A search for UHE neutrinos with the Pierre Auger Observatory

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Pierre Auger Observatory
(completed in June, 2008)

Hybrid detector

24 fluorescence telescopes
(4 buildings)

1660 Cherenkov detectors
Triangular grid. Side = 1.5 km

A unique tool to study the origin, composition and propagation of Ultra High-Energy Cosmic Rays (see A. Olinto’s talk on Thursday)
Surface Detector

Communication antenna

GPS antenna

Electronics enclosure

40 MHz FADC, local triggers, 10 Watt

Solar panels

Battery

Plastic tank with 12 ton of water

3 PMTs (9") for Cherenkov light detection

Angular resolution: 1-2°

FADC trace (25 ns resolution)
Sensitivity to neutrinos in the EeV range

What is a $\nu$?

HORIZONTAL YOUNG (DEEP) SHOWER
ν signature in the surface detector

Hadronic shower

Electrons & Photons
Muons
Interaction point

Downgoing ν

Electrons & Photons
Muons
Interaction point

Upgoing ν

Electrons & Photons
Muons
Tau decay

ν distinctive attribute: broad signal in the early part of the EAS

“Fast & narrow signal”
FADC Trace

“Slow & broad signal”
FADC Trace
Main observable for $\nu$ discrimination

Signal AOP $> 3$

“Slow & broad signal”

“Fast & narrow signal”

Background AOP $\approx 1$

Down-going (DG)

Earth-skimming (upgoing) (UG)

Two search channels:
- $\theta > 75^\circ$
- Signal propagation speed $\langle V \rangle < 0.313$ m/ns
- 4(3) stations with local trigger for DG (UG) $\nu$

- Signal speed relative error < 0.08
- Elongated footprint $L/W > 3(5)$ for DG (UG) $\nu$
Search strategy: Blind analysis

- **Background rejection cuts**
  - Set cuts using a “training sample” of data (equivalent to 1.2 yrs of full detector operation) and $\nu$ Monte-Carlo.
  - Use Monte-Carlo to compute $\nu$ selection efficiencies.
  - Improve discrimination power: Fisher’s linear discriminant.

- **Search for neutrinos**
  - Use the rest of real data after cuts are set.
  
  **WARNING:** “Search” and “training” samples are disjoint sets!
The Fisher's linear discriminant: A reminder

\[ F = a_1 \cdot \text{var}_1 + a_2 \cdot \text{var}_2 \]

\[ R = \frac{(\langle F \rangle_{\text{HAS}} - \langle F \rangle_{\nu})^2}{\sigma_{F,\text{HAS}}^2 + \sigma_{F,\nu}^2} \]

Goal: Maximize \( R \)
The Fisher's linear discriminant

**Variables**

- Area over Peak (AOP) of first four tanks
  - And combinations of them, like for example the product
  - Asymmetry: \(<\text{Early AOP}> - <\text{Late AOP}>\)

**Improved discrimination:**

- Split sample according to number of selected stations \((N)\)
Signal/Background discrimination

Fisher distribution ($6 < N < 12$)

- MC $\nu$
- MC $\nu$ (High Altitude)
- Data

Events vs. Fisher discriminant value
Setting the cut

- Scale up data up to 20 yrs of exposure for full detector
- Set cut such that **Expected Background (20 yrs) < 1**

**Fisher distribution (6 < N < 12)**

- Fit "training data" 3σ tail with exponential
- Expected Background (20 yrs) < 1

<table>
<thead>
<tr>
<th></th>
<th>pred</th>
<th>real</th>
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<tbody>
<tr>
<td>3σ</td>
<td>34.7</td>
<td>31</td>
</tr>
<tr>
<td>4σ</td>
<td>9.4</td>
<td>10</td>
</tr>
<tr>
<td>5σ</td>
<td>2.6</td>
<td>3</td>
</tr>
<tr>
<td>6σ</td>
<td>0.7</td>
<td>0</td>
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Fisher discriminant value
Selection efficiencies

\[ E_{\nu} = 1 \text{EeV}^{-2} \]
NO candidates found!

Search period: Nov 07 - Feb 09
Earth-skimming $\nu_T$

- $(E_\nu = 10^{18}$ eV)
- $L_{\text{decay}}(\tau) \approx 50$ km
- $L_{\text{prop}} \approx 10$ km

- Broad signals in time
  - “ToT triggers” large
  - “L/W” big
  - “<signal speed>” $\sim c$

- Horizontal shower

- Data plots:
  - ToT stations
  - Length / width
  - Mean speed [m ns$^{-1}$]
NO CANDIDATES FULFILLING SELECTION CRITERIA
Aperture calculation with the real SD array

Snapshot of the array configuration in Aug 07

Green squares: events triggering the array
Open squares: events not triggering the array

Warning! Array configuration varies with time

\[ \epsilon_{\text{exposure}}(E_v) = \frac{1}{m} \sum_{i} (\sigma_i(E_v) \int M_{ap}^i(E_v, t) \, dt) \]

\[ M_{ap}^i(E_v) = 2\pi \int \int \int \sin \theta \cos \theta \, \epsilon_{\nu}^i(r, \theta, D, E_v, t) \, d\theta \, dD \, dx \, dy \]

Earth-skimming (\nu_{\tau} CC) 2 yr

Down-going (all flavours) 0.8 yr
Flux Limit: $\Phi = K \times E^{-2}$

Single flavour neutrino limits (90% CL)

assuming $\nu$ flavour $e:\mu:\tau = 1:1:1$

<table>
<thead>
<tr>
<th>AUGER</th>
<th>$K$ [GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]</th>
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<tbody>
<tr>
<td>upper limits</td>
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<tr>
<td>DG</td>
<td>$3.2 \times 10^{-7}$</td>
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<td>1Nov2007-28Feb2009</td>
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<tr>
<td>UG</td>
<td>$4.7 \times 10^{-8}$</td>
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<td>1Jan2004-28Feb2009</td>
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CONCLUSIONS

- The Pierre Auger Observatory is sensitive to UHE neutrinos.

- A search for downgoing neutrinos of all flavours and upgoing tau neutrinos found no candidates so far. \(\Rightarrow\) Paper in preparation for downgoing \(\nu\).

- GZK neutrinos will be probed in 10–15 years of data taking.

- On-going analysis to assess our sensitivity to point sources.