

# HADRON SHOWER PROFILE AND DIRECTION MEASUREMENTS IN A SEGMENTED CALORIMETER

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## INTRODUCTION

Recently a test measurement was made to see how well the direction of the shower induced by neutrino interactions could be determined in the lab-E detector at Fermilab. While the calorimeter in lab-E has very coarse sampling compared to the detectors described at this workshop, the method we used to sample the shower could be employed in other more finely segmented detectors. The shower angle resolution we obtain (36 mr. FWHM) is largely constrained by the sampling. In this test we recorded pulse heights in 2mm. steps across the hadron shower at five points along the shower. This was done with 20 wires and 20 fast ADC's. A standard MWPC system intended to accomplish the same task would have required about 250 wires and 250 ADC channels. This considerable saving in system complexity should be possible for any system where finely segmented pulse height measurements are required.

The lab-E calorimeter is a massive ( $\approx 1000$  metric tons) calorimeter used to detect neutrino interactions. Several data runs have been made in the FNAL narrow band neutrino beam using this detector<sup>1,2</sup>. Presently the detector is instrumented with liquid scintillation counters and spark chambers with magnetostrictive readouts (see figure 1). In anticipation of Tevatron running, where the spark chamber deadtime is a serious problem, we are replacing the spark chambers with drift chambers.

The test described here was done to define how much we would gain by measuring pulse height along the drift. In doing this we measure the profile of the hadron shower in each chamber gap (every 20 cm. of iron) as the shower develops in the calorimeter. This information can be used to extract the direction of the initial hadronic impulse in a neutrino interaction.

## TEST SETUP

A test calorimeter was built in the muon lab. It was instrumented with chambers whose cell design was similar to, but much shorter than (45cm. compared to 300cm.)

those which will be placed in the neutrino detector. The chambers had two cells, each with two sense wires (see figure 2). They were run with a 50-50 mix of Argon and ethane. The field shaping along the drift was established by Copper strips on etched G10 printed circuit boards which served as the top and bottom of the chambers. The cathodes were extruded aluminum 'I-beams' glued with conductive epoxy to the bottom G10 board. The sense wires and a central field shaping wire were held in position by two G10 violin type bridges with machined notches located near the ends of the chamber. The two cells were surrounded by a G10 frame glued to the G10 boards to form a gas tight container. The G10 etched boards were laminated to 1/16 inch aluminum sheets to provide structural strength. For the data described here the cathodes were run at -6Kv, the sense wires at 1.9Kv, and the field wire and the strips beneath the sense wires at ground.

The test calorimeter was constructed with 20cm. iron slabs, each gap contained four counters and one chamber. While the counters were not adequately matched to the chambers to obtain the individual half cell outputs, the total output in the gap can be compared between scintillators and drift chambers for the first few gaps where the shower is well contained by both (see figure 4). The chambers are linear at about the ten percent level over the range of 40 to 350 equivalent minimum ionizing.

The muon lab beam provided 125GeV. hadrons with some ( $\approx 10\%$ ) muons. By using the muons that passed through the detector we could define the mean beam angle (see figure 5), and verified that the beam had a narrow angular spread.

The chamber electronics included a preamp, a 'flash ADC' (TRW's TDC1014J) and a memory for each wire (see figure 6). The ADC digitized the incoming signal (with six bit accuracy) every 33ns. The resulting pulse height was stored in a memory six bits by 64 samples deep. When a trigger came in, the last 64 samples were held until the computer read the memory. The sampling began anew once the interrogation process

was complete. Twelve modules were constructed that contained the electronics for each cell (two wires). During the interrogate cycle both channels were read out simultaneously and placed on the data lines of the 'Nevis Transport Bus'. The data was passed to our computer through a CAMAC interface. Once the module finished outputting all 64 samples, a read request was passed on to the next module in line (not shown in figure 6).

## DATA ANALYSIS

Ion collection and the electronics caused the pulse height from a single minimum ionizing particle to spread out over more than one time sample. The processes that produce the pulse shape should be linear, so by measuring the shape from muons we can correct the pulse height distribution to obtain the distribution of ionization in the cell. Given some distribution of ion pairs in the gap produced by shower particles, the pulse height as a function of time will be given by:

$$V(t) = \int_{-\infty}^{\infty} V^0(t')\mu(t-t')dt'$$

where  $V(t)$  = the measured voltage

$V^0(t)$  = a quantity proportional to the number of drift electrons arriving at the sense wire at time  $t$

$\mu(t)$  = the muon pulse height distribution versus time

(where the time is measured with respect to the arrival of drift electrons at the wire)

If we sample in discrete steps, in an obvious notation:

$$V_i = \sum V_j^0 \mu_{(i-j)} = \sum V_j^0 a_{ij}$$

$$V_i^0 = \sum V_j (a^{-1})_{ij}$$

where the matrix with elements  $(a^{-1})_{ij}$  depends only on the muon pulse height distribution. In addition to this shape correction, the pulse height was corrected for slight cross talk from the neighboring sense wire ( $\approx 7\%$ ) and ADC pedestal ( $\approx 3$  counts). Figure 4 shows the comparison of counter and chamber pulse heights after all of these corrections. The net effect of the shape correction can be quite large. This is demonstrated by a

Monte Carlo example in figure 7. Electronic shaping of the chamber output using a feedback network on the preamp could decrease the size of this correction.

## RESULTS

Showers starting in the first plate were selected on the basis of pulse height in the counter in the middle of the first 20cm. plate or the first gap being greater than twice minimum ionizing. The profile averaged over many showers appears in figure 8 for each of the five gaps.

Given precise knowledge of the initiating hadron position, the simplest way to obtain an angle is to take the mean shower position in a gap less the starting hadron position and divide by the distance between the gap and the average interaction point (the middle of the iron). This method is prone to systematic shifts because it is sensitive to the amount of pulse height at the extremes of the chambers. As a result, if one chamber is missaligned with respect to the others and its active area is shifted, the angle obtained by that chamber will be affected. In order to avoid this problem and to protect against systematics due to the small size of the test calorimeter, we limited all calculations to time bins that fell inside of a cone of opening angle 25mr. with its apex on the supposed interaction point (the middle of the 10cm. plate where the interaction occurred). The axis of the cone was chosen to maximize the enclosed pulse height. The number of events where this cone extends beyond the active area of a chamber gives us an idea of how often the smallness of the apparatus causes some bias. Sixteen percent of the events had the cone touching or beyond the edge of a chamber. The pulse height in these gaps (obtained by using the counters which are larger than the drift chamber cells) was on average twelve percent of the pulse height enclosed inside the 25mr. cone. Since the number of events where there is missing pulse height is small and the amount of missing pulse height in these events is small, the size of the calorimeter should not pose a problem in generalizing these results to a larger device. The measured angle was

taken as the angle of a line passing through the apex of the cone dividing the cone in to two sides with equal total pulse height. The distribution of these 'median angles' is plotted in figure 9 and figure 10 shows how an angle constructed from the median of the pulse height distribution in each gap (only the part of the distribution inside the above mentioned cone is used) shows no sign of systematic effects and yields hadron directions consistent with the direction of the beam muons.

The method of extracting a hadron angle used here can be generalized directly to the measurement of hadron shower directions in charged current neutrino events where the interaction point can be obtained from the muon track. The precision with which the vertex can be determined will not be as good as it was in this test and this may degrade the resolution. Certainly events where no muon track is observed will require a different approach and the resolution will be worse. We hope to study methods that can work for neutral current and other non muon producing processes in the future.

## REFERENCES

- [1] J. Lee, "Measurement of  $\nu$  N Charged Current Cross Sections from  $E_\nu=25\text{GeV}$ . to  $E_\nu=260\text{GeV}$ ." Ph. D. Thesis, Caltech (1981).
- [2] R. Blair, "A Total Cross Section and Y Distribution Measurement for Muon Type Neutrinos and Antineutrinos on Iron" Ph. D. Thesis, Caltech (1982).

## FIGURE CAPTIONS

- Figure 1.) Layout of the Lab E neutrino detector. The spark chambers will be replaced by drift chambers similar to those described here for Tevatron running.
- Figure 2.) Cross sectional view of one of the chambers used in the tests. Copper strips that faced each other across the gap were connected together with external jumper wires. An external resistor chain connected the cathode and its neighboring copper strip across a 10 Megohm resistor and adjacent strips were connected by a 16 Megohm resistor.
- Figure 3.) Layout of test calorimeter. The calorimeter configuration depicted shows the apparatus used for the results described here. The chambers are labeled DC0 through DC5.
- Figure 4.) Chamber linearity. The total chamber response is plotted versus the counter output for the first three gaps. The chamber output is linear at the ten percent level over the whole range of pulse heights observed.
- Figure 5.) Muon direction. The distribution of beam muons shows that the beam has a well defined direction.
- Figure 6.) Read out electronics. A block diagram of the electronics used to read out one wire. The 'Nevis Transport Bus' is a general purpose bus used to send information from the readout modules to the CAMAC interface.

## FIGURE CAPTIONS

Figure 7.) Example showing the magnitude of the correction for shape. A 'test pattern' true distribution is used to construct the distribution that would be measured and then corrected to show how well it corresponds to the original true distribution. In constructing the measured distribution a randomness was introduced in the shape of 5% and a pedestal error of 2 counts was introduced, to demonstrate the insensitivity to small measurement errors.

Figure 8.) Profile of a 125 GeV. shower, averaged over 533 incoming hadrons. The profiles are labeled according to gap number (1 being the gap after the first 20cm. of iron).

Figure 9.) Distribution of angles determined by finding the axis about which the shower is symmetric (equal pulse height on either side). The pulse height is used inside a cone (opening half angle 25mr.) which has its apex on the average interaction site and its axis established so as to maximize the enclosed shower. The FWHM of this distribution is 36 mr. The mean is consistent with the direction of the beam as measured by the beam muons.

Figure 10.) Direction of the hadron evaluated at each gap. The direction is taken to be the angle given by a line extending through the average interaction site and the median of the pulse height distribution measured in a chamber. The errors are purely statistical. Correlations are induced between chambers because the region of the chamber which is used to calculate a median is the region falling inside the cone which has been determined using all the chambers. The solid line depicts the average muon direction.

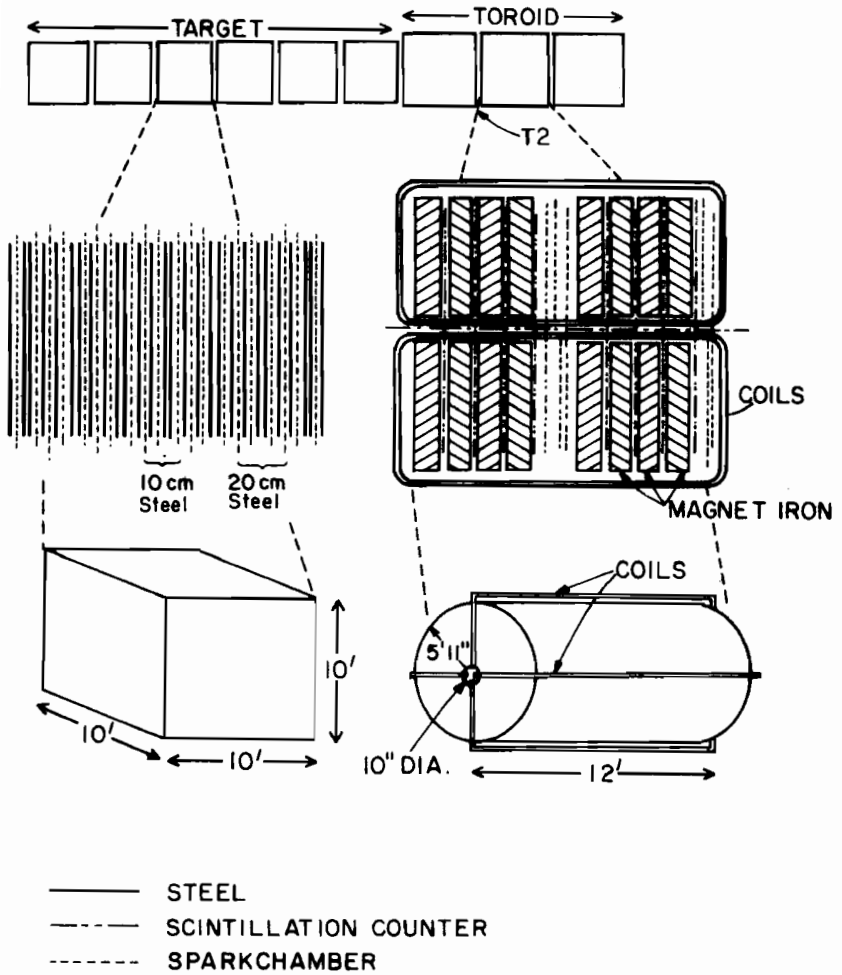
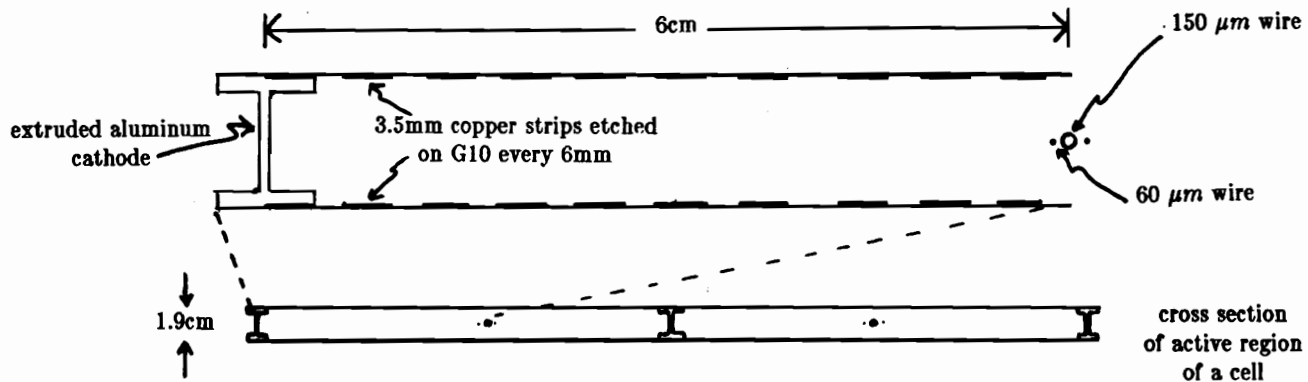


Figure 1

Figure 2



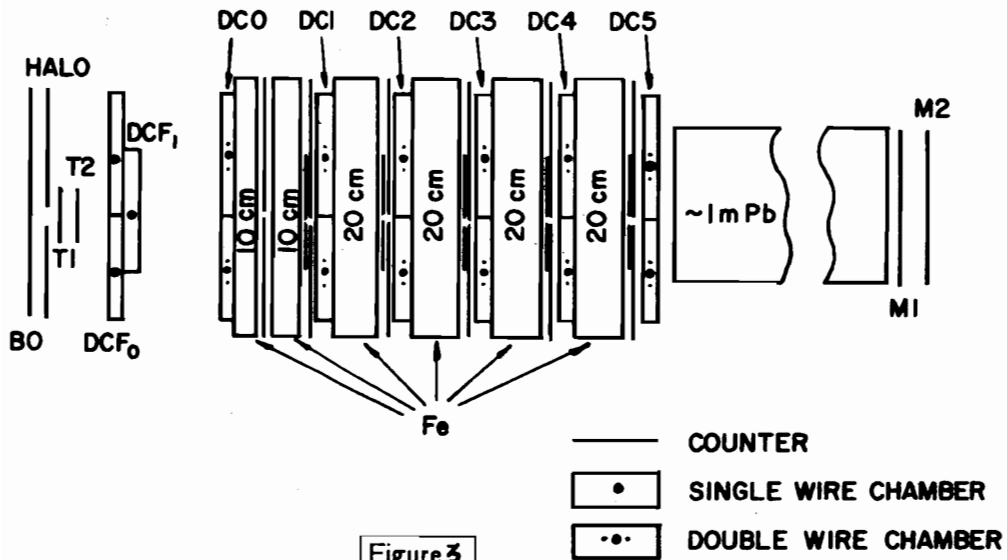


Figure 3

Figure 4

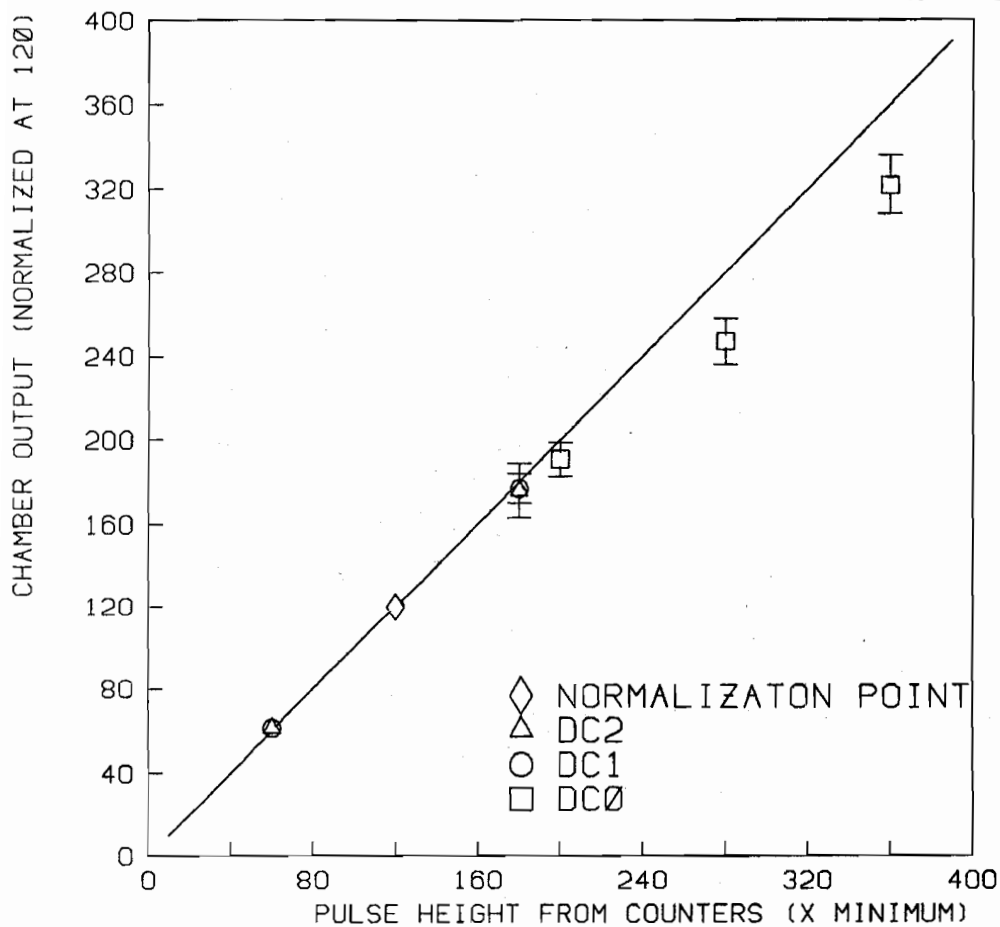
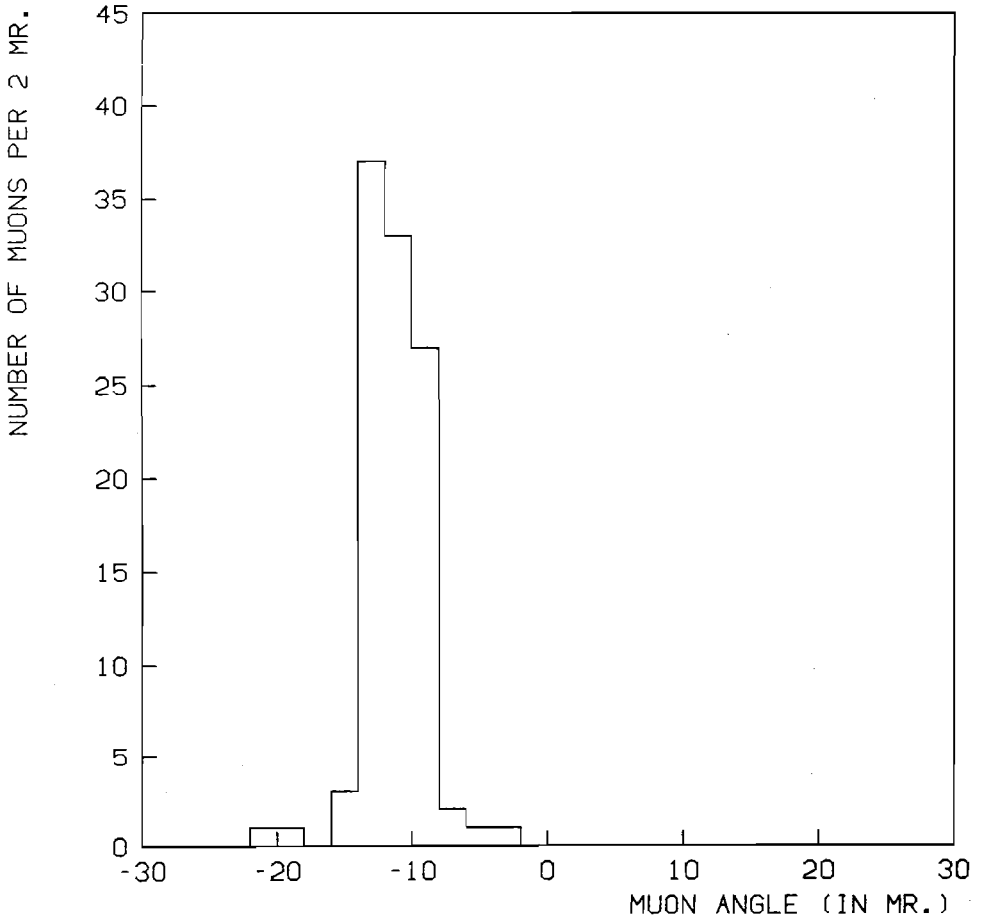


Figure 5



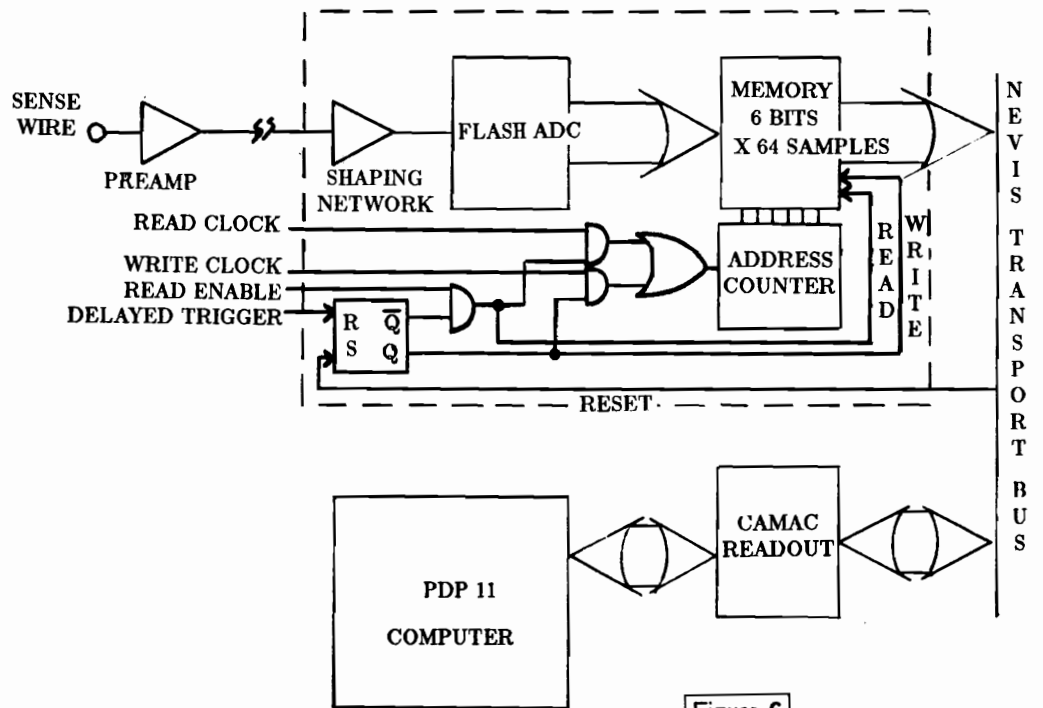


Figure 6

Figure 7

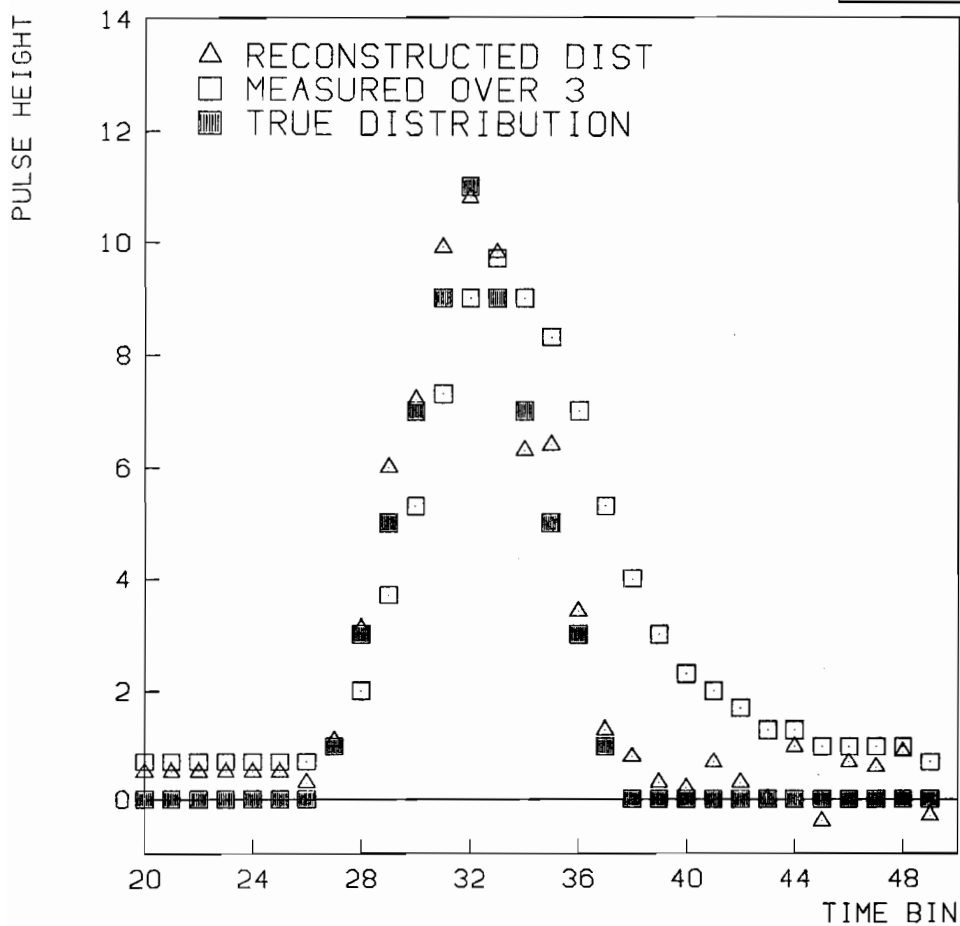


Figure 8

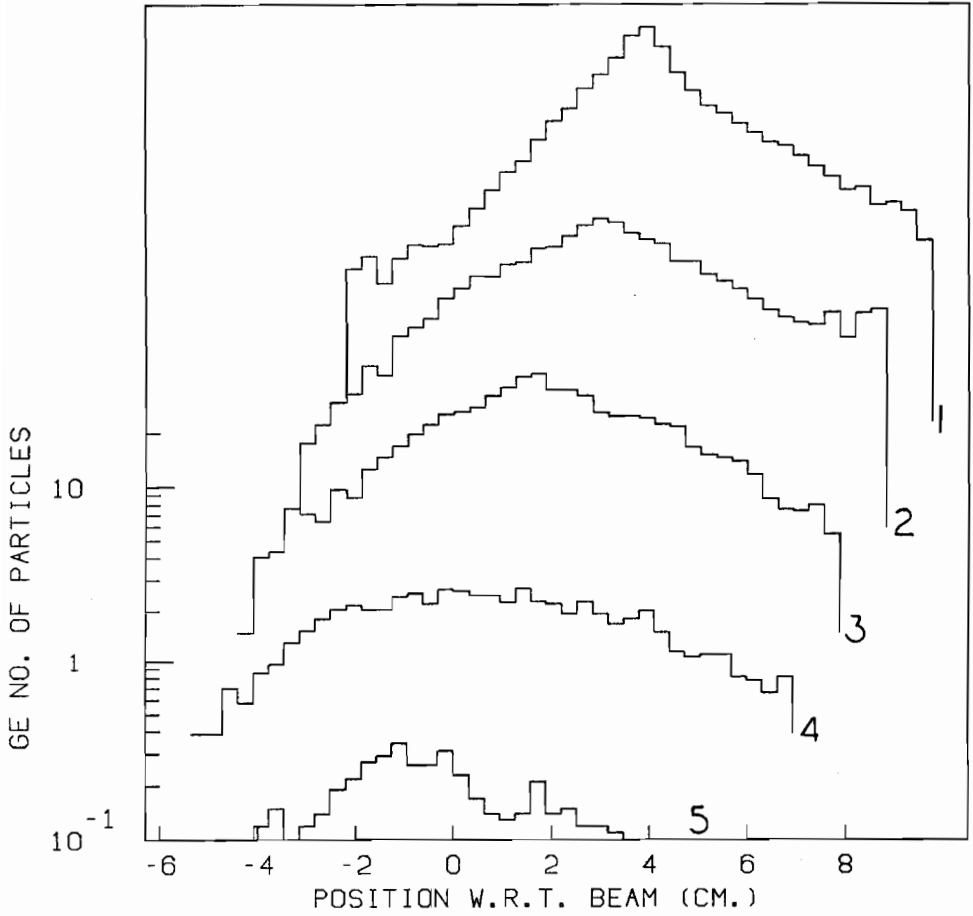


Figure 9

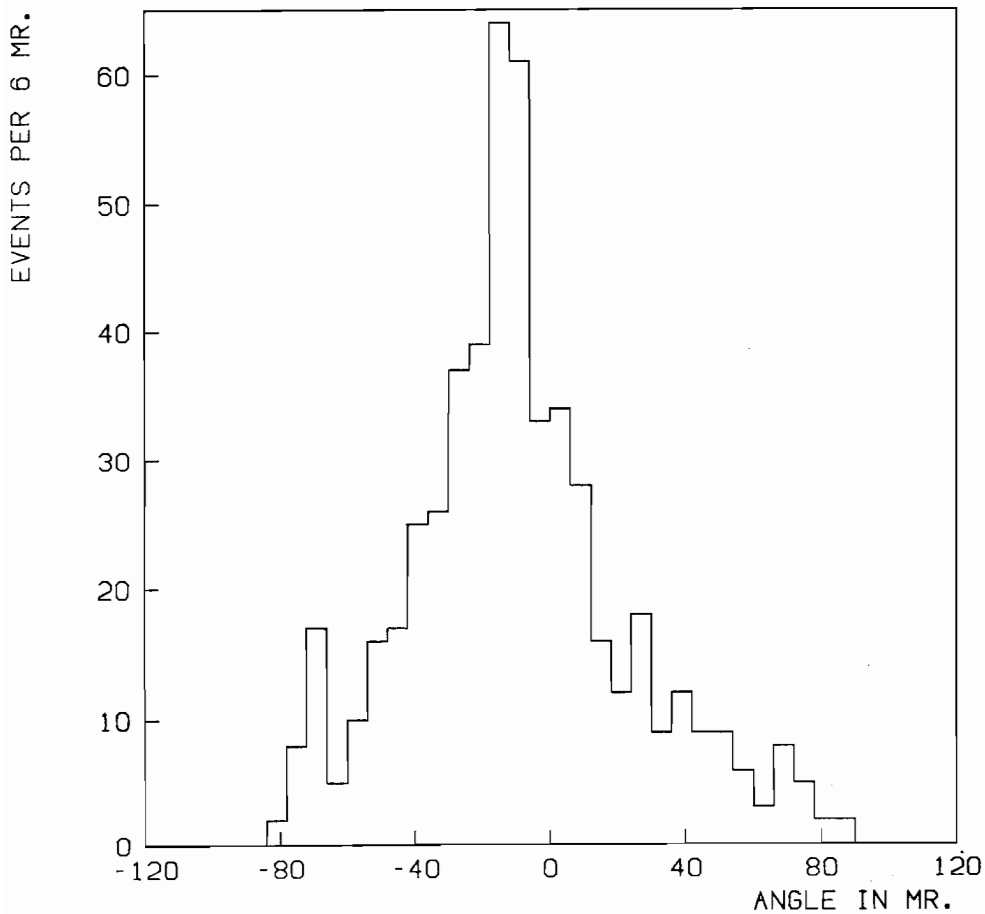


Figure 10

