



Cosmic shower: Analysis of Factors Affecting Events Leading to Cosmic Shower

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EVENTS LEADING TO COSMIC SHOWER**

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**This Work is Dedicated to Men and Women of
Science who labored for the wellbeing of all
humanity.**

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Addis Ababa University

Weldegebriel Lakew

October 2020

Acronyms and Abbreviations Used

| | |
|-----------------|--|
| CRMD | → Cosmic Ray Muon Detector |
| EAS | → Extensive Air Shower |
| eV | → Electrovolt ($1 \text{ eV} = 1.6 \times 10^{-19} \text{ joule}$) |
| GeV | → Gigaelectrovolt ($1 \text{ GeV} = 10^9 \text{ eV}$) |
| μ^+ | → positively charged muons |
| μ^- | → negatively charged muons |
| K^+ | → positively charged kaons |
| K^- | → negatively charged kaons |
| π^+ | → positively charged pions |
| π^- | → negatively charged pions |
| ν_μ | → muon type neutrino |
| $\bar{\nu}_\mu$ | → muon type antineutrino |
| ν_e | → electron type neutrino |
| $\bar{\nu}_e$ | → electron type antineutrino |
| e^- | → electron |
| e^+ | → positron |

Abstract

The aim of this work is to investigate and study the effects of geographic factors on cosmic shower at different locations around the globe.

The Quark Net Cosmic Ray Detector; the data repository and the analysis tool at <http://www.i2u2.org/elab/cosmic/data/> were used to gather and analyze data gathered at different sites across the globe.

The results indicate that events that lead to cosmic shower are strongly correlated to altitude of the locale and factors like longitudinal and latitude of the locations are moderately related to the intensity of events. Further the importance of, cosmic ray, observation for more than 12 hours is inferred from the data.

INTRODUCTION

Cosmic rays are particles originating from space and from sources such as the Sun and supernovae. The Earth's atmosphere receives cosmic rays at the rate of about 1000 per square meter per second. Cosmic rays are ionized nuclei - about 90% protons, 9% alpha particles and the rest heavier nuclei - and they are distinguished by their high energies. Some of those cosmic rays carries extremely high energies, having energies comparable to or somewhat greater than their masses. A very few of them have ultrarelativistic energies extending up to 10^{20} eV, eleven orders of magnitude greater than the equivalent rest mass energy of a proton [1].

Cosmic rays first came to the notice of scientists not long after the discovery in 1896 of radioactivity from chemical elements like uranium. The ionization of the air – atmospheric electricity – was at first mistakenly attributed to radioactive elements on Earth. That notion was dispelled in 1912, however, and the field of cosmic ray physics was born when the Austrian physicist Victor Hess, at great personal risk, carried devices known as electrometers high into the atmosphere in a free-floating hydrogen balloon to measure ionization rates at increasing heights. At an altitude of more than 17,000 feet, Hess discovered that the rate of ionization was nearly four times greater than at ground level, demonstrating that the ions moving fast through the air were of extraterrestrial origin.

After the discovery of cosmic radiation by Hess, a feat that would win him a Nobel Prize in 1936, the next questions for the new field of cosmic ray physics was, what are the particles made of, and how does nature make them? Where do they come from?

To this date the origin of cosmic rays is the fundamental question of cosmic ray physics. How are they accelerated to such high energies is also unanswered question. However, it is clear that nearly all of them come from outside the solar

system, but from within the galaxy. The relatively few particles of solar origin are characterized by temporal association with violent events on the sun and consequently by a rapid variability. In contrast, the bulk of cosmic rays show an anticorrelation with solar activity, being more effectively excluded from the solar neighborhood during periods when the expanding, magnetized plasma from the sun - the solar wind - is most intense. The very highest energy cosmic rays have gyroradii in typical galactic magnetic fields that are larger than the size of the galaxy. These may be of extragalactic origin [1].

Rays of cosmic origin, observed on the Earth are often categorized into two subdivisions: *primary* and *secondary*. Primary cosmic rays mainly consist of protons that collide with the earth's atmosphere, interacting with the nuclei of other atoms – usually O and N. The collision subsequently creates the secondary rays, often referred to as an *air shower*, that include a variety of decay products.

1.1 IMPORTANCE OF THE COSMIC RAY STUDIES

Until the advent of accelerators, cosmic rays and their interactions were the main source of information about elementary particles. The highest energy cosmic rays can still offer clues about particle physics above accelerator energies.

A number of important areas in which a knowledge of particle interactions is necessary to understand the astrophysical implications of cosmic ray data. Examples include:

- the relative amount of secondary cosmic rays gives information about how cosmic rays propagate through the interstellar medium, this in turn gives clue about the nature of the matter and fields that make up the medium.
- seeing point sources of photons, neutrons and other particles imply collision of cosmic rays with material near a site of cosmic ray acceleration. This is a way of identifying specific sources of cosmic ray acceleration and studying how they work.
- inferences can be made about the nature of primary incoming cosmic rays from the secondary cascade they produce.
- searches for exotic particles and new interactions in the cosmic radiation

Thus, the study of cosmic ray is crucial to the development of particle physics. Most research projects about cosmic rays are very complicated and expensive.

However, for there are many simpler experiments designed for accessible and affordable studies about cosmic ray to undergraduate or even high school students. Using scintillation detector, one can study properties about muons such as their angular distribution, decay constant, and cosmic showers [2, 3].

Studying cosmic radiation is important for particle physicists because it provides the opportunity to study neutrinos and very high energy particles of cosmic origin and it yields information about energetic astrophysical processes in the further reaches of the galaxy and beyond for astronomers. The study of cosmic rays has astrophysical implications too. For example the information we obtain from the way secondary cosmic propagate through the interstellar medium provide clue on the kind of interaction that happens and hence about the nature of the matter and fields that make up the medium. Further information on cosmic rays is important to space explorers and aviation industry [4].

1.2 OBJECTIVES OF THE STUDY

1.2.1 General Objectives

The general objective of this study is to analyze cosmic ray data at different locations around the globe using e-lab analysis tools.

1.2.2 Specific Objectives

The specific objective of this study are therefore

- to obtain data and determine cosmic ray shower, using e-lab portal, at different locations;
- to determine geographic parameters and analyze their relationship, if any, to the incidence of events that lead to cosmic shower at the localities studied.

1.3 RESEARCH QUESTIONS

1. What is the rate of events that lead to cosmic shower at different localities across the globe?
2. Is there any relation ship between geographic parameters and rate of cosmic events?
3. Is there any dependence of statistical parameters, describing cosmic shower, to the time observation?

Review of Related Literature

Cosmic rays that originate from outside the solar system have been a matter of interest for scientists, space explorers and the aviation industry since their existence was discovered by Victor Hess in 1912 in balloon experiments at the beginning of the previous century. The discovery of the extraterrestrial origin of cosmic rays started a new era of atmospheric physics and in particular elementary particle physics. Hess' observation of stronger ionisation with increasing altitude was confirmed, beyond doubt, by Kolhorster, who measured the ionisation rate up to 9300 meters. Their nature was a matter of dispute and this dispute was settled by Gerhard Hoffmann after he showed in 1926 that cosmic rays could produce showers in absorber layers [5].

Questions like "Where do cosmic rays come from?" and in particular, "How are they accelerated to such high energies?" are still fundamental questions.

2.1 COSMIC RAY PROPAGATION

Cosmic ray flux, as observed from the Earth, is dependent on many factors such as the earth's magnetic field; solar wind and the energy of cosmic rays. As the energy of cosmic rays increase their flux decrease and vice versa. i.e at energy 10^{11} ev about one particle per second and square meter hits the ground, at energy 5×10^{15} ev about one particle per year and square meter, at energy 10^{19} ev about one particle per year and square kilometer, above this only about one particle per century and square kilometer hits the ground [6].

Cosmic rays in the magnetic field experiences a deflection proportional to their charge and inversely proportional to its energy [7]. Highest energy cosmic rays reaches the surface of the earth without Suffering the strong field deflection. On the other hand, low energy rays are deflected by the field and back into cosmos [8].

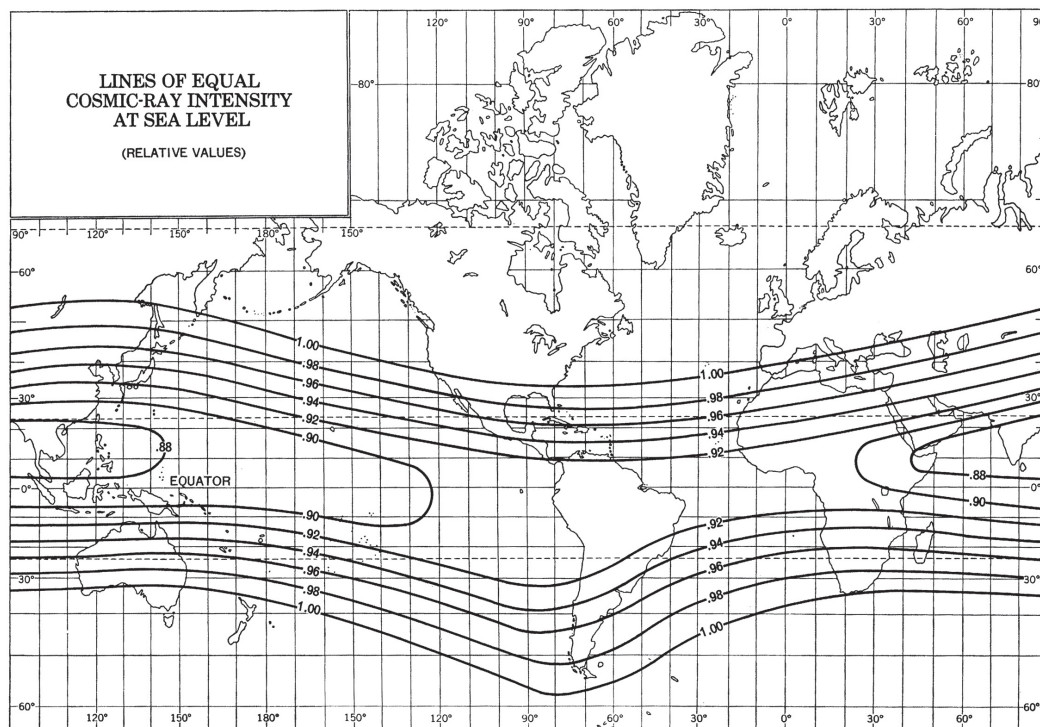


Figure 2.1: Relative Values of cosmic-ray intensity at sea level

2.1.1 Effect of Latitude on Cosmic Rays

Experiments showed that the intensity of cosmic rays is maximum at the poles ($\theta = 90^\circ$), minimum at the equator ($\theta=0$) and nearly constant between 42° and 90° latitudes.

The charged particles that approach at the equator travel in a perpendicular direction to the earth's magnetic field and are deflected away. Only those particles with sufficient energy can reach the surface. Therefore, minimum intensity of cosmic rays occurs at the equator. But, the charged particles approaching the earth's magnetic poles travel almost along the direction of the magnetic line of force. They experience no force. So maximum intensity exists at the poles [9].

2.1.2 Effect of Altitude on Cosmic Rays

It is the variation of cosmic ray intensity (I) with altitude (h). Experiment shows similar results at different places of the earth. That is, intensity of cosmic rays increases with altitude until it reaches a maximum height of 20 km. After that, there is a fall in intensity [2].

2.1.3 East West Asymmetry of Cosmic Rays

The flux of primary cosmic rays protons and nuclei that arrive in the vicinity of the earth surface exhibits east-west effect. This effect produced by primary particles being predominately positively charged then there are more particles travelling from west towards east than in the opposite direction [10]. This is due to the earth magnetic field. The positively charged muons curve towards the east which means the intensity from the west is stronger. Also, a larger effect at the geomagnetic equator than at the poles.

2.2 INTENSITY AND ENERGY SPECTRUM

2.2.1 Primary Spectra

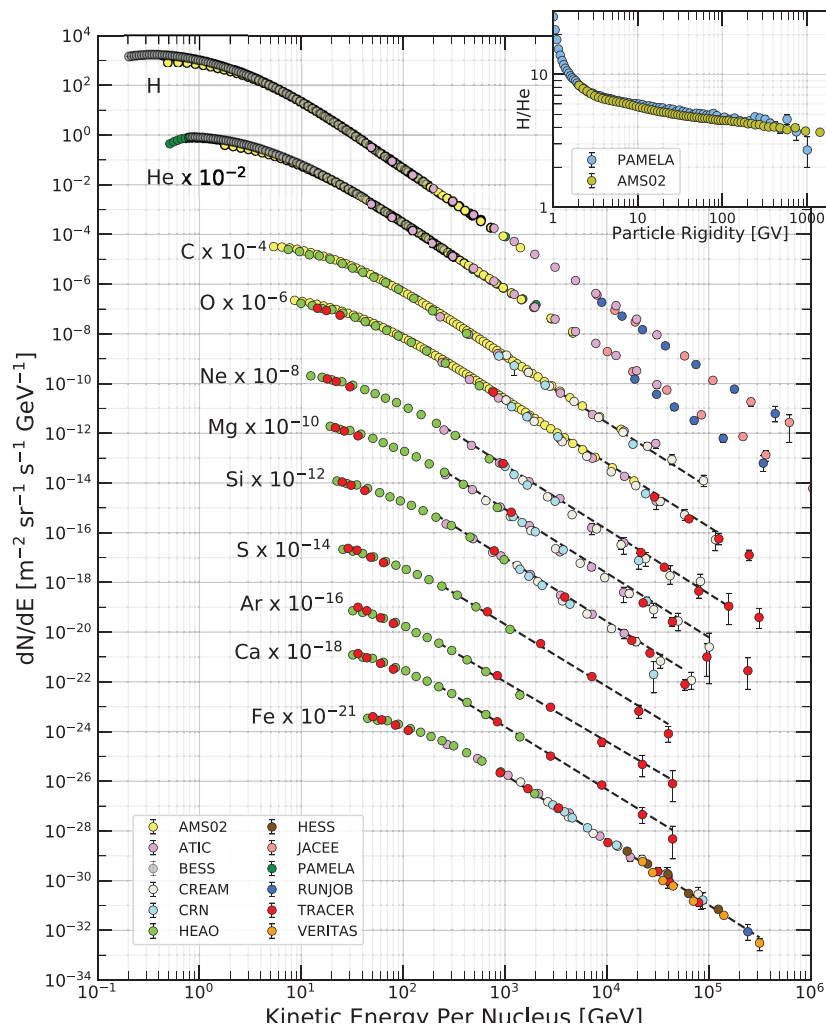


Figure 2.2: Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus using data from Refs [11] and [12]

The cosmic radiation entering the Earth's atmosphere, known as primary cosmic rays, includes all stable charged particles and nuclei with lifetimes of order 10^6 years or longer. Secondary cosmic rays are those particles produced in interaction of the primaries with interstellar gas.

Cosmic rays have an energy range of order of magnitude (10^3 up to 10^{21} eV).

2.3 COSMIC RAY SHOWER (AIR SHOWER)

When cosmic rays enters the earth's atmosphere they sooner or later collides with an atomic nucleus of the air mainly nitrogen and oxygen. In this interaction the energies can be large enough to break apart both or either of the primary particles or target nucleus and a multitude of secondary light particles produced which is known as an air shower [6]. The secondary particles interact again inside the atmosphere generating new particles. The iteration of this process produces the extensive air shower (EAS).

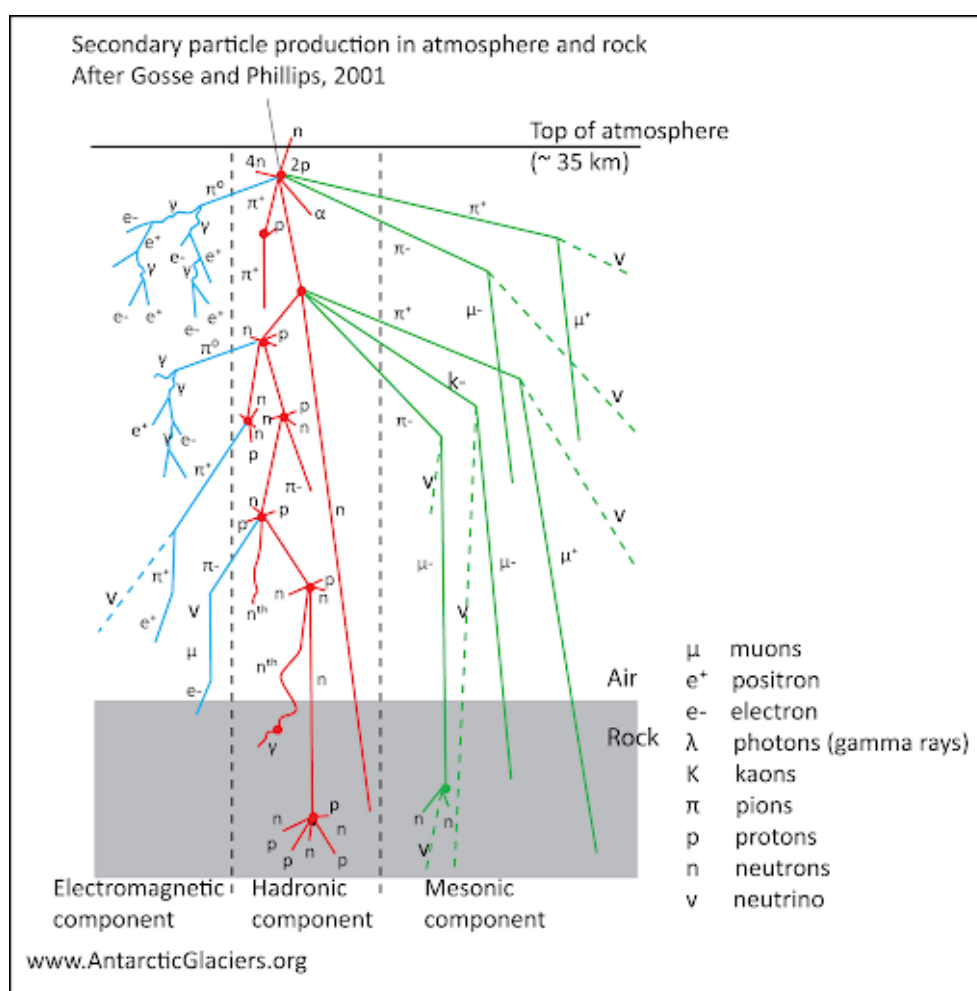


Figure 2.3: Extensive Air Shower

If these secondary particles have sufficient energy, they may interact with the nuclei of another charged particles and generates an enormous number of secondary particles. It includes pions, kaons, protons, neutrons, electrons, positrons, photons, alpha particles.

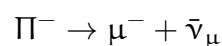
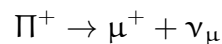
High energy cosmic rays produce air showers which reach the ground. For example, a 10^{19} eV vertical proton produces at sea level about 3×10^{10} particles, with an extension at ground over a few km^2 .

An EAS is formed by essentially three components: hadronic, electromagnetic and muonic [13].

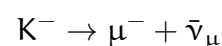
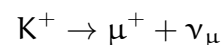
The hadronic component:- is generated at the top of the atmosphere, and gives rise to the muonic and electromagnetic components.

The electromagnetic component this component dominates the evolution of an extensive air shower. It dissipates around 85% of the primary energy.

The muonic components are mostly muons that are very energetic, interact weakly and reach the ground easily(Boulicaut2018). It carries about 10% of the total energy of the shower. It is also produced in an air shower by the decay of Charged kaons and pions. i. e



and



2.3.1 Muons in an Air Shower

One constitute of cosmic ray particles in an air shower that reach on the surface of the earth are muons. From counting all secondary particles detected At sea level, 70% are muons, 29% are electrons and positrons and 1% are heavier particles [14].

Muons were discovered in the studies of cosmic radiations by American physicist Carl.D. Anderson and Seth Neddermeyer in 1936. It is a heavy version of electron

and its anti-matter partner the positron having the same spin(1/2) and charge (-1). But, with a mass of $105.66 \text{ Mev}/c^2$ that is approximately 207 times larger than the electron.

Muons has two forms that is the negatively charged muon and its positively charged anti-particle. It is correctly assigned as a member of the lepton group of subatomic particles that never react with nuclei or other particles through the strong interaction [15].

The high energy muons have sufficient time to reach the ground and easily detected. But, low energy muons decay into electrons or positron and two neutrinos. It has a life time of 2.197 microsecond before decay.

$$\mu^+ = e^+ + \nu_e + \bar{\nu}_\mu$$

$$\mu^- = e^- + \bar{\nu}_e + \nu_\mu$$

muons take a time to decay mathematically expressed as

$$\frac{dN}{dt} = -\lambda N \quad (2.1)$$

rearranging and integrating both sides of equation (2.1), we get

$$N(t) = N(0)e^{-\lambda t} \quad (2.2)$$

$N(t)$ is the number of muons at a time $t = t$, $N(0)$ is the number of muons at time $t = 0$; λ is constant of decay rate; dt is small time interval [16].

The mean life time of muons are the reciprocal of decay rate constant. Thus:

$$\tau = \frac{1}{\lambda} \quad (2.3)$$

It is worth mentioning here that muons are typical examples of time dilation in the theory of relativity. Muons are created at high altitudes where the top of the atmosphere gets bombarded by solar and cosmic protons. The generated muons rain down at high speed approximately the speed of light(0.98 c), some of them decay partway down and others all the way to the ground. As Einstein special theory of relativity states “for an observer in an inertial frame of reference, a clock that is moving relative to him will be measured to tick slower than a clock that is at rest in his frame of reference”. This phenomena known as relativistic time dilation. From an observer on the earth viewing the muon approaching,

The time interval for moving clock will be dilated. Average lifetime of muons(τ_0) are $2.19 \mu\text{s}$.

The dilated average lifetime of muon(τ) with respect to the earth observer is calculated as

$$\tau = \frac{\tau_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (2.4)$$

where, v is the velocity of muon; c is the speed of light in vacuum.

Due to this time dilation effect of special relativity the muons are able to reach sea level and can be detected on ground. From point view of muons the distance to the earth's surface is contracted to a shorter length(L). It is expressed as follows

$$L = L_0 \sqrt{1 - \frac{v^2}{c^2}} \quad (2.5)$$

where L_0 is the height above earth's surface muons produced.

Experimental Method

Cosmic ray studies are often referred to as *Particle Physics Using Nature's Accelerator*. It is known that particle physics is only done with vastly expensive and complicated equipment run by casts of thousands of Highly Qualified Scientists and that particle physics is difficult and esoteric.

Recently there are activities that change this perception. Handy and inexpensive particle detectors that operate in few volts are developed and are accessible even to schools that would like to inspire future particle physicists. Some of the detectors and experimental methods employed in the study of cosmic radiation are described in the following sections.

3.1 DETECTION METHODS OF COSMIC RAYS

There are two main classes of detection methods. That is direct and indirect detection methods.

1. **Direct detection method** : is detection of primary cosmic rays by using high altitude balloons and space-based experiments. Example alpha Magnetic spectrometer.
2. **Indirect detection methods**: is detection of cosmic rays based on the observation of an extensive air shower with ground-based experiments. An extensive air shower (EAS) consists a larger number of particles travelling nearly at the speed of light and reaches at the surface covering several square kilometers. EAS arrays are made of particles detectors measures the charged particles which passes through them. It can observe a broad area of the sky and use plastic scintillator.

3.2 THE FERMI LAB DETECTOR: QUARK NET COSMIC RAY DETECTOR

Quark Net Cosmic Ray detector is one of the Indirect detectors that are used to detect cosmic rays. It is the one used in this work. We discuss this detector in more detail.

3.2.1 Construction and Principles of Operation

As any charged radiation detector, this detector is also based on collection of charged particle that are available due to ionization. It consists of the following parts.

1. **Counters:** To be assembled from the following pieces
 - (a) **Scintillators (4):** $10'' \times 12'' \times \frac{1}{2}''$ scintillator plastic blocks with polished edges and light guide.
 - (b) **Photomultiplier Tubes (PMTs) (4):** SensTech Model P30CW5 photodetector packages, including cables for signal, power and control.
2. **Signal Extension Cables for PMTs (4):** 50 ft. cables with male BNC connectors on each end
3. **Power Extension Cables for PMTs (4):** 50 ft. stereo audio cables with one male and one female connector, to extend power and control circuits from PMTs
4. **Power Distribution Unit (PDU) (1):** Box with 5 VDC power input and 4 outputs including potentiometer controls for each control circuit
5. **PDU Power Cable (1):** 6 ft. mono audio cable.
6. **GPS Receiver Assembly (GPS) (1):** The GPS receiver and interface adapter (GPS module) are in a small gray plastic box to which the following three items are attached:
 - (a) the 100 ft. CAT-5 standard network cable which connects the GPS to the DAQ
 - (b) the temperature sensor cable with the red weatherproof coating on the sensing end

(c) the GPS antenna with 9 ft. MCX cable; antenna has magnetic base

7. **Data Acquisition Circuit Board (DAQ) (1):** This circuit board contains the logic, timing, multipliers, and discriminators for processing the input signals from the counters and creating the output data stream. It has interfaces to the counters, the GPS and the PC.
8. **USB Interface Cable (1):** 9 ft. USB2.0 A to B interface cable for connecting the DAQ to the PC's USB port.
9. **Power Supply (1):** Power supply with 5VDC 1A output, female connector, to provide power to the DAQ.
10. **PC :** with a terminal emulator program.

3.2.2 Possible Experiments

Experiments, that can be done by CRMD, can be categorized in four.

Calibrations and performance studies: Calibrations should be done to study the response of the counters and the board. Calibration studies include plateauing the counters, threshold selection and barometer calibration.

Flux experiments: These category of experiments investigating such things as cosmic ray flux as a function of time of day, solar activity, east/west asymmetry (showing the μ^+/μ^- ratio by assuming these charged particles will bend in the earth's magnetic field), angle from vertical, barometric pressure, altitude.

Muon lifetime experiments: This is one of the interesting experiments that can be done using CRMD. This experiment verifies one of the conclusions of special theory of relativity i.e. time dilation.

Shower studies: This is the main subject of this work.

3.2.3 Shower Studies

In shower studies, the wiring of the above components is done as described in the CRMD manual [14].



Figure 3.1: Unstacked arrangement of the counters (Nuclear physics lab AAU).

The counters in figure 3.1 are receiving power from the power distribution unit and sending signal to the data acquisition board via power and BNC cables respectively (see figure 3.2).

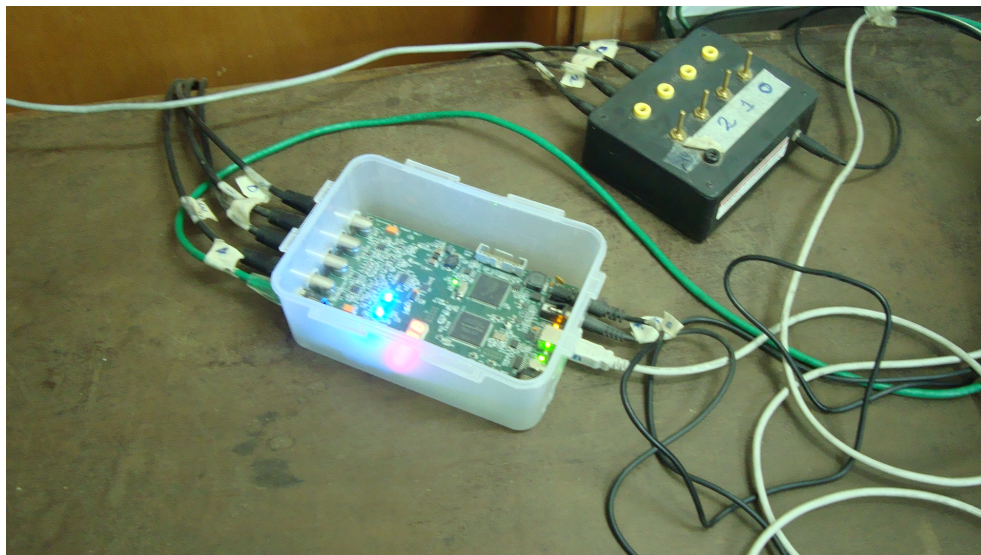


Figure 3.2: Power Distribution Unit (PDU) and Data Acquisition Board (DAQ)

The DAQ receives signal from the photomultiplier tube; receives time and location stamp from the GPS and it communicates the interpreted output data to the PC, via the USB cable, to be recorded.



Figure 3.3: DAQ coupled with PC



Figure 3.4: GPS

The GPS offers an absolute time stamp. Therefore a network of detectors (at the same or different sites) can study cosmic ray showers.

The data, stored in the PC, is conditioned and gets ready, for uploading to the analysis tool by the EQUIP interface See appendix A.

The web analysis tools allow to make predictions about which direction in the sky the shower (and thus the primary cosmic ray) came from. Users select the specific datasets to analyze (these may be from different locations) the coincidence level required, and the time interval between which coincidences must have occurred. A 3-D plot of position on the earth (xy) is graphed as a function of signal time (z). This graph allow us to “see” the direction from which the shower came.

Shower study event plot (5-fold coincidences)
Study from Detector

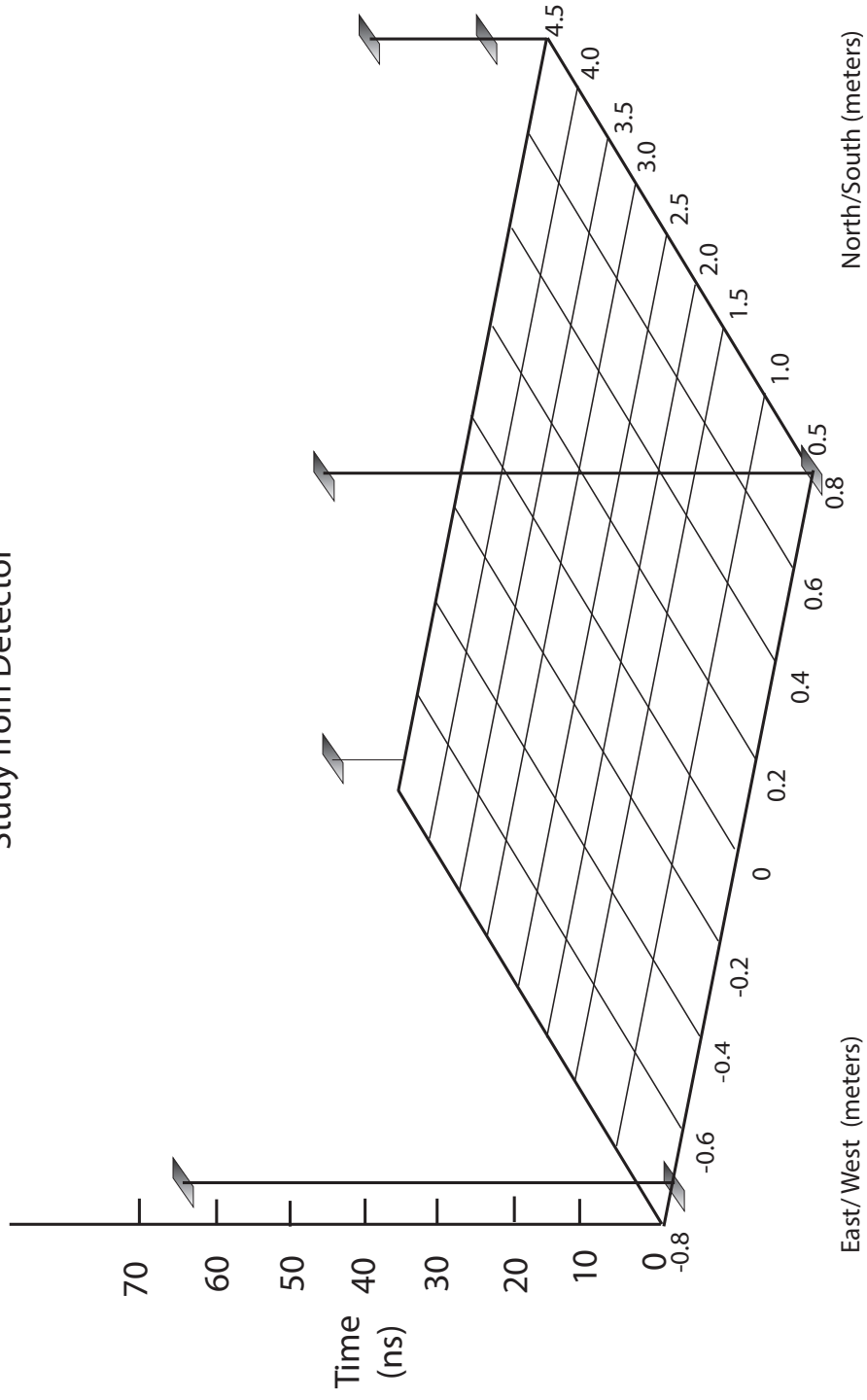


Figure 3.5: Shower study plot showing coincidences within a 70 ns time window [14].

Results and Discussion

The data shown in the long table 4.1 is collected using Quarknet cosmic ray detector and deposited at <https://quarknet.i2u2.org/>. This universal repository is used by researchers all over the world that use Fermi Lab's Cosmic Ray Detector Kit. It provides analysis tools and sample plots in addition to a "blessed" data from measurements from sites where these detectors are operated.

4.1 RESULTS

Cosmic ray detector experiments require only the equipment at local site. Analysis is possible by a website, developed by Quark Net, that allows data uploads, by selecting the "Upload" link from the <http://quarknet.fnal.gov/grid>, and analysis.

The analysis software will create a new file, from the uploaded row data, using coding that comply with data structuring of the analysis tool.

Table 4.1: Cosmic shower data

| Location | Altitude | Latitude | Longitude | | Channel | | | | Total Counting time |
|------------|-----------|-------------|--------------|---------------|---------|--------|--------|--------|---------------------|
| | | | | | 1 | 2 | 3 | 4 | |
| CALIFORNIA | 263.77 m | 36:59.9271N | 122:03.6686W | Total Hits | 93486 | 93414 | 92995 | 92535 | 13053 sec |
| | | | | Total Events | 93315 | | | | |
| | | | | Av. Hit/event | 3.99 | | | | |
| COLORADO | 1525.00 m | 40:34.3592N | 105:04.8322W | Total Hits | 13368 | 13404 | 13400 | 13409 | 11312 sec |
| | | | | Total Events | 13421 | | | | |
| | | | | Av. Hit/event | 3.99 | | | | |
| NEWYORK | 175.89 m | 43:02.22N | 76:08.11W | Total Hits | 50441 | 63829 | 61202 | 65762 | 10422 sec |
| | | | | Total Events | 238919 | | | | |
| | | | | Av. Hit/event | 1.01 | | | | |
| INDIANA | 219.26 m | 41:02.76N | 86:35.75W | Total Hits | 475699 | 164448 | 251267 | 231003 | 82653 sec |
| | | | | Total Events | 485667 | | | | |
| | | | | Av. Hit/event | 2.31 | | | | |
| WYOMING | 1346.22 m | 43:51.00N | 104:12.59W | Total Hits | 664882 | 663690 | 665830 | 664260 | 63200 sec |
| | | | | Total Events | 665606 | | | | |
| | | | | Av. Hit/event | 3.99 | | | | |

Continued on Next Page...

Table 4.1Continued

| Location | Altitude | Latitude | Longitude | | Channel | | | | Total Counting time |
|-----------------|----------|---------------|----------------|---------------|---------|--------|--------|--------|---------------------|
| | | | | | 1 | 2 | 3 | 4 | |
| WASHINGTON | 235m | 47:33.47N | 122:09.32W | Total Hits | 195554 | 366644 | 139424 | 367445 | 62297sec |
| | | | | Total Events | 561339 | | | | |
| | | | | Av. Hit/event | 1.9 | | | | |
| JAPAN(Sandai) | 30.006m | 38:15.017828N | 140:53.534529E | Total Hits | 103965 | 116926 | 116683 | 102311 | 12863sec |
| | | | | Total Events | 117008 | | | | |
| | | | | Av. Hit/event | 3.76 | | | | |
| CHINA(Beijing) | 43.193M | 48:23.0167N | 89:03.7519E | Total Hits | 8 | 10 | 10 | 9 | 2590 |
| | | | | Total Events | 12 | | | | |
| | | | | Av. Hit/event | 2.83 | | | | |
| INDIA(Newdelhi) | 227.814M | 28:41.514794N | 77:12.545163E | Total Hits | 169498 | 164928 | 0 | 0 | 6785 |
| | | | | Total Events | 333025 | | | | |
| | | | | Av. Hit/event | 1 | | | | |
| MERYLAND | 100.227M | 39:19.891N | 76:37.383W | Total Hits | 444918 | 644833 | 694233 | 386127 | 89253 |
| | | | | Total Events | 892943 | | | | |
| | | | | Av. Hit/event | 2.43 | | | | |
| TEXAS | 183.657M | 32:23.7976N | 096:50.9395W | Total Hits | 62102 | 69378 | 16034 | 6515 | 49674 |
| | | | | Total Events | 73067 | | | | |
| | | | | Av. Hit/event | 2.11 | | | | |

Continued on Next Page. . .

Table 4.1Continued

| Location | Altitude | Latitude | Longitude | | Channel | | | | Total Counting time |
|---------------|----------|---------------|----------------|---------------|---------|--------|--------|--------|------------------------|
| | | | | | 1 | 2 | 3 | 4 | |
| MEXICO CITY | 2547.69M | 19:22.1478N | 099:15.82W | Total Hits | 3504 | 3471 | 0 | 0 | 14336 |
| | | | | Total Events | 3372 | | | | |
| | | | | Av. Hit/event | 2.07 | | | | |
| FLORIDA | 3.00M | 25:45.46N | 80:22.49W | Total Hits | 4623 | 1548 | 0 | 0 | 292 |
| | | | | Total Events | 5028 | | | | |
| | | | | Av. Hit/event | 1.23 | | | | |
| MASSACHUSETTS | 30.0M | 42:25.8025N | 71:07.4872W | Total Hits | 372526 | 189744 | 232723 | 404448 | 90086 |
| | | | | Total Events | 499319 | | | | |
| | | | | Av. Hit/event | 2.4 | | | | |
| IDAHO | 1394.63M | 42:51.8089N | 112:26.8033W | Total Hits | 648481 | 599154 | 606724 | 650613 | 52044 |
| | | | | Total Events | 980108 | | | | |
| | | | | Av. Hit/event | 2.56 | | | | |
| KANSAS | 337M | 38:57.432248N | 095:14.933952W | Total Hits | 216941 | 208352 | 150555 | 195741 | 56996 |
| | | | | Total Events | 308448 | | | | |
| | | | | Av. Hit/event | 2.5 | | | | |

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Table 4.1Continued

| Location | Altitude | Latitude | Longitude | | Channel | | | | Total Counting time |
|--------------|----------|---------------|----------------|---------------|---------|--------|--------|--------|---------------------|
| | | | | | 1 | 2 | 3 | 4 | |
| KENTUCKY | 181.405M | 36:55.605725N | 086:24.840322W | Total Hits | 8087 | 8109 | 8097 | 8067 | 83306 |
| | | | | Total Events | 8144 | | | | |
| | | | | Av. Hit/event | 3.97 | | | | |
| MICHIGAN | 215.86 m | 42:21.22N | 083:04.157088W | Total Hits | 182821 | 110272 | 91875 | 128483 | 8521 |
| | | | | Total Events | 298645 | | | | |
| | | | | Av. Hit/event | 1.72 | | | | |
| OHIO | 246M | 36:07.7560N | 084:27.6579W | Total Hits | 97174 | 98778 | 159363 | 162747 | 52472 |
| | | | | Total Events | 263407 | | | | |
| | | | | Av. Hit/event | 1.97 | | | | |
| RHODE ISLAND | 70M | 42:16.5303N | 71:09.3555W | Total Hits | 3303 | 7816 | 8198 | 3856 | 3706 |
| | | | | Total Events | 10738 | | | | |
| | | | | Av. Hit/event | 2.16 | | | | |
| SOUTH DAKOTA | 273M | 41:50.3535N | 088:15.6600W | Total Hits | 117041 | 118887 | 117064 | 117363 | 67583 |
| | | | | Total Events | 117069 | | | | |
| | | | | Av. Hit/event | 4 | | | | |
| TENNESSE | 230M | 36:08.6194N | 86:48.1295W | Total Hits | 3447 | 3722 | 3152 | 3675 | 86230 |
| | | | | Total Events | 6593 | | | | |
| | | | | Av. Hit/event | 2.12 | | | | |

| STATES | ALTITUDES | LATITUDES | LONGITUE | TOTAL EVENTS | EVENT/SEC | COUNT TIME(s) | Corr(alt, event/s) | Corr(lat, event/s) | Corr(long, event/s) |
|--------------|-----------|-----------|----------|--------------|-----------|---------------|--------------------|--------------------|---------------------|
| IDAHO | 1394 | 42 | 112 | 980108 | 19 | 52044 | 0.719547239 | 0.614029363 | 0.472432205 |
| WYOMING | 1349 | 43 | 104 | 665606 | 11 | 63200 | | | |
| KANSAS | 337 | 38 | 95 | 308445 | 5 | 56996 | | | |
| SOUTH DAKOTA | 273 | 41 | 88 | 117069 | 2 | 67583 | | | |
| TEXAS | 183 | 32 | 96 | 73067 | 1 | 49674 | | | |
| WASHINGTON | 235 | 47 | 122 | 561339 | 9 | 62297 | | | |
| MERRYLAND | 100 | 39 | 76 | 892943 | 10 | 89253 | | | |
| MASSACHUSETS | 30 | 42 | 71 | 499319 | 6 | 90086 | | | |
| KENTUCKY | 181 | 36 | 86 | 8144 | 0 | 83306 | | | |
| OHIO | 246 | 39 | 84 | 263407 | 5 | 52472 | | | |
| TENNESSE | 230 | 36 | 86 | 6593 | 0 | 86230 | | | |
| INDIANA | 219 | 41 | 86 | 485667 | 6 | 82653 | | | |

Table 4.2: Sub-table that shows data with $t > 43000$ seconds (half day and above counting time)

4.2 DISCUSSION

The above sub-table shows that the selected data from table 4.2: cosmic shower data table that have counting time more than 43,000 seconds.

Based on the above information calculating correlation coefficient of Geographic parameters (Altitude, Latitude and Longitude) with Respect to cosmic event rate yields as follows.

- i) The correlation between Altitude and cosmic event rate shows a correlation coefficient value of 0.72. It indicates that, the two variables have a strong positive correlation.
- ii) The correlation between latitude and cosmic event rate results a correlation coefficient value of 0.61. It implies that the two variables have a moderate positive correlation.
- iii) The correlation between longitude and cosmic event rate results a correlation coefficient value of 0.47. It indicates that the variables have a moderate relationship. Generally, cosmic event rate are affected by geographic parameters strongly or moderately in a positive relation

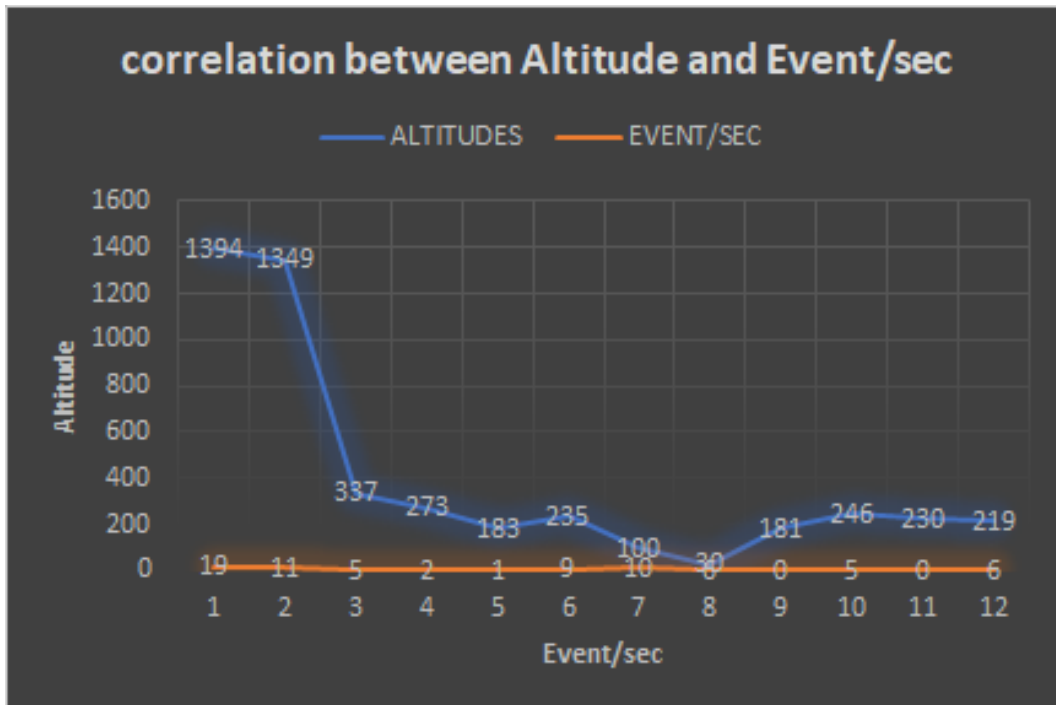


Figure 4.1: Event Rate vs Altitude

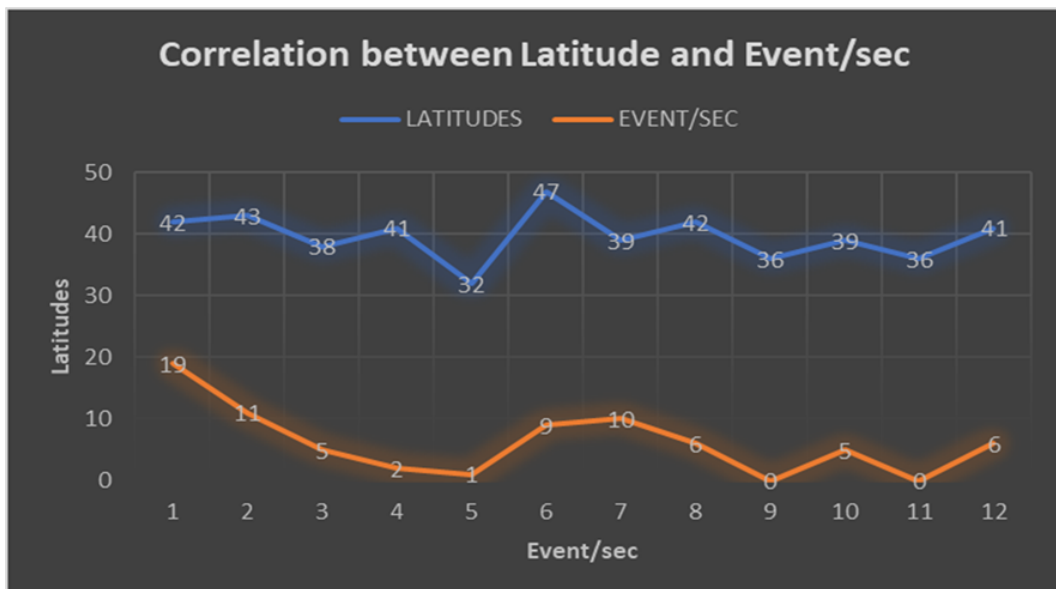


Figure 4.2: Event Rate vs Latitude

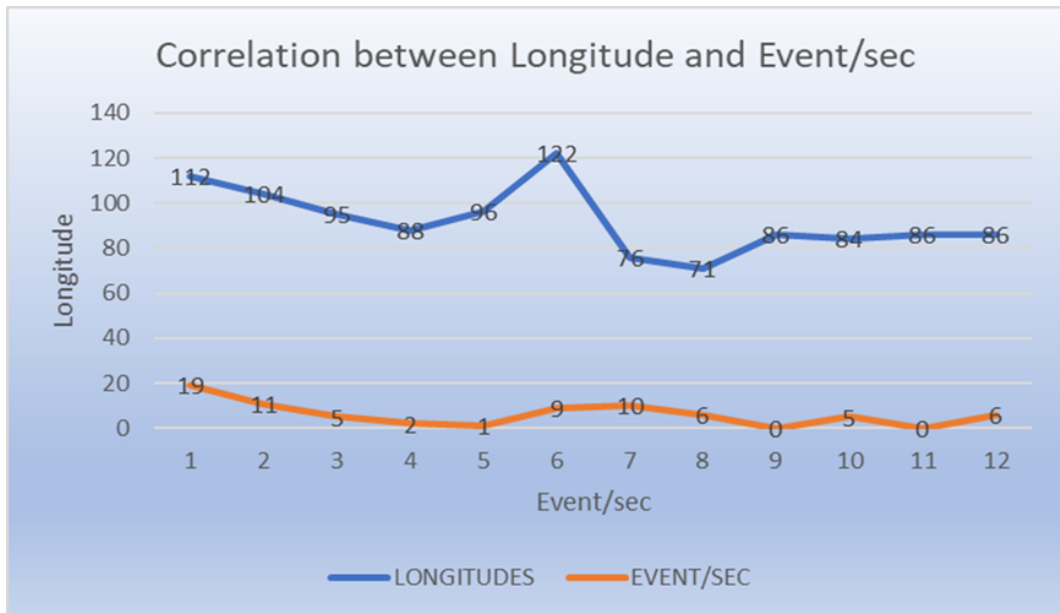


Figure 4.3: Event Rate vs Longitude

Conclusions and Recommendations

5.1 CONCLUSIONS

- The rate of interaction between primary cosmic rays and the Earth's atmosphere (i.e. Cosmic event rate) are different at different localities around the world.
- The rate of interaction between primary cosmic rays and the Earth's atmosphere (i.e. Cosmic event rate) are dependent on geographic parameters (altitude, latitude and longitude) and have a positive correlation.
- Higher counting time for cosmic events will yield a better result. This fact well known in various natural phenomena. In our work we have verified it is true in cosmic events too.
- Quarknet cosmic ray e-lab analysis tools is important to study rate of cosmic events by using our own data or by accessing data gathered by others.

5.2 RECOMMENDATIONS

Countries, states or cities found in higher altitude, higher latitude or longitude are exposed to cosmic radiations relatively higher than those at lower altitudes etc. As the nature of these radiations are having negative health impact on the lives of humans, it is necessary to closely monitor and study cosmic shower and their flux in such localities.

Most importantly such observations are important in

- introducing high energy physics to young students even at school level (the future scientists);
- creating the feel of the presence of extraterrestrial radiation here on earth and in our specific locality;

- serving as one more global collaboration in practical physics in frontier research area at low cost and relatively accessible analysis tool.

Therefore it is imperative to continue to be part of the global observation group and continue this work as this tool is the only one of its kind in Africa from among more than 100 observation centers across the globe.

EQUIP Interface Startup Guide

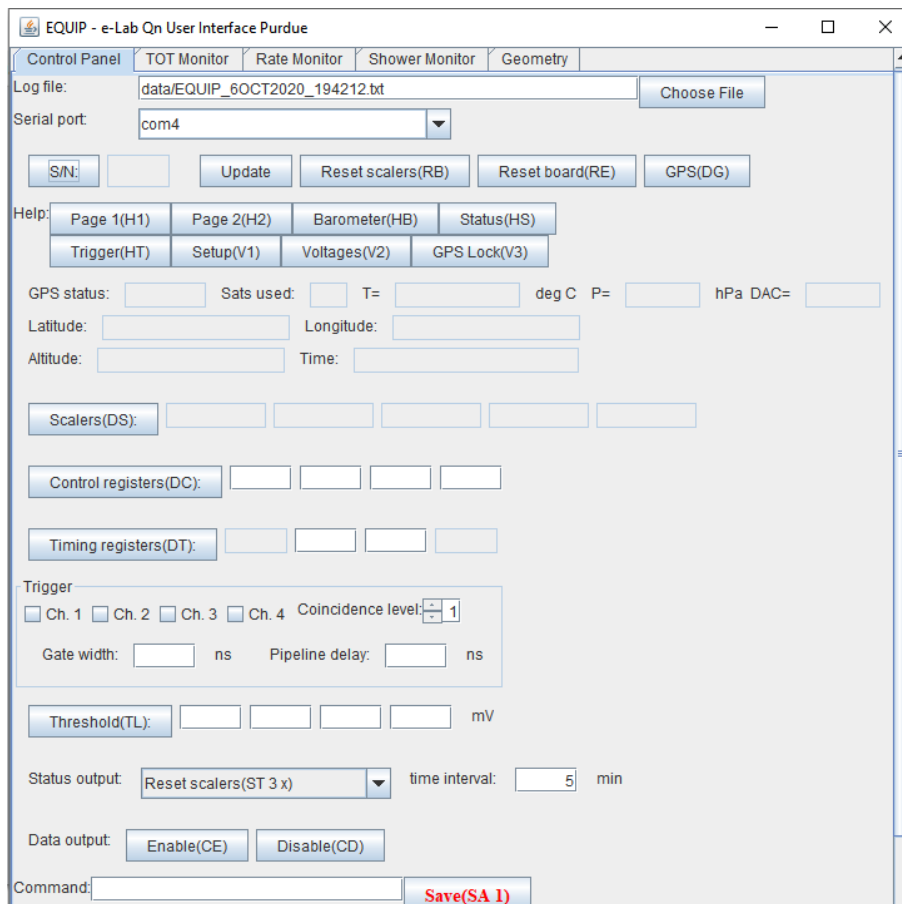


Figure A.1: EQUIP Interface

e-Lab Analysis Interface

Addis-01 [Log out](#)

Cosmic Ray e-Lab

[Project Map](#)
[Library](#)
[Upload](#)
[Data](#)
[Pointers](#)
[Site Map](#)
[Assessment](#)

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Choose data for shower study.

The universe is a big place. Cosmic ray primaries drift around and get energy boosts from multiple sources. Some primaries attain enormous energies. When they strike the upper atmosphere, they create Extended Area Showers. These events create thousands of particles that simultaneously reach a small section of Earth's surface. Can you find out how often nearby detectors "light up" with cosmic rays? If they do, is it a random coincidence or a measurement of violent conditions in another galaxy?

Gain confidence by running a practice search.

Quick Searches: [Addis-01](#), [Tibetian Testing](#), [Addis Ababa University](#), [Addis Ababa ETH](#)

v Advanced Search
 Please enter data in MM/YYYY format (e.g., 01/09/2020).
 You may leave one or both data fields blank.

Start Date: to

All data Refine results with extra parameters

Stacked: No Yes
Blessed: Yes No

[View and Search from selector pane](#)

* To speed up searches by default we are retrieving the last 3 months worth of data for the criteria you chose. You can modify your date range using the Advanced Search criteria.

[Clear selected data](#)

- ▶ IITCAA Pune University Campus
- ▶ Pune, IND
 - 3 data files: 0 stacked, 3 blessed, 327,327 total events.
- ▶ University of Delhi
- ▶ Delhi, IND
 - 25 data files: 0 blessed, 28 stacked, 6,353,440 total events.

Results 1 - 2 of 2 for state: IND Searched 31 files in 0.787 seconds

Analyze

[Help](#)
[Tutorial on Shower Study](#)
[SEARCH PARAMETERS](#)
[FAQ](#)

States include provinces and countries. Enter the [abbreviation](#).

[Related Milestones](#)
[Analyze Data](#)
[Connect Data](#)
[Assemble Evidence](#)

Legend

- View data
- View more info
- Unstacked data
- Stacked data
- Blessed data
- Filter parameters
- Follow for more info
- Unblessed data
- Click to view blessing charts
- Click to view unblessing charts
- Data has comments - Add more/View
- Add comments

You cannot select files with No Cap for Flux Shower or Lifetime Studies.

Figure B.1: e-Lab Analysis Interface

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DECLARATION

ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
DEPARTMENT OF PHYSICS

MSc Thesis

Cosmic shower: Analysis of Factors Affecting Events Leading to Cosmic Shower

Name of Candidate: Weldegebriel Lakew

I the under signed declare that the thesis is my original work and no part of it can be claimed as an intellectual property of anybody else except me and my advisors.

Signature: _____

October 2020