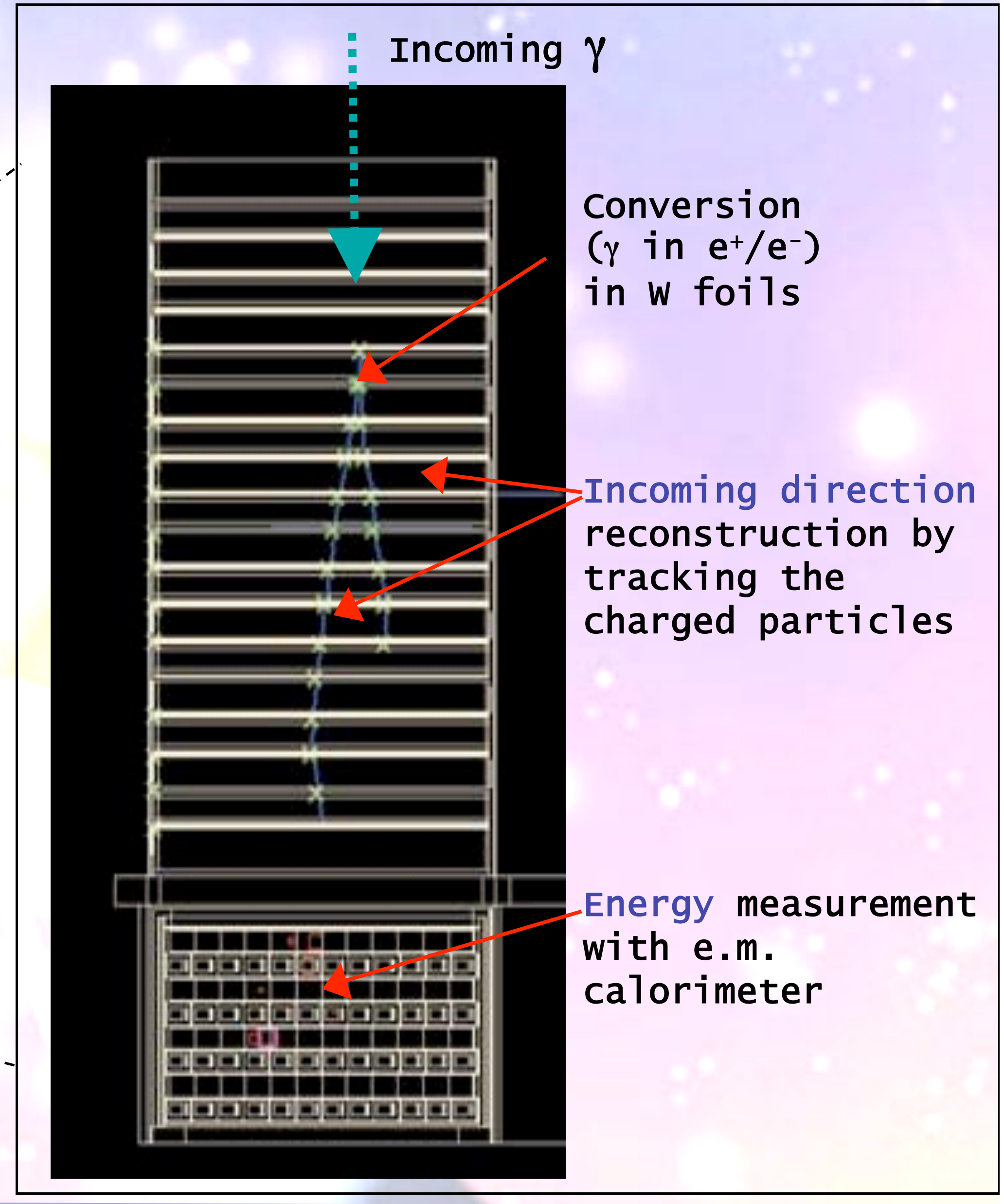
How Fermi LAT detects gamma rays

4 x 4 array of identical towers with:

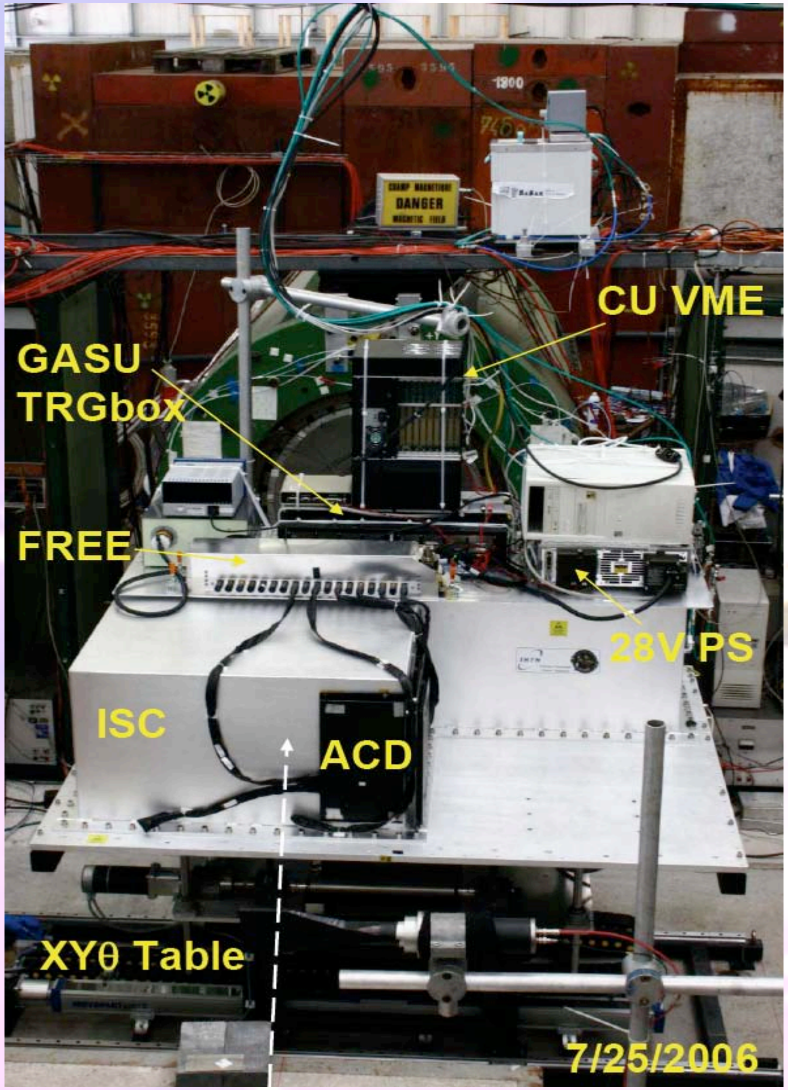
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box



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

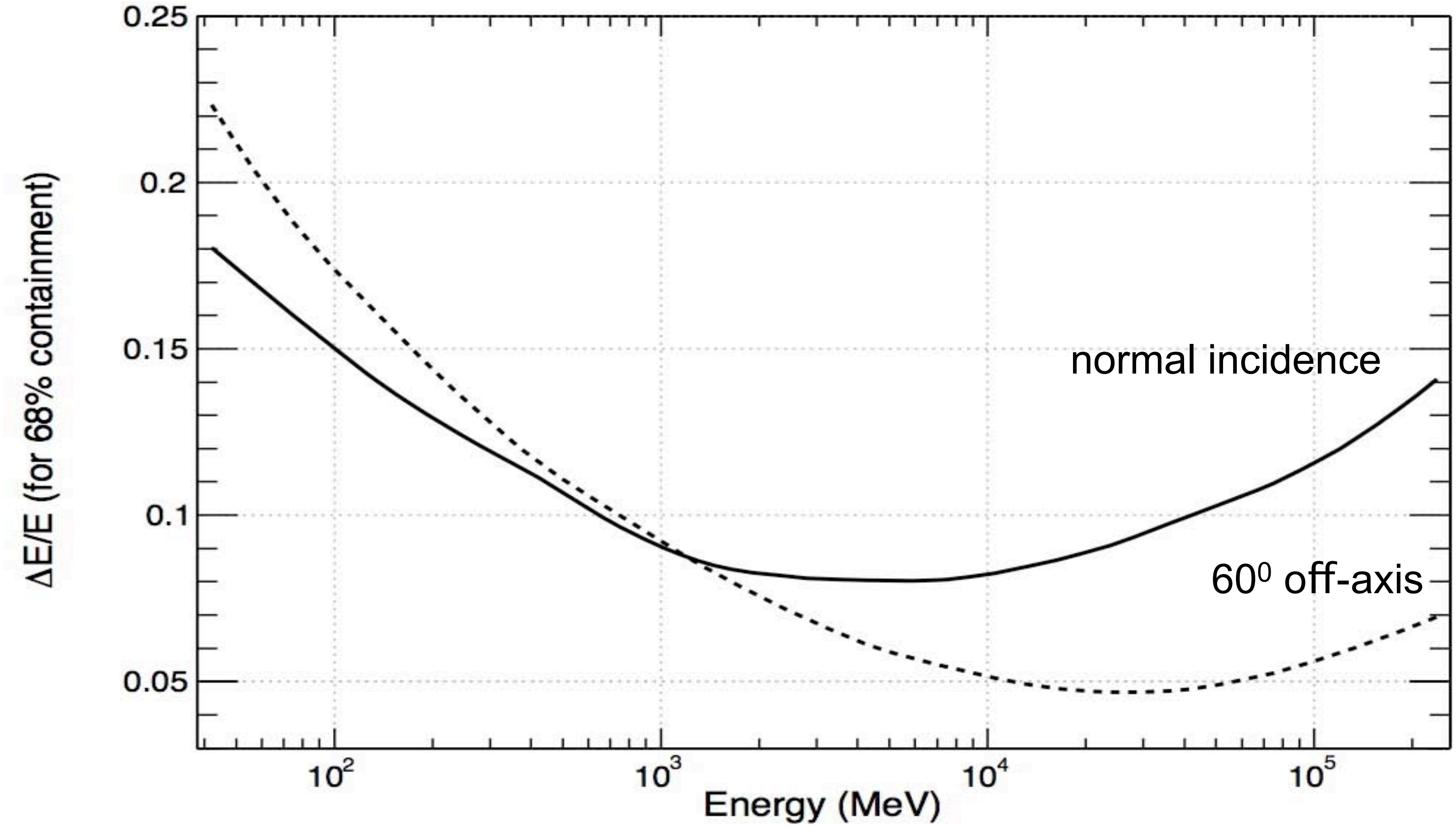


The CERN Beam Test Campaign



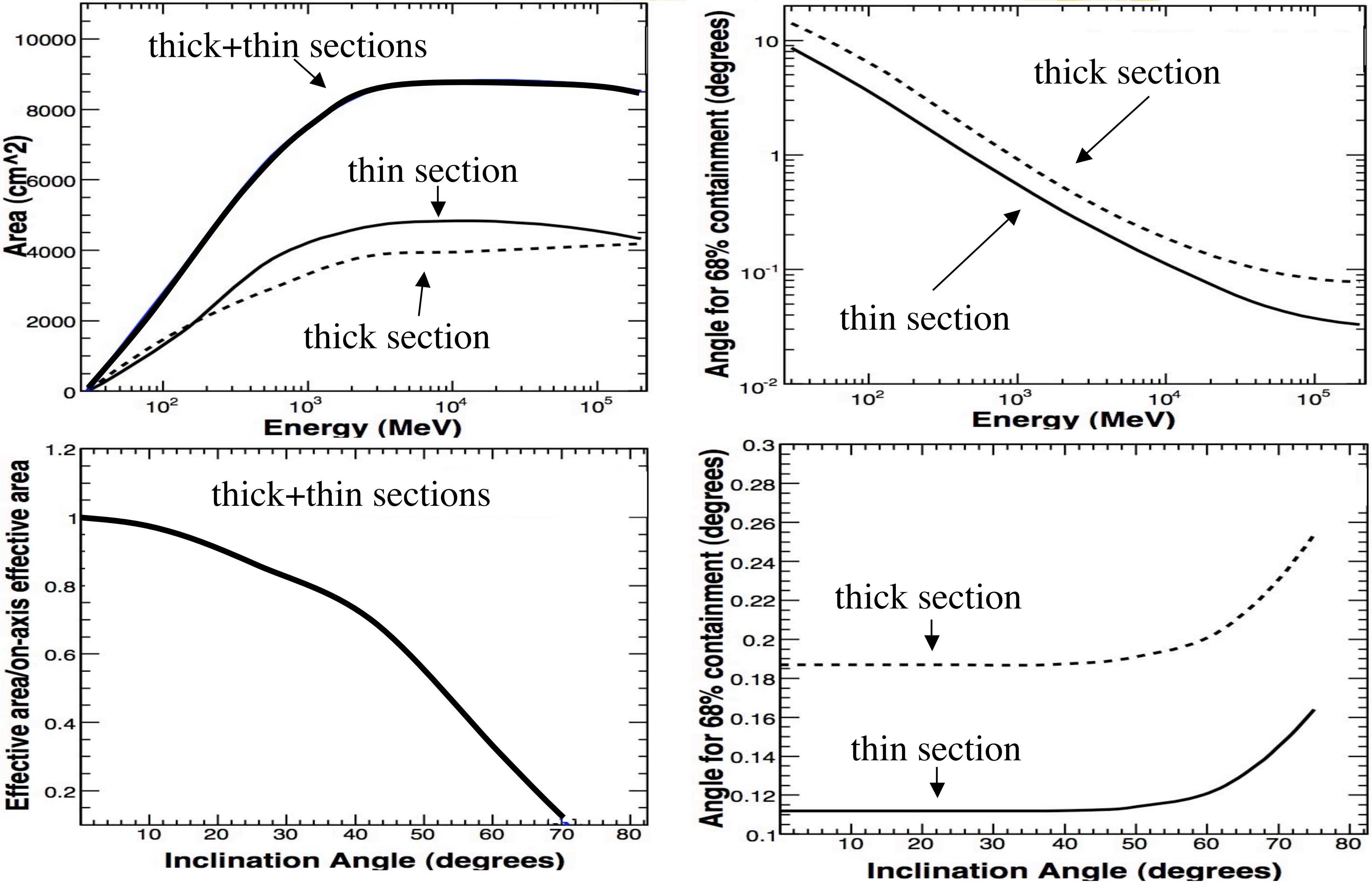
- 4 weeks at PS/T9 area (26/7-23/8)
  - Gammas @ 0-2.5 GeV
  - Electrons @ 1,5 GeV
  - Positrons @ 1 GeV (through MMS)
  - Protons @ 6,10 GeV (w/ & w/o MMS)
- 11 days at SPS/H4 area (4/9-15/9)
  - Electrons @ 10,20,50,100,200,280 GeV
  - Protons @ 20,100 GeV
  - Pions @ 20 GeV
- Data, data, data…
  - 1700 runs, 94M processed events
  - 330 configurations (particle, energy, angle, impact position)
  - Mass simulation
- A very dedicated team
  - 60 people worked at CERN
  - Whole collaboration represented

Energy Resolution

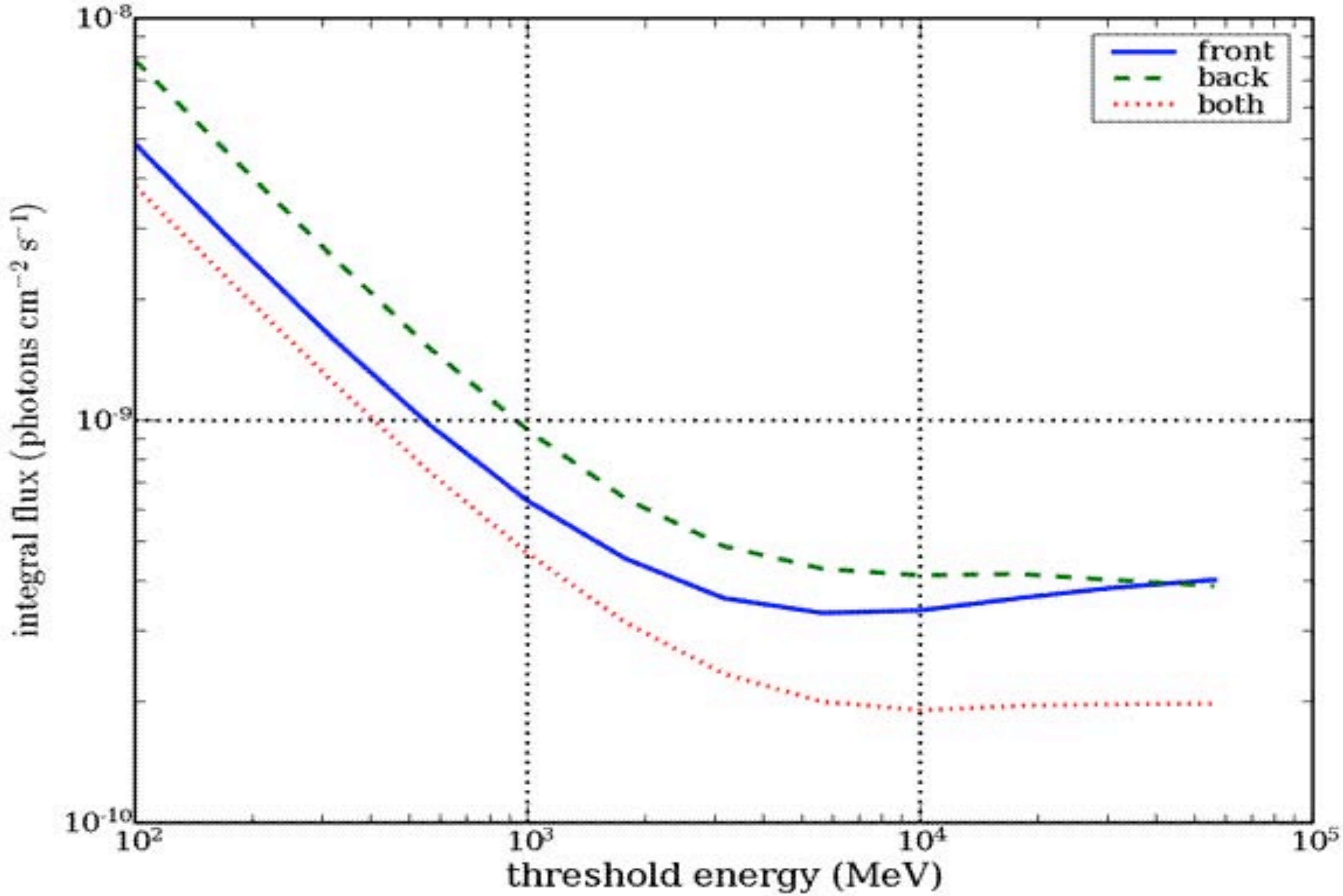


The LAT sensitivity extends to higher energies (> 300 GeV) than that of any previous space-based gamma-ray mission, opening the unexplored energy range above 30 GeV. The energy range of the LAT will overlap those of the next generation ground-based TeV gamma-ray instruments, allowing for inter-calibration between the LAT and these instruments.

Fermi LAT MC Derived Performance

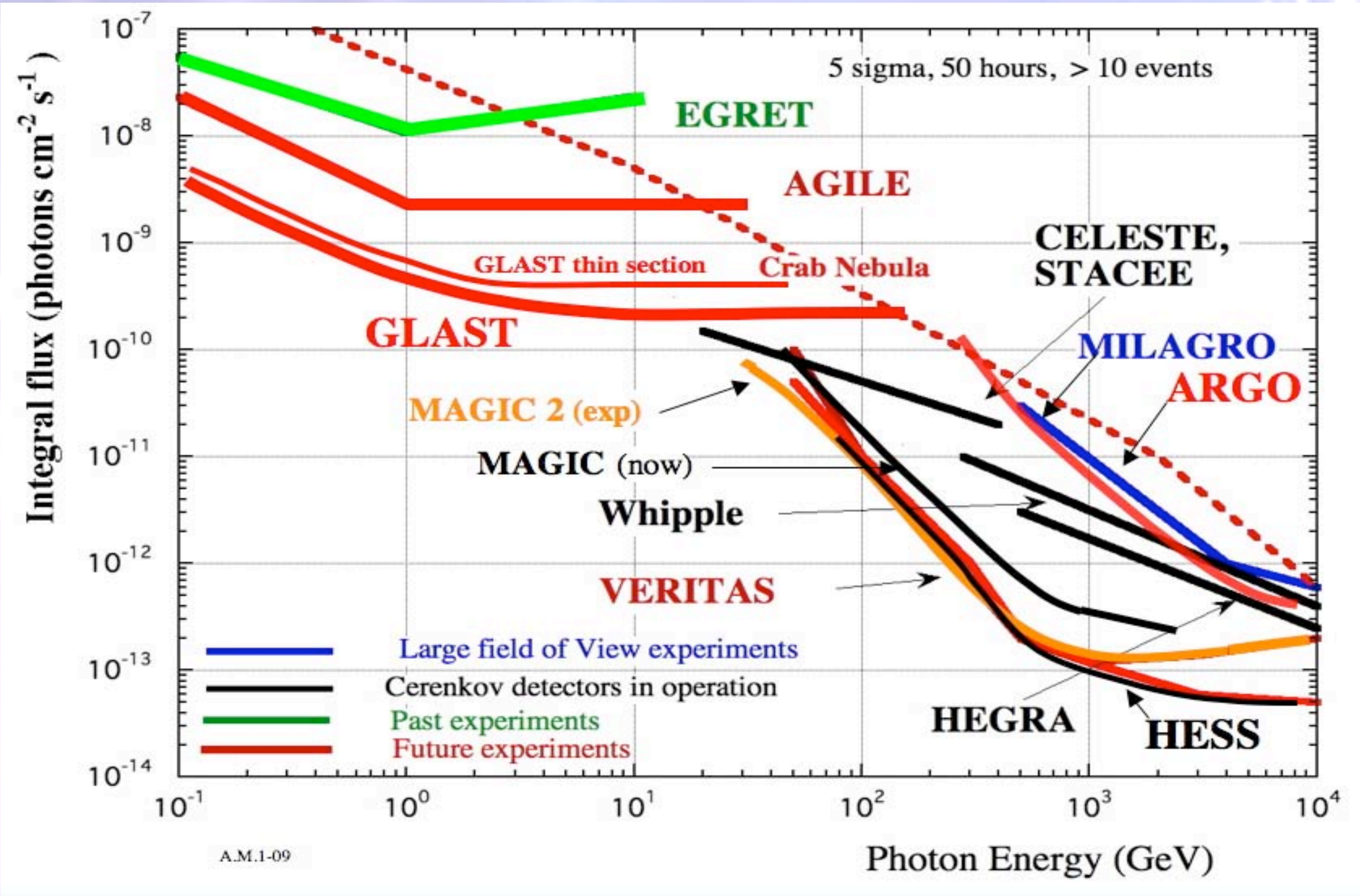


Fermi LAT Sensitivity



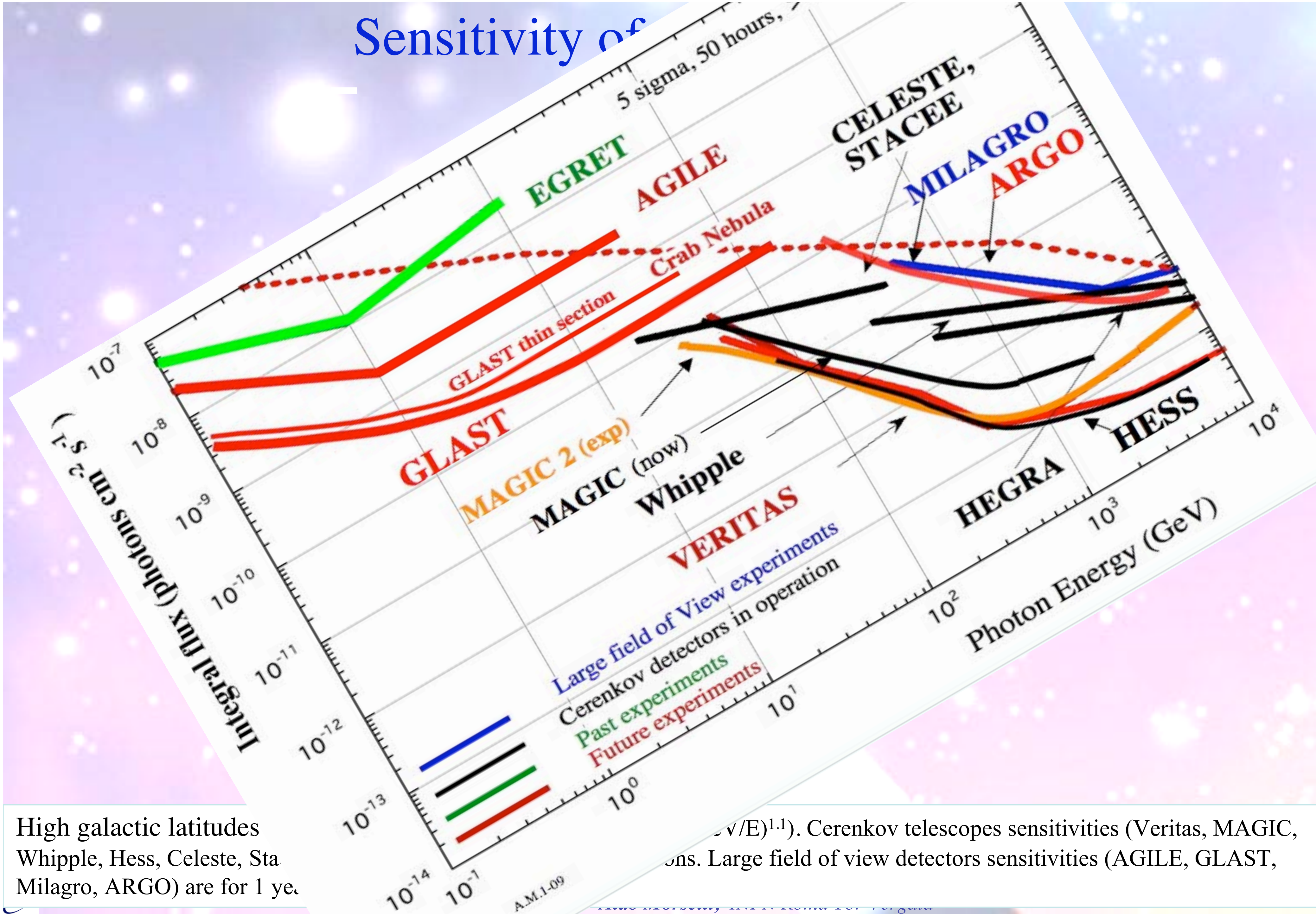
One-year integral sensitivity for the LAT (5σ, E> threshold energy), for a high latitude point source with an E^{-2} spectrum.

Sensitivity of γ-ray detectors



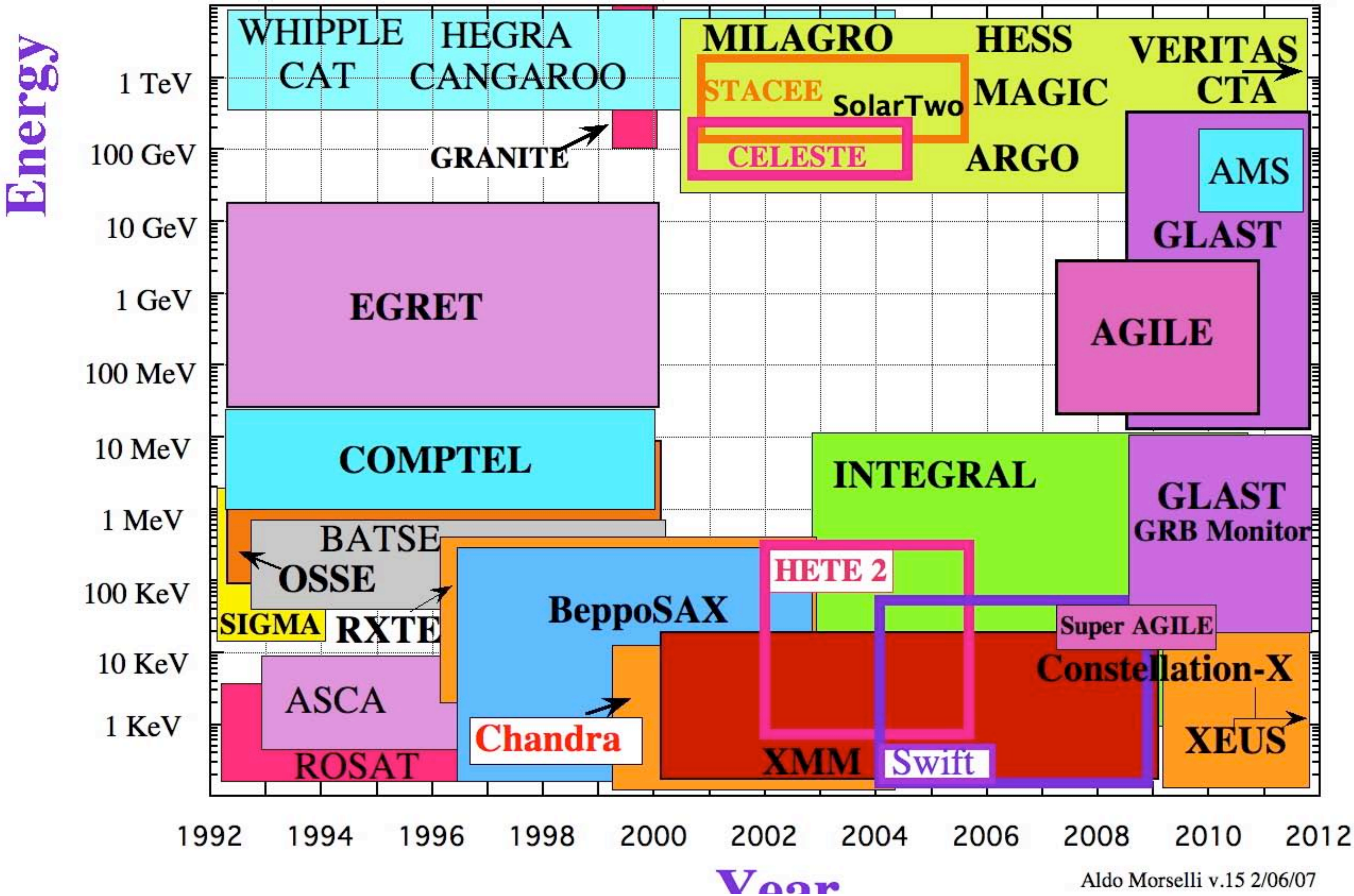
High galactic latitudes (background Φ_b=2 10^{-5} γ cm^{-2} s^{-1} sr^{-1} (100 MeV/E)$^{1.1}$). Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations. Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO) are for 1 year of observation.

Sensitivity of



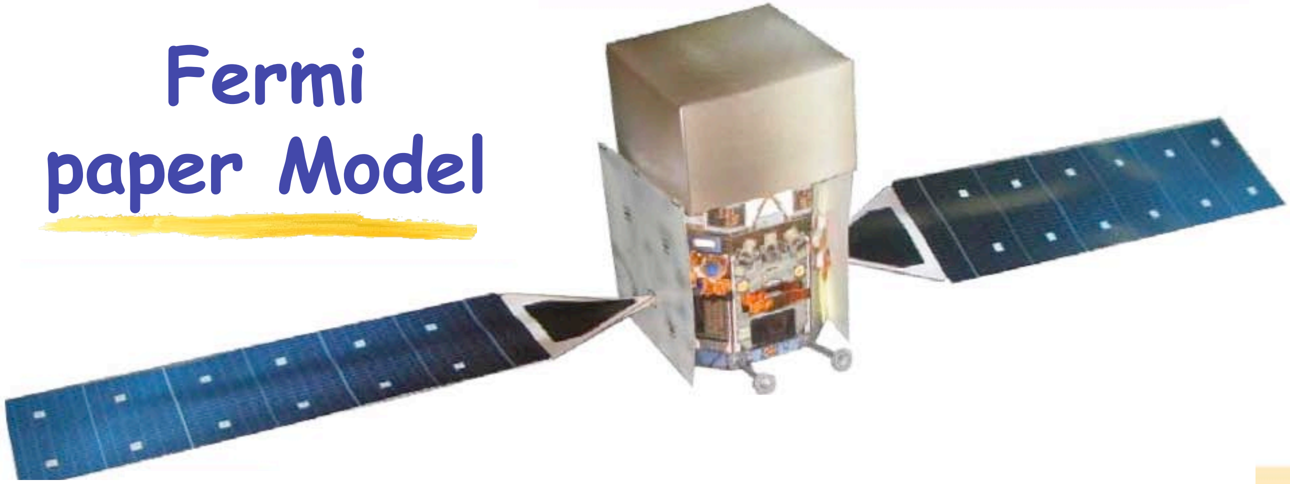
High galactic latitudes ... eV/E)$^{1.1}$). Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Sta... ons. Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO) are for 1 ye...

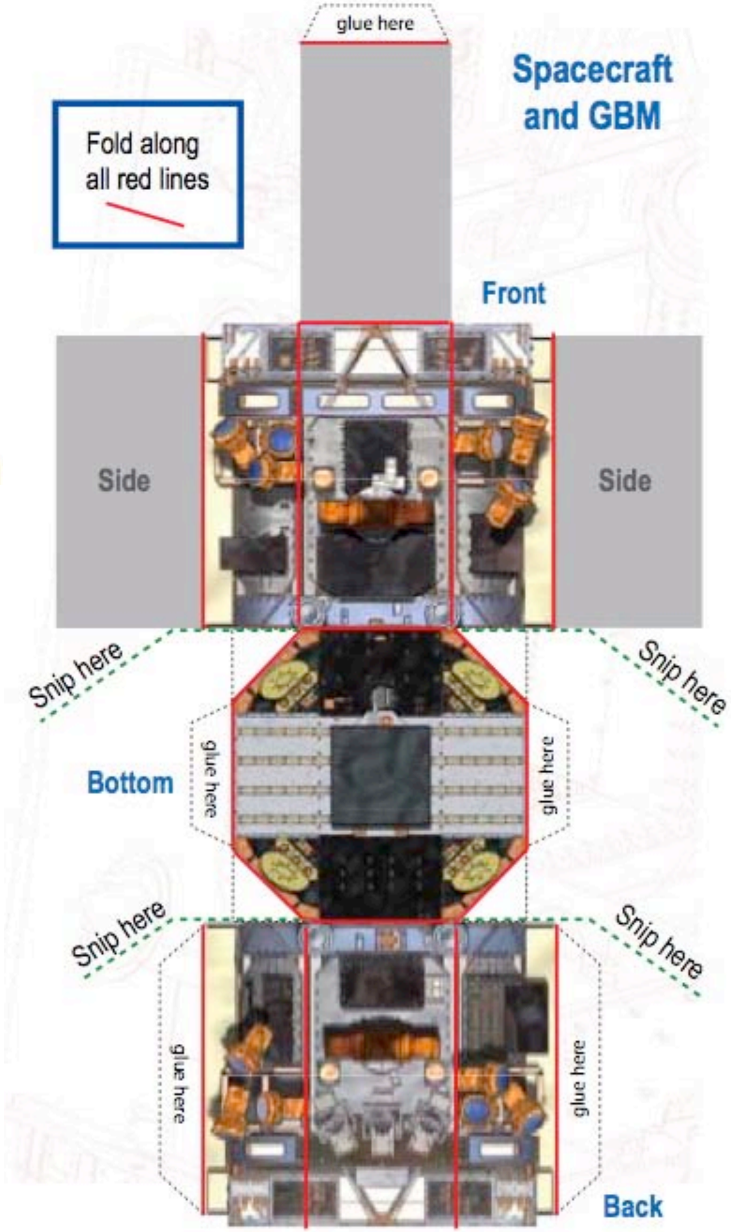
Energy versus time for X and Gamma ray detectors



Fermi Prior to Fairing Installation

Fermi paper Model





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

Fermi Gamma-ray Space Telescope

Fermi
inside the Delta 2


11 June 2008


11 June 2008


11 June 2008

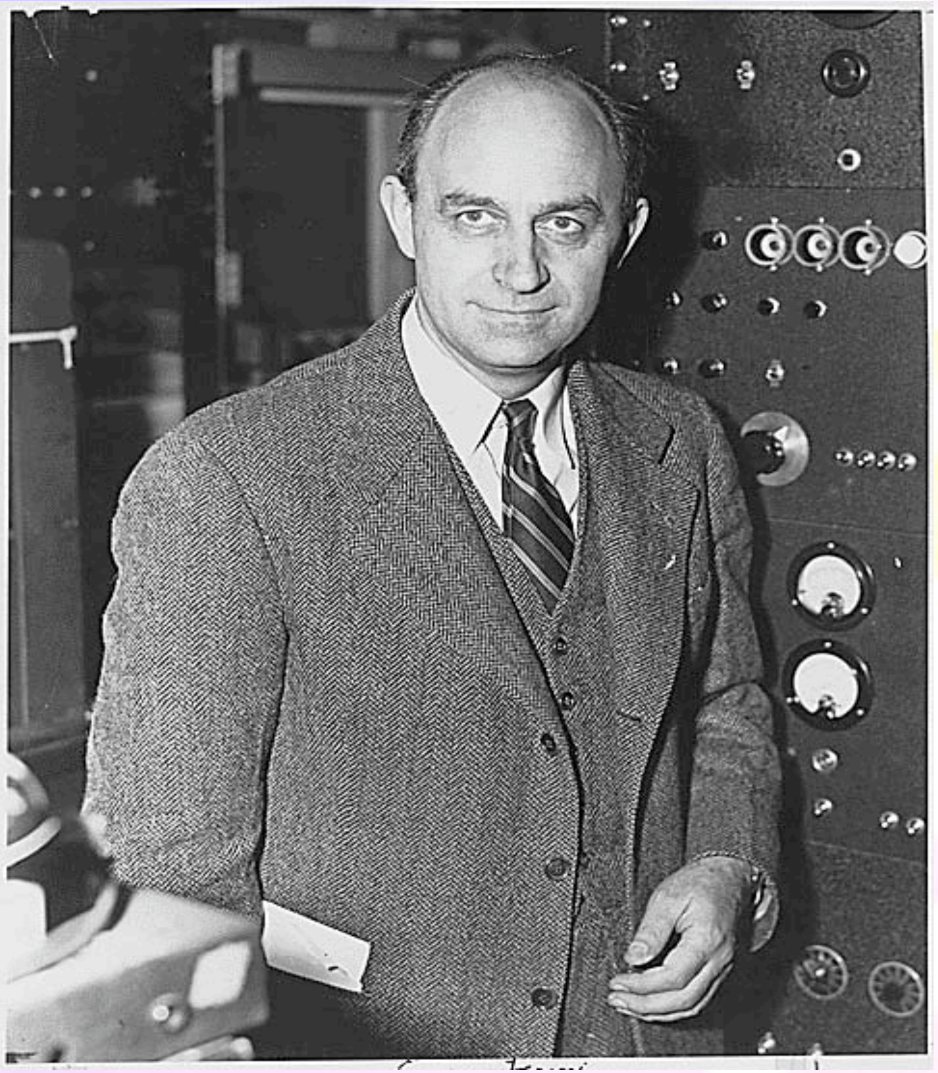

11 June 2008


11 June 2008


11 June 2008

Fermi Gamma-ray Space Telescope

DoE – NASA – international partnership



GLAST renamed *Fermi* by NASA on August 26, 2008

http://fermi.gsfc.nasa.gov/

" Enrico Fermi (1901-1954) was an Italian physicist who immigrated to the United States. He was the first to suggest a viable way to produce high-energy particles in cosmic sources. Since gamma-rays are produced by interactions of such energetic particles, his work is the foundation for many of the studies being done with the **Fermi Gamma-ray Space Telescope**, formerly GLAST.

The Fermi 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, Roma Tor Vergata, 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

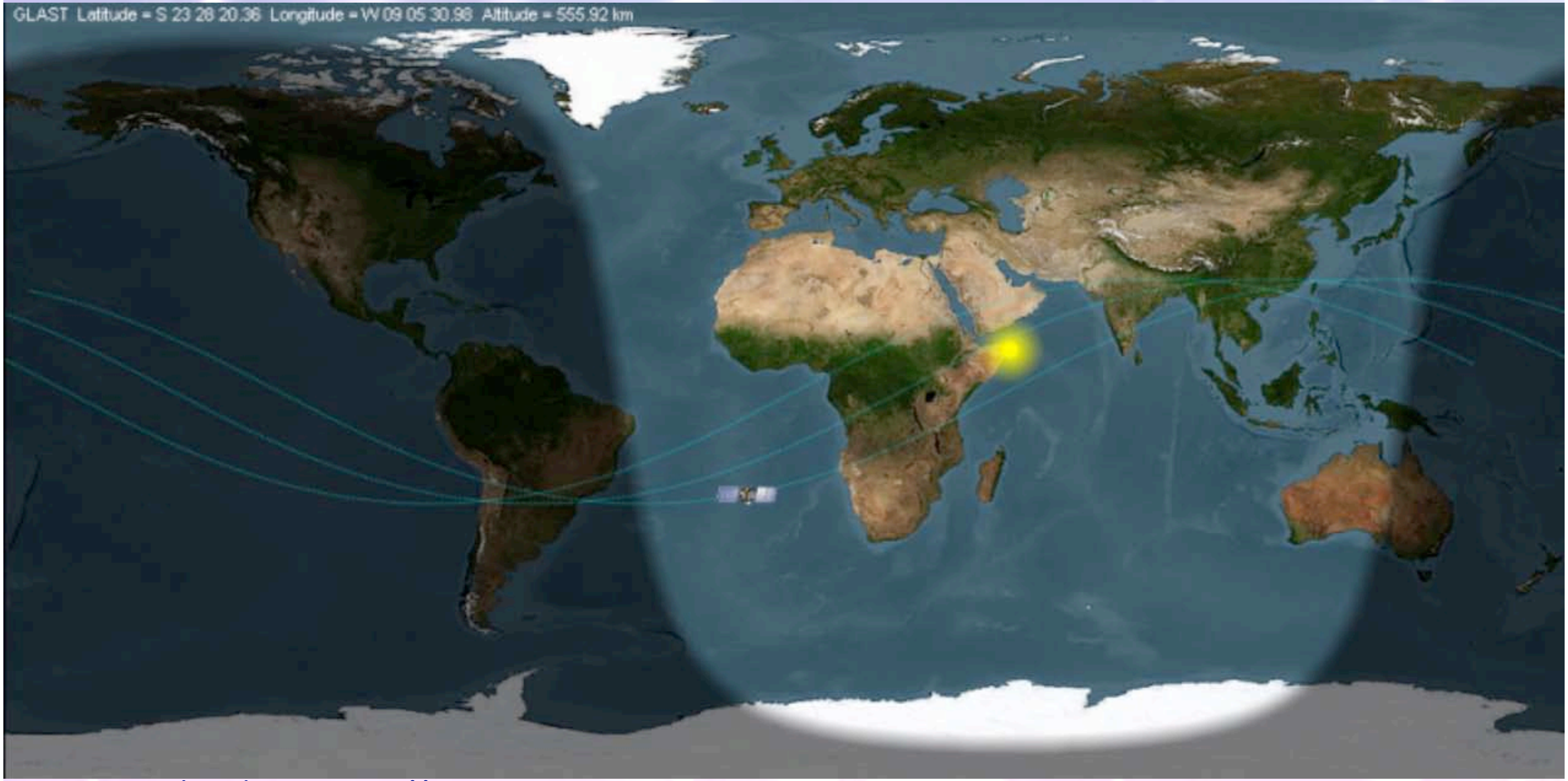
CEA/DAPNIA Commissariat à l'Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nucliaire et de l'Instrumentation Associée, CEA, Saclay
IN2P3 Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
IN2P3/LPNHE-X Laboratoire de Physique Nucléaire 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

KTH Royal Institute of Technology
Stockholms Universitet

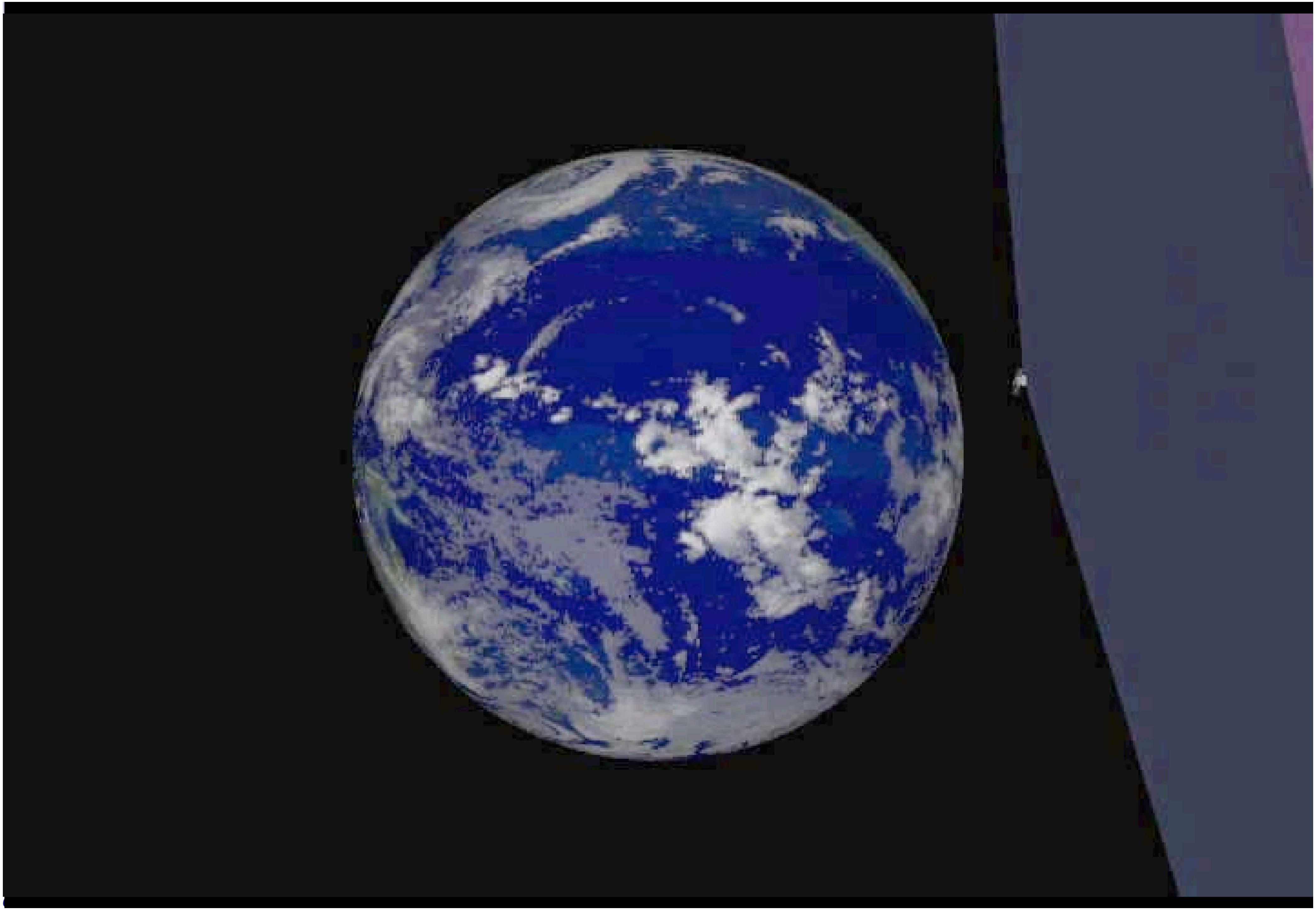
Collaboration members:	**~390**
Members:	**121**
Affiliated Scientists	~96
Postdocs:	68
Graduate Students	105

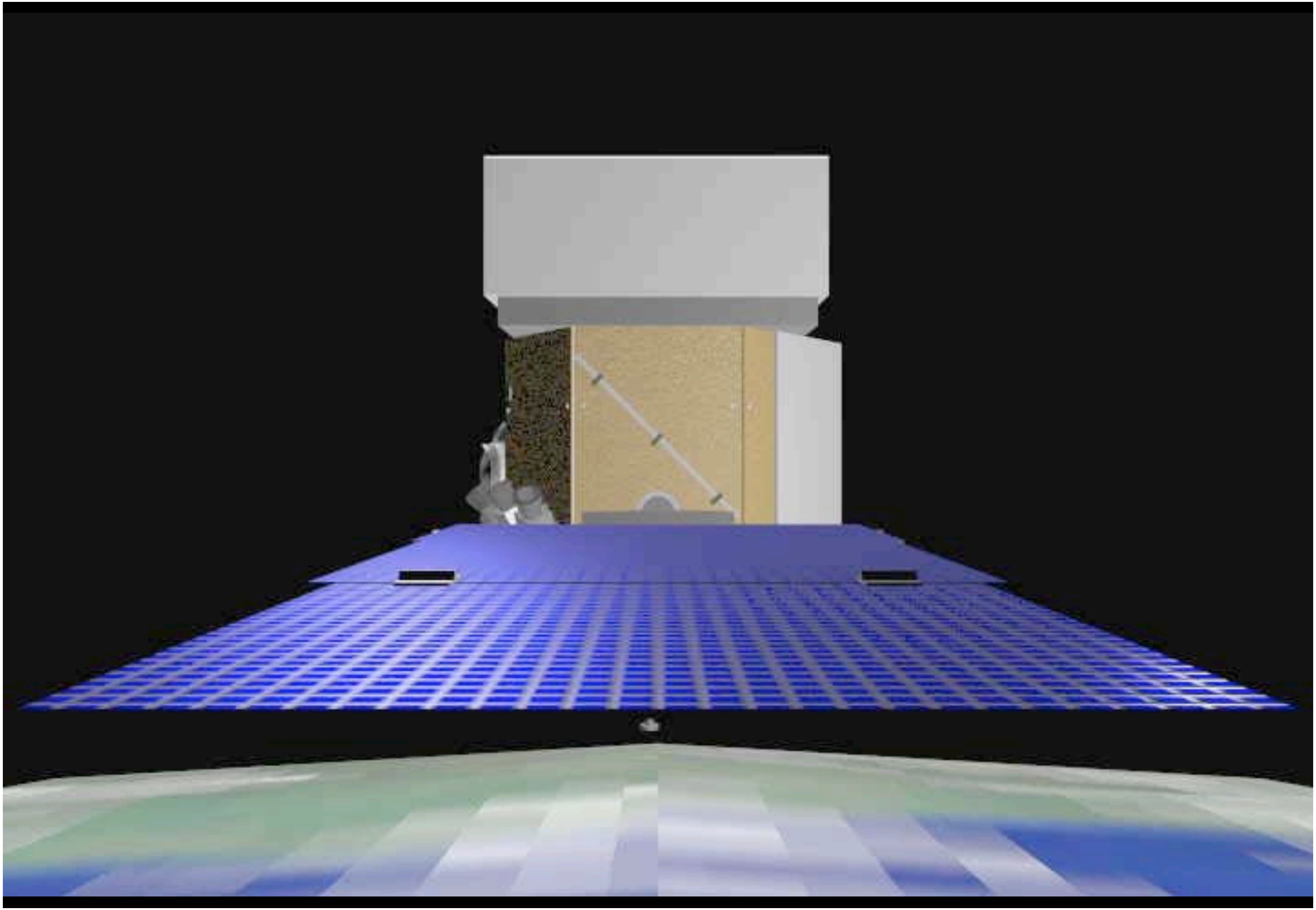
Fermi in orbit



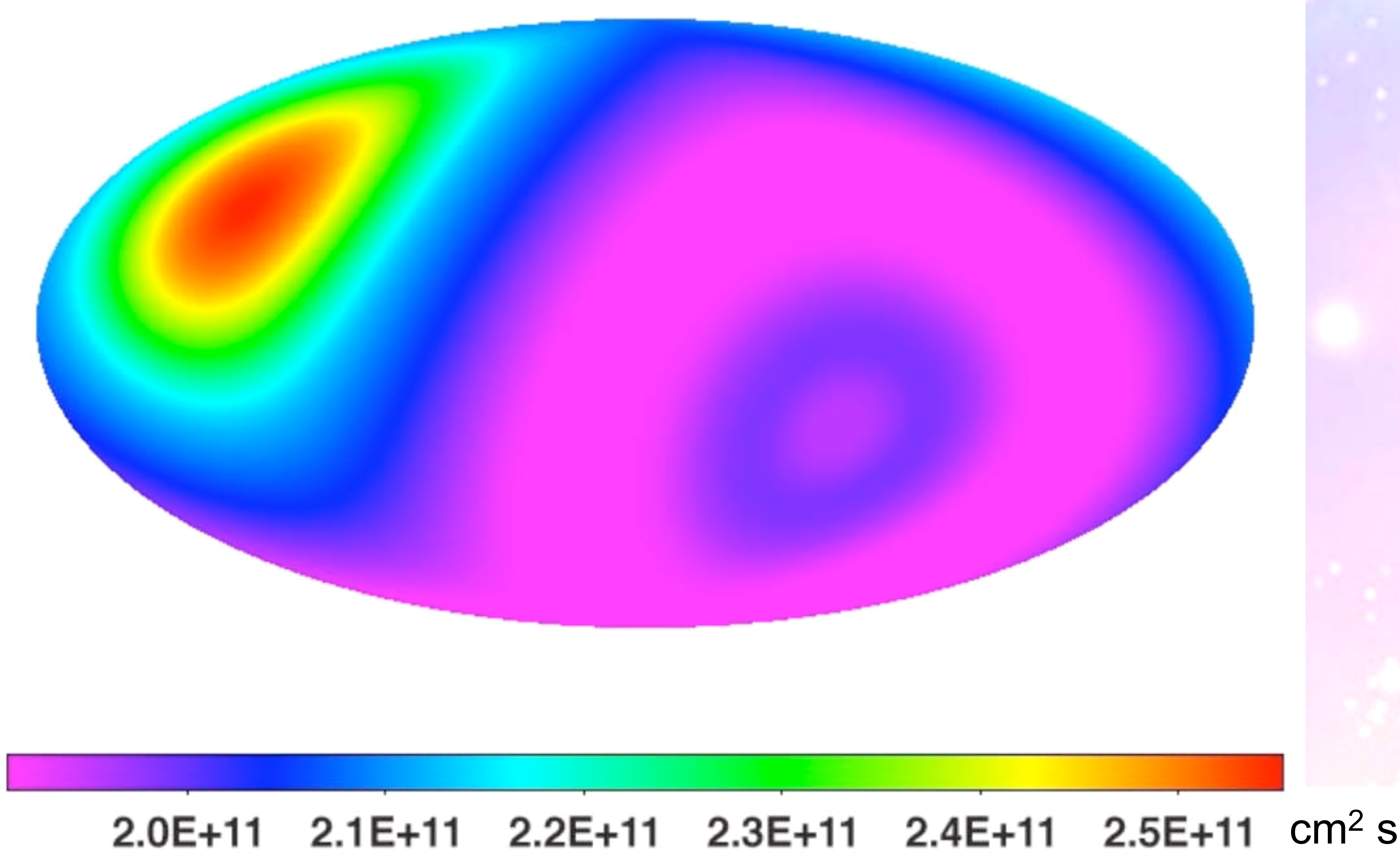
- Track the satellite: http://observatory.tamu.edu:8080/Trakker
- Watch Fermi as it orbits over you home town:

http://www.nasa.gov/mission pages/GLAST/news/glast online.html





Simulated Fermi LAT exposure for five years of all-sky scanning at 100 GeV



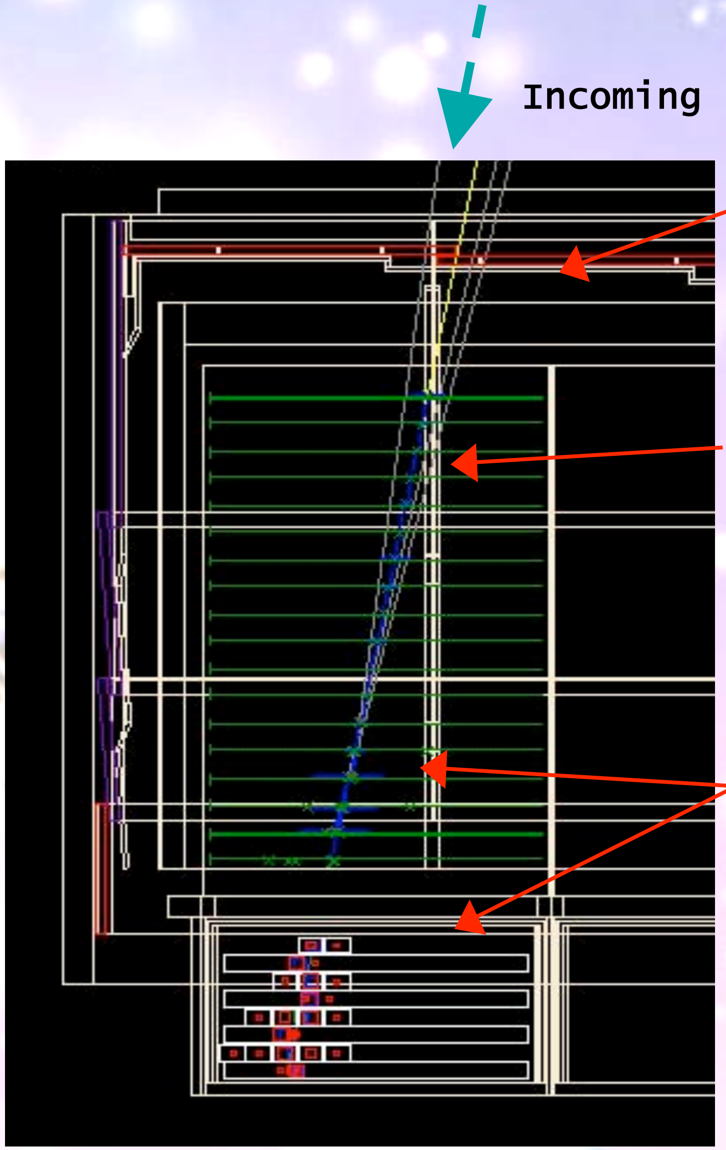
How Fermi LAT detects electrons

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

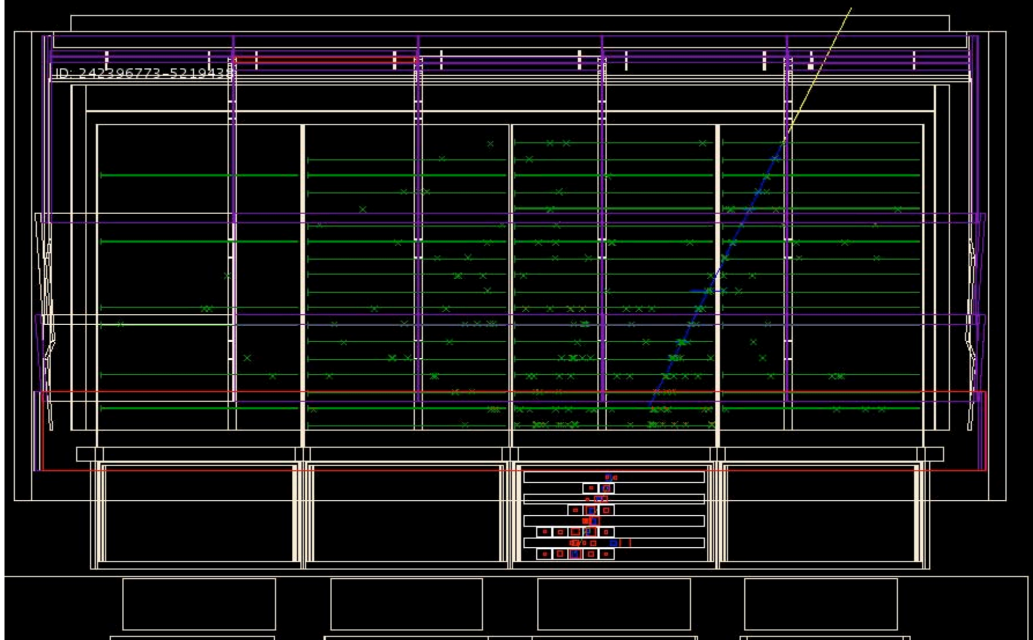
Electron identification

- 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

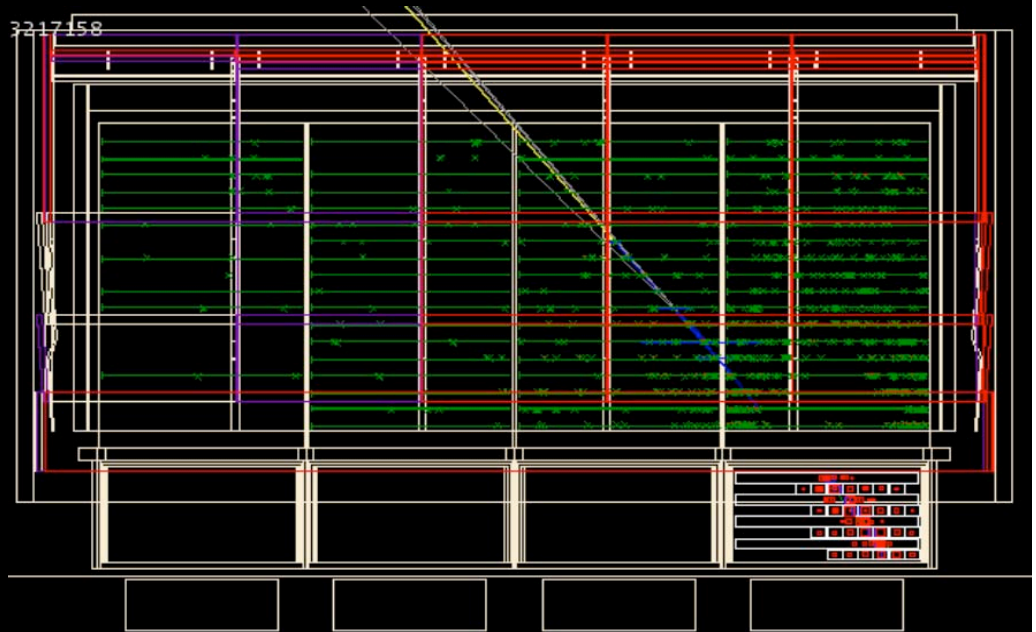


Event topology

A candidate electron
(recon energy 844 GeV)



A candidate hadron
(raw energy > 800 GeV)



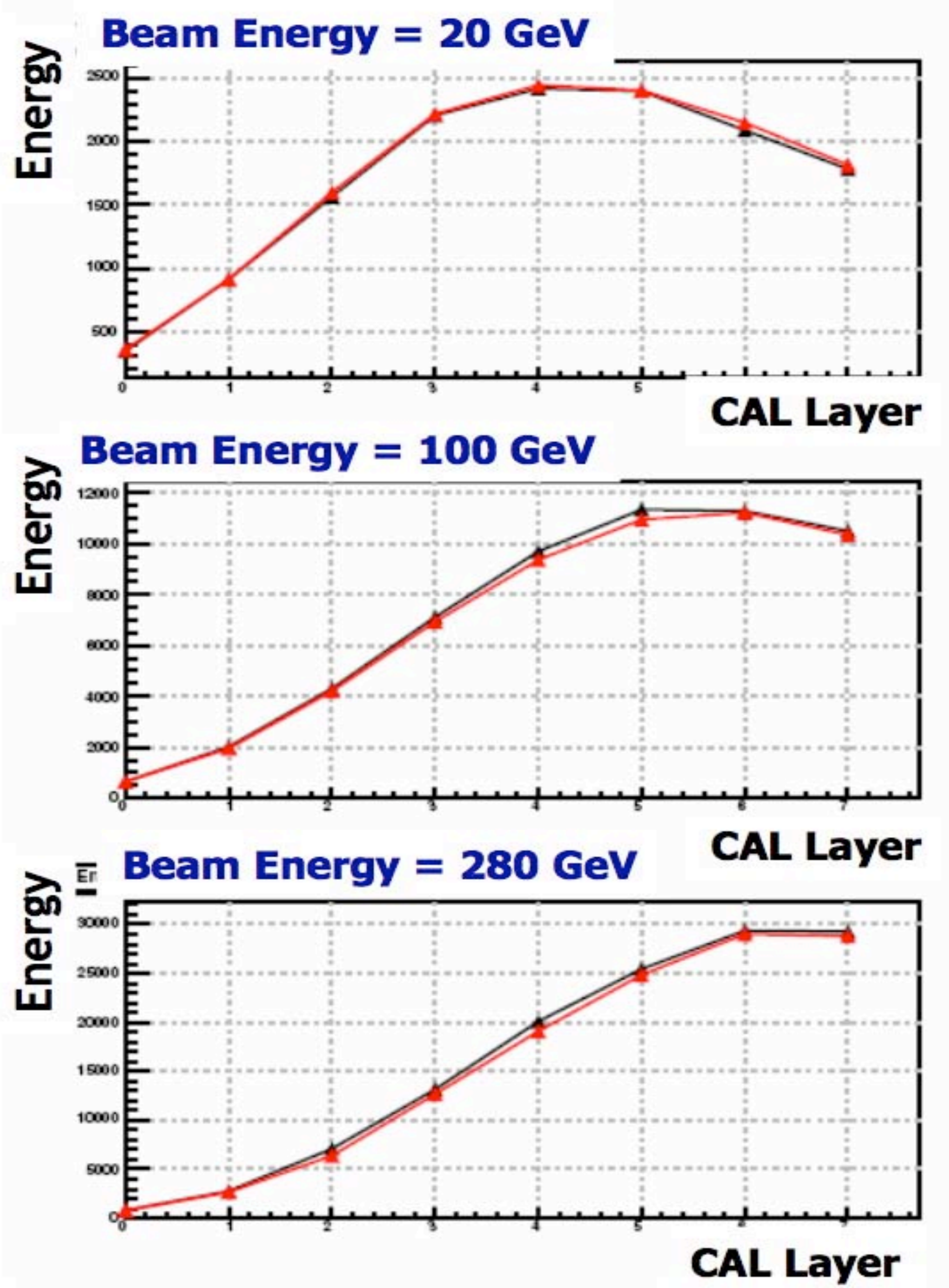
- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

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

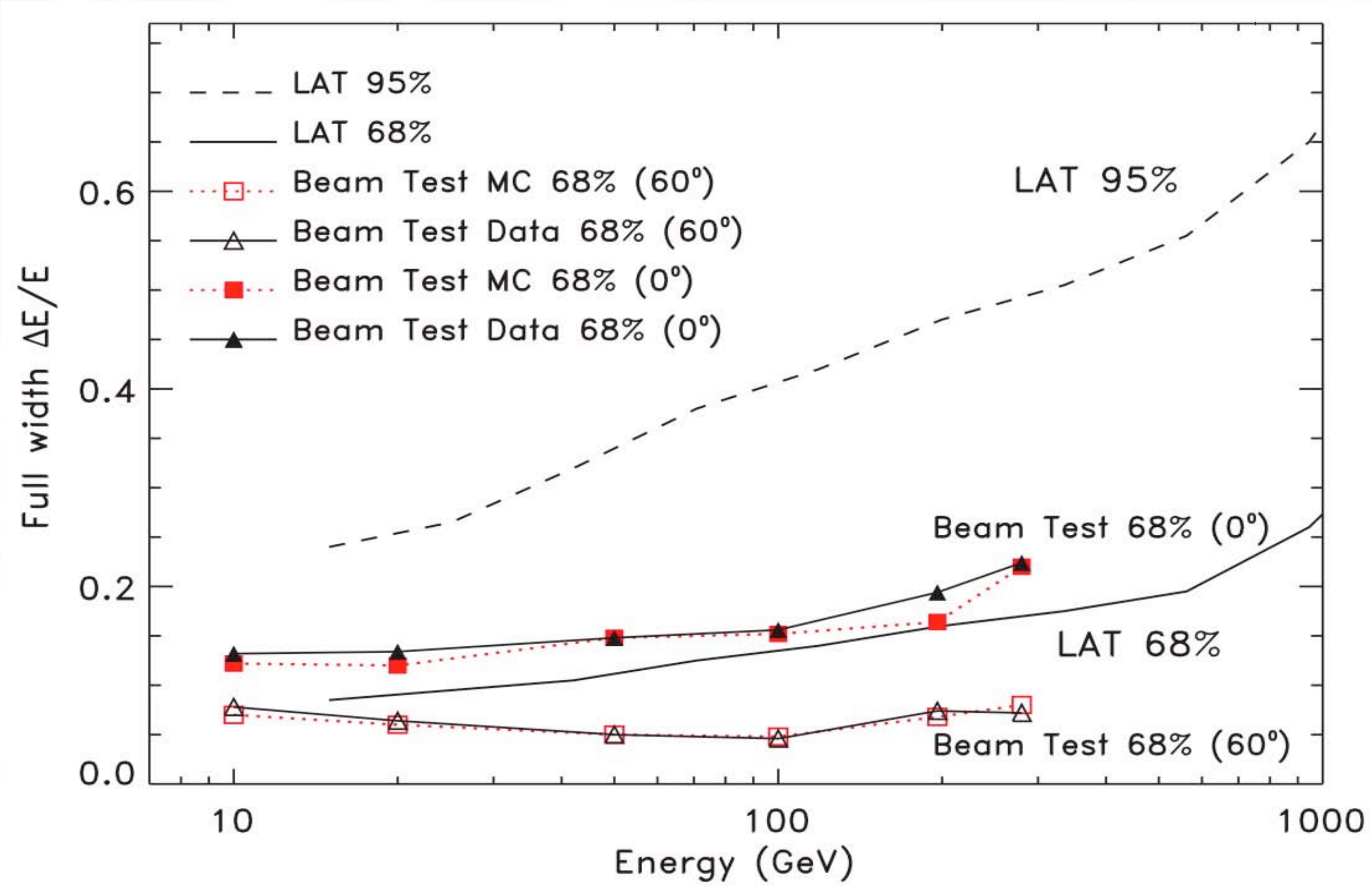
Energy reconstruction

Reconstruction of the most probable value for the event energy:
- based on calibration of the response of each of 1536 calorimeter crystals
- energy reconstruction is optimized for each event
-calorimeter imaging capability is heavily used for fitting shower profile -
-tested at CERN beams up to 280 GeV with the LAT Calibration Unit

Very good agreement between shower profile in beam test data (red) and Monte Carlo (black)

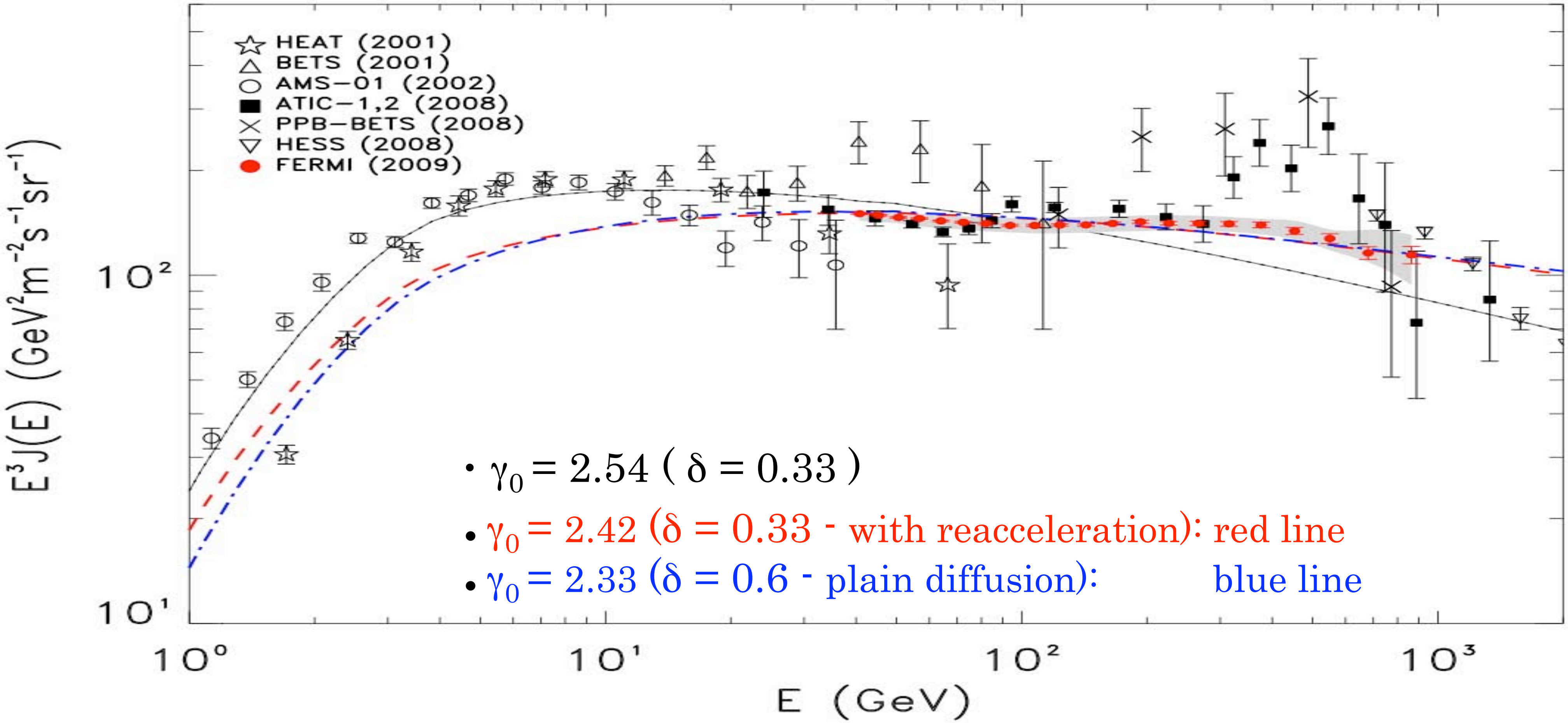


Fermi LAT Energy resolution for electrons



)

Cosmic Ray Electron propagation models

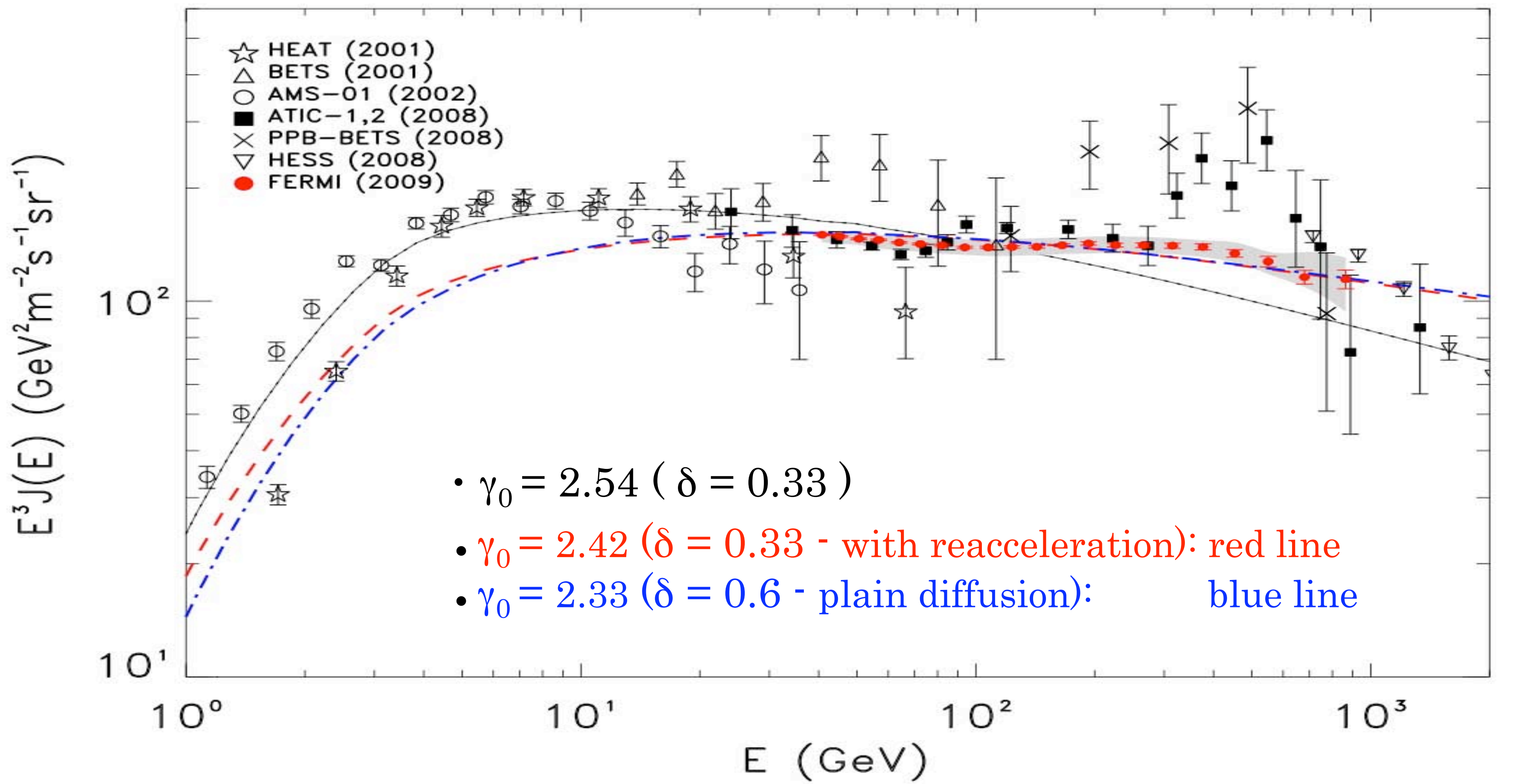


- $\gamma_0 = 2.54$ ($\delta = 0.33$)
- $\gamma_0 = 2.42$ ($\delta = 0.33$ - with reacceleration): red line
- $\gamma_0 = 2.33$ ($\delta = 0.6$ - plain diffusion): blue line

Model #	D_0 (cm^2s^{-1})	δ	z_h (kpc)	γ_0	N_{e^-} ($m^{-2}s^{-1}sr^{-1}GeV^{-1}$)	γ_0^p
0	3.6×10^{28}	0.33	4	2.54	1.3×10^{-4}	2.42
1	3.6×10^{28}	0.33	4	2.42	1.3×10^{-4}	2.42
2	1.3×10^{28}	0.60	4	2.33	1.3×10^{-4}	2.1

Models 0 and 1 account for CR re-acceleration in the ISM, while 2 is a plain-diffusion model. All models assume γ_0 = 1.6 below 4 GeV.

A simple interpretation of Fermi-LAT CRE spectrum

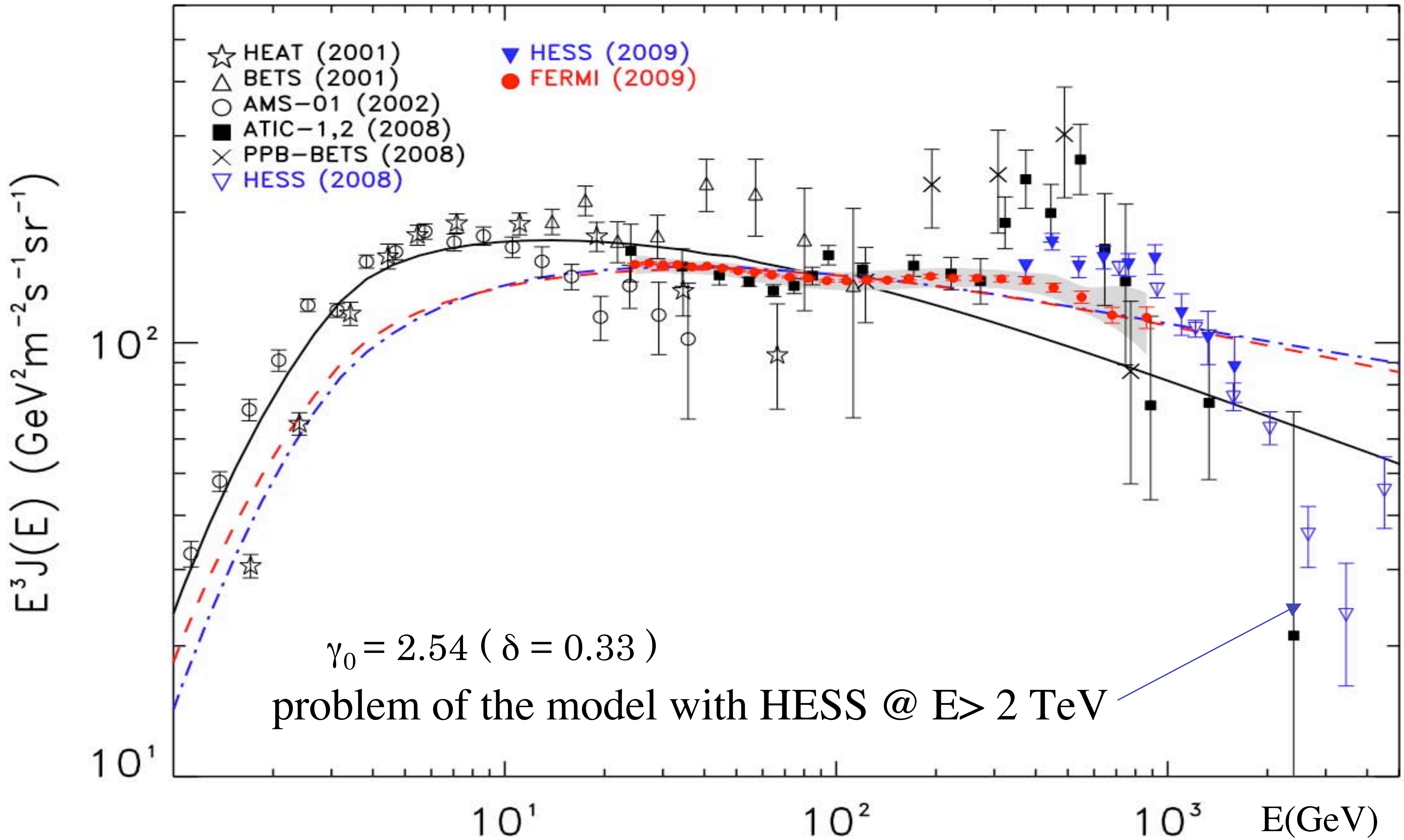


Numerical models of propagation of CR electrons can be tuned to fit Fermi data assuming an **harder injection index**:

•<u>Problems: These tuned models are in tension with low-energy and HESS data</u> (no big problems with gamma-ray data - *work in progress*)

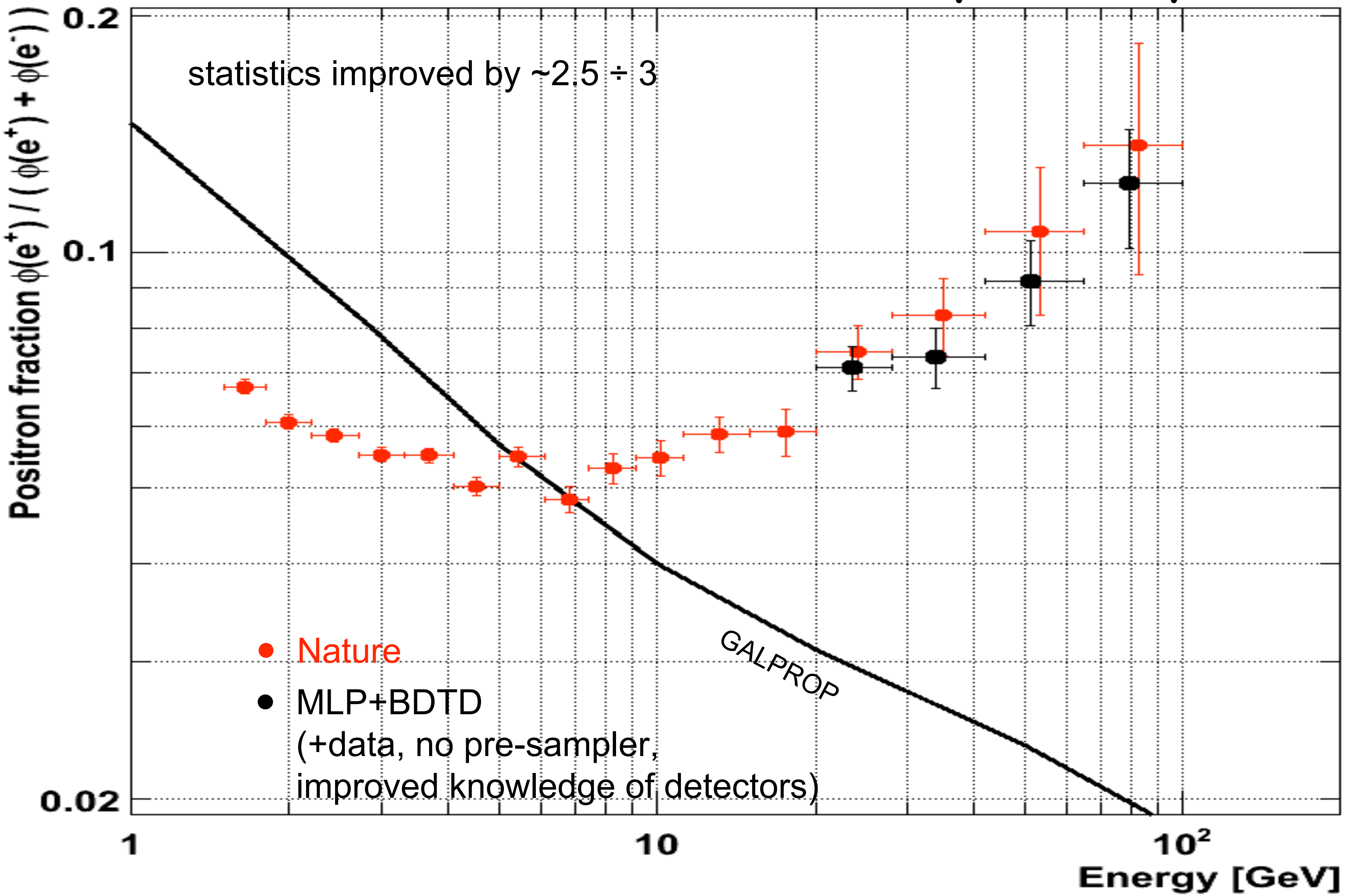
Fermi Gamma-ray Space Telescope

Fermi & HESS data vs the conventional *pre-Fermi* model



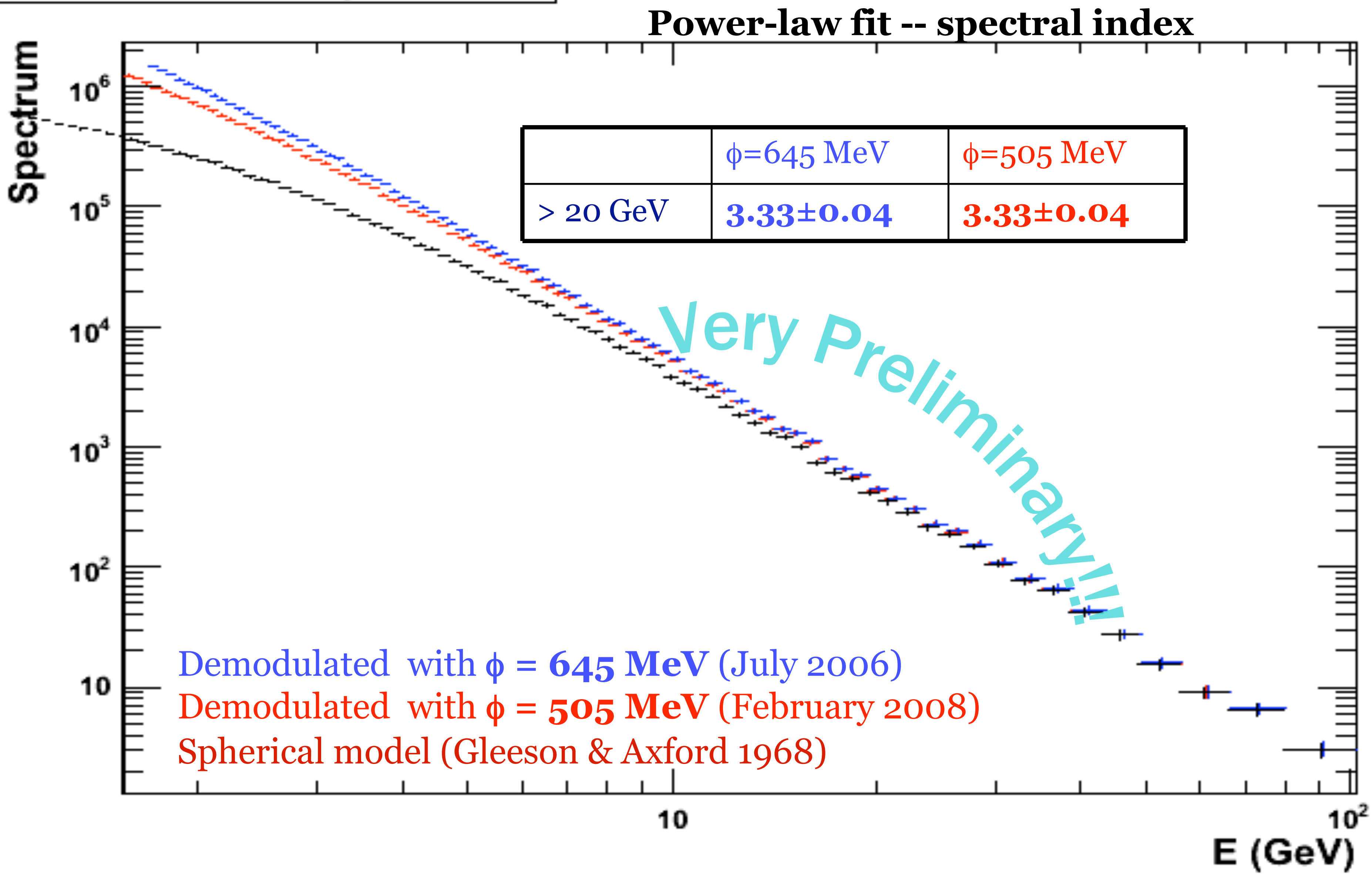
cutoff in the CRE source spectrum or breakdown of the source spatial continuity?

Positron fraction, new analysis May 09



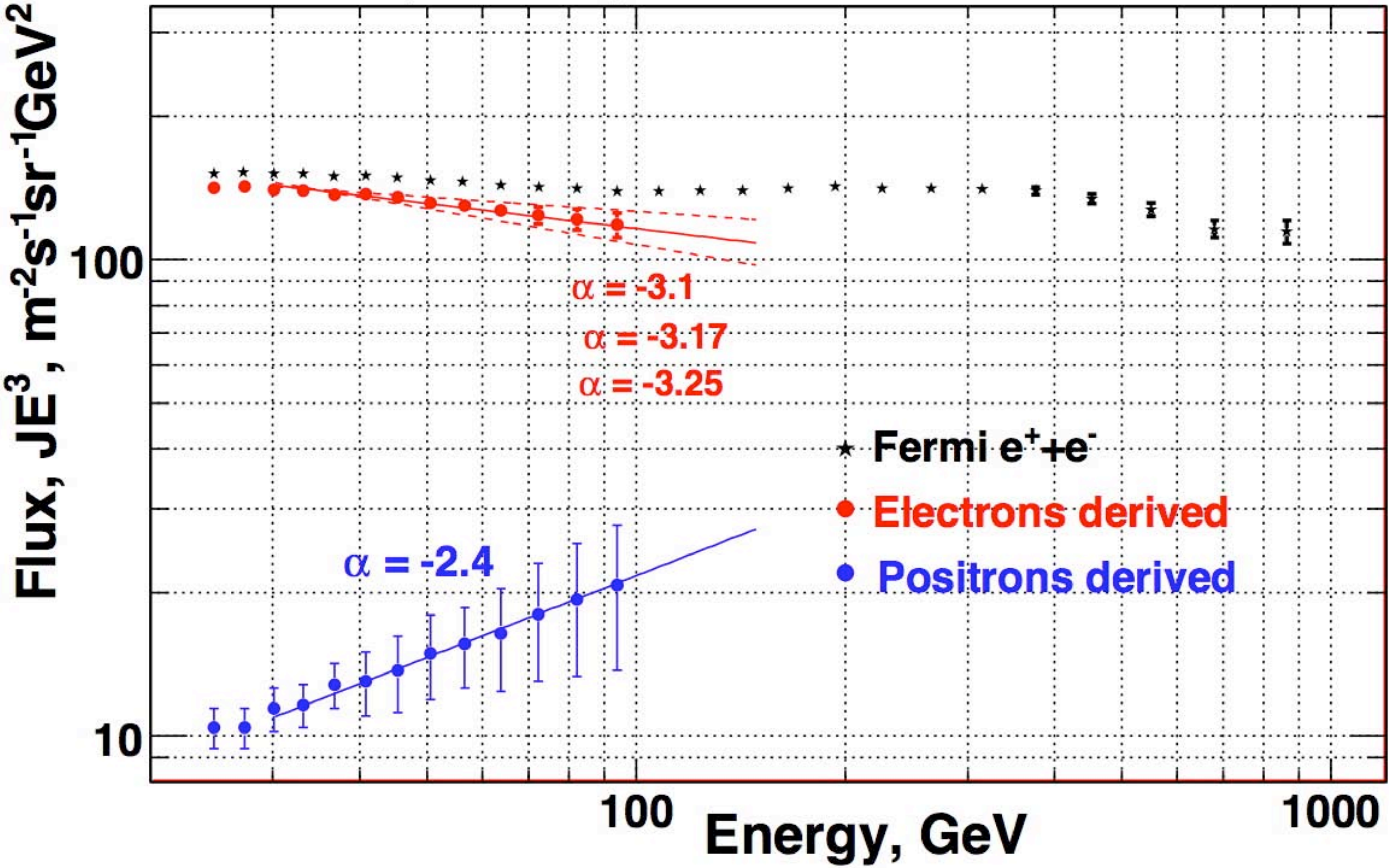
PAMELA electron (e^-) flux

Demodulated spectrum



	ϕ=645 MeV	ϕ=505 MeV
> 20 GeV	**3.33±0.04**	**3.33±0.04**

Electron and positron spectra derived from Fermi and Pamela



Primary electrons in Cosmic Rays

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 70, NO. 11 JUNE 1, 1965

Letters

Observation of the Cosmic Ray Electron-Positron Ratio from 100 Mev to 3 bev in 1964

R. C. HARTMAN AND PETER MEYER

Enrico Fermi Institute for Nuclear Studies and Department of Physics University of Chicago, Chicago, Illinois

R. H. HILDEBRAND

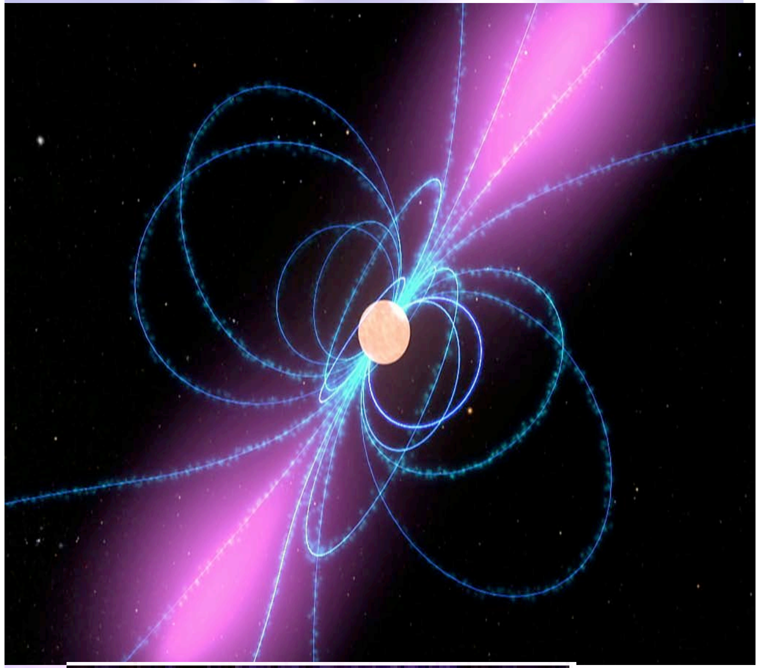
Argonne National Laboratory and University of Chicago Chicago, Illinois

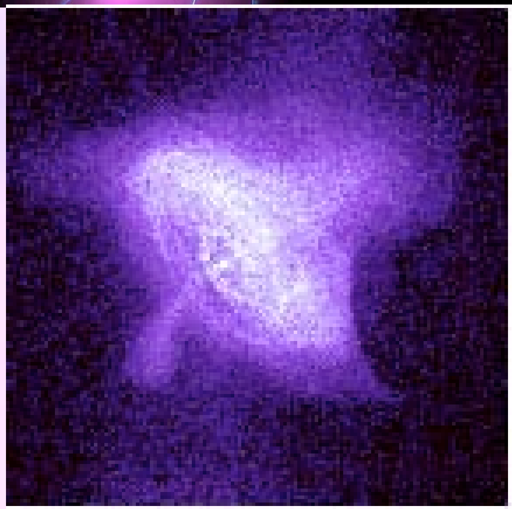
nent. In 1963, *DeShong, Hildebrand, and Meyer* [1964] reported the results of an experiment designed to measure this ratio in the energy interval from 100 to 1000 Mev. They found an excess of negative electrons which led them to conclude that the electron component consists mainly of directly accelerated particles. Their

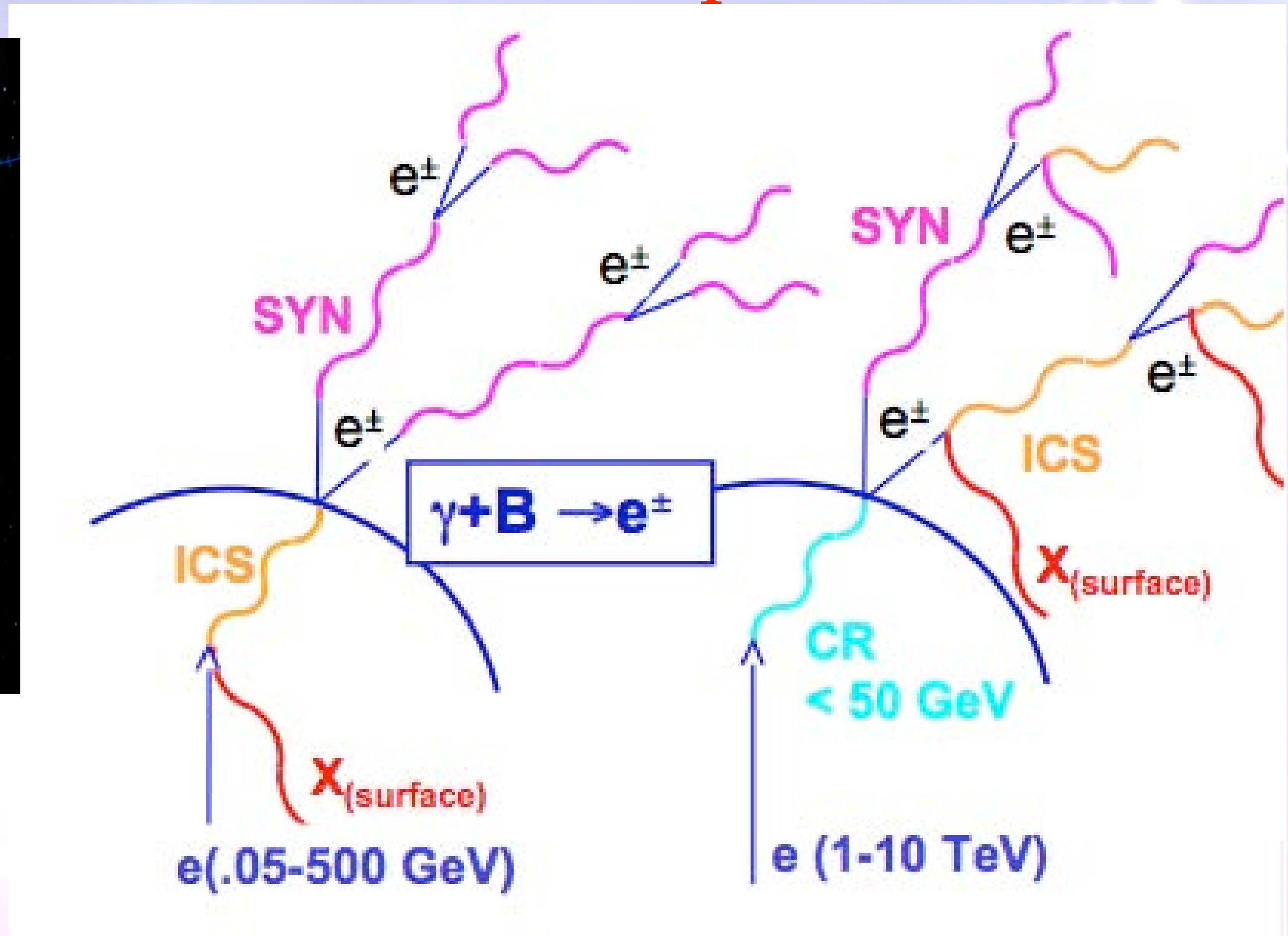
- Now, ~45 years later PAMELA excess in positron fraction and Fermi results on the electron+positron spectrum unavoidably testifies the presence of ***primary positrons*** in CRs

which are the sources of the primary positrons ?

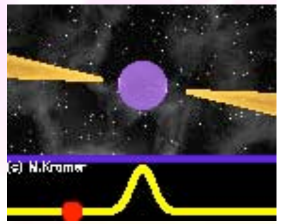
Pulsars as sources of $e^{-/+}$ pairs





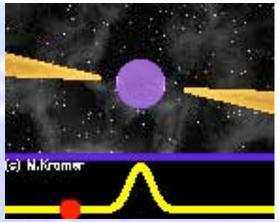


$e^{\pm}$ pairs are produced in the magnetosphere and accelerated by the electric fields and/or the pulsar wind.



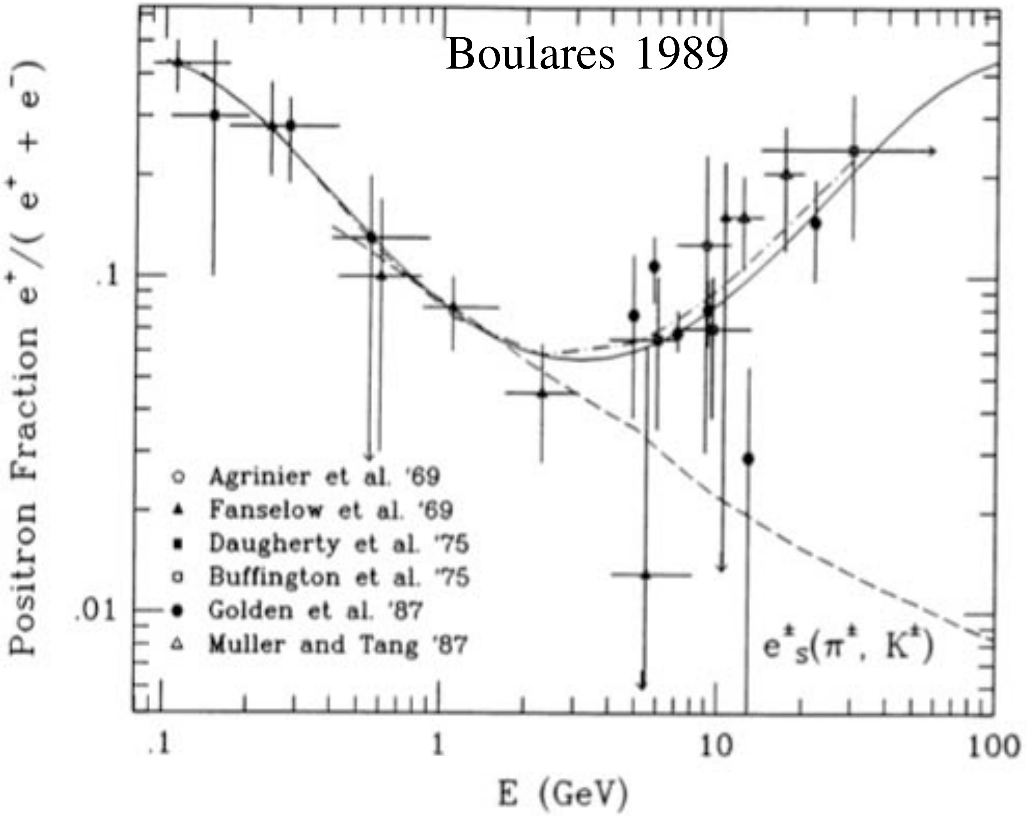
Crab Pulsar Wind Nebula (PWN)

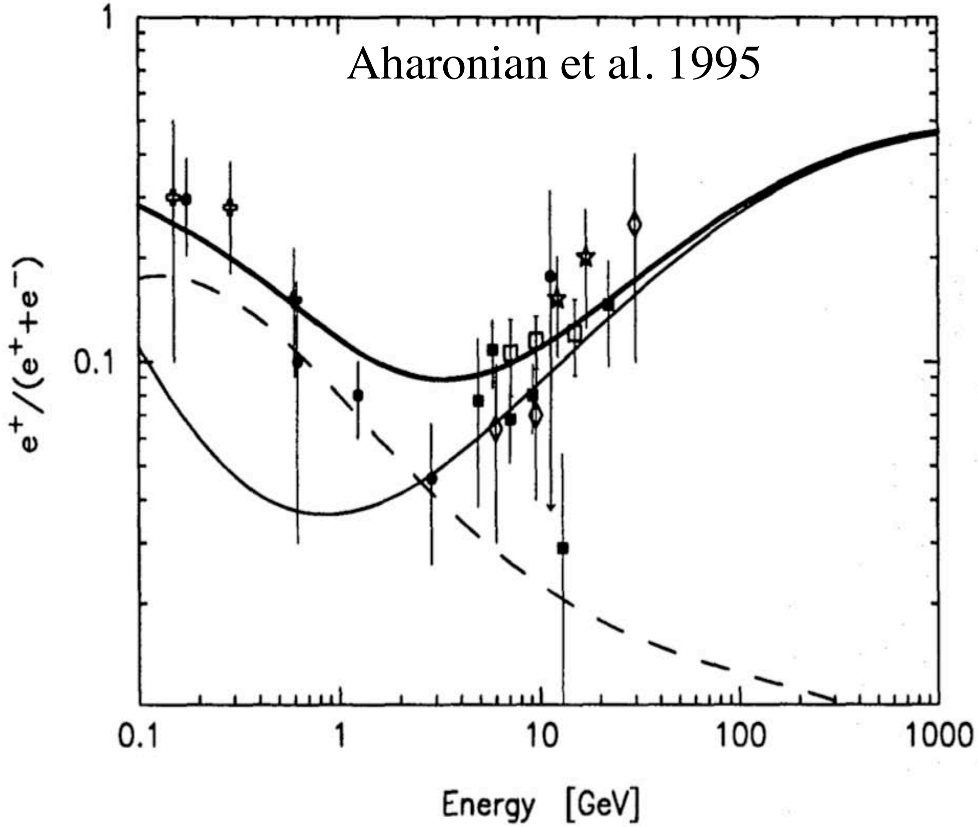
Pulsars as sources of $e^{-/+}$ pairs



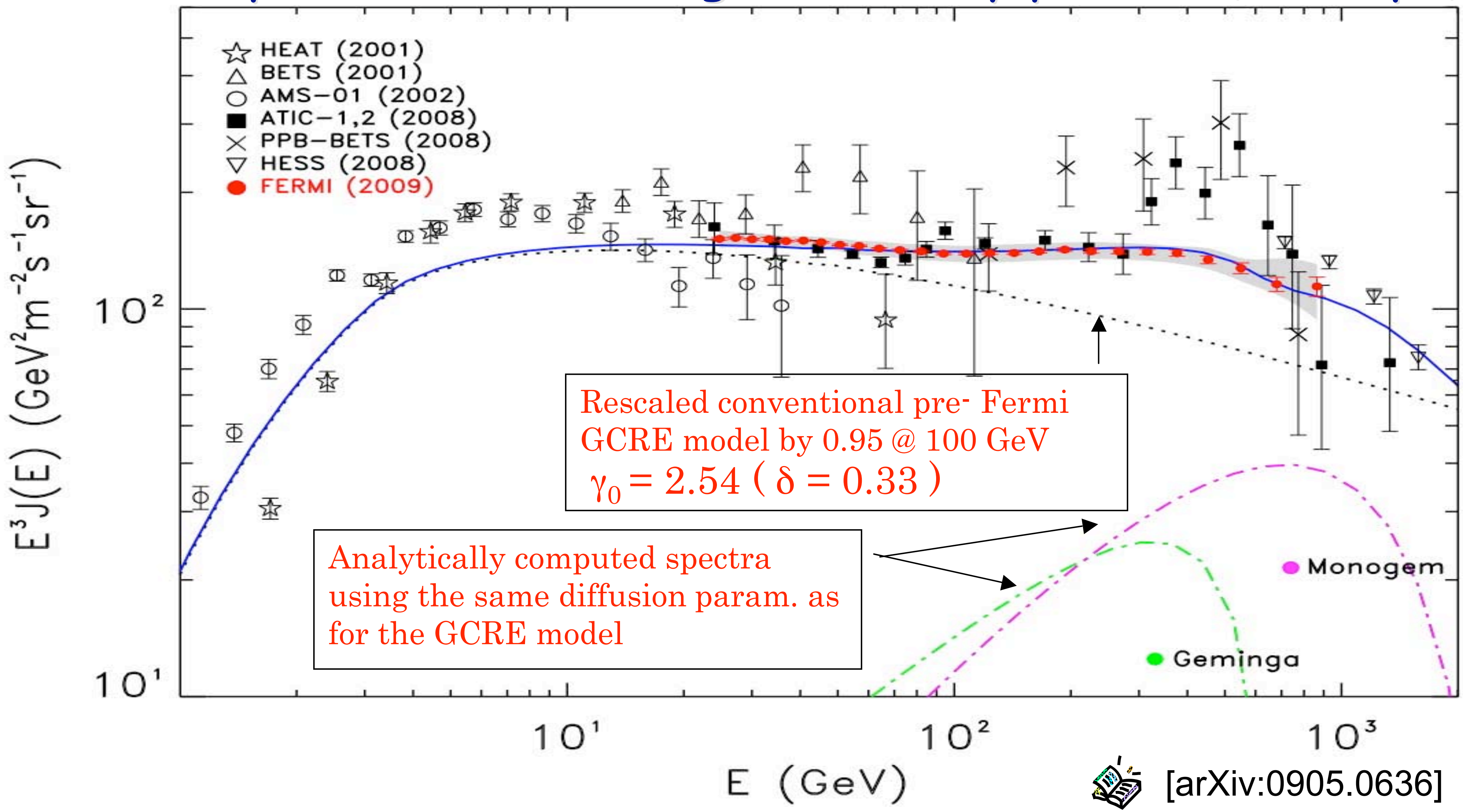
not a new idea

- A.Boulares APJ 342 (1989) 807-813
- Aharonian et al., A&A 294 (1995) L41
- A. M. Atoyan, F. A. Aharonian, and H. J. Volk, Phys. Rev. D52 (1995) 3265.
- T. Kobayashi, Y. Komori, K. Yoshida and J. Nishimura, ApJ 601 (2004) 340.





The CRE spectrum accounting for nearby pulsars (d < 1 kpc)

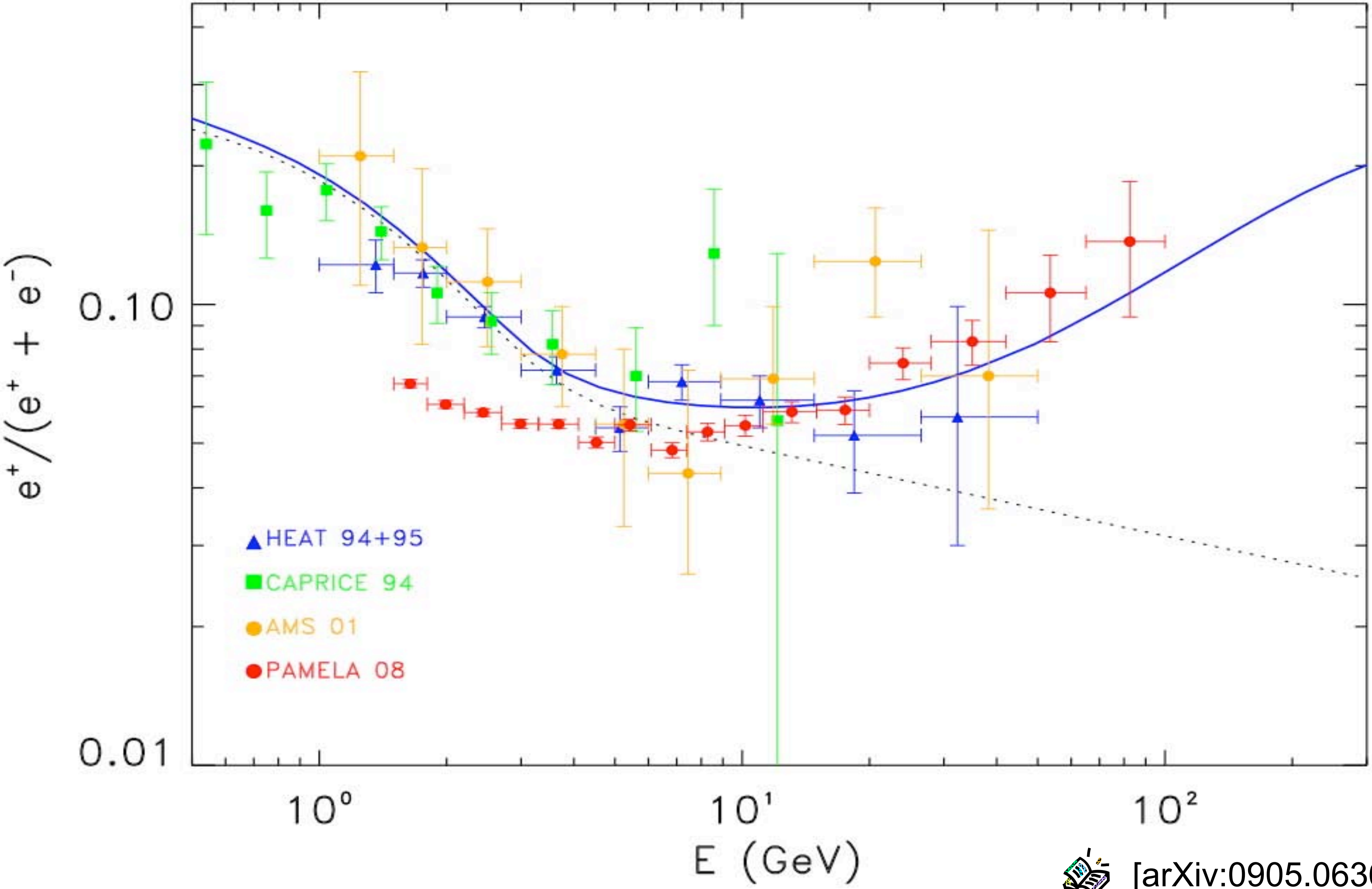


[arXiv:0905.0636]

This particular model assumes: 40% $e^{\pm}$ conversion efficiency for each pulsar

- pulsar spectral index $\Gamma = 1.7$ $E_{cut} = 1$ TeV . Delay = 60 kyr

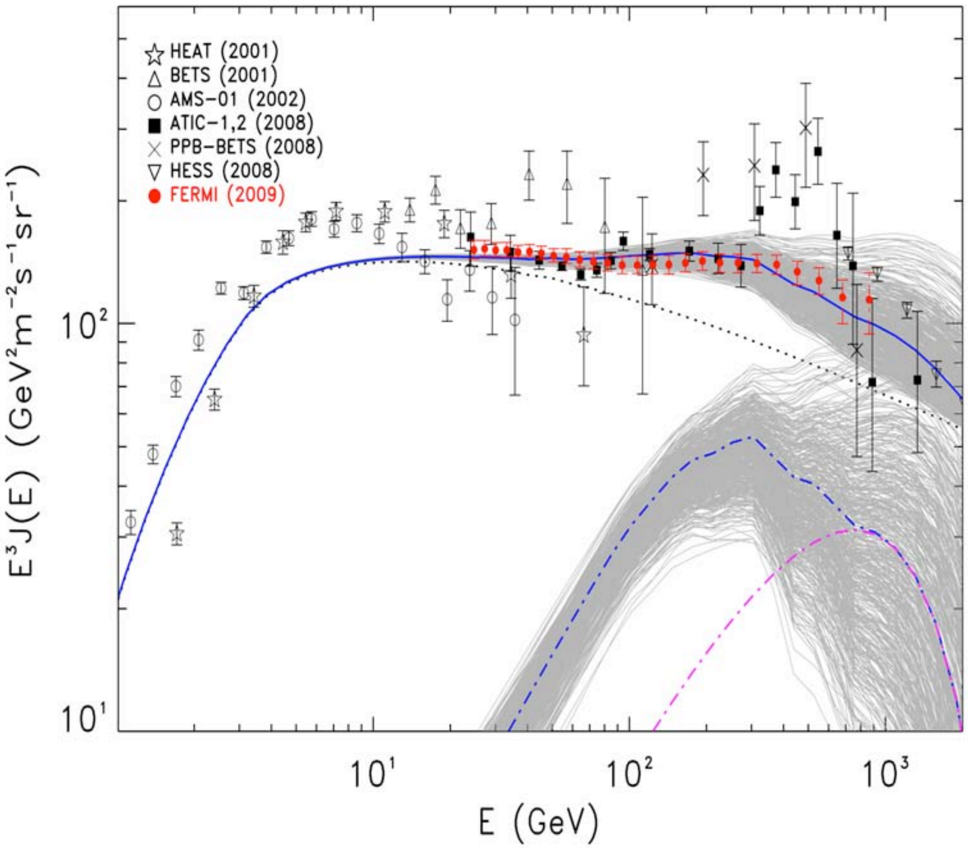
the positron ratio accounting for nearby pulsars (d < 1 kpc)

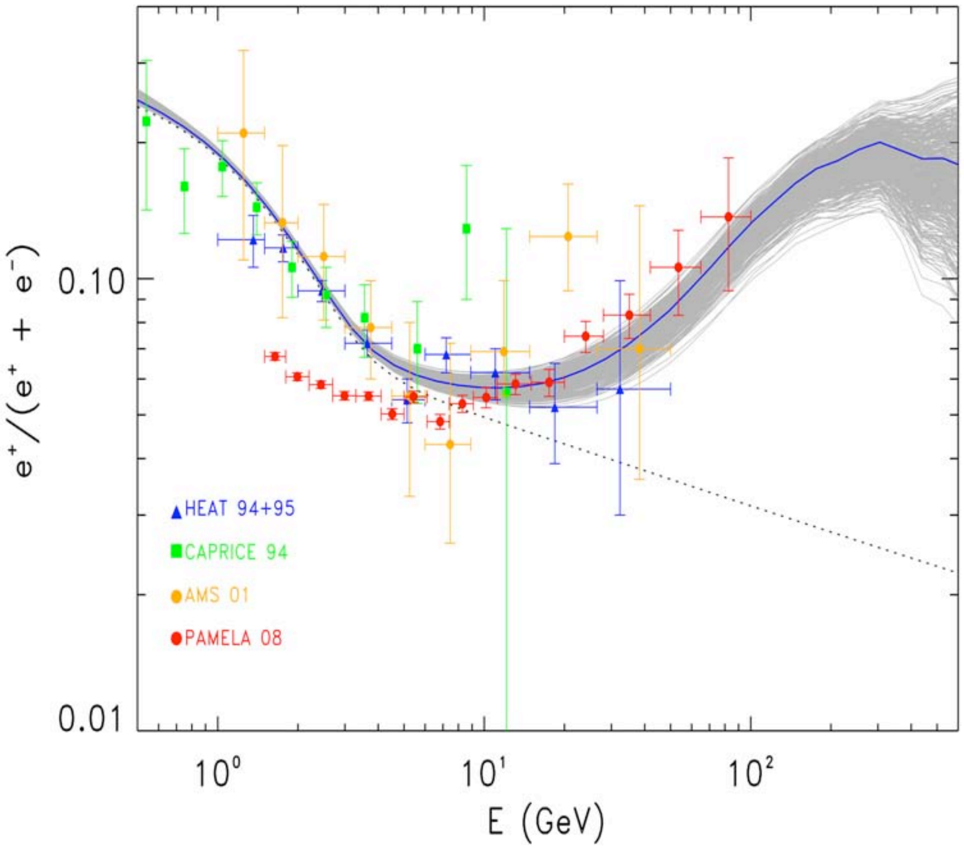


[arXiv:0905.0636]

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

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

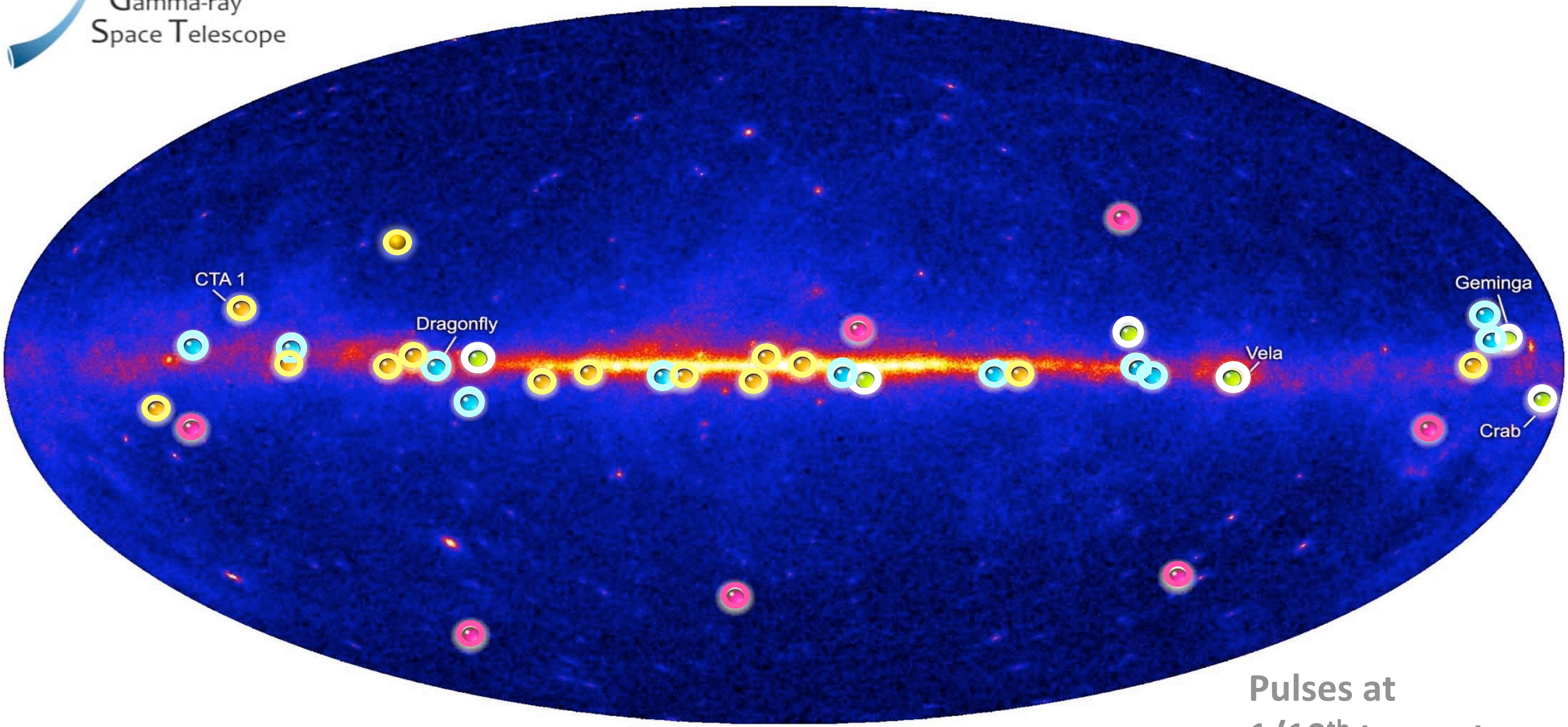




Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

[arXiv:0905.0636]

16 Gamma-Ray Pulsars Through Blind Frequency Searches
Science 325 (5942), 840-844
A Population of Gamma-Ray Millisecond Pulsars Seen with Fermi
Science 325 (5942), 848-852 (14 August 2009)



Pulses at $1/10^{th}$ true rate

The Pulsing γ-ray Sky

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

Pulsars

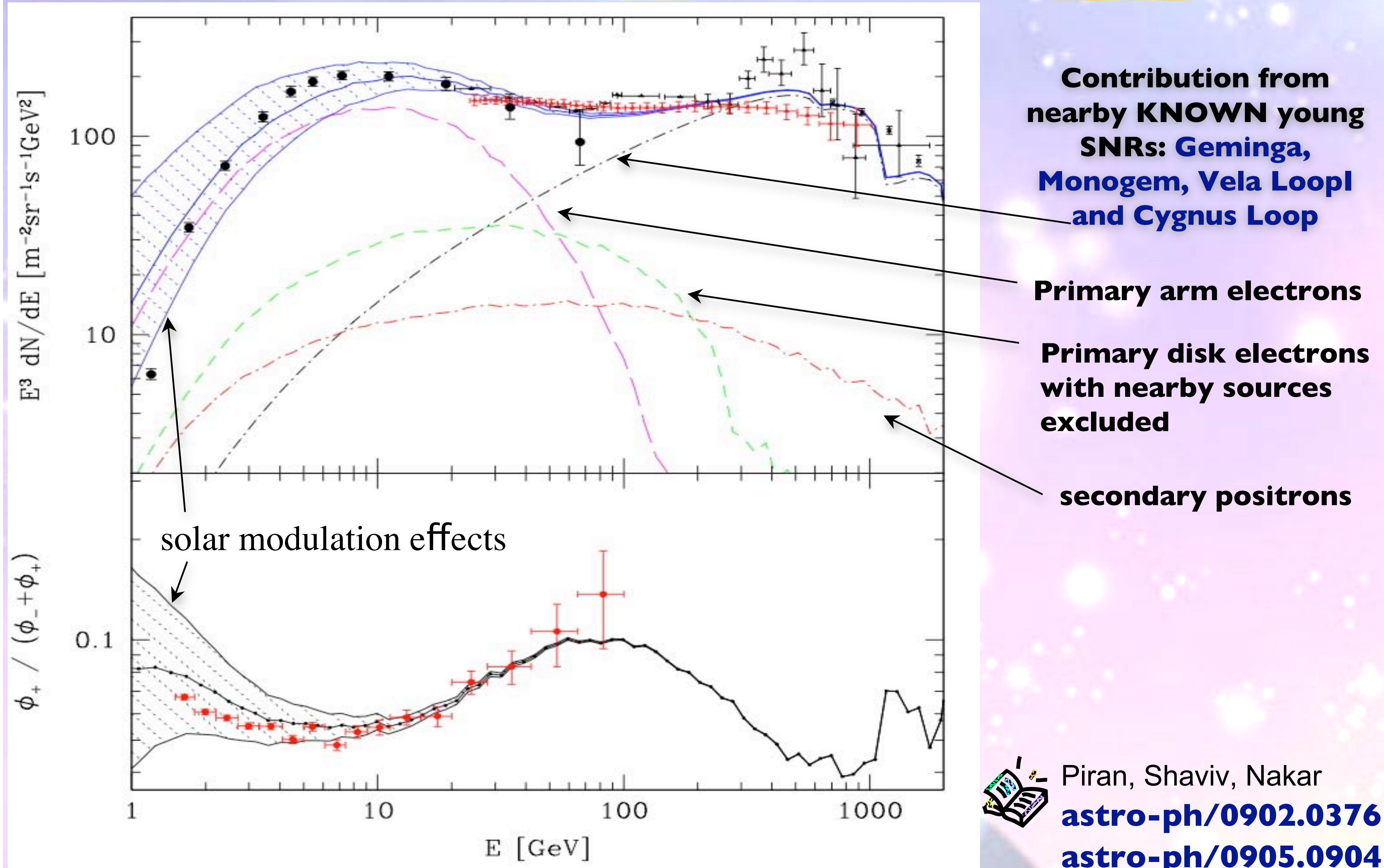
1. On purely energetic grounds they work (relatively large efficiency)

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

e$^+$/(e$^+$+e$^-$) ratio and e$^-$ spectrum from Supernova Remnants

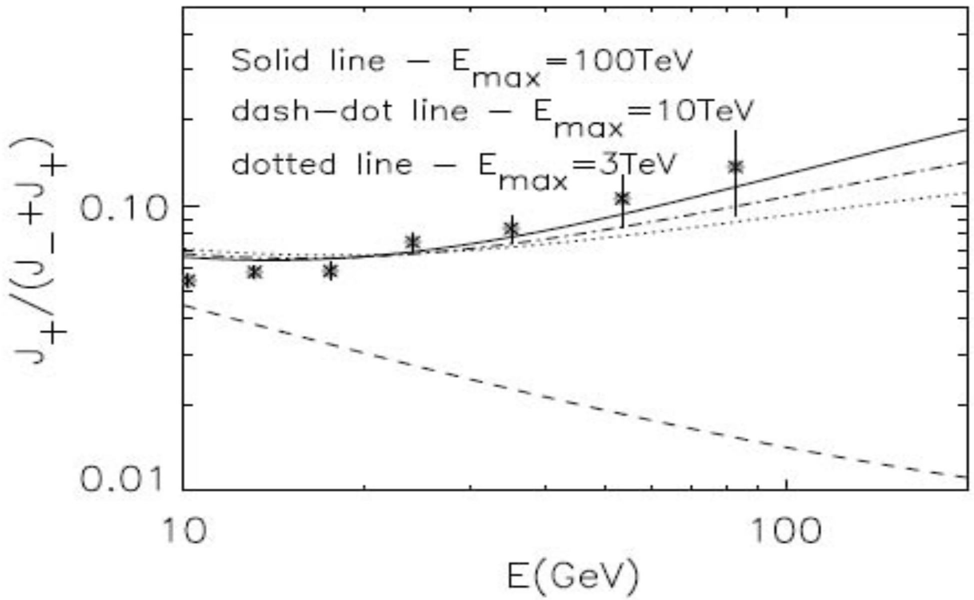


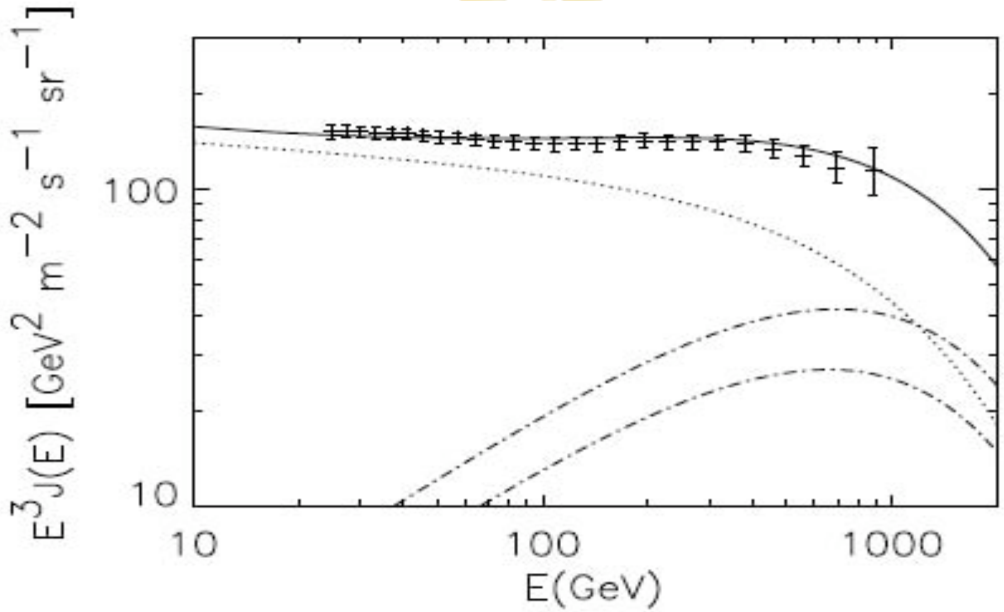
Piran, Shaviv, Nakar

astro-ph/0902.0376

astro-ph/0905.0904

other Astrophysical solution



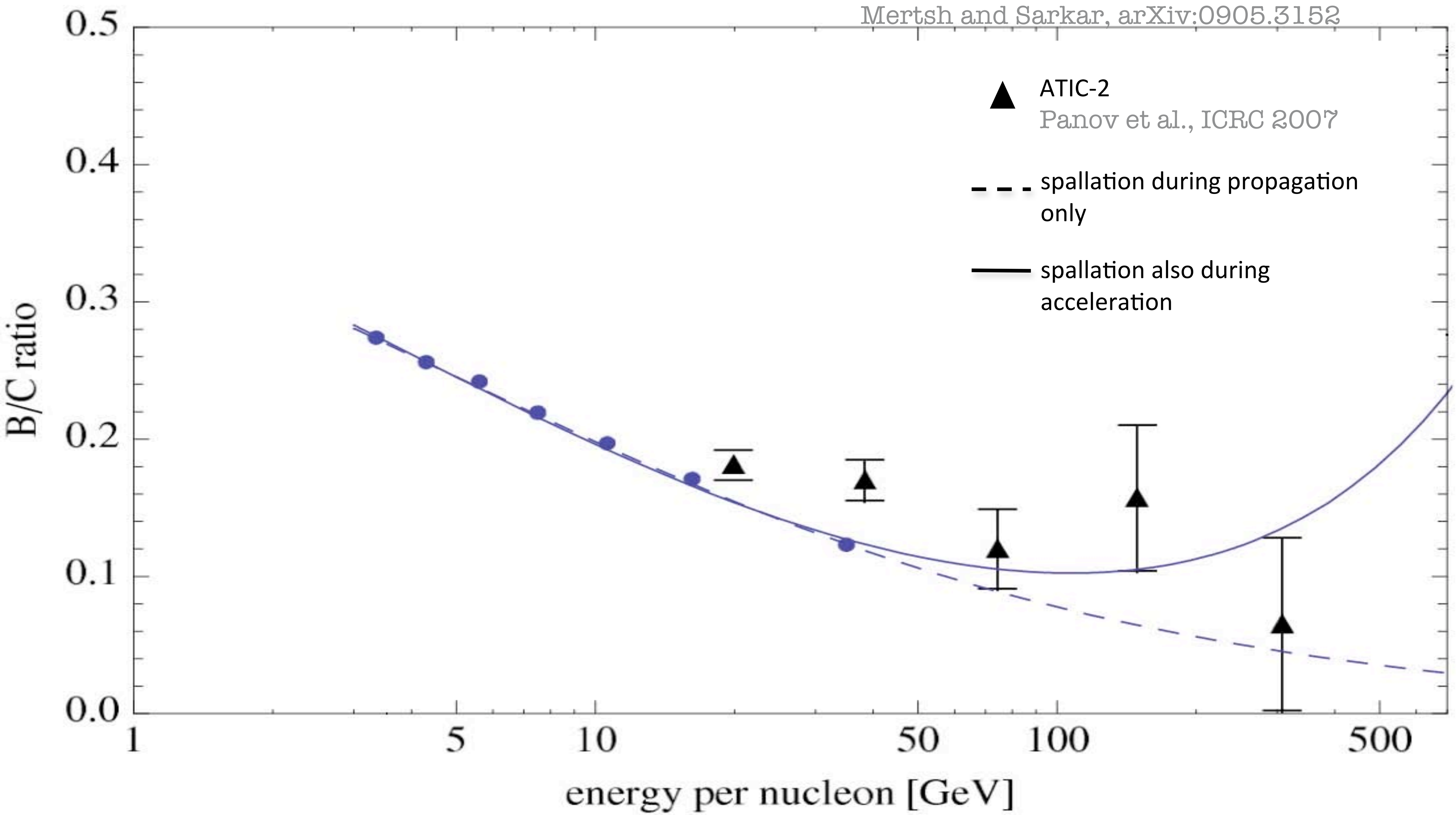


- Positrons created as secondary products of hadronic interactions inside the sources
- Secondary production takes place in the same region where cosmic rays are being accelerated

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

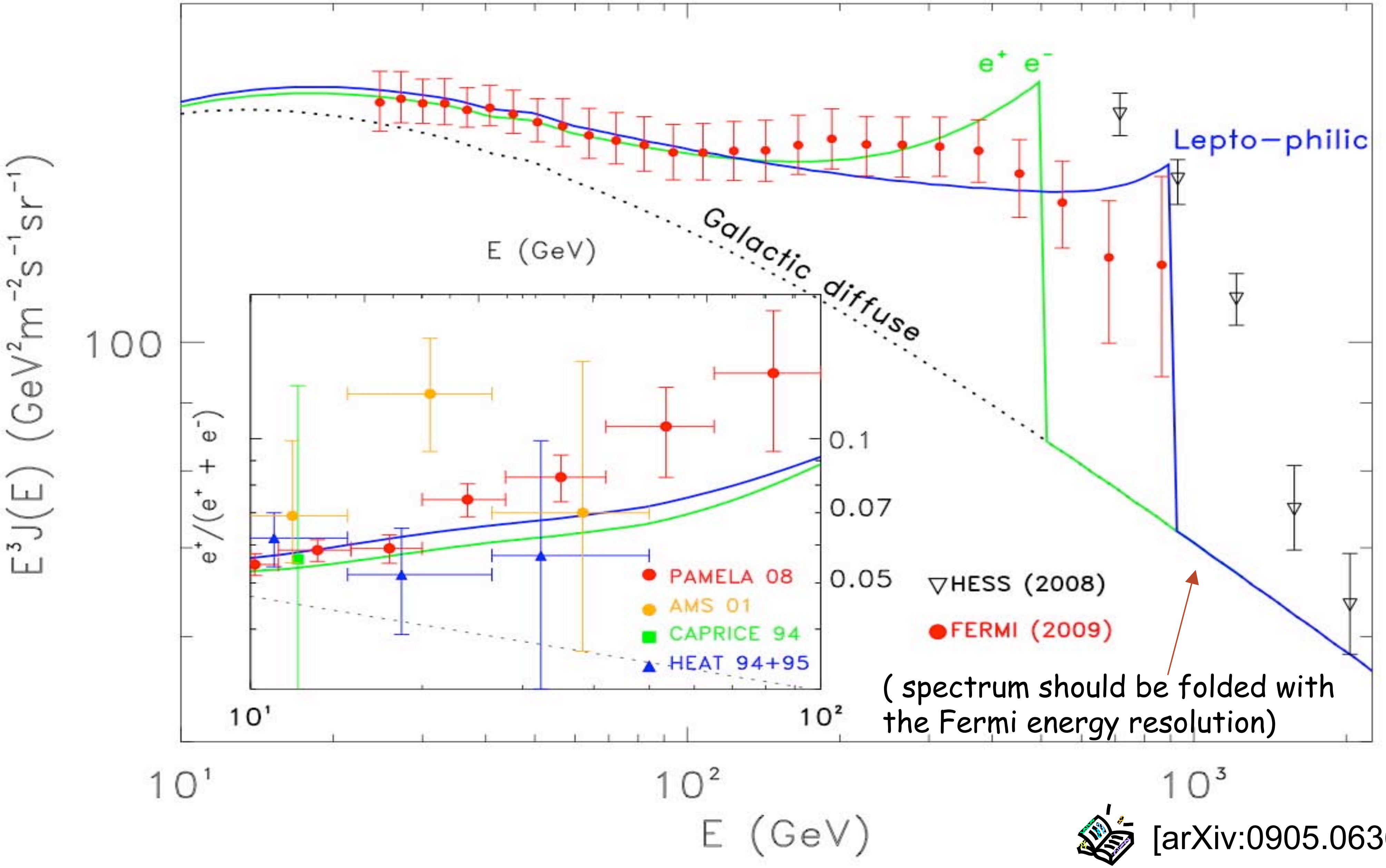
Blasi, arXiv:0903.2794

Boron-to-Carbon Ratio



A rise would rule out the DM and pulsar explanation of the PAMELA positron excess.

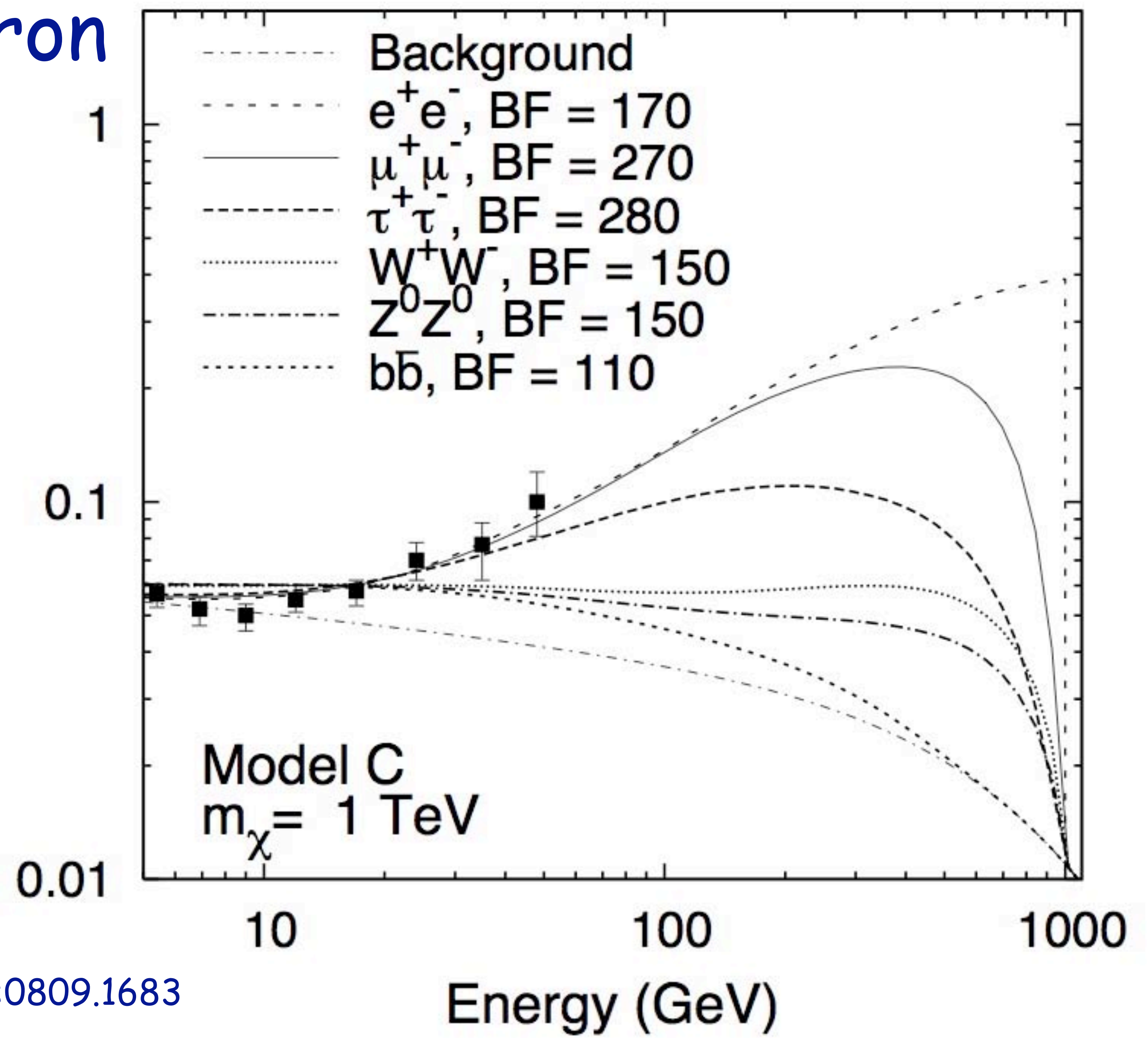
Predictions for the CRE spectrum from two specific dark matter models



(spectrum should be folded with the Fermi energy resolution)

[arXiv:0905.0636]

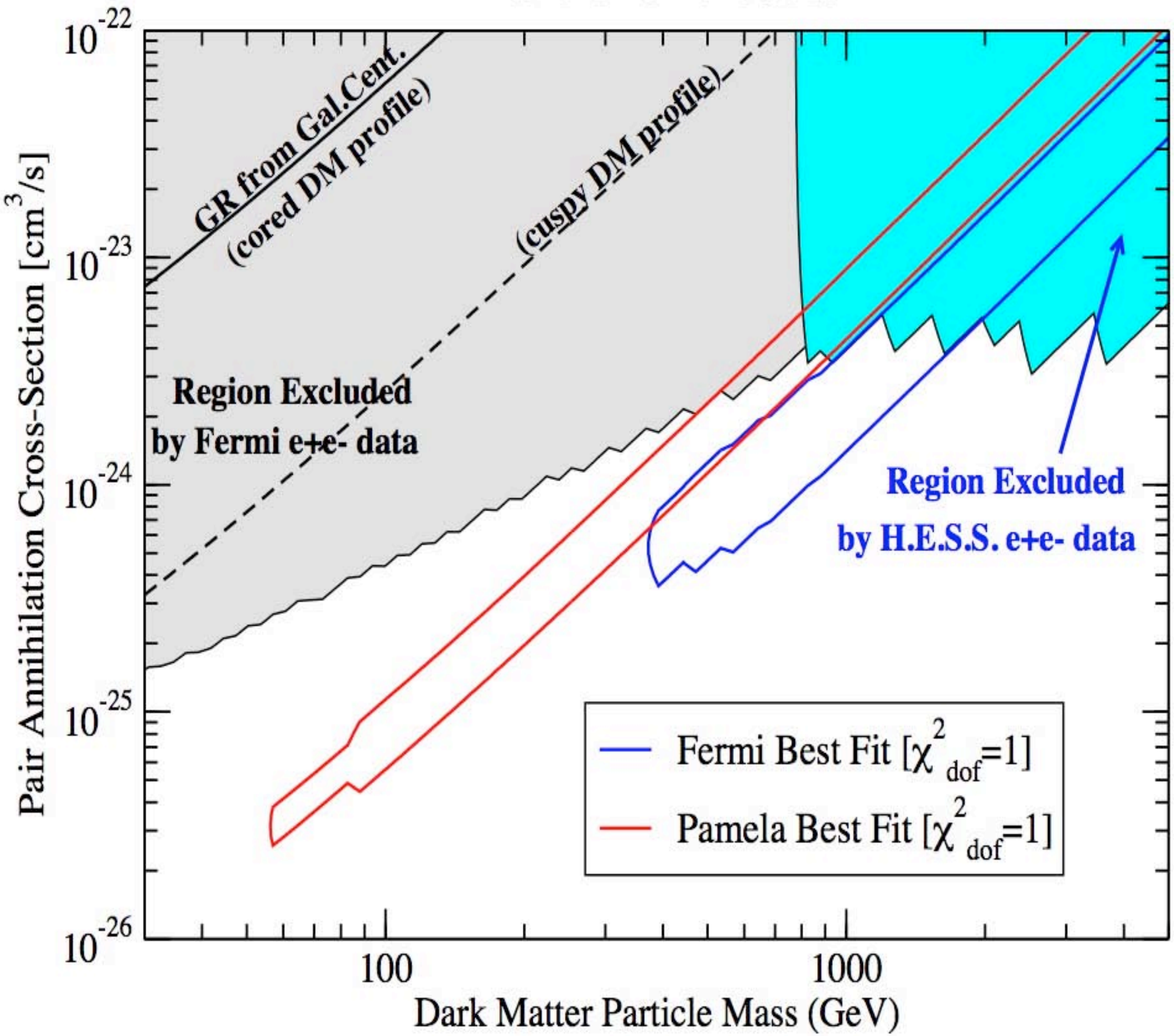
the positron ratio



I.Cholis et al., arXiv:0809.1683

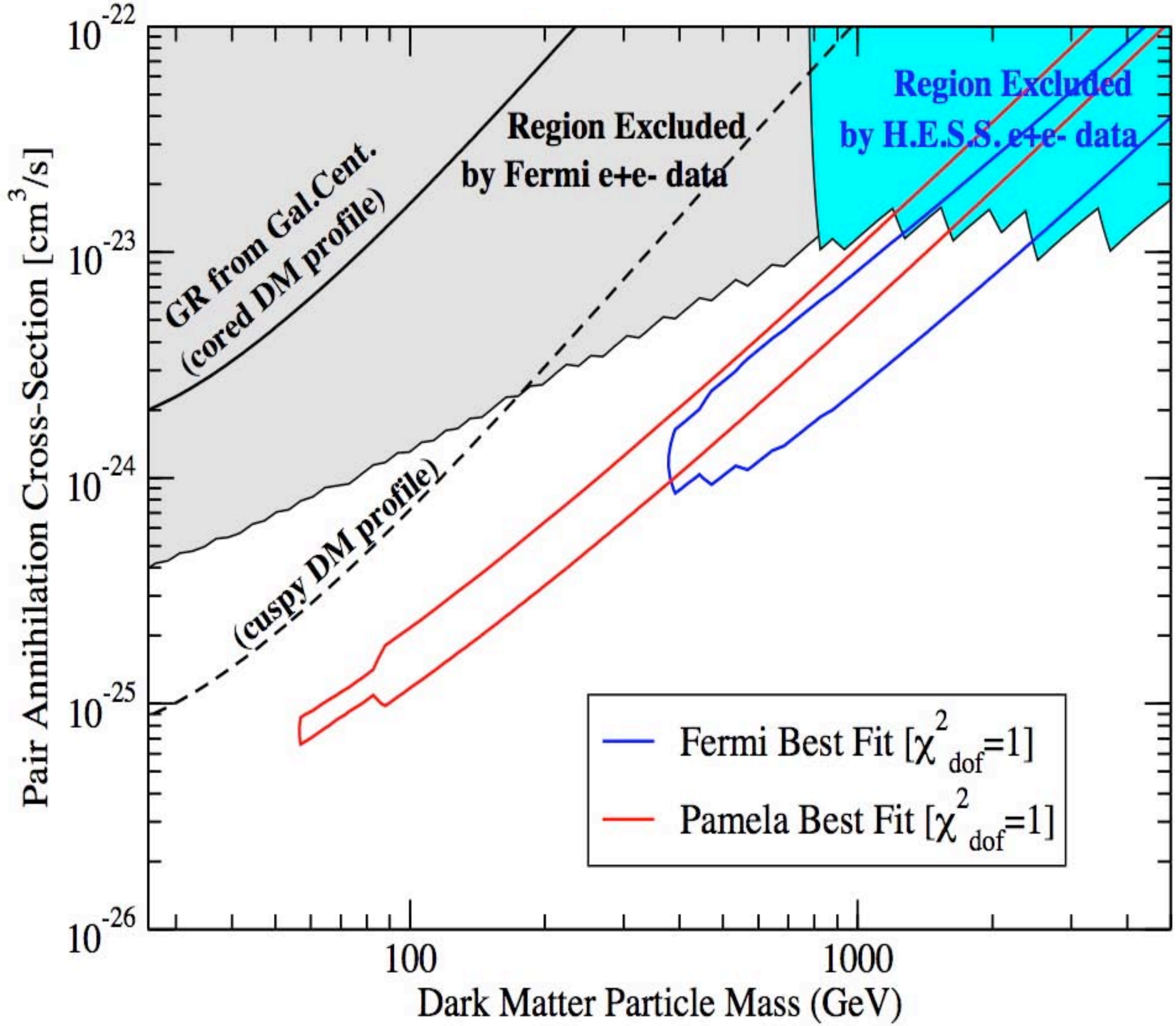
Pure e+e- Models

the dark matter pair annihilation always yields a pair of monochromatic e+e-, with injection energies equal to the mass of the annihilating dark matter particle



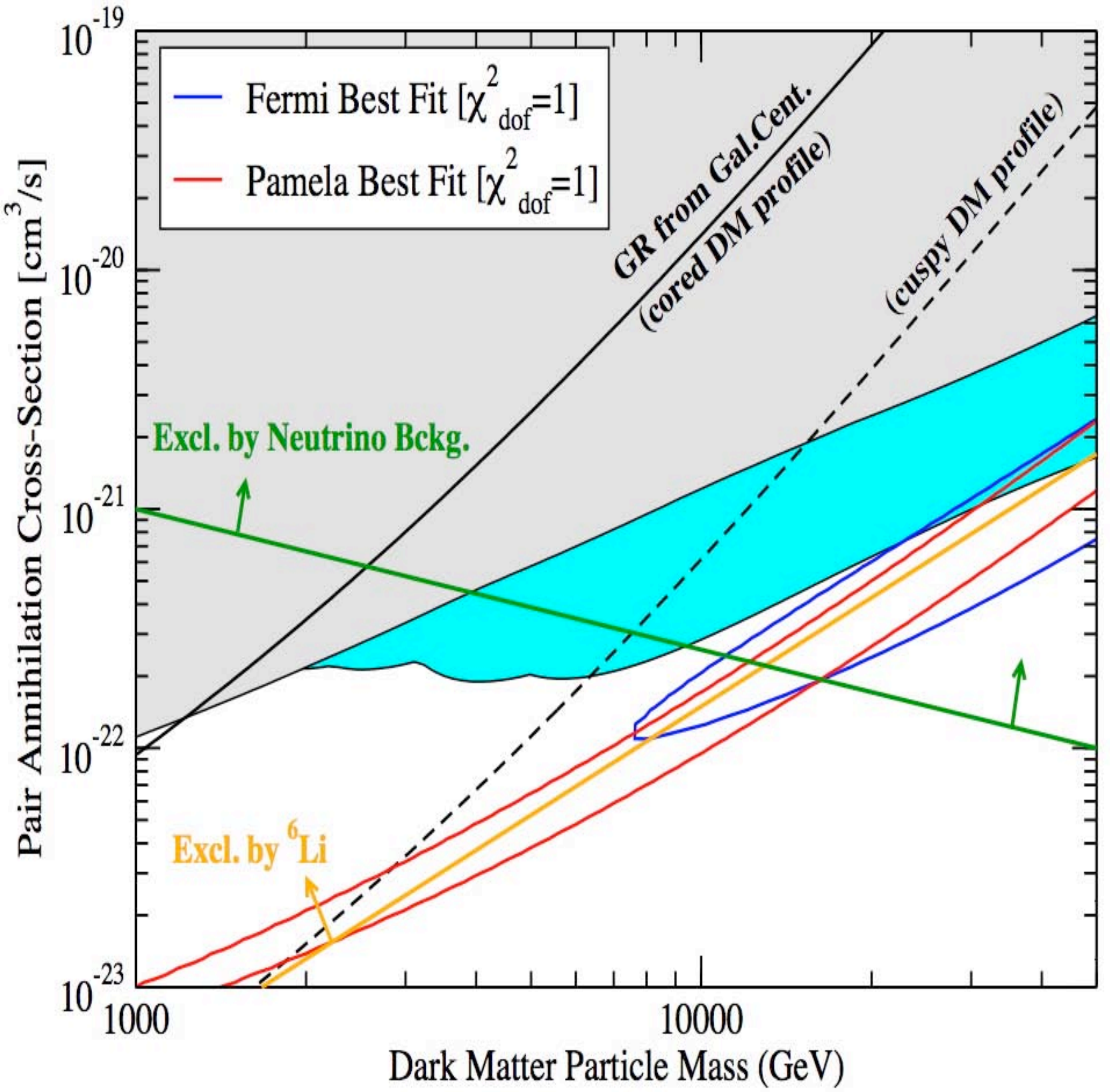
Lepto-philic Models

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.

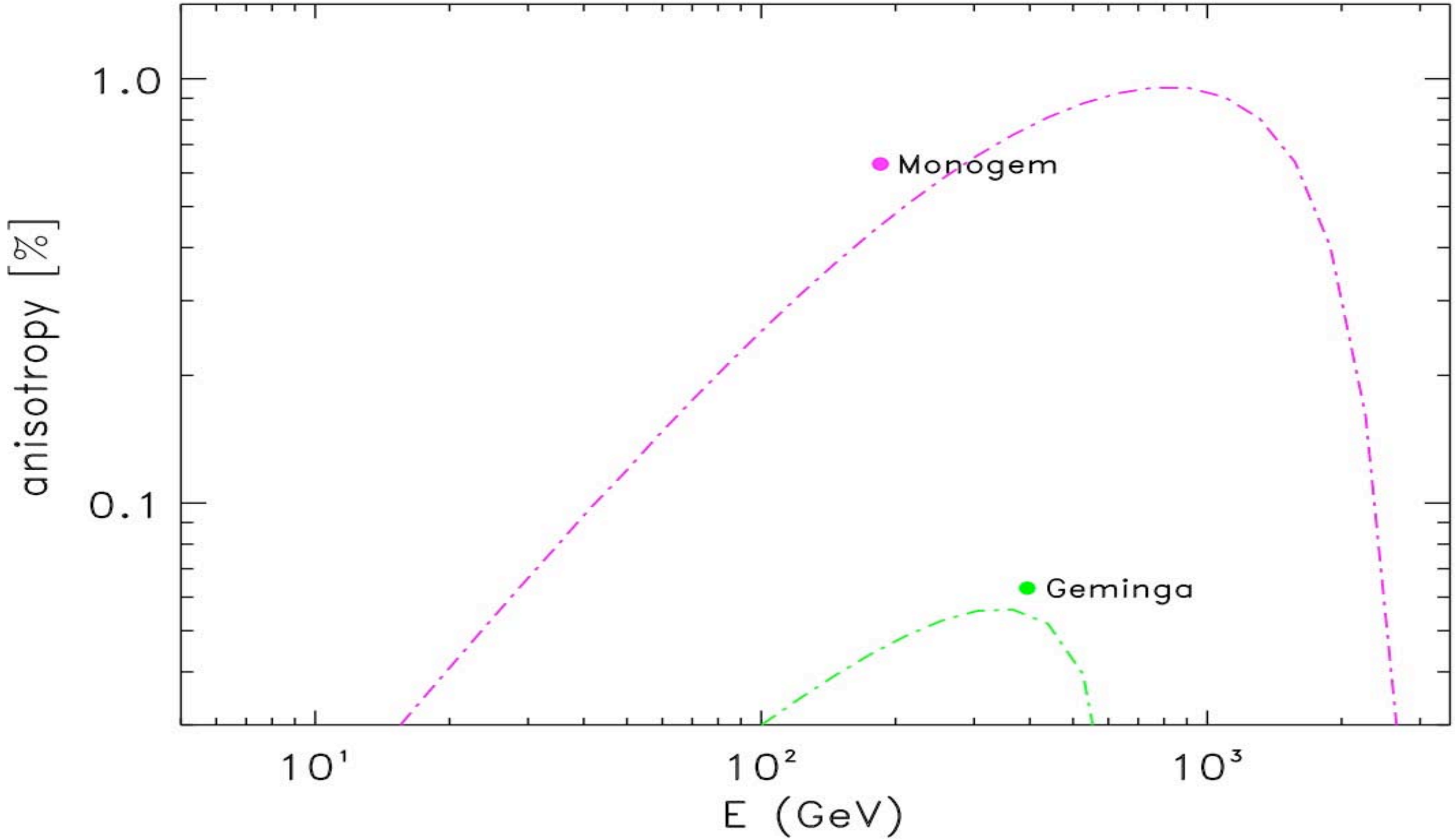


Super-heavy Models (ann. in gauge bosons)

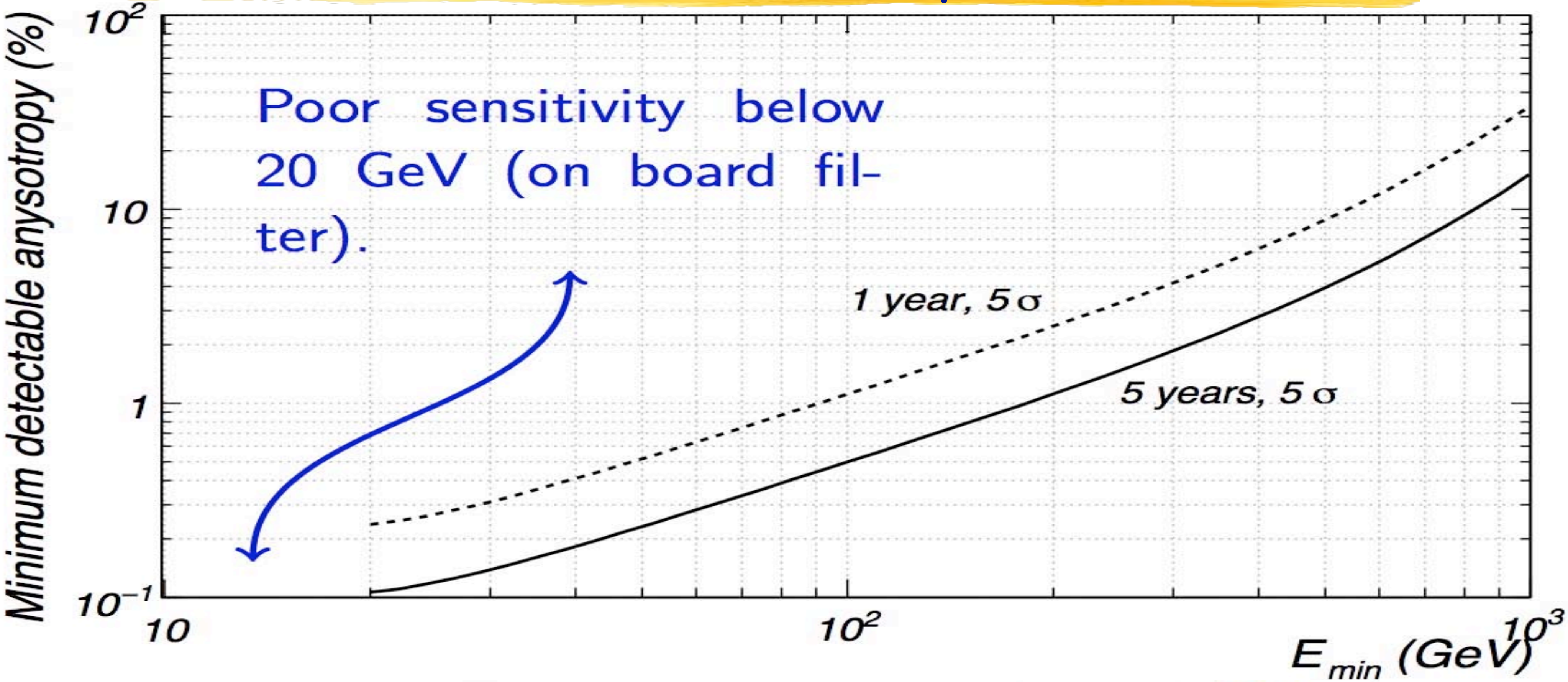
Super-heavy dark matter models: antiprotons can be suppressed below the PAMELA measured flux if the dark matter particle is heavy (i.e. in the multi-TeV mass range), and pair annihilates e.g. in weak interaction gauge bosons. Models with super-heavy dark matter can have the right thermal relic abundance, e.g. in the context of the minimal supersymmetric extension of the Standard Model



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

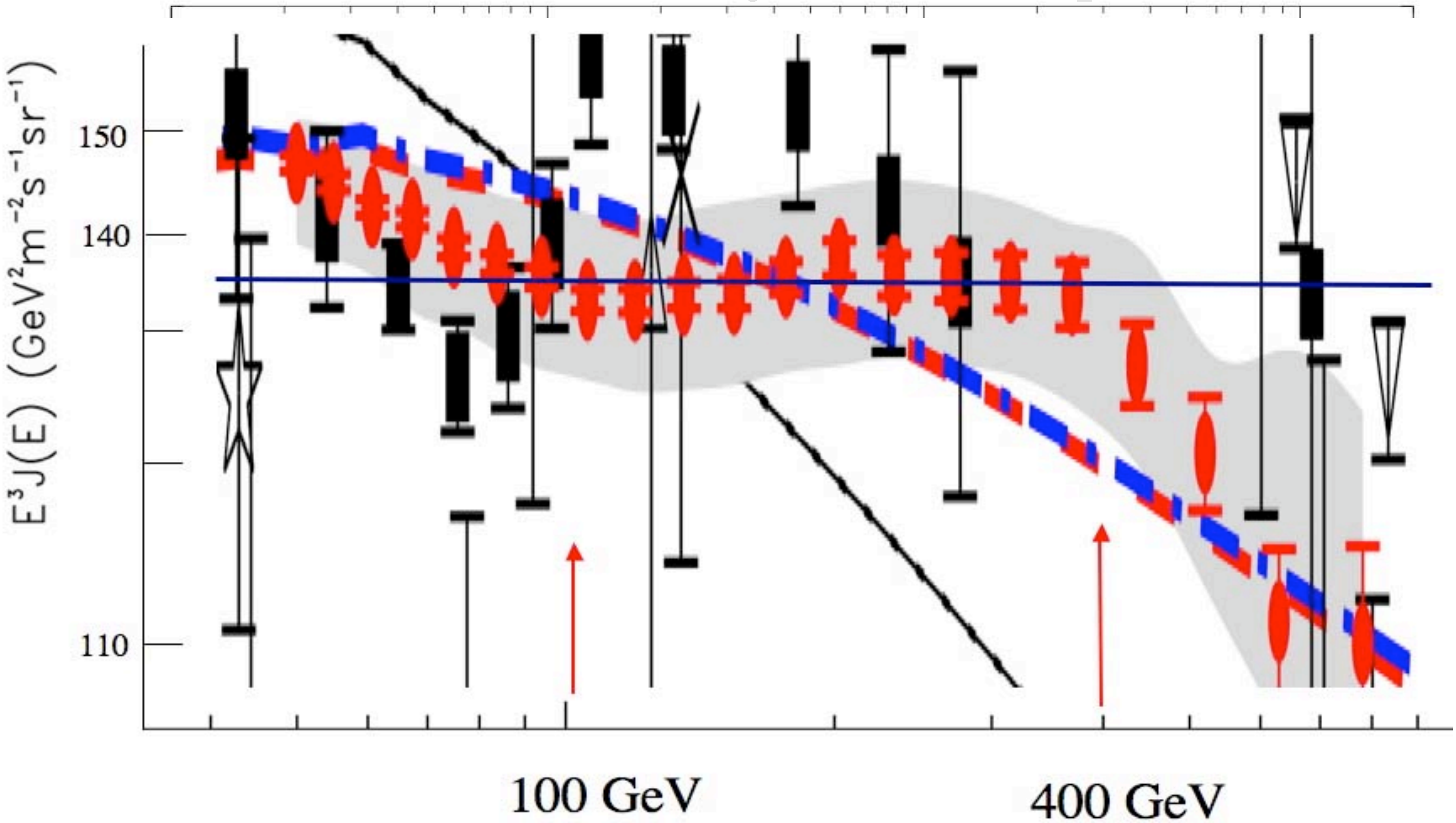


Measurement of anisotropies: statistics



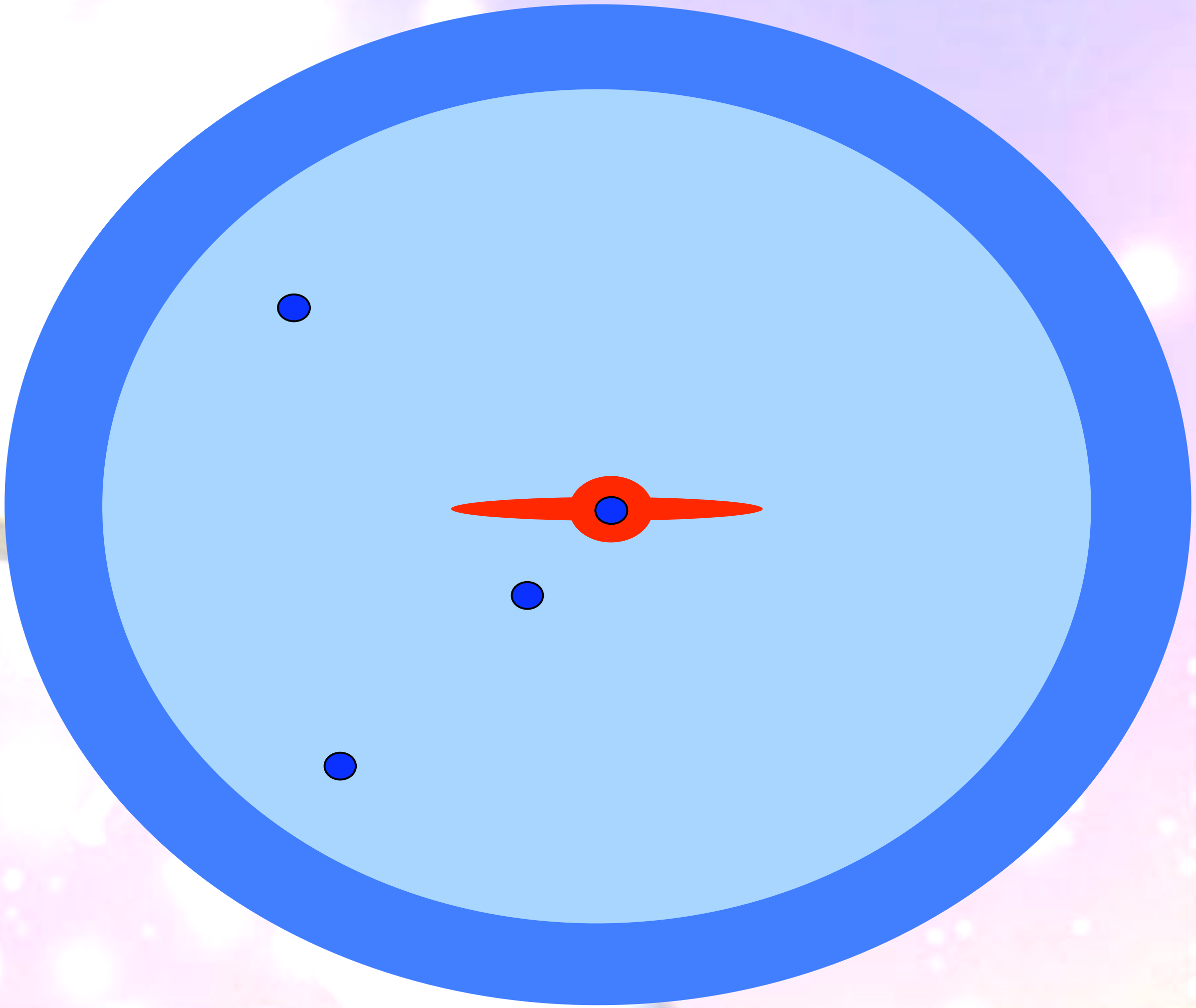
- Statistical limit for the integral anisotropy set by $\delta = \frac{\sqrt{2}N_\sigma}{\sqrt{N_{\rm events}}}$
- The plot includes all the instrument effects:
- Energy-dependent effective geometry factor;
- Instrumental dead time and duty cycle, On board filter.
- Room for improvements with a better event selection!

Fermi-LAT Cosmic ray Electron spectrum

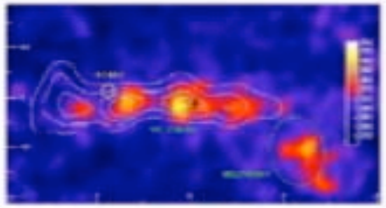
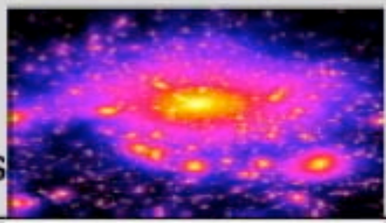
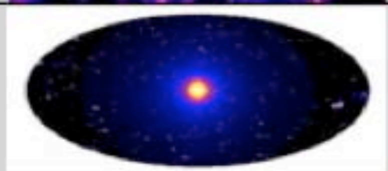
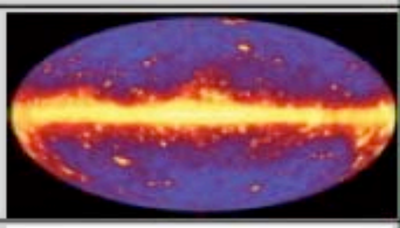
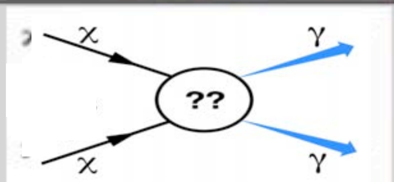


Where should we look for Dark Matter with FERMI ?

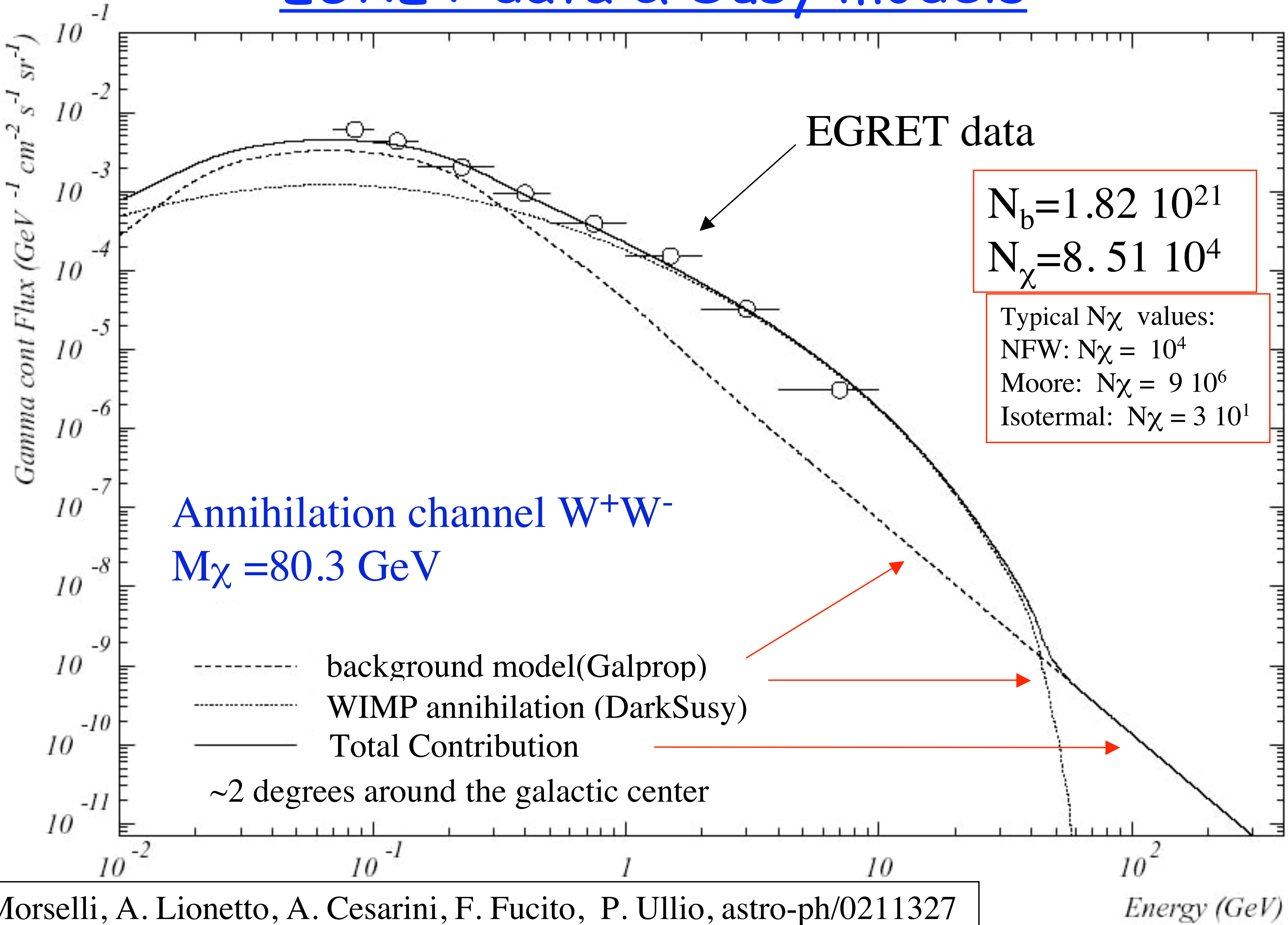
- Galactic center
- Galactic satellites
- Galactic halo
- Extra-galactic



How the GLAST-LAT* telescope could help to disentangle the Dark Matter puzzle ?

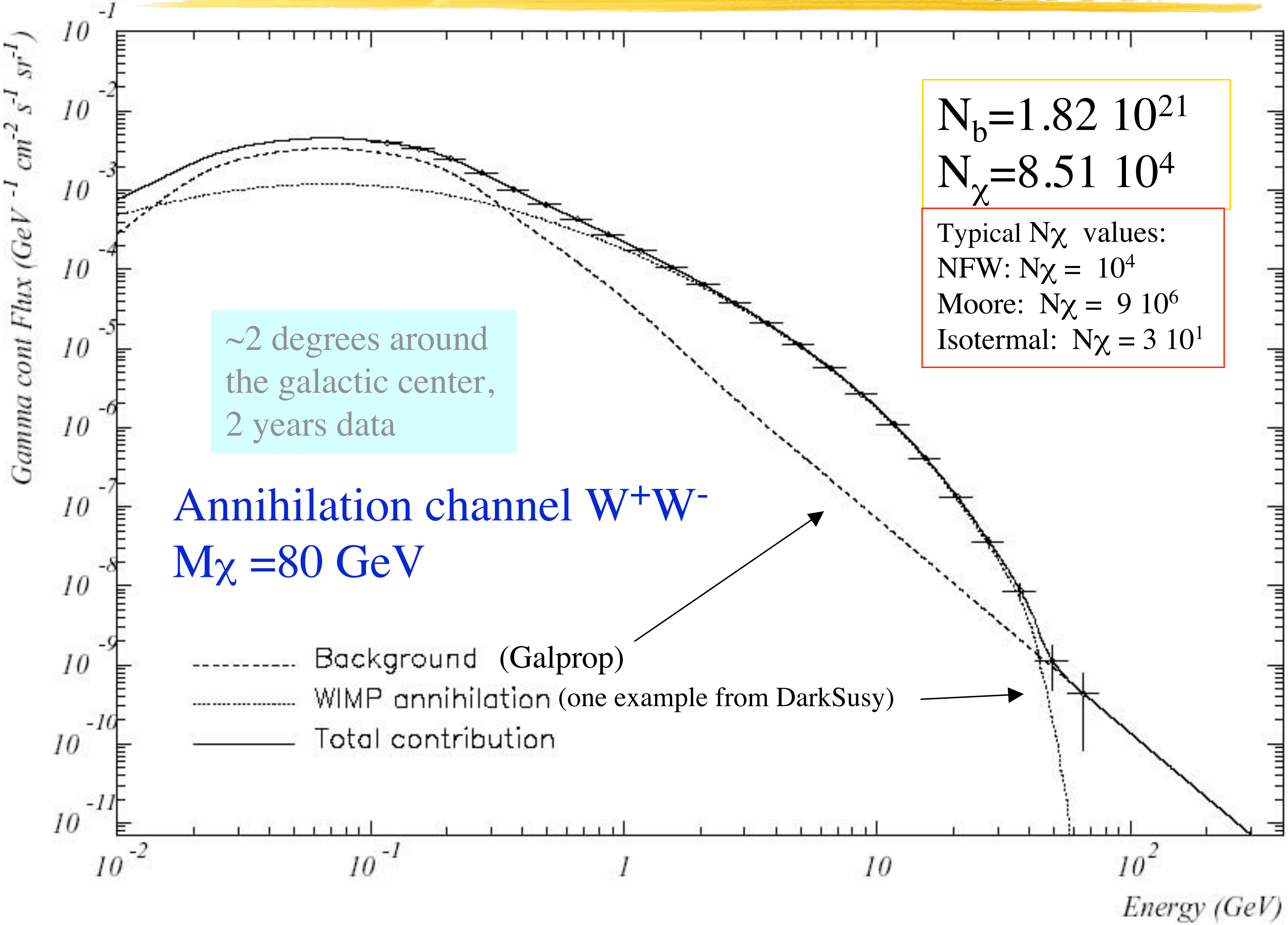
Search Technique		advantages	challenges
Galactic center		Good Statistics	Source confusion/Diffuse background
Satellites, Subhalos, Point Sources		Low background, Good source id	Low statistics
Milky Way halo		Large statistics	Galactic diffuse background
Extra-galactic		Large Statistics	Astrophysics, galactic diffuse background
Spectral lines		No astrophysical uncertainties, good source id	Low statistics

EGRET data & Susy models



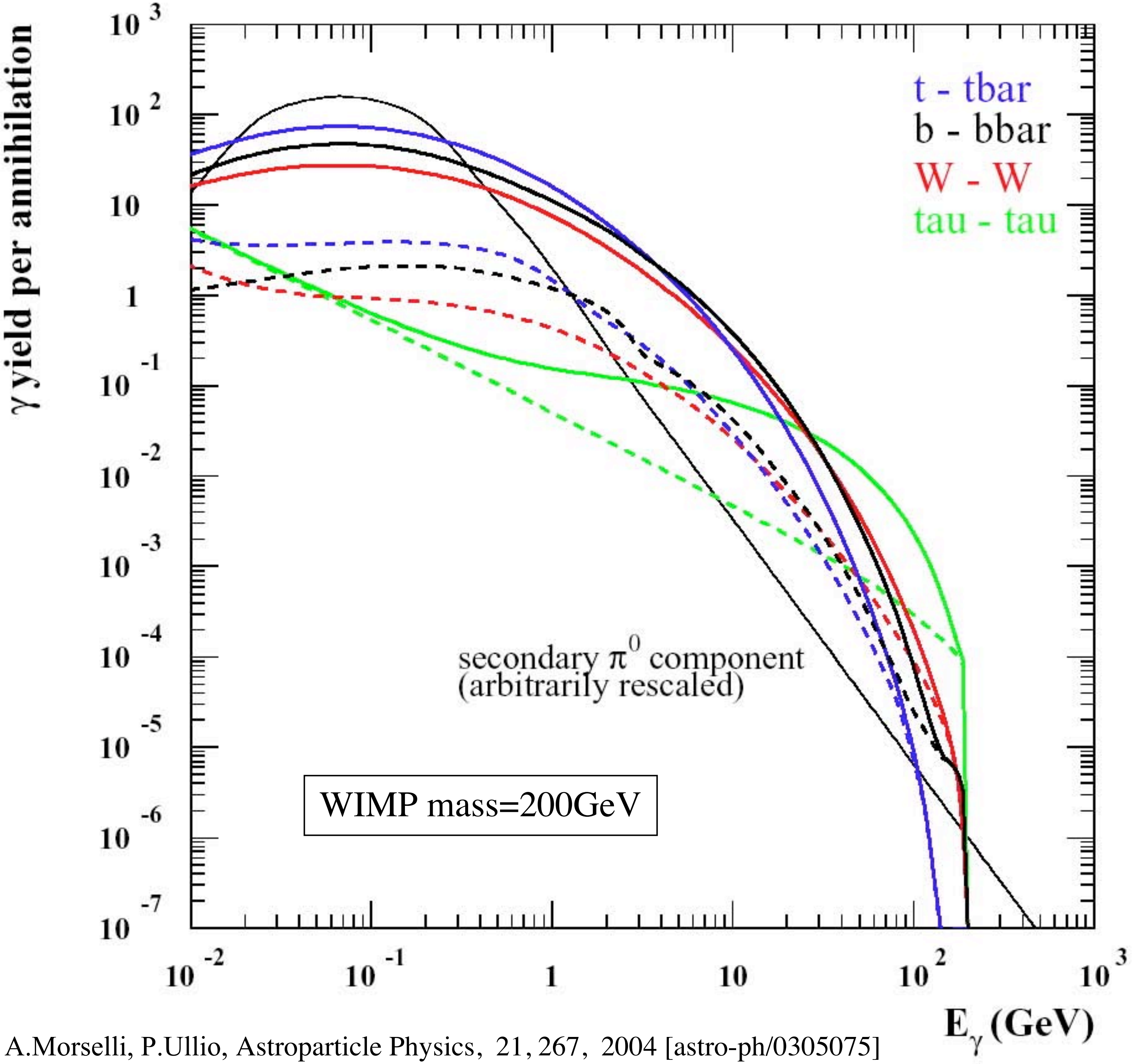
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327

Fermi Expectation & Susy models



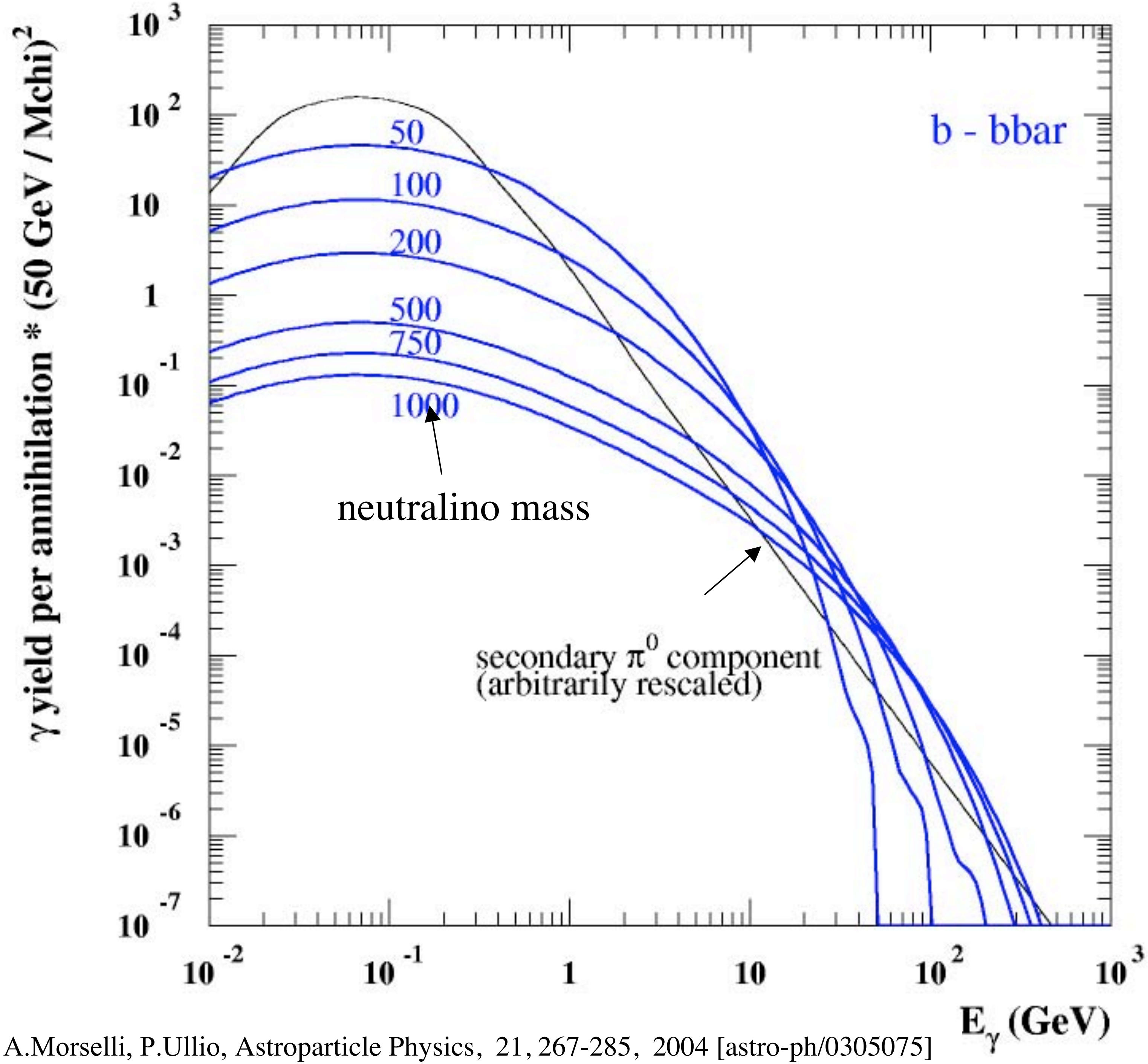
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, June 2004 [astro-ph/0305075]

Differential yield for each annihilation channel



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

Differential yield for b bar

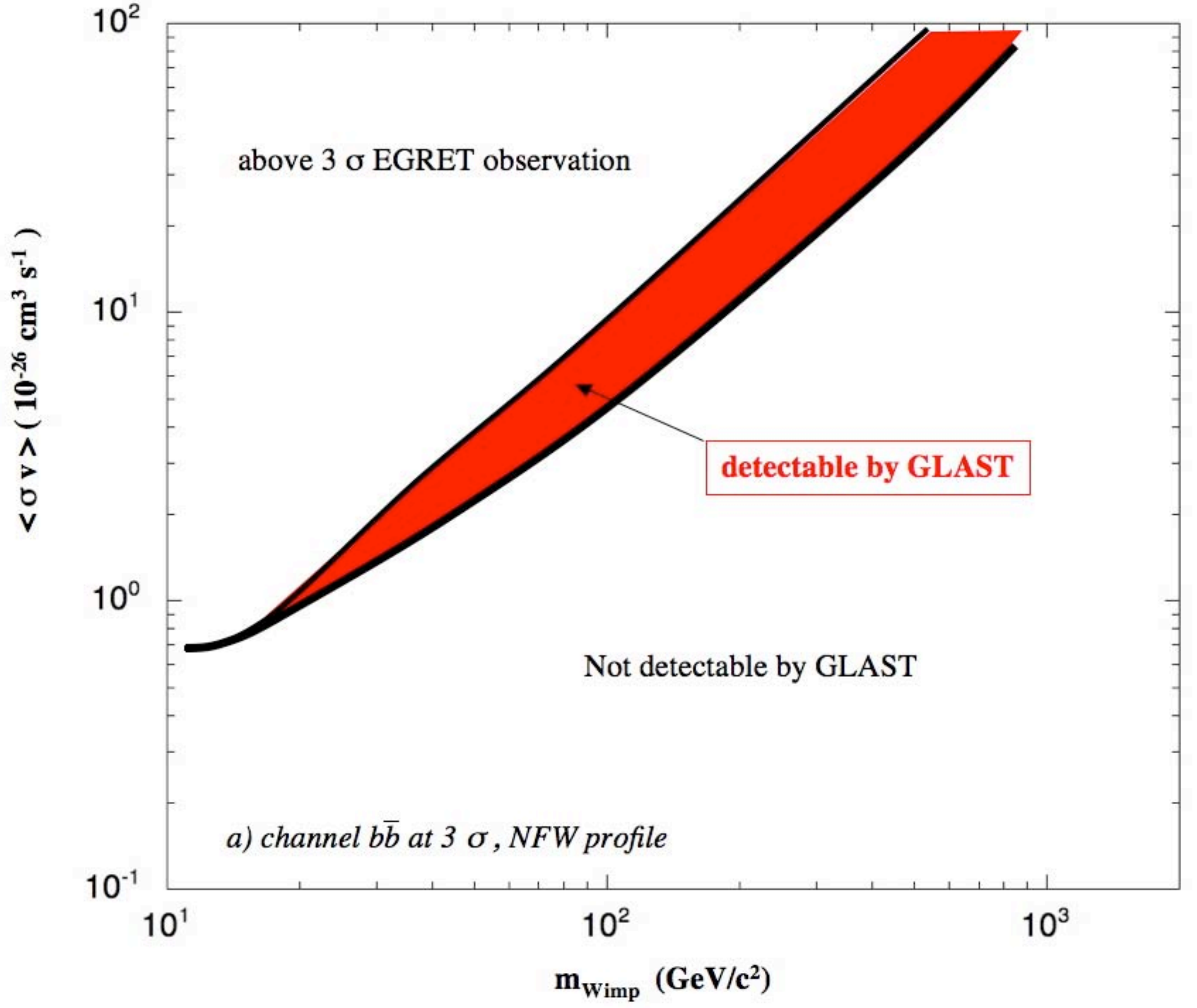


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Model independent results for the GC

after the Fermi Galactic Diffuse Emission data

5 years of operations, truncated NFW



upated from arXiv:0806.2911

Upper limit for dark matter

Upper limit for
DM flux (100MeV-50GeV)
and
DM cross section (100MeV-50GeV)

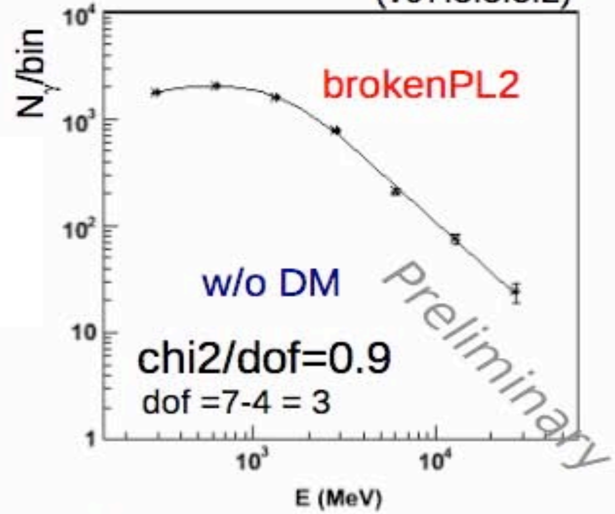
Confidence level 95% (v18.6)
flux(DM) = 2.43 * 10^{-7} cm^{-2} s^{-1}
σ v (DM) = 3.98 * 10^{-25} $cm^3 s^{-1}$

Confidence level 99% (v18.8)
flux(DM) = 3.39 * 10^{-7} cm^{-2} s^{-1}
σ v (DM) = 5.55 * 10^{-25} $cm^3 s^{-1}$

Preliminary

For dark matter DMFit is used, see
Tesla E. Jelterna, Stefano Profumo JCAP 0811:003,2008 arXiv:0808.2641[astro-ph]

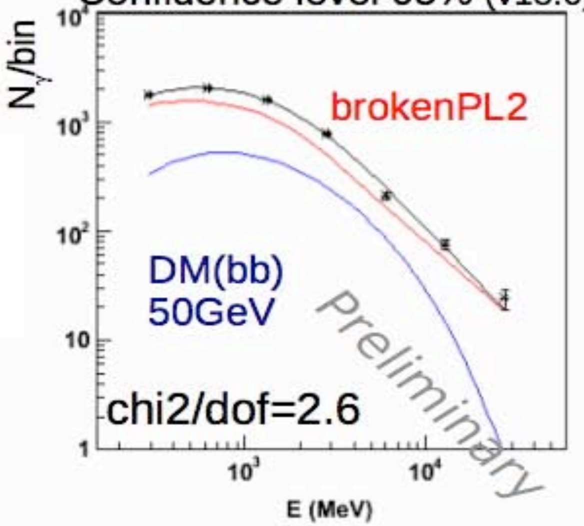
(v07.3.3.3.2)



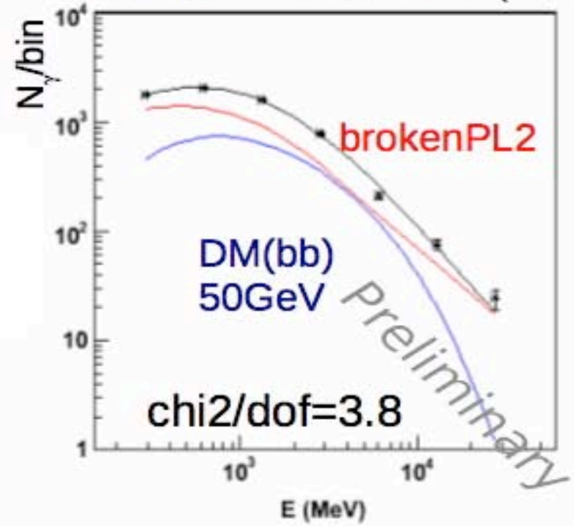
The given upper limits for Dark Matter are conservative ones.

A fit of the GC Fermi spectrum with a Dark Matter model only gives a very bad fit (chi2/dof=66.5!).

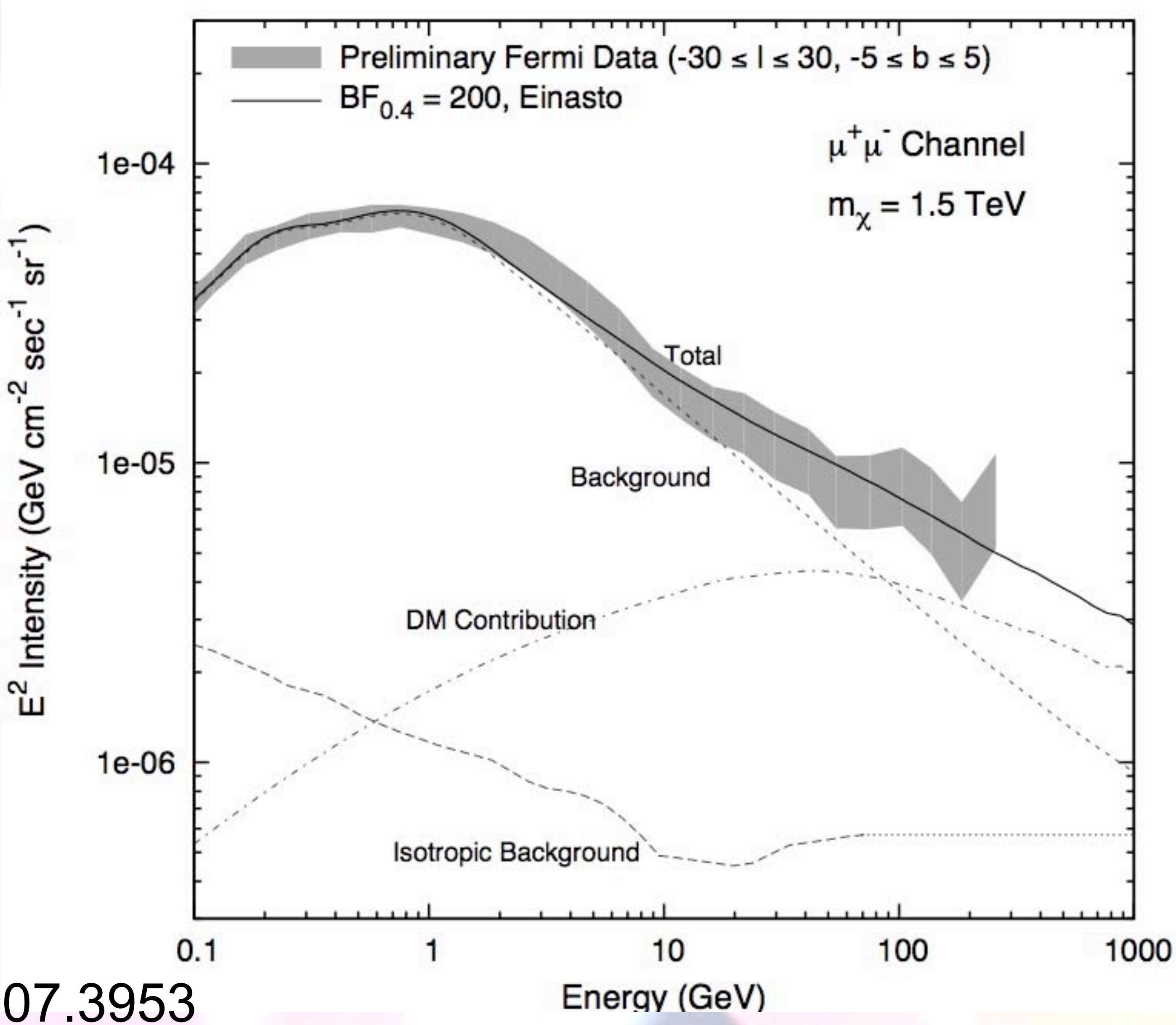
Confidence level 95% (v18.6)



Confidence level 99% (v18.8)



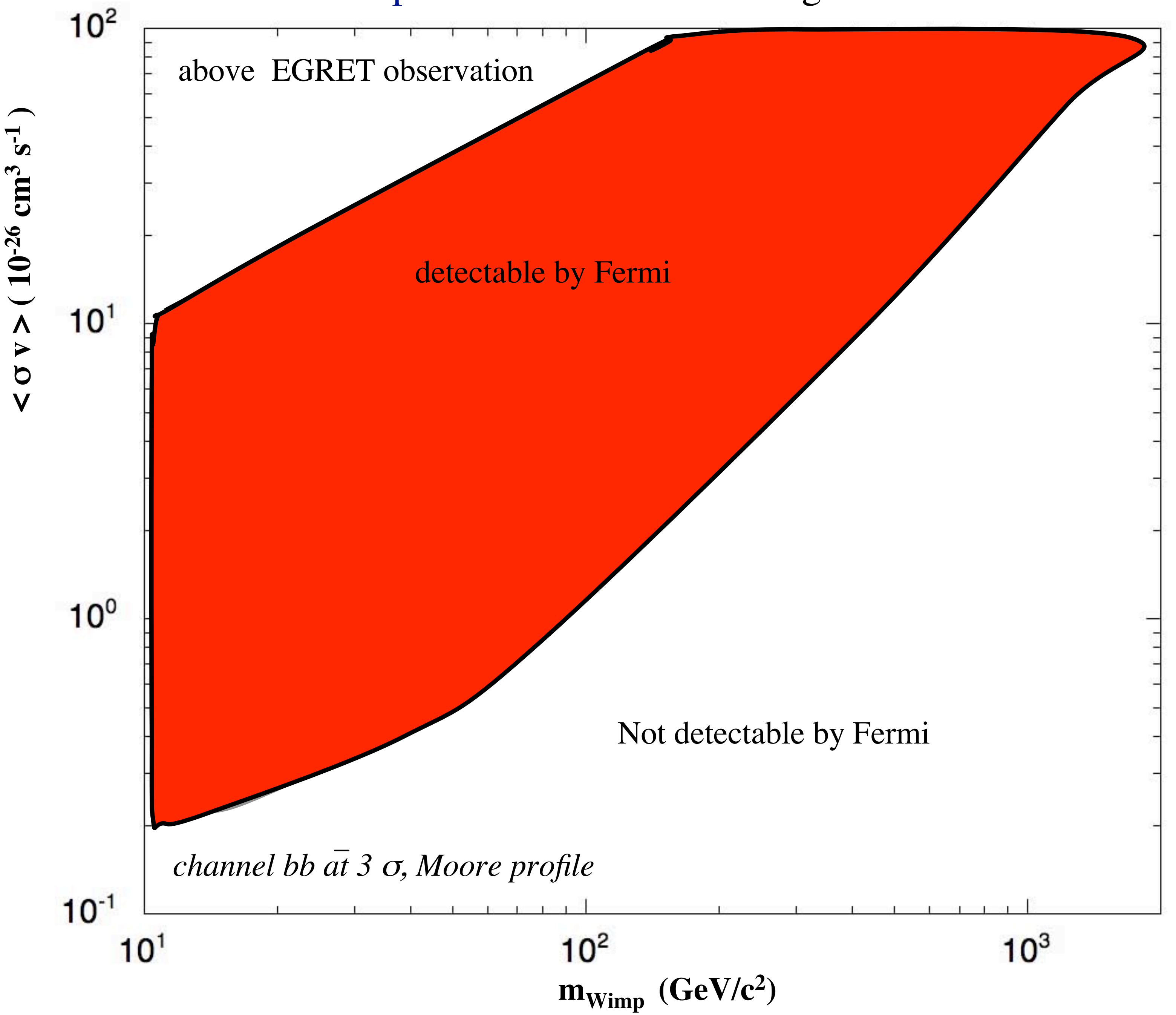
Gamma ray signal in the galactic center



I.Cholis et al., arXiv:0907.3953

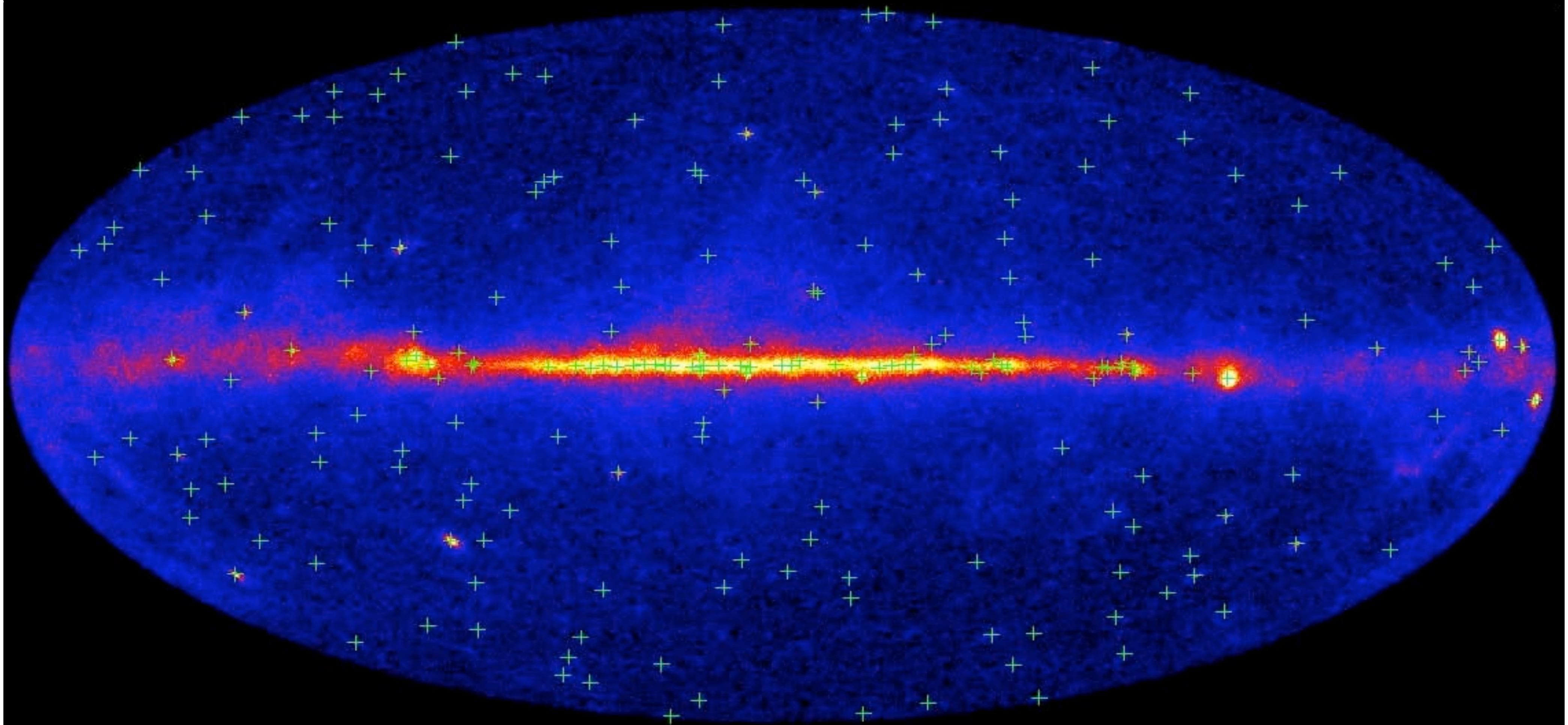
Model independent results for the Sagittarius Dwarft

after the Fermi Galactic Diffuse Emission data



upated from arXiv:0806.2911

205 Preliminary Fermi LAT Bright Sources

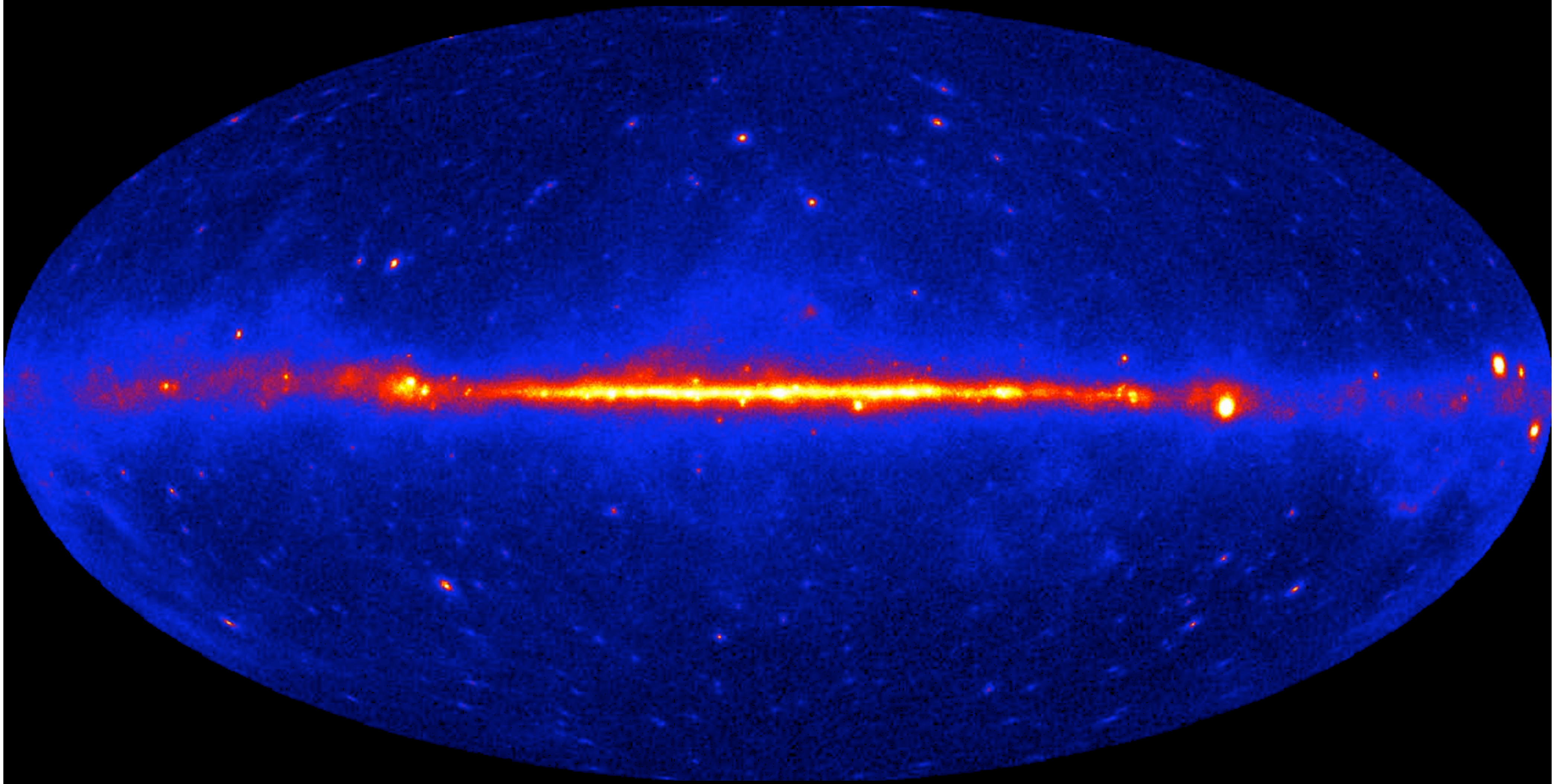


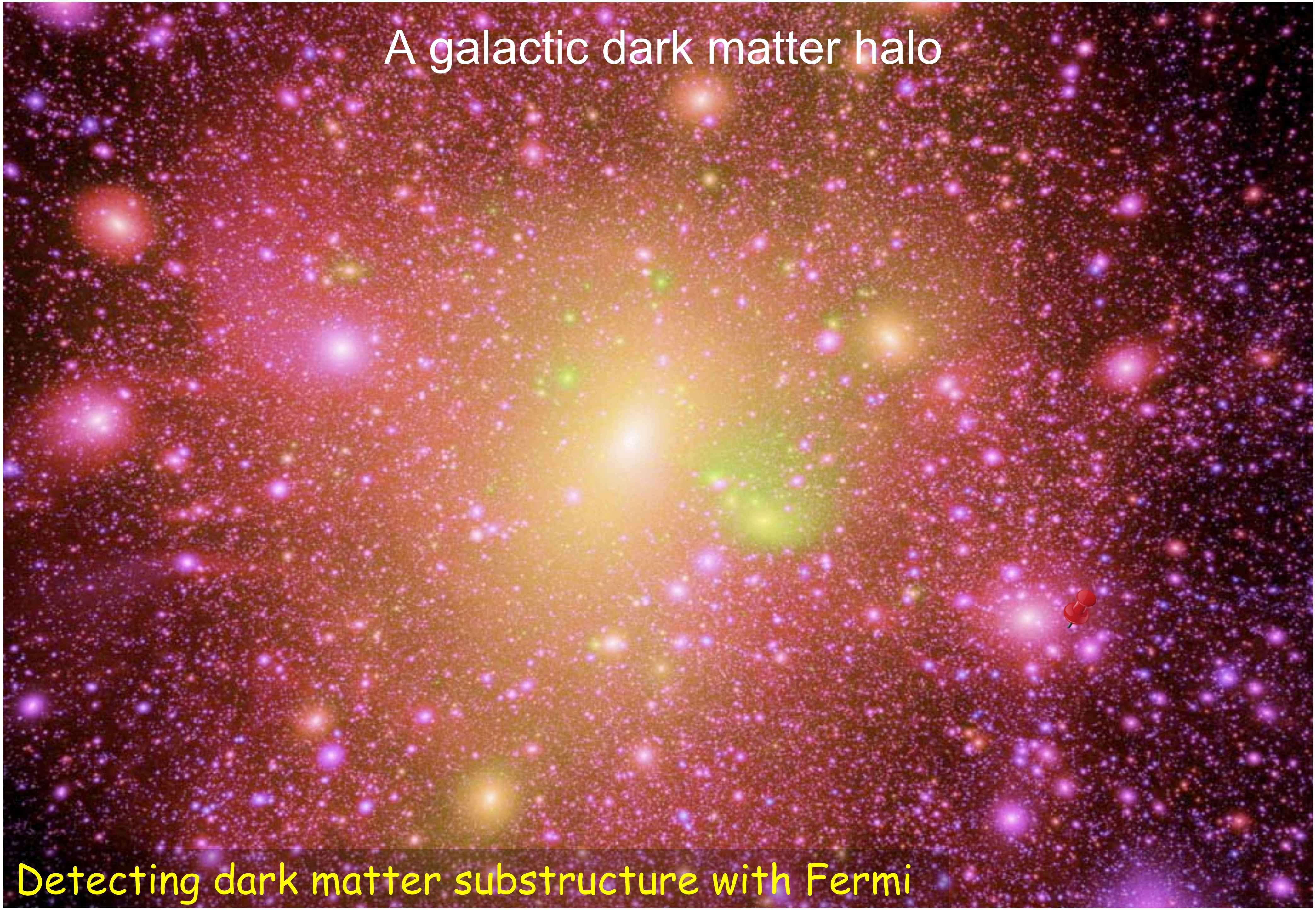
Crosses mark source locations, in Galactic coordinates.

205 Preliminary LAT Bright Sources - Some Information

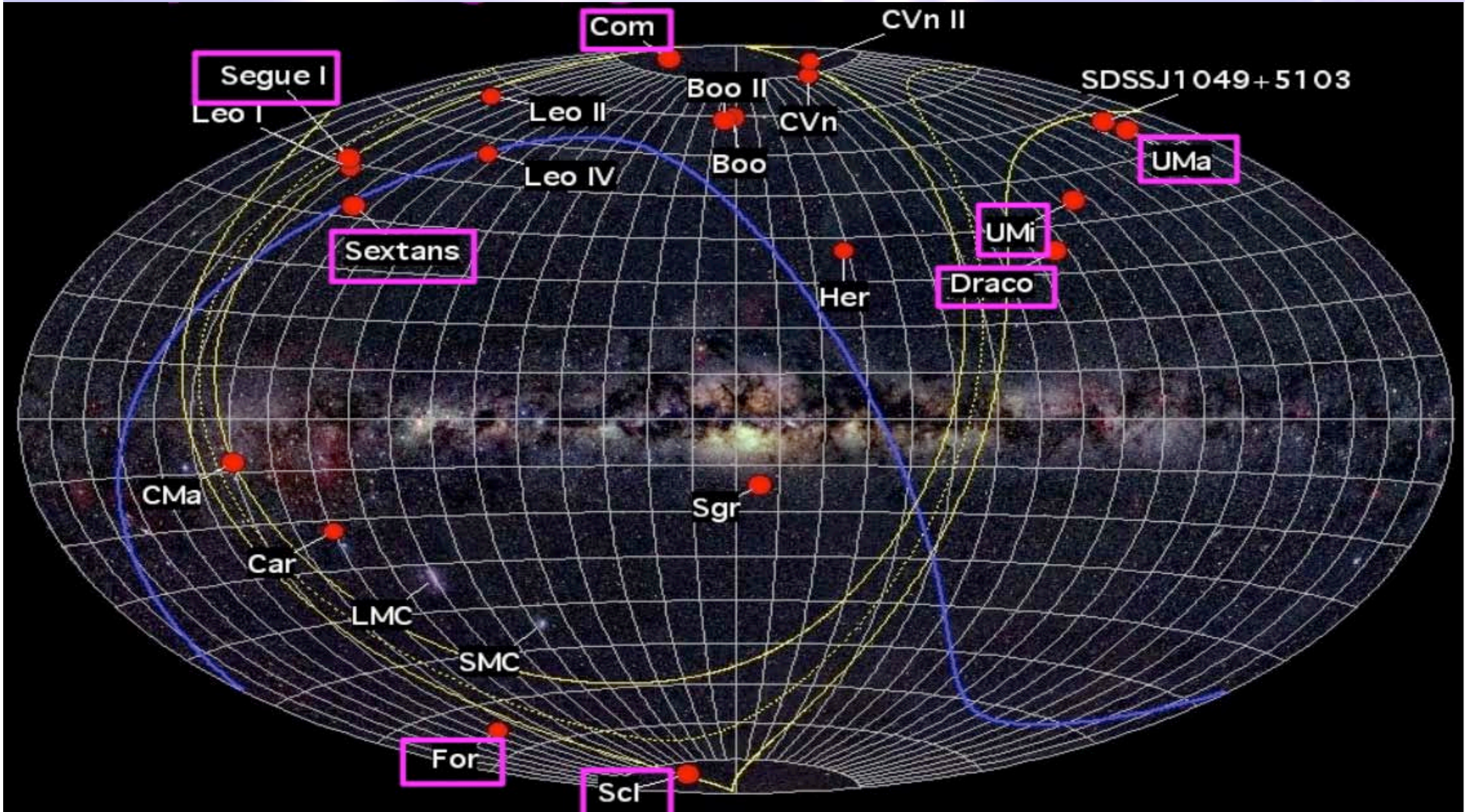
- EGRET on the Compton Observatory found fewer than 30 sources above 10 σ in its lifetime.
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of variability.
- More than 30 pulsars are identified by gamma-ray pulsations.
- Over half the sources are associated positionally with blazars. Some of these are firmly identified as blazars by correlated multiwavelength variability.
- Over 40 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.

9 month observation

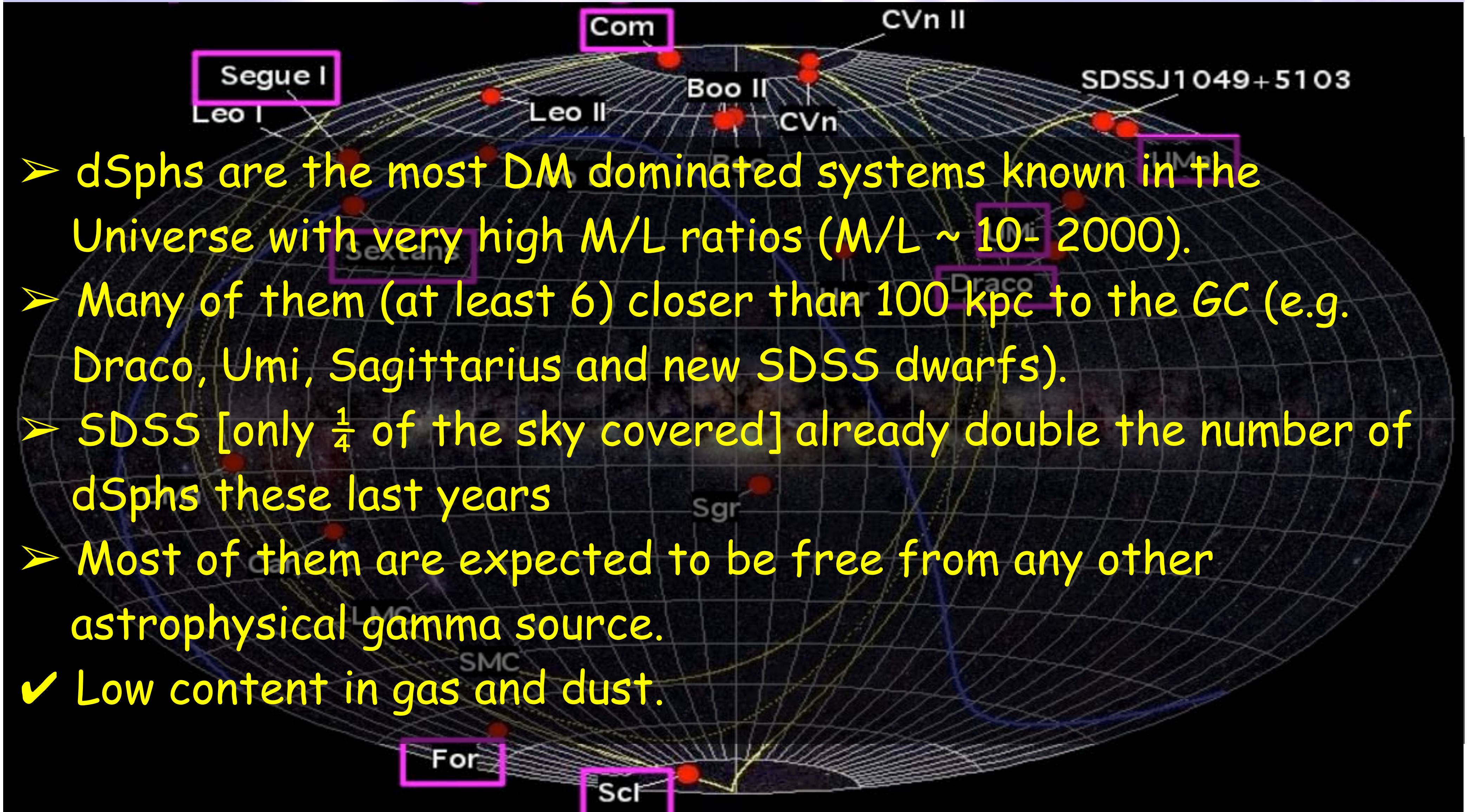



A galactic dark matter halo
Detecting dark matter substructure with Fermi

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

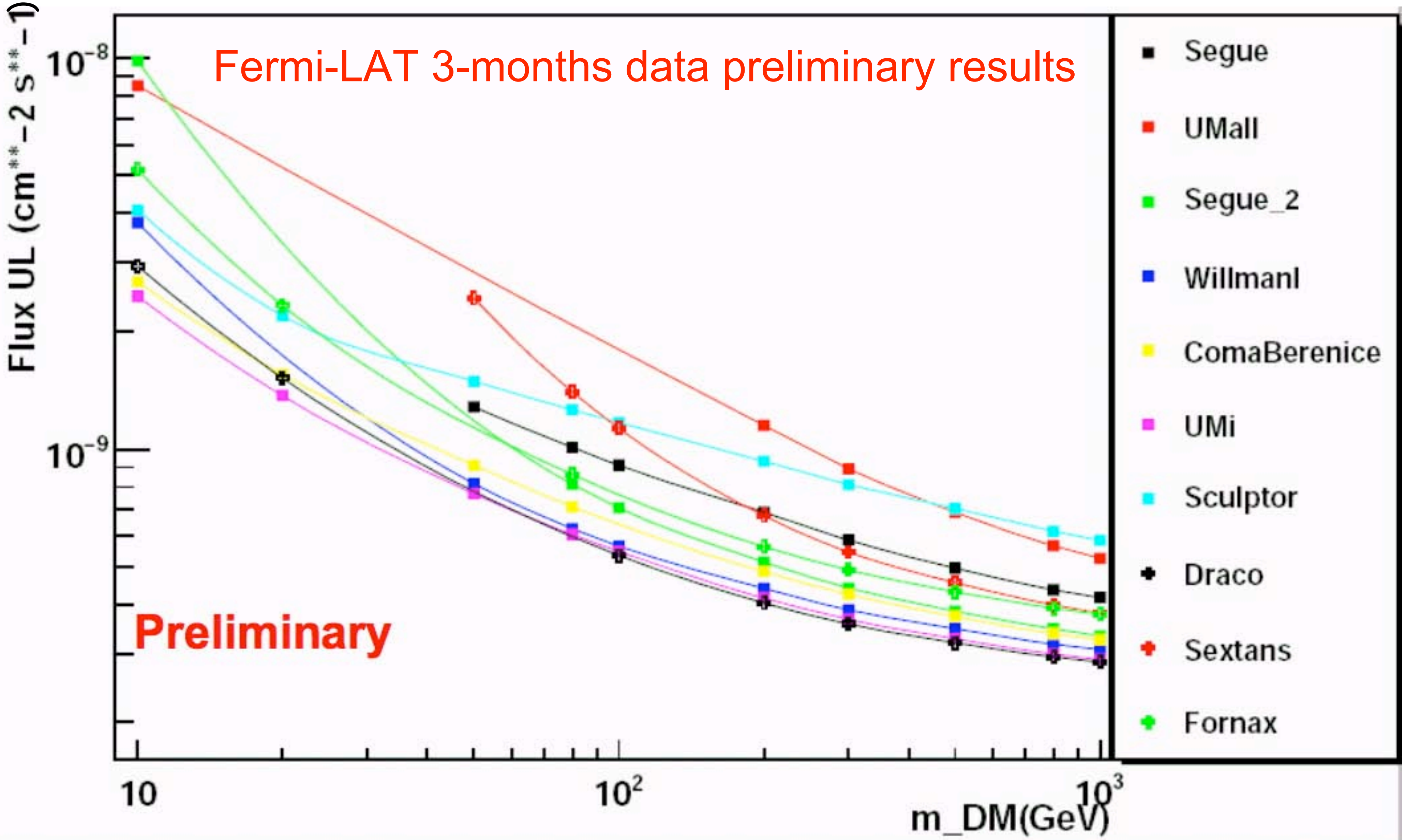


Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

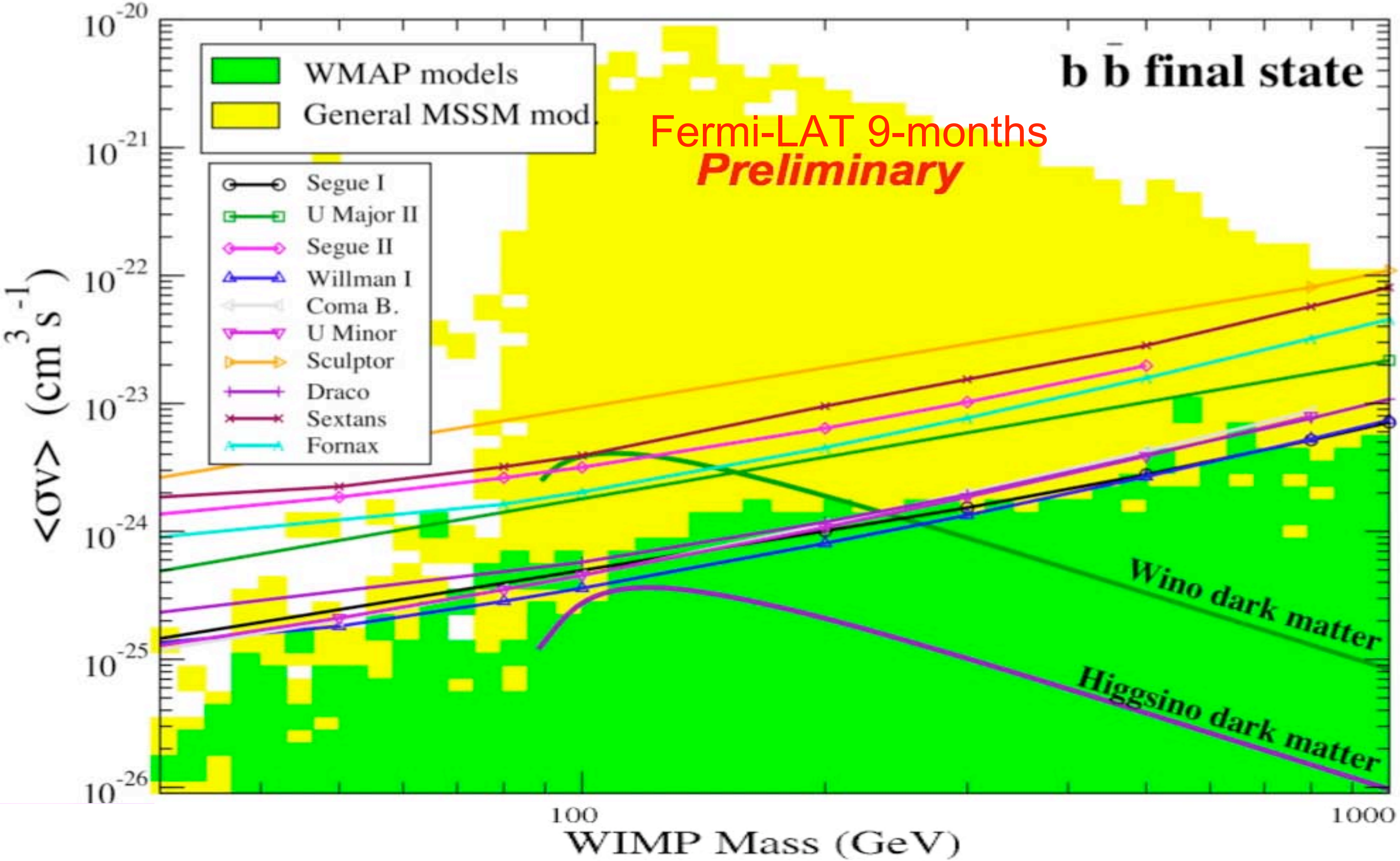


- ➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- ➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- ➢ SDSS [only ¼ of the sky covered] already double the number of dSphs these last years
- ➢ Most of them are expected to be free from any other astrophysical gamma source.
- ✔ Low content in gas and dust.

Dwarf Spheroidal Galaxies upper-limits



Annihilation cross-section upper-limits in Dwarf Spheroidal Galaxies



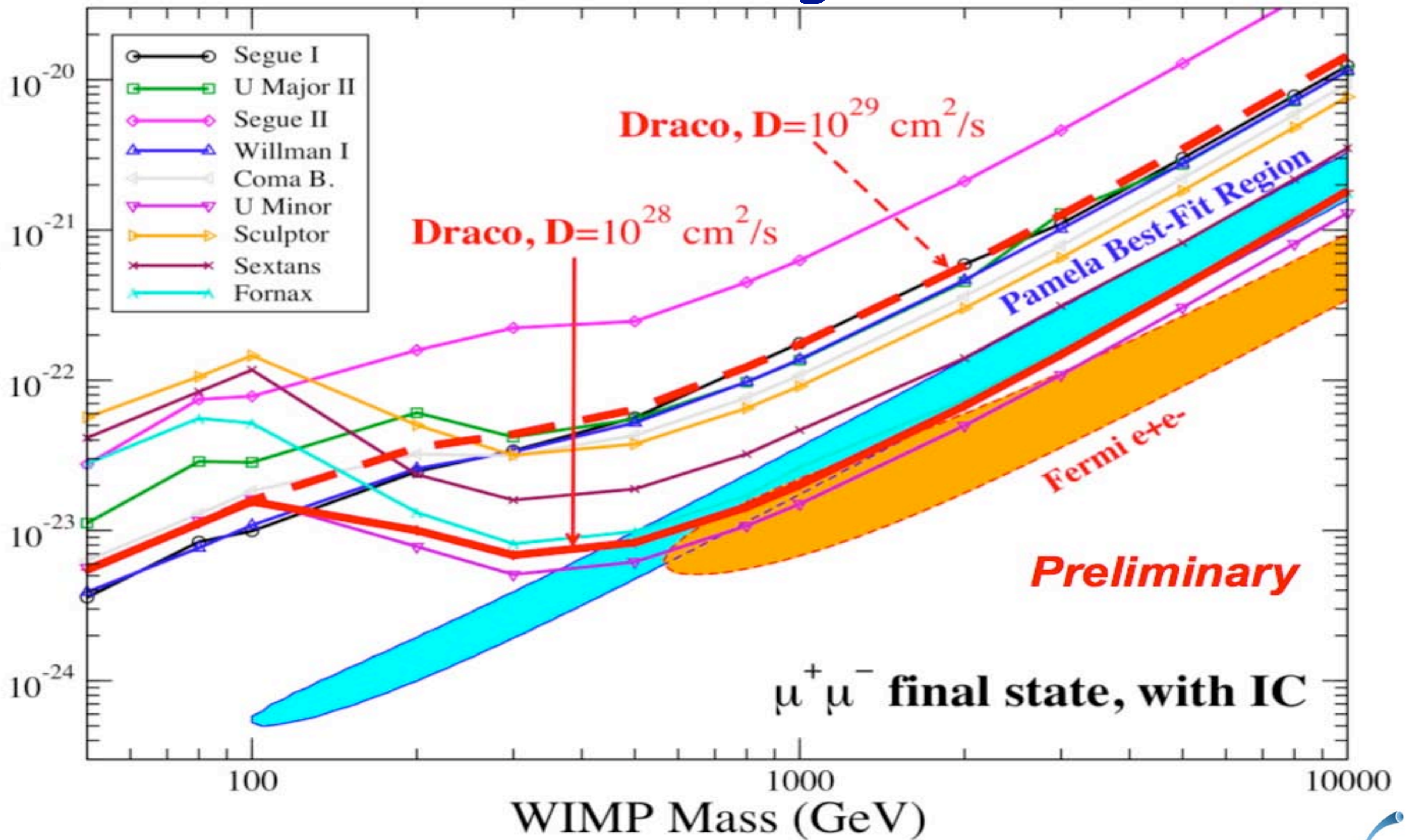
Inverse Compton Emission and Diffusion in Dwarfs

- We expect significant IC gamma-ray emission for high mass WIMP models annihilating to leptonic final states.
- The IC flux depends strongly on the uncertain/unknown diffusion of cosmic rays in dwarfs.
- We assume a simple diffusion model similar to what is found for the Milky Way

$D(E) = D_0\ E^{1/3}$ with $D_0 = 10^{28}\ cm^2/s$

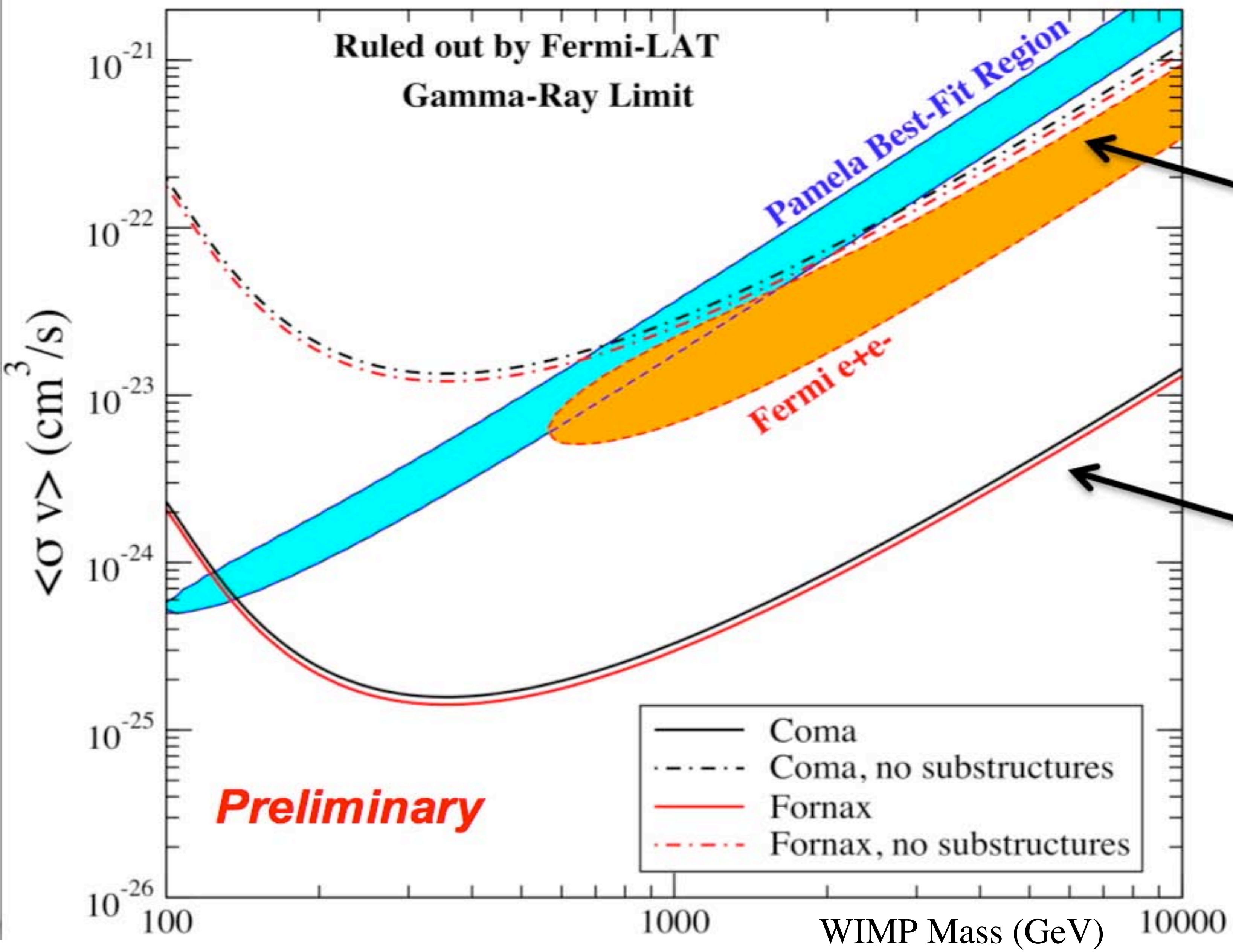
(only galaxy with measurements, scaling to dwarfs ??)

Constraints Including IC Emission



Combined constraints for Final State Radiation (FSR) plus IC with reference diffusion model $D_0 = 10^{28}$ cm^2/s

Cluster of Galaxies: muon antimuon final state

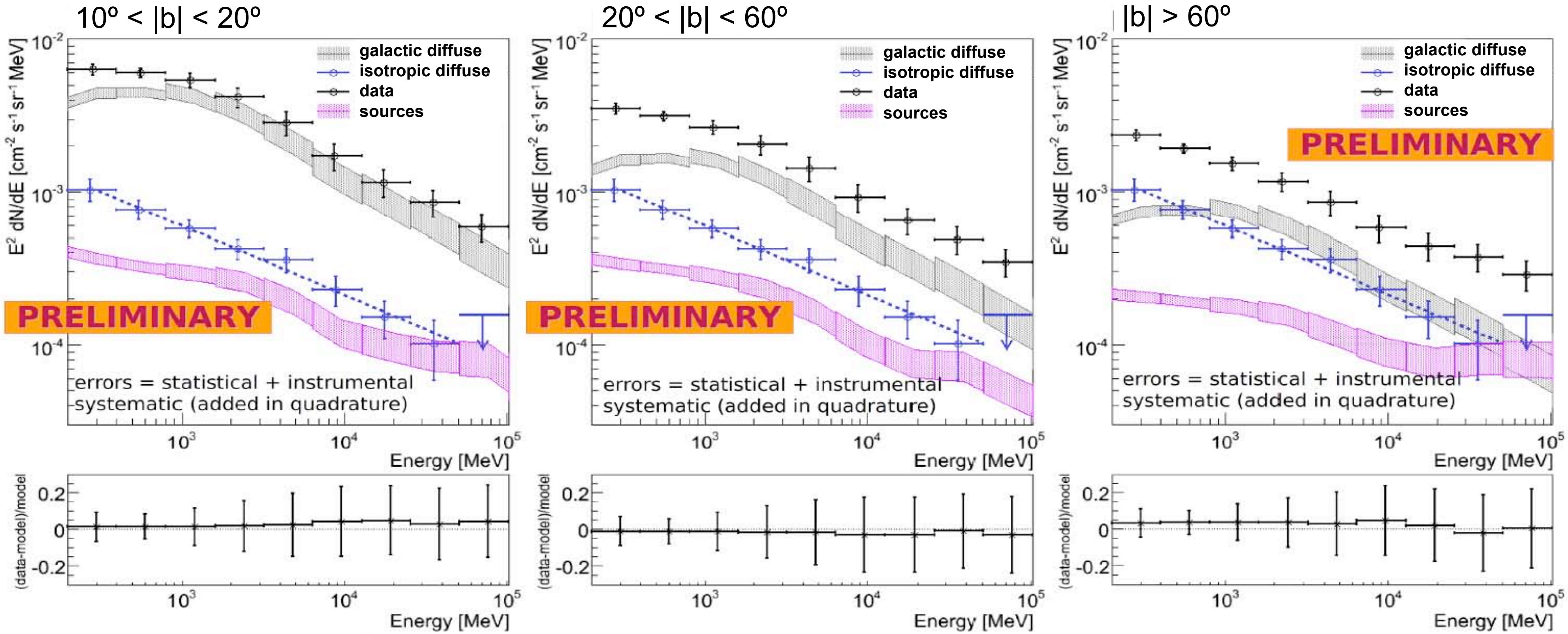


Fornax and Coma clusters: NFW, no substructure

50% of mass in substructure

Combined constraints for Final State Radiation (FSR) plus IC

The LAT isotropic diffuse flux (200 MeV – 100 GeV)



Low galactic latitudes | High galactic latitudes | Galactic poles

Galactic diffuse flux (from fit)

LAT data

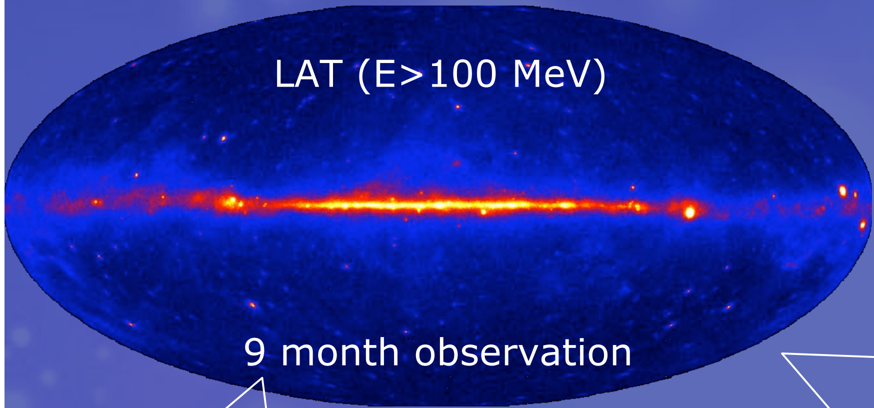
Total point source contribution (from fit)

Isotropic diffuse emission (isotropic component from fit, residual CR background subtracted)

Power law fit to isotropic diffuse emission with index $\gamma = 2.45$

error bars / bands:
statistical error + LAT effective area uncertainty + residual background contamination uncertainty

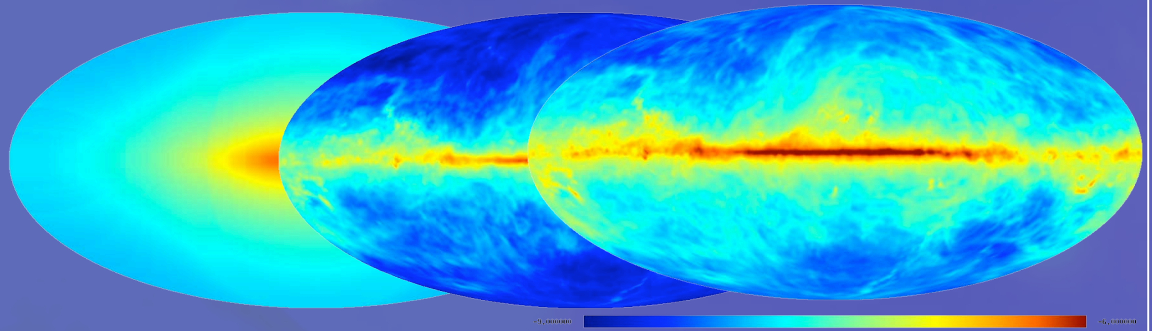
Main contributions to the Fermi gamma-ray sky



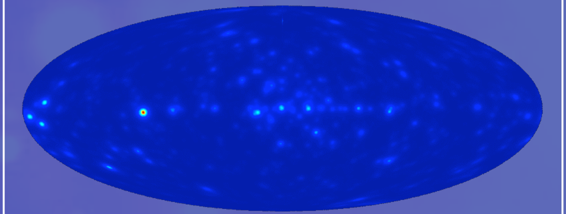
Galactic diffuse emission
(CR interactions with the interstellar medium)

Inverse Compton

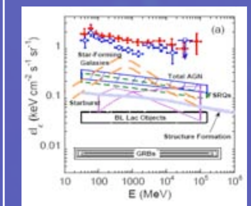
π^0-decay



Bremsstrahlung

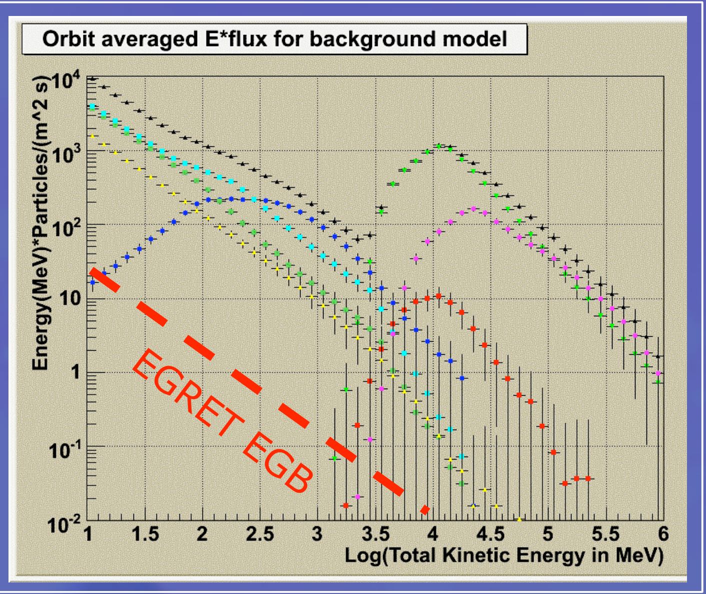


Resolved sources

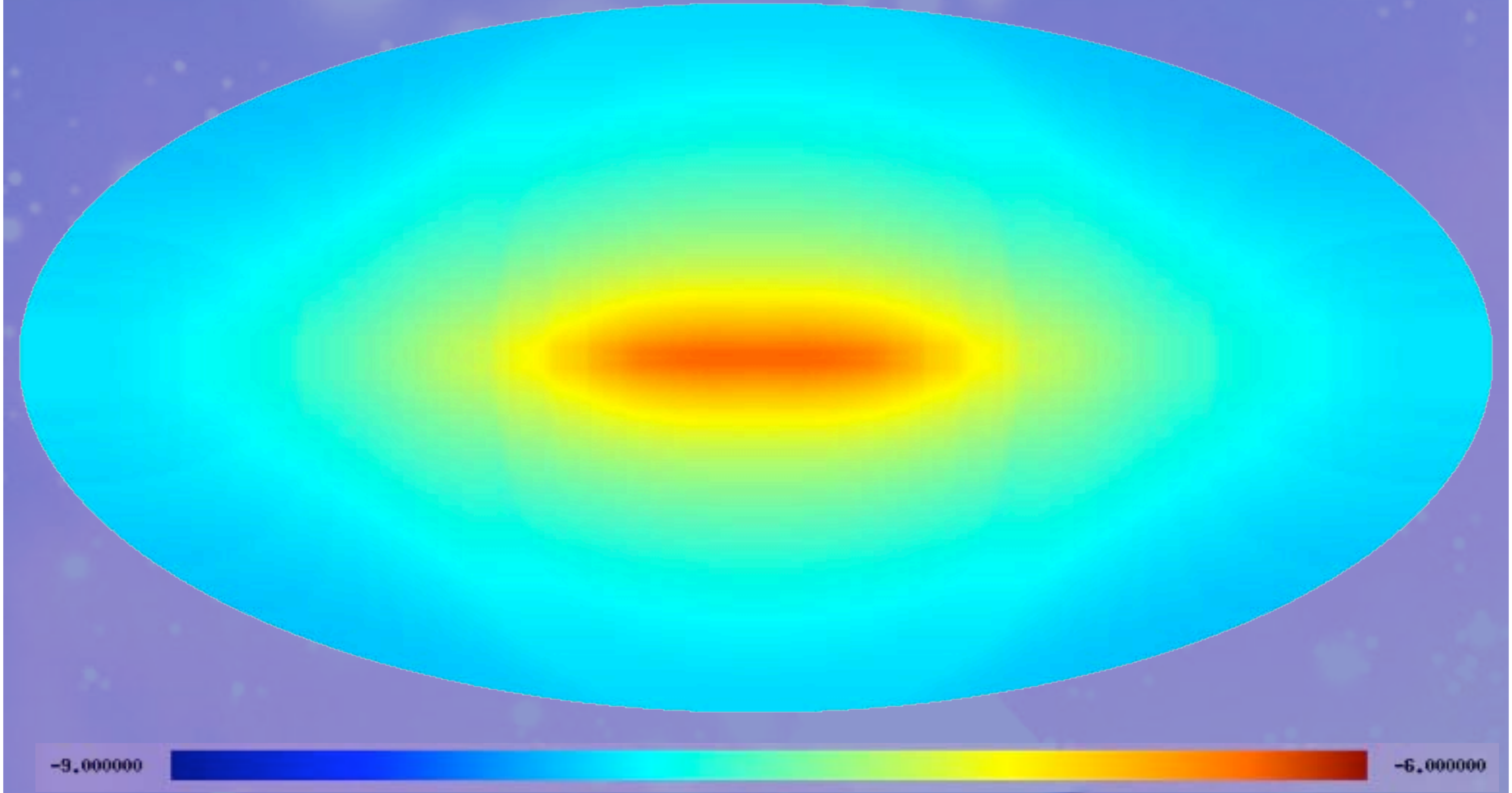


Isotropic diffuse emission

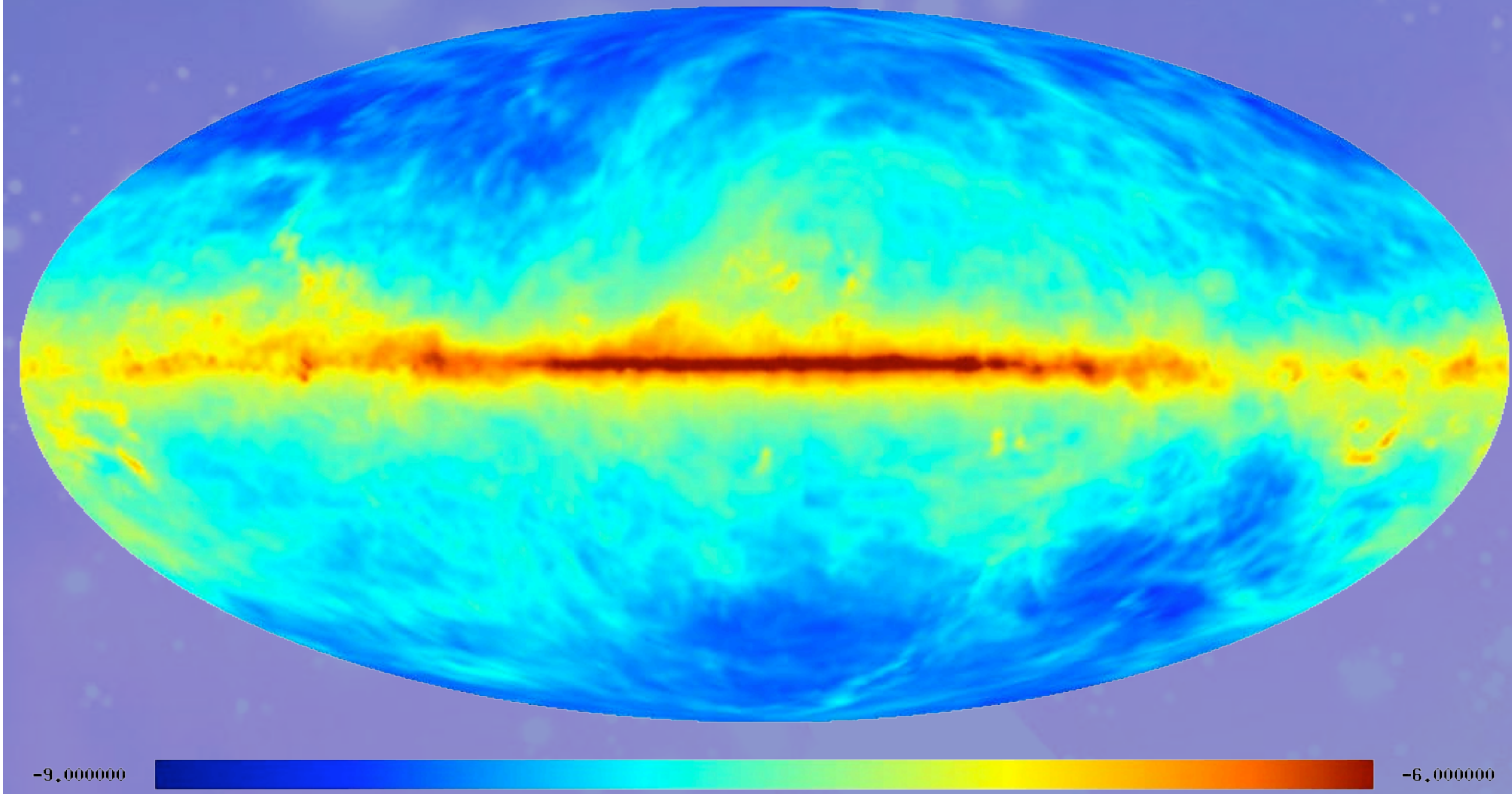
- Residual cosmic rays surviving background rejection filters
- misreconstructed γ -rays from the earth albedo



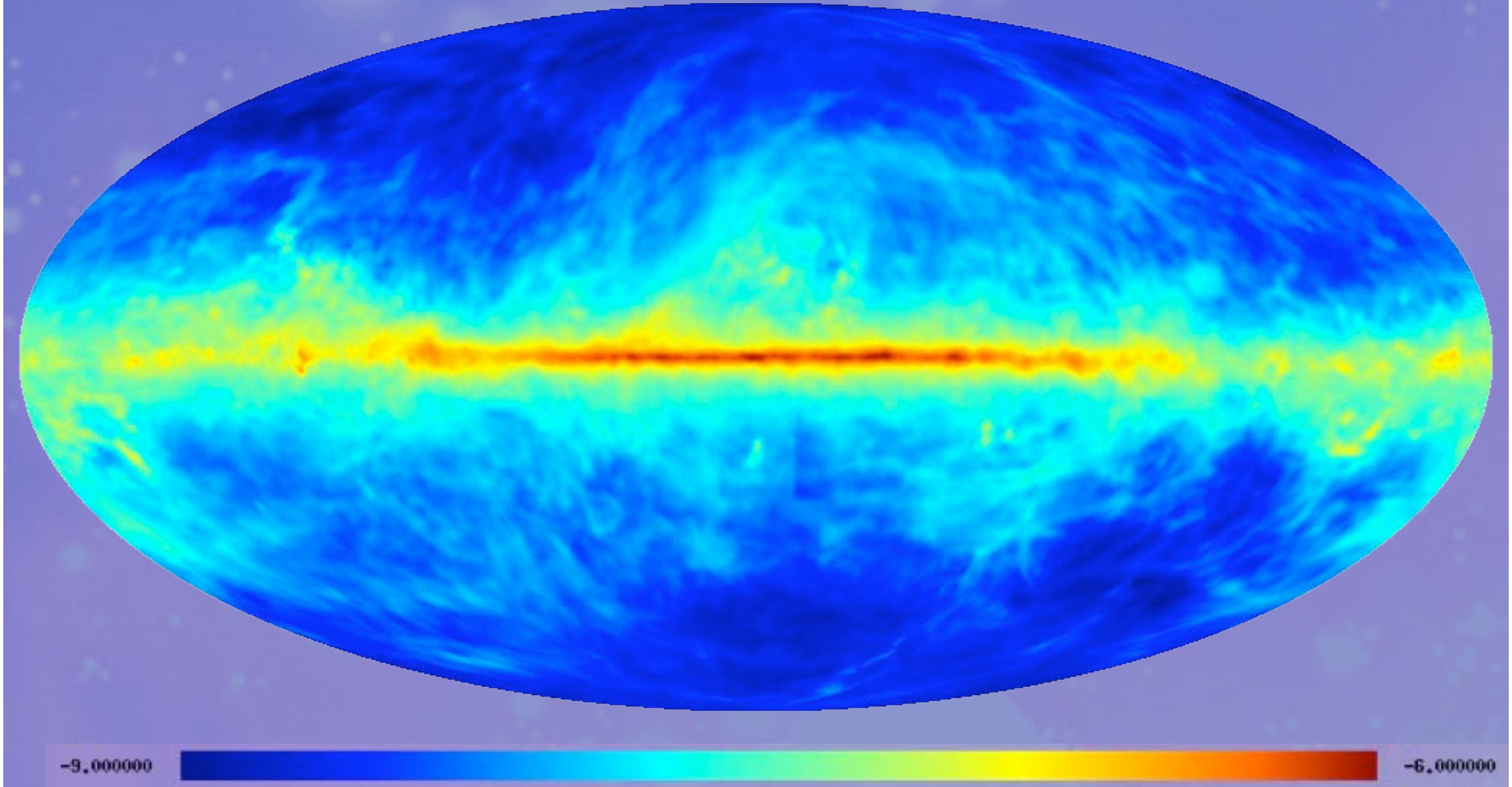
Inverse Compton



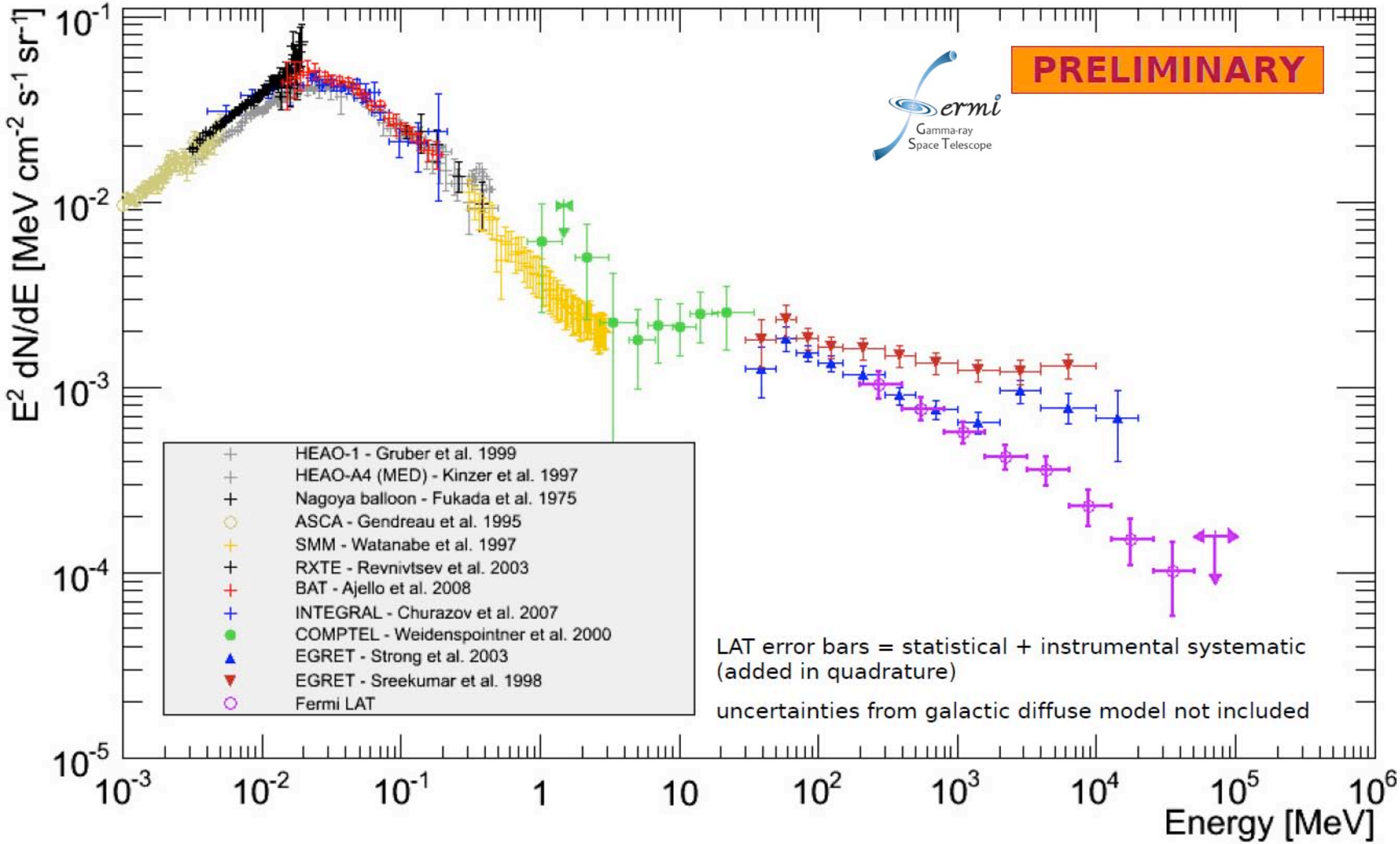
π^0-decay



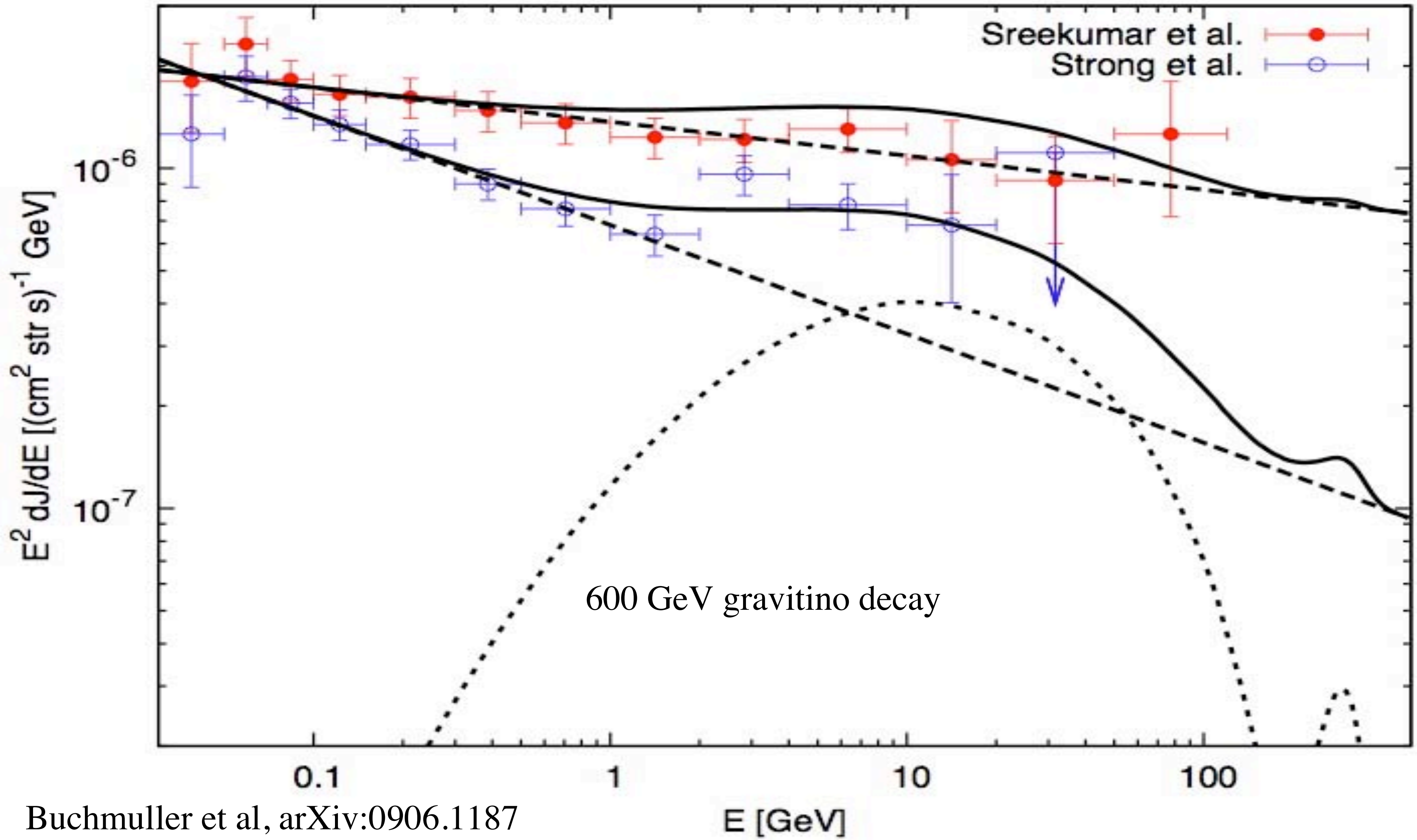
Bremsstrahlung



SED of the isotropic diffuse emission (1 keV–100 GeV)



extragalactic gamma-ray spectrum



Buchmuller et al, arXiv:0906.1187

25 of August: Fermi Data are public

We are pleased to announce that the LAT level-1 data products (photon event lists and associated auxiliary files needed for analysis) are now available for public download through the FSSC web site.

http://fermi.gsfc.nasa.gov/ssc

This data release contains information on individual LAT gamma-ray candidate events and will allow detailed studies of the temporal,spatial and spectral behavior of high energy gamma-ray sources. The current analysis software release can also be obtained from the FSSC web site (follow the "data analysis" link).

http://fermi.gsfc.nasa.gov/ssc/data/

New Data is Forthcoming

Electron Spectrum:

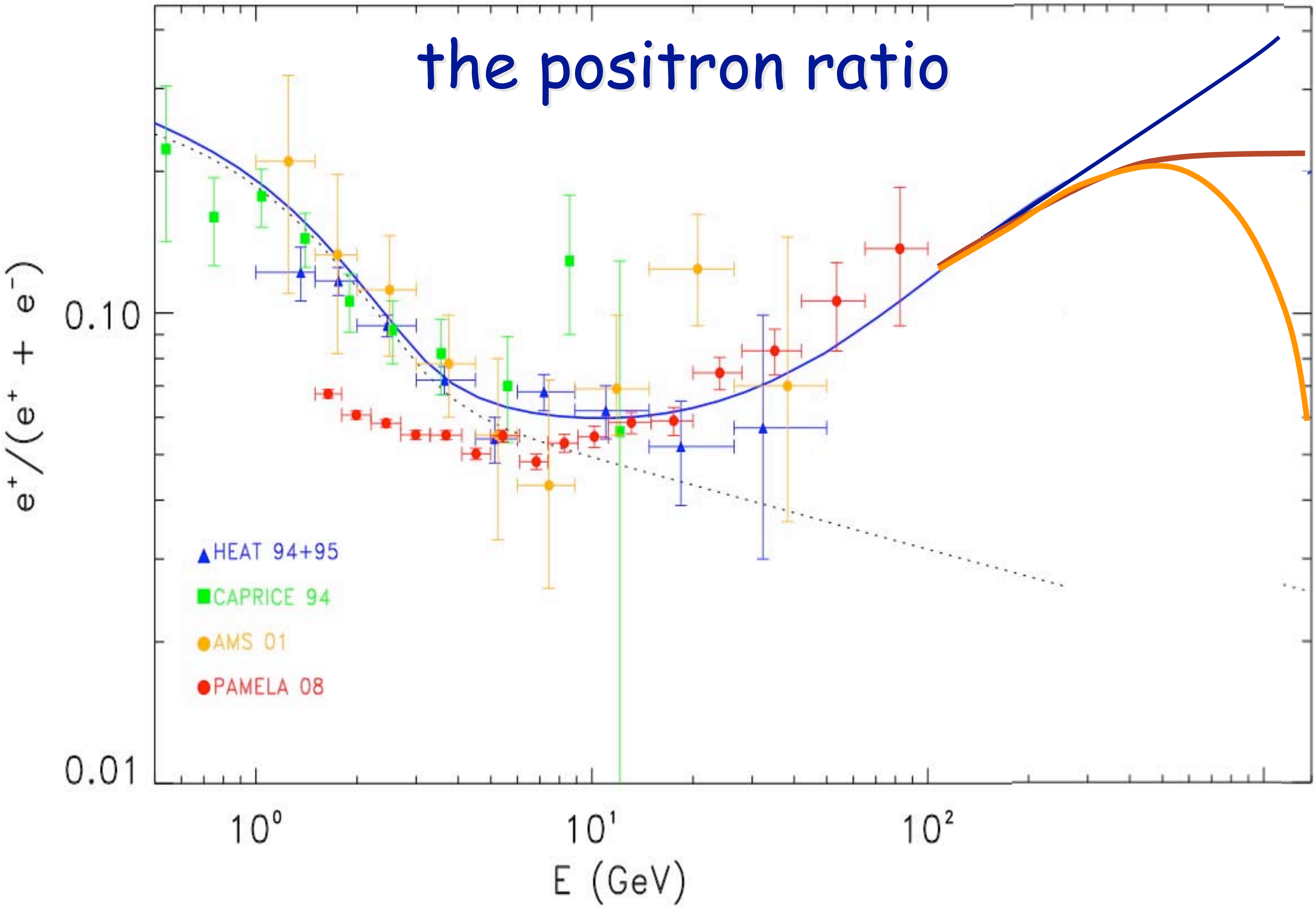
- **PAMELA & FERMI (GLAST)** (taking data in space);
- **ATIC-4** (had successful balloon flight,under analysis);
- **CREST** (new balloon payload under development);
- **AMS-02** (launch date TBD);
- **CALET** (proposed for ISS);
- **ECAL** (proposed balloon experiment).

Comparison of High-Energy Electron Missions

Mission	Upper Energy (TeV)	Collecting Power (m^2sr)	Calorimeter Thickness (X_0)	Energy Resolution (%)
CALET	20	0.75	30.8	< 3 (over 100 GeV)
PAMELA	0.25 (spectrometer) 2 (calorimeter)	0.0022 0.04	16.3	5.5 (300 GeV) 12 (300 GeV) 16 (1TeV)
GLAST	0.7	2.1 (100 GeV) 0.7 (700 GeV)	8.3	6 (100 GeV) 16 (700 GeV)
AMS-02	0.66 (spectrometer) 1 (calorimeter)	0.5 0.06 (100 GeV) < 0.04 (1 TeV)	16.0	< 3 (over 100 GeV)

Positron / Electron Separation: **PAMELA & AMS-02**

the positron ratio



Conclusion:

The CRE spectrum measured by Fermi-LAT is significantly harder than previously thought on the basis of previous data

Adopting the presence of an extra $e^{\pm}$ primary component with ~ 2.4 spectral index and E_{cut} ~ 1 TeV allow to consistently interpret Fermi-LAT CRE data (improving the fit), HESS and PAMELA

Such extra-component can be originated by pulsars for a reasonable choice of relevant parameters

- or by annihilating dark matter for model with $M_{DM} \approx 1$ TeV

- Improved analysis and complementary observations

- (CRE **anisotropy**, spectrum and angular distribution of diffuse γ, DM sources search in γ) are required to possibly discriminate the right scenario.

In September 2009 Fermi data will be open to the community

You are all invited to join !

thank you for the attention !


11 June 2008

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