Hadronic Shower Density Weighting
-
Proof of Principle

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The Physics

- Hadronic showers are complicated beasts:
  - Electromagnetic subshowers due to neutral pion production in the cascade
  - charged hadrons
  - isolated neutrons
  - ...
- The calorimeter responds differently to different components of the shower:
  - A higher signal is seen for electromagnetic subshowers than for hadronic subshowers of the same energy

$$\frac{e}{h} > 1$$

- Large fluctuation of relative contributions event by event
- Leads to limited energy resolution of hadronic calorimeters

The Idea

- Identify electromagnetic and hadronic shower components
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  - The higher the energy density of a particular shower (or shower segment), the higher the probability for an electromagnetic subshower

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- ▸ Electromagnetic showers tend to be denser than hadronic showers
  - ▸ The higher the energy density of a particular shower (or shower segment), the higher the probability for an electromagnetic subshower

- Electromagnetic subshowers get lower weights in the overall energy sum than hadronic subshowers
- ▸ Software compensation

Signal Weighting: The Method

- No black and white between em and hadronic showers: Think greyscale!
- Total energy in one detector is binned according to energy density, each bin has total energy (in MIP) of E_i

$$E_{weighted} = \sum E_i \, \omega_i$$

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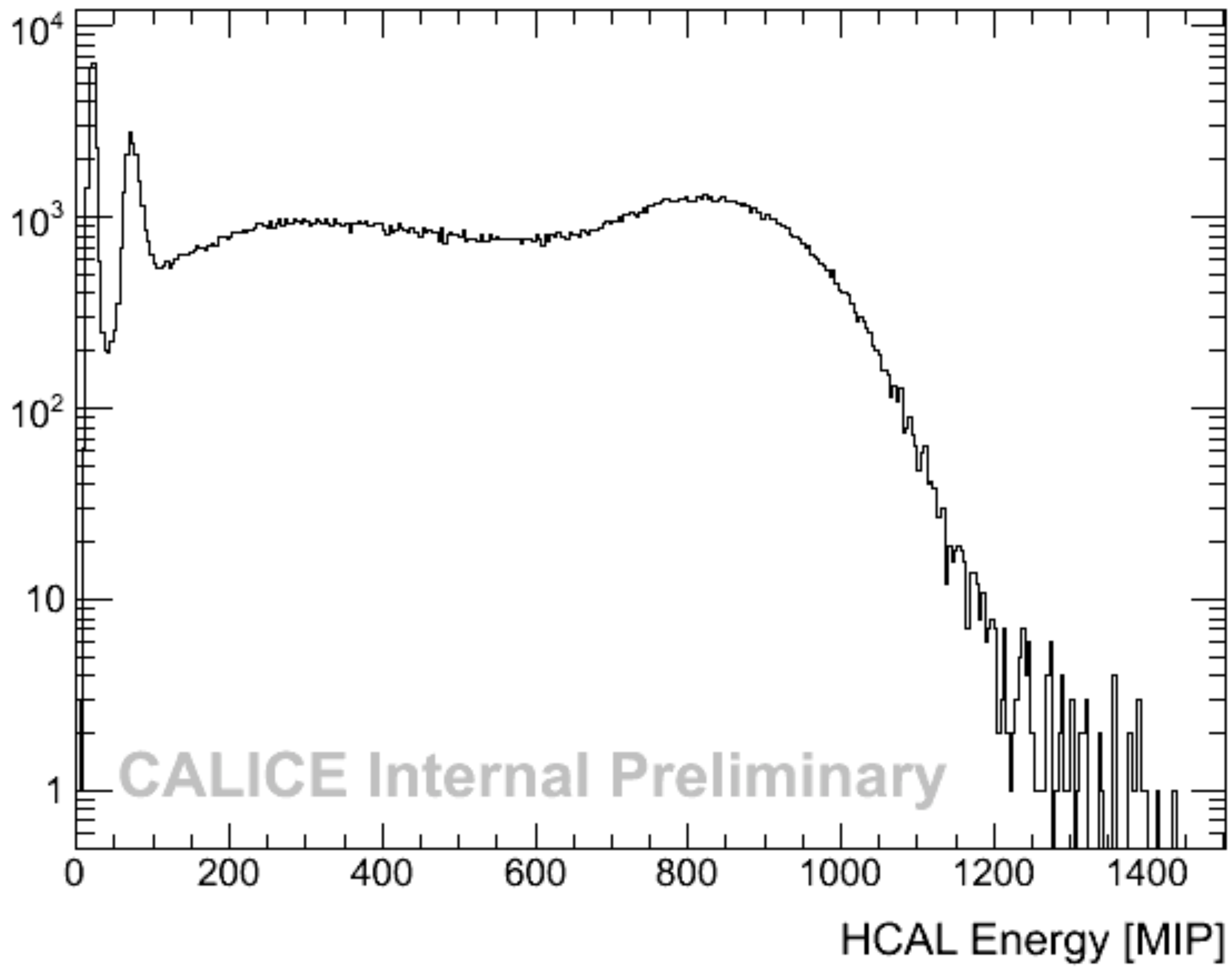
- Chose weights to minimize the energy resolution:
  - Define a χ^2 to be minimized:

$$\chi^2 = \frac{1}{n_{ev}} \sum_{ev} \left(\sum_i E_i \, w_i - E_{true} \right)^2$$

  - χ^2 calculated over all events in one run, MINUIT-minimization of weights is performed

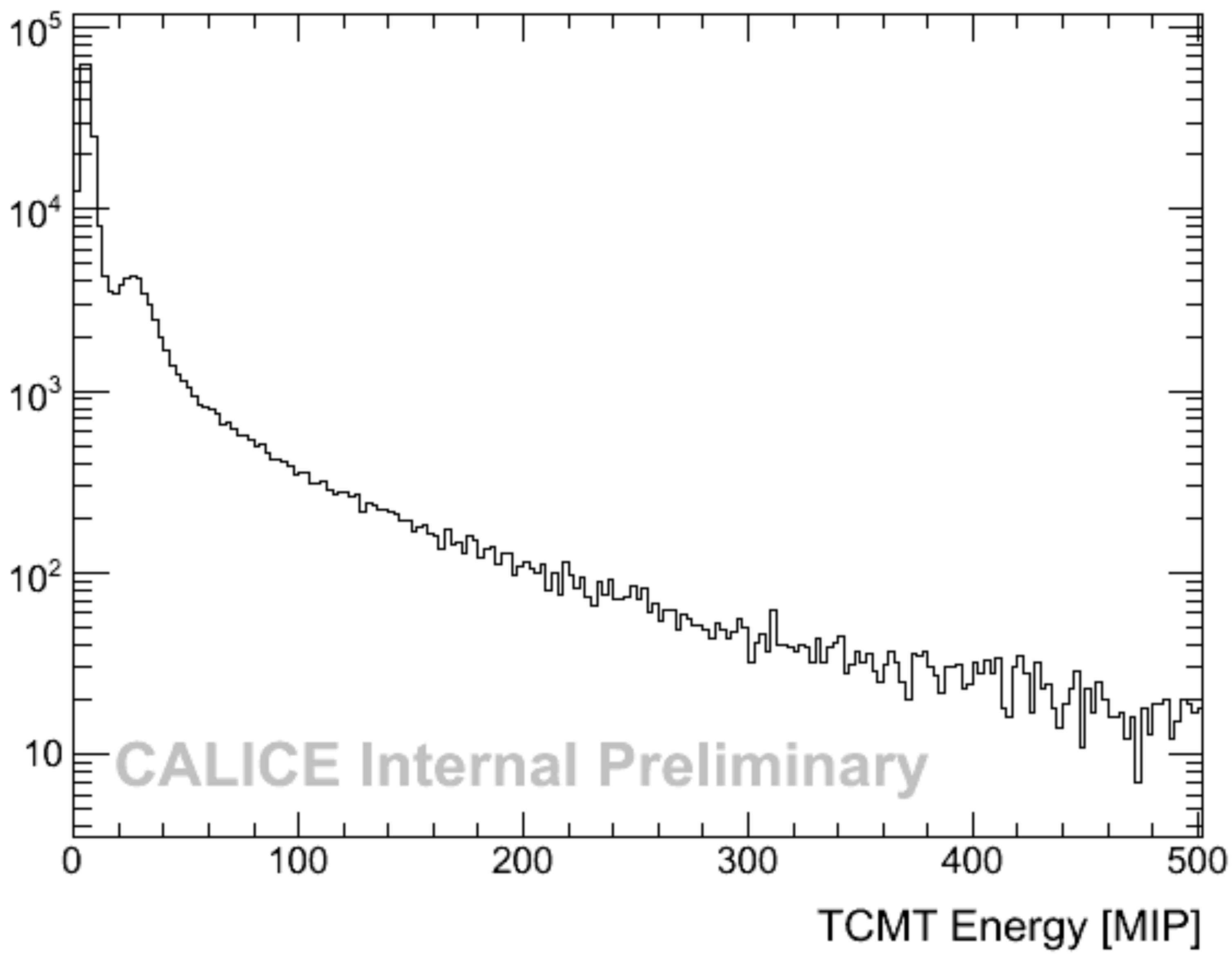
The Input: Energy Distributions: HCAL

Run 330836
25 GeV
negative pions



- Energy distribution in HCAL, no cuts (not even on trigger...)

The Input: Energy Distributions: TCMT



Run 330836
25 GeV
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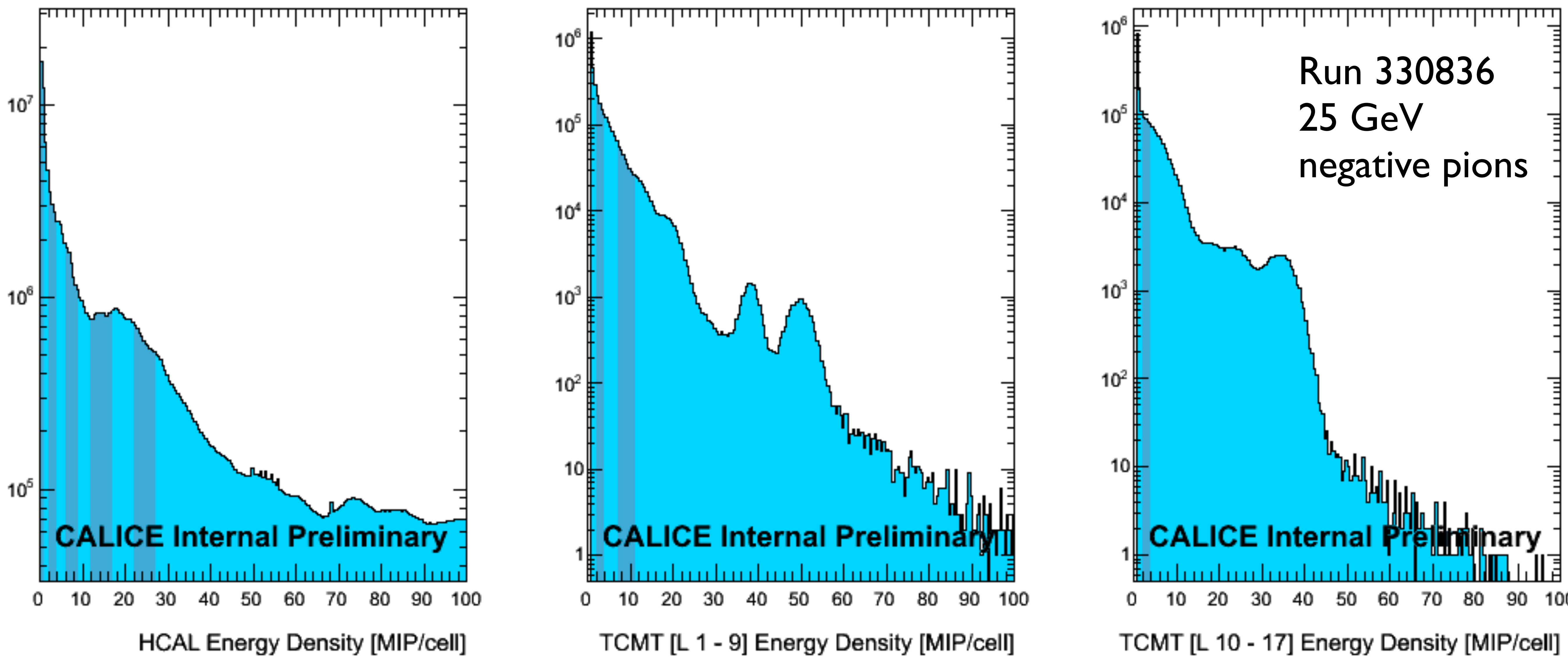
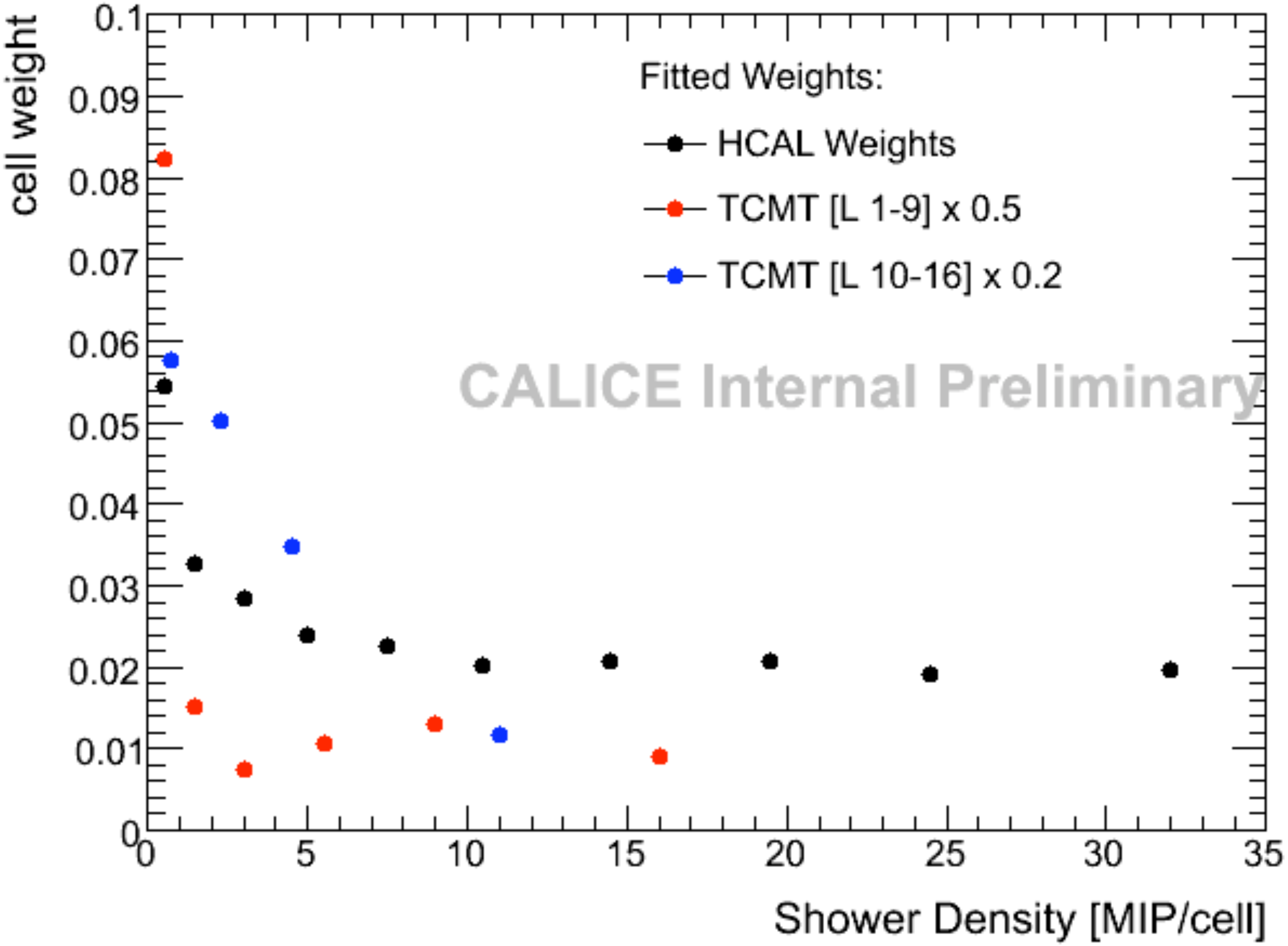
- Energy distribution of TCMT (no cuts, not even on trigger...)

Energy Densities



- Densities calculated cell by cell, using cell energy only
  - for HCAL, the density is calculated based on 3 x 3 cm cells (-> for 6 x 6 cells with the same energy, the density would be 4 times lower)

Fitted Weights

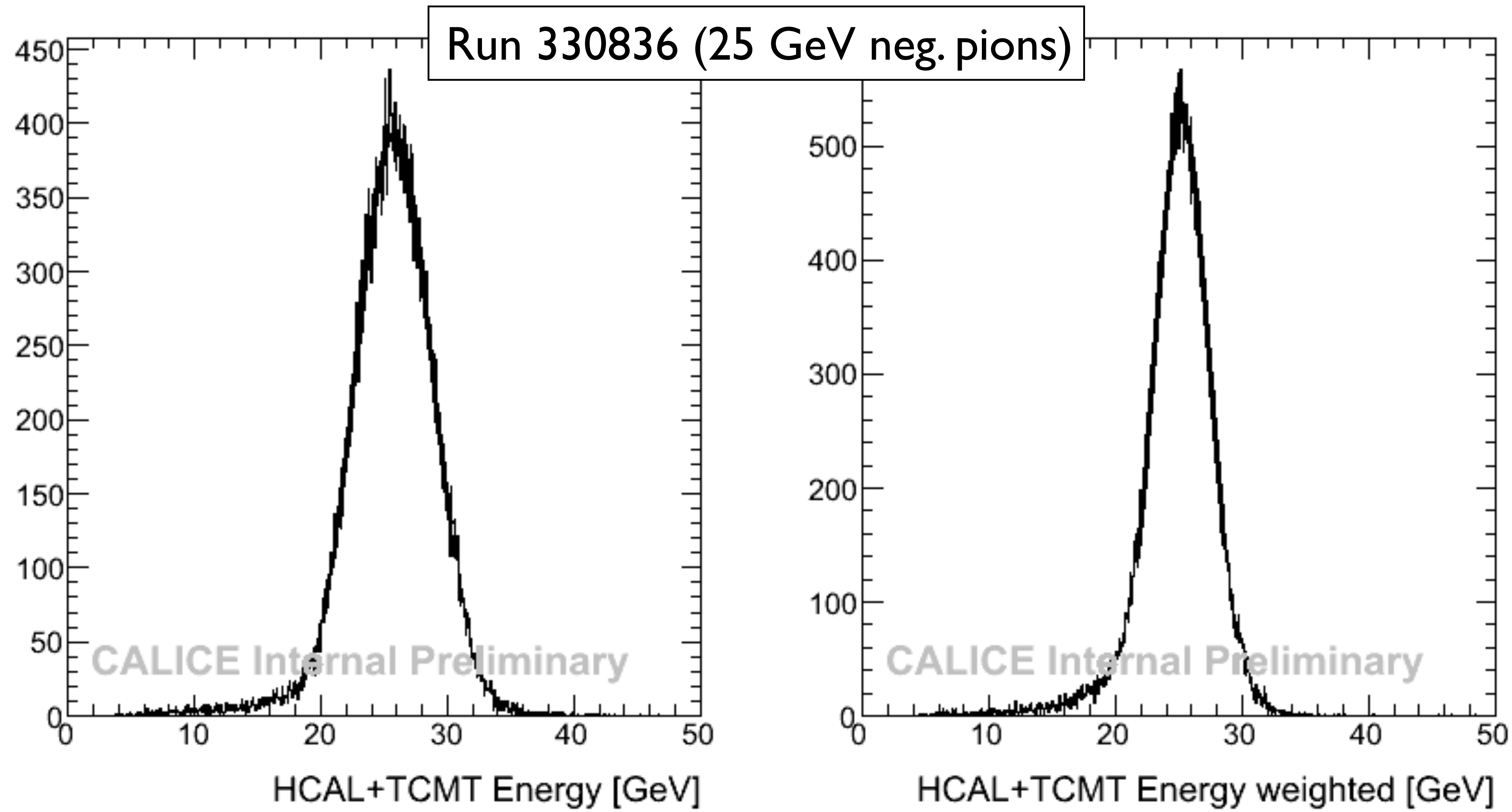


Weights determined from Run 330650 (25 GeV negative pions)

track-like signal in ECAL: 20 MIP < E < 70 MIP

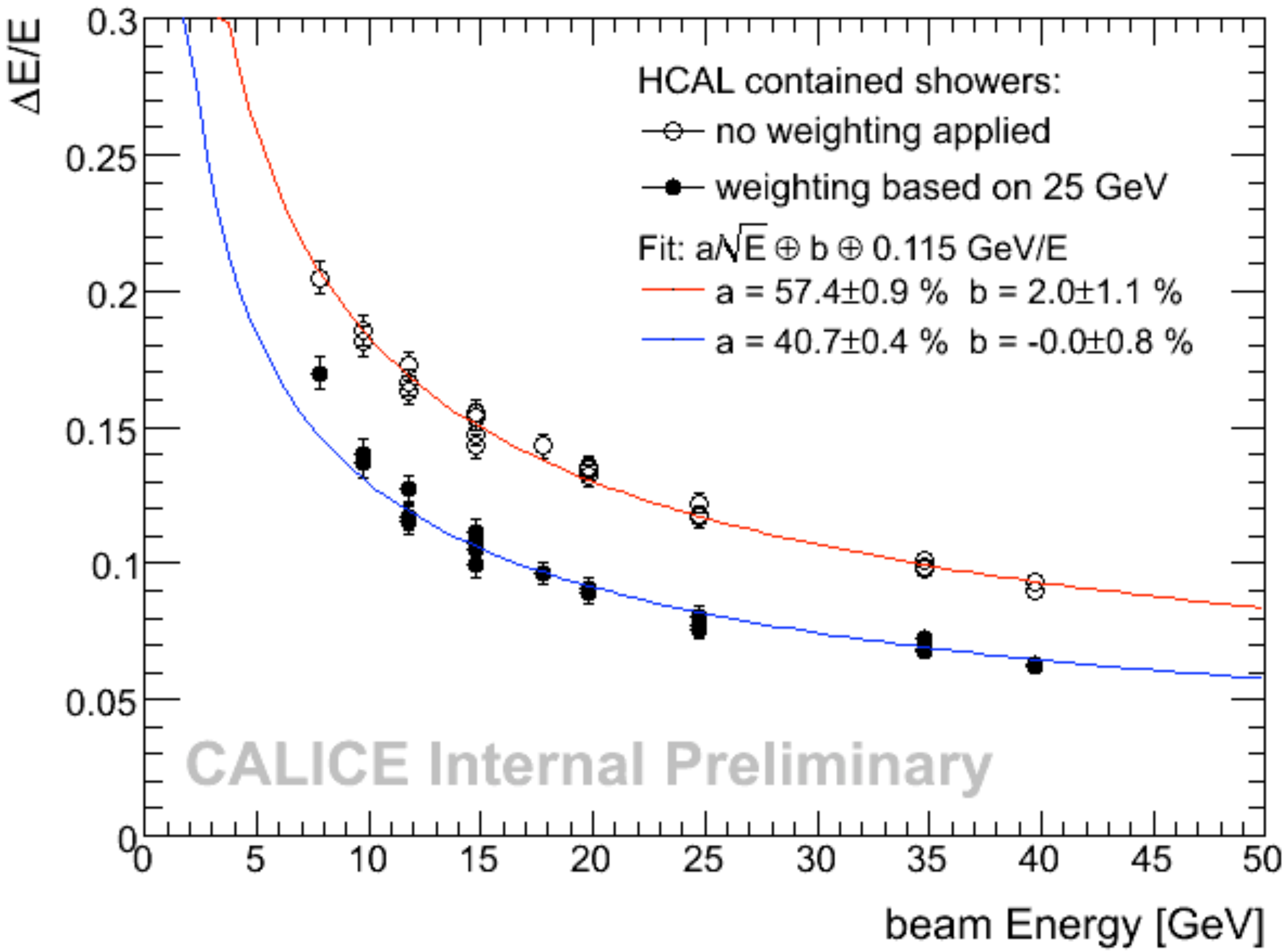
- Well-behaved weights in HCAL
- First layers of TCMT: Excessive 1st weight, large uncertainties
- Second section of TCMT: Large uncertainties (might not be curable)
- Noise gets amplified: contributes only to first bin/weight

Effects on Resolution



- Comparison of unweighted (well: One weight for HCAL, TCMT 1st, TCMT 2nd each) and weighted energy distributions
- ▸ Significant reduction of width

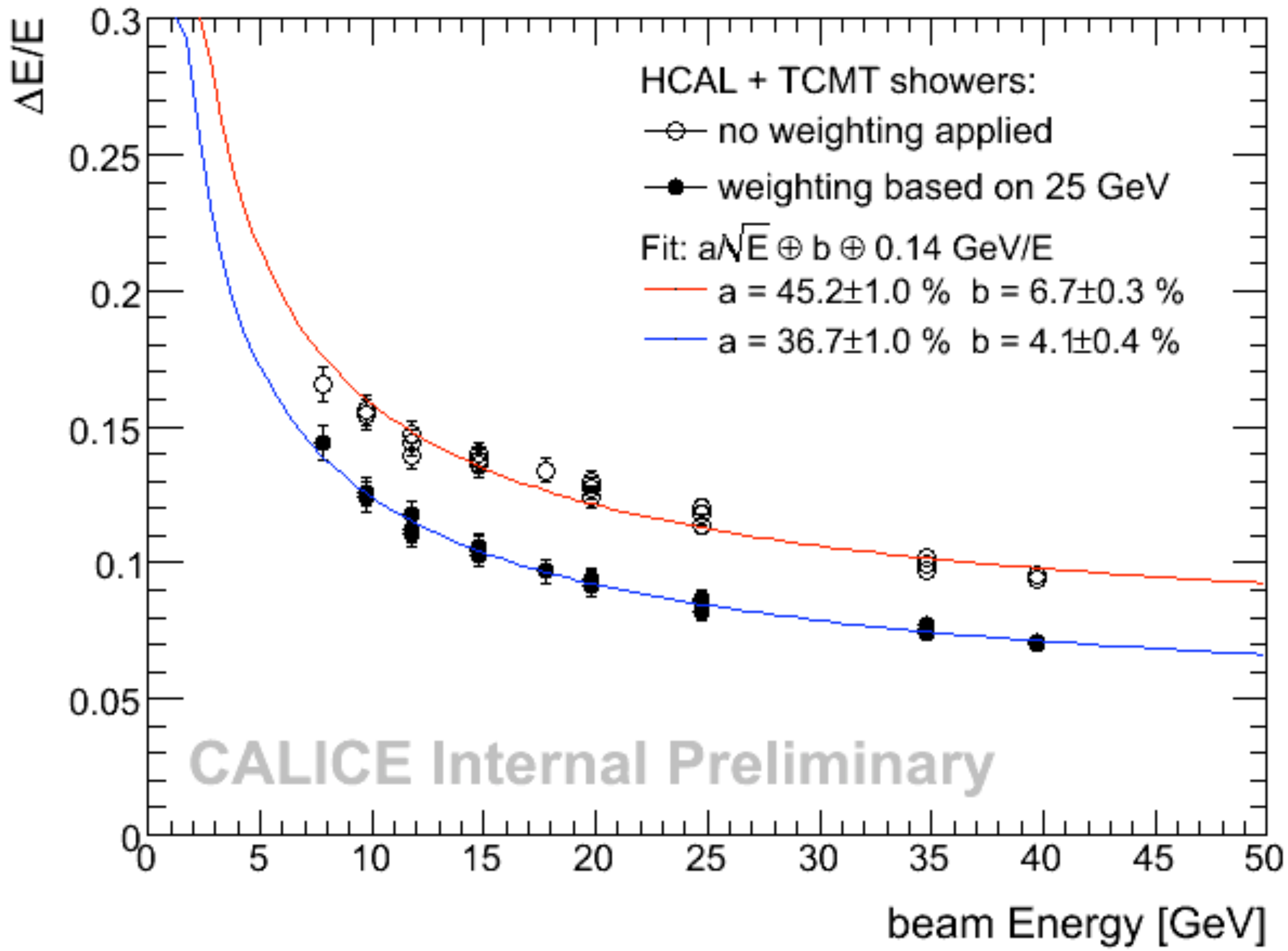
Resolution: HCAL Contained Showers



HCAL containment:
ECAL < 70 MIP
TCMT < 11 MIP

- Weights determined at one fixed Energy (25 GeV)
  - Improvement of Resolution over an extended energy range
  - Fits not to be taken seriously!

Resolution: HCAL + TCMT



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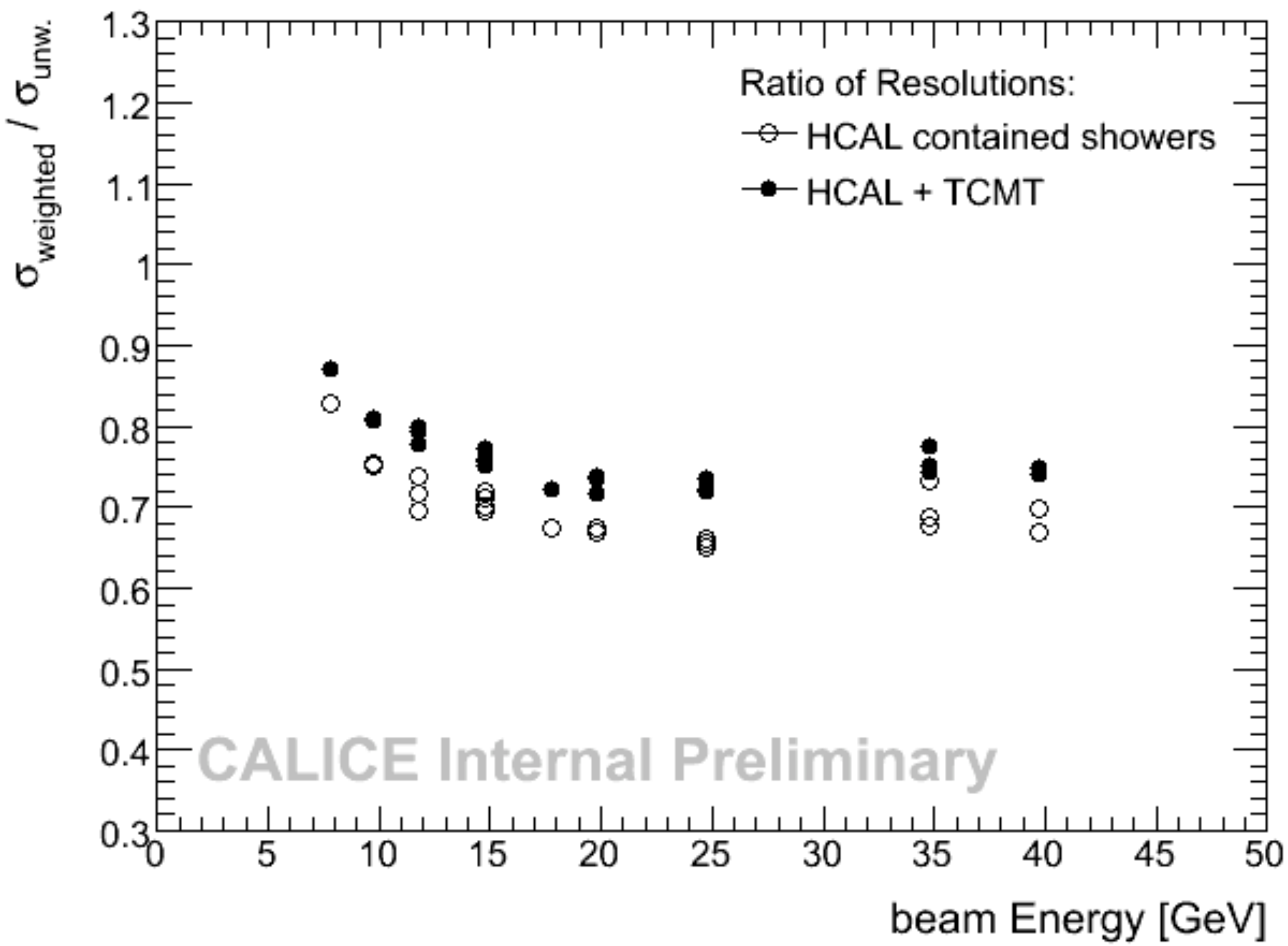
Resolution: Improvement by Weighting



- Improvement of Resolution up to 30% for HCAL contained showers, 25% for HCAL +TCMT
- Deterioration at low E -> Energy dependence of weights

Summary

- Signal weighting based on density of energy deposits can significantly improve hadronic energy resolution

- First prove of principle studies using energy-independent weights determined at 25 GeV
- Up to 30% improvement in energy resolution

- A lot to be done:
  - Clean selection of event sample
  - Clean definition of χ^2
  - Improvement of fit stability
  - Optimization of number and range of weights
  - Energy dependence
  - ...