Fermi-LAT measurement of Cosmic-Ray positron spectrum using the Earth's magnetic field

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on behalf of the Fermi LAT collaboration

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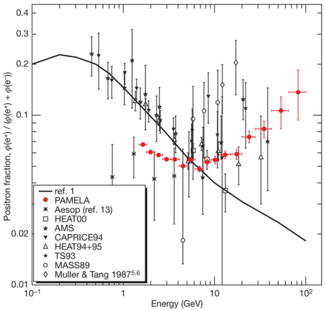
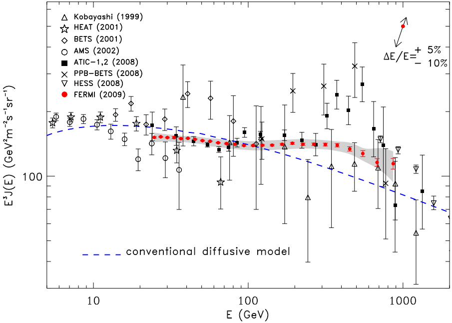
- PAMELA reported an increasing fraction of e^+ as a function of energy
- Fermi-LAT measured a hard $e^+ + e^-$ spectrum up to 1 TeV

PAMELA, Nature 458, 607-609 (2009)

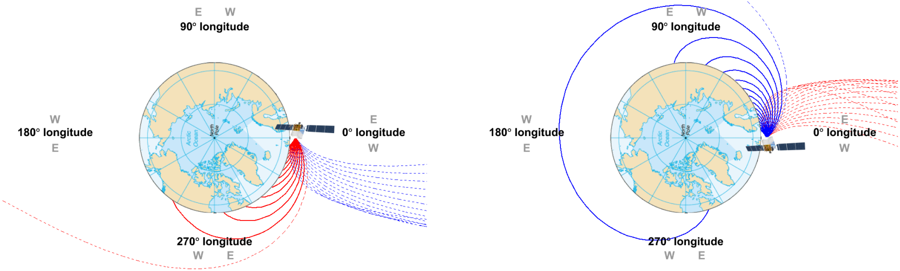


Fermi-LAT, PRL, 102, 181101 (2009)

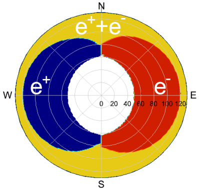


- Conventional paradigm in which e^+ are only secondary particles (i.e. produced by interactions in the ISM) may no longer be accurate
- A new piece to the puzzle from the LAT:
  measurement of the separate e^+ and e^- spectra

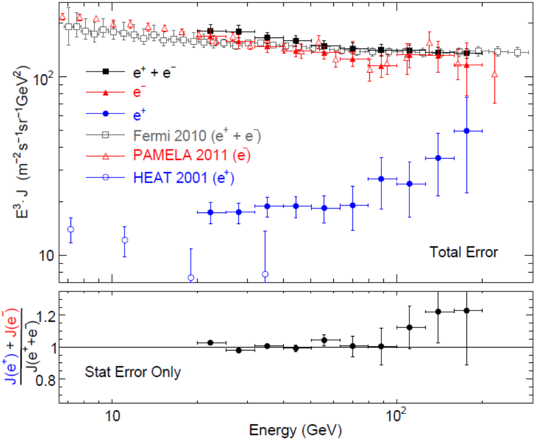
- The LAT is a γ-rays telescope – designed for e.m. showers
  - It doesn't carry a magnet on-board: no direct particle charge measurement
- We can use the Earth magnetic field to identify charge!
  - Geomagnetic field shadows some of the particle's trajectories



- Pure e^+ region in the West direction and pure e^- region in the East
  - Regions vary with particle energy and spacecraft position
  - Need particle tracing code (from Smart&Shea) and a model of the Earth's magnetic field (IGRF)

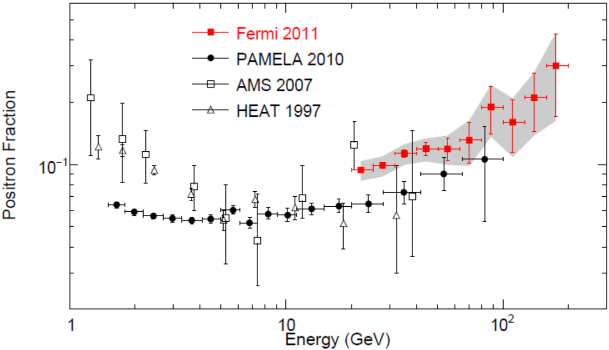


Separate e^+ and e^- spectra



- Energy range up to 200 GeV
  - Constrained by the bending power of the Earth magnetic field
- Two independent background subtraction methods (MC-based and data-driven) in good agreement with each other
- Ratio between sum $\mathrm{J}(e^+) + \mathrm{J}(e^-)$ and $\mathrm{J}(e^+ + e^-)$ is consistent with 1

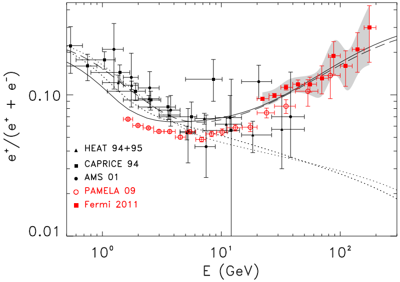
Positron Fraction

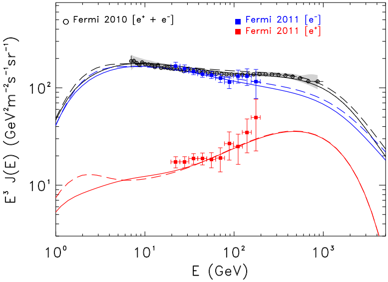


- Derived from separate e^+ and e^- spectra
- Rise with energy is confirmed up to 200 GeV
- Analysis details published on Phys. Rev. Lett. 108, 011103 (2012)
- Many possible explanations: local astrophysical sources, dark matter, nonstandard secondary production, ...

EXTRA

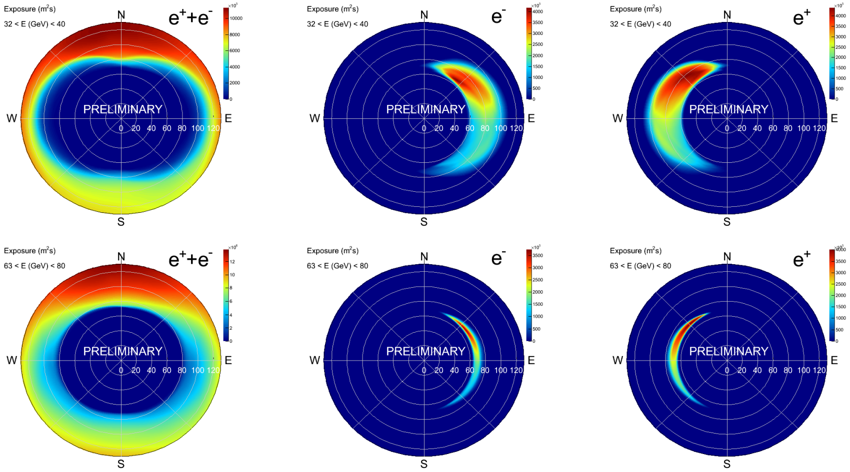
A model with additional source of e^+ and e^-





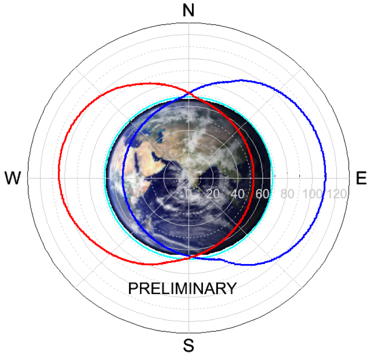
- An example of CR propagation models compared with new Fermi LAT measurement (from arXiv:1110.2591)
  - Conventional propagation scenario (dotted lines in plot on the left)
  - New source of e^+ and e^- added (continuous line in plot on the left)
- Right figure shows how the double component model matches the LAT e^+ and e^- spectra
- This model was proposed in a previous Fermi LAT publication – PRD 82, 092004 (2010) – to fit LAT $e^+ + e^-$ spectra and Pamela positron fraction

Exposure in the 3 regions



- Three regions used in this analysis: $e^+ + e^-$, e^-, e^+
  - Smaller e^-–only and e^+–only as energy increases
- Useful data only when the LAT is looking down at the Earth
  - $\sim$39 days of livetime, up to April 2011, taken in non–survey mode

IDENTIFY e^--ONLY AND e^+-ONLY REGIONS

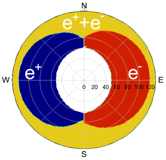


Example of region boundary for one real event:

- e^+ are forbidden inside blue curve
- e^- are forbidden inside red curve

- We find the curve that separates permitted from forbidden part of the sky
  - In Earth-centered coordinate system
  - Assuming e^- and e^+ separately
- Particle trajectories are numerically traced in geomagnetic field
  - Using code written by Smart & Shea (Final Report, Grant NAG5-8009, 2000)
- Region boundaries vary with energy and LAT position in the orbit
  - They are calculated for each event

Background subtraction
Two independent methods



- Main background is residual CR proton
- Up to ∼60% in e^+ after event selection
- 2 independent methods for background subtraction

Fit-Based Method

- Relaxed event selection
- The distribution of transverse shower size in the CAL shows separate signal and background peaks
- Fit the distributions with 2 Gaussians to determine signal

Systematic Errors:

e^+:	5–13%
e^-:	5–9%
$e^+ + e^-$:	5–9%

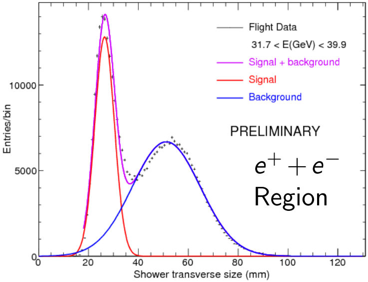
MC-Based Method

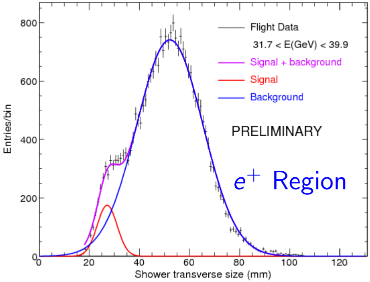
- Use standard event selection
- Produce a large set of CR proton
- Apply event selection to simulation to estimate surviving background

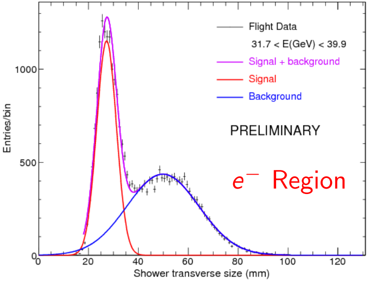
Systematic Errors:

e^+:	8–19%
e^-:	5–8%
$e^+ + e^-$:	5–7%

Fit-Based background subtraction



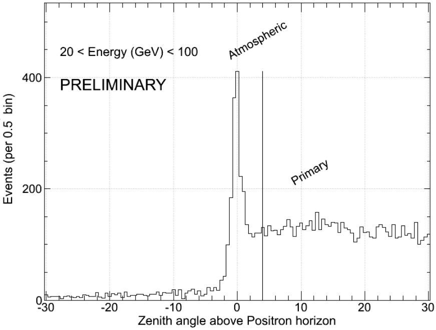




- Gaussian function found to be an adequate approximation for these distributions
- Fitting is “easy” for $e^+ + e^-$ and e^-, but is more challenging for e^+
  - Small signal-to-noise makes fit unstable when all parameters are free
  - Average and σ of signal pdf are fixed using a “reference” dataset: events in $e^+ + e^-$ region resampled in angle

Atmospheric emission

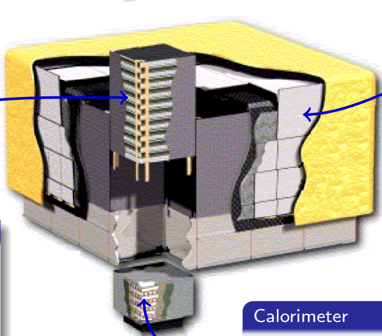
- Region boundaries correspond to location of atmospheric secondary emission
  - CR interacting in the Atmosphere
  - Same mechanism as γ-ray limb
- Atmospheric particle peak observed where the particle trajectory tracing predicts
- A cut (vertical line) is applied to remove atmospheric particles
  - Estimated residual contamination included in systematics



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)



Anti-Coincidence Detector

- Segmented (89 tiles) as to minimize self-veto at high energy
- 0.9997 average detection efficiency

Tracker

- Silicon strip detectors, W conversion foils; 1.5 radiation lengths on-axis
- 10k sensors, 73 m^2 of silicon active area, 1M readout channels
- High-precision tracking, short dead time

Calorimeter

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