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The Northern Site of the Pierre Auger Observatory

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Abstract: The Pierre Auger Observatory is a multi-national project for research on ultra-high energy cosmic rays. The Southern Auger Observatory in Mendoza province, Argentina, is approaching completion in 2007 with an instrumented area of 3,000 km^2. It will accurately measure the spectrum and composition of ultra-high energy cosmic rays up to and beyond the predicted GZK feature. We are obtaining results on the energy spectrum, mass composition and distribution of arrival directions on the southern sky. The Northern Auger Observatory is designed to complete and extend the investigations begun in the South. It will establish charged particle astronomy and thus open a new window into the universe. The distribution of arrival directions of the highest energy events will point the way to unveiling the almost century old mystery of the origin and nature of ultra-high energy cosmic rays. Achieving this goal requires collecting many more events in spite of the steeply falling energy spectrum. The planned northern site will have an instrumented area of 4,000 square miles (10,370 km^2) in Southeast Colorado, USA. The presentation covers the science of charged particle astronomy, the layout and the technical implementation of the Northern Auger Observatory.

Introduction

This paper describes the current design of the Northern Auger Observatory in the context of the science of ultra-high energy (UHE) cosmic rays. The design takes into consideration both the initial science results from the Southern Auger Observatory and our experience with the technologies and methods used.

The need for two observatories, one in each hemisphere, for complete sky coverage at the highest energies was clear from the inception of the Auger Project. The Southern observatory site will be completed in 2007[1].

The Southern Observatory with its 1.5 km triangular spacing and an area of 3,000 km^2 will be able to measure accurately the spectrum and composition from below 10^{18} eV to about 10^{20} eV[2, 3, 4, 5]. The statistics above 10^{19} eV are sufficient to identify the GZK feature[6, 7], but marginal for definitive studies of the source distribution by looking for strong anisotropies in the distribution of arrival directions[8, 9, 10]. However, the data indicate that the bending power of extragalactic magnetic fields is small enough to do charged particle astronomy above 10^{19} eV and to therefore be able to observe the sources of ultra-high energy cosmic rays, given sufficient aperture. This is the main goal of the planned Northern Auger Observatory.

Auger North will retain the basic functionality and features of Auger South. This is important for seamless data integration, e.g. for an anisotropy analysis on the whole sky.

The Northern hemisphere is chosen to be at roughly the same latitude and elevation as the Southern site. An important site feature is the usable area both for initial deployment and possible future expansion. The chosen site in Southeast Colorado has an initial area of 4,000 square miles (10,370 km^2), 3.3 times larger than Auger South.

Deployment of the *Surface Detectors* (SD) is greatly facilitated when they are placed at the

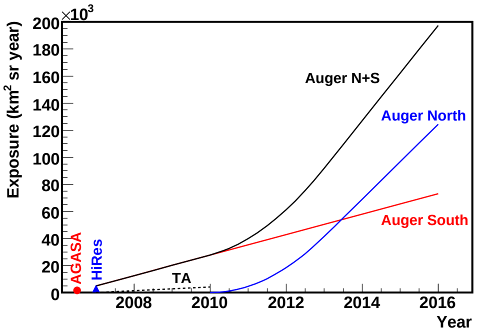

Figure 1: Exposures above 10^{19} eV of Auger North and Auger South as a function of time. Also indicated are the expected exposures of the Telescope Array[11] and the final exposures of the HiRes (monocular)[12] and AGASA experiments[13].

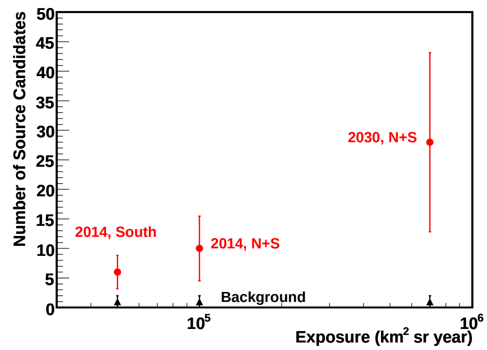

Figure 2: Average number of 5σ source candidates over the lifetime of the full Auger Observatory for events above 10^{20} eV. Black triangles show fake sources from statistical fluctuations, whereas red circular points show the expected number of source candidates.

corners of a *square-mile grid*, corresponding to the grid of roads that exists in Southeast Colorado.

Fluorescence Detectors (FD) will again be used for calibration of the SD, as well as hybrid analysis with accurate composition information and superior angular resolution on a subset of events.

Science

The spectrum and composition of UHECRs below 10^{19} eV is most likely the same in both hemispheres as extragalactic particles below this energy can reach Earth from the entire universe and galactic ones are isotropized by magnetic fields.

Spectral and composition differences may occur once isotropy is broken. As data accumulate above 10^{19} eV, departure from isotropy is expected both from the limited horizon in particle propagation and the weakening of the effects of cosmic magnetic fields. Fig. 1 shows the expected accumulated exposure above 10^{19} eV of Auger South, Auger North, and Auger South+North as a function of time, assuming the construction of Auger North begins in 2009 and is completed in 2012.

Fig. 2 shows the expected number of candidate "point" sources detected for Auger South alone by 2014, for both Auger North and South by 2014, and for Auger North and South combined by 2030. The number of source candidates was found by generating maps for each exposure for energies above 10^{20} eV and for source densities of 10^{-5} Mpc^{-3}, 10^{-4} Mpc^{-3}, and 10^{-3} Mpc^{-3}. The average intensity of each source is adjusted to match the observed spectrum of cosmic rays. Isotropic maps were used to estimate the number of fake sources. The large exposure and full sky coverage provided by Auger North will reward us with the detection of 15 to 40 sources by 2030.

In recent years, the great potential for discoveries in UHE neutrino detections has triggered several experiments, which cover energies from 10^{14} eV up to 10^{26} eV. Given the expected shape of the cosmogenic neutrino flux, which peaks around 10^{18} eV, the combination of both Auger sites provides the best chance to detect cosmogenic neutrinos[14].

Implementation

The layout of the planned Auger North Observatory is indicated in Fig. 3. Surface detectors are situated on a square-mile grid covering

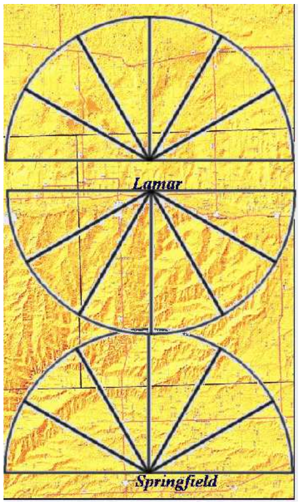

Figure 3: Topographic map of the Auger North site with the fields of view of the 3 fluorescence detector eyes indicated.

a 84x48 mile area in the Southeast corner of Colorado. Three FD eyes overlook the area to provide hybrid coverage.

The square-mile grid layout of the Surface Detector will slightly decrease the acceptance for small hadron showers yielding an increase of the threshold energy. The efficiency is $> 90\%$ for hadron showers with 5 triggered detectors for energies above 10^{19} eV, while in Auger South it is 3×10^{18} eV.

Surface Detectors

The surface detector electronics planned for Auger North is a natural evolution of that which is used in Auger South. The philosophy of real-time station control software, triggering based upon processing flash ADC traces, and GPS based time-stamping, which work so well in Auger South, will remain the same. However, parts obsolescence requires a redesign of the electronics.

One of the improvements to the electronics is increased dynamic range. Conversely, as a cost saving measure, the number of PMTs per tank is reduced from three to one. Studies in Auger South indicate that this does not significantly degrade either the triggering or the reconstruction of the highest energy events.

The integration of the electronics will be increased in order to reduce cabling and improve reliability. Increasing the FADC sampling rate from 40MHz to 100MHz compensates for the reduction in PMTs. The station controller operating system will be changed to a variant of real-time Linux.

Unlike the Auger South tanks, Auger North tanks will require thermal insulation. One technique being developed is rotationally molded polyethylene foam insulation on the interior of the tanks. This technique is commonly used to increase the stiffness of the walls of parts being roto-molded. The Auger North tank design has the main access port in the center for the single main PMT.

Fluorescence Detector

The Auger North FD will be split into 3 half eyes, in order to maximize the number of hybrid events. The design of the FD eyes is similar to that of the South. The HEAT enhancement telescopes[15] serve as a prototype for the North.

Communications Network

Design of the SD communications system for the North takes advantage of advances during the past decade in wireless network communications. The southern tanks each communicate independently with local collectors situated on towers at the FD buildings. Point-to-point microwave links to the campus complete the system. This scheme works well at the southern site, where the FDs and the towers are situated substantially higher than the remarkably flat intervening terrain. The topography of the Southeast Colorado makes this architecture less suitable for the North. Fig. 4 shows the results of a study, using digital elevation maps (DEM) of the site, to determine how many of the 4,000 stations would not have a clear line of site to a collector. Three different scenarios were considered: 1) each tank com-

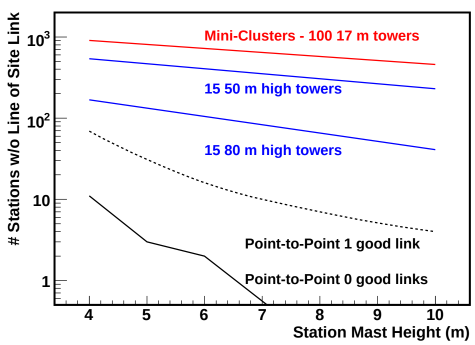

Figure 4: Number of stations (out of 4000) without a line of site communications link.

municates to a tower-mounted base station as in Auger South; 2) Mini-clusters, where each station communicates with a local tower, which are then networked together; 3) A peer-to-peer network where each station communicates with one or more of its nearest neighbors. The peer-to-peer network has many fewer problematic links, and we are thus pursuing that option for Auger North.

A network of fiber optic cables crossing the site will be used to make the trunk connections to the central campus facility (instead of the microwave links used in the South).

Data Acquisition

For Auger South, a comprehensive Central Data Acquisition System (CDAS) was developed. CDAS includes both the hardware and software required to collect incoming data packets from both FD and SD systems, form and relay triggers, and to save and organize experiment data online. Minimal changes will be required to adapt the existing Auger South CDAS system for Auger North.

Summary

By pioneering charged particle astronomy, Auger North will address some of the most compelling questions in science today:

- Where do the highest energy particles that reach the Earth originate?
- What process in nature can reach such extremely high energies?
- What clues to these particles and their interactions offer about the universe and its fundamental laws?

Answering these questions will transform our view of the most energetic sites in the present Universe.

Acknowledgments

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