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Effect of Tracker Material on ECAL Endcap Resolution

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Abstract

Preliminary studies have been carried out using a stand-alone GEANT simulation [1] to evaluate the impact of tracker material on the resolution achievable by the ECAL endcaps for CMS.

Introduction

Preliminary studies have been carried out using a stand-alone GEANT simulation [1] to evaluate the impact of tracker material on the resolution achievable by the ECAL endcaps for CMS. The program version used for these studies modelled a 9×9 array of trapezoidal crystals, positioned at a user-specified pseudo-rapidity. In front of the crystal array is a detailed model of the preshower. At various distances in front of the preshower different thicknesses of aluminium were positioned to study the effect of additional material on the energy resolution of the ECAL endcaps.

The crystal dimensions used are close to the current design values [2] but not identical. No attempt is made to simulate accurately the distribution of tracker material. The results presented here are intended only to show gross trends.

Simulation Parameters

Crystal Geometry

The array of crystals used in the these simulations had the following characteristics:

1. 9×9 array of lead-tungstate crystals,
2. trapezoidal shape, 22 cm long, 2.3 cm front face, rear face calculated from off-pointing angles,
3. centre crystal positioned at $\eta = 1.7$,
4. inter-crystal gap 0.05 cm, air,
5. off-pointing angles of 3 degrees in η and ϕ.

Beam Kinematics

For most runs 120 GeV γ's were aimed at the middle of the crystal array with a spread of ± 0.01 cm in x and y. Some runs were done with 120 GeV e^-'s and some low energy runs with 20 GeV γ's.

Material Distributions

Runs were carried out with the following combinations of material in front of the endcap:

1. no preshower or additional tracker material,
2. standard preshower, no additional tracker material,
3. standard preshower plus 1 X_0 of aluminium at distances of 0, 5, 10, 15, 20, 50, 100 cm from the preshower,
4. standard preshower plus aluminium immediately in front of preshower of thicknesses: 0.6, 1, 2, 3 X_0 .
5. same as 3. but with 1 X_0 of material removed from the first layer of lead in the preshower.
6. standard preshower plus aluminium of varying thickness in front of the preshower: 0.6 X_0 over the $-x$ half of the crystal array, 1.6 X_0 over the $+x$ half. For these runs the size of the target area was increased to ± 0.5 cm in x and y.

In all cases where additional tracker material is specified the physical thickness is adjusted according to the angle of traversal of the beam implied by η such that the beam particle "sees" the actual number of radiation lengths specified. For the case of the reduced preshower thickness no angular correction is done. The distances of the additional material are always expressed in terms of the physical gap size between the aluminium and the front of the preshower, in excess of a minimum gap of 0.5 cm.

Energy Reconstruction Procedure

For these studies the measured energy in the ECAL is taken as the sum of energy deposition in a 5×5 array of crystals centred on the crystal with the largest energy deposited. This energy is then corrected using the energies deposited in the two silicon layers in the preshower as described in [1]. The corrected energy can be written as

$$E_{corr} = \sum_i E_i - 0.5 \times (\alpha E_{pre_1} + \beta E_{pre_2})$$

where the correction factors α, β are obtained fitting the gradient of profile plots of $\sum_i E_i$ against the energies in the two preshower layers. No optimisation was done on the relative weighting of the two preshower contributions, however, the corrections were calculated separately for each run corresponding to different material distributions and beam energy. In each case the profiles were inspected visually and a fit range selected from the linear part of the plot as some of the plots have ragged tails due to poor statistics.

The corrected energy histogram is used to estimate the resolution by fitting the peak region to a Gaussian. The fit is restricted to a region $\pm 3\sigma$ around the peak. The resolutions are plotted for each run as $\sigma/E\%$ where σ is taken from the final Gaussian fit to the corrected energy. For 120 GeV incident γ's there is typically a shift of the peak value down to $117 - 118$ GeV.

Results

Figure 1 shows the energy resolution for 120 GeV incident γ's as a function of additional tracker material. Figure 1a) shows the variation of resolution as a function of distance of the additional material from the front of the preshower. There is a nearly linear rise in σ/E from 0.67% to 1.94% as the additional material is moved from zero to 1 metre away. The open circles correspond to the same conditions but with 1 X_0 of lead removed from the preshower. It can be seen that this largely compensates for the addition of (uniform) tracker material. Figure 1b) shows the variation as the amount of tracker material close to the preshower is increased (more X_0 's). This shows an exponential rise in contrast to the variation with distance and indicates that anything above 1 X_0 of tracker material would be disastrous for the ECAL resolution. The horizontal dashed lines in figure 1 and the following ones indicate the target design resolution of $5\,\%/\sqrt{E}$.

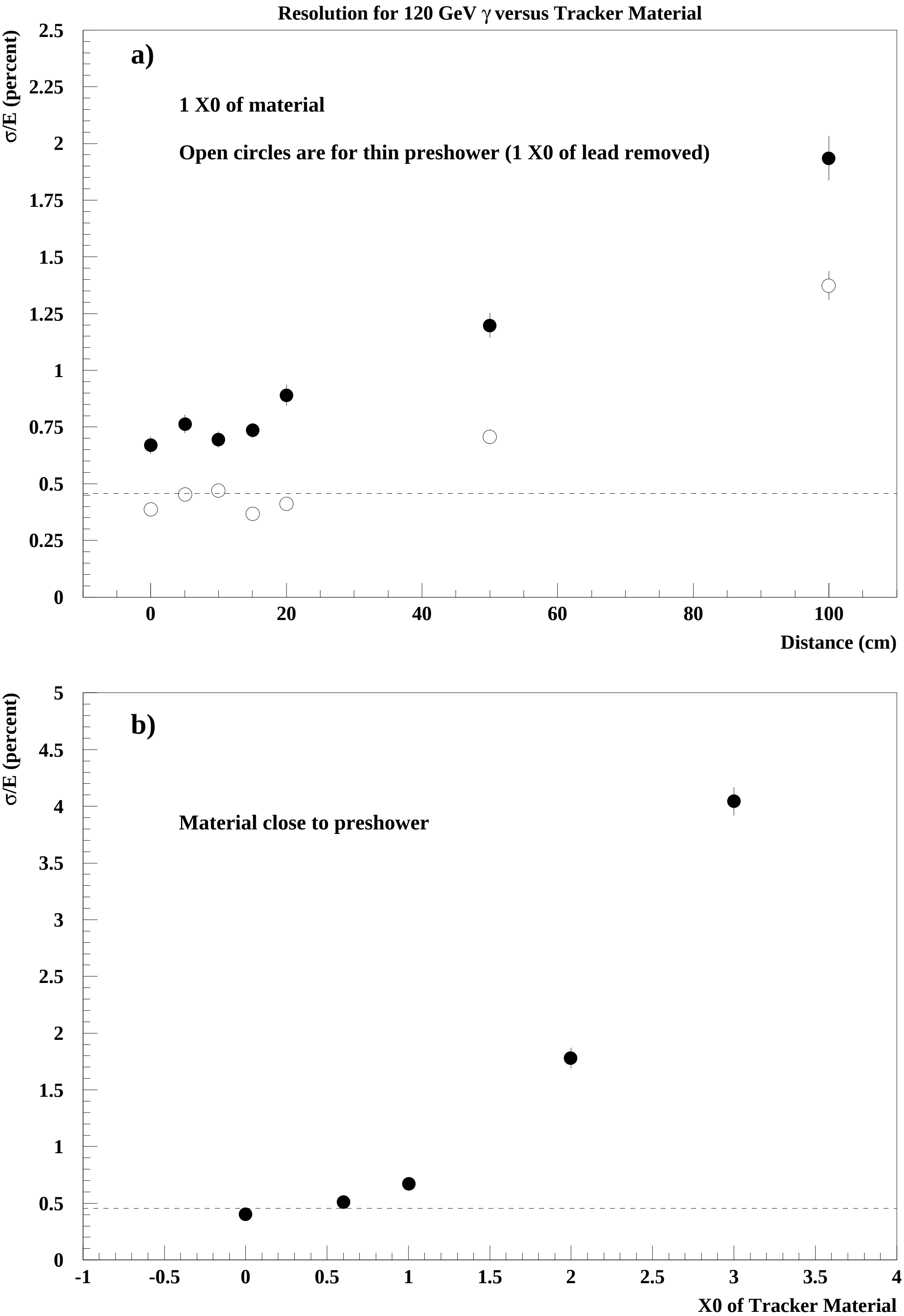

Figure 1: Energy resolution for 120 GeV γ's versus tracker material.

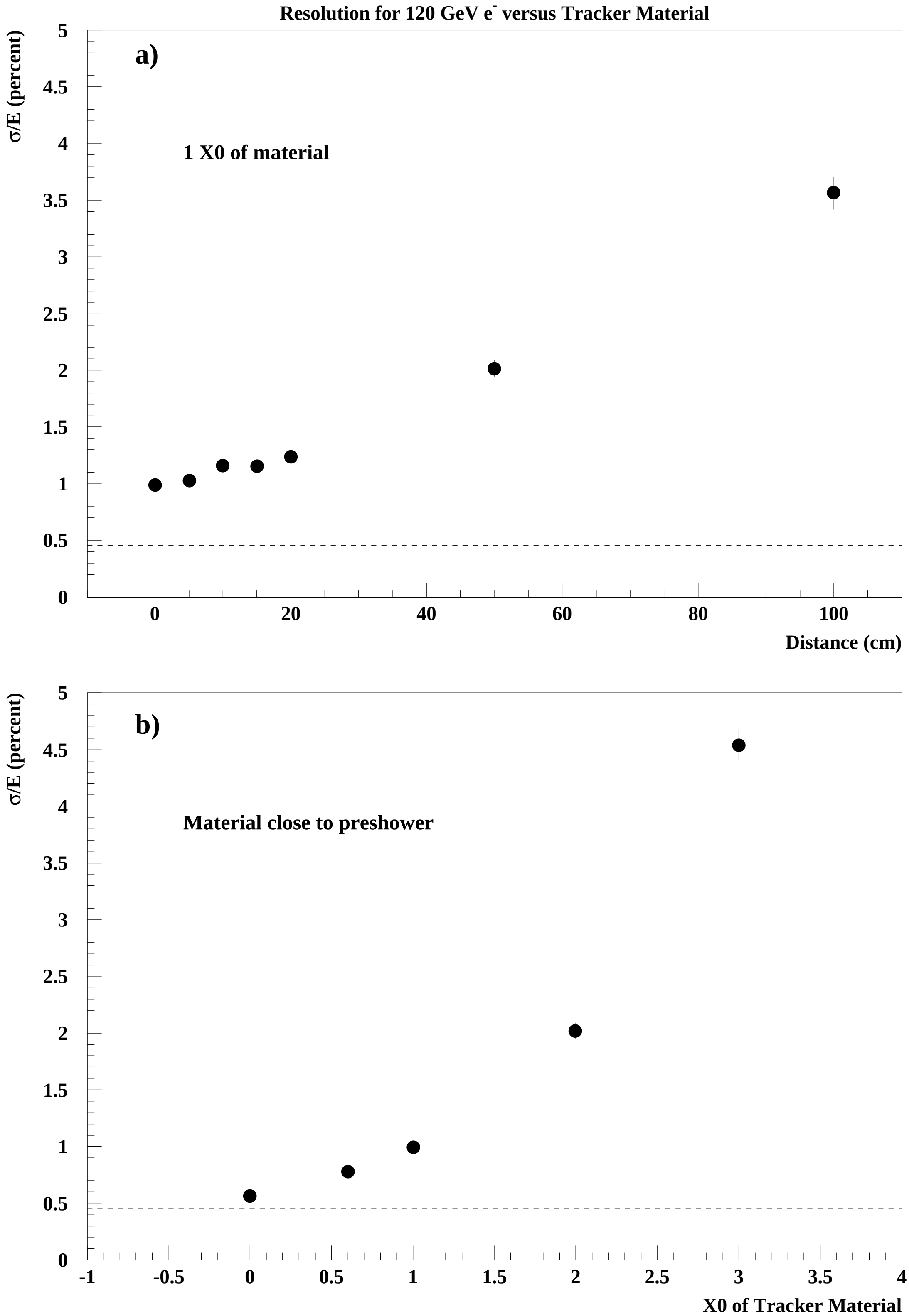

Figure 2: Energy resolution for 120 GeV electrons versus tracker material.

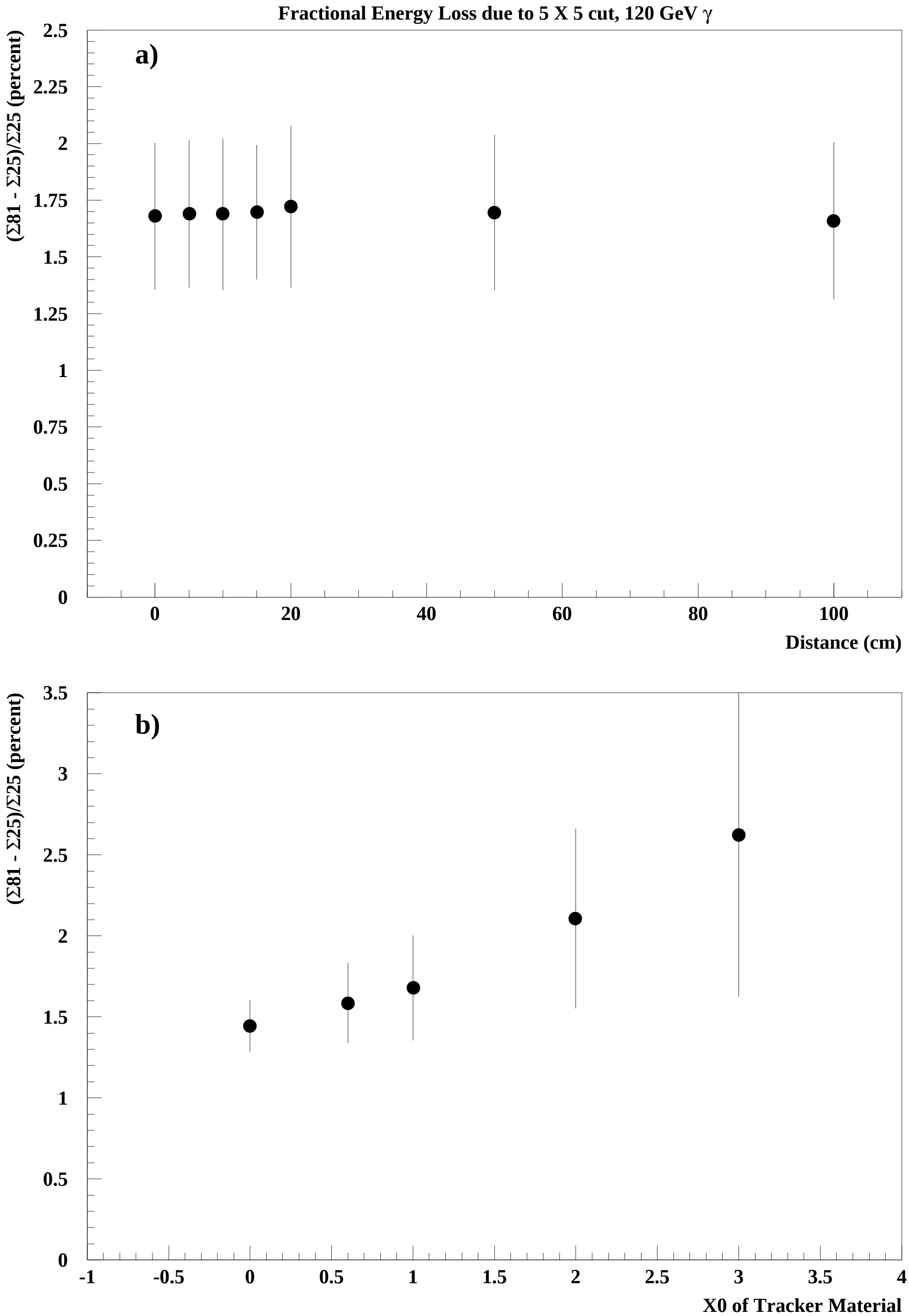

Figure 3: Percentage of energy lost due to 5×5 cluster cut.

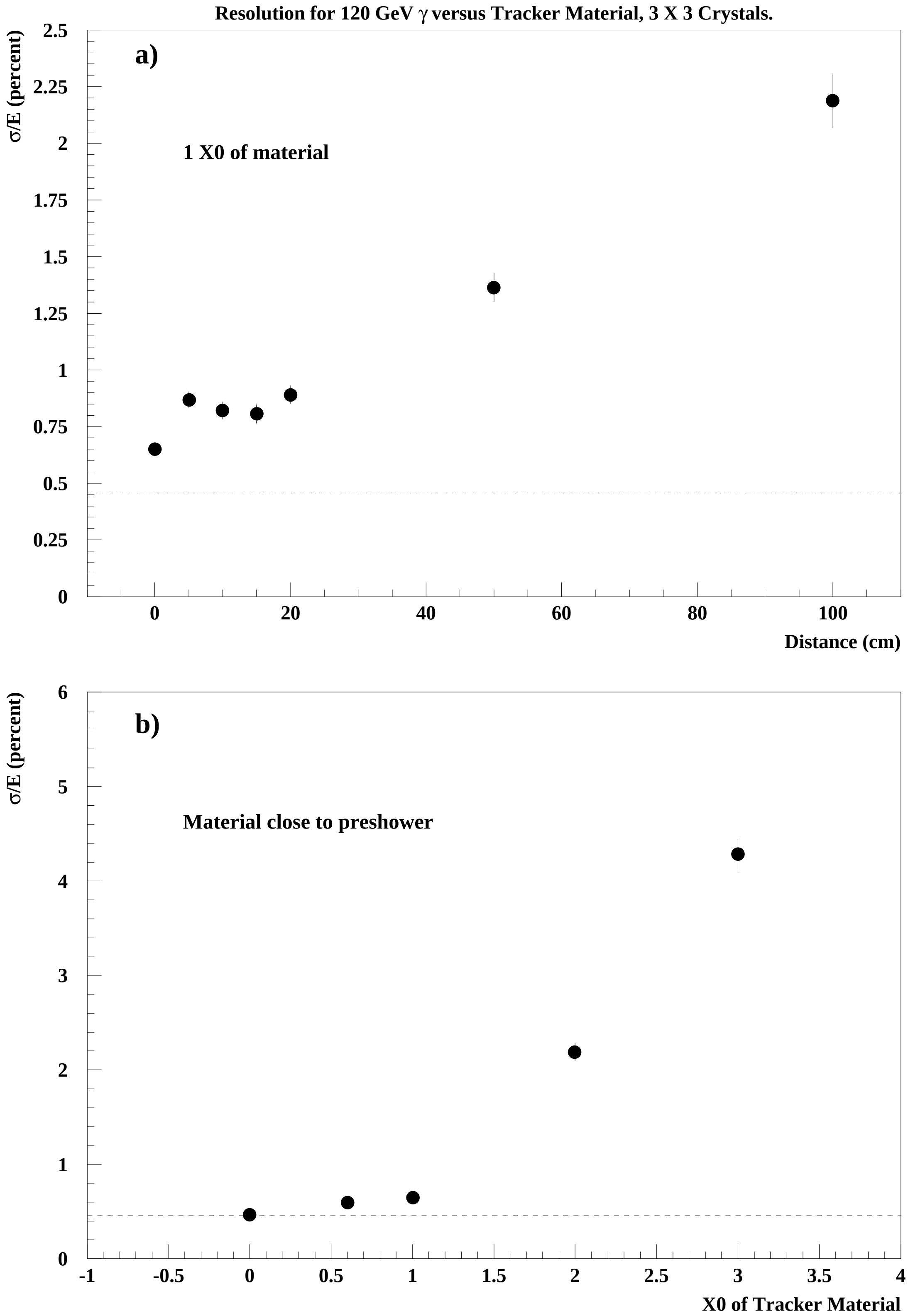

Figure 4: Energy resolution for 120 GeV γ's using a 3×3 cluster size.

Figure 2 shows the same distributions as figure 1 for 120 GeV e^-'s. It can be seen that the resolution is systematically worse for electrons as they always begin showering immediately in the preshower or tracking material.

Figure 3 shows that only about 1.5 % of the energy deposited in the endcap is lost as a result of making a 5×5 cluster cut. This also has almost no dependence on the distance of additional tracker material from the preshower 3a). There is only a weak dependence on the amount of additional tracker material 3b), with the loss rising to 2.5 % with 3 X_0 of additional material. A 5×5 cut has been used as the most optimistic that could be achieved. However, due to the expected high occupancy in the endcap it may be necessary to restrict the cluster size to 3×3. Figure 4 shows the resolution for 120 GeV incident γ's if a 3×3 cluster cut is used instead. It can be seen by comparison with figure 1 that the resolution only degrades slightly with the narrower cluster cut. The effect of the narrower cut is seen more strongly at larger distances and greater thicknesses of tracker material.

To study the effects of non-uniformity in the tracker material runs were done for gammas and electrons with a stepped material in front of the preshower. For these runs half the crystal array saw 0.6 X_0 of tracker material and half saw 1.6 X_0 . The two material thicknesses average out to 1.1 X_0 so these results should be compared with the values for a uniform 1.1 X_0 of tracker material. Figures 1 and 2 were fitted to an exponential distribution to predict the resolution that would be expected at 1.1 X_0 and 1.6 X_0 . The results are shown in table 1. Note that the resolution in the case of the stepped material is worse than that expected for a uniform material of the greater thickness. It can be seen from this result that predicting the ECAL resolution based on a smoothed out distribution of tracker material may be over optimistic if there is a significant degree of non-uniformity in the actual distribution of material.

	Resolution: σ/E		
Beam	0.6–1.6 step	1.1 X_0	1.6 X_0
γ	1.39 %	0.84 %	1.26 %
e^-	1.65 %	1.13 %	1.61 %

Table 1: Comparison of resolution with non-uniform tracker material against average uniform tracker material.

References

[1] D. Barney, “Simulation Package for CMS Endcap ECAL/Preshower Design Optimization”, CMS IN 1997/015

[2] L. G. Denton, B. W. Kennedy, J.M.Hays, “CMS ECAL Endcap Geometry Specification”, draft in preparation.