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PIERRE AUGER OBSERVATORY

Fermilab
21 October 2009

Dr. Pier Oddone
Director – Fermi National Accelerator Laboratory

Dear Pier:

Please find attached the proposal for the Auger Observatory North which is being prepared for submission to the DOE as a Fermilab FWP. A similar proposal has gone to NSF via Fastlane under the sponsorship of the URA. If the proposal is approved we anticipate that DOE and NSF will wish to share the cost equally as they did for Auger South.

The US based Auger Observatory North with broad international participation will be important both to Fermilab and the US scientific enterprise. We hope that Fermilab is willing to be a participant in Auger North and will continue as host of the Pierre Auger Project management. The same exceptional resources that Fermilab brought to Auger South will also be crucial to Auger North. Our skills in project management, computing, engineering and analysis will help ensure the same success.

Best Regards,

Paul Mantsch
Project Manager – The Pierre Auger Project

Project Summary

Auger North: The Pierre Auger Observatory in the Northern Hemisphere

Results from Auger South have settled some fundamental issues about ultra-high energy (UHE) cosmic rays and made clear what is needed now to identify the sources of these particles, to uncover the acceleration process, to establish the particle types, and to test hadronic interaction properties at extreme energies. The cosmic rays above 55 EeV are key. Auger North targets this high energy frontier by increasing the collecting power of the Auger Observatory by a factor of eight for those high energy air showers.

Particles above about 40 EeV have been shown to be subject to propagation energy loss, as predicted by Greisen, Zatsepin and Kuzmin (GZK) in 1966. Moreover, it is now evident that there is a detectable flux of particles from extragalactic sources within the GZK sphere. The inhomogeneous distribution of matter in the local universe imprints its anisotropy on the arrival directions of cosmic rays above 55 EeV. The challenge is to collect enough of those arrival directions to identify the class of astrophysical accelerators and measure directly the brightest sources. Auger North will increase the event rate from 25 per year to 200 per year and give the Auger Observatory full sky exposure.

The Auger Observatory also has the capability to detect UHE photons and neutrinos from discrete sources or from the decays of GZK pions. With the expanded aperture of Auger North, the detection of GZK photons and neutrinos will provide a complementary perspective of the highest energy phenomena in the contemporary universe.

Besides being an observatory for UHE cosmic rays, photons, and neutrinos, the Auger Observatory will serve as a laboratory for the study of hadronic interactions with good statistics over a wide range of center-of-mass energies above what can be reached at the LHC. Auger North will provide statistical power at center-of-mass energies above 250 TeV where the alternative extrapolations of hadronic cross sections diverge.

Auger North is ready to go. The detection techniques have been proven at Auger South. A small R&D array is being constructed at the Colorado site to test minor modifications of the detector units and the revised communications system. The ASPERA roadmap in Europe has endorsed Auger North and recommended funding during the next five years, after which the available resources will be needed for CTA, KM3NeT, and Megaton. Now is the time to step up to a new level of astroparticle science with a systematic approach to the study of trans-GZK cosmic rays.

Broader Impact.
Auger North is an opportunity to bring a major international scientific project to the heartland of the United States funded in large part by international partners. It will provide easy access for graduate and undergraduate students in the US to all aspects of research in ultra-high energy astroparticle physics. This is an excellent opportunity to share the excitement of high energy physics and astrophysics and to promote the importance of basic research with the public at large. The Auger Observatory in Argentina has had a significant impact through its visitor center, public lectures, science fairs, and other outreach efforts. Auger North will build on that experience while adapting and enriching the international outreach program, especially in the communities near the site. These communities will also reap the economic benefits associated with the construction and operation of the facility.

PROJECT DESCRIPTION

1 Introduction

The major goals of the Pierre Auger Observatory are to discover and understand the source or sources of cosmic rays with energies exceeding 10^{19} eV, to identify the particle type(s), and to investigate the interactions of those cosmic particles both in space and in the Earth's atmosphere. The Pierre Auger Observatory in Argentina (referred to as "Auger South") was completed in June 2008 with 1660 surface detector stations[1] and 24 fluorescence telescopes and has a collecting area of 3,000 km^2, yielding an aperture of 7,000 $km^2 \cdot sr$.

A major science result from Auger South has been the discovery that the arrival directions of the highest energy cosmic rays (above 55 EeV) are not isotropic. The inhomogeneous distribution of matter in the local universe appears to be imprinted in the anisotropy of their arrival directions [3]. (See right panel of Fig. 1.)

These particles are above the energy threshold where interactions with photons of the cosmic microwave background (CMB) are expected to limit the range of cosmic rays. Energy loss by pion photoproduction was predicted by Greisen [4] and by Zatsepin and Kuzmin [5] shortly after the discovery of the CMB in 1965 [6]. Photodisintegration of nuclei can produce a similar effect on the cosmic ray energy spectrum [7]. For brevity in our discussion we combine pion photoproduction by nucleons and photodisintegration of nuclei under the rubric "GZK effect" and use "trans-GZK" for events above 55 EeV.

The steepening of the energy spectrum near 40 EeV, measured with the High Resolution Fly's Eye (HiRes) [8, 9] as well as the Auger Observatory [10] (left panel of Fig. 1), is consistent with the expected energy loss due to the CMB. However, it could be attributed to a feature of the average particle injection spectrum instead of energy losses during propagation. The correlation of arrival directions with the large-scale matter distribution inside the GZK sphere of 75 Mpc confirms that cosmic rays from the nearly isotropic visible universe beyond the GZK sphere are indeed strongly suppressed.

More important than establishing GZK energy losses, the anisotropy imprinted by the local universe almost certainly means that there are detectable cosmic ray sources within the GZK sphere, and that magnetic fields do not thoroughly scramble the directions of particles arriving from those nearby extragalactic sources. Neither of these facts was known previously. The detection of anisotropy by Auger South transforms the field, opening the possibility of directly identifying the sources of ultra-high energy cosmic rays.

Initial results from Auger South also strongly motivate measurements of primary masses and hadronic interactions at trans-GZK energies. Fluorescence measurements of the depth of shower maximum (X_{max}) with energy up to 35 EeV show striking trends. That is the limit that can be reached with the aperture of Auger South. These results, when analyzed using current hadronic interaction models, suggest an increasingly heavy (iron-rich) composition, but this interpretation is astrophysically difficult to explain, especially in view of the anisotropy that becomes apparent at somewhat higher energy. To solve this puzzle, it is crucial to examine the X_{max} distribution also in the trans-GZK regime where light and intermediate-mass nuclei photodisintegrate rapidly, leaving just pure protons or heavy nuclei (or conceivably a mixture of those two types) [11]. Measurements in this energy range have crucial implications for both astrophysics and for models of hadronic interactions at center-of-mass energy 25 times higher than can be reached at the LHC.

[1] There is an infill [1] enhancement underway which will relocate 46 of the 1660 stations on a smaller grid. Coupled with an associated extension of the fluorescence telescopes [2], this will provide hybrid measurements down to 10^{17}eV.

	Auger South	Auger North
Location	35° S, 69° W	38° N, 102° W
Altitude	1,300 - 1,500 m a.s.l.	1,300 - 1,500 m a.s.l.
Area	3,000 km^2	20,000 km^2
Number of SD stations	1,660	4,400
(infill)	(46)	(400)
SD spacing	1.5 km	2.3 km ($\sqrt{2}$ mi)
(infill)	750 m, 433 m	1.6 km (1 mi)
PMT sensors / SD station	3	1
Communications network	SD-radio tower	peer-to-peer
SD array 50% efficient at	0.7/1 EeV	8/10 EeV
SD array 100% efficient at	3 EeV	80 EeV
(infill)	(0.1 EeV)	(4 EeV)
FD stations	4	5
FD telescopes	24 (4×6)	39 ($2 \times 12 + 2 \times 6 + 1 \times 3$)
Begin construction	1999	2011
End construction	2008	2016

Table 1: Comparison of the Pierre Auger Observatory sites. The energy ranges for the efficiency refer to iron/proton primaries respectively.

The Auger Observatory has the capability to detect and identify both neutrinos and photons at EeV energies and above ("ultra-high energy" or UHE). Direct observation of UHE neutrinos or photons would confirm GZK pion photoproduction. If the injected cosmic rays are nuclei rather than protons, the GZK energy losses should be attributed to nuclear photodisintegration rather than pion photoproduction. There might then be no GZK photons and only lower energy neutrinos from neutron decays. Measurements of the UHE neutrino and photon fluxes are important cross checks on conclusions about the spectrum and composition of trans-GZK cosmic ray production.

The flux of UHE neutrinos depends not only on the spectrum of injected trans-GZK cosmic protons but also on the cosmic evolution of the sources. Identifying the astrophysical class of cosmic ray sources by anisotropy at trans-GZK energies is therefore essential for an accurate evaluation of the UHE neutrino flux. Trans-GZK measurements of cosmic ray anisotropy by Auger North have the potential to determine the class of sources as well as the particle type(s). Together with the measured energy spectrum, this will determine the UHE neutrino flux. Neutrino detection rates can then be used to constrain models that predict modified neutrino interactions.

The Pierre Auger Observatory in Colorado, USA (referred to as "Auger North"), will target the high energy frontier with an additional aperture that is seven times larger than Auger South. The combined full-sky Auger Observatory will be well poised to determine the origin and nature of ultra-high energy cosmic rays. Auger North will directly address the pressing questions regarding the arrival directions and composition of the highest energy cosmic rays. These trans-GZK cosmic ray messengers, mostly charged particles, provide direct evidence of UHE acceleration mechanisms which complements information that can be derived from lower energy messengers such as photons, neutrinos, and gravitational waves.

While the anticipated scientific harvest from Auger North is abundant, the potential is also strong for unanticipated discoveries. The dramatic increase in collecting area and energy reach for Auger North opens new astrophysical windows based on trans-GZK cosmic rays, UHE photons, and UHE neutrinos.

The design for Auger North builds upon the same detector concepts and technology that have succeeded at the southern site in Argentina. To achieve a significant improvement in measurement sensitivity at trans-GZK energies, the surface detector (SD) will have an area of 20,000 square kilometers, nearly seven times the collecting area of Auger South. This will be accomplished by both increasing the number of water Cherenkov stations and by reducing the station density. Auger North will have 4,000 stations on a regular square $\sqrt{2}$-mile-spacing grid. Another 400 will fill in a dense sub-array of area 2,000 km^2 with one mile separation between nearest neighbors. The in-fill array will have an energy threshold close to the threshold of Auger South, yielding full understanding of threshold effects at Auger North, allowing seamless integration of data from both hemispheres, and providing a rich full-sky data set in the energy region of the spectrum's ankle.

Auger North will also have 39 air fluorescence telescopes, housed at five different stations, providing a hybrid aperture nearly equal to that of the 20,000 km^2 surface array. The fluorescence detector (FD) will make critical measurements of the atmospheric depth of maximum shower size for the study of the primary composition and hadronic interactions. Hybrid shower measurements by the SD and FD together provide a calorimetric energy calibration for the surface detector and also a direct measurement of its angular resolution and its accuracy in determining shower core positions.

Auger North will use the successful modular design of Auger South. Technical modifications for Auger North with respect to Auger South include a reduction in the number of PMTs per tank from 3 to 1, tank insulation to avoid water freezing, enhanced electronics, and a new communication system based on peer-to-peer data transfer. These parameters are summarized in Table 1.

The Pierre Auger Observatory represents a strong international collaboration of scientists and engineers from 18 countries who are eager to begin the construction of Auger North. The cost of Auger North has been evaluated by the same work breakdown structure (WBS) bottom-up procedure that has been used successfully for Auger South. The present cost estimate is \$127M[2] including contingencies. Full construction will take five years to complete, but data will accumulate during construction. With construction starting in 2011, the Auger Observatory will have a total exposure exceeding 100,000 $km^2 sr \cdot yr$ by 2016, increasing by 54,000 $km^2 sr \cdot yr$ each year thereafter. For comparison, the AGASA total exposure after 10 years of operation was 1630 $km^2 sr \cdot yr$. Large exposure is key to understanding the highest energy particles of the universe.

2 Science expectations

Results from Auger South make it clear that understanding the ultra-high energy cosmic rays requires a systematic study of the special energy regime above 55 EeV. The sources of those highest-energy cosmic rays are now known to be extra-galactic and relatively nearby. The sources themselves, however, have not been identified. The challenge is to collect enough arrival directions to identify the astrophysical class of sources and to study the brightest ones individually. Auger South collects only about 25 of the crucial trans-GZK events per year, with fewer than two per year (on average) that also have their longitudinal profiles measured by the air fluorescence detector. This low rate is not sufficient to achieve the objectives of identifying the sources and determining the primary particle type(s). Auger North in Colorado will have seven times the area of Auger South, thereby increasing the combined aperture by a factor of eight. It will enable source detections in all parts of the sky. Together, Auger North and Auger South will measure approximately 2000 trans-GZK particles in 10 years of operation.

[2]The WBS incorporates a 2010 start of construction. Escalation increases the estimated cost for a 2011 start by \$2.1M.

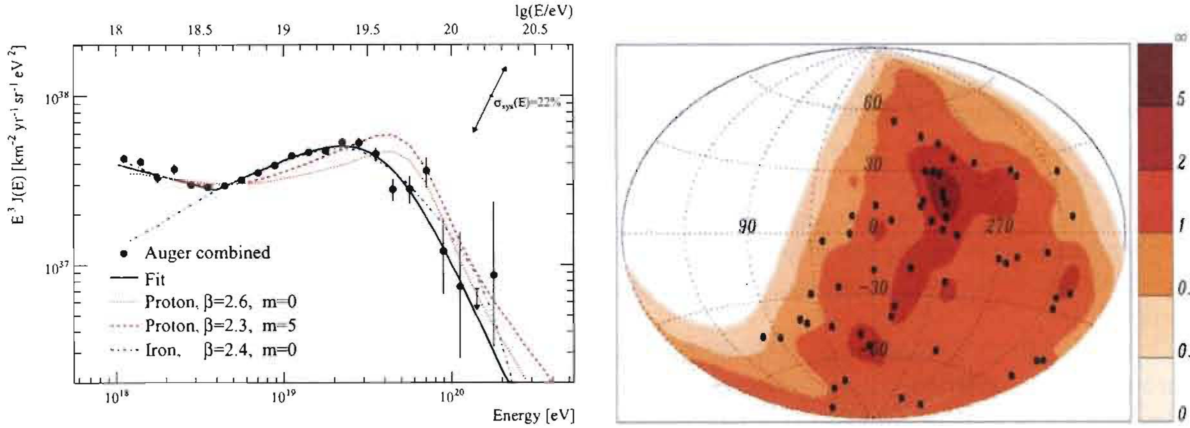

Figure 1: *Left:* The Auger combined energy spectrum compared with several astrophysical models assuming a pure composition of protons (red lines) or iron (blue line), a power-law injection spectrum following $E^{-\beta}$ and a maximum energy of $E_{max} = 10^{20.5}$ eV. The cosmological evolution of the source luminosity is given by $(z+1)^m$. The black line shows the fit used to determine the spectral features. *Right:* Cosmic ray density map predicted from the flux-weighted distribution of X-ray AGNs detected by SWIFT, smoothed with an angular scale of 7°. (An isotropic fraction of 35% was built into the maps to account for catalog incompleteness.) The dots represent the arrival directions of the 58 trans-GZK cosmic rays detected with Auger South up to March 31, 2009.

The trans-GZK particles above 55 EeV are also key to understanding nuclear mass composition. At these energies only protons and heavy nuclei (like iron) are expected to propagate intact from their sources to the Earth, since light and intermediate nuclei photodisintegrate too rapidly [11]. (See left panel of Fig. 2.) The question of composition therefore simplifies to a measurement of protons vs. heavy nuclei, two alternatives with rigidities that differ by a factor greater than 20 for the same energy, allowing us to confirm the dominant component through anisotropy studies without reliance on a model of hadronic interactions.

The Auger Observatory – South and North together – will serve as a laboratory for the study of hadronic interactions with good statistics over a wide range of center-of-mass energies above what can be reached at the LHC. Auger South alone will not have adequate statistics above 35 EeV or center-of-mass (CM) energy 250 TeV, but Auger North can extend the reach to the interval 250 TeV to 450 TeV where alternative extrapolations of the hadronic cross section become very different from each other [12].[3]

Trans-GZK protons are expected to generate a diffuse flux of UHE neutrinos and photons which result from the decays of pions produced by the GZK photoproduction interactions of protons with the CMB. To predict these diffuse fluxes reliably, it is essential to know the fraction of trans-GZK cosmic rays that are protons. Preliminary analyses of data from Auger South at energies just below the GZK suppression indicate that the air showers develop as would be expected for primaries that are heavy nuclei. Heavy primaries above the GZK energy threshold would dramatically reduce the expected GZK neutrino and photon fluxes. (See left panel of Fig. 3.) Moreover, identifying the sources of the primary UHE cosmic rays will provide the information about

[3]These CM energies are based on the assumption that the primary particles are a "beam" of protons. If anisotropy studies and shower developments prove that they are heavy nuclei instead, then Auger North will probe properties of nucleus-nucleus collisions at CM energies in the range 33 TeV to 60 TeV per nucleon.

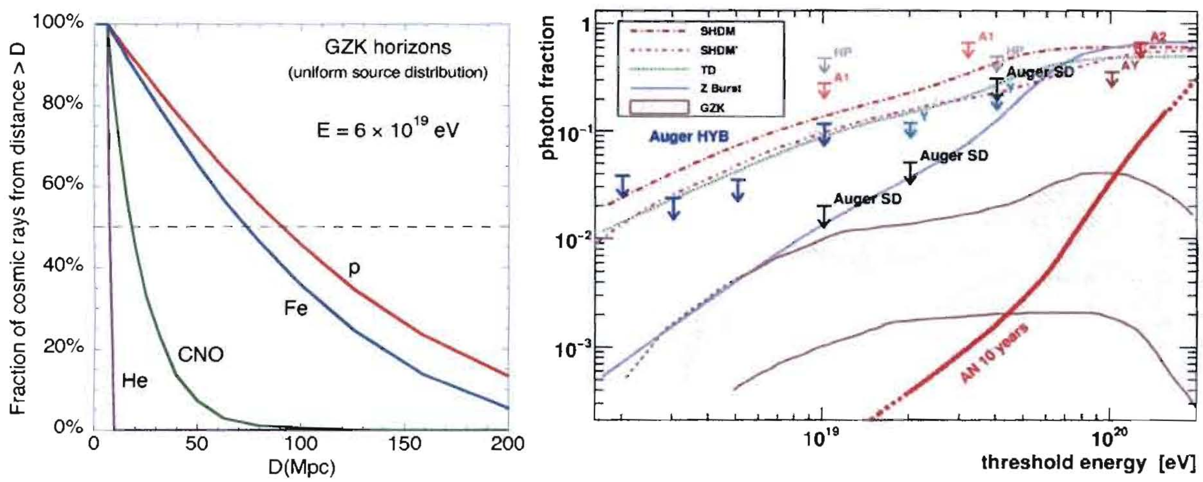

Figure 2: *Left:* Horizons for different nuclei above 55 EeV. For protons, it is governed by pion photoproduction. For nuclei, the horizon is caused by photodisintegration. *Right:* Limits on the diffuse UHE photon flux from air shower measurements. Also shown is the expected sensitivity of Auger North plotted as a 95% C.L. limit curve if there is no measurable flux. The shaded region indicates predictions of GZK generated photon flux with various proton injection spectra.

source evolution that is critical in calculating the diffuse flux of neutrinos.[4]

Studying the diffuse flux of GZK neutrinos is one of the goals of neutrino detectors such as IceCube, ANITA, and KM3NeT, and Auger is also a neutrino observatory. The absence of any EeV neutrino detection so far from Auger South has produced the strongest upper limit on the diffuse flux of GZK τ neutrinos in the crucial EeV energy range. (See right panel of Fig. 3.) Auger South and ANITA flux limits are already starting to constrain scenarios with the strongest GZK neutrino production. The combined results from all of the UHE neutrino observatories will be a valuable probe of neutrino interaction properties in the future. Those results are especially valuable if the diffuse flux of GZK neutrinos is known accurately from Auger determinations of the production rate and its cosmological history. Having a known diffuse flux, a detection rate will determine the neutrino interaction cross section.

UHE photons produce showers that develop to maximum size much deeper in the atmosphere than those produced by hadrons. The Auger Observatory can distinguish UHE photons from hadrons shower-by-shower with its fluorescence detector [13, 14], and the full-time surface array can recognize even a small percentage of photon showers if they are present [15]. The greatly enlarged aperture obtained with Auger North will enable a measurement of the diffuse GZK photon flux as well as a sensitive search for photons produced at cosmic ray sources. (See right panel of Fig. 2.)

Magnetic fields deflect the charged cosmic rays, and the strength and direction of cosmic magnetic fields have been poorly determined. The rich data set of Auger North will make it possible to measure the integrated transverse magnetic field strength along the paths from future identified sources by measuring the deflection of particles as a function of energy. Deflections of multiple particles from a single source will measure the amount of fluctuation that results from integrating the transverse field along those neighboring trajectories, providing information about the irregu-

[4] For example, the aggregate luminosity of gamma-ray bursts (GRBs) has a different dependence on redshift z than does that of active galactic nuclei (AGNs), yielding a factor of 10 difference in the expected GZK neutrino flux.

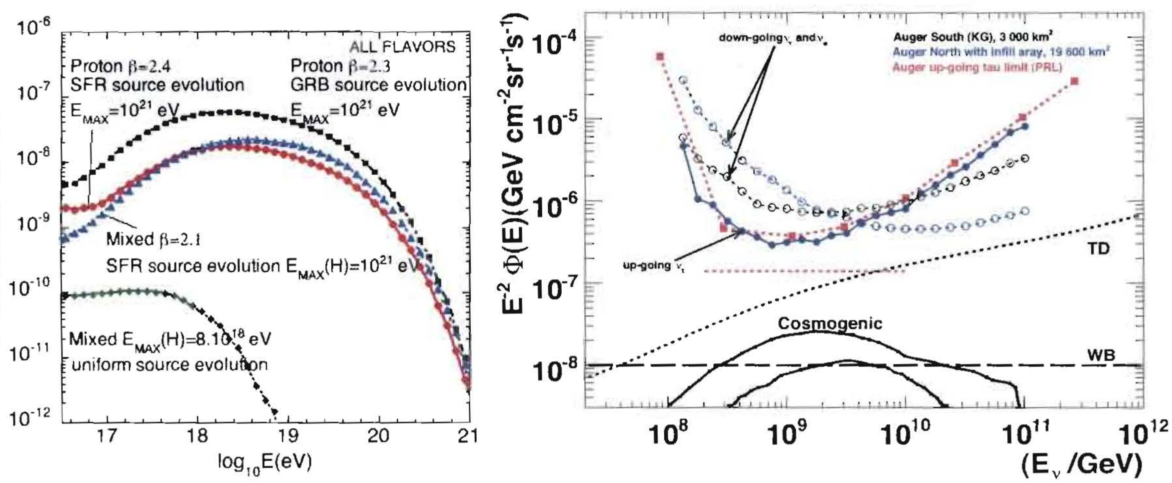

Figure 3: *Left:* The diffuse flux of GZK neutrinos depends strongly on the type of particles that constitute the trans-GZK cosmic rays and the cosmological evolution of the sources. *Right:* Flux upper limits derived from air shower measurements.

larity in the field as well its coherent part. Auger magnetic field measurements are powerful in that they do not rely on an estimate of electron densities (as do inferences from Faraday rotation measures) or polarizable dust grains or energetic electrons producing synchrotron radiation.

2.1 Identifying the sources of cosmic rays within the GZK sphere

The universal CMB photons cause severe energy losses for high energy particles. Protons suffer pion photoproduction, nuclei photodisintegrate, and photons convert to $e^{\pm}$ pairs as a result of collisions with CMB photons. The Auger South cosmic ray spectrum exhibits the expected suppression feature starting near 40 EeV [16]. (See left panel of Fig. 1.) The observed anisotropy confirms that this suppression is indeed due to attenuation and not simply a steepening of the average source spectrum.[5]

In 2007, the Auger Observatory reported that arrival directions from the highest energy cosmic rays are statistically correlated with AGNs listed in the *Véron-Cetty and Véron* (VCV) catalog with distances less than 75 Mpc [17]. This distance corresponds to an estimate of the radius for the GZK sphere, i.e., the volume that contains the sources of most of the cosmic rays observed at Earth with energies above 55 EeV. Prior to the Auger anisotropy results, there was no evidence for the existence of any detectable sources within the GZK sphere, a region which does not contain any quasars or blazars, for example. Anisotropies observed by Auger South show, however, that there are sources to be detected within the GZK sphere, and that neither intergalactic magnetic fields nor fields in our Galaxy destroy the correlation between the arrival directions and the extragalactic source distribution.

In the Auger papers reporting the trans-GZK anisotropy, we emphasized that the correlation with AGNs in the VCV catalog does not necessarily imply that those AGNs are the sources. AGNs trace the overall matter distribution within the GZK sphere, as do other classes of astrophysical objects. The Swift-BAT catalog of X-ray AGNs was not available in 2006 when the VCV catalog

[5]If it were not for the elimination of cosmic rays from distant sources, their isotropy would dilute and mask any pattern imprinted by local sources.

was adopted for a prescribed single-trial test of anisotropy. A catalog of X-ray AGNs is a more natural choice than the VCV catalog for testing a correlation with trans-GZK cosmic rays because potential sources are not obscured in X-rays by dust in the Galactic equatorial region. The flux-limited Swift-BAT catalog is celestially complete, and a new version based on 39 months of satellite observations allows a study out to 250 Mpc. A clear correlation exists between the Auger arrival directions and the X-ray AGNs [18, 19]. Its strength is matched in isotropic simulation data sets with probability only 2×10^{-8}. The optimum values for minimum cosmic ray energy, correlation angle, and maximum AGN redshift have somewhat different values than for the VCV prescribed test. Even if these three parameters are allowed to be optimized for each isotropic simulation, however, the correlation with the X-ray AGNs exceeds what is found in the Auger data in only 10^{-4} of the simulated data sets.

This correlation does not identify the Swift-BAT X-ray AGNs as the sources of the cosmic rays. Auger cosmic rays also correlate well with flux-weighted sources in the Parkes HIPASS catalog [20], and with the 2MASS catalog of galaxies out to 75 Mpc. These correlations confirm the association of cosmic rays with large scale matter distributions within the GZK sphere, but they do not allow us to preferentially select one source class over another. A much greater exposure, including the northern hemisphere, is therefore needed to identify which types of sources are producing the UHE cosmic rays.

We note that the HiRes Collaboration did not find a correlation of their stereo arrival directions with positions of AGNs in the VCV catalog [21]. The HiRes study used 13 cosmic rays above an energy threshold said to correspond to the same energy cut used for the correlation analysis of the 27 highest-energy Auger events (through August 31, 2007). There are a variety of reasons why the correlation might not be apparent in the 13 highest energy HiRes stereo events, and these underscore the need to observe the southern and northern skies using the same detector types and analysis.

An exciting prospect for understanding the nature of cosmic rays with Auger North is the promise of detecting source luminosity distributions. Simulations using a full range of plausible density assumptions and hypotheses for the absolute luminosity function show that the brightest source as seen at Earth is likely to be responsible for at least 10% of the total trans-GZK cosmic rays [22]. With a data set of 2000 events (accumulated in 10 years with Auger North but 80 years otherwise), there should be multiple bright sources with more than 100 events from each. This is enough to measure spectra of individual sources. Auger South and Auger North together will identify the sources within the GZK sphere and measure specific properties of the brightest ones.

Identifying individual astrophysical objects as bright sources of cosmic rays holds great promise for understanding the nature of the acceleration mechanisms. The confinement of such high energy particles to an acceleration region requires a large product of the magnetic field strength and the size of the the region. Fast relative motion of magnetic media is required in most models of acceleration. Energy loss due to synchrotron radiation, pion photoproduction (or nuclear photodisintegration), and nuclear collisions must be slow compared to the rate of energy gain. These constraints are severe, and the acceleration of UHE cosmic rays remains a long-standing puzzle. Auger North offers the chance to directly identify these extraordinary accelerators.

The threshold energy for anisotropy has been found with Auger South to be 55 EeV. There is systematic uncertainty in the energy scale due to uncertainty in the absolute proportionality between air fluorescence and electromagnetic energy deposition as well as uncertainty in the absolute calibration of the fluorescence detector telescopes. The total estimated systematic uncertainty in the energy scale is 22%. There is evidence, discussed below, that the assigned energies may be as much as 20% low. In that case it should be said that the anisotropy of the GZK sphere is evident above 70 EeV rather than 55 EeV. For now, however, the Auger energy scale is fixed by the calorimetric energy measurements of the fluorescence detector which rely on the (uncertain) laboratory measurements of the air fluorescence yield.

2.2 Hadronic interactions

Measurements of air showers by the Auger Observatory provide a study of hadronic interactions at center-of-mass energies well beyond the reach of collider experiments. The development of an air shower is sensitive to cross section, inelasticity, and multiplicity of the first interactions as well as the atomic mass of the primary cosmic ray. The qualitative dependencies can be derived analytically, but quantitative results rely on comparing measured quantities against expectations based on variable hadronic interaction models. The shower observables that have been used so far are the average muon density 1000 meters from the shower core and the shower-by-shower measurements of X_{max}.

First indications of interesting particle physics at Auger energies came from the evident excess of muons relative to model expectations, as measured by the surface detector. This is measured by examining the average shower attenuation with atmospheric slant depth (875 $\sec(\theta)$ g/cm^2 at ground level). Showers of the same energy are selected at different zenith angles by requiring the same flux at all angles, a method which is very precise because of the steeply falling energy spectrum. The dependence of shower size on $\sec(\theta)$ then measures the attenuation of the average shower at a fixed energy. The shape of the attenuation of signal due to muons has almost no model dependence. Similarly, the shape of the attenuation due to the electromagnetic particles has almost no model dependence once the mean depth of maximum for that energy has been determined using events measured also by the FD. Since the electromagnetic attenuation is much faster than the muon signal attenuation, it is possible to distinguish the fraction of signal due to electromagnetic particles from that due to muons using a two-parameter fit to the measured average shower attenuation curve, which we have done at numerous energies. This measure of the electromagnetic signal suggests that the FD energy scale may be low by approximately 20%, and the muon content of air showers is approximately 50% greater than models would predict assuming proton primaries even for that increased energy estimate, or 15% more than the expectation for iron primaries [23]. The excess muon content appears to diminish slowly with energy (relative to what is expected for a fixed composition). Auger North is needed to measure the muon content at trans-GZK energies.

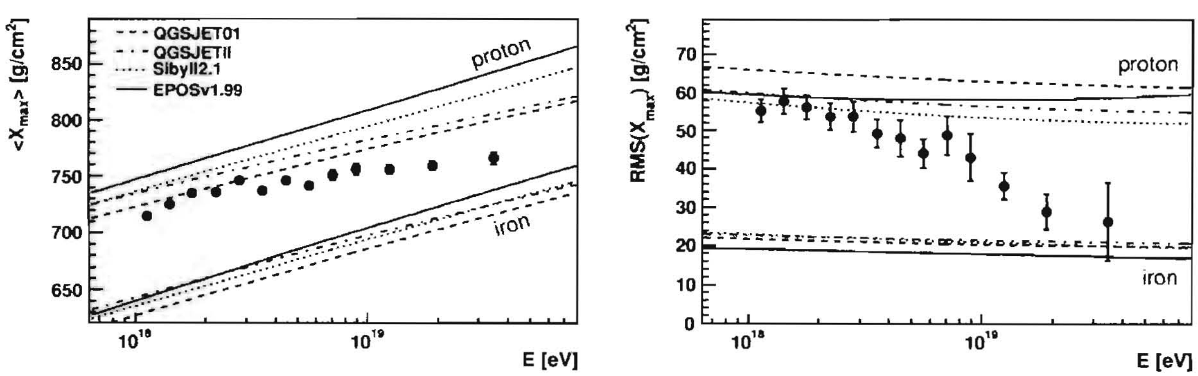

Figure 4: *Left:* The average depth of maximum, $\langle X_{max} \rangle$, as a function of energy. *Right:* The width of the X_{max} distribution as a function of energy.

The Auger FD can identify the atmospheric depth X_{max} where the shower reaches its maximum size with a resolution of 20 g/cm^2. Because of its limited duty cycle, statistical analysis is possible only up to 35 EeV so far (250 TeV center-of-mass). Some interesting trends are apparent, however. The mean value of X_{max} stops increasing with energy at the highest energies studied. Although the HiRes measurements of depths of shower maximum are systematically somewhat larger than those of Auger, the HiRes data [24] yield an elongation rate ($\frac{d\langle X_{max}\rangle}{d(Log(E))}$) that is statistically compatible with that of Auger, including a reduction in the elongation rate near the ankle of the energy spectrum. A striking feature of the Auger measurements is shown in the right panel of Fig. 4. The X_{max} distribution gets narrower with increasing energy, becoming inconsistent with simulations that use a mixed composition or a pure proton composition [25]. This is a fascinating result, but it is essential to examine the X_{max} distributions at energies above the GZK threshold.

One possible interpretation is that the composition becomes dominated by heavy nuclei near 30 EeV. The X_{max} data would then be compatible with present interaction models. These results especially motivate further observations at higher energies. The anisotropy above 55 EeV is not easy to reconcile with heavy nuclei like iron, since highly charged iron nuclei would be deflected by magnetic fields 26 times more than protons. Models of the galactic magnetic field suggest that protons should be deflected typically at least a few degrees en route to Earth. Trajectories of iron nuclei should therefore be bent more than 75°. (As indicated in the left panel of Fig. 2, nuclei of small and intermediate masses should not be significant components above 55 EeV.) However, there remain large uncertainties on magnetic field models.

If the anisotropic flux above 55 EeV is indeed dominated by protons, and if the observed trend of the X_{max} distributions with energy does not reverse, this result will have dramatic consequences for particle physics. If the measured air showers just below 35 EeV were known to be produced by protons, there would be an immediate inference that the proton-air cross section is greater than 1050 mb, far above the normal expectation of 550-650 mb. This result follows directly from the narrowness of the X_{max} distribution. The upper limit on the dispersion of first interactions, inferred from the RMS of X_{max}, translates to a lower limit on the proton-air cross section.

The above limit is conservative in assuming proton showers all develop identically after first interaction. Such behavior is unexpected unless the first interaction produces a kind of fireball rather than the customary inelasticity with stochastic leading particle energies. Extremely narrow X_{max} distributions for proton primaries would imply very high inelasticity and particle multiplicity as well as large cross sections. Measuring the X_{max} distributions in detail can be used to make quantitative inferences about these important interaction properties [26]. For primary protons, the center-of-mass energy at 55 EeV is 320 TeV. Information about hadronic interactions at such high energy would be an important complement to studies at the LHC. Indeed, with the HEAT [2] enhancement at Auger South going down to 0.1 EeV and the large aperture of Auger North gathering statistics on cosmic rays up to 100 EeV, the Auger Observatory will span the center-of-mass energy range from 14 TeV to 430 TeV, i.e., from the maximum LHC energy to 30 times higher energy.

2.3 Detecting UHE photons

Ultra-high energy photons are expected from the decay of neutral pions produced by the GZK pion photoproduction. They can also come directly from the sources of high energy cosmic rays. The window for extragalactic photon astronomy closes at 100 TeV due to pair production by collisions with CMB photons. The attenuation length for a photon beam has a minimum of about 10 kpc near 1 PeV, but then rises again. Detecting photons from the inner part of the GZK sphere is possible above 10 EeV, and the large aperture of Auger North offers the chance to exploit this

UHE photon window. Auger North will certainly be able to measure GZK photons if there is a substantial fraction of protons among the highest energy particles, providing an important cross check on the composition of trans-GZK cosmic rays.

Photon air showers are readily distinguished from hadronic air showers at ultra-high energies due to their slower development. At 10 EeV, for example, the depth of maximum X_{max} for a photon shower is 990 g/cm^2, whereas the distribution of measured X_{max} values near that energy is centered at 740 g/cm^2 with an RMS of only 45 g/cm^2. This difference has led to upper limits on the photon flux using hybrid events measured at Auger South [13, 14].

The surface array measures the shower development speed indirectly. The risetime of the signal in stations far from the core is longer for a shower that reaches maximum size deep in the atmosphere. Moreover, the curvature of the shower front is greater. The combination of these two measured shower properties has led to a more stringent limit on the flux of UHE gamma rays using the full-time surface detector by itself [15]. The various Auger photon limits are shown in the right panel of Fig. 2. These limits severely constrain top-down scenarios of cosmic ray production in which energetic neutral pions would be copiously produced along with the baryonic cosmic rays.

2.4 Detecting UHE neutrinos

Auger North will be a world-class neutrino observatory in the EeV energy range as well as an observatory for cosmic rays and photons. This is the energy range of GZK neutrinos resulting from decays of charged pions produced by GZK collisions of UHE protons and CMB photons. (See right panel of Fig. 3.) The Auger Observatory complements IceCube, which is sensitive in the PeV range, and radio detection experiments such as ANITA that search best in the ZeV energy range. Published flux limits from Auger South [27] are the world's best for τ neutrinos in the EeV range. Auger North will extend this search in neutrino energy and flux sensitivity. With the increased exposure of Auger North, the detection of GZK neutrinos becomes likely if the highest energy cosmic rays are protons, and astrophysical neutrinos directly from cosmic ray sources may be detected as well.

UHE neutrinos are good tools to test for new physics beyond the Standard Model through a measurement of their cross-section well above the TeV scale. At Auger North, this study can be done by comparing the neutrino detection rate with the predicted flux from the GZK effect. In addition, if the UHE neutrino flux is sufficiently high, a comparison between the rate of nearly horizontal down-going showers induced by neutrinos and that of up-going showers produced by neutrino generated τ decay yields a direct test of new physics in the UHE neutrino cross section [28].

Neutrinos are recognized with the Auger Observatory as young electromagnetic cascades very deep in the atmosphere. A strong electromagnetic component in a near-horizontal air shower can be unambiguously identified by slow signals in the individual stations and by large curvature of the shower front. No candidate neutrino event has been found so far at Auger South.

2.5 Summary

The trans-GZK cosmic rays are key to understanding UHE particle physics and astrophysics. Their low flux requires enormous exposure to acquire a data set of adequate size in a reasonable number of years. The left panel of Fig. 5 indicates how the accumulated exposure of Auger North will compare with other instruments. The right panel shows the relative sizes of different surface arrays. Auger North will have the large aperture that is needed to achieve the following goals:

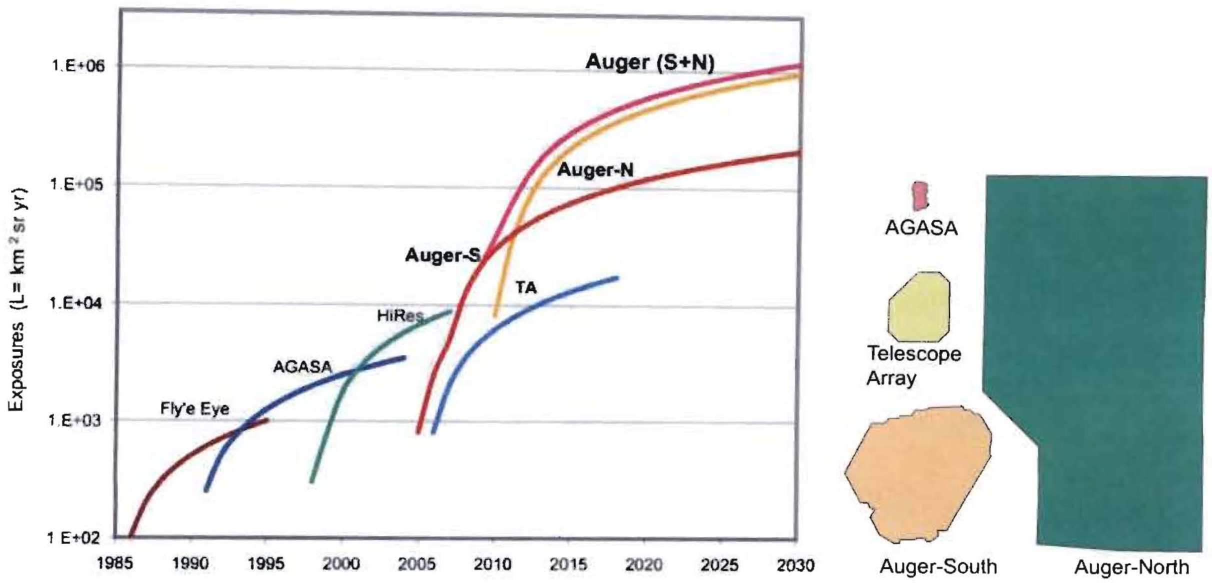

Figure 5: *Left:* Exposures of ground based cosmic ray observatories as a function of time. *Right:* The relative collection areas of the AGASA, TA, Auger South and Auger North arrays.

• Determine the class of astrophysical sources within the GZK sphere which produce trans-GZK particles.
• Identify some individual discrete sources and measure the energy spectra of the brightest ones. Use multi-messenger information to determine the acceleration mechanism and the physical conditions that enable it.
• Determine the primary particle type(s) of trans-GZK cosmic rays.
• Determine properties of hadronic interactions in the CM energy range 250-450 TeV if the cosmic rays are protons. Measure the cross section versus energy and derive lower bounds on the inelasticity and multiplicity.
• Using the cosmic source evolution of the identified source class together with the measured composition of primary particle types, calculate a reliable spectrum for the diffuse flux of UHE neutrinos and a reliable spectrum for the diffuse flux of UHE photons resulting from interactions of those trans-GZK particles with cosmic background radiation.
• Detect UHE neutrinos and search for neutrino emission from the identified trans-GZK cosmic ray sources.
• Detect UHE photons, measure the diffuse photon spectrum, and search for photons emitted by the identified trans-GZK cosmic ray sources.
• Use magnetic deflections of the charged trans-GZK particles to study the galactic and intergalactic magnetic fields.

It may be impossible to anticipate the most exciting discoveries that will result from acquiring significant exposure to the trans-GZK cosmic rays, photons, and neutrinos. Auger North will provide access to new frontiers.

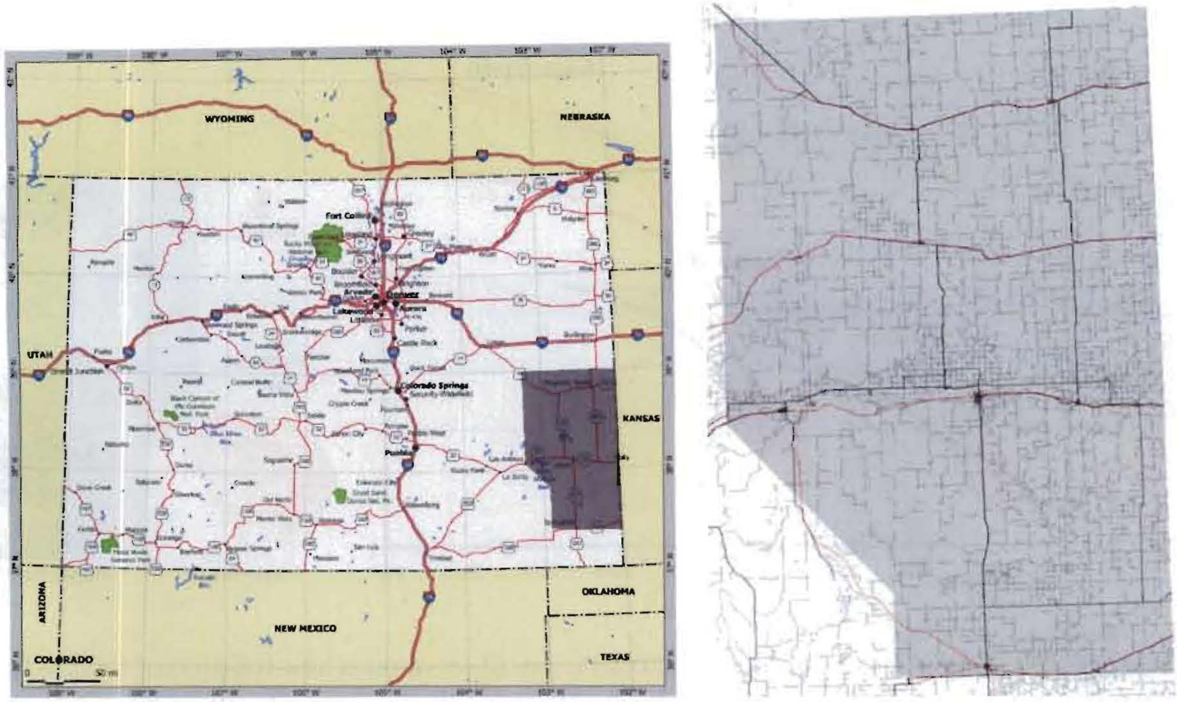

Figure 6: *Left:* Colorado map showing main roads and the site (shaded area at the bottom right). *Right:* US Highways (thick black) and county roads (thin black) on the site. Railways are shown in red.

3 The northern site of the Pierre Auger Observatory

3.1 Features of the location

The site of Auger North is in southeast Colorado (38° N Lat, 102° 30' W Long) on the North American High Plains, about 200 km east of the Rocky Mountains. The average altitude is about 1400 meters above sea-level and can easily accommodate the large array size that is required by the science objectives. East of the main area there is no geographical limitation that would prevent including part of neighboring Kansas in the array.

General infrastructure and accessibility

Most of the area is rural and consists of privately owned land used for farming or ranching with overall population around 27,000. The largest town, Lamar, is located on the Arkansas river which runs west-east through the middle of the site. An extensive network of highways and county roads covers the region. Paved roads run north-south (US 287 and CO 385) and east-west (CO 116, US 50, US 40 and CO 160) making access to all parts of the vast site relatively easy and fast (see Fig. 6).

Denver International Airport is three hours driving time (300 km) away. Lamar is a stop on both the Burlington Northern Santa Fe (cargo) and Amtrak (passenger) rail lines. The town of Lamar, due to its size, amenities and location, is the natural base of operation for the observatory. The Lamar Community College (LCC) is the Outreach and Education Host Institution for Auger North and will host the observatory campus. High-speed Internet services are available in the area, and LCC serves as the local hub for educational uses. Fiber runs along US-287 through Lamar south to Springfield in Baca county and north to the northernmost parts of the site. Fiber also runs east-west through Lamar west to Pueblo, where Colorado State University (CSU) maintains a center, east to the Kansas border, and generally along the other main paved highways surrounding and crossing the site. Purified water sources in the area are being studied; there is a reverse osmosis plant in Las Animas on the western edge of the site that could serve as input to the planned Auger water purification plant.

Atmospheric properties
Measurements in 2004-2005 [29] found that the optical clarity in the 300-400 nm UV scintillation band at the Auger North site is suitable for measuring ultra-high energy cosmic rays using the air fluorescence technique. The study found that the optical clarity in terms of vertical aerosol optical depth is similar to that at other locations, including Utah and Argentina, where FDs have been operated successfully. Additionally, the molecular component is well monitored by radiosondes launched twice-daily from Denver, Amarillo TX, and Dodge City KS. As part of the Auger North R&D plan, a more extensive set of atmospheric measurements will be conducted (section 5). The planned configuration of atmospheric monitoring for Auger North will be discussed in section 4.4.

Environmental considerations
The site was evaluated from an environmental perspective, in particular with respect to potential interference between detector deployment and the local wildlife. In 2005, as part of the site selection process, we solicited input from James Spensley, an environmental lawyer with experience in Colorado. He reviewed the area around and south of Lamar. An excerpt of his report [30] follows:

> "Based on the literature research and consultations, it is my professional opinion that the Pierre Auger Observatory project proposed for southeastern Colorado can be successfully implemented without causing any significant impacts on sensitive resident wildlife or any other environmental resources."

Recent interaction [31] with the Colorado Division Of Wildlife (DOW) did not reveal any particular concerns over the planned location of the observatory, an area larger than the one studied by Spensley. Specific comments were solicited for an area south of Lamar where our activity is presently focused. Under their recommendations, we may have to avoid nesting periods of a few weeks per year in small portions of the array and take other simple precautions. Based on this early interaction with the Colorado DOW we are confident that we can proceed with the deployment of the Auger North surface detector array without any negative environmental impact and satisfy all environmental requirements.

3.2 Surface detector array layout

The science goals for the Auger North instrument require measuring as many events as possible at energies above 55 EeV, and this implies a very large detection area. Auger South is laid out on a grid of equilateral triangles with 1500 m spacing. In order to reduce costs for Auger North we investigated sparser grids. A second issue affecting the placement of tanks is the inconvenience caused to the landowners with tanks on their property. Landownership in the western US is often quantized in 1-mile by 1-mile squares called sections. This is the case in southeast Colorado, and many roads are laid out along the grid. We minimize impacts on the land by using the existing tracks and gates along fences, while ensuring easy access to the detector locations. The choices are to place detectors on the 1-mile square grid, a $\sqrt{2}$-mile square grid, or a 2-mile grid.

A sparser array in general results in a higher trigger energy. Studies with Auger South data and simulations show that the 1-mile grid will be 90% efficient at 4 EeV, which is similar to Auger

South where 100% efficiency is attained at 3 EeV. The $\sqrt{2}$-mile grid will be 90% efficient at 30 EeV, and the 2-mile grid would be 90% efficient only well above 100 EeV. So for most of the northern observatory we plan to use the $\sqrt{2}$-mile grid. We will also use the 1-mile grid over 800 square miles (2,000 km^2) in order to overlap in energy with Auger South (see left panel of Fig. 8).

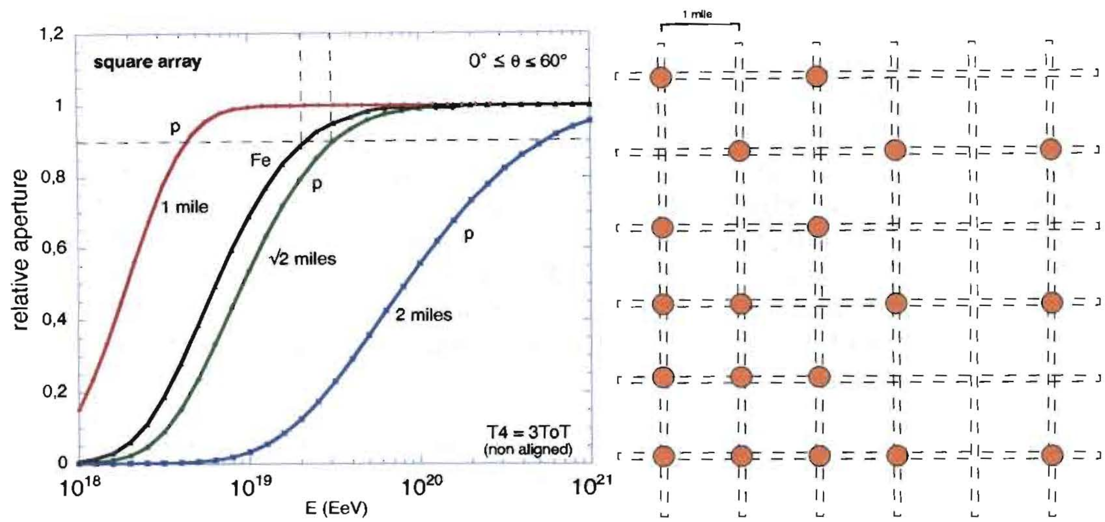

Figure 7: Detection efficiency and array spacing for three possible unit cells. *Left*: Saturation curves for a square array with a side of 1 mile, $\sqrt{2}$ miles and 2 miles, as indicated. All curves are for proton primaries, except for the case of $\sqrt{2}$ miles where the saturation curve for Fe primaries is also shown, for comparison. *Right*: Illustration of different tank deployment options exploiting the square-mile road grid and the resulting detector spacings.

The chosen site is particularly well suited to accommodate the $\sqrt{2}$-mi square grid. The response of landowners polled in 2005 was overwhelmingly positive, but we can accommodate a small number of landowners who don't subscribe to the project. By placing surface detectors on corner sections, we have a choice of as many as four locations (potentially belonging to four separate landowners) to place each detector. In some cases, the county road easement is also a possibility if none of the landowners wishes to participate near some corner.

3.3 Fluorescence detector configuration

Like its proven counterpart in the south, Auger North will be an integrated hybrid instrument with FD coverage extending over most of the SD (Fig. 8). The need to measure the X_{max} of as many extensive air-showers as possible at energies above the GZK threshold is the primary scientific motivation to maximize FD coverage. The most cost-efficient solution is one that minimizes the number of FD stations required to view the atmosphere across the entire surface array, while still maintaining sufficient energy and X_{max} resolution. The solution selected spaces the FD sites so that overlap between FD stations is nearly eliminated. A separation of 80 km has been chosen. This distance is based on the atmospheric clarity measurements at the Colorado site, on experience reconstructing EASs in the South using the FD, and on experience using distant "test-beam" lasers. As in Auger South, the FD measurements in Auger North will be hybrid measurements, in which the monocular (single FD station) longitudinal profile measurement uses a shower axis

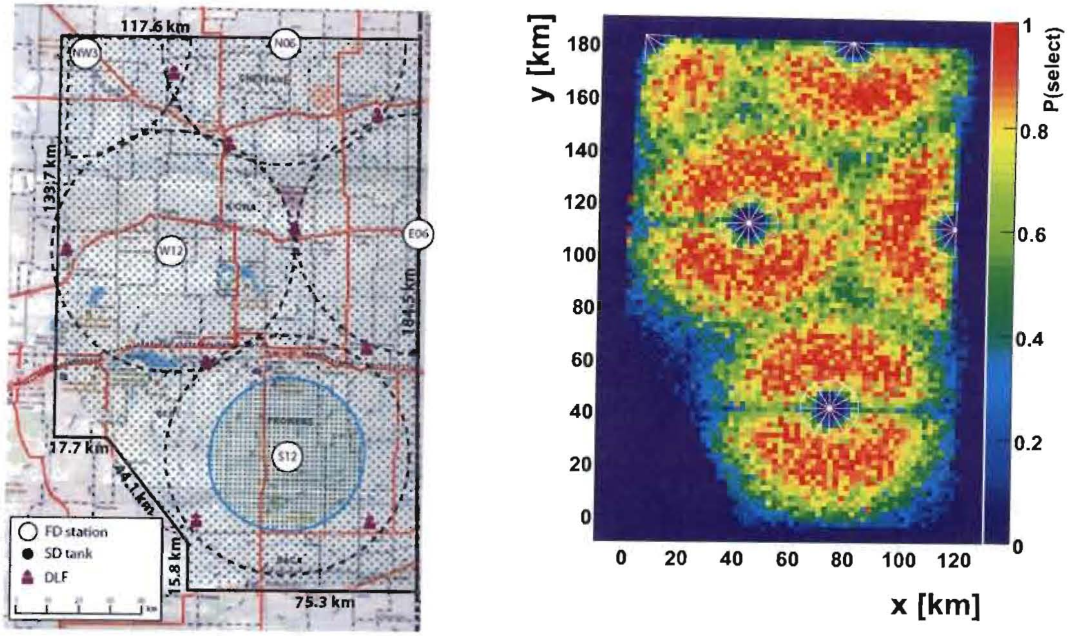

Figure 8: *Left:* Auger North configuration. The SD detectors are arranged on a $\sqrt{2}$-mile square grid together with an infill (shaded) area of 1-mile spacing. Five FD sites, in combination with Distant Laser Facilities (DLFs), span the SD. *Right:* FD EAS reconstruction efficiency at 100 EeV.

geometry fit constrained by timing information from the SD. FD stations will operate in combination with calibrated distant laser facilities (DLFs). Their lasers generate tracks in the FD with optical similarities to the rare tracks from trans-GZK EASs. DLFs will be placed 40 km from FD sites to monitor detector performance across the FD aperture for trans-GZK air showers.

The configuration features two 360° full stations, two 180° half stations and one 90° quarter station for a total of 39 FD telescopes. This arrangement provides nearly 100% trigger coverage of the SD at 10^{20} eV. More importantly, the reconstruction aperture at 10^{20} eV, after quality cuts that include X_{max} bracketing, will be 40,000 km^2 sr (averaged over operating conditions) which is 70% of the SD aperture (Fig. 8 right side). The study used the preliminary in-situ clarity measurements. It also found modest changes in aperture by season of about +10% (fall & spring) and about -20% (summer). At 100 EeV the expected resolution in energy is better than 10% (not including systematic errors) and the resolution in X_{max} is 20 g/cm^2 (Fig. 12).

Each FD location sits about 10-15 meters above the surrounding terrain. The FD stations are located no more than a few km from existing power lines and from existing optical fibers for high-speed data transmission. There is a built-in capability to allow for a configuration extending into western Kansas.

4 Implementation

In this section we describe the main elements of the observatory detection system. While the detection fundamentals for Auger North are essentially identical to those in Auger South, we optimized the detector design to accomplish the science objectives, while minimizing costs. In the process, we took into account the characteristics of the site. SD thermal insulation is required due to harsher weather conditions in Colorado. A new scheme for the SD communication system is needed due to the topology of the site. The reader is invited to consult the technical details of each observatory site, which can be found in the respective design reports [29, 32].

4.1 The surface detector

The surface detector stations are based on cylindrical polyethylene tanks of 3.6 m in diameter and 1.5 m high. The tank contains a Tyvek® liner filled up to a height of 1.2 m with purified water. The required resistivity of the water is 15 MΩ·cm. The tank production itself remains essentially unchanged. Tanks will be fabricated from high-density polyethylene resin by the roto-molding technique. Using this process, it is possible to produce tanks with a light beige outer layer that matches the environment of the site, and a black inner layer that guarantees that the tank is opaque. A careful manufacturing process also results in a uniform wall thickness of 12.7 mm with minimal warping.

Tank design

Following our extensive experience at the southern site, relatively minor modifications to the tank design result in significant savings per unit, and massive saving on the scale of the project. The tanks for Auger South accommodate an arrangement of the three photomultiplier tubes (PMTs), resulting in the three "propeller blade" layout of the tank top, shown in Fig. 9. To reduce costs, there will be only one PMT in each water tank. Based on simulations and field measurements in Auger South, it has been determined that the use of one PMT (instead of three) does not affect significantly the tank response, calibration accuracy, or trigger efficiency. Costs are reduced not only by the smaller number of PMTs, but also by the associated reductions in electronics and power requirements. Consequently, only one solar panel (instead of two) will power each station. The new tank top (also shown in Fig. 9) is designed with different structural features that provide more rigidity with the same tank dimensions. There will be one opening at the center of the tank for access to the PMT and electronics, and a second hatch at 1.2 m from the center for human and large components entry and for water filling operations.

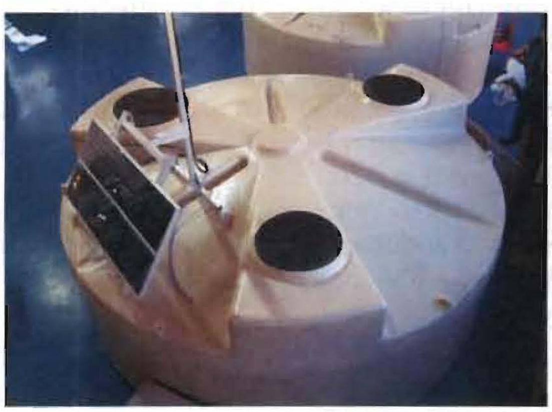


Figure 9: *Left:* Tank used in Auger South. *Right:* Proposed tank design for Auger North.

Insulation

Winters at the northern site are harsher than those in Malargüe, and the SD tanks in Colorado may

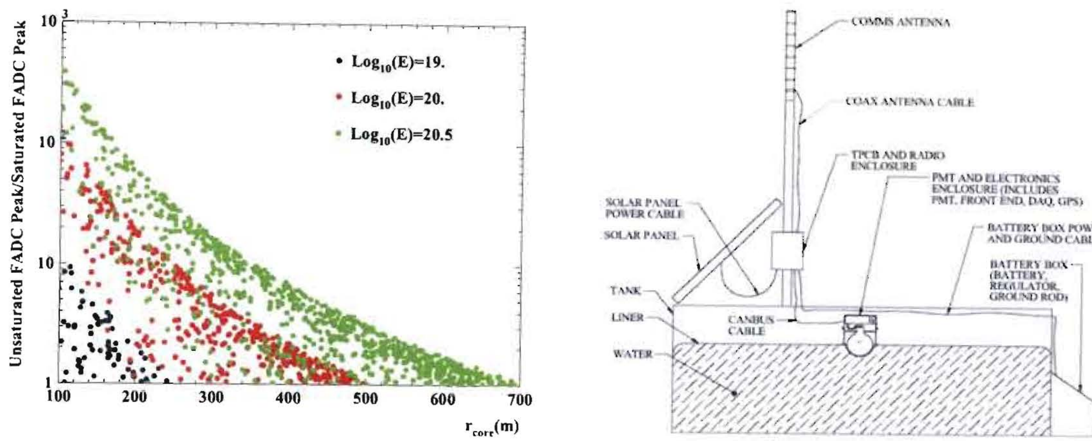

Figure 10: *Left:* Ratio of the true peak to the saturated peak (assuming a 15-bit dynamic range) as a function of the distance to the shower axis for different primary energy simulations. With 15-bit dynamic range (Auger South) saturated signals are present within 500 m of the shower core in 10^{20}eV showers. In Auger North, increasing the dynamic range by a factor of 32 would allow one to reach 200 m from the core before signal saturation occurs, and a factor of 128 would reduce this to 100 m. *Right:* Conceptual drawing of the SD station, showing major components and interconnections.

freeze solid approximately once every 20 years if they are not insulated. Ongoing R&D on tank freezing in Colorado and Malargüe has shown that significant heat flows into the tank from below in the winter, and that insulating the top and sides of the tank can significantly slow freezing and prevent catastrophic damage to the instruments. Working with a heat-flow engineer we have developed a mathematical model of the tank that generally predicts the thermal behavior based on the insulation of the tank and ambient conditions including air temperature, solar irradiance and optical properties of the tank. We then simulated an extreme winter to test different insulation schemes.

Tests are also being made to integrate polyethylene foam insulation on the inside surface of the tank during the rotomolding process. This process may provide significant cost and durability advantages over alternative insulation systems. Another possibility is to cover the outside of the tank with a polyurethane foam, and paint it with an acrylic or polyurea layer for ultraviolet protection. This alternative was successfully tested in tanks that we installed at Fermilab, Illinois and Millard County, Utah. It is used for costing the design because it is a standard industrial process for insulating rotomolded tanks.

Electronics

The design for the surface detector electronics system in Auger North is based on the successful system used in Auger South. The Auger North system is more highly integrated, which is possible due to advances in field programmable gate arrays (also called PLDs) over the past decade. The power consumption of the system will also be about 70% less for Auger North due to advances in low voltage CMOS components and the reduction of the number of photomultipliers from three to one.

The signal in a surface detector varies dramatically both with time and with distance from the shower core, so a wide dynamic range is required. The system must accommodate signals from the photoelectron level for small electromagnetic signals far from the core to large currents due to the passage of peak particle intensity near the shower core. Auger South employs two overlapping 10-bit flash ADCs per PMT, digitizing signals derived from the anode and amplified last dynode to obtain a 15-bit (3×10^4) dynamic range. This results in saturated signals for high energy events. The peak ADC values for several shower energies as a function of detector distance to the shower core are shown in Fig. 10. The saturated region in Auger South is the region of the figure where the points are above 1, which happens within 500 m of the shower core for 10^{20}eV showers. For Auger North the dynamic range will be extended from 15 bits to more than 20 bits. With the dynamic range extended to 20 bits, the saturated radius corresponds to the region of the figure where the points are above 32. For 10^{20}eV showers this now happens only within 200 m of the shower core. If we can reach 22 bits, the saturated radius shrinks to 100 m. Either is a significant improvement over Auger South. The dynamic range extension will be achieved by using signals derived from the anode and from deep (4th or 5th) dynodes. The high voltage supply to the tube is designed so that space charge saturation in the last few dynodes does not feed back to the beginning of the dynode chain. This extended dynamic range provides (non-saturated) signals in stations that are close to the shower core, and a more precise determination of the lateral distribution function for our highest energy events.

As in Auger South [33], a hierarchical trigger is implemented. The lowest level (level 1) trigger is formed by the trigger PLD, which continuously monitors the PMT signals for shower-like signature. A local low power microprocessor applies additional contraints to form level 2 triggers, which are passed on to the observatory campus through the communication system for higher level trigger formation. (see sections 4.2 and 4.5).

The various electronics boards are interconnected via a CANbus cable, which provides power, distribution of GPS timing pulses, and transfer of event and monitoring data among the station radio, the data acquisition board (DAQ), and the tank power control board (TPCB). This scheme is an improvement on the Auger South design, with both fewer cables and more robust data transmission. This is shown in the right panel of Fig. 10.

4.2 Data communication system

Although the altitude variations across the Auger North site are small on average, local variations of a few meters impose contraints on line-of-site communication links. Together with the absence of hills outside or within the surface detector array, these small local altitude fluctuations make the tower-based communication scheme of Auger South, in which each tank transmits to a distant collection point, impractical for Auger North. Consequently, a new communication scheme was designed for Auger North, whereby data are passed from detector to detector and on to the collection point using a real-time wireless protocol. Fundamental principles of the Auger South design are retained: (1) Spatial Reuse Time Division Multiple Access (SR-TDMA) radio network; (2) radio hardware optimized for Auger; (3) custom network protocol optimized for real-time reliable transport of trigger packets.

The new Auger North protocol has been tested in a laboratory setting using 16 radios. A larger test of the communication system is integrated in the R&D array to be deployed south of Lamar and described in more detail in section 5.

Network description

The Auger North design employs the *Wireless Architecture for Hard Real-Time Embedded Networks*

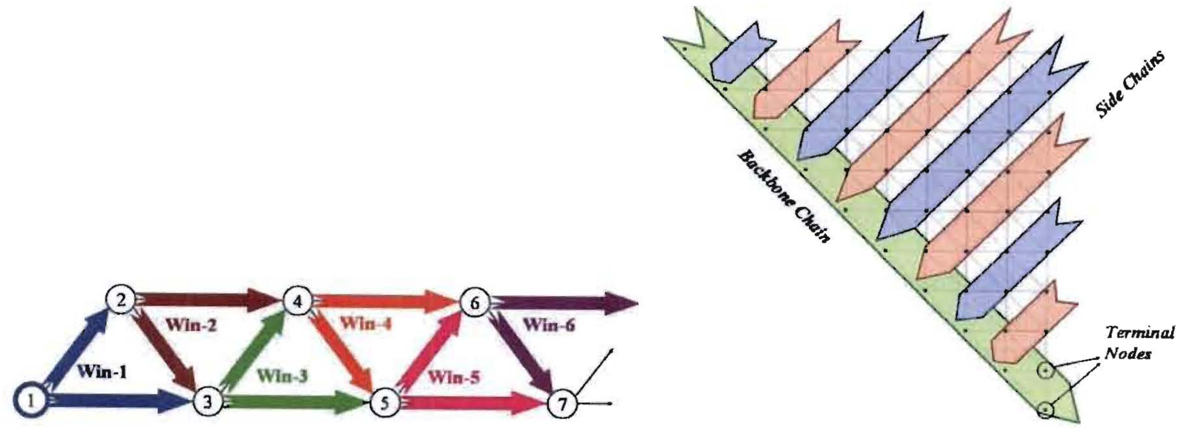

Figure 11: *Left:* Systolic broadcast protocol in a second-order power chain. *Right:* Backbone and side chain example.

(WAHREN) [6] paradigm to provide reliable hard real-time delivery of trigger (and data) messages.[7] The basic infrastrucure topology is a second-order power chain as illustrated in Fig. 11. Each node communicates with both its nearest pair of neighbors and its second nearest pair of neighbors, providing resiliency to the loss of a single node.

A power chain can make a sudden right angle bend with no disruption in the data flow. This permits the entire array to be interconnected by a series of backbones and side-chains (Fig. 11). Furthermore, this ability supports much more complex routing paths, including multiple backbones, and hierarchical layers of backbones and side-chains, allowing the network to be mapped onto amorphous shapes, and to route data around holes or obstacles to RF propagation.

WAHREN uses a strict SR-TDMA communication between nodes, wherein every node may transmit in its assigned slot within a communication window. Upon this base, WAHREN builds a systolic[8] broadcast protocol, in which all nodes initiate a broadcast simultaneously, in their assigned TDMA slots of the same window. Then, in each subsequent window, each node forwards messages received during the previous window (Fig. 11).

Incoming messages from the SD stations converge on a set of concentrator stations (and diverge from them for outgoing messages). The concentrators manage end-to-end error checking and re-transmission, reformat the messages into TCP/IP data packets, and forward them via fiber optic links to the Central Data Acquisition System (CDAS) (see section 4.5) located at the observatory campus. The reverse sequence of operations is performed for messages from CDAS to SD stations. Six concentrator stations are required to meet the data throughput and trigger latency requirements of the SD. Five of these will be located at FD eyes to take advantage of the infrastructure at those locations. The 6th one will be a stand-alone installation.

Network analysis and verification

The WAHREN protocol has been implemented, tested, and verified on a hardware testbed. In

[6]While it has other applications, WAHREN has largely been developed by Auger collaboration members in the context of Auger North.

[7]A small portion of the bandwidth is available for non-real-time communication traffic, for use by "off-grid" devices such as FD calibration lasers or repair trucks.

[8]The term systolic in computer science is applied to array of cells where data is pumped from cell to cell at regular intervals, analogous to the systolic pulses in a cardiovascular system.

addition, a formal analysis of the protocol was undertaken, including formal induction proofs of proper data flow under the design fault hypothesis, and a combination of Abstract State Machine and Generalized Stochastic Petri Net analyses.

Any system as large as the SD communication system is vulnerable to a very short mean time to failure. Therefore, a detailed Markov analysis was conducted to determine the probability that two adjacent SD stations can be out of service simultaneously. The results revealed that WAHREN can be dramatically more reliable than a backbone of microwave towers.

Data rate and RF band

In Auger South each SD station is guaranteed 1200 bits/second hard real-time data rate. This has proved to be sufficient, but puts constraints on diagnostic information. In Auger North we plan to double that.

The Auger South communication system uses the 902-928 MHz ISM band, in which an Argentine federal government decree gives Auger priority on the site and surrounding area. For Auger North, ISM bands are less suitable due to the much higher usage of wireless devices in the US. We submitted, through the DoE Office of Science, a request to the National Telecommunications and Information Administration for access to a portion of the radio spectrum reserved for US government use. We were granted four 11 MHz wide frequency allocations near 4.65 GHz, and are proceeding to implement corresponding hardware.

4.3 The fluorescence detector

The Auger North FD design is based upon the well proven concepts implemented and tested in the FD [34] at Auger South. Some small changes in the design are motivated by experiences gained at the southern site, the obsolescence of certain key electronic components, and various technical developments. Most of the innovations planned for Auger North FD telescopes have been tested in the HEAT enhancement recently constructed at Auger South. Expected energy and X_{max} resolutions, from simulations verified in Auger South, are shown in the right panel of Fig. 12.

FD telescopes

The FD telescope optics are based on a Schmidt design. Light enters the climate controlled and dust-free telescope through a 2.5 m x 2.5 m UV-transmitting filter. A 2.2 m diameter circular opening defines the optical aperture. The outer range of this opening between 1.7 m and 2.2 m diameter is covered by an annular corrector plate. A 14 m^2 segmented spherical mirror brings the light to a focus on an array of 440 PMTs (the camera). Light collecting reflectors are used to minimize dead zones between the photocathodes of neighboring PMTs. The system images a 30° x 30° region of the sky with 1.5°-diameter pixels. The PMTs are protected against bright light, e.g., in case of a shutter failure, by a fail-safe curtain between the filter window and the camera. This curtain, operated by UPS power and gravity, is an important part of the slow control system.

FD Electronics and DAQ

The FD electronics architecture for Auger North is for the most part the same as the Auger South FD electronics system. However, the new system will replace obsolete components, implement a more convenient and compact backplane configuration, and increase the data sampling rate from 10 MHz to 20 MHz.

Each Analog Board (AB) processes the signals from a camera column of 22 PMTs. The analog signals pass through differential line receivers, active anti-aliasing filters, and an amplifier stage with a variable 1X–12X gain (increased from the 1X-2X in Auger South).

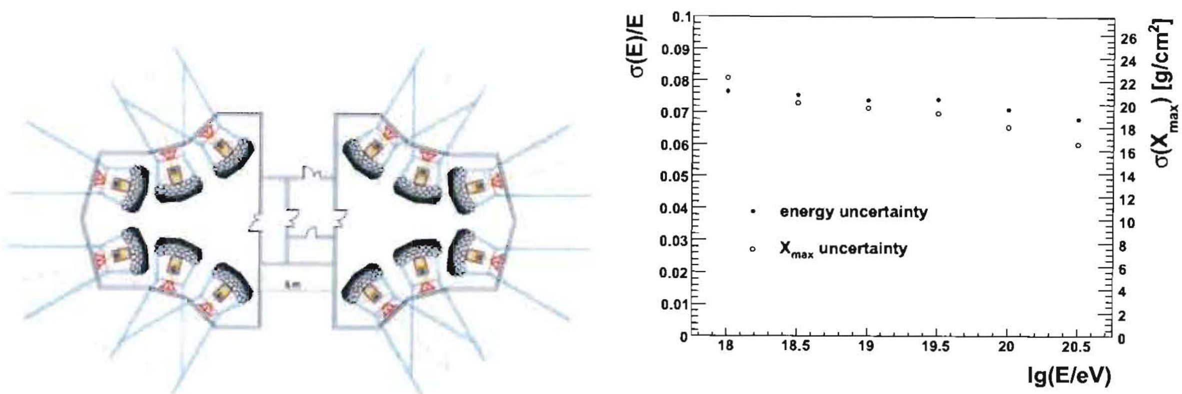

Figure 12: *Left:* Telescope arrangement of a 360° FD site. *Right:* Energy and X_{max} resolution for the Auger North FD.

The telescopes use a multi-level scheme to trigger on distant showers. The first level trigger (FLT) board digitizes conditioned signals from a camera column of 22 PMTs, searching for a running sum above each pixel threhold. In parallel the FLT board FPGA measures the rate of pixel triggers in intervals of several seconds and adjusts the threshold to keep the hit rate constant at 100 Hz in spite of varying light conditions. The second level trigger (SLT) board accumulates the triggered pixel information from the FLTs, finds track segments in the composed camera image, and releases a trigger to start the software controlled readout process. Advances in FPGAs allow higher sampling rates, faster trigger execution, and fewer components than the Auger South design.

Event data stored in FLT and SLT memory are read out by a local processor and tested for space and time correlation. Events passing this software trigger stage are combined with data from other telescopes at the FD site. A time stamp containing limited track information is then sent to the CDAS for the hybrid trigger.

Telescope Buildings

The FD buildings have been redesigned for Auger North to reduce cost. Each building will house either 3 or 6 telescopes depending on its location in the array. The space needed for the telescopes has been optimized compared with the semi-circular FD buildings in Argentina. They will be built using steel frame construction covered with light weight insulating walls and roofs used in industrial buildings in southeast Colorado. The telescope optics will be protected by a commercial shutter, mechanically adapted to the special requirements of the experiment. The construction technique and shutter concept have both been successfully implemented on the HEAT enhancement. Necessary infrastructure functions like power distribution, DAQ, slow control, calibration, and LAN will be centralized in a service building attached to the FD telescope area. The service building will also provide space for workshops, a detector assembly area, and storage.

At two of the FD sites, a pair of buildings will be co-located to achieve 360° coverage. They will share a centrally located service building. The layout of the telescope buildings is shown in the left panel of Fig. 12.

4.4 Atmospheric monitoring and calibration

While the 80 km separation between FD stations will challenge the atmospheric monitoring program for Auger North, the studies applying the in-situ aerosol optical depth measurements to the proposed FD configuration are encouraging. The design for Auger North draws on the extensive and successful monitoring program developed for Auger South. This program has reduced the total systematic uncertainty due to all atmospheric effects to 8% in energy and 8 g/cm^2 in X_{max} at 10^{20} eV (25% smaller at 10^{19} eV) [35, 36].

In Auger South, on-site radiosonde launches and weather stations measure the atmospheric molecular profile [37, 38]. Data for aerosol and cloud distributions are measured by four elastic backscatter LIDARs [39], four IR cloud cameras and two aerosol phase-function monitors [40] at the FD sites, and by FD reconstructions of tracks from two solar-powered distant laser "test-beam" facilities [41, 42] located near the array center. These measurements are made several times per hour during FD operation. The distant lasers are also used to monitor FD trigger efficiency, timing, pointing accuracy, and cross-check end-to-end photometric calibration including atmospheric effects. Cloud information is also extracted from GOES satellite images. A portable calibrated "drum" light source [43, 44] is mounted temporarily over the optical aperture of each FD telescope to measure the absolute photometric calibration about once per year. The method has been cross-checked against FD measurement of tracks from a portable nearby calibrated nitrogen laser [42]. LED light delivered via fiber to each FD telescope is measured nightly to monitor relative calibration.

The Auger North design makes modest updates to these designs and methods. The ratio of distant lasers to FD stations will increase from 2:4 to 9:5. The distant lasers will use slightly higher energy solid-state lasers in combination with robotic systems for absolute calibration of beam energy and polarization. GPS-disciplined rubidium oscillators will improve firing time stability. Satellite imagery from at least two GOES satellites will be available. The LIDARs will be modified to increase the range of near and far-field measurements and we are investigating the possibility of adding Raman channels. To reduce uncertainty in absolute photometric calibration (a limiting factor in translating the measured trans-GZK energy scale to the propagation distance scale), an automated independent nitrogen laser system (NAILS) will be installed near each FD site co-linear with the distant lasers. We do not anticipate that on-site radiosonde launches will be needed for Auger North as the site is well bounded by airports with twice-daily launches.

4.5 Data acquisition and processing systems

The Central Data Acquisition system for Auger North has only minor changes from the smoothly running system used in Auger South. In Auger North, SD level 2 trigger data, event data, and monitoring data are passed from SD stations through the communication system to concentrator stations and then forwarded to the CDAS as TCP/IP packets. The trigger information is combined with any local trigger information from the FD. The trigger data are searched for temporal and spatial correlations to produce level 3 "central triggers". The level 3 triggers are routed back through the communication system to the surface detector stations, which then send the corresponding event data to CDAS.

The level 3 and higher SD triggers will require a slight modification for Auger North because of the change from a triangular grid in Auger South to the square grid in Auger North. This change has been successfully implemented in simulations for Auger North.

Except for the triggering information, the CDAS and FD data acquisition systems are independent. Merging of FD and SD data streams happens off-line following an FD run. The newly acquired data are synchronized on the central storage hardware at the observatory campus after each night of observation, and are then mirrored to primary data mirrors. Primary mirrors transfer the data to secondary mirrors, and from there the data may be transferred to participating institutions, all within a day or so of the acquisition of the data. The data from Auger South and Auger North will be combined on the mirrors and analyzed as a single Auger data set.

The offline data processing system used for Auger South (OffLine) [45, 46] has proven to be very flexible. It implements a hierarchical detector model which facilitates addition of new detector systems. The Auger North detector will be added to the detector model, providing a unified analysis framework for Auger, North+South.

4.6 Towards pre-production

Section 5 below describes on-going R&D for Auger North that is funded. The overall objective of this R&D effort is to validate the most significant changes to the design, such as the modified SD station design, the new communication system, and to study in more detail the properties of the atmosphere in southeast Colorado. Within the limited funds presently available, it is not possible to complete the developments necessary to bring all the components of Auger North to a pre-production level. Hence, a new R&D proposal is submitted concurrently to this proposal and its main aspects are summarized next.

Surface Detector

The modified tanks used in the R&D array discussed in section 5 come from a Brazilian provider of Auger South tanks. This approach is not cost-effective for production because of the shipping costs. Several rotomolders have expressed interest in building a factory in southeast Colorado to provide tanks with minimal shipping costs. We will need to ship the mold from Brazil and modify the support structure to fit the local rotomolders' requirements. Some molding tests, before pre-production begins, are needed to help qualify vendors. The baseline thermal insulation scheme, external polyurethane foam, has disadvantages, including durability, cost, and appearance. Better solutions might be internal foam insulation, either polyethylene or polyurethane. These techniques are new and will require some development before they can be properly evaluated.

For the ongoing R&D effort, the single-PMT SD tanks will be equipped with retrofitted Auger South liners. These liners have been shown to perform well so far, but the manufacture of the dark carbon-loaded polyethylene layer for the Auger South liners was problematic, and the vendor we used then is not willing to use the same formulation again. A new opaque polyethylene layer needs to be developed. We will investigate adding an aluminum layer to the laminate to lower the opacity requirements on the polyethylene layer.

Recently, Photonis, Auger South's PMT provider, announced that they will not be manufacturing PMTs anymore. Evalution of custom-designed PMTs from Hamamatsu and Electron Tubes, two potential providers, needs to be carried out. R&D will also be necessary with respect to the design and pre-production of the bases (for the two kind of PMTs) and the front-end boards. Additionally, the PMT assembly scheme used in the current R&D array will likely need modifications before pre-production.

Atmospheric monitoring

The current atmospheric monitoring R&D (section 5) at the Auger North site is funded to set up equipment and begin measurements. Additional funding will be necessary to accumulate a full year of data and this will require automating several instruments. This hardware will also provide an ideal test bed for the NAILS prototype. We propose to build and field-test the first independent automated NAILS system featuring a nitrogen laser housed in a small temperature controlled shelter with GPS timing and robotic absolute beam calibration.

Communication system

The Auger North SD communication system, as described in the following section, is based on peer-to-peer signaling rather than on peer-to-collector as at the southern site. We plan to test all the hardware for the new system as well as basic algorithms and monitoring software with the current R&D. However, there will still be work to do to bring the system to a pre-production stage. Areas requiring additional work include: characterization of the Auger North communication fault-space, including an independent (hardware) system for monitoring; creation of management tools for assessing system performance and reliability; and development of algorithms for initiating and managing dynamic rerouting.

5 Current R&D in southeastern Colorado

By early 2010, a funded R&D Array (RDA) for Auger North will be operational south of Lamar. In several ways this array is similar to the Engineering Array of Auger South [47]. Our goals for this phase of Auger North R&D are to reconstruct cosmic ray showers with prototype detectors, to bring as many components to the pre-production stage as possible, as well as to test the new communication scheme and to validate cost estimates for the full detector.

In parallel, an atmospheric monitoring program will accumulate a more complete database than the earlier measurements. The database accumulated will be used to refine simulations and reconstruction algorithms for the Auger North hybrid detector in advance of site construction.

Additional work on Auger North components requiring supplementary funds are described in section 4.6.

5.1 Surface detector and communication system tests

We plan to deploy 10 Auger North tanks and 10 stations that have only communication equipment. The R&D array includes one square mile with detectors on all four corners plus a tank at the center and two tanks about 10 meters apart at the center of one of the triangles formed by the corners and center of the square mile. These detectors will be the main ones used for the end-to-end reconstruction of cosmic ray showers, and the two tanks set close together provide a test bed for signal resolution and timing studies as have been done at Auger South. The rest of the small array is on the $\sqrt{2}$-mile spacing and has mostly communication-only stations, outfitted with the same processors as the full stations. The overall layout is shown in the left panel of Fig. 13.

The layout of the R&D array has been designed specifically to support the communication system testing goals. This configuration includes a short backbone and one side chain of sufficient length to test: (1) Interference, signal strength, bit and packet error rates; (2) trigger packet transmission and read out of data from stations; (3) fault tolerance, via fault injection experiments where nodes are purposely put into a failure mode; (4) network capacity, via the introduction of fake traffic.

The critical factor in determining the feasibility of a radio communication link is the received signal strength at the input to the radio receiver. In summer 2008 Auger collaborators made a radio survey of the R&D positions testing each radio link and determined that calculations based upon digital elevation maps of the area and a single knife edge diffraction model accurately predict measured pathlosses.

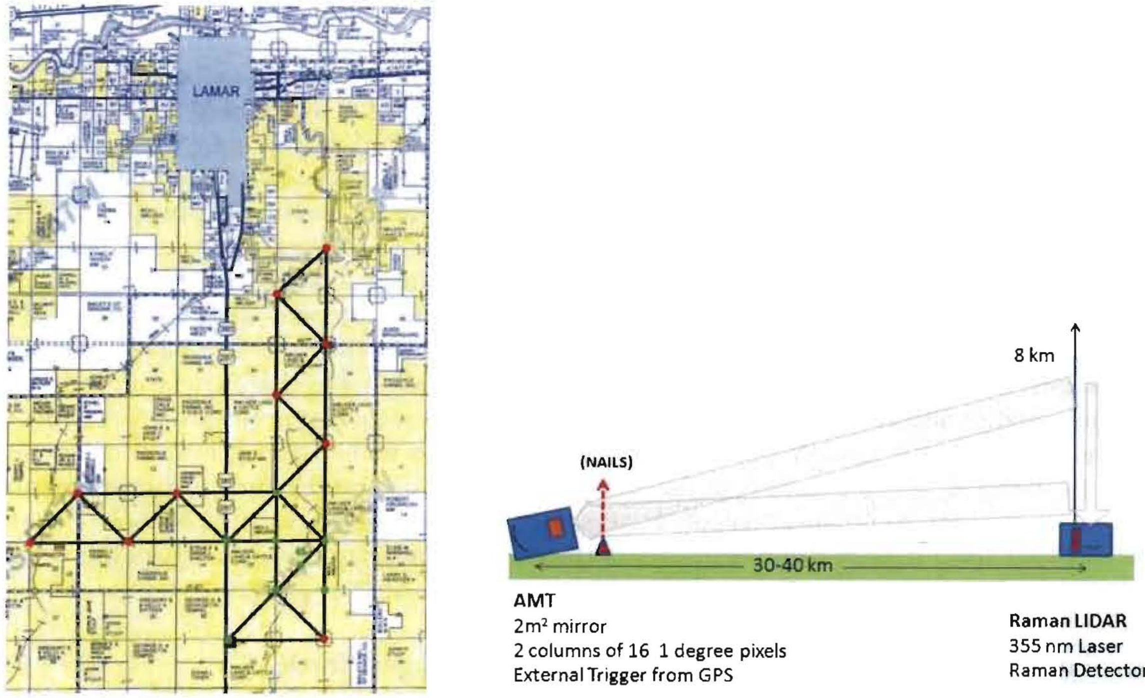

Figure 13: *Left:*R&D array for Auger North. Green circles indicate planned fully instrumented Auger North surface detector stations, and red circles are stations with only communication equipment. The headquarter is at the southernmost green circle, a county building along the main highway US287. *Right:* The laser and Raman LIDAR will be located at the county building, and the atmospheric monitoring telescope will be 38.8 km southeast near the community of Two Buttes.

5.2 Atmospheric monitoring

A database of aerosol vertical optical depth profile measurements will be collected at the northern site over the distances expected for the trans-GZK energy air-shower measurements. The configuration will follow that used at the southern site: an FD telescope recording tracks from a distant vertical pulsed UV laser. We have obtained from Columbia University Nevis Laboratory a simplified FD telescope for this purpose. It will view a 355 nm laser 38.8 km distant (see right panel of Fig. 13) with the FD and laser triggered externally via GPS. The sites where this equipment will be placed fall within the field of view of the S12 FD site (Fig. 8). Installation is in progress. Ideally, data collection should be carried out over a full 12 month period, but will require additional funding (see section 4.6). The laser system will include a back-scatter Raman LIDAR receiver to compare two methods of aerosol retrieval. The FD will be calibrated using a portable nitrogen vertical laser.

6 Broader impact

The Auger collaboration views the advent of Auger North as an opportunity to expand its Education and Outreach Task to promote both local and global efforts that inform and engage students, teachers, and the general public in the science of cosmic rays, particle physics and astrophysics, emerging technologies, and the excitement of discovery.

6.1 Training young physicists

Similar to Auger South, the success of Auger North will rely heavily on U.S. postdocs, graduate students, and undergraduate research assistants who are supported by the base-funding grants of the university groups or other sources. As an example, in September 2009, seven U.S. universities (Chicago, Colo. School of Mines, Colo. State, Michigan Tech, Nebraska, Ohio State, and Penn State) submitted a proposal to NSF's Program in International Research and Education (PIRE) to support postdocs and students to work on Auger South and North, partly in residence at their home institutions and partly at one of several collaborating institutions in Argentina, France, and Germany. The PIRE program extends student recruitment to a broader community (2-year colleges, rural, and underrepresented groups) by involving the City Colleges of Chicago and Lamar Community College in southeast Colorado. Basing Auger North development work in-house at U.S. universities affords hands-on involvement of students both during the academic years and summers. The proximity of Auger North to U.S. universities will allow a greater fraction of students to spend significant periods at the site during the R&D and the construction phases. We expect an educational climate at Auger North similar to Auger South where professors, postdocs, and students from different universities and countries collaborate closely, exchanging not only technical and scientific progress but also contrasting cultures and languages.

6.2 The Auger Education and Outreach Task and Auger North

Education and public outreach (EPO) have been an integral part of Auger since its inception. The collaboration's EPO activities are organized in a separate Education and Outreach Task, established in 1997. Elements include a Visitor Center in the Auger office building in Malargüe which has hosted over 40,000 visitors since 2001, frequent public talks, visits to schools, hands-on courses for science teachers, science fairs sponsored by the Observatory in 2005 and 2007, and science museum exhibits. The Task also maintains online resources that include a Google Earth tour of the Observatory (both sites) [48] and selected recorded air-shower events released for students and teachers to study [49] (available in several languages).

Outreach efforts to convey the excitement of Auger North are already underway. In 2007, the collaboration designated Lamar Community College (LCC) as the Outreach and Education Host Institution for Auger North. LCC employed an Auger outreach coordinator from January 2007 to June 2009. This person has moved to another position, and a search for a replacement is in progress. Examples of Auger North outreach projects, completed or continuing, include the following: The Auger/LCC outreach coordinator and other collaborators have presented talks or hosted public discussions at regional schools and civic or local government groups. SD tanks with the Auger South design are prominently displayed in two of the cities (Las Animas and Lamar) that lie in the footprint of the Auger North surface array. Names for the tanks, Cosmos and Pierre's Dream, were provided by grade school children who were recognized at an unveiling ceremony in October 2007. A temporary Visitor Center was inaugurated at this time in the LCC library. In 2008, two students from Lamar High School won a regional science fair and college scholarships with a project that drew on the publicly-released air-shower data from Auger South.

Several concrete initiatives are foreseen as starting points, some of which call for funding beyond the scope of this proposal. A state of the art Visitor Center is foreseen to be integrated into the Auger campus at LCC. LCC and the collaboration are jointly developing an undergraduate honors science curriculum that provides student research experiences with Auger scientists. A growing number of U.S. institutions plan to become involved in local versions of Nebraska's ongoing Cosmic Ray Observatory Project [50] which enlists teams of high school science teachers and students in the study of cosmic rays using school-based detectors. Presentation materials (Visitor Center talks, information brochures and posters) and online resources will follow the evolution of Auger North R&D and eventual construction. We will explore programs to link Latino students and teachers in southeast Colorado with their counterparts in Argentina. Throughout this process, emphasis will be placed on conveying the opportunities Auger can provide for young physicists and for populations underrepresented in science.

The Observatory is engaging local communities and individual landowners since almost all of the SD stations will be located on private land. Through town meetings, outreach presentations and fliers, the local population has been contacted and informed of our plans. LCC continually contacts local people through the Auger outreach program there, including the interim Visitor Center. For the site selection process in 2005 we contacted landowners south of Lamar with the help of the Southeast Colorado Enterprise Development (SECED). We were able to gain unofficial permission for about 85% of the tank positions on an area larger than Auger South, which was the goal at that time. This process will ramp up as we move into the R&D phase in 2009/10.

6.3 Economic impact in southeastern Colorado

Auger North will bring significant economic benefits to southeast Colorado. The city of Malargüe has reaped benefits over the years of construction and operation of Auger South. Presently, there are 20 permanent jobs in Malargüe with about twice that during construction. Auger North will be significantly larger, therefore generating more jobs in this economically-depressed region. Economic impacts will also result from biannual Auger collaboration meetings, which will bring more than 200 Auger scientists and engineers for a week or more to local hotels and restaurants. As an indication, the Malargüe Chamber of Commerce estimates that business has increased by about 16% partly due to the Observatory.

6.4 Using renewable energy to power Auger North

The State of Colorado is at the forefront of renewable energy development in the U. S., and Colorado Amendment 37 requires power companies to provide 10% of their production by renewable energies by 2017. In southeast Colorado, a major wind farm is already in operation south of Lamar. Auger North has a unique opportunity to showcase the use of renewable energy in a large scientific experiment. Every water Cherenkov tank is powered by solar panels. Renewable energy can also power the FD buildings and the main building on the Auger North campus using a combination of solar panels and the wind farm. Other options are being discussed with energy experts from Auger institutions. Xcel Energy, the electricity distributor in the Front Range, has shown interest in this effort, and is already contributing to the development of the R&D array. They are also considering contributions to the full array. This initiative could benefit LCC, with the development of an education program in renewable energy.

7 Timeline and management plan

The Pierre Auger Observatory will occupy sites in the northern and southern hemispheres. The two sites, located in the United States and Argentina, will operate as a single instrument: the Pierre Auger Observatory. The Pierre Auger collaboration comprises physicists from 18 different countries: Argentina, Australia, Bolivia, Brazil, Croatia, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Poland, Portugal, Slovenia, Spain, United Kingdom, United States and Vietnam. There are now more than 90 participating institutions. Each country has signed the letter of intent to P5 saying that they support the proposal for Auger North and they intend to be participants in it. The U.S. plays a major role, as Jim Cronin was the driving force in its formation, and the project management office is hosted by Fermilab. This proposal assumes that the project management office for Auger North will also be hosted by Fermilab. The Pierre Auger Observatory project is unique in that it is a true partnership in which no country, region or institution dominates. Leadership positions and responsibilities are well-distributed among the collaboration. Indeed Auger is a model for international science projects.

The organizational structure for the Pierre Auger Observatory project was developed in 1998 with the expectation of building observatory sites in both the northern and southern hemispheres. The successful completion of Auger South on budget in 2008 and publication of important physics results have demonstrated the effectiveness of the organization. No significant change in the organization and management is expected in undertaking the construction and operation of Auger North, while continuing to operate Auger South.

7.1 Cost and Schedule

The Auger North cost estimate and schedule are based on direct experience with Auger South. As in Auger South, the budget is derived using a bottom-up work breakdown structure (WBS) analysis with contingency. A five-year construction plan is shown in Table 2. The total construction cost estimate for Auger North including contingency and escalation is summarized in Table 3. Salaries for collaborating scientists and their support such as travel are not included. The cost in 2009 dollars is expected to be about $127M.

Total estimated annual operating cost for Auger North, projected from Auger South, is estimated to be $5.4M per year.

Year	*Milestones*
1	Campus: complete office & assembly buildings FD: construct 1st 12-telescope enclosure; install telescopes 1–6 SD: procure detectors 1–100; install detectors 1–50
2	FD: construct 2nd 12-telescope enclosure; install telescopes 7–18 SD: procure detectors 101–1000; install detectors 51–400
3	FD: construct 1st 6-telescope enclosure; install telescopes 19–30 SD: procure detectors 1001–2400; install detectors 401–1000
4	FD: construct remaining enclosures; install telescopes 31–39 SD: procure 2401–3600; install detectors 1001–2500
5	FD complete SD: procure remaining detectors; install detectors 2501–4400

Table 2: A summary level schedule for the Auger North construction.

7.2 Funding

Funding for Auger South is expected from all of the currently participating countries as well as from new countries that we hope will join the collaboration. As in Auger South, the contribution of each participating country to the construction will be 80% in-kind and 20% to the common fund, as specified in the Pierre Auger Observatory international agreement. In the U.S., the NSF and DOE have contributed equally to the construction of Auger South and the same cost sharing is anticipated for Auger North. The U.S. share of the Auger North construction budget is expected to

WBS	Activity	Base Cost	Escalation	Contingency	Total Project Cost
		M$	M$	M$	M$
	AUGER NORTH Project	91.67	9.05	25.43	126.75
1.0.	FLUORESCENCE DETECTOR	24.13	2.40	6.44	32.97
1.1	FD System	20.10	1.97	5.73	27.81
1.2	FD Electronics	4.03	0.42	0.71	5.17
2.0	SURFACE DETECTORS	49.10	5.04	13.83	68.57
2.1	Surface Detector System	32.63	3.57	8.16	44.95
2.2	Surface Detector Electronics	16.47	1.48	5.67	23.62
3.0	COMMUNICATIONS	5.27	0.46	1.05	6.78
4.0	CENTRAL DATA ACQUISITION	0.23	0.00	0.12	0.35
5.0	DATA PROCESS & ANALYSIS	0.60	0.12	0.36	1.08
6.0	SITE DEVELOPMENT	7.90	0.69	3.32	11.91
7.0	PROJECT MANAGEMENT	4.44	0.33	0.32	5.09

Table 3: Cost estimate summary for Auger North. Escalation shown in the table assumes a 2010 start; if the project starts in 2011, total escalation is projected to be $11.2M, i.e., $2.1M more than indicated above.

be $40M. The State of Colorado is expected to contribute to some of the infrastructure and provide help with land access.

7.3 US institutions

In Auger South, US construction funds were granted to the Universities Research Association (URA) which sub-contracted them to Fermilab. These funds were then dispensed under the direction of the project manager to the participating US institutions via a process of memoranda of understanding (MOUs) and purchase orders.

For Auger North we expect to follow a similar model, modified only due to the change of management contractor organization to the Fermi Research Alliance (FRA). Aside from work done at Fermilab, the work will be further contracted to the collaborating institutions by MOUs.

The contributions of the US collaborating institutions to construction of Auger North are indicated in Table 4. Some construction contributions, such as software development by the collaborating scientists, are funded through their operating grants. These are separately identified in the table.

7.4 Results from prior NSF and DOE support

Prior support from DOE and NSF has been vital for the construction and operation of Auger South. Project management for the Observatory is hosted by Fermilab, and 16 US institutions have made important contributions with support from NSF and DOE. The Pierre Auger Observatory has already produced a better understanding of ultra-high energy cosmic rays and posed new questions about the nuclear mass distribution of the particles and the astrophysical sources that produce trans-GZK particles in the nearby universe. Please see sections 1, 2, 6, and 7 for more details regarding the results of prior funding and the international collaboration.

Institution	*Fluorescence Detector*	*Surface Detectors*	*Data Comms*	*Central DAQ*	*Data Processing*	*Site Development*	*Project Management*	*Outreach*	*Source of Support*
Case Western Reserve U.	Y	X	X	Y				Y	NSF
Colorado School of Mines	X	X	X			Z		Y	NSF
Colorado State U.	X	X				Z		Y	DOE
	X							Y	NSF
Colo. State U.-Pueblo		X						Y	NSF
Fermilab		Y	Y	Y			X		DOE
							X	Y	NSF
Louisiana State U.	X								DOE
New York Univ.					Y			Y	NSF
Northeastern U.		Y			X			Y	NSF
Ohio State U.		X						Y	NSF
Penn. State U.	X				Y			Y	NSF
U. of Chicago		X						Y	NSF
U. of Nebraska	X							Y	NSF
U. of New Mexico		X						Y	DOE
Michigan Technological U.	X	Y	X						DOE
U. of Wisc.-Milwaukee				Y	Y			Y	NSF

Table 4: Planned contributions of US institutions to the construction, deployment, and commissioning of Auger North. funding. Task contributions funded by this proposal are indicated by an "X". Task contributions supported by operating grants are indicated by a "Y" ("Y" is a subset of "X"). Tasks expected to be funded from other sources (eg. state funding) are indicated by a "Z"

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Budget Justification

The Auger Collaboration will be the first international organization in astroparticle physics that builds and operates two very large observatory sites. The appropriate organization structure for this endeavor is already in place. The Auger Project is a partnership where no institution, country or region dominates. Cost and schedule tools are adapted to the particular needs of this partnership, in which many countries have different accounting methods. In general, the contribution of each participating country to project construction will be 80% in-kind. The remaining 20% will be contributed to a common fund that pays for items that cost too much for any one country. The Auger Common Fund account resides at CERN. The CERN Auger team account also serves as a convenient place to receive and disburse operating funds.

WBS Methodology

Work Breakdown Structure (WBS) elements are developed in detail for every activity and component. Each WBS element has a cost estimate which combines the following information: number of units required, labor cost, materials and supplies (M&S) cost, engineering / design / inspection / acceptance (EDIA) costs, indirect costs, and estimates for escalation and contingency. The cost estimate is developed using a bottom-up approach. We estimate the cost for each task-level WBS element, and each subsystem is the roll-up of all its lower level (task level) components. A description of how the cost for each WBS element was estimated is found in the Basis of Estimate. Generally, the basis of estimate is derived from our knowledge of materials, supplies, and commodities costs, labor rates, and other factors that directly impact the cost.

The value of all labor and material is converted to nominal US dollars. In the case of some of the collaborating countries where the value of existing institutional infrastructure is not included in construction grants from funding agencies, the value of that infrastructure contribution is estimated and included in the WBS. The estimated total construction cost of Auger North, including contingency, is $127M. Fund raising efforts are ongoing in all member countries.

US Contributions

The portion of the construction cost that is anticipated to come from US funding agencies, i.e., NSF and DOE, is about $40M, split equally between these agencies. A breakdown of the costs and anticipated contributions is shown in Table 1. The main subsystems for which the US will provide substantial contributions are the Surface Detectors, Communications, and Project Management. The US will also provide calibration and monitoring for the Fluorescence Detectors. Like all countries collaborating on Auger, the US will contribute to a Common Fund, which will be used to purchase high-cost components such as Photomultiplier tubes and polyethylene resin.

We are also expecting support from the State of Colorado for infrastructure and site development costs. This includes the construction of central campus buildings and landowner access rights. These costs are estimated to be $11.9M.

The major cost item of the Surface Detectors is the rotomolding of tanks. Tank rotomolding, based on vendor estimates, is expected to cost $21.6M for 4,400 tanks. Tanks will be insulated by spraying on polyurethane foam, and this is expected to cost $4.8M total. The total expected cost for the Surface Detector tanks, including equipment and shipping, is $27.1M. The requested DOE share of this cost is $5.7M. Other major components of the Surface Detectors for which funds are requested from DOE include the ultrapure water for the SD tanks ($468k), and assembly and deployment costs ($3.2M). The total requested support from DOE for the SD system is $9.4M.

The US contribution to the Fluorescence Detector system will include calibration and atmospheric monitoring. Requested DOE support is $448k, which includes funds for relative and absolute calibration equipment.

The US will be a major contributor to the Communications system. This system is estimated to cost $6.8M. The major subsystems for which DOE funds are requested is the antenna system ($551k), radio boards ($1.76M), radio enclosures ($599k), the test rig ($230k), and the concentrator stations ($156k). Total requested DOE support for the Communications system is $3.50M.

This proposal assumes that the project management office will be located at Fermilab. Project management costs are proposed to be divided between NSF and DOE. These costs are estimated to be about $5.1M. Salaries for scientists and their support, e.g., travel, are not included.

WBS	Activity	Total Project North w/ Contingency K$	common fund	US / DOE	US / NSF	US (Colorado)	Non-US contributions
	Observatory total	**126,747**	**21,955**	**15,887**	**16,012**	**11,908**	**60,984**
1.0.	**FLUORESCENCE DETECTOR**	**32,972**	7,231	448	1,647	0	23,646
1.1	FD System	27,806	7,231	448	1,647	0	18,480
1.2	FD Electronics	5,166	0	0	0	0	5,166
2.0	**SURFACE DETECTORS**	**68,568**	14,725	9,398	10,568	0	33,878
2.1	Surface Detector System	44,953	7,538	9,398	10,568	0	17,449
2.2	Surface Detector Electronics	23,616	7,187	0	0	0	16,429
3.0	**COMMUNICATIONS**	**6,779**	0	3,497	927	0	2,355
4.0	**DATA ACQUISITION**	**350**	0	0	0	0	350
5.0	**DATA PROCESS & ANALYSIS**	**1,081**	0	0	327	0	754
6.0	**SITE DEVELOPMENT**	**11,908**	0	0	0	11,908	0
7.0	**PROJECT MANAGEMENT**	**5,087**	0	2,544	2,544	0	0
	Subtotal			15,887	16,012	11,908	60,984
	Contribution to Common Fund		**22,032**	3,972	4,003		14,057
	Total contributions			**19,859**	**20,015**	**11,908**	**75,041**

Table 1. Overview of costs, including contingency, for Auger North. A breakdown of anticipated contributions from US funding agencies, the State of Colorado, and foreign funding agencies is shown.

Escalation

The base costs for construction are stated in 2008 dollars. Since the project is expected to be spread out over approximately 5 years, costs are escalated to estimate the impact of inflation. Forecasts of inflation over this long a period of time are highly uncertain. With this in mind, our approach is to estimate the annual number of surface detectors and fluorescence telescopes to be procured, assembled, and deployed. An annual inflation rate is applied separately for labor and for M&S. Since the US is the host country for Auger North, it is appropriate to use escalation rates estimated by the US Dept. of Energy, which are 2.0% per year for labor, and 4.5% per year for M&S. Certain processes and commodities, however, may have significantly different inflation estimates. In particular, for civil construction, we use 6.3% per year, and for polyethylene resin, we use 5.65% per year. These values were obtained from historical data collected by the US Bureau of Labor Statistics.

Contingency and Risk Factors

Each WBS element has a contingency factor applied which is an estimate of the uncertainty in the cost due to risk. Unless otherwise specified in the Basis of Estimate, we assign 10% contingency where a recent vendor quotation is available. In cases where catalog prices or other general information from vendors are available, we assign 20% contingency. If engineering and design of a part is required, but the conceptual design is considered fairly sound, we assign 30% contingency. For certain specific WBS items, where the cost has been estimated by qualified consultants, we have used their judgment. In particular, for the construction of the office and assembly buildings, we use 45% contingency, since this is the percentage nominally used for this type of civil construction. The overall project contingency calculated in the cost estimate comes out to be about 20%. This number reflects the fact that we are essentially reproducing the detector components in Auger South for which we have well-understood costs.

Another risk factor is in project funding. In the Auger project there are no legally binding agreements that define the commitments from the participating countries. Completing the full scope of the Auger North project requires that all collaborating countries deliver their promised contribution. The past three decades of large high energy physics experiments that depended on the good will of the participants have been remarkably successful. In fact, participants typically contribute more than they originally promise. Nevertheless there is a risk in international science projects that one or more of the partners may not be able to provide their promised contributions for reasons beyond their control. To mitigate this risk we incorporate a sliding scope contingency beginning at 20% of the total project cost. Since the components of Auger North are modular we devise a plan that contains fewer fluorescence telescopes and/or surface detector stations to accommodate a reduced construction cost. Any reduction in scope, however, entails a corresponding reduction in physics achievement and/or an inefficient extension of the construction in time. We have a construction plan that assumes the full construction and one in which the final scope reaches 80%. As construction proceeds, the funding is reviewed at regular milestone check points and if funding is on track the scope contingency is reduced to reflect progress toward full completion.

Indirect Costs

Table 2, below, shows the calculation of the indirect rates to the project. The total requested direct contribution to Auger by DOE, obtained from Table 1, above, is $19,859k. An annual indirect cost is assessed by Fermilab on pass-throughs to the other US institutions. The pass-through indirect rate is currently 1.5% of the first $500k per year.

Base total DOE	$19,859,000	
Base annual	$3,971,800	
Indirect cost	$7,500	1.50%
total annual DOE	$3,979,300	
n-years	5	
total request DOE	**$19,896,500**	

Table 2. Annual and Cumulative budget requests from DOE with indirect cost applied.

Funding Profile

A simple flat funding profile is assumed, as shown in Table 3.

Year	2011	2012	2013	2014	2015
Base annual	$3,971,800	$3,971,800	$3,971,800	$3,971,800	$3,971,800
Indirect cost	$7,500	$7,500	$7,500	$7,500	$7,500
total annual DOE request	**$3,979,300**	**$3,979,300**	**$3,979,300**	**$3,979,300**	**$3,979,300**

Table 3. Funding profile for the DOE budget request over the five years of the project.

Supplementary Documents

An appendix containing supplementary documents in support of this proposal follows. These documents are:

1. A letter from environmental attorney James W. Spensley to Prof. John Harton concerning his environmental review of the proposed Auger North site.
2. An environmental review of the proposed Auger North site prepared by James W. Spensley.
3. A letter from the Division of Wildlife, State of Colorado, to Prof. John Harton, regarding general comments and recommendations on the environmental impact of the proposed Auger North site.
4. A letter from Bill Ritter, Jr., Governor of the State of Colorado, to Dr. Paul Mantsch, expressing his strong support for Auger North.
5. A memorandum from the Country Representatives of the member countries of the Pierre Auger Collaboration to the P5 chair regarding international enthusiasm and support for Auger North.
6. Fermilab Pass-Through Indirect Cost rate reduction policy.

Spensley & Associates
An Environmental Practice
1635 Ivanhoe Street
Denver, Colorado 80220

May 20, 2005

Professor John L. Harton
High Energy Physics Group
Physics Department
Colorado State University
Fort Collins, Colorado 80523

Dear Professor Harton:

At your request, I have completed an initial environmental review of the proposed Pierre Auger Cosmic Ray Observatory network proposed in southeastern Colorado. Based on my literature search of existing wildlife data and interviews with several state wildlife officials, I would conclude that any significant environmental impacts from the siting and operation of the instrumentation equipment located in the 1200 square mile area is highly unlikely.

I would recommend that at the time of final site selection, each candidate site be assessed to avoid intrusion upon potential sensitive habitat. Given the general character of the land in this area, there appears to be sufficient opportunity to avoid any sensitive habitat. In order to further avoid any conflicts, the actual placement of the tanks should be done outside the nesting season.

I have attached a short report of my findings and conclusions. If you have any questions, please give me a call.

Yours truly,

James W. Spensley
Environmental attorney and consultant

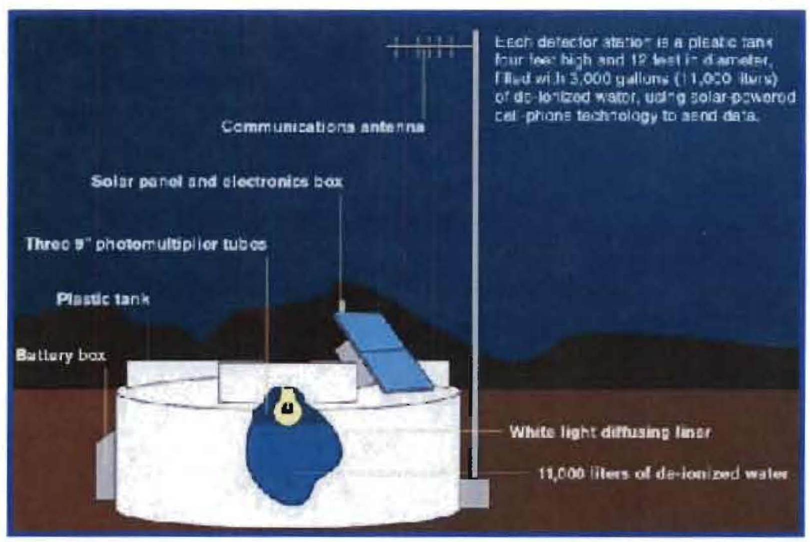
Telephone 303-888-1290 Email: JWSpensley@aol.com

ENVIRONMENTAL REVIEW
of the proposed
Pierre Auger Cosmic Ray Observatory project
Prepared by
James W. Spensley

Background

The Pierre Auger Cosmic Ray Observatory is an international project that plans the construction of a sophisticated network of cosmic ray detection stations – one network in the northern hemisphere and one in the southern hemisphere. The Auger Observatory is designed to link the detector networks in the northern and southern hemispheres to achieve nearly uniform acceptance to cosmic rays from all parts of the sky.

The detection system is comprised of 1200-1600 particle detector stations that form a giant regular array, or grid, covering about 3000 square kilometers. The detector tanks will be about 1.5 km apart. Each station is a four-foot-high, 12-foot-wide plastic tank filled with 12 tons of pure water and is self-contained operating on solar power. They are set directly on level ground without requiring any pad or extensive earthwork. The stations send back their data using cell phone technology, so no wiring is necessary. The tanks have Global Positioning Systems to precisely synchronize their clocks, and they record the timing of each signal to better than one ten-millionth of a second. The stations are designed to require only minimal maintenance and require 4-6 visits initially to get a tank commissioned, then only 1 visit every 3-5 years for maintenance.

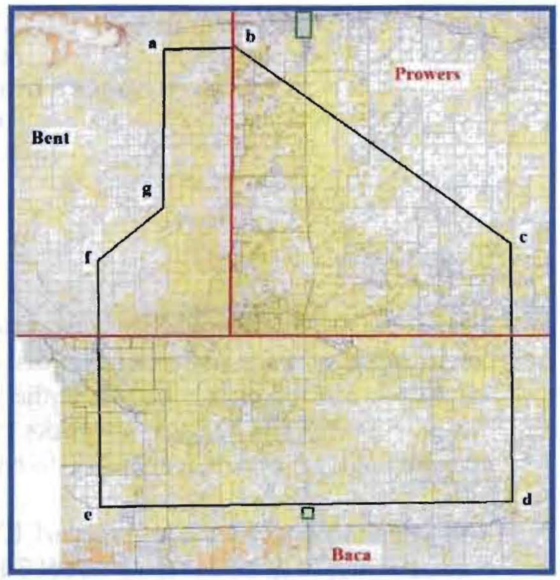


Instruments in each station will measure the number of particles passing through. Shower particles from a high-energy cosmic ray will reach several stations at the same time. When particles strike a station, a small computer will confer by radio with computers in a central data center to decide whether the particles are part of a large shower. If so, information about the shower will be transmitted to the data center. Computers at the data center will combine the measurements of the number of particles and their time of arrival at each station to determine the direction and energy of the original cosmic ray that set off the shower.

Proposed Action and Location

The proposed action will be funded by the U.S. Department of Energy and the National Science Foundation through their respective physical science programs. The proposed project will site 1200-1600 tanks in Prowers, Bent and Baca counties in southeast Colorado on private land. The precise locations within the grid will be determined after a survey of candidate sites and their availability is completed. Thus, this initial environmental review examines the potential environmental issues, if any, in the overall area with the proposed project or action. This review consists of a literature search and selected interviews with wildlife specialists.

Search area



General Environmental Issues

Because of the nature of this proposed research project, it is unlikely that any formal environmental analysis will be required by the state or federal sponsors. The Department of Energy and the National Science Foundation are both federal agencies subject to the provisions of the National Environmental Policy Act. Both agencies have "categorical exclusions" for this type of project that only requires a cursory review of the potential environmental impacts.[1]

Moreover, the stations do not require or anticipate any water discharges or air emissions. Further, the stations do not use any toxic or hazardous materials that could escape to the surrounding environment. From an aesthetic standpoint, the stations are not much more intrusive than livestock watering tanks – except that the Auger stations are completely enclosed and display an antenna and solar panels on the unit.

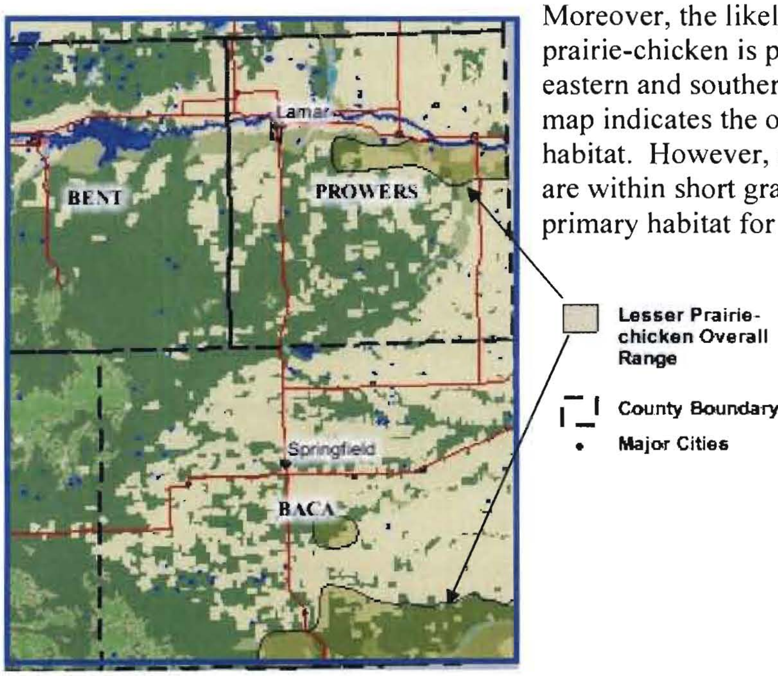
[1] The U.S. Department of Energy has NEPA implementing regulations at 10 C.F.R. 1021 et seq. that identify several categorical exclusions in Appendix B to Subpart D applicable to specific agency actions. Similarly, the National Science Foundation has NEPA regulations at 45 C.F.R. 640 et seq. that recognize categorical exclusions for most scientific research except for certain exceptions that physical intrusions on the natural environment.

Potential Wildlife Issues

A literature research and consultations were conducted with professionals at the Federal Fish & Wildlife Service, the State Department of Wildlife[2] and the Colorado Natural Heritage Program regarding potential wildlife impacts. The results indicated that each of the three counties has some federal or state listed threatened or endangered species within them.

Lesser Prairie-chicken

Of those listed species, the lesser prairie chicken would be of greatest potential concern; however, given the small footprint of the stations, the infrequent visitation needs and the predominant grasslands prevalent in the siting areas, it is unlikely that the stations would affect these species. Each station location would have considerable latitude in its specific location and could avoid any potential species habitat areas.



Moreover, the likely habitat of the lesser prairie-chicken is primarily located on the eastern and southern edge of the state. The map indicates the overall range of their habitat. However, most of the candidate sites are within short grasslands which are not the primary habitat for the lesser prairie-chicken.

Conclusion

Based on the literature research and consultations, it is my professional opinion that the Pierre Auger Observatory project proposed for southeastern Colorado can be successfully implemented without causing any significant impacts on sensitive resident wildlife or any other environmental resources.

---

[2] Consultation with Kevin Kaczmare, CDOW Conservation biologist

STATE OF COLORADO

Bill Ritter, Jr., Governor
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WILDLIFE

AN EQUAL OPPORTUNITY EMPLOYER

Thomas E. Remington, Director
6060 Broadway
Denver, Colorado 80216
Telephone: (303) 297-1192
wildlife.state.co.us

*For Wildlife-
For People*

March 31, 2009

Southeast Region Service Center
4255 Sinton Road
Colorado Springs, CO 80907

Mr. John Harton
Colorado State University
Department of Physics
1875 Campus Delivery
Fort Collins, CO 80523

Re: Pierre Auger R & D Project

Dear Mr. Harton;

The Colorado Division of Wildlife (CDOW) would like to thank you for the opportunity to provide recommendations on the Pierre Auger R & D Pilot Project located in Prowers County. Division staff has reviewed the information provided and respectfully provides the following comments.

Given the limited size of the current project, CDOW will only make general comments and recommendations; however, we wish to reserve the opportunity to provide additional, site-specific comments as the project expands across the larger landscape. CDOW's primary concern is the potential impacts to wildlife species in or near riparian and native short grass prairies.

Ecologically, riparian and wetland areas are rich with species diversity supported by cottonwood galleries, standing and free flowing water, sub-surface water levels, and aquatic vegetation. Typical of riparian areas are mature cottonwood stands which provide much needed raptor nest sites, dead snags for cavity nesting birds and provide structure and stabilization to stream banks. CDOW recommends that all tank placement and associated infrastructures avoid placement within or in close proximity to all riparian and wetland areas.

Native short grass prairies are highly valued for their ability to support obligate species. In Prowers County, riparian and native short grass prairies are found on only a small portion of the landscape, yet they are critical habitat for a high proportion of the counties' wildlife species: Burrowing Owl, Black-tailed prairie dog, Ferruginous Hawk, Swainson's Hawk, Prairie Falcon, Golden Eagle, Mountain Plover, and Swift Fox. Mountain Plover, a state species of Special Concern, have been sighted and nests observed within and adjacent to the project boundaries during the 2003-2006 breeding and nesting seasons. CDOW recommends that construction activity should be avoided during the critical nesting period –April 1st through August 15 where these species are found. However, if pre-construction surveys are initiated and absences of Mountain Plover noted, construction may begin at any time.

Though the project footprint lies within Lesser Prairie Chicken range, no known historic or active leks sites have been identified within the R & D project boundaries. CDOW does recommend that sensitive sand-sage habitat for this state listed bird be identified and considered during infrastructure placement and we suggest that as more detailed planning occurs, you continue to contact DOW representatives to determine specific sensitive areas for each of these species.

It would be very important that any disturbed soil in this area be replanted in native grasses as soon as possible to minimize loss of top soil and the introduction of invasive noxious weeds.

CDOW encourages, through thoughtful design and careful facility siting, any actions that avoid or minimize impacts to wildlife. If you have any questions regarding this letter, please contact District Wildlife Manager, Rick Gardner – (719) 940-3585.

Sincerely,

Dan Prenzlow
Regional Manager

Cc: Travis Black, AWM
Al Trujillo, Energy Liaison
Rick Gardner, DWM

STATE OF COLORADO

EXECUTIVE CHAMBERS

136 State Capitol
Denver, CO 80203 - 1792
Phone (303) 866-2471

Bill Ritter, Jr.
Governor

September 23, 2009

Dr. Mantsch
5640 South Ellis Ave.
Chicago, IL 60637

Dear Dr. Mantsch:

On April 14, 2009, I met with state Senator Ken Kester and physicists and administrators from Colorado School of Mines, Colorado State University at Fort Collins and Pueblo, and Lamar Community College. Their collective enthusiasm and emphasis on the scientific importance of Auger North or the northern hemisphere's Pierre Auger Observatory were extremely convincing, and I lend my full support behind efforts to ensure this project is a success.

The Auger North observatory is an important undertaking for Southeastern Colorado. Expenditures exceeding $100 million for the construction of the observatory will help revitalize the economy of this area by direct outlays and regular visitations. This international project consisting of seventeen countries and more than 300 scientists will culturally enrich all of Colorado. The project will raise the general awareness of science and technology in Southeastern Colorado among the general populous and especially among school-age students. The project can also be an exemplary green model for other undertakings in our state.

We are aware that the project will involve about $12M in infrastructure for things such as roads, buildings and power lines. We are considering various ways to help in this area, and I would like to visit again with Auger management to consider specific ways that the State of Colorado may be useful.

Thank you for proposing this world-class scientific installation in Colorado.

Sincerely,

Bill Ritter Jr.

Bill Ritter, Jr.
Governor

PIERRE
AUGER
OBSERVATORY

Wednesday, 27. February 2008

M e m o r a n d u m

From: Country Representatives of the Pierre Auger Collaboration

To: Professor Charles Baltay, Chair
Particle Physics Project Prioritization Panel

Subject: The Northern Pierre Auger Observatory

Dear Dr. Baltay:

This letter is to support planning for the northern site of the Pierre Auger Observatory. From its conception in 1992 and throughout the project's implementation in 1999, the Auger Project has been an international effort, which is not dominated by a single country. It represents *grass roots science* in its true sense, and is not based at large established laboratories.

The southern Auger Observatory was built first in the province of Mendoza, Argentina. It has delivered excellent physics data since January 2004 and has now yielded the equivalent of one year of full operation with 1600 surface detectors and 24 imaging fluorescence telescopes; the instrument covers an area of 3000 km^2. First results have been published in international conferences, refereed journals and notably in *Science* magazine of November 9, 2007.

In this letter we wish to mention some important aspects of international collaboration and global science in astroparticle physics, and we want to convey our unanimous enthusiasm and support for extending the Auger Observatory to the northern hemisphere. At the same time we confirm our commitment for the continuing operation of the southern Auger site.

The Auger Collaboration consists of more than 400 physicists from 17 countries. The contributions to the construction of the southern site have been provided by coherent efforts in all member countries, united by an excellent and efficient project management. The project goals have been met or exceeded in all cases.

The benefits for senior scientists and young researchers in all countries are enormous. To date, 85 PhD theses have been completed within the Auger project worldwide. The current number of PhD students is about 150. They all experience a unique international environment characterized by friendly competition and scientific stimulation.

The Auger Collaboration also conducts a vigorous outreach and education program. The visitor's center at the southern Auger campus in Malargue attracts 8,000 visitors every year; a preliminary visitor's center has been set up at Lamar Community College, which is ready to host the northern Auger campus.

Instruments like the Auger Observatory require a very large, flat, sparsely populated area with good atmospheric conditions for optical shower measurements. At the same time, infrastructure must be available or has to be created. The site chosen in south-eastern Colorado is the ideal, if not the only place in the northern hemisphere that meets our criteria. It was selected in a transparent process in 2005, supported unanimously be the entire international collaboration making a highly strategic decision. We are now ready to take the next step.

The efforts in our member countries have lead to financial shares of 50% from Europe, 30% from the U.S. (thereof two thirds from DOE and NSF, one third from other sources), and 20% from Latin America. We expect significant benefits for the host country and the state of Colorado; such benefits have been examined in an impact study conducted in Argentina and were found to be very substantial. The enthusiasm for advancing particle and astroparticle physics in an unprecedented way is very high in all our countries. Naturally, the emphasis may be different from country to country, but the key aspects of opening a new window to the cosmos, discovering how the Universe works at its fundamental level, and being at the energy frontier far above man-made accelerators are the most exciting aspects everywhere. In many countries we are about to initiate the formal recognition process for Auger North; it has just started in Germany.

The Auger Collaboration will be the first international consortium in this research area that operates two observatory sites on the globe within one collaboration. We are actively seeking to further strengthen our financial and human resources and are open to new groups, laboratories and countries joining the project.

Sincerely yours,

Alberto Etchegoyen, Argentina	Bruce Dawson, Australia	Carlos Escobar, Brasil
Jan Ridky, Czech Republic	Tiina Suomijärvi, France	Johannes Blümer, Germany
Giorgio Matthiae, Italy	Arnulfo Zepeda, Mexico	Ad van den Berg, Netherlands
Maria Giller, Poland	Mario Pimenta, Portugal	Danilo Zavrtanik, Slovenia
Enrique Zas, Spain	Alan Watson, United Kingdom	Paul Mantsch, USA

Associated countries are Bolivia and Vietnam

Fermi National Accelerator Laboratory

Pass-Through Order Indirect Rate Reduction

Purchase orders that meet the definition of a Pass-Through purchase order are eligible for a reduced indirect rate of 1.5%. The DOE often places funds in the Laboratory's Approved Financial Plan for a particular program or project, where a portion of those funds are intended to be provided to that program's/project's collaborating institution(s) to carry out their agreed-upon work (often specific WBS elements within the program/project). Pass-through orders are those which are transferring such funds to the collaborating institution. The reduced rate reflects the reduced indirect effort associated with such a procurement action. The reduced effort is primarily due to the program/project already having documented the agreement between the institutions, including deliverables, milestones, and due dates, most commonly through a Memorandum of Understanding.

Each request for pass-through action must have the approval of the Chief Financial Officer. All purchase requisitions representing approved pass-through actions must be recorded against expenditure type Subcontract Services Pass-Thru, or the exempt Pass-Thru expenditure type as discussed below. The electronic requisitioning system will then automatically route them for approval by the Chief Financial Officer. Requisitions requesting pass-through treatment must include evidence of the collaborative character of the work with respect to the program/project and must generally meet the condition of requiring reduced indirect effort.

Application of the pass-through rate is subject to the $500,000 ceiling like any other large cap order. Purchase requisitions representing a pass-through action in excess of $500,000 should be recorded against the exempt expenditure type Exempt - Subcontract Services Pass-Thru, instead of expenditure type Subcontract Services Pass-Thru. The electronic requisitioning system will then automatically route them for approval by the Chief Financial Officer.

If you have any questions about this policy, or need help determining whether or not it applies to your particular circumstances, you should see your Division/Section/Center Financial Manager.

Last Updated: November 18, 2008