Questions and answers on extreme energy cosmic rays

a guide to explore the data set of the Pierre Auger Observatory

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LIP – Portugal

1. The Cosmic Ray Spectrum
2. Cosmic Ray Shower Development
3. How to Detect Cosmic Rays
4. How to Measure Cosmic Rays
5. Public Auger Data Analysis
1. The Cosmic Ray Spectrum (scales and experiments)

- LEAP - satellite
- Proton - satellite
- Yakutsk - ground array
- Haverah Park - ground array
- Akeno - ground array
- AGASA - ground array
- Fly's Eye - air fluorescence
- HiRes1 mono - air fluorescence
- HiRes2 mono - air fluorescence
- HiRes Stereo - air fluorescence
- Auger - hybrid

**Cosmic Ray Spectra of Various Experiments**

- Differential Flux (m^2 sr GeV sec^-1)
- Energy (GeV)

1 particle / km² / century
10 EeV ~ 1 Joule

Malargüé, Mendoza, Argentina
students have asked for Particle Physics lectures to really understand models
section joining general concepts and data analysis
autonomous exploration of the Pierre Auger Observatory web pages
Public data set of the Pierre Auger Observatory

1% of the Surface Detector events ~ 35 000 cosmic ray showers

(Cuts: $E < 50 \text{ EeV}$
$\theta < 60^\circ$)

- viewing
- selecting
- downloading (all data or just one event)

+ a glossary updated daily
Public data set of the Pierre Auger Observatory

Basic station signals and event reconstruction are given for each event - a simplified reconstruction can be re-done with available information.

**Event 4128900**

<table>
<thead>
<tr>
<th>Generic Information</th>
<th></th>
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<tbody>
<tr>
<td>Id / Date</td>
<td>41289000 / Tue Oct 30 11:14:14 2007</td>
</tr>
<tr>
<td>Nb. of stations</td>
<td>18</td>
</tr>
<tr>
<td>Energy</td>
<td>4.1 \pm 1.4 E\text{PeV}</td>
</tr>
<tr>
<td>Theta</td>
<td>54.5 \pm 0.1 \text{deg}</td>
</tr>
<tr>
<td>Phi</td>
<td>20.9 \pm 0.1 \text{deg}</td>
</tr>
<tr>
<td>Curvature</td>
<td>19.0 \pm 0.9 \text{km}</td>
</tr>
<tr>
<td>Core Easting</td>
<td>479769 \pm 14 m</td>
</tr>
<tr>
<td>Core Northing</td>
<td>6073404 \pm 25 m</td>
</tr>
<tr>
<td>Reduced (\chi^2)</td>
<td>1.68</td>
</tr>
</tbody>
</table>

- **Position, signal and trigger time of SD station**
- **Position, energy and direction of shower**
- **Position in galactic sky map**
4. How to Measure Cosmic Rays

Basics of reconstruction:
Which stations variables to use?

students feel difficulties in dealing with right / wrong; error / uncertainty; etc...
but, in general, appreciate the fact that they can also do things from scratch
5. What do these data tell us

Reconstruction of cosmic ray energy spectrum and arrival directions maps

Comparison of 1% data with the published Auger results

Choosing the right variables to answer present-day cosmic-ray questions

Using Excel / ROOT / other tools
Experience, reactions and outlook

end-to-end exercise on XXI century physics with high-school level tools
(with particle physics absent from programs, a lot of final grade mathematics)

a) At LIP, 3 or 4 students in 2-week intensive Summer Internships
   - daily contact with researchers, group work with new colleagues and methods

b) At Schools, 5 to 10 students in 1-year-long weekly Science Club
   - complementary approach to science curriculum, and self learning process

c) An inter-school international project (Portugal, Spain, Mexico, Uruguay)
   - permanent contact of all groups, some doing different activities, final meeting

Input from students and teachers to develop:

- new shorter and simplified versions, suitable for more (and younger) students
- extra materials for the answer guide for teachers (physics + mathematics)

Trying to identify possible questions for one-day Cosmic Ray Masterclasses

The English version of the guide is available at http://auger.org/education/
(Portuguese, Spanish versions and answer guide, upon request to sofia@lip.pt)