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EFFECT OF MATERIAL ON ELECTRON TRACKING

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1 Abstract

We have investigated the effect of material in the inner silicon tracker on electron track reconstruction using the SDC GEANT simulation. The efficiency and track quality were found to be comparable for single electrons and muons reconstructed in the silicon system only. At low p_t, track parameters for electrons and positrons were seen to be systematically shifted due to bremsstrahlung. The efficiency for single electrons to pass an E/p cut was evaluated for varying amounts of material, and seen to be independent of p_t. For multi-electron final-states, the efficiencies for different cuts are given.

2 Introduction

The proposed tracking system for the SDC has more material within the volume than previous comparable systems (e.g. CDF). This is due to the fact that the technologies chosen (silicon for the inner system, straw tubes or scintillating fibers for the outer) to meet the requirements for precision momentum measurement and robust pattern recognition, have substantially more radiation lengths per measurement than conventional gas drift chambers. Electrons which undergo bremsstrahlung in the material may be mis-measured in the tracking system, may fail isolation or other criteria in the calorimetry or both.

In general, we can express the efficiency for detecting an electron:

$$\mathcal{E} = \mathcal{E}_{isolation}\mathcal{E}_{tracking}\mathcal{E}_{electron\ id}$$

where $\mathcal{E}_{isolation}$ is the efficiency for the electron cluster to be isolated from other calorimeter energy (process and luminosity dependent), $\mathcal{E}_{tracking}$ is the track finding efficiency for isolated tracks, and $\mathcal{E}_{electronid}$ is the efficiency to pass all electron cuts. For the purposes of this study, we would like to separate this into two parts:

$$\mathcal{E}_{electron\ id} = \mathcal{E}_{E/p\ cut}\mathcal{E}_{other\ cuts}$$

The first term is the efficiency for the track to have measured E/p less than some value, to reduce the background from QCD jets ($\pi^{\pm}\pi^{0}$ overlap). In this study, we focus on this E/p efficiency for single and multi-electron events. It is clear that the cuts are very correlated, as those electrons which emit hard photons at small radii will tend to fail both E/p requirements and calorimeter requirements. Thus, the overall system performance for electron id should be studied with a more complete simulation involving both tracking and calorimetry.

Since bremsstrahlung causes a tracks curvature to change along its trajectory, the usual track reconstruction using the full system weighting by measurement errors is not optimal for electrons. Instead, using the inner subsystem only to fit these tracks ought to have less systematic bias and a smaller tail to the E/p distribution due to radiation. It will give a less accurate p_t measurement, but for reasonably low p_t may be appropriate to base an E/p comparison on. This is the approach taken in this study, largely because we do not yet have a combined track reconstruction for most of the η coverage.

The study was done with single tracks simulated within the SDC GEANT program. The system simulated consisted of a 1 mm Beryllium beam pipe of radius 4 cm, the inner silicon strip subsystem, and the outer straw tube system (though only the silicon data was used in reconstruction). Two configurations for the silicon system were used: the 'descope' configuration (Figure 1A), with 8 layers between 9 and 36 cm radius and 15 forward planes on each end; and the 'default (LOI)' configuration (Figure 1B) with 8 layers between 18 and 39 cm radius and 22 forward planes. No pixel layers were included, though the results should be valid if some of the strip layers were replaced by pixels (assuming the material is the same).

The silicon simulation includes additional material in each layer specified in the parameter file, but does not simulate in detail the support structure, cooling rings, cables, etc. By default, the material in each layer consists of (at normal incidence) 0.35% χ_0 of silicon and 0.5% χ_0 of additional material, amounting to 6.8% χ_0 at 90°. This is somewhat more than the most recent estimate for the system of 5.5% χ_0 averaged over η[1].

Single electrons and muons were generated uniformly within the range $|\eta| < 2$ at several values of p_t. For the electrons, the plot of bremsstrahlung radius (Figure 2) shows the positions of the beam pipe, silicon system, and straw superlayers. The track reconstruction program used the algorithm described in Reference [2].

3 Comparison of Electrons and Muons

We compared the track quality and parameters for electrons, positrons, and muons of both signs in the pseudo-rapidity range $|\eta| < 2$. The particles were generated from $Z = 0$ at p_t values of 5, 50, and 500 GeV/c, cases where the tracking is completely multiple scattering dominated, where the effects of m.s. and resolution are comparable, and where it is resolution dominated. Tracks were required to have 8 points (axial or stereo) to be fit, and the fitting algorithm could add points to tracks which were missed in the initial clustering, or delete points from tracks with poor χ^2. After the fit, tracks were required to have at least 10 hits to be used.

With these criteria, the efficiency for reconstructing the single tracks was typically $\sim$ 99%. The χ^2 distributions for the different samples were nearly identical, the only noticable difference being a small tail at high χ^2 for the 5 GeV electrons which we attribute to bremsstrahlung. The 'axial' fit parameters are systematically shifted for the low p_t electrons, This effect is shown in Figures 3A and 3B for ρ (curvature) and d_0 (impact parameter), respectively, for the LOI geometry without a beam constraint imposed.

4 Effect of Material on Single Electrons

The distribution of $p_{gen}/p_{fit} \sim E/p$ is shown in Figure 4 for 1000 electrons with p_t=50 GeV/c and $|\eta| < 2$, comparing the cases with (solid) and without (dashes) a beam constraint imposed. The tail at high E/p is due to bremsstrahlung. The beam constraint (10μ) narrows the width the central peak, but doesn't affect the tail. This is more easily seen in the integrated plot (Figure 5), which shows the probability for an electron to be observed with $E/p < (E/p)_{cut}$. For $E/p > 1.25$, the distributions are essentially the same. Approximately 2% of the electrons have $E/p > 2.5$. These plots do not include tracking inefficiency ($\sim$ 1-2%) which was seen to be the same for electrons and muons. The E/p efficiency is the same for the descope and LOI layer configurations.

The E/p efficiency is shown for electrons of three different p_t values (10, 50 and 200 GeV/c) in Figure 6; again, for $E/p > 1.25$, the distributions are similar at the 1% level. For the remainder, we use the 50 GeV/c case. The E/p efficiency is shown for varying amounts of additional material in Figure 7, and listed in Table 1. A substantial loss is observed for moderate E/p cuts ($\sim$ 1.5) when the default material is doubled or tripled.

Table 1: Single electron E/p efficiency for p_t=50 Gev/c, $|\eta| < 2$, for varying amounts of material per layer in the inner system, in addition to the 0.35% χ_0 of silicon per layer.

$(E/p)_{cut}$	$0.05\%\chi_0$	$0.25\%\chi_0$	$0.5\%\chi_0$	$1.0\%\chi_0$	$1.5\%\chi_0$
1.25	0.967	0.941	0.931	0.886	0.865
1.3	0.971	0.943	0.934	0.901	0.878
1.4	0.977	0.953	0.943	0.915	0.889
1.5	0.982	0.958	0.949	0.928	0.905
1.6	0.984	0.962	0.955	0.940	0.917
1.7	0.985	0.966	0.960	0.949	0.928
1.8	0.986	0.966	0.961	0.955	0.934
1.9	0.987	0.967	0.964	0.957	0.940
2.0	0.988	0.969	0.969	0.961	0.945
2.1	0.988	0.971	0.973	0.963	0.948
2.2	0.988	0.972	0.975	0.967	0.952
2.3	0.990	0.973	0.975	0.969	0.956
2.4	0.990	0.974	0.976	0.971	0.959
2.5	0.991	0.974	0.979	0.971	0.959

5 Multi-Lepton Final States

To interpret these efficiency results, we need to ask how they affect particular physics measurements. Multi-lepton processes such as a Higgs boson are most sensitive to the efficiency, since it enters once for each lepton. For an intermediate mass Higgs, the lepton p_t distribution is shown in Figure 8. The relevant p_t range is $10 < p_t < 200$ GeV/c, so the E/p evaluated with the inner system may be appropriate in this case.

Ideally, we would like the efficiency for the 4μ, $2e2\mu$, and $4e$ final states to all have high efficiency. Perhaps a reasonable goal is $\sim 80-90\%$ after fiducial selection cuts are made. If tight E/p and other requirements are made on each electron leg as would be appropriate for inclusive electrons, this will be difficult to achieve. One would probably need to adopt asymmetric cuts, tight for one electron and loose for the second. This is done, for example, in the CDF Z analysis, in which case virtually all of the jet background is removed while the efficiency is maximized[3].

For the two electron case, if we choose two cuts with efficiencies $\mathcal{E}_1$ and $\mathcal{E}_2$ $(1 > \mathcal{E}_2 > \mathcal{E}_1 > 0)$, then the pair efficiency is:

$$\mathcal{E}_{1,2} = \mathcal{E}_1^2 + 2\mathcal{E}_1(\mathcal{E}_2 - \mathcal{E}_1) = 2\mathcal{E}_1\mathcal{E}_2 - \mathcal{E}_1^2$$

Expressing $\mathcal{E}_1 = 1 - \delta_1$, and assuming the single cut efficiencies are high such that we can ignore higher order terms, one finds:

$$\mathcal{E}_{1,2} \simeq \mathcal{E}_2^2$$

which means that the efficiency is essentially that of the looser cut squared. Equivalently, you only lose both electrons if they both brem catastrophically. This result is illustrated in Figure 9, which shows the single electron E/p efficiency, that efficiency squared, and the efficiency for a tight cut at $E/p < 1.2$ for one leg. If we required $E/p < 1.5$ for each leg, we get an efficiency of 90%, whereas if we require $E/p < 1.2$ for one and $E/p < 2.5$ for the other, the efficiency is 95%.

For the four electron final state, one could impose cuts in several ways. We calculated the efficiency for imposing tight cuts on all, three, two and one of the electron legs, and also for two requiring the 'good' electrons to have the same sign. In all cases, the efficiency is approximately that of the looser cut to the fourth power. Figure 10 shows this efficiency for the same cut on all four compared to a tight $E/p < 1.25$ for two-same sign legs. As before, a symmetric cut at $E/p < 1.5$ for all four electrons introduces twice the inefficiency of a tight cut at $E/p < 1.2$ on two and a loose cut at $E/p < 2.5$ on the others.

Two caveats should be made: First, as stated above, the efficiency for the E/p cut alone isn't the relevant quantity. The overall efficiency for all electron cuts is, and since the cuts are correlated, making loose E/p cuts on some electrons means you need also to have comparable efficiency for cuts on shower isolation and profile, etc, and these would need to be asymmetric in the same way. Second, it doesn't make a lot of sense to discuss these cuts without knowing what level the backgrounds would be if the cuts were loosened. Previous Higgs studies for the LOI have assumed the non-electron backgrounds to be small, but this ought to be looked at carefully.

6 Conclusions

We have seen that the material within the 8 layer silicon inner tracker does not introduce inefficiency for finding electrons (compared with muons) in the inner system. It does, however, cause small systematic shifts and resolution tails for low p_t electrons, and introduces some inefficiency to an E/p cut. For cuts of 1.2 or greater, the E/p efficiency does not depend significantly on the track p_t, whether a beam constraint was used, or which detector

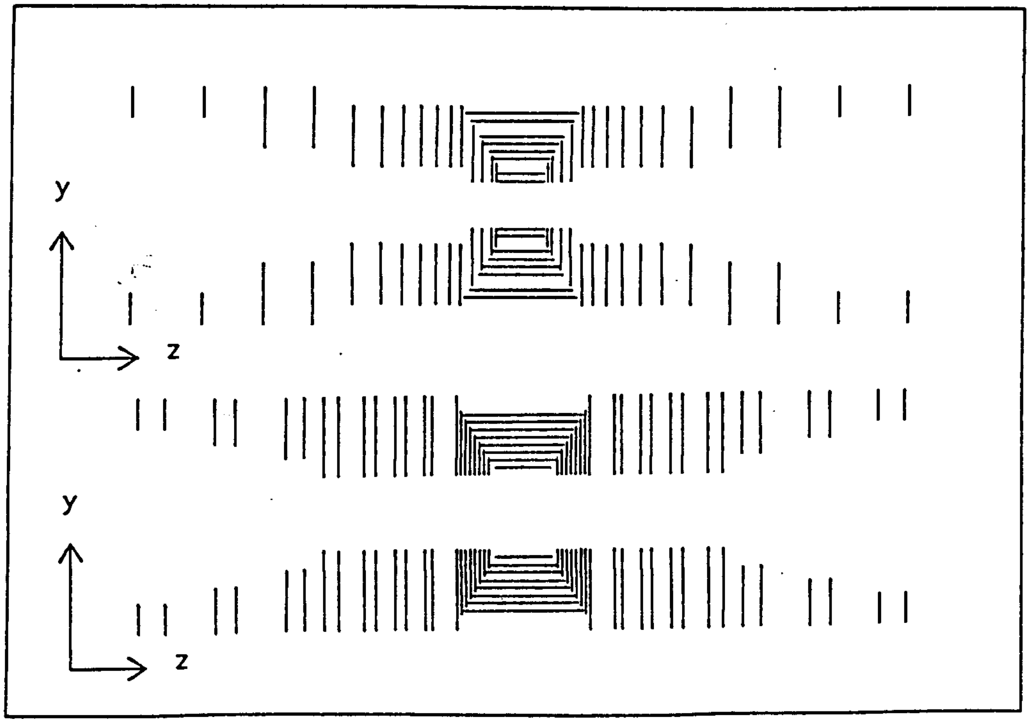

Figure 1: Two configurations simulated for the inner silicon system. A) 'Descope' (now standard) configuration. B) 'Default' (LOI) system.

configuration (LOI vs descope) is chosen. We see that for multi-lepton events, it is important to have asymmetric cuts if this efficiency is to be maximized.

For the eventual system, there may be a compromise between electron id efficiency and the other goals (pattern recognition, momentum precision, vertexing). We think a reasonable goal might be $\sim 90\%$ for two electron events, after fiducial cuts. To achieve this, it will be important to keep the material per layer as low as possible, and see whether the other tracking goals can be achieved with fewer layers. Further work will needed for the proposal, including a combined tracking and calorimeter simulation, and track reconstruction including the outer detector over the entire η coverage. Also, it would be important to focus on the efficiency for particular physics processes (perhaps focussing on $H \rightarrow ZZ^*$), and to estimate the levels of non-electron backgrounds.

References

[1] A.Seiden, private communication, as estimated by R.Stone.

[2] J.Hylen *et al.*, "Silicon Tracker Conceptual Design Report", SCIPP-90/24 (1990).

[3] M.Miller, private communication.

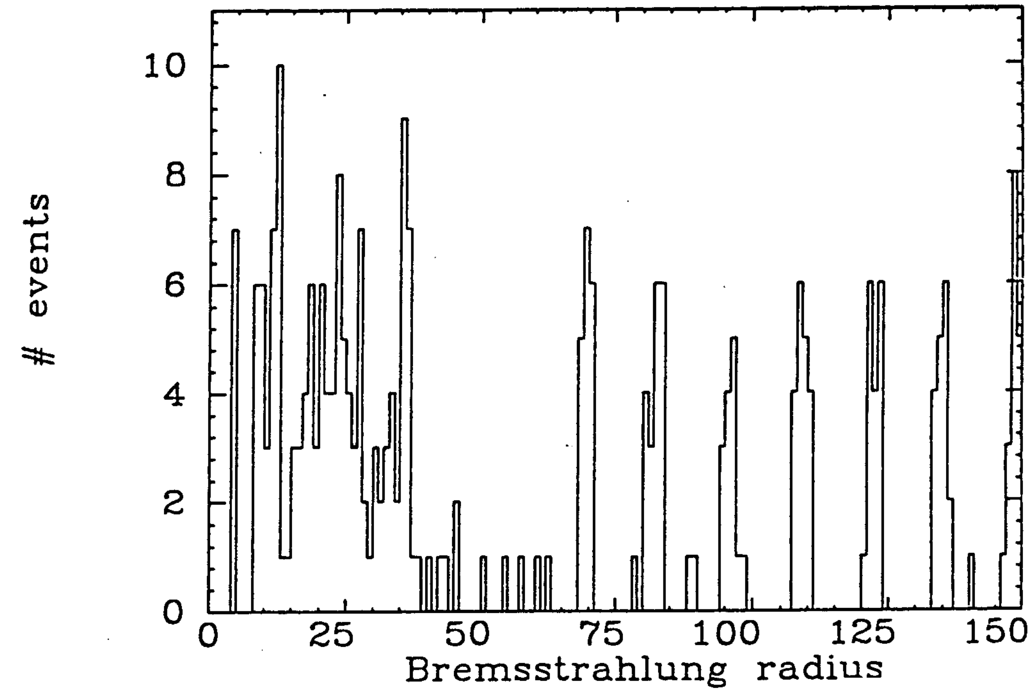

Figure 2: Radius of bremsstrahlung, showing position of tracking material.

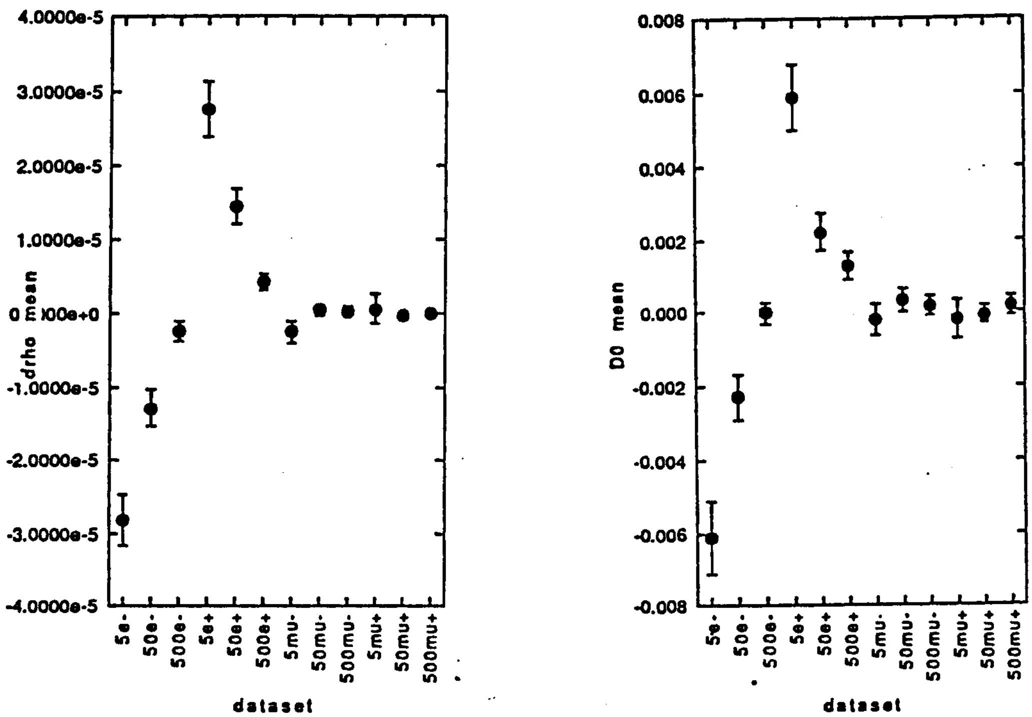

Figure 3: A) Systematic shift of $\rho = -q/r_c$ (curvature) for electrons and muons at three different p_t values. B) Systematic shift of d_0 (impact parameter) for the different data sets.

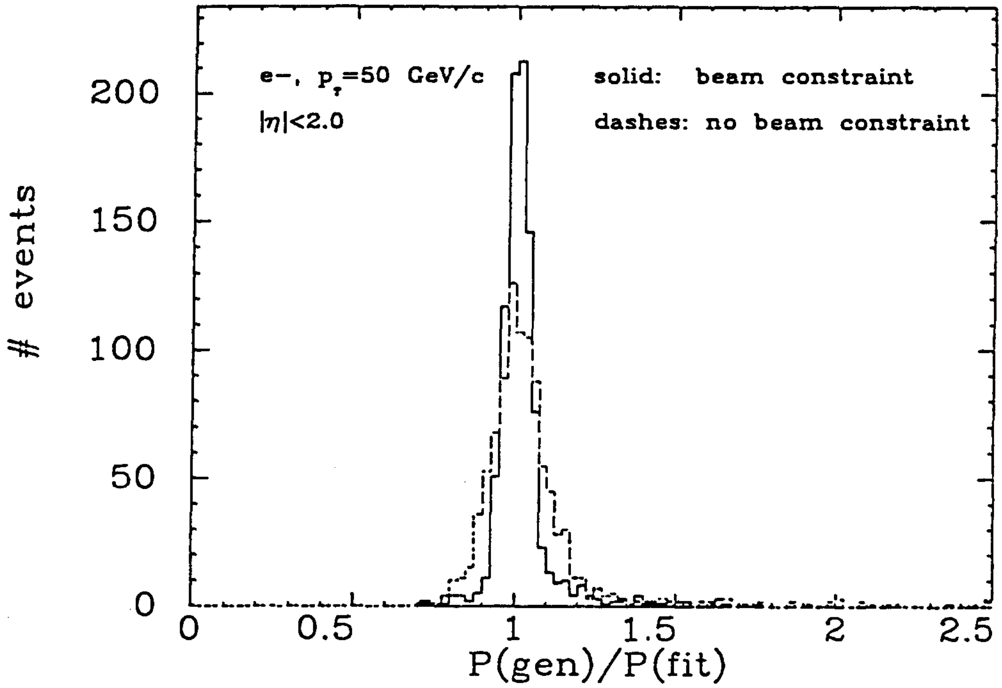

Figure 4: Distribution of $p_{gen}/p_{fit} \sim E/p$ for 50 GeV electrons comparing fit with and without a 10μ beam constraint.

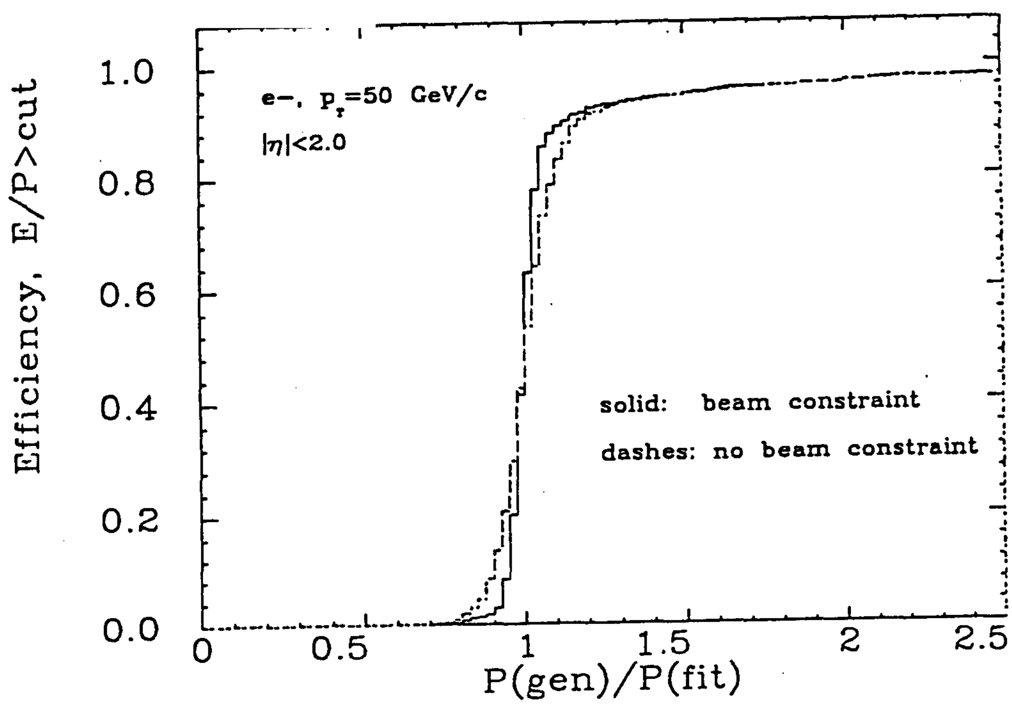

Figure 5: Efficiency for E/p to be less than $(E/p)_{cut}$ for 50 GeV electrons.

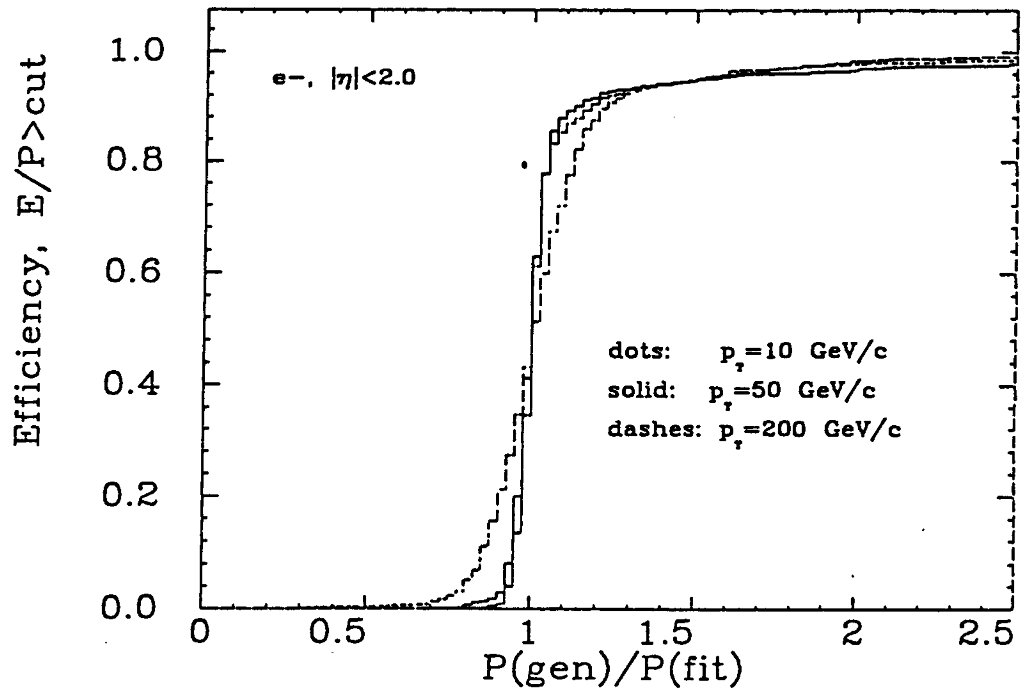

Figure 6: Comparison of E/p efficiency for electrons of 10, 50 and 200 GeV/c.

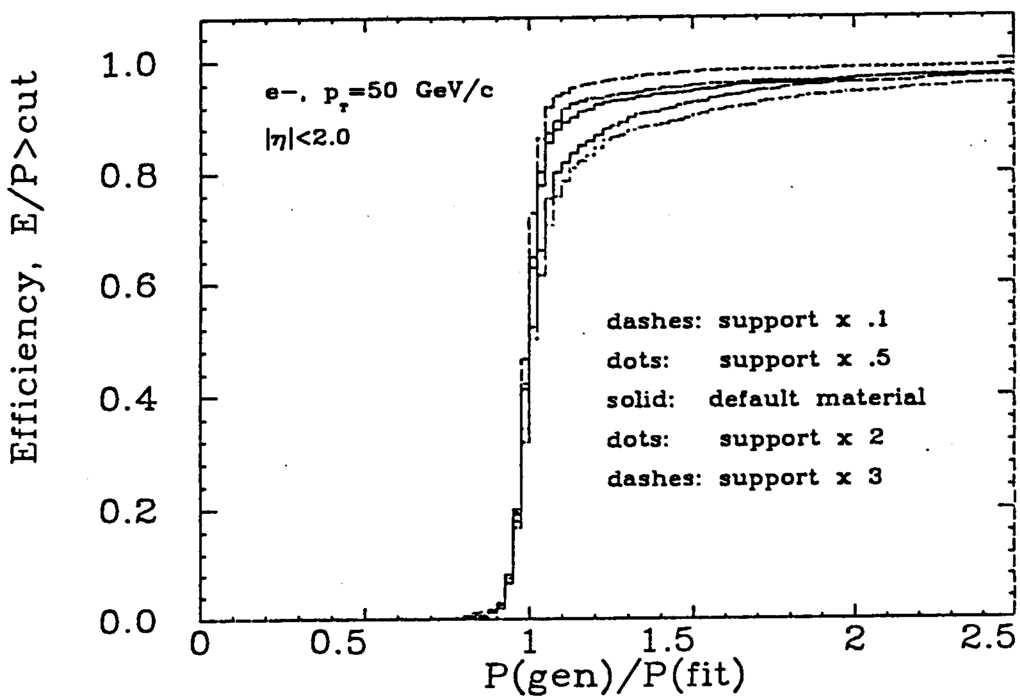

Figure 7: Comparison of E/p efficiency for 50 GeV/c electrons with different amounts of additional material per layer.

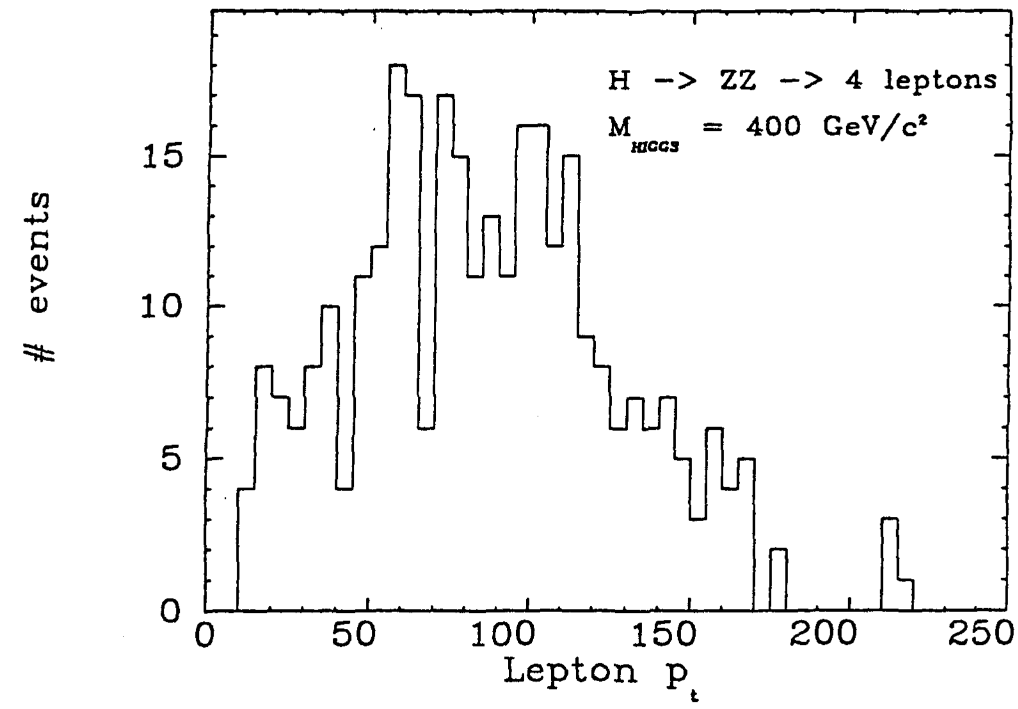

Figure 8: Lepton p_t distribution from Isajet for a 400 GeV/c^2 Higgs boson

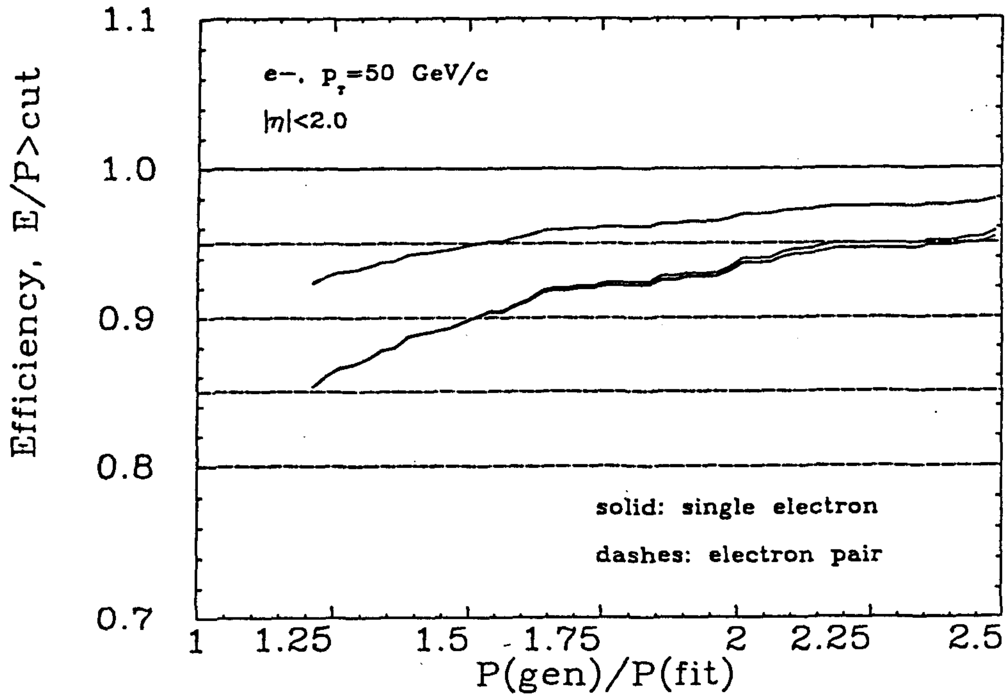

Figure 9: E/p efficiency for a pair of electrons compared with the single electron efficiency. For the pair efficiency, two curves show the efficiency for symmetric cuts in E/p and a tight cut ($E/p < 1.2$) for one electron vs the looser E/p cut applied to the other.

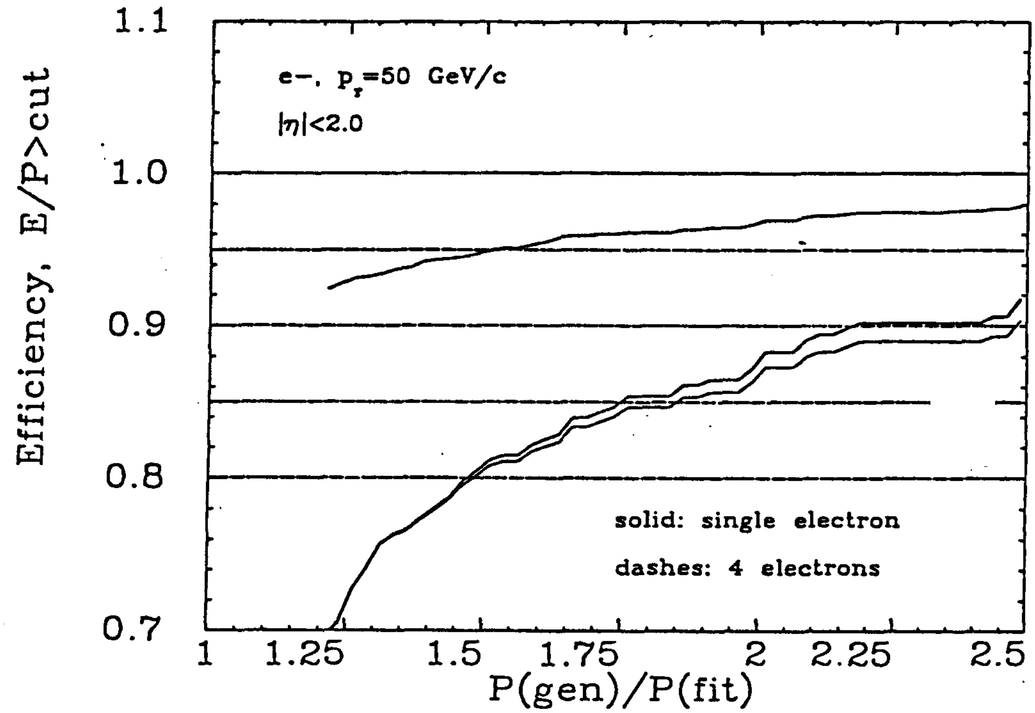

Figure 10: E/p efficiency for four electrons compared with the single electron efficiency. For the four electron efficiency, two curves show the efficiency for symmetric cuts in E/p and a tight cut ($E/p < 1.2$) for two same-sign electron vs the looser E/p cut applied to the others.