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SDC
SOLENOIDAL DETECTOR NOTES

EFFECT OF MAGNETIC SHIELDS IN A CALORIMETER ON HADRON ENERGY RESOLUTION

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Effect of Magnetic Shields in a Calorimeter on Hadron Energy Resolution

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ABSTRACT

We have evaluated the effect of the iron magnetic shields, which will be installed in the liquid argon calorimeter for the SDC, on hadron energy resolution by a simple Monte Carlo simulation. We have confirmed the effect will be about 1.5% in the constant term and 15.0% in the stochastic term, each to be added in quadrature with the intrinsic resolution of the calorimeter. Non-uniformity of response in space will be less than 1%.

Introduction

The SDC liquid argon calorimeter is designed to include magnetic transformers inside the cryostat. It should be necessary to shield the magnetic field from the superconducting magnet, especially in the endcap region, in order to get the transformers to work. The magnetic shields are tubes with inner diameter of 2 cm and outer diameter of 5 cm made of iron. They will be installed every 10 cm, namely with 5 cm spacing. For energy measurement, the shields may deteriorate energy resolution since they are just non-uniformly-installed dead-material. Resolution of calorimeters is usually parametrized as

$$\frac{\sigma}{E} = \sqrt{a^2 + \frac{b^2}{E}},$$

where σ is the standard deviation and E is incident particle energy. Parameters a and b are called the constant term and the stochastic term, respectively. For the SDC liquid argon calorimeter, the constant term due to the non-unity e/h of 1.3 is expected to be about 4%. The stochastic term is expected to be about 60%, which comes from fluctuation of showers in the sampling calorimeter. We will present in this report how much the magnetic shield will degrade the resolution.

Set-Up of the Simulation

We used GEANT/GHEISHA simulation program for this study, with cut-off energies of 0.1 MeV for e/γ and 1 MeV for others. We mainly focused on the dead-material effect and simplified the calorimeter as in figure 1.

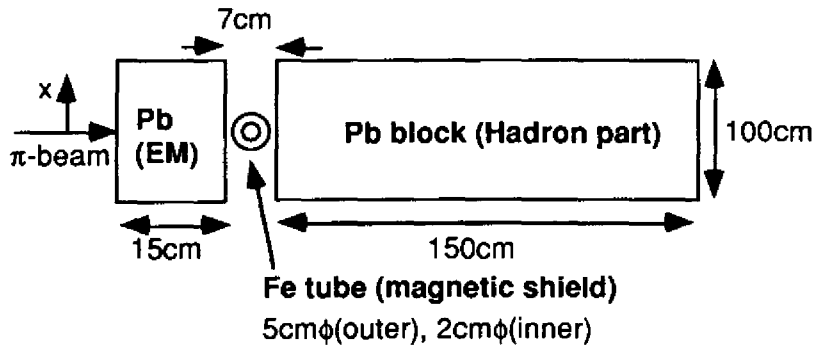


Figure 1: detector configuration in the simulation

Both the EM part and the Hadron part have the same cross section of 100 cm × 100 cm and the length of the Fe tube is also 100 cm. We defined the x=0 position at the center of the Fe tube.

Method to Evaluate the Effect

The simulation required pretty long time such as one minute for a 100 GeV pion with a RISC computer DECstation 5000/200. Therefore we took the incident energy of 10 GeV for the position scan and the incident position of x=0 point for the energy scan. We defined three variables, which are energy depositions accumulated in each event, in the EM part (E_{EM}), in the hadron part (E_{HAD}), and in the shield (E_{MS}). We measured the effect of the magnetic shield as a dead material by comparing the histogram of the total *detectable* energy, $E = E_{EM} + E_{HAD}$ and the total *deposited* energy, $E_0 = E_{EM} + E_{HAD} + E_{MS}$. The E_0 is supposed to present an intrinsic resolution without the dead material.

Since this simulation did not include the fine structure of the calorimeter, the e/h value became up close to 2, which made these distributions be not exact Gaussian. However the difference between the two distributions is essentially due to the dead material. We evaluated the effect by deconvoluting the "induced error" ε_i defined by

$$\varepsilon_i = \sqrt{\left(\frac{\sigma}{m}\right)^2 - \left(\frac{\sigma_0}{m_0}\right)^2},$$

where the σ and σ_0 denote the RMS values and the m's the mean values of the E and the E_0 distributions, respectively. The treatment of the error of ε_i is not very trivial because E and E_0

are not independent but most of the fluctuations of hadronic showers are canceled out for ε_i. The errors of σ and m are generally given by

$$\Delta m = \frac{\sigma}{\sqrt{N}}$$
$$\Delta\sigma = \frac{\sigma}{\sqrt{2N}},$$

where N is a total number of entries of the histogram. Since we could not know how independent σ_i/m and σ_0/m_0 were, we just assumed that σ and m had independent errors given by the formulae above and no errors for σ_0 and m_0, having neglected the cancellation effect for ε_i. Then, the error of ε_i is given by

$$\Delta\varepsilon_i = \frac{1}{2}\left(\sqrt{r^2 - r_0^2 + 2r\Delta r} - \sqrt{r^2 - r_0^2 - 2r\Delta r}\right),$$
$$\text{where, } r \equiv \frac{\sigma}{m},\ r_0 \equiv \frac{\sigma_0}{m_0}, \text{ and}$$
$$\Delta r \equiv r\sqrt{\left(\frac{\Delta\sigma}{\sigma}\right)^2 + \left(\frac{\Delta m}{m}\right)^2}.$$

Because we expect the cancellation between E and E_0, this error may be somewhat overestimated.

Results

Energy Dependence

Figure 3 shows an example of the histograms with incident position of $x = 0$ cm and energy of 100 GeV. Figure 4 shows the energy dependence of the induced error with incident point of $x = 0$ cm. This shows that the induced error behaves almost stochasticly. This is because the dead material reduces the sampling fraction. The dead material may be considered to produce a constant term in the calorimeter resolution which comes from non-uniformity of the sampling and fluctuations in longitudinal shower development. We therefore fitted the data point with formula

$$\varepsilon_i = \sqrt{a^2 + \frac{b^2}{E_\pi}}.$$

Then we got

$$a = 0.015 \pm 0.010,$$
$$b = 0.150 \pm 0.019\ (\sqrt{\text{GeV}}),$$

as shown in figure 4 by the solid line. In addition to the intrinsic constant term of 4%, this 1.5% from the magnetic shield will change the value of the constant term to $\sqrt{4^2+1.5^2}$ = 4.27%. The stochastic term will change to $\sqrt{60^2+15^2}$ = 61.8%. We therefore conclude that the effect of the magnetic shield is small.

Position Dependence

Figure 5 shows the position dependence of the induced error at E_π = 10 GeV, where the magnetic shield was located between -2.5 cm and 2.5 cm. There was no magnetic shield between 2.5 cm and 7.5 cm so that the region between 0 cm and 5 cm is enough to study the effect. There still remain induced errors where the magnetic shield does not exist due to hadronic shower spread. Since the induced error at the center of the shield is negligibly small compared with the intrinsic resolution, non-uniformity of the resolution is negligible.

However, if we cannot know the incident position, the energy loss in the shield cannot be corrected, which results in non-uniformity of pulse height. Provided that this non-uniformity is energy independent, this will produce another contribution to the constant term. Figure 6 shows the mean pulse height versus the incident position. The peak to peak deviation was (2.42% ± 0.54%), which corresponds to the RMS value of (0.70% ± 0.16%) with assuming a uniform distribution in the peak-to-peak range for the non-uniformity.

Conclusion

We have confirmed that the magnetic shields which will be located in the liquid argon calorimeter for the SDC will not give any significant deterioration on the hadron energy resolution. The contribution to the constant term of hadron energy resolution was (1.5% ± 1.0%) and that to the stochastic term was (15.0% ± 1.9%) $\sqrt{\text{GeV}}$, each to be added in quadrature with those of the intrinsic resolution, even if the incident point was at the center of the magnetic shield. The intrinsic resolution of 4% ⊕ 60%/$\sqrt{E}$ will be degraded only to 4.3% ⊕ 62%/$\sqrt{E}$ at most. The non-uniformity of response was (0.7% ± 0.2%), which is also to be added in quadrature into the constant term.

FIGURE CAPTIONS

Figure 1: Detector configuration in the simulation.

Figure 2: Distributions of total detectable energy (a) and total deposited energy (b) for 10 GeV pions incident at $x = 0$ cm.

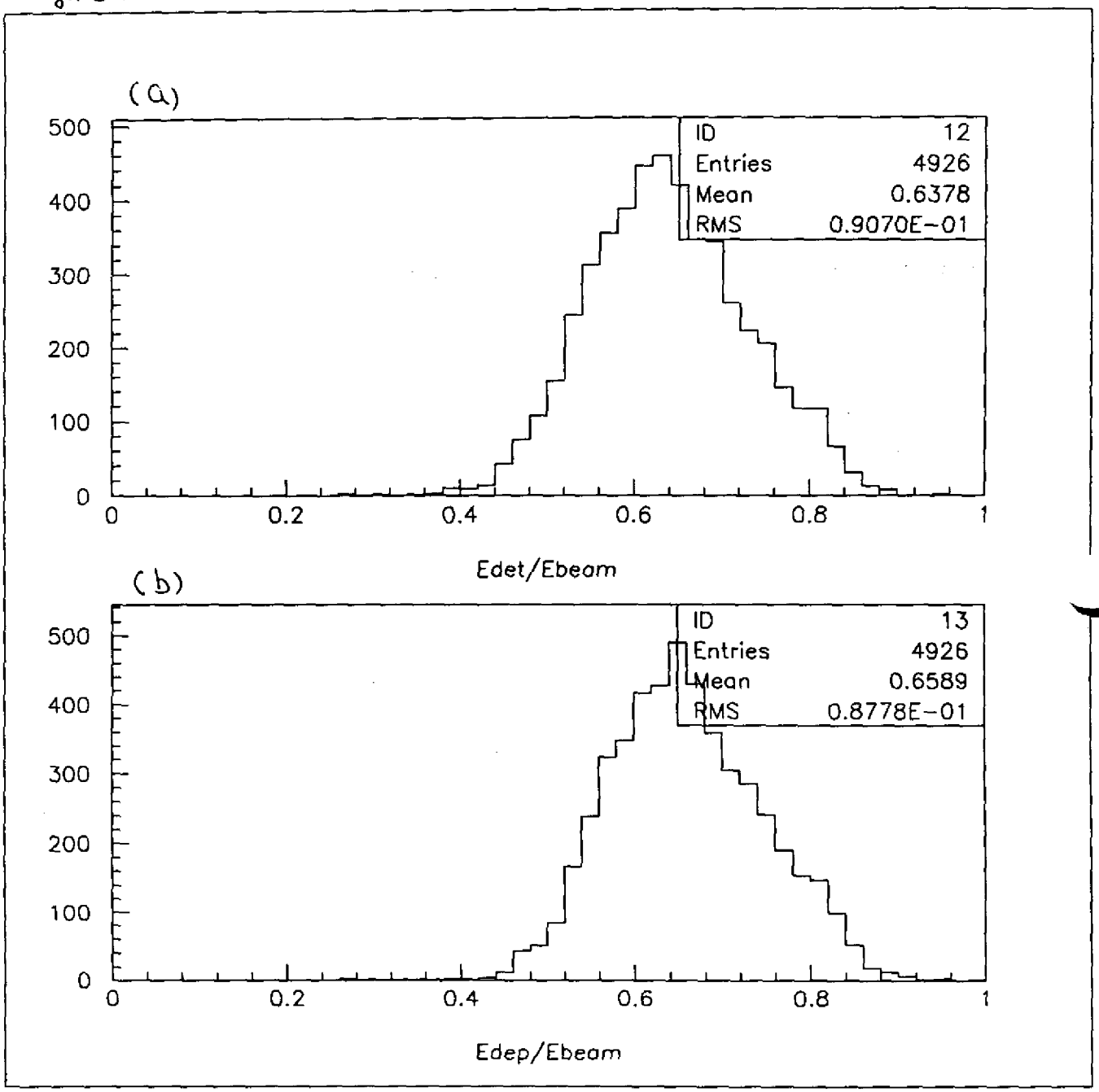
Figure 3: Distributions of total detectable energy (a) and total deposited energy (b) for 100 GeV pions incident at $x = 0$ cm.

Figure 4: Energy dependence of the induced error with $x = 0$ cm.

Figure 5: Incident position dependence of the induced error with $E_\pi = 10$ GeV.

Figure 6: Mean pulse height versus incident position, showing non-uniformity of response (a), and an enlarged graph (b).

Figure 2


(a)
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Entries 4926
Mean 0.6378
RMS 0.9070E-01
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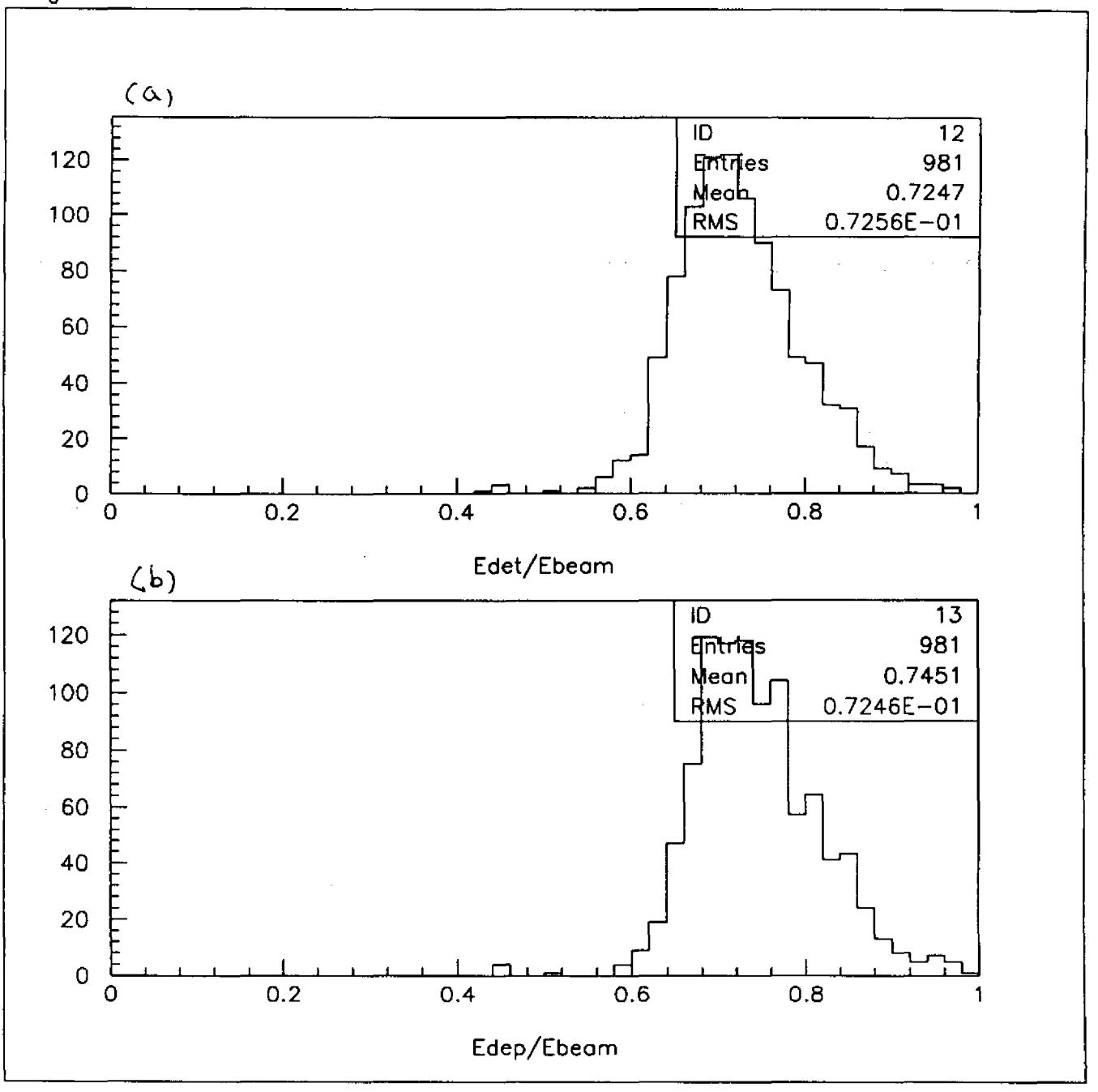
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Edet/Ebeam
(b)
ID 13
Entries 4926
Mean 0.6589
RMS 0.8778E-01
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Edep/Ebeam

Figure 3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ID 12
Entries 981
Mean 0.7247
RMS 0.7256E-01
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Edet/Ebeam
(b)
ID 13
Entries 981
Mean 0.7451
RMS 0.7246E-01
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Edep/Ebeam

Figure 4

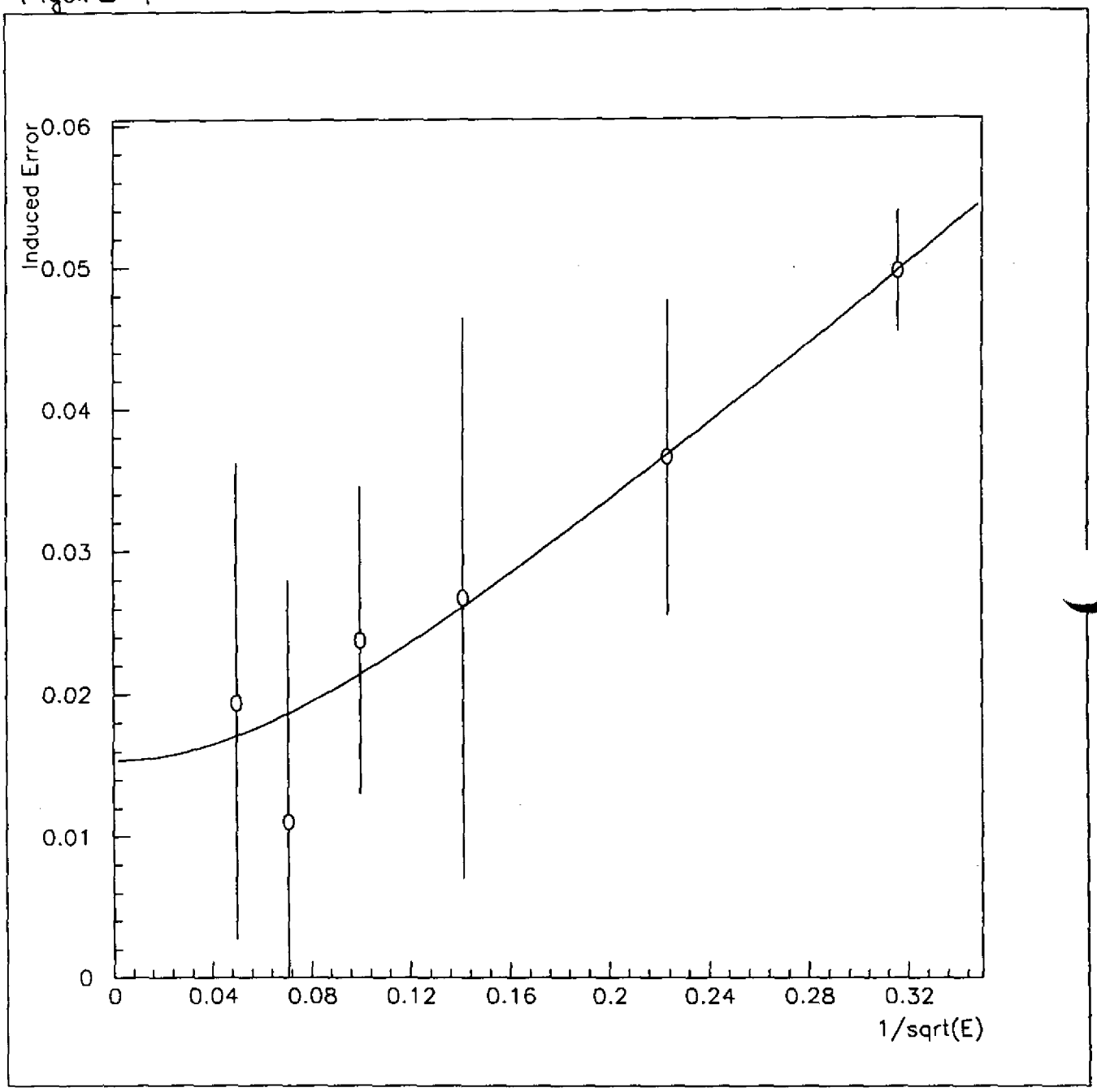

Induced Error
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
1/sqrt(E)

Figure 5

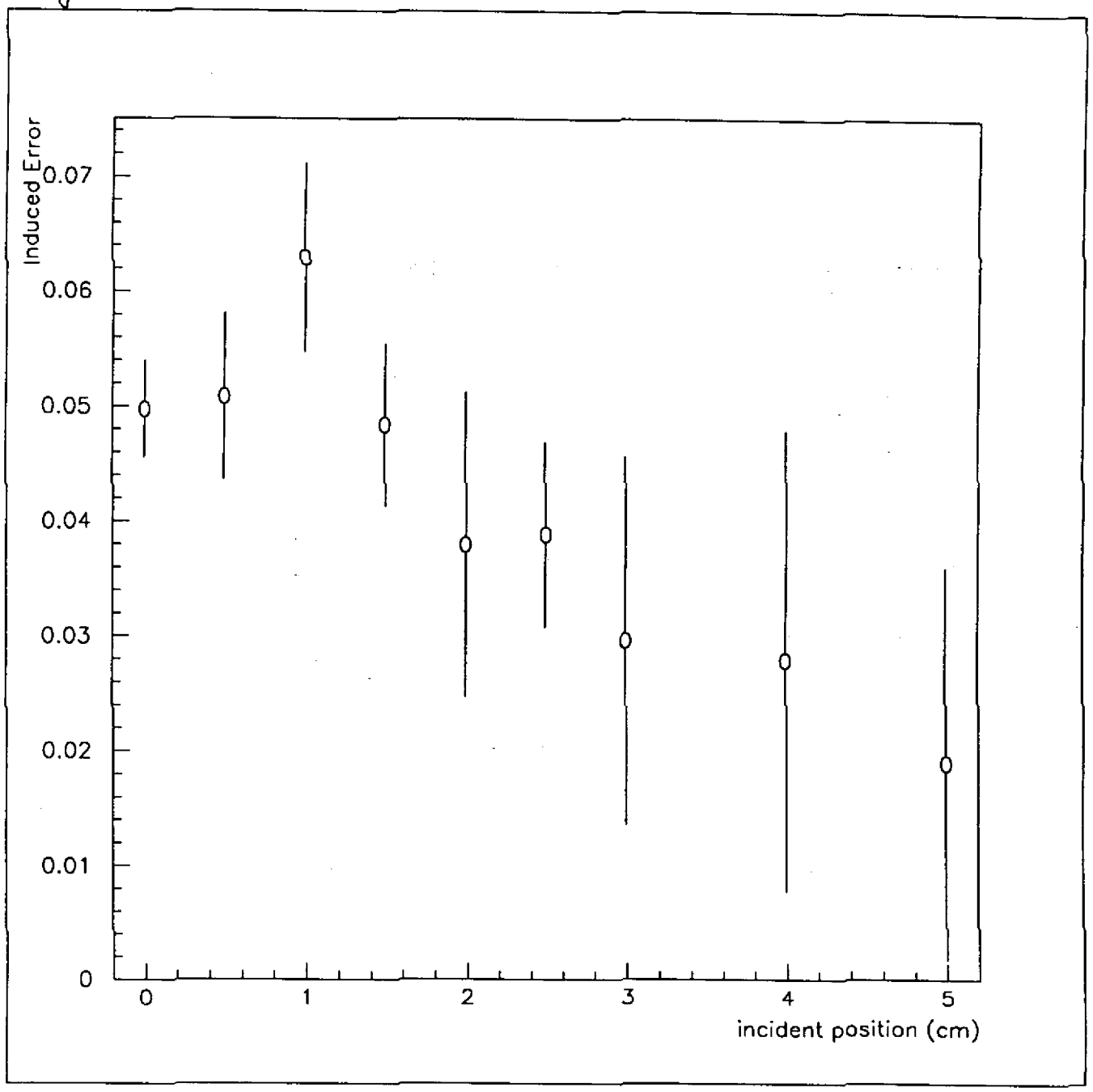
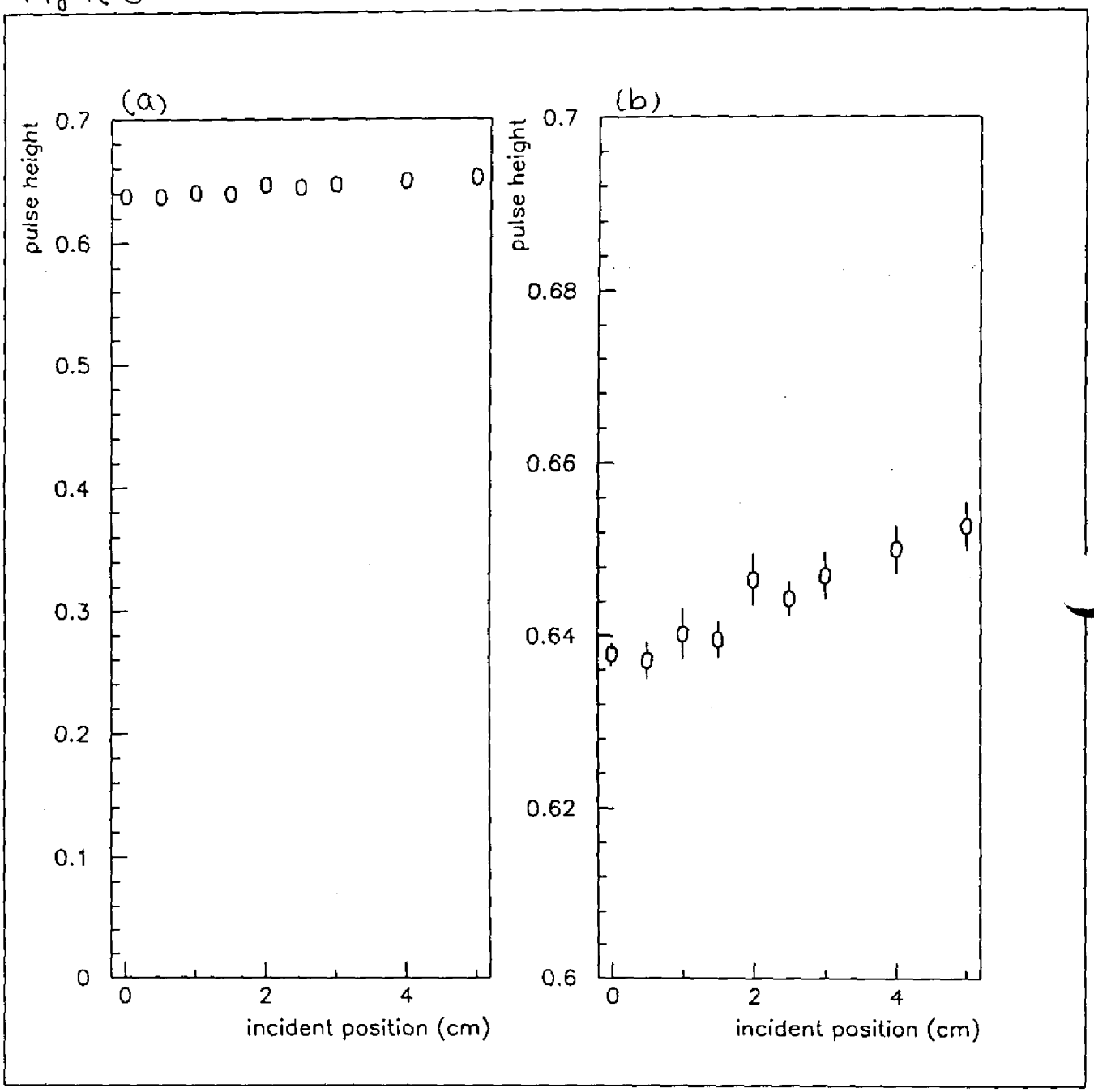

Induced Error
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
incident position (cm)

Figure 6


(a)
pulse height
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
incident position (cm)
(b)
pulse height
0.7
0.68
0.66
0.64
0.62
0.6
0
2
4
incident position (cm)