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# A MEASUREMENT OF THE HADRONIC COMPONENT OF AIR SHOWERS IN A FINE GRAINED CALORIMETER

M.C. Goodman
*Argonne National Laboratory, USA

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

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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 hadronic component of extensive air showers is studied using the E594 fine grained calorimeter and a air shower array trigger. Hadron angle and energy distributions are shown. Events with more than one separated hadron with substantial energy are studied carefully. The correlation of hadronic and muonic components are shown.

1. Introduction. Special purpose cosmic ray detectors tend to emphasize the electromagnetic, muonic or hadronic component of the cosmic ray events. A number of large calorimeters have been built for use in accelerator experiments, which can give information about all three components of cosmic ray air showers. Here we describe a low statistics experiment using the Fermilab E594 detector, with emphasis on the hadronic component.

2. Description of the Detector. The detector was designed and built to study neutral current events in the Fermilab Neutrino beam. The detector was run with a small air shower array in with an air shower trigger for cosmic ray studies. The trigger consisted of the requirement that two out of four 1 $m^2$ shower counters, each 20 m apart, record at least 5 particles. The ability to measure muons in the calorimeter and the electromagnetic component in the air shower array has been described previously./1/ Here the ability to measure the hadronic component is described in more detail. An overview of the detector is given in Figure 1. It consists of 608 flash chambers which are 4 meters by 4 meters, and 37 proportional chambers. The proportional chambers are not used in the muon or electromagnetic shower identification, but are central in the hadron identification. The chambers are extruded aluminum cells which are 2.5 x 2.5 cm. in size. They are filled with 80% Argon 20% Ethane. Each plane of proportional tubes is separated by 46 cm and one half of



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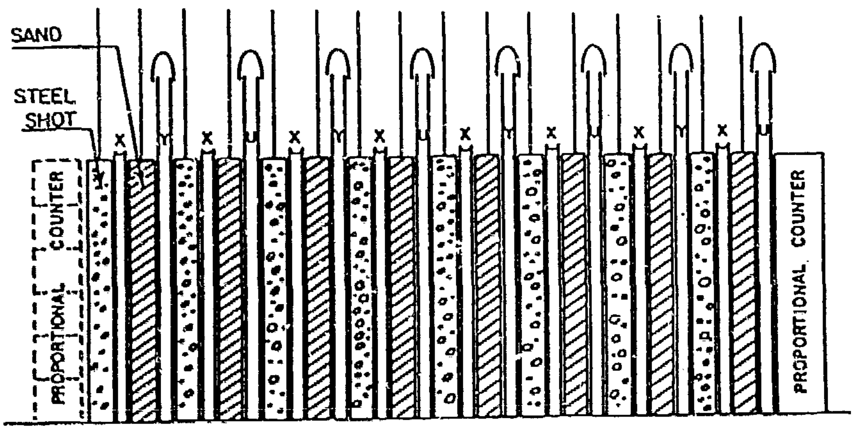


Figure 1: View of a section of the 340 ton neutrino detector with 16 of the 608 Flash Chambers. Neutrinos enter from the left; Cosmic Rays from the top.

an interaction length of iron shot and sand. The average density is 1.6 gm/cm$^3$.

The proportional tubes were calibrated for the neutrino running by using a positive hadron beam perpendicular to the chambers which was set at 100, 200 and 300 GeV. As this preferentially illuminated the chambers near the front (the full detector was 18 interaction lengths), the chambers near the back were checked for calibration, uniformity and stability using single cosmic ray muons and Cadmium 109 source runs between hadron beam spills. Gains of individual channels were uniform with an RMS spread of 4% and stable to 8%. Channel to channel variations were 17%, but were calibrated out to 5%. Further details of the construction, calibration and operation of the proportional counters are available /2/.

The relevance of calibration using hadrons perpendicular to the chambers to the response of the detector to hadrons at small zenith angles was studied by monte carlo techniques. The conclusions of the monte carlo study are as follows:

1. The appropriate calibration constant to use for energy response at small zenith angle is the same as for hadrons perpendicular to the chambers. This is true for hadron energies up to 10 TeV and for zenith angles above 10°.

2. The resolution is substantially degraded due to large fluctuations in energy deposition between the proportional counters, and is very asymmetric towards the low side. This leads to an average energy measurement of about one half of the true energy, with a distribution fairly flat from zero to the true energy.

3. Neither the calibration constant nor the resolution depend strongly on the zenith angle or the impact parameter of the hadron at the top of the detector.

3. Hadron Analysis. In both the data and the simulation, most of the hadron energy measurement, for events with visible hadrons, comes from one or two chambers. This allows the easy separation of hadronic information from electromagnetic and muon contributions. It also allows easy identification of events with more than one separated hadron. Such events are of particular interest in the study of the $p_t$ dependance of the primary interaction in the atmosphere.

Figure 2 shows the distribution of the energy seen in the flash chamber hits ($E^{tot}$) and the

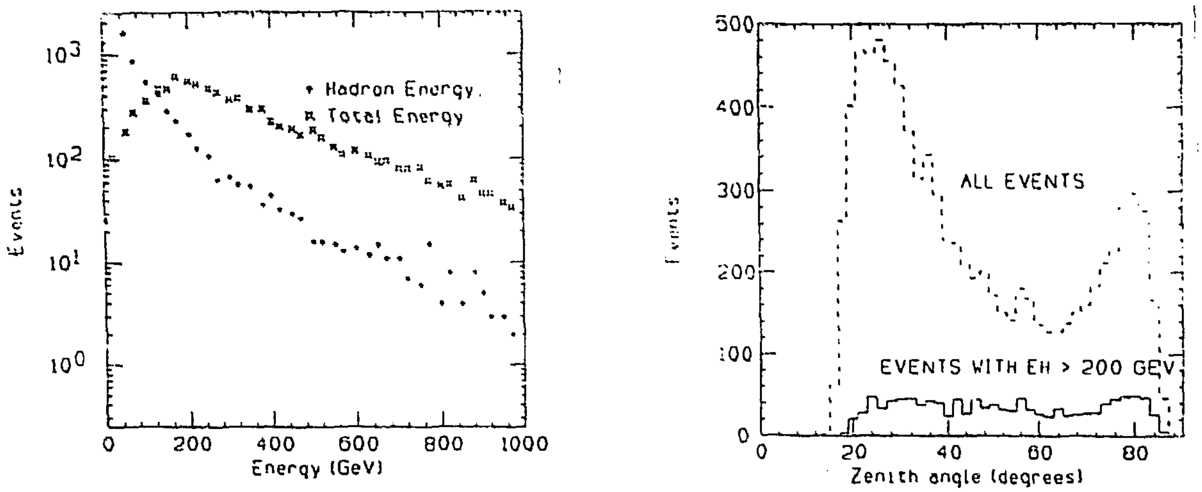


Figure 2: (A) Visible energy spectrum in the flash chambers (electromagnetic and hadronic) and in the proportional counters (hadronic). Proportional counters with a significant amount of electromagnetic energy are cut out. Hadrons above 50 GeV locally saturate the flash chambers. (B) Angle distributions for all events, and those with $E^{had} \geq 200$ GeV.

proportional tube energy ($E^{had}$) in the experiment. The data sample that was used included a cut that at least three muons are reconstructed. The number of flash chamber hits is dominated by the electromagnetic components coming in the top and side of the calorimeter and also includes the muons which penetrate the calorimeter. Substantial saturation of the flash chambers appears even for a 50 GeV hadron normal to the flash chambers. However the proportional tubes are a clear and sensitive indicator of the presence of hadrons in the detector.

The projected angle distributions of events is shown in Figure 2b. The peak at $80^o$ is a result of reconstruction inefficiency and represents about 20% of the plot. It comes from events at less that $20^o$ in which false muons were found at high angle. Also shown is the $E^{had} \geq 200$ GeV sample, in which there appears to be a greater average angle.

4. Correlations In the absence of fluctuations in shower development, and for primary cosmic rays of the same nucleon number, those events with the largest hadronic energy should also have the largest number of electrons and muons. As the hadron, muon and electromagnetic component identification are independent, it is possible to pursue these analyses separately, with little correlation in efficiency. Therefore a search for correlation in the highest 1% of the events in each quantity was done. As the electromagnetic part of the spectrum was done in both the shower counters and the calorimeter, both measurements are included. This is summarized as follows: The event samples were A) $n_\mu \geq 39$, (93 events); B) $E^{had} \geq 900$ GeV, (107 events); C) $n_e \geq 210$, (111 events); and D) $E^{tot} \geq 1.6$ TeV, (90 events). The union of the event samples was BCD–23 events, BC only–0 more events, BD only–20 more events, CD only–21 more events. There was no overlap of the A sample with any of the other three. Thus, the events with large numbers of electrons in the trigger counters are well correlated with the large amount of electromagnetic energy in the flash chambers. They are also well correlated with large amounts of hadronic energy. There are also a few events, however, with substantial hadronic content and very little electromagnetic energy. And the events with large muon content tend to have much more modest electromagnetic energy and practically no high energy hadrons. Monte carlos to understand the significance of these results are in progress.

5. Dihadron sample A filter has been developed to select events in which there are at least two hadrons of 100 GeV each separated by 1 m. 118 such events were found and individually scanned. Such an event is shown in Figure 3. It was found that 39 events had only one hadron or hadron

core which spread out laterally, or where the electromagnetic component penetrated far enough to register significant pulse height in the proportional counters. There were 36 events with two hadrons each greater than 100 GeV, 31 with three, 8 with four, 3 with five and 1 with six.

6. Summary The hadronic content of extensive air showers in the E594 neutrino detector has been studied. Events with high hadronic energy content appear to be minimally correlated with high muon content and weakly correlated with high electromagnetic content. 79 events with more than one 100 GeV hadron separated by 1 meter have been identified.

## References

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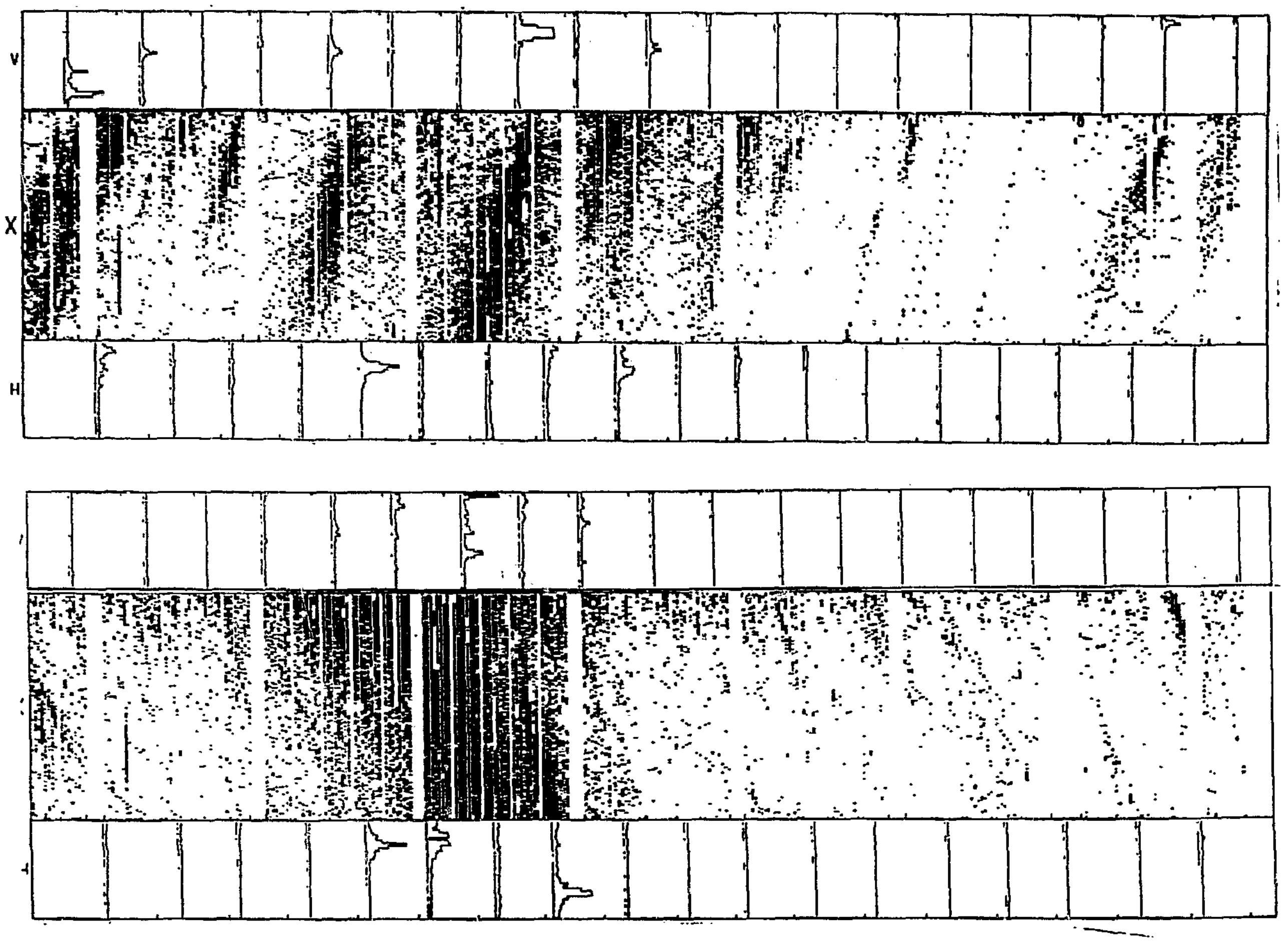


**Figure 3: Two multi-hadron events. Shown is the horizontal view of the flash chambers, and the pulse height information from each of the 40 channels in the 37 proportional chambers. A minimum energy can be determined for each hadron from the proportional counters. Hadron separation can be calculated more precisely in the flash chambers.**