PROCEEDINGS OF SCIENCE

Charge Ratio of Cosmic Muon Spectrum at Madurai, India.

J. M. John,[a,b] **Raj Shah,**[a,b] **G. Majumder**[b] **and Prajjalak Chattopadhyay**[b,*]

[a] *Homi Bhabha National Institute, Mumbai-400094, India.*

[b] *Department of High Energy Physics, Tata Institute of Fundamental Research, Mumbai-40005, India.*

E-mail: jimmjohn007@gmail.com, raj.shah@tifr.res.in, gobinda@tifr.res.in, prajjalak.chattopadhyay@tifr.res.in

The INO-ICAL collaboration has built a prototype detector called mini-ICAL at IICHEP, Madurai, India ($9°56' N, 78°00' E$). The mini-ICAL is being used to measure charge-dependent cosmic muon flux at the earth's surface. Mini-ICAL is a magnetised detector, composed of 11 layers of iron plates interspaced with resistive plate chambers to track cosmic ray muons. The iron is magnetised to a maximum field of $1.5\,T$ by applying a current of $900\,A$ through 32 copper coils. The simulation with Geant4-toolkit by including detector noise and efficiency, which eventually used in the unfolding technique to obtain muon spectrum at the earth's surface from the observed distributions. This talk presents the results of the charge ratio of μ^+ to μ^- as a function of momentum ranges from $\sim 0.8\,GeV/c$ to$3\,GeV/c$ and azimuthal angle of reconstructed muon for different zenith angle and compared with the prediction from different hadronic models in CORSIKA events generator.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

*Speaker

PoS(ICHEP2024)717

1. Introduction

The mini-ICAL, a prototype of the 50 kton Iron Calorimeter Detector (ICAL), was commissioned at the IICHEP transit campus. The detector consists of 11 layers of $4 \times 4\, m$ iron plates, each 5.6 cm thick, with resistive plate chambers ($2 \times 2\, m$) inserted between the iron layers to track cosmic muons. The magnetic field map of the iron layer, in the detector is shown in the Figure 2. In the

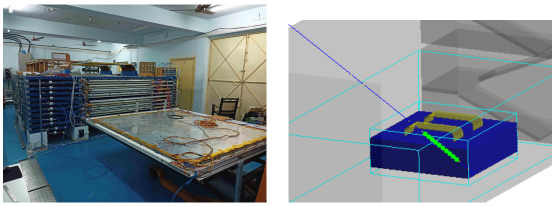

Figure 1: Detector geometry.

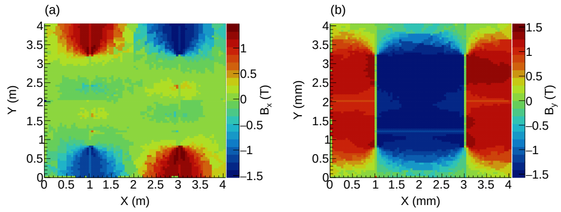

Figure 2: Magnetic field map in the detector.

energy range below 3 GeV/c, the only significant measurements of the muon charge ratio have been made by the BESS experiment [1], which focused primarily on near-vertical muons. The vertical geomagnetic rigidity cutoff at our location is significantly larger than that of similar experiments ($17\, GV$). Owing to its larger surface area, the mini-ICAL can effectively measure inclined muon tracks up to 65°. Additionally, the magnetic field enables muon charge identification within the momentum range of $0.8 - 3\, GeV/c$. However, the scope of the measurements is constrained by the limited number of layers, short lever arm, and relatively lower position resolution compared to conventional tracking detectors.

2. Monte Carlo simulation

The Monte Carlo (MC) simulation involves two main steps: (i) generating secondary particles at the observation level using CORSIKA (v7.6300) [2], and (ii) propagating particles through the detector geometry using GEANT4. For low-energy ranges, hadronic interaction models like FLUKA, GHEISHA, and UrQMD are used. At higher energies, models such as SIBYLL, Quark-Gluon String with JETs, QGSJET 01C, QGSJET II 04, and VENUS are employed. All combinations of these low and high-energy models are simulated. Finally, the secondary muons generated from these interactions are propagated through the detector geometry using GEANT4, allowing an accurate assessment of their behavior and interactions within the detector. The digitization of the simulated hits uses the parameters extracted from real detector data such as efficiency, dead strip information, multiplicity correlations, noise, etc. [3].

3. Analysis and Results

Muon tracks are reconstructed using a track-finding method and a Kalman filter-based fitting approach. To improve data reliability and reduce misidentifications, several criteria are applied: at least 8 layers must be included in the fit, ensuring a path length of at least 80 cm, and only fits with a quality probability greater than (0.015) are considered valid. Detector effects, such as limited resolution, acceptance, and uncertainties in event reconstruction, results in the migration of events

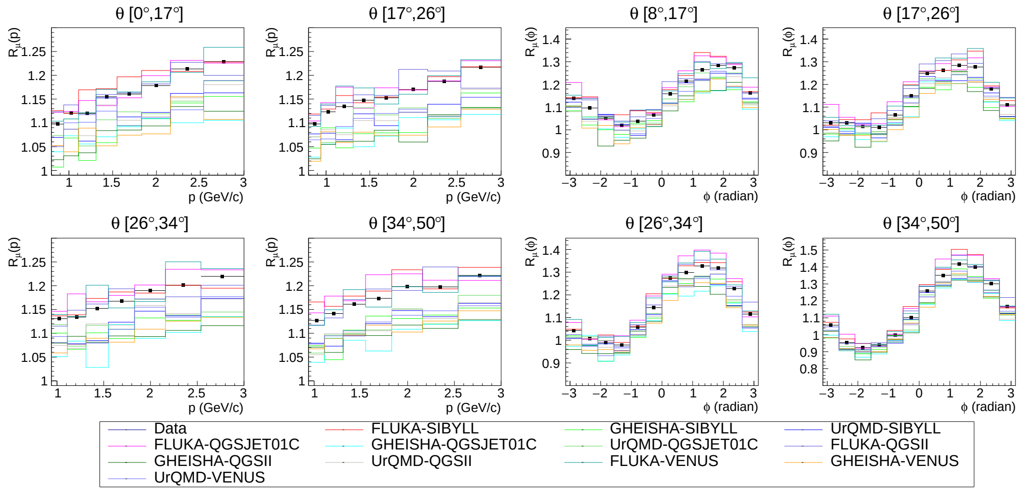

Figure 3: Muon charge ratio as a function of momentum and azimuthal angle. Data is compared with predictions from various hadronic model combinations within the CORSIKA framework.

between different momentum or azimuthal angle bins, as well as the loss of events i.e. reconstructed outside the range of 0.8 – 3.0 GeV/c. Furthermore, each bin is associated with fake events. These effects are corrected using the unfolding technique, implemented via the `TUnfold` package [4]. The reconstructed outputs from all the model combinations is used to create a response matrix to unfold each simulation output as well as actual data. The charge ratio is calculated by dividing the unfolded μ^+ and μ^- spectra. The resulting charge ratio as a function of momentum and azimuthal angle is shown in Fig. 3 alongside all MC predictions.

4. Summary

This study examines the muon charge ratio at the Earth's surface using mini-ICAL data in the momentum range of 0.8–3.0 GeV/c. The results are consistent with CORSIKA model predictions, particularly with the FLUKA model combinations, while significant deviation is observed with GHEISHA as low-energy model. Also Minimal variation is found among the different high-energy models. The charge ratio's azimuthal angle dependence is measured up to 50°, with increasing asymmetry at larger angles due to the varying magnetic rigidity cutoff of primary cosmic rays.

References

[1] Sadakazu Haino et al. Measurements of primary and atmospheric cosmic - ray spectra with the BESS-TeV spectrometer. *Phys. Lett. B*, 594:35–46, 2004.

[2] D. Heck et al. CORSIKA: A Monte Carlo code to simulate extensive air showers. 2 1998.

[3] J. M. John et al. Simulation of RPC responses in mini-Iron Calorimeter for cosmic ray muon studies. *JINST*, 18(11):P11023, 2023.

[4] Stefan Schmitt. TUnfold: an algorithm for correcting migration effects in high energy physics. *JINST*, 7:T10003, 2012.