Estimation of the composition of the primary cosmic ray particles by measurements of the cosmic ray muon component

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Abstract

The primary cosmic ray particles constitute 85% protons, 12% helium, 3% iron, and heavier elements. They interact with the Earth's atmosphere, producing secondary particles known as Extensive Air Showers (EAS). Among the particles produced in EAS are pions and kaons, which subsequently decay into muons. Cosmic ray muons dominate the population of cosmic ray particles on the Earth's surface. The lateral distribution of cosmic ray muons was investigated using two-fold coincidences.

Four detectors were positioned at two-fold coincidence separated at regular intervals. It was determined what the coincidence rate was between these detector stations. To support the understanding of EAS, Monte Carlo (MC) simulations of EAS were performed using the EPOS and GHEISHA models, which account for high and low-energy particle interactions, respectively.

The simulations using EPOS LHC from this work with the measurements of the two-fold coincidence gave a primary composition cosmic ray as (protons (81±0.01) %, helium (10±0.04) %, and (9±5.88) % iron, and heavier elements). The knowledge gained from the lateral distribution of cosmic ray muons is essential for comprehending the development of extensive air showers. Furthermore, this information enhances our understanding of the chemical composition of primary cosmic ray particles.

Introduction

- GHEISHA models were used in this study for the high and low energies respectively. When a primary cosmic ray proton (p) or nucleus collides with nuclei in the atmosphere, secondary particles such as the pions (π) and kaons (K) are produced (2).
- The proton loses energy as a result of these collisions. The produced pions and kaons can be charged or neutral. Charged pions and kaons decay to muons (μ) which further decay into electrons (e-) and positrons (e+). Muons of sufficient energy can reach the earth's surface and beyond. Cosmic ray muons serve as penetrating probes to explore the cosmos.
- This study used four detectors in two-fold coincidence to measure the lateral distribution of cosmic ray muons. We have also determined the variation of cosmic ray muon count rate hourly to understand the flux variations during the day.
- The Cosmic Ray Simulation for the KAscade Grande (CORSIKA) program was used to carry out Monte Carlo simulations of the Extensive Air Showers. The EPOS LHC and GHIESHA

Data & Methodology

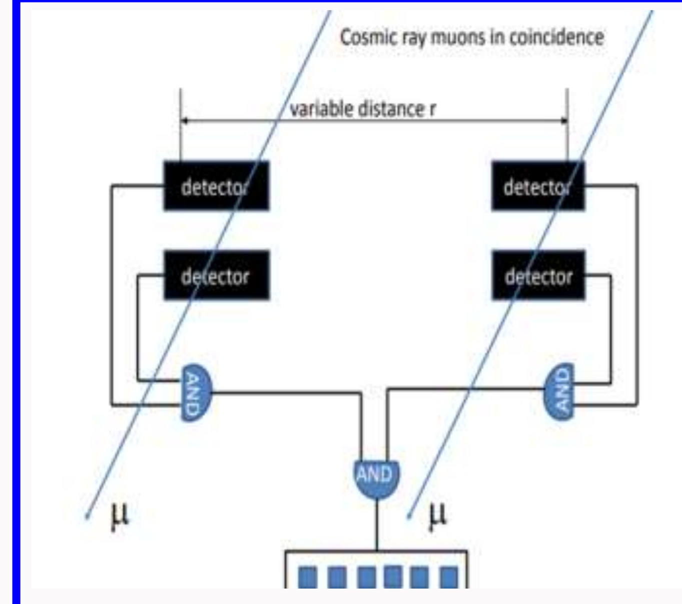

Figure 1: Experimental setup for the detection of cosmic ray muons in two-fold coincidence.

Two-fold coincidences

Measurements of cosmic ray muons were carried out from 6th to 29th June 2023 from 0900 h to 1700 h using a two-fold coincidences technique as illustrated in Fig. 1. Counts were taken at different times of the day at varied distances. The distance between each pair of two detectors has been increased to a maximum of 35.5 m. The output from the detectors was fed to the amplifier and then to the discriminator. This is to filter out the noise from the signal. The output from the discriminator was fed to the quad coincidence unit. The coincidence rate was calculated for each distance between the detectors. The statistical uncertainties were considered and data was recorded in counts/minute. The data was converted to coincidence flux (counts/min /m2/sr) taking into account the detector acceptance

Data & Methodology cont …

Monte Carlo Simulations using CORSIKA (Cosmic Ray Simulation for KAscade Grande Experiment)

i)Choose the high energies for hadronic interactions. EPOS LHC(used in this work)

ii)Choose the low energies for hadronic interactions. GHEISHA(used in this work)

iii) Choose the detector orientation Horizontal flat orientation(used in this work)

iv) Specify the particle its ID and its percentage composition.

Elemental particle	ID [(Ax 100)+Z]	Percentage composition
Proton	14	85%
Helium	402	12%
Iron	5626	3%

- **Specification For Simulations (Steering Card)**

Energy slope	-2.7
Energy cuts	9 GeV for hadrons and muons, 1.E6 GeV for electrons,1.E6 GeV for photon
Energy range	1E4- 1E5 GeV
Zenith angle	0 to 69
Seed numbers	Random number sequence.
Azimuthal angle	-180 to 180
Magnetic Field(for Nairobi)	Bx = 30.89μT and Bz = -12.7973 μT
Observation level in cm	179E3

Results

The parameters obtained after fitting the NKG function to each particle respectively.

ELEMENT	a	b	c	R_0
PROTON	0.6828±0.0001	-0.9995±0.0001	0.0005±0.0002	0.9644±0.0002
HELIUM	0.0573±0.0027	-1.1724±0.0243	-0.2724±0.0358	1.6419±0.0817
IRON	0.0020±0.0002	-1.0931±0.0112	-0.4246±0.0595	14.4102±1.6336

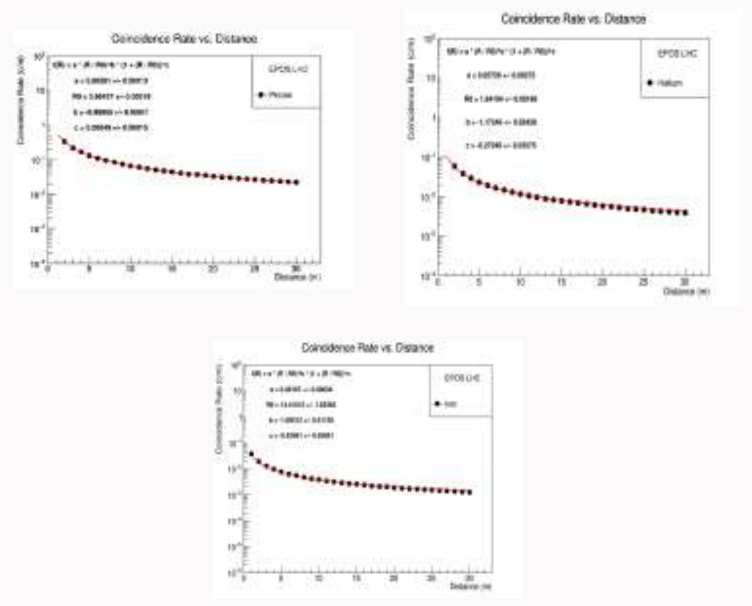

Figure 2:Variation of coincidence flux with distance for proton, Helium and iron respectively

Results cont …

- The sum of parameterization obtained for P, He, and Fe after simulating using EPOS LHC were fitted to the measured two-fold coincidences. where Element(i) represents the contribution in % for proton, helium, and iron.

$$f(x) = Par(1).fp + Par(2).fHe + Par(3).fFe$$

$$Element(i) = E(i) = \frac{Par(i)}{\sum Par(i)} x100\%$$

$$\sigma_{Ei} = \sqrt{\sum_{j=1,3}\left(\frac{\partial Ei}{\partial Par(j)}.\sigma_{Par(j)}\right)^2}$$

- The errors of the parameters par(j) are computed by the MINUIT fitting function

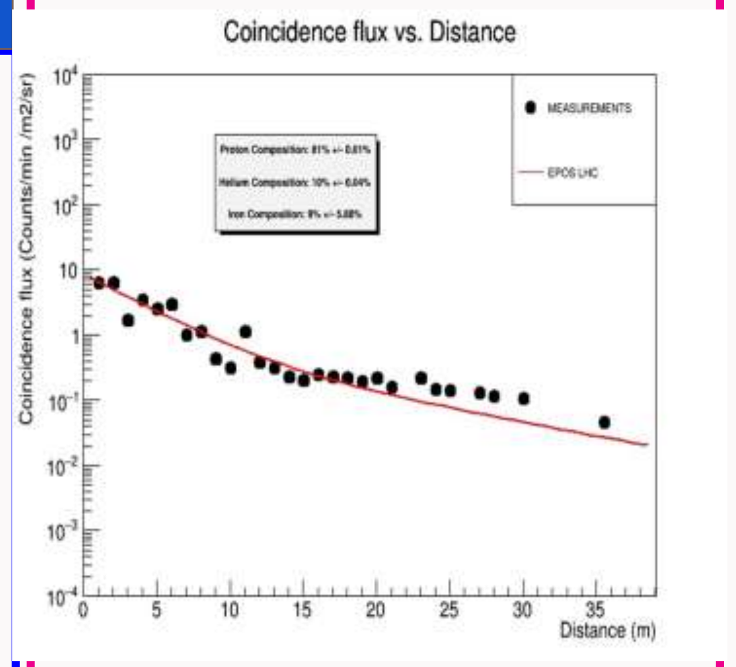

Figure 4: **The estimation of the elemental composition using the two-fold coincidence data..**

- ✓ *The VENUS model was utilized to analyze decoherence curves, leading to the determination of a composition of (77±11)% protons and (23±11)% iron nuclei for cosmic rays (Tcacuic 2006).*
- ✓ *From this work using the EPOS LHC model measured parameters fitted to the measurement of two-fold coincidences indicates a primary composition of (81±0.01)% for protons, (10±0.04)% helium, and (9 ±5.88)% iron.*
- ✓ *Interestingly, the comparison and analysis of different models and experimental data consistently favor the light composition of primary cosmic rays.*
- ✓ *The EPOS LHC accounts for all the primary composition even helium which hasn't been accounted for in the past experiments only the proton uncertainty for this model seems a bit higher compared to VENUS.*

Conclusion

- ✓ The measured coincidence rates for cosmic ray muons using the two-fold coincidences technique decrease with increasing distance between the detectors.
- ✓ From this work the primary composition of the cosmic rays is determined (81±0.01)% for protons, (10±0.04)% for helium, and (9 ±5.88)% iron.

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Acknowledgement

- ★ This work was done in the International Atomic Energy (IAEA) Internet Reactor Laboratory (IRL) at Kenyatta University. The following technical staff facilitated the instrumentation of the work: Mr. Joseph Wataka and Mr. Frederick Mudimba