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SDC
SOLENOIDAL DETECTOR NOTES

EFFECT OF ELECTROMAGNETIC CALORIMETER THICKNESS ON RESOLUTION

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Abstract

EGS has been used to study the effect of leakage on EM resolution as a function of calorimeter thickness. The EM calorimeter consists of 4 mm lead plates alternating with active sampling (4 mm of liquid argon). Five cases are considered for HAD1: it constructed from either 8 mm, 16 mm, 20 mm, or 32 mm lead plate (and is noiseless and calibrated) or it is not used at all. Electron energies of 10 GeV to 400 GeV are considered. For the quadratic increase in resolution (σ_E/E) to be less than 0.003 (0.005), the total EM calorimeter thickness, including preceding dead material, must be $28X_0$ ($26X_0$) if HAD1 is not used or $22X_0$ ($20X_0$) if a HAD1 of 8 mm lead plate is used. Other cases fall between these two extremes.

Introduction

A calorimeter of finite thickness will have leakage from the back. The fluctuations in this leakage will degrade the resolution. The first hadronic section, HAD1, can be used to some extent to correct for the leakage, if it has sufficiently low electronic and pileup noise to be sensitive to the small energy deposits. This study uses EGS to quantify these effects.

The EGS model consists of 70 layers of 4 mm lead interleaved with 4 mm liquid argon. The properties of LAr are unimportant for this study—scintillator would give the same results. No coil, cryostat or any other dead material precedes the first layer. Each layer is $0.73X_0$, giving a total thickness of $51X_0$. The EM compartment is the first 22 to 48 layers (16.0–35.0X_0). The HAD1 section, if it is used, consists of the remaining layers. Four variations are studied: every second, fourth, fifth or eighth LAr gap is used, giving sampling that ranges from 8 mm to 32 mm of lead. The energy deposited in the HAD1 LAr gaps, if used, is added to that deposited in the EM section with relative weight 2, 4, 5 or 8. Other analysis methods have been examined, such as weighting EM2 or HAD1 to compensate for the leakage fluctuations. They do not give significantly different results.

A total of 950 10-GeV, 700 40-GeV, 975 100-GeV and 100 400-GeV electron showers have been simulated. The EGS cutoffs were 0.7 MeV for electrons and 0.1 MeV for photons.

Application to SDC

Three calorimeter designs are being considered by SDC. The liquid argon design has a $26X_0$ thick EM section constructed from 4 mm lead plate. The HAD1 noise is not sufficiently low to allow it to be used in determining electron energies. The combined electronic and pileup noise at standard SSC luminosity is approximately 560 MeV in a HAD1 tower of size $\Delta\eta\Delta\phi = 0.1 \times 0.1$, which is not small compared to $\sigma_E = 1.3$ GEV for a 100 GeV electron.

There are two scintillator calorimeter designs. The HAD1 of Model A is 1 inch iron in the barrel region ($|\eta| < 1.3$) and 2 inch iron in the endcap. In terms of radiation lengths, this is equivalent to 8 mm and 16 mm of lead. The Model B HAD1 is 20 mm lead (barrel) and 32 mm lead (endcap). In both scintillator cases, the EM compartment is $22X_0$ of approximately 4 mm lead (1/8th inch lead, 3.2 mm, is also being considered). The results presented here deal primarily with the increases in σ_E, rather than its absolute value, and so are somewhat insensitive to the details of the EM compartment sampling.

It is assumed that electronic noise and pileup are negligible for a scintillator calorimeter. This is a good approximation at SSC design luminosity.

Analysis

The fraction of incident energy that leaks from the back of EM section is plotted as a function of thickness in Fig. 1(a) for electron energies of 10–400 GeV. The rms of this quantity is plotted in Fig. 1(b). The leakage gives a correctable nonlinearity, even if HAD1 is used. The size of the correction is shown for various EM/HAD1 configurations in Fig. 2.

For each combination of EM thickness and HAD1 configuration, the resolution $\alpha \equiv \sigma_E/E$ is calculated. Figure 3 shows α vs thickness for 10 GeV and 100 GeV incident electrons. The resolution of the full $50X_0$ thick calorimeter, α_0, is $\sigma_E/E \simeq 13\%/\sqrt{E}$. The increase in resolution for each configuration is defined as $\Delta\alpha = \sqrt{\alpha^2 - \alpha_0^2}$. If HAD1 is not used, $\Delta\alpha$ is equal to the fluctuations in the leakage. Figure 4(a)–(d) displays this quantity for 10, 40, 100 and 400 GeV electrons as a function of EM calorimeter thickness for three HAD1 configurations (no HAD1, 8 mm and 20 mm plates). This information is summarized in Table 1. Figure 5 is $\Delta\alpha$ as a function of energy for three different EM/HAD1 configurations. Note that using HAD1 results in $\Delta\alpha$ decreasing with increasing energy, whereas using EM only gives a relatively constant $\Delta\alpha$.

The error bars in the figures are strongly correlated between points, since the same set of events is used for all configurations.

CONCLUSIONS

The nonlinearity introduced by the leakage is small and easily correctable, regardless of the HAD1 configuration. If HAD1 is not used to correct for the lost energy—as would be the case for the SDC liquid argon calorimeter—$28X_0$ total thickness is required for $\Delta\alpha \leq 0.003$, and $26X_0$ for $\Delta\alpha \leq 0.005$. The increase in resolution does not depend strongly on energy. The SDC Model A (iron HAD1) calorimeter provides relatively fine sampling for EM showers; $22X_0$ ($20X_0$) is sufficient for $\Delta\alpha \leq 0.003(0.005)$. The EM calorimeter preceding the Model B HAD1 must be thicker to achieve the same precision; $26X_0$ ($23X_0$) is needed for $\Delta\alpha \leq 0.003(0.005)$. The EM thicknesses required in the endcap are greater for Models A and B, which use coarser HAD1 sampling. The equivalent requirements are $25X_0$ and $22X_0$ for Model A, and $28X_0$ and $24X_0$ for Model B.

Increasing the EM thickness to improve the resolution results in an increase in pion conversions. The loss of e^-/π^- separation may be recoverable by using the EM2/EM1 ratio, but additional study is required. A thicker EM section may also result in an increased calorimeter cost.

Note that dead material preceding the calorimeter, such as the coil or cryostat walls, counts towards the required material. The calculations presented here are for electrons. If precision measurements of photons are desired, the EM calorimeter must be 0.5–1.0X_0 deeper.

Table 1. Increase in resolution (σ_E/E) as a function of EM calorimeter thickness, for various incident electron energies and five different HAD1 sections.

HAD1		EM Thickness (X_0)							
Config	E (GeV)	20.4	21.9	23.3	24.8	26.2	27.7	29.2	30.6
No HAD1	10	.0117 ± .0012	.0088 ± .0011	.0061 ± .0010	.0053 ± .0009	.0043 ± .0009	.0038 ± .0007	.0034 ± .0006	.0028 ± .0006
	40	.0120 ± .0008	.0094 ± .0008	.0067 ± .0007	.0046 ± .0006	.0030 ± .0006	.0021 ± .0006	.0017 ± .0006	.0010 ± .0011
	100	.0130 ± .0005	.0089 ± .0004	.0065 ± .0004	.0050 ± .0005	.0034 ± .0005	.0022 ± .0004	.0014 ± .0004	.0007 ± .0016
	400	.0205 ± .0010	.0139 ± .0009	.0094 ± .0008	.0071 ± .0007	.0046 ± .0009	.0031 ± .0008	.0019 ± .0010	.0009 ± .0008
8 mm	10	.0052 ± .0015	.0040 ± .0024	.0032 ± .0018	.0031 ± .0010	.0019 ± .0015	.0018 ± .0009	.0010 ± .0021	.0010 ± .0015
	40	.0048 ± .0008	.0032 ± .0021	.0022 ± .0019	.0013 ± .0010	.0001 ± .0010	.0001 ± .0010	.0001 ± .0010	.0001 ± .0010
	100	.0039 ± .0003	.0030 ± .0003	.0021 ± .0004	.0019 ± .0003	.0015 ± .0004	.0013 ± .0003	.0011 ± .0003	.0011 ± .0003
	400	.0027 ± .0006	.0023 ± .0006	.0018 ± .0007	.0011 ± .0008	.0011 ± .0006	.0001 ± .0010	.0007 ± .0010	.0003 ± .0004
16 mm	10	.0090 ± .0016	.0096 ± .0013	.0064 ± .0015	.0071 ± .0011	.0041 ± .0014	.0031 ± .0010	.0022 ± .0010	.0061 ± .0004
	40	.0071 ± .0009	.0054 ± .0009	.0041 ± .0011	.0036 ± .0009	.0019 ± .0010	.0013 ± .0014	.0014 ± .0008	.0010 ± .0006
	100	.0071 ± .0003	.0042 ± .0005	.0044 ± .0004	.0025 ± .0004	.0029 ± .0003	.0012 ± .0006	.0023 ± .0003	.0007 ± .0010
	400	.0061 ± .0007	.0046 ± .0008	.0022 ± .0009	.0029 ± .0008	.0001 ± .0072	.0010 ± .0006	.0009 ± .0008	.0004 ± .0004
20 mm	10	.0121 ± .0011	.0105 ± .0011	.0071 ± .0011	.0085 ± .0013	.0070 ± .0009	.0040 ± .0013	.0024 ± .0009	.0061 ± .0006
	40	.0086 ± .0009	.0061 ± .0010	.0055 ± .0008	.0049 ± .0007	.0028 ± .0007	.0032 ± .0006	.0023 ± .0005	.0017 ± .0007
	100	.0081 ± .0004	.0057 ± .0004	.0039 ± .0004	.0037 ± .0004	.0029 ± .0005	.0025 ± .0003	.0014 ± .0006	.0009 ± .0005
	400	.0069 ± .0008	.0046 ± .0011	.0041 ± .0008	.0029 ± .0007	.0001 ± .0011	.0001 ± .0010	.0014 ± .0007	.0012 ± .0007
32 mm	10	.0152 ± .0015	.0117 ± .0014	.0075 ± .0011	.0056 ± .0009	.0079 ± .0010	.0049 ± .0007	.0013 ± .0006	.0065 ± .0006
	40	.0100 ± .0009	.0089 ± .0010	.0060 ± .0008	.0043 ± .0008	.0036 ± .0007	.0029 ± .0006	.0017 ± .0010	.0007 ± .0008
	100	.0095 ± .0004	.0074 ± .0004	.0058 ± .0004	.0038 ± .0005	.0038 ± .0004	.0027 ± .0005	.0027 ± .0003	.0011 ± .0010
	400	.0114 ± .0007	.0084 ± .0008	.0054 ± .0008	.0042 ± .0009	.0027 ± .0007	.0013 ± .0008	.0001 ± .0010	.0011 ± .0004

FIGURE CAPTIONS

1) (a) Fractional energy leakage vs EM calorimeter thickness for $E = 10$ (solid), 40 (dashed), 100 (dotdash) and 400 GeV (dotted). (b) rms of the fractional leakage.

2) Linearity correction vs energy for no HAD1, $26.2X_0$ (crosses); 8 mm lead HAD1, $21.9X_0$ (squares); and 20 mm lead HAD1, $21.9X_0$ (crossed-circles). The uncertainties are similar in all cases.

3) Resolution (σ_E/E) vs EM thickness for 10 GeV and 100 GeV electrons. The three curves in each case are for no HAD1 (solid); 8 mm lead HAD1 (dashed); and 20 mm HAD1 (dotdash).

4) Increase in resolution vs EM calorimeter thickness for electron energy of (a) 10 GeV (b) 40 GeV (c) 100 GeV (d) 400 GeV. The three curves in each case are for no HAD1 (solid); 8 mm lead HAD1 (dashed); and 20 mm HAD1 (dotdash).

5) Increase in resolution vs energy for three EM/HAD1 configurations: no HAD1, $26.2X_0$ (crosses/solid); 8 mm lead HAD1, $21.9X_0$ (squares/dashes); and 20 mm lead HAD1, $21.9X_0$ (crossed-circles/dotdash).

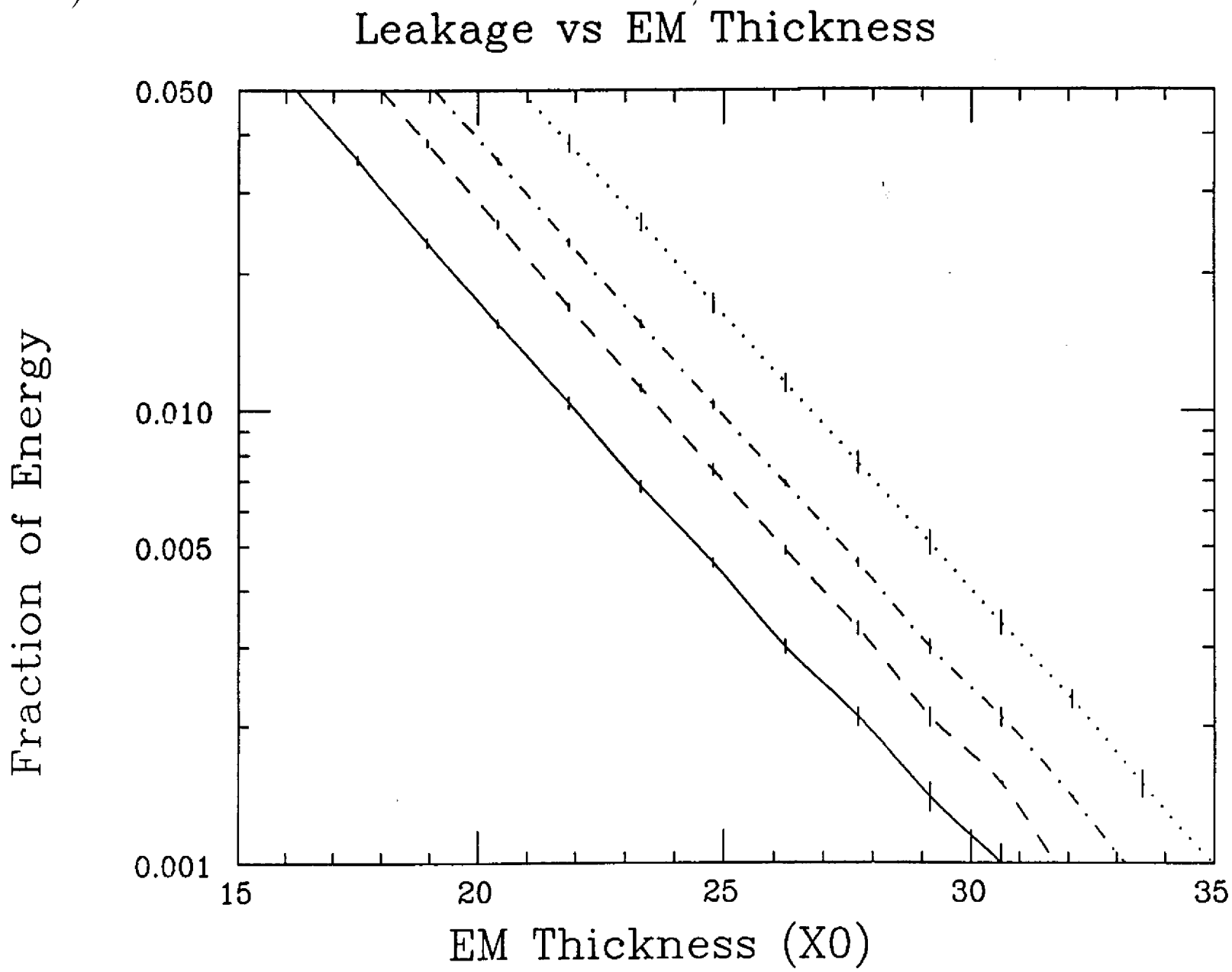
Leakage vs EM Thickness
0.050
0.010
0.005
0.001
Fraction of Energy
15
20
25
30
35
EM Thickness (X0)

Figure 1a

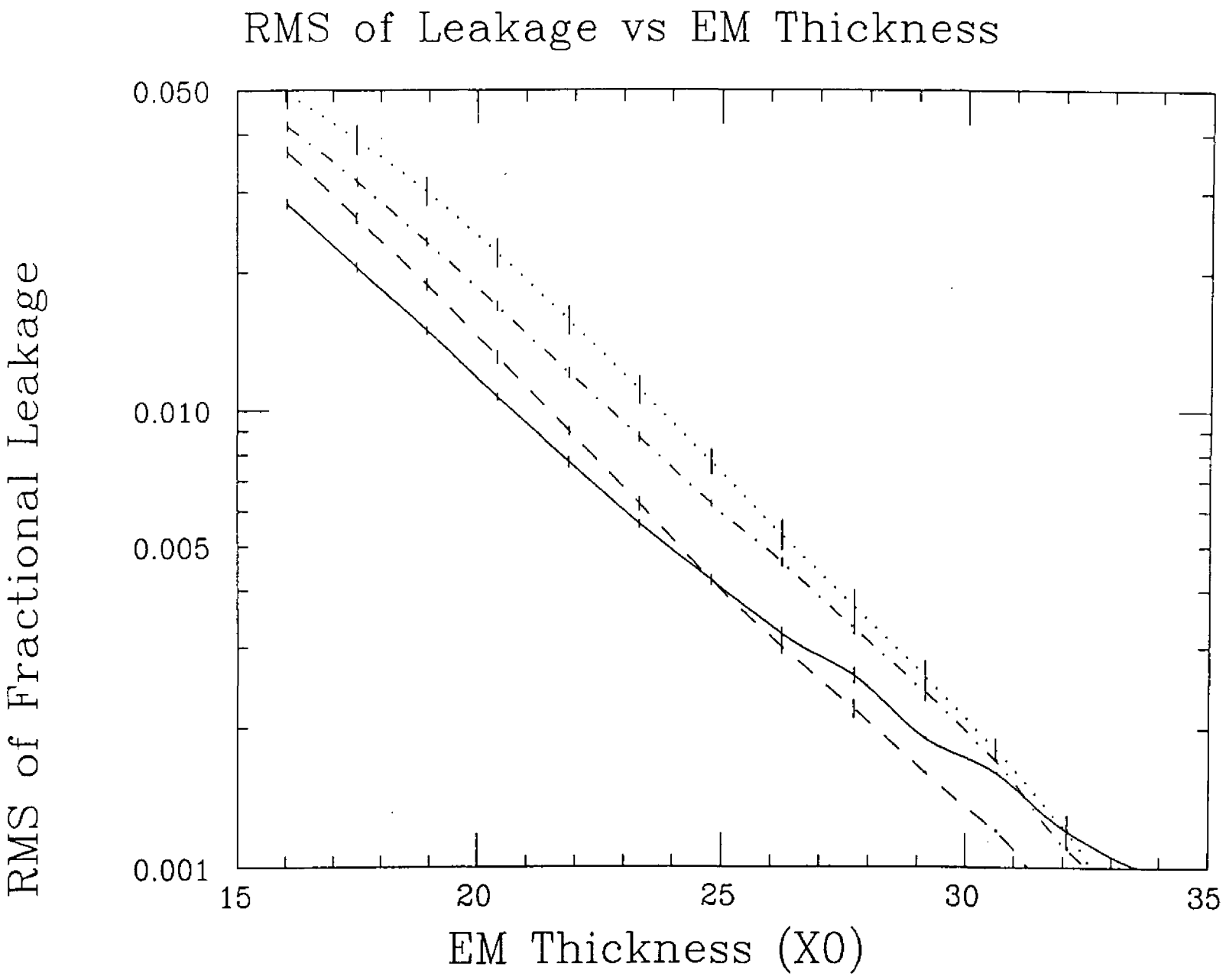
RMS of Leakage vs EM Thickness
0.050
0.010
0.005
0.001
15
20
25
30
35
RMS of Fractional Leakage
EM Thickness (X0)

Figure 1b

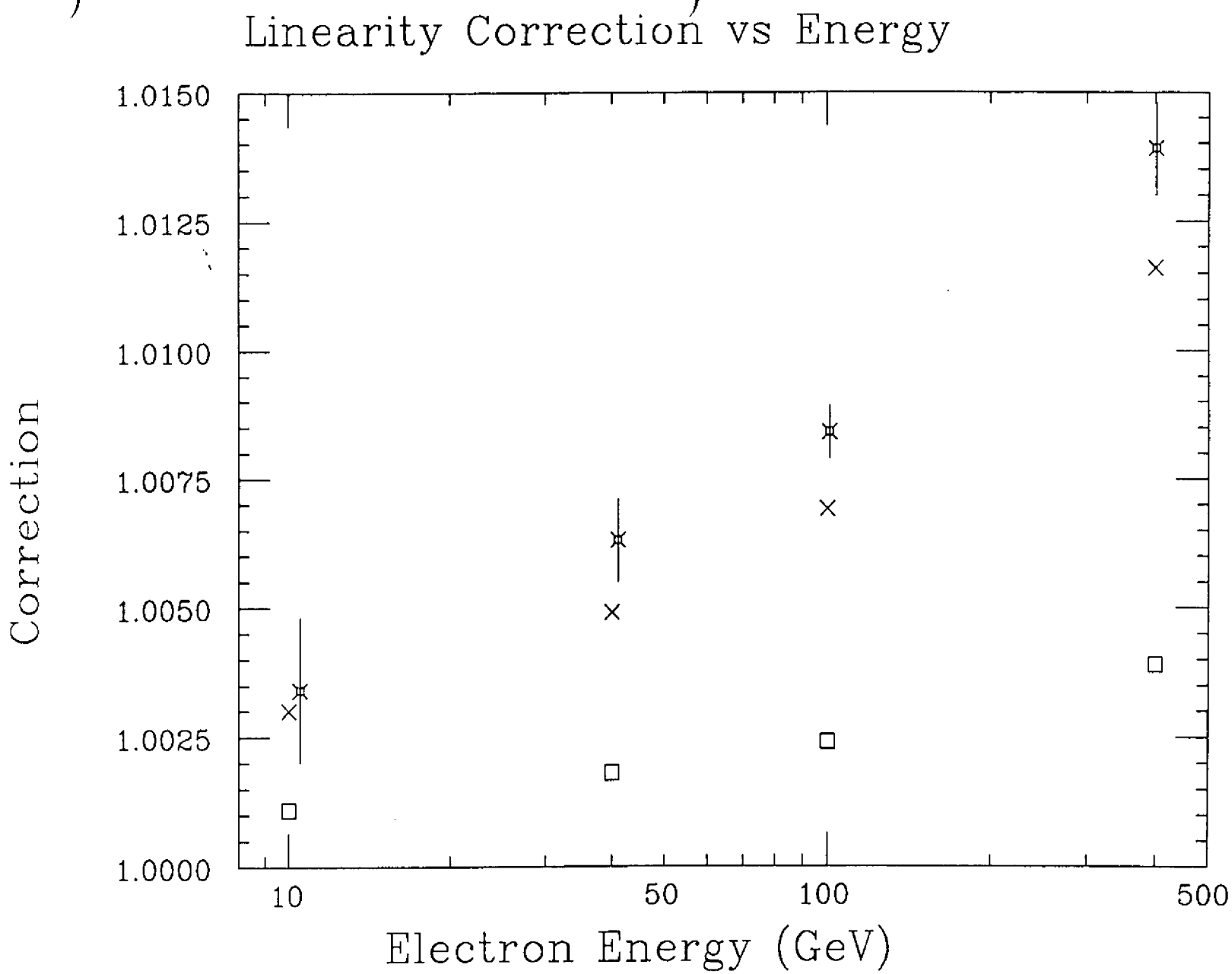
Linearity Correction vs Energy
Correction
1.0150
1.0125
1.0100
1.0075
1.0050
1.0025
1.0000
10
50
100
500
Electron Energy (GeV)

Figure 2

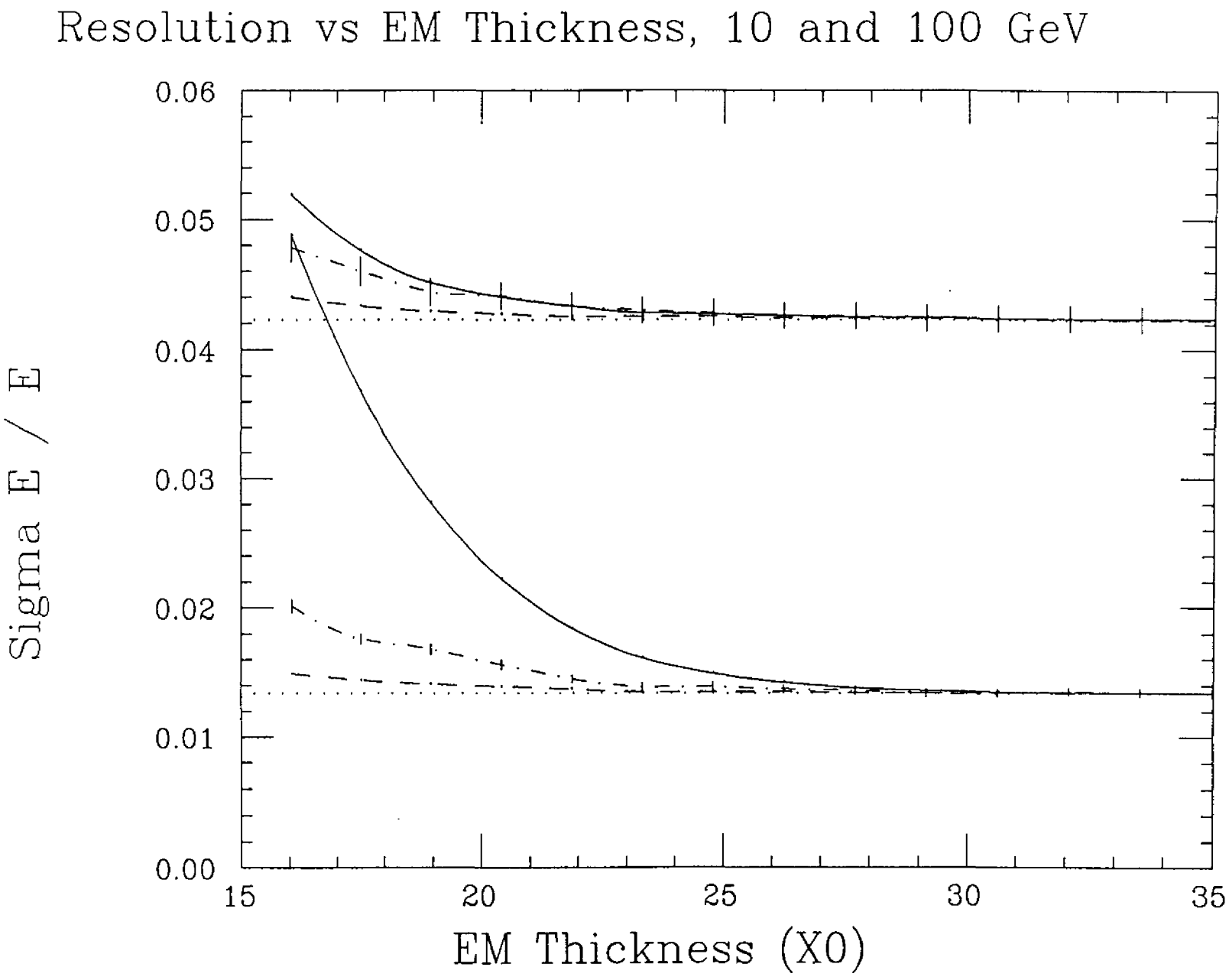
Resolution vs EM Thickness, 10 and 100 GeV
Sigma E / E
0.06
0.05
0.04
0.03
0.02
0.01
0.00
15
20
25
30
35
EM Thickness (X0)

Figure 3

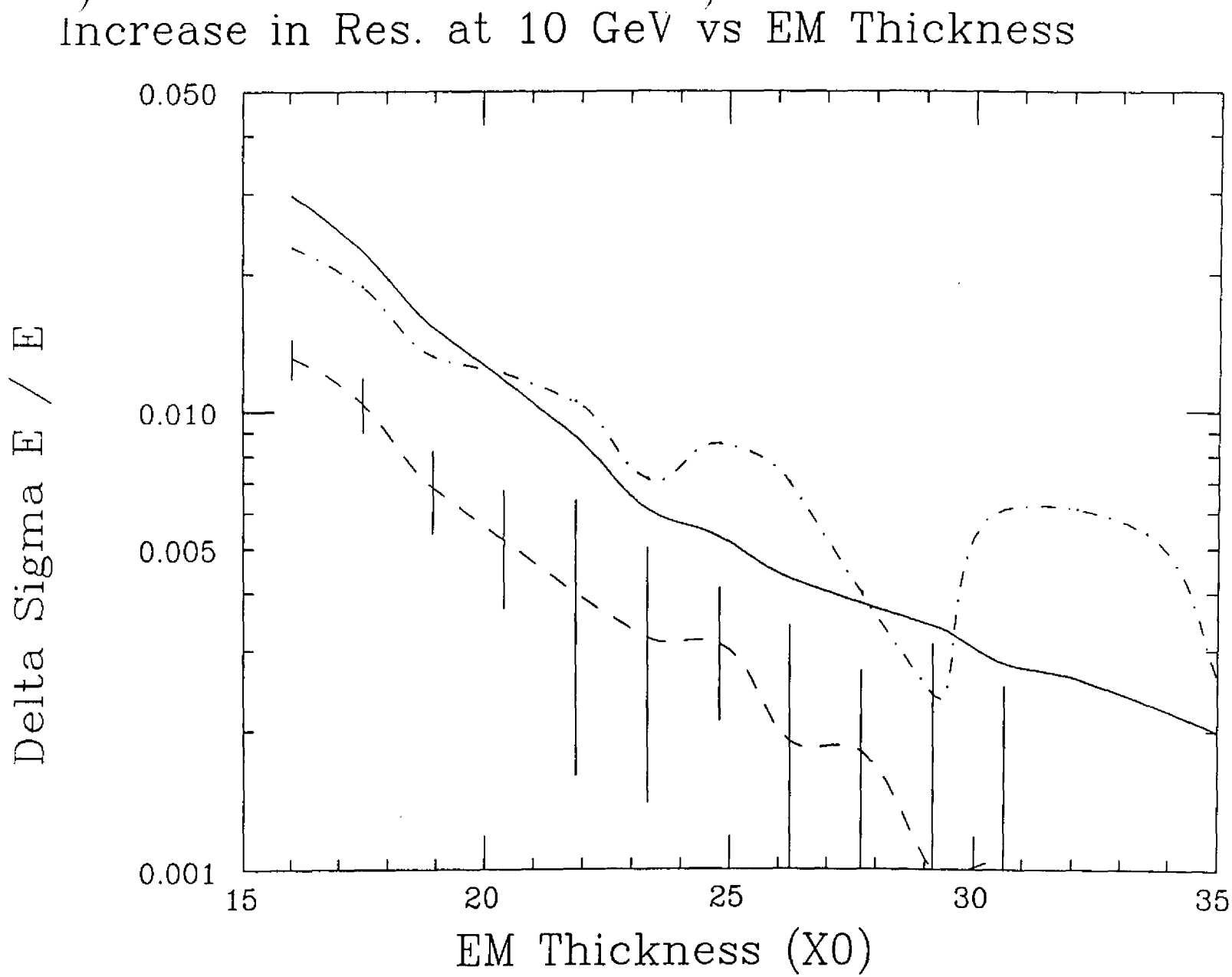
Increase in Res. at 10 GeV vs EM Thickness
0.050
0.010
0.005
0.001
Delta Sigma E / E
15
20
25
30
35
EM Thickness (X0)

Figure 4a

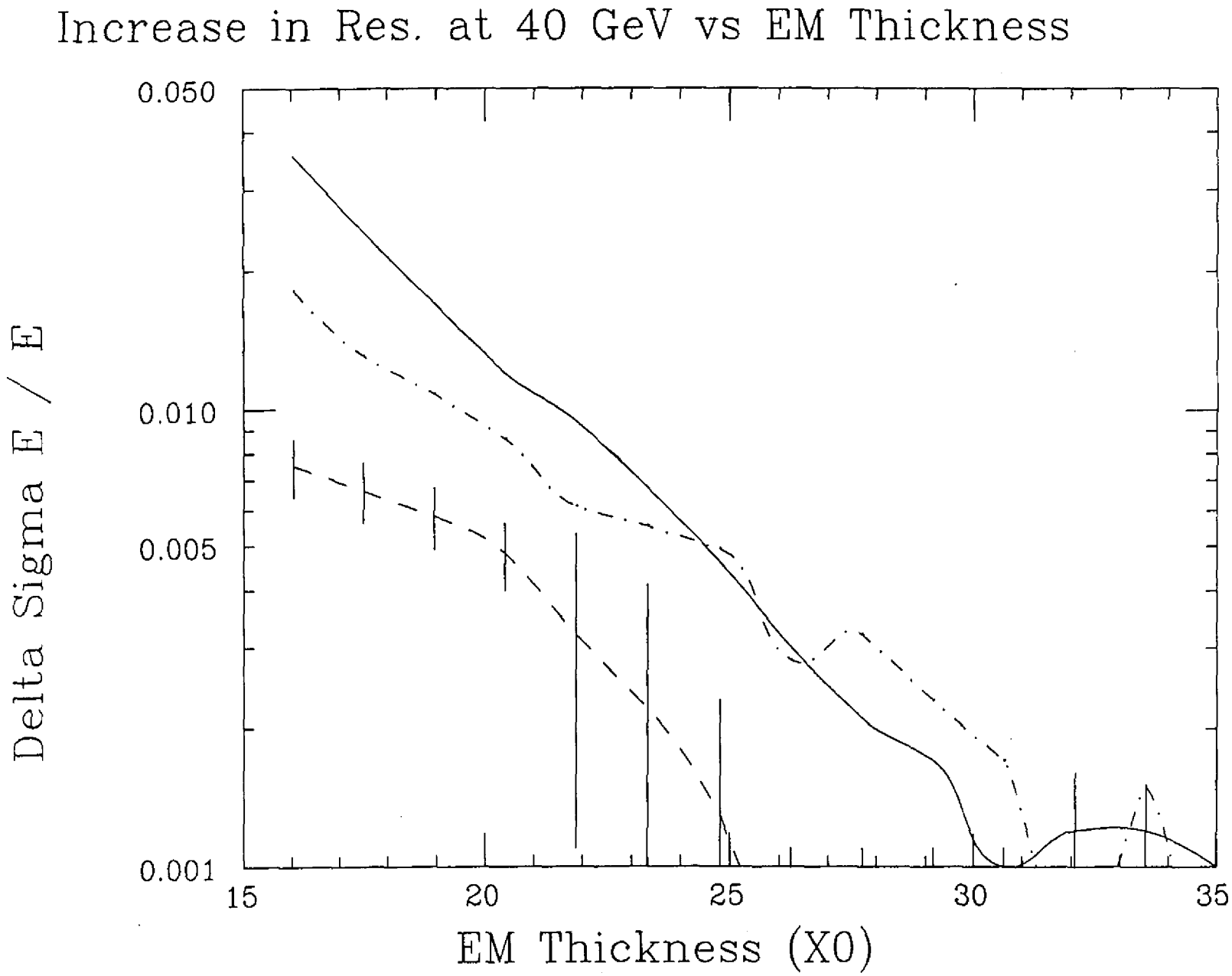
Increase in Res. at 40 GeV vs EM Thickness
0.050
0.010
0.005
0.001
Delta Sigma E / E
15
20
25
30
35
EM Thickness (X0)

Figure 4b

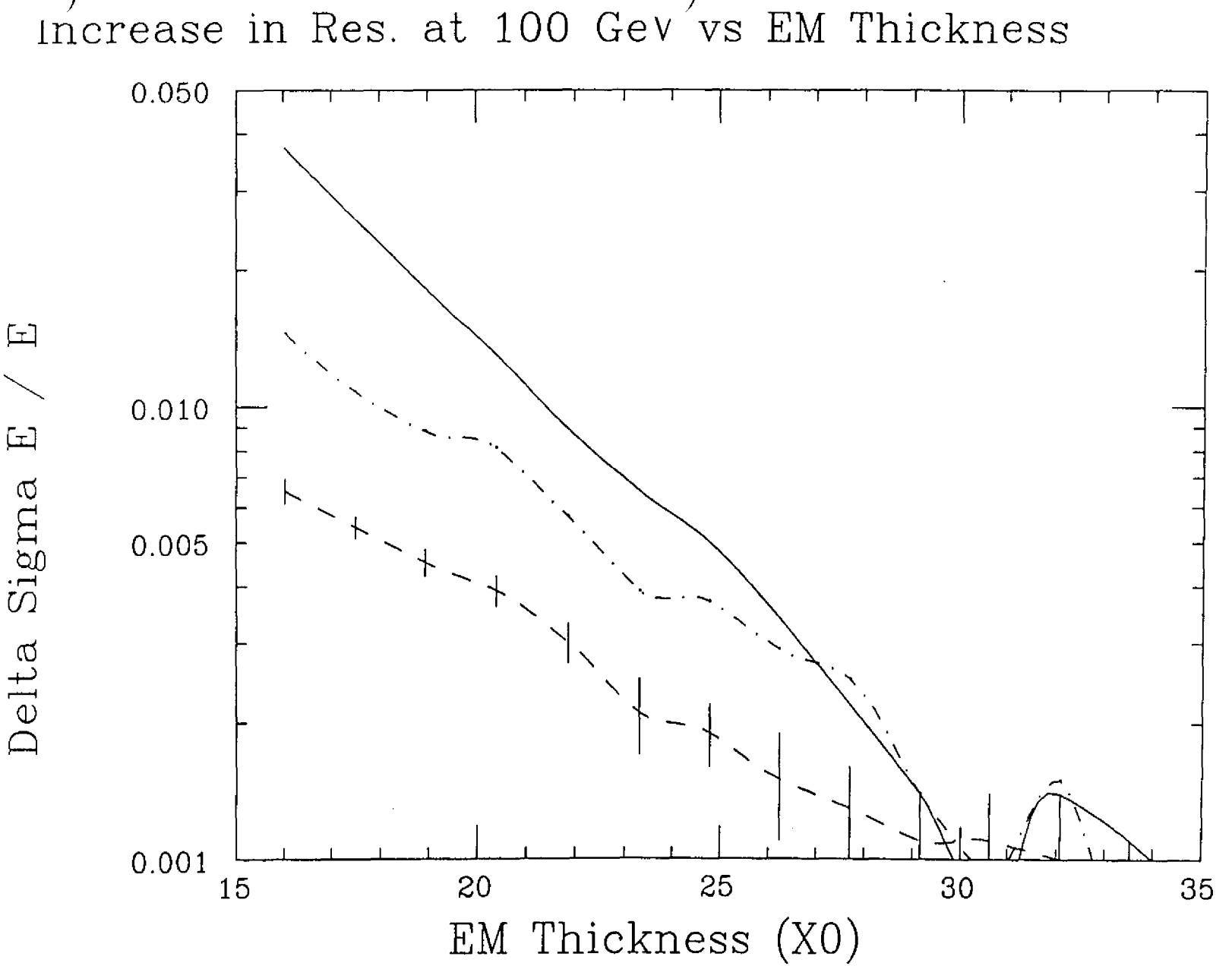
Increase in Res. at 100 Gev vs EM Thickness
0.050
0.010
0.005
0.001
15
20
25
30
35
Delta Sigma E / E
EM Thickness (X0)

Figure 4c

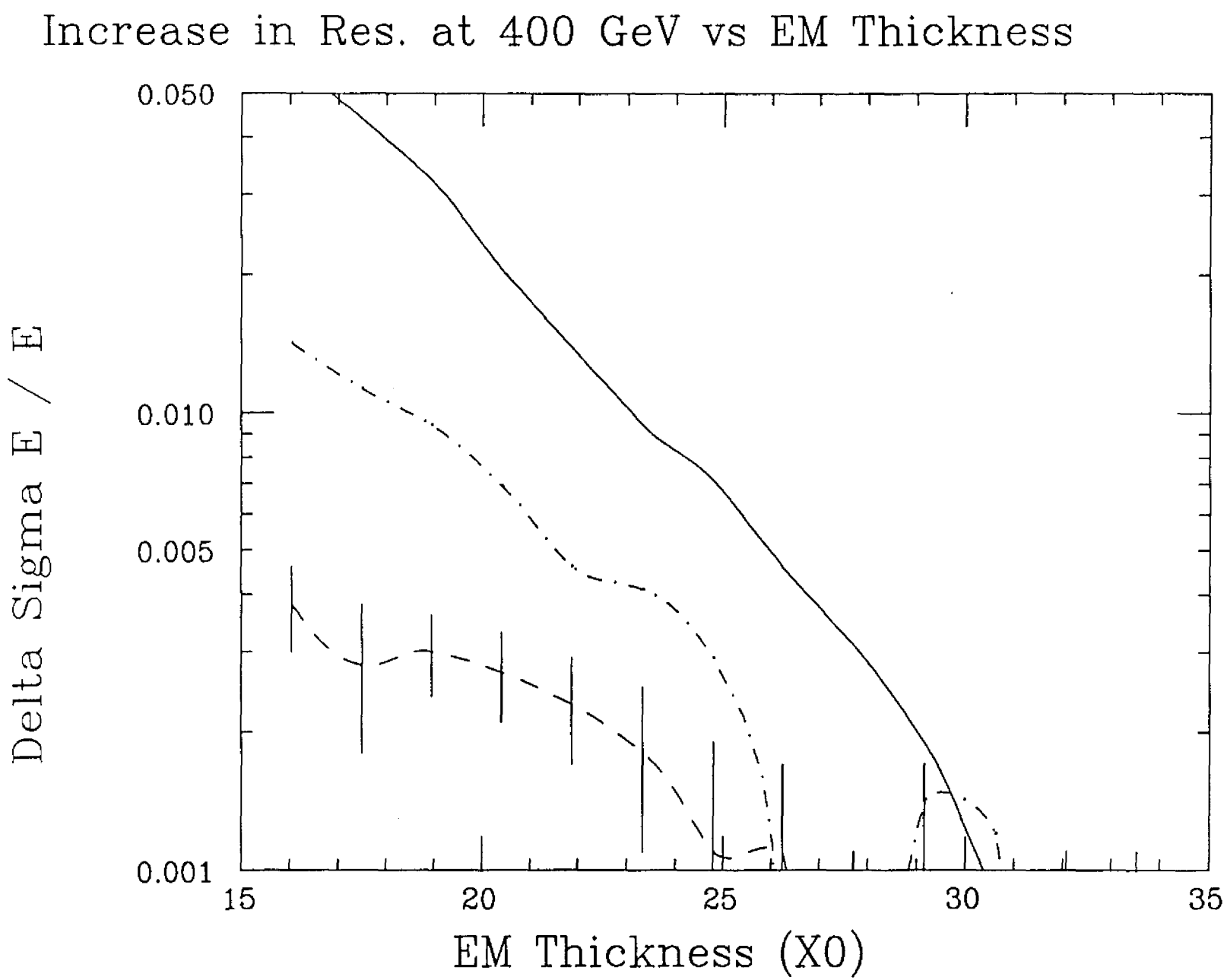
Increase in Res. at 400 GeV vs EM Thickness
0.050
0.010
0.005
0.001
Delta Sigma E / E
15
20
25
30
35
EM Thickness (X0)

Figure 4d

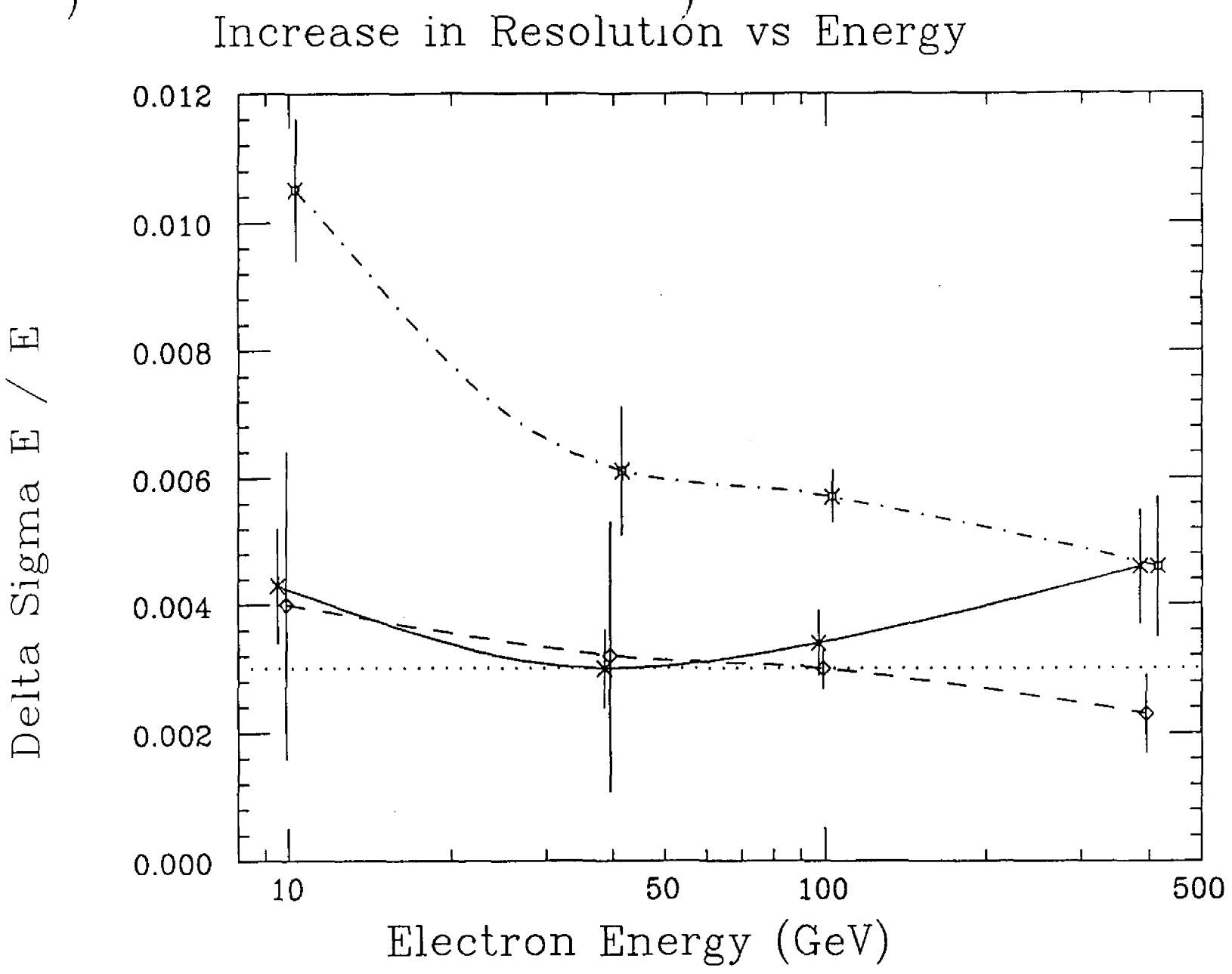
Increase in Resolution vs Energy
Delta Sigma E / E
0.012
0.010
0.008
0.006
0.004
0.002
0.000
10
50
100
500
Electron Energy (GeV)

Figure 5