# Energy Resolution Paper

Katja Seidel[1], Marina Chadeyeva[2]

[1]MPI Munich & Excellence Cluster 'Universe', [2]ITEP

May 19, 2011

# Introduction

- Several software compensation techniques derived for test beam data and MC (CALICE analysis note 15, 21, 28)
  Results presented for the full setup and showers contained in AHCAL
  Data: CERN 2007, particle types: $\pi^-$ and $\pi^+$

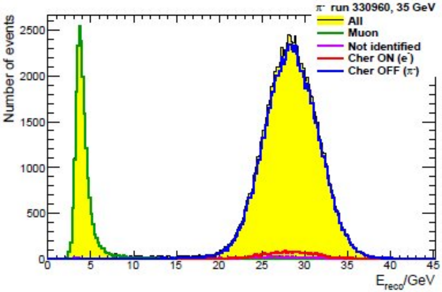
  Paper about local (CAN-15) and global (CAN-28) software compensation technique for hadronic showers which start in the beginning of the AHCAL for test beam and simulated data

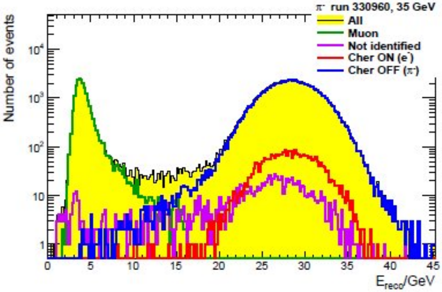
- This talk: Short status to all steps.
  - event and run selection
  - software compensation techniques
  - results on data
  - results on MC
  - to do / plans

# Event selection

- HadronSelection processor:
  - removal of
    - empty events
    - muons
    - multiparticle events
    - not identified events
  - identification of the first hadronic interaction
- Čerenkov trigger: separation of
  - $\pi^-$ from $e^-$
  - $\pi^+$ from protons
- Additional selection for compensation study: only events with shower start in the first 5 HCAL layers

Muon admixture to pion sample $<$0.5% for all runs



# Run selection

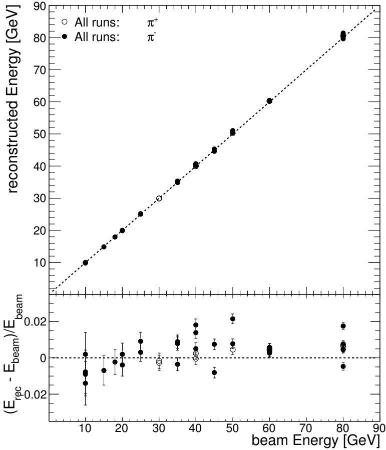
- 45 $\pi^+$ and $\pi^-$ runs were reconstructed with CALICE software version v04_01 by Daniel Jeans $\rightarrow$ Thanks a lot!

- Exclusion of runs if:
  - Complete detector noisy ( 1 run )
  - Muon peak position far from normal (1 run )
  - Unusual Hcal or Tcmt pedestal behavior (1 run)
  - Not good initial reconstructed energy ( 2 runs)
  - Low statistics in final sample ( 2 runs )

# Run selection

- 45 $\pi^+$ and $\pi^-$ runs were reconstructed with CALICE software version v04_01 by Daniel Jeans → Thanks a lot!

- Exclusion of runs if:
  - Complete detector noisy ( 1 run )
  - Muon peak position far from normal (1 run )
  - Unusual Hcal or Tcmt pedestal behavior (1 run)
  - Not good initial reconstructed energy ( 2 runs)
  - Low statistics in final sample ( 2 runs )



# Systematic errors

- So far only statistical errors shown ⇒ but systematic errors are present
- Systematic errors in electromagnetic paper
  - Estimated assuming different gain and saturation values for SiPM
  - Biggest contribution from saturation error
  - Maximal systematic error: 3 % at 40 GeV

Our preliminary approach:

- Saturation will have a smaller effect for pions compared to electrons
- For each beam energy we have determined the RMS of the reconstructed energies ⇒ 0.3 - 0.7 % of the beam energy

⇒ Use 0.7 % of the beam energy for each run

- Systematic error is applied to error on reconstructed energy.
  Error on resolution depends in this.

# Systematic errors

- So far only statistical errors shown ⇒ but systematic errors are present
- Systematic errors in electromagnetic paper
  - Estimated assuming different gain and saturation values for SiPM
  - Biggest contribution from saturation error
  - Maximal systematic error: 3 % at 40 GeV

Our preliminary approach:

- Saturation will have a smaller effect for pions compared to electrons
- For each beam energy we have determined the RMS of the reconstructed energies ⇒ 0.3 - 0.7 % of the beam energy

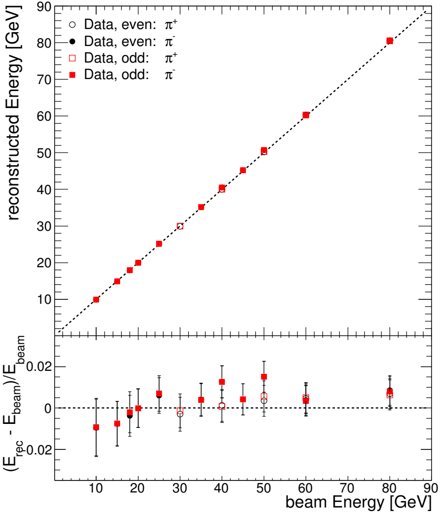
⇒ Use 0.7 % of the beam energy for each run

- Systematic error is applied to error on reconstructed energy.
  Error on resolution depends in this.

Construction of two event samples

- Single runs are split into even and odd events
- Even and odd events of runs with equal energy and particle type are merged
- Even: software compensation factor determination
  Odd: software compensation application

# Initial energy resolution

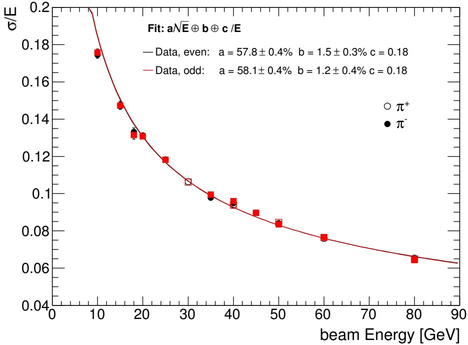



Linearity within $\pm 1\,\%$

$$E = E_{ecal,sum} + E_{hcal,sum} + E_{tcmt,sum}$$

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E[\text{GeV}]}} \oplus b \oplus \frac{c}{E[\text{GeV}]}$$

Noise term fixed for fit: c $=0.18$ GeV
noise width estimated from pedestal events:
$(0.17)_{tcmt} \oplus (0.06)_{hcal}$ GeV



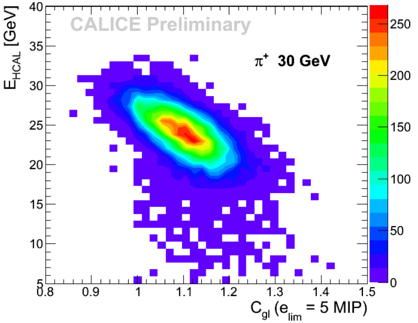
# Global software compensation factor

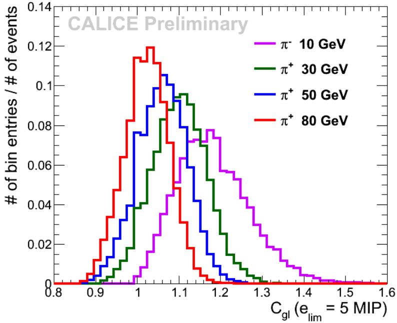
Observables calculated on event-by-event basis:

- mean of hit energy spectrum $\langle e \rangle$ (shower hits only)
- number of hits $N_{lim}$ with energy $e_{hit} < e_{lim}$
- number of hits $N_{av}$ with energy $e_{hit} < \langle e \rangle$
- global compensation factor: $C_{gl} = \frac{N_{lim}}{N_{av}}$

Mean of global compensation factor $C_{gl}$ is energy dependent.

In the studied interval 4.5 MIP $\leq e_{lim} \leq$ 6.0 MIP increasing of $e_{lim}$ leads to better linearity but less improvement in resolution.



# Global software compensation procedure

Event energy correction step-by-step:

1. deposited energies $E_{hcal}$ and $E_{tcmt}$ using electromagnetic calibration factor
2. compensation factor $C_{gl}$
3. corrected shower energy $E_{sh} = C_{gl} \cdot (E_{hcal} + E_{tcmt})$
4. deposited energy $E_{ecal}$ using muon calibration factor for ECAL
5. corrected reconstructed energy $E^{cor}_{reco} = E_{ecal} + E_{sh} \cdot (a_0 + a_1 E_{sh} + a_2 E^2_{sh})$

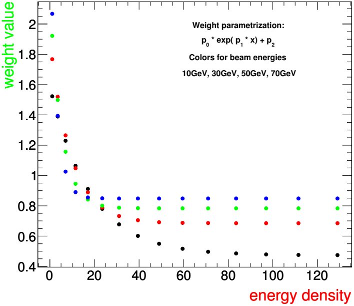
Coefficients $a_0$, $a_1$ and $a_2$ are derived from the polynomial fit to the set of points $(\langle E_{sh}\rangle_i, \frac{E_i^{beam} - \langle E_{ecal}\rangle_i}{\langle E_{sh}\rangle_i})$, brackets indicate means estimated for $i$-th sample.
For 11 $\pi^-$ samples (10-80 GeV) and 5 $\pi^+$ samples (30-80 GeV):

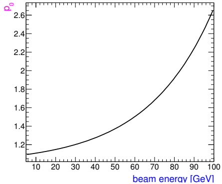
$e_{lim} = 5.0$ MIP
$a_0 = 0.982 \pm 0.007$
$a_1 = 0.0041 \pm 0.0003$ GeV$^{-1}$
$a_2 = (-2.2 \pm 0.3) \cdot 10^{-5}$ GeV$^{-2}$

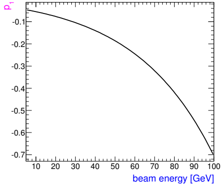
$e_{lim} = 5.5$ MIP
$a_0 = 0.965 \pm 0.007$
$a_1 = 0.0038 \pm 0.0003$ GeV$^{-1}$
$a_2 = (-2.0 \pm 0.3) \cdot 10^{-5}$ GeV$^{-2}$

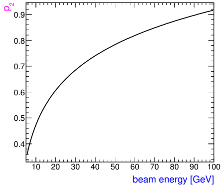
# Local software compensation technique

- Energy density distribution is devided into energy density bins
- $E_{SC} = E_{ecal,sum} + \sum_{\text{hit}} E_{\text{hit}} \cdot \omega_{\text{hit}} + E_{tcmt,sum}$
- The weights depend on energy density ED the initial reconstructed event energy ( in function for $p_0, p_1, p_2$)
- $\omega_{hit} = p_0(E) \cdot \exp(p_1(E) \cdot ED) + p_2(E)$
- Shape of parameters $p_0, p_1, p_2$ is found via an iterative procedure

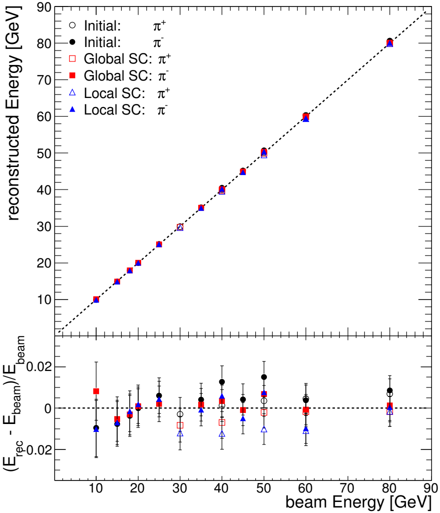


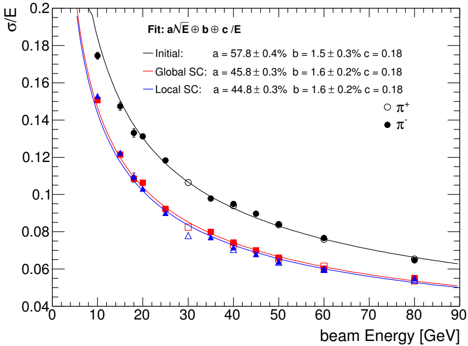



# Results

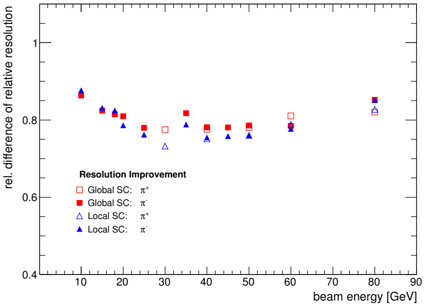



$$\frac{\sigma}{E} = \frac{a}{\sqrt{E[\text{GeV}]}} \oplus b \oplus \frac{c}{E[\text{GeV}]}$$



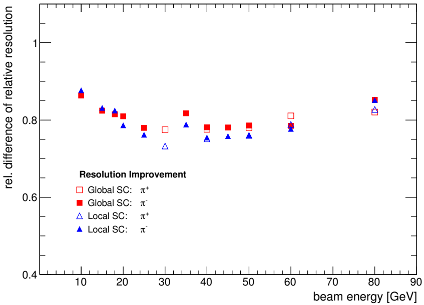

Linearity within $\pm$ 1.5 %

# Results: Improvement




- Improvement approx. 20 %
- Same energy dependence of improvement for both techniques
- Better improvement for local method in the range 30-60 GeV
- Same improvement for $\pi^-$ and $\pi^+$
- Different behavior at 35 GeV

# Results: Improvement




- Improvement approx. 20 %
- Same energy dependence of improvement for both techniques
- Better improvement for local method in the range 30-60 GeV
- Same improvement for $\pi^-$ and $\pi^+$
- Different behavior at 35 GeV

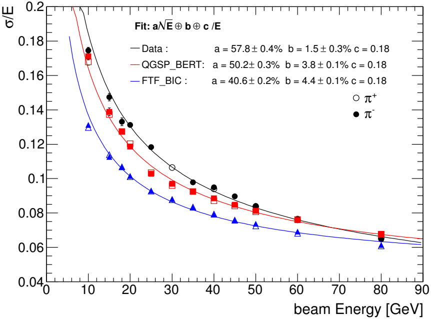
## Application of SC on Monte Carlo Simulation

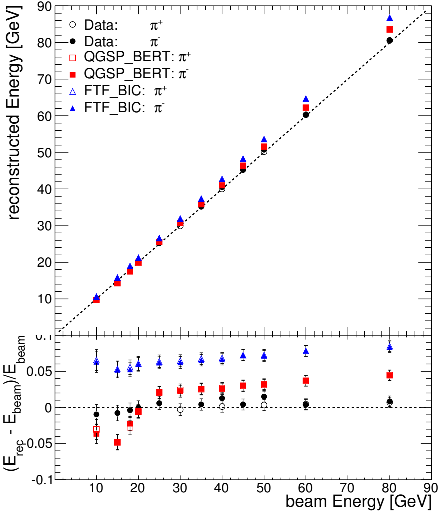
- Physics lists: QGSP_BERT and FTF_BIC
- Energy range: 10 - 80 GeV
- Events: 150,000 each
- Particle Types: $\pi^-$ and $\pi^+$

Produced by Lars Weuste → Thanks a lot!

# Simulated data

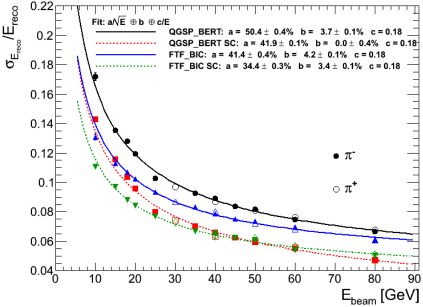
- Same $\frac{e}{\pi}$ ratio used as in data
- Linearity good for FTF_BIC; jumps for QGSP_BERT
- Resolution shape different for MC (higher constant term)
- QGSP_BERT describes data better

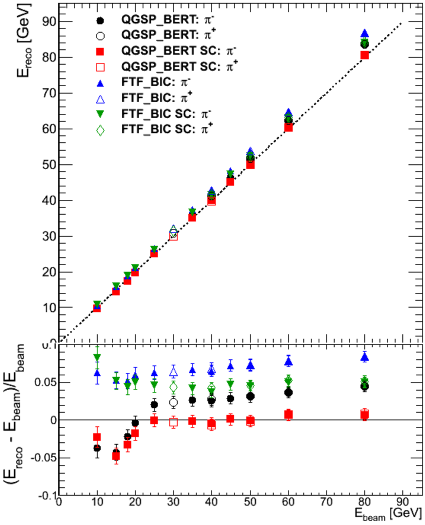


# Application of SC on simulated data - Global SC

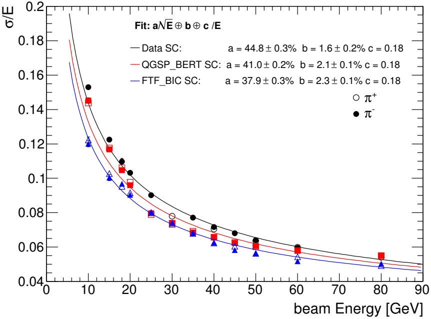
- SC results in better linearity for QGSP_BERT and slightly changes linearity behavior for FTF_BIC
- SC improves resolution for both physics lists
- SC decreases the constant term in resolution fit

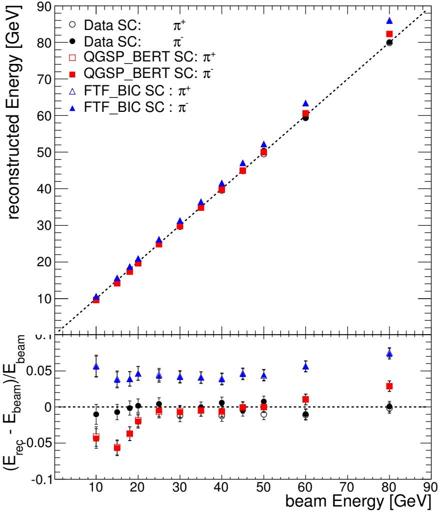


# Application of SC on simulated data- Local SC

- SC keeps shape of resolution for both physics lists
- SC improved resolution for both physics list
- SC decreases the constant term in resolution fit

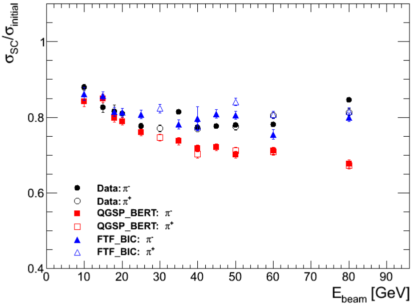


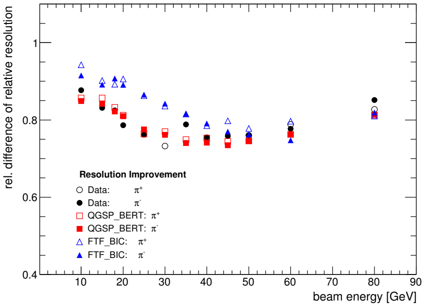
# Application of SC on simulated data

- Improvement compared to initial resolution of data, QGSP_BERT and FTF_BIC
- Local SC: improvement similar for data and QGSP_BERT
- Global SC: improvement similar for data and FTF_BIC
- Local SC: similar behavior of MC models above 30 GeV
- Global SC: similar behavior of MC models below 30 GeV

Global SC technique




Local SC technique



# Conclusion

- Intrinsic relative resolution of the CALICE AHCAL for hadrons: $\sim 58\%/\sqrt{E}$

- Both local and global software compensation techniques based on the analysis of cell energy density
- Software compensation improves hadron energy resolution of test beam data by $\sim$20% in the energy range 10 - 80 GeV
- Both software compensation techniques give similar energy dependence of resolution improvement
- Local technique results in higher improvement in the energy range 30-60 GeV but slightly worse linearity

- Both SC techniques improve energy resolution of simulated data

# ToDo for paper about software compensation

- Get and apply accepted systematic error estimation
- Apply adjusted MIP2GeV factors for physics list FTF_BIC
- Any more issues we need to cover look at?
- Write the paper

Backup

# Effect of run merging

Comparision between single and merged runs.