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Observation of high energy muons associated with air showers with the L3 muon spectrometer

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Abstract. The L3+C experiment at CERN has been extended with an air shower scintillator array. The combination of the measurement of the shower particle density with the precision measurement of cosmic ray muons in the L3 spectrometer provides a new tool to study the physics of cosmic rays.

A study of correlations between the electron-photon and the muon components of air showers with large area detectors has been known to provide information about the composition of the primary cosmic ray flux. For this, new observations on the energy spectrum of muons over a large energy range and the multiplicity distribution of high energy muons are needed. We present here the details of the L3+C experiment relevant for such studies and discuss some preliminary observations.

1 Introduction

The cosmic ray composition beyond the range where direct measurements are possible is an unresolved question. Beyond 100 TeV only indirect measurements are possible due to the steeply falling energy spectrum. One method of accessing the composition at very high energies relies on the study of the muon content of extensive air showers (EAS) (S.M. Kasahara et al., 1997). It is known that heavy nuclei interacting with an atmospheric nucleus produce a larger number of sub-showers than light nuclei. The total available energy is shared over a larger number of pions. Due to their lower energy these pions have a larger decay probability, resulting in an increase of the muon content of the EAS. The L3+C experiment consisting of a muon detector and an EAS array samples both the muon and the electromagnetic component of EAS needed for the study of the cosmic ray composition.

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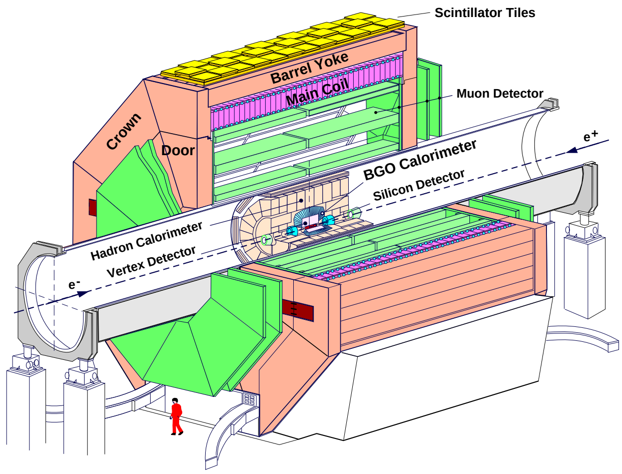

Fig. 1. The L3 detector.

2 The muon detector

The L3+C experiment (O. Adriani et al., 2001) makes use of the unique properties of the muon detector of the L3 experiment [figure 1] at CERNs LEP accelerator. The L3 detector has been used very successfully from 1989 until 2000 to study e^+e^- collisions. The muon spectrometer is located inside a huge octagonally shaped solenoid of a volume of more than 1000 m^3 and with a field strength of 0.5 T. The spectrometer consists of two octagonal rings assembled out of eight octants. Each octant consists of three layers of high precision drift chambers. The middle chambers contain cells with 24 sensitive wires whereas the cells of the inner and outer layers have 16 sensitive wires.

In 1998 additions were made to the L3 detector to form the L3+C setup. 202 m^2 of scintillator where placed on the top three faces of the return yoke of the magnet. These scintillator plates are used to measure the arrival time of the muons, and allow the calculation of the drift times inside the chambers. Also a dedicated data acquisition system (DAQ) was

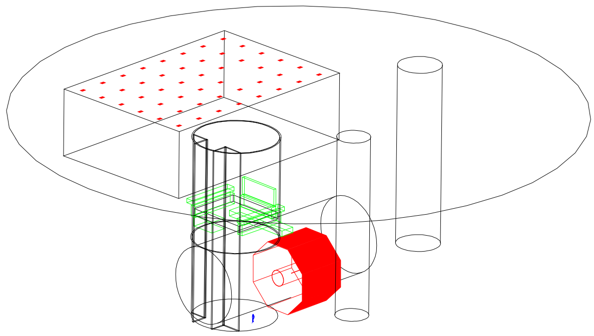

Fig. 2. Location of the air shower array.

added in order to take data entirely independent of the L3 data acquisition state. This setup successfully measured cosmic ray muons in the years 1999 and 2000, collecting over ten billion triggers.

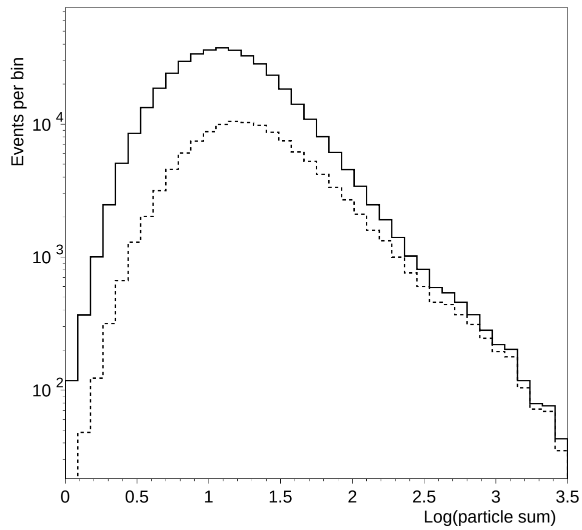

Fig. 3. Spectrum of the sum over all EAS modules of the number of MIPs.

3 The extensive air shower array

In the spring of 2000, a small air shower array was placed on the roof of the hall covering the access shaft to the L3 detector [figure 2]. This array uses 47 scintillation counters of 0.5 m^2 area each, placed in 6 rows of 8 modules over the 30×54 m^2 surface of the roof. The trigger of this array requires a hit in a module in three adjacent rows, and is sensitive to showers of order 10 TeV, centered on the array. It is fully efficient for showers above 100 TeV. Both time of arrival and collected charge are read out for each module. The detector has an independent DAQ system, but the trigger signals are exchanged between the muon detector and the air shower array. Some 25 million showers were recorded during the time both detectors were running. The data presented here are preliminary and represent a small portion of this total.

Each of the modules has been calibrated using a small telescope of 25×25 cm^2 consisting of two layers of scintillator which are used to generate a calibration trigger. The collected charge distribution was measured for one minimum ionizing particle (MIP), allowing to extract the most likely ADC count for 1 MIP. Using these values, the ADC readouts can be expressed in term of number of MIPs. The sum of these values can be used as an estimator of the primary energy of the shower. In figure 3 the particle sum spectrum is shown for a subset of all showers, and for the showers with an associated muon of the same subset (dashed line). As expected high energy showers are more likely to produce an associated muon.

4 Data combination

About one third of the recorded showers have at least an associated muon in the L3 detector. In order to combine the data of the two detectors each event gets a flag when a coincidence occurs. Next to this flag a time stamp is taken at a 100 μs precision from a local clock. The local clocks of the two detectors are synchronized by the same GPS module. The comparison of the time stamps allows to match the coincident events of both data streams.

A first check of the coincidences was to compare the shower direction reconstructed from the time information of the air shower array, with the direction of the muons reconstructed from the muon chambers information. The result for all matched showers with at least 7 modules with time information can be seen in figure 4. It shows a 4 degrees angular resolution which is essentially due to the air shower array since the muon chambers angular resolution is estimated independently to be 0.3 degree using muon pairs with individual energies above 50 GeV.

Quantities associated with muon distributions as function of the primary energy will be studied, as for instance the average number of muons reconstructed in the L3 detector as function of the particle sum in the air shower array [figure 5]. The sensitivity of these distributions to the primary cosmic ray spectrum will be investigated using the CORSIKA air shower simulation program (Heck et al., 1998).

5 Conclusion

The muon content of extensive air showers is known to be sensitive to the cosmic ray primary composition. Measuring

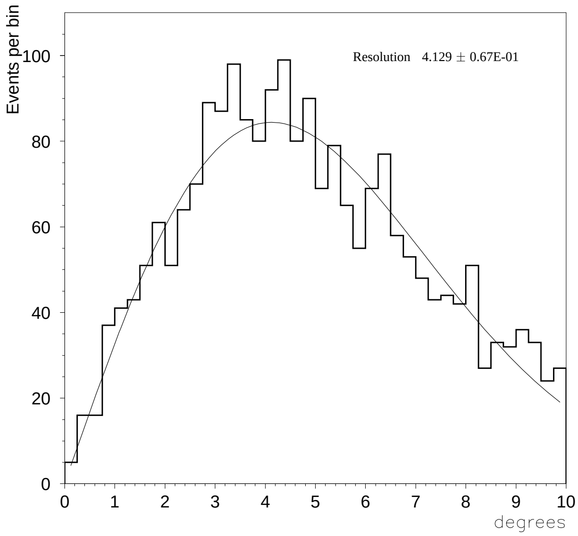

Fig. 4. Angle between the shower axis determined from the EAS array and associated muon.

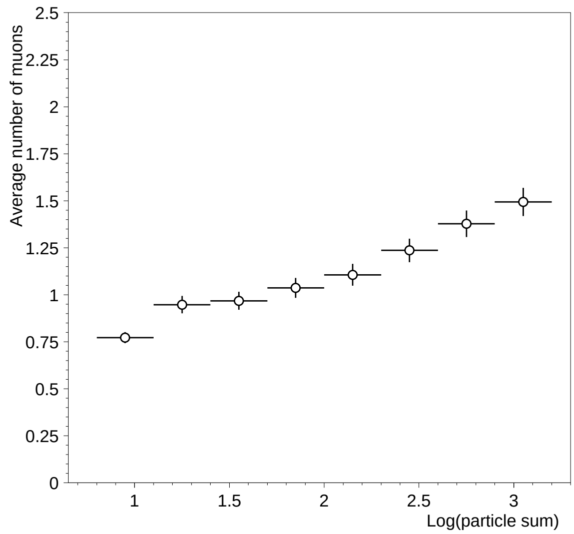

Fig. 5. Average number of muons reconstructed in L3 as function of the particle sum.

part of the electromagnetic component of the air showers as well as the energy of part of their muons the L3+C experiment will contribute to a better understanding of the cosmic ray composition above 100 TeV.

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