New results on high energy cosmic ray electrons from Fermi LAT and their implications on the existence of nearby cosmic ray sources

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WHY HIGH ENERGY ELECTRONS?

- *high energy electrons experience intense loss of energy due to synchrotron radiation and inverse Compton on starlight and 2.7K background radiation*

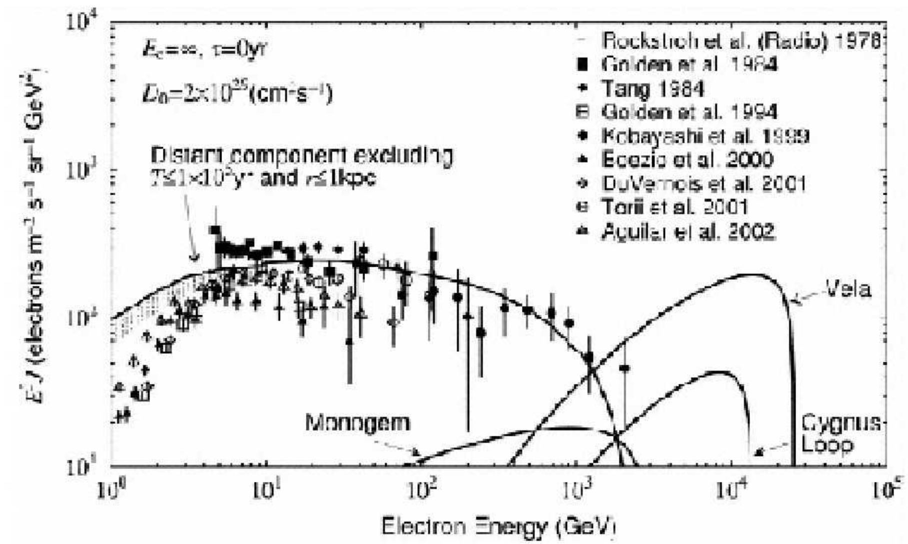
- *life time of high energy electrons against these losses*

  $t_{rad} = E / -dE/dt \approx 3\times10^5\times(1\ TeV/E)$ *yr for B = 4 μG and photon density 1 eV/cm*

- *example for* $D = 3 \times 10^{28} \times (E/7\ GeV)^{0.3}\ cm^2/s$ *: maximum distance from which 1 TeV electrons can reach us is ≈ 350 pc.*

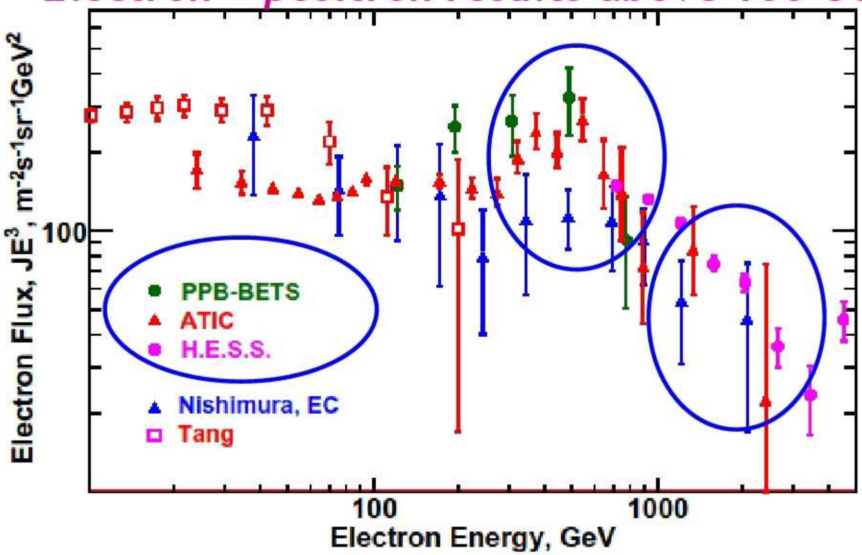
- *Detection of electrons >~ 1 TeV would indicate existence of nearby source*

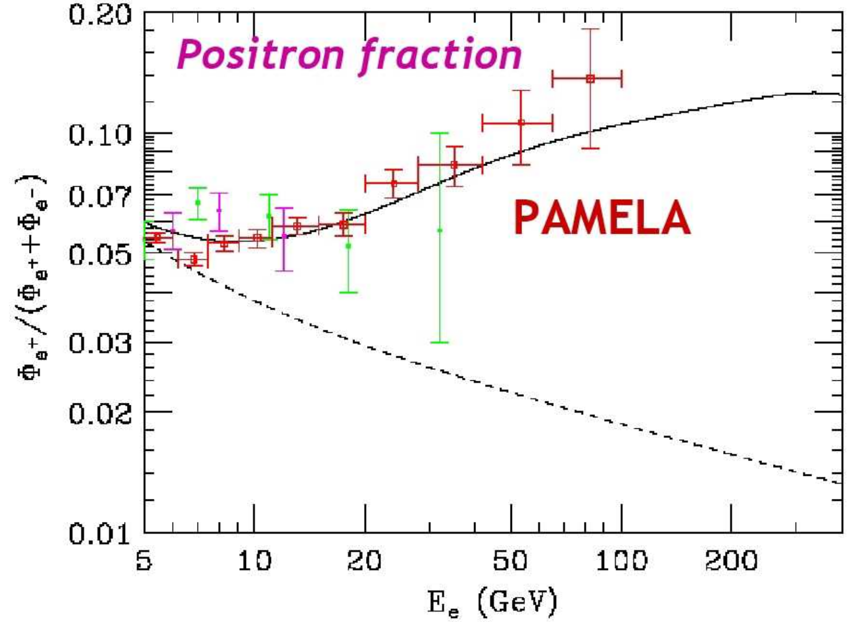
- *excellent probe of cosmic ray origin in nearby Galaxy. Spectral shape contributes to understanding of electrons propagation and their origin*



2008: New results on high energy cosmic ray electrons and positrons

Electron + positron results above 100 GeV





Astrophysicists are excited:

- *Spectral feature at ~ 620 GeV reported by **ATIC** and **PPB-BETS** suggests a nearby source (astrophysical or exotic)*
- ***Pamela :** increase of positron fraction above 10 GeV also suggests new source or production process at high energy*
- ***H.E.S.S.** detects spectrum steepening above ~1 TeV : local source? Weaker re-acceleration?*
- ***More than 100 papers** mentioning these results within a few months*

Fermi LAT Collaboration

United States (NASA and DOE)
- *California State University at Sonoma*
- *Goddard Space Flight Center*
- *Naval Research Laboratory*
- *Ohio State University*
- *Stanford University (HEPL, KIPAC and SLAC)*
- *University of California at Santa Cruz – SCIPP*
- *University of Denver*
- *University of Washington*

France
- *CEA/Saclay*
- *IN2P3*

Italy
- *ASI*
- *INFN (Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine)*
- *INAF*

Japan
- *Hiroshima University*
- *Institute for Space and Astronautical Science / JAXA*
- *RIKEN*
- *Tokyo Institute of Technology*

Sweden
- *Royal Institute of Technology (KTH)*
- *Stockholm University*

122 full members

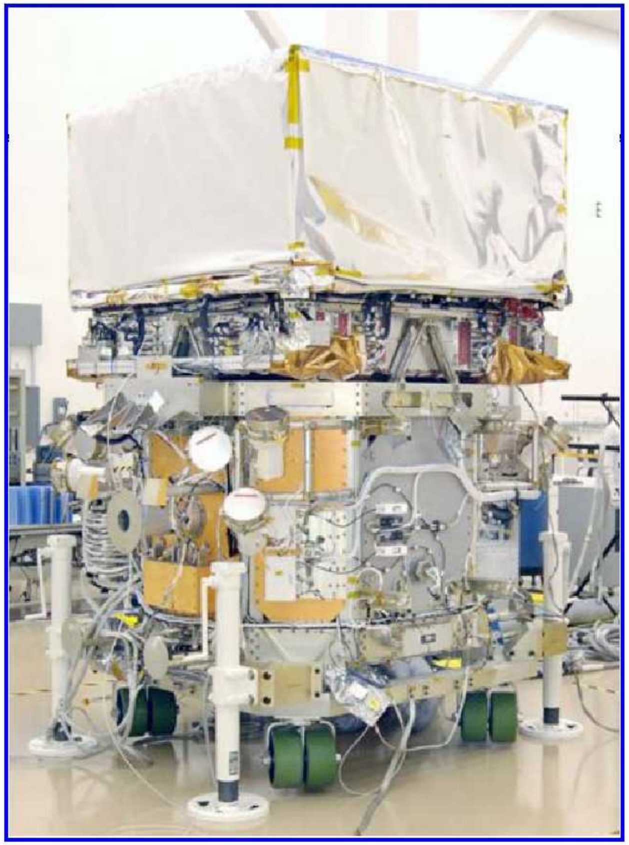
95 affiliated scientists

38 management, engineering and technical members

68 post-doctoral members

105 graduate students

Fermi Gamma-ray Observatory



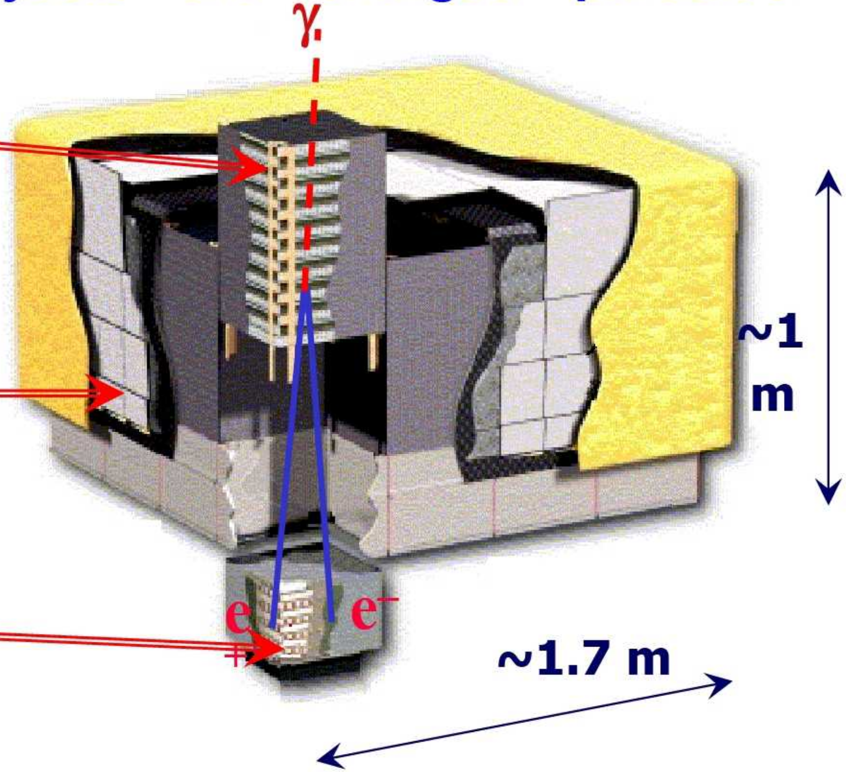
Two instruments onboard Fermi:

- ✓ **Large Area Telescope LAT**
  - **<u>main instrument</u>, gamma-ray telescope, 20 MeV - >300 GeV energy range**
  - **scanning (main) mode - 20% of the sky all the time; all parts of sky for ~30 min. every 3 hours**
  - **~ 2.4 sr field of view, 8000 cm^2 effective area above 1 GeV**
  - **high energy (5-10%) and spatial (~3^0 at 100 MeV and <0.1^0 at 1 GeV) resolution**
  - **1 μs timing, <30 μs dead time**
- ✓ **GLAST Burst Monitor GBM**

5-year mission (10-year goal), 565 km circular orbit, 25.6^0 inclination

The LAT Instrument Overview

Pair-conversion gamma-ray telescope: 16 identical "towers" providing conversion of γ into e^+e^- pair and determination of its arrival direction (Tracker) and energy (Calorimeter). Covered by segmented AntiCoincidence Detector which rejects the charged particles background



Silicon-strip tracker: 18 double-plane single-side (x and y) interleaved with 3.5% X_0 thick (first 12) and 18% X_0 thick (next 4) tungsten converters. Strips pitch is 228 μm; total 8.8×10^5 readout channels

Segmented Anticoincidence Detector: 89 plastic scintillator tiles and 8 flexible scintillator ribbons. Segmentation reduces self-veto effect at high energy.

Hodoscopic CsI Calorimeter Array of 1536 CsI(Tl) crystals in 8 layers.

Electronics System Includes flexible, robust hardware trigger and software filters.

FERMI FLIGHT DATA ANALYSIS FOR ELECTRONS

Main challenges:

Energy reconstruction:
- optimized for energy < 300 GeV; we extended it up to 1 TeV

Electron-hadron separation
- achieved needed 10^3 – 10^4 rejection power against hadrons, with hadron residual contamination < 20%

Validation of Monte Carlo with the flight data:
- carefully compared MC and flight data

Assessment of systematic errors:
- uncertainty in the resulting spectrum is systematic dominated due to very large statistics

Our strong points:

Extensive MC simulations:
- different particles, all energies and angles
- comparison with beam test
- accurate model of CR background

High precision 1.5 X_0 thick tracker:
- powerful in event topology recognition
- serves as a pre-shower detector

Segmented calorimeter with imaging capability:
- fraction of mm to a few mm accuracy position reconstruction depending on energy

Segmented ACD:
- removes gammas and contributes to event pattern recognition

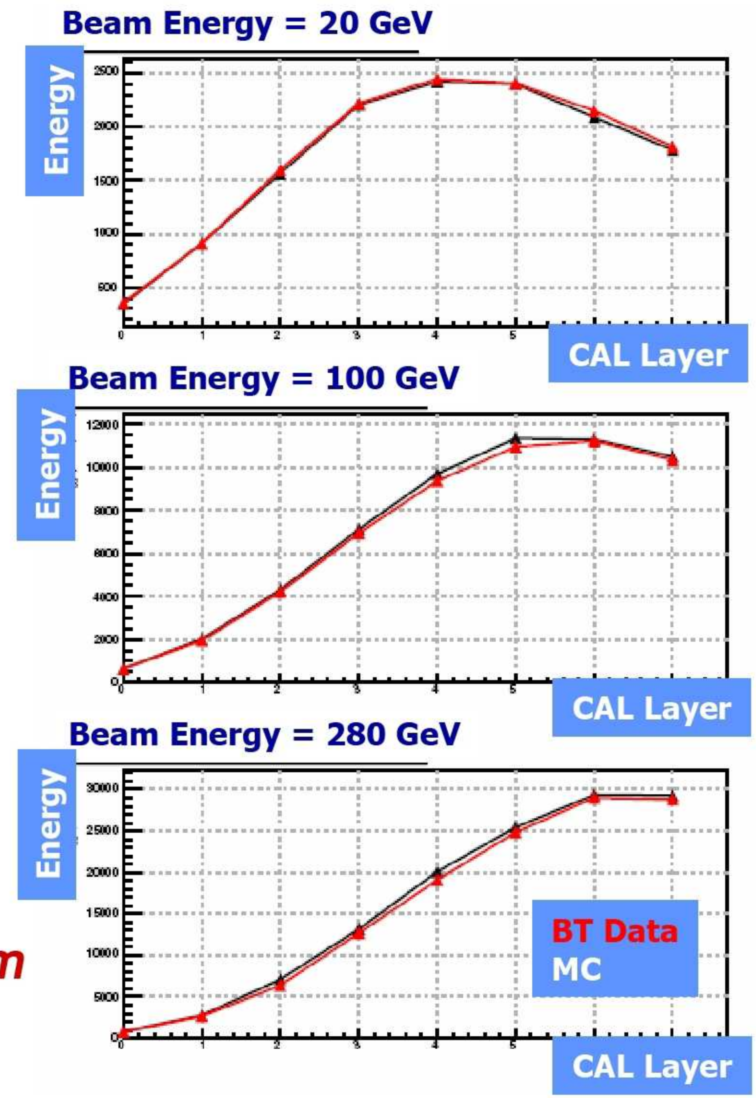
Extensive beam tests:
- SLAC, DESY, GSI, CERN, GANIL

High flight statistics:
- ~10 M electrons above 20 GeV a year

Event energy reconstruction

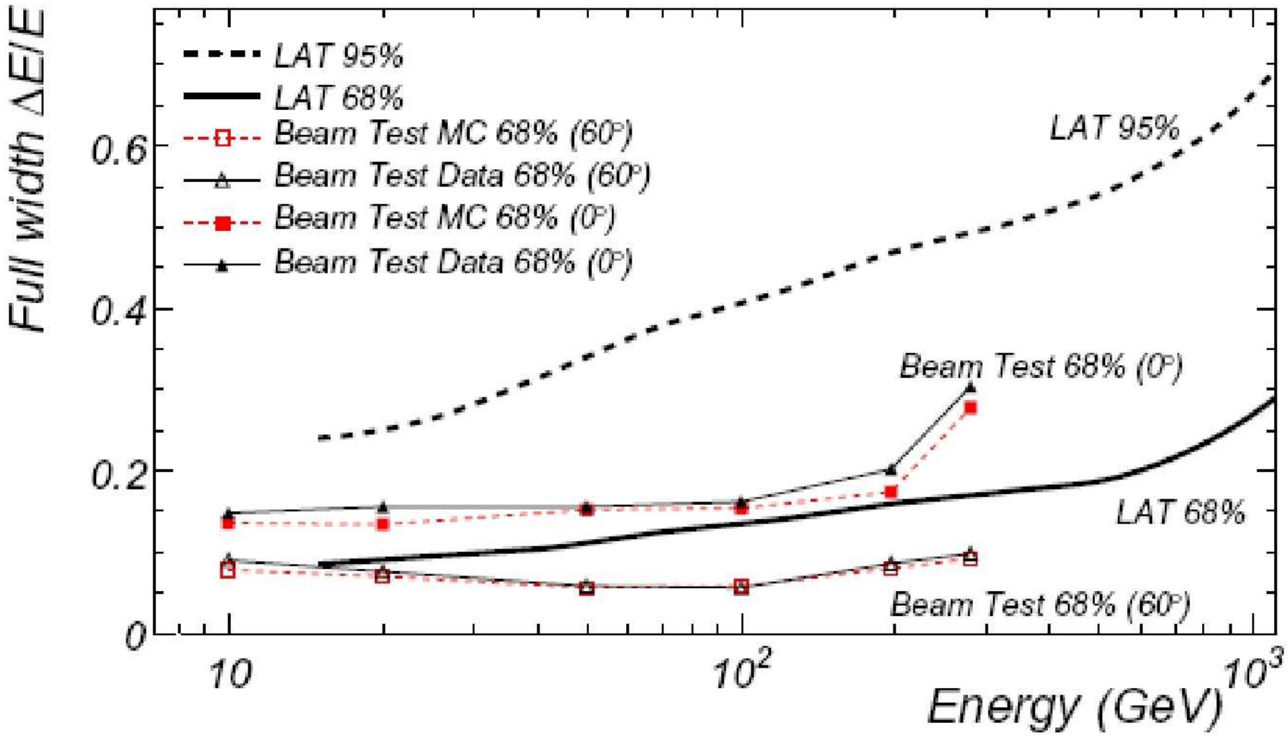
1. Reconstruction of the **most probable value** for the event energy:
   - based on calibration of the response of each of 1536 calorimeter crystals
   - energy reconstruction is optimized for each event
   - calorimeter imaging capability is heavily used for fitting shower profile
   - tested at CERN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

✓ *Very good agreement between beam test and Monte Carlo*



Energy resolution

Agreement between MC and beam test within a few percent up to 280 GeV → we can be confident in MC → *we have reasonable grounds to extend the energy range to 1 TeV relying on Monte Carlo simulations*



Achieved electron-hadron separation and effective geometric factor

Candidate electrons pass on average **12.5 X_0** (Tracker and Calorimeter added together)

Simulated residual hadron contamination (5-21% increasing with the energy) is deducted from resulting flux of electron candidates

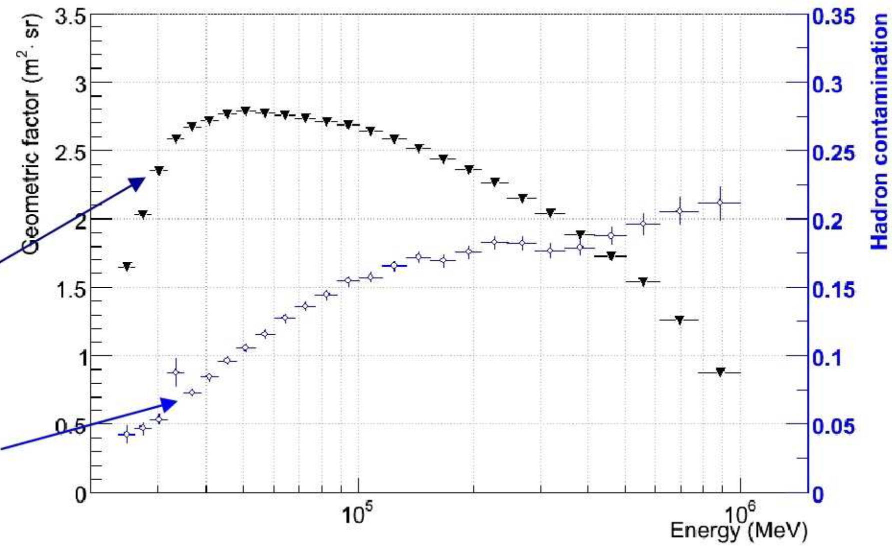
Effective geometric factor exceeds 2.5 m^2sr for 30 GeV to 200 GeV, and decreases to ~1 m^2sr at 1 TeV

Full power of all LAT subsystems is in use: tracker, calorimeter and ACD act together

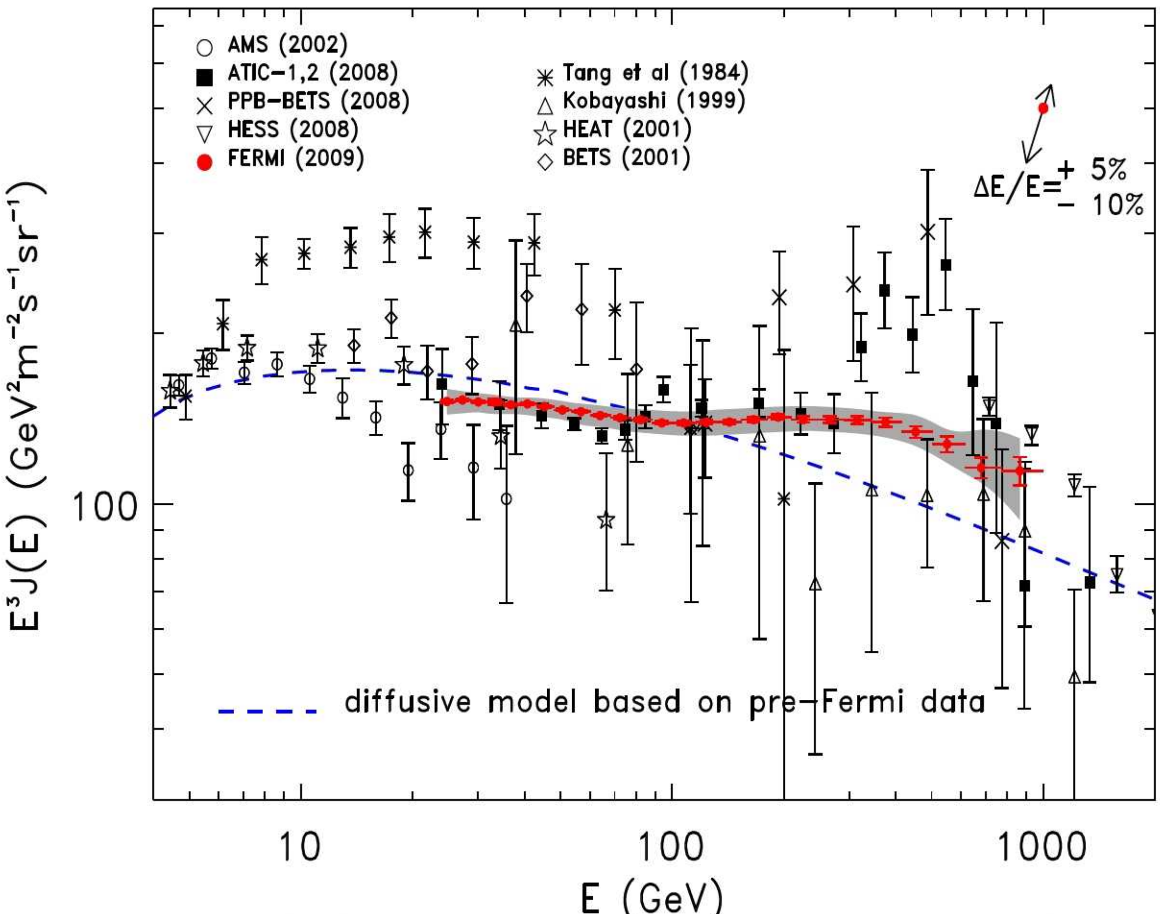
Key issue: *good knowledge and confidence in Instrument Response Function*

Geometric Factor

Residual hadron contamination



Fermi-LAT electron spectrum from 20 GeV to 1 TeV



Submitted to PRL on March 19, 2009

Accepted April 21

Measurement of the Cosmic Ray e++e- Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

A. A. Abdo *et al. (Fermi LAT Collaboration)*

Published 4 May 2009

Physics 2, 37 (2009)

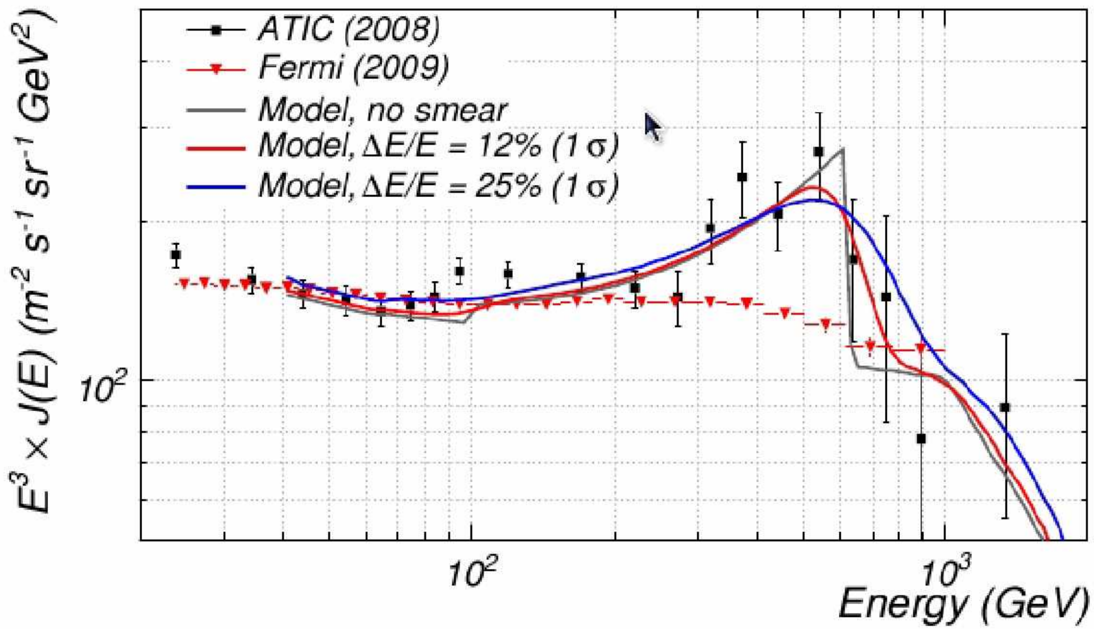
Total statistics collected for 6 months of Fermi LAT observations

- *> 4 million electrons above 20 GeV*
- *> 400 electrons in last energy bin (770-1000 GeV)*

And finally we want to check - could we miss "ATIC-like" spectral feature?

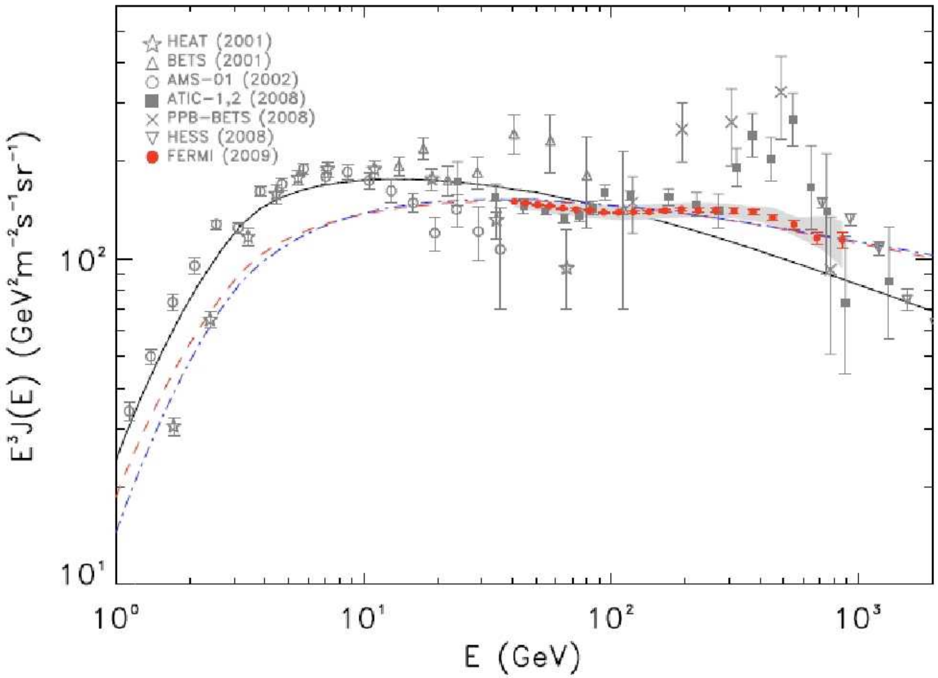
We validated the spectrum reconstruction by:

- ***comparing the results for different path length subsets***
- ***varying the electron selections***
- ***simulating the LAT response to a spectrum with an "ATIC-like" feature:***



This demonstrates that the Fermi LAT would have been able to reveal "ATIC-like" spectral feature with high confidence if it were there. <u>Energy resolution is not an issue with such a wide feature</u>

Some interpretation…



ON POSSIBLE INTERPRETATIONS OF THE HIGH ENERGY ELECTRON-POSITRON SPECTRUM MEASURED BY THE FERMI LARGE AREA TELESCOPE

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astro-ph 0905. 0636 (May 4, 2009)

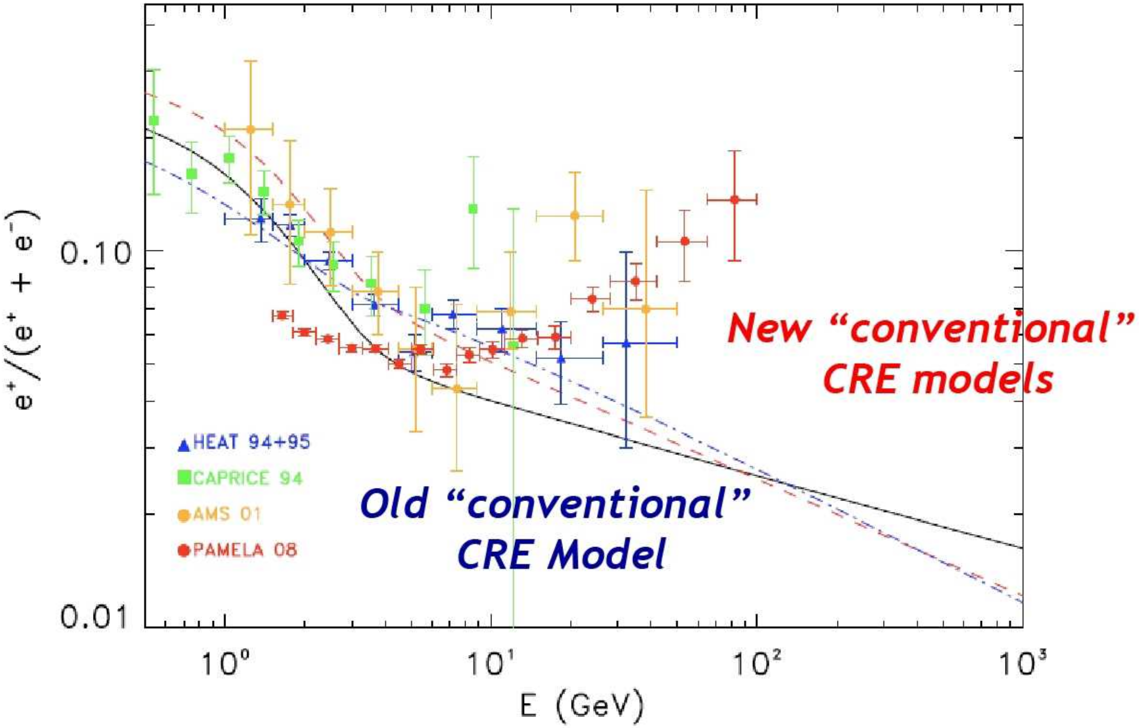
Spectrum can be fit by Diffuse Galactic Cosmic-Ray Source Model (electrons accelerated by continuously distributed astrophysical sources, likely SNR), with harder injection spectral index (-2.42) than in previous CR models (-2.54). All that within our current uncertainties, both statistical and systematic

$$J_{e^\pm} = (175.40 \pm 6.09) \left(\frac{E}{1\ \mathrm{GeV}}\right)^{-(3.045 \pm 0.008)} \mathrm{GeV}^{-1}\mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

with χ^2 per degree of freedom of 9.7 / 23 ***(χ^2 =9.7, d.o.f 24)***

Now – let's include recent Pamela result on positron fraction:

Harder primary CRE spectrum → steeper secondary-to-primary e+/e- ratio

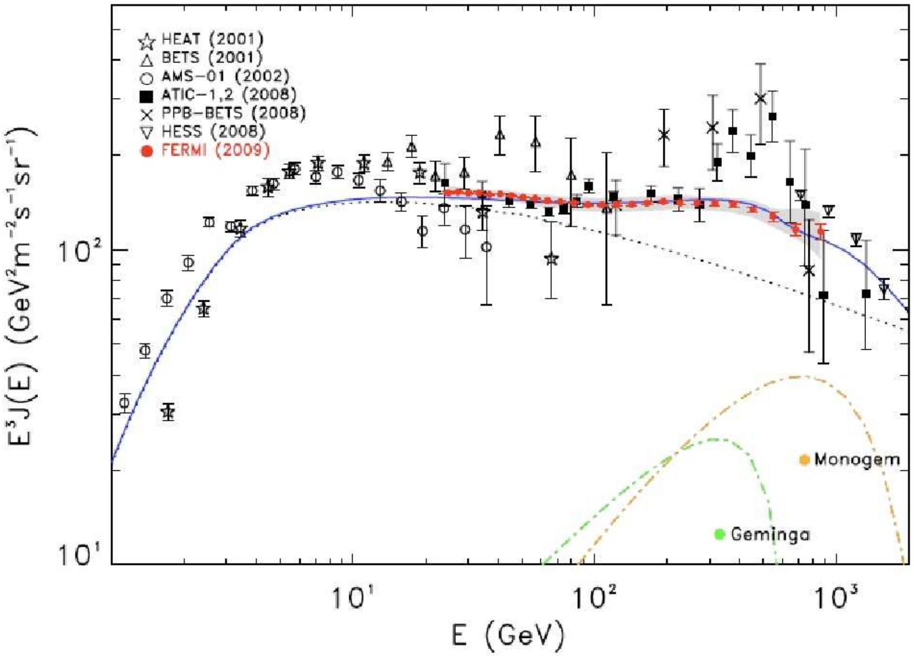


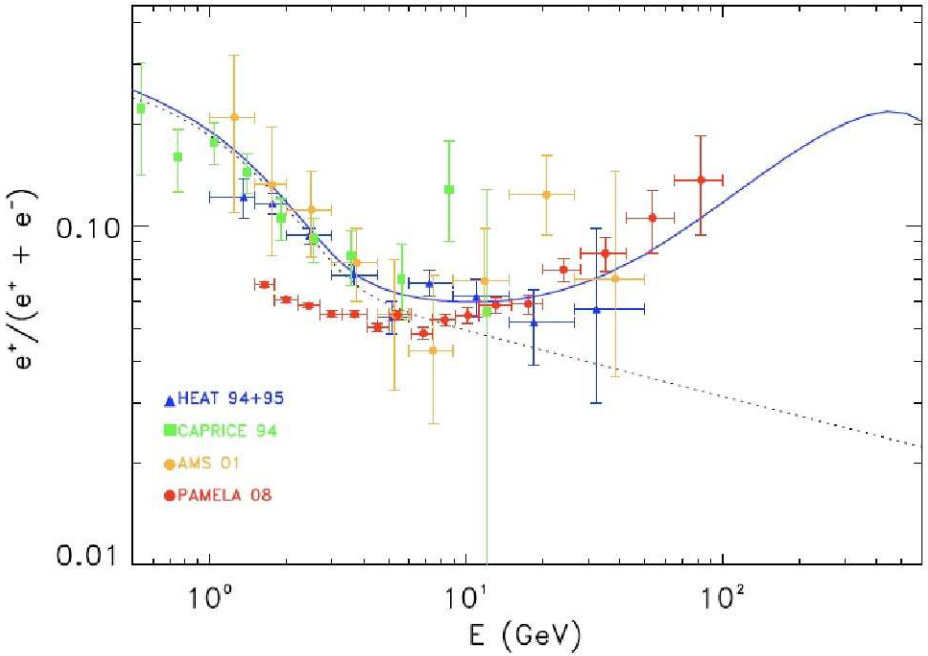
Fermi CRE data exacerbates the discrepancy between a purely secondary diffuse cosmic-ray origin for positrons and the positron fraction measured by Pamela

Need other contributors of electrons:

Pulsars: Most significant contribution to high-energy CRE:

Nearby (d < 1 kpc) and **Mature** ($10^4 < T/yr < 10^6$) Pulsars

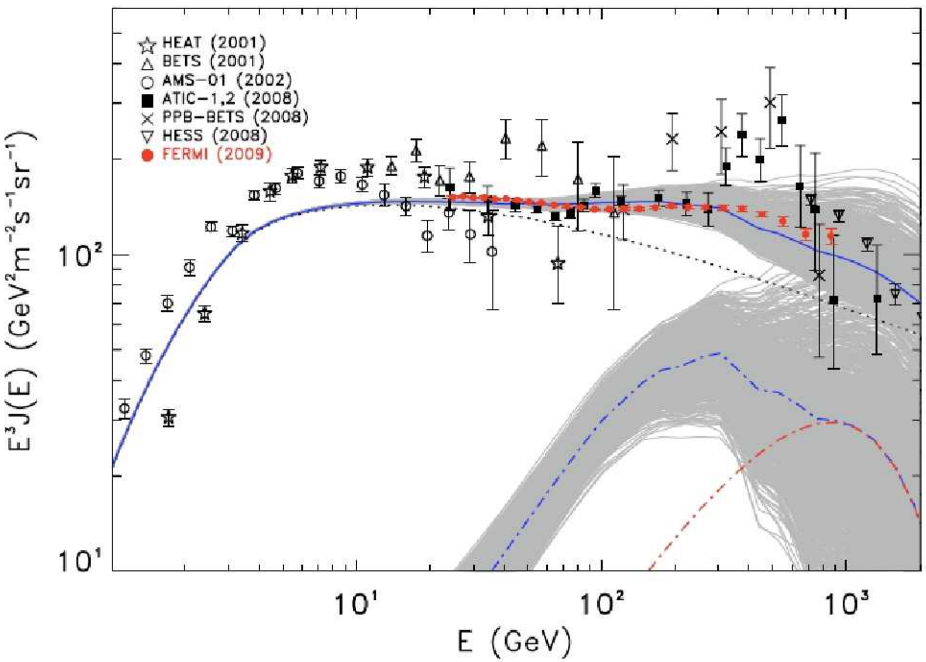


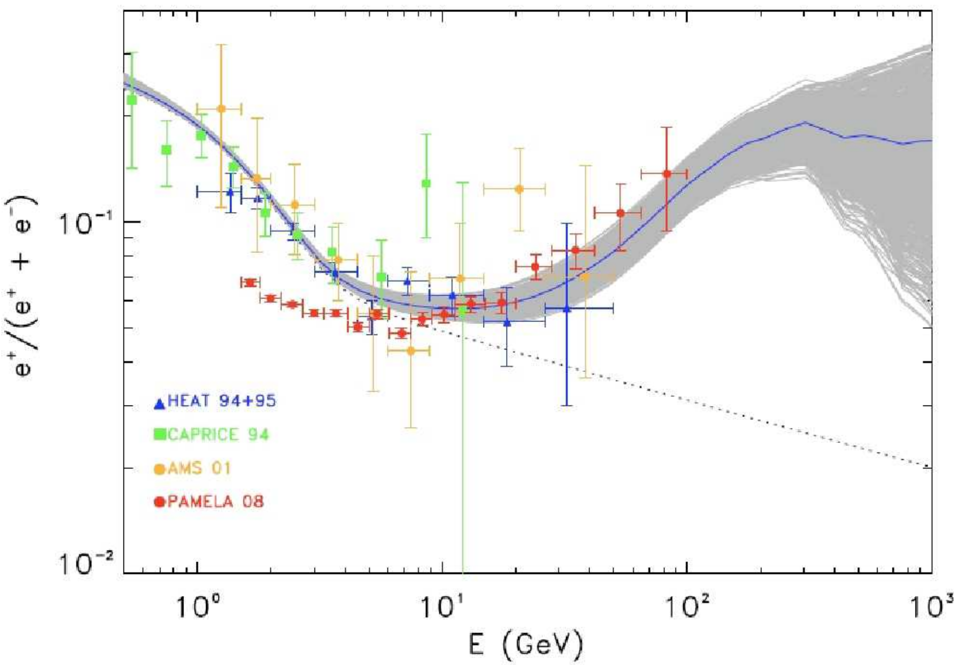


Example of fit to both Fermi and Pamela data with known (ATNF catalogue) nearby, mature pulsars and with a single, nominal choice for the e+/e- injection parameters

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. Maybe too many degrees of freedom, but the assumption is plausible

Dark matter: the impact of the new Fermi CRE data

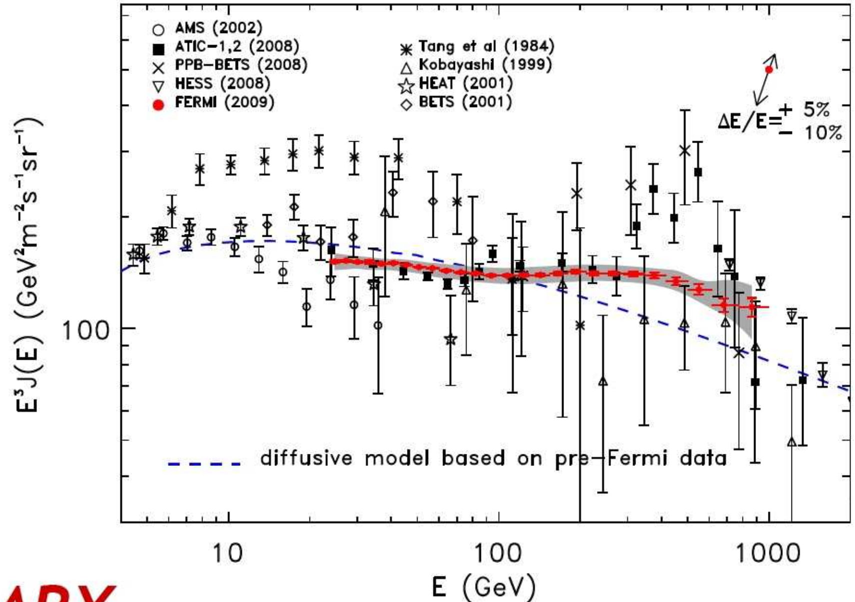
1. *Much weaker rationale to postulate a DM mass in the 0.3-1 TeV range ("ATIC bump") motivated by the CR electron+positron spectrum*

2. *If the Pamela positron excess is from DM annihilation or decay, Fermi CRE data set stringent constraints on such interpretation*

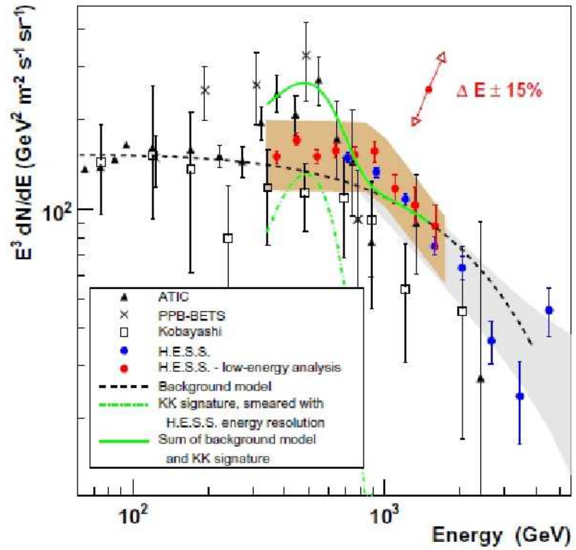
3. *Even neglecting Pamela, Fermi CRE data are useful to put limits on rates for particle DM annihilation or decay*

4. *We find that a DM interpretation to the Pamela positron fraction data consistent with the new Fermi-LAT CRE is a viable possibility. DM origin of CRE is not ruled out*

Origin of the local source is still unclear – astrophysical or "exotic"



H.E.S.S. astro-ph 0905.0105, May 1, 2009 ***NEW***



SUMMARY

- ***The measured spectrum is compatible with a power law within our current systematic errors. The spectral index (-3.04) is harder than expected from previous experiments and simple theoretical considerations***
- ***"Pre-Fermi" diffusive model requires a harder electron injection spectrum (by 0.12) to fit the Fermi data, but inconsistent with positron excess reported by Pamela if it extends to higher energy***
- ***Additional component of electron flux from local source(s) may solve the problem; its origin, astrophysical or exotic, is still unclear***
- ***Valuable contribution to the calculation of IC component of diffuse gamma radiation***

Future plans:

✓ Search for anisotropy in the electron flux – contributes to the understanding of the “extra” source origin

✓ Study systematic errors in energy and instrument response to determine whether or not the observed spectral structure is significant – also critical for understanding of the source origin, as well as models constrains

✓ Expand energy range down to ~ 5 GeV (lowest possible for Fermi orbit) and up to ~ 2 TeV, in order to reveal the spectral shape above 1 TeV

✓ Increase the statistics at high energy end. Each year Fermi-LAT will collect ~ 400 electrons above 1 TeV with the current selections if the spectral index stays unchanged

THANK YOU !