Nuclear Physics B (Proc. Suppl.) 35 (1994) 243–245
North-Holland

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

Multiple Muon Events Observed in the LVD Experiment *

LVD COLLABORATION

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This is a progress report on the multiple muon events recorded by the first tower of the LVD detector at the Gran Sasso Laboratory. About 17,000 multiple muon events have been observed since the LVD first tower started operation in June 1992. Presented here are the measured multiplicity distribution and separation distribution of muon pairs in the bundles.

1. INTRODUCTION

Elemental composition of the primary cosmic rays contains the information about the nature of the cosmic ray sources, mechanisms of acceleration[1] and propagation in the interstellar medium[2]. The multiplicity distribution of underground muon bundles and the separation of muon pairs are sensitive to the spectrum and composition of the primary cosmic rays and properties of hadronic interactions. The primary energies involved at our depth(about 3,300 kwe is the minimum) extend up to about 10^{16}eV, where the spectrum becomes softer. Deep underground detectors attempt to indirectly study the compo-

*Presented by H.Tang for the LVD Collaboration.

SSDI 0920-5632(94)00463-6

sition at high energies by comparing muon multiplicity distributions to Monte Carlo predictions based on various composition models([3] and references therein). The results from other experiments like Baksan, NUSEX and MACRO can be found in [4–6].

2. LVD DETECTOR

LVD(Large Volume Detector, 40m×13m×12m) at Gran Sasso Laboratory will contain 5 identical aligned towers with 38 modules in each tower. Each module contains 8 scintillation counters, which have 3 photomultipliers on the top, and an L-shaped tracking detector attached on the bottom and one vertical side of a module[7].

Each leg of an L-shaped tracking detector contains two layers of 6.3 meters long limited streamer tubes. The basic tube element has 8-cells with 9×9 mm^2 active cross sectional area for each cell. Below and parallel to, and above and perpendicular to the streamer tube wires are 4 cm wide pickup strips (x and y strips),to provide bidimensional information about an ionizing particle's impact point. The staggered double layers of streamer tubes and their orthogonal readout strips of tracking system yield an effective strip width of 2 cm with no dead space, high overall tracking efficiency, and an angular resolution better than 4 milliradians[8].

3. DATA SELECTION

Here we have used the data recorded in 7154 hours of operation with the first tower of LVD from June 1992 to September 1993. In this period 39109 candidates for multiple muon events have been reconstructed. Any event which did not complete in 200 seconds of CPU time was dropped from the sample in this preliminary study. This implies our data for multiplicities greater than 10 are very preliminary.

When a muon passes through the detector, the signal("hit") produced in the tubes is picked up by nearby x and y-strips. A set of adjacent hits is defined as a "cluster". A "LEG" software trigger occurs when at least one x-strip cluster in the horizontal or vertical part of a tracking detector is hit, as well as at least one y-strip cluster. This is the minimum information needed to define a "point". "TK" software trigger occurs when clusters exist in both layers of x-strips of a leg.

The following cuts were subsequently applied to the 39,109 multi muon candidates mentioned above to get the multi muon event data sample:

1. At least one scintillation counter was triggered in the event.
2. Each track should pass three LEGs, one of which is a TK software trigger.
3. The angle between each pair of muon tracks should be not greater than 3°, to exclude non-parallel secondary particles produced by muon interactions in the surrounding rock or in the detector absorber.
4. A sample of the two muon candidates were scanned visually, as showers or a muon plus a shower can be reconstructed as two muons. It was determined that this was a problem only for two muon candidates whose distance was less than 60cm. All such candidates were scanned and evaluated visually.

The effect of these cuts on the data sample are given in Table 1.

Table 1 Data Sample

Sample	Events
Multi muon candidates	39109
Multi muons after cut 1	37109
Multi muons after cut 2	20818
Multi muons after cut 3	19556
Multi muons after cut 4	16875

4. RESULTS

Figure 1 shows the number of multi muon events as a function of multiplicity; only statistical errors are shown. The ratio of the counting rate of multi muon events to single muons is about 0.027.

Figure 2 shows the measured distribution of muon pair separations in 0.5 m bins. The bin

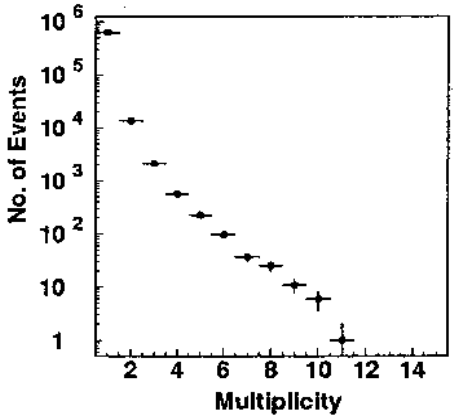

Figure 1. Muon multiplicity distribution.

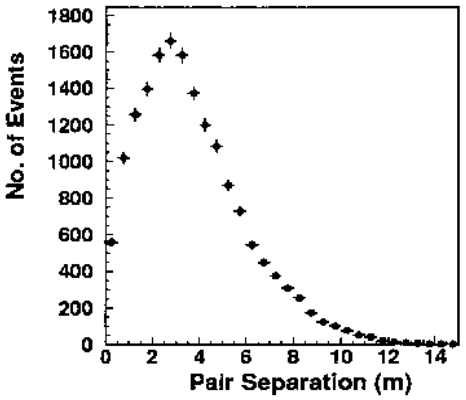

Figure 2. Muon pair separation distribution.

width is much greater than the spatial resolution of the tracking detector ($\sim$ 1 cm). The plot was produced by including each event with unit weight; i.e., each pair in an event with observed multiplicity N is entered with a weight $\frac{2}{N(N-1)}$.

Figure 3 shows the zenith and azimuthal angular distributions of multi muon events in the LVD reference system[9]. They are similar to those for single muons. The dips shown in the ϕ distribution are primarily due to the absorption of the muons by mountain rock.

5. PROSPECTS

By the end of this year, we expect about 20,000 multi muon events from the first tower. Since the second tower will start to take data in the next year, we will soon have higher multiplicity muon events and higher statistics.

A comparison of our results with Monte Carlo predictions from different primary composition models is in progress.

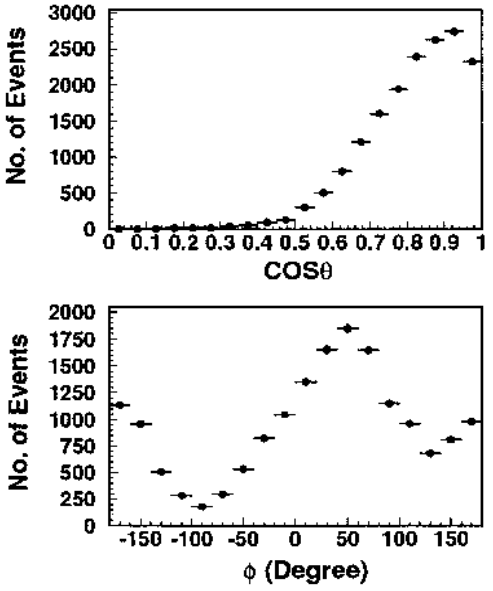

Figure 3. Angular distributions of multi muon events.

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