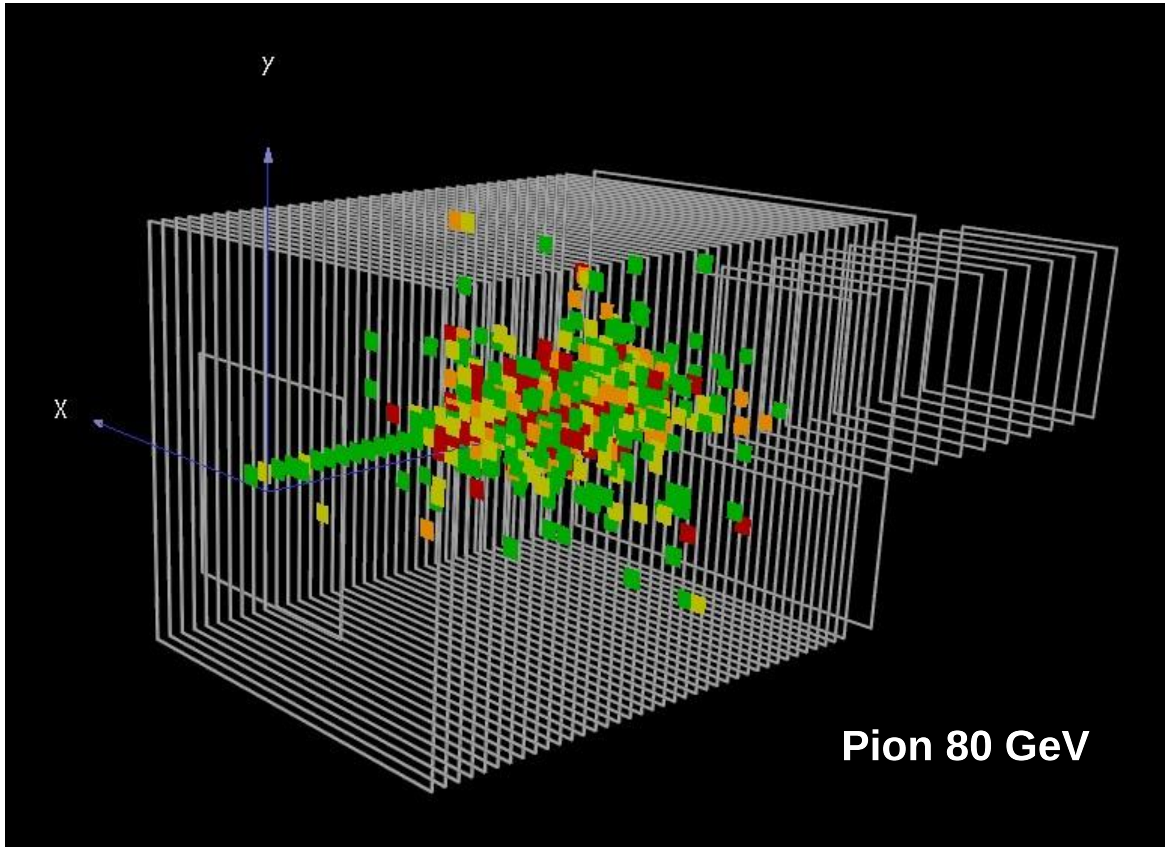
CLASSICAL STUDY OF SHOWER SHAPES IN AHCAL

Olin Pinto
CALICE Virtual Meeting
30th Sept. 2020

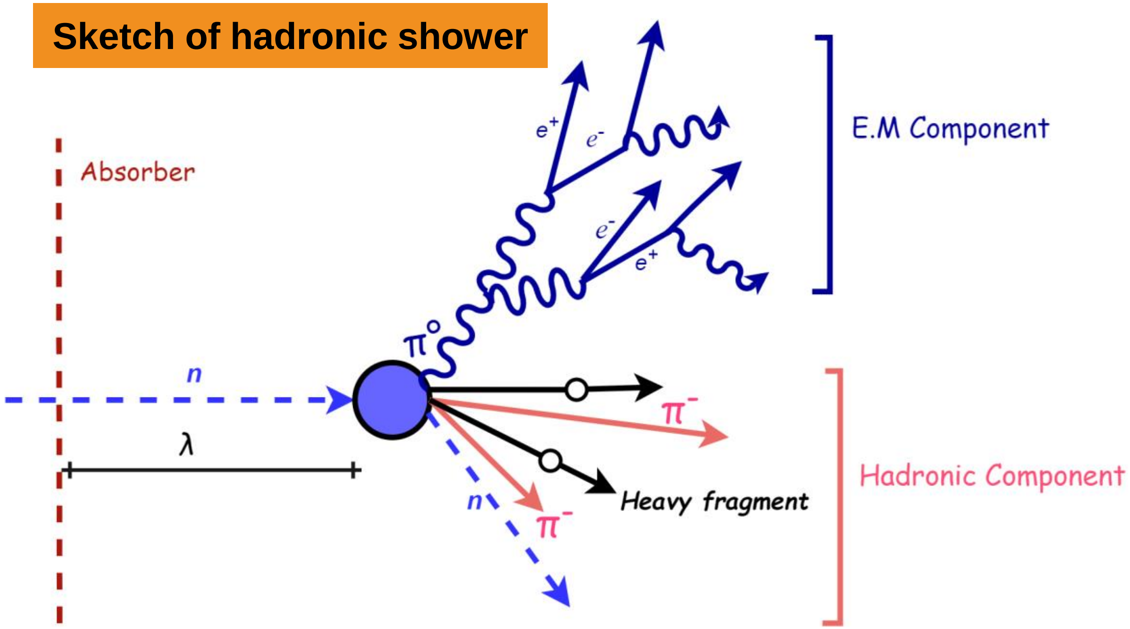


HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
CALICE
Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG
DESY.

Contents

Hadronic Showers

Sketch of hadronic shower



→ The hadronic cascades have two distinct components: **hadronic** (charged pions, heavy fragments, excited nuclei) and **electromagnetic** (γγ)

→ For EM component the relevant scale is $\mathbf{X_0}$, while for the truly hadronic component the scale is $\boldsymbol{\lambda_I}$

→ ~ 1/3 of the pions produced are neutral pions

→ Hadronic showers have a complex structure and are theoretically not as well understood as electromagnetic showers

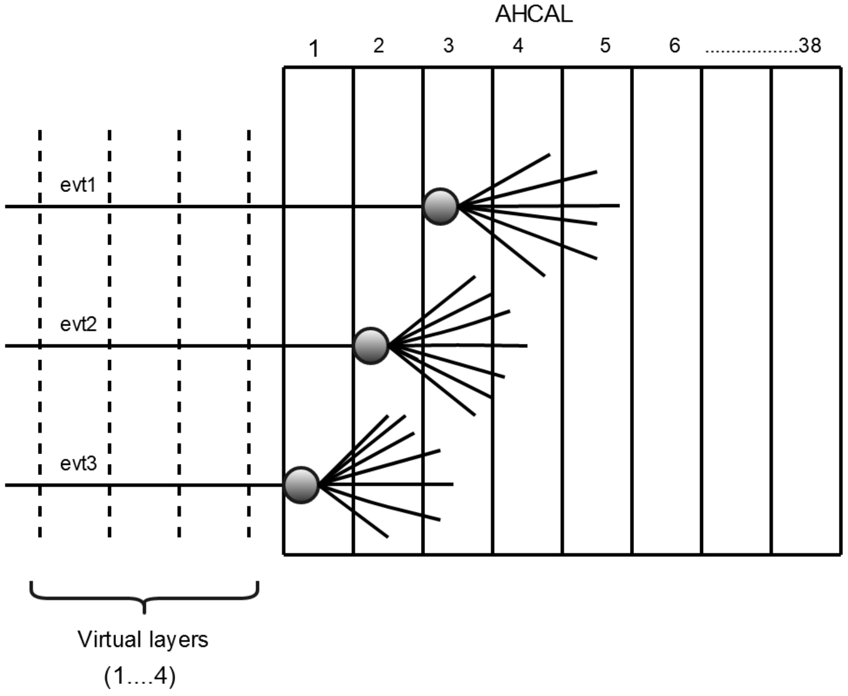
Motivation

→ One important way to understand the shower is to measure shower profiles from the **start point of the shower**

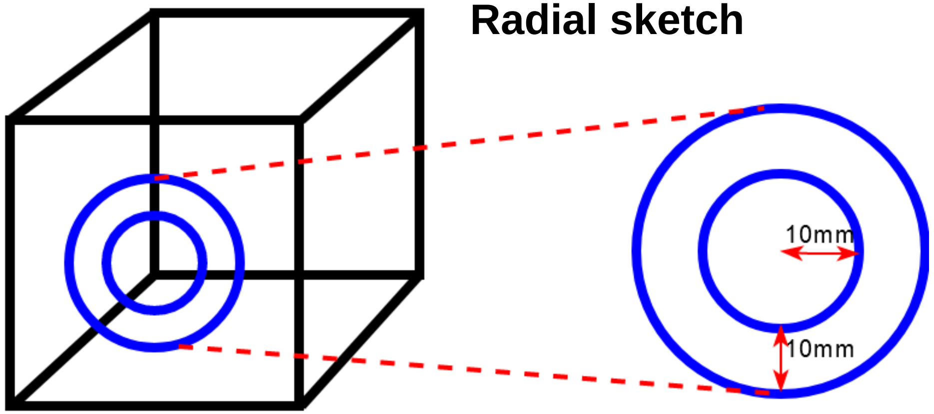
→ The **longitudinal and radial profiles** of showers can be investigated with excellent accuracy, due to fine segmentation of the calorimeter

→ To obtain the contribution of average electromagnetic fraction in a hadronic shower

Longitudinal sketch from shower vertex



Radial sketch



Virtual cells

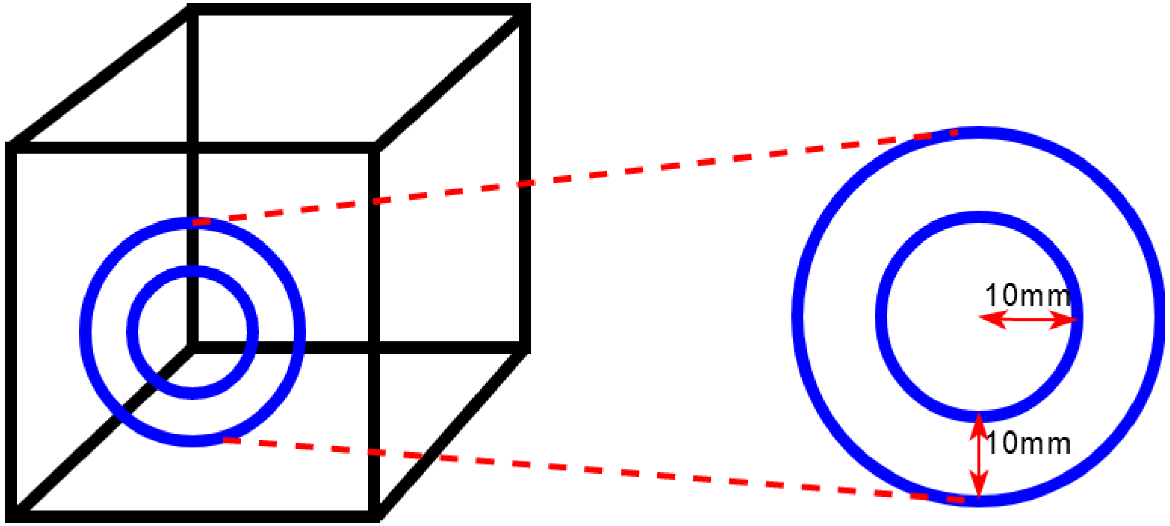
To analyse the **radial shower profile**, finer width is chosen

→ The dimension of the physical AHCAL cell is 30×30 mm^2

→ All physical AHCAL cells are subdivided into virtual cells of 10×10 mm^2

→ In this method the energy deposited in the physical cells is equally distributed over the virtual cells covering its area

Radial sketch



Longitudinal parametrization

→ The longitudinal profiles are parametrised as a sum of “**short**” and “**long**” components

$$\Delta E(z) = A\cdot\left\{\boxed{\frac{f}{\Gamma(\alpha_{short})}\cdot\left(\frac{Z[X_0]}{\beta_{short}}\right)^{\alpha_{short}-1}\cdot\frac{e^{\frac{-Z[X_0]}{\beta_{short}}}}{\beta_{short}}}+\boxed{\frac{1-f}{\Gamma(\alpha_{long})}\cdot\left(\frac{Z[\lambda_I]}{\beta_{long}}\right)^{\alpha_{long}-1}\cdot\frac{e^{\frac{-Z[\lambda_I]}{\beta_{long}}}}{\beta_{long}}}\right\}$$

https://arxiv.org/pdf/1602.08578.pdf

R. K. Bock, T. Hansl-Kozanecka, T. P. Shah, Parametrization of the longitudinal development ofhadronic showers in sampling calorimeters,Nucl. Instrum. Meth.186(1981) 533.

A : scaling factor
f : electromagnetic fraction
Γ : gamma function
$Z[X_0]$ and $Z[\lambda_I]$: distance from the shower start
α_{short} , α_{long} , β_{short} and β_{long} : free parameters

→ “**short**” component, is closely related to the **electromagnetic content** of the shower and “**long**” component, is closely related to the pure **hadronic content** of the shower

Radial parametrization

https://arxiv.org/pdf/1602.08578.pdf

R. K. Bock, T. Hansl-Kozanecka, T. P. Shah, Parametrization of the longitudinal development ofhadronic showers in sampling calorimeters,Nucl. Instrum. Meth.186(1981) 533.

Radial profile is the distribution of the energy density as a function of the radial distance to the shower centre of gravity

Radial distance, $r_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$ x_i , y_i are the position of the centre of the i^{th} cell

The radial profiles are parametrised with the sum of two exponential functions which describe the behaviour near the shower axis (**“core” component close to the shower axis**) and at the shower periphery (**“halo” component distant from the shower axis**)

$$\frac{\Delta E}{\Delta S}(r) = A \cdot \left\{ \boxed{f \cdot \frac{e^{\frac{-r}{\beta_{core}}}}{\beta_{core}}} + \boxed{(1 - f) \cdot \frac{e^{\frac{-r}{\beta_{halo}}}}{\beta_{halo}}} \right\}$$

where,
A: scaling factor
f : electromagnetic fraction
β_{core} and β_{halo}: slope parameters

ΔE is the energy density, and $\Delta S = 2\pi r \Delta r$ is the area of a ring of width Δr at a distance r from the shower axis

Procedure

- → One common method for finding an optimum fit is to minimize a χ^2 function
- → The idea is to first fit the profiles separately, but the goal is to perform a combined fit in the end

Longitudinal

$$\Delta E(z) = A\cdot\left\{\frac{f}{\Gamma(\alpha_{short})}\cdot\left(\frac{Z[X_0]}{\beta_{short}}\right)^{\alpha_{short}-1}\cdot\frac{e^{\frac{-Z[X_0]}{\beta_{short}}}}{\beta_{short}} + \frac{1-f}{\Gamma(\alpha_{long})}\cdot\left(\frac{Z[\lambda_I]}{\beta_{long}}\right)^{\alpha_{long}-1}\cdot\frac{e^{\frac{-Z[\lambda_I]}{\beta_{long}}}}{\beta_{long}}\right\}$$

Radial

$$\frac{\Delta E}{\Delta S}(r) = A\cdot\left\{f\cdot\frac{e^{\frac{-r}{\beta_{core}}}}{\beta_{core}} + (1-f)\cdot\frac{e^{\frac{-r}{\beta_{halo}}}}{\beta_{halo}}\right\}$$

$$\chi^2_{(LONGITUDINAL+RADIAL)} = \sum_i^{N_{LONGITUDINAL}} \frac{(\mu_{iLONGITUDINAL} - f_{iLONGITUDINAL}(\alpha,\beta,f_{em}))^2}{\sigma_{iLONGITUDINAL}^{\;2}} + \sum_i^{N_{RADIAL}} \frac{(\mu_{iRADIAL} - f_{iRADIAL}(\beta,f_{em}))^2}{\sigma_{iRADIAL}^{\;2}}$$

f_{iLONG} and f_{iRAD} : expected value of longitudinal and of radial model
μ_{iLONG} and μ_{iRAD} : i_{th} measurement of radial and of longitudinal
σ_{iLONG} and σ_{iRAD} : uncertainty of i_{th} measurement of radial and of longitudinal

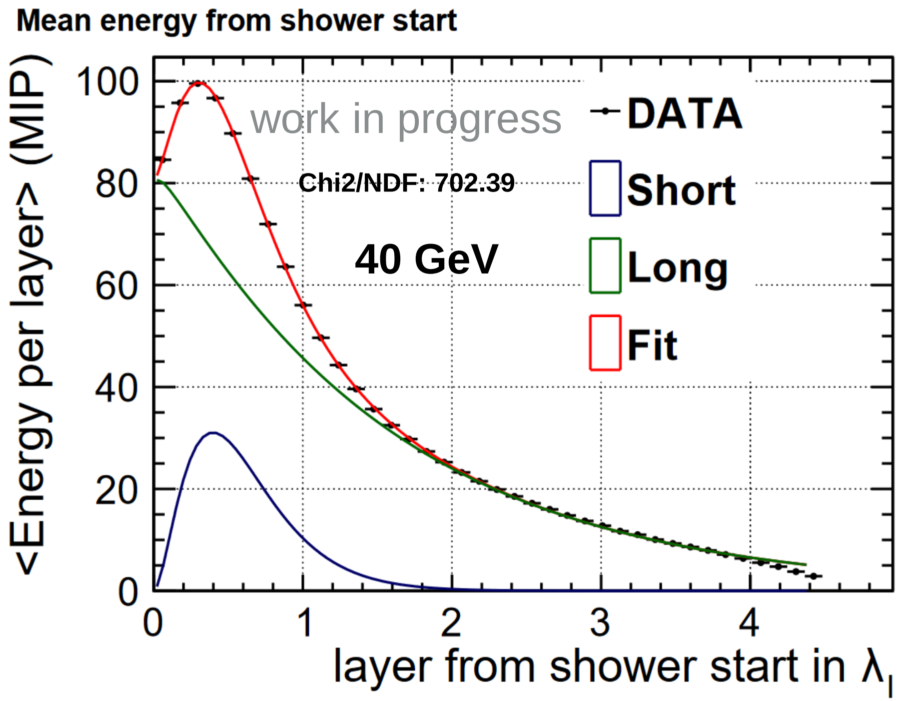
Fits to longitudinal and Radial profiles

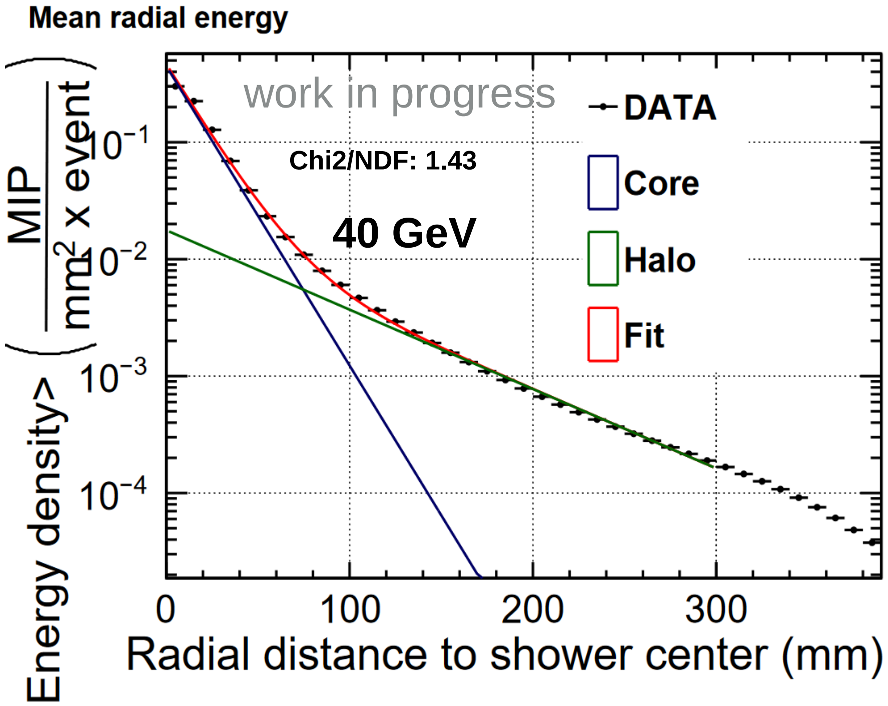
→ 38 points are available for the longitudinal fit up to a depth of ~4.4λ_I. Each bin in longitudinal direction corresponds to ~0.11λ_I

→ The "long" component of the longitudinal profile which dominates in the shower tail, is accompanied around shower maximum by the "short" component

→ For the radial fit, the fine transverse granularity provides 39 points in the range from 0 to 390 mm. Each bin width corresponds to one third of the transverse size of the 30×30 mm^2 cell

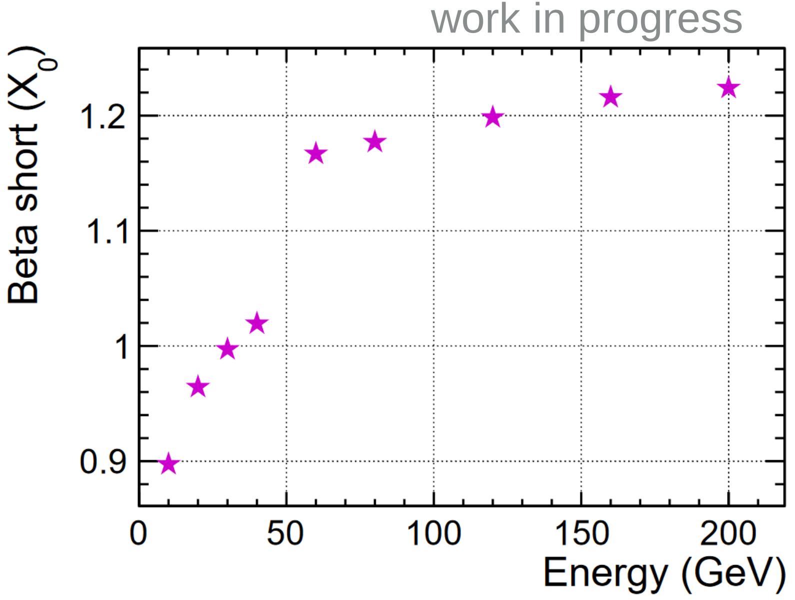
→ The data set includes statistical uncertainties only

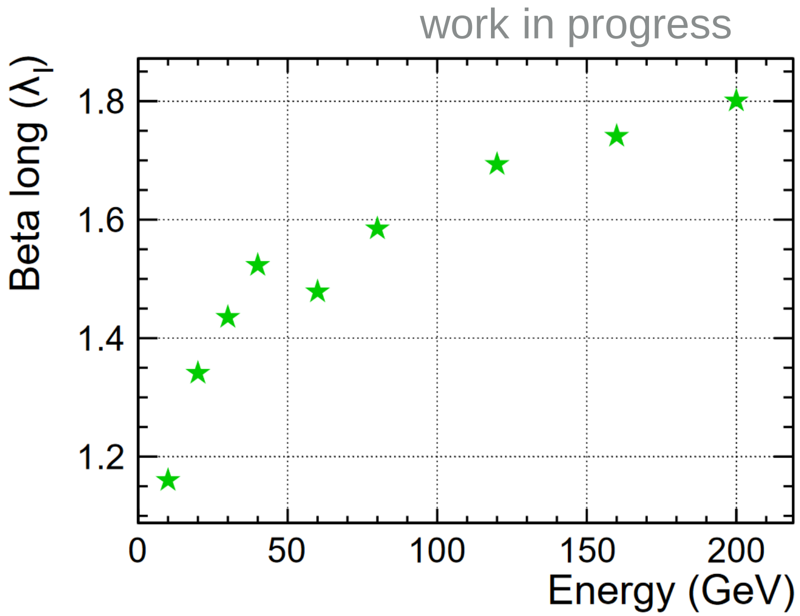


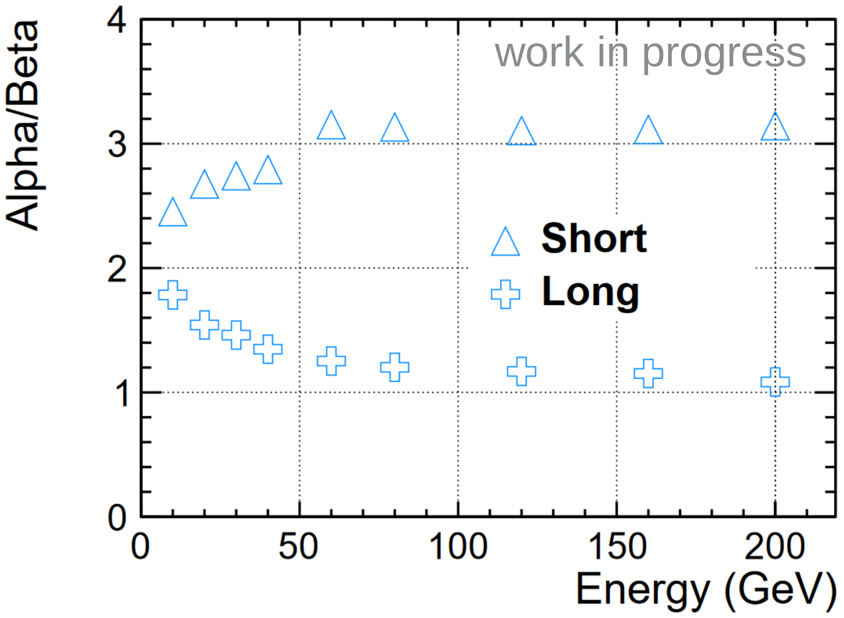


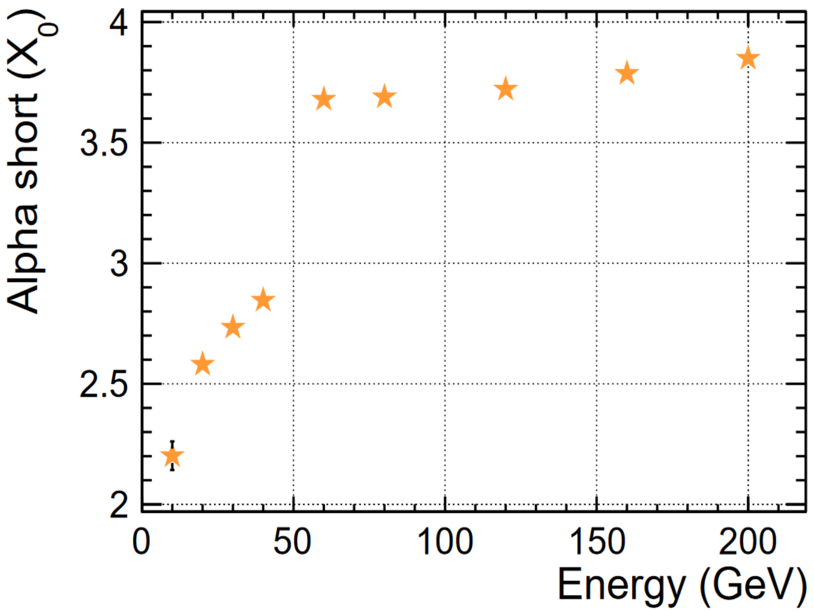
Behaviour of longitudinal Parameters

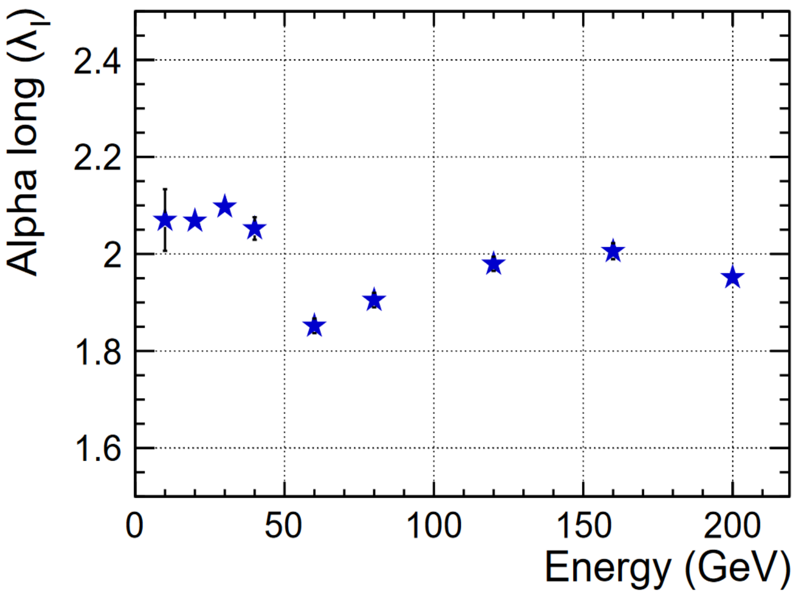
- → There exists a correlation between the short and the long component
- → The short components show similar behaviour
- → **Need to have a closer look into the jump between 40 and 60 GeV**
- → The ratio of alpha and beta gives the maximum of the function





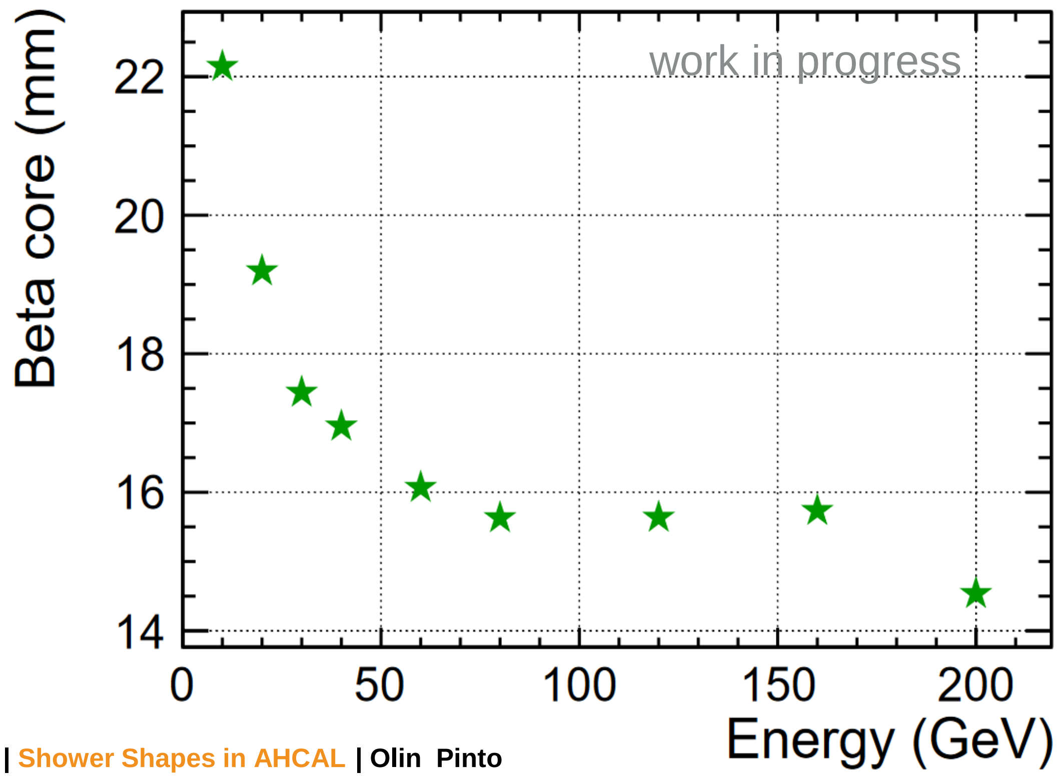


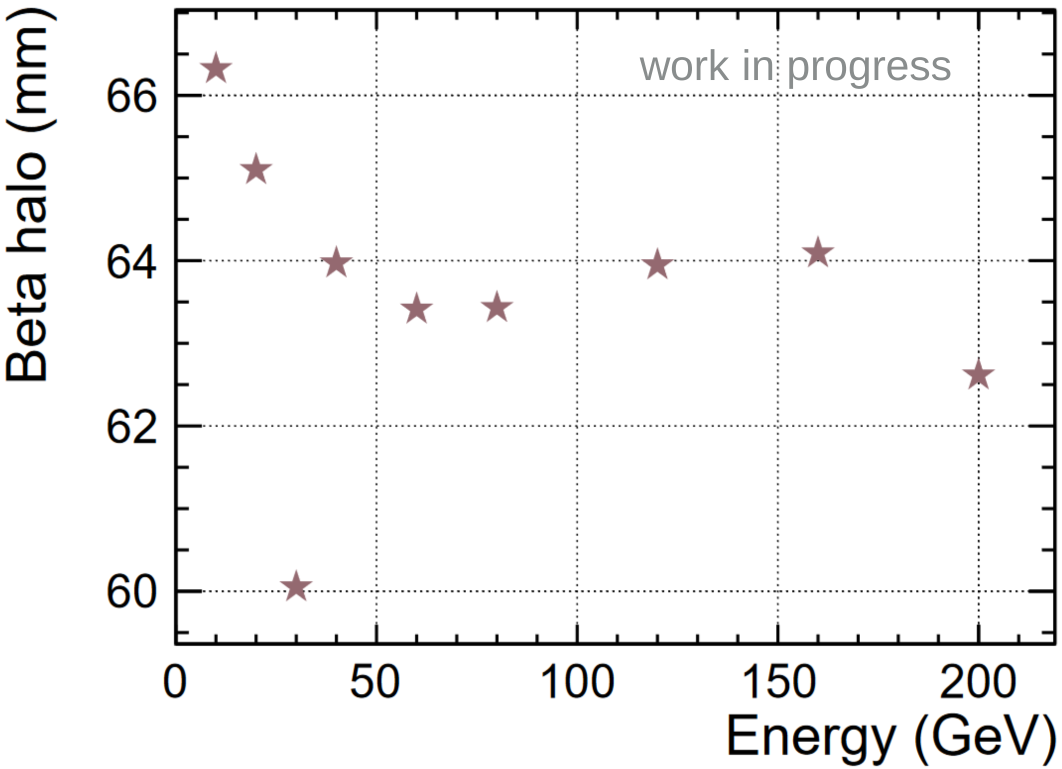




Behaviour of radial Parameters

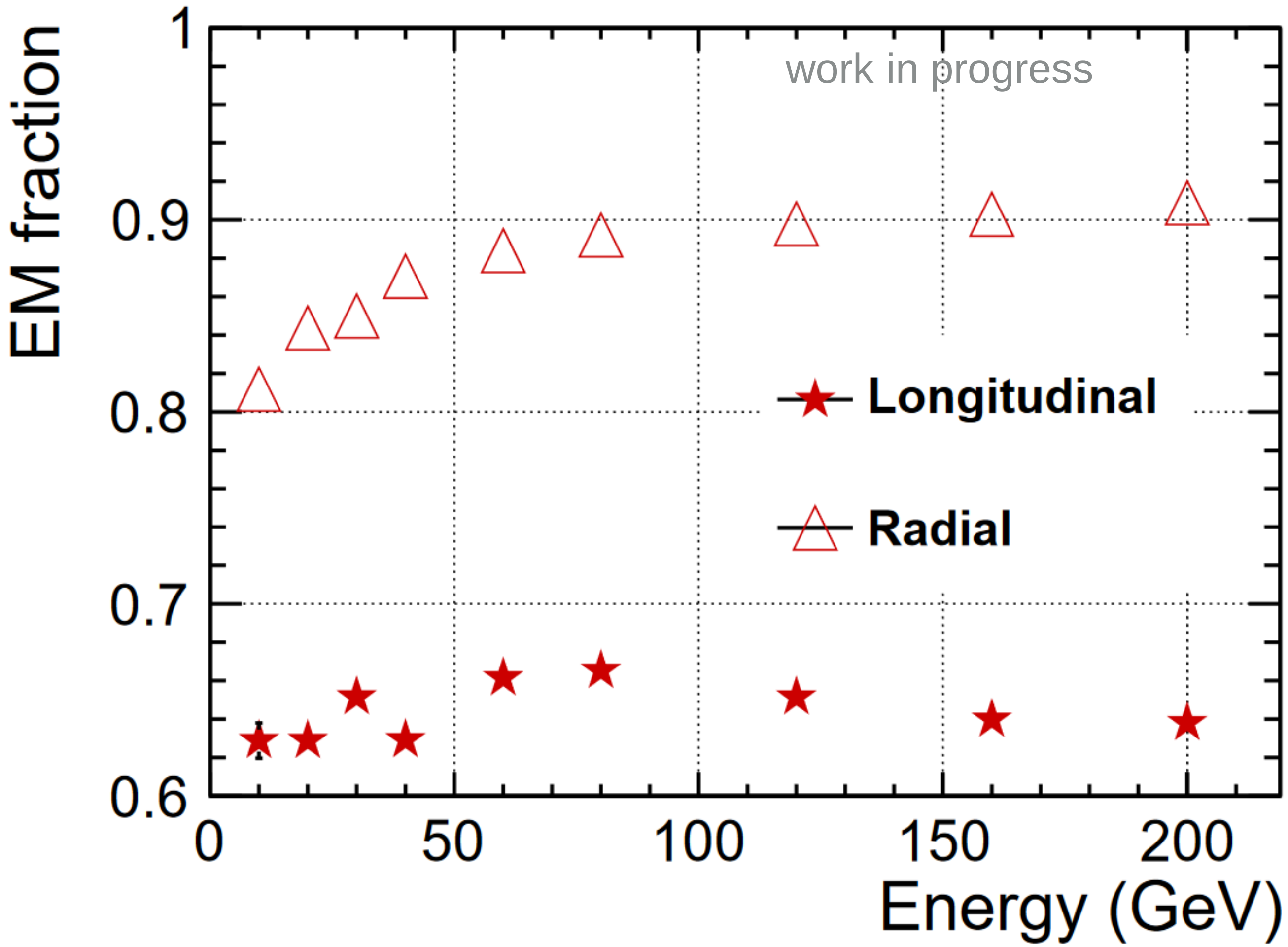
- → The parameter β_{core} characterises the radial shower development near the shower axis and is related to the angular distribution of secondary π^0s from the first inelastic interaction
- → The behaviour of β_{core} parameter decreases with energy
- → In the tail, slope parameter β_{halo} is nearly constant
- → **Need to check the outlier for β_{halo} at 30 GeV**





The average electromagnetic fraction

→ The EM-fraction shows on average 80% and 60% for radial and longitudinal respectively



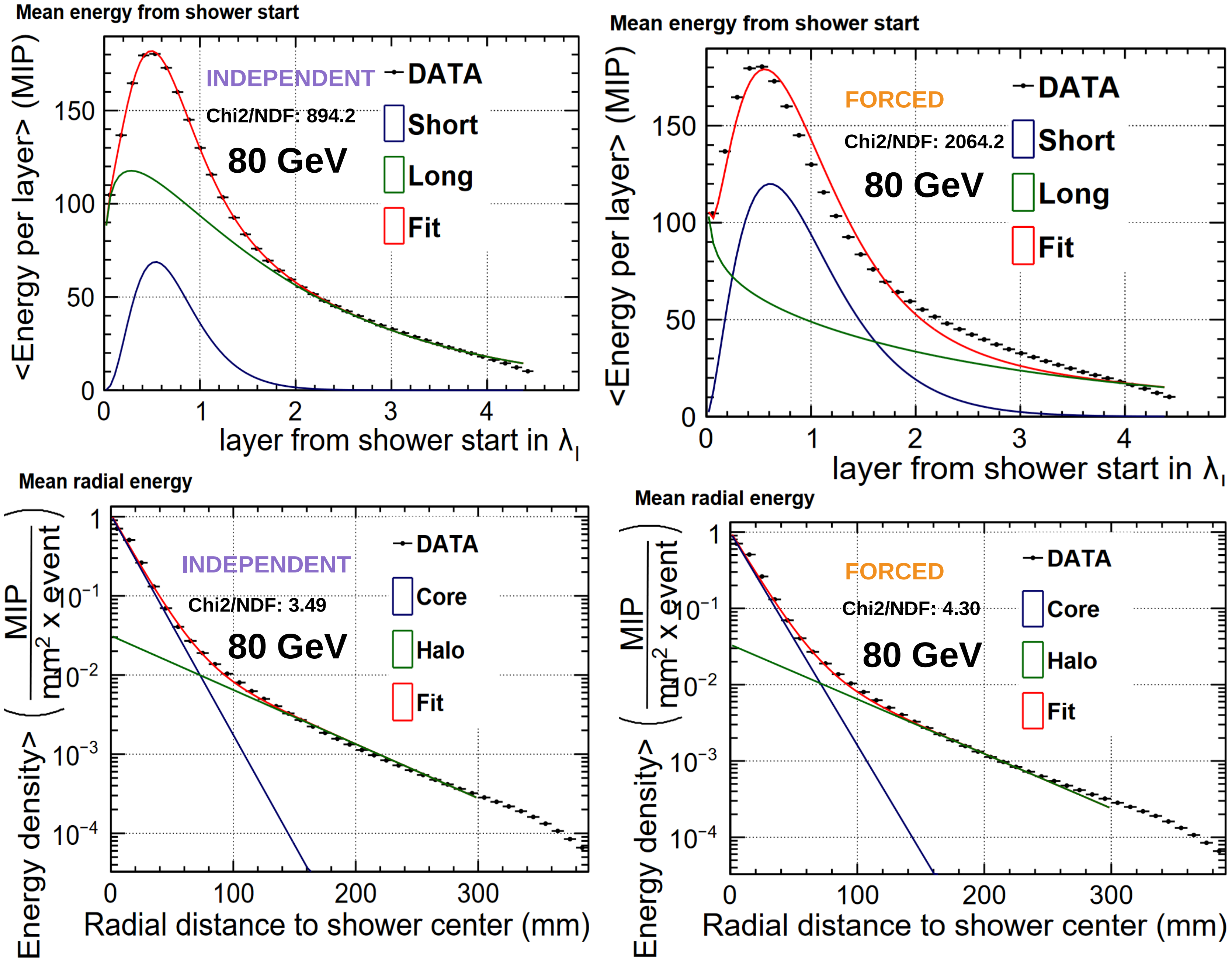
Summary & Outlook

- → Fitting shower shapes has potential to improve calorimeter measurements
- → Fits are performed on the data set as a first step using the χ^2 minimization on the longitudinal and radial functions to obtain the EM-fraction independently
- → The obtained EM-fraction for radial is ~80% and 60% for longitudinal

- → To compare the results from the physics prototype (physics prototype obtained EM fraction of ~20%, in the current analysis the EM fraction is ~60%)
- → The measured results will be compared between MC of different physics list
- → The parameters of the “short” component to be compared with those of electromagnetic showers
- → Furthermore, as a qualitative results a systematic study will be included
- → This method will be followed in the future to perform a 3D modelling of the longitudinal and radial profiles
- → **Perform combined (Longitudinal + Radial) χ2 minimization to obtain the electromagnetic fraction**

Outlook

- → The combined fit technically works, but needs further investigation
- → For example: radial fit looks reasonable, but the longitudinal fit looks bad!



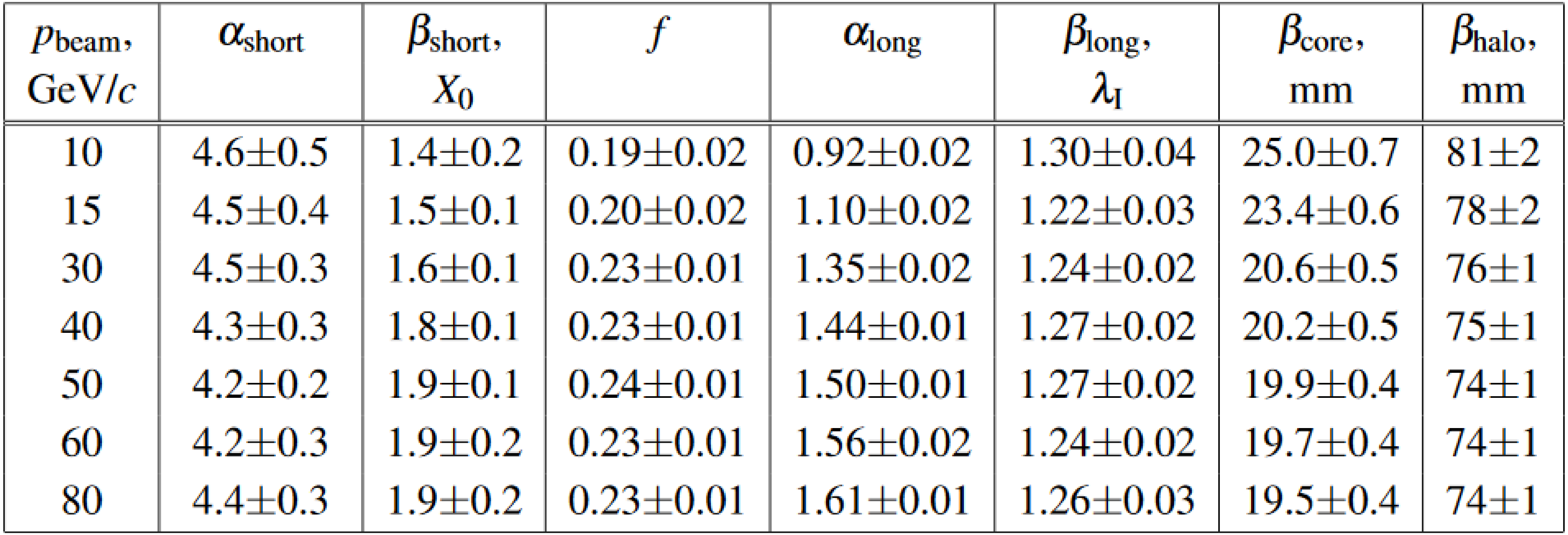
THANK YOU

SPARES

Results from physics prototype

https://arxiv.org/pdf/1602.08578.pdf

Data sample for longitudinal profile



p_{beam}, GeV/c	α_{short}	β_{short}, X_0	f	α_{long}	β_{long}, λ_{I}	β_{core}, mm	β_{halo}, mm
10	4.6±0.5	1.4±0.2	0.19±0.02	0.92±0.02	1.30±0.04	25.0±0.7	81±2
15	4.5±0.4	1.5±0.1	0.20±0.02	1.10±0.02	1.22±0.03	23.4±0.6	78±2
30	4.5±0.3	1.6±0.1	0.23±0.01	1.35±0.02	1.24±0.02	20.6±0.5	76±1
40	4.3±0.3	1.8±0.1	0.23±0.01	1.44±0.01	1.27±0.02	20.2±0.5	75±1
50	4.2±0.2	1.9±0.1	0.24±0.01	1.50±0.01	1.27±0.02	19.9±0.4	74±1
60	4.2±0.3	1.9±0.2	0.23±0.01	1.56±0.02	1.24±0.02	19.7±0.4	74±1
80	4.4±0.3	1.9±0.2	0.23±0.01	1.61±0.01	1.26±0.03	19.5±0.4	74±1