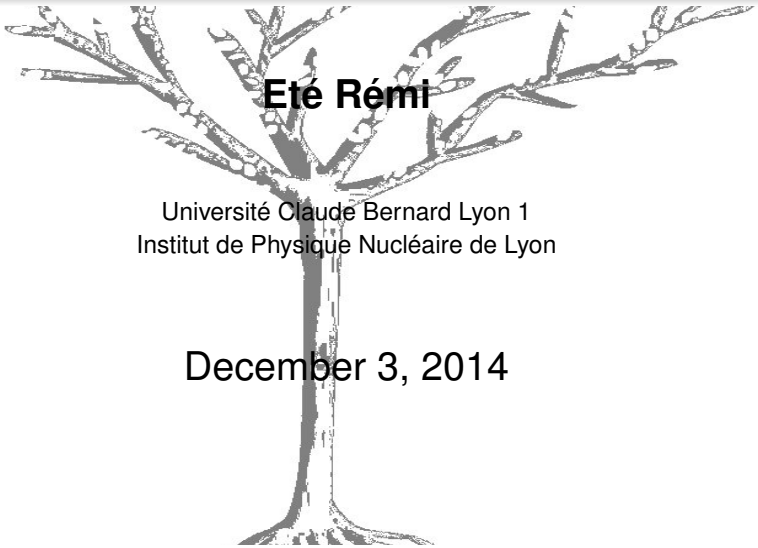
The Arbor Particle Flow Algorithm approach
Reconstruction of single particle and overlaid particles

Journées Collisionneur Linéaire 2014 - Grenoble



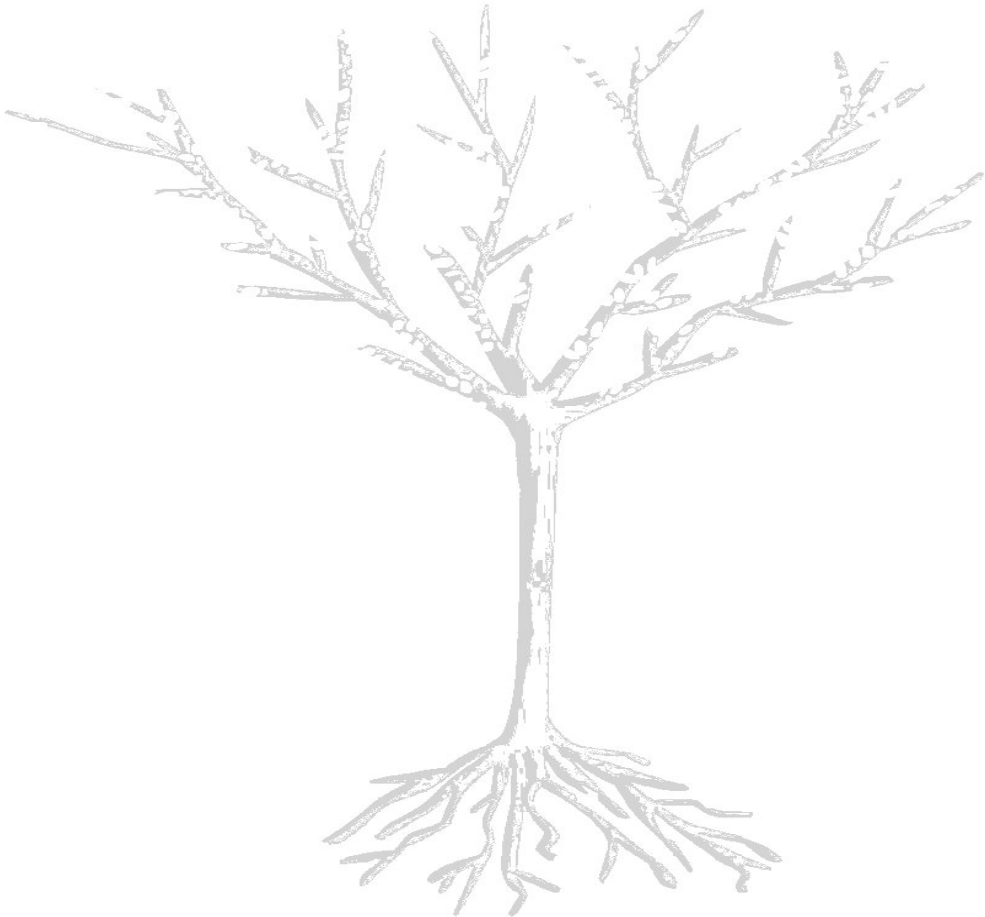
Eté Rémi

Université Claude Bernard Lyon 1
Institut de Physique Nucléaire de Lyon

December 3, 2014

Particle Flow Calorimetry

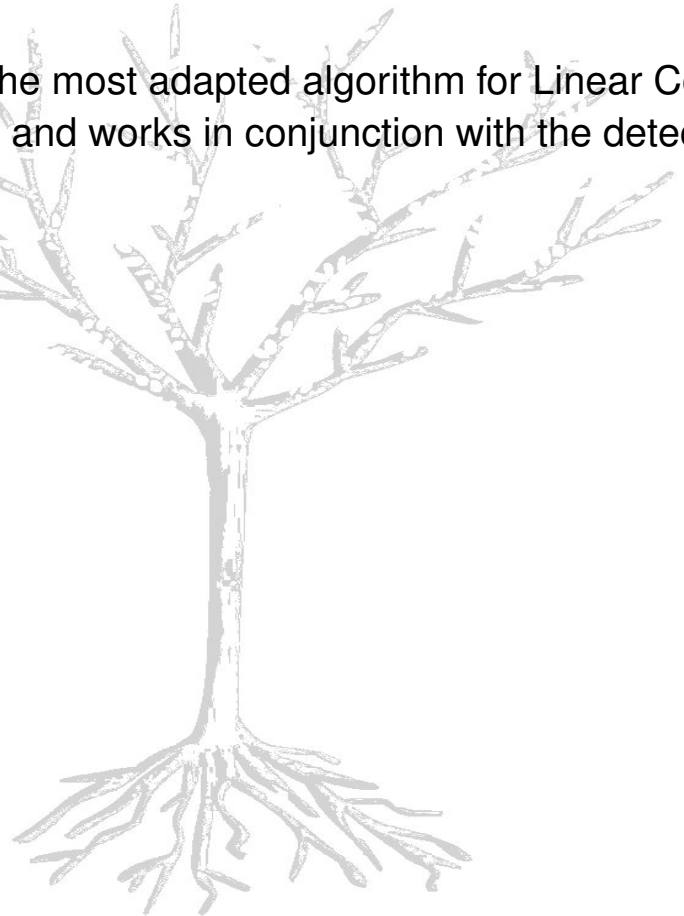
Introduction



Particle Flow Calorimetry

Introduction

Particle flow approach is believed to be the most adapted algorithm for Linear Collider Detectors design.
The software approach is (rather) simple and works in conjunction with the detector granularity (calorimeters).



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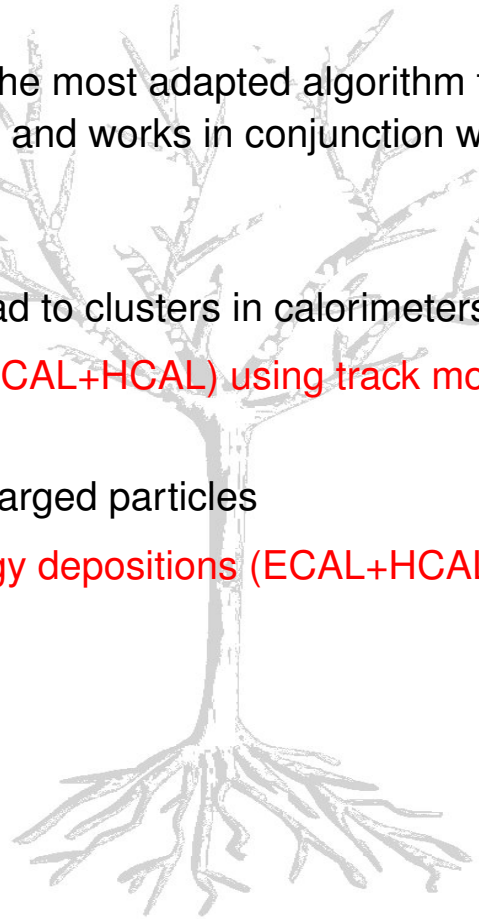

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The software approach is (rather) simple and works in conjunction with the detector granularity (calorimeters).

Working principle :

- Identify tracks (Tracker) that can lead to clusters in calorimeters.
- From these tracks, build clusters (ECAL+HCAL) using track momentum $\rightarrow$ Charged particle reconstruction
- Remove energy deposition from charged particles
- Build clusters from remaining energy depositions (ECAL+HCAL) $\rightarrow$ Neutral particle reconstruction

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The performance of a Particle Flow implementation is mainly characterised by

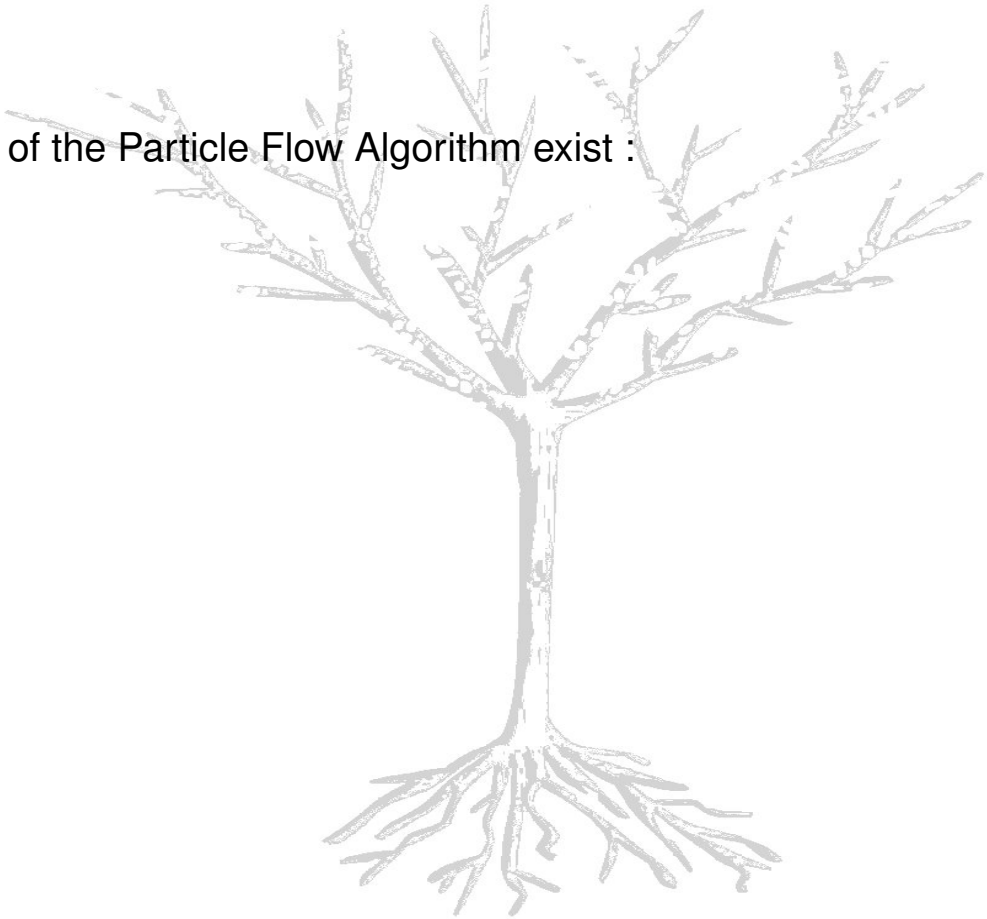
- Jet Energy Resolution (JER)
- Confusion term (mis-identified energy deposition)
- Performance in physics analysis

the three characteristics being correlated ...

Particle Flow Calorimetry

Implementation

Many implementations of the Particle Flow Algorithm exist :



Particle Flow Calorimetry

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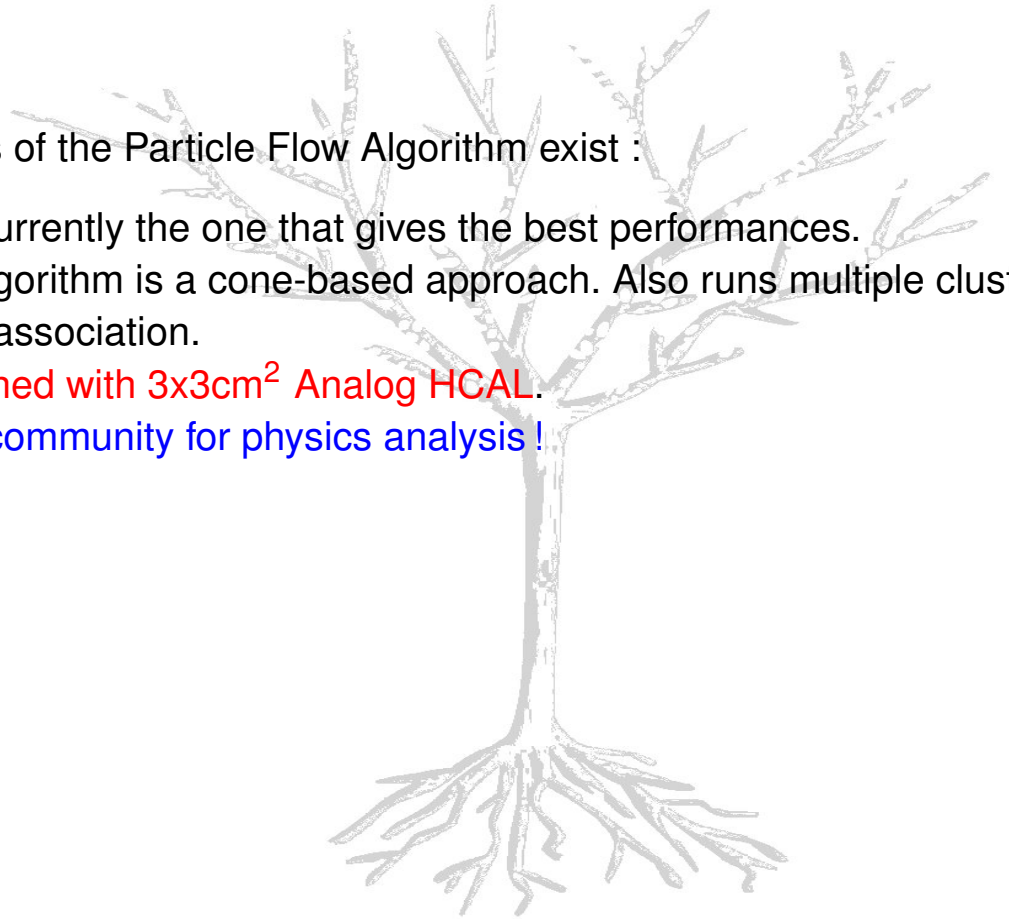

Many implementations of the Particle Flow Algorithm exist :

- PandoraPFA is currently the one that gives the best performances.
  The clustering algorithm is a cone-based approach. Also runs multiple clustering algorithm to optimize the track-cluster association.
  Designed and tuned with 3x3cm^2 Analog HCAL.
  Adopted by ILC community for physics analysis !

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- ArborPFA which is currently under development.
  The clustering algorithm is tree-based approach. No use of energy information within the algorithm for the time being, only topology.
  Designed for any calorimeter.
  Currently tuned for 1x1cm^2 cell size without any energy readout dependency (AHCAL/DHCAL/SDHCAL).
  Still under development

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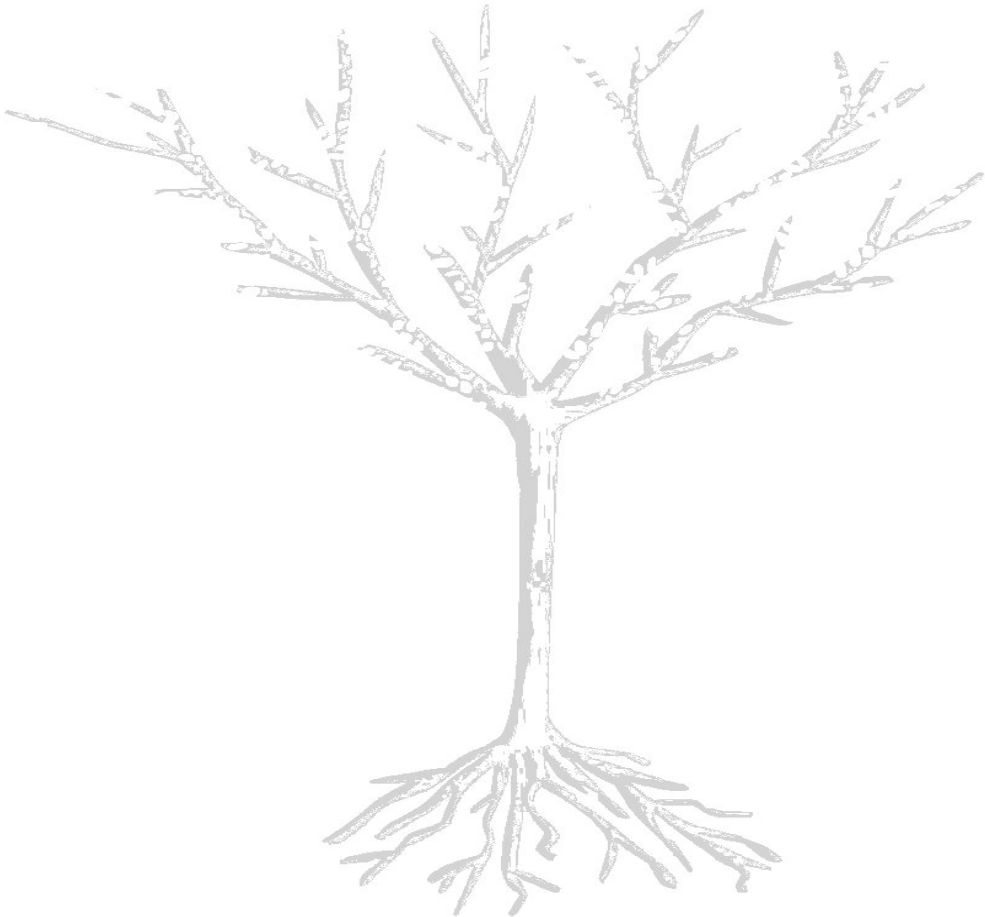
  Still under development
- IowaPFA developped for SiD design.
  Gives similar results to PandoraPFA on physics analysis

The Arbor algorithm

Principle



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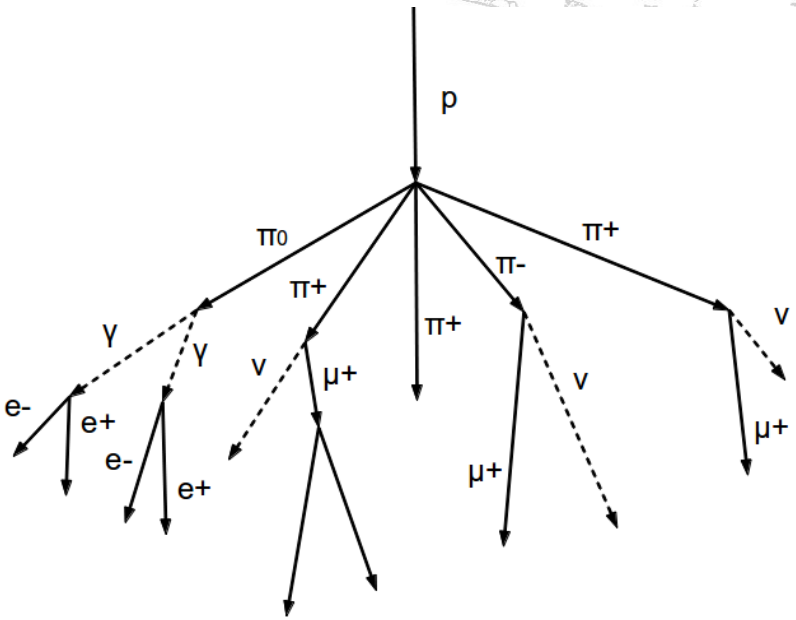

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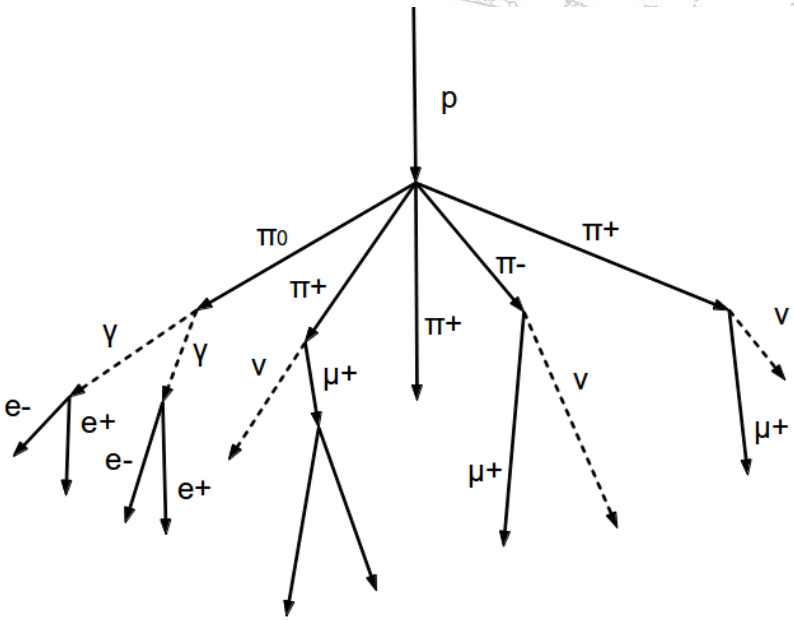

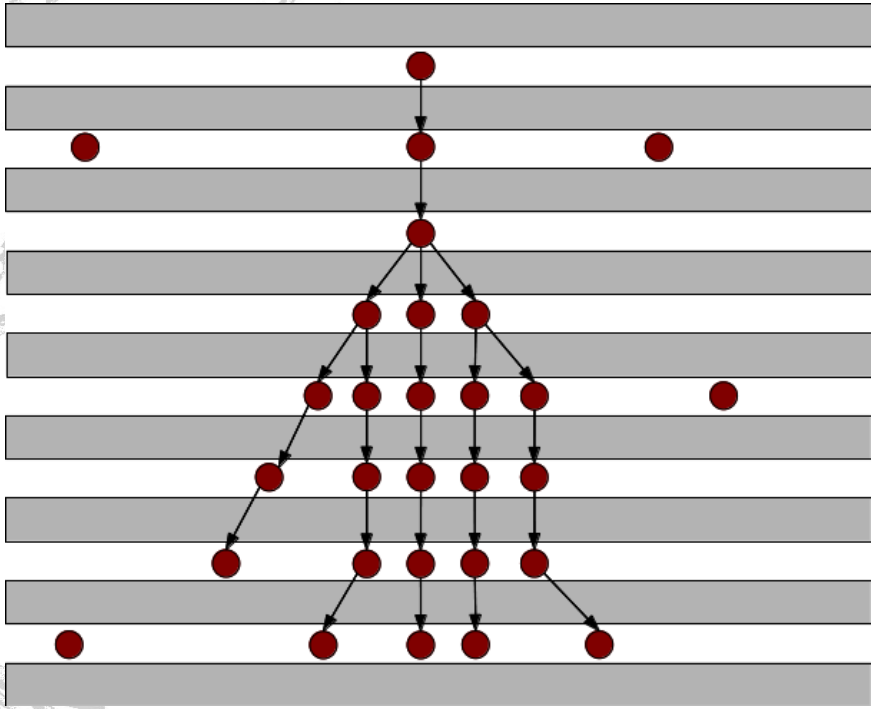

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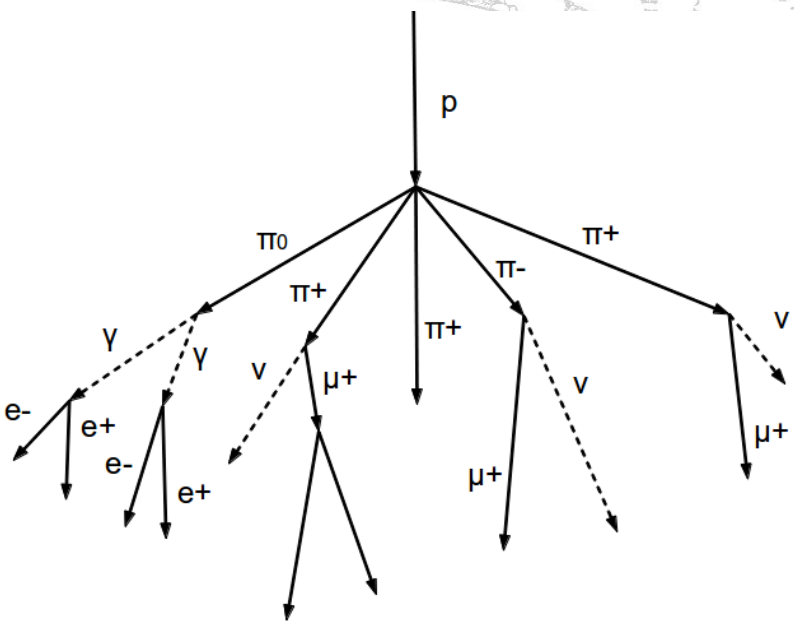
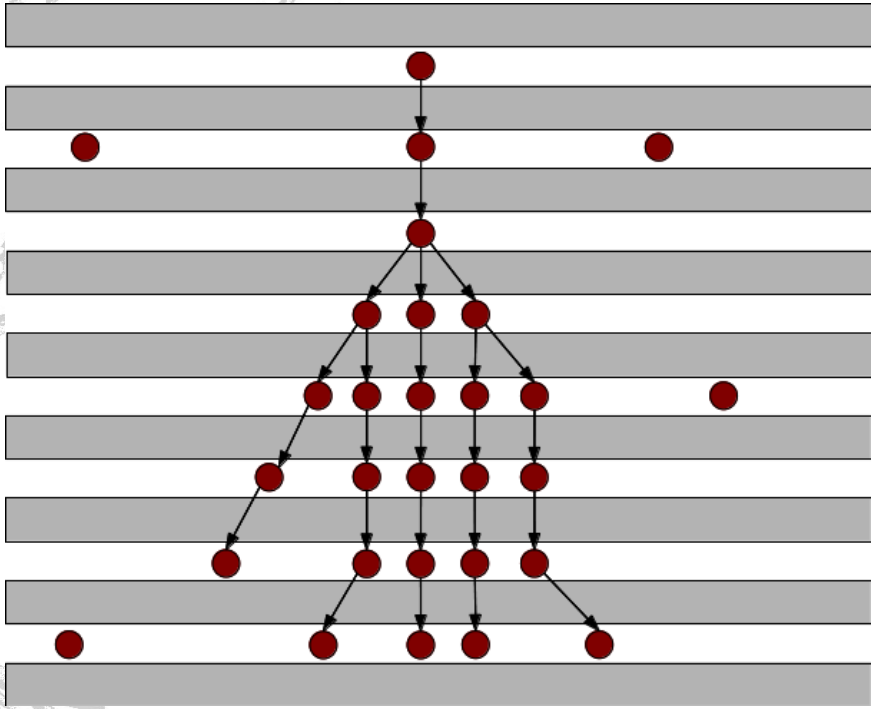
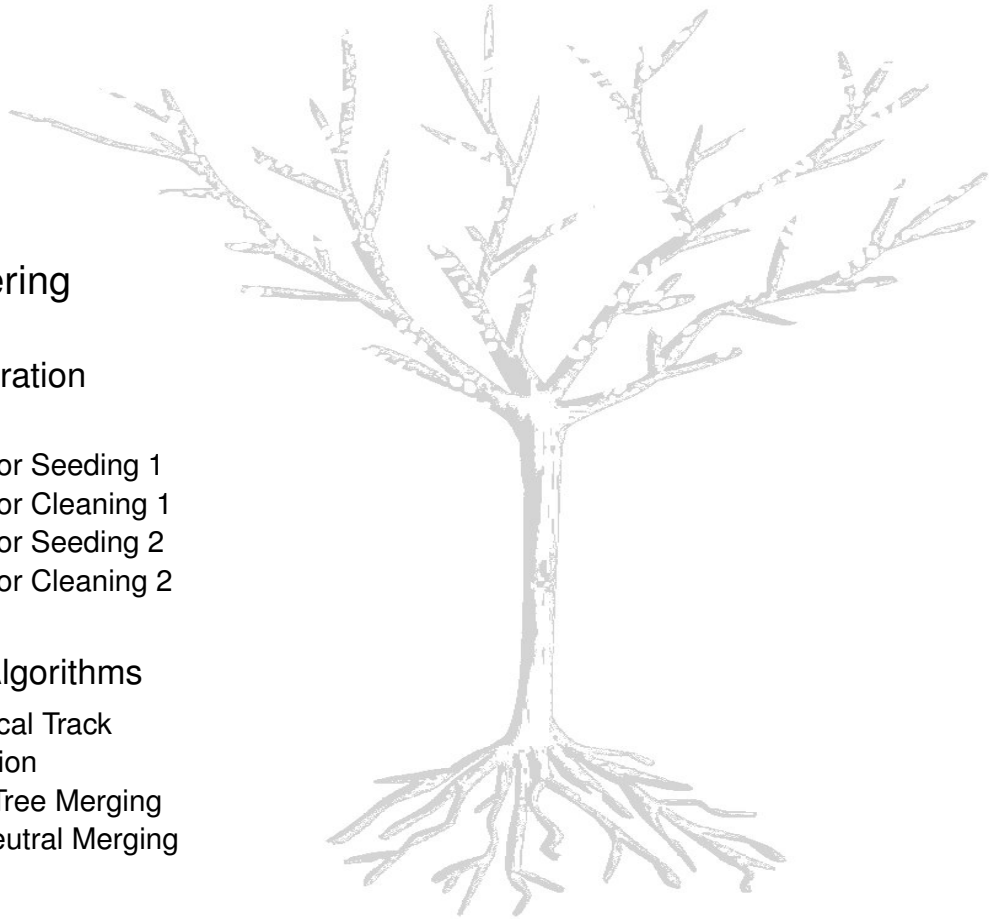




Clustering algorithm that uses connectors between calo hits.
Build clusters with an oriented tree topology.
Key point : **The reconstruction follows the underlying physics principle of the shower !**

The Arbor algorithm

Arbor algorithms



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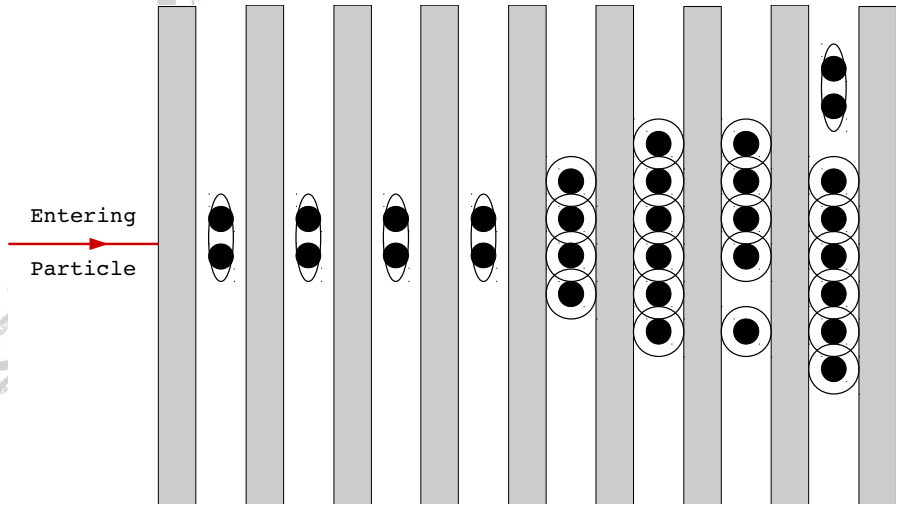
Intra-layer clustering

Group of mip hits and group of isolated hits $\rightarrow$ Objects

Other hits (shower core, larger structures) $\rightarrow$ Objects

Effects in clustering algorithm :

- decrease multiplicity effects
- decrease processing time ($N_{hit} > N_{obj}$)



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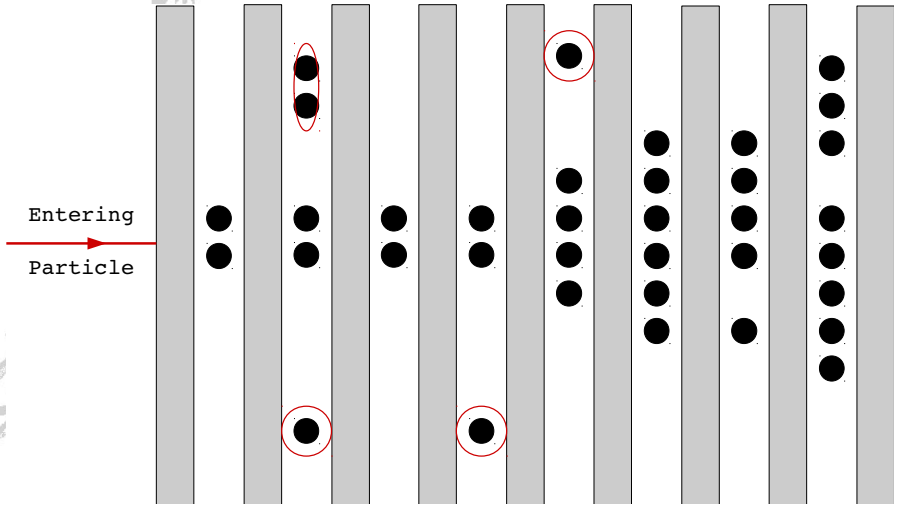
Tag isolated objects that are not part of :

- the shower core
- mips

Special treatment in clustering part ...



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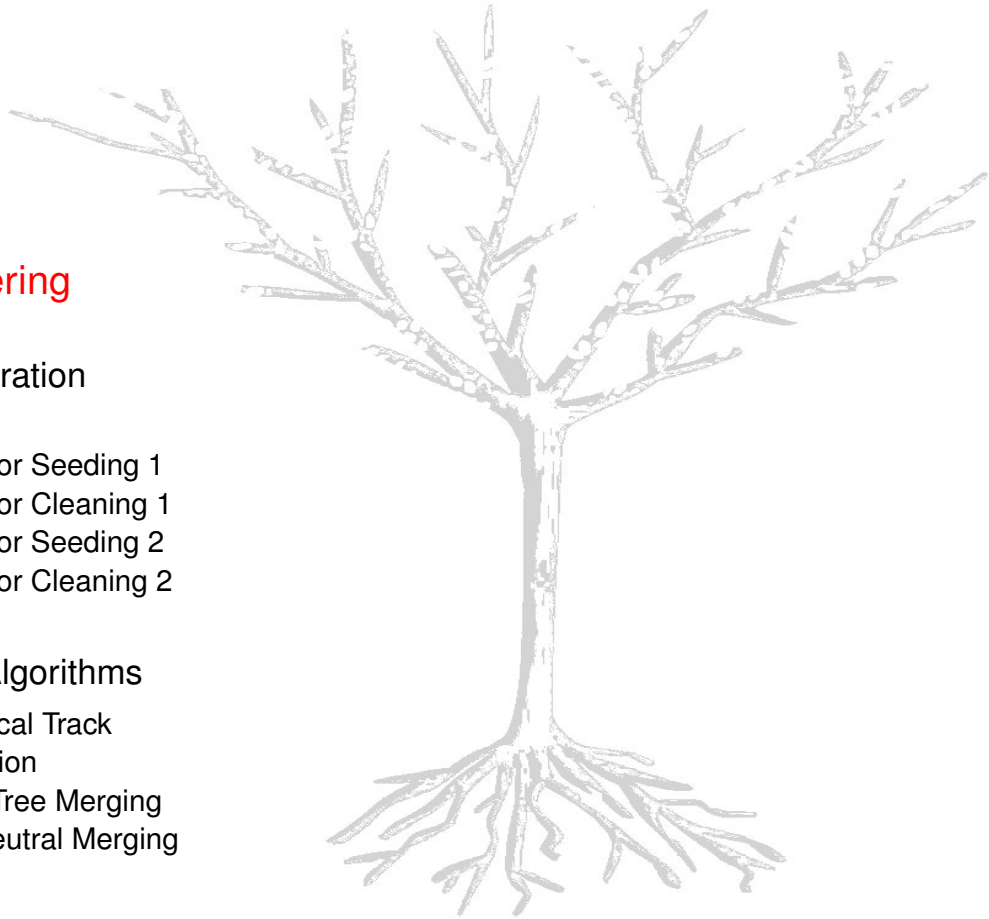

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Look in the forward direction at a maximum distance of Δ_{max} and create many connections with other objects.

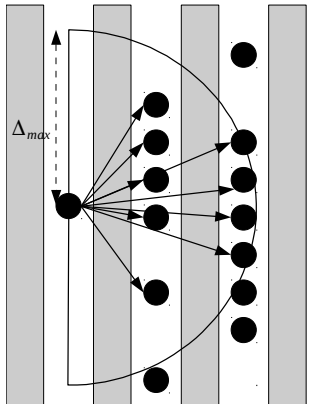

FIGURE : Single object connection

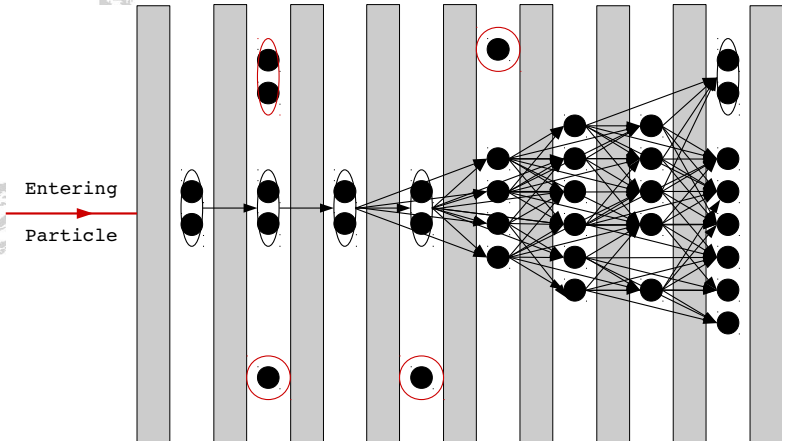

FIGURE : Calorimeter view after seeding connectors

The Arbor algorithm

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Reference direction :

$$\vec{C_{ref}} = w_{fwd} \cdot \sum_f \vec{c}_f - w_{bck} \cdot \sum_b \vec{c}_b \quad (1)$$

Kappa order parameter :

$$\kappa = \left(\frac{\theta}{2\pi}\right)^{p_\theta} \cdot \left(\frac{\Delta}{\Delta_{max}}\right)^{p_\Delta} \quad (2)$$

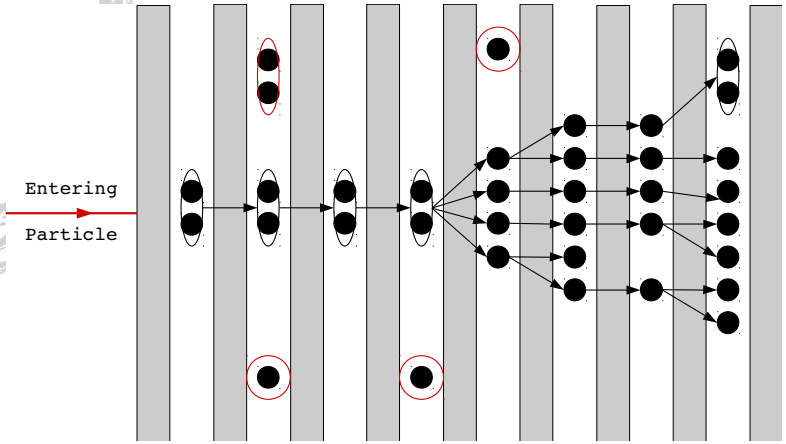

FIGURE : Calorimeter view after first connector cleaning

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Starts from cleaned connections. Look in a forward/backward cone of length $\Delta_{max,c}$ of half angle θ_c and create many connections

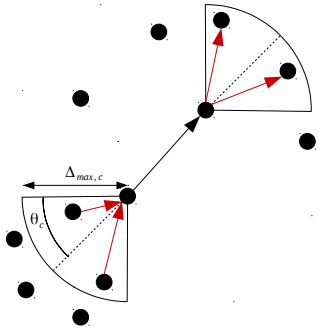

FIGURE : Alignment procedure

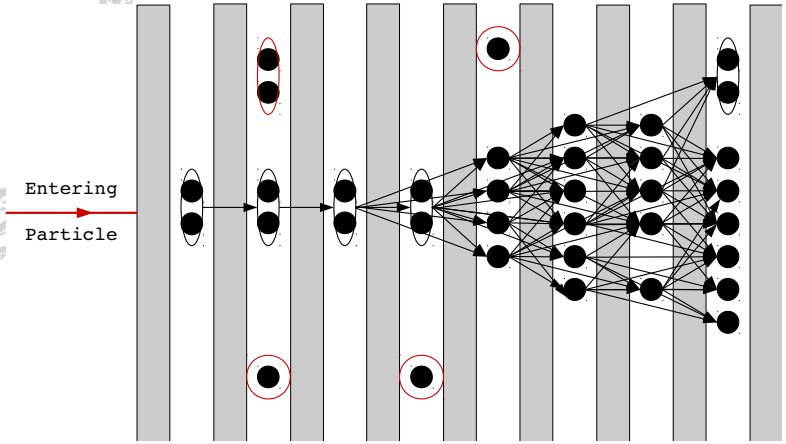

FIGURE : Calorimeter view after the second seeding step

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Same cleaning as before ...

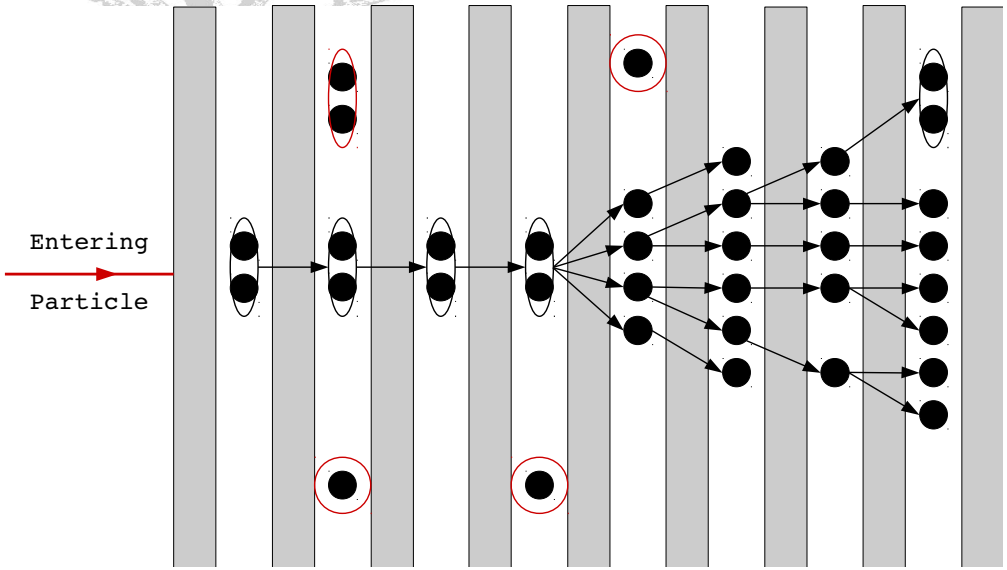

FIGURE : Calorimeter view of the final tree structure

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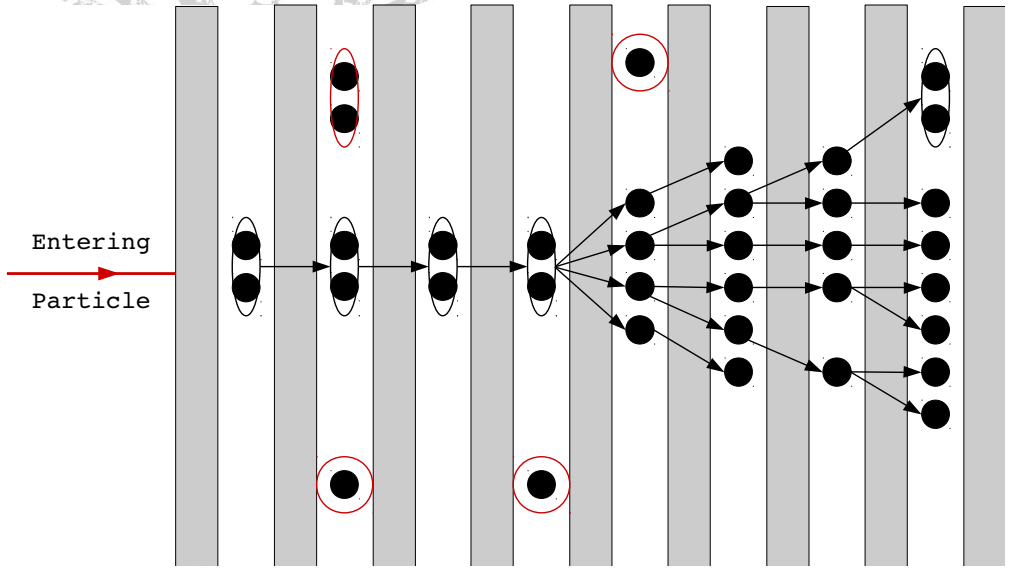

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Project the track entering point on the calorimeter front face and find all tree starting points (seeds) within a distance Δ_{track}. Create an association between the cluster (tree) and the track.

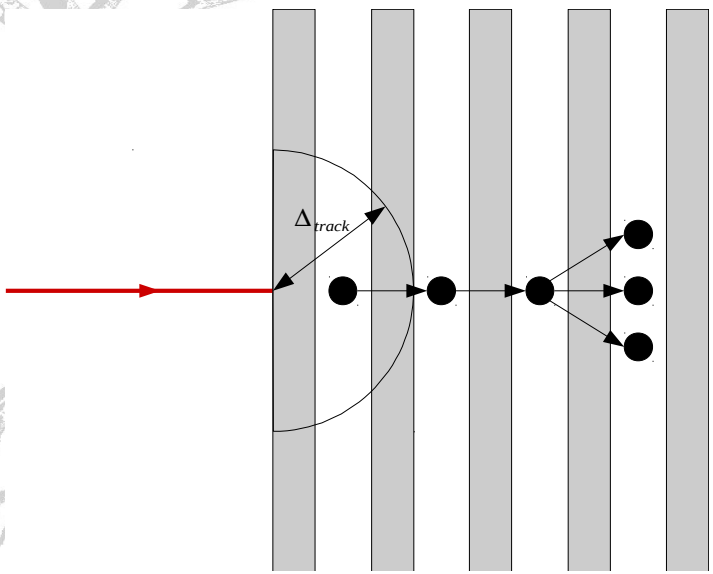

FIGURE : Topological track association view

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Dedicated algorithm for neutral particles.
Merge trees in a single one when their seeds are close to each others within the same layer.

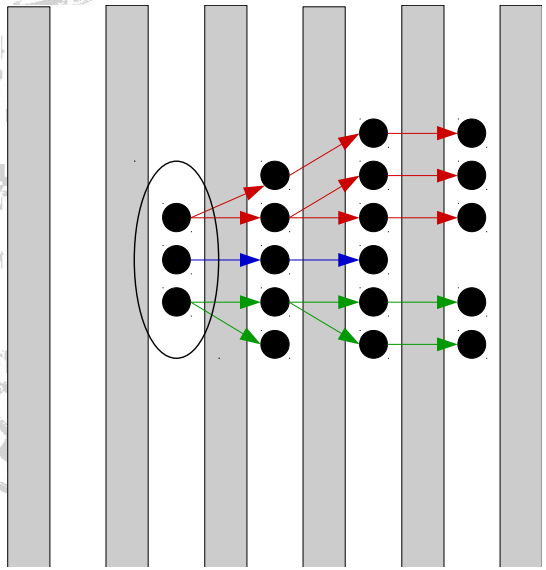

FIGURE : Neutral tree merging view

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Merging of small structures into bigger ones (closest barycenter)

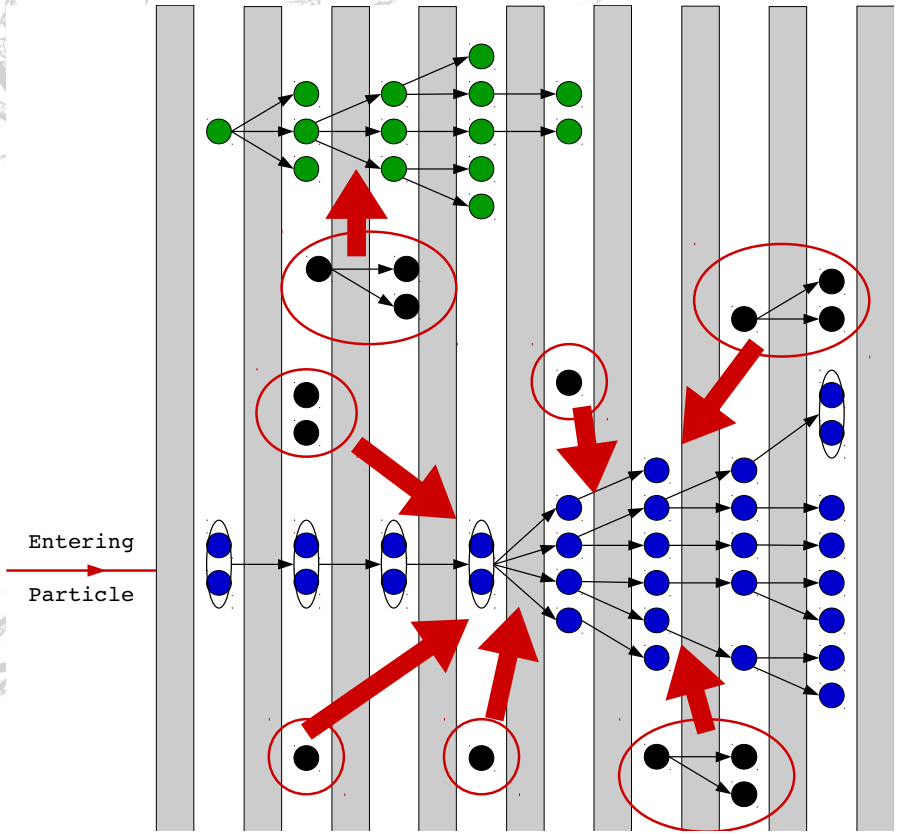

FIGURE : Small neutral fragment merging view

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Create Particle Flow Objects from reconstructed trees and tracks.

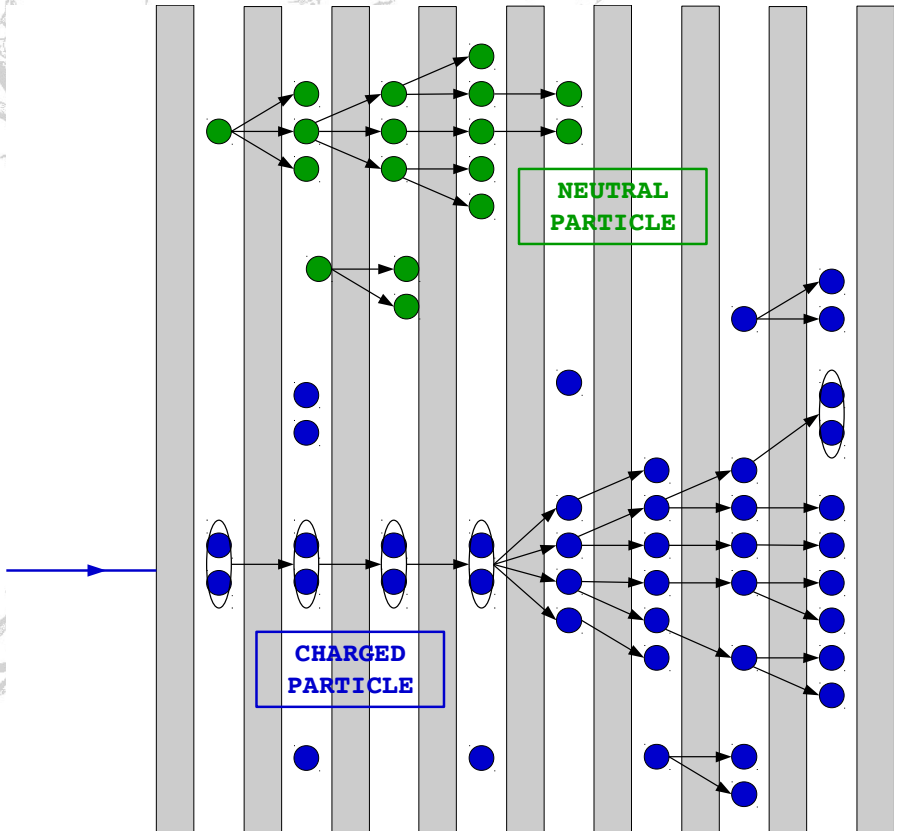


FIGURE : Final output Pfos of ArborPFA

Pfo analysis

Data set

Using Semi-Digital HCAL (3 thresholds) data set of pi^- with

- Standalone Geant4 simulation (A. Steen)
- Test beam data (AUG-SEPT 2012, CERN SPS)

Selection cuts applied on both TB and simulation data (see CAN-037).

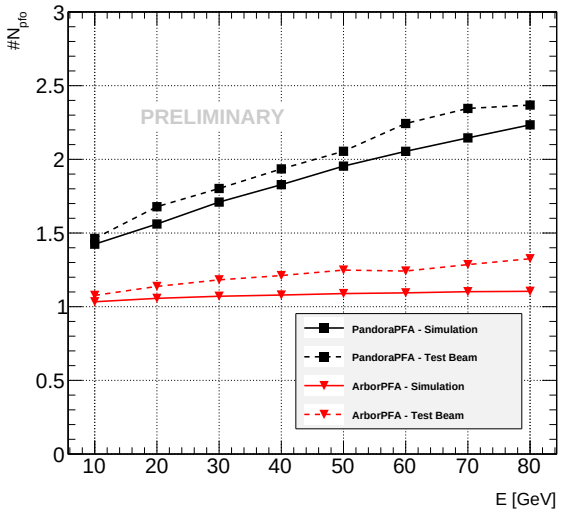
Studying :

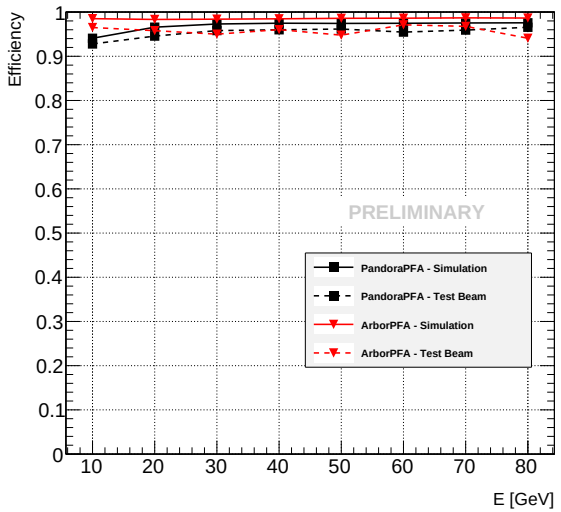
- Single particle reconstruction from 10 up to 80 GeV :
  - Efficiency
  - Reconstructed energy
  - Number of pfos
- Overlaid particles for 10 and 30 GeV neutral pi and 30 GeV charged pi^- and for a separation distance from 5 up to 30 cm
  - Efficiency
  - Purity
  - Reconstructed energies
  - Number of Pfos

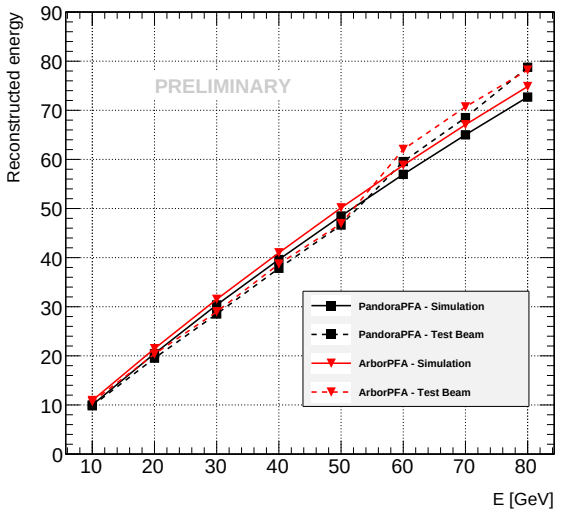
Running ArborPFA (v01-03-00) and PandoraPFA (v00-12) with only a HCAL (SDHCAL) and a set a generated tracks in front of the calorimeter for charged particles

Pfo analysis

Single particle study





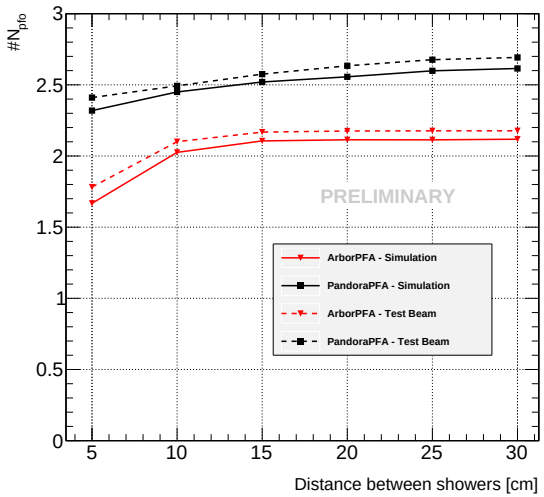


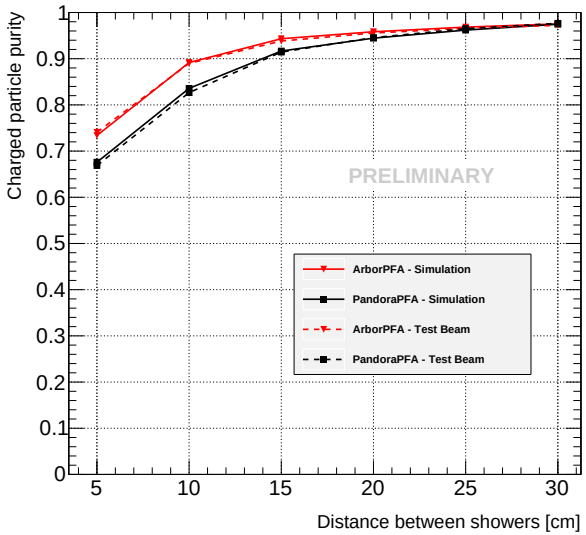
Less splitting of single showers for ArborPFA.

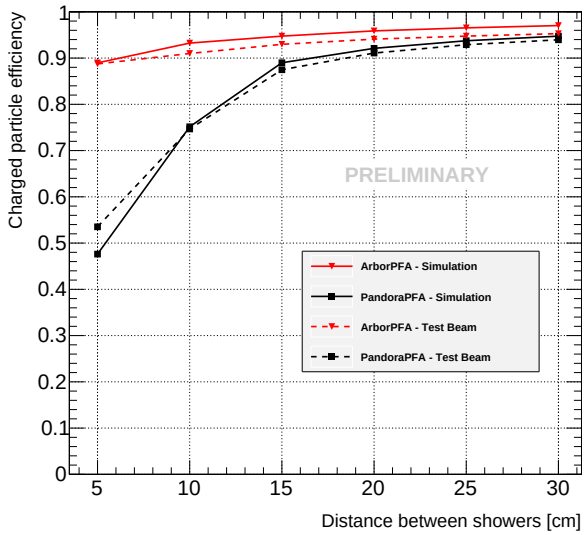
But the efficiency and the reconstructed energy shows similar performance.

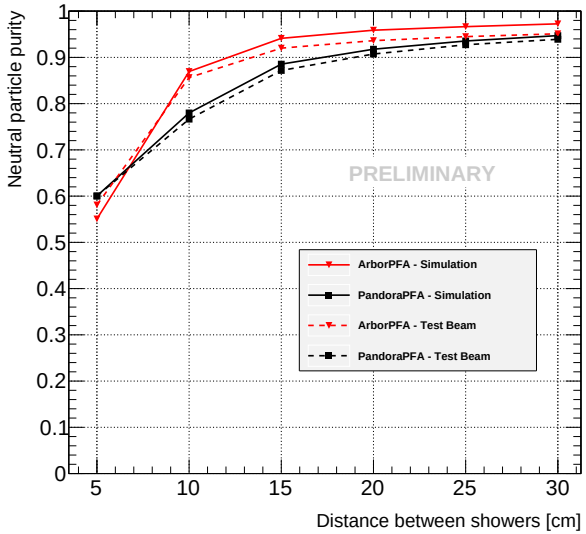
Pfo analysis

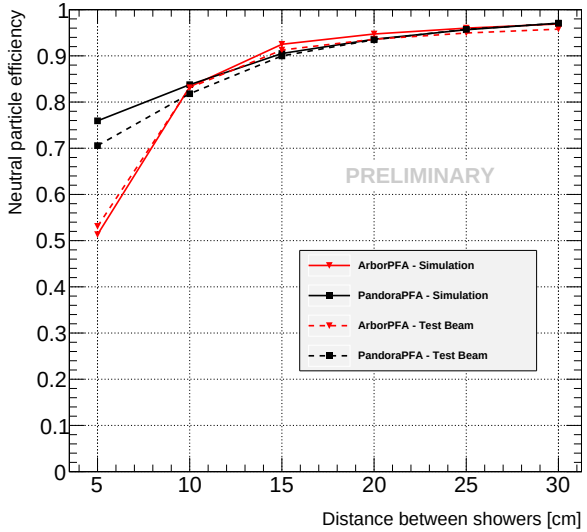
Overlay study. 10 GeV neutral pi + 10 GeV charged pi-











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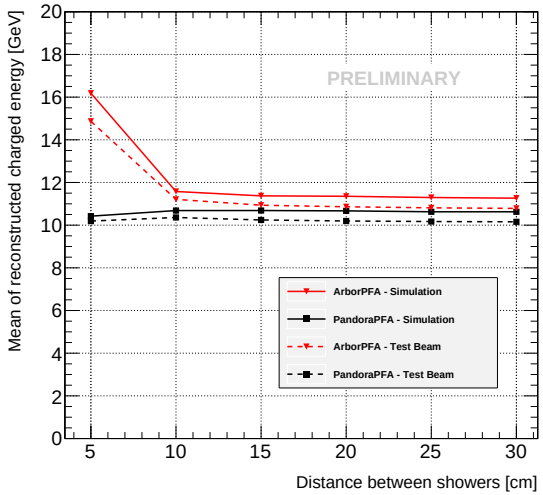
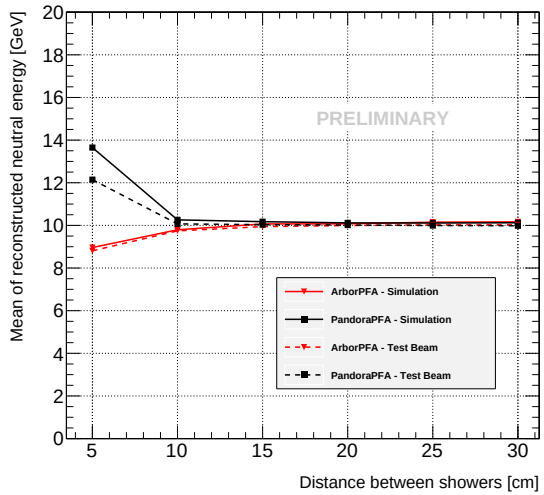
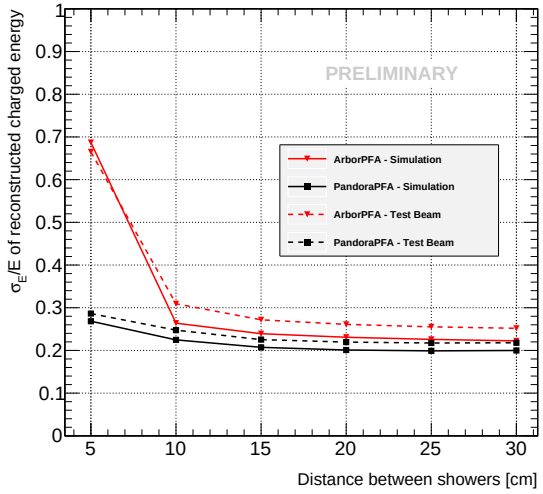
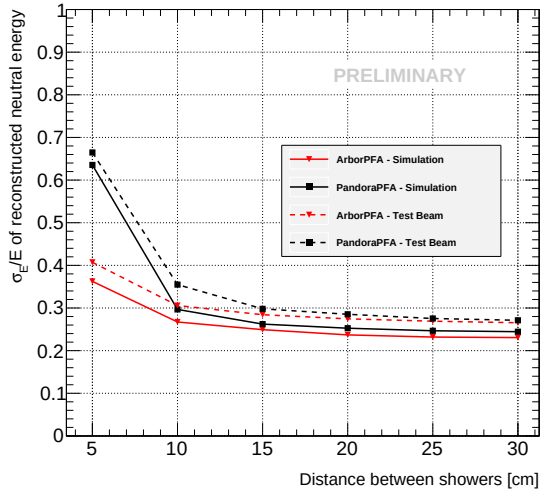
Overlay study. 10 GeV neutral pi + 10 GeV charged pi-



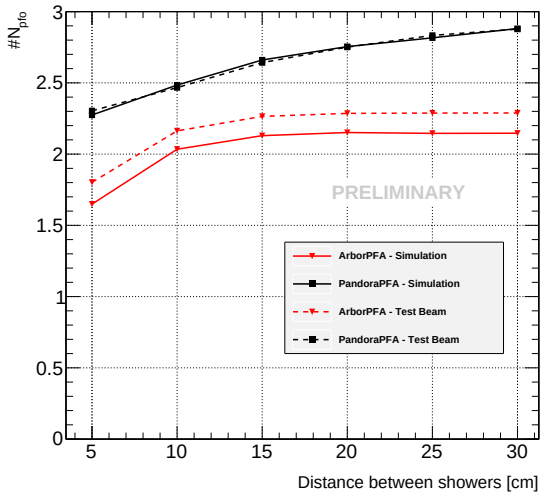


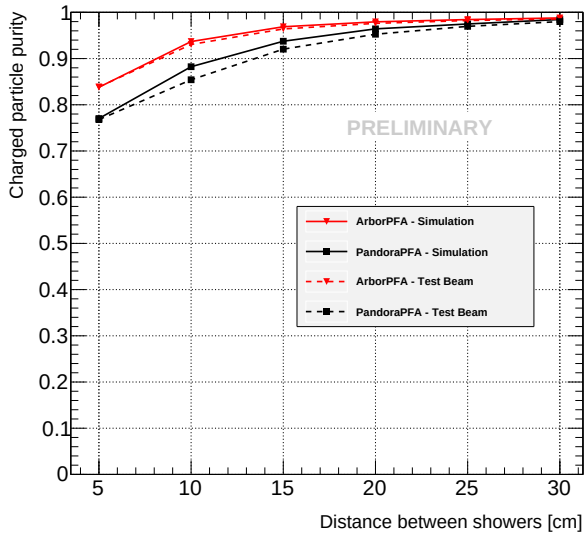


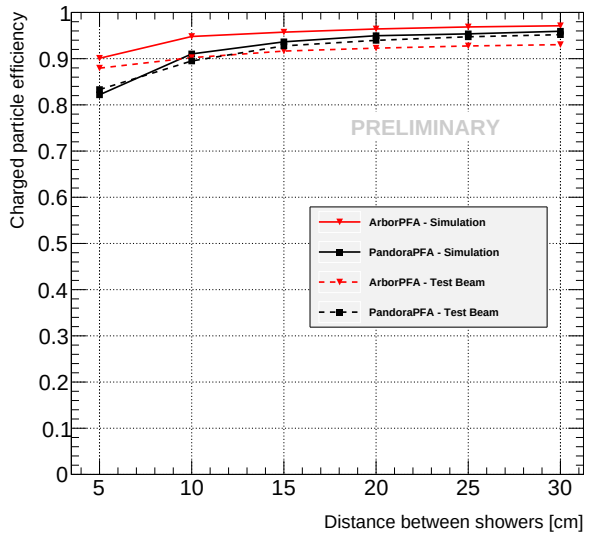


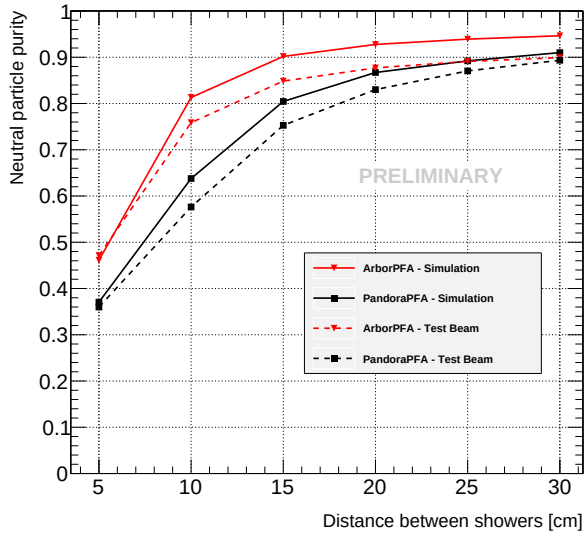
Pfo analysis

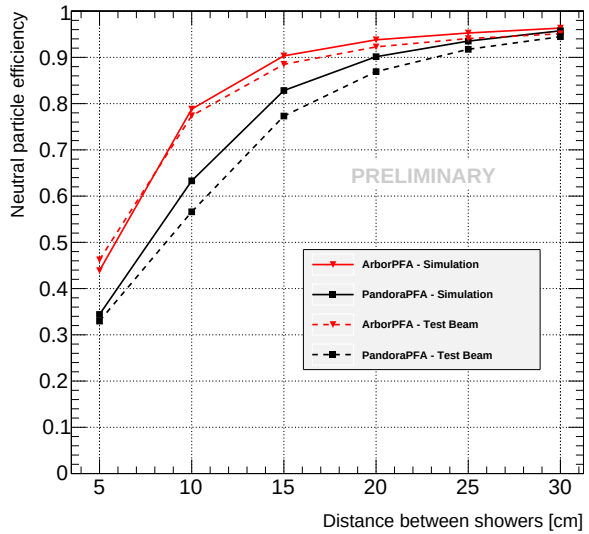
Overlay study. 10 GeV neutral pi + 30 GeV charged pi-





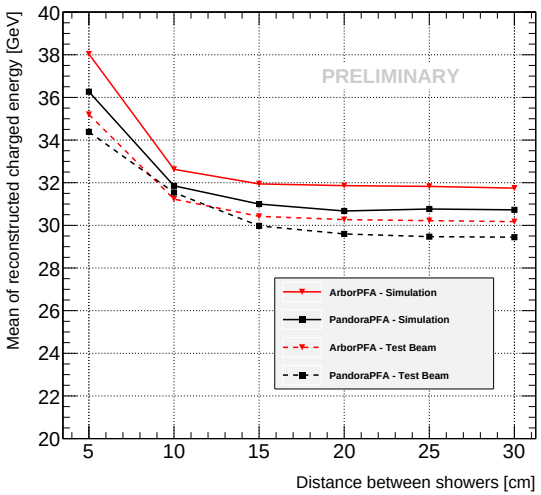


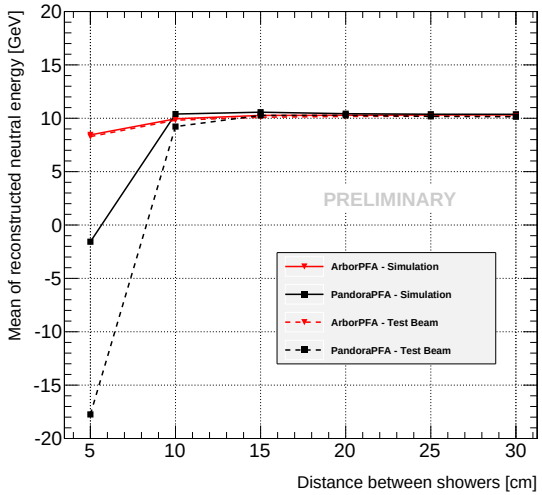


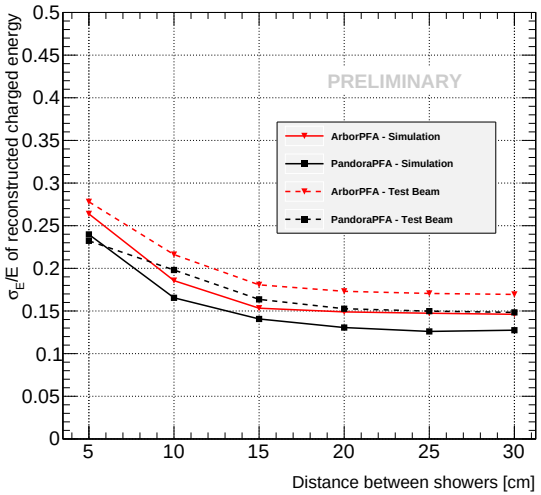


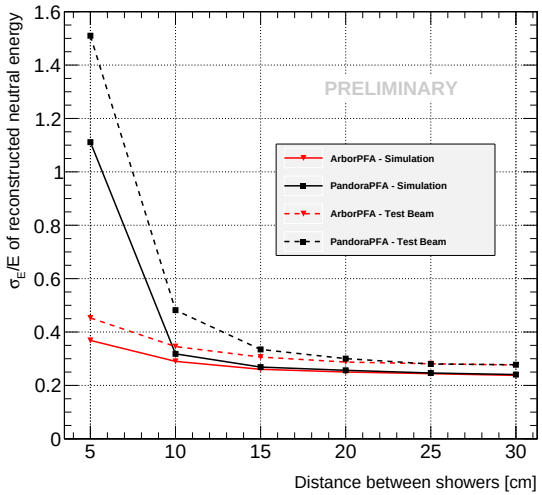
Pfo analysis

Overlay study. 10 GeV neutral pi + 30 GeV charged pi-









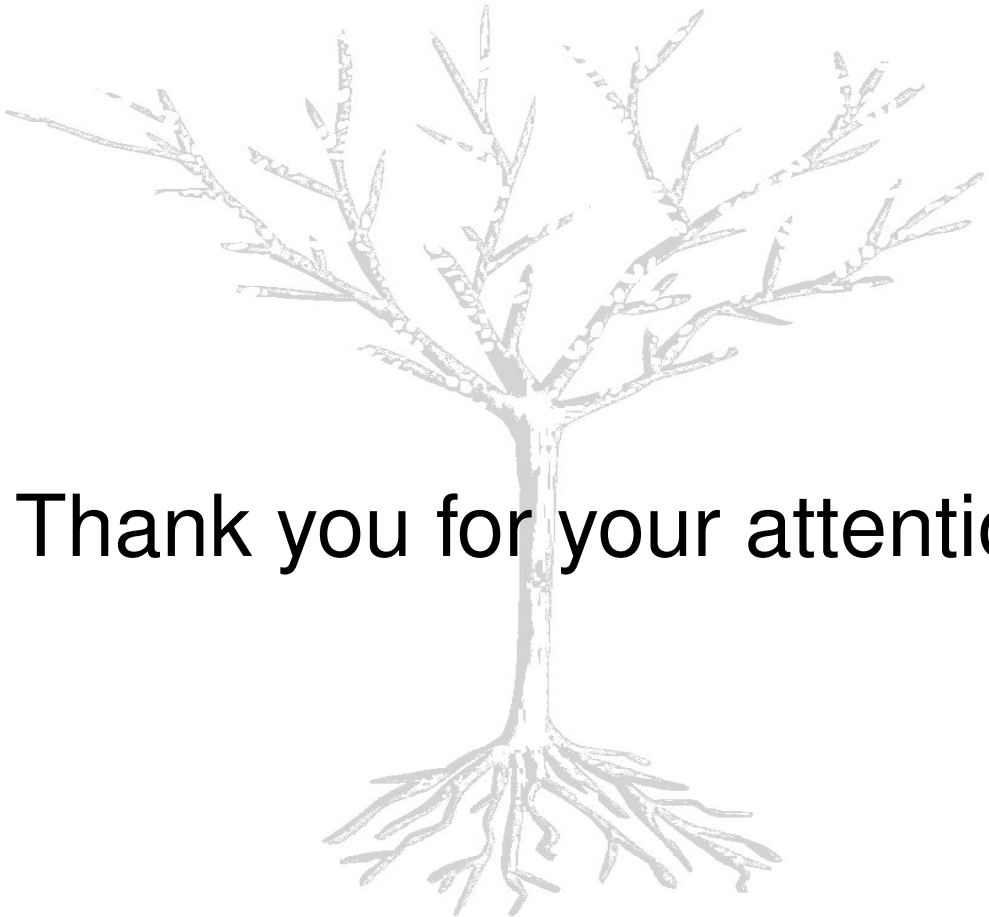
Conclusions and plans

Conclusions :

- ArborPFA and PandoraPFA have both good results for single particle reconstruction in terms of efficiency and reconstructed energy.
- The overlay shower study shows very different behaviors for the 2 algorithms but are able to recover correctly the shower energy until 10 cm separation distance.
- PandoraPFA shows for both single particle and overlaid showers studies a high number of unphysical PFOs ...

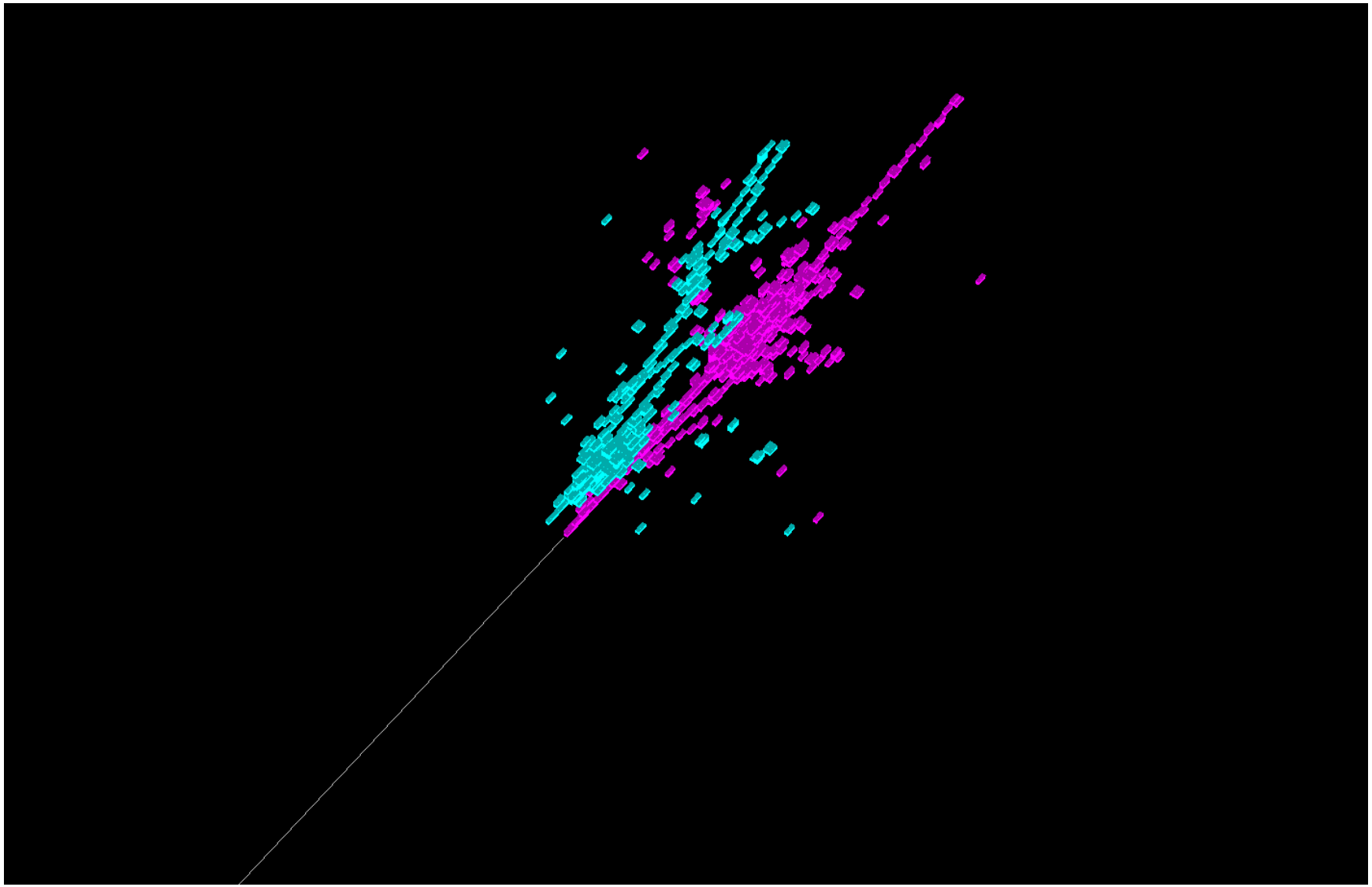
Plans :

- Run PFAs on new test beam data (currently running at CERN SPS ☺)
- Prepare a working version for ILD studies and extract general PFA performances plots.
  - Include photon and electron clustering in the ECAL (GARLIC ?)
  - Manage hadronic shower part in the ECAL.
  - Implement a dedicated algorithm for ECAL-HCAL gap region (cluster connection)
  - Muon clustering (Arbor standalone ? Pandora ? New tracking tools ?)



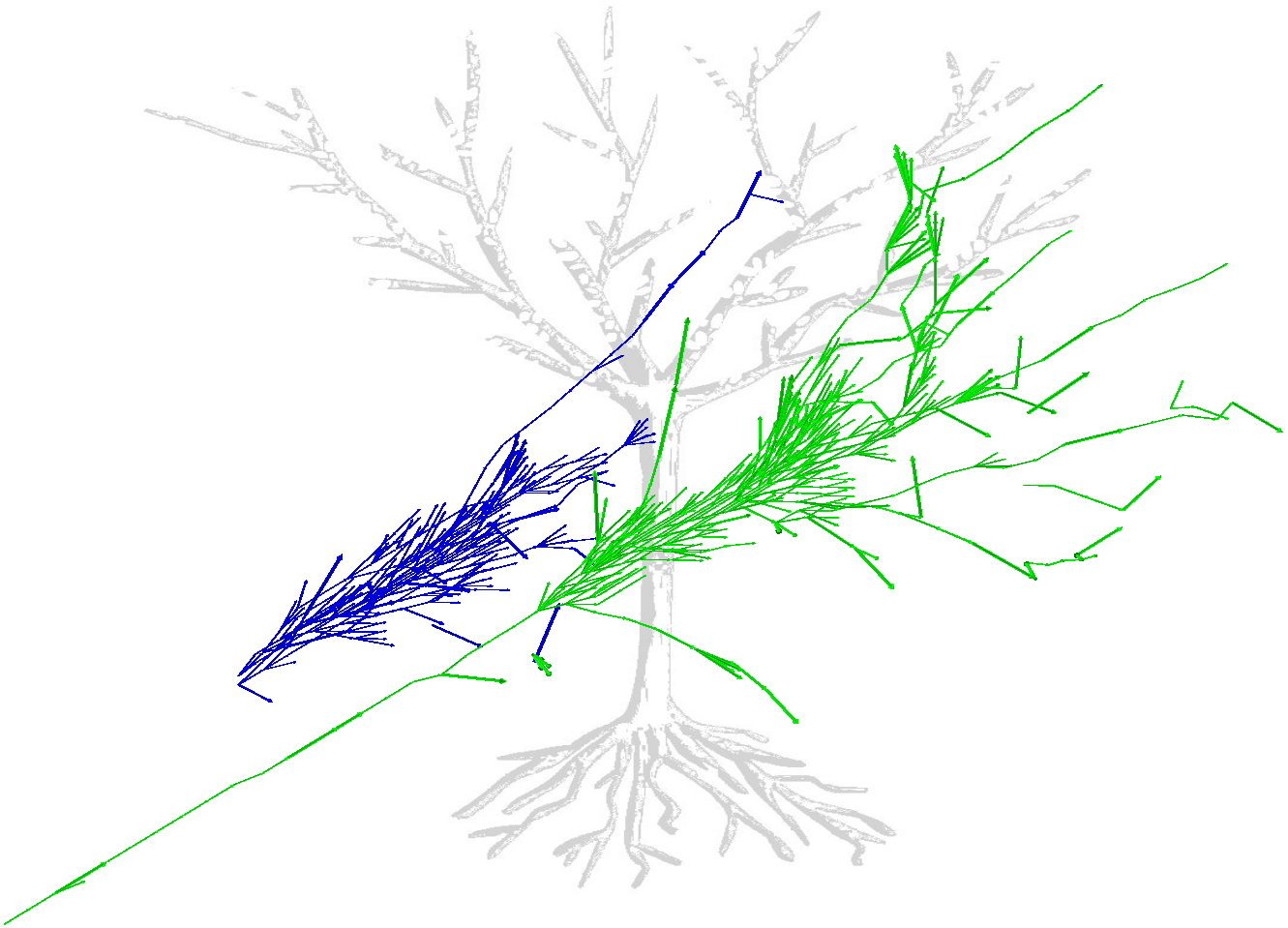
Thank you for your attention !

Event display



Neutral π of 30 GeV overlaid with a charged π^- of 50 GeV at 5 cm distance.

Shower structure



Neutral π of 30 GeV overlaid with a charged π^- of 50 GeV at 10 cm distance.