Comparison of muon flux at Madurai obtained with different phenomenological models

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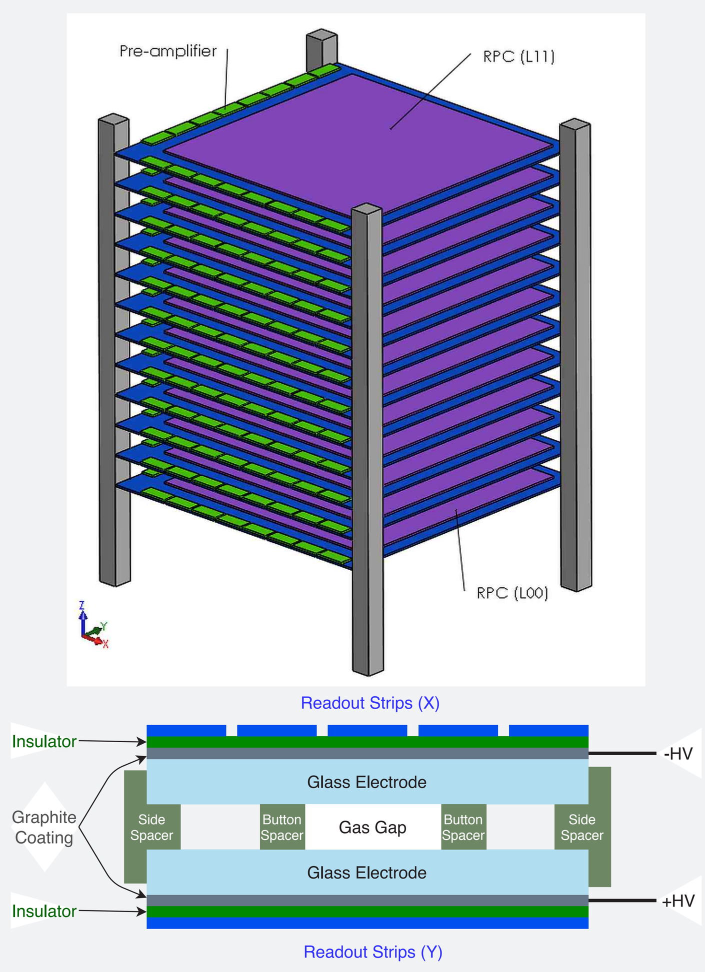
Objectives

1. Measurement of integral intensity of vertical muons and zenith angle spectrum of cosmic muons at sea level.
2. Estimation of muon flux at different (θ, ϕ) bins and comparison with different phenomenological models.

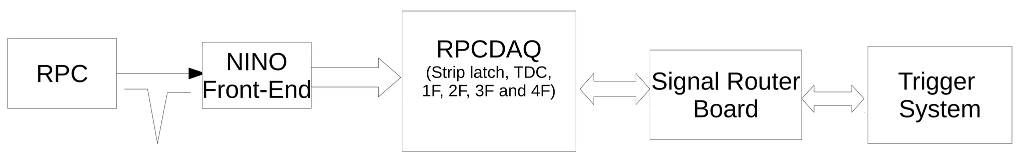
Introduction

1. The 50 kton INO-ICAL is proposed neutrino physics experiment, in which RPCs will be used as an active detectors. The prototype stack of 12 RPC of size $2\,\mathrm{m}\times 2\,\mathrm{m}$ is built to study the stability and performance of large scale RPC and electronics produced in Indian industry.
2. In order to study neutrino oscillation parameters using atmospheric neutrinos, it is vital to understand details about the atmospheric neutrino fluxes such as the flux ratio $(\nu_\mu + \overline{\nu}_\mu)/(\nu_e + \overline{\nu}_e)$ and the angular dependence of the neutrino flux at the experimental site.
3. The various sources, starting from the primary composition, spectral index and hadronic interaction of the primaries in the atmosphere are the main contributors to the uncertainty in the neutrino flux calculation.
4. The experimentally recorded muon flux at various locations on the earth have been used to tune the hadronic interaction models to reduce the uncertainty in the production of pions in the primary interaction.
5. The calibration procedure for the interaction models and the detailed calculation of the neutrino flux has been done by Honda et al. [1] based on the known cosmic muon fluxes at different locations, extrapolated to the present location and may thus include large theoretical uncertainties.
6. This is the motivation for measuring the muon flux at the experimental site.

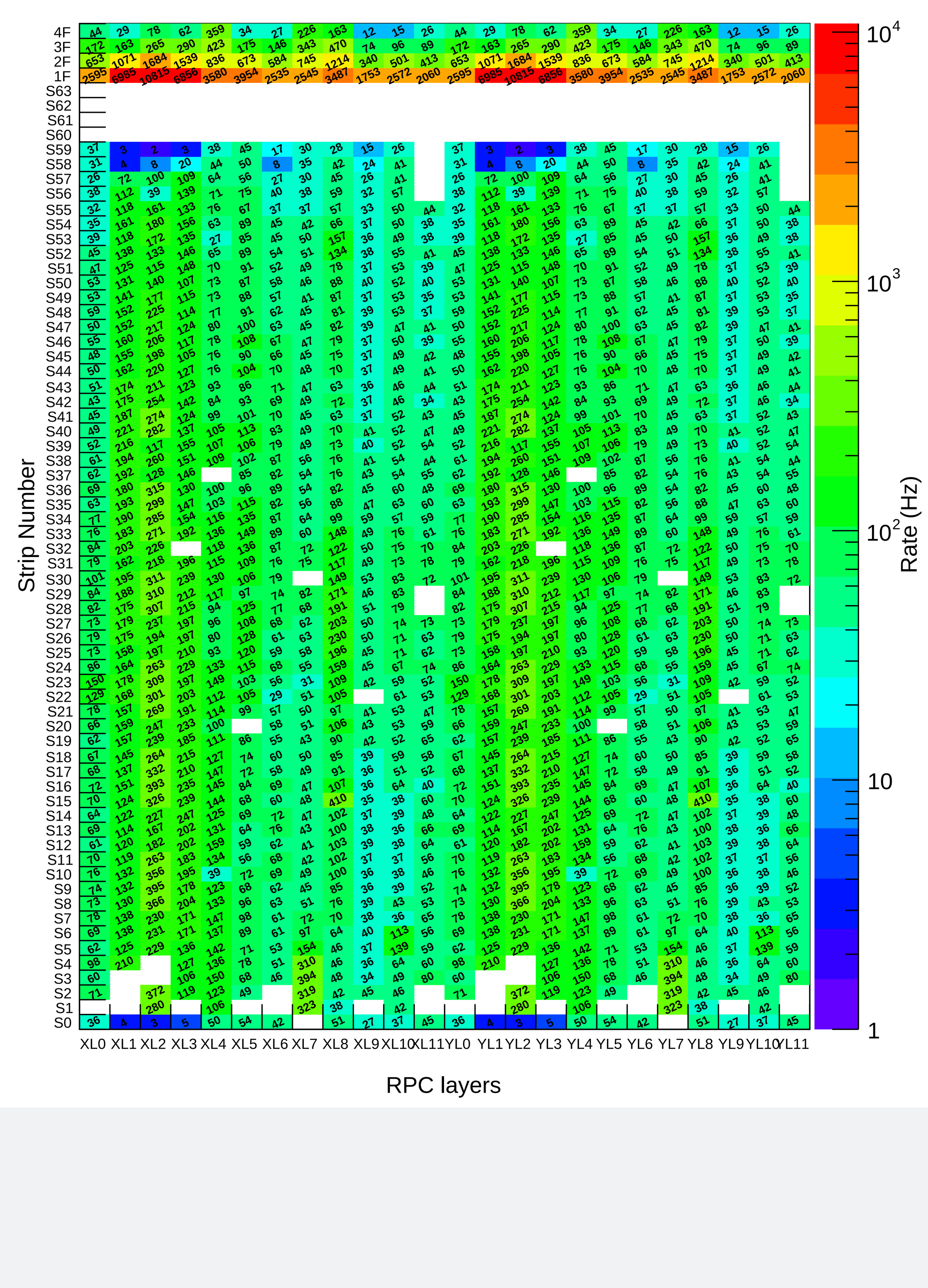
2m x 2m RPC stack



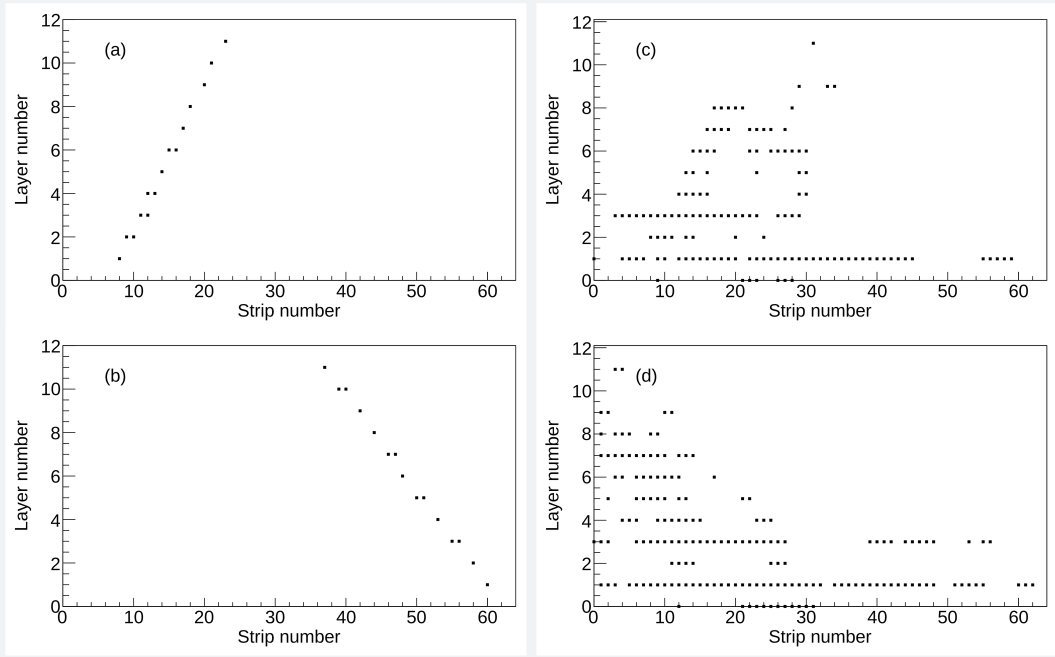
Signal flow



Noise Rate



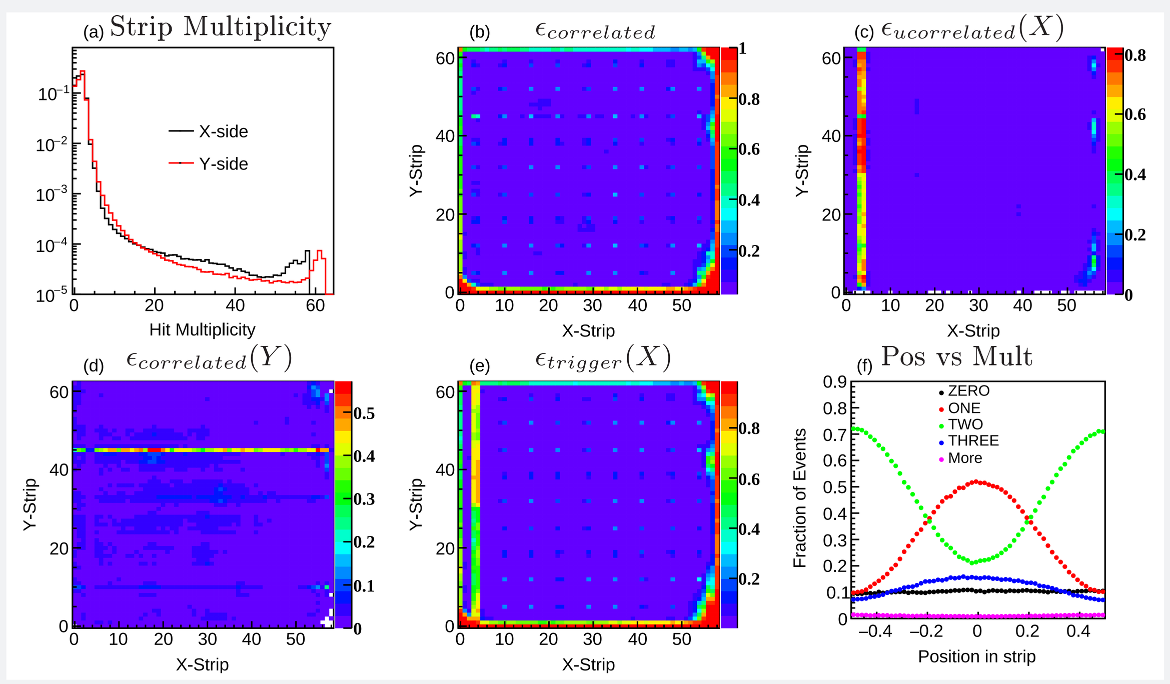
Muon Track and Hadronic shower



Event Selection

1. The algorithm is designed to isolate only muon tracks from the triggered events.
2. As expected the muon event gives more clear track than shower events.
3. The layer has upto three consecutive strips are considered for track fitting. This criteria helps in exclude the shower events and noise arised from electronics and detector.
4. The selected hit positions in different layers are fitted using straight line in both XZ- and YZ-plane.

Performance of RPC detector

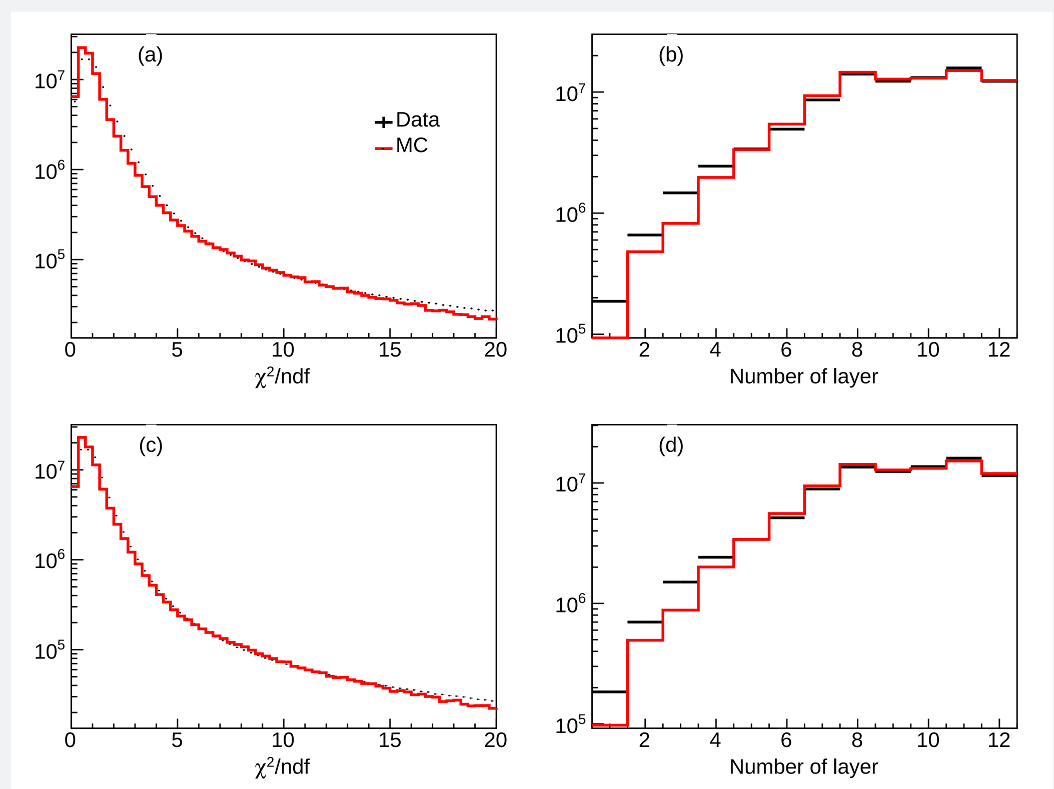


Monte-Carlo Generation

The MC simulation consists of two steps, those are (i) simulation of extensive air-shower using CORSIKA and (ii) GEANT4 framework.

1. The primary proton (90 %) and Helium (10 %) are generated within the energy range of 10 to 10^6 GeV. The zenith and azimuth angle of primaries are 0 to 85° and 0 to 360° respectively.
2. The secondaries produced (E_{min} for muons and hadrons is 100 MeV) in the CORSIKA simulation at observation levels are stored in roottuple. The position information of secondaries are digitised in the area of $2\,\mathrm{m}\times 2\,\mathrm{m}$.
3. The secondary particle information from CORSIKA is given as the input to GEANT4 simulation.
4. For this purpose, the detector geometry along with an experimental hall is developed in GEANT4.
5. Correlated inefficiency, uncorrelated inefficiency, trigger inefficiency, position dependent multiplicity and random noise hits observed from data are incorporated during the digitisation of simulated event.

Comparison of Data and MC



Exponent (n)

The angular distribution of muons at different zenith angles has the following behaviour:

$$I(\theta) = I_0 \cos^n(\theta)\ , \tag{1}$$

where n is an exponent which is a function of momentum, and I_0 is the vertical integral flux of muons. The best fit value for the exponent (n) can be estimated using the experimentally observed θ distribution $(N_{Obs}^{\theta_i})$ and the acceptance of muons in the θ_i bins. The chi-square is defined as,

$$\chi^2 = \Sigma_{\theta_i} \frac{(N_{Obs}^{\theta_i} - P_0 \sin\theta_i \cos^n\theta_i\ w(\theta_i))^2}{N_{Obs}^{\theta_i} + (P_0 \sin\theta_i \cos^2\theta_i \sigma_w)^2}\ , \tag{2}$$

where, $w(\theta_i)$ is the reconstructed fraction, N_{Reco}/N_{Gen}, in each θ_i bin, σ_{w_i} is the error on $w(\theta_i)$, P_0 is a normalization constant, a free parameter and n is the exponent. The best fit value of exponent is found to be, n = $\mathbf{2.00 \pm 0.04(stat) \pm 0.16(syst)}$.

Vertical flux (I_0)

The integral intensity of the vertical muons (I_0) can be estimated from the observed θ distribution which is given as,

$$I_0 = \frac{I_{data}}{\epsilon_{trig} \times \epsilon_{selec} \times \epsilon_{daq} \times T_{tot} \times \omega}\ , \tag{3}$$

where, I_{data} is the integral of the observed θ distribution, ϵ_{trig} is the trigger efficiency, ϵ_{selec} is the event selection efficiency in data, ϵ_{daq} is the efficiency due to dead time in the data acquisition system, T_{tot} is the total time taken to record the data(in seconds) including DAQ's dead time and ω is the accepted solid angle times the surface area, which is further defined as,

$$\omega(\theta) = \frac{AN}{N'} 2\pi \cos^2\theta \sin\theta\, \mathrm{d}\theta\ , \tag{4}$$

where, A is the surface area of the RPC on the top triggered layer, N is the number of events accepted when the generated position on the top and bottom trigger layers are inside the detector, and N' is the number of events generated on top trigger layer. The integral intensity of the vertical muons (I_0) with the same selection criteria is found to be, $I_0 = \mathbf{(7.007 \pm 0.002(stat) \pm 0.526(syst))} \times \mathbf{10^{-3}\ cm^{-2}\ s^{-1}\ sr^{-1}}$.

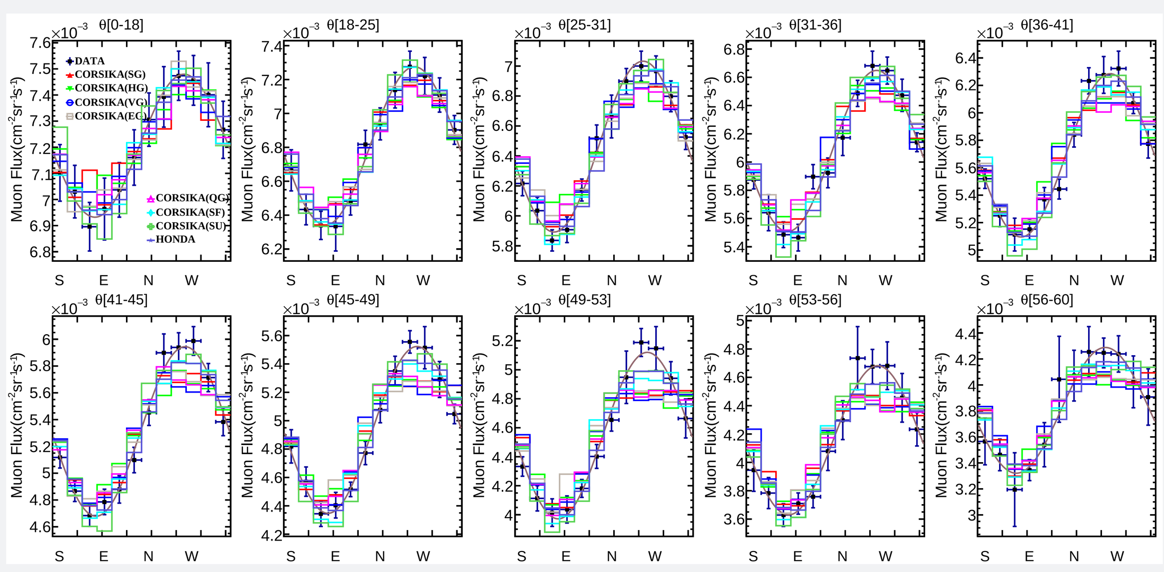
Comparison of I_0 and (n)

Authors	Geomag. Lat. (°N)	Geomag. P$_c$(GV)	Altitude (m)	Muon. Mom (GeV/c)	Integral flux ($\times 10^{-3}$ cm^{-2} s^{-1} sr^{-1})
Crookes & Rastin	53	2.2	40	$\geq$0.35	9.13 $\pm$ 0.12
Greisen	54	1.5	259	$\geq$ 0.33	8.2 $\pm$ 0.1
Fukui et al.	24	12.6	S.L	$\geq$ 0.34	7.35 $\pm$ 0.2
Sinha and Basu	12	16.5	30	$\geq$ 0.27	7.3 $\pm$ 0.2
S.Pal	10.61	16	S.L	$\geq$ 0.280	6.217 $\pm$ 0.005
Allkofer et al.	9	14.1	S.L	$\geq$ 0.32	7.25 $\pm$ 0.1
Present data	1.44	17.6	160	$\geq$ 0.11	7.007 $\pm$ 0.002(stat) $\pm$ 0.526(syst)

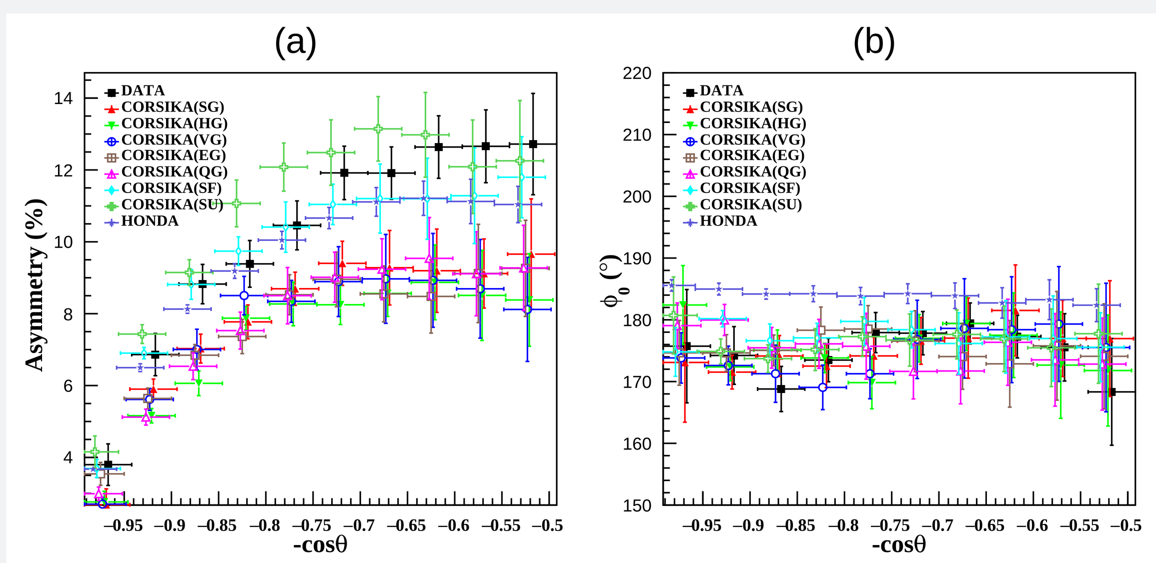
Authors	Geomag. Lat. (°N)	Geomag. P$_c$(GV)	Altitude (m)	Muon. Mom (GeV/c)	n value
Crookes & Rastin	53	2.2	40	$\geq$0.35	2.16 $\pm$ 0.01
Greisen	54	1.5	259	$\geq$ 0.33	2.1
Judge and Nash	53	–	S.L	$\geq$ 0.7	1.96 $\pm$ 0.22
Karmakar et al	16	15.0	122	$\geq$0.353	2.2
S.Pal	10.61	16	S.L	$\geq$ 0.280	2.15 $\pm$ 0.01
Present data	1.44	17.6	160	$\geq$ 0.11	2.00 $\pm$ 0.04(stat) $\pm$ 0.16(syst)

Observed Azimuthal spectrum and Predictions

In addition to vertical flux and the exponent, the azimuthal spectrum at different zenith angle is estimated and compared with CORSIKA and HONDA predictions.



Results and Discussions



1. From the predictions, it is observed that the east-west asymmetry of the secondary cosmic rays is not affected by changing the high energy interaction models.
2. But the low energy interaction models predominantly affect the east-west asymmetry. The measured east-west asymmetry at different zenith angle is having a better match with CORSIKA using FLUKA and urQMD as a low energy physics models.
3. GHEISHA is showing a larger deviation from the observed east-west asymmetry. In the case of HONDA, the east-west asymmetry is comparable with data in the higher cosθ bins.
4. The phase (ϕ_0) of the distribution from CORSIKA with all models are comparable with data.

Conclusions

1. The observed exponent (n) and the vertical flux (I_0) from the present locations is compared with results from other places on the earth.
2. The observed azimuthal spectrum will be used to reduce the uncertainties related to the hadronic interaction models and also better estimation of the neutrino flux at INO-site.

References

References

[1] M. Honda et al. *Calculation of atmospheric neutrino flux using the interaction model calibrated with atmospheric muon data.* PHYSICAL REVIEW D **75**, 043006 (2007), DOI:10.1103/PhysRevD.75.04300.