The Progress of Particle Flow Algorithm in IPNL

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Outline

1. Introduction: PFA and ILD
2. The particle flow algorithm
3. Summary
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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 ($1 \times 1 m^2$)
- Pad: $1 \times 1$ cm$^2$
- Thresholds(pC): 0.11, 5, 15
- Power-pulsing
- Self-supporting structure.
Outline

1 Introduction: PFA and ILD

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Design of algorithm

Jet composition

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

Event preparation
Track driven clustering
Clustering in ECAL
Clustering in HCAL
Nearby hits merging
Closeby seeds merging
Cluster merging for charged hadrons
Cluster merging for photons
Fragments merging
Track-cluster association
PID and PFO creation
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

\[ \mathbf{V}_r = w_b \times \sum_i \mathbf{v}_i^b + w_f \times \sum_j \mathbf{v}_j^f \]  

(1)

- Connector order

\[ \kappa = \theta^p \times d^p \]  

(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
  - $\chi = (E_c - p_t)/\sigma_{E_c}$
  - $\sigma_{E_c}$
    - ECAL: $0.15/\sqrt{E_c}$ for photons.
    - HCAL: $0.55/\sqrt{E_c}$ for hadrons.
  - ECAL energy resolution for hadrons?

Figure: Merging between charged and neutral cluster.
PFO creation

- **Track-cluster association**: position, direction and energy are considered.
- **PID**
  - $\gamma$, $\pi^\pm$, neutral hadron
  - Shower profile, energy deposition and track information are used.

**Figure**: The reconstructed PFOs in an event.
Results

- JER \( \left( \frac{\text{RMS}_{90}(E_j)}{\text{Mean}_{90}(E_j)} \right), |\cos \theta_q| < 0.7 \) at 91.2 GeV: 4.3%; RMS: 4.28 GeV.
- Pandora: 4.1%; Perfect PFA: 3.25%

![Graph showing distribution of Total PFO energy (GeV) with different algorithms.]

- Error estimation

<table>
<thead>
<tr>
<th>stage</th>
<th>error contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clustering</td>
<td>( \sim 0.05% )</td>
</tr>
<tr>
<td>Nearby hits merging</td>
<td>( \sim 0.15% )</td>
</tr>
<tr>
<td>Cluster merging</td>
<td>( \sim 0.50% )</td>
</tr>
<tr>
<td>Track-cluster association and PFO creation</td>
<td>( \sim 0.30% )</td>
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</tbody>
</table>
 Dependencies

- 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]
- mlpack [7]: NeighborSearch, DBSCAN.
It’s April

“名不正，则言不顺”.

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

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1From the Analects.
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Summary

- A particle flow algorithm is developed 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

- Optimization of cluster merging.
- For higher energy: reclustering.
- A little bit far future: machine learning for PFA.
References

Pandora Particle Flow Algorithm. 

Particle Flow Calorimetry and the PandoraPFA Algorithm. 

Arbor, a new approach of the Particle Flow Algorithm. 
References II

GARLIC: GAmma Reconstruction at a LLinear Collider experiment. 

2013.

First results of the CALICE SDHCAL technological prototype. 

mlpack 3: a fast, flexible machine learning library. 
The Pandora Software Development Kit for Pattern Recognition.  

Marlin and LCCD: Software tools for the ILC.  

DD4hep: A Detector Description Toolkit for High Energy Physics Experiments.  
Thanks for your attention.