# Software compensation for the CALICE AHCAL

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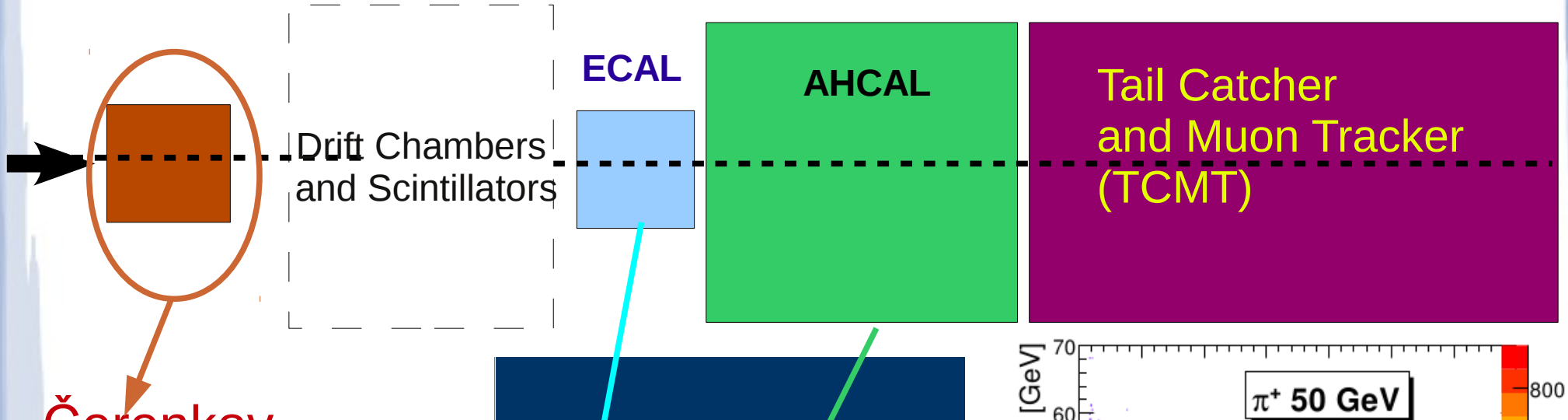
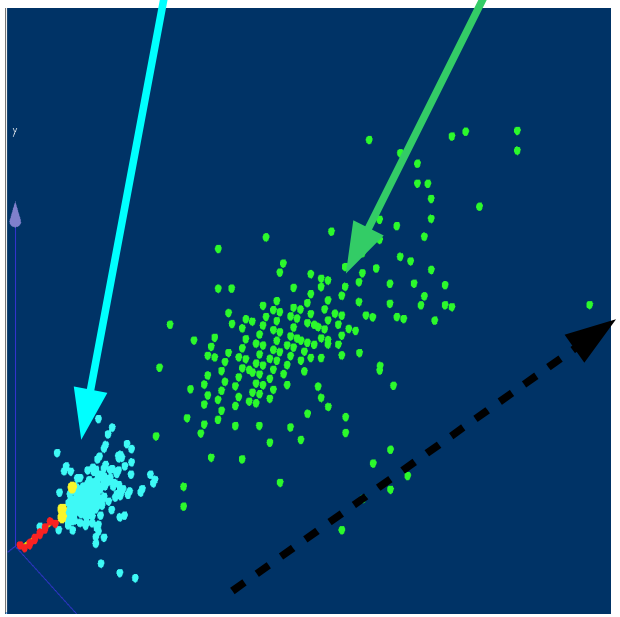
# Data and pion event selection

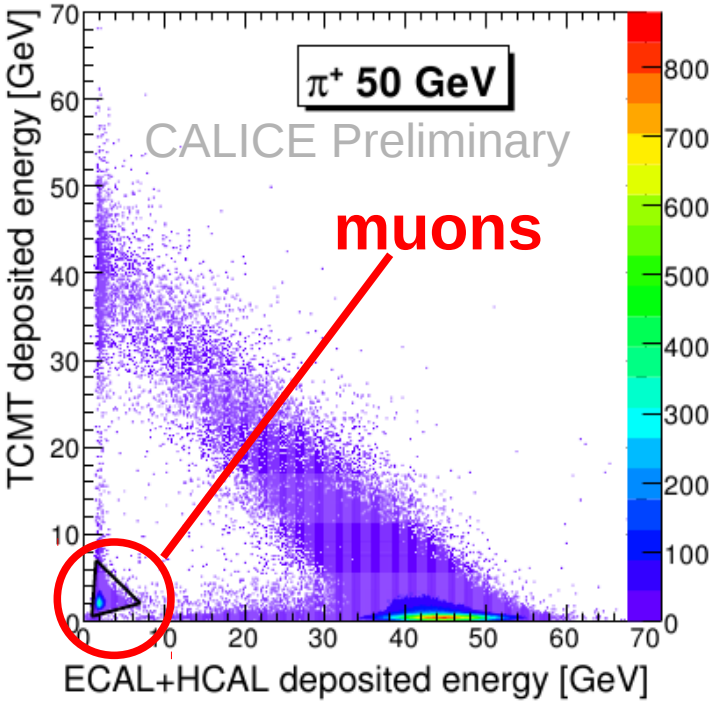
$\pi^-$ and $\pi^+$ of 8 ÷ 80 GeV from test beam at CERN SPS in 2007




Čerenkov

used to remove electrons from the $\pi^-$ runs and protons from the $\pi^+$ runs



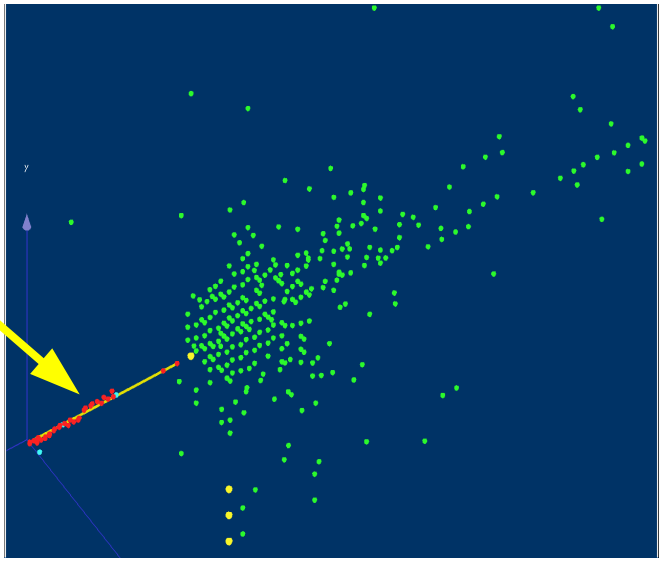


# CALICE AHCAL Prototype

- Fine-granular iron-scintillator calorimeter
- 7608 tiles in ~1 cubic meter (depth ≈ $4.5\lambda_I$)
- Non-compensating ($e/\pi > 1$)

**For software compensation study:**

- pions that start showering in HCAL are selected (track in ECAL)
- for methods with hit spectrum analysis, events with shower start at the beginning of HCAL are selected
- electromagnetic calibration coefficients are used to calculate deposited energy



# Software compensation approaches

Non-compensating calorimeter -> response depends on EM fraction in hadronic shower -> worse resolution for hadrons

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**High granularity allows two approaches:**

| Local | Global |
| --- | --- |
| **Basis:** higher energy density in EM component comparing to HAD | **Basis:** observables correlated with EM fraction value |
| **Implementation:** a weight applied to each cell depends on the energy density in the cell | **Implementation:** a single weight for event energy is calculated from these observables |

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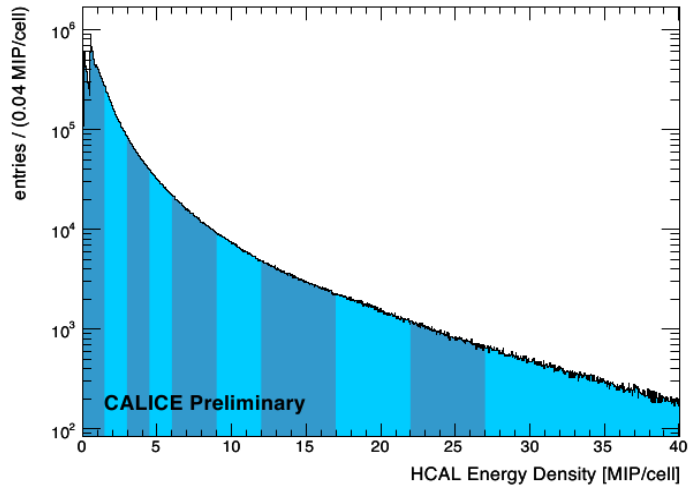
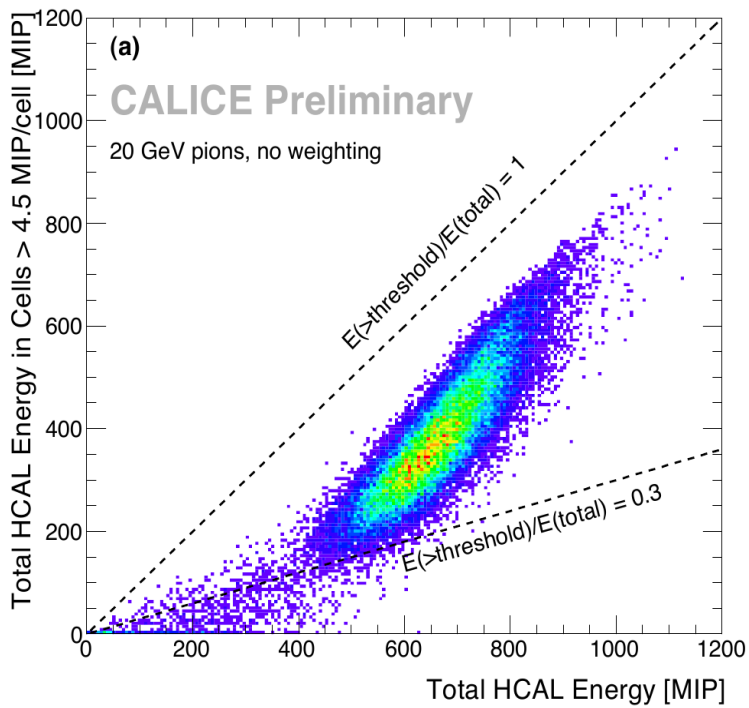
**Both approaches successfully applied to the CALICE AHCAL:**

- local method with individual cell weighting
- global method with hit spectrum shape analysis (in detail in this talk)
- global method with neural network

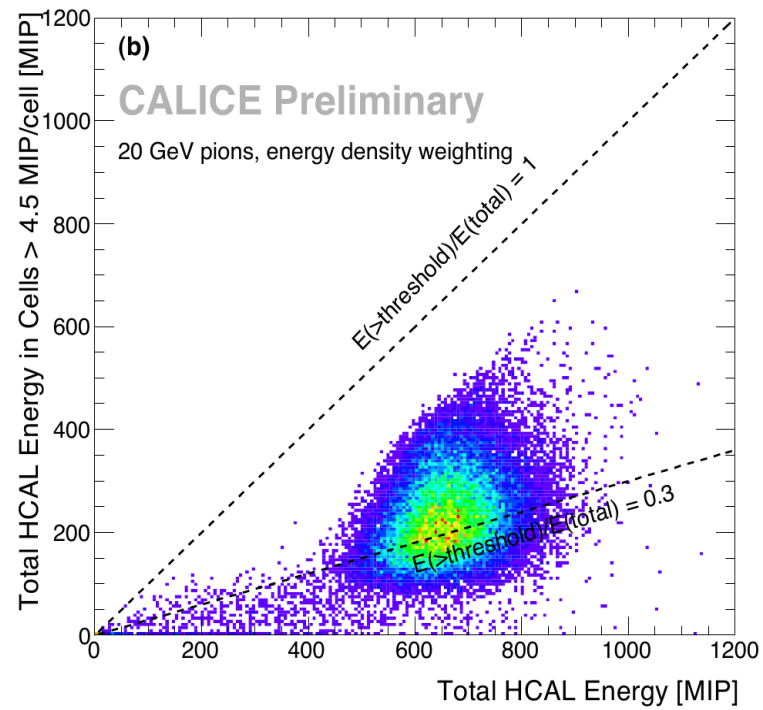
# Software compensation: Local Method




- HCAL hit energy spectrum is divided by groups of cells according their energy density.
- Weights are applied to cells according to their energy, lower weight for cells with higher energy content

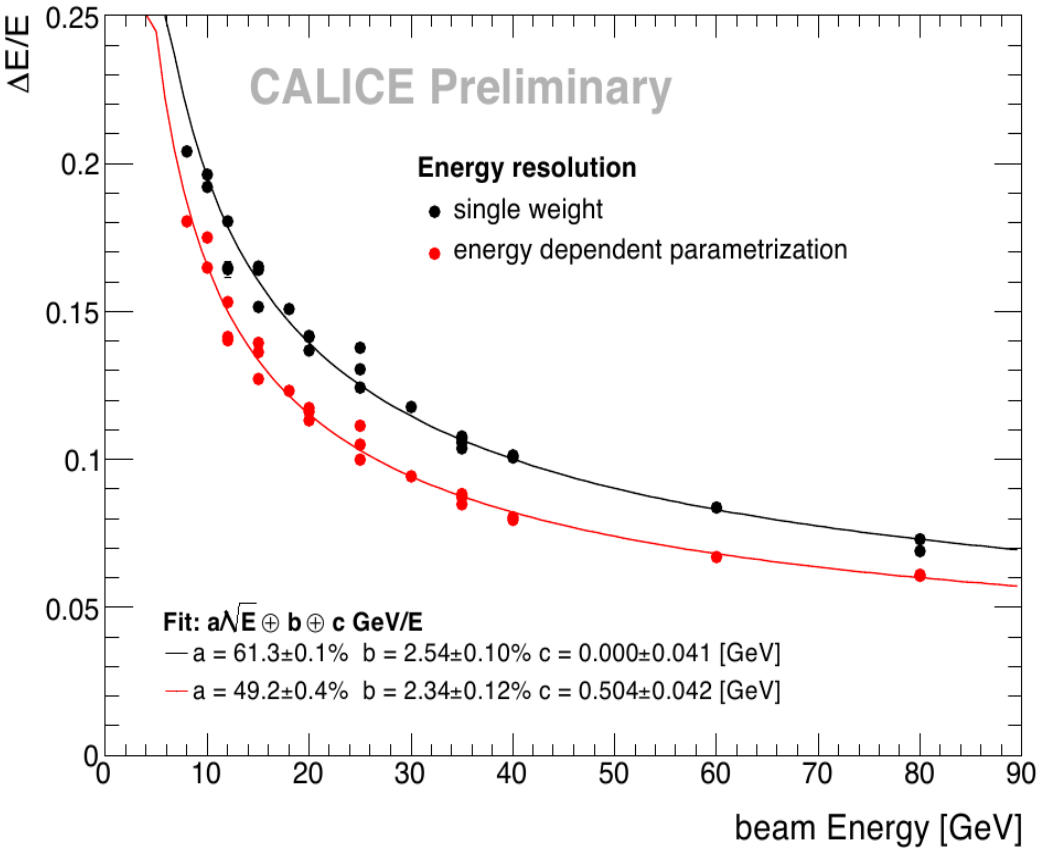



weighting



# Software compensation: Local Method

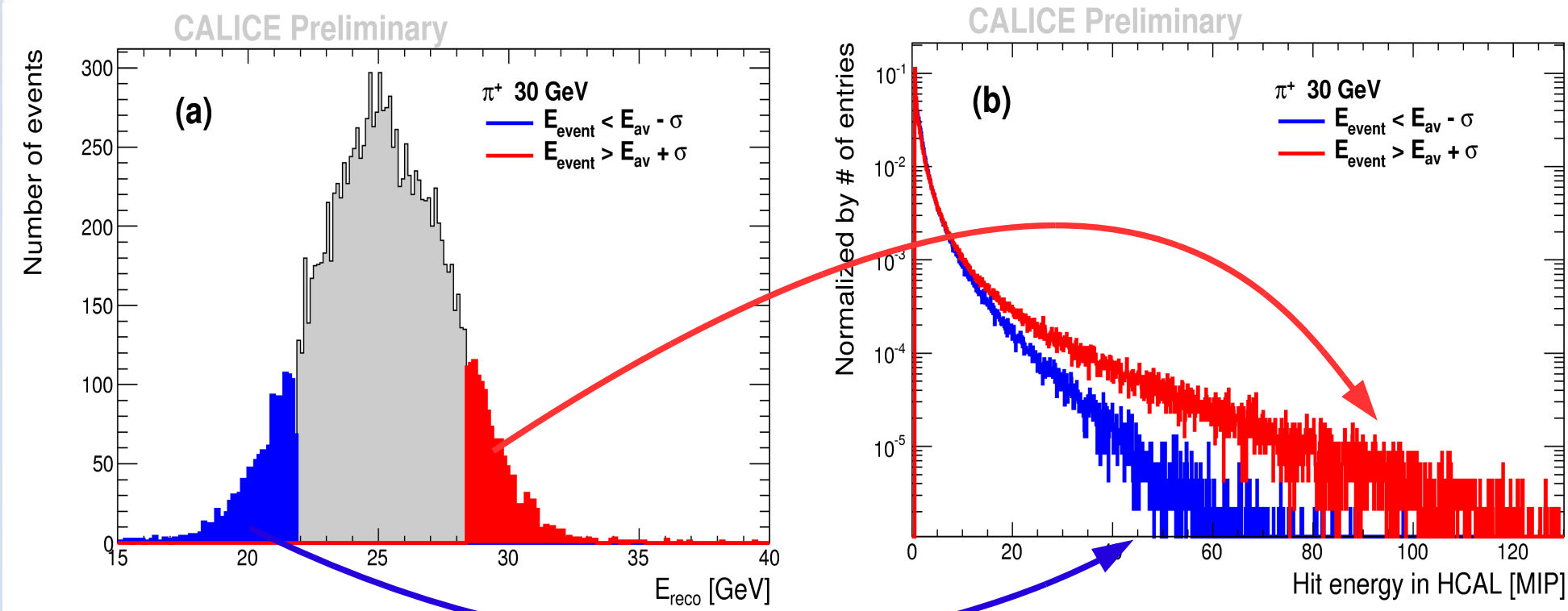
- Weights are determined from data using minimization technique and applied to each individual cell.
- Weight energy dependence is parametrized.




- **No prior knowledge of beam energy necessary for application of the method**
- **Improved linearity of response, within ~3% from 8 to 80 GeV**
- **Resolution improved by ~18%**

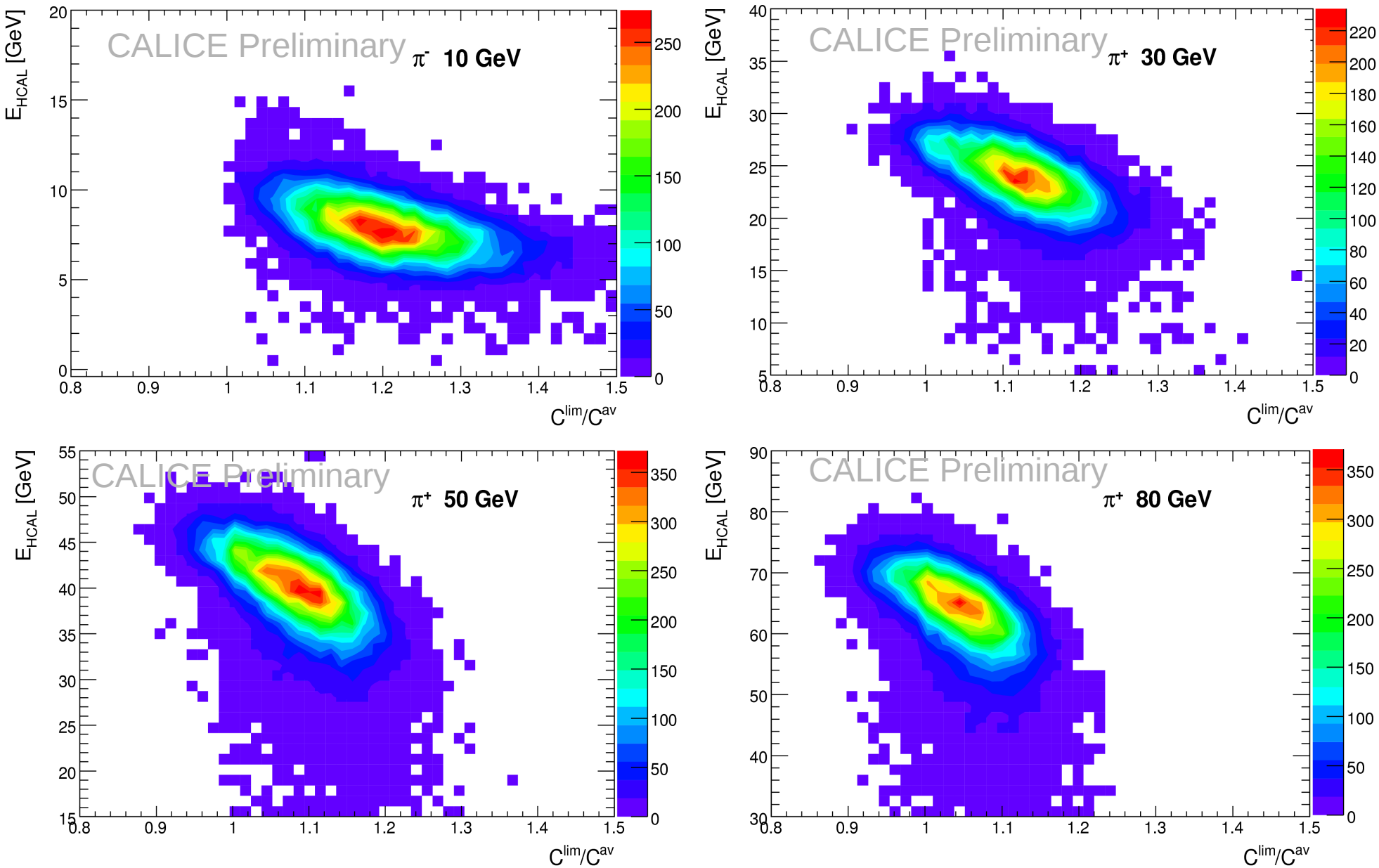
# Software compensation: Global Method

Hit energy spectrum shapes are different for high and low detected response -> spectrum shape is related to the amount of EM fraction




**Observables:** $C^{lim}$ - probability to find a hit with less energy than a fixed value $e^{lim}$ (e.g. 5.5 MIP - in the middle of the spectra crossing region) and $C^{av}$ - probability to find a hit with less energy than average of the event spectrum

# Deposited energy vs. observables




**The ratio $C^{lim}/C^{av}$ is inversely correlated with HCAL deposited energy ($e^{lim}$=5.5 MIP).**

# Compensation for the i-th event

**No prior knowledge of beam energy necessary for method application**

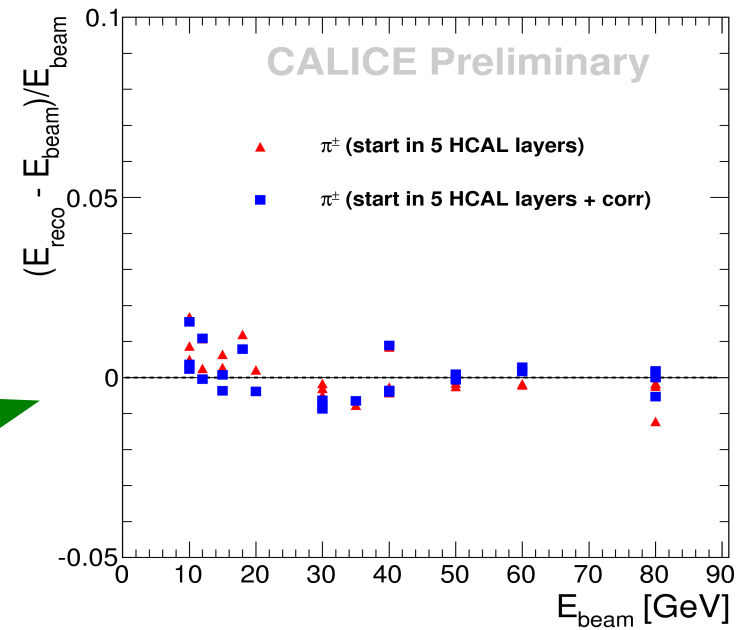
1. Depositions in each subdetector: $E_{ECAL}$, $E_{HCAL}$, $E_{TCMT}$
2. Corrected HCAL energy: $E_{cor} = E_{HCAL} \times C^{lim}/C^{av}$ → Correction factor
3. Corrected shower energy: $E_{sh} = E_{cor} + E_{TCMT}$
4. Polynomial correction to keep linearity:

$$E_{reco} = E_{sh}(a_1 + a_2 E_{sh} + a_3 E_{sh}^2) + E_{ECAL}$$

coefficients are extracted from fit to $\langle E_{sh} \rangle$ vs. $(E_{beam} - \langle E_{ECAL} \rangle)$

24 pion runs, 10 ÷ 80 GeV

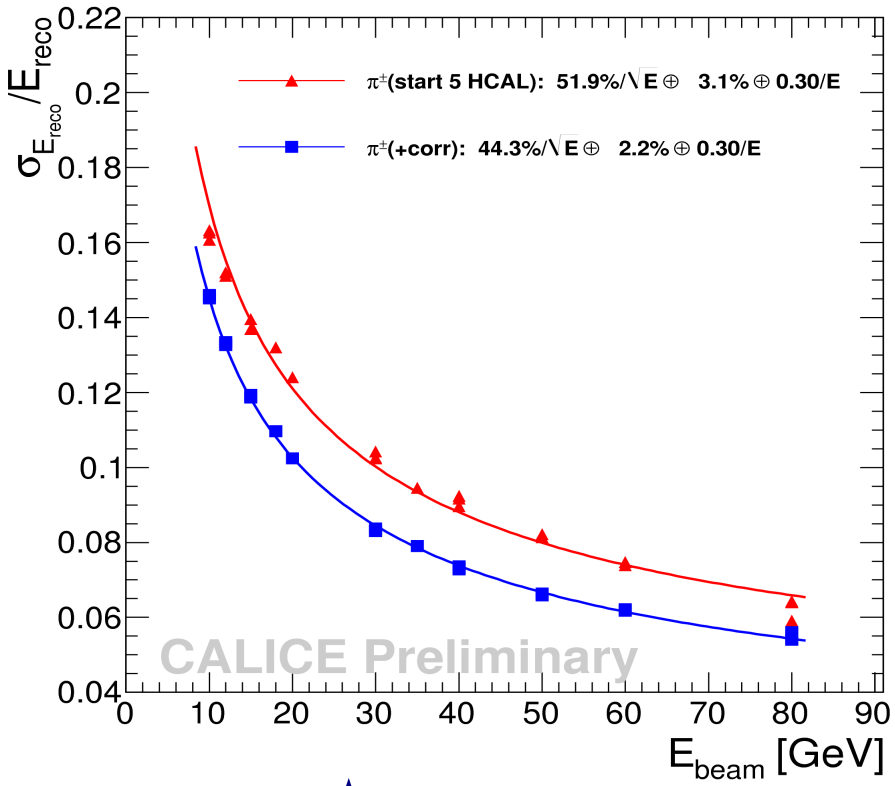
$e^{lim}$ = 5.5 MIP



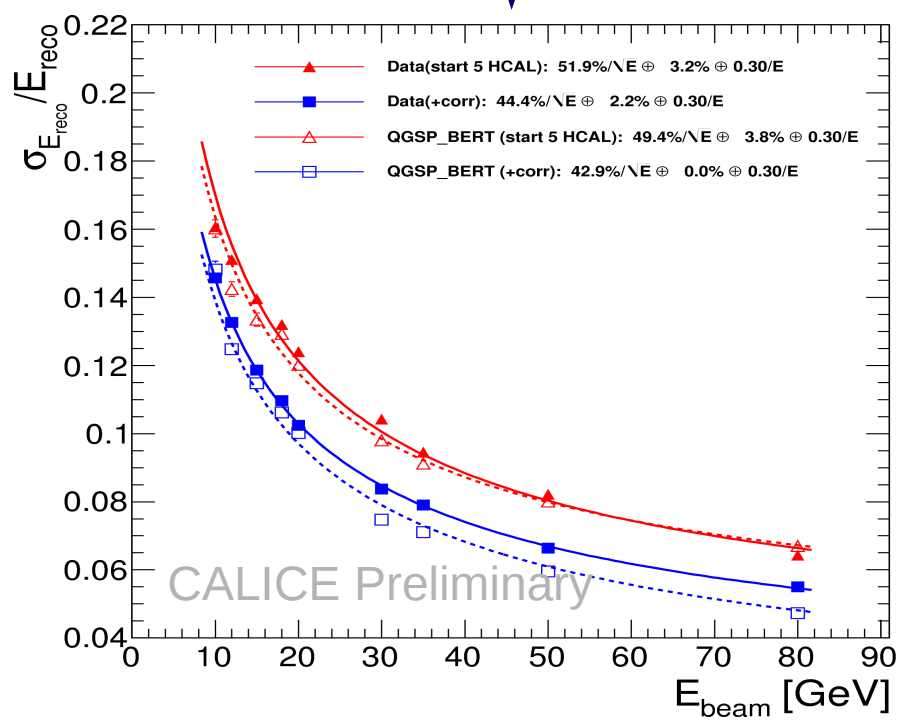

Linearity **without** and **with** compensation **within ~2%**

# Relative resolution for pions

## Before and after compensation




Comparison with MC (QGSP_BERT). The coefficients extracted from data are applied to MC (em calibration and e/π ratio).




**Improvement for data:**

**10% ÷ 20% for 10÷80 GeV**

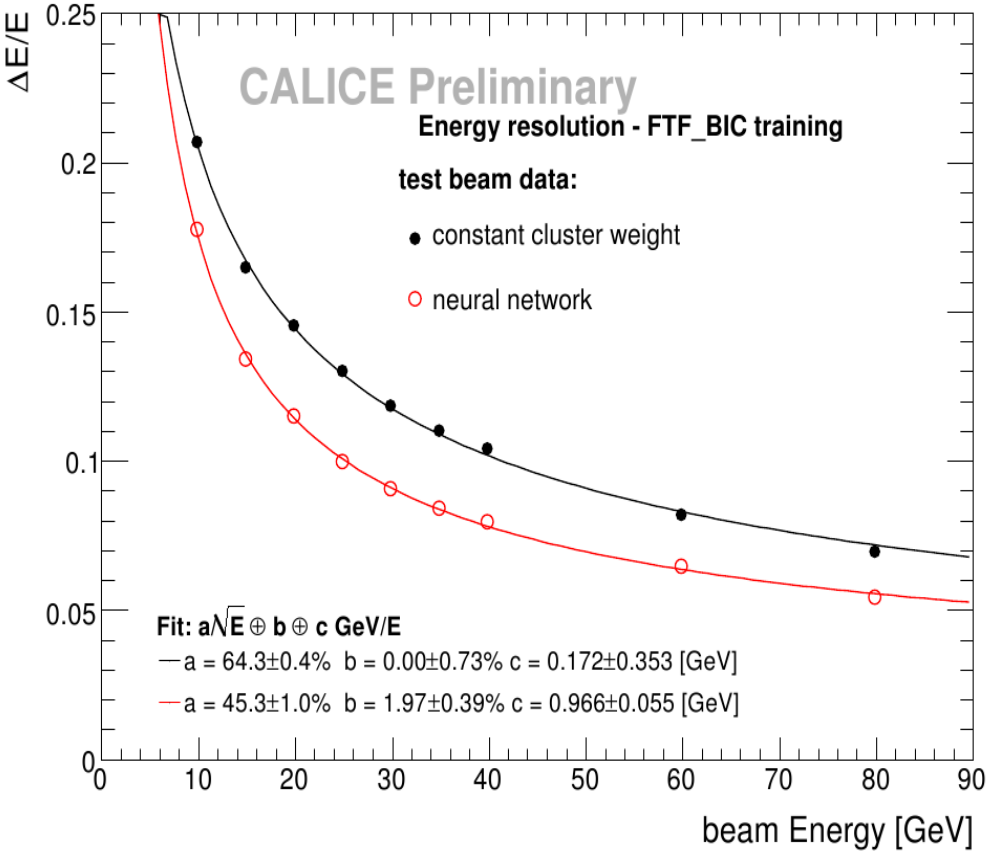
# Software compensation: Global Method with Neural Networks

Cluster finding in HCAL and TCMT to determine properties of the shower: total energy, volume, length, width, energy in TCMT, energy in last 5 HCAL layers

6 observables as input for NN

NN trained with simulations

- **No prior knowledge of beam energy needed for application**
- For NN trained with FTF_BIC resolution improved by ~25% (~15% at 10 GeV, ~20% at 15 GeV)

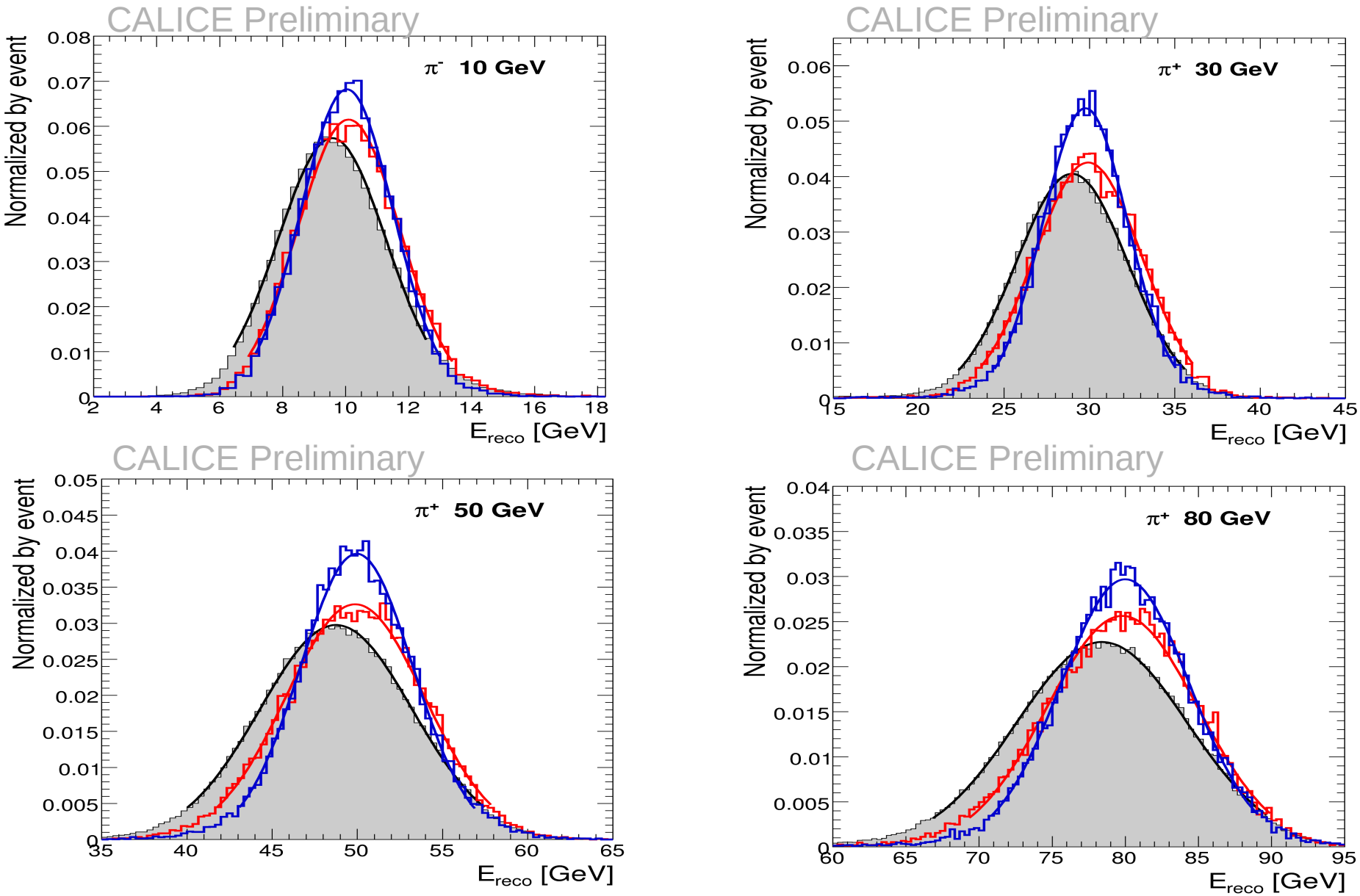


# Summary

- High granularity of the CALICE AHCAL allows the application of different software compensation methods based on both hit spectrum and cluster structure analysis.
- One local and two global methods were successfully applied to improve pion energy resolution for the CALICE AHCAL in the energy range from 8 to 80 GeV. The observed relative improvements are comparable and vary from 10% to 25%.
- Further optimization of compensation methods and implementation of improved calibration constants for the HCAL are expected to make possible a considerable additional improvement of the energy resolution .

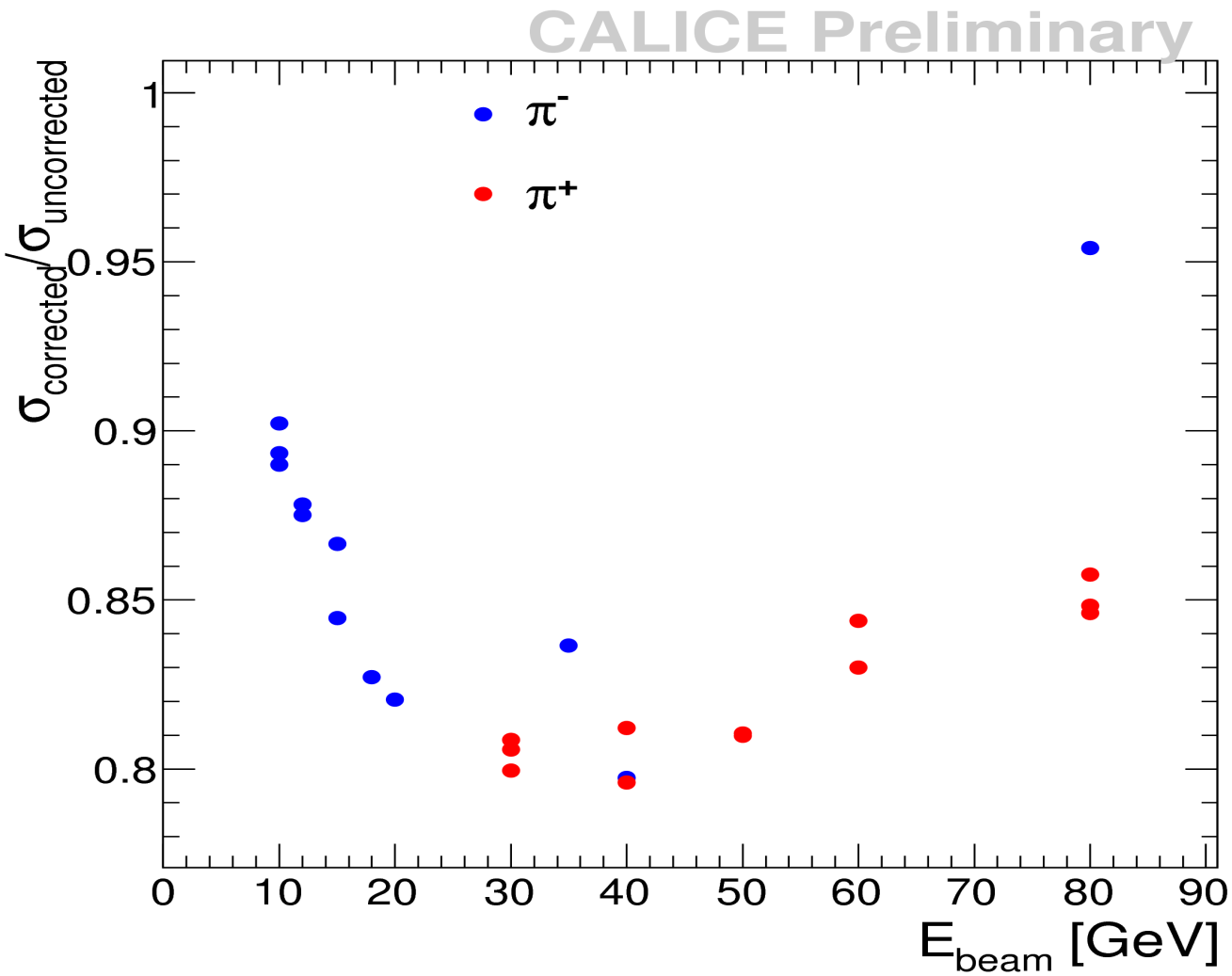
# Backup slides

# Energy distributions for global compensation




**w/o selection by starting layer; start in 5 HCAL layers; +compensation**

# Global compensation: relative improvement

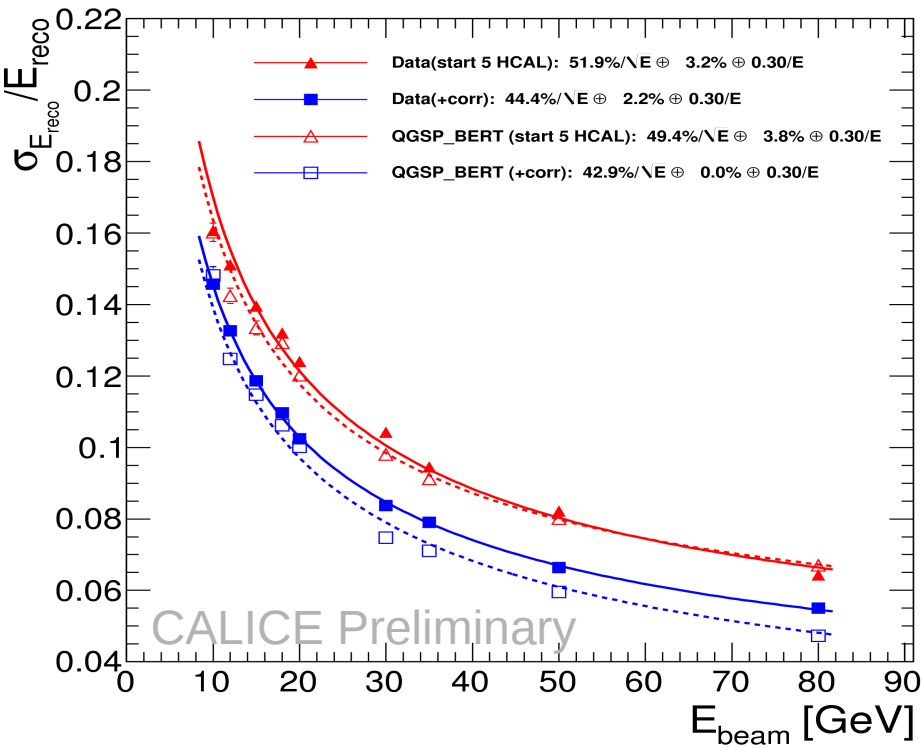


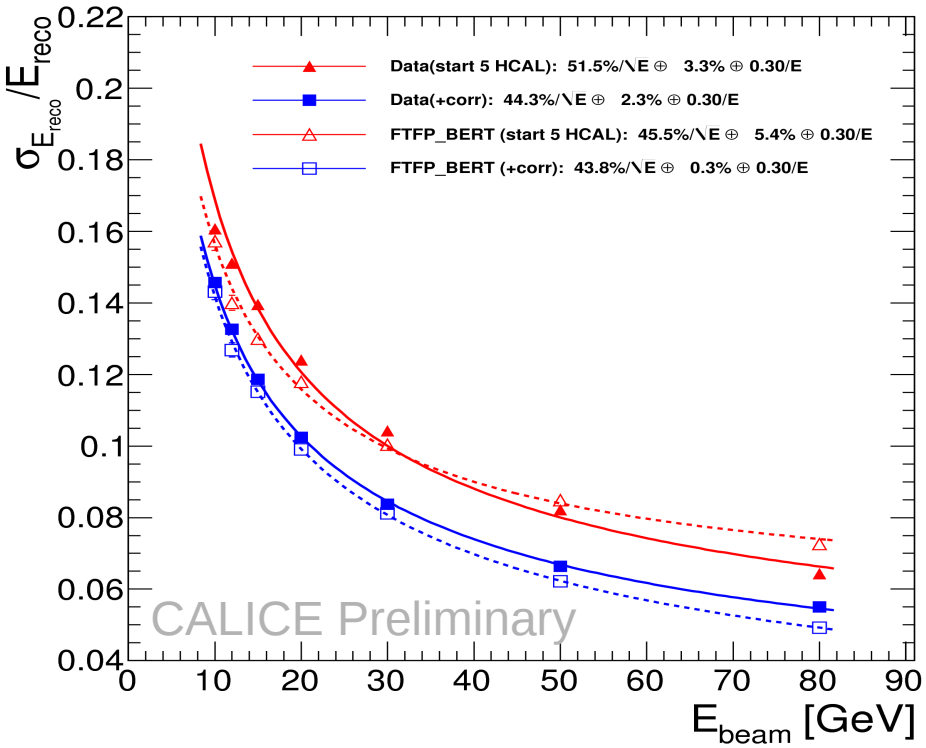

by 5% ÷ 20% for $\pi^-$ (12 runs 10÷80 GeV)

by 15% ÷ 20% for $\pi^+$ (12 runs 30÷80 GeV)

# Global compensation: data and MC

The same mip2gev coefficients from em calibration and e/π ratio are applied to MC samples as to data.




Without compensation QGSP_BERT is in better coincidence with data than FTFP_BERT (FTF_BIC behavior is similar to that of FTFP_BERT).

Both physics lists predict better resolution after compensation for higher energies.

The correction procedure does not change the MC linearity behavior.