

# Portable Cosmic Ray Telescope Design and Construction

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GSU Inagural Cosmic Ray Workshop

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# Outline

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- 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

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- 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

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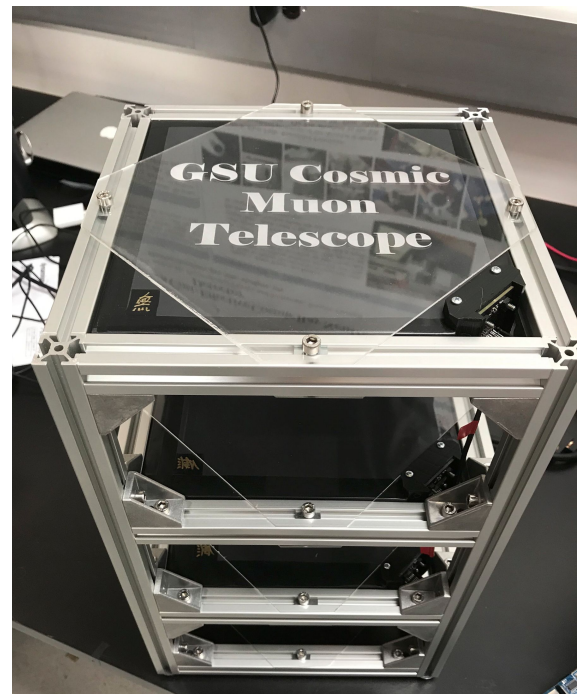
# Early Design

- 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



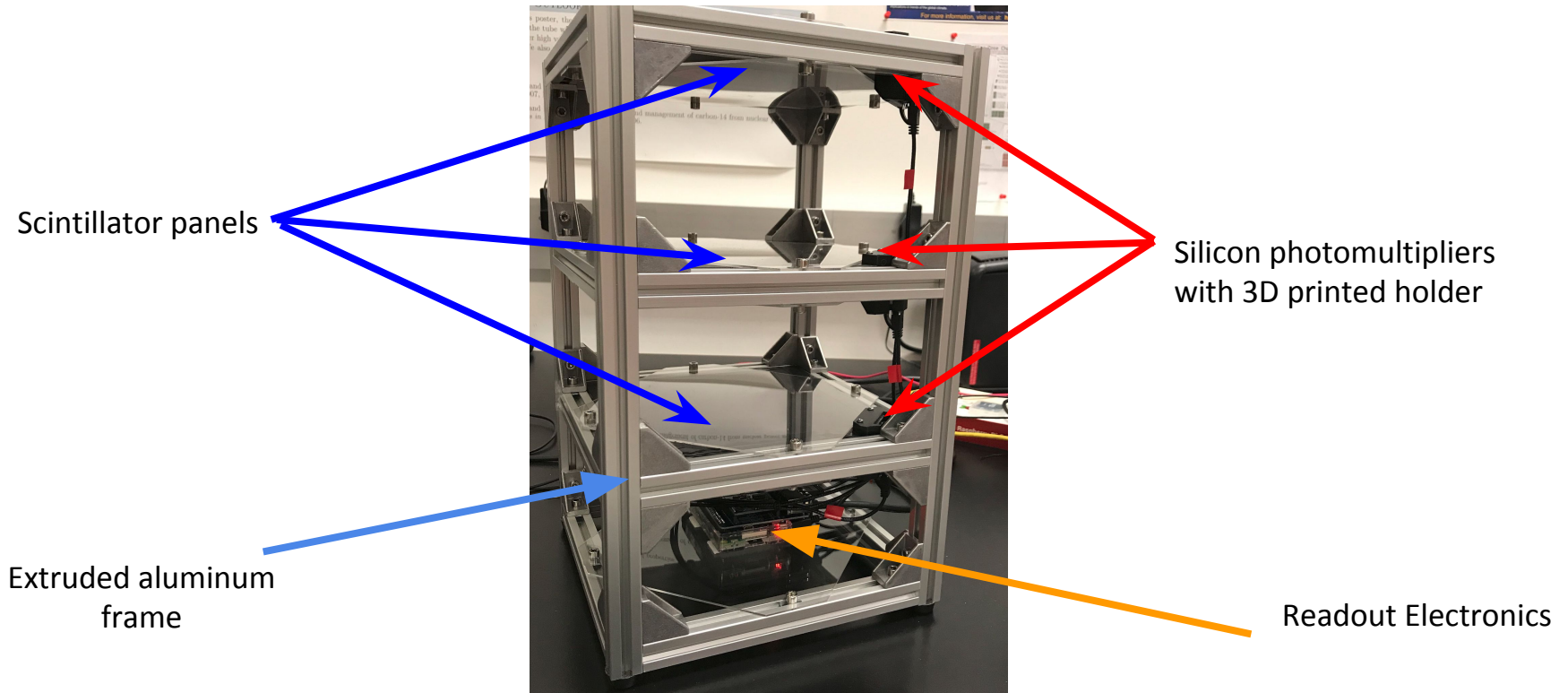
Telescope

# Telescope Advantages cont.

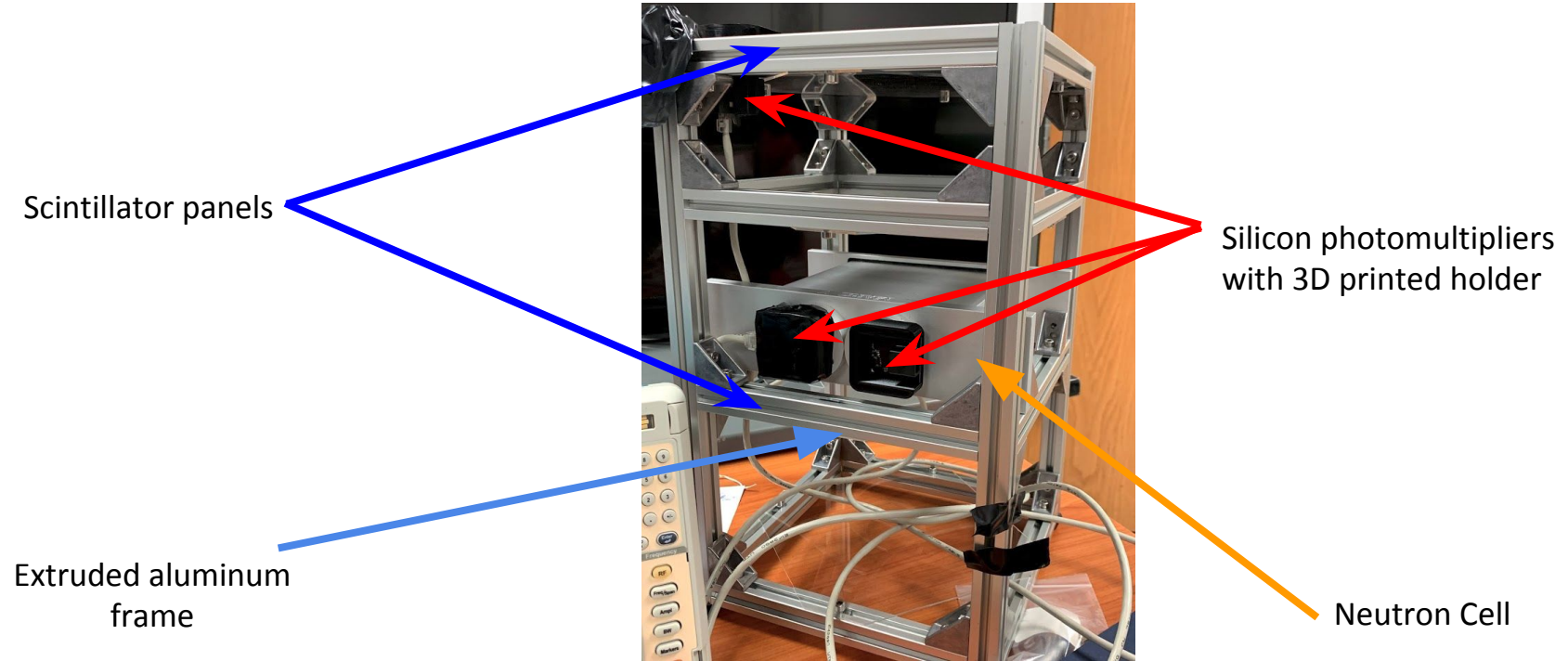
- Not complicated
  - Few parts with potential to break or wear down with age
  - General concept is easy to grasp so can be used for STEM outreach in high/middle schools
  - Maintenance should be low-cost
- Expandable
  - We can continue to expand the telescopes with more tiles, etc. if we want
- Networked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



# Telescope anatomy



# Telescope with Neutron Cell Anatomy





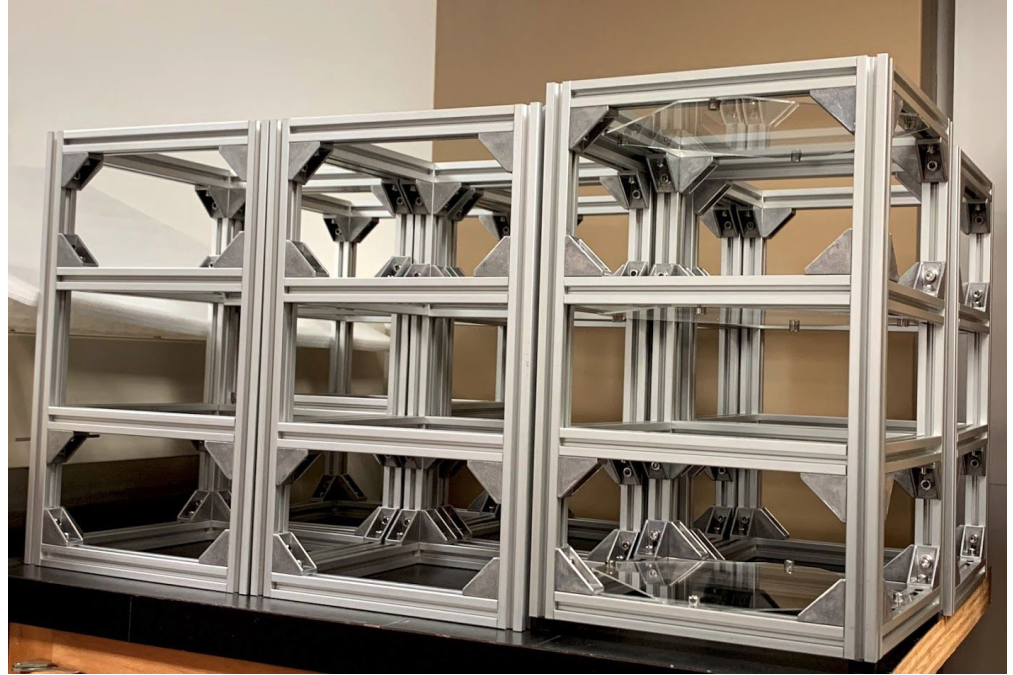
# Frames

- 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



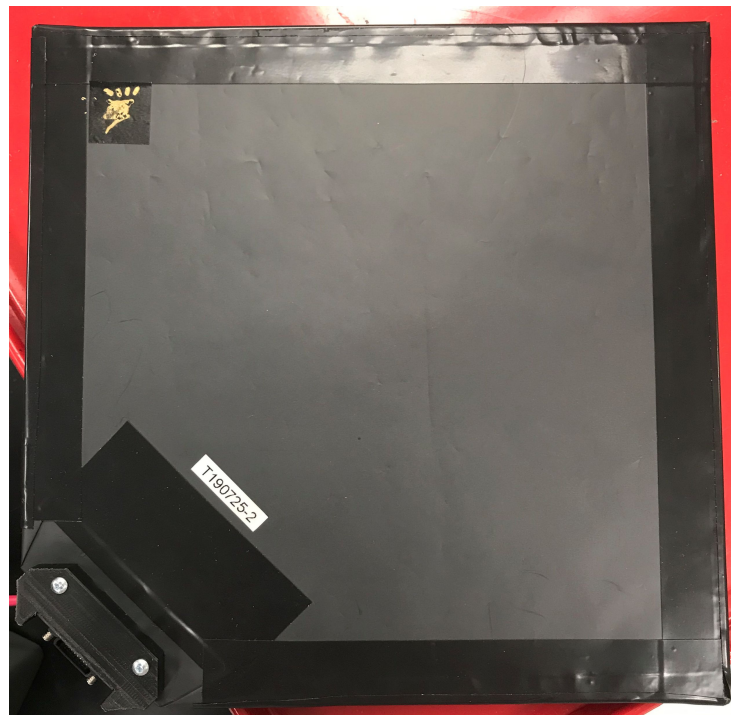
# Frames Cont.

- 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

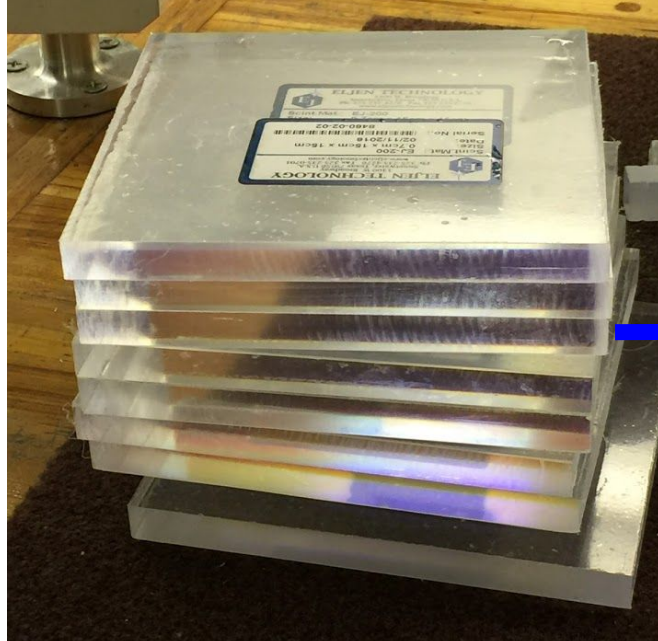
- Detect charged particles (mainly muons) by releasing scintillation light
- This scintillation light is caught by a wavelength shifting fiber which routes the light to to a SiPM
- Developed based on group work with SPHENIX and the scintillator tiles they are using for the outer HCal



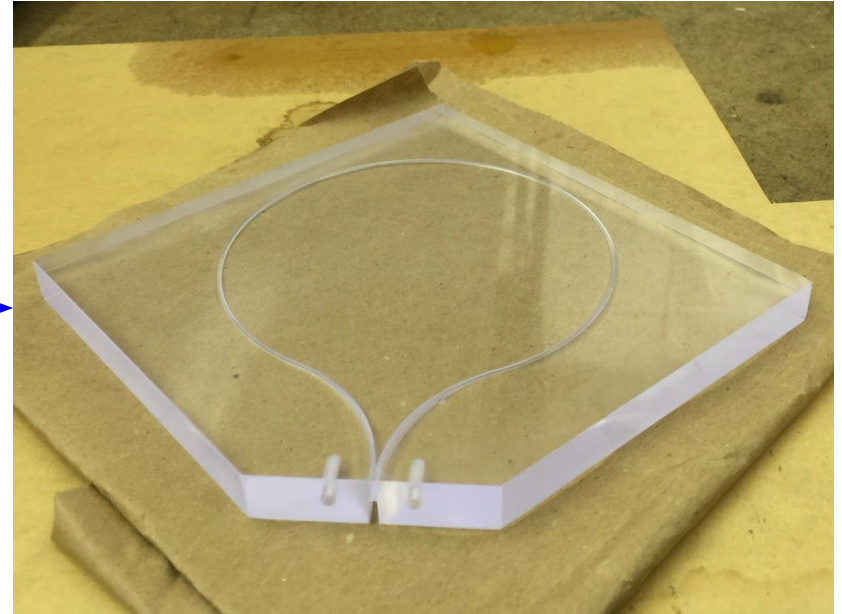
Scintillator Panel wrapped with SiPM



# Scintillator Panel Construction

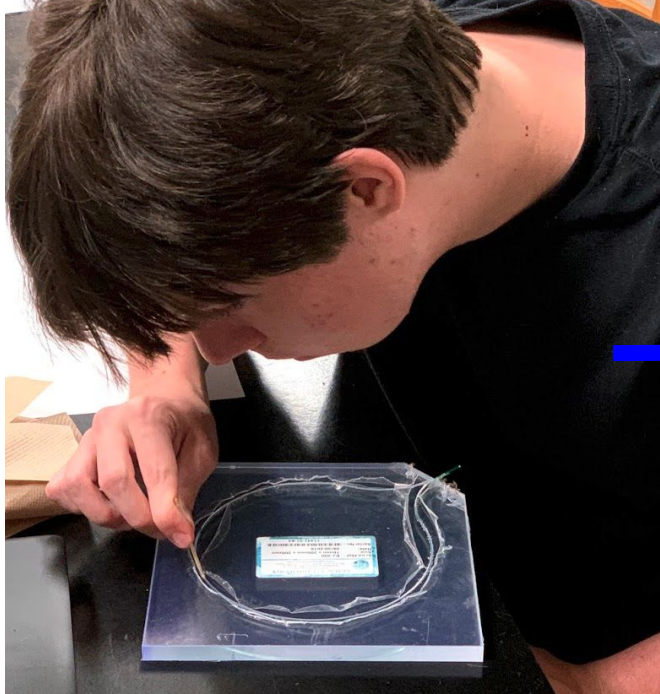


Not yet cut scintillator panels

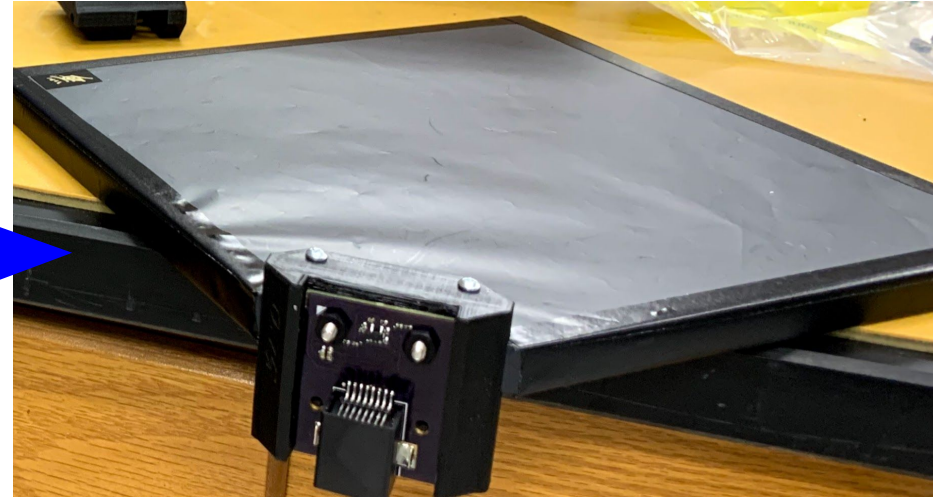


After cutting and grooving

# Scintillator Panel Construction cont.



Gluing the wavelength shifting fiber in place

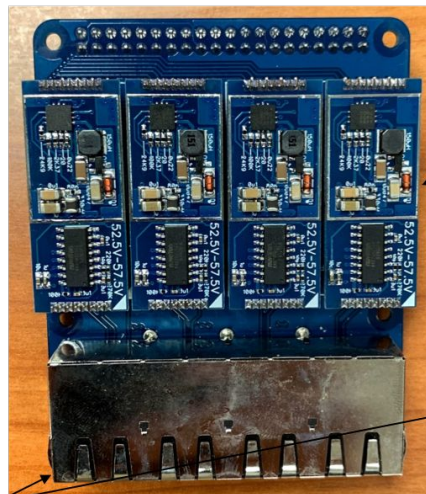


After wrapping the tiles and mounting the SiPM board

# Readout Electronics

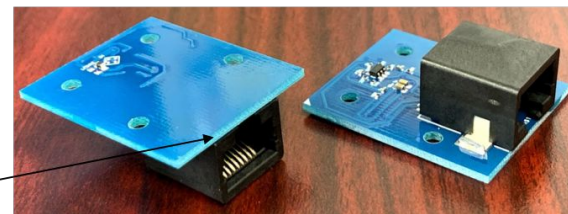
- Custom designed 4 channel board was built to interface with the SiPM board and send data to a Raspberry Pi

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



RJ-45 connectors

SiPM bias voltage daughter board  
(total of four channels)

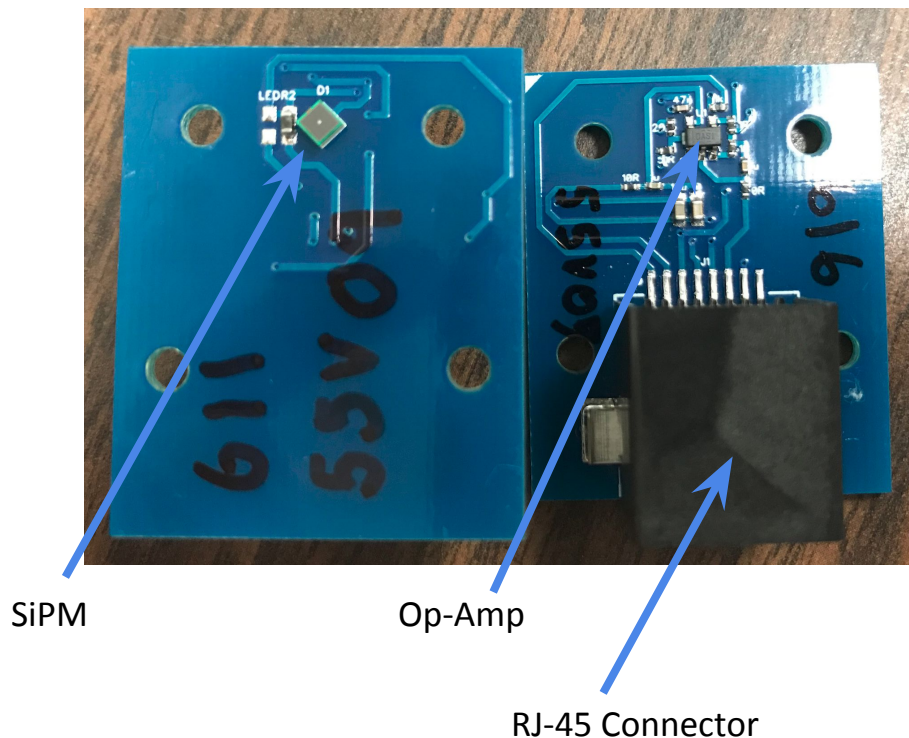


SiPM sensor PCB both for the muon  
scintillator panel and the neutron cell.



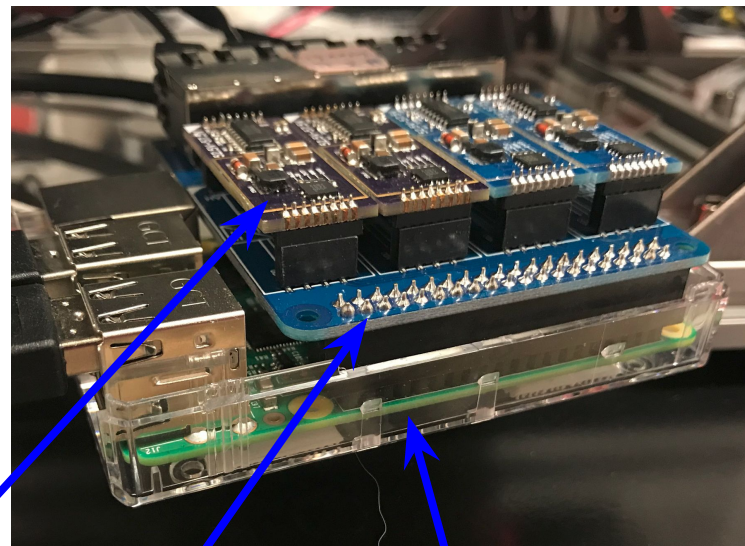
# Silicon Photomultiplier (SiPM) boards

- 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



# 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



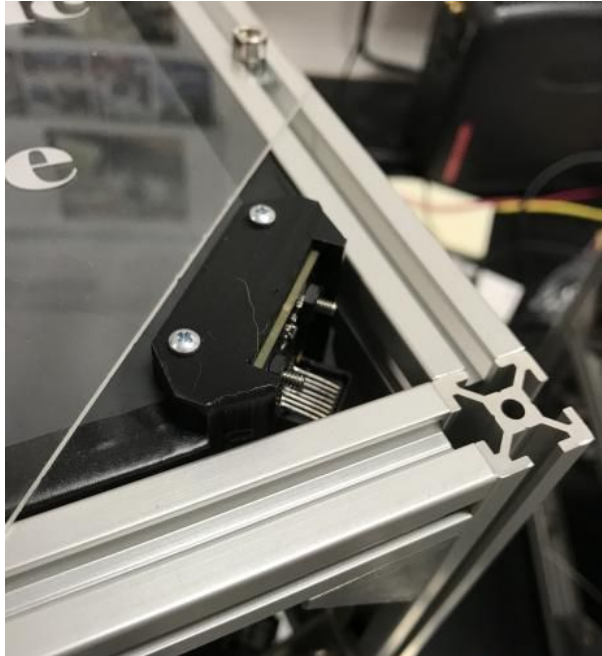
Bias Voltage Boards

4-Channel Board

Raspberry Pi

# Particle Detection - Bringing it all together

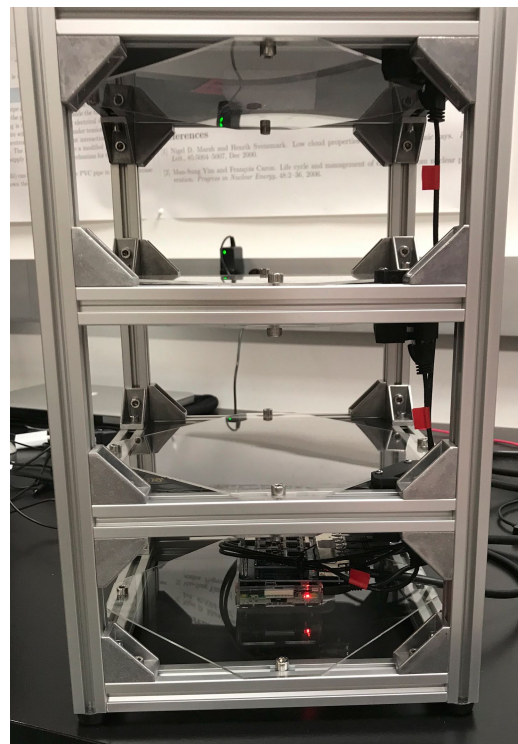
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- Panels release scintillation light on incidence with charged particles which is caught in the wavelength shifting fiber
- Scintillation light is collected by the SiPM, amplified, sent to the 4 channel board, and counted on the Raspberry Pi

# 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



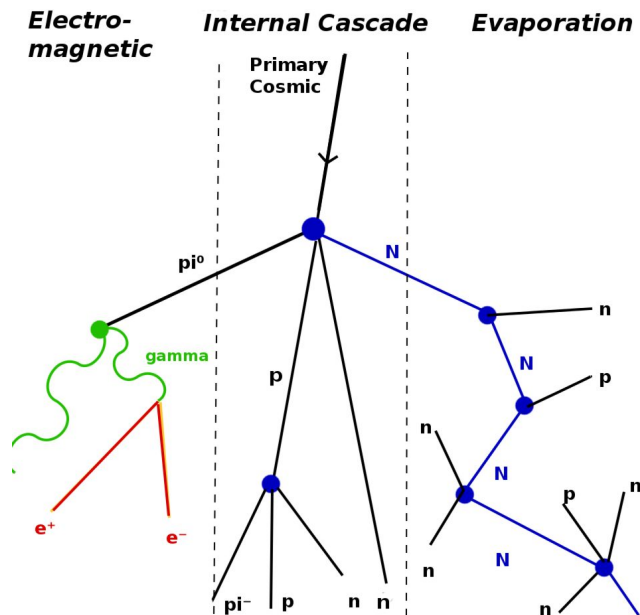
Channel 1

Channel 2

Channel 3

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

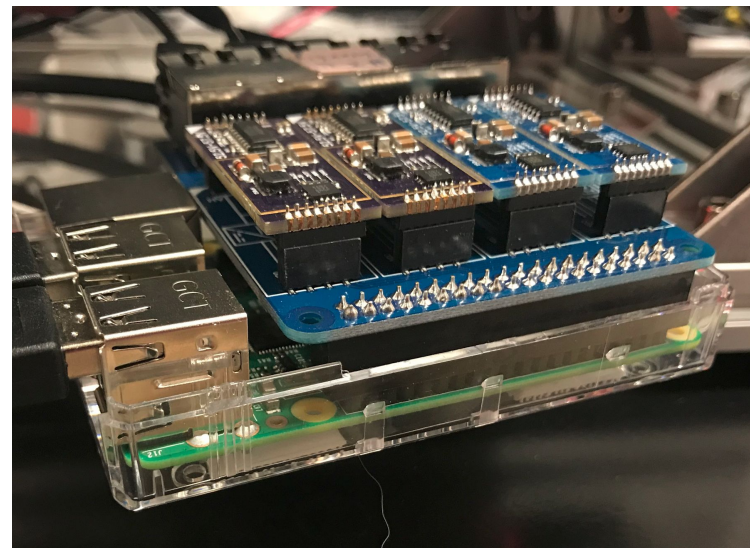
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# Setting and reading the bias voltage

```
10-03112:30:20.8932,0,0,0,151,0,0,0,2024,1438,0,
10-03112:31:20.8912,0,0,0,132,0,0,0,2015,1451,0,
10-03112:32:20.8962,0,0,0,154,0,0,0,1943,1452,0,
10-03112:33:20.9082,0,0,0,141,0,0,0,1994,1390,0,

31 ls
32 ls -lt
33 pwd
34 ls
35 sudo ./voltageDump.sh
36 history
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./voltageDump.sh
board 0x081 Channel 0 | Channel 1 | Channel 2 | Channel 3 | Channel 4 | Channel 5 | Channel 6 | Channel 7 |
|-----|-----|-----|-----|-----|-----|-----|-----|
|Target (U)| 0.000000 | 54.000000 | 54.000000 | 59.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|Voltage (U)| 4.470794 | 54.034788 | 57.239000 | 58.453052 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|Temp (C)| 11.174347 | 11.174347 | 11.174347 | 19.613160 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./setTarget.sh 3 0
cosmic@muonTelescopeAlpha:~/dev-tools $
cosmic@muonTelescopeAlpha:~/dev-tools $
cosmic@muonTelescopeAlpha:~/dev-tools $
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./setTarget.sh 1 0
[sudo] password for cosmic:
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./setTarget.sh 2 0
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./setTarget.sh 3 0
cosmic@muonTelescopeAlpha:~/dev-tools $ sudo ./voltageDump.sh
|Board 0x081 Channel 0 | Channel 1 | Channel 2 | Channel 3 | Channel 4 | Channel 5 | Channel 6 | Channel 7 | |
|---|---|---|---|---|---|---|---|---|
|Target (U)| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|Voltage (U)| 4.474248 | 54.837512 | 57.239580 | 4.451115 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|Temp (C)| 11.174347 | 11.174347 | 11.174347 | 20.349914 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
cosmic@muonTelescopeAlpha:~/dev-tools $
[0] 0:hash=
```

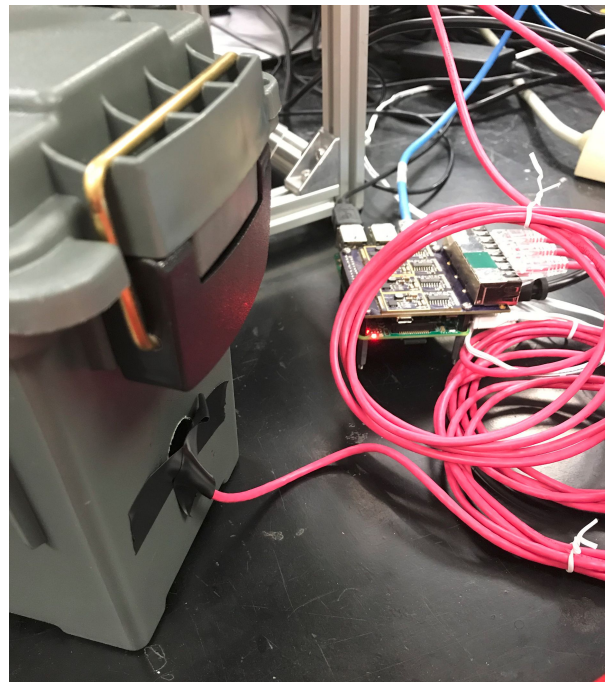
Setting and reading back the bias voltages



Boards that set bias voltage on the 4-channel board

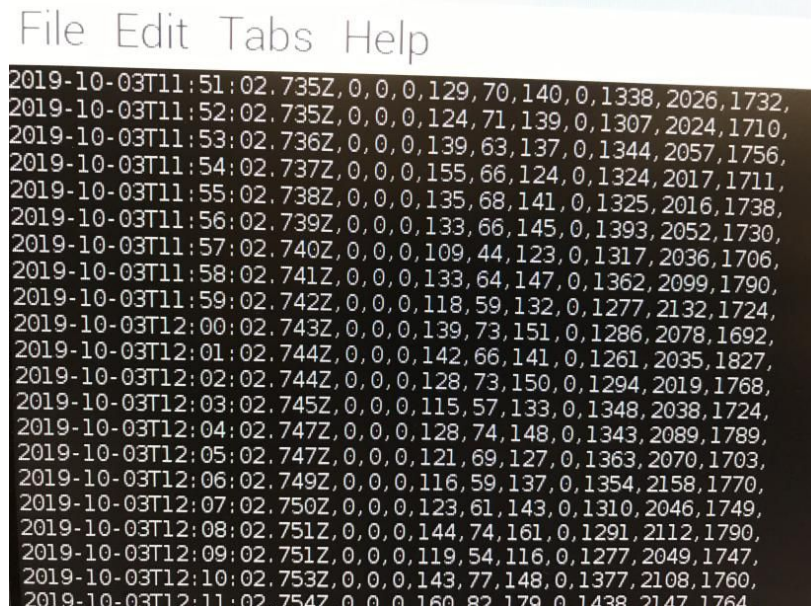
# Testing the SiPMs and boards

- 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



The screenshot shows a window titled 'File Edit Tabs Help' containing a log of data collection events. Each line represents a timestamp followed by a series of numerical values, likely representing raw counts from SiPMs and coincidence data. The timestamps range from 2019-10-03T11:51 to 2019-10-03T12:11.

```
2019-10-03T11:51:02.735Z,0,0,0,129,70,140,0,1338,2026,1732,
2019-10-03T11:52:02.735Z,0,0,0,124,71,139,0,1307,2024,1710,
2019-10-03T11:53:02.736Z,0,0,0,139,63,137,0,1344,2057,1756,
2019-10-03T11:54:02.737Z,0,0,0,155,66,124,0,1324,2017,1711,
2019-10-03T11:55:02.738Z,0,0,0,135,68,141,0,1325,2016,1738,
2019-10-03T11:56:02.739Z,0,0,0,133,66,145,0,1393,2052,1730,
2019-10-03T11:57:02.740Z,0,0,0,109,44,123,0,1317,2036,1706,
2019-10-03T11:58:02.741Z,0,0,0,133,64,147,0,1362,2099,1790,
2019-10-03T11:59:02.742Z,0,0,0,118,59,132,0,1277,2132,1724,
2019-10-03T12:00:02.743Z,0,0,0,139,73,151,0,1286,2078,1692,
2019-10-03T12:01:02.744Z,0,0,0,142,66,141,0,1261,2035,1827,
2019-10-03T12:02:02.744Z,0,0,0,128,73,150,0,1294,2019,1768,
2019-10-03T12:03:02.745Z,0,0,0,115,57,133,0,1348,2038,1724,
2019-10-03T12:04:02.747Z,0,0,0,128,74,148,0,1343,2089,1789,
2019-10-03T12:05:02.747Z,0,0,0,121,69,127,0,1363,2070,1703,
2019-10-03T12:06:02.749Z,0,0,0,116,59,137,0,1354,2158,1770,
2019-10-03T12:07:02.750Z,0,0,0,123,61,143,0,1310,2046,1749,
2019-10-03T12:08:02.751Z,0,0,0,144,74,161,0,1291,2112,1790,
2019-10-03T12:09:02.751Z,0,0,0,119,54,116,0,1277,2049,1747,
2019-10-03T12:10:02.753Z,0,0,0,143,77,148,0,1377,2108,1760,
2019-10-03T12:11:02.754Z,0,0,0,160,82,179,0,1438,2147,1764,
```

## Data Collection

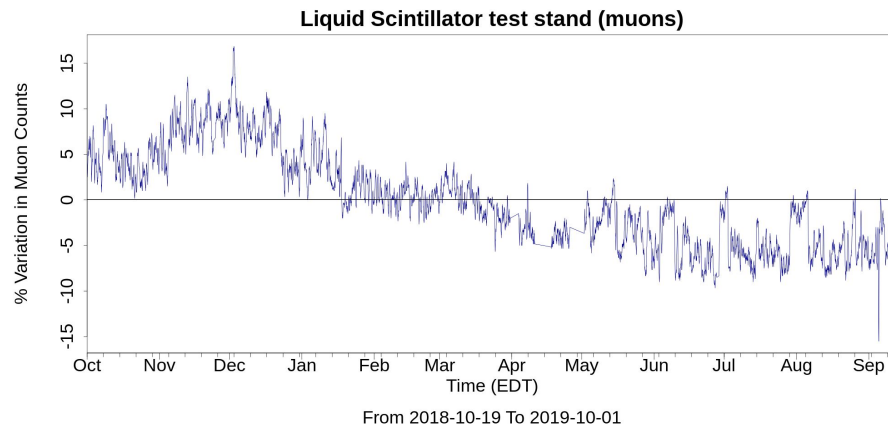
- Log file is created containing the date, raw counts from each SiPM, and every combination of coincidences
  - 6 coincidence combinations for our 4-channel board, current designs uses 3 of the channels

# Online Monitoring

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# Online monitoring

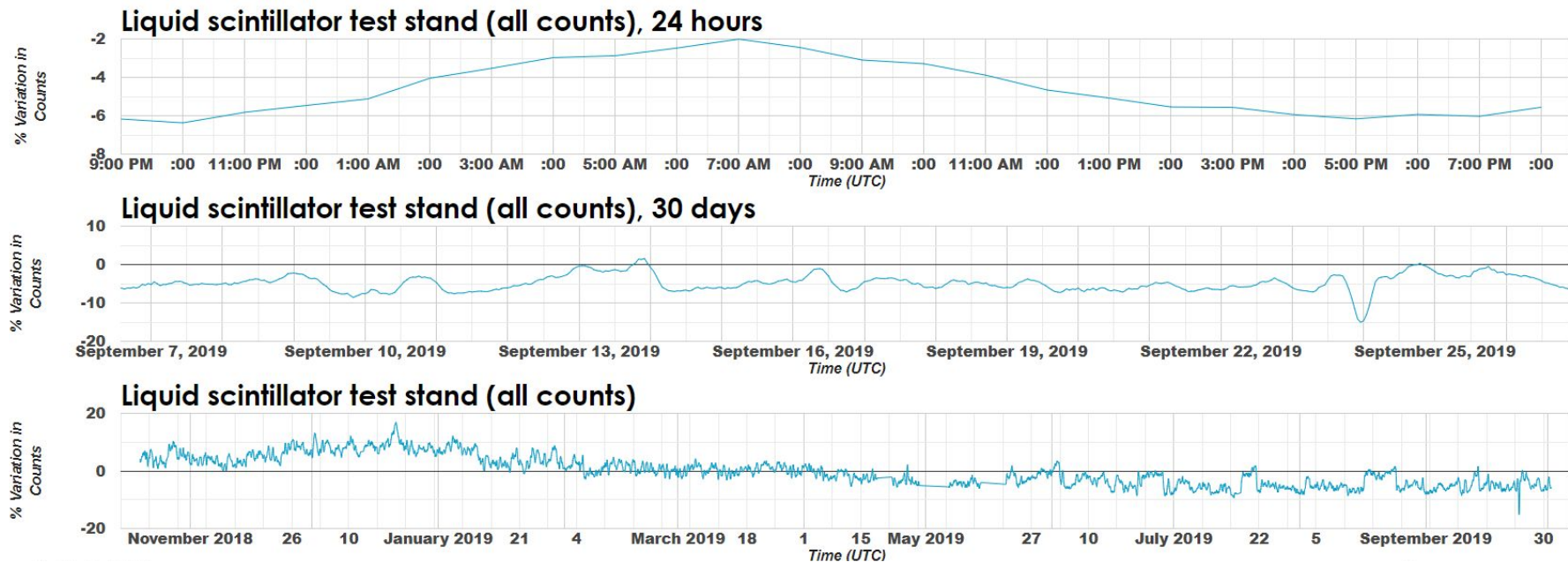
- Software was developed in house to create plots of all our long-running detectors
- Update all the data daily
- Our online monitoring setup has been running for nearly a year now



Static plot from [phynp6.phy-astr.gsu.edu/~cosmic](http://phynp6.phy-astr.gsu.edu/~cosmic)



# Dynamic plots



Example of our online monitoring



# Online monitoring advantages

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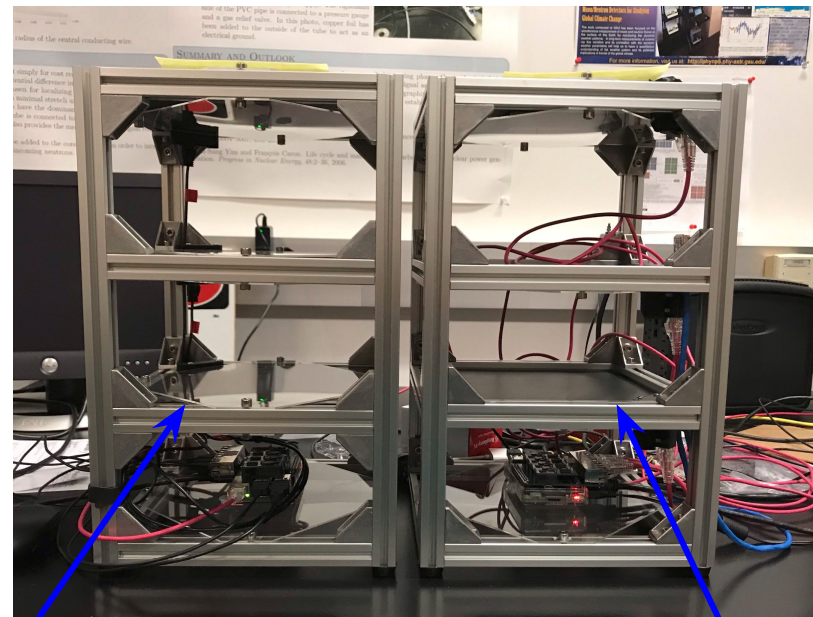
- As our worldwide network of telescopes grows, the software is in place to begin monitoring them
- The status of all the telescopes can be monitored remotely at any given time
- All our data is widely available to anyone who wants to use it
- Lots of other worldwide monitors use a number of different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

# Data Analysis

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# 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



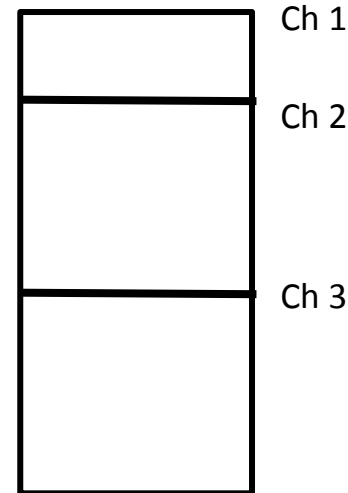
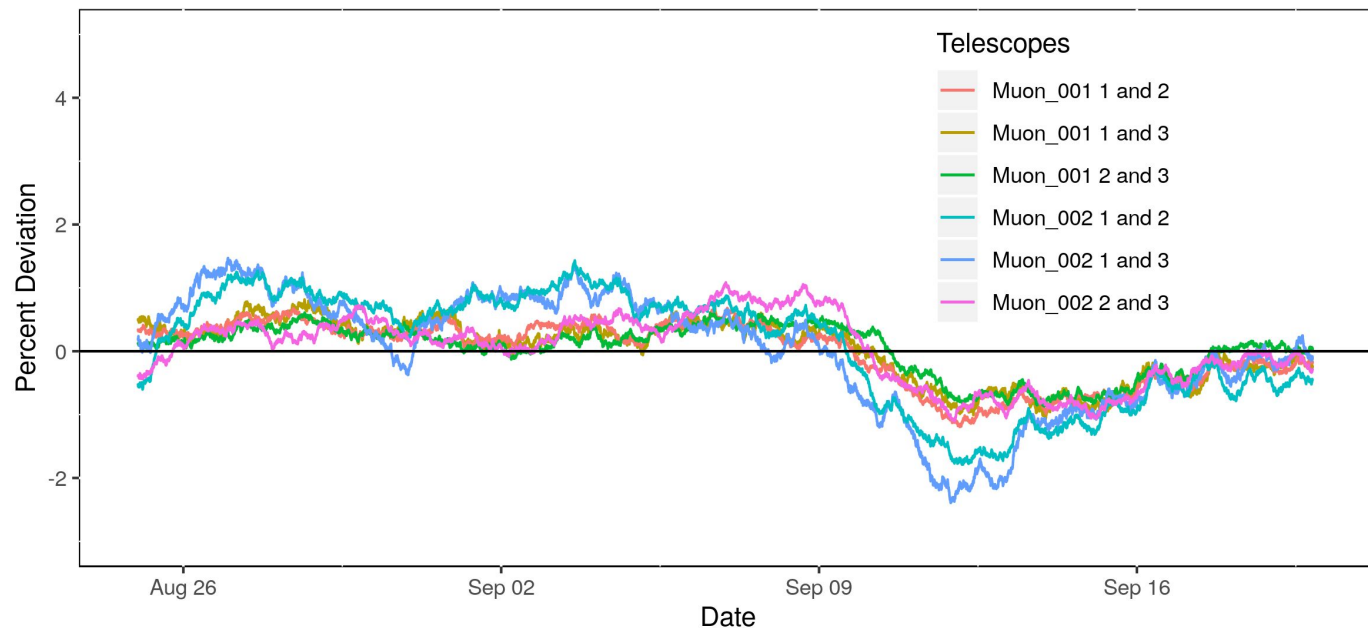
'Muon\_001'

'Muon\_002'

Setup for telescope consistency test

# Telescope Consistency cont.

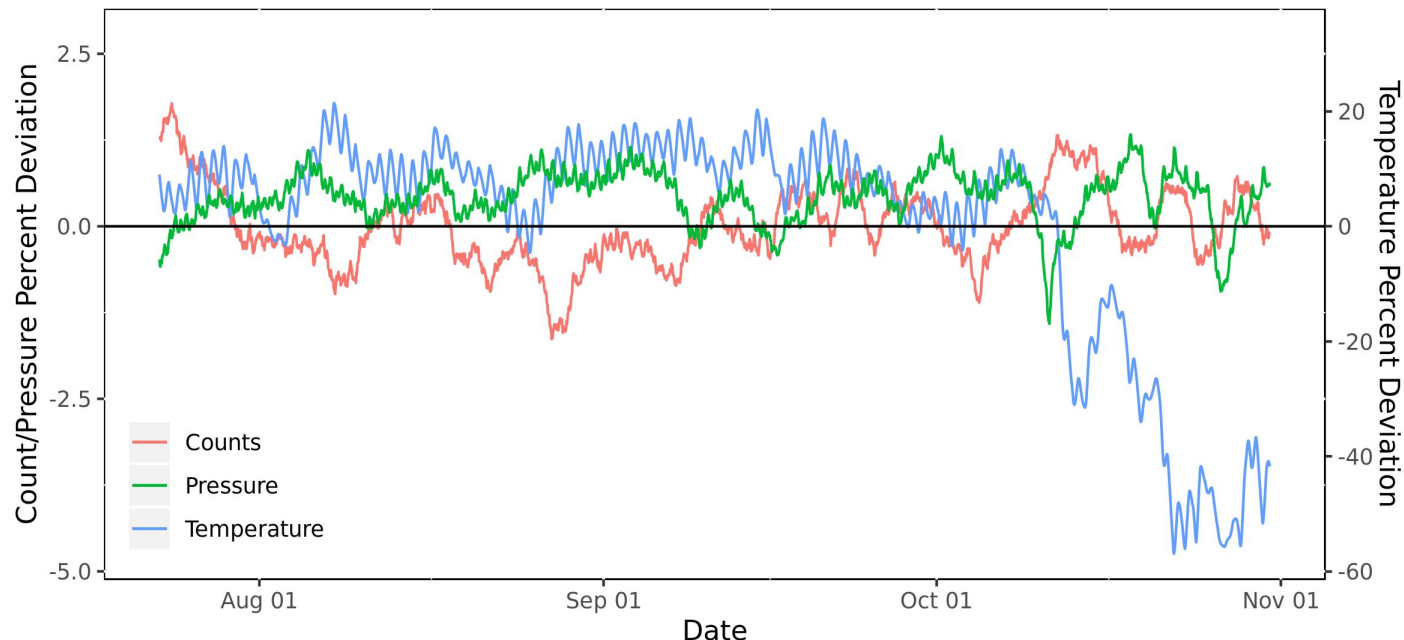
Full Telescope Percent Deviation Comparison



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

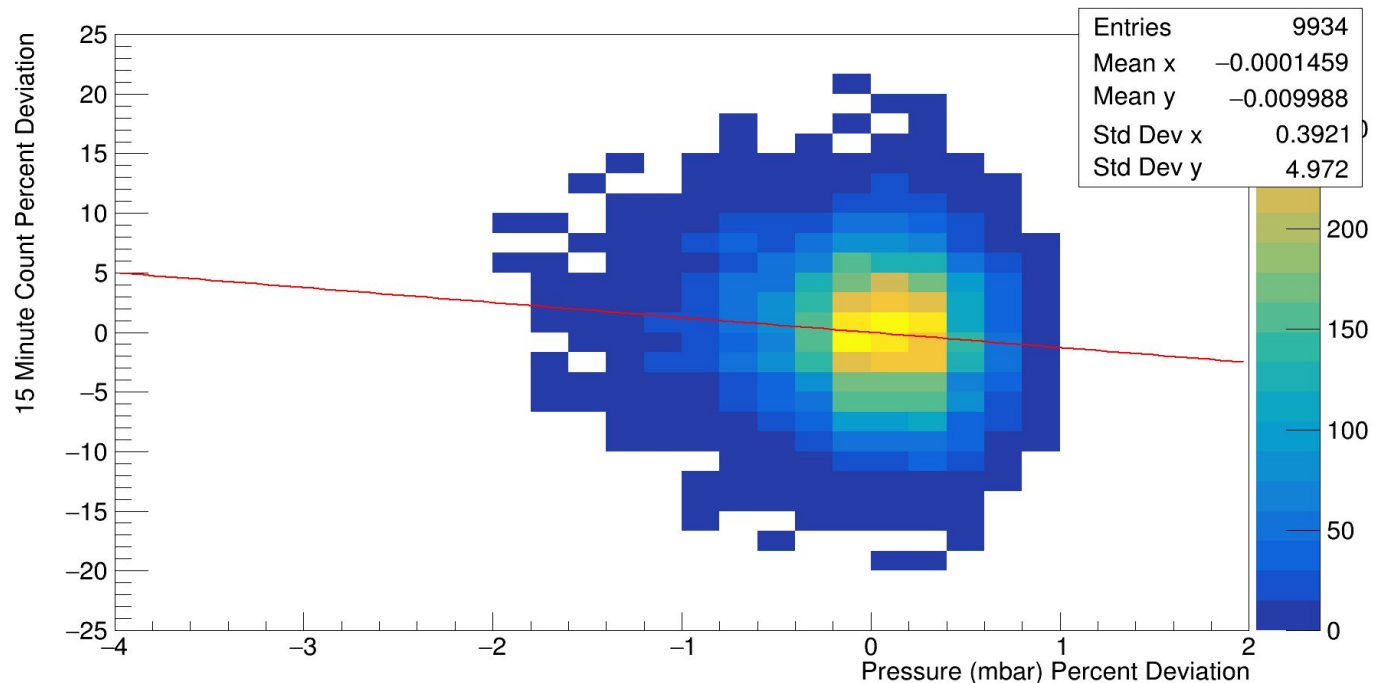
# Weather Correlations

Hour Count, Temperature, and Pressure Percent Deviation over Time



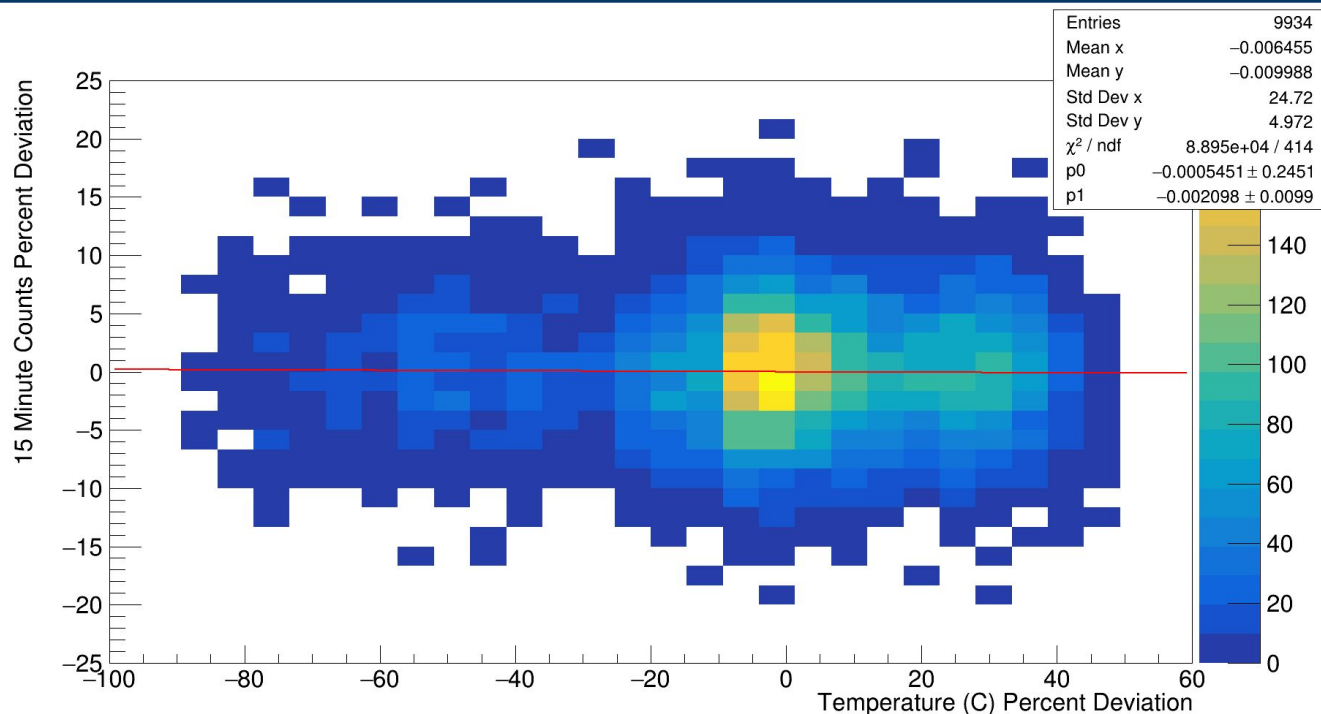
Plot of counts between the top and bottom of the telescope and various weather effects, weather data was obtained from local weather stations. Counts are Ch 1 and 3

# Pressure Correlations



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

# Temperature Correlations



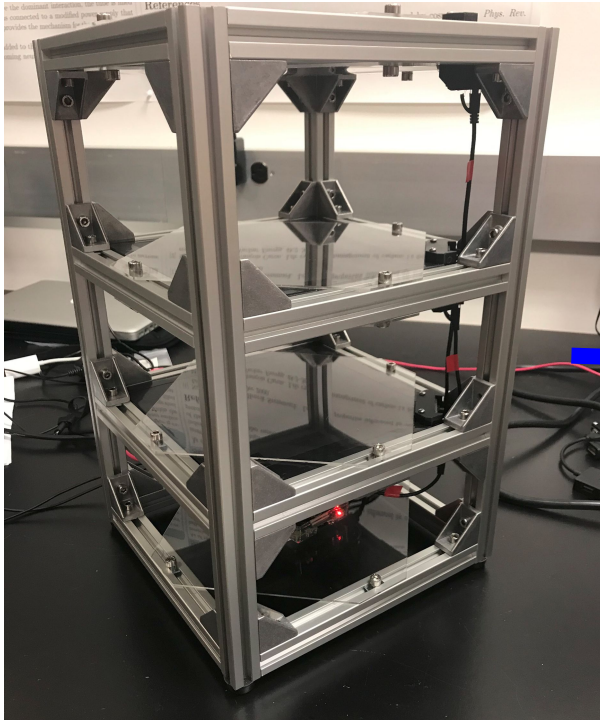
2D histogram of the counts percent deviation versus the temperature percent deviation

# Geant4 Simulation

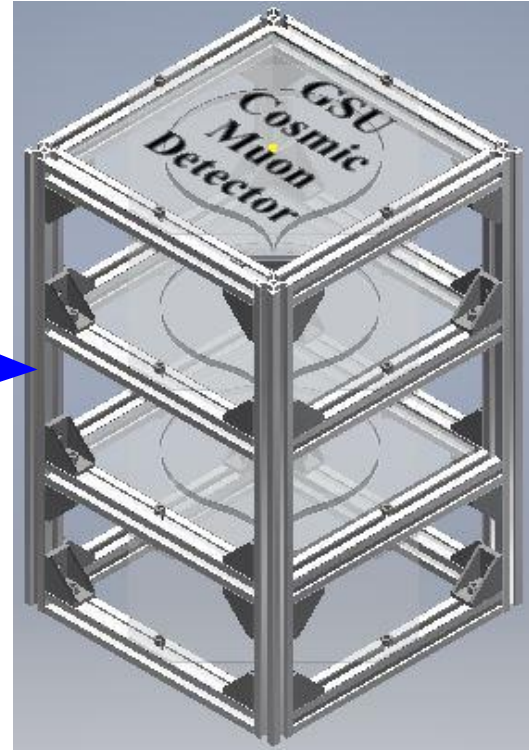
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# 3D model



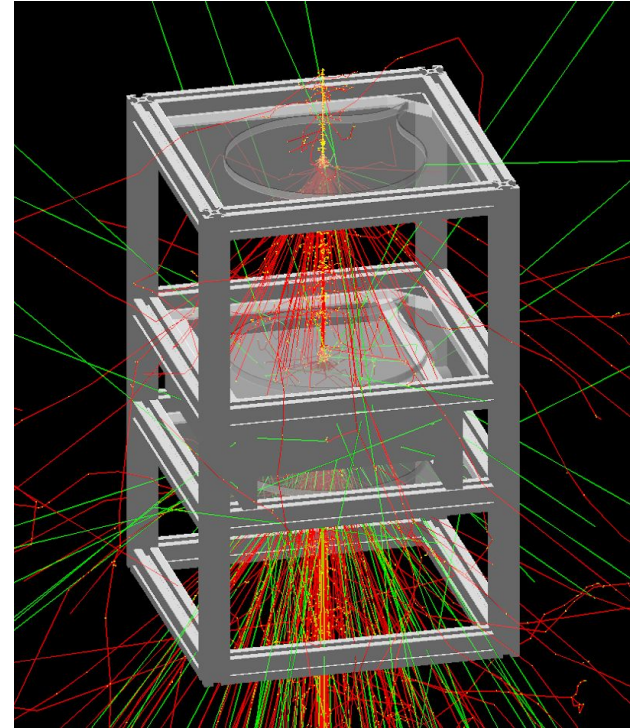
Real Telescope



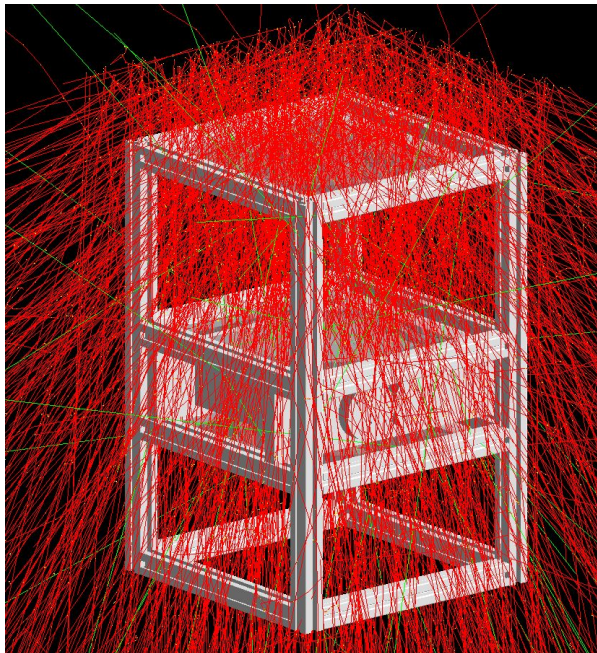
3D Model of Telescope

# 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



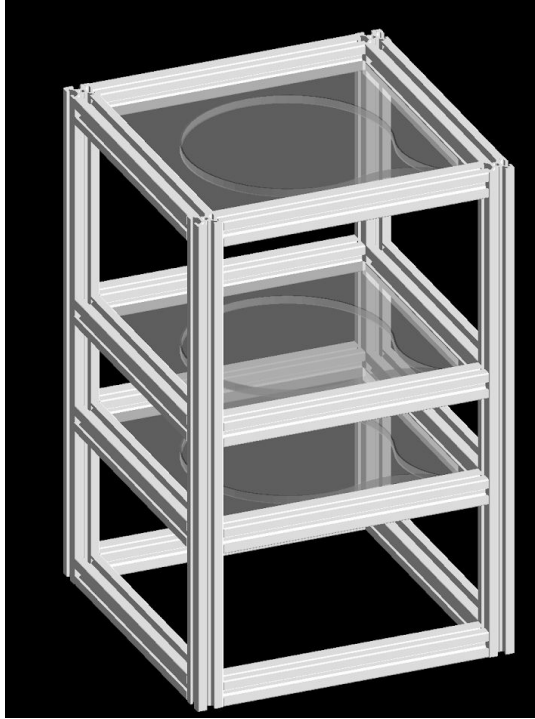
# Geant4 Simulation



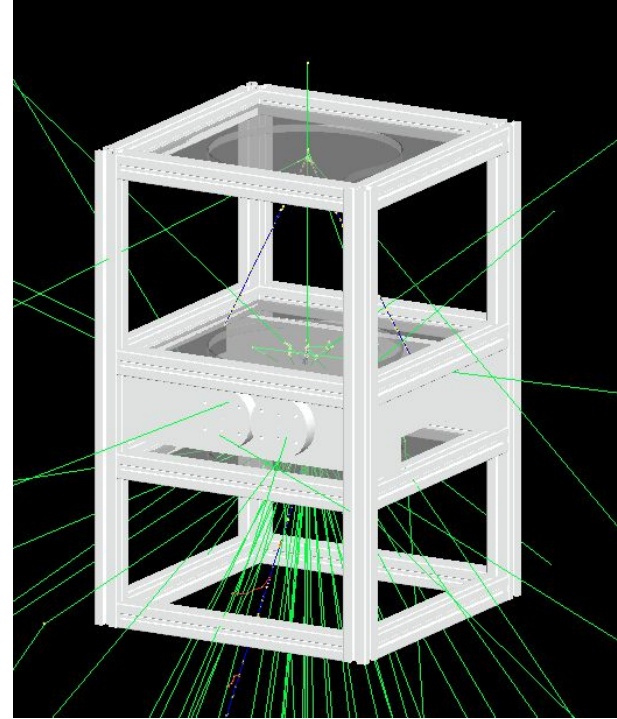
Telescope simulation: 1k cosmic muons

- Particles come from a plane with randomized energy (in the range expected of typical cosmic particles)
- Angle of incidence is randomized to  $\pm 70^\circ$  in the x and z direction, and position is randomized to  $\pm 15$  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



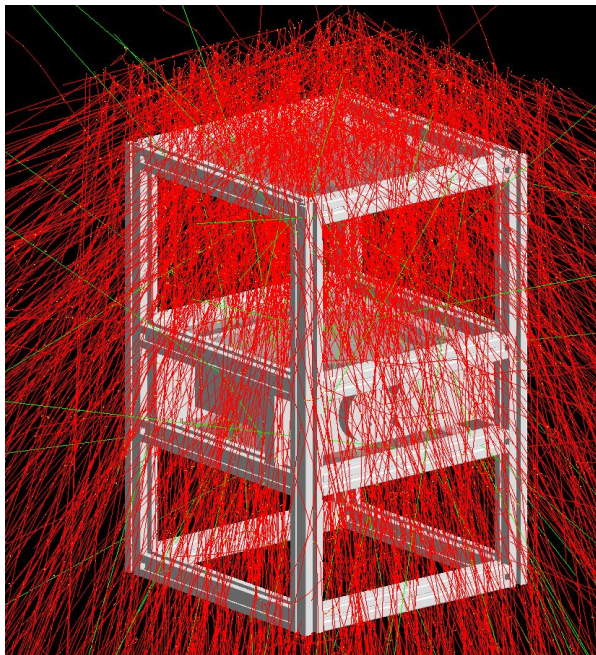
Without Cell



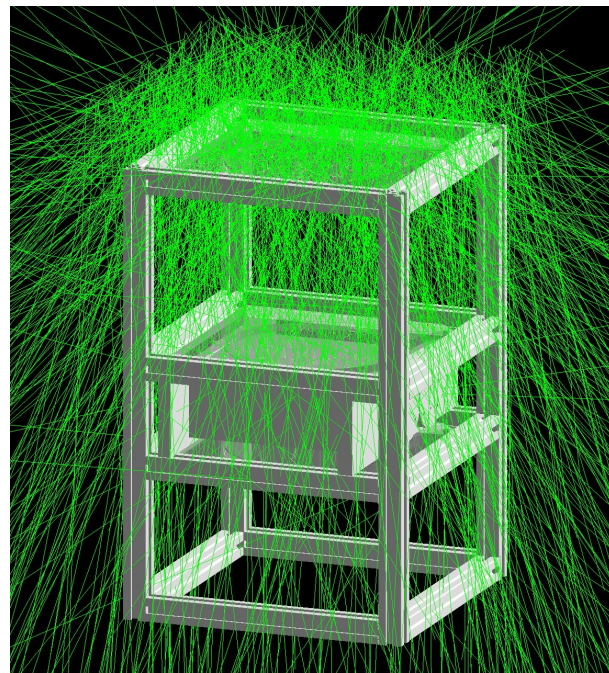
With Cell



# Neutrons vs. Muons



Simulation with 1000 cosmic muons



Simulation with 1000 cosmic neutrons

# Summary and Outlook

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- 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.