Muon distributions at Earth: A study with CORSIKA

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Introduction

The primary cosmic ray consist of protons (90%), helium nuclei (9%) and other heavy nuclei (1%) which are accelerated to enormous energies by supernova explosion and other cosmic phenomena with energy range 1 GeV to 10^8 TeV. Upon entering the atmosphere, the primary cosmic particles interact with nuclei of the air molecules roughly at 15 km above sea level. These interactions lead to the production of shower of hadrons mainly pions and kaons with small percentage of heavier hadrons. The shower of these particles move downwards with many of them decaying to muon and muon neutrinos. In this work we obtain muon distributions at sea level using CORSIKA (COsmic Ray SImulations for KAscade) [1] and compared with experimental data.

CORSIKA Simulation

CORSIKA is a program which simulates cosmic ray interactions with atmosphere using various hadronic interaction models. The higher energy models are QJSJET (QJSJET-II) and SIBYLL and the lower energy models are GHEISHA and UrQMD used in our CORSIKA (version: 7.5600) simulation. The proton energy (10 GeV $< E <$ 1 PeV) and arrival directions ($0^o \leq \theta \leq 90^o$) are given as input to CORSIKA from distributions:

$$I(E) = AE^{-2.7} \tag{1}$$

$$I(\theta) \sim \sin\theta \cos\theta \tag{2}$$

The energy distribution of primary cosmic rays follows power law E^{-n}. The muon distribution also follow the same power law which is modified in the low energy region [2] as:

$$I(E) = I_0 N (E_0 + E)^{-n} \tag{3}$$

Here; $N = (n-1)(E_0 + E_c)^{(n-1)}$ is the normalization.

Fig. 1 shows the proton flux as function of momentum falling at the top of atmosphere measured by balloon experiment [3] along with the input proton spectrum and Eq. 3.

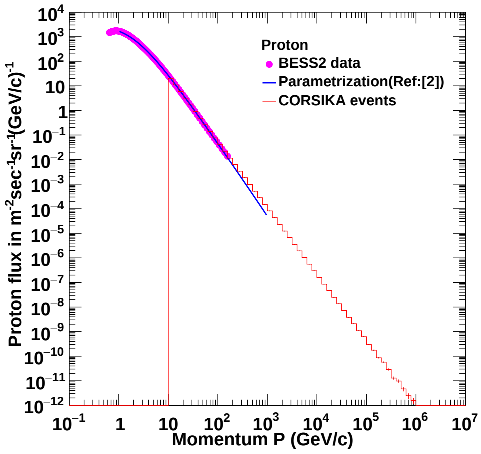

FIG. 1: Proton flux vs Momentum at the top of atmosphere(balloon experiment) [3], input proton spectrum and eq.3.

Results and discussions

Fig. 2 shows the muon flux as a function of momentum at sea level using different hadronic interaction model combinations along with the experimental data [4,5]. The parametrizations given by Eq.3 and Gaisser formula [6] are also shown. The value of χ^2 is calculated for all the models as a measure of

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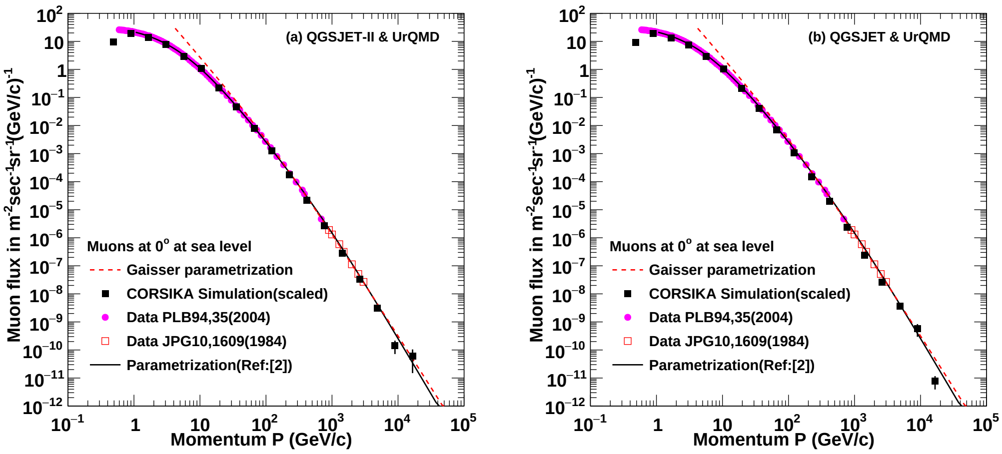

FIG. 2: The momentum distribution of atmospheric muons at 0^o zenith angle at the sea level calculated by CORSIKA models (a) QGSJET-II & UrQMD and (b) QGSJET & UrQMD.

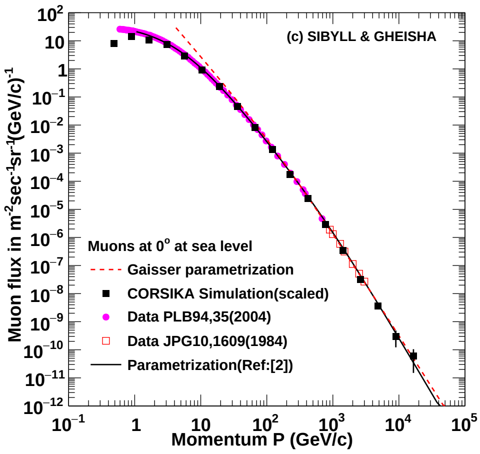

FIG. 3: Same as Fig.2 with different model (c) SIBYLL & GHEISHA.

deviation of muon flux from data as:

$$\chi^2 = \sum_{i=1}^{16} \left(\frac{\phi_i^{data} - \phi_i^{corsika}}{\phi_i^{data}} \right)^2 \quad (4)$$

For this calculation we considered momentum of muons higher than 1 (GeV/c). From the Table-I it is clear that SIBYLL & GHEISHA is the best combination of models used in CORSIKA.

Table-I χ^2-table from CORSIKA models.

	Model name	χ^2**-value**
(a)	QGSJET-II & UrQMD	1.30
(b)	QGSJET & UrQMD	1.67
(c)	SIBYLL & GHEISHA	0.92

Summary

All the CORSIKA models gives reasonably good description for muon data at sea level but there are deviations in lower energies. SIBYLL & GHEISHA looks the best models.

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