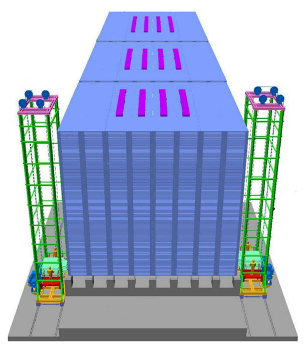
CHARGE RATIO OF COSMIC MUON SPECTRUM AT MADURAI, INDIA



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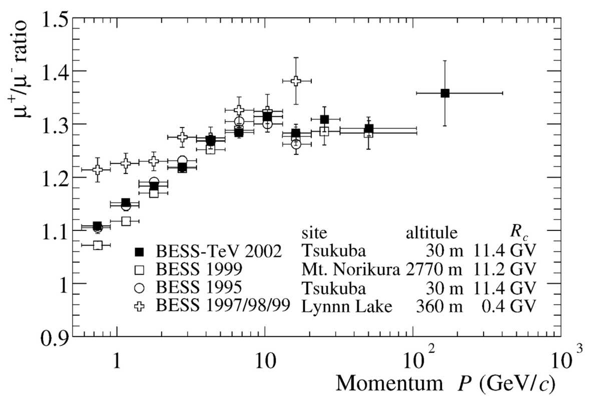
INTRODUCTION

The mini-ICAL is a small prototype of the 50 kton iron calorimeter detector (ICAL) is commissioned in IICHEP transit campus. The prototype is made of iron of size 4 m×4 m, weighing approximately 85 tons. It has been taking cosmic ray muon data since August, 2018 within the IICHEP, Madurai (9°56'N, 78°00'E) until 2023.

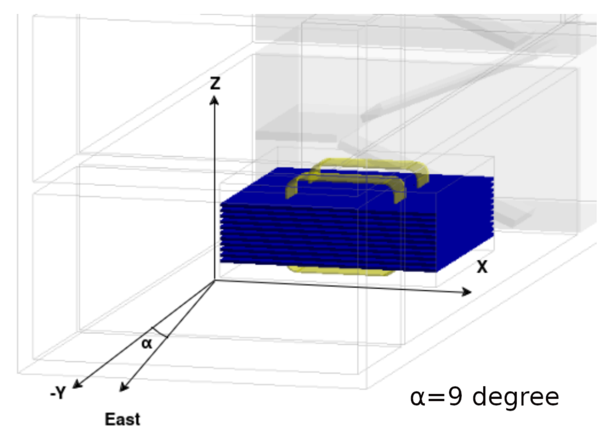
LITERATURE SURVEY

There were few measurements in cosmic rays in this energy range. One was with the Balloon-borne Experiment with a Superconducting Spectrometer (BESS) [1]. The μ^+/μ^- charge ratio can vary between 1.1 to 1.2 in this energy range for a rigidity cutoff of ∼11 GeV at Tsukuba location [2]. The vertical geomagnetic rigidity cutoff for Madurai is ∼17.4 GeV.



BESS spectrometer focuses on near vertical cosmic muons upto zenith angle ∼17°,whereas this measurement is extended upto 50°.

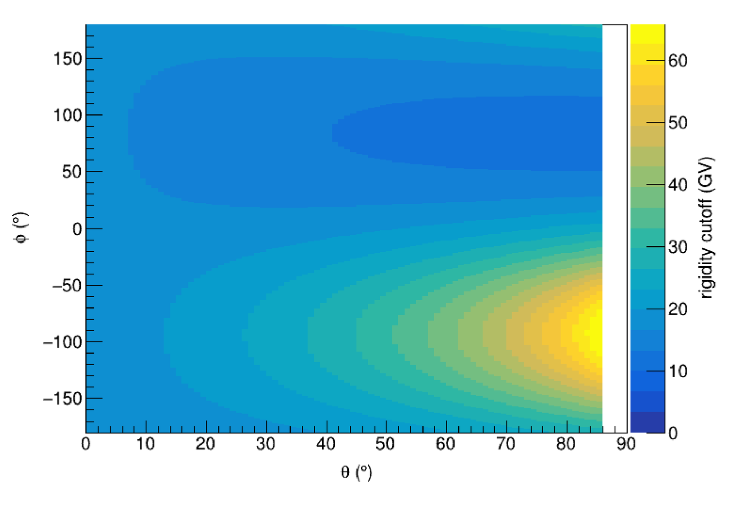
EXPERIMENTAL SETUP



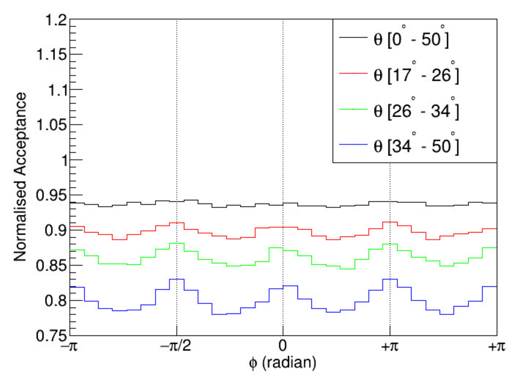
- 11 layers of iron plates with 10 RPCs interspersed between them.
- Large area RPCs (175 cm × 185 cm).
- The detector is magnetized by passing about 900 amp direct current.
- Each RPC contain two pickup panels places orthogonally on both sides of the RPC to precisely locate the traversing particle's position.

CORSIKA SIMULATION

Low energy - FLUKA & GHEISHA
High energy - SIBYLL, QGSJET 01C, QGSJETII 04, VENUS



ACCEPTANCE



The Acceptance is just the ratio of events which pass the trigger selection criteria to the total events generated in the particular bin.

DATA ANALYSIS

1. Once the trigger (hit in top four layers) is formed, the hit information is collected till ∼21 μs after the trigger time.
2. Initial offset correction for both time and position
3. Use only hits within $\Delta t \leq \pm 5$ ns of the expected hit in the top layers is used for fitting.
4. In a specific Z plane, all potential combinations of X and Y strips within a ±5 ns window are combined to generate 2D-hits position.
5. The event selection process employs a track finder algorithm.
6. The reconstruction of events employs a Kalman filter algorithm
7. The state vector is characterized by (x, y, dx/dz, dy/dz, q/p).
8. Measurement errors arise due to strip width, inefficiency and other factors, with the extrapolation error defined by a propagator matrix.
9. An iterative procedure of calculating the kalman gain and estimating state vector at each layer is employed.
10. Finally, the q/p value, along with azimuthal and zenith angles, is determined on the topmost layer of RPC with a measured point.
11. Quality cuts are applied with p-value and number of layer in fit.

The fractions of events retained after the application of each cuts/selection.

	Data	Simulation
Total Events	N = 70×10^6	24×10^6
criterion	Fraction Retained	
No criteria	1.0	1.0
trigg events	1.0	0.78
reco/trigg	0.86	0.88
sel/trigg	0.76	0.78

UNFOLDING

- The impacts of detector effects and statistical fluctuations can result in events being reconstructed in incorrect momentum/ϕ bins or potentially lost.
- Both the bin migration and the inefficiency can be mathematically expressed in the following way.

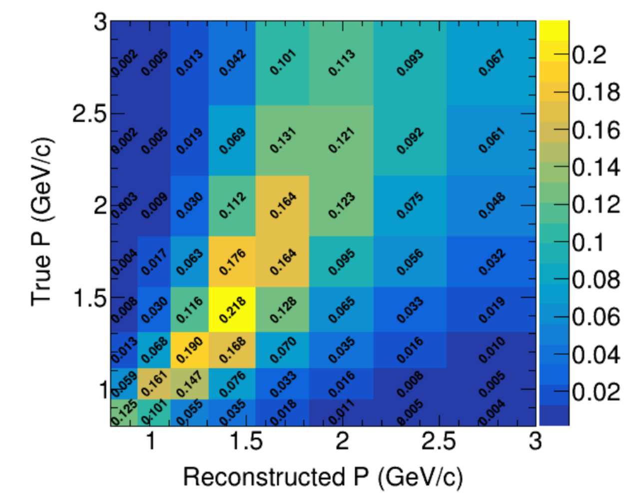
$$\sum_{j=1}^{m} \mathbf{A_{ij}x_j} + \mathbf{b_i} = \mathbf{y_i} \qquad (1)$$

where **x** is the generator level vector of dimension **m, y** is the detector level vector of dimension **n**, and **A** is the response matrix with elements $\mathbf{A}_{ij}$ specify the probability to find an event generated in bin **j** to be measured in bin **i**.

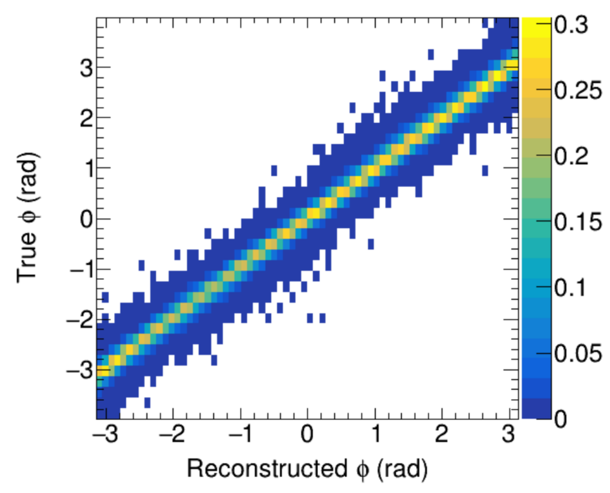
THE RESPONSE MATRIX

The response matrix and the background (**b**) is estimated using the monte carlo simulation.

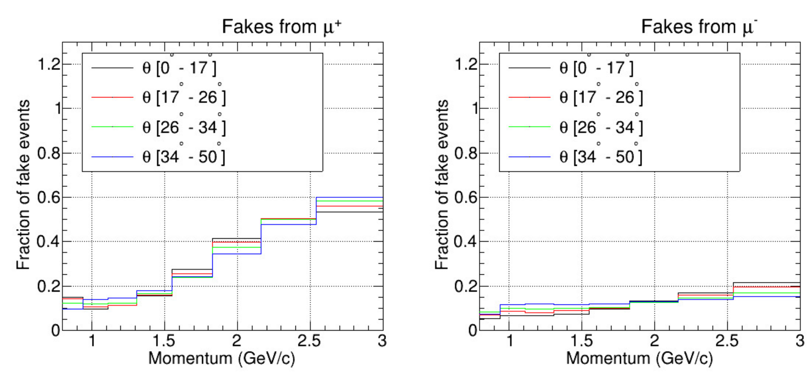
Momentum Response Matrix



Azimuth Response Matrix

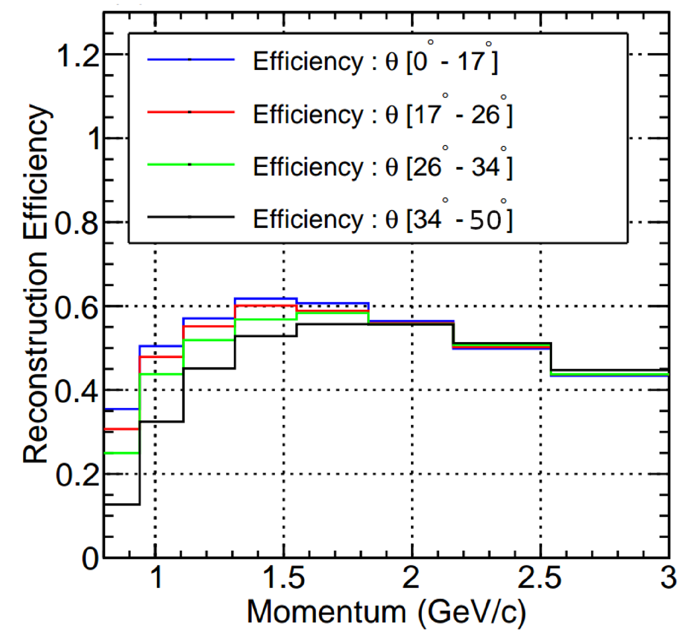


THE FAKE RATE FOR μ^+



MINI-ICAL STACK

RECO EFFICIENCY



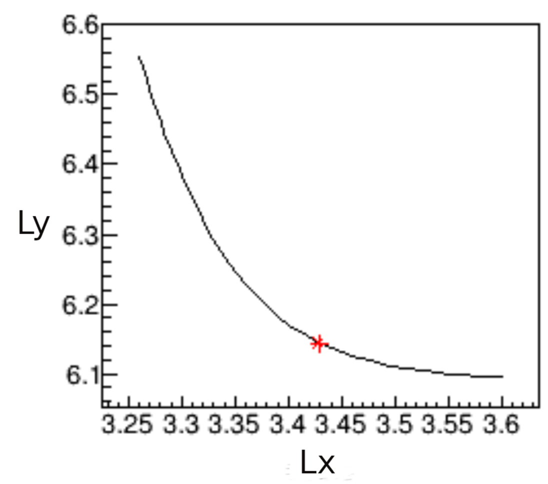
Both the unfolded spectra are corrected for both efficiency and the fake rates.

REGULARIZATION

To avoid fluctuations on linear inversion of the response matrix [3].

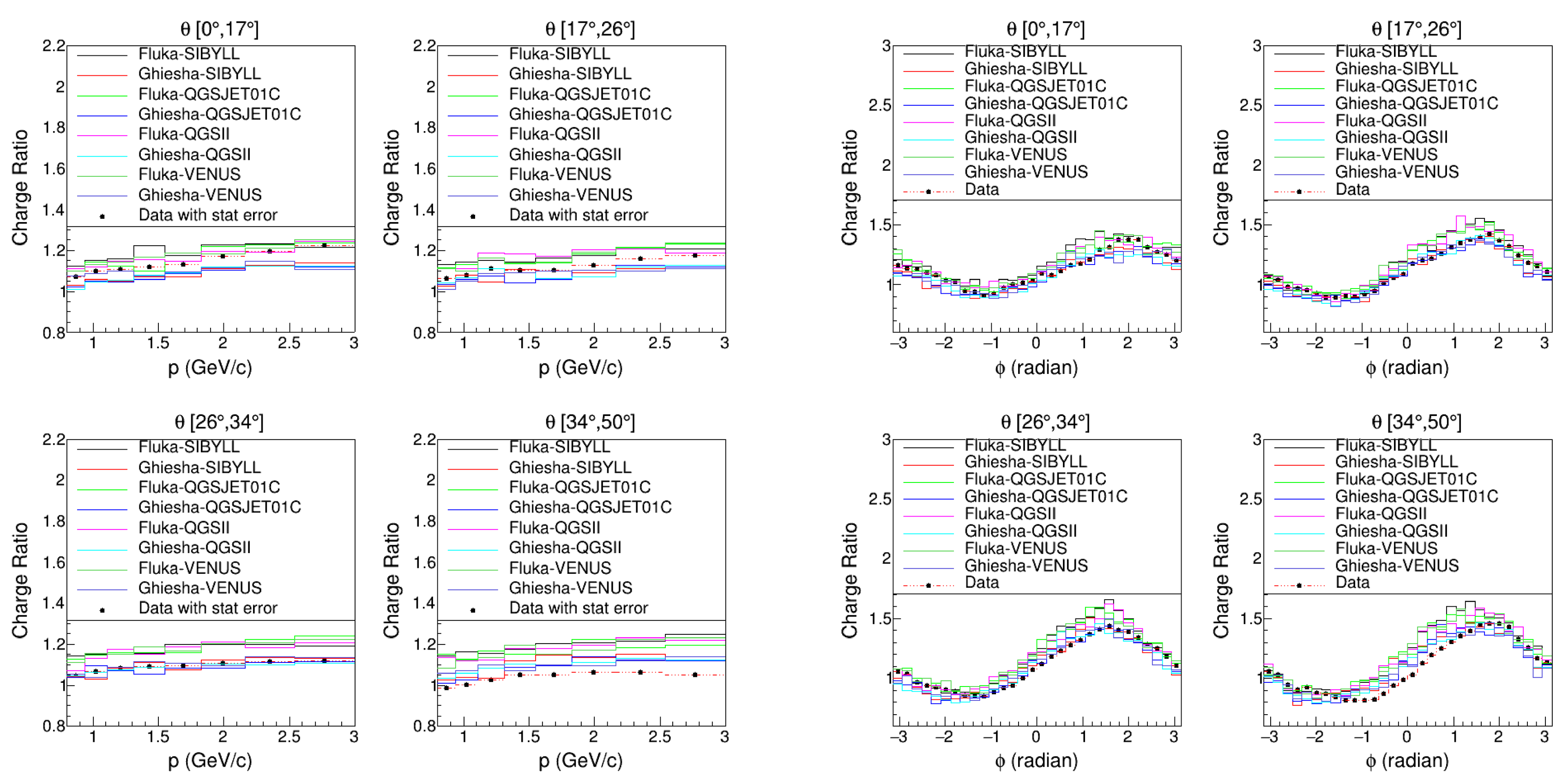
$$\begin{aligned} L(x,\lambda) &= L_1 + L_2 \\ L_1 &= (y - Ax)^T V_{yy}^{-1} (y - Ax) \\ L_2 &= \tau^2 (x - f_b x_0)^T (L^T L)(x - f_b x_0) \end{aligned} \qquad (2)$$

L_1 is from a least square minimization and L_2 describes the regularisation



- The read marker denotes the point for the optimum regularization strength (τ).

CHARGE RATIO



- At lower zenith angle (0° to 17°), the data exhibits a closer alignment with FLUKA-simulated models.
- At moderate zenith angle, Ghiesha shows better comparison.
- For large zenith angle data shows much lower ratio than all predictions.

SUMMARY

The charge ratio is defined by $R_\mu = \frac{N_{\mu+}}{N_{\mu-}}$. The charge ratio with respect to momentum shows a systematic reduction with larger zenith angles. The study by [2] indicates that with a higher rigidity cutoff, the momentum charge ratio decreases. At an 11 GV rigidity cutoff, within the same momentum range, the ratio falls between 1.1 and 1.2 in their study. However, [2] primarily observed smaller zenith angles, aligning with our findings in the range of 0° to 17°. Yet, at larger zenith angles, the ratio appears to decrease, an observation not reported in the literature for this energy range and zenith angle.

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