Cosmic Ray Muon Physics with the LEP Detectors at CERN; an Overview

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Traditional studies of cosmic ray muons were carried out by either underground detector systems, where the inclusive muon spectrum could be deduced from the differential range data [1], or with magnetic spectrometers at the surface [2]. Studies of multimuons were also carried out [3], [4]. The references cited are older examples. An excellent recent review of cosmic ray muon data is given in a paper by Bugaev, et al. [5]. At this Workshop, he will summarize existing muon data.

The LEP detectors at CERN each represent over 100 million Swiss francs of capital investment and countless man-years of effort; much more than could be justified for cosmic ray muon studies. However it was recognized that, with a modest incremental effort, these detectors possessed an exceptional potential to contribute to our knowledge of cosmic ray muons. For the L3 Detector, a $200m^2$ scintillator layer has been added above the iron magnet yoke to serve as a T0 trigger counter, and the electronics have been modified to provide a totally independent readout of the muon drift chambers so that cosmic ray data can be taken with 100% live time and without interference with the LEP electron-positron physics data collection. At the ALEPH detector, the TPC chamber output is recorded during every LEP beam-crossing for several microseconds, providing several percent overall livetime during which cosmic ray events are recorded.

Up to the present, the focus of the "L3+Cosmics" group has been on determining an inclusive muon spectrum to a precision of one or two percent, as functions of zenith angle, muon charge, etc. [6] This will be more than an order of magnitude better than the existing inclusive muon data, and such data has assumed much greater importance with the observations by Super-Kamiokande of evidence for atmospheric neutrino oscillations [7]. The physicists who have calculated the atmospheric neutrino spectrum [8] have very strongly urged the collection of these more precise data. H. Wilkens discusses the L3+Cosmics program further in his presentation at this Workshop.

Members of the ALEPH Collaboration have focused on studying multimuon events, and have collected a good sample of such data from the 1997 -

1998 LEP runs. They have compared these data with multimuon predictions from the Monte Carlo simulations developed by the Karlsruhe group, and observe a significant excess of five events with exceptionally high multiplicities. These results and analysis are also presented at this Workshop by J. Strom and A. Bruhl. The Monte Carlo programs used to calculate the muon multiplicities, etc., of course must assume a model for the particle physics of the primary cosmic ray particle collision with air nuclei in the upper atmosphere, and these models must rely on very uncertain extrapolations of much lower energy accelerator data. D. Heck discusses the Karlsruhe Monte Carlo programs, and C. Taylor and R. Engel discuss the physics of forward particle production at this meeting. Note that there is a fundamental ambiguity between the mass composition of the primary cosmic rays and the x-distribution of the forward-produced particles in the primary interactions in interpreting sea-level data, hence as many observables as possible are desirable.

The Cosmo-ALEPH group has also made measurements of the "decoherence curve" for underground muons; i.e. the coincidence rate of muons as a function of the separation of two detectors in the LEP tunnel near ALEPH. M. Schmelling discusses these data, and J. Kempa discusses corresponding calculations here.

While the L3 group has so far focused on inclusive muon spectra and the ALEPH group on multimuons, both groups plan to pursue the broad spectrum of muon physics issues. The detectors are quite complimentary; L3 is under only 30 m of rock, hence has a muon threshold of about 15 GeV, while ALEPH is under 150 m of rock, with a muon threshold of about 75 GeV. Both groups have discussed adding surface air shower arrays to correlate air showers with the multi-muon events; at this meeting, S. Tonwar presents the plans of the L3+Cosmics group, while K. Eggert and V. Avatin discuss the addition of other detectors around the ALEPH installation.

A. De Roeck from DESY is also participating in this Workshop; as the HERA detectors (ZEUS and H1) are under a much shallower overburden, cosmic ray muons down to 2 or 3 GeV could be studied at HERA, nicely complementing the CERN activities.

Other cosmic ray muon topics which will be pursued at CERN include the search for astronomical point sources, including possible primary energetic cosmic gamma rays [9]. If the resolution is sufficient, the moon's shadow should be visible in the muon directional data. If so, it will be shifted from its true position in the sky due to the Earth's magnetic field. By seeking evidence for an "anti-shadow", it may be possible to put limits on the flux of negatively-charged (i.e. antimatter) primary cosmic ray baryons in a new, higher-energy domain.

H. Wachsmuth had earlier proposed that coincidences be searched for between the four LEP detectors. Such a coincidence would be evidence of an unusual astrophysical process, as it is virtually impossible for a single primary cosmic ray, interacting in the stratosphere, to initiate such a coincidence. Wachsmuth's proposed "CosmoLEP" search was in part stimulated by a published Swiss search for a 4-fold coincidence (more accurately, a time correlation) between detectors spaced by over 100 km [10]. A subsequent Japanese report has discussed a search for such time correlations between small air shower arrays in widely-spaced cities [11]. It is possible that the HERA detectors could also couple into this study, using the GPS precise time technology to seek off-line time correlations with LEP detectors.

The Chinese IHEP group are active participants in the L3+Cosmics group, and have discussed the search for a particular WIMP (weakly interacting massive particle) candidate which they believe other, older evidence suggests. They note an unusual track recorded in a cloud chamber (1972) which they interpret as a charged particle with a rest mass of at least 40 GeV. And they argue that events seen in the Kolar Gold Fields detectors and in the LVD detector in the Gran Sasso Tunnel are compatible with the decay of very massive neutral particles [12]. They conclude that the evidence is compatible with a neutral and a charged WIMP, each of at least 40 GeV rest mass, which may be found among cosmic rays and which may charge exchange through nuclear collisions. It is interesting to note that the IMB collaboration also observed events which they referred to as "Isobursts" in their proton decay detector; these (unpublished) observations appeared altogether compatible with the KGF and LVD reports. If such particles exist and decay in a LEP detectors, their properties and decay products should be amenable to unambiguous analysis.

In conclusion, the cosmic ray muon studies with the LEP detectors at CERN contain the ingredients of the ideal experimental program: (1) They will produce certain physics results which, though perhaps not exciting, are surely useful (e.g. the inclusive muon spectra). (2) At the same time, there are potentially very exciting observational possibilities, which, if something is found, would open the door to new physics (e.g. CosmoLEP and the IHEP WIMP search). In between, other studies, such as multimuons, will add to our understanding of both the primary cosmic ray composition and the physics of high-energy strong interactions.

References

[1] S. Miyake et al., Il Nuovo Cimento **XXXII** (1964).

[2] F. Ashton, et al., Proc. Phys. Soc., **87** (1966) 79.

[3] V.K. Batanov, et al., Proc. XXIV Int'l Cosmic Ray Conference **1** (1995) 561.

[4] S. Miyake, et al., J. Phys. Soc. Japan **18** (1963).

[5] Bugaev, et al., Phys. Rev. **D 58** 054001 (1998).

[6] J. Baehr, et al., L3 Internal note No. 1977 (1996).

[7] Y. Fukuda et al., Phys. Rev. Lett. **82** (1999) 2644.

[8] V. Agrawal, et al. Phys Rev. **D 53** (1995) 1314; T.K.Gaisser, et al. Phys. Rev. **D 54** (1995) 5578; M. Honda, et al. Phys. Rev. **D 52** (1995) 4985.

[9] F. Halzen, T. Stanev, and G.B. Yodh, Phys. Rev. **D 55** (1997) 4475.

[10] O. Carrel and M. Martin, Physics Letters **B 323** (1994) 526.

[11] T. Wada, et al. "Observation of time correlation in cosmic air shower network" presented at the X International Symposium on Very High Energy Cosmic Ray Interactions, Gran Sasso, Italy, July, 1998 (to be published).

[12] H.S. Chen, et al., Physics Reports **283** (1997) 1.