The Auger Fluorescence Detector Prototype Telescope

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Abstract

The Pierre Auger Cosmic Ray Observatory will study cosmic rays above 10 EeV using both atmospheric fluorescence measurements and ground level particle detectors. A demonstration hybrid observatory will commence operation in Argentina's Mendoza Province next year (2000). This paper documents the design for the prototype fluorescence telescope whose field of view is 30x30 degrees. The large field of view is made possible by using a Schmidt diaphragm that eliminates coma aberration. Reflective light collectors at the focal surface resurrect dead spaces between PMT cathodes. The nearly uniform focal surface simplifies the translation of FADC data to fluorescence light flux as a function of time, and hence shower size as a function of atmospheric depth. The primary objective for the Auger fluorescence detector is to measure accurately the longitudinal development profiles of showers that are detected in conjunction with the surface array.

1 Introduction

In development since 1992, the Pierre Auger Project is a collaboration of physicists in 19 different countries, dedicated to the construction of a powerful new observatory for studying the highest energy cosmic rays (Cronin et al., 1992; Auger Collaboration, 1997). The detector will have good sensitivity to all cosmic rays above the spectrum's ankle, with constant aperture above 10^{19} eV. In order to achieve nearly uniform exposure to the full celestial sphere, the plan calls for two matching sites – one in Argentina's Mendoza Province and the other in Millard County of Utah. Work has begun at the southern site. The full-time aperture will be 7000 $km^2 \cdot sr$ at each site, provided by arrays of water Cherenkov detectors on the ground. Atmospheric fluorescence measurements of the air shower longitudinal profiles will be made at night using optical telescopes. The symbiotic operation of the surface array and fluorescence detectors (FDs) will provide a "hybrid" data set with redundancy, cross checks on systematics, and unprecedented sensitivity to primary particle types. This paper describes the present design for the Auger FD telescopes and plans for a prototype to become operational next year. Information about the Auger Project is available at *www.auger.org*, and further details about the FD can be found at *www.physics.utah.edu/∼sommers/hybrid/*.

2 The telescope design

The Auger FD telescope design is based on the successful Fly's Eye and HiRes detectors (Baltrusaitis et al., 1985; HiRes Collaboration, 1997). There are significant innovations, however, including

Schmidt optics and a new electronics design. (Plans for the FADC electronics and trigger system are reported separately.) In order to minimize measurement uncertainties due to the variable atmosphere, multiple "eyes" will be built so that showers will be seen at closer range and smaller factors will be required to correct for atmospheric attenuation by Rayleigh and Mie scattering. With the present layout plan for the southern site, the median R_p is 14 km, where R_p is the perpendicular distance between eye and shower axis.

Figure 1 is a schematic diagram of an Auger telescope. The field of view is approximately $30° \times 30°$. An aperture stop (diaphragm) eliminates coma aberration. With its spherical focal surface, the system is almost spherically symmetric about the point at the diaphragm's center. The spot size (point spread function) is governed by spherical aberration and is nearly the same for any arrival direction within the field of view. (There is some variation of the camera's obscuration.) Specific optical parameters and properties of this design are summarized in Table 1.

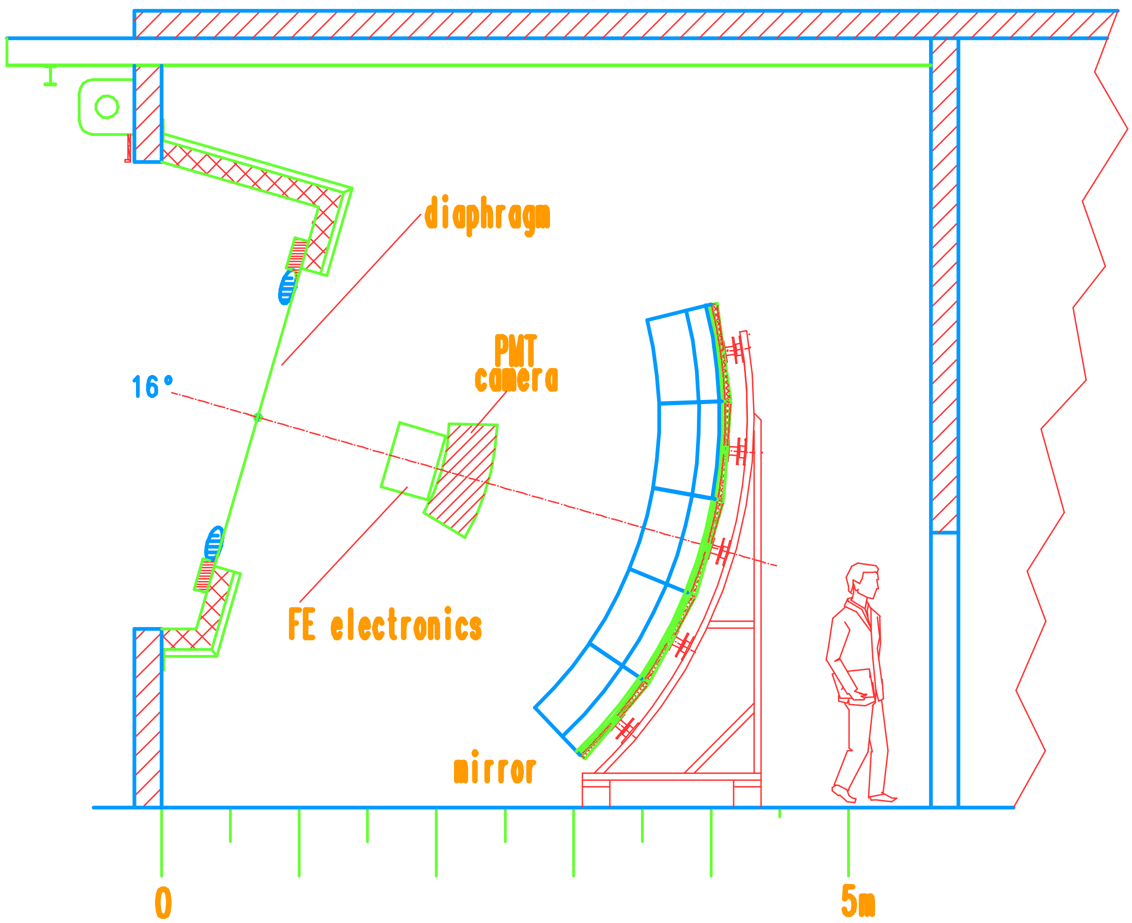

Figure 1: Diagram of Auger telescope design.

Table 1: FD Telescope Specifications

Field of view (FOV)	$30°$ azimuth $\times 28.6°$ elevation
Diaprhagm aperture	1.7-m diameter
Mirror radius of curvature	3.4 m
Mirror size	$3.5m \times 3.5m$ (square)
Mirror segmentation (probable)	5×5 almost square segments
Focal surface radius of curvature	1.743 m
Coma aberration	None
Spherical aberration	$0.5°$
Optical filter in diaphragm	UV transmitting 320-400 nm
Camera pixellation	22 rows with 20 hexagonal pixels each
Camera size	93 cm in azimuth, 86 cm in elevation
Camera shadow	35% at center of FOV, 20% at corners
Hexagonal pixels	$1.5°$ (45.6 mm) side-to-side
Hexagonal PMT candidates	Photonis XP3062 or Electron Tube 9974

The task of the FD is to measure air shower longitudinal development profiles. Exploiting only some timing information from the surface array, the geometry of the shower axis is accurately determined by a single eye (Sommers, 1995; Dawson et al., 1996). The place of light emission in the atmosphere is therefore known for the arriving light flux at each instant. Knowing the distance and atmospheric attenuation from that place, one can infer from the light flux the amount of emitted fluorescence light and therefore the shower size at that atmospheric depth. An accurate measurement of the light flux as a function of time is the paramount objective since it gives the longitudinal profile in this way.

The optical spot size ($0.5°$) will be small compared to the pixel size ($1.5°$), so the entire signal from a distant shower is normally captured by a single PMT at any instant. Signals (and backgrounds) need to be combined from multiple PMTs only when the spot is on the boundary between pixels. (With 100-ns FADC time slices, the duration of increased background noise can be accurately delimited.)

Uniformity of detector response over the focal surface is critical for achieving the paramount objective: a reliable measurement of light flux as a function of time. In particular, it is important that the response not depend strongly on whether the spot is near a pixel center or straddling the boundary between pixels. Highly reflective sloping walls will be positioned over the (dead) edges of PMTs to deflect the signal photons at pixel boundaries onto active cathodes.

The Schmidt optics (suggested first by the Auger group in Puebla) has some important advantages:

- Large field of view (reduced number of telescopes, fewer edge effects).
- Uniformity (no off-axis coma).
- Dust, temperature, humidity, and rodent control (using the optical filter as a window in the diaphragm).
- Relatively small shutters in front of the diaphragm suffice to close the telescope during the day-

light.

• The reduced number of telescopes makes it practical to house an entire eye within a single building.

The prototype will test the reference design and also some minor variations:

◦ By incorporating a Schmidt corrector plate, it may be possible to increase significantly the light collecting area (diaphragm) without degrading the spot size.

◦ All-aluminum mirrors and polished glass mirrors will be compared against simple slumped glass mirrors.

◦ Bonding small optical filters to the PMTs may have advantages over a large filter in the diaphragm.

3 Plans for the prototype

The FD prototype telescope will make hybrid measurements of air showers in conjunction with an "engineering surface array" consisting of 40 water Cherenkov tanks. The water tanks will have the 1.5-km separation of the reference design and will be arranged in a hexagonal pattern centered at a distance of 10 km from the prototype telescope. With a 10% duty factor for dark sky and good weather, the expected number of hybrid showers with this engineering array is 386 above 10^{18} eV in one year, with 9 of those showers above 10^{19} eV.

In addition, controlled tests of the FD telescope will be performed using a "laserscope" that can produce (upward-going) artificial shower tracks of arbitrary direction from arbitrary points on the ground. Light scattered from the laserscope's beamed UV pulse mimics the fluorescence emission from an air shower front. At the Argentine site's altitude, a 10^{19} eV shower at maximum size corresponds to Rayleigh scattering from a laser pulse of 210 μJ. These laser studies will test the telescope's important properties:

• Trigger efficiency. Does the telescope trigger on 210-μJ laser pulses over the part of the final surface array that it is expected to cover?

• Angular resolution. How well is the track-detector plane determined? Is the laser axis within that plane well determined using the "hybrid" timing information of the FD pixels together with the laser position and time of firing? The expected angular resolution is about $0.5°$.

• Longitudinal profile resolution. Lidar instrumentation operating in conjunction with the laserscope will provide a vertical profile of light that is scattered backward. This can be corrected for the combined Rayleigh and Mie differential scattering cross section to give the longitudinal profile that should be measured by the telescope.

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