https://ntrs.nasa.gov/search.jsp?R=20100031209 2019-08-30T11:35:49+00:00Z

Fermi LAT results and perspectives in measurements of high energy galactic cosmic rays

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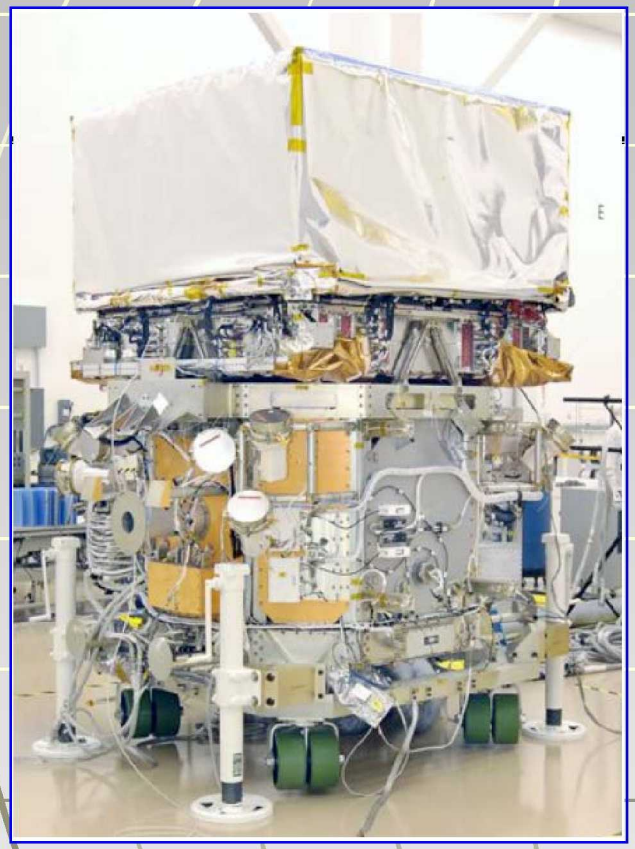
Outline

- Fermi gamma-ray space telescope as a detector of cosmic ray electrons
- Cosmic ray electrons: key issues of the analysis and the result
- Results on electron anisotropy
- Fermi LAT capability to measure CR positrons
- Fermi LAT capability to measure protons

Fermi Gamma-ray Space Telescope was launched on June 11, 2008 and demonstrates excellent performance

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

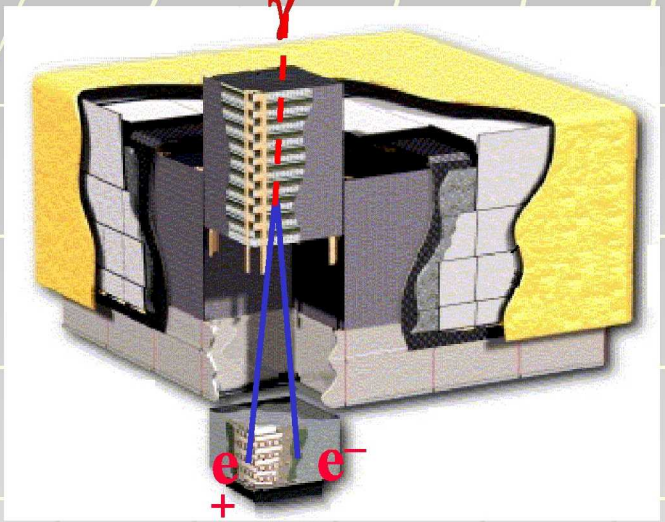
Fermi Gamma-ray Space Telescope



Two instruments onboard Fermi:

- ✓ **Large Area Telescope LAT**
  - main instrument, 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
  - good energy (5-10%) and spatial (~3^0 at 100 MeV and <0.1^0 at 1 GeV) resolution
- ✓ **GLAST Burst Monitor GBM**

LAT as a detector of high energy cosmic ray electrons



- The LAT is composed of a 4x4 array of identical towers. Each tower has a Tracker and a Calorimeter module. Entire LAT is covered by segmented Anti-Coincidence Detector (ACD)

- Although the LAT was designed to detect photons, it was recognized early in its design that the LAT is a capable detector of high energy electrons too

- The electron data analysis is based on that developed for photons. The main challenge is to identify and separate electrons from all other charged species, mainly CR protons (for gamma-ray analysis this is provided by the Anti-Coincidence Detector)

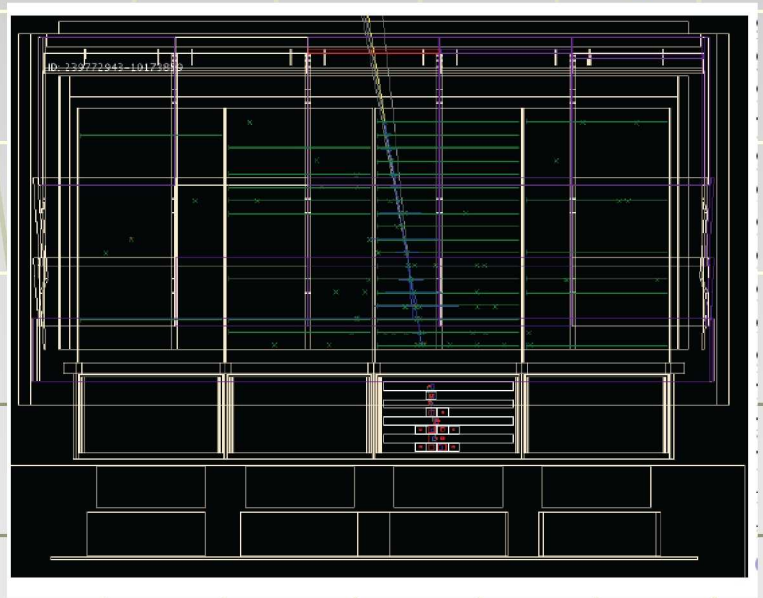
- The hadron rejection power must be $10^3 – 10^4$ increasing with energy

Electron Event Selection

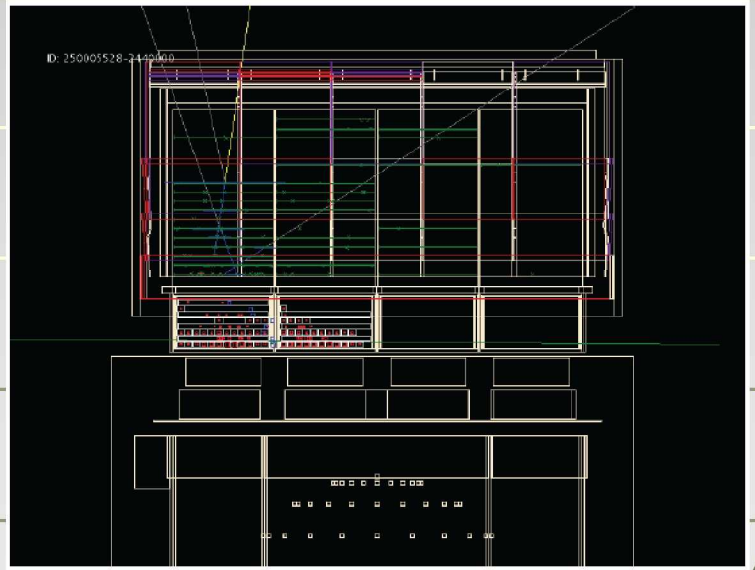
- All the LAT subsystems – tracker, calorimeter and ACD contribute to the event selection

- Event selection is based on the difference between electromagnetic and hadronic event topologies in the instrument

Flight event display



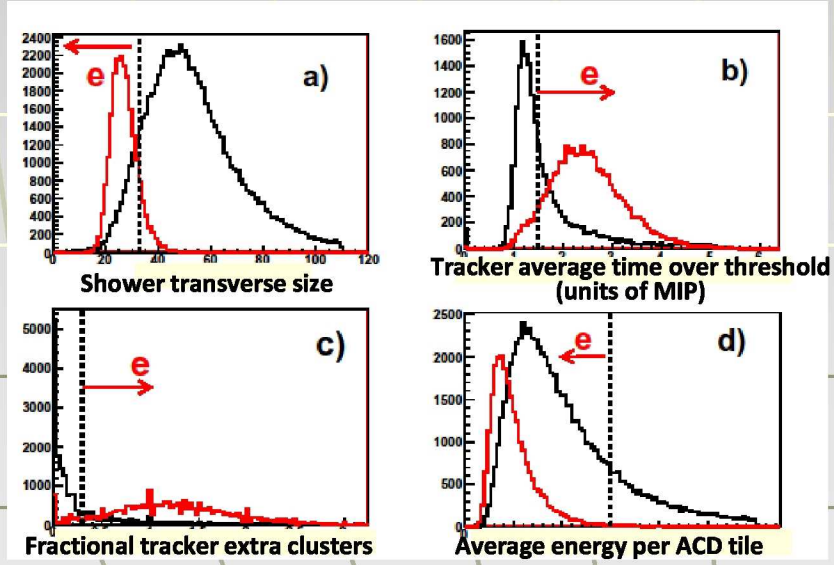
Electron candidate, 844 GeV



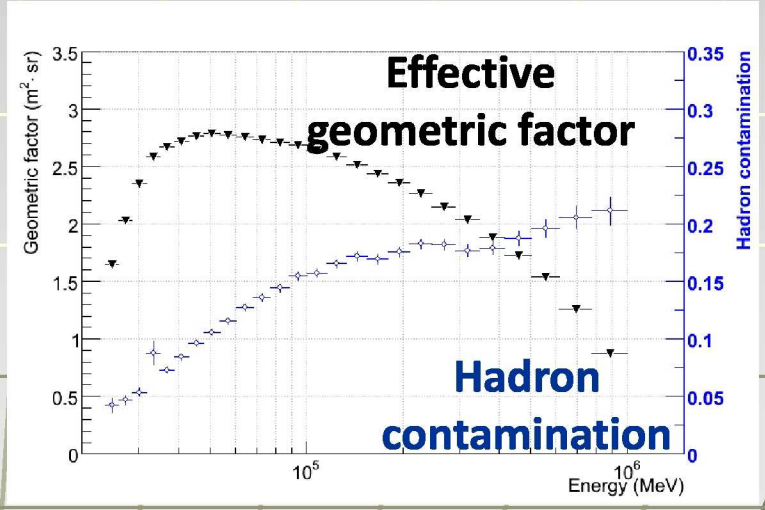
Background event, 765 GeV

Electron event selection (cont.)

- Electron event selection is a complicated, highly-optimized process that utilizes numerous physical variables from all 3 LAT subsystems, as well as combined variables calculated with the Classification Tree method
- Most of the selections are energy dependent or scaled with the energy
- The most powerful separators between electromagnetic and hadronic events are the lateral distributions of the shower image

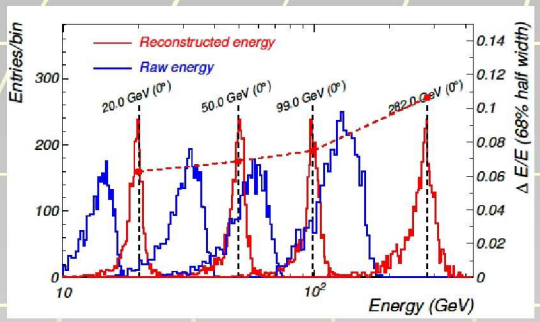


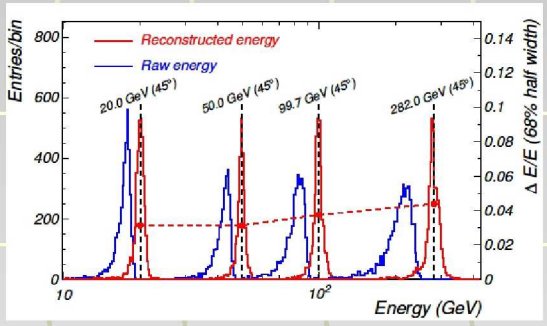
Histograms of selected variable distributions for the electron (red) and proton (black) events

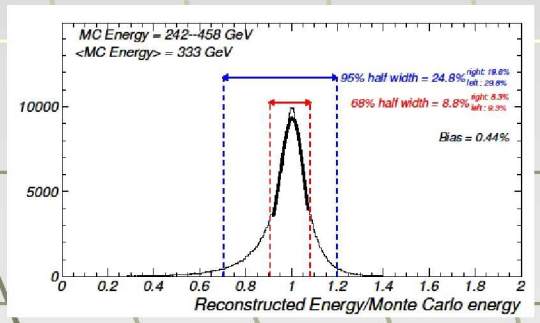


Hadron contamination rate is subtracted from the rate of electron candidate events

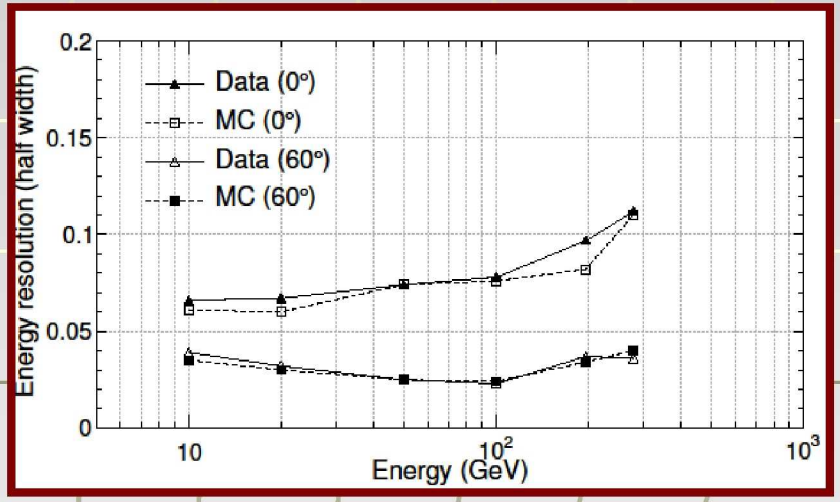
Event energy reconstruction and validation







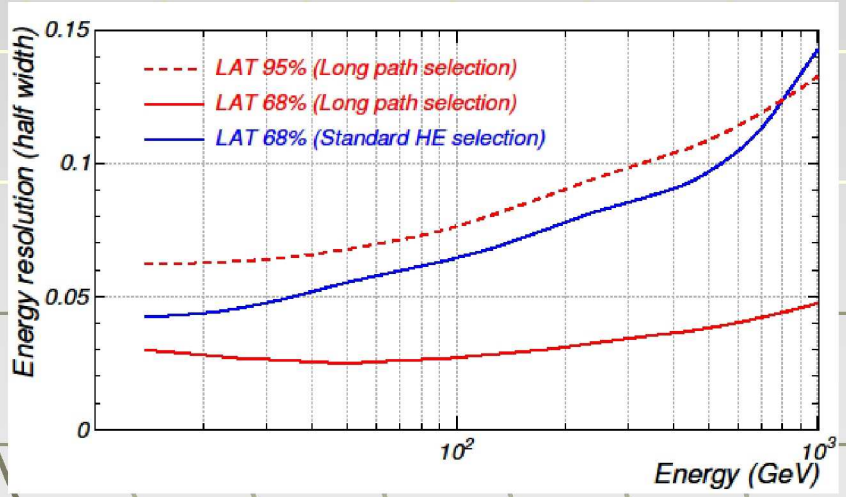
- **Based on the algorithms developed for the LAT photon analysis**
- **Extended to 1 TeV for the electron analysis**
- **Validated in extensive beam tests (SLAC, CERN, GSI). Practically unbiased**

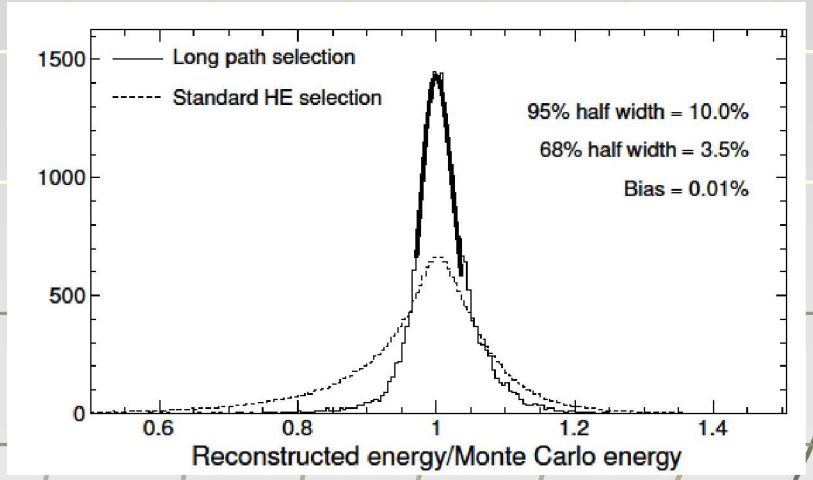


Agreement between MC and beam test data up to 280 GeV gives us a solid ground to rely on simulations for extended energy range

Energy resolution

- 6% at 20 GeV, gradually increasing to 13% at 1 TeV (half width for 68% event containment)
- To test the effect of limited energy resolution, we selected events with long paths in the calorimeter (> 12 X_0 ; average path length ~16 X_0). For this subset the energy resolution better than 5% up to 1 TeV is achieved





Comparison of standard and "long path" analysis

Systematic uncertainties

- Very high event counting statistics → our result is dominated by systematic uncertainties.

- Careful analysis of contributions to the systematic uncertainty:

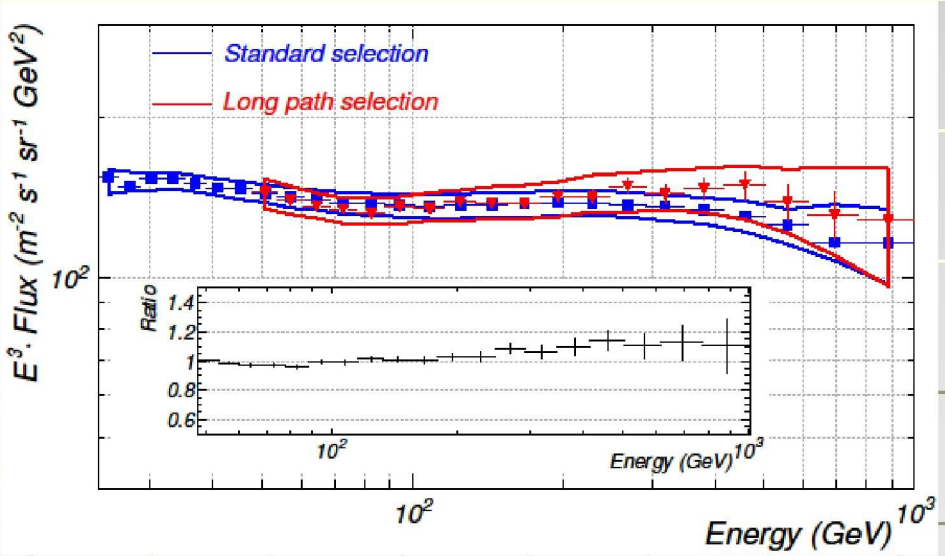
  - uncertainty in knowledge of the LAT response (mainly the effective geometric factor, 5-20% increasing with energy)

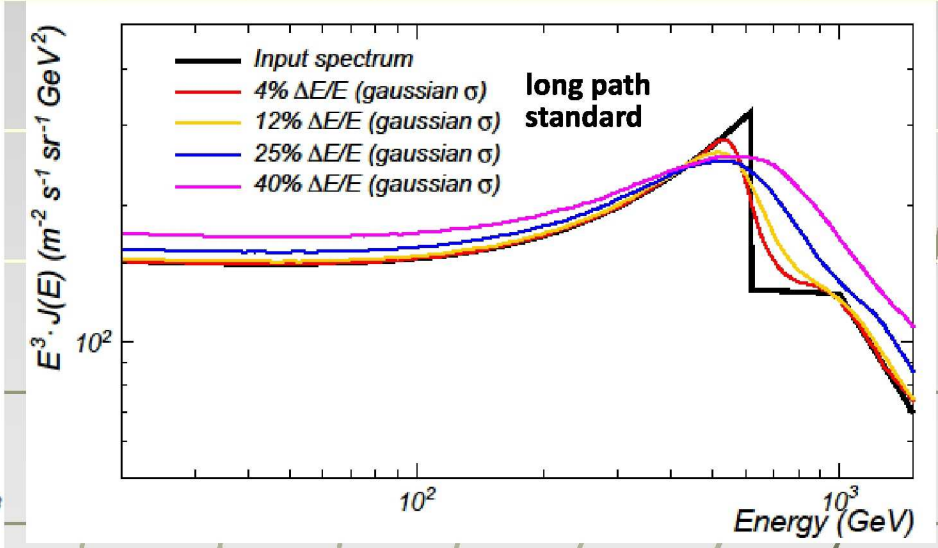
  - uncertainty of residual hadron contamination (< 5%)

- Uncertainty in absolute energy scale (+5-10%)

Capability to reconstruct spectral features

- Since our result does not confirm exciting ATIC result, we carefully checked our capability in spectral reconstruction
- It was cross-checked with subset of events with long paths in the calorimeter, providing best energy resolution
- We simulated how an ATIC-like spectral feature would be detected by the LAT





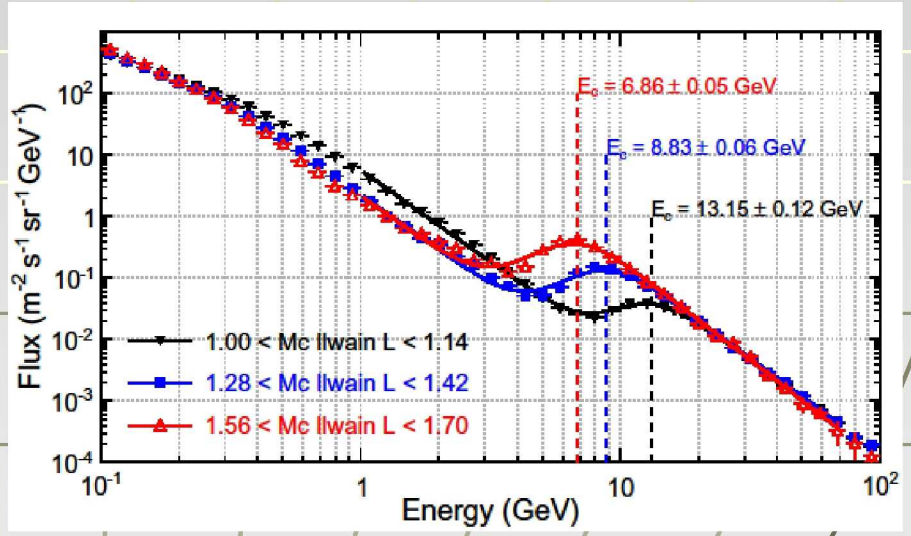
Comparison of the electron spectra reconstructed by the standard and "long path" analyses

Measurement of the spectrum below 20 GeV

- Requires consideration of the shielding effect of the Earth's magnetic field
- Important for understanding the solar modulation of the IS electron flux
- Extended down to 7 GeV, lowest geomagnetic cutoff energy accessible to the Fermi satellite
- The lowest energy of primary electrons that can be measured strongly depends on the satellite geomagnetic position

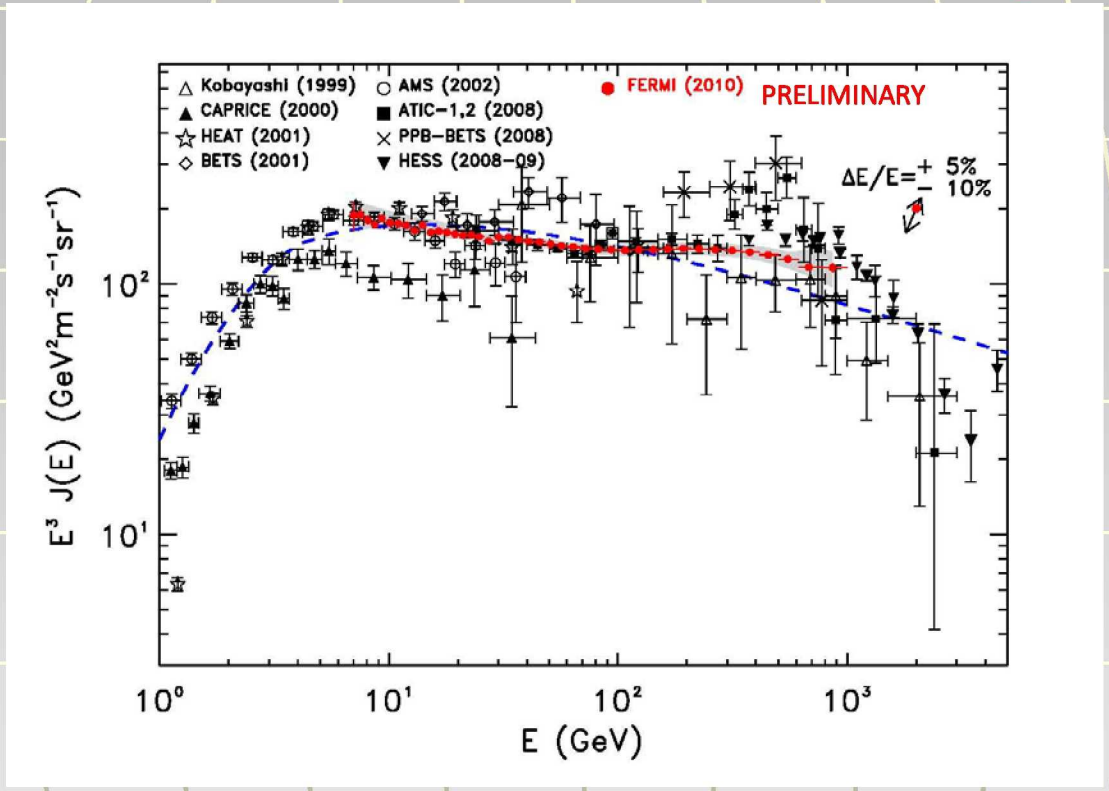
Approach:

- all data are divided in 10 intervals of McIlwain L parameters
- for each interval only events with $E > 1.15 \times E_c$ are used for the analysis to minimize the effect of geomagnetic cutoff (1.15 is a safety padding)
- the cutoff energy E_c for each interval is determined from our data



Fermi LAT electron+positron spectrum 7 GeV – 1 TeV

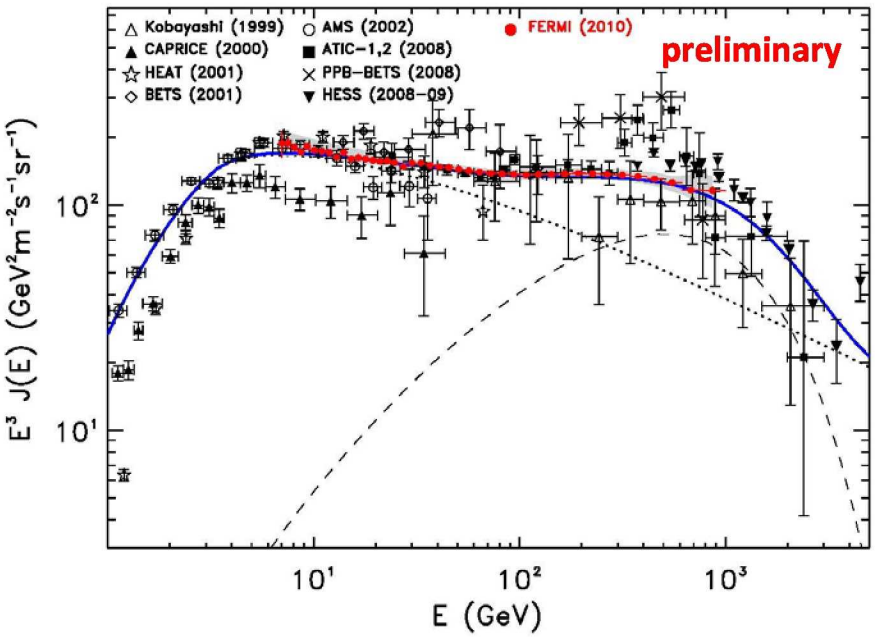
Ackerman et al., Fermi LAT Collaboration, Phys. Rev. B, submitted



Data collected for the first 12 months of operation

- Total statistics 7.95 M electron candidate events
- More than 1000 events in highest energy bin (772 – 1000 GeV)
- Noticeable deviation from single power law spectrum

Interpretation



- Number of papers published on the interpretation of Pamela and Fermi results
- No good fit with a pre-Fermi conventional model to satisfy both
- Introduction of an additional hard component provides a good fit of the Fermi LAT spectrum.
- To satisfy the Fermi LAT spectrum, this component can comprise of e^- only , but Pamela result requires e^+e^- pairs.
- Nature of such a component is still a question. Can be astrophysical (e.g. pulsar systems), exotic (DM), or other effects

The e^-+e^+ spectrum computed with the GALPROP (blue line) with injection spectrum Γ=1.6/2.7 below/above 4 GeV and an additional component with an injection spectrum Γ=1.5 and exponential cutoff.

CR Electrons Anisotropy

For details please see the poster by M. N. Mazziotta. Also Ackermann et al., submitted to PRD

Search for CR electrons anisotropy can provide information on:

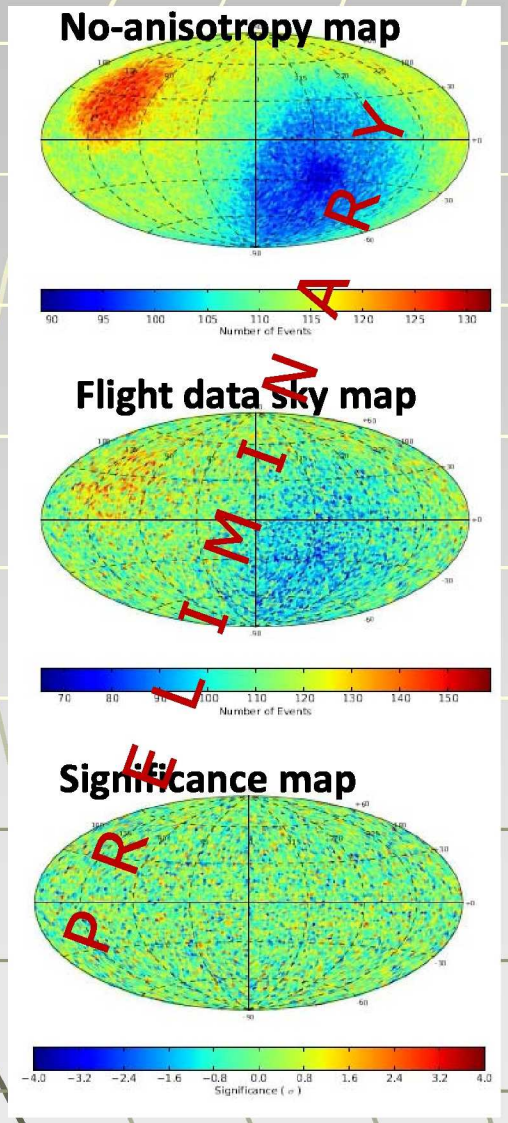
- **Local CR sources and their distribution in space**
- **propagation environment**
- **heliospheric effects**
- **presence of dark matter clumps producing e^+ e^-**

Due to its large statistics and high angular resolution, the Fermi LAT is very capable for such study

Approach:

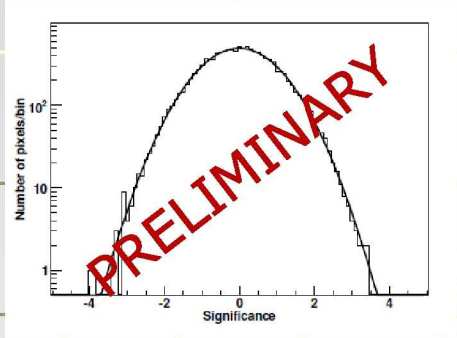
- **statistical comparison of "no anisotropy" sky map of electron counts with the flight data. Energy from 60 GeV to ~600 GeV**
- **"no anisotropy" sky map is made of the flight data by either randomizing the reconstructed directions of the detected events, or by a direct integration**
- **analysis is performed in several energy intervals by either direct bin-to-bin comparison or by spherical harmonic analysis**

CR Electrons Anisotropy (cont.)



Result:

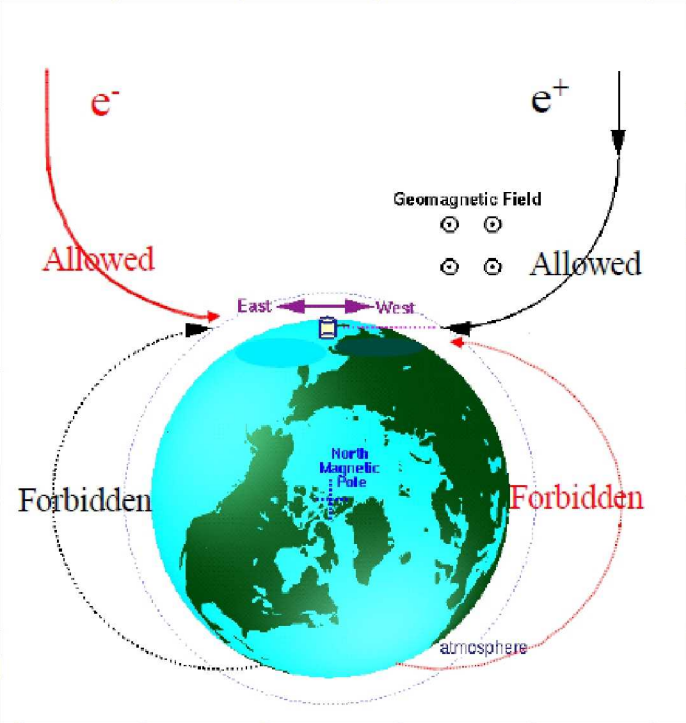
- More than 1.6 million electron events with energy above 60 GeV have been analyzed on anisotropy
- Upper limit for the dipole anisotropy has been set to 0.5 – 5% depending on the energy
- Upper limit on fractional anisotropic excess ranges from a fraction to about one percent depending on the minimum energy and the anisotropy's angular scale



Distribution of significance, fitted by a Gaussian

CR Positrons

Approach: Use the Earth Magnetic field to distinguish e^+ and e^-



- There is a pure e^+ region in the west and same for e^- in the east (in the Earth zenith coordinates)
- The regions depend on particle energy and LAT position
- To locate those regions, we use a code of D.F. Smart and M.A. Shea to calculate a particle trajectory in the Earth magnetic field
- We read out the data in calculated regions in each given LAT position and then for each energy bin create the e^+e^- livetime and exposure maps
- We should be able to measure positrons up to 200 GeV
- As expected, proton contamination is a problem

The work is in progress

CR Protons

For details see P. Smith and M.-E. Monzani in Proceedings of the 1-st Fermi Symposium

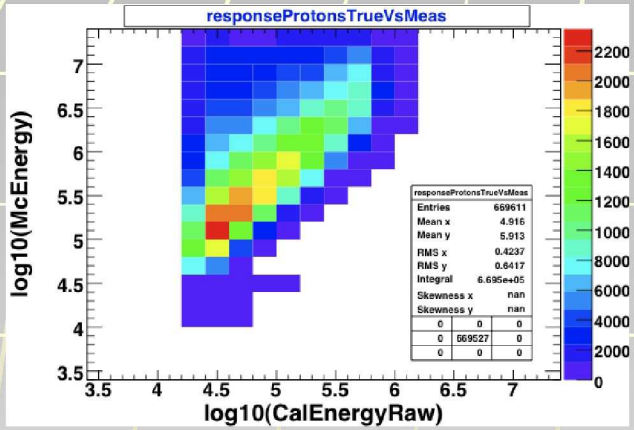
Successful measurement of CR electrons encouraged us to attempt measuring CR protons

- Much more difficult to reconstruct the event energy for protons (the calorimeter is too thin) – key issue for this analysis
- Particle identification is less stringent requirement compared with the electron analysis due to the dominating proton flux

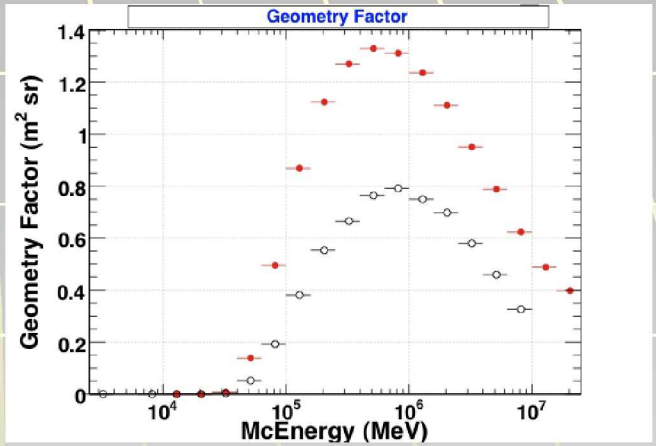
Approach:

- Select proton events from the data
- Subtract MC estimated background
- Unfold the count spectrum using Bayesian algorithm
- Reconstruct the energy spectrum

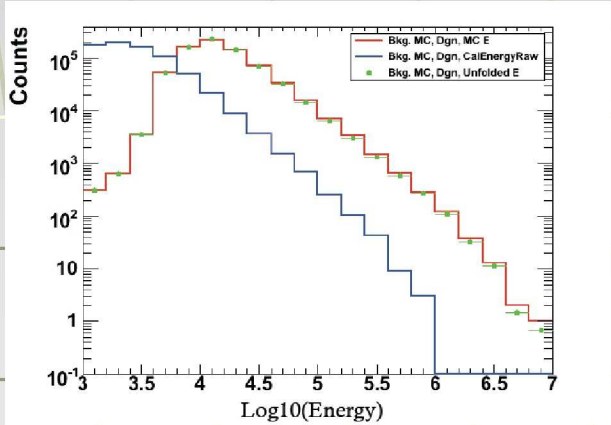
CR Protons (cont.)



Proton energy reconstruction (smearing matrix)



Effective Geometry Factor for two sets of proton selections



Proton spectrum reconstruction (Monte Carlo)

- Encouraging perspectives to measure the proton spectrum up to at least a few TeV
- Considering development of dedicated energy reconstruction algorithm for hadrons instead of unfolding

Work is in progress

SUMMARY

- Real breakthrough during last 1-1.5 years in cosmic ray electrons: ATIC, HESS, Pamela, and finally Fermi-LAT. New quality data have made it possible to start quantitative modeling

- With the new data more puzzles than before on CR electrons origin. Need "multi-messenger" campaign: electrons, positrons, gammas, X-ray, radio, neutrino…

- It is viable that we are dealing with at least two distinct mechanisms of "primary" electron (both signs) production: a softer spectrum of negative electrons, and a harder spectrum of both $e^+ + e^-$. Exotic (e.g. DM) origin is not ruled out

- Upper limits on CR electrons anisotropy are set

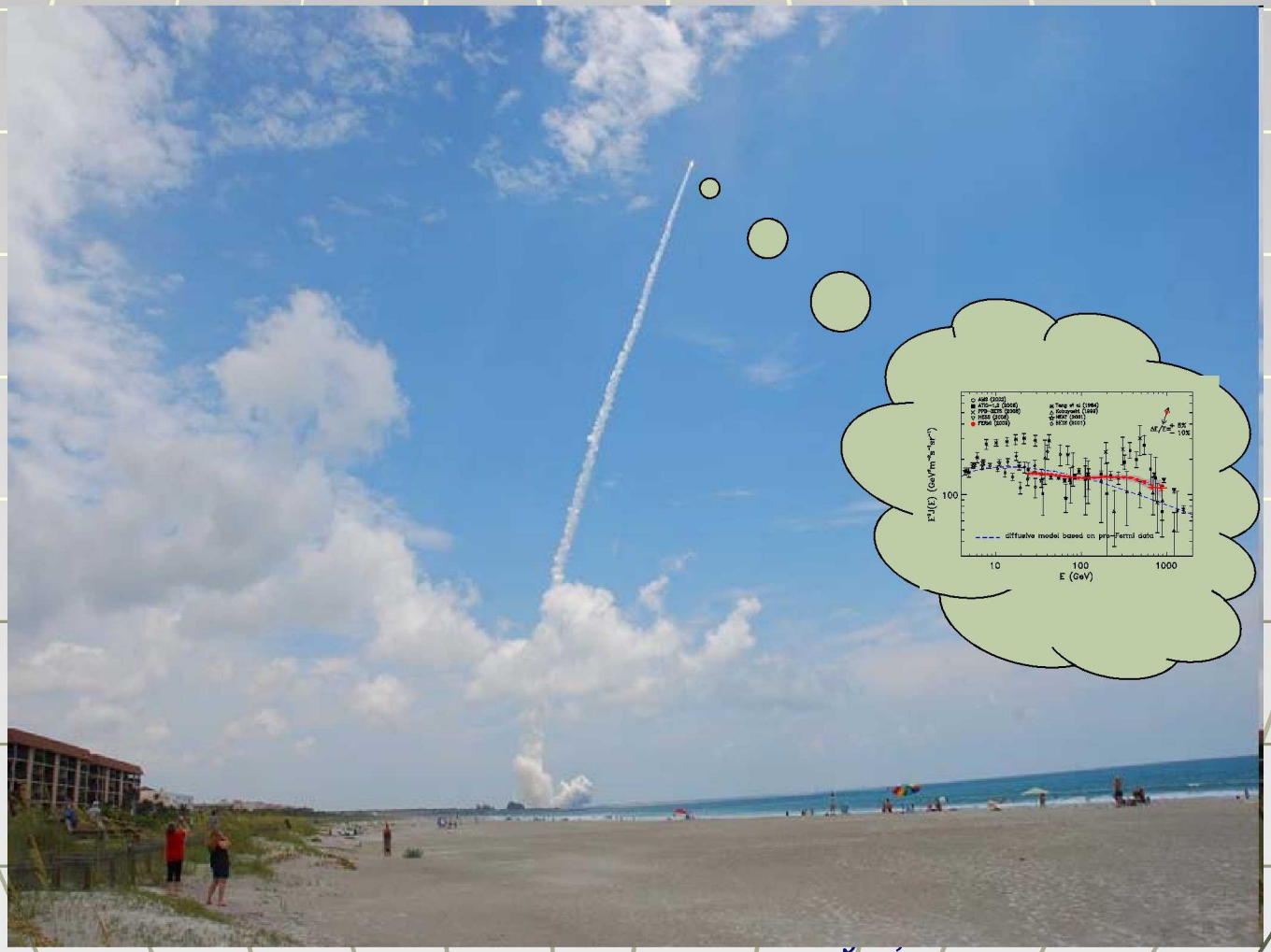
- Good perspectives to have the Fermi LAT results on proton spectrum and positron fraction

SPARE SLIDE to replace all proton and positron slides if I be short in time

Fermi LAT on CR protons and positrons

- Success in measuring CR electrons encouraged us to investigate the Fermi LAT capabilities to measure other charged CR
- Our initial studies demonstrate that the Fermi LAT is capable to measure cosmic ray protons and positrons
- Approach in measuring positrons is based on the use of the Earth magnetic field to distinguish e^+ and e^-
- Main problem in proton analysis is the event energy reconstruction
- Main problem in positron analysis is an effective and reliable removal of the proton background
- The Fermi LAT team is intensively working on these topics

THANK YOU!


E³J(E) (GeV²m⁻²s⁻¹sr⁻¹)
100
10
100
1000
E (GeV)
diffusive model based on pre-Fermi data