Atmospheric Calorimetry above $10^{19}$ eV: Shooting Lasers at the Pierre Auger Observatory

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Calor 2008 May 28th Pavia
The hybrid nature of Auger

Fluorescence Detector
- E + longitudinal development
- Time ≈ direction
- ≈ 10% duty cycle

Trigger efficiency
Energy-direction calibration, syst. errors

Surface Detector
- Shower size ≈ E
- Time ≈ direction
- 100% duty cycle

300-400 nm light
from de-excitation of atmospheric nitrogen
(flourescence light)
≈ 4 γ's / m / electron

10^{19} eV ⇝ 10^{10} e
Detector Configuration (Almost Completed)

Central Laser Facilities
“Test Beams”

Fluorescence Detectors
4 “Eyes”
+Atmospheric Monitoring Systems

Surface Detector Array
1600 detector stations
3000 Km²

STATISTICS ENGINE
An Auger Surface Detector Station
(1 of 1600, 1.5 km spacing)

- Three 8” PM Tubes
- Plastic tank
- Solar panel and electronic box
- Battery box
- White light diffusing liner
- 12 m² of de-ionized water
- Comm antenna
- GPS antenna
view of Los Leones Fluorescence Eye
The Air Fluorescence Technique

Use the Atmosphere as a Calorimeter
Total amount of scintillation light proportional to shower energy
Measurement of UHECR Energy

SD events, $\theta < 60$

SD energy estimator calibrated by calorimetric measurement from Fluorescence Detector in Hybrid Events

$L(1000) \sim E$

SD

FD

Lateral density distribution
FD Energy Calibration

F. Yield: 196 (14%)
Reconstruction: 100 (10%)
Detector Calib.: 90 (9.5%)
Aerosols: 16-64 (4-8%)
Air Density, Humidity: 49 (7%)
Invisible Energy: 16 (4%)

Quadrature Sum (22%)
(Assumes terms are uncorrelated)
Energy Calibration with Fluorescence Detector

**NOTE:** Both $S_{38}$ and $E_{SD}$ are determined experimentally. We DO NOT rely on shower simulation!

$$E_{SD} = A (S_{38})^b$$

$b \sim 1$

Energy resolution better than 20%
The CLF sends light simultaneously to the Surface Detector and to the Fluorescence Detector.
Examples of steered shots (as seen by Los Leones)
Many Uses of Laser “Test Beams”

- Check Cabling of FD
- FD-SD Clock offsets
- Check Pointing of FD
- Study FD Angular resolution
- Atmospheric Clarity (Time, Eye)
- Clouds
- Up-Time & Triggering Studies
- Measure speed of the Laser track
- End to End test of Absolute Photometric Calibration
Laser – Air Shower Equivalence

Laser @ 27 km (50 shot average)

5x10^{19} \text{ eV}
Air Shower
@ 16 \text{ km}

5x10^{19} \text{ eV}
Air Shower
@ 28 \text{ km}

photons/(m^2 \text{ time bin})
Measure Laser Energy by reconstructing track seen in calibrated FD

Measure Laser Energy Locally with a calibrated pyroelectric energy probe

Roving Laser @ 4km

Central Laser @ 27km
Laser Tests of Photometric Calibration – *In Progress*

Roving Laser @ 4km
analysis-V. Verzi (Roma)

Mean 1.01
RMS 0.06

One Atmosphere

Use Atmos. Hourly Data Base

CLA @ 27 km
Analysis -L. Valore (Napoli)

Entries 44479
Mean 0.9021
RMS 0.2424

Entries 33035
Mean 1.043
RMS 0.06718
eXtreme Laser Facility to be installed October 2008,
The Pierre Auger Observatory of Ultra-High Energy Cosmic Rays

Northern site: Colorado
21000 km²
(Planned)

Argentina
Australia
Brazil
Bolivia*
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA
Vietnam*

Southern site: Argentina
3000 km² 1x provencia Pavia (Operational)

> 300 PhD scientists from
> 70 Institutions
and 17 countries

*Associate Countries
<table>
<thead>
<tr>
<th></th>
<th>South</th>
<th>North</th>
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</thead>
<tbody>
<tr>
<td>SD units</td>
<td>1,600</td>
<td>4,400</td>
</tr>
<tr>
<td>SD area</td>
<td>$3,000 \text{ km}^2$</td>
<td>$21,000 \text{ km}^2$</td>
</tr>
<tr>
<td>3 light sensors</td>
<td></td>
<td>1 light sensor</td>
</tr>
<tr>
<td>Non-insulated tank</td>
<td></td>
<td>Insulated tank</td>
</tr>
<tr>
<td>tank→center comms</td>
<td></td>
<td>tank→tank</td>
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<tr>
<td>1.5 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 buildings with 6 telescopes each</td>
<td></td>
<td>≈ 7 buildings with 6 telescopes each</td>
</tr>
<tr>
<td>large stereo coverage</td>
<td></td>
<td>little stereo coverage</td>
</tr>
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</table>
Conclusion

Auger North
Planned for Colorado
R&D Test Array - Funded,
Full proposal in preparation

New Collaborators Welcome!

Auger South
Nearly finished. ~100 tanks remain to deploy
Detector is working well.
Laser “Test Beams” were and are used in many ways
Many first science results are being published
Fluorescence Detector Photometric Calibration

Drum for uniform illumination of each fluorescence camera

Calibrated Roving Nitrogen Laser: Deliver known light flux via scattering

Atmospheric Monitoring

LIDAR at each fluorescence eye for atmospheric profiling - “shooting the shower”

Radiosondes for air density profile
R&D for Auger North

HEAT = R&D for northern FD
Being installed at Auger South.

Mostly European effort.
New electronics. Telescopes very similar to Auger South.

R&D Array (RDA) south of Lamar for SD and Comms systems.

10 SD units + 10 additional comms-only stations. US + European effort

New tank – freezing challenge
New comms – rolling terrain
End-to-end test of SD w/ comms
Deployment, water, working in SE CO
Cosmic Ray Energy Spectrum
(Pierre Auger Observatory)

SD events, $\theta < 60^\circ$  20000 events  $> 3 \times 10^{18}$ eV  submitted to PRL
Cosmic Rays Loose Energy in the Cosmic Microwave Background Radiation

\[ p + \gamma_{cmb} \rightarrow \Delta^+ \rightarrow p + \pi^0 \rightarrow n + \pi^+ \]

Energy Threshold \( \sim 5 \times 10^{19} \text{ eV} \)

Distance Scale is a strong function of Energy
One Motivation for Energy Calibration

\[ \Delta E/E \ 25\% \]
\[ \Delta V/V \ >10 \]

(for protons in CMBR)

\[ 8 \times 10^{19} \text{ eV} \]
\[ 90 \text{ MPC} \]

\[ 6 \times 10^{19} \text{ eV} \]
\[ 200 \text{ MPC} \]

\[ \Delta E/E \ of \ 1\% \ corresponds \ to \ a \ change \ in \ volume \ of \ \sim 10^6 \]
\[ \text{MPC}^3 \]

Our local supercluster of galaxies occupies \(10^5 \text{ MPC}^3\)

1 MPC = 1 Million parsecs = 3 Million Light Years