A muon scintillation detector has been calibrated by measuring the magnitude and angular dependence of high energy cosmic background radiation events. Optimizing dark current as a function of voltage across the photomultiplier tube (PMT) detector was essential for accurate counting of current pulses as narrow as the counts in the PMT. Measurements of the cross-section zenith angle were also optimized by sweeping the detector across the horizon and from the zenith to nadir angle. The detector is now operating within proper Poisson distribution statistics for counting particle experiments, and is ready for the next step in determining coincidence between the muons and the cathodoluminescence events. Samples of highly disordered insulating material irradiated with 1-30 keV electron beams have been found to produce three forms of light emission with differing duration: arcs (<1 s duration), flares (~100 s duration), and cathodoluminescence (as long as beam is on). The arc and cathodoluminescence phenomena are well understood, while the flares are not. Measured rates of ~2 flares per hr were within a factor of 2 of the expected altitude-dependant muon cosmic background cross-section at an altitude of Logan, UT (1370 m). Based on this suggestive evidence, we have proposed incorporation of our standard muon coincidence detection apparatus into our vacuum cathodoluminescence test facility. If muon events are shown to coincide with the flare events, this will provide definitive evidence that flares are triggered by high energy particle penetration, which causes discharge and subsequent recharging of the charged highly insulating samples during our previous electron-beam characterization tests of space materials.

Muon Origins

High energy cosmic rays interacting with the upper atmosphere decay into muons that are present at the surface. Due to interactions with the atmosphere, these muons have a decay rate proportional to the altitude. With this information, we estimate the number of muons passing through the luminescence sample in our test chamber to be ~1 hr \(^{-1}\) cm\(^{-2}\) in Logan Utah (altitude 1370 m).

Photomultiplier Tube (PMT)

How do PMTs work?

1. The photocathode uses the photoelectric effect to convert light (photons) into charged electrons.

2. A large applied negative potential propels electrons from the photocathode, through the focusing electrode, and hit the first dynode.

3. Each dynode produces several secondary electrons that are accelerated to the next dynode. This produces a cascade of electrons.

4. The anode pulse is spread over time due to varying electron trajectories.

Counting Pulse Analysis

- **Transit Time (t)**: Time between the photons entering the tube and the current pulse being detected outside the tube. (t \(_0\) = 52 ns for Hamamatsu PMT)
- **Rise Time (t)**: Time it takes for the current pulse to reach 90% of current max height (t \(_R\) \approx 905 ns for Hamamatsu PMT)
- **Dark Current (I\(_D\))**: Background current noise of 2 nA as a function of accelerating voltage and photon counts.

All of these together function as ensuring that the counts stay discrete and limit the overlap of photon counts for the least counting error. (exhibited in Fig. 5)

Detector Validation and Calibration

Steps used to successfully calibrate the muon coincidence system are:

1. **Dark Current**
   - Ensure observed noise in the PMT is in its expected range and that the circuit is setup for reading the proper pulse signal.

2. **Signal to Noise**
   - Choose triggering voltage to ensure only true counts are measured above the background noise.

3. **Checking Angular Dependence (Single Cross-section)**
   - Rotate the surface normal of the detector and measure changes in counts to give insights into the angular dependence of the incoming muons with respect to the zenith, and the detector efficiency.

4. **Checking Angular Dependence (2-detectors)**
   - With both of the detectors setup to count muons with a discriminator to determine that only counts that are made simultaneously are counted coincidence events.

5. **Coincidence Setup**
   - The two muon detectors configured in coincidence mode established the timing of muons with trajectories traveling through the sample. A second coincidence between muons with proper trajectories and flares is deformed by matching times of the electrometer and camera flare signatures. (Fig. 2b)

6. **Ramasifications**
   - The flux of cosmic rays is much higher in the actual space environment, so in space flares would be much more prevalent.

References and Acknowledgements

The Material Physics Group studies electron-induced light emission of materials used in the construction of space-based observatories under simulated space environment conditions [Dennison, 2013; Anderson, 2014; Dekany, 2014]. This induced emission of light was observed as three separate phenomena: a glow that is sustained as long as the electron beam is on (termed cathodoluminescence), short duration arcs (<1 s) from electrostatic discharge, and intermittent emission of flares (duration ~10-100 s) [Dennison, 2013]. The electron current and light emissions signatures of the three types of emission are illustrated in Fig. 1. Unlike arc and glow, the cause of flares is still not known.

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