Cygnus Paper Analysis & $A_4$ Properties

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Michigan State University
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Outline

- $A_4$ Properties
  - General Behavior
  - Core Dependence
  - Zenith Angle Dependence
  - Energy Dependence
- Cygnus Paper Analysis
  - Epochs in Milagro
  - PSF Weights
  - Gamma-Hadron Weights
- Improvements over Cygnus Paper
A₄ Properties

General Behavior of A₄ Compared to X₂

GEANT 4.0 v 2.1 Monte Carlo no air under cover

Cosmic Ray MC sample: 35% Helium, 65% Proton
Excellent match between data and CR MC.
$A_4$ Core Location Dependence

- $A_4$ works better for off-pond events
- On-Pond Gamma ray showers are harder to separate from Cosmic ray showers

On-Pond Events

- More events at low $A_4$

Off-Pond Events

- More events at high $A_4$
Core Location Dependence

- $Q(\text{Off}) > 50\% \ Q(\text{On})$

MC CR as Background

Data as Background
$X_2$ Core Location Dependence

- Similar behavior as $A_4$

MC CR as Background  

Data as Background
Zenith Angle Dependence

- No noticeable difference in the $A_4$ distribution for different zenith angle ranges
A \_4 Zenith Angle Dependence

• No Significant Differences
Energy Dependence

- Good energy dependence between 5 and 30 TeV

Integral $A_4$ Bins

Differential $A_4$ Bins
Cygnus Paper Analysis

• Data Set: July 20, 2000 To March 23, 2006

• Event Selection Cuts:
  ➢ $N_{\text{fit}} \geq 40$
  ➢ Zenith Angle $\leq 60^\circ$

• Excluded Data Runs (Bad Run List in Milinda):
  ➢ Data runs during September repair periods
  ➢ Calibration runs
  ➢ Runs with deep water on cover
  ➢ Periods with sudden rate and/or zenith angle changes
  ➢ Events with clock errors
  ➢ Corrupt data
  ➢ Short runs (Integration time $< 3600$ s)
Cygnus Paper Analysis

- Epochs In Milagro
  - Necessary due to changes in Detector configurations:
    - Different reconstruction algorithms
    - Different calibration softwares
    - Different trigger cards
    - PMT conditions (% of PMTs that are dead)

<table>
<thead>
<tr>
<th>Epoch #</th>
<th>Start date</th>
<th>Core Finder</th>
<th>Trigger</th>
<th>Special</th>
<th>% AS Dead</th>
<th>% MU Dead</th>
<th>% OR Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2000 07 19</td>
<td>COM</td>
<td>Multiplicity</td>
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<td>5</td>
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<td>100</td>
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<tr>
<td>2</td>
<td>2000 12 10</td>
<td>Off Pond</td>
<td>Mult/VME</td>
<td></td>
<td>5</td>
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<td>100</td>
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<td>3</td>
<td>2003 05 18</td>
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<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2004 10 06</td>
<td>3 Layer</td>
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<td></td>
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</tbody>
</table>
Analysis Summary

- Slice the data in each epoch in 12 $A_4$ slices
- Use scaled $A_4$ for pre-outrigger data
  
  \[ 0.5 \leq A_4 < 1.0, 1.0 \leq A_4 < 1.5, \ldots, 6.0 \leq A_4 \]

- Post-outrigger data
  
  \[ 1.0 \leq A_4 < 2.0, 2.0 \leq A_4 < 3.0, \ldots, 12.0 \leq A_4 \]

- Simulate each epoch with the proper number of dead PMTs, core fitters, and reconstruction algorithms (GEANT 4.0 v 2.0).
- Use Gamma MC to estimate the PSF weights for each $A_4$ slice in each epoch
- Use Gamma MC and data to estimate the G/H weights for different $A_4$ slices for each epoch
- Add all maps in one map.
PSF Weights

Milagro Point Spread Function is a 2D Gaussian function of the form:

\[ f(r) = Ar \left( e^{-\frac{r^2}{2\sigma_1^2}} + Re^{-\frac{r^2}{2\sigma_2^2}} \right) \]

Angular resolution improves with harder $A_4$ cuts

- $3.0 \leq A_4 < 4.0$
- $12.0 \leq A_4$
For each slice in $A_4$ estimate:

- $<S_i> = \text{Number of Signal events from Gamma MC events}$
- $<B_i> = \text{Number of Background events from Real data}$
- Weight events in each slice by:

$$\omega_i = \frac{<S_i>}{<B_i>}$$

<table>
<thead>
<tr>
<th>Slice Number</th>
<th>Cuts</th>
<th>$N^\text{Exp}_\gamma$</th>
<th>$N^\text{Meas}_B (x 10^6)$</th>
<th>Weight</th>
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<tbody>
<tr>
<td>1</td>
<td>$1 \leq A4 &lt; 2$</td>
<td>1262.5</td>
<td>409.314</td>
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<tr>
<td>2</td>
<td>$2 \leq A4 &lt; 3$</td>
<td>700.3</td>
<td>126.831</td>
<td>1.79</td>
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<tr>
<td>3</td>
<td>$3 \leq A4 &lt; 4$</td>
<td>410.1</td>
<td>50.166</td>
<td>2.65</td>
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<tr>
<td>4</td>
<td>$4 \leq A4 &lt; 5$</td>
<td>254.1</td>
<td>23.601</td>
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<tr>
<td>5</td>
<td>$5 \leq A4 &lt; 6$</td>
<td>182.4</td>
<td>13.055</td>
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<td>6</td>
<td>$6 \leq A4 &lt; 7$</td>
<td>162.2</td>
<td>8.404</td>
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<td>7</td>
<td>$7 \leq A4 &lt; 8$</td>
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<td>8</td>
<td>$8 \leq A4 &lt; 9$</td>
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<td>0.275</td>
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<tr>
<td>12</td>
<td>$12 \leq A4 &lt; \infty$</td>
<td>5.1</td>
<td>0.159</td>
<td>32.01</td>
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</table>
Improvements over Cygnus paper

- Use GEANT 4.0 v 2.1 no air under cover
- Add more data (7 months)
- Change the zenith angle cut from 60° to 45° (As in our MC sample)
- Split the data in more epochs
  - Epoch 2: Multiplicity trigger and VME trigger
  - Epoch 5: Before and after repair
### Epochs In Milagro (Five Epoch Scheme Used in the Cygnus paper)

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Further splitting is necessary

### Epochs In Milagro (Eight Epoch Scheme)

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<td>Cali603</td>
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New Data (7 Months)
Improvements over Cygnus paper

Crab significance increased from 14 to 15.6 Sigma
Improvements over Cygnus Paper

MGRO J2019+37 significance increased from 10 to 11.2 Sigma
Inner Galaxy

Hot Spot at RA 287.35 and Dec 6.35 visible at 7.7 Sigma

Nearest Source:
NVSS J190814+053438 Radio Pulsar at RA = 286.45, Dec = 5.49
Improvements over Cygnus Paper

Mrk421 visible at 7.6 Sigma

Last seven months 5.2 Sigma
Single $A_4$ Cut Analysis

Apply a single $A_4$ cut on the same data set and weight it with the proper PSF weights

<table>
<thead>
<tr>
<th>Source</th>
<th>$A_4 &gt; 1.0$</th>
<th>$A_4 &gt; 2.0$</th>
<th>$A_4 &gt; 3.0$</th>
<th>$A_4 &gt; 4.0$</th>
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<tbody>
<tr>
<td>Crab</td>
<td>9.06</td>
<td>11.46</td>
<td>10.21</td>
<td>10.10</td>
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<tr>
<td>MRK421</td>
<td>8.00</td>
<td>7.30</td>
<td>6.24</td>
<td>5.05</td>
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<td>MGRO 2019</td>
<td>5.93</td>
<td>6.27</td>
<td>7.79</td>
<td>9.17</td>
</tr>
</tbody>
</table>

Map of Significances

Distribution of Significances

[Graph showing distribution of significances with data points for Crab and MGRO J2019+37, highlighting MRK421]