# Tracking within hadronic showers in the SDHCAL

Imad Laktineh

# Outline

- Hough Transform (HT)
- HT in hadronic showers
- HT in the SDHCAL
- Using HT tracks  for in situ calibration
- Using HT tracks to study hadronic shower models.
- HT for PFA
- Conclusion

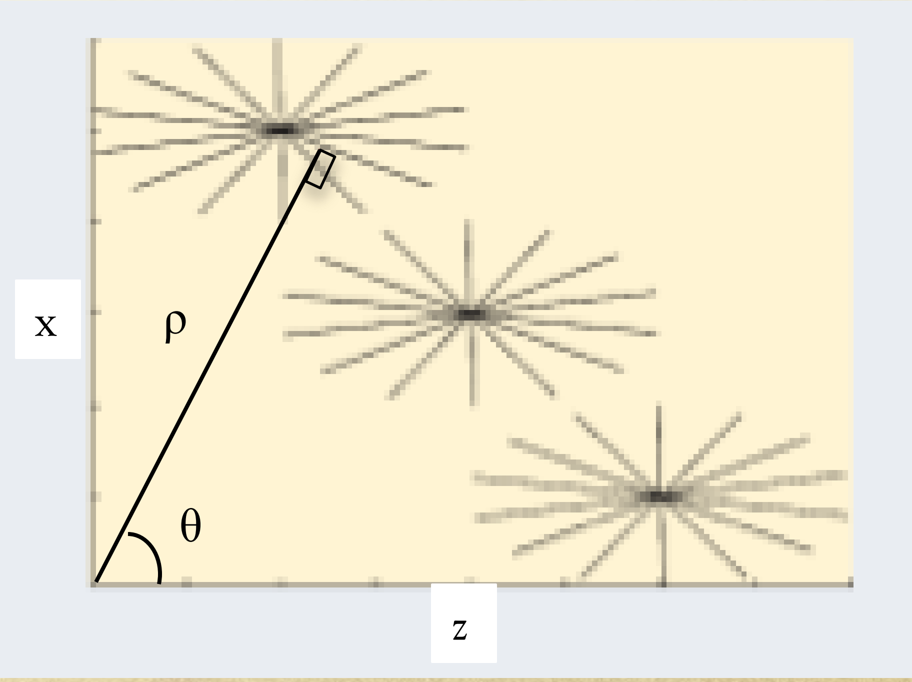
# Hough Transform

This method was proposed by P.V.C Hough in 1962 to automate the tedious task of detecting and plotting the tracks of subatomic particles in bubble chamber.

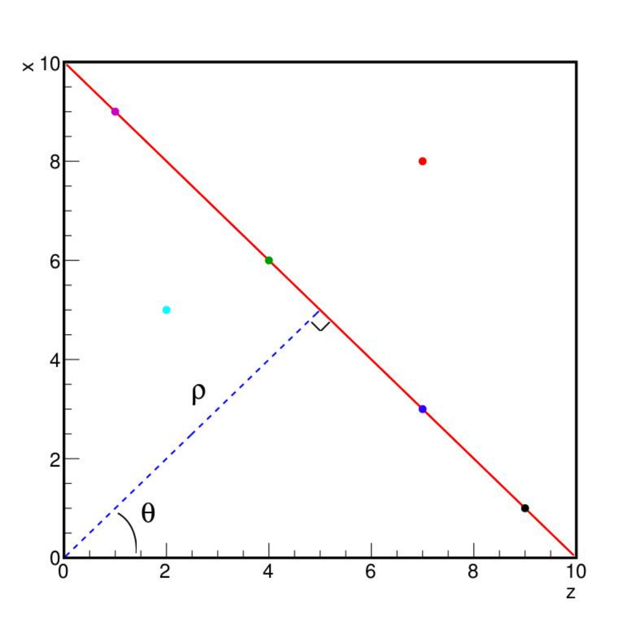
The Hough transform is one of the methods that are the most used in computer vision applied to digital images to detect geometrical features: straight lines, circles….

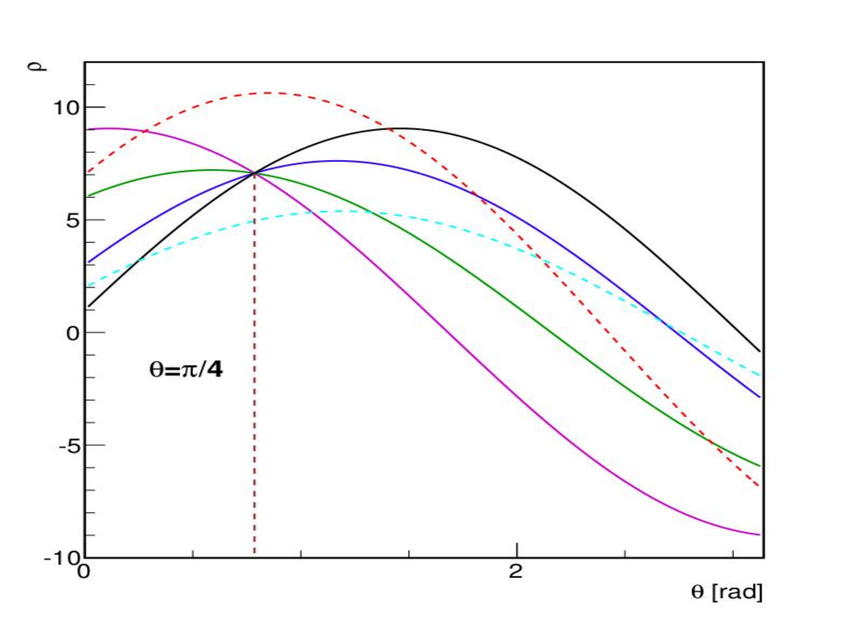
Hough Transform is based on the idea that increasing the dimensionality of a problem may make it easier to solve.
For points aligned on a straight line, a zero-dimension point is replaced by one dimension line.

Each point is replaced by a curve representing the distance (ρ) between the origin point (0,0) and all possible straight lines passing through this point as a function of the angle (θ) of these lines with the abscissa axis.



# Hough Transform




Each point defined by ( z,x) coordinates is transformed into a curve defined by:

$$\rho = z \sin(\theta) + x \cos(\theta)$$

To achieve this, one needs to replace the (z,y) plane by a 2D histogram.
The bin size should take into account the detector resolution and the "straightness" we would like to achieve

# Hough Transform in hadronic shower

## Goals

• Use the tracks produced in a hadronic shower to control the efficiency and pad multiplicity in situ.

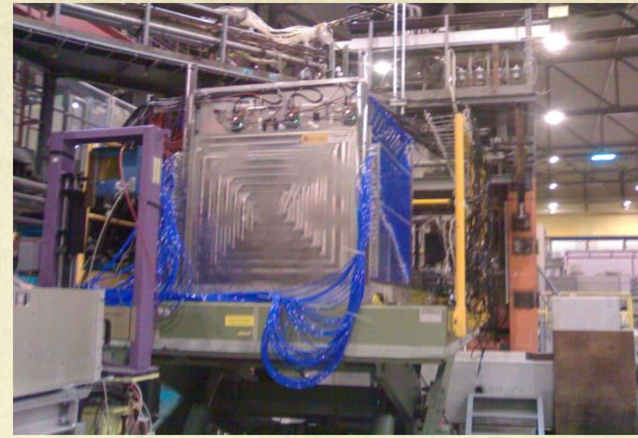
• Use the tracks to identify the charged particle in the hadronic calorimeter and to improve connection between hadronic "belonging to the same hadronic shower

• Improve separation between hadrons and electrons

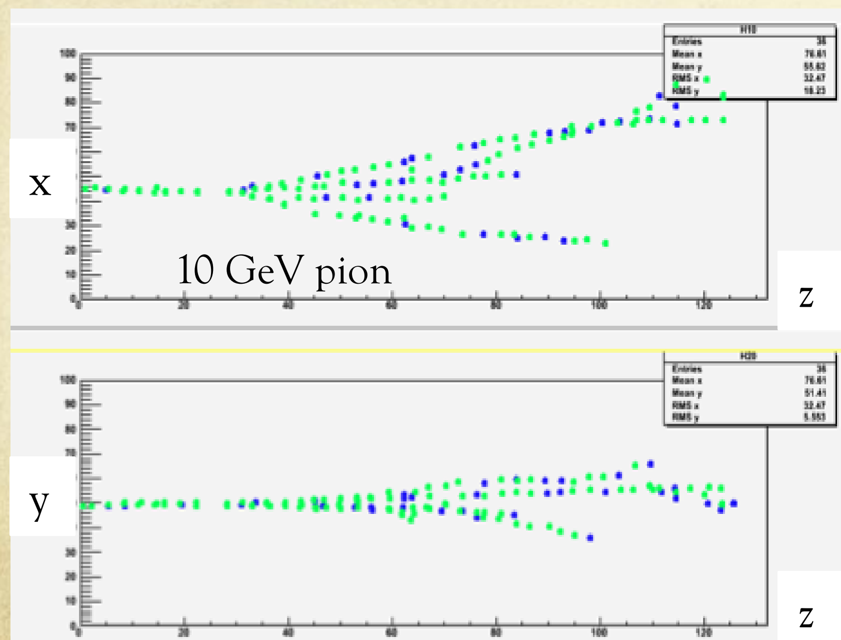
• Use the number and length of tracks to discriminate hadronic shower models

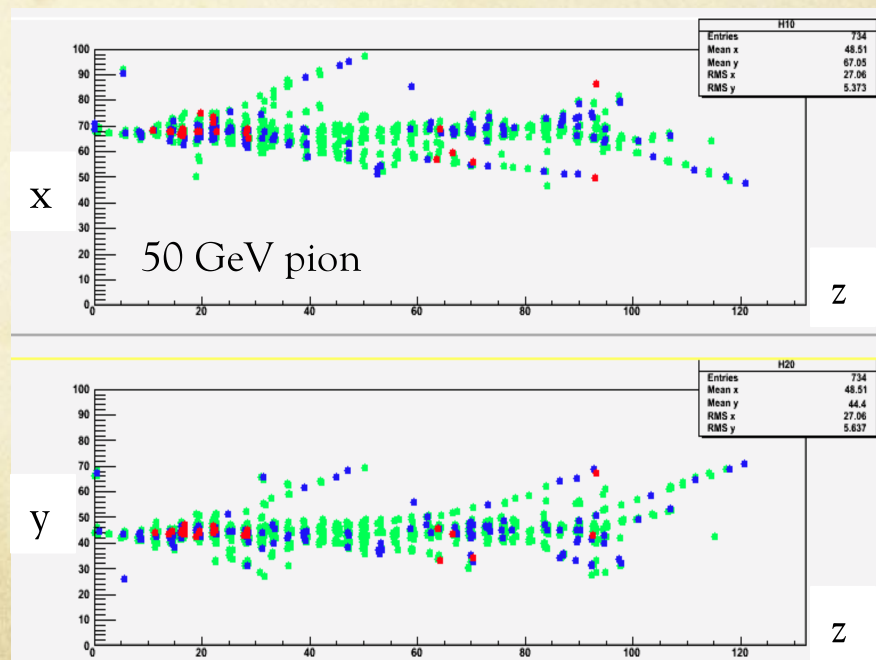
# Hough Transform in hadronic showers in the SDHCAL

**The SDHCAL prototype:**
48 active layers (0.6 mm)+ 48 absorber (2 cm)
Readout pads of 1 $cm^2$, 3-hreshold electronics readout (the three colours in the event displays)
This is almost identical to the one proposed for ILD.



**Calibration the SDHCAL using HT tracks:**
Cosmic rays are one source to calibrate the active layer behaviour in situ but it could not cover all of them efficiently. Tracks left by charged particles produced in the hadronic shower. HT could then help



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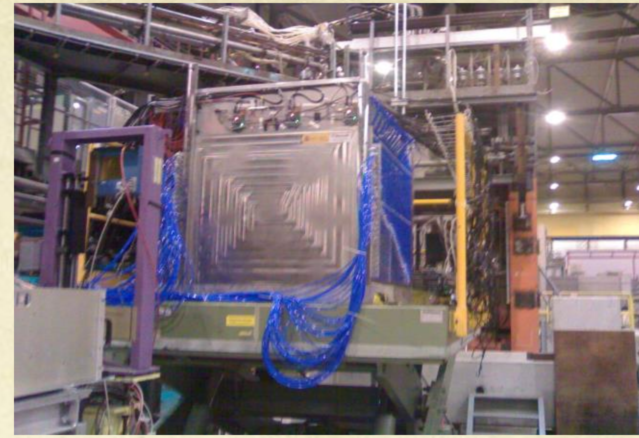

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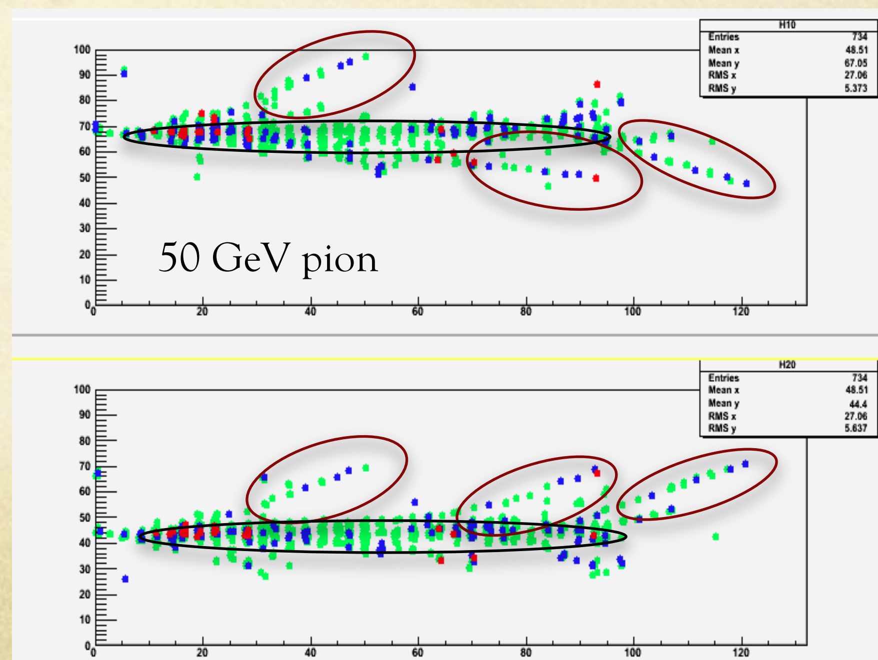
## HT in dense environment:

HT could not be applied efficiently  in a dense environment.  Many tracks could be made of the electromagnetic part of the hadronic shower.
To overcome this difficulty, one should get rid of the dense part of the shower.



**Procedure to extract tracks using HT in the SDHCAL hadronic shower events:**

0: Select hadronic shower events ( see presentation of A. Steen)

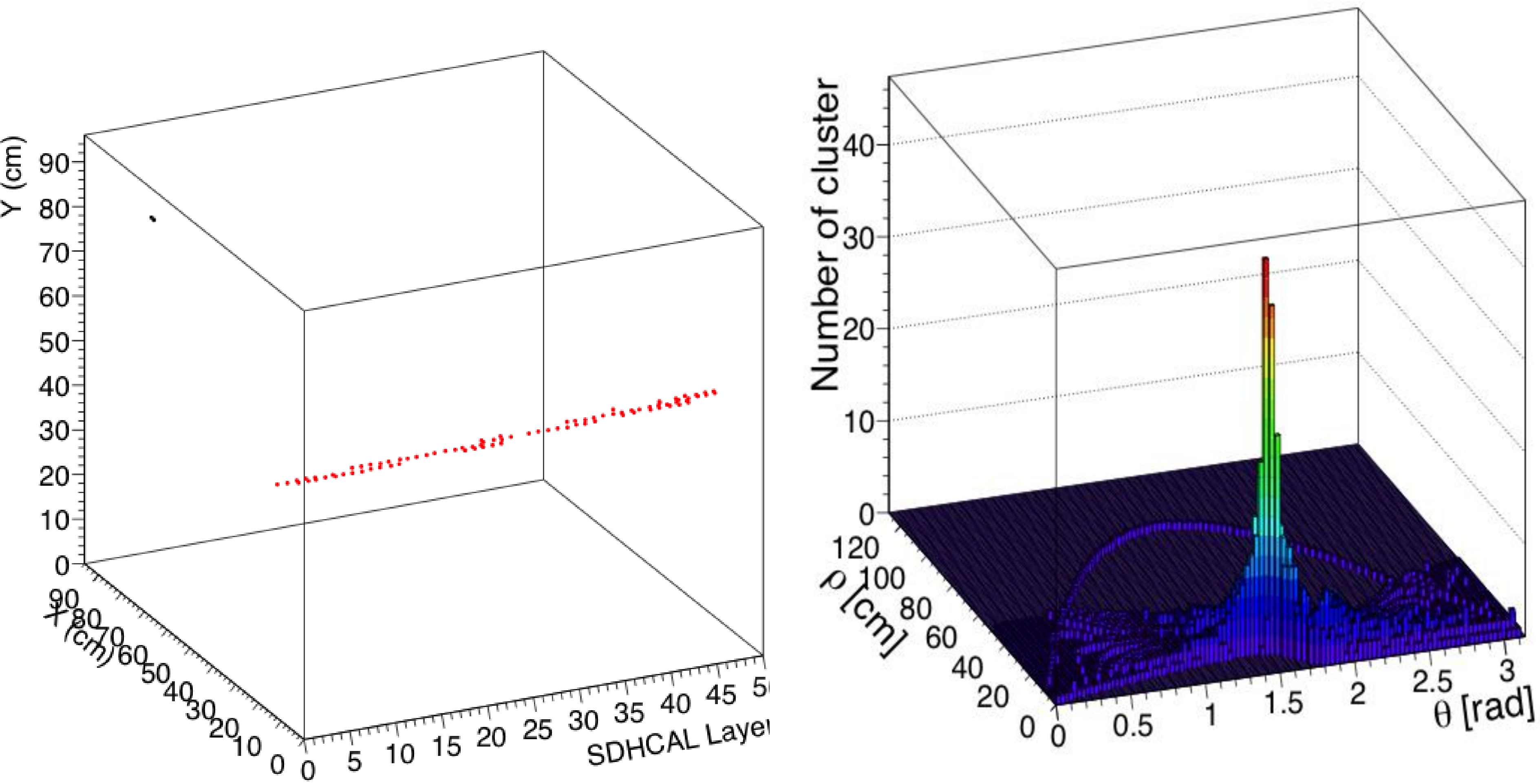
1- Produce clusters from topologically connected fired pads. Determine their barycentre. Only clusters are relevant in this study. This allows to reduce the cpu time consumption.

2- Take away clusters if they have more than 2 clusters un their neighbouring defined by a square of (10x10 $cm^2$) centred around the cluster in the same layer.

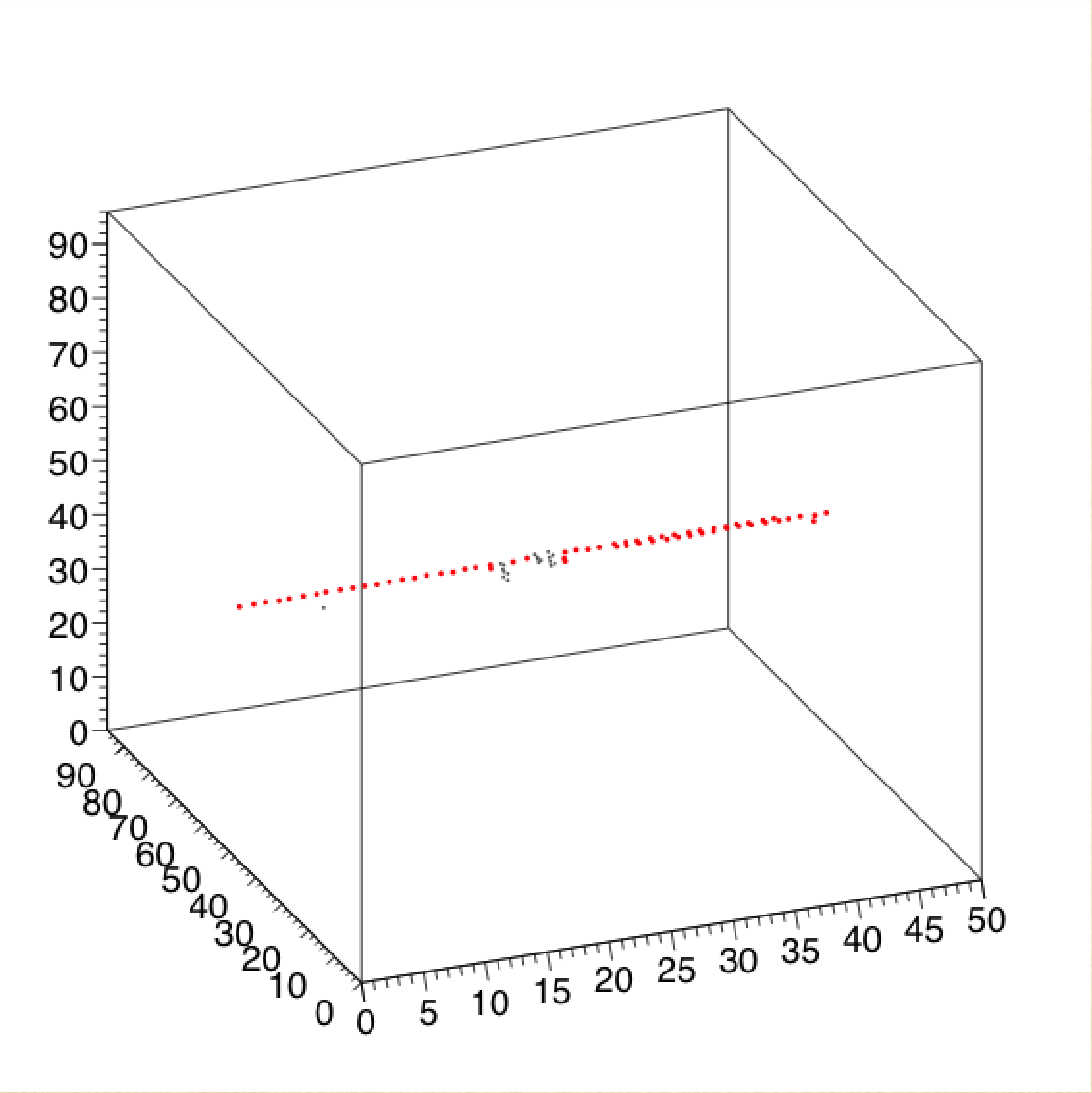
3- Apply the HT to the remaining clusters as follows:

A: First by using the (z,x) plane and building a HT histogram in the associated ($\rho_1$,$\vartheta_1$) plane. Select the bins that have > 5 clusters.
B: For each selected bin, use the associated clusters to build a new HT histogram in the ($\rho_2$,$\vartheta_2$) plane associated to the (z,y) plane.
C: Select the clusters of bins featuring more than 5 clusters.
D: The clusters of one bin are kept if they have at least 2 clusters of the same bin in a cube 18x18x18 cm. This allows to eliminate artificially aligned clusters
E: Determine the track associated to the selected clusters.
F: Repeat the B step for all the selected bins in the A step.

Validation:
First check on muon and cosmic events

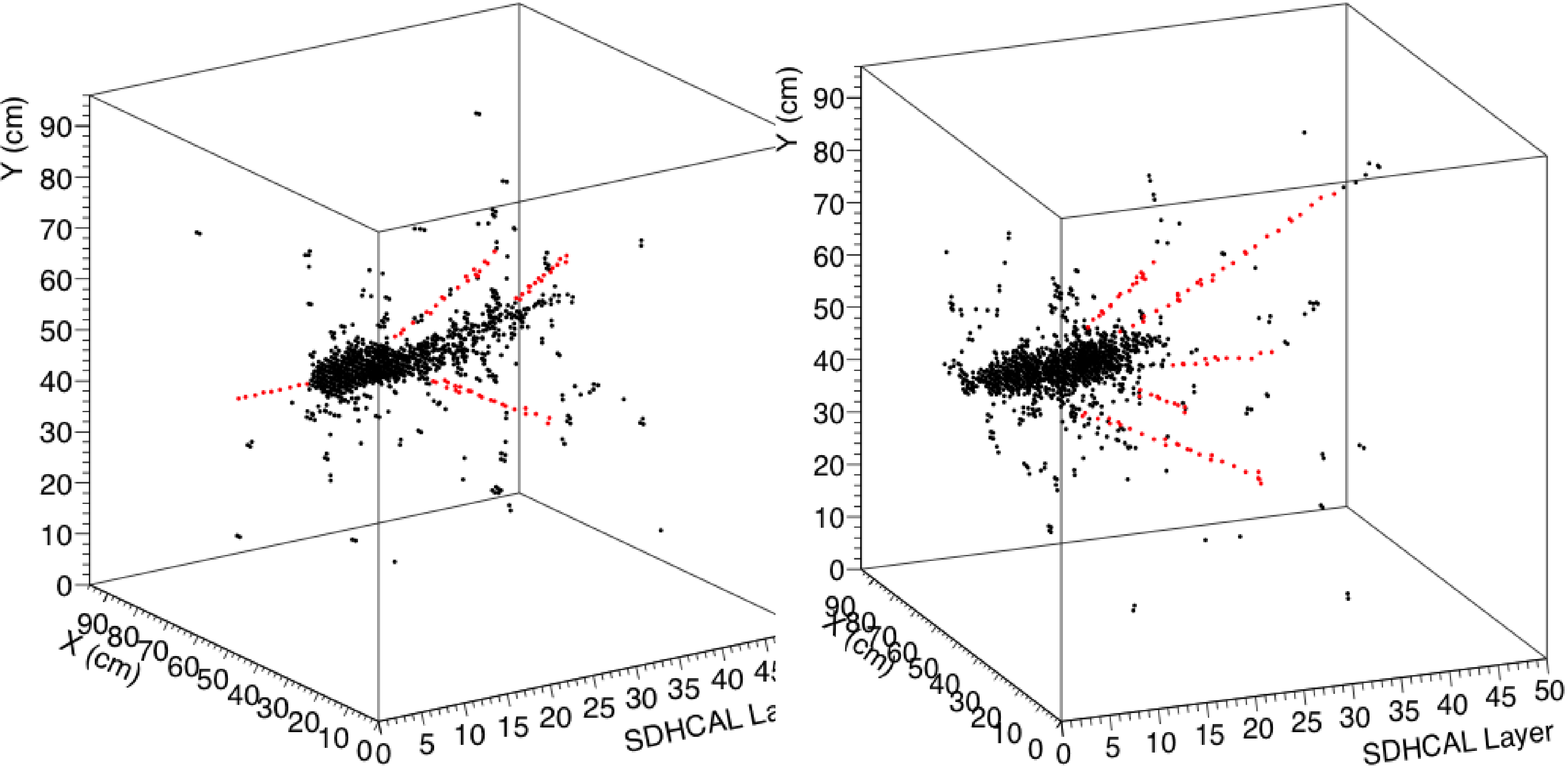


Validation:
Check what happens in case of irradiative muons

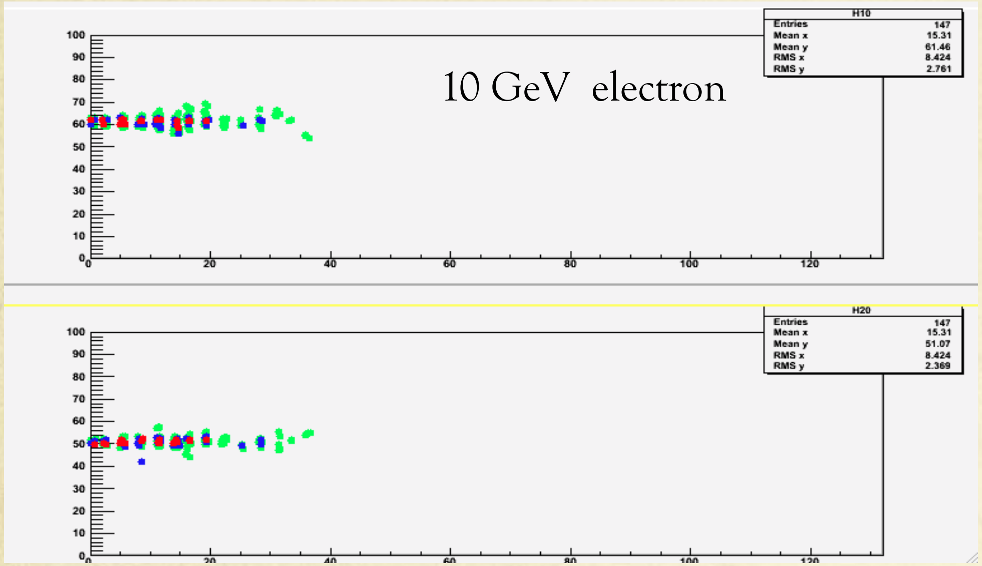


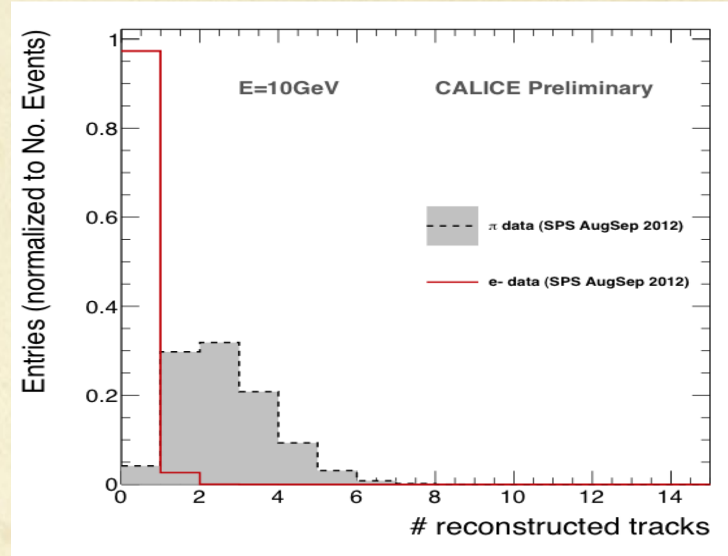
Validation:

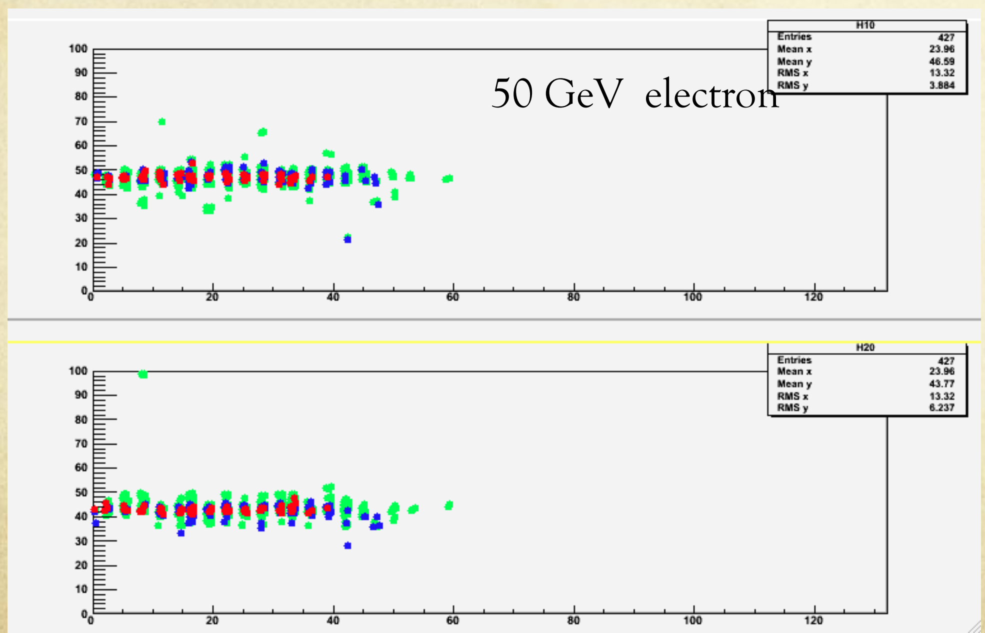
Apply the procedure on hadronic showers and visualize the tracks

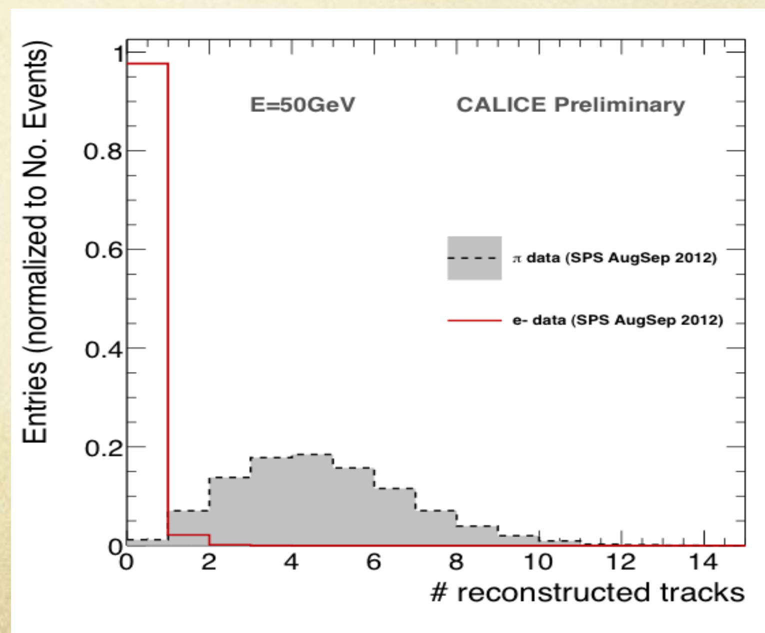


Validation:
Apply the procedure to electron samples. This allows to check that dense environment is well neutralized.



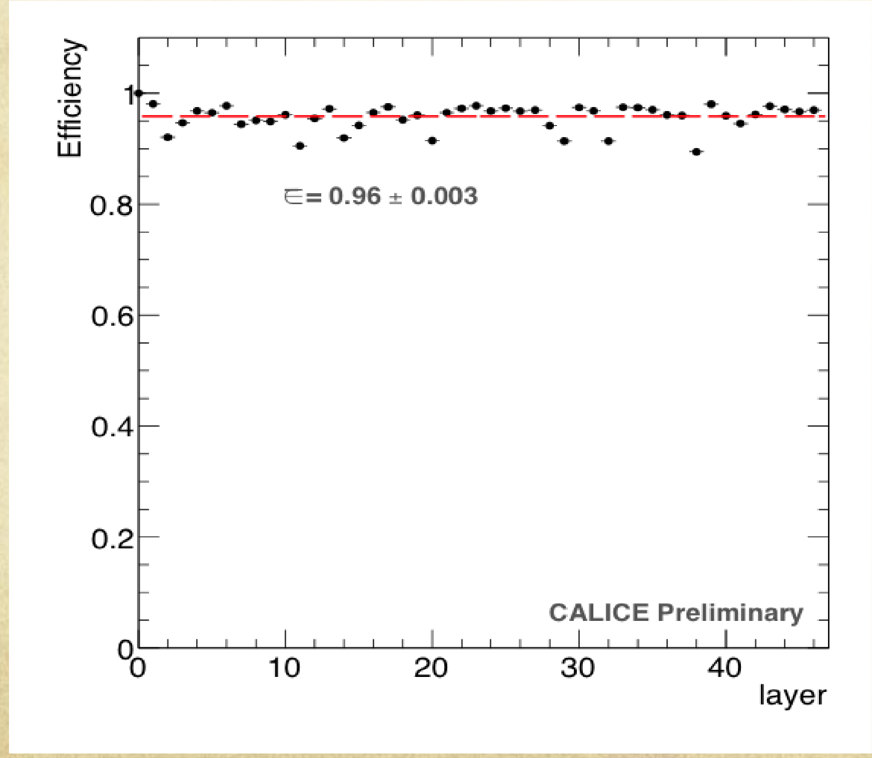



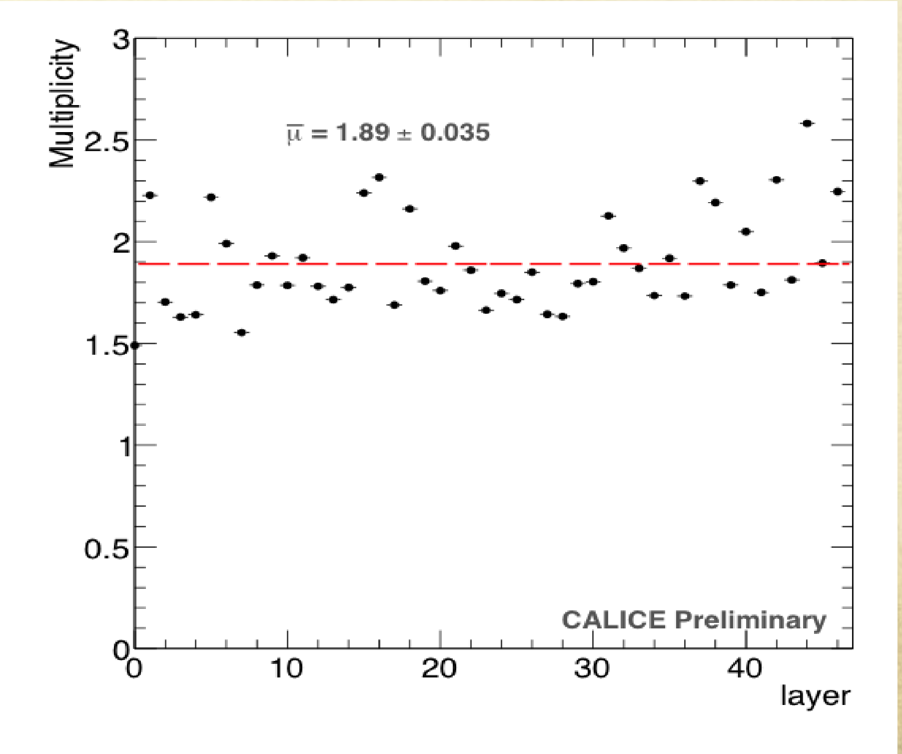
# SDHCAL calibration in situ

To study the efficiency and the pad multiplicity of one layer, the HF selected clusters associated to the same Hough histogram bin and which contains clusters on both side of the layer ( excluding those belonging to the concerned layer) are then used to build a track. If the $\chi^2$ of the track is good (< 3 in this analysis) then one can use it to study the efficiency and multiplicity of the layer.

The same procedure used to study the efficiency and pad multiplicity with the muon beam is used here again. Clusters within 2 cm around the track impact in the considered layer are looked for.

The results are in good agreement with those found with muon beam studies.



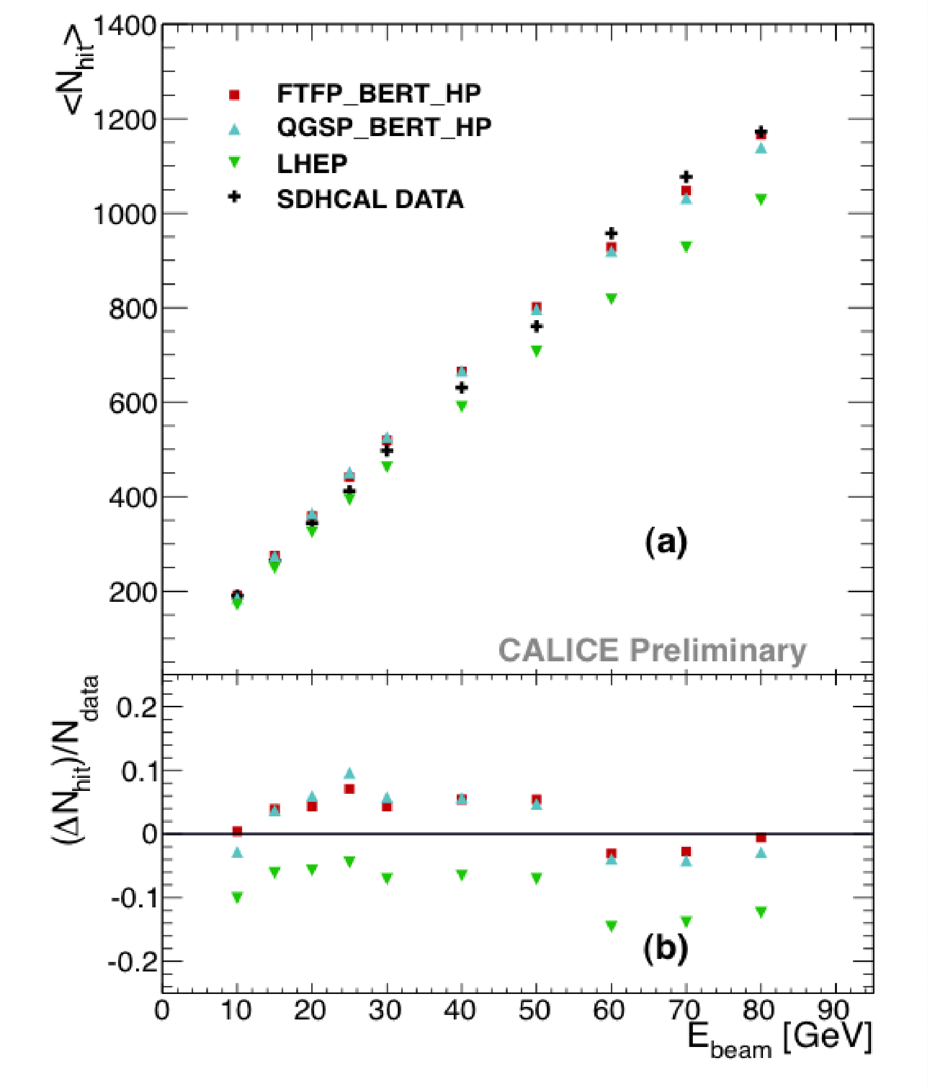
## Testing the hadronic showers models using the racking in the SDHCAL.

The number of tracks and their length could be good variables to discriminate the different hadronic models.
To achieve this, a digitizer to reproduce the charge left by particles in the GRPC is needed.
A digitizer based on results obtained with the threshold scan study with beam muons was developed.

To take into account screen effect in case of closed-by particles, an exclusive separating distance "d" between particles is introduced.
if two particles are closer than d only the charge of one of them is taken into account.

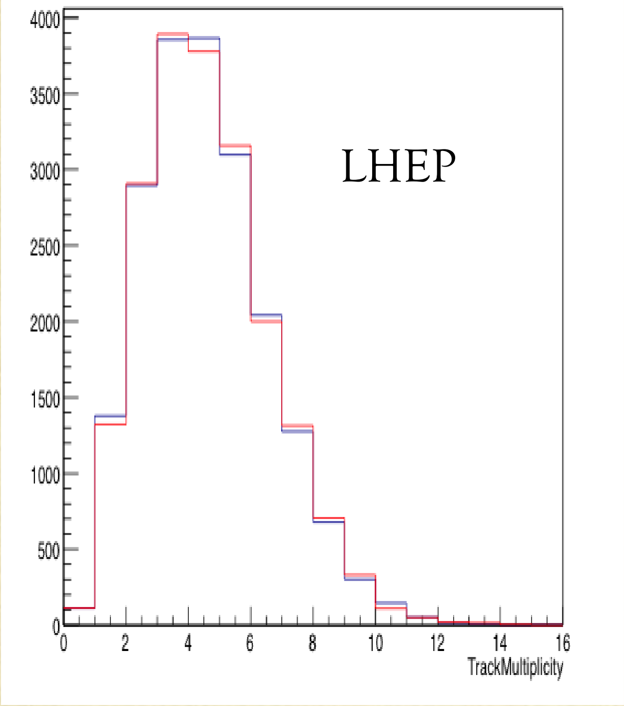
"d" was tuned so that the total number of hits in the simulation reproduce fairly that of the data ( **hadron-tuned digitizer**)

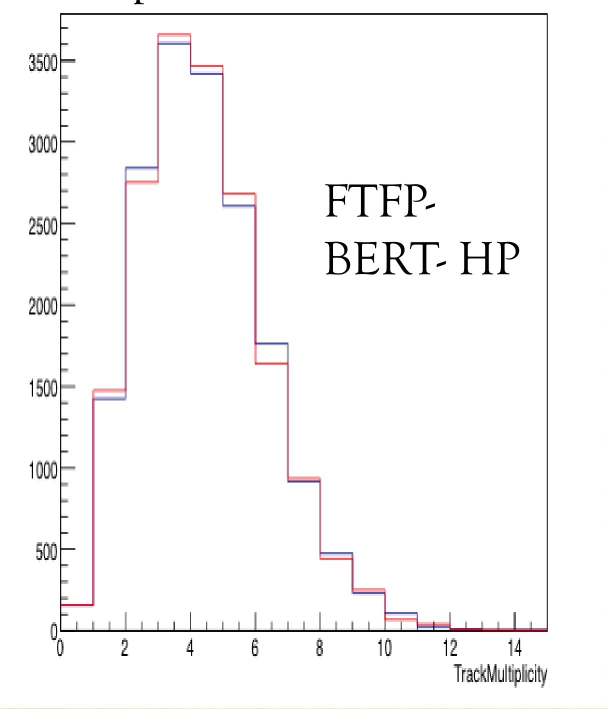
The optimization was based on one FTF__BERT_HP physics list but found to to be also optimal as well the other models.

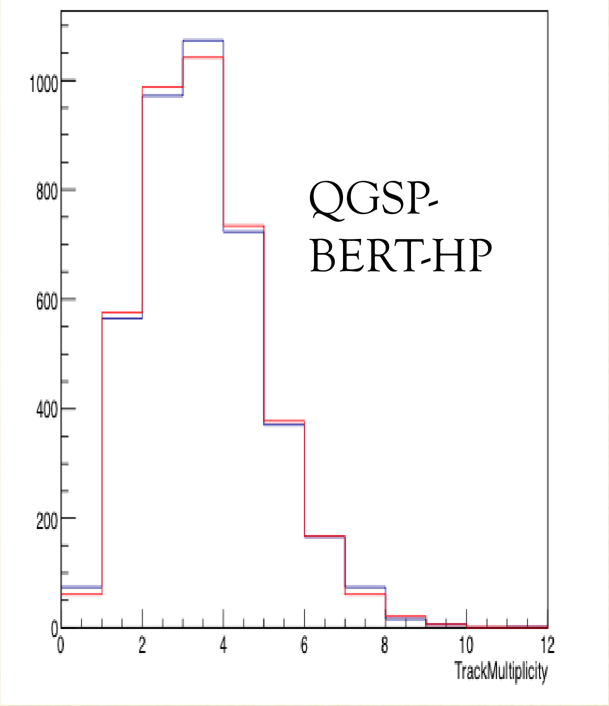


Although the digitizer is hadron-tuned one, for the tracks of the shower this should not be an issue. This was checked by putting d=0. The variation observed in the tracks number was found to be negligible. Thus, one can use the HT tracks to compare the hadronic shower models using variables

40 GeV pion events simulated with:



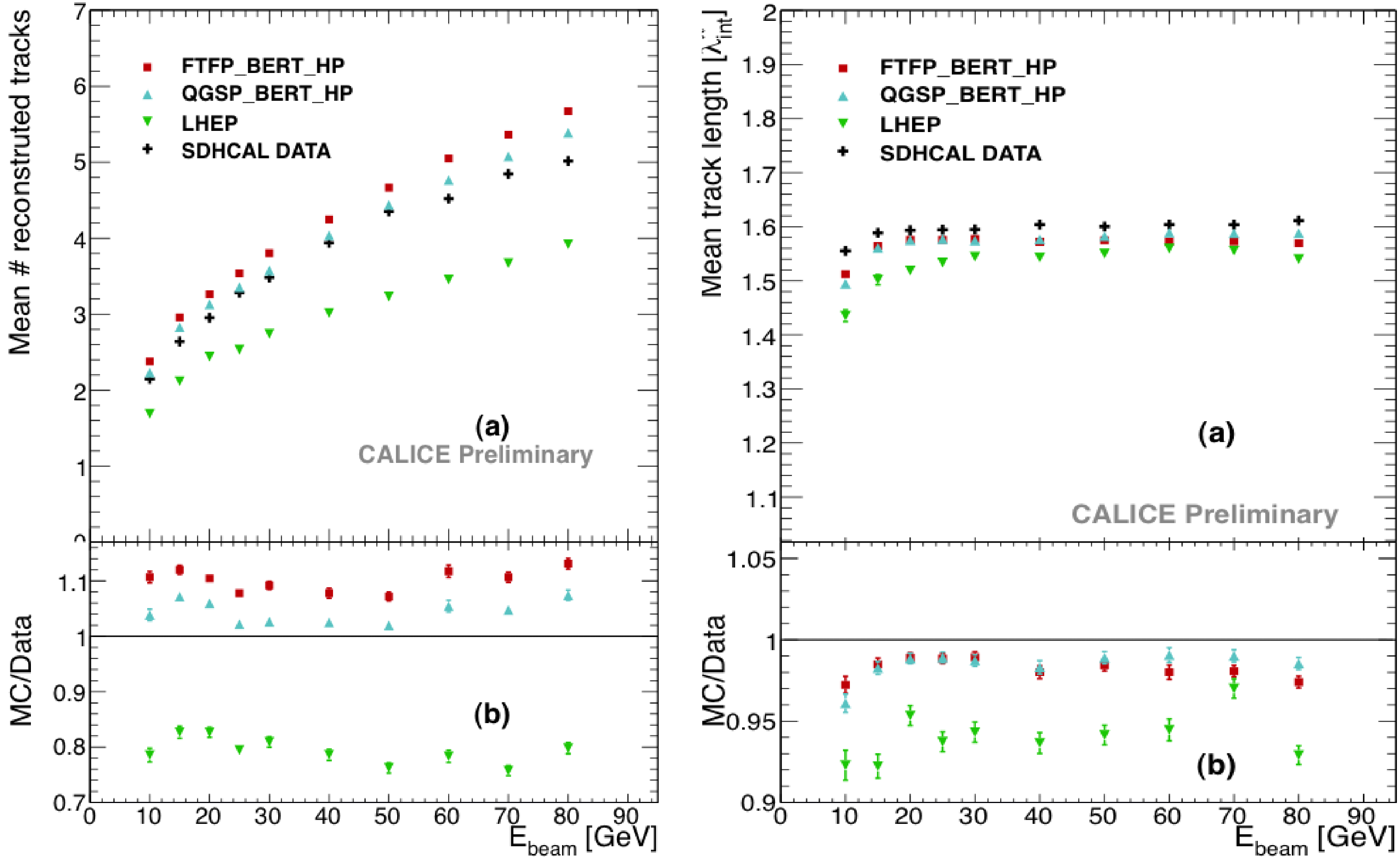




Black : d = 0 ( no hadron-based optimization)
Red : d (optimized using hadron data)

# HT tracks in hadronic shower models

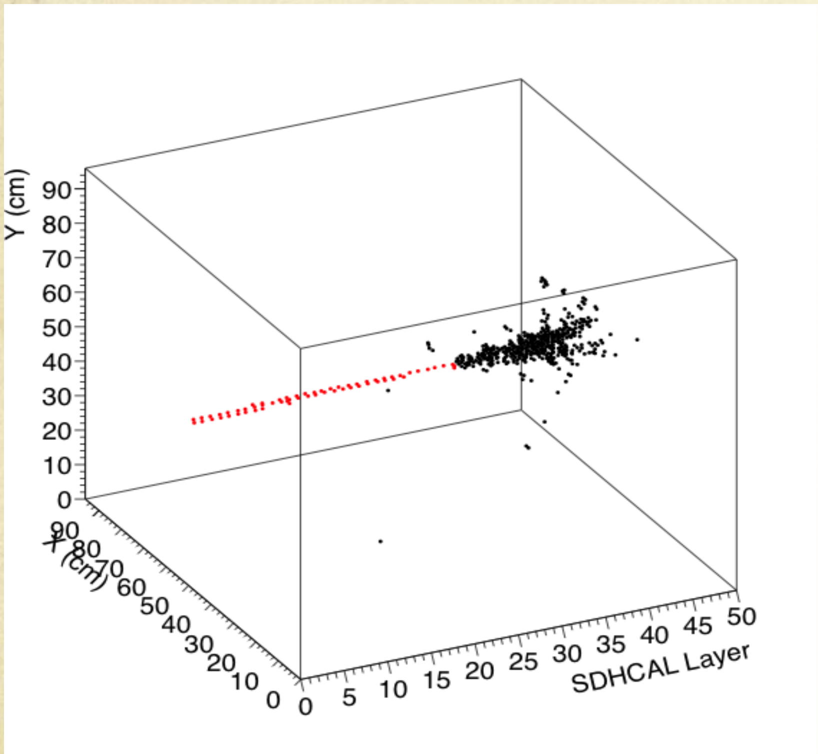
**Warnings** :
systematics are not included here

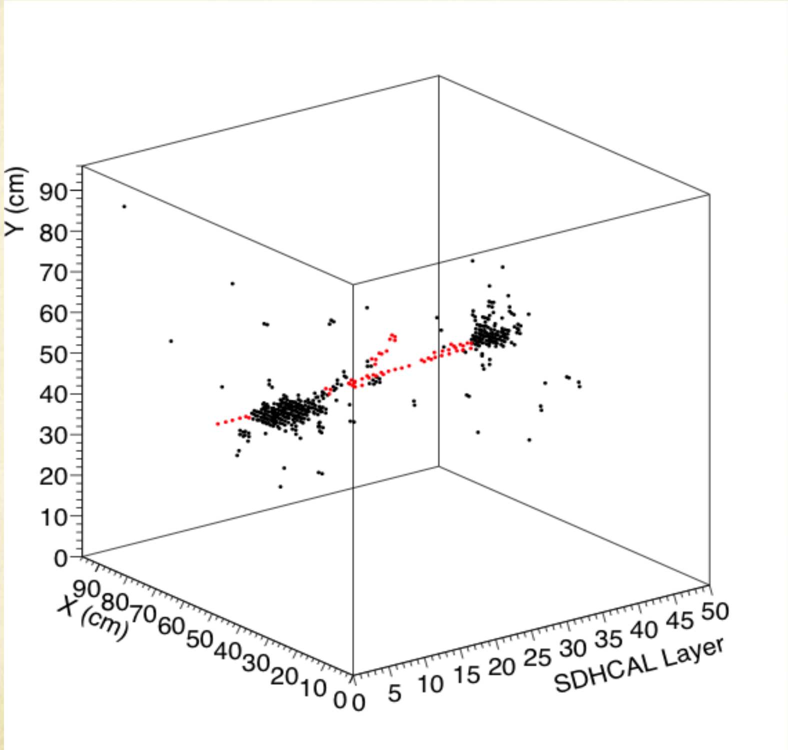


Tracking within SDHCAL for PFA:

The HT tracks could also be helpful to improve on the PFA performance.

1: Tracks in the beginning of the shower could help determine the starting point.
2: Tracks could help to connect two "bulbs" belonging to the same hadronic shower



**Extending HT to tracks finding in the future ILD**

The presence of the magnetic field will not significantly affect the high-energy tracks. For these tracks the method applied here will prevail.

Low energy particles will produce spiralling tracks. However, HT is not limited to straight lines finding. It is also applied to other shapes. Circles could also be determined using HT. In this case three variables are needed.

By projecting on the plane perpendicular to the B field one can search for clusters located on a ring. The selected clusters will be then filtered by projecting the selected ones on an axis parallel to the B field and passing through the circle centre and then eliminating those located far from the barycentre of the clusters positions on this axis.

## CONCLUSION

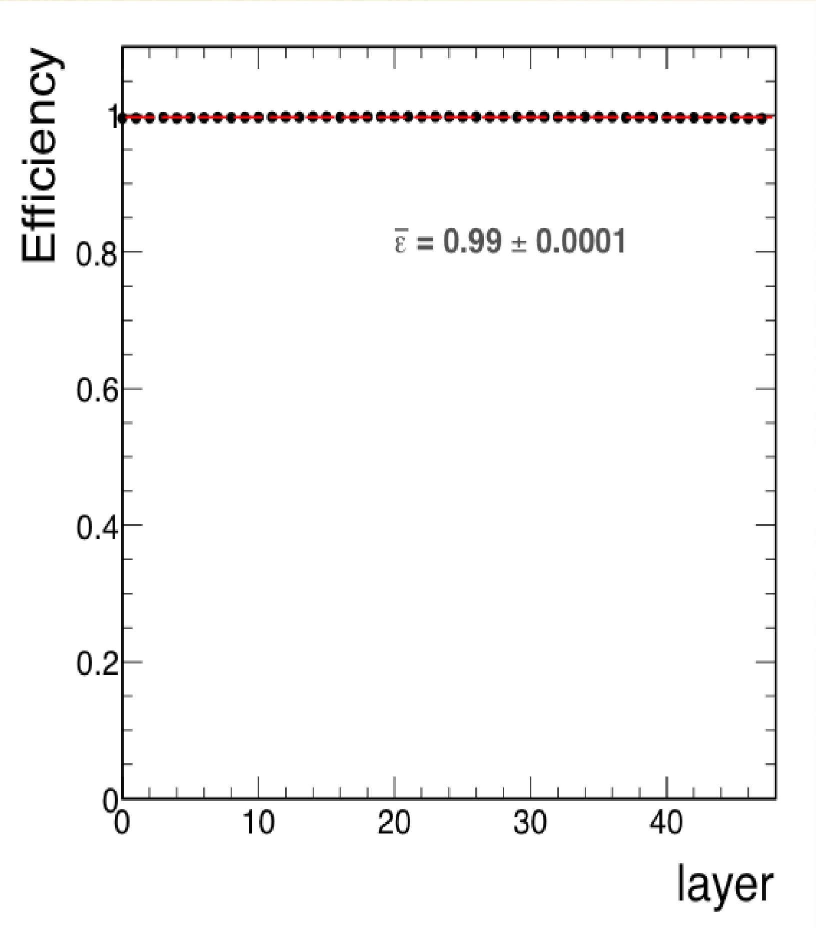
→ Hough Transform is applied to 3-D hadronic showers events successfully

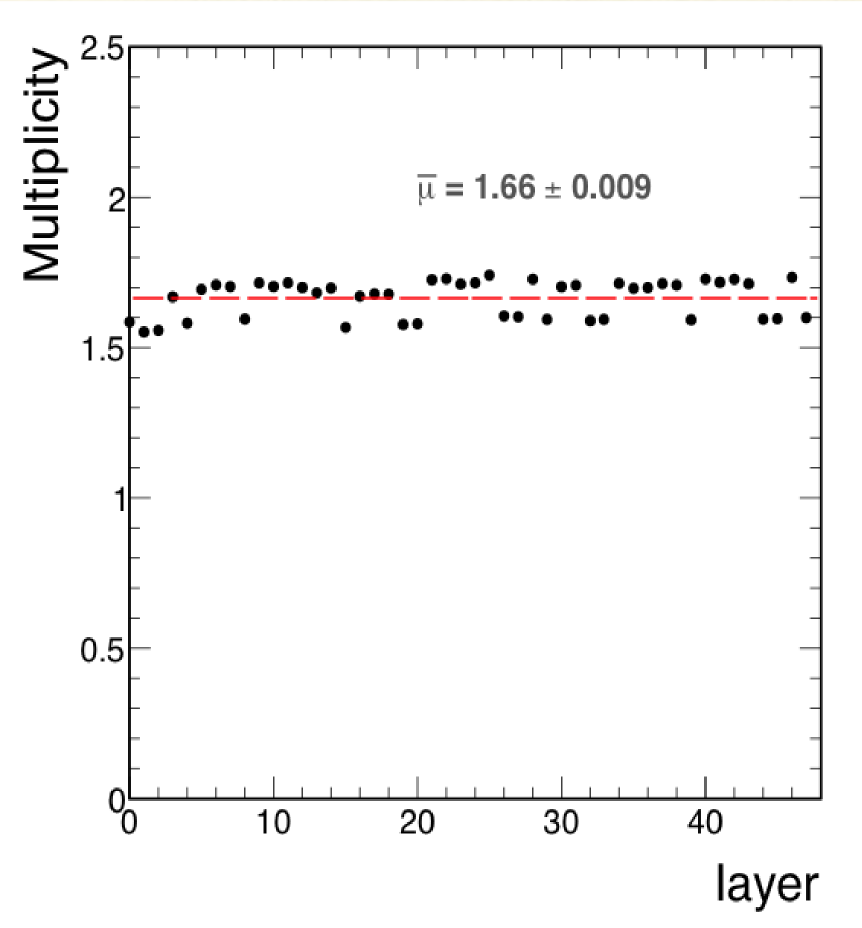
→ Dense environment could be dealt with efficiently

→ Tracks found with HT could be used to monitor the active layer behaviour in situ

→ Tracking in hadronic shower is a good tool to discriminate hadronic shower models

→ Tracks in the hadronic showers are an important element for the PFA performance and should be exploited cleverly to improve on.




Muon efficiency and pad multiplicity in the simulation

Correction on the number of clusters/track when efficiency is corrected for the simulation for 10, 40 and 70 GeV simulated pions.