Implementing Time in Particle Flow with APRIL

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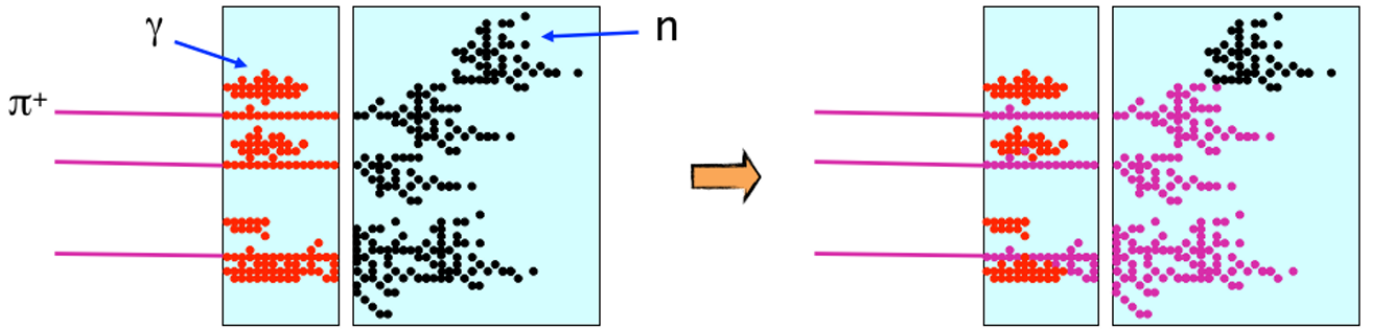
What is particle flow algorithm

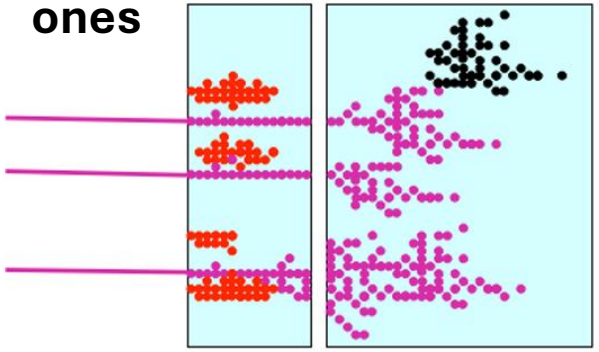
- Reconstruction of ***stable particles*** using the sub-detector information (basically ***hits***)
- Main Idea: best combining information: measure the particle using the most suitable sub-detector, i.e.,
  - Trackers for charged particles
  - Calorimeters for neutral particles



What is PFA

- Typical main steps:
  - Clustering (hits -> clusters)
  - Topological association (merge clusters) & Track Clusters association & Re-clustering (split and merge cluster)
  - (Fragments removal)
  - PFOs creation
  - (PFOs removal)
- Jet energy errors arise from
  - **False clustering /association**
    - Neutral hits merged into charged
    - Charged hits leak to neutral
  - ECAL/HCAL/Tracker resolution

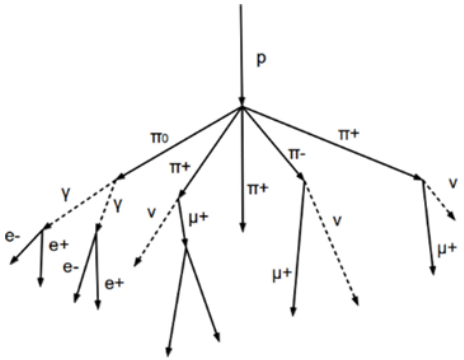
For the total energy of jet, we need separate calorimeter hits of **charged particle** from **neutral ones**



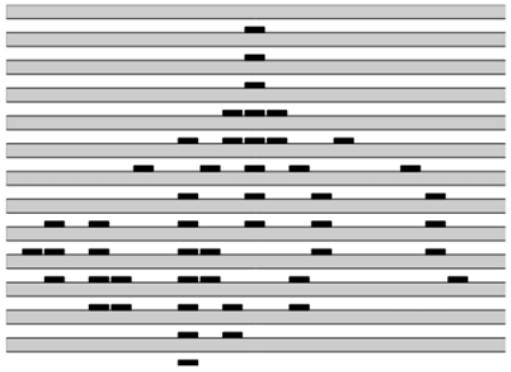
$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

Existing FPA

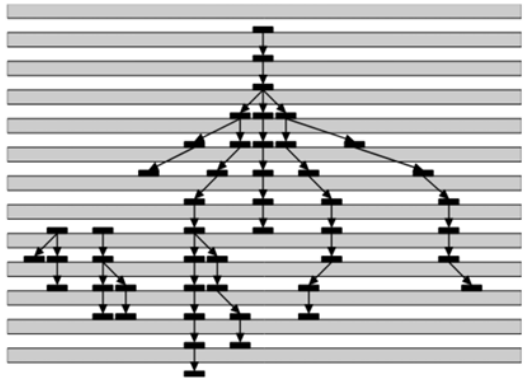
- Pandora
  - Built-in in key4hep & ILCsoft & default
- ***APRIL***
  - Implemented within PandoraSDK
  - Leverage the (shower develops like) Arbor concept



Hadronic shower



Hits in calorimeter



Clustering by Arbor

Rémi Ete

Why does time information matter

- *Clustering*
  - *Purity & eff. of cluster*

Cell size = 1 cm x 1 cm x 1cm

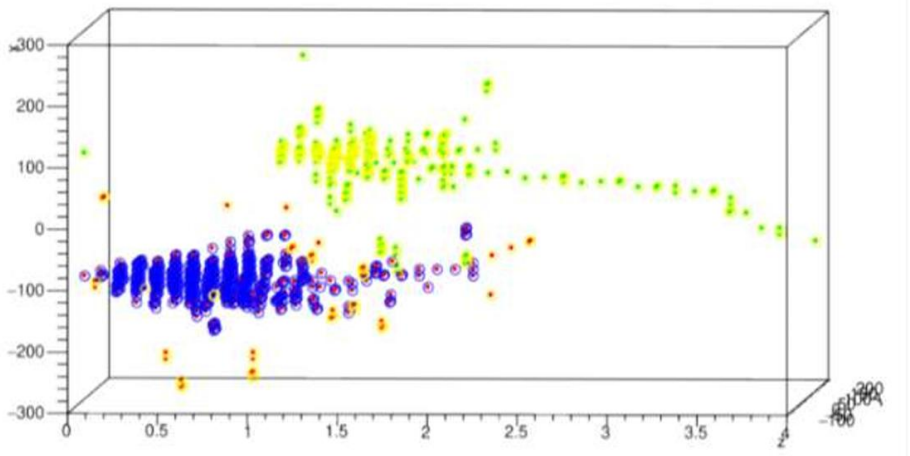
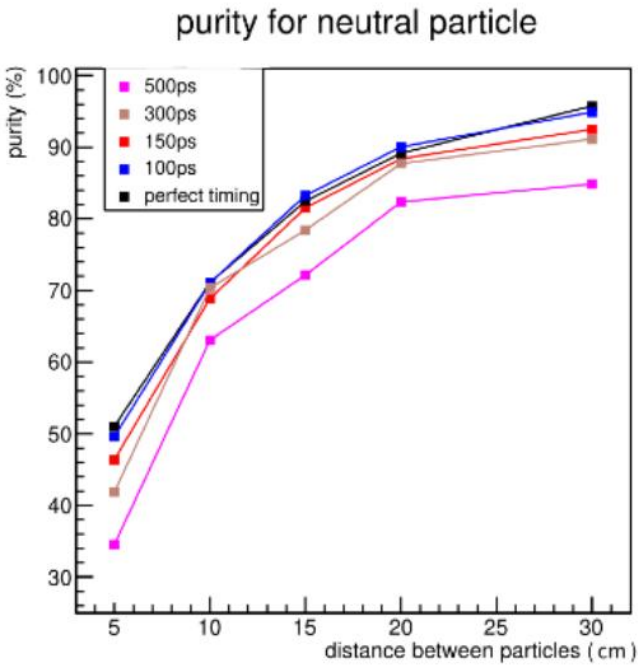
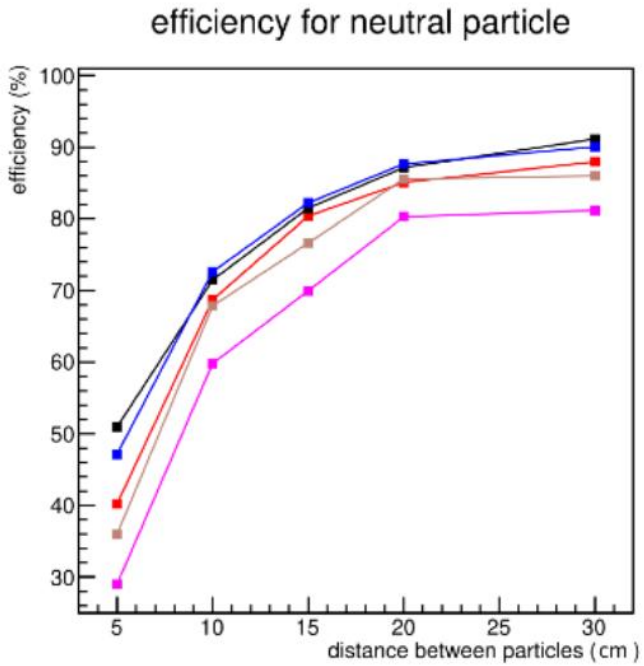


Fig. 5 AMSTER reconstruction of a simulation of a 30 GeV charged pion (red simulated and blue reconstructed) with a 10 GeV neutral kaon (green simulated and yellow reconstructed) separated by 20 cm inside a prototype SDHCAL volume.

AIDAinnova-MS50

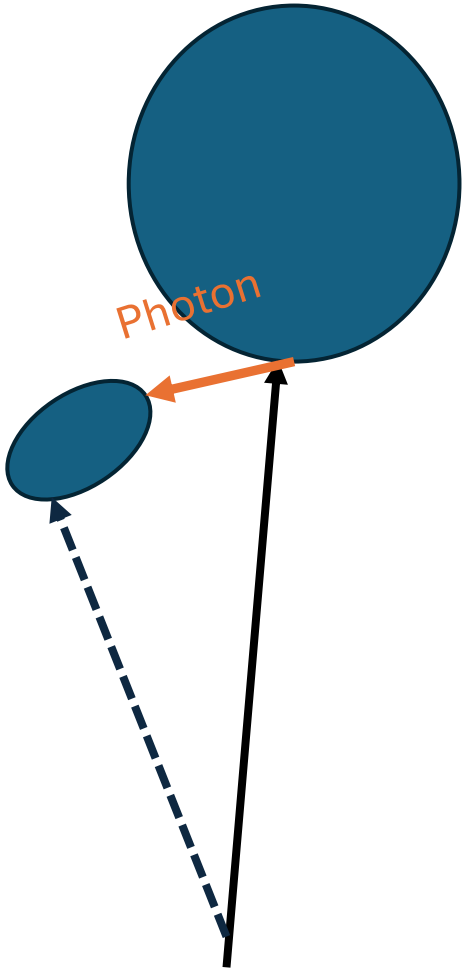




arXiv:2502.03555v1

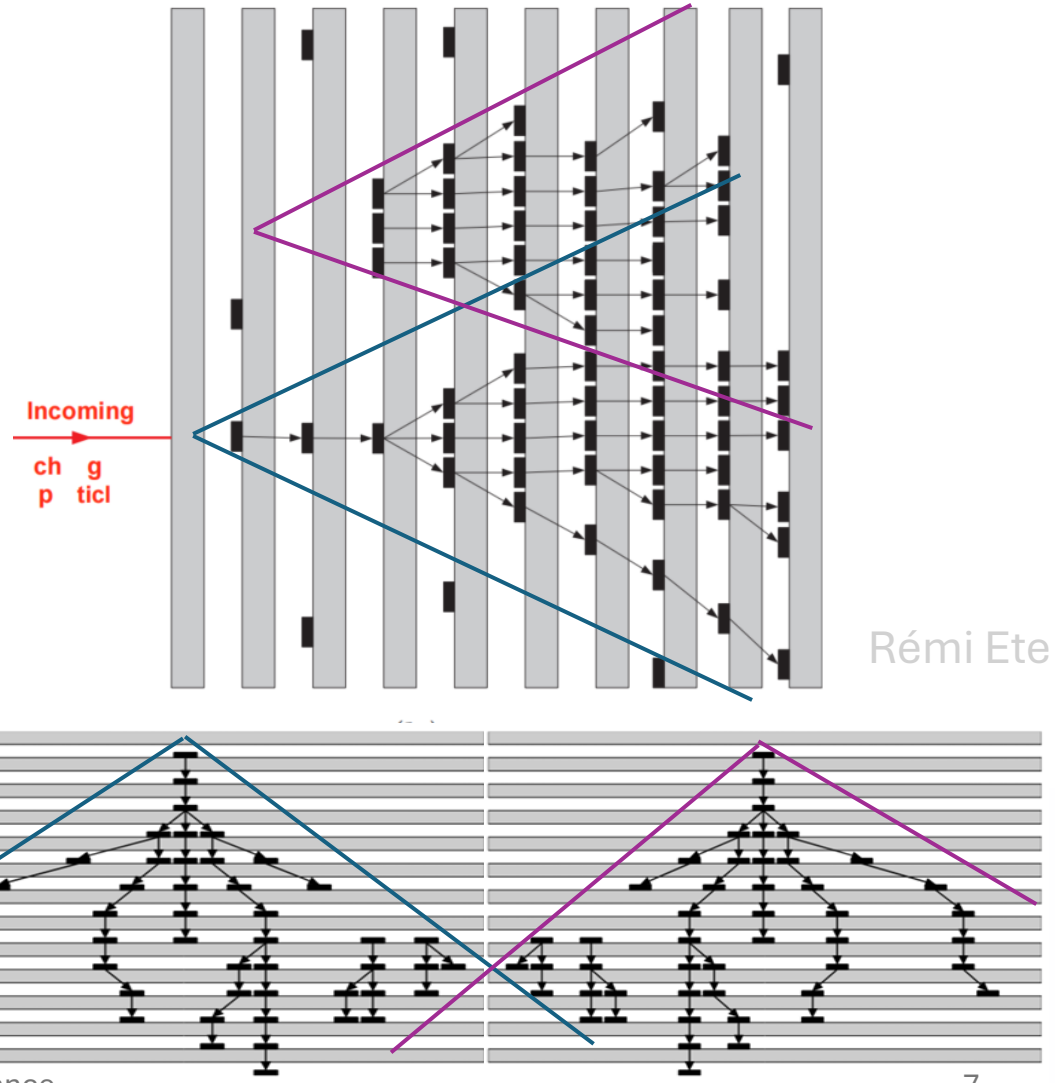
Why does time information matter

- *Clustering*
  - *Purity & eff. of cluster*
  - An concreate example: back scattering
- PID - Time of flight
  - e.g., arXiv:2209.02932v2
- Software compensation for shower energy
  - e.g., arXiv:2203.01317v2



How is time information used

- Causality
  - Clustering
  - Association
- Merging
  - We can more aggressively merge a cluster/hit with larger distance to the main cluster, so that we can increase the eff.



How is time information used

- Causality
- A trick – replace spatial pseudo layers with time pseudo layers

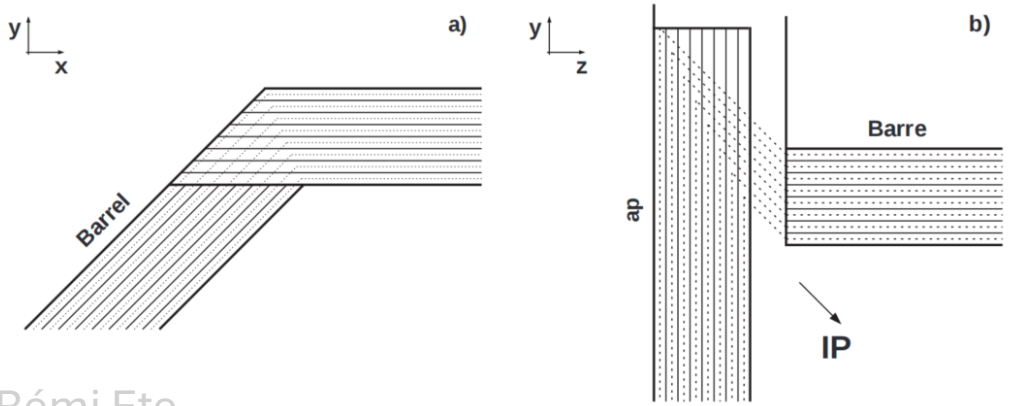


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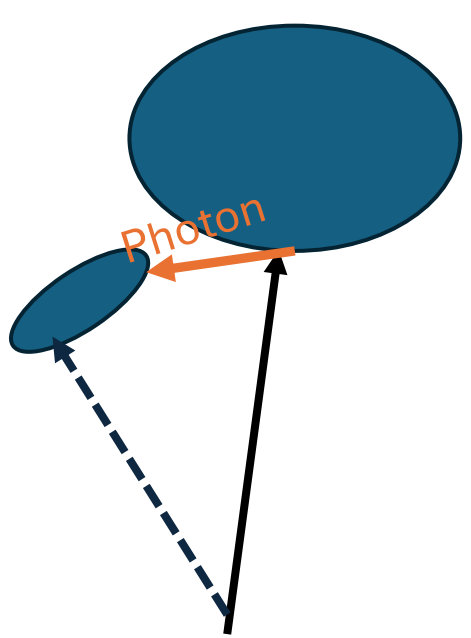
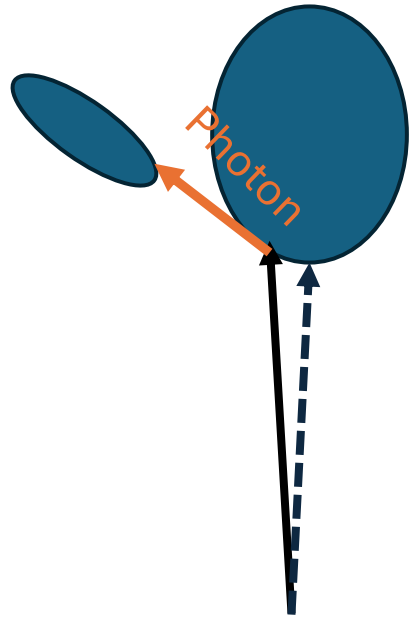
FIGURE 4.3 – Segmentation of the detector geometry into pseudo-planes in a) the barrel region and b) the stub region. Solid lines represent the physical planes of the electromagnetic calorimeter, while dashed lines denote the pseudo-planes.



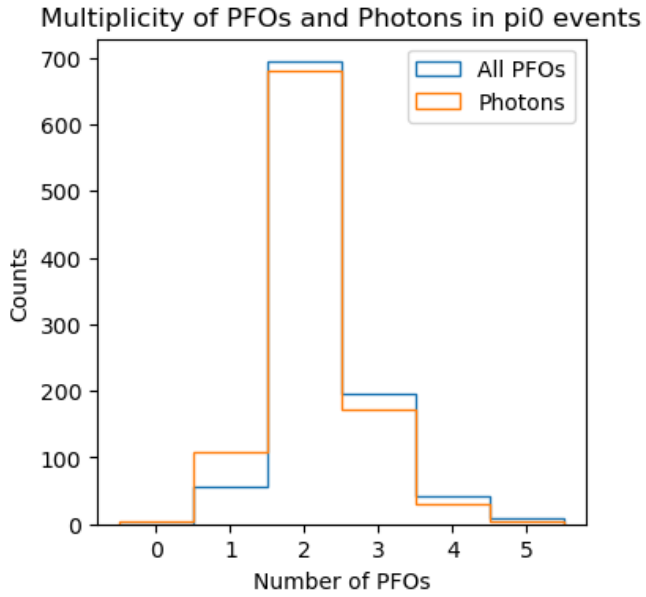
Spatial pseudo layers

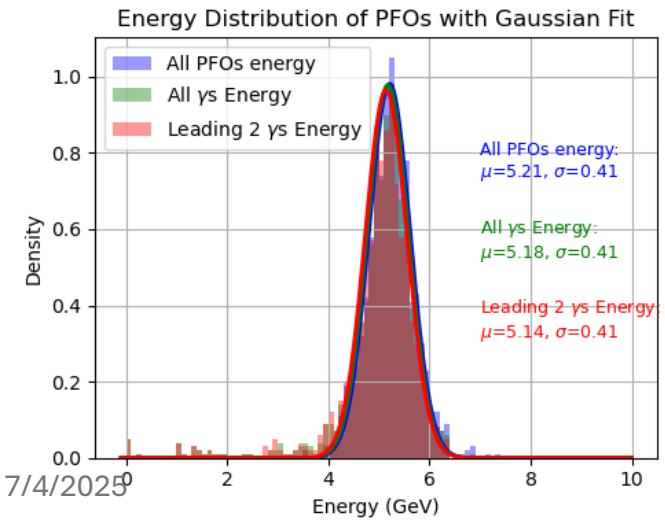


Time pseudo layers

Spatial pseudo layers

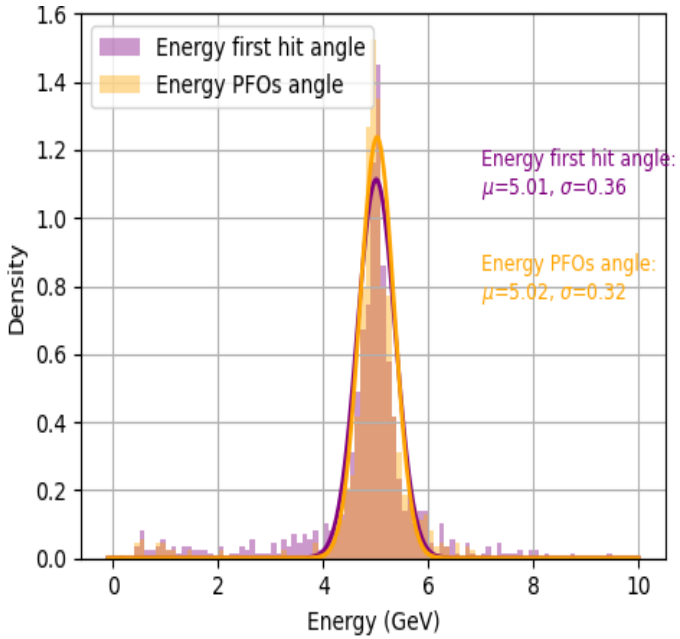
Setting up the metric

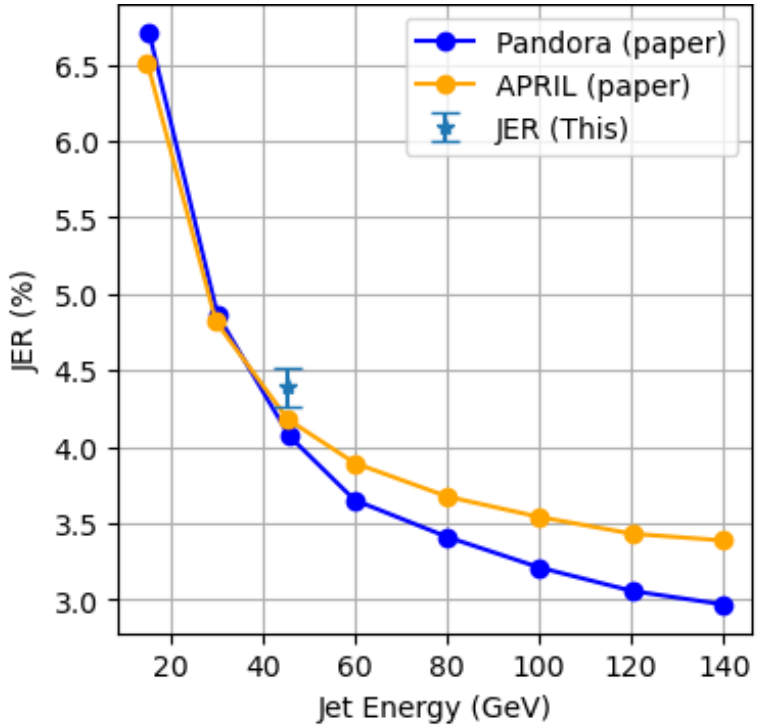




single pi0

$$m^2_{\pi^0} = 2E_{ph1}E_{ph2}(1-\cos\theta_{photons})$$





Conclusion

- Implementing time in PF seems beneficial
- Work started with APRIL
- Some results are coming soon (with ILD detector)
  - Build up the metric:
    - JER decomposition (decompose JER into ECAL/HCAL/Tracker resolution & double counting & lost)
  - Implement the time
  - Machine learning to label cluster/inter-cluster-relationship & even to promote particles
  - Compare the performance!

Discussion is welcome!

Thanks