CONF-9105263--2

LBL-31168

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

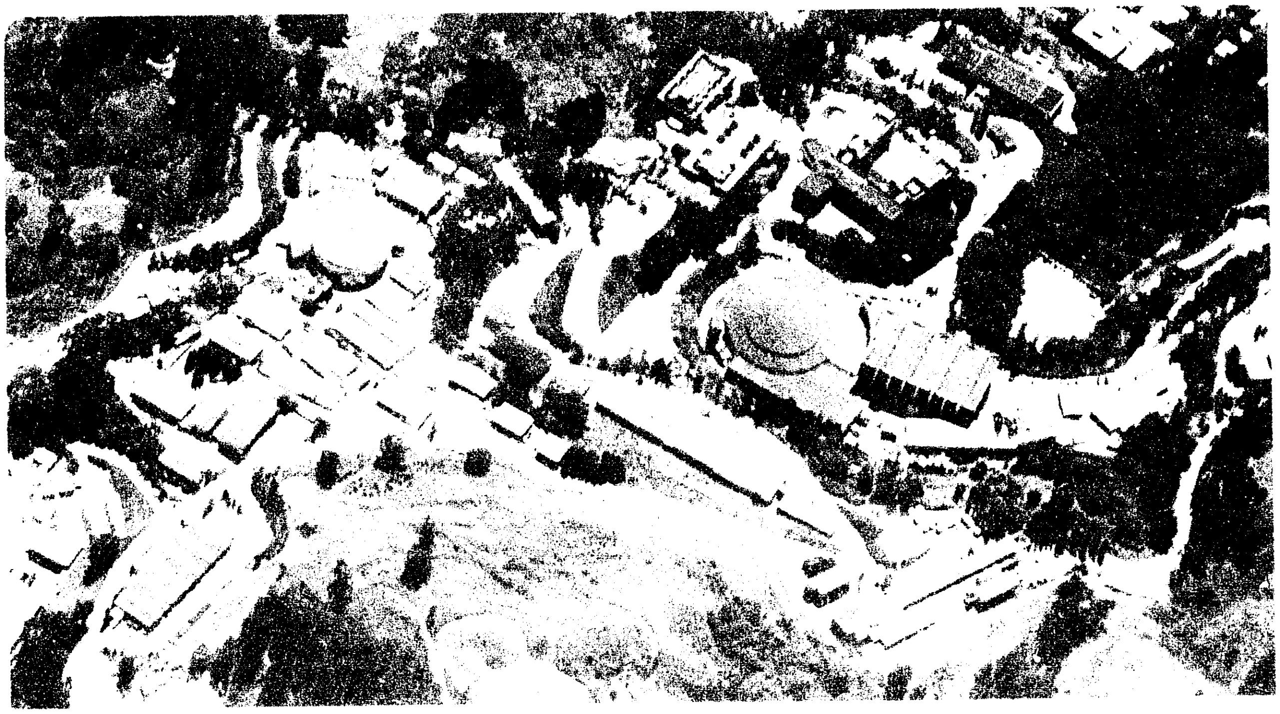
Physics Division

Presented at the 5th Pisa Meeting on Advanced Detectors,
Elba, Italy, May 26–31, 1991, and to be published
in the Proceedings

Test Beam Results from the D0 Liquid Argon End Calorimeter Electromagnetic Module

A.L. Spadafora

August 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL--31168

DE92 000809

TEST BEAM RESULTS FROM THE D0 LIQUID ARGON END CALORIMETER ELECTROMAGNETIC MODULE[1]

Anthony L. Spadafora

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

August 1991

---

[1] This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Test Beam Results from the D0 Liquid Argon End Calorimeter Electromagnetic Module

Anthony L. Spadafora*
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720 USA

Representing the D0 collaboration†

August 12, 1991

Presented at the 5^{th} Pisa Meeting on Advanced Detectors
Elba, Italy, May 26-31, 1991

Abstract

Results are presented from a test beam study of the D0 liquid argon end calorimeter electromagnetic module prior to its installation at the Fermilab Tevatron Collider. Using electron beams with energies ranging from $10 - 150$ GeV we have obtained an energy resolution of $15.7\%/\sqrt{E(GeV)}$ with a small constant term of 0.3% and a linearity of better than ±0.5%. The position resolution of the calorimeter is found to be approximately 1 mm for 100 GeV electrons.

---

*This work was supported by the Director, Office of Energy Research of the U.S. Department energy under Contract No.DE-AC03-76SF00098.

†The D0 collaboration includes members from Universidad De Los Andes Colombia, University of Arizona, Brookhaven National Laboratory, Brown University, University of California Riverside, Columbia University, Centro Brasileiro de Pesquisas Fisicas Brazil, Fermi National Accelerator Laboratory, Florida State University, University of Florida, University of Hawaii, University of Illinois Chicago, Indiana University, Institute for High Energy Physics Serpukhov USSR, Iowa State University, Lawrence Berkeley Laboratory, University of Maryland, University of Michigan, Michigan State University, New York University, Northern Illinois University, Northwestern University, University of Notre Dame, Purdue University, Rice University, University of Rochester, CEN Saclay France, State University of New York - Stony Brook, Tata Institute of Fundamental Research Bombay India, Texas A&M University, University of Texas at Arlington and Yale University.

1 Introduction

The D0 experiment, which will begin taking physics data in the 1992 run of the Fermilab Tevatron Collider, features a uniform, fine-grained uranium liquid argon calorimeter which provides good energy resolution and hermetic coverage for electrons, photons and jets. A test beam facility has been established at Fermilab to study the response of the electromagnetic and hadronic modules that comprise the central (CC) and end (EC) calorimeters (Fig 1.) This paper will present results from the test beam study of the response of the end calorimeter electromagnetic module (ECEM) to electron beams. The response of the combined electromagnetic and hadronic modules to pion beams can be found in Ref.[1] and test beam results from CC modules in Ref.[2, 3].

2 The ECEM Module

The ECEM module, shown schematically in Fig. 2, provides full azimuthal (ϕ) coverage in the forward region ($1.4 < \eta < 4.0$)[‡]. 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 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. A more detailed description of the module's construction can be found in Ref.[4]. Signals are read out in four longitudinal sections and transverse segmentation is provided by semi-projective towers of approximately square pads 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

---

[‡] η is the pseudorapidity defined as $\eta = -ln \tan(\theta/2)$, where θ is the polar angle from the beam axis.

position resolution. See Table 1 for a summary of the readout segmentation.

3 Test Beam Setup

The D0 calorimeter test beam facility has been established in the Fermilab Neutrino-West beam line which provides electron and pion beams with momenta from 10 to 150 GeV/c. A system of proportional wire chambers (PWC's) and Cerenkov counters provides particle momentum and identification on an event-by-event basis. The spread of the beam momentum is typically 1.5% (measured to an accuracy of 0.2%) and the pion contamination in the electron beam is negligible (less than 10^{-5}). A set of scintillation counters provides the trigger.

The test beam run described here was performed with the final D0 ECEM and ECIH (end calorimeter inner hadronic) modules prior to their installation at the collider. The test beam cryostat has a thin window (two 1.6 mm thick steel plates) in the region illuminated by the beam and was configured with a liquid argon excluder, a 2.5 cm thick stainless steel 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 strikes it along projective towers as do particles at the collider. The region illuminated by the beam (±15 degrees in ϕ and the full extent in η) and a surrounding border zone were instrumented with the readout electronics (1452 channels in total) and internal cryostat cables which will be used in the final D0 detector. The overall sensitivity [5] of the electronics is ~ 0.57 fC per ADC count or 3600 electrons per count.

4 Test Beam Results

The analysis of the calorimeter data proceeds by first correcting for the electronic channel pedestals and gains, which were measured once per eight hours and once per day, respectively. The pedestal widths vary with the channel capacitance but were about 8 MeV for a typical 2 nF cell. The spread in the beam momentum was corrected event-by-event using the momentum measured by the PWC system.

The energy of electromagnetic showers was reconstructed by summing all four longitudinal sections in the ECEM and the first section of the ECIH. Relative sampling fractions for each longitudinal section were obtained by simultaneously minimizing the energy resolution and the deviation from linearity for electron momenta ranging from 10 to 150 GeV/c. These optimized values, shown in the last column of Table 2, are not very different from the relative values calculated from minimum ionizing dE/dX losses. The analyses presented here used a single set of energy independent relative sampling fractions. The number of towers summed to contain an electromagnetic shower varies with η, corresponding to the variation of pad size with η. For example, for intermediate size pads of 5 cm square, 99.5% containment is achieved by summing an array of 5 by 5 towers, while for pads of 1 cm square an array of 9 by 9 towers is needed.

"Benchmark" runs at a selected point in the module ($\eta = 1.95$) were repeated almost daily to monitor the stability of the apparatus. For the three month duration of the run the mean value of the response for 100 GeV electrons was found to be constant with an rms spread of 0.3%.

The results of a high voltage scan with 100 GeV electrons is shown in Fig. 3. Our operating voltage of 2.5 kV (11 kV/cm) is well located on the plateau. The curve in Fig. 3 is a fit to the form of Ref[6] and yields an estimate of the oxygen contamination of $0.52 \pm 0.03\,\mathrm{ppm}\,O_2$. Such scans were repeated approximately every ten days and no measurable change was found.

Clear signals for muons were seen in the calorimeter arising from the approximately 3% muon component of the hadron beam. A muon peak is distinguishable above pedestal in all longitudinal sections of the calorimeter. The pulse height spectrum for 15 GeV muons in the third EM layer is shown in Fig. 4. From the fitted most probable value of the muon spectrum in each layer, we obtain an average value of 9.8 ± 0.1 ADC counts/cm of liquid argon. Comparing the ratio of pulse height to deposited energy for electrons and muons, we find for 15 GeV muons:

$$e/\mu = \frac{PH(e)/E(e)}{PH(\mu)/E(\mu)} = 0.69 \pm .05$$

Pulse height distributions from electrons of various beam momenta are shown in Fig. 5. The mean value in ADC counts of the Gaussian fits are shown in Fig. 6a as a function of beam energy and, in Fig. 6b, the residuals from a linear fit of the form:

$$\mu(\mathrm{cts}) = E_{\mathrm{beam}}(\mathrm{GeV}) \times (263.0 \pm 0.1)\,\mathrm{cts/GeV} - (23 \pm 4)\,\mathrm{cts}$$

The fractional energy resolution, calculated as σ/μ from a Gaussian fit, is shown in Fig. 6c. 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: $C = 0.003 \pm 0.002$, $S = 0.157 \pm 0.005(\sqrt{\mathrm{GeV}})$, and $N = 0.329 \pm 0.030(\mathrm{GeV})$. The the noise term, N, is consistent with the value obtained for an array of 5 by 5 towers from the pedestal widths.

The small pads (widths range from 1.4 cm square to 5 cm square) of the third EM layer are used to obtain a measurement of the shower transverse shape and impact position. The one-dimensional shower profile can be written as a sum of "core" and "tail" exponential terms:

$$\frac{dE}{dx} = a_1 e^{-|x-x_0|/b_1} + a_2 e^{-|x-x_0|/b_2}$$

where x_0 is the shower impact position. The fraction of the shower energy that is found to one side of a pad edge is calculated from the double exponential form to be:

$$\frac{E_R}{E_{tot}} = \frac{\int_0^{\infty} \frac{dE}{dX}}{\int_{-\infty}^{\infty} \frac{dE}{dX}} = 1 - \frac{a_1 b_2 e^{-b_1|x_0|} + a_2 b_1 e^{-b_2|x_0|}}{2(a_1 b_2 + a_2 b_1)} \qquad (x_0 > 0)$$

where E_R and E_{tot} are the energy to the right (i.e. increasing x) of a pad edge and the total energy, respectively. Using the shower impact position projected from the track trajectories measured with the PWC system independently of the calorimeter, we fit for the double-exponential parameters and obtain the results given in Table 3.

For determination of the position resolution we use the center of gravity algorithm with a correction term to remove the bias with distance of the shower from a pad edge. Approximating the shower transverse shape by a single exponential term, the corrected center of gravity is given by[7]

$$x = x_c + b\sinh^{-1}\left(\frac{x_c - x_m}{\Delta}\sinh\frac{\Delta}{b}\right)$$

where x_c = the x coordinate of the shower center of gravity, x_m = pad center, Δ = pad halfwidth, and b is the single-slope characteristic length for which we have found 5 mm to be the optimum value. This algorithm is somewhat simpler than the double exponential technique and yields the same value for the position resolution. The resolution obtained for 100 GeV electrons and pads 2.5 cm square in the third EM layer is shown in Fig. 7 as a function of x_e, the distance from the pad edge. The dependence of the resolution on x_e is fit by a quadratic form: $\sigma = a_0 + a_2 x_e^2$ where $a_0 = (0.081 \pm 0.001)$ cm and $a_2 = (0.023 \pm 0.002)$ cm. Applying this analysis to data taken at varying beam energies, we obtain an energy dependence of the position resolution averaged over the pad of approximately: $\sigma = (1.3 \pm 0.1)\text{cm} \times \text{E}^{(-0.61\pm.02)}$ where E is in GeV.

Although the above measurements of energy and position resolution were obtained at selected spots in the calorimeter, we have taken uniformity scans to verify that such performance can be achieved throughout the module. The results of a scan in azimuth (ϕ) at a constant η is shown in Fig. 8. The mean response is constant to 0.5%. Data was also taken scanning the only two sources of non-uniformity in response: the tie-rods that penetrate the stack and the small crack between the uranium plates. The regions affected by these features comprise only a few percent of the active area of the module.

5 Conclusion

The performance of the D0 end calorimeter electromagnetic calorimeter module was studied using electrons with energy ranging from 10 to 150 GeV. The calorimeter response was found to be uniform across the instrumented area and stable for the duration of the run. The energy resolution is $15.7\%/\sqrt{E\ (\mathrm{GeV})}$ with a small constant term of 0.3% and the response is linear to better than ±0.5%. A position resolution for the localization of electromagnetic showers of 1 mm is achieved for 100 GeV electrons impacting on a tower edge.

I would like to thank H. Aihara, W. Dharmaratna, and N. Roe for their contribution to the analyses presented in this paper. The D0 Calorimeter group would like to thank the Fermilab Accelerator Division and the staffs at our individual institutions for their contributions to the success of this project. This work was supported by the Director, Office of Energy Research of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

[1] N.Amos, Proceedings of the International Conference on Calorimetry in High Energy Physics, Batavia, IL Oct. 29 - Nov. 1, 1990, to be published.

[2] M.Abolins et al., Nucl. Instr. and Meth. **A280** (1989) 36.

[3] P.Franzini, Nucl. Instr. and Meth. **A289** (1990) 438

[4] A.Spadafora, Proceedings of the International Conference on Calorimetry in High Energy Physics, Batavia, IL Oct. 29 - Nov. 1, 1990, to be published.

[5] M.Demarteau, Proceedings of the International Conference on Calorimetry in High Energy Physics, Batavia, IL Oct. 29 - Nov. 1, 1990, to be published.

[6] J.Engler et. al., Nucl. Instr. and Meth. **120** (1974) 157.

[7] G.A.Akopdjanov, et. al., Nucl.Instr.and Meth. **140** (1977) 441; A.DeAngelis and F.Mazzone, Nucl. Instr. and Meth. **A287** (1990) 397.

Table 1 : Longitudinal and transverse segmentation of the ECEM readout.

Layer	# Cells	Absorber		$\Delta\eta \times \Delta\phi$
EM1	2	1.6 mm Fe	$0.2X_0$	$.1 \times .1$
EM2	2	4 mm DU	$2.6X_0$	$.1 \times .1$
EM3	6	4 mm DU	$7.9X_0$	$.05 \times .05$
EM4	8	4 mm DU	$9.2X_0$	$.1 \times .1$

Table 2 : The sampling fractions calculated for a minimum ionizing particle, these values normalized to the third EM layer, and the relative values found from the resolution/linearity minimization. The values in parentheses were not varied in the fit.

	dE/dX		Fit
Layer	SF	$\frac{SF(3)}{SF(i)}$	$\frac{SF(3)}{SF(i)}$
EM1	.047	1.82	1.61
EM2	.090	0.96	0.96
EM3	.086	(1.0)	(1.0)
EM4	.081	1.06	1.10
IH1	.056	1.52	(1.52)

Table 3: The fitted shower shape parameters from the double exponential form. The amplitude of the second term, a_2, is set equal to 1.

a_1	$3.71 \pm .09$
b_1	$(2.87 \pm .7)\,\mathrm{mm}$
a_2	1.00
b_2	$(10.3 \pm .1)\,\mathrm{mm}$

Figure Captions

Fig.1 The D0 liquid argon calorimeters.

Fig.2 The ECEM Module.

Fig.3 High Voltage plateau curve of the ECEM taken with 100 GeV electrons.

Fig.4 Pedestal subtracted pulse height spectrum for 15 GeV muons in the third EM layer.

Fig.5 Pulse height distributions of electrons for various beam energies, normalized to the same number of events.

Fig.6 a) Mean pulse height as a function of beam energy, b) residuals from a linear fit, and c) fractional energy resolution as a function of beam energy.

Fig.7 Position Resolution of the ECEM as a function of the distance from edge of a pad. σ is the rms of the difference between the corrected center of gravity impact position in the third EM layer and that projected from the track reconstructed from the PWC's. The fit is the quadratic form given in the text.

Fig.8 Mean pulse height for 100 GeV electrons runs at a fixed η but varying azimuth. The azimuth is given as the arc length at the calorimeter $S = R \times \phi$ where R for this scan is 59 cm.

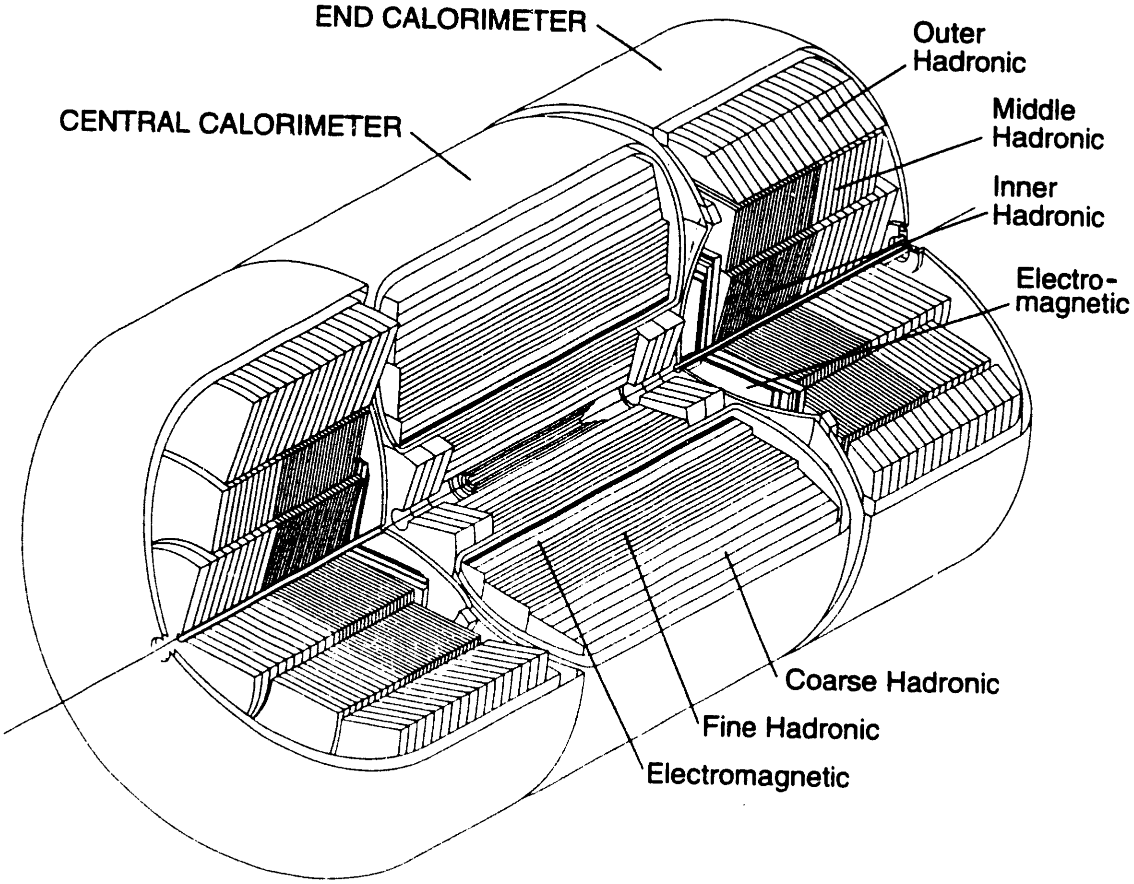

END CALORIMETER
CENTRAL CALORIMETER
Outer Hadronic
Middle Hadronic
Inner Hadronic
Electro-magnetic
Coarse Hadronic
Fine Hadronic
Electromagnetic

Figure 1:

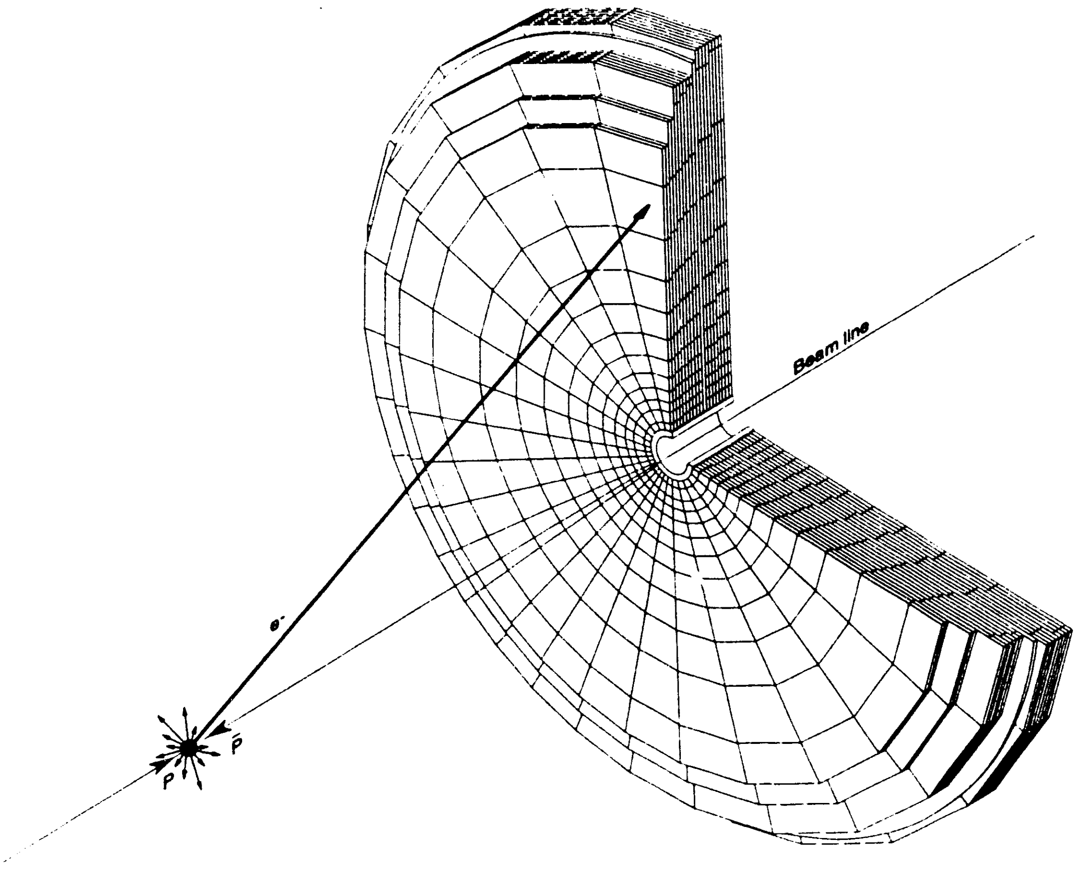


Figure 2:

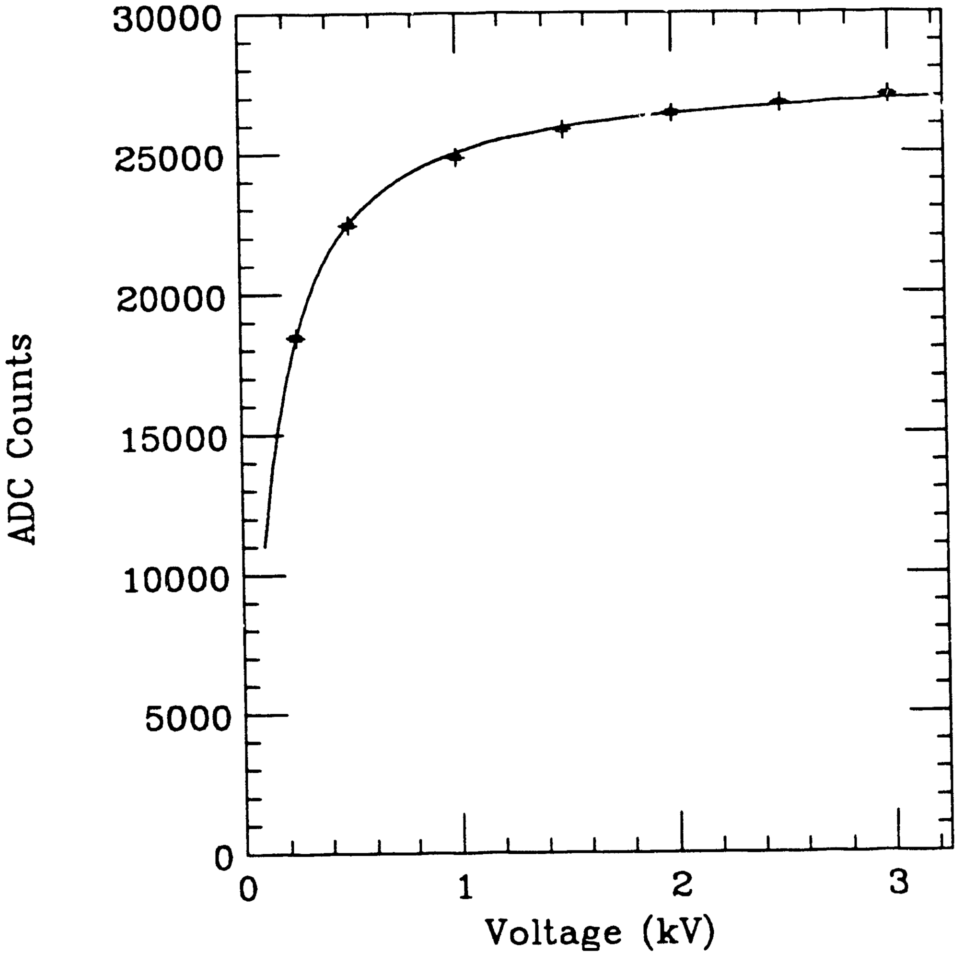

ADC Counts
30000
25000
20000
15000
10000
5000
0
0
1
2
3
Voltage (kV)

Figure 3:

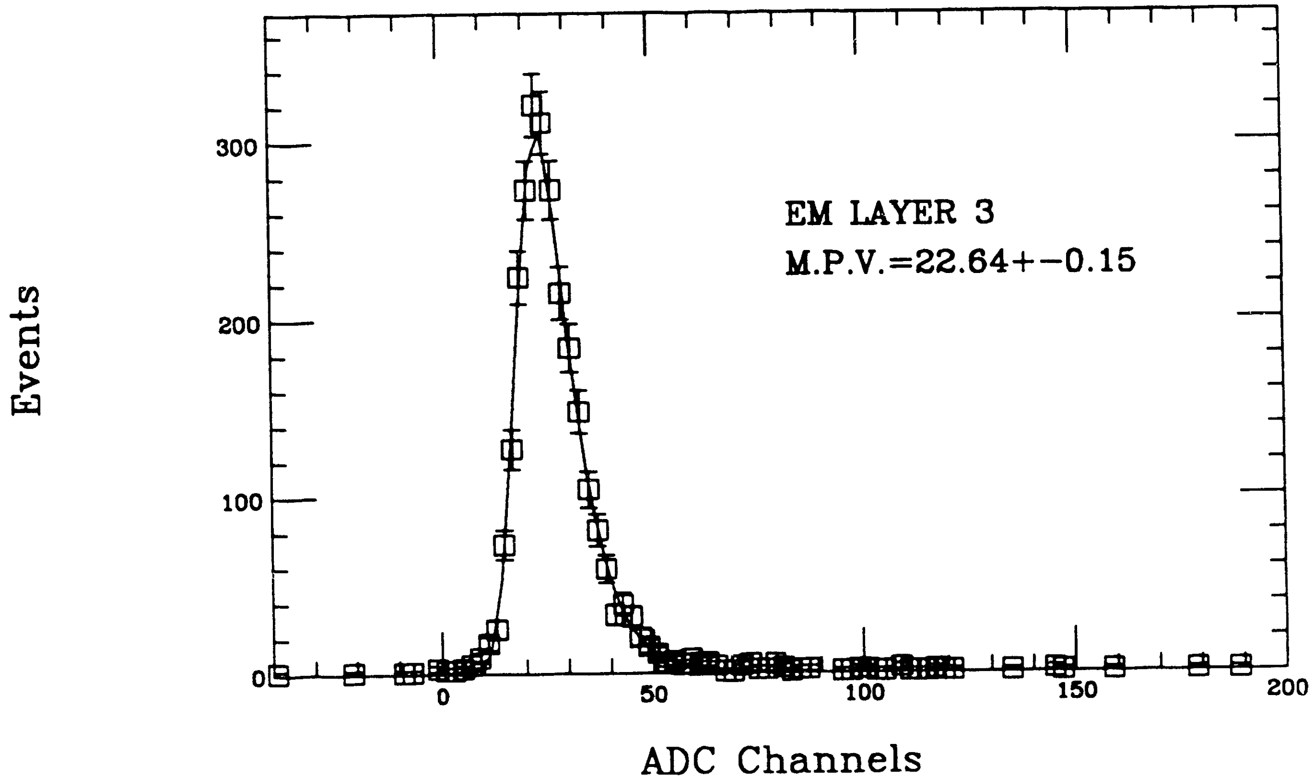
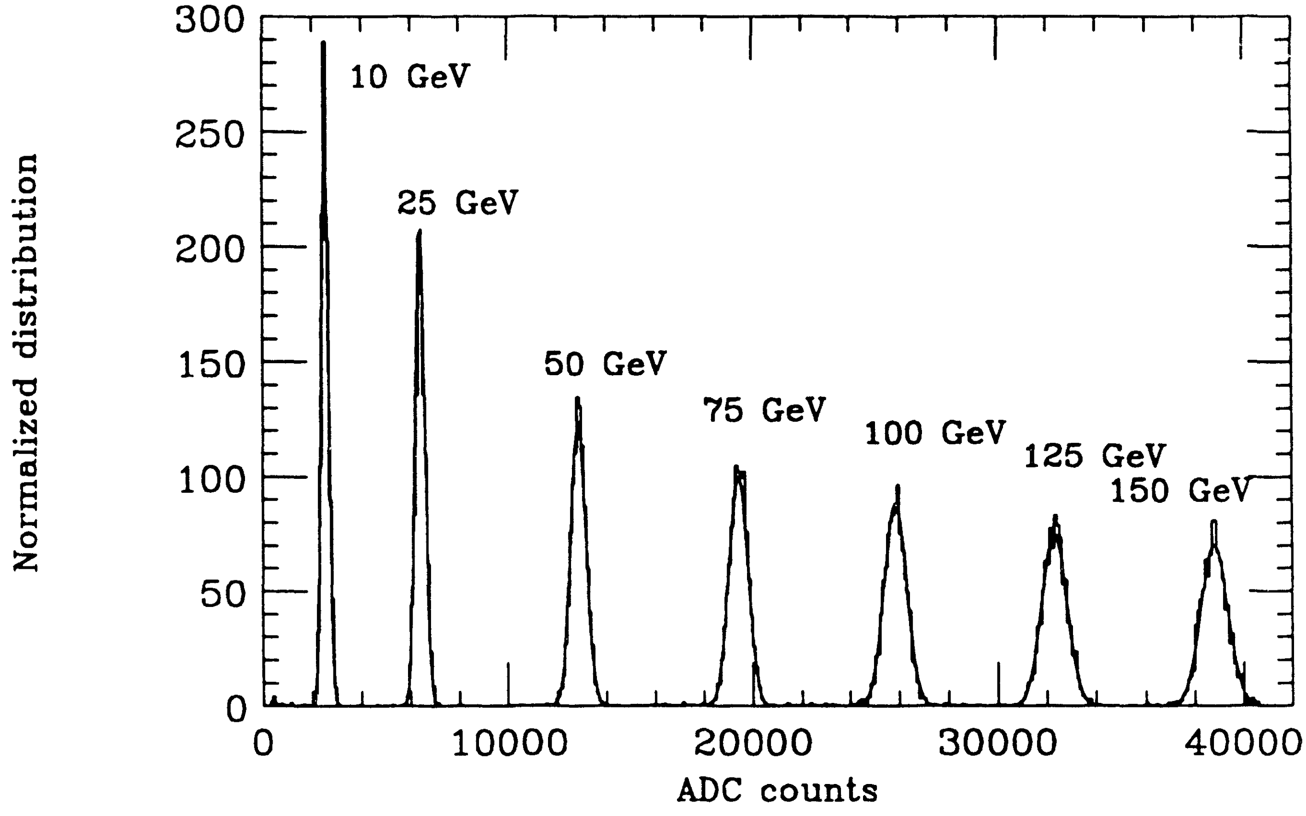

Events
300
200
100
0
0
50
100
150
200
ADC Channels
EM LAYER 3
M.P.V.=22.64+-0.15

Figure 4:



10 GeV
25 GeV
50 GeV
75 GeV
100 GeV
125 GeV
150 GeV
Normalized distribution
300
250
200
150
100
50
0
0
10000
20000
30000
40000
ADC counts

Figure 5:

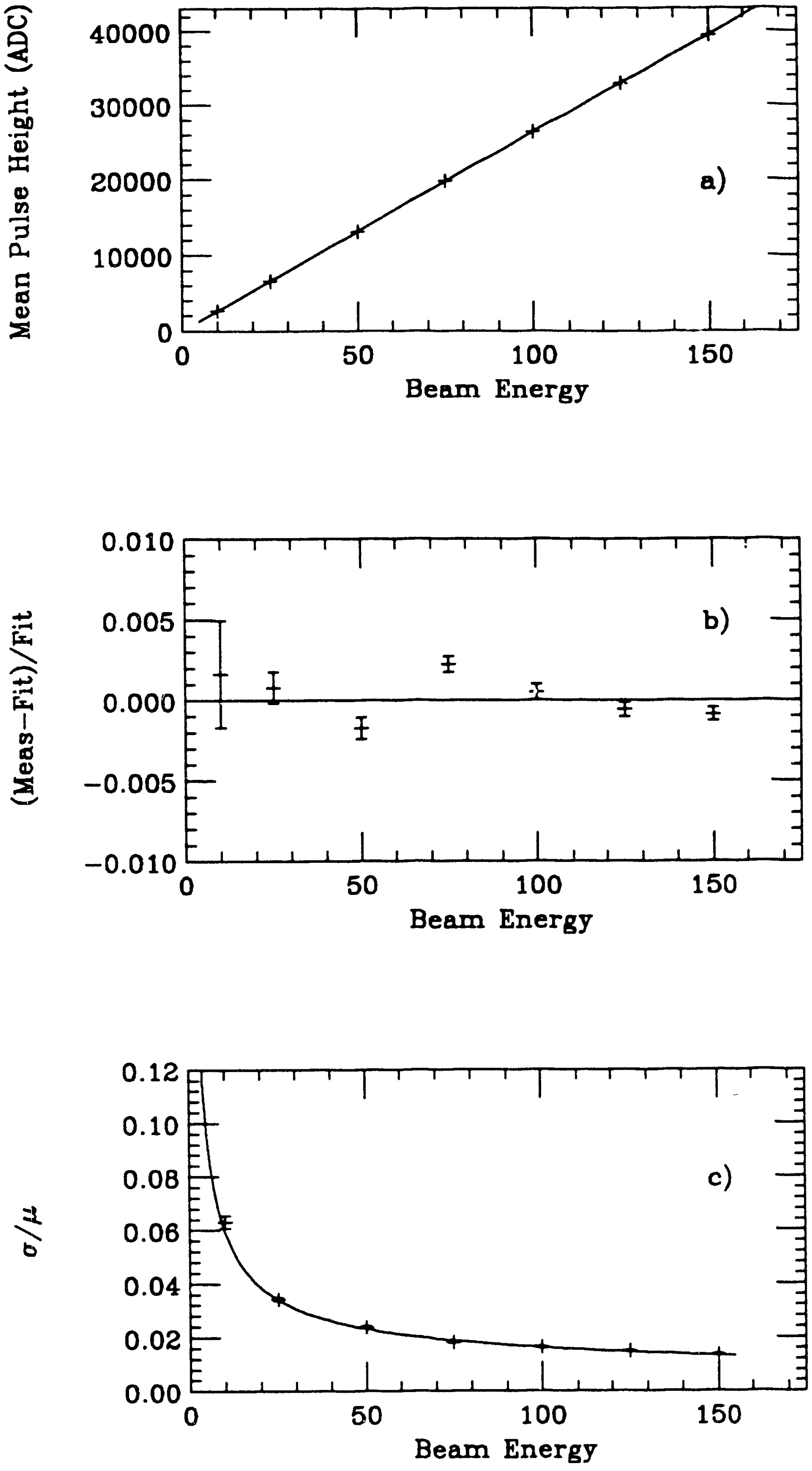

Mean Pulse Height (ADC)
40000
30000
20000
10000
0
0
50
100
150
Beam Energy
a)
(Meas-Fit)/Fit
0.010
0.005
0.000
−0.005
−0.010
0
50
100
150
Beam Energy
b)
σ/μ
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
50
100
150
Beam Energy
c)

Figure 6:

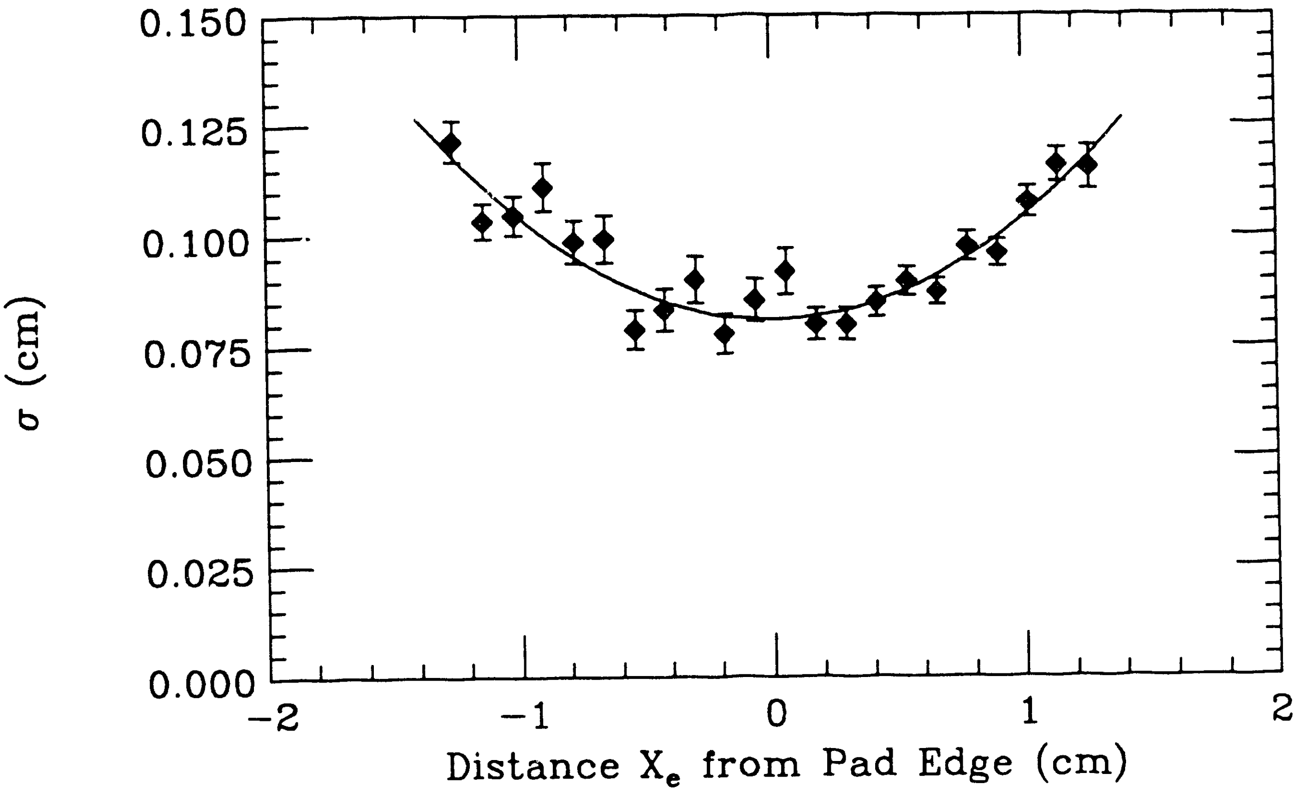

0.150
0.125
0.100
0.075
0.050
0.025
0.000
−2
−1
0
1
2
σ (cm)
Distance X_e from Pad Edge (cm)

Figure 7:

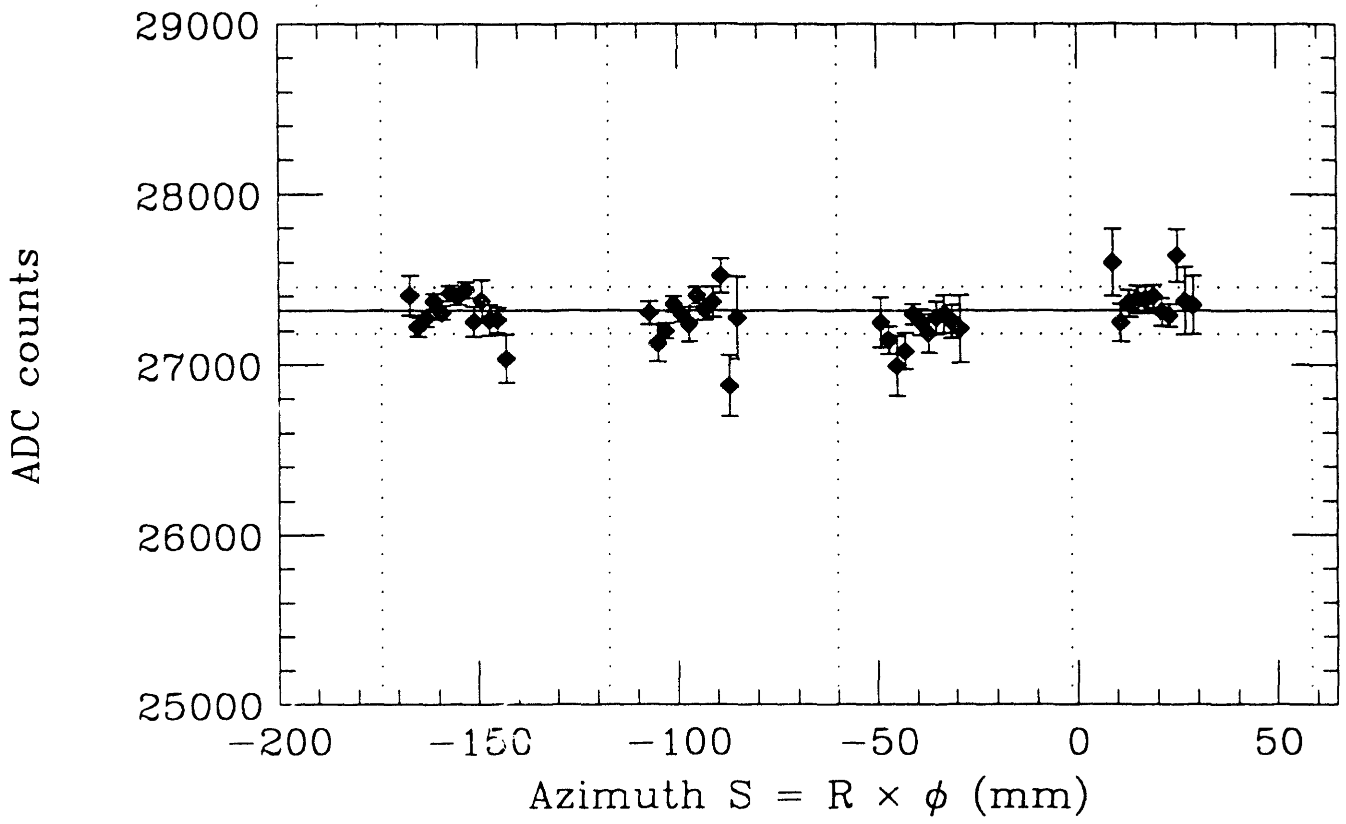

29000
28000
27000
26000
25000
ADC counts
−200
−150
−100
−50
0
50
Azimuth S = R × ϕ (mm)

Figure 8:

END

DATE FILMED

11/14/91