Fermi National Accelerator Laboratory

FERMILAB-Conf-97/071
GAP-97-016

The Pierre Auger Observatory

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March 1997

Presented at the *Rencontres de Moriond*, Les Arcs, France, January 17-25, 1997

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

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The Pierre Auger Observatory is an international collaboration for the detailed study of the highest energy cosmic rays. It will operate at two similar sites, one in the northern hemisphere and one in the southern hemisphere. The Observatory is designed to collect a statistically significant data set of events with energies greater than $10^{19} eV$ and with equal exposures for the northern and southern skies.

1 Introduction

The Pierre Auger Observatory (PAO) is an international collaboration of particle physicists and astro-physicists from 18 countries [1]. The PAO goals are to extend cosmic ray data well above GZK [2] energies, to collect data for the southern and northern skies with identical large aperture detectors, to identify possible sources, to search for anisotropies on the source locations and to determine the primary mass composition. These goals are to be achieved utilizing a hybrid technique of atmospheric fluorescence and surface detectors. PAO spokespersons are Jim Cronin, University of Chicago and Alan Watson, Leeds University. The utilization of PAO for the detection of atmospheric neutrinos is discussed elsewhere in these proceedings.

The PAO idea was conceived and developed at workshops in Paris 1992, Adelaide 1993, Tokyo 1993 and Fermilab 1995. During the organizational meeting at UNESCO in Paris, November 1995, the southern site location was selected to be in Argentina. At the collaboration meeting in San Rafel, Argentina, September 1996, the northern site was selected to be in the USA.

2 The atmosphere as a calorimeter

Both fluorescence and surface detection are based on the utilization of the earth's atmosphere as a high energy particle calorimeter. A primary cosmic ray, whose energy and species are of interest, can be characterized by the secondary particles produced by interactions within the atmosphere and the resulting Extensive Air Shower (EAS). The atmosphere has a total depth of order $1000gm/cm^2$, with the shower maximum (at which the shower contains the maximum number of secondary particles) located at a depth of about $850gm/cm^2$ or a height above sea level of $1500m$. Both PAO sites will be located at a height of about $1400m$.

The surface detector is a sampling calorimeter, taking one sample at shower maximum. The number of particles available at shower maximum could be as high as 10^{11}, depending on the primary energy, made up of 89% γ's, 10% electrons (and positrons) both with average energies of the order of $1MeV$ and about 1% μ's with average energies of $1GeV$. The surface detector can determine the impact point and the radial density of particles in the shower. In addition, quantities related to the μ content such as the shower front rise time and the ratio of μ's to electromagnetic particles will be also measured. The determination of the primary energy is based on the radial density of shower particles and information on the primary species can be obtained from the μ's related quantities. Both these measurements are based on shower simulation.

It is possible to reconstruct the primary particle energy to a precision of 10% at the highest energies using a fluorescent detector. The fluorescent detector technique is discussed elsewhere in these proceedings. Data taking with the fluorescent detector is limited by the presence of background light to about 10% of the time. This fraction may be increased to above $> 15\%$ with a surface detector trigger.

PAO will utilize the 10% to 15% hybrid events for accurate reconstruction of the shower characteristics and for the normalization of simulations of the surface detector.

3 Cosmic ray fluxes

For each decade of increasing energy, the CR flux decreases by three orders of magnitude [3]. The slope of the flux versus energy exhibits some structure near 10^{16} eV and also around 10^{19} eV, the so called "knee" and "ankle" features. No "toe" has been found [4]. Cosmic ray events at the highest energies are very rare indeed. The expected number of events above $10^{17} eV$ is $30,000 Km^{-2} yr^{-1}$ integrated over a 2π solid angle, falling rapidly to 220 above 10^{18} eV and to the order of 1 above 10^{19} eV. Only about 10 events with energies around 10^{20} eV have been detected to date by existing experiments.

In order to accumulate a statisticallly significant sample of events above 10^{20} eV, the combined design acceptance for both sites of PAO is $14,000 Km^2 sr$, yielding an estimated data collection rate of the order of 100 events per year.

4 Pierre Auger Observatory specifications

Surface Detector
- Aperture $14,000 Km^2$ sr (both sites)
- Surface $3,000 Km^2$ each site
- Azimuthal angular acceptance $90°$ to $30°$
- Energy resolution $\leq 20\%$ at 10^{20} eV
- Angular resolution $\leq 2°$
- Time resolution $20 ns$
- Detector type $10 m^2$ $1.2 m$ deep Čerenkov water tanks
- Number of detectors 1600 at each site
- Distance between detectors $1.5 Km$
- Photomultipliers 3 x $20 cm$ diameter per tank

Fluorescent Detector
- Acceptance $\leq 20\%$ of Surface Detector
- Angular resolution $\leq 0.5°$
- Energy resolution 10% at 10^{20} eV
- Depth of shower maximum resolution $15 gm/cm^2$
- Time resolution $100 ns$
- Number of fluorescent eyes 3 at each site

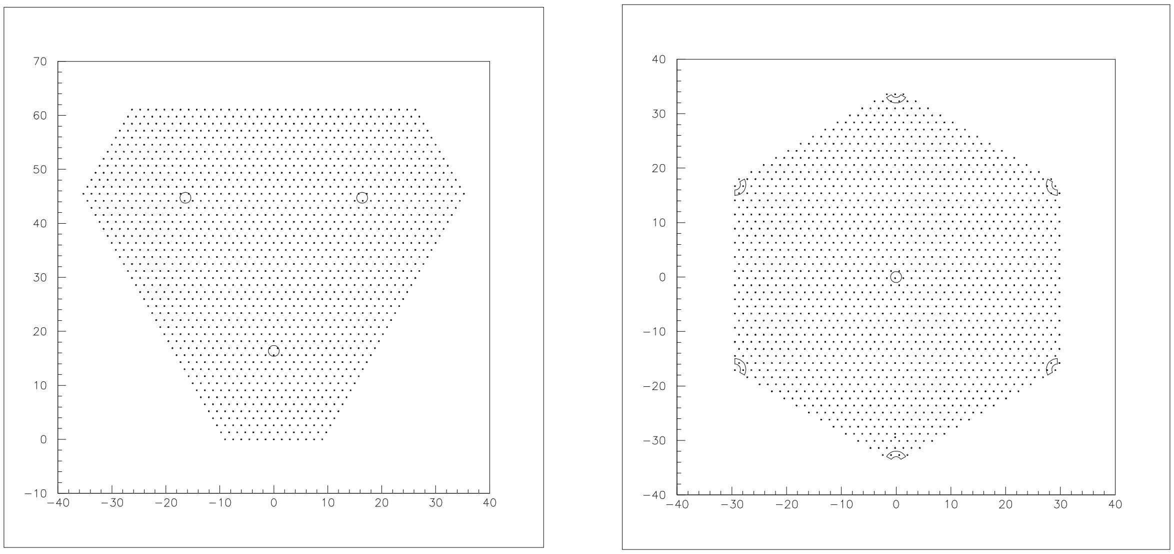

Figure 1: The Pierre Auger Observatory proposed layouts, Superman and Filled Hex. Units are Km. Each dot represents a surface detector. Both layouts have 3 fluorescent eyes indicated by the circles. In the Filled Hex configuration 2 of the eyes are distributed on the corners of the hexagon.

Eye angular acceptance (each) 360° in azimuth, 2° to 30° in elevation
Pixel size 1.5° x 1.5°

Cost

Total cost US$ 100 Million
Construction period 5 years (starting late 1998)
Funding proposals to be presented during 1997

Schedule

2nd year each site $340Km^2$ instrumented
3rd year each site $1,600Km^2$ instrumented and 1st Fluorescent eye
4th year each site $3,000Km^2$ instrumented and 2nd Fluorescent eye
5th year both sites completed

At the end of the second year of construction the PAO will be the largest surface detector in operation. For the southern sky this will be the first look at the highest energy CR spectrum.

5 Site layout

The placement of the three fluorescent eyes at each site will depend on the layout of the site, see Figure 1. In the Superman configuration the eyes are at three locations with the surface detectors arranged symmetrically with respect to them. In the Filled Hex one full eye is located at the center of the hexagon and the other two are distributed at the corners of the hexagon. Although, for the latter, a larger number of events are observed by more than one, or even two eyes, more buildings and services are required.

6 Trigger efficiency versus primary energy

A surface detector trigger is formed by requiring a number of stations to report coincident alerts within a minimum time. Figure 2 shows the predicted trigger efficiency for the surface detector as a function of primary energy and the number of alerted stations required. Trigger

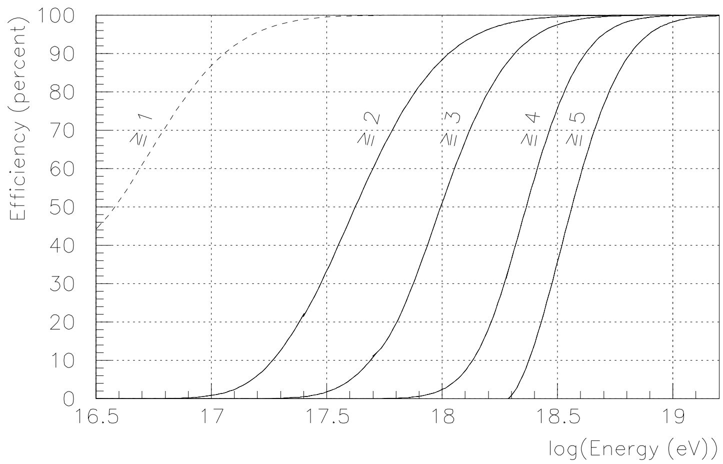

Figure 2: Trigger efficiency versus primary energy for vertical showers.

information from the fluorescent detector could be used to improve triggering efficiency at the lower multiplicities.

7 Conclusions

Early in the 21st. century PAO will have cataloged hundreds of CR with energies $> 10^{20} eV$, some 10% of those being "gold plated" events. Detailed knowledge of the spectrum at the highest energies will open a new dimension to the study of the origen and propagation of CR.

Acknowledgments

The author would like to thank Murat Boratav and the organizers for the invitation. Warm thanks to the very helpful staff at the Rencontres de Moriond.

References

1. Pierre Auger Design Report, Second Edition, 14 March 1997.
2. The GZK refers to the energy loss due to pion production by interaction of cosmic rays with the microwave background radiation limiting the observed energy to $10^{19} eV$ for far away sources. See e.g. F. A. Aharonian and J. Cronin, *Phys. Rev.* D **50**, 1892 (1994)
3. See T. K. Gaisser and T Stanev, *Phys. Rev.* D **54**, 122 (1996).
4. A "toe" would indicate the end of the spectrum, A. DeRujula, this meeting.