Hadronic Energy Reconstruction
&
Density Weighting

Frank Simon
MPI for Physics & Excellence Cluster 'Universe'
Munich, Germany

CALICE Collaboration Meeting, Manchester, UK, September 2008

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Calorimeter for ILC

Excellence Cluster Universe

Outline

- Hadronic energy: motivation
- The principle of density weighting
- Hadronic energy reconstruction and resolution in HCAL , HCAL + TCMT
- Full CALICE detector: ECAL + HCAL + TCMT
- Linearity of response
- Summary

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
  1. Direct topological identification: Deep analysis
  2. Statistical identification based on energy density

The Idea

- Identify electromagnetic and hadronic shower components
  1. Direct topological identification: Deep analysis
  2. Statistical identification based on energy density

- 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

The Idea

- Identify electromagnetic and hadronic shower components
  1. Direct topological identification: Deep analysis
  2. Statistical identification based on energy density

- 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

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

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

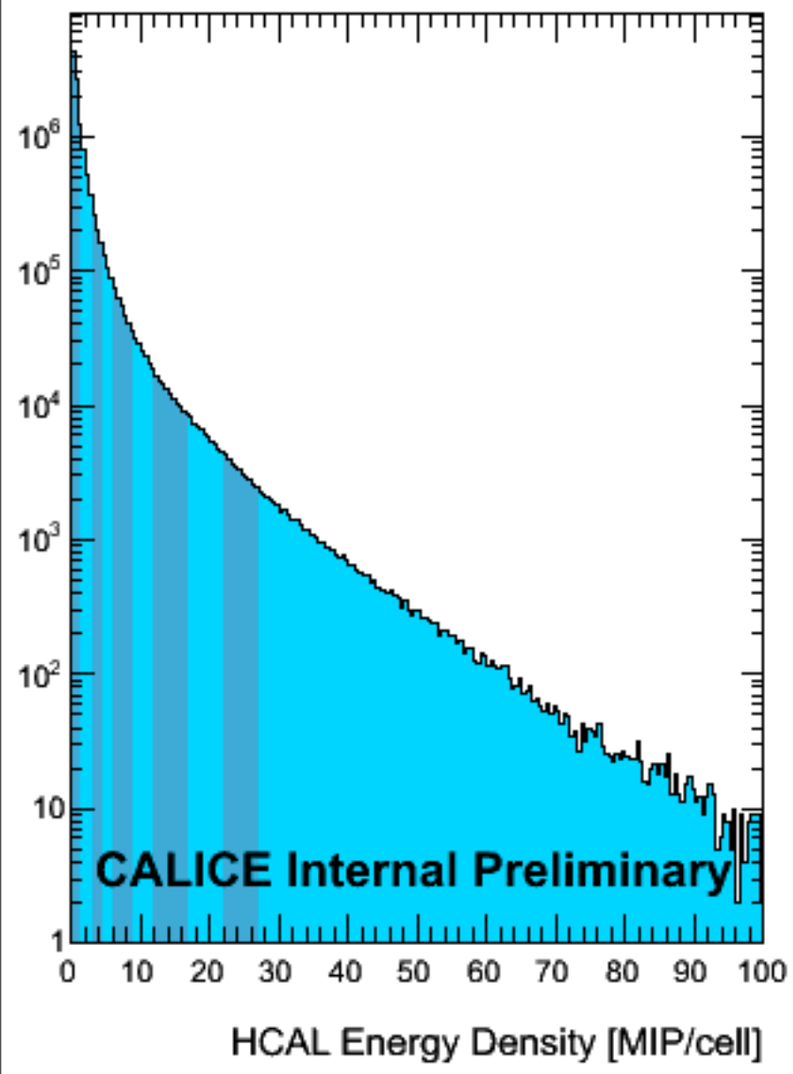
$$E_{weighted} = \sum E_i \, \omega_i$$

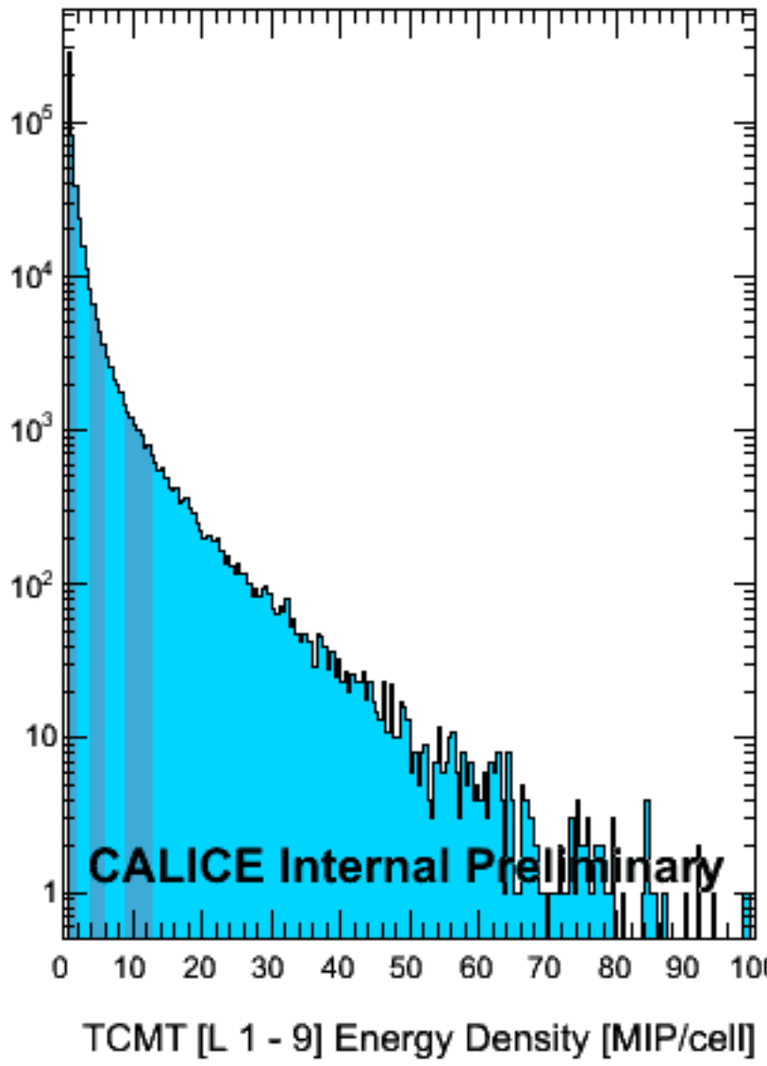
- Choose weights to minimize the energy resolution:
- Define a χ^2 to be minimized:

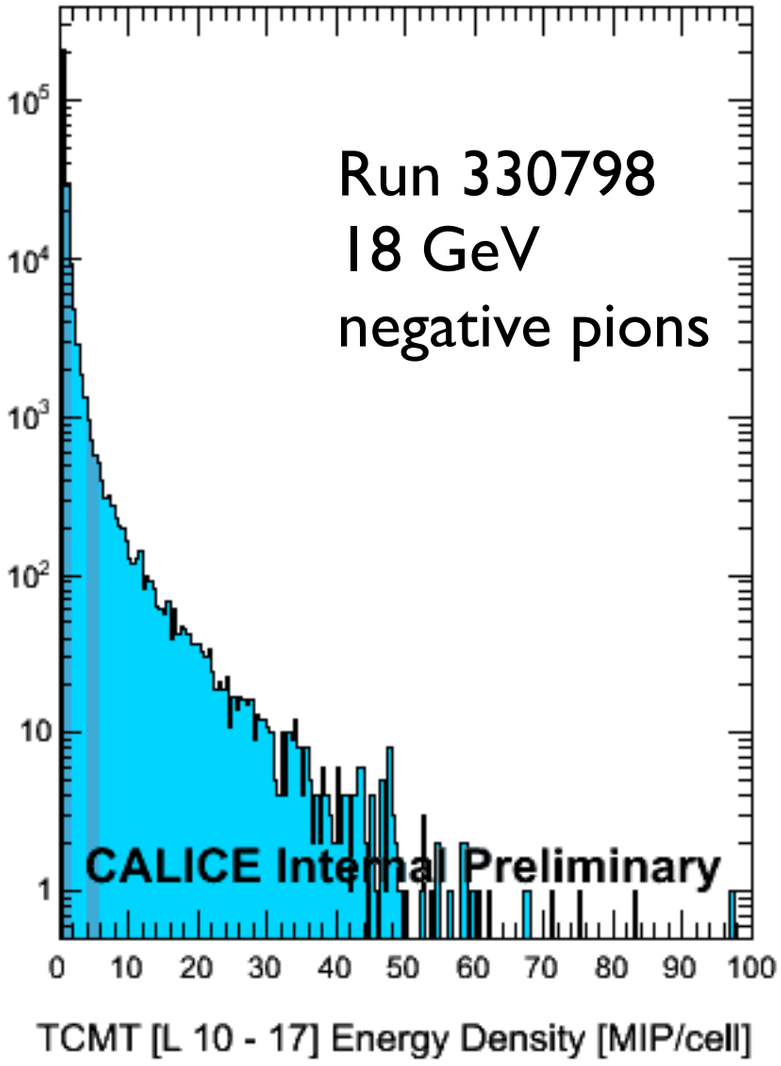
$$\chi^2 \;=\; \frac{1}{n_{ev}} \sum_{ev} \left(\sum_i E_i \, w_i \;-\; E_{true} \right)^2$$

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

Energy Densities

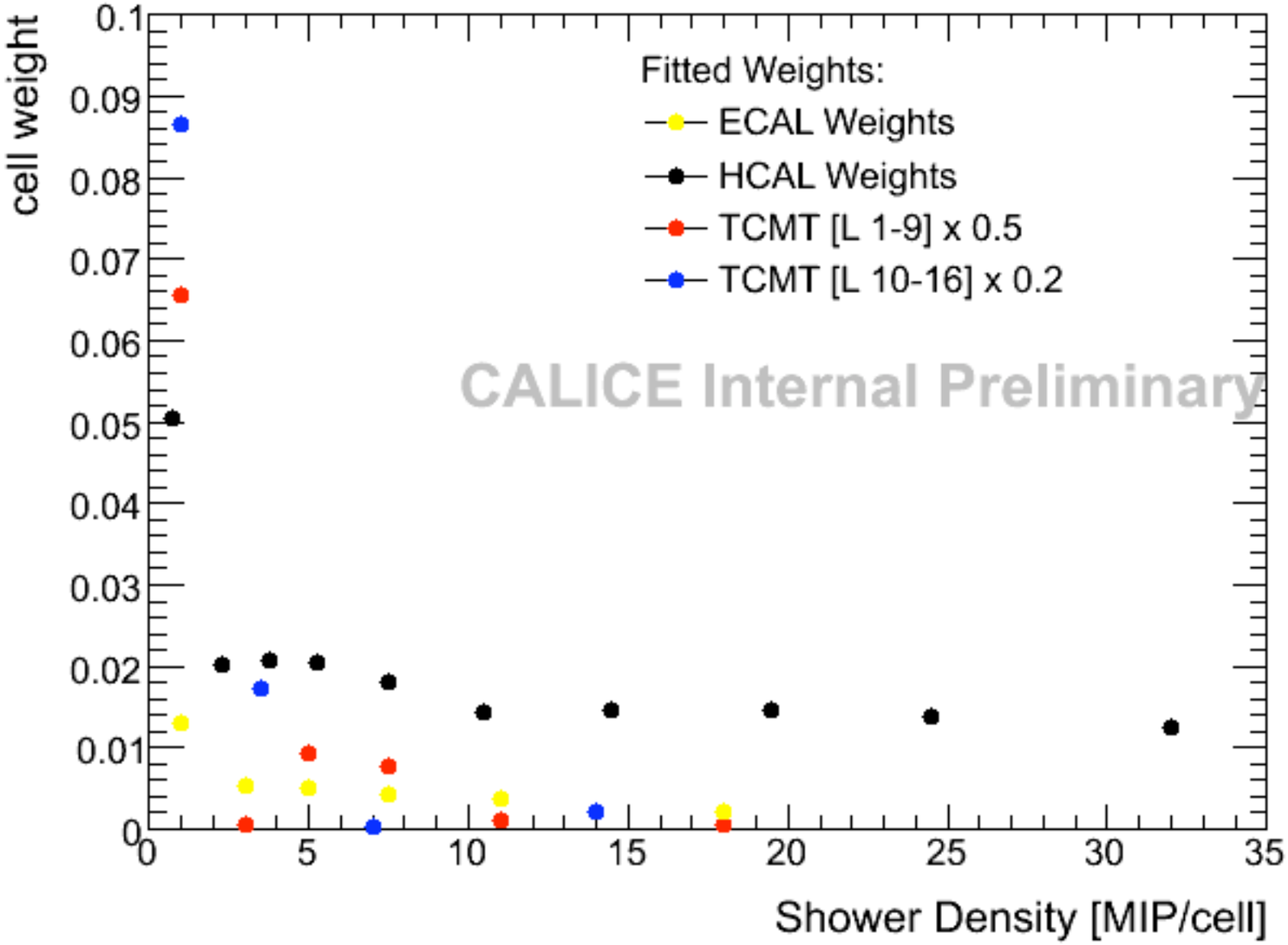






- Densities calculated cell by cell, using cell energy only
  - for HCAL, the density is calculated based on 3 x 3 cm cells (-> for 6 x 6 cells with the same energy, the density would be 4 times lower)

Fitted Weights



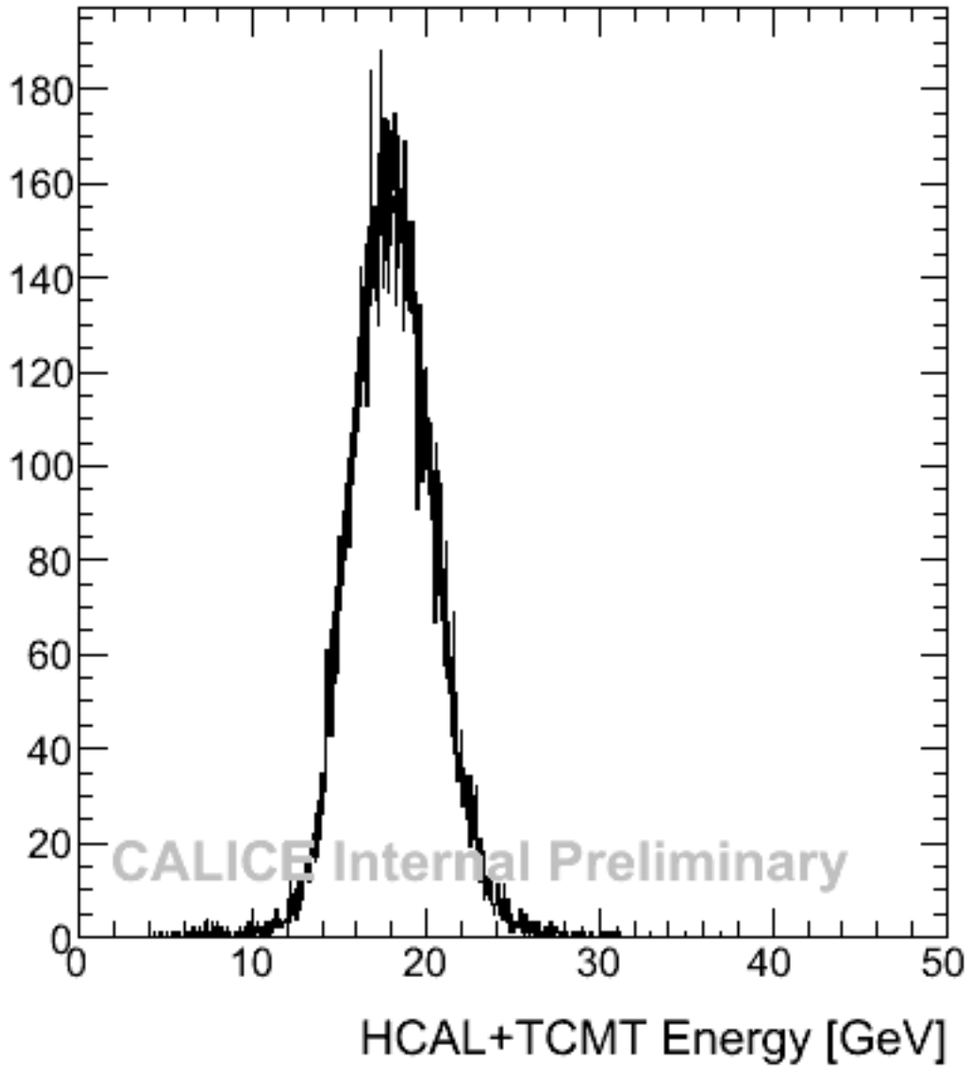
Weights determined from Run 330798 (18 GeV negative pions)

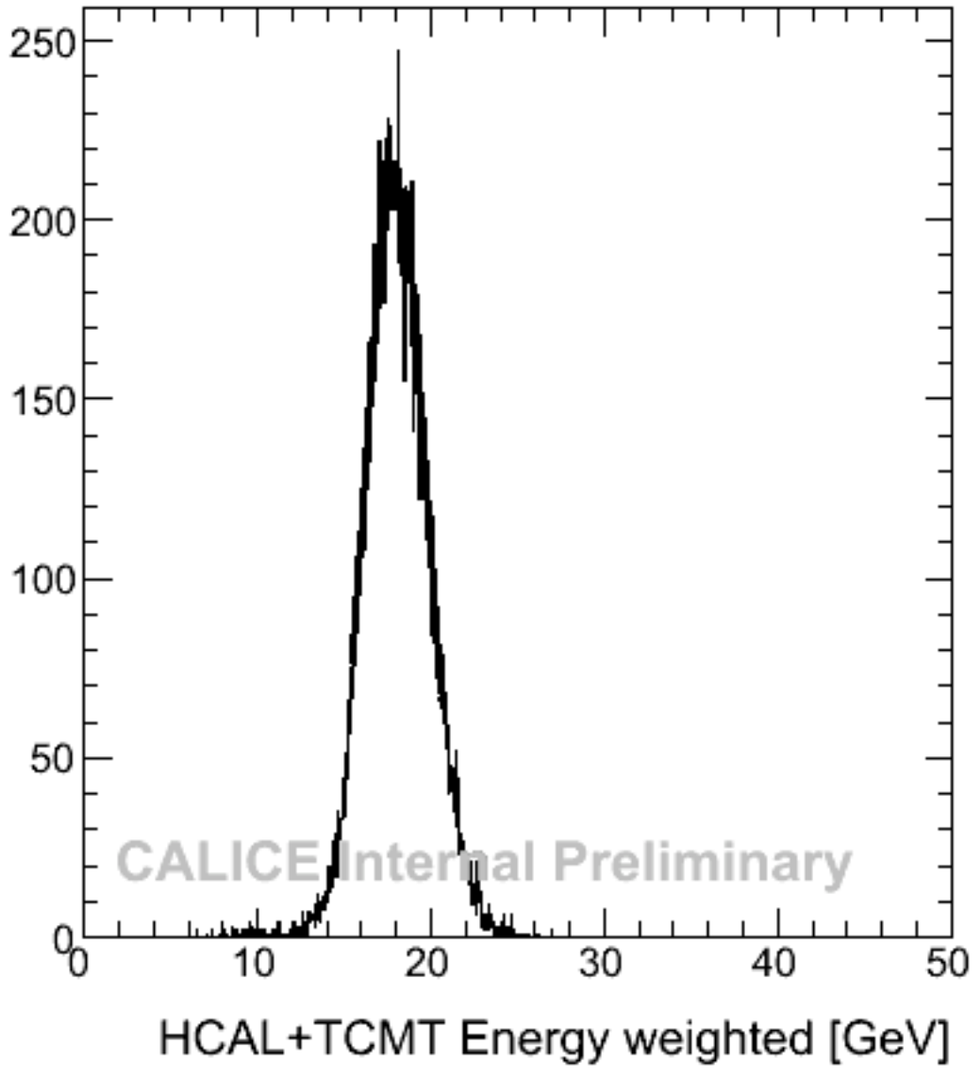
beam trigger required
Minimum of 100 MIPs and 50 Hits above threshold in HCAL

- Well-behaved weights in HCAL, ECAL, but large uncertainties, fit convergence problematic
- 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

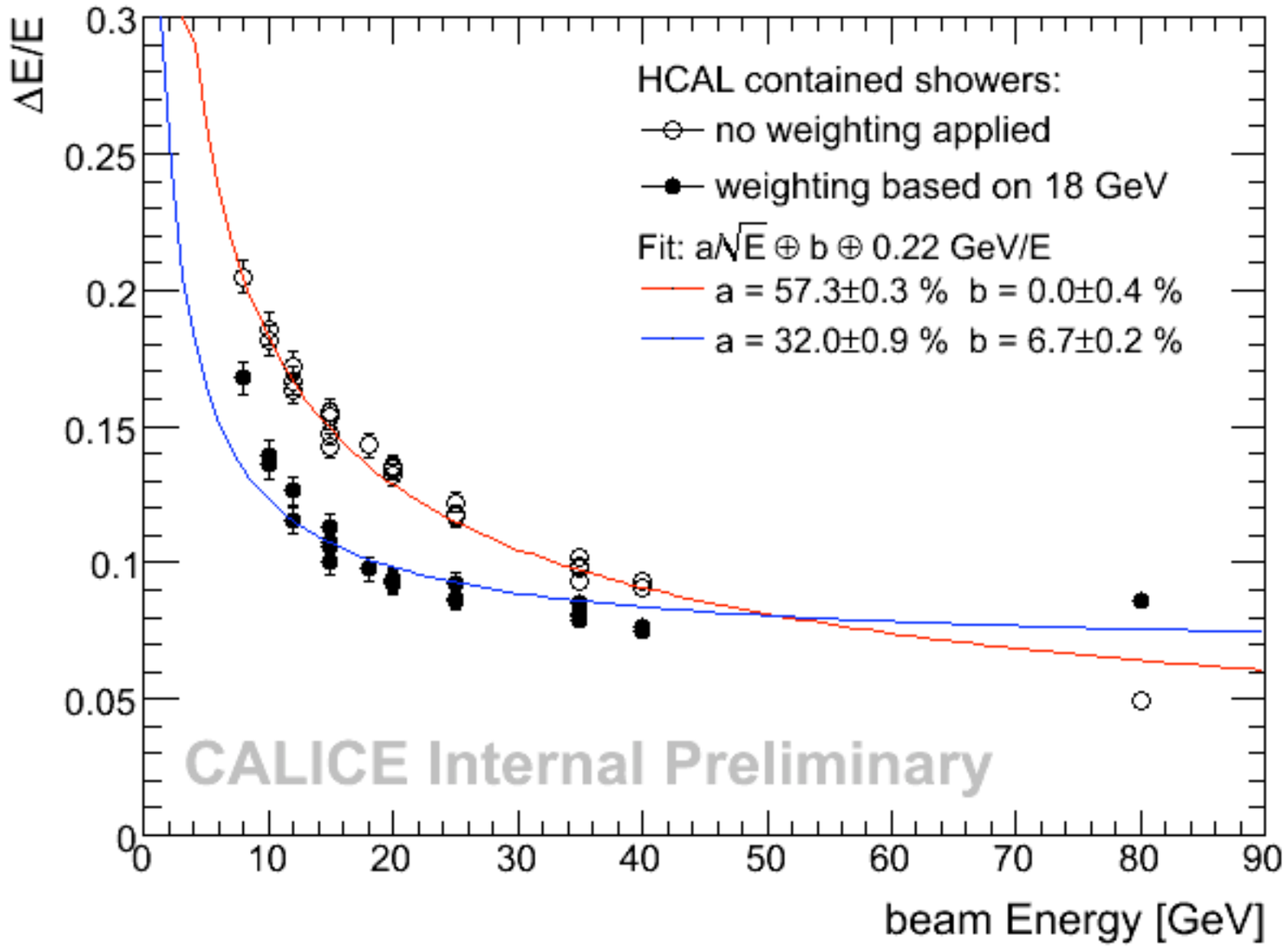
Run 330798 (18 GeV neg. pions)





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

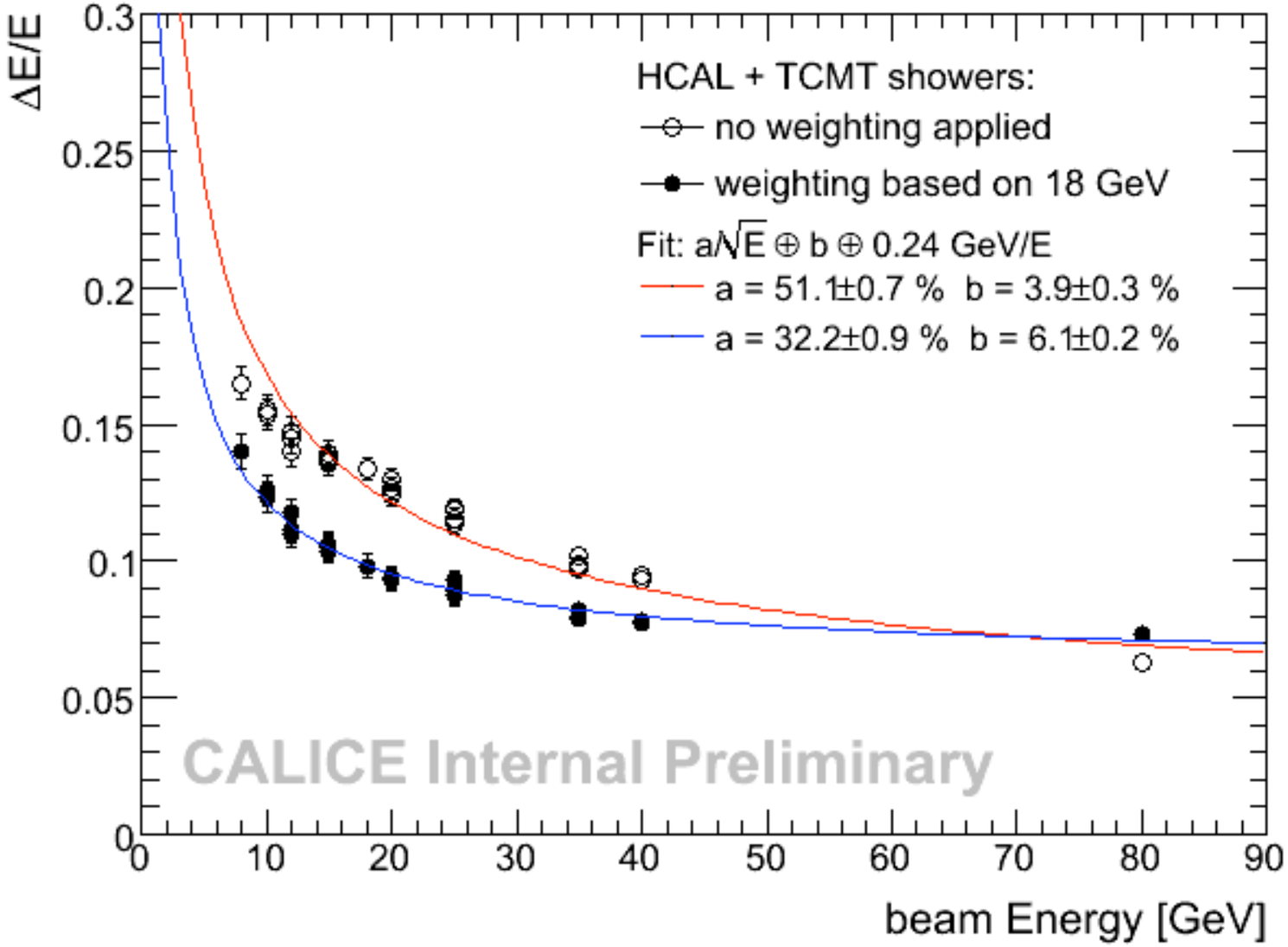
Resolution: HCAL Contained Showers



HCAL containment:
ECAL < 70 MIP
TCMT < 11 MIP

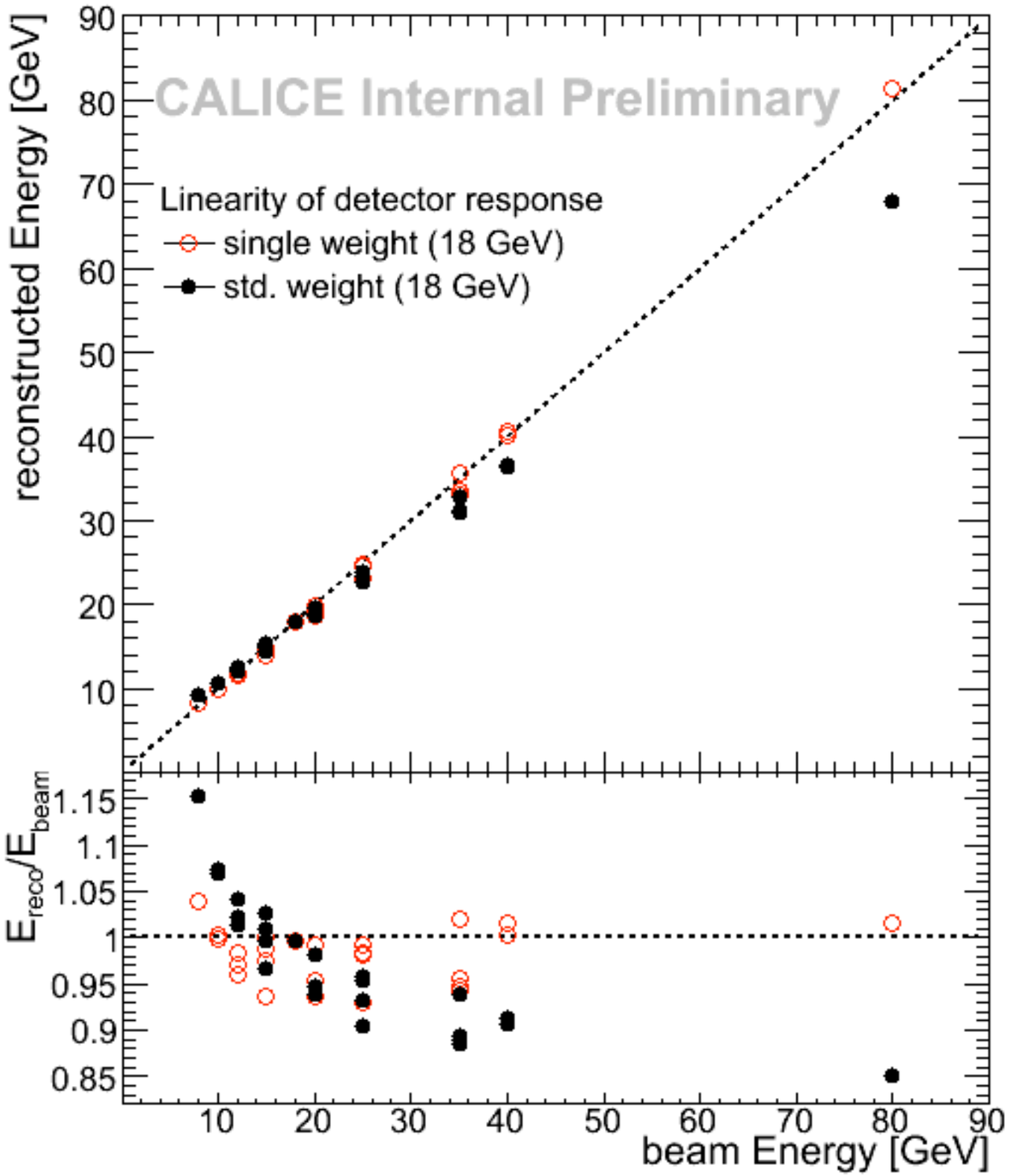
- Weights determined at one fixed Energy (18 GeV)
- Improvement of Resolution over an extended energy range, breaks down at high energy
- Fits not to be taken seriously!

Resolution: HCAL + TCMT



- Weights determined at one fixed Energy (18 GeV)
- Improvement of Resolution over an extended energy range, breakdown at high Energy
- Fits not to be taken seriously!

Linearity with and without Weighting



- Application of weights compromises linearity of the detector response
- Energy dependence of weights!

Expanding the View: Adding ECAL

- For an analysis such as this the ECAL is daunting:
  - 3 different samplings: Ideally treated as three separate detectors
  - Low hadronic shower probability in first section(s), hard do determine weights

- The strategy:
  - Treat ECAL as a single detector, hard-code sampling fractions: multiply energy deposit in first ten layers by 1, second 10 by 2, third 10 by 3
  - As a first round, determine single weights, one for each detector (ECAL, HCAL, TCMT, TCMT last layers)
  - MIP -> GeV conversion

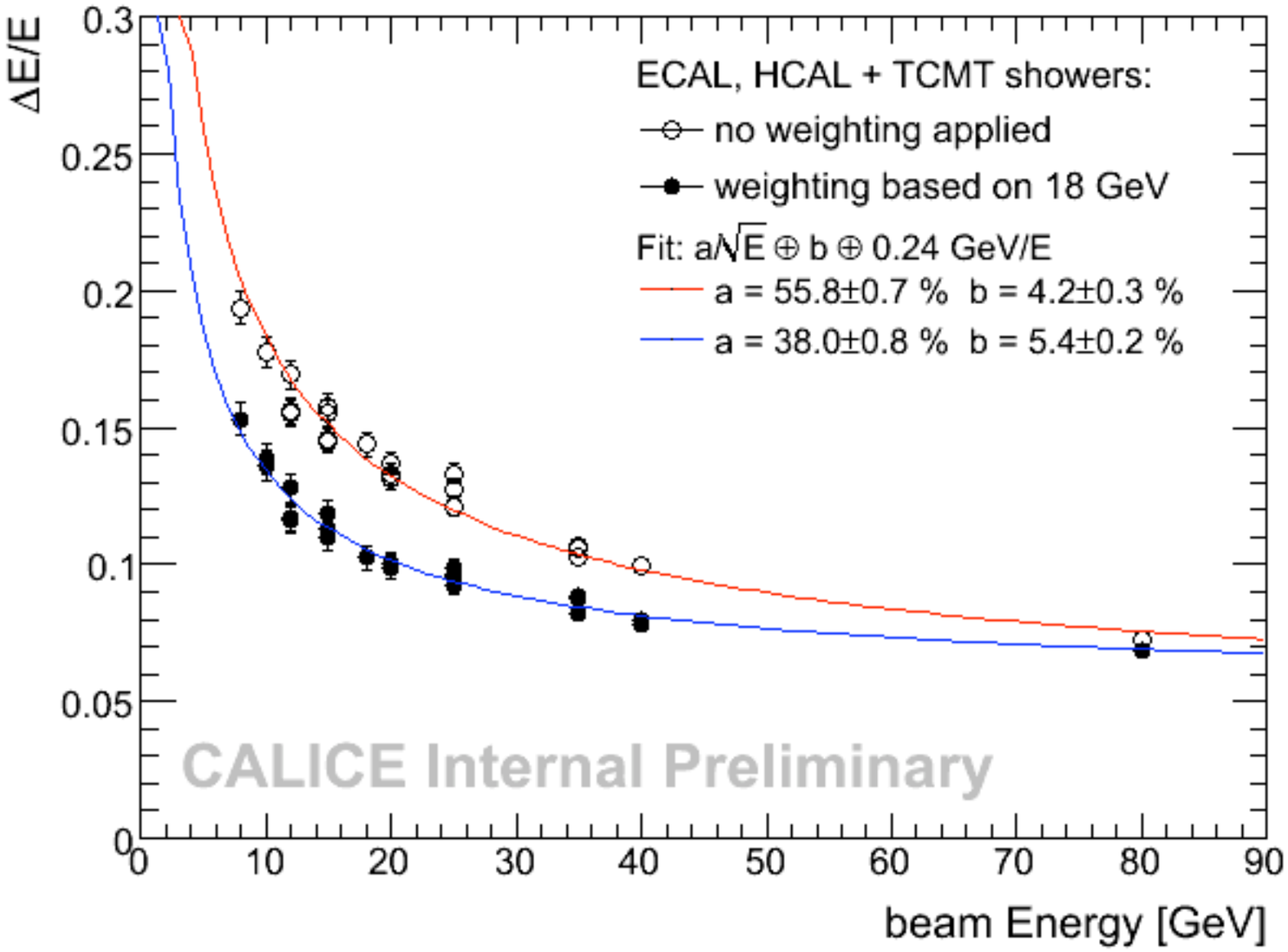
    ECAL: 0.0047

    HCAL: 0.028

    TCMT: 0.03

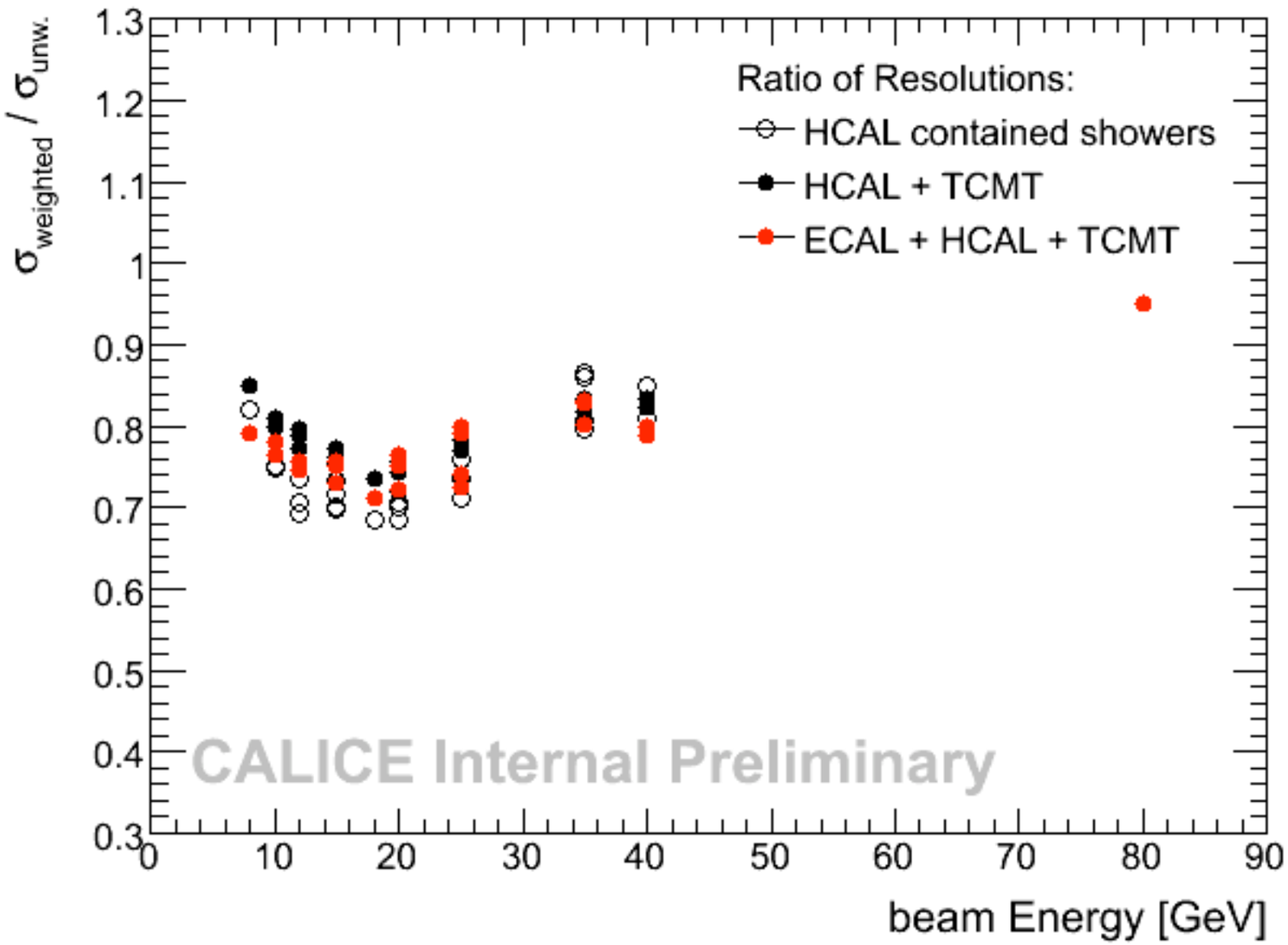
    TCMTC: 0.126

Energy Resolution: Full Detector



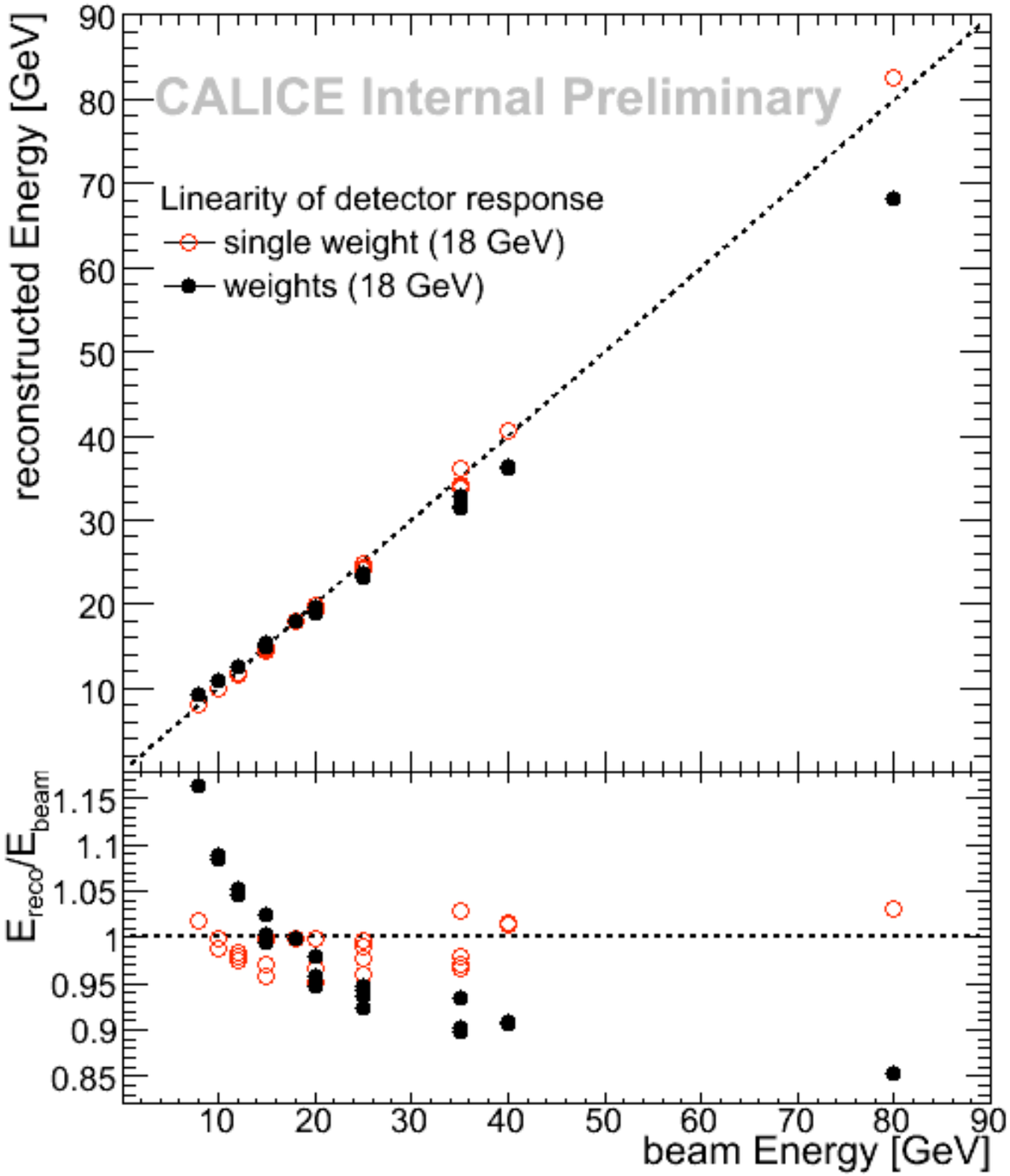
- Weights determined at one fixed Energy (18 GeV)
- Improvement of Resolution over an extended energy range, breakdown at high Energy
- Fits not to be taken seriously!

Full Detector: Improvements in Resolution



- Good improvement of resolution using a single weight, but beware....

Full Detector: Linearity



- Using weights at one fixed energy severely compromises the linearity of the detector response
  - This is also true for HCAL and HCAL + TCMT without ECAL

- Improvement of resolution will be compromised by this breakdown of linearity

Improving Fit Stability: Parametrization

- The fitted weights can be reasonably well approximated by a function with four parameters:

$$\alpha\, e^{-\beta\, x} + \frac{\gamma}{x} + \delta$$

x is the center of the respective density bin

- slight reduction of the number of free parameters in the fit, smooth behavior of weights is enforced

- The analysis is constantly evolving: Parametrization currently only tested for full combined data (ECAL, HCAL, TCMT)
  - Still problems with fit convergence...
  - only limited improvement of linearity of response with a single set of weights, and with a small penalty on the achieved resolution improvement

Pushing for Linearity

- First try to improve the linearity in the response with a weighting scheme
  - Energy dependence of weights is mandatory
  - use a simple parametrization of the weights (simplification of weight function):

$$\alpha\, e^{-\beta\, x} + \gamma$$

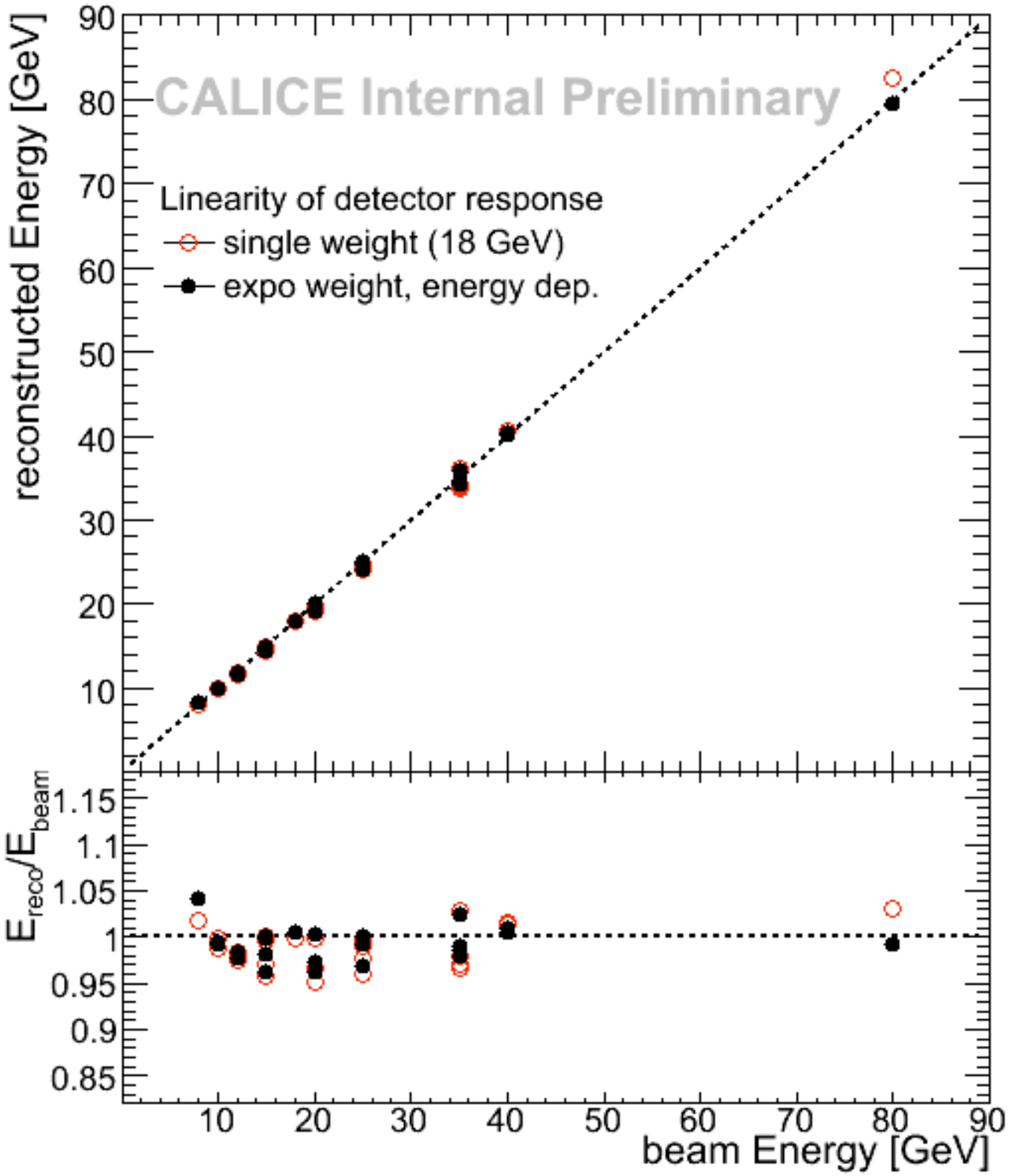
x is the center of the respective density bin

- use a simple parametrization of the energy dependence of the weights:
  α, γ are energy independent

$$\beta \;=\; p_1\, e^{p_2\, E} + p_3$$

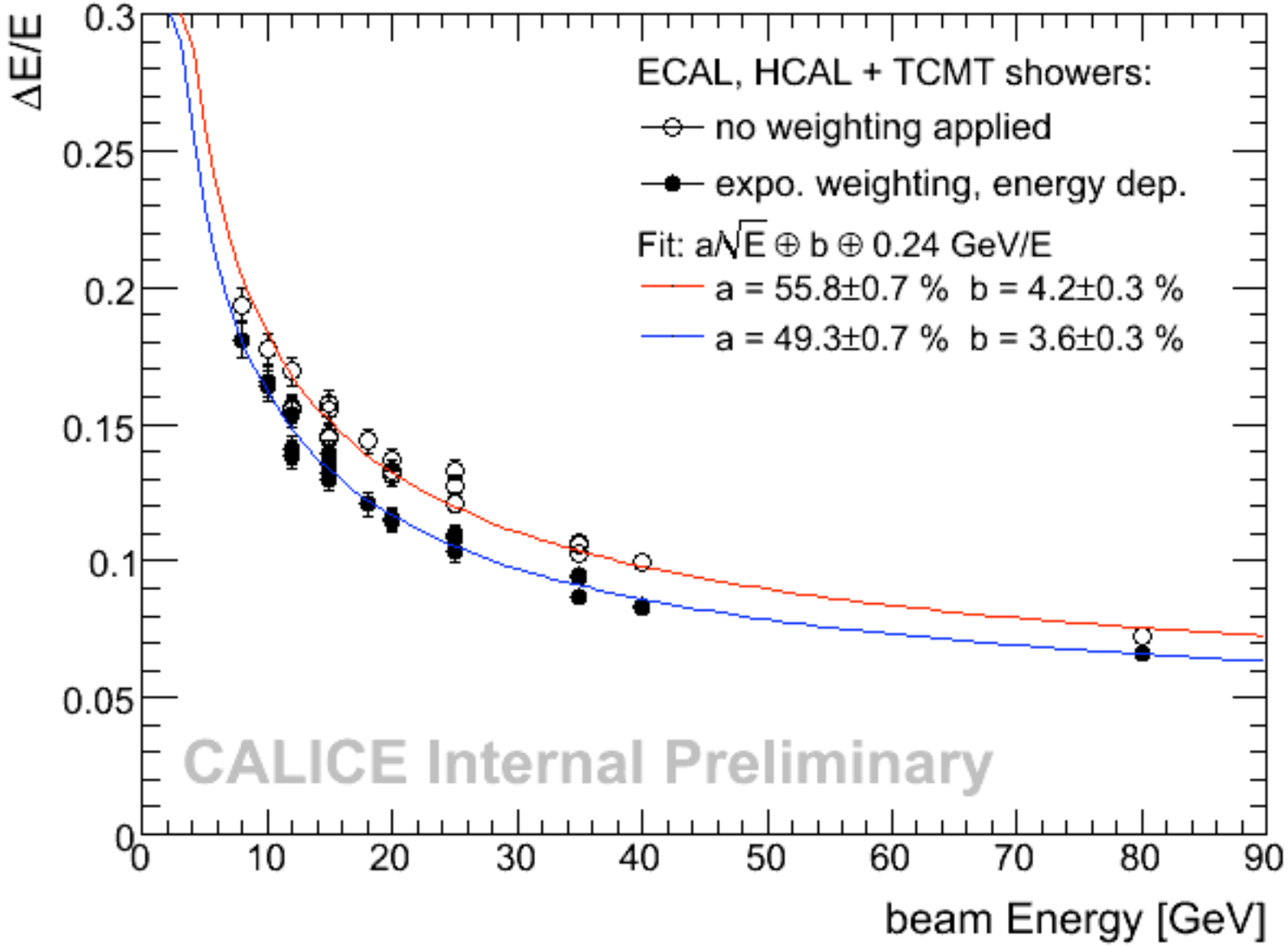
- parameters α, γ are determined for 18 GeV (run 330798), parameters p_1, p_2 and p_3 are determined from fits to the energy evolution of β determined from weight fits at different energies
- performed for all four "detectors"

The Gain: Linearity



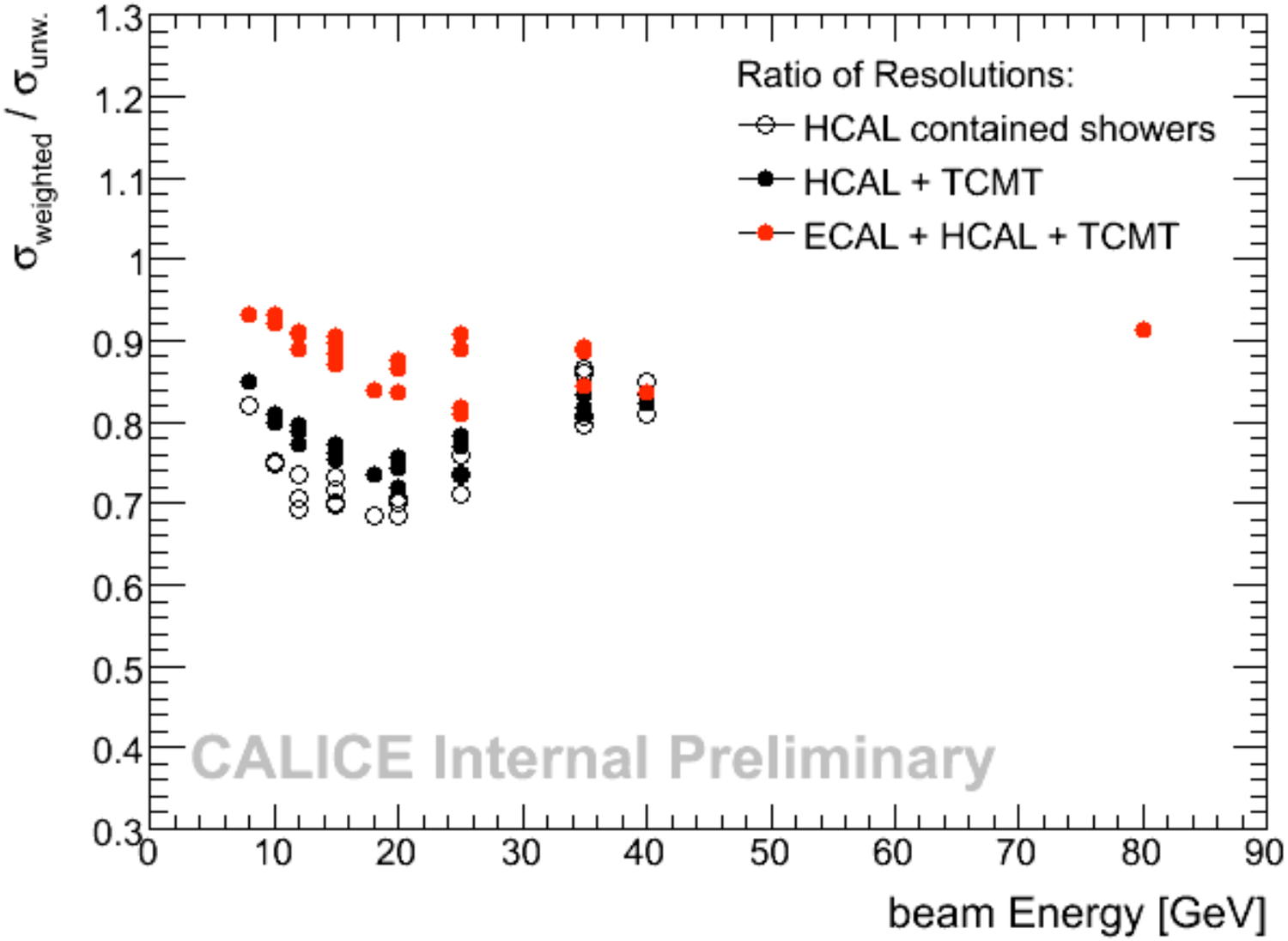
- Linearity of weighted sample outperforms the single weight reconstruction (except at the lowest energy)
- within 5% over the full range
- Remember: No Temperature correction applied, some of the runs used here were specifically selected for maximum temperature excursions (-> see talk by Shaojun)... I know, bad idea...

The Price to Pay: Resolution



- Energy dependend weighting
- Moderate improvement of Resolution over the full energy range
- Fits not to be taken seriously!

The Price to Pay: Resolution



- Only a moderate gain in resolution from weighting: 7% - 10%
- But: works also out to the highest energies

Summary

- Signal weighting based on density of energy deposits has the potential to significantly improve hadronic energy resolution
  - Simple approaches have serious problems with linearity

- First prove of principle studies using energy-independent weights determined at 18 GeV
  - Up to 30% improvement in energy resolution, but breaks linearity
    (-> Improvement requires the knowledge of the beam energy)

- First try with a simple energy dependent parametrization shows inproved linearity, but only ~ 10% gain in achieved resolution

- A lot to be done, but promising first results!