Hadronic Energy Reconstruction in CALICE Calorimeter Prototypes

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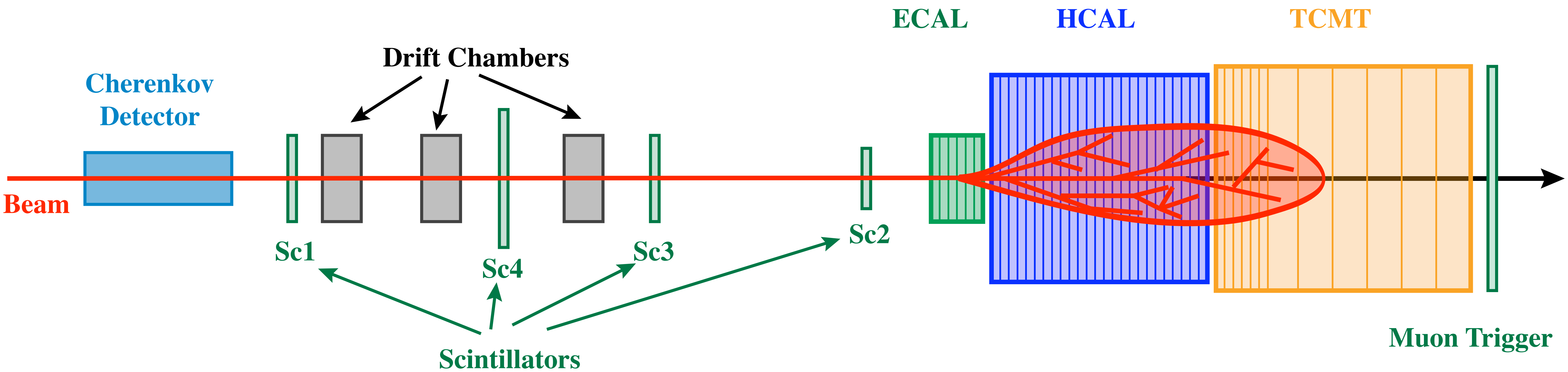
Calorimeter for ILC

Excellence Cluster
Universe

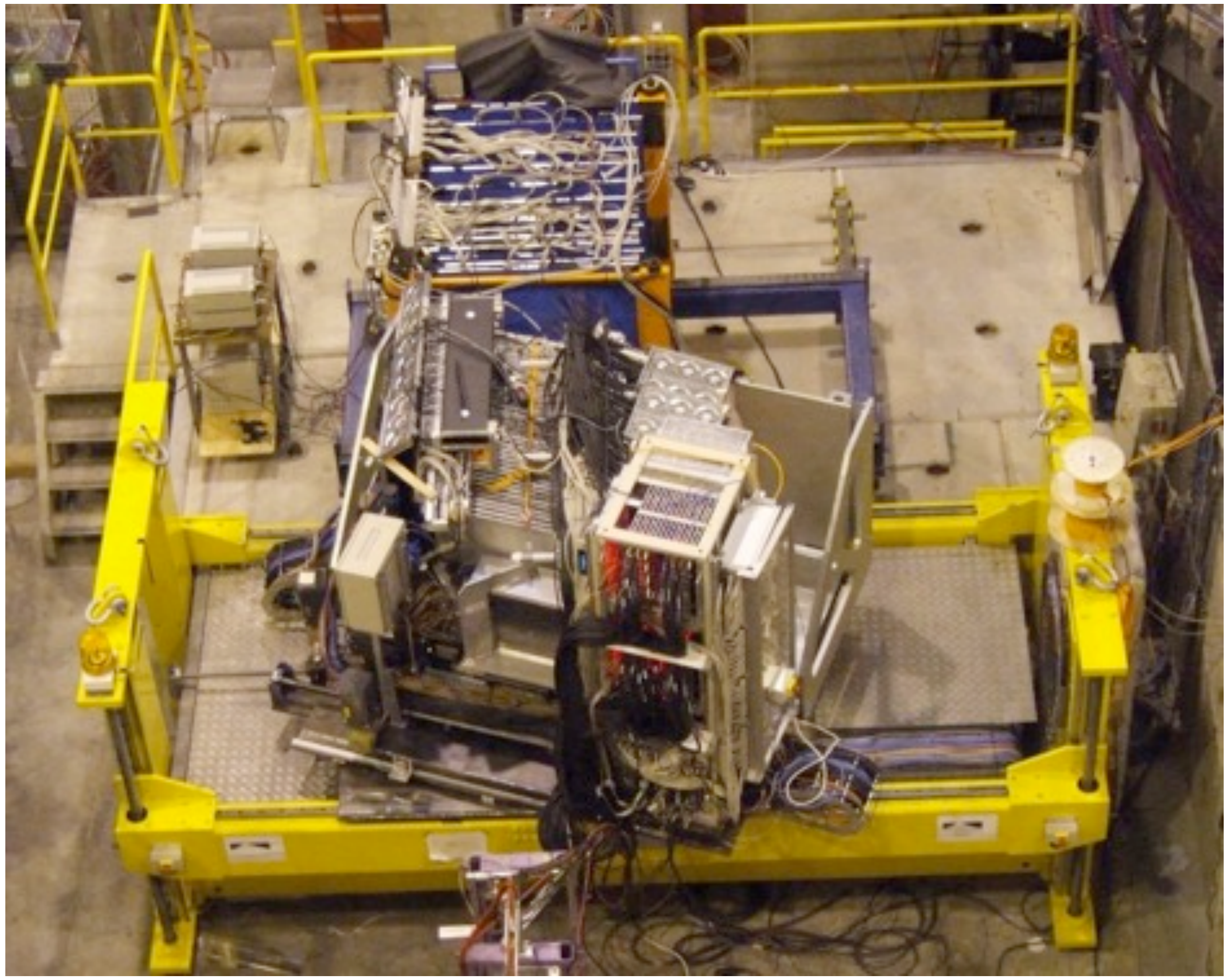
Outline

- The CALICE test beam setup
- The Analog Hadron Calorimeter
  - Detector Layout
  - Calibration
- Energy Reconstruction & Shower Weighting
  - Reconstruction Technique
  - HCAL contained Showers
  - CALICE Combined Analysis
- Summary

The CALICE Program

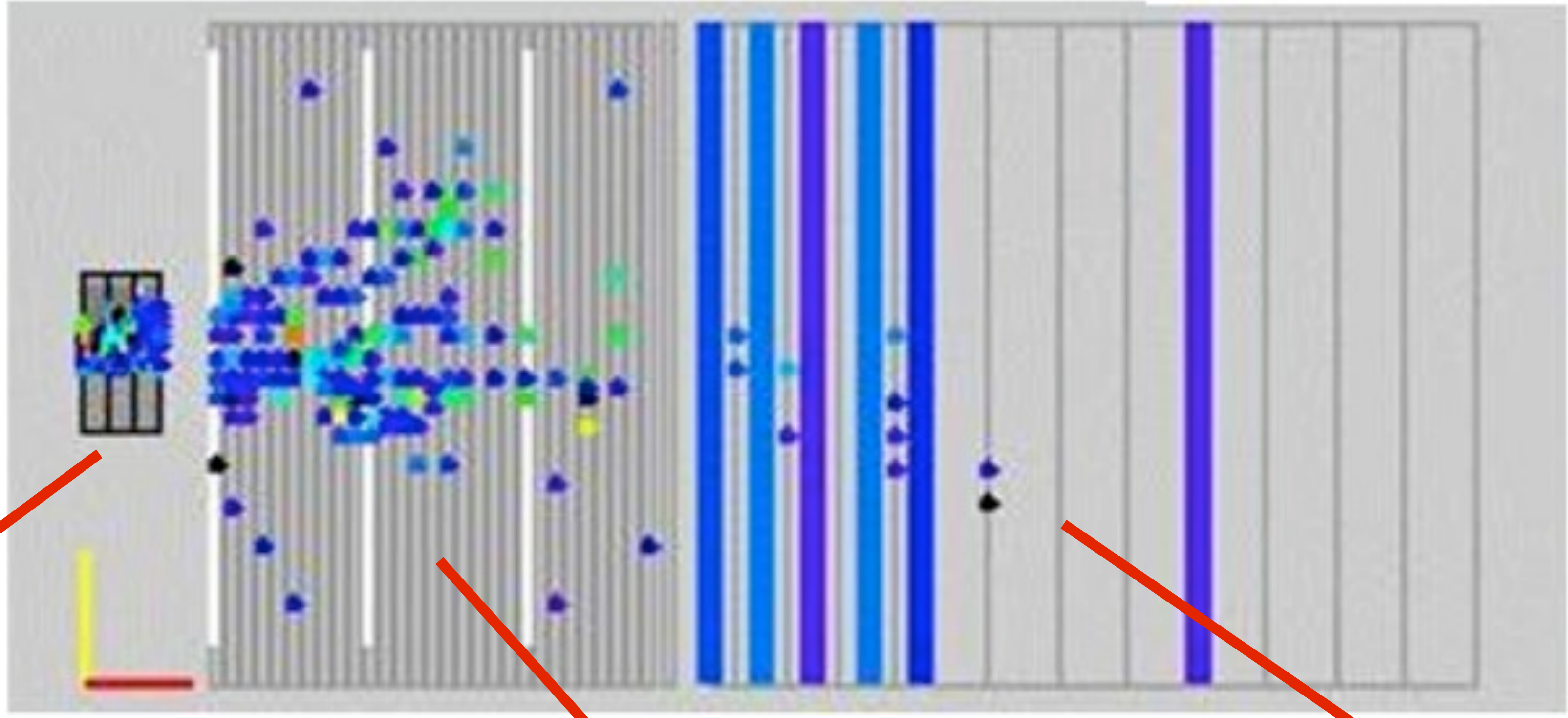


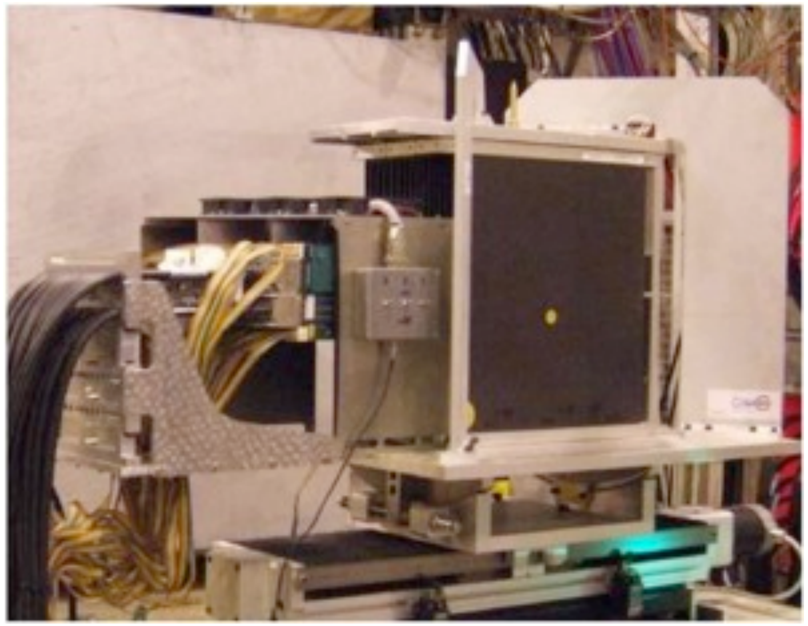
- Extensive test beam campaign
  - DESY: 2006
  - CERN: 2006, 2007
  - FNAL: 2008, ...
- Wide variety of beam energies and particle species
  - 2 GeV to 80 GeV
  - muons, $e^{\pm}$, $\pi^{\pm}$, unseparated hadrons



CALICE Calorimeter Setup

- 40 GeV negative pions



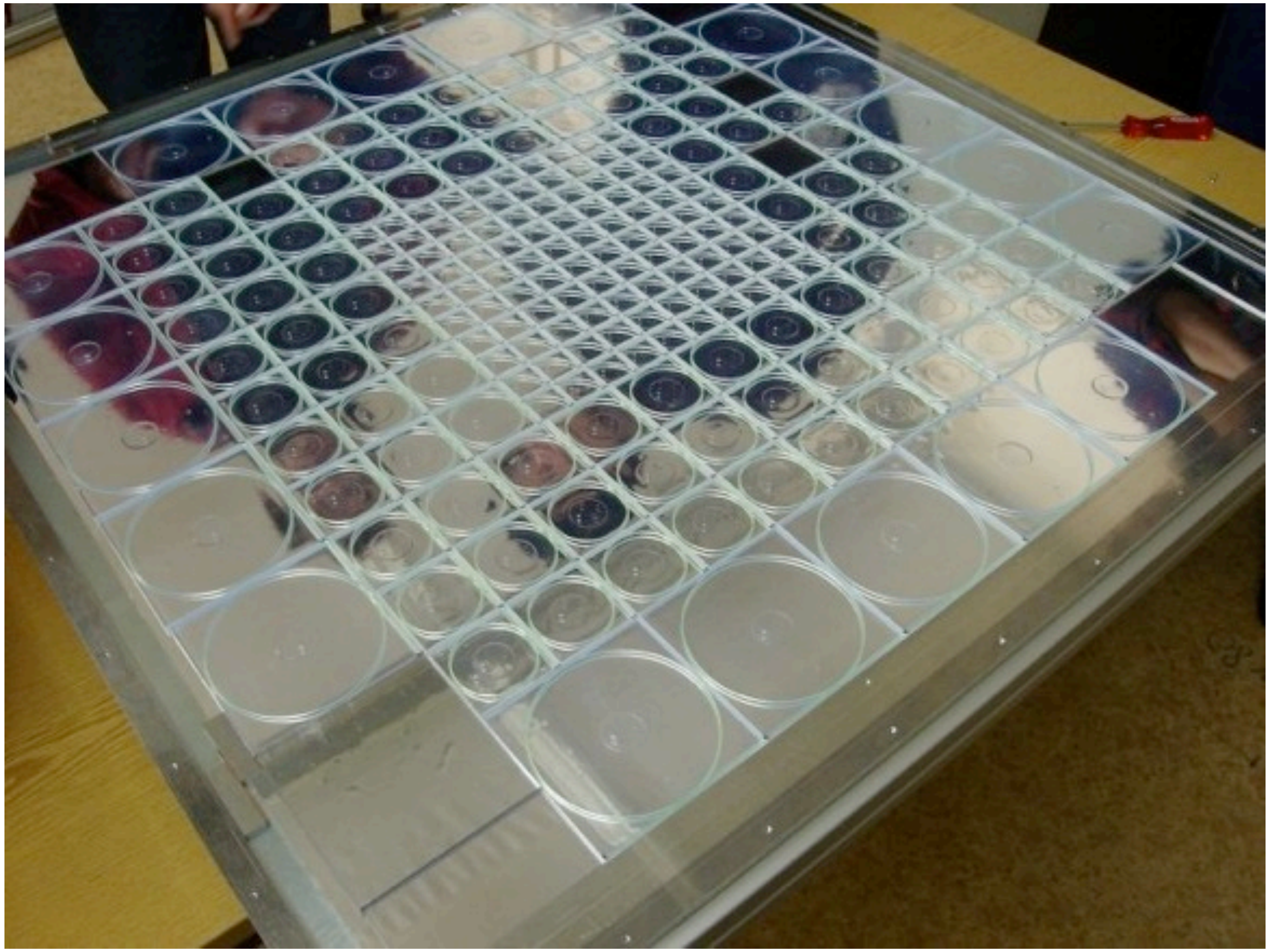


Si-W ECAL
1x1 cm^2 lateral segmentation
30 layers, ~ 0.9 λ, 30 X_0
~ 10 k channels

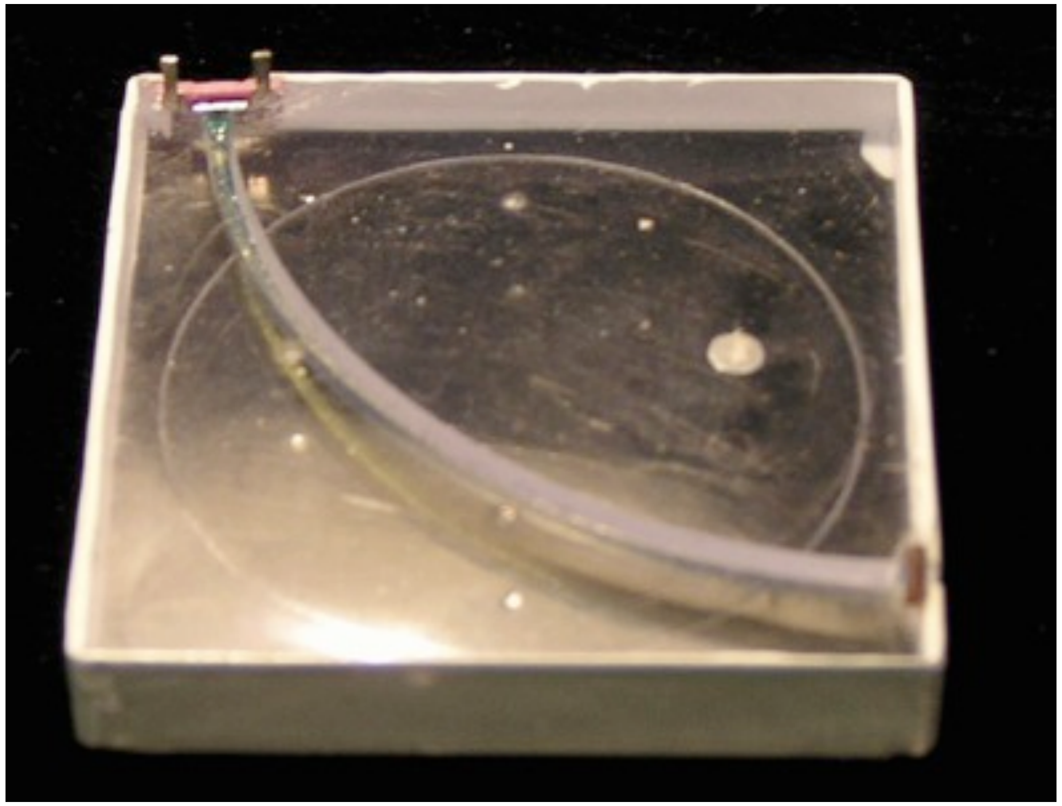
Analog HCAL
3x3 - 12x12 cm^2 lateral segmentation
38 layers, ~ 4.5 λ
~ 8 k channels

Tail Catcher / Muon Tracker
5 x 100 cm^2 Scintillator Strips
16 layers
~ 300 channels

The CALICE Analog HCAL



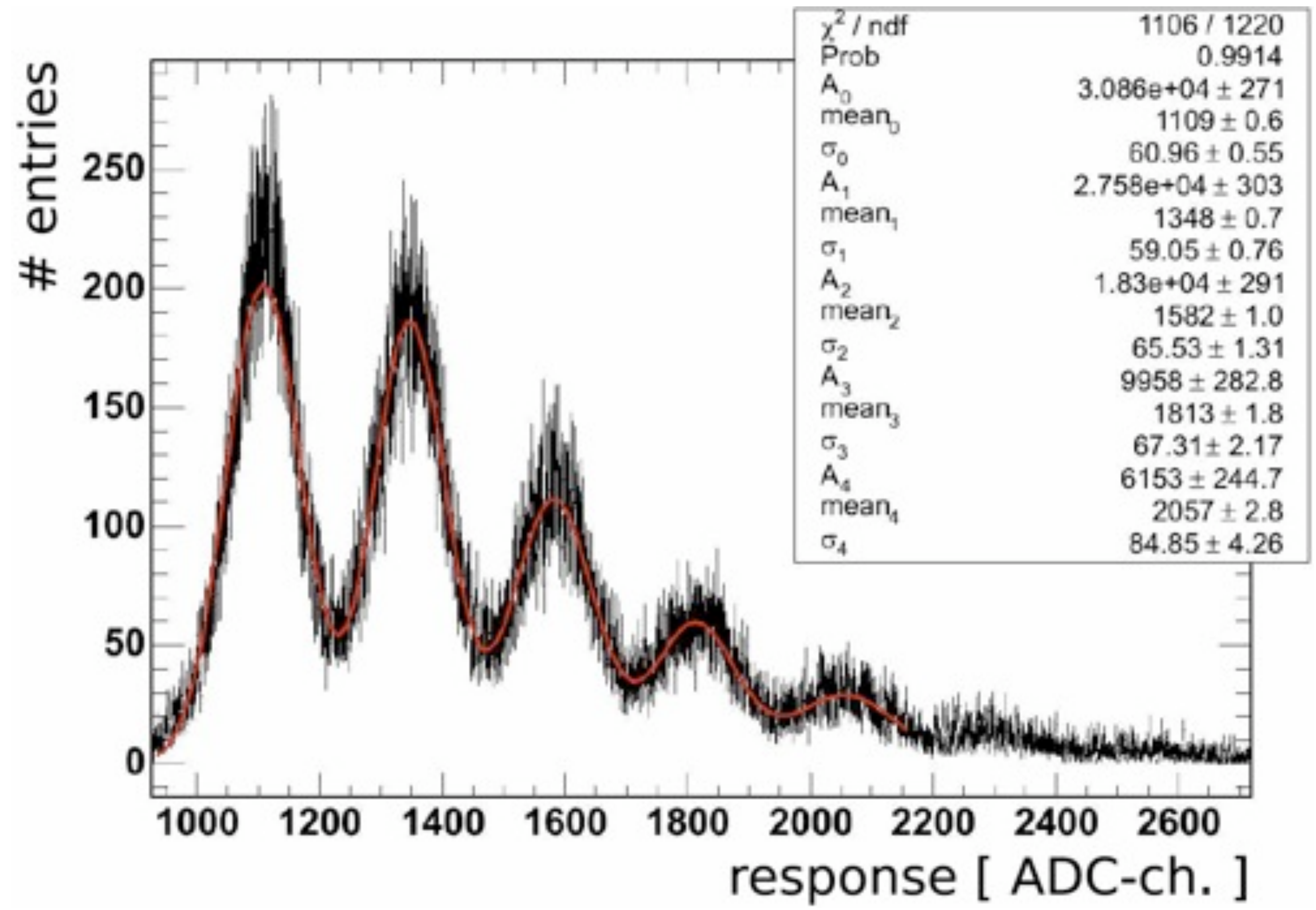
- Iron absorber structure:
  - 38 layers
  - 2 cm total absorber thickness per layer ($1.1\ X_0$, $0.12\ \lambda$)
  - total ~ $4.5\ \lambda$



- Active layers: Scintillator tiles
  - high granularity in the layer center: 100 3x3 cm^2 tiles, then 6x6 cm^2 and 12 x12 cm^2
  - light collection via wls fiber, read out with SiPM

Analog HCAL: Calibration

- Auto-calibration of SiPM gain: Individual photons can be resolved
  - Low-intensity LED light coupled into each detector cell
  - high gain setting of front-end electronics



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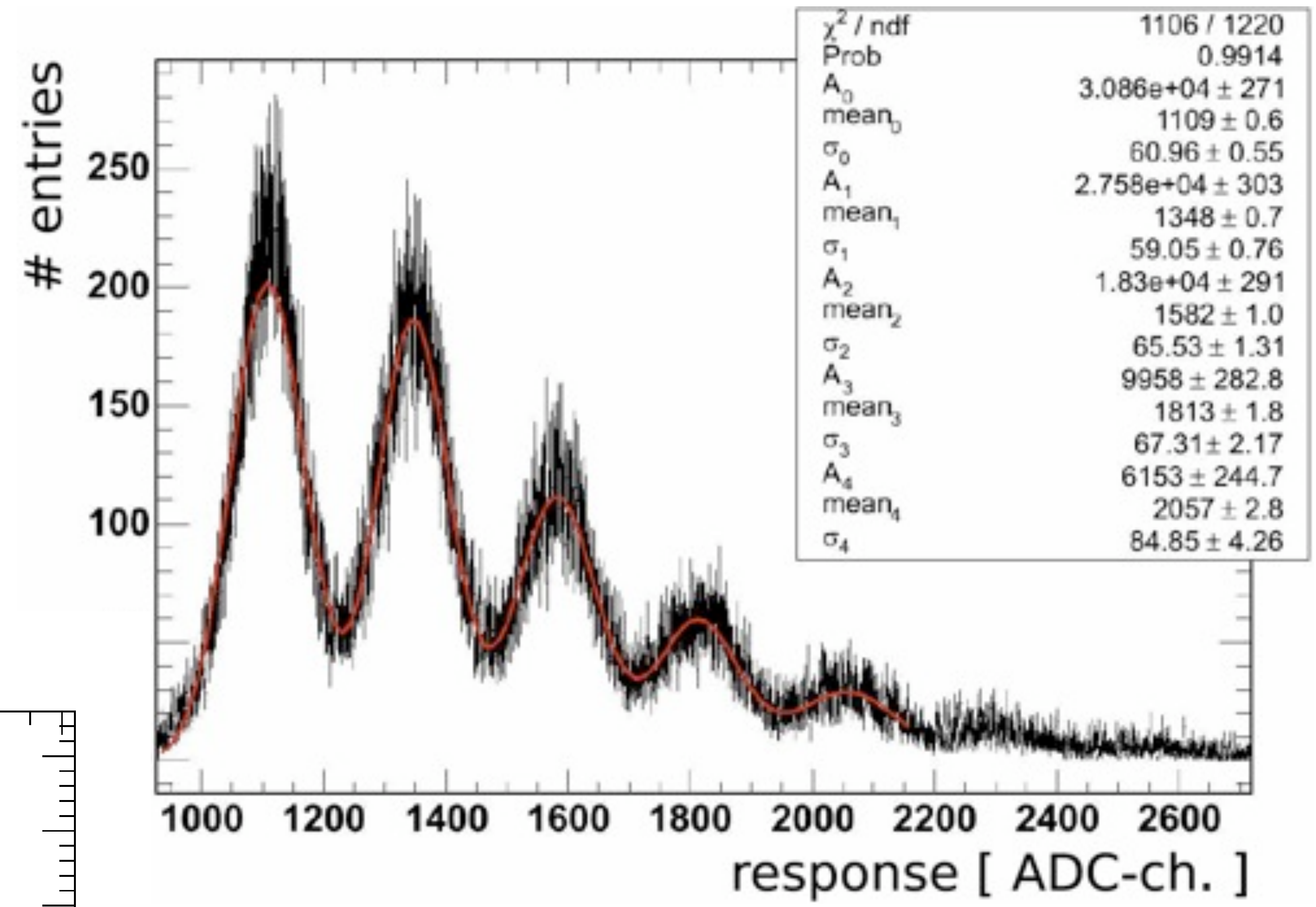
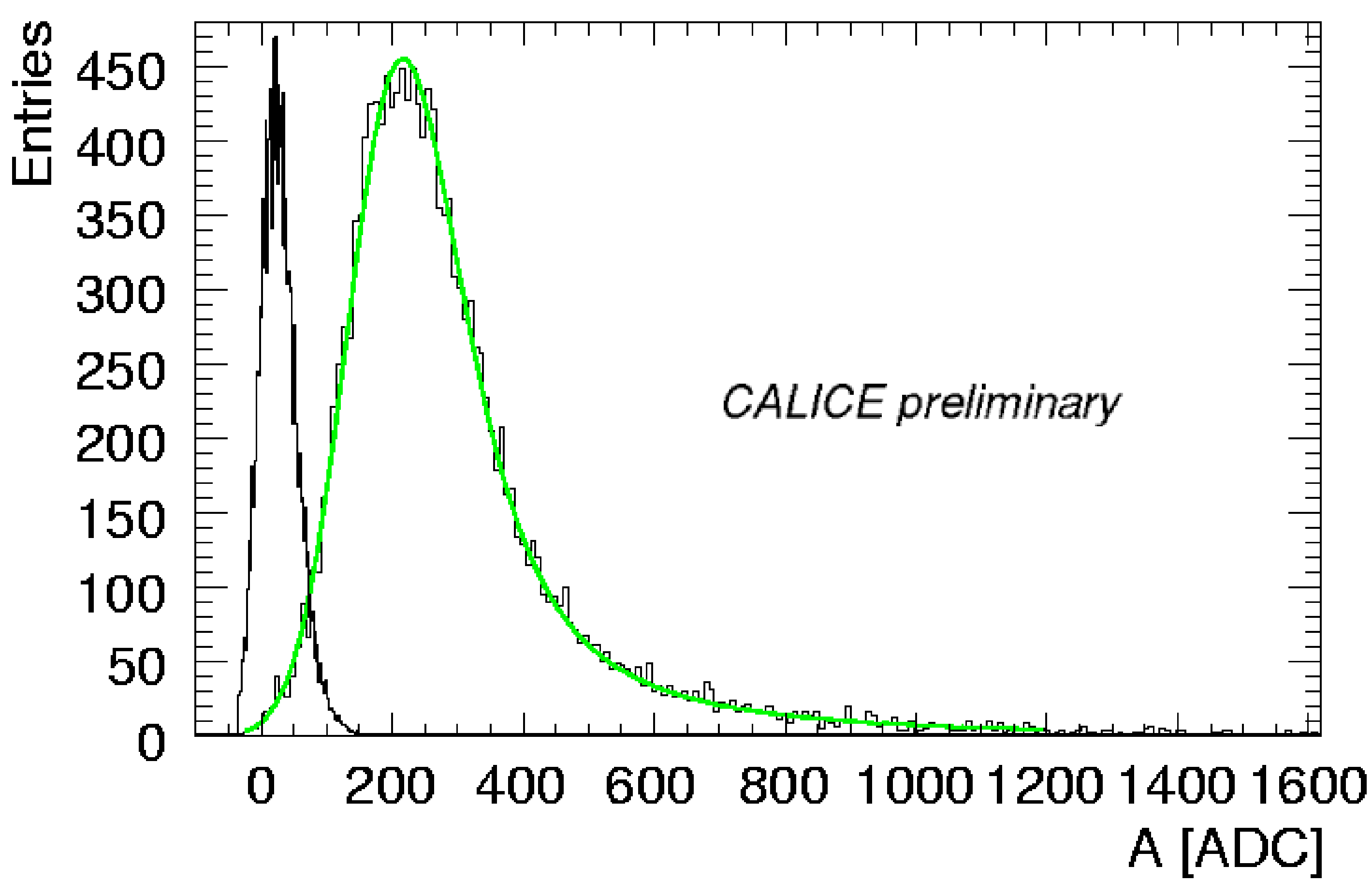




- MIP-Calibration with Muons
  - Complete detector illuminated with high energy muons
  - equalization of response of all cells by matching the MPV position

Energy Reconstruction

- Analog information available for each cell in each of the three detectors
  - Reconstructed energy is the sum of all cell energies, each with a suitable weight

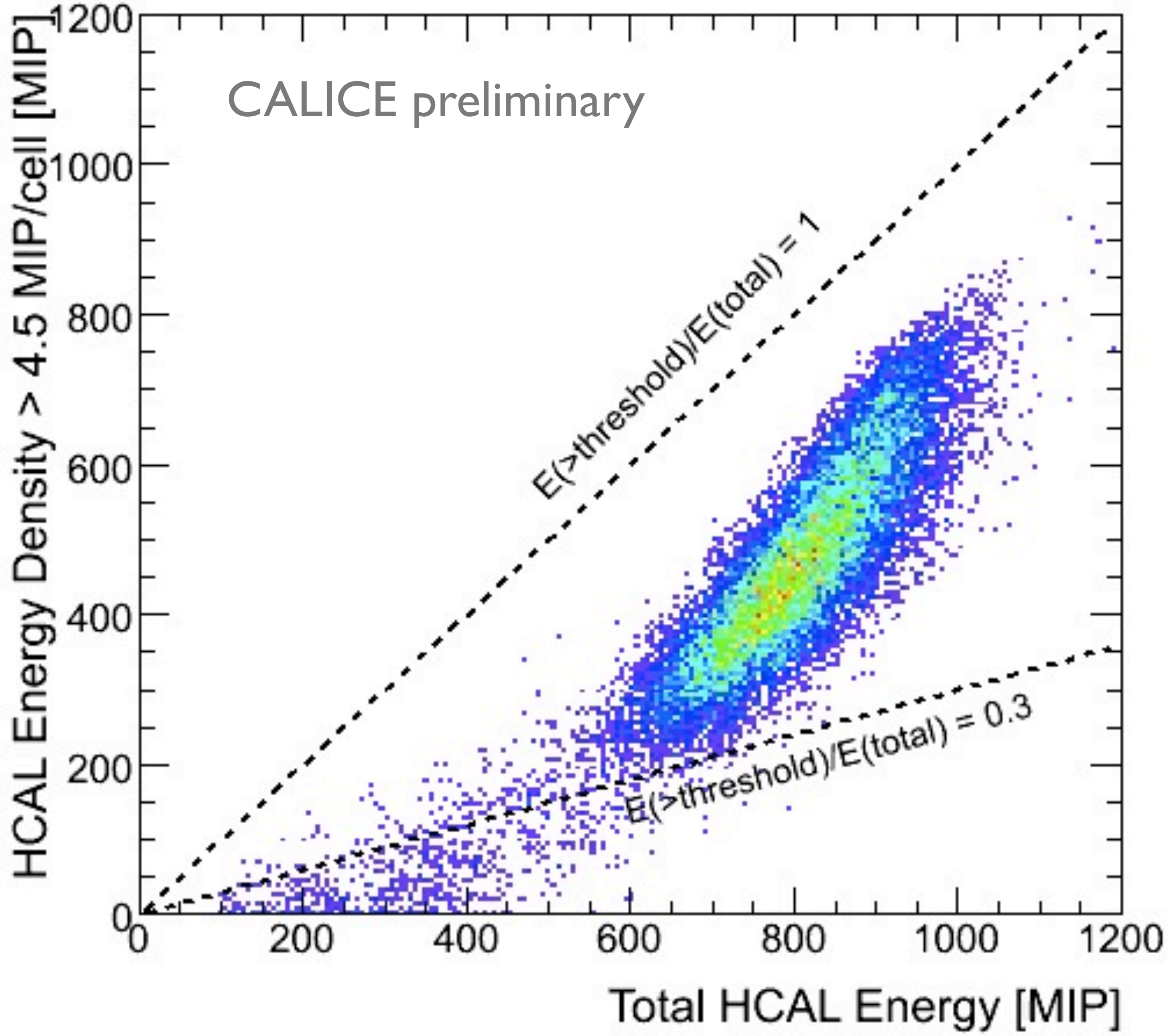
- In total 6 different sampling structures in the calorimeter setup
  - 3 different W plate thicknesses in the ECAL: 1.4, 2.8 and 4.2 mm, 10 layers each
  - uniform sampling in the HCAL: 20 mm Fe absorber per layer
  - 2 different samplings in the TCMT: 19 mm Fe absorber for the first 8 layers, then 102 mm Fe absorber

Intercalibration factors including the conversion from the MIP to the GeV scale were determined with data using a minimization technique

- For the ECAL, these do not correspond to the ratio of absorber thickness (shower development is folded in!)

Shower Weighting

- In a non-compensating calorimeter (CALICE HCAL: e/π ~ 1.2):
  - fluctuations in the em fraction of the events deteriorates energy resolution
  - change of em fraction with energy leads to non-linear response
- ▸ Improved resolution by identification of the shower components



- Electromagnetic showers tend to be denser than purely hadronic ones:
  - clear correlation between reconstructed energy and energy in high density shower regions
- ▸ Apply weights to energy deposits according to the local energy density in the shower to correct for difference in detector response

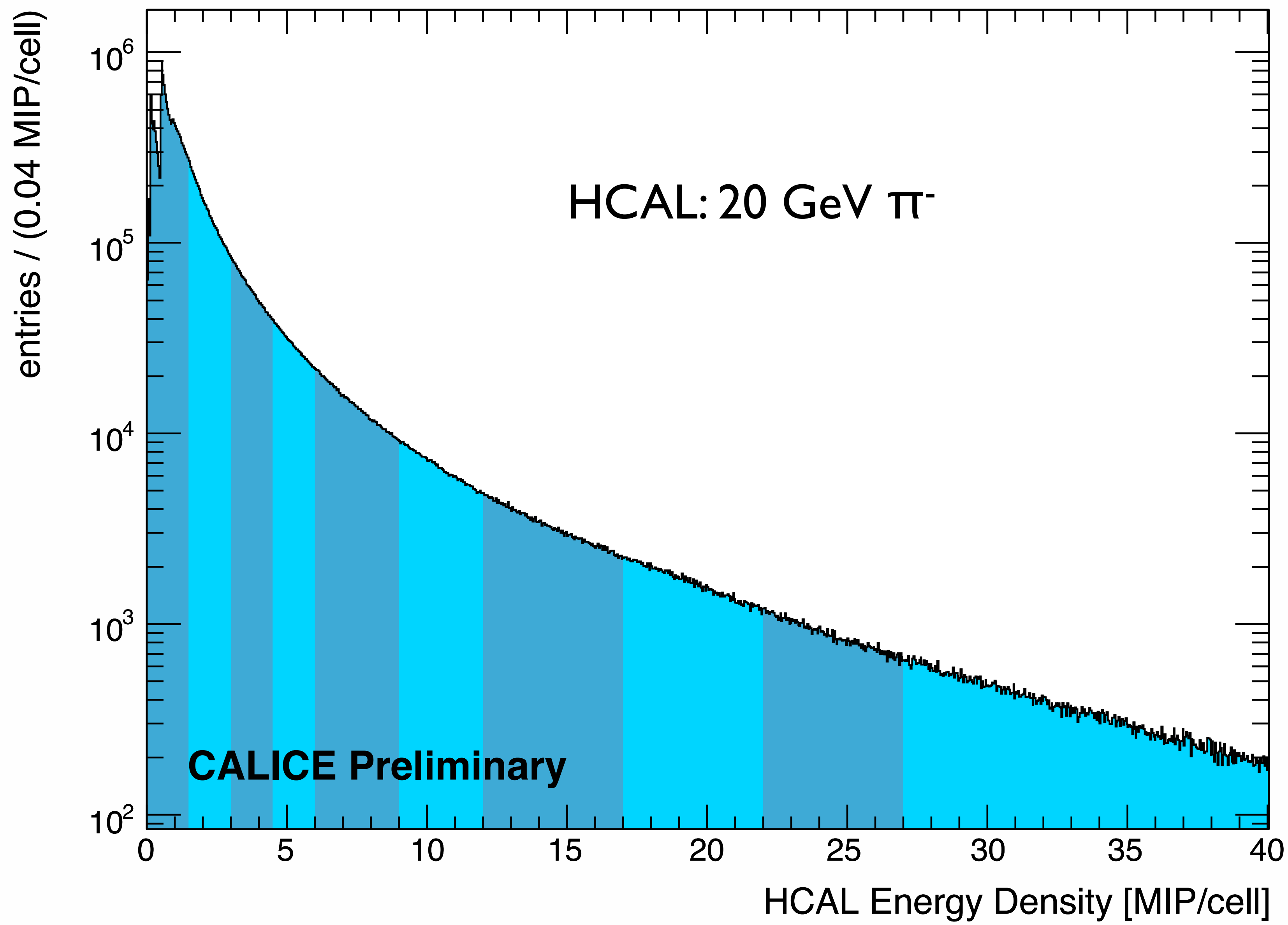
Hadronic Energy Resolution: Optimization with Weighting

Simple approach: Weight calorimeter cells according to their energy content

- Apply higher weights to cells with low energy density

Technicalities:

- Subdivision into 10 energy density bins for HCAL (6 bins for TCMT and ECAL)
- Weights are determined with a minimization technique from data
- Weights are energy dependent!
    - Parametrization used, no prior knowledge of beam energy necessary to apply weights

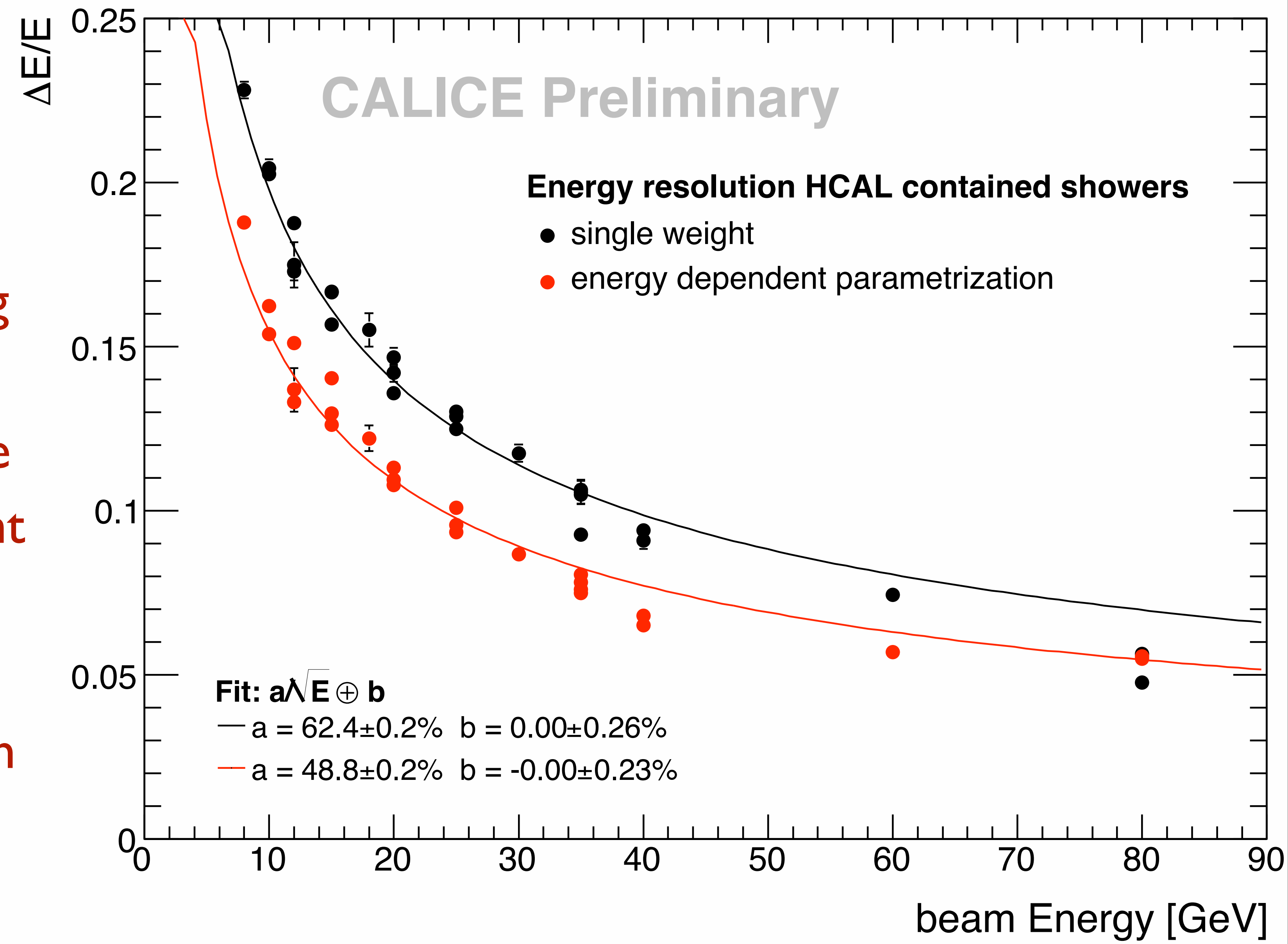


Resolution for Showers contained in HCAL

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!



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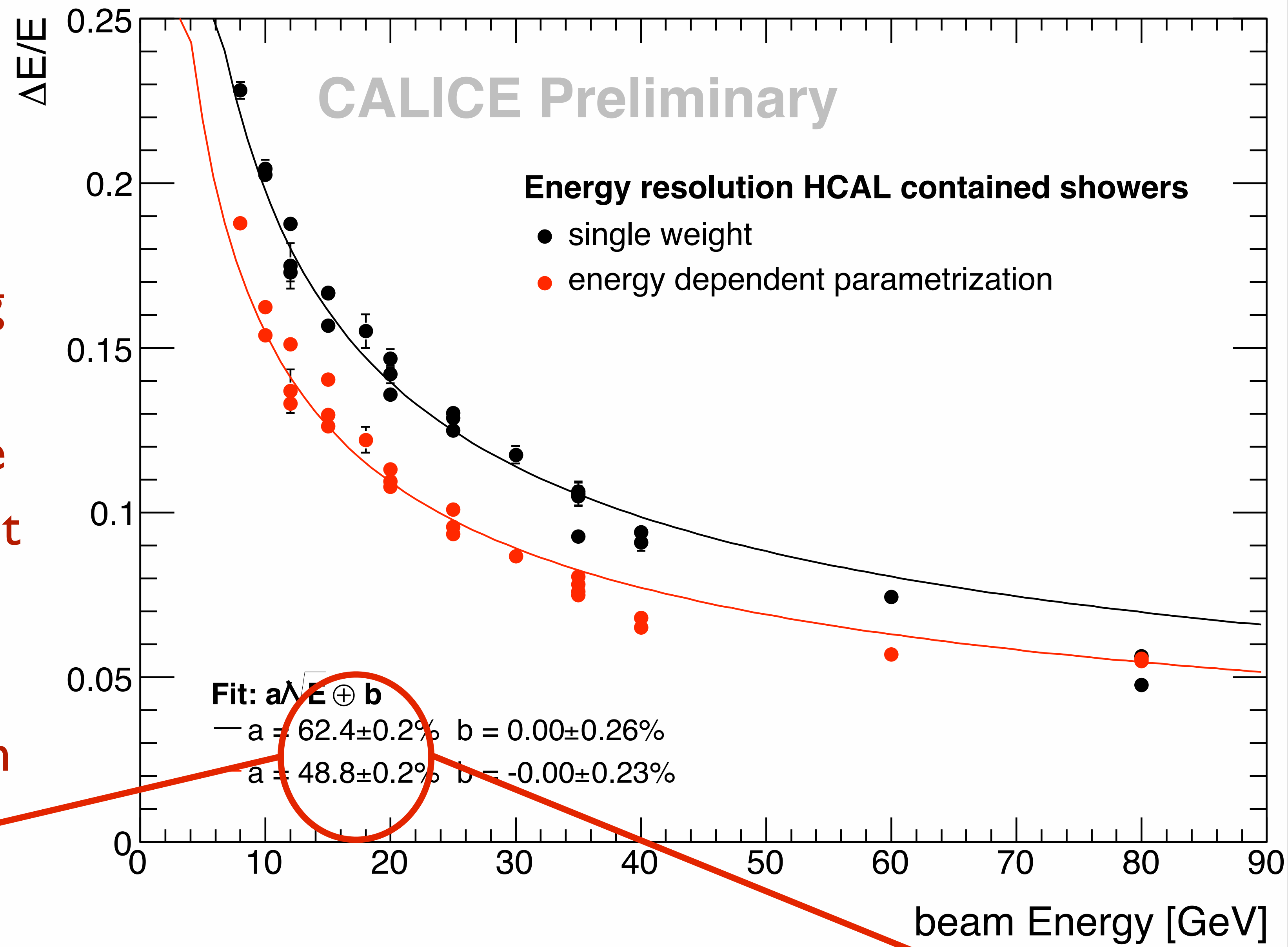
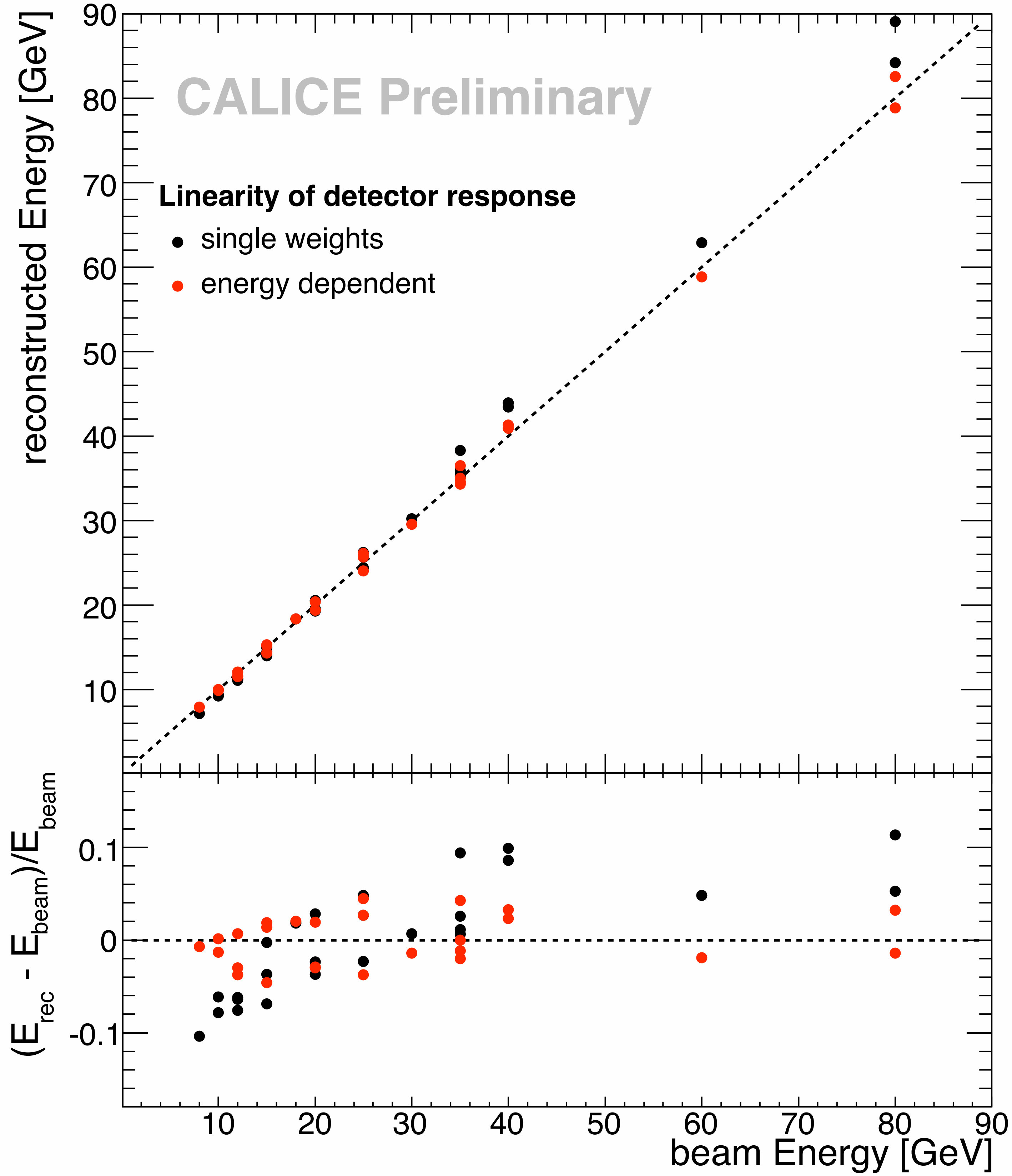


stochastic term w/o weighting: 62.4%, with parametrized weighting 48.8%

HCAL: Improvements in Linearity

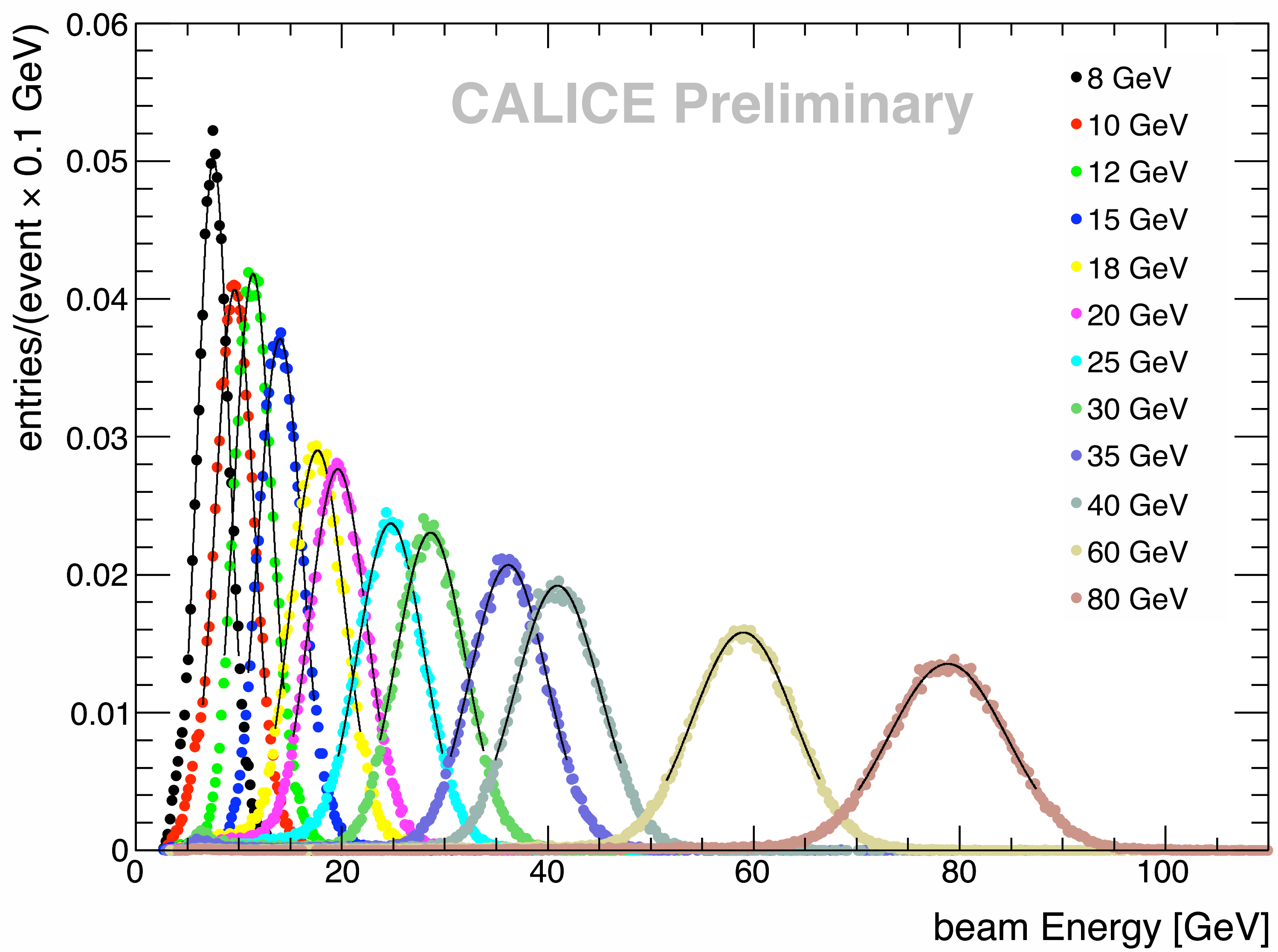
- Density dependent weighting improves the linearity of the detector response!

- No temperature correction to data applied: significant spread from run to run at the same energy due to temperature variations



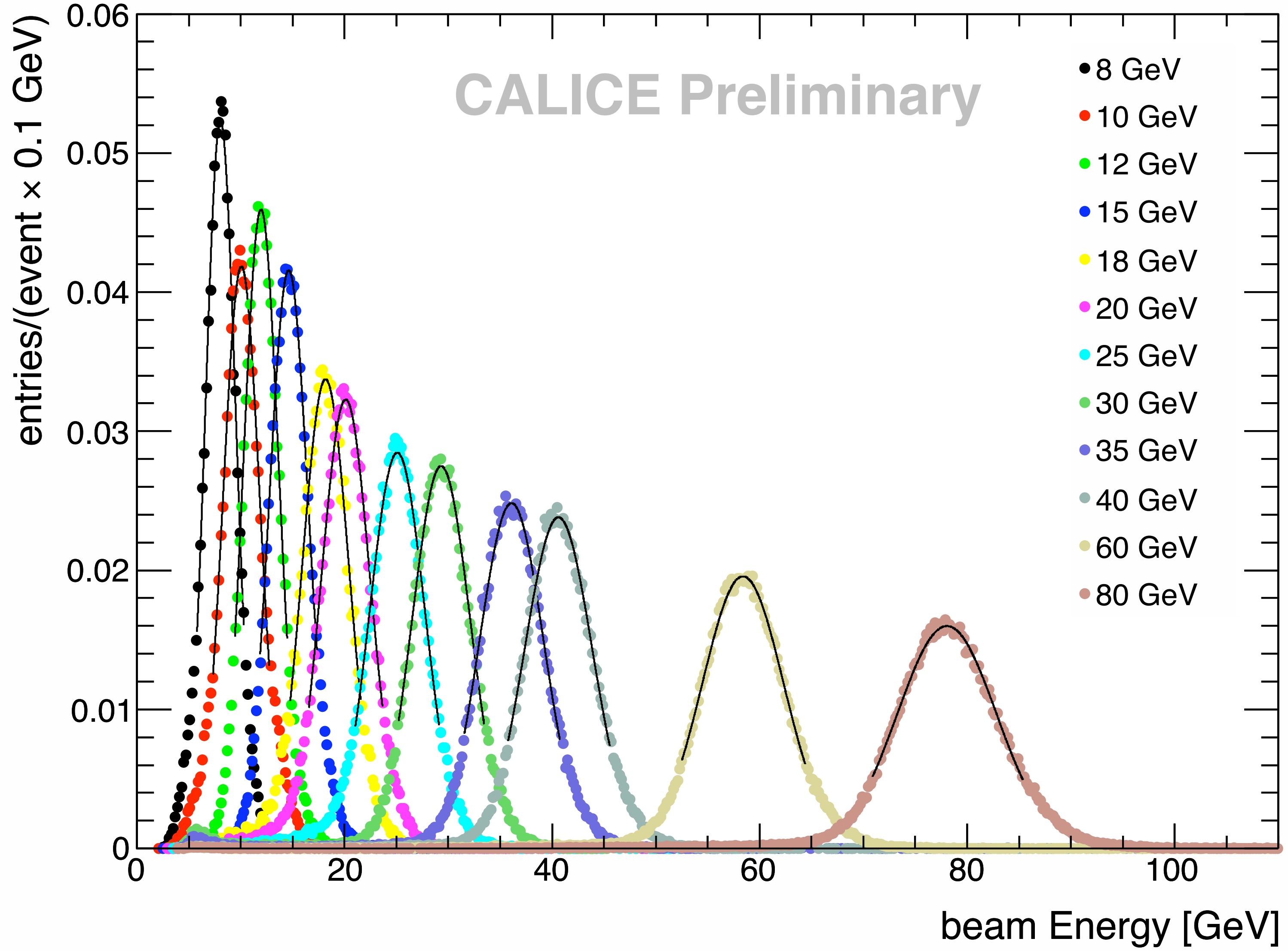
Expansion to the Full Setup

- Two reconstruction methods:
  - No weighting: one calibration factor (MIP to GeV) per subdetector (ECAL, HCAL, TCMT)



Expansion to the Full Setup

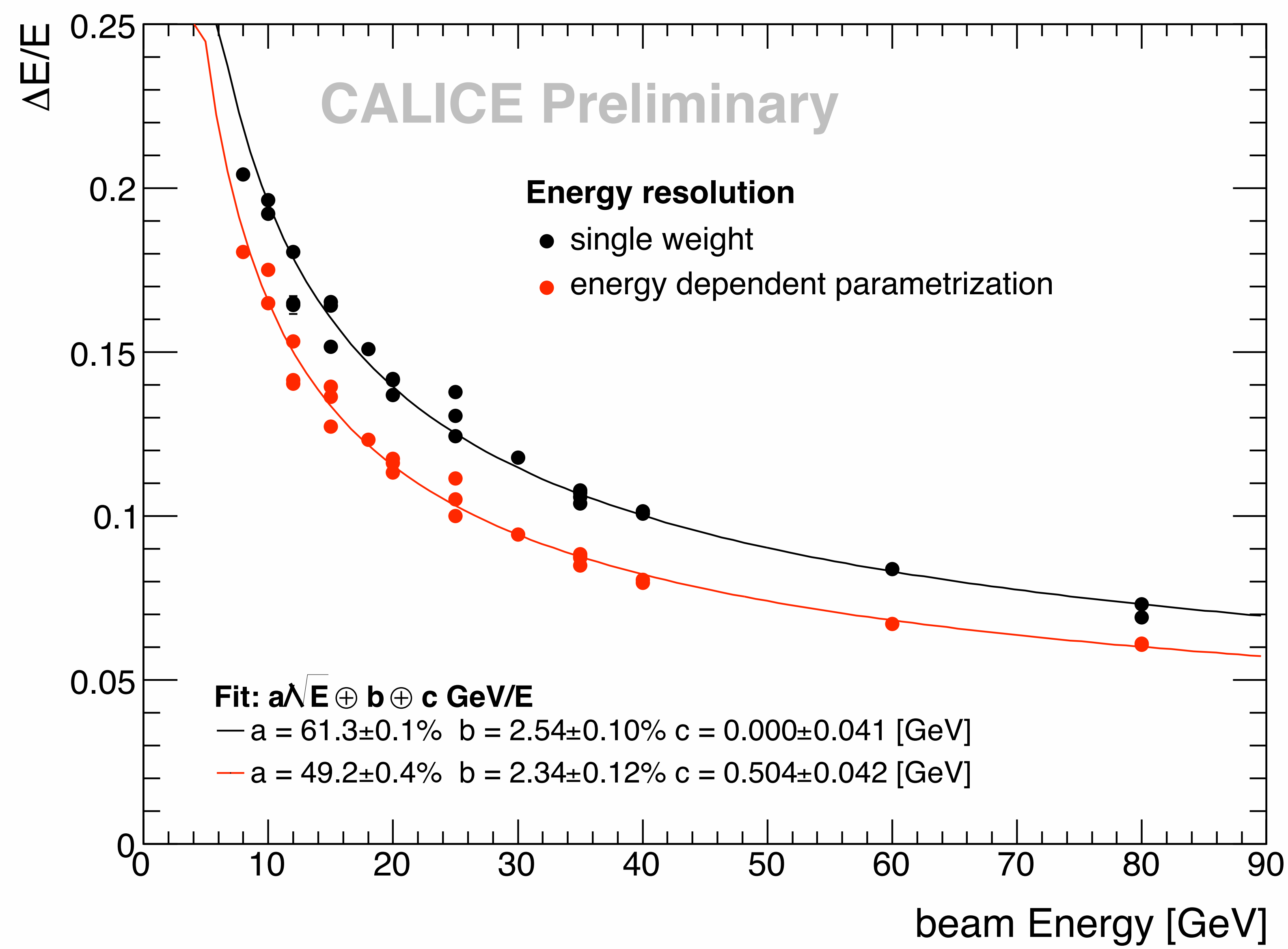
- Two reconstruction methods:
  - No weighting: one calibration factor (MIP to GeV) per subdetector (ECAL, HCAL, TCMT)
  - Energy density dependent weighting, parametrized energy dependence



Complete CALICE Setup: Resolution

- Expansion to the complete setup: ECAL, HCAL, TCMT
  - separate weights in each of the detectors

- Same technique as for HCAL only study
  - Significant improvement of resolution with weighting technique (~ 20%)



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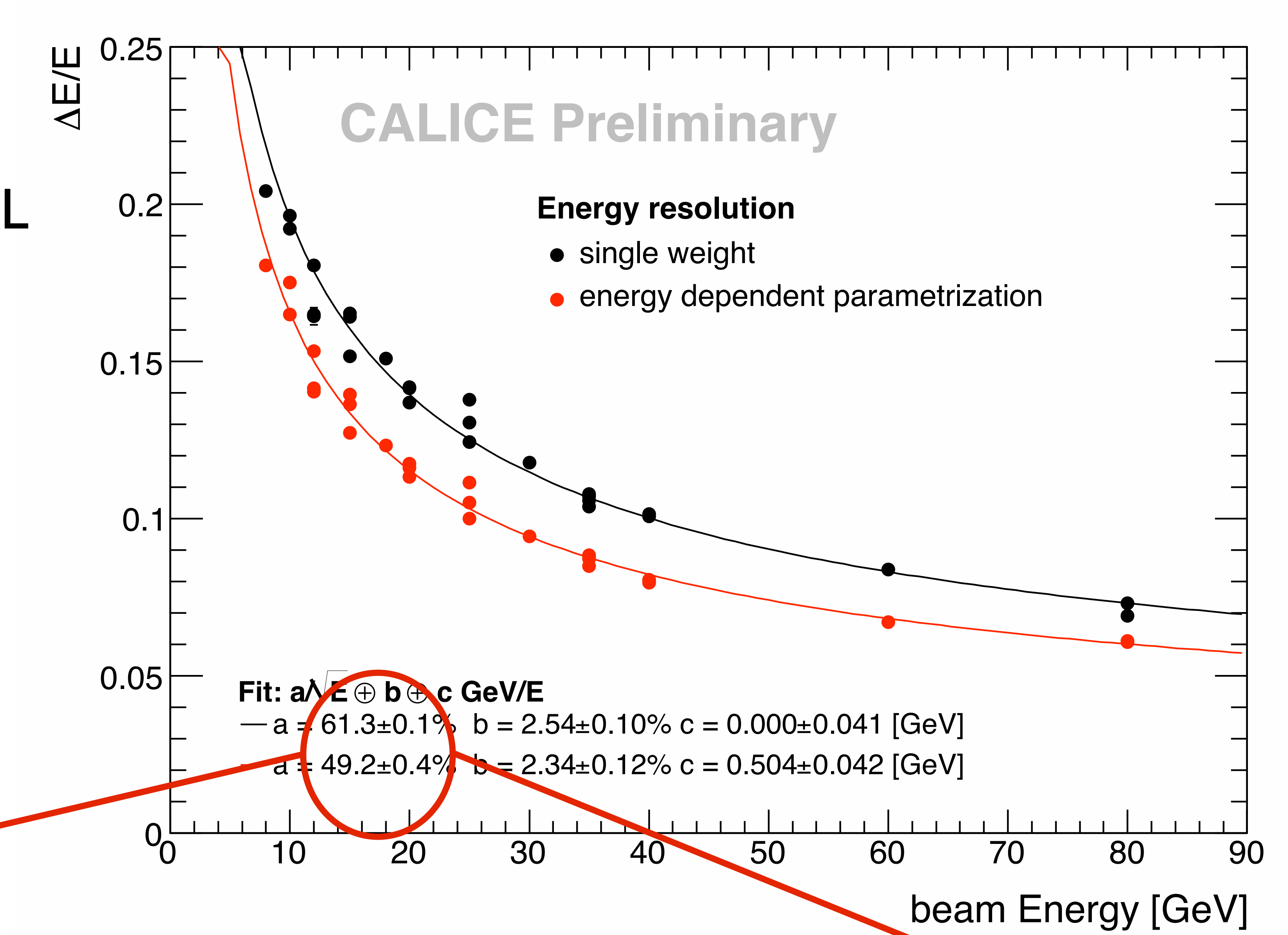
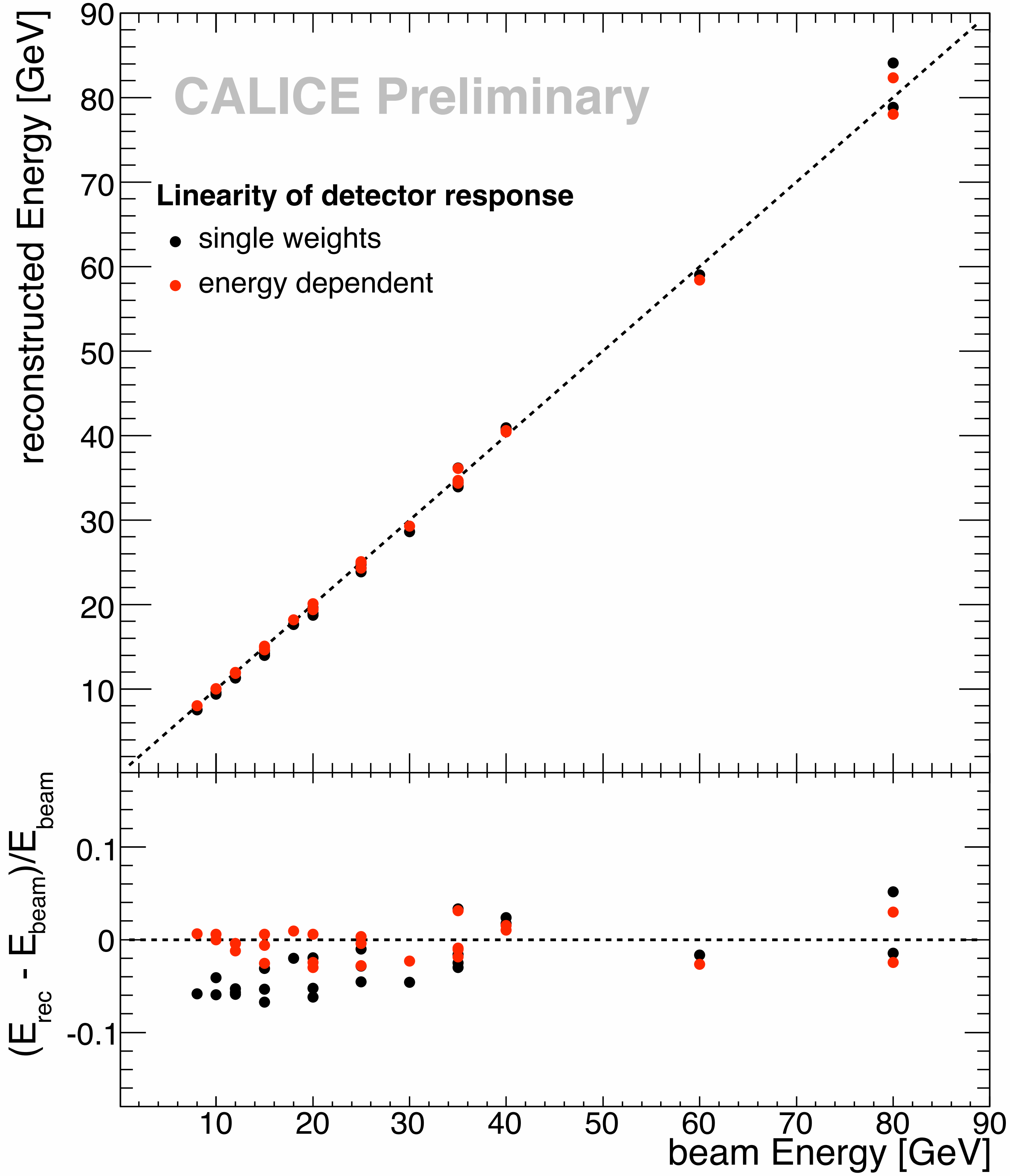


stochastic term w/o weighting: 61.3%, with parametrized weighting 49.2%

Linearity of Energy Response: Combined Setup

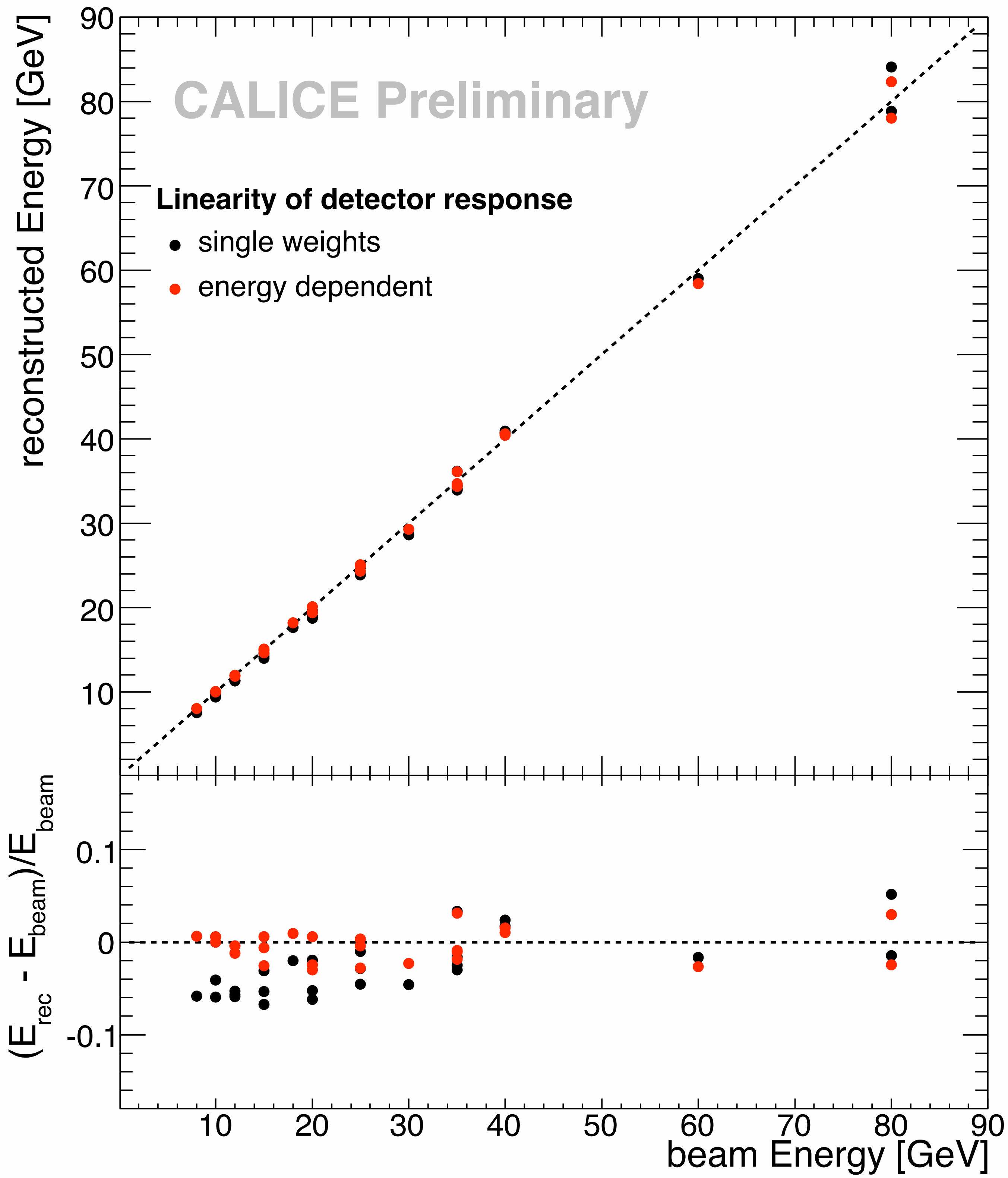
- Energy reconstructed with single conversion factors and with parametrized density dependent weighting
- Noise rejection: Isolated noise hits (and isolated neutrons) rejected in the analysis



Linearity of Energy Response: Combined Setup

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

- 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 not yet included: leads to a run-to-run spread at a given energy



Summary and Outlook

- CALICE tests imaging calorimeters for future high energy lepton colliders
- The high granularity can be used for software compensation:
  - First successful tests with weighting based on the energy of each cell: 20% improvement in energy resolution, both for showers contained in the HCAL and for the complete CALICE setup
- Future steps:
  - Combination with clustering algorithms
  - Evaluation of neural networks