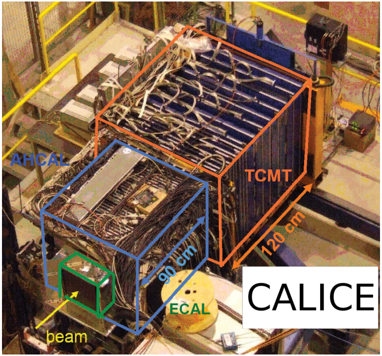
Hadronic Energy Reconstruction in the CALICE Combined Calorimeter System

Yasmine Israeli
March 22, 2018

Testbeam Analysis of a Full Calorimeter System

CALICE physics prototypes:

SiW ECAL	AHCAL	TCMT



Testbeam experiments:

- CERN 2007
- FNAL 2008

Datasets:

- π^- 4-80 GeV (10-80 GeV, 4-60 GeV)
- GEANT4 10.1
  FTFP BERT & QGSP BERT

Reconstruction Methods:

- Standard reconstruction
- Software compensation (SC)

Full Calorimeter Systems

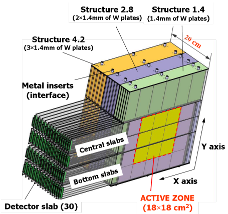
Si-W ECAL — Silicon Tungsten Electromagnetic Calorimeter

1.4mm, 2.8mm, 4.2mm W

Silicon sensors

24.6 χ_0

9720 channels



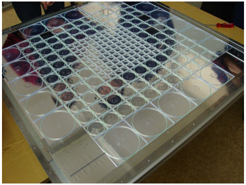
AHCAL — Analog Hadronic Calorimeter

21mm Fe

Scintillators & SiPMs

5.3 λ_I

7608 channels



TCMT — Tail Catcher Muon Tracker

21mm, 105mm Fe

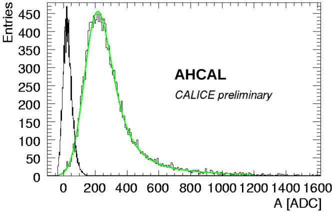
Scintillators & SiPMs

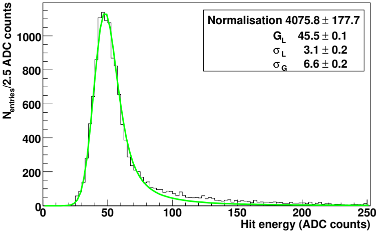
5.8 λ_I

320 channels

MIP Calibration

- To equalize the response of the cells in each sub detector
  → a cell-to-cell calibration from ADC counts to MIPs unit





- For each channel:
  - Clean muon sample
  - The energy spectrum is fitted with a convolution of a Landau distribution and a Gaussian function
  - Most probable value⇒MIP calibration factor

Standard Energy Reconstruction

- Collect hits from each detector

$$E_{reco}^{event} = \sum_{hits}^{ECAL} E_{hit} \qquad + \left(\sum_{hits}^{AHCAL} E_{hit} + \sum_{hits}^{TCMT} E_{hit} \right.$$

Standard Energy Reconstruction

- Collect hits from each detector
- Calibrate hits from MIPs to GeV

$$E_{reco}^{event} = \sum_{hits}^{ECAL} E_{hit} \cdot C_{ECAL} + \left(\sum_{hits}^{AHCAL} E_{hit} + \sum_{hits}^{TCMT} E_{hit} \right) \cdot C_{AHCAL}$$

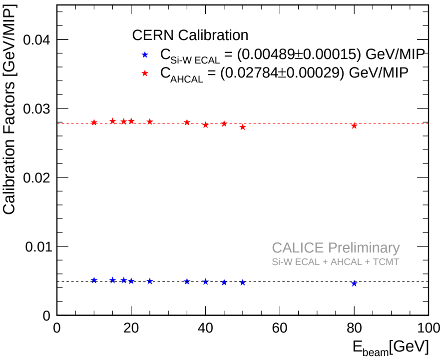
Standard Energy Reconstruction

- Collect hits from each detector
- Calibrate hits from MIPs to GeV

$$E_{reco}^{event} = \sum_{hits}^{ECAL} E_{hit} \cdot C_{ECAL} + \left(\sum_{hits}^{AHCAL} E_{hit} + \sum_{hits}^{TCMT} E_{hit} \right) \cdot C_{AHCAL}$$

$MIP \rightarrow GeV$ calibration factors

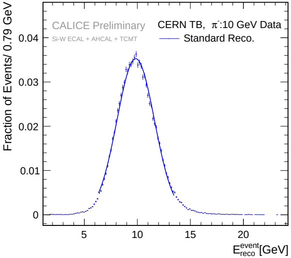
- χ^2 minimization for each energy
- averaging



Energy Resolution

The distribution of E_{reco}^{event} is fitted with a gaussian

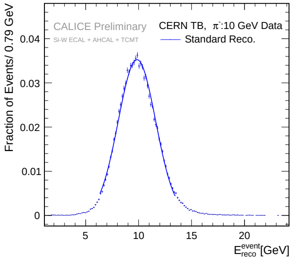
$\hookrightarrow$ $\langle E_{reco}^{event} \rangle$ defines the E_{reco}
$\hookrightarrow$ energy resolution is defined as $\sigma / \langle E_{reco}^{event} \rangle$

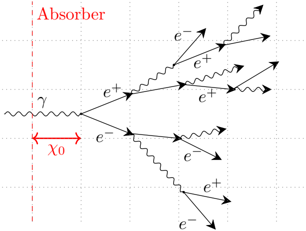


Energy Resolution

The distribution of E_{reco}^{event} is fitted with a gaussian

$\hookrightarrow \langle E_{reco}^{event} \rangle$ defines the E_{reco}
$\hookrightarrow$ energy resolution is defined as $\sigma / \langle E_{reco}^{event} \rangle$

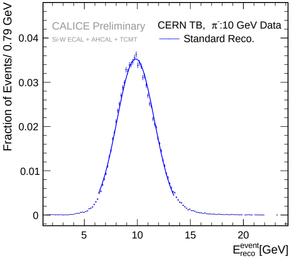


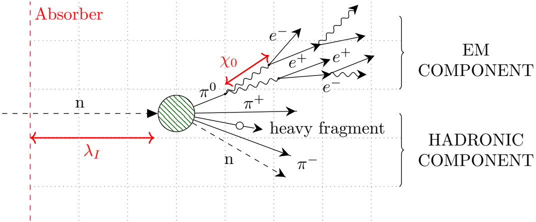


Energy Resolution

The distribution of E_{reco}^{event} is fitted with a gaussian

$\hookrightarrow$ $\langle E_{reco}^{event} \rangle$ defines the E_{reco}
$\hookrightarrow$ energy resolution is defined as $\sigma / \langle E_{reco}^{event} \rangle$





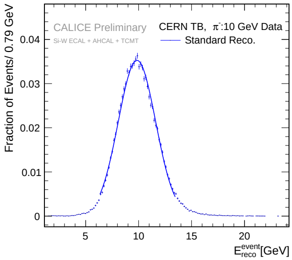
- ⋆ **EM sub-showers**
- ⋆ **invisible energy**
  - nuclear binding energy
  - slow neutrons
  - neutrinos

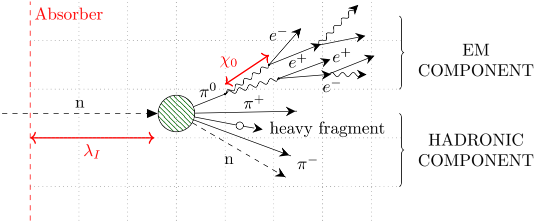
Energy Resolution

The distribution of E_{reco}^{event} is fitted with a gaussian

$\hookrightarrow$ $\langle E_{reco}^{event} \rangle$ defines the E_{reco}

$\hookrightarrow$ energy resolution is defined as $\sigma / \langle E_{reco}^{event} \rangle$





⋆ **EM sub-showers**

⋆ **invisible energy**

- nuclear binding energy
- slow neutrons
- neutrinos

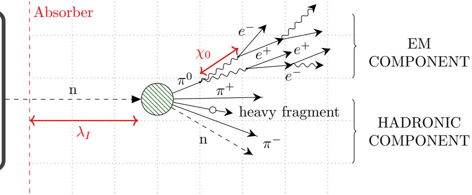
⋆⋆ **Fluctuating from event to event $\hookrightarrow$ energy resolution decreases**

Software Compensation

EM showers are **denser** than hadronic showers

⇕

hits with higher energies

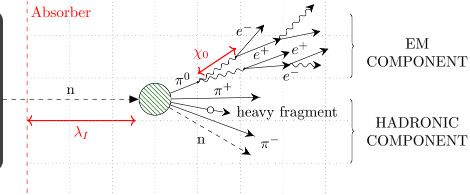


Software Compensation

EM showers are **denser** than hadronic showers

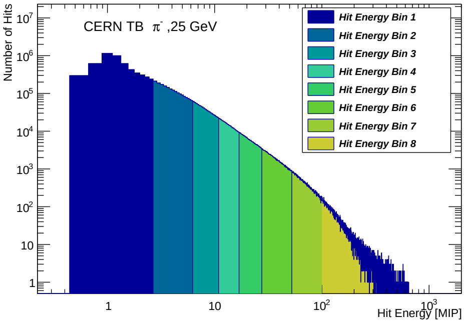
⇕

hits with higher energies



For each detector:

- ⋆ Define j energy bins
- ⋆ Sum the hits in each bin $E_j = \sum_{hits} E_{hit}$
- ⋆ Apply weight ω_j to bin j: $\omega_j \cdot E_j$



Software Compensation Weights

Bin weights are parametrised with particle energy $\omega_j(E)$

⟶ 2^{nd} order polynomials

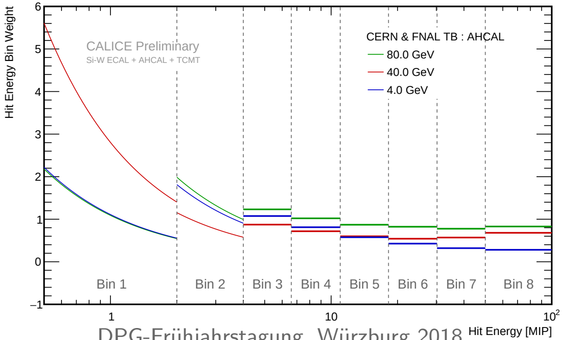
⟶ 3 parameters for each bin: a_j, b_j, c_j

E_{beam} in optimization

E_{reco} in SC reconstruction

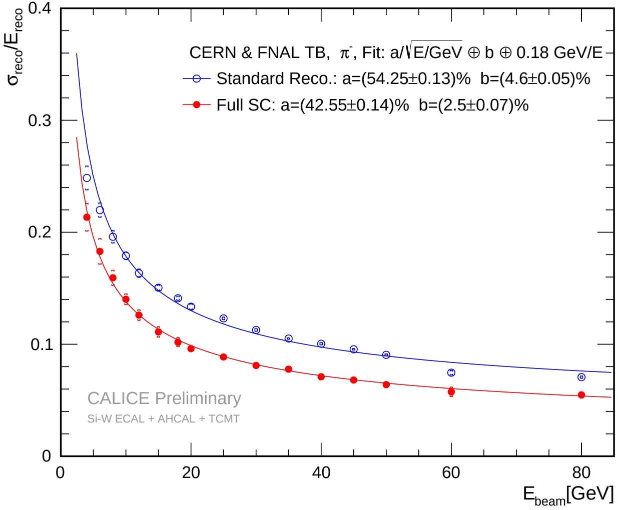
For 3 detectors: total 51 parameters

$$\chi^2 = \sum_{\text{events}} \frac{\left(E^{\text{event}}_{\text{Full SC}} - E^{\text{event}}_{\text{beam}}\right)^2}{\left(55\%\sqrt{\text{GeV}}\right)^2 \cdot E^{\text{event}}_{\text{beam}} \cdot N^{\text{events}}_{\text{beam}}}$$



Energy Resolution

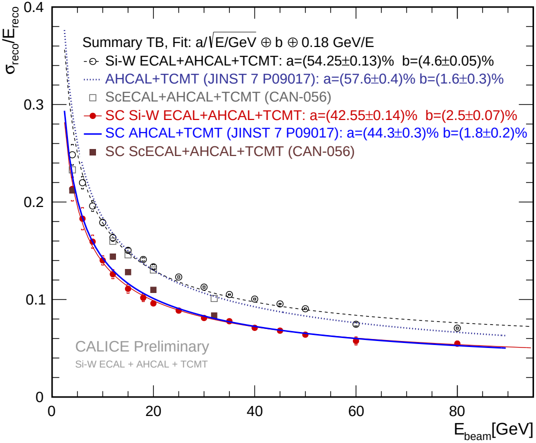
Up to 30% improvement



Comparison with Previous Analyses

Si-W ECAL+AHCAL+TCMT : CAN-058 (this analysis)

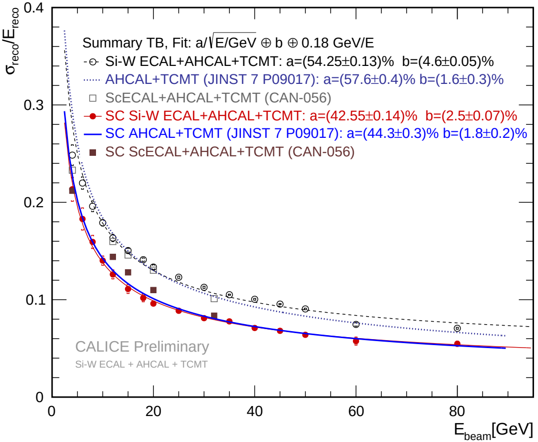
- ▷ SC applied to Si-W ECAL+AHCAL+TCMT
- ▷ Up to 30% improvement



Comparison with Previous Analyses

AHCAL+TCMT : JINST 7 P09017

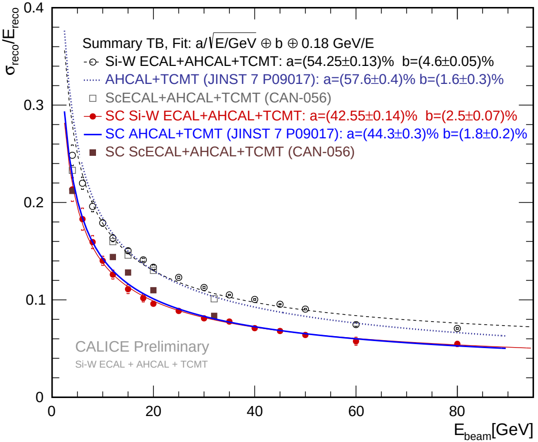
- ▷ Showers start: first 5 layers of AHCAL
- ▷ SC applied to AHCAL+TCMT



Comparison with Previous Analyses

ScECAL+AHCAL+TCMT : CAN-056

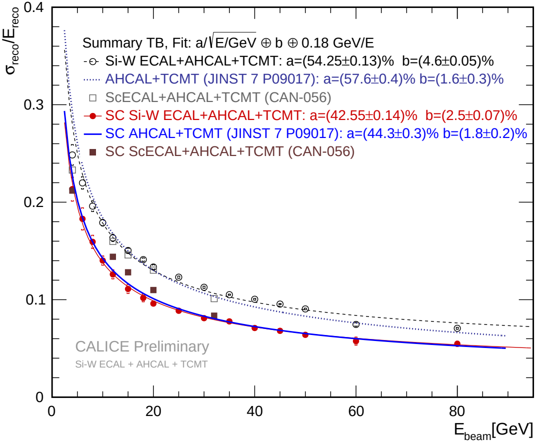
- ▷ Scintillator+SiPMs system
- ▷ Showers start:ScECAL till 5^{th} layer of AHCAL
- ▷ SC applied to ScECAL+AHCAL+TCMT



Comparison with Previous Analyses

Similar performance despite the:

- ▷ different absorber material (W, Fe)
- ▷ different structure (Si-W ECAL)
- ▷ different readout techniques (Si sensor,Scintillators+SiPMs)



SC in Different Detectors

ECAL SC

SC in the Si-W ECAL

24 parameters

HCAL SC

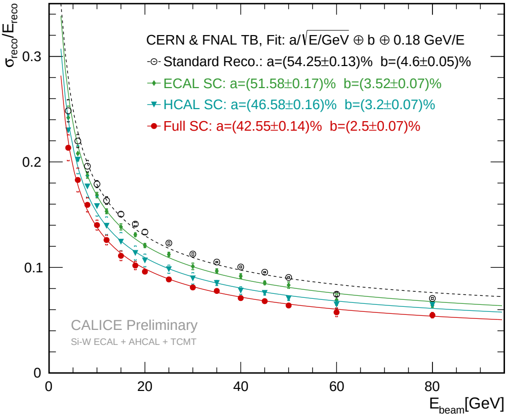
SC in the AHCAL & TCMT

27 parameters

Full SC

SC in 3 detectors

51 parameters



SC in Different Detectors

ECAL SC

SC in the Si-W ECAL

24 parameters

→ up to 8%

HCAL SC

SC in the AHCAL & TCMT

27 parameters

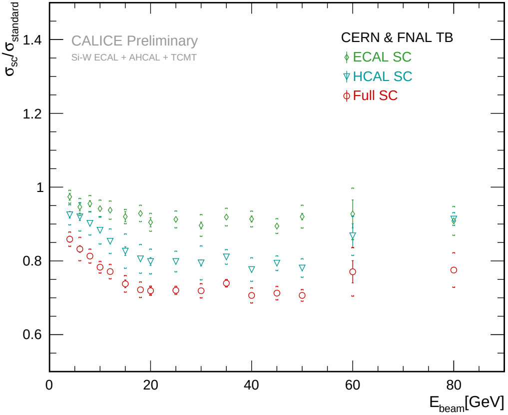
→ up to 23%

Full SC

SC in 3 detectors

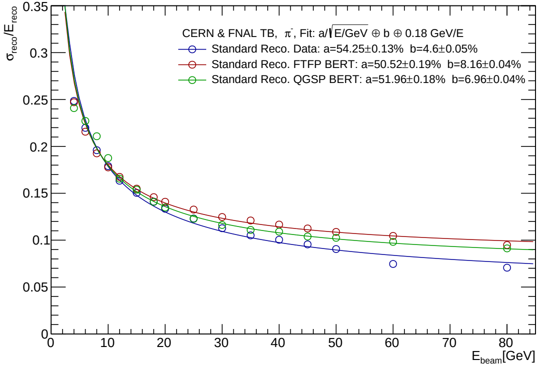
51 parameters

→ up to 30%



Comparison with Simulations : Resolution

Optimizing weights for data and for MC

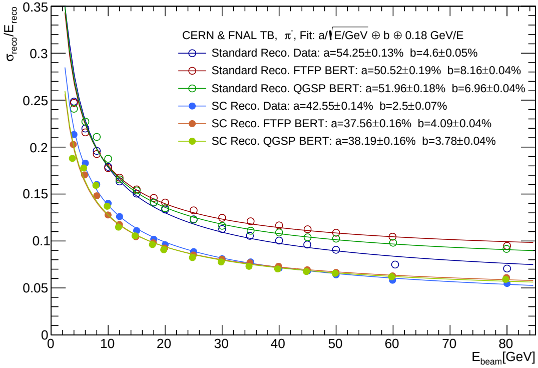


GEANT4 10.1:
FTFP BERT
QGSP BERT

Standard reco.: an energy dependent deterioration of the simulation resolution

Comparison with Simulations : Resolution

Optimizing weights for data and for MC



GEANT4 10.1:
FTFP BERT
QGSP BERT

Standard reco.: an energy dependent deterioration of the simulation resolution

SC reco.: similar resolutions between 30-80 GeV

Summary

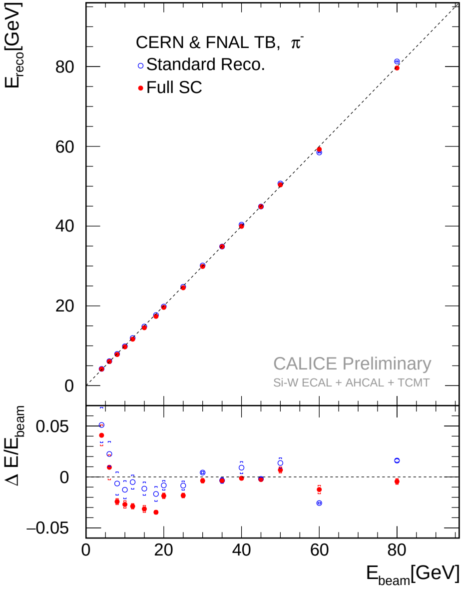
- ☑ Analysis of CALICE high granularity combined full calorimeter system
- ☑ Similar performance as "less complexed" previous analyses
- ☑ Data vs MC: agreement with Full SC reconstruction(from $\sim 30\,\mathrm{GeV}$)
- ☑ Applying SC to different detectors
  energy resolution improvement:
  Full SC - up to 30%
  HCAL SC - up to 23%
  ECAL SC - up to 8%

Thank you for your attention ☺

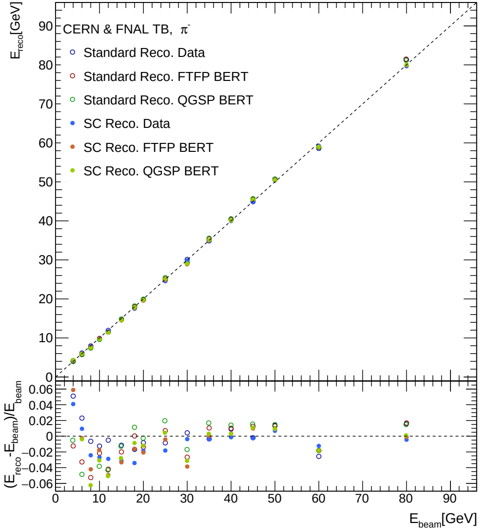
BACKUP

Linearity

Deviations< 5%



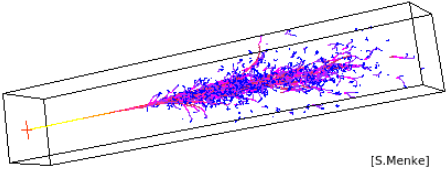
Comparison with Simulations : Linearity

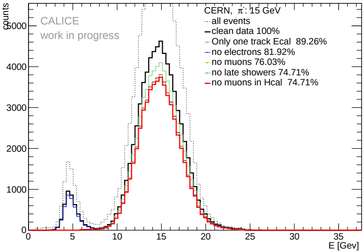


GEANT4 10.1:
FTFP BERT
QGSP BERT

- ⋆ Deviations are < 6%
- ⋆ From 35 GeV:
  SC results are
  more compatible

Event Selection for Single Pion





- ◎ clean data
- ◎ only one particle entering ECAL
- ◎ electrons rejection: First Interaction Layer (FIL) $> 6^{th}$ layer
- ◎ muons rejection: only events with interaction
- ◎ reject incomplete showers FIL $<$ layer 55
- ◎ reject muons entering AHCAL from around ECAL