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"Massless Gap" Corrections to the SDC EM Energy Resolution

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1. Introduction

Often the calorimeter system is not the first material that particles emerging from an interaction encounter. Therefore, the problem of inert material upstream of a calorimeter is endemic. The purpose of this note is to use existing "Hanging File = HF" [1] data to quantify the effect of this material and to examine ways to alleviate those effects. Previous studies have been made using CDF test beam data [2] and using the EGS Monte Carlo program to study the electromagnetic response [3].

2. Effect of Material on Resolution

HF data at nominal energies of 15, 25, 50, 100, and 150 GeV (observed mean energy $\langle E \rangle$ 17.51, 30.89, 62.09, 110.56, and 170.26 GeV) were used. This data consists of calibrated readout of each layer of a 95 layer "stack". The stack has 40 plates of 1/8" Pb (22.8 Xo) followed by 55 plates of 1" Fe (79.2 Xo) interspersed with 2.5 mm plastic scintillator. The most upstream layer is Pb, so that the first active sampling layer is at a depth of 0.6 Xo. The calibration was done using 1 mip muons in each compartment separately; the electromagnetic (EM) and hadronic (HAD). There is one overall relative calibration of compartments. It was chosen to make the e/pion response roughly energy independent [1], not to minimize the energy resolution.

Inert material can be simulated by dropping front layers from the energy sum of the calorimeter. The results of this procedure are given in Fig. 1 and in Table 1. In Fig. 1 is shown the mean energy, scaled to the energy of the full stack, as a function of the depth of

Pb traversed before active sampling. Note that this depth, t , cannot be less than $0.6 X_0$ due to the construction of the stack, as noted above.

The mean is decreased by 10% for $t > 3.5$ at $E = 15$ GeV and for $t > 5.2$ for $E = 150$ GeV. This behavior is implicit in the logarithmic increase with energy of the depth of the maximum of the energy deposition of an EM shower [4].

The HF data has an "intrinsic" energy error, dE , due to sampling statistics ("stochastic term") and due to inhomogenities in the detector ("constant term"). The rms error in the energy distribution is increased as layers are dropped from the energy sum. An "induced" fractional energy error is defined to be that error which, when folded in quadrature with the error, dE/E , with no active layers dropped, yields the observed fractional energy error, $dE(t)/E(t)$. Both the scaled mean and the "induced" fractional energy error, at a depth $t = 4.0 X_0$, are given in Table 1. The induced error decreases rapidly with energy. A rough $\sqrt{E}$ dependence is seen, so that a plot of $(dE/E)\sqrt{E}$ vs t for different energies is shown in Fig. 2. Clearly, within a factor ~ 2 , that scaling leads to an error which grows approximately as $\exp(t/t_c)$, [2], and is energy independent. Representative values are given in Table 1.

TABLE 1

	E	$\langle E(4.0) \rangle / \langle E \rangle$	$(dE(4.0)/E)$ Induced	$(dE(4.0)/E)\sqrt{E}$ Induced
WT=1	15	0.868	0.084	0.35
	25	0.898	0.035	0.19
	50	0.931	0.035	0.27
	100	0.947	0.020	0.21
	150	0.958	0.016	0.21

3. "Massless Gap" Weighting

The SDC requirements are a total effective stochastic term of $<15\%$ and a total constant term of $<1\%$ [5]. Examination of Fig. 2 leads one to conclude that no more than 2-3 X_0 of material is tolerable upstream of the SDC EM calorimeters.

One way to partially evade that conclusion is to give the first layer after the inert material (the "massless gap" = MG or "preshower" = PS) a calibration which differs from the other layers. This difference reflects the different sampling fraction seen by this layer with respect to all the other layers. For example, at a depth of $t = 4.0 X_0$, with $E = 50$ GeV data, the first active gap sees 2.1 GeV on average, while the remaining layers see a total of 55.71 GeV. Roughly 7% of the energy is lost in the inert gaps. With a weight of 3.5 for the first gap, the MG/PS sees 7.3 GeV, which yields a total of 63 GeV to be compared to the mean seen in the whole stack of 62 GeV. Clearly, on average, one can correct for the lost energy. The remaining questions are if that correction is energy dependent (induced nonlinearity) and if that correction reduces the fluctuations (reduced induced rms).

The $E = 50$ GeV data was studied first. The MG/PS weight = WT was varied, as shown in Fig. 3, and the effect on the mean energy and the induced rms fractional energy error was plotted. The best weight in terms of energy error is ~ 3.75 , while the best weight for linearity is about 3.0. The induced error can be roughly halved by the choice of the optimal weight. Fortunately, the minimum for the induced error is shallow, so that a compromise may be struck. In what follows, a weight = 3.5 is chosen independent of energy. This situation might obtain if the "gain" of the first plate was fixed, and the plate was passively added to the energy sum. One can also contemplate a separate readout of the MG/PS with an energy dependent weight, although such a scheme would be more costly.

The results for the mean and rms of the energy distribution are shown in Fig. 4 and in Table 2, for a depth of $t = 4.0 X_0$ and with fixed weights of WT = 1, 3.5 as a function of energy. Clearly, the induced energy error is roughly halved at all energies at fixed WT. Furthermore, the induced energy nonlinearity is quite small. From $E = 15$ GeV to $E = 150$ GeV, the corrected (WT=3.5) energy mean is linear to $< 2.5\%$, while the uncorrected nonlinearity is $\sim 9\%$.

TABLE 2

E	$\langle E(4.0) \rangle / \langle E \rangle$		$(dE(4.0)/E)$ induced	
	WT=1	WT=3.5	WT=1	WT=3.5
15	.868	.993	0.084	0.066
25	.898	1.005	0.035	0.018
50	.931	1.014	0.035	0.021
100	.947	1.017	0.020	0.008
150	.958	1.017	0.016	0.007

Summarizing, the weighting of the first layer in a calorimeter may be used to alleviate the effects of upstream material. In this study, the energy error for 4.0 Xo of inert material could be maintained to be $< 1\%$ (constant term) and the induced nonlinearity in the range $E = (15, 150)$ GeV was kept $< 2.5\%$.

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Fig. 1 Mean EM energy observed in the HF calorimeter stack as a function of the depth t in Xo units before active sampling begins. The mean is scaled to the mean at t=0.6. The curves are for 15, 25, 50, 100, and 150 GeV nominal e beam energy.

Fig. 2 The rms of the EM energy observed in the HF calorimeter stack as a function of the depth t in X_0 units before active sampling begins. The rms is the "induced fractional error" obtained by unfolding dE/E at a given t from dE/E at $t=0.6$ in quadrature. The curves are for 15, 25, 50, 100, and 150 GeV nominal e beam energy. The induced fractional error has been multiplied by $\sqrt{E}$ which brings the data points at different energies into rough congruence.

Fig. 3a The mean EM energy observed in the HF calorimeter stack at a fixed depth of $t = 4.0 X_0$ before active sampling begins as a function of the weight given to the first active sampling layer for 50 GeV incident electrons. The mean is scaled to the mean at $t=0.6$.

3b The fractional rms error in EM energy, dE/E , at a fixed depth, $t=4.0 X_0$. The rms is the "induced fractional error" obtained by unfolding dE/E at a given weight and fixed t from dE/E at $t=0.6$ in quadrature.

Fig. 4a The mean EM energy observed in the HF calorimeter stack at a fixed depth of $t=4.0 X_0$ and with fixed weights = 1 and 3.5 as a function of incident e energy, E. The mean is scaled to the mean at $t=0.6$.

4b The rms EM energy observed in the HF calorimeter stack at a fixed depth of $t=4.0 X_0$ and with fixed weights = 1 and 3.5 as a function of the inverse square root of incident e energy, E. The rms is the "induced fractional error" obtained by unfolding dE/E from dE/E at $t=0.6$ in quadrature. The values of dE/E should be compared to a 1% constant term. At $1/\sqrt{E} = 0$ with a slope of 15% "stochastic term" [5].