Pions and protons in the CALICE Sc-Fe AHCAL: preliminary results

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Outline

Data and software

Data

CERN 2007 test beam data, positive hadrons @ 30-80 GeV,
10 runs from software compensation study (see CAN-035) + run 331337 (50 GeV)
Runs taken at the same energy were merged.

Software

calice_soft v04-05
GEANT 4.9.4p02, Mokka v07_06p02 (many thanks to Lars Weuste)

Event selection

HadronSelection processor (see CAN-035)

- muon separation
- shower starting layer
- primary track coordinates

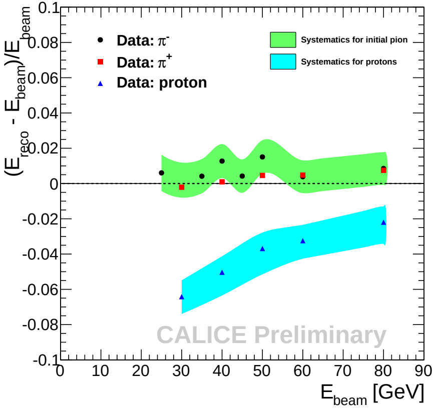
Events with shower start at the beginning of AHCAL were selected for the analysis.

Reconstructed energy: Data

$E_{\mathrm{reco}} = E^{\mathrm{track}}_{\mathrm{ECAL}} + \frac{e}{\pi} \cdot (E_{\mathrm{AHCAL}} + E_{\mathrm{TCMT}})$

the same procedure as described in CAN-035

$\frac{e}{\pi} = 1.19$ (averaged over 10-80 GeV)



π^+ and π^- are in good agreement

$1.07 > \frac{\pi}{\mathbf{p}} > 1.03$

Purity of proton sample, η_p

$\eta_\mathrm{p} = \frac{\text{number of real protons}}{\text{number of identified protons}}$

$\eta_\mathrm{p} = 1 - \frac{N_\pi}{N_\mathrm{p}} \frac{1-\epsilon}{\epsilon}$

N_π - number of identified pions

N_p - number of identified protons

ϵ - efficiency of the Čerenkov counter

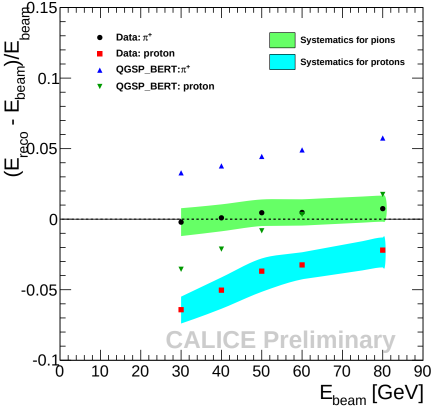
$\epsilon = \frac{\text{number of muons ON}}{\text{total number of muons}}$

Beam energy, GeV	η_p
30	0.95
40	0.84
50	0.78
60	0.88
80	0.78

η_p contribution to the systematic uncertainty of E_{reco} is $\leq 1\%$

Reconstructed energy: Data and MC (the same scaling)

QGSP_BERT

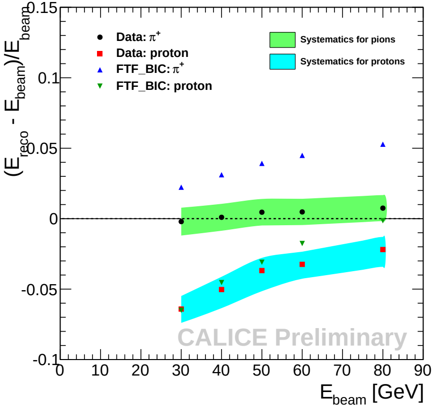


Pions: 3.5-5% overestimation

Protons: 3-4% overestimation

$1.07 > \frac{\pi}{p} > 1.04$ (as in data)

FTF_BIC

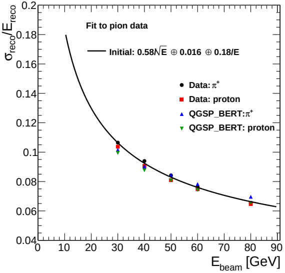


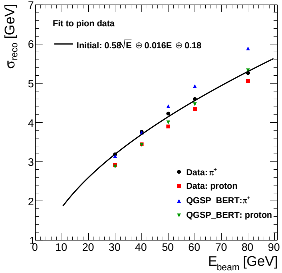
Pions: 2.5-4.5% overestimation

Protons: agreement within 2% (!)

$1.09 > \frac{\pi}{p} > 1.05$ (higher than in data)

Energy resolution: MC and Data



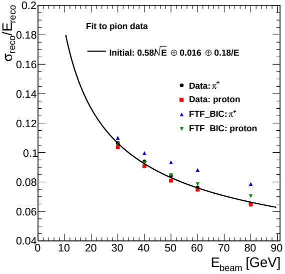


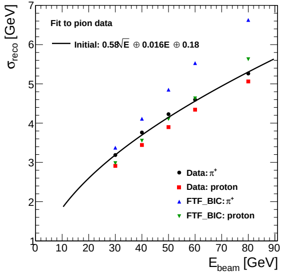
QGSP_BERT

Pion: $0.99 < \frac{\sigma_{\text{MC}}}{\sigma_{\text{Data}}} < 1.12$

Proton: $0.99 < \frac{\sigma_{\text{MC}}}{\sigma_{\text{Data}}} < 1.05$

Good agreement for relative resolution





FTF_BIC

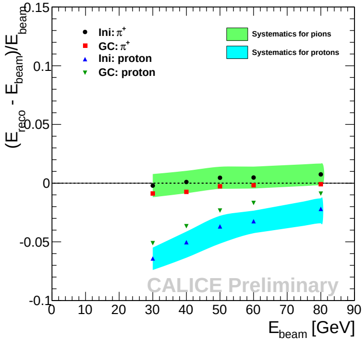
Pion: $1.06 < \frac{\sigma_{\text{MC}}}{\sigma_{\text{Data}}} < 1.26$

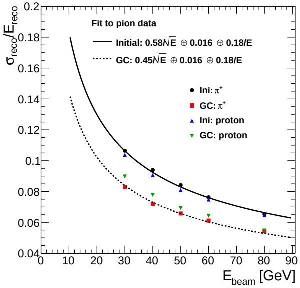
Proton: $1.02 < \frac{\sigma_{\text{MC}}}{\sigma_{\text{Data}}} < 1.11$

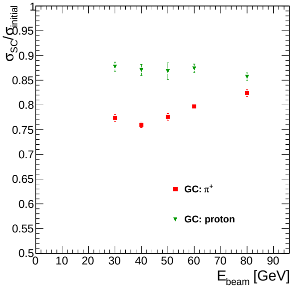
Overestimated relative resolution

Energy resolution: software compensation

Global software compensation





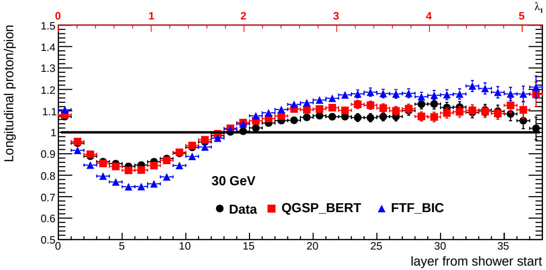


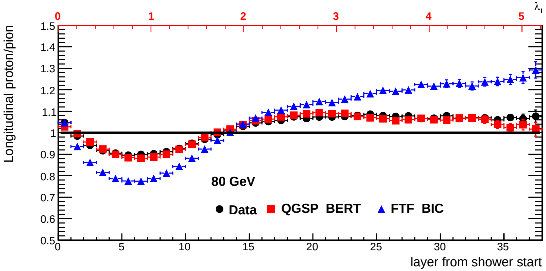
Response for protons improved by ∼2%

Improvement of resolution for protons is smaller than for pions in the same energy range.

Longitudinal profiles: proton/pion ratio

Ratio of longitudinal profiles proton/pion



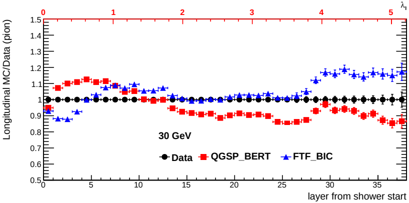


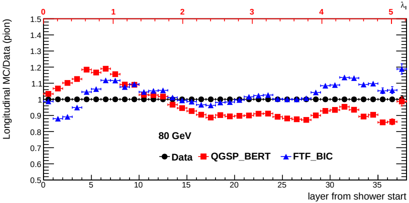
QGSP_BERT well reproduces the relative proton/pion behavior observed for data.

FTF_BIC predicts bigger difference between proton and pion energy density. This model overestimates pion energy density w.r.t. that of protons in the region of shower maximum and underestimates it in the shower tail.

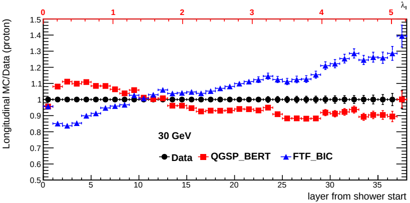
Longitudinal profiles: MC/Data

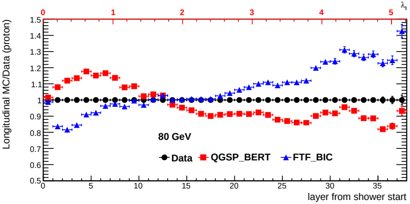
π^+





Proton





For pions, profile predicted by FTF_BIC is shifted but better follows data.

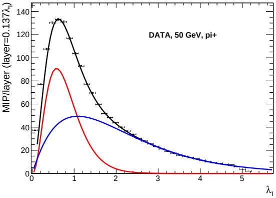
For protons, QGSP_BERT and FTF_BIC show different behavior w.r.t. data.

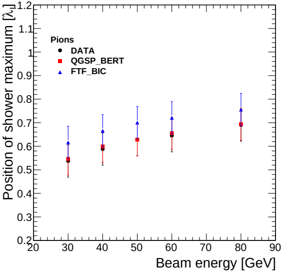
Longitudinal profiles: position of shower maximum L_{max}

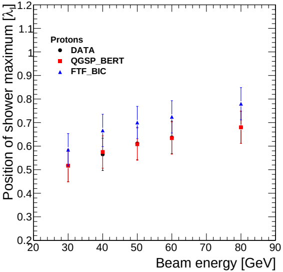
To find L_{max}, fit a longitudinal profile with

$$\frac{dE}{dz} = E_0 \left(f \left(\frac{z}{\lambda_1}\right)^{\alpha_1} \frac{e^{-z/\lambda_1}}{\lambda_1 \Gamma(\alpha_1)} + (1-f) \left(\frac{z}{\lambda_2}\right)^{\alpha_2} \frac{e^{-z/\lambda_2}}{\lambda_2 \Gamma(\alpha_2)} \right),$$

where E_0 is an integral under longitudinal curve,
$f, \alpha_1, \lambda_1, \alpha_2, \lambda_2$ are free parameters







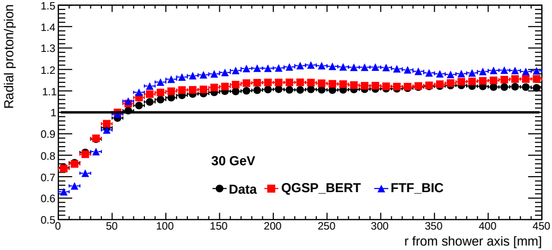
QGSP_BERT reproduces a shower maximum position observed for data within 2% for pions and within 1% for protons.

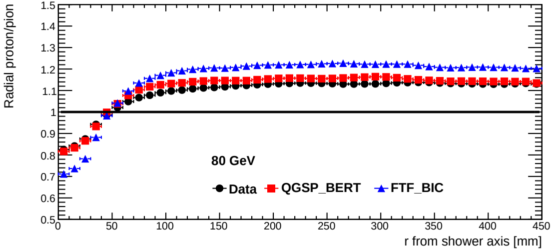
FTF_BIC overestimates L_{max} by ∼15%.

Error bars = HCAL layer thickness $\approx 0.14\lambda_I^{eff}$

Radial profiles: proton/pion ratio

Ratio of radial profiles proton/pion



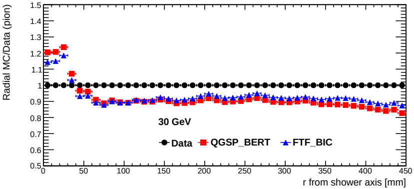


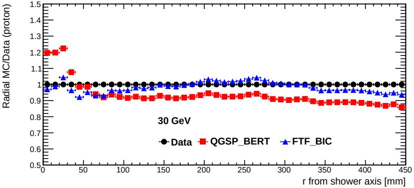
QGSP_BERT well reproduces the relative proton/pion behavior observed for data.

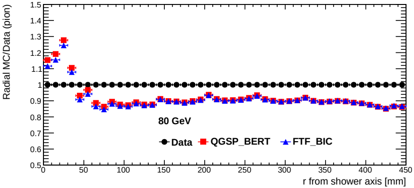
FTF_BIC predicts bigger difference between proton and pion energy density. This model overestimates pion energy density w.r.t. that of protons in the core region.

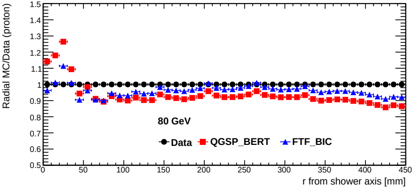
Radial profiles: MC/Data

π^+	**Proton**





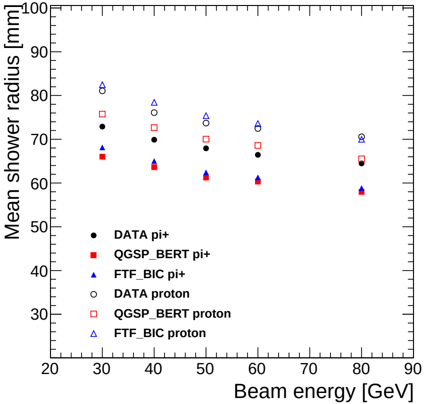




For pions, both models overestimate energy density in the shower core region.

For protons, FTF_BIC follows data much better than QGSP_BERT.

Mean shower radius



Shower radius $r_s = \frac{\sum_{hit} r_{hit} e_{hit}}{\sum_{hit} e_{hit}}$, is a sum of hit distances r_{hit} to shower axis weighted by hit energy e_{hit}.

Mean shower radius R_s is a mean of event-by-event distribution of r_s.

Mean shower radius:

- decreases with energy by $\sim$12% in the studied energy range (is $\sim 3X_0^{eff}$ on average)
- for data, R_s^{proton} is by $\sim$10% larger than R_s^{pion}
- R_s^{pion} is underestimated by $\sim$8% by both QGSP_BERT and FTF_BIC
- R_s^{proton} predicted by FTF_BIC agrees with data within 2%

Conclusion

Pions and protons in data

- $\frac{\pi}{p}$ decreases from 1.07 (at 30 GeV) to 1.03 (at 80 GeV)
- σ_{reco} for protons better by ~5-10%
- shower maximum positions coincide within 2%
- mean shower radius for protons is larger by ~10%

MC to data comparison

QGSP_BERT

- $\frac{\pi}{p}$ agrees with data
- E_{reco} overestimated by ~3-5%
- $\frac{\sigma_{reco}}{E_{reco}}$ agrees with data
- σ_{reco} overestimated up to 12%
- L_{max} agrees with data within 1-2%
- R_s underestimated by ~8%

Better prediction for pions

FTF_BIC

- $\frac{\pi}{p}$ overestimated
- E_{reco} for protons within 2%
- $\frac{\sigma_{reco}}{E_{reco}}$ overestimated
- σ_{reco} overestimated up to 25%
- L_{max} overestimated by ~15%
- R_s for protons within 2%

Better prediction for protons

Backup slides

Nuclear interaction length

Estimates from found shower starting layer

π^+

Beam energy, GeV	λ_π, mm
Data	
30	264 ± 5
40	266 ± 5
50	268 ± 5
60	272 ± 5
80	272 ± 5
QGSP_BERT	
30	272 ± 5
40	271 ± 5
50	271 ± 5
60	273 ± 5
80	277 ± 5

Proton

Beam energy, GeV	λ_I, mm
Data	
30	225 ± 4
40	216 ± 4
50	218 ± 5
60	217 ± 4
80	221 ± 4
QGSP_BERT	
30	221 ± 4
40	219 ± 4
50	216 ± 4
60	218 ± 4
80	218 ± 4

Reference values

GEANT4: $\lambda_\pi^{true}(80\text{ GeV}) = 259$ mm
(CAN-026: estimates from true shower start, averaged over physics lists)

PDG data: $\lambda_I^{eff} = 231$ mm
(from Angela's description of the Sc-Fe AHCAL geometry for Mokka)