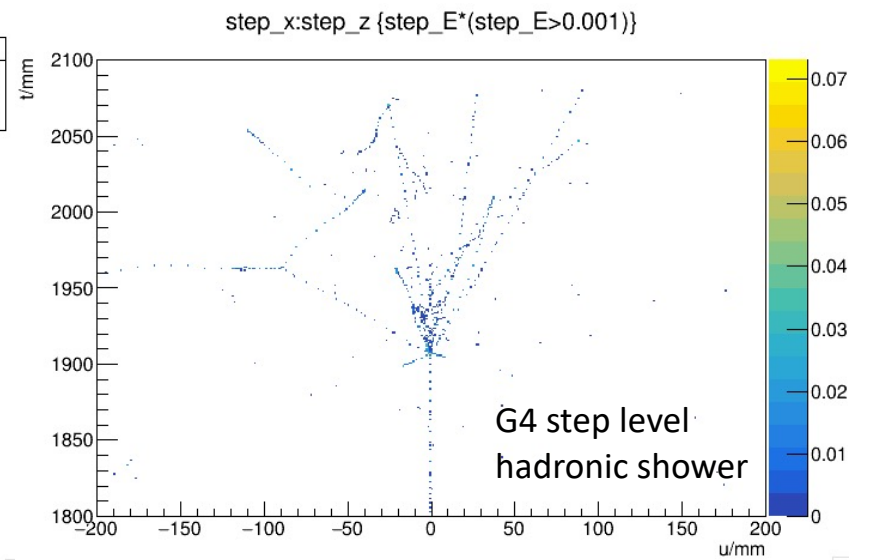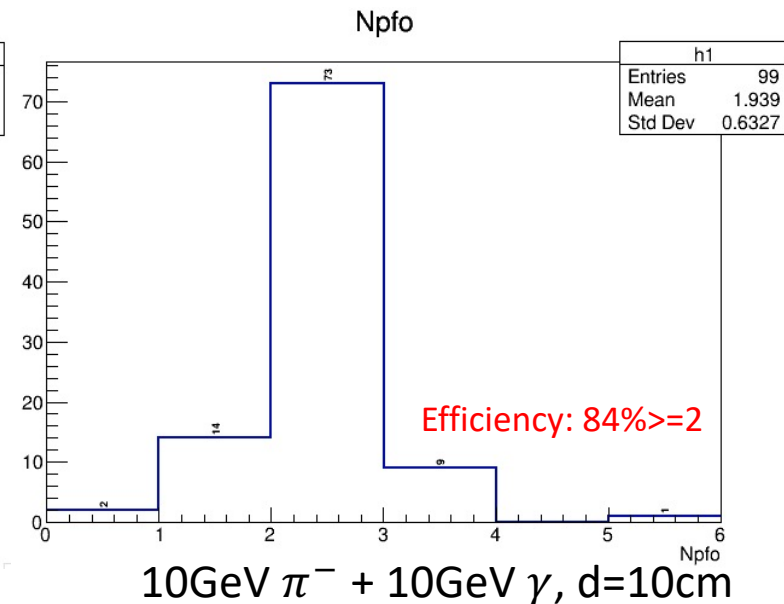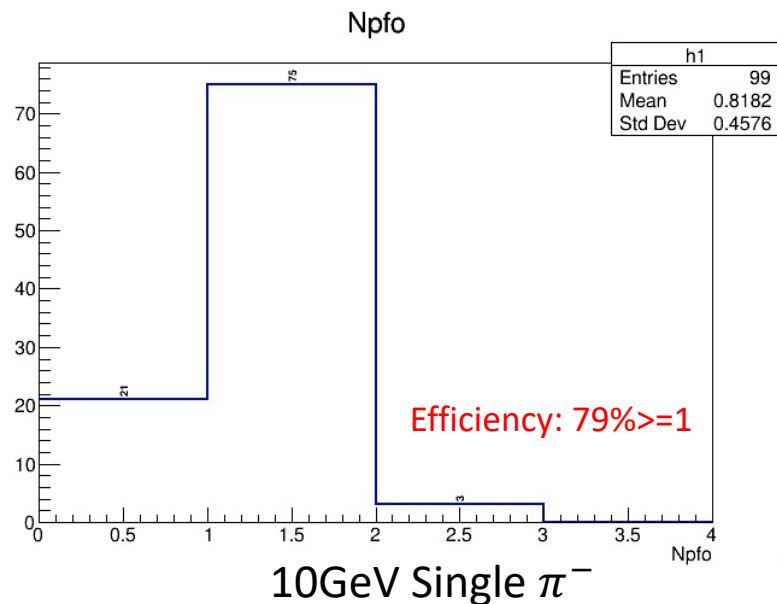# Hadronic shower reconstruction in crystal ECAL

Previous review

Iteration-based reconstruction flow: 1D clustering -> 2D matching -> 3D ConeClustering.

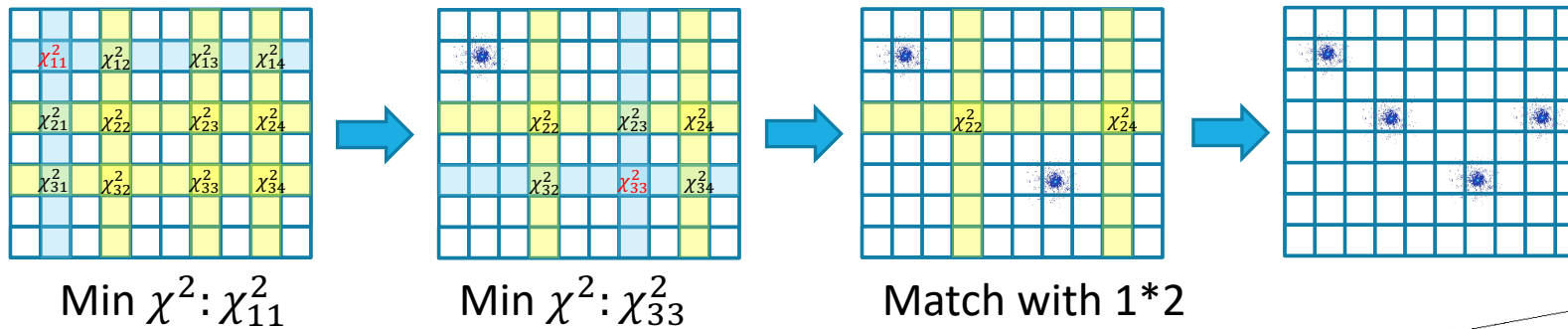Can well deal with single muon, single photon, $\mu + \gamma$, $\gamma + \gamma$ cases.
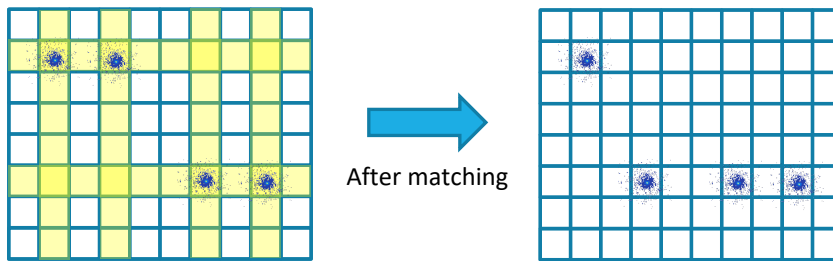
Hadronic shower reconstruction has some problem

10GeV Single π^-

Efficiency: 79%>=1

10GeV π^- + 10GeV γ, d=10cm

Efficiency: 84%>=2

G4 step level hadronic shower

Hadronic shower reconstruction

Difficulty 1: complex hits after the beginning of hadronic shower

◦ Ghost hits and real hits are mixed together. Old algorithm can only deal with N*N cases.

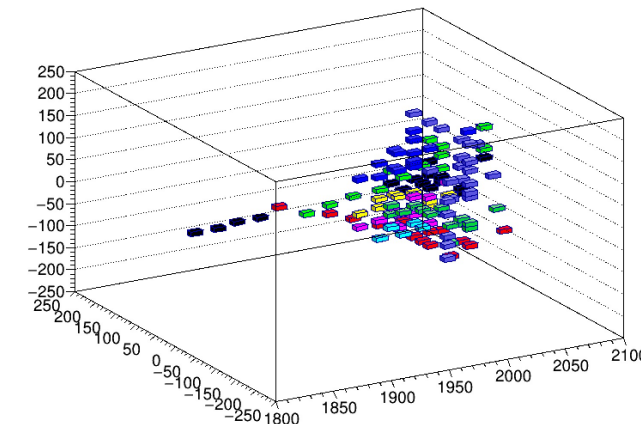◦ New ghost hit removal: Match with minimum chi2, reduce M*N to 1*(M-N).

Min χ^2: χ^2_{11} Min χ^2: χ^2_{33} Match with 1*2

Remind of chi2 definition:
$$\chi^2_{point} = \chi^2_E + (\chi^2_{Tx} + \chi^2_{Ty}).$$
$$\chi^2_E = \frac{(E_X - E_Y)^2}{\sigma^2_E}, \quad \chi^2_T = \frac{(z_T - z_Y)^2}{1cm^2 + \sigma^2_{z(t)}}$$

◦ WARNING: Must be wrong in this case:

After matching

Hadronic shower reconstruction

Difficulty 2: Old ConeClustering criteria can't connect all 2Dshowers together (too tight)
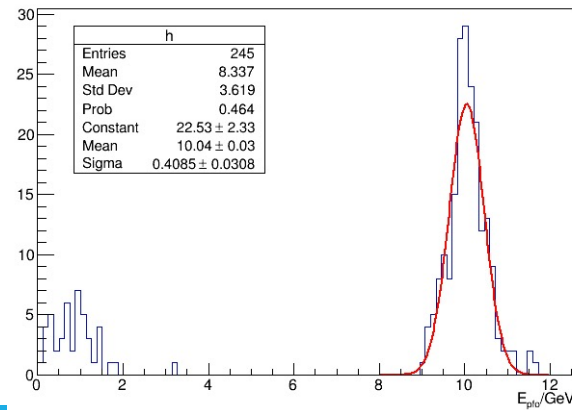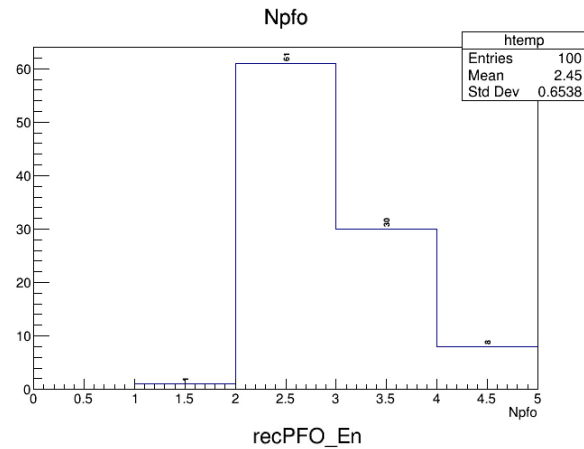
- Consider Arbor's idea in connecting:
  - Connect 2Dshowers from inner layer to outer layer: only connect showers in next layer, but large distance threshold: $R = 40 + 0.5 * Layer\ (mm)$ (Value=40, slope=0.5. Not enough actually).
  - Clean the connections with kappa-order: $\kappa = \theta^{p_\theta} \times d^{p_d} \times \Delta E^{p_E}$. Now $p_\theta = p_d = p_E = 1$.
  - Define good tree: cover >= 3 layers. Merge bad trees and isolate nodes to closest good tree.
- No complex tree merging and splitting yet. No iteration for tree building. Not use the branch information.

Difficulty 3: Old photon/MIP longitudinal information can not be used when reconstructing hadronic showers.
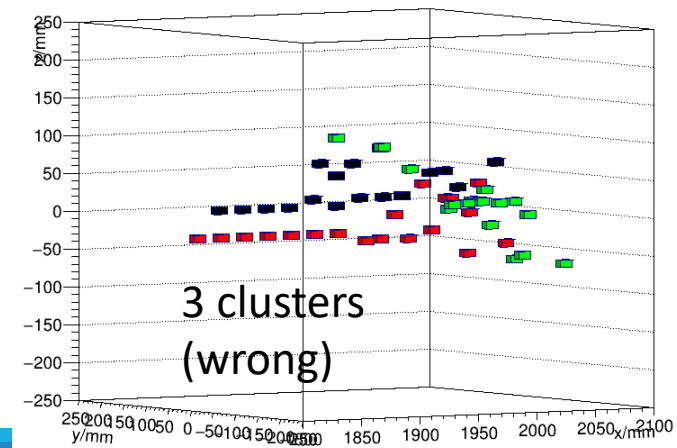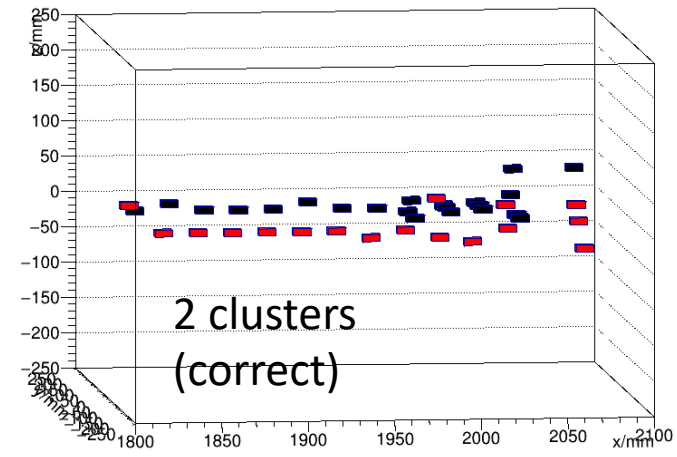
- Reduce old 3 iterations to 2:
  - Iteration 0: Make longitudinal linking for all clusters, but only make candidates in first 5 super-layers (10 cm).
  - Iteration 1: Use ArborClustering to reconstruct tree structure for hadronic showers.
- Use ArborTree to reconstruct clusters and PFOs.

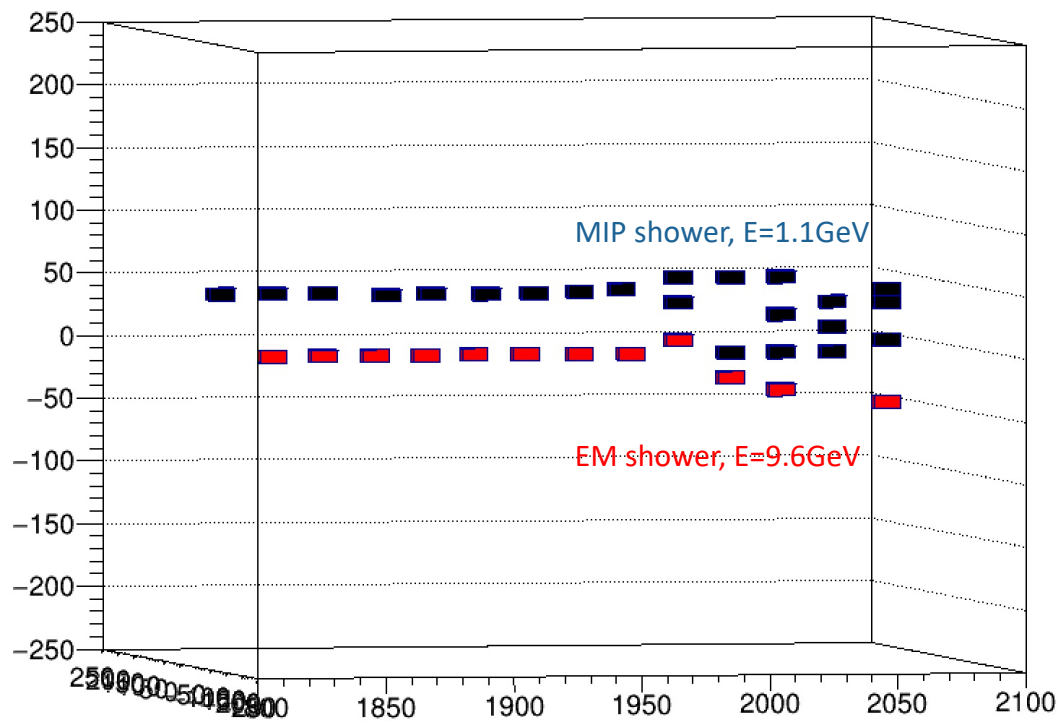# Performance check

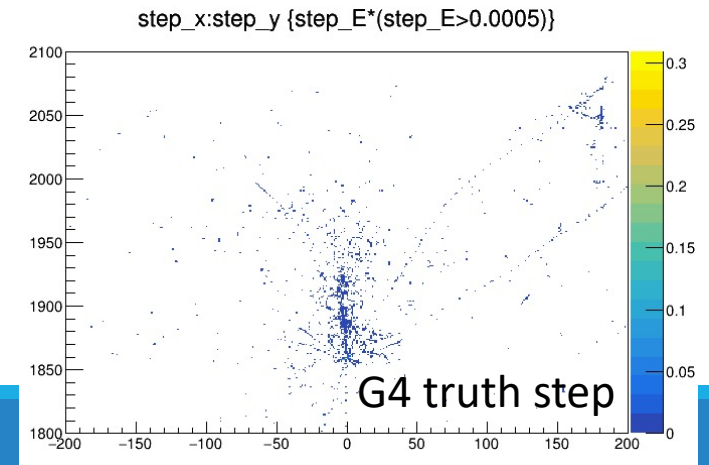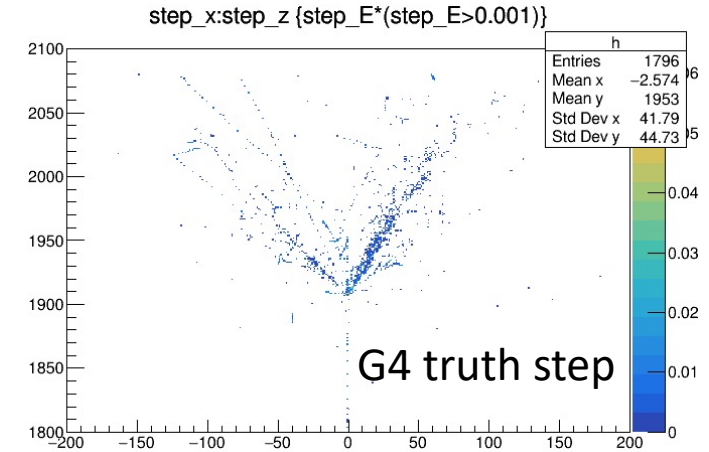10GeV di-photon, $\Delta x = \Delta y = 5cm$.
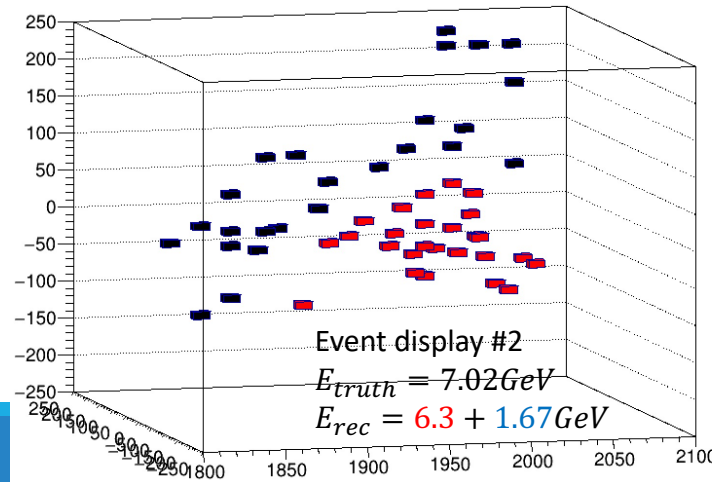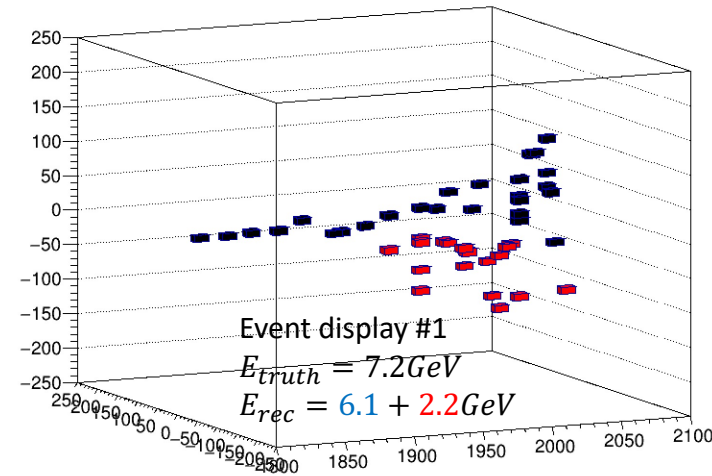

Event display:

2 clusters (correct)

3 clusters (wrong)

Performance check

Photon + MIP event display

MIP shower, E=1.1GeV

EM shower, E=9.6GeV

Performance check

Single π^- reconstruction

Npfo

htemp	
Entries	100
Mean	1.49
Std Dev	0.866

No cluster lost.
But need to merge
some clusters

recPFO_En

htemp	
Entries	149
Mean	6.16
Std Dev	4.183

Most clusters can
match to a track.

Event display #1
$E_{truth} = 7.2 GeV$
$E_{rec} = 6.1 + 2.2 GeV$

Event display #2
$E_{truth} = 7.02 GeV$
$E_{rec} = 6.3 + 1.67 GeV$

step_x:step_z {step_E*(step_E>0.001)}

h	
Entries	1796
Mean x	−2.574
Mean y	1953
Std Dev x	41.79
Std Dev y	44.73

G4 truth step

step_x:step_y {step_E*(step_E>0.0005)}

G4 truth step

Performance check

$\gamma + \pi^-$ (~1/3 π^- would interact as MIP).

$E_{rec1} = 11GeV$ (z=0, Gamma)
$E_{rec2} = 0.62GeV$ (z=50, had)
$E_{rec3} = 4.48GeV$ (z=50, had)

Summary and next step

Specific algorithm for hadronic shower reconstruction:

- New chi2 methods to remove more ghost hits.
- Remove some longitudinal information to keep all hits in hadronic shower.
- Arbor Clustering logic for hit connection.
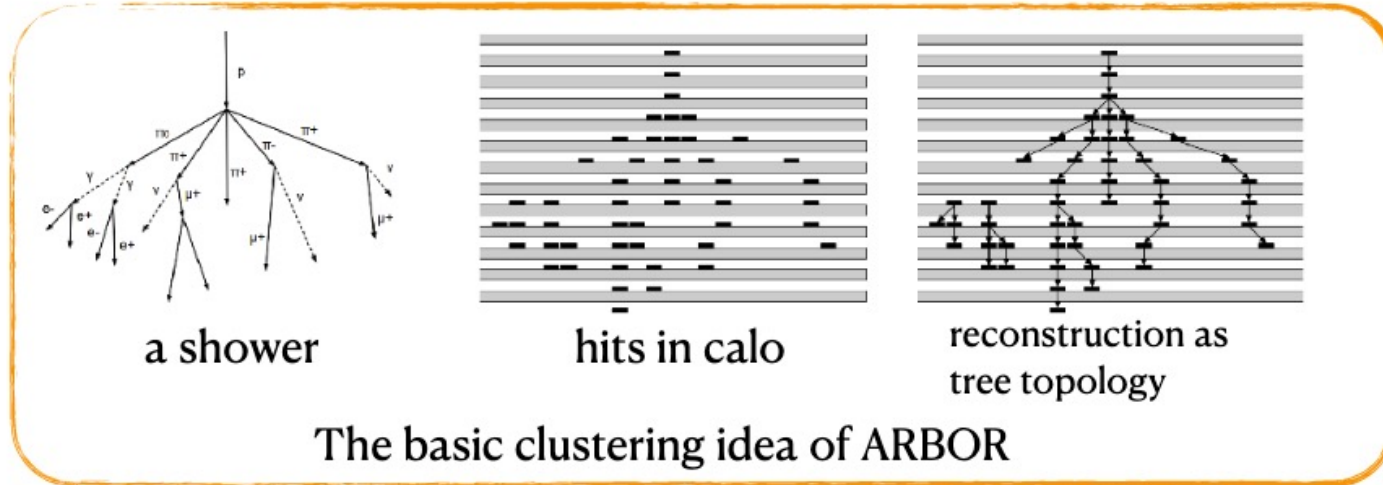
Performance check:

- Can keep all hadronic showers.
- Reduced single photon & di-photon efficiency.
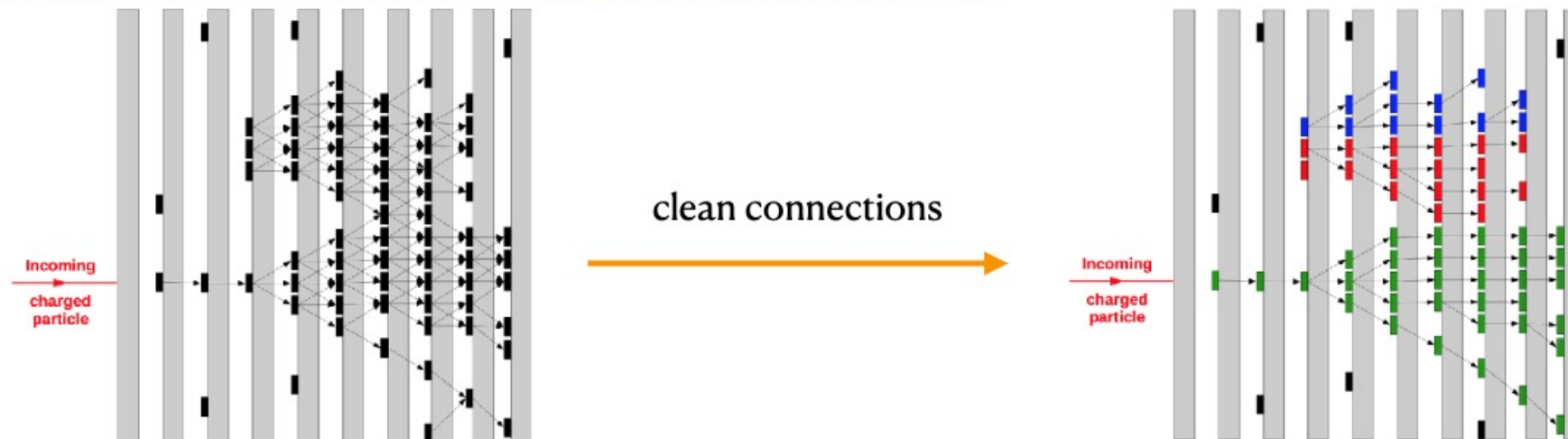- Have some ability to distinguish hadronic shower and nearby EM shower.
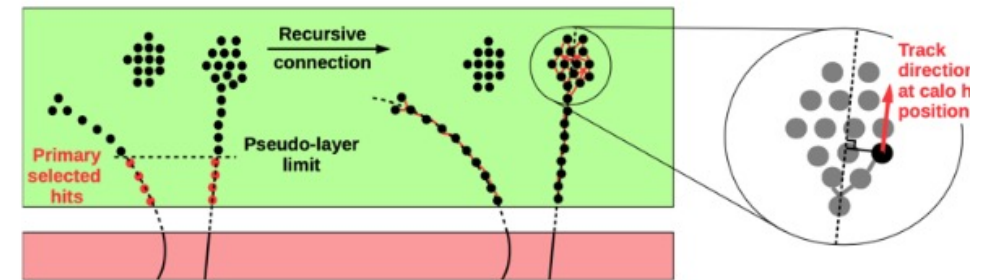
Next step:

- New algorithm for cluster merging.
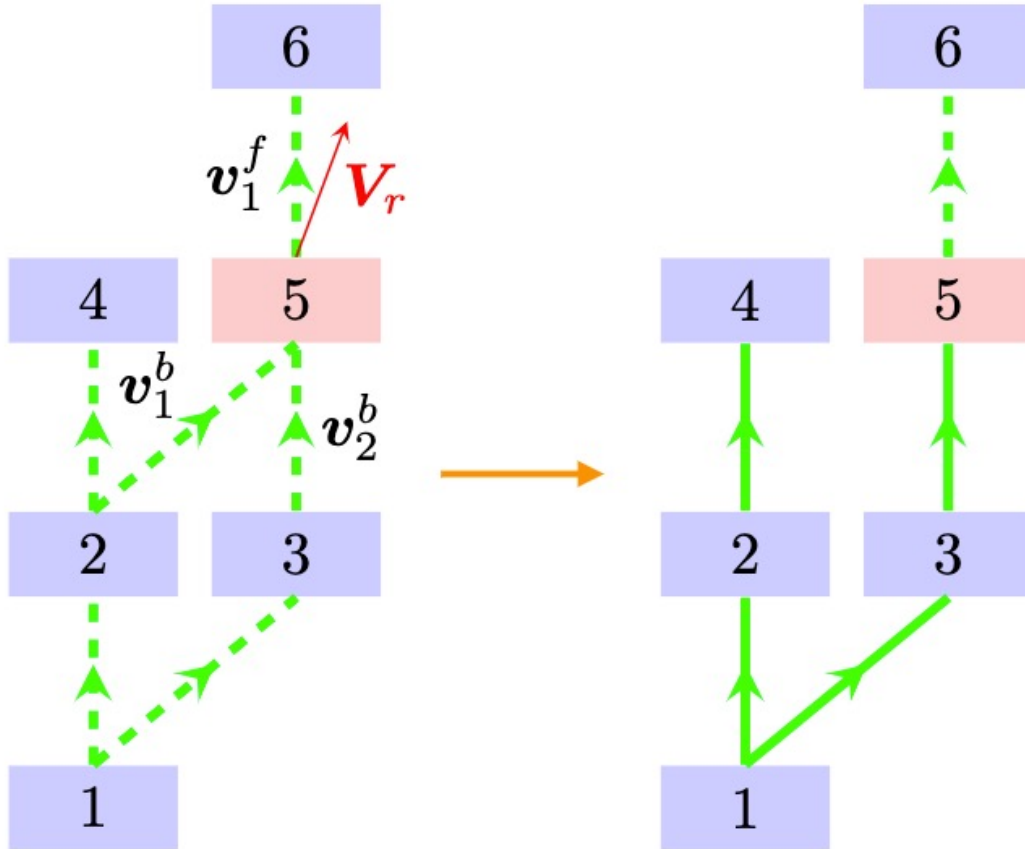- Make use of ArborTree branch information.

Backup

Clustering

a shower

hits in calo

reconstruction as tree topology

The basic clustering idea of ARBOR

Track-driven clustering

Recursive connection

Primary selected hits

Pseudo-layer limit

Track direction at calo hit position

Tracking in the calorimeter

Incoming charged particle

clean connections

Incoming charged particle

Hits connection

'Small' parameters are chosen, so the clustering at this stage has small error on merging two clusters into a single one

- Reference direction

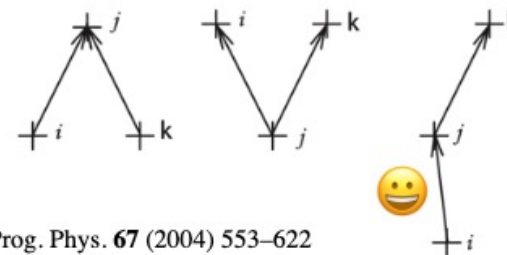$$V_r = w_b \cdot \sum_i v_i^b + w_f \cdot \sum_j v_j^f$$

- Connection order

$$\kappa = \theta^{p_\theta} \cdot d^{p_d}$$

- θ: angle between connection and reference direction
- d: the connection length

- It is similar to the tracking method with neural network

The system energy E is a function of
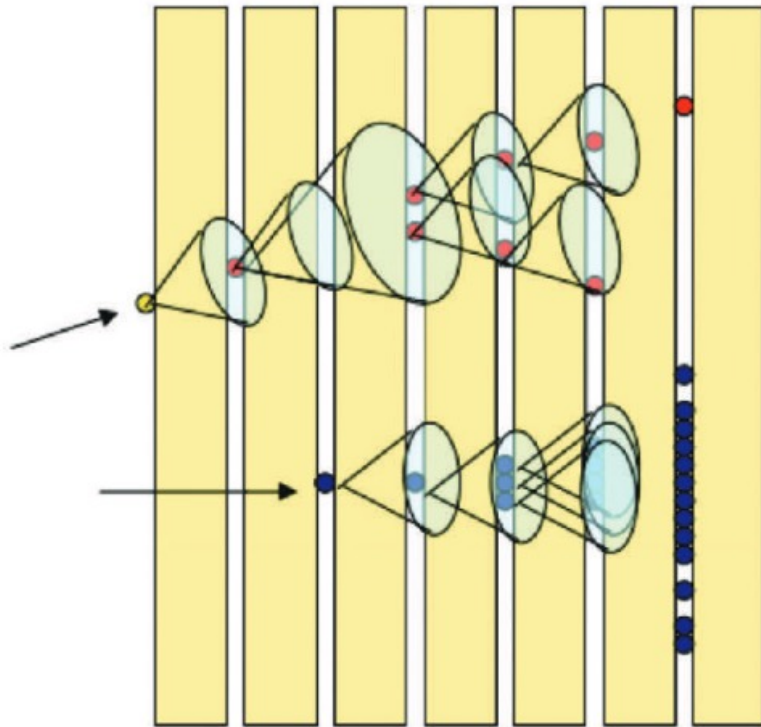
$$\frac{-\cos^m \theta_{ijl}}{d_{ij} + d_{jl}}$$

Rep. Prog. Phys. **67** (2004) 553–622

In principle, this clustering method of ARBOR can be updated to NN method

The clustering in PandoraPFA
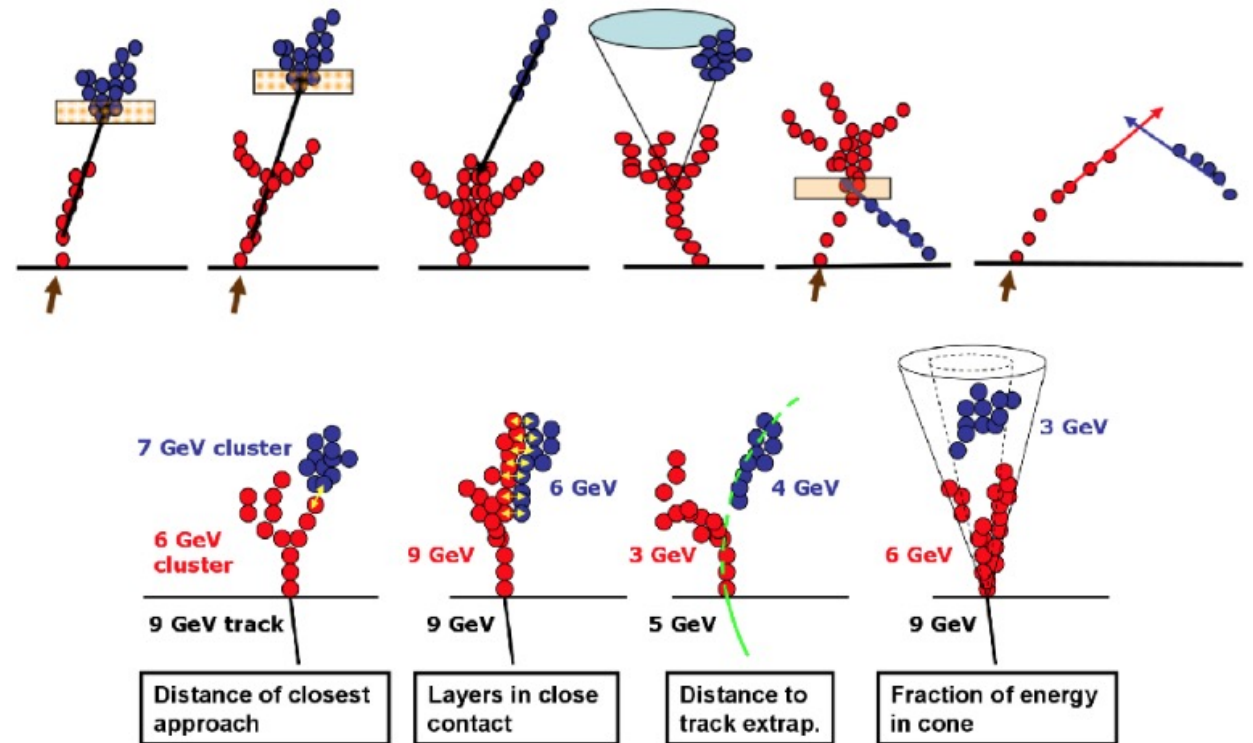
Cone based clustering

The cone parameters: cone angle and distance

A cluster merging procedure is needed after clustering. Without that, it may induce double counting.

Topological cluster merging in PandoraPFA