Software compensation algorithm

for the CALICE AHCAL

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Data and software

DATA: CERN 2007 test beam runs with complete CALICE setup

π^- 10, 12, 15, 18, 20, 35, 40 and 80 GeV

π^+ 30, 40, 50, 60 and 80 GeV

official reconstruction software as of April 2010

MC: QGSP_BERT, FTFP_BERT and FTF_BIC physics lists

π^- 10, 12, 15 and 20 GeV

π^+ 30, 50, 80 GeV

(thanks to David Ward and Lars Weuste)

official digitization software as of April 2010

Event selection

Before any analysis:

Apply 0.5-MIP cut to both ECAL and HCAL hits

⇓

Exclude muons using $E^{dep}_{ECAL} + E^{dep}_{HCAL}$ vs. E^{dep}_{TCMT} histogram (Vasily's method)

⇓

Exclude trash and multiparticle events

⇓

Separate electrons from π^- (Čerenkov counter)

Separate protons from π^+ (Čerenkov counter)

For analysis:

Select events by shower start position (found by PrimaryTrackFinder)

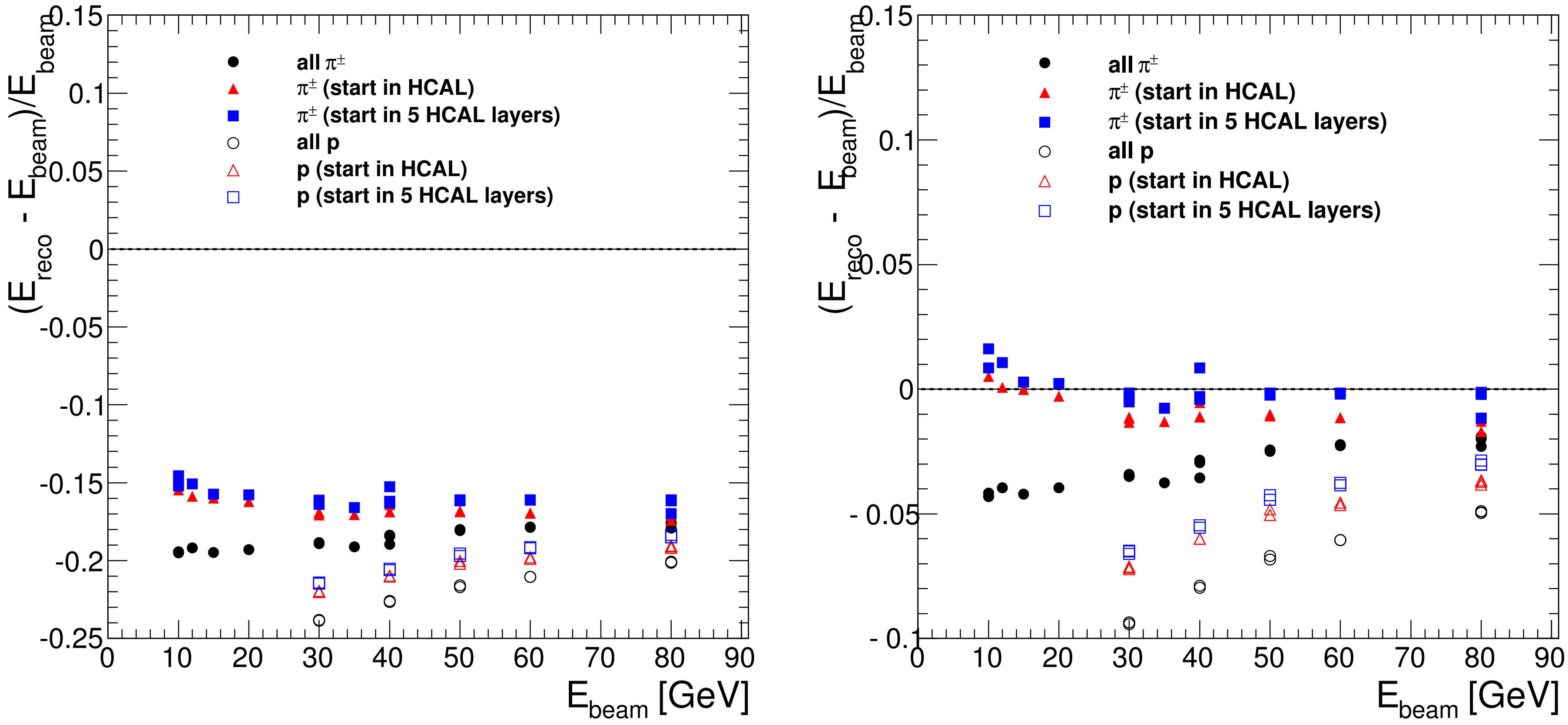
3 samples: all events, with start anywhere in HCAL, with start in first 5 HCAL layers

Coefficients from EM calibration:

ECAL: $0.00376\ \frac{GeV}{MIP}(\times 1, \times 2, \times 3)$

HCAL: $0.02353\ \frac{GeV}{MIP}$

Linearity



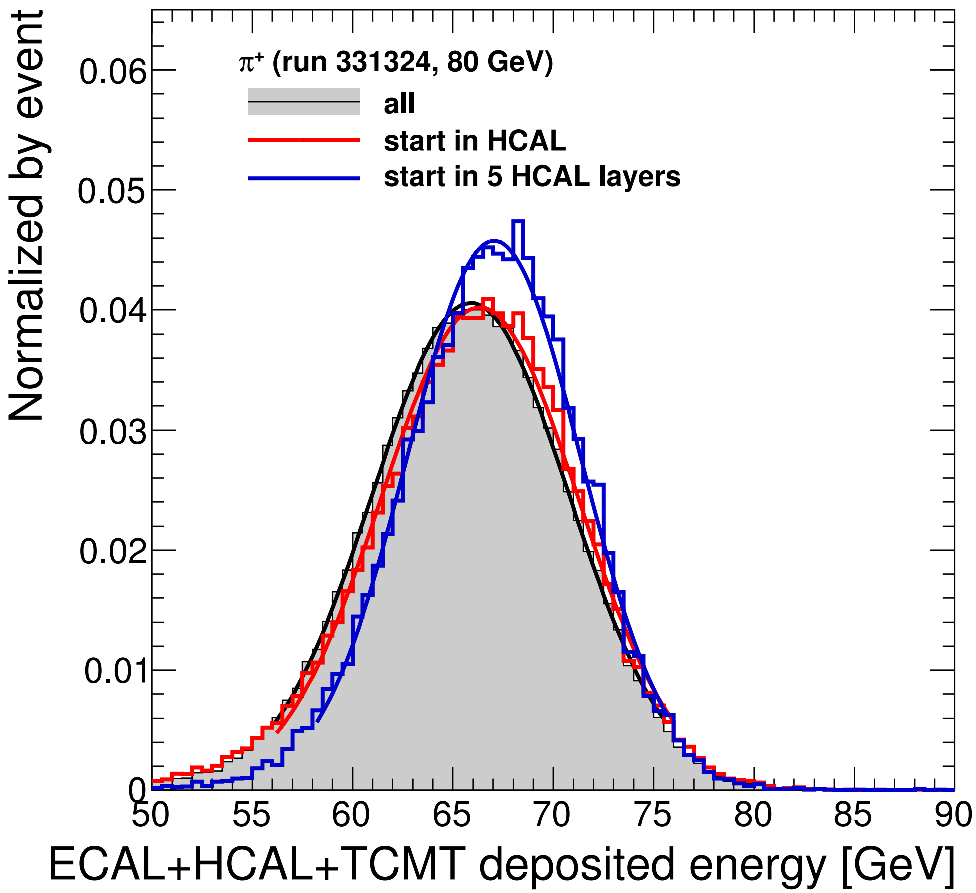
For pions in the HCAL one scale coefficient for the given energy range can be introduced: 1.19.

If EM calibration is correct, it can be considered as $\frac{e}{\pi}$ ratio estimation for the CALICE AHCAL.

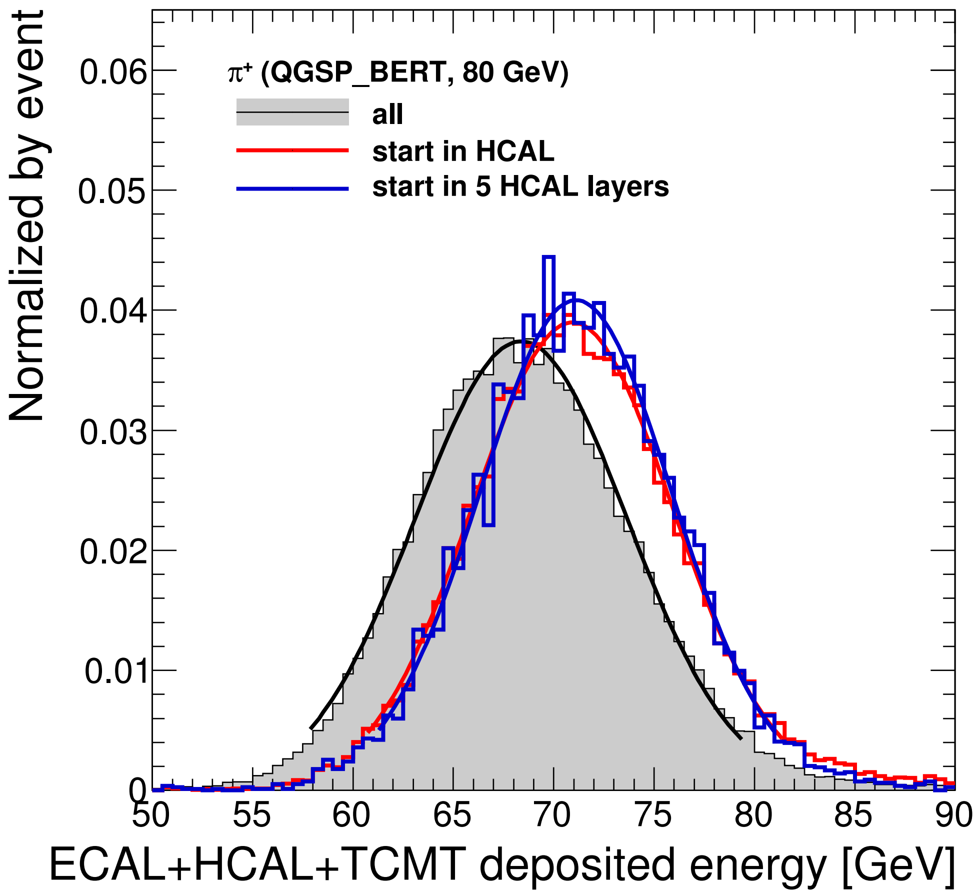
Linearity $\sim$2% for $\pi^{\pm}$

Energy distributions

Data



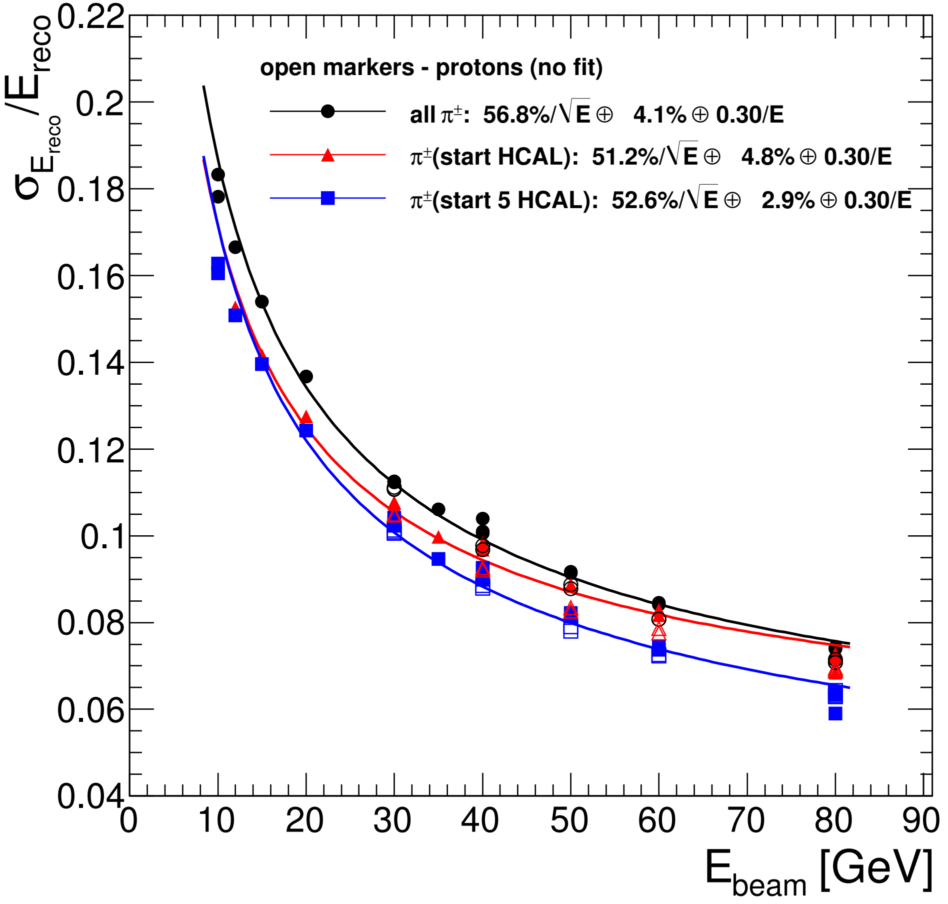
QGSP_BERT

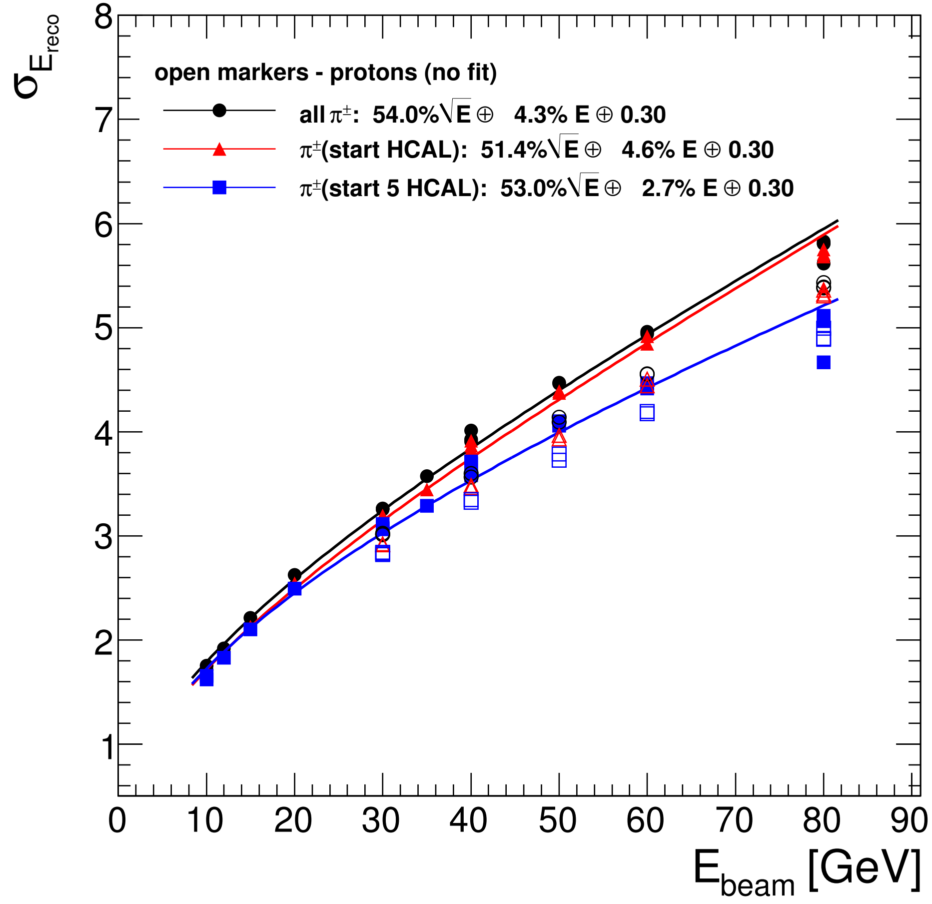


The left tail presents in the red distribution (start anywhere in HCAL) but disappears in the blue one (start in the 5 HCAL layers).

There is no such an effect for QGSP_BERT because MC models predict shorter hadronic showers.

Energy resolution

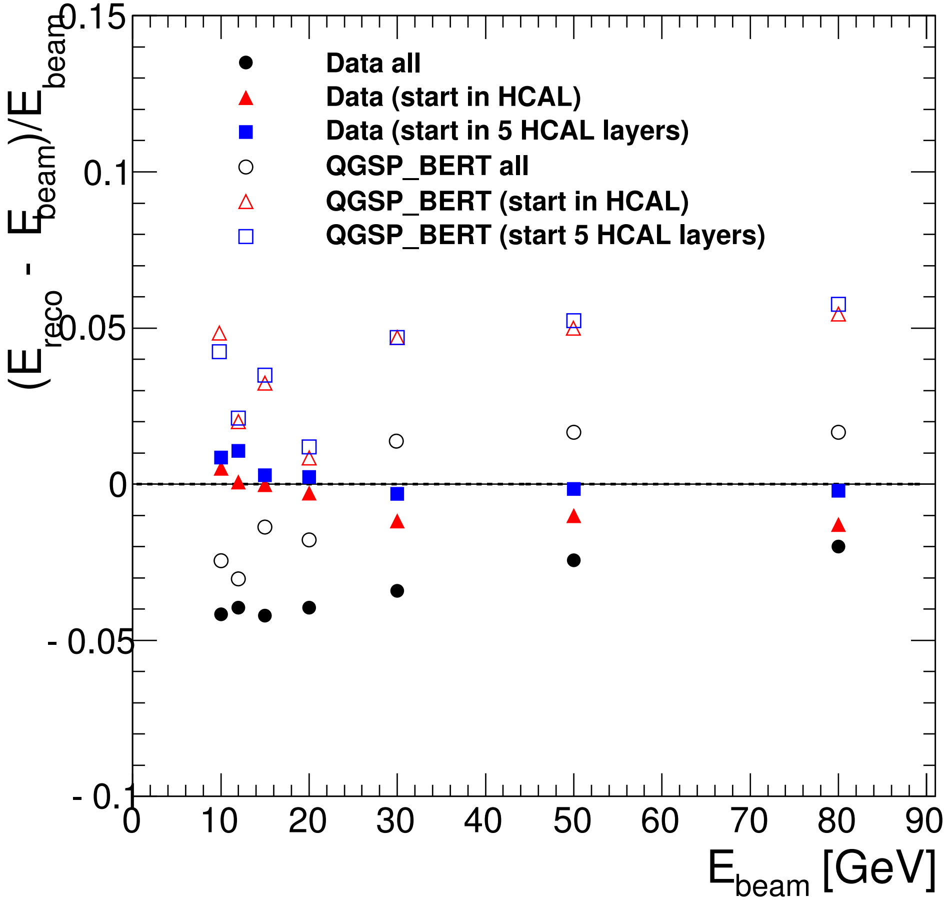


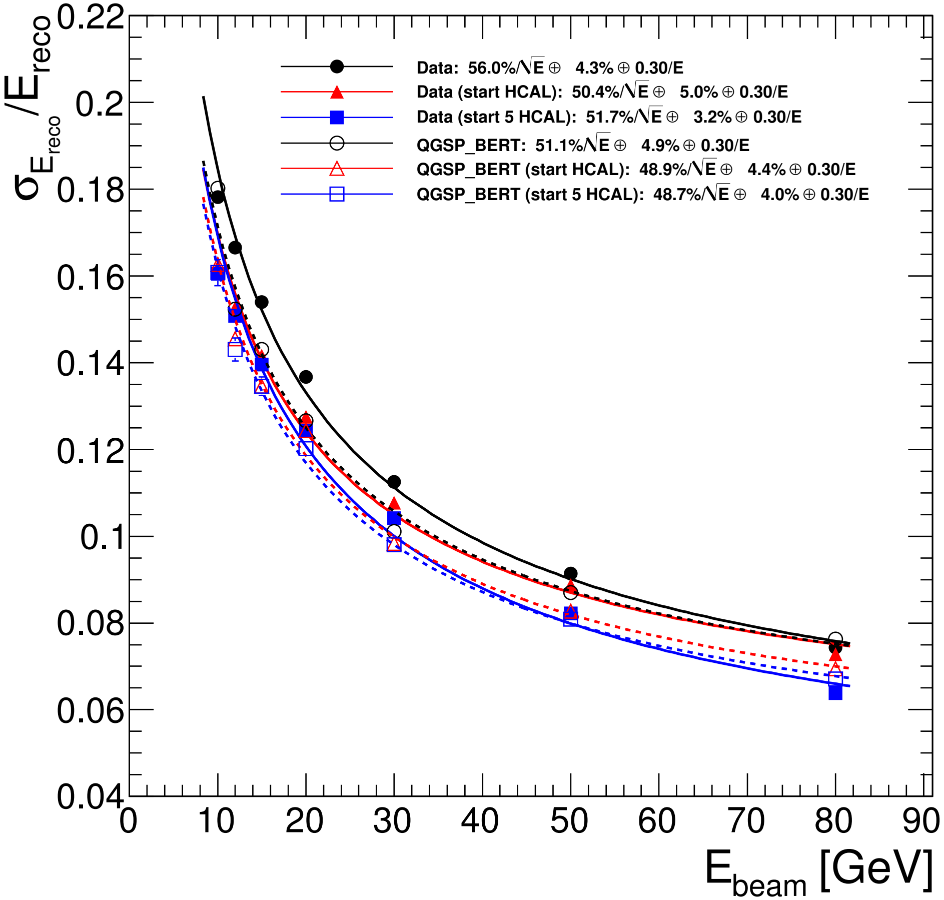


$$\frac{\sigma_E}{E} = \frac{(52.6 \pm 0.2)\%}{\sqrt{E/GeV}} \oplus (2.9 \pm 0.1)\% \oplus \frac{0.3}{E/GeV}$$

Energy resolution and linearity for data and QGSP_BERT

The same $\frac{GeV}{MIP}$ coefficients and scaling factor are applied to digitized MC and data.





Unlike data, the non-linearity of QGSP_BERT does not decrease after selection.

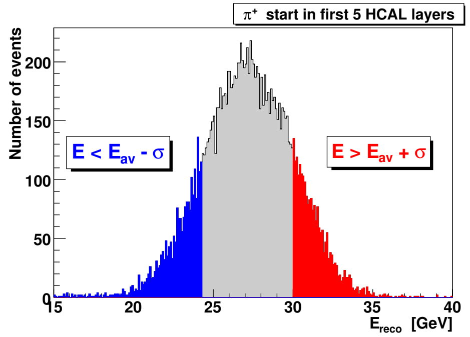
Data and QGSP_BERT resolution behavior are in good agreement.

The idea of software compensation approach

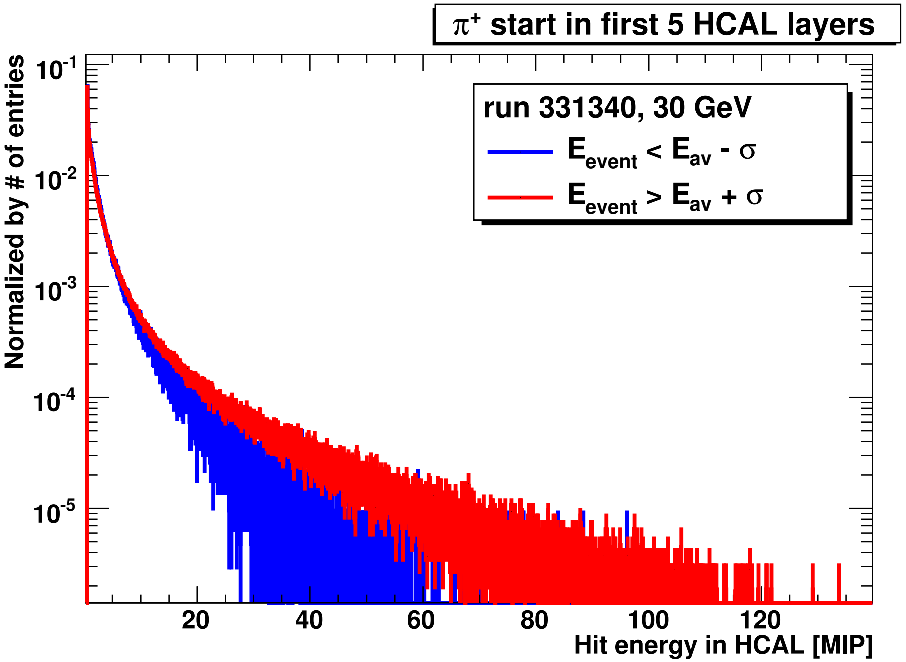
Compare hit spectra of events with low and high energy deposition

Different shape ⇒ different integral up to fixed value in hit spectrum

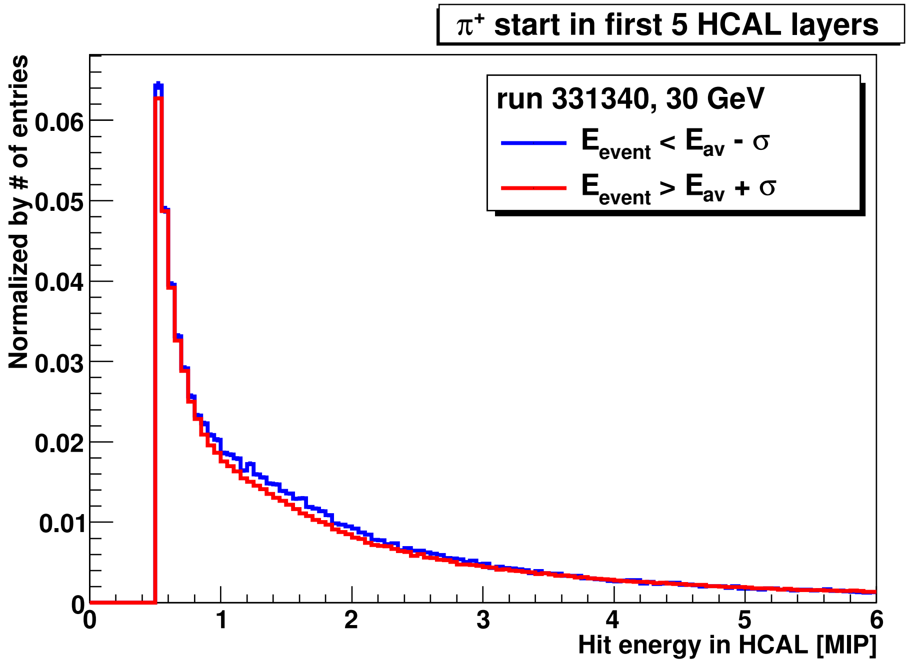
Inspect correlation between these integral values and deposited energy



30-GeV π^+



Full spectra in log scale



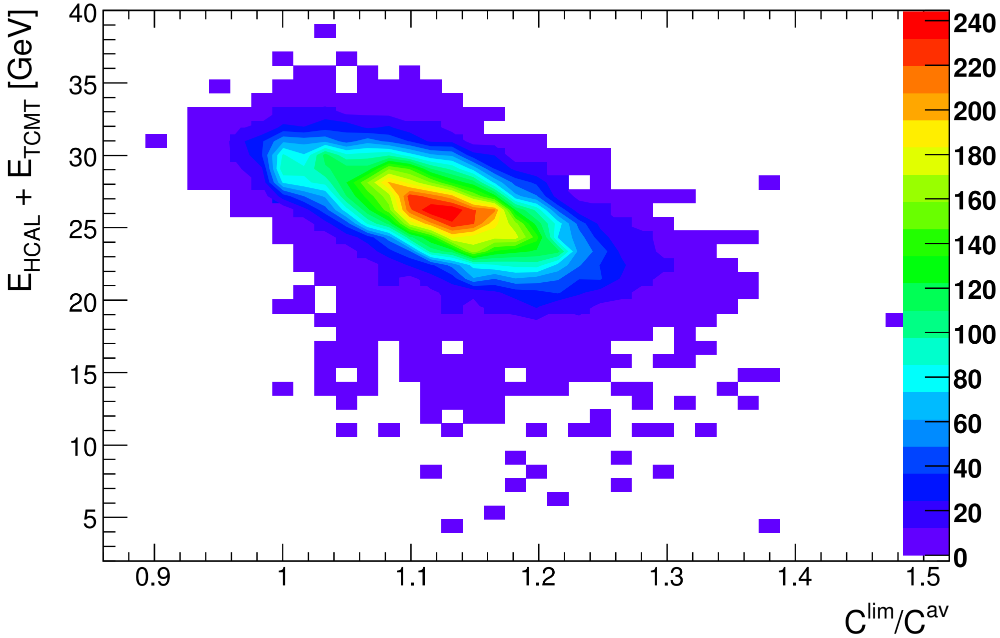
Left part of spectra in linear scale

Integral spectrum characteristics

The following integral values can characterize a hit spectrum $h_i(e)$ of the i-th event:

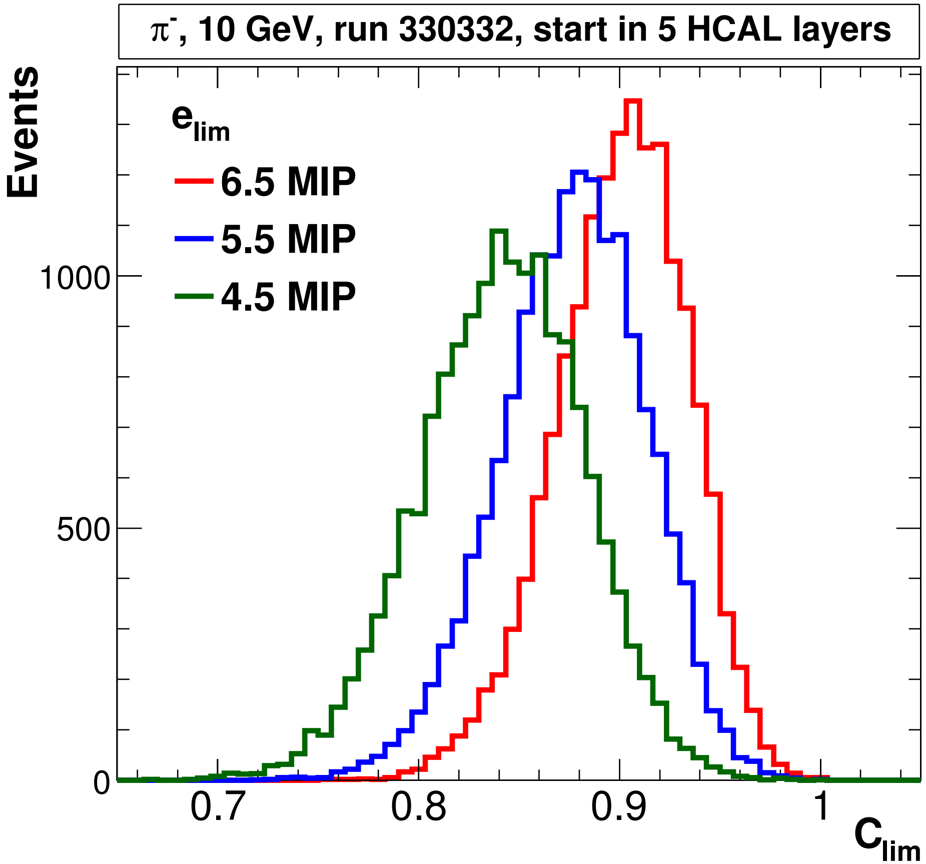
$$C_i^{lim} = \int_0^{e_{lim}} h_i(e)de \quad \textbf{and} \quad C_i^{av} = \int_0^{e_i^{av}} h_i(e)de$$

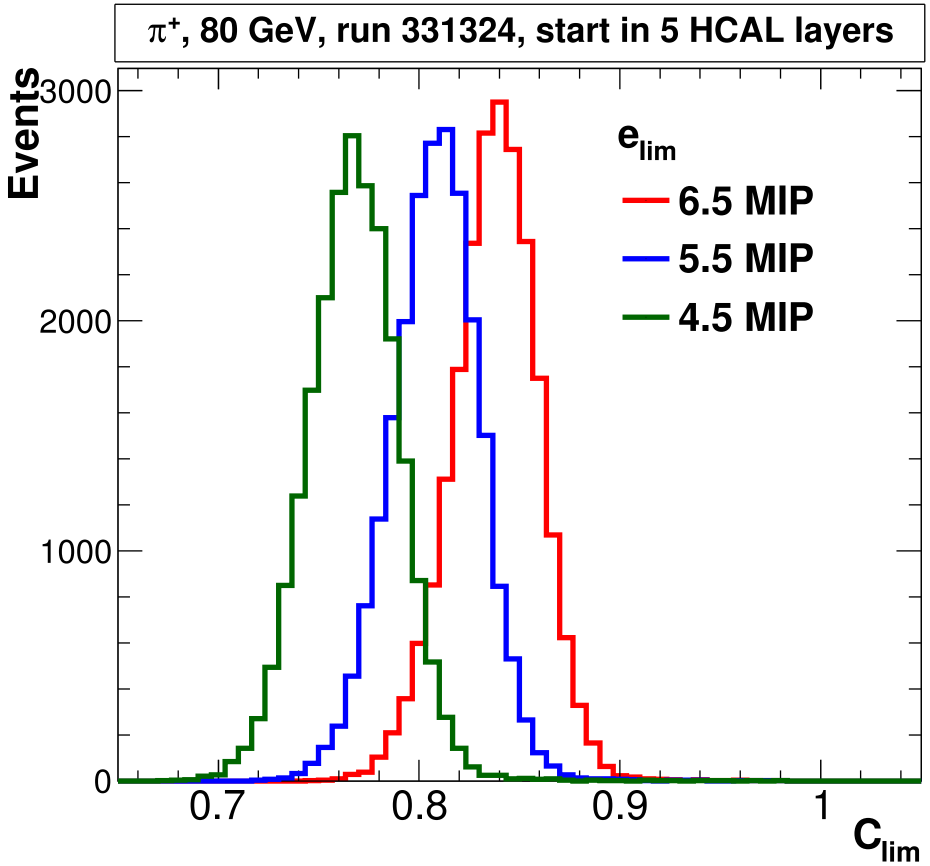
where $e_{lim} = 5.5$ **MIPs** **and** $e_i^{av} = \int_0^{e_{max}} e h_i(e)de$



The ratio $\frac{C_i^{lim}}{C_i^{av}}$ is inversely correlated with the energy deposited in the event.

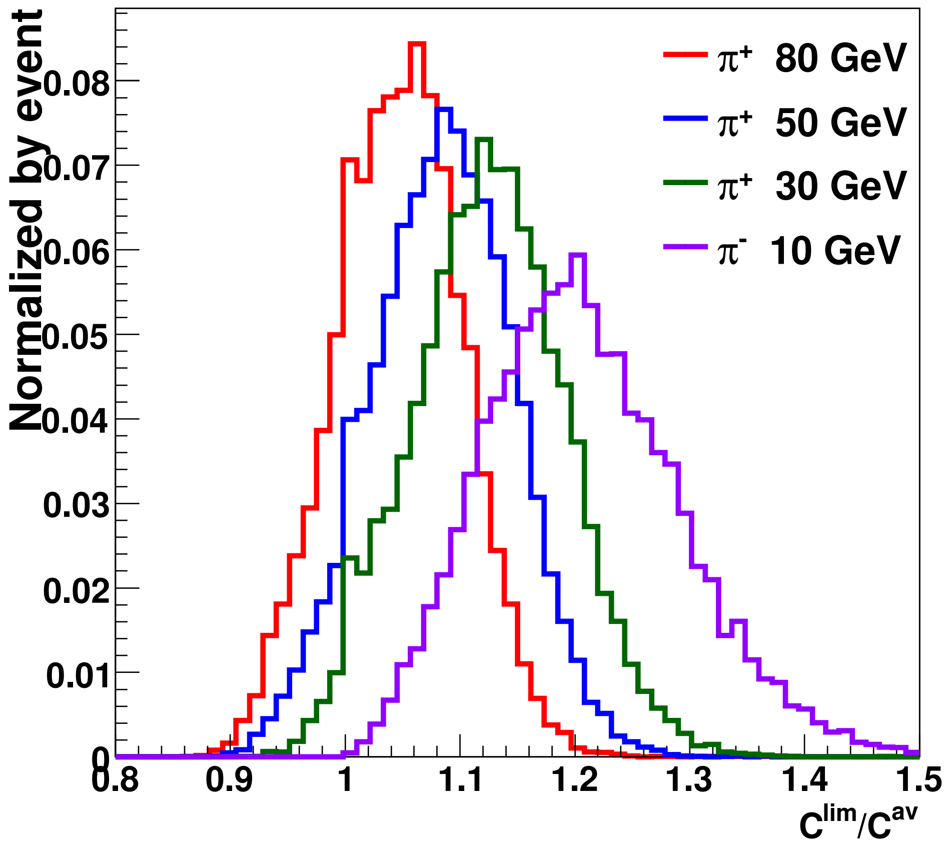
C_{lim} distribution



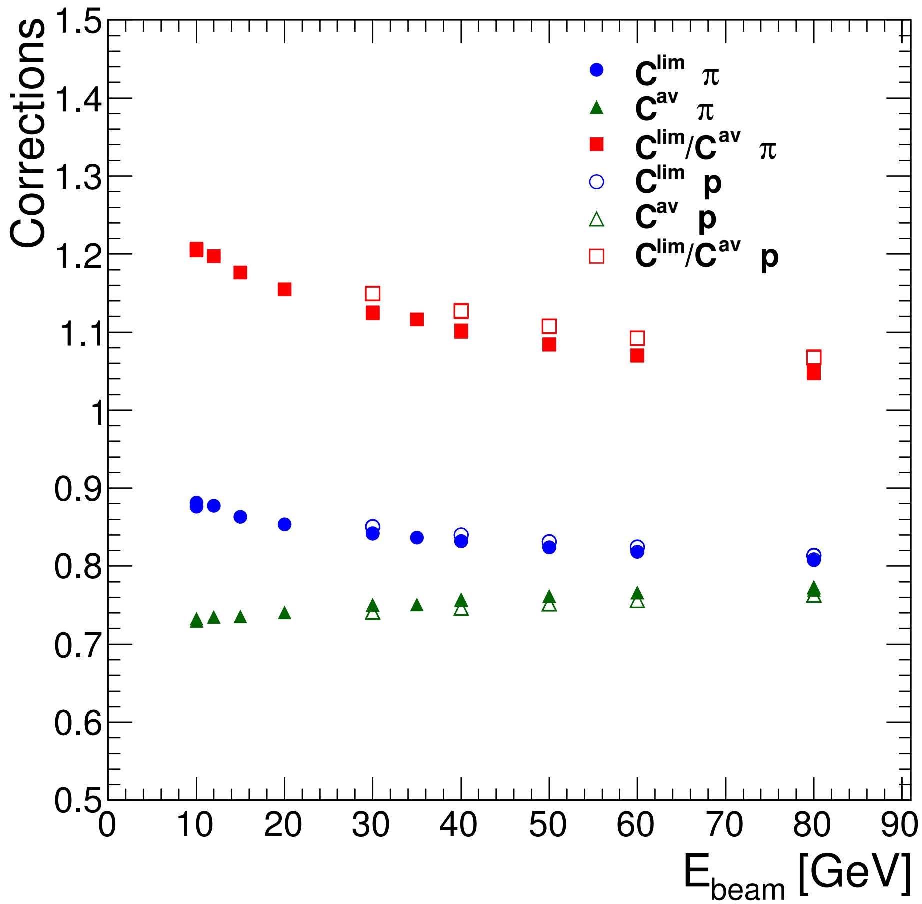


With increasing of e_{lim} the distribution becomes narrower but asymmetric and closer to 1 for low energies.

Correction factor energy dependence



Distributions for $e^{lim} = 5.5$ MIPs



The mean value $\frac{C^{lim}}{C^{av}}$ is energy dependent, the dependence being near linear.

Correction procedure for i-th event

Calculate uncorrected deposited energies E_i^{HCAL}, E_i^{ECAL}, and E_i^{TCMT}

$\Downarrow$

Calculate correction factors C_i^{lim} and C_i^{av} from hit spectrum

$\Downarrow$ 1^{st} step

Correct HCAL energy: $E_i^{cor} = E_i^{HCAL} \cdot \frac{C_i^{lim}}{C_i^{av}}$

$\Downarrow$

Calculate shower energy: $E_i^{sh} = E_i^{cor} + E_i^{TCMT}$

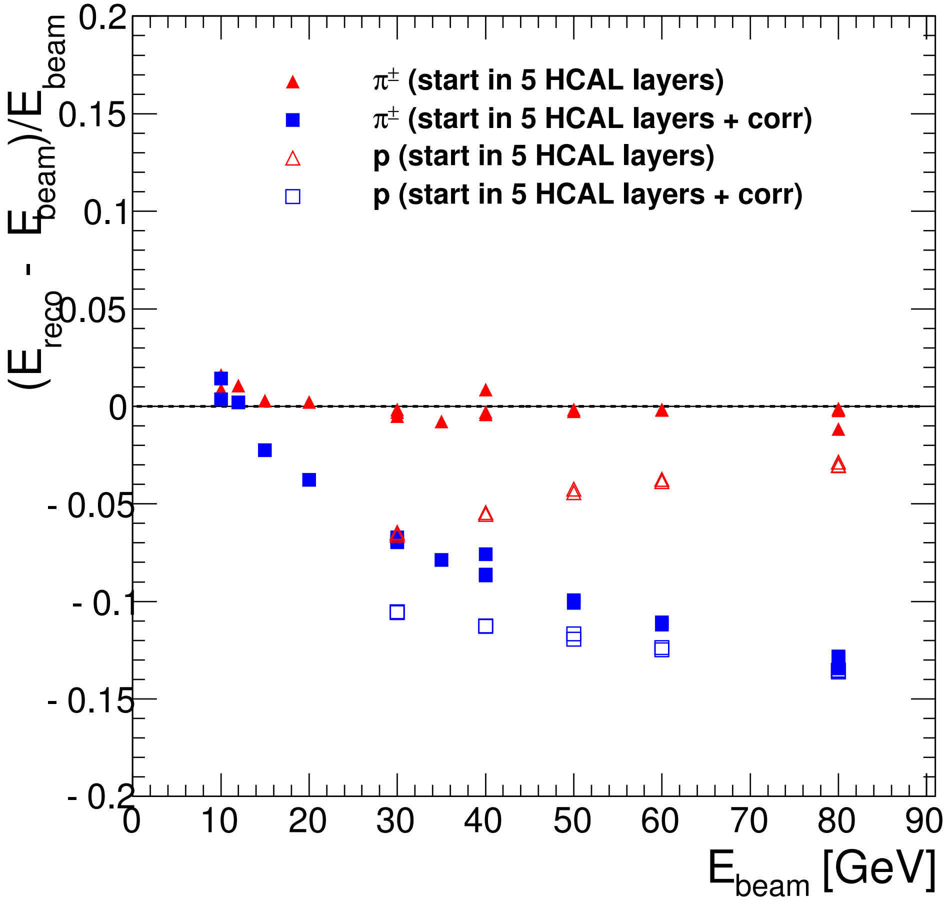
$\Downarrow$ 2^{nd} step

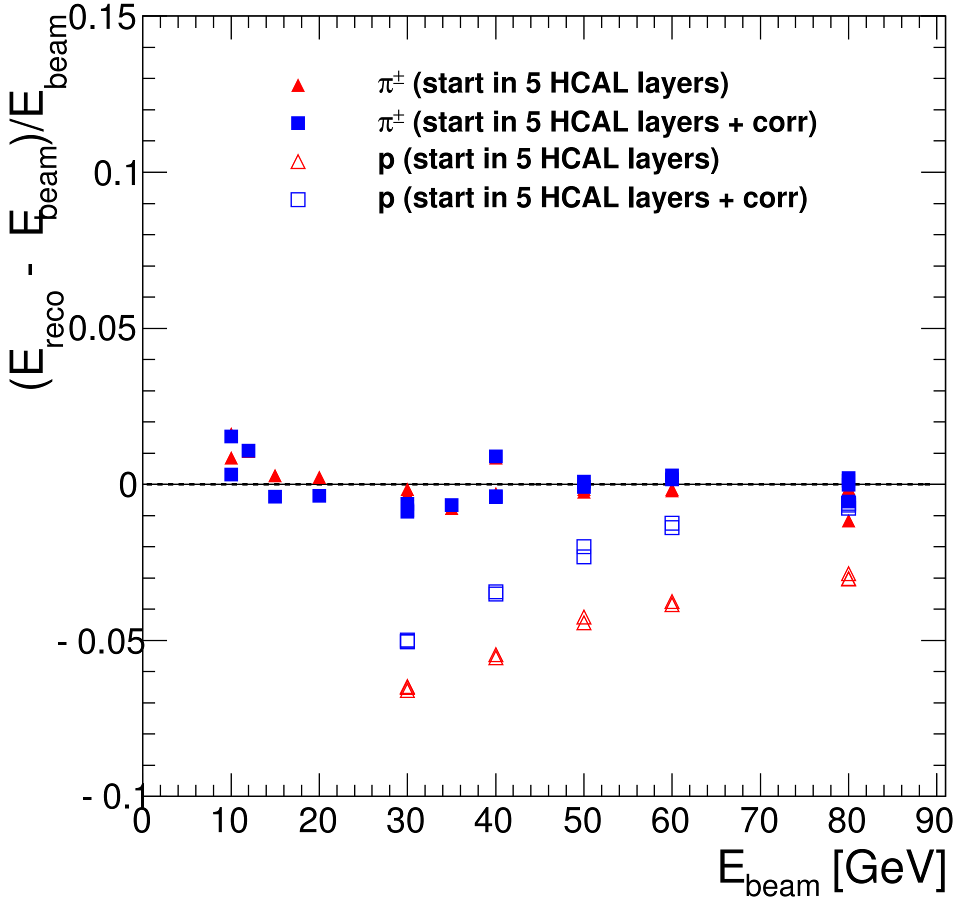
Correct energy dependence and calculate total energy:

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

where $a_1 = 0.958$, $a_2 = 0.0047$ GeV^{-1} and $a_3 = -2.78 \cdot 10^{-5}$ GeV^{-2}

Linearity after correction

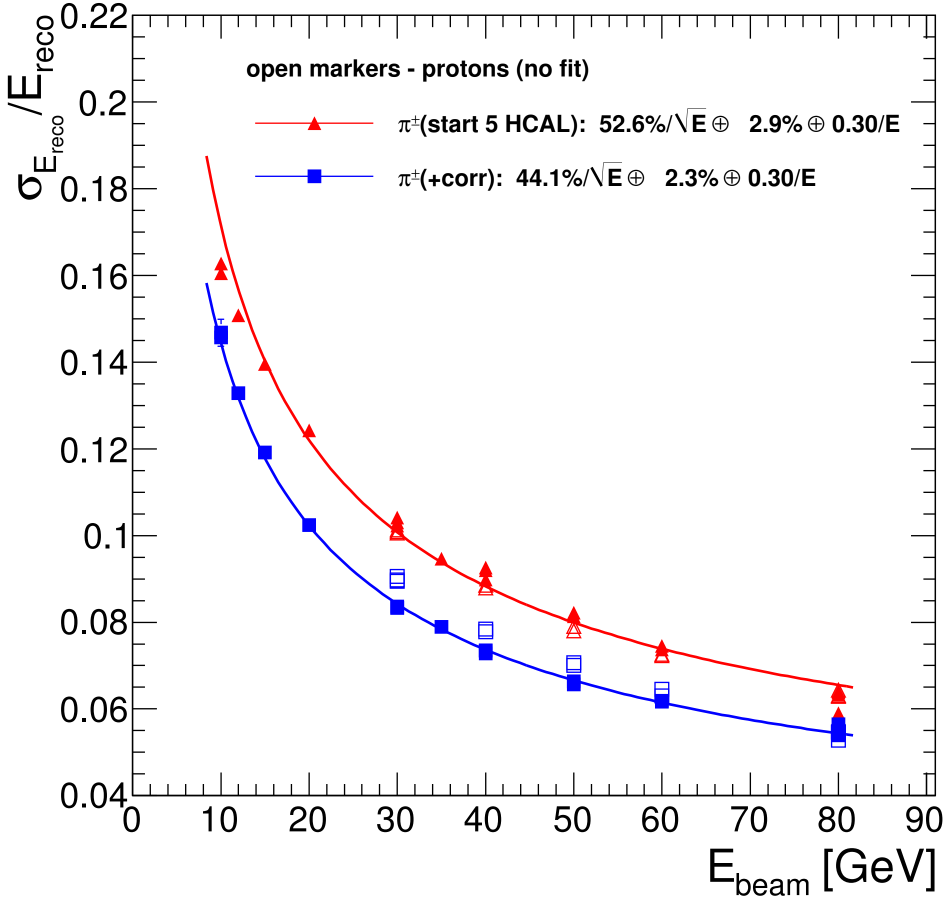


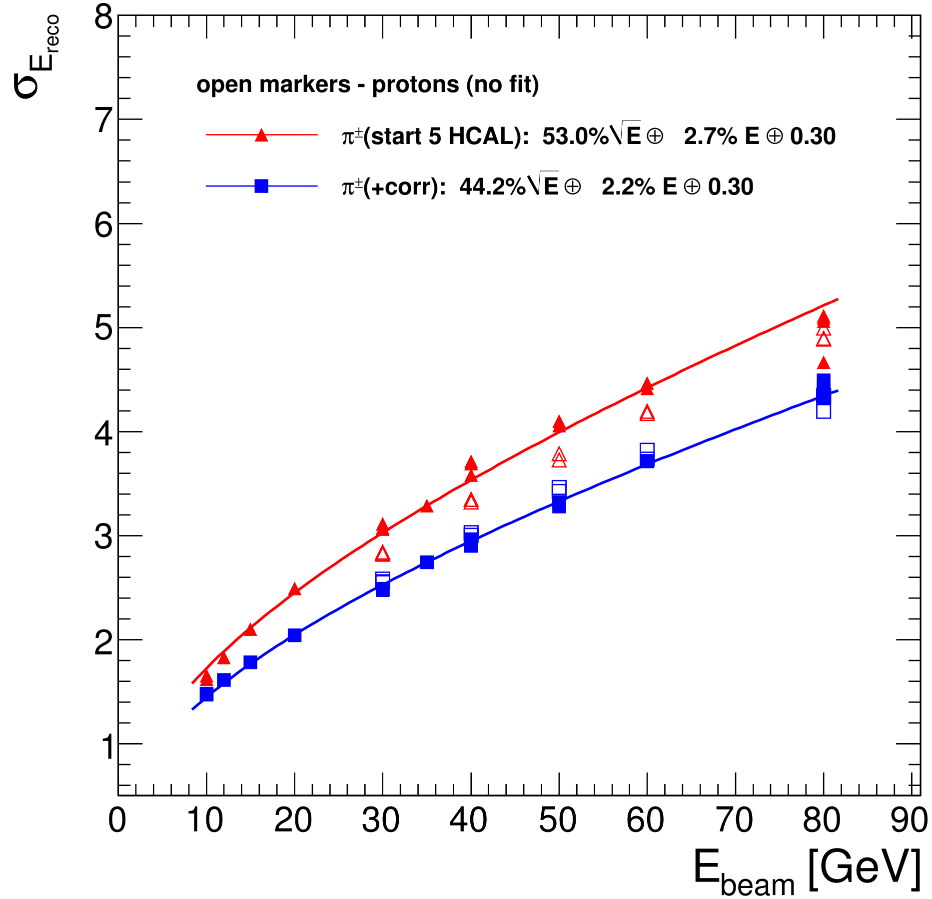


After the 1^{st} step the linearity is distorted.

The 2^{nd} step of correction procedure helps to keep the linearity for pions and improve it for protons.

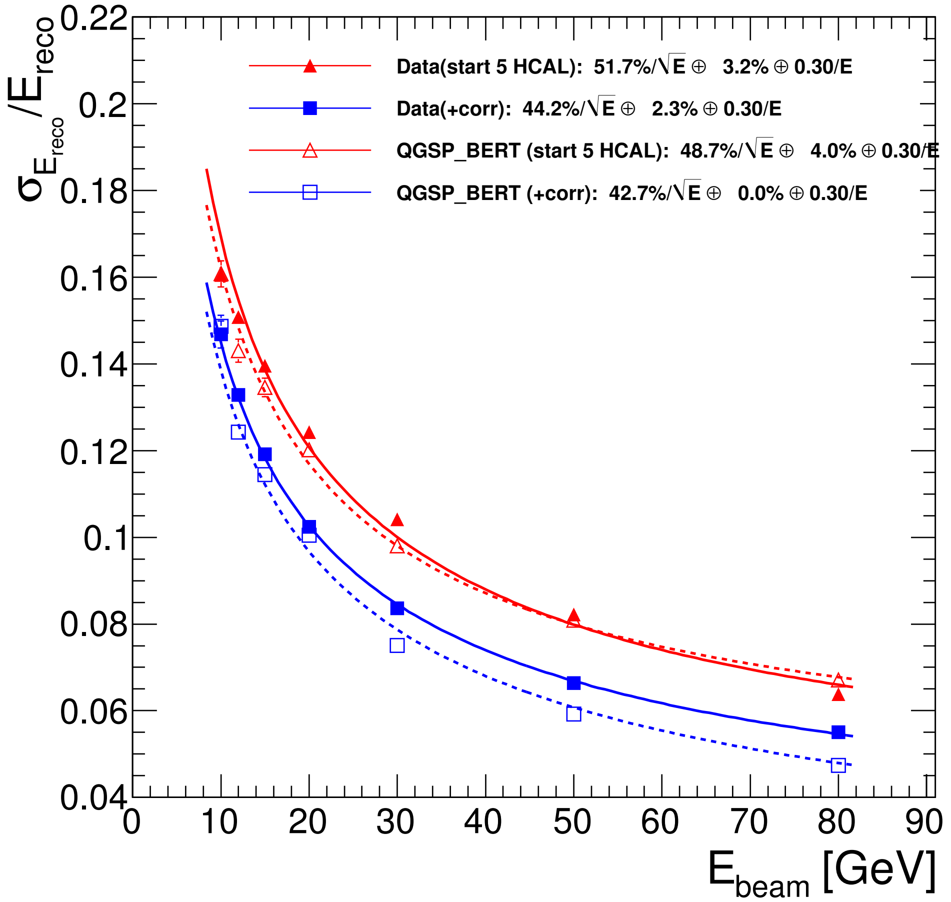
Resolution after correction

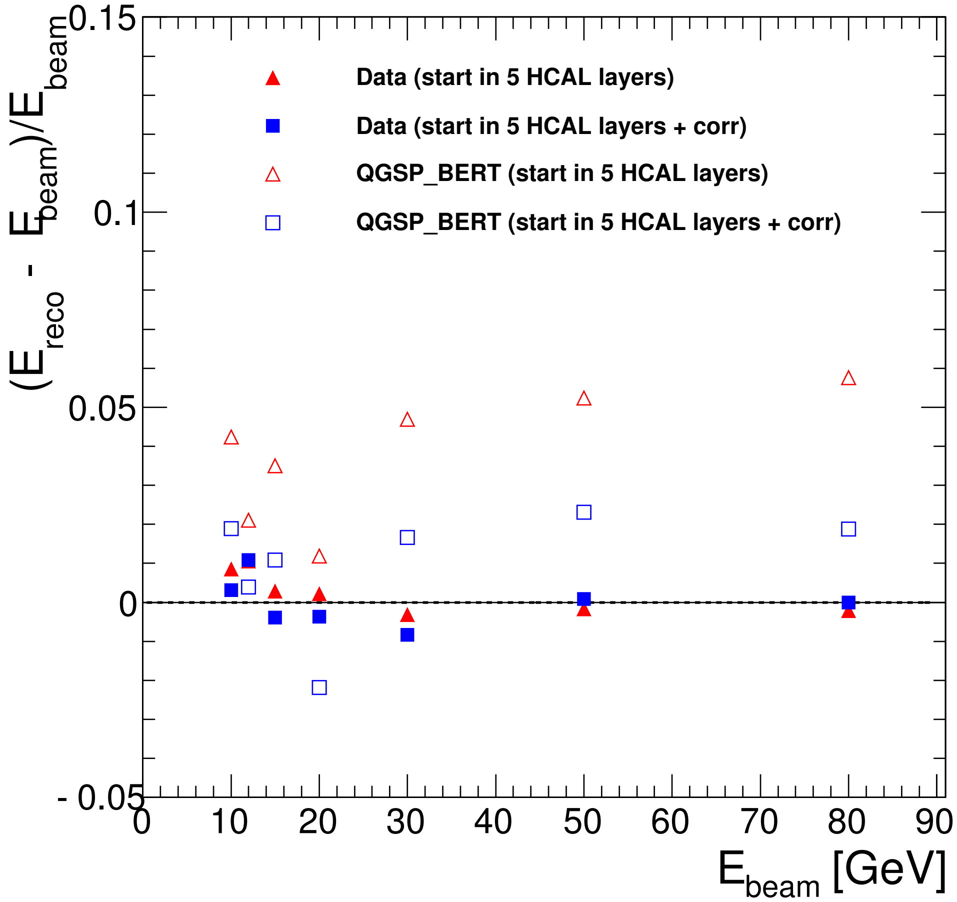




$$\frac{\sigma_E}{E} = \frac{(44.1 \pm 0.2)\%}{\sqrt{E/GeV}} \oplus (2.3 \pm 0.1)\% \oplus \frac{0.3}{E/GeV}$$

Resolution and linearity after correction for QGSP_BERT

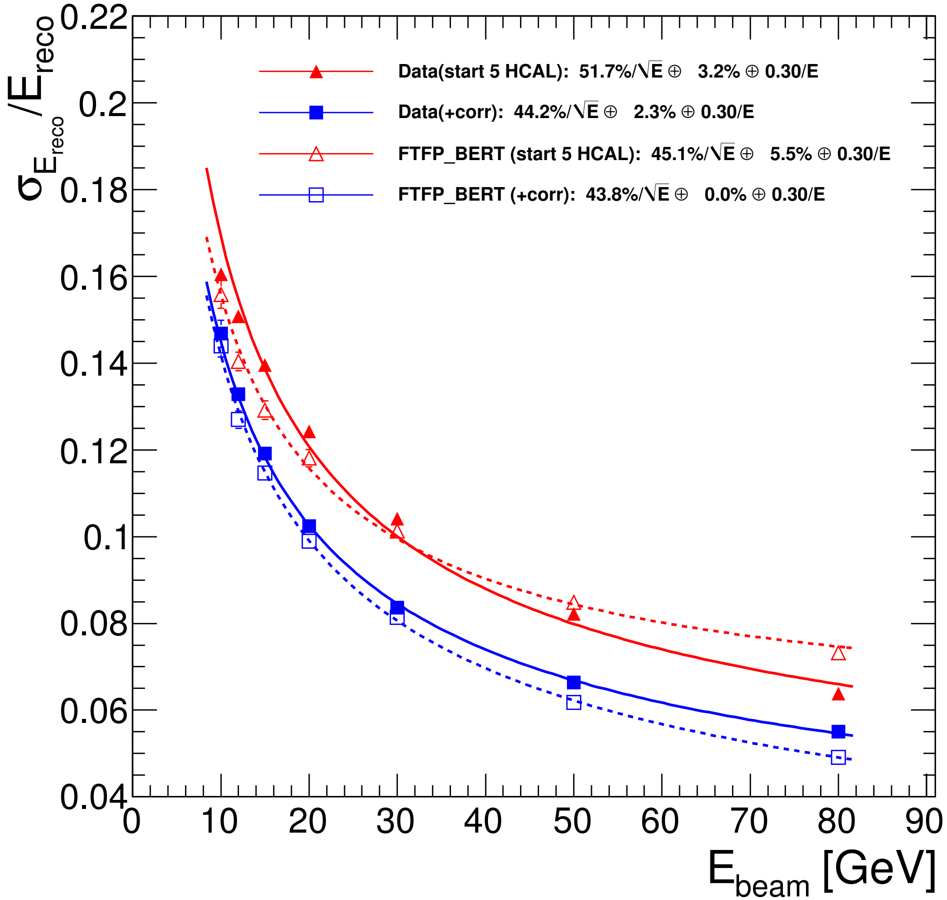


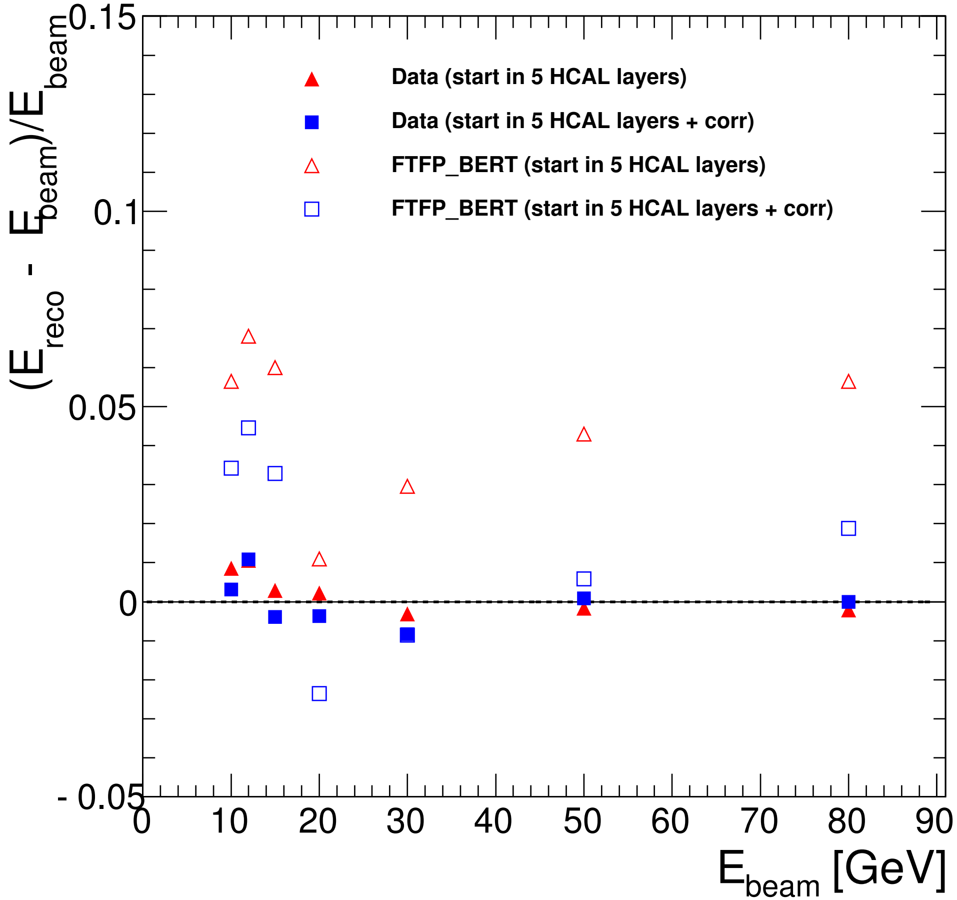


QGSP_BERT model predicts more significant improvement for high energies.

The linearity curve after correction repeats the behavior of non-corrected curve.

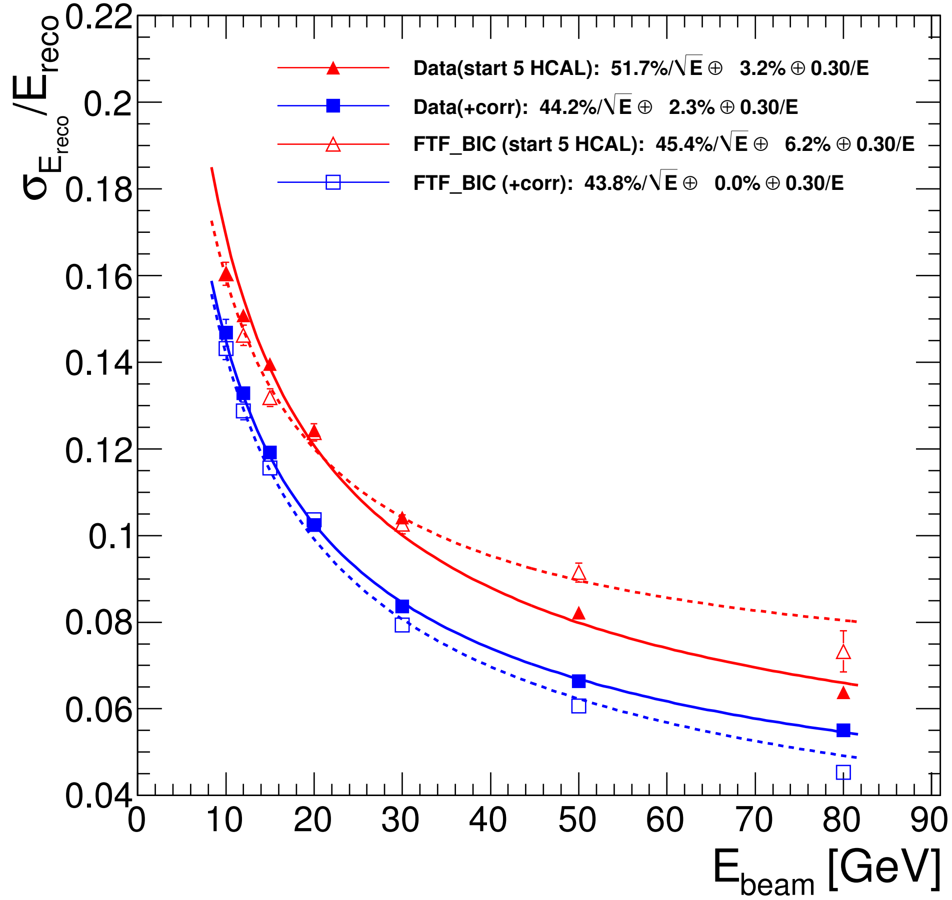
Resolution and linearity after correction for FTFP_BERT

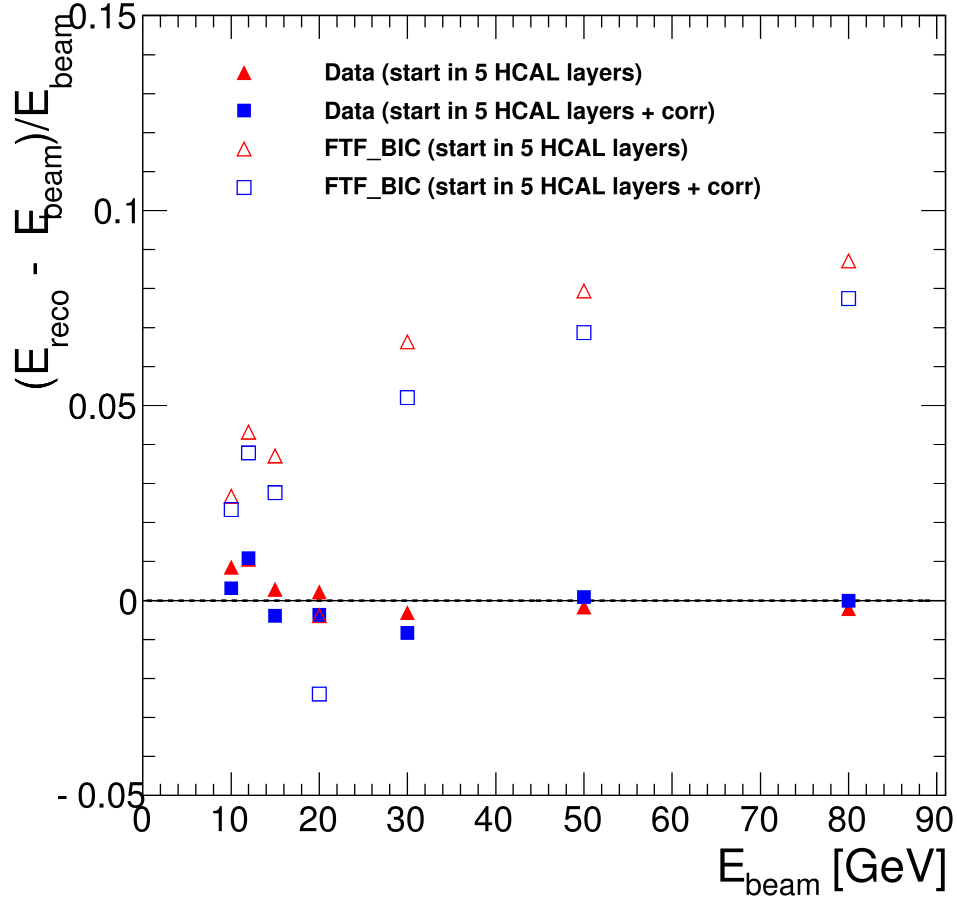




FTFP_BERT is more different from data than QGSP_BERT but also predicts higher improvement.

Resolution and linearity after correction for FTF_BIC





FTF_BIC is also more different from data than QGSP_BERT.

Conclusion

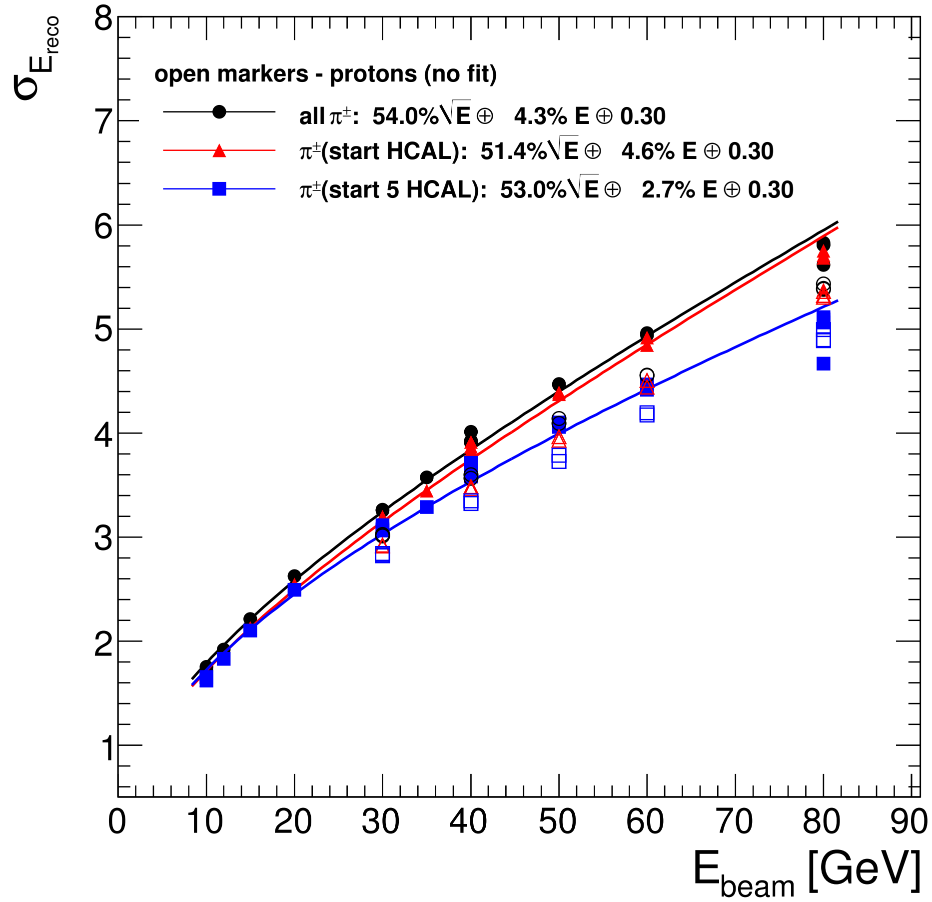
Proposed method of software compensation enables to improve the HCAL energy resolution by ∼10% compared to its value without correction.

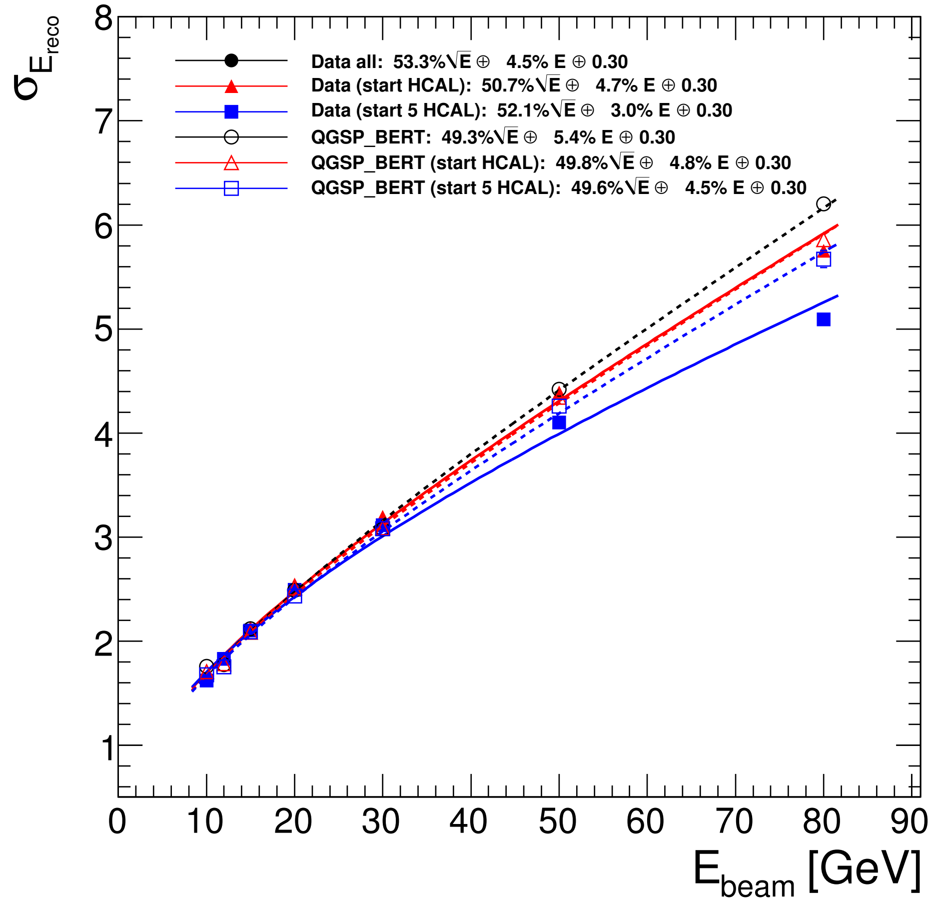
The algorithm invokes only one correction parameter applied to HCAL energy sum and three additional parameters to take into account the relatively weak energy dependence and retain linearity.

The QGSP_BERT, FTFP_BERT and FTF_BIC models predict the same resolution behavior after correction procedure but more significant resolution inprovement.

Backup slides

Energy resolution after selection

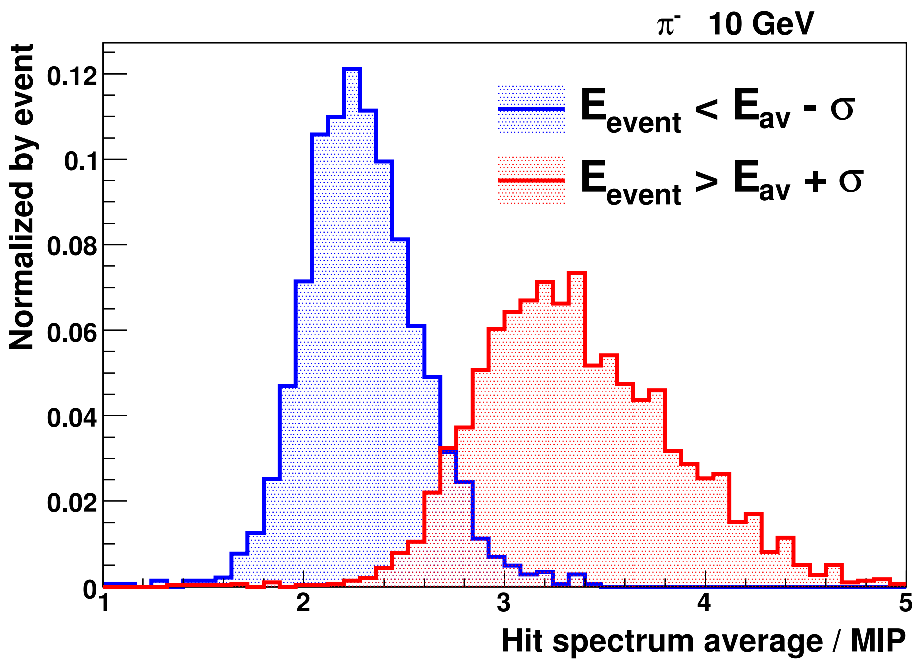


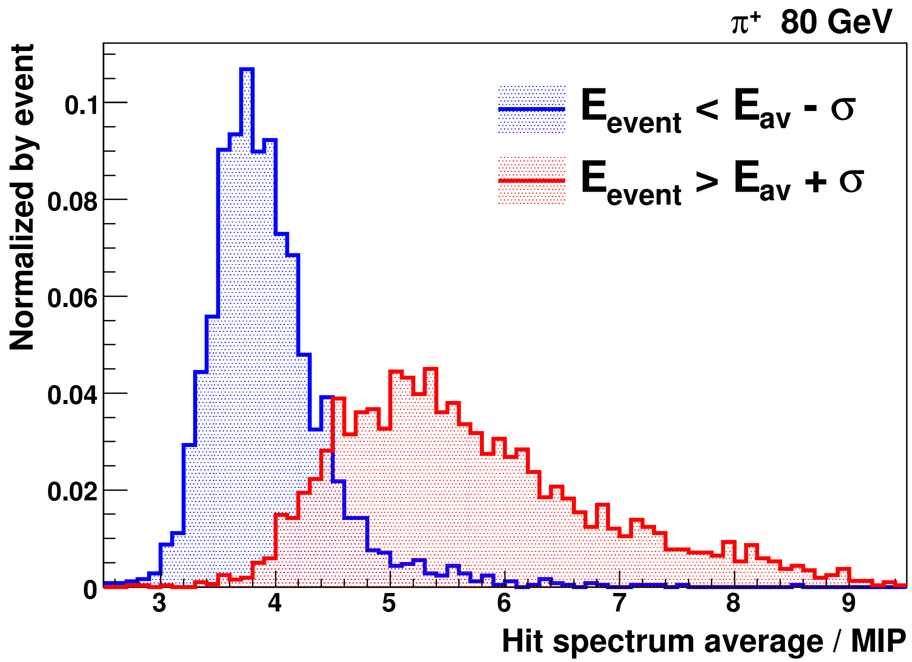


Data (20 $\pi^{\pm}$ runs)

Data and MC (7 energy points)

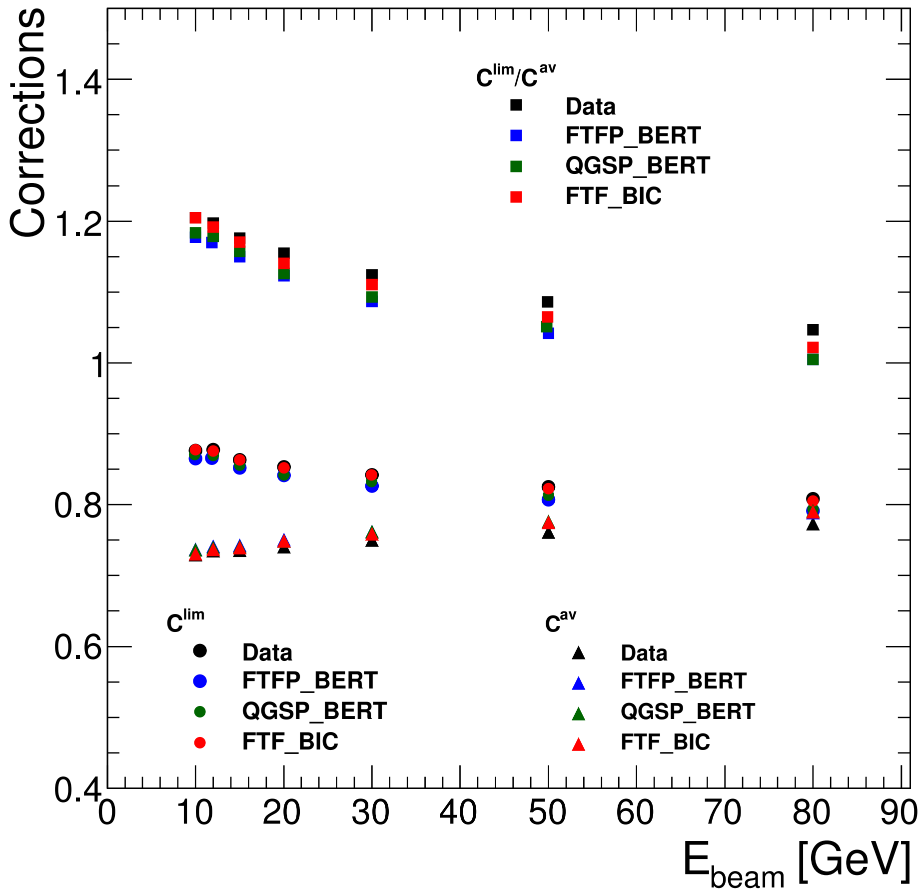
Hit spectrum mean value





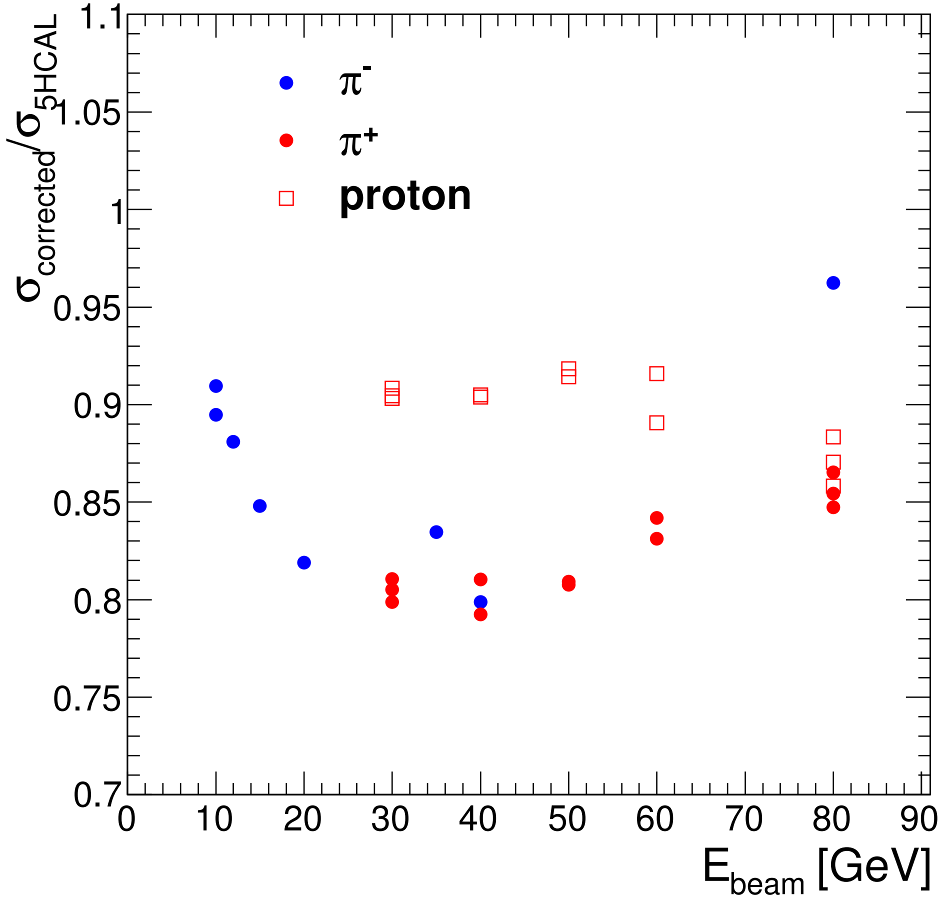
Correction factor energy dependence for MC

$\pi^{\pm}$

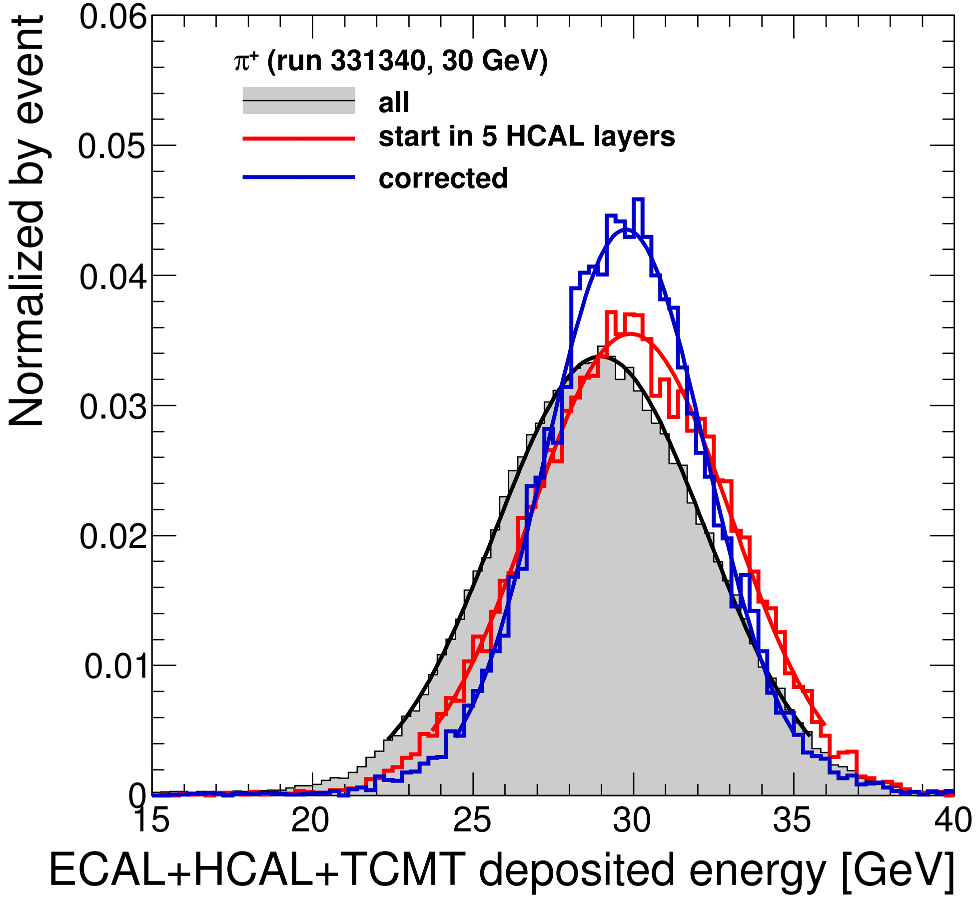


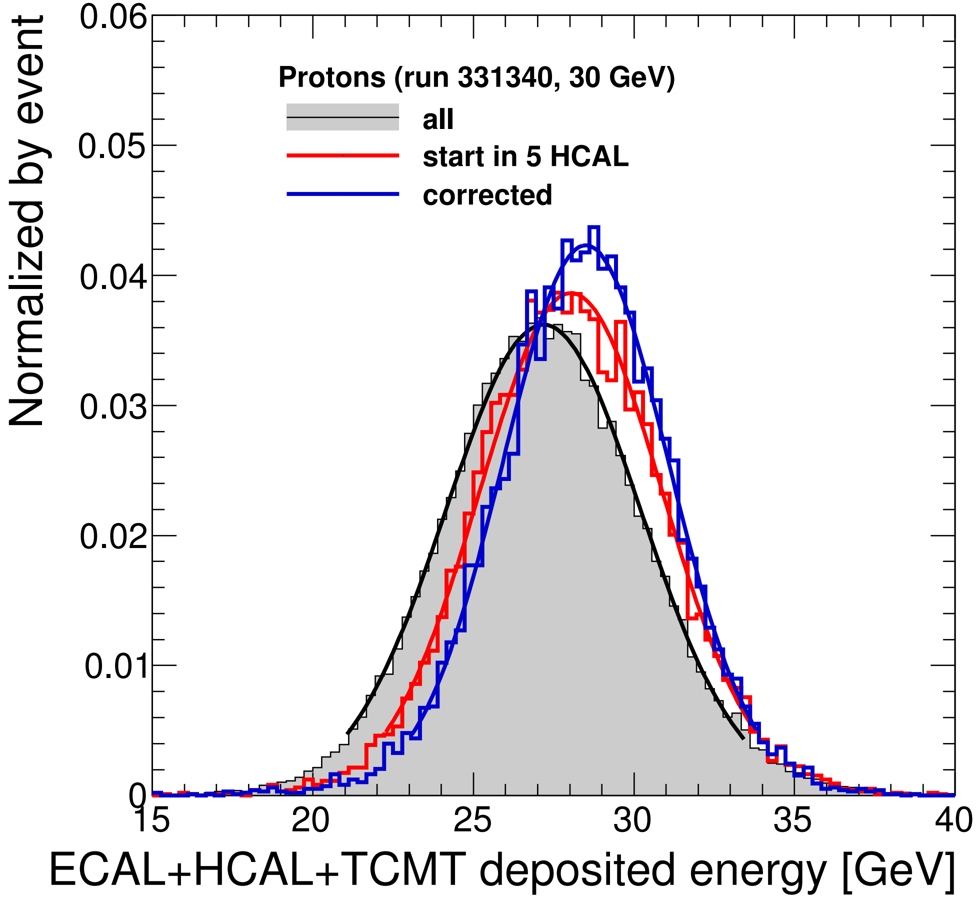
The MC correction factor behavior is similar to that of data, the FTF_BIC being most close to data.

Relative resolution improvement



Energy distributions after correction





The correction procedure improves energy distributions while keeping them Gaussian for both pions and protons.