PATTERN RECOGNITION FOR HADRONIC SHOWERS IN THE CHARM COLLABORATION

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ABSTRACT

The pattern-recognition procedure for hadronic showers in the fine-grained CHARM calorimeter is presented. The vertex and angular resolutions achieved after the upgrading of the detector are given.

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1. INTRODUCTION

The fine-grained calorimeter, used by the CERN-Hamburg-Amsterdam-Rome-Moscow (CHARM) Collaboration to perform various measurements in the CERN neutrino beams, has recently been upgraded with a plane of 256 streamer tubes in each of the inter-plane gaps. These streamer tubes are read out in digital mode. The detector and its upgrading have been described in detail in several papers [1-5]. The information available for event recognition is provided by 128 proportional drift tubes (3 cm width), 20 scintillators (15 cm width), and 256 streamer tubes (1 cm width), following each of the 78 marble plates of the target calorimeter.

2. THE SHOWER PATTERNS

This paper deals with hadronic showers produced either in charged-current (CC) or neutral current (NC) interactions of neutrinos on nuclei, or for test purposes by pions of a test beam. The CHARM detector is also capable of identifying electromagnetic showers; this subject will be covered in a forthcoming paper.

To compare CC and NC data it is necessary to process the showers in an equivalent way, which makes it necessary to remove the primary muon of CC events from the shower before the determination of the shower parameters starts.

The required shower parameters are the energy, the vertex, and the angle of the shower. They have to be extracted from a pattern measured by each type of active element in two projections. The determination of the shower energy will not be discussed here. Figure 1a shows the Z-projection of a hadronic shower induced by a 140 GeV pion, as measured by the scintillators. Figure 1b shows the same projection of the same event as measured by the proportional tubes. The streamer-tube patterns reveal even more details but, as already mentioned, without pulse height information.

3. PATTERN RECOGNITION

There are two possible approaches to obtaining the shower parameters: either first to determine the angle and then the vertex, or vice versa. In the first

case the lateral vertex position is obtained from the shower axis and the starting plane of the shower; in the second case one first looks for the starting plane on which the lateral vertex position has to be calculated. Thus for both methods a good determination of the starting plane is essential. Looking at the shower of figs. 1a and 1b, the problem seems to be trivial, but for the event shown in figs. 2a and 2b it certainly is not.

As the starting plane is also needed for the decision as to whether a muon is associated with the primary interaction or not (needed to separate NC from CC events), its position has to be determined right at the beginning of the pattern-recognition program.

3.1 Starting plane and backscattering

The problem of determining the starting plane for the event shown in fig. 2 is caused by a phenomenon called backscattering. Soft particles -- neutrons, protons, and photons -- are evaporated from the target nucleus. The backward going ones can cause hits before the marble slab in which the neutrino interaction took place. Backscattering is more efficiently detected in scintillators than in gas counters, because the probability that a neutron or photon activates a scintillator is higher than the probability of interacting with the gas of the tubes.

In order to investigate the phenomenon of backscattering, a small calorimeter consisting of three planes equipped similarly to the main detector plane was built. This calorimeter had a hole around the beam line of the pion test beam. Selecting events starting in the first marble plate of the main detector (the first possible plane of interaction) made it possible to measure the percentage of events in which backscattering occurs in a pion test beam that was also used to determine vertex and angular resolutions. In total about 70% of all events show backscattering, of which 35% are restricted to the first gap in front of the interaction slab.

Choosing the wrong starting plane can seriously affect the determination of the lateral vertex position. Backscatter hits are sometimes well apart from the shower axis. If the barycentre of the energy deposited in such a "backscatter-plane" is then used to calculate the lateral shower vertex, the calculation goes

wrong. In figs. 1 and 2 the hole in the detector and the interaction point are indicated; the interaction point was known from the test beam. Using the plane marked with an arrow as starting plane would push the reconstructed vertex towards the cluster in the box.

Fortunately such a special backscatter pattern as in fig. 2a can be recognized by calculating a rough shower axis and looking whether the energy barycentre of a predicted starting plane is compatible with it. Backscattering in the direction of the shower axis as in fig. 2b cannot be recognized, but this does not affect the lateral vertex calculation severely.

3.2 Determination and resolution of the vertex

We have adopted the approach of first determining the shower vertex and then calculating the angle of the shower. After the starting-plane determination, muons are looked for in order to classify the event. The track-finding has been reported at the 1980 Wire Chamber Conference [6,7]. Muons are removed before a shower box is defined in which the energy and the energy-barycentre of the shower are calculated. Then the vertex algorithms are applied. We use two independent methods for calculating the vertex. One method makes no use of the streamer tubes in order to be able to process equivalently old and new data (without and with streamer tubes); the other relies strongly on streamer tubes.

The first method calculates tube barycentres in the first two planes of each projection of the shower. It uses the pulse heights of the scintillators closest to each tube to weight the tube instead of the pulse height of the proportional tube itself. The scintillators are used because their pulse heights do not suffer big fluctuations as do proportional tube pulse heights. In addition, the tubes are weighted according to the hit pattern around them. The weight depends on whether the tube is in the first or second plane of the shower. Thus the resulting weight is a product of "pulse height" and "pattern weight".

The second method looks mainly in the very first gap behind the starting plane. This gap contains proportional tubes in one projection and scintillators and streamer tubes in the other projection. Depending on the projection, either the

streamer tubes or the proportional tubes are taken as reference elements for calculating the barycentre in this first gap. A streamer-tube hit is not taken into account if there is no hit in the first following proportional tube plane of the same projection which is close enough. The proportional tubes are compared with the streamer tubes following in the same projection. In both cases the nearest scintillator is used to give a weight to the tube. The proportional tubes are weighted with their own pulse height in addition. The second method gives energy-dependent vertex resolutions (r.m.s.), which are up to 1.5 cm better than the resolutions for the first method.

As both methods use partly different information about the shower, it is useful to combine the results. We calculate a linear combination of the two values obtained in each projection. The best results were achieved by giving the second method a weight of 60% over the whole energy range. The vertex resolutions obtained in this way are given in fig. 3. They are compared with the vertex resolutions previously obtained with a vertex algorithm based on a straight-line fit through the barycentres of the first four scintillator planes, on the overall barycentre of the scintillators, on the integrated profile of the first four proportional tube planes. This algorithm turned out to be significantly worse [2-4 cm in resolution (r.m.s.) over the whole energy range] than each of the two methods described above. All the vertex resolutions are not Gaussian. A big advantage of the new methods is that the tails of the distributions are compatible with a Gaussian distribution. Figures 4 and 5 show the shape of the old and new distributions for 15 GeV and for 140 GeV showers, respectively.

3.3 Angle determination and angular resolution

To determine the shower angle we also use two independent methods and then compute a linear combination of the results.

The first method simply calculates the straight line through the barycentre and the vertex of the shower.

The second method is an iterative one to find in each projection the line starting at the vertex and dividing the shower in such a way that there is the

same amount of energy deposited on both sides of the line. This algorithm uses only proportional tubes. It takes the result of the first algorithm as a starting value for the iteration. In order to suppress fluctuations coming from the edges of the shower, a weight function is used favouring the shower core.

Both methods give compatible results. Since different information is used, a weighted average improves the final result. Giving the first method a weight of 60% over the whole energy range optimizes the r.m.s. resolution. The angular resolution (r.m.s.) is given in fig. 6, where it is compared with the results obtained with the same algorithms to determine the angle using the abandoned vertex algorithm also referred to in fig. 3.

4. CONCLUSIONS

The upgrading of the CHARM detector with streamer tubes and the improvements in the off-line software have resulted in a substantial improvement in vertex and angular resolutions. The vertex resolution is now less than 4 cm (r.m.s.) above 15 GeV and less than 3 cm above 50 GeV. The angular resolution is less than 80 mrad (r.m.s.) above 15 GeV and less than 30 mrad above 50 GeV. Further improvements will be achieved by work going on at the moment to use the streamer tubes not only for determining the vertex but also in the algorithms to determine the shower angle.

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Figure captions

- Fig. 1 : a) The Z-projection of a hadronic shower of 140 GeV as measured in the scintillators. The numbers across the top are scintillator numbers; those down the side are plane numbers. Each scintillator fired is represented by its pulse height on a scale of 0 to 99 minimum ionizing particles (m.i.p.), the symbol * standing for a signal above 99 m.i.p. The vertex is indicated by a star. The straight line represents the shower axis. The hole in the detector is given as a channel in front of the vertex.
- b) The same projection of the same event as in in fig. 1a, but as measured in proportional tubes. The numbers across the top are proportional tube numbers; those down the side are plane numbers. Each fired proportional tube is represented by its pulse height on a scale of 0 to 35 keV (0-Z), the symbol * standing for a signal above 35 keV. Indications as in (a).
- Fig. 2 : a) The Z-projection of a hadronic shower of 15 GeV as measured in the scintillators. The dotted line represents the front of the main detector. The arrow indicates a special choice of the start-plane; the box marks a certain scintillator cluster.
- b) The Y-projection of the event from (a) in scintillators.
- Fig. 3 : The vertex resolutions (r.m.s.) are given versus the shower energy. The new values are compared with values obtained before the hardware and software upgrading.
- Fig. 4 : a) Vertex distribution for events observed in the 15 GeV test beam. The x-axis gives the difference between the impact point as known in the test beam and the vertex as reconstructed by the new algorithm.
- b) As (a) but for the old algorithm.

- Fig. 5 : As fig. 4 but with the beam energy set to 140 GeV. Additionally Gaussian fits to the distributions are plotted.
- Fig. 6 : Angular resolutions (r.m.s.) are given versus the shower energy. The new values are again compared with values achieved before the upgrading.

Fig. 2

Fig. 3

Fig. 4

VERTEX DISTRIBUTIONS

Fig. 5

Fig. 6