Hadronic energy reconstruction in the CALICE combined calorimeter system

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Linear Collider Collaboration (e^+e^- collider)

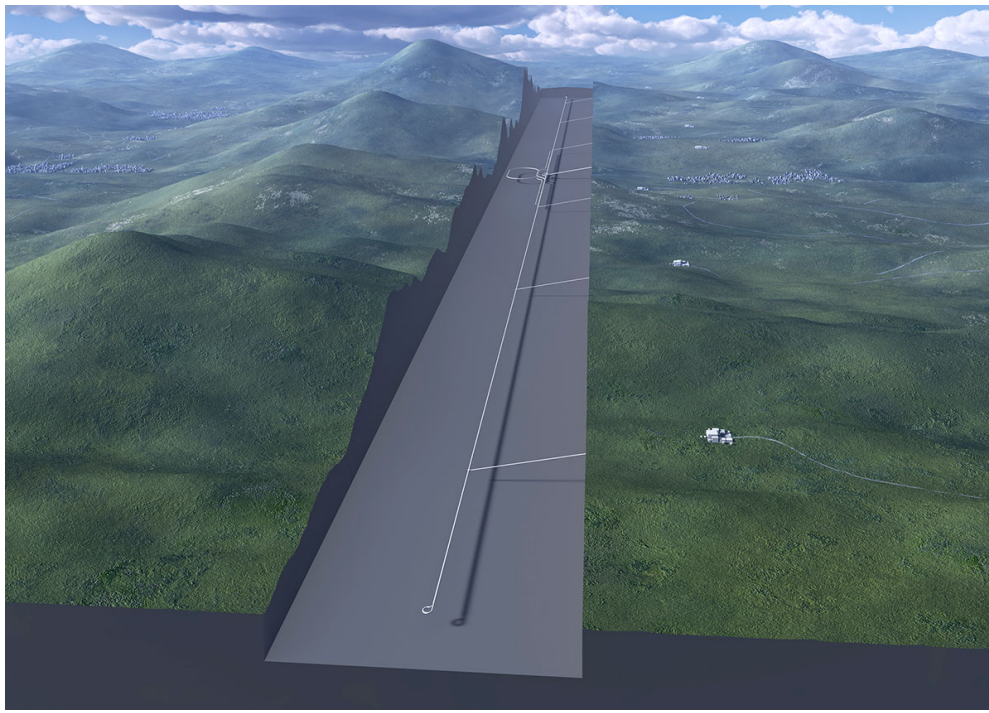
Clean Initial State
Model-Independent Measurement

International Linear Collider (ILC):

- baseline energy: 500 GeV
- $L \sim 2x10^{34}\ cm^{-2}s^{-1}$
- Kitakami, Japan

Compact Linear Collider (CLIC):

- up to 3 TeV
- $L \sim 6x10^{34}\ cm^{-2}s^{-1}$
- CERN, Switzerland



Detectors based on Particle Flow Algorithms

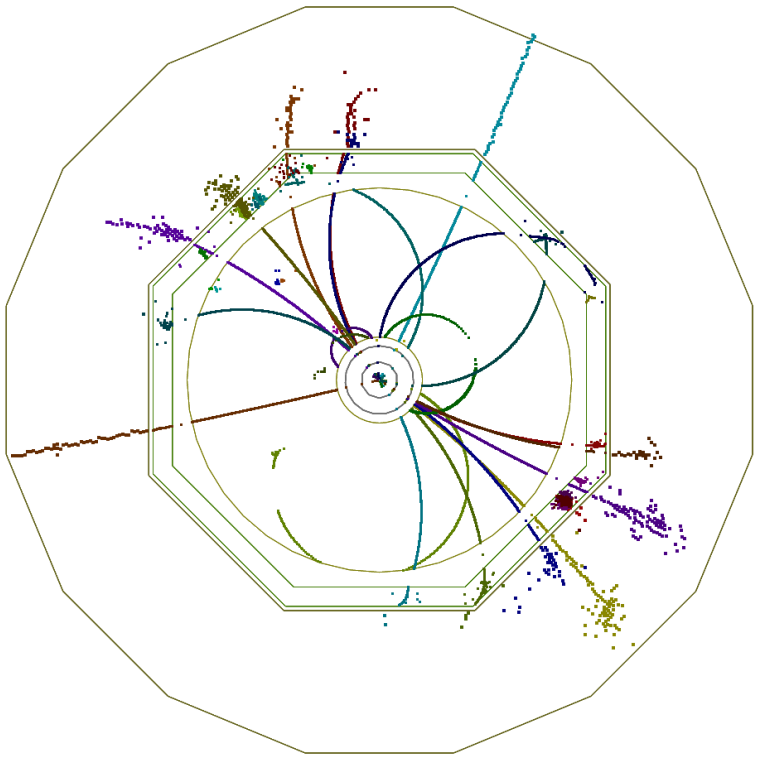
Typical jet composition:

- 60% charged hadrons
- 30% photons
- 10% neutral hadrons

Classical jet reconstruction:

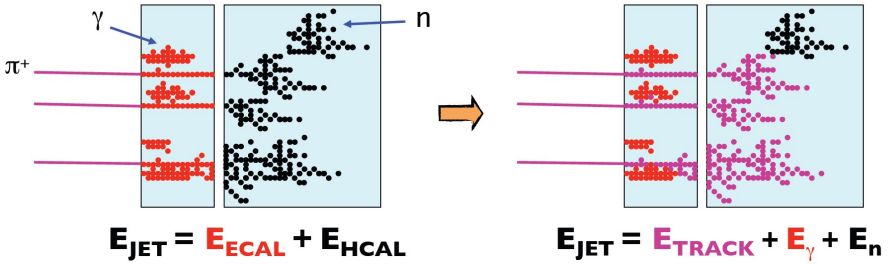
- 70% energy in HCAL
- $\sigma(E)/E \sim 60\%/\sqrt{E[GeV]}$

$e^+e^- \rightarrow Zh \rightarrow \mu^+\mu^- h$



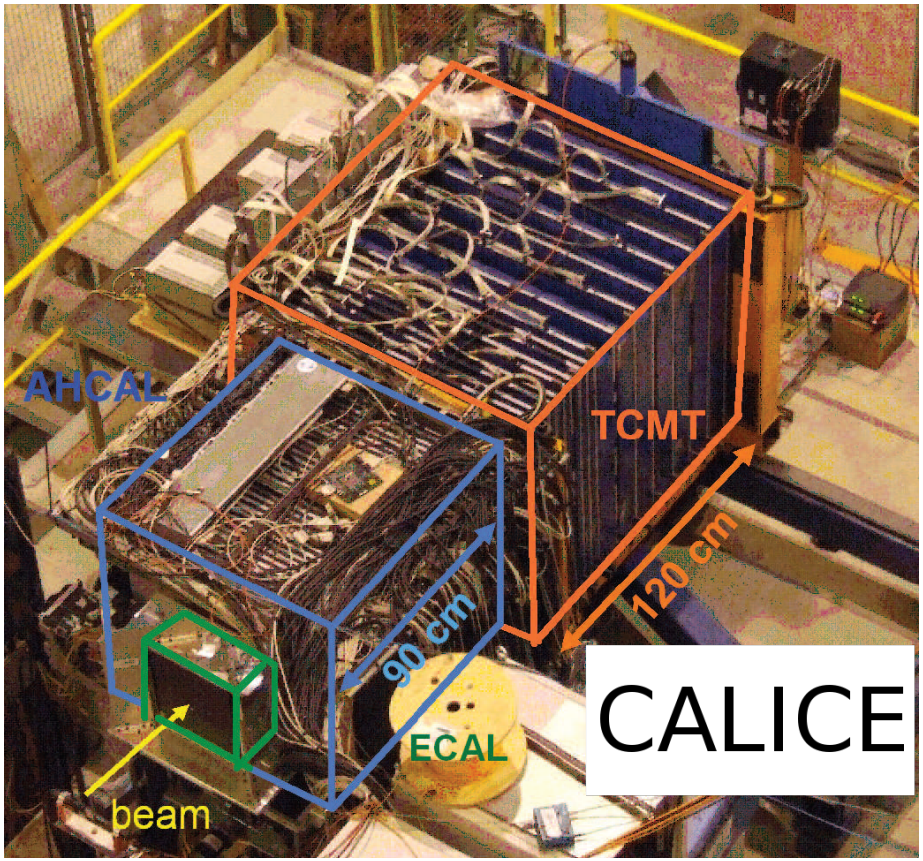
Particle Flow:

- Charged particles (also hadrons) $\rightarrow$Tracker.
- $\gamma \rightarrow$ ECAL.
- Only **10% energy**$\rightarrow$ HCAL



CALICE Prototype

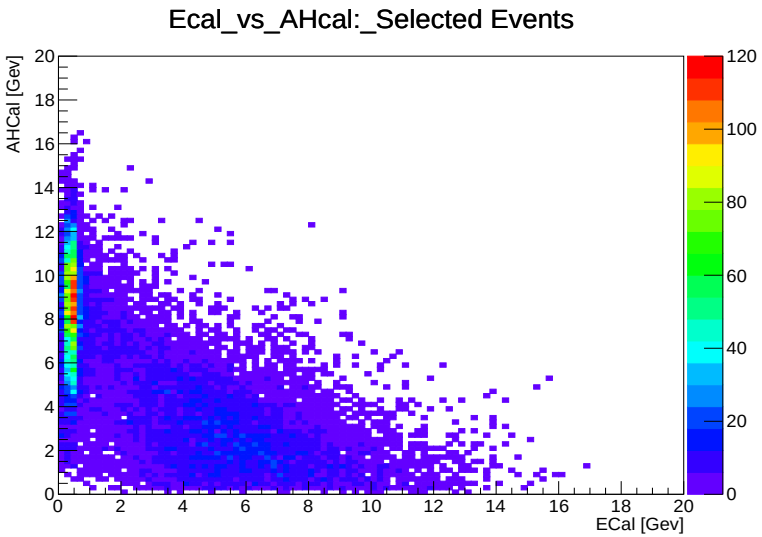
Combined system consisting of three sampling calorimeters with different technologies:

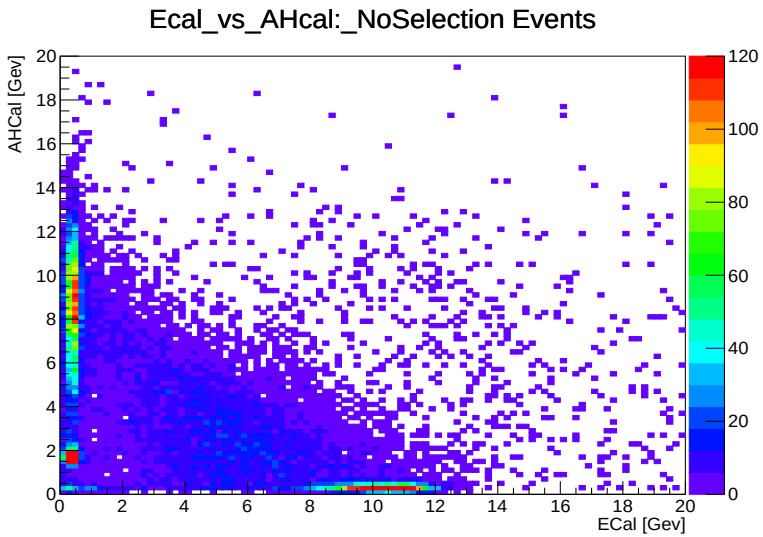


- **SiW ECAL**
  - Silicon sensors
  - Absorber Material: tungsten
  - 30 layers, 9720 channels
- **AHCAL**
  - Silicon photomultipliers
  - Absorber material: steel
  - 38 layers, 7608 channels
- **TCMT**
  - Silicon photomultipliers
  - Absorber material: steel
  - 16 layers, 320 channels

Test beams from 2006 - 2011 at DESY, CERN, FNAL

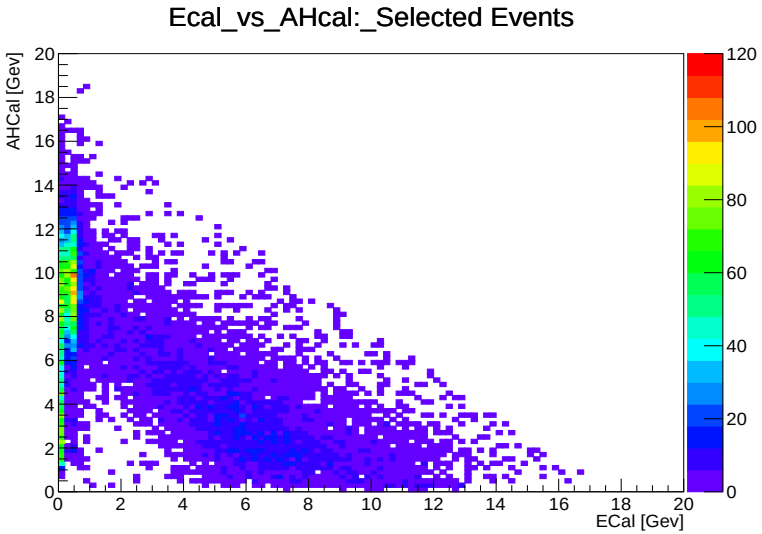
Event Selection for CERN Data (π^-):

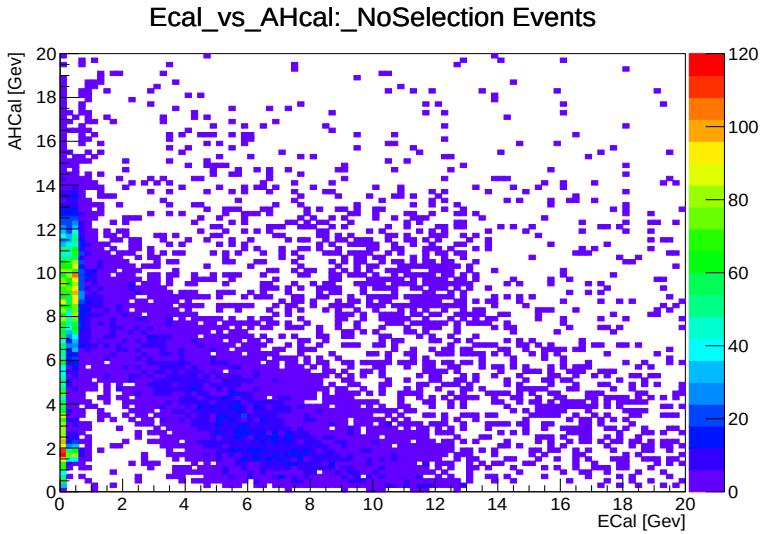


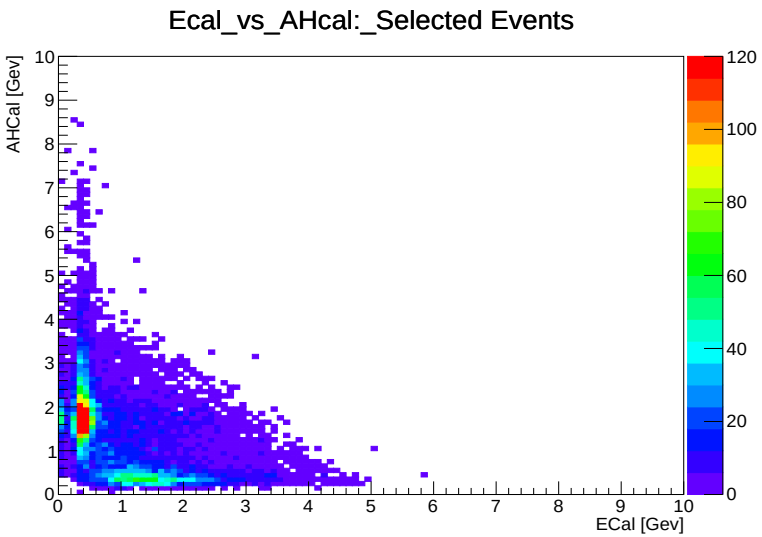


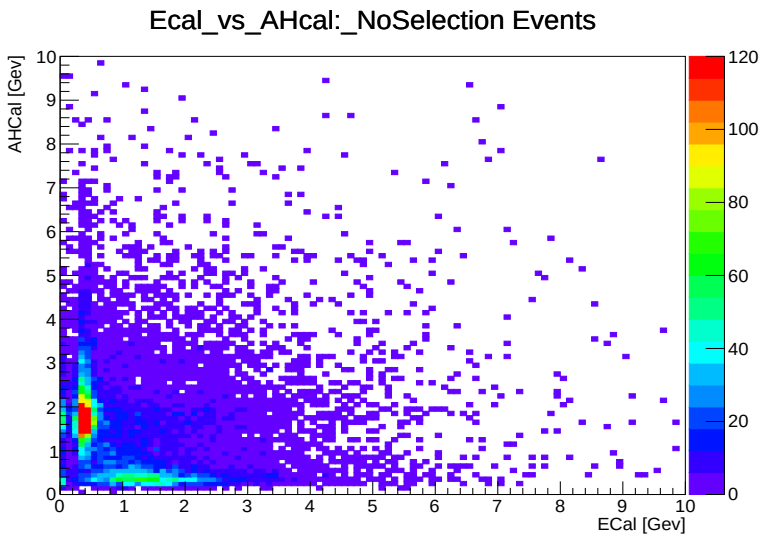
- Empty, not identified and bad events rejection
- Electron events rejection
- Multi-particle events rejection
- Muon events rejection

FNAL Data (π^-) with the same Selection:









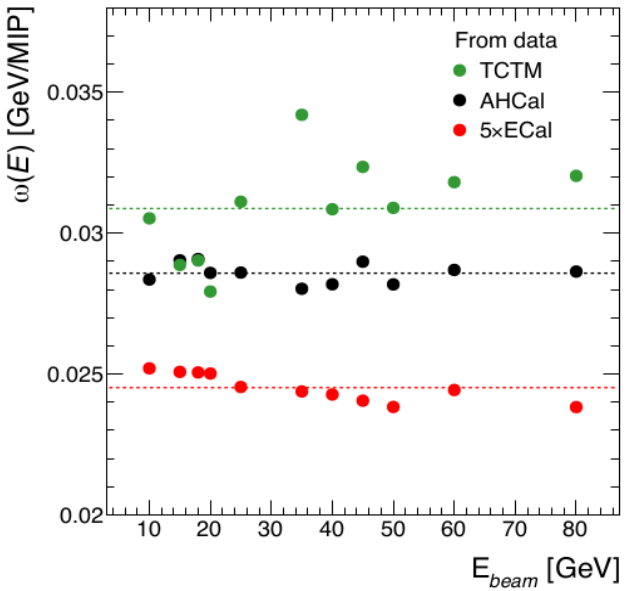
Need to be optimized!

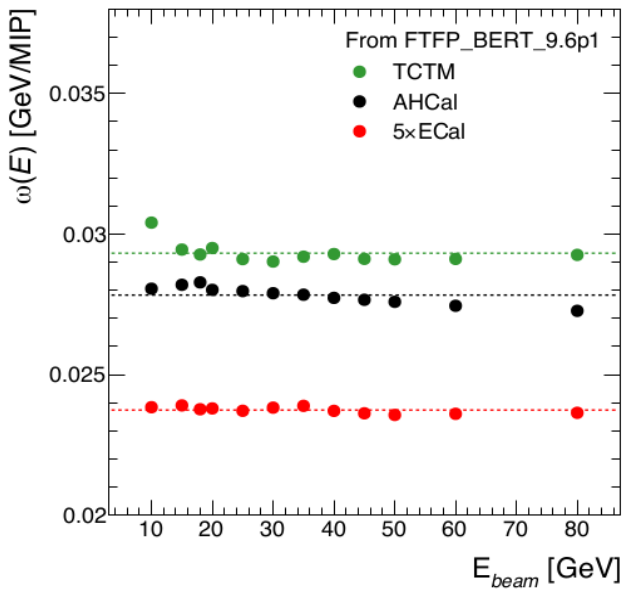
Combining and Calibrating the sub-detector energies:

- Using the χ^2 minimization procedure with the formula:

$$\chi^2 = \sum_{events} \left(\sum_{ECalhits} E_{hit}\omega_{ECal} + \sum_{AHCalhits} E_{hit}\omega_{AHCal} + \sum_{TCMThits} E_{hit}\omega_{TCMT} - E_{beam} \right)^2$$

to obtain the calibration factors $\omega_{ECal}(E), \omega_{AHCal}(E), \omega_{TCMT}(E)$

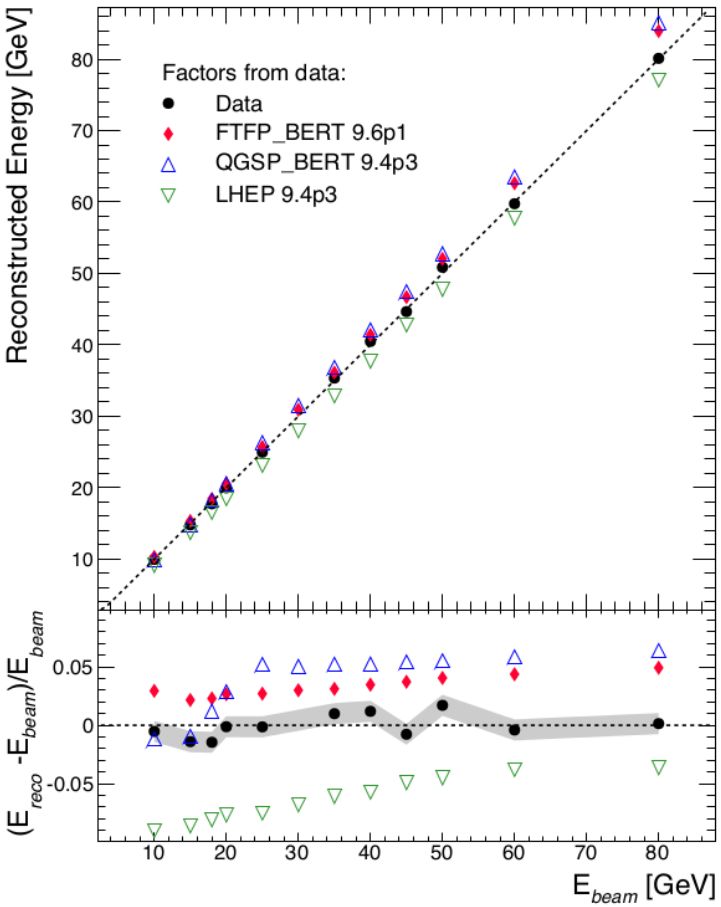


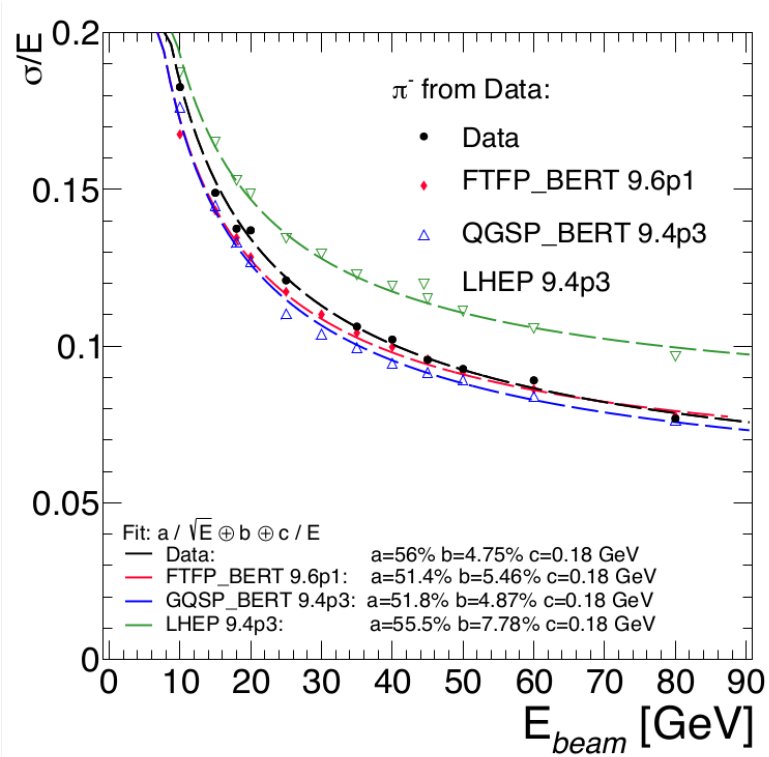


Standard Reconstruction:

Averaging over the energies→ Energy independent factors

$$E_{reconstructed} = \sum_{ECalhits} E_{hit}\omega_{ECal} + \sum_{AHCalhits} E_{hit}\omega_{AHCal} + \sum_{TCMThits} E_{hit}\omega_{TCMT}$$





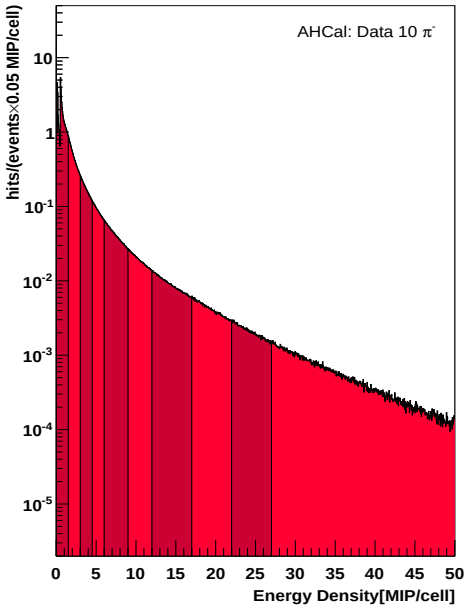
Local Software Compensation:

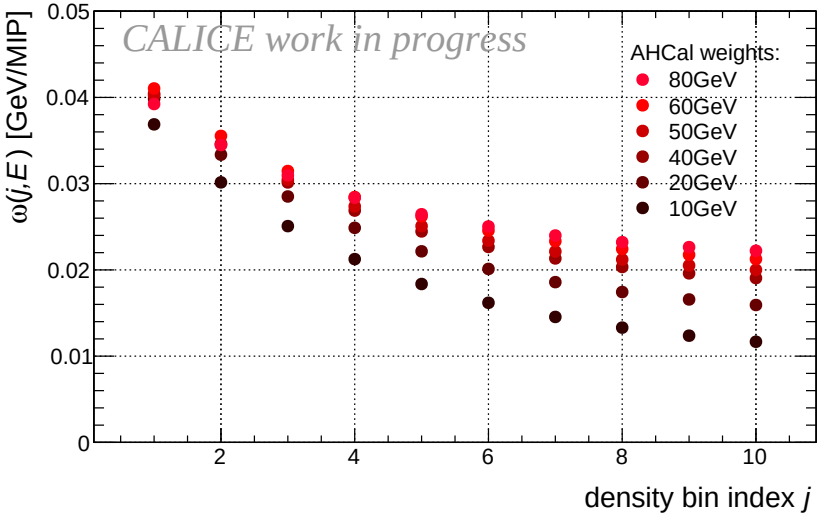
Problem in detection: $\frac{e}{\pi} > 1 \Rightarrow$ Lost energy in the hadron decay.

- EM showers are denser than hadronic showers.
  $\rightarrow$ Classification of hits based on the energy density
- χ^2 minimization:

$$\chi^2 = \sum_{events} \left(\sum_{hits} E_{hit} \omega_j - E_{beam} \right)^2$$

j=Energy density index





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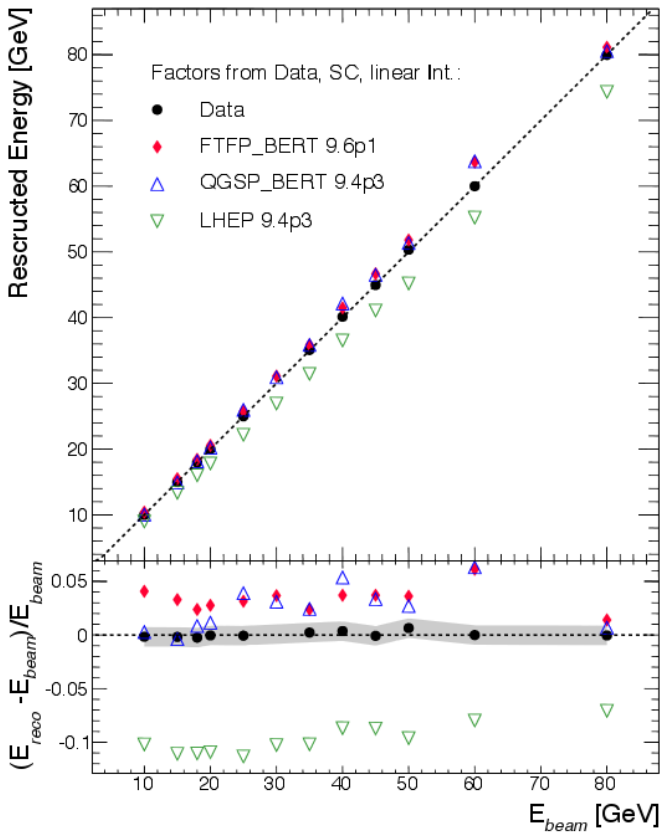
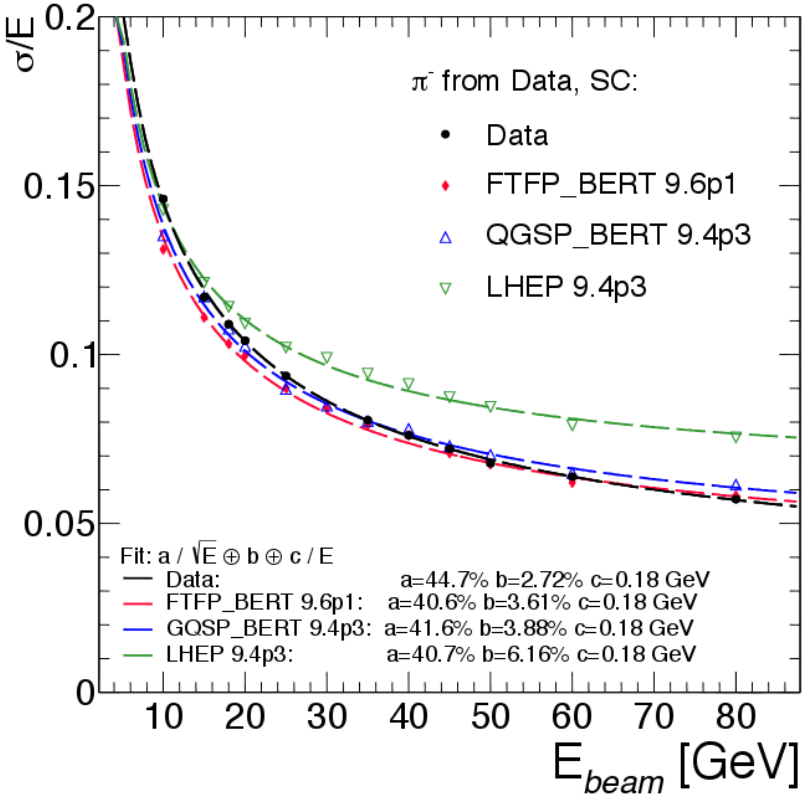




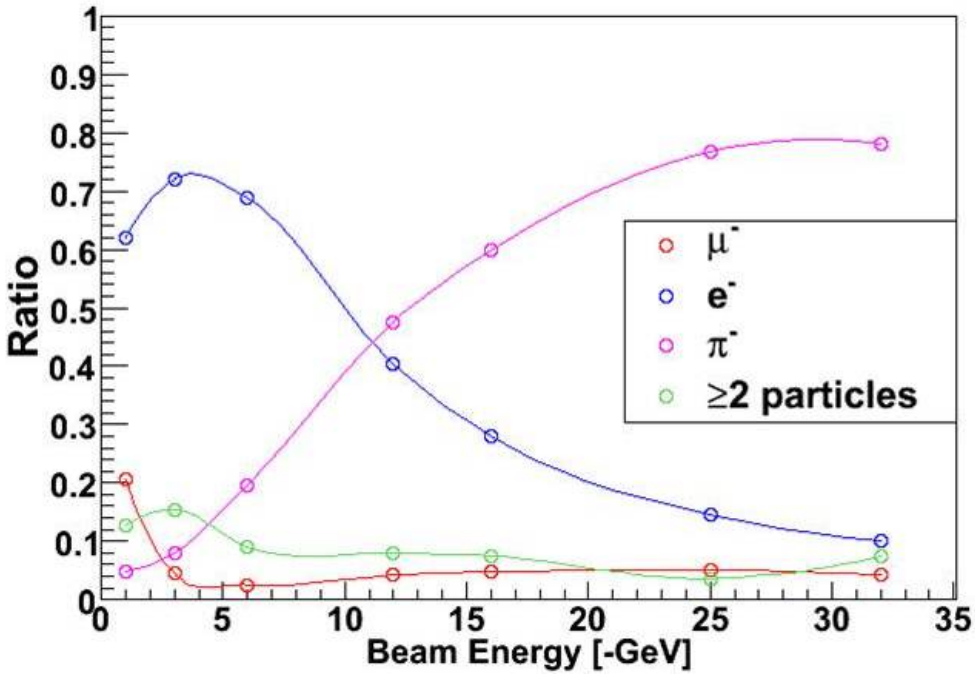
- Substantial improvement of resolution compare to previous result.
- Also work when taking weights from MC.

Summary and Outlook:

- Particle flow algorithms(PFA): from 70% to 10% energy reconstruction in HCAL.
- CALICE has developed a high granularity prototype optimized for the PFA.
- Tested by CERN and FNAL test beams.
- Software compensation techniques were used on CERN data, improving the energy resolution substantial.
- FNAL data for the lower energies range:
  - Event selection optimization
  - Standard reconstruction
  - Testing different software compensation techniques

BACKUP

FNAL test beam



A large international RD collaboration:

~300 scientists in 17 countries on 4 continents