Performance of Muon identification in PandoraPFA

1. New yoke geometry for CLIC detector for tail-catching & muon ID
2. New Pandora algorithm for muon reconstruction

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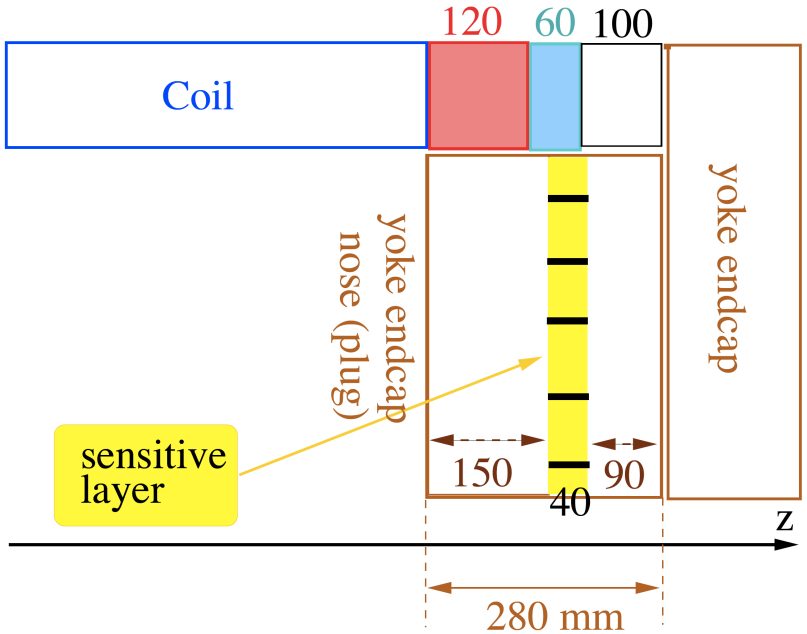
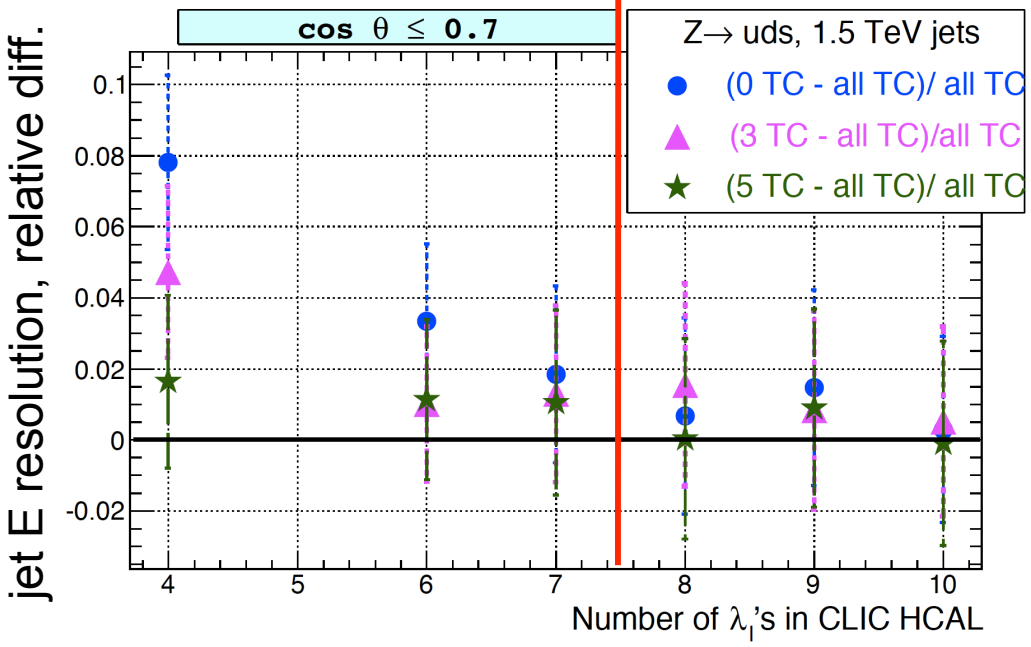
CLIC detector - tailcatcher

Engineering: need yoke endcap aligned to coil

- Avoid 28 cm of steel before first sensitive layer: insert 1 layer after 15 cm.



HCAL design: 7.5 λ, ECAL: 1.0 λ



- Jet energy resolution studied with different HCAL- and tailcatching depths
- In endcap and barrel start yoke instrumentation with three sensitive layers.

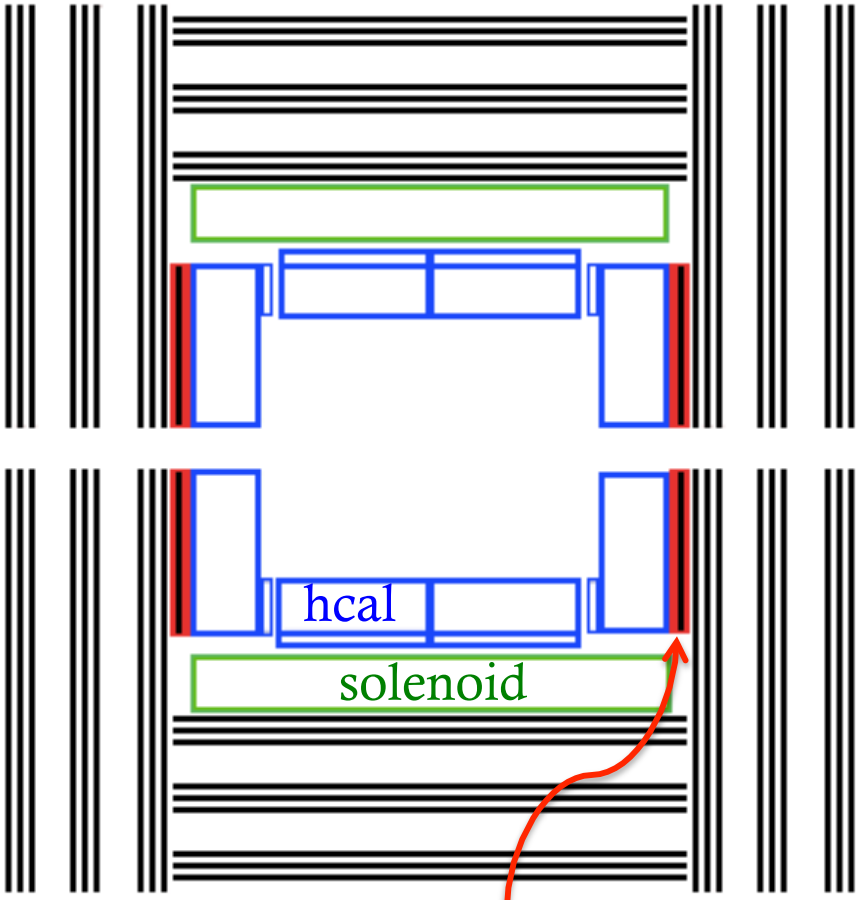
CLIC detector - full geometry

- For muon ID & pattern recognition
  - 2x three layers beyond tail-catcher

➢ Yoke barrel: 9 sensitive layers
  - Starting with active layer directly after solenoid

➢ Yoke endcap: 10 sensitive layers
  - Including single plug layer

- Granularity: 3 x 3 cm^2 sensor size
- Sensor type: RPC (digital) or scintillators (analog)



3x3 layered muon system, identical in CLIC_ILD & CLIC_SiD

CLIC detector – angular coverage

- For muon ID & pattern recognition
  - 2x three layers beyond tail-catcher

➢ Yoke barrel: 9 sensitive layers
  - Starting with active layer directly after solenoid

➢ Yoke endcap: 10 sensitive layers
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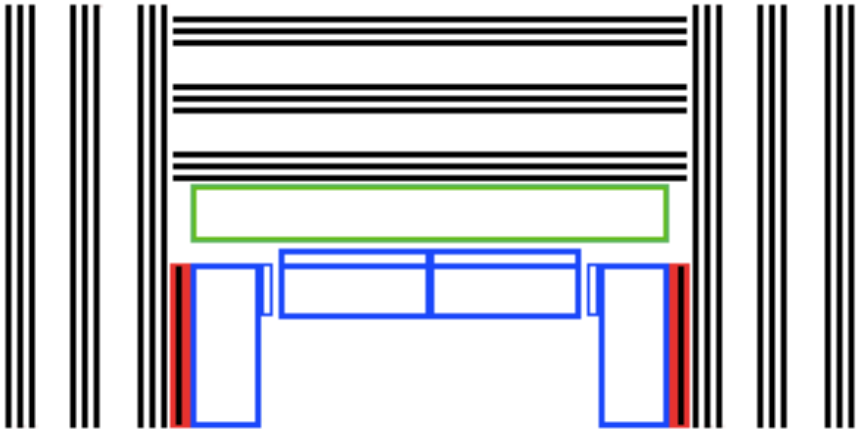
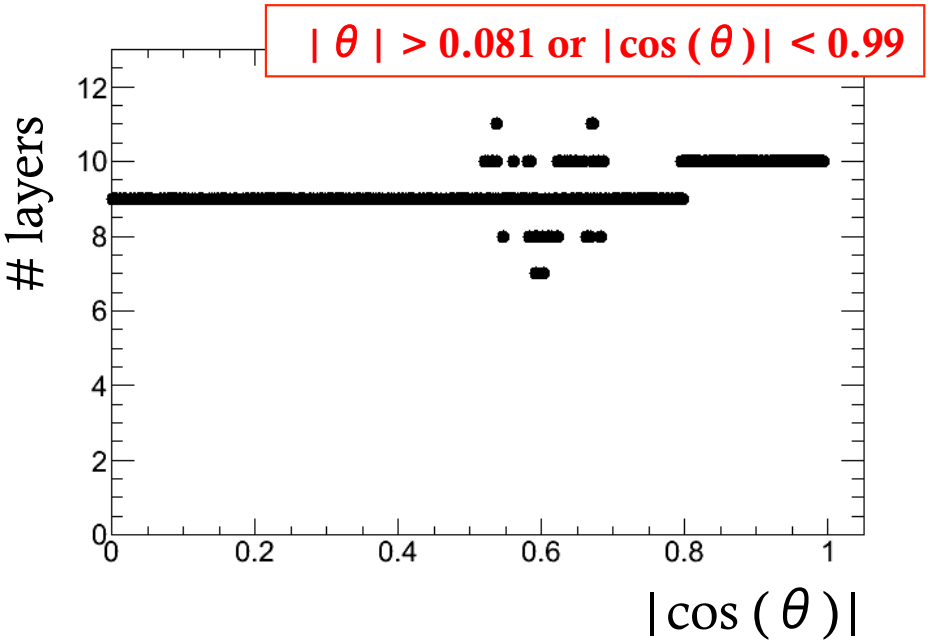
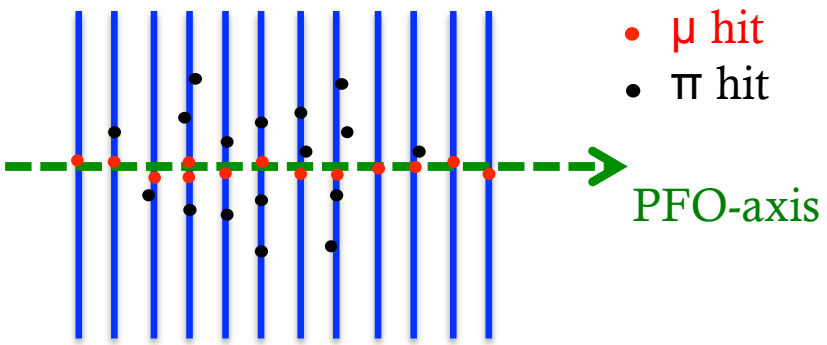




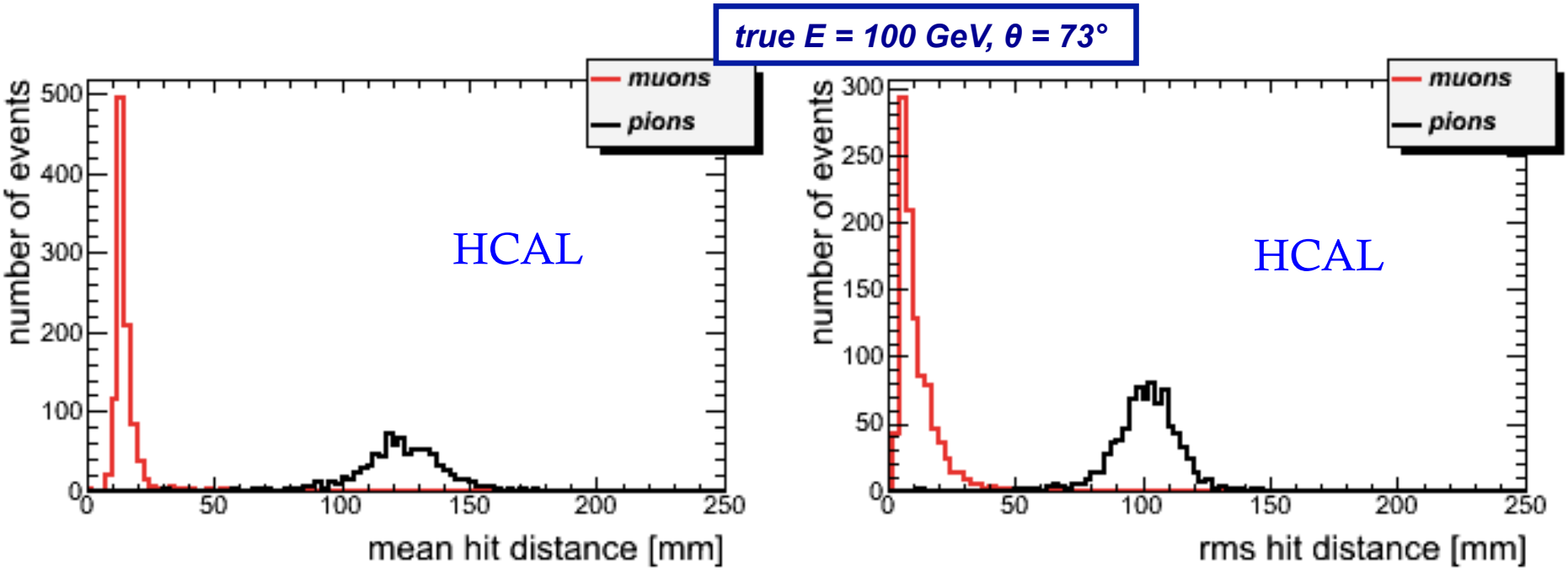
- In the transition region from barrel to endcap ($0.5 < |\cos(\theta)| < 0.8$) the muon passes sometimes less, sometimes more than 9 layers.

Identification of isolated muons

- From each PFO extract the mean and width of the hit distances to PFO-axis



- Pandora is able to 'see' fine granularity of HCAL:



Identification of isolated muons

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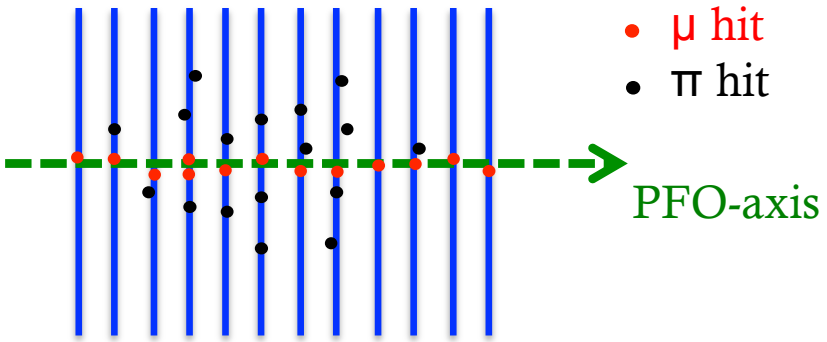
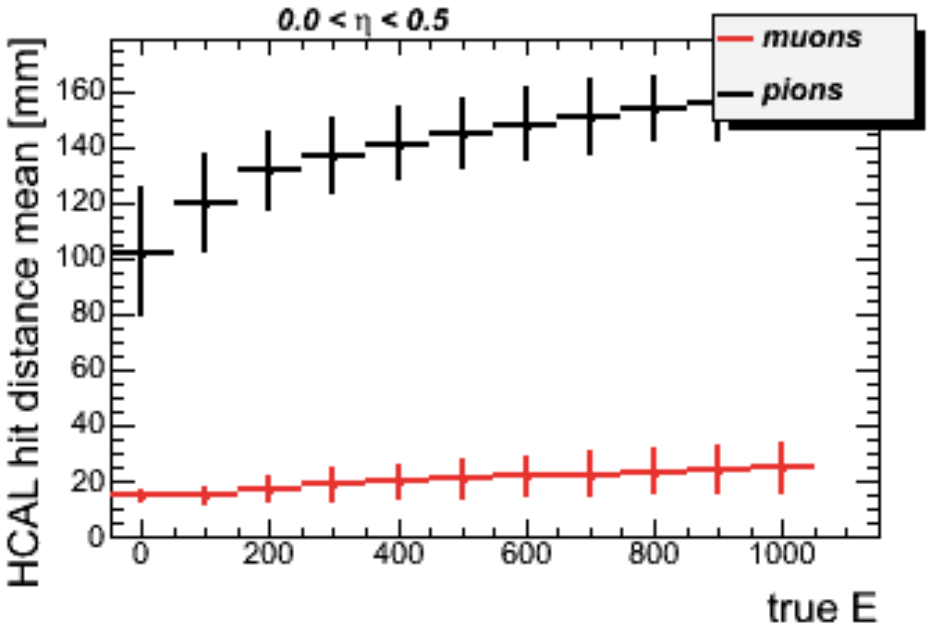


- For muons dependency on energy is small:



➢ These results are obtained with muons & pions particle gun and indicate that, under certain conditions, Pandora is able to identify muons using the HCAL information.

Reconstruction of muons in a particle shower

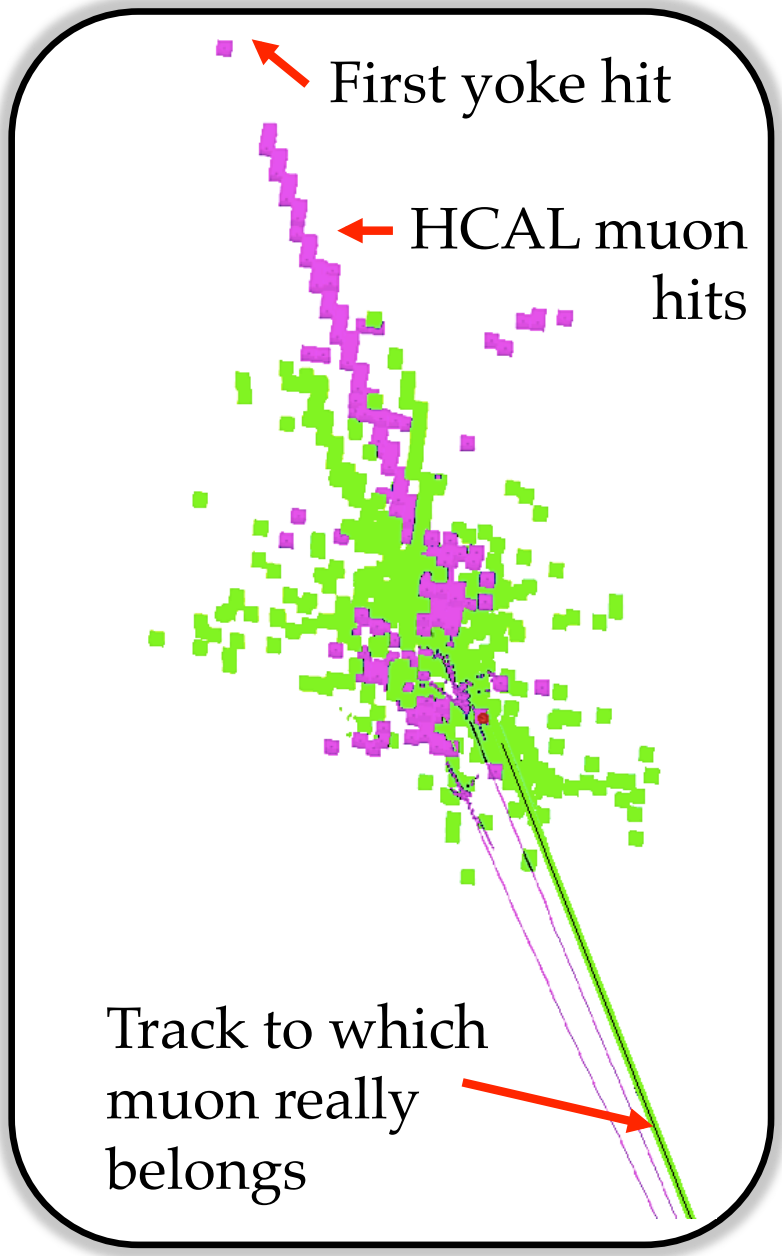
Green and purple are two reconstructed PFOs.

Pandora clusters the hits outwards

- In a dense environment it occasionally has wrong hit assignment for muon hits in the HCAL.

To prevent this:

- start with a new algorithm that matches Inner Detector tracks to tracks in the yoke.
- Then use fine granularity of the HCAL to pick up HCAL hits along this newly defined muon track

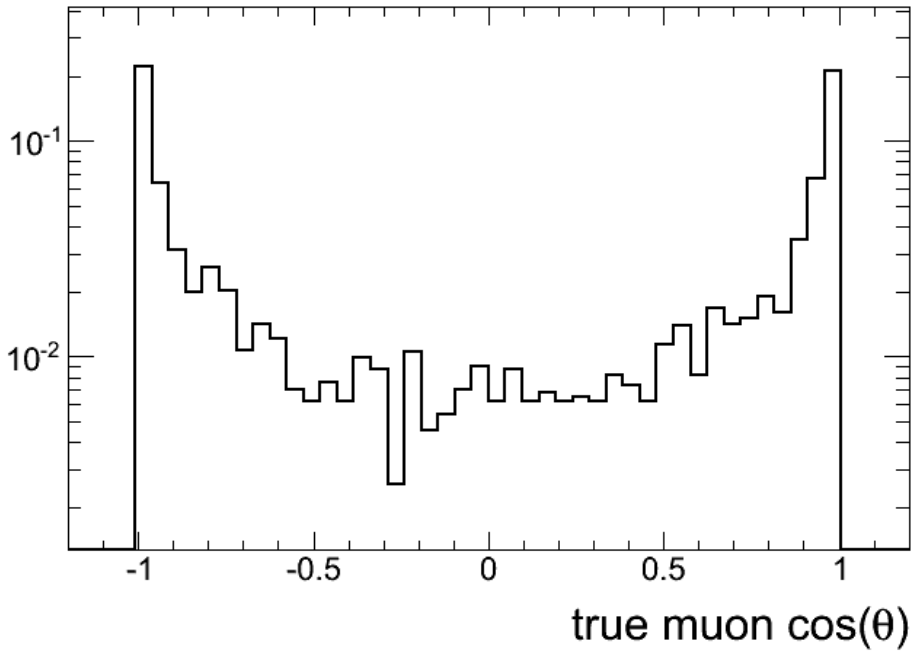


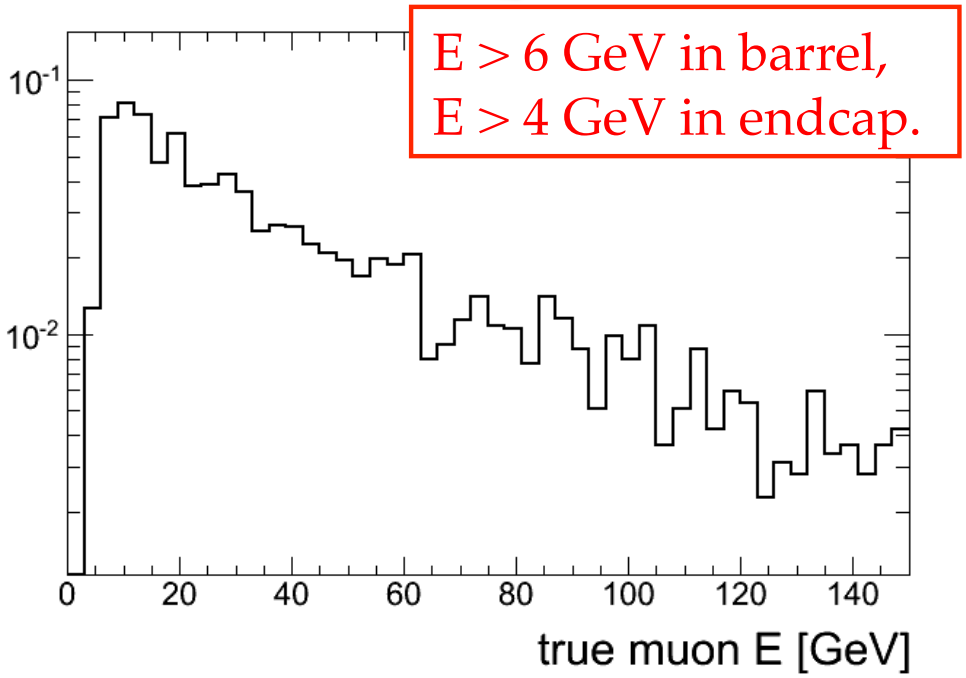
Reconstruction of muons in a particle shower

To test the new algorithm we use Z' → bb → μX

- Created 6000 Z'(1.5 TeV) → bb, with at least one muon in final state.
- These b-jets have approximately the energy expected in 4b-jet final state events at CLIC.

Distributions for muons which made it through all layers of detector:

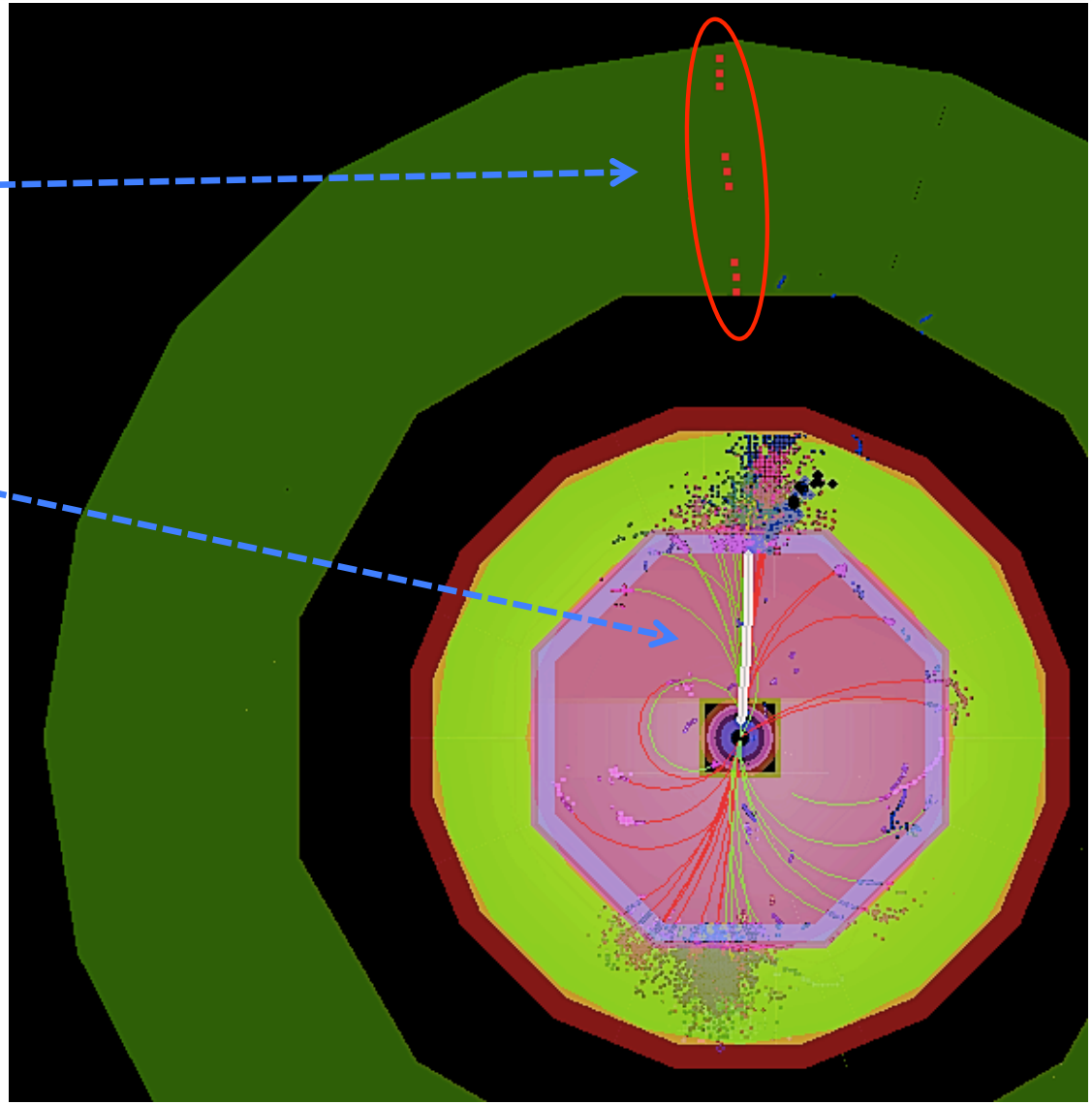




Reconstruction of muons in a particle shower

Algorithm steps:

1. Cluster hits in yoke
   - Determine direction of cluster; currently a linear fit
2. Loop over all tracks in Inner Detector
3. From a helix extrapolation of the track to the first layer of the yoke determine:
   - Angle between extrapolated track and cluster direction
   - Distance between extrapolated track and the cluster hit in the first layer.



- Track with best of both variables is muon track candidate
  - identify the hits in ecal & hcal along the helix as muon hits.

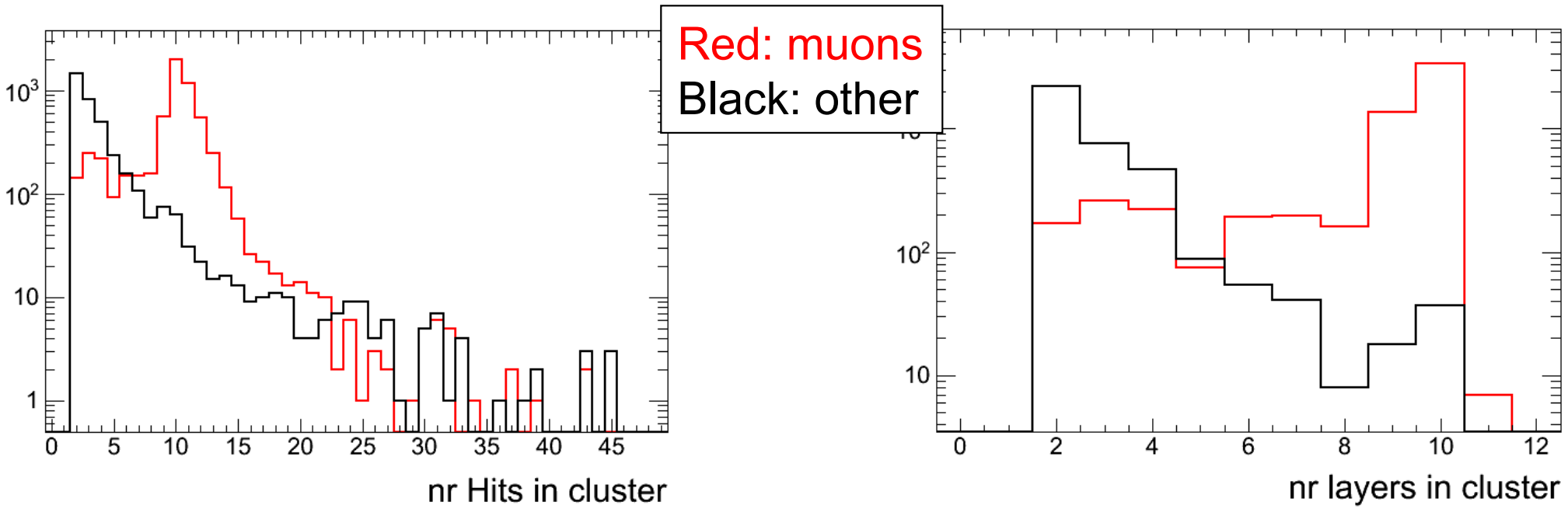
Cluster selection in the muon system

Hits in the yoke are clustered only by a narrow cone-approach to the next layer, mimicking a track-fitting.

- Clusters can come either from muons or from hadrons (punchthroughs / leakage).

➢ Criteria for clusters in muon system as originating from muons:

- Maximum of 30 hits in muon system cluster
- At least 8 layers hit



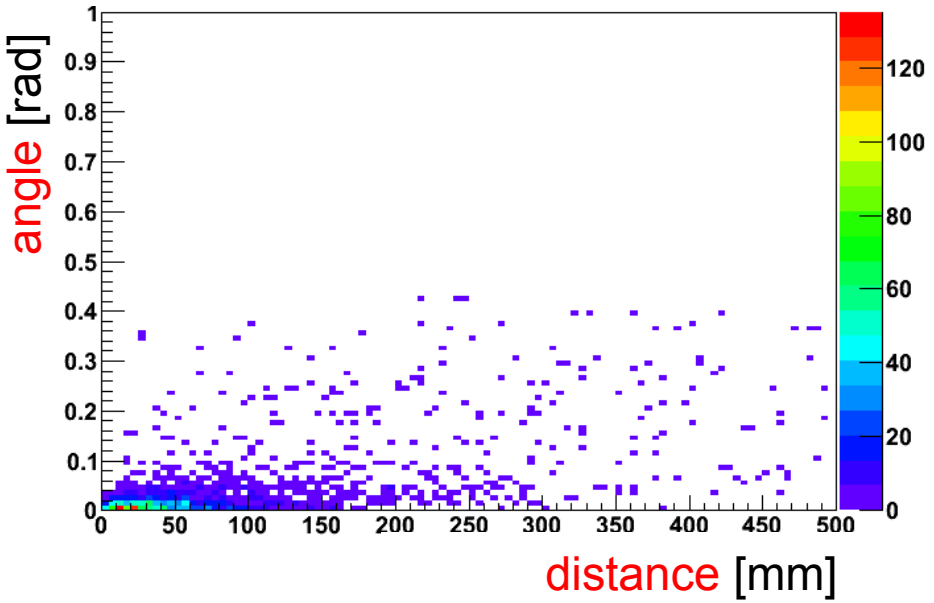
Track selection

Select on:

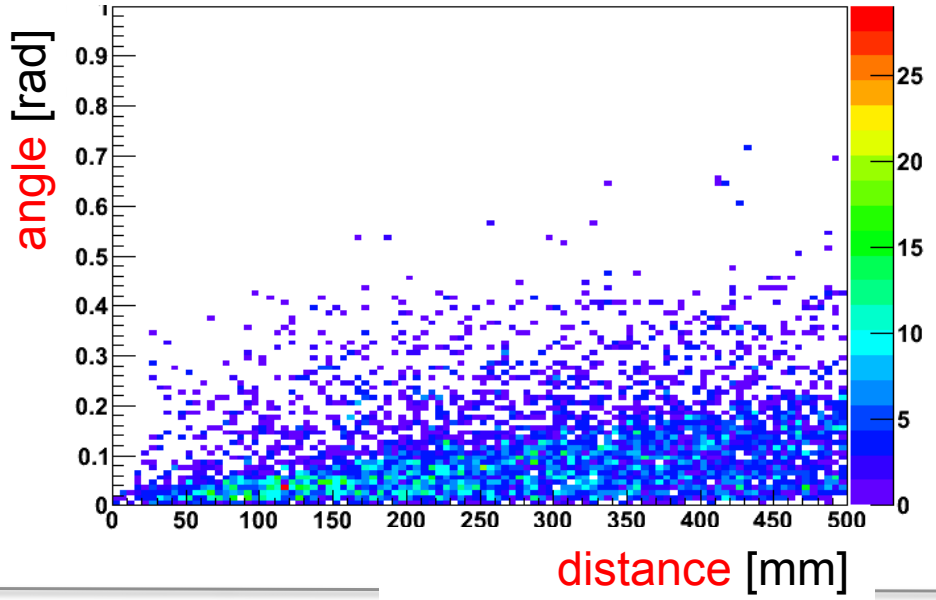
- Angle between the track extrapolated to the first yoke layer and the cluster direction.
- Distance between extrapolated track and the cluster's first hit.

- Distance typically below 3 cm (=tile size), yet even for matched tracks the distance goes up to 40 cm.
- Angles for non-muon tracks are larger than angles for muon tracks.

Muon tracks in endcap, E > 10 GeV



Non-muon tracks in endcap, E > 10 GeV

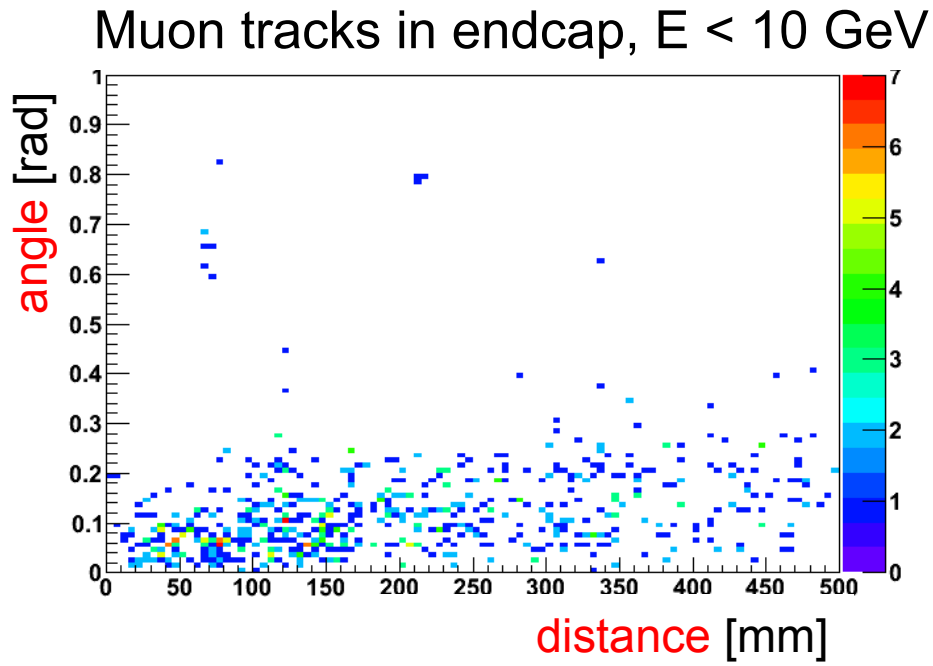


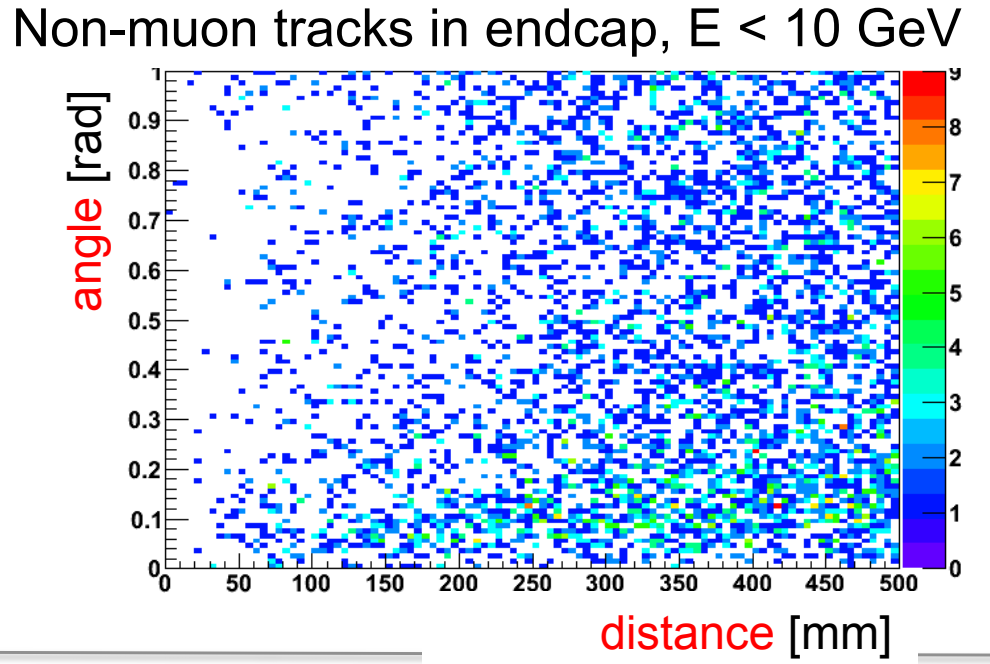
Track selection

- For low energies (E < 10 GeV) the angle & distance can get larger, even for muon track.
- Mostly due to scattering and bad linear direction fit of cluster.

- To be sure not to identify a non-muon track as coming from a muon, apply :
  - E > 4. GeV
  - angle < 0.1 rad
  - distance < 200 mm

➢ Track with smallest distance is defined as muon track.



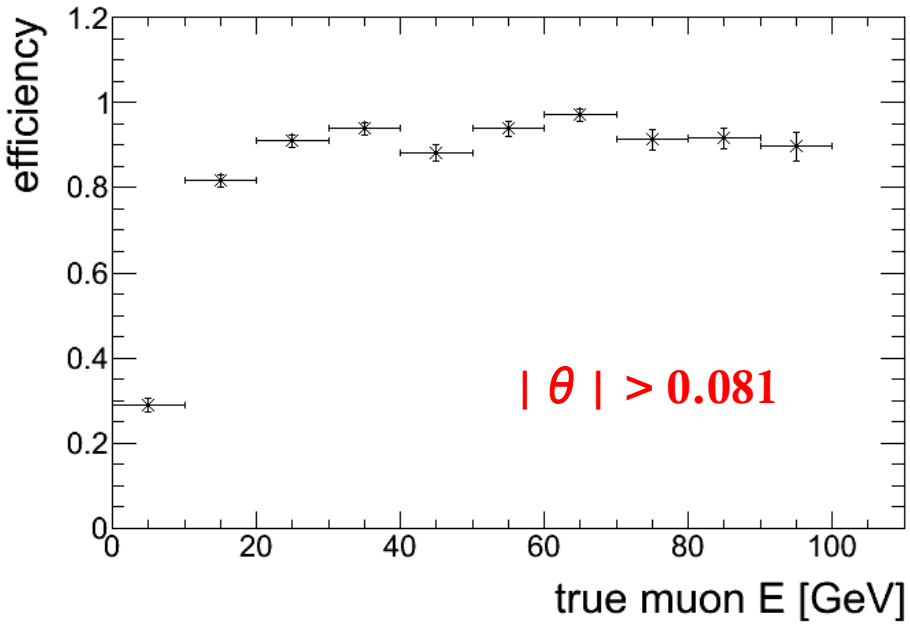


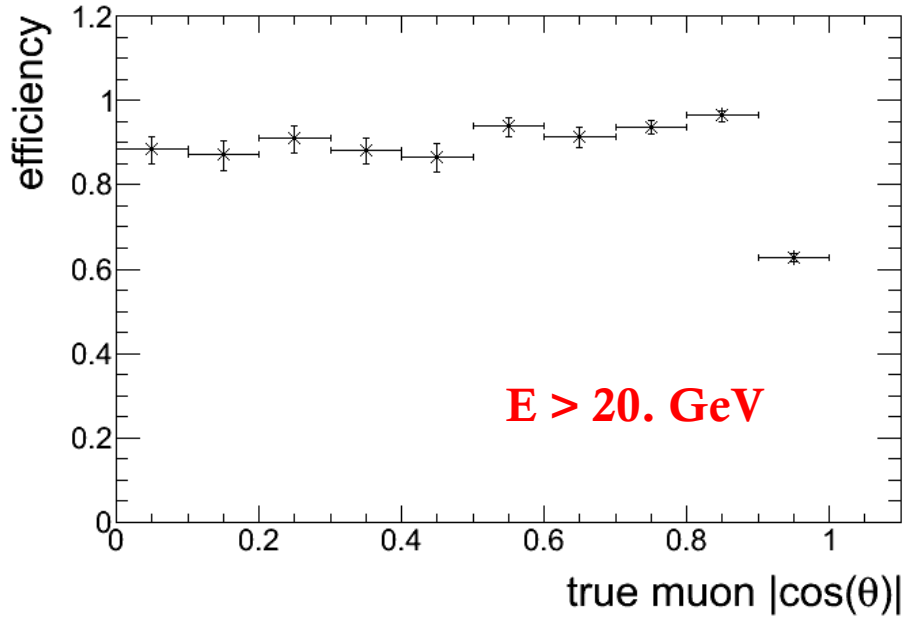
Efficiency of identifying a muon

For the efficiency all muons are considered with E > 6 GeV (barrel) and E > 4 GeV (endcap).

- The severe cuts make that for muons with E < 10 GeV the efficiency is low.
  For higher energies the efficiency goes up to 90-95%.

- For very forward muons the track is difficult to find.
  (insufficient coverage of
  | cos(θ) > 0.99 |)



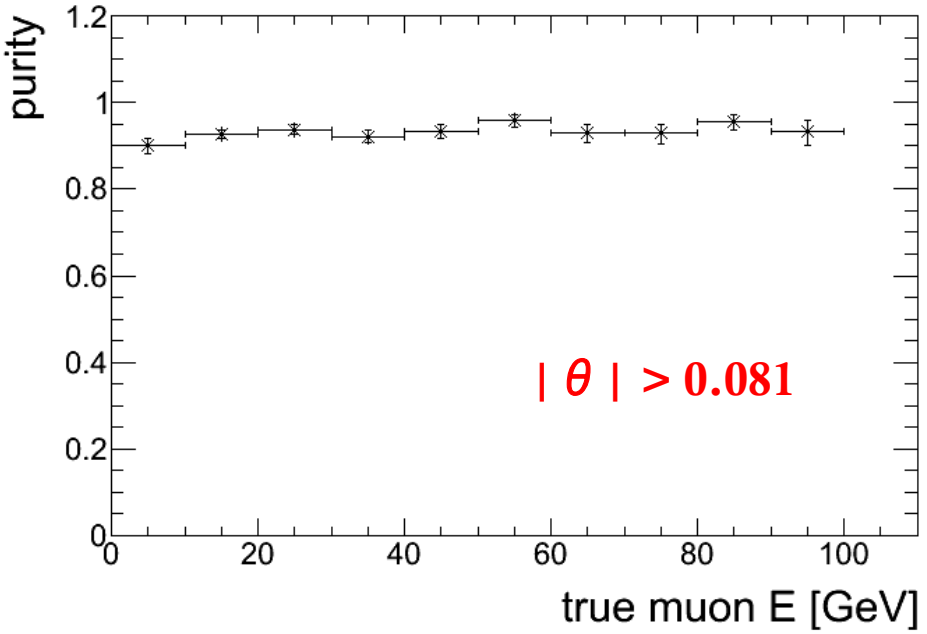


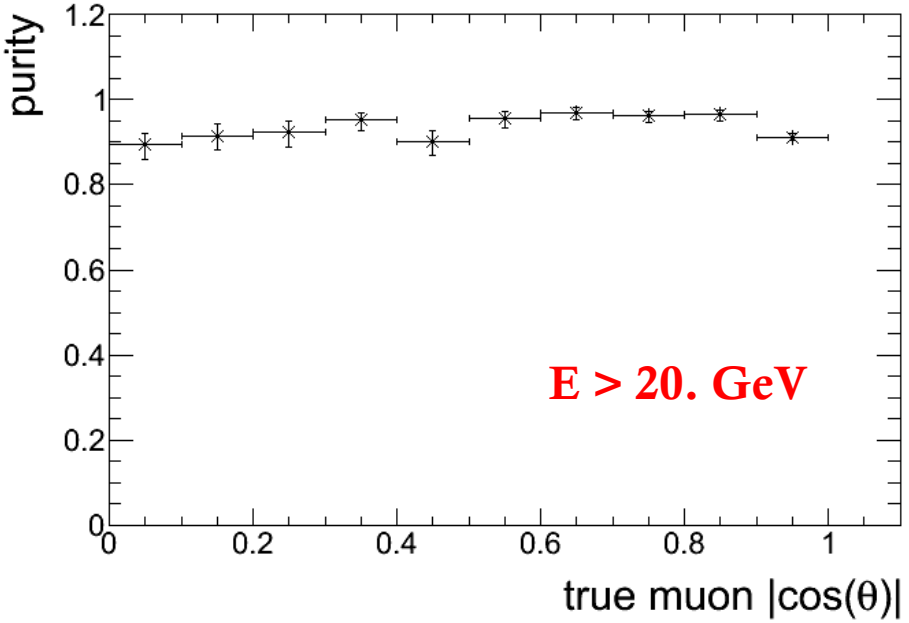
Purity of the identified muon sample

- If inside a jet a wrong track is assigned as coming from a muon, it will affect the energy reconstruction in Pandora. (which matches track energies to calorimeter cluster energies)

➢ The cuts are therefore selected such that the purity is high.

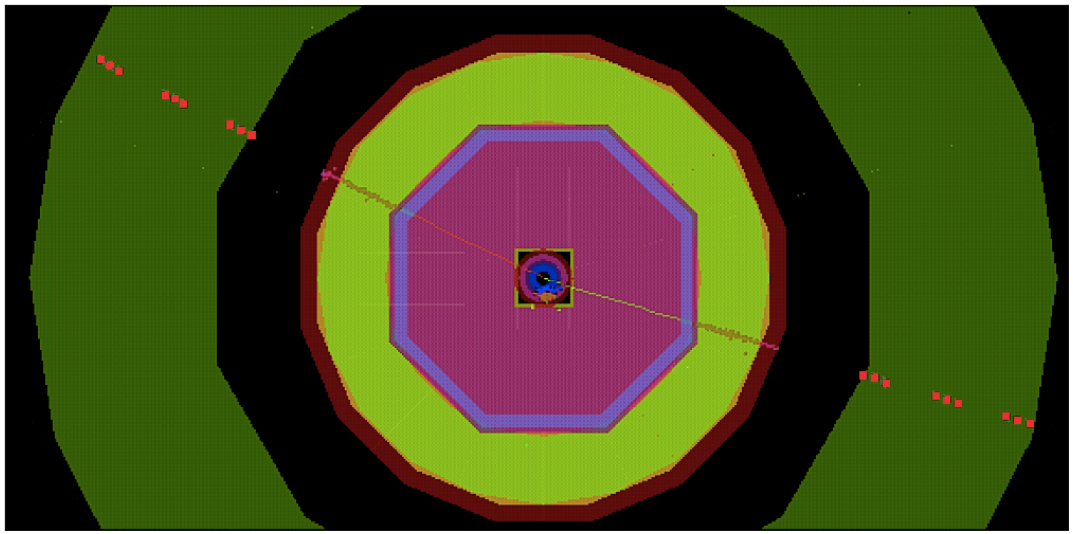
- Similar to the results for the efficiency, in the transition region from barrel to endcap we see that the reconstruction is a bit worse.

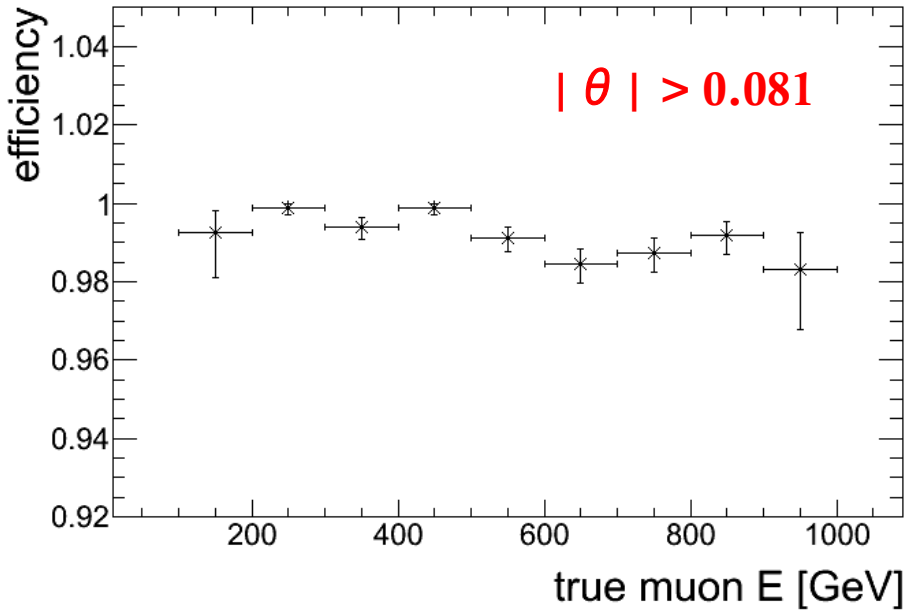




Performance on single muons

- Tested the reconstruction on single muons in a susy sample: 3000 scalar-muon pair events simulated with the cMSSM point K parameters. Final state muons have mostly 200 < E < 900 GeV.





- Efficiency > 98%
  - Only muons passing in cracks or which left no tracks are lost.

Conclusion & outlook

- New yoke geometry for tail-catcher and muon identification proposed for CDR.
  - Transition region from barrel to endcap needs more attention, to have same number of layers hit at any polar angle
- Muon reconstruction in b-jets efficiency & purity are at > 90%
  - Stringent cuts applied to keep purity high. Cuts could be tuned more.
- For low energy muons the definition of the cluster direction needs a helix fit, instead of linear fit.

Outlook:

- Hit identification in ecal & hcal. First results have been obtained and look promising, no effect on jet energy resolution. *(Almost done)*
- Use the hit-tracklets that the muon left in the outer layers of the HCAL to improve the yoke track reconstruction inward. *(next step)*