Positive hadrons in the CALICE Sc-Fe AHCAL

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Outline

Data samples and simulations

Test beam data

CERN 2007 runs, positive hadrons @ 30-80 GeV (ECAL+HCAL+TCMT)
FNAL 2009 runs, positive hadrons @ 10 and 15 GeV (HCAL+TCMT)
Reconstruction with calice_soft v04-01

Simulations (thanks to Lars Weuste)

GEANT4.9.4p03, Mokka v07_07p04
Physics lists: QGSP_BERT, QBBC, CHIPS, FTFP_BERT, FTF_BIC
calice_soft v04-05, 816 keV/MIP, 0.1 light crosstalk for AHCAL

Sample cleaning

- HadronSelection processor is used to reject muons, multiparticle and empty events (described in CAN-035).
- Additional cuts were applied to reject positrons and multiparticle events from FNAL runs (see backup slides).
- The same selection procedure is applied to MC and data samples.

Event selection

Proton separation

Selection of protons from data samples was done with Čerenkov. The purity of proton sample η_{p} is estimated using independent muon identification procedure (see CAN-035).

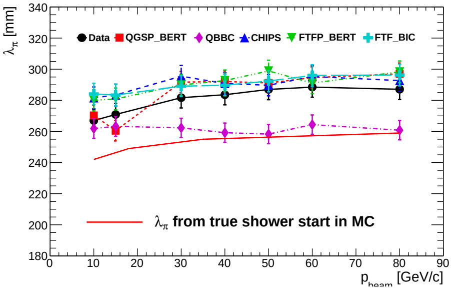
p_{beam}, GeV/c	10	15	30	40	50	60	80
η_{p}	0.64	0.72	0.95	0.84	0.78	0.88	0.78

Selection by shower start

Shower starting layer and primary track were identified using the procedure implemented in the PrimaryTrackFinder processor (see CAN-026 and CAN-035).

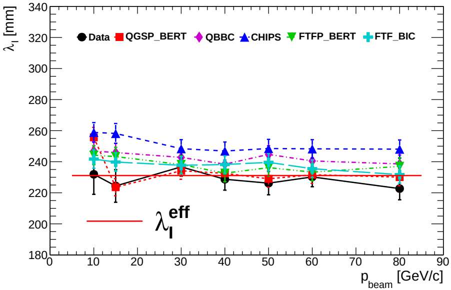
For shower parameters study, events are selected with shower start in the 3$^{\mathrm{d}}$ and 4$^{\mathrm{th}}$ AHCAL layers. The 2 first AHCAL layers are excluded due to FNAL samples (w/o ECAL) purity requirements.

Nuclear interaction length (from found shower start)



Pions

For both data and MC (except for QBBC physics list), the found λ_π is $\sim$10% bigger than the $\lambda_\pi^{\rm true}$ (solid red line, CAN-026).



Protons

For **data** and **QGSP_BERT** (except for 10 GeV), the found $\lambda_{\rm I}$ is in good agreement with calculated $\lambda_{\rm I}^{\rm eff} = 231.1 mm$. **CHIPS** overestimates $\lambda_{\rm I}$ by $\sim$10%.

$$\frac{<\boldsymbol{\lambda_\pi}>}{<\boldsymbol{\lambda_{\rm I}}>} \approx \mathbf{1.23}$$

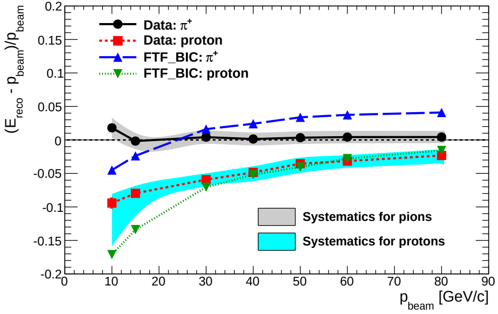
Reconstructed energy and calorimeter response

Reconstructed energy

For each event: $\mathbf{E_{event} = (E^{track}_{ECAL})_{MIP\ scale} + \frac{e}{\pi} \cdot (E_{AHCAL} + E_{TCMT})_{EM\ scale}}$

$\frac{\mathbf{e}}{\boldsymbol{\pi}} = 1.19$

$\mathbf{E_{reco}}$ and $\boldsymbol{\sigma}_{\mathbf{reco}}$ are obtained from Gaussian fit in $\pm\mathbf{2}\boldsymbol{\sigma}$ interval.



Pion response is underestimated below 20 GeV and overestimated above.

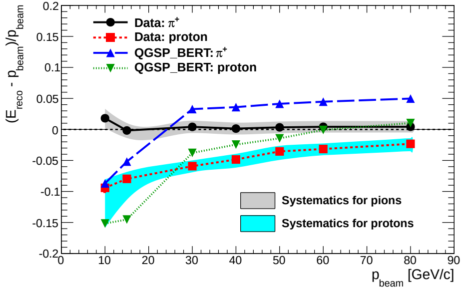
FTF_BIC physics list gives a very good prediction for proton response above 30 GeV.

Calorimeter response: available energy

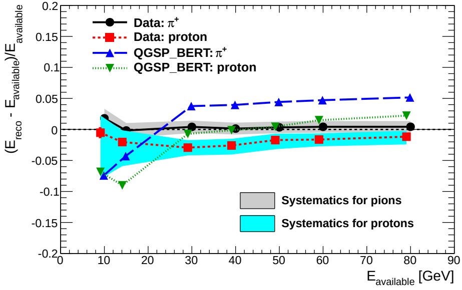
Available energy

$$E^{\mathbf{proton}}_{\mathbf{available}} = \sqrt{P^2_{\mathbf{beam}} + m^2_{\mathbf{proton}}} - m_{\mathbf{proton}}$$

vs. $P_{\mathbf{beam}}$



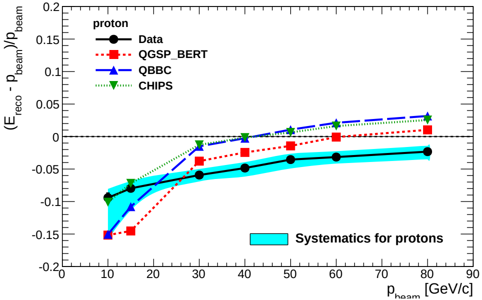
vs. $E_{\mathbf{available}}$



Pion response is underestimated by QGSP_BERT physics list below 20 GeV and overestimated above.

If available energy is considered the difference between pion and proton response still remains at the level of several percent (up to 4% around 30 GeV).

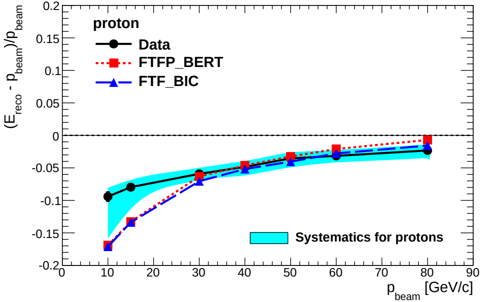
Calorimeter response for protons: data and MC



QGSP_BERT: underestimates proton response below 20 GeV and overestimates it by ∼3% above 30 GeV

QBBC: the overestimation is ∼6% above 30 GeV

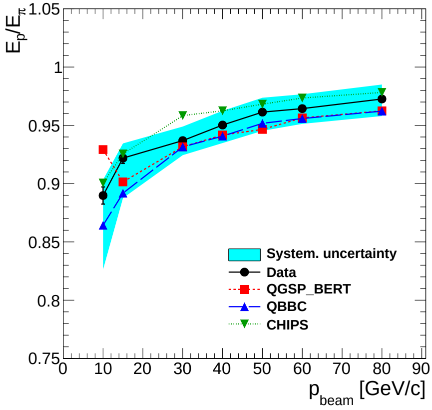
CHIPS: in agreement below 20 GeV and overestimates by ∼6% above 30 GeV

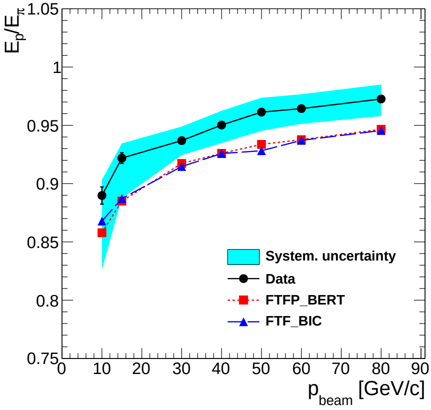


FTFP_BERT and **FTF_BIC** are in good agreement above 30 GeV and underestimate proton response by several percent below 20 GeV.

p/π ratio: data and MC

$E_{\rm p}/E_\pi$ is a ratio of mean reconstructed energies.



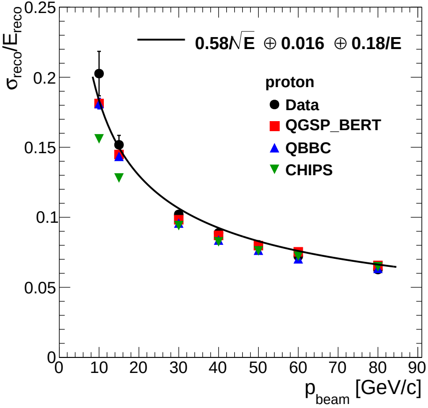


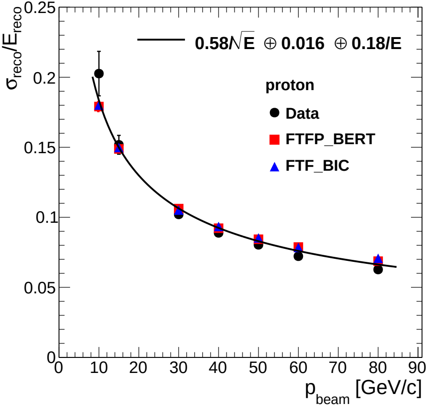
QGSP_BERT, QBBC and CHIPS physics lists reproduce p/π ratio within uncertainties.

FTFP_BERT and FTF_BIC physics lists overestimate pion response w.r.t. proton one.

Fractional resolution for protons

The black curves correspond to the estimated AHCAL resolution for pions based on $\pi^{\pm}$ samples from CERN 2007 test beam data (see CAN-035).



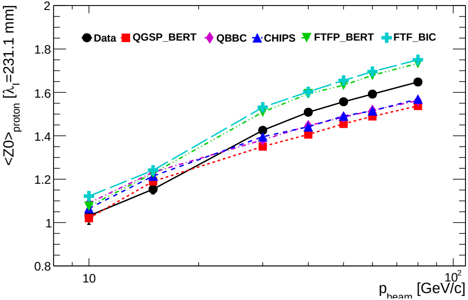


For protons, **data**, **QGSP_BERT** and **QBBC** show similar resolution and agreement with pion data, **CHIPS** predicts better resolution below 40 GeV.

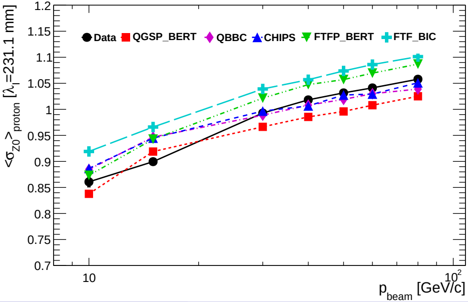
FTFP_BERT and **FTF_BIC** are in good agreement with data and with pion estimates from data.

Longitudinal shower development: protons

$< \mathbf{Z0} >$



$< \boldsymbol{\sigma_{Z0}} >$



Center of gravity in longitudinal direction $Z0$ is calculated w.r.t. shower start in each event:

$$\mathbf{Z0} = \frac{\sum \mathbf{e_i \cdot z_i}}{\sum \mathbf{e_i}}, \text{ where}$$

$\mathbf{e_i}$ is a hit energy,
$\mathbf{z_i}$ is a distance from hit layer to shower start layer

The r.m.s. of center of gravity

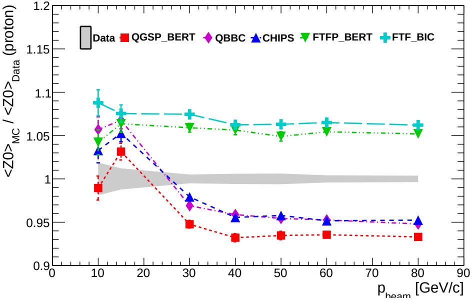
$$\boldsymbol{\sigma_{Z0}} = \sqrt{\frac{\sum \mathbf{e_i \cdot (z_i - <Z0>)^2}}{\sum \mathbf{e_i}}}$$

Mean values $< \mathbf{Z0} >$ and $< \boldsymbol{\sigma_{Z0}} >$ are shown in units of $\boldsymbol{\lambda_I^{eff} = 231.1}$ mm

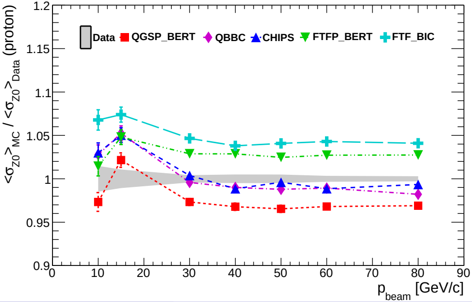
$< \mathbf{Z0} >$ increases as **log(E)**.

Longitudinal shower development: MC/Data, protons

$$\frac{<Z0>_{MC}}{<Z0>_{Data}}$$



$$\frac{<\sigma_{Z0}>_{MC}}{<\sigma_{Z0}>_{Data}}$$



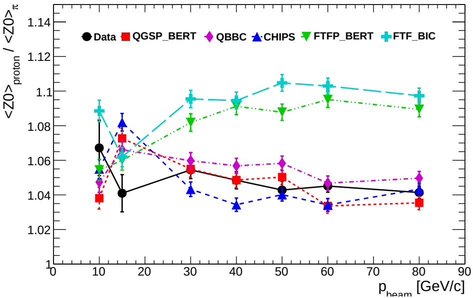
Above 20 GeV, shorter proton showers than observed in data are predicted by **QGSP_BERT** (by ∼6%), **QBBC** and **CHIPS** (by ∼5%).

QBBC and **CHIPS** give good predictions of $<\sigma_{Z0}>$ above 30 GeV.

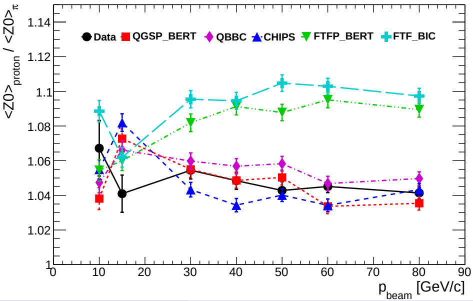
FTF_BIC and **FTFP_BERT** overestimate both mean shower depth $<Z0>$ (by ∼5-7%) and its fluctuations $<\sigma_{Z0}>$ (by ∼4-6%).

Longitudinal shower development: proton / pion

$$\frac{<Z0>_p}{<Z0>_\pi}$$



$$\frac{<\sigma_{Z0}>_p}{<\sigma_{Z0}>_\pi}$$



Data: proton-induced showers are by 4-6% longer than pion showers and with higher fluctuations.

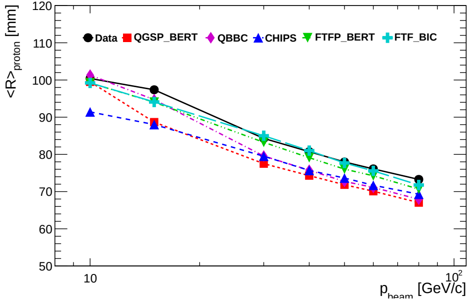
QGSP_BERT is in good agreement with data.

QBBC and CHIPS are not far from data.

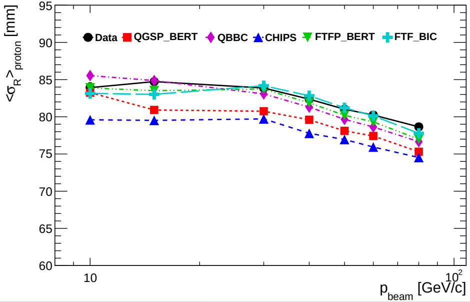
FTFP_BERT and FTF_BIC predict higher differences between pions and protons above 20 GeV for both mean shower depth $< Z0 >$ (up to 10%) and its fluctuations $< \sigma_{Z0} >$ (up to 12%)

Radial shower development: protons

$< \mathbf{R} >$



$< \sigma_\mathbf{R} >$



Shower radius **R** is calculated w.r.t. shower axis in each event:

$$\mathbf{R} = \frac{\sum \mathbf{e_i r_i}}{\sum \mathbf{e_i}}, \text{ where}$$

$\mathbf{e_i}$ is a hit energy,
$\mathbf{r_i} = \sqrt{(\mathbf{x_i} - \mathbf{x_0})^2 + (\mathbf{y_i} - \mathbf{y_0})^2}$
is a distance from hit to shower axis, $\mathbf{x_i}$ and $\mathbf{y_i}$ are hit coordinates, $\mathbf{x_0}$ and $\mathbf{y_0}$ are coordinates of shower axis obtained from track or from shower CoG.

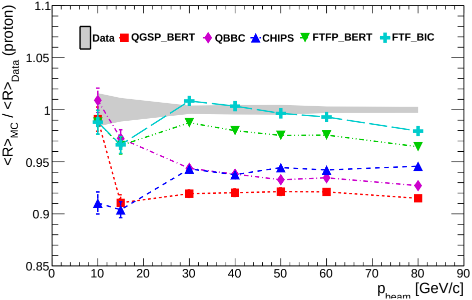
The r.m.s. of shower radius

$$\boldsymbol{\sigma}_\mathbf{R} = \sqrt{\frac{\sum \mathbf{e_i}(\mathbf{r_i} - <\mathbf{R}>)^2}{\sum \mathbf{e_i}}}$$

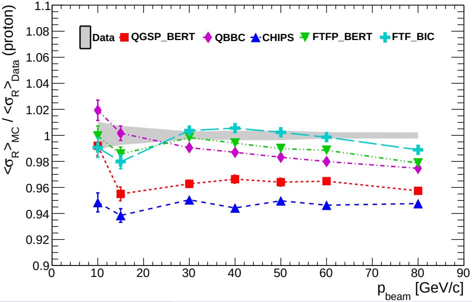
Mean shower radius decreases as **log(E)**.

Radial shower development: MC/Data, protons

$\frac{<\mathbf{R}>_{\mathbf{MC}}}{<\mathbf{R}>_{\mathbf{Data}}}$



$\frac{<\sigma_{\mathbf{R}}>_{\mathbf{MC}}}{<\sigma_{\mathbf{R}}>_{\mathbf{Data}}}$



FTF_BIC gives a perfect prediction of $<\sigma_R>$ in all energy range and of $<R>$ in the range 30-60 GeV.

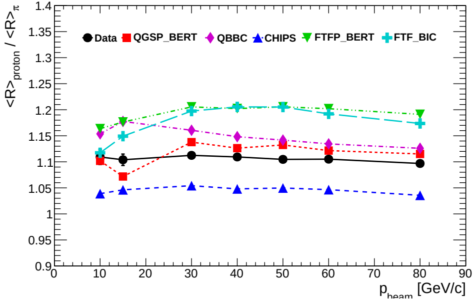
FTFP_BERT is in agreement with data within 3-4% for $<R>$ and within 2% for $<\sigma_R>$.

QGSP_BERT and **QBBC** underestimate mean shower radius by ∼8% except for 10 GeV.

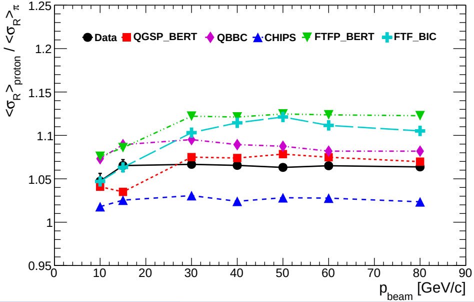
CHIPS underestimates mean shower radius by ∼6% and even up to 10% below 20 GeV.

Radial shower development: proton / pion

$$\frac{<R>_p}{<R>_\pi}$$



$$\frac{<\sigma_R>_p}{<\sigma_R>_\pi}$$



Data: proton-induced showers are by ∼10% wider than pion ones. No energy dependence of this difference is observed in the studied energy range.

QGSP_BERT is in good agreement with data.

CHIPS predicts twice smaller difference between pions and protons for both mean shower radius and its fluctuations.

FTFP_BERT and **FTF_BIC** predict up to 20% difference between mean radii of pion and proton showers above 20 GeV.

Summary

Pions and protons in test beam data

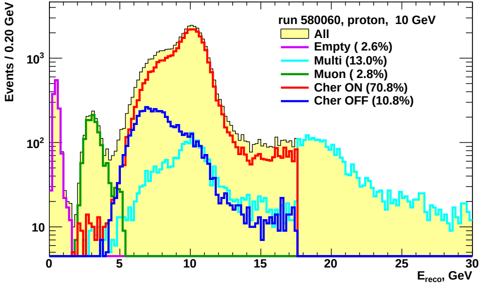
- The estimated nuclear interaction length for pions in the Sc-Fe AHCAL is ∼20% higher than for protons.
- Response for protons is lower than that of pions. The maximum difference between pion and proton response which cannot be explained by "available" energy is ∼4% at 20-40 GeV.
- Proton showers are by ∼5% longer and by ∼10% wider than pion showers.
- Differences between means of pion and proton shower parameters are smaller than event-by-event fluctuations of these parameters.

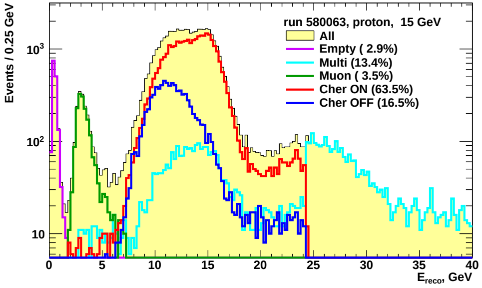
Proton test beam data and simulations

- Physics lists with Fritiof models give a very good prediction of proton response and mean shower radius (the best is FTF_BIC physics list), though they overestimate mean shower depth (longitudinal center of gravity of proton showers).
- QGSP_BERT, QBBC and CHIPS overestimate proton response (by ∼4%, ∼6% and ∼6% respectively) and underestimate both depth and width of proton showers above 20 GeV.

Backup slides

Samples from FNAL runs





Event selection by HadronSelection processor

Rejected:

- empty
- multiparticle (including both cher ON)
- muons

Remained:

- positron admixture
- multiparticle

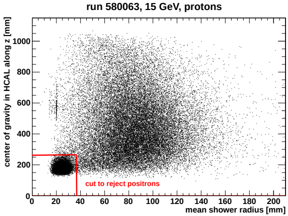
Identified:

- shower starting layer
- primary track or CoG

Additional cuts for FNAL runs

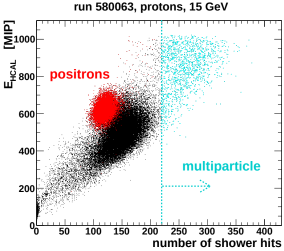
Cut to remove positrons:

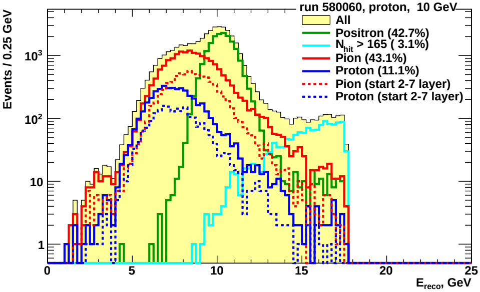
$R_{shower} < 37$ mm AND $Z_{cog} < 260$ mm

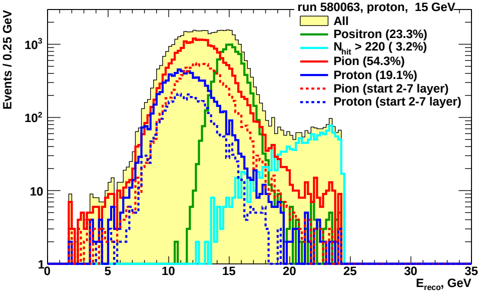


Cut to remove multiparticle:

$N_{hit} < 220$ (15 GeV) or 165 (10 GeV)

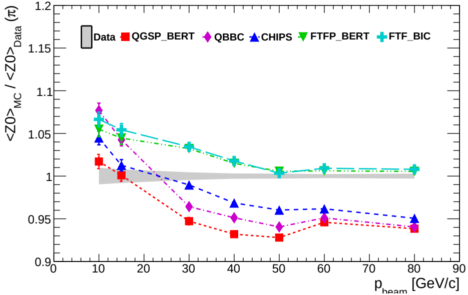




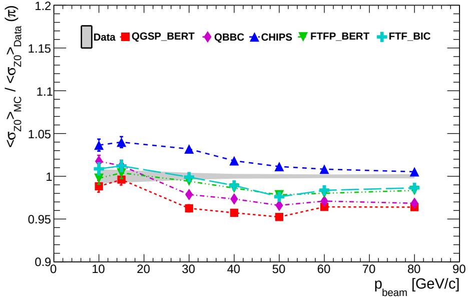


Longitudinal shower development: MC/Data, pions

$$\frac{<Z0>_{\mathrm{MC}}}{<Z0>_{\mathrm{Data}}}$$

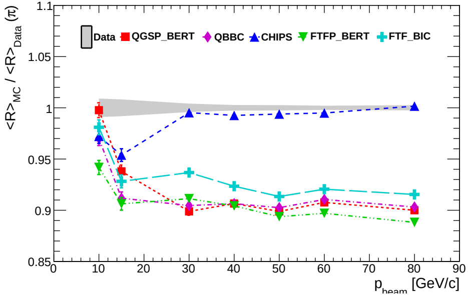


$$\frac{<\sigma_{Z0}>_{\mathrm{MC}}}{<\sigma_{Z0}>_{\mathrm{Data}}}$$



Radial shower development: MC/Data, pions

$$\frac{<R>_{\mathrm{MC}}}{<R>_{\mathrm{Data}}}$$



$$\frac{<\sigma_R>_{\mathrm{MC}}}{<\sigma_R>_{\mathrm{Data}}}$$