Calibration of Muon Detector for Coincidence Cathodoluminescence Experiments

Kenneth Zia and JR Dennison

USU Materials Physics Group

Utah State University, Logan, UT 84332-4414

Phone: (435) 363-4704, E-mail:kennethzia@gmail.com

UtahStateUniversity UNDERGRADUATE RESEARCH

UtahStateUniversity MATERIALS PHYSICS GROUP

Muon and Cathodoluminescence Coincidence

Fig. 1

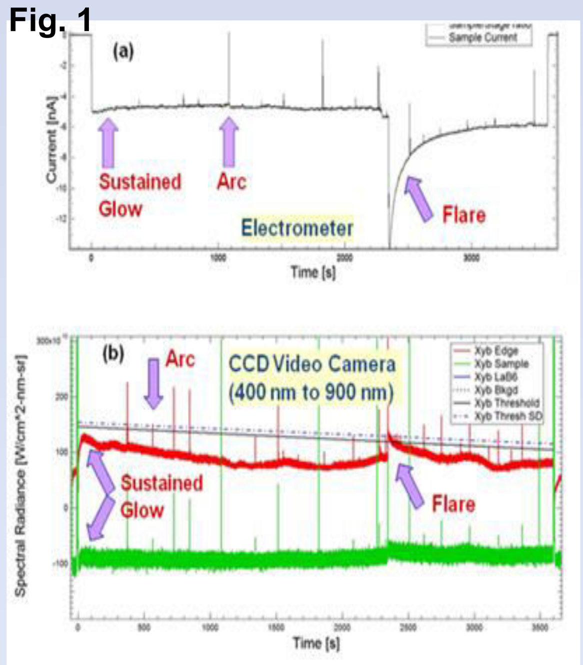


Fig. 2

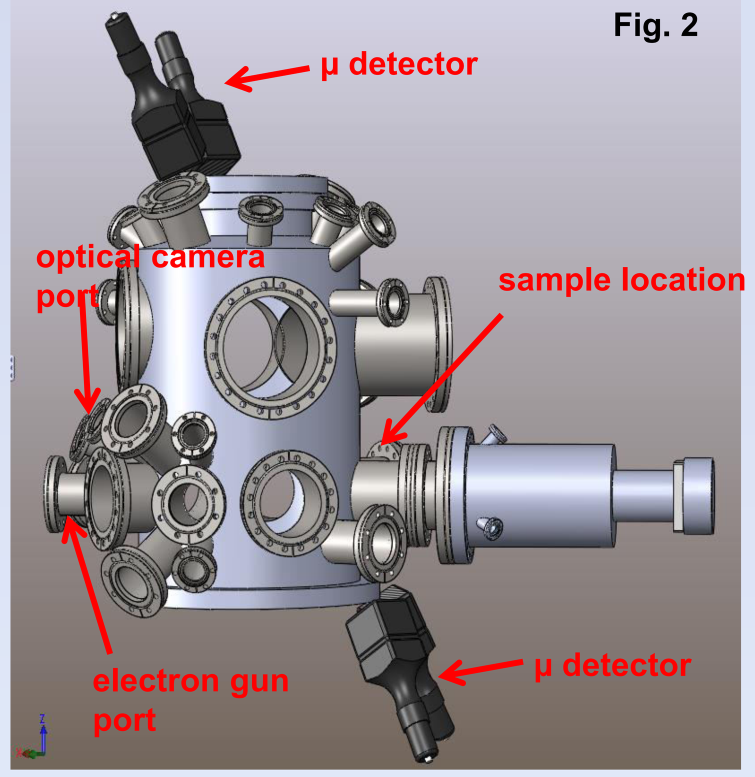


Fig. 3

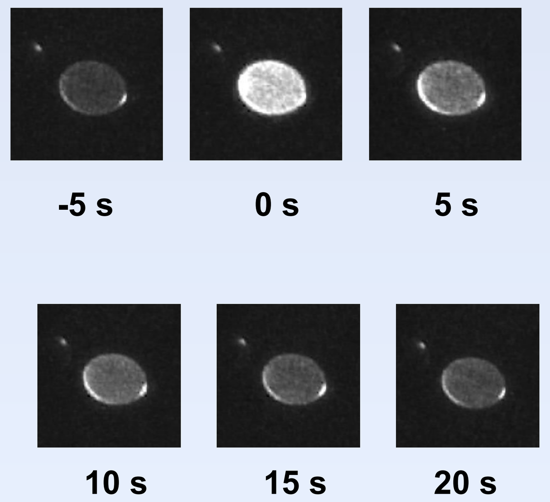


Fig. 1– Coincidence experiment schematic.

Fig. 2 – Vacuum electron emission test chamber with coincidence scintillation dete-ctors arranged around the sample [Dennison 2013]. (Top: Current vs. Time. Bot.: Intensity vs. Time

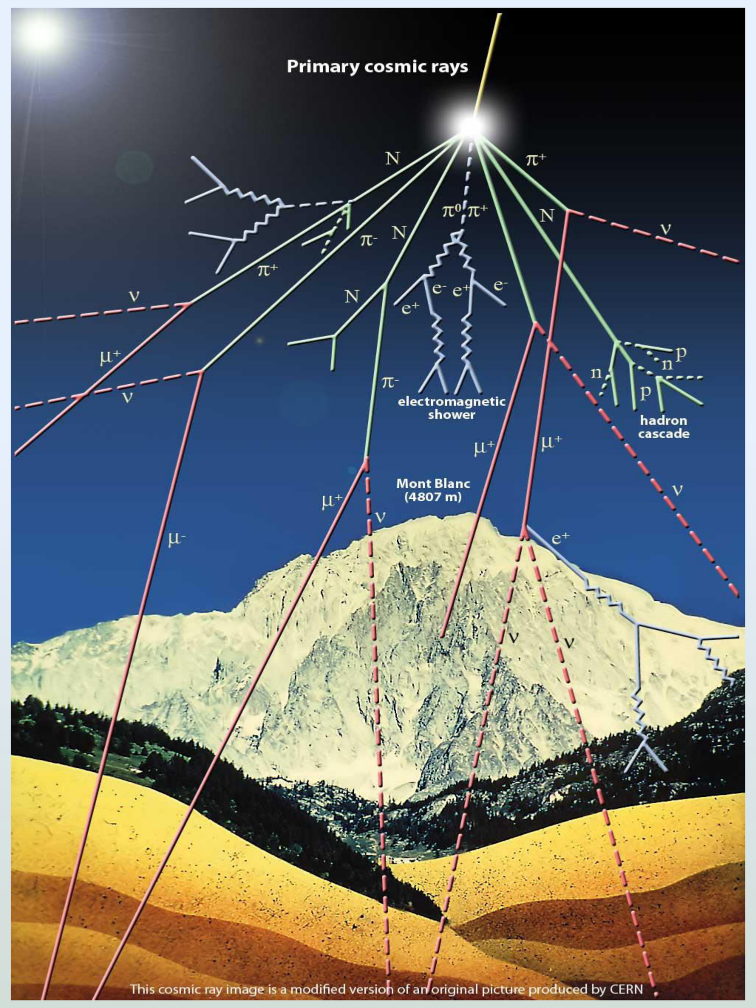
Fig. 3 – Time lapse photographic images at 5 s intervals, using camera in Fig. 8 of the chamber [Dekany 2014].

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 phenomenon: a glow that is sustained as long as the electron beam is on (termed cathodoluminescence), short duration arcing (<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.

Muon Origins

High energy cosmic rays interacting with the upper atmosphere decay into muons that are present at the surface. Due to inte-ractions with the atmo-sphere, these muons have a decay rate prop-ortional to the altitude. With this information, we estimate the number of muons passing thr-ough the luminescence sample in our test chamber to be ~1 hr-1cm-2 in Logan Utah (altitude 1370 m) Fig. 4.

Fig. 4 – Shows decay of cosmic rays into muons



Abstract

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.

Photomultiplier Tube (PMT)

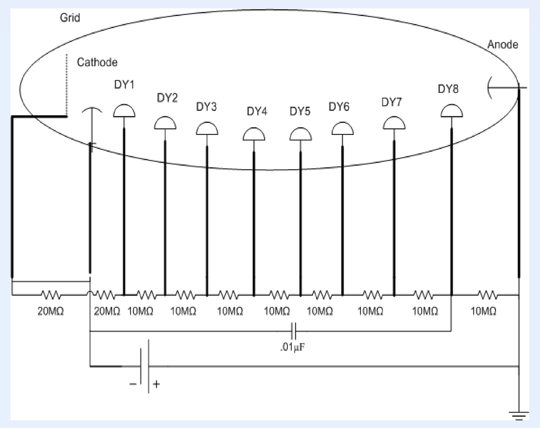


Fig. 6 – PMT schematic.

Fig. 7 – Wired 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 (Fig 8).

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.

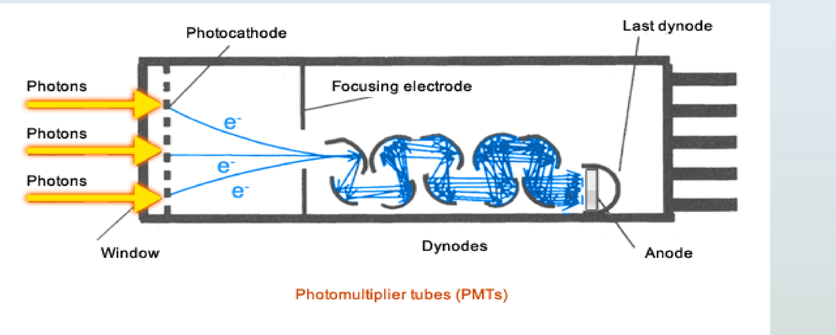


Fig. 8 – Diagram of PMT producing current.

Counting Pulse Analysis

- **Transit Time (t_t)**
  Time between the photons entering the tube and the current pulse being detected outside the tube. (t_t=52 ns for Hamamatsu PMT)
- **Rise Time (t_r)**
  Time it takes for the current pulse to reach 90% of current max height (t_r = 905 ns for Hamamatsu PMT)
- **Dark Current (I_{dark})**
  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)

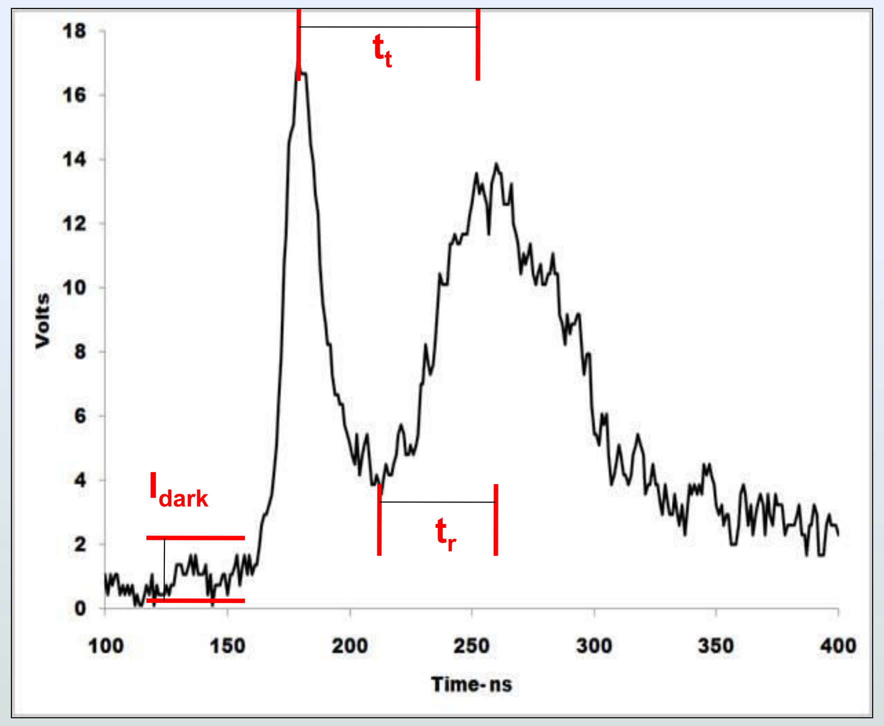


Fig. 5 – Example of counting pulses.

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.

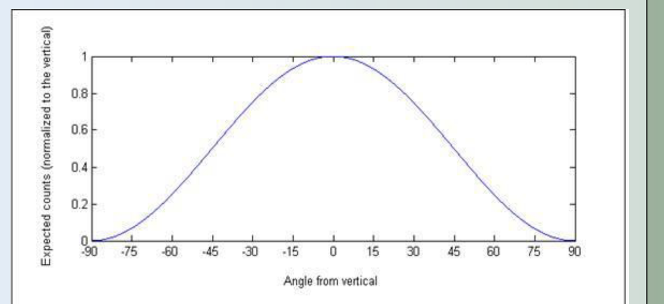


Fig. 9– Angular dependence of muon counts [Gaisser, 2002].

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. 2&10)

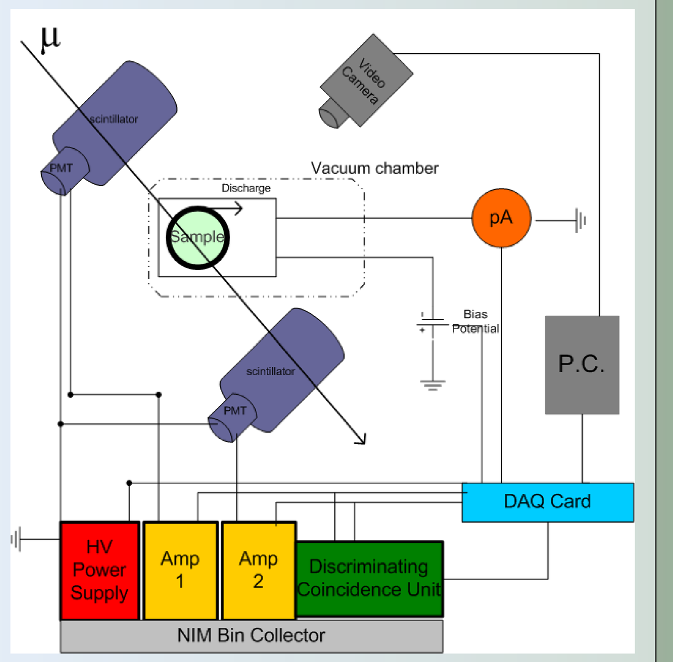


Fig. 10– Schematic of final setup to achieve coincidence between flares and muons.

6. **Ramifications**
   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

A. Andersen, JR Dennison, A. M. Sim and C. Sim, "Electrostatic Discharge and Endurance Time Measurements of Spacecraft Materials: A Defect-Driven Dynamic Model," Abstract 127, *Proceedings of the 13th Spacecraft Charging Technology Conference,* (Pasadena, CA, June 25-29, 2014), 11 pp..

J. Corbridge Gillespie, JR Dennison and A. M. Sim, "Density of State Models and Temperature Dependence of Radiation Induced Conductivity," Abstract 113, *Proceedings of the 13th Spacecraft Charging Technology Conference,* (Pasadena, CA, June 25-29, 2014), 8 pp.

M. Circella. "Cosmic Ray Muon Spectrum in the Atmosphere" 23rd International Cosmic Ray Conference, Vol. 4, July 19-30, 1993

"Cosmic Ray Muon Detector" http://hermes.physics.adelaide.edu.au/astrophysics/muon/. (University of Adlaide 2005).

J. Dekany, R.H. Johnson, G. Wilson, A. Evans and J.R. Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *Proc. 12th Spacecraft Charging Techn. Conf.,* (Kitakyushu, Japan, May, 2012).

J. Dekany, R. H. Johnson, G. Wilson, A. E. and JR Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *IEEE Trans. on Plasma Sci.*, 42(1), 2014a, 266-271.

J. Dekany, J. Christensen, JR Dennison, A. E. Jensen, G. Wilson, T. Schneider, C.s W. Bowers and R. Meloy, "Variations in Cathodoluminescent Intensity of Spacecraft Materials Exposed to Energetic Electron Bombardment," Abstract 179, *Proceedings of the 13th Spacecraft Charging Technology Conference,* (Pasadena, CA, June 25-29, 2014b), 7 pp.

J.R. Dennison, J. Dekany, J.C. Gillespie, P. Lundgreen, A. Anderson, A.E. Jensen, G. Wilson, A.M. Sim, and R. Hoffmann, "Synergistic Models of Electron Emission and Transport Measurements of Disordered SiO_2," *Proc. 13th Spacecraft Charging Techn. Conf.,* (Pasadena, CA, June, 2014).

J.R. Dennison, A.E. Jensen, J. Dekany, G. Wilson, C.W. Bowers and R. Meloy, "Diverse Electron-induced Optical Emissions from Space Observatory Materials at Low Temperatures," *Proc. SPIE Cryogenic Optical Systems and Instr. Conf.*, Vol. 8863, 2013, pp. 88630B1-88630B15.

D. Denisov, "Detection of Muons," Fermilab: Academic Lecture, (April 5, 2000).

Drake. "Chasing a Cosmic Engine," Science News, July 14, 2012.

D.C. Ferguson, J.-M. Krezan, D.A. Barton, J.R. Dennison, and S. Gregory, "On the Feasibility of Detecting Spacecraft Charging and Arcing by Remote Sensing," *J. Spacecraft and Rockets*, 2014, in press.

T. K. Gaisser, "23. Cosmic Rays," http://pdg.lbl.gov/2002/cosmicrayrpp.pdf, (University of Deleware March 2002).

A.E. Jensen, J.R. Dennison, G. Wilson, J. Dekany, C.W. Bowers, R. Meloy and J.B. Heaney, "Properties of Cathodoluminescence for Cryogenic Applications of SiO_2-based Space Observatory Optics and Coatings," *Proc. SPIE Cryogenic Optical Systems and Instr. Conf.*, Vol. 8863, 2013, pp. 88630A1-88630A10.

P. B. Landecker "Cosmic-ray muon fluxes deep underground: Intensity vs. depth, and the neutrino-induced component," Phys. Rev .D,18,7 (1978).

J. Christensen, J. Dekany, and J.R. Dennison, "Stochastic Variations of Cathodoluminescent Intensity of Bisphenol/Amine Epoxy Exposed to Energetic Electron Bombardment," Utah State University Student Showcase, Logan, UT, April, 2014.

N. Ramesh. "Flux Variation of Cosmic Muons" Journal of the Arkansas Academy of Science, Vol. 65, 2011.

K. Zia with JR Dennison, "Cathodoluminescence Events Coincident with Muon Detection," SDL Undergraduate Research Equipment Funds, ($700, September 2014a to June 2015).

K. Zia, J. Dekany and JR Dennison, "Cathodoluminescence Events Coincident with Muon Detection," *American Physical Society Four Corner Section Meeting,* Utah Valley University, Orem, UT, October 17-18, 2014b.

UtahStateUniversity MATERIALS PHYSICS GROUP

We gratefully acknowledge contributions from the Materials Physics Groups This work was supported through funding from SDL.

Scan code to access the USU Material Physics Group papers and presentations.