

# Cosmic Rays and Cosmic Ray Muon Detection

## Background

Cosmic rays are primarily high-energy protons and helium nuclei. When these particles collide with gas atoms in the upper atmosphere, an air shower is created. The air shower consists primarily of pions that decay into muons and other particles created by the high energy collision. Since the muons carry much energy, weakly interact with the air, and have a relatively long mean lifetime, many muons are detected at Earth's surface.

Standard Model of Elementary Particles

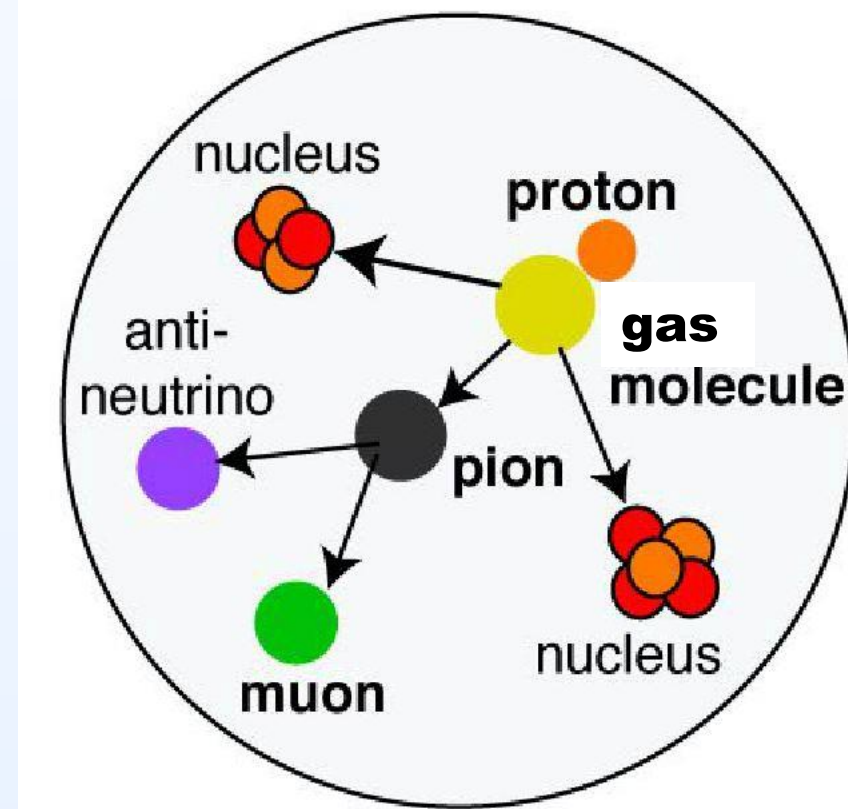
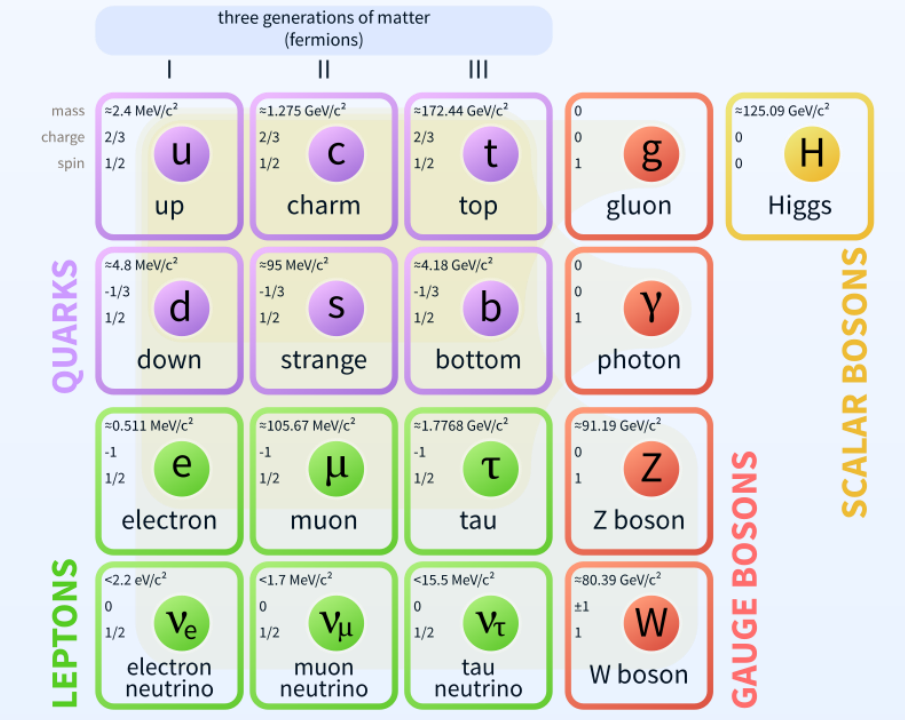


Photo: H. J. Drescher, Universität Frankfurt

## Kinds of Measurement

Using a setup of various scintillators (counters) for a given detector, many aspects can be studied.

Stacked configuration:

- Flux
- Time of Flight
- Muon Lifetime



Array configuration:

- Shower study



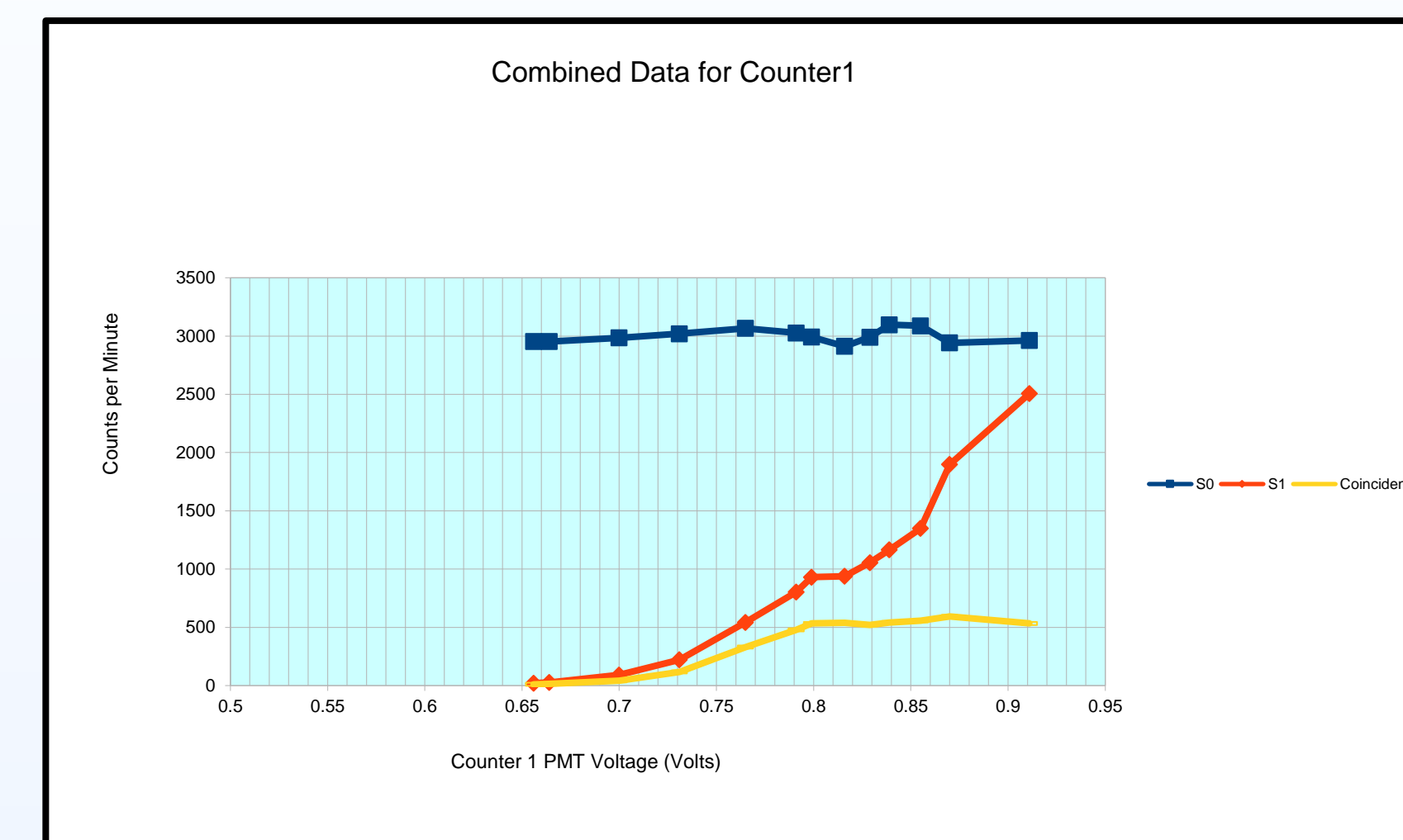
## Factors to be Considered

- Geometry of setup
- North-South versus East-West orientation
- Overlap area, separation
- Zenith angle
- Amount of material muons pass through
- Angle of Acceptance
- Latitude, longitude, altitude
- Barometric pressure
- Veto

## Setup Specifications

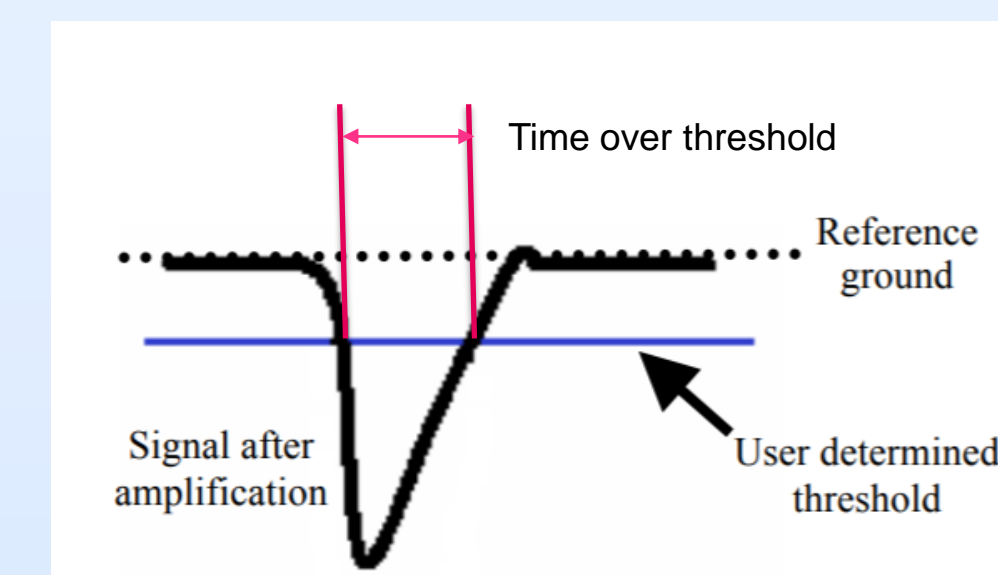
### Plateauing

High voltage on each photomultiplier tube must be optimized for efficient performance.



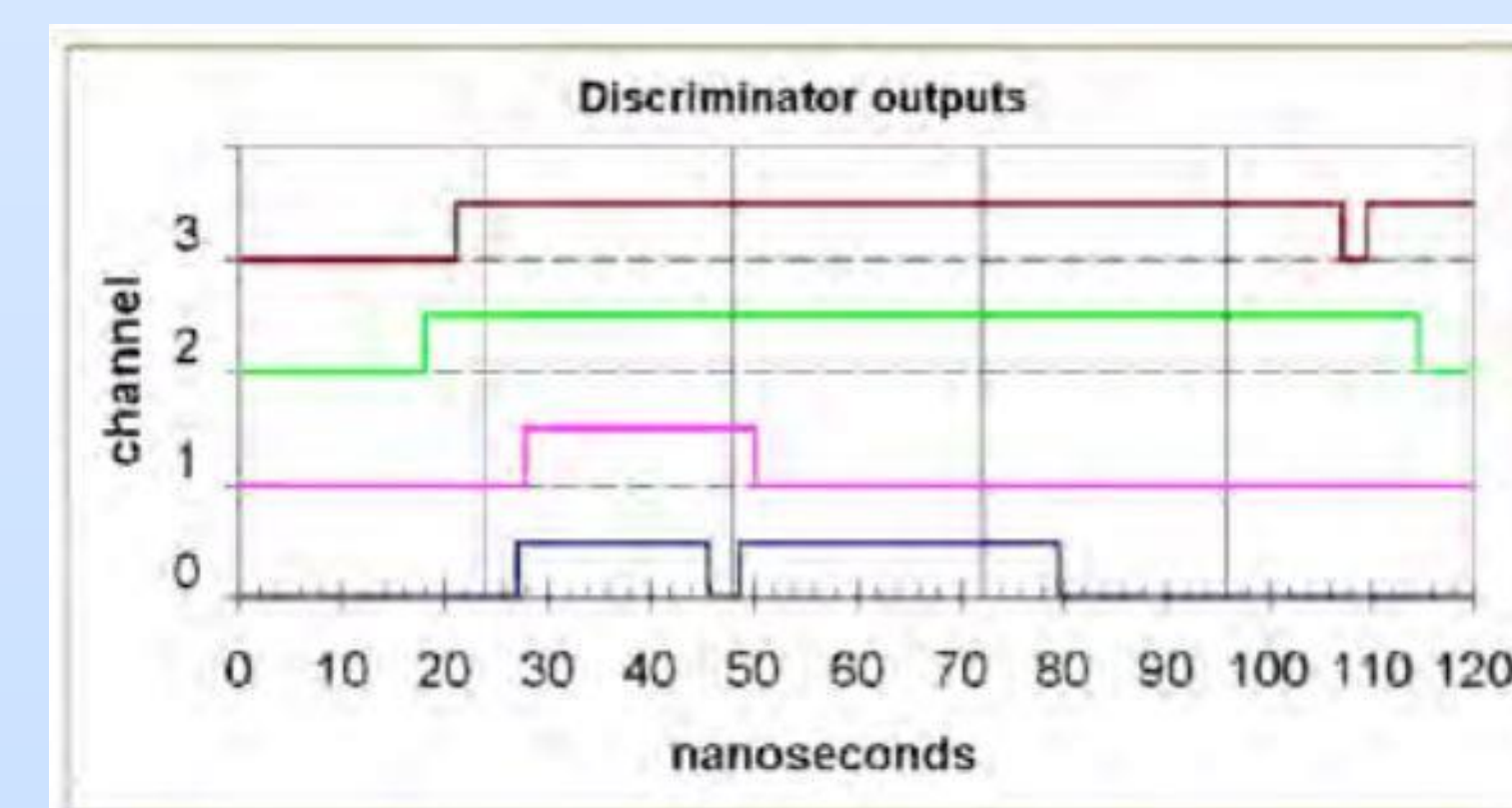
### Time over threshold

The photomultiplier tube sends electrical pulses to the data acquisition board. A balance needs to be struck between too low of a threshold, which yields a noisy signal, and too high of a threshold that discards legitimate counts.



### Gate

The gate window is how close in time pulses must occur to cause a trigger.



### Coincidence

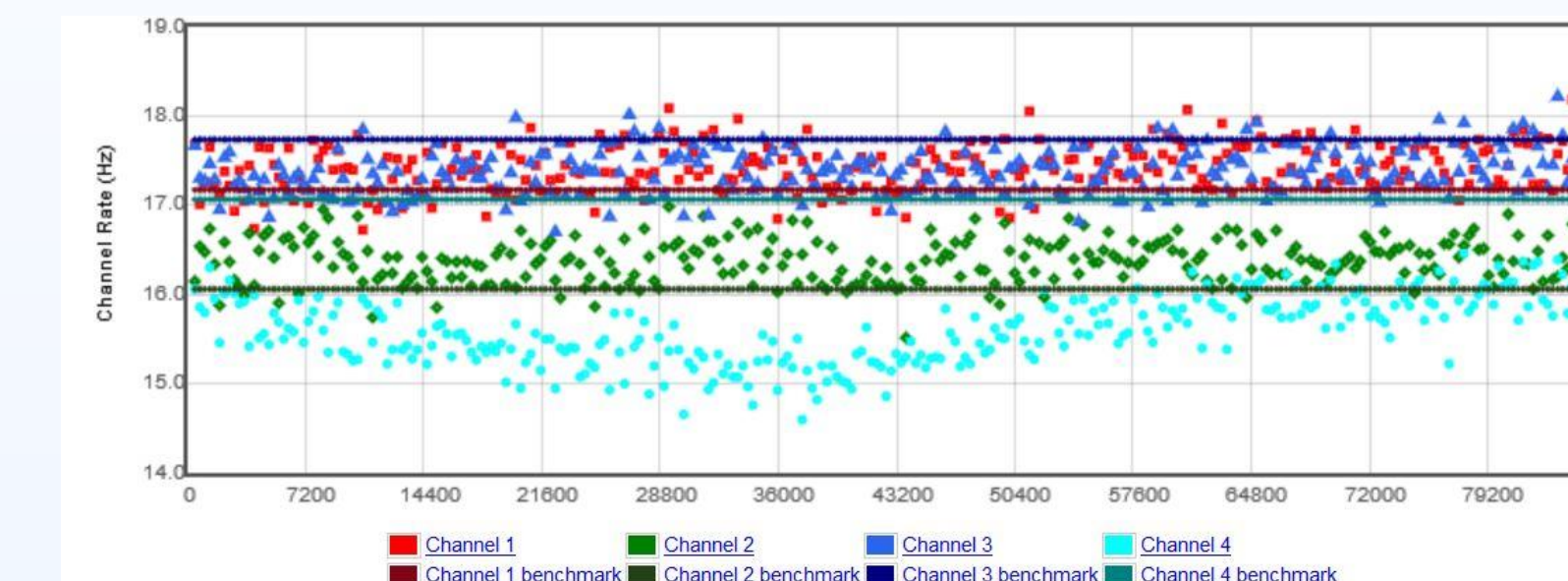
To discern that counts in different channels are coming from the same event, 2-fold or higher coincidence is chosen. This means that within a certain gate of time, at least two counters show signal.

## Sample Results

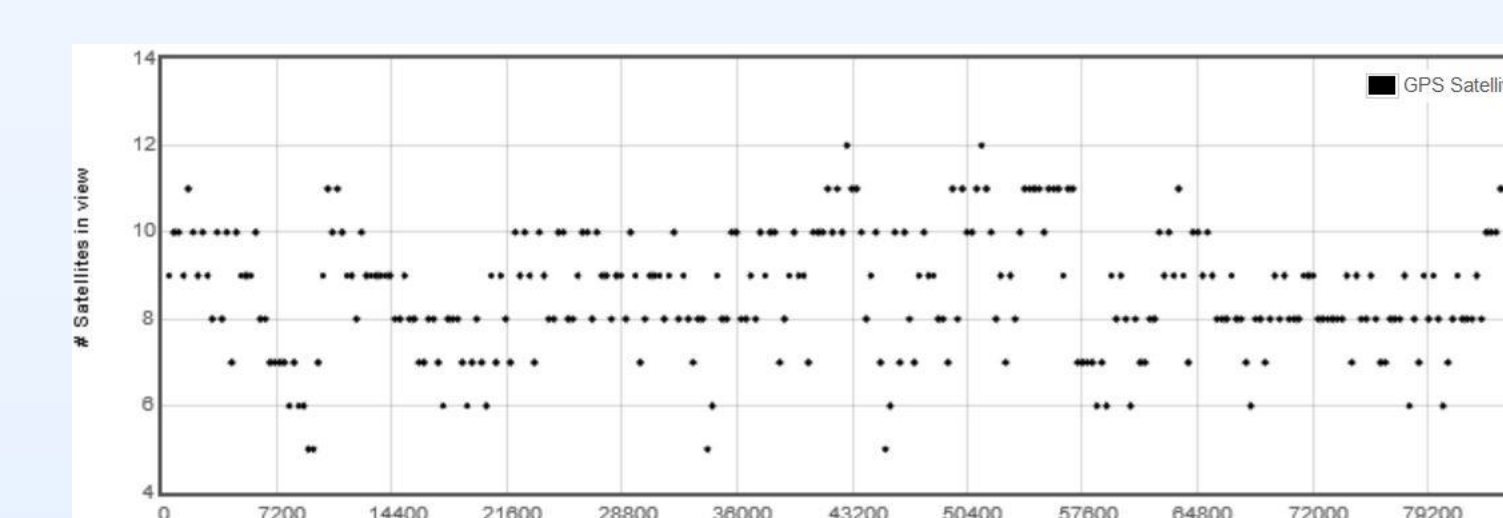
### Blessing plots

These plots show characteristics of the detector behavior and helps determine the validity of the data. All horizontal axes are in seconds past midnight Universal Time.

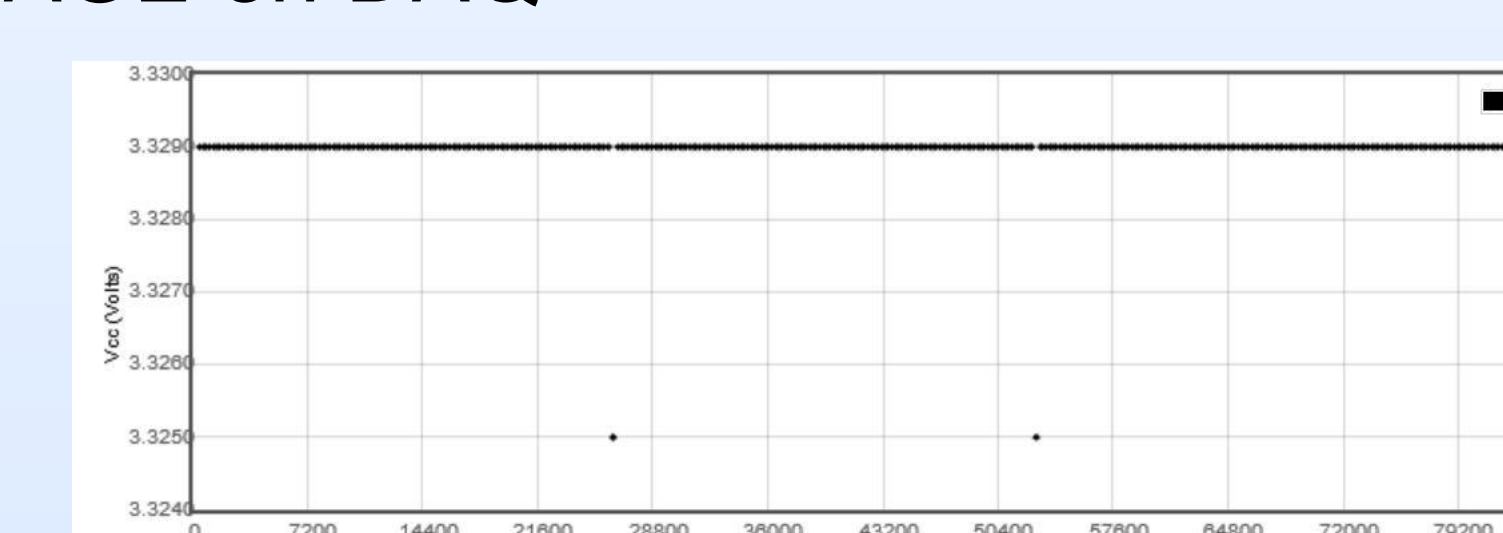
### RATES



### SATELLITES



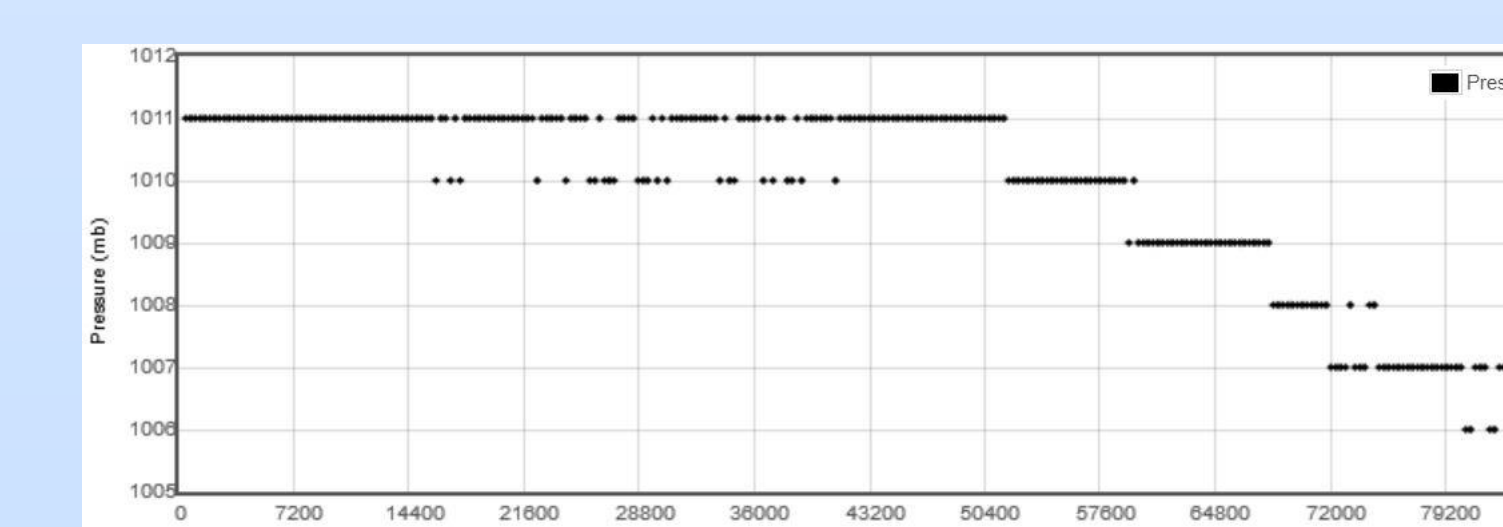
### VOLTAGE on DAQ



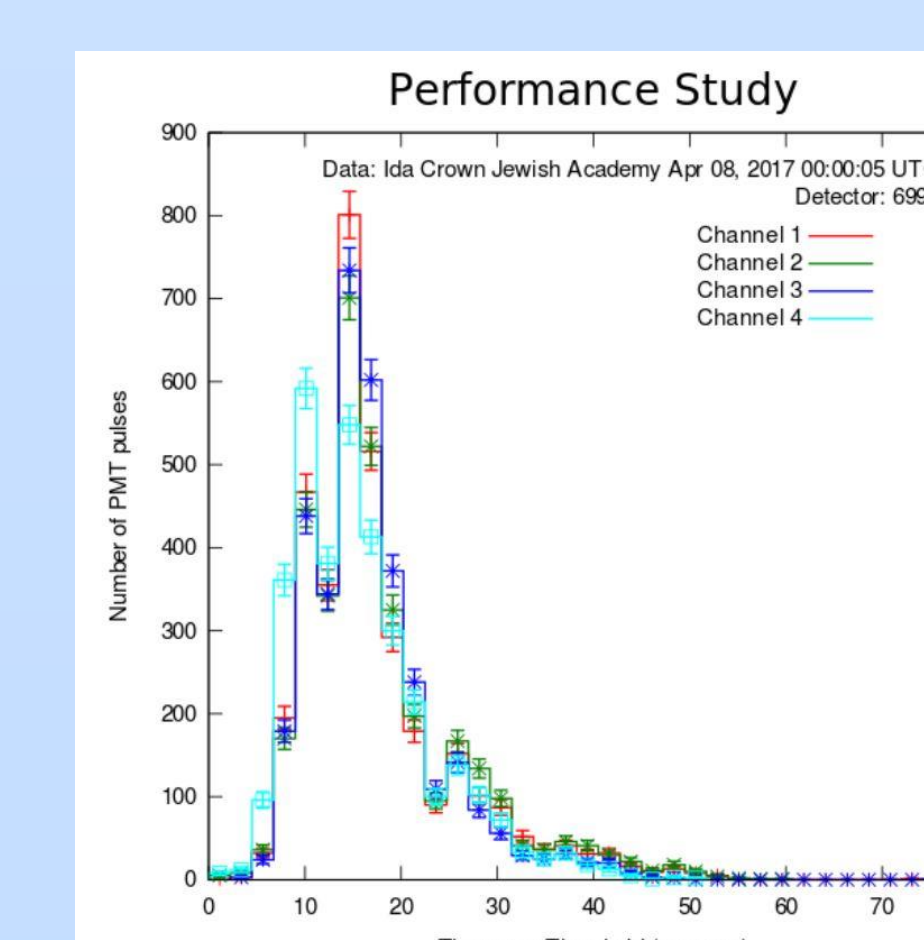
### TEMPERATURE



### PRESSURE

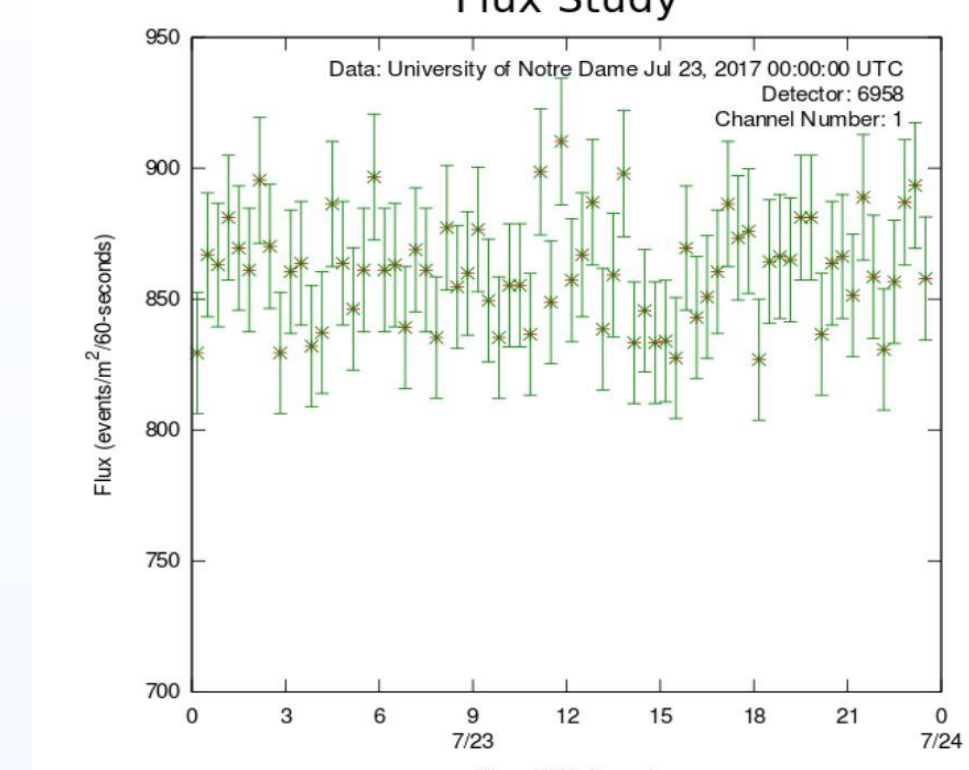


### PERFORMANCE

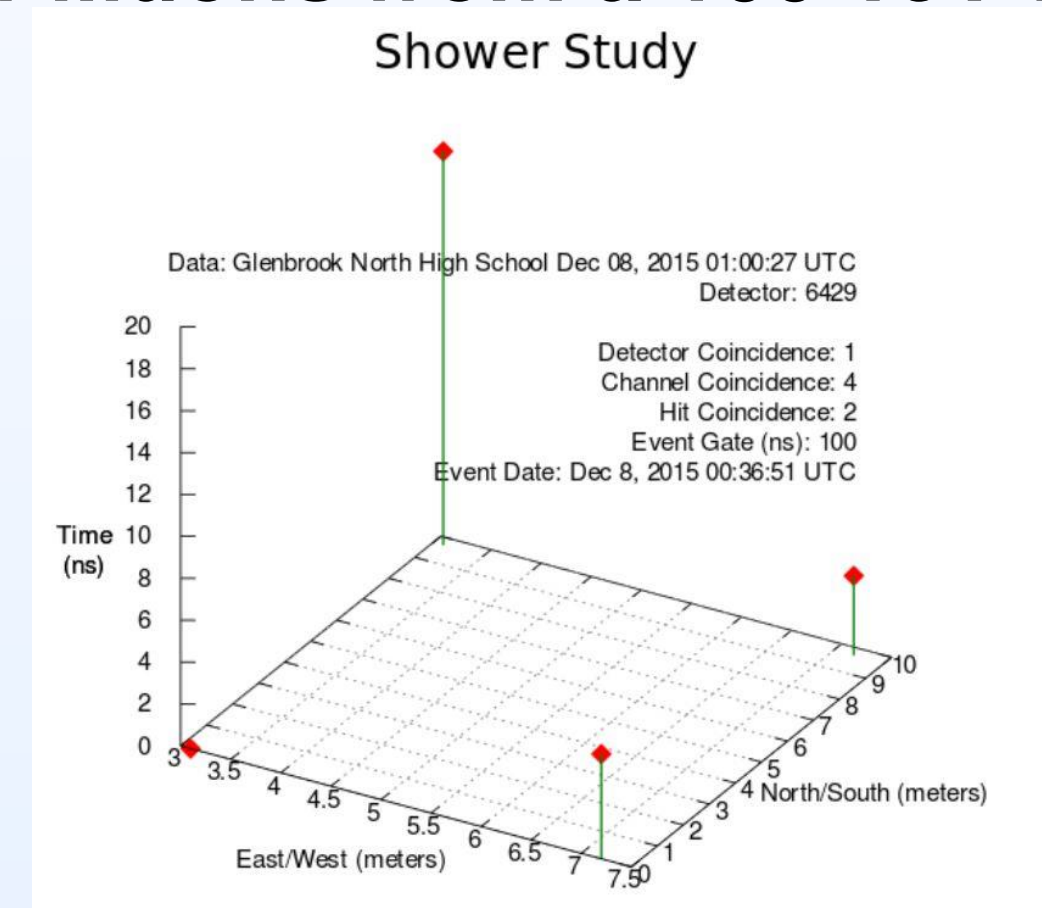


## Sample Studies

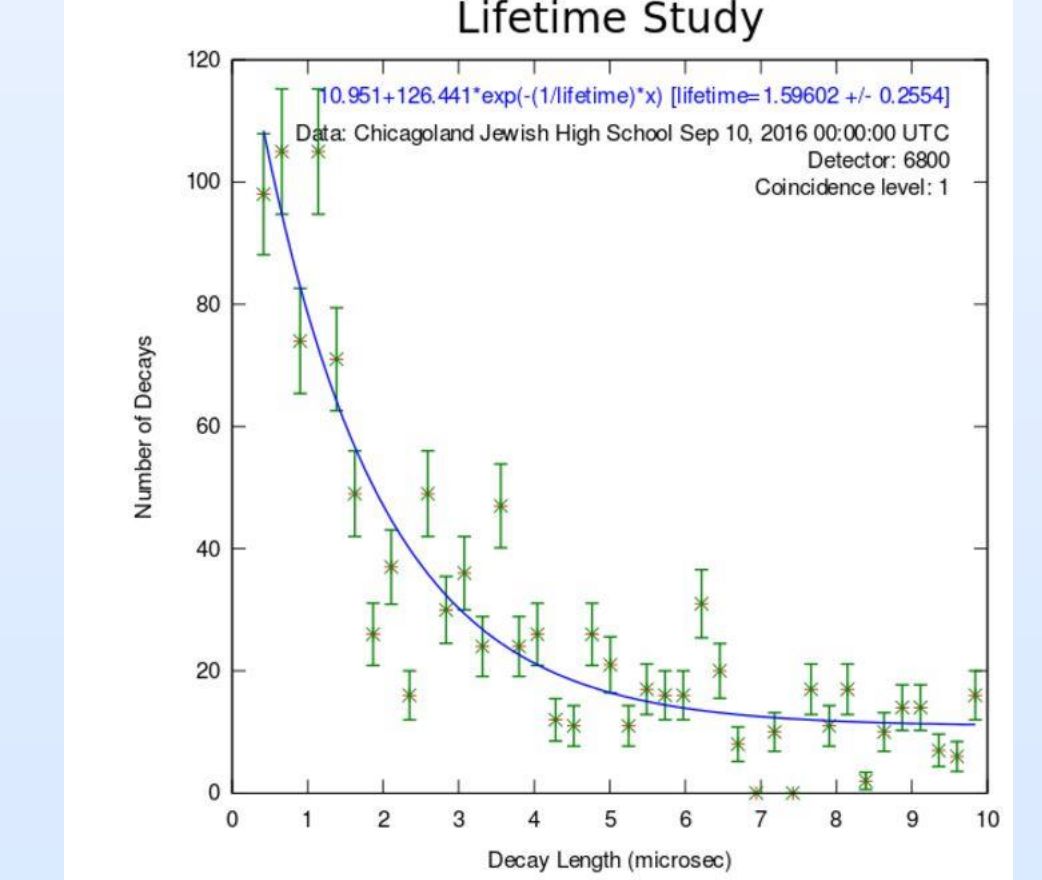
### Flux Rate of Muons



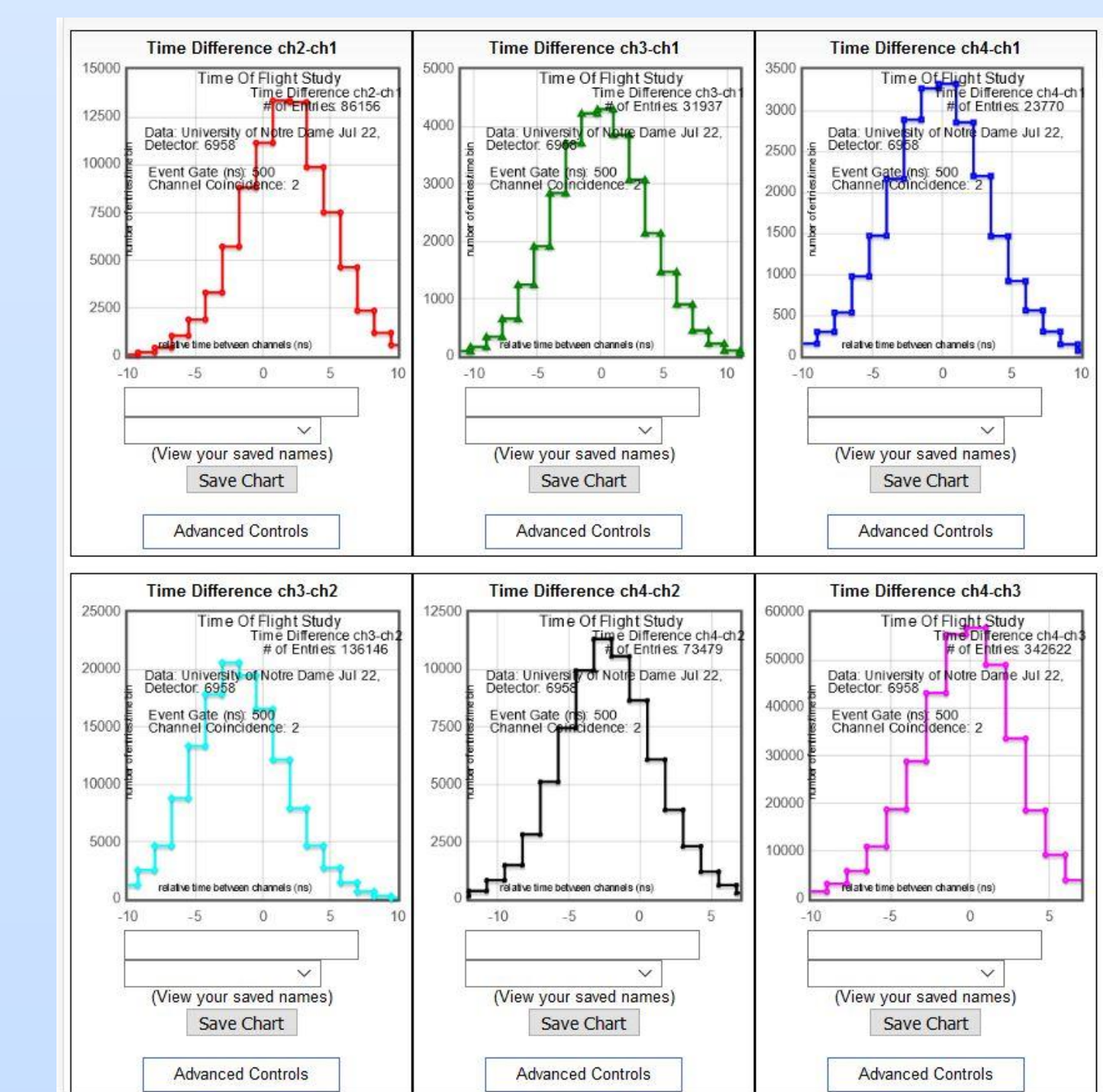
### Shower of Muons from a 100 TeV Event



### Muon Lifetime



### Time of Flight



## Acknowledgements

Fermi National Accelerator Laboratory

