THE CDF FORWARD ELECTROMAGNETIC CALORIMETER

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Abstract

We have designed and tested a large electromagnetic calorimeter system for use in the small angle region (2^o - 10^o) of the Collider Detector at Fermilab (CDF). The system uses proportional tube calorimetry with lead sheets as the radiator. The proportional tube planes are constructed using a novel technique which combines aluminum tubes and cathode pad readout: extruded aluminum channels form three walls of the proportional tubes and the cathode pad circuit boards are bonded to these with resistive epoxy. The calorimeters are symmetrical; each is approximately 3 m square and 1 m deep and has 30 layers of lead and proportional tube planes. The thickness of each layer is 90% of a radiation length. The cathode pads from successive layers are ganged into towers which project to the interaction point. The total system (both ends of the CDF detector) has approximately 3000 pad towers which are read out in two depth segmentations. Four calorimeter quadrants have been built and tested in a high energy electron beam at Fermilab. The energy response of the calorimeter as a function of energy was linear up to 200 GeV and the measured energy resolution was approximately 3% at 100 GeV. The position resolution varied between 2 mm and 4 mm depending on location in the calorimeter.

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Introduction

The Collider Detector at Fermilab has two layers of particle-detection calorimetry covering most of its solid angle and extending to within two degrees of the beam in both directions[1]. In this paper the Forward Electromagnetic Calorimeter, which covers the small angle region (2^0 - 10^0) at both ends, will be described[2]. This is a gas-tube calorimeter utilizing lead sheets as the radiator and employing cathode pad readout. Its purpose is to measure the electromagnetic energy flow in jets and to isolate high-energy electrons and π^0's. This device has been developed and fabricated by a Harvard University - Brandeis University collaboration. It is followed by a hadron calorimeter of the same design which is being produced by Texas A&M University and which is the subject of the following talk[3].

The Forward Electromagnetic Calorimeter is located approximately 6.5 meters from the interaction point and encloses the beam pipe at either end of CDF. One end of the CDF detector is shown schematically in Fig. 1. Each calorimeter consists of 30 sampling layers separated by 90% of a radiation length of lead. A perspective view of one half of one calorimeter is shown in Fig. 2; the total unit is roughly 3 meters on a side, 1 meter deep, and weighs about 20 tons.

The gas tube layers in the calorimeter are divided into quadrants; the quadrants are self-contained chambers which can individually be removed. The radial cathode pad geometry of a typical quadrant chamber is shown in Fig. 3. Each pad subtends 0.1 units of pseudorapidity and 5^0 of azimuthal angle. The pads are ganged longitudinally into towers which project to the interaction point. This is accomplished by scaling the pad size in the radial dimension every second layer. These pad towers have two depth segmentations, both 15 layers thick. There are 1440 pads per layer, resulting in 5760 towers to be independently read out for both ends.

The anode wires are strung vertically and are ganged together in five sectors per chamber. These sectors are read out independently for each layer, resulting in an additional 120 signals. The anode data are intended primarily for diagnostic purposes, but may also be used to investigate the longitudinal profile of isolated showers.

Construction Techniques

One side of each chamber in the calorimeter consists of an aluminum channel plate which forms the three walls of the approximately 120 tubes. Each tube has an inner cross section of 7 mm in the beam direction and 10 mm transverse to the beam. The tubes are separated from each other by a 1.6 mm - thick wall. This channel plate is manufactured at Harvard by epoxying strips of aluminum that have been extruded with a "T" cross section to a large aluminum sheet. This operation is performed on a flat table ensuring the flatness of the resulting chambers.

After extruded plastic electrode strips have been epoxied to each end of the channel plate, 50-micron gold-plated wires are soldered into each of the tubes. The wire that is used has been "nickel flashed" to obtain a reliable solder connection. As soon as the wiring is completed, 3 kV of high voltage is applied to the chamber. Any loose or damaged wires identify themselves by drawing excessive amounts of current.

The cathode pads are etched commercially on large G10 panels which are copper-clad on one side only. These panels are attached directly to the pre-wired aluminum channel plates and are oriented such that the cathode pads are on the outside surface. The inside surface is coated with a thin, uniform layer of resistive epoxy. The epoxy bonds the cathode pad panels to the aluminum channels and its conductivity prevents the surface from charging up during chamber operation. The epoxy is applied to the panel using silk screen techniques giving a smooth, very uniform coating. A cross-sectional view of a chamber is shown in Fig. 4.

The resistivity of the epoxy can be varied when it is mixed. It is allowed to vary between 20 and 80 MΩ/sq.; the chamber performance is not sensitive to variations in this range. For higher surface resistivities there is a danger of the surface charging up under high-rate conditions such as those near the beam pipe. This can have two deleterious effects: the field in the tube will change lowering the gas gain locally and a sustained discharge ("glow mode") may result. For lower values of the surface resistivity the cathode pad signals will be attenuated as the resistive surface quickly restores itself to ground potential. If the signal integration time is long this may be a problem. Finally, local variations in the resistivity are not a problem because the resistive surface is grounded to each tube wall.

For our tube geometry there is a simple relationship between the value of the surface resistivity and the cathode signal attenuation time constant: the time constant in μseconds is approximately equal to the surface resistivity in MΩ/sq. This relationship makes possible a rather simple test of the surface resistivity of a chamber after the cathode panels have been installed. A 10-volt step is applied to the anode wires, which induces a charge pulse on each pad. By observing the integrated pad charge on an oscilloscope, the time constant of its decay and hence the resistivity can be directly observed. This test is performed on selected pads on each chamber as a quality control measure. It can be re-checked at any time after the chamber has been completely assembled to test the long term stability of the epoxy and the integrity of the bond with the aluminum channel.

The cathode signals are carried to the edge of the chamber by a ribbon cable harness. These ribbon cables are sandwiched between the cathode pad panels and the outside aluminum wall of the chamber. Alternate wires in the ribbon cables are soldered directly to the pad surface. The other wires in the ribbon cables are grounded at the chamber edge and are left unconnected at the pad end. At the edge of the chamber, a long narrow circuit board takes the signals through the gas seal to external connectors. This circuit board also contains a 100Ω resistor in series with each pad line; the resistor eliminates ringing of signals between longitudinally ganged pads. After the harness has been attached, and before the lid of the chamber is sealed, the continuity of all cathode pad connections is tested.

A completed chamber is an aluminum box about 1.5 m on a side and about 1.6 cm thick. Extruding from the box on one edge are the ribbon cable connectors for the 360 cathode pad signals and the 5 anode signals, a single high-voltage connector, and the gas inlet and outlet. Another side has a plastic rail for supporting the chamber in the final mounting frame. Finally there is a three-sided notch in one corner which forms an octagonal beam hole in the final calorimeter.

Before the completed calorimeter chambers are shipped to Fermilab they are given two final tests. First they are extensively leak tested and repaired wherever necessary. Second they are scanned with a collimated ^{106}Ru source to map their response. The position of the source is remotely controlled by a VAX computer. The computer positions the source over a group of pads, switches the amplified signals from those pads to a pulse-height-analyzer, and records the source spectrum. This is automatically repeated at about 50 points across the face of the chamber. Although a single peak is not observed using ^{106}Ru, a beta emitter, the shape of the observed spectrum should be invariant and will be scaled by the chamber gain, assuming the chamber walls are uniform. Empirically it is observed that the upper edge of the spectrum falls-off exponentially; the observed slope of this exponential is then directly related to the gain. This measurement cannot be considered a precise measurement of the chamber response, but it is an excellent test that a healthy chamber has been produced. The final gain mapping is performed at Fermilab when a complete calorimeter section has been assembled.

As of August 1985 four complete quadrants of chambers had been completed and calibrated in a test beam at Fermilab. The remaining four quadrants are scheduled to be completed in early 1986.

Test Beam Calibration

An extensive program of testing and calibration has been underway at Fermilab in the MBottom beamline both for this and the other CDF gas-tube calorimeters. The major goal of this program has been to measure the electromagnetic energy response and resolution as a function of the beam postion and the operating conditions. The hadronic energy resonse has also been investigated.

The calorimeter was operated with an argon-ethane (50-50) gas mixture for the test beam work. (Ethyl alcohol is not added to the mixture as it attacks the resistive epoxy of the cathode surface.) The normal operating high voltage was 1900 volts, which corresponds to a gas gain of approximately 5000. The gas gain was continuouly monitored with a pair of proportional tubes containing ^{55}Fe sources. These tubes were mounted in series on the gas inlet and outlet respectively of one chamber, and were run at the same high voltage as the chambers. The ^{55}Fe spectra were read out with a pulse height analyzer at the beginning of every run.

A special mount was designed to rotate an entire quadrant around the virtual beam axis in such a way that the test beam was always aligned with the tower geometry. Since this motion was remotely controlled from the counting room, for most running it was not necessary to enter the beam area.

The readout of the pads and wires was accomplished using the same front-end electronics that will be used in the colliding beam mode (RABBIT system). However, for the test beam work the RABBIT system was coupled to a PDP-11 computer via a CAMAC interface. Eventually this system will be coupled to a FASTBUS network.

Figure 5 displays the calorimeter data for the impact of single 100-GeV positrons. The longitudinal and transverse shower profiles are shown for two separate events. The pads have been orthogonalized for the transverse profiles. Increasing pseudorapidity is shown along the left edge and increasing azimuthal angle along the right edge of the plot. The lower event is in the region of smaller pads, hence the shower appears to have a wider transverse spread.

Summary plots from a typical 100-GeV positron run are shown in Fig. 6. The upper two plots show the anode and cathode energy peaks after correcting for the spread of the incident beam. The third plot shows the correlation between the first two. The tail to lower values is the result of pion contamination in the beam. The final three plots show the average longitudinal and transverse shower profiles for the run. In the transverse profile most of the energy is concentrated in three or four pads.

The energy response of the calorimeter to high-energy positrons is shown in Fig. 7, both as a function of high voltage and of the beam energy. The high-voltage dependence is stable and exponential in the vicinity of our standard operating point, 1900 volts. Although there may be some saturation starting at 200 GeV, the calorimeter response is linear for lower beam energies. The energy resolution, as seen in Fig. 8, is approximately 3% at 100 GeV, and varies as expected like $1/\sqrt{E}$.

Over a period of weeks we found that the gas monitor tubes and the actual calorimeter gain tracked to within 3% . This can be seen from Fig. 9 where the ^{55}Fe source peak position is plotted against the 100-GeV positron peak for many different runs at four different locations on the calorimeter face. In addition to scanning the entire face of the calorimeter, the same four points were repeated every shift change.

Finally, Fig. 10 demonstrates the position resolution of the device. A 100-GeV positron beam was scanned in small steps across several pad boundaries. Figure 10a is a plot of the shower centroid in the direction of the scan versus the beam position as measured in the upstream PWC position monitors. The vertical sections of the resulting "S" curve are where the beam crosses a pad boundary and the value of the centroid rapidly changes. The second figure shows the same data where the centroid has been corrected for the finite pad size. Here the two quantities track well, but the correlation is weaker when the beam is near a pad center. This is seen clearly in the final two plots of the difference between the corrected centroid and the measured position, first at a pad center and second at a pad boundary. In summary, the calorimeter can measure the position of electromagnetic showers to an accuracy of between 2 mm and 4 mm depending on the location of the shower.

Conclusions

The CDF Forward Electromagnetic Calorimeter has been designed and fabricated using a method that combines a rigid aluminum structure together with cathode pad readout – two features that are normally incompatible. By having independent chambers for each sampling layer the production and testing processes are greatly simplified. The method of coupling the cathode pad panels to the aluminum channels with resistive epoxy is a success. The entire system has performed well in a test beam envoirnment and should be installed and ready when CDF starts to take data in 1986.

We gratefully acknowledge the excellent work done by the technical staffs of Harvard and Brandeis, in particular Jim McElaney and Rick Haggerty of the Harvard HEPL Machine Shop. We also thank the Experimental Areas Department of Fermilab and Ron Shailey for facilitating our test beam work.

References

1. CDF Design Report, Fermilab Publication, 1981.
2. C. Blocker *et al.*, Proceedings of the Sante Fe Meeting, p.363, 1984.
3. J. Buchholz *et al.*, Fermilab Gas Sampling Calorimetry Workshop, 1985.

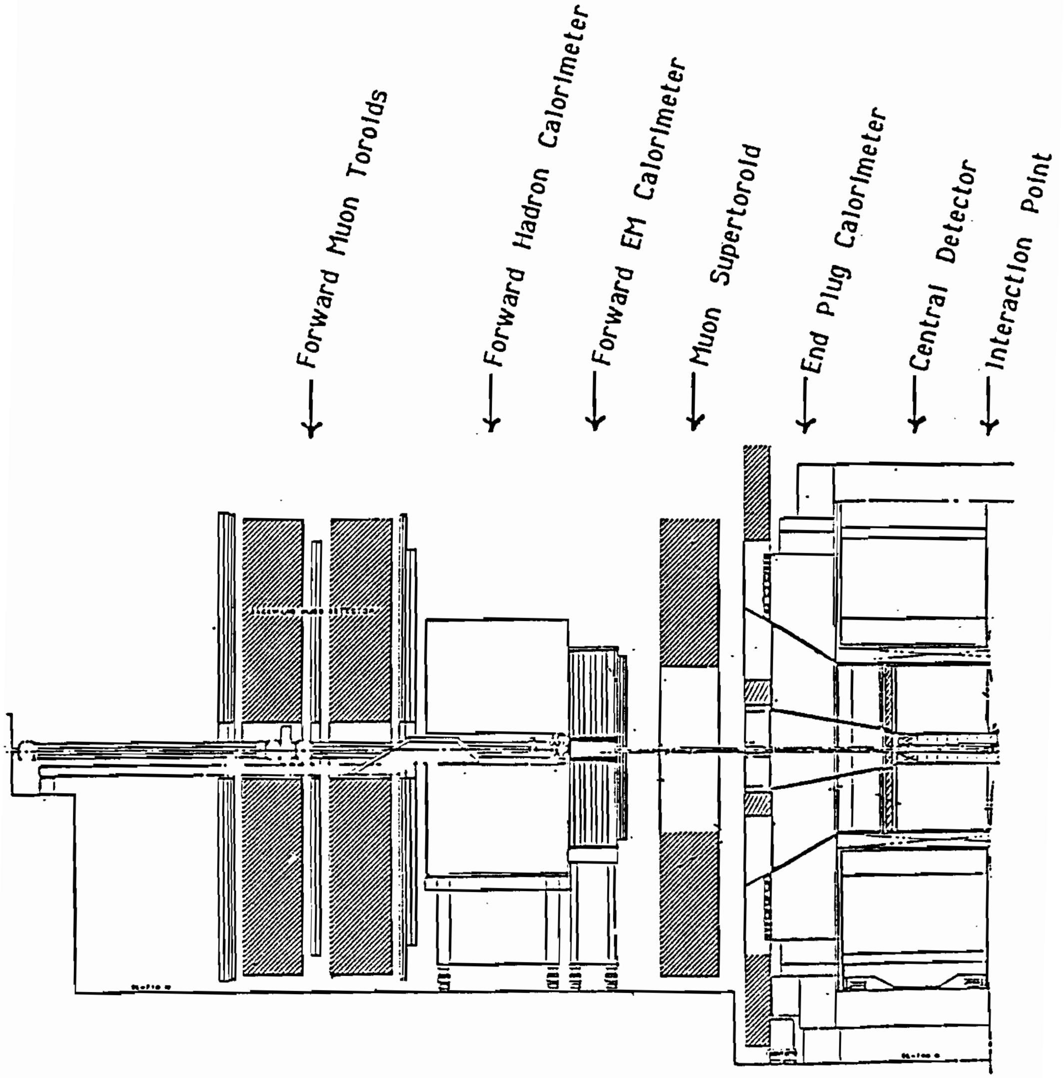

Figure 1 Side view of the forward half of the CDF detector. The Forward Electromagnetic Calorimeter is approximately 6.5 m from the Interaction Point.

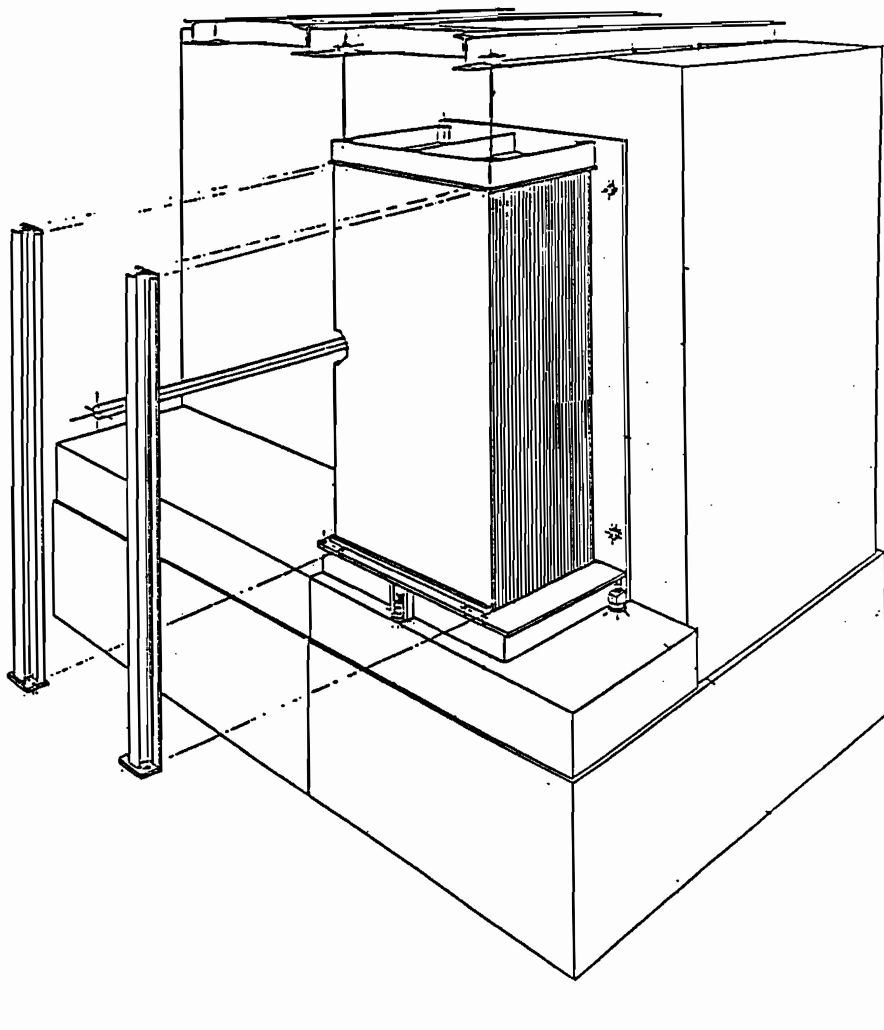

Figure 2 One half of the Forward Electromagnetic Calorimeter shown mounted on the front face of the Forward Hadron Calorimeter.

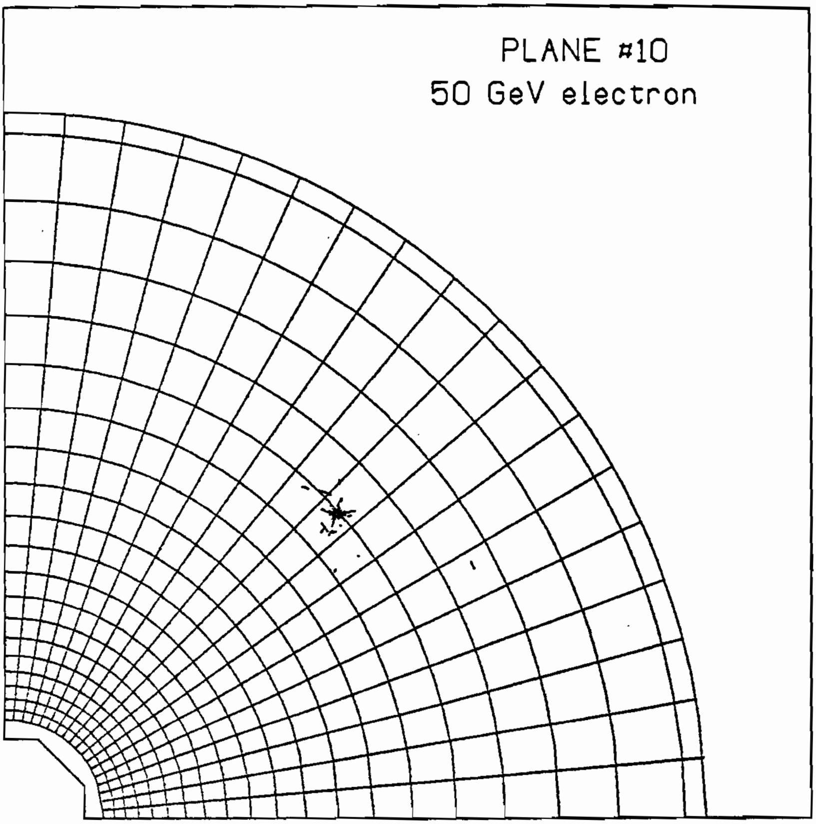

Figure 3 The pad geometry of the quadrant chamber in the tenth layer of calorimeter. The imprint of a simulated 50 GeV shower is shown for reference.

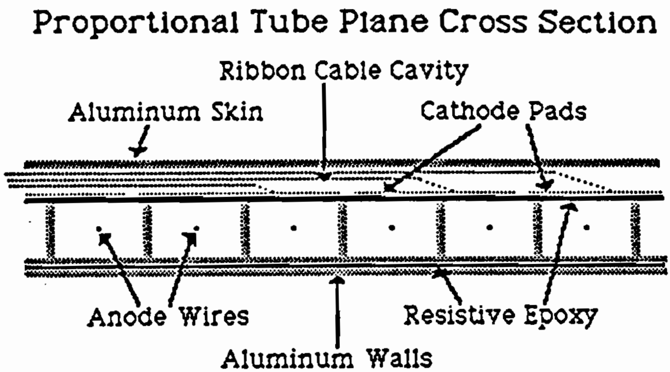

Figure 4 A cross section of a calorimeter chamber.

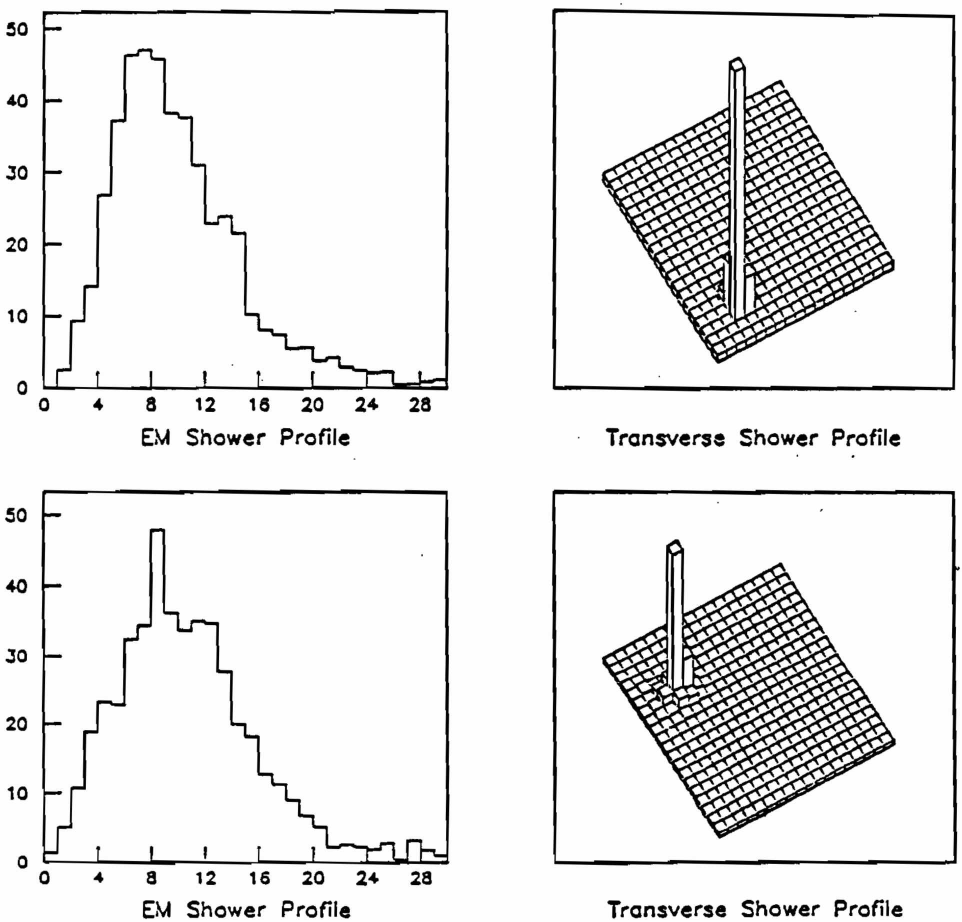

Figure 5 The longitudinal and transverse profiles for two typical 100-GeV positrons. The pads have been orthogonalized in the right-hand plot: the bins are $\Delta\eta = 0.1$ by $\Delta\phi = 5^{\circ}$.

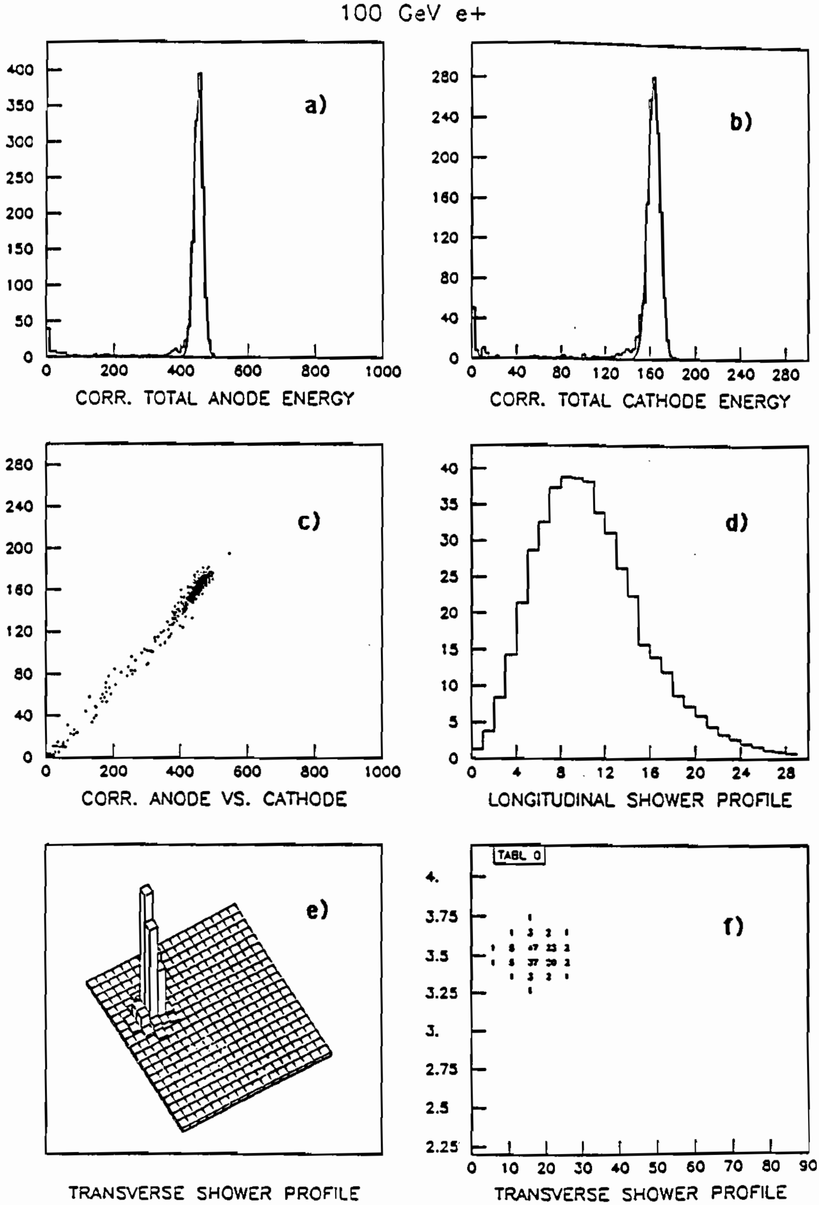

Figure 6 A typical 100-GeV positron run. a) and b) show the corrected anode and cathode response while c) is a correlation of these. d) and e) show the longitudinal and transverse profiles and f) is a digitized version of e).

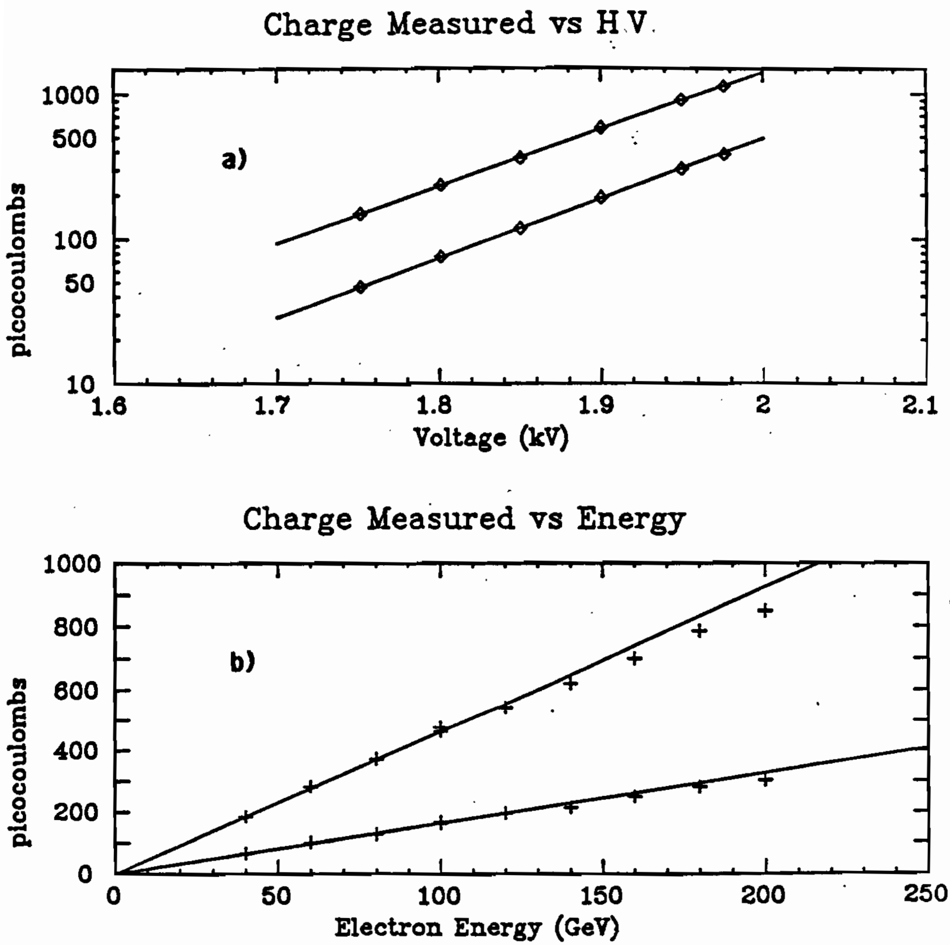

Figure 7 The energy response of the calorimeter for incident positrons as a function of a) HV at 100GeV and b) Energy at 1.9 kV. The top and bottom curves show the anode and cathode respectively.

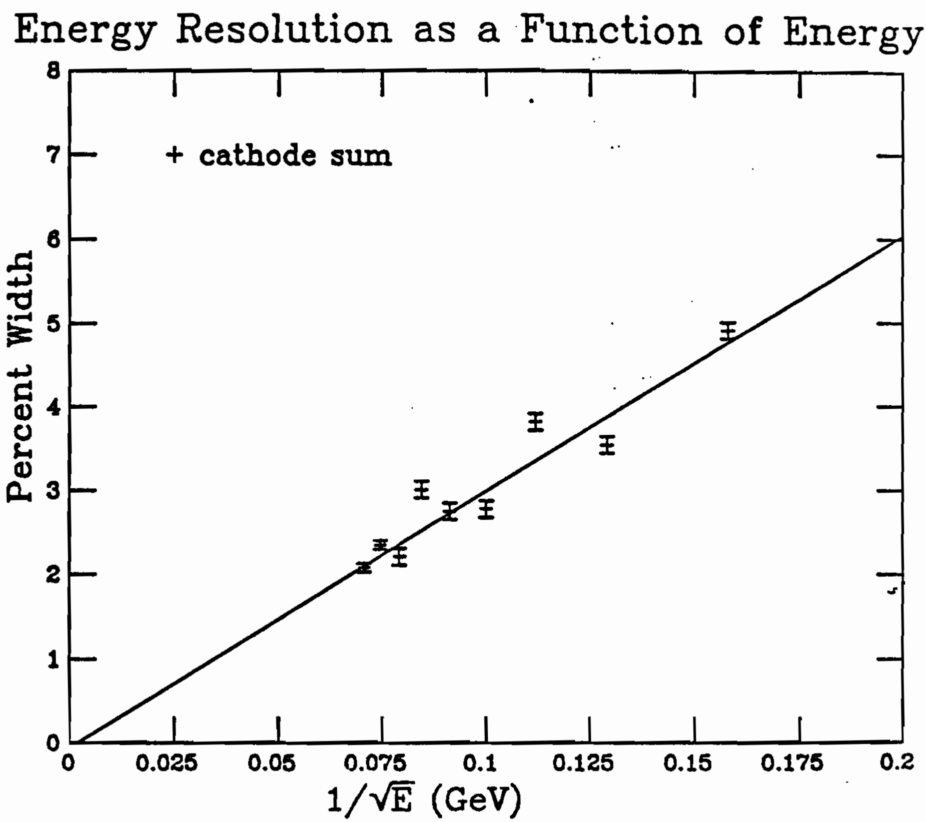

Figure 8 The energy resolution of the calorimeter as a function of $1/\sqrt{E}$.

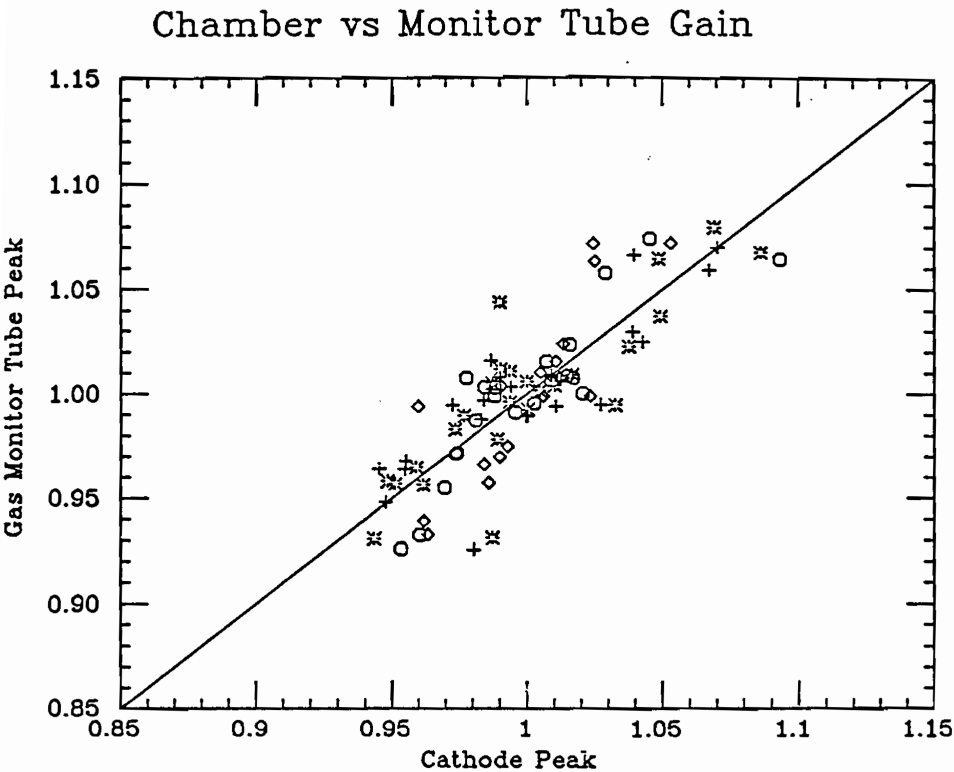

Figure 9 A correlation plot of the peak position of the ^{55}Fe source in a gas monitor tube vs. that for 100-GeV positrons in the calorimeter. Each point is a separate run and the different point styles are for different locations on the calorimeter face.

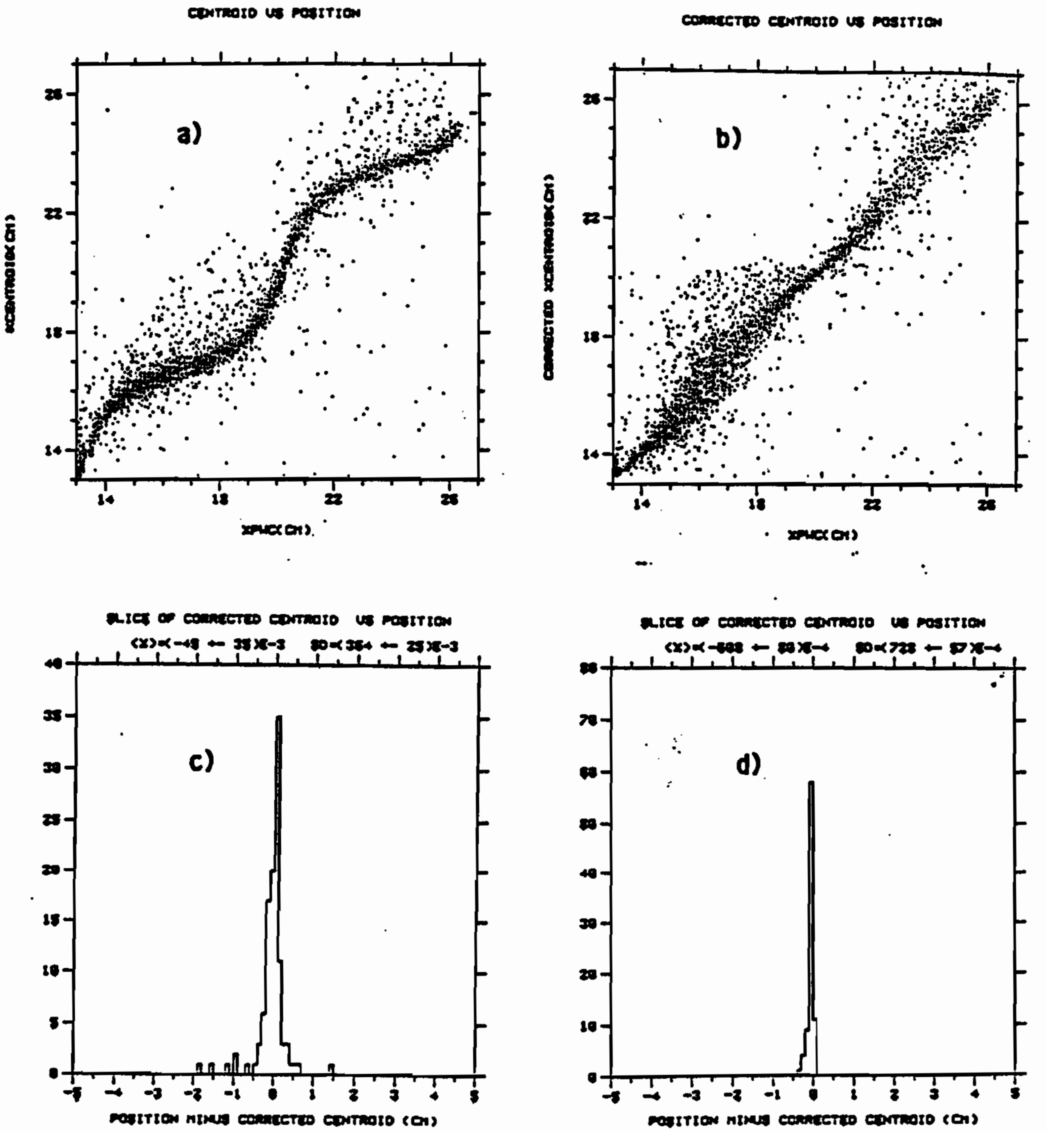

Figure 10 A study of the position resolution for a 100-GeV positron beam. a) shows the shower centroids plotted against the known beam position while b) has the centroid corrected for the finite pad size. c) and d) show the position resolution obtained from b) at a pad center (c) and at a pad boundary (d).