# Portable Cosmic Ray Telescope Design and Construction

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GSU Inagural Cosmic Ray Workshop

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# Outline

- Group introduction
- Hardware
  - Development and construction
  - Telescope operation
- Analysis
  - Online monitoring
  - Early data analysis
- Geant4 simulation
- Summary and outlook

# GSU NPG Interests in Cosmic Rays

- Detector development
  - Deploy cosmic ray monitors worldwide
  - Hardware, Software, and Simulation
- Applications of measurements
  - Monitor atmospheric properties: temperature, pressure, etc.
  - Monitor space weather: solar wind, geomagnetic fluctuations, etc.
  - Using the telescopes for STEM outreach

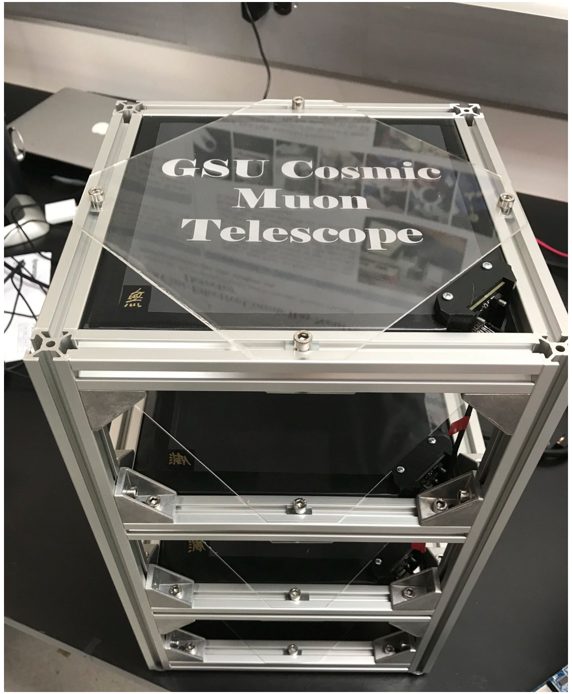
# Construction and Development

# Early Design

- Vacuum photomultiplier tubes (PMTs) were used to read scintillation light (2000$ +)
- Very large and bulky
- Difficult to maintain over long periods of time
- Dangerous
  - 2 kV PMT bias voltage

# Telescope Advantages

- Portable
  - It is light and small relative to other detectors.
- Low-cost
  - Each fully assembled detector costs ~600 USD
  - Continuing to decrease the price
    - Cheaper electronics
- Standardized
  - Every detector will have the same hardware and same software



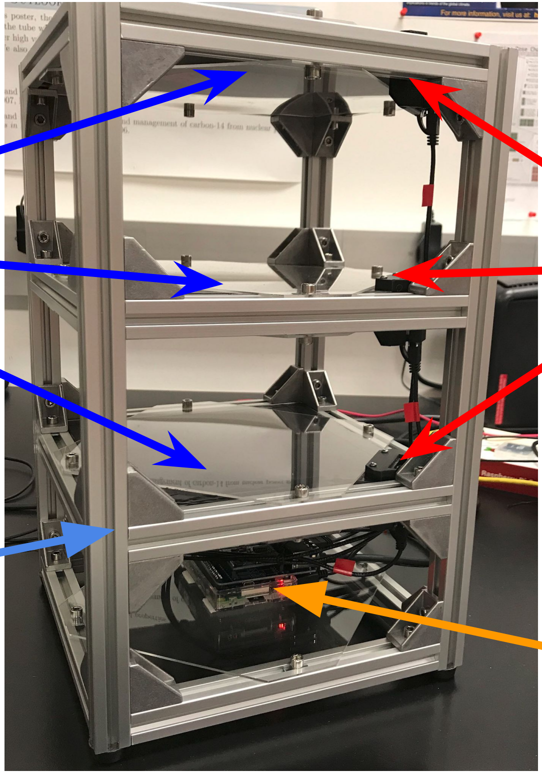

Telescope

# Telescope Advantages cont.

- Not complicated
  - Few parts with potential to break or wear down with age
  - General concept is easy to grasp so can be used for STEM outreach in high/middle schools
  - Maintenance should be low-cost
- Expandable
  - We can continue to expand the telescopes with more tiles, etc. if we want
- Networked
  - Accessible worldwide

# Telescope anatomy

Scintillator panels

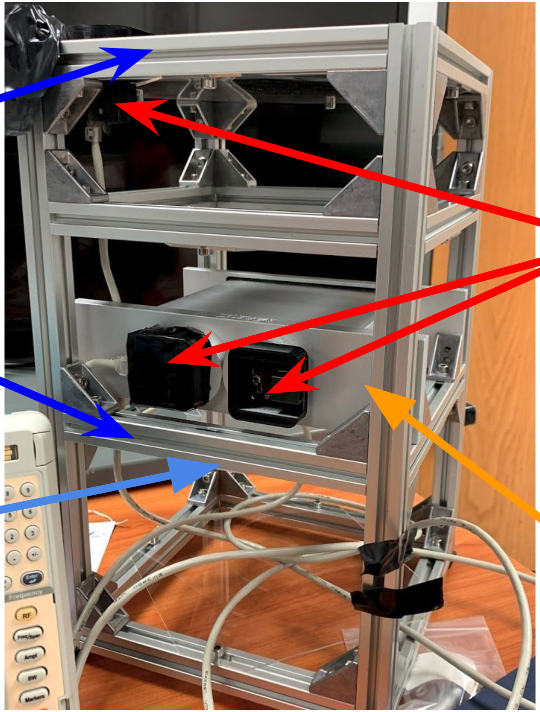


Silicon photomultipliers with 3D printed holder

Extruded aluminum frame

Readout Electronics

# Telescope with Neutron Cell Anatomy

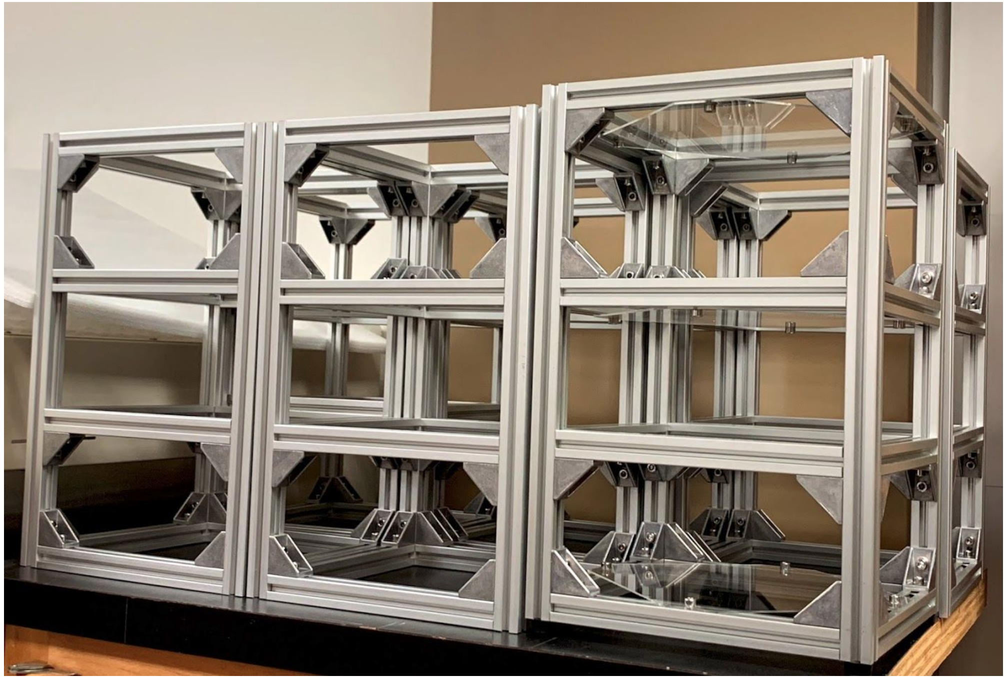


# Frames

- Extruded aluminum with stainless steel hardware
- 22 x 22 x 40 cm
- Light and low cost
  - Still durable and robust
- Due to the brackets used, it is very easy to quickly adjust the separation of the scintillator tiles in our design

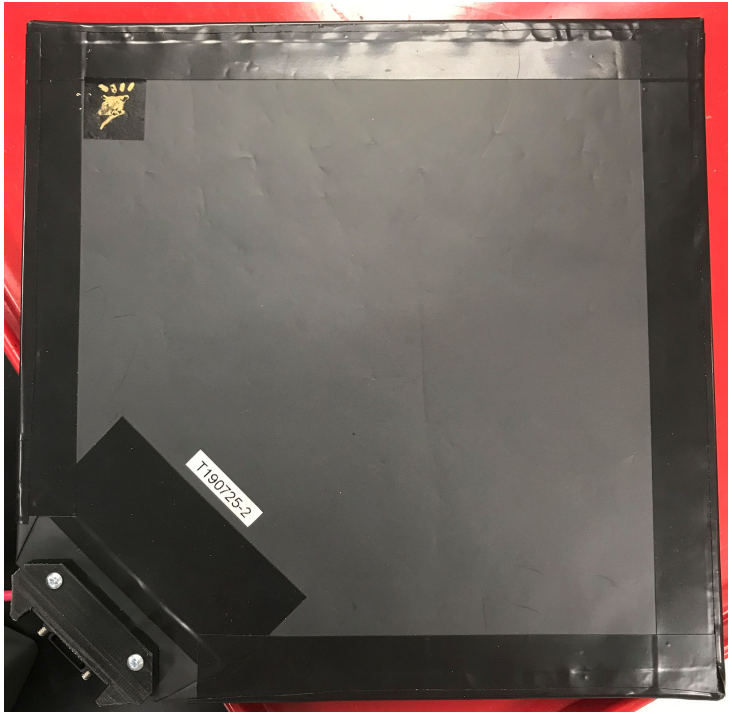
# Frames Cont.

- Expandable for more panels and sensors
- 22 have been constructed
- Part of our STEM outreach efforts, had a high school student assist with building the frames



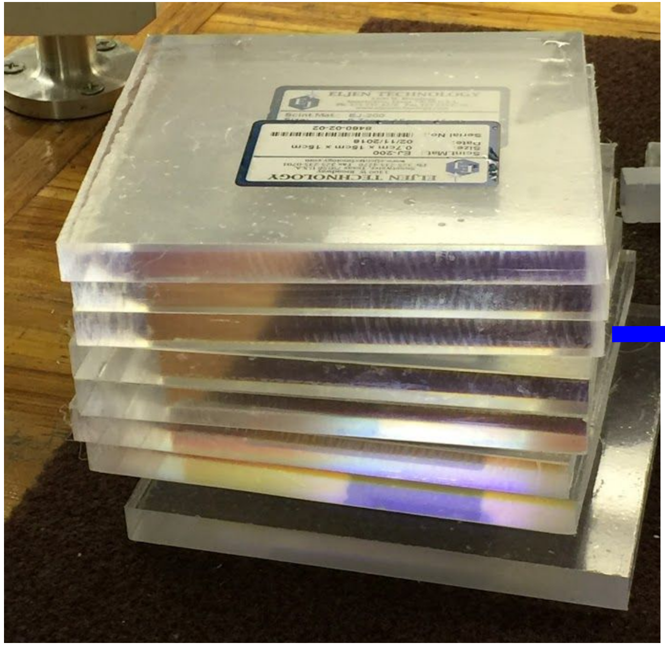
# Scintillator Panels

- Detect charged particles (mainly muons) by releasing scintillation light
- This scintillation light is caught by a wavelength shifting fiber which routes the light to to a SiPM
- Developed based on group work with sPHENIX and the scintillator tiles they are using for the outer HCal

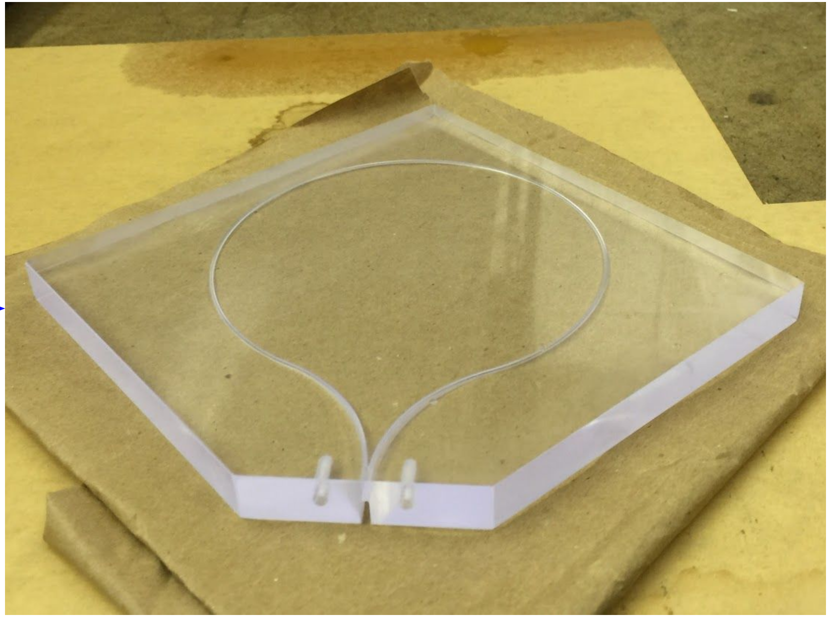



Scintillator Panel wrapped with SiPM

# Scintillator Panel Construction

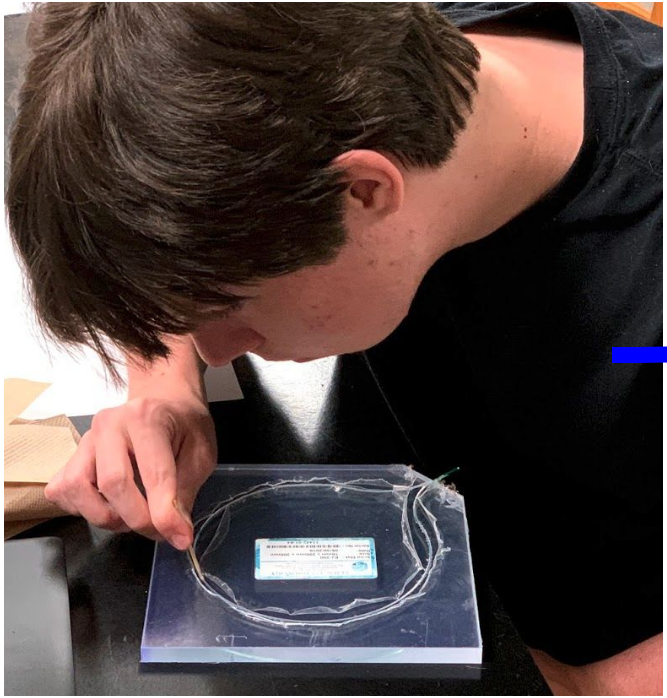


Not yet cut scintillator panels



After cutting and grooving

# Scintillator Panel Construction cont.



Gluing the wavelength shifting fiber in place

After wrapping the tiles and mounting the SiPM board

# Readout Electronics

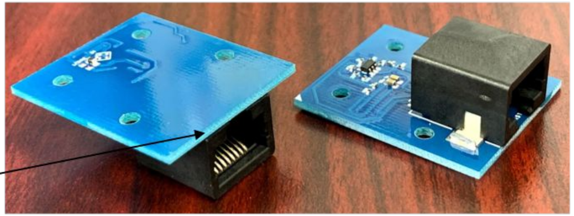
- Custom designed 4 channel board was built to interface with the SiPM board and send data to a Raspberry Pi

(a) 4-ch SiPM interface PCB (back)


(a) 4-ch SiPM interface PCB (front)


SiPM bias voltage daughter board (total of four channels)

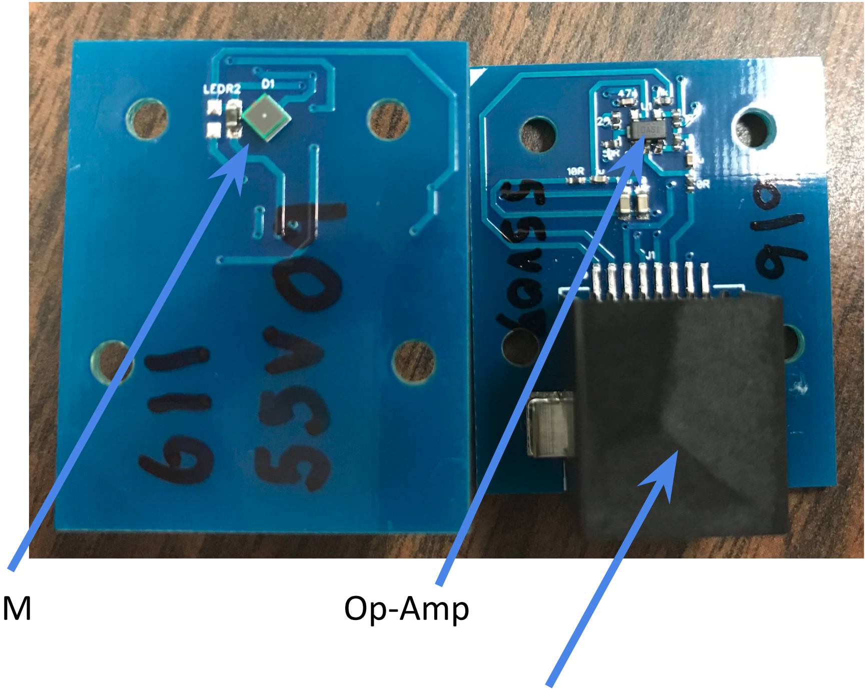
RJ-45 connectors



SiPM sensor PCB both for the muon scintillator panel and the neutron cell.

# Silicon Photomultiplier (SiPM) boards

- SiPMs collect the scintillation light after it's routed through the wavelength shifting fiber
  - Low cost ($15 compared to $2k for PMT)
  - High noise
- Use 2mmx2mm SiPMs with 55V bias voltage
- On-board OP-AMP amplifies signal before sending it to 4 channel board



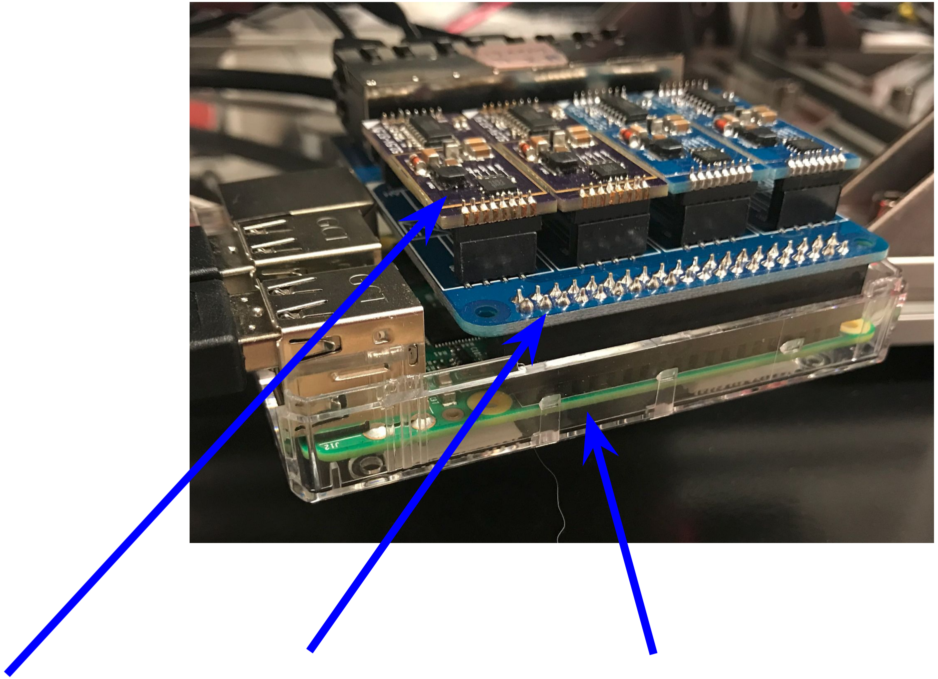
SiPM

Op-Amp

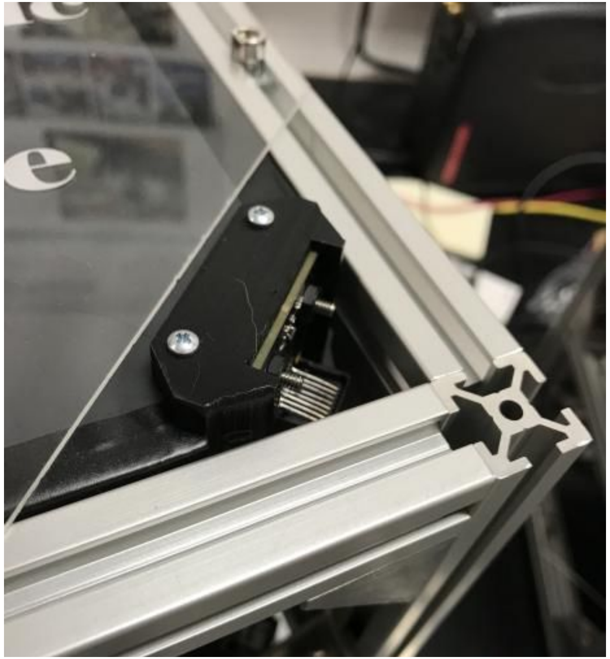
RJ-45 Connector

# 4 Channel Boards

- Connects to the SiPM boards
- Interfaces onto a Raspberry Pi
  - Small, low-cost computer with network capabilities
  - Standard Debian based Linux
- 4 boards on it provide SiPM bias voltage
  - Can set voltages from 52.5 to 57.5 V with high precision. Encapsulates the operating voltage of our SiPMs
- Raspberry Pi provides readout and logging



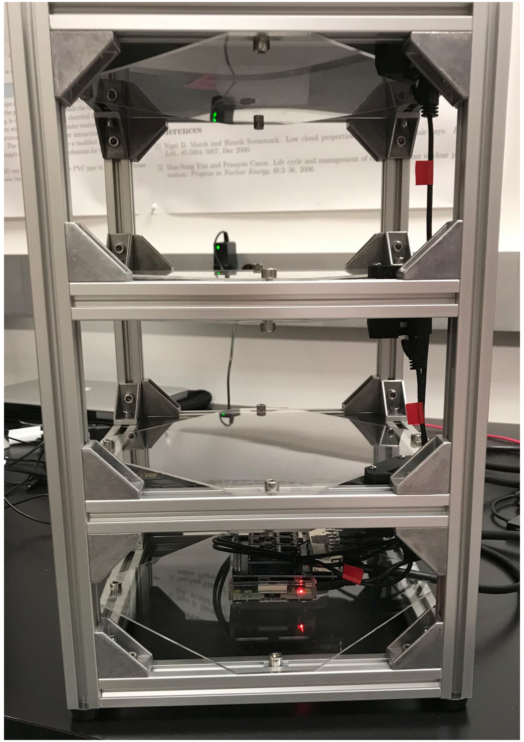
# Particle Detection - Bringing it all together



- Panels release scintillation light on incidence with charged particles which is caught in the wavelength shifting fiber
- Scintillation light is collected by the SiPM, amplified, sent to the 4 channel board, and counted on the Raspberry Pi

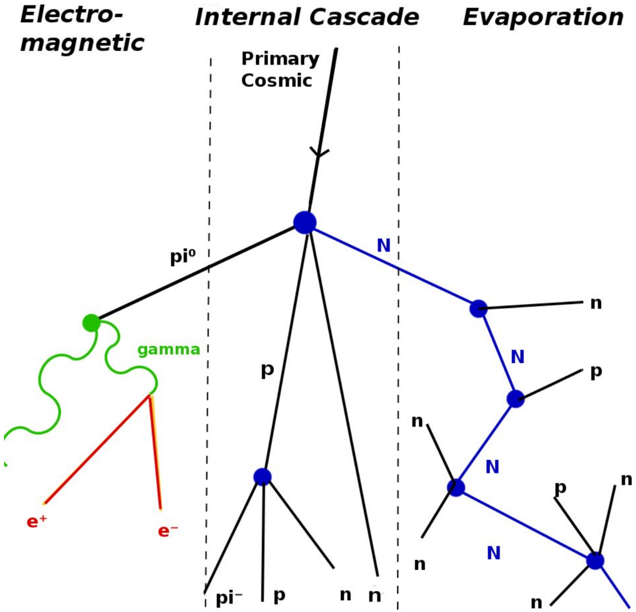
# Data Recording

- The 4 Channel board sends both raw counts from each individual SiPM and ‘coincidence’ counts
- Coincidence counts, where two tiles trigger at the same time, are determined by our 4 channel board and sent to the Raspberry Pi
- Currently monitor coincidence for 3 channels




Operational Telescope

# Neutron detection




Neutron production in cosmic ray decay chain
Picture Source:
https://arxiv.org/abs/1311.5531

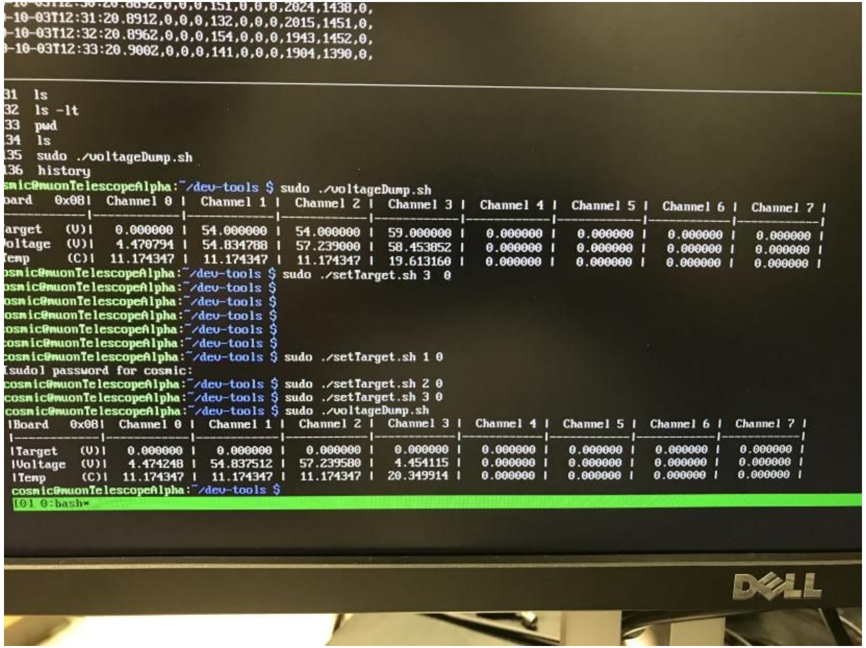
- EJ-200 scintillator panels are only sensitive to charged particles
- An upgrade will be fitted to some of the telescopes with the capability to detect neutrons

# Neutron Cell

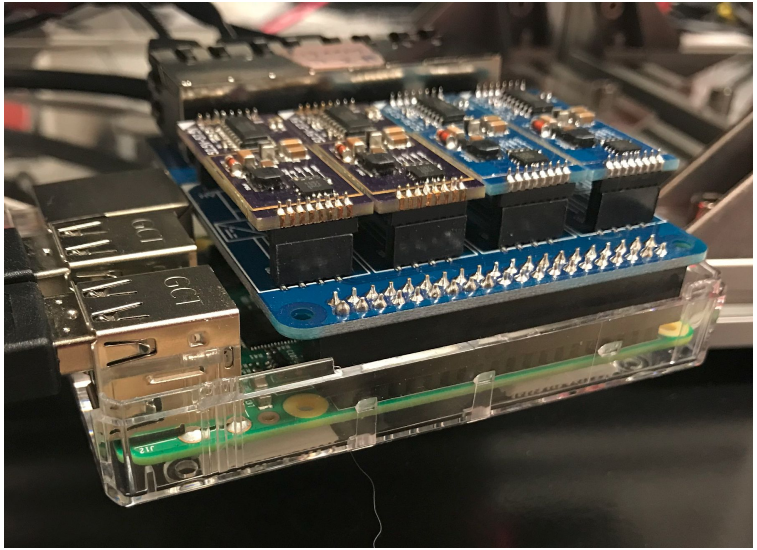
- Cell filled with liquid scintillator
    - Sensitive to both charged and uncharged particles
- Use the same readout electronics as the scintillator panels
- Can isolate neutron events by determining if the particle triggered the scintillator panels too

# Telescope Operation

# Setting and reading the bias voltage



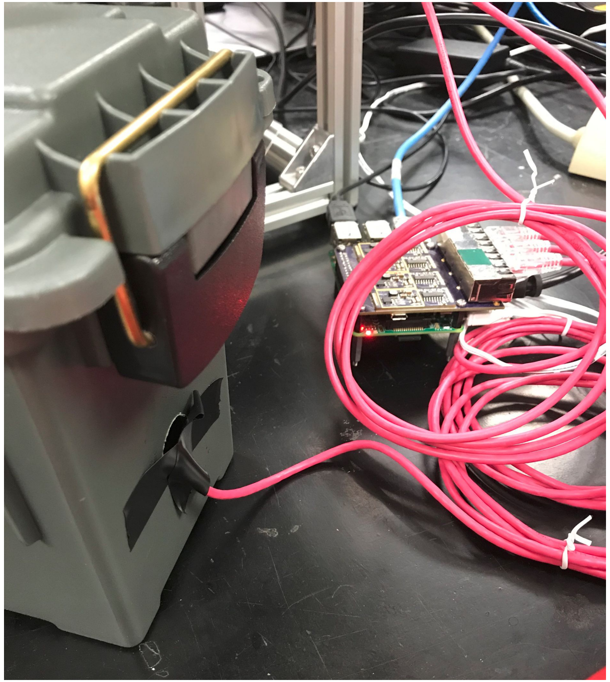

Setting and reading back the bias voltages



Boards that set bias voltage on the 4-channel board

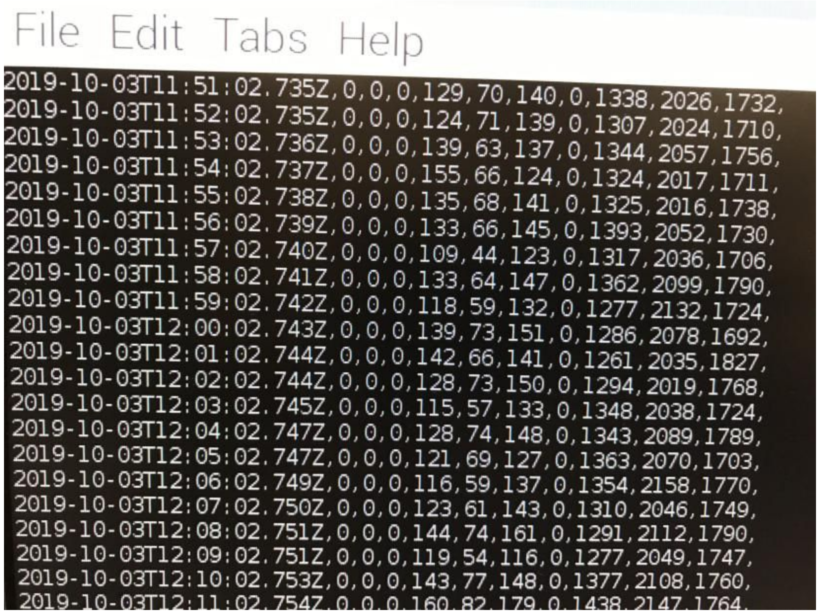
# Testing the SiPMs and boards

- Put the SiPM in a light-tight box and set the bias voltage to approximately 55V
- With the bias voltage set we expect to see noise counts
  - If we see no counts, we can safely assume it does not work
- If bias voltage is set and the SiPM is connected to a board, there are a range of values we can expect to see to determine operation of the tiles



SiPM testing apparatus

# Data collection



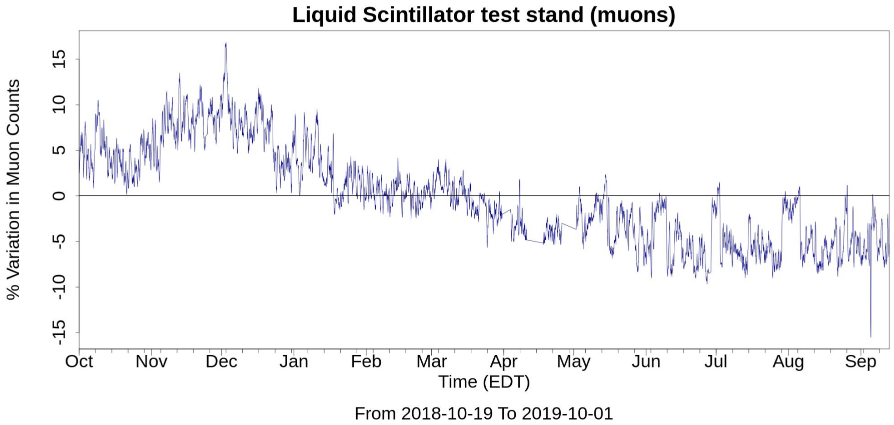

Data Collection

- Log file is created containing the date, raw counts from each SiPM, and every combination of coincidences
  - 6 coincidence combinations for our 4-channel board, current designs uses 3 of the channels

# Online Monitoring

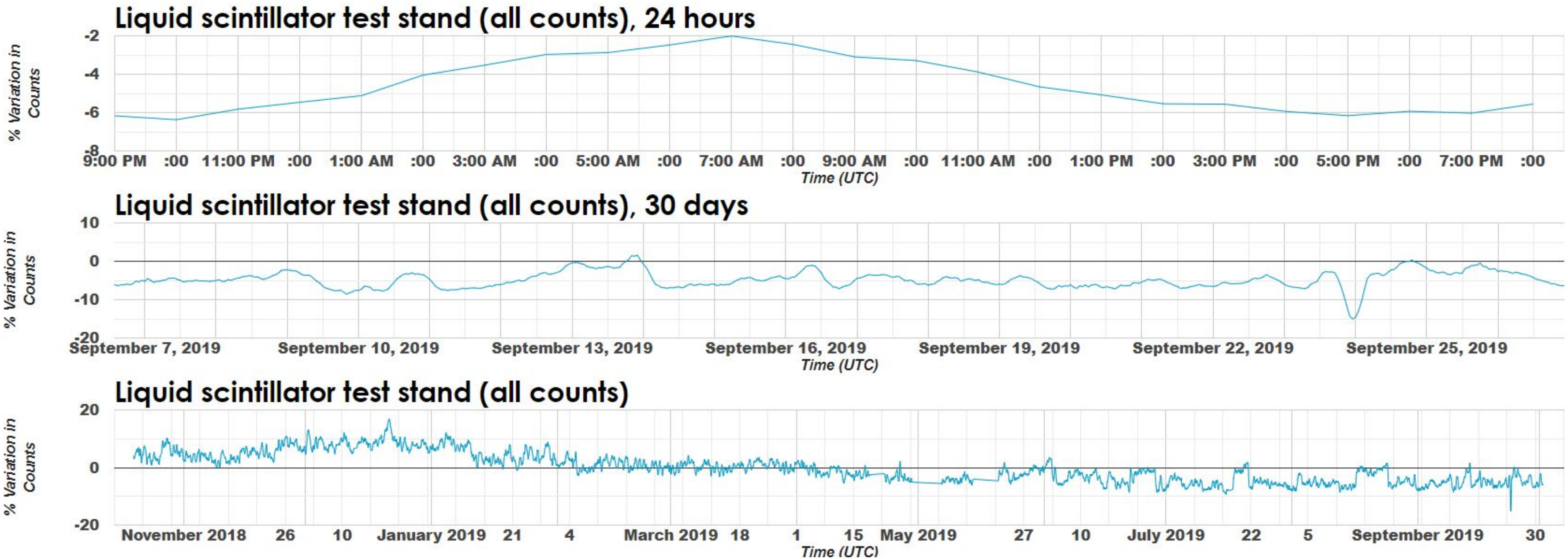
# Online monitoring

- Software was developed in house to create plots of all our long-running detectors
- Update all the data daily
- Our online monitoring setup has been running for nearly a year now




Static plot from phynp6.phy-astr.gsu.edu/~cosmic

# Dynamic plots




Example of our online monitoring

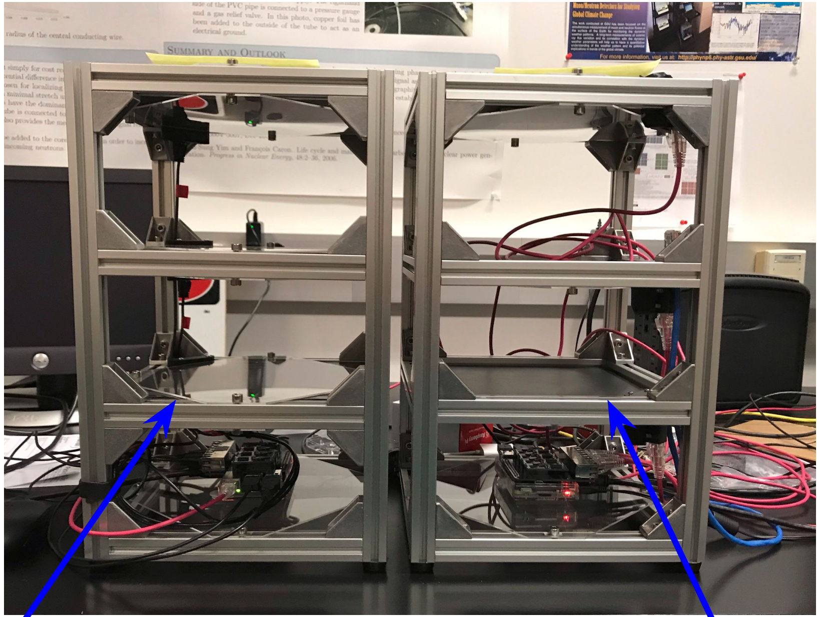
# Online monitoring advantages

- As our worldwide network of telescopes grows, the software is in place to begin monitoring them
- The status of all the telescopes can be monitored remotely at any given time
- All our data is widely available to anyone who wants to use it
- Lots of other worldwide monitors use a number of different detectors at each given location, all of our telescopes will be consistent

# Data Analysis

# Telescope Consistency Test

- Test was run with two independent telescope stations
- Single channel counts were matched between the two to set proper SiPM bias voltage for each tile
- Allows us to monitor the consistency of the telescopes, i.e., if two independent telescopes ran in identical conditions performed the same

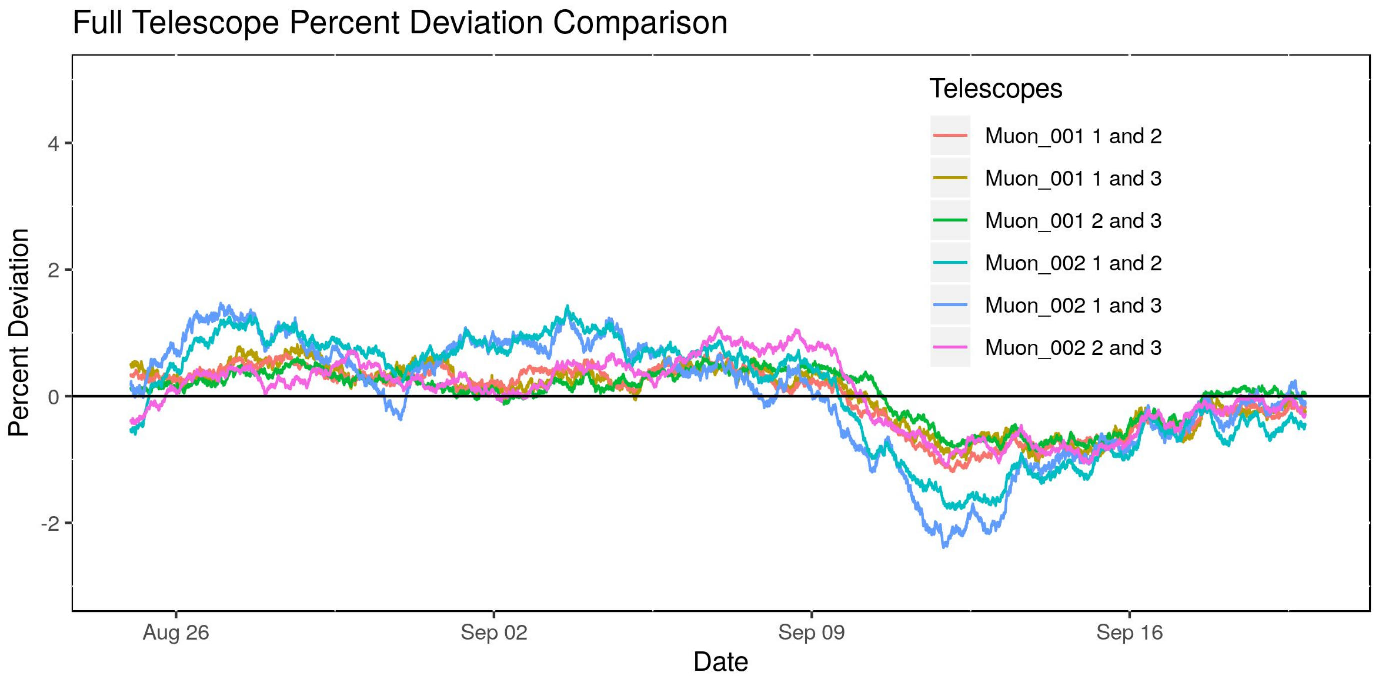


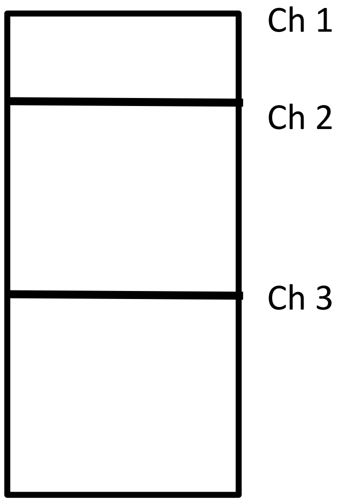
‘Muon_001’

‘Muon_002’

Setup for telescope consistency test

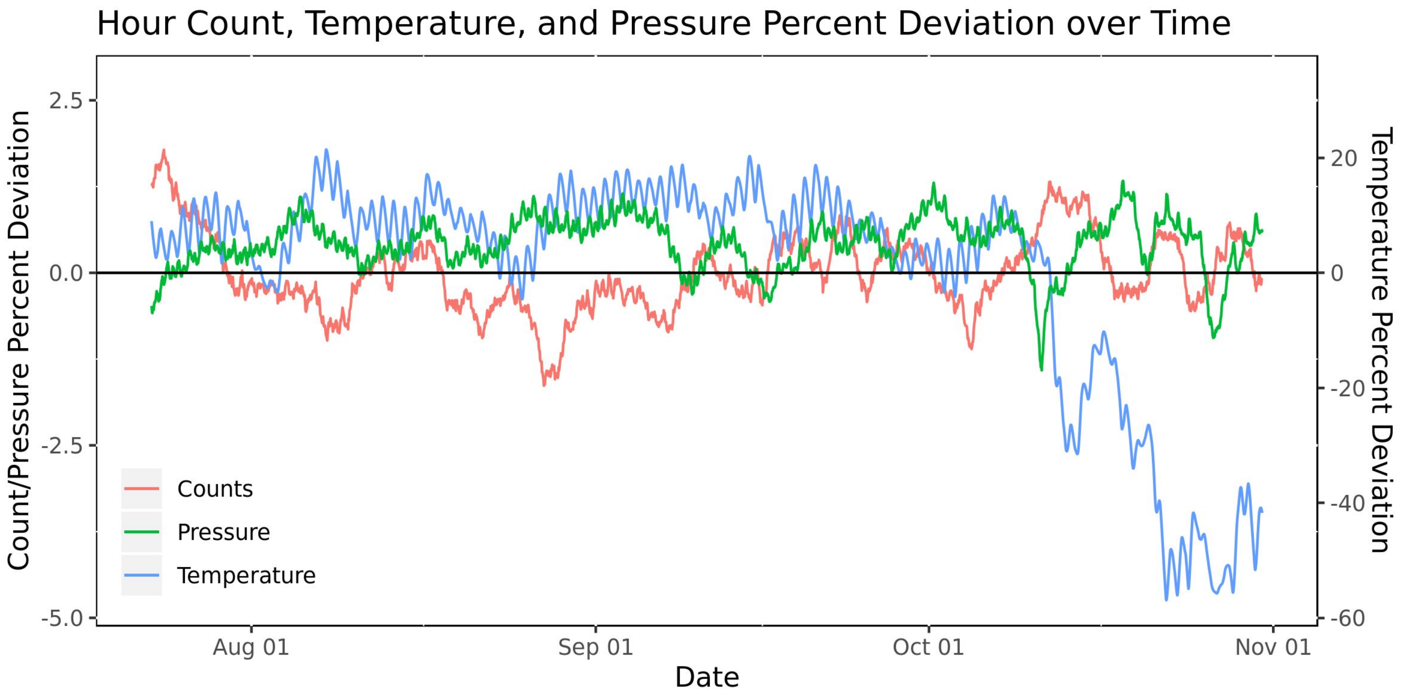
# Telescope Consistency cont.



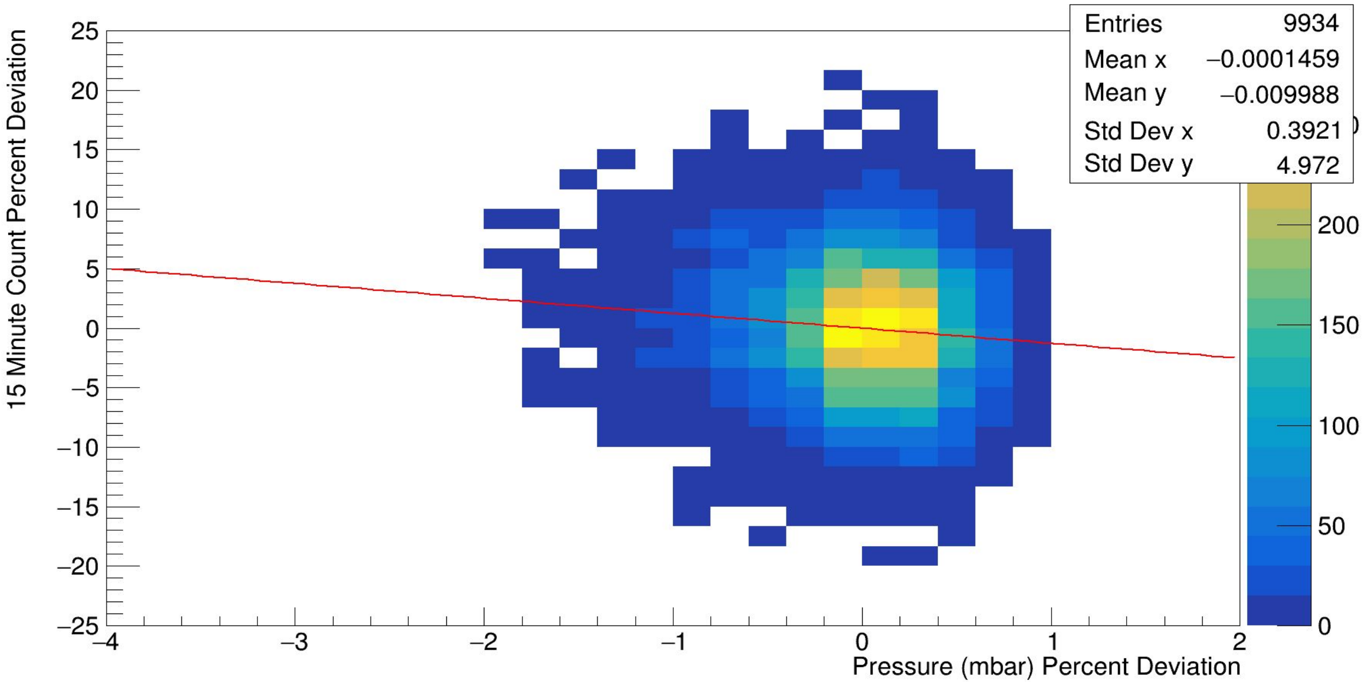

Results of telescope consistency test, all channels stay within about 1% of each other throughout the test

# Weather Correlations



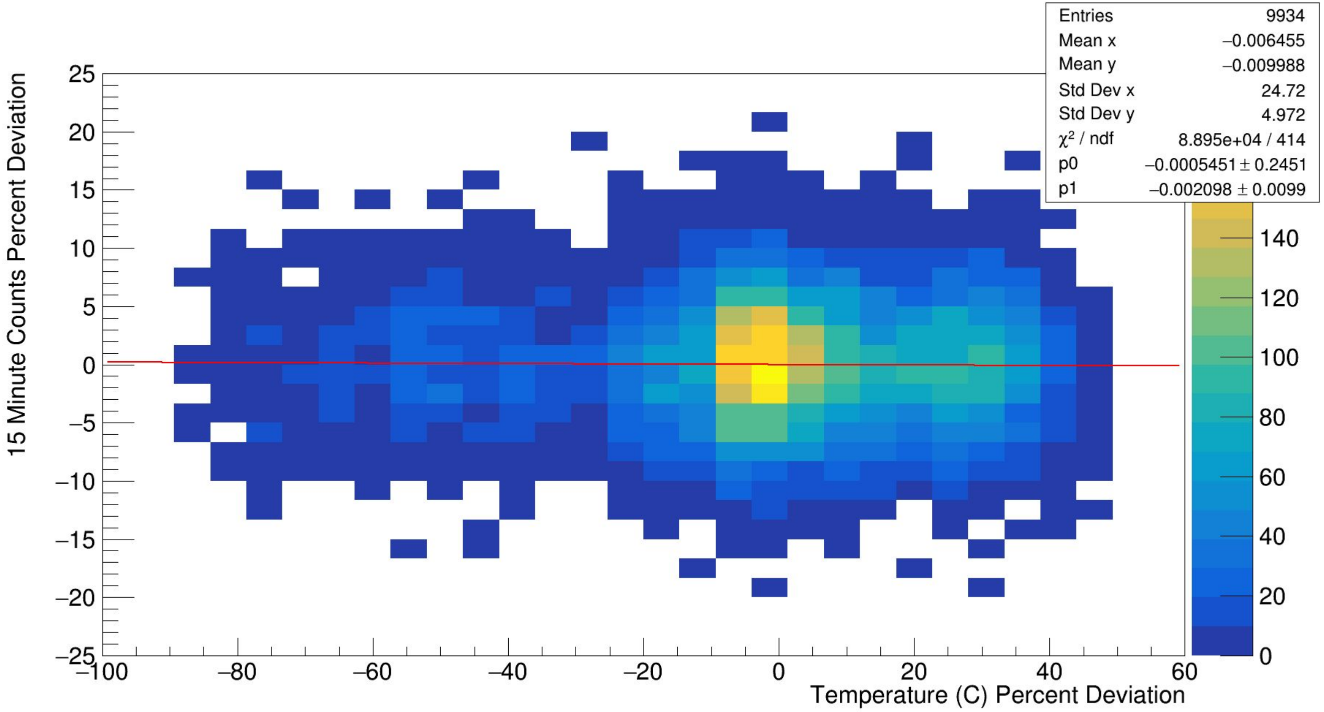

Plot of counts between the top and bottom of the telescope and various weather effects, weather data was obtained from local weather stations. Counts are Ch 1 and 3

# Pressure Correlations




2D histogram of the counts percent deviation versus the pressure percent deviation

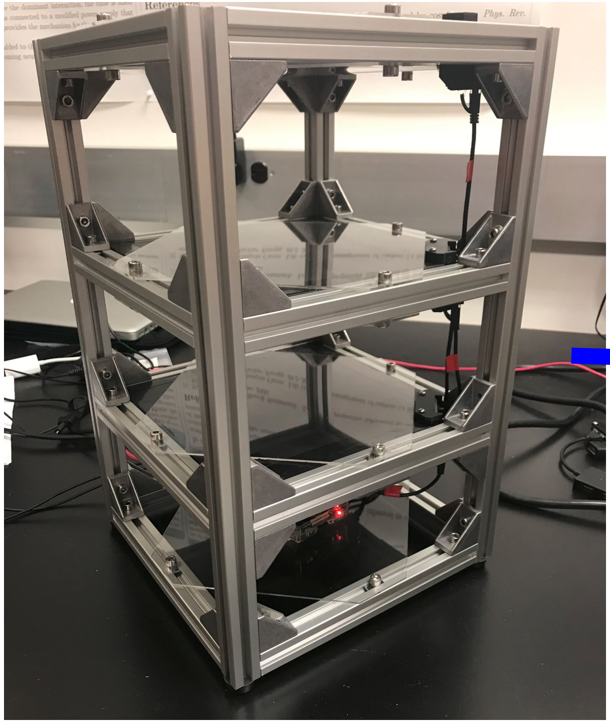
# Temperature Correlations



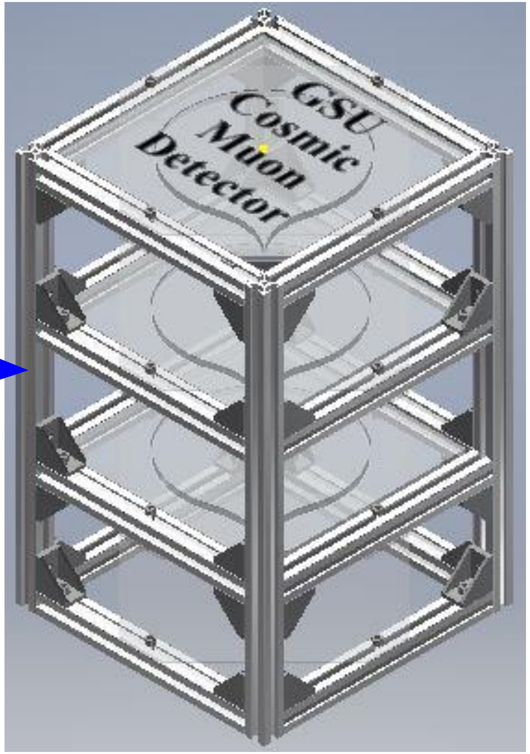

2D histogram of the counts percent deviation versus the temperature percent deviation

# Geant4 Simulation

# 3D model



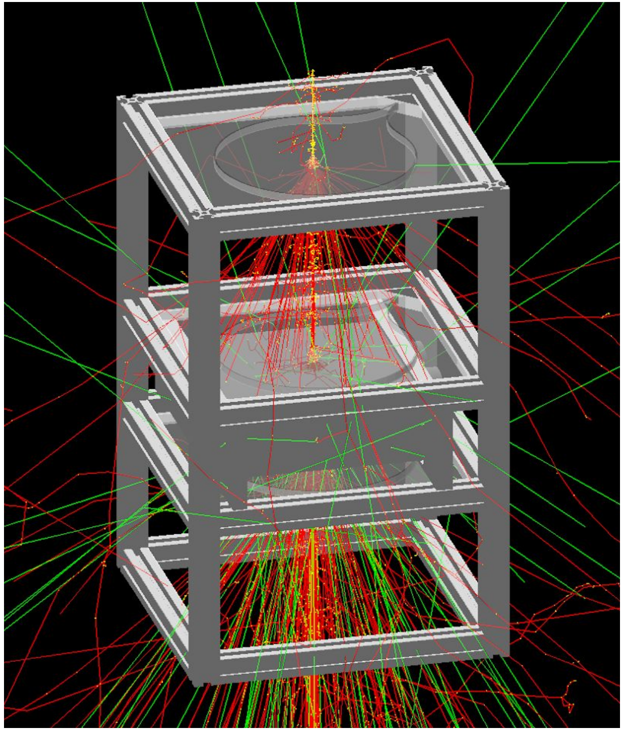
Real Telescope



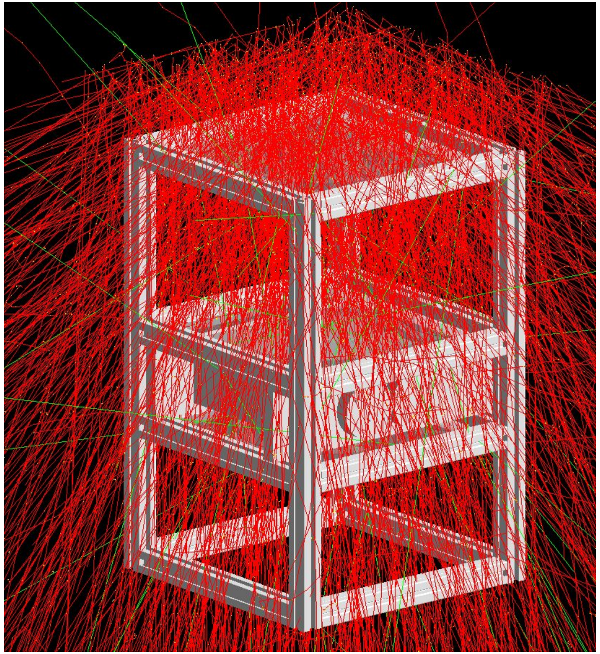

3D Model of Telescope

# Development

- Imported the CAD model into Geant4
- Began development with a point source of same energy particles
- Does not model actual cosmic ray events, cosmic particles do not come straight down



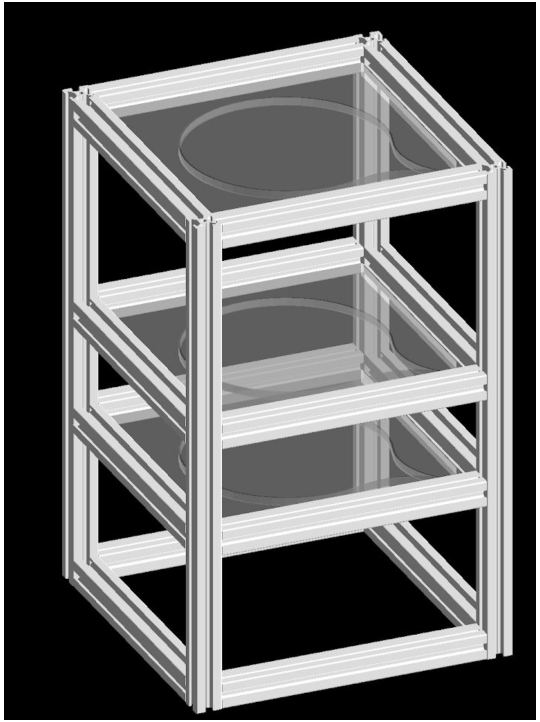
# Geant4 Simulation



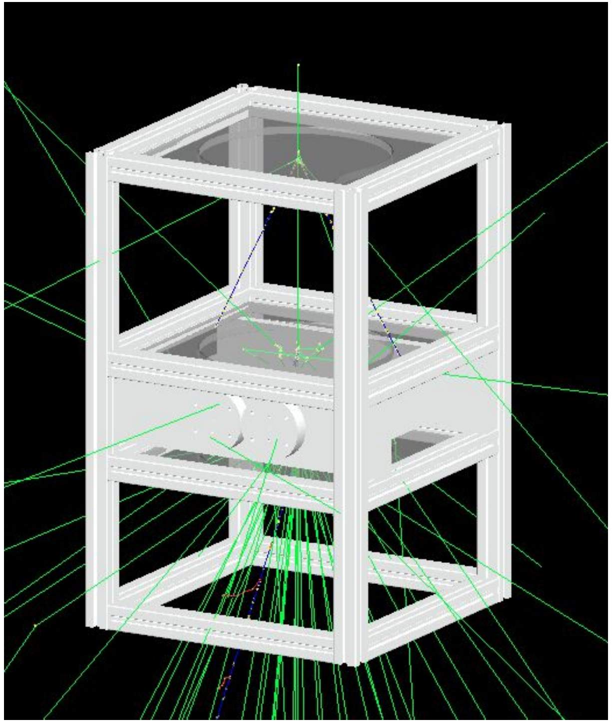
Telescope simulation: 1k cosmic muons

- Particles come from a plane with randomized energy (in the range expected of typical cosmic particles)
- Angle of incidence is randomized to ± 70° in the x and z direction, and position is randomized to ± 15 cm in the x and z direction
- More accurately models real cosmic ray shower events.
- Allows us to model our telescope in simulation; we can use this to test the telescope
- Allows testing of efficiency and acceptance

# Different Simulation Models

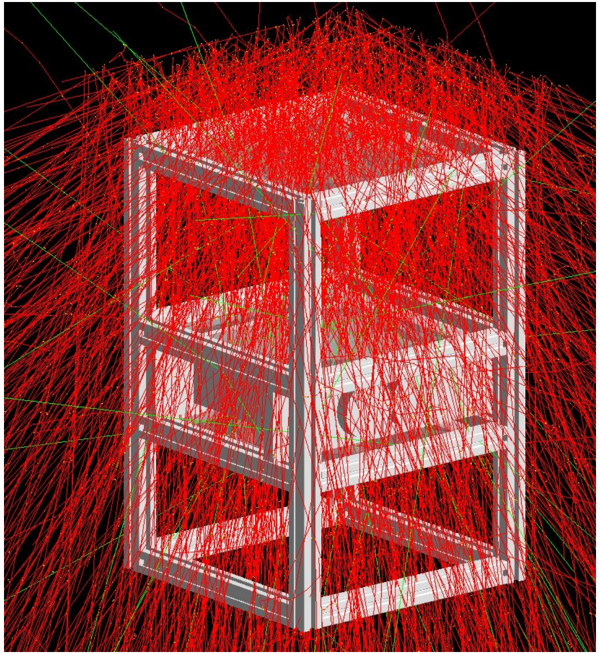


Without Cell

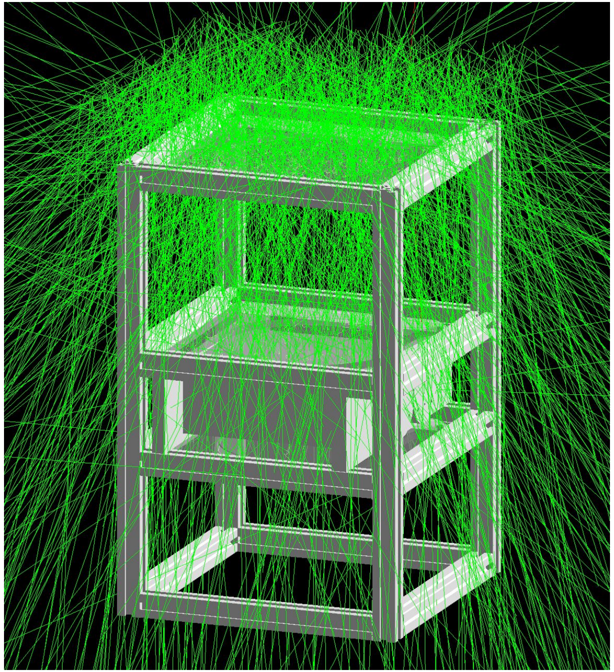


With Cell

# Neutrons vs. Muons



Simulation with 1000 cosmic muons



Simulation with 1000 cosmic neutrons

# Summary and Outlook

- Have developed low-cost, portable cosmic muon and neutron detectors.
- We are currently testing and building 30 total telescopes to be distributed worldwide.
  - Will allow us to monitor atmospheric and astrological effects going forward
- Using online monitoring, we can check the status of our detectors remotely and gather their data to analyze
- We are continuing to develop a simulation to study the telescope acceptance and performance.