Using Coincidences to Investigate Zenith Angle Dependence of Stratospheric Cosmic Rays

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Abstract

Cosmic ray air showers result when high-energy particles from outer space strike atmospheric nuclei and produce downward sprays of secondary rays including electrons, positrons, muons and neutrinos. The charged particles in such cosmic ray showers can trigger Geiger counters as they pass through the detectors. Hence monitoring coincidences between two or more Geiger counters can provide insight into the direction of travel and/or the physical spatial extent of a cosmic ray shower. We present a preliminary report on a stratospheric ballooning payload designed to make coincidence measurements of charged particles traveling at zenith angles of 0 degrees (vertical) and 90 degrees (horizontal). This was a follow-on to an earlier experiment in which we used a stepper motor to repeatedly change the angle (with respect to zenith) of a pair of coincidence-counting Geiger counters during a stratospheric balloon flight. The new payload contains four fixed pancake-shaped RM-80 Geiger counters – two stacked vertically (aligned with zenith) and two stacked horizontally (aligned perpendicular to zenith). Each pair of detectors is separated by 18 cm, so as to narrow the opening angle of the coincidence detector. This configuration can sample both vertical and horizontal coincidences simultaneously, with no moving parts as was done with the stepper motor. Although the new configuration cannot study coincidences at intermediate angles, it also allows us to study triple and quadruple coincidences.

Background

- Galactic Cosmic Rays (GCRs) are constantly impinging Earth's atmosphere typically in the form of protons.

- This interaction ionizes the nitrogen and oxygen found in the atmosphere where the protons interact with atmospheric nuclei and then produces a cascade of high energy secondary particles called a Galactic Cosmic Ray Shower (GCRS) (Figure 1).

- GCRs are the result of distant sources, such as stars or remnants of a supernova.

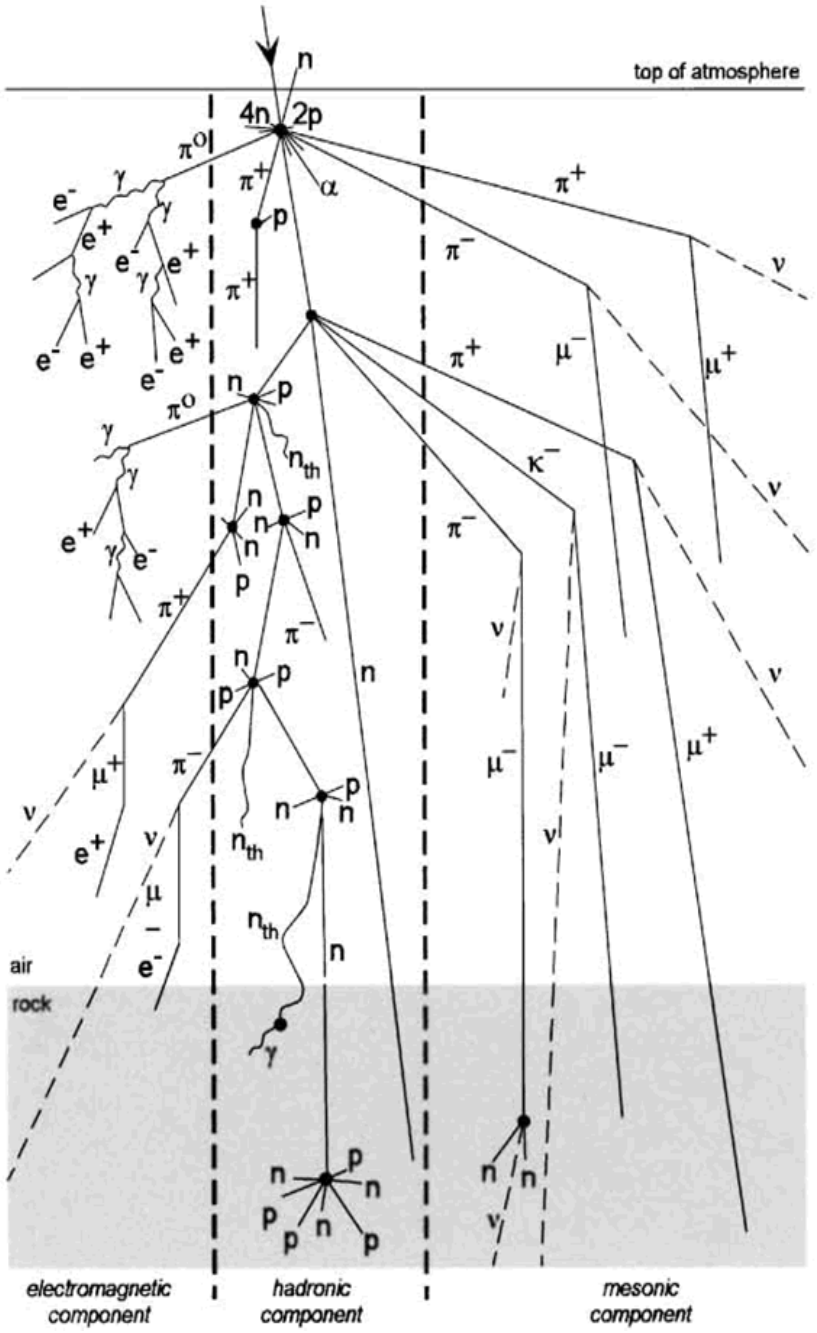


Figure 1: Cosmic Ray Shower.

Cont.- Background

- Post collision secondary particles are a shower of protons, neutrons, electrons, and muons. This secondary shower depends on altitude, latitude, solar activity, and air pressure.

- By the time these secondary particles reach the Earth's surface, they are mostly muons. In order to detect the most diverse range of particles, readings must be taken in situ.

- Figure 2 details the various group of cosmic ray spectra which are the result of a broad range of energy. At lower energies there is a higher level of flux and fewer particles fall into this area. It can be noted that in the balloon and satellite area the level of flux is high.

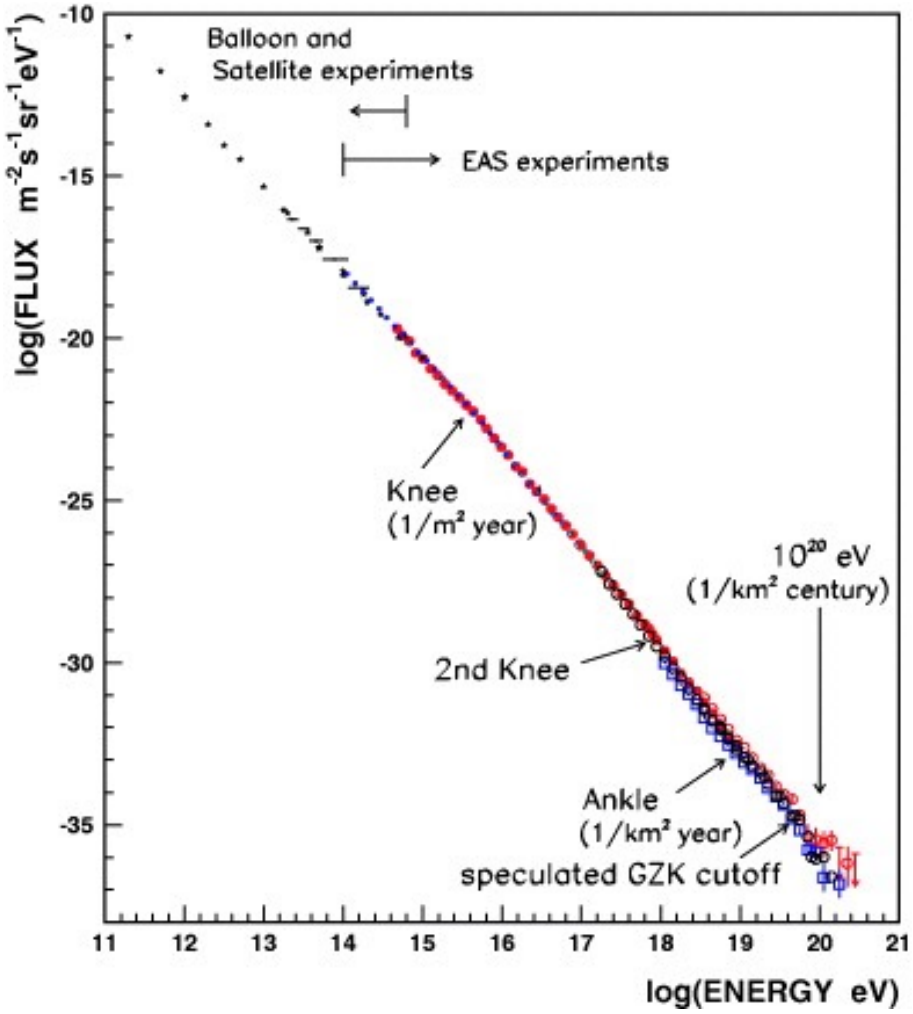


Figure 2: Energy spectrum of primary cosmic rays.

History of The R-P Maximum

- Measurement of ionization production was conducted deep under water and in the atmosphere in the1930s.
- A maximum is reached in the atmosphere.
- Used to discover supernovae as a source of GCR.
- Regener's student Pfotzer is often entirely credited. Regener was forced into retirement by Nationalist Socialists in Germany due his wife's Jewish ancestry.

Figure 3: Erich Regener

Figure 4: Georg Pfotzer

The R-P Max.

- Between 15 and 25 km in altitude lies the R-P maximum.

- The R-P max. is the altitude at which the maximum number of counts can be measured with a Geiger Müller (GM) detector.
  - Each count is the detection of a single high-energy particle.

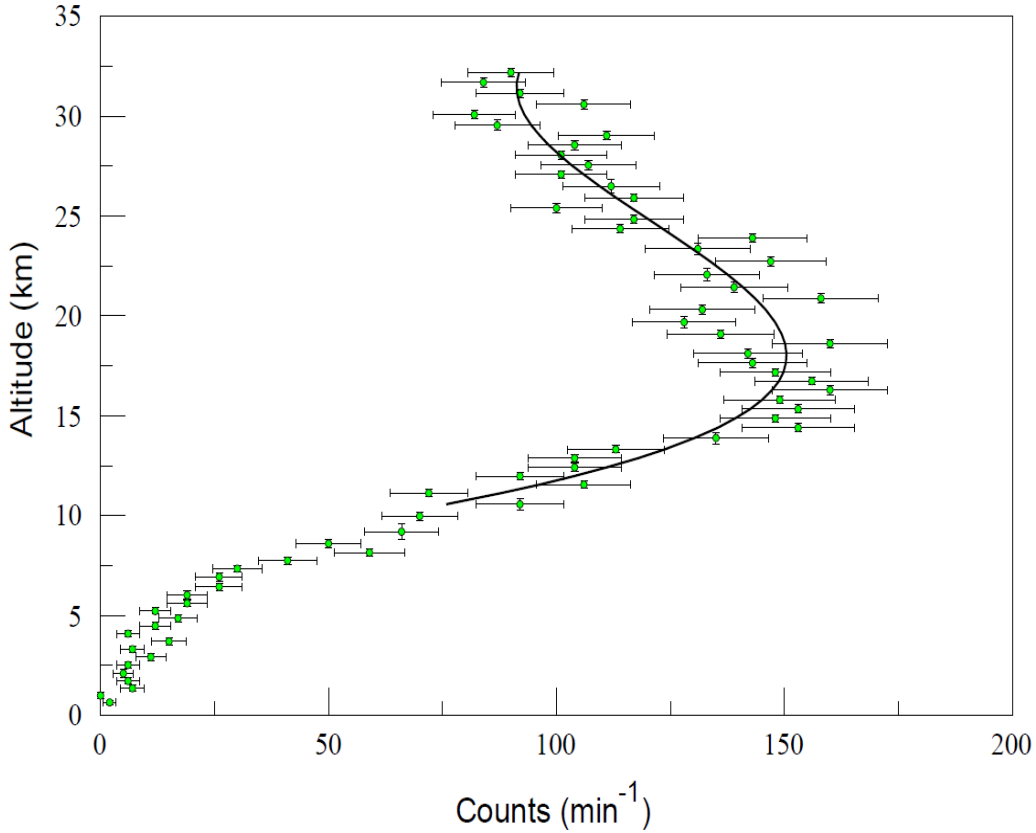


Figure 5: Altitude versus horizontal coincidence, R-P maximum at 18.1 km ± 1.0 km.

R-P Max. Applications

- The R-P maxima shift in altitude depending on:
  - solar activity
  - pressure, temperature, density
  - geomagnetic latitude
- Secondary particles in GCRS undergo decays and energy loss through interactions as they travel through the atmosphere. The changing profiles of these particles and energies are generated, and these profiles have peak intensities at the R-P maxima.
- The omnidirectional, vertical, and horizontal coincidence maxima do not occur at the same altitude.

Detectors: RM-80

RM-80 (Pancake Detector)

Area: 1552 mm^2

Weight: 214.08 g

Count Range: 3545 cpm

Alpha Sensitivity: < 2.5 MeV, 80% at 3.6 MeV

Beta Sensitivity: 35% at 50 KeV, 95% at 300 KeV

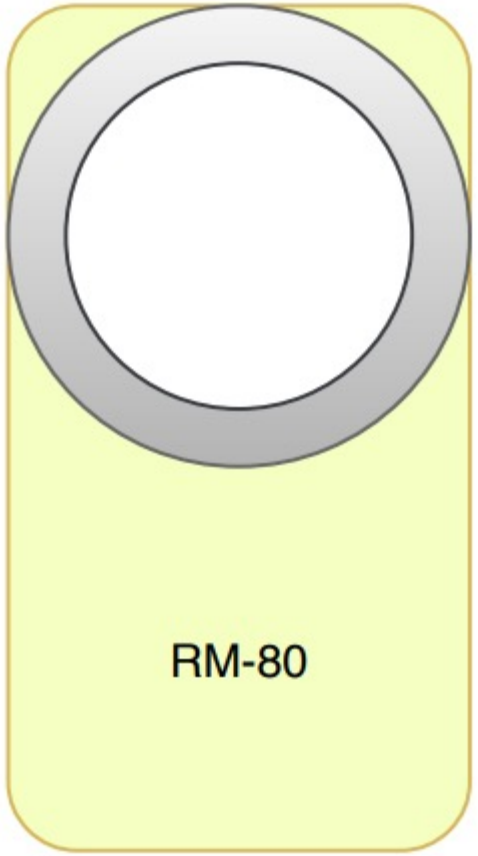


Figure 6: RM-80 Geiger detector.

Field of View

Each detector has a field of view represented by the solid angle. Figure 7 shows the solid angle of detector 2 superimposed on the solid angle of detector 1. The solid angle of the vertical coincidence is the intersection of detector 1 and 2.

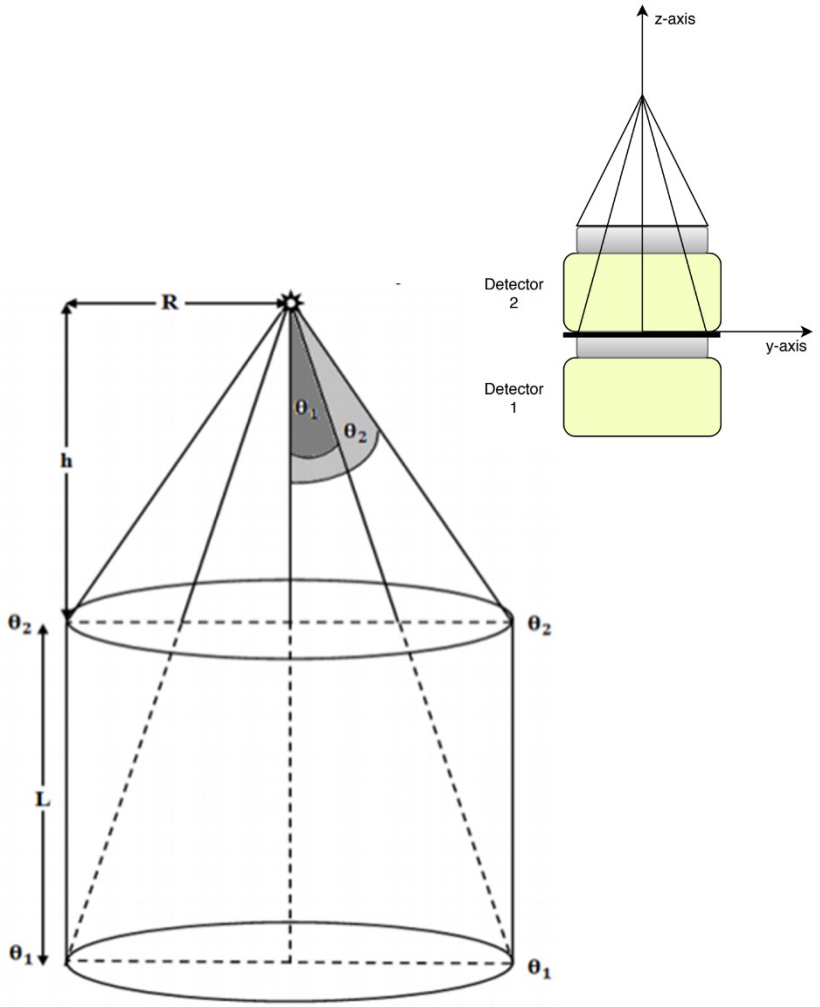


Figure 7: An axial point source with Cylindrical Detector.

Vertical Coincidence

Vertical coincidence occurs when two detectors are aligned vertically as in Figure 8. The detection of a particle both detectors simultaneously is vertical coincidence. This gives insight into the direction of the particle's movement.

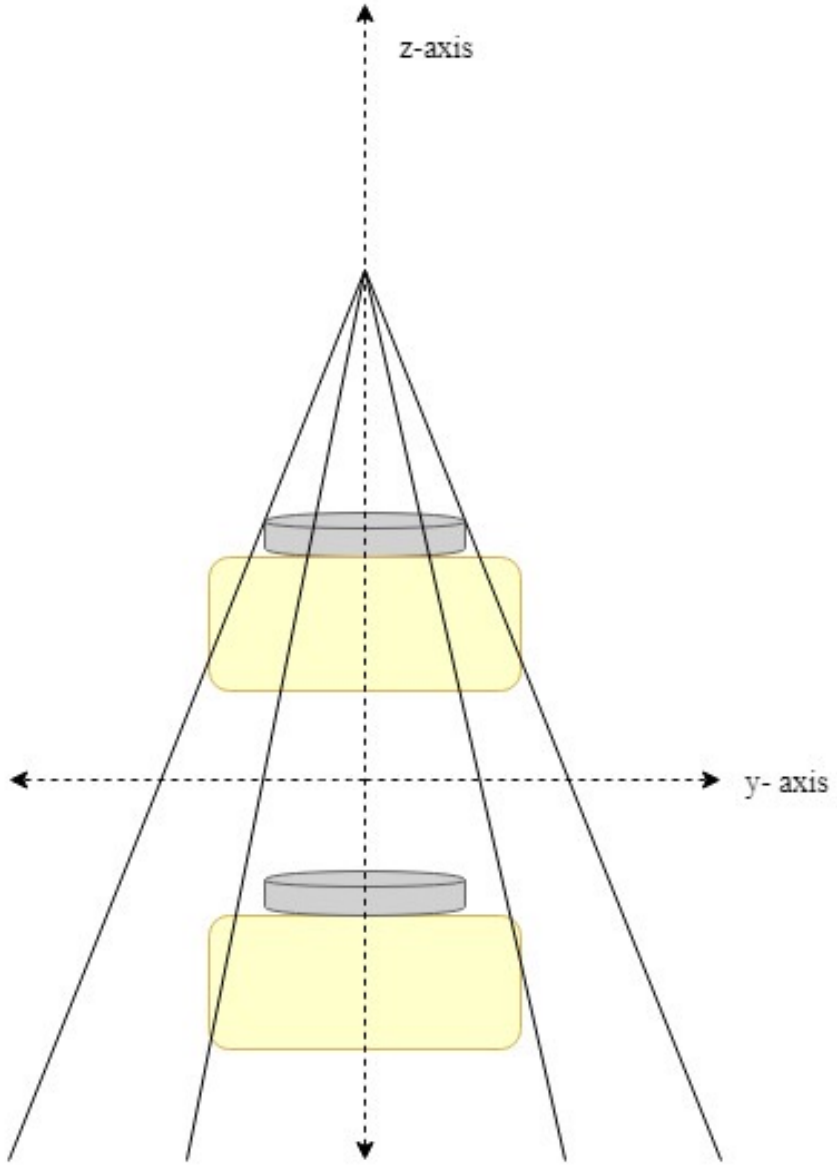


Figure 8: Vertical coincidence represented using two separated RM-80 Geigers.

Horizontal Coincidence

Horizontal coincidence occurs similarly to vertical coincidence; however, the two RM-80 Geigers are aligned and rotated -90 degrees shown in Figure 9.

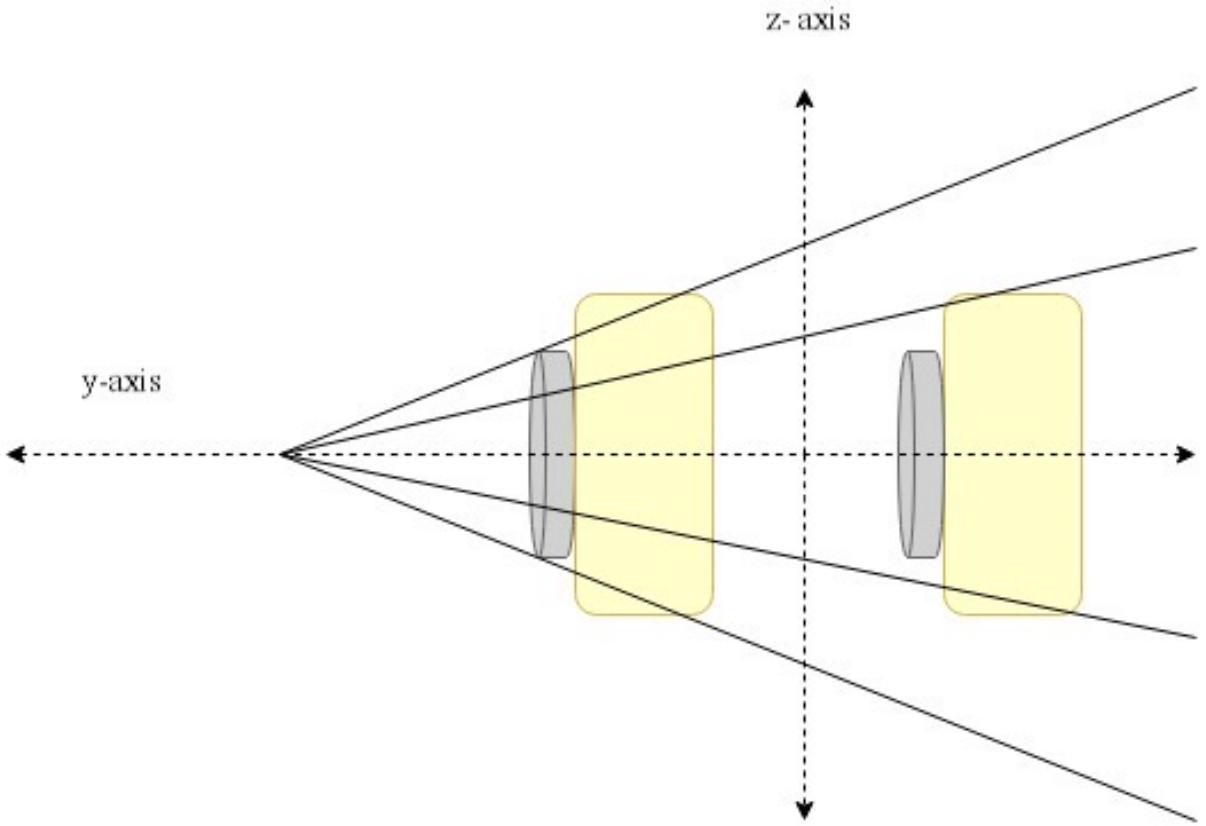


Figure 9: Horizontal coincidence represented using two separated RM-80 Geigers.

Motivation

Geiger Monster

	Time (s)	Zenith Angle (°)
Starting Point	0	0
A	15	-45
B	30	0
C	45	45
D	60	0

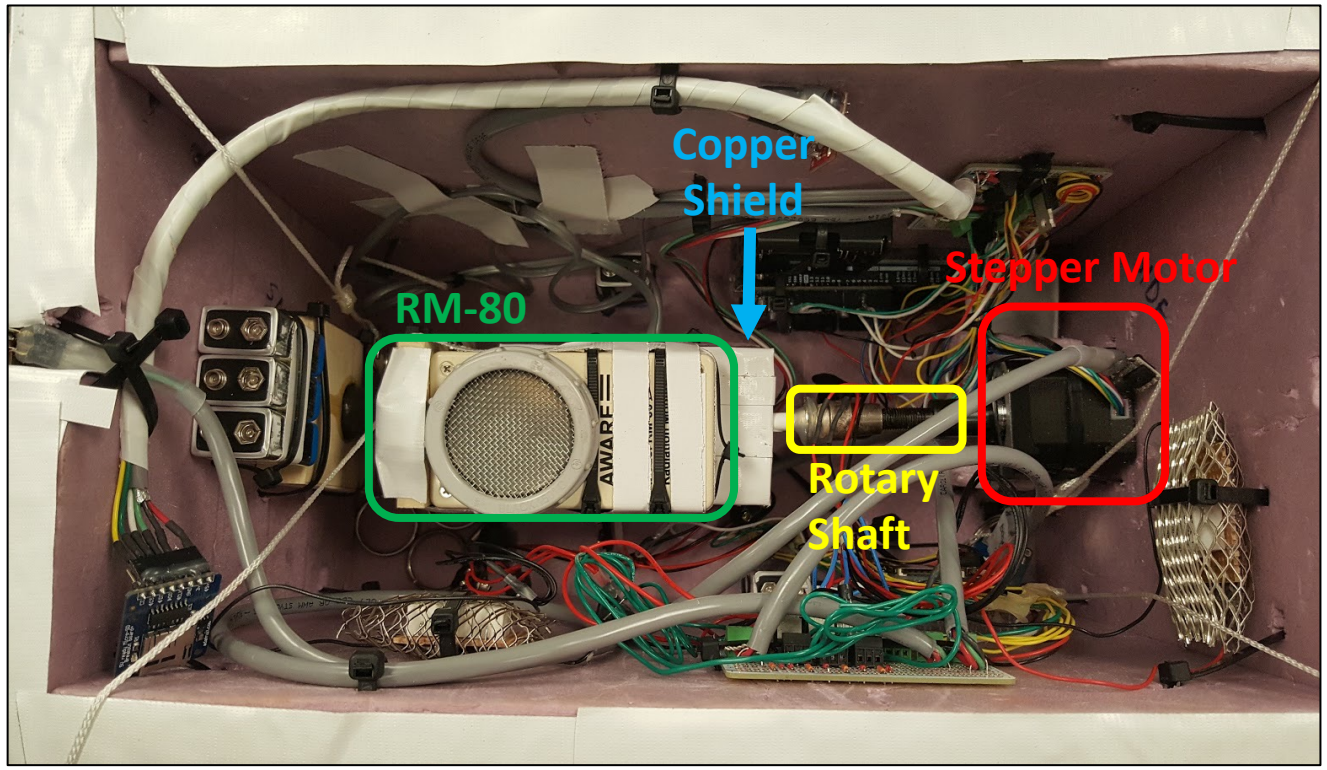


Figure 10: Horizontal coincidence represented using two separated RM-80 Geigers.

Geiger Monster Data

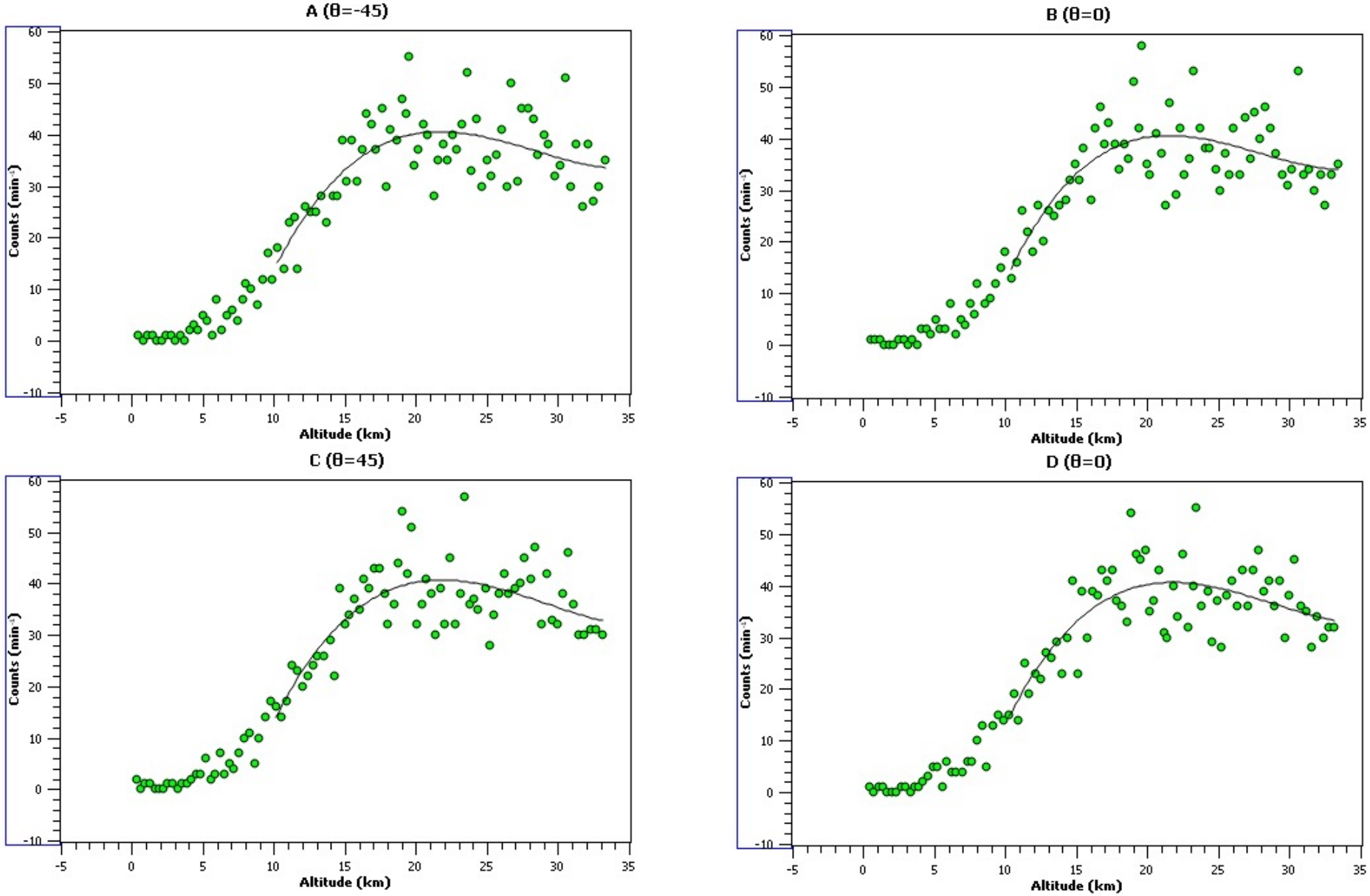


Figure 11: Horizontal coincidence represented using two separated RM-80 Geigers.

Design of Experiment

The Quad Box

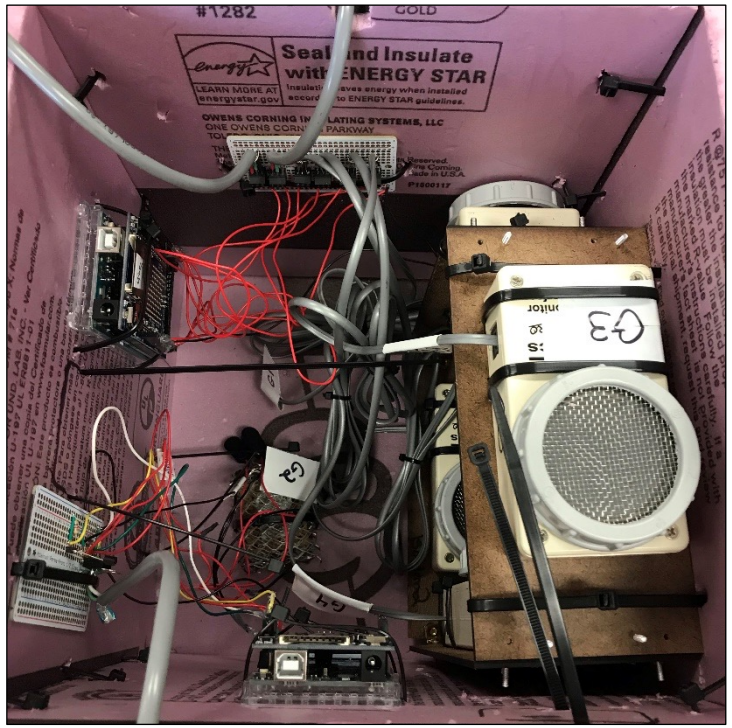


Figure 12: Top view of Quad Box.

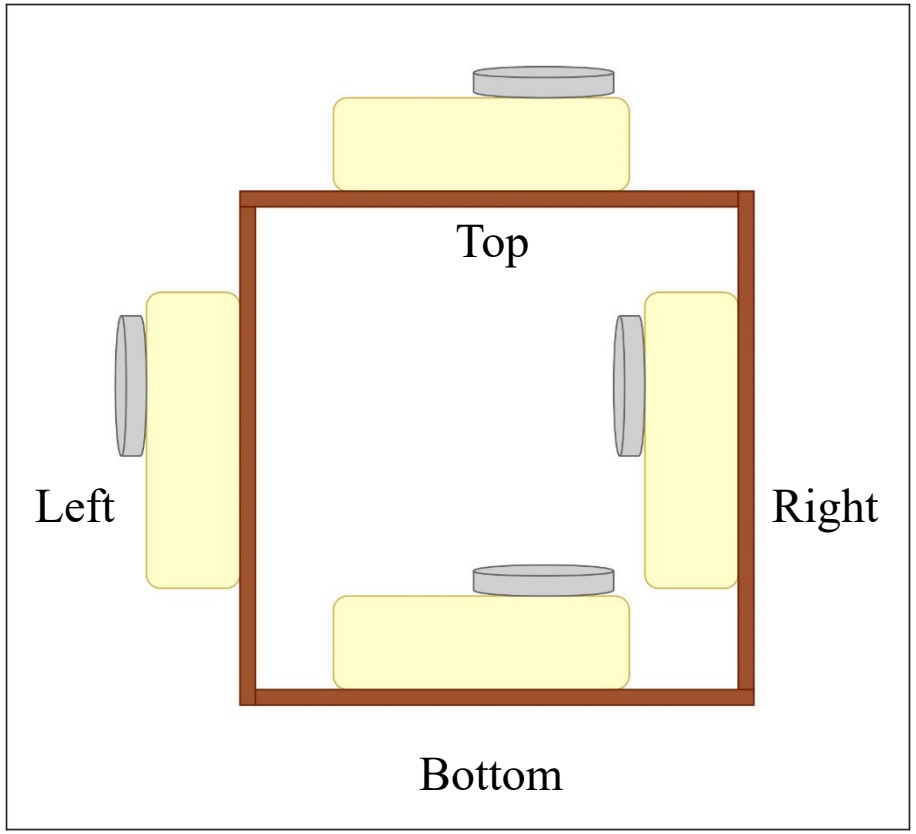


Figure 13: Design of Quad Box.

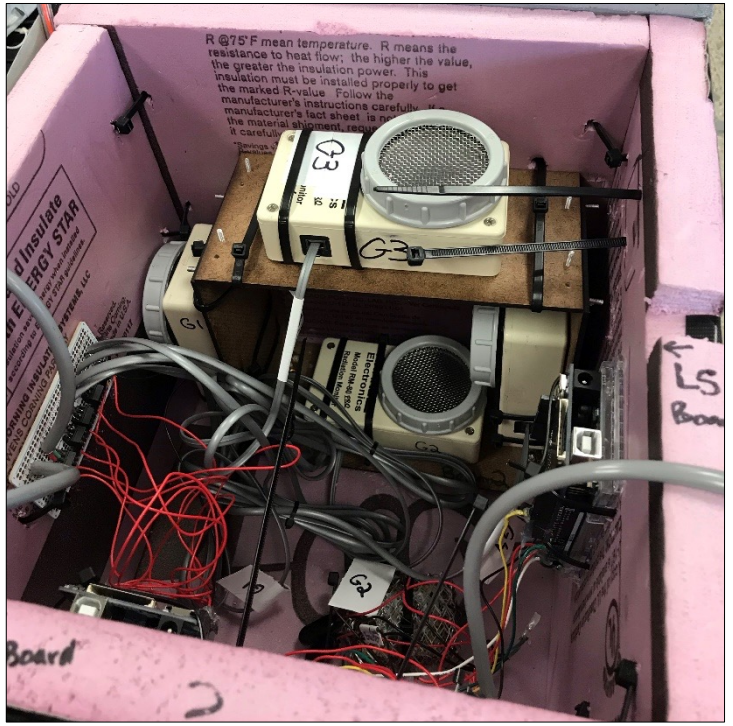


Figure 14: Side view of Quad Box.

Experiments

First Flight 6/7/19 (1)	Launch at 11:31am CDT Burst at 1:29pm CDT Duration: 2 hrs. 13 mins.
Second Flight 6/13/19 (2)	Launch at 11:53am CDT Burst at 1:27pm CDT Duration: 2 hrs. 4 mins.

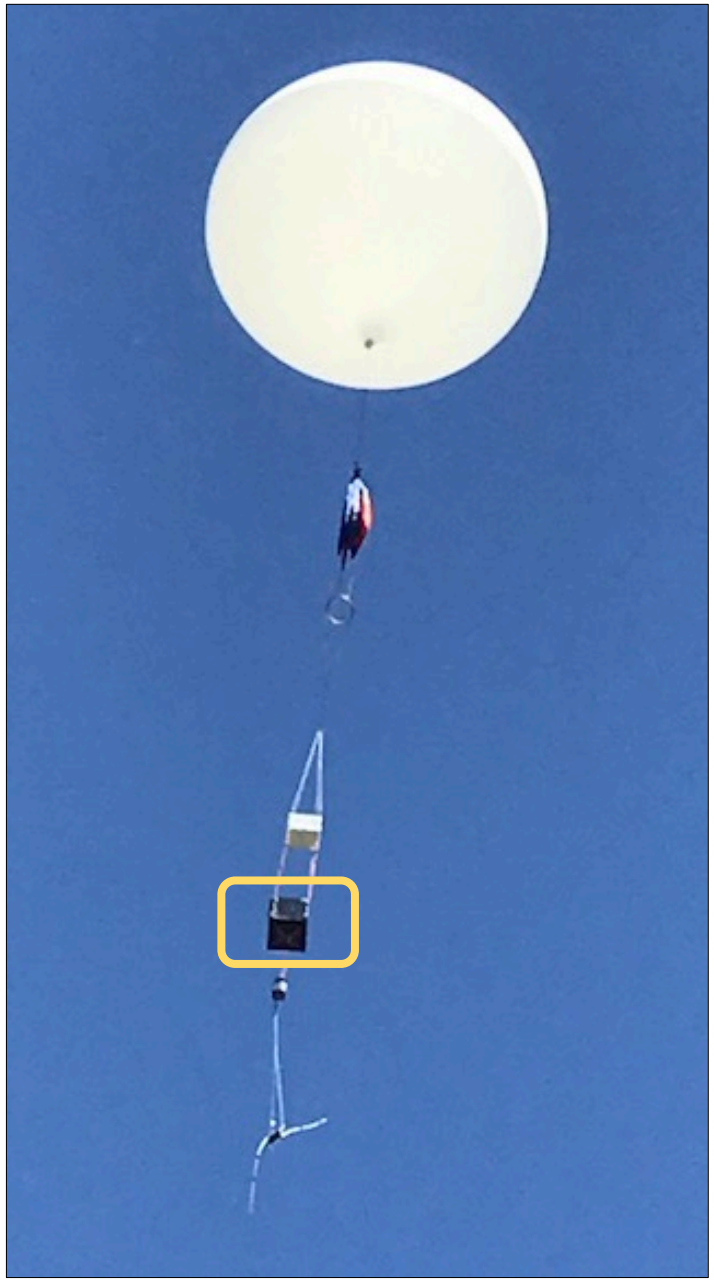
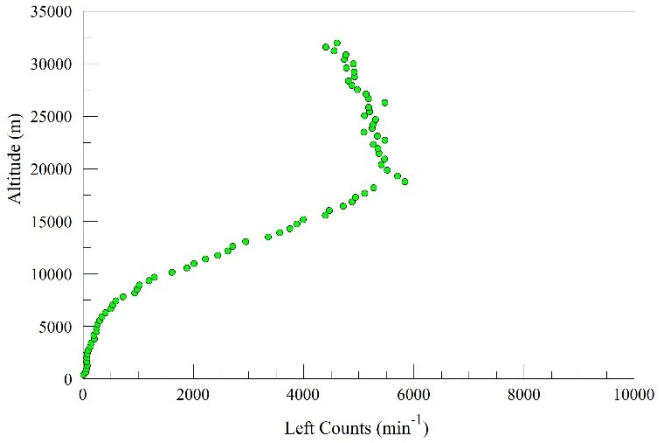
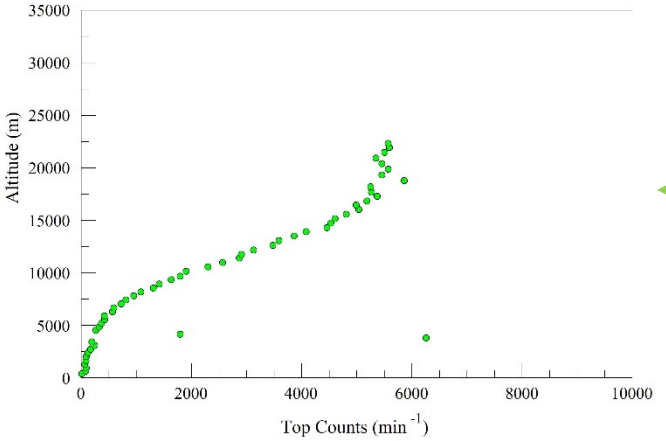


Figure 15: Stack set-up from flight 6/13/19 (2).[15]

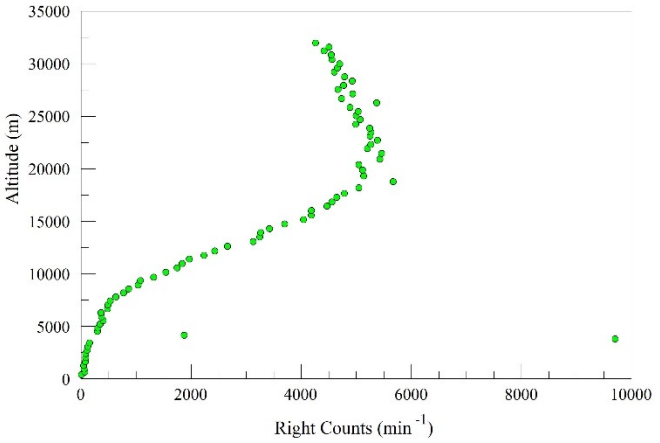
Results





Top Geiger malfunction

Flight 1: 6/7/19



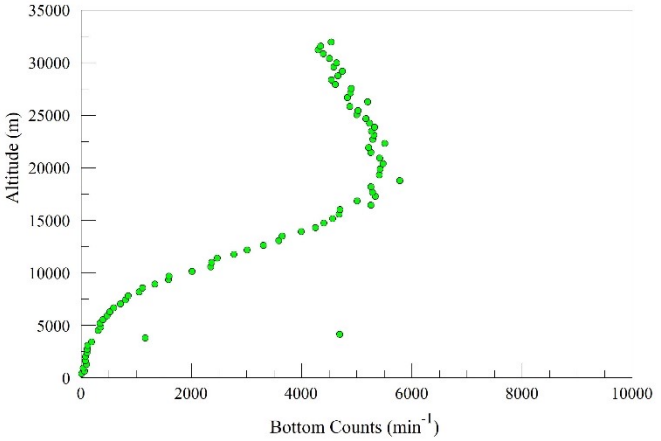


Figure 16: Total counts that were obtained from four RM-80 Geiger detectors on flight 6/7/19.

Results

Flight 1: 6/7/19

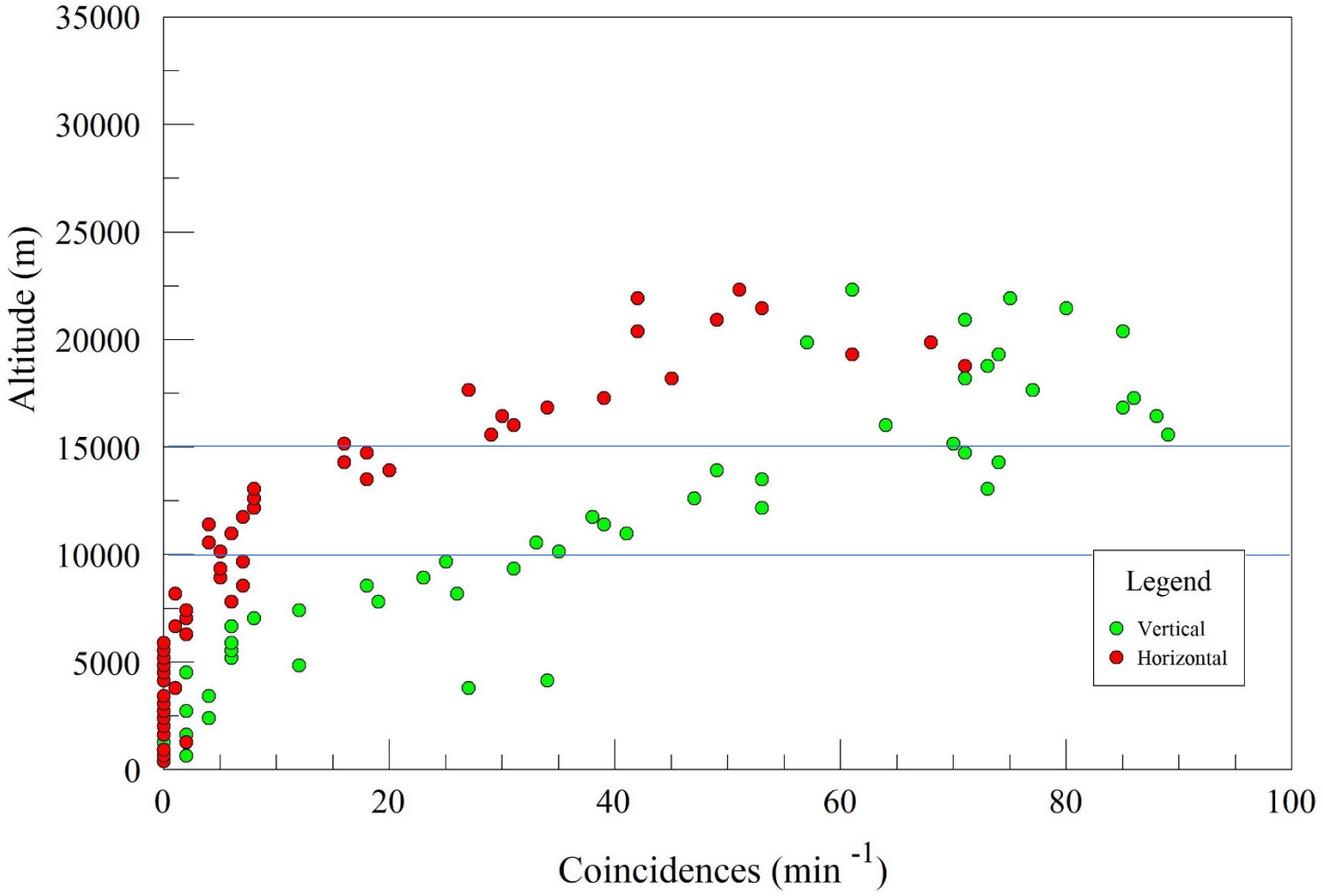
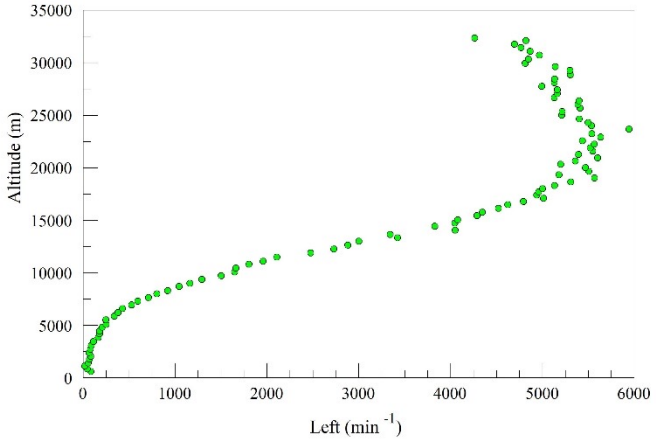
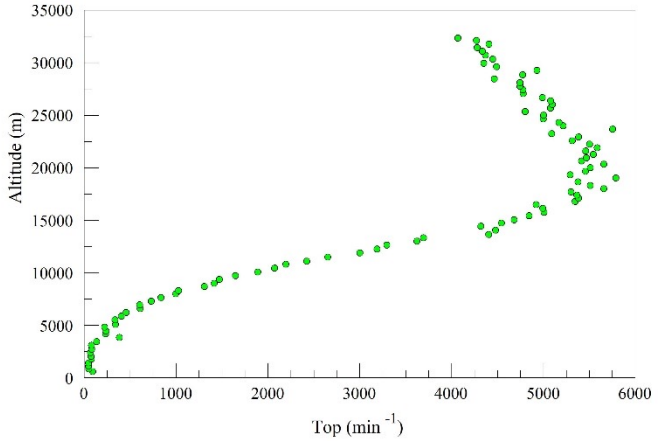


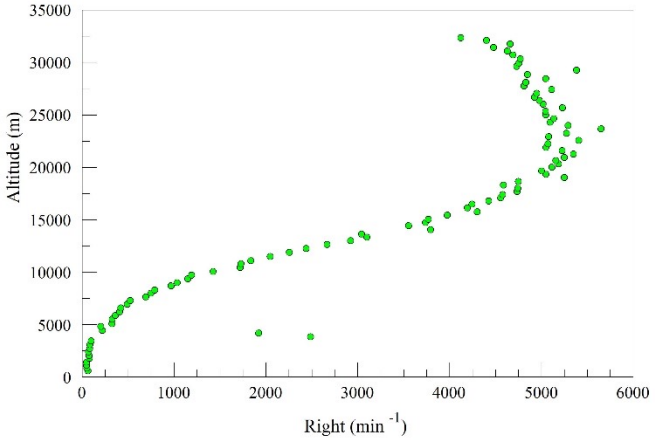
Figure 17: Plot of vertical (green) and horizonal (red) coincidences versus altitude on flight 6/7/19.

Results





Flight 2: 6/13/19



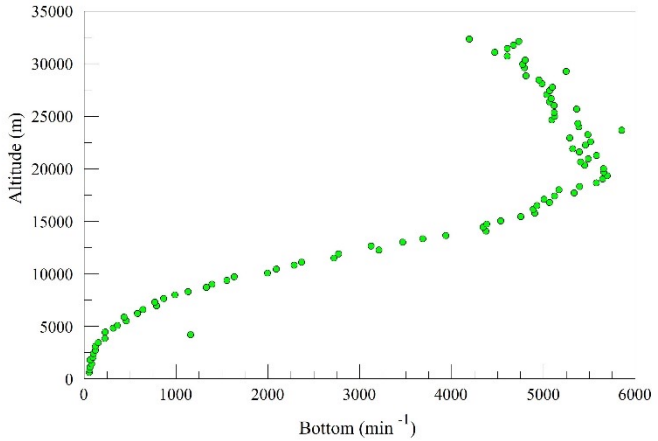


Figure 18: Total counts that were obtained from four RM-80 Geiger detectors on flight 6/13/19.

Results

Flight 2: 6/13/19

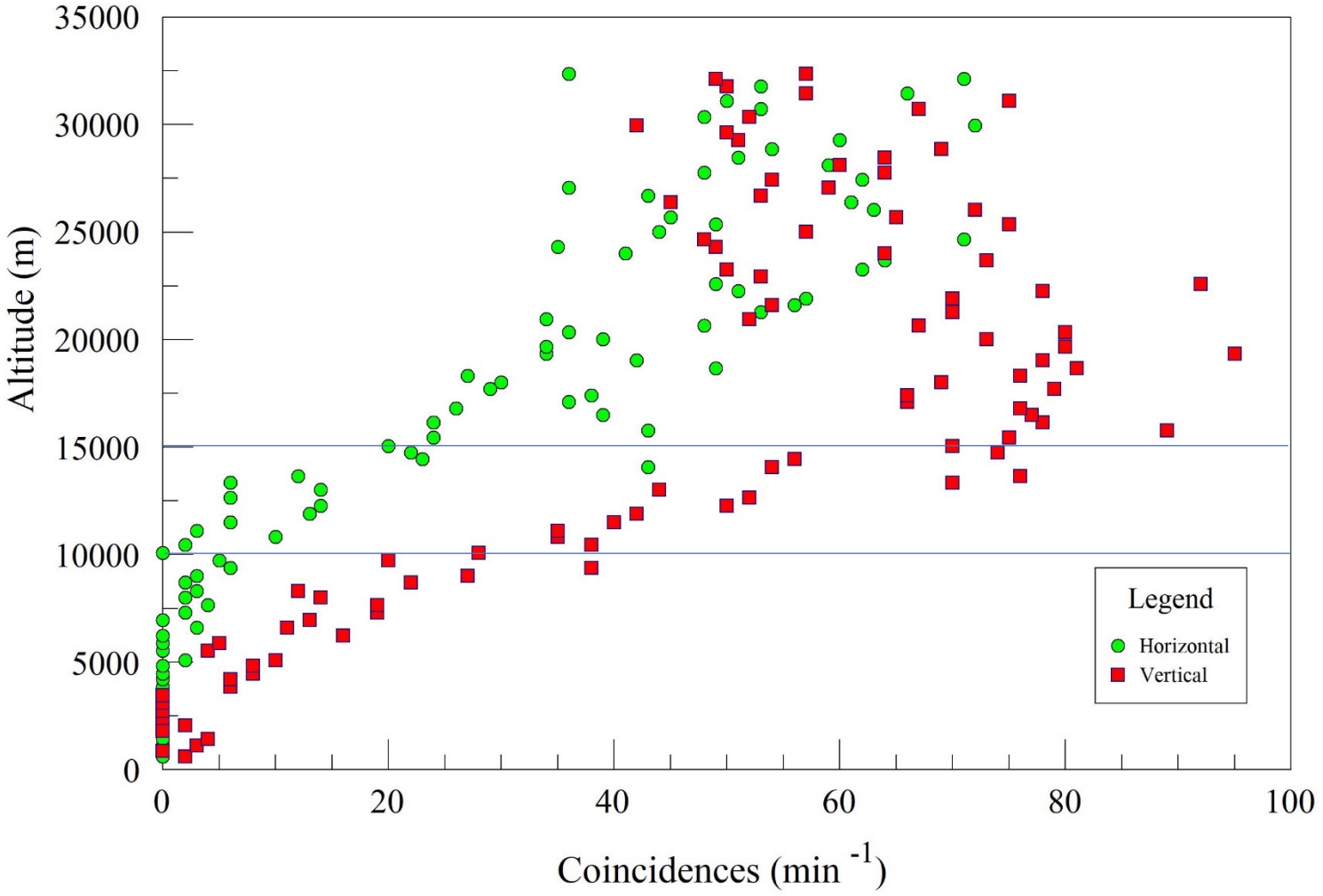
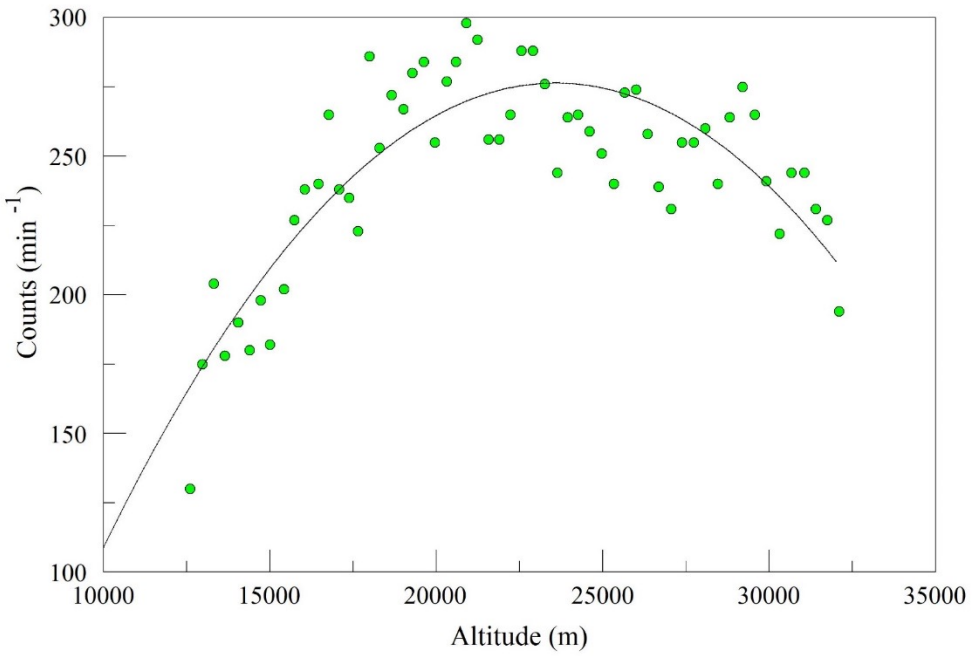


Figure 19: Plot of vertical (red) and horizonal (green) coincidences versus altitude on flight 6/13/19.

Results



R-P Max	Flight 1 Altitude	Flight 2 Altitude
Horizontal	23.70 km	24.20 km
Vertical	22.66 km	22.65 km
Omnidirectional	22.70 km	23.60 km

Figure 20: Plot of counts obtained from an RM-60 Geiger detector on 6/13/19.

Results

Coincidence	Altitude
Horizontal max.	28.90 km
Vertical max.	18.50 km

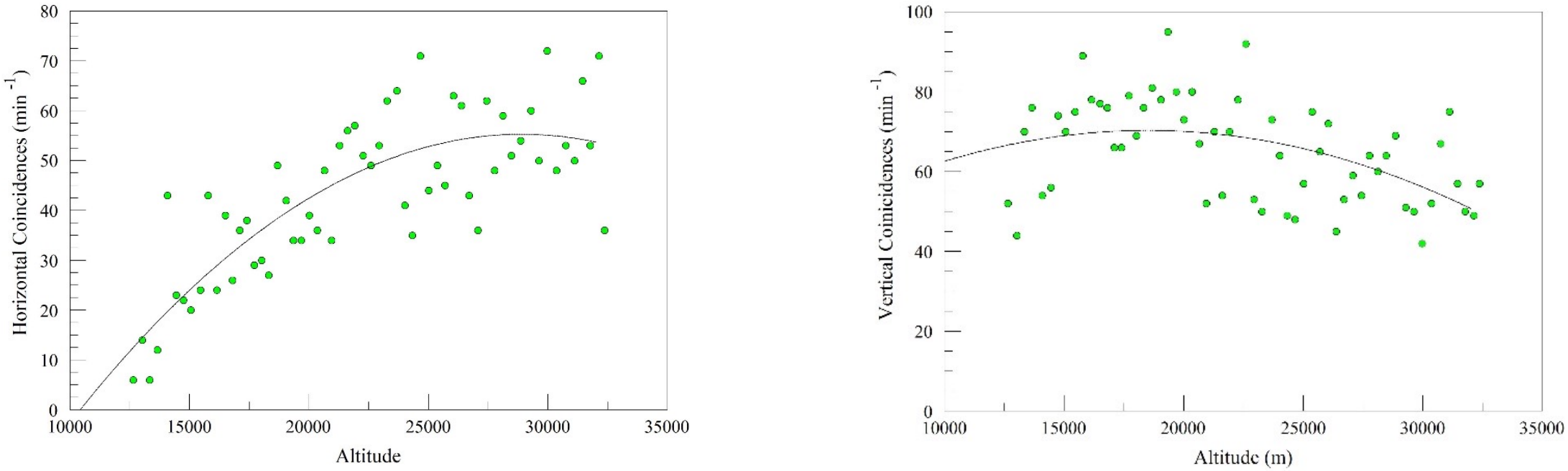


Figure 21: Plots of vertical and horizontal coincidence versus altitude on 6/13/19 flight.

Future directions

- Third order spline fits
- Process data for triple and quadruple coincidence
- Investigation of physics behind secondary-particles
- More flights

Figure 22: Stack set-up from flight 6/13/19 (2).

References

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- Liam Taylor

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Questions?

Flight Path #1: 6/7/19