The Cosmic Ray Muon Spectrum and Charge Ratio in CosmoALEPH

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Abstract

The ALEPH-experiment at the LEP e^+e^- storage ring at CERN has been used to measure the momentum spectrum of cosmic ray muons. ALEPH is located at a vertical depth of 320 m.w.e. underground close to the Jura mountains. The time projection chamber (TPC) of ALEPH with its excellent spatial resolution allows to reconstruct tracks of single and multiple muons with high accuracy. A strong magnetic field of 1.5 Tesla provides the basis of the momentum measurement.

About 1.4 Million triggers with single and multiple muon events have been analysed. The obtained muon momentum spectrum and the charge ratio in the range from 80 to 2500 GeV/c is presented. After corrections for energy loss in the overburden the muon spectrum at surface is obtained. The results are compared to results from other experiments.

1. Introduction

High energy muons are the decay products of mesons produced in interactions of primary cosmic rays with nuclei in the Earth's atmosphere. The study of cosmic ray muons is connected to the chemical composition of primary cosmic rays and the production of pions and kaons in high energy hadronic interactions. For cosmic ray physics the forward production at large rapidities is relevant. In general, this kinematic domain is difficult to study in fixed target or collider ex-

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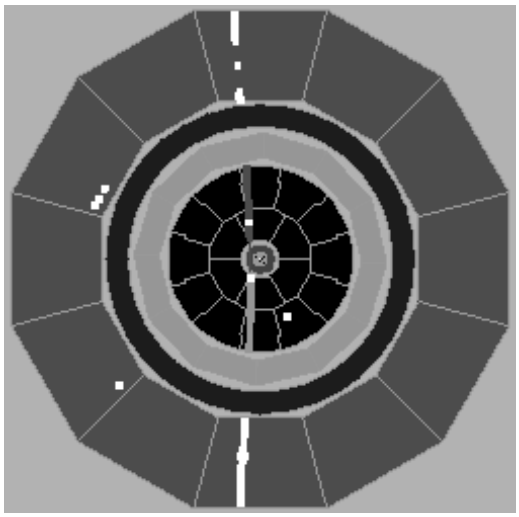

Fig. 1. ALEPH detector with a comic ray muon crossing it.

periments at accelerators. Therefore there are important connections between high energy astrophysics and elementary particle physics which can be studied by measuring the muonic component of air showers underground.

Since muons are produced along with neutrinos, the muon momentum spectrum also throws some light on the atmospheric neutrino spectrum, which in itself is an important input for the study of neutrino oscillations using atmospheric neutrinos.

2. Experimental Setup

To study the momentum spectrum and the charge ratio of cosmic ray muons the ALEPH detector is used. It was one of the four LEP detectors at CERN and was built to detect the products of e^+e^- interactions, but it has been used for cosmic ray physics as well. ALEPH is located at ≈ 320 m.w.e. underground leading to a threshold energy of 70 GeV for vertically incident muons.

The ALEPH detector has been described in detail in [1]. For cosmic runs just the hadron calorimeter (HCAL) and the time projection chamber (TPC) were used (see Fig. 1). With the high spatial resolution of the TPC of 160 μm a maximum detectable momentum of 3 TeV for cosmic ray muons is achievable. For this work we analysed special *dedicated CosmoALEPH runs* taken without beams in LEP using CosmoALEPH trigger. The CosmoALEPH trigger is active if at least eight planes in one HCAL module and eight planes in any of the three opposite modules fired simultaneously [5]. The data of 1.4 Million events were collected in one week in April 1999 with a trigger rate of 2.5 Hz.

3. Data selection

We restricted our analysis to good muon events and applied a momentum cut at 10 GeV. In addition we present just vertically incident muons up to 10° for a region with a uniform distribution in the azimuth. This leaves us with a total of 6282 muons.

4. Results

The momentum spectrum measured at the ALEPH level was corrected for the energy losses in the overburden. With the measured energy in ALEPH, $E_{\aleph}$, and a depth of $R = 320$ m.w.e., the extrapolated energy at the surface (little difference to sea level), E_μ, is:

$$E_\mu = \frac{a}{b}\left(e^{bR/\cos\theta} - 1\right) + E_{\aleph} \tag{1}$$

where a describes the energy loss due to ionisation and b the energy loss due to bremsstrahlung, direct electron pair production and nuclear interactions. This correction takes the zenith angle dependence of the energy loss into account but not its energy variation. To compare the spectrum with other experiments and model calculations we normalised the spectrum at 200 GeV to the world average by Hebbeker and Timmermans [3] obtained from previous measurements. Fig. 2 shows the comparison to this average (dashed curve) and to several other experiments (taken from [3]). The vertical muon spectrum measured by L3+C looks very similar to ours [4]. The solid curve is obtained with the nuclear-cascade model of E. Bugaev [2].

The charge ratio, R_μ, of positive and negative muons is given for different momentum regions in Fig. 3. It is compared with a world average obtained by Hebbeker and Timmermans [3] ($R_\mu = 1.268 \pm [0.008 + 0.0002 \cdot p/GeV]$) and two other experiments [3]. We obtained an average value of 1.278 ± 0.011 (for 80 to 2500 GeV/c).

5. Outlook and Conclusion

The preliminary results of the analysis of dedicated cosmic ray runs obtained with the ALEPH detector show general agreement with earlier measurements of muons at sea-level and underground. Due to the high momentum resolution the muon momentum spectrum and charge ratio could be measured up to 2.5 TeV. There are, however, some improvements and corrections to the data necessary, e. g. the detector acceptance and the track reconstruction effciency have to be carefully studied. This does not affect the charge ratio measurement, since there all systematic effects are cancelled. Intensity measurements in scintillator arrays in the vicinity of the ALEPH experiment permit to determine the absolute

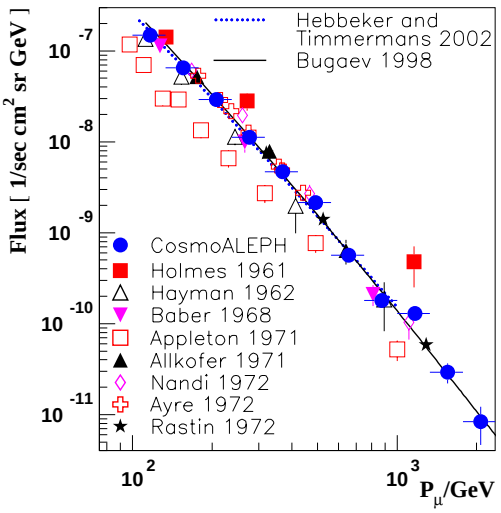

Fig. 2. Momentum spectrum of vertical muons.

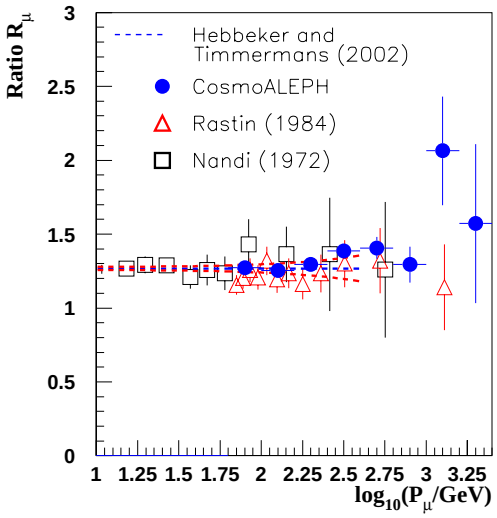

Fig. 3. Charge ratio of cosmic ray muons.

flux of muons with energies in excess of 70 GeV thereby providing an independent means to calibrate the absolute intensity of the measured momentum spectrum.

6. Acknowledgement

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