# Design of Power & Controls Circuits and Experiment Enclosures for Cosmic Ray Muon Detectors


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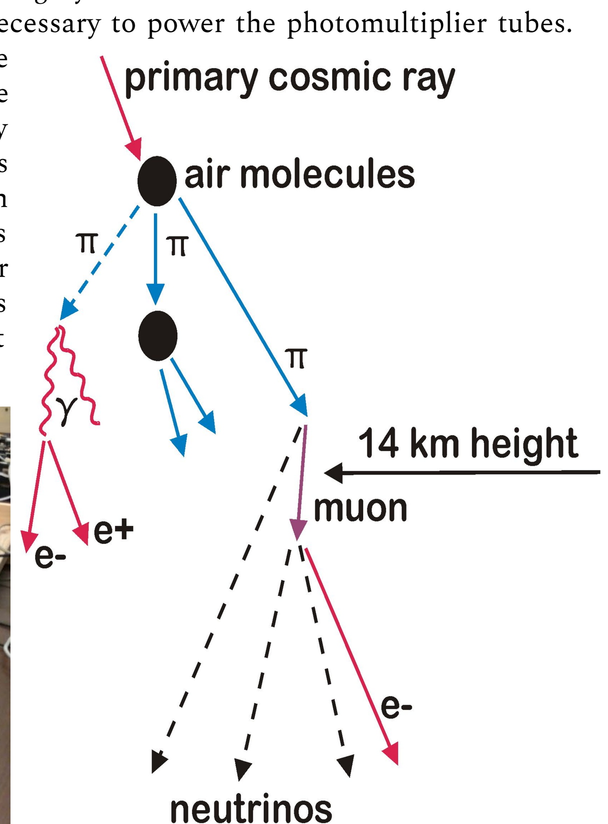
## Abstract

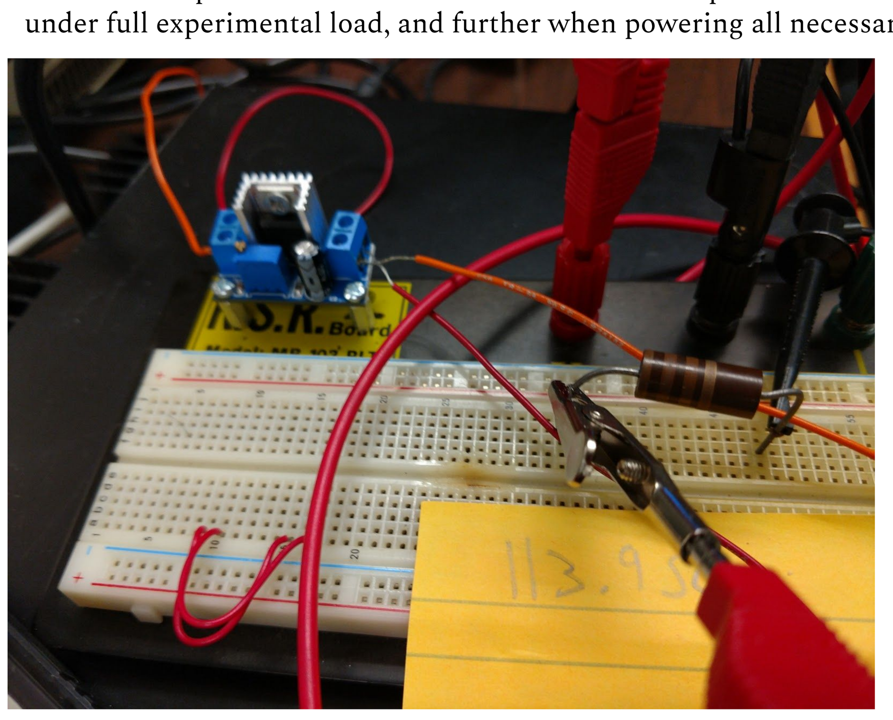

Cosmic Rays are ionized atomic nuclei; 90% are Hydrogen (Protons), 9% Helium (Alpha Particles), 1% heavier atomic nuclei (HZE ions). These particles are jettisoned from the sun, active galactic nuclei, supernovae, and quasars at relativistic speeds. When these primary Cosmic Rays collide with Earth, they first strike nucleons in the upper atmosphere. These high energy collisions cause secondary Cosmic Ray showers of daughter particles including charged Pions, which undergo leptonic decay into Muon and Muon-Neutrino pairs. These Muons experience relativistic time dilation, allowing the Muons to reach Earth-bound detectors despite a mean lifespan of 2.2 microseconds. The CUNY Cosmic Ray Muon Detector array uses sheets of polyvinyltoluene (PVT) plastic with fluorescent hydrocarbon molecules as detection media. Charged Muons collide with these counters, ionizing molecules which emit photons that can be detected using photomultiplier tubes. In creating an array of detectors in multiple sites across New York to study particle astrophysics and atmospheric physics, a streamlined experiment including power distribution, network, and control circuits, experiment and equipment enclosures must be developed. Experiment control includes transferring power and data between between various subsystems, including GPS, sensors for atmospheric conditions, Arduino and Raspberry Pi. LM317 IC were thoroughly tested for use as Power Distribution Units to ensure a reliable and accurate power supply for EMCO high voltage converters necessary to power the photomultiplier tubes. Characterization, modifications and circuit design are presented. Enclosure designs are streamlined to reduce size and cost. Scintillator and photomultiplier tube enclosures were found to be leaking light, introducing ambient noise. Detecting the photons emitted by scintillator detectors via photomultiplier tubes requires a noise free environment as photomultiplier tubes are highly sensitive and produce their own noise due to the high voltages involved (dark rates). Further characterization of experimental equipment is presented. Future work includes the development of 10 fully developed prototypes for rigorous testing under full experiment conditions. Design modifications resulting from this initial prototype testing, continuing development of DAQ Front End, and other equipment improvements by colleagues is expected.

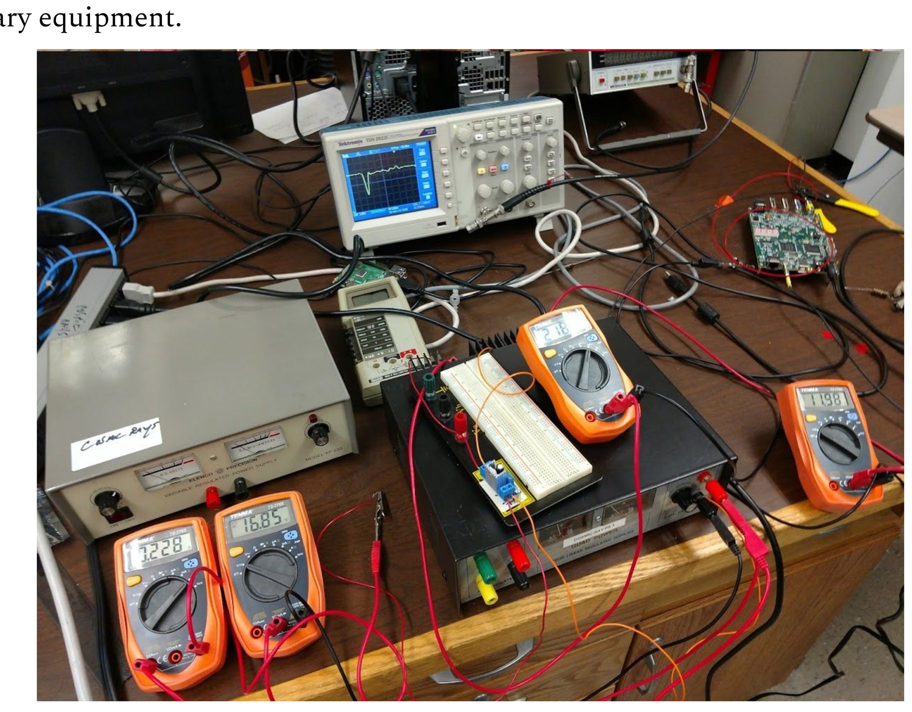

Anatomy of a Cosmic Ray and CUNY array

## Circuit Modifications

The LM317 has been found to maintain Load regulation if a minimum of 10mA is provided to the OUT pin. Due to R1 being a 200Ω resistor, there is only 6.25mA on OUT. Using a lower resistance for R1 of 100Ω will provide 12.5mA for IOUT, enough current to maintain regulation irrespective of external load. For these purposes, the original circuit has been modified to use this 100Ω resistor, as well as the addition of a protection diode from VOUT to VIN to prevent C2 from discharging through the IC. This was demonstrated to be effective under full experimental load, and further when powering all necessary equipment.



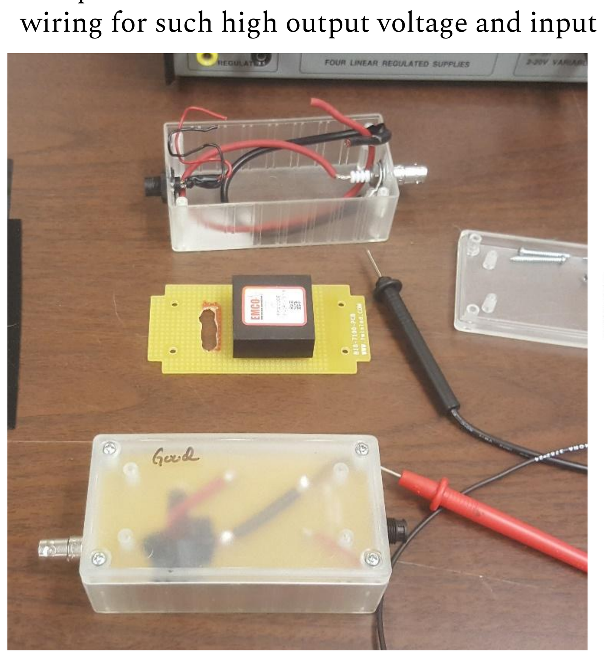
PDU initial testing

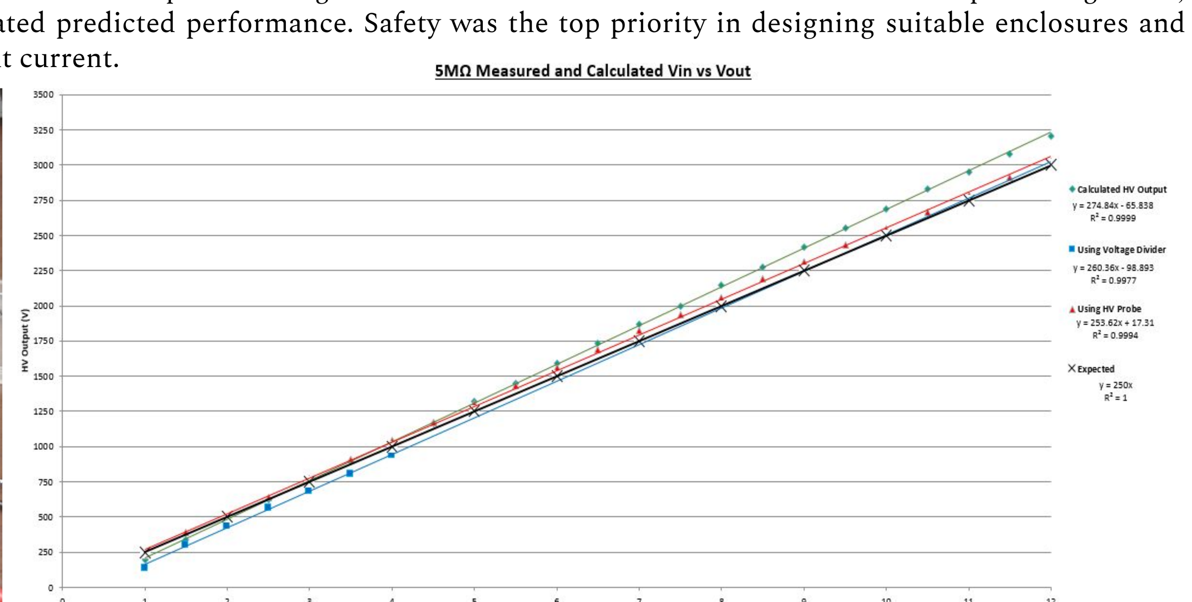


PDU fully functional when powering PMT with successful muon detection on oscilloscope

## Low to High Voltage Converters

The EMCO G30 Low to High Voltage converter was determined meet requirements to power the PMT's (Photomultiplier Tubes) inside our detectors. Converter output is load dependent, and was measured with variable loads corresponding to common PMT impedances used in the array. Lower impedances corresponded to a lower maximum voltage for rated input than the 3KV necessary. The minimum operating range was determined to be any PMT with impedance of greater than 5MΩ. The G30 was determined to be power regulated, and paired with the LM317 PDU demonstrated predicted performance. Safety was the top priority in designing suitable enclosures and wiring for such high output voltage and input current.

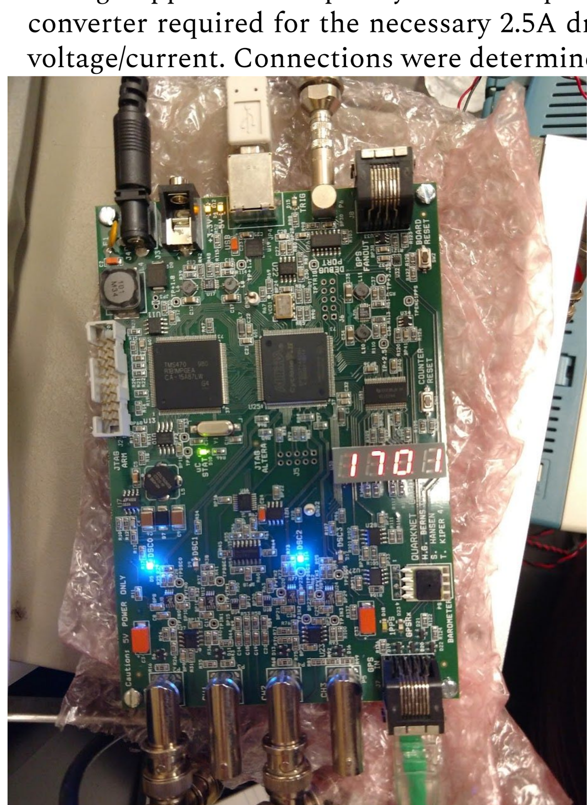


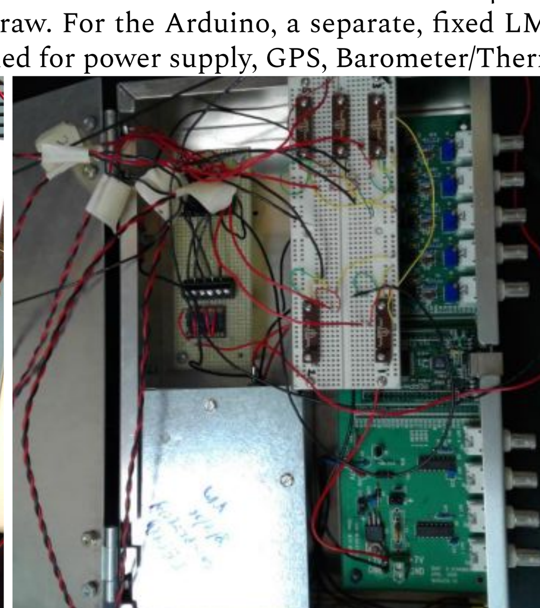


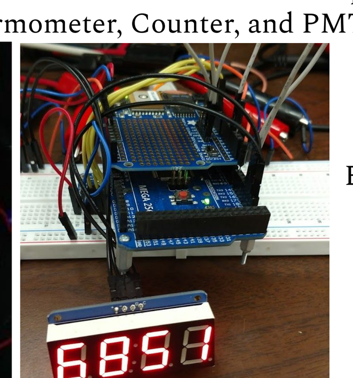

Top: 5MΩ corresponds to minimum impedance for required output HV
Left: EMCO G30 assembly and enclosure

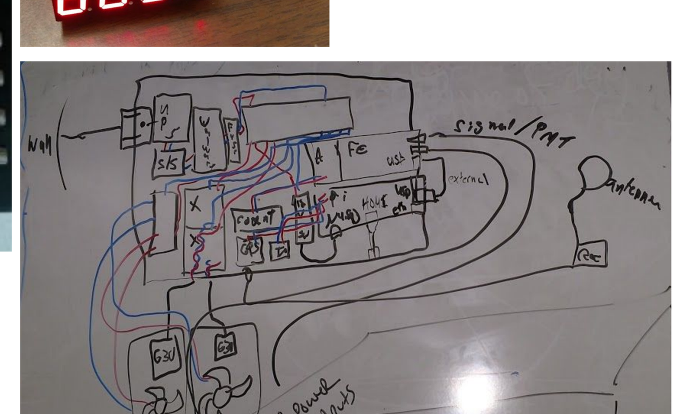
## DAQ Electronics Assembly

Previously, an old DAQ FE assembly was used and later the Quarknet DAQ. In moving forward with the experiment design, a new DAQ is being designed and tested at Brookhaven National Lab by other members of our group. To accomodate this and other necessary components, design and assembly of the controls circuit for the DAQ FE was required, including all necessary inputs for data and power. Voltage applied to Raspberry Pi GPIO pins was measured to be common with μUSB input and was used for power purposes, with a converter required for the necessary 2.5A draw. For the Arduino, a separate, fixed LM317 was determined to step down to the necessary voltage/current. Connections were determined for power supply, GPS, Barometer/Thermometer, Counter, and PMT signal.









Left: GPS, Barometer/Thermometer, Arduino and Counter

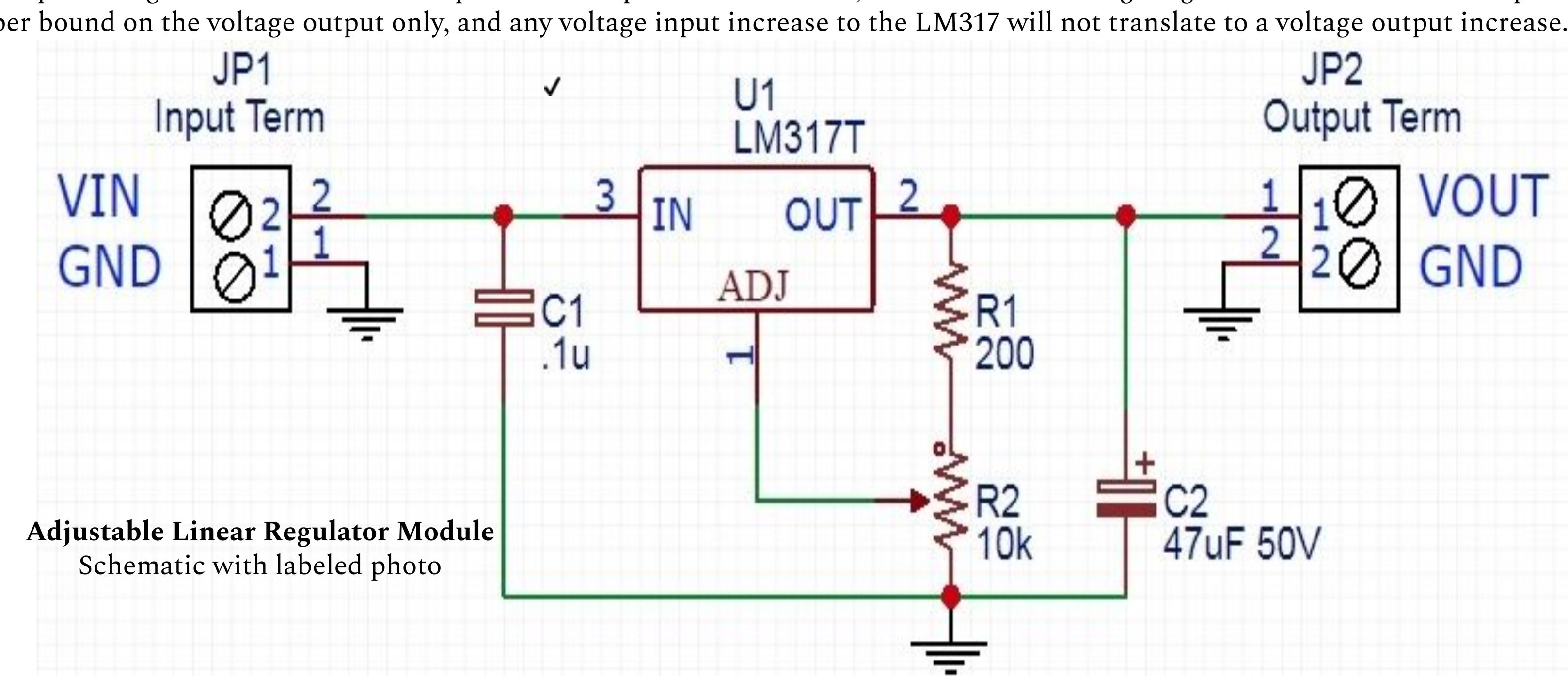
Bottom DAQ FE new preliminary design

Top: Old DAQ FE

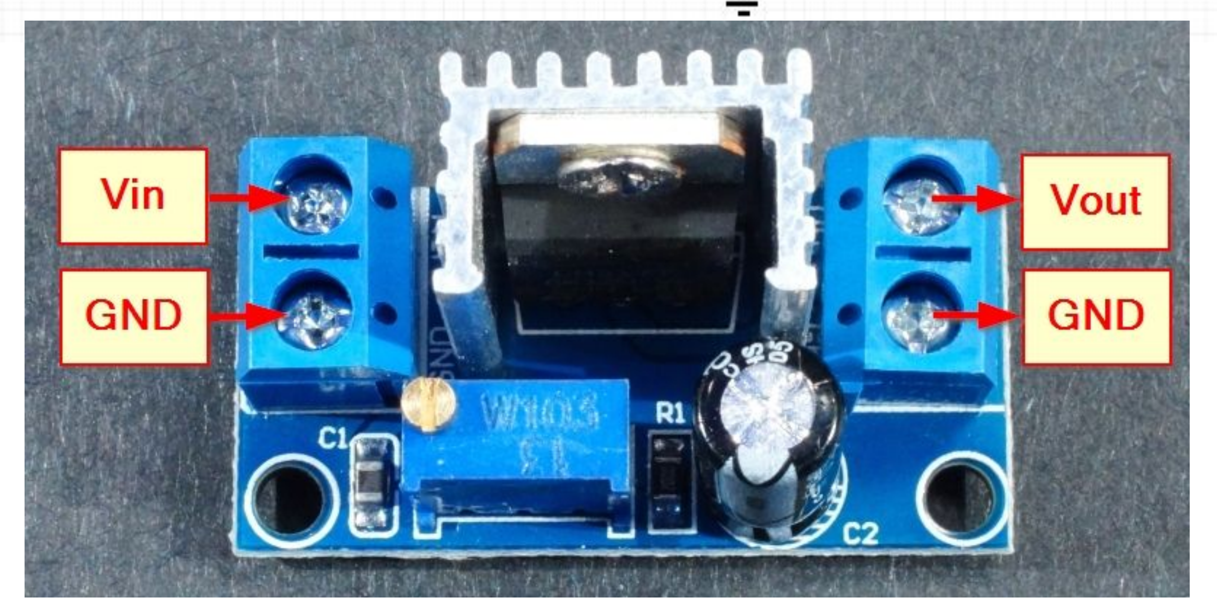
Left: Quarknet DAQ

## LM317 as a Power Distribution Unit

PDUs will be used to distribute power from an external source to the EMCO G30 converters, which will convert low voltage DC to high voltage to power the Photomultiplier Tubes, while serving to put an upper bound on the voltage output. This serves to provide a constant, user set voltage to the EMCO G30 and therefore the PMTs. A LM317 Adjustable Linear Regulator Module will be used as the PDU, with an on-board potentiometer used to set the desired output voltage. The LM317 is a step-down Linear Voltage Regulator and can only have an output voltage that is less than the input. In an important distinction, the LM317 is a voltage regulator in the sense that it provides an upper bound on the voltage output only, and any voltage input increase to the LM317 will not translate to a voltage output increase.



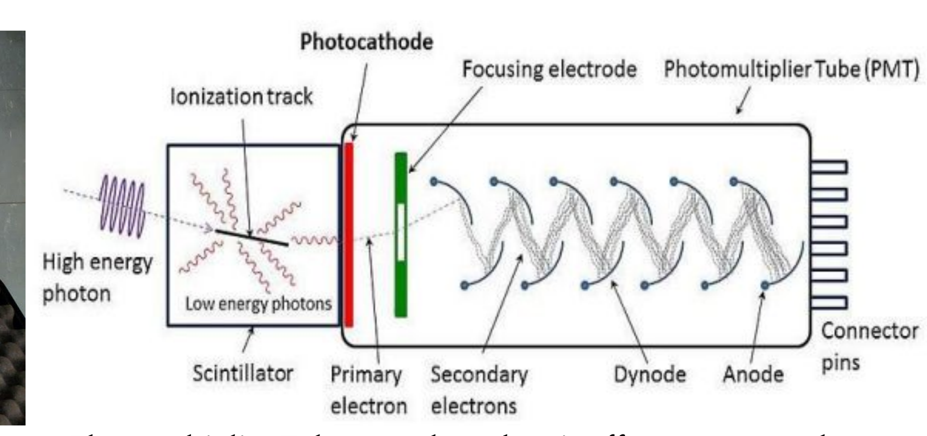

**Adjustable Linear Regulator Module**
Schematic with labeled photo



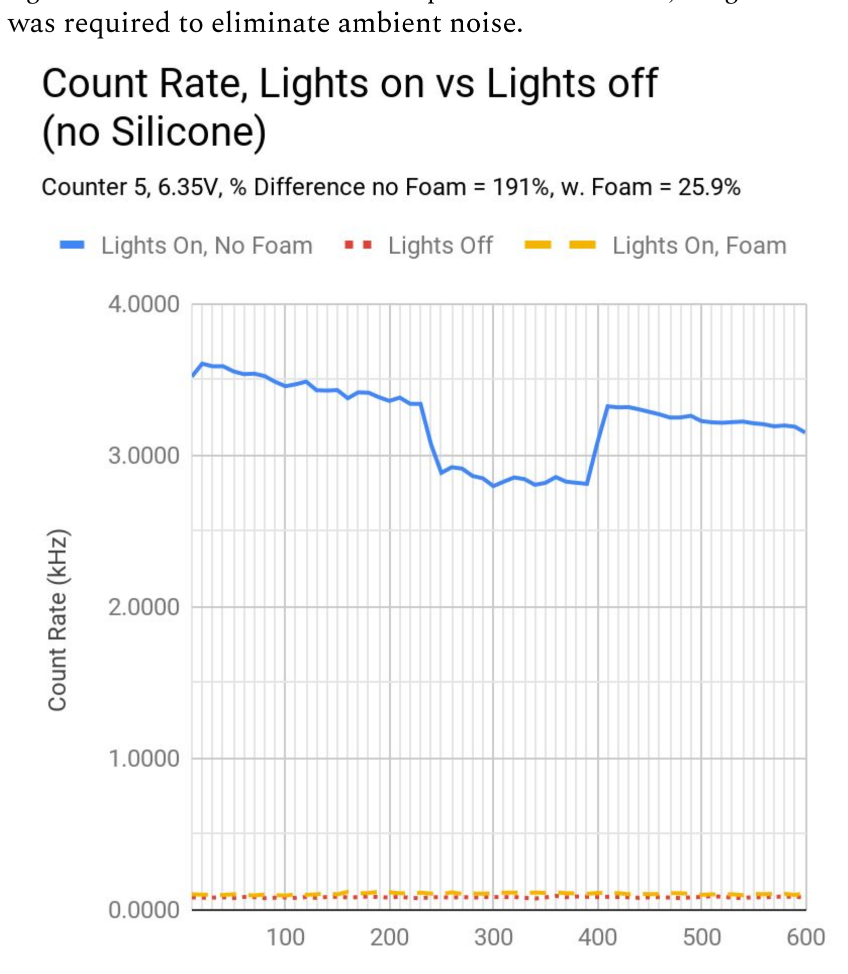

## Plastic Scintillator Detectors

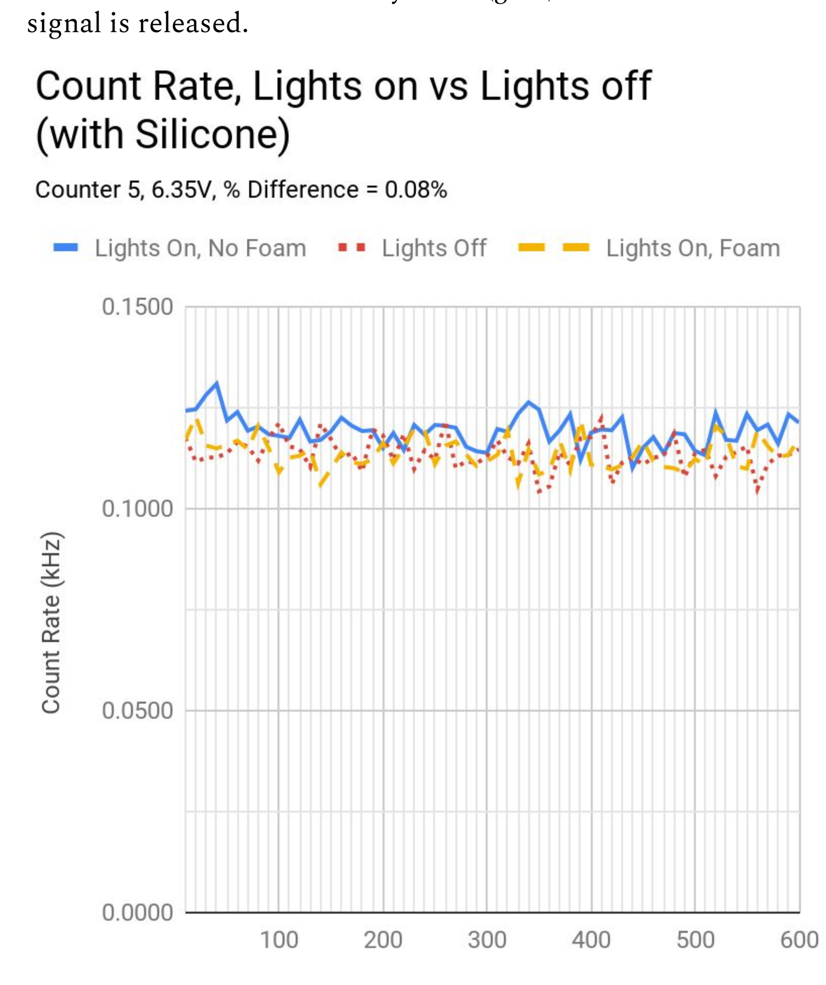
Once the detectors are receiving reliable power, they must be optimized for experiment conditions. Charged Muons collide with plastic sheet counters, ionizing molecules which emit UV photons in a process known as scintillation. These photons are contained within the plastic by tightly wrapping them in reflective Tyvek. Each sheet of scintillator plastic is pressed up against the cesium Photocathode of an ADIT PMT, which converts the colliding photons into electrons via the photoelectric effect. The energy of the electrons is magnified, resulting in a fast pulse of electric current of a magnitude that can be measured. The PMTs have internal noise (Dark Rates), so all outside noise be eliminated as fully as possible to maintain quality of data. This includes maintaining a constant power supply with protections against power surges and light leaks. Black silicone was used to create a light-tight seal for this purpose.

Plastic Scintillator Detector secured in experiment enclosure with PMT. Foam is used to secure components in place and absorb light to reduce noise. This alone proved insufficient; a tighter seal was required to eliminate ambient noise.




Photomultiplier Tube uses photoelectric effect to convert photons hitting photocathode into electrons, stepping up the number of electrons released between dynodes (gain) until a measurable signal is released.




Enclosures with ultra tight seal demonstrated to reduce noise by up to 190%

## Conclusions and Future Work

LM317 proved reliable PDU with low error and excellent load regulation with a few, simple modifications to circuit design, light leak was successfully eliminated, and all components can be reliably powered. Next steps include testing the longevity of these ICs; Cosmic Ray detection requires the experiment to remain on for months at a time, and equipment needs longevity to be useful to the experiment. Design of DAQ assembly and enclosure has completed its first iteration, and assemblies are being prototyped by new students. Ensuring all components, such as DAQ Front End, Raspberry Pi, Arduino, GPS Receiver and Barometer must all function with similar longevity and reliability within the power distribution system. Further design modification is expected resulting from this prototyping, as well as prototyping and changing hardware/software requirements by colleagues' work continuing to develop. Once this process is completed, experimental Cosmic Ray Muon data will be collected in various experiments in Astroparticle Physics and Atmospheric Physics.

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