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Effect of Dead Materials on Calorimeter Response and Monte Carlo Simulation

W.G.D. Dharmaratna
for the DØ Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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EFFECT OF DEAD MATERIALS ON CALORIMETER RESPONSE AND MONTE CARLO SIMULATION.

W. G. D. Dharmaratna
Department of Physics, Florida State University
Tallahassee, Florida 32306

ABSTRACT

The DØ calorimeter system, cylindrical central calorimeter and two end calorimeters, is constructed with minimal cracks and dead regions in order to provide essentially hermetic coverage over the full solid angle. The effect of the existing few construction features which could perturb the uniformity of the calorimeter is studied in detail with beam tests. The results with the correction algorithms are presented. A comparison with the Monte Carlo simulation is made.

1. Introduction

The uranium liquid argon calorimeter system of the DØ detector[1], which recently started its operation at the Tevatron Proton–Antiproton collider at the Fermi National Accelerator Laboratory, consists of a central calorimeter and two end calorimeters covering the full solid angle down to within 1° of the beamline. The calorimeter system is designed with minimal cracks and dead materials in order to provide essentially hermetic coverage over the full range of pseudo–rapidity(η) and azimuthal angle(ϕ).

The uniformity in the region between the central and the end calorimeters, where the effect of the dead material(end plates, support walls and cryostat walls) is most significant, is preserved by using an inter–cryostat detector and massless gaps (see[2] for test results). The remaining few construction features within each calorimeter, module cracks, notches etc., which could perturb the uniformity of the calorimeter are studied with beam tests. In this paper we will present beam test results on the effect of the cracks and dead materials with correction mechanisms to preserve the uniformity when necessary and will demonstrate the ability to reproduce the effect in the Monte Carlo simulations. Sections 2 and 3 will discuss the effects in the electromagnetic section of the central calorimeter(CCEM) and the end calorimeter(ECEM) respectively. Section 4 will discuss the Monte Carlo simulation.

2. Cracks and Dead Materials in CCEM

The cylindrical central calorimeter consists of the inner electromagnetic section surrounded by the fine hadronic(CCFH) section and the outer coarse hadronic section(CCCH) covering the full azimuthal angle. As shown in Fig.1(a), there are

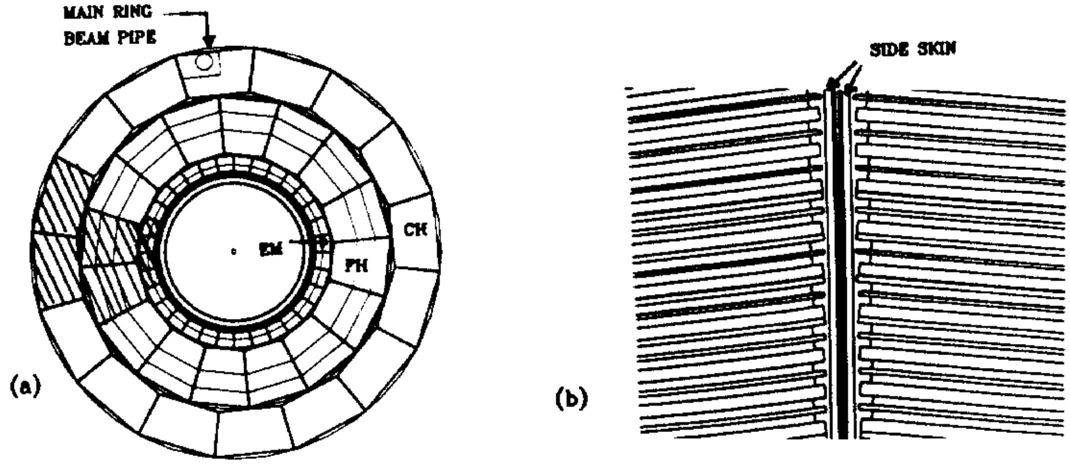

Figure 1: (a) ϕ view of the central calorimeter. (b) Section of a CCEM module crack.

32, 16 and 16 modules (therefore module cracks) in CCEM, CCFH and CCCH respectively, which are placed so that the module cracks from different sections do not align with each other. Each module covers the full η region of the central calorimeter. The first layer of the fine hadronic section is about twice as thick in radiation lengths (40.4) as the total electromagnetic section (20.1). Therefore, any electromagnetically interacting particle, at energies of interest, passing through a CCEM crack will be fully contained in the first layer of the CCFH section.

A section of a side view of a module crack, edges of the uranium plates and signal boards and side skins of the modules, is shown in Fig.1(b). The space between the edges of the uranium plates is about 1.4 cm and the stainless steel side skins are about 2 mm each. All the other structural features in CCEM, spacers, connectors and keys, are positioned at the edge of the module at several positions in η so that they overlap with the module cracks minimizing the dead regions of the calorimeter.

2.1. The effect of the module cracks

An assembly of modules (identical to those installed in DØ) corresponding to the shaded area in Fig.1(a) was used during the 1991 test beam run, to study the calorimeter response in the central and the inter–cryostat region[3]. In order to understand the effect of the module cracks, they were scanned in ϕ with e^- and π^- beams of 10, 25, 50 and 100 GeV at several η locations.

The response of the calorimeter to 25 GeV electrons is shown in Fig.2(a)-(b). The variation of the measured mean energy with the "arc length" is given. Arc length is defined as the distance from the center of the crack to the intersection point of the cylindrical mid surface of the third layer and the projected track from the beam line PWC's. As expected a significant fraction of the energy is collected from the first layer of the CCFH when the particle goes through the crack. There is a net energy loss (maximum of 15–18%) if the particle goes between the edges of

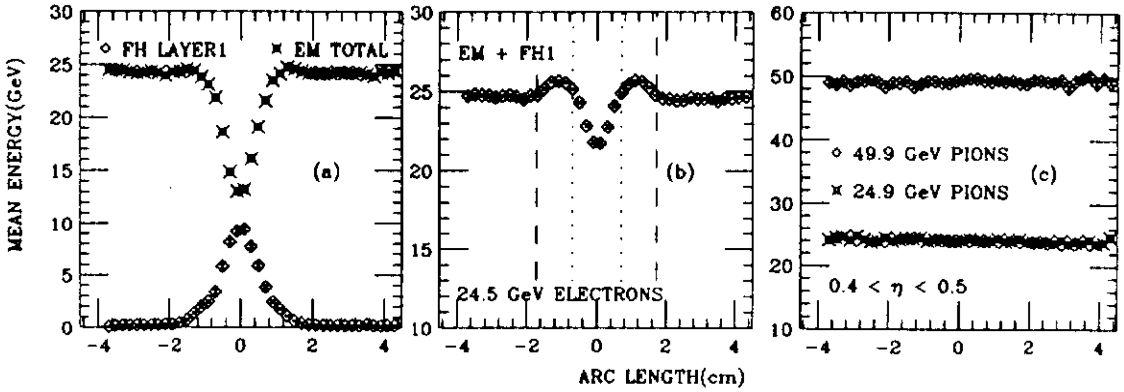

Figure 2: Measured mean energy vs arc length, (a)-(b) for e^- and (c) for π^-, in the vicinity of the CCEM module crack.

the pads as indicated by the dotted lines. An excess energy of 4–7% is observed if the particle trajectory is next to the pad edge. In this particular case, where some of the connector notches (uranium removed) is included in the scanned region, the excess energy is observed up to the boundary of the connector notch as indicated by the dashed line. The reason for the increase in signal is due to the locally increased sampling fraction in the calorimeter because of the absence of the uranium in this region. From this measurement, we estimate that only about 6% of the active area of the CCEM is affected by more than 4% of the mean signal. The uniformity of the calorimeter to π^- is not affected by the CCEM module cracks as shown in Fig.2(c). This is not surprising since most of the energy is deposited in the hadronic calorimeter.

2.2 The correction mechanism

Once the effect is known, it is straightforward to have a mechanism to correct for it. We have developed a general method of correction for energy of an isolated particle going through a module crack. Our main goal here is to have a correction for isolated e^-/e^+s if they are passing in the vicinity of the CCEM module cracks, but the model can be used even for neutral particles. The only restriction is the crack has to be symmetric around its center as is the case in DØ. The approach made here is to parametrize the dead energy by using only the energy measured in the calorimeter.

By knowing the calorimeter cell energies for an isolated electron, one can find the total energy on each side of the crack, for example the energy on the left side (E_l) and the right side (E_r). These two quantities are used in the parametrization as follows.

$$\alpha = \frac{E_l - E_r}{E_l + E_r} \qquad E_{dead} = F(\alpha) E_{obs}$$

The parameter α determines the path of the particle with respect to the center of the crack. $E_{obs} = E_l + E_r$ and E_{dead} is the dead energy. When $\alpha = -1(1)$ the particle is on the right(left) side of the crack with no significant effect of the crack. The function $F(\alpha)$ is determined from the test beam data. Here, E_{dead} equals the energy of the incoming particle minus E_{obs}.

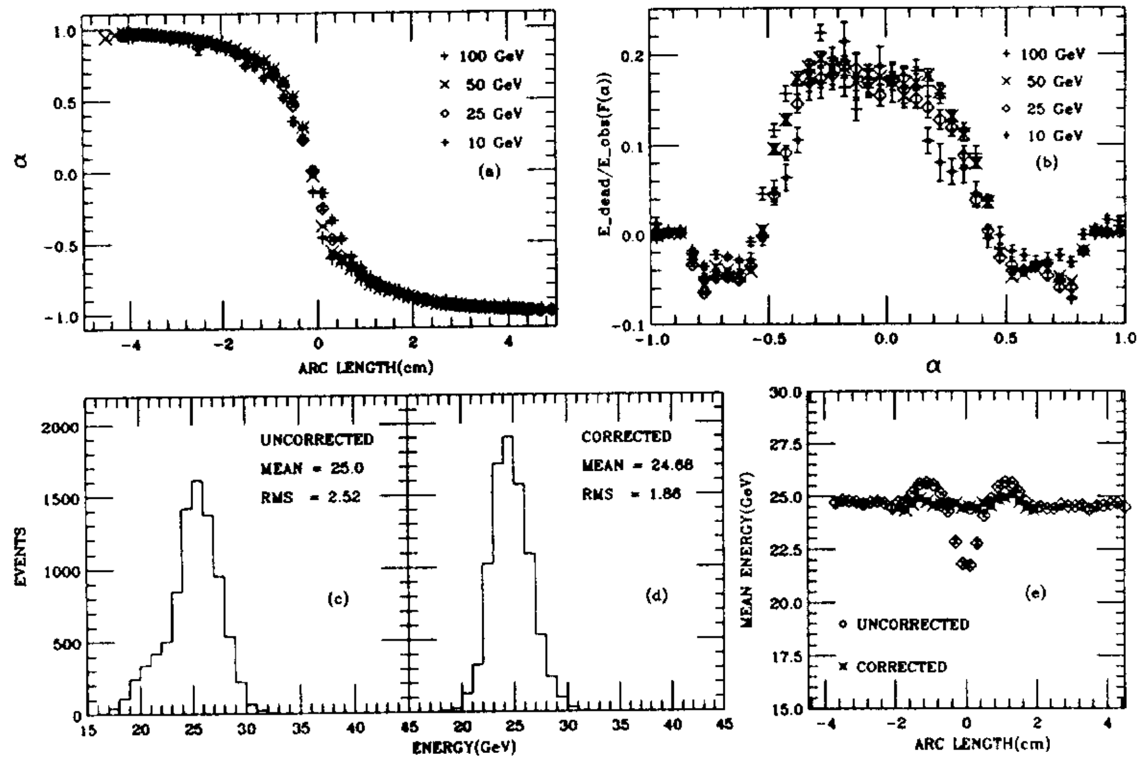

Figure 3: (a) α vs arc length. (b) E_{dead}/E_{obs} vs α. Uncorrected (c) and corrected (d) energy spectra(24.5 GeV e^- beam). (e) Mean energy vs arc length before and after the correction.

The parameter α has the expected behaviour as illustrated in Fig.3, where the average values for 10, 25, 50 and 100 GeV e^- are included. Most importantly, both α (Fig 3(a)) and $F(\alpha) = E_{dead}/E_{obs}$ (Fig 3(b)) are approximately independent of the energy for the range studied. Note that the parameter α expands the central region of the crack, where the variation is most significant. The correction function $F(\alpha)$ is obtained by fitting a polynomial in α to the curve in Fig.3(b). The calorimeter response before and after the correction is compared in Fig.3(c)-(d). The uniformity is better than 2% for most of the region and the resolution is improved significantly by the correction.

3. Cracks and Dead Materials in ECEM

One of the two identical end calorimeters was studied[4] in a test beam at Fermilab during the 1990 run before its installation in the DØ detector. The construction and performance of the electromagnetic section is described in detail in a separate publication[5]. Each of the ECEM modules is constructed as a monolithic unit by assembling signal boards and uranium plates into disks to minimize the energy loss in cracks.

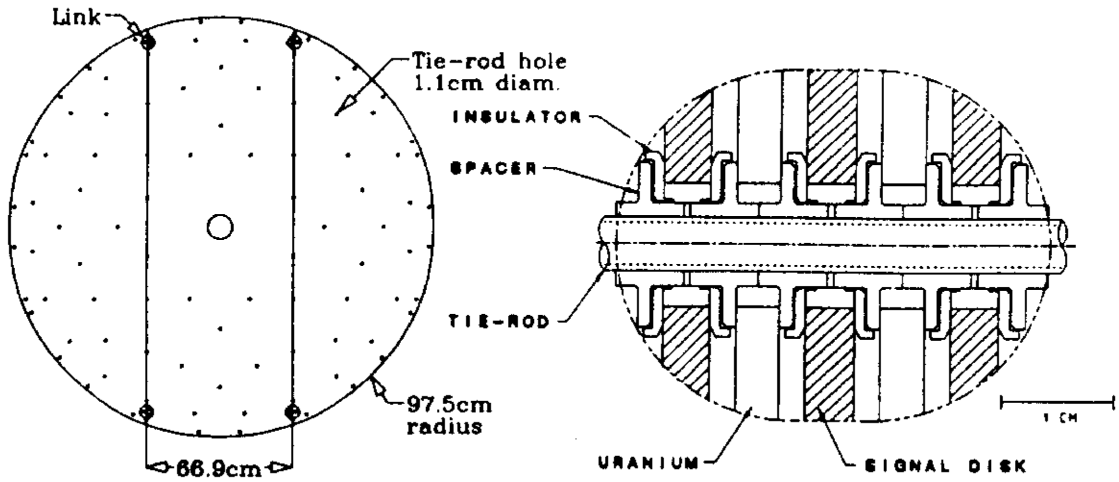

Figure 4: (a) An EM3 uranium disk assembly. (b) A section of a tie–rod assembly.

Fig.4 illustrates the two construction features that perturb the uniformity in the ECEM. They are the two small gaps(1mm each at $x = \pm 33.5$ cm) in uranium disks (made with a central plate and two side plates) and the 96 titanium tie–rods(4.8 mm diameter) that penetrate the module to maintain the spacing of the liquid argon gaps and the flatness of the uranium plates. The tie–rods are arranged in an eight-fold symmetric pattern. Both the uranium gap and the tie-rods are parallel to the beam axis and hence they are not projective relative to the interaction region.

3.1. The Effect of the Uranium gaps and the Tie-rods

The effect of these features has been studied during beam tests. The mean calorimeter response to 100 GeV electrons in the vicinity of the uranium gap (Fig.5(a)) as a function of the x coordinate of the shower, and of the tie-rod as a function of ϕ (Fig.5(b)) and the polar angle(θ)(Fig.5(c)) are shown. The effect of the uranium gap is to increase the response, maximum of 5% with a full width at half maximum of 1.4 cm. As in the case of the CCEM module cracks, the increase in the signal can be explained by a local increase in the sampling fraction. The effect of the two uranium gaps is that 2.5% of the active area of the ECEM module has an increase in signal $\geq 1\%$. In the vicinity of the tie-rod, a loss of signal (maximum of 15%) is observed when the particle passes through the area where the high voltage bearing resistive coat has been removed from the signal boards as indicated by the dotted lines in Fig.5(b) & (c). The effect of the tie-rods is that 8%(1.5%) of the active area of the ECEM has a loss of signal greater than 1%(5%).

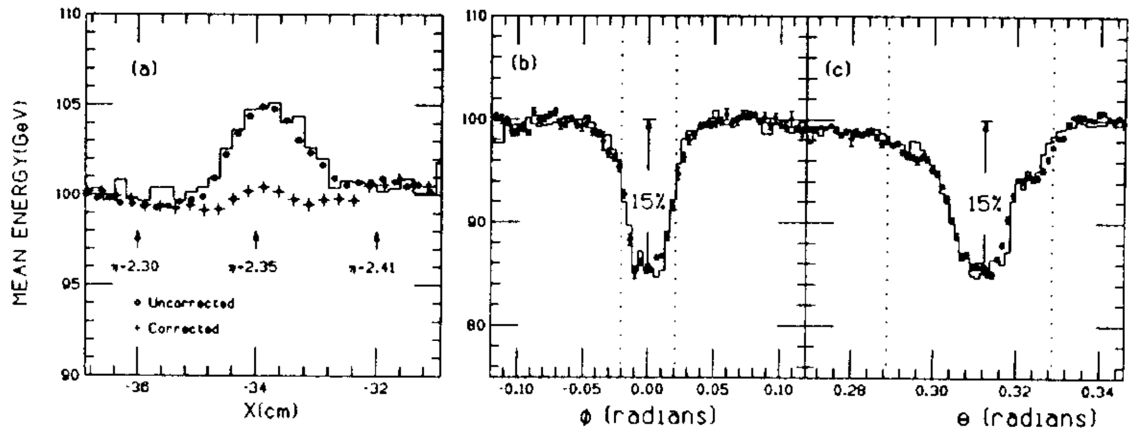

Figure 5: Calorimeter response to 100 GeV e^-s. (a) Mean energy vs x before and after the correction in the vicinity of the uranium gap. (b) Mean energy vs ϕ and (c) Mean energy vs θ in the vicinity of the tie–rod. The points are the data and the histograms are from the Monte Carlo simulation.

3.2 The correction mechanism

The parametrization of the response function at the uranium gap is done by using a gaussian in x, but due to the non–projective nature of the uranium gap the form is more complex than for the CCEM cracks. The functional form used is:

$$E_{obs} = E_{corr}(1 + F(x)) \qquad F(x) = F_{peak} e^{\frac{-(x-x_0)^2}{2\sigma^2}}$$

where

$$F_{peak} = F_o(z_{em3} - z_{int})/z_{em3} \qquad x_o = x_{crack} + x_{offset} + \delta x$$
$$\delta x = -\tan(x) \;\; z_{\delta x} \;\; \ln(E_{corr}/E_{\delta x}) \qquad \tan(x) = x_{crack}/(z_{em3} - z_{int})$$

here E_{obs} and E_{corr} are the observed and corrected energies. z_{int} and z_{em3} are the z coordinates at the interaction position and at the center of EM layer 3. x_{crack} is the position of the crack($\pm$ 33.5 cm). All other parameters are determined from a fit to the test beam data. When using the correction function we may use E_{obs} instead of E_{corr} in forming δx since this produces no significant effect. The corrected response, which is included in Fig.5(a), shows better than 1% uniformity. Work is in progress to obtain the correction algorithm for the effect due to tie-rods.

4. Monte Carlo Simulation

A comprehensive effort was made to setup up the DØ Monte Carlo(MC) system to simulate the detector response. Excellent agreement between the MC and the test beam data for the end calorimeter has been obtained[4][5] by using the version 3.14 of the CERN MC program GEANT[6]. The geometry of the calorimeter (individual uranium plates, argon gaps and signal boards) and the materials upstream of the calorimeter including the cryostat walls are modelled in detail.

The effect of the dead materials in ECEM (uranium gap and tie–rods) are modelled in the MC simulation. The response in the vicinity of the uranium gap is modelled by including a 0.9mm(instead of 1mm) gap in the MC and summing all energy deposited in the argon in to the signal. This reproduces the calorimeter response very well as shown in Fig.5(a). The structure of the tie-rod is more complicated as shown in Fig.4(b). However, by using a model which approximates all components, spacers, insulators and dead argon etc., we were able to simulate the effect very well as shown in Fig.5(b)–(c). It is interesting to point out that the model is capable of simulating the response on individual layers as well (Fig.6). The dotted lines in the figure indicate the boundary within each section of the 20 mm diameter zone where the resistive coat has been removed from the signal disk.

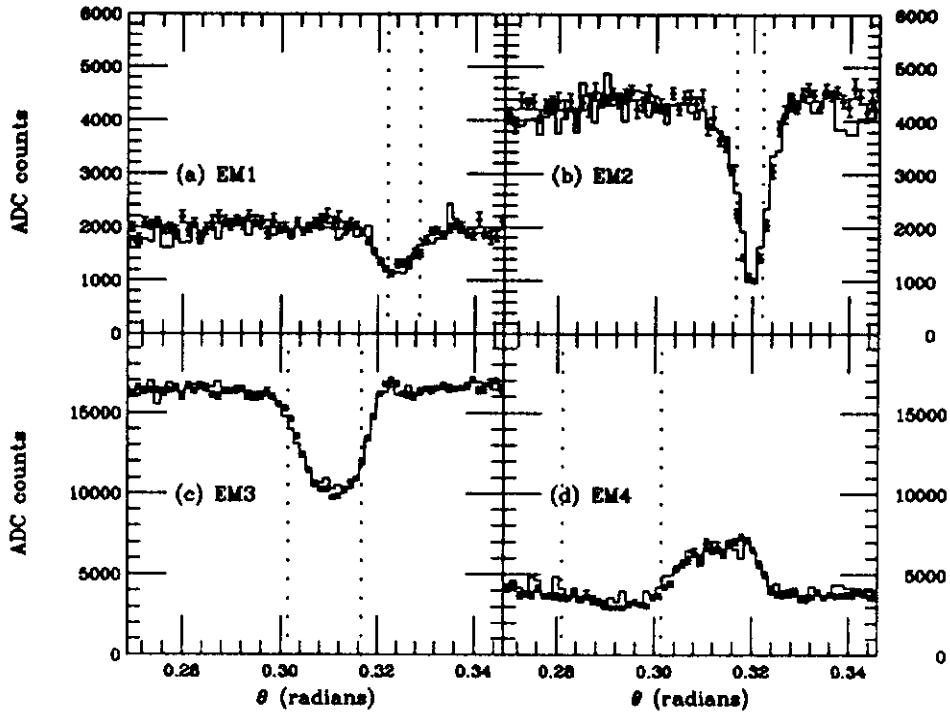

Figure 6: Mean pulse height vs polar angle(θ) for individual layers. The points are the data and the histograms are from the Monte Carlo simulation.

5. Summary

We have been successful in understanding, in correcting when necessary and in simulating, the effect of the cracks and dead materials in the electromagnetic section of the DØ calorimeter. While the effect of these structural features are as large as 15%–20% at the maximum, we are able to correct most of the affected area to have the response uniform to better than 2%. This will certainly help to improve the accuracy of our forth–coming physics results.

6. Acknowledgements

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