Energy Weighting for CMS-HCal Upgrade

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PHYSICS AT THE TERA SCALE
Helmholtz-Alliance

Overview

- Motivation
- Idea of Weighting
- Consistency checks
- Results
- Conclusion / Outlook

Vladimir Andreev, Kerstin Borras, Isabell Melzer-Pellmann, Peter Schleper

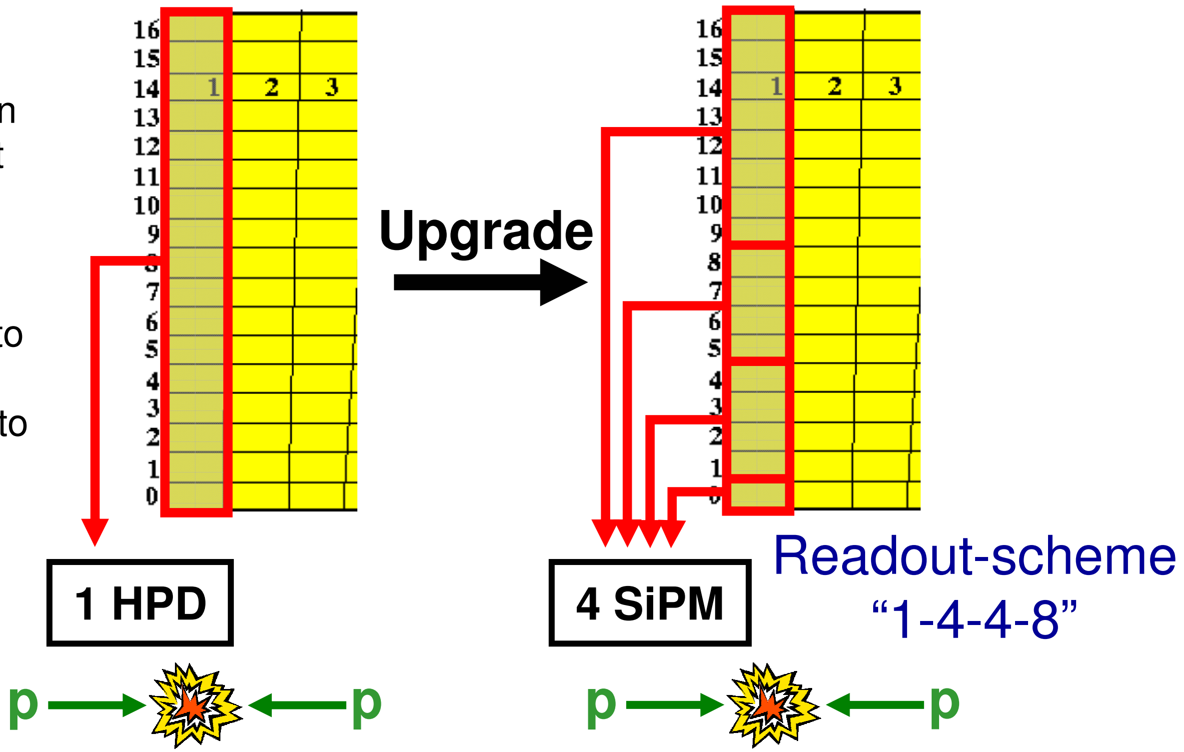
HCal Upgrade

➔ **Upgrade: 4 x more readout channels**

- Plan: additional segmentation in longitudinal direction

Schematic illustration of the HCAL readout before and after the upgrade.

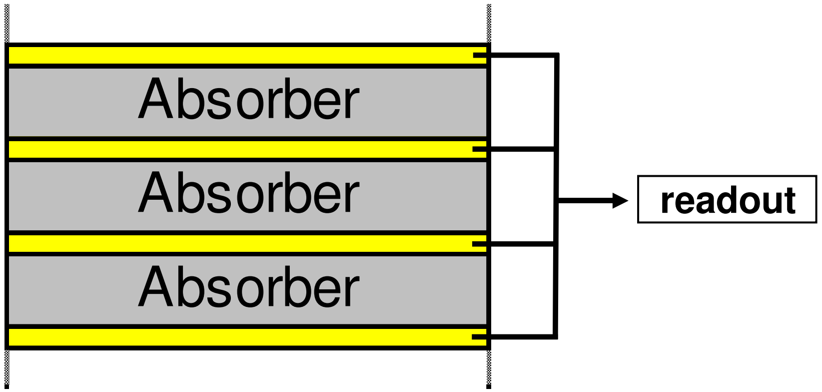
HPD = "**H**ybrid **P**hoto **D**etector";
SiPM = "**Si**licon **P**hoto **M**ultiplier".

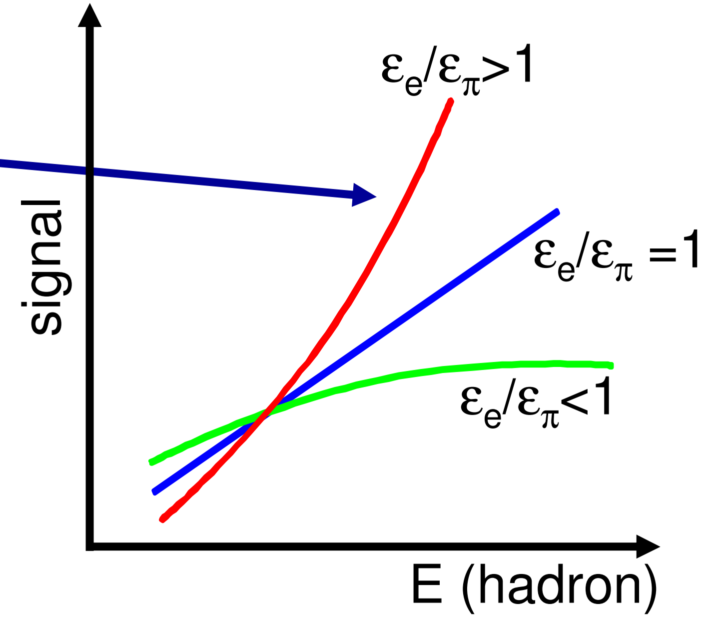


- Resolve parts of showers in **longitudinal direction** after the upgrade

Motivation

- CMS HCal is a **non-compensating sampling calorimeter ➔** $e/\pi \approx 1.2 > 1$





Sketch of detector signal for different e/π-ratios as a function of energy.

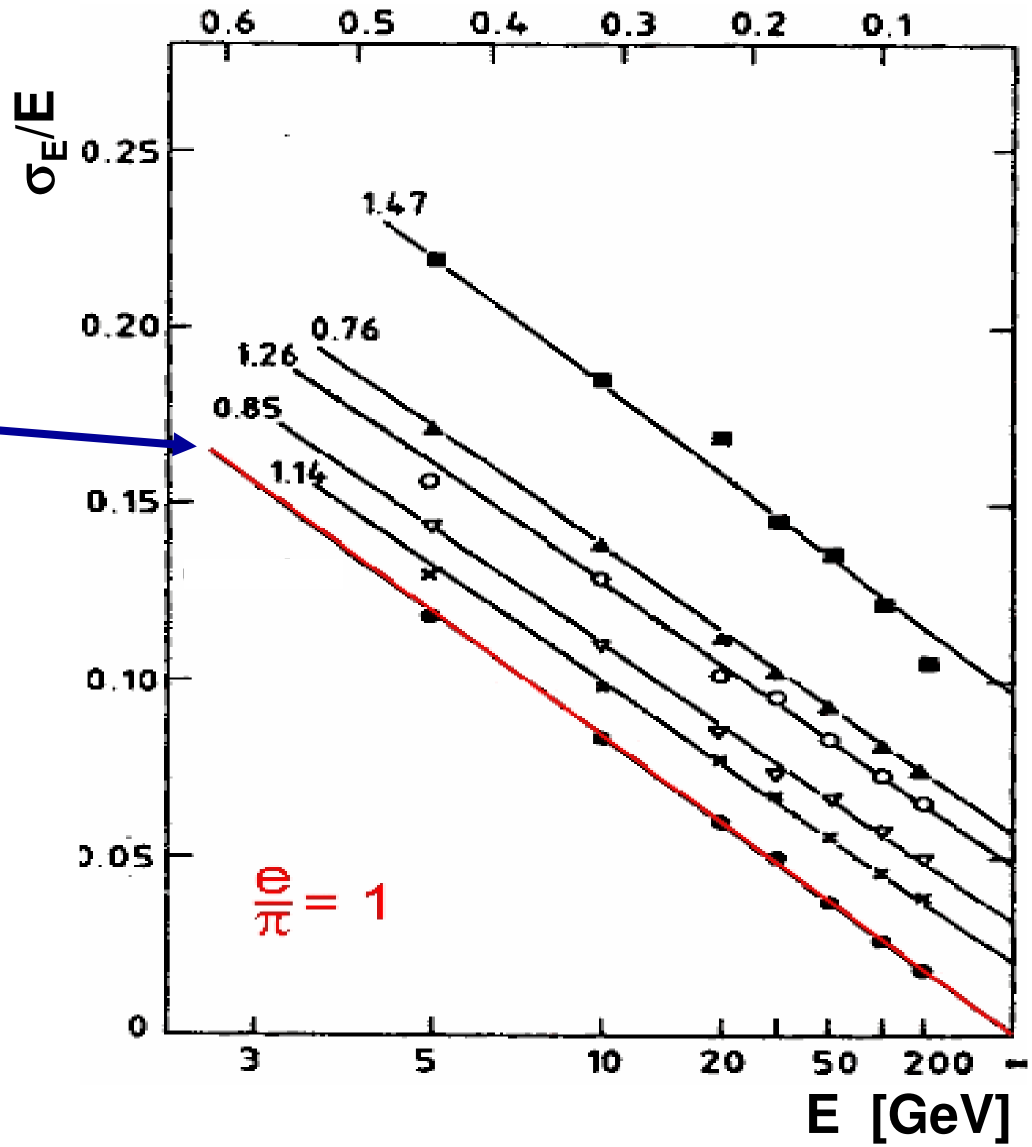
- A sampling calorimeter is a sandwich, made from
  - Absorber (passive → cannot be measured)
  - Scintillator (active → is measured)

  ↳ Only about **1%** of the deposited energy is measured

- Efficiency to measure em energy depositions (ε_e) is higher than efficiency to measure had energy depositions (ε_π)

Motivation

- **Consequence:**
  Linearity and **energy resolution** worse than for calorimeters with e/π = 1
- **Ansatz for improvement:**
  Weighting ➔ estimate which energy deposition is em or had and weight differently
- **Aim:**
  ☺ **Improve linearity**
  ☺ **Improve energy resolution**

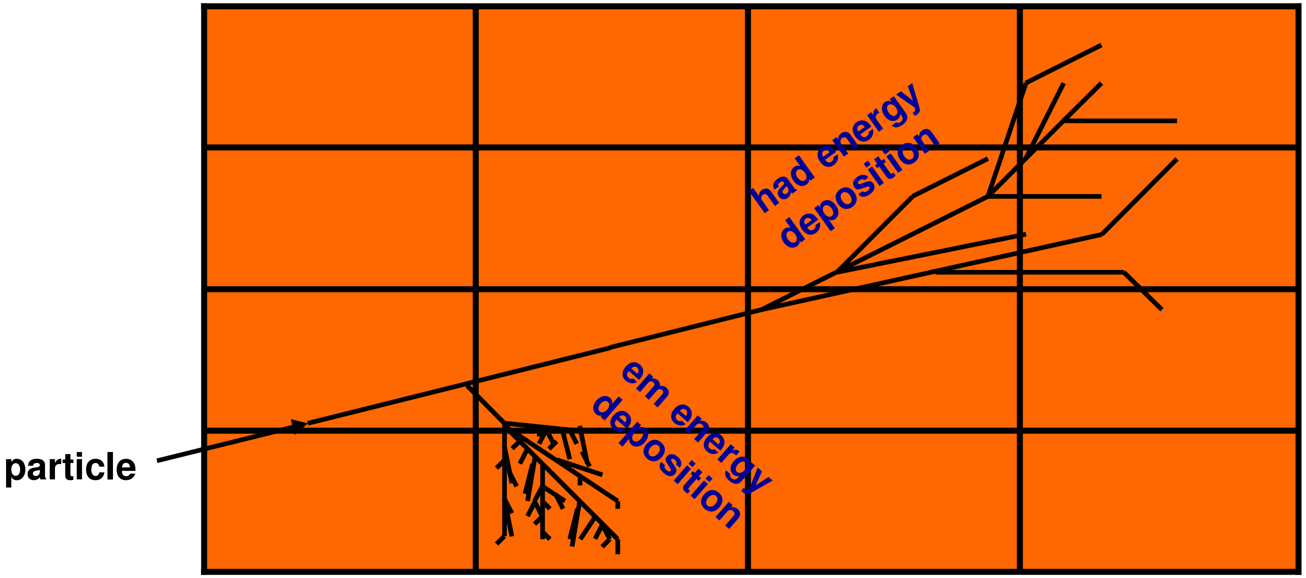


Exemplary energy resolution for different e/π ratios. Red: e/π =1; black: e/π ≠1.

Linearity : $\langle E^{meas} \rangle / E^{beam}$ vs. E^{beam}

rel. Energy resolution : $\Delta E/E \equiv \sigma_E/E$ vs. E^{beam}

- Particle in matter induces a **shower** (secondary particles)
- **Average** energy deposition per distance (dE/dx) well-described in formulas
- **But:** single particle shower looks inhomogeneous



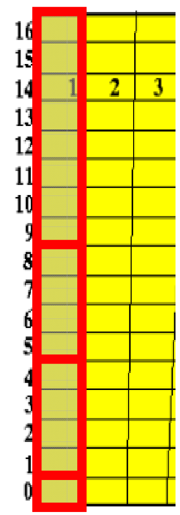
Showering of a particle penetrating Matter.

- **Grid** = segmentation/ granularity of the detector

Weighting Factors

- Em shower deposits (on average) a larger amount of energy per channel than broad had shower
- Estimator for energy deposition (em or had): **Energy density "ρ"**

$$\rho_i = \frac{E_i^{meas}}{\text{\# Layers in readout channel "i"}}$$



- **Weights "w"** depend on energy density ρ, total shower energy and channel number "i":

$$w_{i,E^{beam}}(\rho) = \left\langle \frac{E^{truth}}{E^{meas}} \right\rangle_{i,E^{beam}}$$

not available in CMSSW!

$E_i^{truth} = E_i^{abs} + E_i^{sci} + E_i^{inv}$
E^{beam} = beam energy
E_i^{abs} = absorber energy
E_i^{sci} = scintillator energy
E_i^{inv} = invisible energy
i = no of readout channel

➔ Use Geant3 standalone simulation of HCal (by Vladimir Andreev)

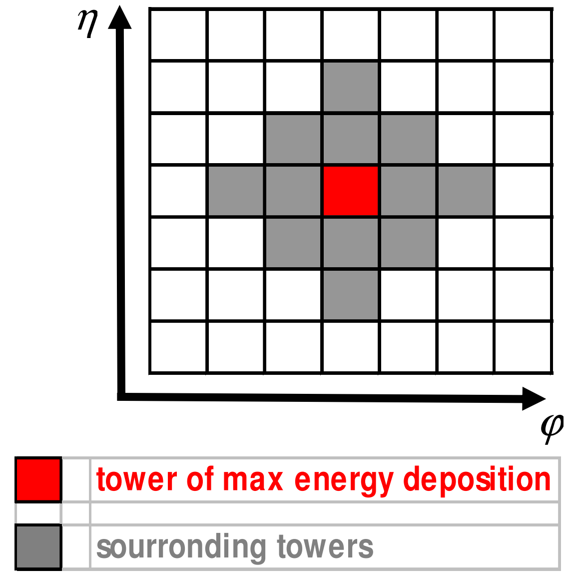
Weighting concept

In the past:

- Obtain/ apply weights only from/ to tower with maximum energy deposition

Now:

- Obtain/ apply weights from/ to well-defined cluster
  - ➔ consider surrounding towers
  - ➔ Get better results



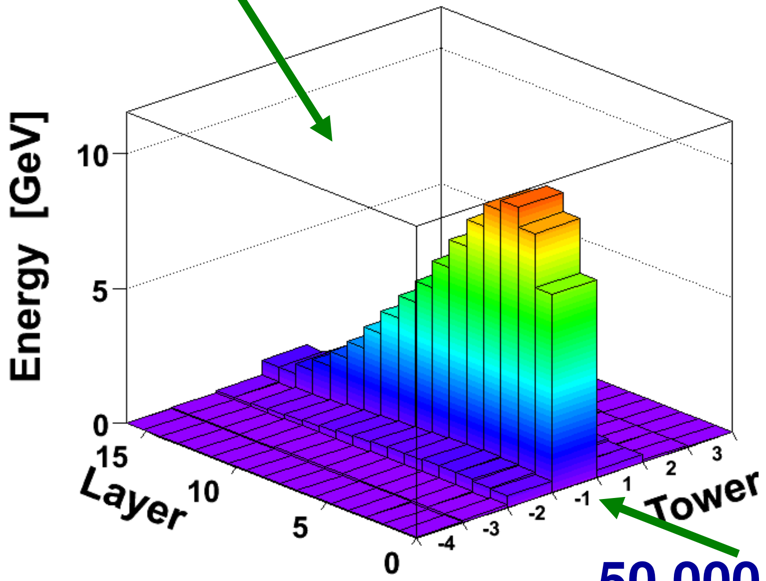
- In principle: for different shower algorithms
- Here: Gcalor

NB: Favorite Gcalor because:

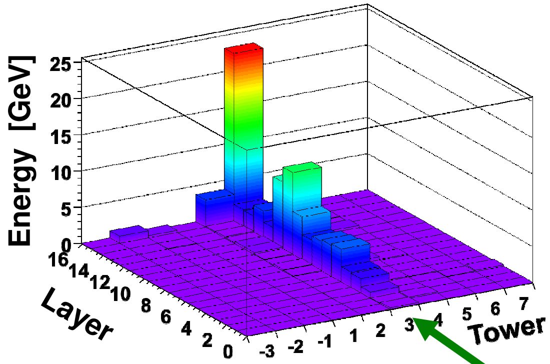
Avramovv, V. V.; Acharya, B. S.; Akchurin, N.; Atanasov, I. H.; Baiatian, G.; Ball, A.; Banerjee, S.; De Barbaro, P.; Barnes, Virgil, e.l Bencze, G. L. et al.: **“Studies of the Response of the Prototype CMS Hadron Calorimeter, Including Magnetic Field Effects, to Pion, Electron, and Muon Beams”**

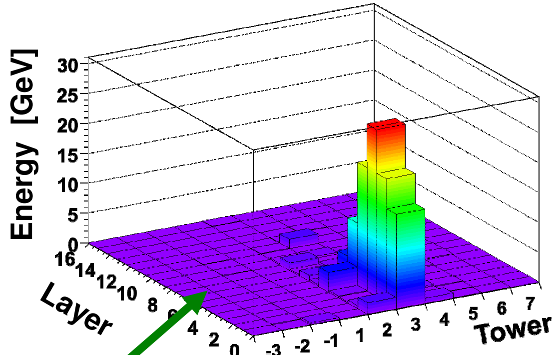
Showers for 100 GeV π Events

Average energy deposition

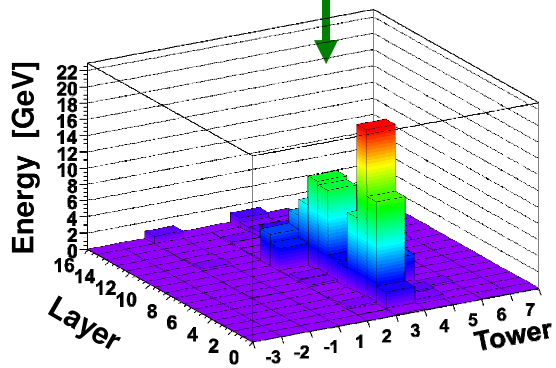


50.000 x π





Single events



- Shower shape **“Smooth” on average**
- Strong **fluctuations** in shower shapes on event-by-event basis.

→ Use longitudinal resolution to distinguish between em (high energy density) and had part of the shower

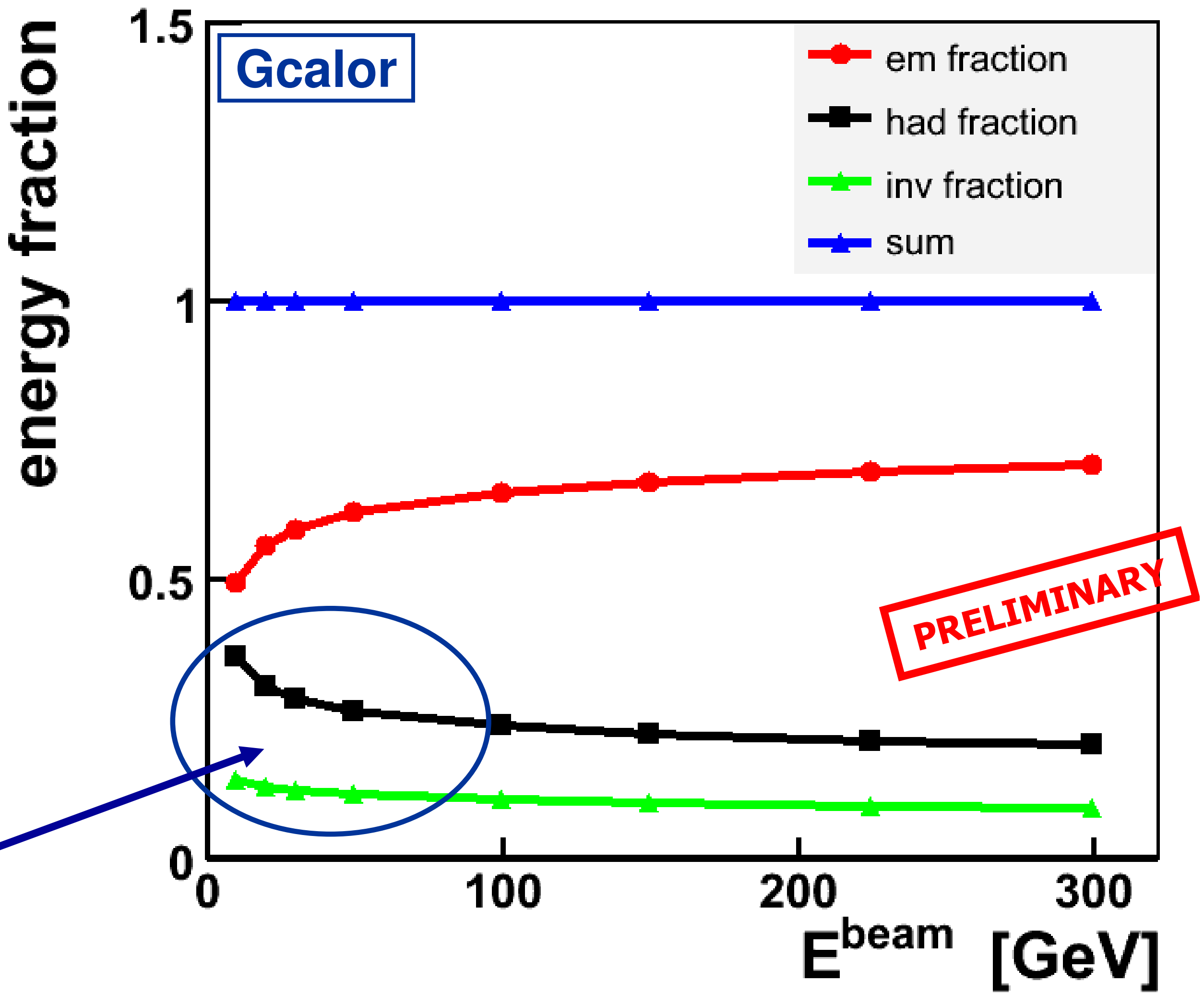
Potential of the Method

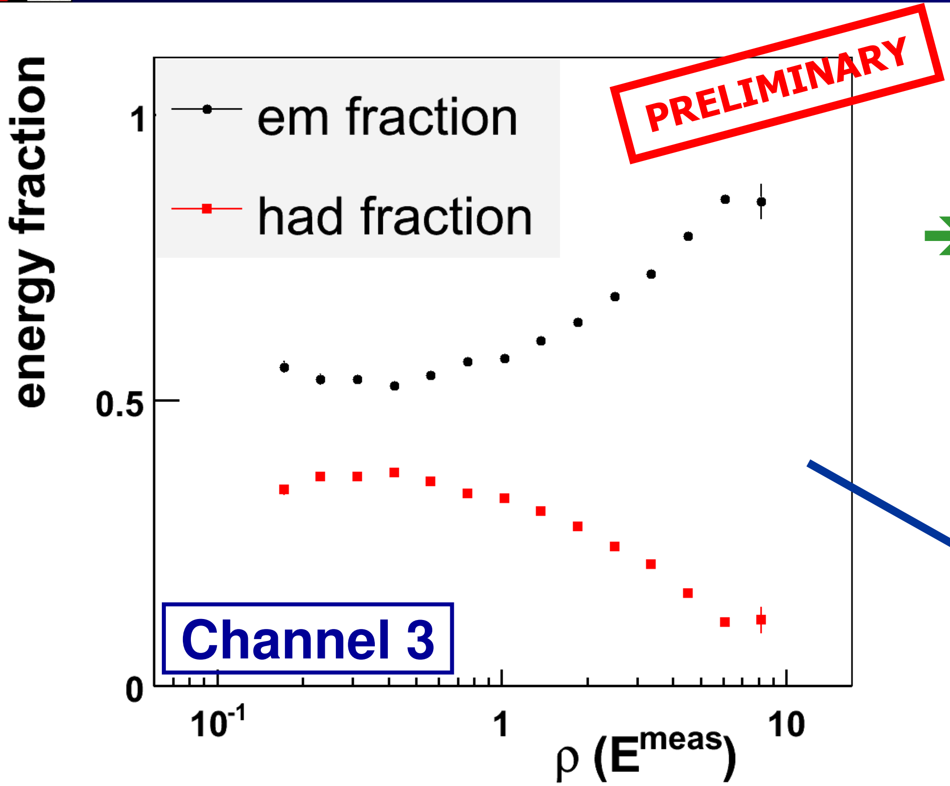
$$\text{x fraction} = \frac{\text{x energy deposition}}{\text{total energy deposition}}$$

- Had and inv fraction depend on energy
  ➔ expectation: improve **sampling term** of energy resolution

$$\underbrace{\left(\frac{\sigma(E)}{E}\right)^2}_{\text{Energy resolution}} = \underbrace{\frac{a^2}{E}}_{\text{sampling term}} + \underbrace{c^2}_{\text{constant term}}$$

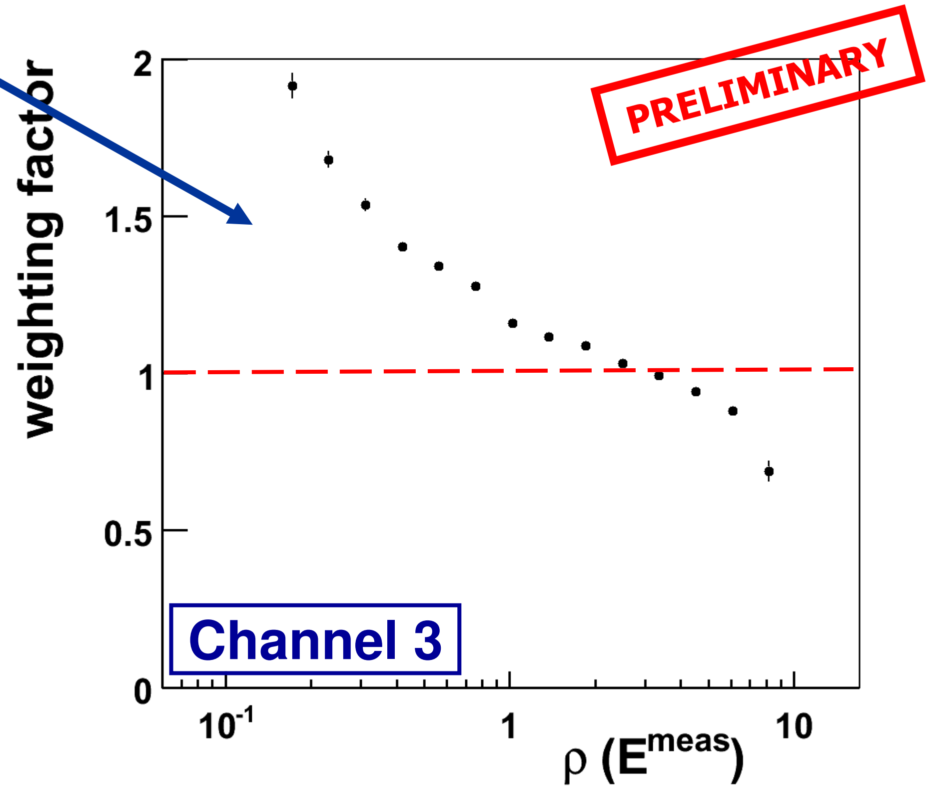
- The higher the energy, the smaller had and inv fraction
  ➔ Potential for weighting is higher for **smaller energies**





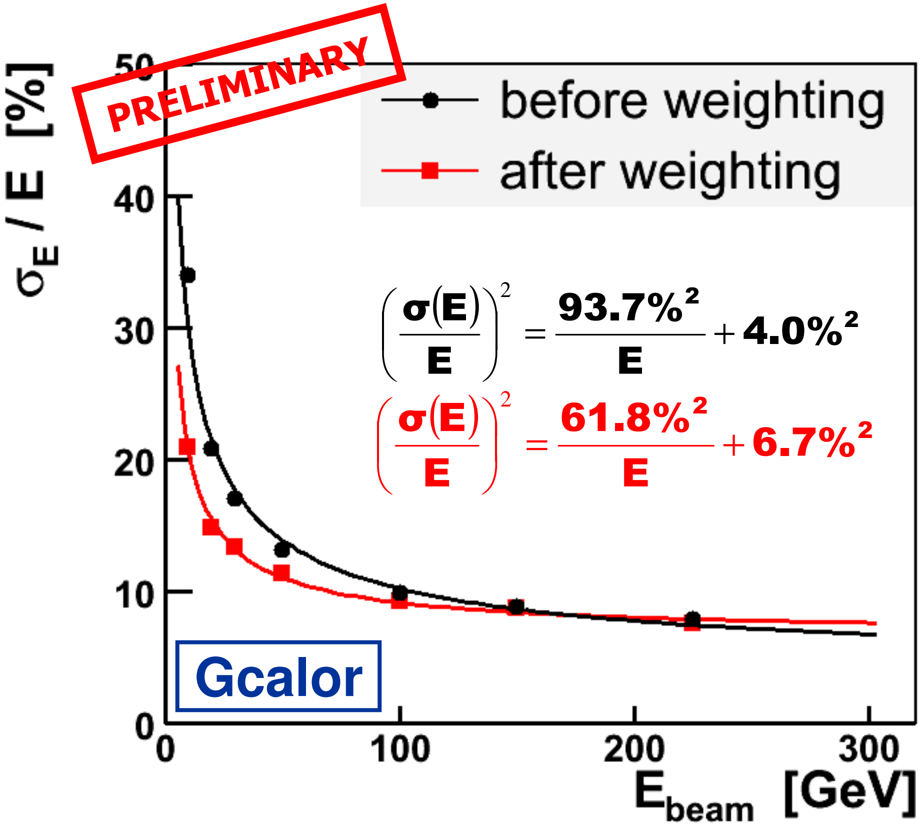
➔ Energy fractions as expected:
The bigger the energy density,
the bigger the em fraction

Results obtained from a MC data sample of 50.000 π at 30 GeV.

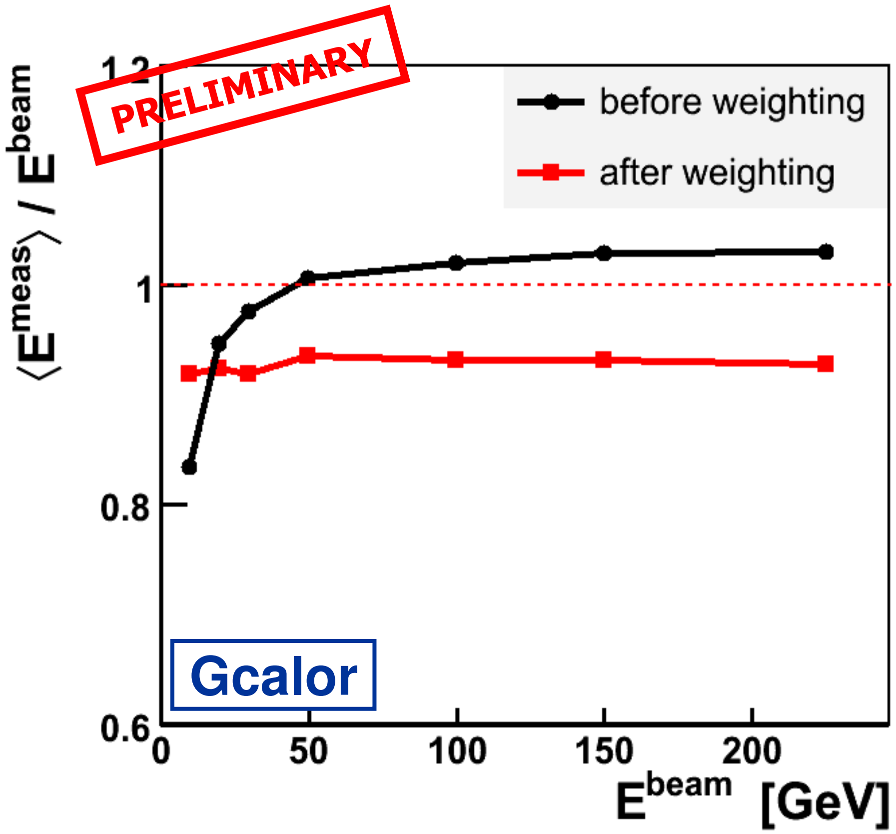


➔ Weighting factors as expected:
The bigger the energy density,
the smaller the weights

Energy Resolution



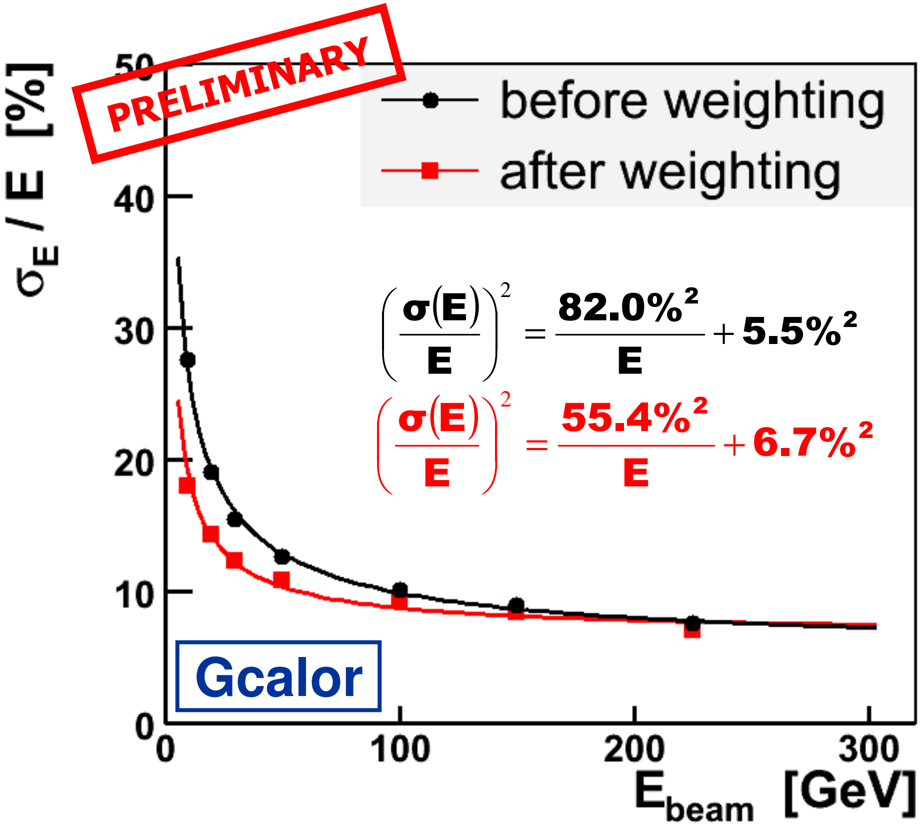
Linearity



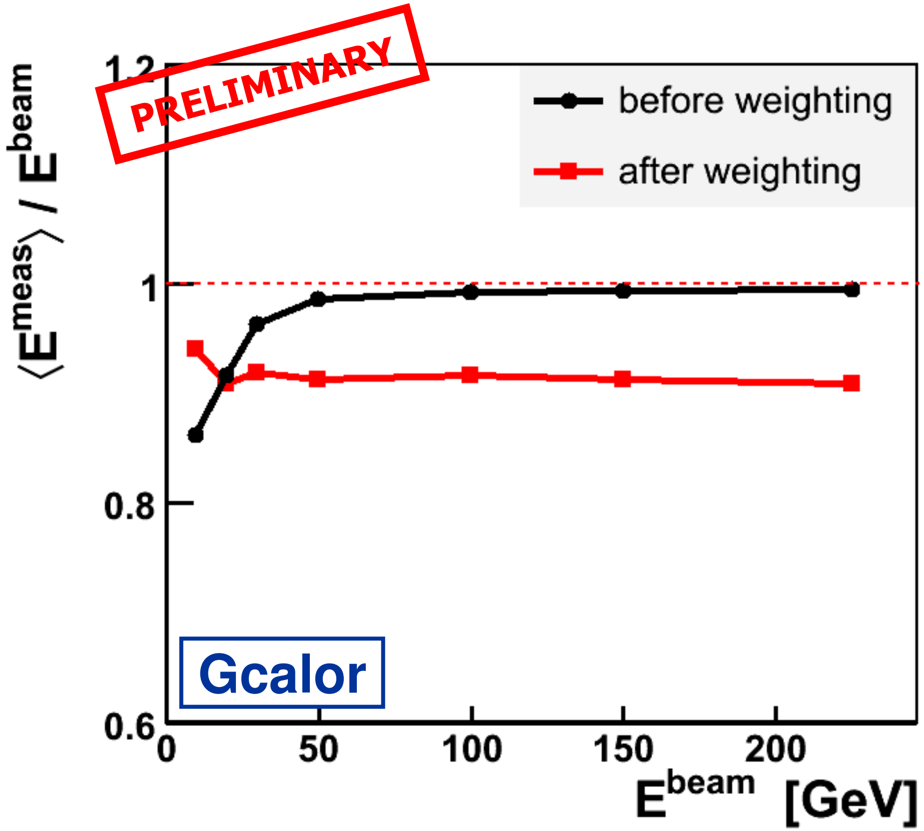
☺ **Energy resolution (sampling term) improved**

☺ **Linearity improved**

Energy Resolution



Linearity



➔ **Weights taken from Geant3 standalone simulation!**

☺ **Energy resolution (sampling term) improved**
☺ **Linearity improved**

Conclusion / Outlook

Conclusion

Weighting works fine:

☺ Considerable improvement of energy resolution (sampling term)
☺ Considerable improvement of linearity
- Even better results with a cluster-algorithm

➔ Strong motivation for a longitudinal segmentation

Outlook

- Investigate other shower algorithms (for systematic error estimation)
- Find correction function instead of tabulated weights (first promising investigations have been made)
- Find optimal readout scheme
- Realize weighting within CMSSW
- Study impact on physics analysis (e. g. W-reconstruction)

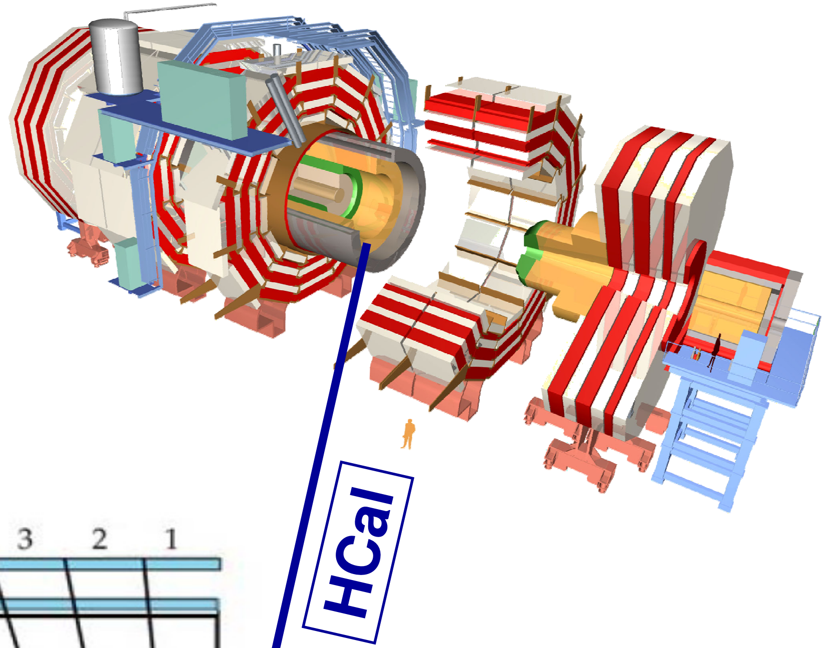
Backup

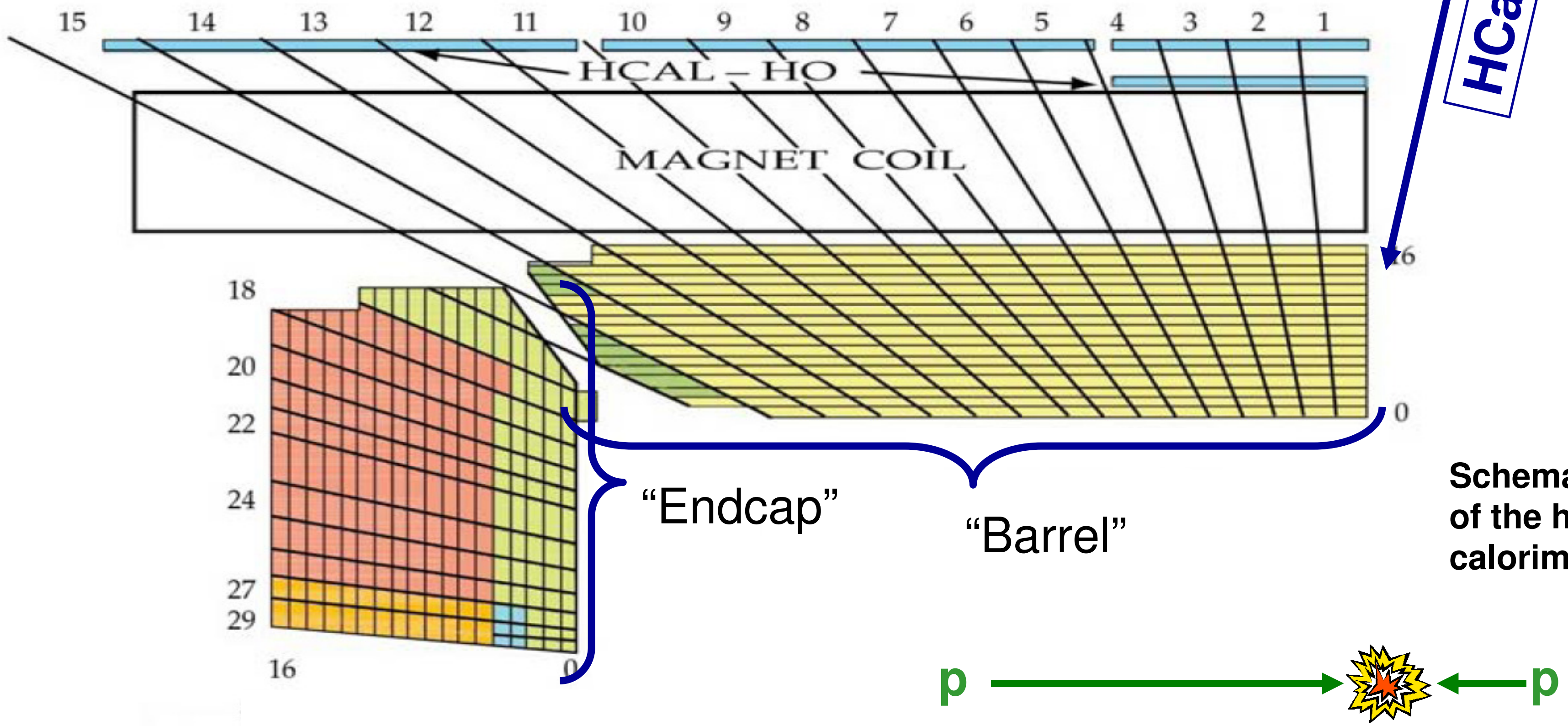
CMS-HCal

- Coverage:
  $|\eta| < 1.3$ (barrel),
  $1.3 < |\eta| < 3.0$ (endcap)

- Granularity: 0.087 x 0.087 (φ x η)

- One tower consists of 17 layers





Schematic section view of the hadronic calorimeter of CMS.

Consistency Checks

- Energy deposition
  - ↳ on average
  - ↳ on event-by-event basis
- Energy fractions
- Weighting factors

In Principle:
For different shower algorithms

Here:
Gcalor

➔ All for **simulated** events

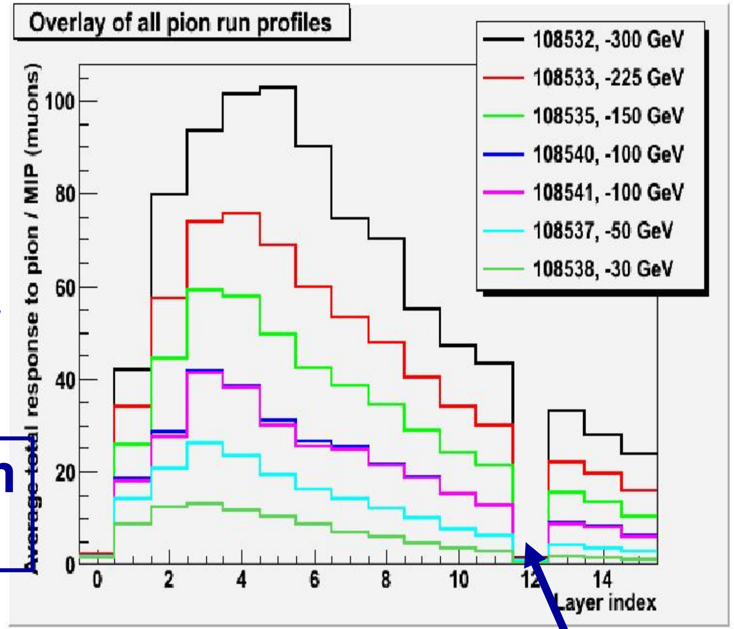
NB: Favorite Gcalor because:

Avramovv, V. V.; Acharya, B. S.; Akchurin, N.; Atanasov, I. H.; Baiatian, G.; Ball, A.; Banerjee, S.; De Barbaro, P.; Barnes, Virgil, e.l Bencze, G. L. et al.: **"Studies of the Response of the Prototype CMS Hadron Calorimeter, Including Magnetic Field Effects, to Pion, Electron, and Muon Beams"**

☺ Only slight differences between different shower algorithms

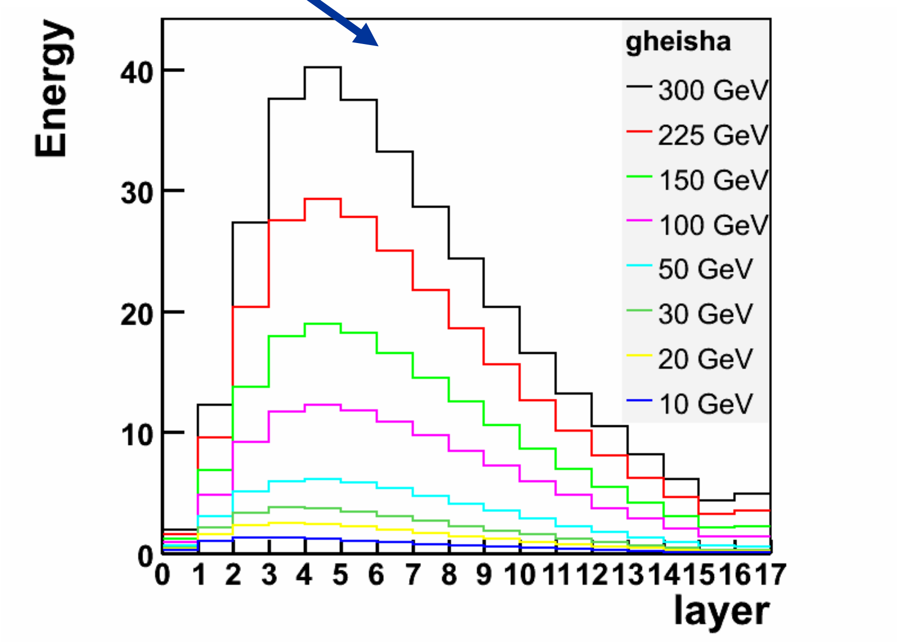
☹ Differs from test beam

Test beam 2009

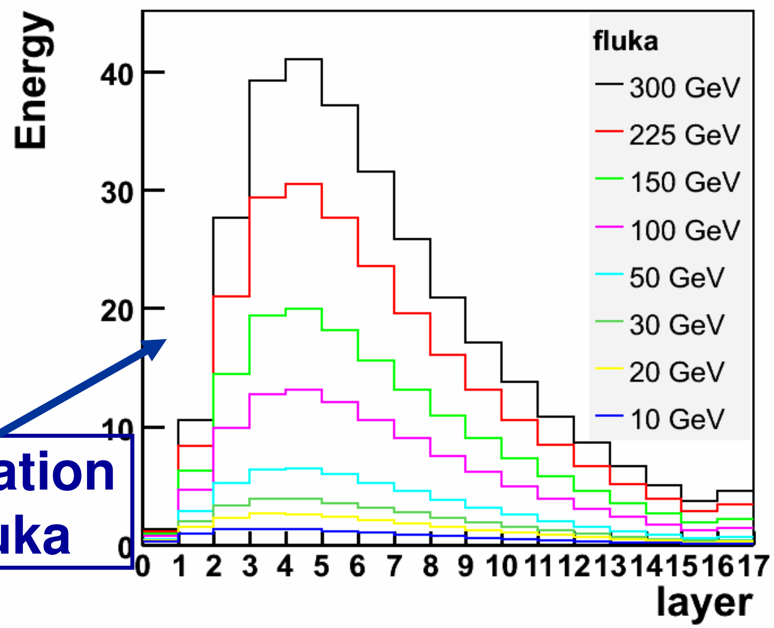


"Hole" due to a readout defect

Simulation – Gheisha



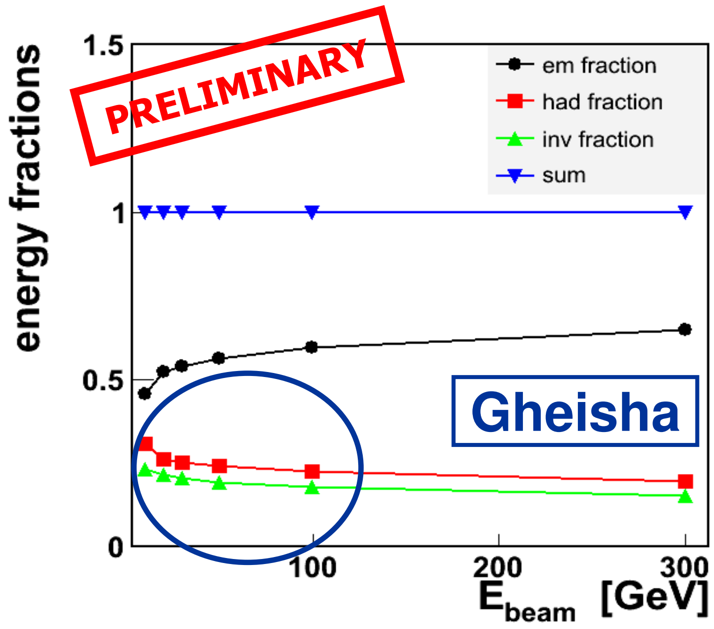
Simulation – Fluka

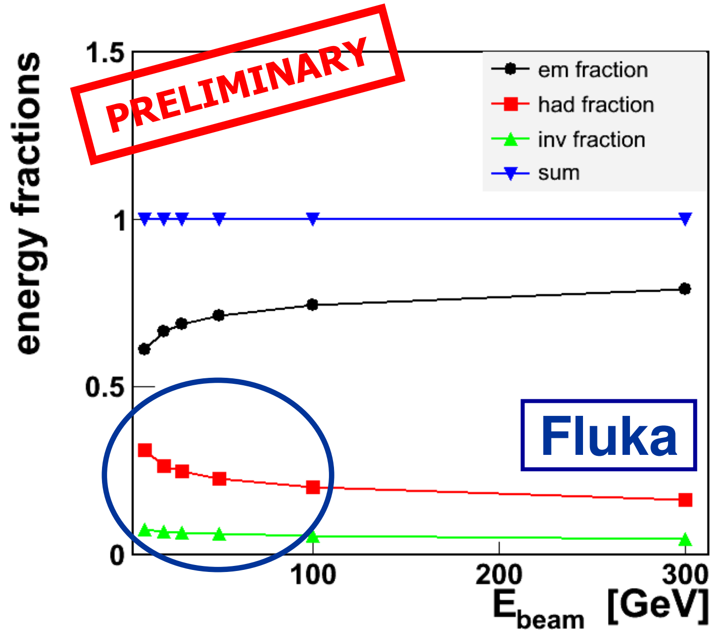


Potential of the Method

$$\text{x fraction} = \frac{\text{x energy deposition}}{\text{total energy deposition}}$$

- The higher the energy, the smaller had and inv fraction
- Large **differences** for different shower algorithms
- Potential for weighting is higher for **smaller energies**

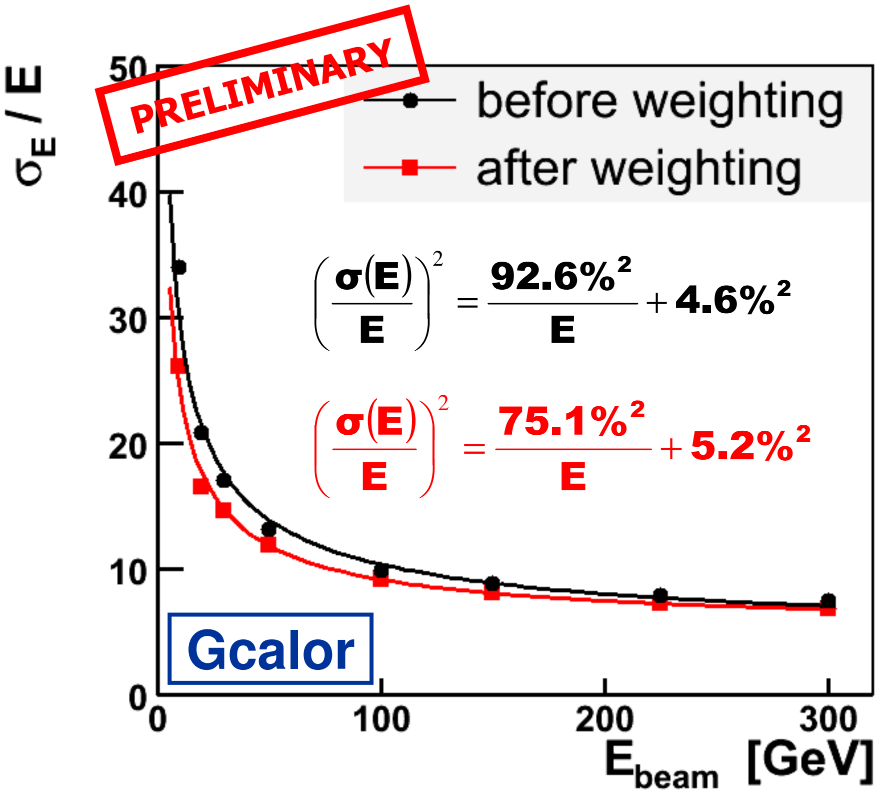


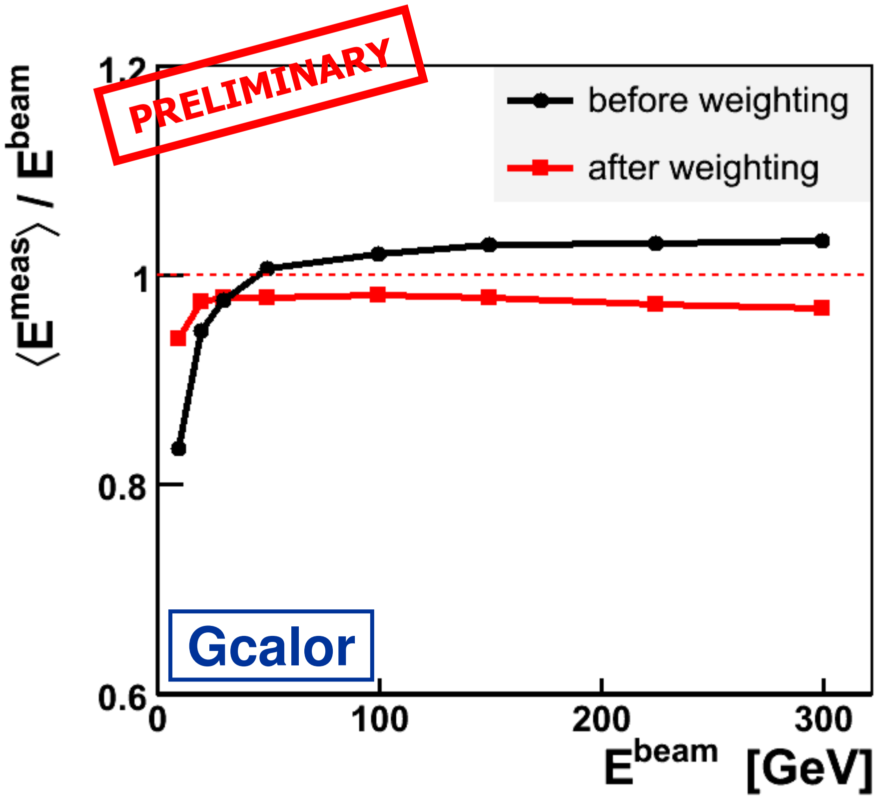


Results: Energy Resolution + Linearity

- Obtain
- Apply

weights only from tower with maximum energy deposition





☺ **Energy resolution (sampling term) improved**

☺ **Linearity improved**

Other investigations

H1 (DESY, Hamburg, HERA)

- Higher energies
- e/pi is not so high
- Granularity worse

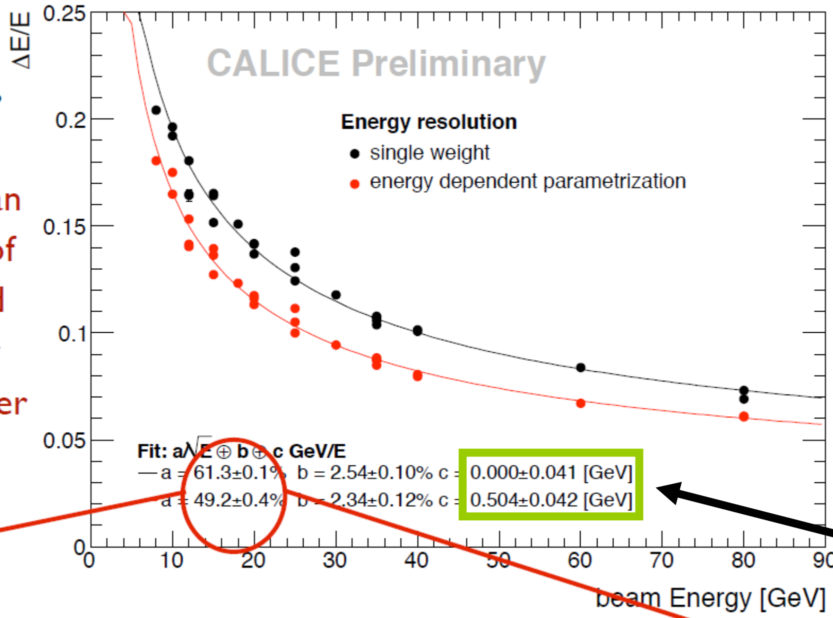
➔ Lower potential for a gain by a weighting, especially at higher energies

CALICE (CERN)

- Similar results

2 ways to reconstruct the energy:

- One conversion factor per detector, no density dependent weighting
- Density dependent weighting using an energy dependent parametrization of the weights, the weights are selected event by event using the first energy estimate obtained with one factor per detector: prior knowledge of beam energy not necessary!

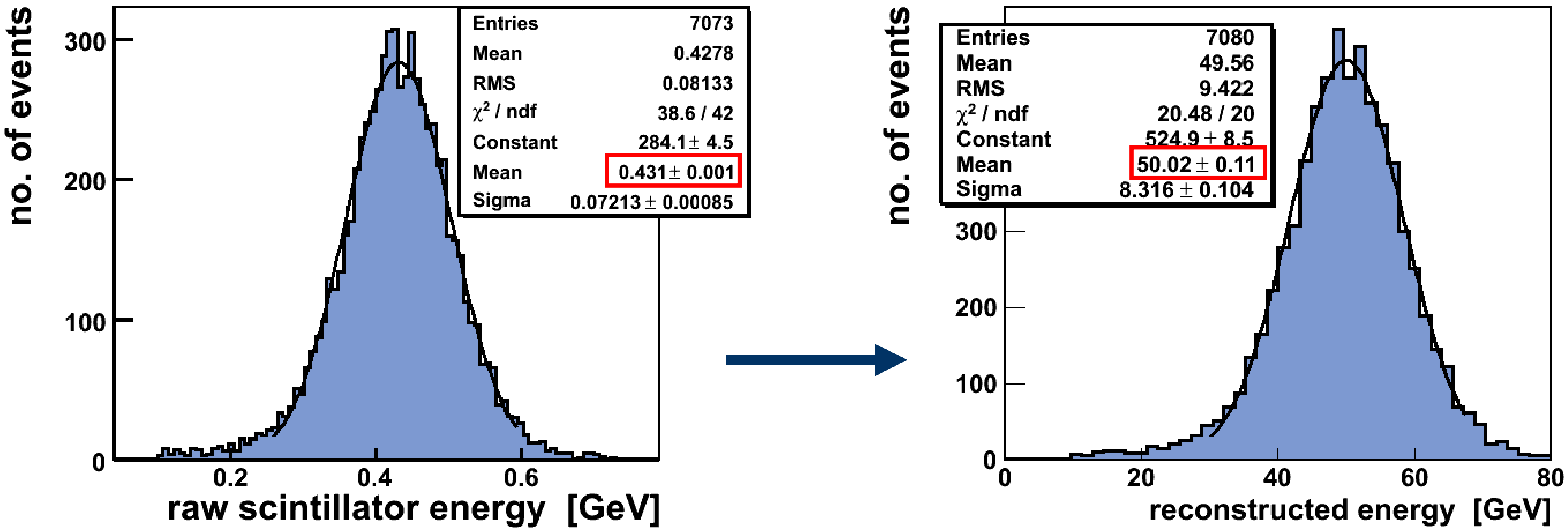


stochastic term w/o weighting: 61.3%, with parametrized weighting 49.2%

The constant term also increases

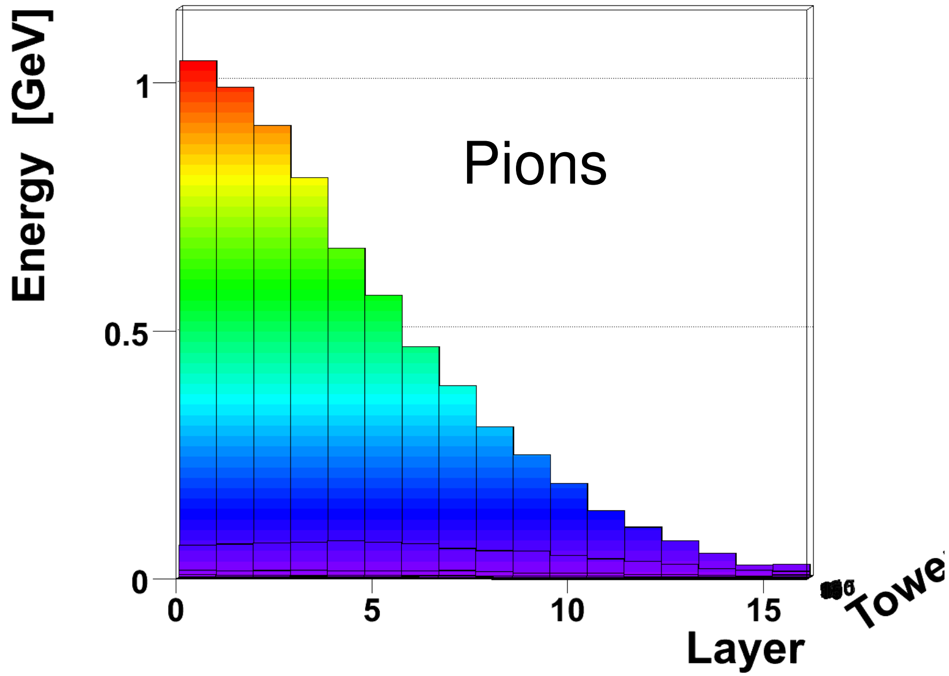
[Stolen from Frank Simon]

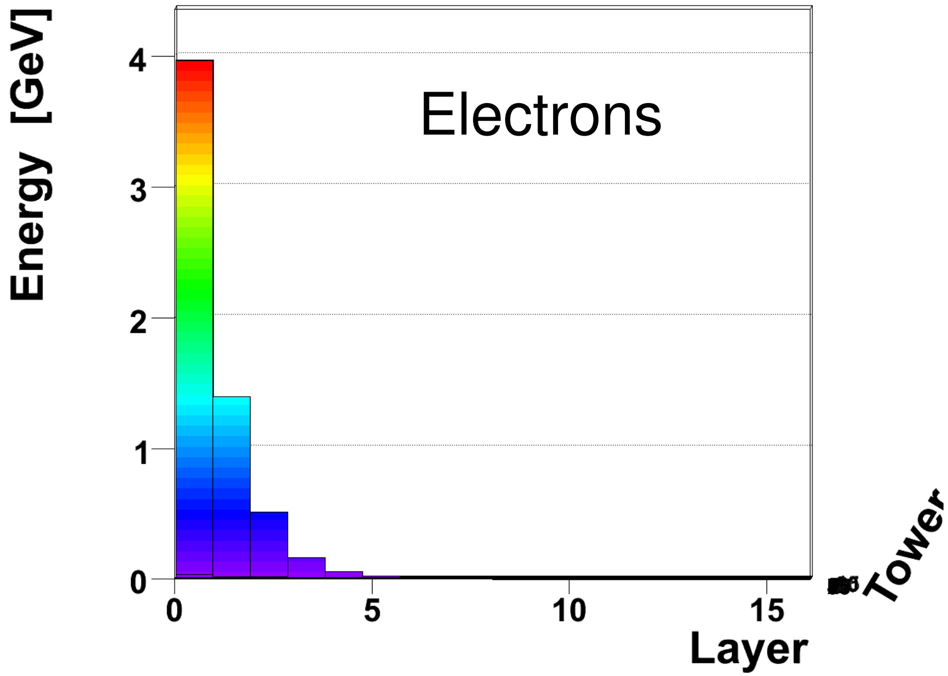
- 50 GeV π has been used
- From the raw scintillator energy follows the calibration factor



➔ Calibration factor = 50/0.431 ≈ 116

Shower shape, 10 GeV, Fluka, 1-4-4-8





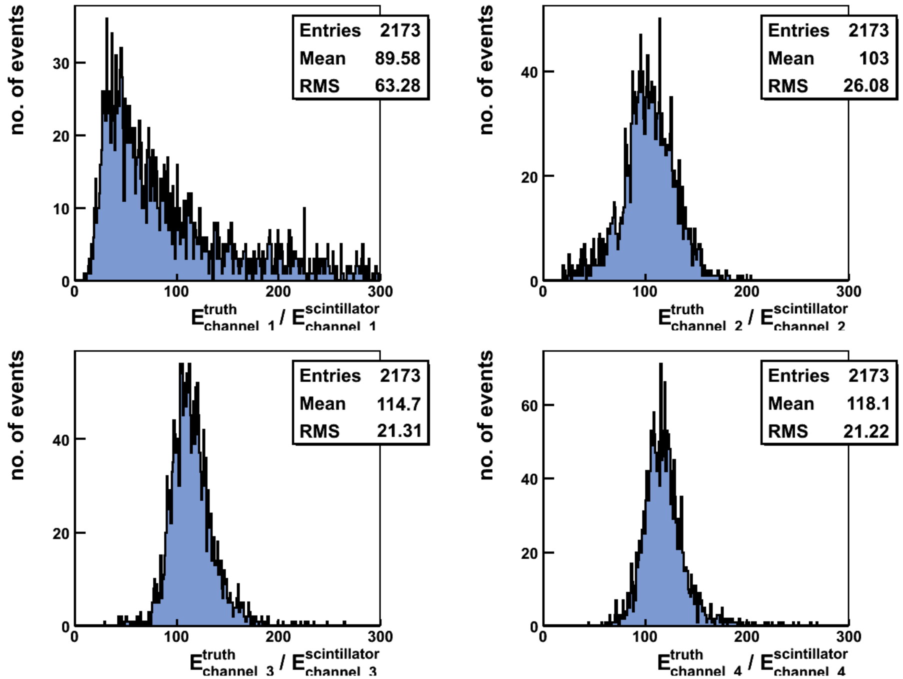
- Hadronic showers much longer => first layer much more important for Electrons

But: first layer is special: thicker!

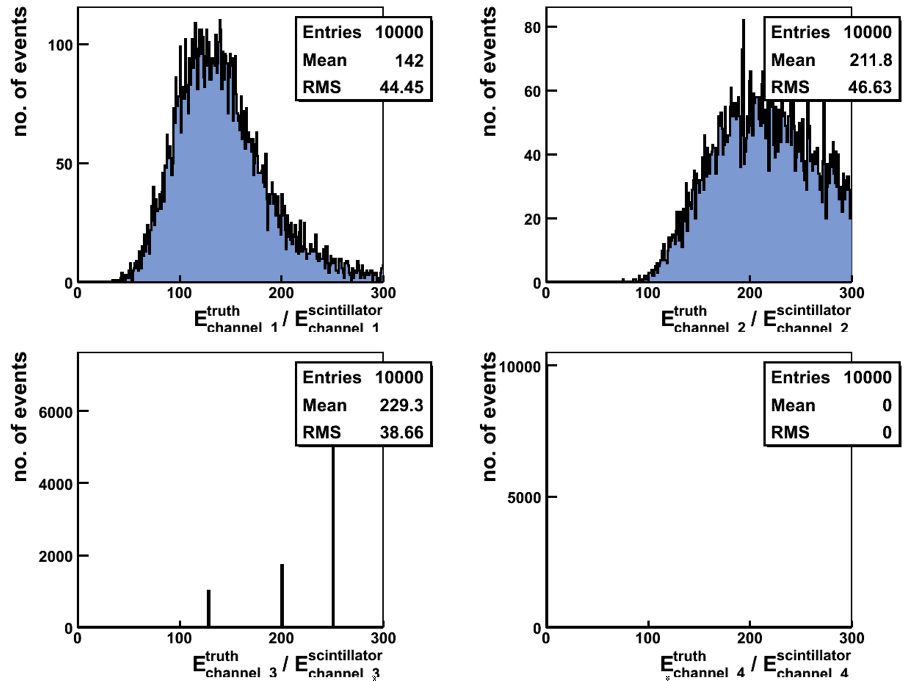
=> Calibration for first layer wrong -> strongly influences electrons and Therefore the e/pi ratio

Calibration, 10 GeV, Fluka, 1-4-4-8

Pions

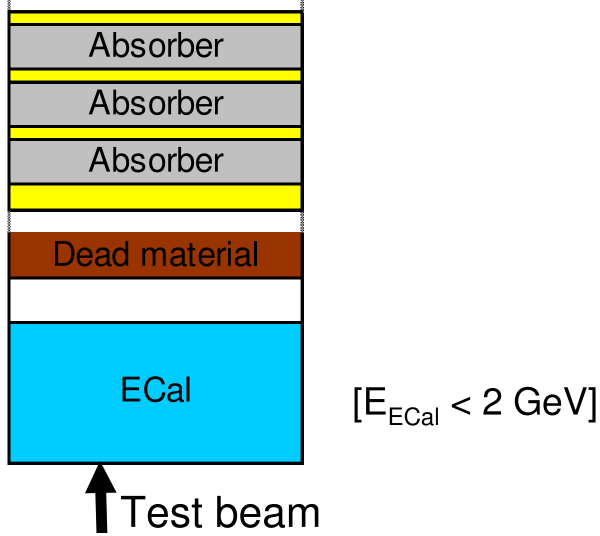


electrons



→ First layer miscalibrated due to construction
→ Influences electrons much more strongly
➔ Reason for strange e/pi ratio.

<u>Solution:</u> shoot test beam directly on hcal
(first layer excluded in this way)
Not realistic but a cross-check for the "real" e/pi ratio
→ Work in progres…(Ilka Geisel)



Cuts

- Particles always shot into the middle of one tower, then cuts are applied:

E (ECAL)	< 2 GeV	
E (HCAL)	> 10% • Egen	
E (max tower)	> 70% • Egen	(max tower = tower with max energy dep.)
Etruth (channel)	> 0.5 GeV	(to be used for weight calculation) (channel = sum of layers on one SiPM)
Etruth	> 2% • Egen	(to be used for weight calculation)
Emeasured	> 2% • Egen	(weight application)
Eleakage	< 20%	
Nevent/channel	> 20	(to be used for weight calculation)