An introduction to the particle flow algorithm for ILC, ArborPFA

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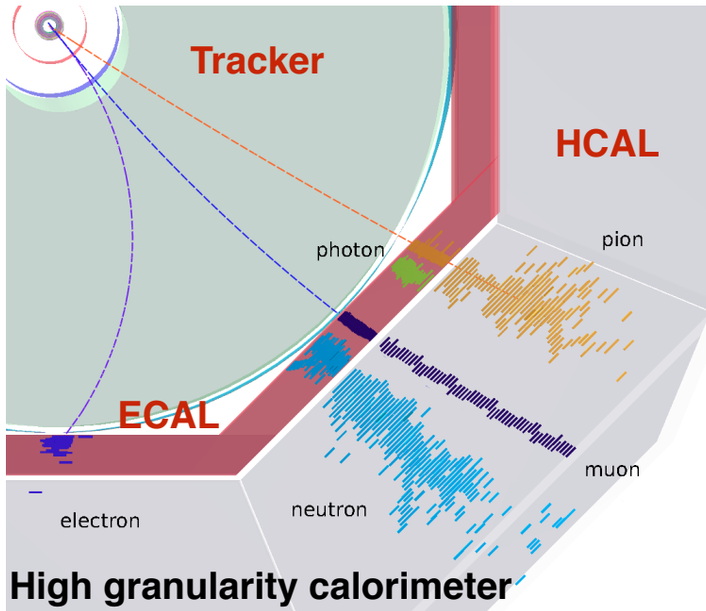
CHEF2017, Lyon

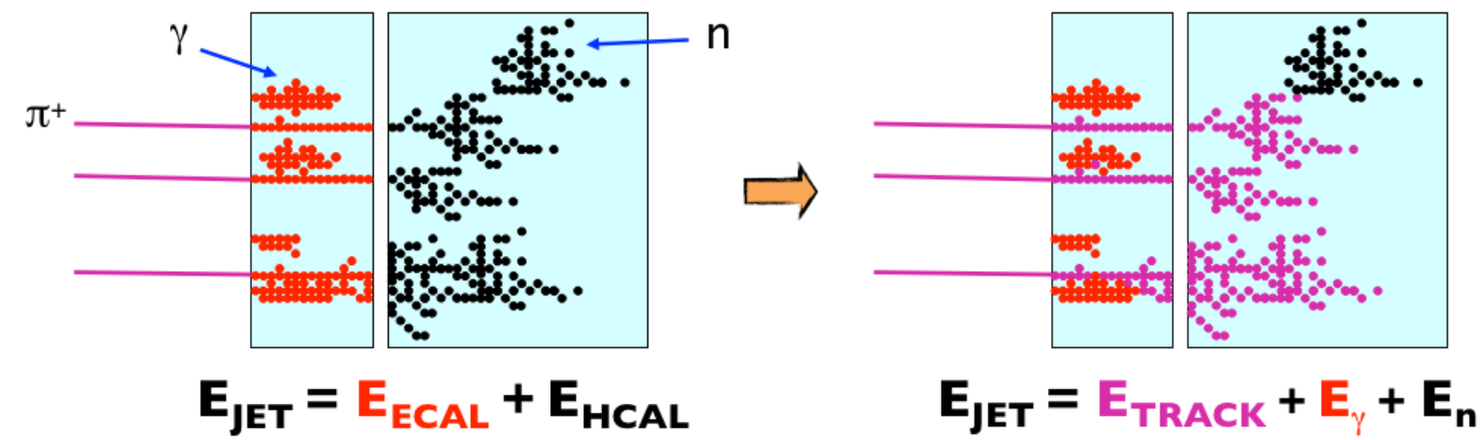
Outline

- Particle flow algorithm
- ArborPFA
- Optimization
- Conclusion

Particle flow algorithm

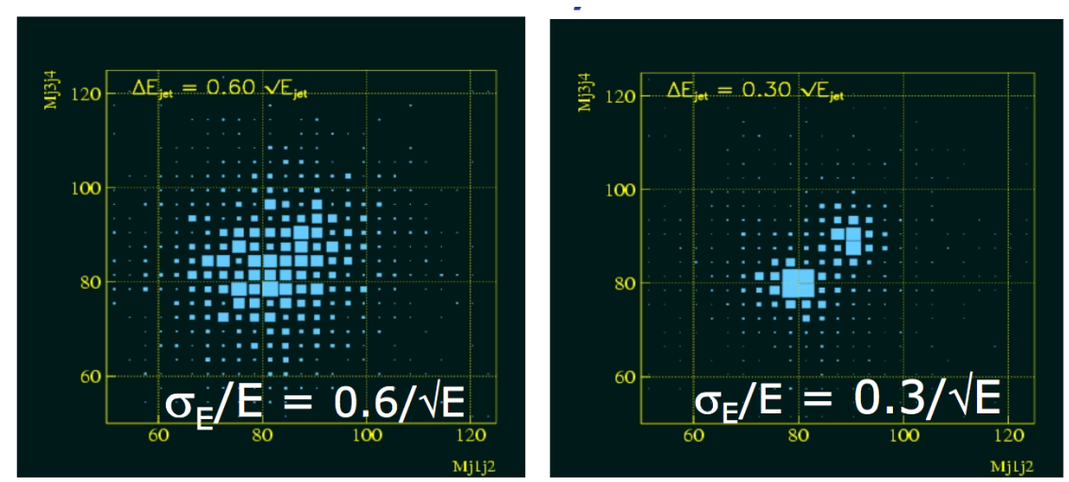
- Particle flow algorithm (PFA): an algorithm that tries to reconstruct individual final state particle from the record in detector.





arXiv: 1308.4537

- It can lead to measure jet energy accurately, and consequently improve the reconstruction reconstruction and event identification



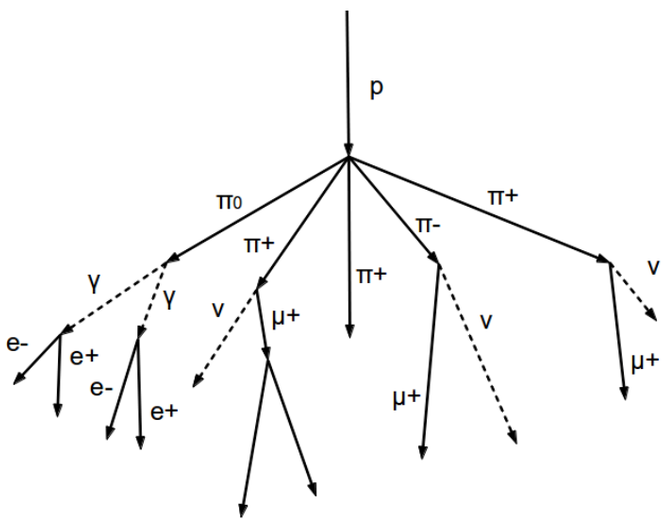
- Jet energy resolution at ILC: $\sigma_E/E \lesssim 3.5\%$ from 50 to 500 GeV

ArborPFA

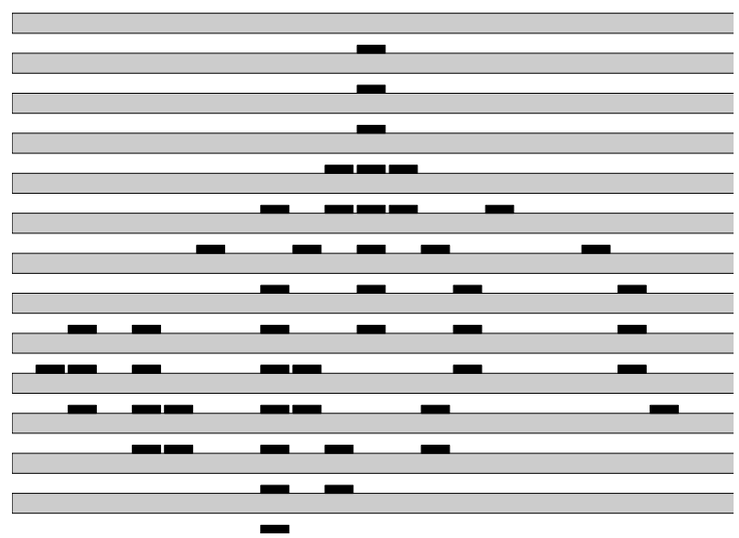
- The necessity of ArborPFA
  - Besides PandoraPFA, it is another code to validate an optimize the concept of particle flow algorithm for ILD.
  - It is also expected to implement some new ideas for PFA in this algorithm, such timing and tracking.
  - MIP scale in Pandora is used in the algorithms which is not valid for SDHCAL.
- Brief history
  - Rémi built ArborPFA for SDHCAL prototype study,
  - then for ILD detector model (ILD_o2_v05); PandoraSDK as the framework. (arXiv:1506.05348)
  - For ILC physics research, the code is under optimization to improve jet energy resolution.

The algorithm of Arbor

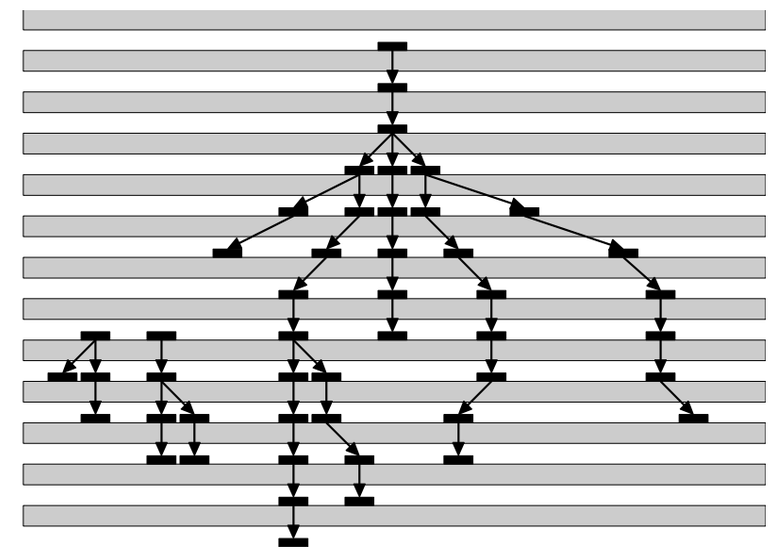
- Arbor is an algorithm for clustering the hits in calorimeter based on tree topology (H. Videau, M. Ruan, arXiv:1403.4784)



Hadronic shower



Hits in calorimeter

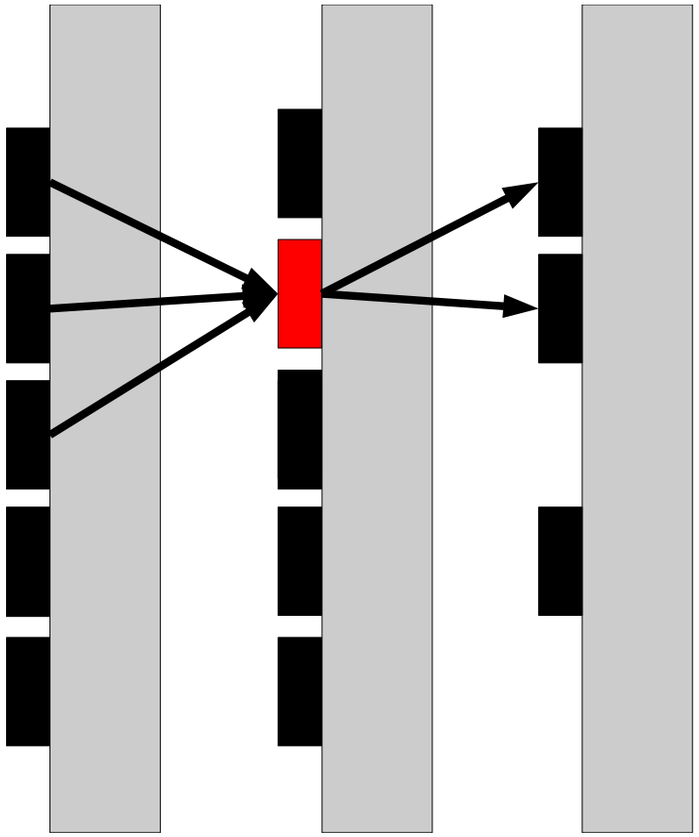


Clustering by Arbor

- Vertex: hit in calorimeter space
- Connector: oriented link between two vertices
- Tree: the structure of linked vertices by connectors
  - the root vertex has no predecessor
  - all other vertices have only one predecessor

Hit clustering in ArborPFA

- Nearby hits connection

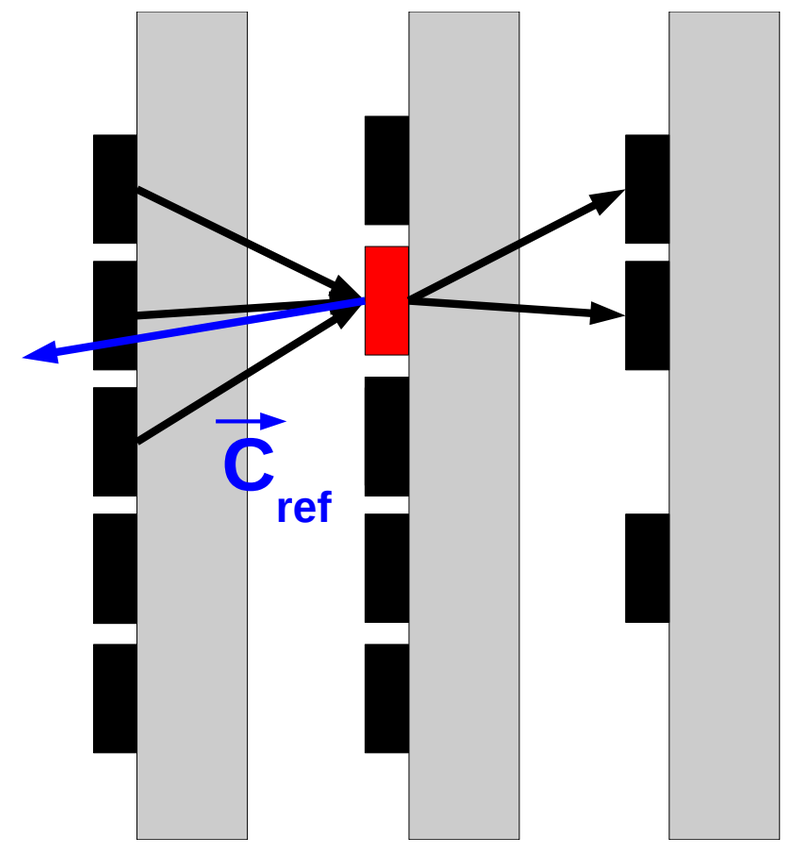


Hit clustering in ArborPFA (cont.)

- Nearby hits connection
- Reference vector

$$-\vec{C}_{ref} = w_{bck} \cdot \sum_{b} \vec{c}_b$$

$$+w_{fwd} \cdot \sum_{f} \vec{c}_f$$



Hit clustering in ArborPFA (cont.)

- Nearby hits connection
- Reference vector

$$-\vec{C}_{ref} = w_{bck} \cdot \sum_{b} \vec{c}_b$$

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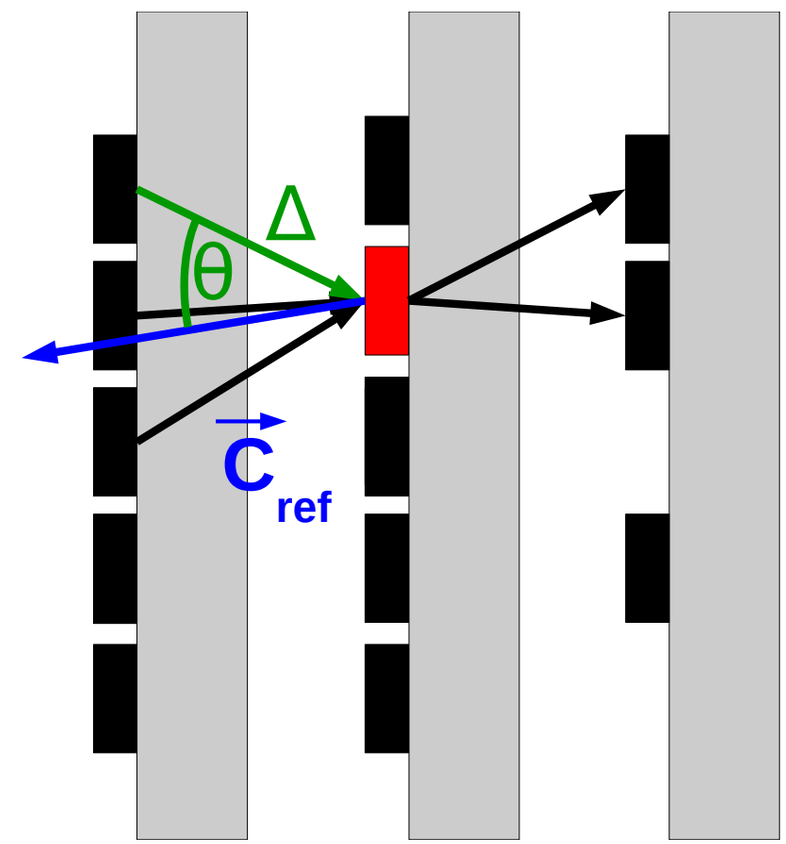
- The most probable connection is determined by order

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

$$(p_\theta = 1, p_\Delta = 5)$$



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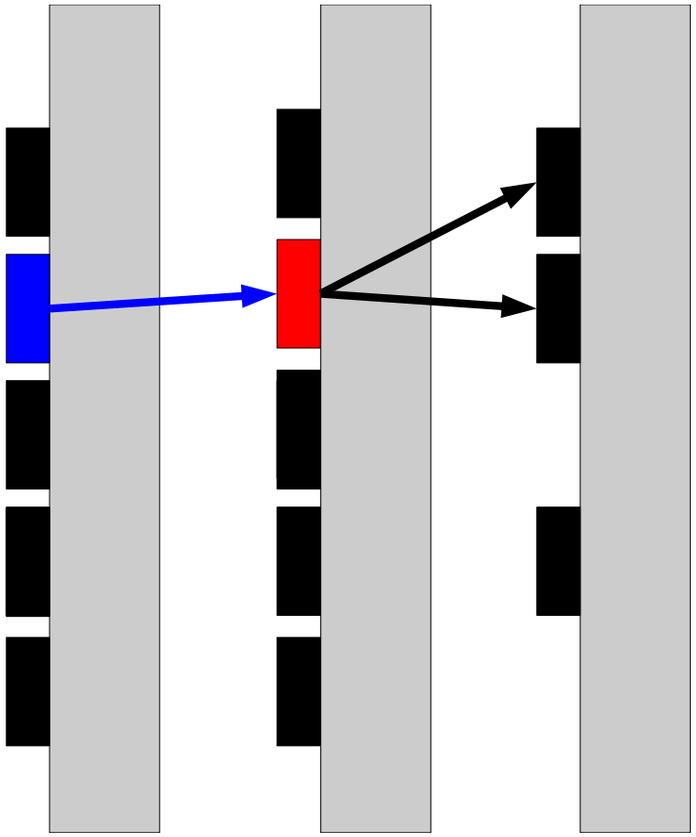

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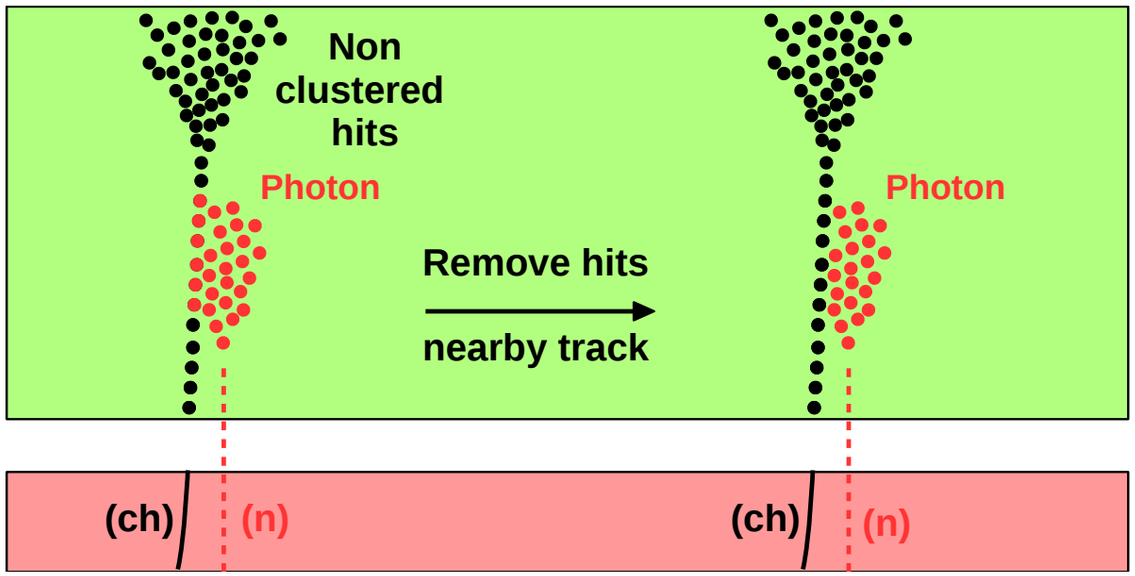
- Connector cleaning

Photon reconstruction

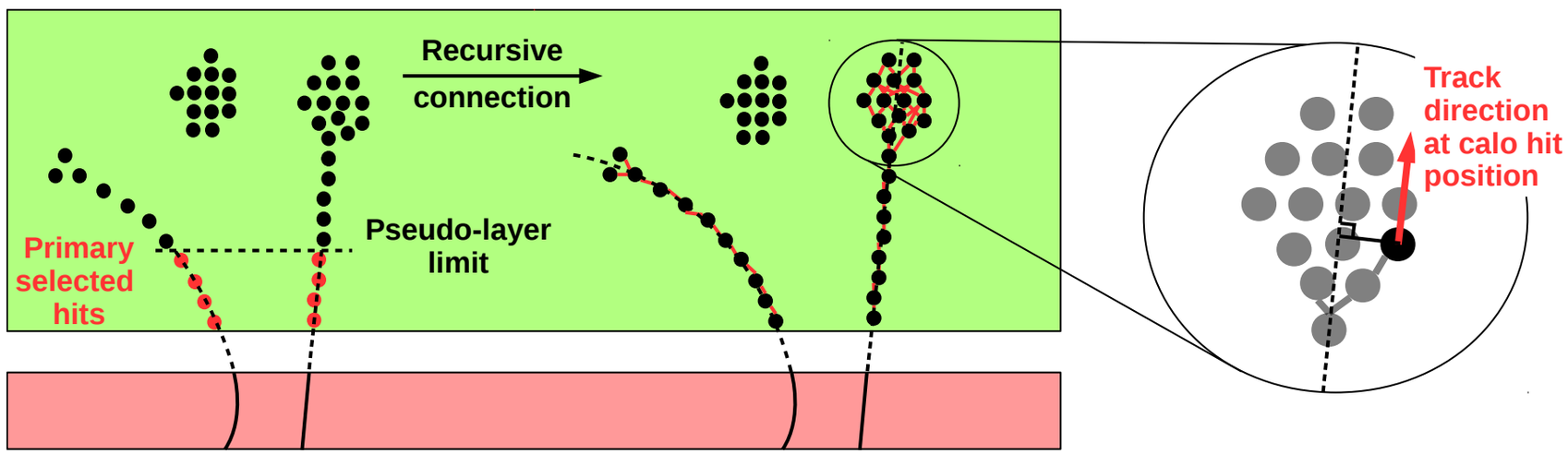
- Preparation of the event
  - CaloHits, tracks
  - Identification of V_0, kink and prong

- Reconstruction of photons
  - Clustering in ECAL
  - Remove hits from nearby track

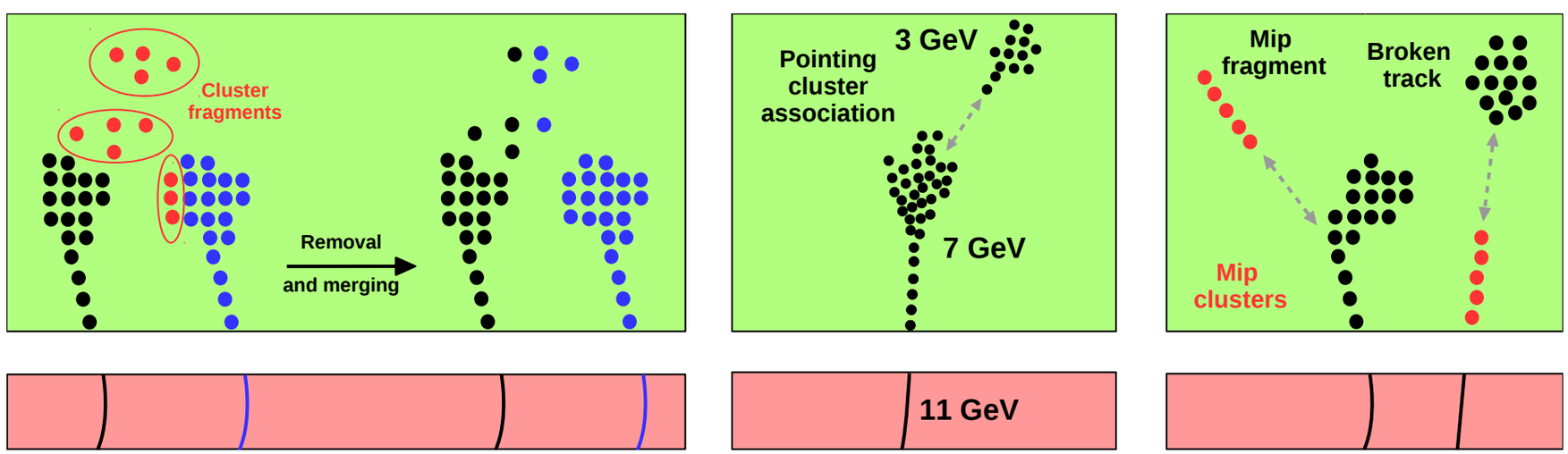


Clustering of particles

- Track driven clustering

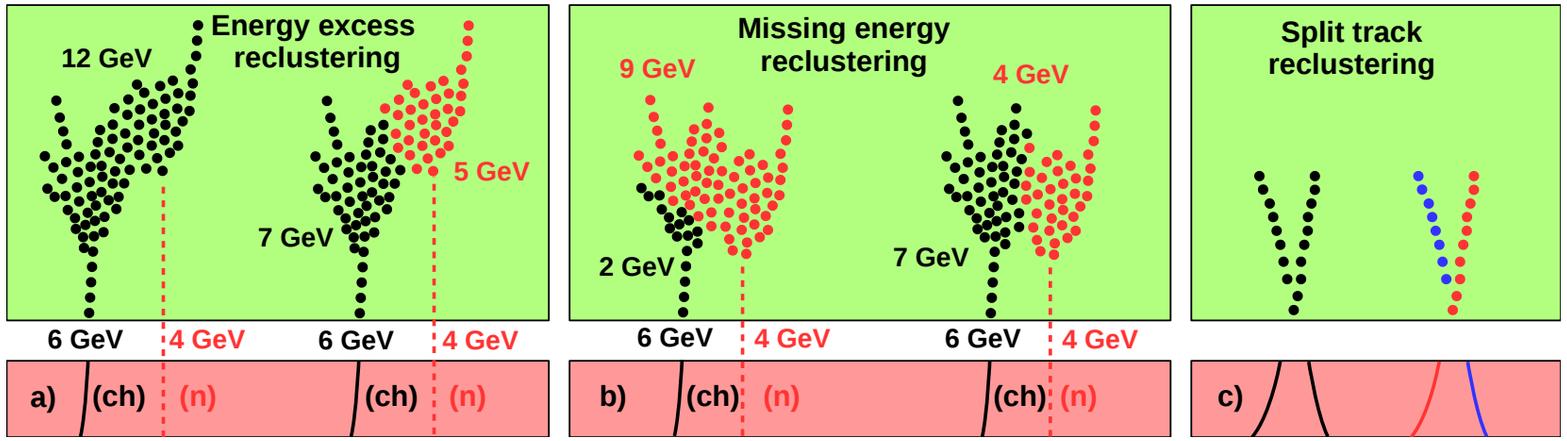


- Topological association for cluster fragments



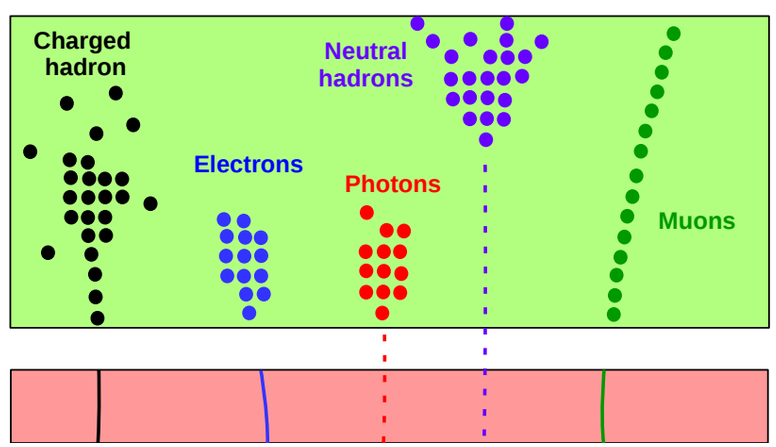
Reclustering

- Reclustering is to correct cluster assignment based on the energy of track in cases of:
  - excessing energy
  - missing energy
  - track-cluster multiple association

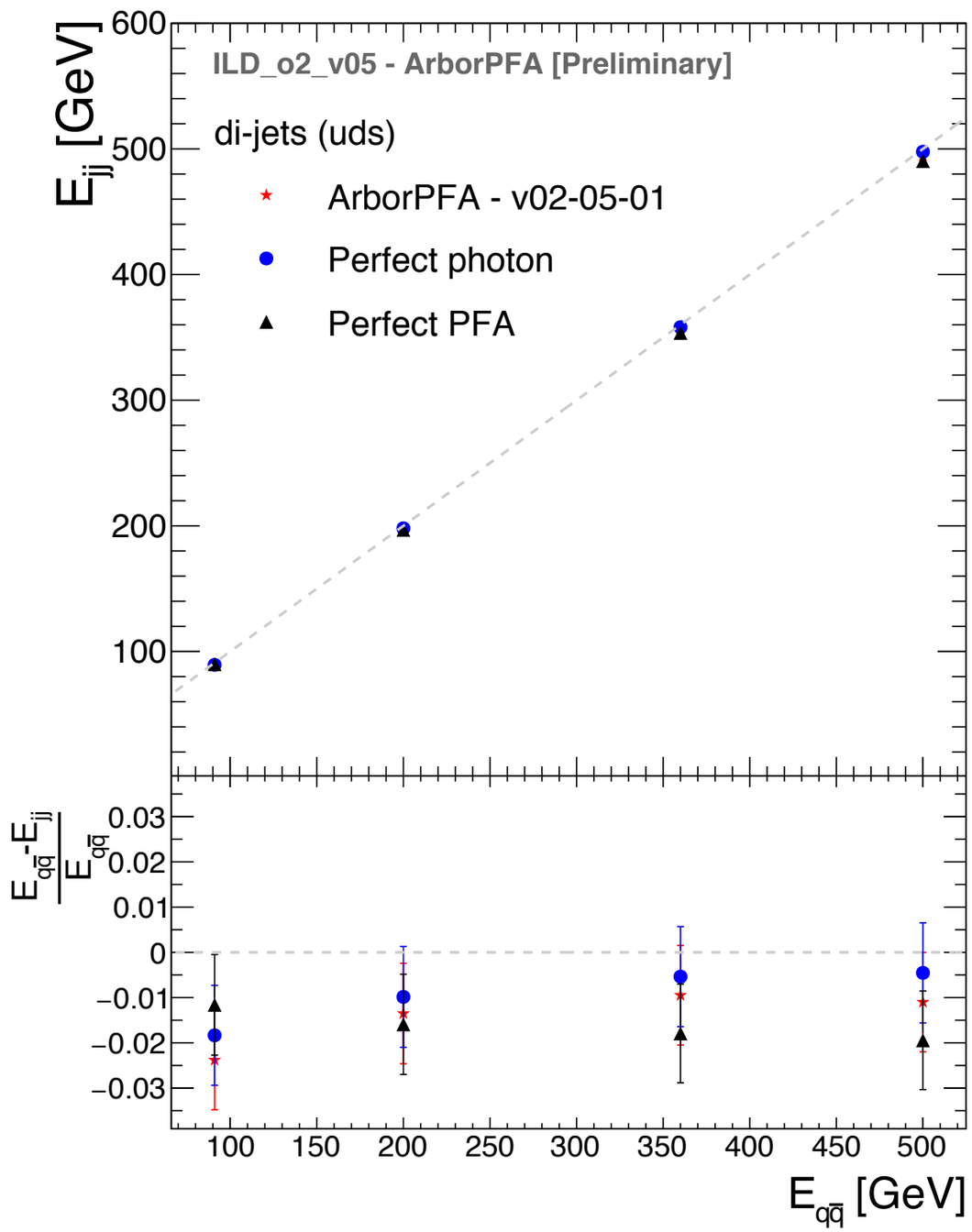


- Create and identify the particle object

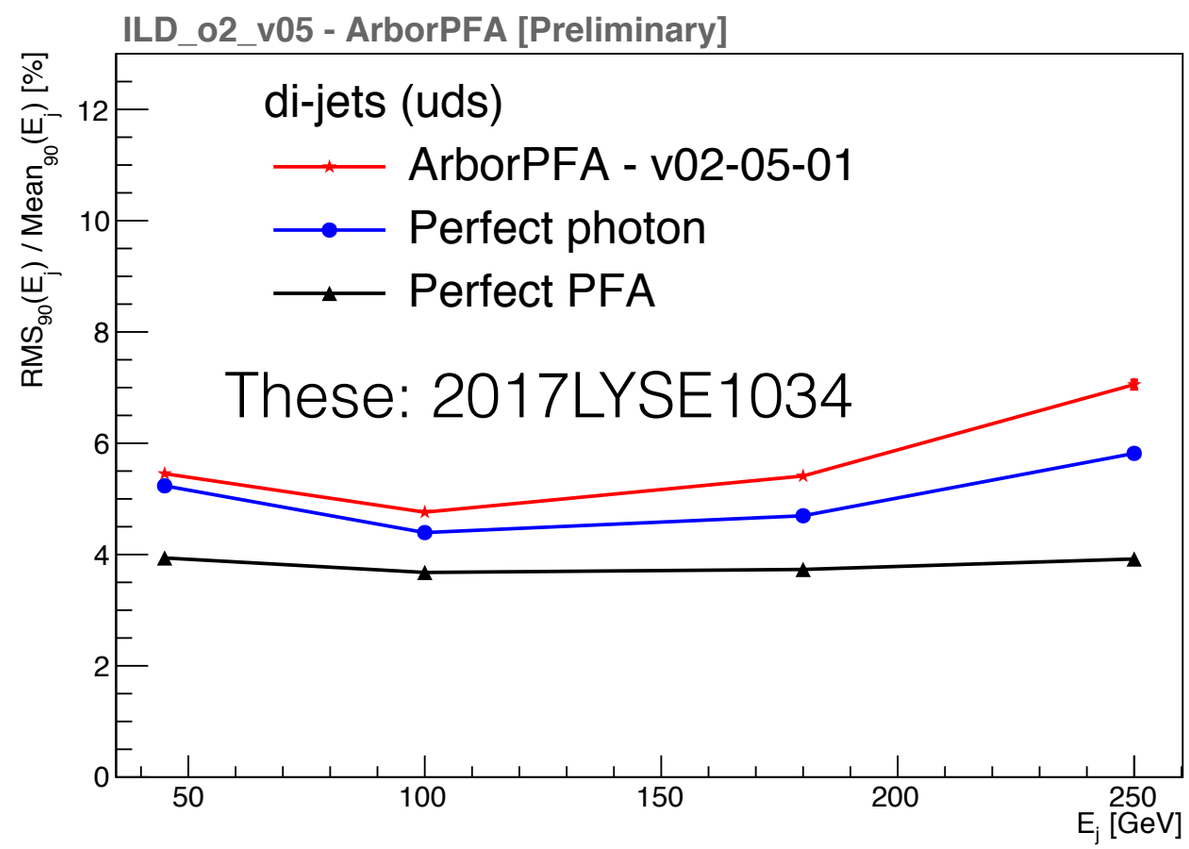
But, this is not real life…



Performance



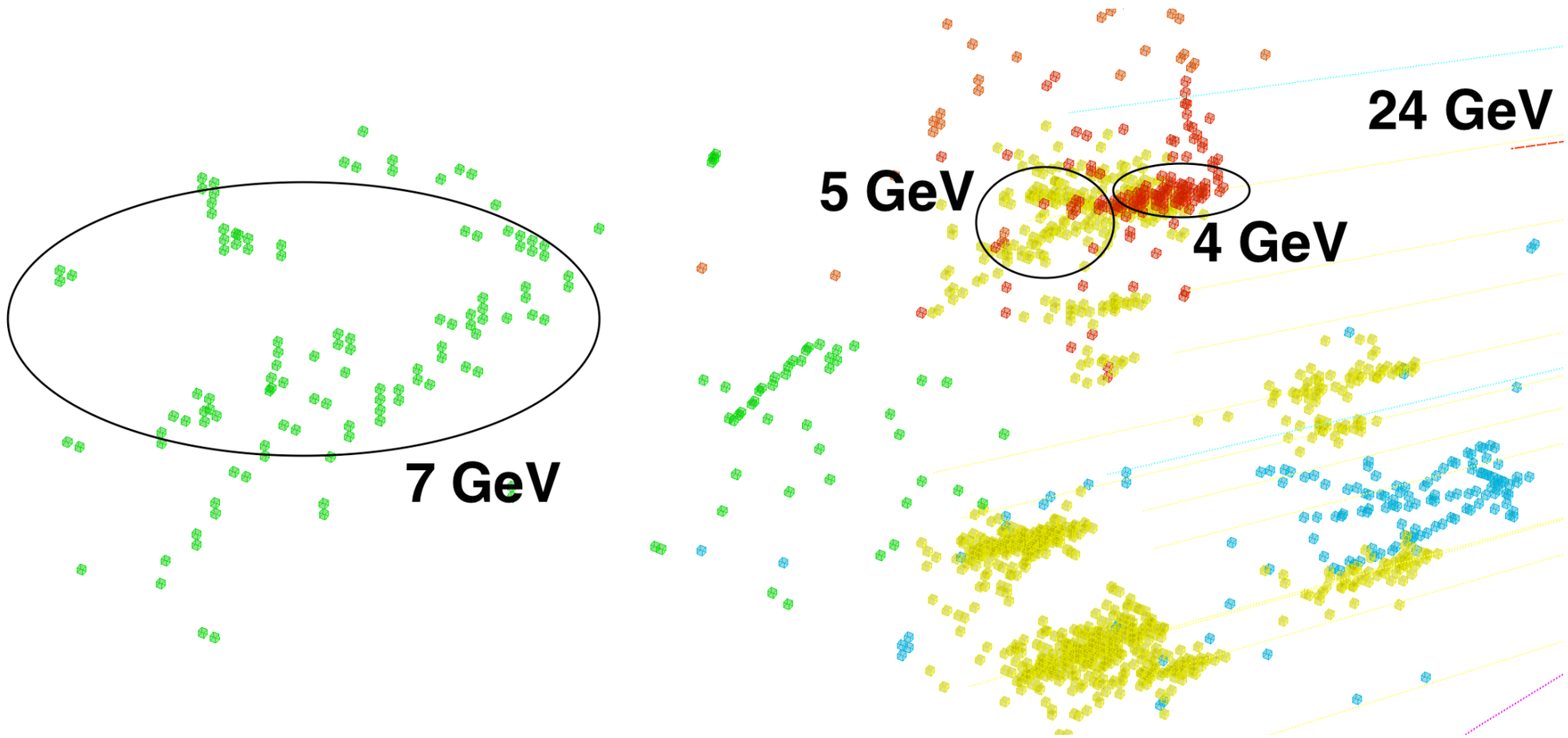
- Performances of ArborPFA
  - non-linearity: 1 ~ 2%
  - JER: 5~7%



- To make ArborPFA useful for ILC, we must improve the energy resolution.
- But how ?

Reclustering for missing energy

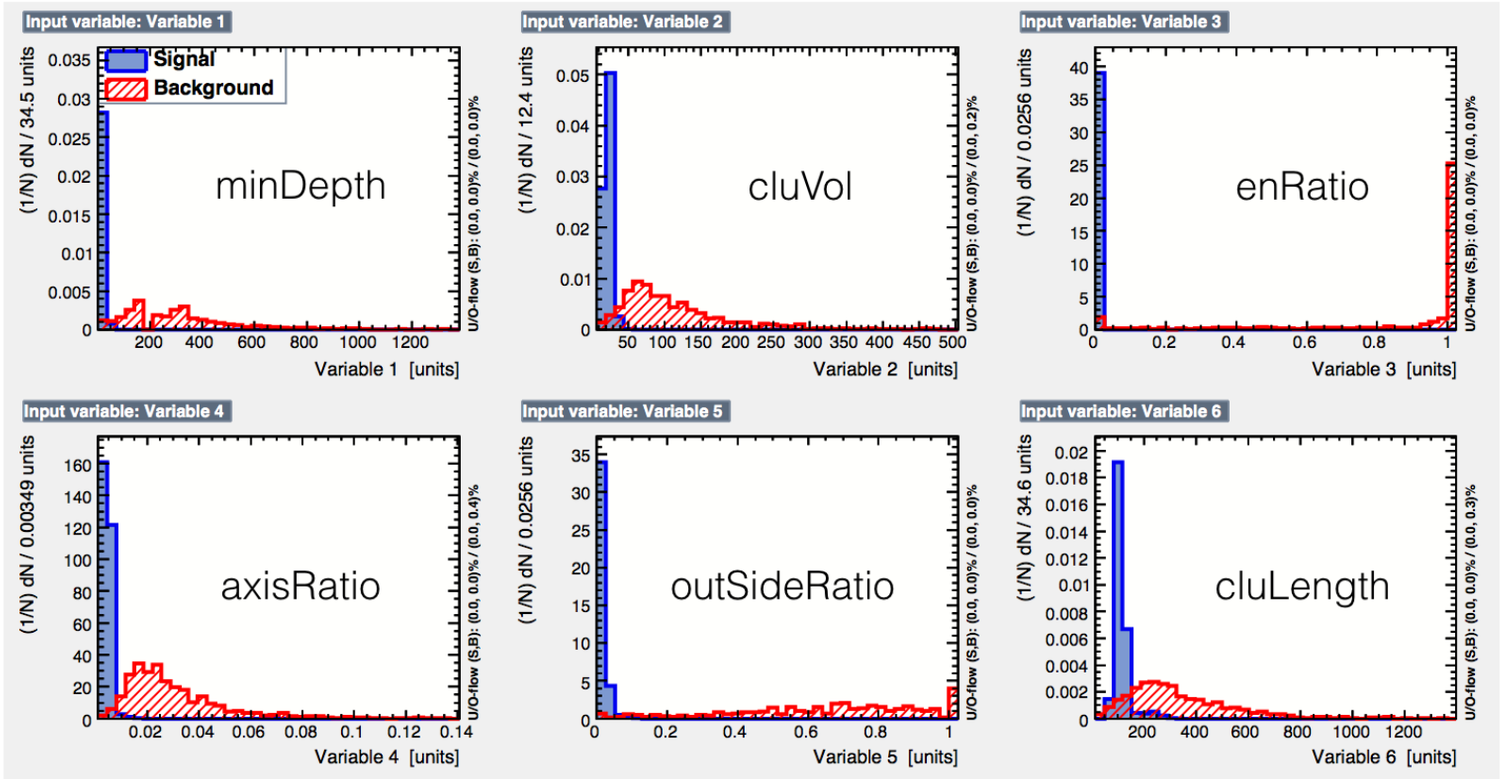
Maybe we can have a look at an event display…



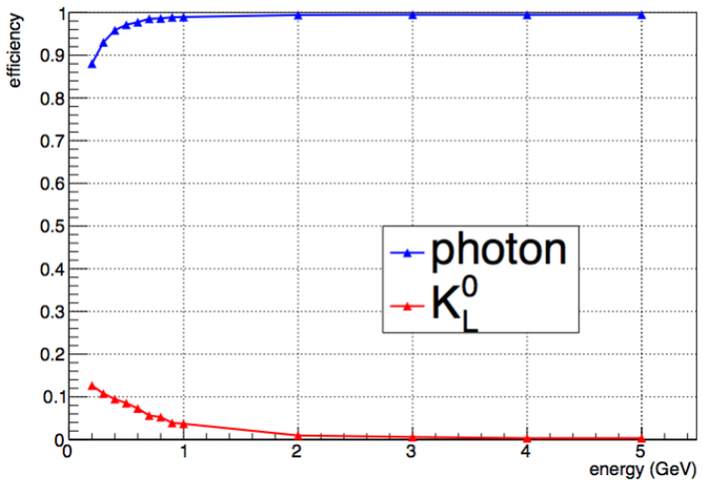
- The photon cluster maybe should also be considered in the reclustering.
- It will be safe if we have a sophisticated cluster identification function.
- The reclustering process will go until no neutral cluster can be merged into the original cluster.

Neutral cluster identification

- The distribution of cluster property variables at 2 GeV

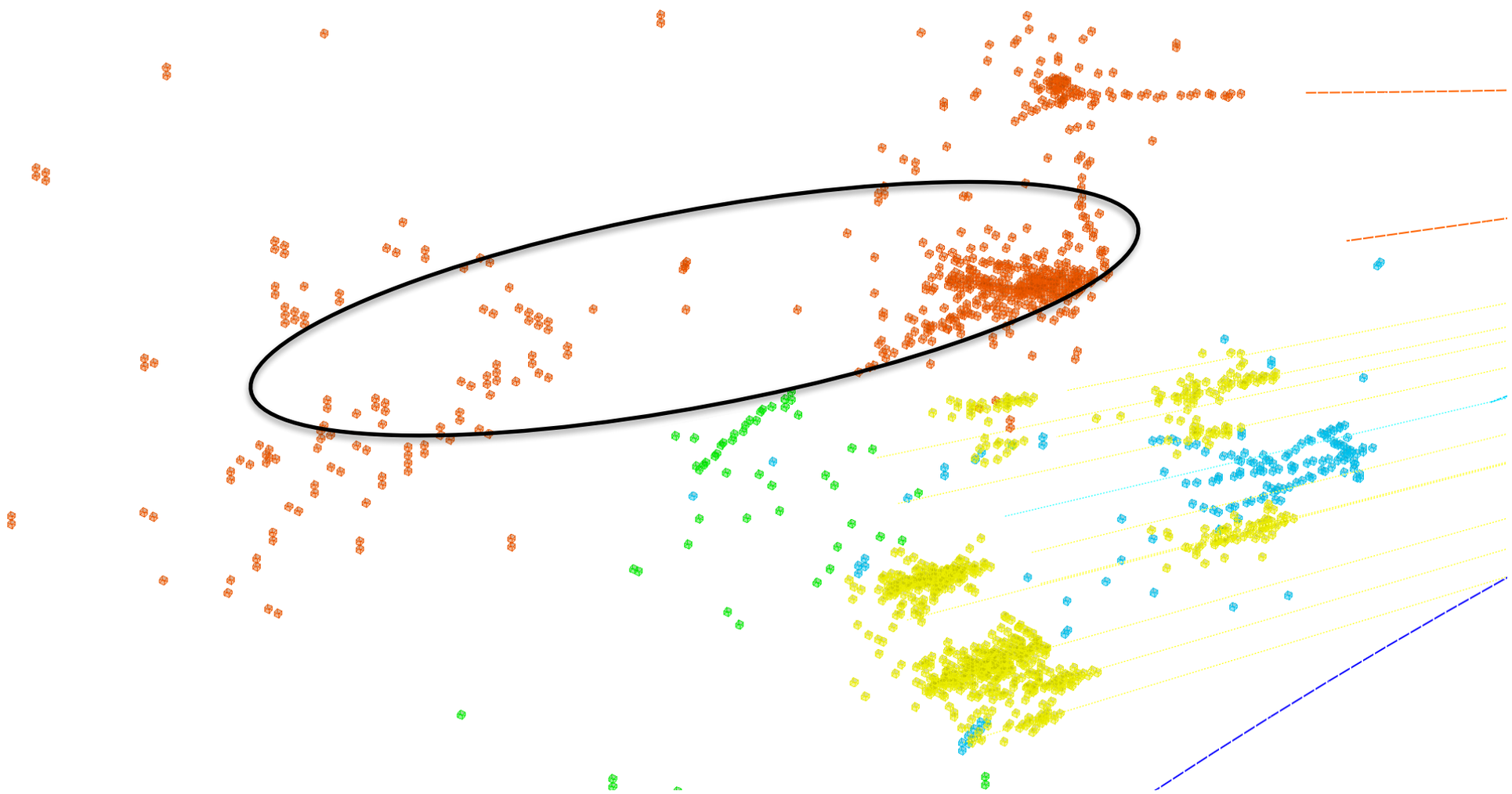


- The photon efficiency of identification for photon cluster and neutral hadronic cluster



BDT based photon identification function

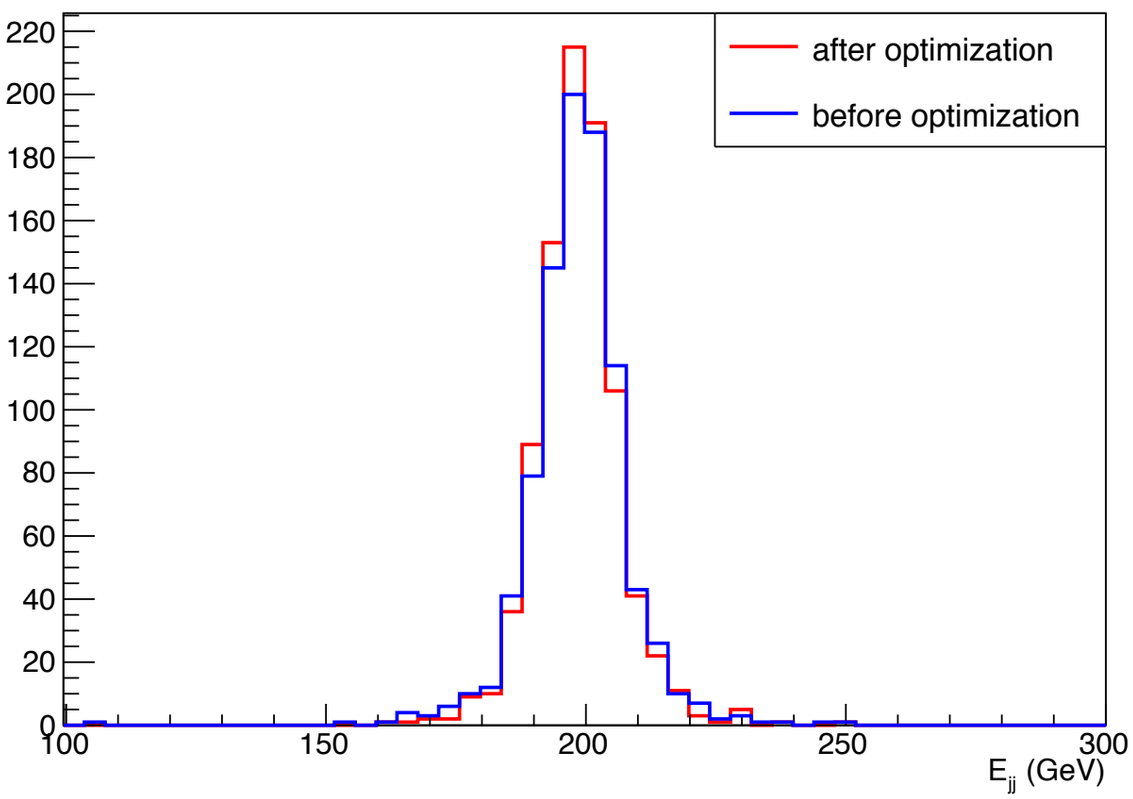
After correction

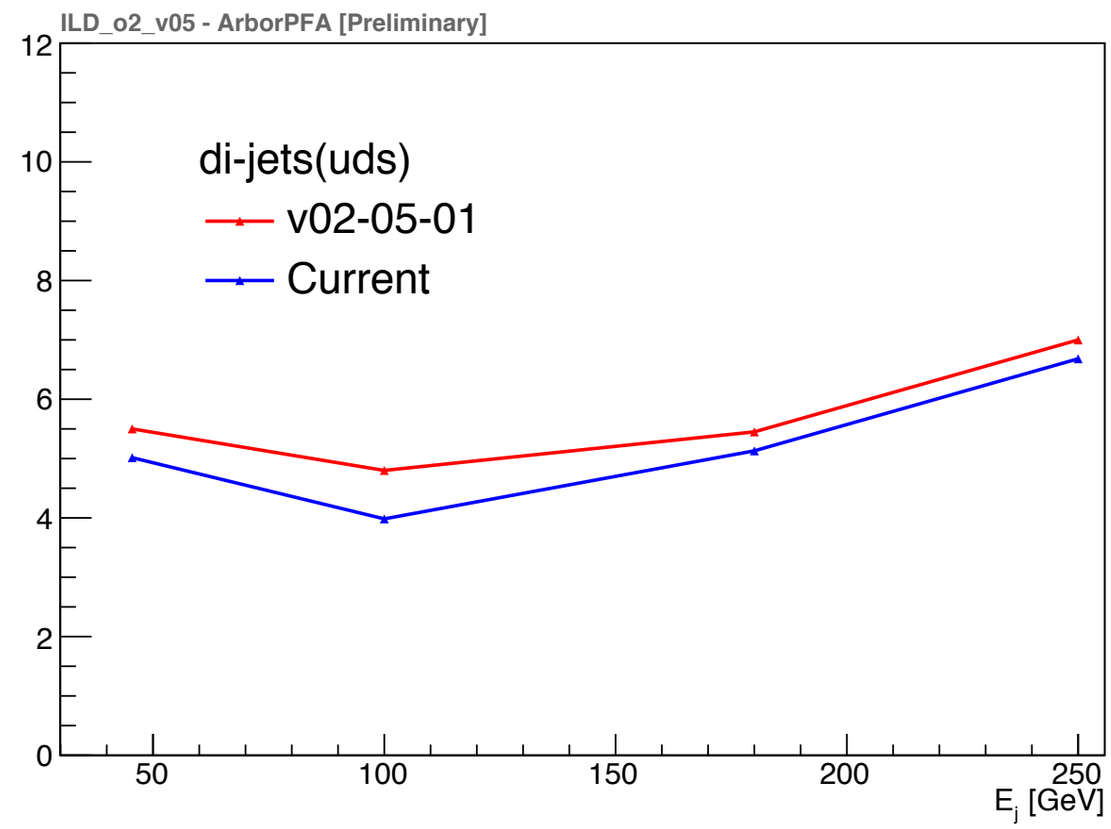


- Reclustering of energy excessing also have similar issues. The main problem for jet energy resolution is on reclustering.

Current performance

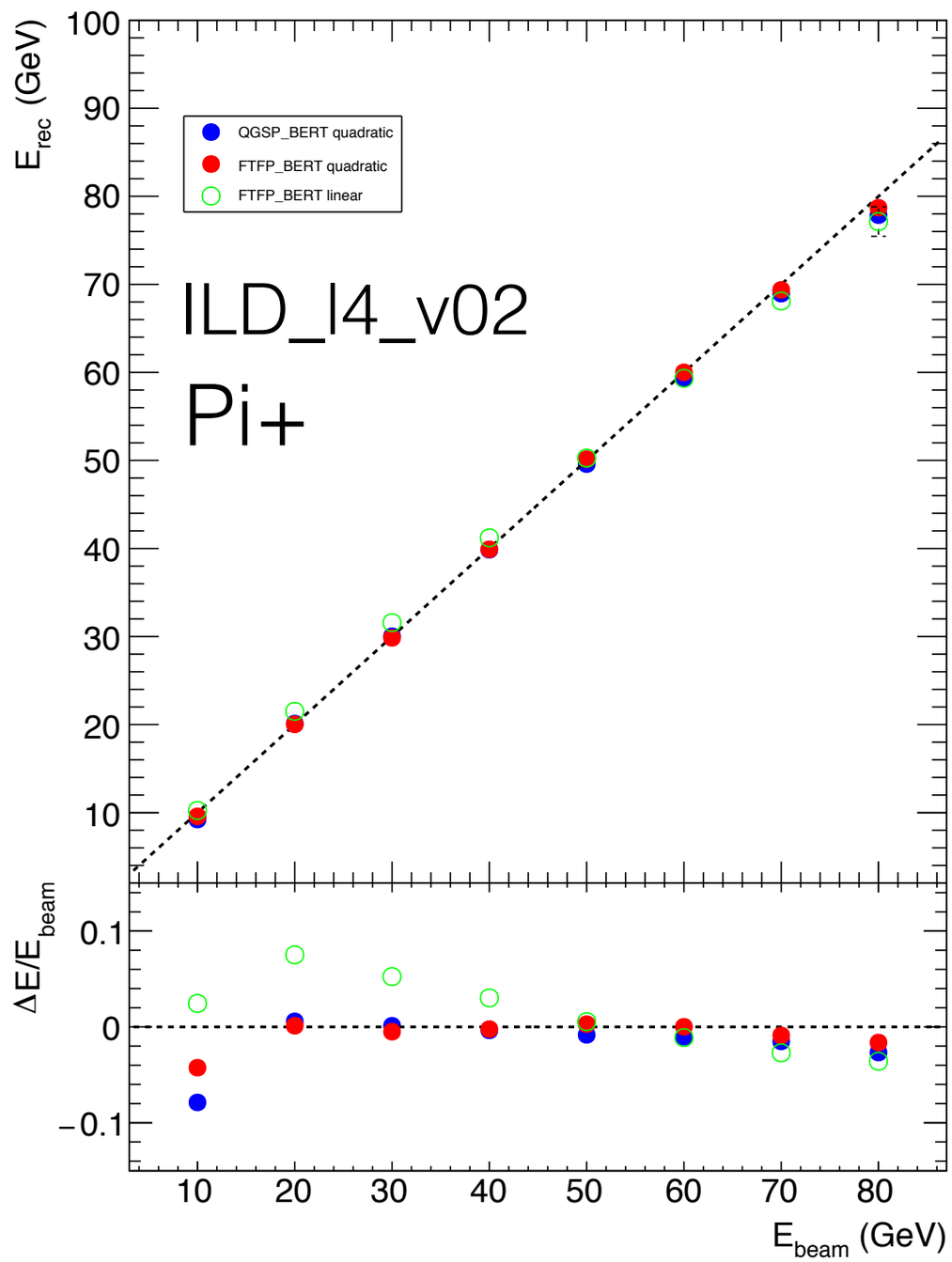
- Problematic events (not all of them) have been fixed at 200 GeV





- The improvement in total energy range is still not enough, however,
  - JER at 200 GeV is close to the requirement at ILC.
  - The direction to optimize code seems reasonable.

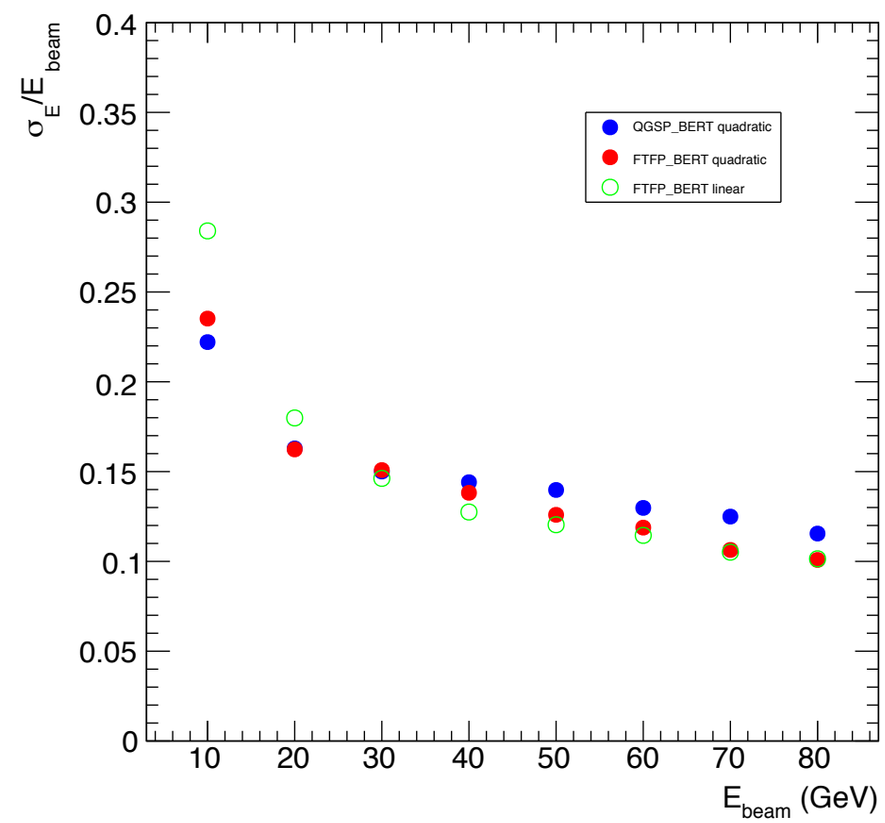
Energy reconstruction



- The energy formulae of shower in SDHCAL

$$E_{\text{lin}} = \alpha N_1 + \beta N_2 + \gamma N_3$$

$$\begin{aligned} E_{\text{quad}} = &(\alpha_1 + \alpha_2 N_{tot} + \alpha_3 N_{tot}^2) N_1 \\ &+ (\beta_1 + \beta_2 N_{tot} + \beta_3 N_{tot}^2) N_2 \\ &+ (\gamma_1 + \gamma_2 N_{tot} + \gamma_3 N_{tot}^2) N_3 \end{aligned}$$



- To apply the quadratic formula in PFA, we also need to investigate the performance for
  - nearby showers
  - shower in ECAL + HCAL

Conclusion

- ArborPFA is created for the studies on prototype and ILD.
- The performance on jet energy resolution is improved, but we have still lots of issues to check and fix.
- ArborPFA is maintainable
  - using nice framework
  - code in high quality

Thanks for your attention!