THE VIEW
FROM
AUGER

E. ZAS

RADEP-2000
UCLA
PIERRE AUGER
OBSERVATORIES

- 2 OBSERVATORIES
  - SOUTH Argentina (started)
  - NORTH Utah (planned)

FULL SKY COVERAGE

- 2 TECHNIQUES
  - Track Det.
  - Particle array: Water Čerenkov tanks

- 3000 km² AREA

- HEXAGONAL ARRAY 1.5 km SEPARATION

- FOUR D 'EGU'

MEASURE CR EAS WITH $E > 10^{19}$ eV
CONSTRUCTION HAS BEGUN!
ENGINEERING ARRAY

55 km²  40 tanks

Could be doing Physics next year.
ESQUEMA DE DISTRIBUCION PROPUESTO

PARA EL AREA EL NIHUIL

REFERENCIAS

- Detector de fluorescencia
- Comino existente
- Comino consolidado
- Línea de suministro eléctrico propuesto 33 Kv
- Camino de huella
- Camino consolidado a construir
- Ferrocarril
Pulse Shapes in Water Ch. Detectors
2 tanks operate in AGASA (JAPAN) for 2 years

25 μs FADC
Simulation of a $10^{19}$ eV proton EAS using the MOCCA program. A sample of tracks at > 300 m from the shower axis are shown. Frame box: 6 x 6 x 12 km high. Color code: $\gamma$ green, $e$ red, $\mu$ blue. *Drawn by Clem Pryke — University of Chicago*
Hybrid Design....

Both the ground array technique and the FD technique have been used separately in the past. (eg Haverah Park, Fly's Eye)

The hybrid combination provides a ~10% sample of data with cross calibration of angular and energy reconstruction and shower development characteristics.

- **Ground array features**
  - Aperture well defined and large
  - 100% duty cycle
  - Uniform right ascension exposure for anisotropy
  - direction by timing (energy by density and model)
  - muon/em ratio, shower front curvature and risetime

- **FD features**
  - Direct calorimetric energy estimator
  - good angular resolution, improves with gnd array
  - Xmax and longitudinal development measured

- **Combination hybrid ....**
Acceptance (km$^3$ w.eq. sr)

Logarithmic scale:
- Shower Energy (GeV)
- 10$^{-1}$ to 10$^2$
- 10$^8$ to 10$^{12}$

Figure 2
INCLINED SHOWERS

\[ d = \text{Acceptance} = \int A(\cos \theta) d(\sin \theta) d\theta = \pi A [1 - \cos^2 \theta_{\text{max}}] \]

\[ A = 3000 \text{ km}^2 \]

Typically \( \theta < 45^\circ \) to avoid large angle effects

\[ d = \frac{\pi A}{2} \times 4500 \text{ km}^2 \text{ sr} \]

If \( 45^\circ < \theta < 90^\circ \) can be analyzed

DOUBLE ACCEPTANCE!

\[ A = 9000 \text{ km}^2 \text{ sr} \]

(This started as a \text{V} background study!)
TOY MODEL
for µ's in HAS

\[ r = \frac{p_1}{\Phi} \cdot d \sim \frac{cR}{E} \cdot d \]

Fix \( p_1 \) & \( d \)

µ Energy spectrum
\[ \frac{dN}{dE} = \Phi(E) \]

\( \Phi(E) \) lateral distribution specified

\[ p_x(R) = \frac{-\Phi(E) dE}{2\pi r} = \frac{cR d}{2\pi r^3} \Phi(E(x)) \]
SIMULATIONS

No $B$ field $10^{19} \Phi$ (100 showers)

AIRES

distribution of muons arriving at GROUND:

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$d$(km)</th>
<th>$\Delta d$</th>
<th>$&lt;E_\mu&gt;$ at production</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ$</td>
<td>4</td>
<td>2.8</td>
<td>8.1 GeV</td>
</tr>
<tr>
<td>$60^\circ$</td>
<td>16</td>
<td>6.5</td>
<td>18.9 GeV</td>
</tr>
<tr>
<td>$70^\circ$</td>
<td>32</td>
<td>10</td>
<td>32.9 GeV</td>
</tr>
<tr>
<td>$80^\circ$</td>
<td>88</td>
<td>17</td>
<td>77 GeV</td>
</tr>
<tr>
<td>$84^\circ$</td>
<td>27.6</td>
<td>31</td>
<td>204 GeV</td>
</tr>
</tbody>
</table>

\[
\frac{dN_\mu}{d \log_{10} E_\mu}
\]
\[ \log_{10} E_{\text{GeV}} \]

\[ \log_{10}(r) \text{ (m)} \]

\[ \langle E_\mu \rangle \propto r \]

\[ p_L = 200 \text{ MeV} \]

\[ \langle cI \rangle \] from \[ \frac{dN_\mu}{dE_{\text{Em}}} \] simulation
B EFFECTS

Small $\delta x \rightarrow \delta x \approx \frac{d^2}{R^2} = \frac{eB_1 d^2}{2p} \approx \frac{eB_1 d}{2p_\perp}$

$\delta x = x r$

recalling $r = \frac{p_\perp}{p}$ constant

No B field

B field

Can do transformation

$x = x + \alpha \sqrt{x^2 + y^2}$

$y = y - \bar{y}$

$\bar{p} (\bar{x}, \bar{y}) \rightarrow p (x, y)$
HAVERAH PARK

M. Aue
J.A. Hinton
R.A. Vazquez
A.A. Watson
E. Zas
Astrop. Phys. 2010

Diagram with coordinates and labels for points A, B, C, D, E, F, H, A1, A2, A3, and A4. Relative Heights in m are indicated.
**RATE SIMULATION**

- **GENERATE $\bar{n}_\mu$ MAPS**
  - 40 Ebins $10^{16} - 10^{20}$ eV
  - 15 $\theta$-bins $60^\circ - 88^\circ$
  - 18 $\phi$-bins

- **SIMULATE IMPACT POINTS $n_{\mu}$**
  - $n = 10,000$
  - $d = 8$ km

- **READ $\bar{\rho}_\mu$ AT TRIGGER ($\pm 20\%$ fluct.)**

- **GENERATE TANK SIGNAL corrections**

- **TEST TRIGGER CONDITION**

- **GET TRIGGERING PROBABILITY $\to A_{eff}$**

- **CONVOLVE WITH CR FLUX** (AXENO + H.P)
  - Nagano & Watson
  - Rev. Mod. Phys. 2000

- **SHAPE WITH $\theta$ ERROR**
also: $\frac{dN_\mu}{dr}$

100 Showers averages

Fluctuations: $\sqrt{N_\mu} \approx 20\% N_\mu$
QUALITY CUTS

1. distance < 2 km

2. $\chi^2$ probability > 1%

3. $\Delta E_p < \frac{E_0}{2}$ (downward energy error)
   (No events $\theta > 80^\circ$ left)

$$\Delta E_p = \sqrt{\Delta E_{H+E}^2 + \Delta E_{\Delta\theta}^2}$$

$E_p > 10^{19}$

46

$E_p > 4 \times 10^{19}$

7

$E_p > 10^{20}$

2
TABLE 1. Zenith angle, arrived direction coordinates and shower energy (assuming proton)

<table>
<thead>
<tr>
<th>Date</th>
<th>RA</th>
<th>Dec</th>
<th>Zenith</th>
<th>Energy</th>
<th>MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>19/2</td>
<td>1.6</td>
<td>0.0</td>
<td>7.0</td>
<td>4.0</td>
<td>7.0</td>
</tr>
<tr>
<td>12/7</td>
<td>2.2</td>
<td>3.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>26/7</td>
<td>3.0</td>
<td>2.0</td>
<td>5.0</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>19/4</td>
<td>4.0</td>
<td>3.0</td>
<td>2.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>19/4</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>19/4</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>12/2</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>12/2</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>12/2</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Note: Reported X^2 values refer to the energy. The primary of selected showers with energy < 4 x 10^19 eV. MR is the event record number.
UHECR
conclude @ 95% C.L.
for $E > 10^{19}$ eV less than 41% of $\gamma$'s
for $E > 4 \times 10^{19}$ eV less than 65% of $\gamma$'s