The Galactic Cosmic Ray $e^- + e^+$ spectrum from 7 GeV to 1 TeV measured by the Fermi LAT

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on behalf of the Fermi LAT collaboration

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The measured spectrum in first 6 months

- High statistics: \( \sim 4.5 \) million events in 6 months for \( E \geq 20 \) GeV.
- Not compatible with pre-Fermi diffusive model (\( \Gamma = 3.0 \) instead of 3.3)

Fermi LAT measures the Cosmic-Ray electron spectrum from 20 GeV to 1 TeV.

Next challenge: Extend the measurement of the Cosmic-Ray electron spectrum down to lower energies.

Main topic of this talk.
The Fermi orbit
http://observatory.tamu.edu:8080/Trakker (to track the satellite)

- Altitude of 565 km
- Nearly circular orbit with an inclination of 25.6°
- Orbital position fixes the lowest energy of cosmic ray electrons we can measure due to the geomagnetic field.
For $E$ below $\sim 20$ GeV need to consider the shielding effect of the geomagnetic field.

- Effect can be characterized by the cutoff rigidity.

- McIlwain $L$ parameter useful for characterizing cutoff rigidities.
  - Two positions in space with the same McIlwain $L$ are magnetically equivalent.
Shape of spectrum can be parameterized by:

\[
\frac{dN}{dE} = c_s E^{-\Gamma_s} + \frac{c_p E^{-\Gamma_p}}{1+(E/E_c)^{-6}}
\]

Each L binned spectrum has an associated $E_c$.

Apply conservative padding factor of 15% to $E_c \Rightarrow$ minimum energy of the primary electron flux not affected by the Earth’s magnetic field.
One year of statistics:

- $\sim 8.4$ million electron candidates in energy range 7 GeV to 1 TeV.

Energy overlap region between the two independent analyses are in agreement within statistical errors.
Conclusions

- Cosmic ray electron spectrum measured by the Fermi LAT now spans from $\sim 7$ GeV to 1 TeV.
  - Data requires a revision of Cosmic-Ray propagation and diffusion models, including hypothesis on sources.
- Further details on the extension of the spectrum presented in poster ID: 36.01.
- Results verified using a subset of events with improved energy resolution (long deep tracks in the instrument), presented by C. Sgrò in poster ID: 36.02.
Candidate electron
475 GeV raw energy, 834 GeV reconstructed

- 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.

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

Candidate hadron
823 GeV raw energy, 1 TeV reconstructed

- Small number of extra clusters around main track, many clusters away from the track.
- Different backsplash topology, large energy deposit per ACD tile.

Transverse shower size: 34.4 mm
Fractional extra clusters: 0.17
Average ACD tile energy: 10.2 MeV
Energy reconstruction quality: 0.15
**Candidate electron**
475 GeV raw energy, 834 GeV reconstructed

- 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

- 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.

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

Transverse shower size: 34.4 mm
Fractional extra clusters: 0.17
Average ACD tile energy: 10.2 MeV
Energy reconstruction quality: 0.15
The McIlwain L parameter is a geomagnetic coordinate defined as the distance in Earth radii from the center of the Earth’s titled, off-center, equivalent dipole to the equatorial crossing of a field line.

Two positions in space with the same McIlwain L value are magnetically equivalent.
Select subsample of events with long path length
  - Average $X_0$ of $\sim 16$
  - Improves energy resolution $\Rightarrow$ down to 5% at 1 TeV (68% containment half width)
  - Instrument acceptance to $\sim 5\%$ of standard acceptance
    - Much higher systematics
  - The two selections are consistent within their own systematics.
Large Area telescope

- Overall modular design.
- $4 \times 4$ array of identical towers (each one including a tracker and a calorimeter module).
- Tracker surrounded by and Anti-Coincidence Detector (ACD).
- Numerology: $1.8 \times 1.8 \, \text{m}^2$ footprint, 3000 kg weight, 650 W power consumption.
The Large Area Telescope

**Large Area telescope**
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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 (160 W).
- 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.
The Large Area Telescope

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>EGRET</th>
<th>Fermi LAT</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak $A_{\text{eff}}$¹</td>
<td>1500 cm²</td>
<td>8000 cm²</td>
<td>×4 geometric area</td>
</tr>
<tr>
<td>Field of view</td>
<td>0.5 sr</td>
<td>2.4 sr</td>
<td>Aspect ratio (no TOF)</td>
</tr>
<tr>
<td>Angular resolution²</td>
<td>5.8° @ 100 MeV</td>
<td>3.5° @ 100 MeV &lt; 0.15° @ 10 GeV</td>
<td>SSD vs. spark chambers</td>
</tr>
<tr>
<td>Energy resolution³</td>
<td>10%</td>
<td>&lt; 10% @ 0.1–10 GeV</td>
<td>Hodosscopic calorimeter</td>
</tr>
<tr>
<td>Dead time per evt</td>
<td>100 ms</td>
<td><strong>26.5 µs minimum</strong></td>
<td>SSD vs. spark chambers</td>
</tr>
</tbody>
</table>

¹ After background rejection.
² Single photon, 68% containment, on axis.
³ 68% containment, on axis.