Positive hadron shower profiles in CALICE AHCAL:

π^+ and proton comparison

ITEP team

CALICE Analysis meeting, DESY, March 2009

Plan

1. **Data used and selection of events**
2. **Starting point distributions: π^+ and protons**
3. **Longitudinal profiles: π^+ and protons**
4. **Transversal profiles: π^+ and protons**
5. **Conclusion**

Data and Event Selection

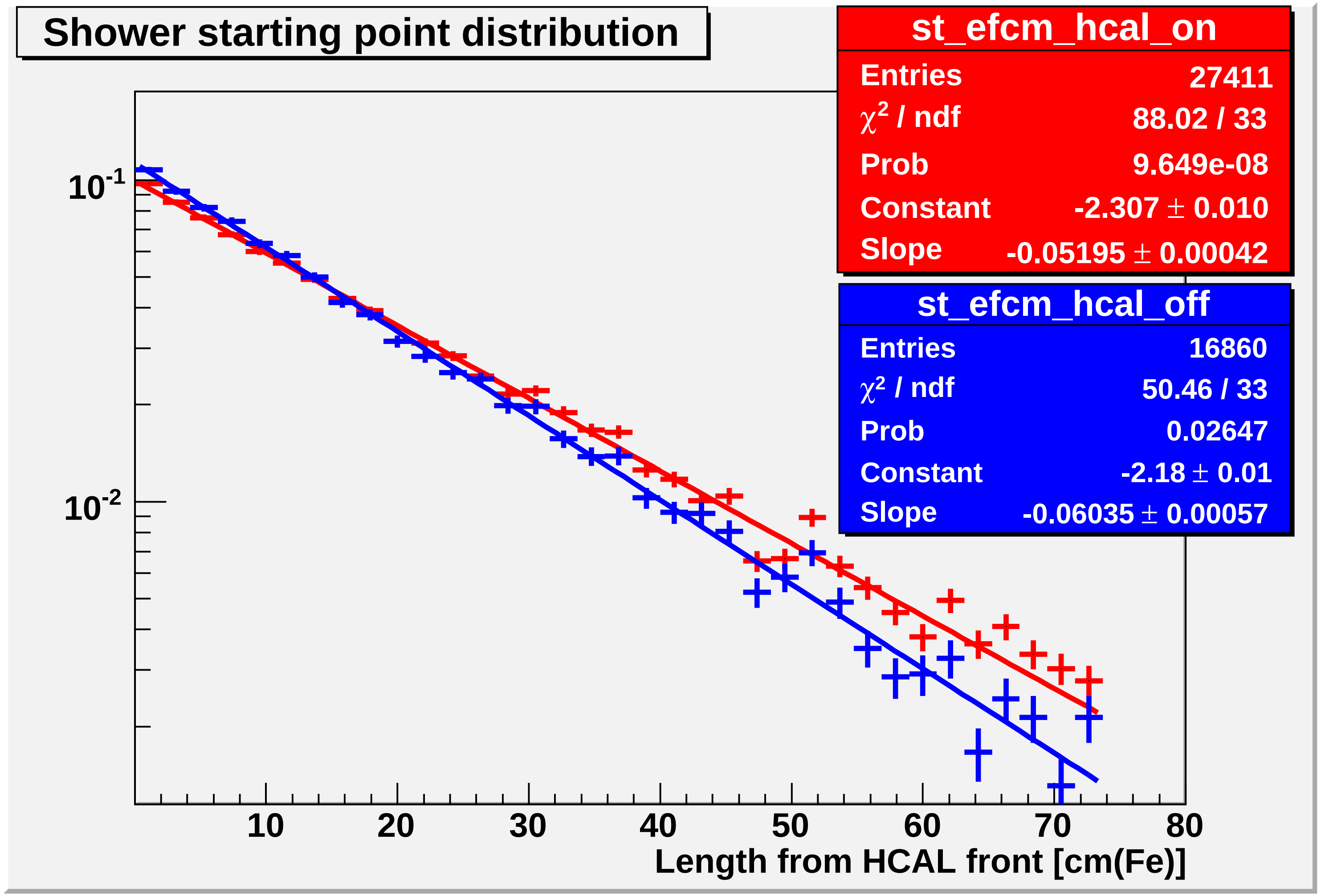
Data: runs from CERN 2007 test beam with complete CALICE Setup (ECAL+HCAL+TCMT)
positive hadrons of 30, 40, 50, and 80 GeV
(331296, 331298, 331340, 331341, 331290, 331338, 331339, 331335, 331337, 331280, 331324)

Selections: exclude muon and trash events (see V. Morgunov talk on CALICE meeting in Dec 2008)
shower start in HCAL and track in ECAL: exclude events with shower start in ECAL

π^+ or proton: by Cerenkov trigger data stored in data files
purity of proton sample is ~95% except for 80-GeV runs where it was ~75%
(see V. Morgunov talk on CALICE meeting in December 2008
about the estimation of proton sample purity)

Thanks to Shaojn Lu (MPI, Munchen) for Monte–Carlo simulations.

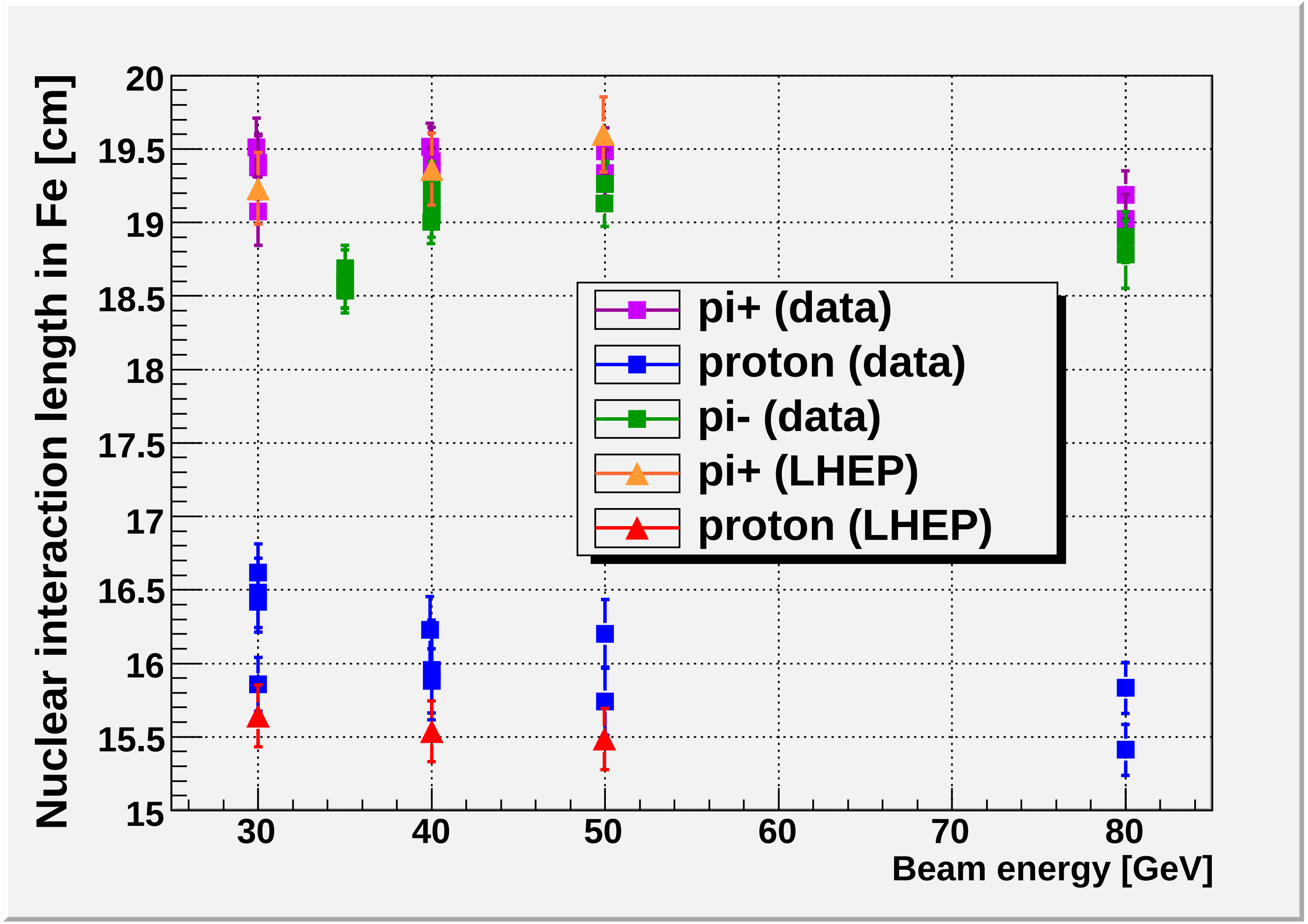
Shower starting point distributions



The spatial length of track is recalculated to cm of iron. Taking in account that $\lambda_I \sim \frac{A}{\sigma_I \rho}$ the additional thickness of other components (scintillator and air) was estimated to be equivalent to ∼1.5mm of iron per layer.

Nuclear interaction length estimation

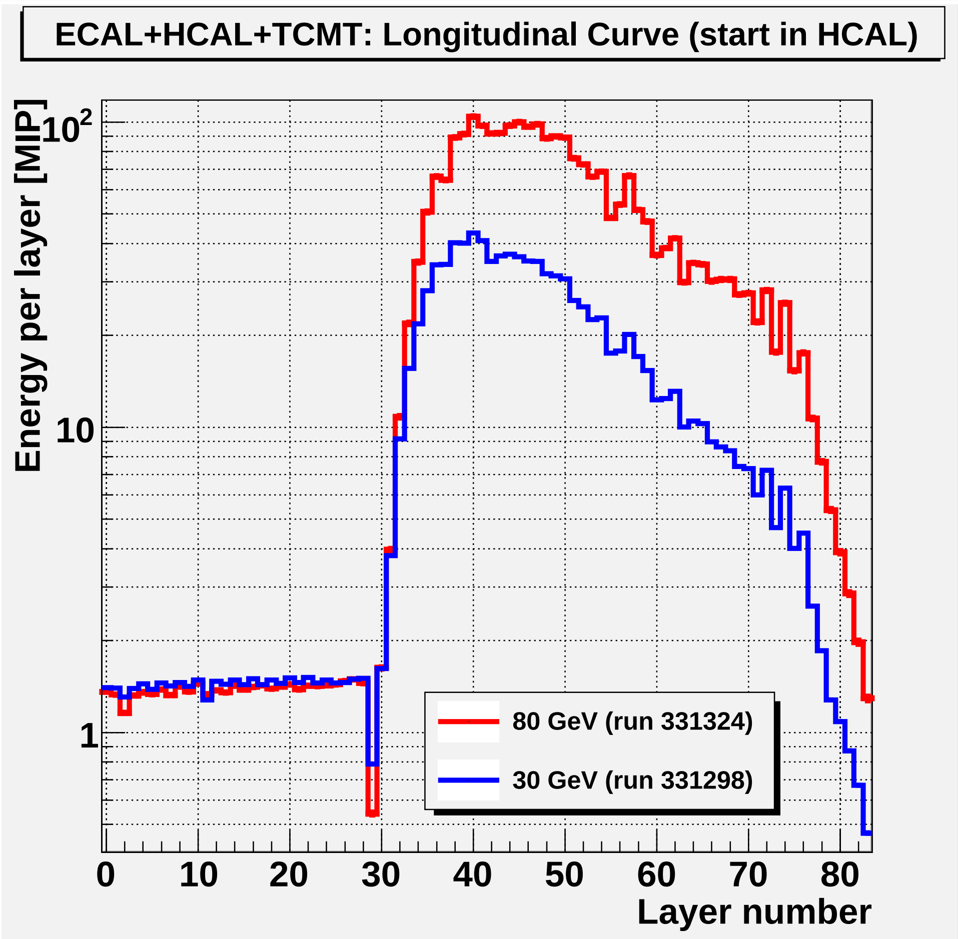
Nuclear interaction length was estimated from data (π^+, π^-, proton) and LHEP (π^+, proton) at different energies.

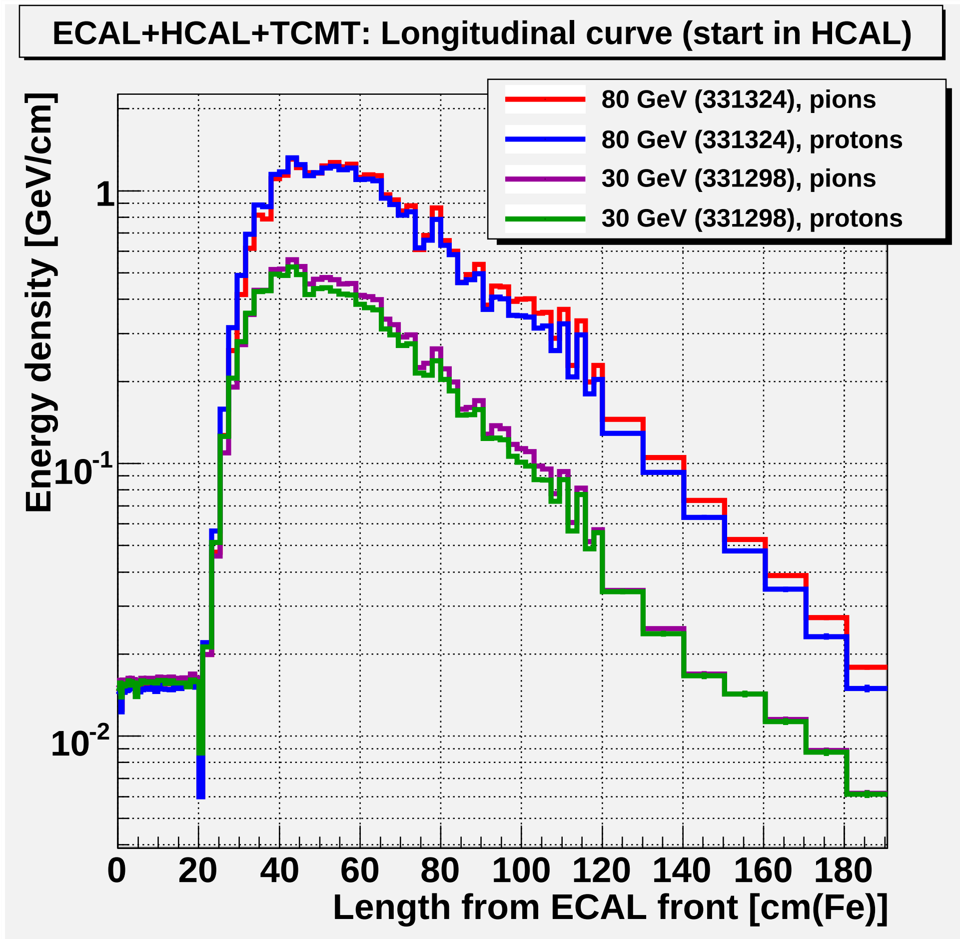


Longitudinal curves for complete CALICE setup

Longitudinal curves for 30 and 80 GeV beams are shown in MIPs per layer (left) and in GeV per cm of iron (right).

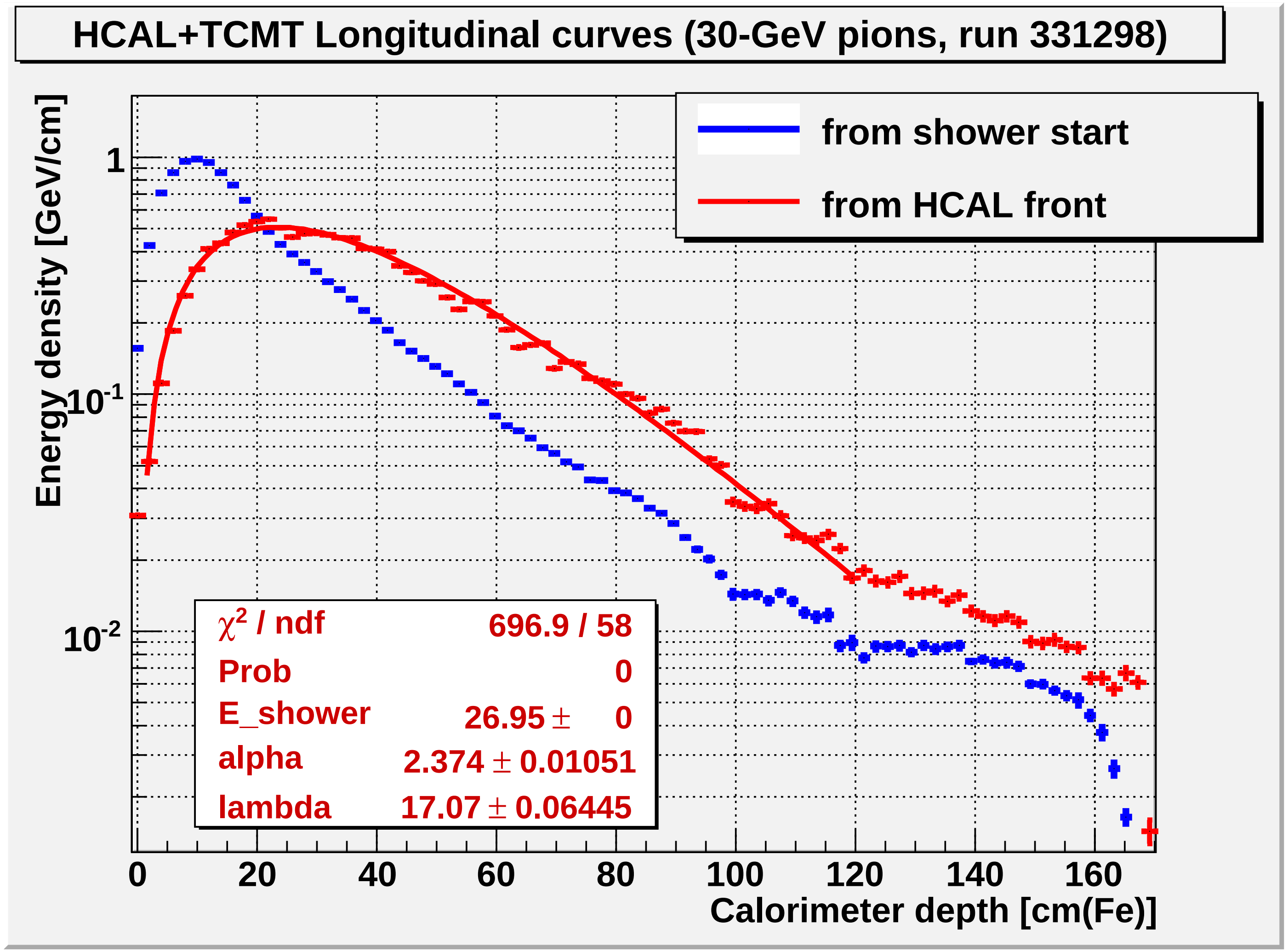
The selected events consist of tracks in ECAL and shower starting in HCAL.





The track signal is slightly above 1 MIP. For both energies the 1-MIP level can be achieved only in TCMT.

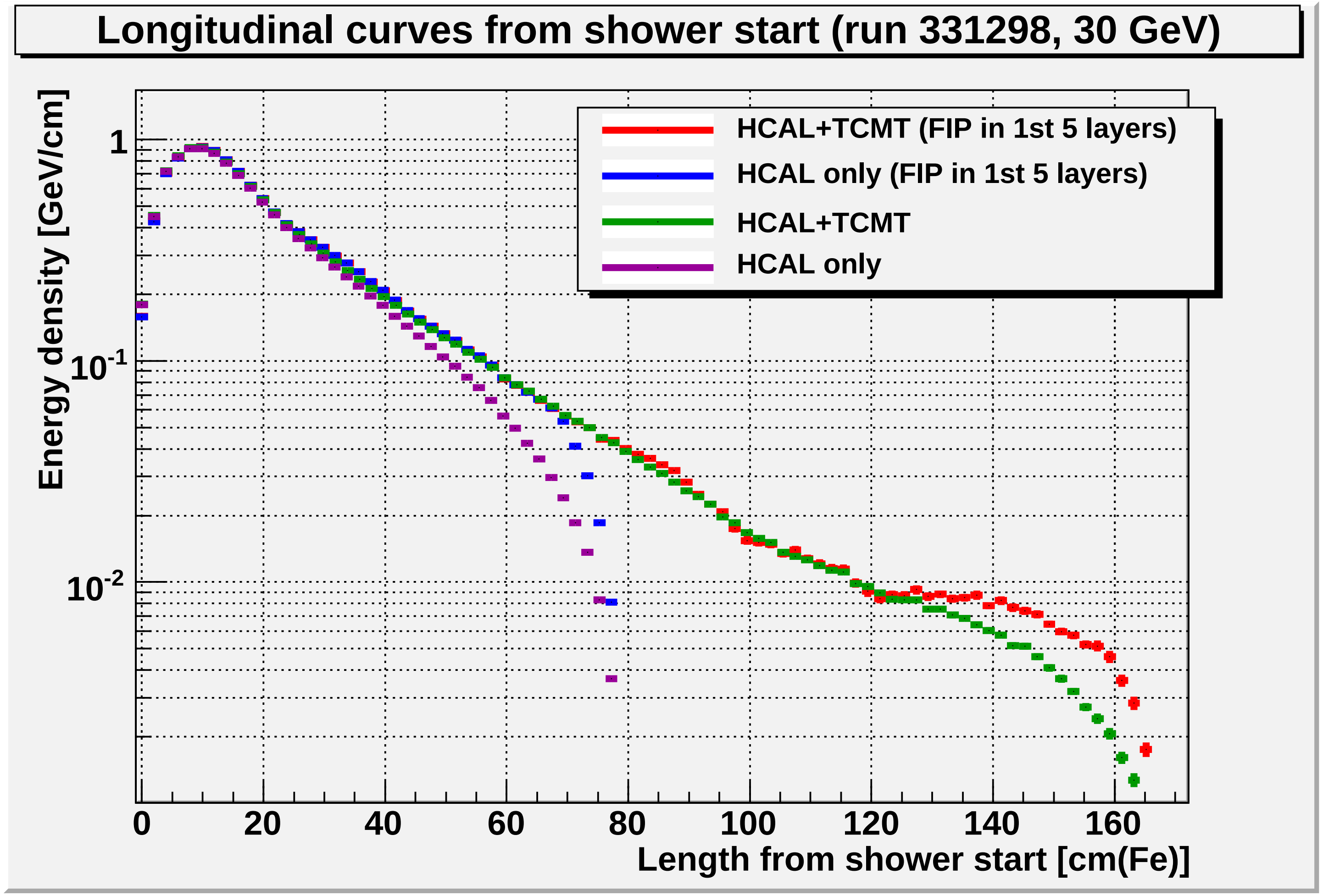
Longitudinal curves from calorimeter front and shower start



Longitudinal curve from calorimeter front was fitted by standard gamma distribution function $\frac{1}{\lambda\Gamma(\alpha)}(\frac{x}{\lambda})^{\alpha-1}exp(-x/\lambda)$. λ obtained from the fit can be compared with hadron nuclear interaction length.

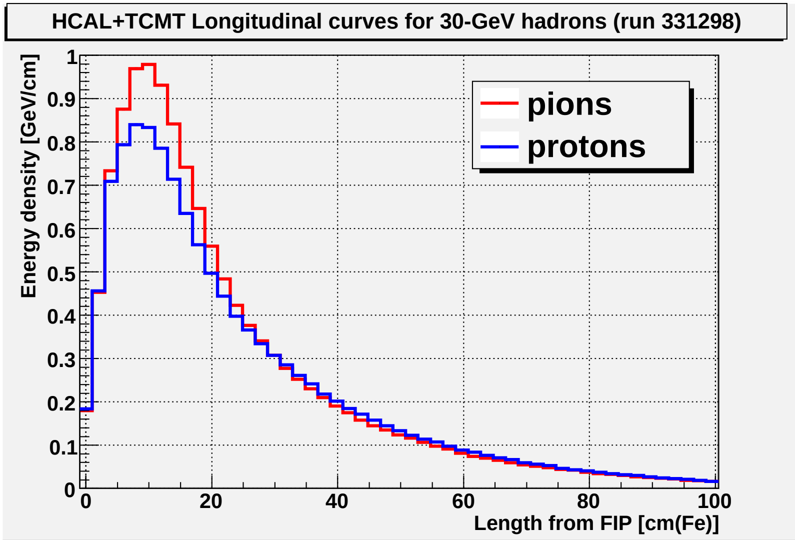
Longitudinal curves from shower start

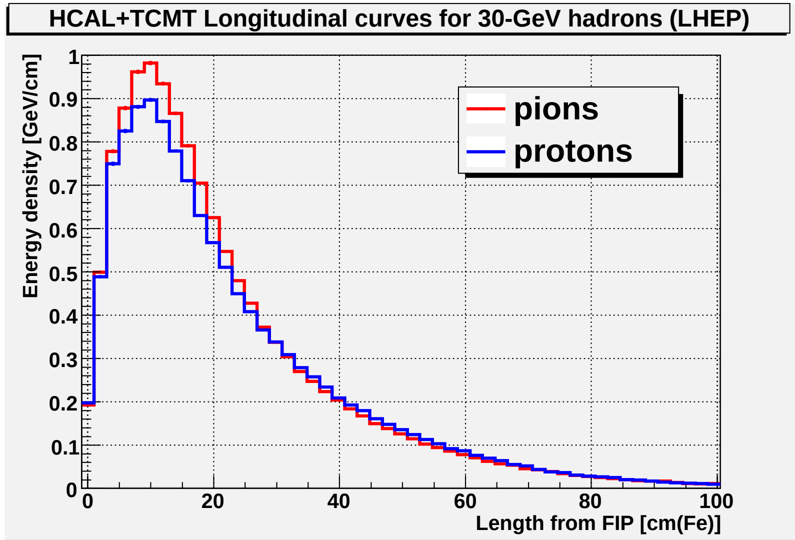
The addition of data from TCMT allows to decrease the leakage of shower.



The selection of events that start in first 5 layers of HCAL changes the slope of longitudinal curve. The right slope can be obtained by using TCMT data or selecting events starting in the beginning of HCAL.

Longitudinal curves for pions and protons

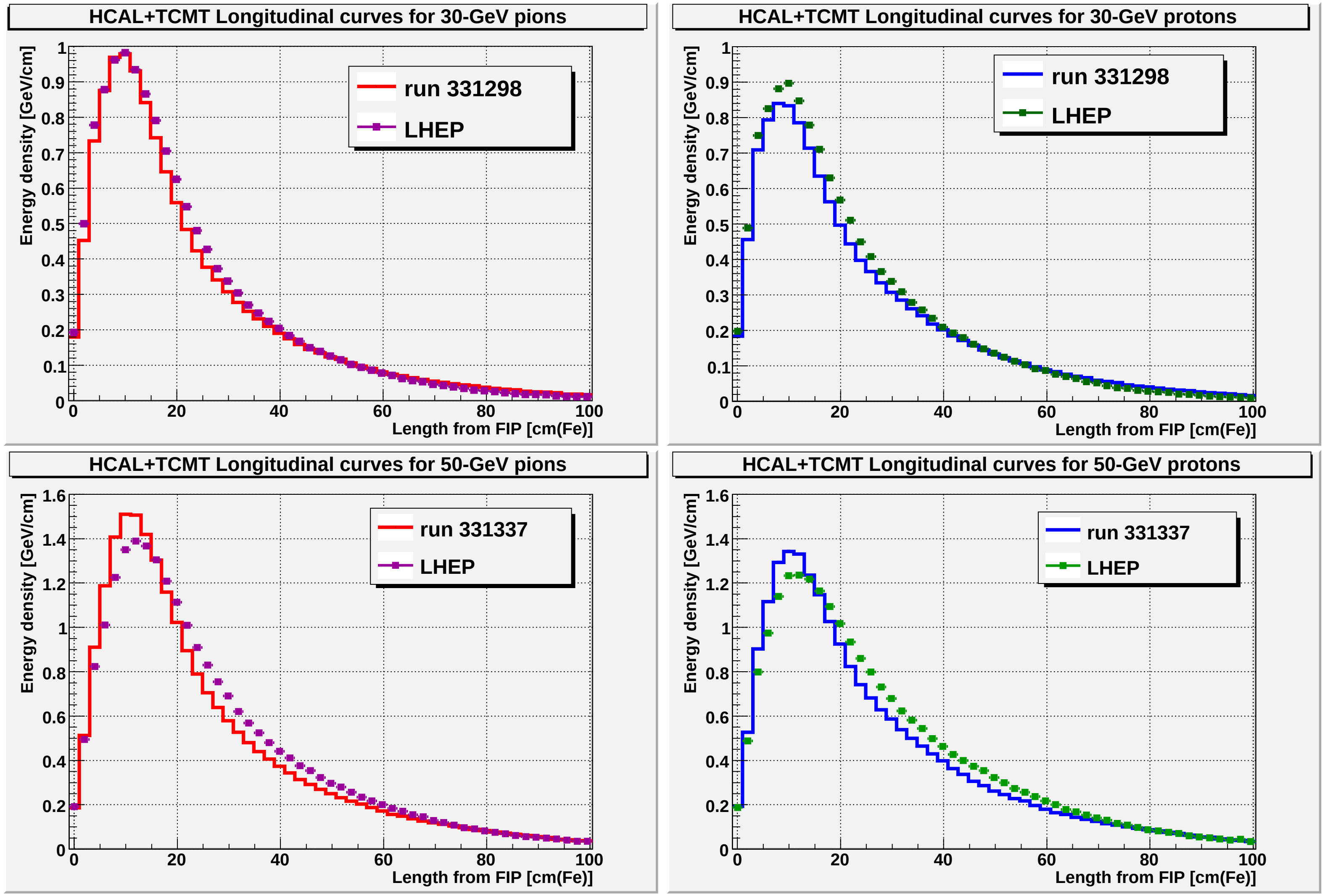




Beam energy	Shower energy, GeV		$(E^s_\pi - E^s_p)/E^s_\pi$	Max. energy density, GeV/cm		$(D^{max}_\pi - D^{max}_p)/D^{max}_\pi$	
GeV	E^s_π	E^s_p	%	D^{max}_π	D^{max}_p	%	
30	27.0	25.4	5.8	0.98	0.84	14.0	Data
40	36.1	34.4	4.7	1.25	1.09	12.8	
50	45.5	43.6	3.9	1.51	1.34	11.4	
80	71.7	69.8	2.4	2.19	1.98	9.6	
30	27.0	25.9	4.1	0.98	0.90	8.7	LHEP
40	36.8	35.6	3.4	1.19	1.09	8.8	
50	46.6	45.2	3.0	1.39	1.24	11.0	

LHEP reproduces the decrease of integral differences but does not reproduce differences in shower maximum.

Longitudinal curves: data and MC



The similar behaviour of integral values from LHEP and data is due to compensation of different behaviour in maximum by differences in the tails of distribution.

Parameterization of longitudinal curve: function

The parameterization of EM shower longitudinal development with gamma distribution function was proposed in 1975[1]. Later the similar parameterization was introduced for hadronic showers[2] as the following 2-component function:

$$\frac{dE}{dz} = E\left(\frac{w}{\lambda_1\Gamma(\alpha_1)}(z/\lambda_1)^{\alpha_1-1}exp(-z/\lambda_1) + \frac{1-w}{\lambda_2\Gamma(\alpha_2)}(z/\lambda_2)^{\alpha_2-1}exp(-z/\lambda_2)\right) = f1 + f2,$$

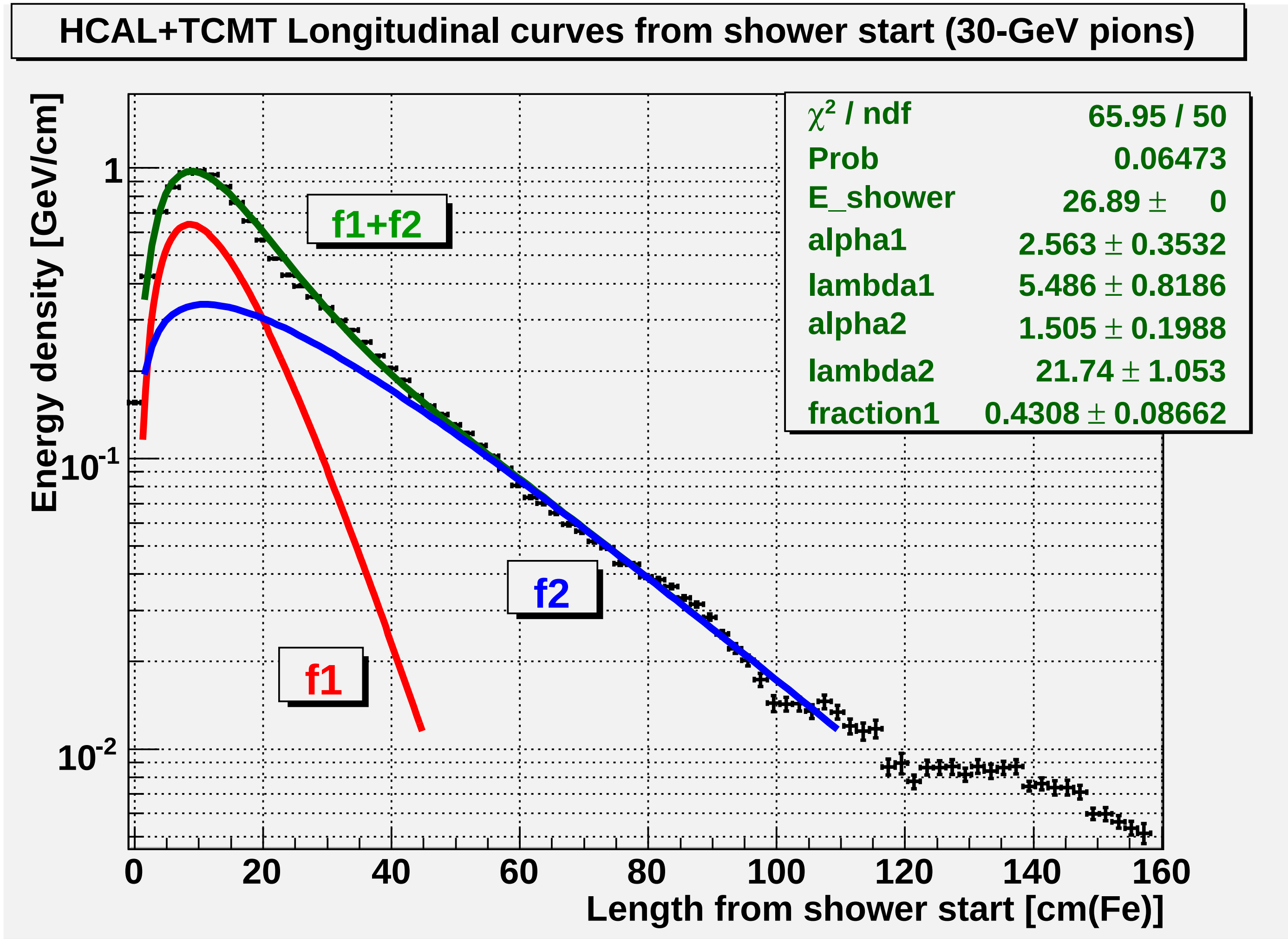
where E - integral under the longitudinal curve, w - weight (or fraction) of the first component, α_1, α_2, λ_1, λ_2 - free parameters.

The first term of this equation can be considered as electromagnetic component and the second one as hadronic component of the pion- or proton-induced shower.

[1] E.Longo and I. Sestili, NIM, 128 (1975), 283.

[2] R.K. Bock et al. NIM, 186 (1981), 533.

Parameterization of longitudinal curve: example



Two slopes on the longitudinal curve from shower start correspond to the general notion that hadron-induced shower consists of two components with different behaviour: electromagnetic (π^0, γ) and hadronic.

Parameter estimations from the longitudinal curve fit

Parameters of longitudinal curve were estimated separately for pions and protons.

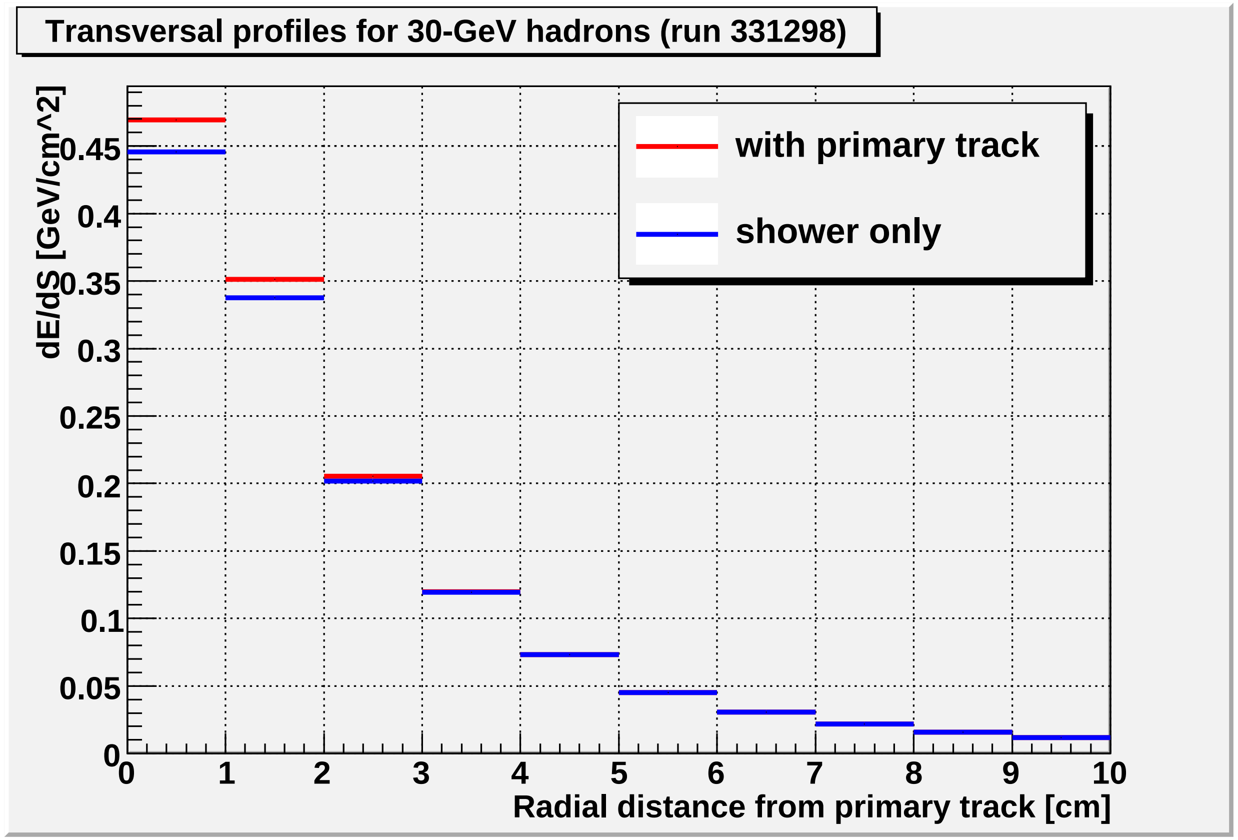
Beam energy GeV	Shower energy GeV	w	λ_1 cm	λ_2 cm	α_1	α_2
Protons						
30	25.4	0.31	5.4	21.9	2.6	1.4
40	34.4	0.22	4.2	21.3	3.3	1.5
50	43.6	0.30	4.7	20.2	3.0	1.8
80	69.8	0.49	6.2	17.2	2.7	2.7
π^+						
30	27.0	0.46	5.7	22.1	2.5	1.5
40	36.1	0.47	5.9	17.9	2.8	2.2
50	45.5	0.55	5.9	17.8	2.6	2.4
80	71.7	0.62	6.2	15.6	2.9	3.3

The fraction of EM component for pions is higher than those for protons for all energies.

Additional conditions for transversal profiles

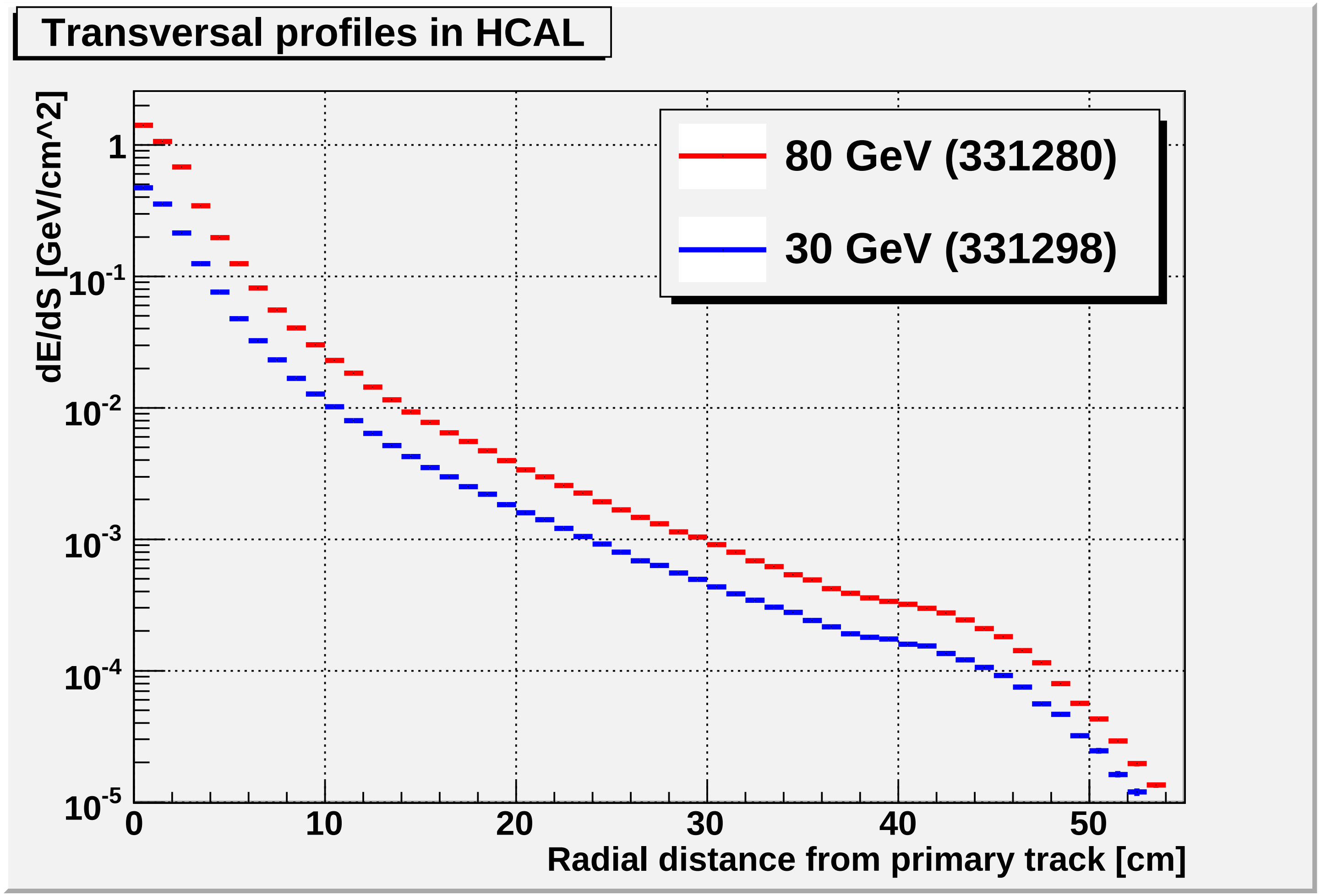
DC track or track found by Track Finder

Randomization of x and y coordinates inside cells to smooth the radial distribution



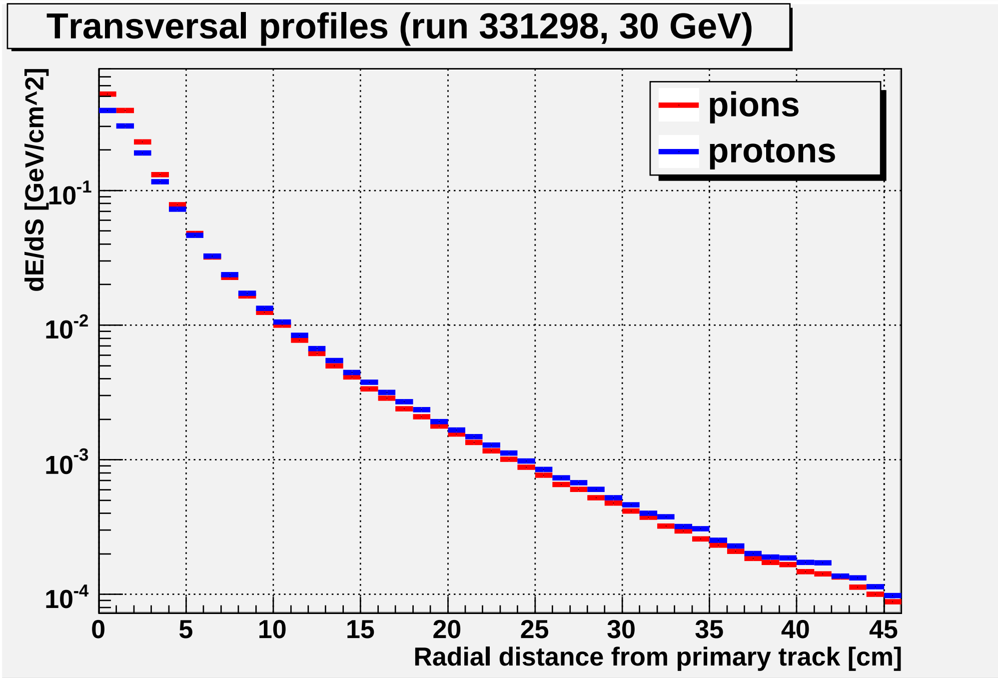
The core region is of most interest in the context of comparing pions and protons. The contribution from primary track to the central region is $\sim$5%, thus we analyse transversal profiles plotted from shower starting layer.

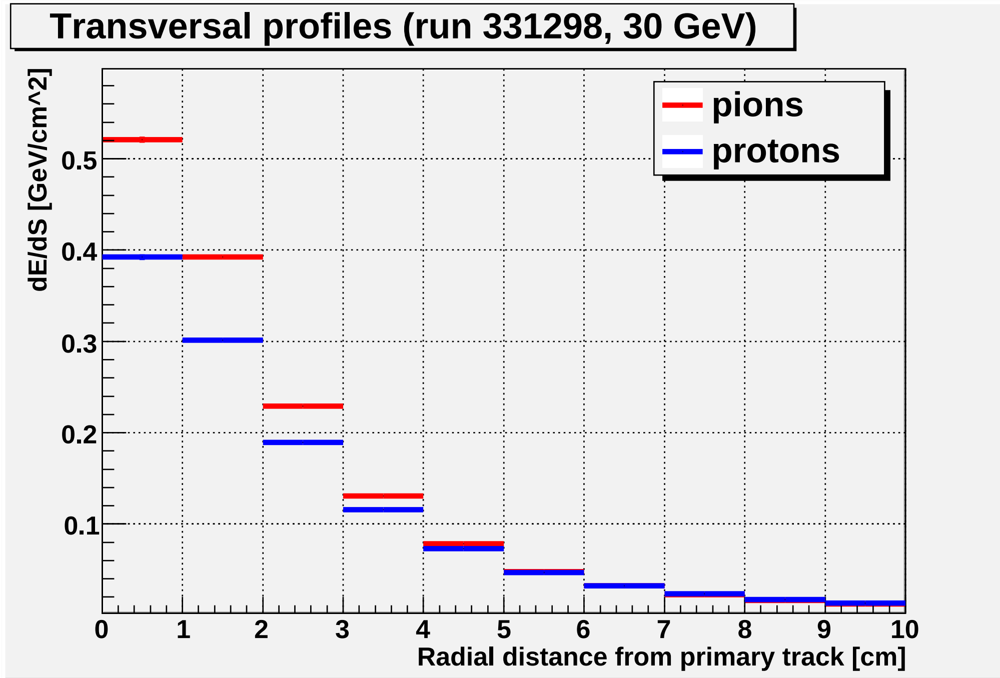
Transversal profiles at different energies



In the analysed energy range the shapes of transversal curves are very similar at different beam energies.

Transversal profiles for pions and protons

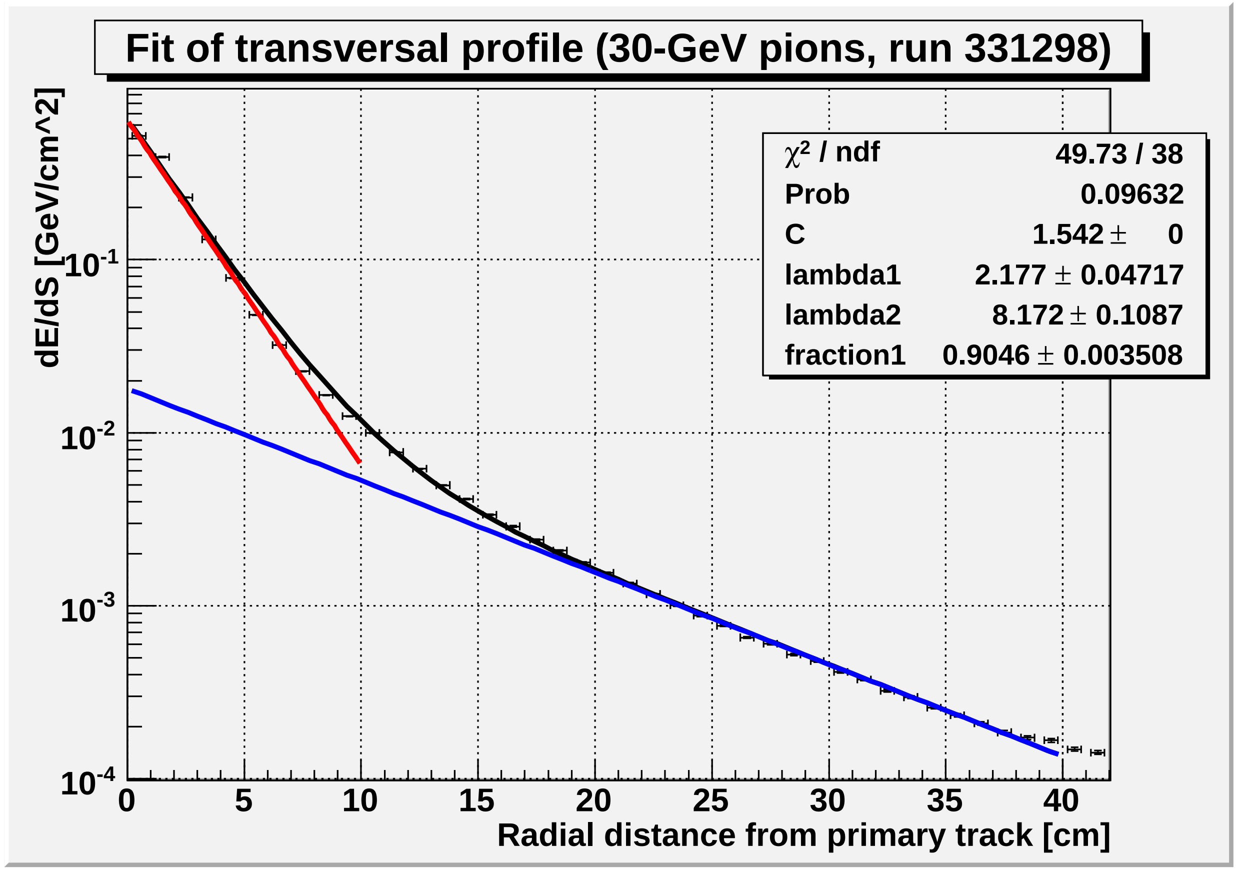




In the core region the difference in energy density for pion- and proton-induced showers is ∼20% for 30-GeV hadrons. For 80 GeV this value falls to ∼17%.

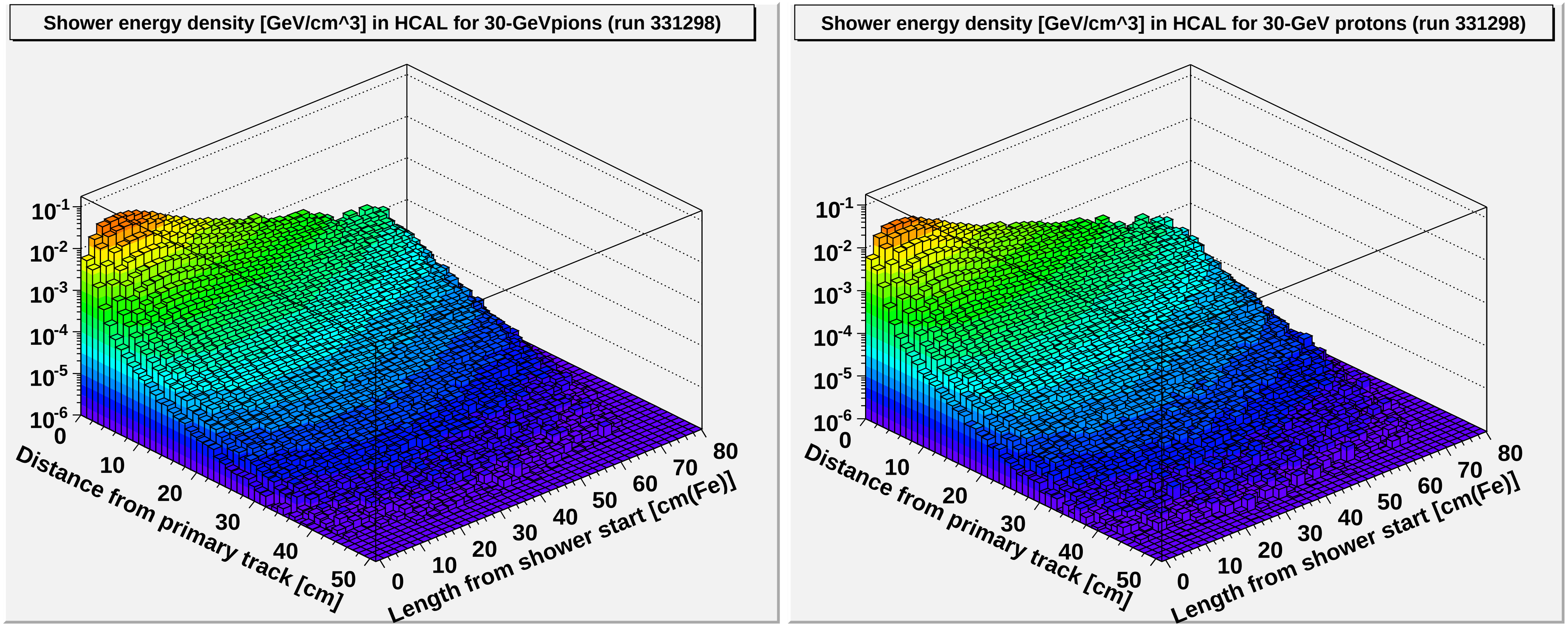
Fit of transversal profiles

Transversal profiles were fitted with sum of two exponent: $N(w \cdot exp(-r/\lambda_1)/\lambda_1 + (1-w)exp(-r/\lambda_2)/\lambda_2)$**,**
where N **is normalization factor,** w **- weight of the first component,** λ_1 **and** λ_2 **- free parameters.**



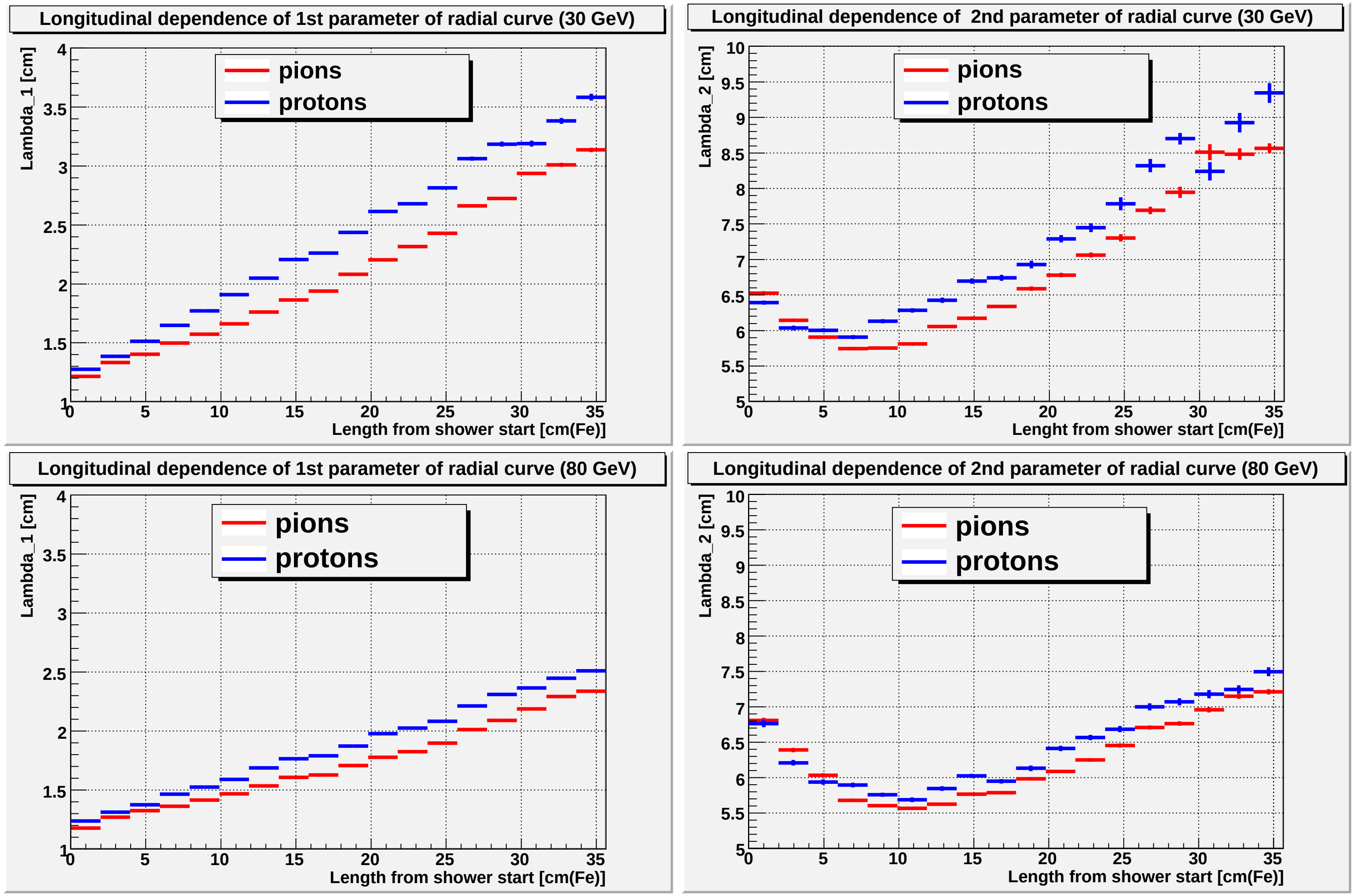
For parameters λ_1 (core exponent) and λ_2 (halo exponent) the values $\sim$2 cm and $\sim$8 cm were obtained.
These values do not virtually change with energy.

2D view of pion- and proton-induced showers



The shapes of radial curves are very similar along the longitudinal direction. The behaviour of longitudinal curves at different radial distances from primary track is more complicated.

Fit parameters of transversal profiles



core **halo**

The difference between pion an proton parameters decreases with increasing energy.

Conclusions

The estimation of nuclear interaction lengths from starting layer distributions for three analysed energies gives values that agree with MC results (LHEP) for π^+ but lie higher than MC for protons.

The difference (both integral and in shower maximum) between longitudinal curves for pion- and proton-induced showers decreases with increasing energy as is expected if assume the increase of π^0 production in first interaction. The parameterization of longitudinal curves by sum of two gamma disribution functions allows to estimate contributions from electromagnetic and hadronic components. To make an estimation of e/h ratio more sophisticated procedure is necessary, e.g. Deep Analysis approach.

In transversal direction two regions can be distinguished: halo region and core region where the differences in energy density of pion- and proton-induced showers are most significant.

The average size of the region where the most significant differences between pion- and proton-induced showers are observed is relatively small: $\sim 10\dot{X}_0$ in longitudinal direction and $\sim 2\dot{X}_0$ in radial direction from the first interaction point.