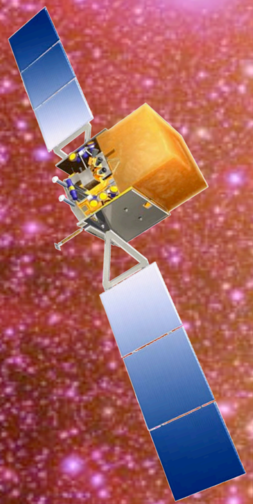
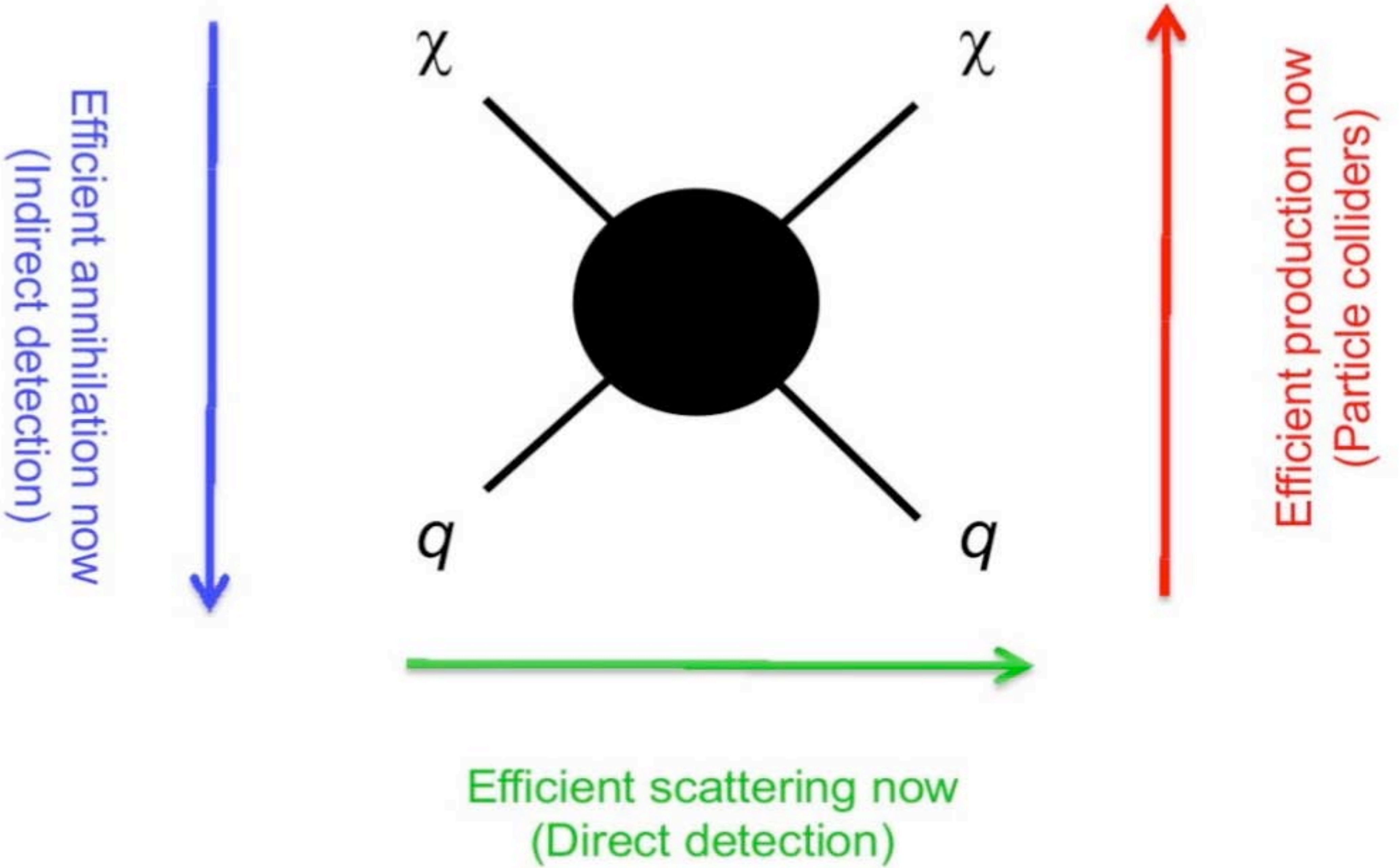
Search for Dark Matter in the Fermi and PAMELA era



Aldo Morselli
INFN Roma Tor Vergata

Mini Workshop on Dark Matter
UAM Madrid, 17 /09/ 2009

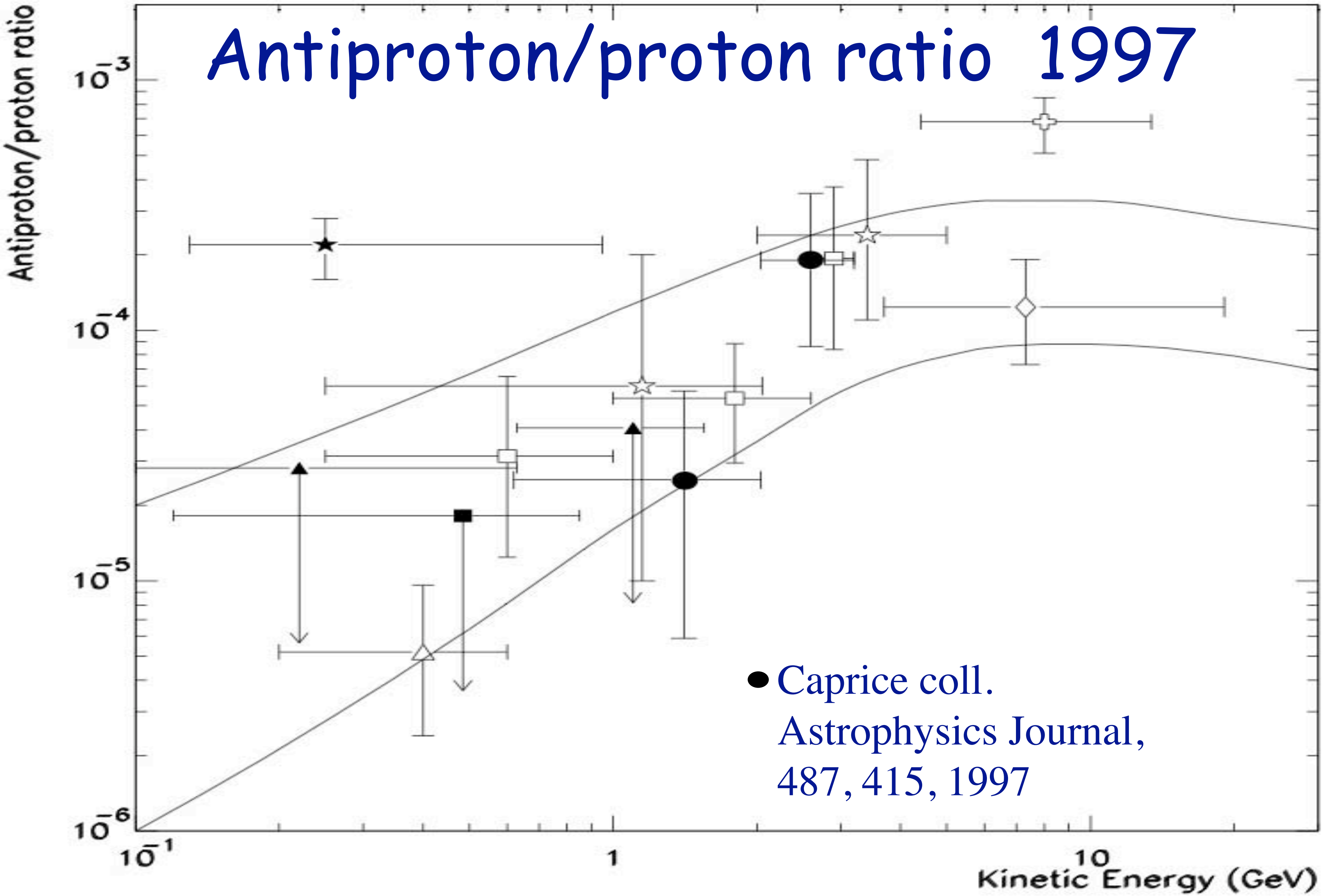

Efficient annihilation now
(Indirect detection)
χ
χ
q
q
Efficient production now
(Particle colliders)
Efficient scattering now
(Direct detection)

Neutralino WIMPs

Assume χ present in the galactic halo

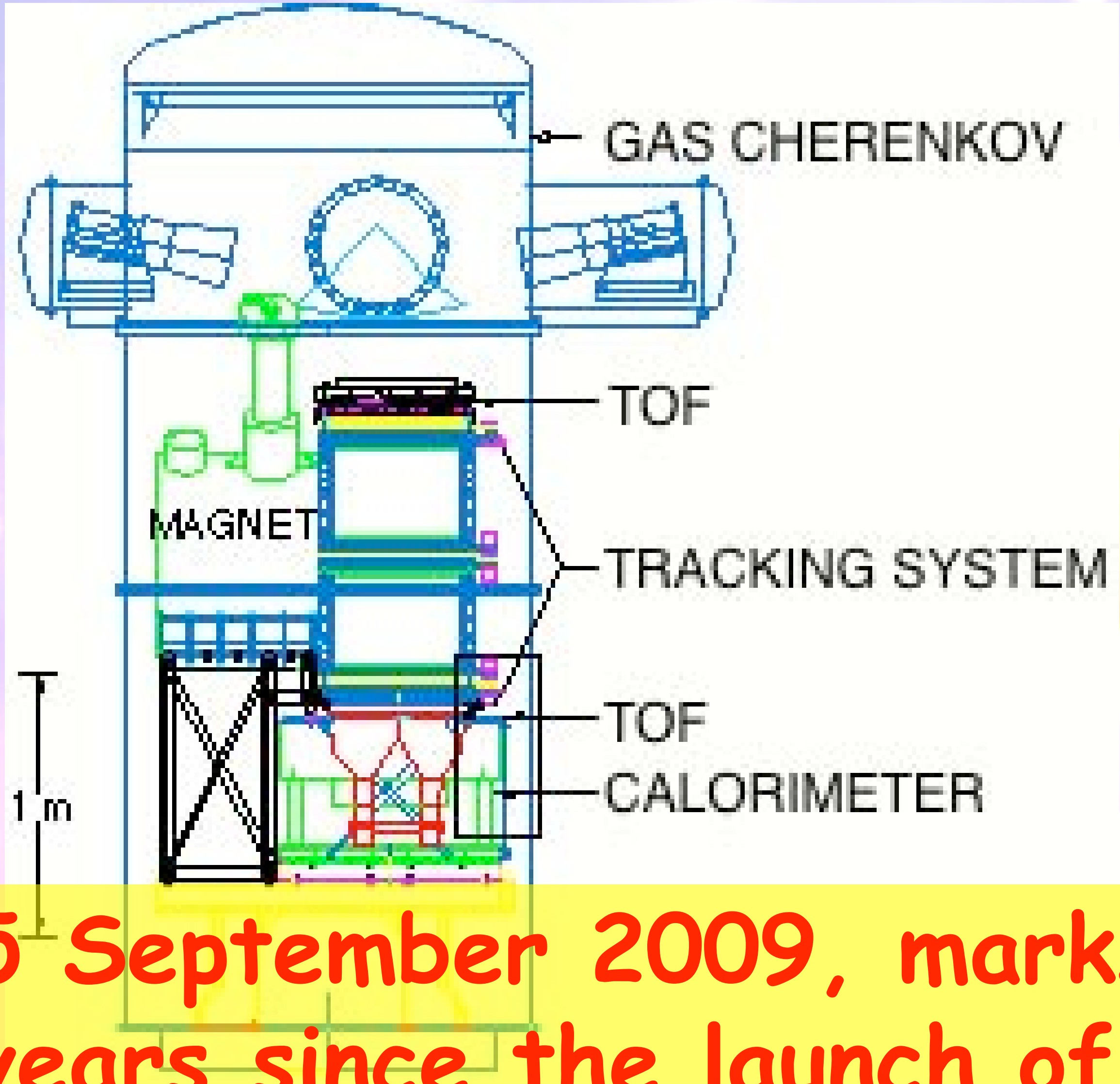
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) 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



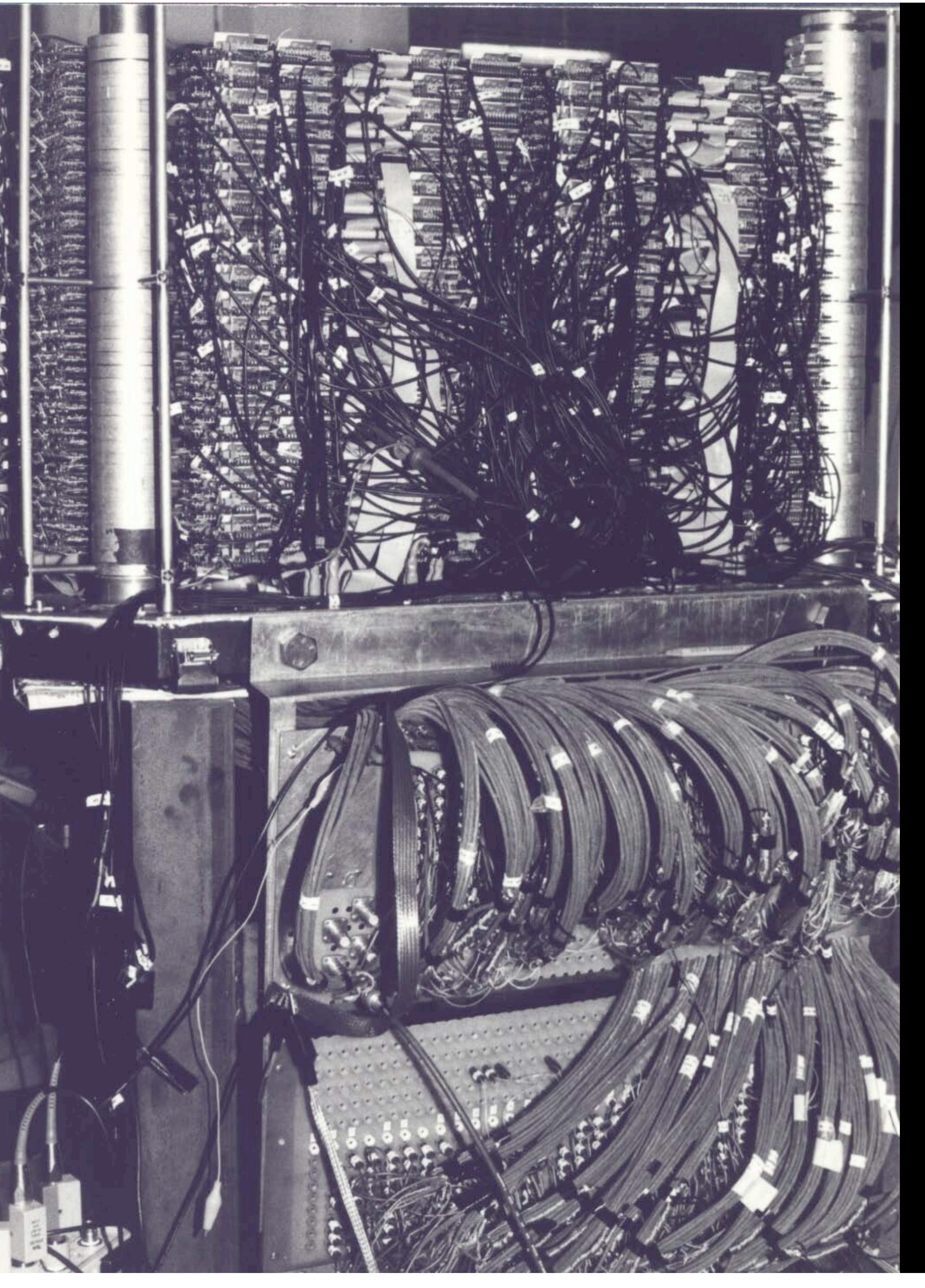
● Caprice coll. Astrophysics Journal, 487, 415, 1997

MASS Matter Antimatter Space Spectrometer

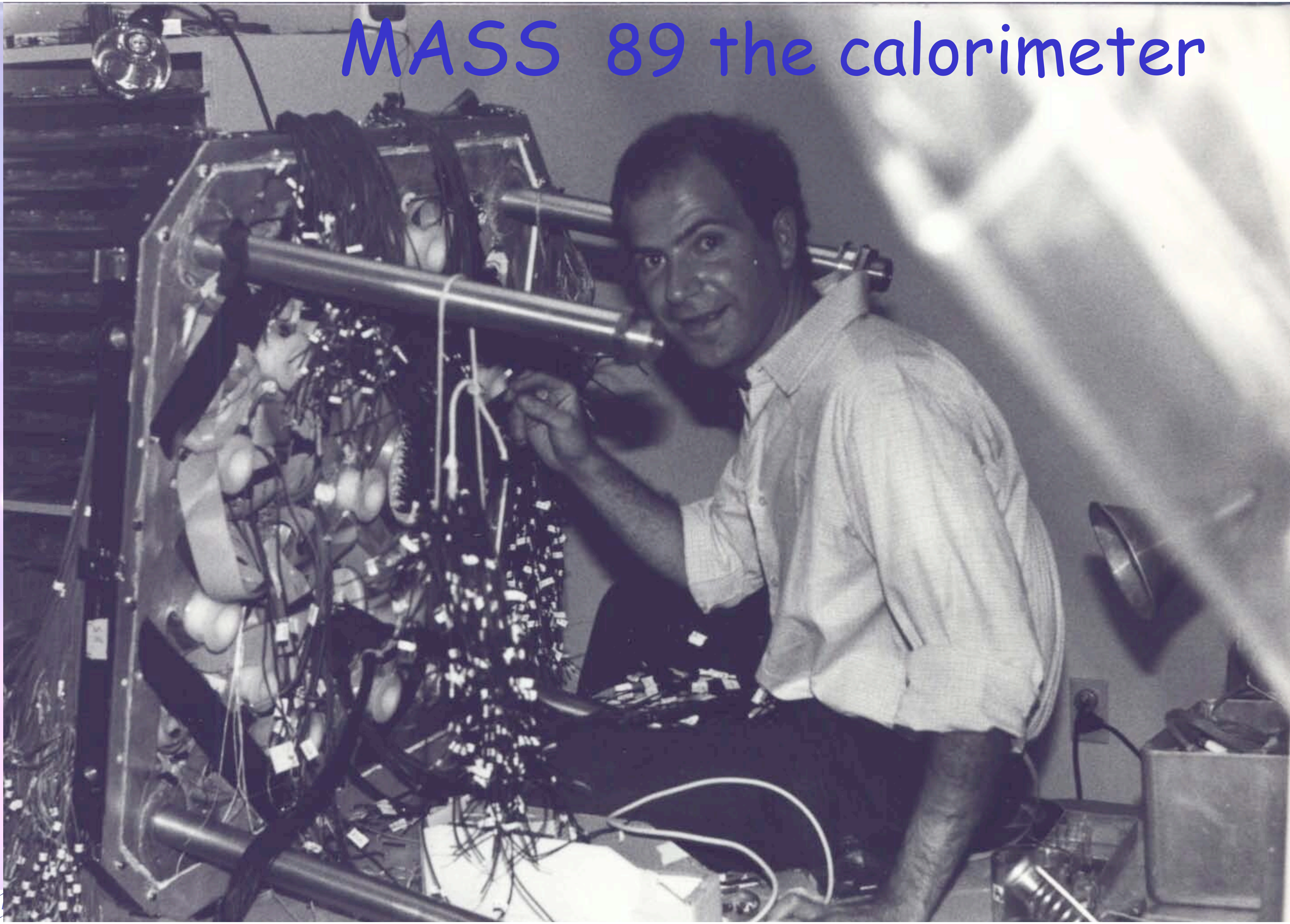


5 September 2009, marks twenty (!) years since the launch of MASS 89 !!!

the MASS89 Calorimeter



MASS 89 the calorimeter



from Las Cruces to Prince Albert


HOLD

MASS 89 flight


MASS 89 flight


MASS 89

PAMELA

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

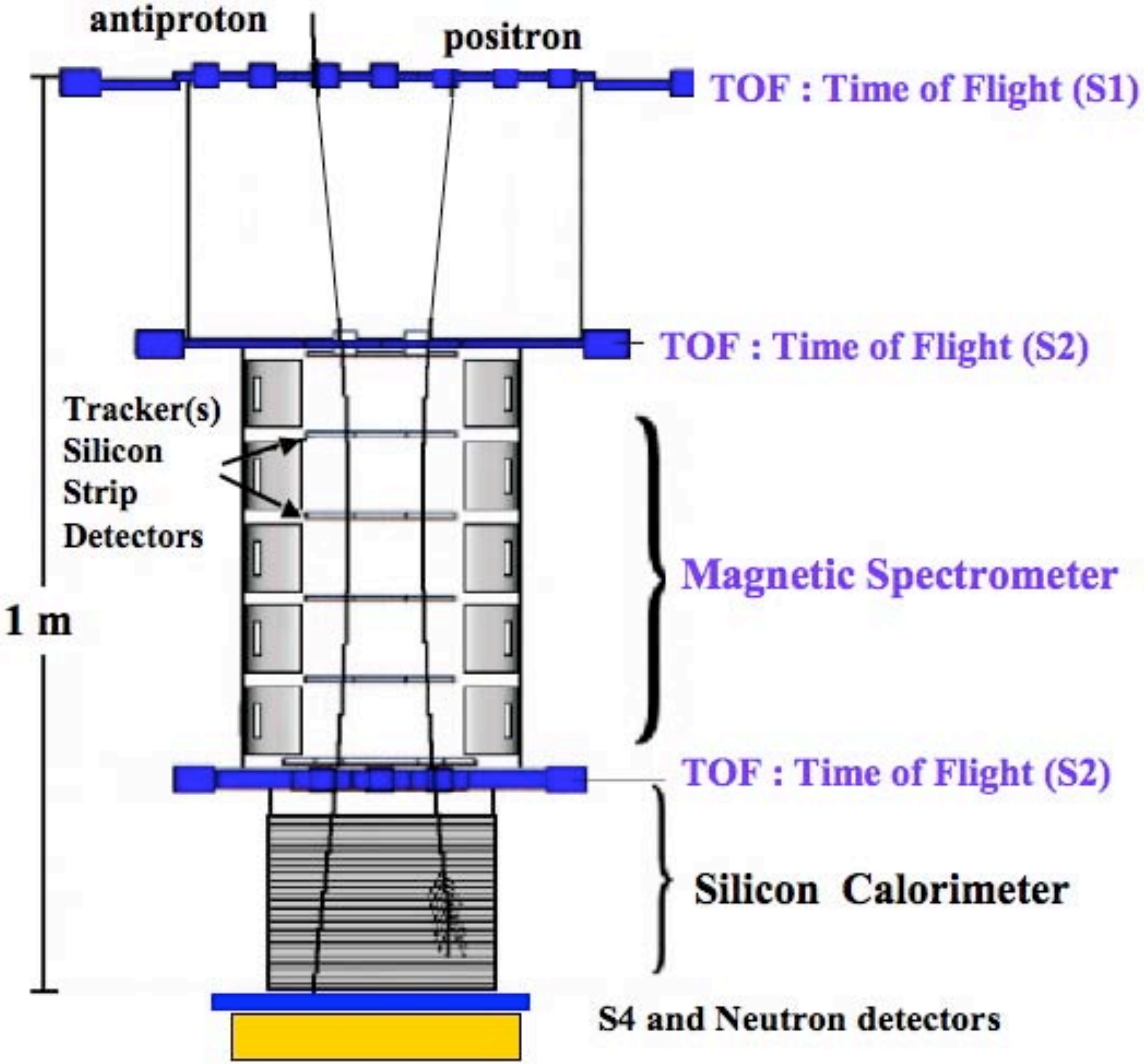
In orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

First switch-on on June 21 2006

From July 11 Pamela is in continuous data taking mode

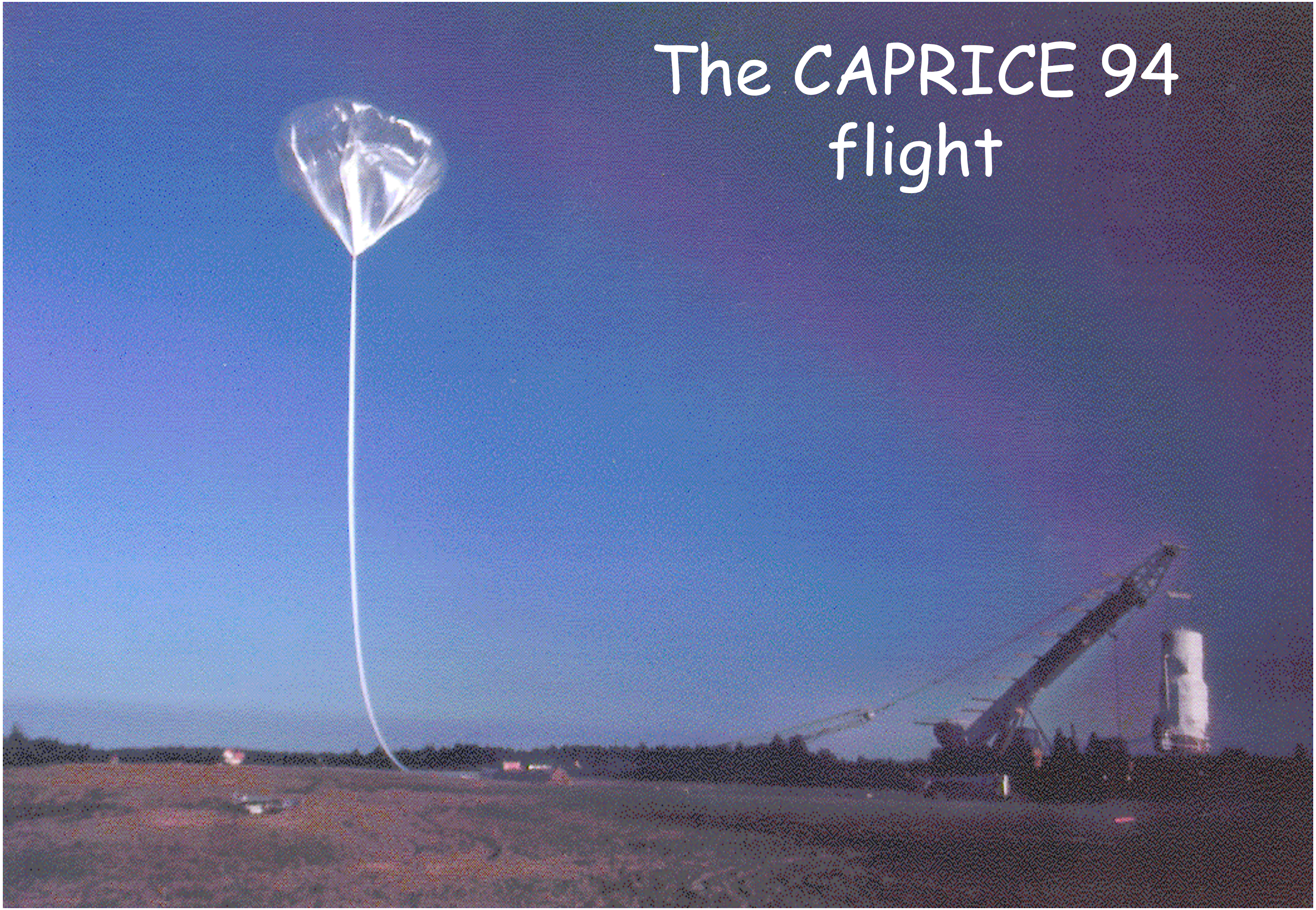
Pamela

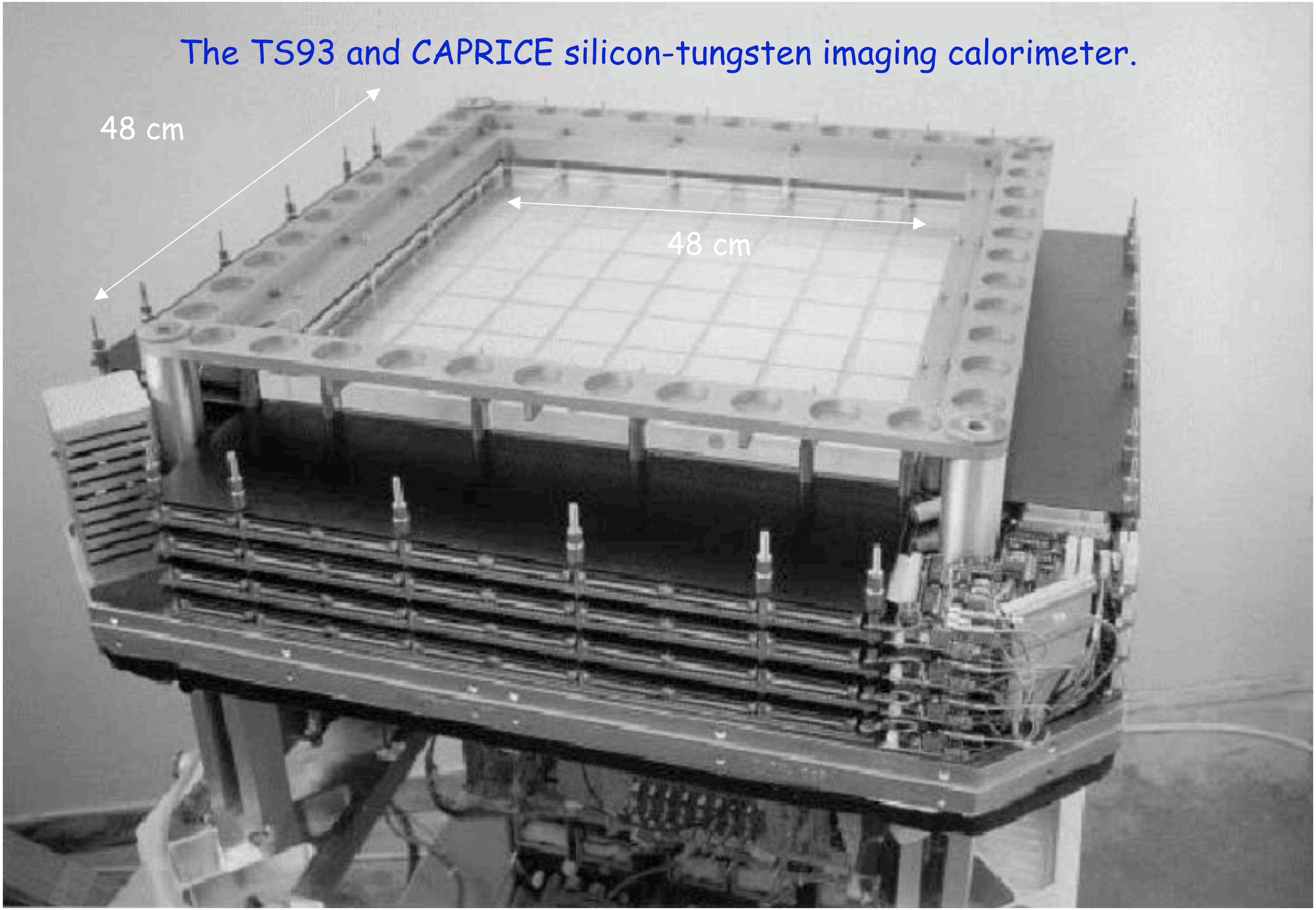
Separating p from e$^-$



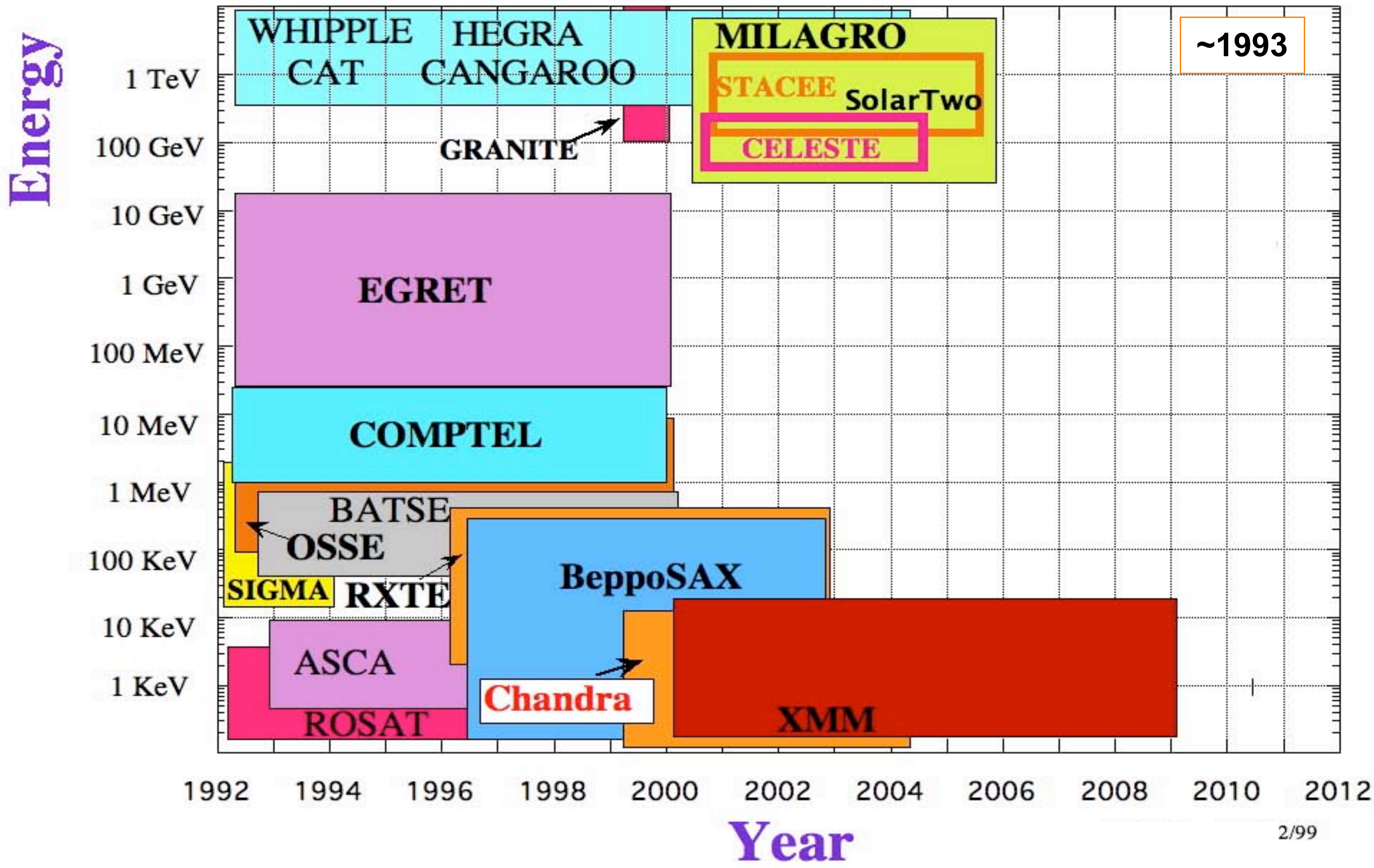
- ~ 3 years from PAMELA launch

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


The CAPRICE 94
flight


The TS93 and CAPRICE silicon-tungsten imaging calorimeter.
48 cm
48 cm

High Energy Gamma Experiments Experiments



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

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

ELSEVIER

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]

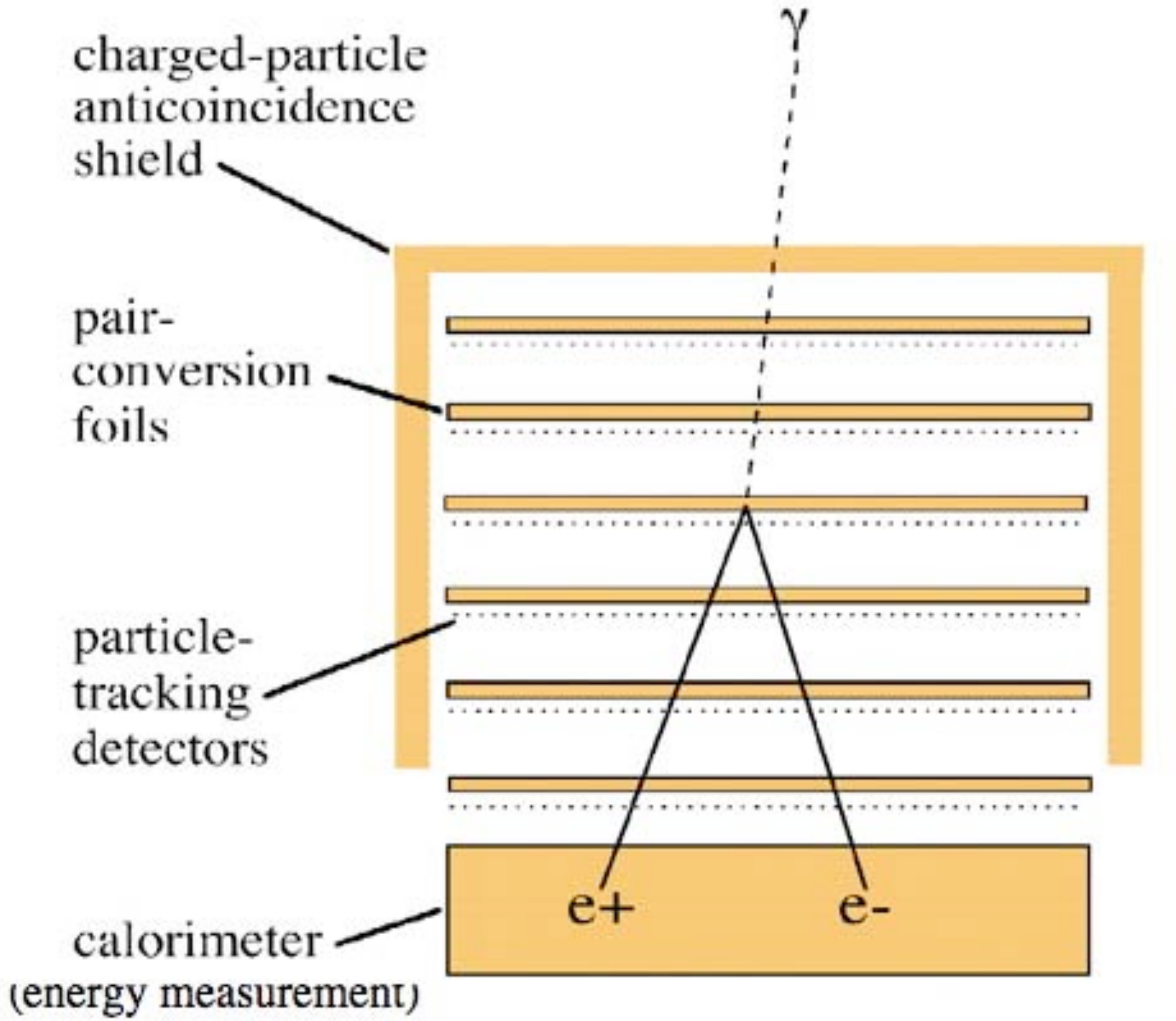
[a] *Dept. of Physics, Univ. of Trieste and INFN, Italy*
[b] *Dept. of Physics, II Univ. of Rome "Tor Vergata" and INFN, Italy*
[c] *Dept. of Physics, Univ. of Firenze and INFN, Italy*
[d] *INFN Laboratori Nazionali di Frascati, Italy*

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.

Elements of a pair-conversion telescope

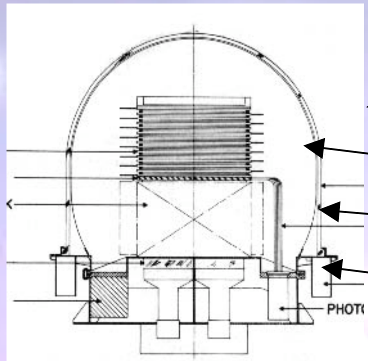


- photons materialize into matter-antimatter pairs:

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

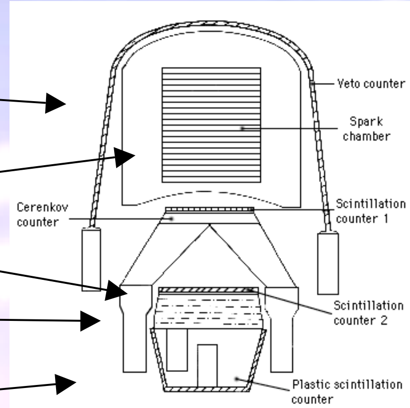
- electron and positron carry information about the direction, energy and polarization of the γ-ray

The gamma-ray missions

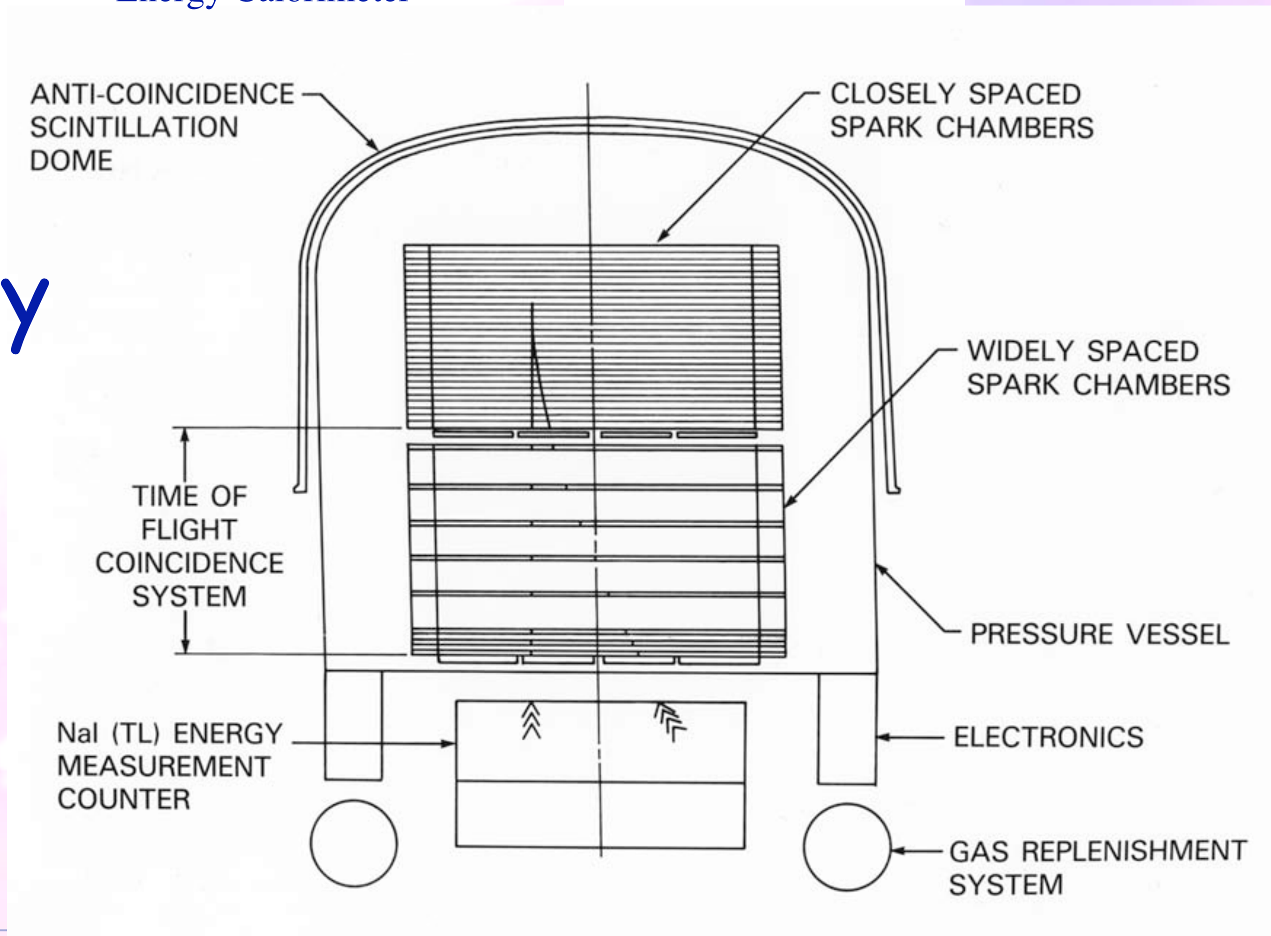


SAS-2
11/1972-7/1973

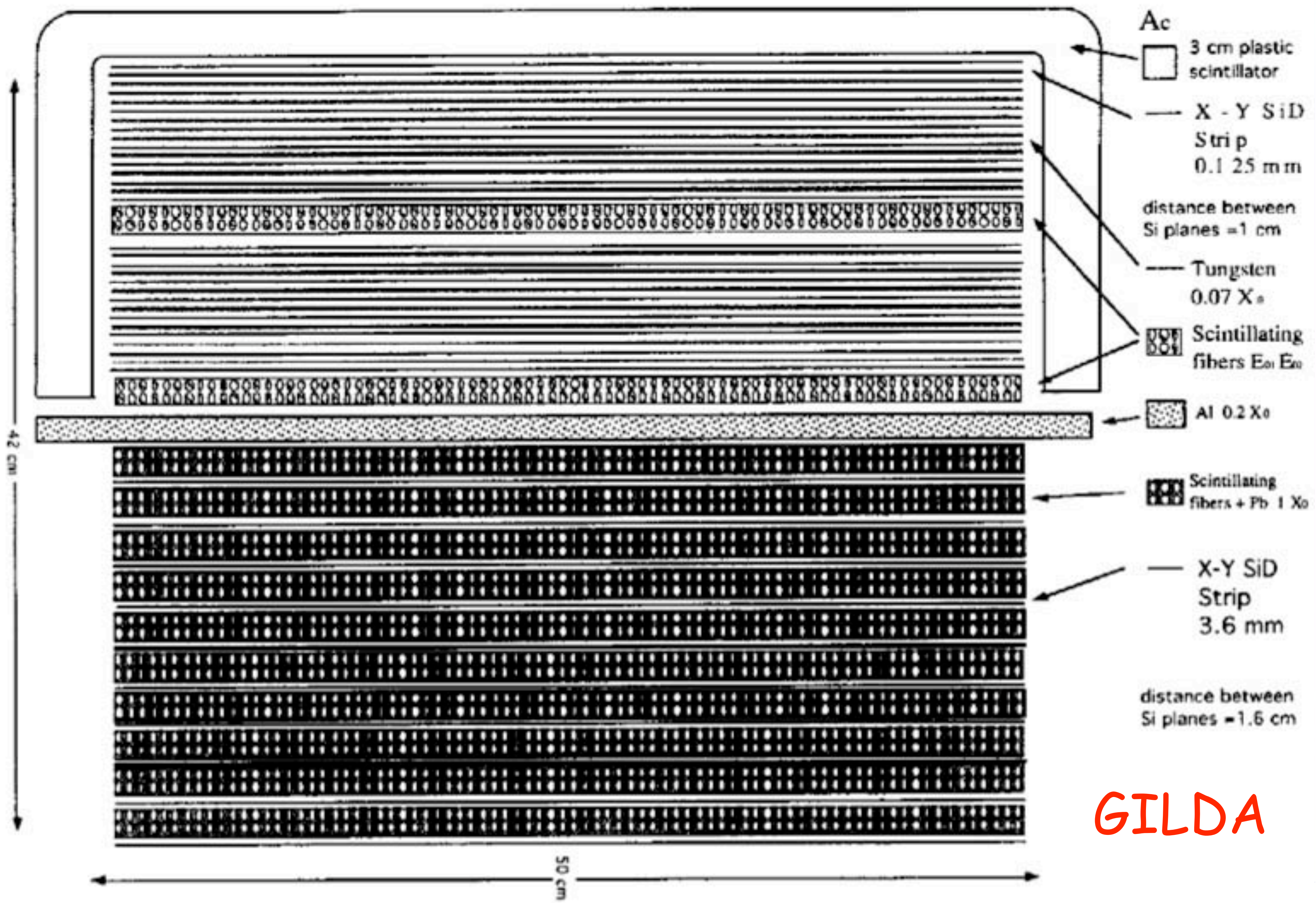
Anti-Coincidence Dome
Spark Chamber
Trigger Telescope
Cerenkov Counter
Energy Calorimeter



Cos-B
8/1975-4/1982

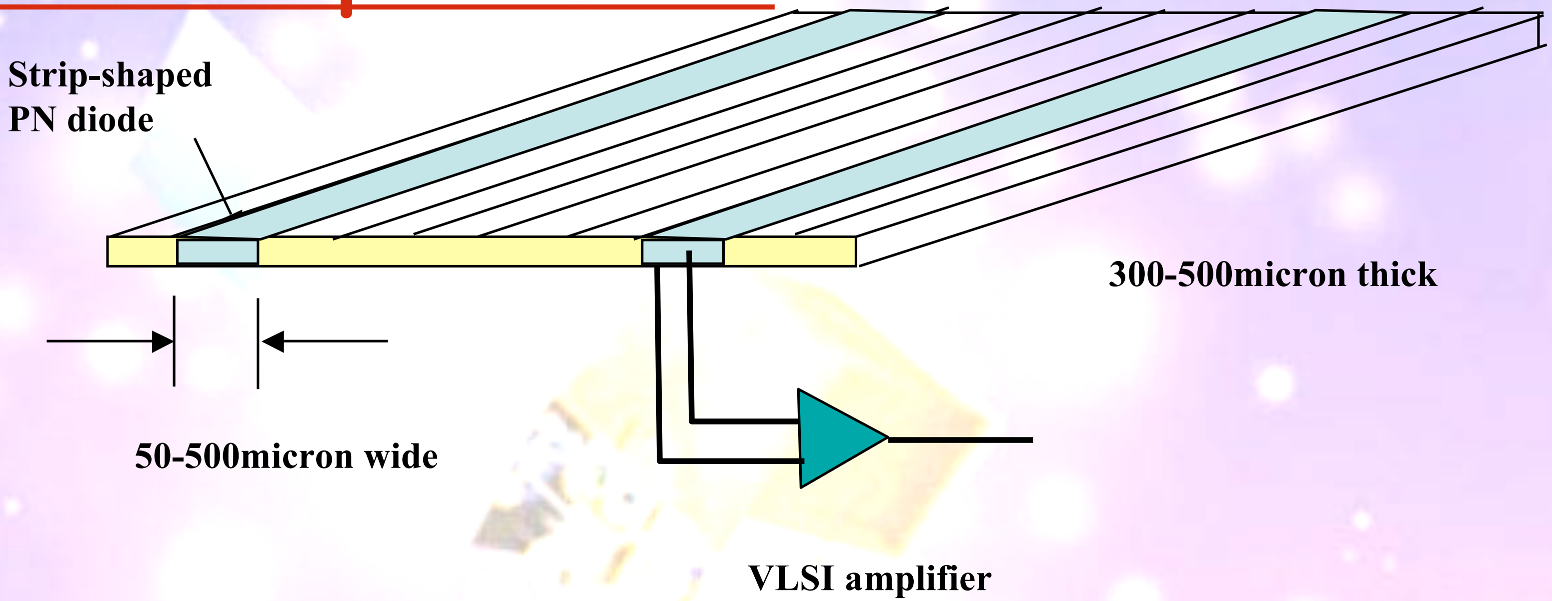


EGRET
4/1991-1999


Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
distance between Si planes =1 cm
Tungsten 0.07 X₀
Scintillating fibers
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

New Detector Technology

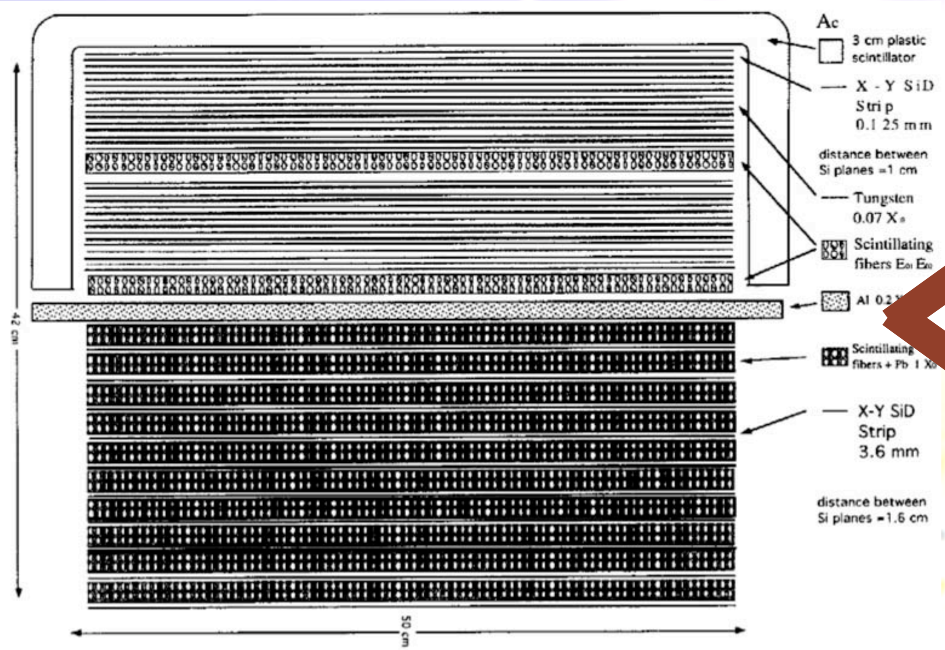
- **Silicon strip detector**



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)

GILDA


Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
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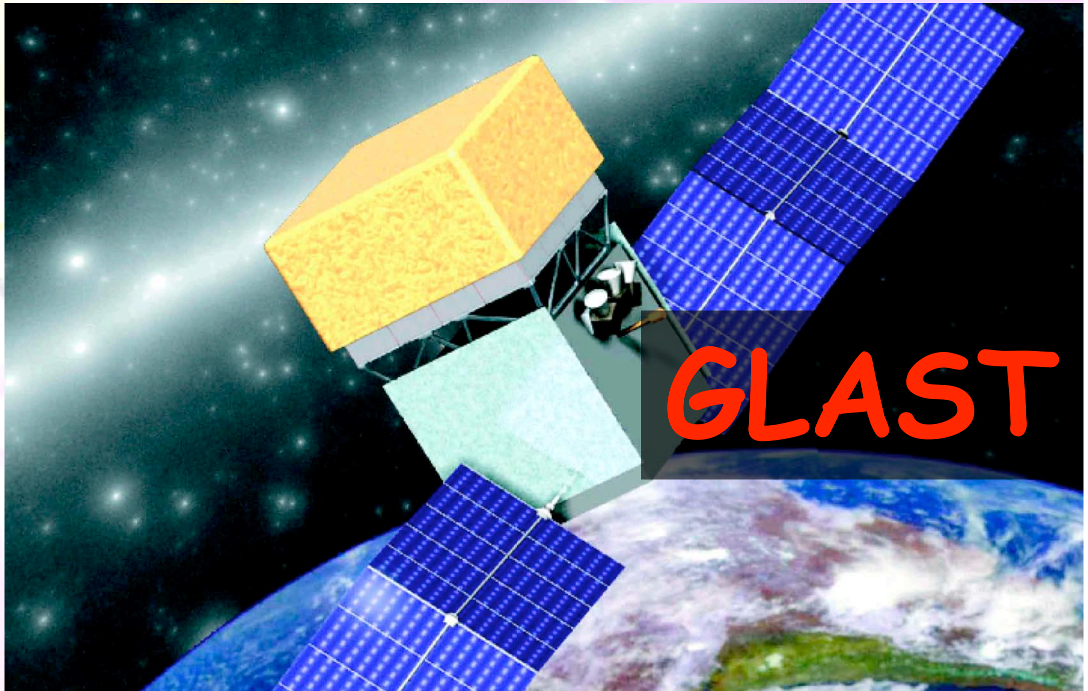
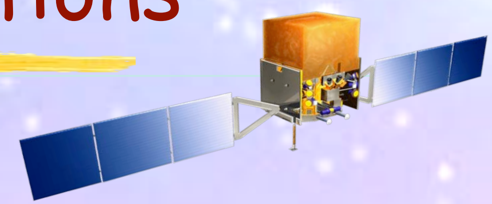
Tungsten 0.07 X₀
Scintillating fibers
Al
Scintillating fibers + Pb
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm


agile
Astro-rivelatore Gamma
a Immagini Leggero
INAF
INFN
Alenia
telespazio


GLAST

The GLAST 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

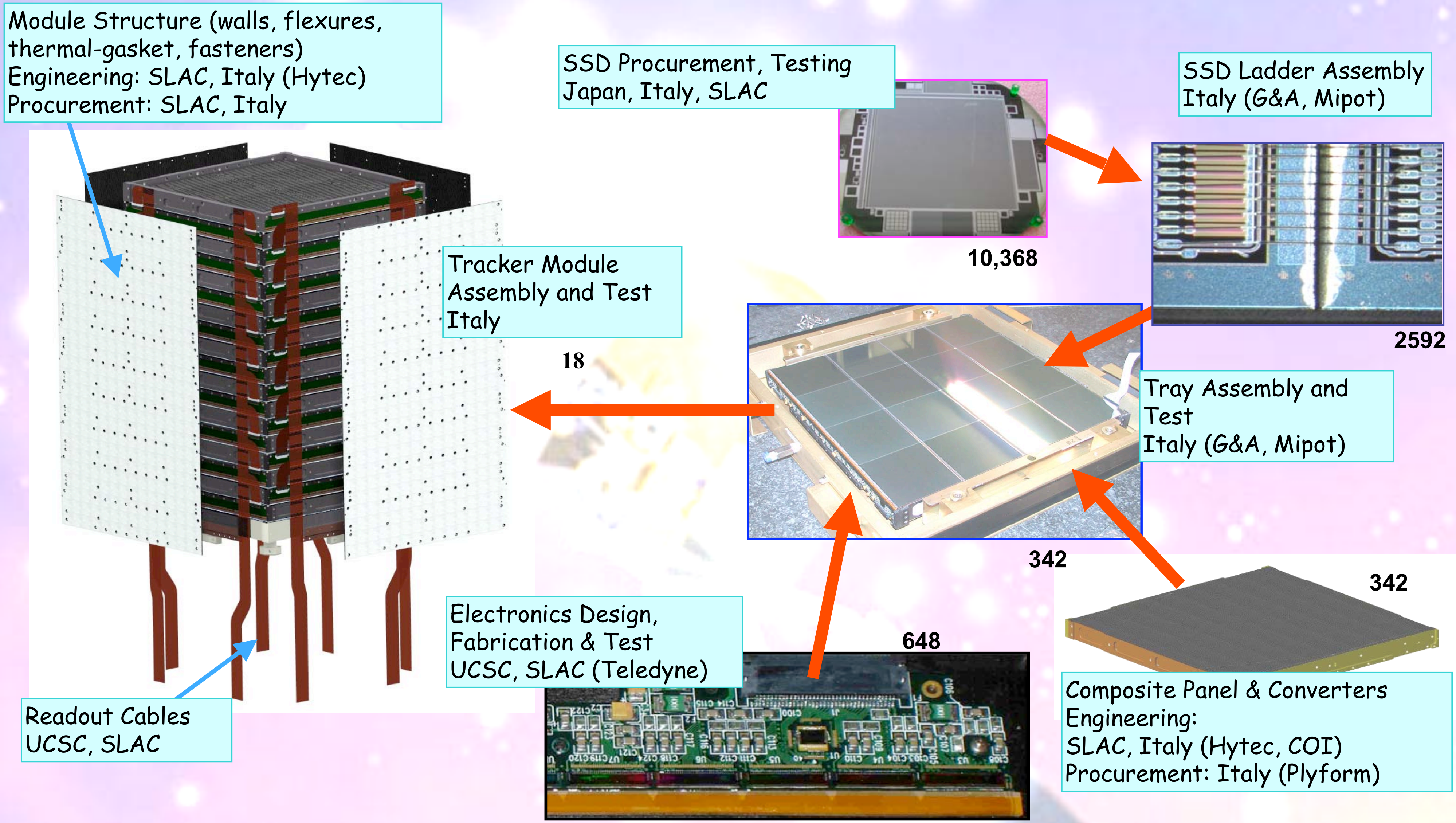
CEA/DAPNIA Commissariat à l'Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nucliaire et de l'Instrumentation Associée, CEA, Saclay
IN2P3 Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
IN2P3/LPNHE-X Laboratoire de Physique Nucléaire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

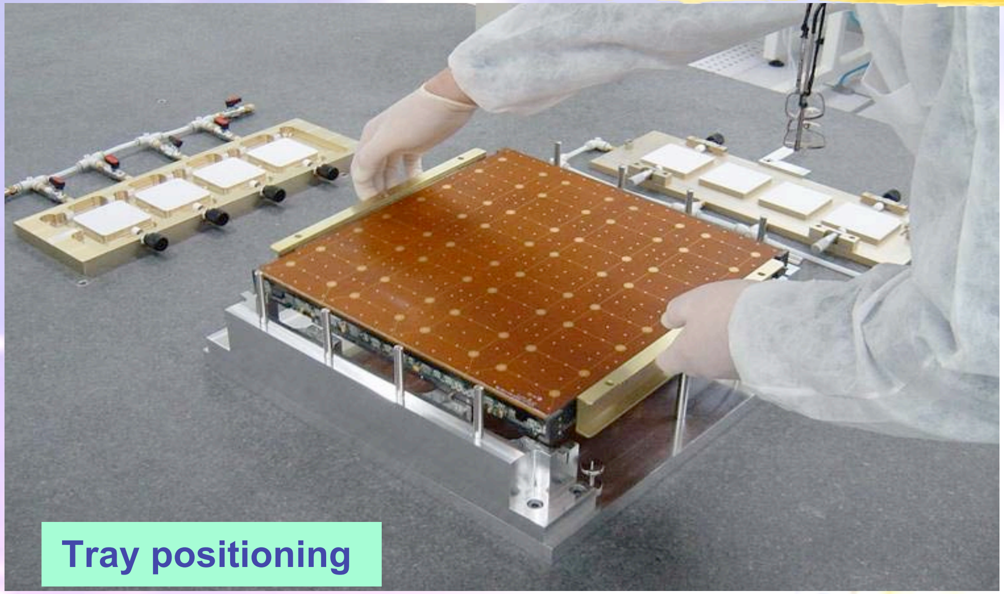
KTH Royal Institute of Technology
Stockholms Universitet

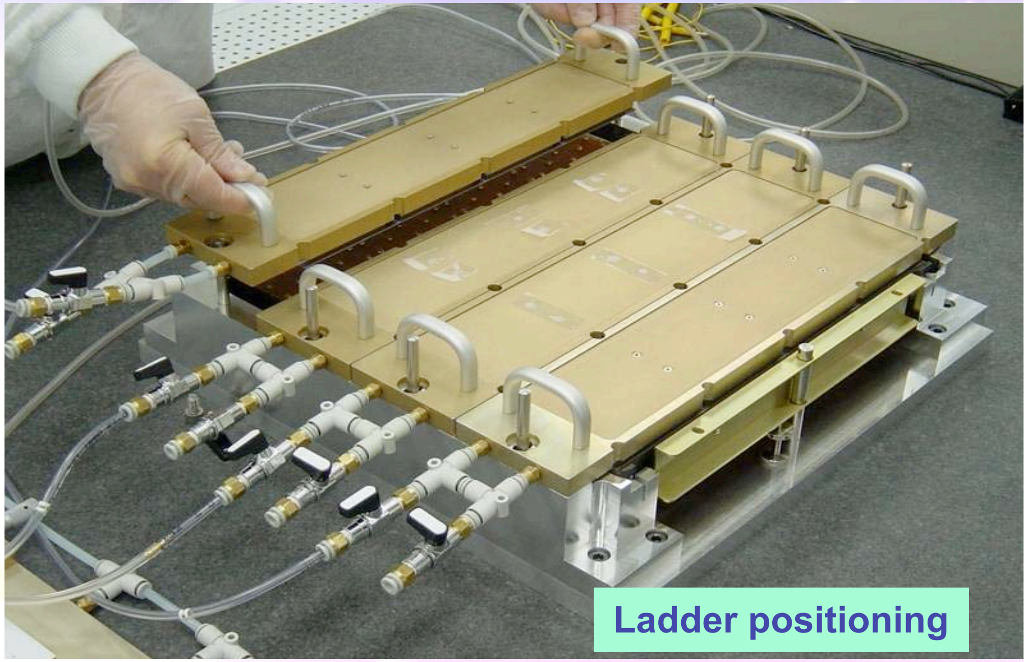
Collaboration members:	**~390**
Members:	**121**
Affiliated Scientists	~96
Postdocs:	68
Graduate Students	105

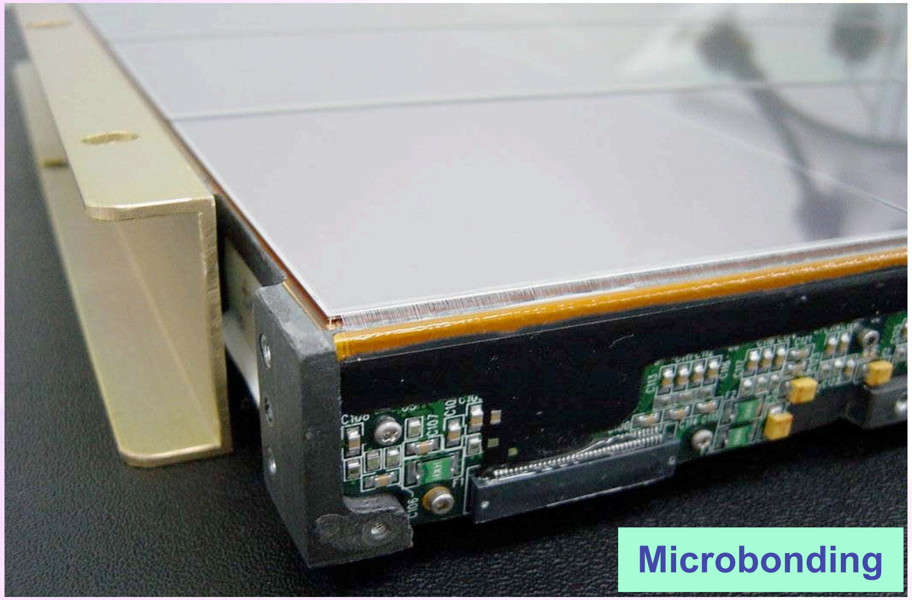
Tracker Production Overview



Tray assembly in G&A

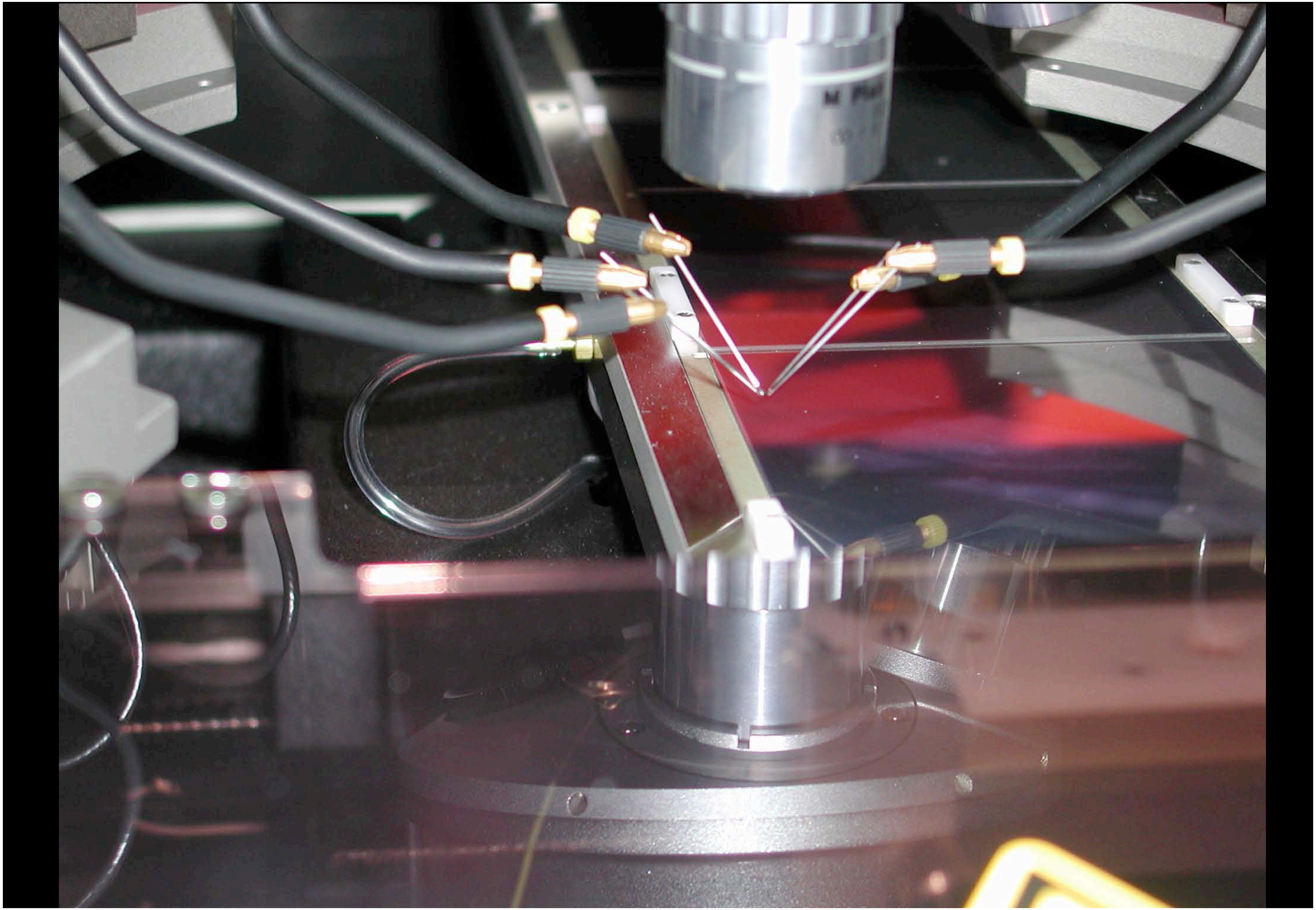


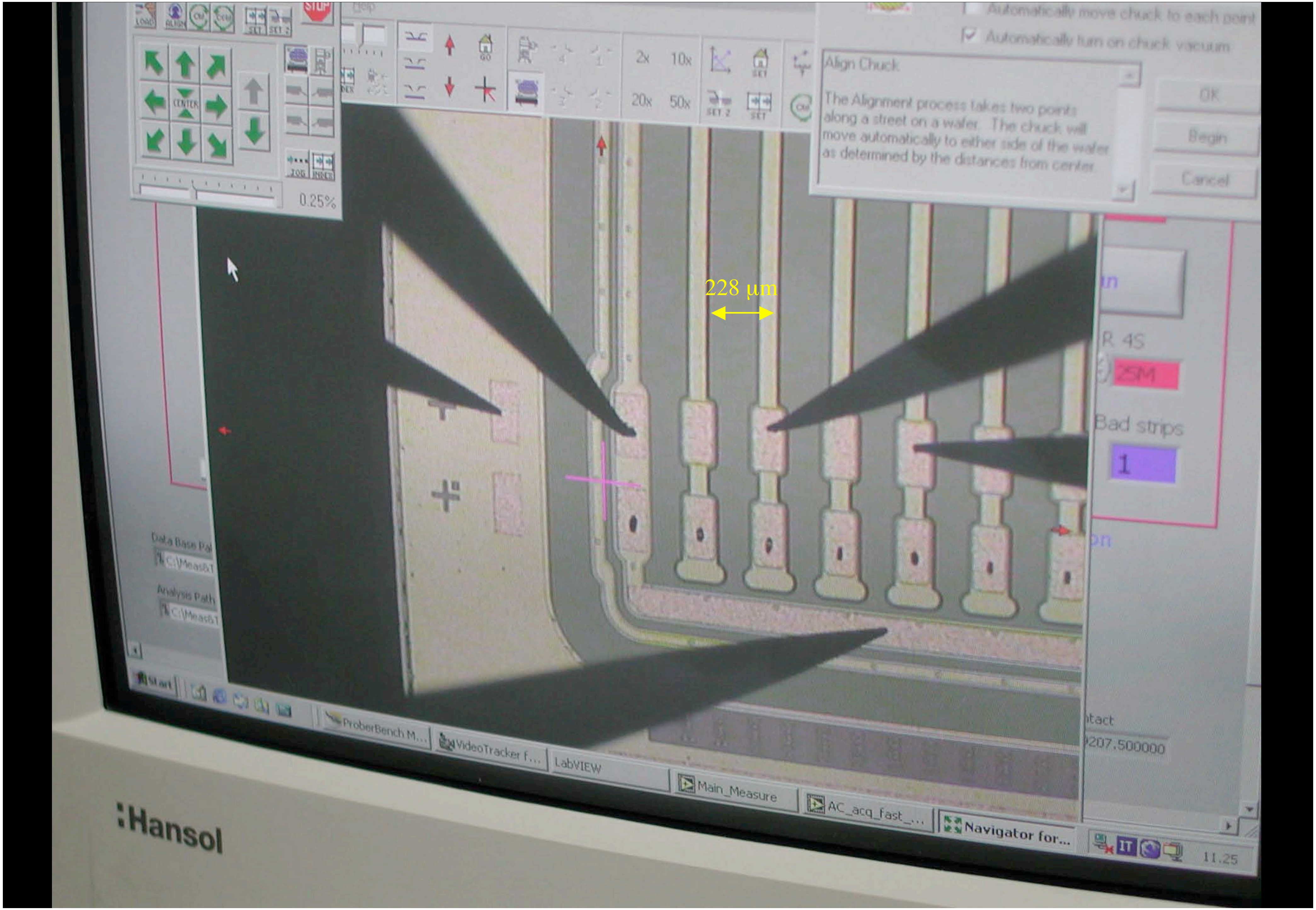




- 160 bare panels produced
- 100 tested and qualified for integration with ladders
- completed trays for 3.3 towers
- 6 assembly chain ready
- Max assembly rate : 3 trays/day/shift


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
2x
10x
20x
50x
0.25%
Bad strips
1
ProberBench M...
VideoTracker f...
LabVIEW
Main_Measure
AC_acq_fast_...
Navigator for...
Hansol

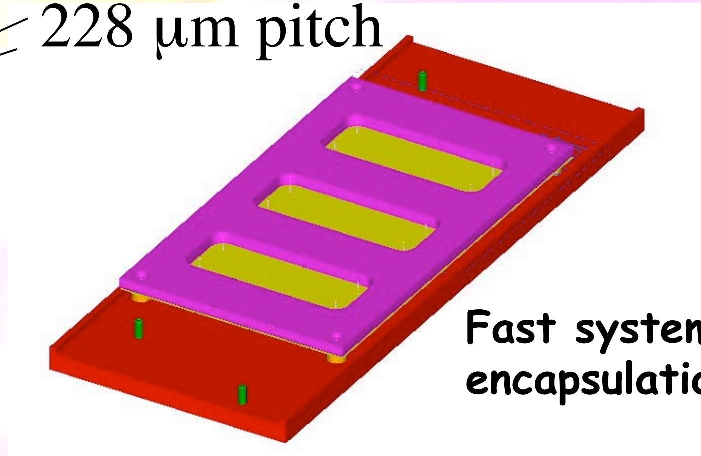
Encapsulation

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**

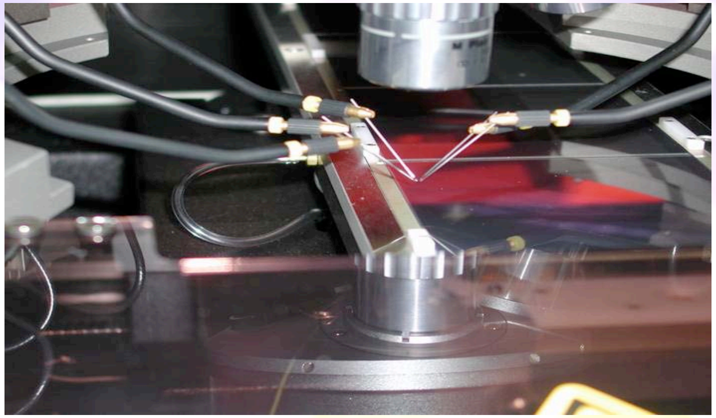
228 μm pitch

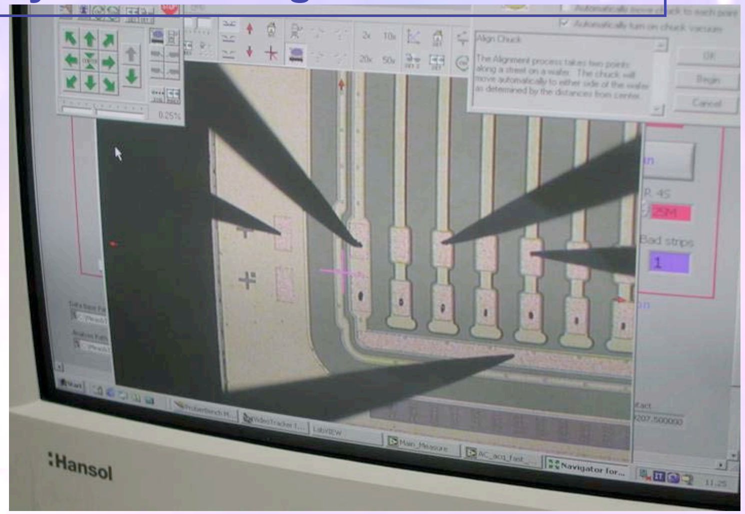


Fast system to check encapsulation height

Ladders testing

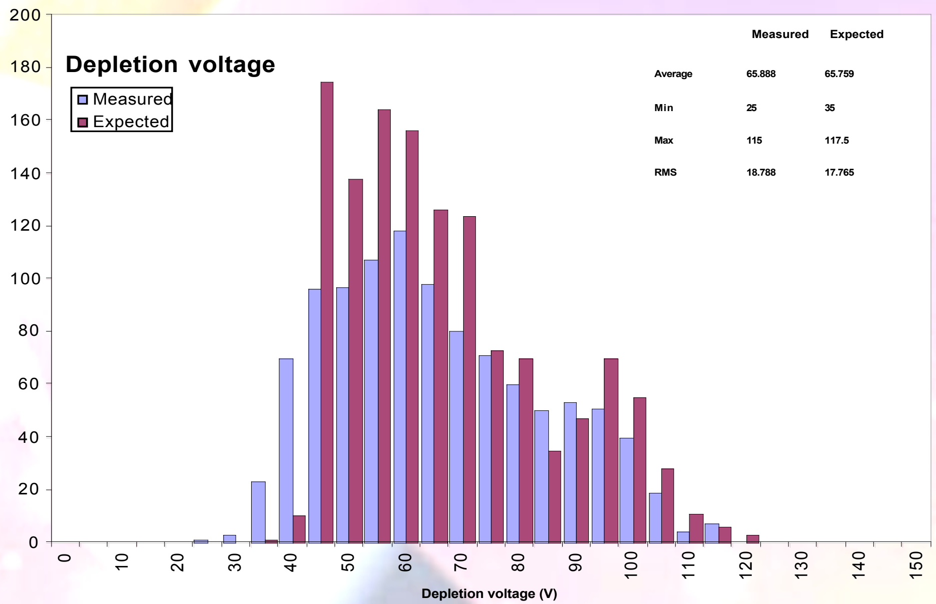
Ladders probe station: 5 probes are used to measure body and single strip I, C to check sanity of each single channel

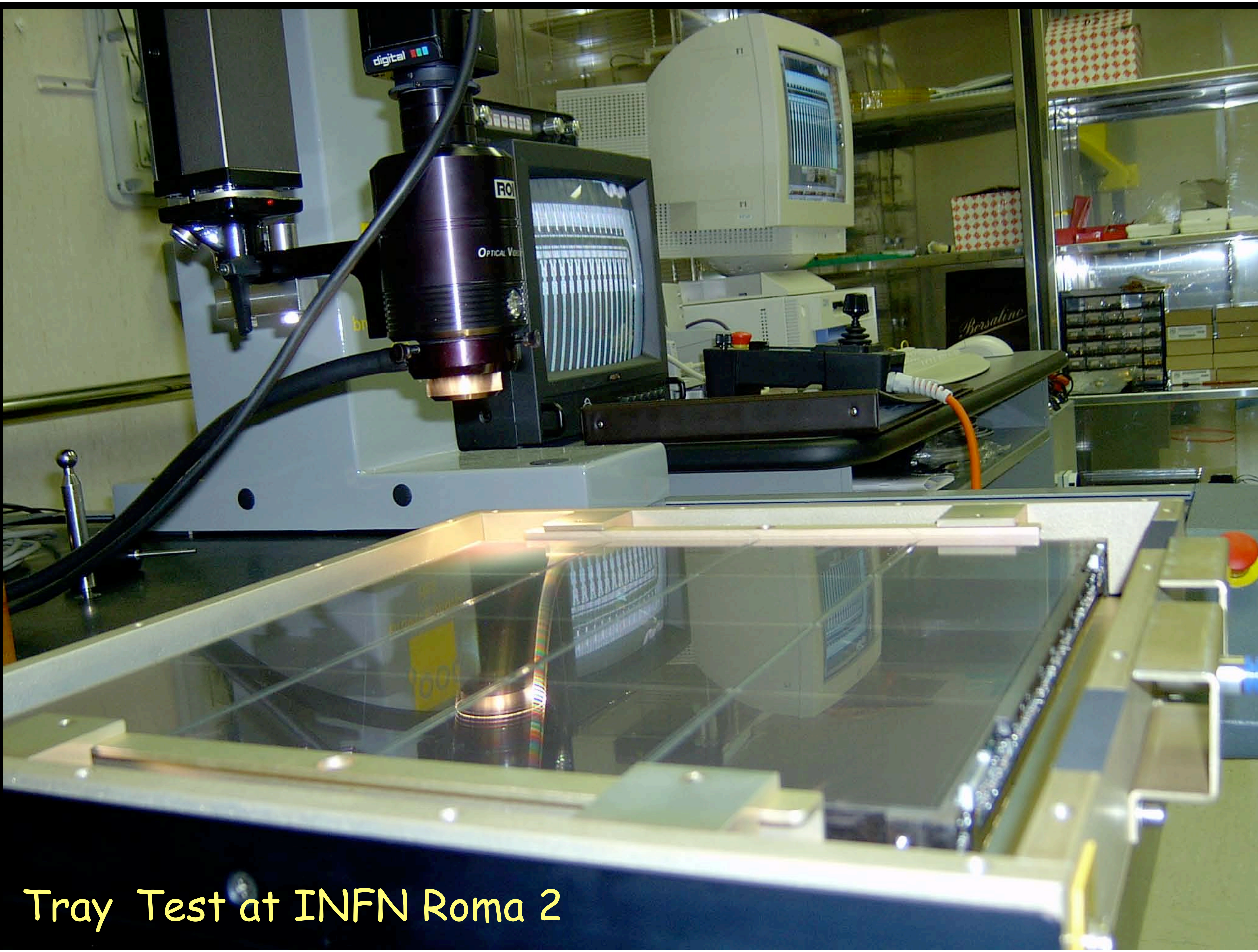




Flight ladders production status:

- Completed and tested (INFN BA/RM2/PG) 1900
- Under construction 800
- rejected ~ 1%
- 0.016% bad chans caused by bonding or probing
- 2μm RMS alignment spread
- All results in good agreement with what expected from SSDs



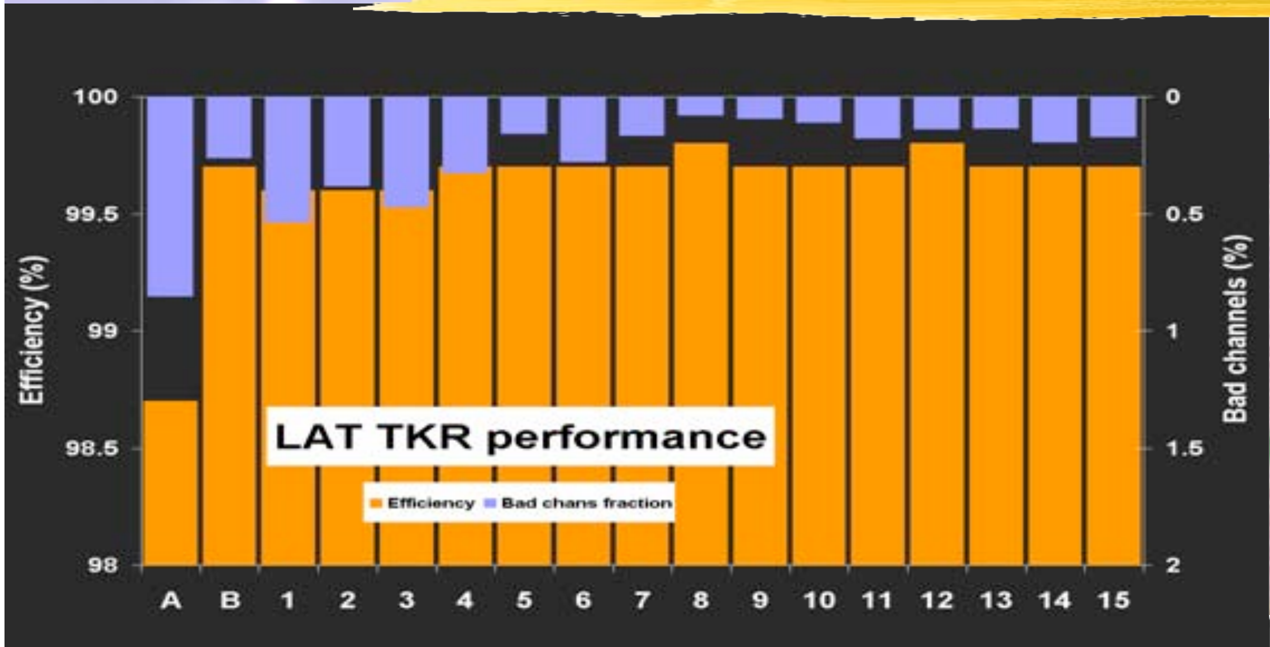


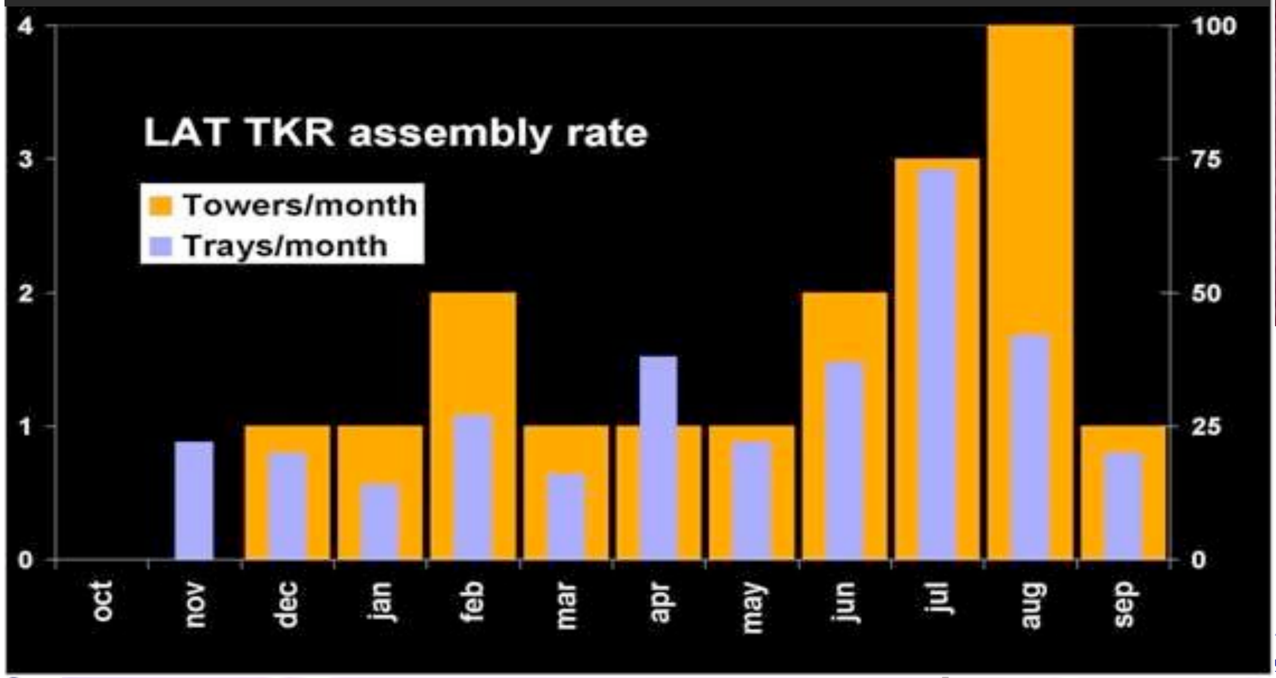
Tray Test at INFN Roma 2

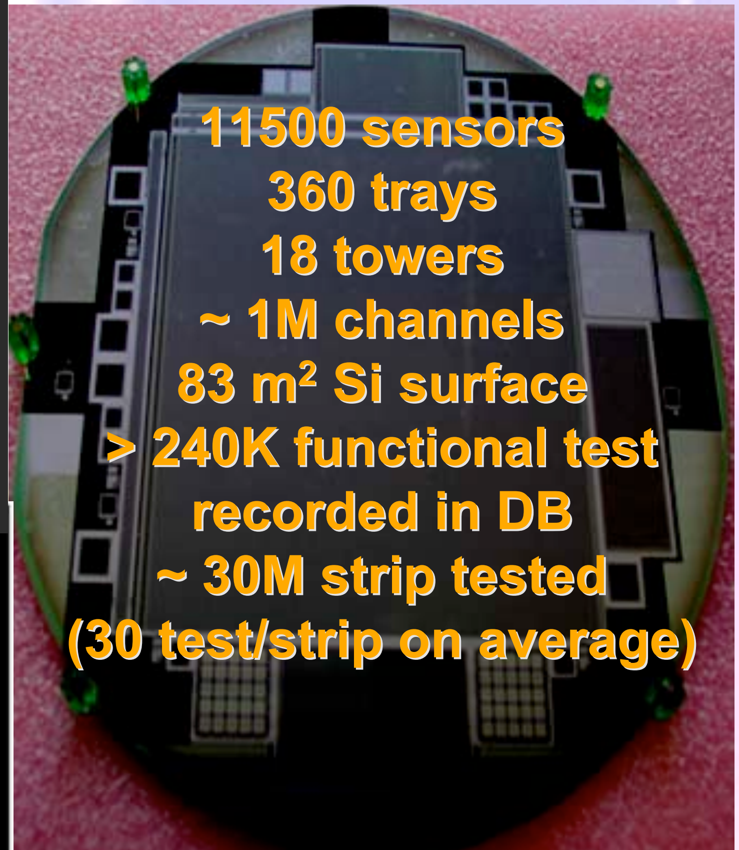
GLAST @ SLAC

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

The LAT Tracker numbers







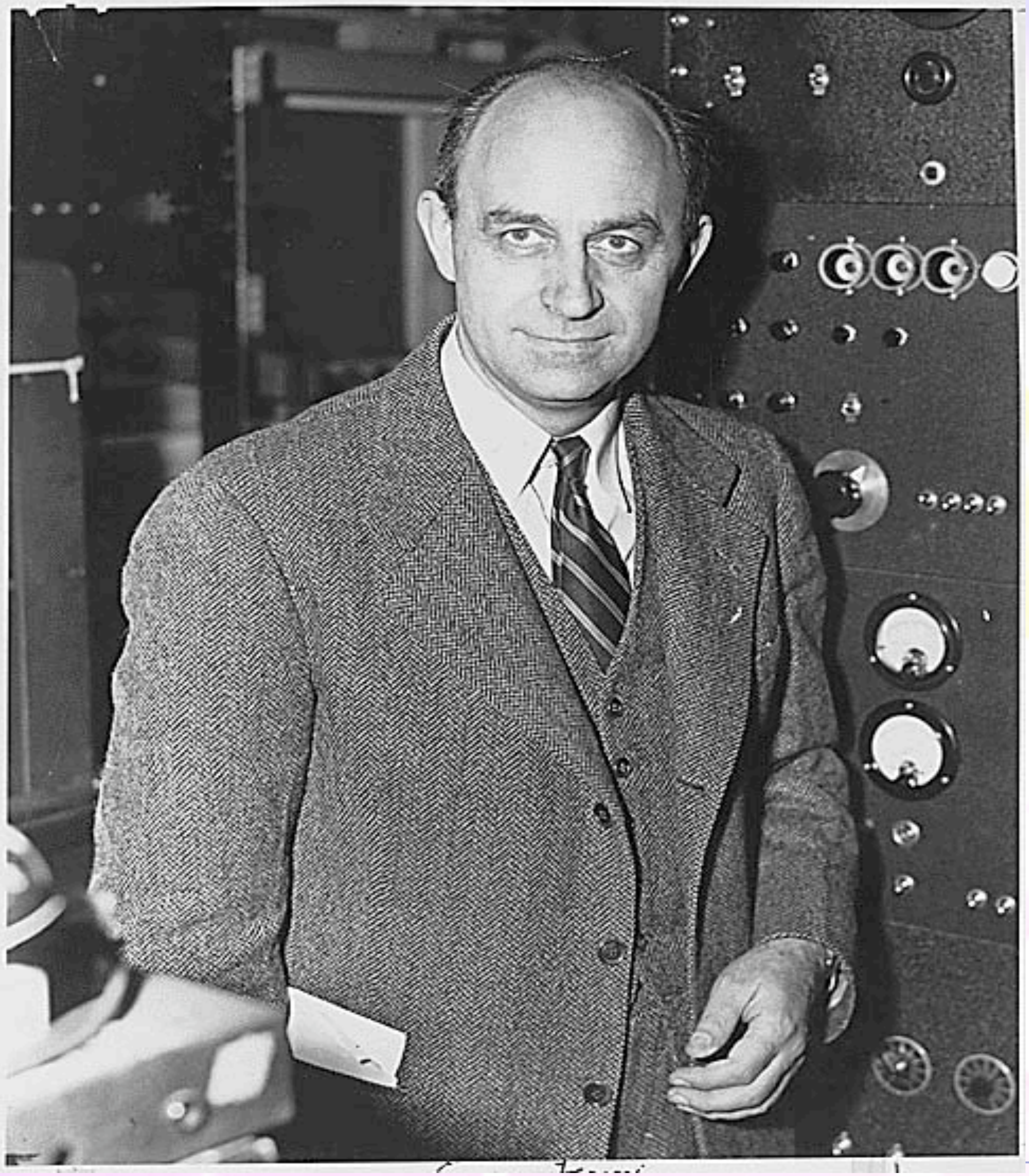
Celebrations for the end of Tracker construction

52 attendees from INFN, ASI, SLAC, NASA, italian industrial partners


ATTENTION
OBSERVE PRECAUTIONS
FOR HANDLING
ELECTROSTATIC
SENSITIVE DEVICES

Fermi Gamma-ray Space Telescope

DoE – NASA – international partnership



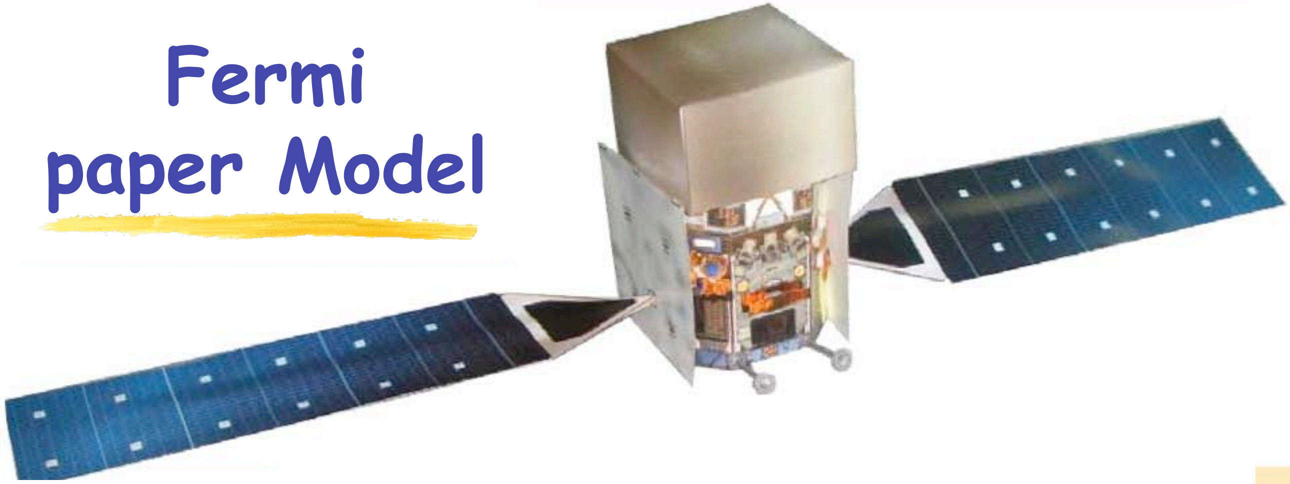
GLAST renamed *Fermi* by NASA on August 26, 2008

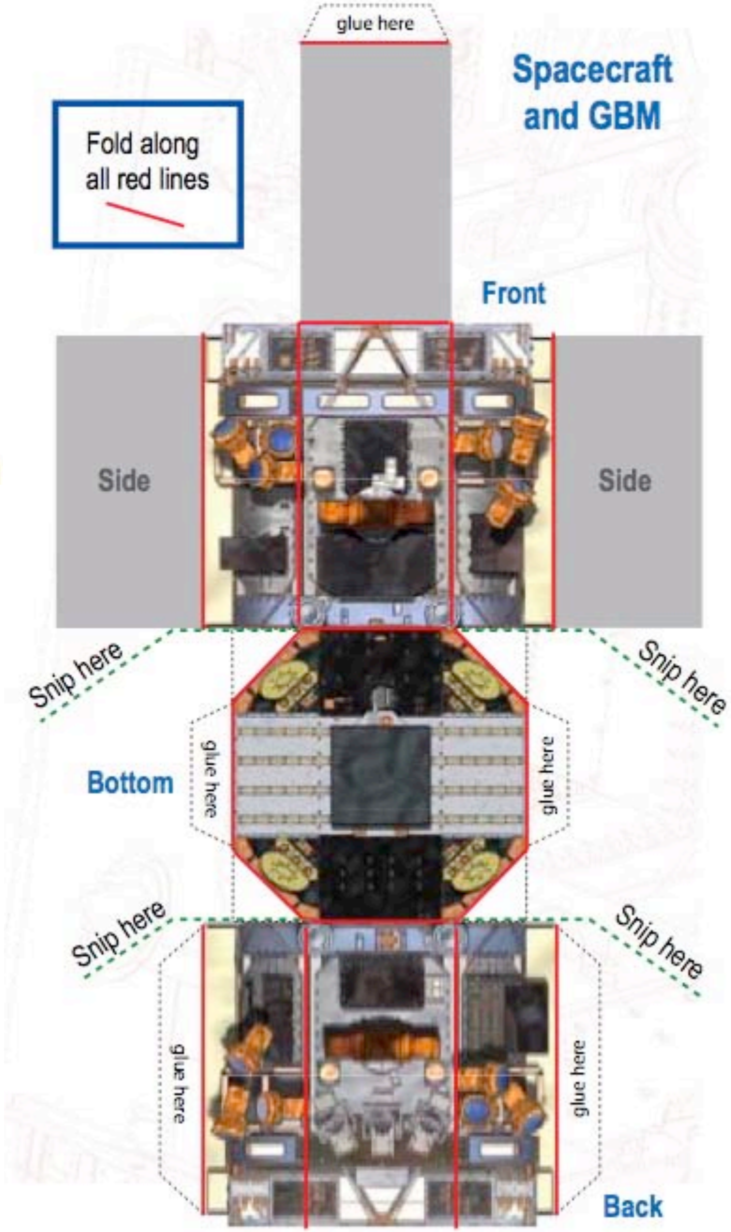
http://fermi.gsfc.nasa.gov/

“ 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.

Fermi Prior to Fairing Installation

Fermi paper Model





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

Fermi
inside the Delta 2


11 June 2008


11 June 2008

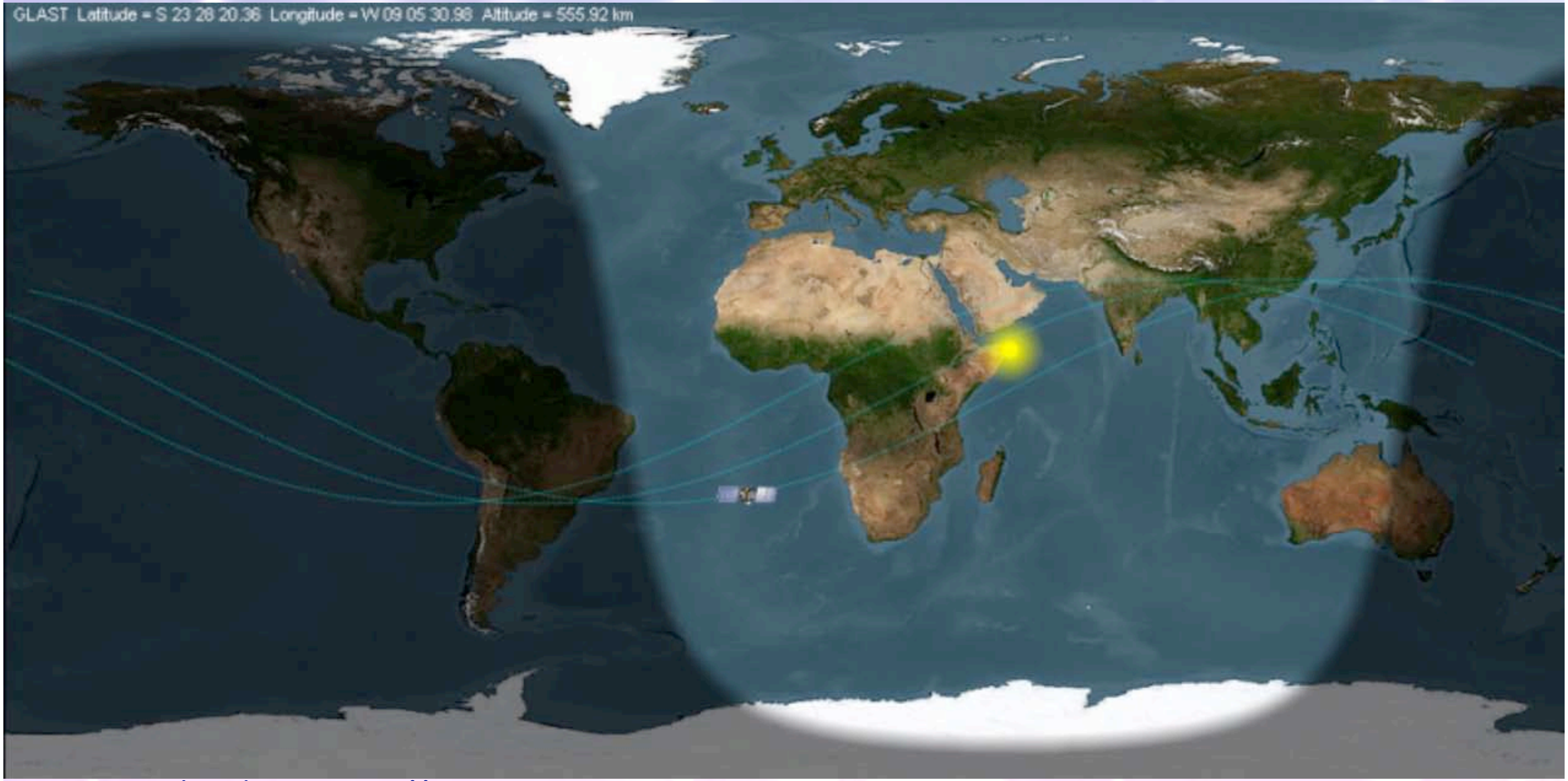

11 June 2008


11 June 2008


11 June 2008


11 June 2008

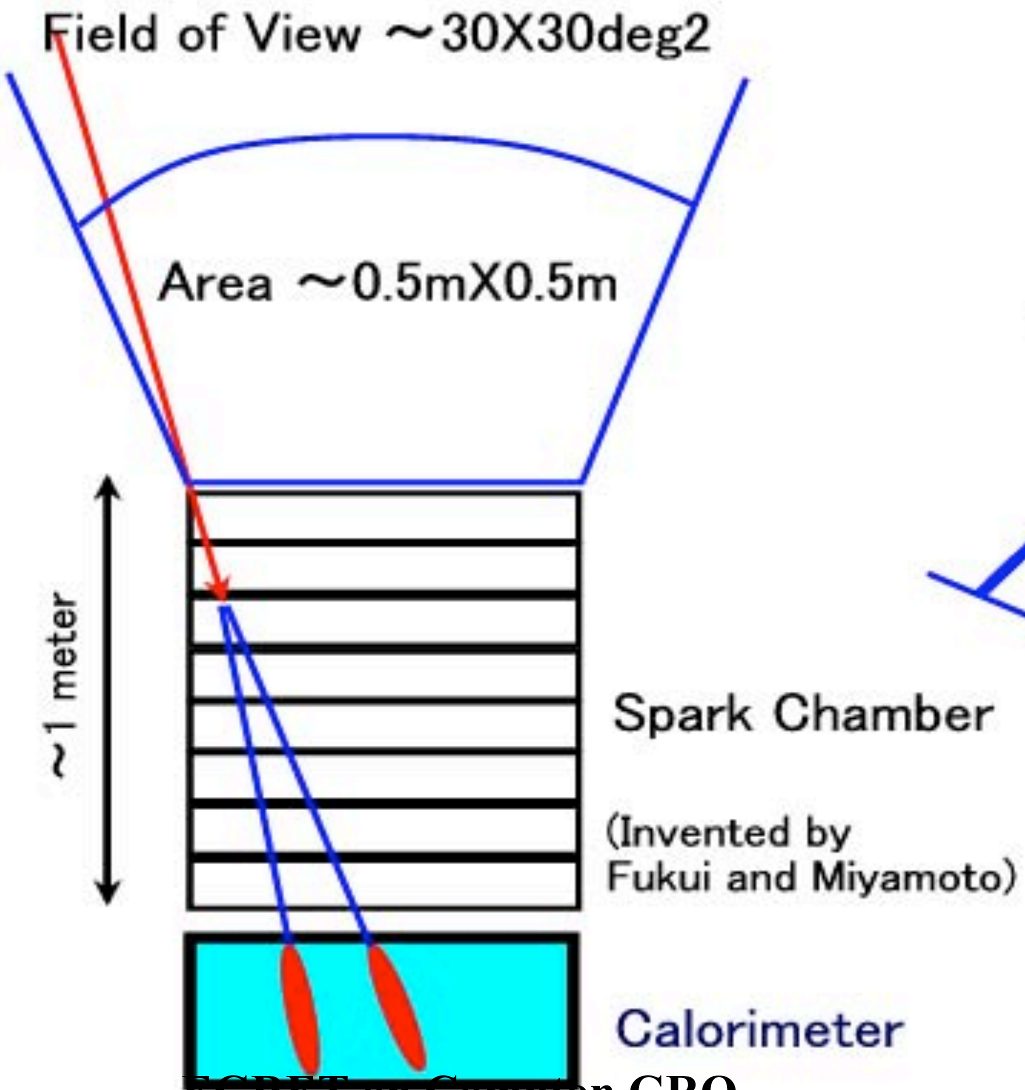
Fermi in orbit



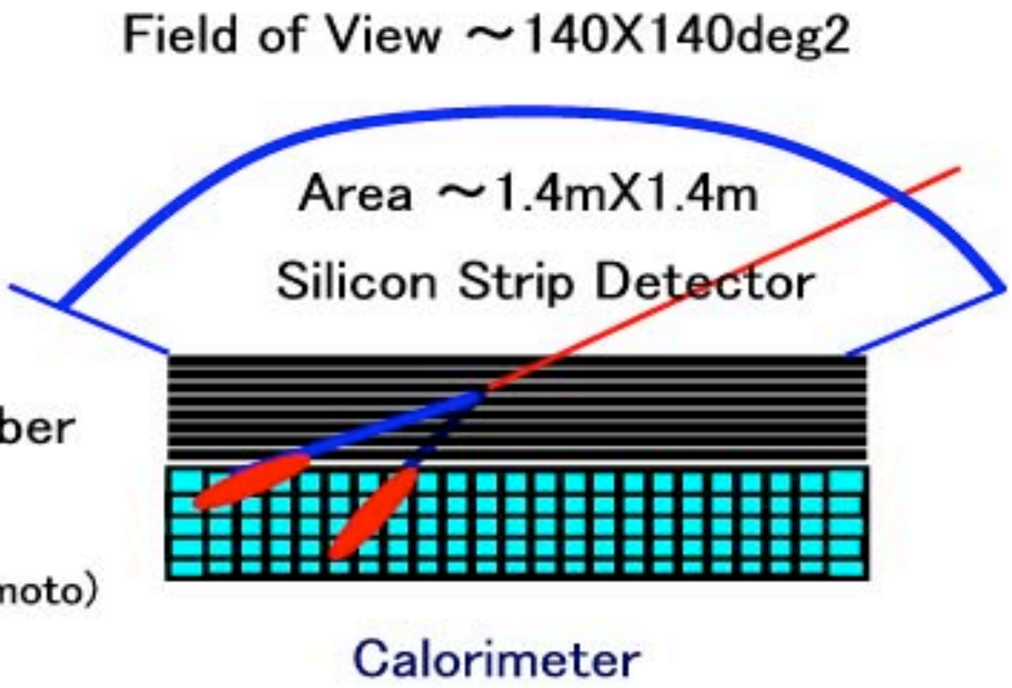
- Track the satellite: http://observatory.tamu.edu:8080/Trakker
- Watch Fermi as it orbits over you home town:

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

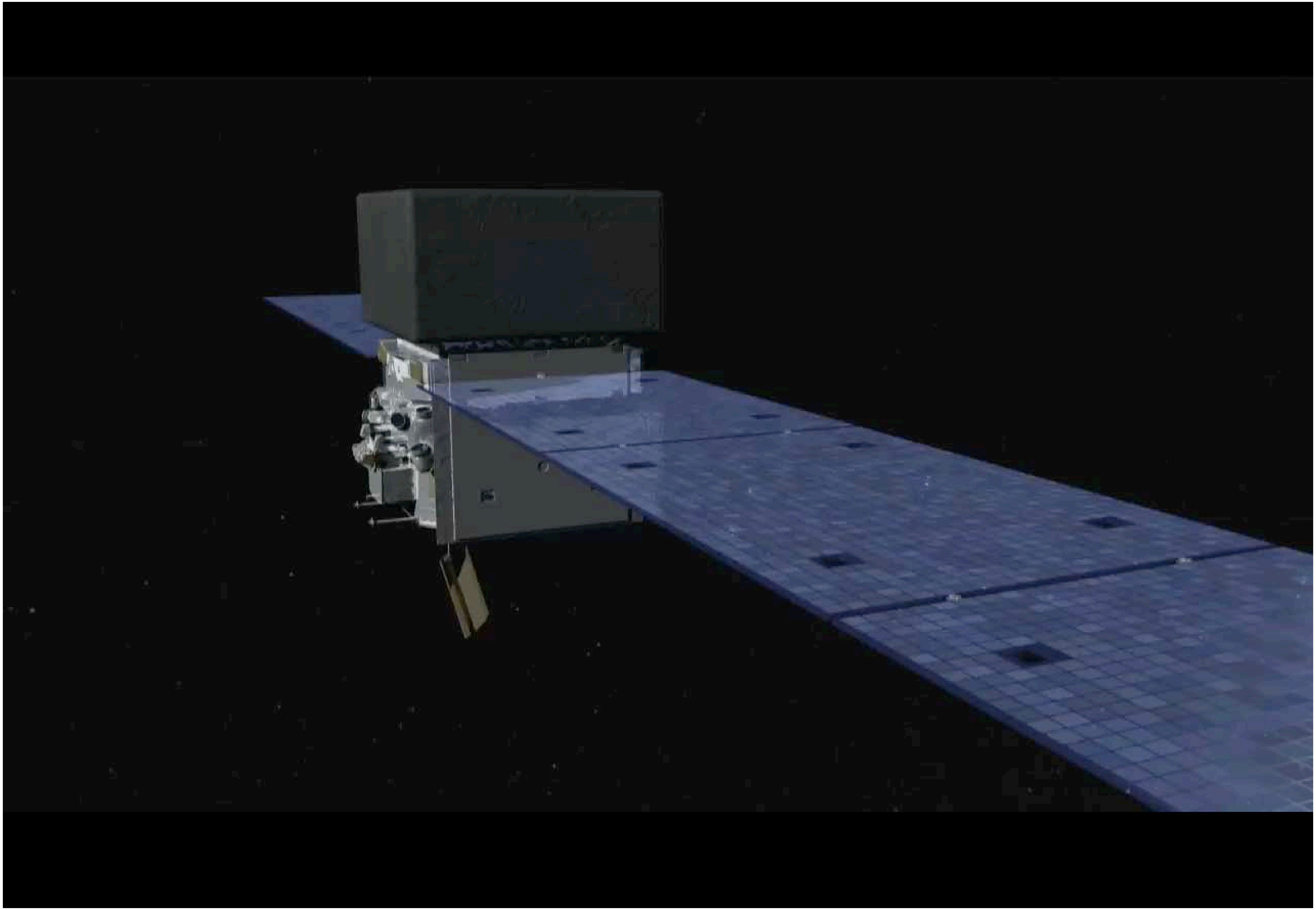
EGRET(Spark Chamber) VS. GLAST(Silicon Strip Detector)

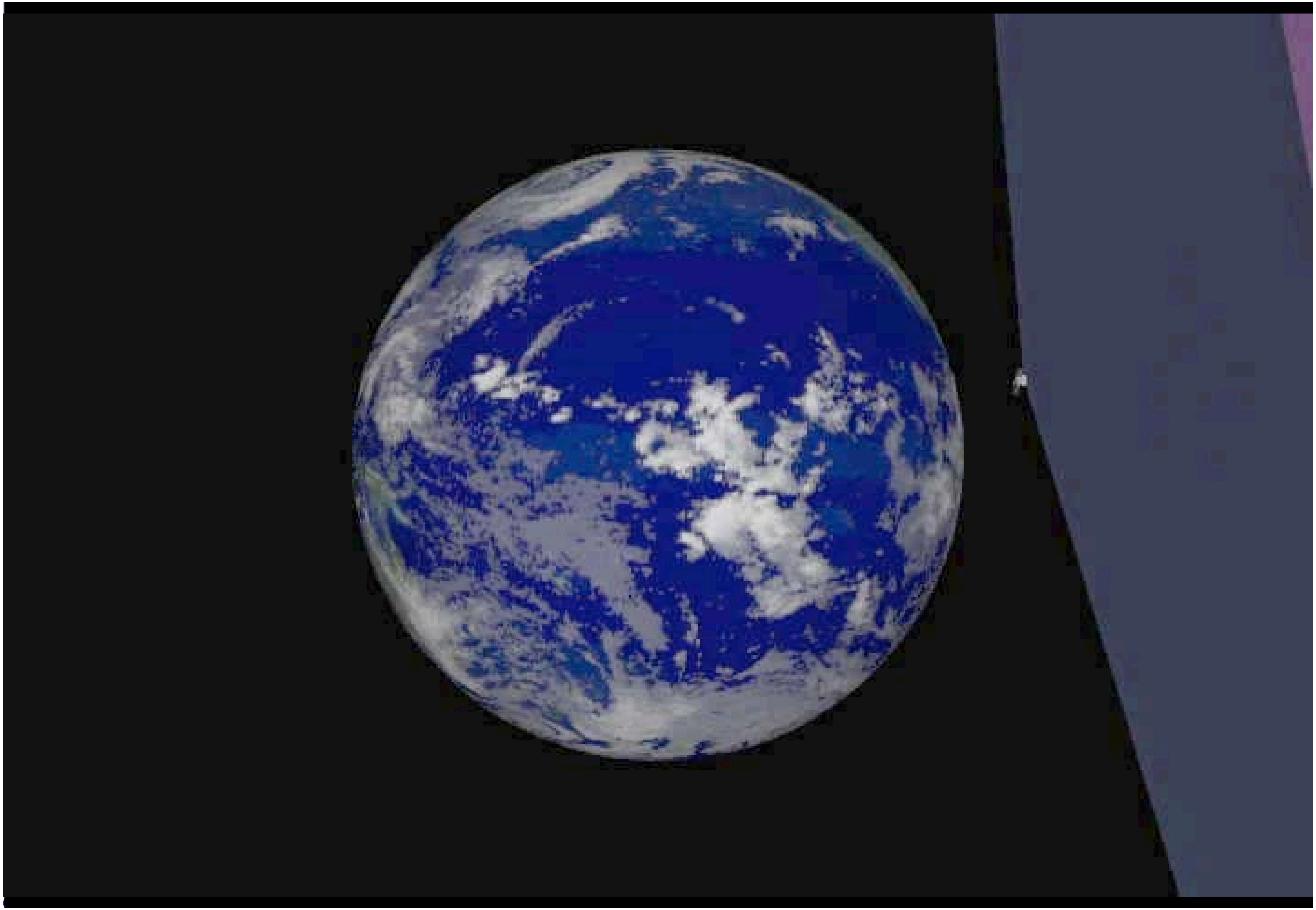


EGRET on Compton GRO
(1991-2000)



GLAST Large Area Telescope
(2006-2015)

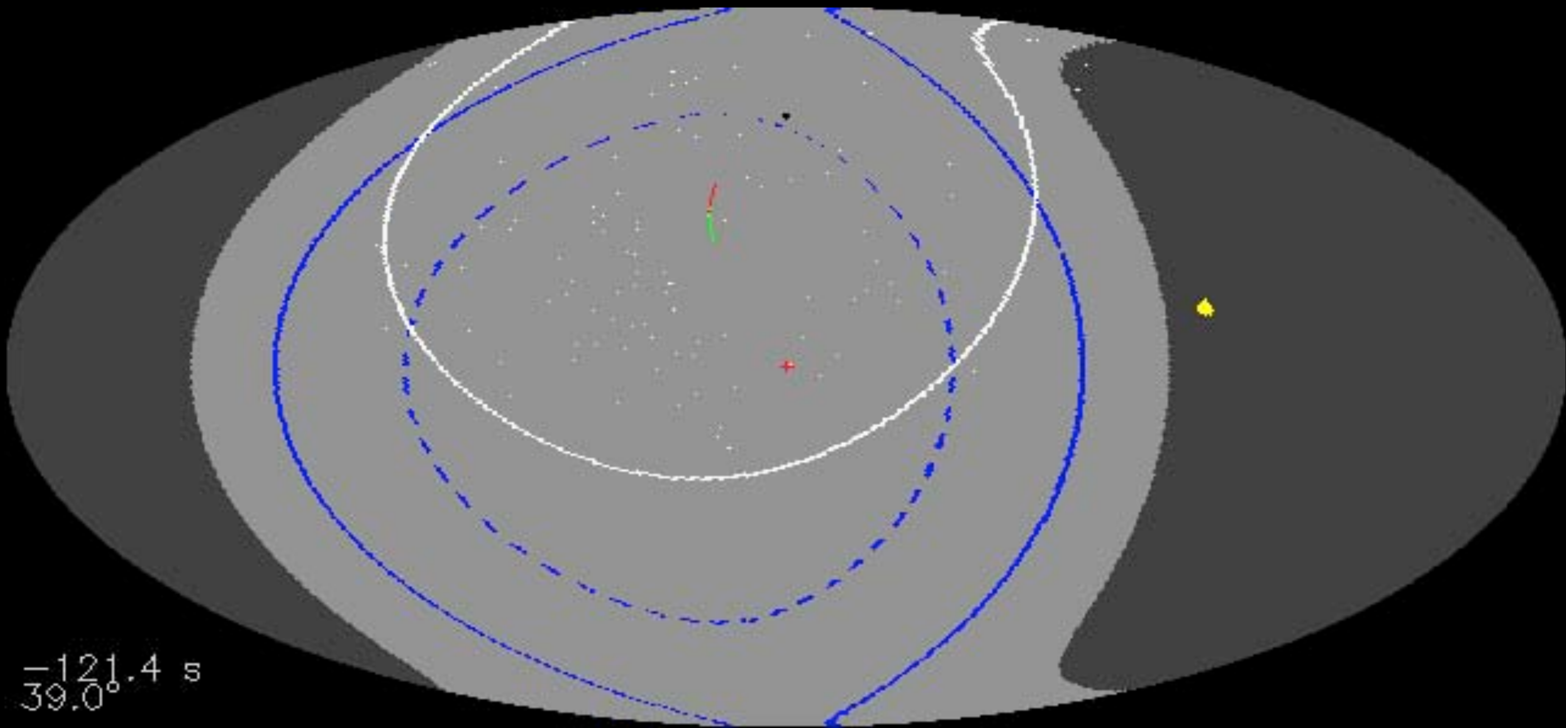




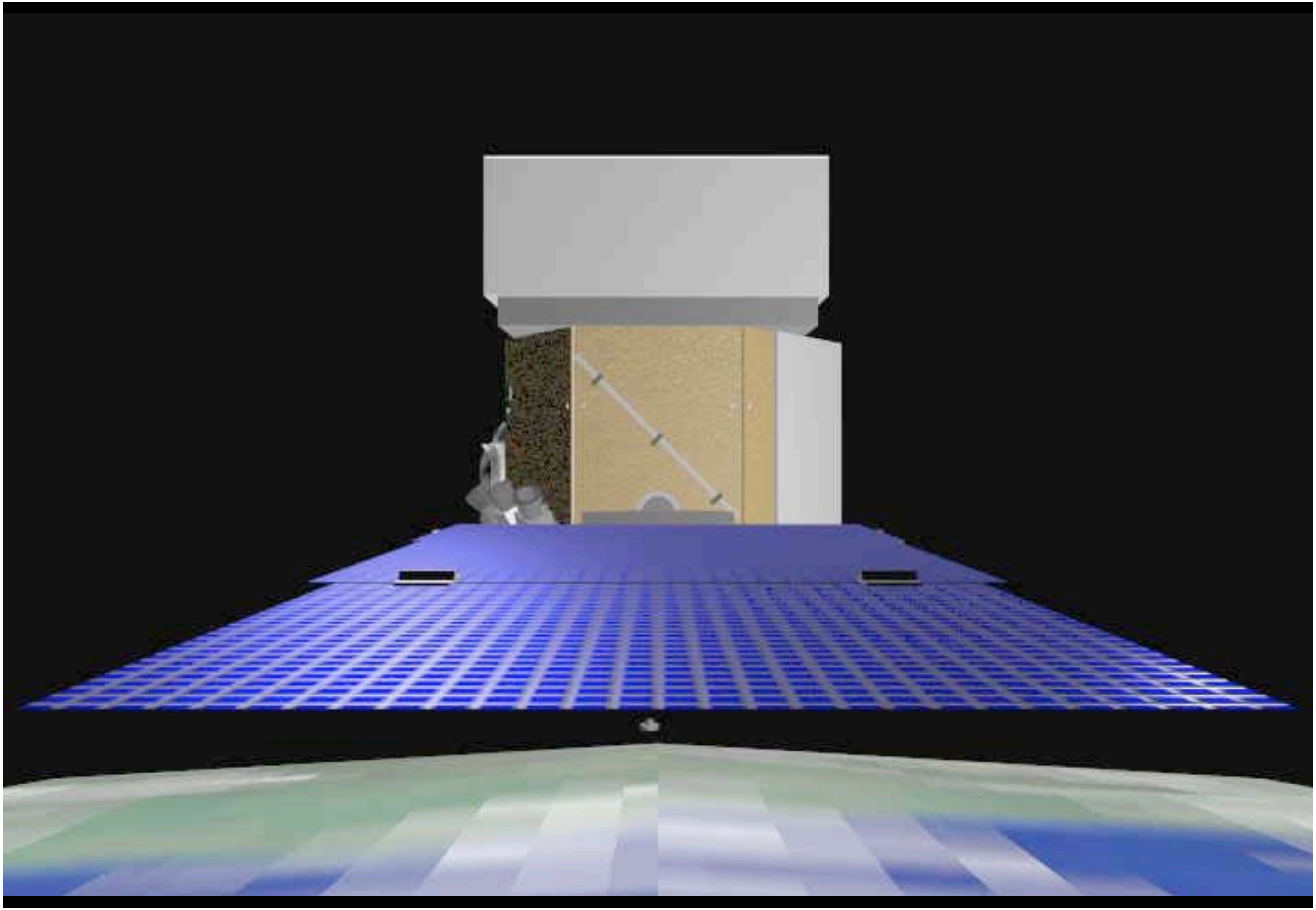
GRB 090902B - Autonomous Repoint Request

LAT pointing in celestial coordinates from -120 s to 2000 s

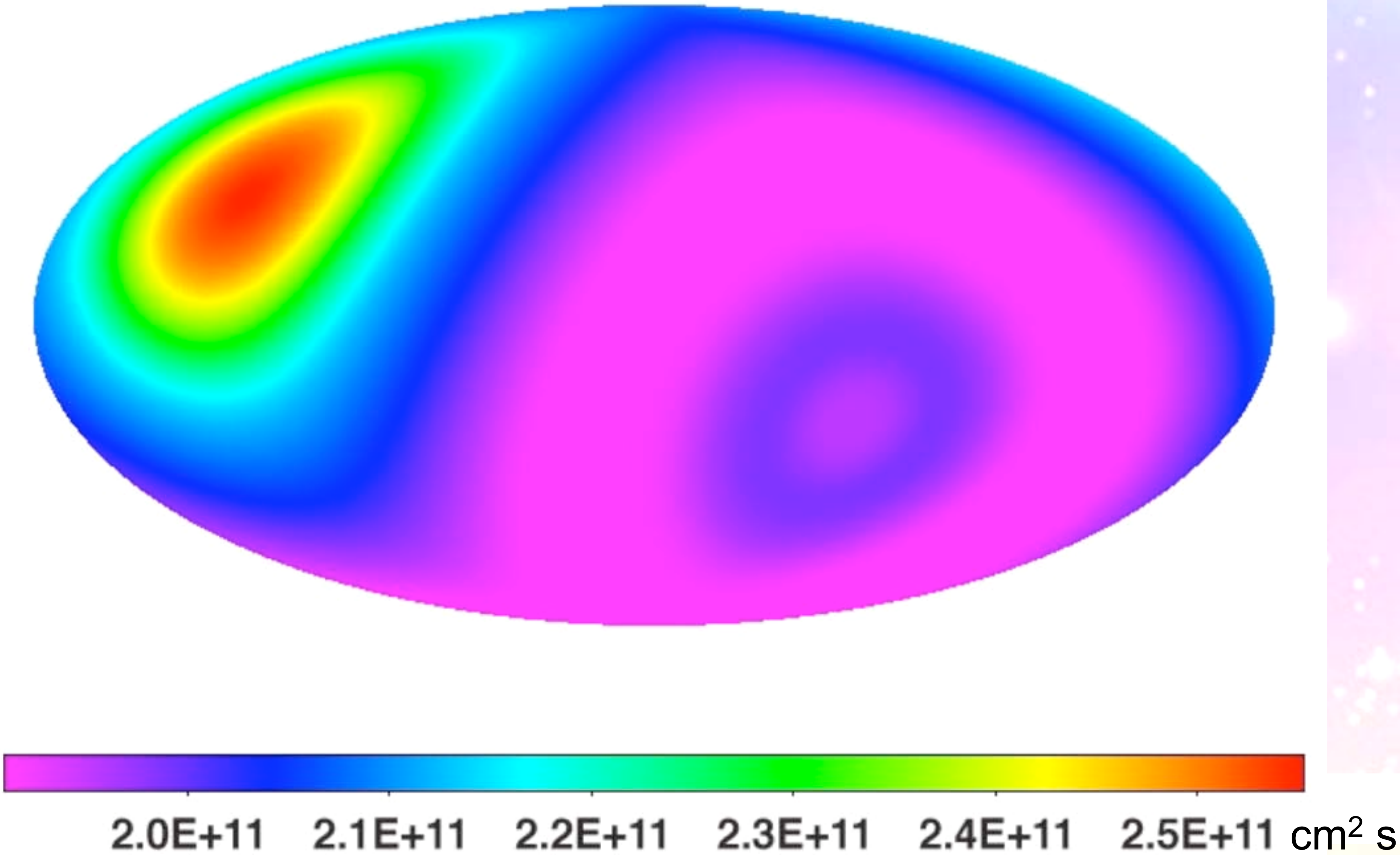
- **Red cross = GRB 090902B**
- **Dark region = occulted by Earth (θ_z>113°)**
- **White line = LAT FoV (±66°)**
- **Blue lines = 20° (Earth avoidance angle) / 50° above horizon**
- **White points = LAT transient events (no cut on zenith angle)**



Public data → GRB090902B paper submitted to ApjL, arXiv:0909.2470



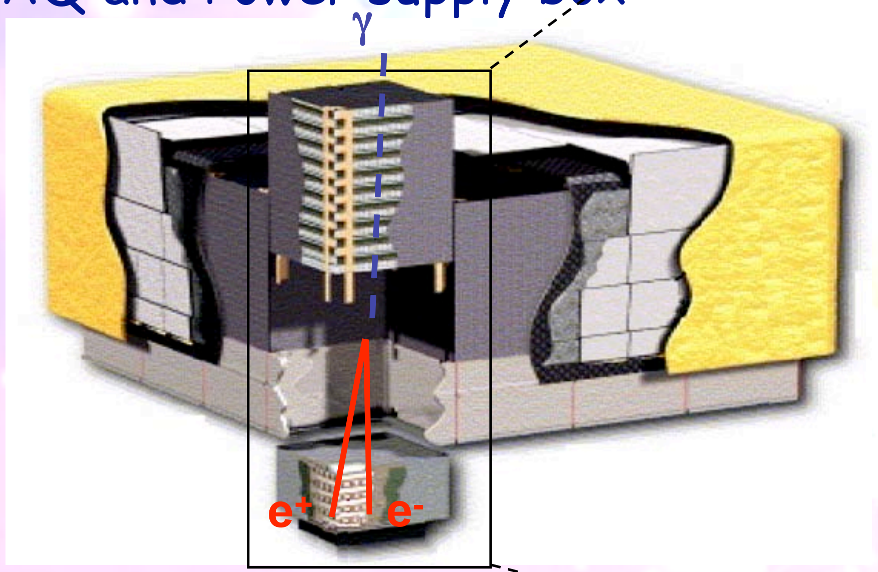
Simulated Fermi LAT exposure for five years of all-sky scanning at 100 GeV

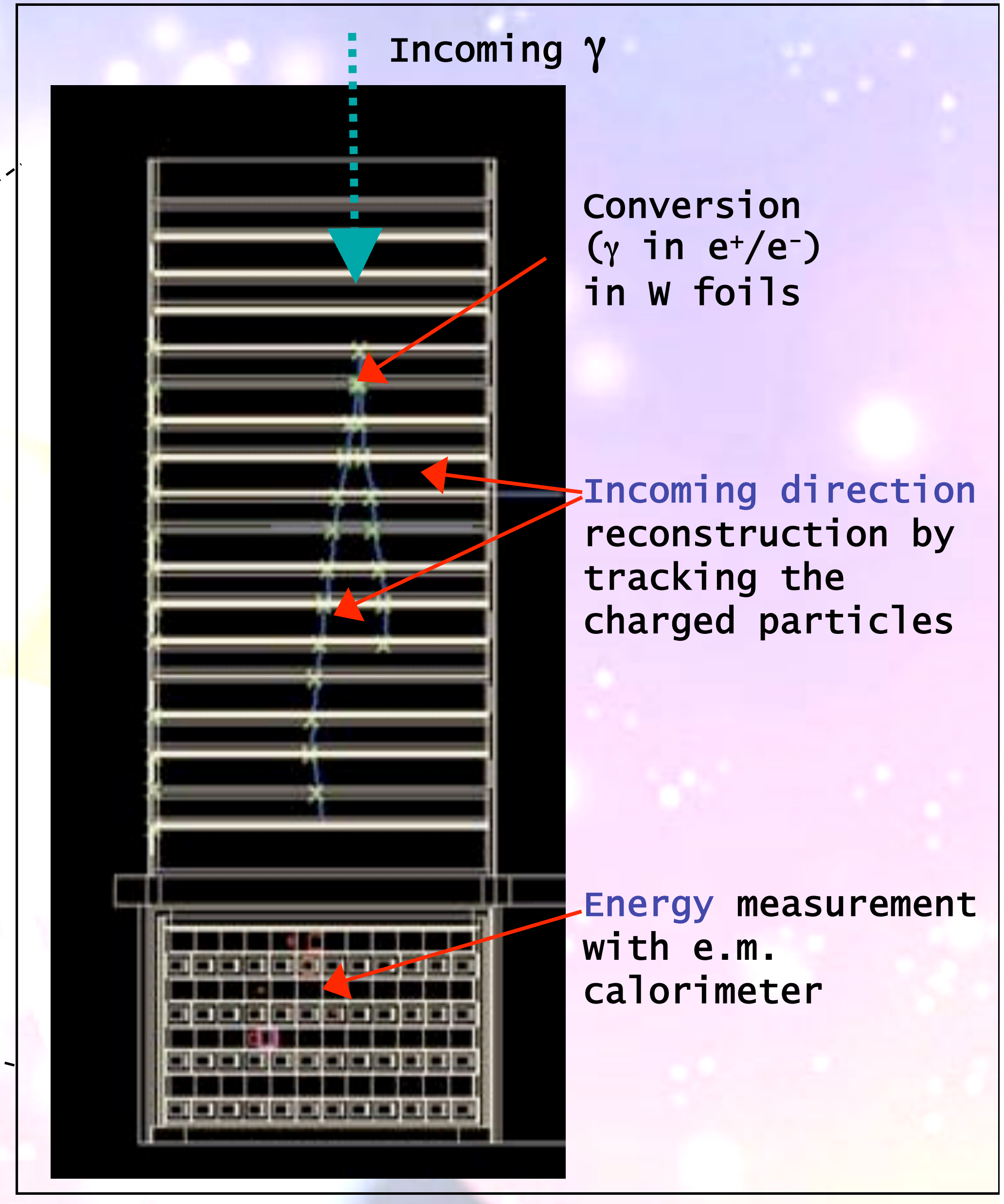


How Fermi LAT detects gamma rays

4 x 4 array of identical towers with:

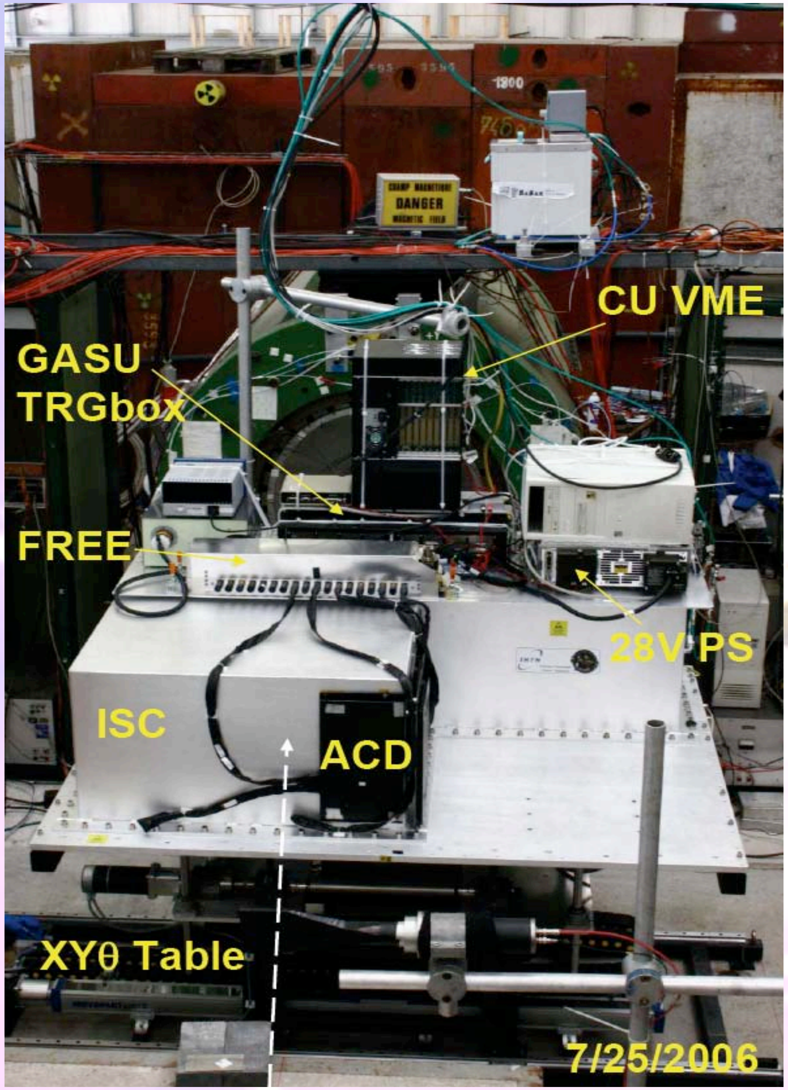
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box





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

The CERN Beam Test Campaign

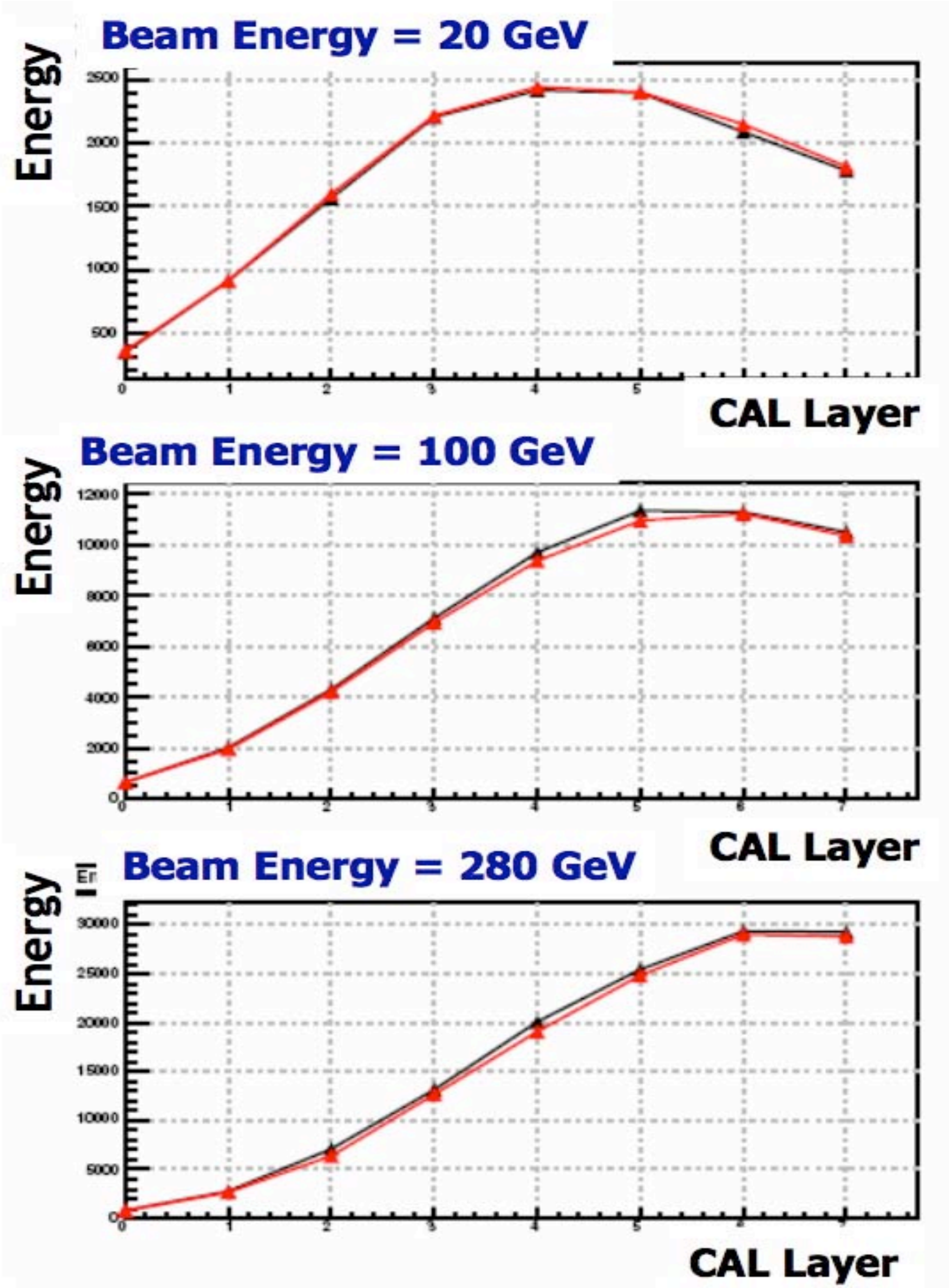


- 4 weeks at PS/T9 area (26/7-23/8)
  - Gammas @ 0-2.5 GeV
  - Electrons @ 1,5 GeV
  - Positrons @ 1 GeV (through MMS)
  - Protons @ 6,10 GeV (w/ & w/o MMS)
- 11 days at SPS/H4 area (4/9-15/9)
  - Electrons @ 10,20,50,100,200,280 GeV
  - Protons @ 20,100 GeV
  - Pions @ 20 GeV
- Data, data, data…
  - 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

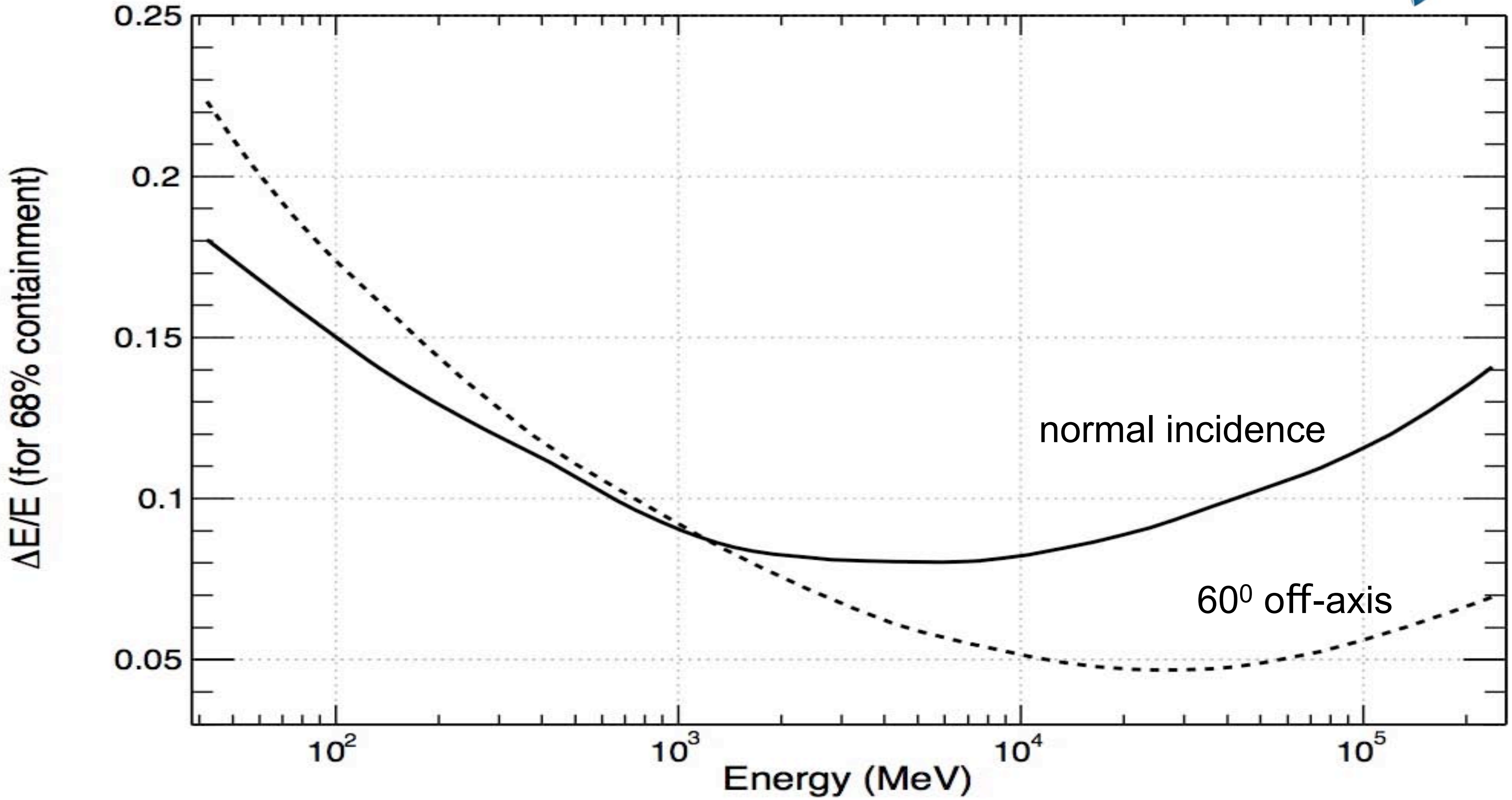
Energy reconstruction

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)

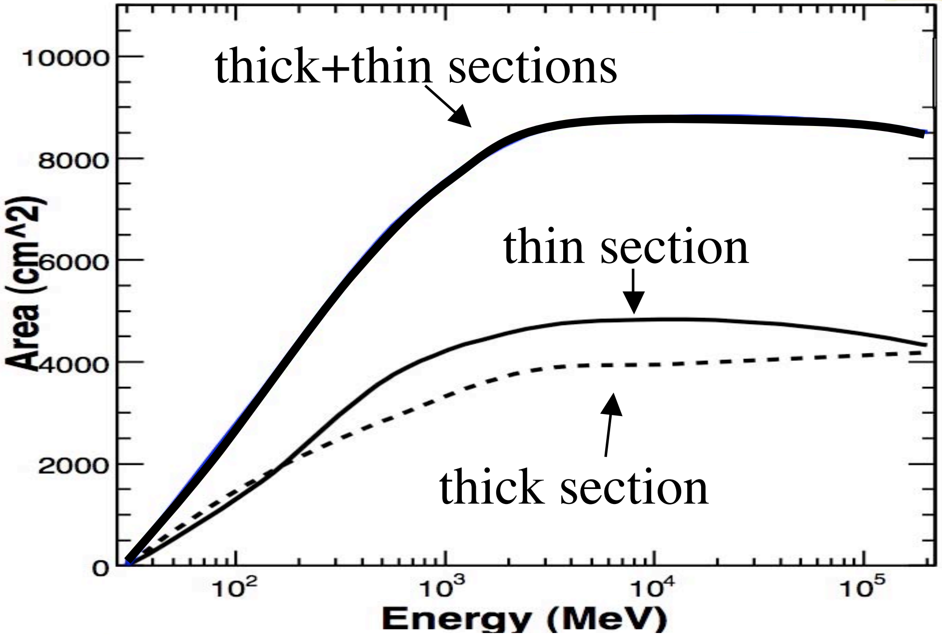


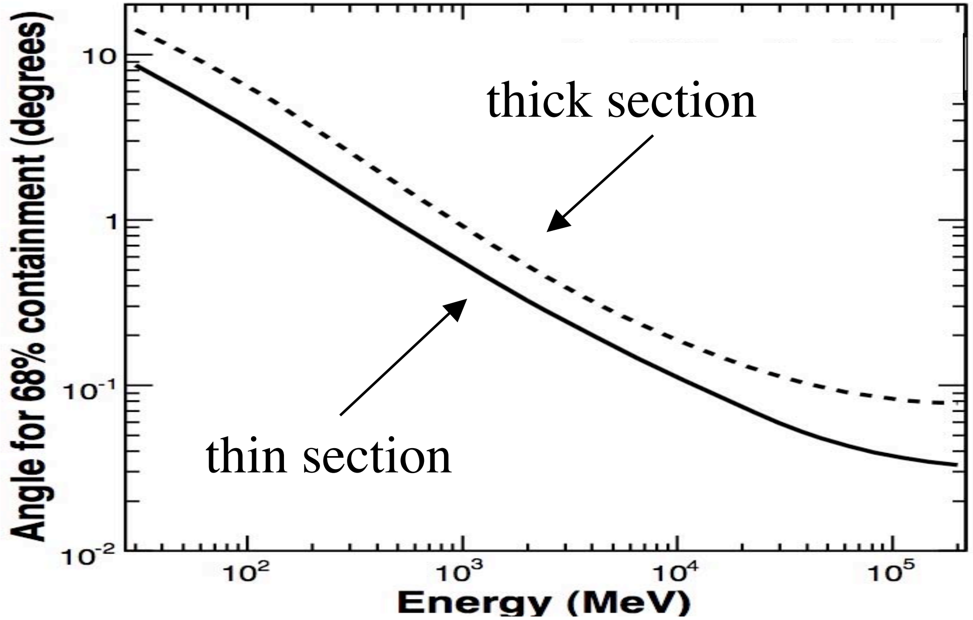
Energy Resolution

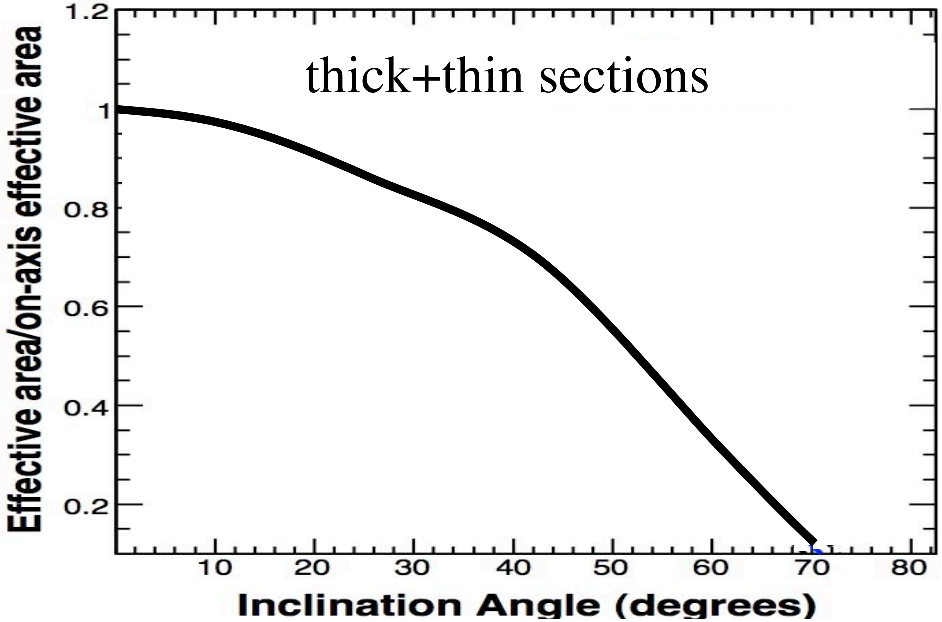


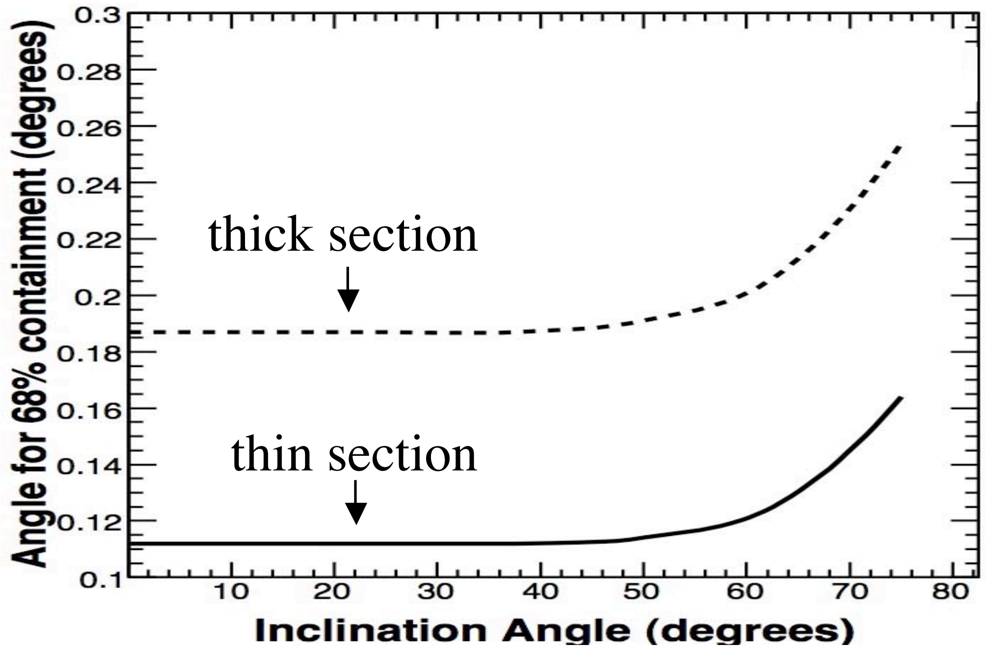
The LAT sensitivity extends to higher energies (> 300 GeV) than that of any previous space-based gamma-ray mission, opening the unexplored energy range above 30 GeV. The energy range of the LAT will overlap those of the next generation ground-based TeV gamma-ray instruments, allowing for inter-calibration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

Fermi LAT MC Derived Performance



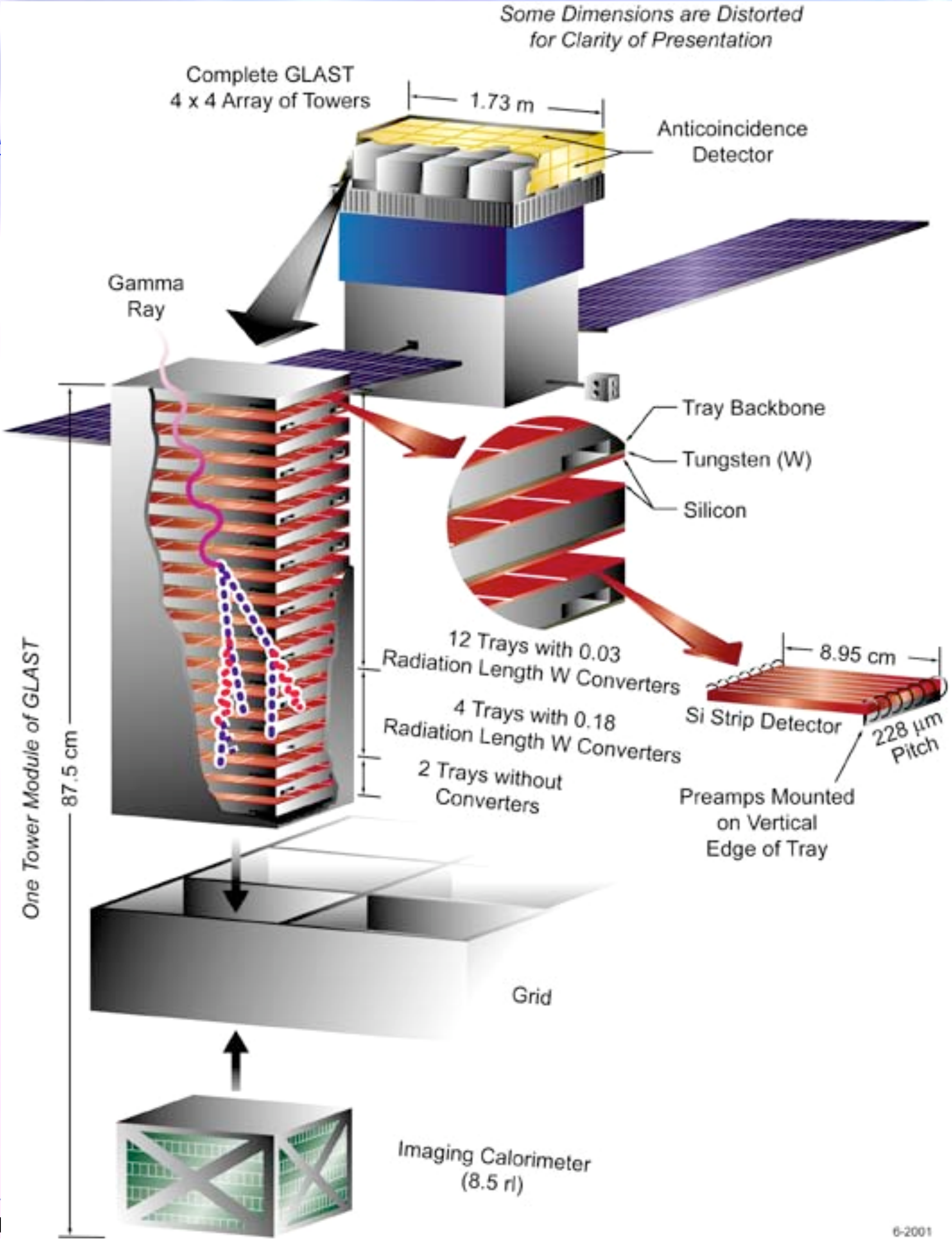




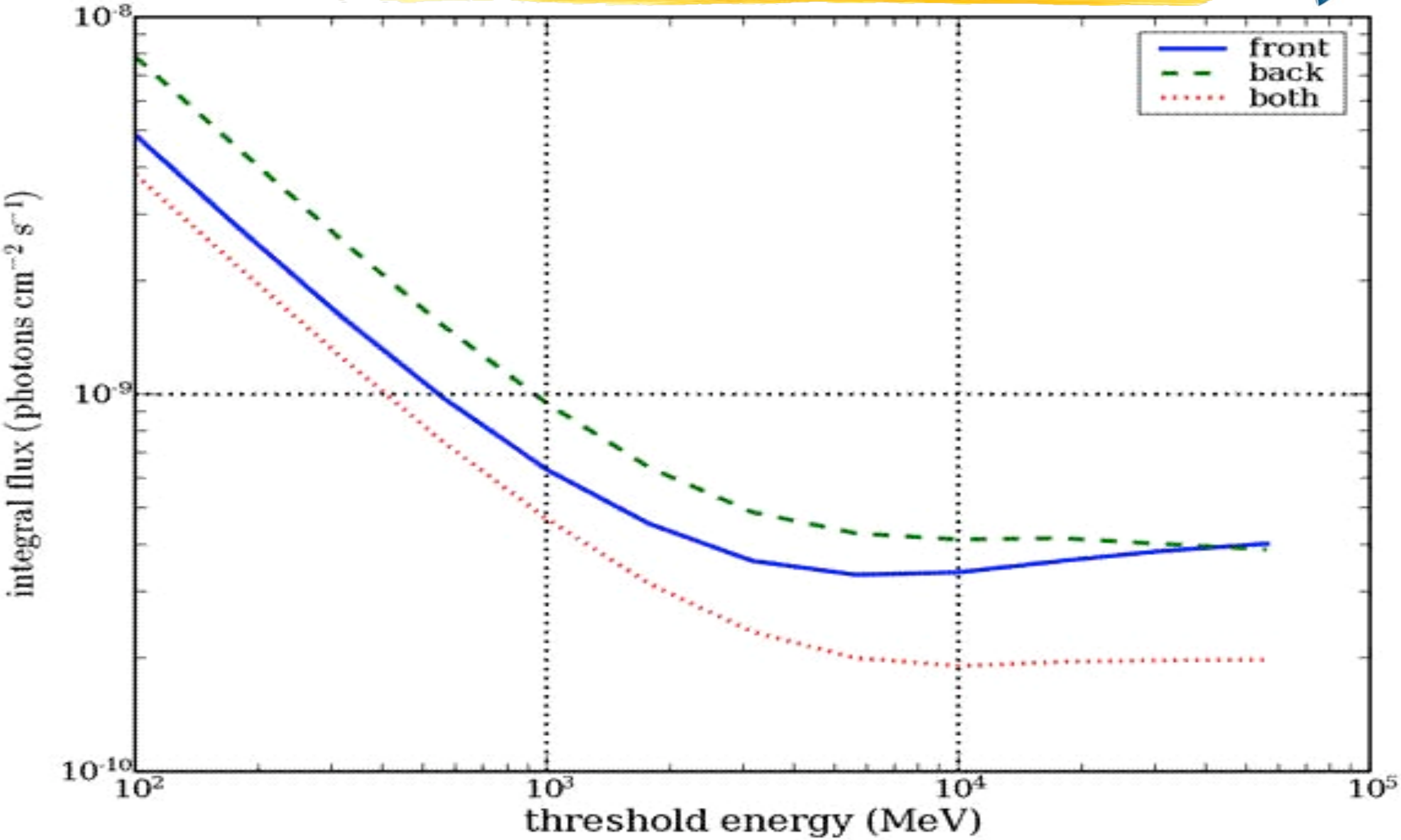


Gamma-Ray Large Area Space Telescope

GLAST Scheme

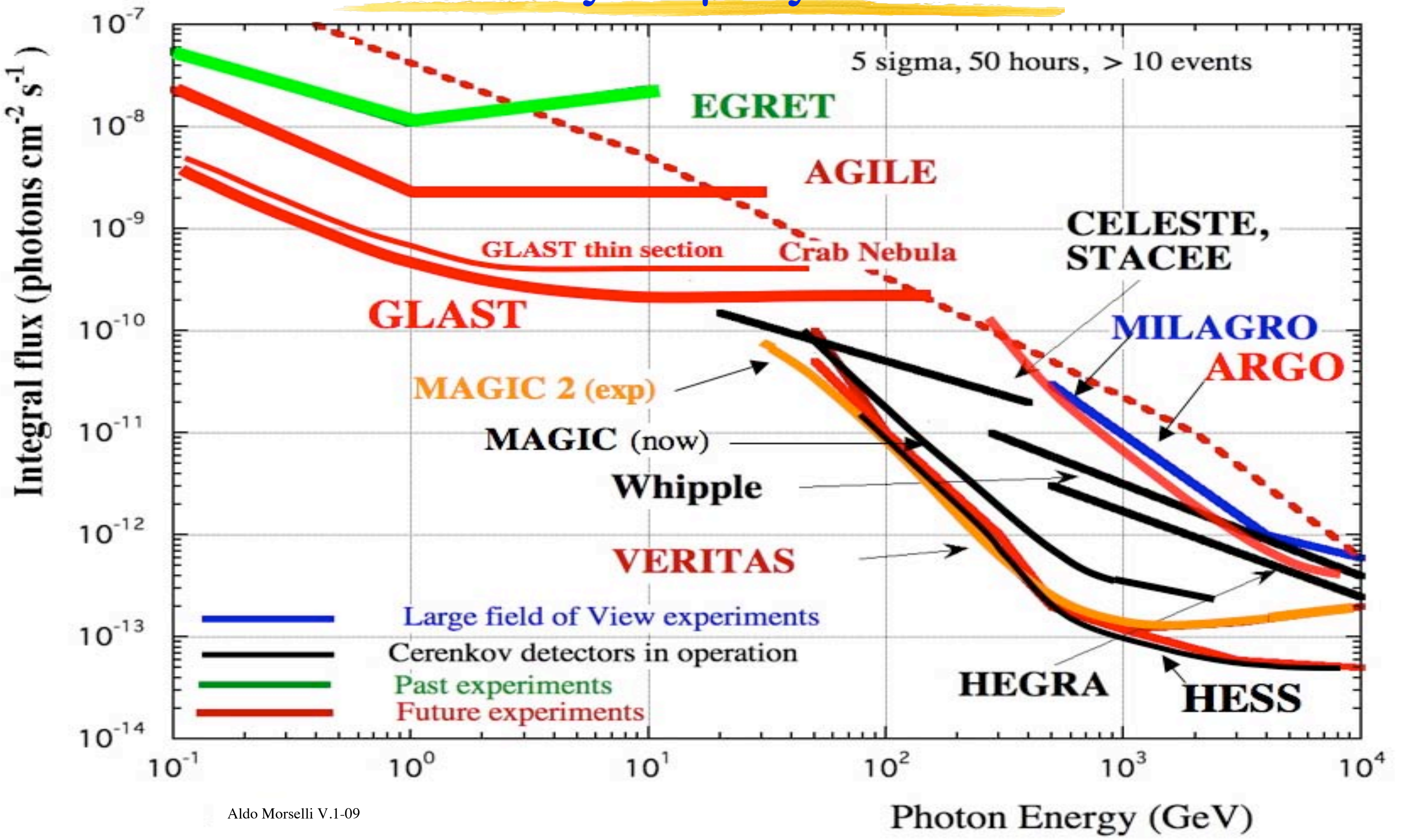


Fermi LAT Sensitivity



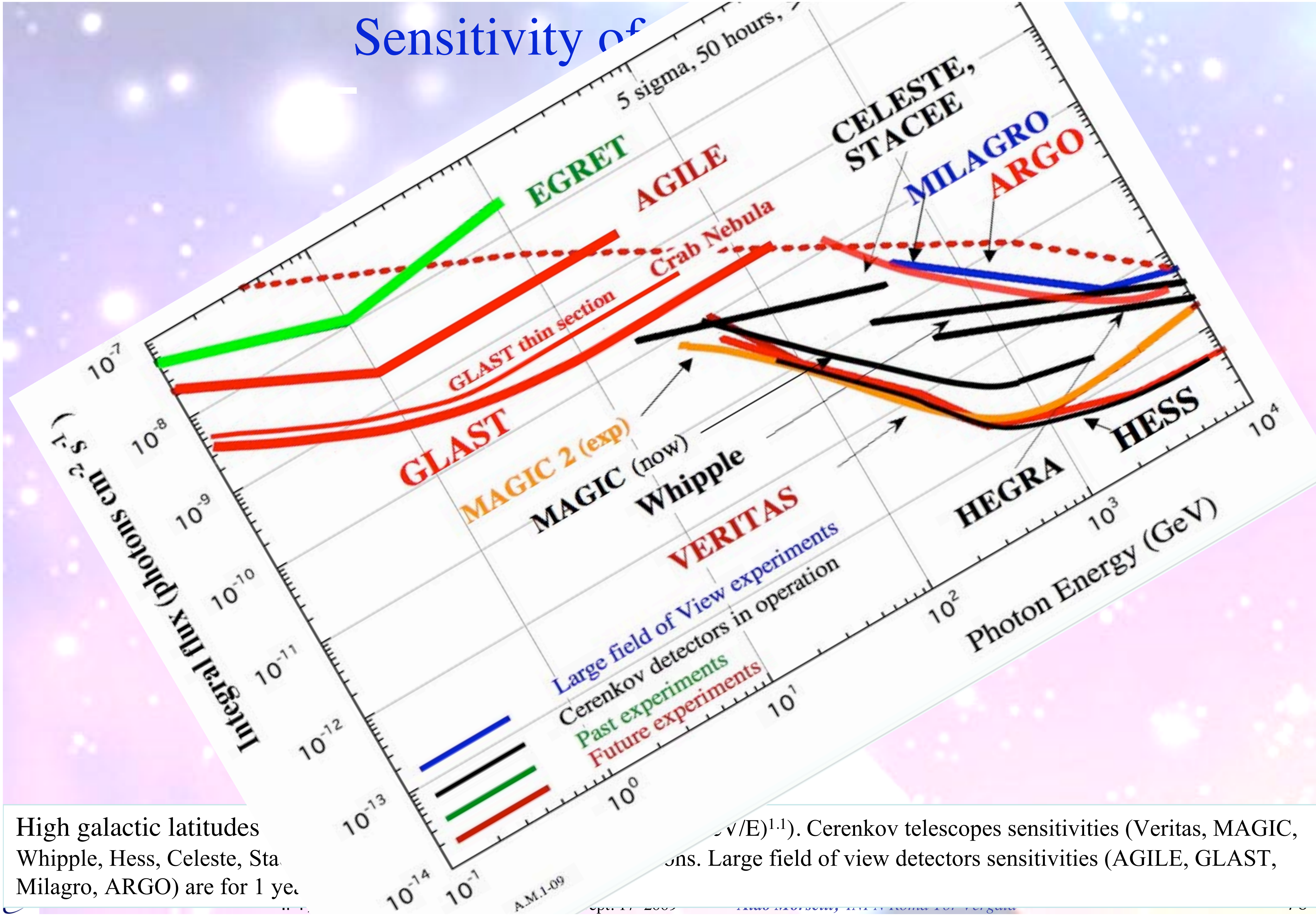
One-year integral sensitivity for the LAT (5σ, E> threshold energy), for a high latitude point source with an E^{-2} spectrum.

Sensitivity of γ-ray detectors



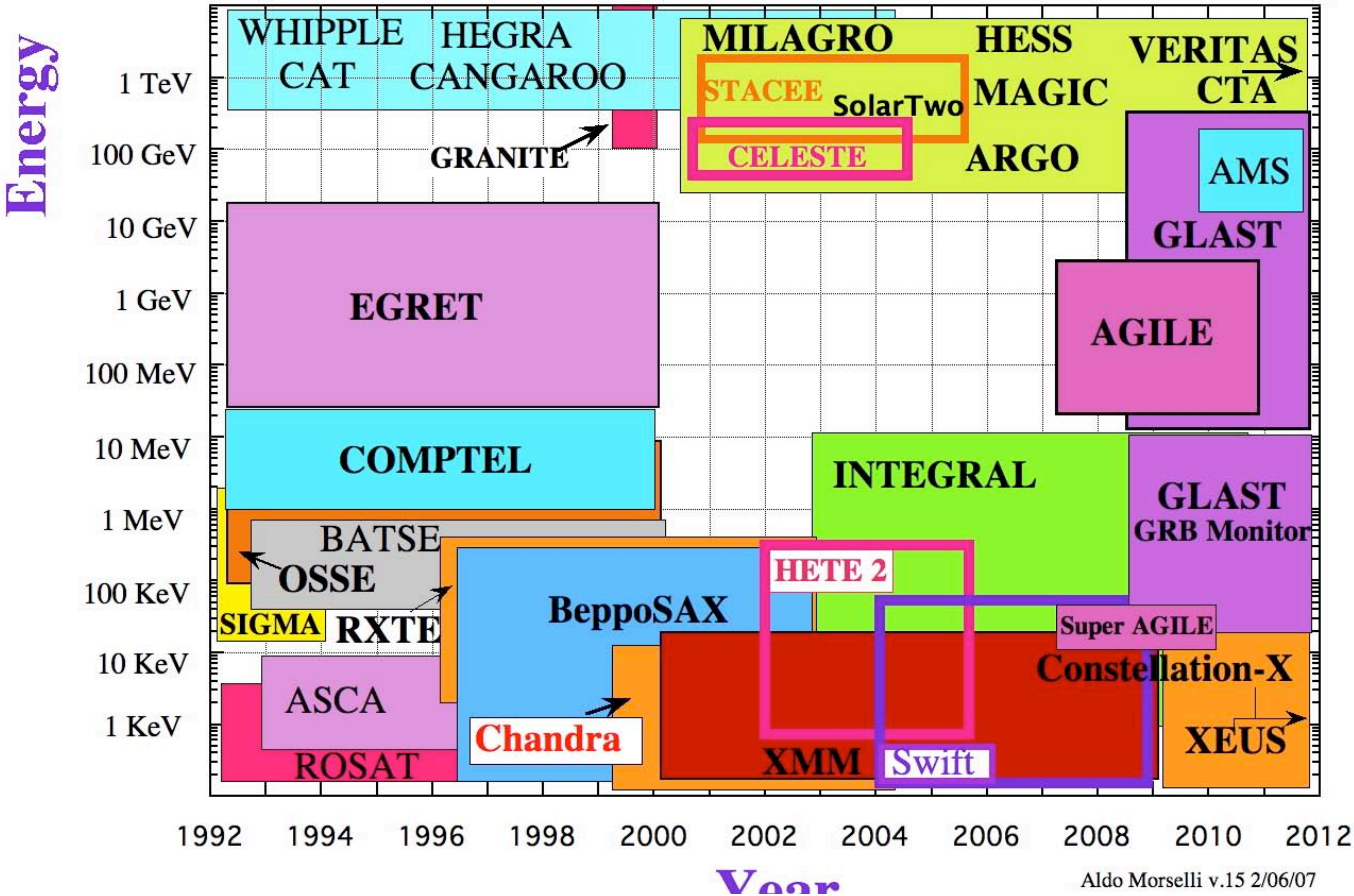
High galactic latitudes (background $\Phi_b = 2\ 10^{-5}\ \gamma\ cm^{-2}\ s^{-1}\ sr^{-1}\ (100\ MeV/E)^{1.1}$). Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations. Large field of view detectors sensitivities (AGILE, GLAST, Milagro,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

Sensitivity of



High galactic latitudes … V/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



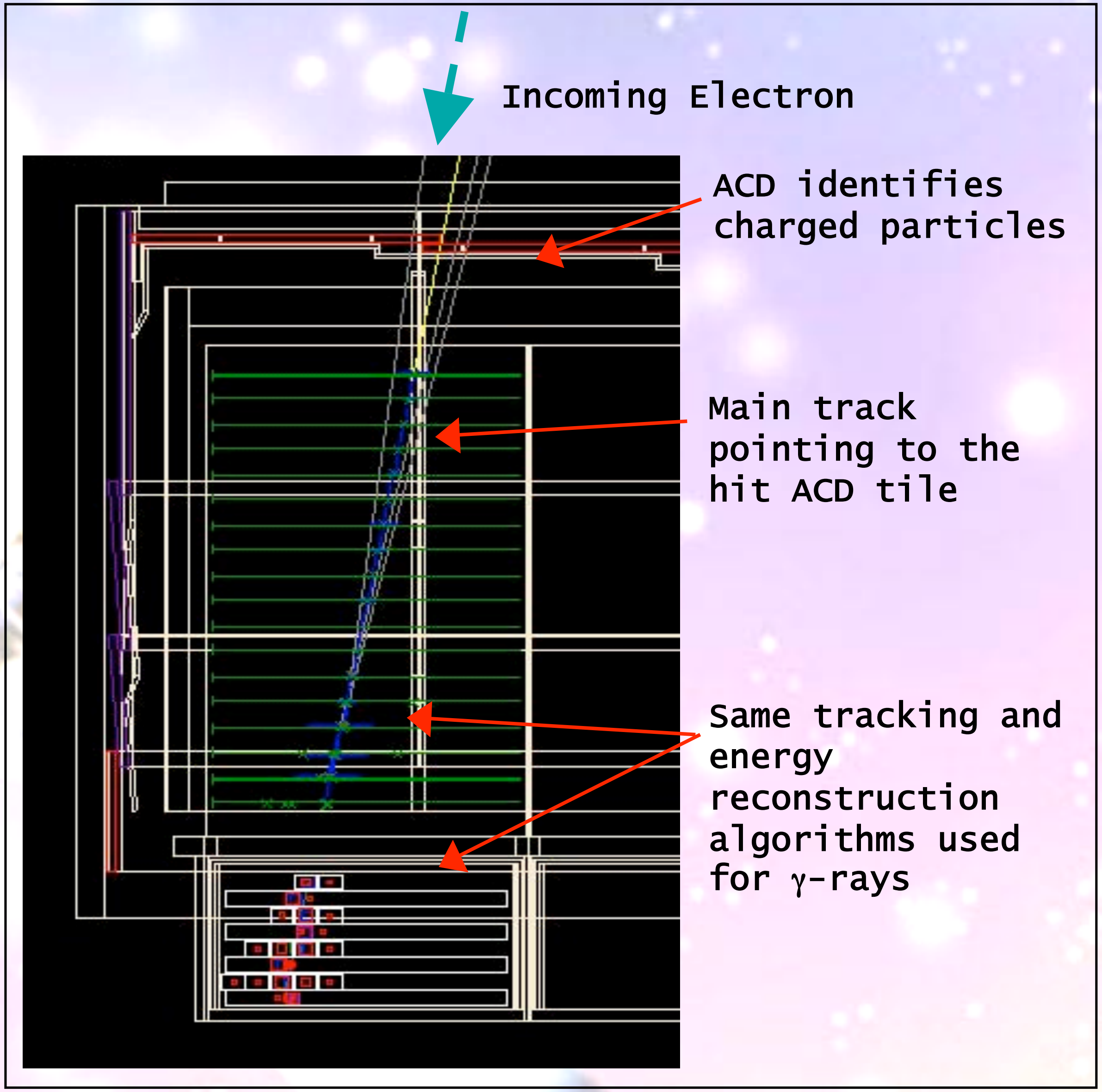
How Fermi LAT detects electrons

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

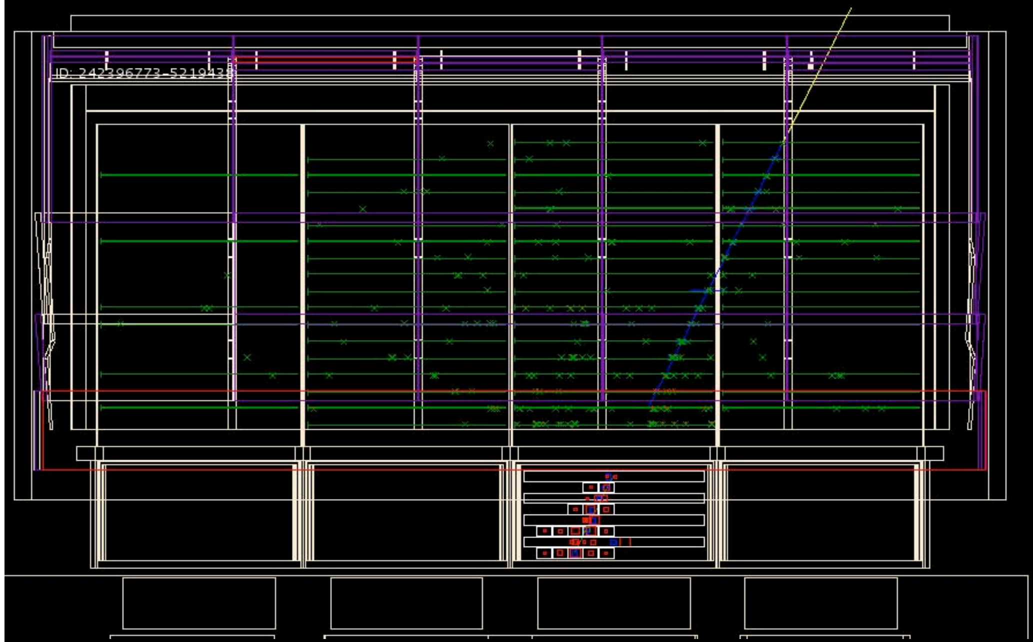
Electron identification

- 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



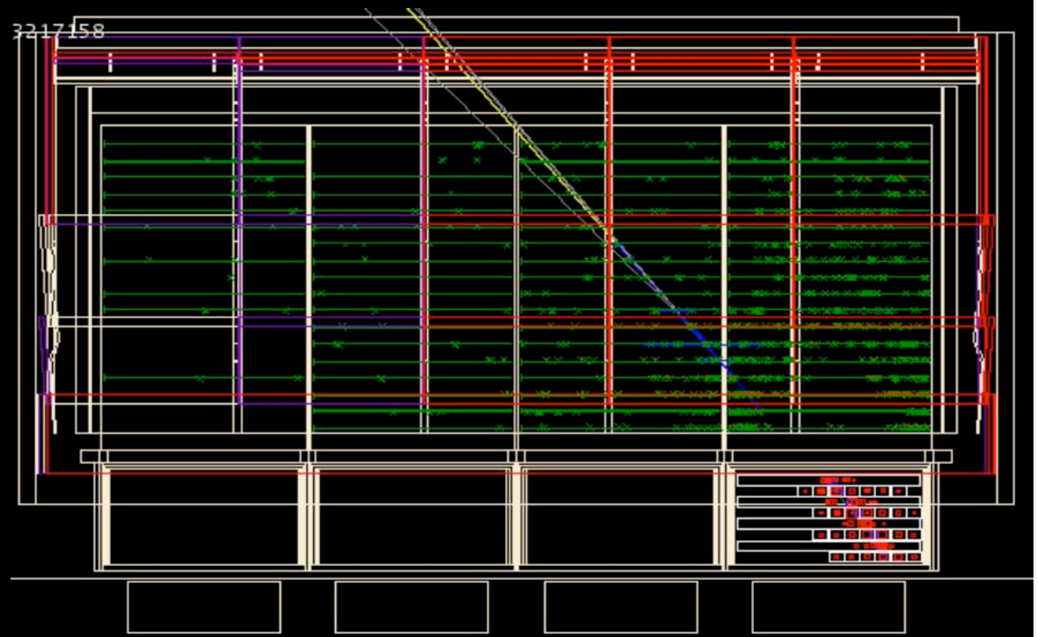
Event topology

A candidate electron (recon energy 844 GeV)



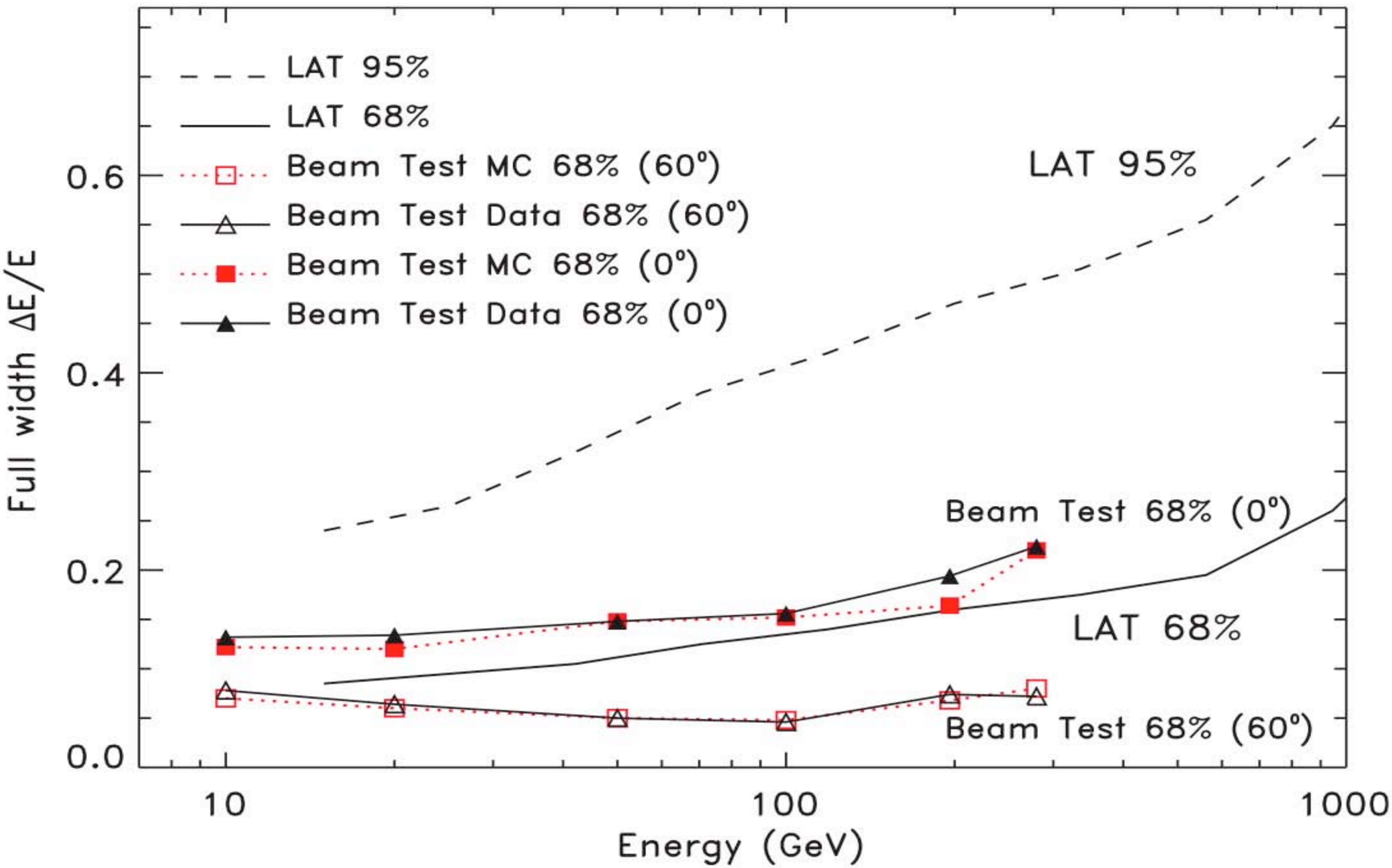
- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

A candidate hadron (raw energy > 800 GeV)



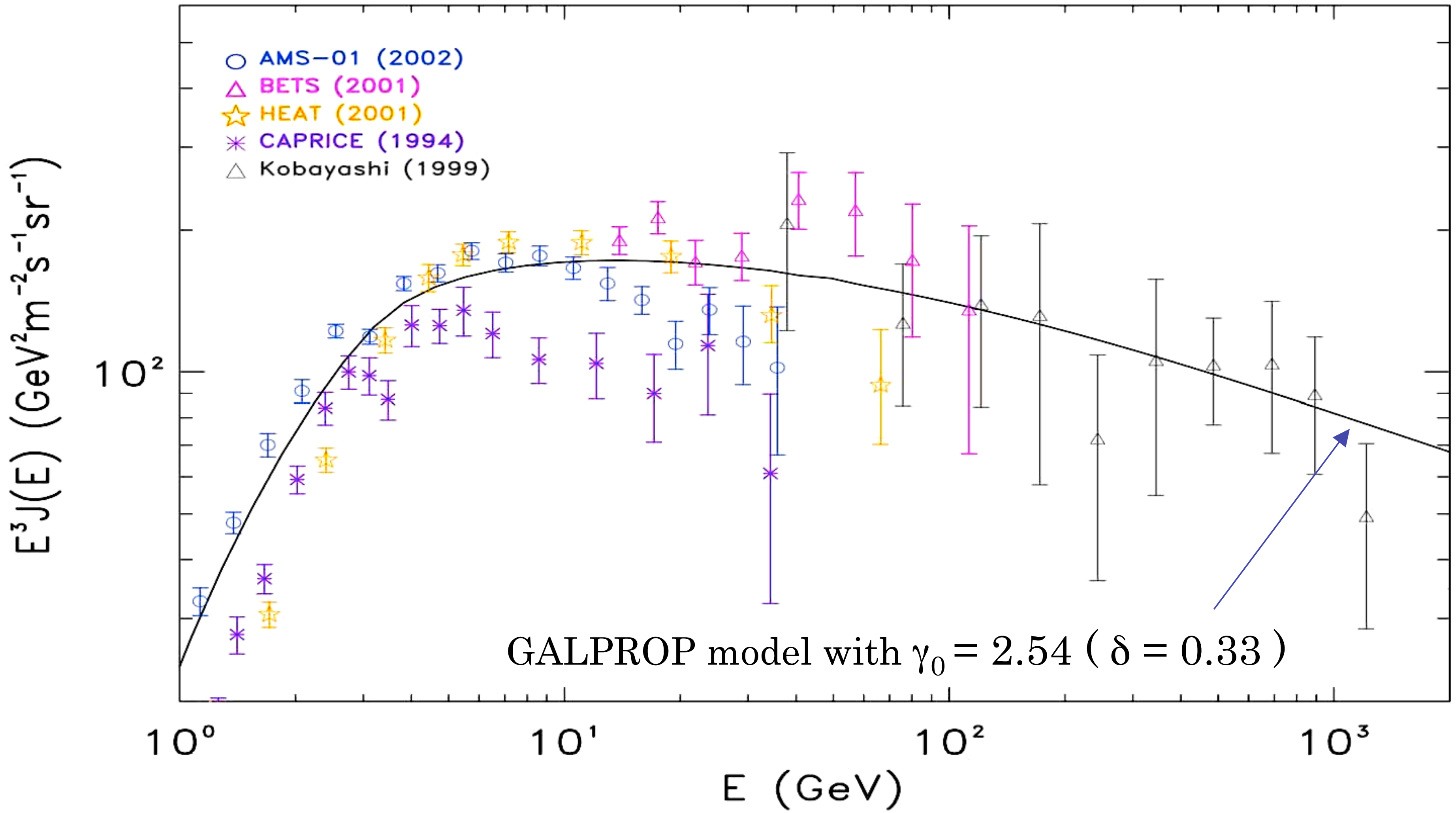
- TKR: small number of extra clusters around main track
- CAL: large and asymmetric shower profile
- ACD: large energy deposit per tile

Fermi LAT Energy resolution for electrons



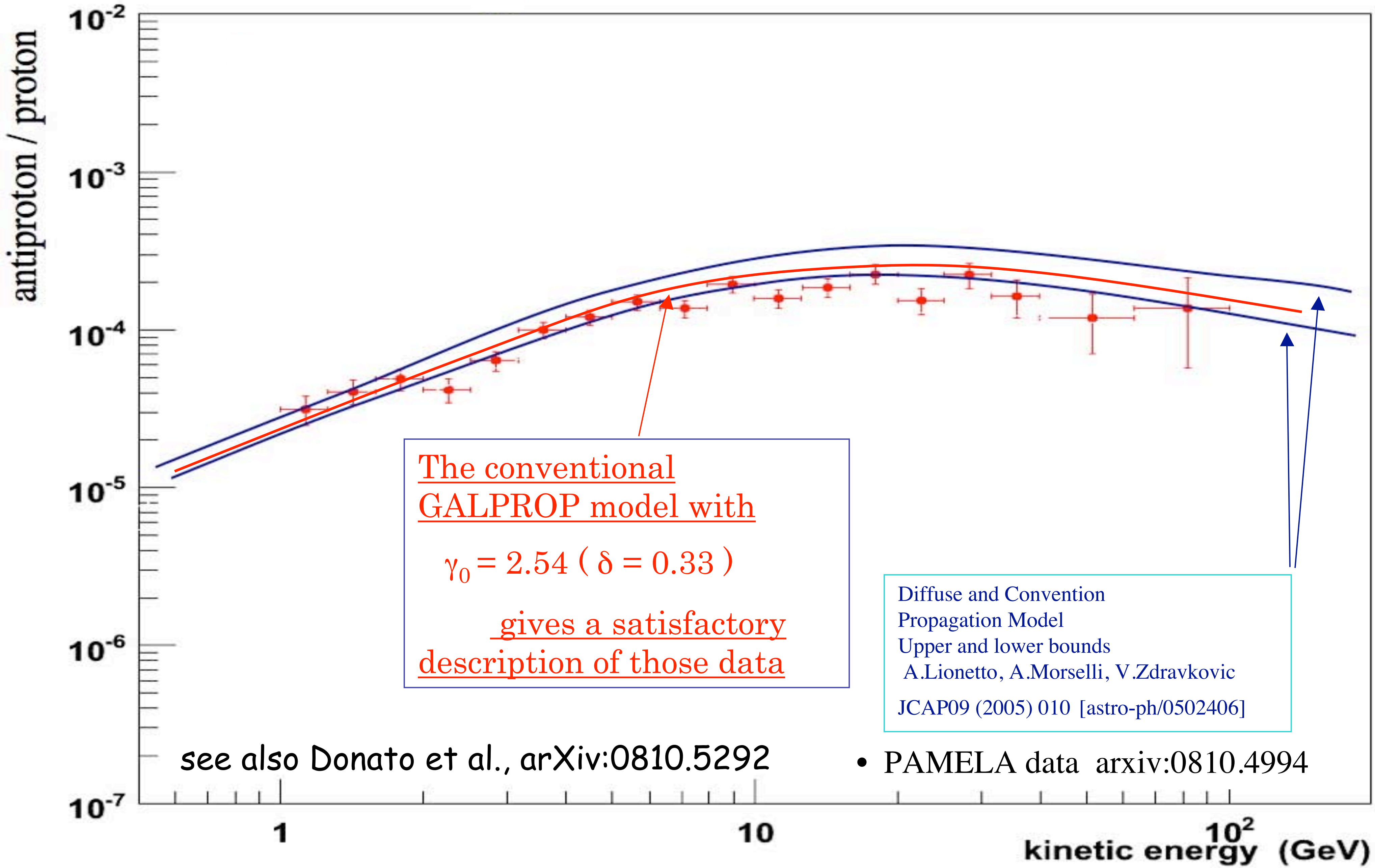
The situation before 2008

Electron + positron spectrum

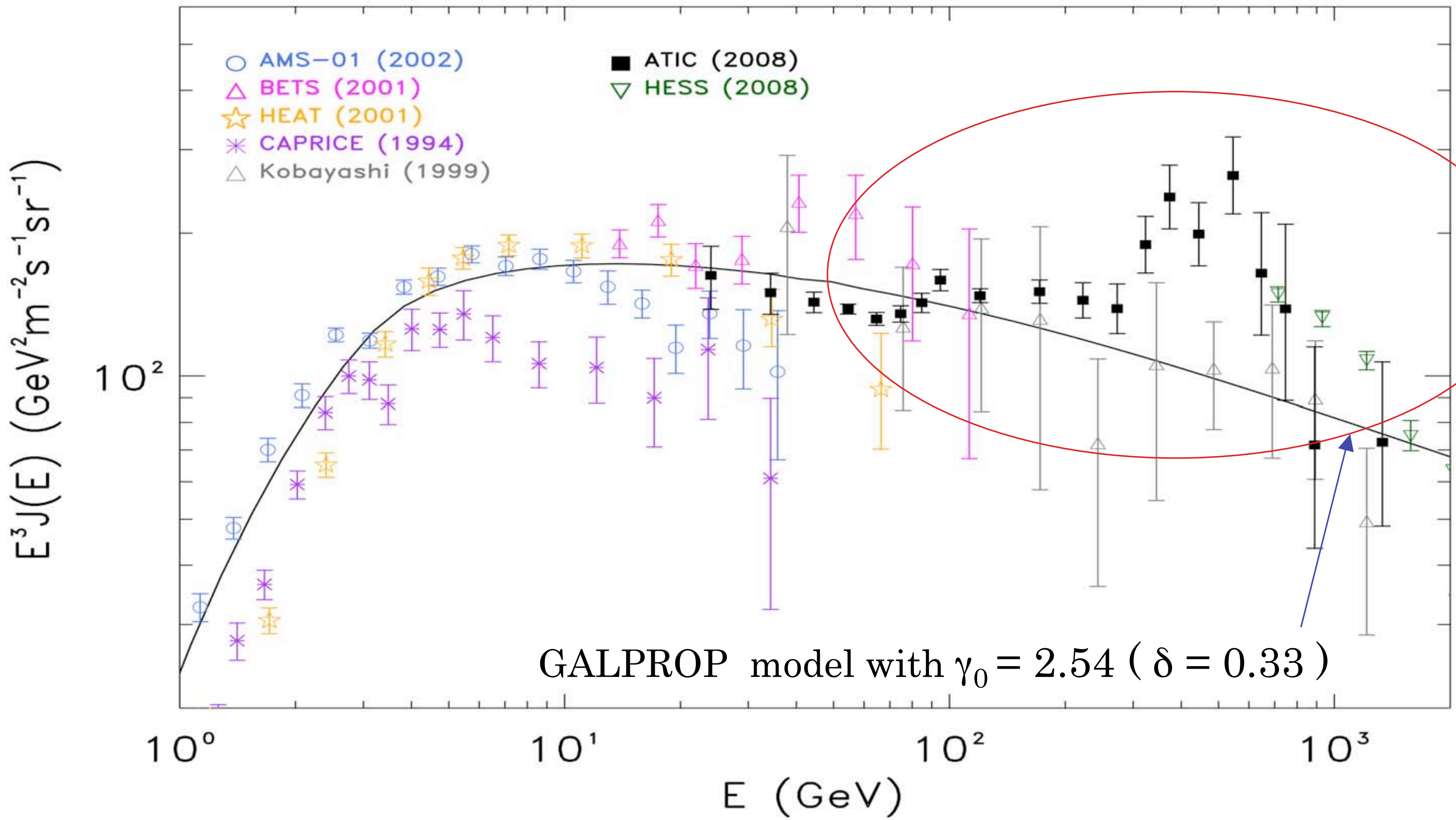


Data were compatible with conventional large-scale Galactic models of CRs tuned to fit gamma-ray data and other observables

Antiproton-Proton Ratio

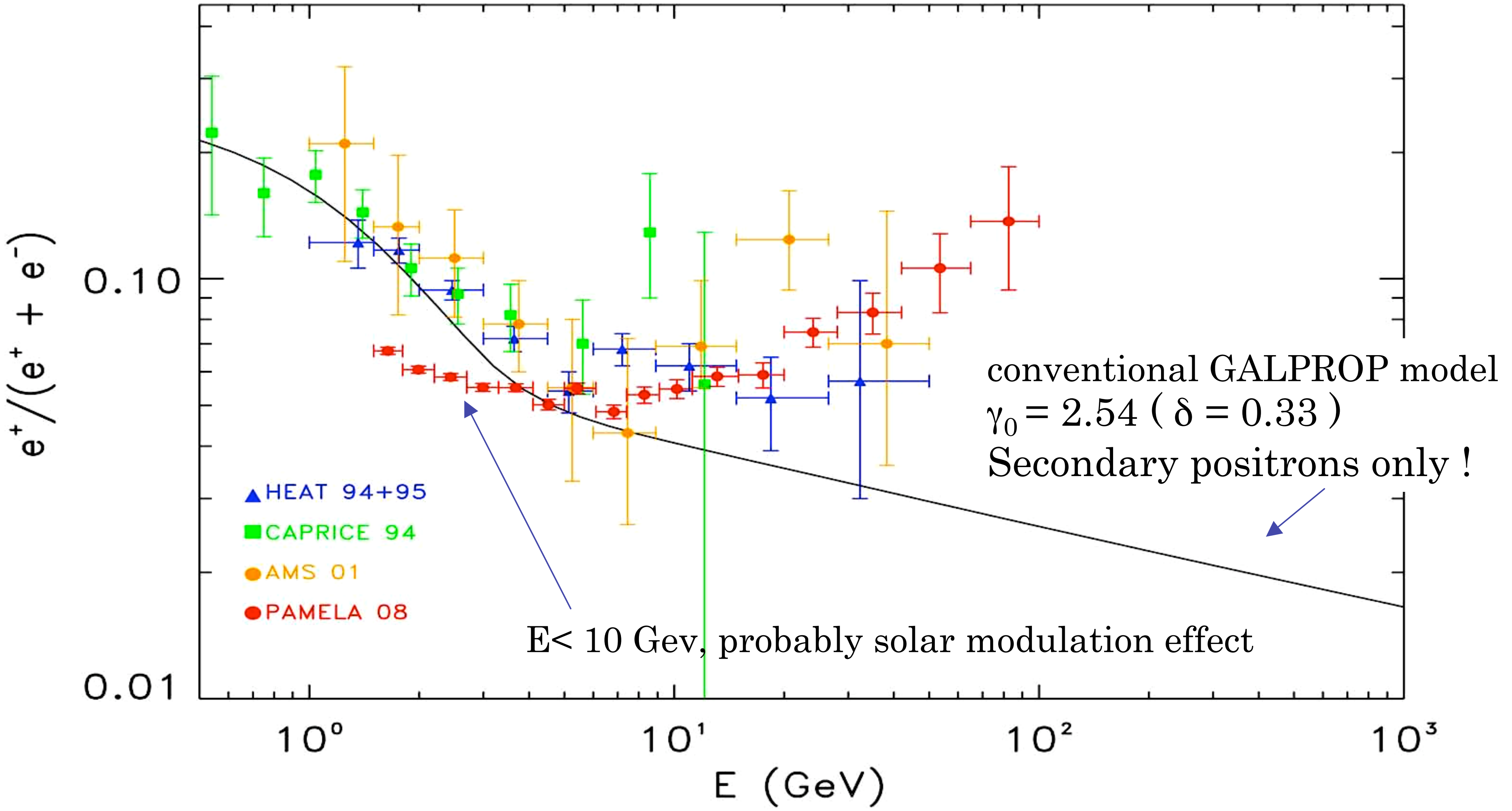


2008: Results from ATIC and HESS



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



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

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

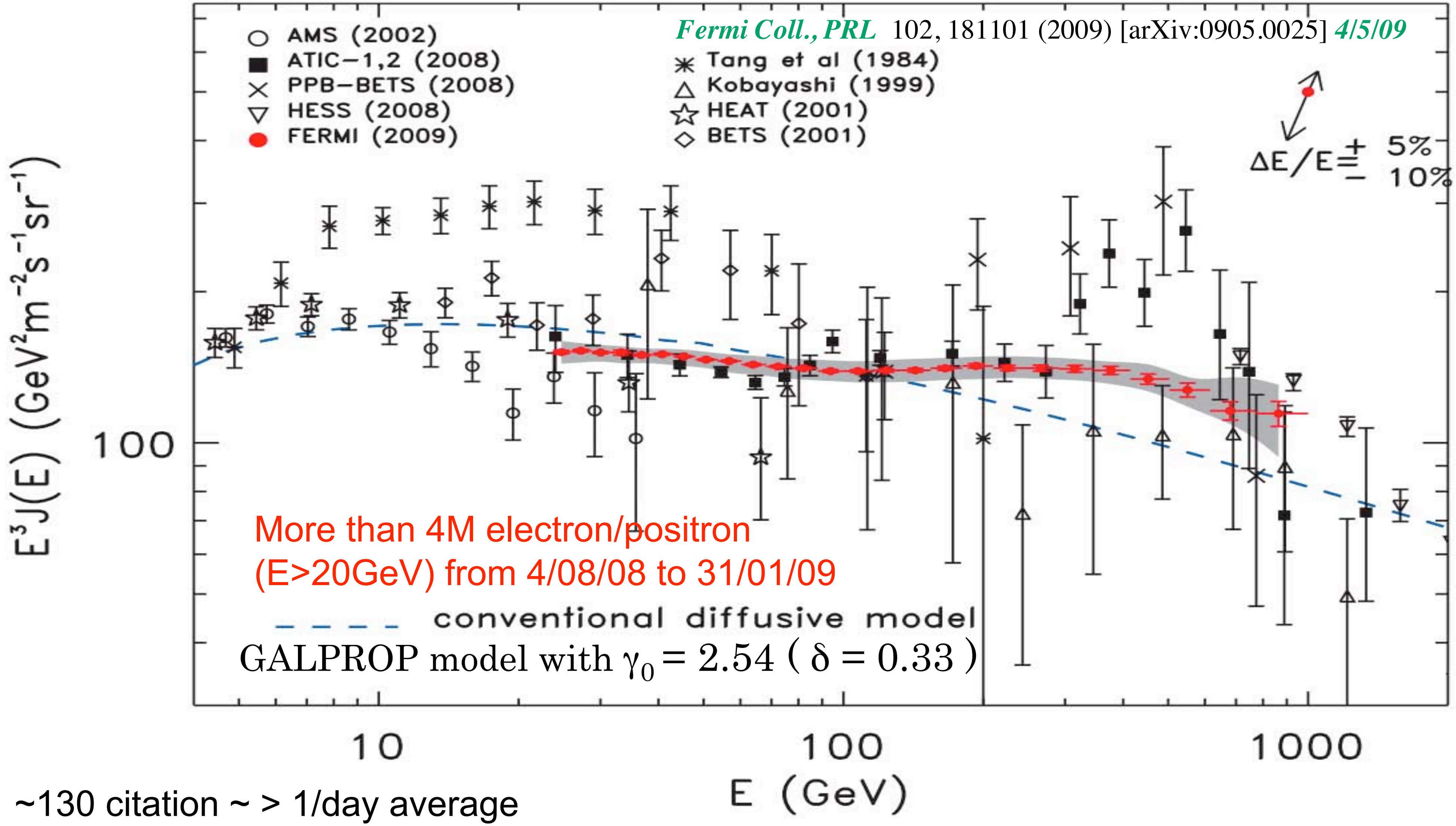
some articles about the positron excess

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

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



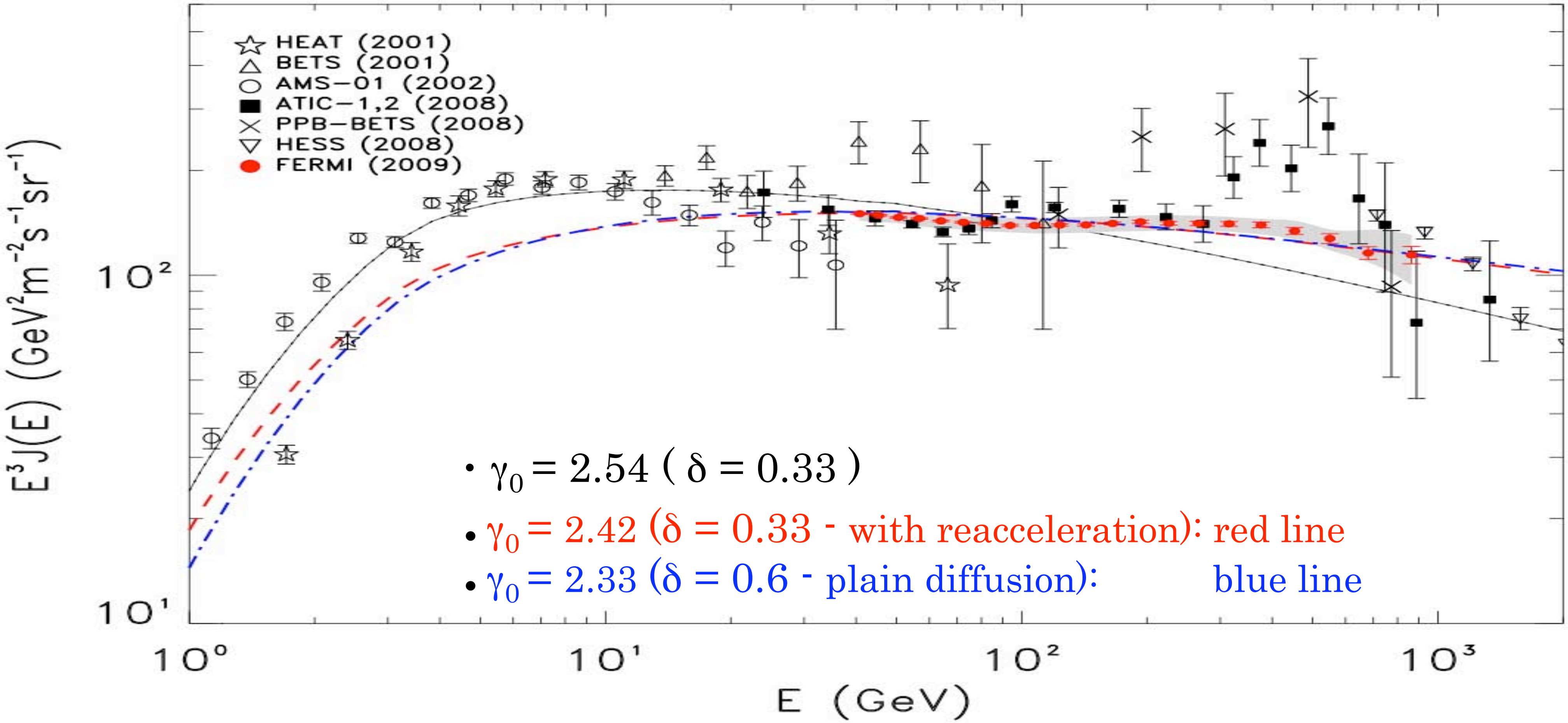
~130 citation ~ > 1/day average

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

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

Fermi Gamma-ray Space Telescope

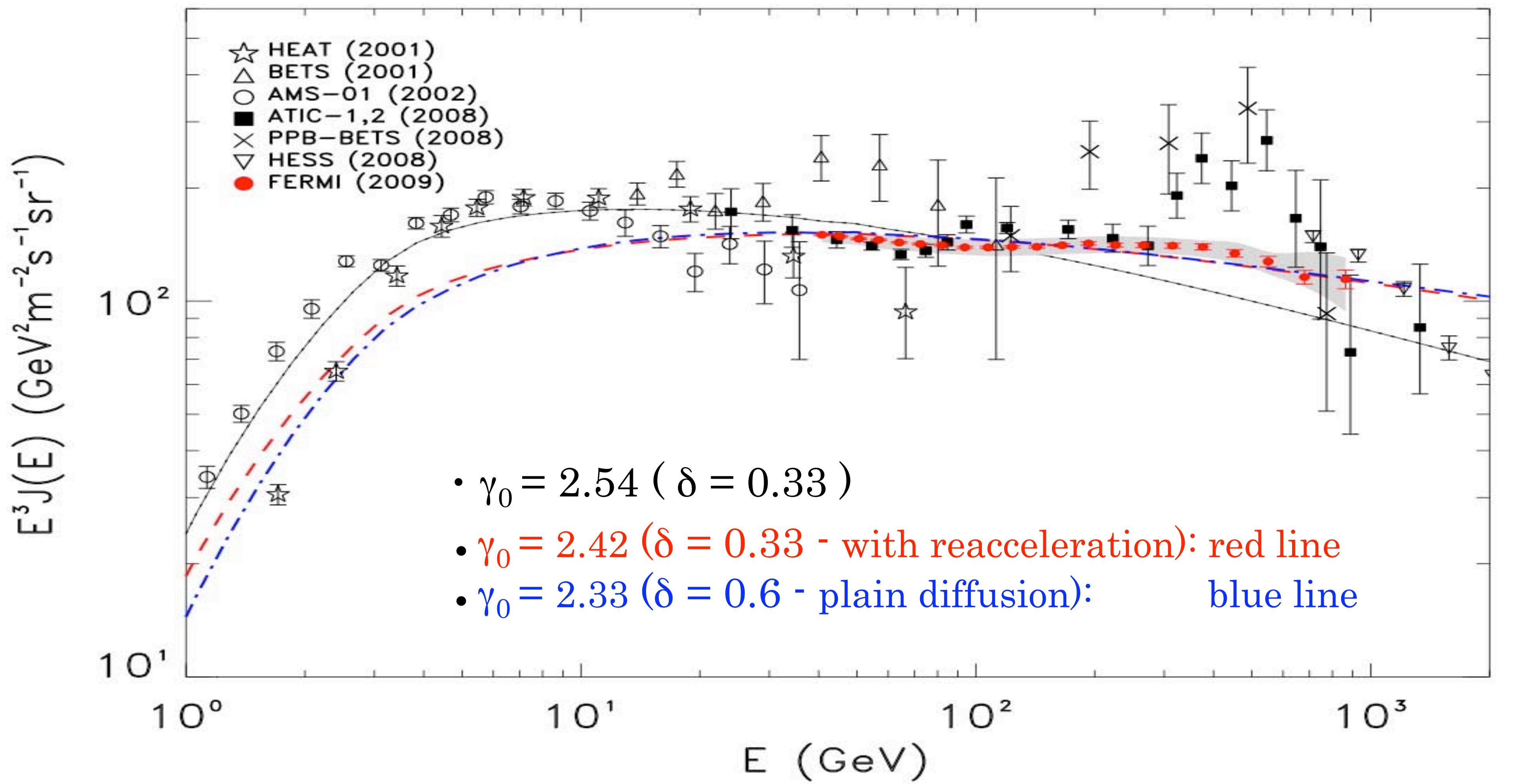
Cosmic Ray Electron propagation models



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

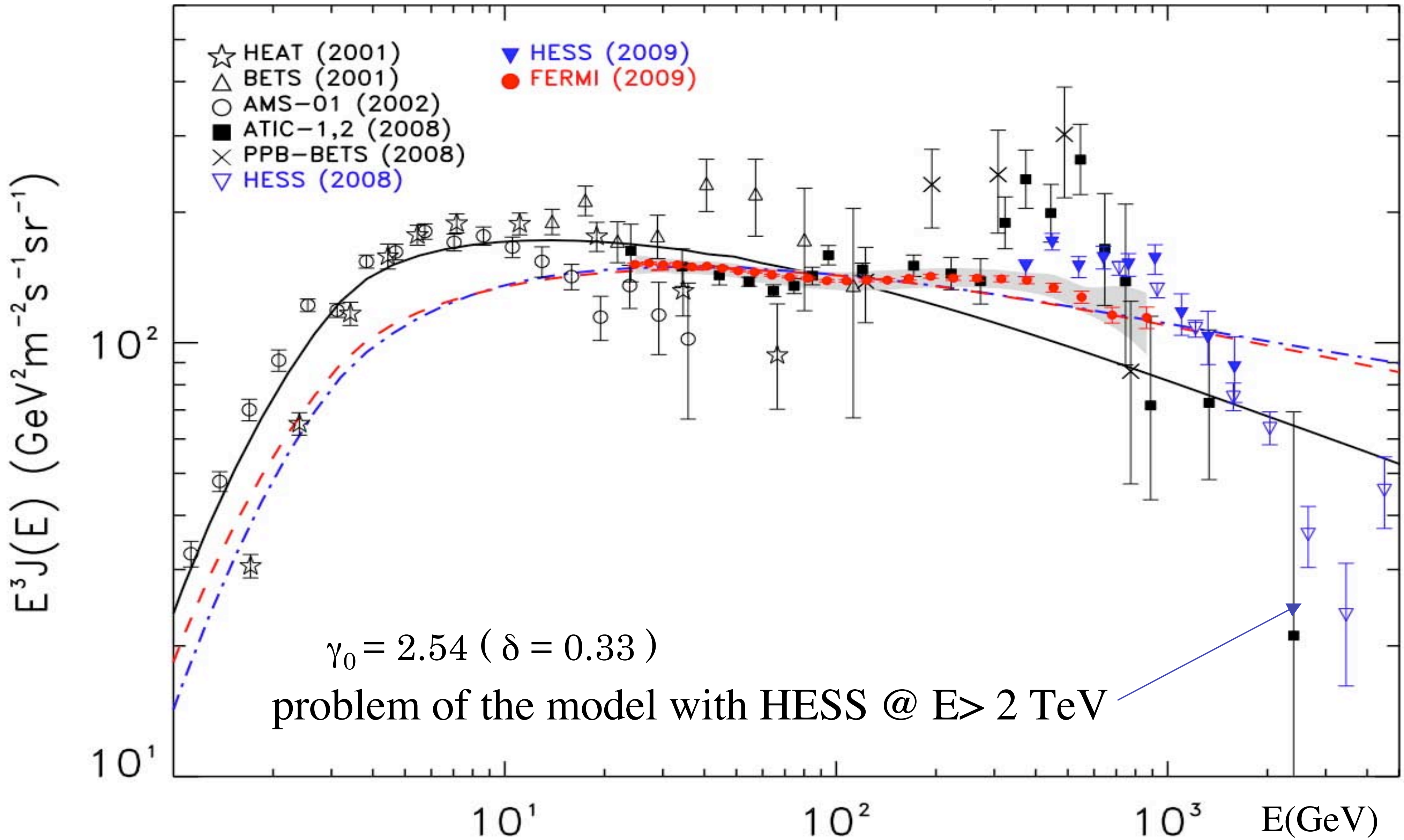


Numerical models of propagation of CR electrons can be tuned to fit Fermi data assuming an **harder injection index**:

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

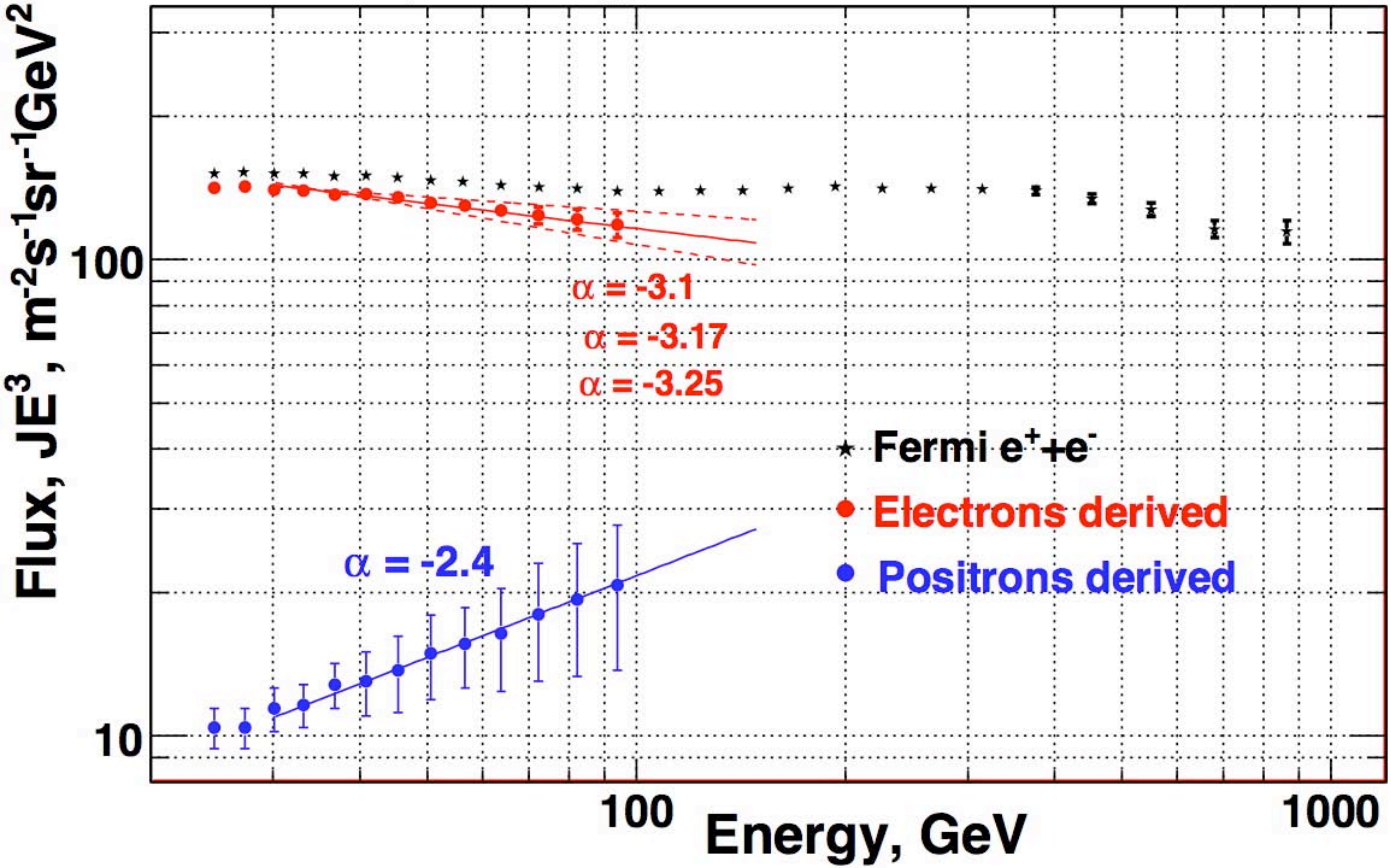
Fermi Gamma-ray Space Telescope

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



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

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

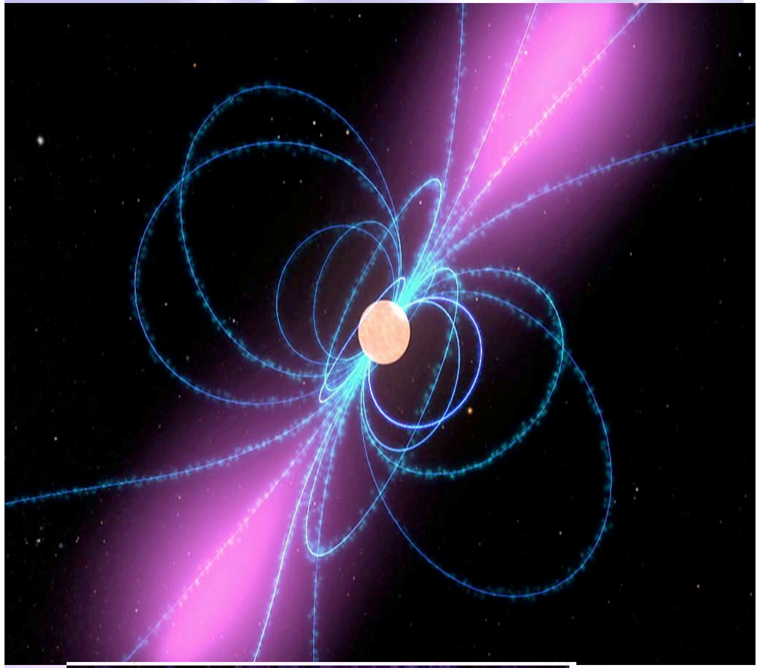
Argonne National Laboratory and University of Chicago Chicago, Illinois

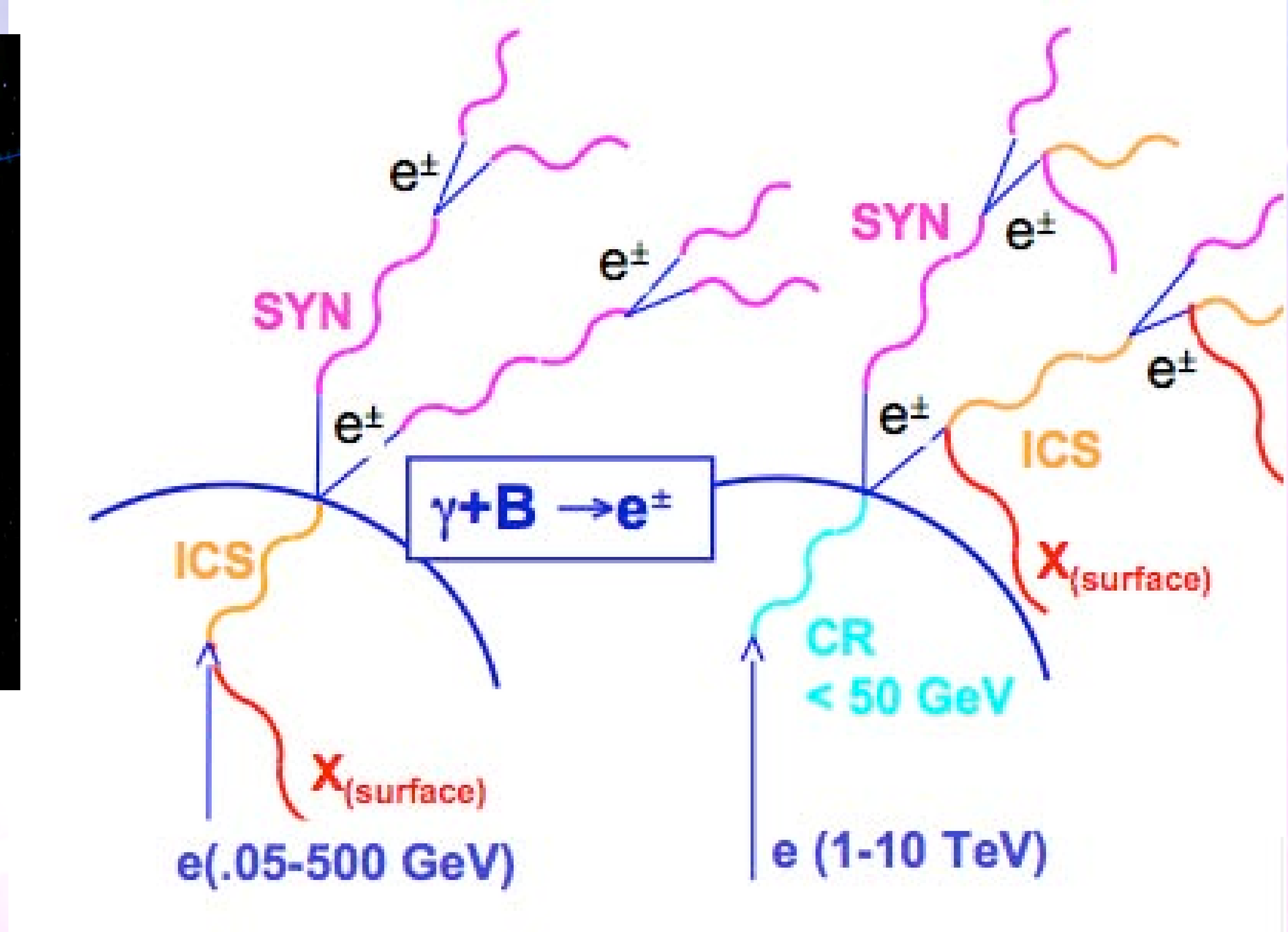
nent. In 1963, *DeShong, Hildebrand, and Meyer* [1964] reported the results of an experiment designed to measure this ratio in the energy interval from 100 to 1000 Mev. They found an excess of negative electrons which led them to conclude that the electron component consists mainly of directly accelerated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

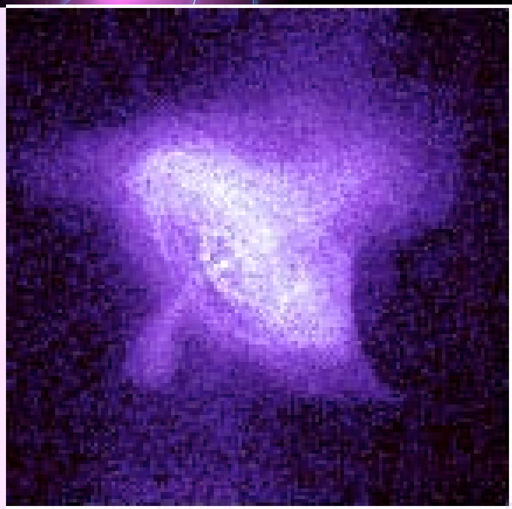
- Now, ~45 years later PAMELA excess in positron fraction and Fermi results on the electron+positron spectrum unavoidably testifies the presence of ***primary positrons*** in CRs

which are the sources of the primary positrons ?

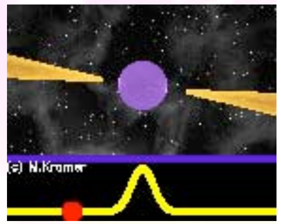
Pulsars as sources of $e^{-/+}$ pairs





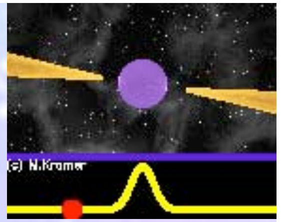


$e^{\pm}$ pairs are produced in the magnetosphere and accelerated by the electric fields and/or the pulsar wind.



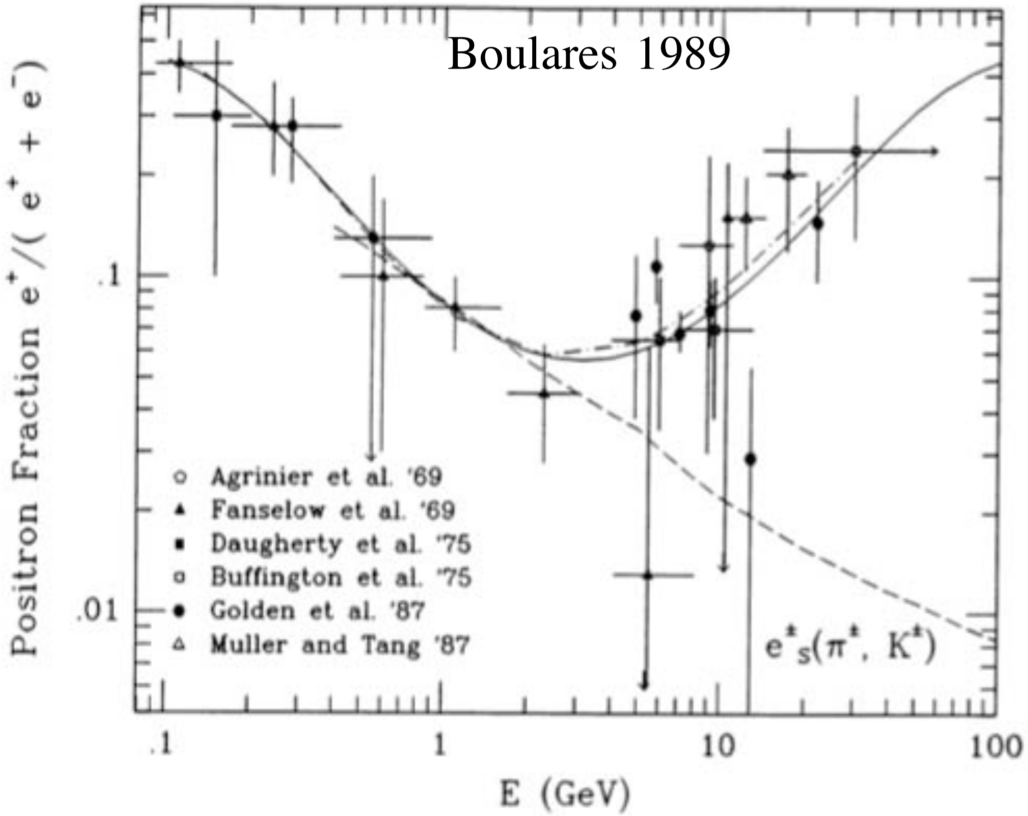
Crab Pulsar Wind Nebula (PWN)

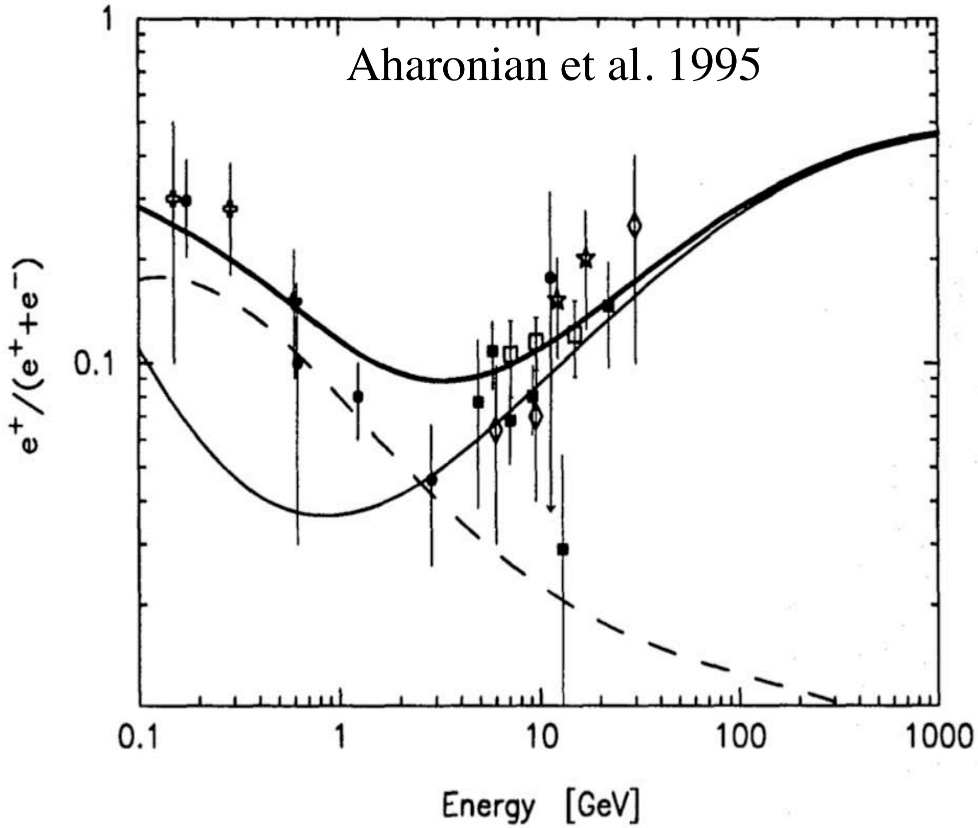
Pulsars as sources of $e^{-/+}$ pairs



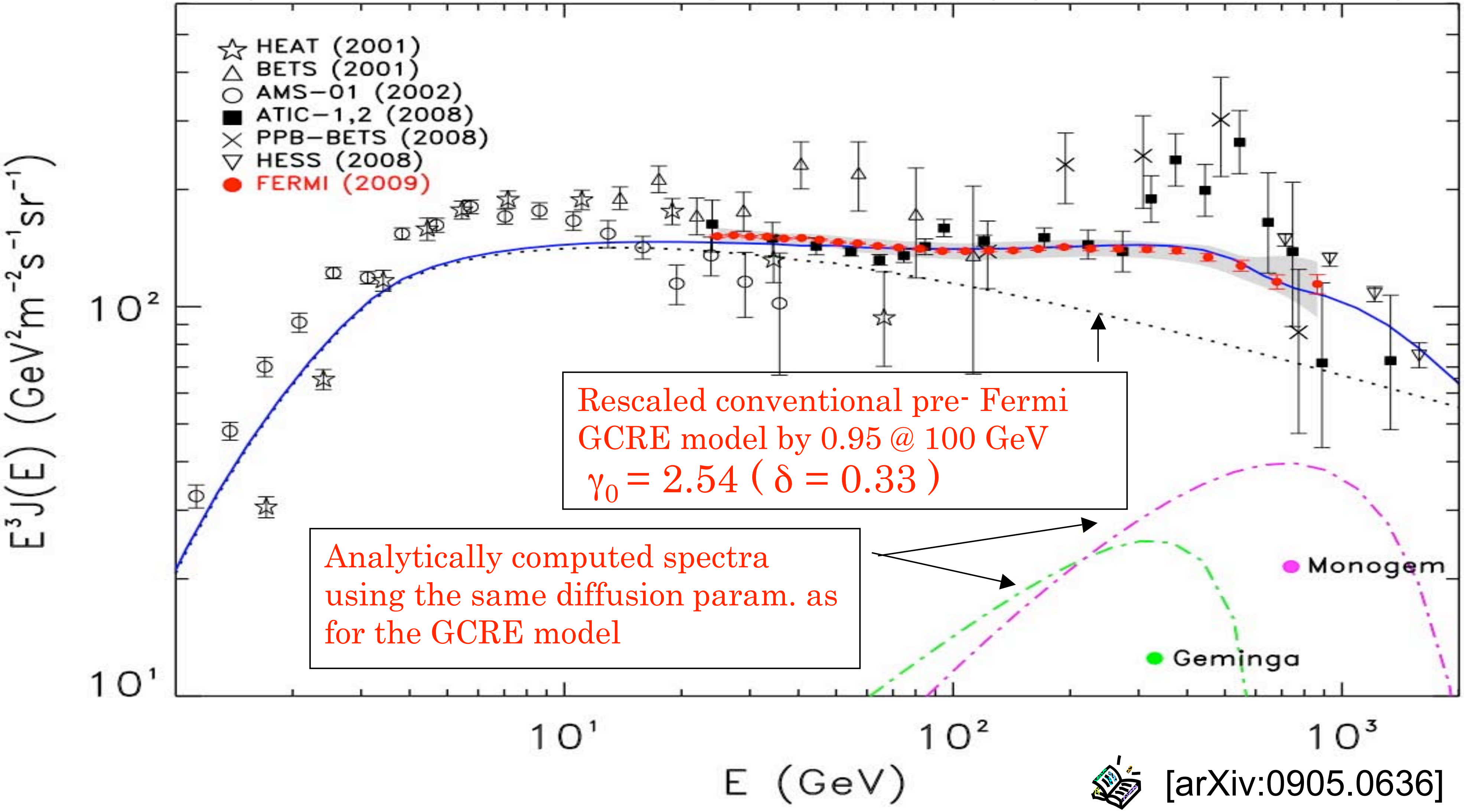
not a new idea

- 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)

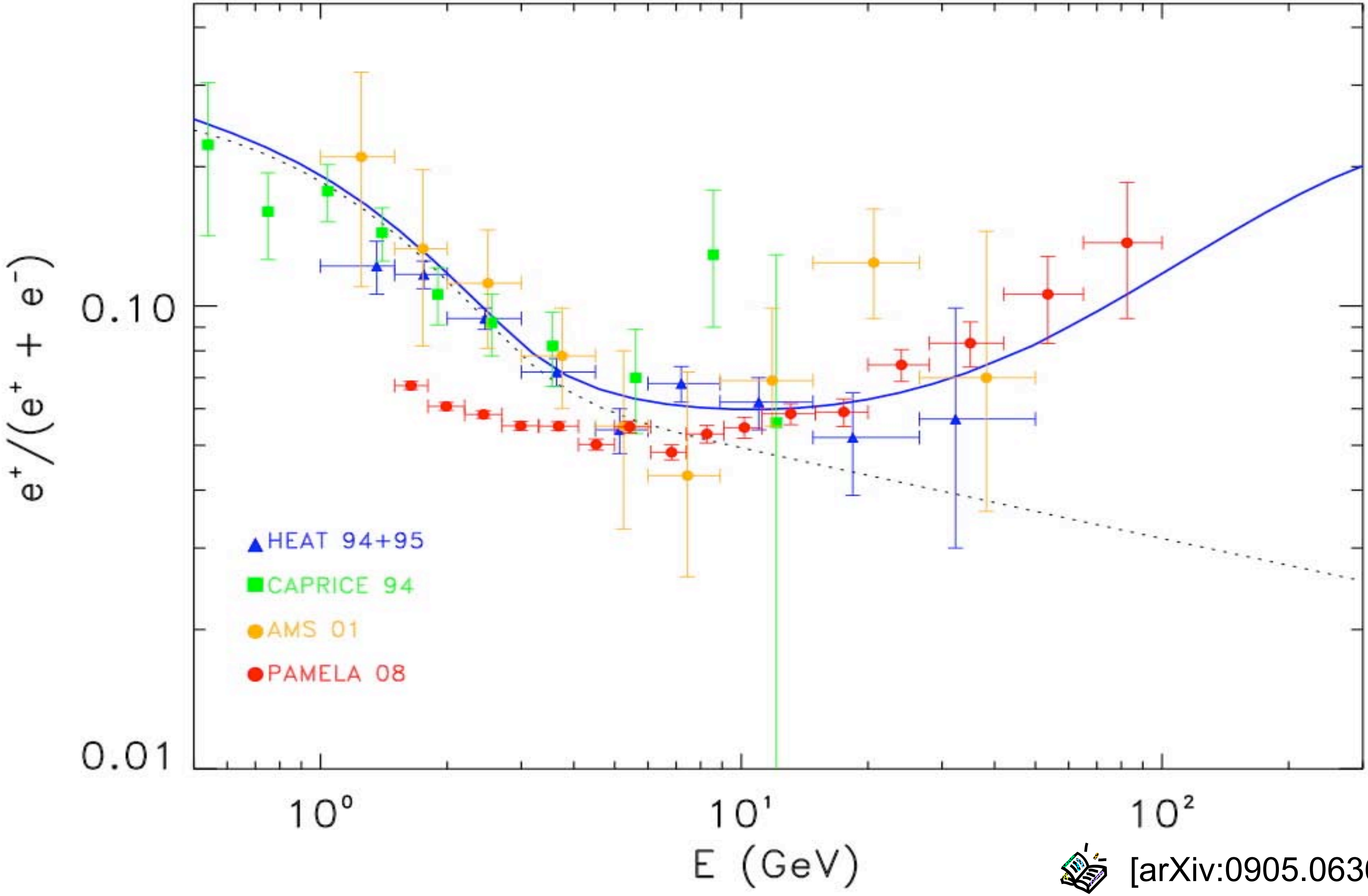


[arXiv:0905.0636]

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

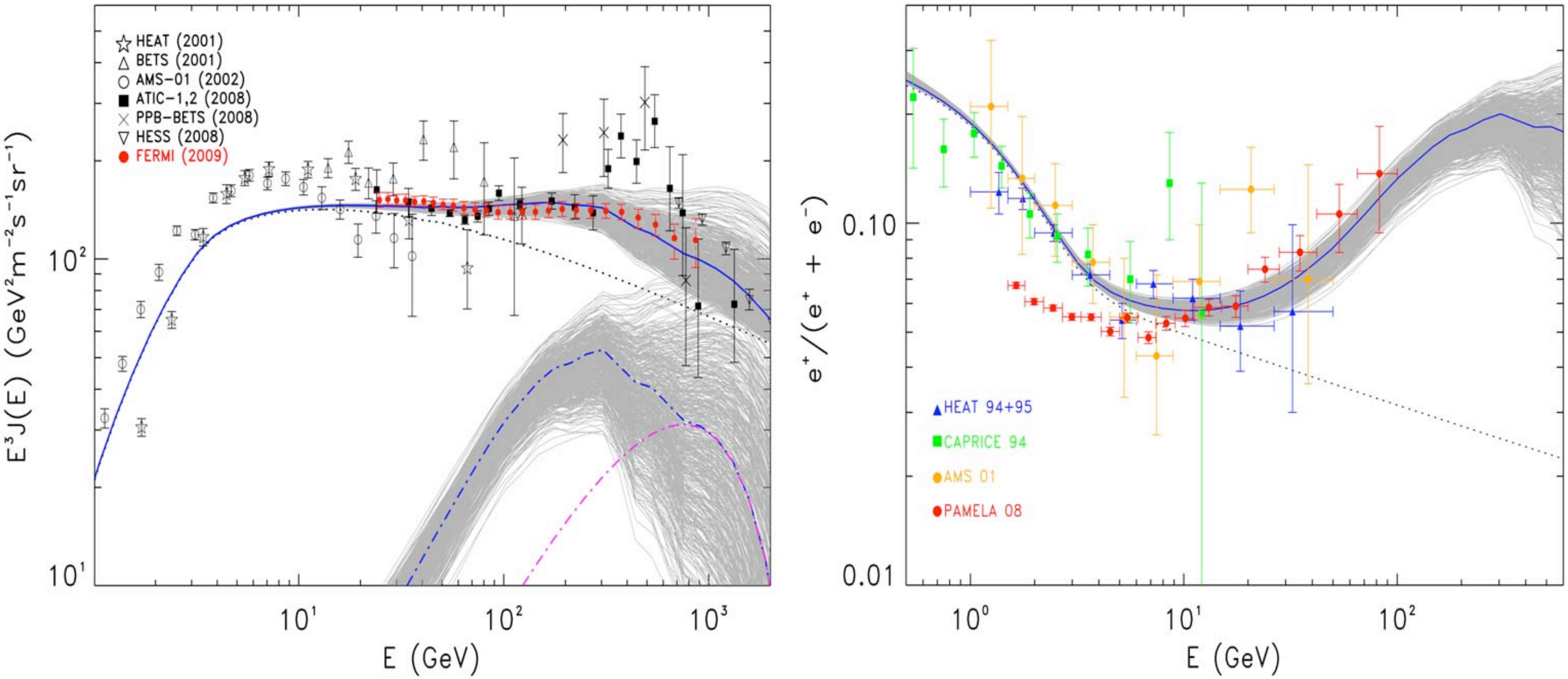
the positron ratio accounting for nearby pulsars (d < 1 kpc)



[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*)

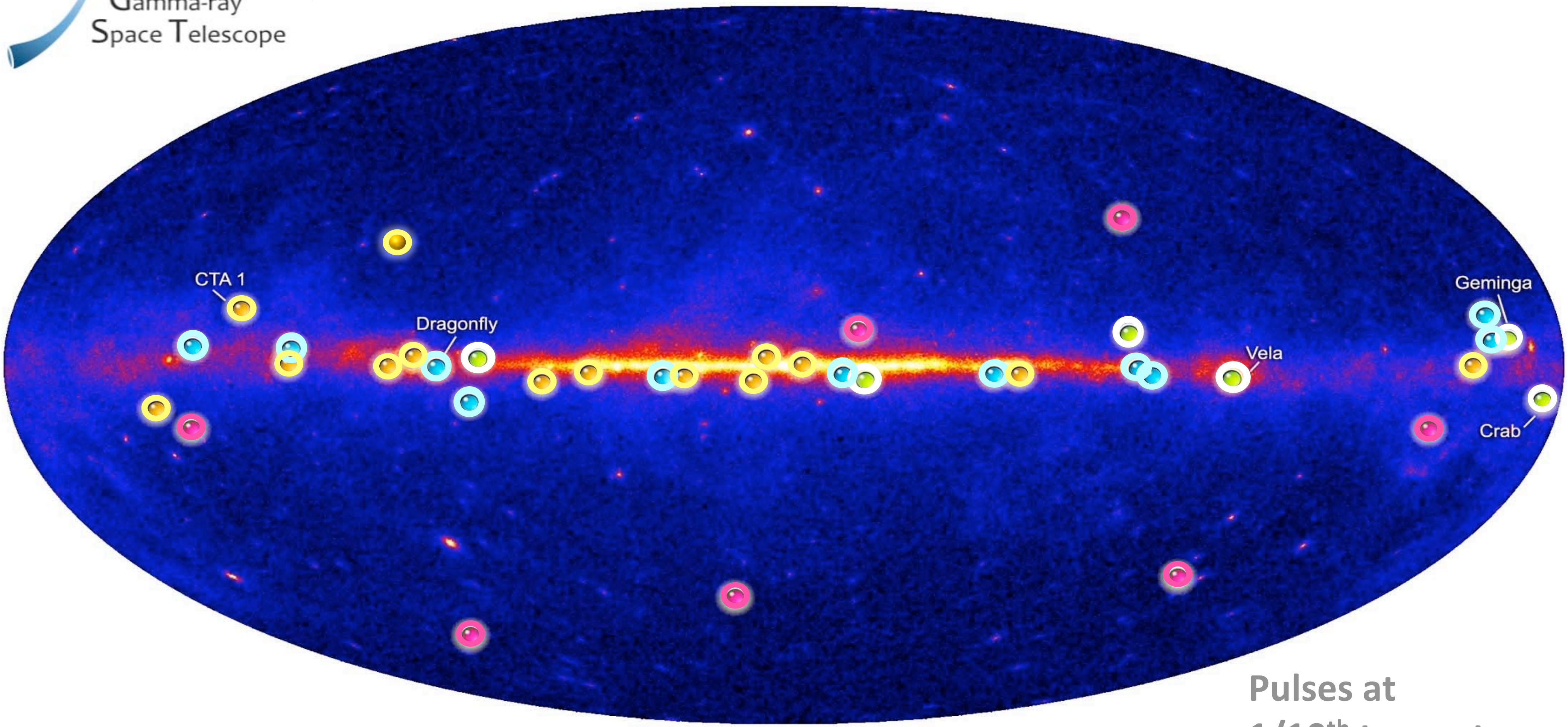


Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

[arXiv:0905.0636]

Gamma-ray Space Telescope

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 1/10th 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


14 August 2009 | $10
Science
Fermi
Detecting Gamma-Ray Pulsars
AAAS

Pulsars

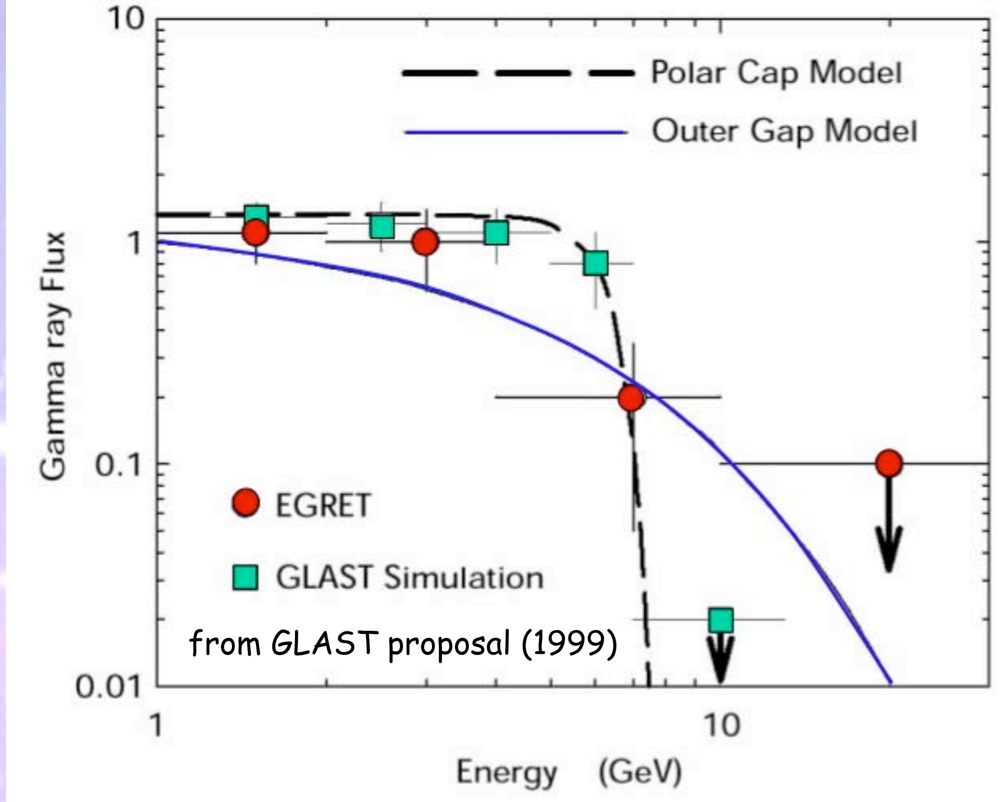
1. On purely energetic grounds they work (relatively large efficiency)

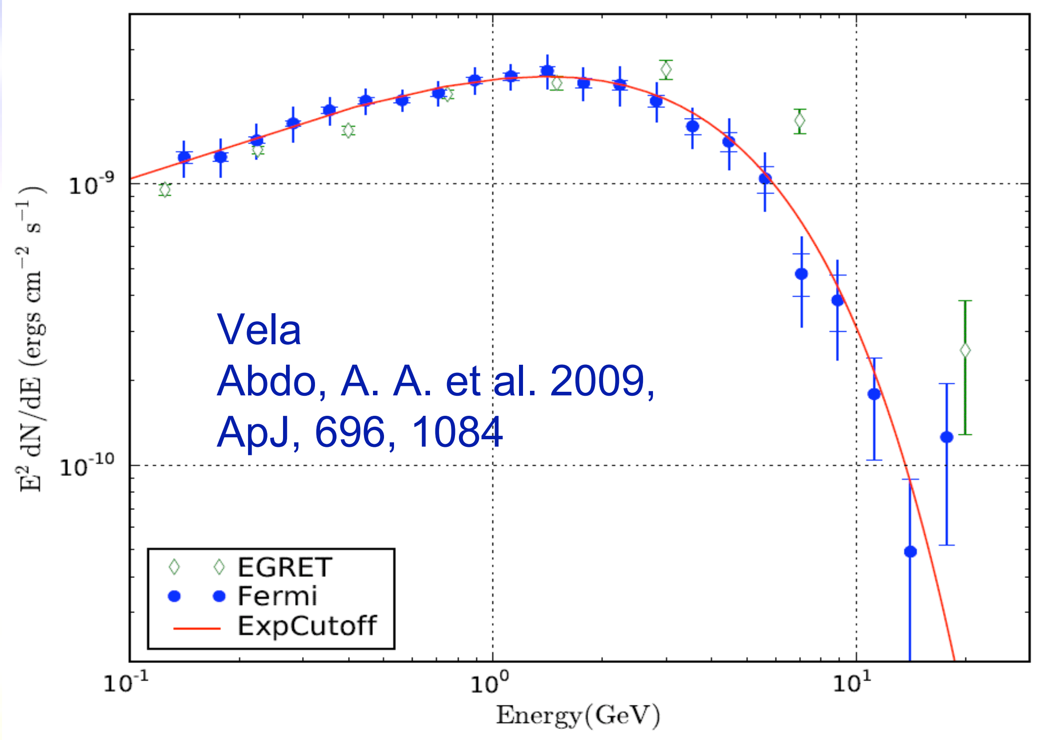
2. On the basis of the spectrum, it is not clear
   1. The spectra of PWN show relatively flat spectra of pairs at Low energies but we do not understand what it is
   2. The general spectra (acceleration at the termination shock) are too steep

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

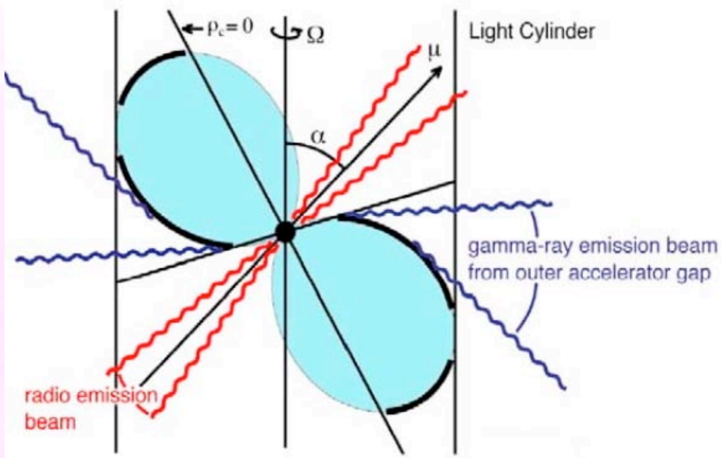
Spectral measurements and emission models

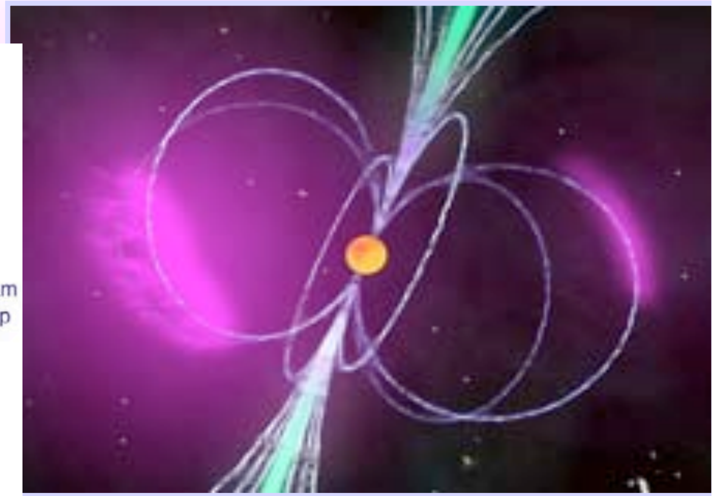




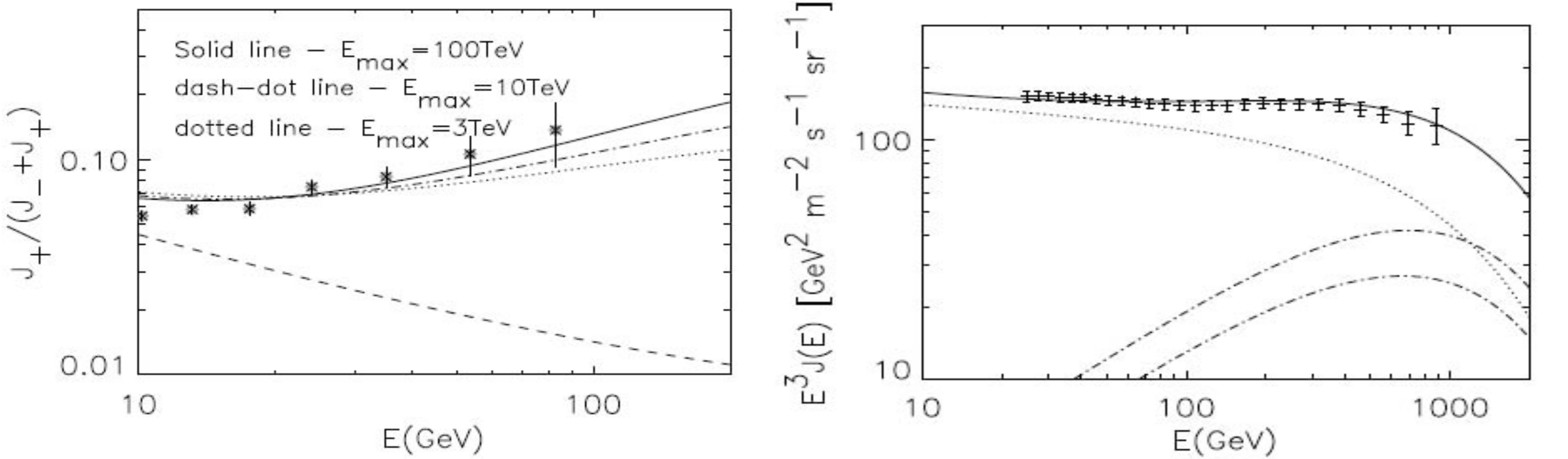
Evidence of γ-ray emission in the outer magnetopshere due to absence of super-exponential cutoff

- Radio and γ-ray fan beams separated
- γ-ray only PSRs





other Astrophysical solution

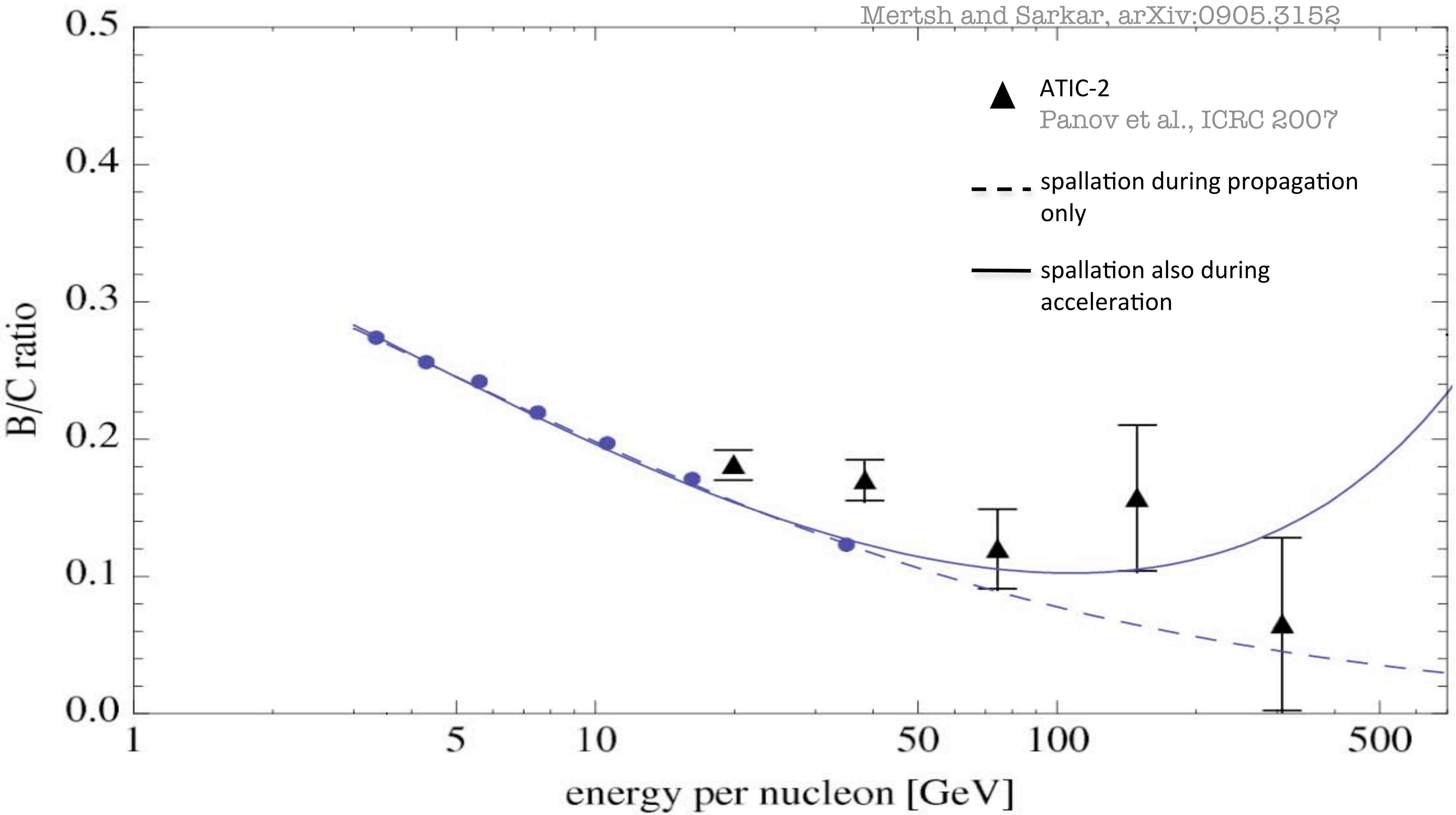


- Positrons created as secondary products of hadronic interactions inside the sources
- Secondary production takes place in the same region where cosmic rays are being accelerated

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

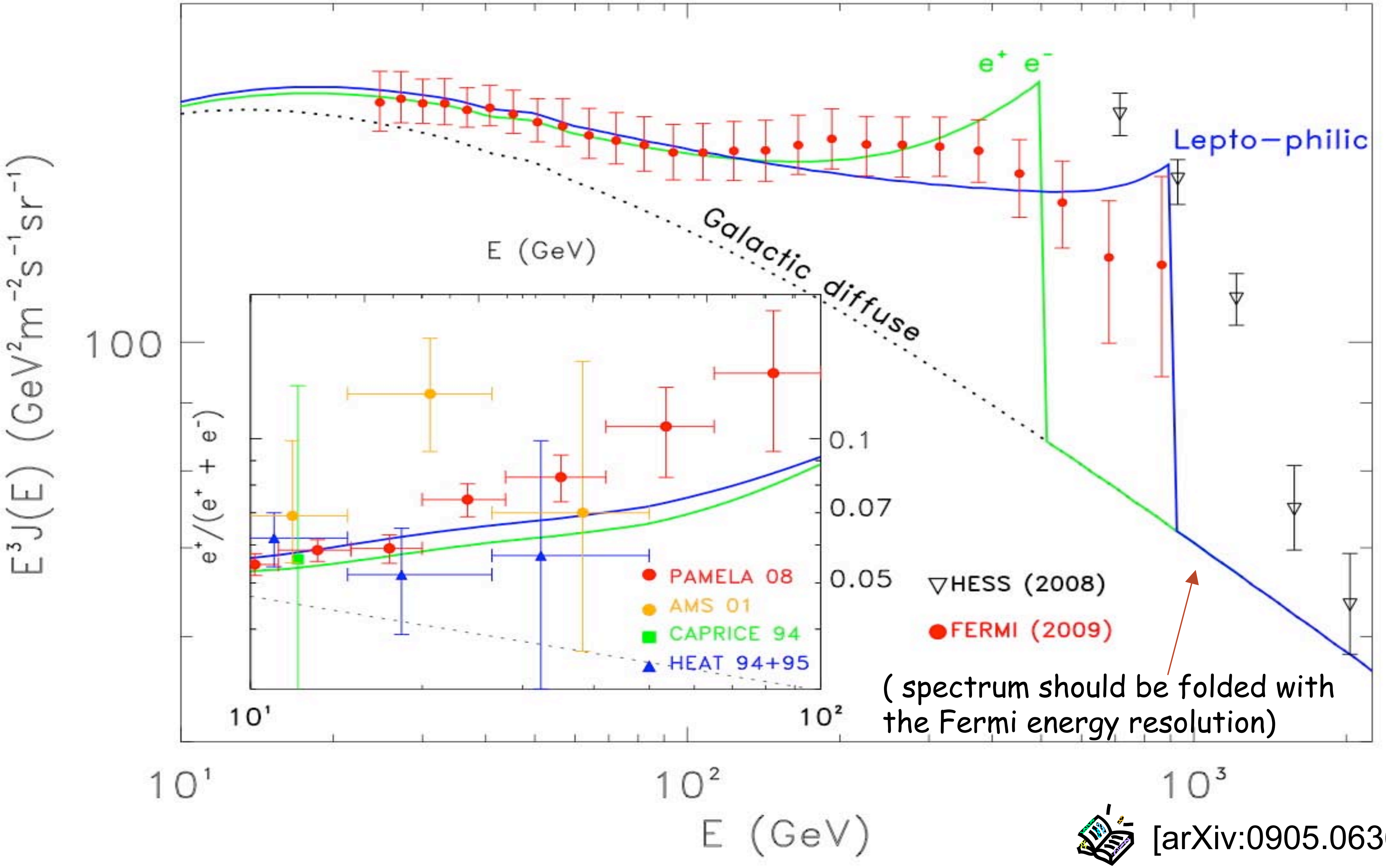
Blasi, arXiv:0903.2794

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

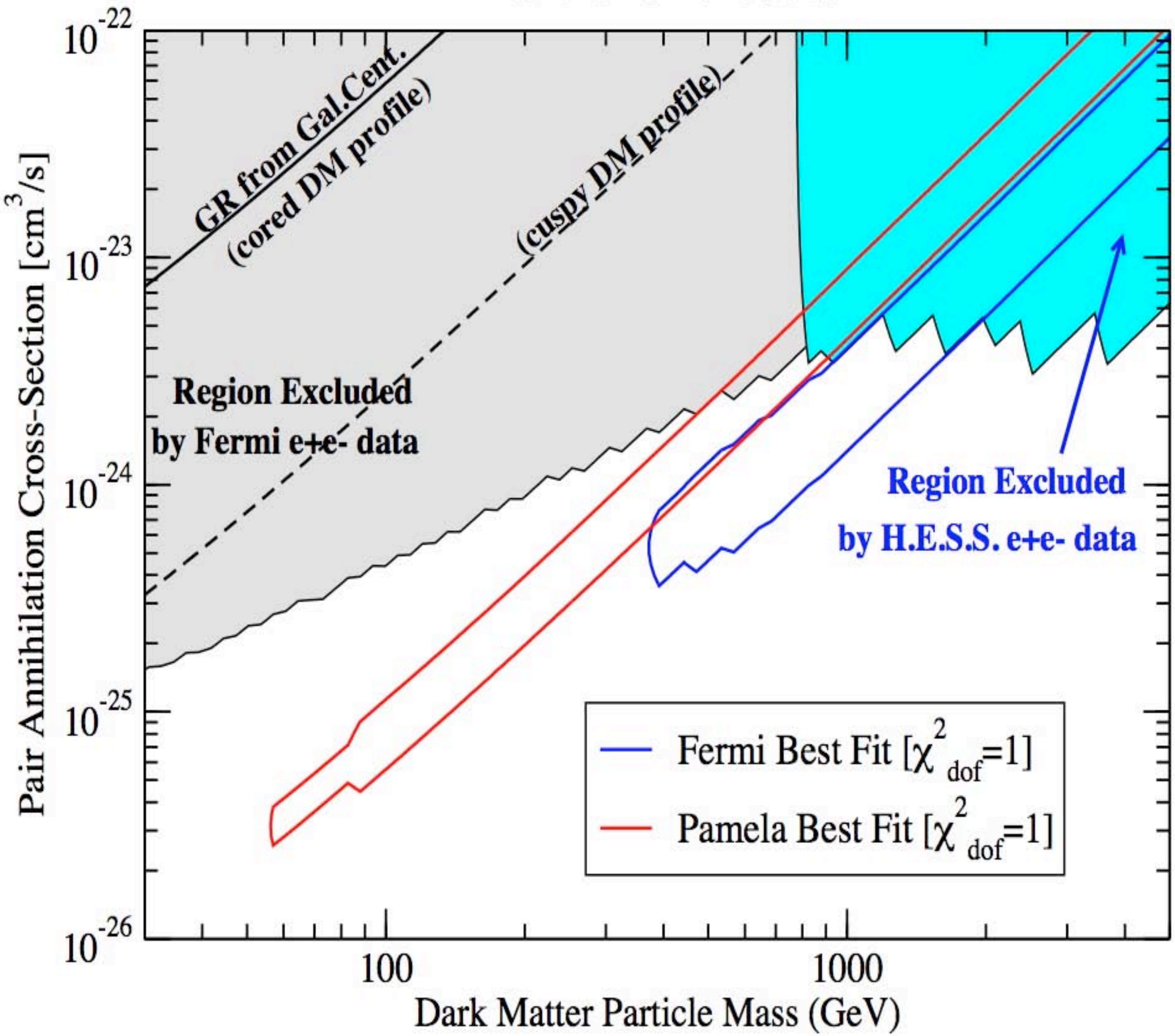


(spectrum should be folded with the Fermi energy resolution)

[arXiv:0905.0636]

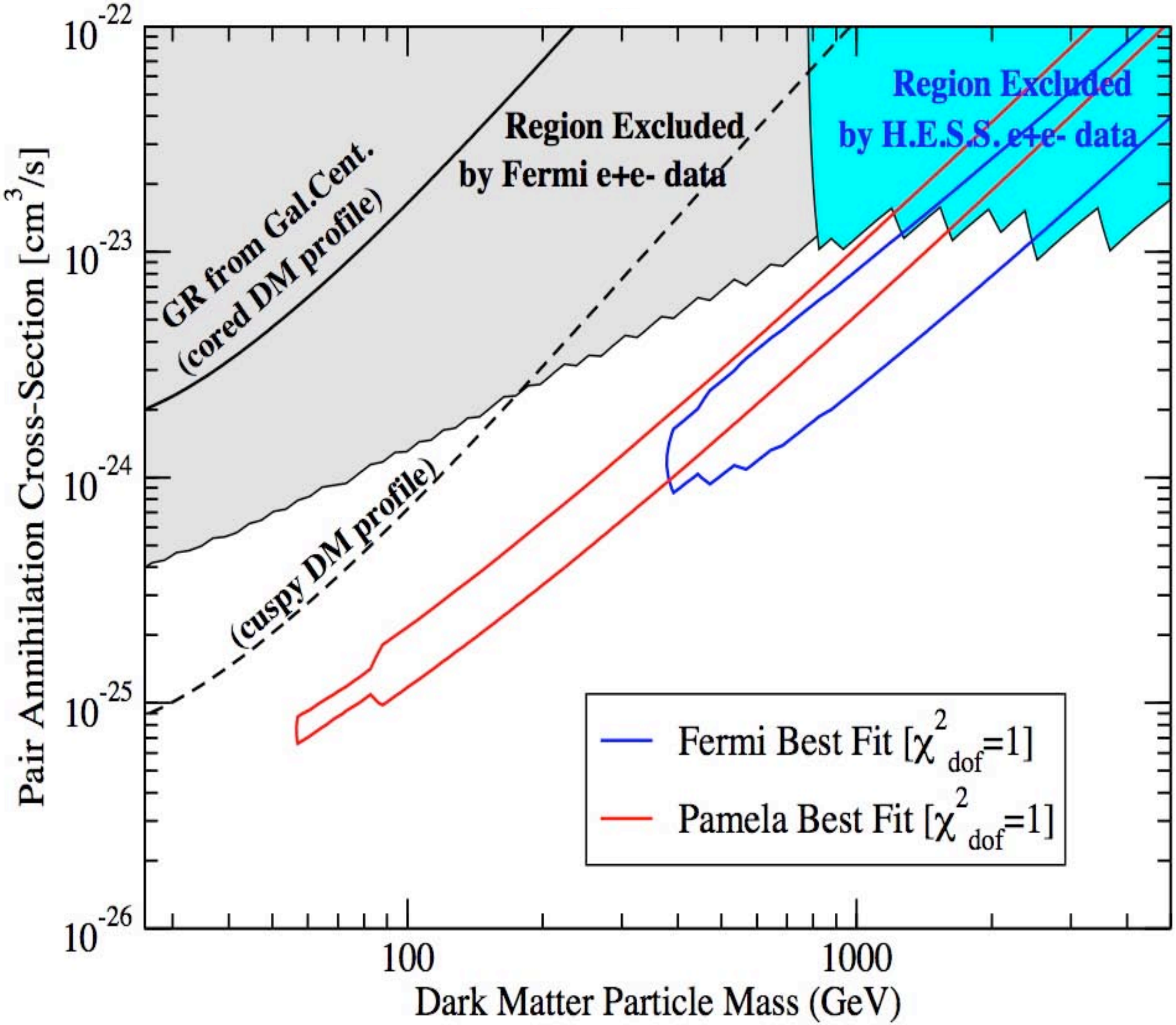
Pure e+e- Models

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



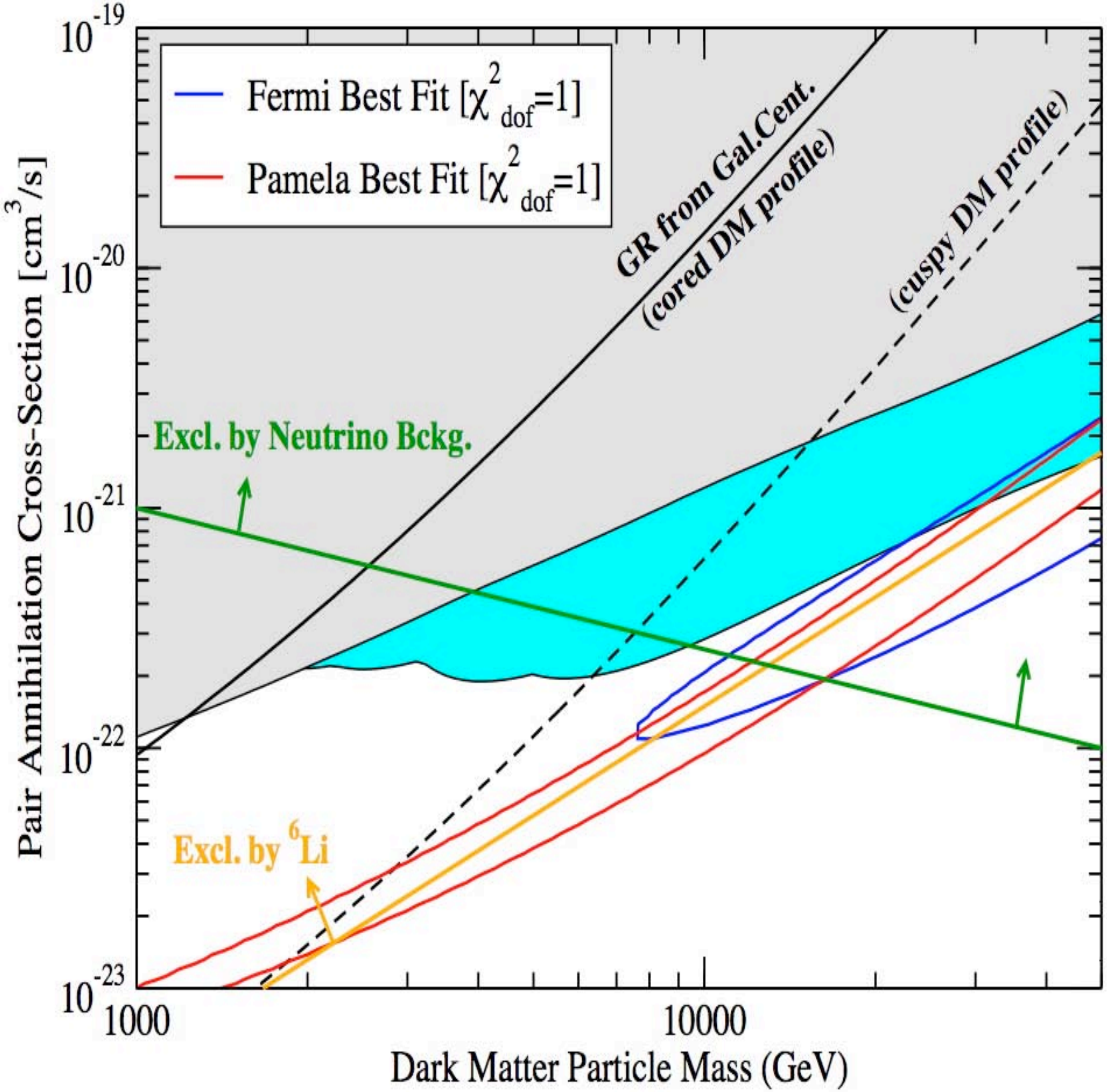
Lepto-philic Models

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.

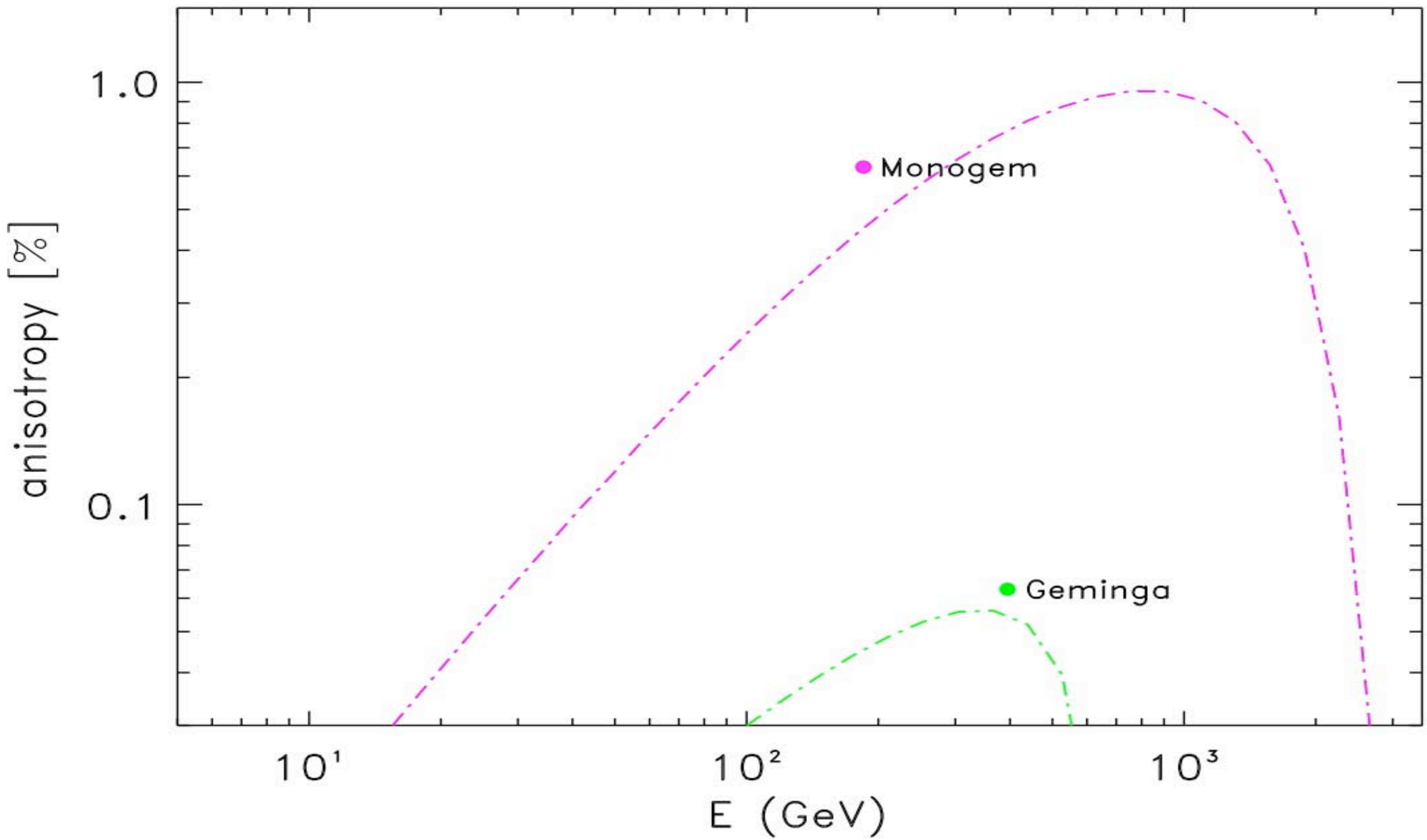


Super-heavy Models (ann. in gauge bosons)

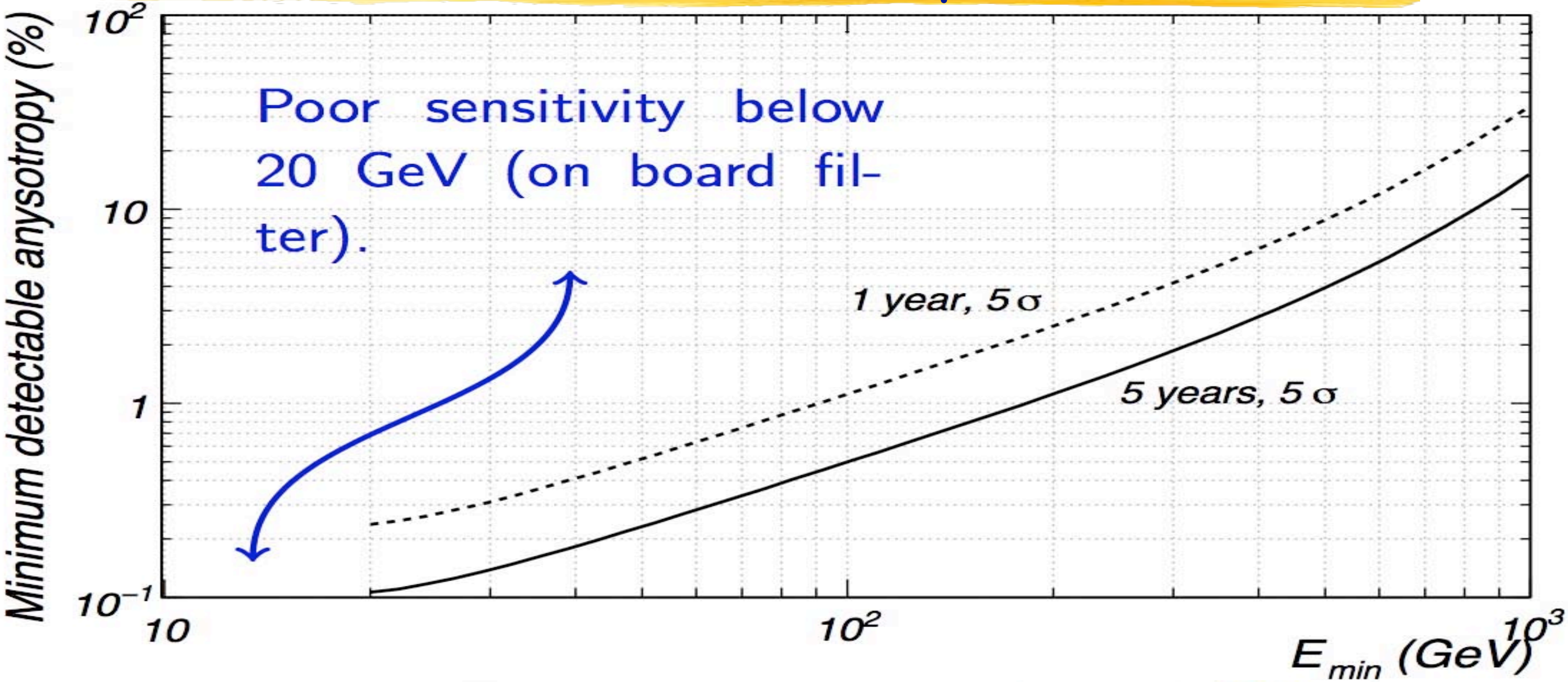
Super-heavy dark matter models: antiprotons can be suppressed below the PAMELA measured flux if the dark matter particle is heavy (i.e. in the multi-TeV mass range), and pair annihilates e.g. in weak interaction gauge bosons. Models with super-heavy dark matter can have the right thermal relic abundance,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

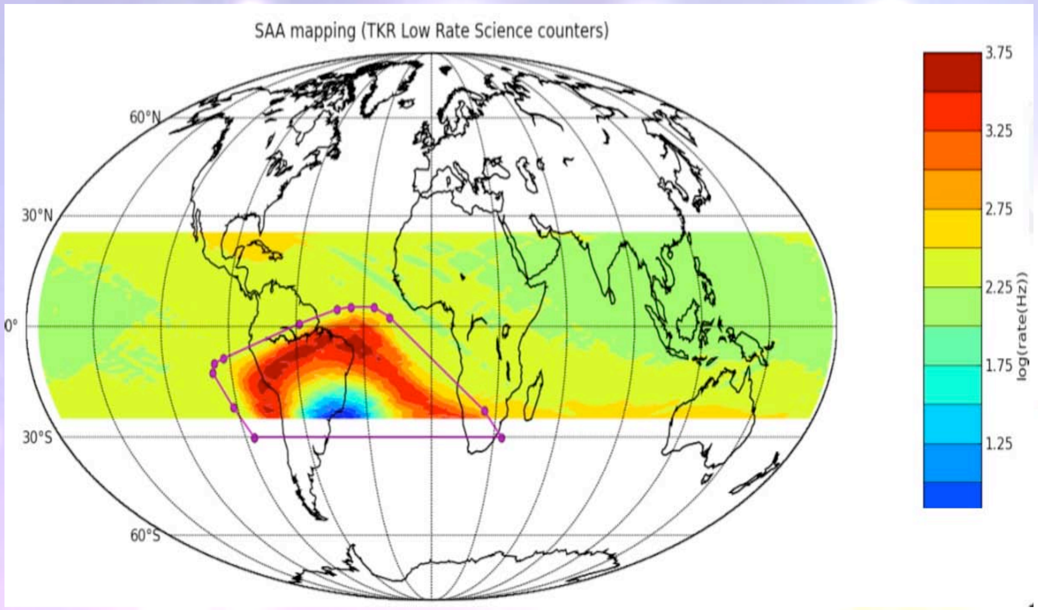


Measurement of anisotropies: statistics

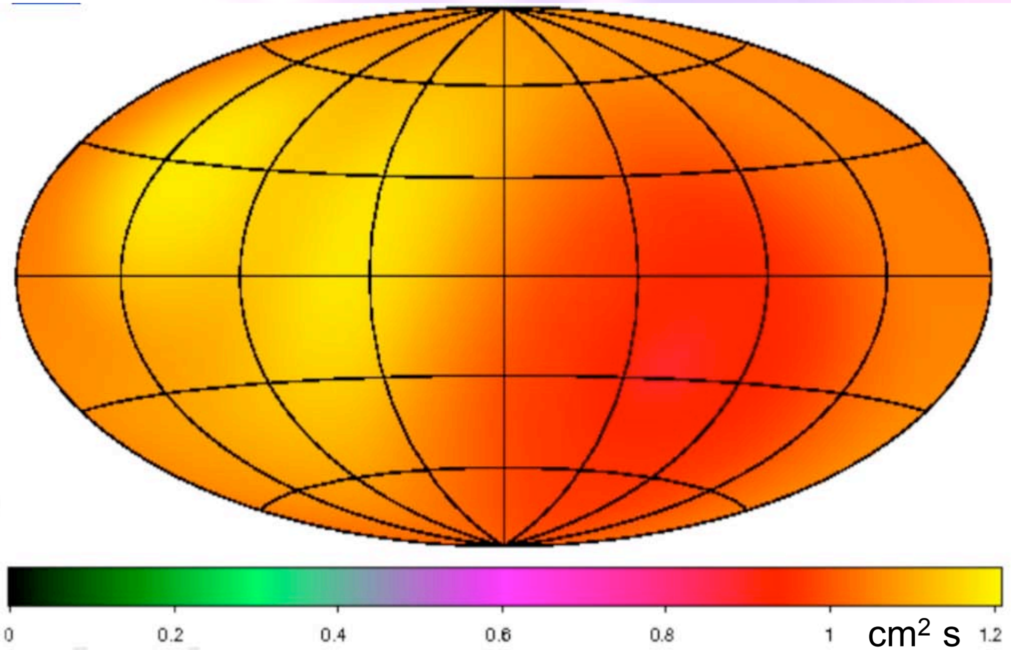


- Statistical limit for the integral anisotropy set by $\delta = \frac{\sqrt{2} N_\sigma}{\sqrt{N_{\text{events}}}}$
- The plot includes all the instrument effects:
- Energy-dependent effective geometry factor;
- Instrumental dead time and duty cycle, On board filter.
- Room for improvements with a better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

Measurements of anisotropies: systematics



Terrestrial coordinates (South Atlantic Anomaly clearly visible). Fermi does not take science data within the SAA polygon.

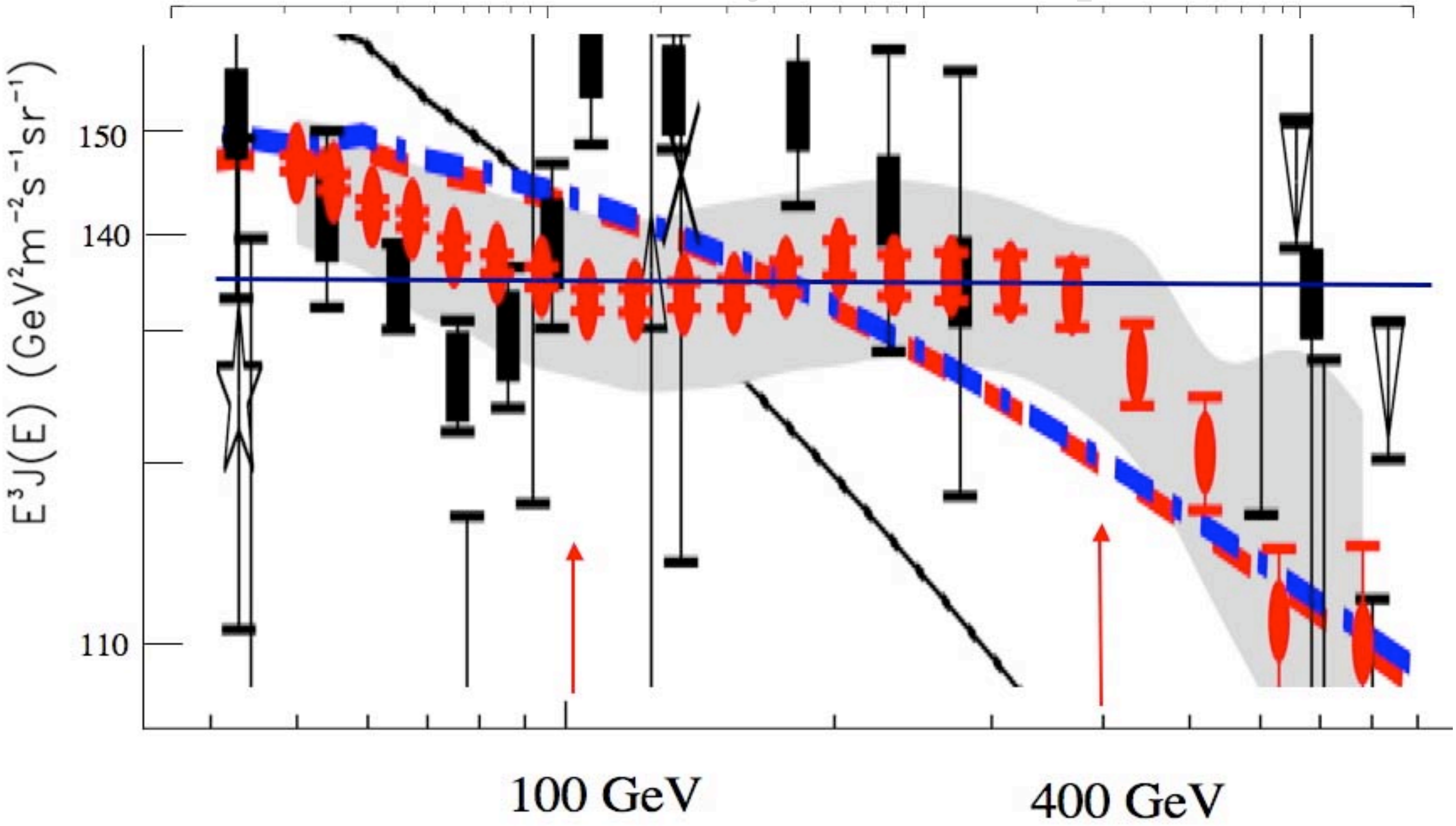


Exposure map
For gammas, after three months of mission (used for the bright source list).
It will not be very different for the electrons and for longer time periods.

- ≈ 25% disunformity in the exposure map induced by the SAA.

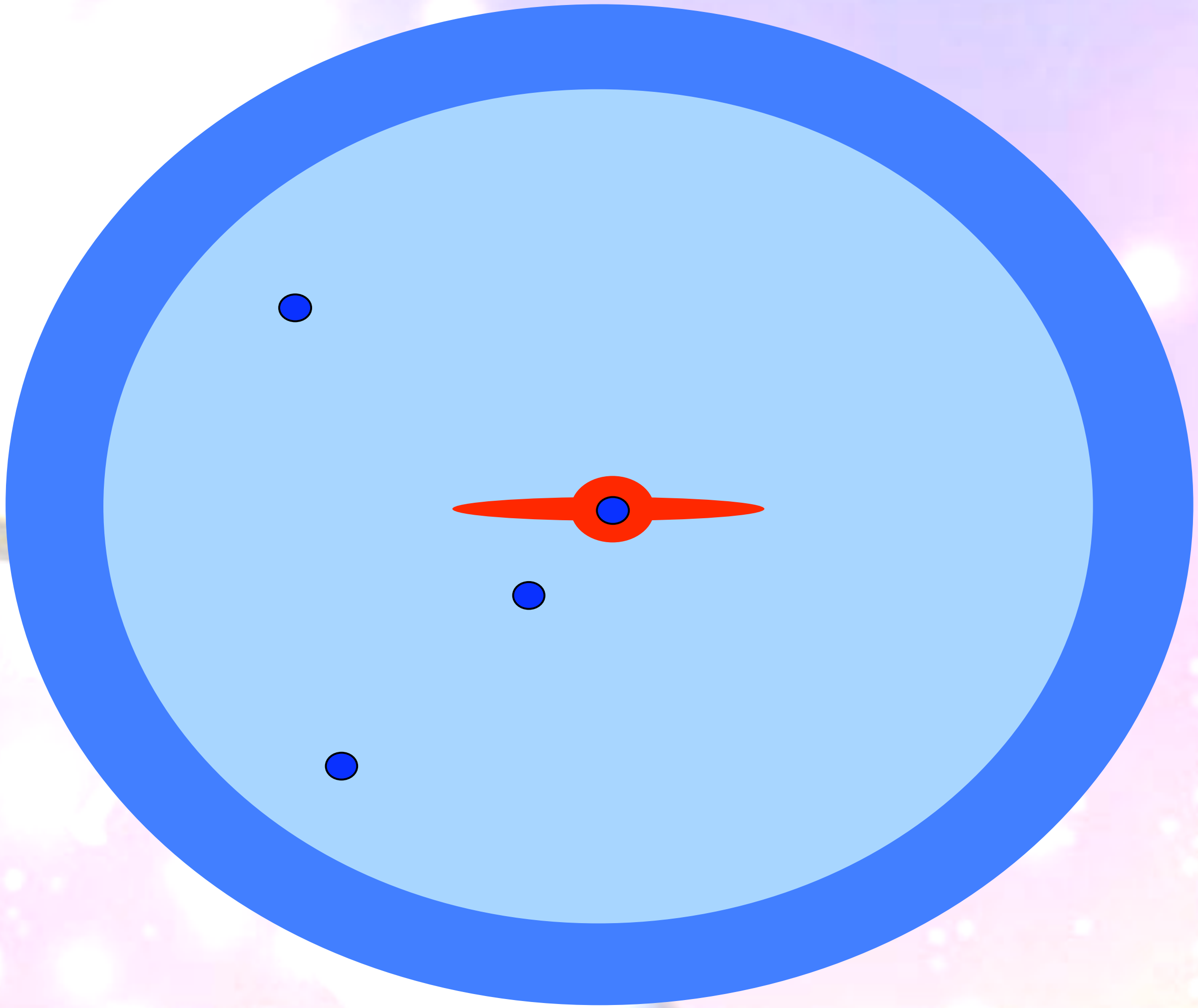
Measuring a 0.1% anisotropy requires a knowledge of the exposure map at the ≈ 0.1% level.

Fermi-LAT Cosmic ray Electron spectrum

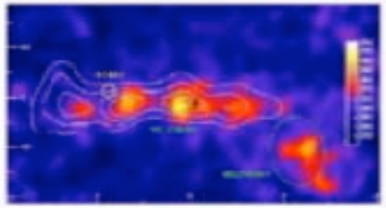
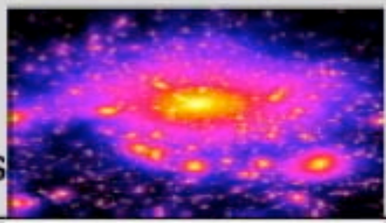
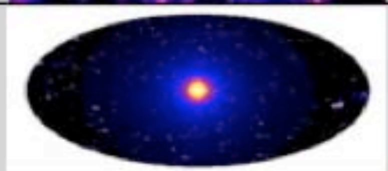
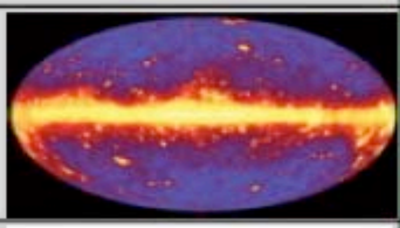
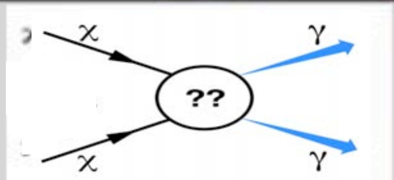


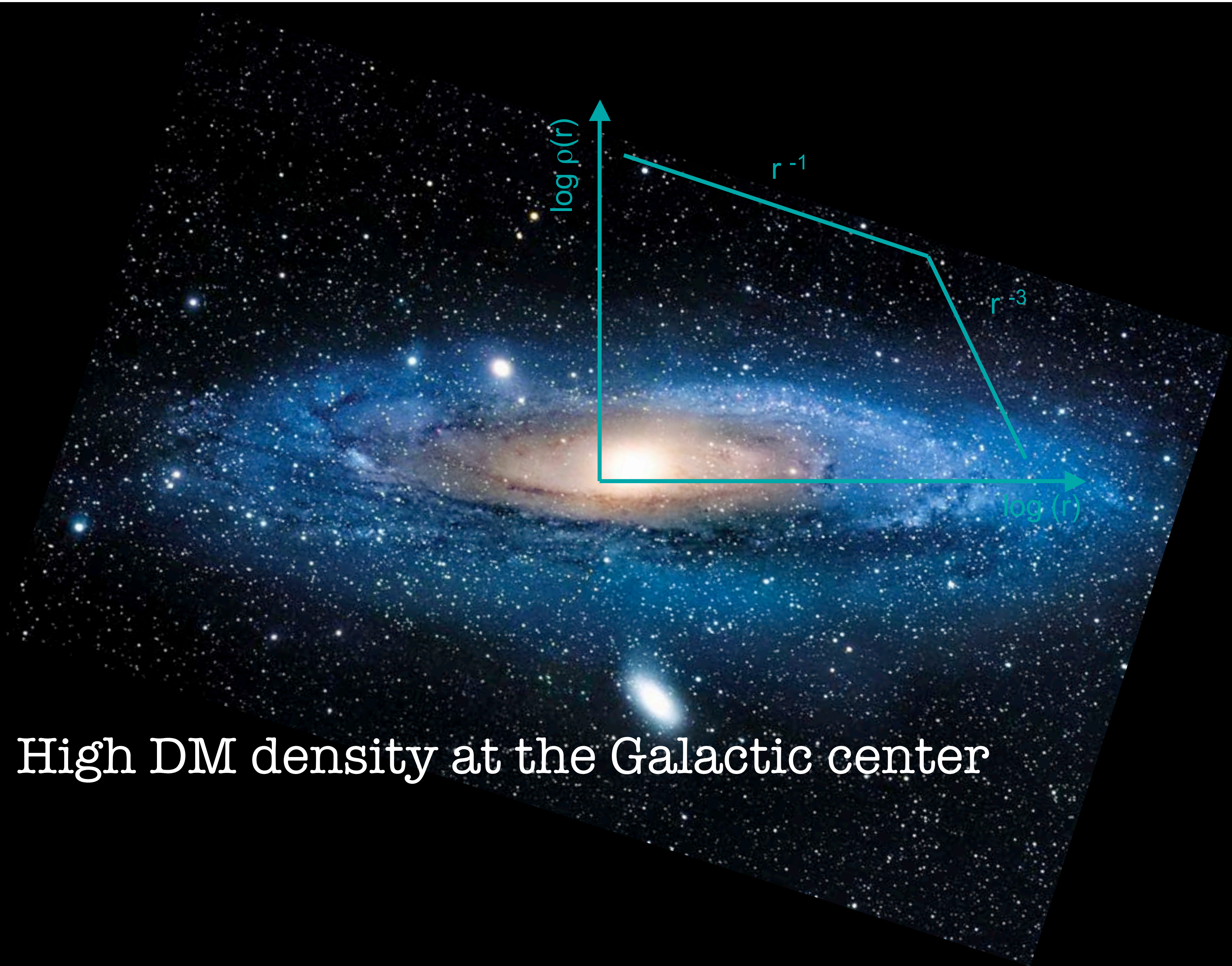
Where should we look for Dark Matter with FERMI ?

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

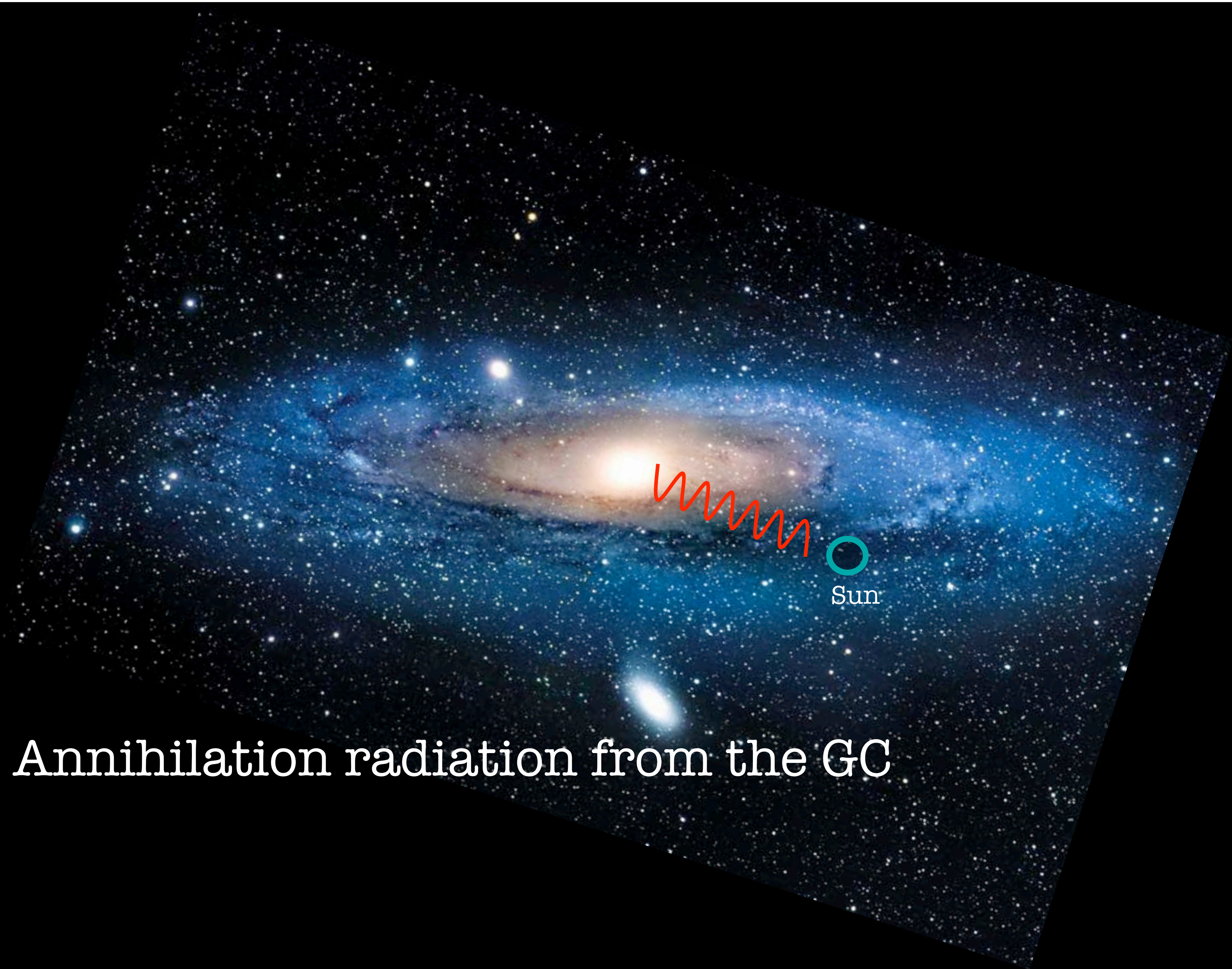


How the GLAST-LAT* telescope could help to disentangle the Dark Matter puzzle ?

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



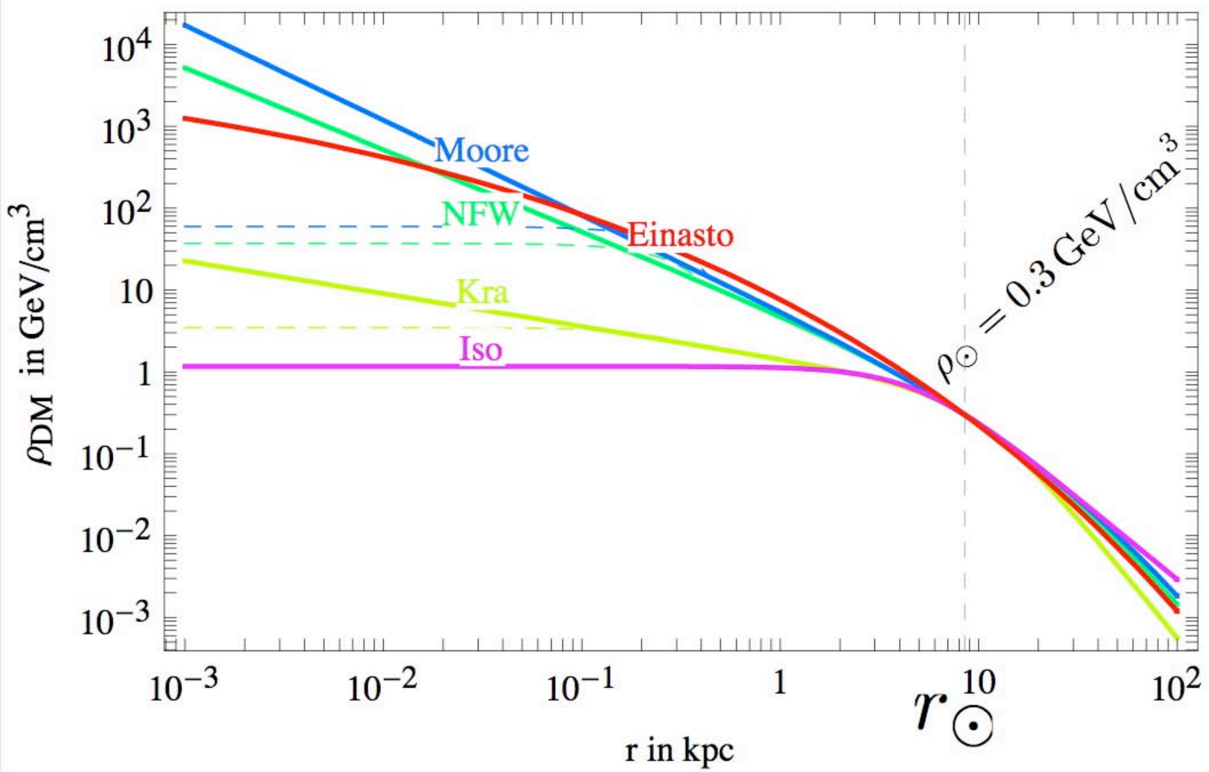
High DM density at the Galactic center



Annihilation radiation from the GC

The Galactic Center possible profiles

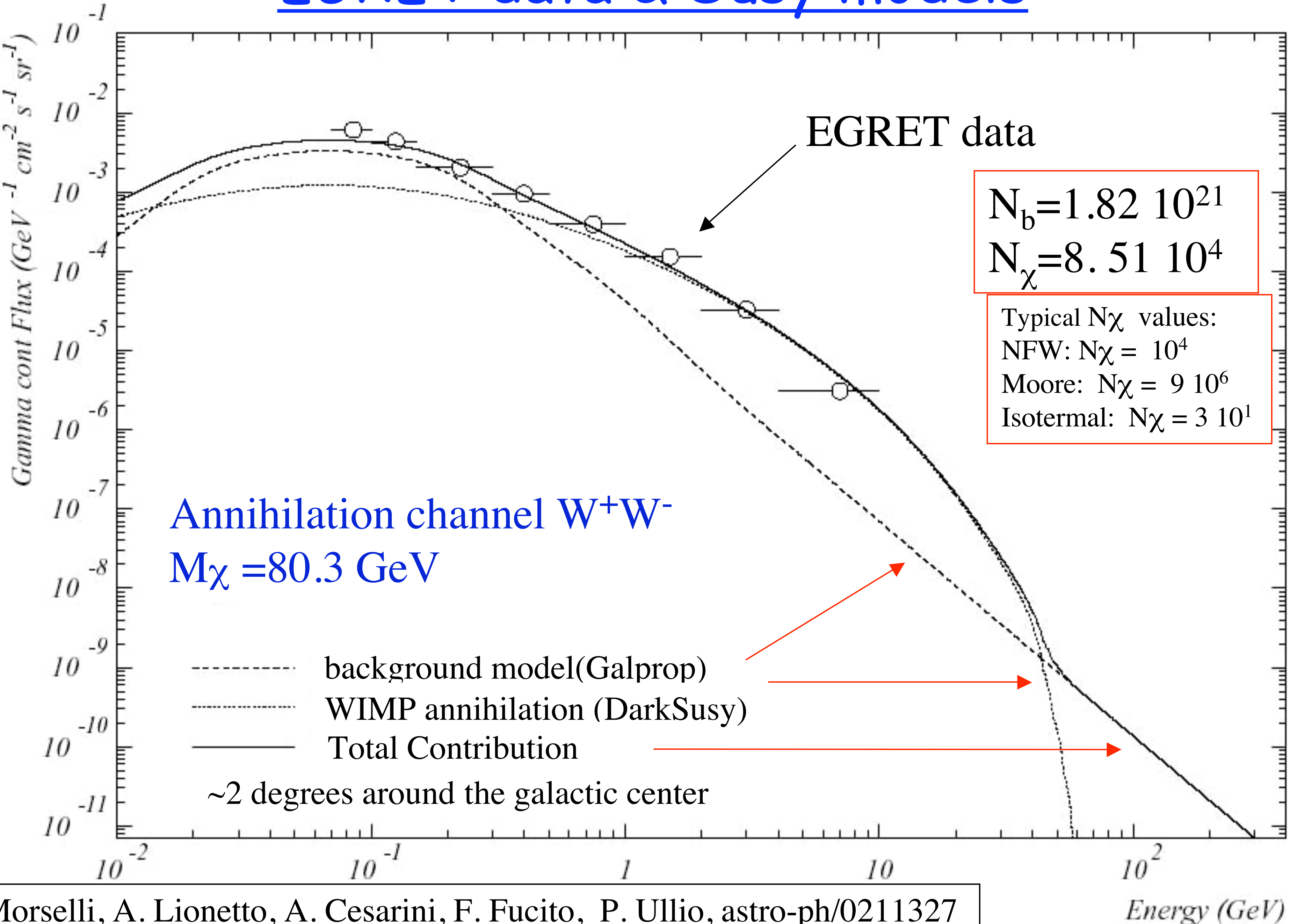
$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/r_s)^\alpha}{1+(r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$



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

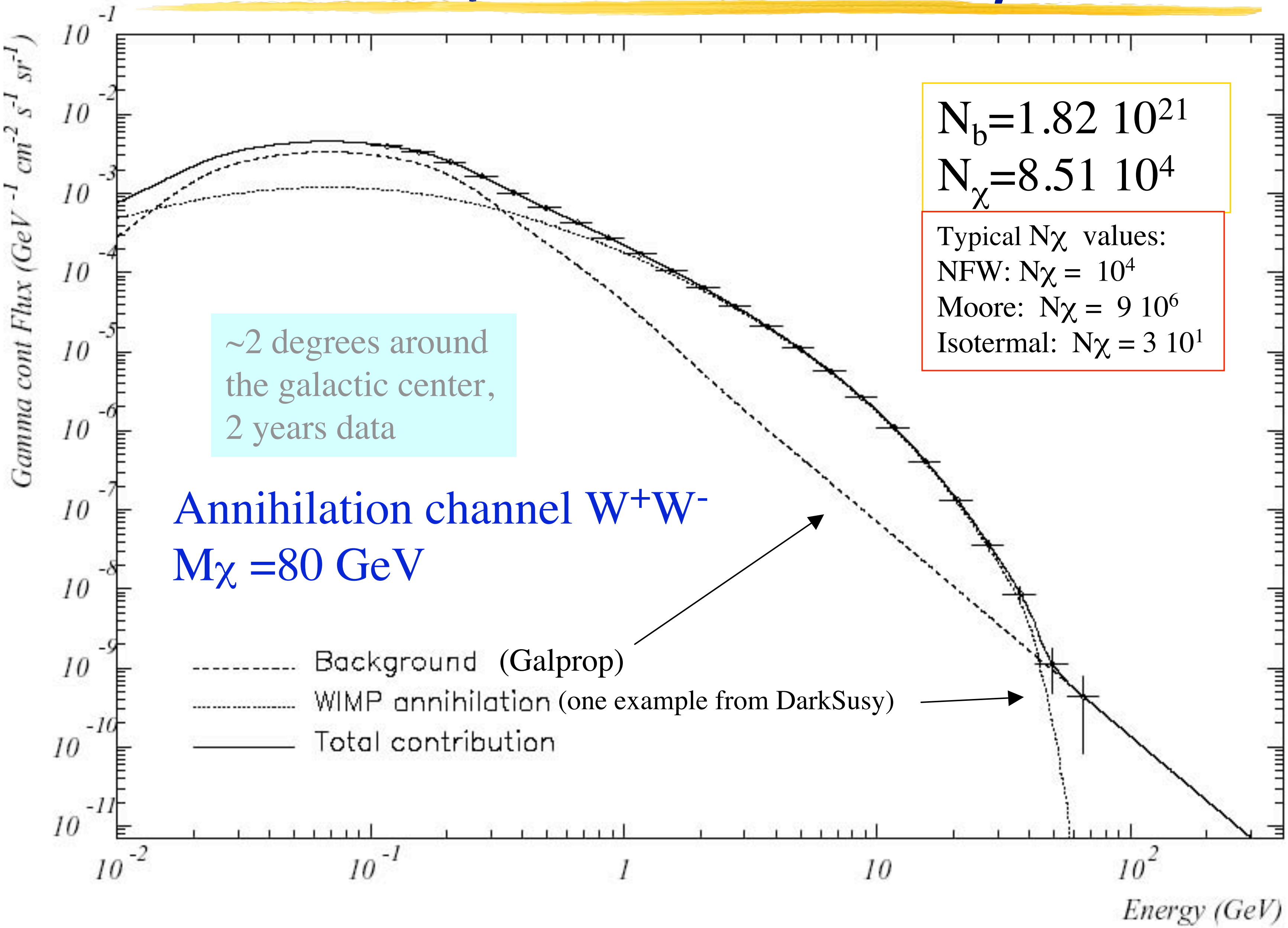
Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$

EGRET data & Susy models



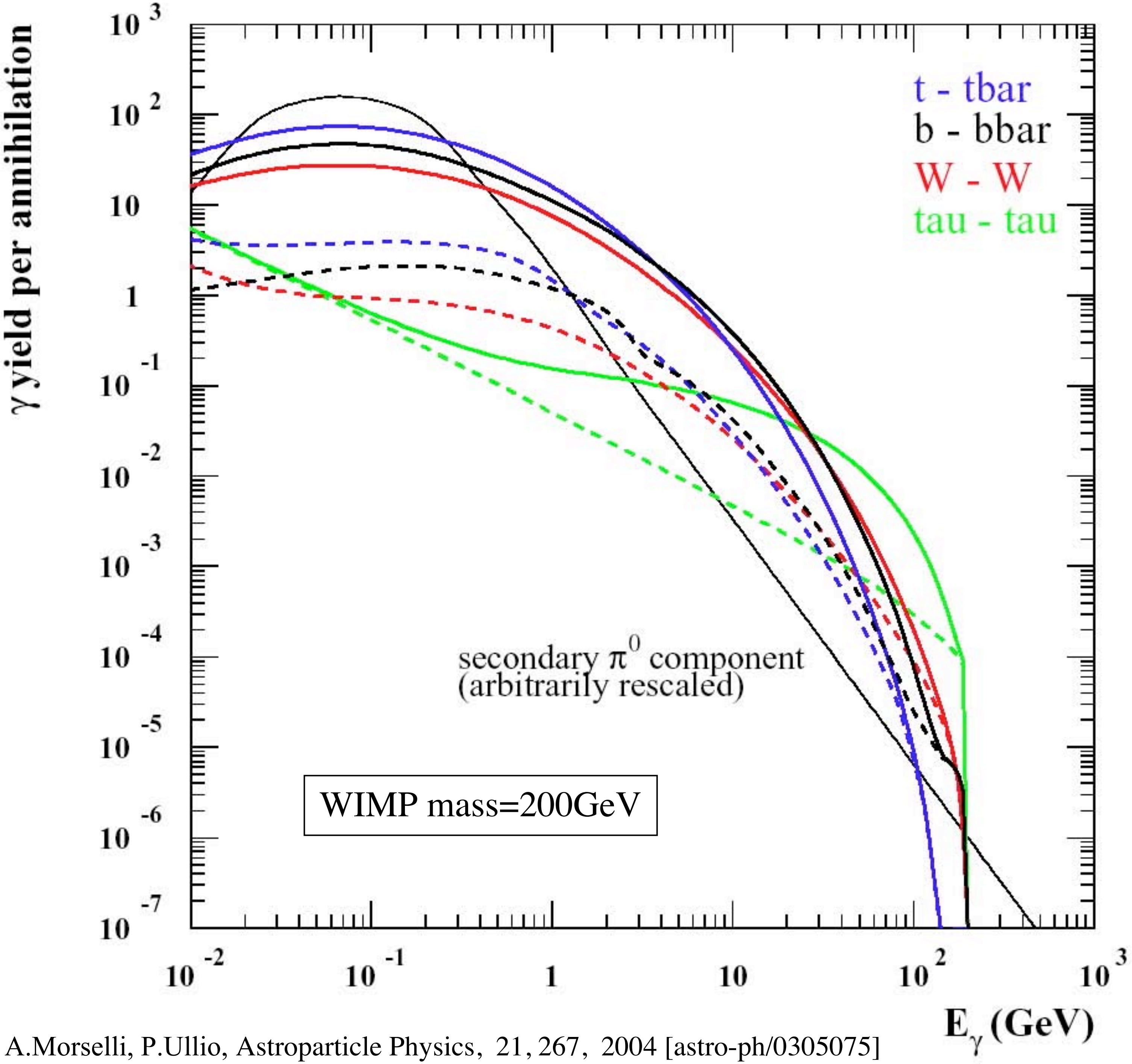
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327

Fermi Expectation & Susy models



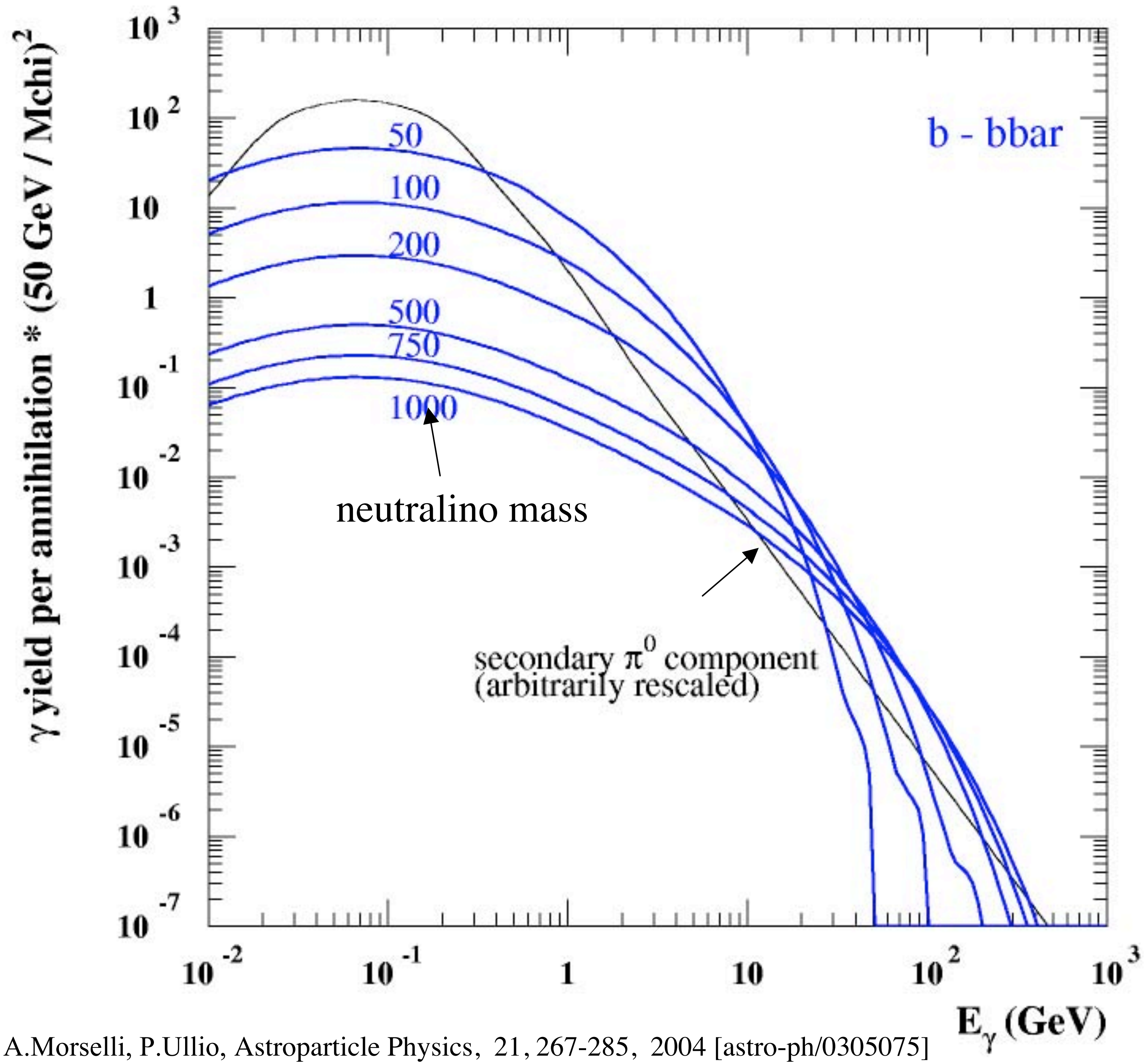
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, June 2004 [astro-ph/0305075]

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

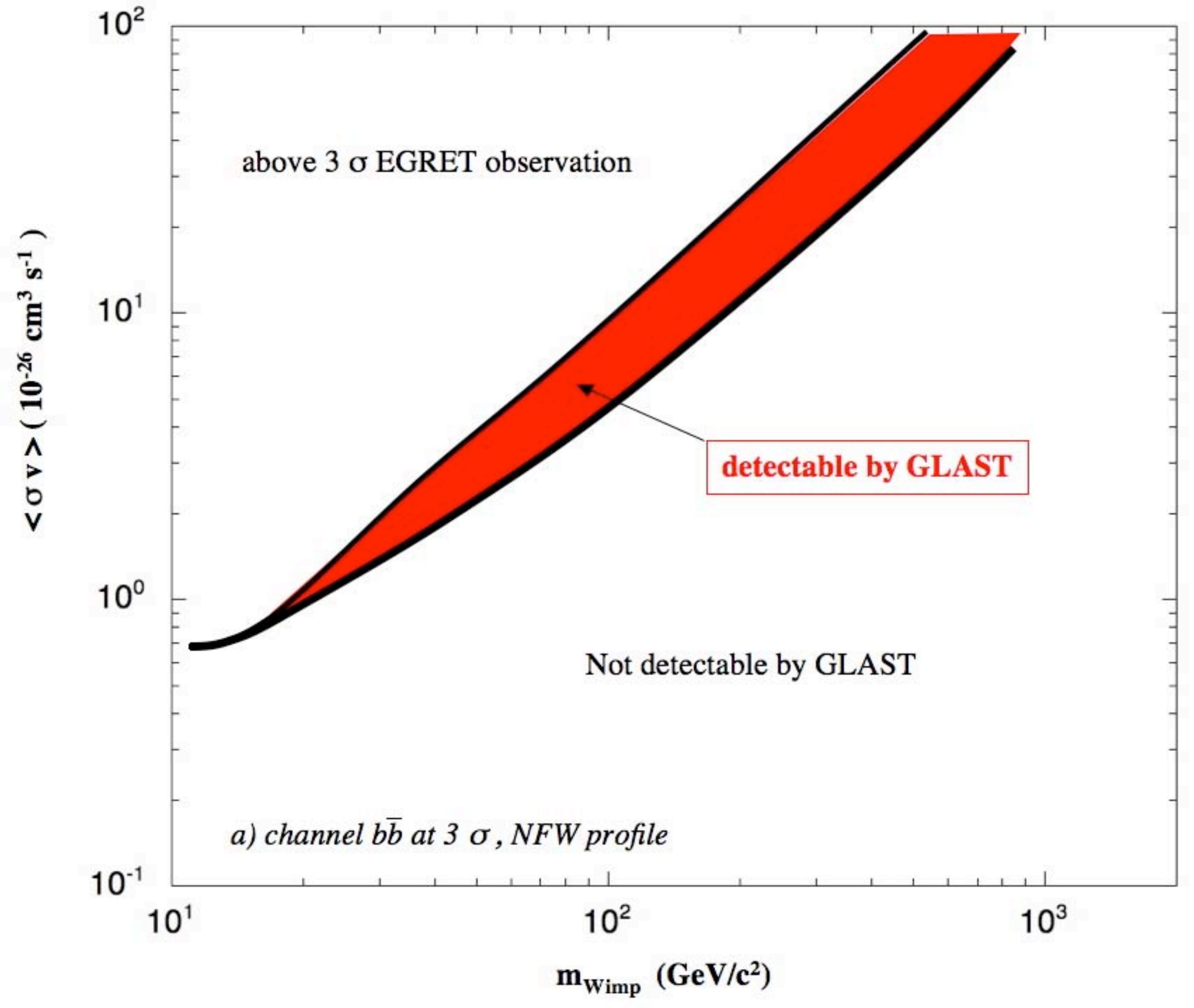


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Model independent results for the GC

after the Fermi Galactic Diffuse Emission data

5 years of operations, truncated NFW

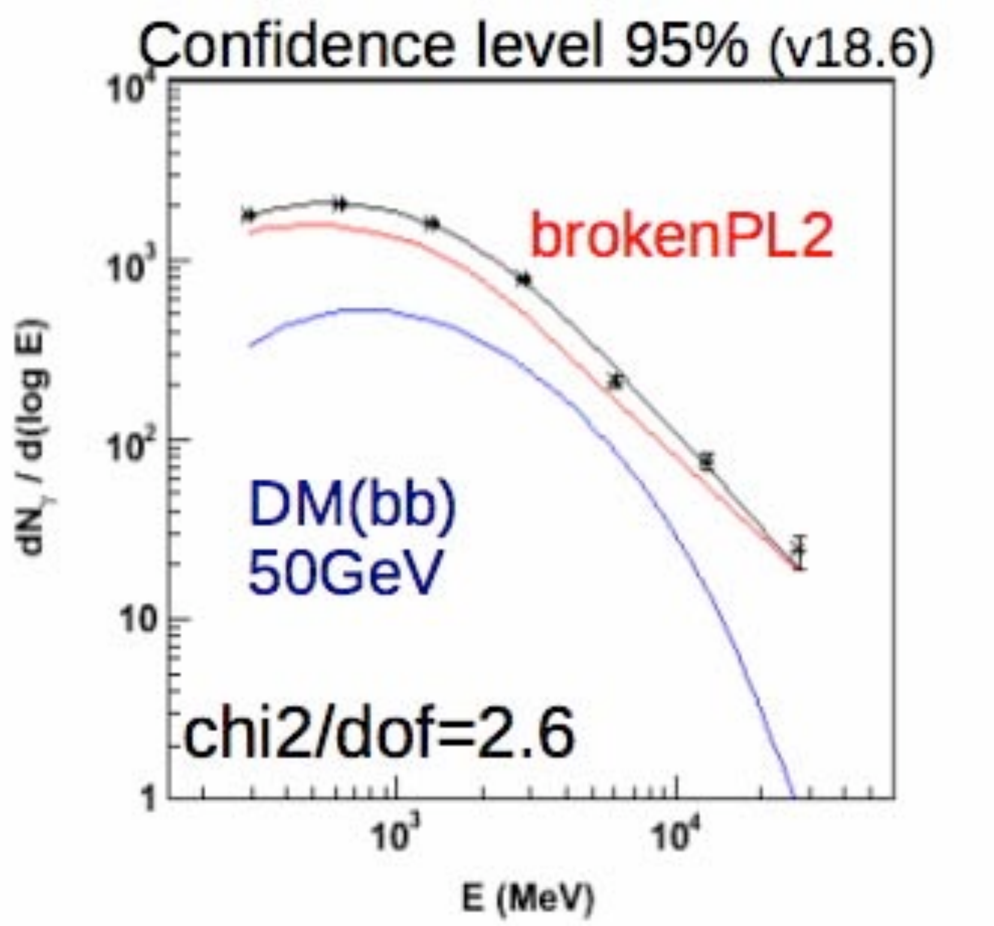


upated from arXiv:0806.2911

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

<u>Confidence level 95% (v18.6)</u>
flux(DM) = 3.05 * 10^{-6} cm^{-2} s^{-1}
σ v (DM) = 4.99 * 10^{-24} cm^{-2} s^{-1}

<u>Confidence level 99% (v18.8)</u>
flux(DM) = 4.26 * 10^{-6} cm^{-2} s^{-1}
σ v (DM) = 6.97 * 10^{-24} cm^{-2} s^{-1}

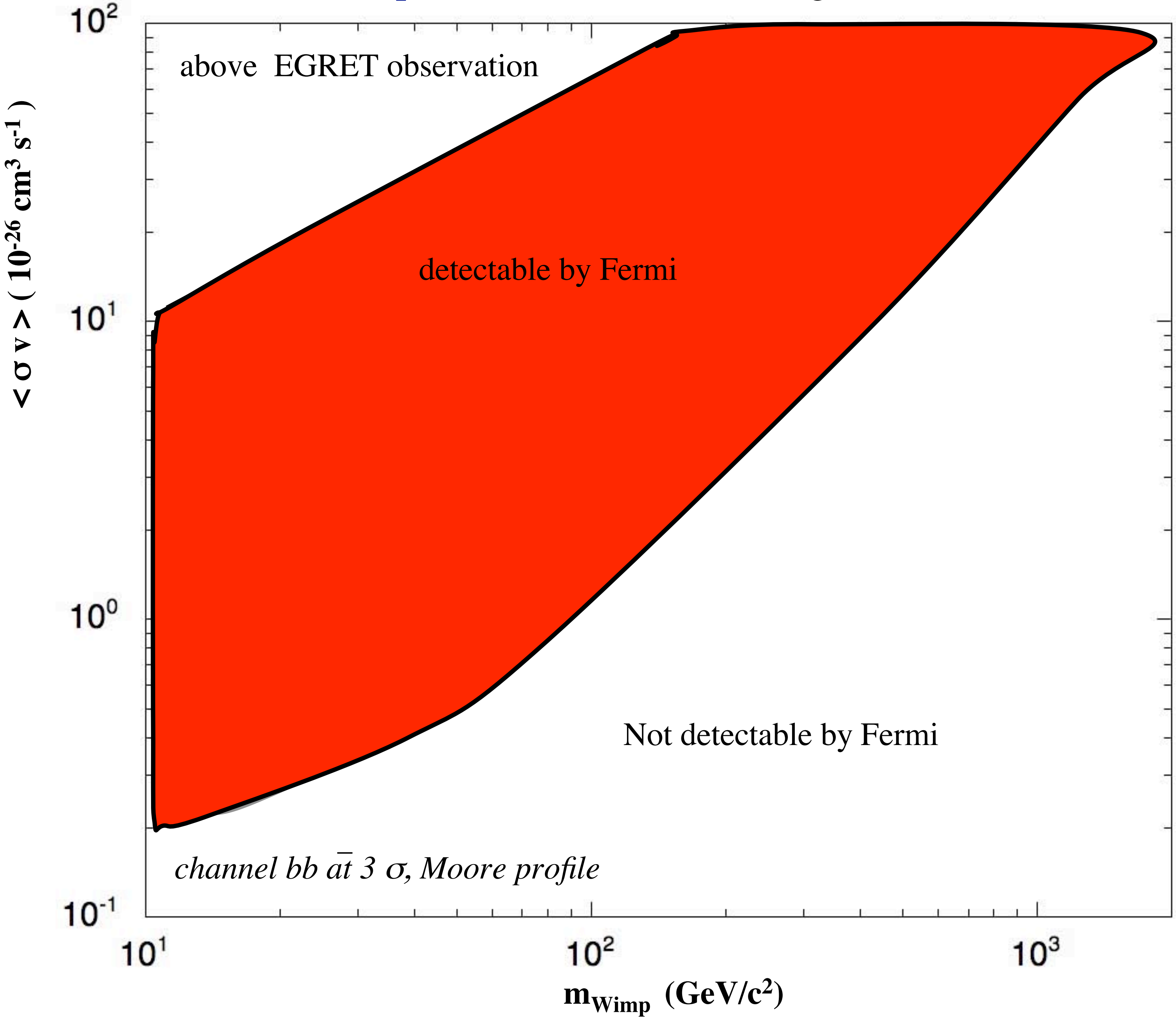


The given upper limits for Dark Matter are conservative ones.

Vincenzo Vitale and Aldo Morselli for the Fermi Lat Collaboration, ICRC09

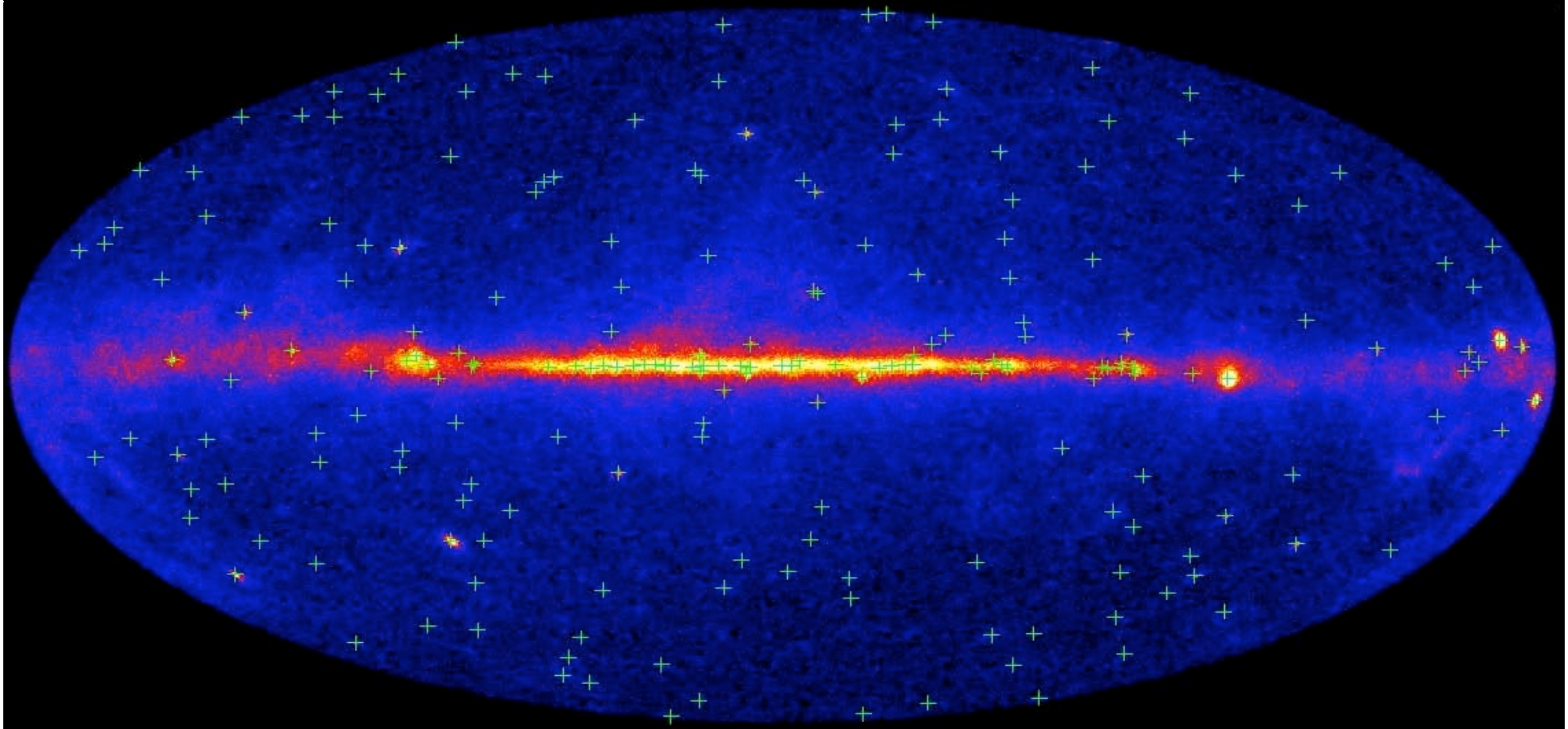
Model independent results for the Sagittarius Dwarft

after the Fermi Galactic Diffuse Emission data



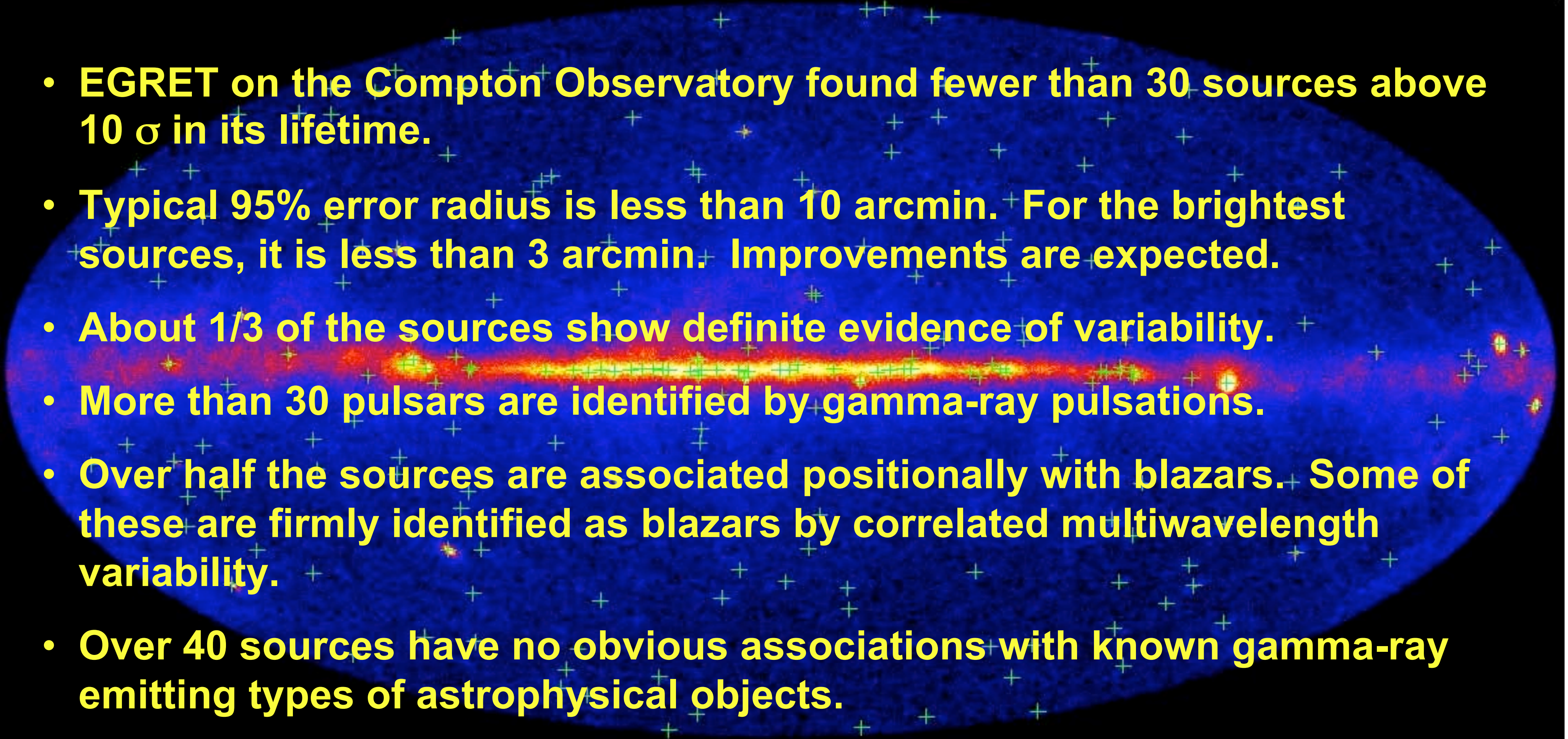
upated from arXiv:0806.2911

205 Preliminary Fermi LAT Bright Sources



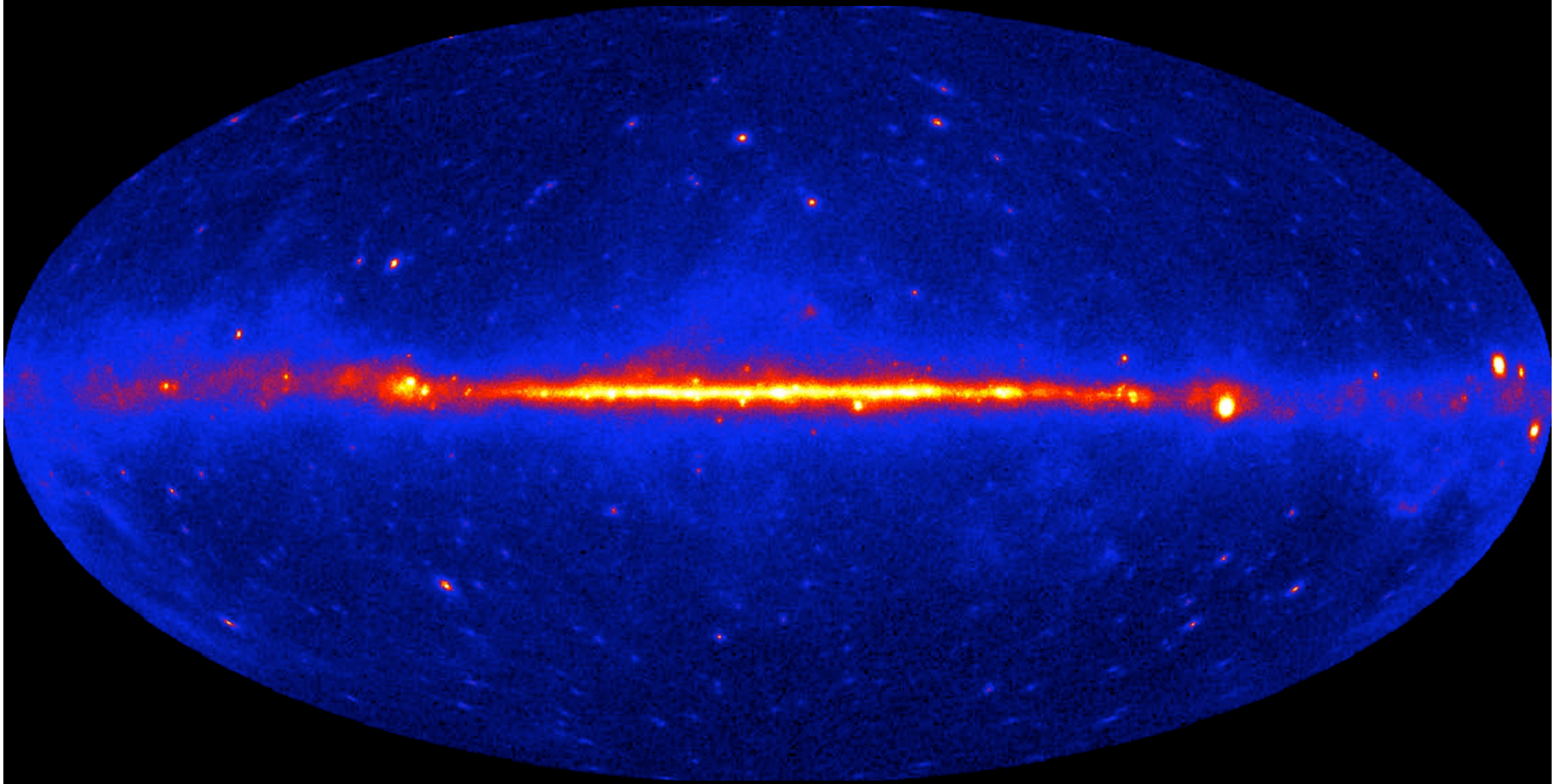
Crosses mark source locations, in Galactic coordinates.

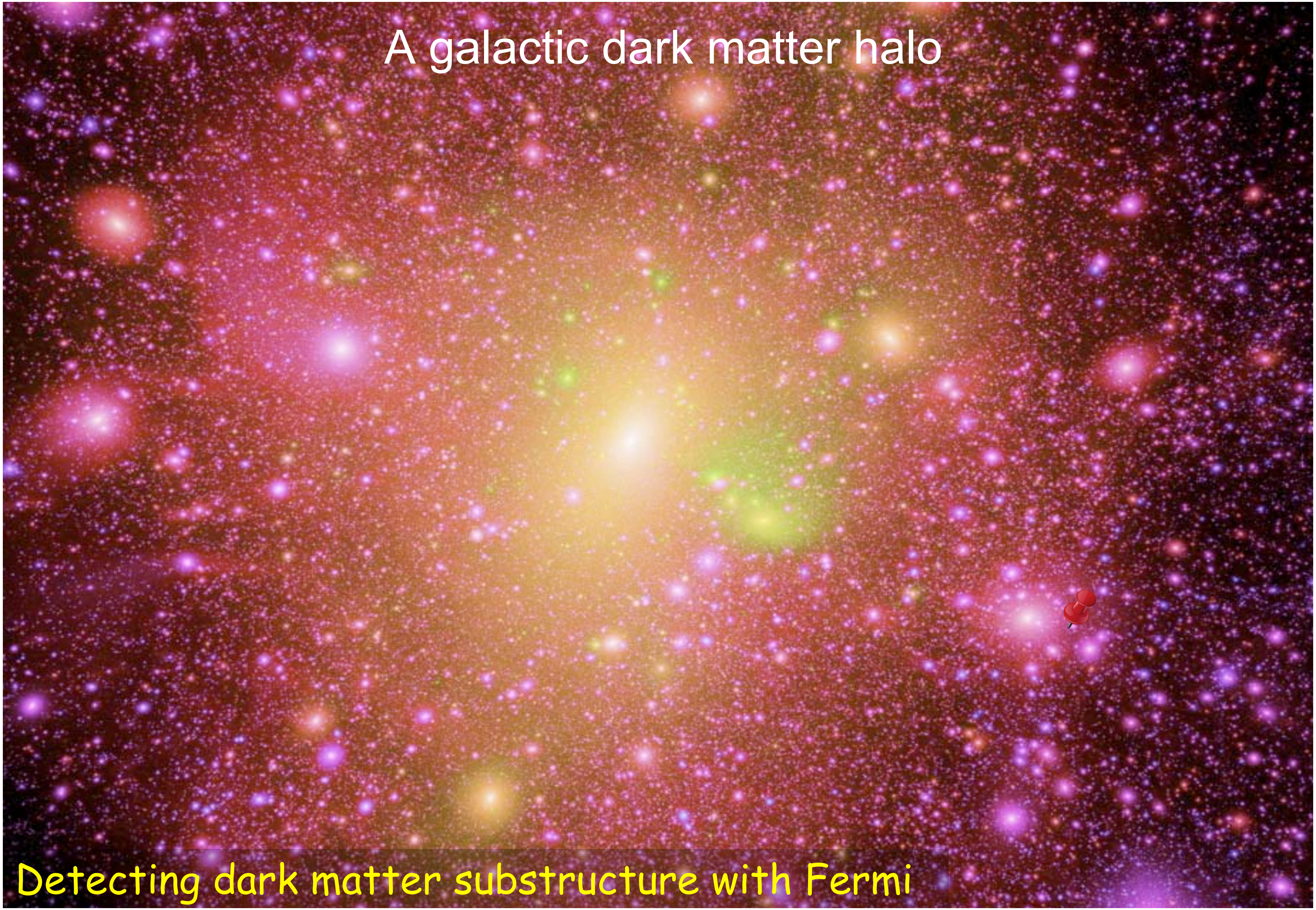
205 Preliminary LAT Bright Sources - Some Information

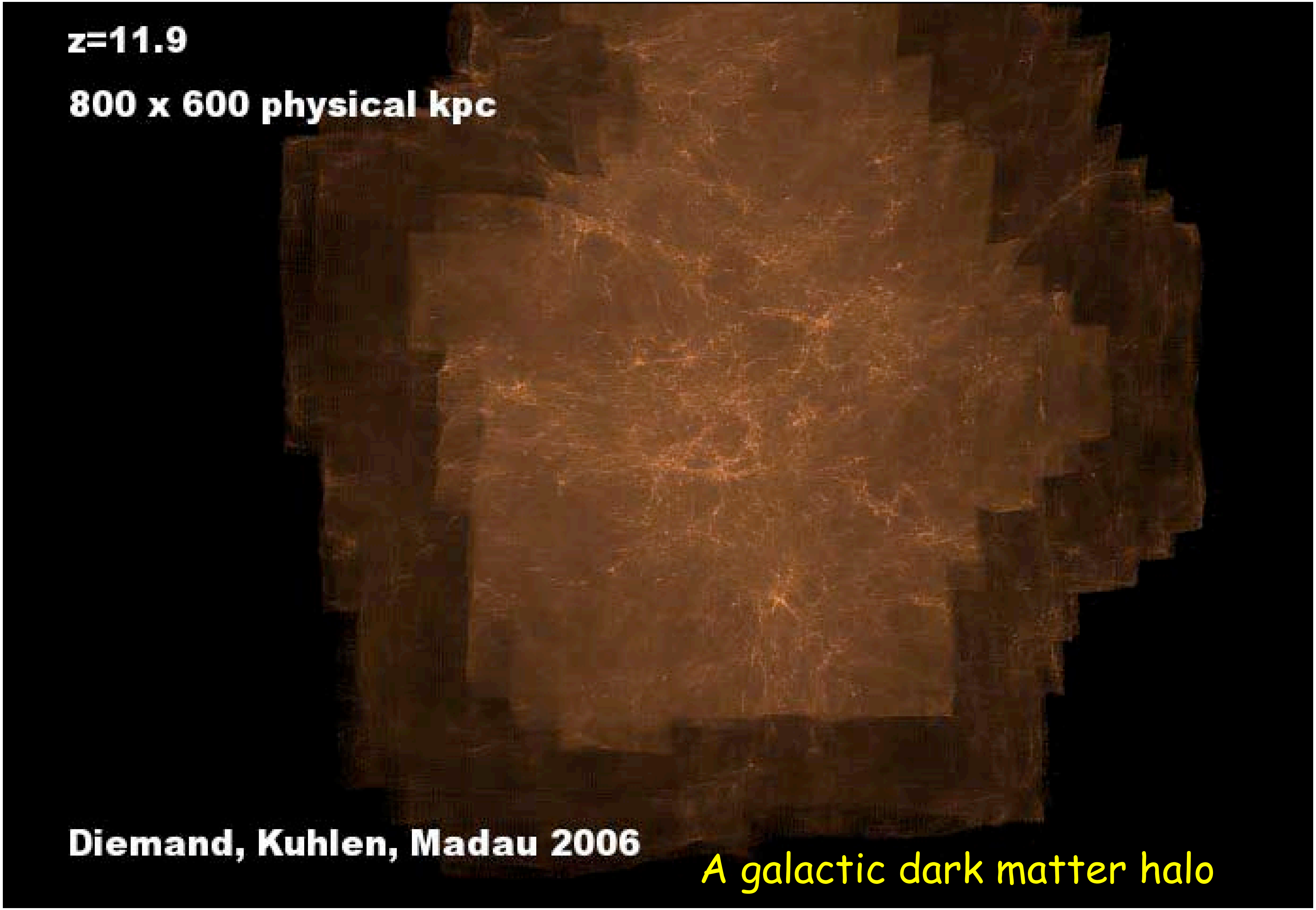


- EGRET on the Compton Observatory found fewer than 30 sources above 10 σ in its lifetime.
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of variability.
- More than 30 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.

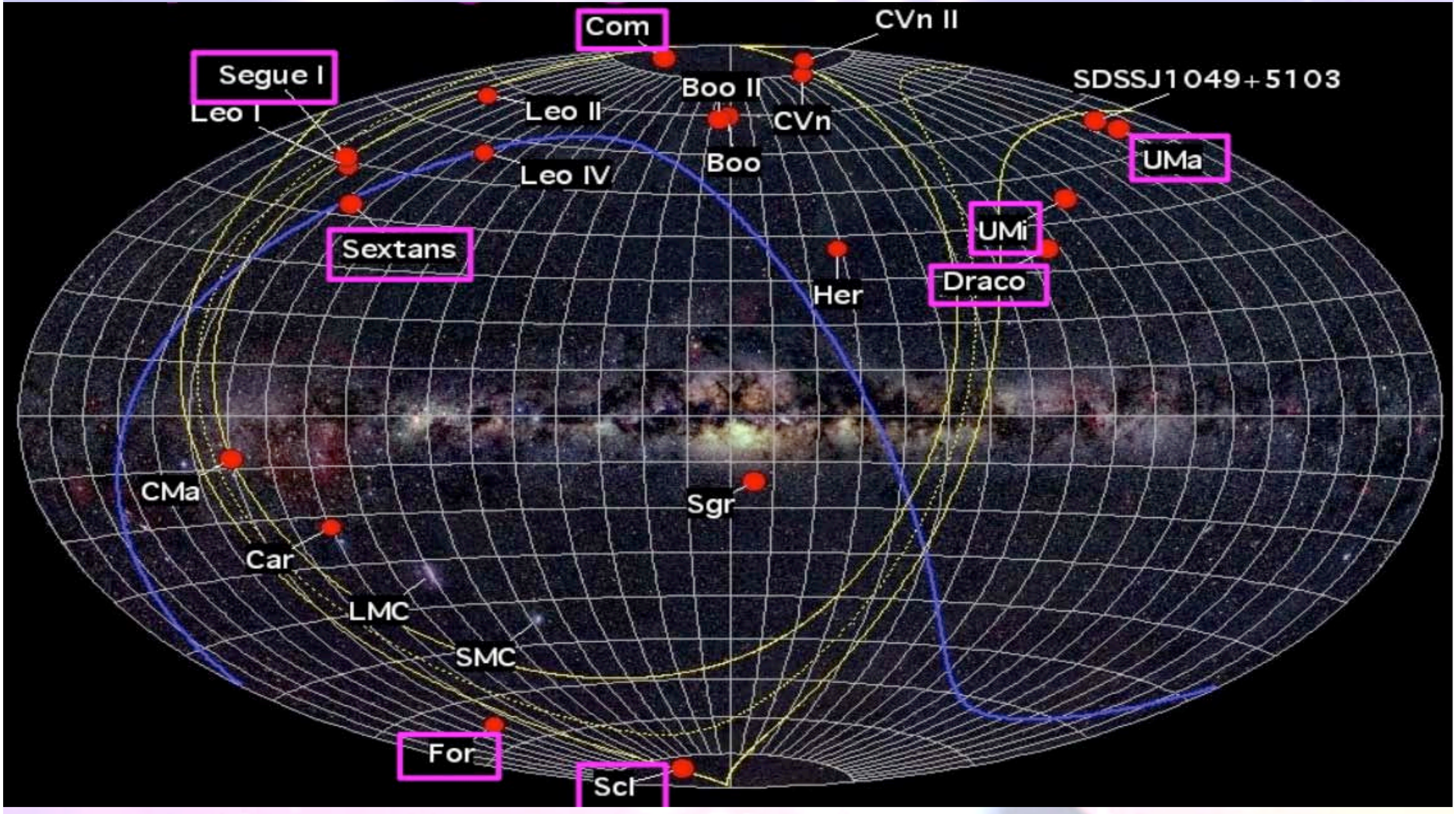
9 month observation



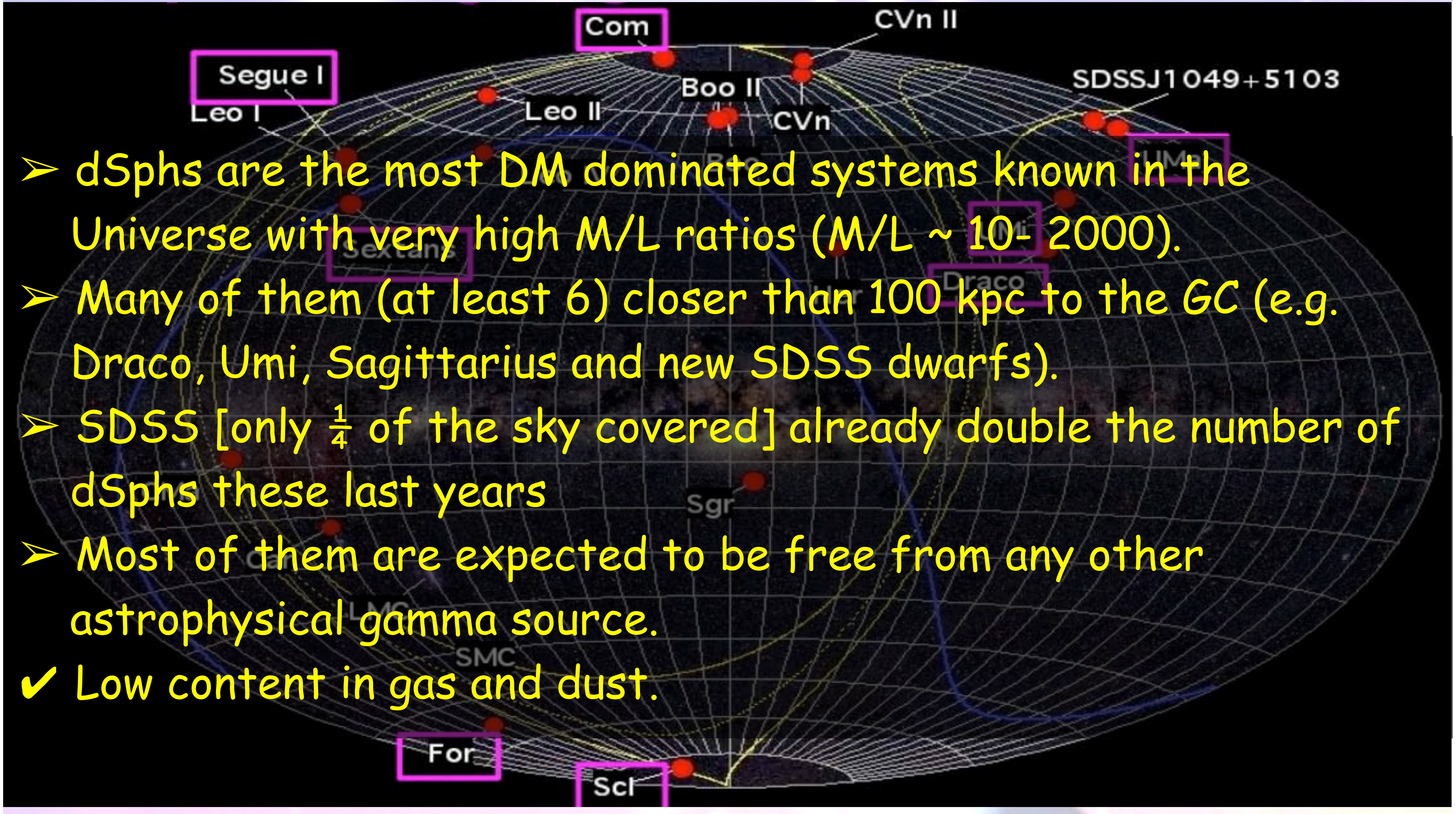

A galactic dark matter halo
Detecting dark matter substructure with Fermi


z=11.9
800 x 600 physical kpc
Diemand, Kuhlen, Madau 2006
A galactic dark matter halo

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

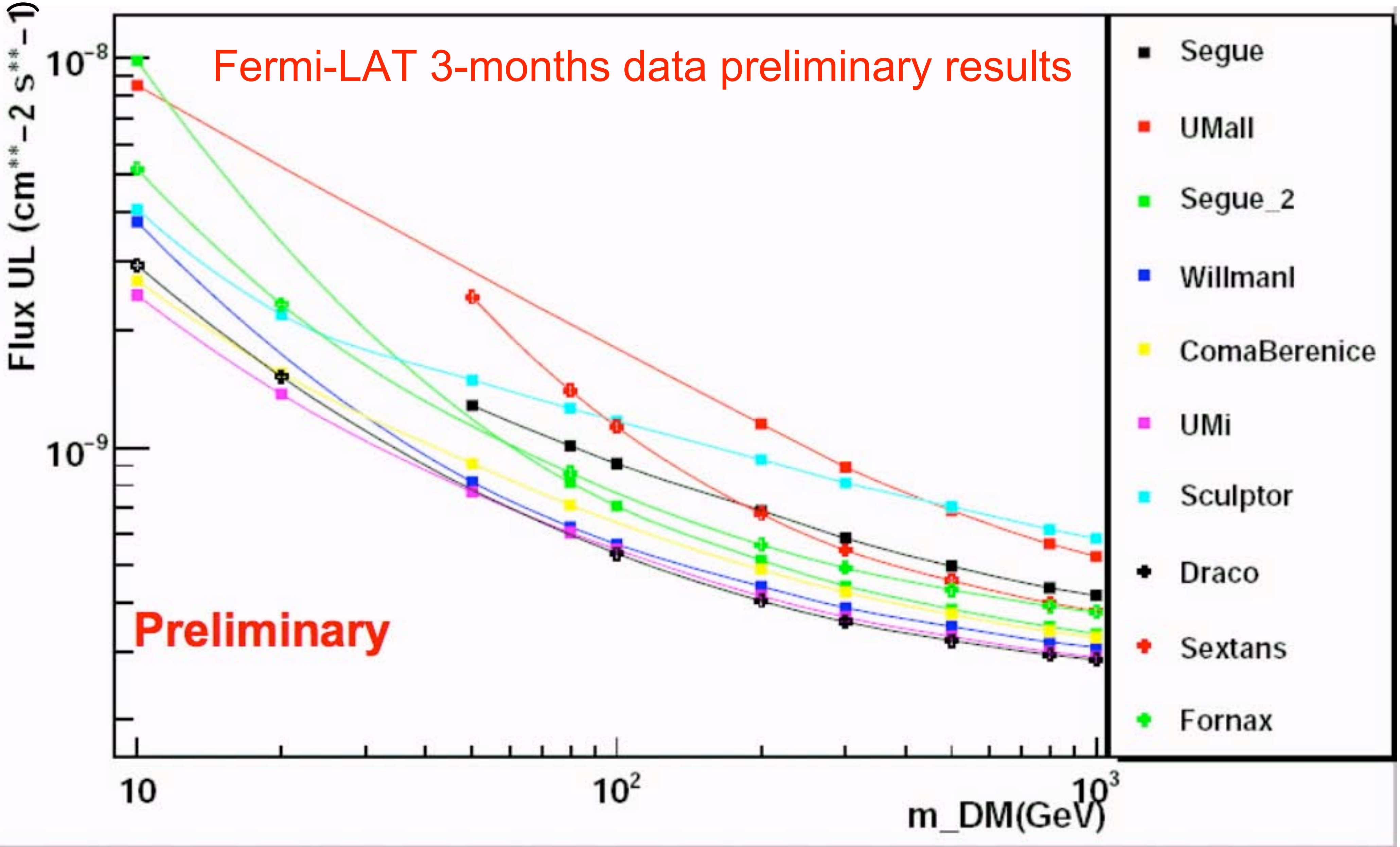


Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

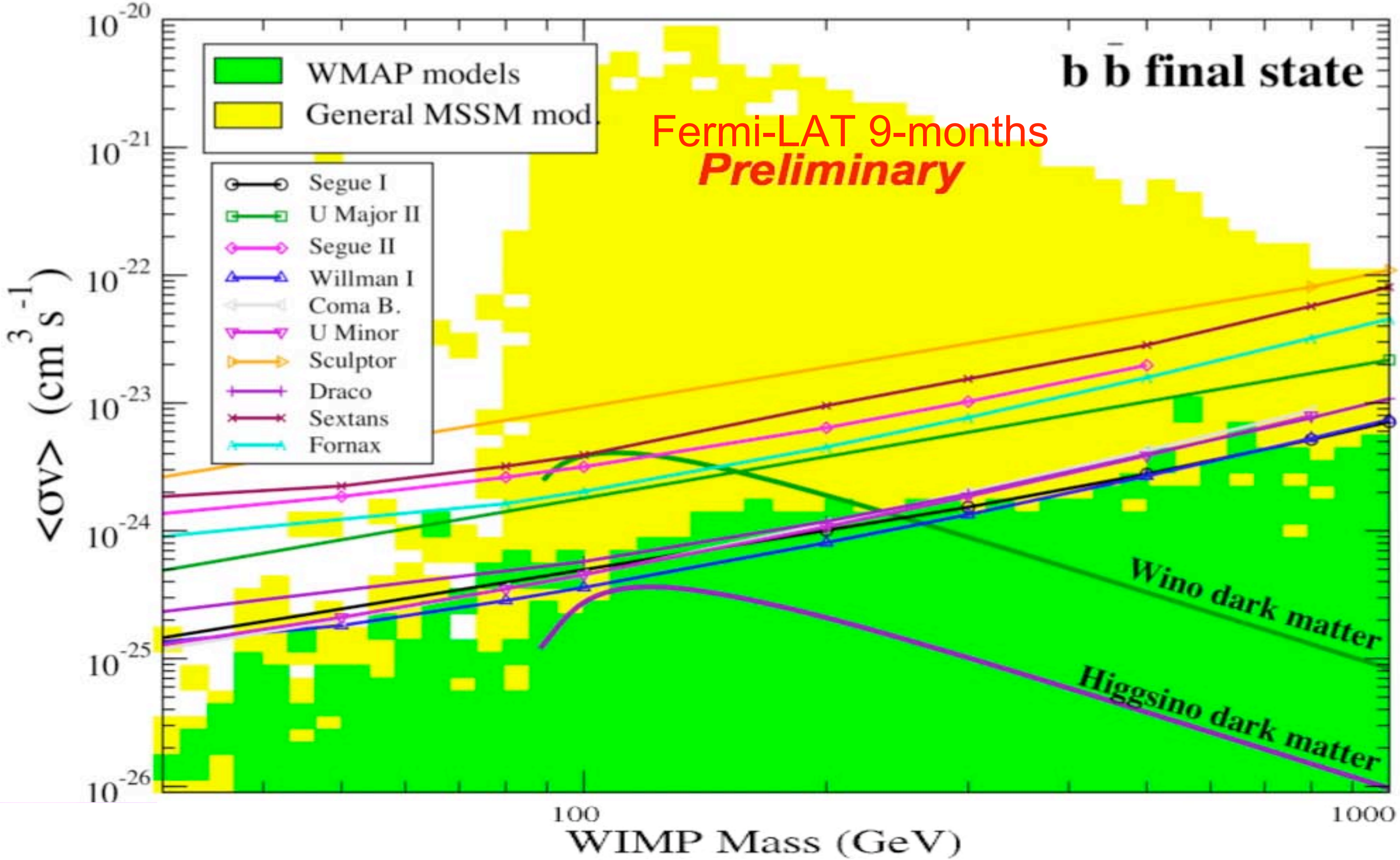


- ➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- ➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- ➢ SDSS [only $\frac{1}{4}$ of the sky covered] already double the number of dSphs 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



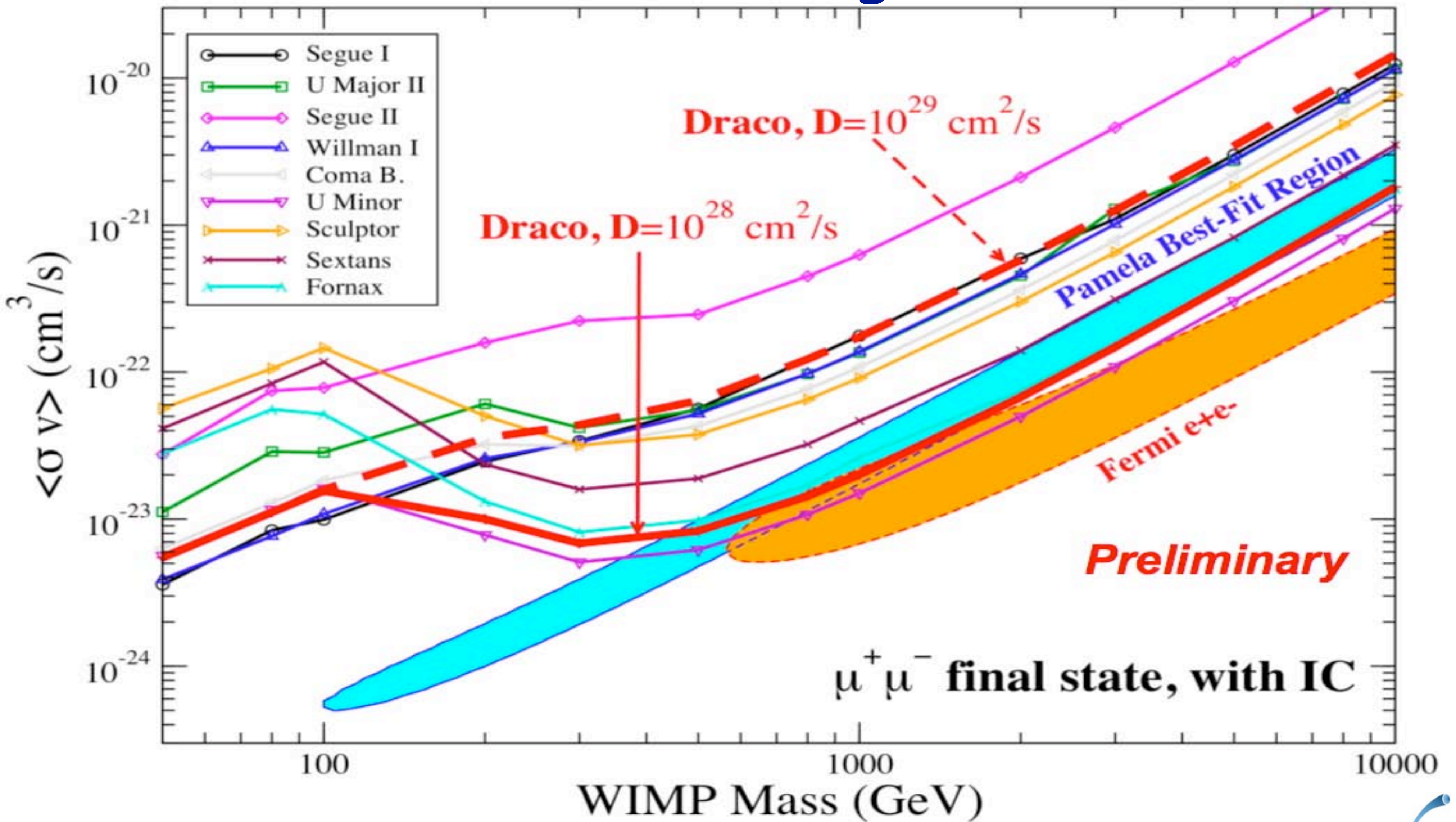
Inverse Compton Emission and Diffusion in Dwarfs

- 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 $D_0 = 10^{28}\ cm^2/s$

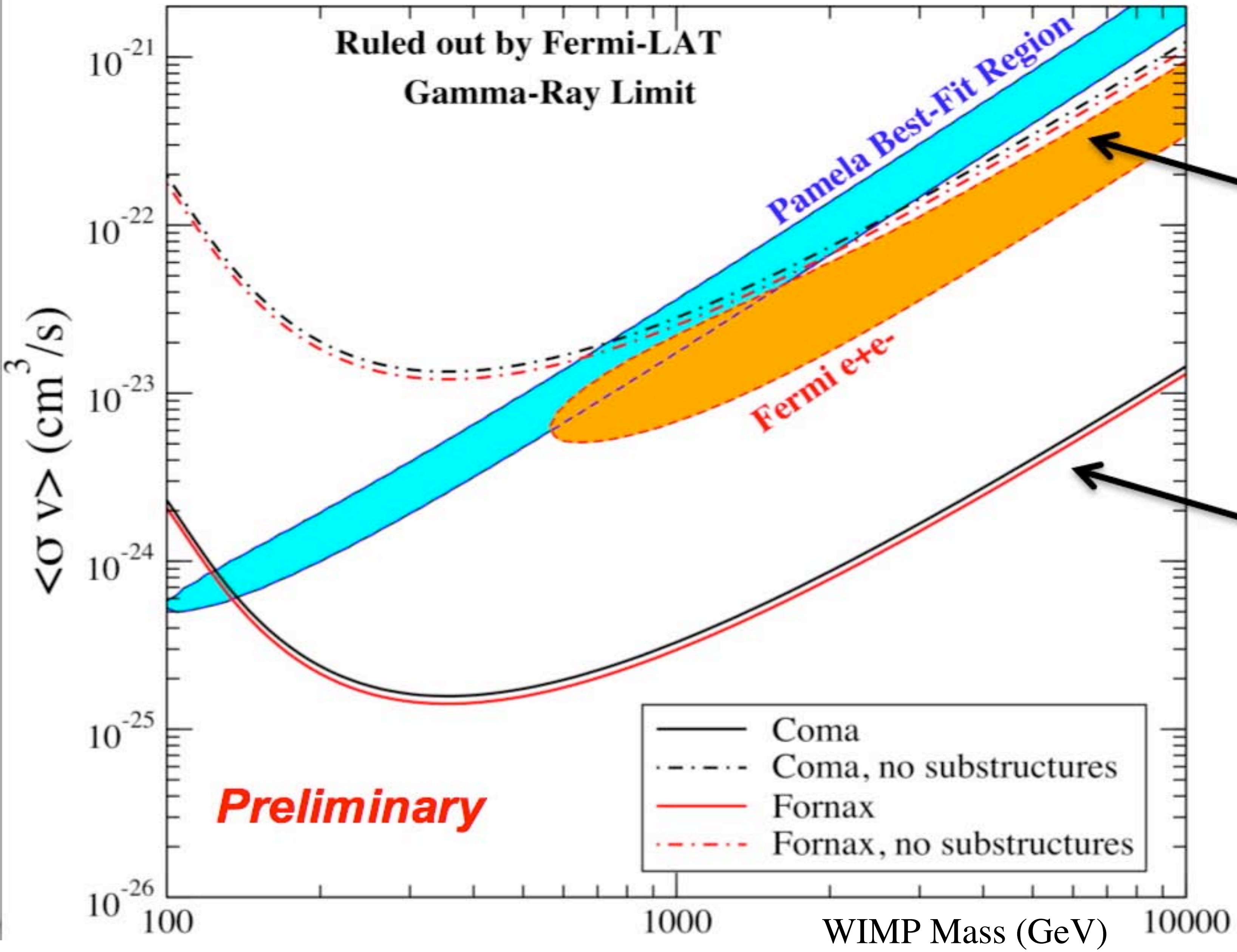
(only galaxy with measurements, scaling to dwarfs ??)

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

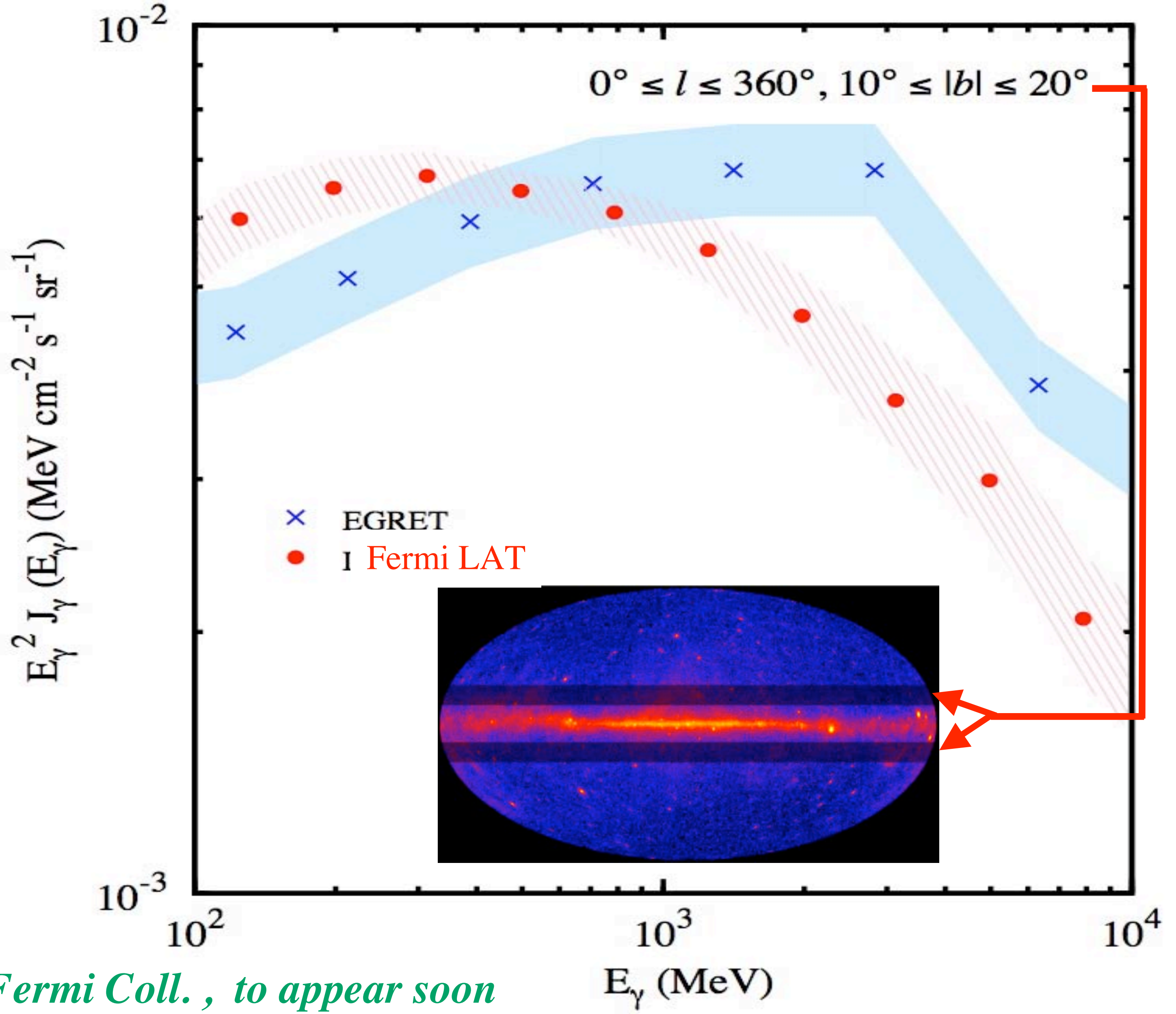


Fornax and Coma clusters: NFW, no substructure

50% of mass in substructure

Combined constraints for Final State Radiation (FSR) plus IC

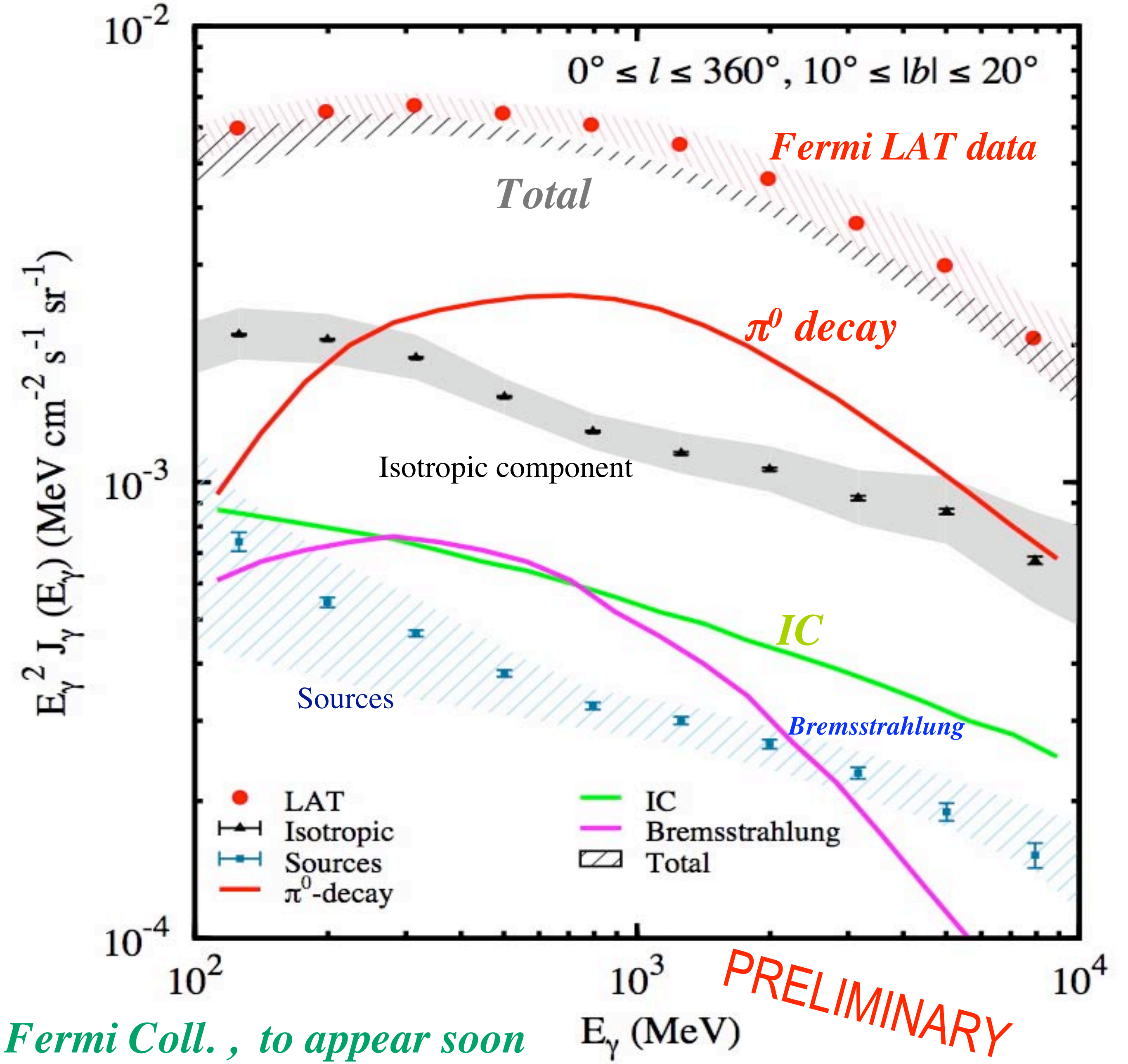
The Galactic Diffuse Emission



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



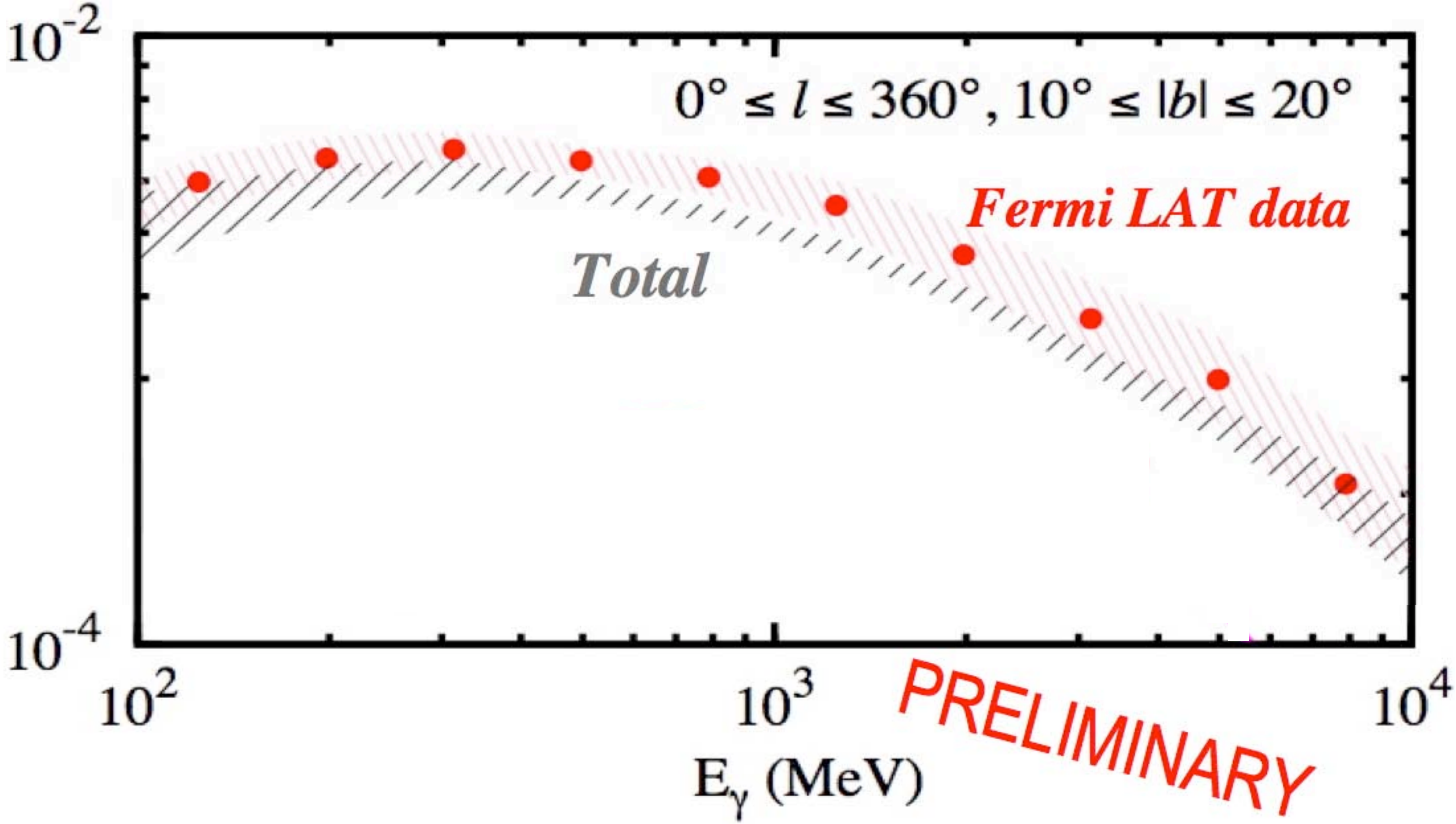
Fermi Coll. , to appear soon

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

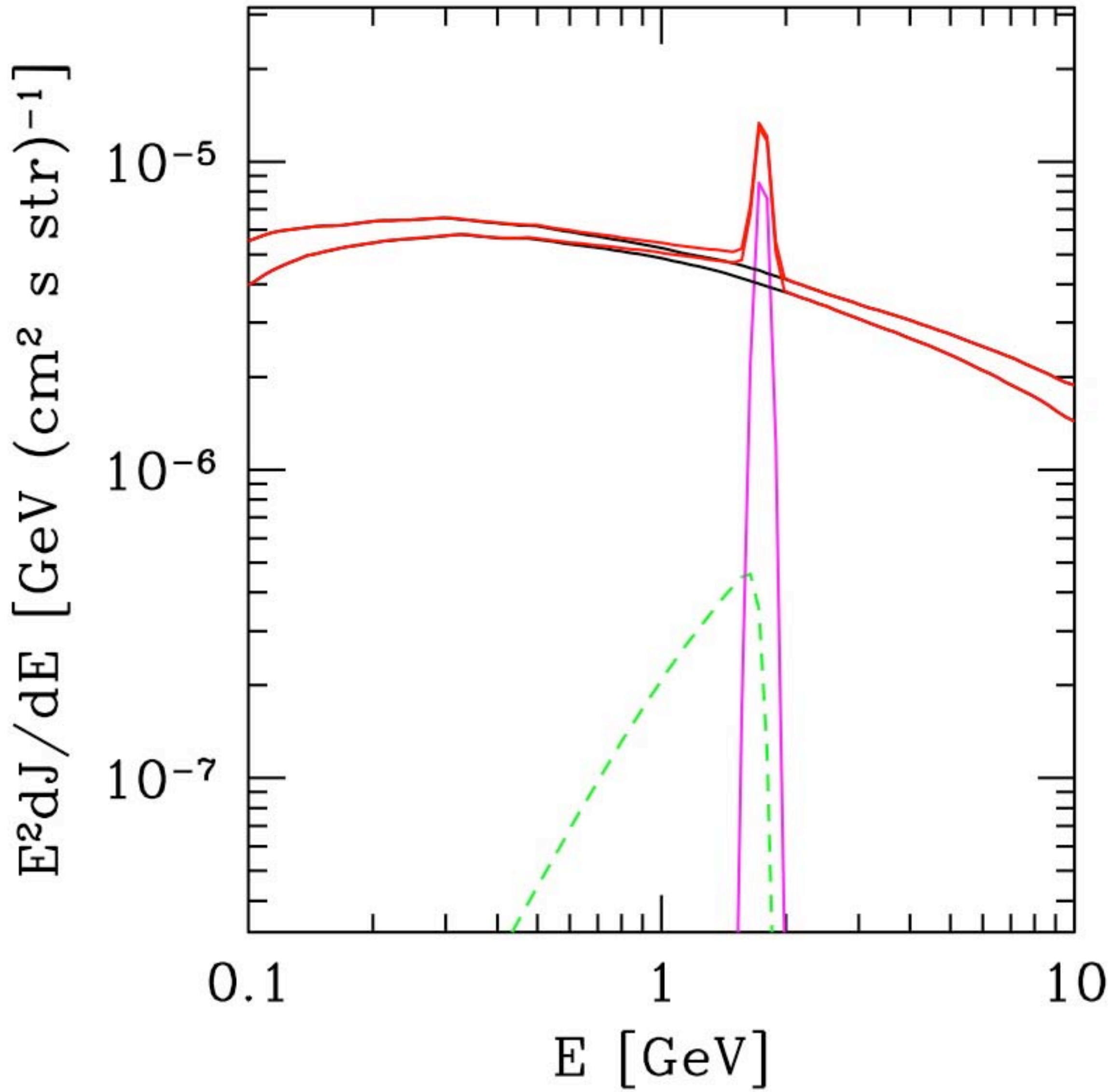
Conventional model are weakly affected by small changes in the electron spectrum.

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



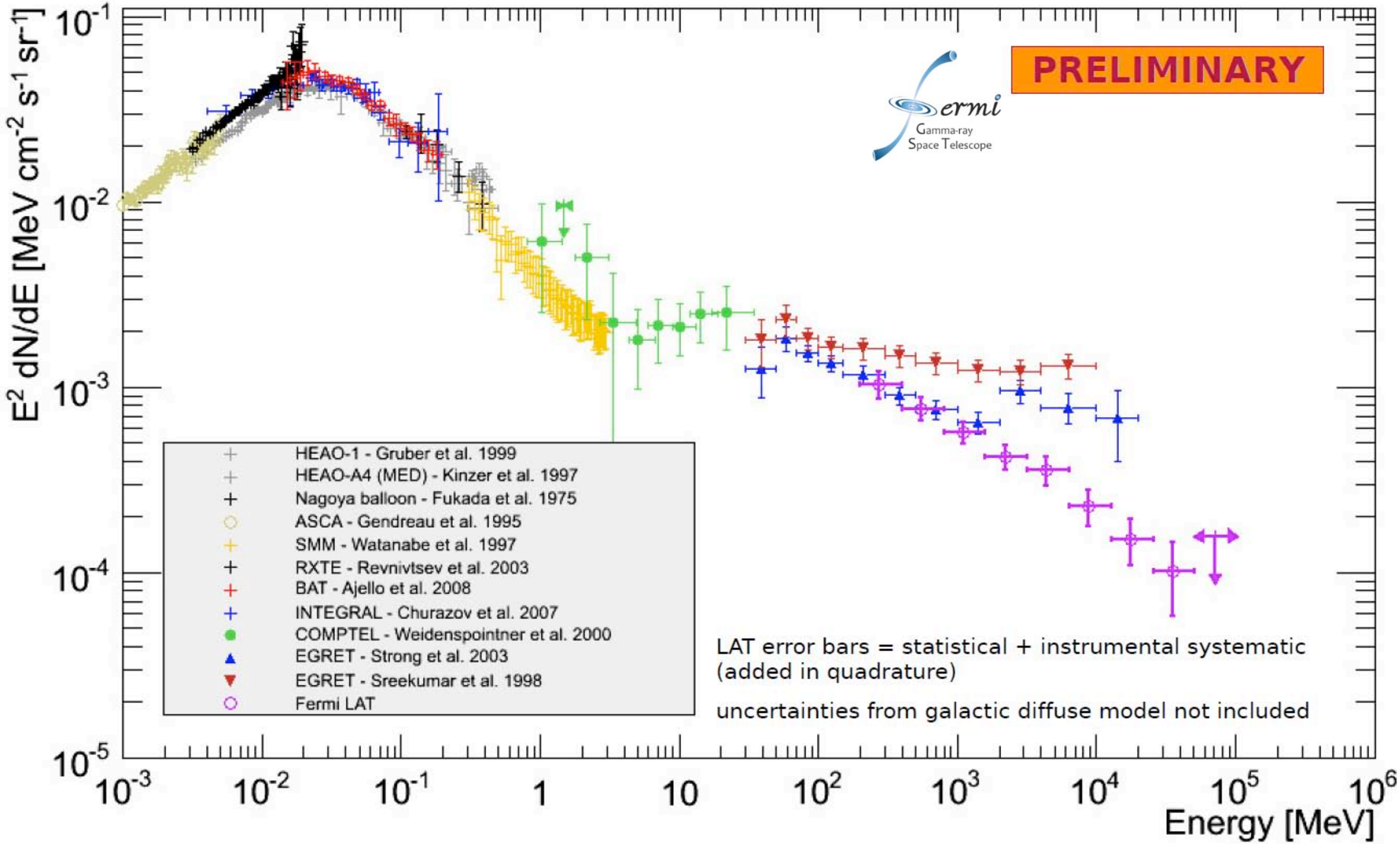
gamma-ray spectrum for an example of gravitino dark matter decay in the mid-latitude range

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

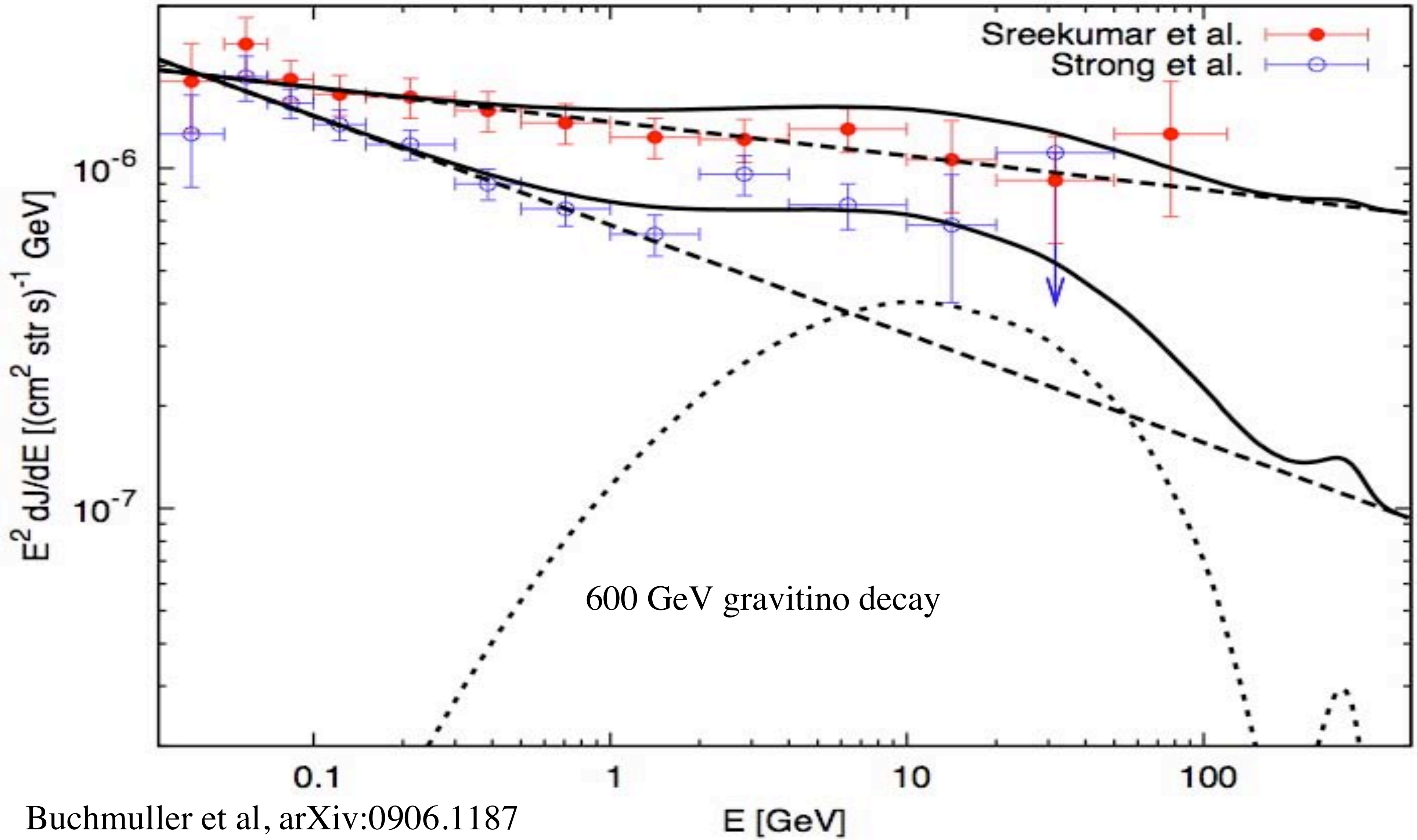


Gamma-ray detection from gravitino dark matter decay in the μνSSM arXiv:0906.368

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

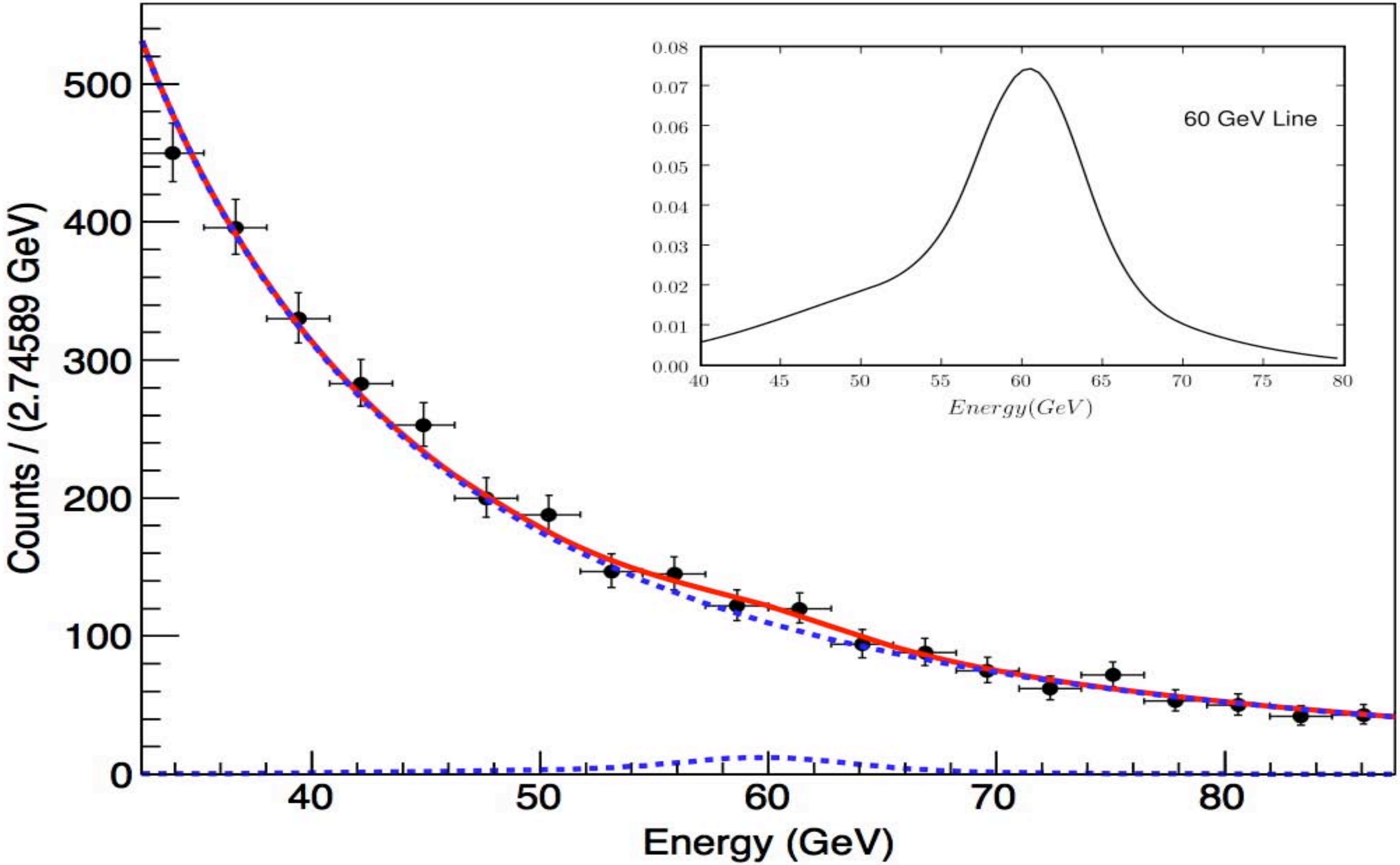


extragalactic gamma-ray spectrum



Buchmuller et al, arXiv:0906.1187

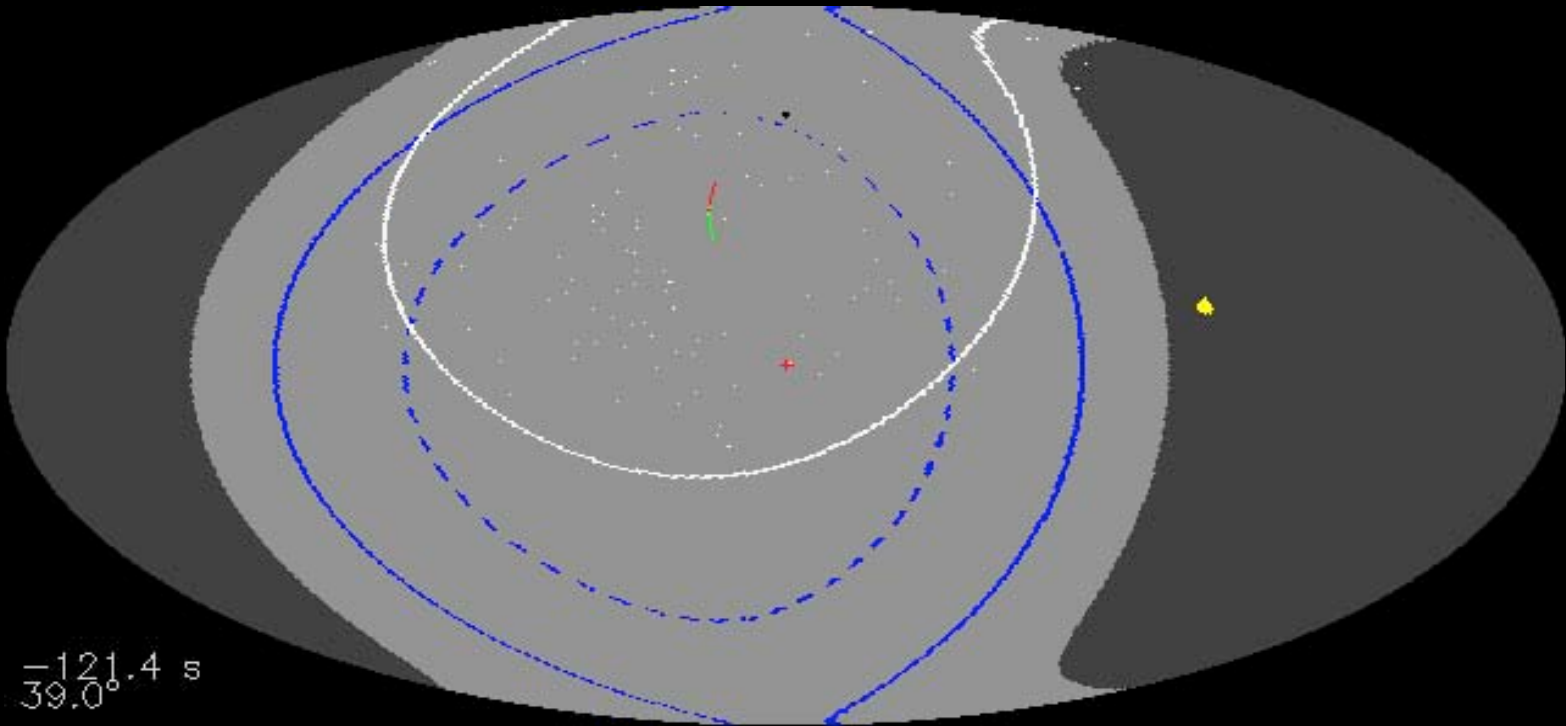
Wimp lines search



GRB 090902B - Autonomous Repoint Request

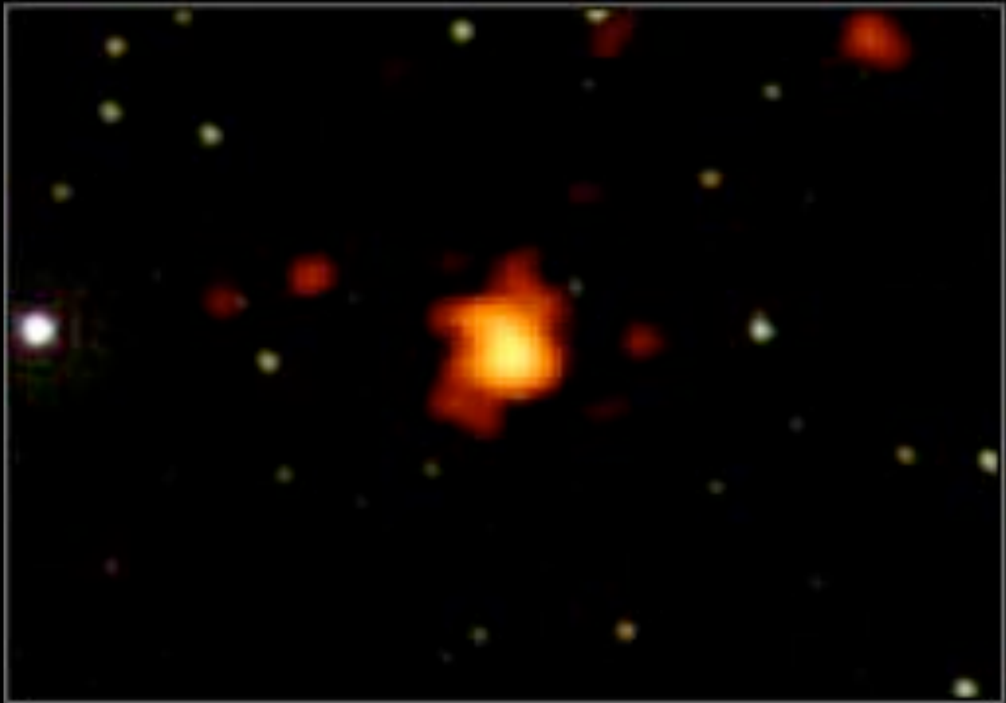
LAT pointing in celestial coordinates from -120 s to 2000 s

- **Red cross = GRB 090902B**
- **Dark region = occulted by Earth (θ_z>113°)**
- **White line = LAT FoV (±66°)**
- **Blue lines = 20° (Earth avoidance angle) / 50° above horizon**
- **White points = LAT transient events (no cut on zenith angle)**



Public data → GRB090902B paper submitted to ApjL, arXiv:0909.2470

Fermi Sees Most Extreme Gamma-ray Blast Yet



located at 12B light years from us using observations of optical afterglow by the GROND observatory

The first burst to be seen in high-res by the Fermi telescope had the greatest total energy, the fastest motions and the highest-energy emissions ever seen

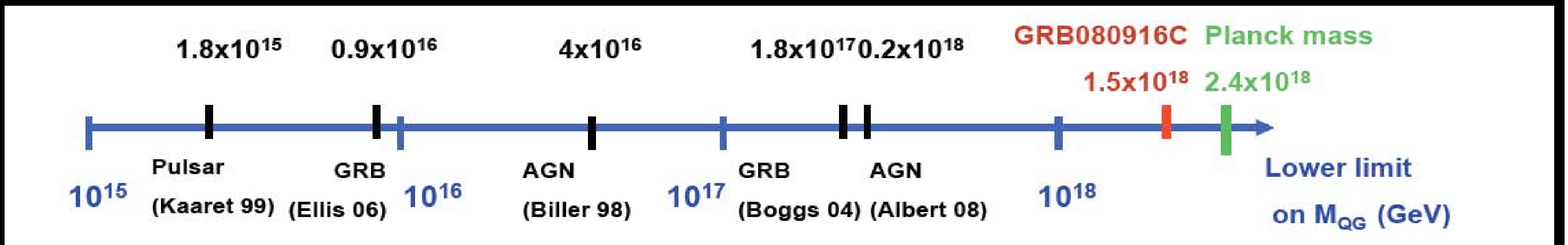
19-2-2009

Large fluence (2.4×10^{-4} erg/cm^2)

& redshift ($z = 4.35 \pm 0.15$)

$\Rightarrow$ record breaking

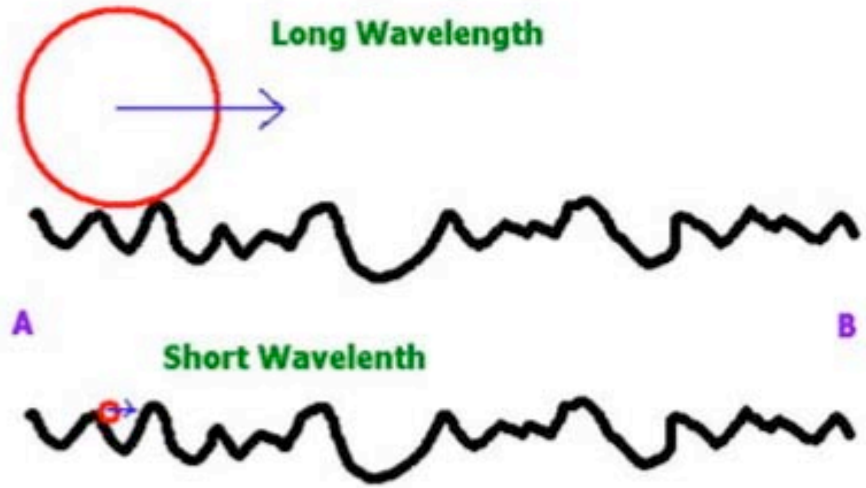
- $E_{\gamma,iso} \approx 8.8\times10^{54}$ erg $\approx 4.9\ M_{\odot}c^2$
- $\Gamma_{min} \approx 890 \pm 20$
- $M_{QG} > 1.5 \times 10^{18}$ (GeV)



Energy dependence of the Speed of light

• Space-time at large distances is "smooth" but, if Gravity is a quantum theory, at very short distances it might show a very complex ("foamy") structure due to Quantum fluctuations.

• A consequence of these fluctuations is the fact that the speed of light in vacuum becomes energy dependent.



• The energy scale at which gravity is expected to behave as a quantum theory is the Planck Mass

$$E_{QG} = O(M_P) = O(10^{19})\ \text{GeV}$$

Test of Quantum Gravity

historical slides ~1999

Candidate effect (after Ellis et al. 1992, Amelino-Camelia et al, 1998):

$$c^2 P^2 = E^2 (1+ f(E/E_{QG}))$$

E=photon energy E_{QG} =effective quantum gravity energy scale

Deformed dispersion relation with function f model dependent function of E/E_{QG}

if $E \ll E_{QG}$ series expansion is applicable

$$c^2 P^2 = E^2 (1+ \alpha(E/E_{QG})+ O(E/E_{QG})^2)$$

$$\Rightarrow \quad v = \delta E/\delta P \sim c (1+ \alpha(E/E_{QG}))$$

vacuum as quantum-gravitational medium which respond differently to the propagation of particle of different energies.

(analogous to propagation through an electromagnetic plasma)

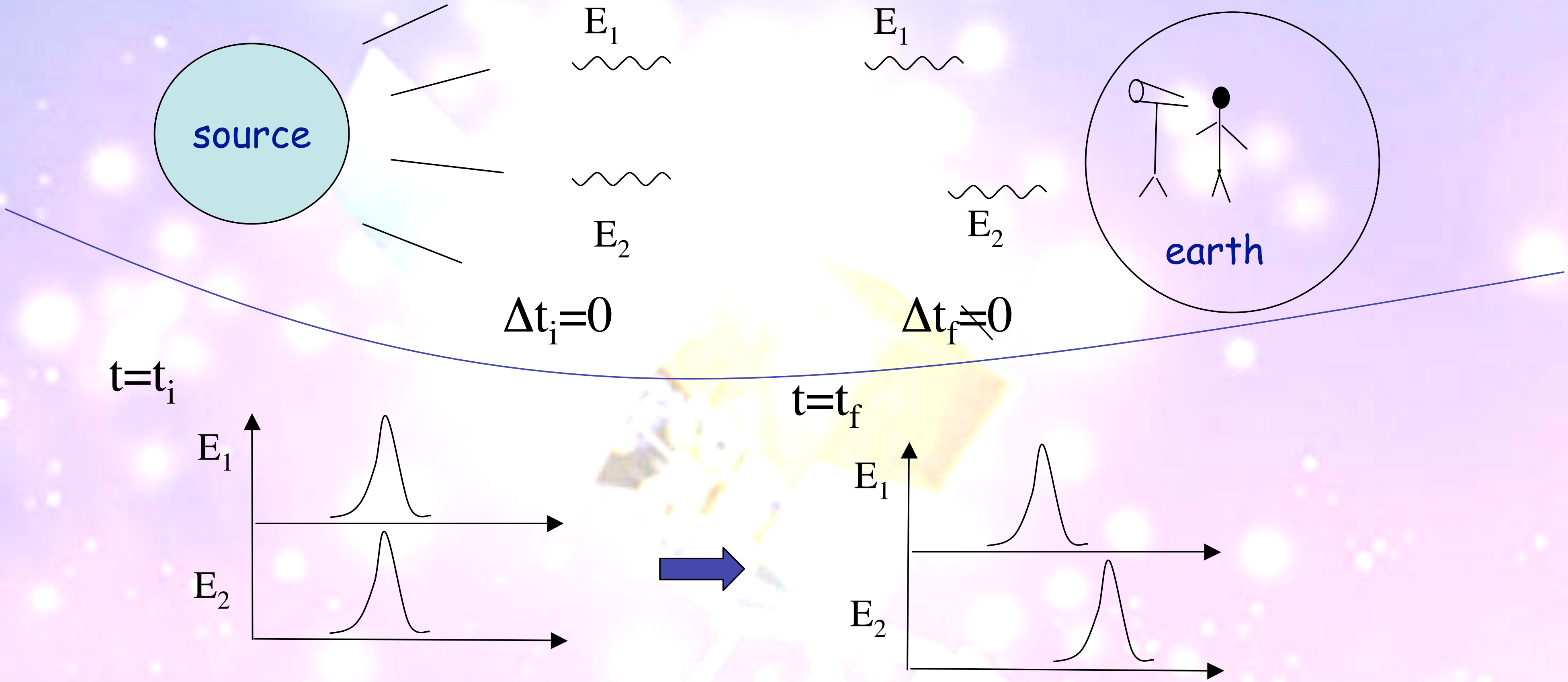
Medium fluctuation at a scale of the order of $L_p \sim 10^{-33}$ cm

$$\Rightarrow \quad \Delta t = \sim \alpha \, \Delta E/E_{QG} \, D/c$$

Test of Quantum Gravity

$$\Delta t = \sim \alpha \, \Delta E / E_{QG} \, D/c$$

historical slides ~1999

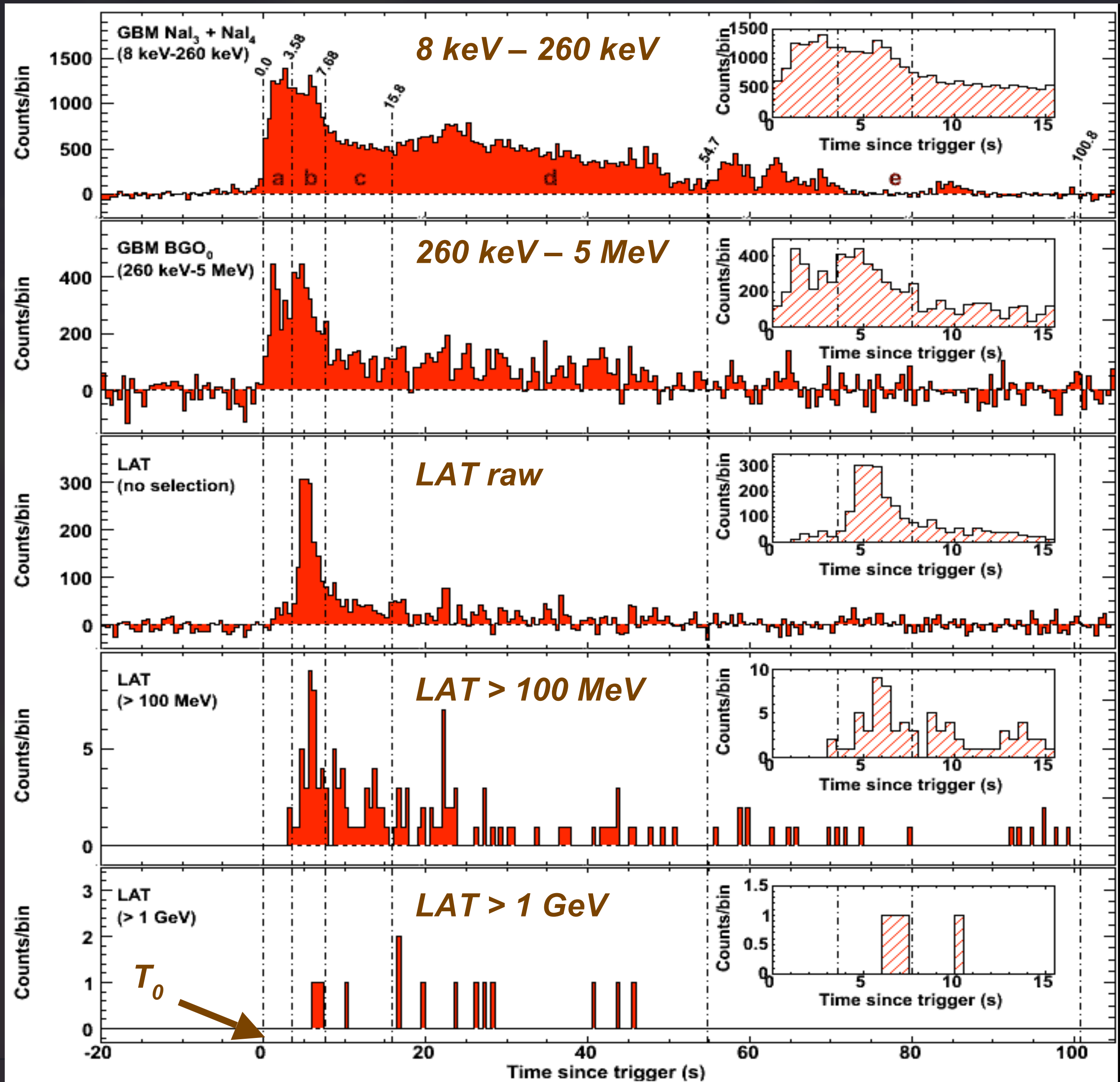


$D \sim 2\ 10^{28}$ cm, $E_{QG} \sim 10^{19}$ GeV, $c \sim 3\ 10^{10}$ cm $\Rightarrow$ $\Delta t(\mathrm{ms}) \sim 60\ \Delta E(\mathrm{GeV})$

even at pulsars distance:

- $D \sim 6\ 10^{21}$ cm if $\Delta t(\mu s) \sim 100$ $\Delta E(\mathrm{GeV}) \sim 1$ $\Rightarrow$ $E_{QG} \sim 2\ 10^{15}$ GeV

GRB 080916C - Highlights



- For the first time, can study time structure > tens of MeV, 14 events above 1 GeV
- First low-energy GBM peak is not observed at LAT energies
- z = 4.35 +/0.15

- **High energy emission delayed**
- The bulk of the emission of the 2nd peak is moving toward later times as the energy increases
- Clear signature of **spectral evolution**
- $E_{\gamma,iso} \approx 8.8\times10^{54}$ erg $\approx 4.9\ M_{\odot}c^2$
- $\Gamma_{min} \approx 890 \pm 20$
- $M_{QG} > 1.5 \times 10^{18}$ (GeV)

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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/

Fermi Gamma-ray Space Telescope

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 ($m^2 sr$)	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**

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 !