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TEST BEAM RESULTS FROM THE D0 ENDCAP ELECTROMAGNETIC CALORIMETER MODULE[1]

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TEST BEAM RESULTS FROM THE D0 ENDCAP ELECTROMAGNETIC CALORIMETER MODULE*

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Abstract

We have constructed the endcap electromagnetic modules of the D0 Uranium Liquid Argon Calorimeter. Details of the module design and construction are discussed and initial results from a test beam run with beam momenta ranging from 10 – 150 GeV/c are presented. We obtain an energy resolution with electron beams of $15.5\%/\sqrt{E(\mathrm{GeV})}$ with a small constant term of $\sim 0.5\%$ and a linearity of better than $\pm 0.5\%$.

1 Introduction

The construction of the D0 experiment is nearing completion in preparation for the start of data taking at the Fermilab Tevatron Collider in late 1991. The detector features a uniform, fine-grained uranium liquid argon calorimeter which provides good energy resolution and hermetic coverage for electrons, photons and jets. The calorimeter is constructed as three separate cryostats: central (CC) and two endcaps (EC), each of which contains electromagnetic and hadronic calorimeter modules. Figure 1 shows the layout of the central and endcap calorimeters.

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† The D0 collaboration includes members from University of Arizona, Brookhaven National Laboratory, Brown University, University of California Riverside, Columbia University, Fermi National Accelerator Laboratory, Florida State University, University of Florida, University of Hawaii, Indiana University, Lawrence Berkeley Laboratory, University of Maryland, University of Michigan, Michigan State University, New York University, Northern Illinois University, Northwestern University, University of Rochester, CEN Saclay France, Institute for High Energy Physics Serpukhov USSR, State University of New York - Stony Brook, Tata Institute of Fundamental Research Bombay India, Texas A&M University and Yale University.

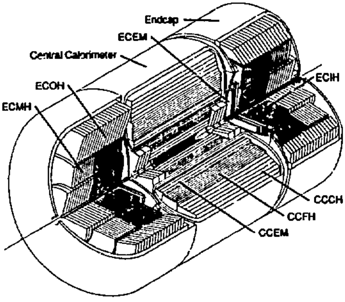

Figure 1: The D0 liquid argon calorimeters.

In order to calibrate the various modules that comprise the D0 calorimeter, a test beam facility has been established at Fermilab. During the period June-August 1990 we studied the response of the final Endcap Electromagnetic (ECEM) and Inner Hadronic (ECIH) modules prior to their installation at the Tevatron. This paper will discuss the response of the ECEM module to electrons beams; the combined ECEM-ECIH response to pion beams and a description of the readout electronics can be found in separate contributions to this conference.[1, 2]

2 The ECEM Module

The ECEM module, which is designed to mount on the front of the endcap hadronic modules, provides full azimuthal (ϕ) coverage in the forward region $(1.4 < \eta < 4.0)^{\ddagger}$. The module (Fig. 2) consists of 18 sampling cells in depth and has a total thickness 23.8 cm (approximately 20.1 radiation lengths (X_0) of material at normal incidence.) Signals are read out in four separate longitudinal sections of 0.3, 2.6, 7.9 and 9.3 X_0. Transverse segmentation is provided by the readout pads on the signal boards, each covering an η, ϕ interval of $\Delta\eta \times \Delta\phi = 0.1 \times \pi/32 (\approx 0.1)$. In the third longitudinal section, which typically contains 65% of the electromagnetic shower, the transverse segmentation is doubled in both directions (0.05×0.05) to provide better shower position resolution. These pads are arranged in a semi-projective tower geometry which continues from the EM into the hadronic modules behind it. (The semi-projective pads differ from exact towers in that the same pad layout is used for adjacent pairs of layers (groups of 4 in the last longitudinal section) in order to

$^{\ddagger}\eta$ is the pseudorapidity defined as $\eta = -ln\tan(\theta/2)$, where θ is the polar angle from the beam axis.

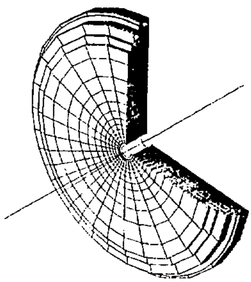

Figure 2: The ECEM Module

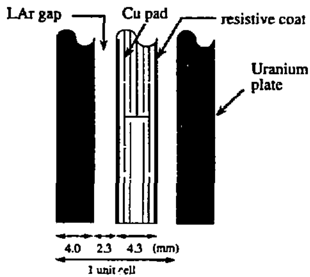

Figure 3: The basic sampling cell of the ECEM, showing uranium plates, liquid argon gaps and a *multilayer PC signal board.*

simplify signal board fabrication.) The module has a total of 7488 readout channels.

In order to minimize losses due to internal cracks, the module is built as a single unit. Both the signal boards and the absorber plates are preassembled as disks of typically 1 m radius and then stacked to assemble the module.

The basic sampling cell of the module, shown in Figure 3, consists of a 4 mm depleted uranium absorber plate, a 2.3 mm liquid argon gap, a NEMA G-10 signal board and another 2.3 mm liquid argon gap. The signal boards are 5-layer printed circuit (PC) boards with copper pads on the outer surfaces and signal traces on the innermost layer which bring the signals to the connectors mounted at the outer radius of the module. Two shielding ground planes reduce crosstalk to a negligible level. The multilayer PC boards were fabricated as 22.5° wedges and then assembled into disks and laminated with face sheets of NEMA G-10 (0.5 mm thick) that had been print-screened with a thin coating of a high resistivity ($\sim 50\mathrm{M}\Omega/\Box$) carbon-loaded epoxy. Positive high voltage is applied to this resistive coat. Both the pads and aborber plates are at gound potential with the face sheet serving as a blocking capacitor. The normal operating voltage is +2.5 kV, corresponding to a drift field of 1.1 kV/mm in the gap.

With the exceptions noted below, the absorber disks are made of 4 mm thick rolled depleted uranium plate. Each uranium disk is made by joining three smaller plates (approximately 60 cm wide by 2 m long) side by side at their edges. Ground connections to the uranium were made by percussion-welding niobium pins. The first two absorber disks are thin (1.6 mm) stainless steel disks to form massless gaps to monitor the energy flow through the cryostat wall which has a total thickness of about $2X_0$. All absorber and signal disks are supported by an aluminum central tube which is in turn supported by a 2 cm thick stainless steel strongback in the

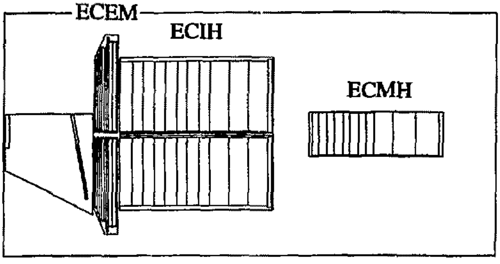

Figure 4: Arrangement of modules in the test beam cryostat. A liquid argon excluder, ECEM, ECIH and ECMH are shown.

middle of the module. A 1.6 mm stainless steel disk was also used for the absorber plate that follows the strongback so that the average sampling fraction for these two cells equals that of a uranium cell, as determined by a Monte Carlo calculation for 50 GeV electrons. The thickness of each disk was measured with an ultrasonic probe at points on a 10 cm $\times$ 10 cm grid. The variation in thickness was $\sim 2.3\%$ and $\sim 1\%$ in uranium disks and signal disks, respectively.

Twenty-six platinum resistance temperature devices (RTD's) are attached to the module to monitor the temperature during cooldown and warmup. The cooldown and warmup of the module for the test beam run each took about four days and the temperature difference between any two sensors was kept to $< 50°$C.

3 1990 Test Beam Run

The D0 calorimeter test beam facility has been established in the Neutrino-West beam line at Fermilab. This beam line provides electron and pion beams with momenta from 10 to 150 GeV/c. A system of proportional wire chambers (PWCs) and Cerenkov counters provided the particle momentum and identification on an event-by-event basis. The spread of the beam momentum was typically 1.5% and the pion contamination in the electron beam was negligible (less than 10^{-5}). A set of scintillation counters provided the trigger.

The arrangement of modules in the test beam cryostat is shown in Fig. 4. An ECMH (Middle Hadronic) module was placed behind the ECIH to monitor the leakage of hadronic showers. The cryostat has a thin window (two 1.6 mm thick steel plates) in the region illuminated by the beam. The setup includes a liquid argon excluder, a 2.5 cm thick stainless plate to simulate the D0 cryostat walls, and a 4.4 cm thick aluminum plate at small angles to simulate the D0 vertex detector endplates and electronics. The test beam cryostat is equipped with a computer controlled transporter that orients the module so that the beam stikes it along projective towers as do particles at the collider. The cryostat can be positioned so as to sweep the beam over ± 15 degrees in ϕ and the full extent in η. The region illuminated by the beam and a surrounding border zone (1452 channels in total) were instrumented with the readout electronics and internal cryostat cables which will be used in the final D0 detector. The overall sensitivity [2] of the electronics is ~ 0.57 fC per ADC count or 3600 electrons per count. (From the test beam data, we find that one ADC count corresponds to ~ 4 MeV of electromagnetic energy deposited in the ECEM.)

4 Data analysis

ADC pedestals and gains were corrected for each channel based on calibration data taken with a precision pulser. The spread in the beam momentum was corrected event-by-event using the momentum measured by the PWC system. Electrons which showered in the upstream material in the beam line were removed offline using the information from a PWC mounted on the face of the cryostat.

The energy of the electromagnetic shower was reconstructed by summing all 4 longitudinal sections ($20.1X_0$) in the ECEM and the first section ($30X_0$) of the ECIH. Relative sampling fractions for each longitudinal section were obtained by minimizing the width of the energy response of a separate set of data. These values are consistent with sampling fractions calculated from dE/dX losses. The analyses presented here used a single set of energy independent relative sampling fractions. The energy scan results given below were taken at $\eta = 1.95$ ($16°$ incidence) where adding nine towers about the shower maximum was found to contain 99% of the incident energy. The effect of variation in thickness of the uranium plates and signal boards was corrected tower-by-tower by using thickness maps obtained during the construction.

5 Performance

Figure 5 shows the data from a high voltage scan obtained with 100 GeV electrons. Our operating voltage (2.5 kV) is located well on the plateau. Such scans were repeated approximately every ten days and the ECEM response was constant to better than $\pm 1\%$ for the duration of the run. Also shown is the plateau curve of a liquid argon purity monitor (β cell[†]) which agrees well with the ECEM data. From an analysis of the monitor data [3] we estimate that the purity of liquid argon was ≤ 0.6 ppm oxygen-equivalent contamination over the entire period of data taking.

Pulse height distributions with superimposed gaussian fits are shown in Fig.6 for electrons with various beam momenta. Figure 7a shows the mean pulse

[†] β cell is a double liquid argon gap with Ru(106) β source. [3]

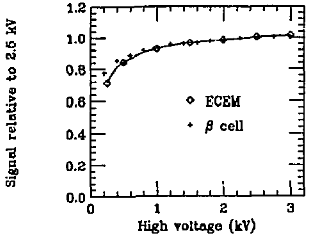

Figure 5: High voltage plateau curve of the ECEM taken with 100 GeV electrons. Also shown is the plateau curve of the liquid argon purity monitor (β cell).

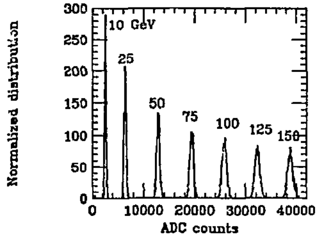

Figure 6: Pulse height distributions for electrons for various beam momenta, normalized to the same number of events.

height versus beam momentum with a linear fit, and Fig.7b shows the deviation from linearity which is less than $\pm 0.5\%$ over the entire momentum range.

The linear fit yields

$$\mathrm{E(GeV)} = \mu(\mathrm{ADCcounts})/(259.0 \pm 0.1) - 0.09 \pm 0.01(\mathrm{GeV}).$$

The fractional energy resolution, calculated as σ/μ from a gaussian fit, is shown in Figure 8. We assume the energy dependence of the resolution is of the form $(\sigma/\mu)^2 = C^2 + S^2/\mathrm{E} + N^2/\mathrm{E}^2$, where E is the beam energy in GeV, C is a constant contribution from systematic errors such as remaining channel-to-channel variation in gain, S is due to the statistical error in sampling, and N represents energy independent contributions to σ such as electronic and uranium noise. The results of the fit are:

$$\begin{aligned} C &= 0.005 \pm 0.001, \\ S &= 0.155 \pm 0.003(\sqrt{\mathrm{GeV}}), \text{ and} \\ N &= 0.226 \pm 0.023(\mathrm{GeV}). \end{aligned}$$

The value of the noise term, N, agrees well with the directly measured value.

6 Conclusion

The performance of the D0 endcap electromagnetic calorimeter module was studied using electrons with energy ranging from 10 to 150 GeV. The energy resolution is $15.5\%/\sqrt{\mathrm{E}\ (\mathrm{GeV})}$ with a small constant term of $\sim 0.5\%$ and the response is linear to better than $\pm 0.5\%$.

We would like to thank the Fermilab Accelerator Division and the staffs at our individual institutions for their contributions to the success of this project.

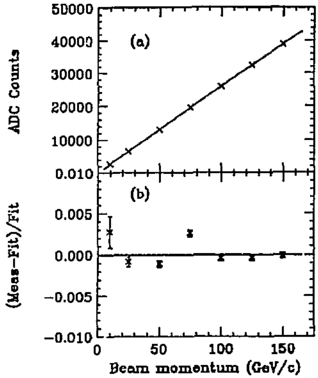

Figure 7: (a)The mean pulse height vs beam momentum with a linear fit superimposed. (b)Fractional differences between measured response and a linear fit.

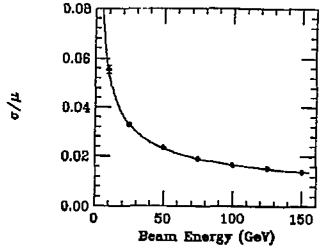

Figure 8: The fractional energy resolution σ/μ as a function of electron beam energy superimposed with the fit described in the text.

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