Fermi National Accelerator Laboratory

FERMILAB-TM-1736

Effect of Inert Material on ZZ Mass Resolution for $H \rightarrow ZZ \rightarrow eeee$

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April 1991

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

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1.0 Introduction

A detector with a modest sized magnetic field volume will , of necessity, have inert material (solenoid coil) in front of the calorimetry. It is therefore crucial to assess the impact of that material on the physics of interest. Since the thickness of material is of order a radiation length, Xo, and only a fraction of a nuclear interaction length, the physics topics concern the EM calorimetry. In this note, a Higgs boson with a wide variety of masses is used as a paradigm of SSC physics. Low mass Higgs bosons approximate the kinematics of inclusive Z production, while high mass Higgs bosons probe the extremes of phase space to be explored at the SSC. The scale of interest is the natural width of the Z, since backgrounds will increase should the resolution due to the inert material exceed this basic scale.

2.0 Degradation of Energy Resolution

The loss of resolution can be studied by Monte Carlo, EGS, techniques. The results of such a study [1] are shown in Fig. 1. The points correspond to energy loss in 1,3, and 5 Xo of material as a function of photon energy. The variable t is the thickness of material in Xo units. The Monte Carlo results are well represented by the form;

$$\Delta E/E = a/E^b$$
$$a = ce^{(t/to)}$$
$$b = d + ft \qquad (1)$$

The values of the parameters are, c = 0.23, to = 2.95, d = 0.7, and f = -0.04. Note that the fractional energy loss decreases as a power of the energy. This means that the high energy scales of the SSC will be affected less than the Tevatron scale for physics. The loss of

energy depends exponentially on the thickness, with the characteristic thickness being 2.95 radiation lengths.

The fluctuations in the loss of energy lead to a worsening of the energy resolution of the calorimeter behind the absorber. Points from a Monte Carlo study [1] are shown in Fig. 2. Also shown are CDF data [2] with the calorimeter resolution removed by assuming that it was folded in quadrature with a term representing the error due to the material. An "intrinsic" resolution, $dE/E = 0.21/\sqrt{E} \oplus 0.013$ was assumed. The deconvoluted data and the Monte Carlo points agree in shape and their magnitude is within a factor of 1.6.

The form of the fractional energy resolution due to inert material is described sufficiently well by the form;

$$(dE/E) = (g/\sqrt{E})e^{(t/tc)} \tag{2}$$

The parameters for this form have the values, g = 0.019 and tc = 1.58. As with the energy loss, the resolution decreases as a power of the energy and increases exponentially with t, where the scale is set by the characteristic length tc.

In order to get an idea of the scales involved, an excellent calorimeter with resolution $dE/E = 0.15/\sqrt{E} \oplus 0.01$ is assumed. This resolution is shown in Fig. 3a as a function of photon energy. It sets the scale for the allowable thickness of inert material. In Fig. 3b is shown the thickness, as a function of energy, where the resolution due to inert material is equal to the "intrinsic" resolution of the EM calorimeter. This thickness is a very soft function of energy. It varies from 3.2 Xo at 0.01 TeV to ~ 4.6 Xo at 1.0 TeV. For comparison, the SDC detector [3] has a ~1 Xo scale set in the specification of the allowable solenoid coil thickness.

3.0 "Toy" Monte Carlo Results for H --> ZZ --> eeee

A simple Monte Carlo was written to examine the consequences of inert materials using Eq. 2. The Higgs bosons were produced flat in rapidity out to ymax -2, where ymax = $\ln(M/\sqrt{s})$. The transverse momentum squared of the Higgs was chosen to be

exponentially distributed with a characteristic scale of $0.3M_H^2$. All decays were assumed to be isotropic. The electrons had an intrinsic resolution as quoted above, $dE/E = 0.15/\sqrt{E} \oplus 0.01$. The coil was assumed to be of a uniform thickness, and to extend out to 24 degrees. Electron energies were smeared by this coil according to Eq. 2.

The mass resolution due to the energy smearing of the calorimeter caused by the coil alone is shown in Fig. 4 as a function of the 90 degree thickness of the coil in Xo units. The curves correspond to Higgs masses of 0.2,0.4,0.8, and 1.6 TeV as described in the Fig. caption. Clearly, the point where the coil contributes equally with the "intrinsic" resolution is at ~ 3 Xo units. For a coil thickness below ~ 2 Xo, the resolution of M_Z appears to be unaffected. Clearly, higher mass Higgs bosons, which mean higher energy Z bosons, have better resolution at all thicknesses. This is expected since the "intrinsic" stochastic term decreases with energy, as does the term due to inert material (Eq. 2). However, only at the highest masses for the Higgs do the Z bosons receive enough boost so that the resolution due to energy error is less than the natural width scale set by the Z itself.

4.0 Summary and Conclusions

The allowable depth of inert material in front of an EM calorimeter has been investigated. The energy loss in such material has a length scale of 2.95 Xo. The error in energy due to fluctuations in this lost energy has a length scale of 1.58 Xo (exponential scale, fluctuations going as the square root of the leakage). The error decreases with energy, with roughly the same behavior as the "stochastic" term in the "intrinsic" resolution of the calorimeter. This fact leads to an allowable thickness which is only weakly energy dependent. A "toy" Monte Carlo study indicates that below 2 Xo the coil has no effect. At 3 Xo the coil degrades the EM calorimeter determination of the Z mass by $\sqrt{2}$. This conclusion is essentially independent of the mass of the Higgs boson (transverse momentum of the Z).

References

1) H. Hirayama, Proceedings of the International Workshop on Solenoidal Detectors for the SSC, April 23-25, 1990.

2) J. Elias, unpublished CDF data, private communication.

3) Letter of Intent by the Solenoidal Detector Collaboration, Nov. 30, 1990.

Figure Captions

1. Energy lost in an inert absorber as a function of photon energy. The points ,•, o , and ∇ correspond to 5, 3 and 1 radiation lengths respectively. The lines are a parametrization described in the text.

2. Data and Monte Carlo for fractional energy resolution as a function of the depth, in radiation lengths, of inert material in front of a calorimeter. The points are CDF data at 25 (•), 50 (o), 100 ⊕, and 150 GeV (∇) and EGS Monte Carlo at 50 GeV, (⊙). The lines correspond to a form described in the text.

3. a. The assumed fractional energy resolution for an EM calorimeter as a function of energy. The smooth curve is to guide the eye.

   b. The thickness of inert material where the additional resolution is equal to the resolution given in a. as a function of energy. The smooth curve is to guide the eye.

4. Fractional Z mass resolution as a function of thickness of inert material in radiation length units. The shaded area is the scale set by the natural width of the Z. The points correspond to Higgs bosons of mass 0.2 TeV, (•) , 0.4 TeV, (o), 0.8 TeV (∇), and 1.6 TeV (□). The smooth curves are to guide the eye.

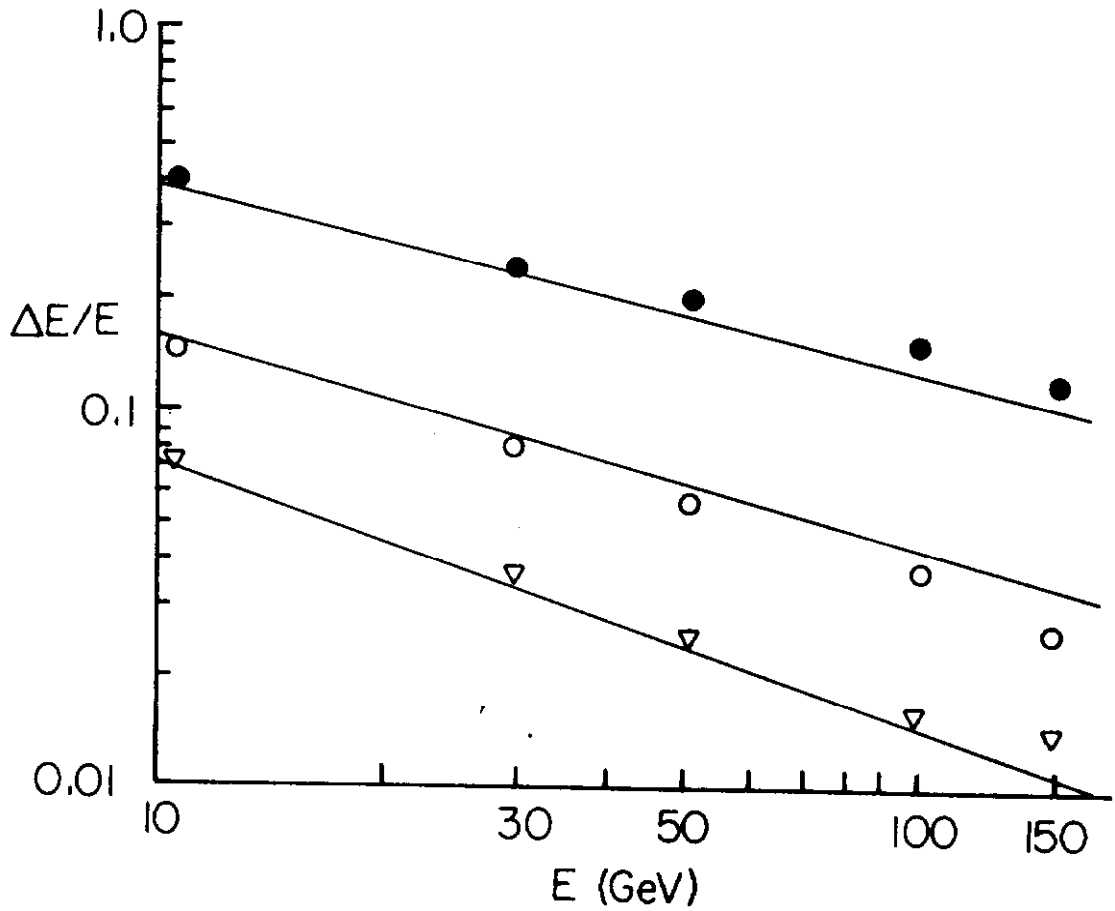

Fig. 1

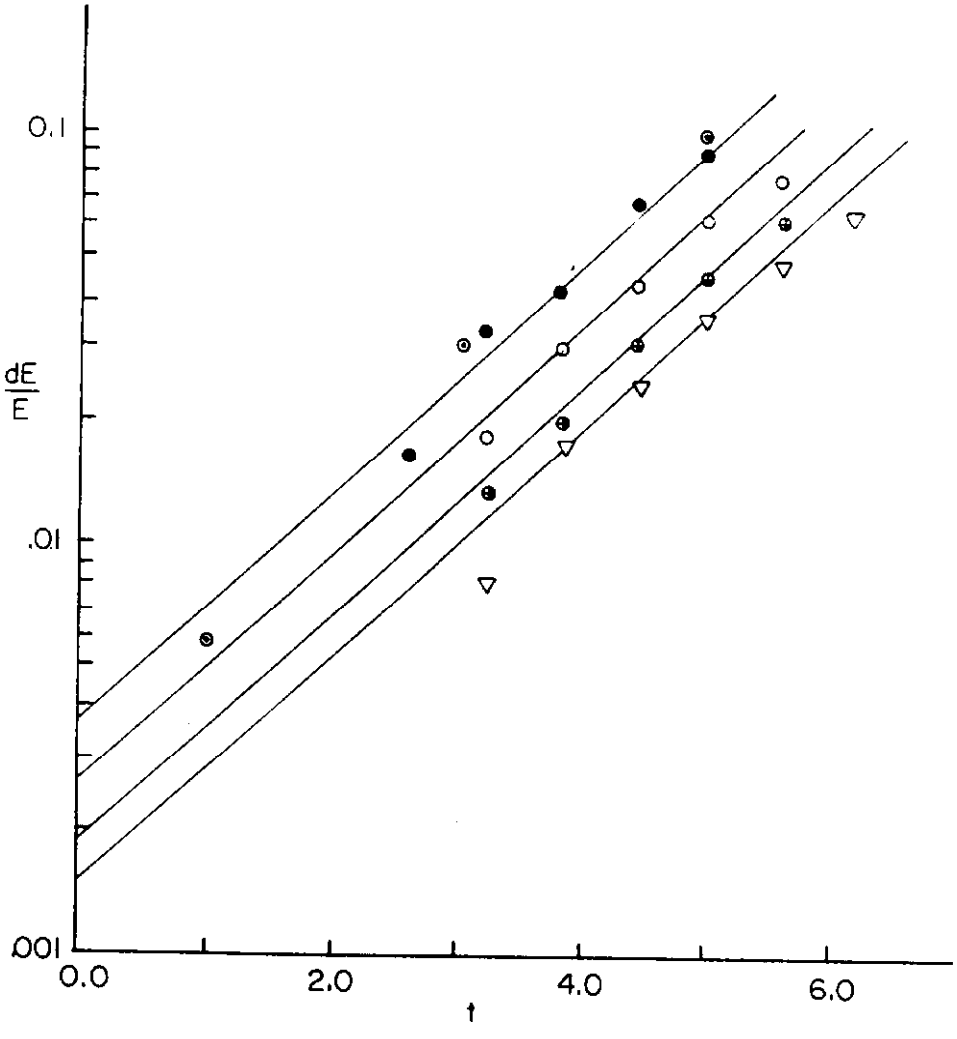

FIG. 2

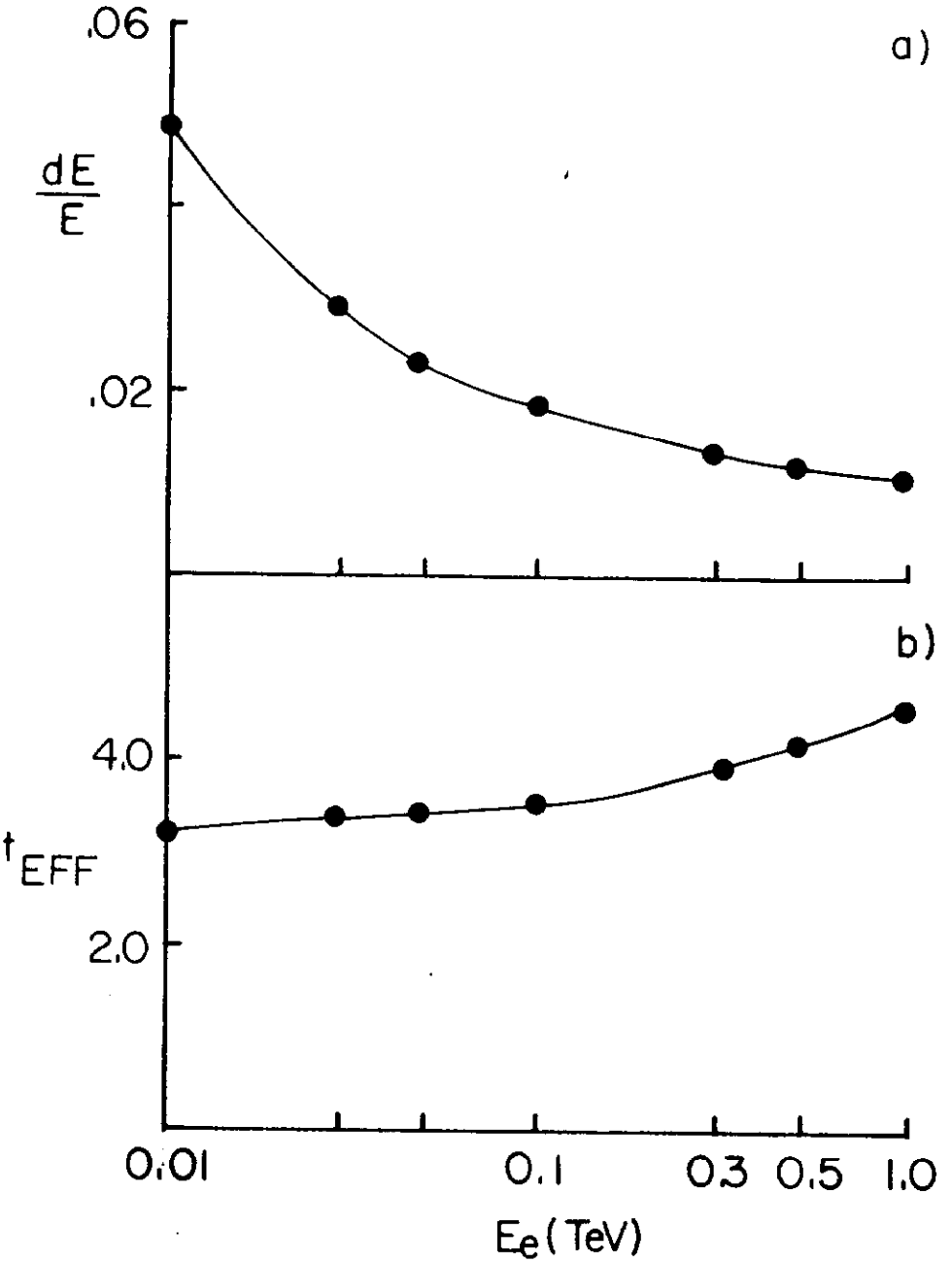

FIG. 3

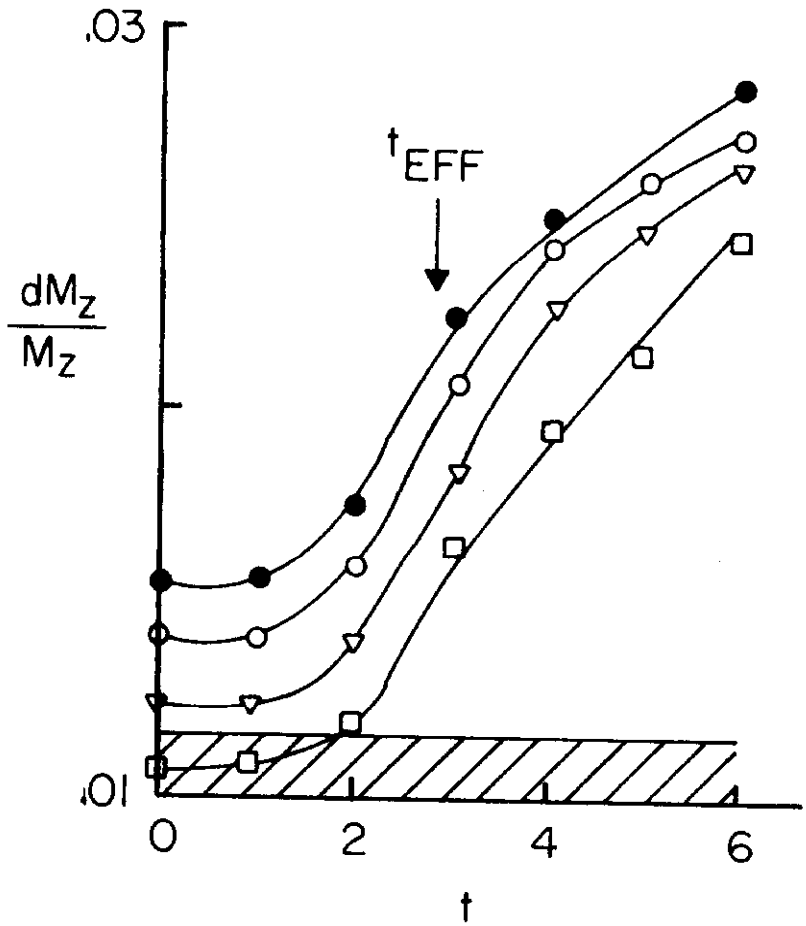

FIG. 4