Progress with the Northern Part of the Pierre Auger Observatory

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***Abstract*. It is planned to build the northern part of the Pierre Auger Observatory in southeast Colorado, USA. Results from the southern section of the Auger Observatory, which has recently been completed, imply a scientific imperative to create a much larger acceptance for the extremely rare cosmic rays of energy above a few times 10^{19} eV. The plan for Auger North is to cover an area greater than 20,000 km^2, seven times the area of Auger South in Argentina. The motivation for Auger North and the status of preparations will be presented including: R&D work at the Colorado site on a small surface detector array; atmospheric monitoring measurements; R&D on new electronics and communications equipment; and outreach and relations with the local community.**

***Keywords*: Ultra-high energy, Cosmic rays, Auger.**

I. Auger South Review

The southern Pierre Auger Observatory near Malargüe, Argentina was completed in June 2008 and has produced science results for events with primary cosmic ray energies in the EeV range and above. The published results are based on exposures taken while the observatory was growing, and the integrated exposures are about 9,000 $km^2\ sr\ yr$. One year of data taking with the full Auger South instrument (including arrival direction zenith angles from 0 to 60 degrees) represents approximately 7,000 $km^2\ sr\ yr$. These results include the energy spectrum, with observation of the 'ankle'and GZK-like features [1], and limits on the flux of primary photons [2] [3] and tau neutrinos [4]. The photon limits are already restricting some top-down models of cosmic ray production, and the neutrino limit is the best across the energy range expected for neutrinos produced in the GZK interaction. Studies of the arrival directions of the highest energy particles show that they correlate with the matter density within about 100 Mpc, and they may correlate with relatively nearby active galactic nuclei [5] [6]. The steep drop in flux, first published by HiRes [7], occurs at about 60 EeV and generally corresponds in the Auger data to the threshold energy for the correlation with directions to nearby extragalactic objects. So the most energetic cosmic rays, those with the trans-GZK energies, appear to be of extragalactic origin. In addition data from Auger South have been used to study the average position of maximum shower development in the atmosphere, X_{max}, and its correlation with primary cosmic ray type. For sources further than about 20 Mpc from Earth, light nuclei, such as carbon, nitrogen, and oxygen will break up due to interactions with photons more readily than iron, so the only nuclei expected to survive these distances in significant percentages are iron nuclei and protons. The Auger South result on X_{max} shows that X_{max} is tending to smaller values as energies approach the GZK feature, and this can be interpreted to indicate, within current models of hadronic interactions that are extrapolated from lower energies, that the primary composition is getting heavier [8] [9]. This measurement could signal new hadronic physics if the primary cosmic rays are protons.

The Auger South instrument is composed of an array of detectors to measure particles from extensive cosmic ray showers that reach the ground and optical detectors that overlook the surface detectors. The optical detectors, which function on dark and clear nights, measure the fluorescence of atmospheric nitrogen along the axis of the particle shower. The surface array of Auger South is comprised of over 1,600 water Cherenkov detectors placed on a triangular grid with 1.5 km spacing, covering 3,000 square kilometers [10]. On the periphery of the surface array are four buildings each housing six telescopes [11] that record the nitrogen fluorescence.

The results from Auger South present compelling evidence that the sources of cosmic rays above 60 EeV are extra-galactic and that the GZK effect reduces primary energies below this level for particles from sources more distant than the nearby universe. Thus it will be possible to study the nearby sources at highest energies without a diffuse background from the entire universe. Additionally, Auger South data allow one to measure particle interactions at energies not accessible to manmade accelerators, up to $\sim$500 TeV in the center of mass system, and there may be hints of new particle physics.

II. Auger North

The Auger South results imply an imperative to study the highest energy cosmic rays with the greatest statistical precision possible. The Auger South detector records approximately 20-25 trans-GZK events per year. The plan for Auger North is to build a ground array covering 20,500 km^2 with near complete fluorescence detector coverage. Auger North is proposed for southeast Colorado, USA - see Figure 1. The acceptance is seven times that of Auger South, so the full Auger Observatory, South plus North, will detect (assuming flux about the same in the north as in the south) approximately 180 of the most interesting events per year - hopefully enough

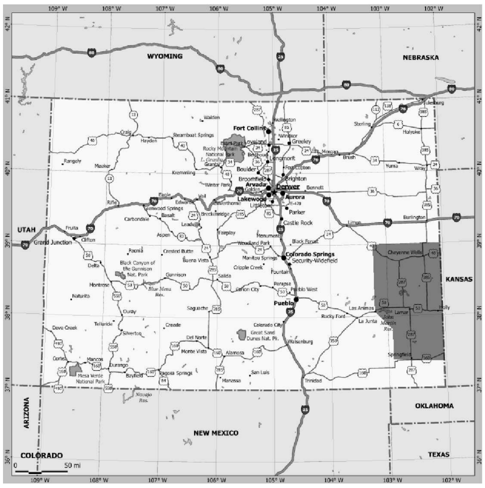


Fig. 1: Site of the northern part of the Pierre Auger Observatory. The shaded area in the southeast corner of this Colorado map shows the 8,000 square miles (20,500 square kilometers) planned for Auger North. The site could extend eastward into Kansas.

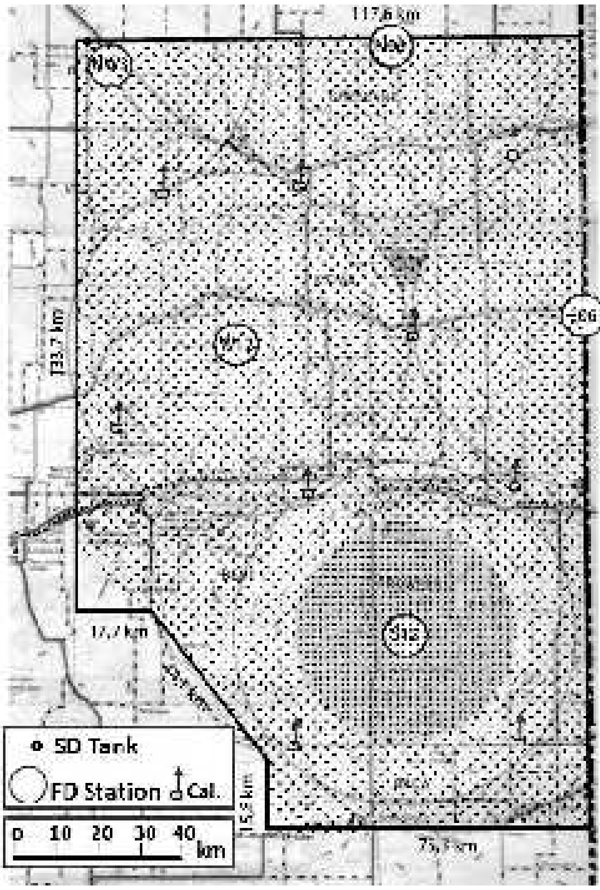


Fig. 2: Layout of the northern Auger detector. Each dot represents a Cherenkov detector. The fluorescence detector positions are given by circles, and the permanent calibration lasers are shown as small arrows. The 2000 km^2 infill is shaded (lower right) and has higher density of surface detectors .

to study the energy spectra from individual sources in 10-20 years of observation.

The design of Auger North focuses on the highest energies while profiting from the successful experience with the southern Auger instrument. Water Cherenkov detectors and fluorescence detectors similar to those in the south are planned. There will be a few changes. The most important is that the Auger North surface detector spacing will be $\sqrt{2}$ miles (2.28 km) on a square grid. This spacing takes advantage of the land ownership pattern and partial road grid in the western United States, which is based on 1-mile (1.6 km) squares. For most of the array only every second corner of the square mile grid will have a surface detector unit. We plan 4,000 detectors covering 8,000 square miles for the majority of the array. On 800 square miles (2000 km^2) we will place a detector on every grid corner. Four-hundred additional surface detectors are needed for this in-fill, which will provide a connection to the high statistics at Auger South. The energy at which Auger South approaches 100% trigger efficiency is 3 EeV. Studies using Auger South data indicate that the trigger efficiency on the $\sqrt{2}$-mile pattern will be 90% at 30 EeV and that the 800 square-mile infill will be 90% efficient at 4 EeV. We plan to build five fluorescence detector buildings with a total of 39 telescopes at Auger North. Figure 2 shows the layout of Auger North. The telescopes will be farther apart than in the south to minimize costs, but above 30 EeV Auger North will still have near full hybrid coverage.

Other important changes include the use of only one large PMT in each surface detector instead of the three at Auger South (cost savings), and the need to insulate the Cherenkov tanks (colder winters in Colorado than in Malargüe). The topography in Colorado is not as flat as at the Auger South site, and there are no hills surrounding Auger North as there are in the south. These factors make it impossible to use the communications paradigm at Auger South in which data are transmitted from individual detectors to the fluorescence buildings on the perimeter of the surface array. At Auger North the data will flow from tank to tank until reaching a collection point. At Auger South the absolute calibration of the fluorescence detector is based on periodically placing a calibrated light source at the aperture of each telescope [12] to illuminate all 440 PMTs in the detector. This calibration is checked from time to time using a mobile laser positioned a few km from the telescope [13]. The laser is fired vertically, and the calculable flux of scattered photons is used to check the calibration of a line of PMT pixels in the telescope. The method is cumbersome since it requires moving the laser in the field to illuminate different telescopes or pixels. At Auger North we plan an array of permanent lasers to complement the method using a light source at the telescope aperture.

The fluorescence detectors for Auger North will be very similar to those in Malargüe. The basic design is

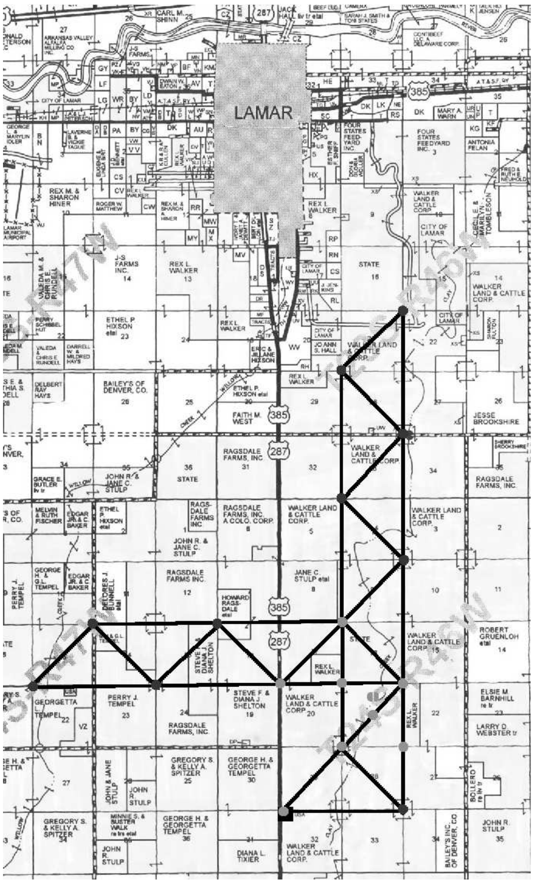


Fig. 3: Tentative layout for the Auger North R&D array. Light circles represent possible sites for fully functioning tank detectors; darker circles indicate sites for communications-only equipment. The two arms are the minimum needed to test the tank-to-tank communications system.

unchanged, but the electronics and slow control will be updated. The main testbed for the Auger North fluorescence detector is the three HEAT telescopes [14] being built at Auger South.

III. R&D FOR AUGER NORTH

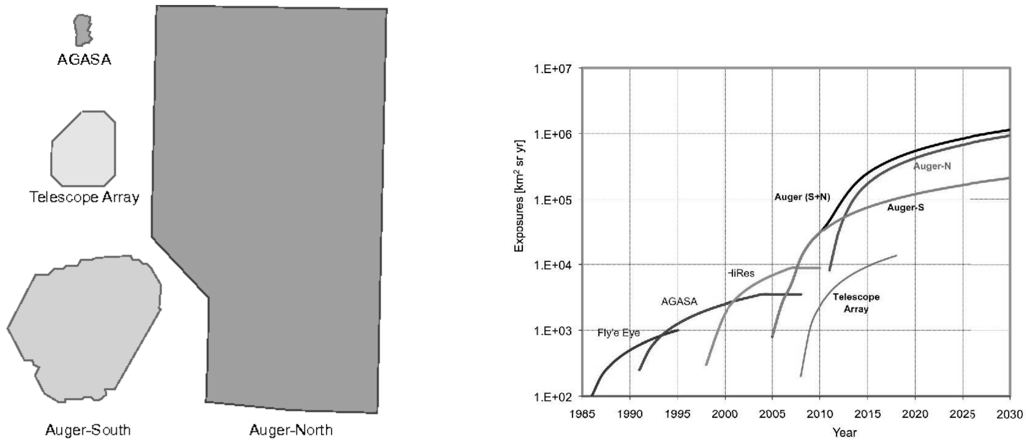
The main changes for Auger North require R&D to confirm the new designs and and in some cases to solve technical challenges. To this end the collaboration is building a small R&D array south of Lamar, Colorado, the main city in the site region. Lamar Community College (LCC), located a few miles north of the R&D array, is the host institution for education and outreach for Auger north. LCC is operating an interim visitors' center at the college, and puts on lectures for local residents at schools. Plans call for the main Auger North campus to be built at LCC.

Figure 3 shows the layout of the R&D array. We plan to deploy 6 to 10 fully functioning Auger North tanks and 10 to 14 stations that have only communications equipment. We plan to start the deployment in 2009. The layout of the R&D array is driven by the new communications system, which uses the long and short arms to funnel the data to the central data acquisition center. In summer 2008 Auger collaborators made a survey of the signal transmission from all points on the R&D array to the neighboring stations.

The Auger South tanks are made of roto-molded polyethylene without insulation. One approach to insulate the Auger North tanks is to use a chemically foaming resin inside the tank as a manufacturing step. The technique is promising, and a few insulated tanks have been produced, but it is not yet at a production stage. We have made studies over the past few winters with non-insulated and hand-insulated Auger tanks in Colorado and Argentina with temperature probes in and around the tanks. We have measured significant heat flow from the ground into the tank in the winter, which indicates that the bottom of the tank should not be insulated. Our thermal models generally predict the water temperature as a function of ambient temperature and incident sunlight as the tanks approach freezing and ice starts to form. Work continues with the newly manufactured tanks insulated using the foaming resin. The goal is to optimize the thickness of the insulation (for cost) in the face of a simulated historical period of extreme cold.

Atmospheric studies at the Colorado site are moving forward with a system based on successful work at Auger South. We plan to install a vertically firing laser that will be viewed by two detection systems: a Raman LIDAR receiver installed at the laser site and directed along the laser beam to record the backscattered signal; and a system with a mirror and PMT camera similar to those used at HiRes (but with only a narrow stripe of PMT's installed) which we call the AMT (Atmospheric Monitoring Telescope). The AMT will be placed 30-40 km from the vertical laser beam, and so it is very similar to the CLF[15]/XLF technique used at Auger South to measure the vertical aerosol optical depth up to approximately 6 km. The two systems will make independent measurements of the aerosols while providing a test bed for Auger North atmospheric monitoring. In addition, we plan to place a nitrogen laser approximately 4 km from the AMT to test the concept of the permanent absolute calibration laser. The AMT will use the electronics developed for the HEAT telescopes.

Other R&D includes work on surface detector electronics to extend the dynamic range of the Cherenkov detectors, and studies with new GPS receivers. We will also exercise deployment techniques and in general learn about working in Colorado to build Auger North. This R&D array is similar to the Engineering Array [16] of Auger South in that the goals are to fully reconstruct extensive air showers at each site - separately with the surface detector in Colorado and the HEAT fluorescence detectors in Argentina. The aim is to bring as many components as possible to the pre-production stage and to validate cost estimates for Auger North.



(a) Array areas to scale. (b) Exposures

Fig. 4: Array areas and recorded or planned exposures for ground arrays of UHECR detectors: AGASA; Telescope Array; the southern part of the Auger Observatory; and the northern part of the Auger Observatory. The exposure plot is on a log scale.

IV. Outlook

The goals of the Auger Observatory have been, since the inception of the project, to *"discover and understand the source or sources of cosmic rays with energies exceeding* 10^{19} *eV.*". Results from the southern section of the Observatory in Argentina have shown that the highest energy particles are likely of extra-galactic origin and that the flux of these particles drops significantly at the energy where a correlation with matter in the nearby universe sets it. The highest energy cosmic rays do not arrive isotropically at 99% confidence level. The data from Auger South indicate that the primaries are not photons and that they are tending toward heavier nuclei as the energy approaches the energy of the flux drop and the correlation with extra-galactic matter. The correlation and the tendency toward shallow X_{max} pose a challenge to our understanding from the astrophysical point of view. The solution lies in gaining more data at energies at and above the energy of the flux drop and correlation, which is about 60 EeV. The Auger South detector is large enough to detect about 20-25 of these events a year. Figure 4a shows scale outlines of four cosmic ray detector arrays, and 4b plots corresponding exposures (assuming a certain start date for Auger North). The left half of Figure 4a shows AGASA, which is no longer taking data, the Telescope Array near Delta, Utah, USA, and Auger South at Malargüe, Argentina. The proposed northern part of the Auger Observatory is also shown; it is about seven times the area of Auger South. Assuming the flux of trans-GZK events in the northern hemisphere is about the same as that measured in the south, Auger North and Auger South together will measure approximately 180 trans-GZK events per year.

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