FIRST RESULTS ON THE HIGH ENERGY COSMIC RAY ELECTRON SPECTRUM FROM FERMI LAT

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for the Fermi LAT Collaboration
2008: New results on high energy cosmic ray electrons and positrons

Astrophysicists are excited:

• Spectral feature at ~ 620 GeV reported by ATIC and PPB-BETS suggests a nearby source (astrophysical or exotic)

• Pamela increase of positrons above 10 GeV also suggests new source or production process at high energy

• H.E.S.S. detects electrons above 1 TeV: local source? Weaker re-acceleration?

• More than 50 papers mentioning these results within a few months
Main issues we addressed:

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
Achieved electron-hadron separation and effective geometric factor

- Candidate electrons pass on average $12.5 \times X_0$ (Tracker and Calorimeter added together)

- Simulated residual hadron contamination (5-17% increasing with the energy) will be deducted from resulting flux of electron candidates

- Effective geometric factor exceeds $2.5 \text{ m}^2\text{sr}$ for 30 GeV to 200 GeV, and decreases to $\sim 1 \text{ m}^2\text{sr}$ at 1 TeV

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

Contributors:

1. Uncertainty in geometric factor - comes from the residual discrepancy between Monte Carlo and the data. Carefully estimated for each variable used in the analysis

2. Uncertainty in determination of residual hadron contamination
   - comes mostly from the uncertainty of the primary proton model
   - we validated the hadronic interaction model with beam test data

Contributors 1 and 2 result in total systematic error ranging from 10% at low energy end to 25-30% at high energy end (full width)

3. Possible bias in absolute energy determination
   - Included separately in the resulting spectrum as (+5, -10)% - estimated from MC simulations, calorimeter calibration and CERN beam test
Fermi-LAT electron spectrum from 20 GeV to 1 TeV

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Accepted April 21

Total statistics collected for 6 months of Fermi LAT observations

- ~4.5 million candidate electrons above 20 GeV
- 544 candidate electrons in last energy bin (770-1000 GeV)
• 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.

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>GF (m^2·sr)</th>
<th>Residual contamination</th>
<th>Counts (GeV^-2·m^-2·sr^-1)</th>
<th>E^2·J_E (GeV^2·m^-2·sr^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.6-26.0</td>
<td>1.65</td>
<td>0.04</td>
<td>478929</td>
<td>151.6 ± 1.217,3 ± 8.3</td>
</tr>
<tr>
<td>26.0-28.7</td>
<td>2.03</td>
<td>0.05</td>
<td>502083</td>
<td>152.6 ± 0.916 ± 7.3</td>
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<td>28.7-31.7</td>
<td>2.35</td>
<td>0.05</td>
<td>487890</td>
<td>151.4 ± 0.851,6 ± 6.5</td>
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<td>31.7-35.0</td>
<td>2.59</td>
<td>0.09</td>
<td>459594</td>
<td>151.3 ± 1.852,5 ± 6.5</td>
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<tr>
<td>35.0-38.8</td>
<td>2.67</td>
<td>0.07</td>
<td>385480</td>
<td>149.6 ± 0.714,5 ± 6.8</td>
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<td>38.8-43.1</td>
<td>2.72</td>
<td>0.08</td>
<td>330061</td>
<td>150.2 ± 0.714,5 ± 6.0</td>
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<td>43.1-48.0</td>
<td>2.76</td>
<td>0.10</td>
<td>276105</td>
<td>148.6 ± 0.714,9 ± 6.2</td>
</tr>
<tr>
<td>48.0-53.7</td>
<td>2.79</td>
<td>0.11</td>
<td>233877</td>
<td>146.5 ± 0.714,9 ± 6.1</td>
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<td>53.7-60.4</td>
<td>2.77</td>
<td>0.12</td>
<td>194062</td>
<td>145.5 ± 0.714,7 ± 6.1</td>
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<td>60.4-68.2</td>
<td>2.76</td>
<td>0.13</td>
<td>155585</td>
<td>143.2 ± 0.714,7 ± 6.6</td>
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<tr>
<td>68.2-77.4</td>
<td>2.73</td>
<td>0.14</td>
<td>126485</td>
<td>141.9 ± 0.835,6 ± 7.0</td>
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<tr>
<td>77.4-88.1</td>
<td>2.71</td>
<td>0.14</td>
<td>100663</td>
<td>140.8 ± 0.835,6 ± 7.0</td>
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<tr>
<td>88.1-101</td>
<td>2.68</td>
<td>0.15</td>
<td>77713</td>
<td>139.0 ± 0.916,4 ± 6.8</td>
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<td>101-116</td>
<td>2.64</td>
<td>0.16</td>
<td>61976</td>
<td>139.0 ± 0.916,4 ± 6.4</td>
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<td>116-133</td>
<td>2.58</td>
<td>0.17</td>
<td>46865</td>
<td>139.4 ± 1.016,9 ± 7.2</td>
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<tr>
<td>133-154</td>
<td>2.52</td>
<td>0.17</td>
<td>35105</td>
<td>139.5 ± 1.252,7 ± 7.4</td>
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<td>154-180</td>
<td>2.44</td>
<td>0.17</td>
<td>27293</td>
<td>140.8 ± 1.317,4 ± 7.3</td>
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<td>180-210</td>
<td>2.36</td>
<td>0.18</td>
<td>19722</td>
<td>142.3 ± 1.317,4 ± 7.4</td>
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<td>210-246</td>
<td>2.27</td>
<td>0.18</td>
<td>13919</td>
<td>140.9 ± 1.717,4 ± 6.8</td>
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<tr>
<td>246-291</td>
<td>2.14</td>
<td>0.18</td>
<td>10019</td>
<td>140.9 ± 1.917,4 ± 6.7</td>
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<tr>
<td>291-346</td>
<td>2.04</td>
<td>0.18</td>
<td>7207</td>
<td>140.4 ± 2.217,4 ± 6.9</td>
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<td>346-415</td>
<td>1.88</td>
<td>0.18</td>
<td>4843</td>
<td>139.4 ± 2.617,4 ± 7.3</td>
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<tr>
<td>415-503</td>
<td>1.73</td>
<td>0.19</td>
<td>3036</td>
<td>134.0 ± 3.117,9 ± 7.3</td>
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<tr>
<td>503-615</td>
<td>1.54</td>
<td>0.20</td>
<td>1839</td>
<td>127.4 ± 4.118,8 ± 8.6</td>
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<tr>
<td>615-772</td>
<td>1.26</td>
<td>0.21</td>
<td>1039</td>
<td>115.8 ± 4.815,9 ± 10.9</td>
</tr>
<tr>
<td>772-1000</td>
<td>0.88</td>
<td>0.21</td>
<td>544</td>
<td>114.4 ± 6.519,1 ± 17.8</td>
</tr>
</tbody>
</table>
And finally we want to check - could we miss “ATIC-like” spectral feature?

We validated the spectrum reconstruction by different ways including the simulation the LAT response to a spectrum with an “ATIC-like” feature:

6-month Fermi LAT spectrum with the added spectral feature reported by ATIC, scaled for the statistics to be obtained by LAT for the same observation time:

Black points - LAT electron spectrum

Blue points: LAT spectrum + “ATIC-like” bump. LAT $\Delta E/E$ (68%, FW) = 18%. The excess would be ~ 7,000 events on the top of “background” of ~ 14,000 events between 300 and 800 GeV

Red points - the same but if LAT had twice worse energy resolution

This demonstrates that the Fermi LAT would have been able to reveal “ATIC-like” spectral feature with high confidence if it were there

Alexander Moiseev  May 4, 2009  APS meeting
Future plans:

✓ Search for anisotropy in the electron flux
✓ Study systematic errors in energy and instrument response to determine whether or not the observed spectral structure is significant
✓ 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 and provide more overlap with the H.E.S.S. data
✓ 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