A New Detector For High-Energy Cosmic Rays

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Introduction

Cosmic Rays are high-energy particles that originate outside the realm of Earth. For years, scientists have been trying to determine where exactly these mysterious rays come from. Currently, an international collaboration is working at the Pierre Auger Observatory in Argentina to answer this question and more. The easiest way to detect cosmic rays is to observe their interaction with Earth’s atmosphere. When a high-energy particle reaches the atmosphere, two important events occur. First, the collision sends a shower of particles down to the surface of the Earth. Second, a flash of Cherenkov radiation is released. This phenomenon is caused by the impacting particles travelling faster than light in the medium of the atmosphere. The goal of our project was to build an array that can detect both the particle showers and the Cherenkov radiation from these cosmic ray collisions. Since the two events occur simultaneously, we sought to create a system that would cause the shower detectors to trigger the Cherenkov light detector, thus allowing us to observe the entire cosmic ray interaction at once.

Theory

- Particles from showers quickly decay into muons, which travel at relativistic speeds to the surface and do not readily interact with matter.
- Area of a muon shower depends on energy of impacting cosmic ray: higher energy particles result in showers with larger area.
- If multiple muon counters trigger at the same moment, this indicates a shower.
- Cosmic rays vary in energy from about $10^6$ eV to $10^{20}$ eV. The higher the energy, the lower the flux. For example, for a $10^9$ eV ray, the rate of impact is only 1 particle/km²/yr.

Testing The Photomultiplier Tubes

We built four muon-detecting panels which consisted of a PMT attached to a piece of square scintillating plastic. After light-proofing these panels, we tested them by stacking them directly on top of each other and measuring the pulse heights of the penetrating muons with a smaller “hockey puck” PMT. We expected that the larger (negative) pulses should occur when the puck was closer to the center of the panel.

Experimental Design

- 4 Photomultiplier Tubes (PMTs) mounted on scintillating plastic, light proofed
- 1 central PMT to collect Cherenkov light
- Coincidence unit, counting module connected to NIM Logic crate
- High Voltage Supply for all PMTs
- "Crab" sandboxes for weatherproofing

The Central PMT

The PMTs used for the panels were 1.5 inches in diameter, but the apparatus for the central PMT requires a 2 inch tube. Since none of our 2 inch tubes were fully operational, we performed the rate tests with only the four panels detecting muons and no central detector. As a result, these tests only measured the particle showers and not the Cherenkov light. However, during the rate tests we attempted to create a useable central detector. In order for a PMT to be useful for this project, it needs to have a base consisting of a voltage divider and a signal filter. We were able to construct a rough prototype base for a 2 inch PMT. This particular tube had considerably lower gain than the tubes in the muon counters, but because the Cherenkov light is so bright, this base should be suitable for the central PMT. Incorporation of an amplifier is an easy solution in case the gain needs to be increased to collect Cherenkov light.

Results

The rate tests were performed both in the lab and on the roof. The indoor results were very consistent with the theory that as the array got larger, the coincidence count rate should decrease.

<table>
<thead>
<tr>
<th>Separation</th>
<th>Counts/hr</th>
</tr>
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<tbody>
<tr>
<td>3 meters</td>
<td>18.48 ± 8.3</td>
</tr>
<tr>
<td>1 meter</td>
<td>8.61 ± 5.4</td>
</tr>
<tr>
<td>2 meters</td>
<td>5.08 ± 2.1</td>
</tr>
</tbody>
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The indoor rate test nicely shows the expected result that as the separation increases the count rate will decrease, corresponding to the lower frequency of high-energy cosmic rays. A decaying exponential curve is fitted to the indoor graph. The outdoor data is surprising in that the count rate at a separation of 1 meter is slightly higher than the count rate at the .3 meter separation.

Conclusions

- Four working panels have been built, tested, and are ready for further study with the central PMT
- Need to finalize base design for central PMT
- Next step is to test full setup with central PMT at night at a location free of light pollution
- Must then determine a way to mass produce at lowest possible cost

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References


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