Nature of 100 TeV Hadronic Interactions in the Forward Region Seen from Muon Data of the L3+C Experiment

Qingqi Zhu[1], on behalf of L3 Collaboration
(1) Institute of High Energy Physics, Beijing, PR China

Abstract

Since the primary cosmic ray composition have been directly measured at energies up to 100 TeV, the multi-muon data of L3+C in the corresponding energy region could be used to determine the nature of the hadronic interactions in the forward region at these energies. Monte Carlo simulation of two hadronic interaction models, implemented in two separate air shower generators, are compared with the L3+C data in this paper.

1. Introduction

It is known that the major characteristics of cosmic ray cascades are mainly determined by two aspects: the high energy hadronic interactions in the forward region and the primary composition. This "two-factor-twining" problem has been an essential difficulty in super-high energy cosmic ray studies for tens of years. It should be noted that the primary cosmic ray composition, in the energy region up to 100 TeV has been directly measured [2]. Thus, in this energy region, it might be possible to study separately the phenomena of hadronic interactions in the forward region from cosmic ray fixed target experiments, and escaping from the "two-factor-twining" puzzle.

Near the energy region we are interested in, the collider experiments of interest were performed at the CERN Sp$\bar{\text{p}}$S: the UA7 measurements of the pseudo-rapidity of the inelastic interactions at $\sqrt{s} = 630$ GeV, and the P238 measurements of the pseudo-rapidity of the non-single diffraction (NSD) interactions at the same energy [3]. Discrepencies exist between them at large pseudo-rapidity.

We use the COMUGEN [6] and CORSIKA [4] codes to generate air shower events. Two interaction models are used for comparison. One is the Minijet model of COMUGEN which fits the UA7 data well. The other is the QGSJET model of CORSIKA that, according to the private communication with the CORSIKA authors, fits the data of P238 well.

The properties of the L3+C experiment [1], a shallow depth underground muon experiment using the unique features of the L3 spectrometer, allow for such a study.

pp. 1607–1610

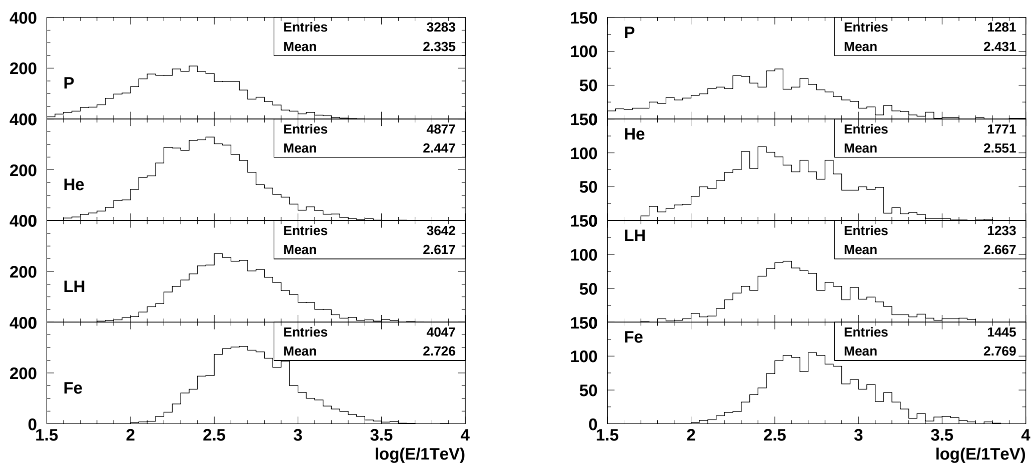
2. Monte Carlo Simulation

The interpretation of underground muon data requires a detailed simulation including a hadronic interaction model and an air shower development code, combined with a description of the detector.

In our analysis the following strategy has been adopted. Events are simulated using cosmic ray primaries in the energy region from 30 TeV to 10^4 TeV up to a zenith angle of 60°. For each event, the impact position of the shower core is randomized over an area much larger than that of the L3 muon detector. The range of primary energies and the sampling area are set wide enough to guarantee that the events out of this range fulfill the event selection criteria used in the analysis, is less than 1%.

As to the primary spectrum around 100 TeV, measurements of two major experiments, JACEE and RUNJOB, were used. Their difference is used to estimate the uncertainty of the flux at the energy region of interest and is found to be about 20%. An integrated all particle flux of 4.5×10^{-4} $m^{-2}s^{-1}sr^{-1}$ above 30 TeV is used. Four different primary compositions, p, He, LH (light heavy nuclei) and Fe are simulated with ratios of 2:2:1:1.

In total 1.06×10^7 and 5.85×10^6 events were simulated for COMUGEN and CORSIKA respectively.



(a) (b)

Fig. 1. The primary energy distribution selected for the generation of events in COMUGEN (a), and CORSIKA (b).

3. Results and discussion

Two sets of selection criteria for multi-muon events were used, defined as:

1) $N_\mu(E_\mu \geq 100 \text{ GeV}) \geq 5,\ 6 \leq N_\mu \leq 14, \text{zenith} \leq 45°$;

2) $1.6 \text{ TeV} \leq \Sigma E_\mu \leq 10 \text{ TeV},\ 7 \leq N_\mu \leq 14, \text{zenith} \leq 45°$.

The analyses on each data set gave similar results. Only results obtained from the first selection criteria will be shown below.

Figure 1 shows primary energy distributions of the selected events from the 4 simulated primary compositions. The mean energy is 300 TeV for COMUGEN and 400 TeV for CORSIKA. 1.5×10^9 muon events, corresponding to a live-time of 40.5 days, were used. In the figures below, the samples of the simulations are normalized to this live-time and to the primary flux. Event multiplicity distributions for data and Monte Carlo are given in figure 2. The absolute intensity from CORSIKA is 35% lower than that from data. Figure 3 shows the muon momentum distribution. Figures 4 and 5 show the zenith and azimuth distributions of the selected events.

Both the absolute event numbers and the shape of some distributions are model dependent. The absolute intensity of the Minijet model is favored by the data. No shape variable was found to be discriminative between the two models.

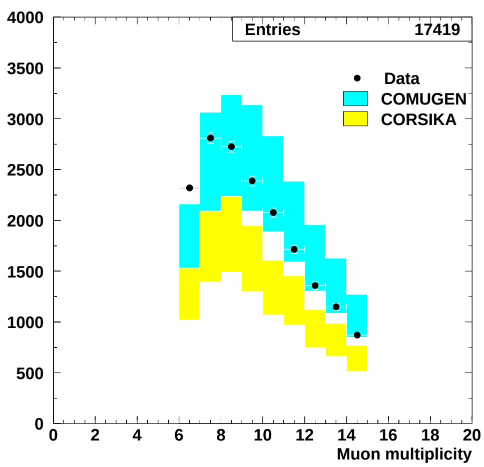


Fig. 2. Multiplicity distribution of selected events. The uncertainty bands of the Monte Carlo simulations are obtained from the 20% uncertainties in the primary flux.

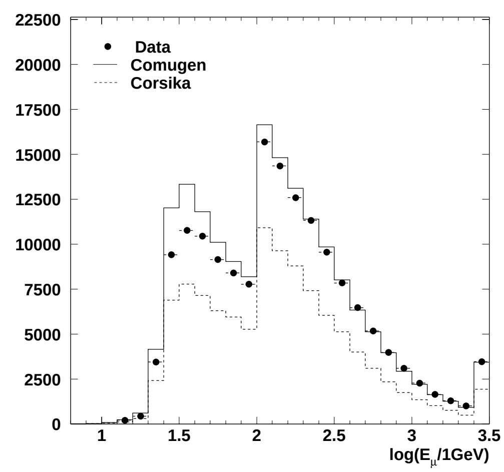


Fig. 3. Momentum spectrum of muons in selected events. Momenta above 3 TeV are accumulated in the last bin. The bump in the spectrum is due to the event selection.

The uncertainties on the results mainly arise from the primary flux and our knowledge of the detector performance with respect to multi-muon events. Other sources of uncertainties are small in comparison.

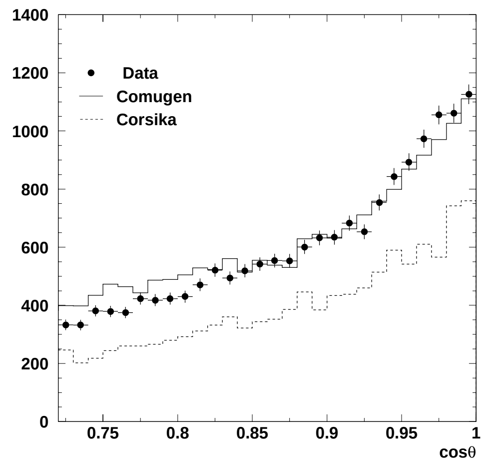


Fig. 4. Distribution in cosine of the zenith angle of selected events.

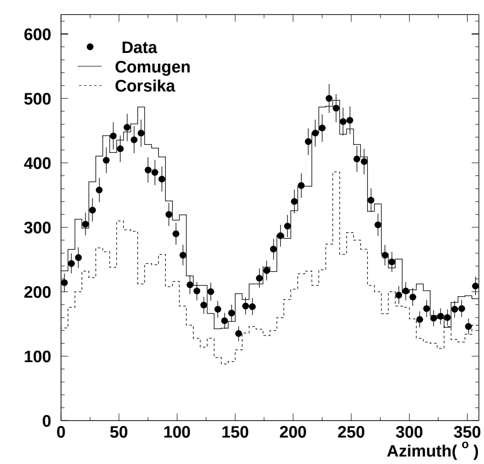


Fig. 5. Azimuth distribution of selected events.

4. Conclusions

The absolute intensity of the data agrees with Minijet within systematic and statistical uncertainties. QGSJET can not explain the abundant muon production at high muon and modest primary energies. This result agrees with the analysis of the muon spectrum and another work on high energetic muons, combining information of the muon detector with the extensive air shower array of our experiment [5].

5. References

1. Adriani, O. *et al.* (L3+C Collaboration) 2002, The L3+C detector, a unique tool-set to study cosmic rays, *Nucl. Inst. Meth.* **A488**, 209.
2. Asakimori, A. *et al.* 1998, Astrophys. J. 502, 278.
   Apanasenko A. *et al.* 2001, Proceedings of the 27th ICRC, vol. 5, p1662.
3. Harr R. *et al.* 1997, Phys. Lett. **B401**, 176.
4. Heck D. *et al.* Forschungszentum Karlsruhe, Technik and Umwelt.
5. Wilkens H., 2003, Proceedings of the 28th ICRC.
6. Zhu Q. *et al.* 1994, J. Phys. **G.20**, 1383.
   Cheng T. and Zhu Q. 1995, Proceedings of the 24th ICRC, vol. 1, 143.