Hadronic showers in SDHCAL

CALICE Collaboration Meeting in Hambourg

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Outline

SDHCAL Digitizer

a) Simulation of the deposit charge by one G4 step → Polya distribution :

$$\left(\frac{q}{\alpha}\right)^{\beta+1} e^{-(\beta+1)\frac{q}{\alpha}} \tag{1}$$

$\alpha = 1.6\ pC \rightarrow$ average charge
$\beta = 16.3 \rightarrow$ free parameter related to the width of the distribution

b) Hit construction → Fix the charge spreading with :

$$f_2(x, y) = \sum_{i=0}^{2} \alpha_i e^{-\frac{(x-x_0)^2+(y-y_0)^2}{\sigma_i^2}} \tag{2}$$

(x_0, y_0) : cell center position
$\alpha_0 = 1; \alpha_1 = 0.003; \alpha_2 = 0.00045$
$\sigma_0 = 1.4; \sigma_1 = 9.0; \sigma_2 = 90.0$

c) Integration of this function on the pads area → charge ratio for the pads

Variable definition

a) Shower Starting Point : first layer with at least 4 hits and with the three following layers with at least 4 hits.

b) (CoG_x, CoG_y, CoG_z) : shower barycenter without taking into account hits before shower starting point.

c) Radius : $\sqrt{\sum_{i=0}^{n} \frac{(x_i - CoG_x)^2 + (y_i - CoG_y)^2}{n}}$.
   - n hit number after shower starting point.

d) N_{Layer} : number of fired layers.

e) $Nlast_{Hit}$: number of hits in the seven last layers.

f) Multiplicity : number of hits for a MIP in one detector.

Multiplicity : number of hits for a MIP in one detector

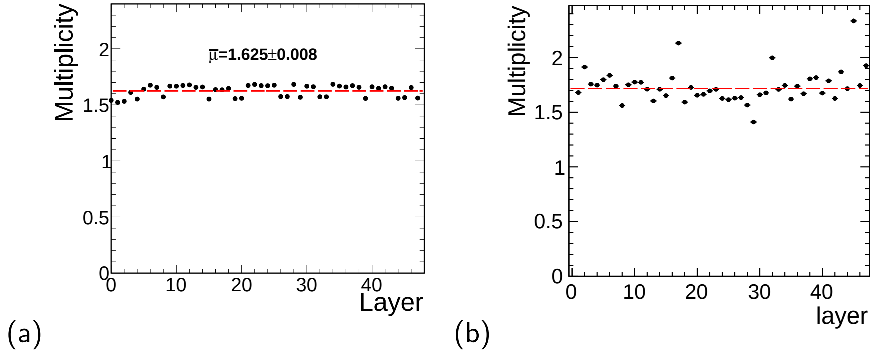

FIGURE: (a) : QGSP_BERT simulation. (b) : DATA from SPS test beam (august 2012)

Pion selection

a) Beam/Cosmic muon rejection :
   - $\frac{N_{Hit}}{N_{Layer}} > 3$

b) Leakage reduction :
   - $\frac{Nlast_{Hit}}{N_{Hit}} < 0.15$

c) Radiative muon rejection :
   - $\frac{Radius}{CoG_z} < 0.3$

d) Electron rejection

Electron Rejection

- $LongitudinalCut = \frac{N_{Hit}\ \ in\ \ the\ \ first\ \ 15\ \ Layers}{N_{HitTot}}$
- $TransversalCut = \frac{N_{Hit}\ \ in\ \ the\ \ 13*13\ \ central\ \ Cells}{N_{HitTot}}$

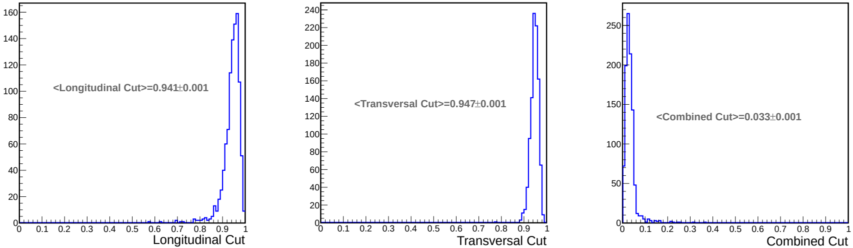

FIGURE: Longitudinal, Transversal and Combined cut distributions for 40 *GeV* simulated electrons (QGSP_BERT)

$$CombinedCut = \sqrt{(LCut - MeanLCut)^2 + (TCut - MeanTCut)^2} > 0.2 \qquad (3)$$

Electron Rejection

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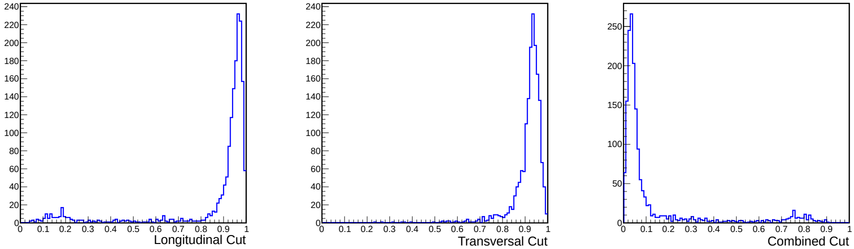


FIGURE: Longitudinal, Transversal and Combined cut distributions for 40 *GeV* data electrons

Electron Rejection

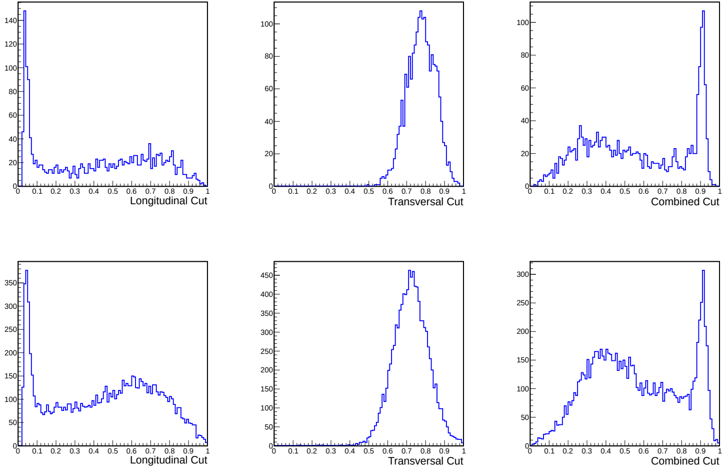
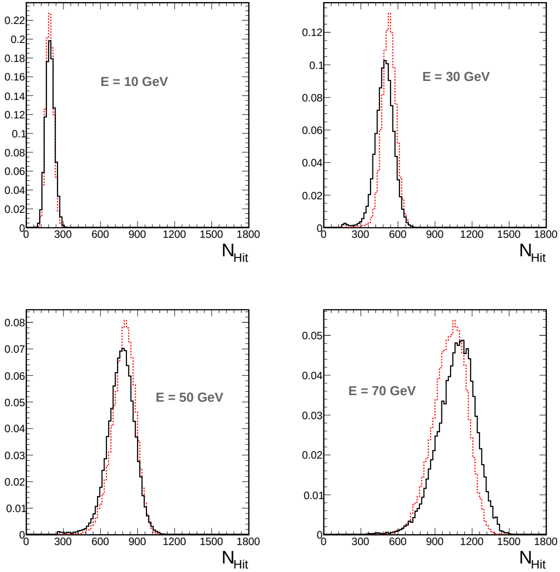


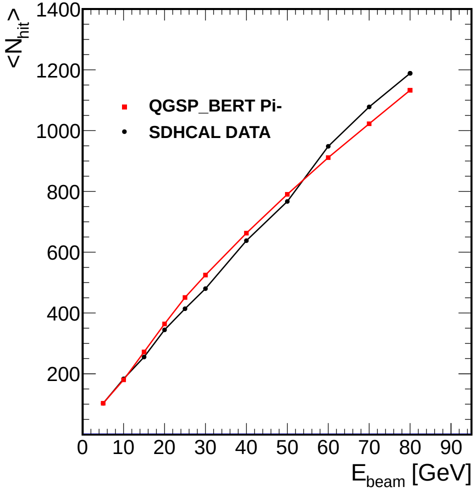
FIGURE: Longitudinal, Transversal and Combined cut distribution for 40 *GeV* : simulated pions on the top (QGSP_BERT) ; data on the bottom

Nhit Results



solid black line : DATA from SPS test beam (august 2012)
dotted red line : QGSP_BERT Simulation

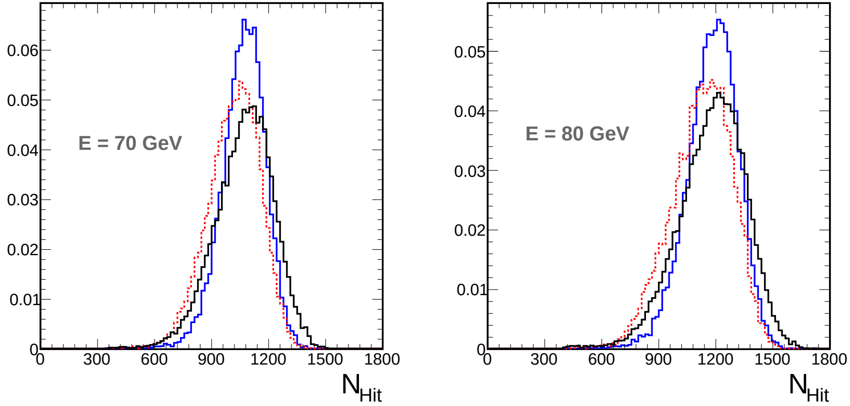
Nhit Results



- Quite good agreement
- Proton contamination, on H6 SPS beam line, could explain the high energy behaviour *[Study of energy response and resolution of the ATLAS barrel calorimeter to hadrons from 20 to 350 GeV, Nuclear Instruments and Methods in Physics Research A 621 (2010) 134-150]*

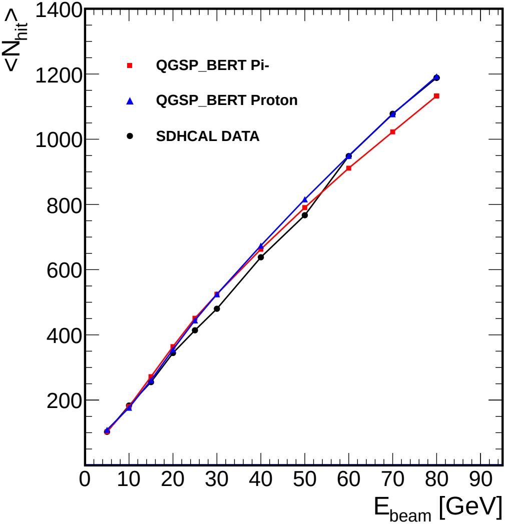
Energy [*GeV*]	Fraction of protons
50	0.45 ± 0.12
100	0.61 ± 0.06

Nhit Results



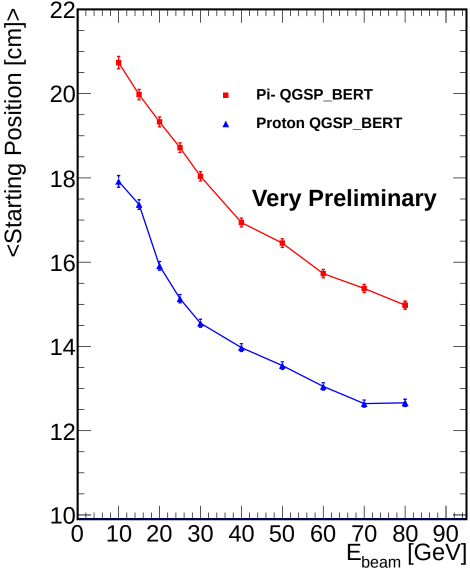
solid black line : DATA from SPS test beam (august 2012)
dotted red line : Pi- QGSP_BERT Simulation
solid blue line : Proton QGSP_BERT Simulation

Nhit Results



The simulated number of hits for a proton beam case is in a good agreement with our data at high energy.

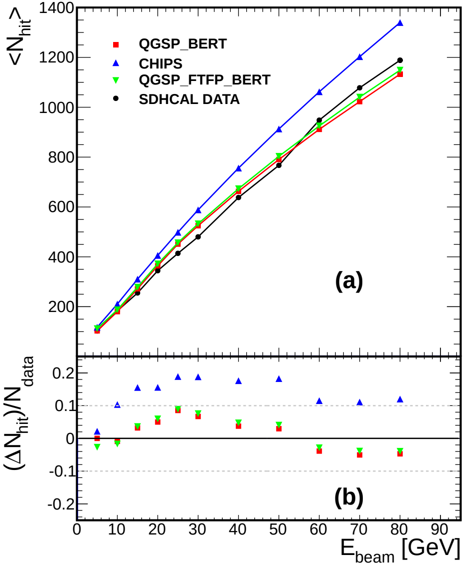
Shower starting point



Starting Position : First layer with at least 4 hits and with the three following layers with at least 4 hits.

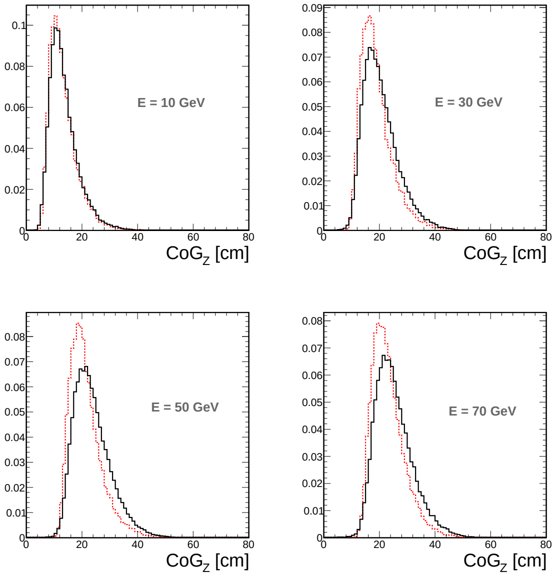
- This difference can explain the the difference for the number of hits
- No systematics
- Algorythm efficiency using MC history will be estimated

Comparison with other physics lists



- Digitizer parameters tunning has been done with QGSP_BERT physic list
- QGSP_BERT and QGSP_FTFP_BERT physic lists are almost equivalent
- More hits in CHIPS physic list
- Only pions for the simulation here

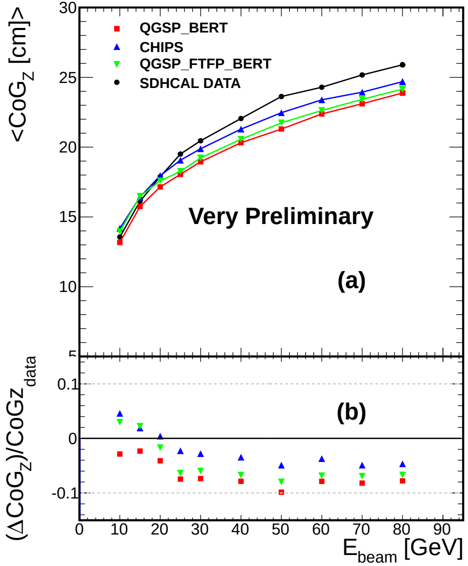
Longitudinal shower shape : preliminary results



CoG_z : shower barycenter

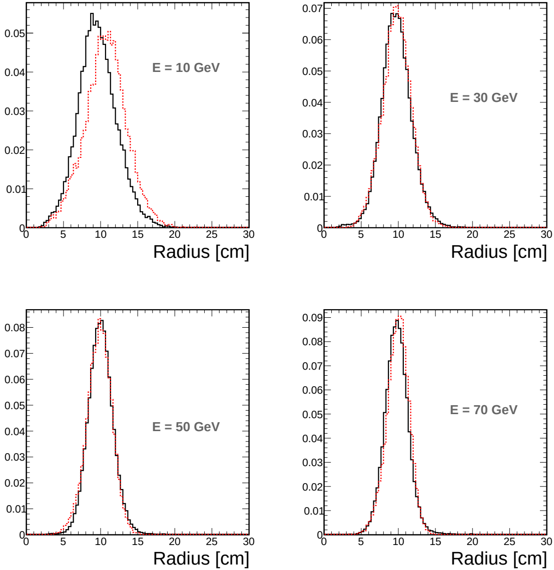
solid black line : DATA from SPS test beam (August 2012)
dotted red line : QGSP_BERT Simulation

Longitudinal shower shape



- Hadronic showers are shorter for all three physic lists than data
- CHIPS physic list create longer shower than others
- Only pions for the simulation here

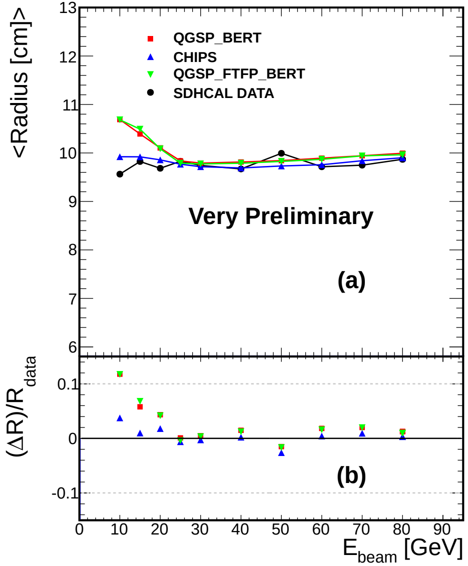
Lateral shower shape : preliminary results



Radius : $\sqrt{\sum_{i=0}^{n} \frac{(x_i - X_0)^2 + (y_i - Y_0)^2}{n}}$.

solid black line : DATA from SPS test beam (august 2012)
dotted red line : QGSP_BERT Simulation

Lateral shower shape : preliminary results



- Except at low energy the agreement between Data/MC is good
- CHIPS physic list has the best agreement with data
- Only pions for the simulation here

Goal

Tracks segments within the hadronic showers could be used to study the detector behaviour in time. Efficiency and multiplicity could be studied and problems detected. This can also be used to better estimate the energy by :

1- Giving a different weigth to hits belonging to an isolated track.

2- Calibrating the detector reponse in a more appropriate way.

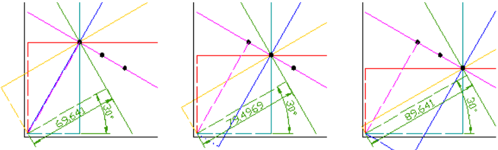
Hough tansform method

Building parameters space

1- Hit$(x, y, z) \Rightarrow$ 2 sinusoidal curve (ρ_x, θ_x),(ρ_y, θ_y)

2- $\rho_x = z.cos(\theta_x) + x.sin(\theta_x)$; $\theta_x \in [-\pi/2; \pi/2]$

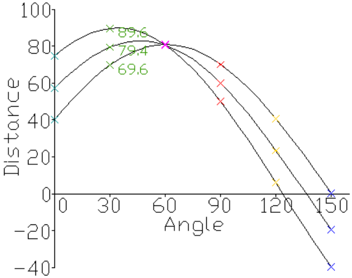
3- $\rho_y = z.cos(\theta_y) + y.sin(\theta_y)$; $\theta_y \in [-\pi/2; \pi/2]$



Angle	Dist.
0	40
30	69.6
60	81.2
90	70
120	40.6
150	0.4

Angle	Dist.
0	57.1
30	79.5
60	80.5
90	60
120	23.4
150	−19.5

Angle	Dist.
0	74.6
30	89.6
60	80.6
90	50
120	6.0
150	−39.6



In practice

1- Build clusters with adjacent hits in each layer

2- Select only clusters with less than 8 hits and apply isolation criterion

   i At most one other cluster in a 6×6 cm^2 x-y extension arround it.

   ii At least one other cluster in a 5×5 cm^2 x-y extension in the 2 layers after and before the cluster's layer

   iii At most 1 cluster with more than 8 hits in a 5×5 cm^2 x-y extension in the 2 layers after and before the cluster's layer

3- For each selected cluster $\Rightarrow$ estimate $Int(\rho_x)$ for each θ_x with a step of $\pi/100$ and then increment an accumulator $A_x(\theta_x, Int(\rho_x))$

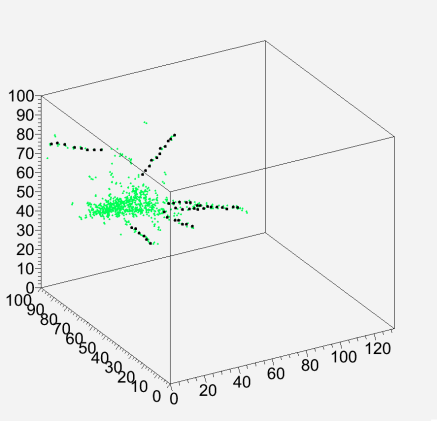
4- Select $(\theta_x, Int(\rho_x))$ with $A_x(\theta_x, Int(\rho_x)) > 5$

5- The clusters belonging to the selected $(\theta_x, Int(\rho_x))$ are then used to increment an accumulator $A_y(\theta_y, Int(\rho_y))$ for the other plan

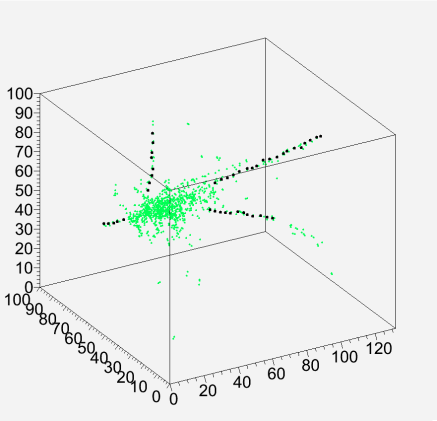
6- Select $(\theta_y, Int(\rho_y))$ with $A_y(\theta_y, Int(\rho_y)) > 5$

Clusters which pass through these cuts are finally the clusters in tracks

Pictures



100
90
80
70
60
50
40
30
20
10
0
100 90 80 70 60 50 40 30 20 10 0
0 20 40 60 80 100 120



100
90
80
70
60
50
40
30
20
10
0
100 90 80 70 60 50 40 30 20 10 0
0 20 40 60 80 100 120

Hough transform on muon beam

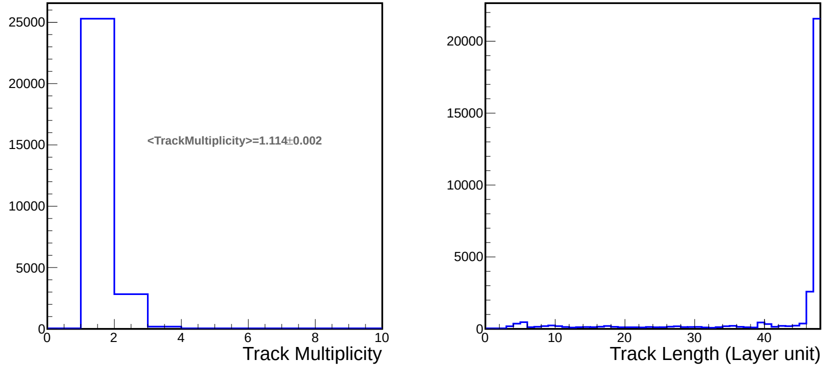
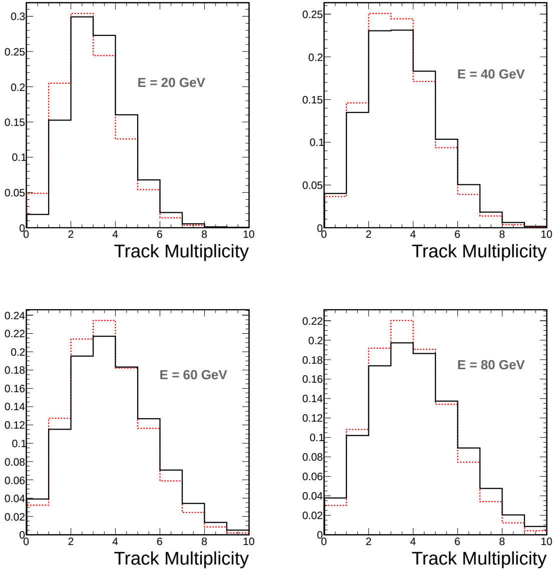


FIGURE: Track multiplicity (on the left) and track length (on the right) for a 30 *GeV* muon data sample

Hough transform algorythm applied on MIP, finds most of the time only one track with a length of 48 layer.

Hough transform on hadronic showers



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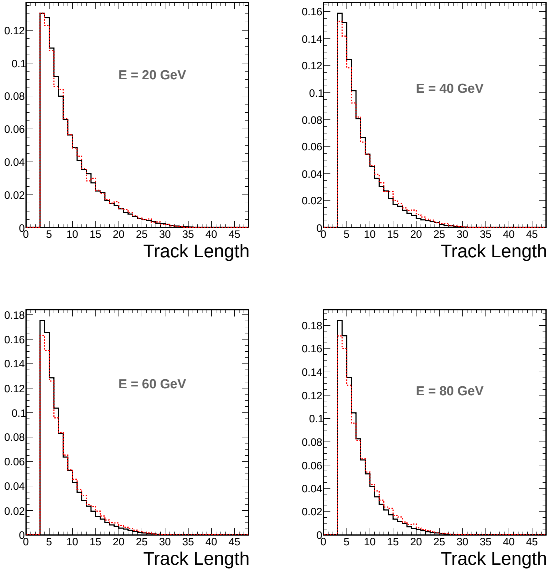
Hough transform on hadronic showers



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Hough transform on hadronic showers

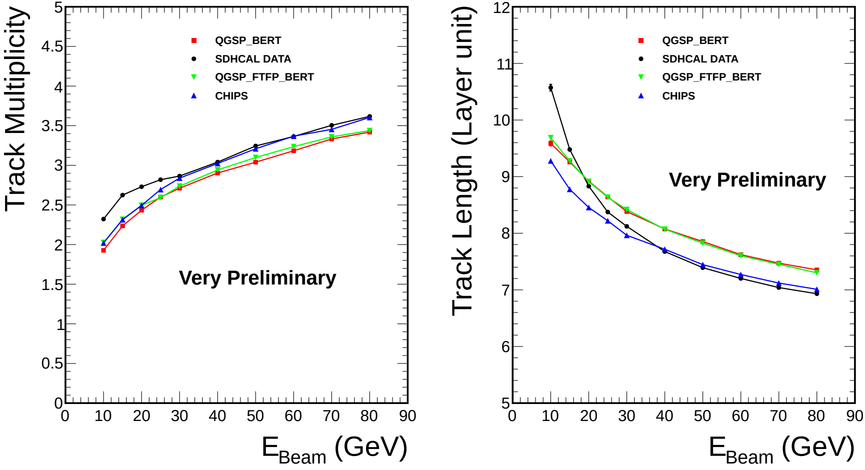


FIGURE: Mean value of the track multiplicity versus the beam energy (on the left). Mean value of the track length versus the beam energy (on the right).

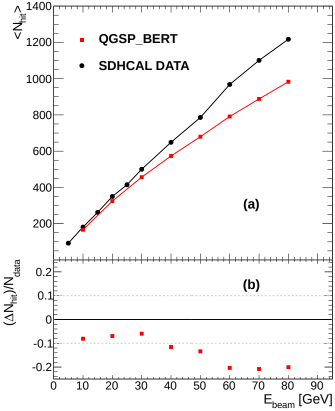
Conclusion

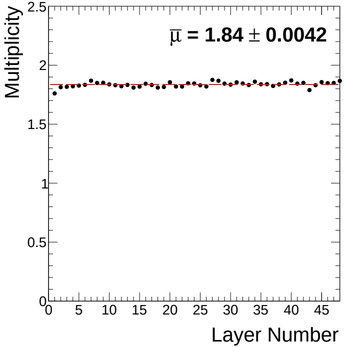
- Current digitisation reproduces the data quite well. Including a large fraction of protons in the beam, improves the agreement
- The preliminary results on topological shower shape are encouraging
- The Hough Transform is a powerful tool to find tracks within the hadronic showers. It could be used to study the efficiency and to have a better estimation of the energy

Back-Up

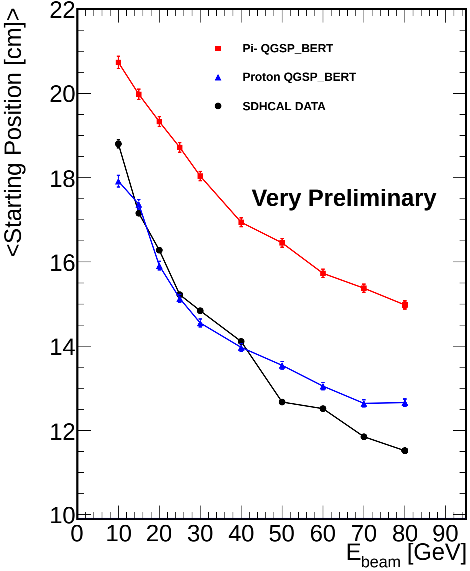
Previous digitizer parametrization : only one width paremeter

$$f(x,y) = \frac{1}{\cosh\left(p_0\sqrt{(x-x_0)^2+(y-y_0)^2}\right)} \quad (4)$$





Shower starting point



Starting Position : First layer with at least 4 hits and with the three following layers with at least 4 hits.

- No noise in the simulation
- No systematics
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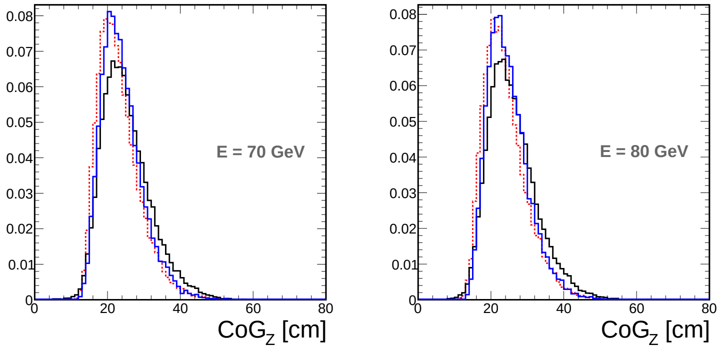
Longitudinal shower shape



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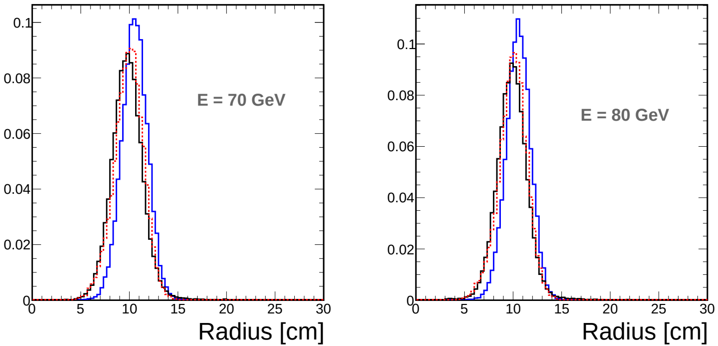
Lateral shower shape



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