MC study of the relationship between empirical compensation factor and true EM fraction

Marina Chadeeva, ITEP

Motivation

The empirical compensation factors, both local and global, successfully used in CALICE analyses are based on the fact that the high energy hits come mostly from EM component of hadronic shower.

This study was aimed to answer the following questions:

- **How strong is the correlation between true EM fraction and empirical global compensation factor?**
- **How significant is the impact of intrinsic fluctuations inside hadronic fraction?**
- **How big is the effect of empirical compensation comparing to that from direct compensation using known EM fraction?**

For the analysis MC samples provided by Alex Kaplan were used:

π^- in the energy range from 10 to 80 GeV
QGSP_BERT and FTF_BIC physics lists from GEANT 4.9.3
simulations for complete CALICE setup
official digitization chain applied
value of AHCAL EM component stored as event parameter

Variables under study

Hadronic showers well contained in the HCAL are analyzed, i.e. events with shower start at the beginning of HCAL.

The following variables are calculated for each event:

- **Reconstructed energy E_{reco} (using em calibration)**

  $E_{reco} = (E_{HCAL} + E_{ECAL} + E_{TCMT}) \cdot \frac{e}{\pi}$

  $\frac{e}{\pi} = 1.19$ **(from data)**

- **Compensation factor C_{EM} from electromagnetic fraction f_{EM}**

  $f_{EM} = (E_{\pi^0} + E_{\eta \to neutral})/E_{beam}$ (see Alex's talks on shower decomposition)

  - track in ECAL → no EM component in ECAL
  - low tail in TCMT → low probability of EM component in TCMT

- **Empirical compensation factor C_{SP}**

  based on hit spectrum analysis (see CAN-028 for details)

Empirical compensation factor C_{SP}

Compensation procedure: $E^{SP}_{reco} = E_{HCAL} \cdot C_{SP} + E_{ECAL} + E_{TCMT}$

C_{SP} **is calculated from event hit spectrum as follows:**

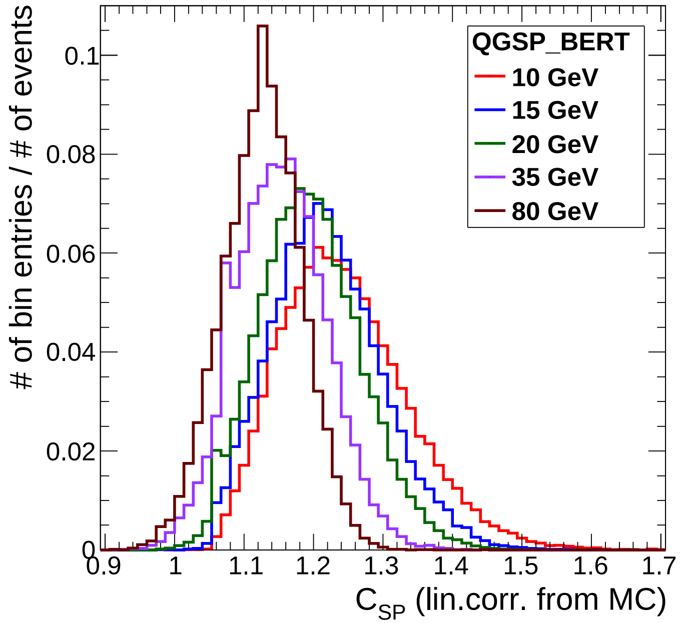
$$C_{SP} = C \cdot (a_0 + a_1 E_{cor} + a_2 E^2_{cor}),$$

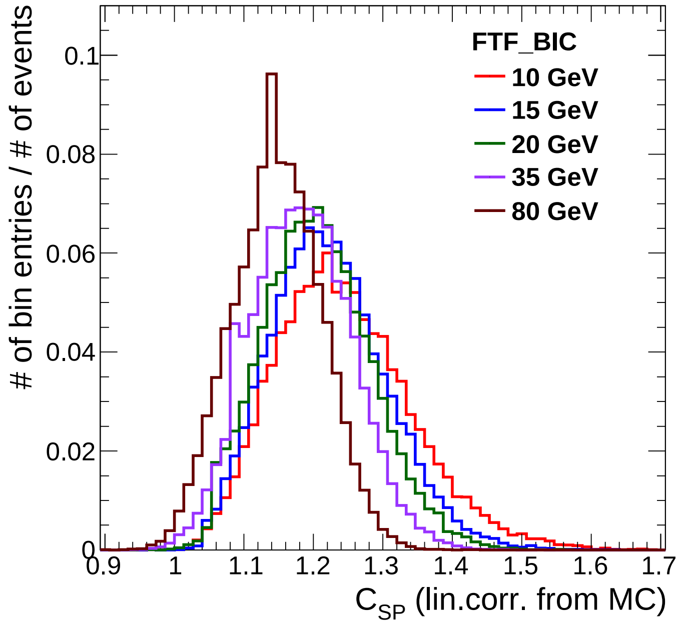
where $C = \frac{N(e_{hit}<5.5\ MIP)}{N(e_{hit}<e_{av})}$, $E_{cor} = E_{HCAL} \cdot C$,

e_{av} **is a mean of event hit spectrum.**

Coefficients a_0, a_1 **and** a_2 **were introduced to keep linearity, they can be extracted both from data and MC. The results with coefficients extracted from MC are shown.**

C_{SP} **fluctuations decrease with energy** $\Longrightarrow$



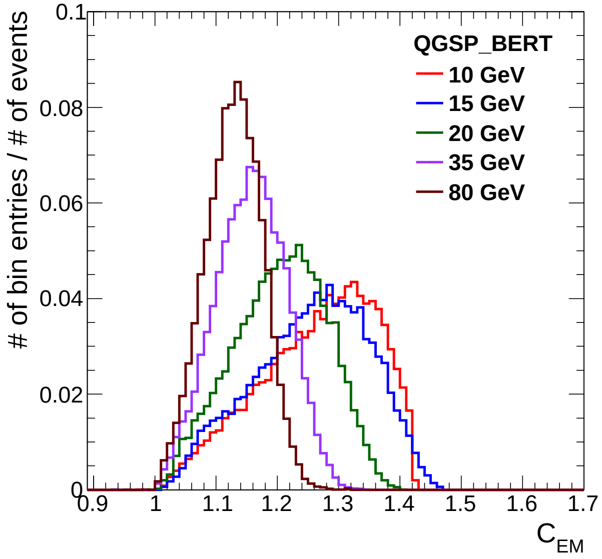


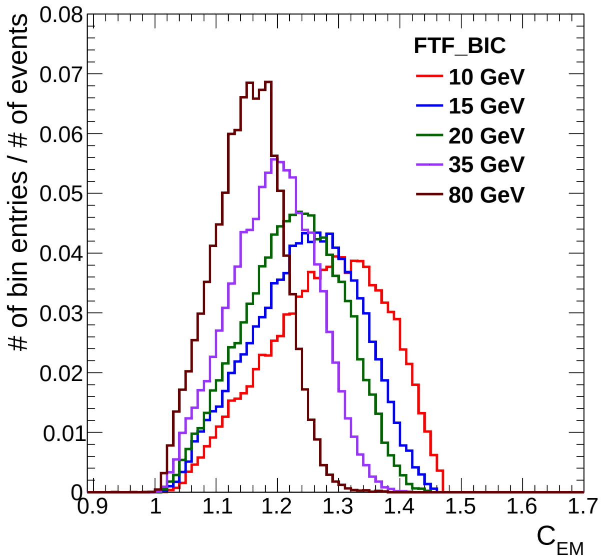
Compensation using known f_{EM}

If one knows an electromagnetic fraction f_{EM} in each event, then $E_{shower} = e \cdot E_{beam} \cdot f_{EM} + h \cdot E_{beam} \cdot (1 - f_{EM})$, where e and h are average efficiencies of detecting electromagnetic and hadronic components respectively. Electromagnetic calibration results in $e = 1 \pm \frac{0.2}{\sqrt{E_{beam}}}$

$h_{event} = \frac{1}{(1-f_{EM})} \cdot (\frac{E_{shower}}{E_{beam}} - e \cdot f_{EM})$. The mean value of h can be estimated from its distribution.

Update from weekly meeting: E_{TCMT} involved in h calculation, otherwise h was underestimated by ∼5% in spite of the applied selection. The right treatment of E_{track} is still under question.



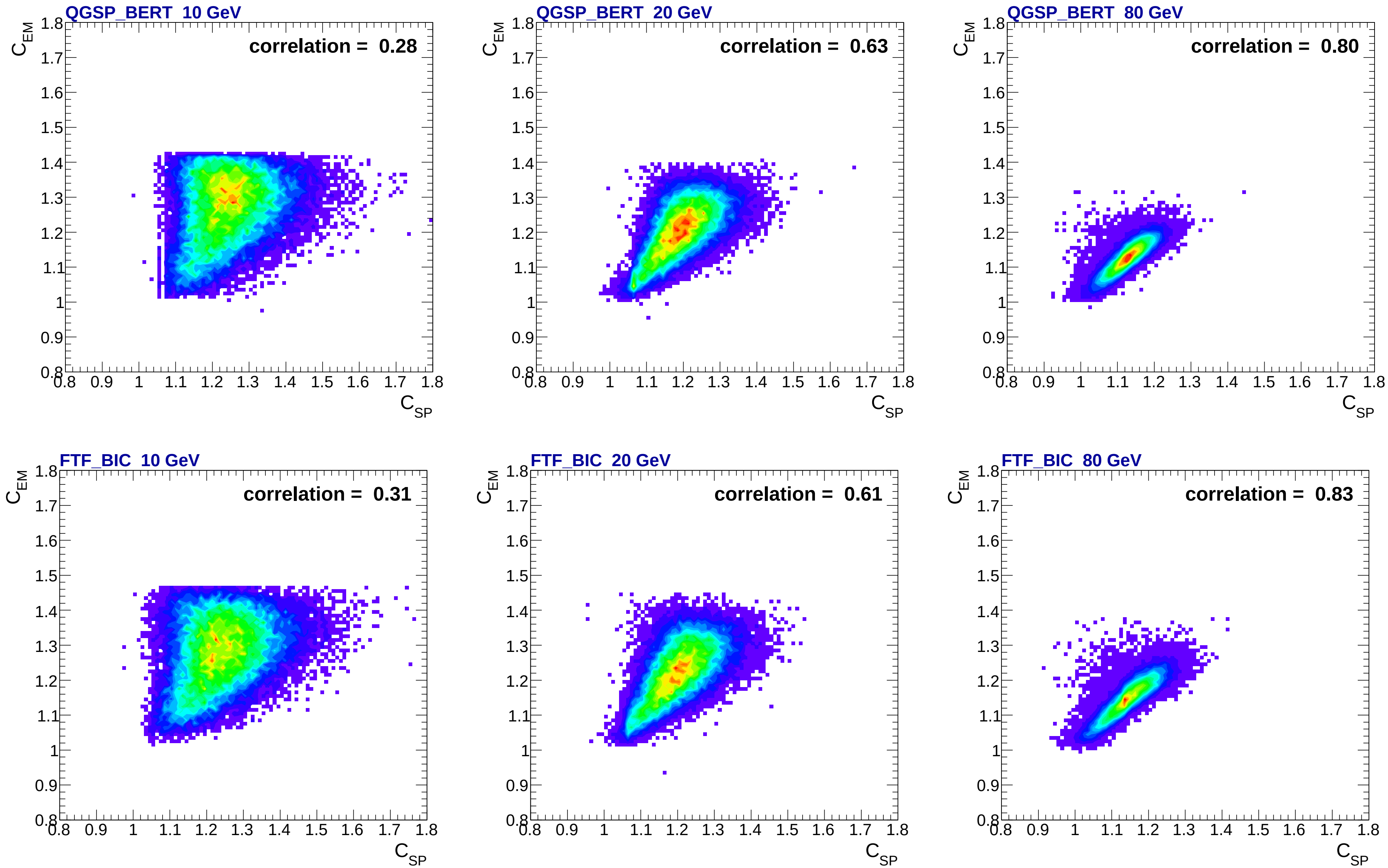


The event energy can be corrected using the factor

$$C_{EM} = \frac{1}{f_{EM}(1-h)+h} \quad \Rightarrow$$

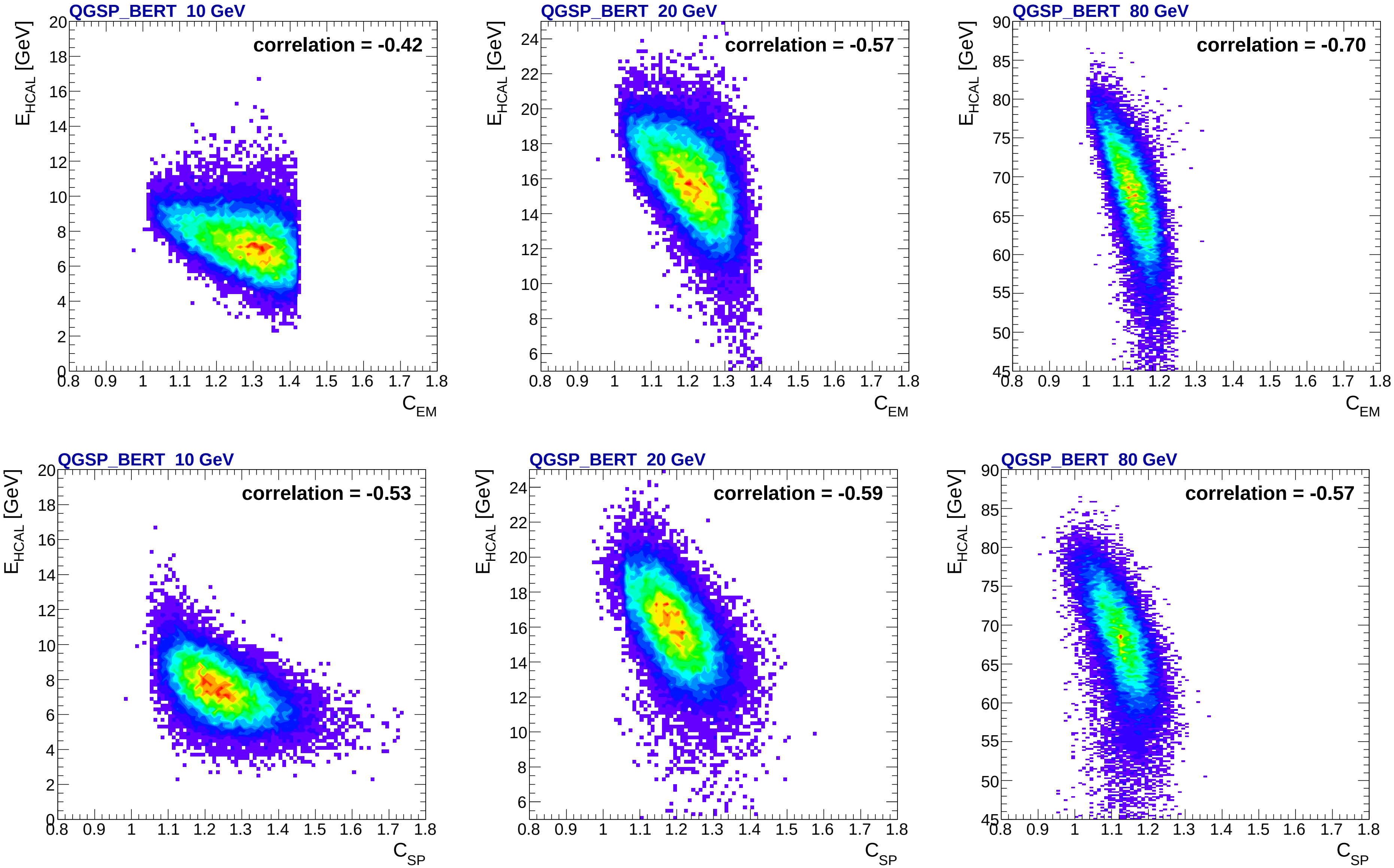
$$E^{EM}_{reco} = E_{HCAL} \cdot C_{EM} + E_{ECAL} + E_{TCMT}.$$

Correlation between C_{SP} and C_{EM}



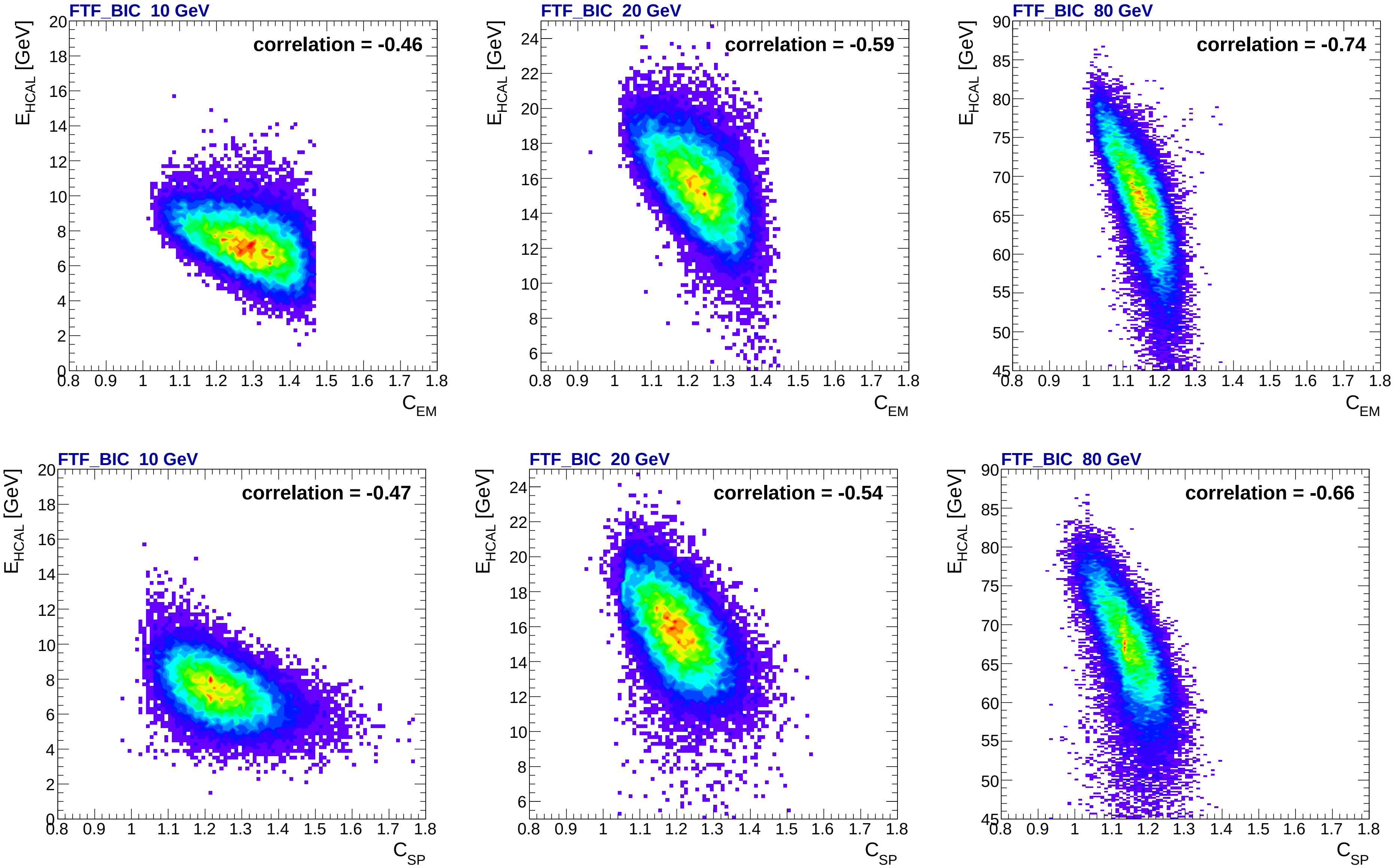
There is no correlation at 10 GeV, but it appears with increasing energy.

Correlation with E_{HCAL} for QGSP_BERT



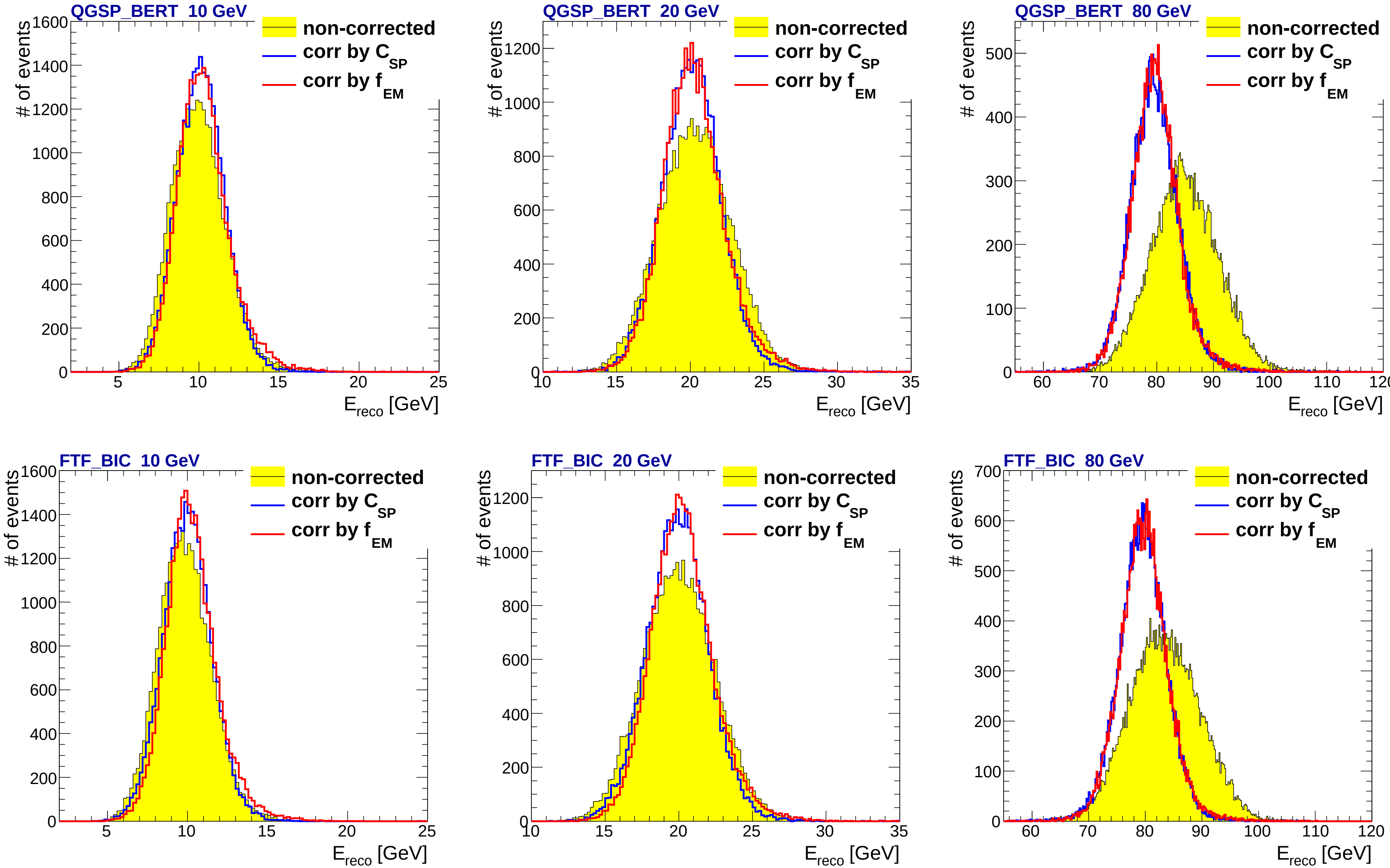
At 10 GeV C_{SP} demonstrates higher correlation with deposited energy than C_{EM}

Correlation with E_{HCAL} for FTF_BIC



The same tendency as for QGSP_BERT with stronger correlations at higher energies.

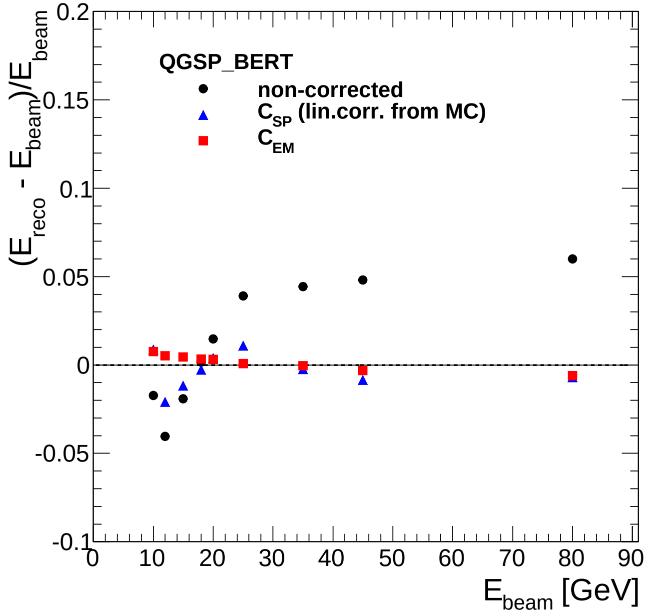
Reconstructed energy



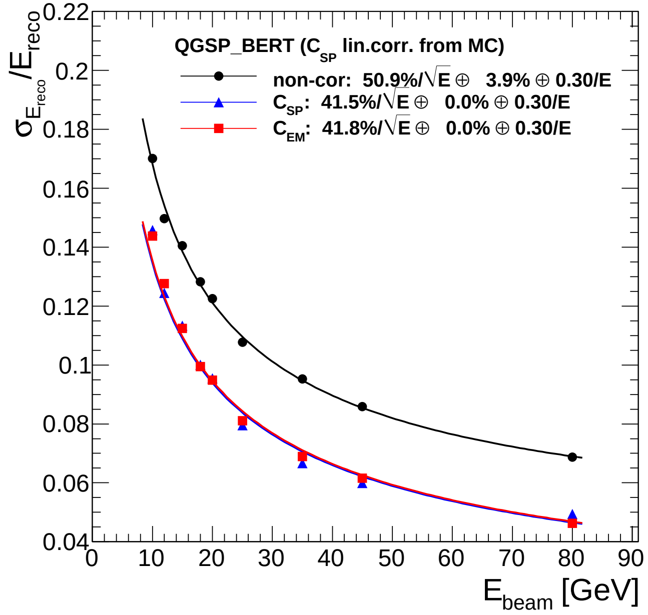
For QGSP_BERT the empirical approach works even better at low energies!

Energy resolution and linearity for QGSP_BERT

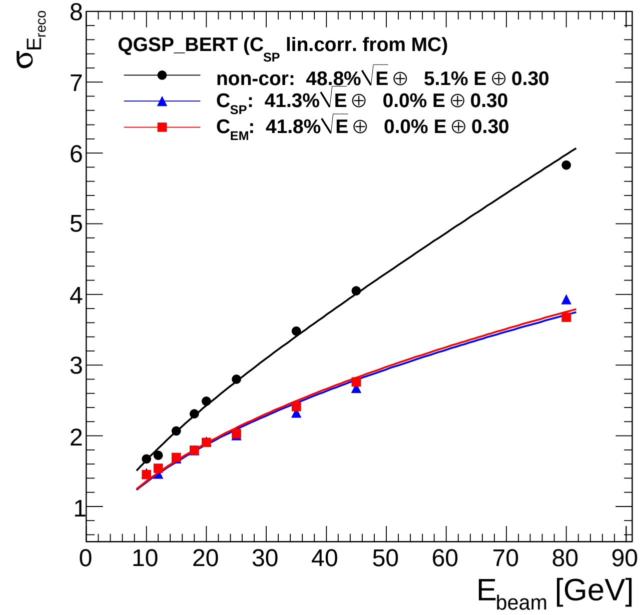
Linearity



Relative resolution



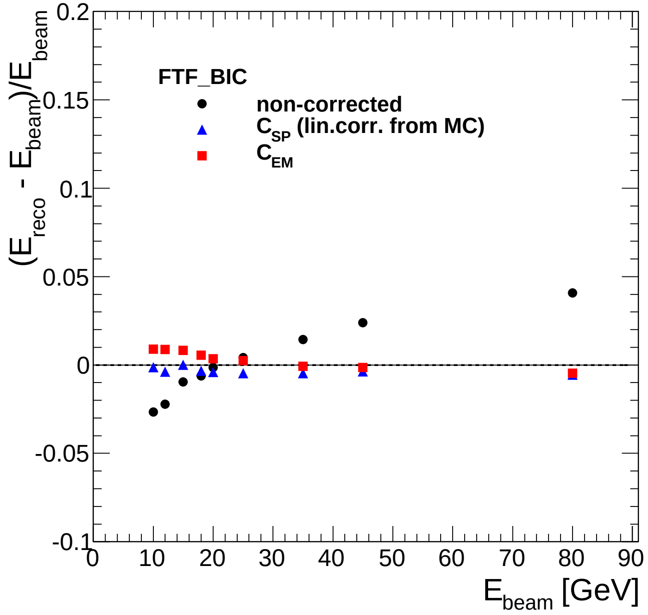
Absolute resolution



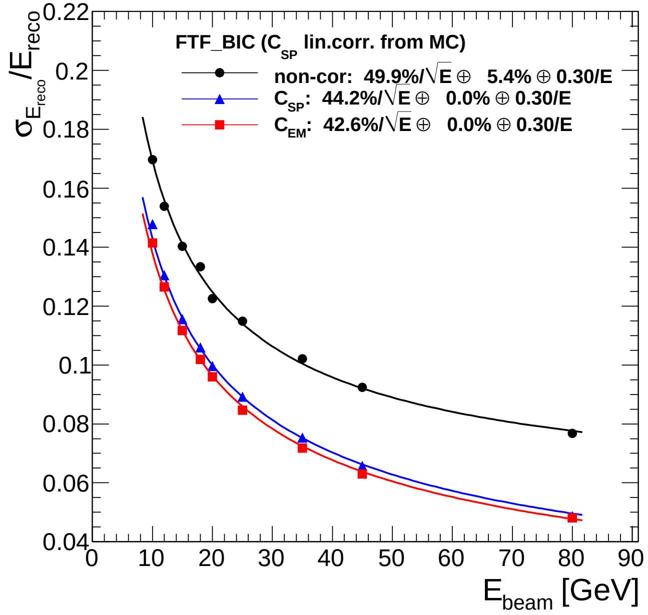
The application of coefficients extracted from MC to empirical factor results in good coincidence between resulting empirical and theoretical curves. Compensation based on the knowledge of true f_{EM} in each event automatically helps to restore linearity. The remaining nonlinearity is probably due to wrong treatment of track energy in ECAL.

Energy resolution and linearity for FTF_BIC

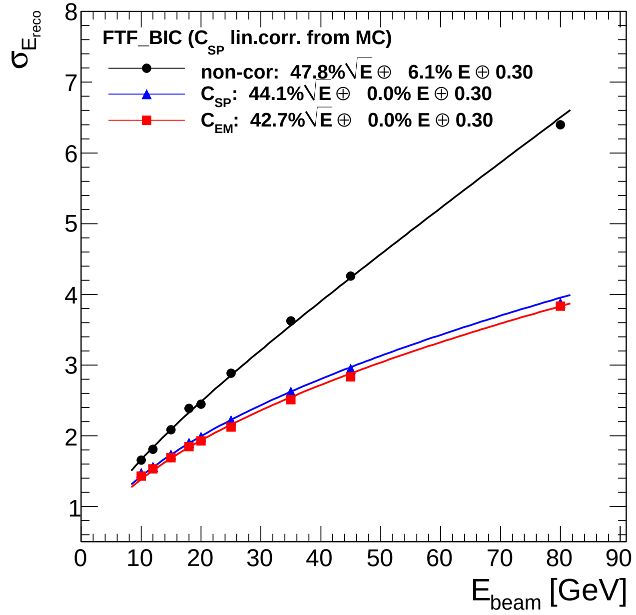
Linearity



Relative resolution



Absolute resolution



The empirical compensation works a little bit worse than in case of QGSP_BERT, nevertheless the empirical resolution curve is very close to the theoretical one. Better linearity after empirical compensation is observed than for QGSP_BERT.

Conclusions

The empirical software compensation approach based on hit spectrum analysis was compared with the compensation based on the knowledge of EM fraction. For this study MC samples were used generated in GEANT 4.9.3 with QGSP_BERT and FTF_BIC physics lists for π^- in the energy range from 10 to 80 GeV.

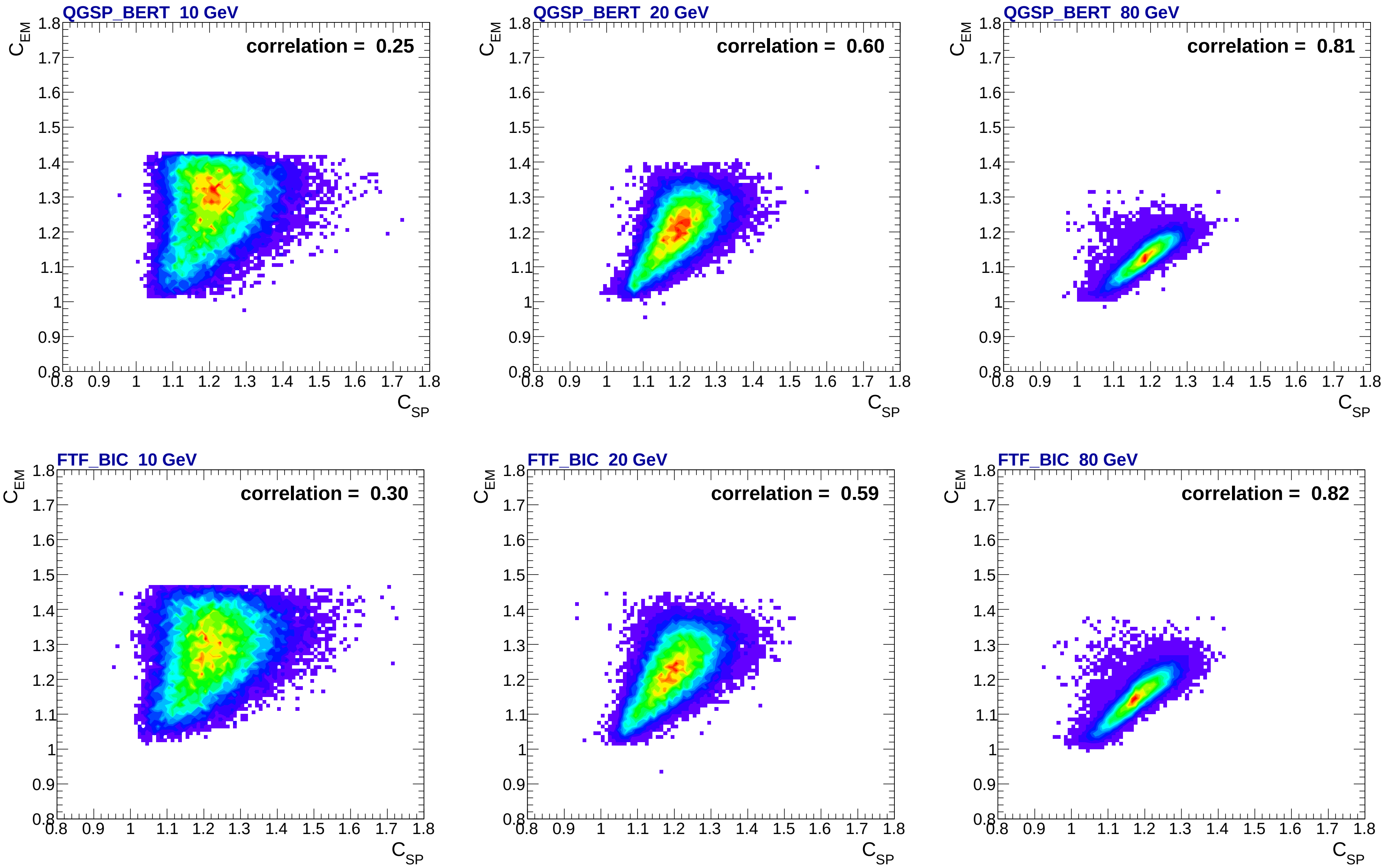
The correlation between empirical factor C_{SP} and factor directly extracted from known f_{EM} is not observed at low energies, appears above 25 GeV and increases with energy.

At low energies the empirical approach based on hit spectrum analysis gives a little bit better improvement in absolute resolution than the direct approach. This follows from the fact that at low energies (and relatively low average f_{EM}) the intrinsic fluctuations of h play a defining role. As follows from the correlation between empirical compensation factor and deposited energy, this empirical factor partially takes into account these intrinsic fluctuations.

Thus, the empirical software compensation approach allows to obtain an almost maximum improvement in resolution which could be acieved by excluding fluctuations of electromagnetic fraction.

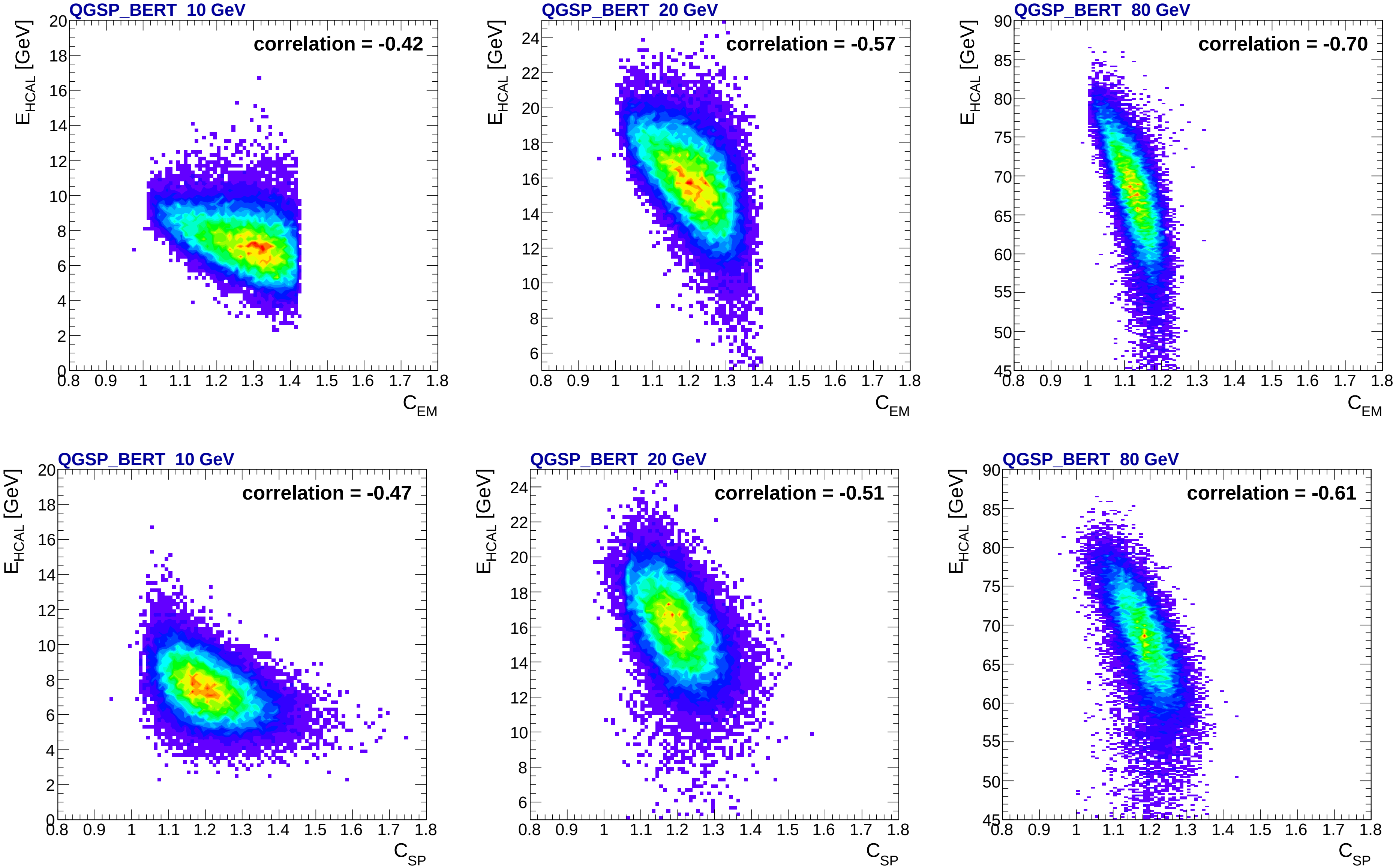
Backup slides

Correlation between C_{SP} and C_{EM}



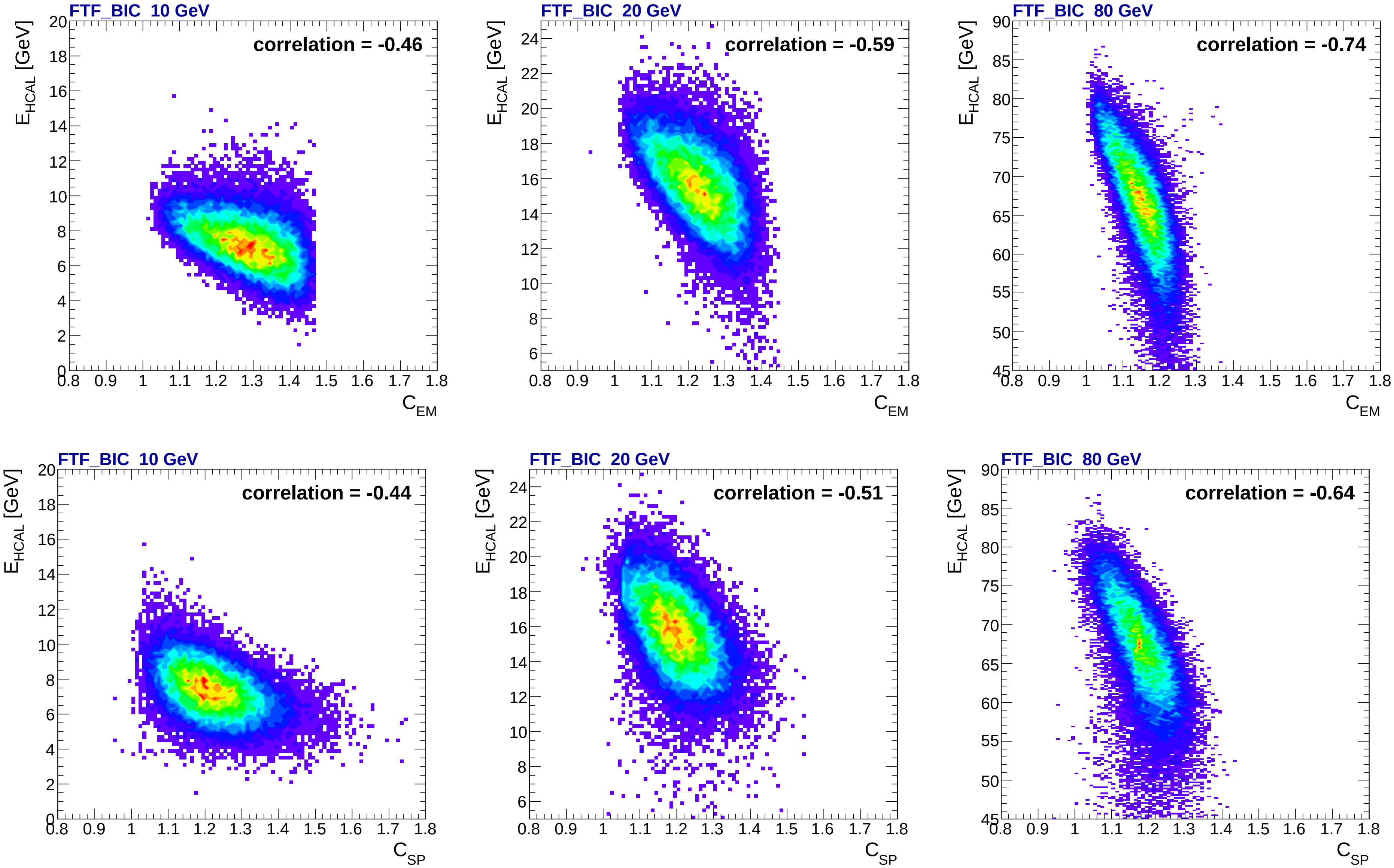
Coefficients for empirical factor extracted from data.

Correlation with E_{HCAL} for QGSP_BERT



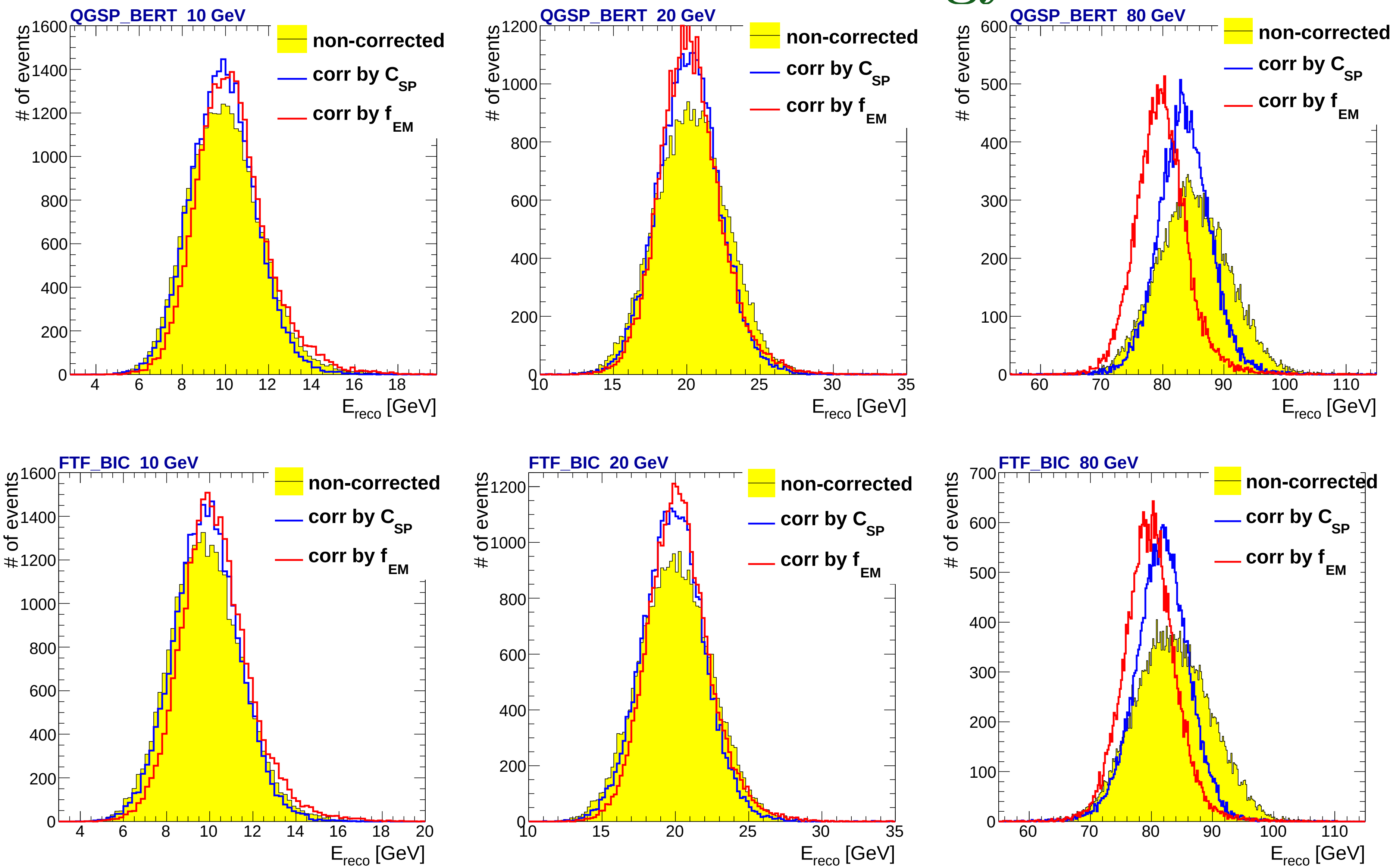
Coefficients for empirical factor extracted from data.

Correlation with E_{HCAL} for FTF_BIC



Coefficients for empirical factor extracted from data.

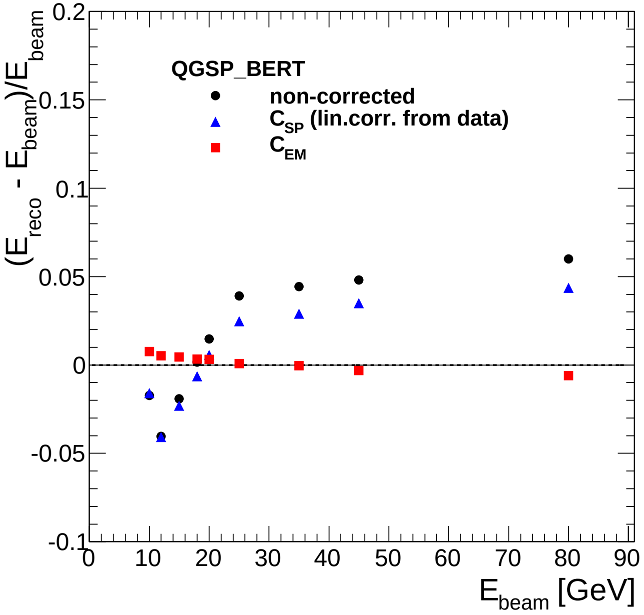
Reconstructed energy



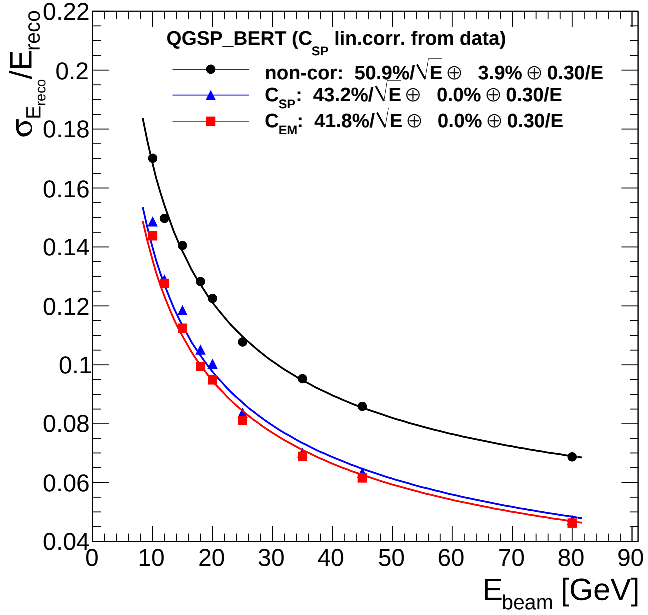
Coefficients for empirical factor extracted from data.

Energy resolution and linearity for QGSP_BERT

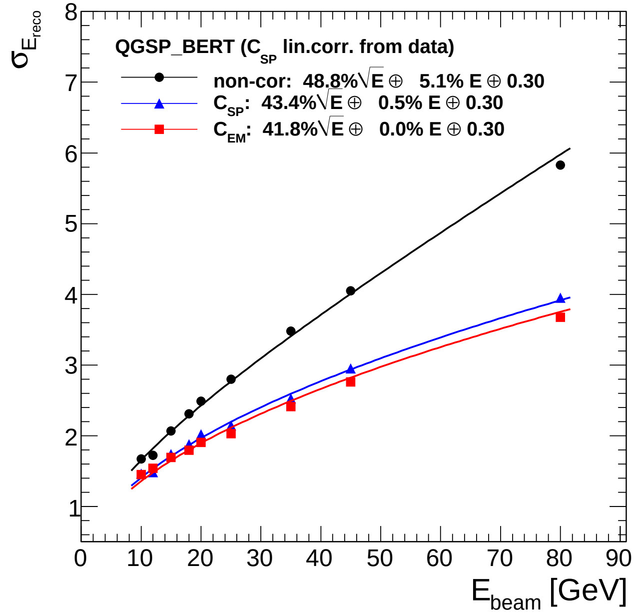
Linearity



Relative resolution



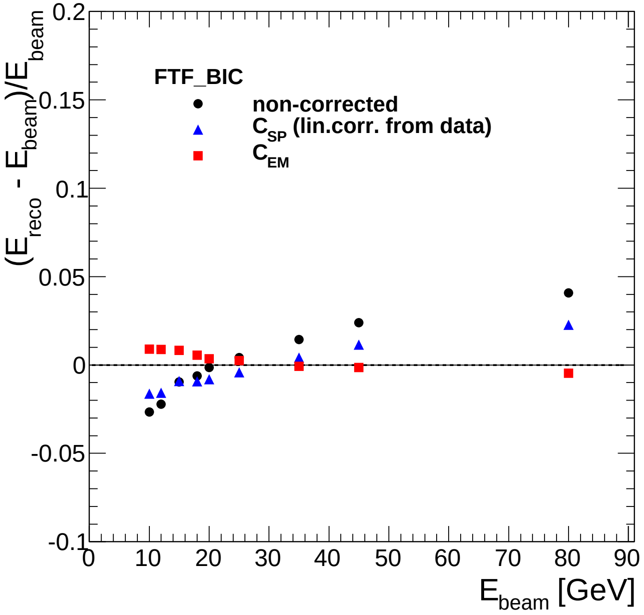
Absolute resolution



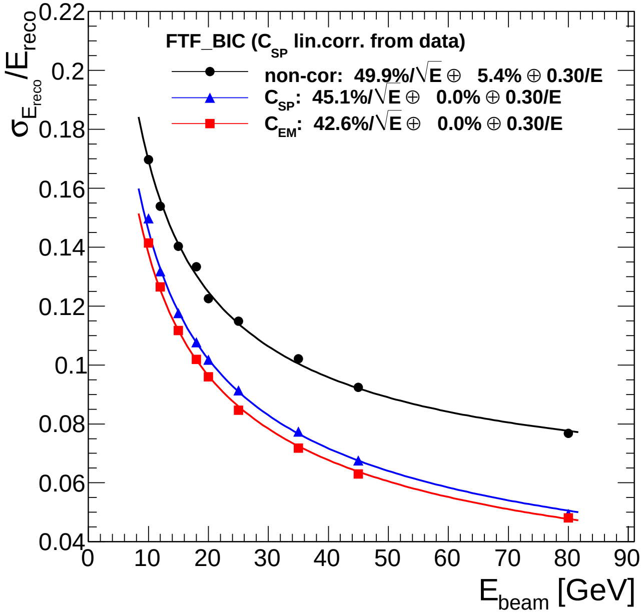
Coefficients for empirical factor extracted from data.

Energy resolution and linearity for FTF_BIC

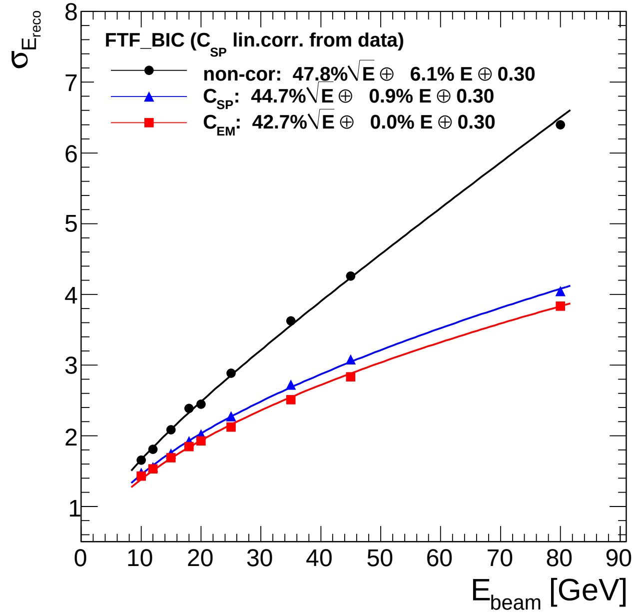
Linearity



Relative resolution



Absolute resolution



Coefficients for empirical factor extracted from data.

Energy dependence of correlation