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Momentum spectrum of cosmic muons at a depth of 320 mwe

N.O. Hashim[a], C. Grupen[a], S. Luitz[b], A. Mailov[a], F. Maciuc[c], A.-S. Müller[d], A. Putzer[e], H.-G. Sander[f], S. Schmeling[g], M. Schmelling[c], R. Tcaciuc[a], H. Wachsmuth[g], Th. Ziegler[h] and K. Zuber[i]

(a) Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany
(b) SLAC M/S 41, 2575 Sand Hill Rd, Menlo Park, CA 94025, USA
(c) Max-Planck-Institut für Kernphysik, D-69029, Heidelberg, Germany
(d) Institut für Synchrotronstrahlung, FZ Karlsruhe, D-76021 Karlsruhe, Germany
(e) Kirchhoff-Institut für Physik, Universität Heidelberg, D-69120 Heidelberg, Germany
(f) Fachbereich Physik, Universität Mainz, D-55099 Mainz, Germany
(g) CERN, CH-1211 Geneva 23, Switzerland
(h) Department of Physics, Princeton University, Princeton NJ 08544, USA
(i) Experimental Physik IV, Universität Dortmund, D-44221 Dortmund, Germany
Presenter: N.O. Hashim (hashim@hep.physik.uni-siegen.de), ger-hashim-NO-abs1-he11-oral

Cosmic muons are produced through interactions of primary cosmic radiation in the atmosphere. They are a component of extensive air showers which can also be measured underground. The CosmoALEPH experiment used the ALEPH detector at the European Laboratory for Particle Physics, CERN, to measure cosmic muon events at a depth of 320 mwe underground. The momentum spectrum and charge ratio of the cosmic muons are measured. The results are compared with the expectations from MC simulations based on different hadronic interaction models.

1. Introduction

Since their discovery, great progress has been achieved in the field of cosmic ray physics particularly towards the understanding of the origin, transport and acceleration mechanisms of the high energy particles that constitute primary cosmic rays, their interaction processes in the galactic and extra galactic media, and also in the Earth's atmosphere[1]. The interaction of primary cosmic ray particles in the Earth's atmosphere leads to the production of a cascade of secondary particles or Extensive Air Showers (EAS) with various components - electromagnetic, hadronic, muon and neutrino components. There is a large number of models to describe these interactions.

Many cosmic ray experiments have used a variety of observables in EAS that provide an understanding of the hadronic interactions and also shed some light on the chemical composition of the primary particles. The muon flux at the surface provides a useful tool for the calculations of neutrino fluxes, the reconstruction of EAS and it can serve as a test of various interaction models.

The CosmoALEPH detector, which was one of the experiments in CosmoLEP[2, 3] used the ALEPH detector at the European Laboratory for Particle Physics, CERN, to measure the muonic component of EAS. Preliminary results[4] have recently shown that the momentum spectrum and charge ratio for cosmic muons measured by CosmoALEPH are well within the world average [5]. This work reports on further improvements in the reconstruction of the cosmic muon events and data analysis.

2. Experimental Setup

The ALEPH detector and its applicability as a tool for cosmic ray measurements has been well described [6, 7, 8, 9]. It was located at a depth of 320 mwe, which corresponds to an energy cut-off of about 70 GeV for vertical muons. For measurements of cosmic muon events, the hadron calorimeter HCAL and time projection chamber TPC have been used. The trigger efficiency for HCAL is about 85% for vertical muons and a spatial resolution of about 160μm in the TPC allows the measurements of up to 3 TeV. A total of about 1.1 million cosmic muon events from dedicated cosmic runs is analysed in this work. The data are compared with Monte Carlo simulations.

3. Data Selection and Analysis

A total of 65,946 vertical cosmic muons, zenith angle θ up to 10°, with momentum greater than 5 GeV measured in ALEPH was selected for analysis. The muon energies at the surface E_{μ} are extrapolated from their respective energies measured in ALEPH $E_{\aleph}$ at the depth R using the relation,

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

which takes into account the energy losses due to ionisation, bremsstrahlung and direct electron pair production described by the terms $a = 2.2\,\mathrm{MeV}\cdot\mathrm{cm}^2/g$ and $b = 0.004\,\mathrm{cm}^2/g$ respectively[1].The momentum spectra are corrected for geometrical acceptance and effects of the angular distribution around the vertical using a Monte Carlo simulation. The data are then corrected for the track reconstruction efficiency which is estimated to be about 79%. The momentum spectrum is unfolded using Bayesian technique [10] taking into account the detector resolution and energy losses in the overburden. This is achieved by a complete simulation of cosmic muon events in the CosmoALEPH experiment using the following programs; CORSIKA[11] for air shower simulations, GEANT[12] for muon transport and interactions in ALEPH including the overburden. A detailed description is in preparation [13].

4. Results and Discussion

The preliminary momentum spectrum and the charge ratio for vertical muons at the surface are shown in Figure 1. The data are similar to results of earlier experiments and a recent compilation [5]. The charge ratio, R_{μ}, of positive to negative muons obtained has an average value of 1.278 ± 0.011. Only statistical uncertainties are shown. Systematic uncertainties are expected to be below 10%. A comparison with the Monte Carlo Simulations based on different hadronic interaction models is shown on Figure 2. The MC simulations are normalised to the selected number of events in the data. The slope of the number of muons at the surface predicted by the models agrees very well with our data. However, some systematic effects are evident in the calculations of the charge ratio. SIBYLL, which is known to generate a relatively lower muon content[14, 15], shows systematically higher values for the muon charge ratio compared to our measurements. A similar trend is observed by the L3+C experiment [16] which was also one of the cosmic ray experiments at LEP. The muon flux is closely related to the neutrino flux and the muon charge ratio is a sensitive observable for precision tests of muon and neutrino production in EAS [17].

5. Outlook

The preliminary results show a momentum spectrum that is consistent with previous measurements and the charge ratio is well described by Monte Carlo simulations. This work shows that the charge ratio for cosmic

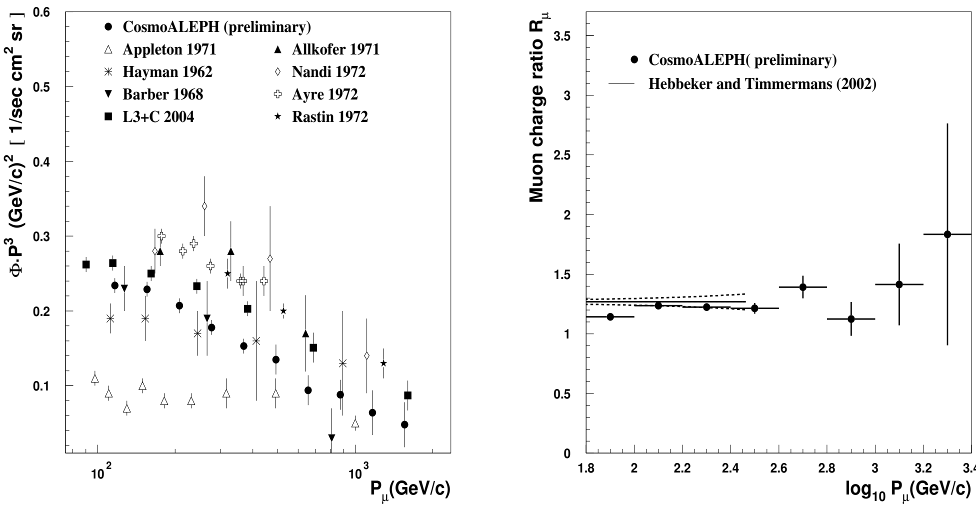

Figure 1. Momentum spectrum and charge ratio for vertical muons compared with other experiments[5, 18].

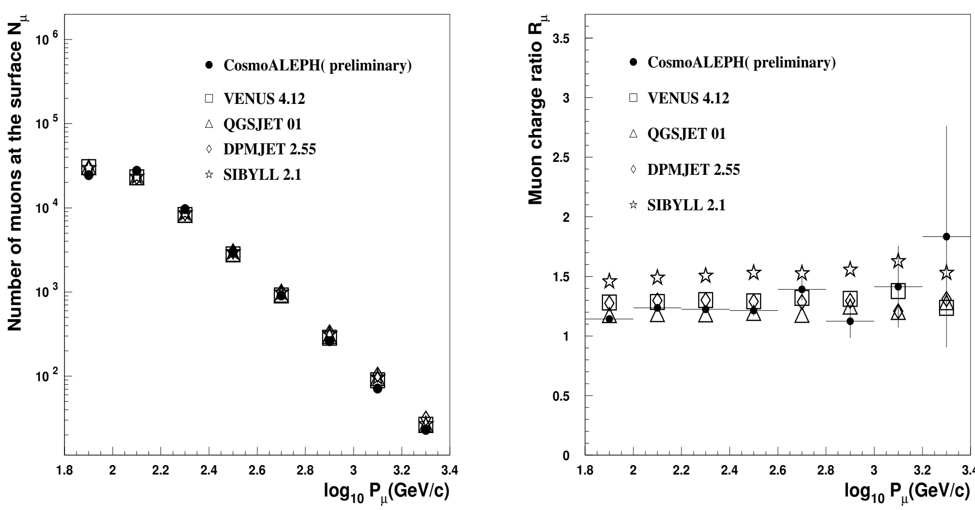

Figure 2. Number of vertical muons at the surface and their charge ratio compared with MC simulations based on different hadronic interaction models.

muons measured in CosmoALEPH is indeed an observable in EAS that can be used for testing theoretical hadronic interaction models. Further work is in progress to compare the data with updated models for high energy interactions such as QGSJET-II [19] and NEXUS 3 [20] which will be included in the next version of CORSIKA[15, 21]. A more detailed analysis of the detector acceptance and trigger efficiency as function of muon momentum for inclined muons is in progress.

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