The Pierre Auger Project

Technical Design Report

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The Auger Collaboration

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Forward

3-October-2001 Draft of the Pierre Auger Project Technical Design Report

The Technical Design Report is intended to give a complete technical description of the Auger Observatory detector system. On the date when this draft version of the report was assembled, a complete review of the baseline design had not yet been completed, and some final design decisions not yet made. As a result, this Design Report will contain some inconsistencies and open design choices.

This draft version of the Technical Design Report was prepared for use in the Auger Finance Board Review, to be held at the Auger Observatory in Malargüe, Argentina, on 27-30 October 2001.

Table of Contents

0. Introduction

0.1. The Pierre Auger Project

The Pierre Auger Project is an international effort to make a high statistics study of cosmic rays at the highest energies. To obtain full sky coverage two nearly identical air shower detectors will be constructed, one to be placed in the Northern Hemisphere and one in the Southern Hemisphere. Each installation will have an array of about 1600 particle detectors spread over 3000 km^2. Atmospheric fluorescence telescopes placed within and on the boundaries of the surface array will record showers that strike the array. The two air shower detector techniques working together form a powerful instrument for these studies. Construction has begun on the southern site of the Auger Observatory located in the Province of Mendoza, Argentina.

0.2. Technical Design Report – Scope and Organization

The objective of the Auger Project Technical Design Report is to provide a technical description of all of the components of the Auger Observatory. For details of the physics goals of the Auger Project in the context of current understanding of the ultra high energy cosmic rays refer to the Auger Design Report [1]. It should be noted that, since the Design Report was written, the physics goals have been enhanced by the prospect of neutrino detection.

The Technical Design Report follows the organizational structure of the project. The fluorescence detector effort is divided into the Fluorescence Detector System Task (mirrors, camera and structure) and the Fluorescence Detector Electronics Task. Similarly the surface detector is divided into the Surface Detector System Task (detector tanks, solar power, etc.) and the Surface Detector Electronics Task. The sections describing the Communications Task, the Central Data Acquisition System Task, the Data Processing and Analysis Task and the Site Development Task follow.

0.3. Observatory Performance Objectives

The scientific goal of the Pierre Auger Observatory is to discover and understand the source or sources of cosmic rays with energies exceeding 10^{19} eV. The method measures the energy spectrum, the arrival directions, and the nuclear composition of these particles. A detailed and thorough study of cosmic rays above 10^{20} eV is particularly important toward this end.

To achieve these goals it is necessary to measure the energy spectrum, to accumulate substantially more events than previous and current experiments, to determine accurately the arrival directions of the particles and to use the characteristics of the events to estimate the masses of the primaries. The experiment measures these properties of extensive air showers.

A unique feature and strength of the Auger Observatory is that it is a hybrid detector consisting of a surface detector and an atmospheric fluorescence detector. The duty cycle of the surface detector should be nearly 100% whereas the fluorescence detector duty cycle may be only

10%. The hybrid data set obtained when both detectors are working together will be especially important for evaluating the systematics of both detectors. It will also provide an energy spectrum with small energy uncertainties. The hybrid data set will also provide the best evaluation of the primary particle composition utilizing all of the known parameters that are sensitive to the primary particle type. The hybrid data set will be limited in statistics, however. At the highest energies, the spectrum and composition measurements will rely primarily on the surface detector alone. The correlation of hybrid and surface detector-only analyses in the high-statistics regime will justify the reliance on surface detector-only data at the highest energies.

The surface array measures the lateral density distribution of particles in the shower front. Muons and electromagnetic particles are separately identified. The shower energy is obtained by assessing the size of the shower, usually through the determination of the density at a particular radius of 600 to 1000 m. This method is fairly independent of the type of primary particle. The expected energy resolution [2] is shown in Table 0.1.

Table 0.1: Surface Detector Energy resolution.

RMS	12% for all events
	10% for events with energy > 10^{20} eV

About 6% of the error shown is measurement error. The rest, added in quadrature, is shower to shower fluctuation. These are fluctuations about a mean. There will be about a 10% systematic error that will come from the cross calibration with the fluorescence detector.

The direction of the primary is inferred from the relative arrival times of the shower front at different surface detectors. Reconstruction accuracy for the surface array [2] is summarized in Table 0.2.

Table 0.2: Surface detector direction error (Space angle containing 68% of the events).

Zenith angle	protons/iron		Unconverted photons*
	All energies	E > 10^{20} eV	
20°	1.1°	0.6°	4.0°
40°	0.6°	0.5°	2.5°
60°	0.4°	0.3°	1.0°
80°	0.3°	0.2°	1.0°

**Converted photons are easy to identify at the 10% level by shower front curvature, rise time and muon content.*

Heavy primary particles tend to produce more muons and fewer electromagnetic particles than do lighter primaries, when measured at the same total energy. Iron and proton showers can be differentiated using surface detector data alone through the analysis of the ratio of muons to electromagnetic particles, as well as through the arrival time distribution of particles in the shower front

The limiting aperture of the surface array is 7350 km^2-sr. for zenith angles of less than 60 degrees. If events above 60 degrees can be effectively analyzed, as appear likely, the above aperture will increase by about 50%. The efficiency for detecting events [2] is shown in Table 0.3.

Table 0.3: Surface Detector Efficiency.

Energy	Efficiency	
	Zenith angle < 60°	Zenith angle > 60°
1×10^{18} eV	0.00	0.00
3×10^{18}eV	0.30	0.50 @ 70°, 0.75 @ 75°, 0.80 @ 80°
1×10^{19} eV	0.98	1.00
3×10^{19} eV	1.00	1.00
1×10^{20} eV	1.00	1.00

The longitudinal shower profile measured by the fluorescence detector provides a nearly model-independent measure of the electromagnetic shower energy. The primary energy can be estimated as 10% greater than the electromagnetic shower energy, and simulations show that this estimate is systematically in error at most by 5%, regardless of the type of primary particles.

The Auger fluorescence detector is expected to operate always in conjunction with the surface detector. This is known as the hybrid mode. Its primary purpose is to measure the longitudinal profile of showers recorded by the surface detector whenever it is dark and clear enough to make reliable measurements of atmospheric fluorescence from air showers.

The fluorescence detector requirements are driven by $Xmax_2$ resolution that is necessary for evaluating the composition of the cosmic ray primaries. The $Xmax_2$ resolution (uncertainty in atmospheric depth where a shower reaches maximum size) should be small compared to the (approximately 100 g/cm^2) difference expected between $Xmax_2$ for a proton shower and for an iron shower of the same energy. Moreover, the experimental resolution should not significantly increase the spread of values for any one component of the composition by itself. The width of the expected $Xmax_2$ values for any nuclear type decreases with mass A and the distribution of iron $Xmax_2$ values has an rms spread of approximately 30 g/cm^2. We will therefore require that the experimental $Xmax_2$ resolution be no greater than 20 g/cm^2.

An accurate longitudinal profile (achieving 20 g/cm^2 $Xmax_2$ resolution) requires good geometric reconstruction of the shower axis. At large zenith angles, a small error in zenith angle causes a significant error in atmospheric slant depth. Averaging over the range of hybrid shower zenith angles (0-60 degrees) leads to a rule of thumb that an error of one degree in zenith angle leads to an error of 20 g/cm^2 in $Xmax_2$. The angular resolution of the hybrid showers must therefore be significantly better than 1 degree, since other uncertainties also contribute to the $Xmax_2$ uncertainty.

The longitudinal profile of each shower must be well measured in order to determine the depth of maximum to 20 g/cm^2. In particular, the profile will be well enough measured that the profile integral (proportional to the total shower electromagnetic energy) will have less than a 10% fitting uncertainty contributing to the shower energy uncertainty. Good energy resolution is therefore implicit in the $Xmax_2$ resolution requirement. The errors shown in Table 0.4 are statistical only. Hybrid performance is shown in Table 0.4 – Table 0.6.

Table 0.4: Hybrid Energy Resolution.

Energy	Energy Error			$Xmax_2$ Error		
	50%	68%	90%	50%	68%	90%
10^{18} eV	9.5%	13%	21%	21 g/cm^2	38 g/cm^2	74 g/cm^2
10^{19} eV	4.5%	6.5%	13%	14 g/cm^2	25 g/cm^2	62 g/cm^2
10^{20} eV	2.5%	5.5%	17%	12 g/cm^2	24 g/cm^2	69 g/cm^2

Table 0.5: Energy Resolution.

Energy			
	50%	68%	90%
10^{18} eV	9.5 %	13.0 %	21 %
10^{19} eV	4.5 %	6.5 %	13 %
10^{20} eV	2.5 %	5.5 %	17 %

Table 0.6: Direction Error.

Energy			
	50%	68%	90%
10^{18} eV	0.50°	0.73°	1.55°
10^{19} eV	0.35°	0.51°	1.10°
10^{20} eV	0.35	0.51°	0.90°

0.4. The Auger Observatory – An Overview

0.4.1. The Observatory Design

To obtain the performance goals shown above at minimum cost we have endeavored to optimize the integration of a large area surface array with an array of air fluorescence telescopes. The objective was to match the operational apertures of the two detectors so that the instantaneous fluorescence detector aperture matches the surface detector aperture.

For the surface detector, it is important to cover as much area as possible at the least cost while retaining the crucial knowledge of lateral distribution of the shower particles. The optimization process led to a detector spacing of 1.5 km. The total area of the array (3000 km^2) was chosen based on the statistics goal as well as an overall self-imposed cost constraint of about $50MUSD per hemisphere.

The number, distribution and resolution of the fluorescence telescopes was determined by the requirement that showers be visible over the entire surface array at energies above 10^{19} eV. The Auger Observatory will have a total of 30 telescopes located in four enclosures located within or on the edge of the surface array.

0.4.2. Observatory Site

The southern site of the Auger Observatory is located in western Argentina in the Province of Mendoza. The area covered by the array is an ancient lake bed sufficiently flat to accommodate line of sight radio communications between each detector station and one of four antenna towers located adjacent to the fluorescence detector buildings. On the boundary of the surface array, elevated surface features have been selected for the fluorescence buildings that elevate them above possible ground fog. Figure 1 shows the array and the positions of the four fluorescence detector stations.

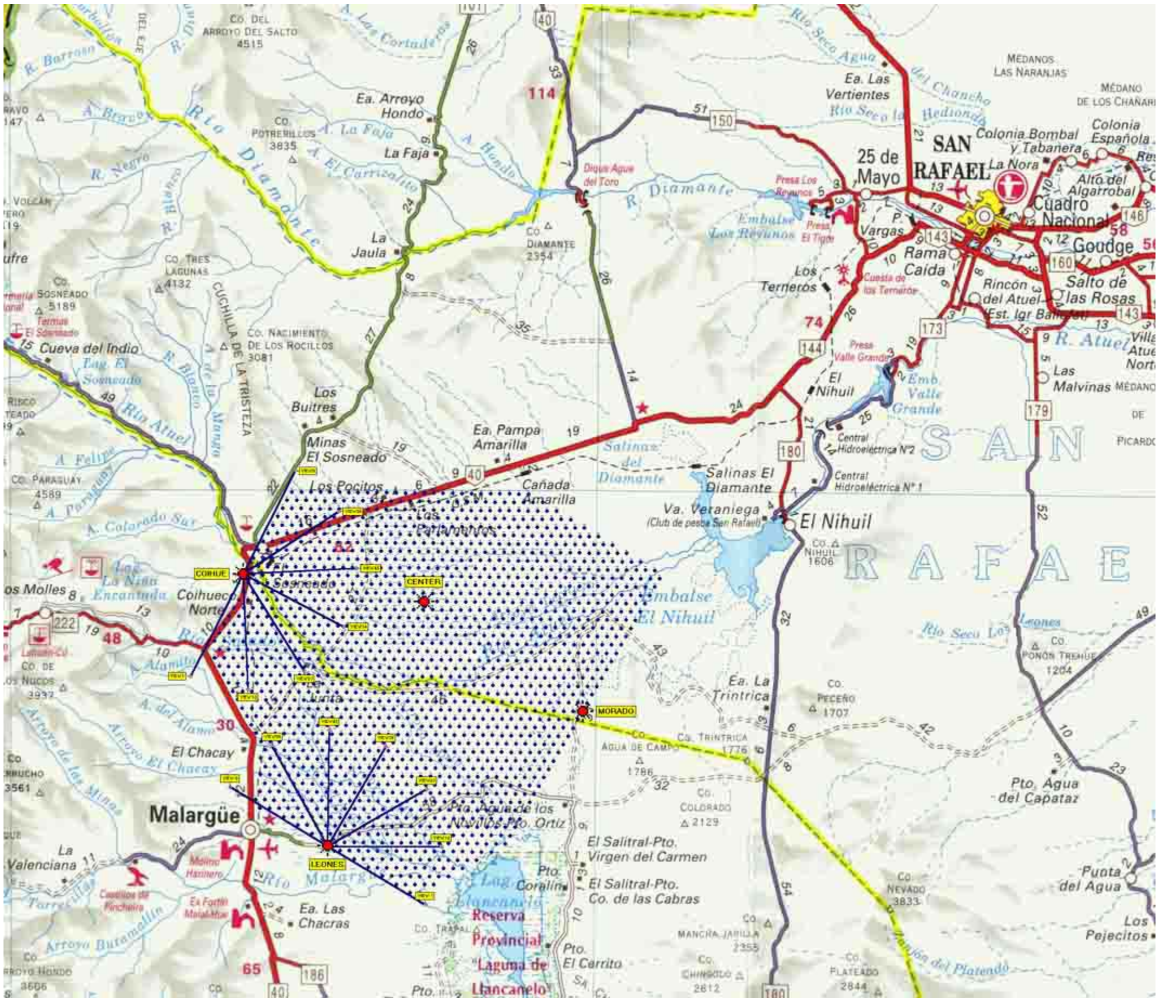

Figure 0.1: The Auger Observatory.

0.5. Construction Plan and the Engineering Array

The construction of the southern site of Auger Observatory was planned to take place in two steps. The first two years were devoted to the Engineering Array followed by three years to complete full observatory construction. The Engineering Array consists of 40 prototype surface detector stations and two-prototype fluorescence telescopes. The two fluorescence detector prototypes over look the prototype surface array. Construction of the Engineering Array began in January of 2000.

In the course of design and fabrication every detector system is subject to a series of technical reviews. The technical review panels typically consist of three reviewers from the collaboration and one or two outside experts. The Preliminary Design Review (PDR) validates the design for detailing and fabrication of prototypes. The Critical Design Review (CDR) validates the final design for pre-production or production. Pre-production of a limited number of units is intended understand production engineering, production cost and quality control processes. Pre-production is anticipated where large numbers units are involved. For the surface detector the number of pre-production units was chosen to be about 100. Components will be subject to a Production Readiness Review as required. Reports from these reviews are posted on the Auger web page.

Preliminary Design Reviews were held between December 1998 to September 1999 usually in conjunction with scheduled collaboration meetings. Prototypes of all components were produced for deployment in the Engineering Array based on the designs emerging from these reviews.

Drawing heavily on the experience of the Engineering Array, final production designs were prepared and were subject to Critical Design Reviews. The Critical Design Reviews were started in July 2001 and will be completed by December of 2001.

The objective of the Engineering Array was to evaluate the performance of every component and system in the field before proceeding to full production and deployment. We realize the following benefits:

1) Validation of the design and performance of the prototype surface detector stations with their power systems and electronics under field conditions.

2) Validation of the design and performance of the fluorescence detectors, their enclosure and supporting systems.

3) Test of the performance of the data communications system

4) Test of the data acquisition and data analysis systems.

5) Test of the performance of hybrid surface/fluorescence operation by simultaneous recording of showers.

6) Test of the surface detector deployment strategies subject to seasonal and weather constraints.

7) Understanding of the detailed costs of both the components and their installation in order to plan for production and full deployment. These costs are contained in the Auger Project Work Breakdown Structure (WBS).

8) Fine-tuning of the construction schedule based on actual installation experience and increased efficiencies.

The Technical Design Report was prepared when essentially all of components had been or were being tested in prototype in the field as part of the Engineering Array and most had been subject to Critical Design Reviews.

Full construction and deployment are expected to take three years. After the first year of construction, routine data taking will begin. At that time, the Auger Observatory will be the world's largest air shower array.

A description of project management tools such as the Work Breakdown Structure and the Project Schedule may be found in the Auger Project Management Plan (Auger Project Management Plan 26-June-2001).

References

[1] Pierre Auger Project Design Report, Nov. 1999.

[2] Pierre Billoir, Auger Technical Note GAP 2000-025.