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Uniformity Requirements in CMS Hadron Calorimetry

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Introduction

Practical considerations of calorimeter systems require a specification of the allowed manufacturing tolerances. The tightness of these requirements directly makes an impact on the assembly costs of the calorimeter. For that reason, a precise and well defined set of criteria is mandatory. In addition, the intrinsic limitations of hadron calorimetry define the level of accuracy needed in the manufacture of such devices. Therefore, considerations of the limitations on energy measurement accuracy due to Physics should define the needed level of effort to produce a uniform calorimetric device.

Electromagnetic Uniformity

The electromagnetic calorimetry (ECAL) which precedes the hadronic (HCAL) has a distinct effect on the energy resolution of incident hadrons. As a device which simply measures electrons and photons, those cascades fluctuate in space on the scale of a radiation length, Xo. Therefore, considerable front to back nonuniformity is allowed in a deep (~ 25 Xo) ECAL. However, such a device has a depth of order one hadronic absorption length. Therefore, for the ~ 20 % of the energy deposited in ECAL by an incident hadron, there is also a uniformity requirement. In this case the hadronic shower fluctuates over the entire depth of the ECAL, and hence probes the ECAL nonuniformity over the full depth of the device.

This effect was studied using "hanging file" data with 3/4" uniform Pb sampling and individual readout in depth [1]. The data set for 250 GeV incident pions was studied. One might assume that hadrons with lower energies would be more distorted because a larger energy fraction would be deposited in the ECAL compartment. The first 8 samples were taken to approximate the CMS ECAL compartment. They were given a linear front to back nonuniformity f by imposing a weight equal to 1 - [(8-j)/7]f on the first 8 layers labeled by j, j=1,8. Therefore, the front to back response is 1-f:1.

The resulting rms of the energy distribution was unfolded in quadrature from the rms when f = 0 (dE/E |f=0 = 0.0424). The final dE/E is plotted as a function of f for 250 GeV MT SDC test beam data in Fig.1. Clearly there is a rough linear relationship between dE/E and f. Given that the CMS HCAL is expected to have a constant term of ~ 4 %, an induced error of 2 % would only degrade the high energy behavior of HCAL by ~12%. Therefore, we require a front to back uniformity for ECAL of 10% or better.

HCAL Manufacturing Tolerances

The HCAL in CMS will be assembled of "towers" of scintillator coupled to wave length shifter (WLS) fiber [2]. In this note we explore the tolerances on the variations of the individual samples. It is assumed that they can be characterized as a Gaussian with a given rms. and with the same mean. Thus, we ignore timing variations and variations of the mean, as might be caused by different tile sizes or different optical cable lengths of the tile to the transducers. It is assumed that they are either controlled to an acceptable level, or that they are optically "masked" to fall within an acceptable limit. Variations in "batch to batch" in the scintillator can be controlled by measuring and matching, if a local calibration is assumed.

The definition of acceptable rms. values was studied using 375 GeV pion data taken in the CERN H4 test beam during CMS R&D data taking [3]. This data had individual readout of 3 cm Cu samples (HCAL1) followed by 6 cm Cu samples (HCAL2). The PbWO4 ECAL in front of the Cu-scintillator stack was unsegmented.

This data set was used to model the manufacturing process. Towers were "built" by choosing an ensemble of tiles chosen from a Gaussian distribution with mean = 1 and a variable rms. Each of these towers had a distinct energy distribution. The fractional rms spread in the mean of the towers is shown in Fig.2 as a function of the Gaussian rms. Clearly, it is the particular variations in the samples near hadronic shower maximum that shift the mean of the tower energy distribution. The effect is roughly linear, with an 8 % rms in the tower means for a 50% rms in the tile manufacturing process. Clearly, this effect causes the difference between "global" and "local" calibrations, as is explored below.

The required manufacturing tolerence clearly depends on the scheme used in calibration. For example, if each tower is put in a test beam and the means of the energy distributions are then equalized, the errors due to manufacture can be reduced. This is called a "local" calibration scheme in this note. By comparison, the shifts shown in Fig.2 can be ignored because there is not sufficient time or resources to calibrate each tower. In that case, the calibration is "global" in tha one conversion factor from signal to GeV is adopted. The unfolded effect of tile variations is shown in Fig.3. The fractional error, dE/E, is shown as a function of the tile rms. Data points are shown for both global and local calibrations, illustrating the worse behavior of global operation indicated in Fig.2. Obviously, if each tower can be calibrated, it is desirable to do so. In principle, this can also be accomplished after installation by the use of well controlled reactions (e.g. photon + jet).

The data indicate that if one wants at most a 12% degradation in the expected constant term or a 2 % induced constant term, one needs to make tiles with a 10% or better uniformity. Note that this conclusion depends on the expected calibration technique and strategy. It also depends on the sampling fraction. Clearly, a larger numbers of tile samples reduces the requirements on any given tile. As an example, an SDC analysis of Lab E (FNAL) data is shown in Fig.4. That data, with 10 cm sampling, indicates that a 5% tile rms leads to a 2% induced dE/E, while Fig.3 indicates 10% tile error would be appropriate. Clearly, the difference is due to the sampling, 3cm compared to 10 cm.

Summary

The requirements on ECAL uniformity and on HCAL tile uniformity have been examined using a variety of test beam data. The criteria has been that the high energy hadronic energy measurement, assumed to be 4 %, not be degraded by more than 12%. In order to limit the damage, the ECL crystals must have a front to back nonuniformity better than 10%. Using the same criterion, the HCAL active sampling tiles must be kept within 10% rms either by manufacture or by testing and rejecting. Optical "masking" to achieve the required level of uniformity is also possible, but at the cost of a reduced light yield. The latter requirement depends both on the calibration scheme and on the passive sampling depth and these factors must be kept in mind.

References

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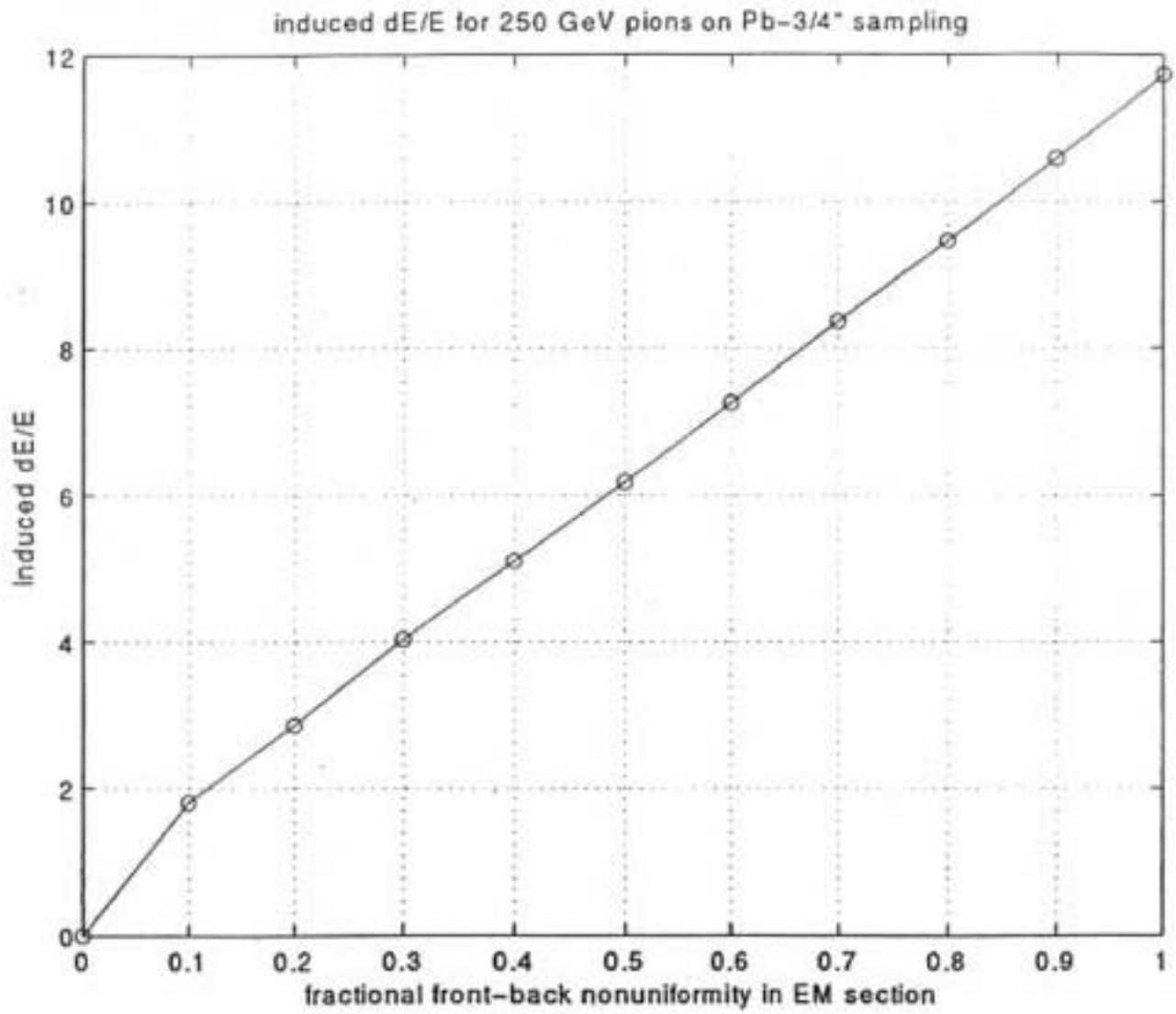

FIGURE 1
Induced error dE/E due to ECAL fractional front to back linear nonuniformity for 250 GeV pions incident Pb.

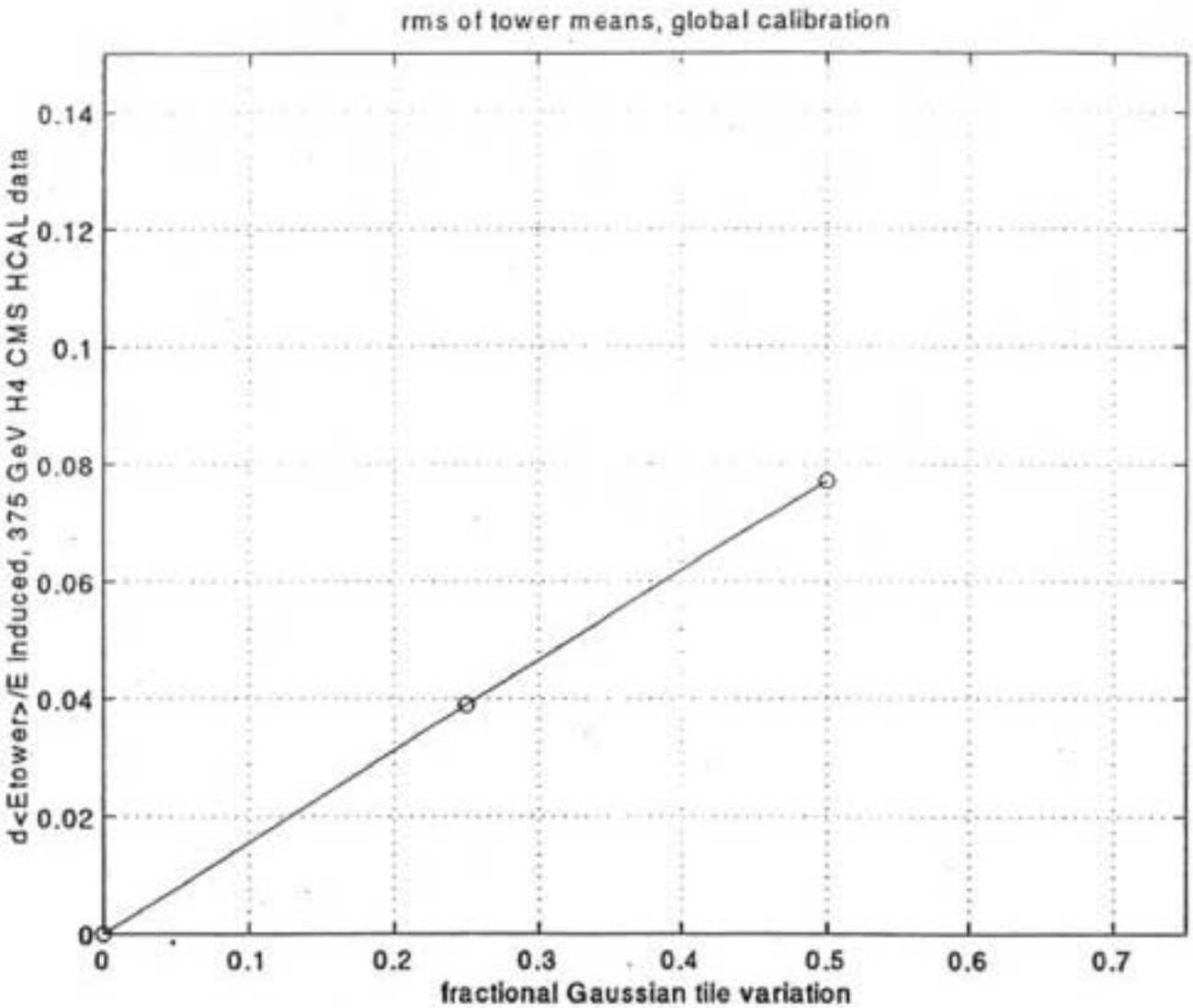

FIGURE 2

Root mean square (rms) deviation of mean of towers constructed of tile samples with a given rms deviation. The plot is derived from 375 GeV H4 CMS HCAL test beam data.

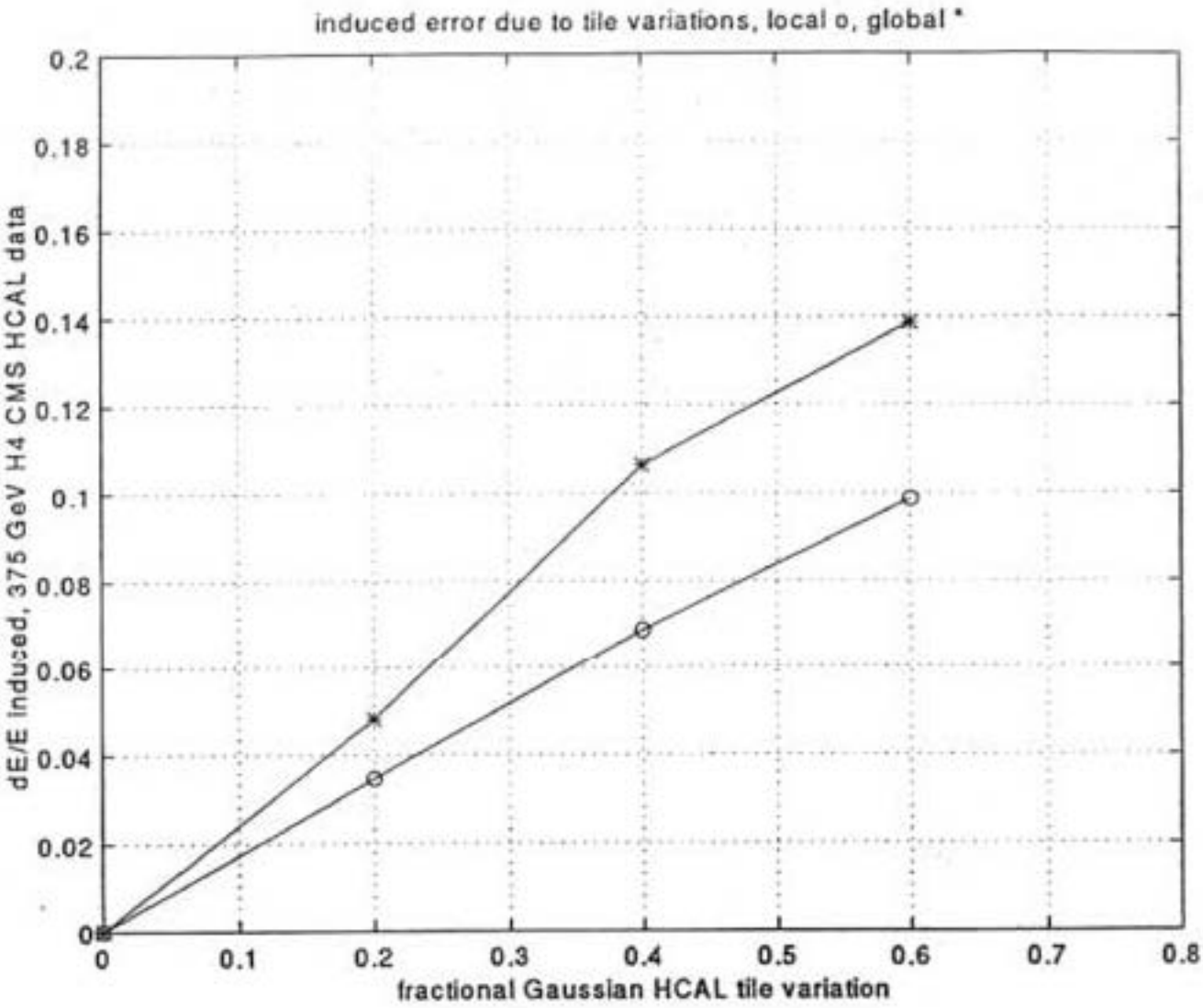

FIGURE 3

Induced error dE/E due to construction of sampling with tiles with a given rms deviation. The plot is derived from 375 GeV H4 CMS HCAL test beam data. The two plots correspond to global calibration (assuming all means are equal) and local calibration where the means of all towers are first equalized Sampling is 3 cm Cu in the first compartment, and 6 cm sampling in the second

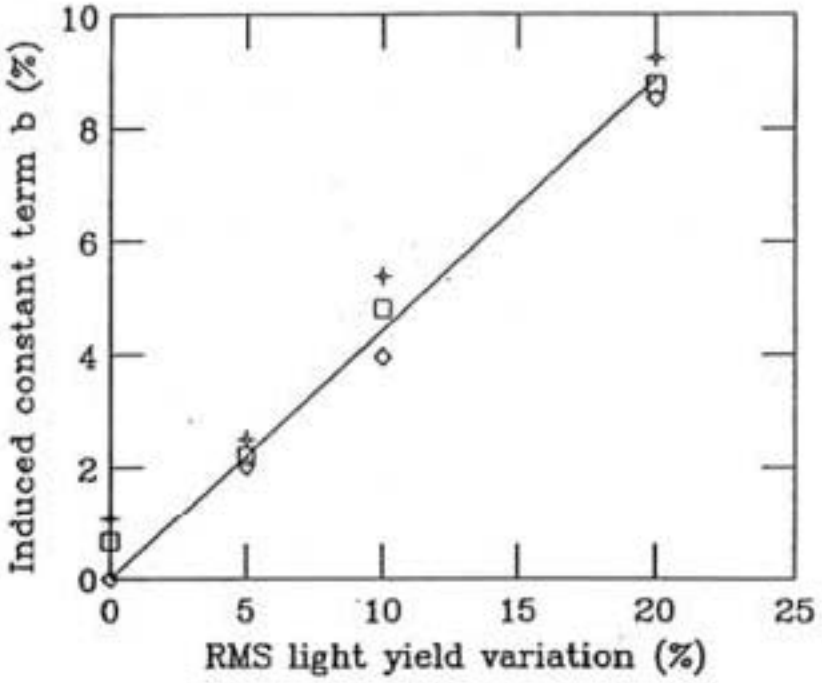

FIGURE 4
As in Fig. 3 for global calibration except that the data used was 300 GeV Lab E test beam data and the sampling was 10cm Fe. A rough scaling of the induced error, dE/E with sampling thickness is seen.