# Development of ILC shower clustering algorithm using GNN

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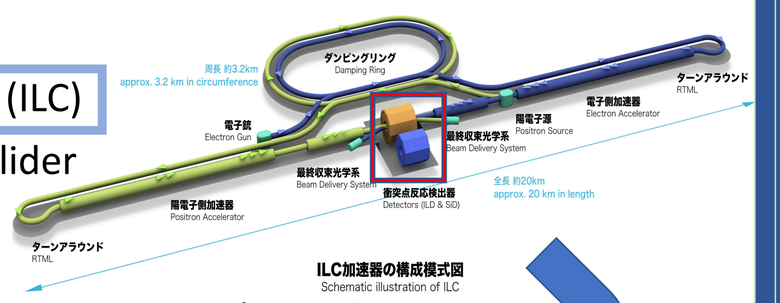
## 1. Introduction

### International Linear Collider (ILC)




ILC加速器の構成模式図
Schematic illustration of ILC

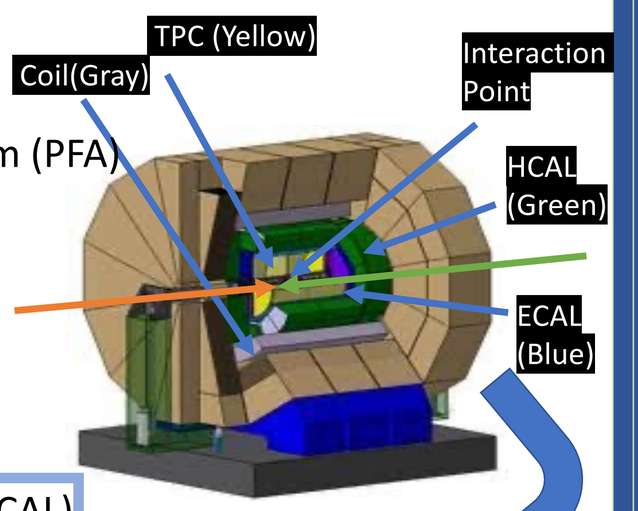
**Feature**：$e^+ e^-$ Linear Collider

**Construction Site**：
Japan, Iwate Prefecture

**Center-of-mass Energy:** 250 GeV - more than 1 TeV

**Main Purpose**：
Precise Measurement of the Higgs Boson
Search of Beyond Standard Model

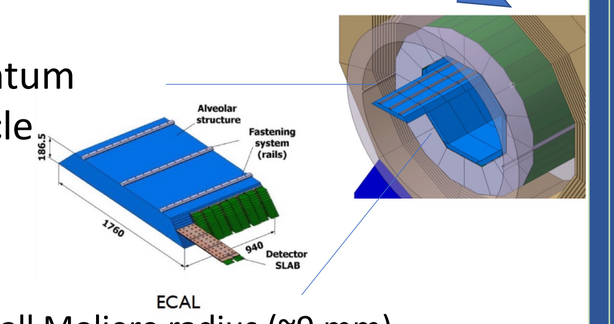
### International Large Detector (ILD)




**Feature:**
Optimized for Particle Flow Algorithm (PFA)

**Components:**
Vertex Detector
Time Projection Chamber (TPC)
Electromagnetic Calorimeter (ECAL)
Hadron Calorimeter (HCAL) etc.

### SiW Electromagnetic Calorimeter (ECAL)



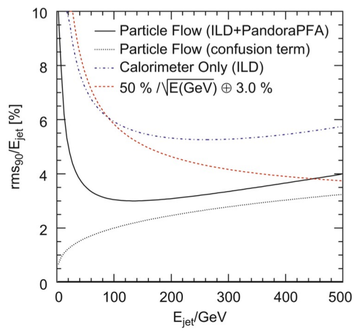

**Purpose**：
Detecting position / energy / momentum of the photon and the charged particle with high granularity
→ Important for PFA

**Components:**
- Tungsten (30 layers / 24 $X_0$ in total ) : Small Moliere radius (~9 mm)
- Silicon sensor (320 um – 500 um thick / 5×5 $mm^2$)

### Particle Flow Algorithm (PFA)

Improving the jet energy resolution by detecting the photon / charged particle / neutral hadron separately

**Charged Particle** : Tracker
**Photon** : ECAL
**Neutral Hadron**：HCAL
→ Separation of particles with high accuracy is essential



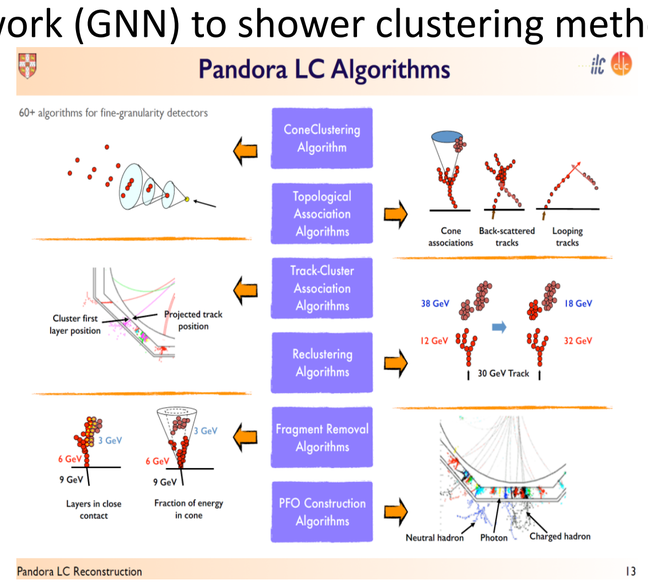

Figure：
Comparison of performance of jet energy resolution with PFA

## 2.Application of DNN for Particle Flow Algorithm

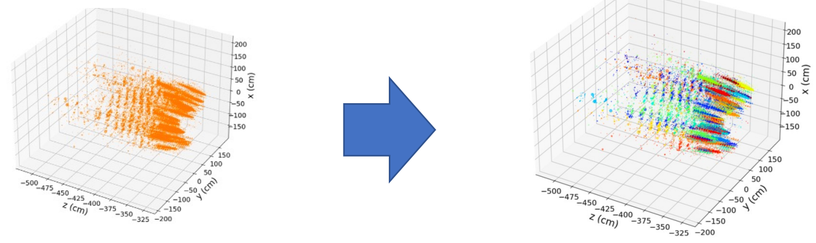
### Current PFA algorithm

**Pandora PFA**
→ Method of cutting by manually set threshold
Further improvement by replacing for Deep Neural Network

This Study :
Apply Graph Neural Network (GNN) to shower clustering method

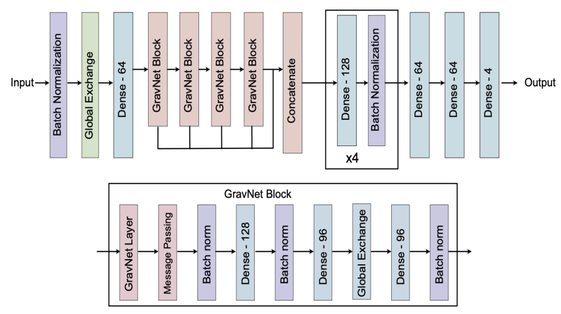



### Shower Clustering

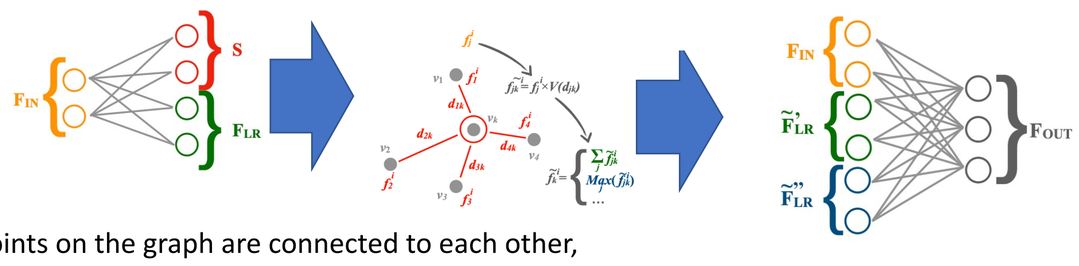


Input: feature values of hits in the calorimeter
e.g., position, energy etc.
Output: $\beta$ (likeliness of a condensation point) /
Coordinates representing distance from condensation points per each hit

Deep Learning Architecture
Mainly consists of GravNet Block



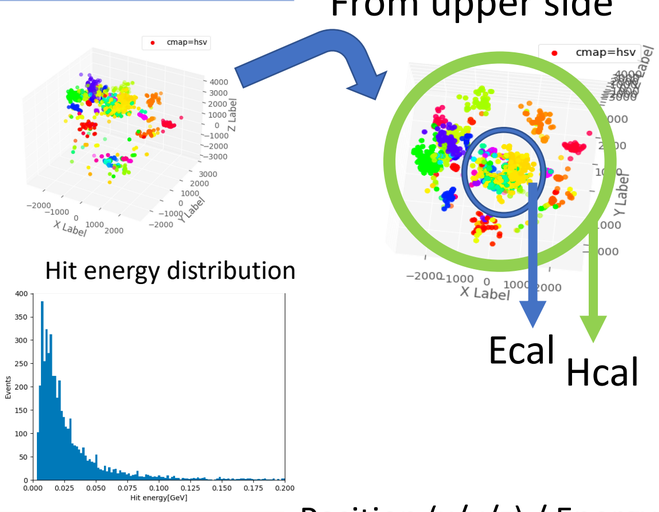

### GravNet Layer




Points on the graph are connected to each other,
and points connected close together have a large influence on each other.
The contributions of connected features are calculated at each node
The output contains information on the characteristics of each vertex and its surrounding points in the graph.

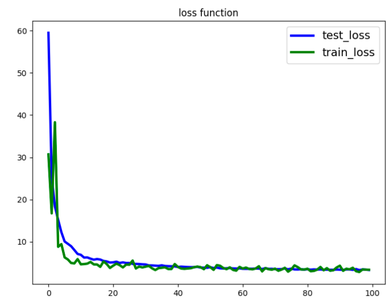
## 3.Performance Evaluation

### Simulation Data



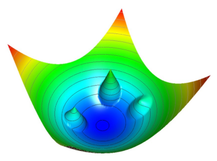

**Input parameter**
Position (x/y/z) / Energy deposit
→ Normalized between [-1,1]
1600 events

### Results




Loss functions of both training and testing data are decreasing
→ Learning works correctly.

### Object Condensation (Loss function)



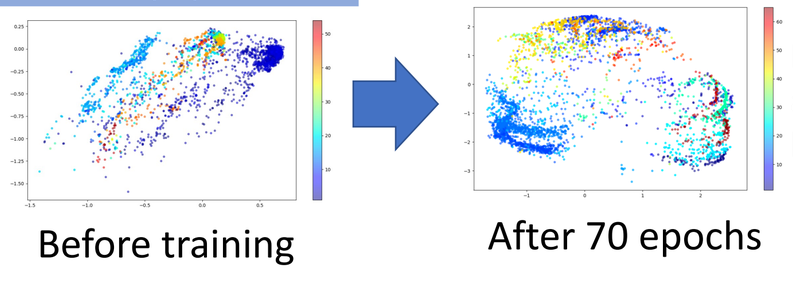
Get the output of the network as $\beta$ ($0 < \beta < 1$)

$$L = L_V + L_\beta$$

$L_V$ : minimizing distance to condensation point of the same true cluster and maximizing distances to other condensation points

$L_\beta$ : $\beta$ converges to 1 for each particle, only one corresponding to a true cluster

### Representation Space (2D)



Before training

After 70 epochs

Easily identifiable clusters are separated,
but many clusters are mixed

## Summary

- Application of Graph Neural Networks for shower clustering
- Confirming the decrease of the loss function
- Need to develop how to evaluate the network