Search for Diffuse PeV Gamma-ray Emission from the Galactic Plane with IceCube

Hershal Pandya and Zach Griffith
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PeV Gamma-rays & Neutrinos

CASA-MIA Upper Limits

Gamma-ray Attenuation

IceCube Astrophysical Neutrinos (6 yrs)
IceTop
81 Stations
324 DOMs
1 km²

IceCube
86 Strings
5160 DOMs
1 km³

Diffuse Gamma-rays from the Galactic Plane

Shower Footprint
GeV μ’s

TeV μ’s
IceTop Reconstruction of Air Shower

Sample IceTop Event

Signal at 125m ($S_{125}$) = Energy Proxy

- Fit a shower curvature function to obtain Zenith and Azimuth angle of primary particle
- Fit a lateral distribution function to obtain shower size – which is our Energy proxy
- VEM=Vertical Equivalent Muon

Lateral Distribution Function

$$S(R) = S_{125} \left( \frac{R}{125 \text{ m}} \right)^{-\beta - 0.303 \log_{10}(\frac{R}{125 \text{ m}})}$$

$S (R)$ is signal measured at perpendicular distance $R$ from the shower axis
Identify Gamma-rays with IceTop

Probability Distribution Functions shown for $0.3 \leq \log(S125) < 0.4$ and $0.9 \leq \cos\theta < 0.95$

<table>
<thead>
<tr>
<th>Air Shower Property</th>
<th>IceTop Observable</th>
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</thead>
<tbody>
<tr>
<td>Number of GeV Muons</td>
<td>~1 VEM signal at large lateral distance</td>
</tr>
<tr>
<td>Shower Age</td>
<td>Steepness of the LDF</td>
</tr>
<tr>
<td>Hadronic content</td>
<td>Local charge fluctuations</td>
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</table>

Calculate a Log-likelihood Ratio:

$$LLHR = \log_{10} \left( \prod_{i=1}^{162} P(Q_i, R_i | H_\gamma) \right) / \left( \prod_{i=1}^{162} P(Q_i, R_i | H_{CR}) \right)$$

Poster Contribution:
Identify Gamma-rays with IceTop

Time Distribution of Charges

Simulated Gamma-rays

Cosmic rays

Simulated Gamma-rays

Cosmic rays

• We calculate Log-likelihood ratios using all three PDFs
• Combined log-likelihood ratio used for analysis

Normalized Histogram

Poster Contribution:
Gamma-ray showers have significantly less TeV muons as compared to cosmic rays. Charges measured in-ice quantify energy deposited by muons.
Event Selection

**IceTop-IceCube Coincident Events**

- Random Forest (RF) trained to discriminate simulated gamma-ray events from the highly abundant cosmic ray events
- Gamma-ray events are weighted with $E^{-3}$ spectrum
- Features supplied to RF are:
  - IceTop LLH Ratio, InIce Charges
  - Geometric containment of the shower track
  - Zenith angle, $S_{125}$
Search for Emission from the Galactic Plane

- Events with RF score > 0.7 selected to obtain an enriched sample of gamma-like events
- Enriched sample used for a template analysis for the Galactic plane in IceCube Field of View

Pion Decay Template of the FermiLAT diffuse emission model
Template Analysis

- Signal PDF constructed from the Fermi template by multiplying with detector acceptance and convolving with point spread function of reconstructed events

- Unbinned maximum likelihood analysis performed with the likelihood function described above

- No significant evidence found to exclude the null hypothesis

Ref: PoS(ICRC2017) 1011
Result: Upper Limit

- Template analysis yields normalization $A$ to spectral energy distribution of the angular-integrated flux from the entire field of view

$$E^2 \phi'(E) = A \left( \frac{E}{E_0} \right)^{2-\gamma}$$

- We compare with CASA-MIA, previous IceCube Analysis, models by comparing ‘scaled angular-integrated’ fluxes.

$$\Phi_{\text{template}} = \Phi \Delta \Omega \frac{\int_{\text{all sky}} S_{\text{Fermi}} d\Omega}{\int_{\Delta \Omega} S_{\text{Fermi}} d\Omega}$$
Gyeongju Astronomical Tower
632-647 AD
BACKUP SLIDES
Upper Limit Comparisons

Flux from a Boxed region

Scaled Angular-integrated Flux

![Graphs showing upper limit comparisons for different datasets, including IceCube Preliminary, CASA-MIA, IC-86, and Vernetto & Lipari'17. The graphs illustrate the comparison of template angular-integrated flux at different energies, with specific limits and integrated flux values indicated.]