Hadronic Energy Resolution with Weighting Methods - Follow-Up

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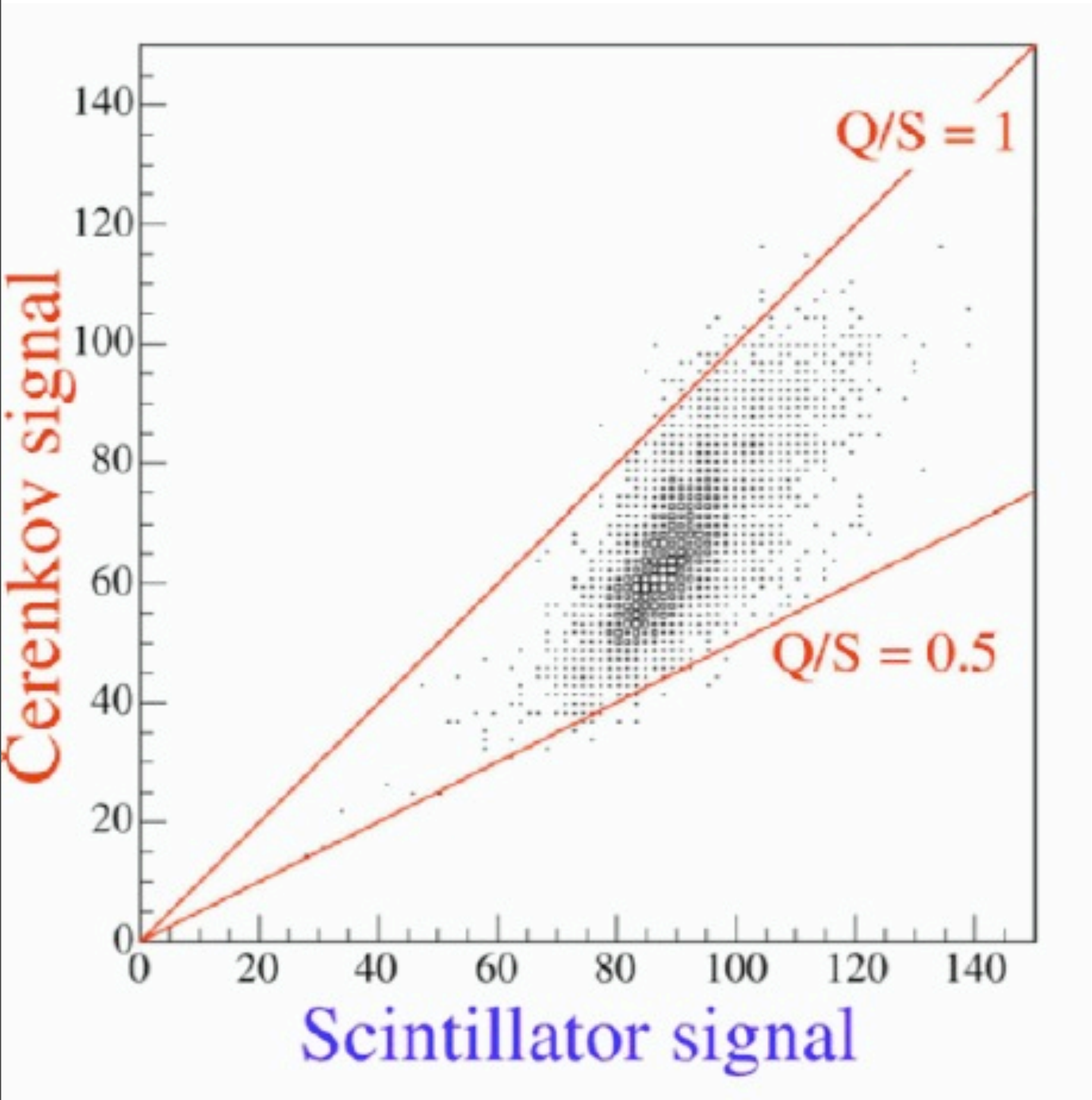
Overview

- Analysis Overview
- The principle of software compensation based on local energy density
- Electromagnetic Cross-Check
- HCAL-only studies
- Complete CALICE setup
- Summary / Outlook

Analysis: Introduction

- Analysis performed on 2007 CERN hadron data taken with combined detector
- Reconstruction using standard CALICE framework, run locally at Munich
  - No temperature correction
  - Saturation correction based on ITEP saturation curves and overall scaling by 0.8 to account for imperfect coupling of fiber to SiPM
- Statistically independent data-sets for weight determination and analysis: first half of each run used in the minimization, second half used to determine resolution and linearity
- Noise rejection algorithm used for all detectors
  - In ECAL and HCAL, a 3D density is calculated taking the cell under study and all neighboring cells in 3D (including diagonals) into account: Just use the energy sum
  - In the TCMT, the 3D density is given by the sum of the neighboring strips in the same layer, and the total energy in the layers up- and downstream of the channel under study
  - ‣ Noise hits will have a low value for this 3D density

DREAMing of Compensation



The DREAM "money plot": the reconstructed energy given by the scintillator signal can be improved with the Cherenkov signal (e.m. component) since the slope of the distribution is ≠ 1

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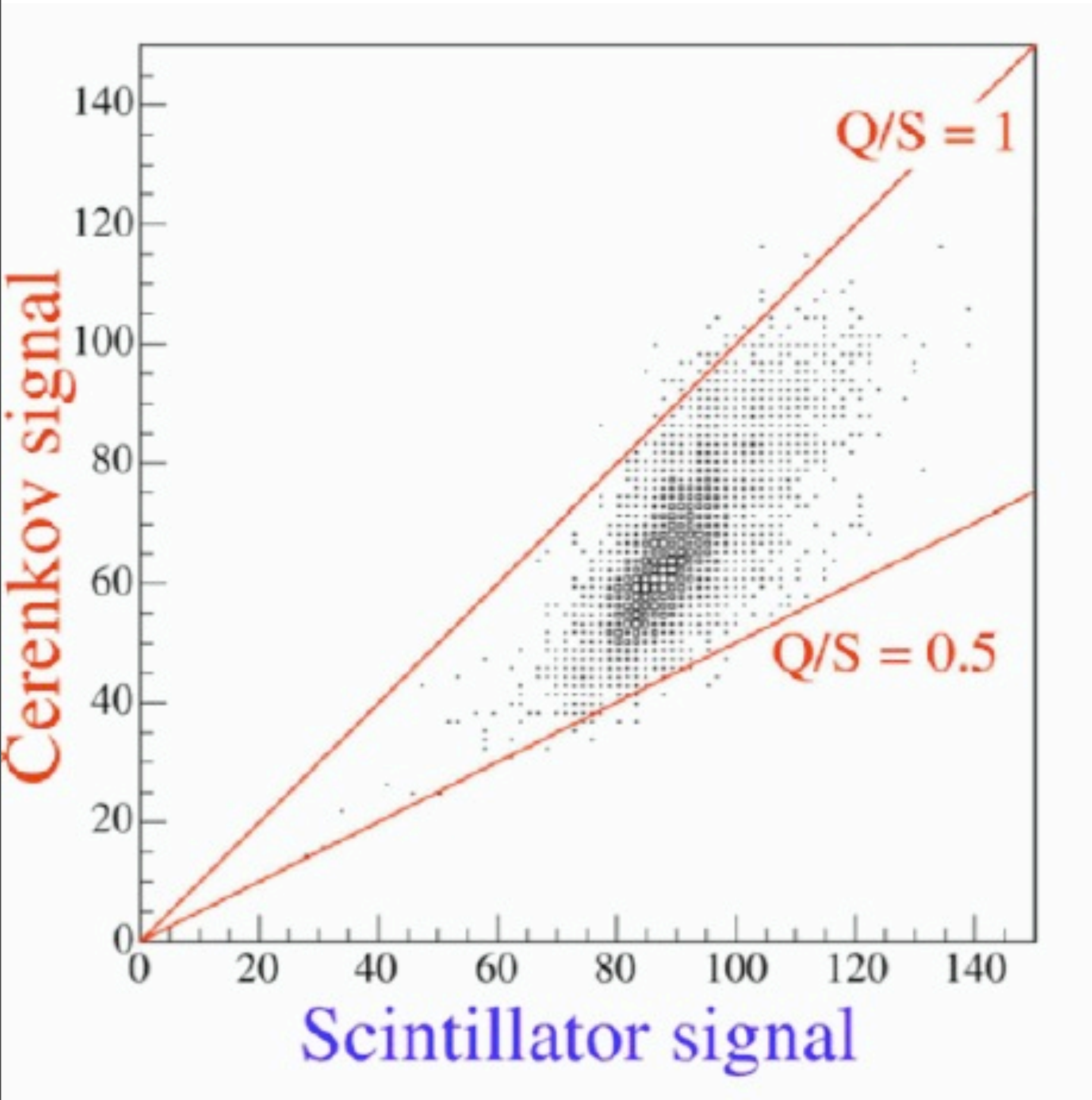

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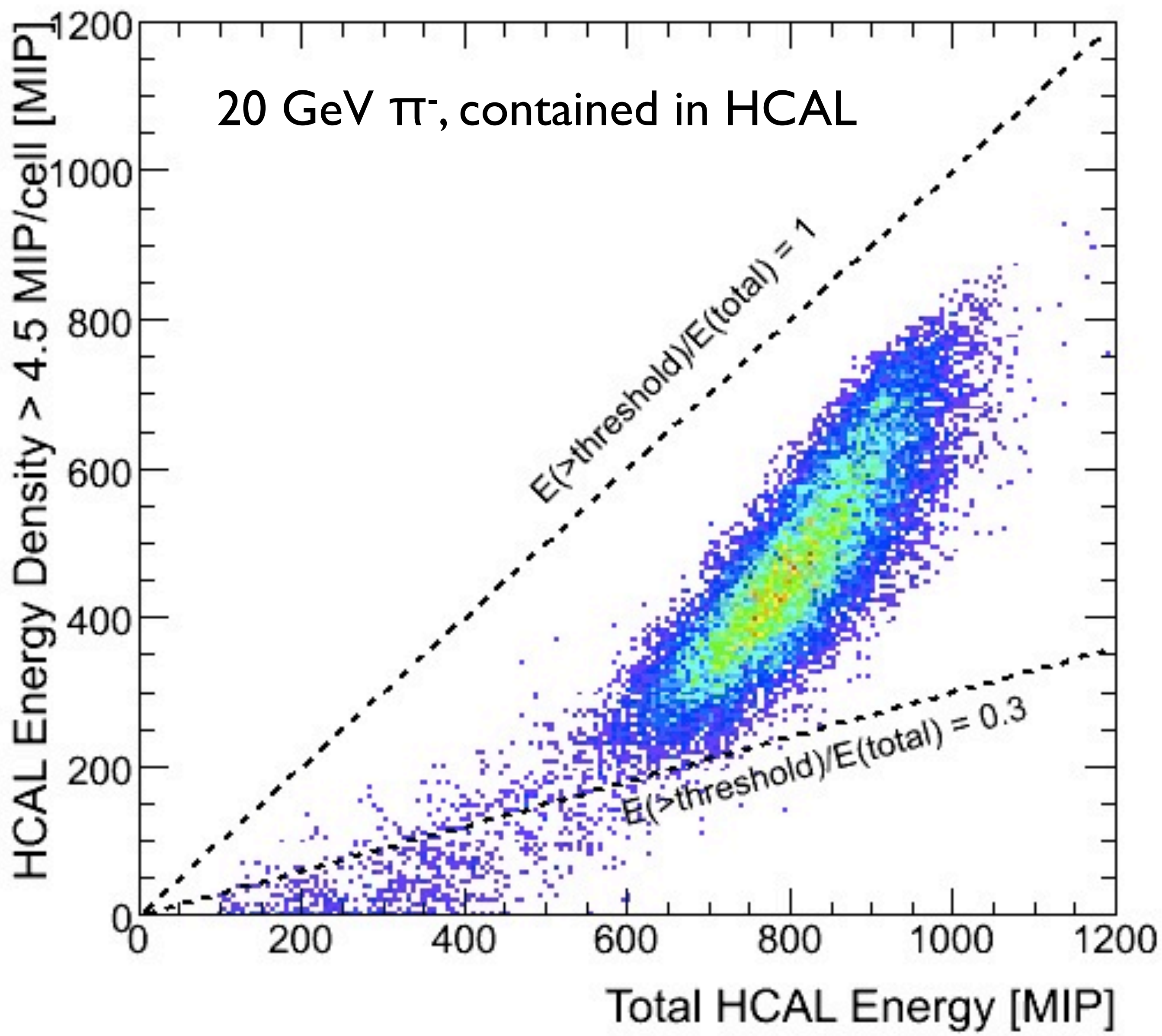
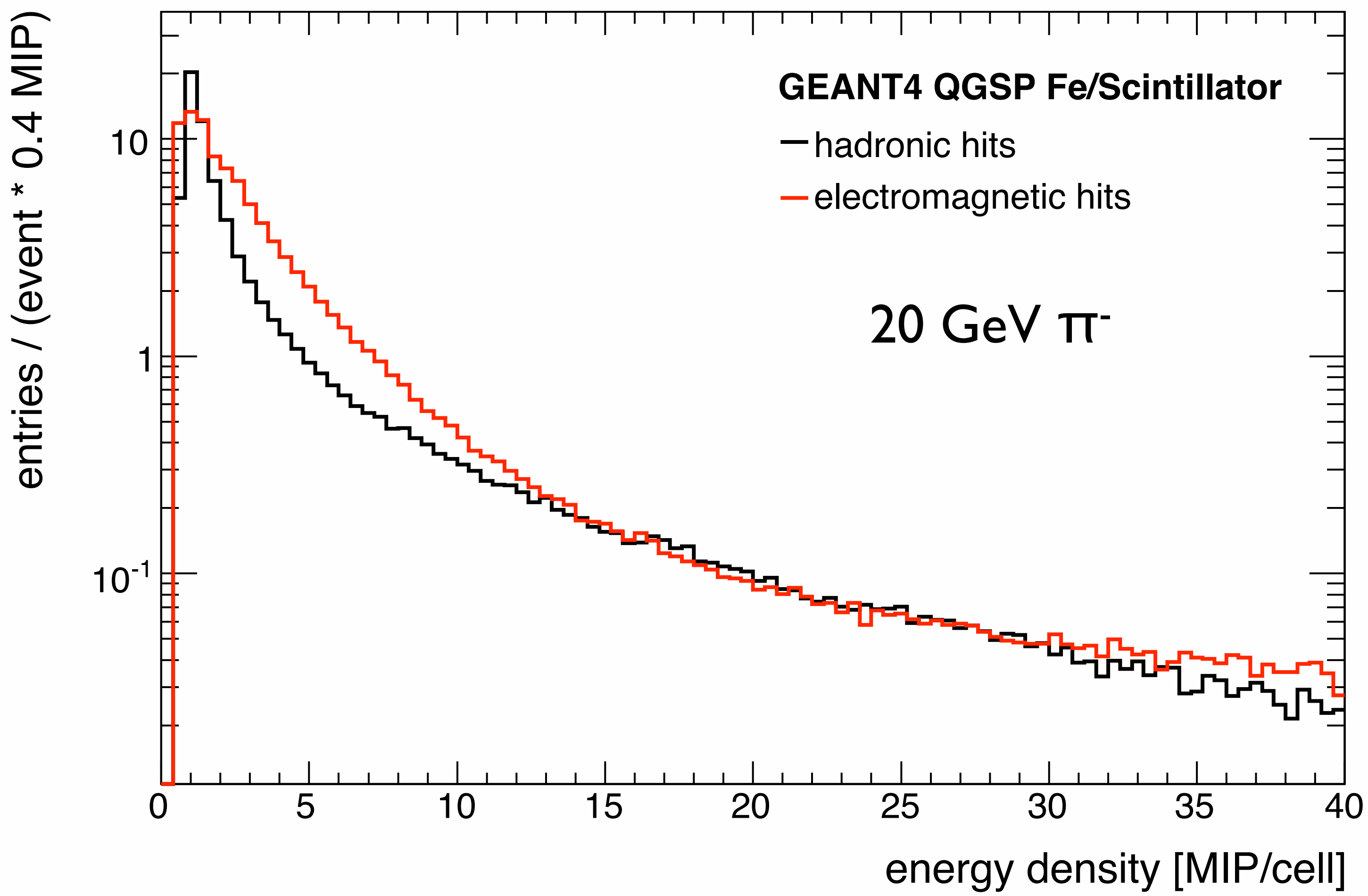


Local energy density works pretty much the same: events with a low total energy have a lower fraction of high density cells, this information can be used to improve the resolution: We can "DREAM", too...

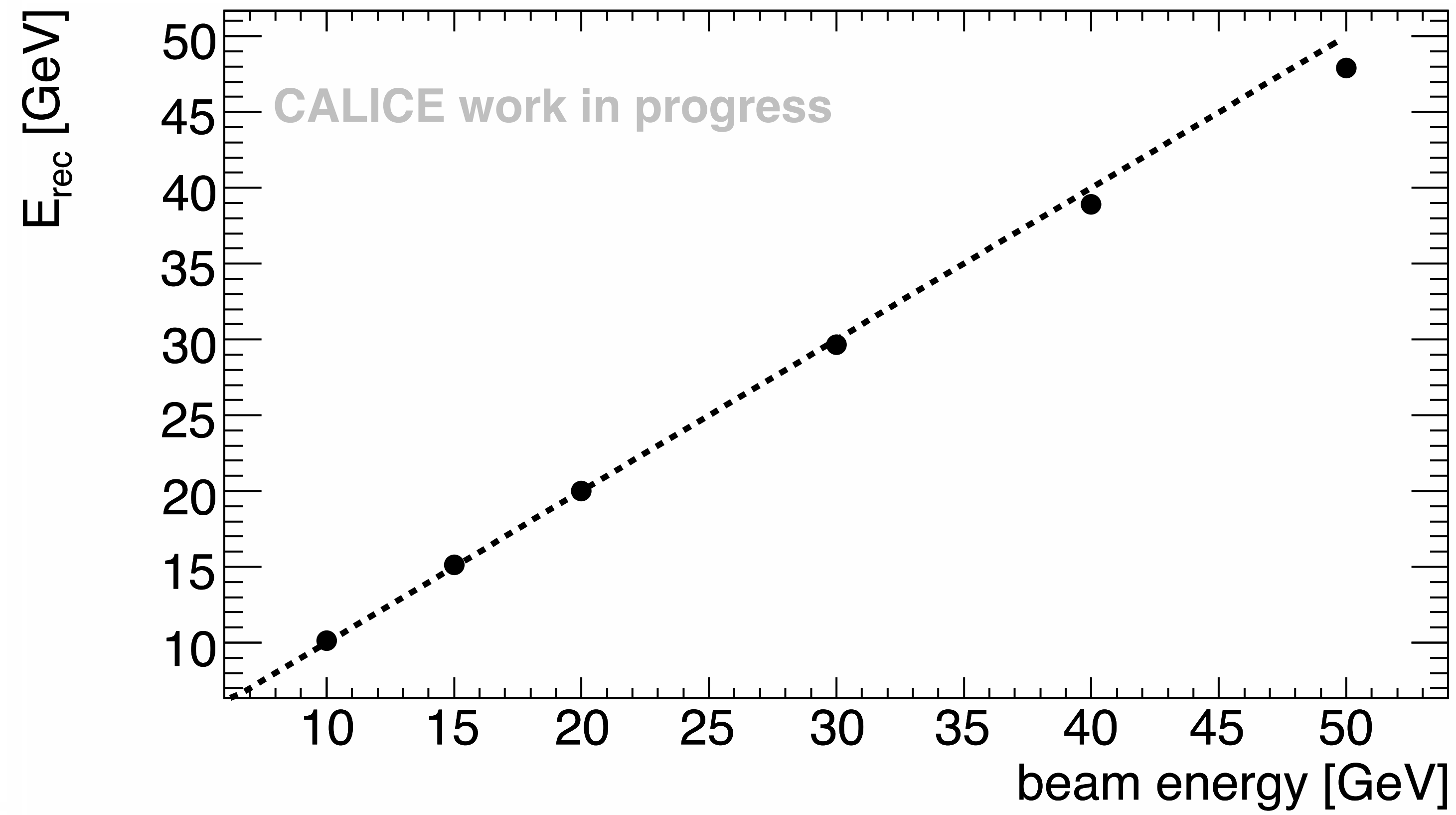
Energy Density & Type of Deposit

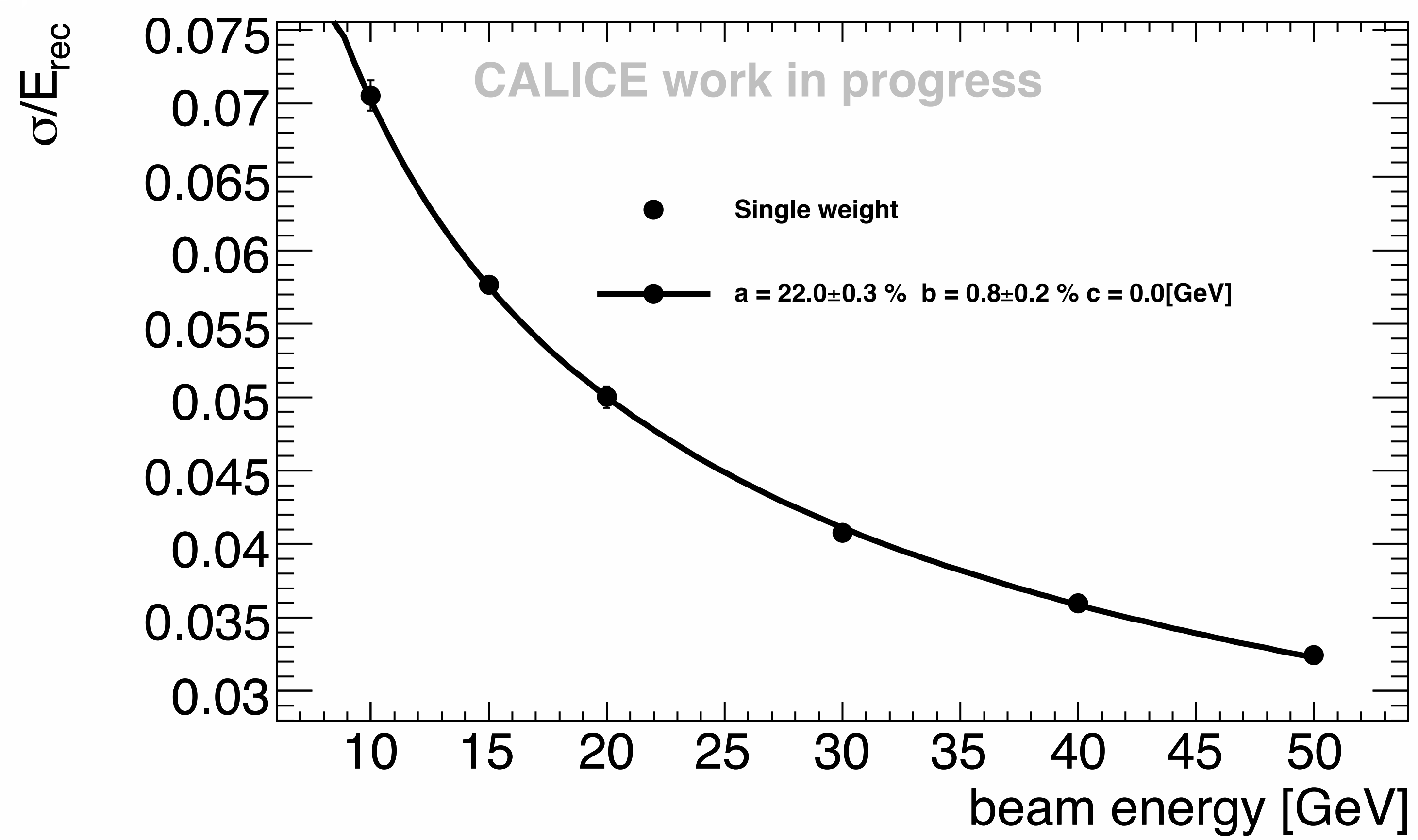


- Simple GEANT4 simulation: CALICE-like geometry: 2 cm Fe, 5 mm scintillator, 3x3 cm^2 cells
  - Hit classification: if more than 50% of the energy in the cell is deposited by electrons it is called electromagnetic
- Electromagnetic hits tend to have higher energy density: Basis for software compensation

Electromagnetic Cross-Check, e/h

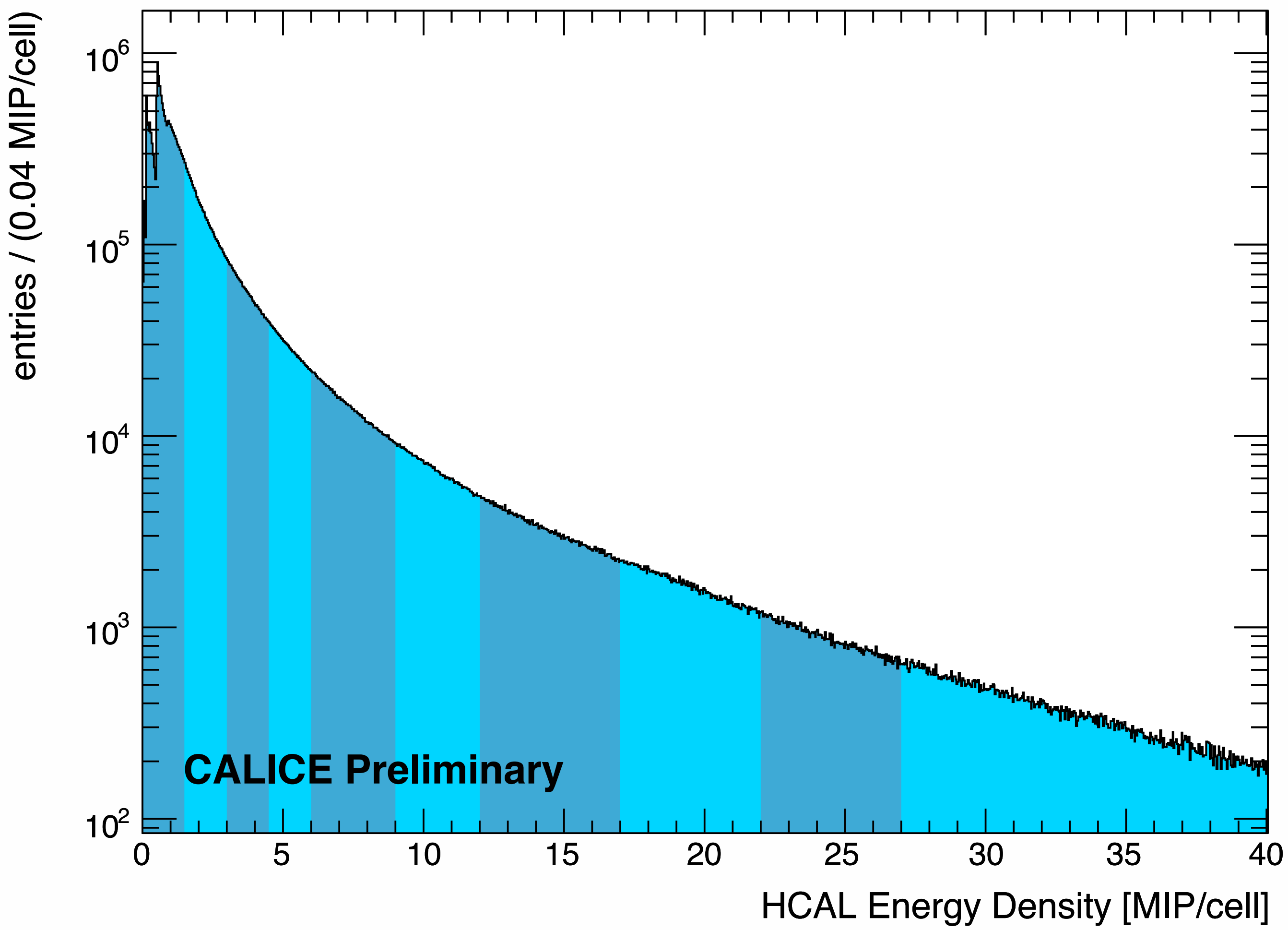
- Determine the conversion MIP -> GeV
  - for electromagnetic showers using HCAL only positron runs 0.0258 GeV/MIP
  - for hadrons using confined showers with a track in the ECAL 0.030 GeV/MP





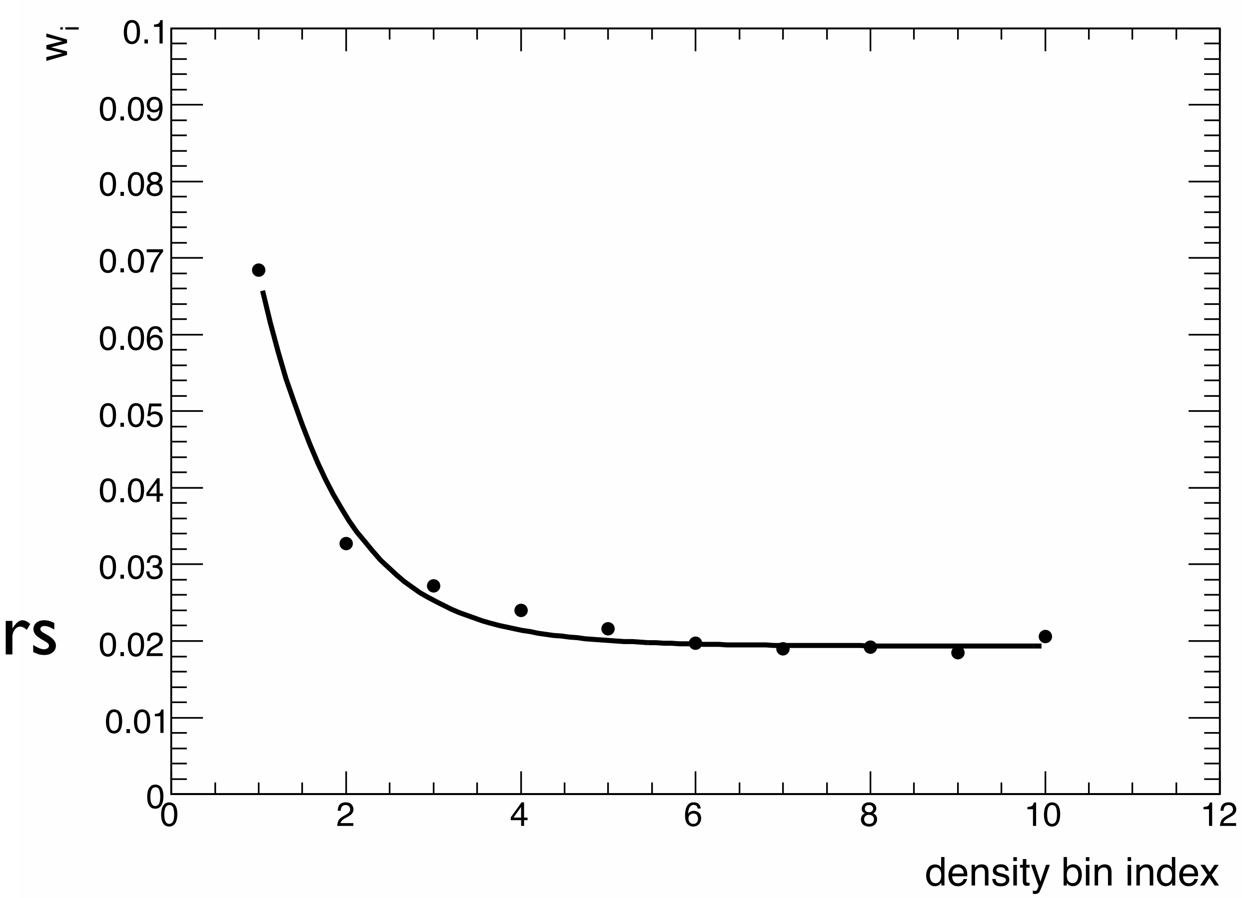
- e/π ~ 1.16
- already quite close to 1, tough for software compensation procedures...

HCAL Only: Energy Density & Weighting



- Subdivision of HCAL hits into density bins (calculated by E_{hit}/volume)
- Determination of weights for each density bin by minimizing

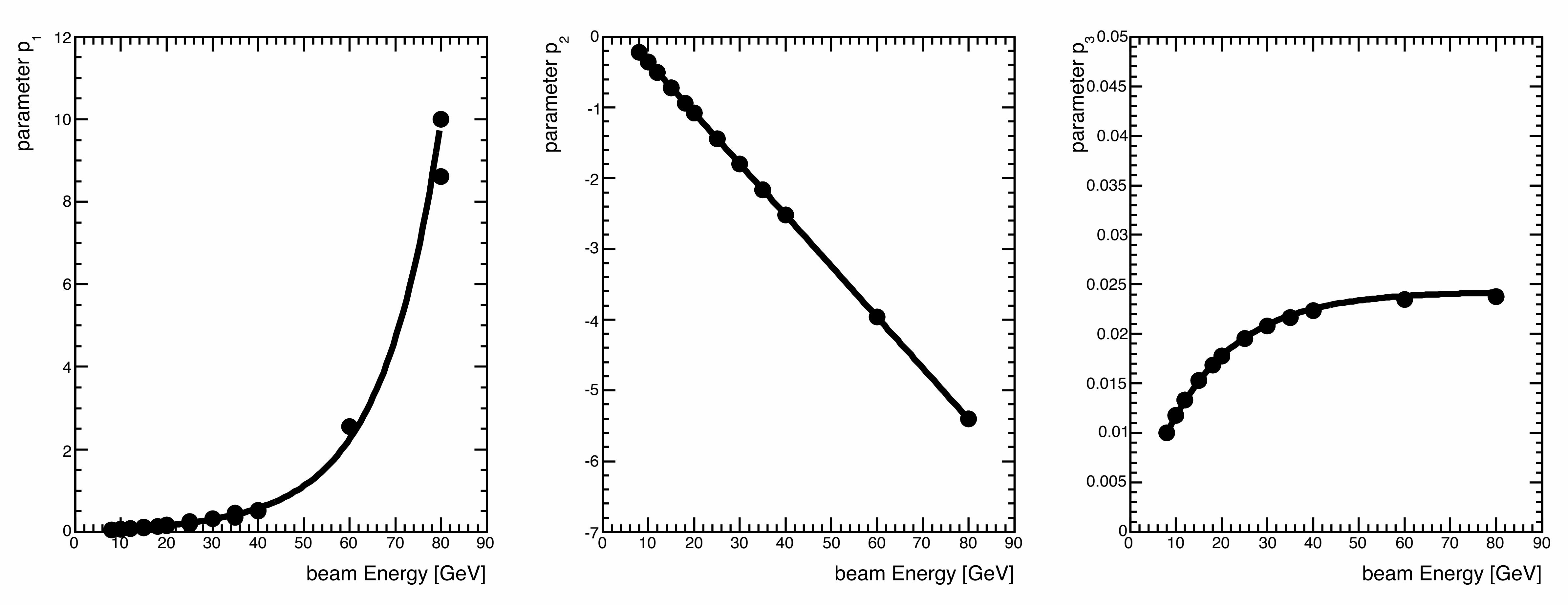
$$\chi^2 = \sum_{events} \left(\sum_i E_i \omega_i - E_{beam} \right)^2$$



- Weights are energy dependent (no surprise there, shower properties change with energy), parametrize the weights with a simple function with E-dependent parameters

$$\omega_i(E) = p_1(E)\, e^{(p_2(E)*i)} + p_3(E)$$

Parametrization of Energy Dependence of Weights

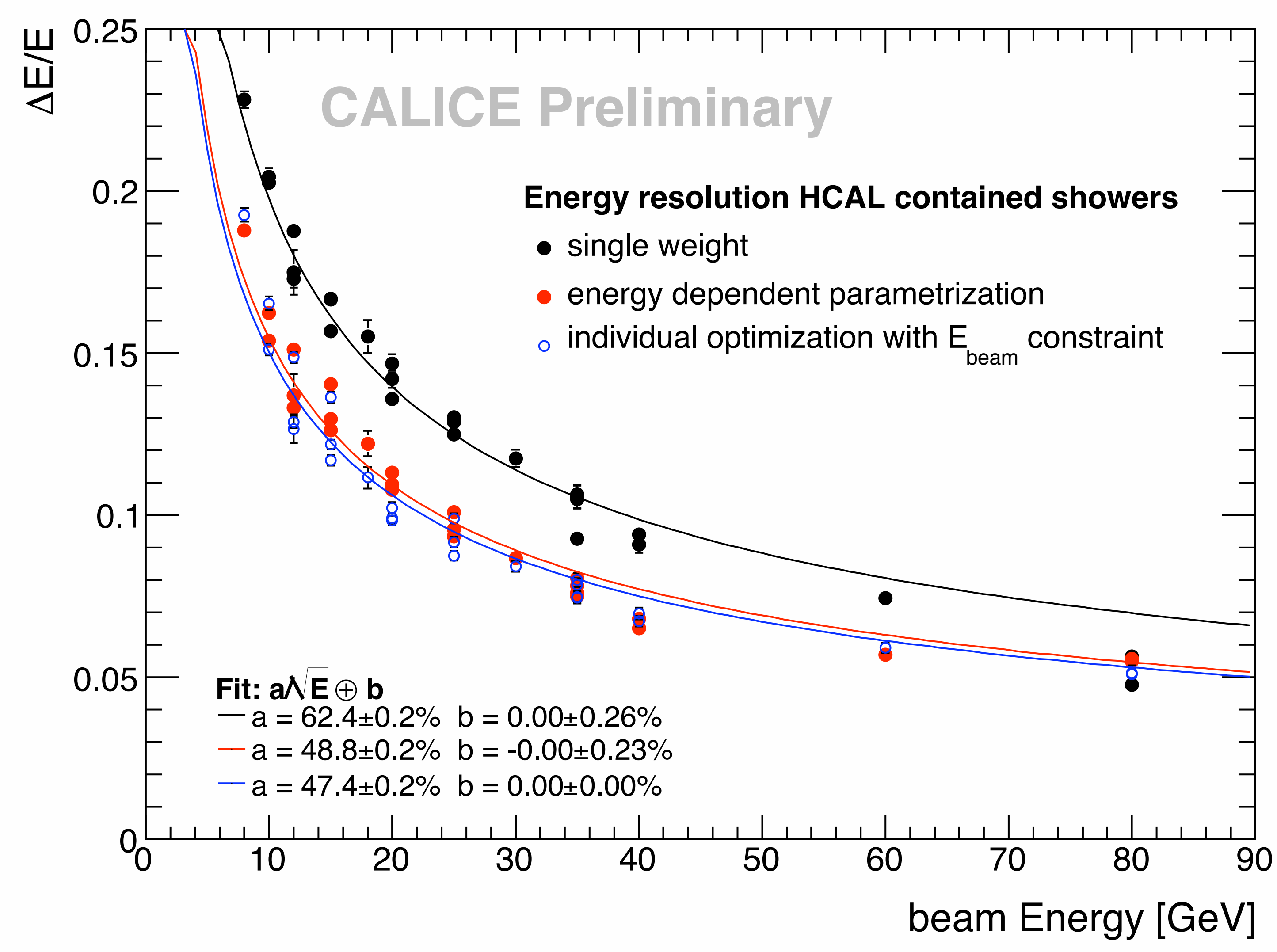


- The energy dependence of the 3 parameters in this function is determined by a minimization for each run, using the function to get the best parameters
  - Energy dependence determined in an iterative procedure: first the dependence of p_3 is fixed, then p_2 and p_3. The parameters are also parametrized with smooth functions

HCAL only Resolution

3 ways to reconstruct the energy:

- One conversion factor per detector, no density dependent weighting
- Density dependent weighting, using a beam energy constraint
- 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!



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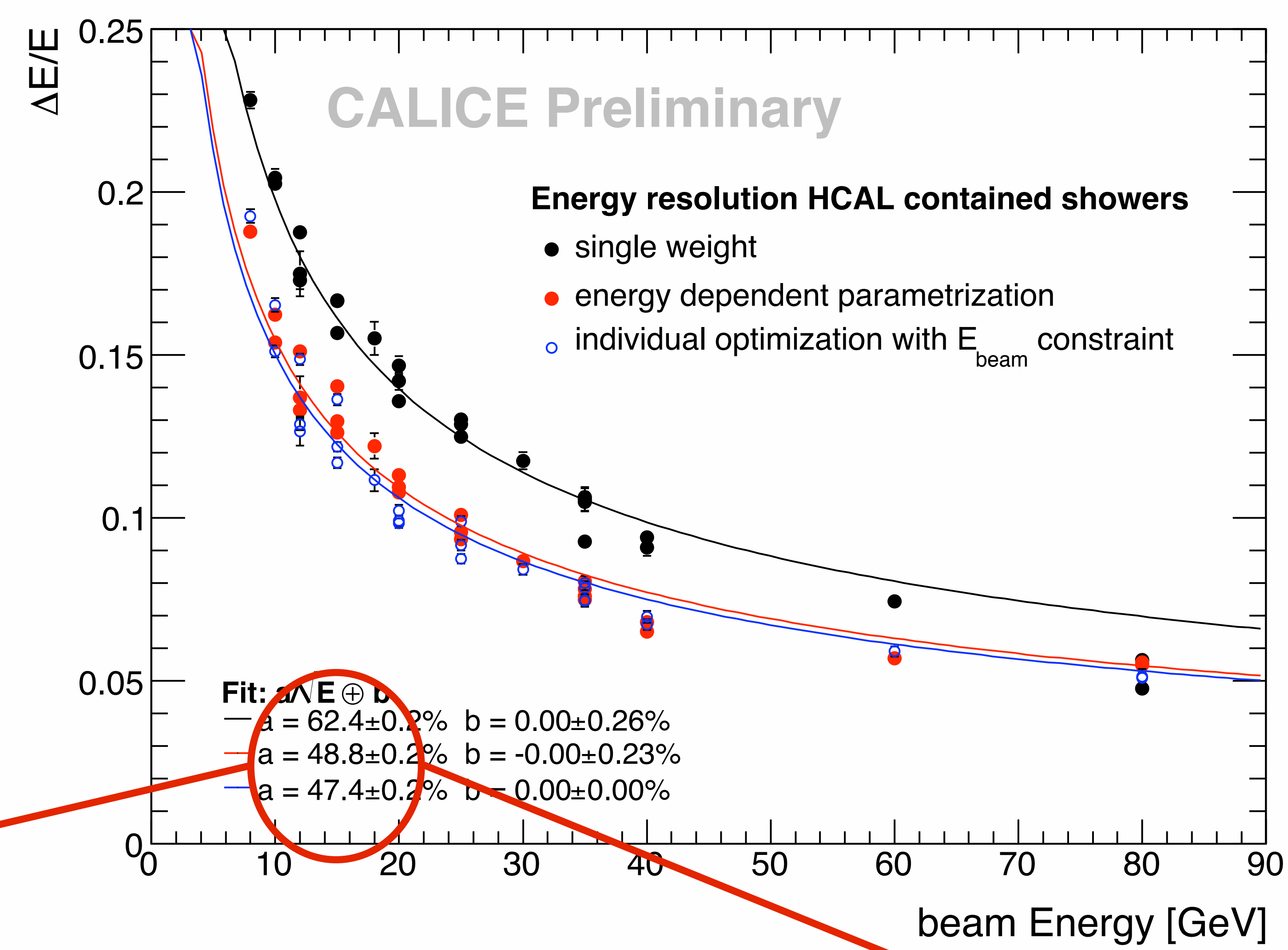
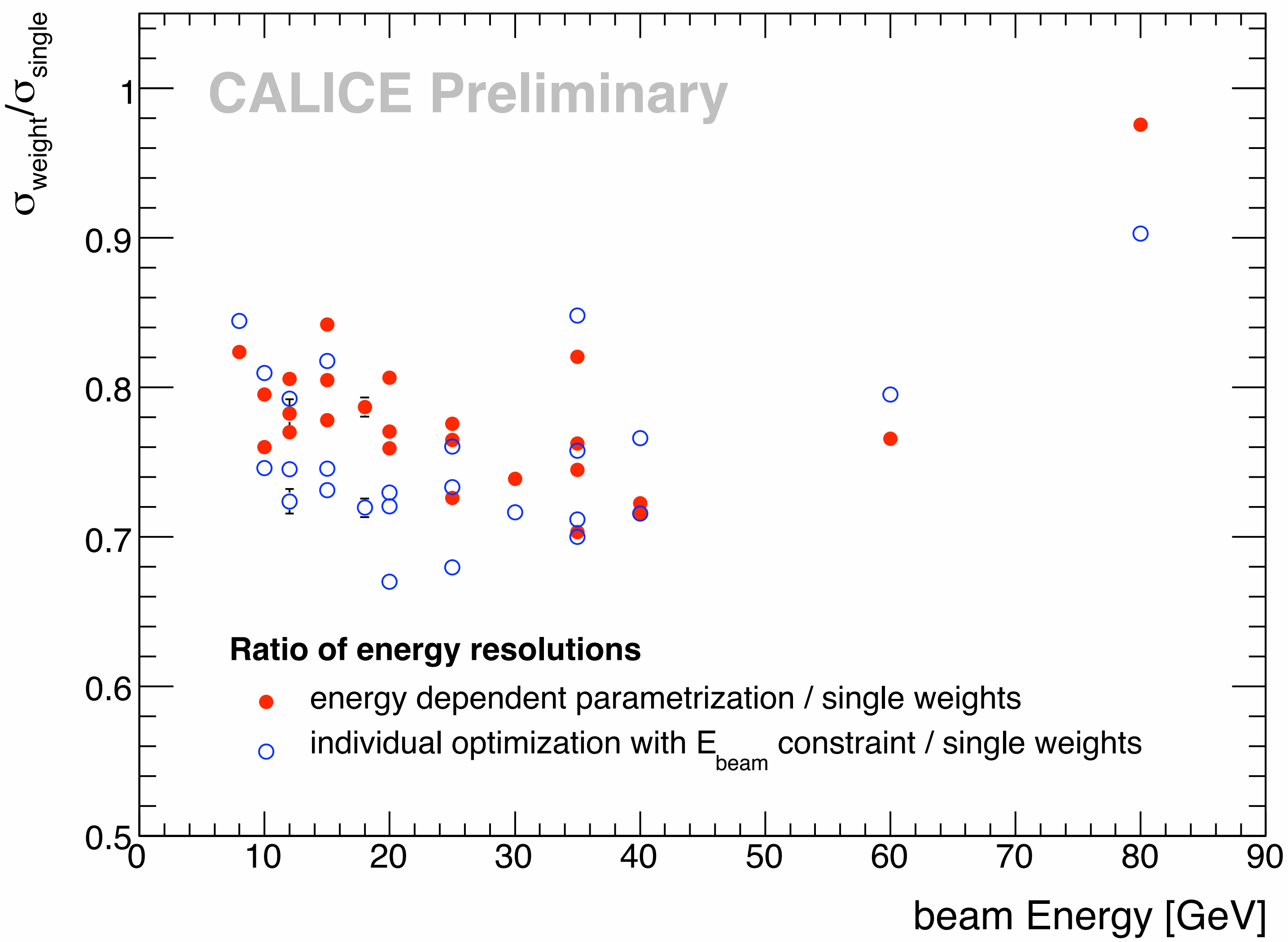


stochastic term w/o weighting: 62.4%, with parametrized weighting 48.8%

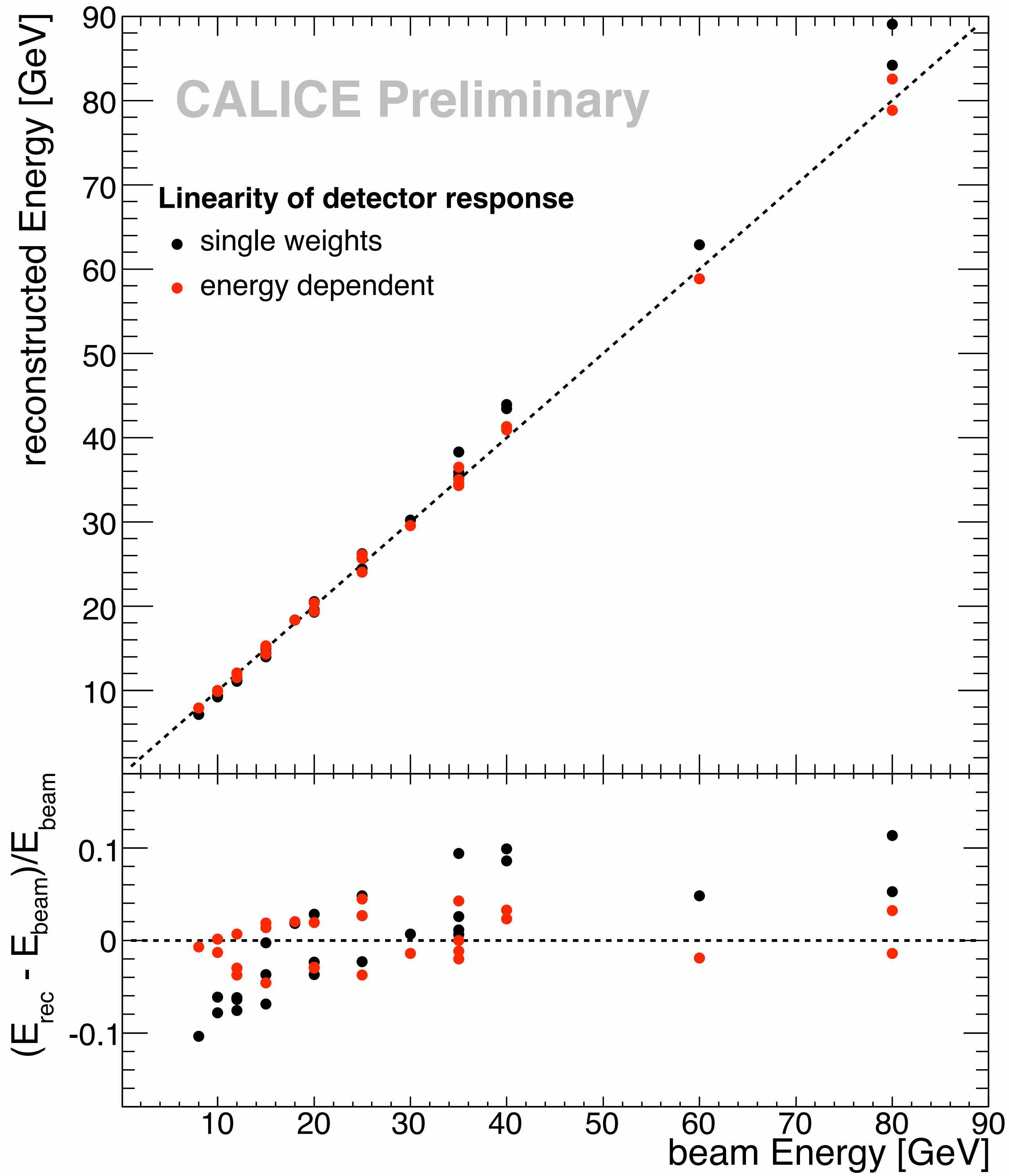
Improvement with Weighting



- Parametrized weights not using the energy constraint almost as good as the cheated case with run-by-run optimization
- Typically 20% improvement in energy resolution
- Breakdown at high energies: Requirement of containment changes showers!

HCAL only Linearity

- Energy reconstructed with single conversion factor and with parametrized density dependent weighting
- Noise rejection: Isolated noise hits (and isolated neutrons) rejected in the analysis



HCAL only Linearity

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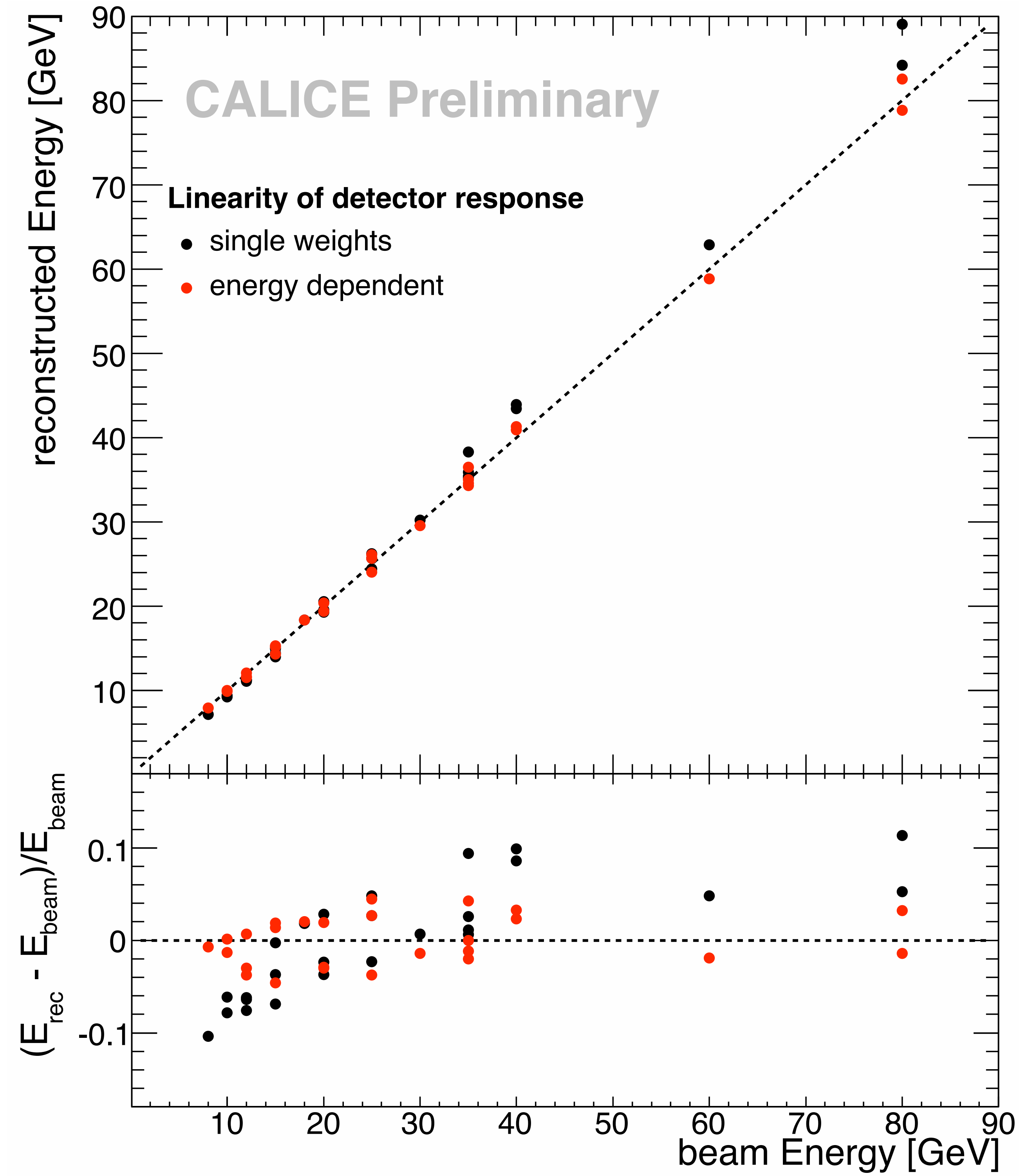
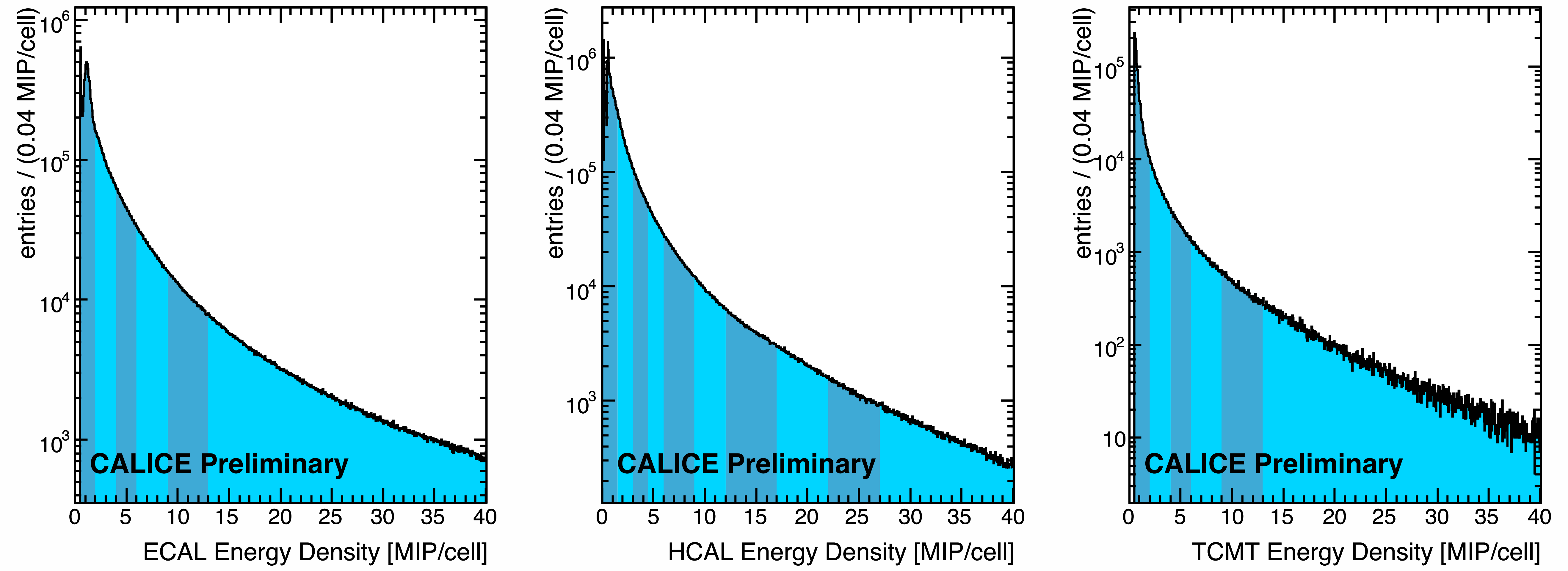
- Weighting of cells according to their energy content improves linearity of the detector: better than 4% from 8 to 80 GeV
- Cell-by-cell temperature correction in development, will reduce run to run fluctuations



Full CALICE Setup



- Expand the method to the full setup: Look at energy density in all three detectors

Detector Intercalibration: No Weighting

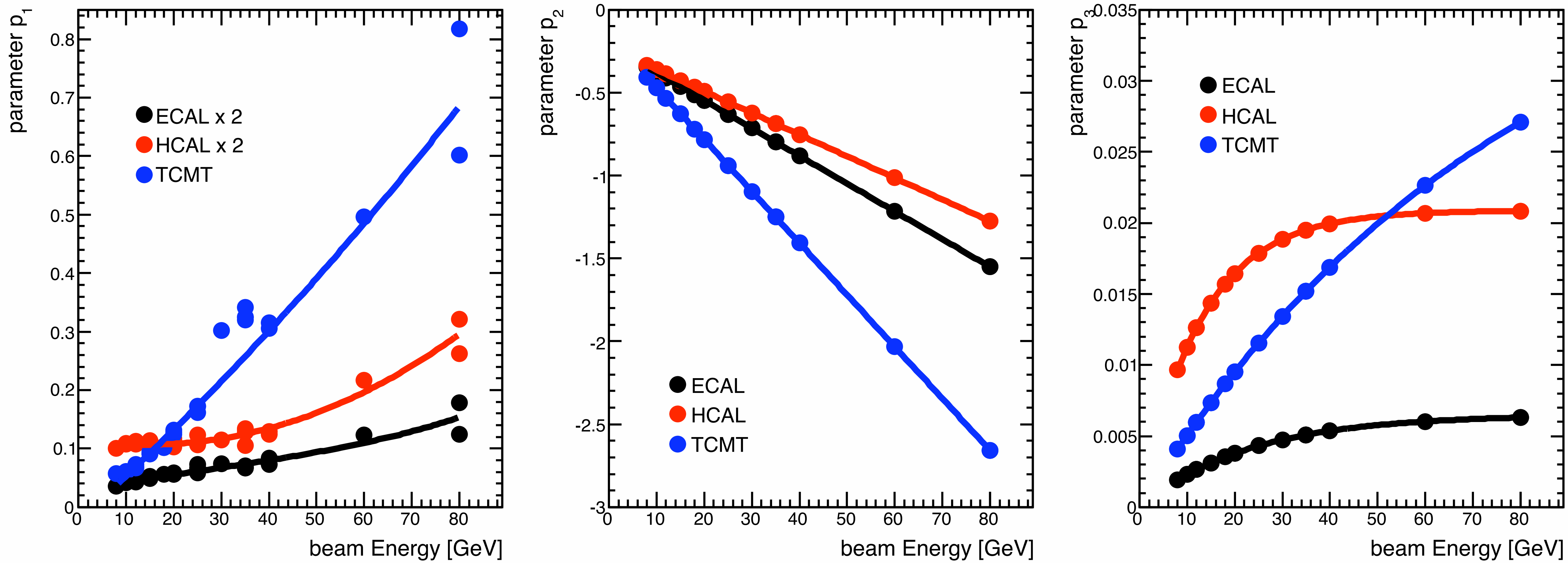
- Determine intercalibration factors using the same minimization technique, but no energy density dependent weights

Detector section	conversion factor [GeV/MIP]
ECAL 1	0.0081 ± 0.0011
ECAL 2	0.0092 ± 0.0005
ECAL 3	0.0134 ± 0.0004
HCAL	0.0289 ± 0.0003
TCMT 1	0.0335 ± 0.0027
TCMT 2	0.1524 ± 0.0142

- Derive one factor per detector using fixed weights for the different sections:
  - ECAL: 1:1.124:1.629
  - TCMT: 1:4.55

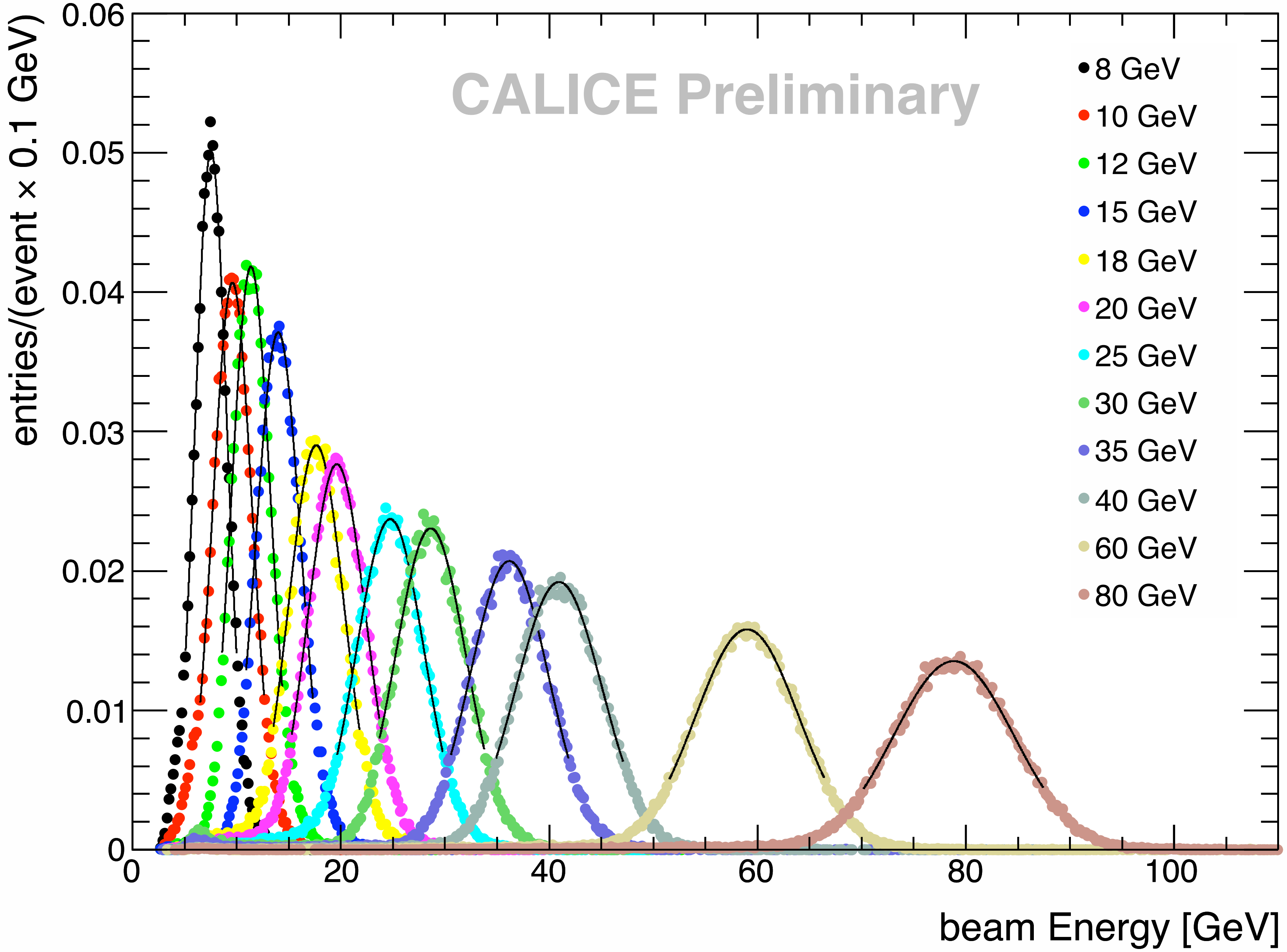
Detector	conversion factor [GeV/MIP]
ECAL	0.00827
HCAL	0.0293
TCMT	0.0337

Parametrization of Weights



- Parametrization of weights: Same principle as for the HCAL only analysis
  - Iterative determination of functional form for the three parameters

Reconstructed Energy



- Significant improvement of energy resolution with the use the parametrized weights (no knowledge of beam energy necessary)

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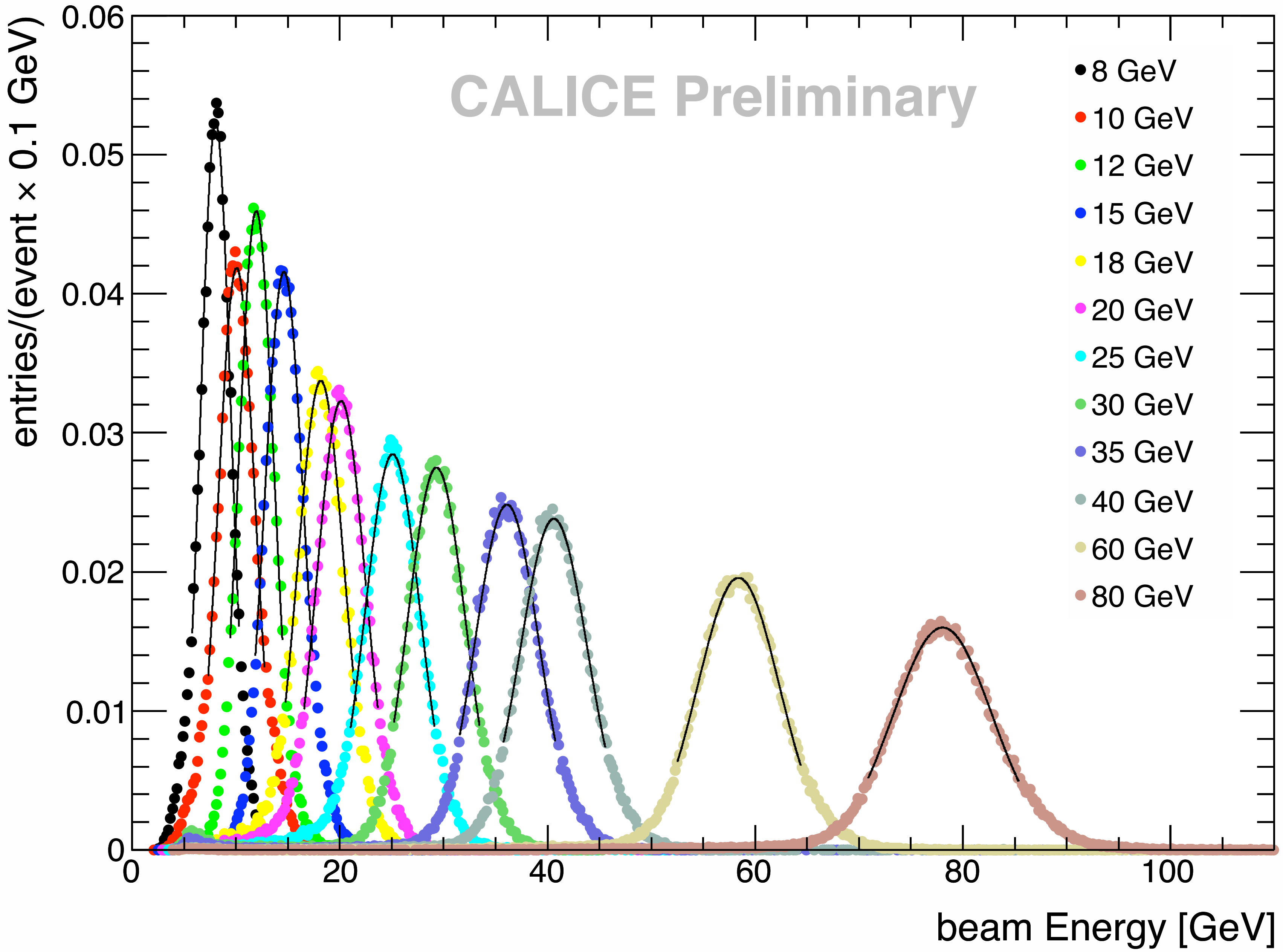

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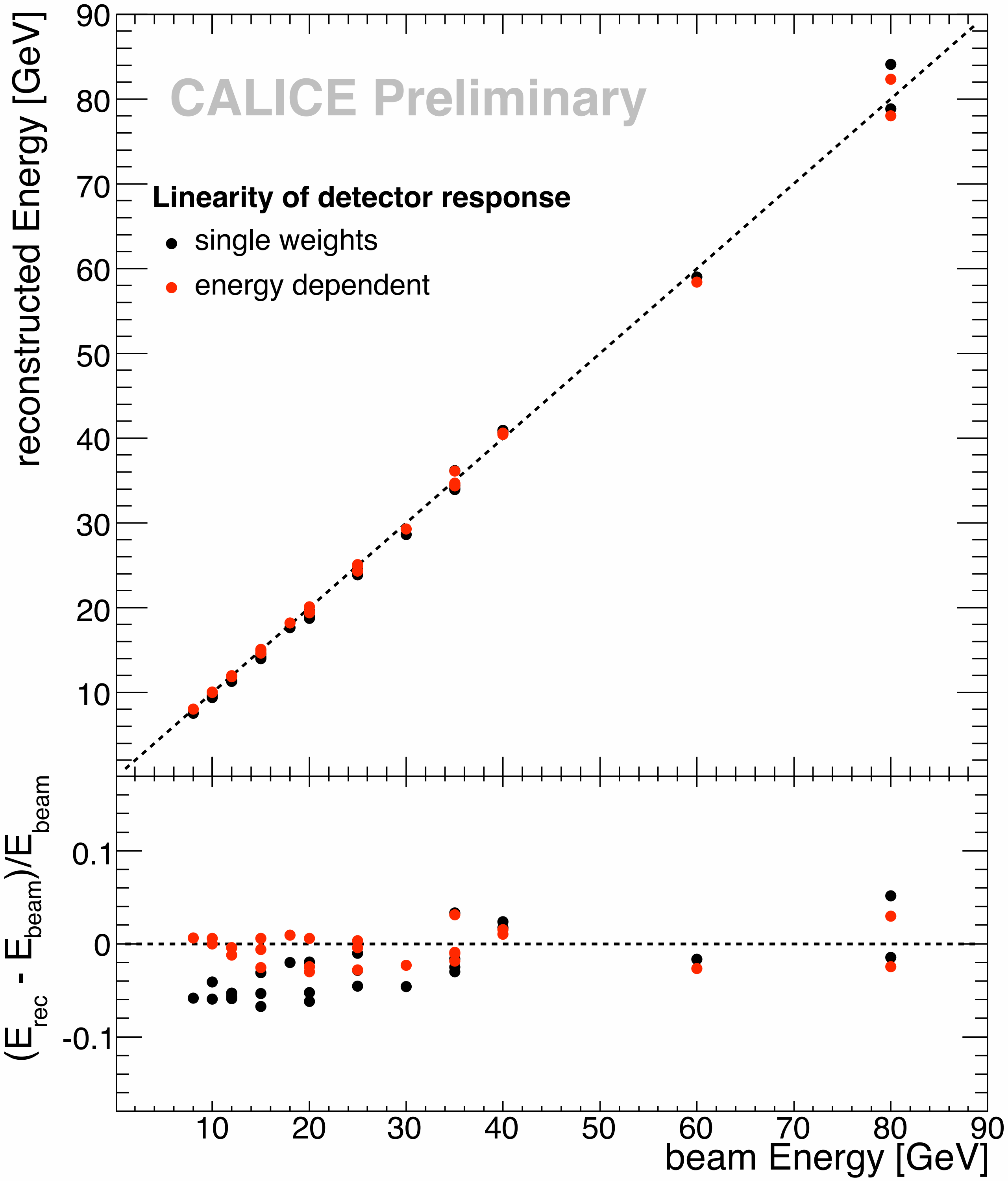
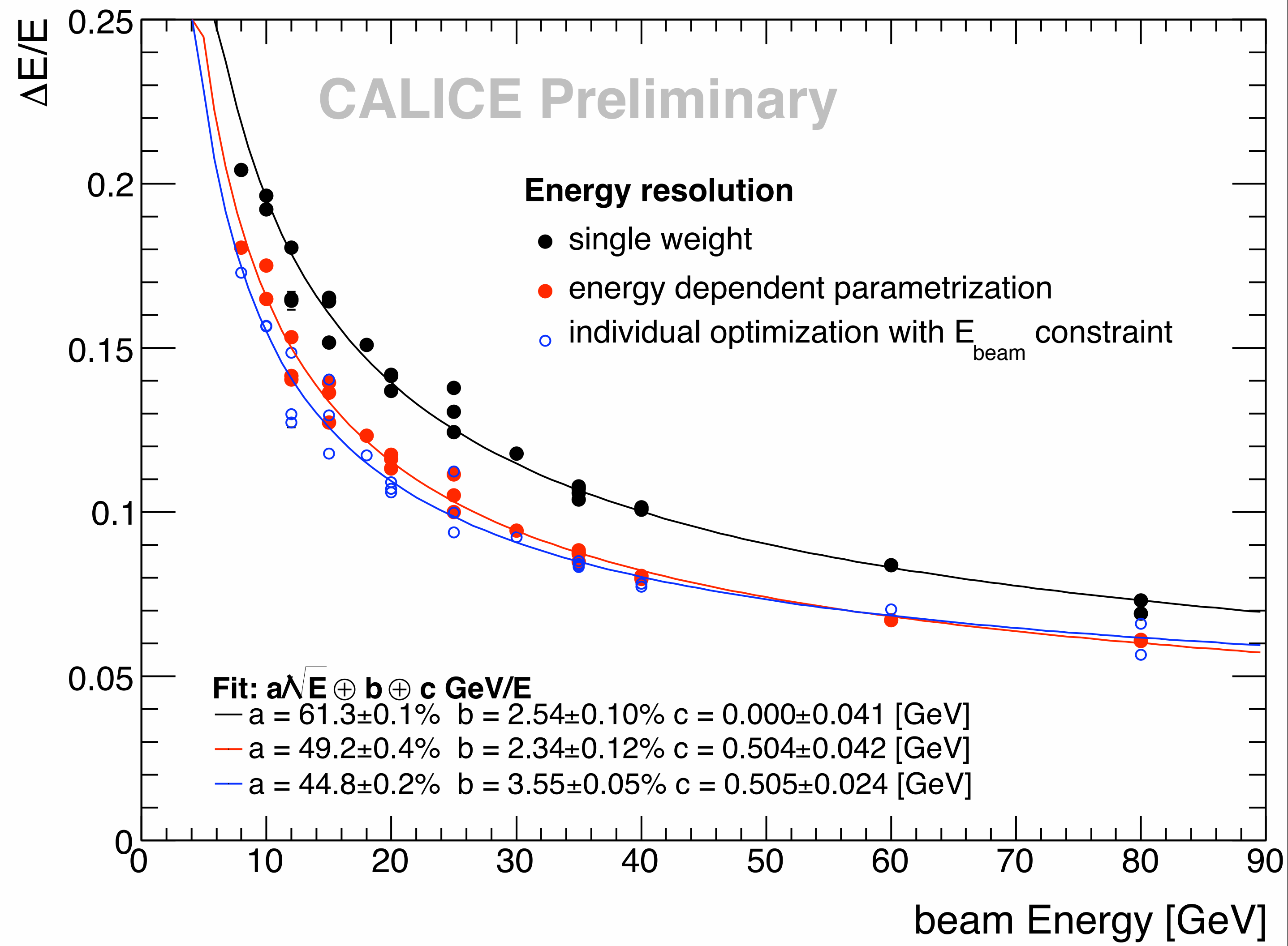
Full Setup Energy Resolution & Linearity





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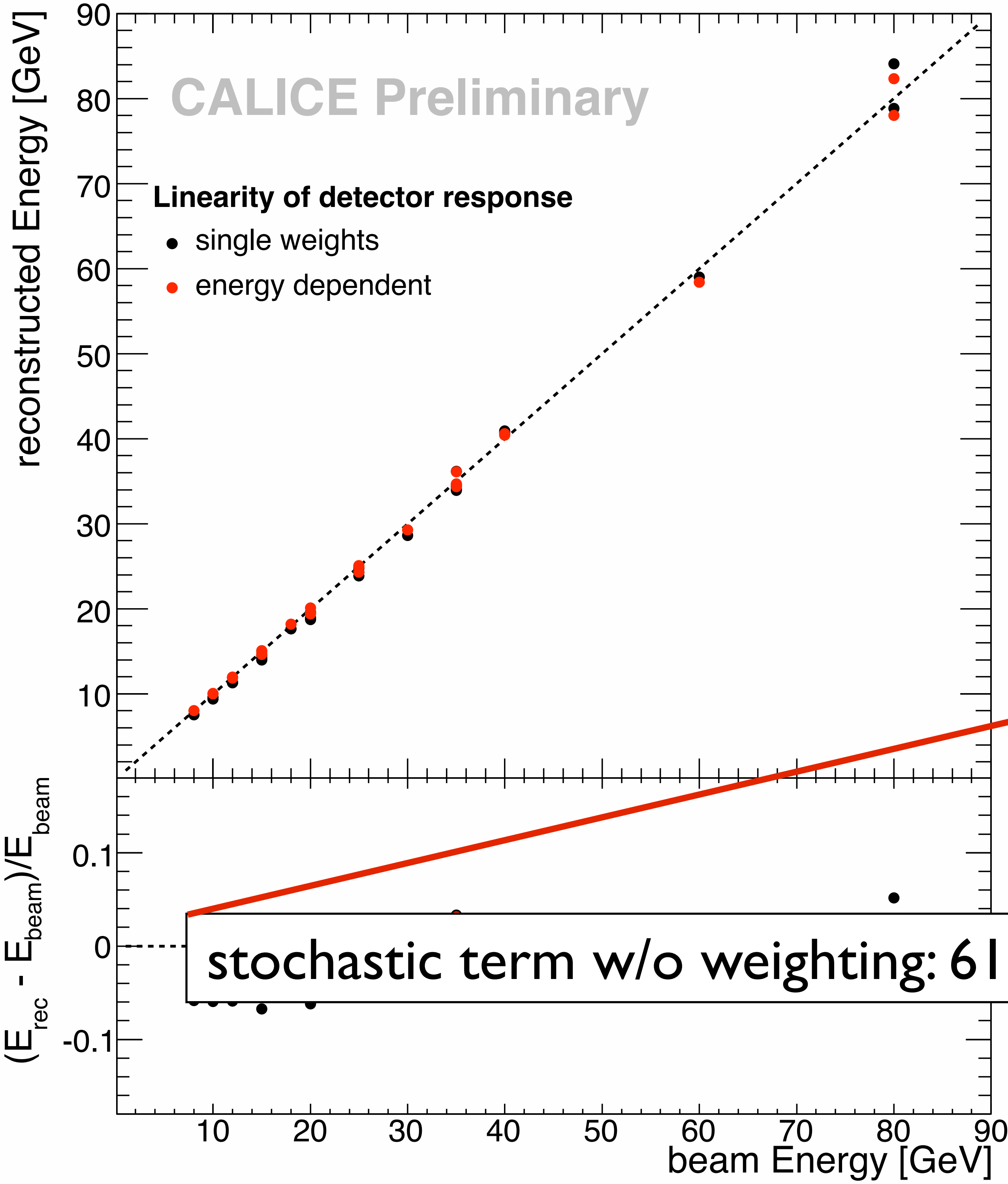
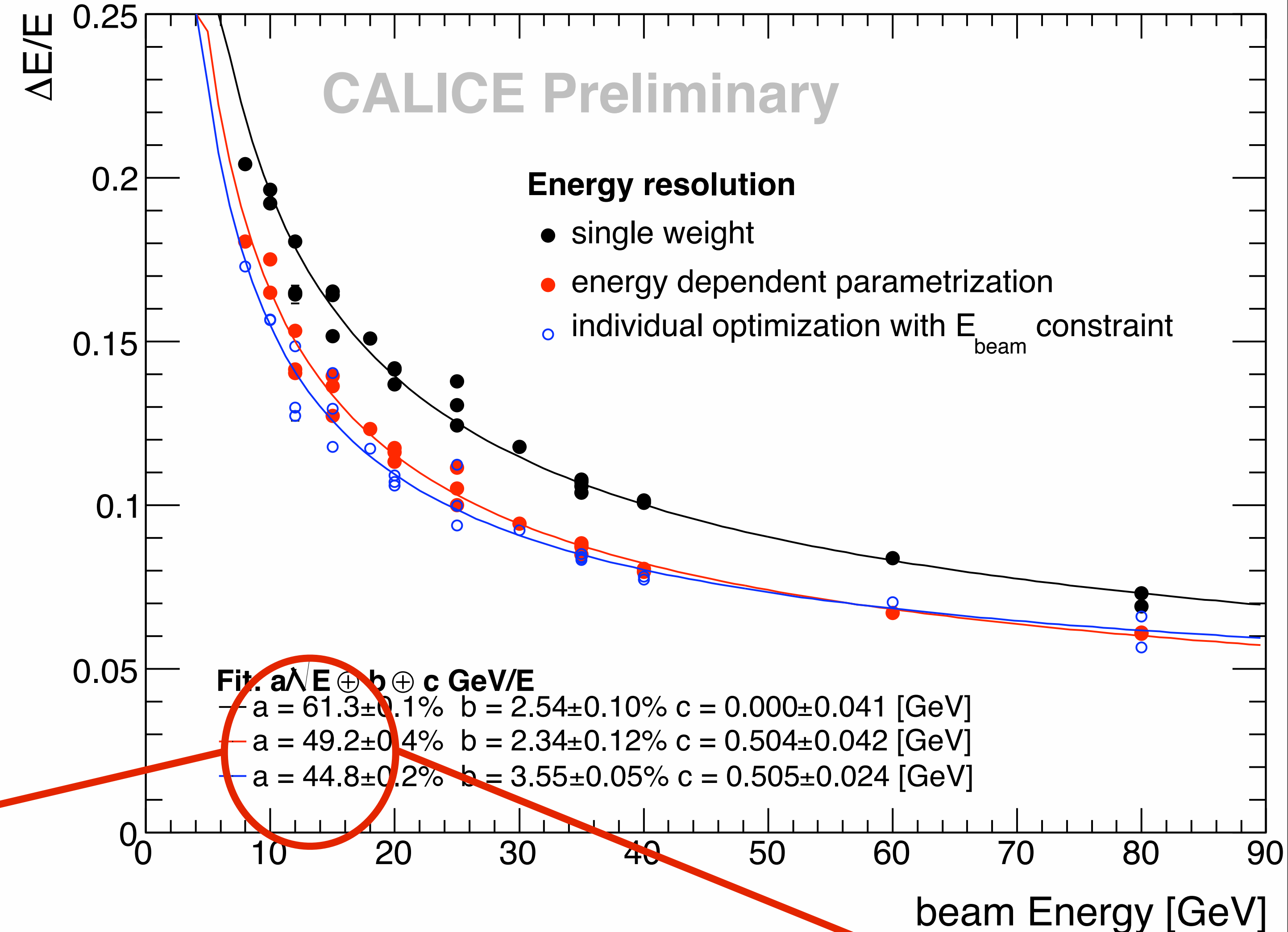
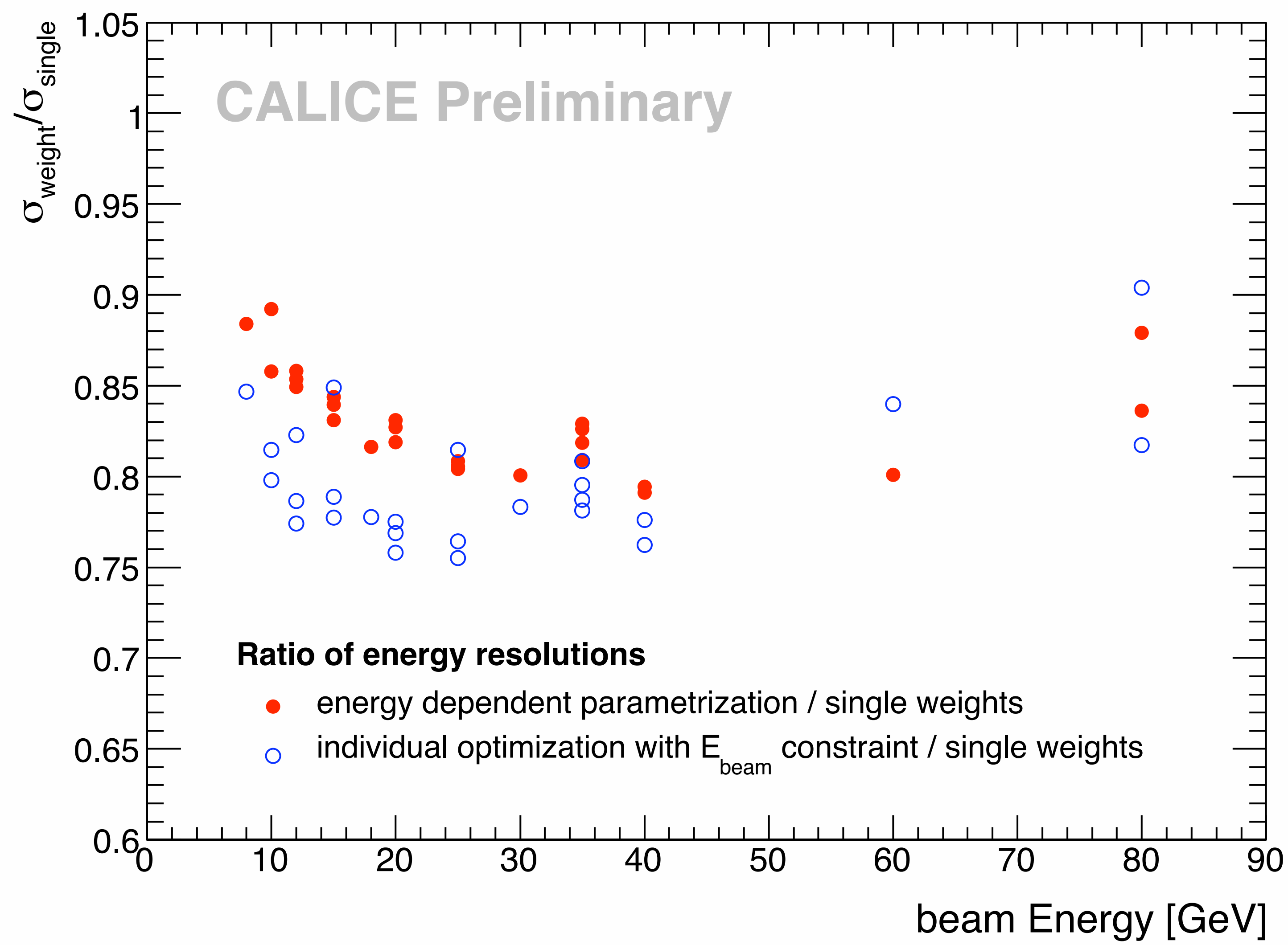




stochastic term w/o weighting: 61.3%, with parametrized weighting 49.2%

Improvement with Weighting



- Improvement with parametrized weights typically 18%, in particular at lower energy more improvement seems possible

Summary, Outlook

- Initial study of weighting methods based on local shower density to improve the energy resolution for hadrons
  - Improvement of the resolution of ~ 20% is reached for the full CALICE setup and for the HCAL alone
  - Stochastic term in both cases a bit below 50%
  - Linearity of the detector response is improved

- Next steps
  - Study weighting based on the 3D density used for noise rejection, first promising indications
  - Comparison to simulations
  - Expand compensation studies to clustering algorithms