Evaluation of Flat Microchannel Plate Photomultipliers for Use in a Portable Air Fluorescence Detector

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Abstract

Future applications of the air fluorescence technique will require robust, portable detectors, versatile enough to be deployed in remote areas with little infrastructure. One such experiment is the *Gamma Ray and Neutron Decay Scan* of the Galaxy (GRaNDScan), which proposes to survey the EeV sky by observation of γ and cosmic ray air showers in the southern hemisphere.

To view a 30° field at or exceeding a resolution of 1°, GRaNDScan will employ a lensless Schmidt optical system, with the light-sensitive element in each detector consisting of a spherical surface of tiled photomultipliers. Currently, the BURLE 85001 microchannel plate photomultiplier (MCP PMT), a low profile device appropriate for tiling, is the primary candidate for these cameras.

In this paper, we discuss the preliminary design of the GRaNDScan optics, the basic characteristics of the 85001 photomultiplier, and the suitability of this device for use in a portable air fluorescence detector.

1. Introduction

The GRaNDScan experiment seeks to observe cosmic rays in the energy range from 10^{17} to 10^{19} eV, where the composition, spectral features, and arrival directions of cosmic rays have not been studied by a dedicated instrument [1]. Viewing these energies, GRaNDScan will be sensitive to the Galactic and extragalactic components of the cosmic ray flux at Earth, enabling the study of a number of possible acceleration sources. To ensure good visibility of the Galactic center, a probable cosmic ray acceleration region, GRaNDScan will operate in the southern hemisphere [1].

The present design calls for a stereo air fluorescence detector, in which two sites observe the fluorescent light of atmospheric nitrogen excited by extensive air showers. This technique, utilizing PMT telescopes at each site, yields an accurate reconstruction of cosmic ray primaries' arrival directions, energies, and compositions. In GRaNDScan, the distance between the two detector sites will be adjustable, optimizing the experiment's sensitivity to different energies.

Unfortunately, the limitations of the air fluorescence technique — dark

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and clear skies are a necessity — restrict locations for GRaNDScan to dry, remote areas. Since these locations generally lack the infrastructure needed to operate power-consuming electronics, the detector must run on solar power alone.

To operate within strict power constraints, GRaNDScan will consist of telescopes with a large field of view, keeping the overall number of telescopes small. Furthermore, by using multi-anode PMTs rather than conventional phototubes, each camera will consist of a relatively small number of devices, reducing the power costs and weight of each telescope.

2. Optics

Since the GRaNDScan telescopes will view a large field, a logical design choice is the Schmidt optical system, which consists of a spherical mirror with a large aperture stop (e.g., $f/\# = 1$) located at its center of curvature. The mirror gives uniform images over a surface concentric with itself, though the images suffer from spherical aberration [2].

In a classical Schmidt system, these aberrations are corrected by a refractive plate at the aperture. However, because the resolution of a photomultiplier camera is determined by the pixel size of the PMT, a reduction of the image spot to a size much smaller than the pixel width is unnecessary.

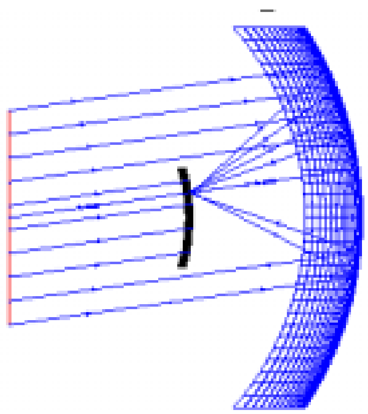
For the GRaNDScan telescopes, simulations with the ray tracing program ZEMAX [3] suggest that a "lensless" Schmidt system (i.e., without a corrector plate) would yield a reasonable resolution per pixel, provided that the field of view is not much larger than $30° \times 30°$. Hence, in considering telescope designs, we are guided by the following requirements:

- a 30° by 30° field of view,
- 1° per pixel resolution (or better),
- the size of the image spot is roughly the pixel size,
- the camera obscures the mirror by less than 25-30%.

The parameters of such a telescope, whose camera is assumed to consist of a 15×15 array of BURLE 85001 photomultipliers, are listed in Fig. 1.

3. Photomultipliers

The photomultiplier currently being considered for GRaNDScan is the BURLE Planacon$^{\text{TM}}$ 85001 flat tile photomultiplier. The 85001 is a multi-anode metal-ceramic microchannel plate (MCP) based PMT, with a standard bi-alkali photocathode grown on a quartz faceplate. The output stage is provided by four anodes (2×2), so that each device consists of four square PMTs 25.4 mm wide [4].



Aperture diameter	1900.0 mm
Mirror curvature	3125.0 mm
Mirror size	3400.0 mm
Camera curvature	1622.2 mm
Camera arc length	883.9 mm
Anode pixelation	(2×2) 25.4 mm
Spot diameter	25.4 mm
1° size	28.3 mm
Resolution	0.9° per pixel
Field of view	30°
Camera obscuration	26.9% center, 24.4% corner

Fig. 1. Schematic of a 2 m^2 effective aperture telescope [3], with table of parameters.

Notably, the pixelation of the anodes may be altered; consider an 8×8 device currently offered by BURLE [5].

The following characteristics of the 85001 make it quite suitable for the GRaNDScan experiment:

1. Low Profile: The height of the 85001 MCP PMT, including a voltage divider network, is 27 mm [4]. The compactness and low weight of this device allow for easy tiling on a spherical camera surface.

2. Multi-anode capability: As discussed above, using multi-anode PMTs greatly reduces the total number of devices in each camera. Furthermore, the 85001 MCP PMT can be manufactured in a variety of configurations (e.g., 3×3 anodes), meaning that the GRaNDScan telescope of Fig. 1 could be scaled down to maximize portability.

3. Timing: Typical anode pulse rise times for the 85001 PMT are 0.3 ns, with pulse widths of 1.8 ns (FWHM) [4], fast enough to handle expected air shower count rates.

4. Spectral Response: Quantum efficiency is 25% at 400 nm, roughly in the center of the nitrogen emission line spectrum [6].

5. Response uniformity: The response of the active area of the 85001 MCP PMT is quite uniform, on the order of 1:1.5 (compares favorably to alternate flat tile PMTs [7]), simplifying shower track reconstruction.

However, not all of the characteristics of the 85001 MCP PMT are ideal for GRaNDScan. For example, measurements of the single electron response at Columbia University confirm a rather large dispersion in the anode pulse amplitude distribution (>100% resolution at FWHM). In addition, the typical gain

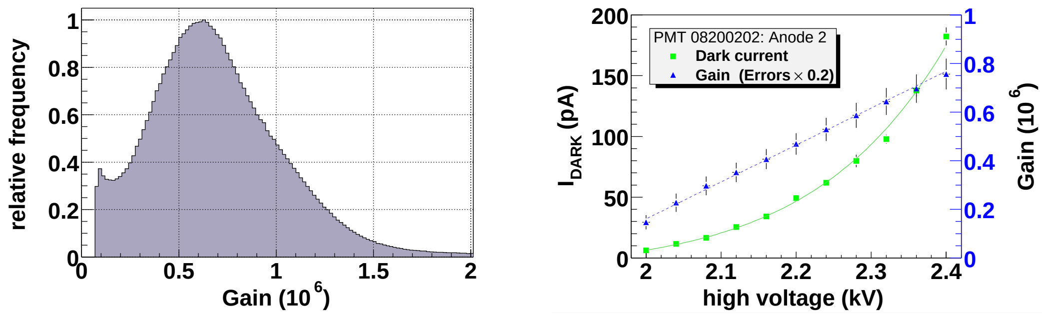


Fig. 2. Characteristic 85001 single electron spectrum, dark current, and gain.

of the device is on the order of 0.5×10^6, meaning that significant amplification will have to occur during the readout of the PMT — an important point if the detector is to operate at low power. Still, this gain is apparently characteristic of other flat tile PMTs [7].

Also of some concern is the significant amount of inactive space on the BURLE 85001, more than 25% of its head-on surface area. Importantly, BURLE is addressing this issue, with plans to improve the MCP PMT packing density (active area/external size) to 85% within a year.

4. Conclusion

In most of its basic characteristics, such as compactness, response uniformity, and timing, the BURLE 85001 MCP PMT appears suited for a detector like GRaNDScan. While the device fairs poorly in several respects, including gain and packing density, these characteristics are at least well understood. We are in the process of modeling the effect of the PMT's inactive area on air shower reconstruction, and will present the results at the conference.

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5. References

1. Adams T., Loh E.C., BenZvi S., Westerhoff S. 2003, e-print astro-ph/0303484
2. Born M., Wolf E. Principles of Optics. 1987, Pergamon Press, New York
3. ZEMAX Optical Design and Analysis Software. 2002, Focus Software, Inc.
4. BURLE Planacon 85001-501 Data Sheet. Nov. 2002, BURLE Industries, Inc.
5. BURLE Planacon 85011-501 Data Sheet. Nov. 2002, BURLE Industries, Inc.
6. Sadowski P.A. et al. 2002, Astroparticle Phys. 18, 237-248.
7. Hamamatsu H8500 Data Sheet. Oct. 2002, Hamamatsu Photonics K.K.