The status of Particle Flow Algorithm in IPNL

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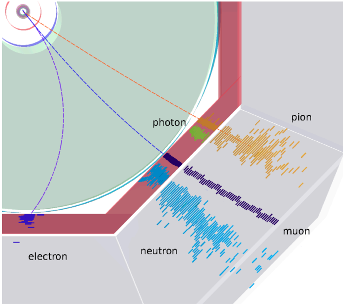
Outline

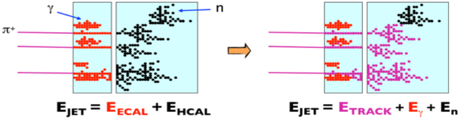
1. Introduction: PFA and ILD
2. The particle flow algorithm
3. Summary

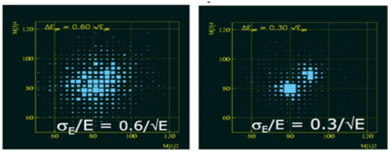
Outline

Particle flow calorimetry

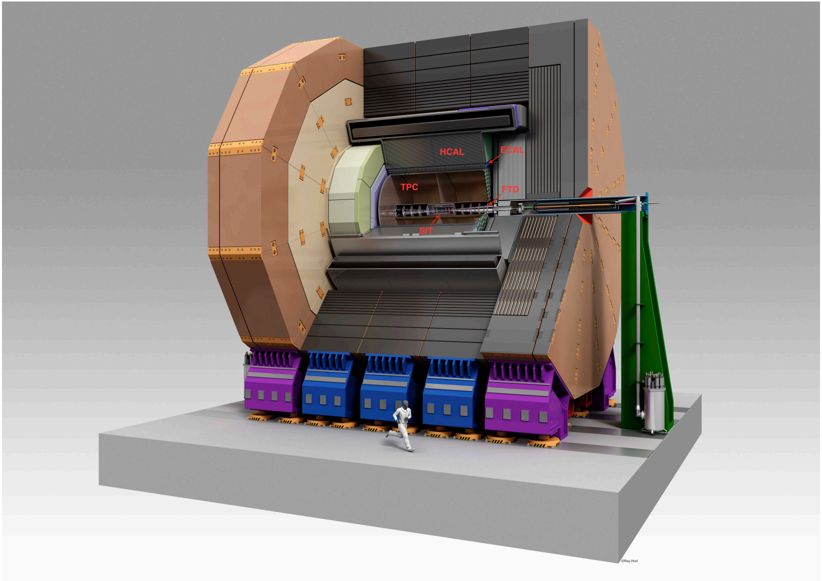
- Particle flow calorimetry: attempt to reconstruct visible final state particles from the information recorded by detector.
- Jet energy resolution at ILC: $\sigma_E/E = 3 \sim 4\%$ in the energy range from 50 to 500 GeV [1].
- Algorithms: Pandora [2], Arbor [3], Garlic [4].







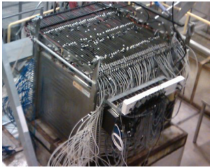
International Large Detector [5]

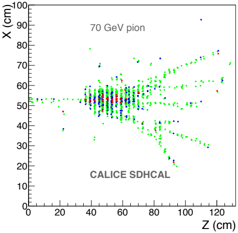


Semi-Digital HCAL

Two high granularity HCAL options at ILD

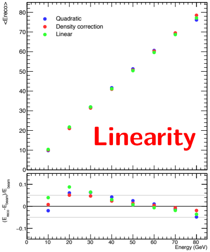
- Analog HCAL (AHCAL)
- Semi-Digital HCAL (SDHCAL [6])

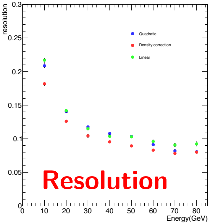




SDHCAL prototype

- 48 layers, $6\lambda_I$
- GRPC $(1 \times 1m^2)$
- Pad: $1 \times 1\ \mathrm{cm}^2$
- Thresholds(pC): 0.11, 5, 15
- Power-pulsing
- Self-supporting structure.



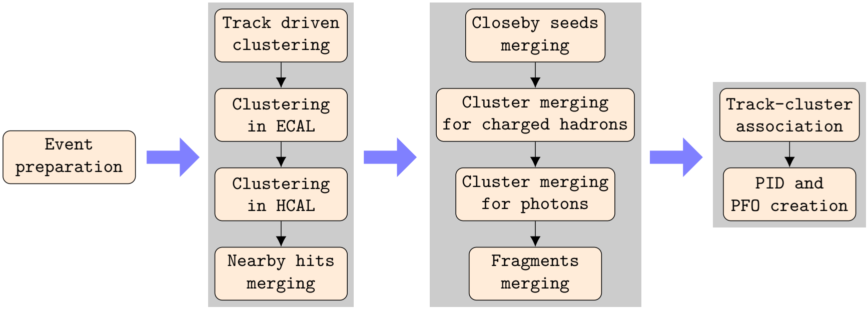


Outline

Design of algorithm

Jet composition

- Charged particles: $\sim 60\%$
- Photons: $\sim 30\%$
- Neutral hadrons: $\sim 10\%$



Clustering

- Arbor [3] : use it as the algorithm for clustering the hits in calorimeter with tree topology.
- Nearby hits are linked by *connector*. The nearby hits are searched by the NeighborSearch (and NearbySearch) in mlpack [7].
- *Reference direction*

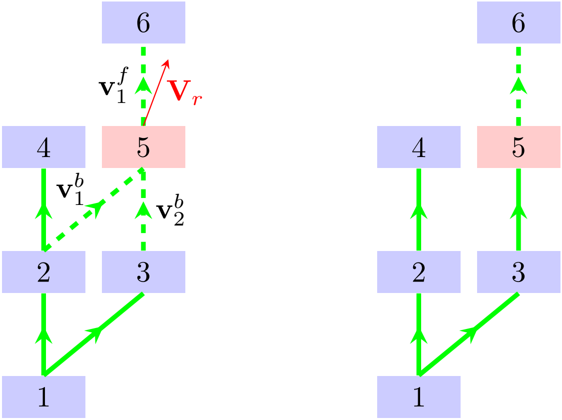
$$\mathbf{V}_r = w_b \times \sum_i \mathbf{v}_i^b + w_f \times \sum_j \mathbf{v}_j^f \tag{1}$$

- *Connector order*

$$\kappa = \theta^{p_\theta} \times d^{p_d} \tag{2}$$

- Ambiguity: connector order at small angle, e.g., $\theta = 0$.
- Hits which are not clustered are dealt with by DBCAN in mlpack.
- To restrain the error in clustering, the parameters are set to avoid forming big clusters.

Clustering (continued)



(a) Reference direction (b) After clean

Cluster merging

- For cluster merging, the geometrical properties of cluster are utilized; The **order of cluster connection** can be define by such variables:
  - Distances: COG distance, closest distance approach;
  - Angles: cluster axis, direction between clusters.
- The energy criteria for cluster merging
  - $\chi = (E_c - p_t)/\sigma_{E_c}$
  - σ_{E_c}
    - ★ ECAL: $0.15/\sqrt{E_c}$ for photons.
    - ★ HCAL: $0.55/\sqrt{E_c}$ for hadrons.
  - ECAL energy resolution for hadrons ?
- Cluster merging is under optimisation.

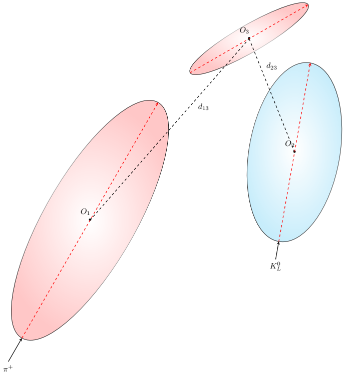


Figure: Merging between charged and neutral cluster.

Distance of clusters axes

- Cluster axis is computed by PCA (Principal Component Analysis).
- Distance: In 3D space, the axes of two clusters can be reprented by

$$\boldsymbol{y}_i = \boldsymbol{x}_i + \lambda_i \boldsymbol{b}_i \tag{3}$$

where $i = 1, 2$. The distance of the two lines is given by

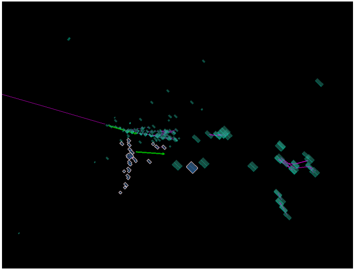
$$d = |\boldsymbol{n} \cdot (\boldsymbol{x}_2 - \boldsymbol{x}_1)|, \boldsymbol{n} = \frac{\boldsymbol{b}_1 \times \boldsymbol{b}_2}{|\boldsymbol{b}_1 \times \boldsymbol{b}_2|} \tag{4}$$

The nearest point to axis 2 on axis 1 is given by

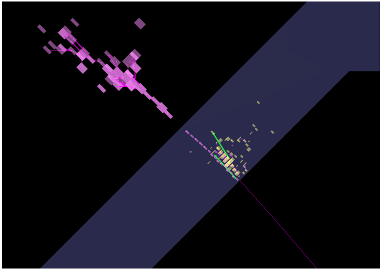
$$\boldsymbol{p}_1 = \boldsymbol{x}_1 + \frac{(\boldsymbol{x}_2 - \boldsymbol{x}_1) \cdot \boldsymbol{n}_2}{\boldsymbol{d}_1 \cdot \boldsymbol{n}_2} \boldsymbol{d}_1 \tag{5}$$

in which, $\boldsymbol{n}_2 = \boldsymbol{d}_1 \times (\boldsymbol{d}_2 \times \boldsymbol{d}_1)$ To compute the nearest point on the line 2, just exchange the index 1 and 2 in Eq.(5).

Current issues in cluster merging



(a) Axis issue



(b) PID issue

- To improve the axis computation, we can re-connect the hits of a cluster.
- Further, it seems that a lot of small charged segments ($\lesssim 1$GeV) are not merged to the main clusters, probaly due to axis computation issue. For small segment, its axis is not well defined.

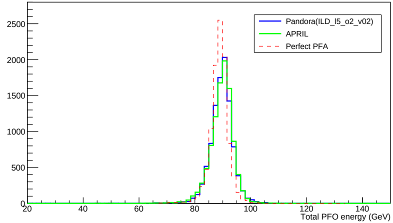
PFO creation

- Track-cluster assocaition: position, direction and energy are considered.
- PID
    - γ, $\pi^{\pm}$, neutal hadron
    - Shower profile, energy deposition and track information are used.

Figure: The reconstructed PFOs in an event.

Results

- JER ($\frac{\text{RMS}_{90}(\text{E}_j)}{\text{Mean}_{90}(\text{E}_j)}$, $|\cos\theta_q| < 0.7$) at 91.2 GeV: 4.2%; RMS: 4.24 GeV.
- Pandora: 4.1%; Perfect PFA: 3.25%



- Error estimation

stage	error contribution
Clustering	$\sim$ 0.05%
Nearby hits merging	$\sim$ 0.15%
Cluster merging	$\sim$ 0.50%
Track-cluster association and PFO creation	$\sim$ 0.30%

The code

- Algorithms developed by using the PandoraSDK [8]
  - Multi-algorithm approach
  - Objects: track, hit, cluster, PFO
- ILCSoft (https://github.com/iLCSoft)
  - Marlin [9]
  - Tracking
  - Calorimeter digitizers (SimDigital for SDHCAL)
  - Geometry: ILD detector mode implemented by lcgeo, which is based on DD4hep [10]
  - LCCalibration: automated energy calibration for calorimeters at ILC (https://github.com/iLCSoft/LCCalibration).
- mlpack [7]: NeighborSearch, DBSCAN.

→ For the *Algorithm of Particle Reconstruction at ILC developed in Lyon*, we'd like to name it **APRIL.**

Outline

Summary

- A particle flow algorithm is deveoped in the framework of up-to-date ILCSoft.
- The current result is quite close to our expectation.
- We proposed a cluster merging approach by constructing the cluster connection order from the computation of cluster geometrical properties.
- Plans
  - For higher energy: reclustering.
  - A little bit far future: machine learning for PFA.

References I

[1] J. S. Marshall and M. A. Thomson.
Pandora Particle Flow Algorithm.
In *Proceedings, International Conference on Calorimetry for the High Energy Frontier (CHEF 2013): Paris, France, April 22-25, 2013*, pages 305–315, 2013.

[2] M. A. Thomson.
Particle Flow Calorimetry and the PandoraPFA Algorithm.
Nucl. Instrum. Meth., A611:25–40, 2009.

[3] Manqi Ruan and Henri Videau.
Arbor, a new approach of the Particle Flow Algorithm.
In *Proceedings, International Conference on Calorimetry for the High Energy Frontier (CHEF 2013): Paris, France, April 22-25, 2013*, pages 316–324, 2013.

References II

[4] D. Jeans, J. C. Brient, and M. Reinhard.
GARLIC: GAmma Reconstruction at a LInear Collider experiment.
JINST, 7:P06003, 2012.

[5] Halina Abramowicz et al.
The International Linear Collider Technical Design Report - Volume 4: Detectors.
2013.

[6] V. Buridon et al.
First results of the CALICE SDHCAL technological prototype.
JINST, 11(04):P04001, 2016.

[7] Ryan R. Curtin, Marcus Edel, Mikhail Lozhnikov, Yannis Mentekidis, Sumedh Ghaisas, and Shangtong Zhang.
mlpack 3: a fast, flexible machine learning library.
Journal of Open Source Software, 3:726, 2018.

References III

[8] J. S. Marshall and M. A. Thomson.
The Pandora Software Development Kit for Pattern Recognition.
Eur. Phys. J., C75(9):439, 2015.

[9] F. Gaede.
Marlin and LCCD: Software tools for the ILC.
Nucl. Instrum. Meth., A559:177–180, 2006.

[10] Markus Frank, F. Gaede, C. Grefe, and P. Mato.
DD4hep: A Detector Description Toolkit for High Energy Physics Experiments.
J. Phys. Conf. Ser., 513:022010, 2014.