FIRST TESTBEAM RESULTS FOR THE QIE-DEMONSTRATOR READOUT FOR THE CMS HADRONIC CALORIMETER

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Abstract

First results of QIE based electronics used to readout the HE calorimeter in the H2 testbeam at CERN are presented. Beam, LED, and calibration data are discussed along with descriptions of the system and DAQ.

1. QIE CONCEPT AND DISCRIPTION

The basic concept of the QIE (Charge Integrate and Encoder) is to allow the input charge from a phototube to be measured over a very large dynamic range with good precision over the entire range. The QIE is designed to continuously put out an exponent (range) and an analog voltage within that range corresponding to the integrated charge within one clock period[1]. The QIE and DBC (Driver-Buffer Clock) ASICs used for the demonstration in the test beam were originally designed for the KTeV experiment at Fermilab[2,3] and provide continuous charge sampling at up to 60MHz. The QIE system was run at the nominal LHC beam RF rate of 40 MHz.

The QIE is a pipelined device with 4 stages in the pipeline. The output of the QIE is a 3-bit range number and an analog voltage corresponding to the value in that range. This analog voltage is converted to digital by an 8-bit FADC and the data is stored in the DBC ASIC until readout is requested. In the lowest range, with the preamp installed, each LSB corresponds to about 2000 electrons within a 25 nsec time interval. This is equivalent to 13 nanoamps/LSB. Each event is comprised of 32 time slices of the input signal where each slice has an "Exponent" (Range) and Mantissa (FADC) as well as a Capacitor ID which indicates which of the 4 integrating capacitor banks produced the data. These 32 slices allow the charge input to be studied as a function of time; thus we can get a time profile of the beam signal.

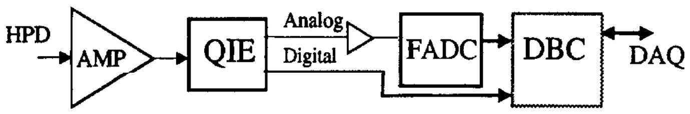

Figure 1: A simplified Block diagram of the QIE electronics for one channel of the 6 channel boards used in the CMS testbeam effort.

2. TESTBEAM SETUP

2.1 *HE calorimeter*

The testbeam readout system consisted of 21 channels of KTeV style QIE electronics that were used to instrument the HE (Hadronic EndCap) Figure 2.

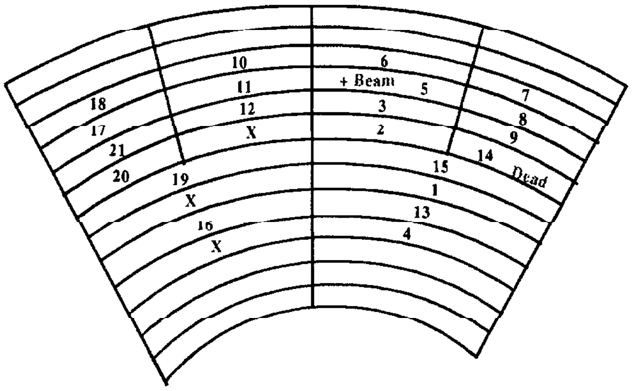

Figure 2: HE Channel Map Beam's eye view.

The HE calorimeter is made up of alternating layers of scintillator and 2 cm brass layers with 18 layers being read out for each tower[4]. The light is collected via waveshifting fibers and brought to the readout-decoder box via clear waveguide fibers. The light is converted using HPDs (Hybrid Photo Diodes)[5], which have a quantum efficiency of about 13% and a gain of about 2000.

This low gain and the fact that the charge pulse is positive required a pre-amplifier, which inverted the signal and had a gain of 20. This allowed the output of the HPDs to match the existing KTeV QIEs, which expect a negative current pulse typical of photomultiplier tubes. The final version of the CMS QIE is under design at this time and will accept both positive and negative polarity signals.

2.2 *Beam*

The beam trigger was comprised of two small scintillator counters in coincidence. The H2 beam line could deliver muons and pions at several energies. Muons were available even when the beam stop was installed. The pion beam still contained muons. We used a motion table to position the calorimeter so that the beam was approximately centered in channel 5 (see Fig 2.) An LED calibration system and a moving wire radioactive source were available for calibration purposes.

2.3 DAQ

The Data Acquisition system used for the QIE demonstrator was based on a PC running Windows NT 4.0 and Visual Basic 6.0, which could communicate with a CAMAC crate. The DAQ provided both data recording and data analysis capabilities. Pedestals, energy sums, timing plots, and various histograms were available on-line. This allowed us to adjust the system timing and verify that things were working very quickly.

3. PEDESTAL DATA

One important way to study the noise performance and stability of the readout system is to study the behavior of the pedestals as a function of time. The pedestal value and RMS width are good indicators of the performance of the system, especially with the added complication of a pre-amplifier in front of the QIEs. During KTeV's running the pedestals were stable and had an RMS width of 0.3 LSBs. However, each LSB for KTeV was equivalent to about 40,000 electrons. For the HE system each LSB is only 2000 electrons due to the use of the pre-amplifier.

In the previous year's testbeam effort we had serious oscillation problems with the pre-amps at a very low frequency (~ 0.5 Hz). This problem was fixed and we could no longer see this low frequency oscillation. The HPDs, however, were grounded to the detector, and from tests done at Fermilab, we knew this increased noise in the system. Figure 3 shows the pedestal for a "good" channel, (channel 12) it has an RMS of about 4.3 counts or about 9000 electrons.

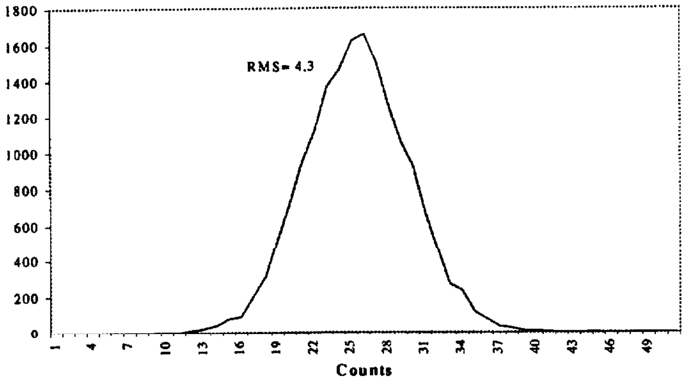

Figure 3 Pedestal distribution for channel 12 RMS=4.3 LSBs.

Figure 4 shows the same pedestal distribution in log mode. Unfortunately some channels were much noisier; Figure 5 shows a noisy channel.

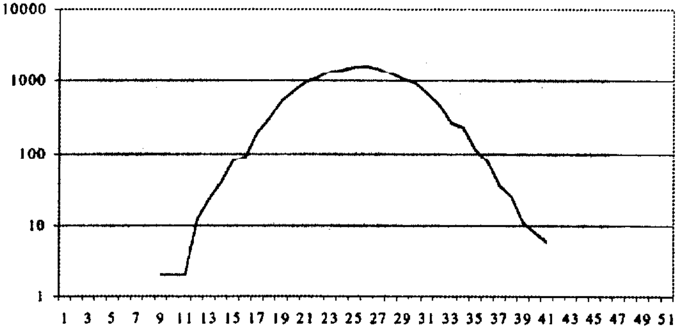

Figure 4: Pedestal distribution for channel 12 log scale.

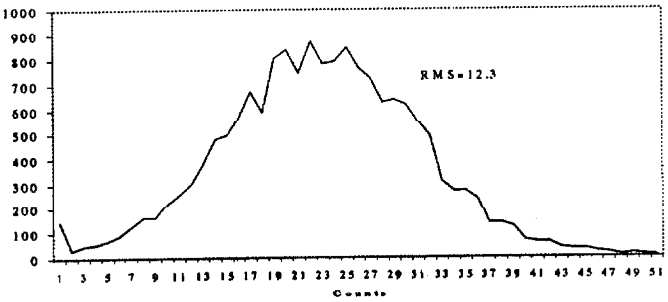

Figure 5: Pedestal distribution for a noisy channel.

4. BEAM DATA

4.1 Pion Data

The H2 testbeam at CERN was able to provide pions at several energies. We took data at 250, 200, 125, and 50 GeV with pions. One of the first things we needed to study was the timing of the signal. Using the online DAQ we were able to set the pion signal to be in time slice 6 of the 16 slices we were reading out.

Figure 6 shows the time structure for 250 GeV pions and indicates the pedestal and data regions. The ringing and undershoot are artifacts of the pre-amp used in front of the QIE.

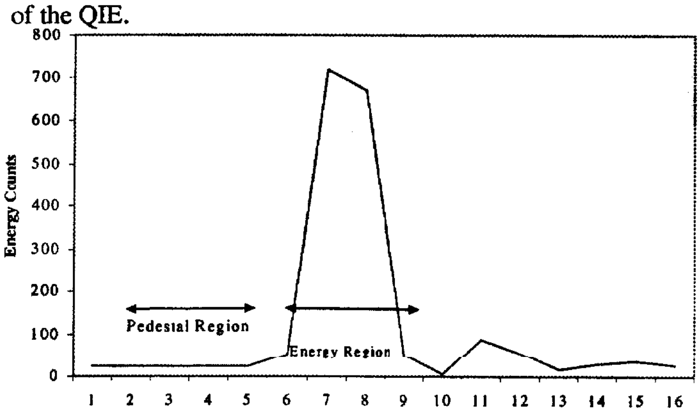

Figure 6: Time structure for 250 GeV pion signal.

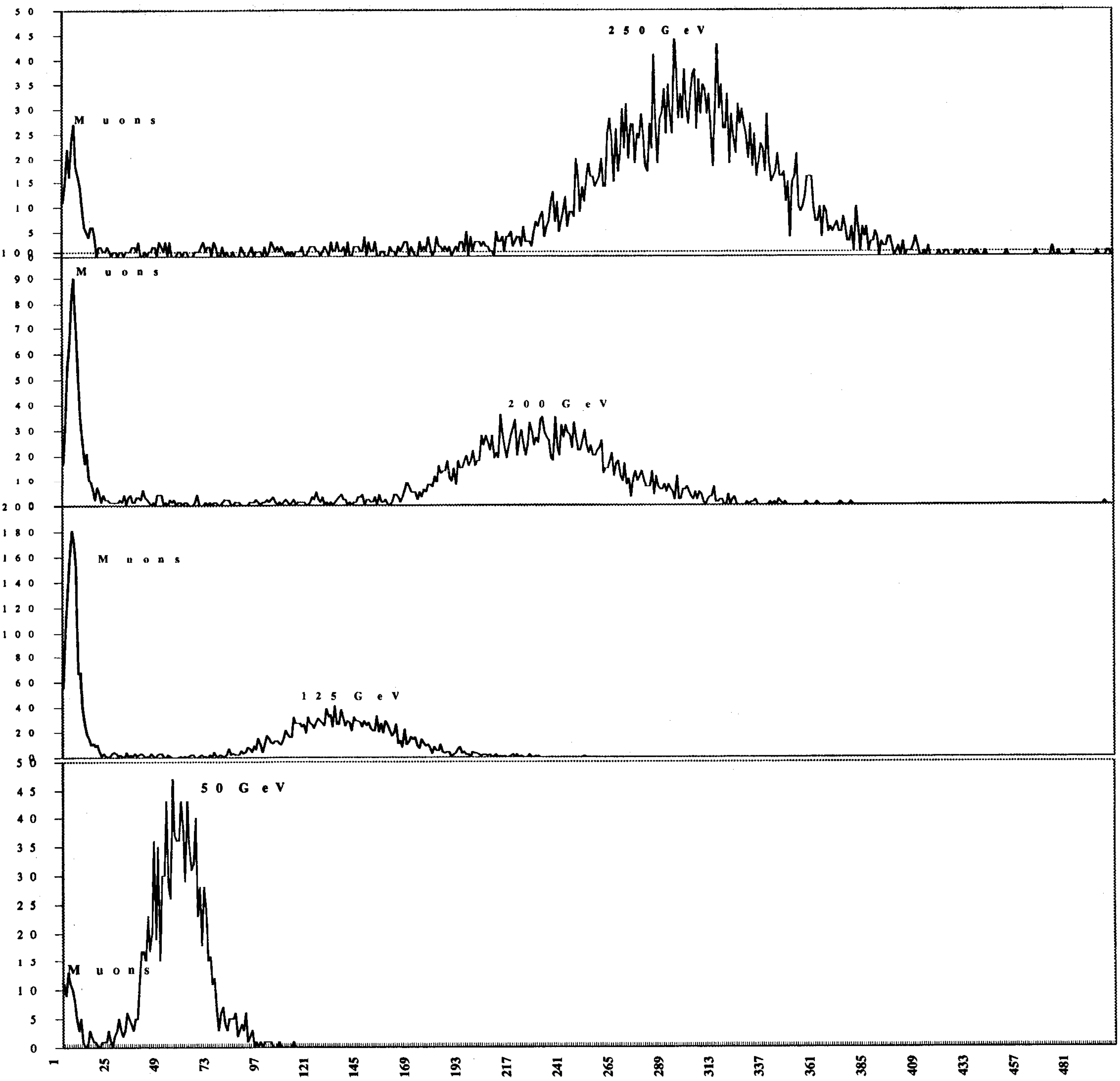

Figure 7. Pedestal subtracted energy Histograms for 250, 200, 125, and 50 GeV Pions. Axis is in counts/10 where each count equals about 2000 e^-. A clear muon peak is also observed at the low end of the scale for each distribution.

An energy histogram of the pion data also shows a Muon peak. Figure 7 shows the pion energy sums for the four beam energies used. Figure 8 shows the pion beam energy plotted vs. the central tower pulse energy sum. The algorithm used to make the pedestal subtracted energy sum was to sum slices 6 through 9 and subtract the sum of slices 2 through 5 (see Figure 6). The response is reasonably linear with only slight deviations, which can be explained by shower leakage to adjacent towers, which are not included in the sum.

4.2 Muons

We were able to take Muon data during open access to the test beam. One of the main goals was to verify that single muons could be seen above pedestal. We also wanted to study the time response of the calorimeter to muons. Figure 9 shows the time response of the system to muons, Figure 10 shows a single Muon event. The pedestal noise can be seen in the single event, and future work is needed to reduce this noise.

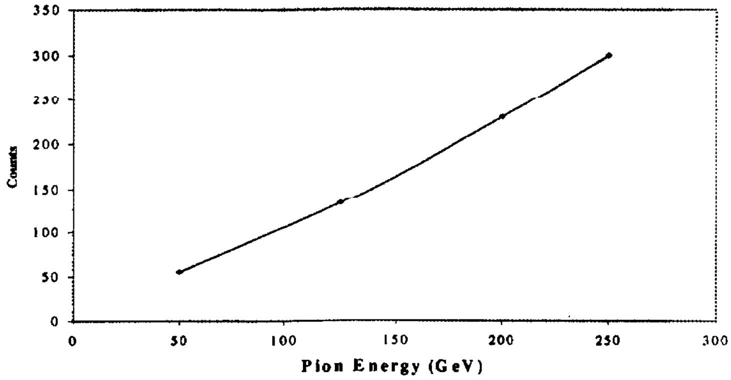

Figure 8: Energy vs. response for pions in the HE calorimeter.

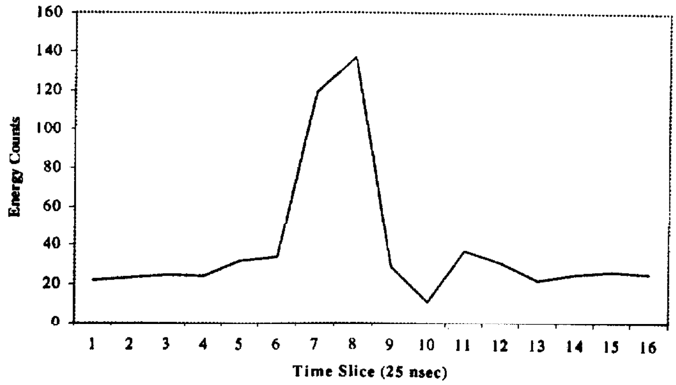

Figure 9. Muon Pulse shape vs. time averaged over 100 events to smooth pedestal noise. After-Pulse undershoot and ringing is caused by the amplifier used in front of the QIE.

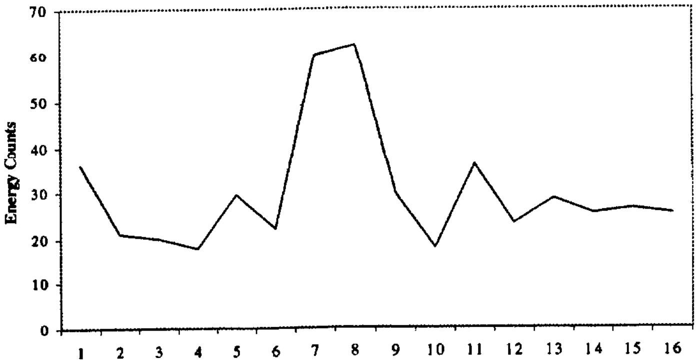

Figure 10. A single Muon event pulse shape vs. time. Note the pedestal noise.

5. CALIBRATION

5.1 LED system

The calorimeter was equipped with an LED flasher system, which could be used to illuminate all channels of the detector; fiberoptic signals were delivered to each HPD channel. We took several LED runs in order to study the uniformity of the response to the LED signals. Figure 11 shows the time response of channel 5 (the beam channel) to the LED system. The LED pulse is longer than a normal beam pulse. Figure 12 shows the energy sum response to the LED system. Note that the distribution is narrow and gaussian over several decades. The conclusion is that the LED system will work to track the performance of the detector.

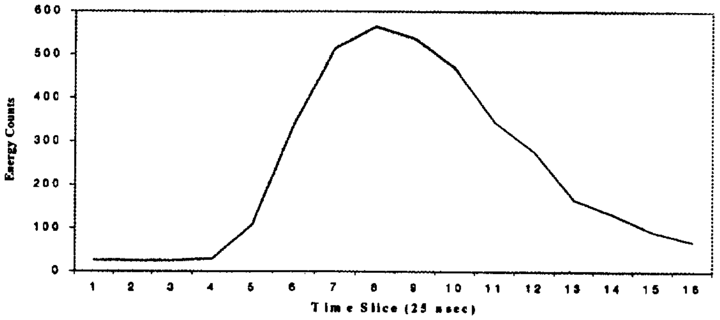

Figure 11: Time profile for LED pulse measured via the QIE system.

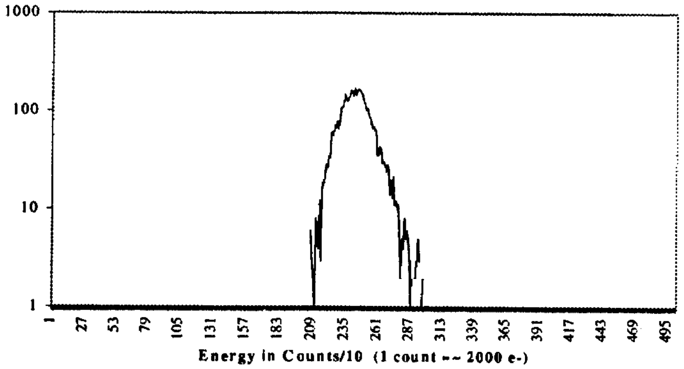

Figure 12: LED energy response for Channel 5 log scale.

5.2 Source Calibration

The calorimeter is also equipped with a moving wire radioactive source calibration system. This system allows the response of each tile to be measured. The source calibration system will be used to correct for radiation damage to the tiles as the detector ages. The instrumentation problem with the source system is the very small size of the source signal, only 0.5 LSBs. The method of measuring this small signal is extreme oversampling[6]. The basic method is to measure the pedestal to great precision both with and without the source. The difference between the two measurements is the source signal. This method requires a stable pedestal during the measurement time, some noise (usually not a problem), and the taking of lots of pedestal data.

At this time we did not quite meet 2 of the 3 requirements and stumbled on the third. The pedestals were stable but had a remnant of the low frequency oscillation that plagued us during last year's test beam. Figure 13 shows the pedestal vs. time for a single channel. Note there still is a 0.2 to 0.5 Hz oscillation at about the 0.2 LSB level. This oscillation can be removed manually as it occurs on all channels at the same phase. However, when you are trying to measure a source of 0.15 LSBs to a precision of .01 LSBs, any extra coherent noise is a problem.

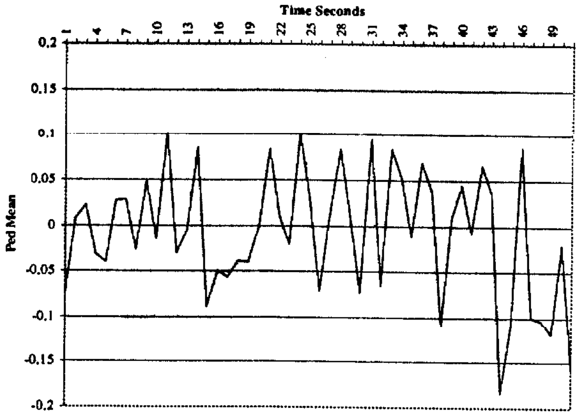

Figure 13: Pedestal deviation of mean as a function of time. Full scale is +/- 0.2 LSB.

The second problem we had was that the source driver was temporarily broken. This prevented us from moving the source to one of the quiet channels. The noise level on the channel where we could position the source had an RMS of about 12 counts. For that RMS, we would have needed about 1,000,000 pedestal measurements to recover the source to .01 LSBs. At the time we were taking data we did not realize this and only took about 100,000 to 200,000 pedestals. The statistical nature of this measurement combined with an RMS of 12 only allows for a precision of about +/-0.03 LSBs in the measurement of the pedestal.

Given that the pedestals were not quite stable, (low frequency oscillation) and that the noise was too large (RMS of 12, we expect final system to be 1.5-2) and that we did not take long enough pedestal runs, we were unable to achieve our goal of measuring the pedestal and hence the source to 0.01 LSBs. We did however, measure the pedestals to a precision of 0.03 LSBs, and we understand why we were limited to that resolution.

6. CONCLUSIONS

The QIE overall run was a success. The DAQ worked very well and provided good online displays.

The response of the system for Muons, Pions and LED pulses was measured. Muons were clearly separated from the pedestals. The Pion energy response was linear. The LED system produced very gaussian pulse distributions.

The time structure of the response of the calorimeter was measured for Muons, pions and the LED system. The LASER calibration system was not yet online during our run, so we have not yet measured the response of the system to the LASER pulser.

We did have some shortfalls. The cross talk and ringing in the pre-amplifier compromised our ability to study shower energies that were shared across more than a single tower. The channel to channel cross talk corrupts the energy sum for the calorimeter, and we will be working to correct this problem. We observed that we still have a pedestal oscillation, which coupled with increased noise, compromised our ability to do detailed radioactive source measurements. We did measure the source at the level of 0.15 LSBs +/- 0.03 LSBs, but did not reach our goal of +/- 0.01 LSBs. Further work on this front will continue using low level LED signals.

7. REFERENCES

[*] Work supported by the U.S. Dept. of Energy under contract No. DE-AC02-76CH03000.

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