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A measurement of high multiplicity muon events with the L3+C detector

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Abstract: Using L3+C experimental data, a preliminary analysis of high multiplicity muon events observed in a single drift chamber layer ($5 \times 10.6 \times 0.18$ m^3) is presented. About 49309 multiple muon events with a multiplicity between 5 to 110 have been recorded for a total live-time of 109.5 days. The obtained multiplicity distribution is compared with results from Monte Carlo simulations based on CORSIKA/QGSJET01. This particular model calculation gives about 20% less muons than observed in the data for muons originating from primaries with energies below the "knee" and for an assumed primary composition corresponding to a compilation of primary fluxes. At the energy regions of "knee" and above, the data are located in between two extreme primary compositions.

Introduction

The multiplicity distribution of underground muons induced by primary cosmic rays has been studied by many groups [1, 2, 3]. Actually the distribution is a convolution of the primary energy spectrum and mass composition with the interaction properties of cosmic rays in the atmosphere.

In the energy region before the "knee", the mass composition and the spectrum of primary cosmic rays has been directly measured by balloon and satellite experiments. But the validity of hadronic interaction models in the very forward region is not well known, since accelerator experiments cannot reach large rapidity values. Underground cosmic ray muon experiments can give important informations on this topic by comparing measured and simulated data based on one or several hadronic interaction models.

In the energy region of the "knee" and beyond the "knee", it is difficult to directly detect primary cosmic rays due to the very low flux. However, the muon multiplicity distribution of underground experiments can be used to study the primary spectrum and the mass composition once a good hadronic interaction model has been chosen.

L3+C experiment

The L3+C muon detector[4] is mounted within the L3 spectrometer, located below 30 m of molasse (68.5 m.w.e.), equivalent to a 15 GeV muon energy threshold. An air shower array is installed at the surface. The solenoid magnet of L3 has a field of 0.5 Tesla and a volume of about 1000 m^3. High precision drift chambers (P-chambers) are installed on an octagonal structure residing inside of the magnet. Each octant of the muon chambers is made out of 3 layers of chambers (called MO, MM, MI) to record the track of charged particles in the plane perpendicular to the magnetic field. Additional Z-chambers measure the track coordinates along the field. Each P-chamber is divided into many cells, each of which consists of 16 (in MO and MI), or 24 (in MM) signal wires. Figure 1 gives a detailed picture of these cells.

Each P-chamber itself is a good muon track detector: the segment of a muon track is reconstructed out of 16, respectively 24 wire signals. Multiple muon track segments produced in a high energy primary cosmic ray event, are all parallel to each other and easily reconstructed. In this preliminary analysis only the MO chamber in octant 6 is used to measure the muon multiplicity distribution.

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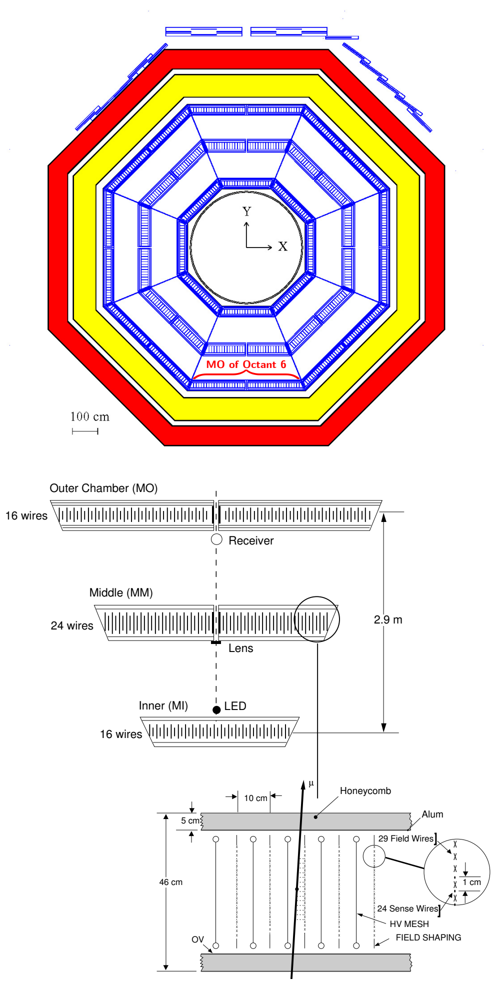

Figure 1: The octant structure of the L3 detector (top) and the detailed alignment of cells in one of the P-chambers (bottom).

Data selection and reconstruction

Using the approach of measuring the muon multiplicity with a single chamber, we analyzed a data sample corresponding to a collection live-time of 109.5 days. We identify the number of hits in a chamber as the muon multiplicity of an event. We first pre-select the data in the following manner:

- $N_{\text{PHit}} > 250$;
- $N_{\text{ZHit}} > 40$;
- $\theta < 60°$.

Where N_{PHit} and N_{ZHit} stand for the numbers of recorded hits in all P-chambers and Z-chambers of the detector respectively, and θ is the angle between the direction of the segment and the signal wire plane. After this selection, the data sample amounts to 136311 events with a muon multiplicity greater than 5.

In order to improve the signal-to-noise sensitivity, especially to eliminate the noise caused by electromagnetic cascades, the data are further selected in the following way:

- the curvature of each segment is $< 0.004\ \text{cm}^{-1}$, and
- $\alpha < 25°$,

where α is the angle between the average incident direction of each event and the signal wire plane. The restriction to segments with low curvature effectively eliminates the tracks with low momenta (mostly electron background). The restriction for the incident direction is dictated by the cell-map particularity of the drift chamber. The L3 detector, with it's octagonal structure of the muon spectrometer, was designed to detect events originating from the beam collision point. The cell-map function is therefore not valid for large track angles. The limitation of accepted angles reduces therefore the data sample to 61%. Finally, a total of 49309 events with a muon multiplicity greater than 5 remains after these selections.

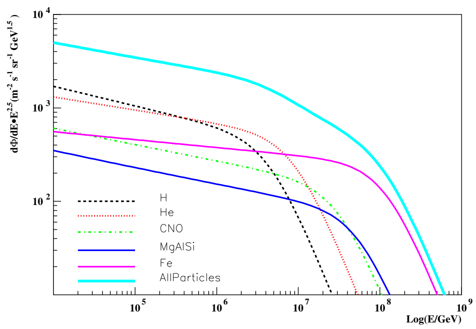

Figure 2: The fitted primary cosmic ray energy spectra according to [7].

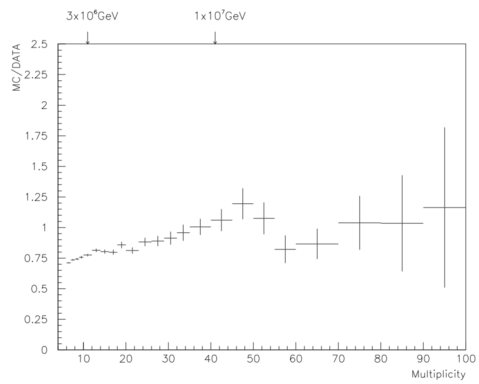

Figure 3: Muon multiplicity distribution obtained by counting the track segments in a single P-chamber. The data are compared with the ones from a CORSIKA/QGSJET01 simulation normalized to the effective live-time.

CORSIKA/QGSJET simulation

The CORSIKA simulation package [5] is used in the present analysis to describe the evolution of atmospheric showers. The QGSJET01 model [6] is included to simulate the hadronic interactions between nuclei. In reference [7] a lot of collected measurements of the cosmic ray energy spectrum are reported. The energy spectra for each mass component were fitted to the experimental data (see Figure 2). We take the fitted results from this reference as our input mass composition and energy spectrum. Air showers within an angular range of 0–70° and an energy range of 2×10^2–10^9 GeV are simulated. Each shower is scattered over a circular area with a radius of 2000 m centered at the L3 detector position.

Results and discussion

Counting muon tracks within a single P-chamber layer for each event one gets the muon multiplicity distribution observed underground (see Figure 3). No correction for some efficiency loss at large multiplicities has yet been applied. But we assumed that the efficiency loss for the data is the same as for the simulated events.

Assuming that the compilation of the primary mass composition and the spectrum of [7] corresponds exactly to the truth, the comparison between the experimental and the simulated data could be used to check the validity of the hadronic interaction model. From Figure 3 we conclude that the number of muons generated by the simulation is about 20% lower than the observed one at lower multiplicities (below 15). This agrees well with the result of another approach which uses the 3 dimensional track reconstruction method to measure the muon multiplicity (Figure 4). Both approaches indicate that in the energy region below the “knee”, the muon production rate of the CORSIKA/QGSJET01 simulation needs to be increased.

Figure 5 shows a comparison between the experimental and the simulated data for the case of a mixed composition, or a pure proton, or a pure iron primary component model respectively, where all the simulated samples are normalized to the effective live-time of the data acquisition.

The data and the simulation of the mixed composition model agree with each other for multiplicities $20 < N_\mu < 70$. The simulation shows that the mean energy corresponding to these multiplicities is between 6×10^6 GeV and 2×10^7 GeV. For the region with larger multiplicities, the simulation seems to contribute to more muons than the data. This may suggest that at energies above 2×10^7 GeV, either the primary spectrum and the

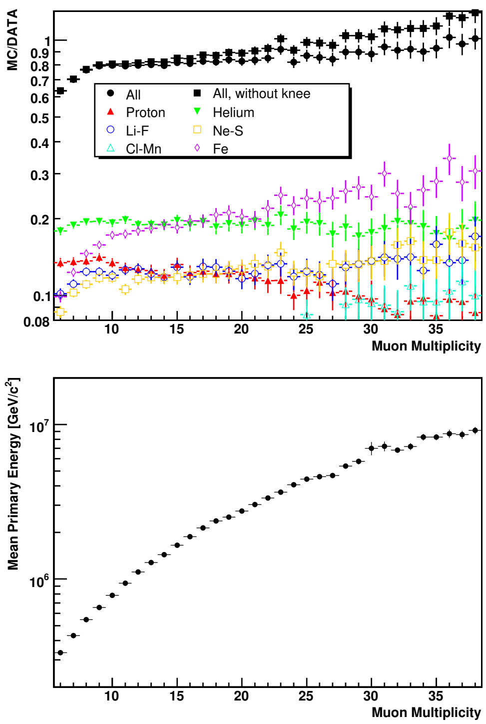

Figure 4: The muon multiplicity distribution ($N_\mu < 40$) [8] measured by the 3 dimensional reconstruction program of L3+C. The corresponding energy range is also given in the bottom figure.

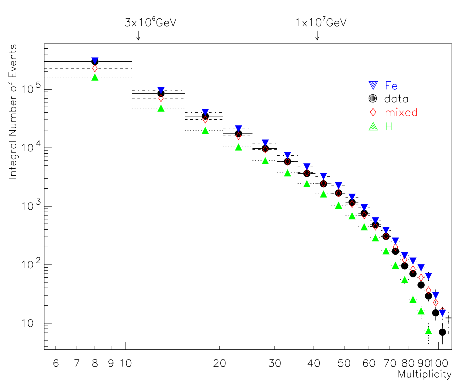

Figure 5: Integral distribution of the muon multiplicity measured in the single P-chamber. For comparison, the simulation results from both, the mixed and the single component model (i.e., pure proton and pure iron) are shown as well.

mass composition in reference [7] is not correct, or that the muon production mechanism of CORSIKA/QGSJET01 is not appropriate. However, the data points for all considered multiplicities are located in between the two extreme cases, for a pure proton and a pure iron primary composition. That means, due to the uncertainty of the primary flux and the uncertainty of the muon production rate of CORSIKA/QGSJET01 at and beyond the "knee" region, we are not able yet to tell more on this topic.

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