Electron and muon densities from cosmic ray showers in the energy range of 0.1 to 10 PeV, measured at L3+C

Henric Wilkens [1] on behalf of the L3 Collaboration
(1) Department of High Energy Physics, Nijmegen University, The Netherlands

Abstract

Using the L3+C detector at CERN, correlations between densities of energetic muons underground and EAS charged particles at the surface have been measured in the energy range of 0.1 to 10 PeV. The comparison of these two densities is known to provide relevant information to the understanding of the primary interaction. The measurements are compared with predictions from the high energy interaction models DPMJET, QGSJET, SIBYLL, and VENUS, using CORSIKA as a transport code, and proton and iron primary cosmic rays. A significant excess of the measured muon densities has been observed when compared with model predictions under the assumption of a primarily light composition in this energy region.

1. Introduction

The cosmic ray mass composition gives information about the nature of the sources of this radiation, and on the propagation of this radiation in the interstellar medium. In the energy region of the *knee* ($\approx 3\,\mathrm{PeV}$), direct measurements are not possible due to the low intensity of the cosmic ray flux. Several methods are used, among which ground based air shower arrays observe the particles appearing in cosmic ray induced air showers, telescopes observe the air Čerenkov radiation, or the fluorescence light produced by the propagation of these particles. Comparison with predictions from air shower simulations have to be used to unfold the mass composition of the primary cosmic rays. In these simulations the largest uncertainty comes from the extrapolation of QCD predictions far beyond the range where these can be tested against measurements made at the large accelerators. In this paper, we shall show that the number of muons observed in coincidence with air showers turns out to be much larger than expected from shower simulations under the assumption of a light composition below the knee.

2. The L3+C experiment

The L3+C experiment has been described in [1]. It uses a large magnetic volume (over $1000\,\mathrm{m}^3$), containing large high precision drift chambers, which are

pp. 1131–1134 ©2003 by Universal Academy Press, Inc.

also used to measure cosmic ray induced muons. In addition to the L3 hardware, 202 m^2 of scintillation detector, serving as a set of timing counters, was installed in 1999, as well as a dedicated readout system. This detector is located in a large underground cavern with an overburden of 30 m of molasse. During the spring of 2000, a small air shower array was added to the setup. On the top of the $30{\times}50\,\mathrm{m}^2$ roof of the construction hall, 47 scintillation modules of $0.5\,\mathrm{m}^2$ have been disposed in 6 rows. Events from the two detectors are combined using the exchange of trigger signals between the two DAQ systems. Also every event from each detector receives a time-stamp from a local clock. The two clocks are synchronised to the same GPS module, allowing to unambiguously match the events.

3. Shower simulations

Air showers were simulated using the CORSIKA [2] program, for both proton and iron primary particles, with the DPMJET [3], QGSJET [4], SIBYLL [5] and VENUS [6] interaction models. The detector and surroundings were simulated using a detailed GEANT [7] description. The spectral index was taken to be -2.7 and care was taken to simulate the complete relevant phase space both in energy (starting at the trigger threshold) and space. Showers are scattered on a $70{\times}70\,\mathrm{m}^2$ surface, and the surface was tiled periodically with the same pitch as the scattering surface. In each of the tiles the detector simulation is performed. This technique allows to reuse showers and simulate them at any distance from the detector, without introducing correlations. The analysis on the simulated data was performed with the same program used to analyse the real data.

4. Muon densities

From the air shower detector data, the core location, shower size, age, and direction are extracted. From the data recorded in the muon chambers, the number of muons is estimated with two different algorithms, the results of which are found to agree within expectations. Combining the air shower and muon information allows to study the muon multiplicity in different shower size ranges. In figure 1. the multiplicities are compared with the obtained predictions from proton and iron induced showers, obtained with the QGSJET model. The predictions from the other models are very similar. The data and the predictions for iron induced showers agree, whereas the predictions for proton showers fall short of describing the observations.

Making use of the shower core position, it is possible to estimate the distance of the muons to the shower core, and assuming a fixed interaction height of 17 km altitude, to assign a pseudorapidity to the observed muon bundle. The main advantage is that it allows to present the results without dependences on

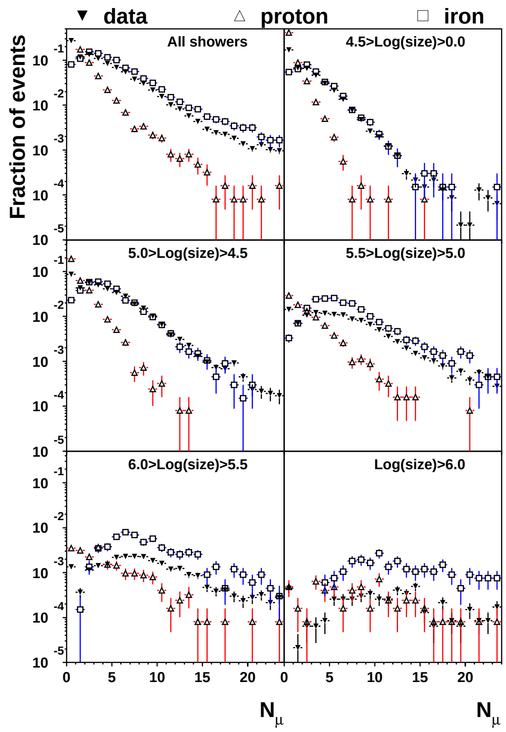

Fig. 1. Multiplicities observed in the muon detector, for all showers and for five selected shower ranges.

the specifics of the setup (unlike the raw multiplicity distributions). The results are shown in figure 2.. The grey band covers the prediction of the four tested interaction models, the leftmost four sub-figures show the comparison between proton predictions and data, for four selected shower size ranges, whereas in the rightmost four sub-figures data and iron predictions are compared. At all but the highest shower sizes, the proton predictions fall short of describing the data. A conclusion valid independent of the pseudorapidity, i.e. distance from the shower core.

5. Conclusions

Summarising the obtained results, the multiplicity and pseudorapidity distributions for muons with an energy above 15 GeV have been measured as a function of the air shower size. The results, when interpreted through current interaction models indicate a dominance of heavy ions below the knee, which is in disagreement with direct measurements by balloon and satellite experiments.

Current air shower models thus fall short of explaining the rather abundant muon production at high muon momenta and modest primary energies. Data

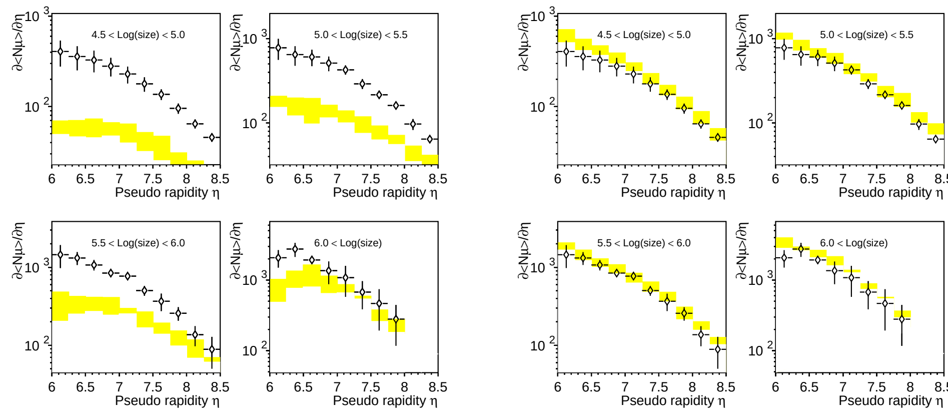

Fig. 2. Muon pseudorapidity distributions, compared with the predictions obtained from proton showers (left) and from iron showers (right) in four different shower size ranges.

are presented as a function of variables likely to be relevant when searching for improvements of current models, namely pseudorapidity and shower size.

6. References

1. Adriani O. et al, NIM **A-488**,pp 209-225, 2002
2. D. Heck, J. Knapp, J. N. Capdevielle, G. Schatz and T. Thouw, **FZKA-6019**, Forschungszentrum Karlsruhe, 1998
3. J. Ranft, Phys. Rev. **D51**, pp 64-84, 1995
4. N. N. Kalmykov, S. S. Ostapchenko, A. I. Pavlov, Nucl. Phys. **B52**, pp 17-28,1997
5. R. S. Fletcher, T. K. Gaisser, P. Lipari, T. Stanev, Phys. Rev. **D50**, pp 5710-5731, 1994
6. S. S. Ostapchenko, T. Thouw and K. Werner, Nucl. Phys. **B52**, pp 3-7, 1997
7. R. Brun et al., CERN, Geneva,