Measurement of the Cosmic-Ray electron spectrum with the Fermi LAT

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on behalf of the Fermi LAT collaboration

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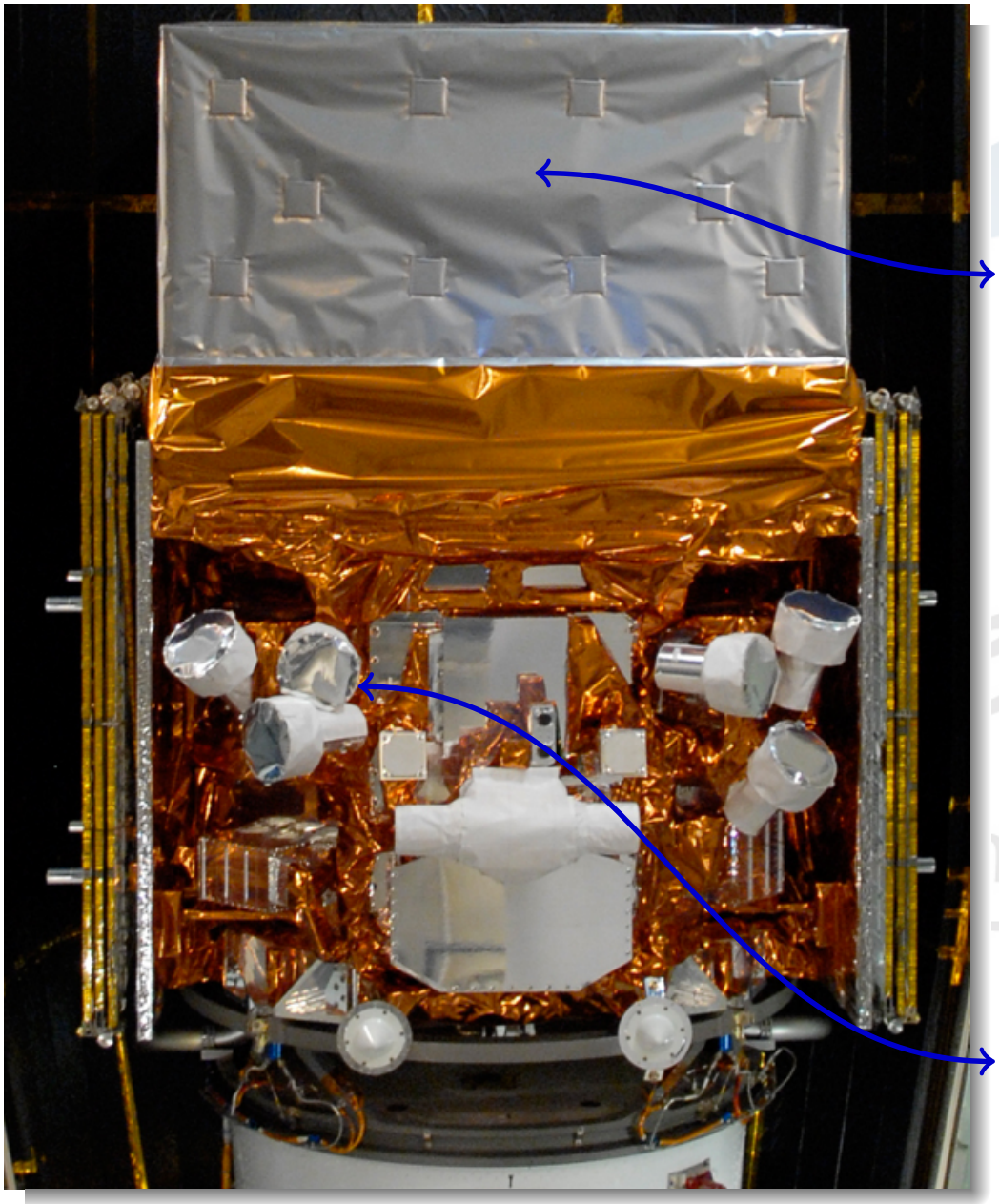
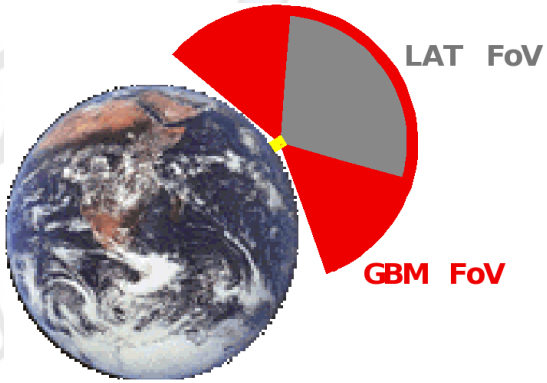
The Fermi observatory



Large Area Telescope (LAT)

- Pair conversion telescope.
- Energy range: 20 MeV–> 300 GeV
- Large field of view ($\approx$ 2.4 sr): 20% of the sky at any time, all parts of the sky for 30 minutes every 3 hours.
- Long observation time: 5 years minimum lifetime, 10 years planned, 85% duty cycle.

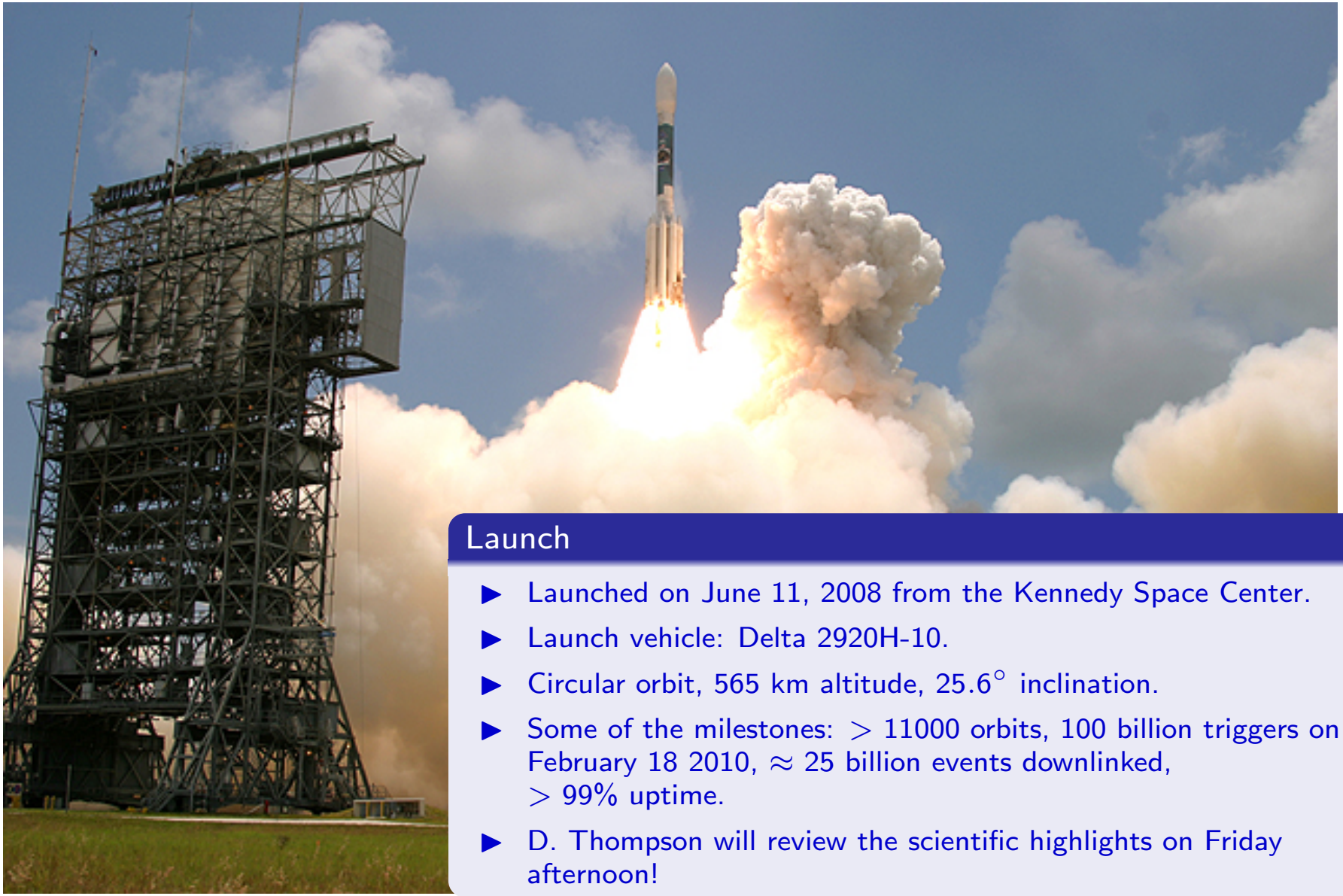


Gamma-ray Burst Monitor (GBM)

- 12 NaI and 2 BGO detectors.
- Energy range: 8 keV–40 MeV.

The launch

Just turned two years in orbit



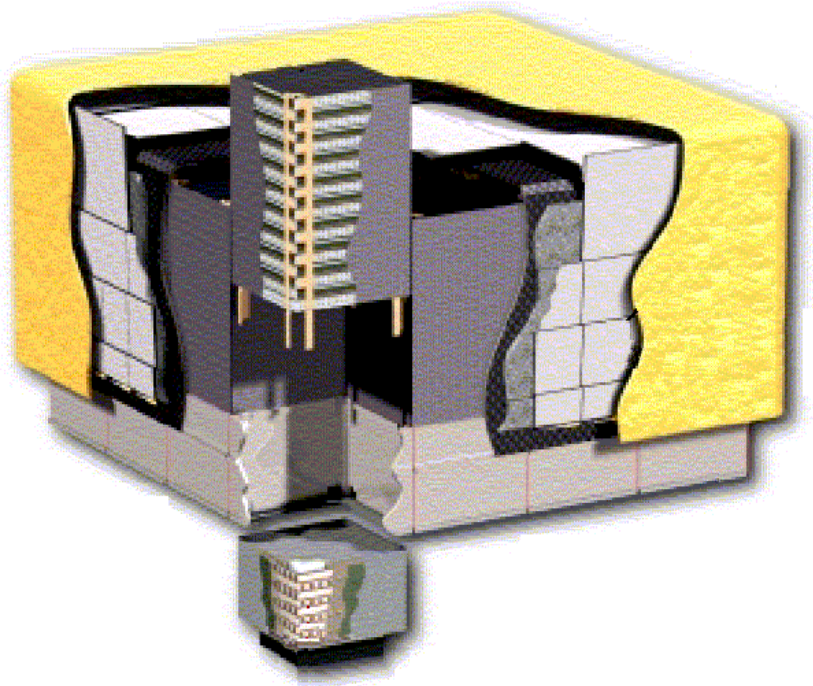
Launch

- Launched on June 11, 2008 from the Kennedy Space Center.
- Launch vehicle: Delta 2920H-10.
- Circular orbit, 565 km altitude, 25.6° inclination.
- Some of the milestones: $>$ 11000 orbits, 100 billion triggers on February 18 2010, $\approx$ 25 billion events downlinked, $>$ 99% uptime.
- D. Thompson will review the scientific highlights on Friday afternoon!

The Large Area Telescope

Large Area telescope

- Overall modular design.
- 4×4 array of identical towers (each one including a tracker and a calorimeter module).
- Tracker surrounded by an Anti-Coincidence Detector (ACD)



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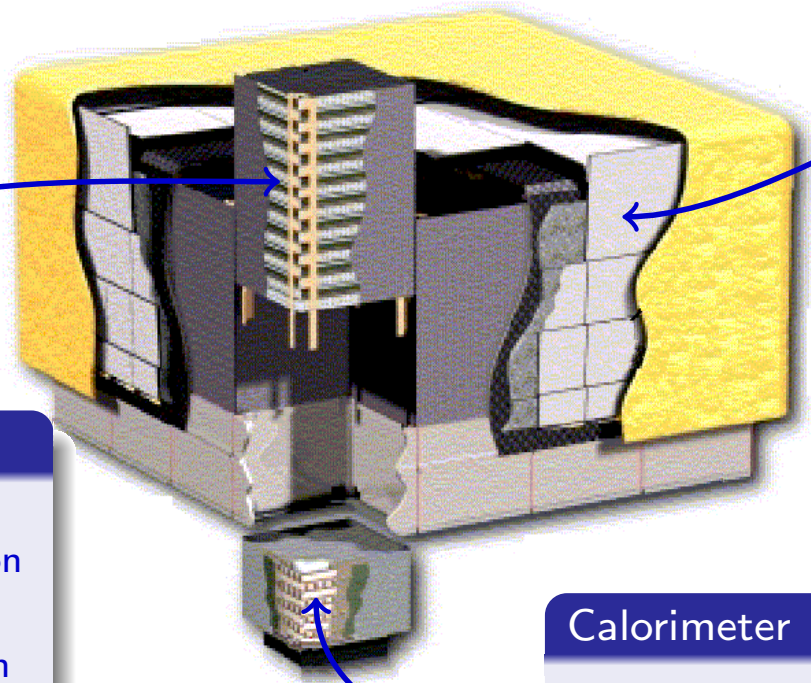


Tracker

- Silicon strip detectors, W conversion foils; 1.5 radiation lengths on-axis.
- 10k sensors, 80 m^2 of silicon active area, 1M readout channels.
- High-precision tracking, short instrumental dead time.

Anti-Coincidence Detector

- Segmented (89 tiles) to minimize self-veto at high energy.
- 0.9997 average efficiency (8 fiber ribbons covering gaps between tiles).

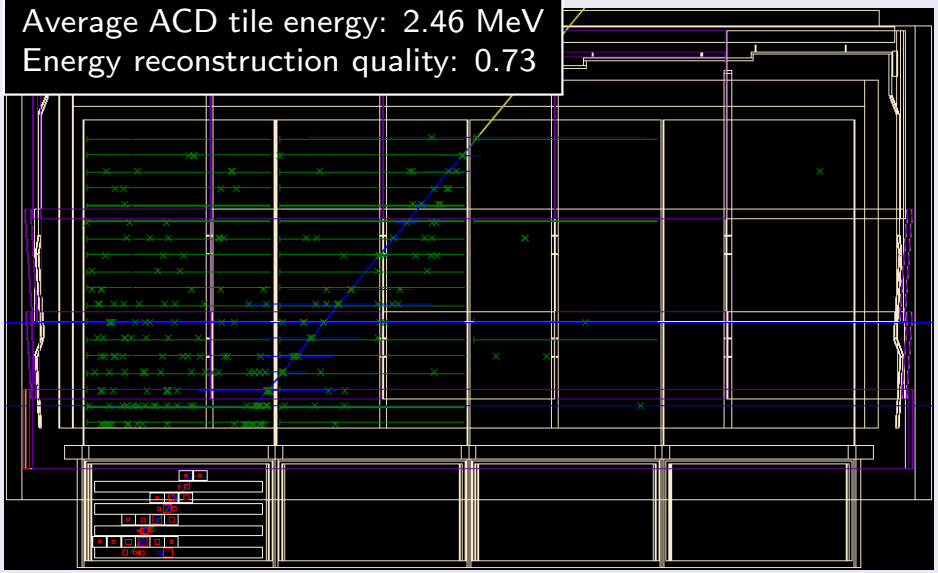
Calorimeter

- 1536 CsI(Tl) crystal; 8.6 radiation lengths on-axis.
- Hodoscopic, 3D shower profile reconstruction for leakage correction.

Flight event displays

Candidate electron
475 GeV raw energy, 834 GeV reconstructed

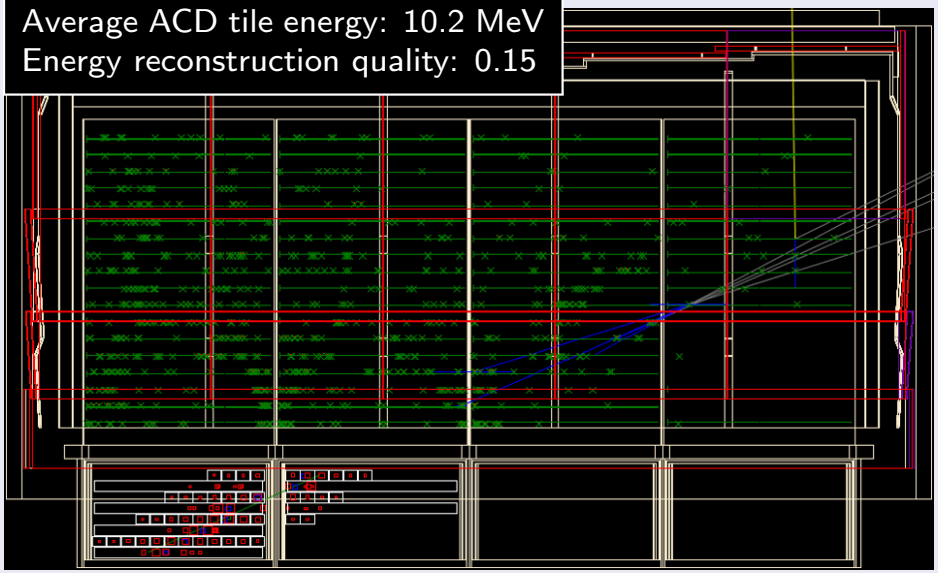
Transverse shower size: 23.2 mm
Fractional extra clusters: 1.48
Average ACD tile energy: 2.46 MeV
Energy reconstruction quality: 0.73



- Clean main track with extra clusters close to the track (note backsplash from the calorimeter).
- Relatively few ACD tile hits, mainly in conjunction with the track.
- Well defined (not fully contained) symmetric shower in the calorimeter.

Candidate hadron
823 GeV raw energy, 1 TeV reconstructed

Transverse shower size: 34.4 mm
Fractional extra clusters: 0.17
Average ACD tile energy: 10.2 MeV
Energy reconstruction quality: 0.15

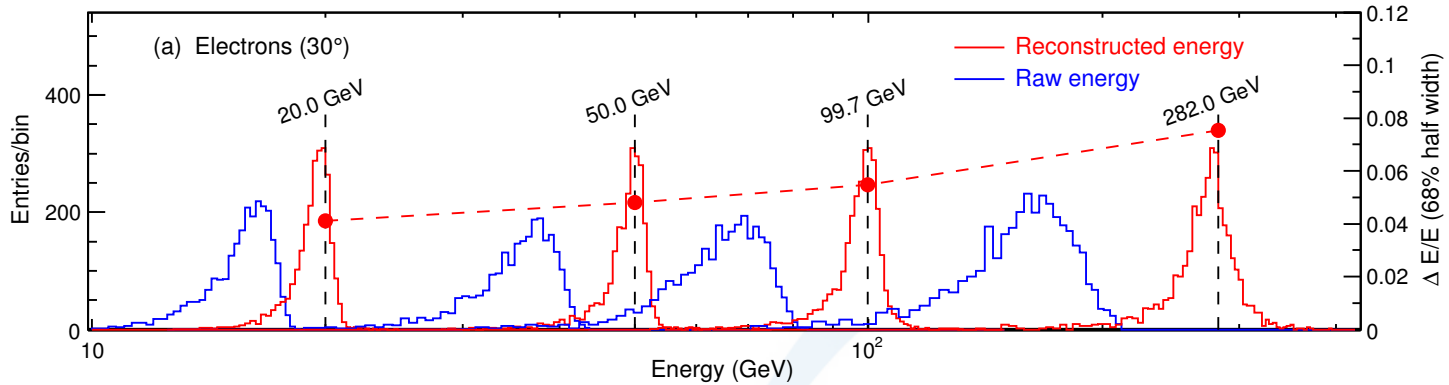


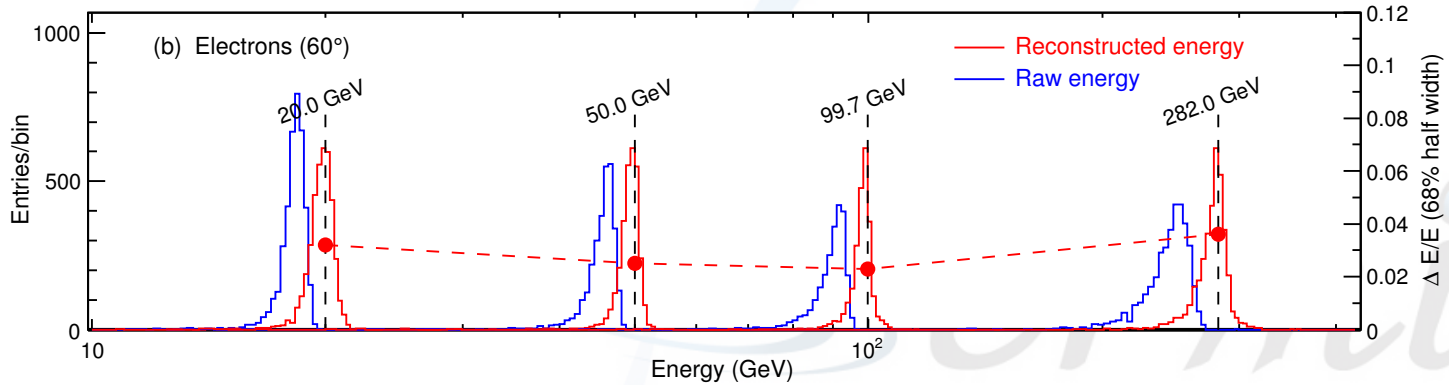
- Small number of extra clusters around main track, many clusters away from the track.
- Different backsplash topology, large energy deposit per ACD tile.
- Large and asymmetric shower profile in the calorimeter.

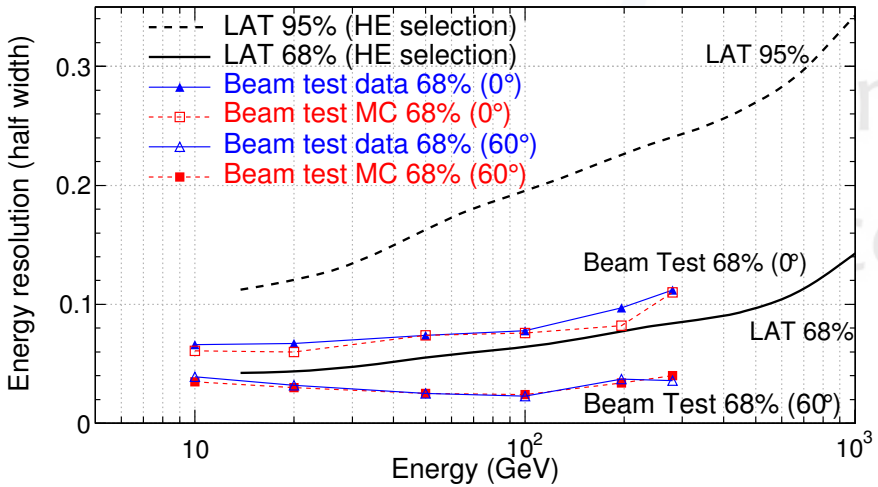
Event selection

- All the three LAT subsystem contribute to the rejection of the hadronic (mainly protons) background
  - The measurement of the shower development in the calorimeter plays a prominent role
- Peak effective geometry factor of almost $\approx 2.8\ m^2\ sr$ around 50 GeV
  - Given the large statistics, the *knowledge* of the effective geometry factor dominates the systematic uncertainties
  - Quantified by means of extensive analysis of data/Monte Carlo discrepancies using both flight and beam test data
  - Data/Monte Carlo also exploited to provide feedback to the selection
- The estimated hadronic contamination after the electron cuts is below $\approx 20\%$
  - Background rate subtracted from the rate candidate electrons

Energy reconstruction



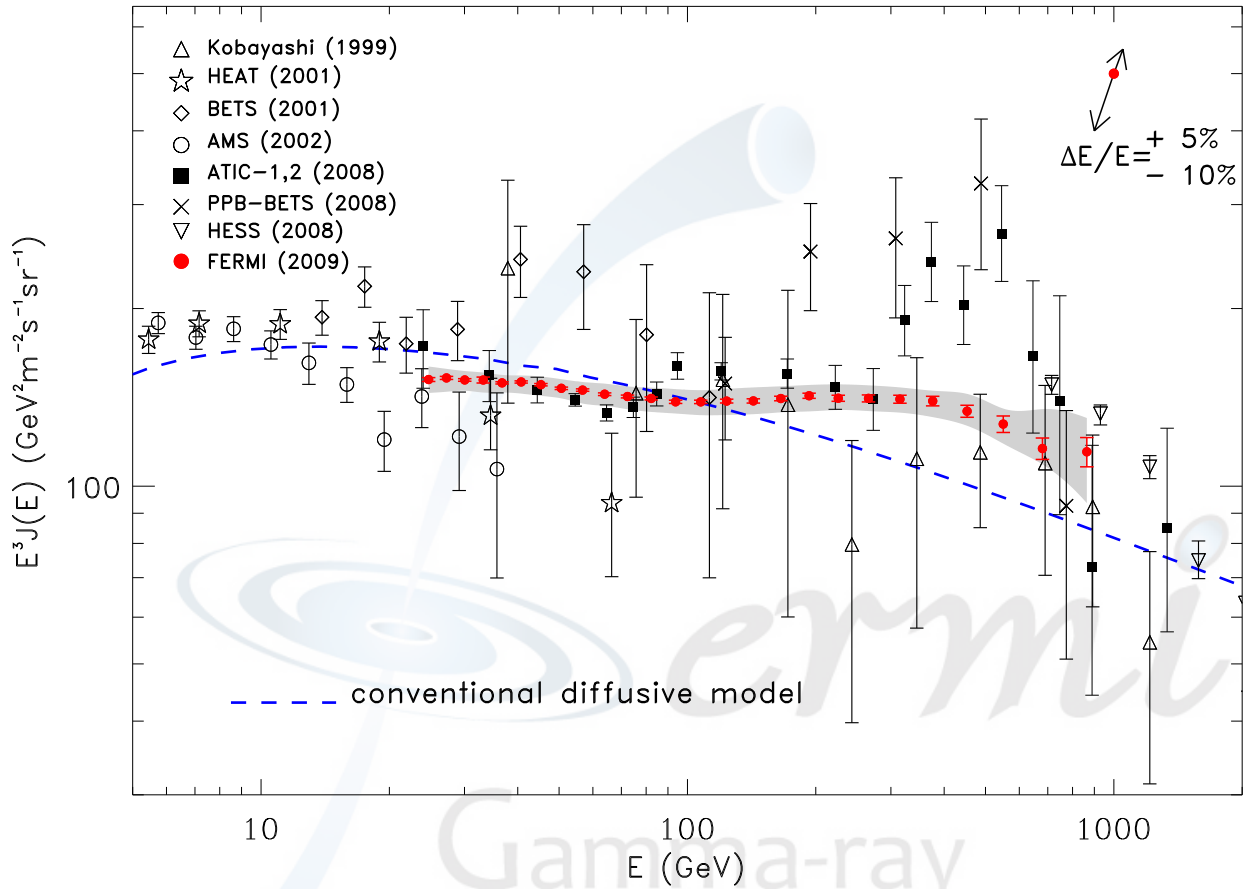




Energy reconstruction

- Same algorithms used for the γ analysis.
- Validated with electron beams at CERN.
- The excellent data/MC agreement gives us solid ground in extrapolating to 1 TeV.
- 5–15% (20 GeV–1 TeV, 1 σ) for an isotropic flux, after the electron cuts.

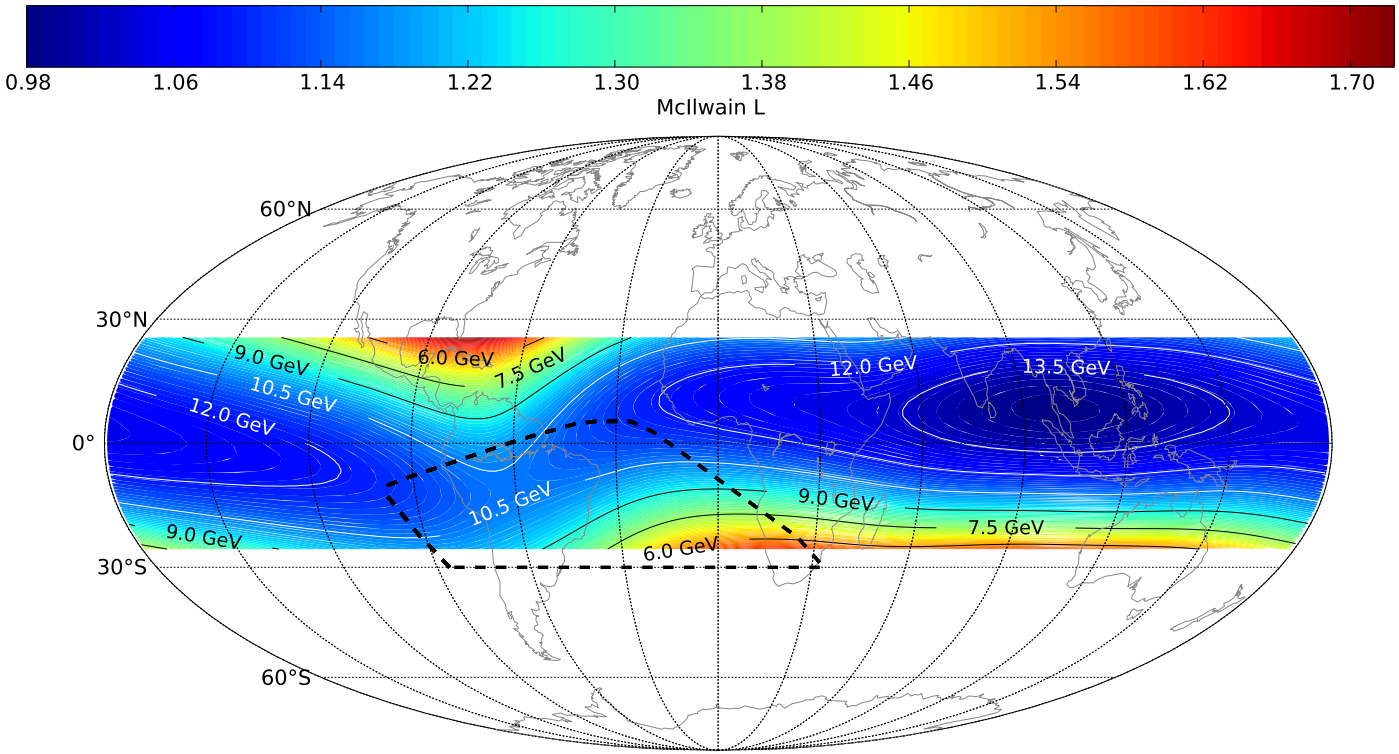
Phys. Rev. Lett. 102, 181101 (2009)



What's new since then?

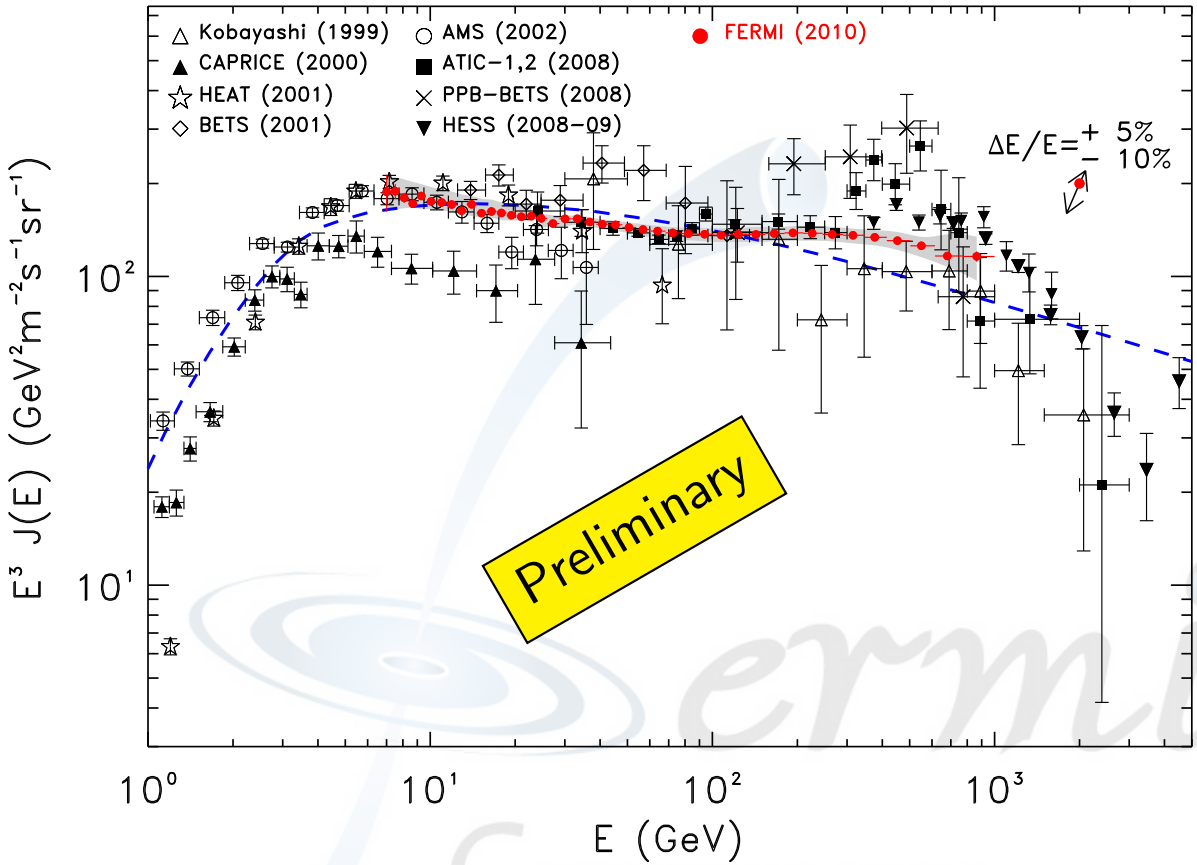
- CRE analysis paper submitted to Physical Review D
  - Detailed description of the electron analysis, spectrum extension down to ≈ 7 GeV, cross check with an alternative event selection optimized for energy resolution
- CRE anisotropy paper submitted to Physical Review D

Low-energy extension



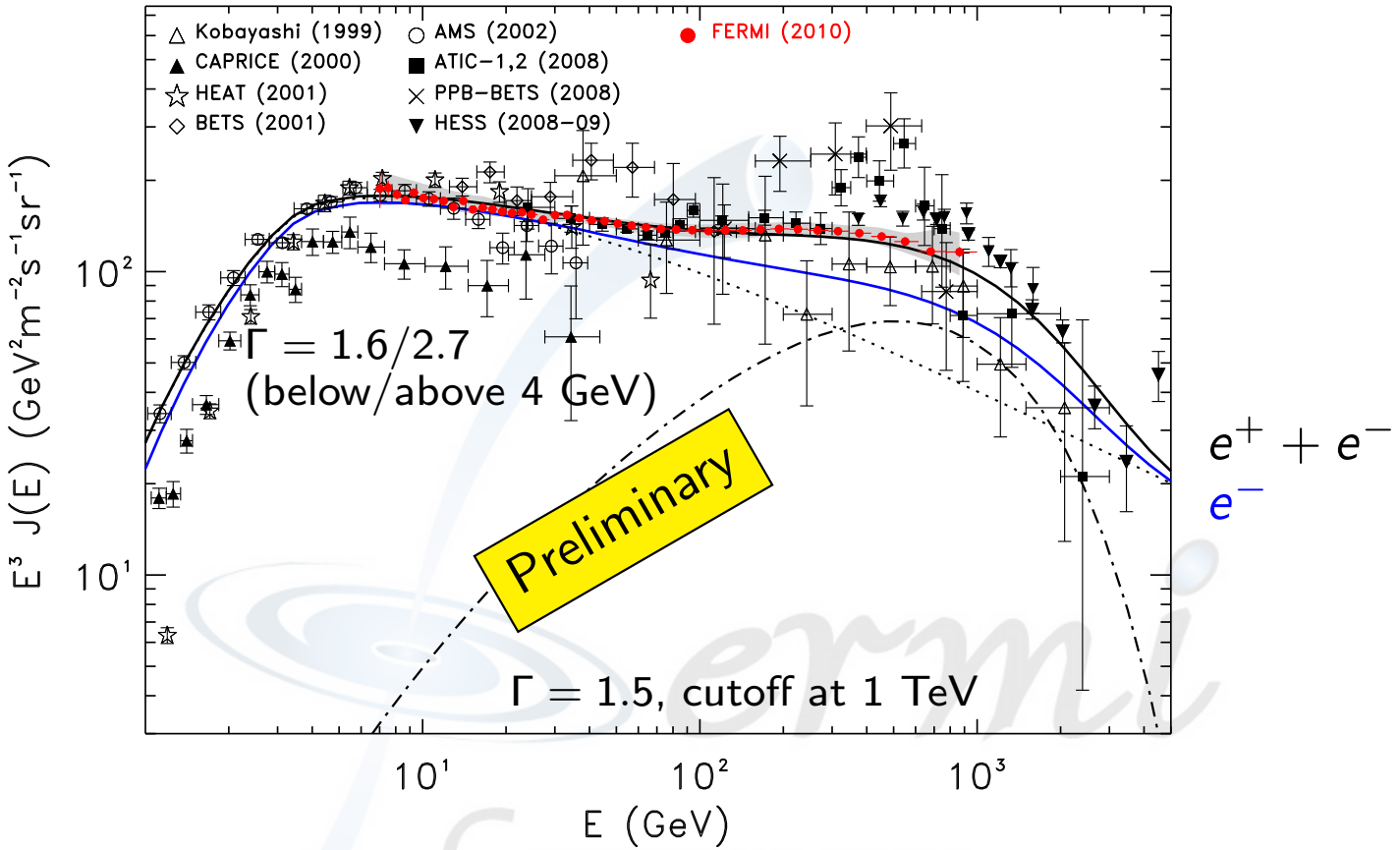
- Need to take into account the effect of the Geomagnetic field
- Rigidity cutoff depends on the detector geomagnetic position
  - ≈ 7 GeV is the minimum energy accessible in the Fermi orbit
- Data are divided in 10 independent McIlwain L bins
  - For each energy bin only the McIlwain bins for which the measured cutoff is significantly below the low edge are used

Low-energy extension



- Almost 8M electron candidates collected in the first year of operations
  - More than 1000 in the highest-energy bin (772–1000 GeV)
- The new (low energy) data point exacerbate the tension with the hypothesis of a single power law.

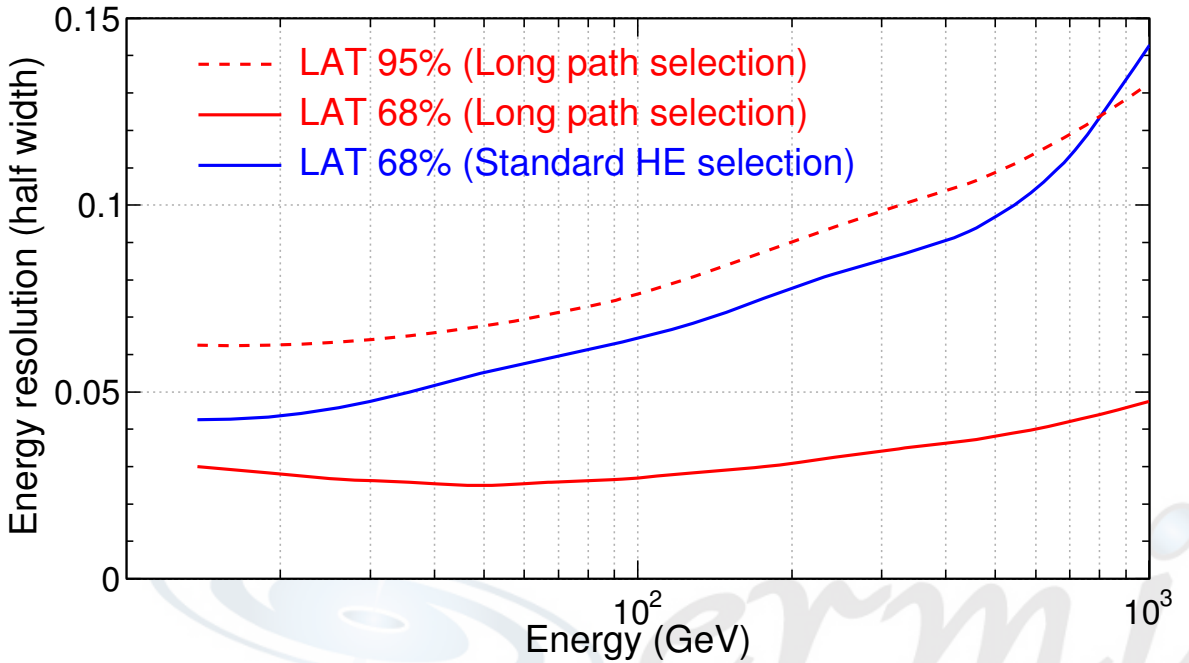
Spectrum interpretation



- Hard to get a good fit with a single-component diffusive model
- Good fit possible with an additional high-energy component
  - If it's an e^+/e^- (e. g. nearby pulsars or dark matter), the Fermi spectrum and Pamela positron fraction can be simultaneously fitted

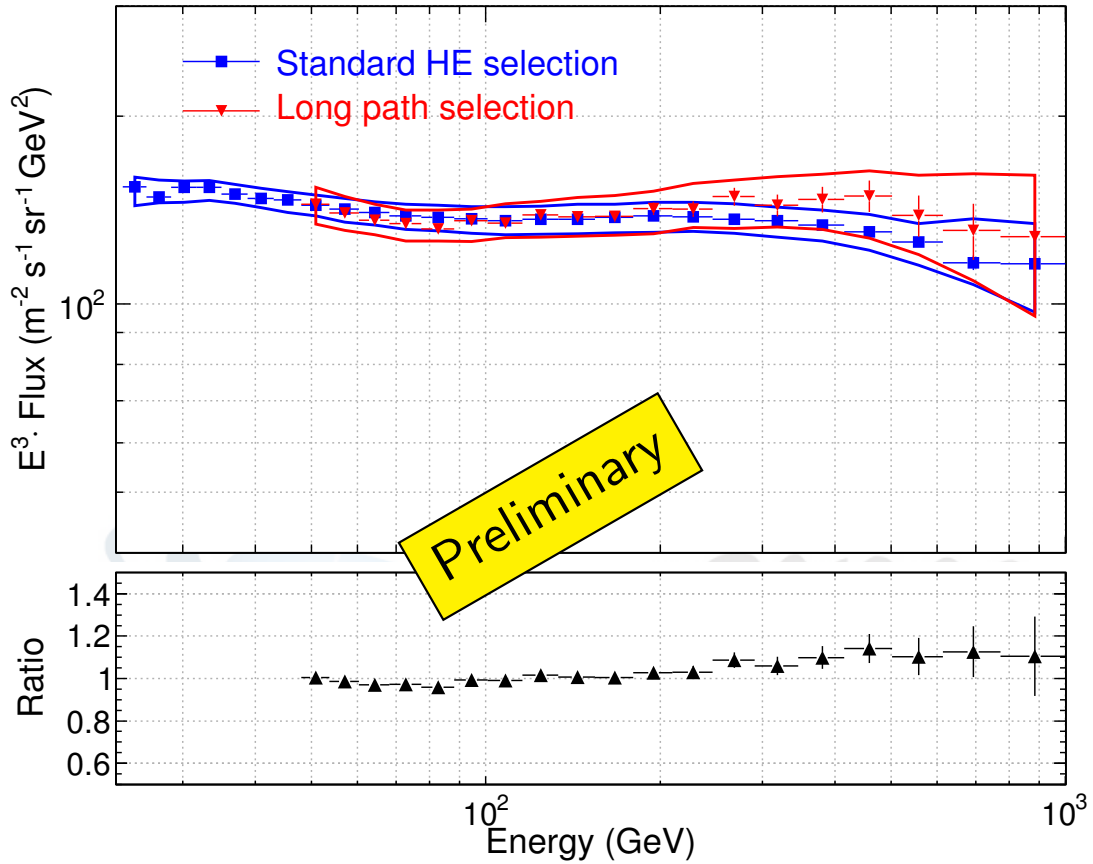
Alternative event selection

Optimized for energy resolution



- Test possible systematic effects related to the energy resolution of the detector
- Events with long path (13 X_0 min, 16 X_0 average) in the instrument and contained in a single calorimeter module
  - Energy dispersion much narrower and more symmetric, energy resolution better than 5% (1σ) up to 1 TeV
  - Acceptance reduced to 5% of the *standard* one

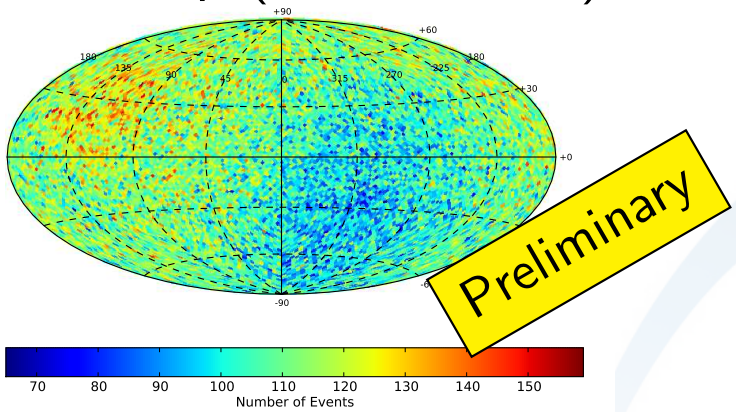
Alternative event selection
Optimized for energy resolution



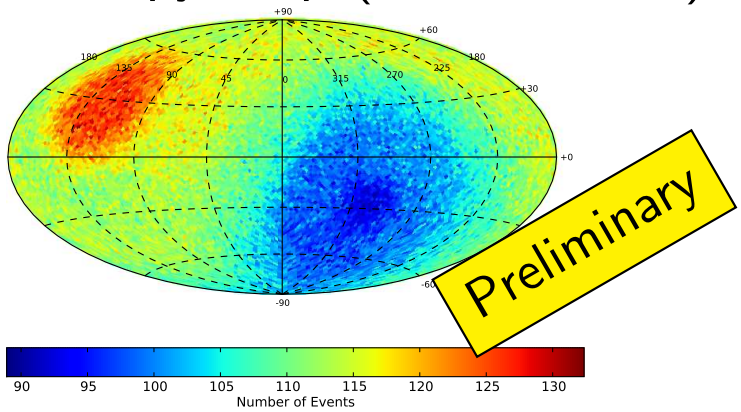
- The two spectra are consistent within the systematic errors
- Long path selection only optimized for energy resolution
  - More challenging in terms of systematics (small sample)
  - Really a cross check, not necessarily more accurate!

Search for anisotropies

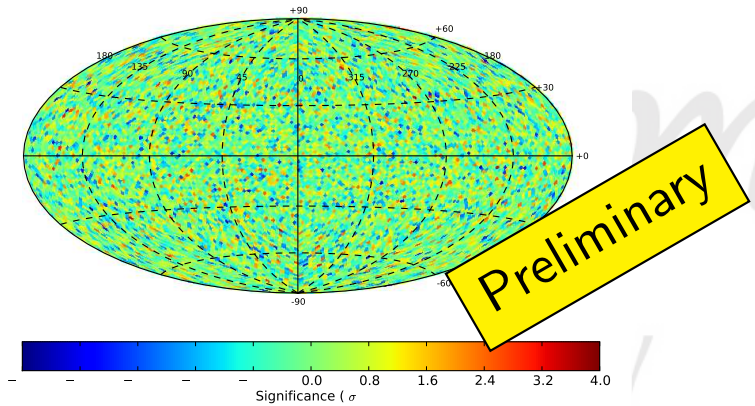
Count map ($E > 60$ GeV)



No-anisotropy map ($E > 60$ GeV)



Significance map ($E > 60$ GeV)



- Fermi offers a unique opportunity for the measurement of possible CRE anisotropies (large exposure factor)
- The *no anisotropy* map accounts for non uniform exposure
  - Two different methods: shuffling and direct integration

Search for anisotropies

- More than 1.6M candidate electrons above 60 GeV collected in the first year of operation.
- The whole sky was searched for anisotropies in Galactic coordinates
  - Healpix pixelization scheme (12288 pixels, $\approx 3\ \mathrm{deg}^2$) used for the skymaps
- Search for possible anisotropies with different energy thresholds and on different angular scales:
  - Direct bin-to-bin comparison
  - Integrated skymaps with different ROIs (10–90°)
  - Spherical harmonic analysis
- Upper limits for the dipole case ranging from $\approx 0.5\%$ (above 60 GeV) to $\approx 5\%$ (above 480 GeV)
  - Comparable to the values expected for a single nearby source dominating the high-energy electron spectrum

Conclusions

- Fermi has published the first systematic-limited measurement of the Cosmic-Ray Electron spectrum up to 1 TeV
- Now extended down to the lowest energy accessible by the Fermi-LAT, given its orbit
  - Covering almost 2.5 decades in energy
- No evidence for anisotropies in the arrival directions of CREs above 60 GeV
  - Upper limits (a fraction of % to tens %, depending on the energy threshold/angular scale) are already interesting in terms of modeling
  - Will improve as more data are collected