



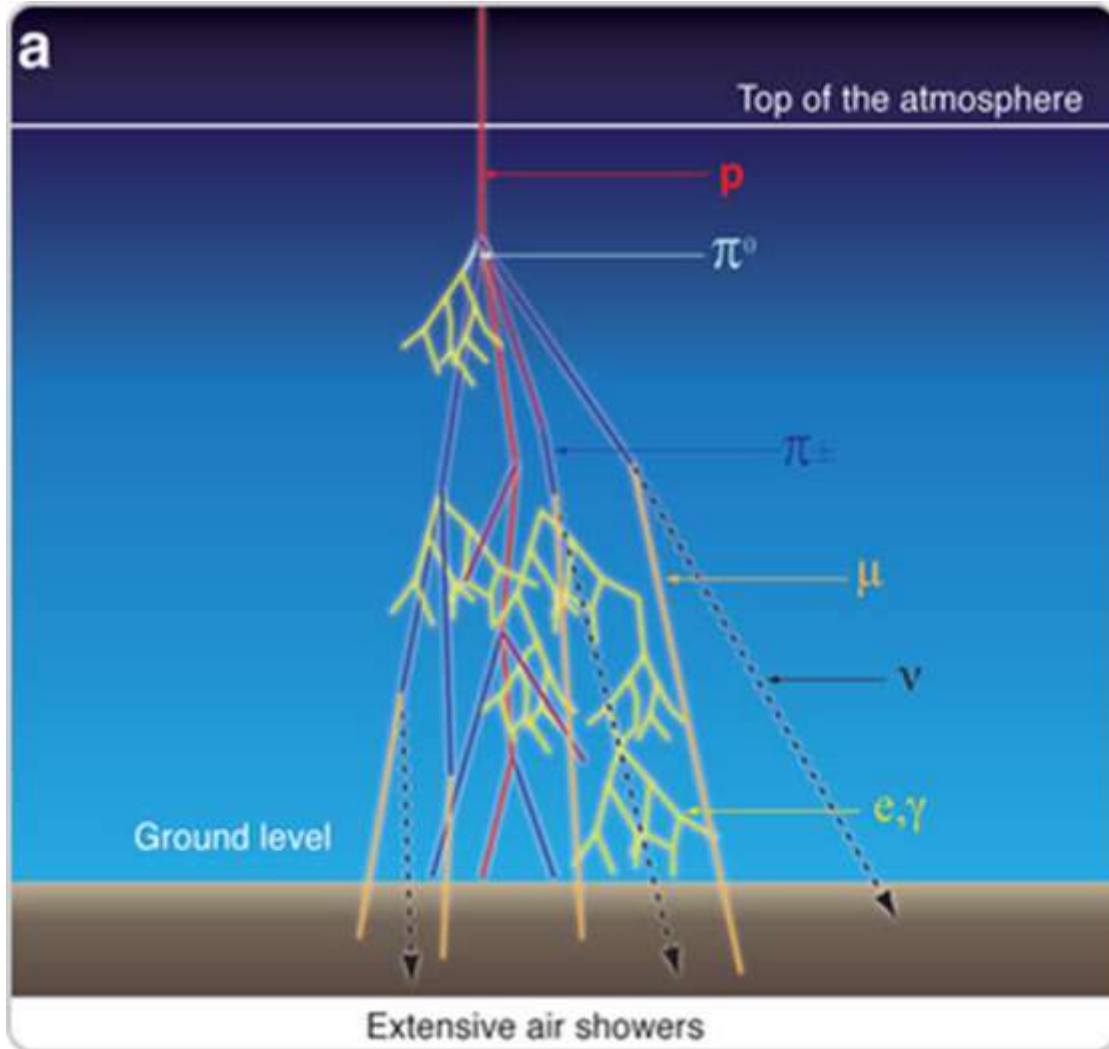
Estimation of the composition of the primary cosmic ray particles by measurements of the cosmic ray muon component

VERONICAH N.KIHAGI

Prof. Nadir O. Hashim, Dr. Naftali Kimani

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workshop

Introduction



- Interaction of cosmic rays in the atmosphere to produce secondary particles.

- $p + nucleus \rightarrow \pi^\pm + \pi^0 + x$ (1)

- $\pi^0 \rightarrow \gamma + \gamma$ (2)

- $\pi^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)$ (3)

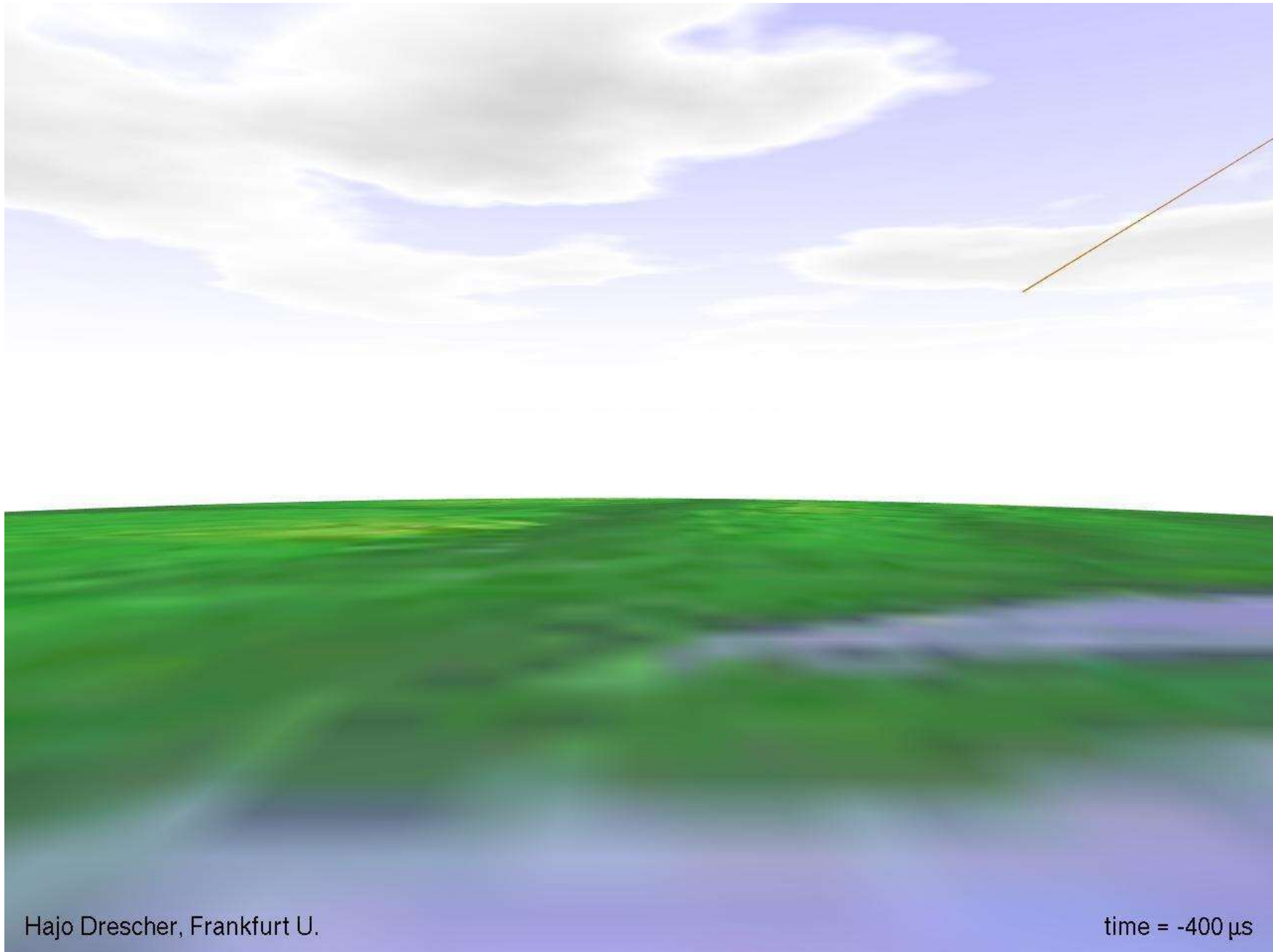
- $K^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)$ (4)

- $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$ (5)

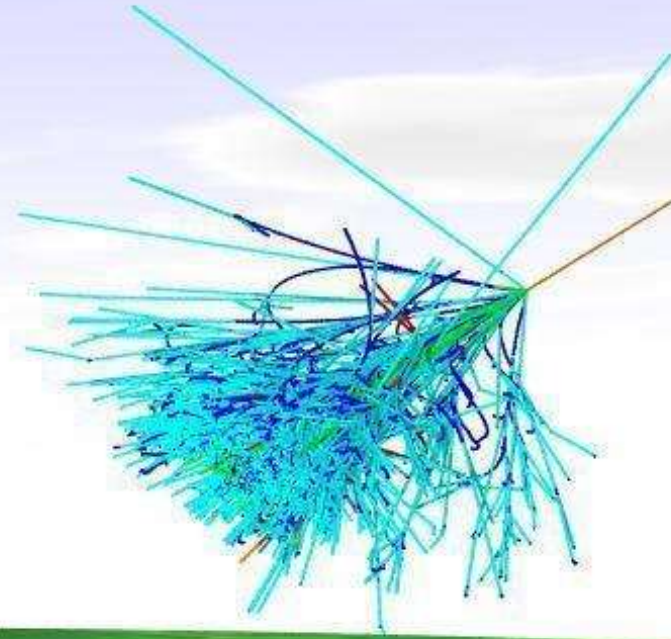
- $\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$ (6)

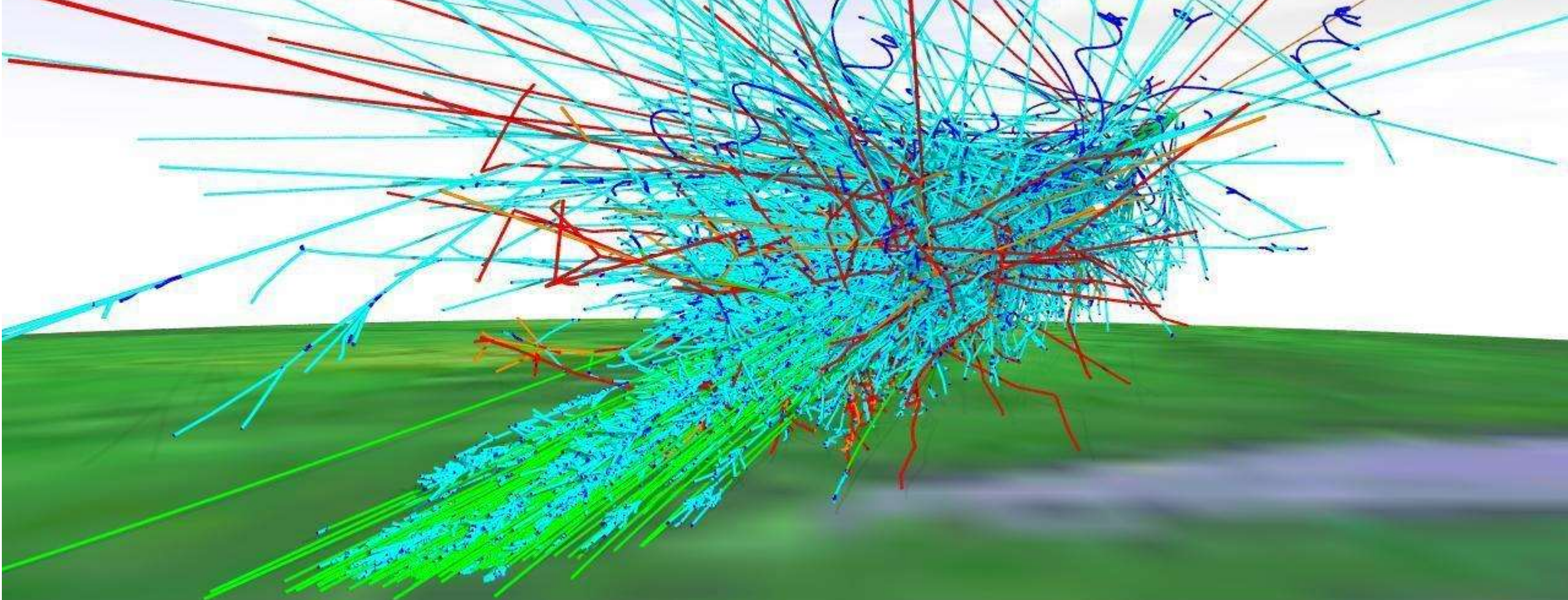
π^0, π = pions ν = neutrinos N = Neutron μ = Muons e^+ = Positron P = Proton γ = Gamma ray e^- = electron

primary
particle interacts
with the
atmosphere



Proton
pion
muons
electrons
neutrons





Proton
pion
muons
electrons
neutrons

Statement of problem

In the past two detectors of stacked adjacent paddles gave a muons flux relatively close to the expected muon flux.

There is no significant data for muon hourly variation found yet along the equator.

The research increased the number of detectors to four to enhance quality data collection for cosmic ray muons.

Using the two-fold coincidence technique reduces faults that may arise from the ground.

Determination of hourly variation for cosmic ray muon flux enhanced and improved its data.

The comparison between different models and experimental data highlights the significance of refining our understanding of cosmic ray composition.

Significance of study

- Better knowledge of the composition of primary cosmic rays and their energy spectrum by investigating the lateral distribution of muons.
- This technique filters out background noise and random events, resulting in a clearer and more precise signal specific to cosmic ray muons. Which is critical for precise analysis and improved interpretations.
- . We can learn about the complex interaction between cosmic rays, atmospheric elements, and external factors by investigating these variations.

Materials and Methodology

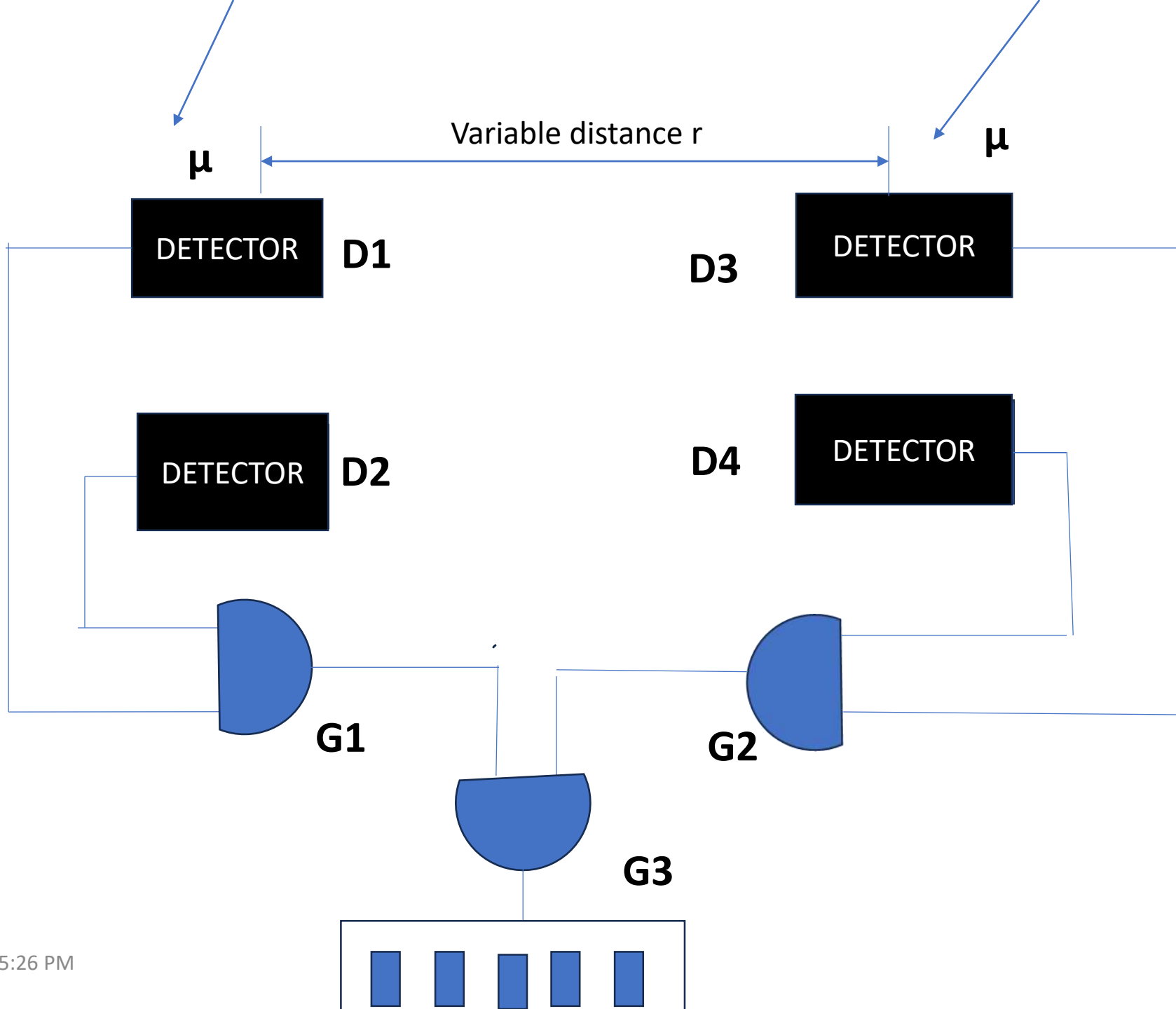


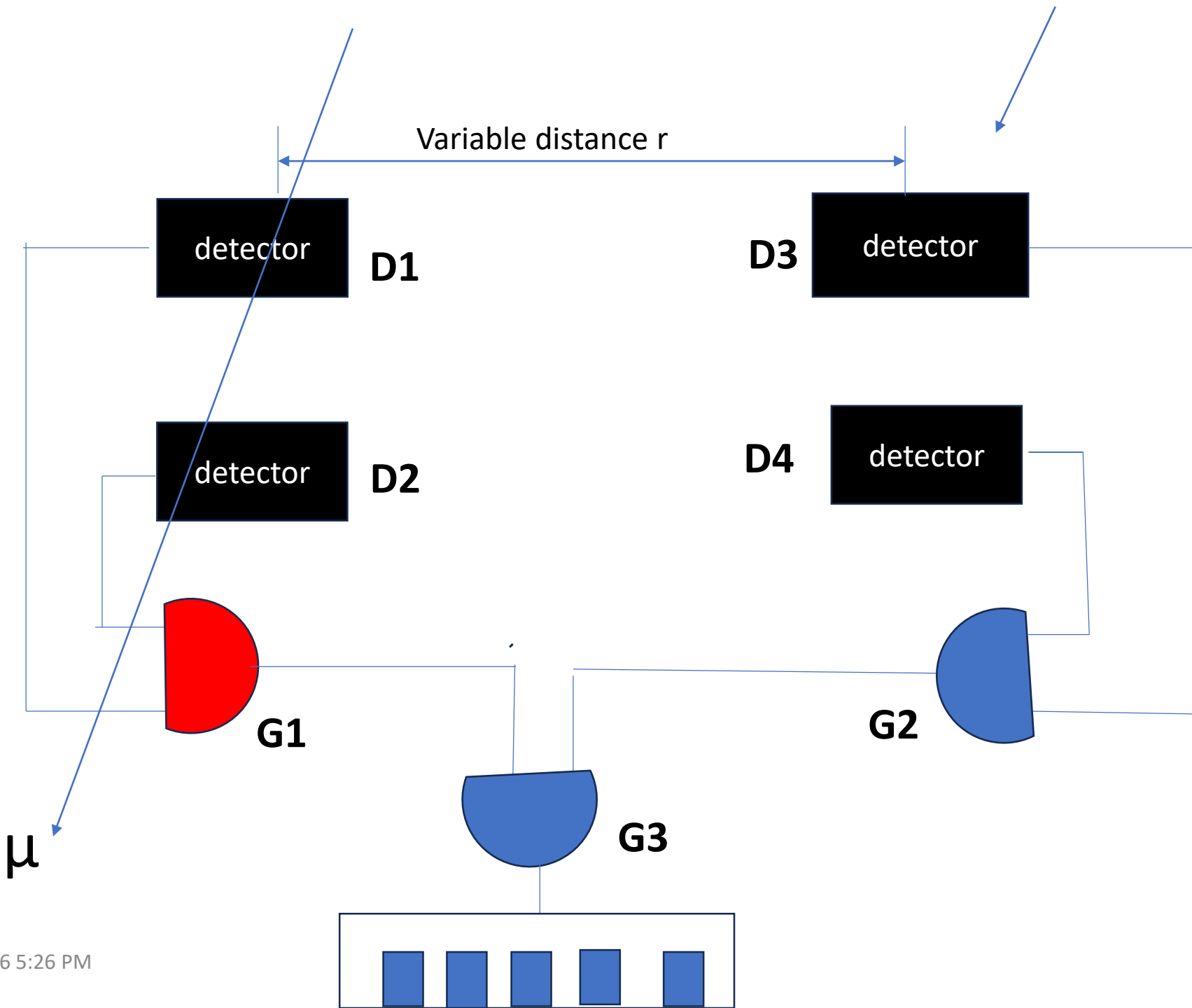
- The following equipment was used:
 - High voltage power supply
 - Four NaI(Tl) detectors
 - Power and signal cables
 - UPS
 - Nuclear Instrument Module(NIM) with the following:
 1. LeCroy model 612 AM (Amplifier)
 2. LeCroy model 622 (Quad Coincidence)
 3. Model 620 BL 8- channel discriminator
 4. Coincidence counter (Siegen University)
 5. ORTEC 771 time counter

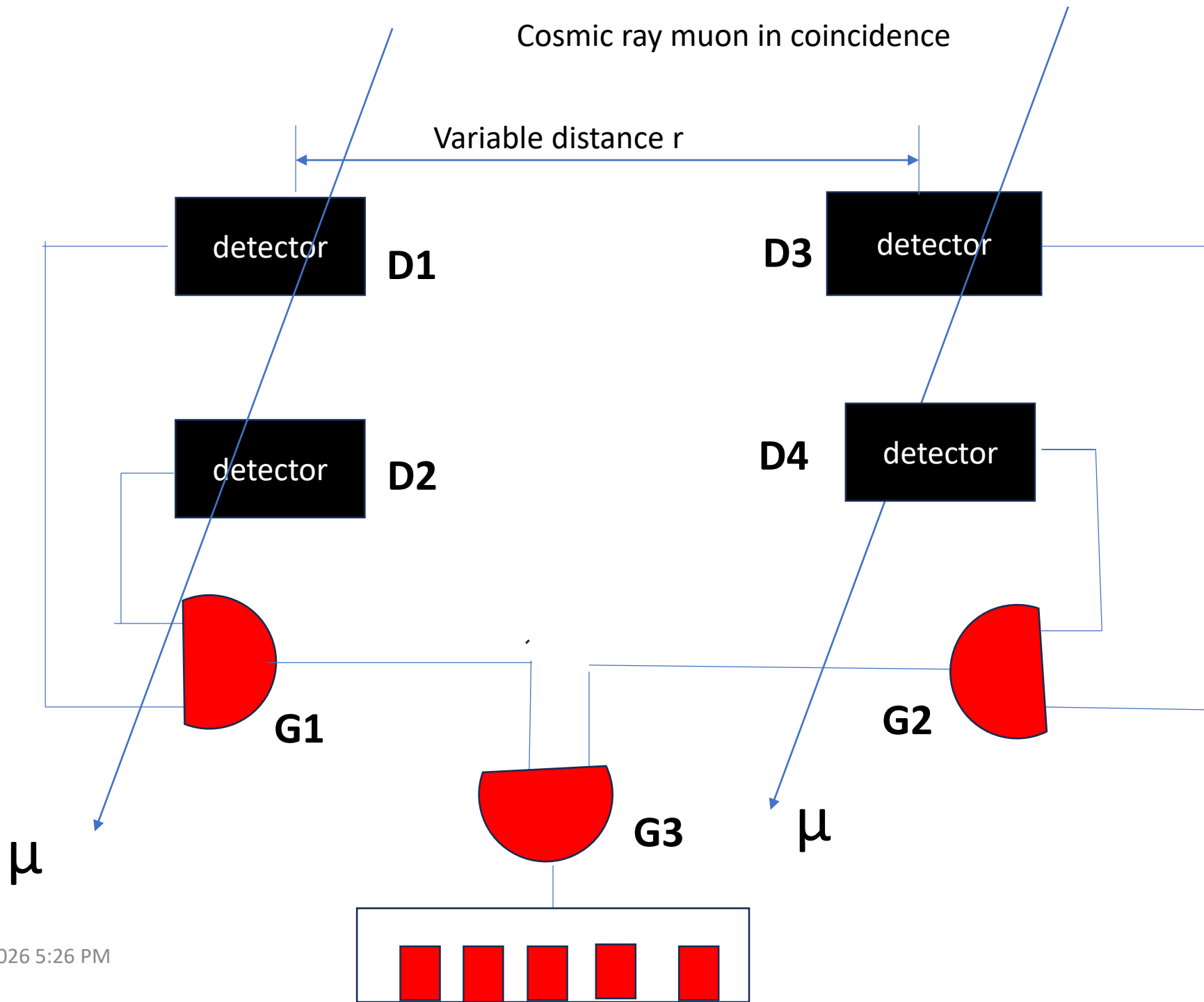
Methodology



- The distance between each set of two detectors was varied.
- The four detectors are powered to 950 V. Then each signal is connected to the amplifier.
- The amplified signal was channeled to the discriminator to remove noise. The output was fed to a quad coincidence set at the AND gate selection.
- The counter was used to measure the coincidence rate.







Methodology

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

i) Choose the high energies for hadronic interactions.

- DPMJET VENUS
- SIBYLL EPOS LHC(used in this work)
- QGSJET
- NEXUS

ii) Choose the low energies for hadronic interactions.

- FLUKA
- GHEISHA(used in this work)
- UrQMD

Methodology

iii) Choose the detector orientation

Non- flat orientation(for very large distances between detectors,>10-100km)

Horizontal flat orientation(used in this work)

Vertical orientation

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

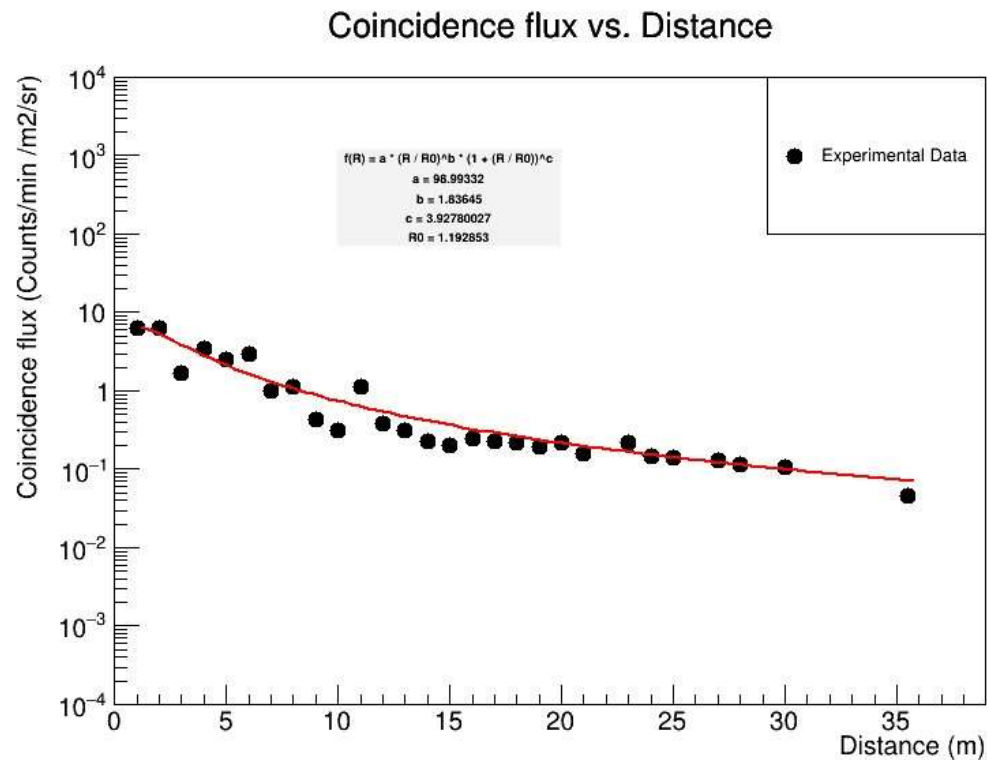
Elemental particle	ID [(Ax 100)+Z]	Percentage composition
Proton	14	85%
Helium	402	12%
Iron	5626	3%

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)	$B_x = 30.89\mu\text{T}$ and $B_z = -12.7973\mu\text{T}$
Observation level in cm	179E3

Results and Discussion

- The data collection was carried out during the day - from 0900hrs to 1700hrs.
- The lateral distribution of cosmic ray muons has been analyzed by a preliminary form of the NKG function.



$$F(x) = a \cdot \left(\frac{x}{R_0}\right)^b + \left(1 + \frac{x}{R_0}\right)^c \quad (7)$$

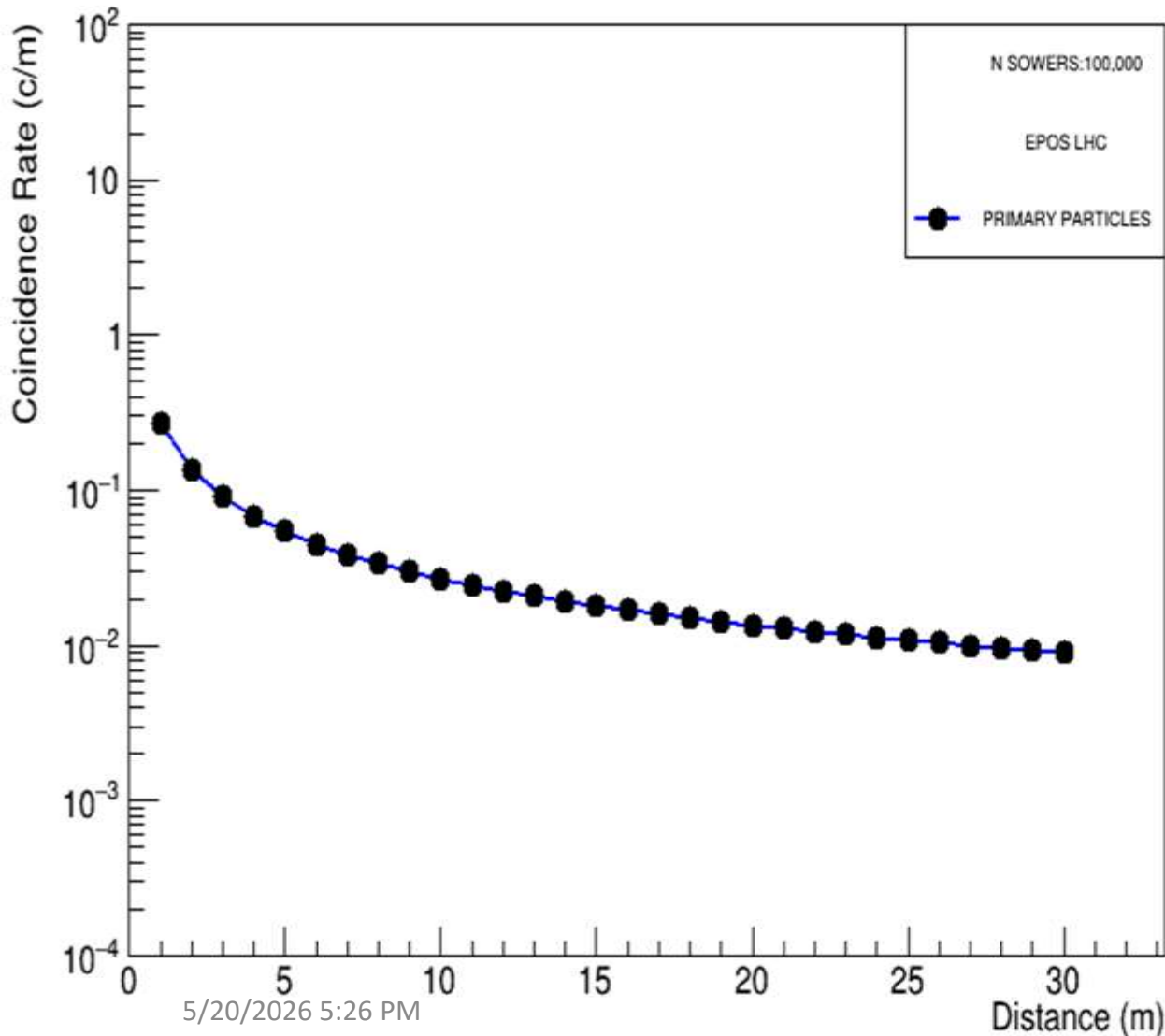
Where a is the normalization factor

R_0 is the Moliere radius

b and c is the show age

Results and Discussion

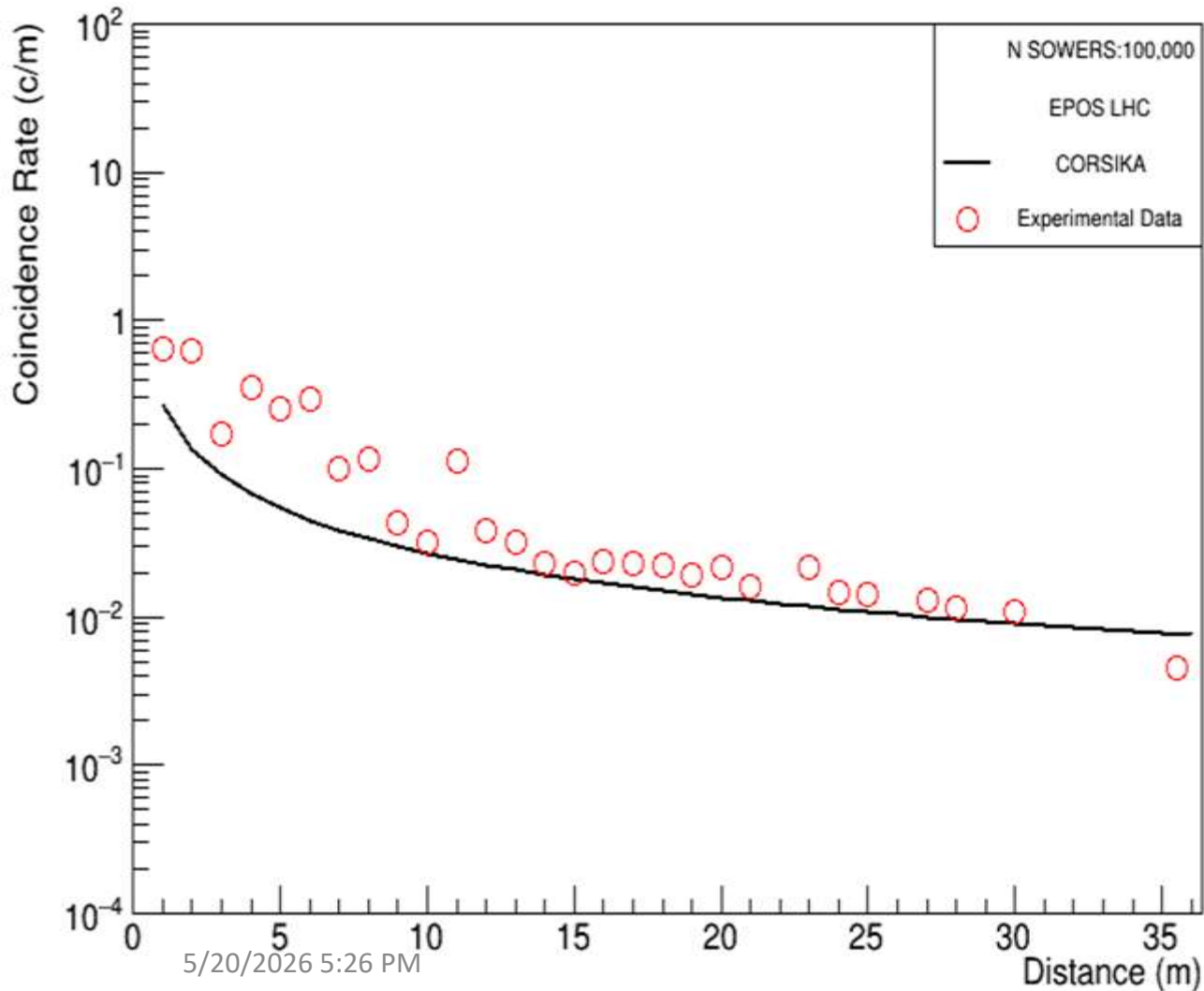
Coincidence Rate vs. Distance



- This graph shows the combined lateral distribution of CR muons for 100,000 showers using EPOS LHC.
- For protons (85000), helium (12000) and iron (3000) summing up the number of showers to 100,000.

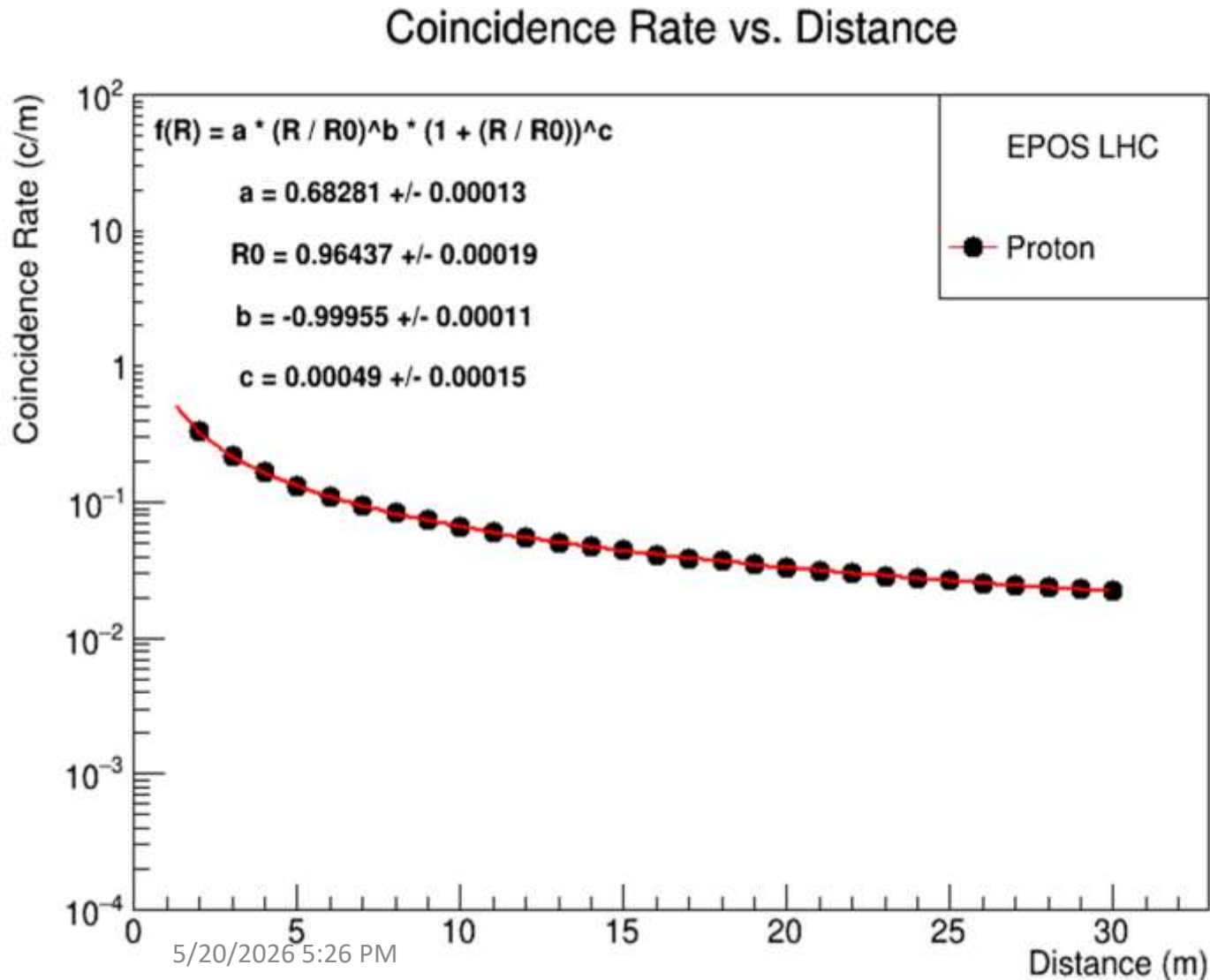
Result and Discussion

Coincidence Rate vs. Distance



- The measurements using the two-fold coincidences technique were compared to the MC simulations using EPOS LHC.
- The experimental data shows a consistent trend with the MC simulations done.
- Which means the physics implementation is correct.

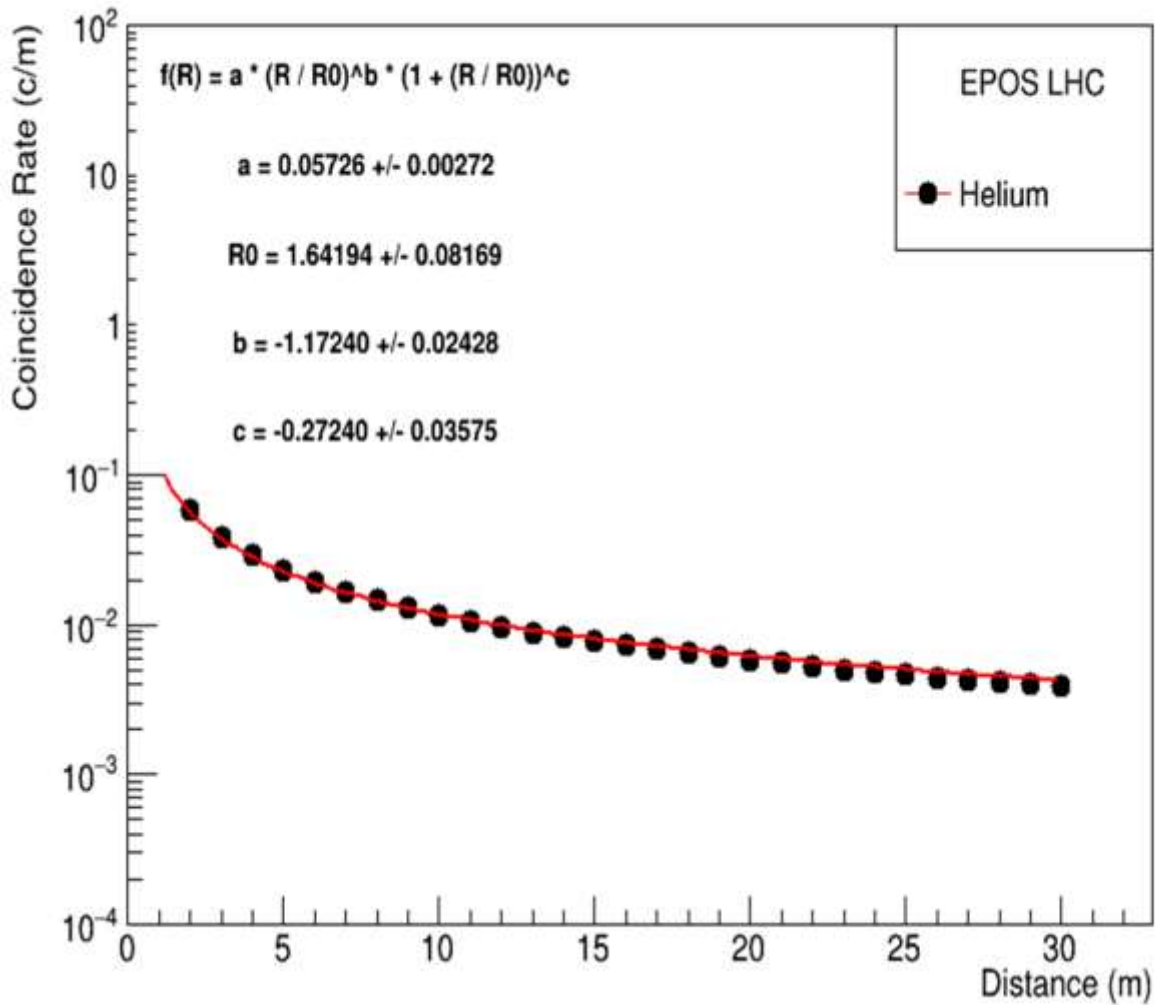
Results and discussion



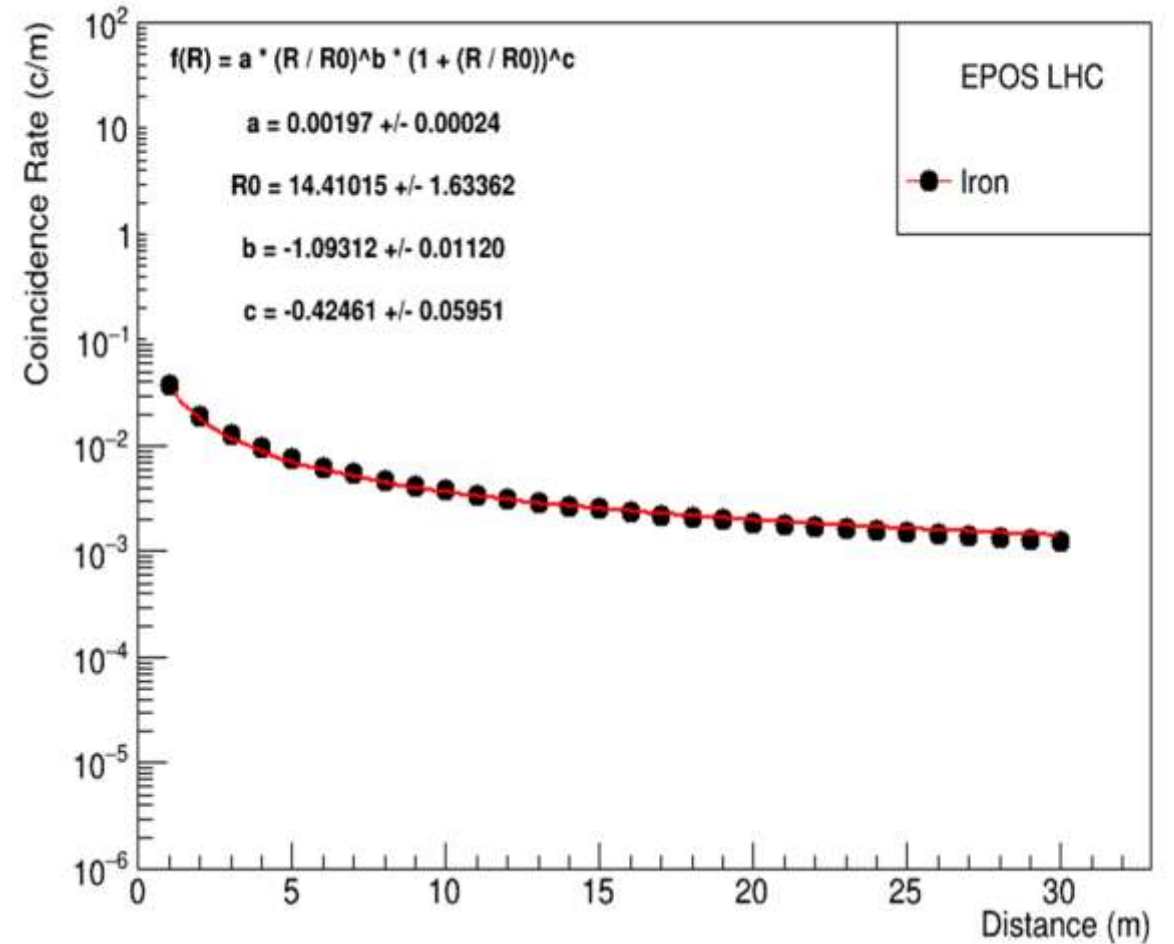
- Proton used as a primary particle in MC simulations of EAS
- Number of showers is 85000(85%)
- The NKG function fitted to the MC simulations of EAS.
- Fit results used to estimate the elemental composition of primary cosmic ray particles.

Results and discussions

Coincidence Rate vs. Distance



Coincidence Rate vs. Distance



Results and Discussion

- Below are 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

Estimation of the elemental composition of primary cosmic ray particles

$$f(x) = Par(1).fp + Par(2).fHe + Par(3).fFe \quad (8)$$

The sum of parameterization obtained for P, He, and Fe after simulating using EPOS LHC were fitted to the measured two-fold coincidences.

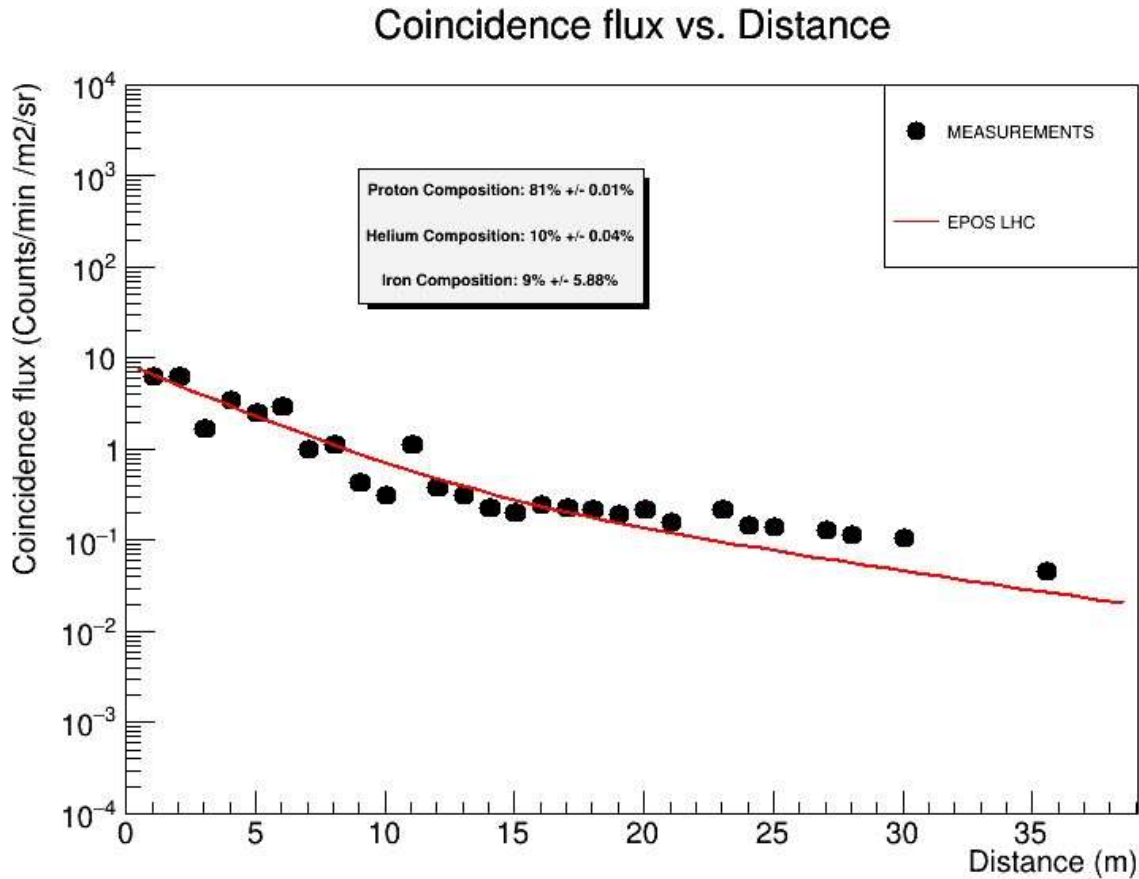
where Element(i) represents the contribution in % for proton, helium, and iron.

$$Element(i) = E(i) = \frac{Par(i)}{\sum Par(i)} \times 100\% \quad (9)$$

$$\sigma_{Ei} = \sqrt{\sum_{j=1,3} \left(\frac{\partial E_i}{\partial Par(j)} \cdot \sigma_{Par(j)} \right)^2} \quad (10)$$

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

Results and discussion



- The primary composition of the CR muons is 85% proton, 12% helium, and 3% iron and heavier metals.
- This works give and elemental composition of $(81 \pm 0.01)\%$ proton, $(10 \pm 0.04)\%$ helium and $(9 \pm 5.88)\%$ iron.

Results and Discussion

- One of the fundamental insights into cosmic ray composition comes from the DICE/CASA/MIA air shower setups. These experiments provide valuable information about the composition of cosmic rays in this energy range.
- According to (Swordy et al. 2000), cosmic rays with total energies below 10 PeV are predominantly composed of 70% protons and alpha particles.
- The comparison between different models and experimental data highlights the significance of refining our understanding of cosmic ray composition. QGSJET and SIBYLL models were compared to a simple model containing only protons and 24 iron nuclei.
- Notably, QGSJET achieved an 80% match with the data, while SIBYLL reached 60% accuracy for protons (Abbasi, 2005).

Results and discussion

- The VENUS model was utilized to analyze decoherence curves, leading to the determination of a composition of $(77 \pm 11)\%$ protons and $(23 \pm 11)\%$ 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 $(81 \pm 0.01)\%$ for protons, $(10 \pm 0.04)\%$ helium, and $(9 \pm 5.88)\%$ iron.
- Interestingly, the comparison and analysis of different models and experimental data consistently favor the light composition of primary cosmic rays.

Conclusion

- The measured count rate is observed to decrease with increasing distance between the detectors.
- The count rate is observed to be maximum at about mid-day and minimum towards sunset.
- From the results attained from simulations made using EPOS LHC :
 - i) The experimental data and the simulated data by the EPOS LHC model comparison show that the muon flux aligns with the expected data.
 - ii) From this work the primary composition of the cosmic rays is determined $(81 \pm 0.01)\%$ for protons, $(10 \pm 0.04)\%$ for helium, and $(9 \pm 5.88)\%$ iron.

Recommendation

- Use of other hadronic models like QGSJET-II-04 Monte Carlo to further enhance the knowledge on the primary cosmic ray composition.
- Future researchers can use other different techniques of operation and increase the number of detectors to attain more precise data below 8 meters and enhance knowledge on the lateral distribution of cosmic ray muons.
- In this research hourly variations have been done future analysis can be done for more hours and days to better enhance the knowledge of cosmic ray muon variation.

Acknowledgment



Thank you