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Momentum dependence of the vertical muon flux and charge ratio measured by the L3+Cosmics experiment

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Abstract. $12. \cdot 10^9$ cosmic ray muon events above 20 GeV have been collected with the L3+C detector at LEP, CERN, in 1999 and 2000. A preliminary momentum spectrum is presented and discussed.
The muon spectrometer of L3 consists of a set of high precision drift chambers installed inside of a magnet with a volume of 1000 m^3 and a field of 0.5 T. Muon momenta are thus measured with a resolution of a few percent at 50 GeV. The detector is located under 30 m of overburden. The goal is to get the muon spectrum with a precision of 2.5 % in the range of 20 to 2000 GeV, as well as the charge ratio and the angular dependence.

1 Introduction

The precise measurement of the atmospheric muon spectrum is one of the fundamental exercises in the field of cosmic rays. The information one gets out of the momentum distribution, the charge ratio and the zenith angular dependence are numerous: about the primary spectrum, the chemical composition of the primaries, as well as about the inclusive cross-sections of meson production in air (cascade calculations). These points are of interest for answering questions in the field of astrophysics and particle physics. Probably the most important motivation for this measurement these days is the possibility to gain confidence in the calculated atmospheric muon neutrino flux, which is directly related to the muon flux. Experimental indications for neutrino oscillation can therefore be discussed by getting reliable predictions on absolute event numbers. Also reliable background estimates e.g. for large neutrino telescopes searching for point source signals, can be made.

Since 1934 (Anderson and Neddermeyer, 1934) the muon momentum spectrum has been measured with many different detectors located at the earth surface, underground or in balloon payloads. The experimental methods choosen were either spectrometers with absorbers and with or without magnetic fields. In recent times quite sophisticated detectors have been used. Nevertheless several compilations of results have revealed quite important differences in the absolute flux values found (Bugaev, 1998; Hebbeker, 2001). Systematic errors have obviously been underestimated.

The above mentioned facts have motivated the L3+C group to take advantage of the unique properties of the L3 spectrometer (Adeva, 1990) and to perform a precise measurement of the atmospheric muon momentum spectrum, the charge ratio and the angular dependence over a wide momentum range (Le Coultre, 1997; Timmermans, 1999; Adriani, 2001). At this conference we shall present results for the vertical spectrum and the charge ratio over the range of 50 to 1000 GeV/c, with the presently best estimation of our systematic errors (the main contribution to the overall error).

2 The L3+C set-up

The L3+C experiment uses part of the L3 detector in combination with a surface scintillator air shower array above:

The L3 experiment is located underground at the CERN Large Electron-Positron collider, LEP, near Geneva (6.02^0 E, 46.25^0 N, 450 m above sea level). 30 m of molasse rock shield the detector against the electromagnetic and hadronic air shower components. A solenoidal magnet with a field of 0.5 T and a volume of 1000 m^3 contains eight sets of high precision drift chamber layers (Fig. 1) measuring the coordinates in the track bending plane of the magnet. Four additional layers are recording the coordinates along the axis of the solenoid.
At the center of the magnet, vertex detectors and calorimeters are installed. These are not used for the cosmic ray experiment. In order to get the time of arrival of cosmic ray muons (necessary to get the track position in the drift chambers), 202 m^2 of scintillators have been mounted on top of the magnet. A special trigger and readout system has been

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designed in order to run independently of the L3 $e^+ e^-$ data collection.

A scintillator air shower array has been installed on the surface, on the roof of a hall above the L3 detector. It consists of 50 scintillation counters (50 x 100 cm^2) distributed over 30 x 54 m^2. This array provides an estimate of the energy of the air shower associated with the muon(s) measured with the L3+C spectrometer. This subject will be presented in a separate contribution to this conference (Wilkens, 2001).

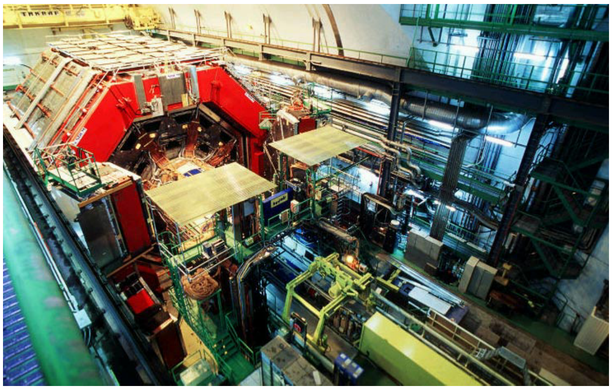

Fig. 1. The L3 detector covered with timing scintillators, especially installed for recording cosmic ray muon events. The magnet pole pieces are in "open" position. Some drift chambers are visible.

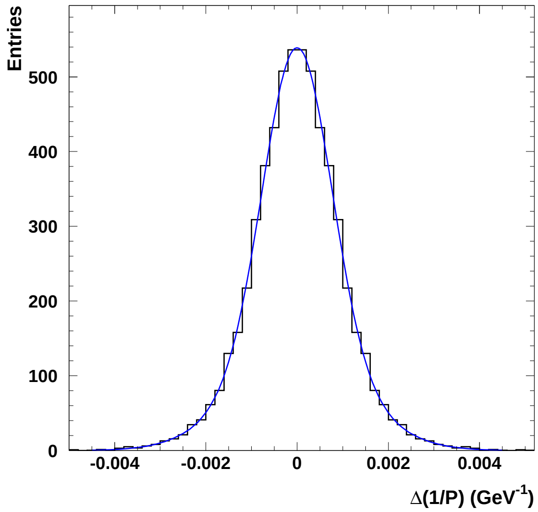

Fig. 2. Momentum resolution $\Delta(1/p)$ measured between 100 and 120 GeV).

3 Detector performance and data collection

A unique feature which should be mentioned here, is the possibility to verify the momentum measurement, measure the momentum resolution and check the detection efficiency at 45 GeV/c with the observation of muons from LEP-produced Z boson decays. The resolution for cosmic muons at any momentum can be measured by comparing the measured momenta in two different octants for the same particle. This is shown in Fig. 2 for $\approx$ 100 GeV muons, where the momentum error is seen to be 7.4 %.

Data collection has started in 1999 and ended after the LEP shutdown on Nov.13th 2001. Altogether $12.\cdot 10^9$ events have been collected over a total of 312 days of livetime. The trigger conditions were such that practically any type of event was accepted, and the trigger rate was almost equal to 450 Hz. For vertically incident muons, the molasse implies an energy threshold of about 15 GeV and an angular resolution of less than 4 mrad above 100 GeV due to multiple scattering.

4 Results and discussion

The analysis of a fraction of all our muon events is presented. A momentum spectrum of the vertically incident muons at an altitude of 450 m above sea level has been extracted. Only tracks with zenith angles less than 10^o have been selected. The errors are presently dominated by systematics and are estimated, comparing the results for different event selection criteria, comparing the measurement of a given muon track in the upper and lower octant, and by comparing two independent analysis. The methods will be refined in the future in order to reduce the overall systematic errors. Also the momentum range will be extended.

Extensive MC data and studies have been produced in order to extract our acceptance, making profit from the experience gained with the L3 detector for getting precision cross-sections of $e^+ e^-$ collisions. Efficiencies of the chambers and of the timing scintillators were extracted from the data themselves. The trigger efficiencies for the different trigger classes were measured through a particular prescaled trigger class. The trigger process was simulated with these events to know how many events should pass the particular trigger.

The spectrum is in good agreement with other available data (Bugaev, 1998), (Hebbeker, 2001). The calculated spectra (Bugaev 1998; Agrawal 1996) are shifted towards higher absolute flux values. Adjusting the primary spectrum according to BESS-98 data (Sanuki, 2000), as done in a most recent calculation (Naumov, 2001) (this one in fact is centered on smaller momenta, but valid up to 100 GeV) one gets agreement with L3+C data in the low energy part, as well as with the CAPRICE (Kremer, 1999) and MASS (De Pascale, 1993) experimental results.

To get the vertical momentum spectrum at sea level, one has still to apply the altitude correction, which is expected to be at the 1 % level at the lower end of the spectrum shown and even less at higher momenta.

The charge ratio for the vertically incident muons has also been extracted from the data and is much less dependent on systematical errors. The value is quite constant over the whole momentum range analyzed. Assuming a primary composition as compiled in (Gaisser, 2000) a CORSIKA (version 6.00) Monte Carlo calculation (Heck, 1998) shows that out of the six available high energy interaction models only VENUS (Werner, 1993) and DPMJET (Ranft, 99) describe our data.

5 Conclusions

The presented vertical muon momentum spectrum together with the charge ratio are preliminary results obtained by the L3+C high resolution, large volume detector. In the future we intend to reduce the systematic errors, to extend the momentum range and give the angular dependence. This will sharpen the conditions on possible primary composition and parameters of interaction models, as well as constrain further the atmospheric muon neutrino flux.

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