π^+ and proton shower profiles in CALICE AHCAL

Marina Chadeeva, ITEP

CALICE week at IPN Lyon, September 2009

Data and Event Selection

Data: **CERN 2007 test beam with complete CALICE Setup (ECAL+HCAL+TCMT)**
positive hadrons of 30, 40, 50, and 80 GeV
331298, 331340, 331338 331339, 331335, 331337, 331280, 331324

Selections: **exclude muon and trash events (see V. Morgunov talk on CALICE meeting in Dec 2008)**
shower start in layers 1-5 of HCAL and track in ECAL

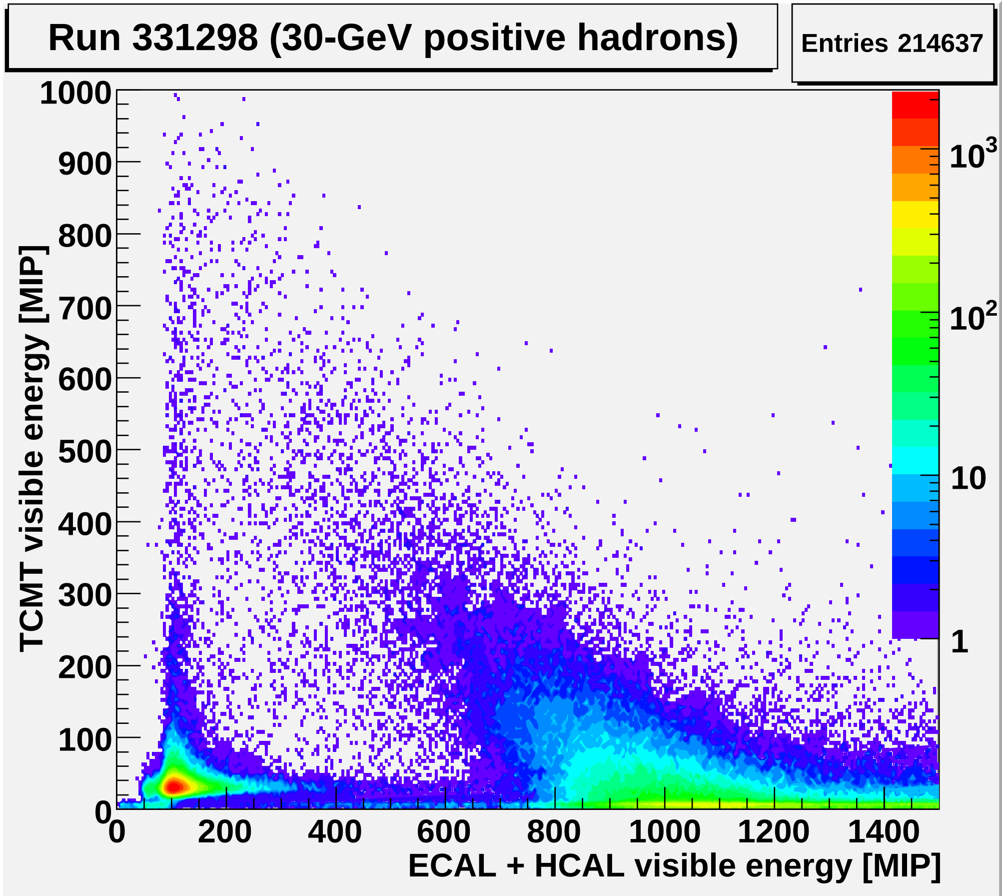
MC simulation: **GEANT4 9.2 (FTFP BERT, QGSP BERT and QGSC BERT)**
(by V.L. Morgunov) **digitization + noise from pedestal run (CERN2007 330237)**

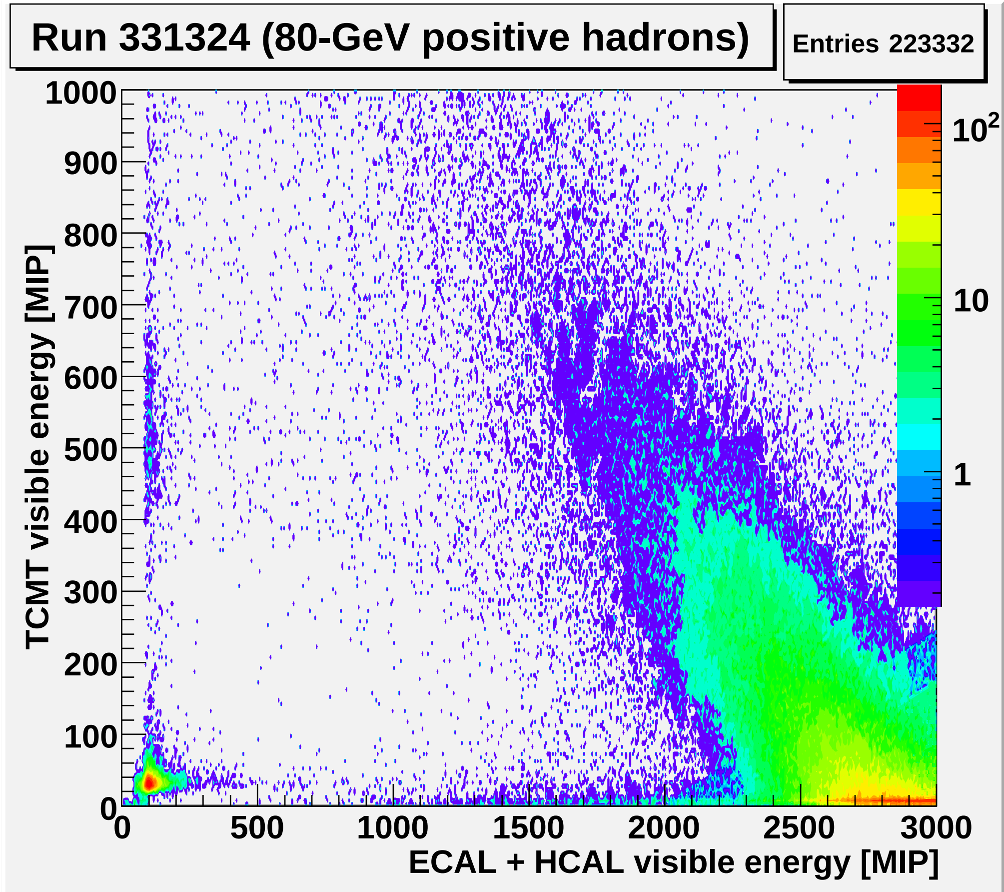
π^+ **or proton**: **by Čerenkov trigger data stored in data files**
purity of proton sample is from $\sim$95% for 30 GeV down to $\sim$75% for 80-GeV runs
(see V.L. Morgunov's talk on CALICE meeting in December 2008)

Run statistics

Run number	Beam energy [GeV]	Number of events				Proton sample purity
		Total	Muon	After selections		
				π^+	p	
331298	30	214637	62829	28319 (61%)	17889 (39%)	95%
331340	30	215560	62578	28237 (61%)	18186 (39%)	95%
331338	40	224082	9940	57500 (83%)	11695 (17%)	83%
331339	40	225511	9986	55552 (83%)	11619 (17%)	85%
331335	50	227387	9618	58403 (85%)	10550 (15%)	78%
331337	50	224884	9362	57787 (85%)	10359 (15%)	80%
331280	80	264645	7954	52861 (69%)	24126 (31%)	75%
331324	80	223332	5746	44676 (69%)	20415 (31%)	83%

Selections: muon identification

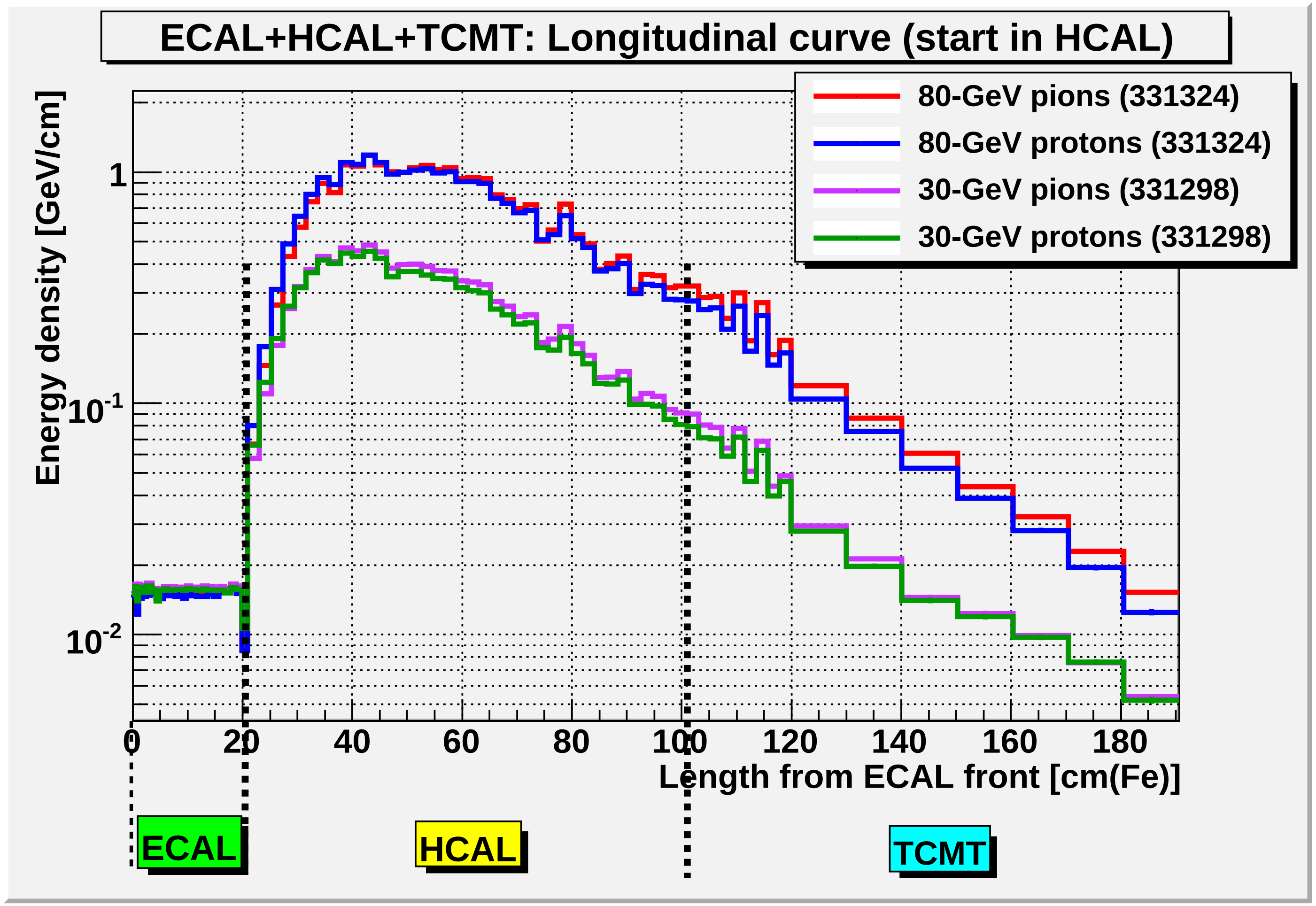




Muon events correspond to the bottom left spot on the shown histograms

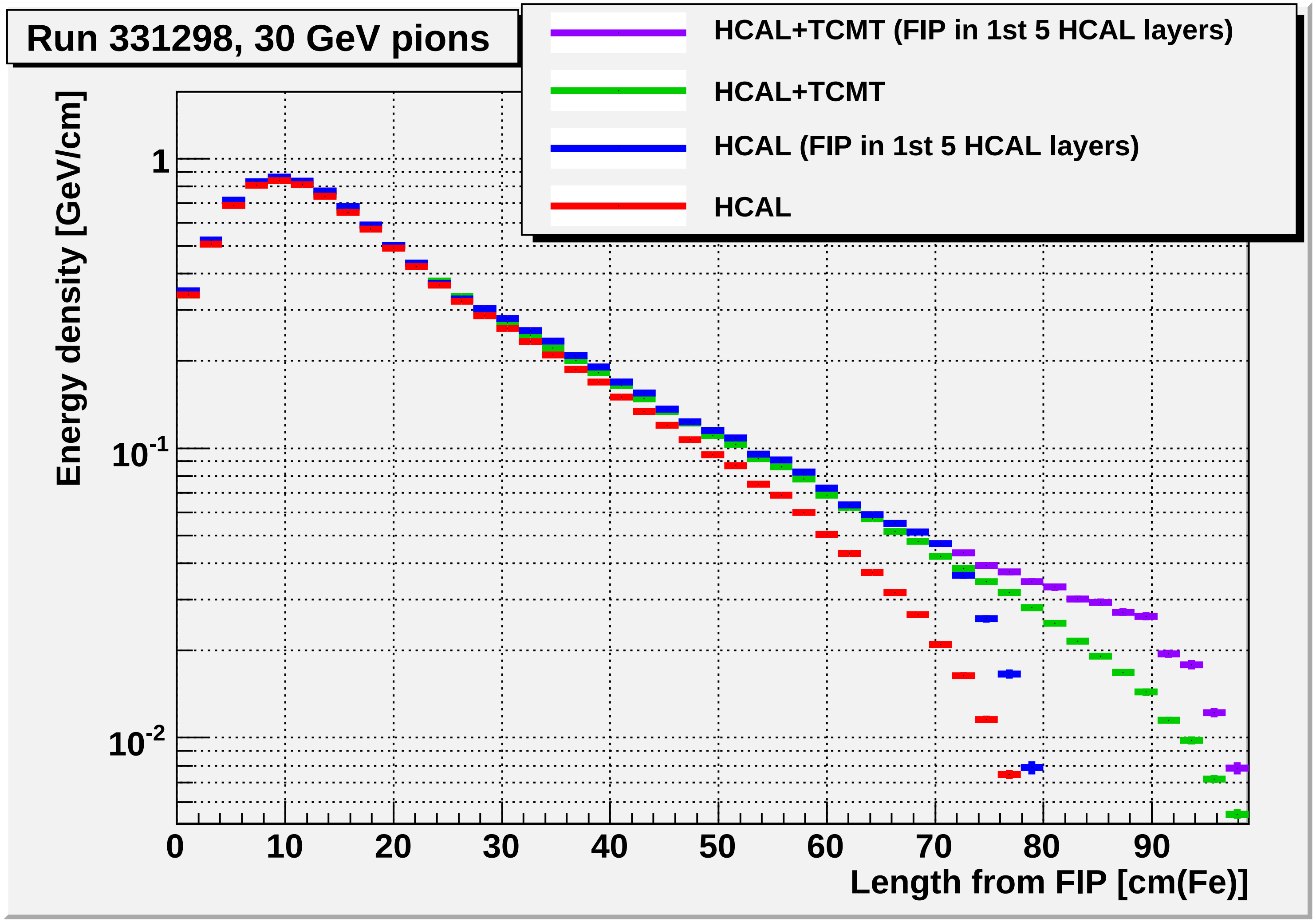
(see V.L. Morgunov talk on CALICE meeting in Dec 2008).

Selections: track in ECAL



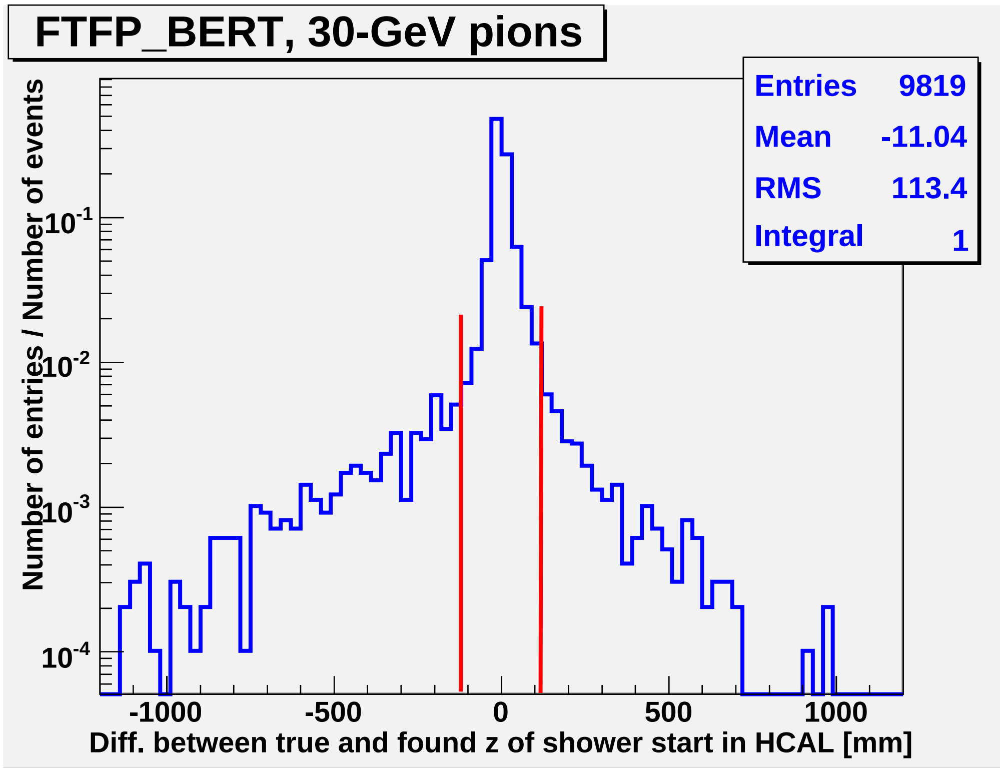
On longitudinal profiles plotted from ECAL front it is seen that selected events consist of track in ECAL and shower starting in HCAL.

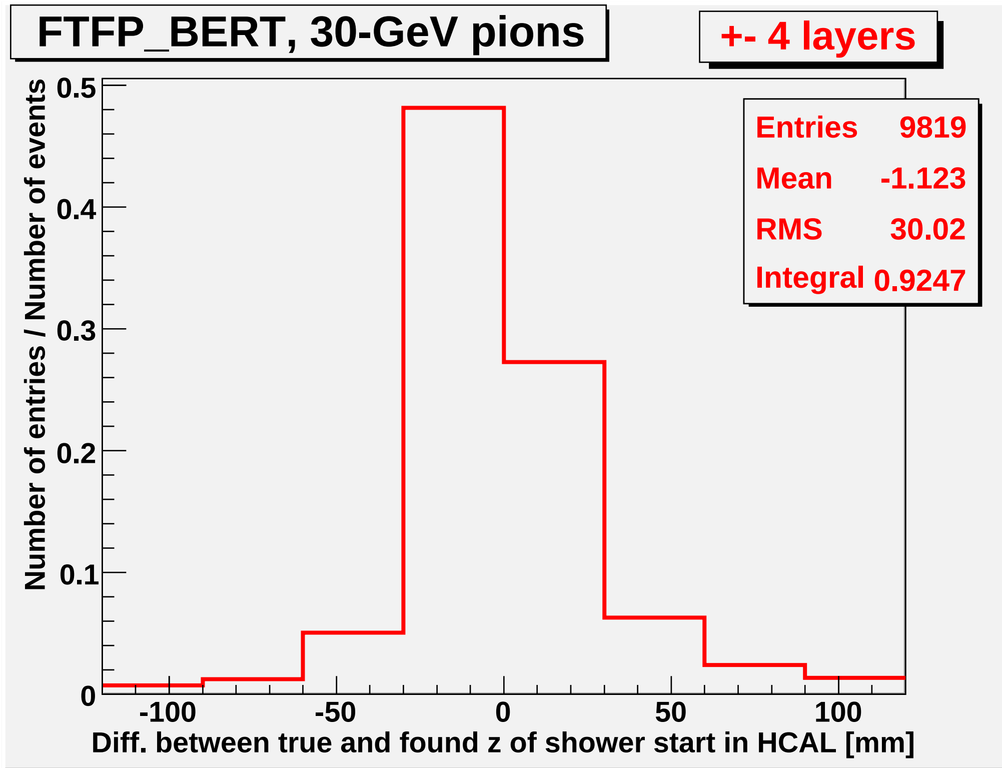
Selections: first 5 layers of HCAL



The selection of events that start in first 5 layers of HCAL (or including TCMT data) changes the shape of longitudinal curve. This helps to diminish the impact of leakage on longitudinal profile.

Estimation of interaction point finding accuracy



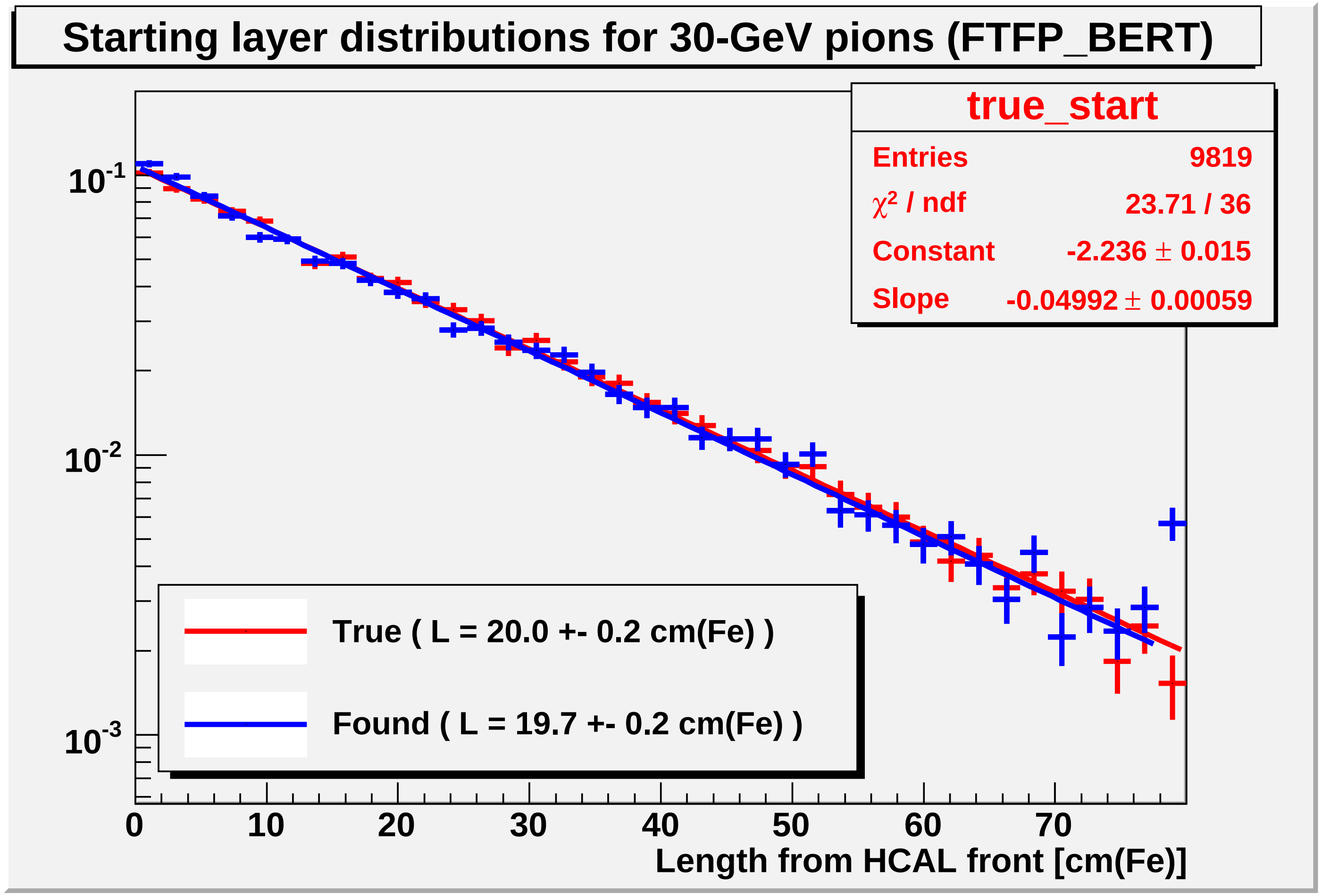


100% of events

92% of events (± 4 layers)

86% of events fall within ± 2 layers, about 75% - within ± 1 layer from true interaction point.

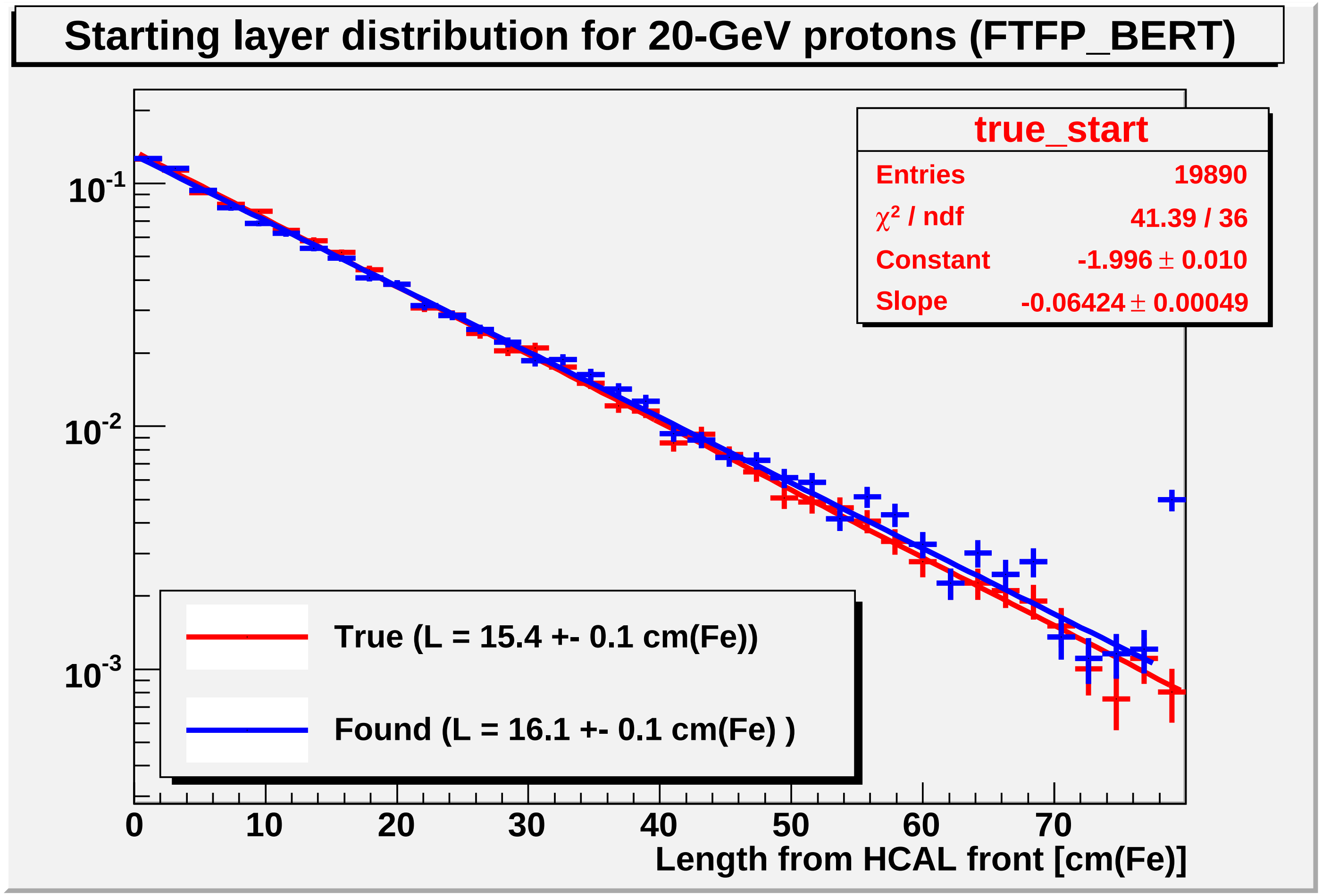
Comparison of estimated nuclear interaction lengths for pions



The last point includes all non-found starting points and is not included in the fit.

The slopes of true and found starting point distributions are in good coincidence.

Comparison of estimated nuclear interaction lengths for protons



For protons the percentage of non-found starting points is higher than for pions that can indicate on possibly higher number of track-like events for protons. The coincidence is worse than for pions.

MC digitization procedure

Conversion of MC signal from MeV to MIP $\longrightarrow e_{MIP}$

$\Downarrow$

Generation of random number of photoelectrons n_{pe}
from Poisson distribution with $\langle n_{pe} \rangle = e_{MIP} \cdot N_{pe}$ **(**$N_{pe} = 11$**)**

$\Downarrow$

Calculation of number of pixels n_{pixel} **taking in account saturation and cross talk** C**:**
$n_{pixel} = N_{total} \cdot \frac{(1-x)}{(1-C \cdot x)}$ **where** $x = \exp(-n_{pe}/N_{total})$, $C = 0.25$, $N_{total} = 1156$

$\Downarrow$

Generation of random signal n^{new}_{pixel} **from Gaussian distribution** $Gaus(\langle n_{pixel} \rangle, \sigma_G)$
where $\sigma_G = 3$ **pixels (**≈ 0.2 **MIP)**

$\Downarrow$

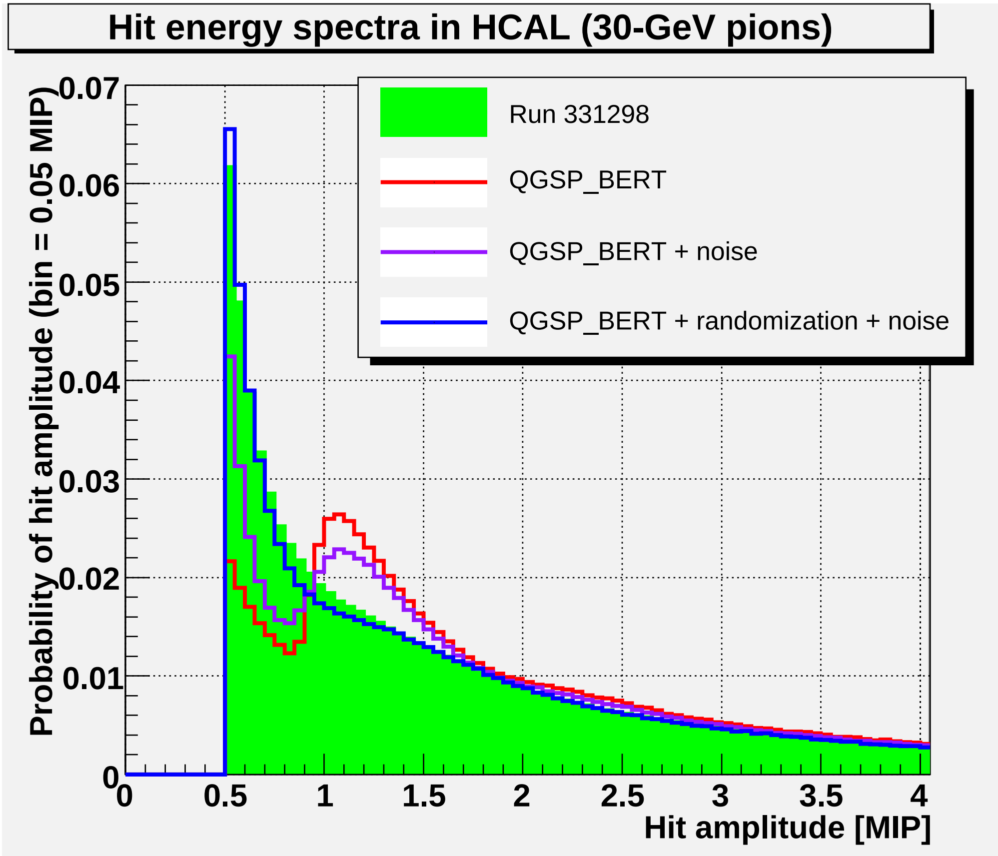
Recalculation from pixel to MIP: $e^{new}_{MIP} = \frac{N_{total}}{N_{pe}} \cdot \ln(\frac{N_{total} - C \cdot n^{new}_{pixel}}{N_{total} - n^{new}_{pixel}})$

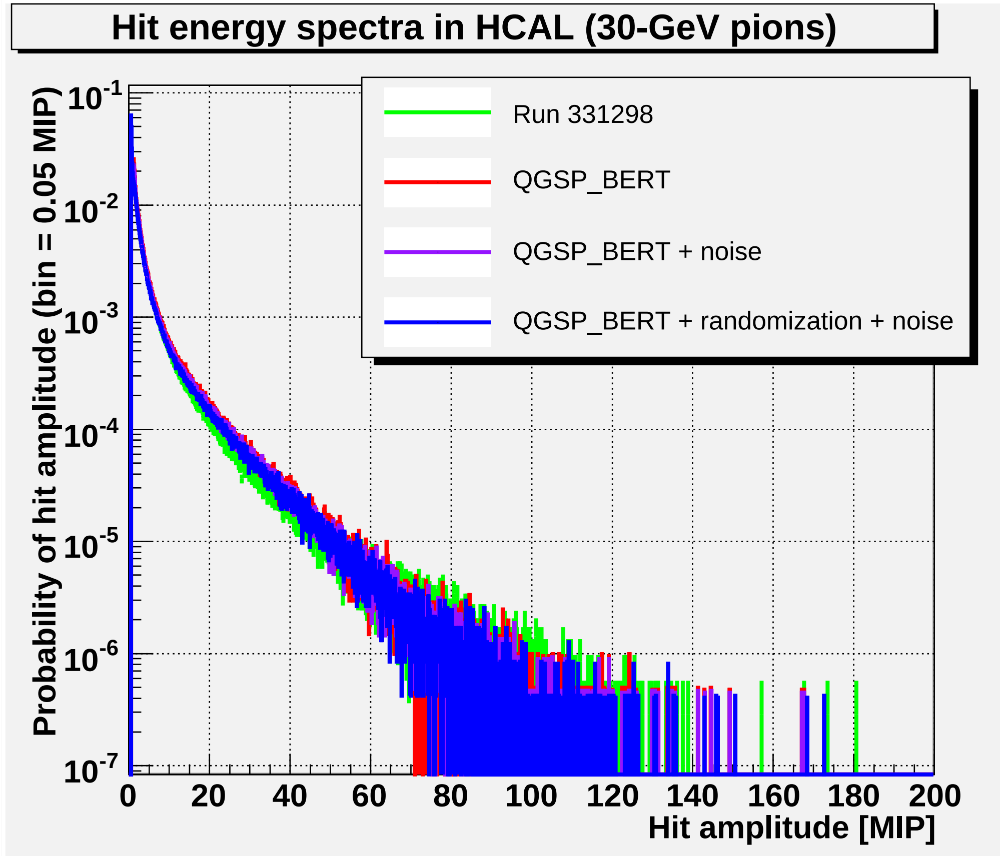
$\Downarrow$

Adding noise hits from random event of pedestal run cell to cell

This digitization procedure does not include light cross talk between tiles.

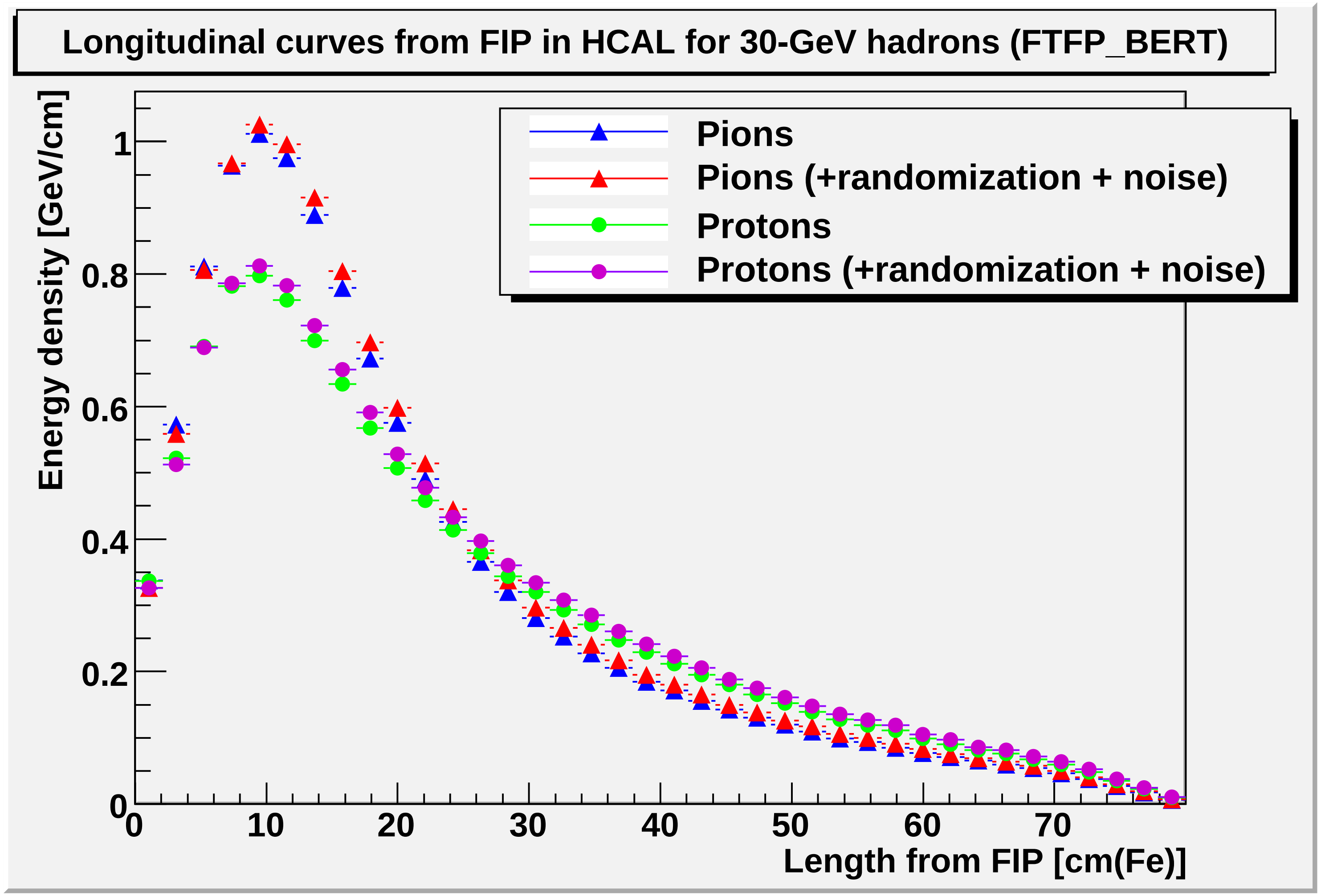
Hit spectrum for MC and data





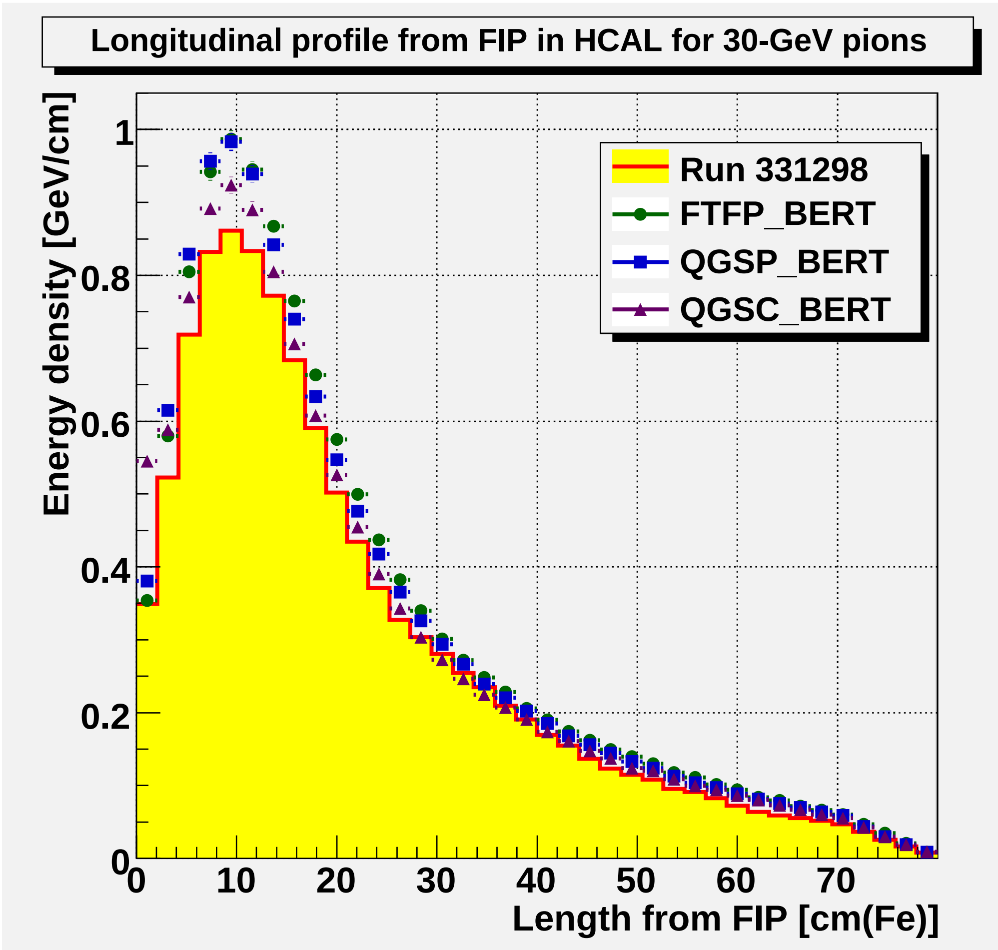
Digitization with given above parameters plus adding noise from pedestal run allow to obtain a good agreement between MC hit spectrum and data hit spectrum in the 1 MIP region.

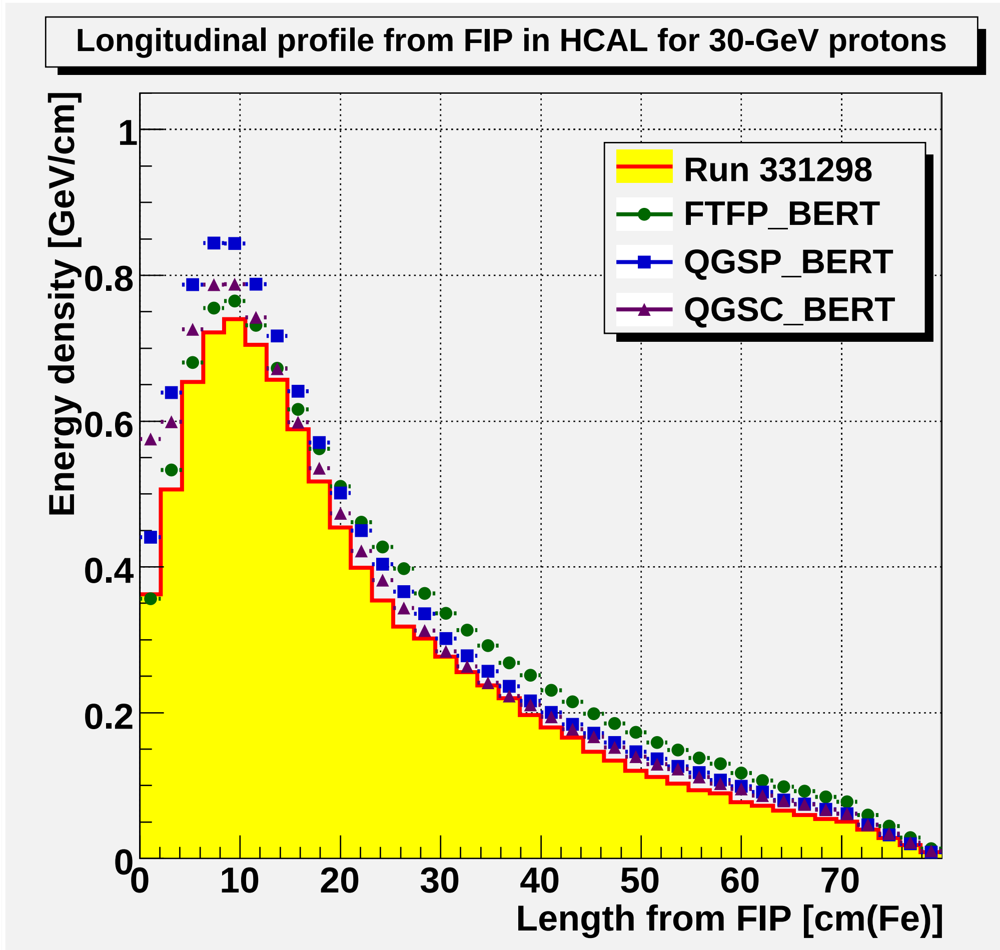
Digitization impact on MC longitudinal profiles



The digitization procedure slightly changes MC longitudinal curves.

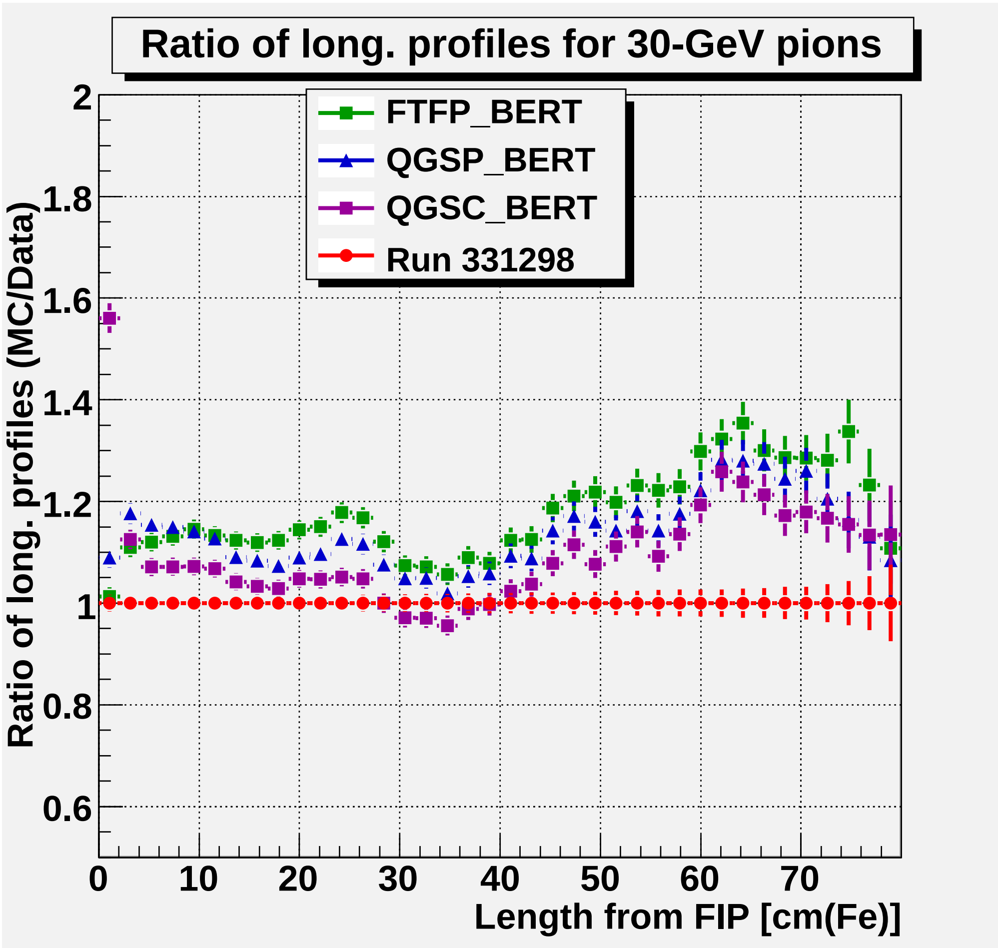
Longitudinal curves in HCAL: data and MC

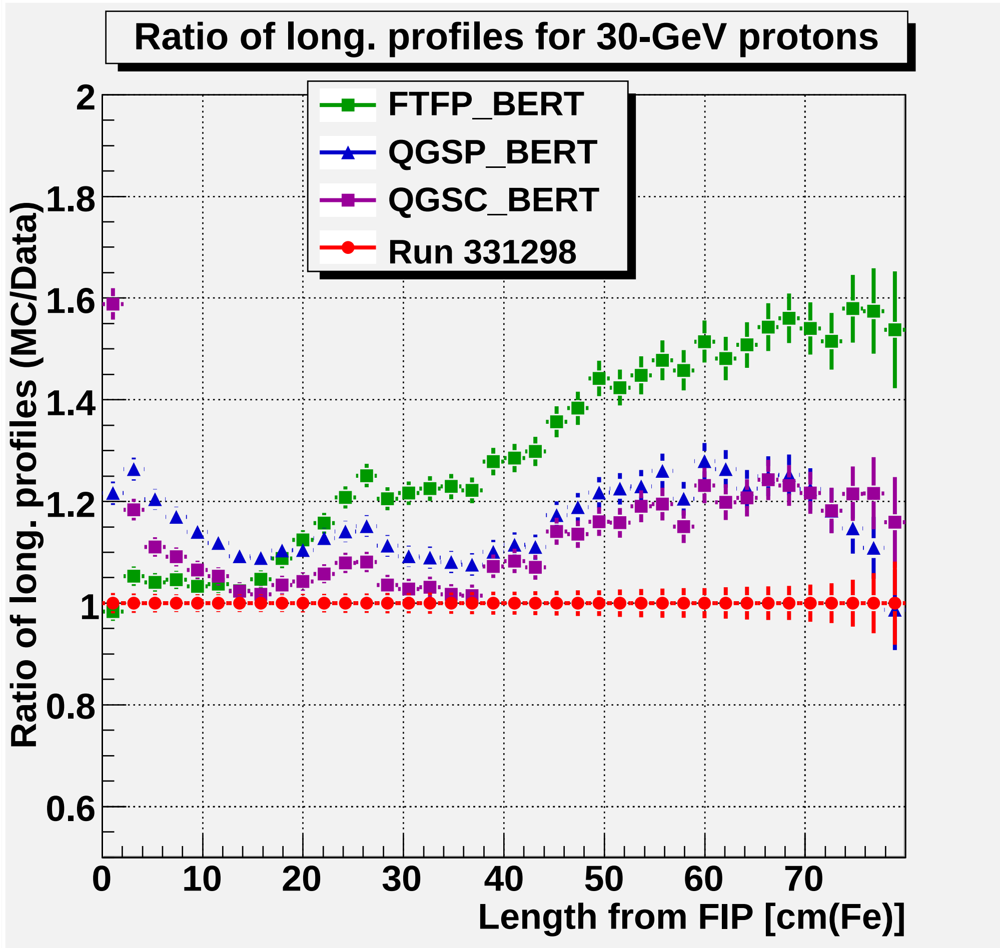




MC longitudinal profiles are higher than data in peak region. FTFP_BERT describes peak region better for protons while the tail is worse reproduced.

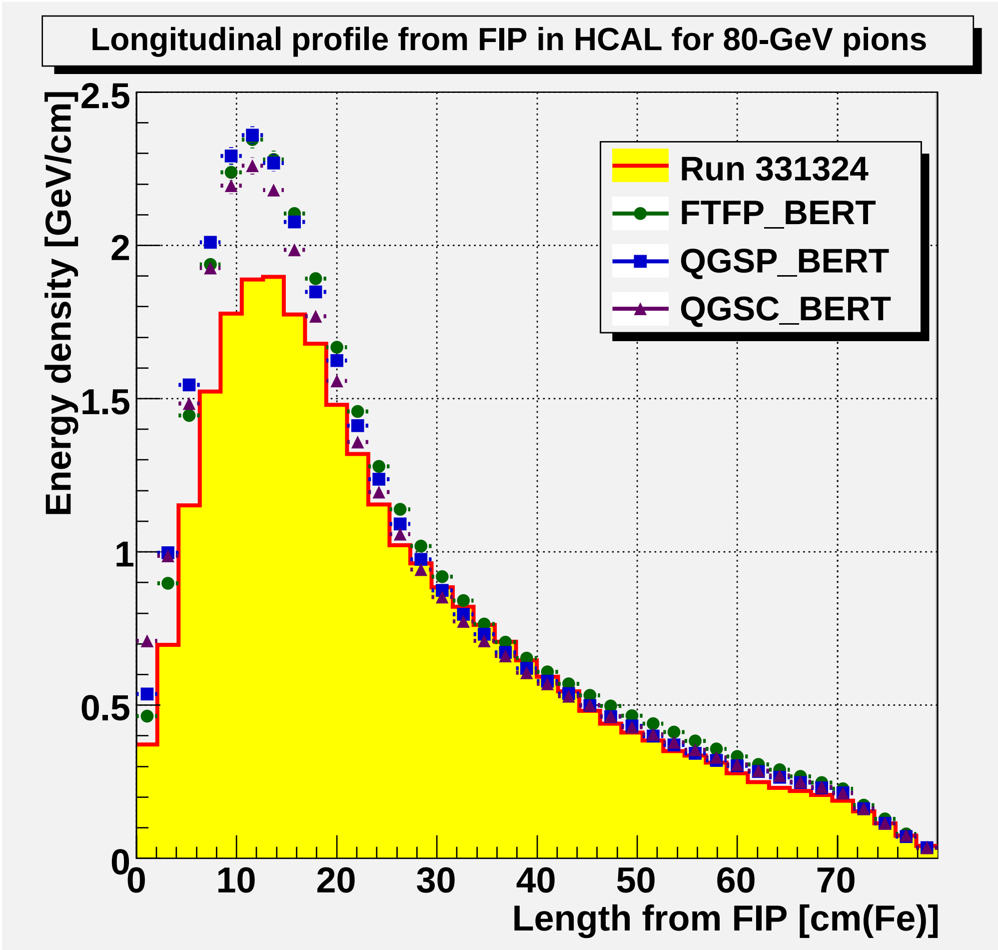
Ratio of longitudinal profiles in HCAL: MC/Data

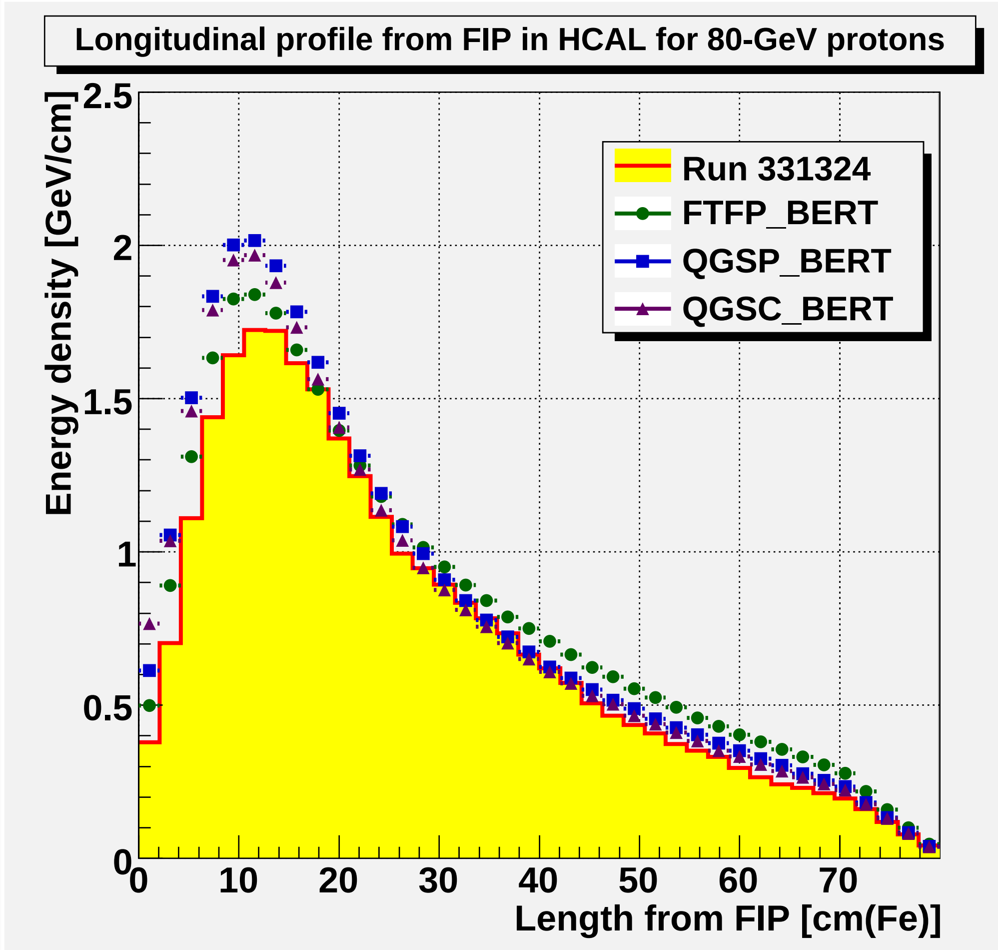




For pions, the difference is about 20% (except of first bin of QGSC_BERT) and up to 30% in the tail. For protons, FTFP_BERT shows the difference of about 5% near shower start but up to 60% in the tail region.

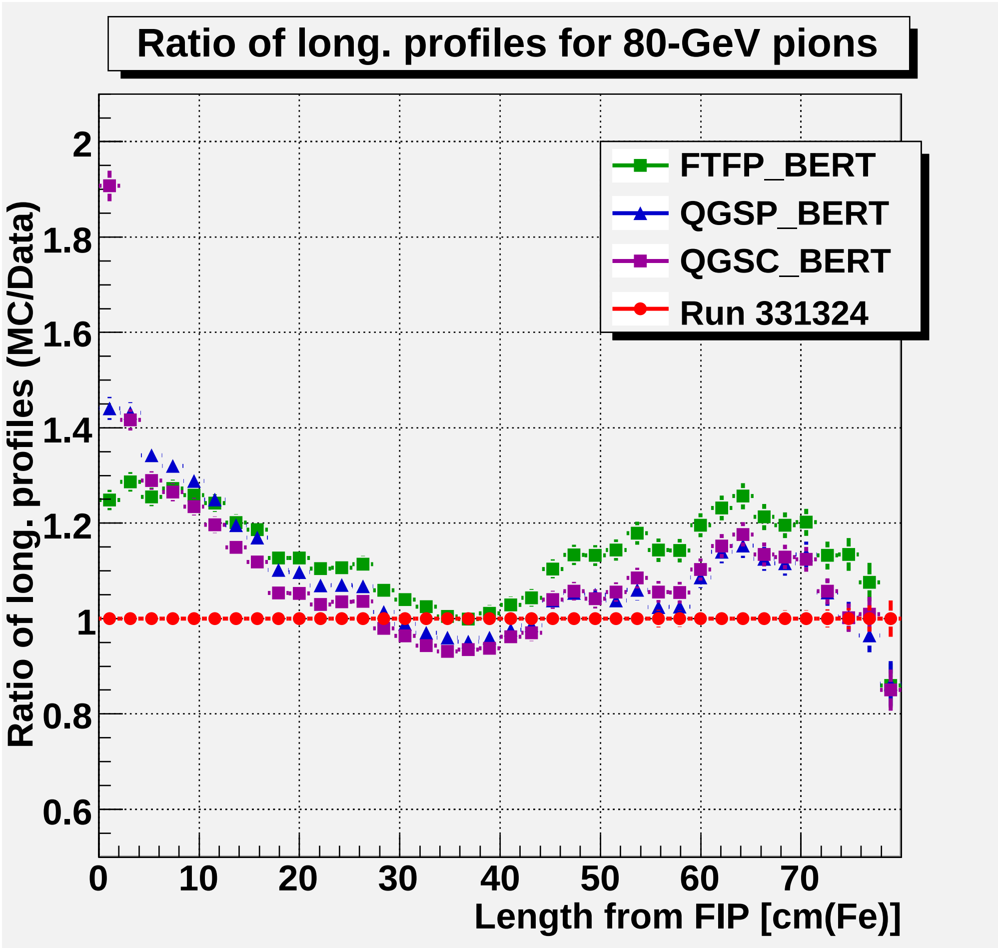
Longitudinal curves in HCAL: data and MC

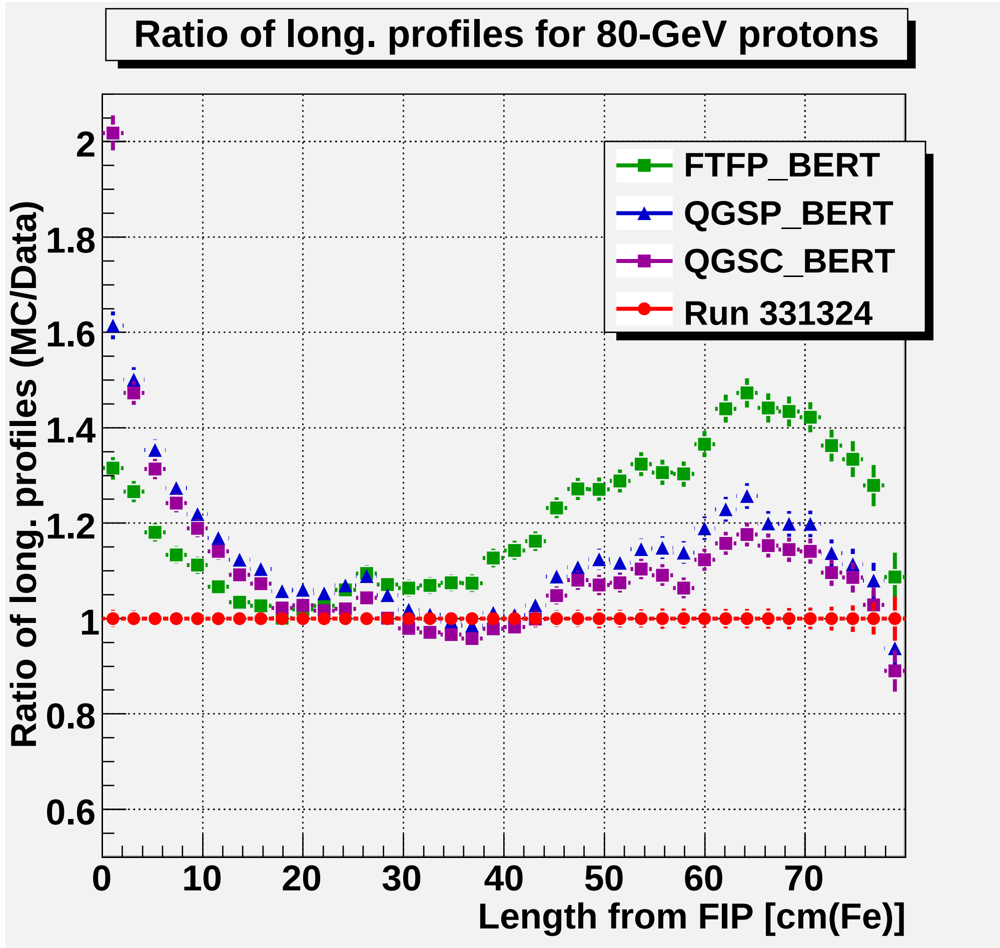




For 80-GeV hadrons the difference of MC from data becomes higher in peak region.

Ratio of longitudinal profiles in HCAL: MC/Data





For 80-GeV hadrons higher differences are observed than for 30-GeV. While the differences in the tail region are of the same order of magnitude, the difference near shower beginning rises up to 40% for pions and 60% for protons.

Energy deposited in HCAL

pions

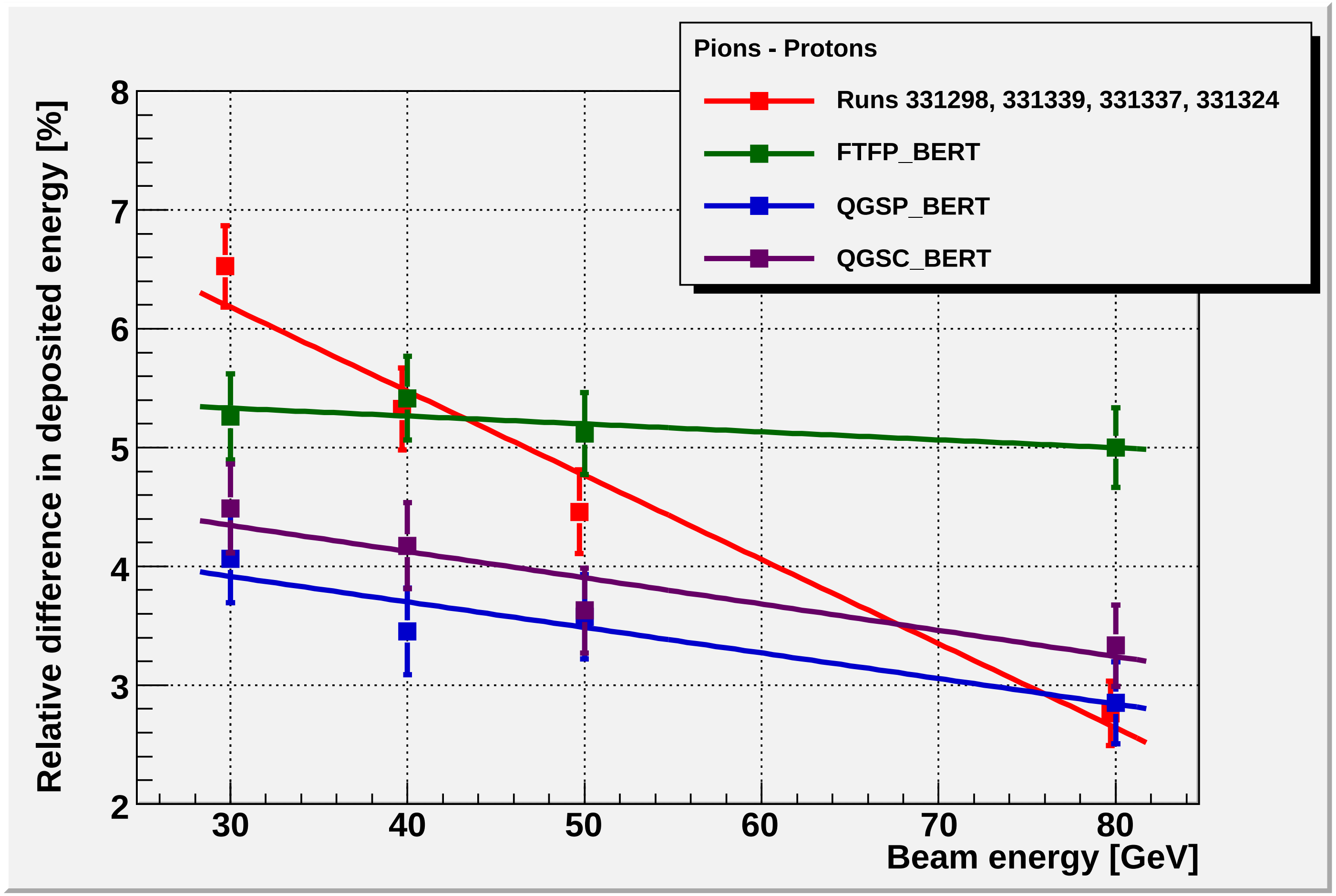
Beam energy, GeV	Energy deposited in HCAL, GeV			
	Data	FTFP_BERT	QGSP_BERT	QGSC_BERT
30	22.70 ± 0.05	25.76 ± 0.07	25.34 ± 0.07	24.36 ± 0.07
40	30.45 ± 0.05	34.3 ± 0.1	33.7 ± 0.1	32.7 ± 0.1
50	37.98 ± 0.06	42.8 ± 0.1	42.1 ± 0.1	40.9 ± 0.1
80	59.2 ± 0.1	68.2 ± 0.2	67.0 ± 0.2	65.5 ± 0.2

protons

Beam energy, GeV	Energy deposited in HCAL, GeV			
	Data	FTFP_BERT	QGSP_BERT	QGSC_BERT
30	21.22 ± 0.06	24.41 ± 0.06	24.31 ± 0.06	23.27 ± 0.06
40	28.8 ± 0.1	32.48 ± 0.08	32.52 ± 0.08	31.29 ± 0.08
50	36.3 ± 0.1	40.6 ± 0.1	40.6 ± 0.1	39.4 ± 0.1
80	57.6 ± 0.1	64.8 ± 0.1	65.1 ± 0.2	63.3 ± 0.1

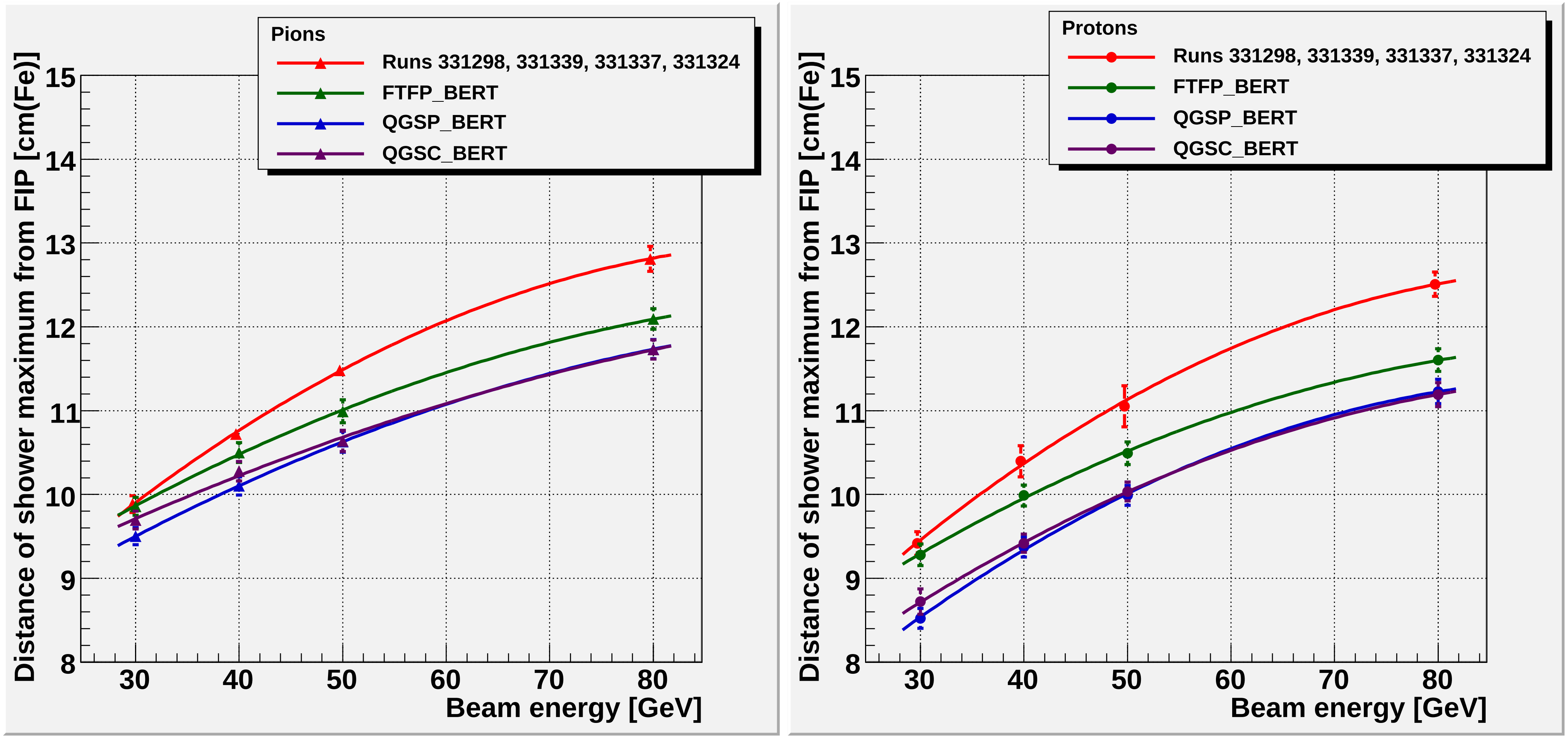
Relative differences in energy deposited in HCAL

$$(E^{dep}_{pion} - E^{dep}_{proton})/E^{dep}_{pion}$$



The relative difference between pion and proton shower energy in HCAL falls down for data faster than MC models predict. Taking in account the proton sample impurity will increase this disagreement in behaviour.

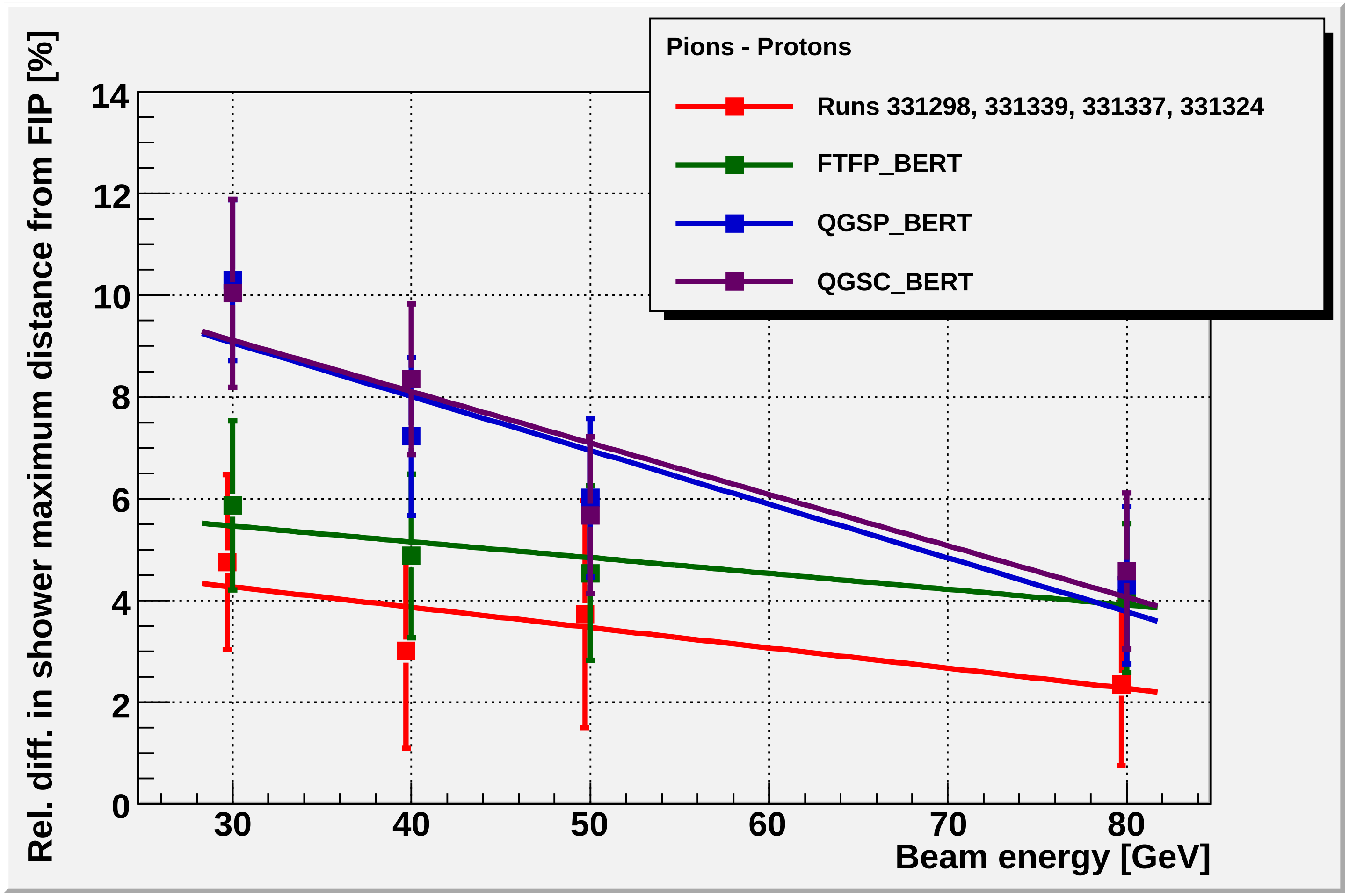
Energy dependence of shower maximum position from FIP



The distance of shower maximum from shower start is larger for pions than for protons.

Relative differences in shower maximum position

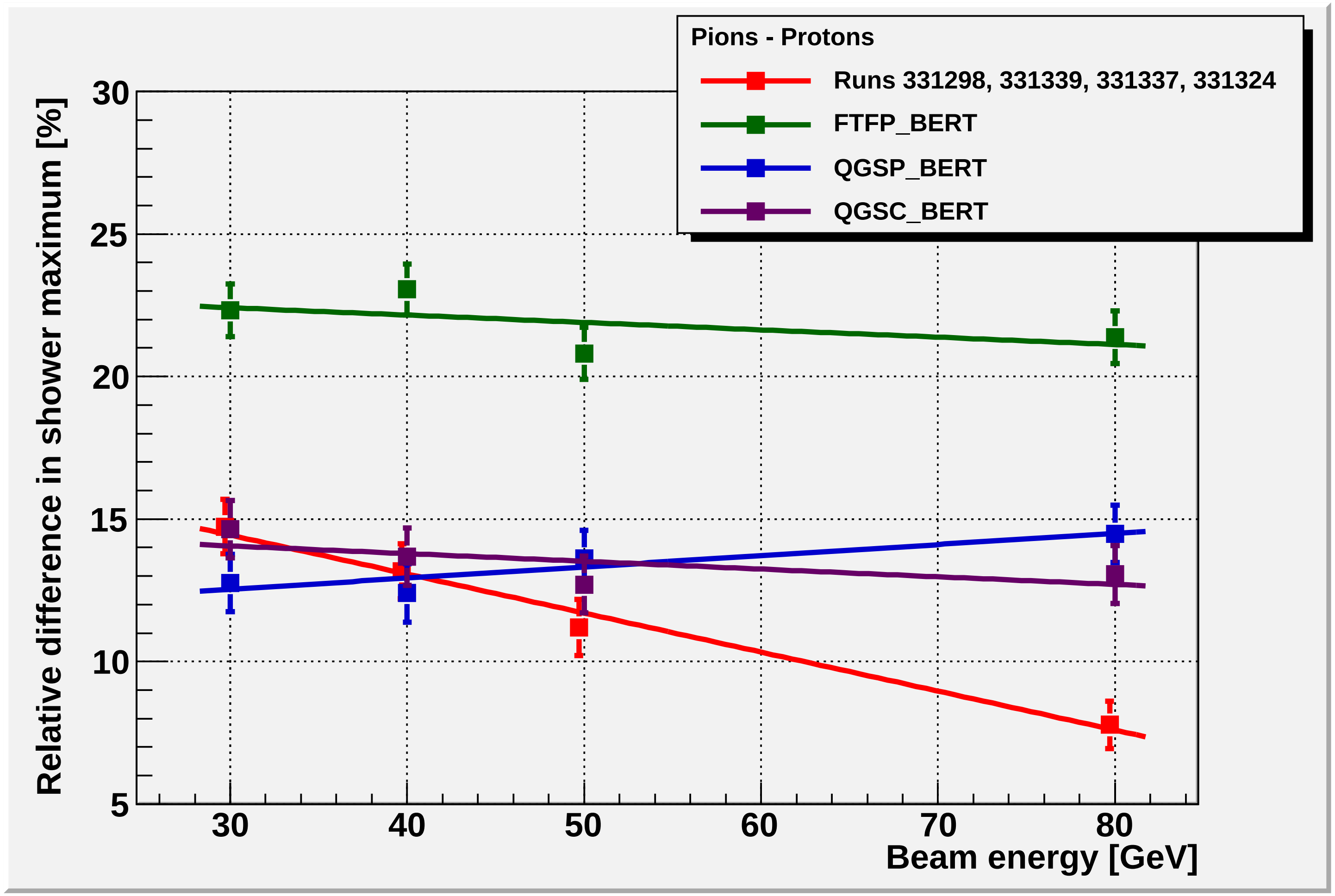
$$(Z^{max}_{pion} - Z^{max}_{proton})/Z^{max}_{pion}$$



MC models predict higher difference between pion and proton shower maximum distance from FIP. At the same time this difference decreases with increasing energy for both MC and data.

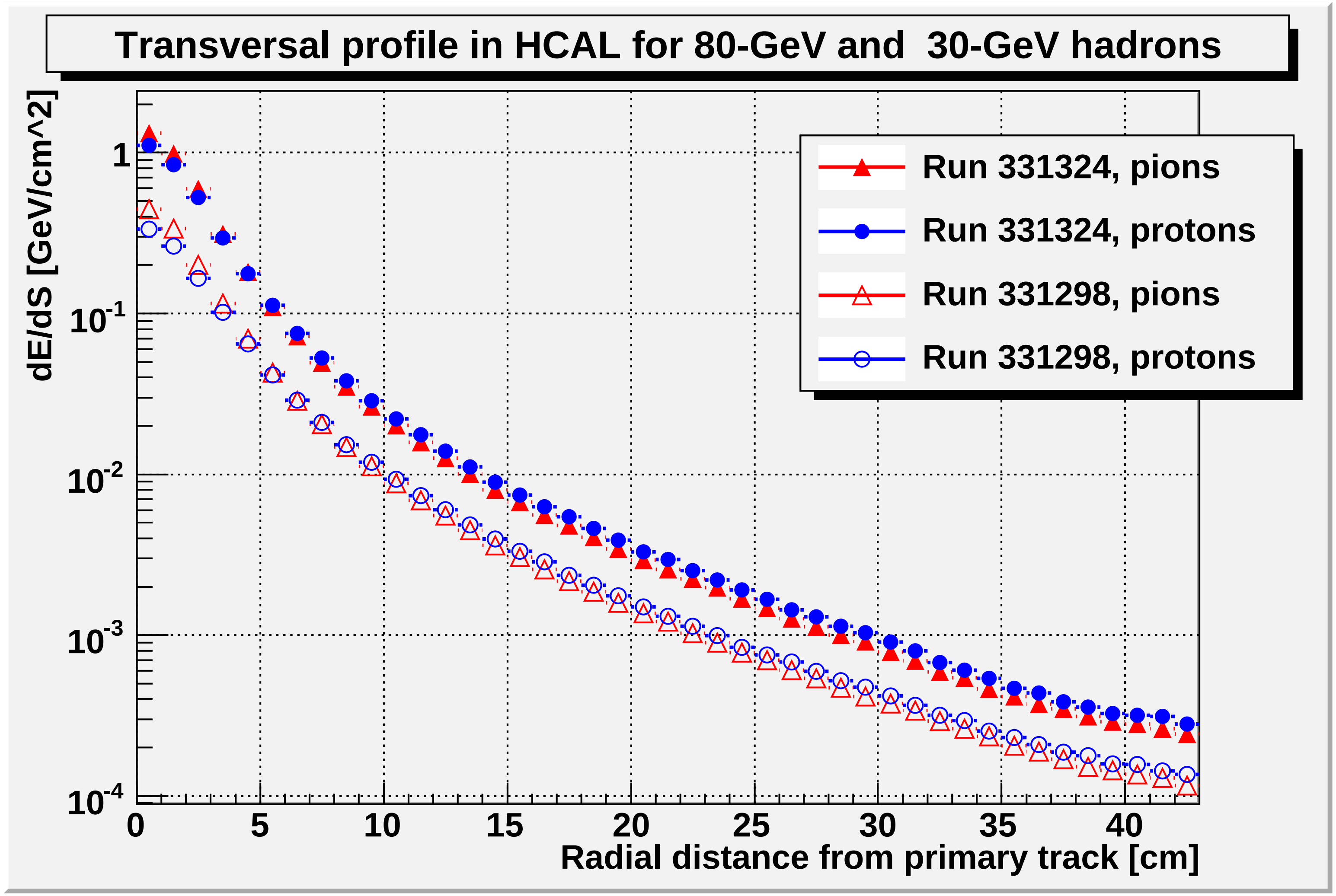
Relative differences between energy density maxima

$$(D^{max}_{pion} - D^{max}_{proton})/D^{max}_{pion}$$



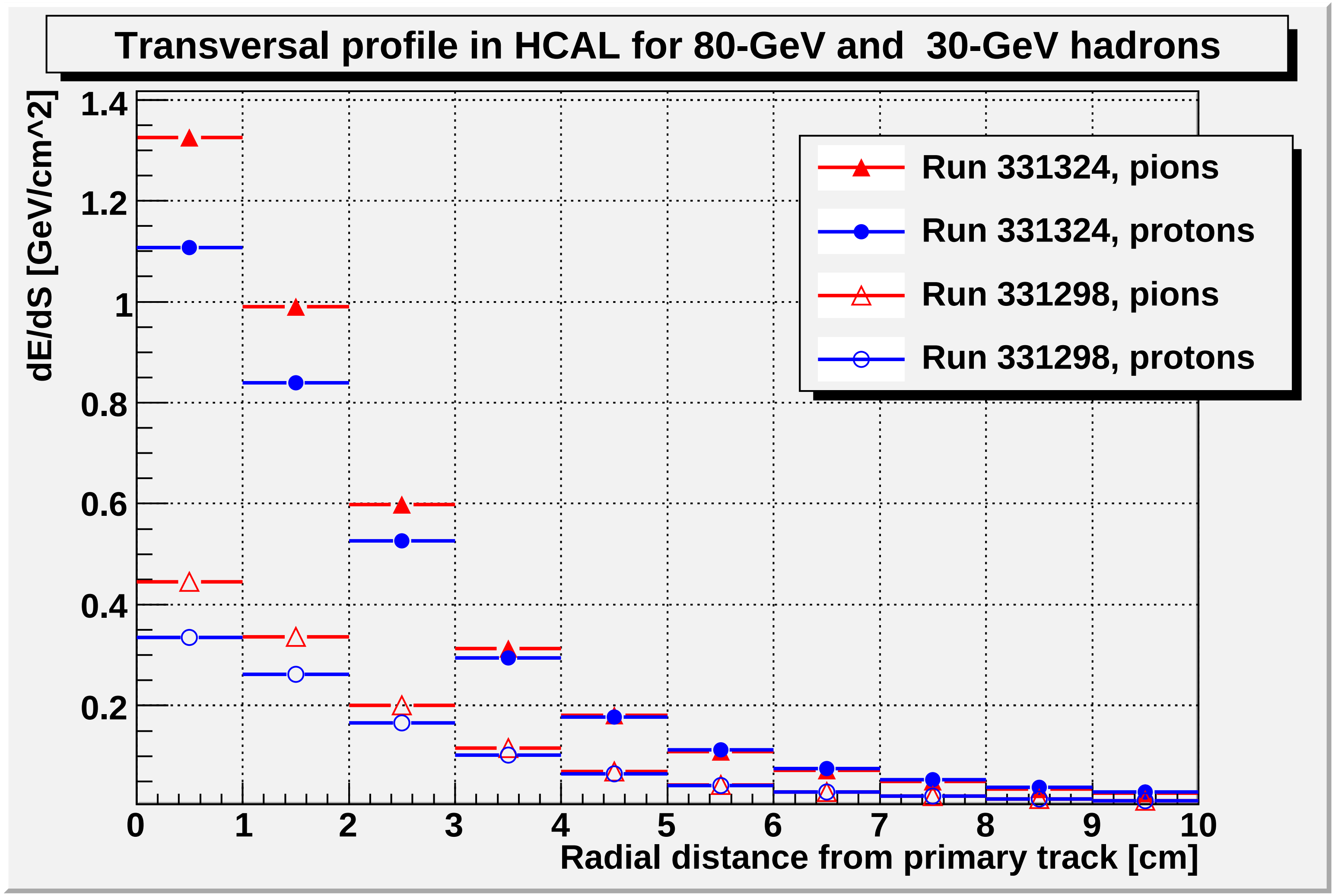
FTFP_BERT predicts significantly higher difference in maximum energy density between pion- and proton-induced showers (up to 23%) than is observed in data and predicted by other MC models.

Transversal profiles



Transversal profiles of pion and proton showers intersect at the radial distance from primary track of about 5 cm.

Central region of transversal profile

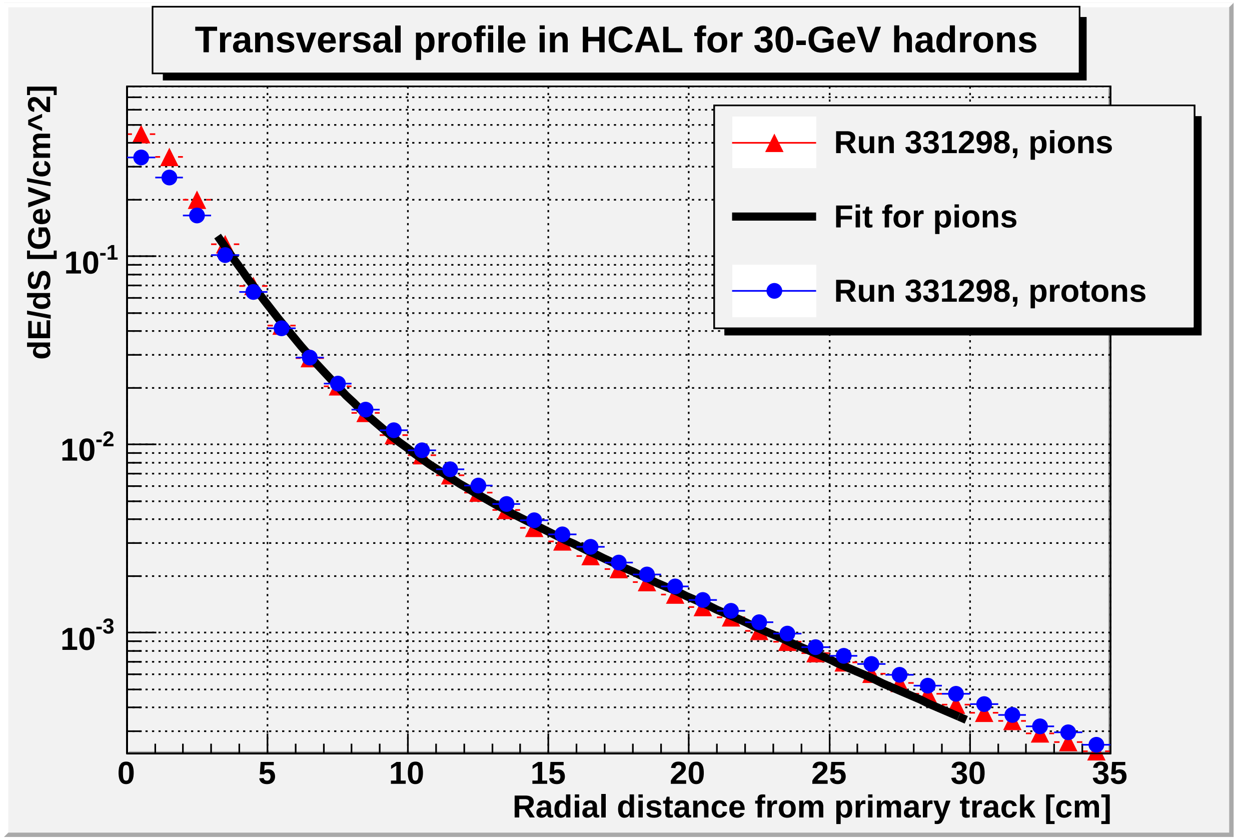


The most significant differences between pion and proton profiles are observed in core region.

Fit of transversal curve

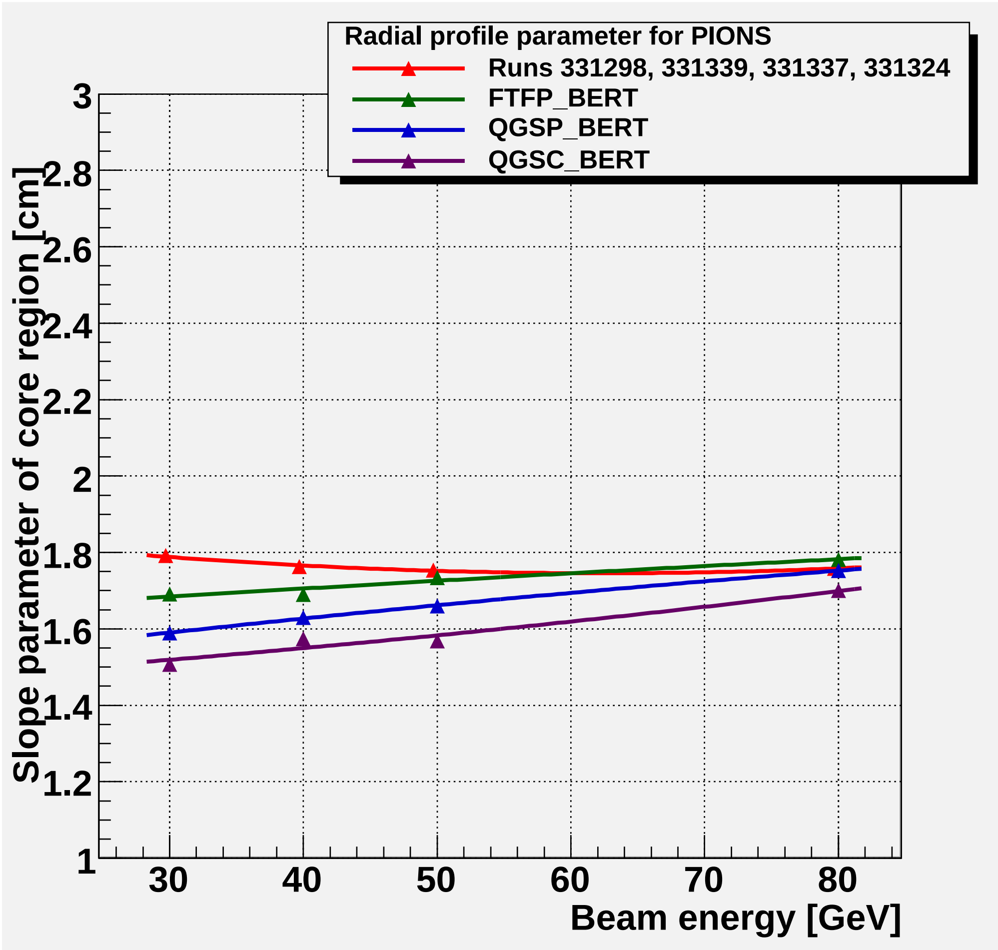
Transversal curve consists of at least two exponent and was fitted with sum of two exponent:

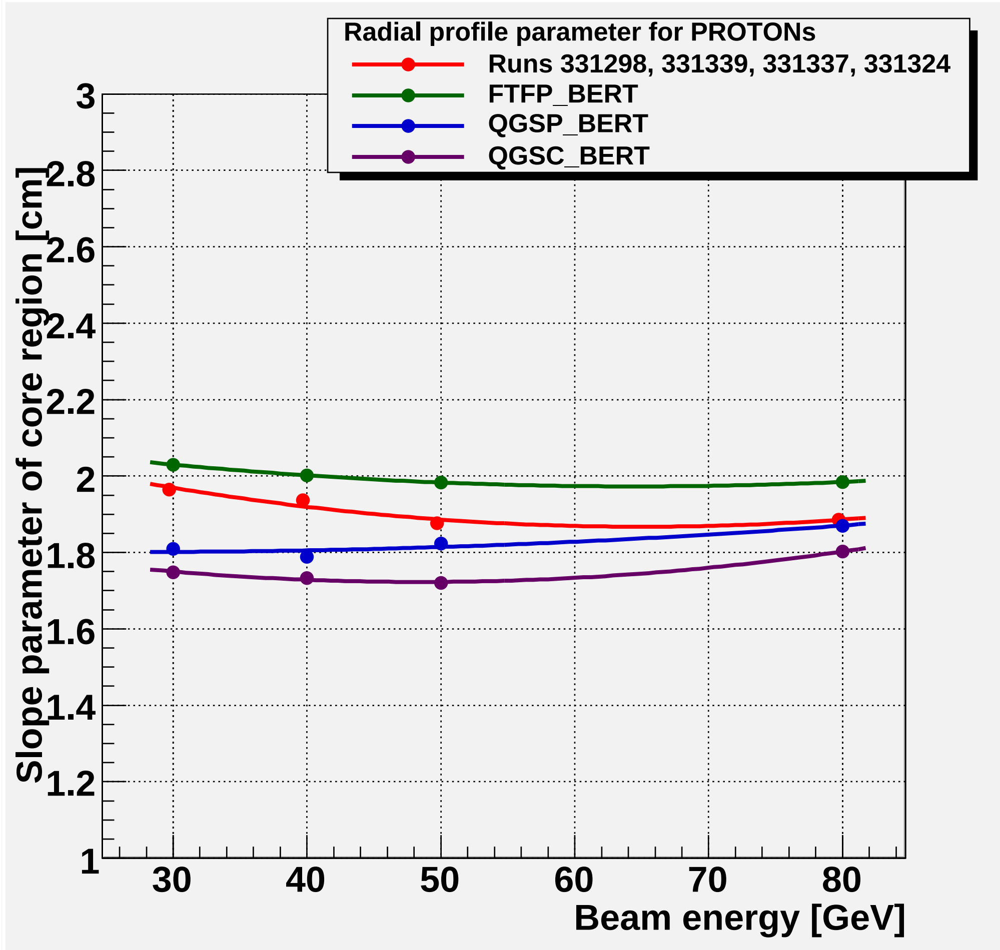
$$a_1 \cdot exp(-r/\lambda_1) + a_2 \cdot exp(-r/\lambda_2)$$



The fit was performed for restricted region from 4 cm to 30 cm.

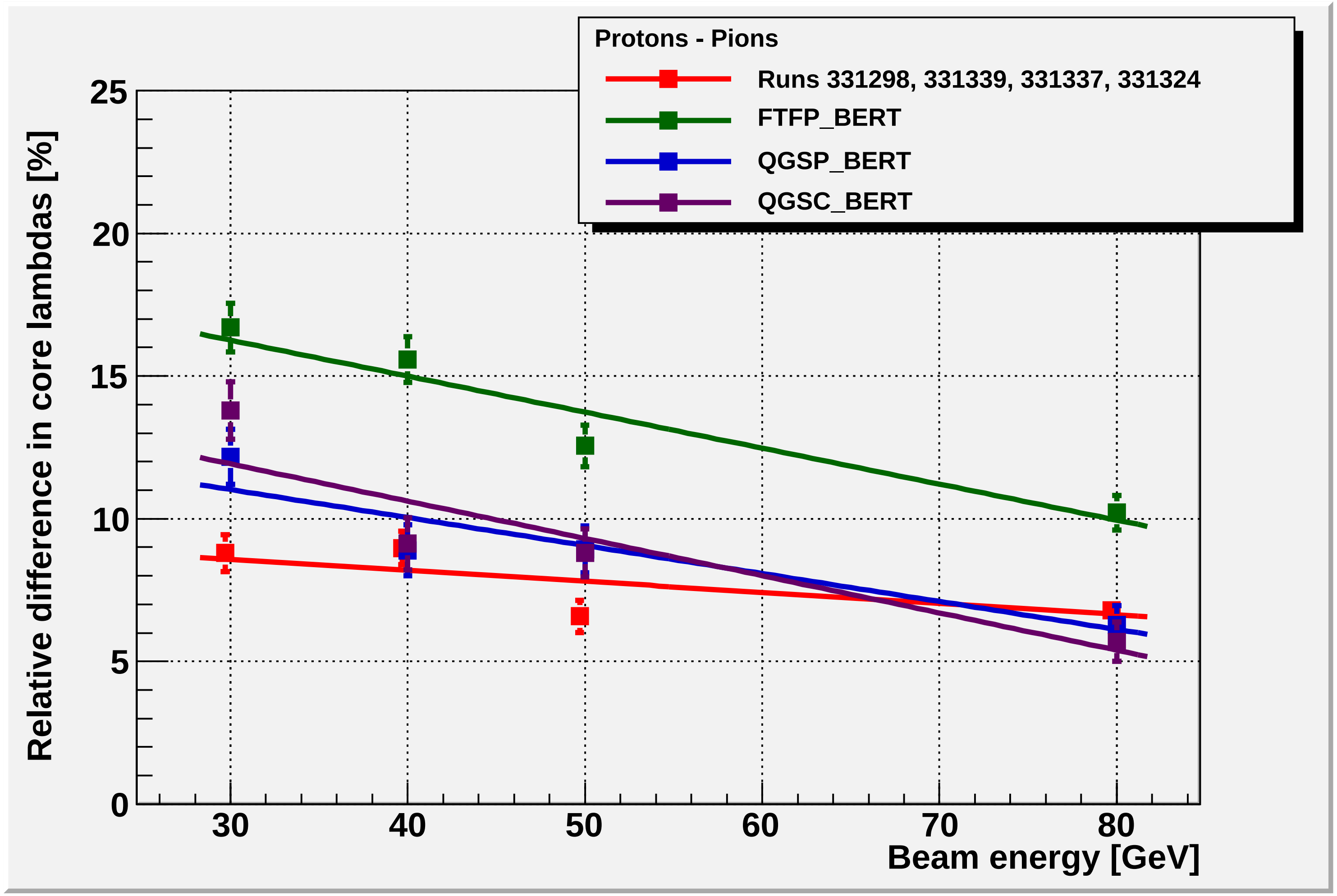
Transversal curve parameter in core region





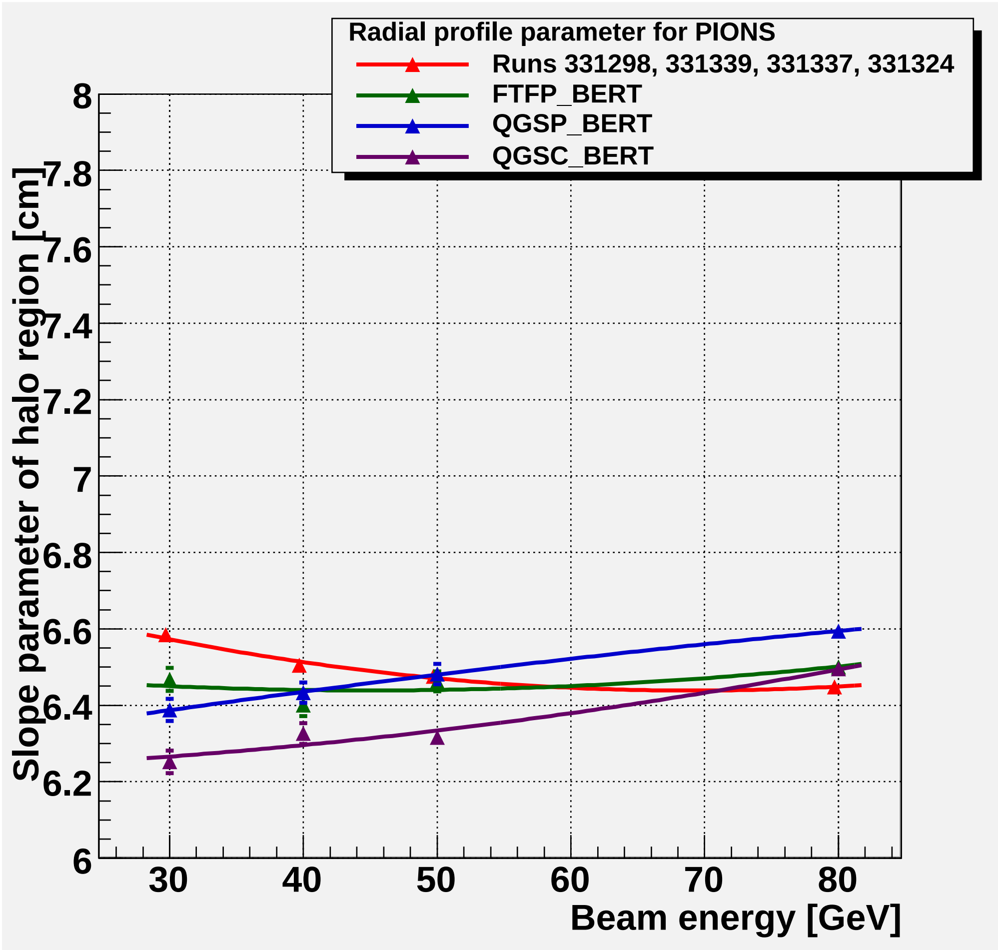
MC models reproduce slope parameter of central region with the accuracy of 16% for pions and even better for protons.

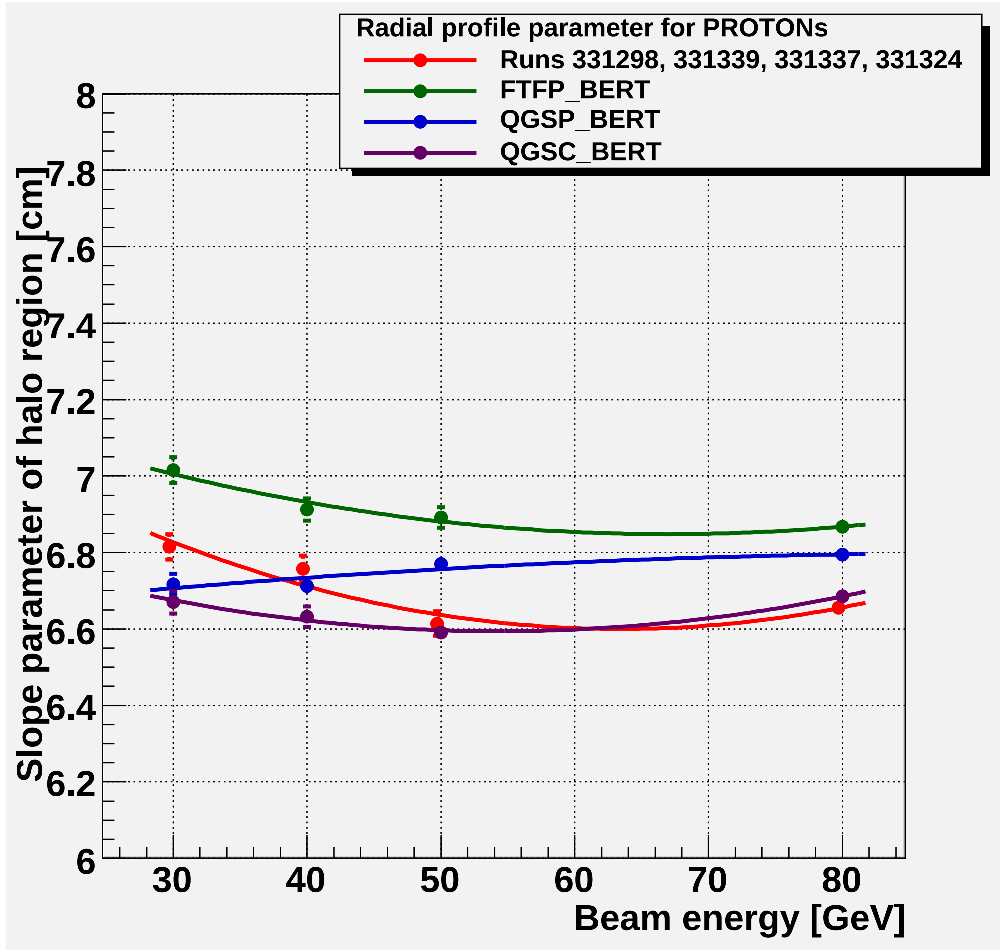
Difference in core slope parameter



FTFP_BERT predicts higher differences between pion and proton shower parameters as was also noted for longitudinal profiles.

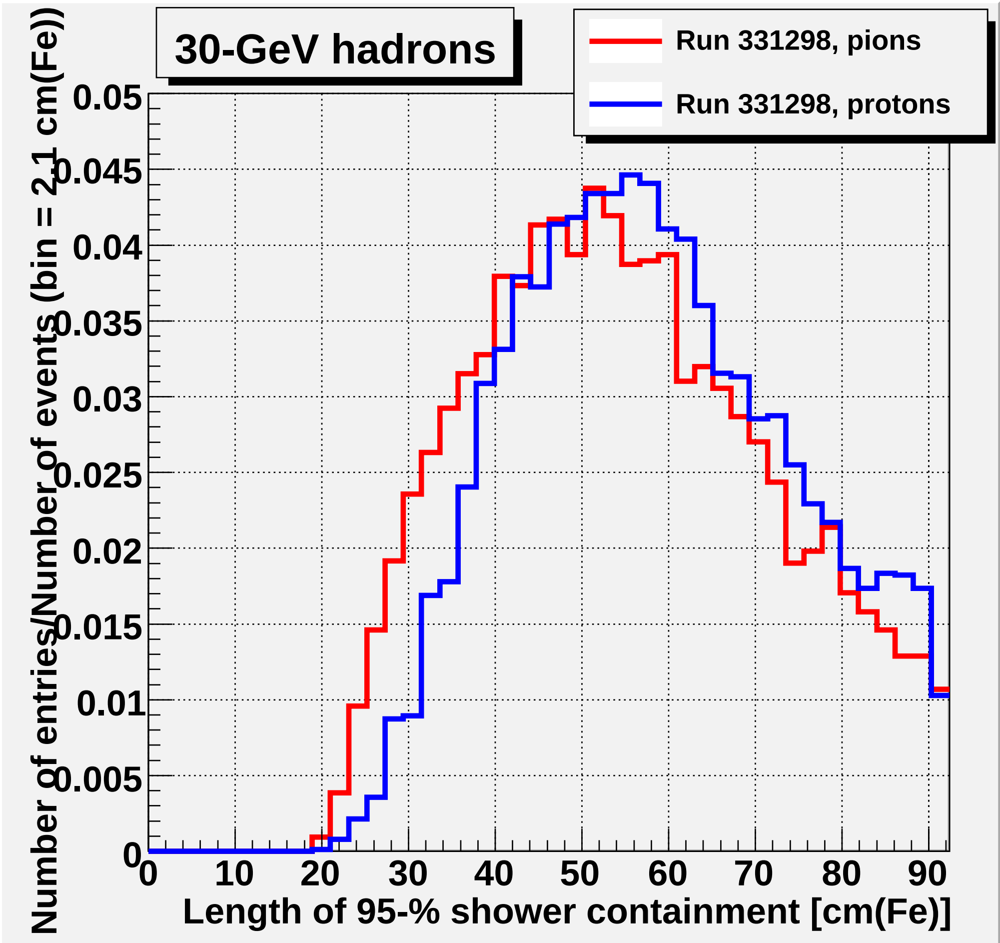
Transversal curve parameter in halo region

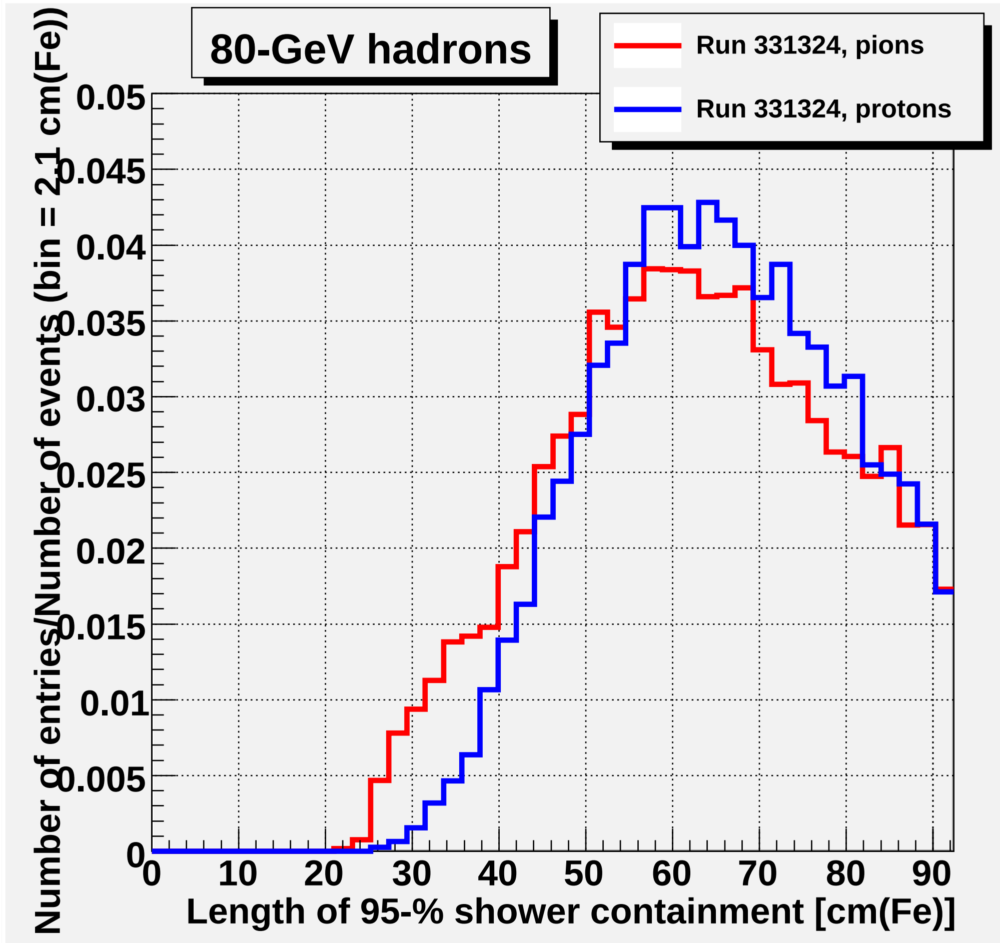




For both hadrons the difference in halo slope parameter between MC and data does not exceed 6%.

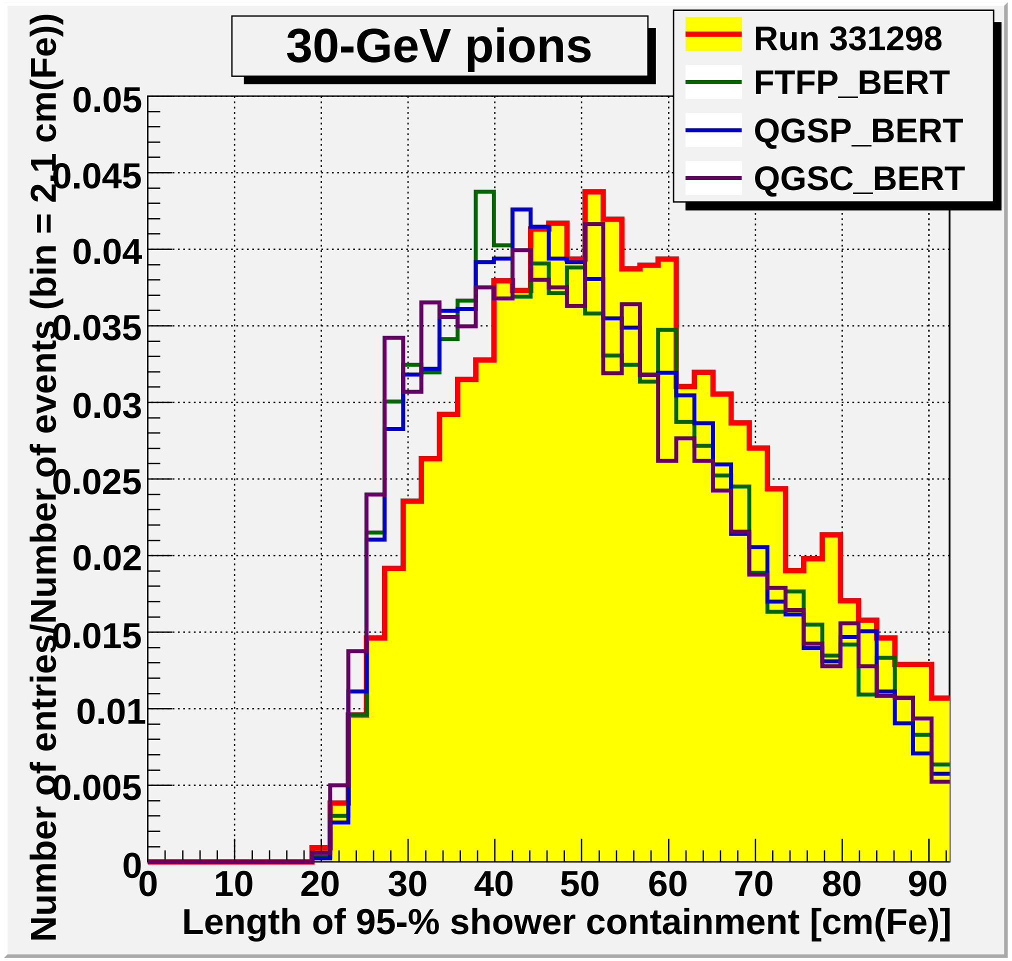
Longitudinal size of hadron showers

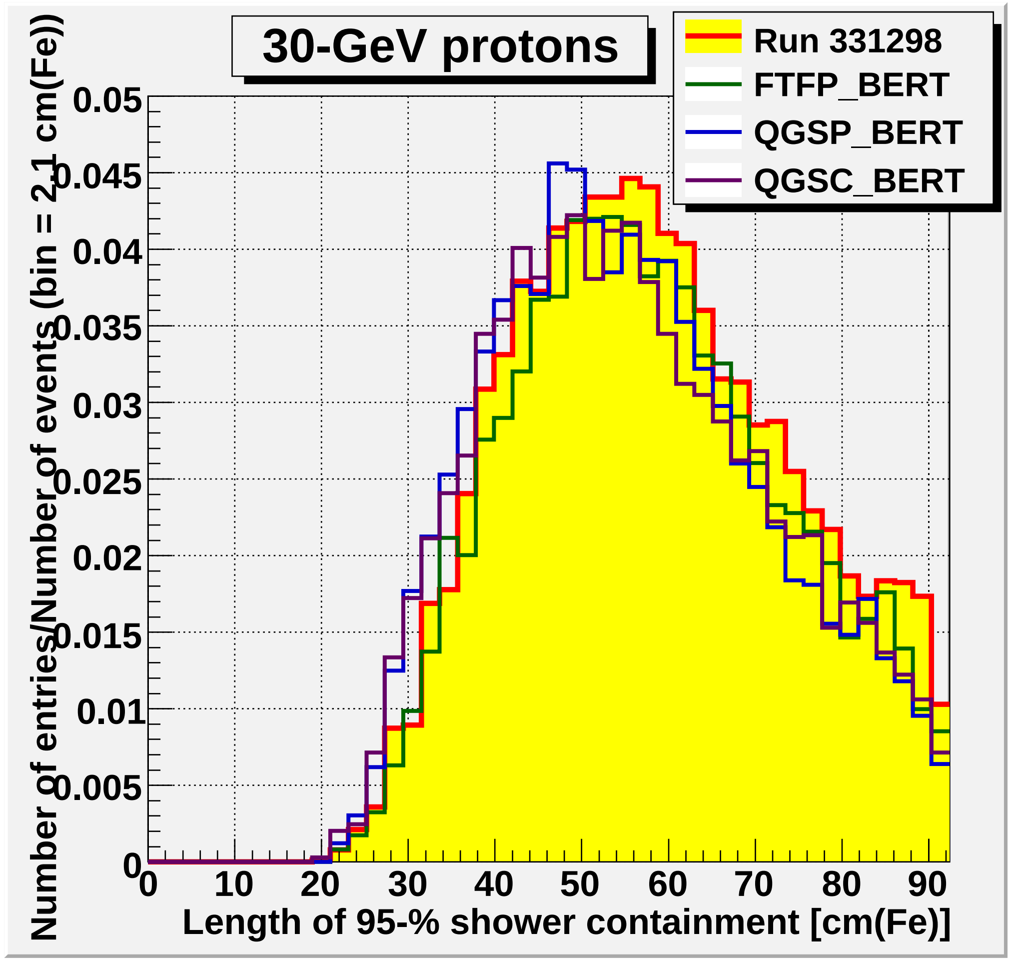




We define longitudinal size as the length from FIP up to which 95% of shower energy is deposited.

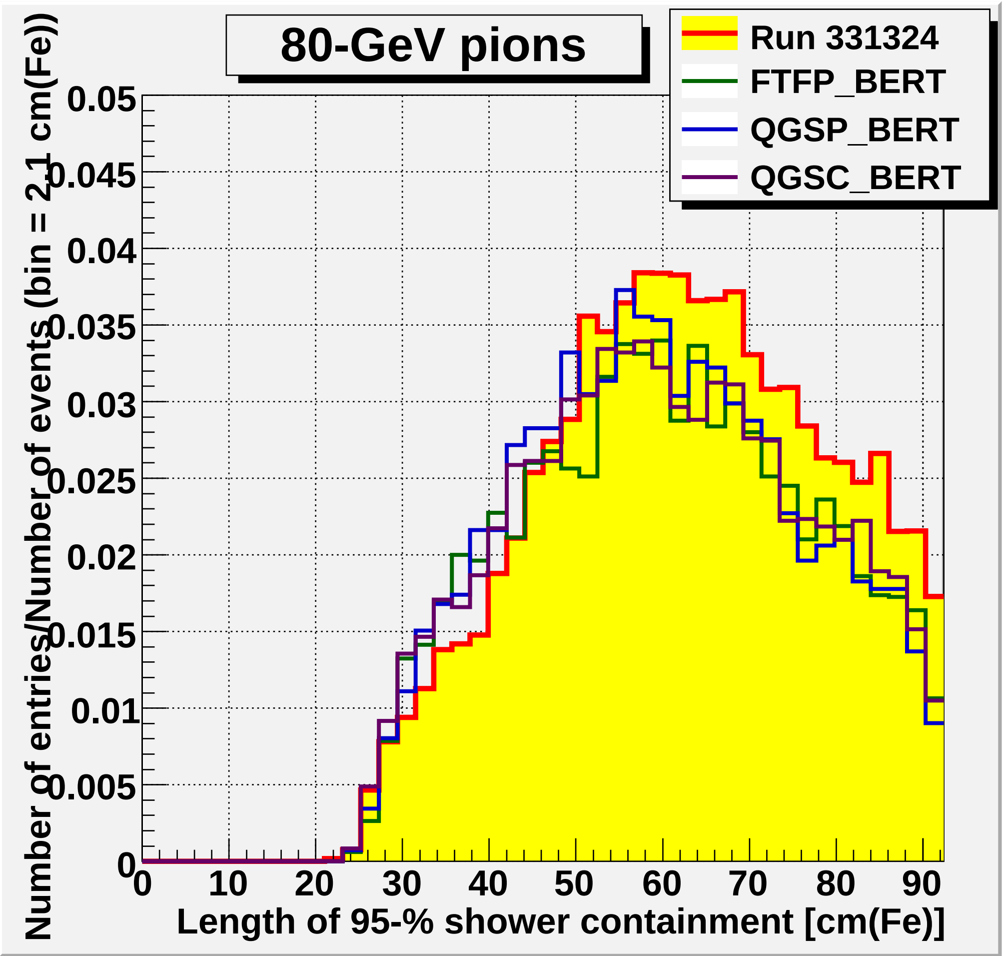
Longitudinal size of hadron showers: data and MC

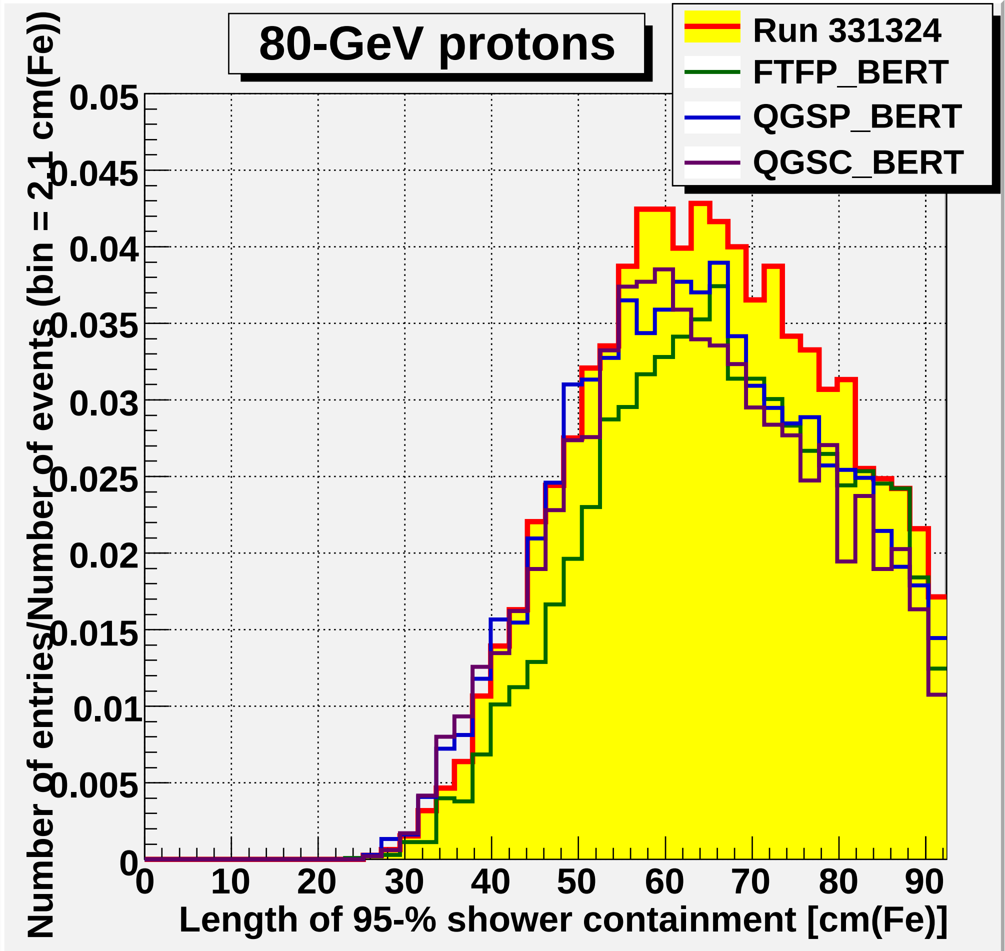




MC models predict a bit shorter showers both for pions and for protons.

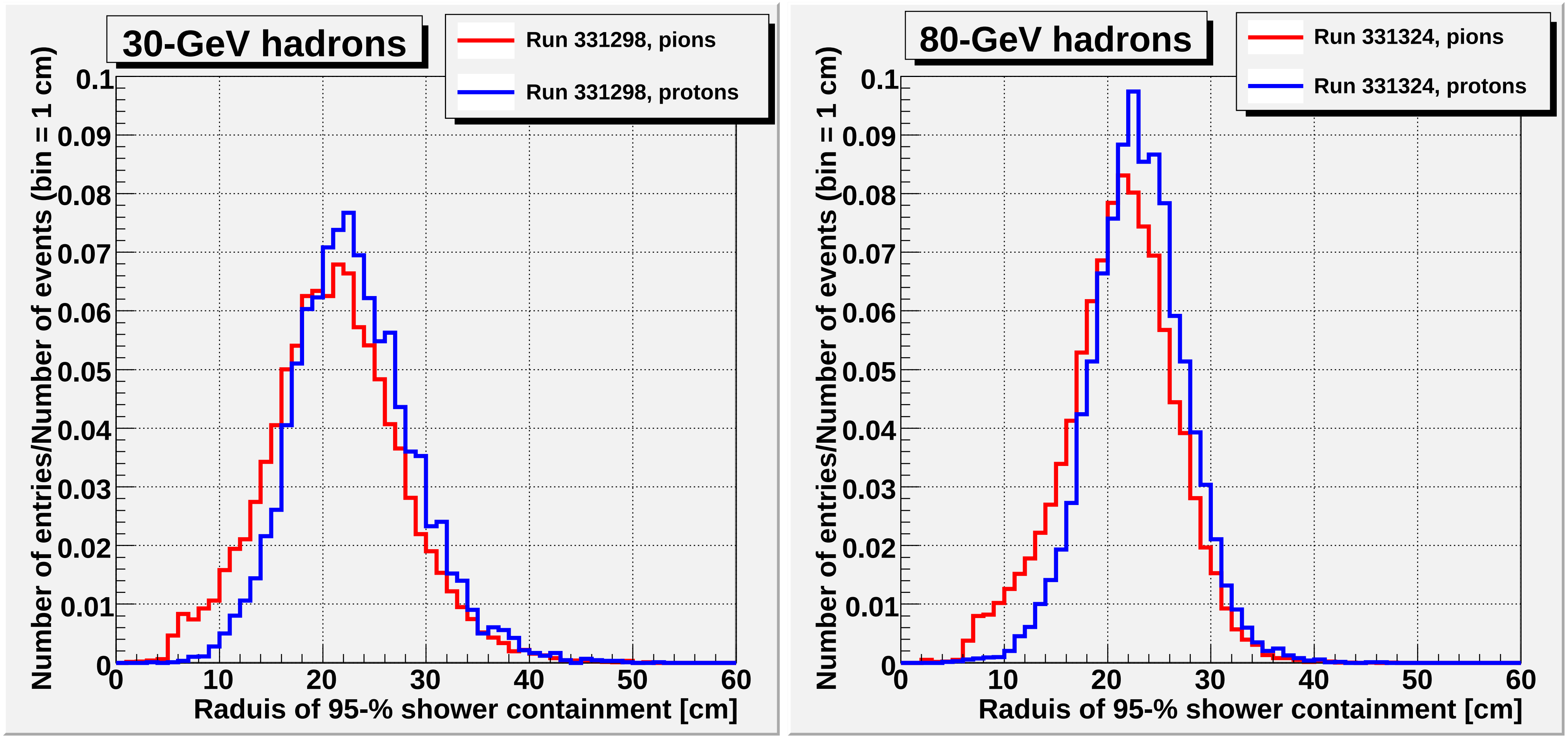
Longitudinal size of hadron showers: data and MC





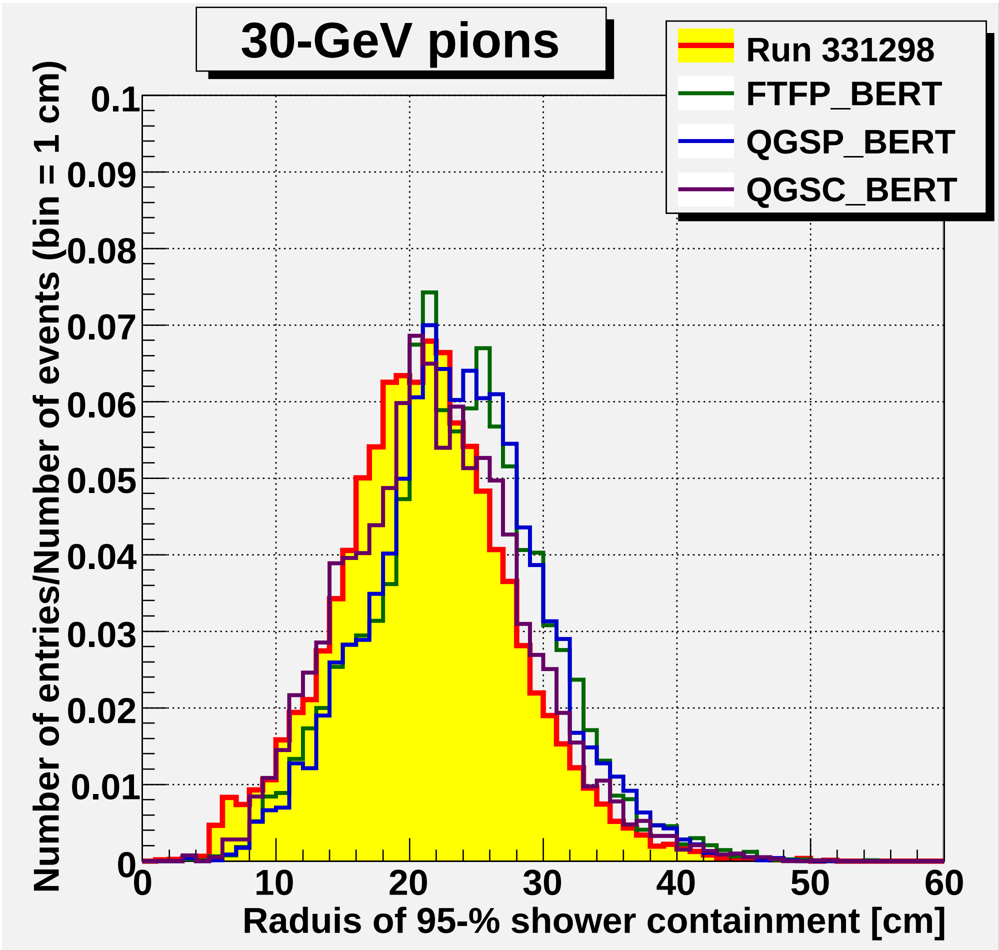
For both energies longitudinal size of showers is reproduced by MC models slightly better for protons than for pions.

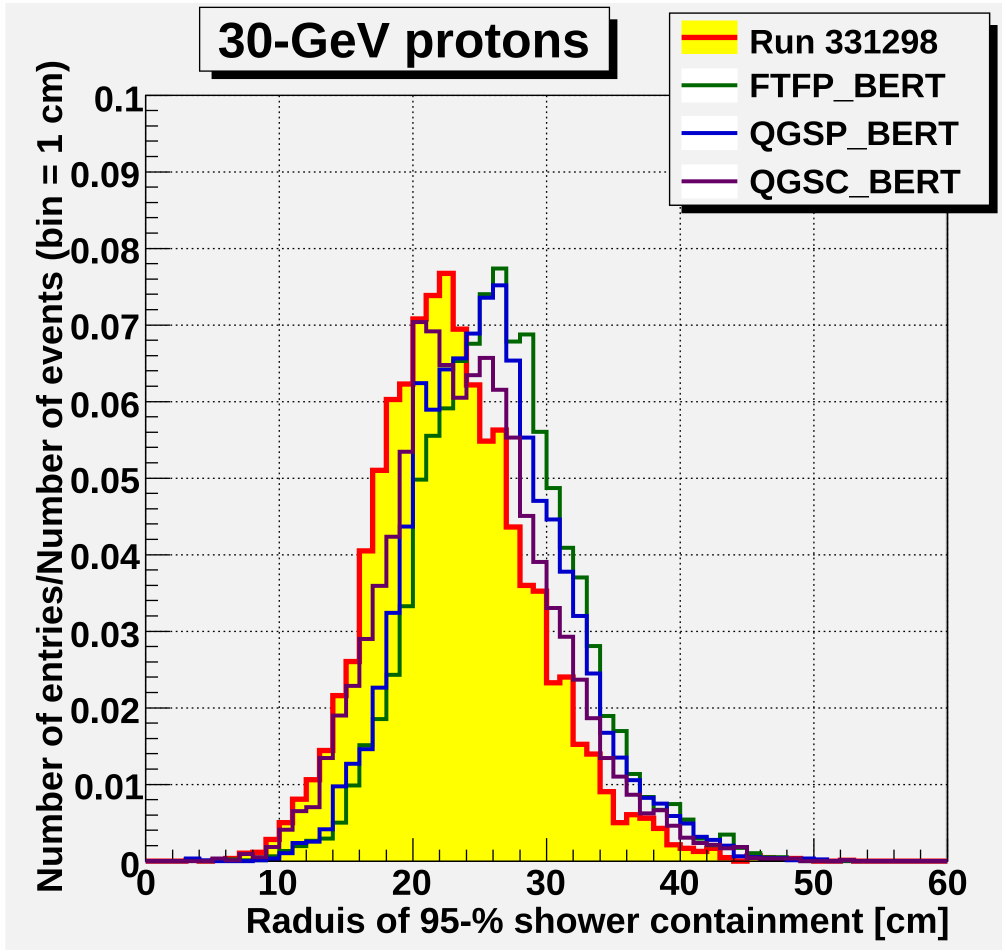
Radial size of hadron showers



We define radial size as the radius of cilinder inside which 95% of shower energy is deposited.

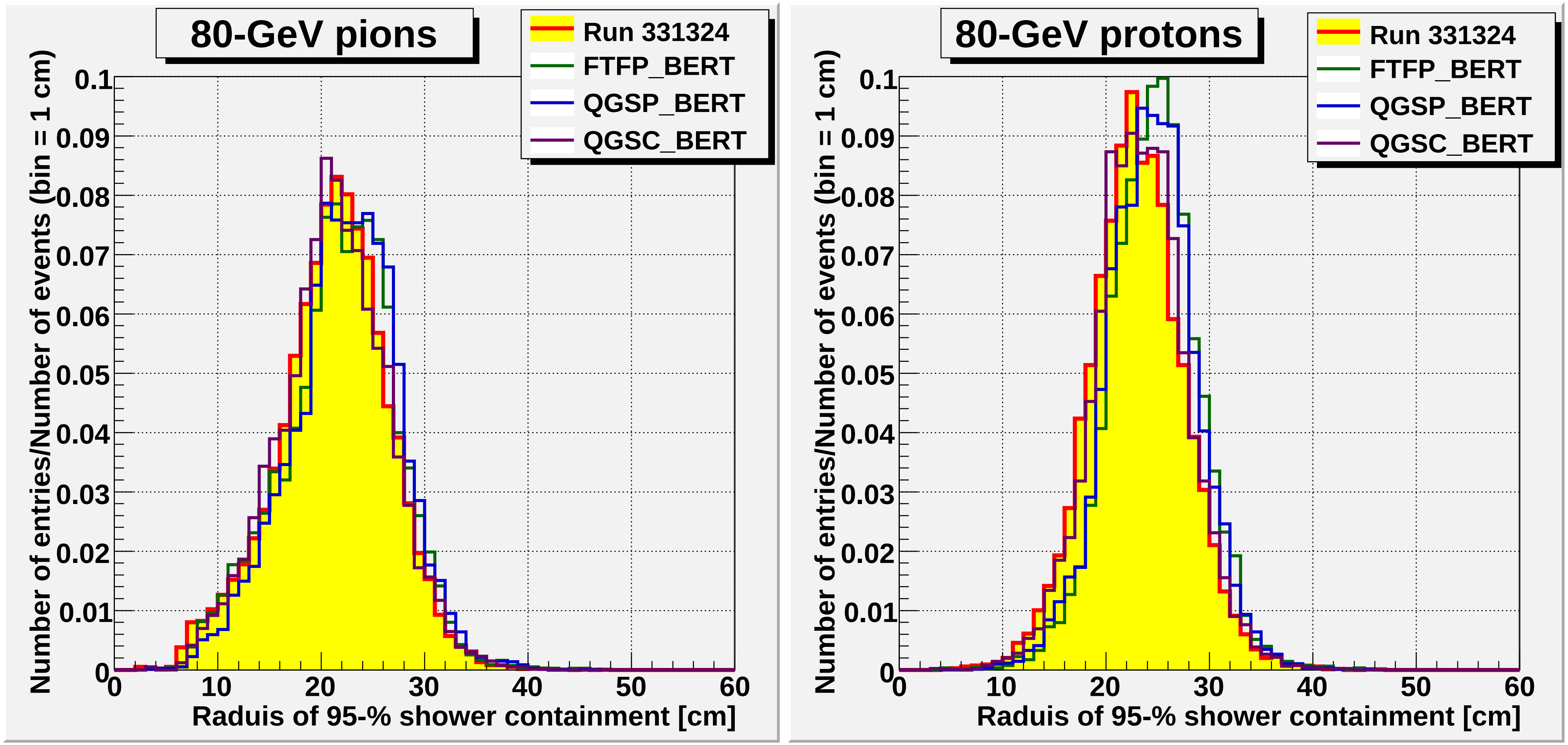
Radial size of hadron showers: data and MC





All MC models predict a bit wider showers for both hadrons at 30 GeV.

Radial size of hadron showers: data and MC



At 80 GeV better agreement between MC and data is observed.

Conclusions

Pions and protons

Pion showers are shorter in longitudinal direction and more narrow in radial direction than the proton ones.

With increasing energy the relative differences between pion- and proton-induced showers decrease (of shower maximum value and position from FIP).

MC and data

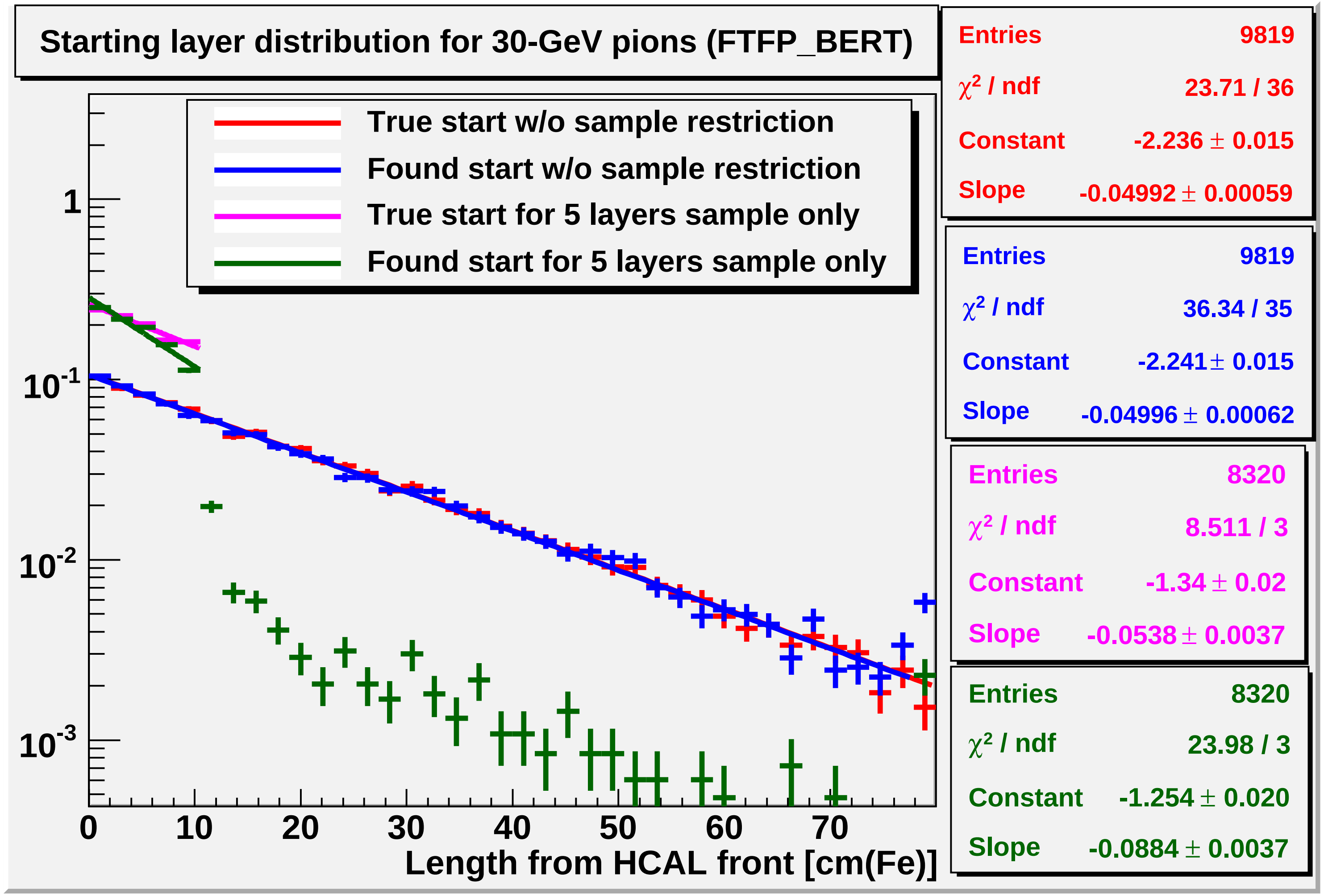
Predicted by MC models maximum values of energy density in longitudinal profiles significantly exceed those of data for pions (up to 20% at 80 GeV). For protons, values of maximum for MC and data are closer but the tail of longitudinal curve is worse reproduced by all MC models. With increasing energy, the difference between maxima of pion- and proton-induced showers decreases faster than it is predicted from MC. The same is observed for deposited energy.

The transversal profiles from data and MC are in good agreement. The difference between MC and data transversal profile slopes does not exceed 16% in central region and 6% in halo region.

All MC models predict shorter pion showers and reproduce longitudinal size of proton showers quite well. For radial size, all MC models predict wider hadron showers at 30 GeV and are in good agreement with data at 80 GeV.

Backup slides

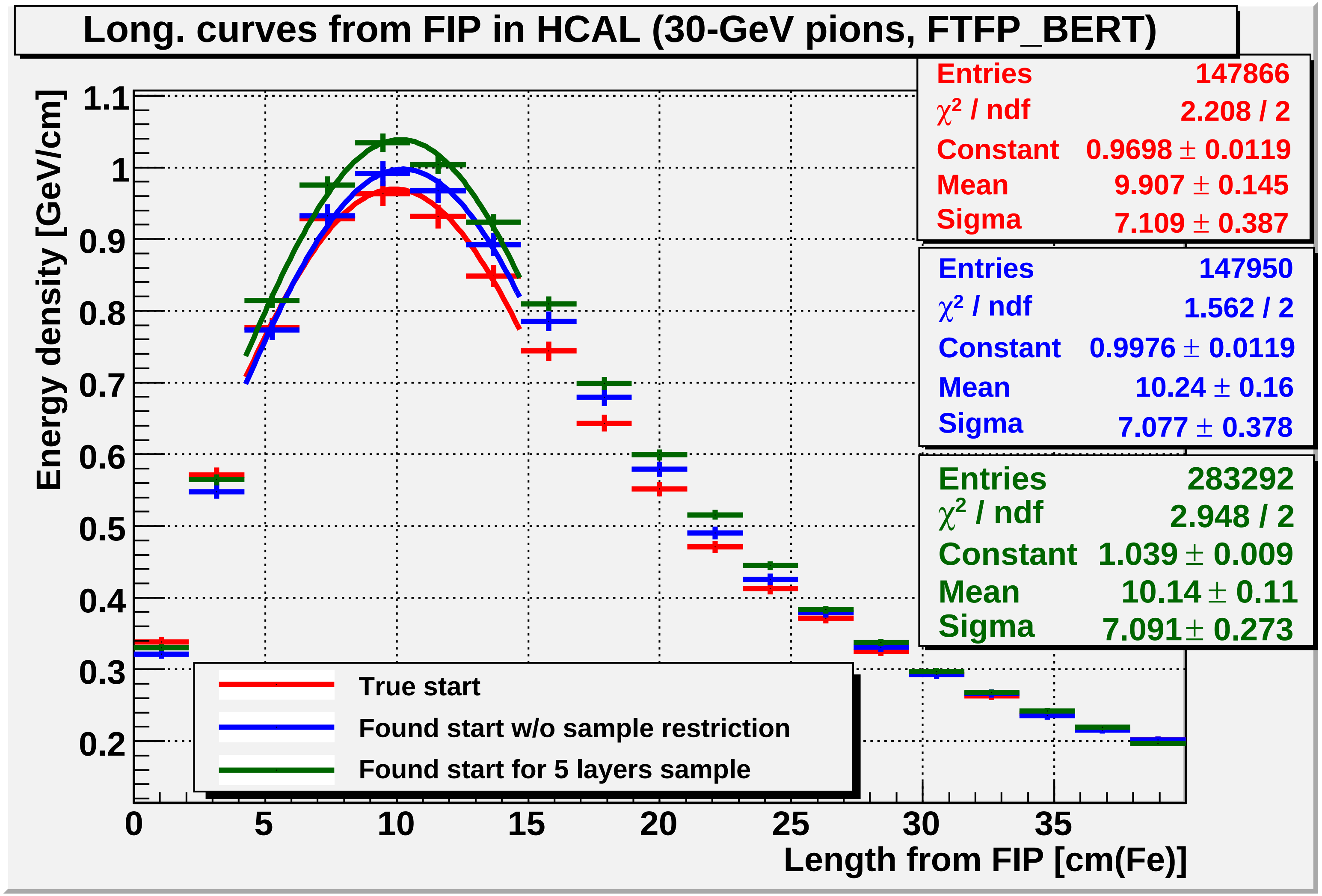
True shower start vs. found



For a priori restricted sample the found slope differs significantly from the true one.

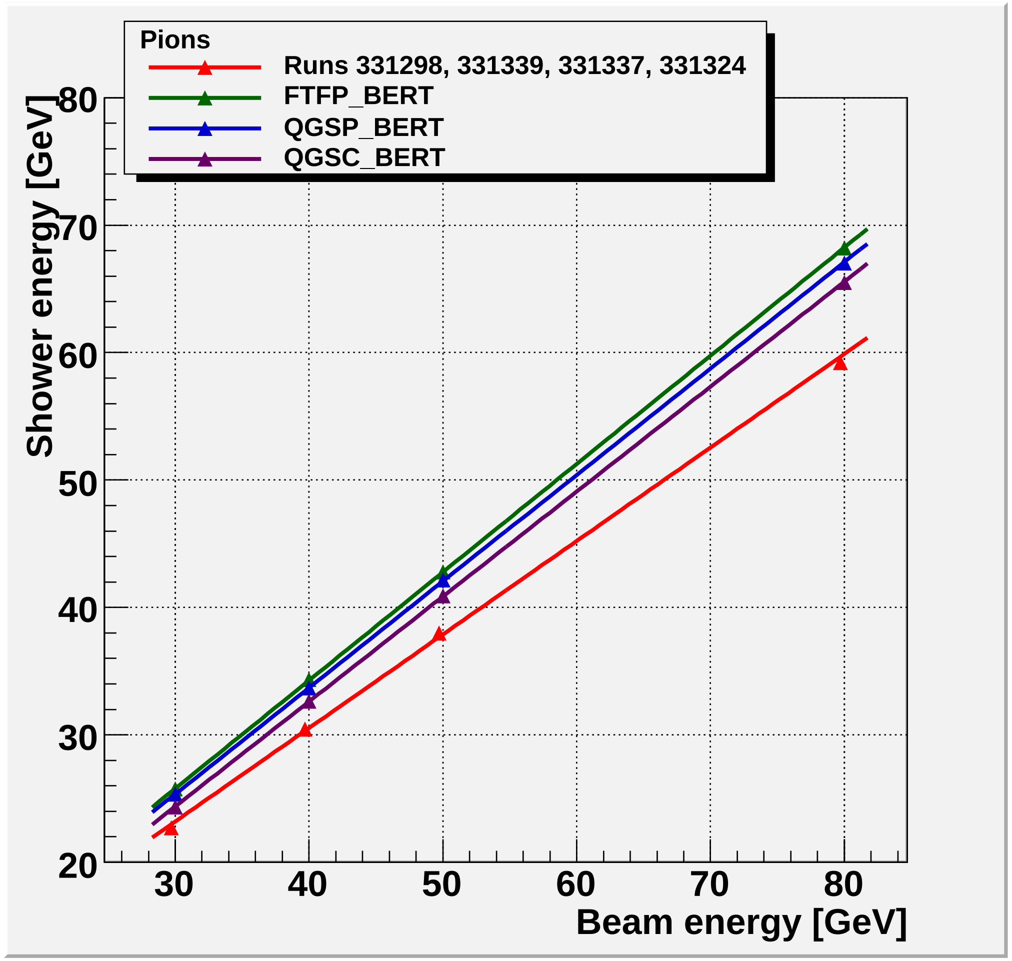
Therefore it is necessary to use true interaction point to construct profiles.

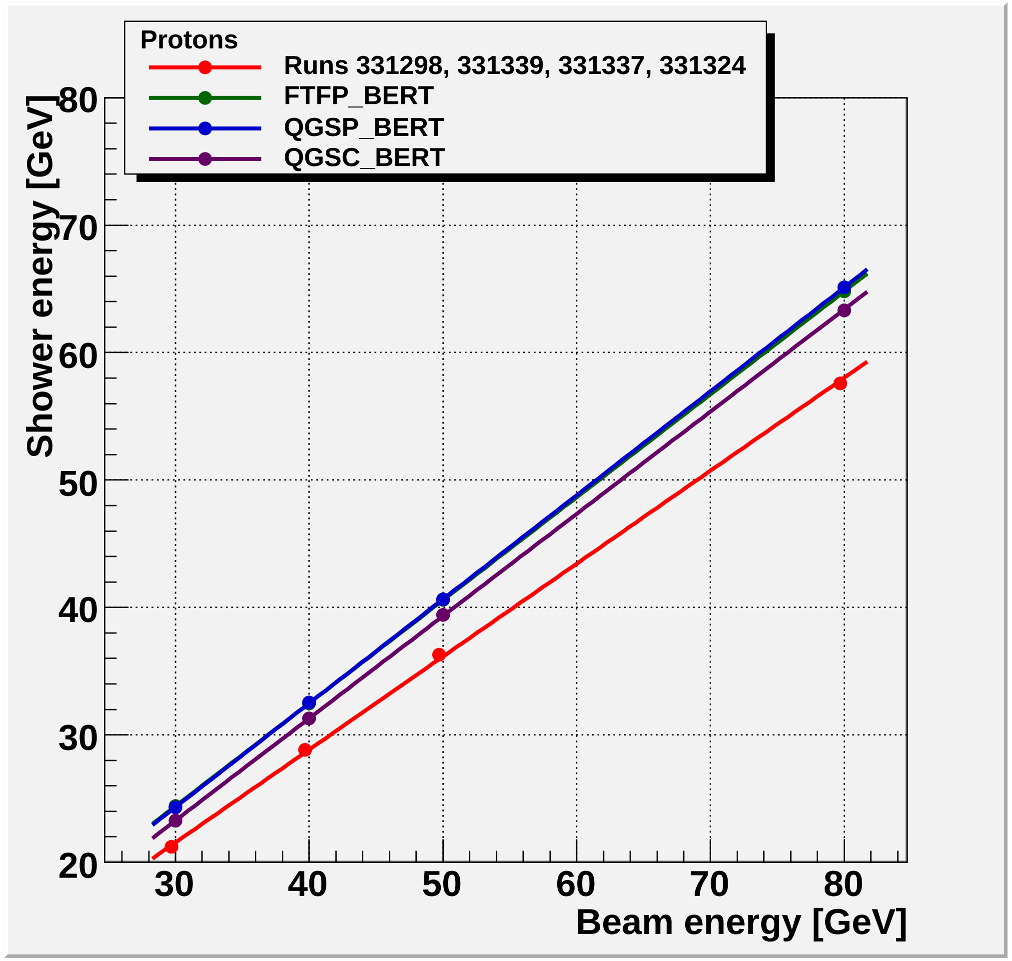
True shower start vs. found: shift of longitudinal curve



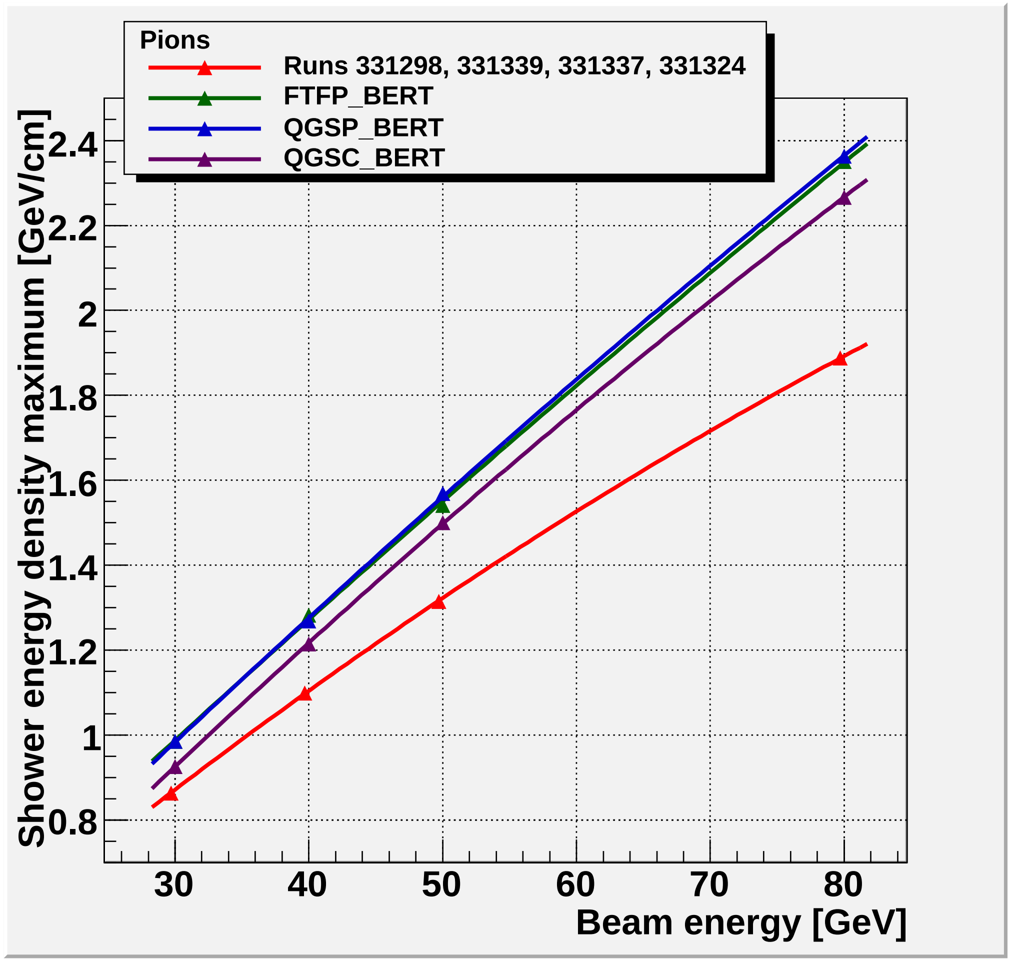
The shift of longitudinal curve is larger for a priori restricted sample than for full sample as in experimental data.

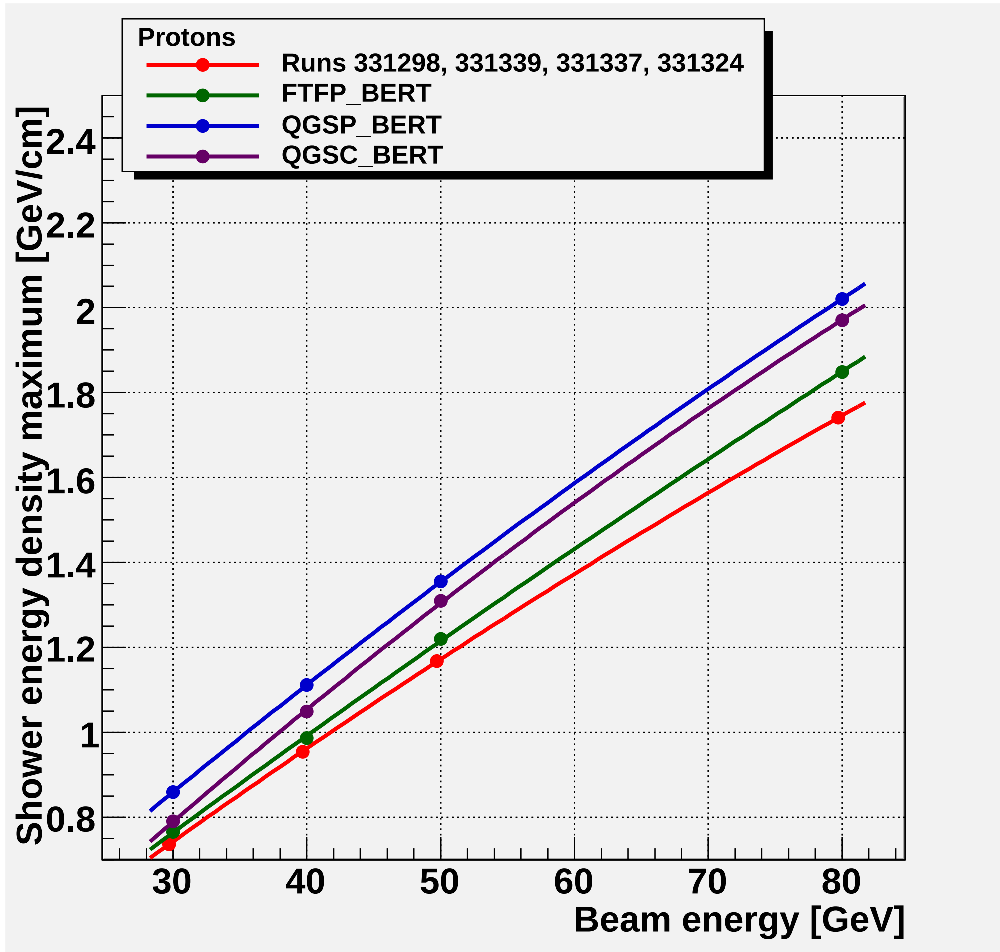
Energy deposited in HCAL vs. beam energy



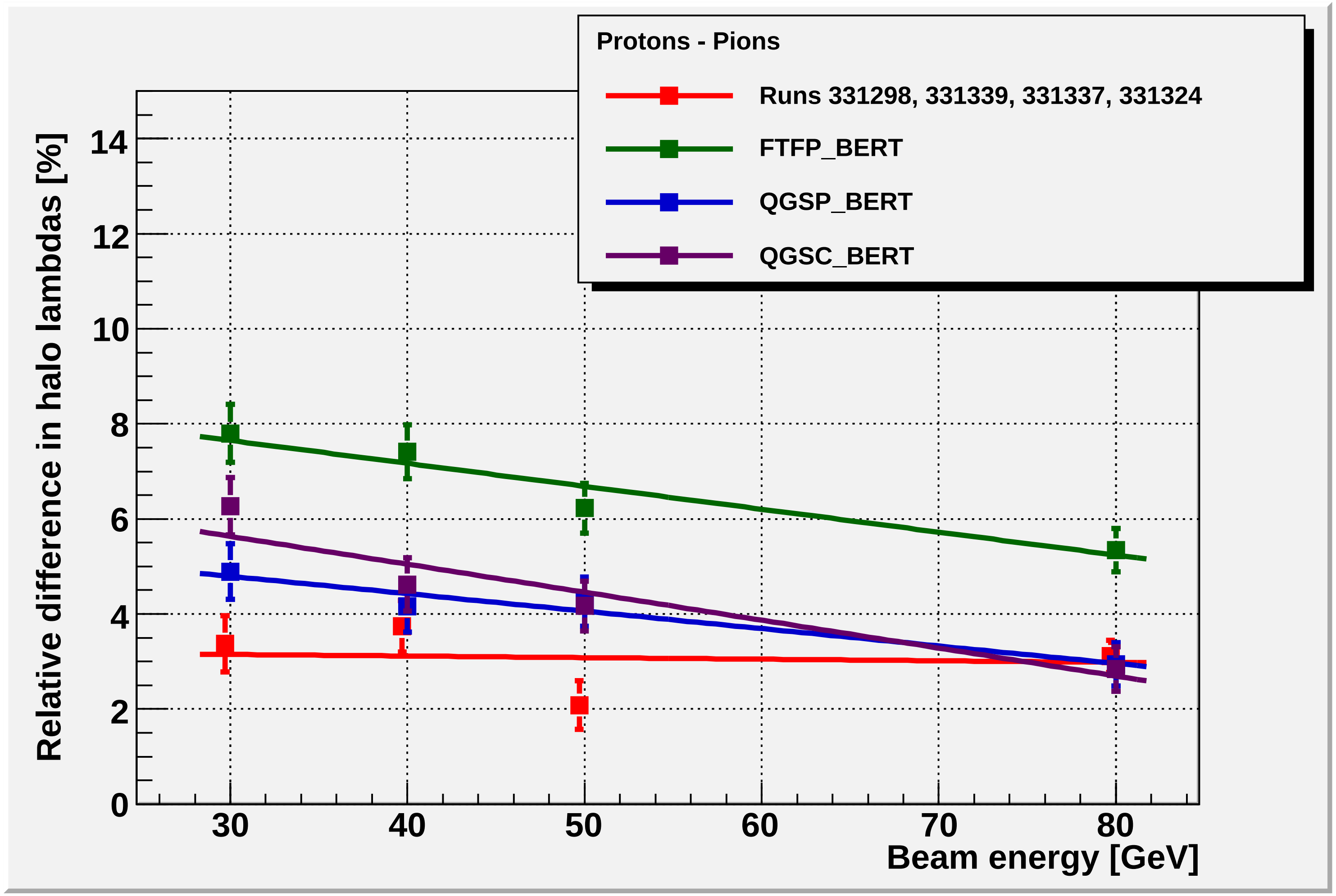


Energy dependence of energy density maximum





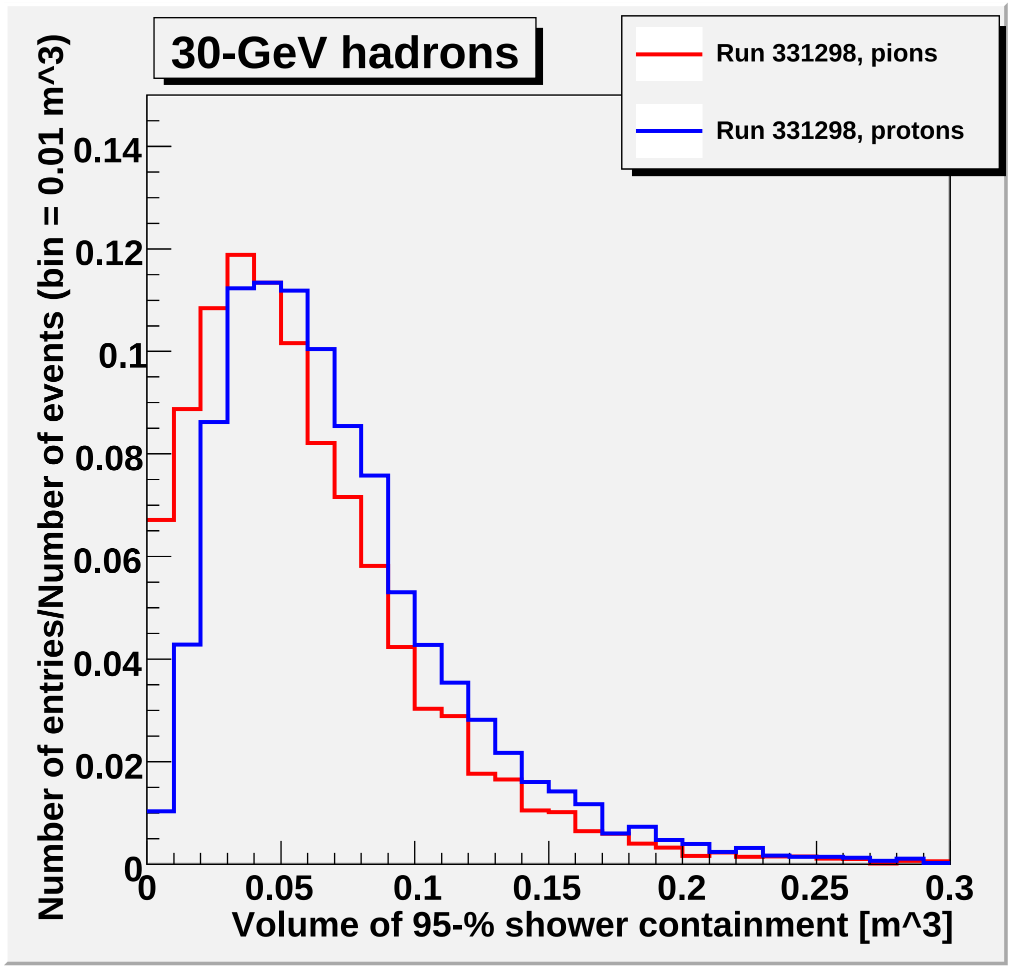
Relative differences in halo slope parameter

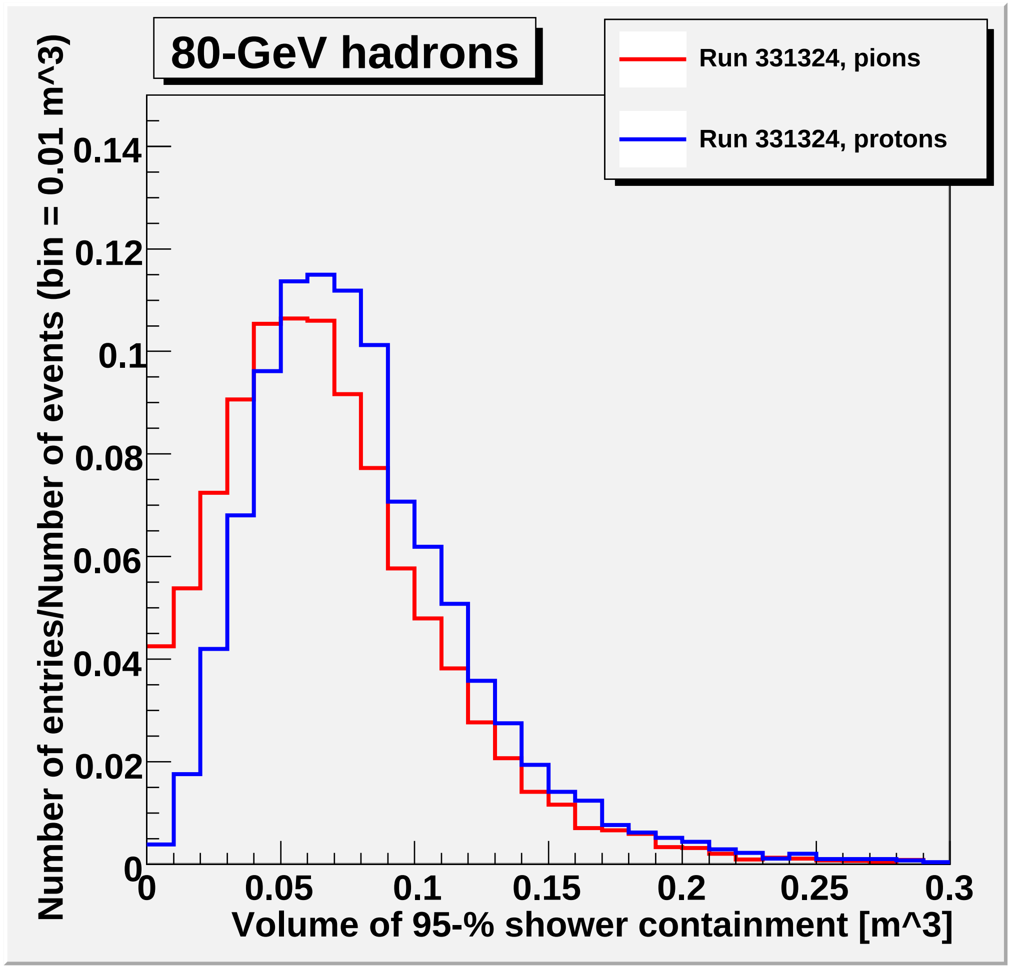


No changes in relative difference between pion and proton showers with increasing energy is observed for data.

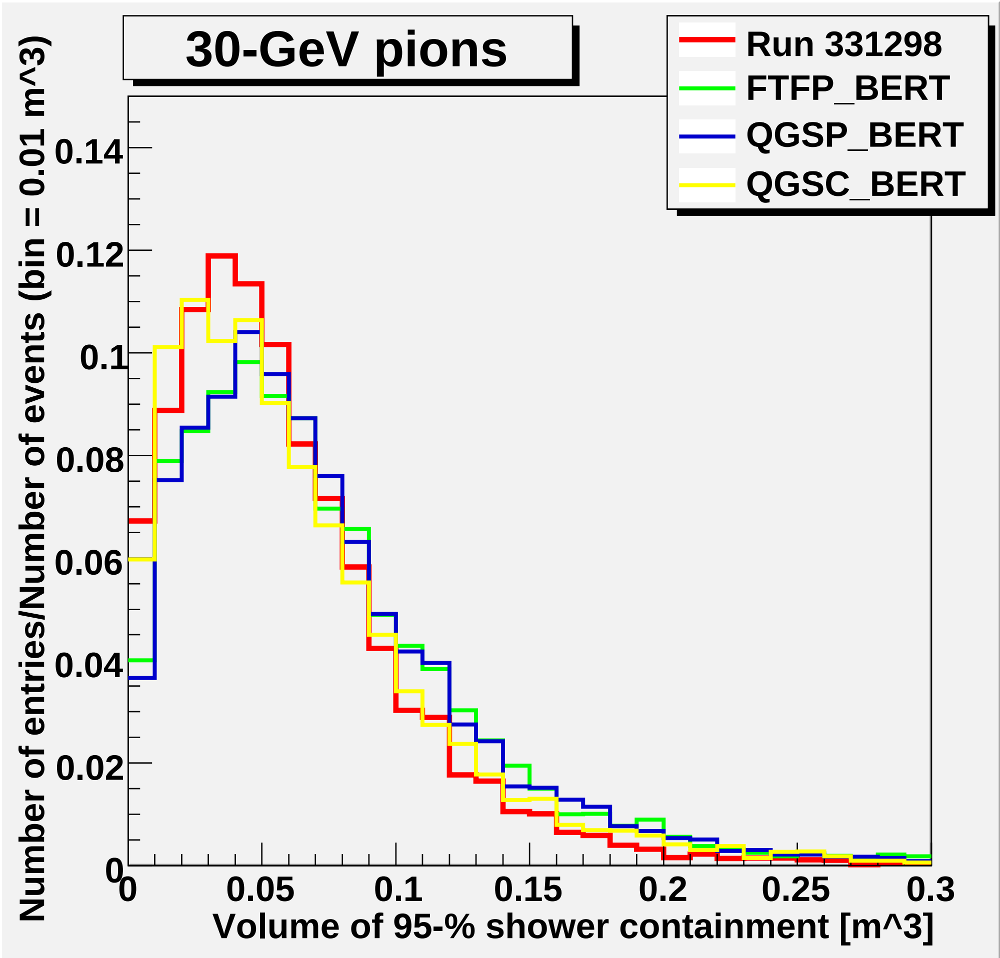
But taking in account the proton sample impurity can make the data behaviour more similar to the MC one.

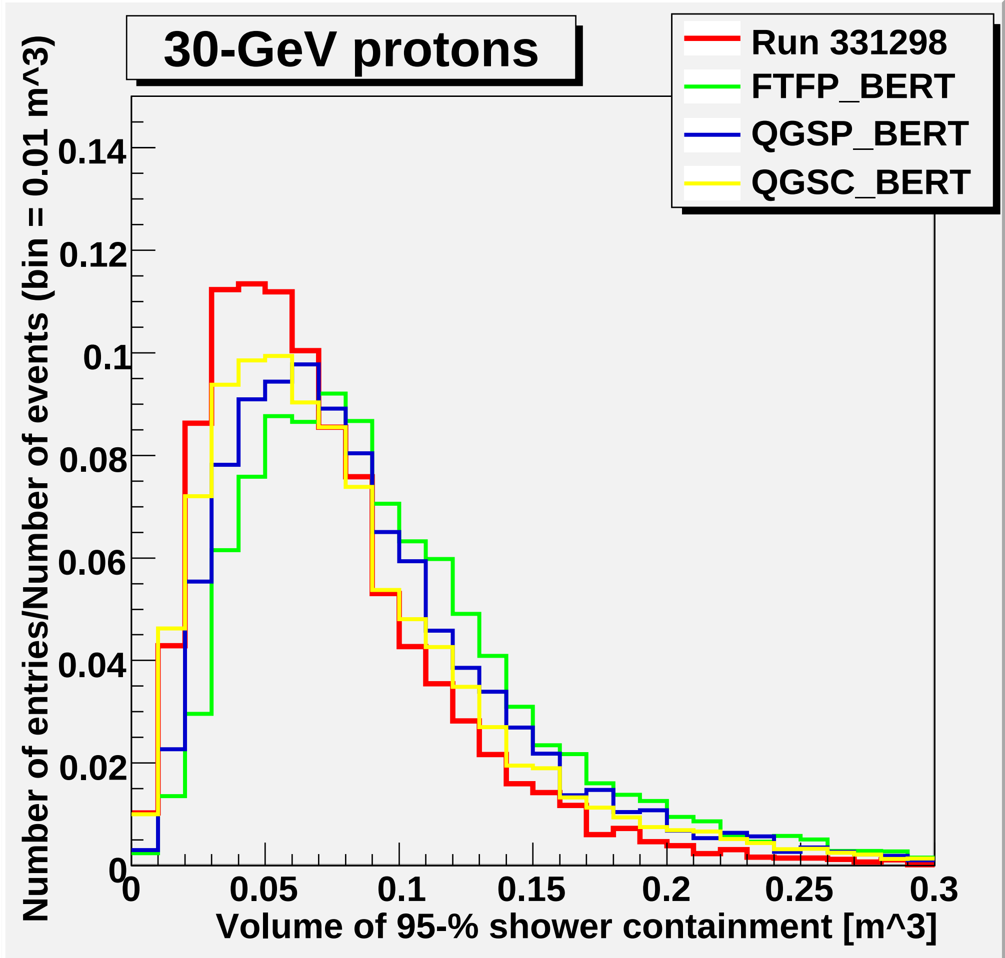
Volume of hadron showers



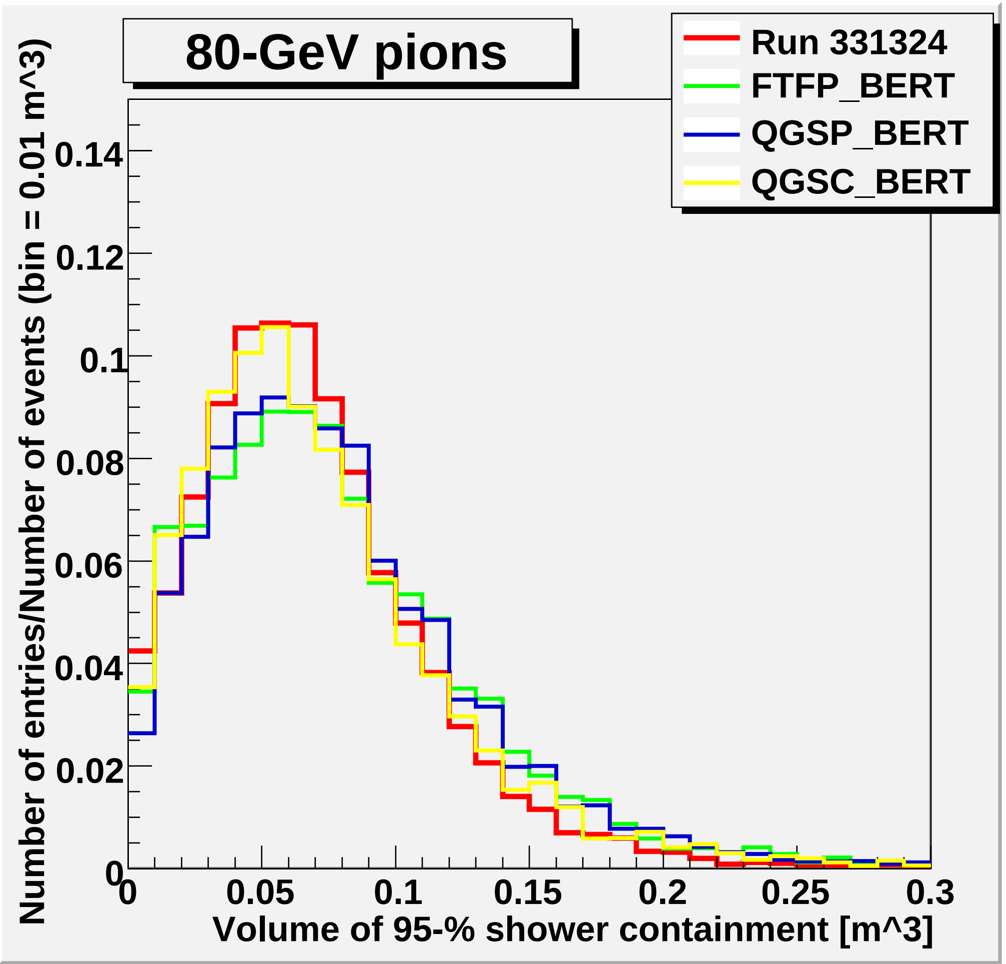


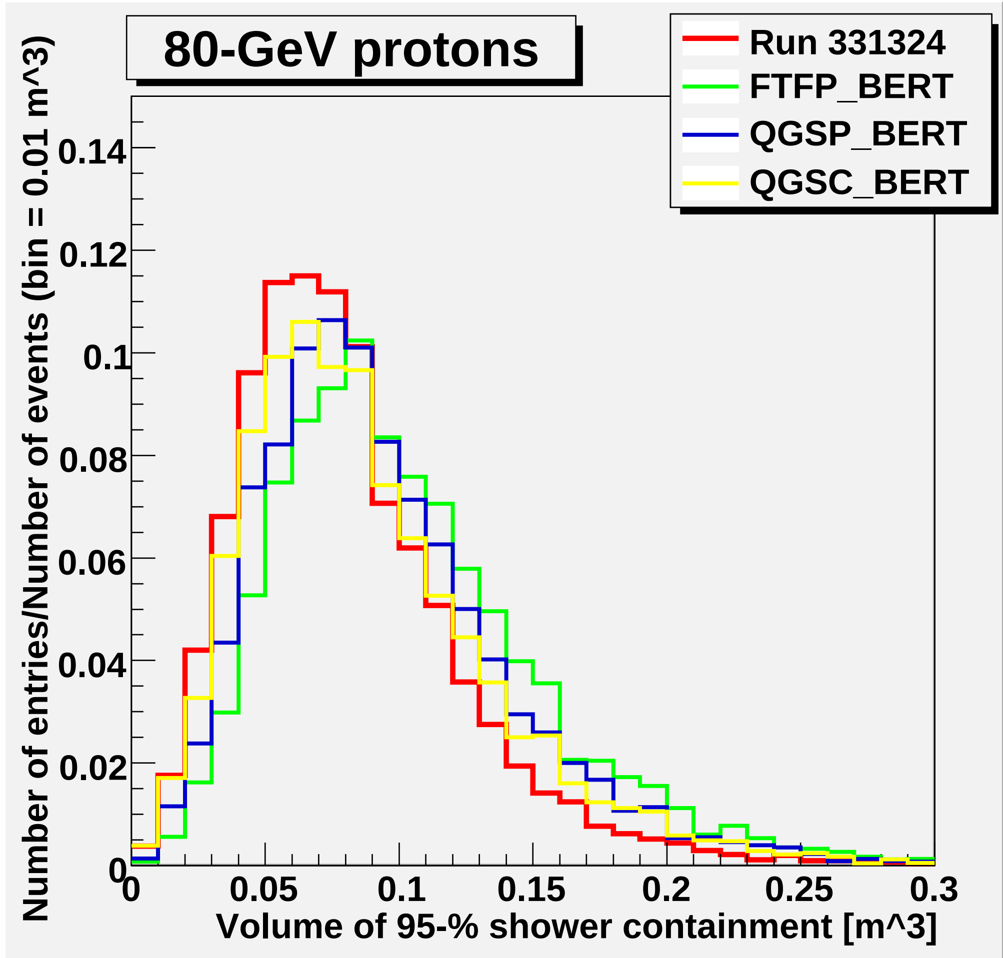
Volume of hadron showers: data and MC



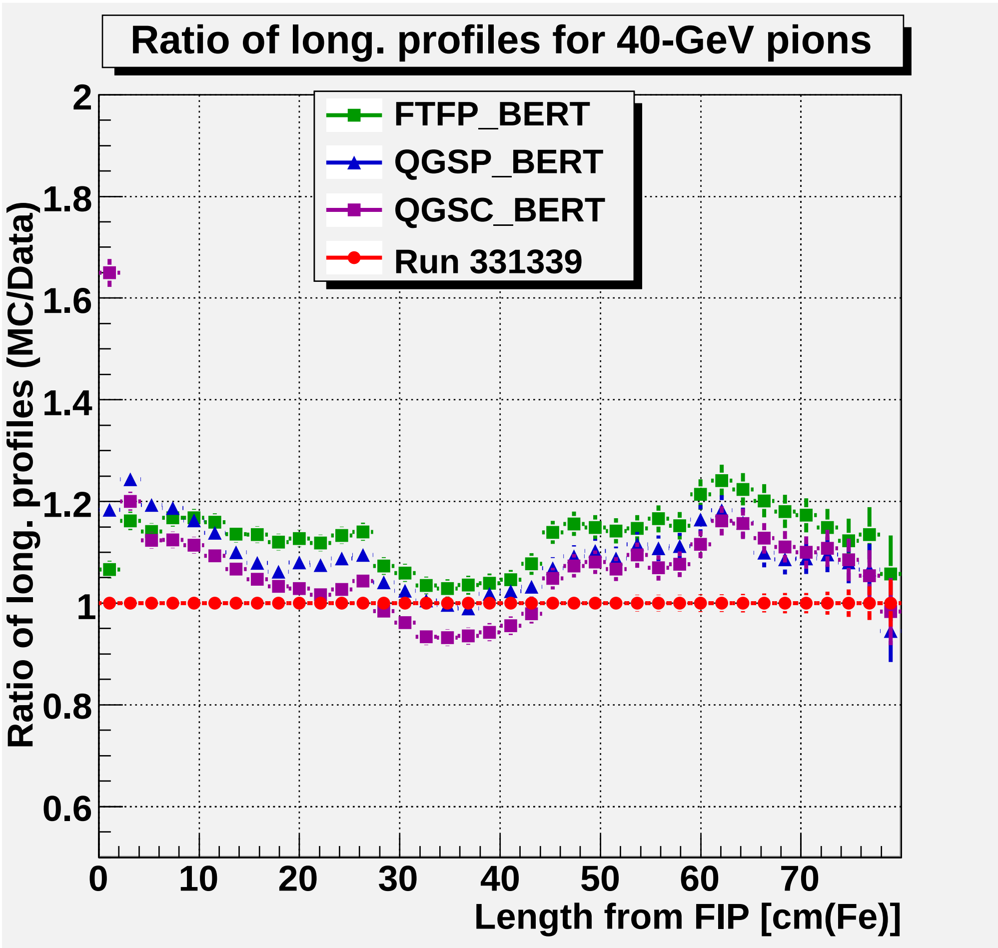


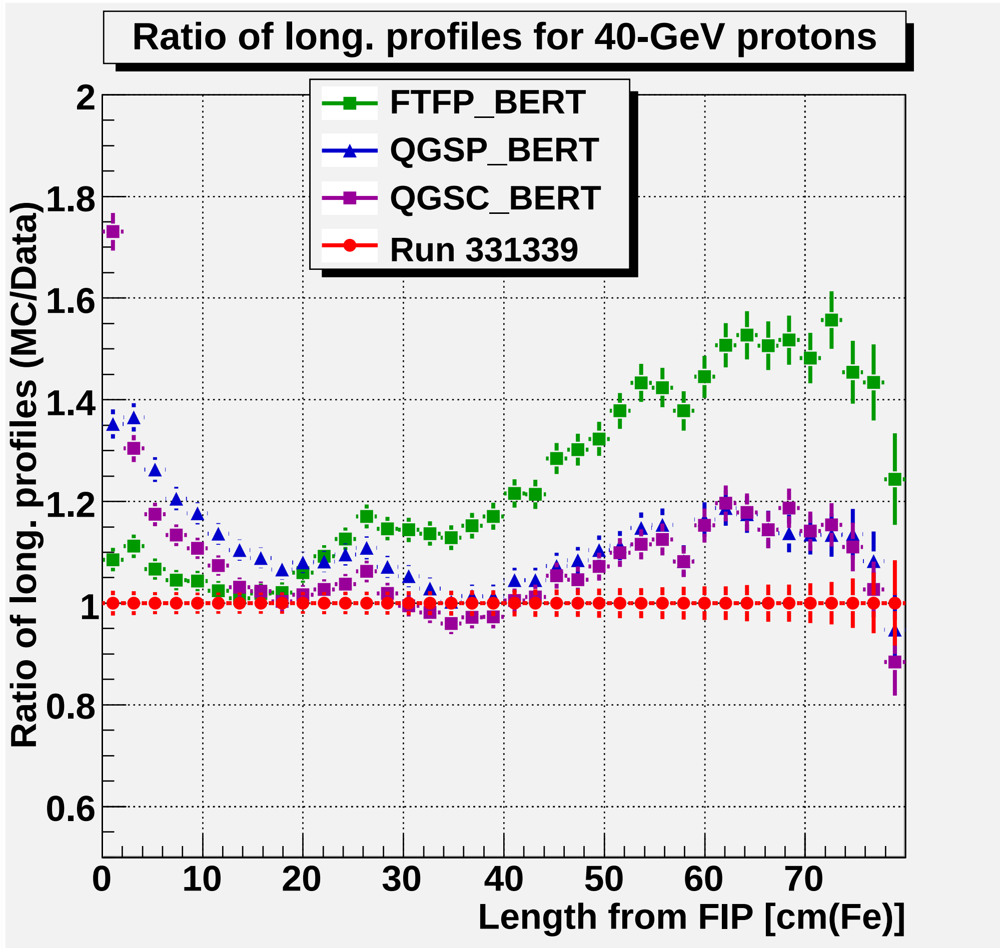
Volume of hadron showers: data and MC



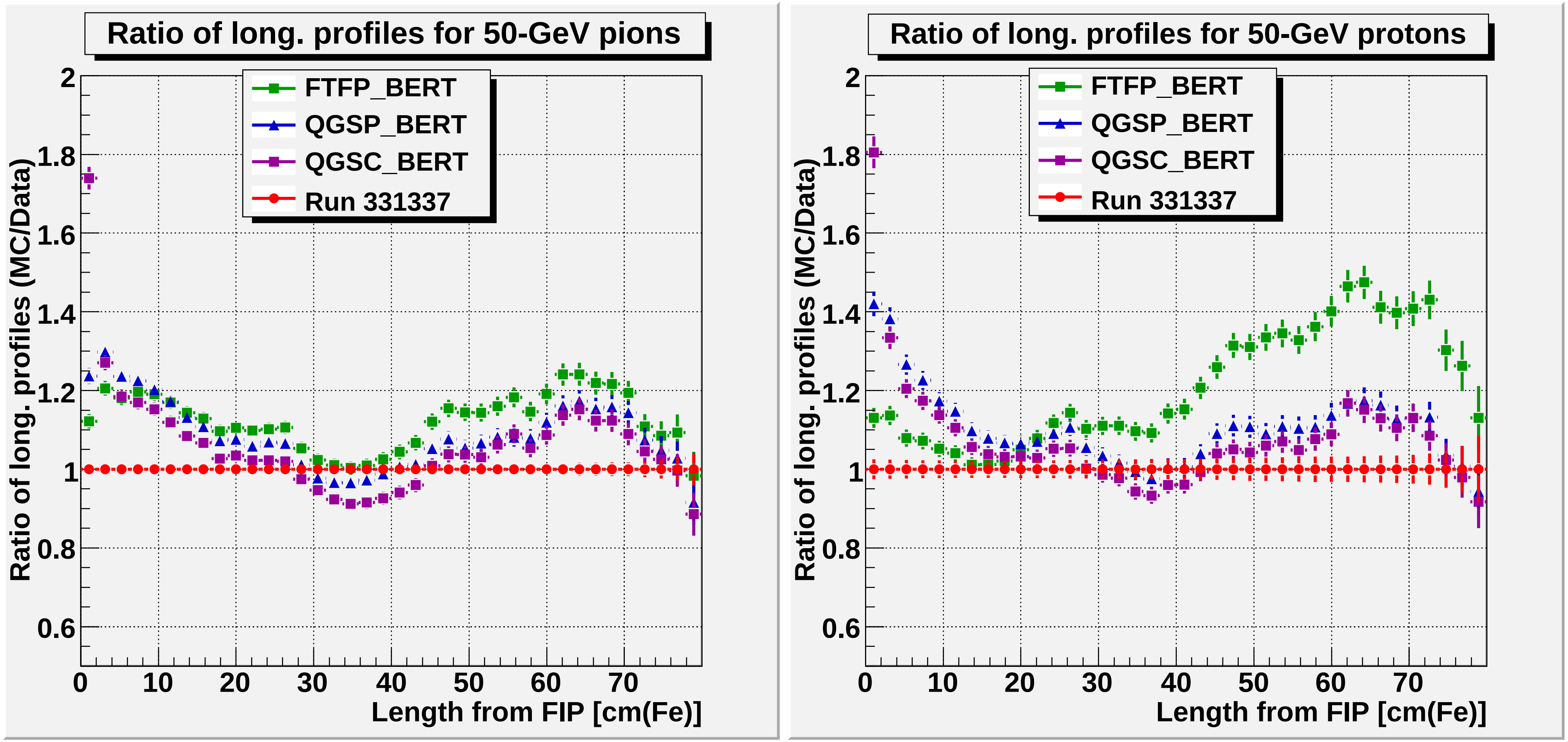


Ratio of longitudinal profiles in HCAL: MC/Data

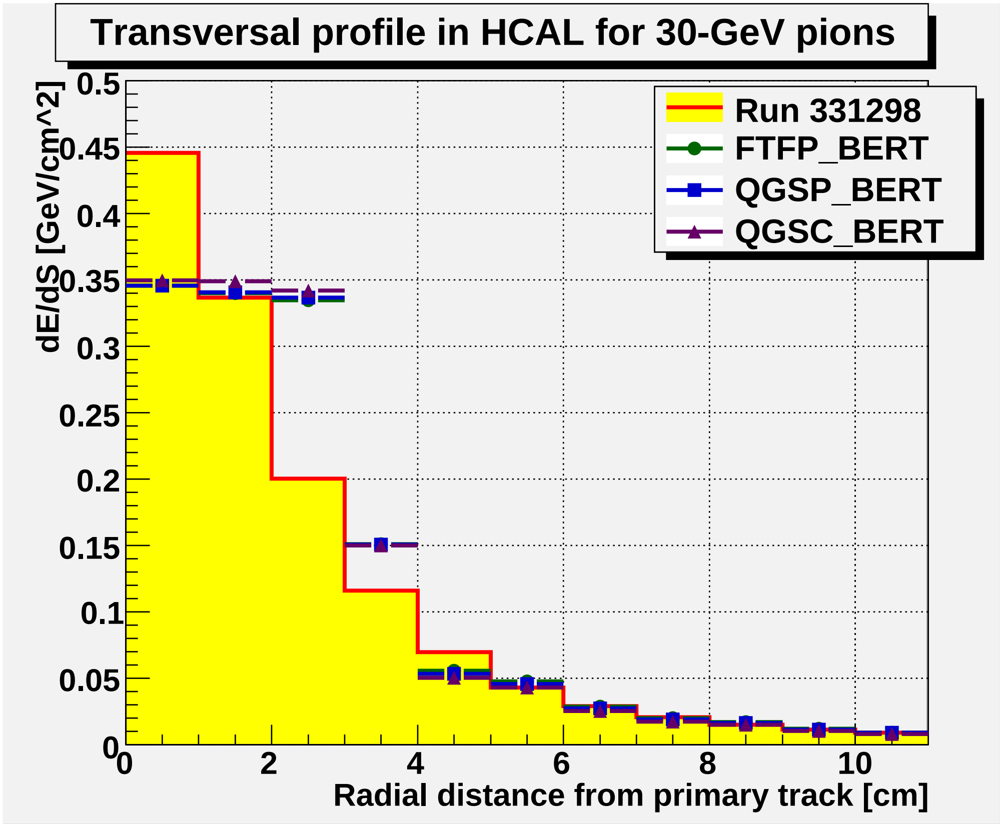


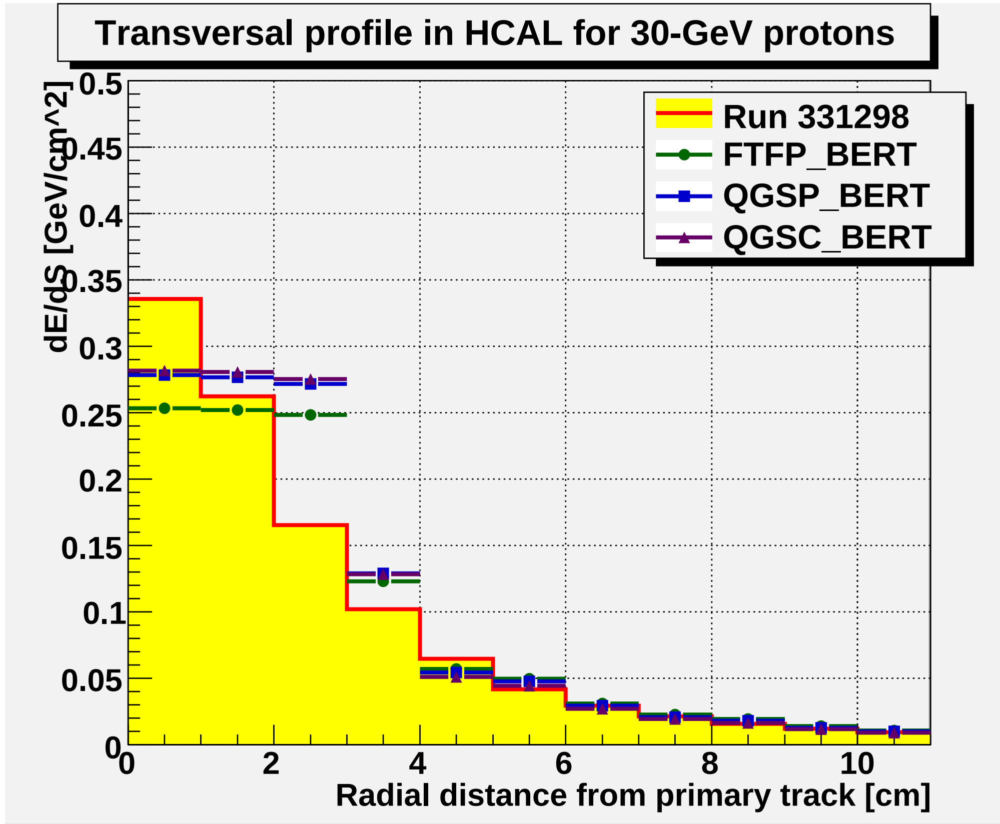


Ratio of longitudinal profiles in HCAL: MC/Data



Transversal profiles in core region at 30 GeV





Transversal profiles in core region at 80 GeV