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MULTIPLE MUON EVENTS IN SOUDAN 2*

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Abstract

This is a progress report on multiple muon events recorded by the Soudan 2 detector.

__Introduction__ The number of underground muons produced as a result of the interaction of a cosmic ray nucleus with the earth's upper atmosphere depends upon the primary particle's mass and energy. Deep underground detectors attempt to indirectly study the composition at high energies by comparing muon multiplicity distributions to Monte Carlo predictions based on various composition models. A number of different models have been advocated in the literature. These models predict compositions at high energy which range from heavy (p-poor, Maryland) to medium and very light (Constant-mass, Linsley).[1] The effectiveness of the underground muon approach can be improved by the use of a surface array in conjunction with the underground detector.[2][3][4] In addition to composition studies, the properties of underground multiple muon events can be used in the study of prompt muon production, multiple muon astronomy, and high energy nucleus-nucleus collisions.

__Soudan 2 Detector and Shield__ The Soudan 2 detector is a tracking calorimeter located at a depth of 2090 mwe corresponding to a muon threshold surface energy of 0.6 TeV.[5] At completion, the detector will be 1 kiloton, with each module containing 240 layers of 1.6mm-thick corrugated steel sheets interwoven with 7560 15mm-diameter by 1m long plastic drift tubes. For multiple muon events, Soudan 2 has exceptional capabilities for both track resolution ($\sim 1\ cm$) and angular resolution ($< 1^o$).

The Soudan 2 main detector is surrounded by a 14x10x31m proportional tube veto shield.[6] For multiple muons, the shield provides an enhanced acceptance area for events which have at least one track through the main detector. The top surface area of the shield is 431 m^2 or 3.3 times the top surface area of the main detector at 130 m^2. The fraction of all muon events which are multiples in the shield is expected to be 0.10, while in the detector it is expected to be approximately 0.04. This is a projected rate of 200,000 detector and 500,000 shield multiple muon events per year.

An example of a dimuon event is shown in Figure 1. Shield hits which match the two

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main detector tracks are shown. There is an additional pair of hits which correspond to a third muon passing through the shield but outside the main detector.

Data A sample of 275,000 muon events were recorded in the main detector during an effective operational time of 500 hours during May 1991. During this period, the active main detector consisted of 160 modules with an 80 square meter top surface area. 4.37% of all muon events were selected as multiple muon events based on the criteria that the angle between reconstructed tracks be less than 10^o. The multiplicity distribution has not yet been corrected for systematic errors, and in particular the track reconstruction efficiencies for multiple muon events are not yet known. The results of a scan of a small number of multiple muon events verses the multiplicity determined by the reconstruction software is tabulated in Table 1.

In the same data set, 7.28% of all main detector muon events were selected as shield multiple muon events. To determine the shield multiplicity, shield hits which were adjacent in space and time (within 1 μsec) were first combined to form shield "groups". The multiplicity was then determined as the number of pairs of coincident shield groups which formed a line parallel to the main detector track. This selection procedure produced a shield multiple muon rate of 40 events/hour.

The abundance of multiple muon events is due to Soudan 2's relatively shallow depth. A slant depth cut will enable a selection on the events which have a higher energy primary cosmic ray. The statistics after such a cut would be comparable to a similar detector at a depth corresponding to the slant depth cut.

Lateral Distribution and Angular Separation Uncorrected distributions of lateral and angular separation between muons are shown in Figures 2 and 3. The average track separation is 4.8m with a rms of 2.5. The separation is restricted to 14.3m by the dimensions of the detector. Plots of track separation recorded at various slant depths can be used as the basis of decoherence curves. Such curves are used to determine the average transverse momenta of the muon parent particles as a function of energy.

Conclusion Analysis of multiple muon events in the Soudan 2 detector is actively underway. Future plans include work to utilize the rapidly increasing sample of multiple muon data to test models of the primary cosmic ray composition.

References

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	Reconstructed Multiplicity					
Scanned Multiplicity	1	2	3	4	5	6
2	7	201	2	-	-	-
3	-	4	23	1	-	-
4	-	-	-	8	-	-
5	-	-	-	1	4	-
6	-	-	-	1	1	3

Table 1: Tabulated values of scanned multiplicity verses reconstructed multiplicity for a small number of events.

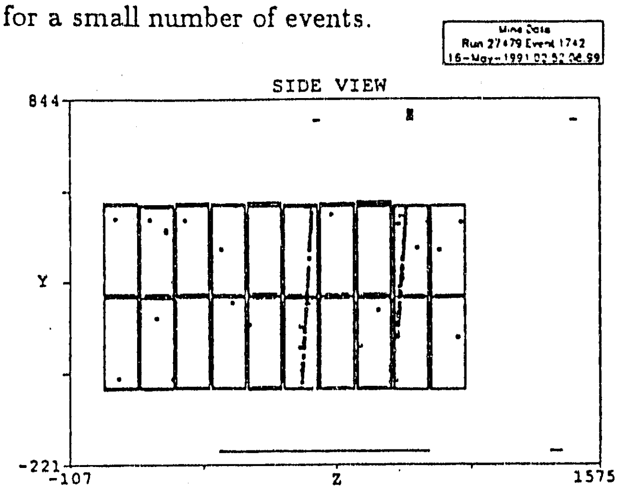

Figure 1. The side view of a reconstructed multiple muon event in which two muons pass through the detector and a third passes through the shield but outside the main detector. Dimensions in the z and y directions are shown in centimeters.

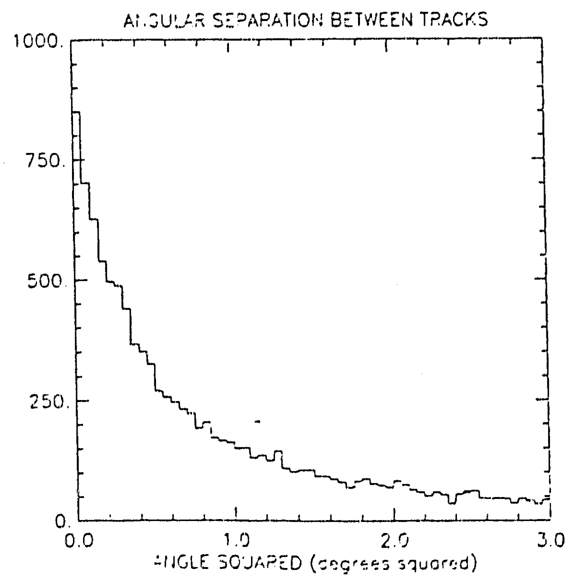

Figure 2. Uncorrected lateral distribution shown with 0.08 meter binning. The mean track separation is 4.79 meters.

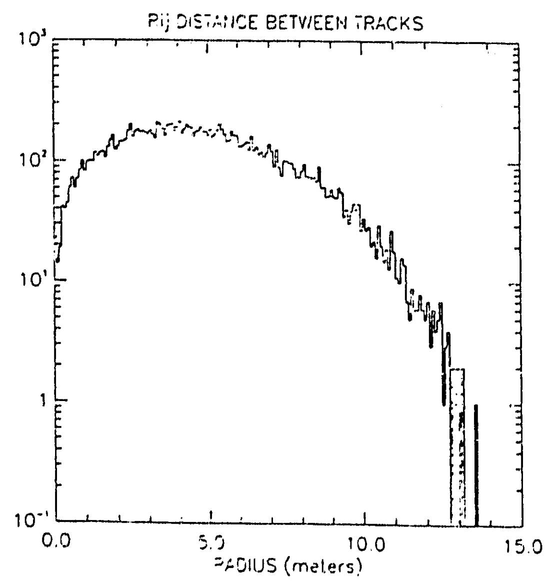

Figure 3. Uncorrected angular distribution shown with 0.05 degree binning.

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