Measurements of the Lateral Distribution of the Muon Component of Extensive Air Showers Underground

V. Kotaidis[1], A. Mailov[1], C.Grupen[1], S.Luitz[2], A.-S. Müller[3], A. Putzer[5], B.Rensch[6], H.-G. Sander[7], S. Schmeling[4], M. Schmelling[8], R. Tcaciuc[1], H. Wachsmuth[4,7], Th. Ziegler[9], D. Zimmermann[1], K. Zuber[10]
(1) Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany
(2) SLAC M/S 41, 2575 Sand Hill Rd, Menlo Park, CA 94025, USA
(3) FZ Karlsruhe, Institut f. Synchrotronstrahlung, D-76021 Karlsruhe, Germany
(4) CERN, CH-1211 Geneva 23, Switzerland
(5) Institut für Hochenergiephysik, Universität Heidelberg, Germany
(6) erphi electronics GmbH, Gewerbering 15, D-83607 Holzkirchen, Germany
(7) Fachbereich Physik, Universität Mainz, D-55099 Mainz, Germany
(8) Max-Planck-Institut f. Kernphysik, D-69029 Heidelberg, Germany
(9) Department of Physics, Princeton University, Princeton NJ 08544, USA
(10) Experimentalphysik IV, Univ. Dortmund, D-44221 Dortmund, Germany

Abstract

The ALEPH detector at LEP has been supplemented with five scintillator stations to measure the muon component of cosmic ray showers underground. We report the measurements of coincidences over distances up to about 1 km which are sensitive to the forward production of hadronic interactions and the chemical composition of primary cosmic rays in the energy range around 10^{15} eV. The results are compared to the expectations obtained from Monte Carlo simulation. Our results indicate that the observed decoherence curve of muons is compatible with a light primary composition.

In addition, the arrival times of muons underground as measured with scintillator stations allow to reconstruct the muon arrival directions in 3-fold coincidence events. These results are compared to shower simulations.

1. Introduction

The origin of high-energy cosmic rays is still an unsolved problem. Various mechanisms are proposed to explain the acceleration and propagation of cosmic rays up to energies of about a few PeV [1]. Well above this energy (so called 'knee' region) the origin of primary cosmic rays is unknown. A clue on possible sources can be provided by measuring the elemental composition of primary cosmic rays. Recent measurements [2] indicate that the 'knee' is caused by a rigidity dependent cut-off of individual species of primaries.

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Measurements of the lateral distribution of the penetrating muon component of extensive air showers (EAS) underground and reconstruction of arrival directions of muons are sensitive to the chemical composition of primaries, their energy and interaction characteristics.

The aim of this analysis is to estimate quantitatively the mass composition of primary cosmic rays in the energy range around the 'knee', where the CosmoALEPH experiment has the best sensitivity.

2. Experimental Setup

The CosmoALEPH experiment located in the ALEPH pit of the e^+e^- storage ring LEP at CERN uses the ALEPH detector and five scintillator stations in the LEP tunnel to measure the muon component of extensive air showers underground at a depth of $\approx$ 320 m.w.e. The muon cut-off energy due to the molasse-rock content of overburden is about 70 GeV for vertical incidence. A complete description of the experimental setup is given elsewhere [3]. The data used in the analysis of double coincidences were taken between January and November 2000. During the data taking period $2.7 \cdot 10^8$ events were recorded with all detector stations within a time window $\pm$ 200 μsec. In addition, the data recorded in the years 1999 and 2000 are used to search for 3-fold coincidence events.

3. Results

CosmoALEPH measures coincidences of muons between scintillator stations to infer the muon lateral separation distribution. The distributions of muon arrival time differences for some pairs of stations are shown in Fig. 1 (distances between stations are given in meters). The signals of muon coincidences are clearly

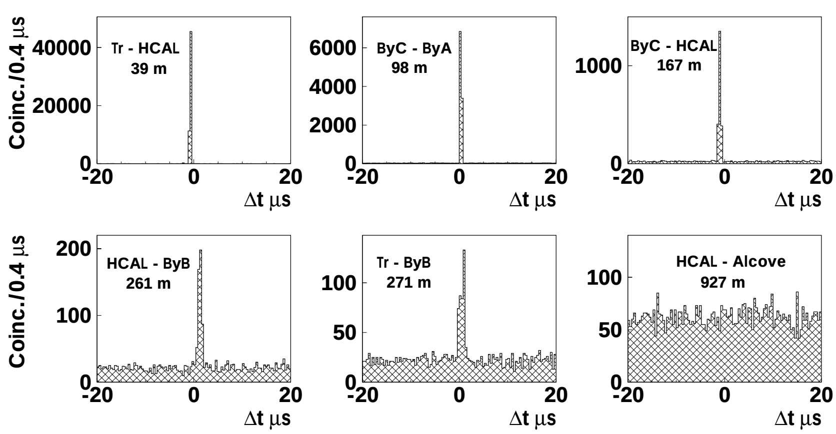

Fig. 1. The arrival time differences of muons for different pairs of stations.

seen and indicate the presence of extensive air showers with lateral spreads of up to $\sim$ 300 m.

The background-subtracted coincidence rates per unit station area per unit time corrected for detector inefficiencies as a function of distance between detector stations are presented in Fig. 2.

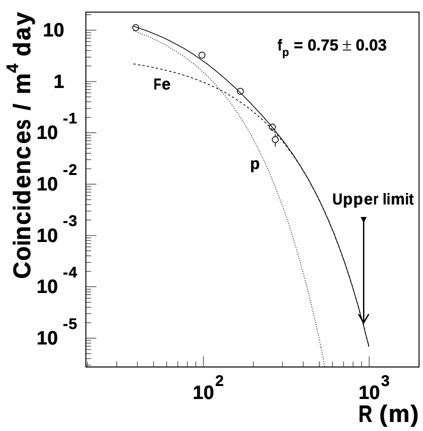

Fig. 2. Normalized coincidence rates as a function of distances R between detector stations compared with a MC simulation.

In the same figure our data are compared to a fast Monte Carlo-generated lateral distribution based on parameterisations of basic features of EAS [4]. Although the parameterization [4] was not optimized for the underground depth of CosmoALEPH, it can nevertheless be expected to give a qualitative description of the decoherence curve shown in Fig. 2. Assuming that only two components (p, Fe) contribute to the observed decoherence curve our preliminary results are best described by a proton fraction $f_p = 0.75 \pm 0.03$.

A search for 3-fold coincidences was done by looking for triplets of stations, requiring the arrival time differences Δt_{ij} for all pairs to satisfy the condition $|\Delta t_{ij}| \leq \frac{d_{ij}}{c}$. Here d_{ij} is the distance between the pairs and c the velocity of light. All candidate events are found between the closest stations Trolley, BypassC and HCAL. The arrival directions of muons are reconstructed in an iterative procedure using a plane approximation of the shower front. The two independent direction cosines are derived from fitting a plane perpendicular to the direction of muons. The reconstructed zenith and azimuthal angle distributions for selected 3-fold coincidence events are given in Fig. 3.

The experimental results are compatible with expectations evaluated by a full Monte Carlo simulation of muons underground using the GEANT package. Deviations of the data from the Monte Carlo expectation for the azimuthal distribution at 50° and around -70° might be due to an imperfect approximation of the geometry around the ALEPH detector and the surrounding. As it hap-

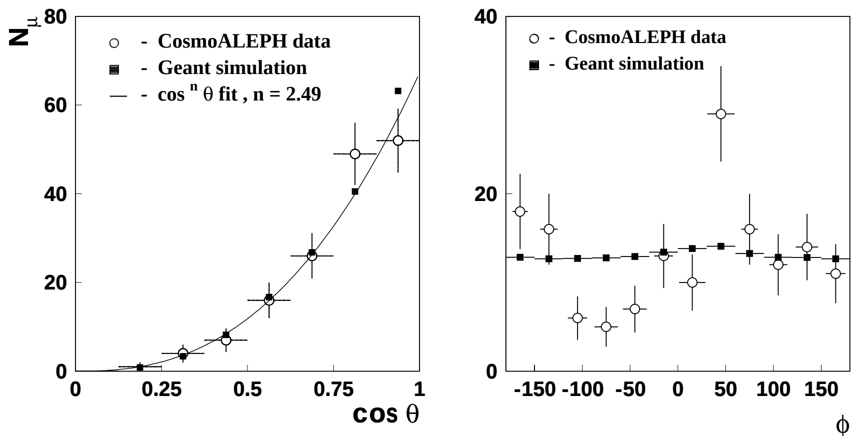

Fig. 3. The distributions of muon arrival directions in 3-fold coincidence events.

pens the drop around -70° coincides with the direction to the Jura mountains. A single power law fit to the zenith angle distribution yields the value of exponent $n = 2.49 \pm 0.35$ for the assumed $\cos^n\theta$ dependence. Systematical uncertainties in angular measurements are also taken into consideration.

4. Conclusion

The observed lateral distribution of cosmic ray muons underground at a depth of 320 m.w.e. indicates a dominantly light composition of primary cosmic rays. Using triple-coincidences, the arrival directions of muons are reconstructed and the zenith angle distribution is well described by a power law in $\cos^n\theta$ with exponent $n = 2.49 \pm 0.35$.

5. Acknowledgement

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6. References

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