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OPTICAL DESIGN AND EXPECTED EVENT RATE OF THE UTAH FLY'S EYE DETECTOR.

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In order to measure the nitrogen fluorscence light produced in high energy (10^{16} - 10^{21} eV) extensive air showers, an array of 79 60-inch F/1.0 mirrors, each with a cluster of 12 3.5-inch phototubes will be fabricated and then assembled in western Utah. The optical design, overall system assembly, and method of calibration will be discussed. The expected event rate of the system has been calculated and the anticipated event rate for a single mirror unit will be presented. It is expected that a single unit will be operational by the end of the summer.

1. Introduction. We present here the design parameters of the optical system of the Fly's Eye air fluorescence detector as described in the previous paper along with its expected event rates.

2. Array Design. The Fly's Eye consists of an array of 948 phototubes, each looking at a different part of the sky. Ninety four percent of the sky above an altitude of 2 degrees will be covered (5.67 steradians). The tubes will be clustered in groups of 12 and each cluster will be located in the focal plane of a 1.52 meter (60 inch) mirror. Seventy nine mirrors will be required for the entire array. Figure 1 shows a shower and how it is recorded by the detector. Successive segments of the shower are seen by different phototubes of the array. As previously described, from the pulse geometry and timing, the trajectory of the shower can be reconstructed, and knowing the atmospheric extinction, the brightness of the shower can be calculated.

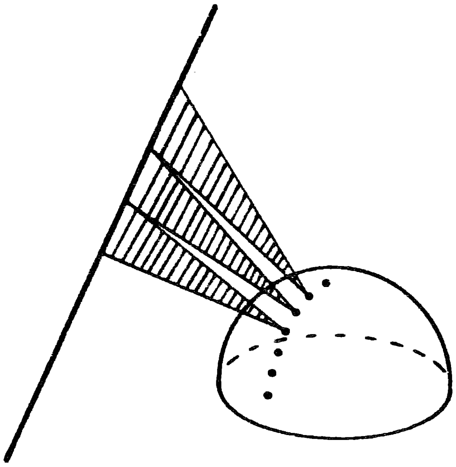

Fig. 1. Segments of a high energy cosmic ray shower as seen by three phototubes of the Fly's Eye detector.

Assuming the mirrors are mounted on a hemisphere, the physical size of the array should be slightly less than 15 meters (50 feet) in diameter. The experimental site is roughly 100 miles due west of the University of Utah near Wildcat Mountain, a 300 meter protuberance situated on broad flat desert plain in Western Utah. The site is free from the effects of city lights, air pollutants, weather build-up and moisture. It was so chosen in order

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to optimize both visibility and experimental duty cycle.

3. Phototubes. The nitrogen fluorescence spectrum shown in Figure 2 has a large component in the near ultra violet and we therefore desire a tube with a U. V. transmitting window. Because of the sky background and the wide aperture of each photomultiplier, the cathode current will be somewhat large for a bialkali tube. In particular, occasional large signals would severely saturate the tube due to the high resistivity of the bialkali photocathode. We have therefore chosen an EMI tube with a super S-11 surface and an extended U. V. response. The efficiency of this tube ($\epsilon \simeq 24\%$) is actually almost as high as that of the bialkali tube, but its resistivity is an order of magnitude lower and its venetian blind structure promises a more stable operation. Furthermore, in order to avoid rapid gain deterioration with time due to excessive anode DC currents we intend to operate the tube at a gain of merely 10^4. We have developed an inexpensive fast current-to-voltage converter which will be attached to the anode of each tube. A 5σ pulse of 50 nsec. duration will be about 50 photoelectrons. This will correspond to about 50 millivolts across 51 ohms at the output of the phototube current-to-voltage converter combination. In order to cut down on the number of tubes required, we have chosen a 90 mm phototube. The actual photocathode has an average diameter of about 82.9 mm which with our mirror, fixes the solid angle seen by each tube at 0.006 steradians.

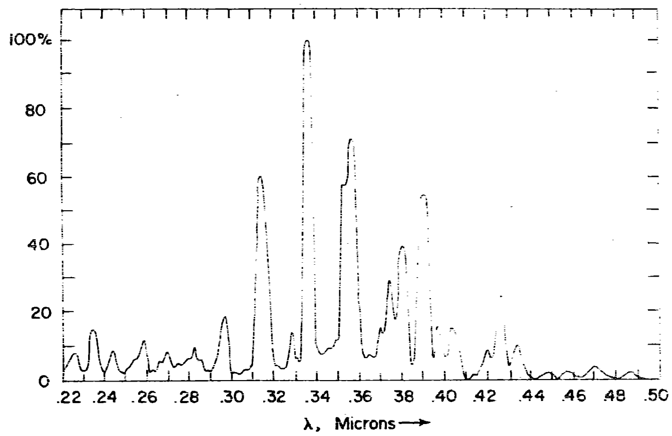

Fig.2. Nitrogen fluorescence spectrum normalized to 4.32 γ/MeV at .3371 microns.

4. Mirror Unit. The entire array will be composed of 79 mirror units as pictured in Figure 3. After reflecting off the mirror, the light enters one of the 12 light funnels which are attached to the front of the phototubes. The light funnels, as shown in Figure 4, are the Winston design (Winston, 1970) except the aperture has been made into a hexagon so the funnels can be efficiently packed together without any light loss. Each tube will have a field of view of 5.5 degrees along the maximum diameter of the hexagon.

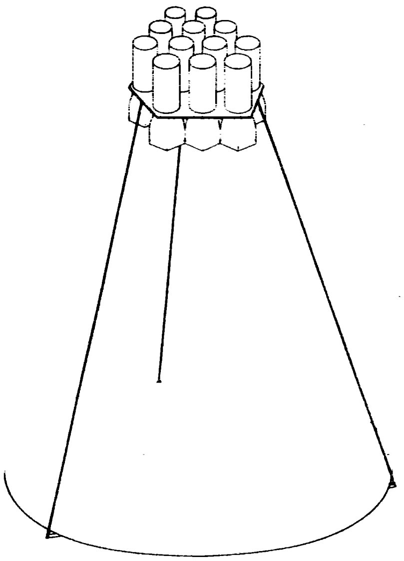

Fig. 3. Mirror unit.

The mirror is a 60 inch F/1.0 spherical mirror. The focal length has been kept as short as possible to minimize the obscuration by the funnels which should be no more than about 12%. The diameter of the mirror has been made as large as possible to increase the light collection and to make the field of view of each tube as large as possible. With such a short focal length, our only concern is with aberrations. Light passing through the optics of previous experiments designed to look at air fluorescence suffered such large scattering and aberrations that the light was actually spread over several photomultipliers which dramatically degraded the signal to noise factor. Here we have attempted to keep the image size several times smaller than the phototube funnel entrance aperture. Consequently, we have written a ray tracing program to calculate the aberrations in detail and have discovered that the best focus for the off axis rays occurs at 147 cm. (58 inches). The theoretical spot produced by a point source on axis and 9.5 degrees off axis is shown in Figure 5 superimposed on the front of the light funnel array. The maximum off axis ray which we expect to see makes an angle of 10.2 degrees with the central axis of the mirror. Since the mirrors will not be of optical quality, the actual spot will be somewhat larger depending on the quality of the mirror. We feel that the on axis spot can be kept to less than 5 cm. (2 inches) in diameter. Off axis we hope to confine 85% of the light to a spot 5.6 cm. (2.2 inches) in diameter.

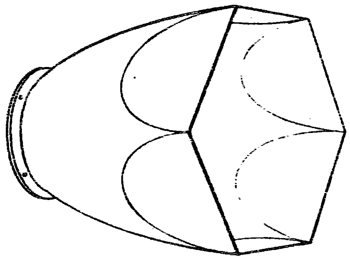

Fig. 4. Hex-face light funnel.

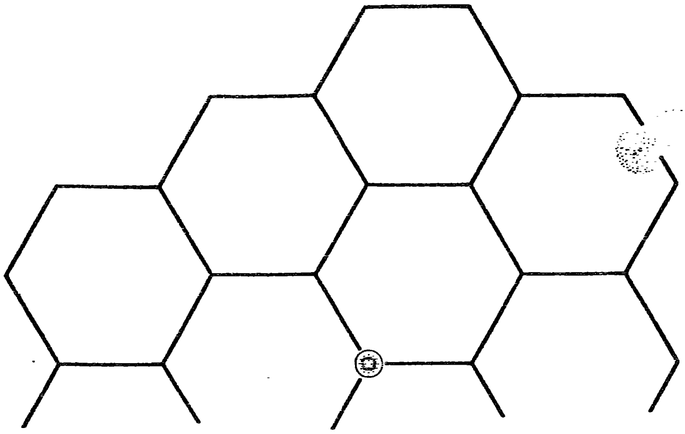

Fig. 5. Spot size for an on axis ray and a 9.5 degree ray. Each dot represents 1% of the light.

5. Event Rates. We have developed a Monte Carlo program in order to simulate the response of the Fly's Eye to real extensive air showers. Requiring 4 pulses each with a 4 standard deviation signal for the trigger yields an event rate as a function of primary energy as shown in Figure 6. These yearly rates were calculated assuming the Fly's Eye would be operated only on clear moonless nights which means a duty cycle of about 10%. The difference between the pessimistic and the optimistic curves reflects primarily the uncertainties in our knowledge of the atmospheric extinction factor. The event rate as a function of impact parameter (perpendicular distance to the shower) is shown in Figure 7 in order to give an idea of the area that the detector will cover. A single mirror unit will be in

operation shortly to test the overall feasibility of the technique. We expect an event rate of 10^3 to 10^4 per year with this unit.

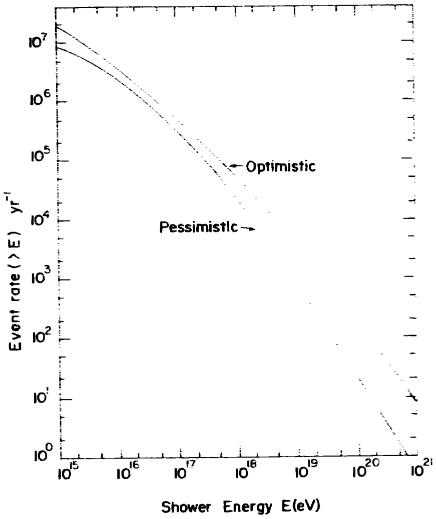

Fig. 6. Event rate as a function of primary energy.

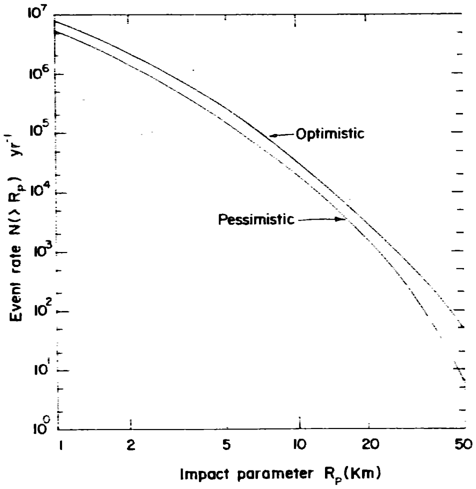

Fig. 7. Event rate as a function of impact parameter.

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References

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