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Simulation of variable HV and calibration in the EM endcap calorimeter

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Abstract

The effect of a high voltage varying in rapidity on the energy resolution of the EM endcap calorimeter is studied by simulation and compared with a constant high voltage. The results are similar within statistical errors. In addition, the alternative of a calibration depending on rapidity is applied with a constant HV. The energy resolution does not change within errors.

1 Introduction

The electromagnetic (EM) endcap calorimeter uses the liquid argon accordion technique, with pleated absorber sheets arranged radially around the nominal beam axis. To cover the necessary rapidity range, it is divided into two wheels: a large one covering $1.4 < |\eta| < 2.4$ and a smaller one covering $2.4 < |\eta| < 3.2$.[1] The calorimeter is divided into three longitudinal samplings, the first one short with a high granularity. The small, inner wheel has a granularity of $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$, except in the last sampling, where it is 0.05×0.1. The outer wheel has a granularity $\Delta\eta = 0.025$ except in the first compartment where it has strips with a fine granularity of $\Delta\eta = 0.025/8$. The granularity $\Delta\phi$ is 0.1, 0.025 and 0.05 for the samplings [1].

The thickness of the plates is constant for each wheel, but the angle of the folds change with radius. The argon gap also increases with radius, leading to a changing sampling fraction f_{samp}. (See ref. [2] for details.) Besides the sampling fraction, the signal S from a liquid argon calorimeter with fast readout is a function of the drift velocity v_d of electrons in liquid argon and of the argon gap width g. The signal can be expressed as:

$$S \propto f_{\text{samp}} \frac{v_d}{g}. \tag{1}$$

Since v_d is a function of the electric field E across the gap, varying as $E^{0.3}$, and E is a function of the high voltage U and the gap size, with $E = U/g$, eq. 1 can be rewritten in terms of design parameters:

$$S \propto \frac{f_{\text{samp}}}{g^{1.3}} U^{0.3}. \tag{2}$$

[1] Recent changes have been made to this design, but the outer wheel is still very similar and should have a comparable performance.

In the original design [3], it was assumed that to avoid additional fluctuations due to non-uniformity, the calorimeter signal should not depend on the impact point of the particle, and so the above expression should be constant over all positions. In addition, the electric field is required to be high enough to produce enough charge within the shaping time. A minimum field of 3 kV/cm has been demonstrated to produce normal charge collection in the prototype for the EM endcap [3, 4]. With a high voltage varying with radius, the calorimeter fulfill the requirements above. (An alternative solution would be to vary the values of the feedback resistors in the readout circuit [5].) In practice, the high voltage would have to vary as a function of rapidity since the high voltage divisions have to follow the projective cell divisions in η, but with a coarser granularity. The proposed granularity of the HV "steps" was $\Delta\eta = 0.05$, with two longitudinal divisions [1].

With the latest design with absorber plates of constant thickness plus a HV constant over the whole calorimeter, the signals from incident particles of the same energy would vary by only $\sim$25% (15%) along the rapidity range of the outer (inner) wheel. In addition, a constant HV of, for example, 1.5 kV can produce an electric field from 6 (9) to 13 (17) kV/cm over the rapidity range of the outer (inner) wheel, sufficiently above the minimum value of 3 kV/cm. Certainly before using the signals coming from the calorimeter, they must be corrected for the change with radius with a constant HV. The correction, however, can be made with a granularity (in radius or η) finer than the large steps of the HV level in η for the "hardware correction."

Furthermore, a signal varying with position should not pose a problem for the first level calorimeter trigger. The trigger decision is based on the transverse energy, requiring a conversion at the trigger level based on the angle, and so an extra factor to account for the changing signal with rapidity can easily be included in this.

In this note, we simulate and compare the performance of the calorimeter in terms of energy resolution for the two scenarios described above, *i.e.*, with variable and with constant HV. In sect. 2, details of the simulation are given. The analysis and comparison itself is presented in sect. 3. Finally, the conclusions are drawn in the last section.

2 Detector description and simulation

2.1 Geometry description in DICE95

This study uses GEANT in the DICE95 [6] framework for the simulation of the entire EM endcap. All the materials and shapes are described, as in ref. [2]. However, the electric field over the liquid argon gap, and hence the charge transport and collection, is not included. Instead, the uncalibrated signal is taken to be

$$S = \frac{E_{\mathrm{LAr}}}{g^{1.3}} C_{\mathrm{HV}}, \tag{3}$$

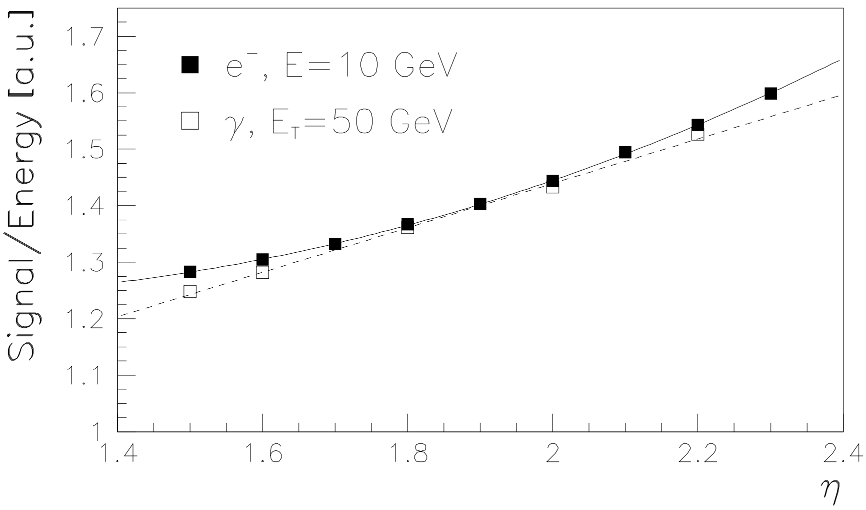

Figure 1: *The mean signal, normalized to the generated energy, at various positions along the outer wheel. The solid squares are from a scan of 10 GeV electrons, with the solid line showing the best fit to this data. This is the data used to determine the HV factors and the position-dependent calibration. The open squares show a check of this using photons with a transverse energy of 50 GeV, with the dashed curve showing a fit to a straight line.*

where $E_{\rm LAr}$ is the energy deposit in the active material which is proportional to $f_{\rm samp}$.[2] The factor $C_{\rm HV}$ simulates the HV, as described below.

The signal was taken to be the sum over all cell: no clustering was made. The periodic signal modulation as a function of ϕ was corrected using a fit made to the 100 GeV data at $\eta = 2.0$, as discussed in [7]. No electronic noise or pile-up noise is simulated. No dead material in front of the calorimeter is included. No correction was made for leakage, which should not affect the comparison between different HV cases.

The variable HV values are simulated by applying factors $C_{\rm HV}$, one factor per $\Delta\eta = 0.05$, to the value of the signal (eq. 3) from each readout cell. These factors were determined by a scan with the simulation program of 10 GeV electrons over the entire rapidity. The mean calorimeter response at a given position in η was taken from the Gaussian fitted mean of the measured signal distribution of 200 events. These values are shown in fig. 1 as function of η (solid squares) for the outer wheel. A fit was made using several simple functions, and it was found that a second-degree polynomial best described the data, as shown by the solid line. A high-energy calibration would be more desirable because of its application to high-energy showers, but this 10 GeV scan was quickly generated and was meant to be just an approximation of a

[2]The charge collection has now been put into the routine and will be checked, but previous studies have indicated that the results should be very similar.

final calibration. A smaller scan of high-energy photons, with transverse energy of 50 GeV (corresponding to a total energy between 120 and 230 GeV), at only four η positions, can used to check the accuracy of the 10 GeV calibration for higher energies. The normalized mean signal for each position is plotted also on fig. 1 with a straight line fit. They are different because the calorimeter is non-linear with energy by up to ~1% over this energy range [4, 7]. At $\eta = 2$, the position used for the HV studies, the two data sets are very close and therefore the 10 GeV calibration can be reliably used here. From the fit to this data, the factor C_{HV} which makes the signal constant was found for the middle η value of each HV cell. This factor is proportional to $U^{0.3}$ (eq. 2). Unlike the proposed longitudinal division, the same factors were used throught the depth of the calorimeter.

The same fit to the 10 GeV data was used to determine an expression for the variable calibration constant. The difference from the variable HV is in the way it is applied. First, the signal from each readout cell was multiplied by the calibration constant for the middle η value of that cell. This initial calibration is needed in the determination of the η position of the shower. A calibration constant for this value of η is then applied to the sum of the raw signals.

2.2 Generated data

In order to investigate whether a variable high voltage would have an effect on the energy resolution, three cases were studied:

- The high voltage is kept constant over the whole rapidity range, and no calibration constant is applied. This signal varies with η.
- The factors simulating the HV varying with rapidity are applied, resulting in a constant signal over the rapidity range.
- The high voltage is kept constant, but the calibration as a function of η (described in the previous section) is applied, resulting in a signal independent of η.

The first two cases are made to compare the effects of the HV application on the energy resolution The last case serves two purposes: to compare the coarse variable HV (which has a granularity largerer than the readout cell size) with a finer calibration that can be done with software, and to check this method of calibration.

Single electrons of 10, 50, 100, 200 and 300 GeV were generated at three rapidity values, to vary the effects of entering at the border between regions of different high voltage ($\Delta\eta = 0.05$) and/or between readout cells in η ($\Delta\eta = 0.025$ for the second and third longitudinal samplings). These values were:

- $\eta = 2.0$ (on the border between HV cells and readout cells)
- $\eta = 2.0125$
- $\eta = 2.025$ (on the border between readout cells)

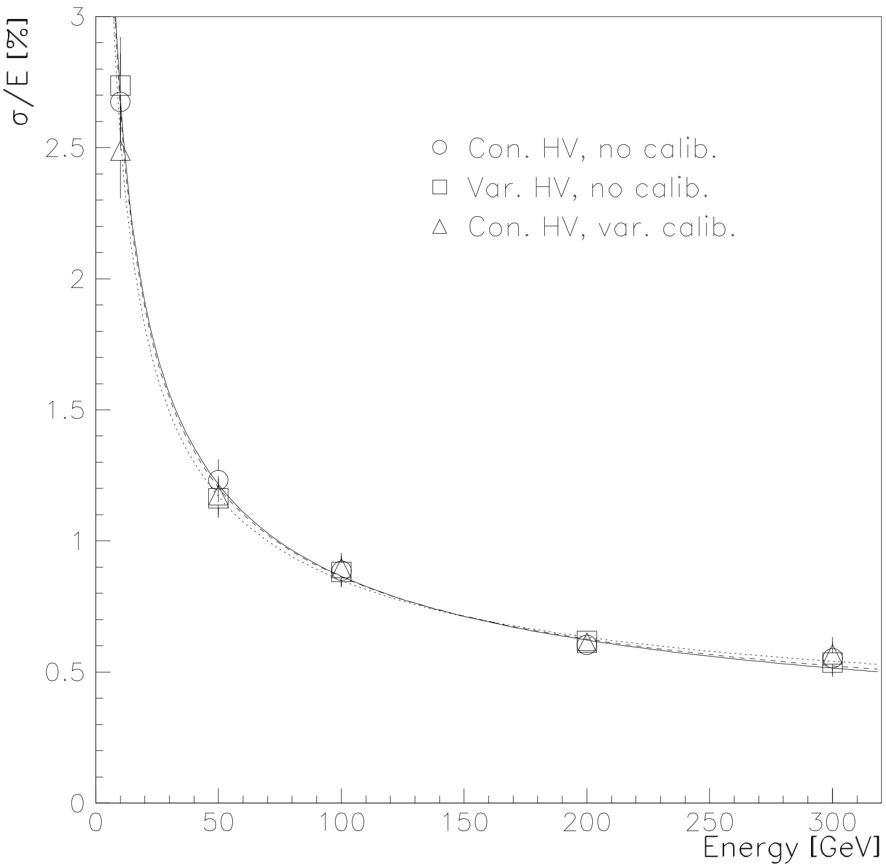

Figure 2: *The energy resolution as a function of energy for electrons entering the EM endcap at* $\eta = 2.025$ *for the three methods of high voltage and calibration. The curves are the best fits to eq. 4.*

For each value of energy and η, 200 events were generated, except there were only 50-75 events at 300 GeV. This last point has a large error bar on this last point, but it does add some extra restriction on the fit of the energy resolution as a function of energy. Events were generated over two readout cells in the azimuthal direction.

3 Results

The energy resolution was plotted as a function of energy for each calibration case and η position, as shown in fig. 2 for $\eta = 2.025$. A fit was made of the form

$$\frac{\sigma_S}{S} = \frac{a}{\sqrt{E}} \oplus b, \tag{4}$$

where E is the generated energy in GeV. Qualitatively, the three cases show similar results for $\eta = 2.025$.

For a more quantitative comparison, the fit parameters are listed in table 1

	Sampling term coefficient a		
	$\eta = 2.0$	$\eta = 2.0125$	$\eta = 2.025$
constant HV	7.7±0.31	7.6±0.39	8.5±0.45
variable HV	7.8±0.38	7.1±0.44	8.4±0.43
calibration	7.8±0.33	7.3±0.42	8.0±0.44
	Constant term b		
	$\eta = 2.0$	$\eta = 2.0125$	$\eta = 2.025$
constant HV	0.40±0.06	0.38±0.07	0.15±0.18
variable HV	0.38±0.07	0.44±0.08	0.20±0.13
calibration	0.36±0.07	0.42±0.06	0.28±0.10

Table 1: *The parameters from the fit of the energy resolution to eq. 4 for simulations of constant HV, variable HV with η and an η-dependent calibration, for three positions in η.*

and plotted on fig. 3. A comparison of the sampling term coefficient a at a single value of η (fig. 3 and table 1 top), reveals no differences, within the uncertainties, between having a variable or constant HV. The variable calibration does not change the value either. There is also no significant difference in the constant term b among the three cases, within the statistical errors in this energy range. (See the bottom of both fig. 3 and table 1.)

Comparing the parameters from one η value to another, there is a bigger difference, but still within errors. Looking at the corresponding sampling and constant terms, an anti-correlation can be seen. The difference between the three positions is therefore probably due to the large correlation between a and b. More statistics at low and high energy would provide a better determination of these values, and might show a real difference (if any) between showers shared between cells or not.

The sampling term of the resolution is consistent with that determined previously, but the absolute value of the constant term (0.3-0.4%) is somewhat higher than the value of ~0.2% determined in previous energy resolution studies [7]. The difference results from the contribution due to leakage, which is about 0.5% except at low rapidity ($\eta \leq 1.6$) where the calorimeter is shortest. The effect on the constant term due to leakage was determined using the data for the energy resolution studies, and can be seen in fig. 4 for various values of η. The resulting value for the constant term at $\eta = 2.0$, on the bottom plot, is similar to that obtained for the HV studies.

4 Conclusions

Within the precision of this study, no difference in energy resolution is evident between a constant and a variable high voltage with the η range of the EM endcap calorimeter. Therefore, it is not a criterion for choosing between them. A practical granularity of $\Delta\eta = 0.05$ was used. This value was not optimized,

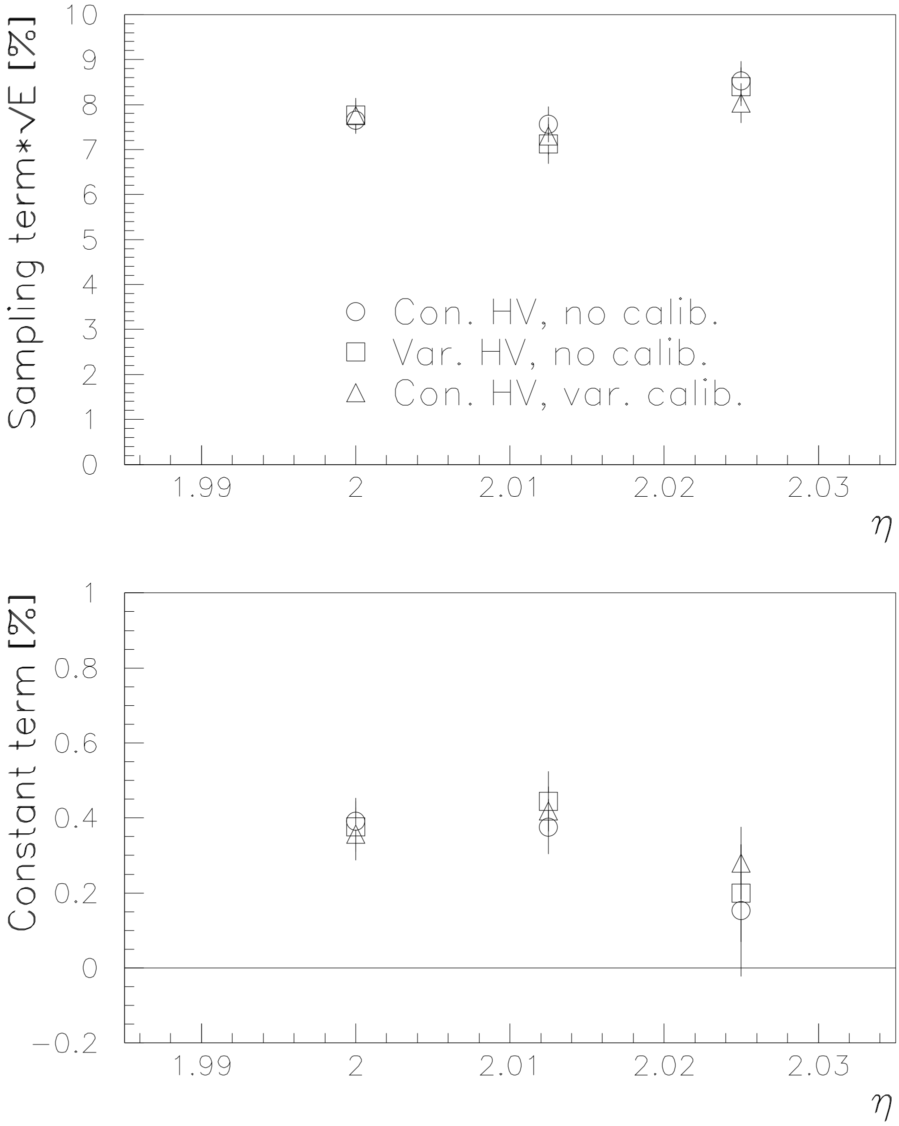

Figure 3: *The coefficient of the sampling term (top) and the constant term (bottom) of the energy resolution as a function of rapidity, for the EM endcap for various cases of variable or constant high voltage with or without a variable calibration.*

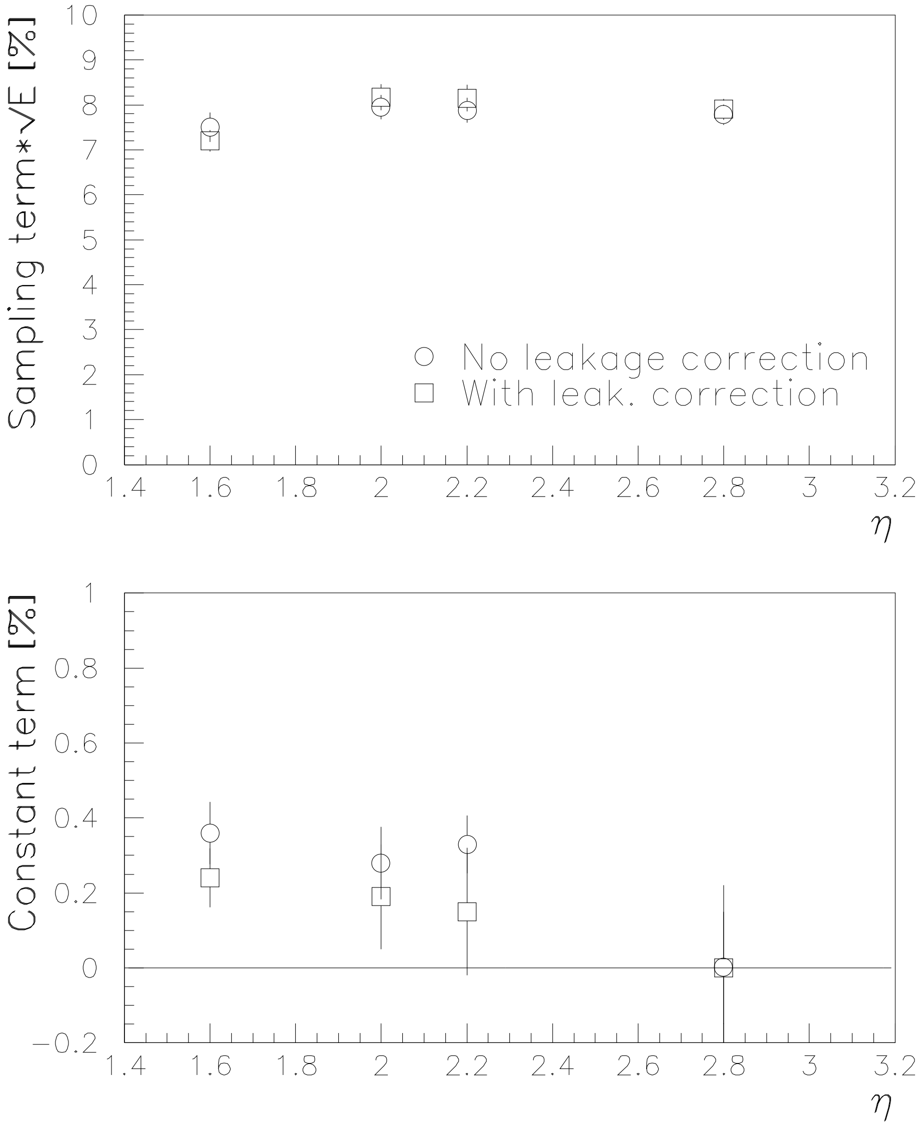

Figure 4: *The coefficient of the sampling term (top) and the constant term (bottom) of the energy resolution as a function of rapidity, with and without a correction for leakage .*

but the results are expected to be similar with different granularities.

If there is a single HV value over the whole calorimeter, a calibration as a function of the rapidity would have to be applied offline. This was simulated in order to check that it was feasible and did not deteriorate the energy resolution. No difference was seen in the simlation, although one would expect a better resolution.

The study was performed at three values of η: 2.0, 2.0125, 2.025. No dependence was seen within the uncertainties on position or on whether the shower is shared between HV cells or readout cells.

In conclusion, the decision whether to go for constant or variable HV should be based on other requirements. It may be simpler just to have a constant HV, and then correct the signal with a calibration constant.

References

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