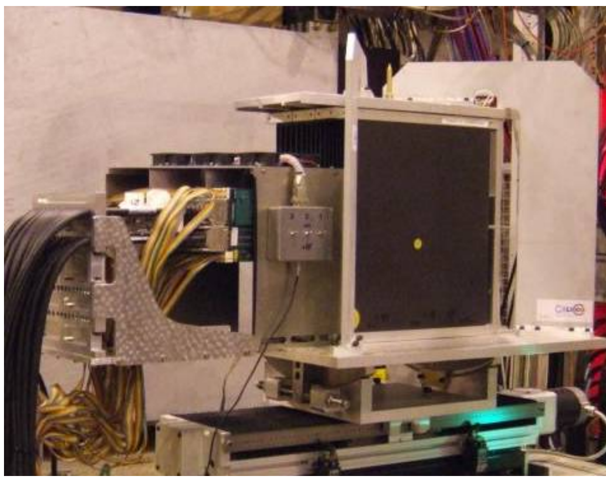
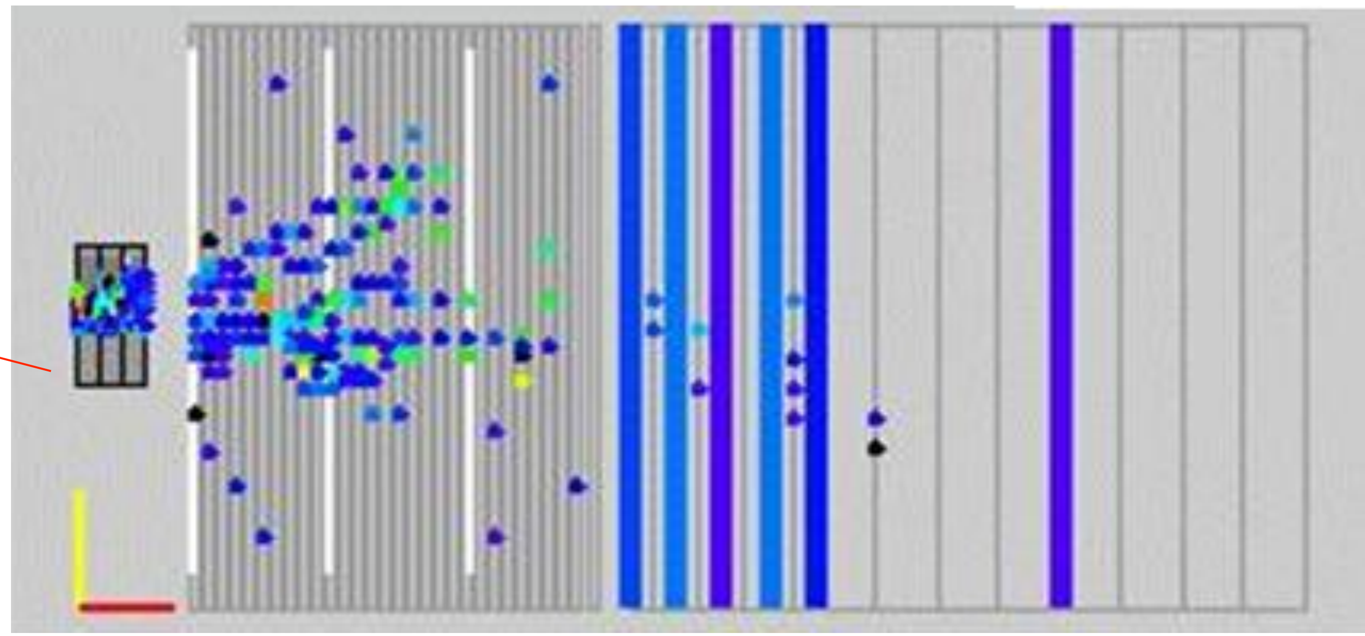
Generalizing the dEdx calibration method for a lower cost, inhomogeneous, CALICE-like ECAL





(pictures from N. Watson ILD-UK meeting 2007)

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ALCW, Fukuoka 福岡, 日本, May 2018

Introduction

Based on: SP, A.Psallidas, A.Steen **JINST 12 (2017) no.06, P06013**

- CALICE-like Si EM-Cal calorimeters are typically calibrated using dEdx.
- However one can design a calorimeter that samples more in the shower max and less in the back.
  - Cheaper solution for some loss in performance.
  - Passive layer thickness increases with depth.
  - Call this: “Inhomogeneous Calorimeter”.
- The CMS HGCAL has such a design.
- In this work we present a more traditional method that generalizes dEdx.

Definitions

dEdx method (and variations):

$$E_{rec} = \left(N_1 \times \Delta E^{MIP}_{passive,1} + \Delta E_{silicon,1}\right) + \sum_{i=2}^{30} \left(\frac{N_{i-1} + N_i}{2} \times \Delta E^{MIP}_{passive,i} + \Delta E_{silicon,i}\right)$$

Alternatively one can use the total Sampling Fraction (SF):

$$SF = \frac{\sum_{i=1}^{30} E_{active,i}}{\sum_{i=1}^{30} E_{active,i} + \sum_{i=1}^{30} E_{passive,i}}$$

To calculate the EM shower energy by a simple weighting of the visible energy:

$$E_{rec} = \sum_{i=1}^{30} E_{active,i} \times SF^{-1}$$

dEdx method: open questions

- In the case of inhomogeneous calo, even in hit level G4 studies, a large (~0.5%-level) constant term is observed. This has been a puzzle and a worry.
  - (such const term is absent in the homogeneous case)

- To use dEdx*Nmip is always questionable since:
  - Inside the passive material there is brem and pair creation (also absorption), not taken into account.
  - MIP is too ideal: even if a particle is a MIP entering the passive material it will quickly turn to higher ionizing.

- For new cost-saving designs one would like to evaluate the performance with a calibration method that is not compromised by the new design!

Inhomogeneous Calorimeters

Table 1: Layout of a realistic inhomogeneous 30-layer silicon electromagnetic calorimeter, inspired by similar designs proposed by the CMS collaboration [8]

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Inhomogeneous calorimeter	
Thermal shielding	2mm Aluminium+26mm Foam+2mm Aluminium
Layer 1	0.5mm Cu+2mm Air+1.2mm FR4+0.3mm Si+3mm Cu+1mm Pb
5 modules	1.75mm W+0.5mm Cu+2mm Air+1.2mm FR4+0.3mm Si 3mm Cu+1mm Pb+3mm Cu+0.3mm Si+1.2 FR4+2mm Air+0.5mm Cu
5 modules	2.8mm W+0.5mm Cu+2mm Air+1.2mm FR4+0.3mm Si 3mm Cu+2.1mm Pb+3mm Cu+0.3mm Si+1.2 FR4+2mm Air+0.5mm Cu
4 modules	4.2mm W+0.5mm Cu+2mm Air+1.2mm FR4+0.3mm Si 3mm Cu+4.4mm Pb+3mm Cu+0.3mm Si+1.2 FR4+2mm Air+0.5mm Cu
Layer 30	4.2mm W + Layer 1

In this study we use:

- A CALICE-like design of a homogeneous calorimeter with identical passive-active layers, W, Si, PCB and air. A W passive layer is of 0.86**X**0, while the PCB is 1 mm thick and the air gap between layers is 2.5 mm.

- An inhomogeneous (non-uniform) calorimeter inspired by the LHC phase-2 CMS experiment, presented in Table 1 (see next slide)

- A detailed hit-level Geant4 simulation in order to study calibration methods.

Inhomogeneous Calorimeters

Total X_0 25.9089

Layer 1 0.0919987	Layer 16 0.87511
Layer 2 0.927787	Layer 17 0.798519
Layer 3 0.602529	Layer 18 0.87511
Layer 4 0.575468	Layer 19 0.798519
Layer 5 0.602529	Layer 20 0.87511
Layer 6 0.575468	Layer 21 0.798519
Layer 7 0.602529	Layer 22 1.27463
Layer 8 0.575468	Layer 23 1.20832
Layer 9 0.602529	Layer 24 1.27463
Layer 10 0.575468	Layer 25 1.20832
Layer 11 0.602529	Layer 26 1.27463
Layer 12 0.87511	Layer 27 1.20832
Layer 13 0.798519	Layer 28 1.27463
Layer 14 0.87511	Layer 29 1.20832
Layer 15 0.798519	Layer 30 1.27463

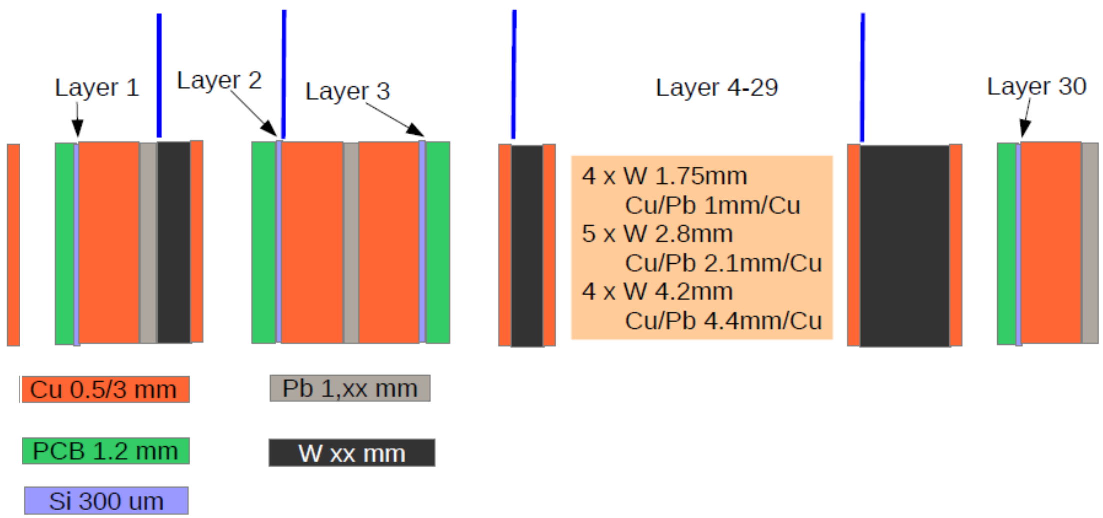


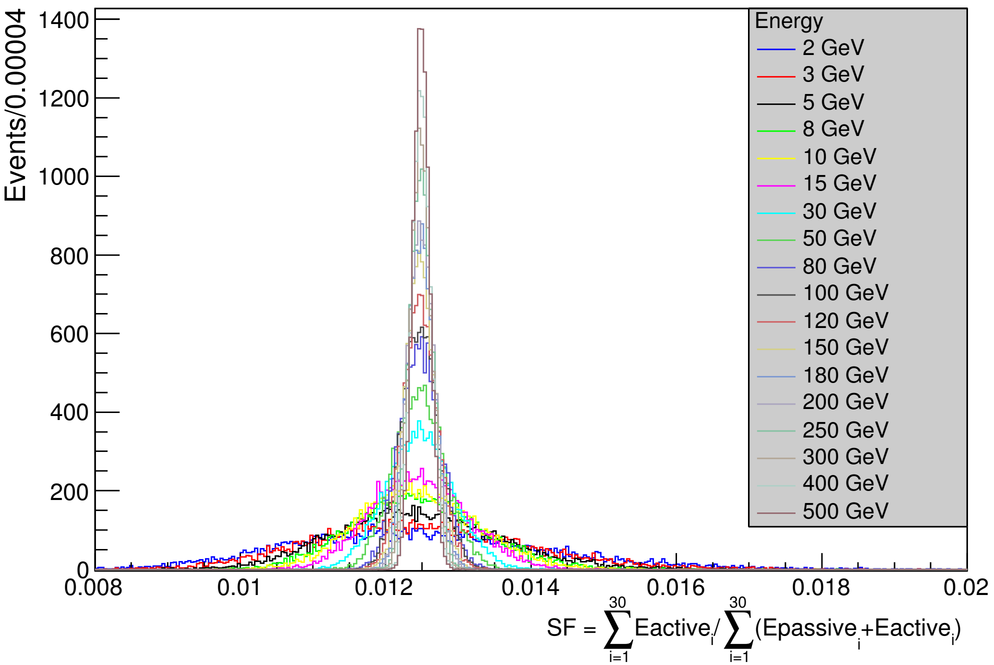
Fig. from A.M.Magnan

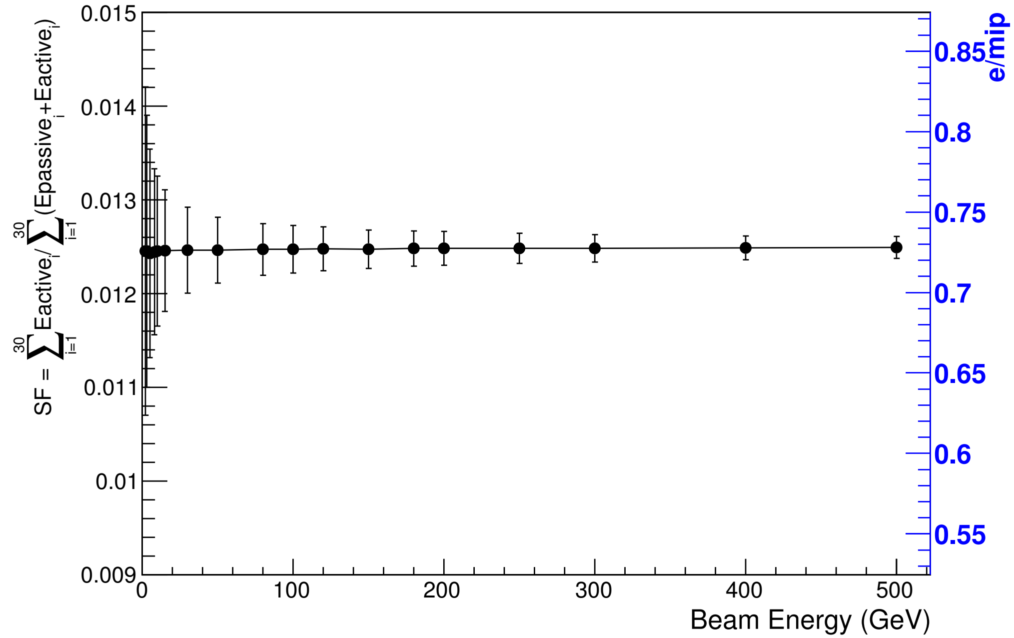
Homogeneous: same X_0

0.86 X_0/layer

Total X_0 25.8

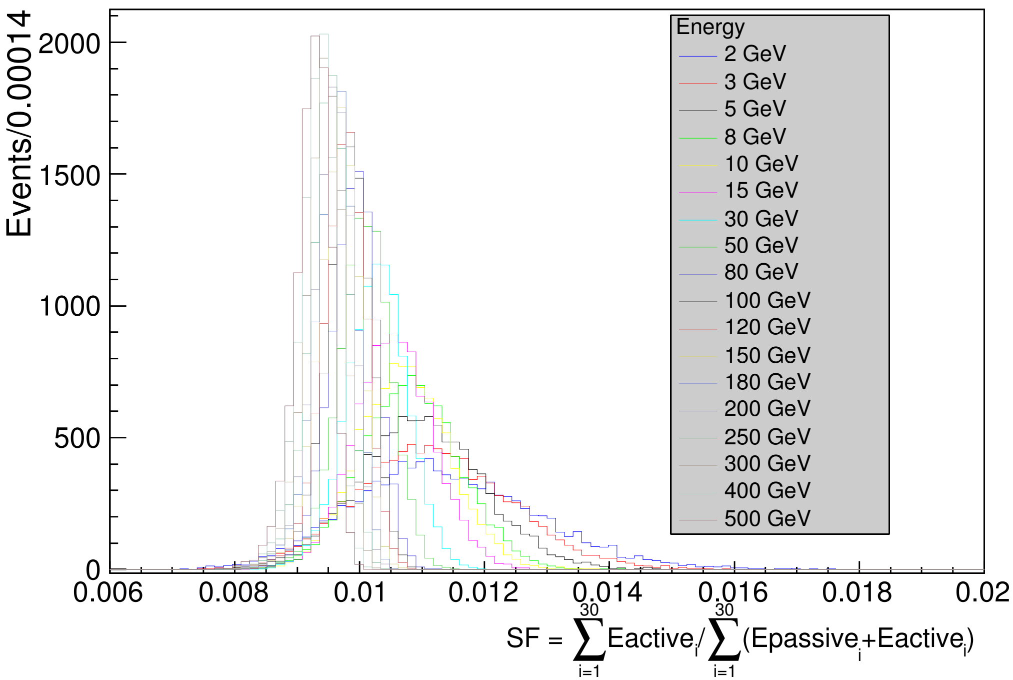
Homogeneous EM-Cal: <SF> has no E dependence

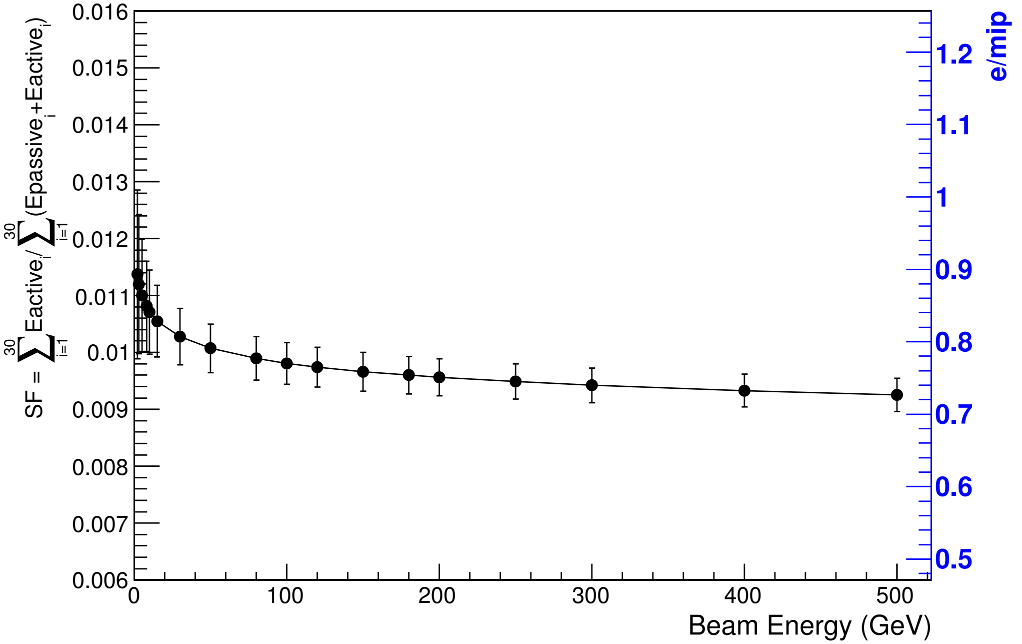




- This is the standard CALICE-like ECAL case.
- The <SF> has no dependence on Energy.
- So, practically, the <SF> method and the dEdx method are (almost) equivalent.

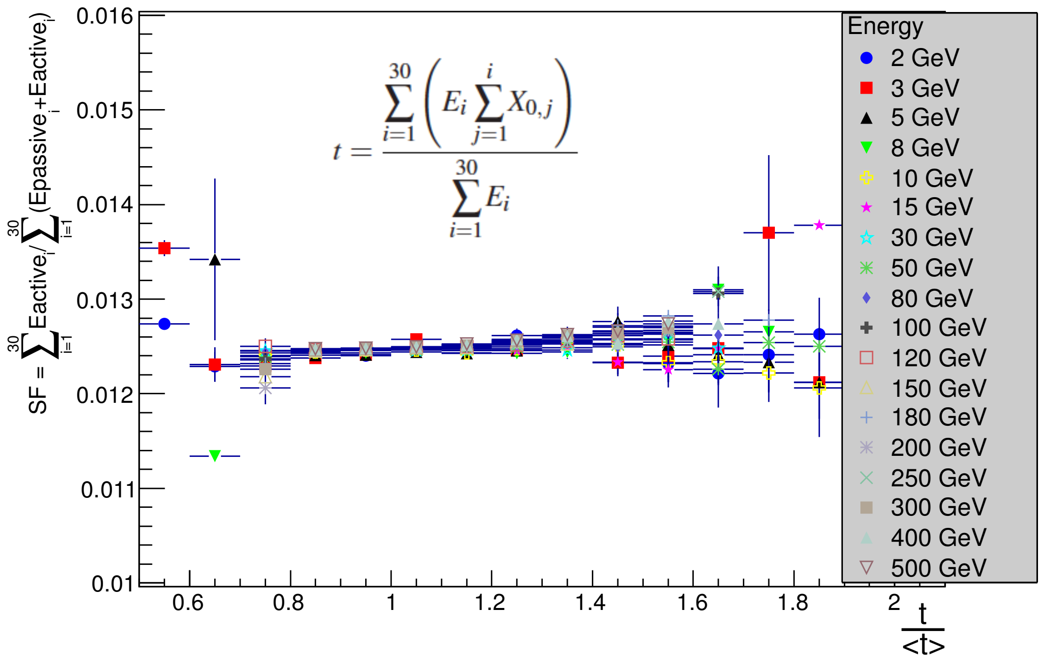
Inhomogeneous EM-Cal: E dependence on <SF>

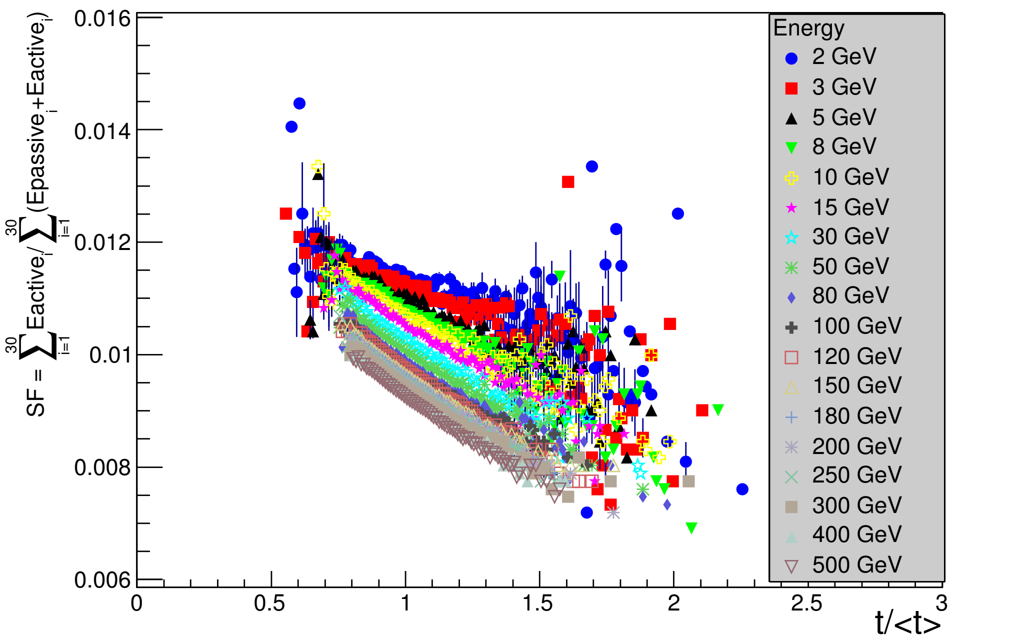




- This is the inhomogeneous ECAL case.
- The <SF> drops with Energy: deeper showers are sampled less due to the fact that the passive layer thickness increases with depth.
- Can we parameterize this behaviour and correct?

<SF> dependence on shower depth





Homogeneous EM-Cal shows no dependence on shower depth.

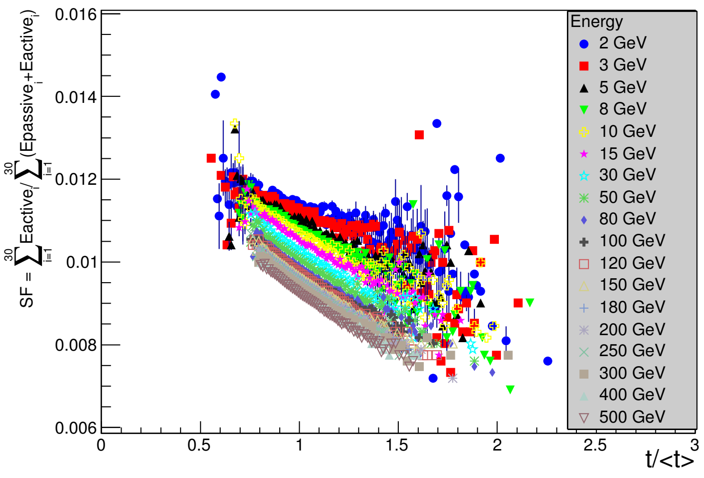
Inhomogeneous EM-Cal shows strong dependence:

- Deeper layers have more passive material → smaller SF.
- For deeper showers SF drops.

Calibration Method: use <SF> with per-event shower depth correction

$$E_{rec} = \sum_{i=1}^{30} E_{active,i} \times SF^{-1}$$

Very similar to the dEdx method but with a corrected (SF) factor.



$$SF_{corr} = \lambda \times \left(\frac{t}{<t>}\bigg|_{l} - \frac{t}{<t>}\bigg|_{bin} \right) + <SF>\bigg|_{bin}$$

Measured Shower depth in a single event

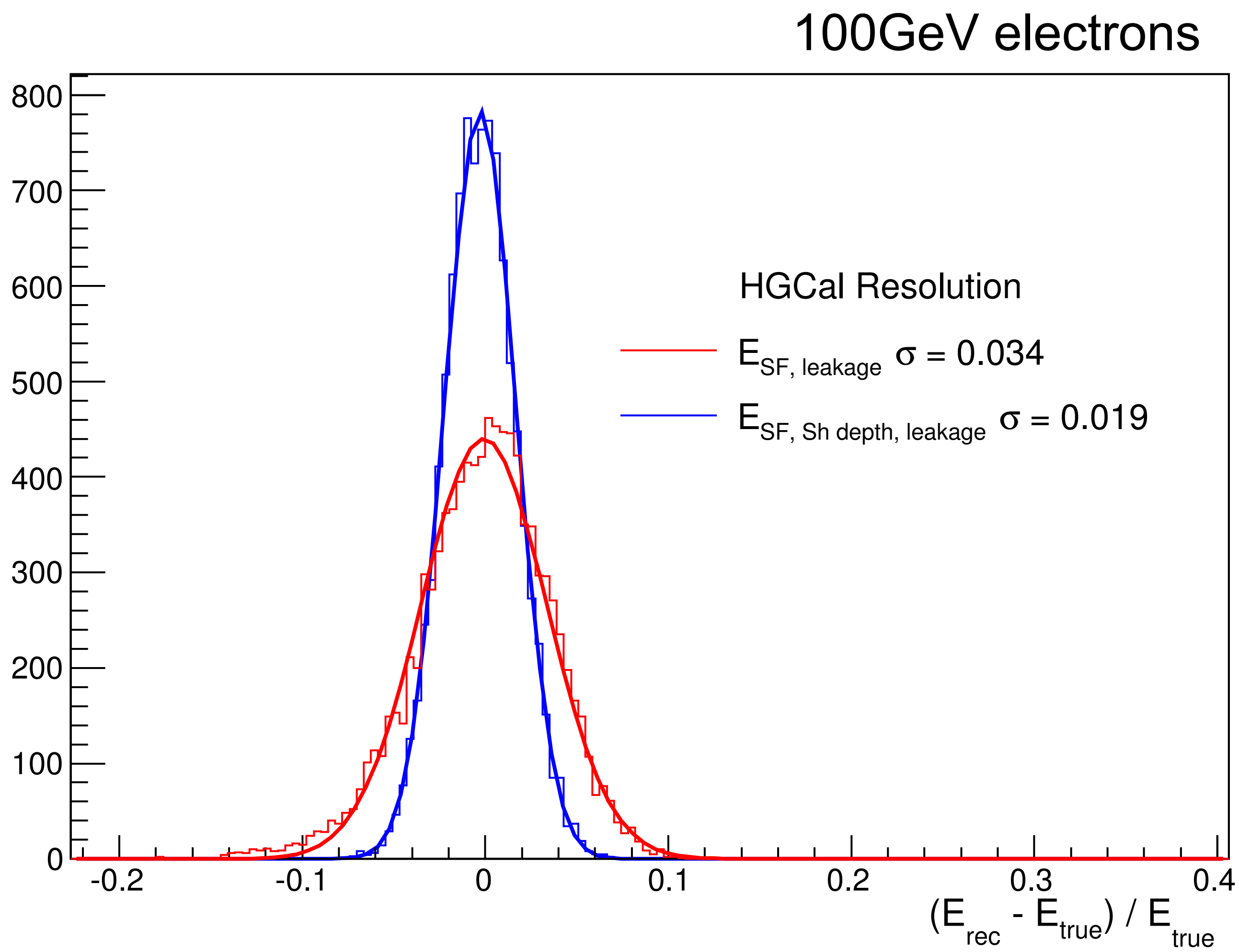
Average shower depth for particular energy (bin)

Fit <SF>(depth,energy) using MC

Get slopes and offsets (here we use a single slope λ and offset)

Needs Validation with Test Beams: started with first HGCal prototypes

Effect of the shower-depth correction



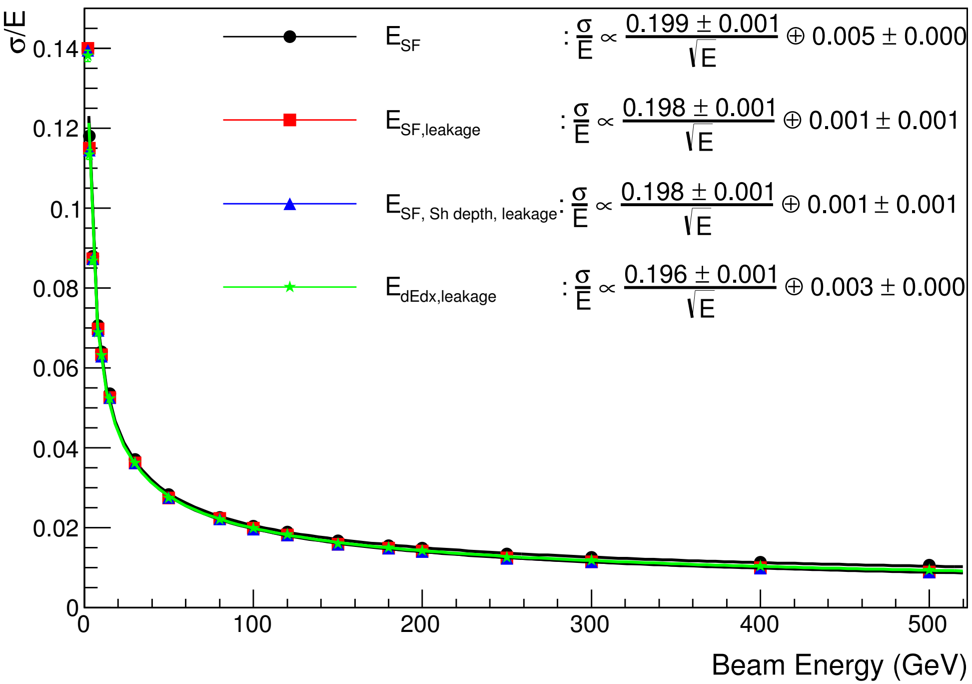
Correcting the <SF> on an event-by-event basis according to the measured shower depth, leads to significant improvement (this has been checked with data).

Comparison between dEdx and <SF>

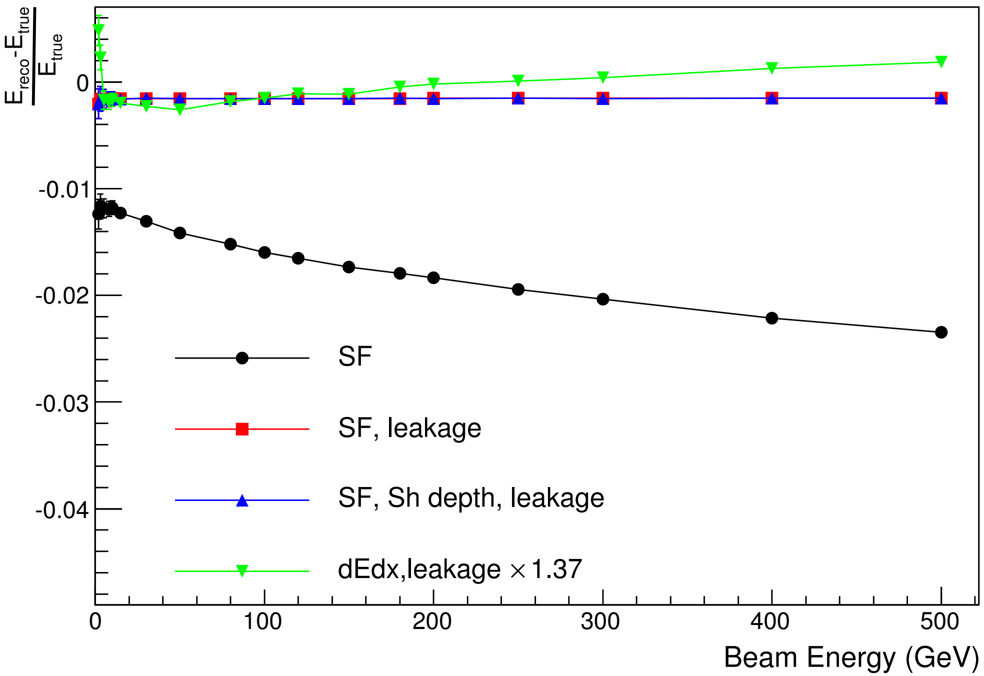
- Apply <SF> factor without any other correction.
- Apply <SF> factor plus Energy leakage (from the back and side) correction.
- Apply <SF> method (shower depth correction) + Energy leakage
- Apply dEdx method + Energy leakage correction

Homogeneous EM-Cal

Resolution



Linearity

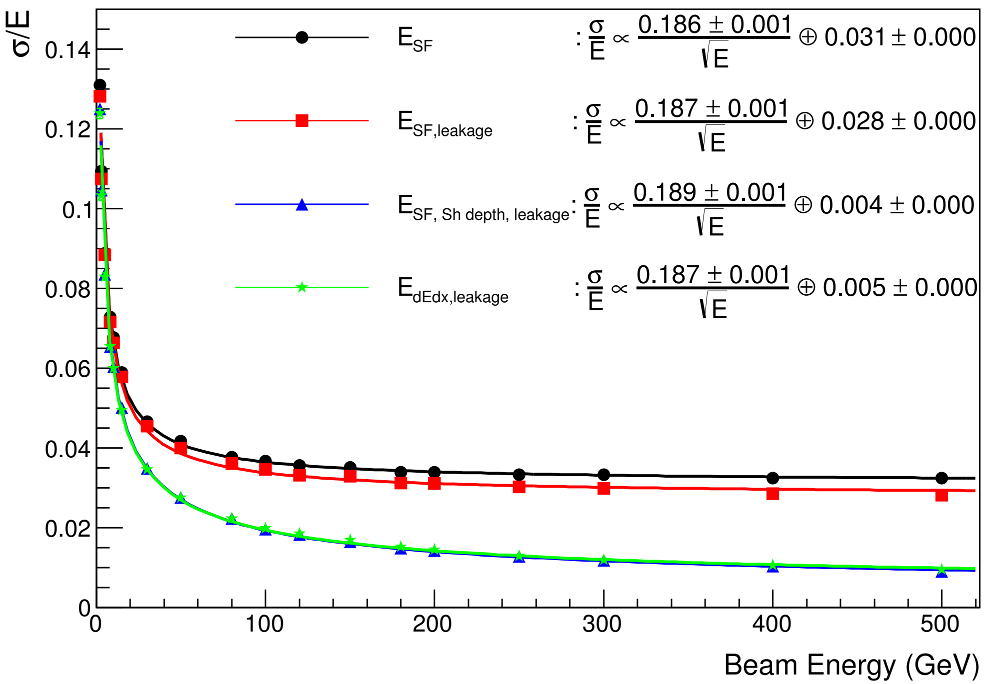


SF method including shower depth correction and dEdx

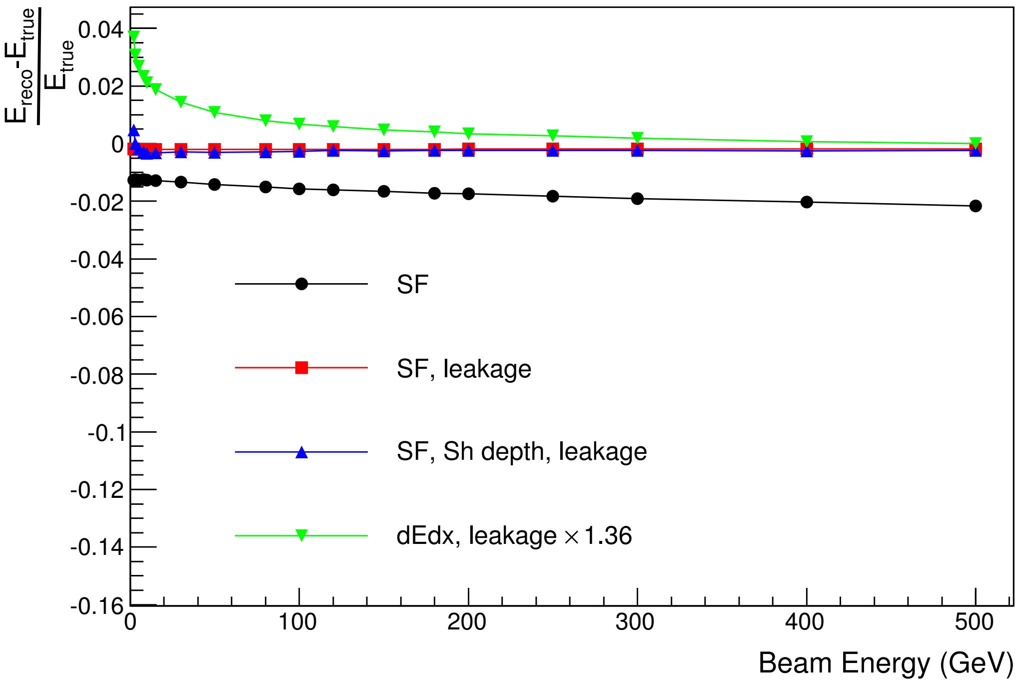
- Resolution: no observable difference.
  - No constant term.
- Linearity: in dEdx scale is off but linearity is preserved.

Inhomogeneous EM-Cal

Resolution



Linearity



- SF method improves linearity and resolution constant term
  - Improvement in constant term is of order 20%

- dEdx method has few %-level nonlinearities below 150GeV.

Summary

- A new EM calibration method for Silicon-based CALICE-like calorimeters is presented.

- The method is applicable for lower-cost inhomogeneous designs, as a generalization of the std dEdx calibration.
  - Improves linearity (no need for extra factors).
  - Improves the constant term.

- Upcoming test beams at CERN with more than 20 sampling layer inhomogeneous ECAL will demonstrate these improvements.

$$e/mip = SF / \frac{\sum_{i=1}^{30} dEdx_{active,i}}{\sum_{i=1}^{30} dEdx_{active,i} + \sum_{i=1}^{30} dEdx_{passive,i}}$$