Gamma-ray/Electron Separation and CALET One Year Exposure Map

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γ/e separation

• Goal: Develop algorithm for separation of gamma-rays from electron dataset
• Method: Cut events based on ionization energy deposit thresholds in CHDx and CHDy
• How: Generate and study gamma-ray and electrons events in the CAL using EPICS/Cosmos instrument Monte Carlo code
Event generation

• Approximately 2,000,000 events generated for electrons and gamma-rays in three energy bins:
  – 10 – 100 GeV
  – 100 – 1000 GeV
  – 1 – 10 TeV

• Events generated on the LSU-HPC SuperMike-II cluster using the CALET-LSU allocation
  – EPICS 9.161, Cosmos 7.644, CAD Rev 15
  – Important sphere configuration parameters to note are:
    • sphere radius = 78cm, sphere midpoint = 24.53cm, sphere theta = 0-110°
  – Important sepicsfile input parameters to note are:
    • InputP = ‘usph’, Xinp = 180, Yinp = 0, Zinp = 110, InputA = ‘cos 1’, CosNormal = (0.0, 1.0)
Mapping ‘hit’ components

• ‘Hit’ components are those passed through by the primary particle trajectory.

• Event in image:
  – Input: trajectory direction cosines
  – Output: list of component numbers passed through (blue)
Event selection

• Filtered events based on trajectory:
  – Primary path must pass through the top of the CHD and the bottom of the TASC (type B geometry as defined in M. Mori 2013)

• For events that have more than one strip per layer hit, the energy deposits for those strips have been summed
CHD histograms (e-)
CHD histograms (γ)
CHD coincidences

10-100GeV CHDy vs. CHDx

- e- 10-100GeV
- gamma 10-100GeV
CHD coincidences

100-1000GeV CHDy vs. CHDx

- e- 100-1000GeV
- gamma 100-1000GeV
CHD coincidences

1-10TeV CHDy vs. CHDx

- e- 1-10TeV
- gamma 1-10TeV

CHDy deposit (GeV)

CHDx deposit (GeV)
## Separation statistics

<table>
<thead>
<tr>
<th>Primary species</th>
<th>Energy range</th>
<th># thrown</th>
<th># in geometry</th>
<th>ID’d as $\gamma$ (num)</th>
<th>ID’d as $\gamma$ (%)</th>
<th>ID’d as e (num)</th>
<th>ID’d as e (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>10-100 GeV</td>
<td>2,000,896</td>
<td>7675</td>
<td>8</td>
<td>0.104%</td>
<td>7667</td>
<td>99.9%</td>
</tr>
<tr>
<td></td>
<td>100 GeV – 1 TeV</td>
<td>2,000,896</td>
<td>7554</td>
<td>5</td>
<td>0.0662%</td>
<td>7549</td>
<td>99.9%</td>
</tr>
<tr>
<td></td>
<td>1-10 TeV</td>
<td>2,000,896</td>
<td>7485</td>
<td>5</td>
<td>0.0668%</td>
<td>7480</td>
<td>99.9%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>10-100 GeV</td>
<td>2,000,896</td>
<td>7482</td>
<td>7217</td>
<td>96.5%</td>
<td>265</td>
<td>3.54%</td>
</tr>
<tr>
<td></td>
<td>100 GeV – 1 TeV</td>
<td>2,000,896</td>
<td>7649</td>
<td>7275</td>
<td>95.1%</td>
<td>374</td>
<td>4.89%</td>
</tr>
<tr>
<td></td>
<td>1-10 TeV</td>
<td>2,000,896</td>
<td>7573</td>
<td>5797</td>
<td>76.5%</td>
<td>1776</td>
<td>23.5%</td>
</tr>
</tbody>
</table>
Exposure map

• Goal: Estimate the number of photons detected by CALET in orbit and the significance of steady sources
• Method: Generate a full-sky exposure map for one year of CALET orbit and use Fermi-LAT reported fluxes to calculate event rates
• How: Calculate ISS zenith pointing as function of time and convolve with known fluxes and CALET geometrical factor and efficiency
Gamma-ray sources

• Three broad classes of high-energy gammas:
  – Steady point sources – systems such as AGN
  – Transient point sources – systems exhibiting flares
  – Diffuse flux – background radiation from cosmic-ray interactions and, possible, dark matter annihilation

• Needed for calculation:
  – Steady source flux – Fermi-LAT source catalog
  – Diffuse flux – Fermi-LAT gamma-ray galactic background and isotropic models
  – Exposure map – Generated using orbit parameters
Determining exposure

- Fermi-LAT diffuse background model divided into $0.125^\circ \times 0.125^\circ$ galactic latitude (b) and galactic longitude (l) bins
- Angular separation between two bins with central coordinates (l, b) and (l’, b’) calculated using Haversine formula:

$$s = 2 \times \arcsin\left( \sqrt{\sin^2\left(\frac{b - b'}{2}\right) + \cos(b) \cos(b') \sin^2\left(\frac{l - l'}{2}\right)} \right)$$
Calculating the orbit

- Orbit calculated using AGI STK
- ISS zenith RA and Dec (J2000) generated for 2015/11 – 2016/10 at 1s resolution
- Translated to galactic coordinates using C WCS routines
Exposure algorithm

• Given a pointing \((l, b)\) and the knowledge that the pointing is approximately constant over a 1s window:
  – Find bin that \((l, b)\) lie within
  – Find all bins with centers \((l', b')\) within 45° of the pointing direction \((l, b)\)
  – Increment the exposure time for all of those bins by 1 second
  – Repeat for all pointing directions
1. Start with the pointing bin at (l₀, b₀)
2. Log bins with l = l₀ and b between b₀ - 45° and b₀ + 45°
3. Start at top bin and step to the right until a bin is found that has Δs > 45°
4. Repeat until minimum b is reached
5. Reflect these across the central line
6. Increment exposure of all bins within these boundaries
Exposure map

CALET 1-year exposure map in days

$\rho$ (deg)

$\lambda$ (deg)
Photons incident

- Using an effective area of 500 cm$^2$, the number of type-B geometry photons incident is
  - Approx. 3500 from combined galactic diffuse (10-500 GeV) and isotropic (10-600 GeV) sources
  - Approx. 350 from persistent sources
    - 15 sources with $\geq 3$ photons
    - 4 sources with $\geq 10$ photons, including Crab, Vela, and Mkr 421
# Photons Incident

<table>
<thead>
<tr>
<th>1FHL Designation</th>
<th>Common Name</th>
<th>Type</th>
<th># of photons</th>
</tr>
</thead>
<tbody>
<tr>
<td>J0835.3-4510</td>
<td>Vela</td>
<td>PWN</td>
<td>22</td>
</tr>
<tr>
<td>J0534.5+2201</td>
<td>Crab</td>
<td>PWN</td>
<td>19</td>
</tr>
<tr>
<td>J2028.6+4110e</td>
<td>MGRO J2031+41</td>
<td>N/A</td>
<td>12</td>
</tr>
<tr>
<td>J1104.4+3812</td>
<td>Mkn 421</td>
<td>HBL</td>
<td>11</td>
</tr>
<tr>
<td>J0617.2+2234e</td>
<td>IC443</td>
<td>Shell</td>
<td>8</td>
</tr>
<tr>
<td>J0633.9+1746</td>
<td>Geminga</td>
<td>PWN</td>
<td>7</td>
</tr>
<tr>
<td>J2158.8-3013</td>
<td>PKS 2155-304</td>
<td>HBL</td>
<td>7</td>
</tr>
<tr>
<td>J1709.7-4429</td>
<td>HESS J1708-443</td>
<td>PWN</td>
<td>5</td>
</tr>
<tr>
<td>J1824.5-1351e</td>
<td>HESS J1825-137</td>
<td>PWN</td>
<td>5</td>
</tr>
<tr>
<td>J0222.6+4302</td>
<td>3C 66A</td>
<td>IBL</td>
<td>4</td>
</tr>
<tr>
<td>J1923.2+1408e</td>
<td>W51C</td>
<td>Shell</td>
<td>4</td>
</tr>
<tr>
<td>J2021.0+4031e</td>
<td>VER J2019+407</td>
<td>N/A</td>
<td>4</td>
</tr>
<tr>
<td>J0538.8-4405</td>
<td>N/A</td>
<td>N/A</td>
<td>4</td>
</tr>
<tr>
<td>J1801.3-2326e</td>
<td>W28</td>
<td>SNR</td>
<td>3</td>
</tr>
<tr>
<td>J2253.9+1608</td>
<td>N/A</td>
<td>N/A</td>
<td>3</td>
</tr>
</tbody>
</table>
Photons incident
Electron contamination

• The electron flux was obtained via PAMELA results.

• Integrating the spectrum from 10-600 GeV yields an expectation of:

\[ 5 \times 10^{-3} \text{ sr}^{-1} \text{ s}^{-1}, \text{ with an average of 0.07 per sky bin after 1 year.} \]
Crab flares

• Estimated number of
  – Approximate exposure time for Crab on day when it is optimally in field of view is 21600s (25% of day)
  – Denoting as $\alpha$ the flaring Crab flux in units of ambient Crab flux ($\alpha = \Phi_{\text{flare}}/\Phi_0$), the number of photons expected for one ideal day of flare observation is
    \[ N^{(\text{day})} = (8 \times 10^2) \]
  – For a 1-day flare, $\alpha = 25$ gives an expectation of 2 photons
Historical flares:
- 04/2011: $\alpha \approx 30, t \approx 10$ d
- 03/2013: $\alpha \approx 20, t \approx 14$ d

Scale relation to 16% of day (average, rather than ideal)

Expected number of photons:
- 15 from either of the noted flares ($\sim 3.8\sigma$ significance)

Detection at these energies would indicate inverse Compton source (only synchrotron observed to date)
Results

• Gamma-rays can be separated from electrons up to 1 TeV with >95% efficiency and electron rejection of better than 1 in $10^3$

• CALET will significantly detect some persistent sources, but will not be able to compete with Fermi-LAT on studying these

• All-sky scanning will be possible with CALET, making it a valuable tool for detecting high-energy flares such as those from Crab
Extra slides
Sample exposure map generated using three pointing directions. In galactic coords., $(l, b) = (0.0, 0.0), (190, -30), (60, 57)$. 

Example results
Coordinates

North polar cap

South polar cap
100ks frames