Cosmic multi-muon bundles measured at DELPHI

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The DELPHI detector at LEP, located 100 m underground, has been used to detect the multi-muon bundles by cathode readout of its hadron calorimeter and its tracking detectors (TPC, muon chambers). The experimental apparatus allows us to study muon bundles originating from primary cosmic particles with energies in the interval 10^{14} - 10^{17} eV. The cosmic events registered during the years 1999 and 2000 correspond roughly to 1.6 10^6 s of effective run time. The aim of the work is to compare the measured muon multiplicity distributions and predictions of high energy interaction models for different types of primary particles and also to determine the absolute flux of events in certain muon multiplicity range. The presentation describes the current status of the analysis.

1 Introduction

Cosmic multi-muon bundles are products of atmospheric showers, initiated by cosmic rays interacting in the upper atmosphere. The Monte Carlo models (NEXUS, QGSJET, SIBYLL, . . .) which simulate the nucleus-nucleus interaction are used by cosmic ray experiments to correlate measured quantities with primary particle energy and type. These models are tuned to data from accelerator detectors at much lower energies. Even if the large progress has been obtained in this field during last years (eg. KASKADE results [1]) it is clear that the models should be tuned to as many measurements as possible. The data presented here were recorded by the DELPHI experiment (CERN) at an intermediate underground depth (100 m) corresponding to energy cutoff for vertical muons ~ 50 GeV. The study of multi-muon bundles in this underground depth is motivated by observed excess of high multiplicity events in the COSMO-ALEPH experiment [2]. The independent cross-check of interaction models is the main aim of this work.

2 Data

The data were taken during years 1999 and 2000 in the parasitic mode of e^+e^- data taking as well as in dedicated cosmic runs. The muon tracks have been reconstructed from barrel part of DELPHI Hadron Calorimeter (HAC) using its fine granularity.

The ability of the accelerator experiment to record cosmic events was given by special cosmic trigger defined by the coincidence of 3 active sectors in the Time of Flight detector (TOF). The run selection was done according to the trigger conditions and all runs with the cosmic trigger correctly implemented have been chosen for the analysis. The consistency between different trigger configurations has been checked in terms of the event rate.

The muon multiplicity distribution as measured in the HAC is plotted in Fig. 1 a). The values of primary particle energies that are needed to produce showers with corresponding multiplicities are shown in the upper part of this picture.
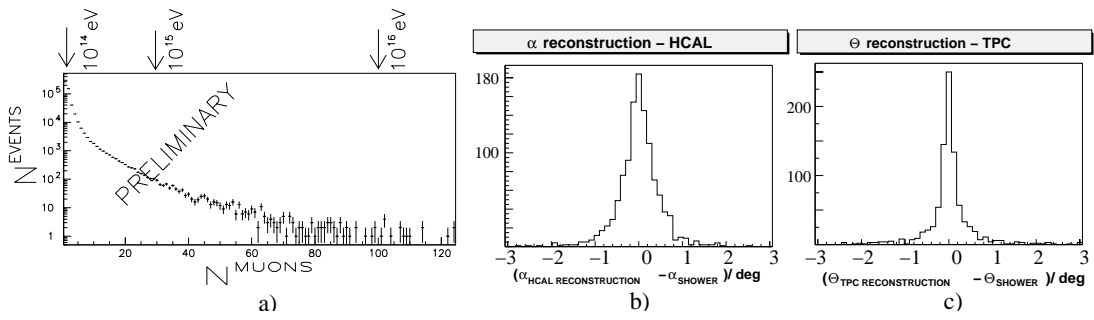
Figure 1: a) Muon multiplicity as measured by DELPHI hadron calorimeter during ~ 1.6 s data taking time; b) The difference between generated and reconstructed shower angle from HAC in the test MC sample; c) The difference between generated and reconstructed shower angle (zenith) from TPC

Additionally to events plotted in Fig. 1 a) 7 events with saturated hadron calorimeter have been found in the data sample. The number of anode hits from muon chambers has been used to extrapolate multiplicities for 2 saturated events. There are indications that multiplicity is higher then 150 in both cases.

3 Simulation

The following describes the status of the Monte Carlo (MC) simulation in the time of the presentation. Production of large MC data sets is in progress.

The interaction model (QGSJET) is implemented to the CORSIKA [3] simulation package which simulates passage of particles through the atmosphere and shower development. The rock above the DELPHI detector is represented by 5 layers of materials with different densities in a simple GEANT geometry. Full simulation of the detector response is used. Shower centres are smeared over circular area ($R = 200m$) around the DELPHI detector. Large data sets are simulated for proton and iron primary particles in the energy range 10^{14} - 10^{18} eV. Comparison between data and MC could show the expected trend to heavier elements in the primary particle composition [1]. The independent check of the relevance of the interaction model will be provided.

The test sample of proton central showers ($\sim$ 1000 showers with $E = 10^{15}$ eV) has been used to check the quality of reconstruction programs. The differences between generated and reconstructed angles of shower directions are plotted in Fig 1 b) and c) for HAC and TPC reconstruction.

4 Conclusions

The cosmic multi-muon data are analysed at the DELPHI experiment. The distribution of muon multiplicities is measured. Simulation of large MC data sets is in progress. MC predictions expresed in terms of multiplicity distributions for pure proton and iron composition are to be compared with the data in order to search for possible excess in the range of high multiplicities. The increasing fraction of heavier elements as a function of energy would apear in the data with increasing multiplicity as a transition from the proton MC curve to the iron one.

References

1. By KASCADE Collaboration (T. Antoni *et al.*) *Astropaticle Physics* **16** 245 2002.
2. V. Avati *et al*, *CERN EP/*2000-192.
3. D. Heck *Nachr.Forsch.zentr.Karlsruhe* **33** 113 2001.