Cosmic ray studies with the L3 detector at LEP
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The L3 detector at the LEP accelerator offers good prospects for the study of high energy cosmic ray muons. Efforts made by the collaboration to provide a new tool for cosmic ray detection are described. The experimental status and the physics perspectives are reviewed.

1. Introduction

The electron-positron collider LEP, at Cern Geneva, is surrounded by four large $4\pi$ detectors, one at each intersection point of the two particle beams. They have been built in the 1980s and operated since then to study W and Z bosons and search for particles of new physics possibly showing up at high energy. All the four detectors are also good cosmic ray detectors but only a few years ago, it was realized, that during their pretty long lifetime, they could also make interesting contributions to astroparticle physics. Several projects have emerged from the different collaborations. We present below the pioneer project of the L3 collaboration, known as L3+C [1]. The different upgrades to register cosmic rays in good conditions are described and the main physics goals mentioned.

2. L3 as a cosmic ray detector

The L3 detector [2] shown in Figure 1, is one of the four large detectors at the Cern LEP electron positron facility. It has 2 essential ingredients for cosmic ray studies:
- An axial magnetic field of 0.5 Tesla inside a volume of more than 1000$m^3$, produced by an Al coil within an iron return yoke of about 7800t.
- A muon spectrometer, made of large drift chambers, organized on an octogonal basis, filling the whole volume. Each octant shown in Figure 2, consists of 5 different precision drift chambers arranged in 3 layers, three "P chambers" measuring the track position in the $r-\phi$ plane for momentum determination, two "Z chambers", above the first and third layer for measuring the $z$ coordinate. Each track coming from the center of the detector is measured on a 2.9 m distance by respectively 16, 24 and 16 wires. This experimental setup provides a momentum resolution, as measured on the Z resonance, of 2.5% for 45 GeV track coming from the vertex. The precision on the angular determination is less than 0.1 mr and the maximum detectable momentum around 1.8 TeV.

As a muon cosmic ray detector, the L3 experimental setup has some advantages when comparing to others underground detectors:
- Its shallow depth with only 30 m of molasse
above the detector (80 interaction lengths, 290 radiation lengths) is just enough to stop the electromagnetic and hadronic components of air showers. The ground level is flat and the ground composition well known, making energy loss corrections for incoming particles small.

- The cosmic muon flux is very high (around 500 Hz) when compared to other detectors. Energy threshold corresponds to approximately 15 GeV, but the effective threshold can be tuned thanks to the momentum analysis capacity.

- Small depth means also low multiple scattering and small energy losses for incoming cosmic ray muons. For example, multiple scattering for a 100 GeV/c muon is less than 3 mr, the main contribution to the angular resolution.

- The detector has a fairly good homogeneous acceptance in the \( \phi \) direction (the angle in the plane perpendicular to the axis of the detector). This constitutes an important feature when comparing to the usual parallelepipedic shape of the underground detectors.

- The unrivalled muon momentum resolution provides a new dimension in the cosmic ray muon analysis. The momentum range for a given study can be optimized or a charge selection can be made. All with very low systematic uncertainties.

3. The L3-C experiment

In the normal L3 data acquisition system, cosmics are considered as background and a lot of efforts has been done in the previous years, to minimize their contribution to the acquisition rate. To adapt cosmic detection to the L3 detector, some upgrades were needed and have been implemented. This is known as the L3+C experiment.

- It was necessary to make the two experiments, L3 and L3+C, as independent as possible and for that an independent readout and data acquisition system has been developed for the cosmos. The muon spectrometer is now serving 2 separate experiments. Signals from each wire is splitted at the front end electronics. Then each part is going through its own electronic, readout, trigger and data acquisition systems.

- Muon chambers need a dedicated reference time, \( t_0 \). This is necessary in order to have good track fits and good momentum resolution. In L3, this is provided by the precise crossing time of the two particle beams at the intersection point. For L3+C, a scintillator array has been constructed and installed over the top of the magnet (see Figure 1). A total of 34 modules are covering the 3 upper octants, providing altogether a scintillator area of 204 m\(^2\). Each module is divided into 6 cassettes 1 \( \times \) 1m\(^2\). Each cassette is made of 16 tiles, each one readout by 2 \( \times \) 4 wavelength shifting fibers along its surface, and clear fibers running up to the phototubes. Each tile has a 2 cm thickness and a size of 25 \( \times \) 25cm. In total 68 phototubes are used to readout the whole detector. The time resolution has been measured to be better than 1.5 ns on the whole area. The muon track, as seen in the muon chamber, is first roughly reconstructed back to the particular scintillator tile. From the impact point a precise \( t_0 \) information can be obtained and the momentum computed.
4. Status and preliminary results

In 1998, scintillators were installed above the upper octant and new electronics was added for 2 octants. A running-in period could take place, with the data collected for the first time as an independent experiment. The remaining of the equipment was completed in spring 99 just before the beginning of the LEP operation and since then, data is continuously accumulating at the rate of about 500 Hz, still with a lifetime exceeding 96%. The $2.10^{9}$ event mark was reached on July 20. Analysis production is just starting. Figure 3 shows a reconstructed dimuon event and Figure 4 examples of distributions obtained with 19K reconstructed events. Observed structures in the azimuthal distributions reflect the presence of the various shafts around the L3 location and is rather well reproduced by the preliminary simulation using CORSIKA.

Figure 4. Azimuthal (data and Monte Carlo) and momentum distributions obtained in L3+C with cosmic muons

5. Physics perspectives

A primary objective of the L3+C experiment is a precision measurement of the muon momentum spectrum. Numerous sea level data have been obtained, mainly in vertical or horizontal direction [3]. Results are in rather poor agreement with one another, even though each experiment in itself has very good statistical accuracy (Figure 5). This points to significant systematic errors, as high as $30 - 35\%$ in the range below 1 TeV. L3+C is aiming to provide a measurement of the absolute flux at the level of a few %, in the momentum range 20-2000 GeV/c.

The measurement has a great interest, especially for the calculation of the neutrino flux [4]. The point is that atmospheric muons and neutrinos are generated in the same process. So the accuracy on the neutrino flux calculation can be improved by forcing the models to fit the data on the muon flux. Measurement of the muon mo-
Figure 5. The differential sea level muon momentum spectrum from the vertical direction.

Figure 6. The momentum spectrum in the knee region.

The differential sea level muon momentum spectrum can then be used as a normalisation for the \( \nu \) calculations. The L3+C results, important for the upward going muon flux, must have small systematic errors:

- the acceptance of the detector is well known (after 10 years of LEP data)
- the extrapolation of the measured flux to the flux at the surface is small and through a well known medium.
- there is a good control of the various inefficiencies (trigger, scintillator and muon chamber inefficiencies, dead time ...)
- well calibrated muons from Z decays are available at the beginning of each year.

Of course, the muon charge ratio, the zenith angle dependance, the possible time variations, as function of momentum, will also be investigated. There are all of considerable interest.

A very well known feature of the primary energy spectrum is the change of slope observed in the region of 1000 TeV to 3000 TeV (Figure 6). Knowledge of the mass composition in this region would be important as it can allow to validate some of the models built to account for the structure [5]. One way to select events from the knee region is to choose high multiplicity events with high energy muons. By measuring the multiplicity versus the muon energy threshold (which can be as high as 2 TeV), L3+C can provide new data to solve the problem of the origin of cosmic rays in the knee region.

There is no experimental measurement of the \( \overline{p}/p \) ratio at high energy. The ratio, if due to secondary production processes, is expected to decrease with energy [6]. On the other side, a primary origin for the antiproton, as a result of models from symmetric universe with an antimatter extragalactic component, would lead to an increase of this ratio, at level as high as 10% at 1 TeV [7]. So the interest to make a measurement there, where no limit exists (Figure 7). One way to measure the \( \overline{p}/p \) ratio in the TeV region is to use the shadowing effect of the moon. The latter acts as an absorber and the earth magnetic field as a charge and energy analyser, leading to a separate shadow for the muons coming from protons and antiprotons. At 1 TeV, the separation is around 40 mr, the moon radius is 4.5 mr. The correlation between the muon and the primary nuclei is good at these energies. The experiment is certainly difficult and simple calculations shows that 3 years of data would be necessary to set a 10% limit on the \( \overline{p}/p \) ratio, using a muon threshold of 100 GeV.
Search of evidence for point sources as spatial and temporal accumulation in muon data is quite important [8]. Muons from point sources cannot be explained in the standard model. Photons, the only neutral messengers are particularly inefficient in producing muons. So the affirmation that some excesses were observed in the past, sometimes in coincidence with a radio burst, is rather puzzling. Due to the large data bank of muons available, the very good angular resolution and the possibility to tune the momentum threshold, L3+C can reach a very high sensitivity in this search.

During the last year, the so-called neutrino atmospheric anomaly has turned more and more to an evidence for neutrino oscillations. This is mainly the result of the Super-Kamiokande water Čerenkov detector. The evidence concerns sub-GeV, multi-GeV as well as the dependence of the flavor anomaly on the lepton zenithal angle. Another evidence could come from the measurement of upward going muons. If neutrino oscillations are the explanation of the observed anomaly, then there must be a suppression factor for the upgoing muon flux, and both the energy and zenithal distribution must be strongly affected. In fact, both Kamiokande [9] and Super-Kamiokande [10] have measured a reduced flux of upgoing muons. However due to the large uncertainties in the absolute flux, the evidence is not so strong and it is precisely the aim of L3+C to improve the knowledge of the expected absolute flux. But thanks to the measurement of the crossing time, at the scintillators and at the chamber anode planes, L3+C can also do its own measurement of upward going muons, adding with the muon momentum determination a new dimension to the measurement. The effect of the oscillation can be observed on the momentum spectrum, independently of the absolute normalisation. This may proved to be very valuable, in particular to differentiate any oscillation due to sterile or tau neutrino [11].

6. Conclusions

The items mentioned in the previous paragraph are only some of the physics topics which could be investigated with such an experiment measuring precisely, direction and momentum of cosmic ray muons, both downwards and upwards. All the studies will not be completed with the end of L3+C. In particular, the expected stop of the LEP accelerator will put severe statistical limitations on some of the studies. However, L3+C can find interesting results in the coming years and pave the way for more extended cosmic ray measurements in the future.

REFERENCES