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Optics and mechanics of the Auger Fluorescence Detector

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(on behalf of the Pierre Auger Observatory Collaboration)

Abstract. The design of the Auger Fluorescence Detector telescopes is based on the Schmidt system which avoids the coma aberration. The main components are a large spherical mirror with 3.4 m radius of curvature, a UV transmitting filter placed on the diaphragm and a light sensitive device (camera). Each telescope has a field of view of about 30x30 degrees.

1 Introduction

The basic function of the Fluorescence Detector is to measure the longitudinal profile of the shower produced by high-energy cosmic rays in the atmosphere. The desired resolution on the measurement of the shower profile implies the following requirements on the parameters of the telescope [1].

– Aperture with of at least 1.5 m^2 effective area for light collection

– Pixel size not larger than 1.5 degrees

We have adopted the Schmidt optics where the aperture of the system is defined by a circular diaphragm centered on the center of curvature of the spherical mirror [2]. The Schmidt optics offers the advantage of eliminating the coma aberration. The circle of least confusion ("spot") as given by the spherical aberration is independent of the incident direction. This nice feature of the Schmidt optics is obtained at the price of enlarging the size of the mirror with respect to the conventional design where the aperture is defined by the mirror itself.

For a given aperture the size of the spot due to the spherical aberration decreases with the radius of the mirror R as $1/R^2$. A reasonable compromise between the requirement of reducing the size of the spot on one side and technical complications and cost on the other side is the choice of the f/1 optics. The diameter of the diaphragm was fixed to 1.7 m, giving an effective area for light collection of 1.5 m^2 when the shadow of the camera is taken into account. The radius of the mirror is 3.4 m and the angular size of the spot from spherical aberration comes out to be 0.5 degree, i.e. 1/3 of the pixel size which was fixed to 1.5 degrees.

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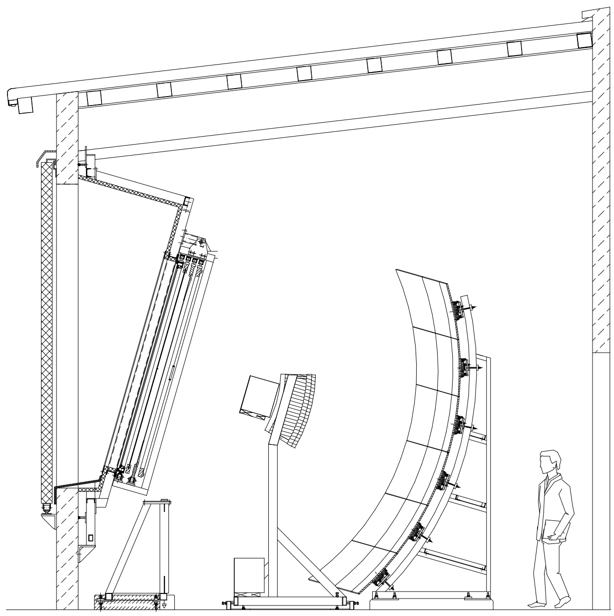

Fig. 1. The Auger Fluorescence Detector telescope.

The sensitive element of the telescope (camera) is an array of 440 hexagonal pixels placed on the focal surface. To each pixel a photomultiplier with photocathode of hexagonal shape is associated.

The main elements of the telescope are shown in Fig.1. From left to right we see the external shutter, the aperture system with the circular diaphragm and the UV transmitting filter, the camera and the large spherical mirror. The telescope is mounted inside a light tight enclosure.

A fluorescence detector "eye" is composed of six adjacent telescopes placed inside a building on top of a small hill on the Observatory site, near Malargue in Argentina.

Aperture of the diaphragm	1.7 m diameter
Light collection area	1.5 m^2
Mirror radius of curvature	3.4 m
Mirror size	3.5 m x 3.5 m
Pixel shape	hexagonal
Pixel size side-to side	1.5 degrees (45 mm)
Spot diameter	0.5 degrees (15 mm)
Field of view	30 degrees azimuth
"	28.6 degrees elevation
Telescope axis	16 degrees elevation
Camera size (hor x vert)	94 cm x 86 cm
Camera shadow	35% middle, 20% corners
Number of pixels	440

Table 1. *The basic parameters of the telescope.*

2 The UV filter

In order to reduce the dark night background with respect to the signal from fluorescence of the nitrogen, we make use of a UV trasmitting filter placed on the diaphragm [3]. The filter also serves the purpose of window of the telescope to protect the equipment from dust. Sheets of commercial M-UG6 glass, 3.25 mm thick, are used. The transmission curve peaks at about 85% for the wavelength of 350 nm and drops down to nearly 20% at 300 nm and 400 nm.

We expect a reduction of the dark sky background by about a factor of 8. However, the improvement on the signal-to-noise ratio which depends on the fluctuations of the noise varies with the square root of the background and is therefore only a factor of 2.

A picture of the UV filter is shown in Fig.2.

Fig. 2. Picture of the UV transmitting filter.

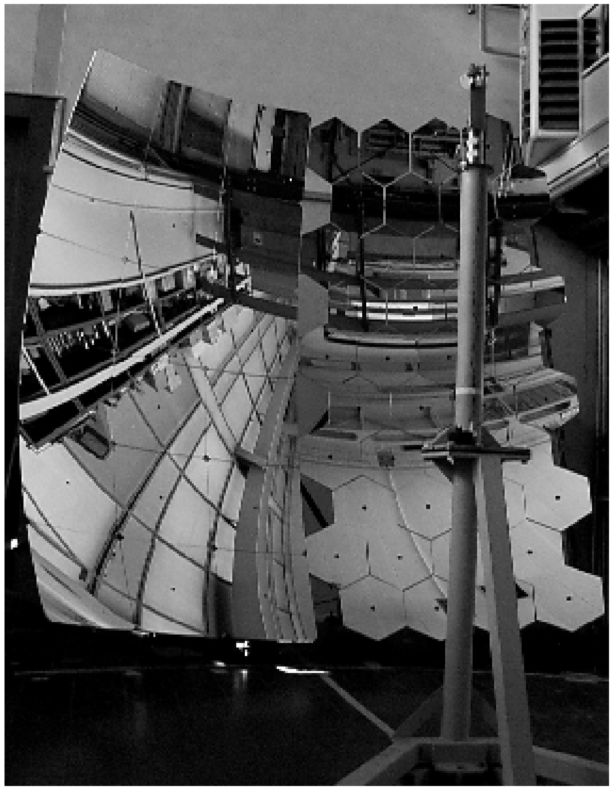

Fig. 3. Picture of the first telescope mirror. In this provisional mounting the aluminum mirrors (square shape) are combined together with the polished glass mirrors (hexagonal shape). The system for alignment is also visible on the front.

3 The mirror system

The telescope mirror is spherical with radius of curvature R = 3.4 m. The shape of the mirror is nearly square due to the square field of view. For practical reasons of construction it is segmented in 6 x 6 smaller elements.

The first prototype built for the Auger Engineering Array was made using the slumped glass technique. Glass sheets bent to the right shape using a mould were then aluminized. This technique is simple and inexpensive. The mirrors were found of good quality and within the specifications.

For the overall Observatory, however, it was decided to use two different techniques which allow better reproducibility. The first technique avoids the use of glass. The mirrors are made by machining a special aluminum alloy. The reflecting surface is covered by a protecting layer of Al_2O_3. In the second technique high quality glass mirrors are produced by machining and polishing. After aluminization the reflecting surface is covered by a layer of SiO_2.

A picture of the mirror system is shown in Fig.3.

Accurate quality tests were made on several samples of both, the aluminum and the polished glass mirrors. The reflectivity was measured at the wavelength of 370 nm. The geometrical accuracy of the reflecting surface was measured using a point-like source placed very near to the center of curvature. The intensity distribution on the image observed at the center

Fig. 4. Picture of the support structure of the mirror elements.

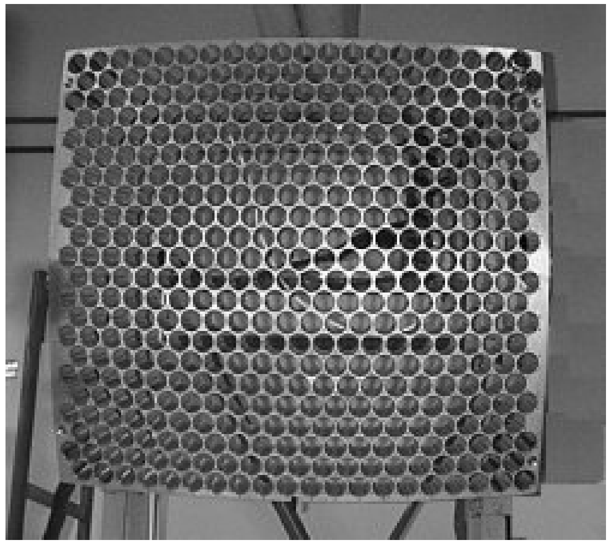

Fig. 5. Front picture of the camera body. The photomultipliers are inserted inside the cilindrical holes of the aluminum block.

of curvature reflects the geometrical accuracy of the mirror because for the small size mirror elements (about 60 cm x 60 cm) the spherical aberration is negligible. The integrated intensity of the reflected light was measured within a circle of 10 mm diameter. It was observed that most of the reflected light falls inside this circle. This result corresponds to what would be observed using a parallel beam of light in a circle of diameter equal to 5 mm, placed on the focal plane. Therefore we conclude that mirror imperfections contribute to the spot size by about one third of the effect due to the spherical aberration produced by the full mirror (the spot diameter from spherical aberration is 15 mm).

The results of the measurements of reflectivity (performed with protective layer) and of the integrated intensity are reported on Table 2. The quality of the mirrors produced with both techniques is very good, in fact better than our own specifications.

	Aluminum	Polished glass
Reflectivity	88%	86.3%
Integrated intensity	93%	98.7%

Table 2. *Results of quality tests on the mirror elements*

The mirror elements are mounted on a rigid support structure (Fig.4) where each element can be aligned independently. The alignment of the overall system, i.e. the mirror elements and the camera, is performed with respect to a mechanical reference point which defines the center of curvature. Distances from this point are measured with precision distance rods and also with an electronic device using a laser beam.

4 The camera

The actual focal surface of the telescope is spherical in shape. It is concentric with the mirror and has a radius of 1.743 m, slightly larger than the standard value R/2 = 1.70 m which refers to paraxial rays. The camera is an array of 440 hexagonal pixels arranged in such a way as to adapt on this spherical surface [4]. In practice the camera body is made of a single aluminum block. It consists of an accurately machined plate, 6 cm thick, approximately square (94 cm horizontal x 86 cm vertical) with inner and outer surface of spherical shape (Fig.5). The photomultiplier tubes are positioned inside cilindrical holes which are drilled through the plate. The photomultiplier array is made of 22 rows and 20 columns. We are using 8 stages hexagonal photomultipliers (XP3062) with active divider and grounded photocathode.

The hexagonal shape of the photomultiplier cathode ensures the optimal coverage of the focal surface. However, some space between the photomultiplier tubes is needed for a safe mechanical package. Moreover the effective cathode area is smaller than the area corresponding to the glass envelope of the tube.

In order to maximize light collection and guarantee a sharp transition between adjacent pixels, each photomultiplier is surrounded by a simplified version of the classical ”Winston cones”. The ”cone” is in fact realized by an hexagonal set of flat reflecting surfaces as shown in Fig.6. The basic element of the light collector is a ”mercedes” star fixed at the vertex of three adjacent pixels.

The properties of the light collectors were tested using a light source filtered in the 300-400 nm region which pro-

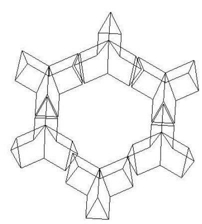

Fig. 6. Sketch of the light collector for one pixel. The six “mercedes” stars are arranged to form a hexagon.

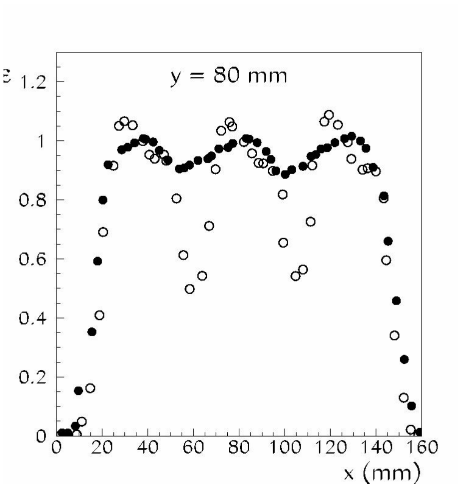

Fig. 7. The light collection efficiency was measured for a row of three adjacent pixels with (full points) and without (open points) the light collectors.

duced an image that simulates the spot created by the mirror [5]. The recuperation of the light using the light collectors is demonstrated in Fig.7 where the results of scanning a row of three adjacent pixels is shown. At the photomultiplier borders the efficiency rises from about 50% to more than 90%.

5 The corrector plate upgrade.

The basic design will be upgraded in order to increase the effective aperture of the telescope by about a factor of 2 without deteriorating the quality of the spot [6].

A corrector plate having annular shape with radial extension of 25 cm (inner radius of 0.85 m and outer radius of 1.10 m) will complement the standard circular diaphragm of 0.85 m radius. For practical reasons of construction, the corrector plate will be splitted into 24 sectors.

The plate, made of UV transmitting glass will have appropriate aspherical profile [7] in order to compensate for the spherical aberration, thus avoiding an increase of the size of the spot. In fact without corrector the spot size would increase as the third power of the linear dimension of the aperture, leading to a deterioration of the image that we consider not acceptable.

6 Installation and commissioning.

The first fluorescence detector telescope was installed in May 2001 in the “eye” building on top of the small hill on the Observatory site which is known as “Los Leones” (see Fig.8).

The commissioning of the telescope started immediately after assembling. The first measurement was a check of the geometrical alignment of the mirror elements. A screen was placed on the focal surface and the image of a bright star

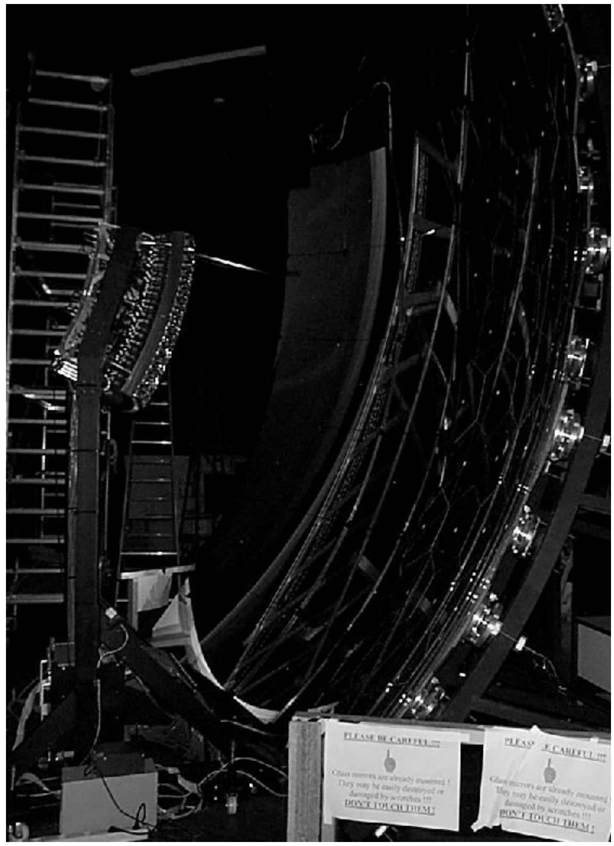

Fig. 8. The first fluorescence detector telescope assembled in the building of “Los Leones” on the Observatory site in Argentina. The camera on its support faces the mirror which is visible on the right side.

contained in the field of view of the telescope was observed and measured with a CCD camera. The size of the image corresponds to what expected from the spherical aberration.

The telescope has been operated in moonless nights and candidate events have been recorded having the typical configuration of showers produced by high-energy cosmic rays.

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