L3+COSMICS: an atmospheric muon detector at CERN

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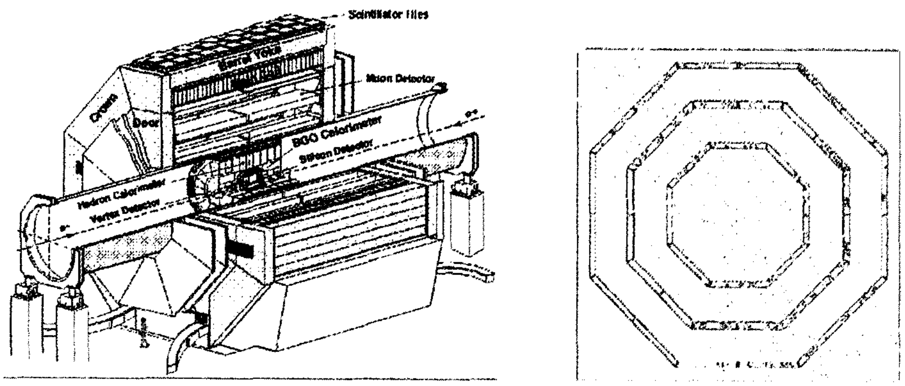
The L3+C experiment studies the muon component of the atmospheric showers induced by primary cosmic rays. It combines the high precision spectrometer of the L3 detector at LEP, CERN, with a small air shower array. The momenta of the cosmic ray induced muons can be measured from 20 to 2000 GeV/c. Up to now, almost 12 billion of muon events have been recorded on tape, as well as over 33 million air shower events. Here the first results on the muon momentum spectrum and charge ratio will be presented.

1 Introduction

Nowadays many arguments, particularly the new evidence for neutrino oscillations, make the attention focus on the neutrinos' related muon flux (originating in the atmospheric showers mostly from charged pion decays $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu})$; contributions to the flux of secondary importance come also from analogue decays of kaons) , its energy spectrum and the ratio between the abundances of the positive and negative muon components. These are the main targets of the L3+Cosmics experiment, which is an extension of the already existing L3, one of the four detectors at the LEP e^{+} e^{-} accelerator at CERN Laboratories, located near Geneva (6.02° E, 46.25° N) at an altitude of 450 m.

L3 [1] (Fig. 1.a) is underneath 30 m of molasse ($\sim$ 72 m.e.w), with a 15 GeV minimum energy cutoff for downgoing muons. The high precision muon spectrometer is composed of layers of drift chambers, occupying a volume of $\sim$1000 m^3, and is completely inside an uniform magnetic field $\vec{B}$ of 0.5 T.

L3 has operated very successfully since 1989 up to the first days of November 2000 when the LEP machine was shut down. Since April 1998 the muon spectrometer has been converted into a powerful detector of atmospheric muons, without affecting the normal L3 activity. Such conversion has been possible thanks to additional equipment, the t_0 system, composed of plastic scintillators, and by means of an independent trigger and DAQ electronics. The wide energy



a. b.

Figure 1: a. The L3 detector. The muon spectrometer and the dedicated scintillator tiles on the top form the L3+Cosmics experiment. b. A reconstructed cosmic muons shower penetrating into the muon spectrometer.

range under inspection (20 - 2000 GeV), *ad hoc* ground-filtering of unwanted non-muon secondaries, a precise momentum resolution and huge statistics characterize the measurement of the muon spectrometer of L3. As being a continuously monitored detector, active during more than 6 months per year, the spectrometer provides as well the conditions to study short time dependent phenomena such as muon bursts, or to determine fine effects, such as sidereal asymmetries.

Since the beginning of year 2000, a small air shower array has been added on the roof of the L3's pit access hangar, located at the surface level above L3 (Fig. 2.a). The trigger signal from both the spectrometer and the shower array are exchanged, to enable an offline merging of the two data streams, in order to reconstruct a possible primary energy and composition, and to put constraints to models describing the development of a shower in the atmosphere.

2 The L3+C experiment

The muon spectrometer, together with the magnet and scintillators, is shown in Fig. 1.a. as part of the L3 detector. It consists of 80 precision drift chambers (P-chambers) to measure positions in the XY bending plane of the magnet, transverse with respect to $\vec{B}$, and 96 drift Z-chambers to measure the coordinate along the magnetic field. The P-chambers are arranged in 2 groups of 8 *octants*, in 3 layers per octant. The Z-chambers are arranged in 2+2 layers *sandwiching* the inner and the outer P-chamber layers. Chamber alignments are continuously monitored and are known to 20 μm. Each chamber's single wire resolution is 200 μm. By means of measuring the sagitta S of the muon trajectory (with an absolute spatial resolution of about 54 μm), the transverse muon momentum $P_\perp$ is determined in one octant by using the formula $P_\perp = \frac{c\,B\,L^2}{8\times10^9\,S}$, where L is the extension of the octant and c the speed of light (expressing P in GeV/c and the other quantity according to SI). The information along Z is then used to perform a helix-fit to the trajectory, refining the momentum measurement.

The muon detector is enclosed in a 12 m diameter magnet (coil and yoke) which is exited by a current of 30 000 A to generate the strong magnetic field inside the spectrometer.

The arrival time of the muons is requested for determining the drift time inside the chambers, thus the experiment is provided by the t_0 detector, consisting of 202 m^2 of scintillators installed outside the magnetic yoke, on the faces of the three upper octants. Such a wide external scintillating coverage allows to take advantage of the big acceptance of the spectrometer, triggering even muons whose trajectories cross multiple octants, flying far from the central core

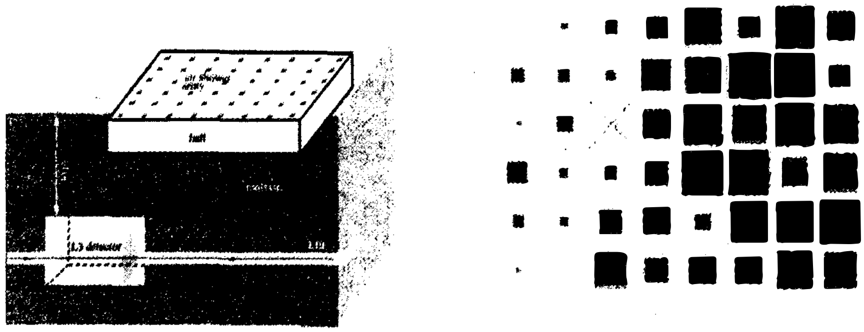


Figure 2: a. Sketch of the shower array with the underground detector; b. The array event display. Each rectangle correspond to the locations of the scintillators on the roof: the larger is their size, the bigger is the number of detected particles.

of L3 (Fig. 2.b). Since a performing software able to reconstruct such multi-octant crossing events is currently under progress, the present work restricts its analysis only to events which go through inside a single octant. In this case, the maximum allowed zenith angle is of the order of $\sim 50°$, and the geometric factor is ~ 200 m^2 sr. The air shower detector consists of 50 scintillator modules each with a surface of 0.5 m^2, which are distributed over an area of 30×54 m^2. The independent array's trigger has an energy threshold of about 10 TeV and is fully efficient above a shower energy of 100 TeV. The energy resolution of the air shower array is 30% for events with the core contained in the array. An accuracy of 1°-2° on the zenith angle is expected. The L3 muon spectrometer together with the surface array form the L3+C experiment.

The status of the L3+C detector is continuously monitored (run conditions, muon chamber voltages and discriminator thresholds, t_0 scintillators conditions, status of the magnet, atmospheric pressure at surface, etc.), in order to collect necessary on-line information for the data base.

3 Performance and data taking

The 30 m of molasse above the muon spectrometer provides a shielding against the electromagnetic and hadronic components of the air showers. It also sets a minimum muon momentum threshold of 15 GeV/c, and limits the angular resolution to 0.2° at 100 GeV/c.

A double measurement of the muon momentum (using independently the upper and lower octants of the detector) gives the muon momentum resolution, which is 7.4% at 100 GeV/c. In particular, the momentum resolution of the spectrometer has been calibrated using muons with a precise momentum, i.e. muons originating from the Z boson decays. Few hundreds of events such as $e^+e^- \to Z/\gamma \to \mu^+\mu^-$ are produced yearly during LEP calibration runs. These back to back muons have the same topology as a cosmic muon going through the spectrometer by its centre, thus it has been possible to determine a momentum resolution of 5.1% at 45.6 GeV/c.

The spectrometer data taking officially started in 1999. From May to November a total 5 billion events were recorded, with a live-time of ~ 124 days. From April to November 2000 a total of 6.8 billion events have been collected with a live-time of 188 days. The air shower array has been fully operational since April 2000 and by November 12th ~ 33 million air shower events have been recorded. Almost one third of these shower events are accompanied by muon(s) down in the spectrometer.

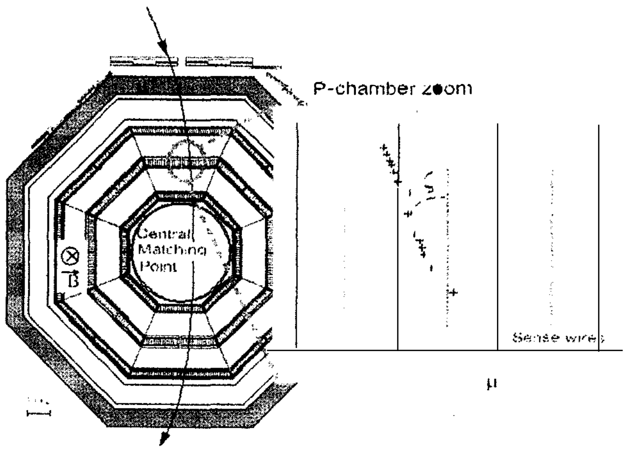


Figure 3: Principal muon event selection criteria: hit in the scintillator tiles and in 3 P-layers per octant, up and down tracks matching and zenit angle less than 10 degrees.

4 First results: the muon spectrum and charge ratio

A first muon momentum spectrum from 50 to 500 GeV/c has been determined by using data from September to November 1999 recorded by the sole muon spectrometer (a preliminary analysis which uses and combines also the array data is still in progress). The related total live-time was slightly more than 30 days. Strict quality cuts have been applied (refer to Fig. 3), requiring in particular a good measurement of the tracks in both upper and lower octants and a good matching of them, to get the entire muon track. This has been achieved by selecting those tracks whose helix-fit was related to a $\chi^2/\mathrm{dof} < 10$. The zenith angle ζ has been restricted to a range of $0°$ to $10°$ to measure the vertical flux. The consequent acceptance is then reduced to 0.5 m^2 sr.

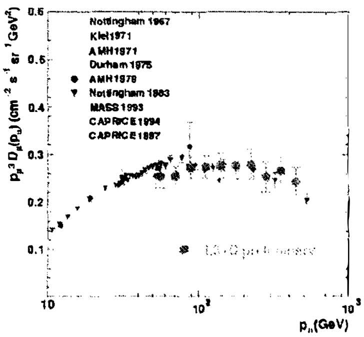


Figure 4: Spectrum of down-going muons multiplied by p_μ^3. The error bars take into account of both sistematical and statistical errors.

In Fig. 4 the measured flux weighted by P^3 together with the results of other experiments [2 3 4 5 7] is shown. The systematic error of $\sim 9\%$ dominates the total error bars. In the future we hope to get the total error less than 3%, and to extend the momentum range from 20 to 2000

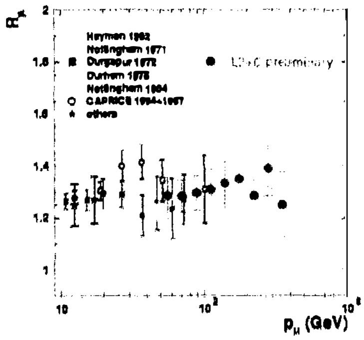


Figure 5: Charge ratio of down-going muons. Only data points with error (systematical + statistical) smaller than 10% are shown.

GeV/c.

The charge ratio was obtained from the same event sample. The preliminary result can be seen in Fig. 5 together with the results of other published experiments [7 4 5]. Due to the small sample of data considered for the analysis, at high momenta the statistical error is dominating.

5 Conclusion

L3+C is a new type of cosmic rays detector, which combines air shower data with precise muon momentum measurements. First preliminary results on the muon spectrum and charge ratio in the range from 50 to 500 GeV/c have been presented, using a partial sample of data recorded. A substantial reduction of the statistical and systematic errors is expected in the future, by using the total amount of collected events.

References

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