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A MEASUREMENT OF THE ANGULAR RESOLUTION OF AIR SHOWERS A USING THE MUONIC COMPONENT AT GROUND LEVEL

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M.C. Goodman
*Argonne National Laboratory, USA

G.B. Ellsworth
George Mason University, Fairfax Virginia, USA

J. Bofill, D. Bogert, R. Burnstein, R. Fisk,
J. Morfin, T. Ohska, L. Stutte, J. Walker and G.P. Yeh
Fermilab, Batavia Ill., USA

H. Freudenreich, J.A. Goodman and G.B. Yodh
University of Maryland, College Park Md., USA

W. Busza, T. Eldridge, S. Fuess, J.I. Friedman, H.W. Kendall,
T. Lyons, R. Magahiz, T. Mattison, A. Mukherjee, L. Osborne,
R. Pitt, L. Rosenson, A. Sandacz, F.E. Taylor, R. Verdier and S. Whitaker
Massachusetts Institute of Technology, Cambridge Massacusetts USA

M. Abolins, R. Brock, A. Cohen, J. Ernwein, D. Owen,
G. Perkins, J. Slate, M. Tartaglia, H. Weerts and A. Werthmann
Michigan State University, East Lansing Michigan, USA

S.C. Gupta, K. Sivaprasad and S. Tonwar
Tata Institute , Bombay, India

Abstract

The angular resolution of cosmic ray air showers is found to be 13.4 mr using single tracks and as good as 2 to 4 mr from all of the tracks for selected events by using the muonic component of air showers and a fine grained calorimeter. The sample of events was 8776 events triggered by an air shower array in which 3 to 76 muons were reconstructed. There was very little dependence of the single track angular resolution on either the number of muons or the shower angle.

1. Introduction The question of angular resolution for ultra high energy gamma ray showers is an important one in the possible location of sources of high energy gamma rays. Angular resolutions as good as 9 mr are being reported for large air shower arrays. /1/ The angular resolution from events initiated by charged protons or heavy nuclei has not been considered as important, because galactic magnetic fields cause the fluxes of charged particles to impinge on the earth isotropically. However, results from the Kiel detector /2/ and underground muon experiments /3/ have suggested the possibility that showers with normal muon content may have a component caused by particles which do point back to astrophysical sources. Also the angular resolution from the muon content can serve as a calibration of electromagnetic direction detection since showers with muons also contain

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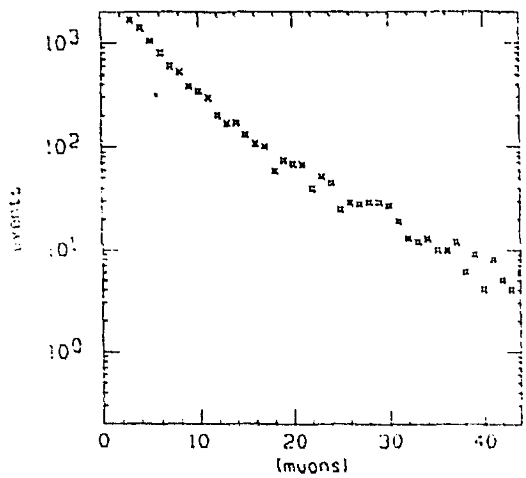

Figure 1: Muon number distribution

an electromagnetic component.

2. Data Analysis The results obtained here were taken by a small shower array placed near the $80m^2$ E594 neutrino detector at Fermilab which had a two week run in 1984. The trigger was a requirement that at least two of the four 1 m^2 shower counters which were 20 m apart be above a threshold of 5 particles. The detector and muon identification techniques have been discussed previously /4/. There were 8776 events in which three or more muon tracks were seen traversing the detector. Using a local density cut, a pattern recognition program was able to ignore the electromagnetic and hadronic parts of the shower, and then do standard track fitting with the muons. For a muon traversing from the front to the back of the detector, the geometrical resolution is 1 mr. The actual achIEved resolution from accelerator muons was 1.5 mr. The geometrical resolution for typical cosmic ray muons, which enter at an angle from 20 to 50 degrees from vertical, is 3 mr.

The distribution of the number of muons detected is given in Figure 1. The detection efficiency rises as the number of muons increases, due to the pattern recognition algorithm. Scanning a large number of events led to the conclusion that some of the $n_\mu = 3$ to $n_\mu = 7$ events were actually events with a projected x angle less than 20^o in which no muons were visible, and false muons were found near 80^o. Also for events with a large number of muons, some of the muons are partially obstructed in the calorimeter by electromagnetic and hadronic components of the shower. Neither of these effects contribute to the angular resolution for events between 20^o and 50^o.

A typical x view of an event with a large number of muons is shown in Figure 2. Since the detector was designed to point at the neutrino beam, the orthoganal projected angle was not well measured. Track finding is done with an algorithm which first eliminates dense regions of tracks in the detector, and then looks for angular correlations among all clusters of hits. After an approximate event angle is found this way, projections along that angle are made throughout the detector to find muon tracks. A fit to the angle of each muon is individually made within a narrow road around the track. A weighted average

Figure 2: X view of an event. Notice the electromagnetic component ranging out in the top fifth of the detector, and a large muon component.

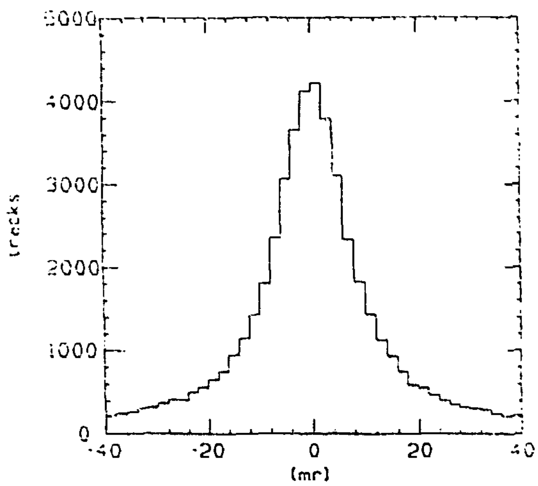

Figure 3: Single track deviation from weighted mean

angle is then determined iteratively by using the measured global angular resolution as a trial function for a fit to the muon angles in each event. This improves the single track angular resolution by 40% over using the mean angle. The deviation of each track from the weighted mean is indicative of the information that a single muon provides regarding the direction of the event. Using all of the muons in an event gives an error of the mean which is a better indication of the true event direction.

These deviations for all muons are plotted in Figure 3. A cut is made on those muons which deviate from the average by more than 40 mr. The deviation as a function of muon number is shown in Figure 4. The one muon resolution obtained is 13.4 mr. It is seen that there is almost no dependance on muon number in the deviation. The corresponding error in the mean, assuming that the deviation of muon directions from event directions is uncorreleated is also shown in Figure 4, and ranges from 8mr for $n_\mu = 3$ to 2 mr for n_μ ¿ 40. Deviations due to resolution effects in the detector, multiple scattering in the atmosphere and multiple scattering in the detector should dominate the resolution and be uncorrelated. However there may be correlations among the muons as they are emitted in the shower and due to geomagnetic effects. This corresponds to the best determination of the event angle. For $n_\mu > 10$, the resolution is 2-4 mr, or at least 4 times better than air shower array techniques.

3. Discussion The angular resolution does not seem to vary at all when a cut on the

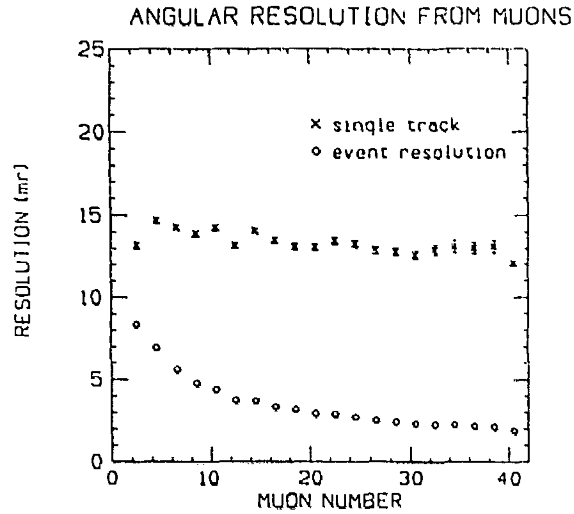

Figure 4: Muon number dependance of track resolution

electromagnetic component of the shower is made. However there is a significant difference between the events which are low angle (20 to 30 degrees) and high angle (30 to 50 degrees). The low angle resolution is 14.5 mr while at high angle it is 12.3 mr. This is counter-intuitive, but may mean that higher angle showers which penetrate the thicker atmosphere have higher energy muons which undergo less multiple scattering.

The muons were not momentum analyzed, though they had to minimally traverse 660 gm/cm^2 in the detector plus the atmosphere, which implies a minimum energy of 2.5 GeV. However, two different methods were used to estimate that the mean muon energy was 4 ± 1 GeV. The angular divergence of tracks within an event could be accounted for by the multiple scattering in the atmosphere and the detector if the average muon energy is 5 GeV. Also, a monte carlo showed that the mean residual along the track was a fairly sensitive indication of the average muon energy as it traversed the detector. The best match for the mean residuals in the data occurred using a monte carlo of 4 GeV muons.

4. Conclusion In conclusion, we have measured a projected muon angular resolution from single tracks in cosmic ray air showers of 13.4 mr. For selected events with large numbers of muons, the event angular resolution accuracy is 2 to 4 mr.

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