Progress of Reconstruction for Long Crystal Bar ECAL

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on behalf of CEPC ECAL software group

CEPC Physics and Detector Plenary Meeting

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Outline

Introduction

Long crystal bar electromagnetic calorimeter

Update of clustering algorithm

Update of photon recognition

Summary and plan

Introduction

Physics motivations of CEPC:

- precise Higgs and EW measurement
- flavor physics and BSM

In a typical jet:

- 60% of jet energy in charged particles
- 30% in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)
- 10% in neutral hadrons (mainly n and K_L)

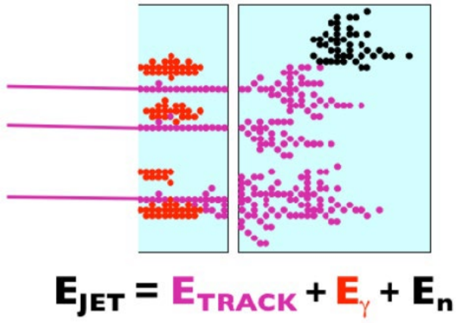
Reconstruction of each individual particle in the jet:

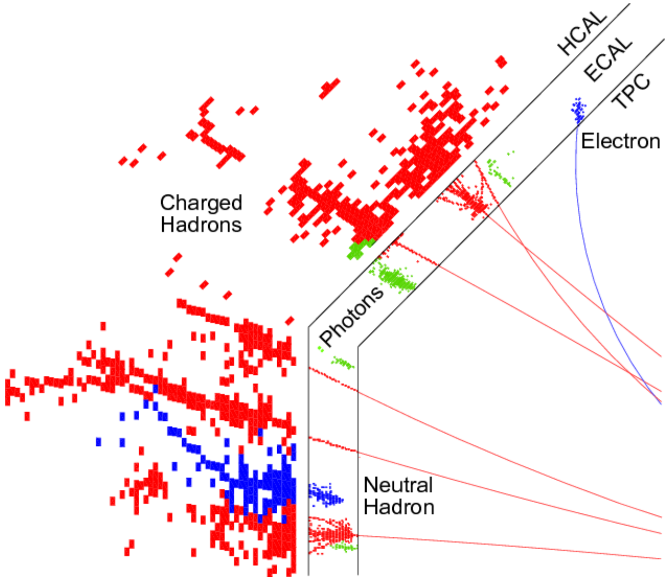
- Charged particle momentum measured in tracker.
- Photon energies measured in ECAL.
- Neutral hadron energies measured in HCAL.

Confusion is the limiting factor in PFA:

- Avoid double counting of same particle
- Separate energy from different particles

Component	Detector	Energy Fraction	Energy Resolution	Jet Energy Resolution
Charged Particles ($X^{\pm}$)	Tracker	$\sim 0.6\ E_J$	—	—
Photons (γ)	ECAL	$\sim 0.3\ E_J$	$\mathbf{0.15}\sqrt{E_\gamma}$	$\mathbf{0.08}\sqrt{E_J}$
			$\mathbf{0.03}\sqrt{E_\gamma}$	$\mathbf{0.016}\sqrt{E_J}$
Neutral Hadrons (h^0)	HCAL	$\sim 0.1\ E_J$	$0.55\sqrt{E_{h^0}}$	$0.17\sqrt{E_J}$

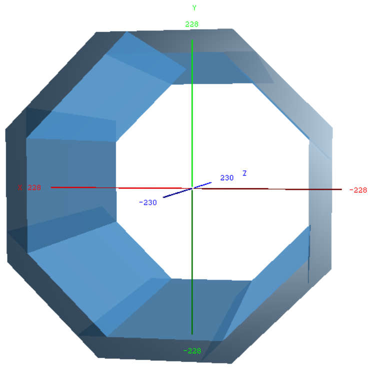


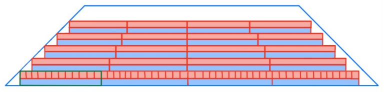


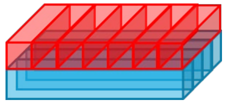
$$\sigma_{Jet} = \sqrt{\sigma_{Track}^2 + \sigma_{EM}^2 + \sigma_{Had}^2 + \sigma_{Confusion}^2}$$

Long crystal bar electromagnetic calorimeter

Long crystal bar electromagnetic calorimeter detector design:







- ✓ optimal energy resolution $\frac{3\%}{\sqrt{E}} \oplus 1\%$, better γ/π^0 reconstruction
- ✓ Significant reduction of number readout channels (15%)
- ➢ larger R_m → increase probability of showers' overlap
- ➢ smaller λ_I/X_0 → increase probability of hadronic shower

Material	X_0 /cm	R_M /cm	λ_I /cm	λ_I/X_0
W	**0.35**	**0.93**	**9.6**	**27.4**
BGO	**1.12**	**2.23**	**22.8**	**20.3**
Ratio	3.2	2.4	2.4	0.74

Key issues for reconstruction algorithm:

- ✓ Ambiguity caused by matching of horizontal and vertical bars.
- ✓ Identification of energy deposits from each individual particle.

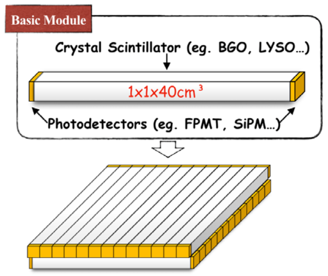
Detector description and digitization

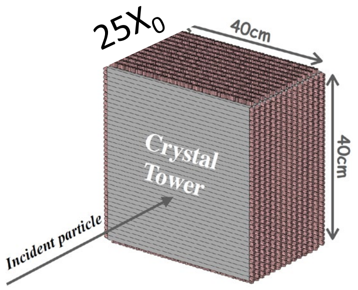
A BGO crystal barrel ECAL:

Crystal Bar: $1 \times 1 \times 40{\sim}60\ cm^3$

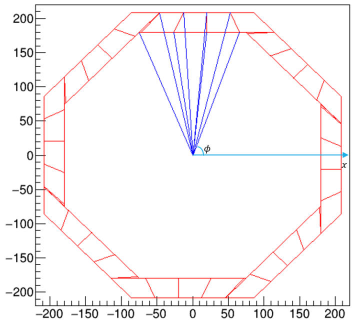
Super Cell: 2 layers of perpendicularly crossing bars $\sim 40 \times \sim 60 \times 2\ cm^3$

Detector: $R = 1.9m$, $L = 6.6m$, $H = 28cm$, 8 same trapezoidal staves, avoid gaps point to IP





Focusing on software performance, ignoring dead area, supporting and cooling mechanics, etc



Simulation is performed using GEANT4: electromagnetic and hadronic interactions

Simplified digitization for one long crystal bar:

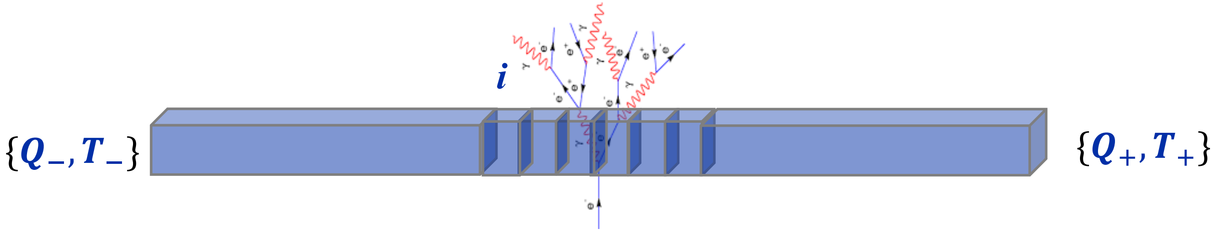
Contribution of each G4step $\boldsymbol{i}$

$$Q_{\pm}^{i} = E_0 \cdot e^{-\frac{L/2 \pm z_i}{L_{Atten}}}, \qquad T_{\pm}^{i} = T_0 + Gaus(z_{\pm}^{i}/v,\ \sigma_T)$$

Readout at both ends: $\boldsymbol{Q}_{\pm}$ and $\boldsymbol{T}_{\pm}$

$$\boldsymbol{Q}_{\pm} = \sum_{step} Q_{\pm}^{i},\ \boldsymbol{T}_{\pm} = T_{\pm}^{k} \mid \left(\sum_{i=1}^{k} Q_{\pm}^{i} > thres\right)$$

Simplified Conditions: $L_{Atten} = \infty$

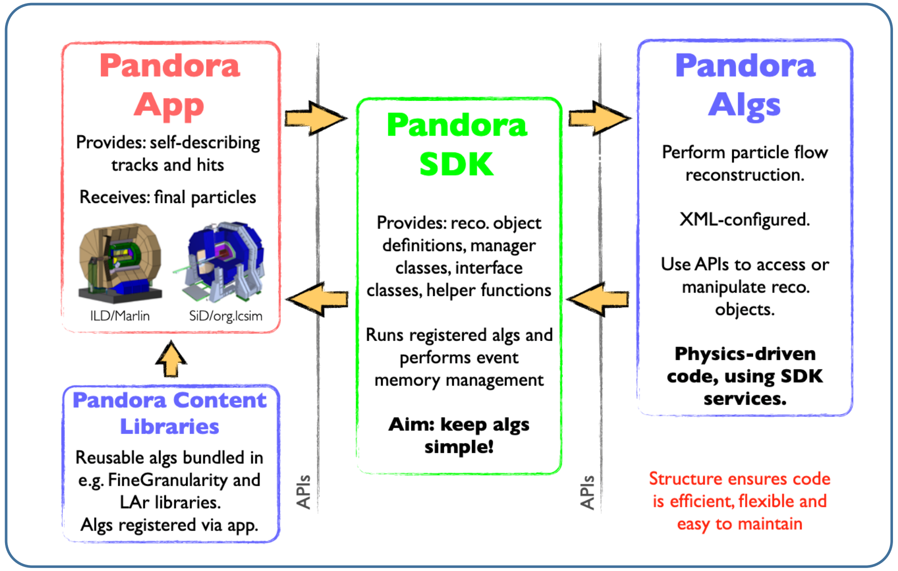


Reconstruction software

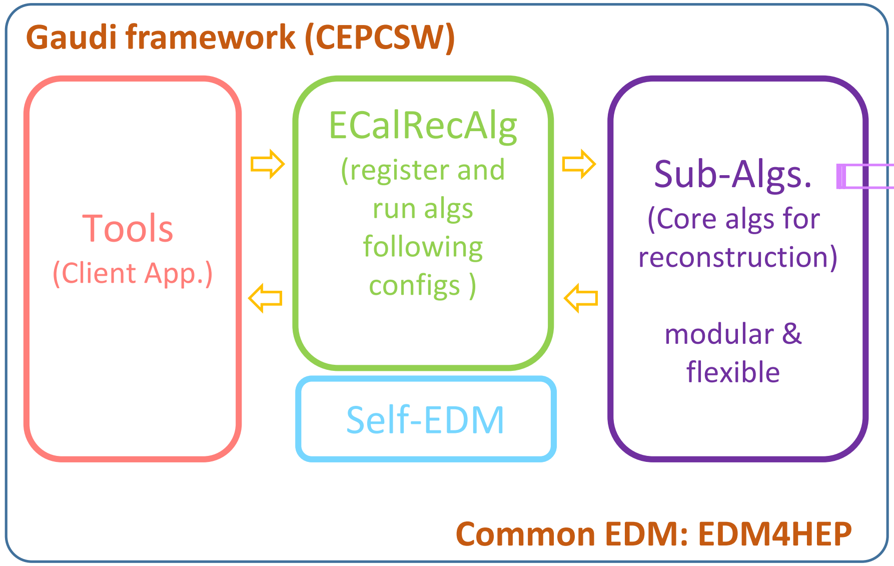
Design the reconstruction software as a proto-PFA:

✓Follow the idea of PandoraSDK: flexible, reusable, modularization (*Many thanks!*)

✓Develop in CEPCSW: based on the common HEP software stack Key4HEP.



J.S.Marshall, CHEF 2013



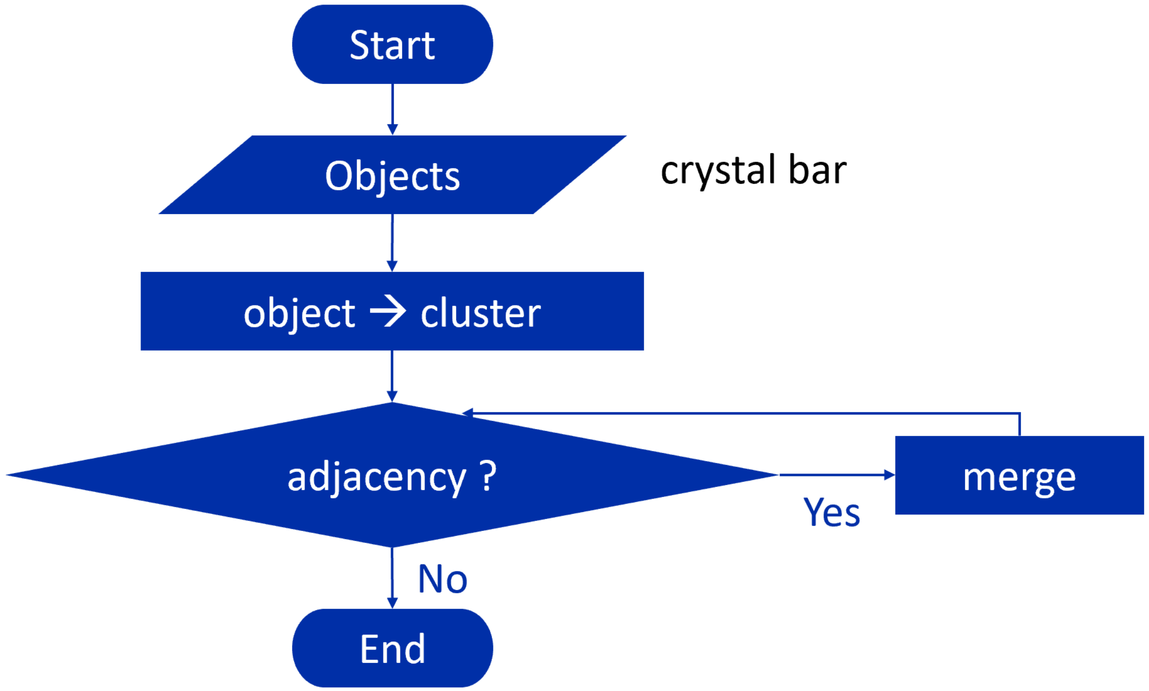
1. Clustering
2. Particle recognition
3. Energy splitting

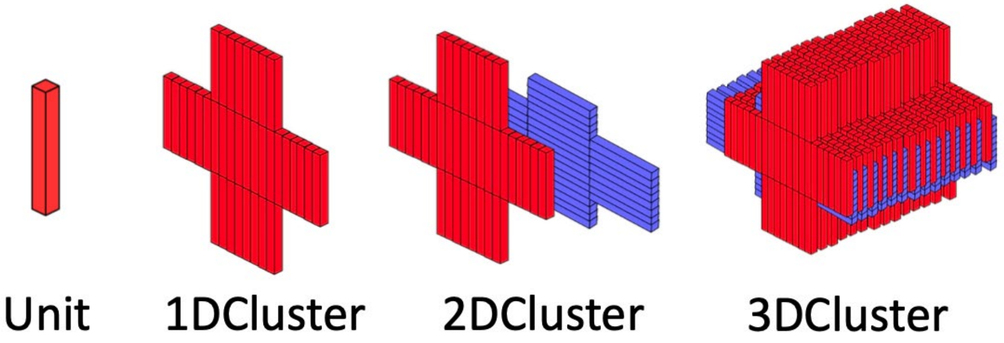
Reconstruction algorithm

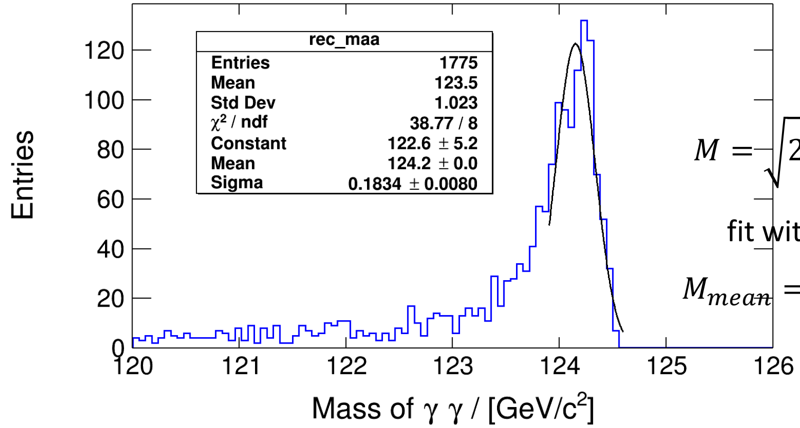
Clustering algorithm for long crystal bar ECAL

A cluster is a group of adjacent units whose energy is greater than noise threshold

Clustering based on identification of adjacency or not







$H \to \gamma\gamma$

$$M = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - cos\theta_{\gamma_1\gamma_2})}$$

fit with gaussian function

$$M_{mean} = 124.151 \pm 0.010GeV$$

https://indico.ihep.ac.cn/event/17809/

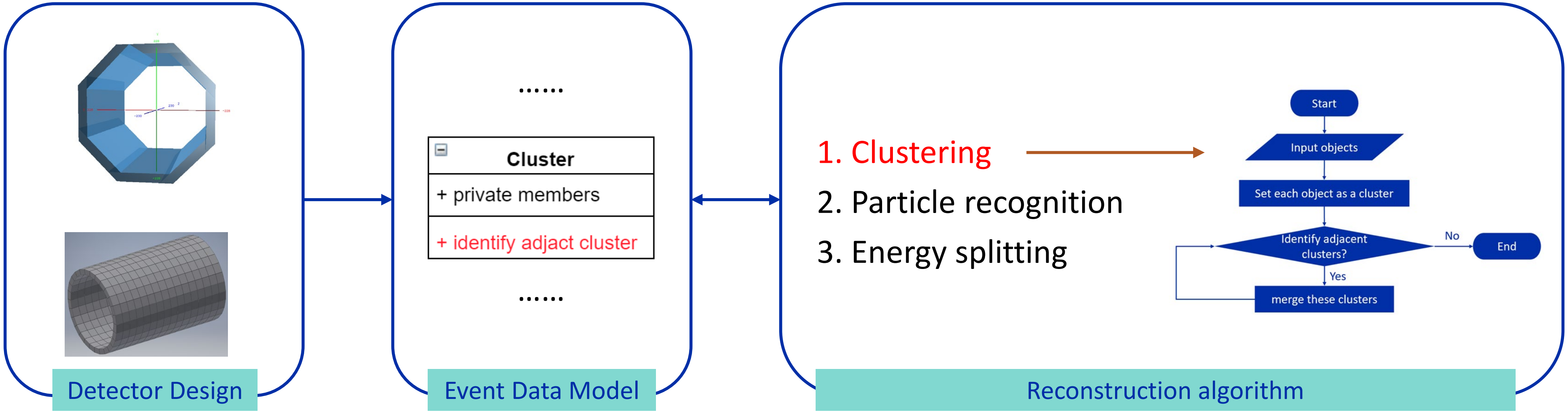
Feature of clustering algorithm

1. Abstract concept

   clustering function template is used from units to 3D cluster

2. Modularization

   easy to migrate, adapted to different detector design, such as endcap ECAL and HCAL



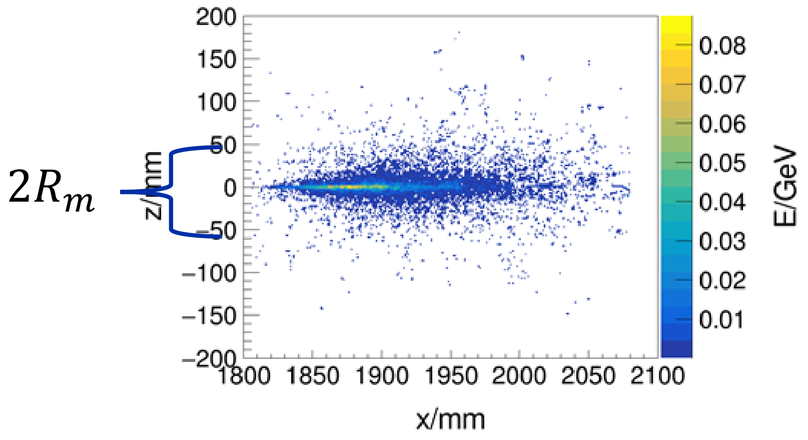
Update of clustering algorithm

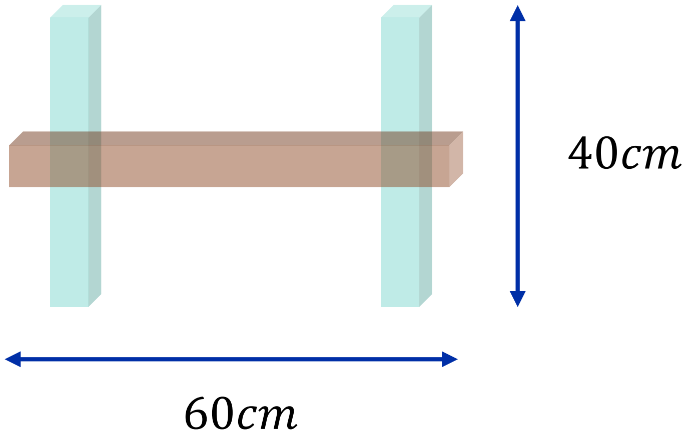
Performance check using $H -> gg$:

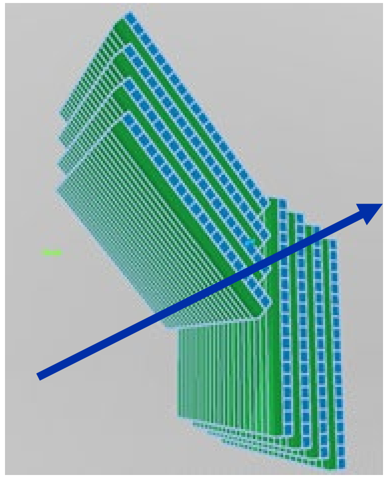
a cluster contains multi particles

Identification of energy deposits from each individual particle:

1. larger lateral width of electromagnetic shower in crystal
2. connection of vertical and horizontal units by accident
3. stave structure for ECAL





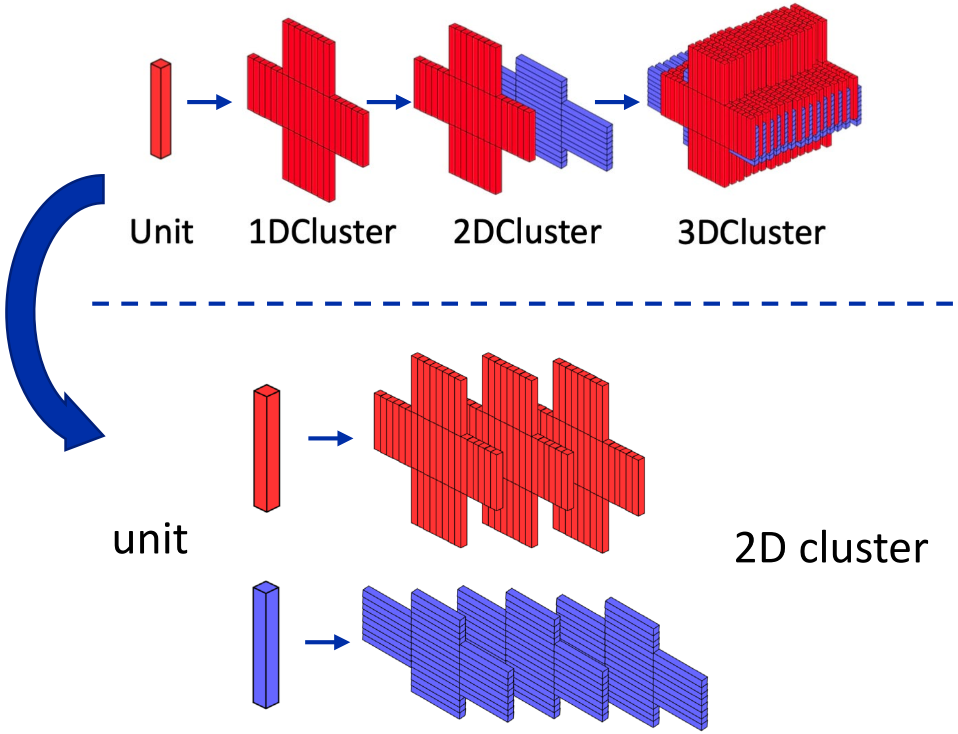


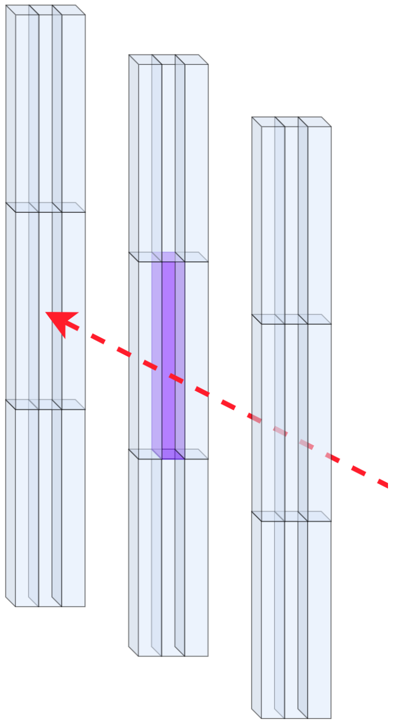
Design of clustering algorithm

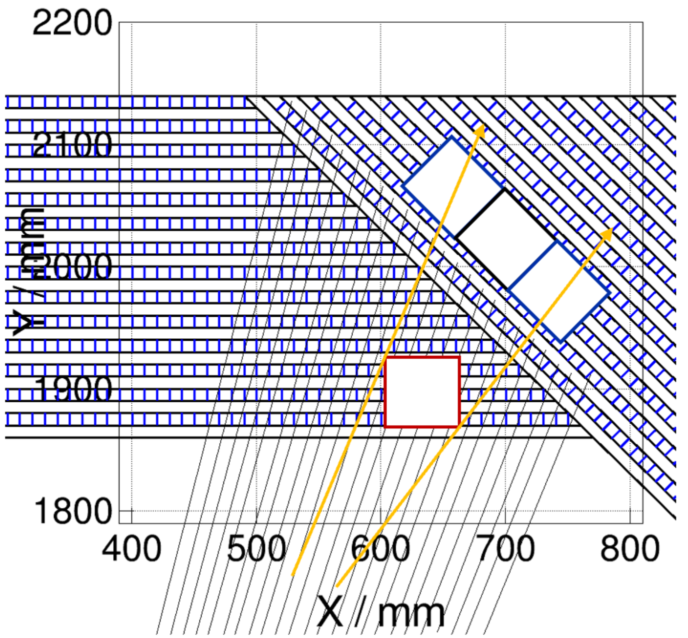
1. Vertical and horizontal units are clustered respectively
2. More strict criteria of adjacency
3. Adjacent two modules: dictionary lookup method

PFA need a imaging calorimeter

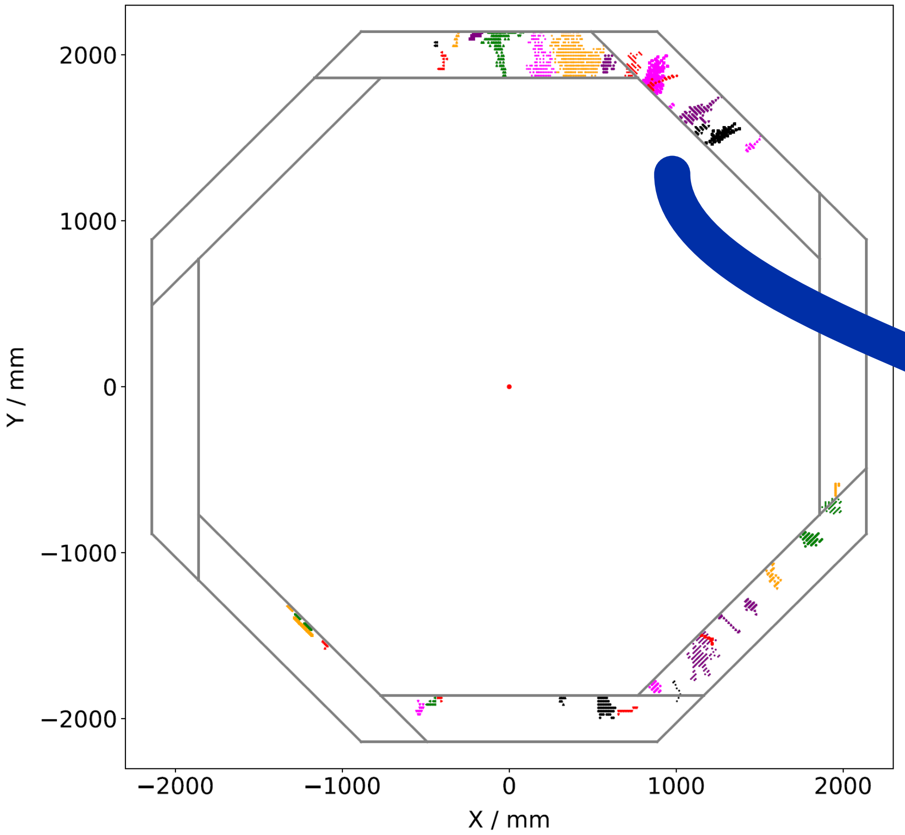
Projection of vertical and horizontal units make it possible!



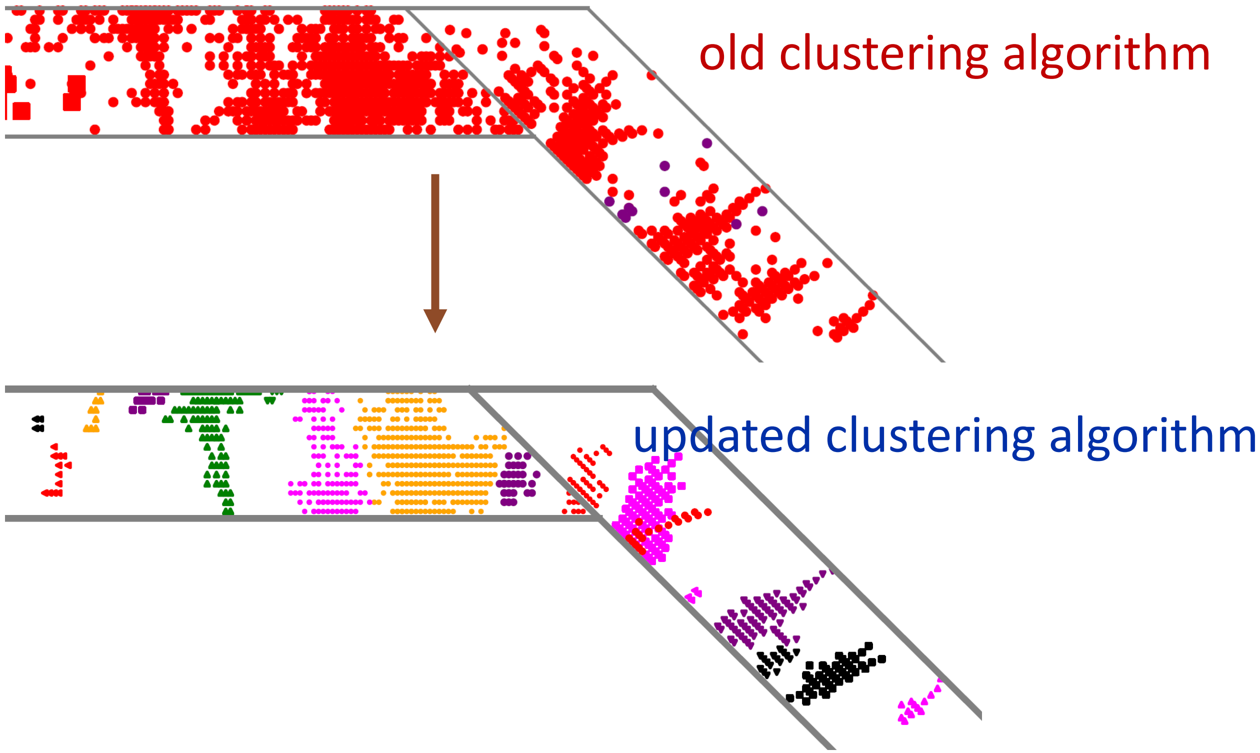




Clustering results for $H \to gg$ event



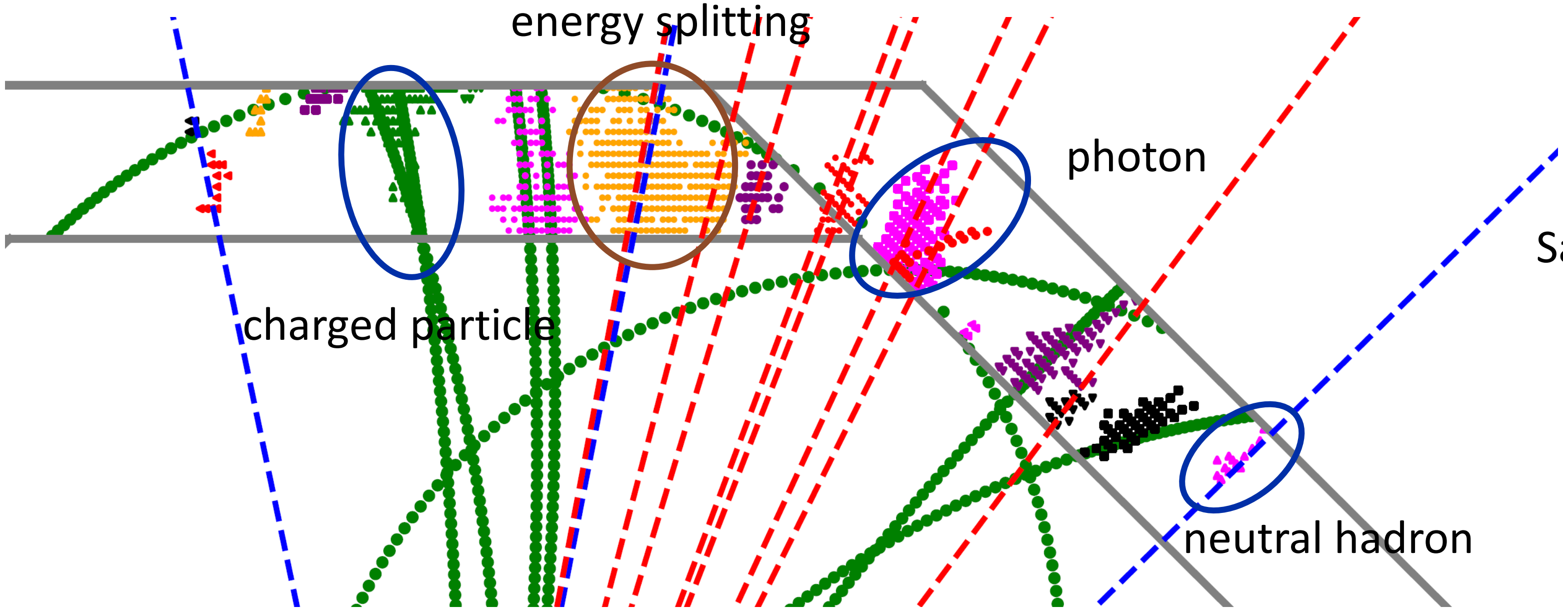
Points of different colors belongs to a single cluster



Separation power is improved significantly

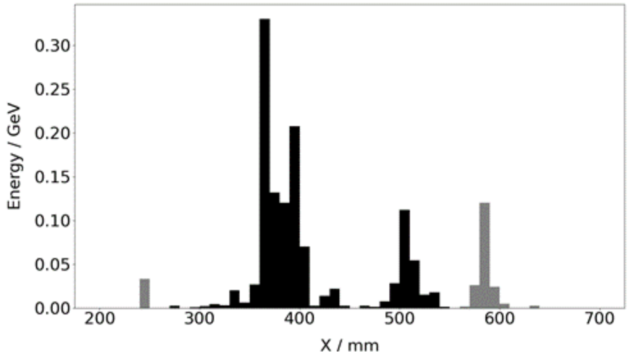
Crystal bar ECAL behave like an imaging calorimeter

Match of cluster with MC truth



Same event display as last page:

1. green circle points: charged particles
2. red dashed lines: photons
3. blue dashed line: neutral hadrons

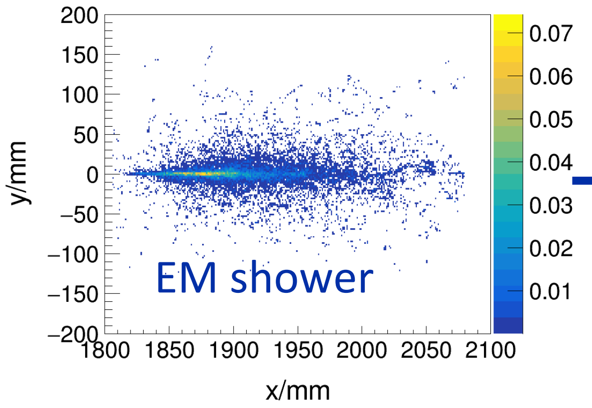


There is a clear relationship between individual cluster and single particle.

Waiting to particle recognition and energy splitting!

Photon recognition

Energy “Core” recognition → Photon recognition



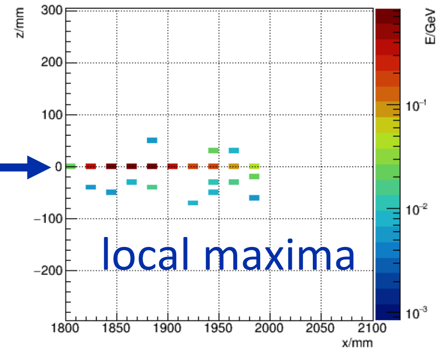
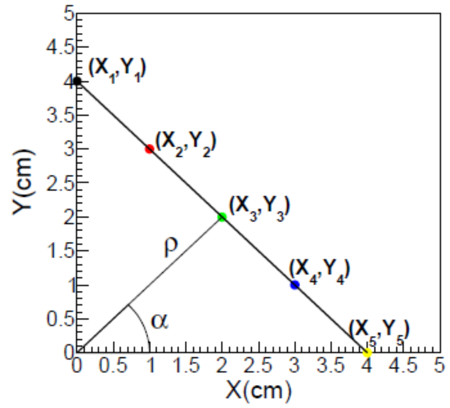
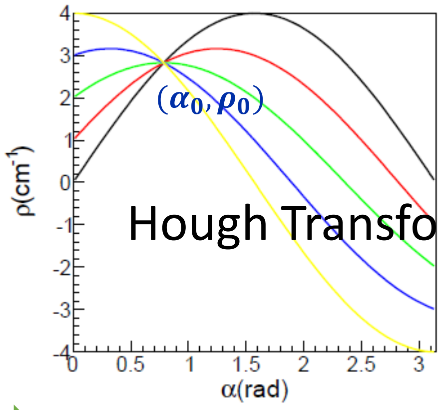


Image Space



Hough Space



Hough Transformation

(x_i, y_i)

Series of Points

$\rho = x_i \cos\alpha + y_i \sin\alpha$

Series of Curves

(α_0, ρ_0)

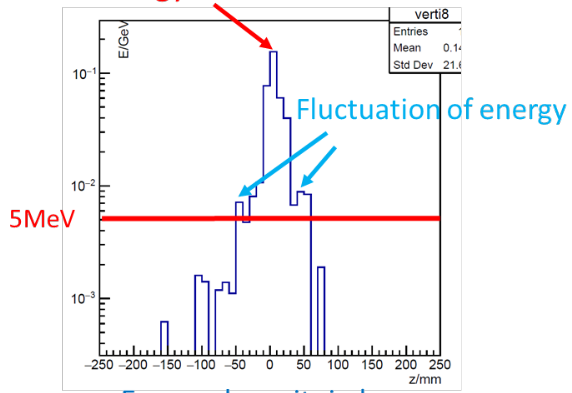
Point

$\rho_0 = x\cos\alpha_0 + y\sin\alpha_0$

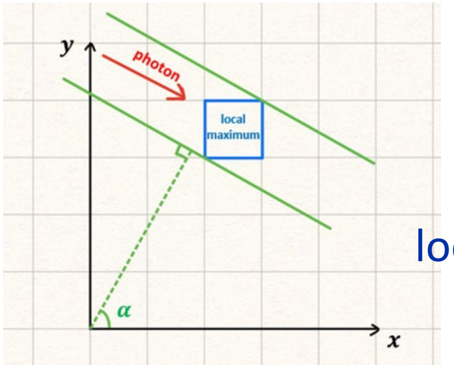
Line

Hough Transformation in ECAL: cube, not a point

Energy core



Energy deposits in bars of one layer



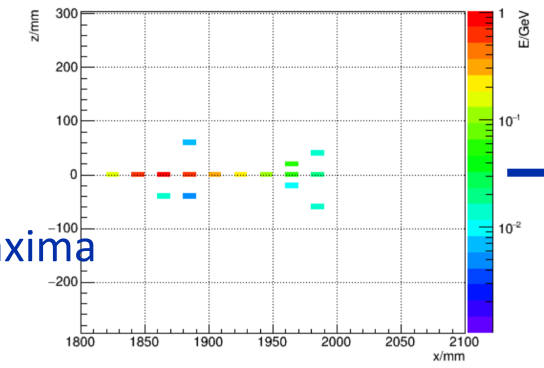
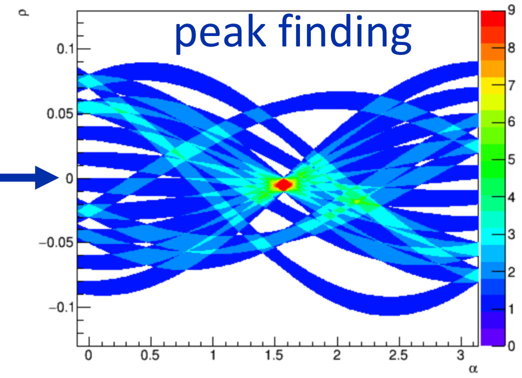


Image Space



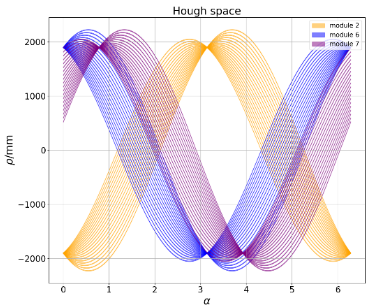
Hough Space

Generalization of photon recognition algorithm

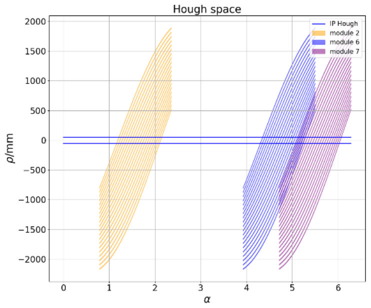
Identify photons in jets:

1.Much larger Hough space

→ Much larger memory & more computation required



Original Hough space



After limitation

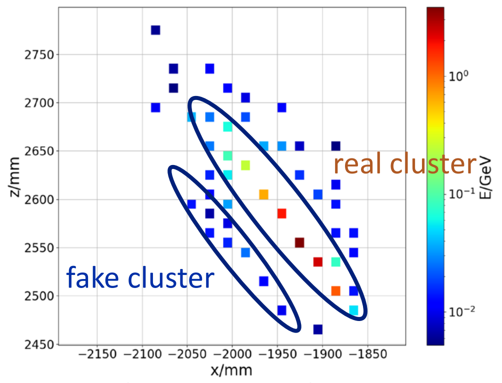
0	0	0	1	0
0	1	0	1	0
0	0	2	0	0
0	0	3	0	0
0	1	0	0	0
0	1	0	0	0

Original 2D matrix

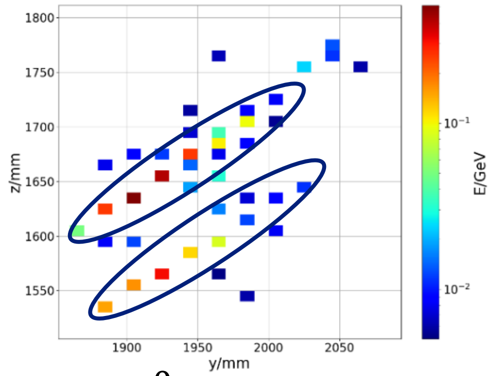
Row	Column	Value
1	4	1
2	2	1
2	4	1
3	3	2
4	3	3
5	2	1
6	2	1

Sparse matrix

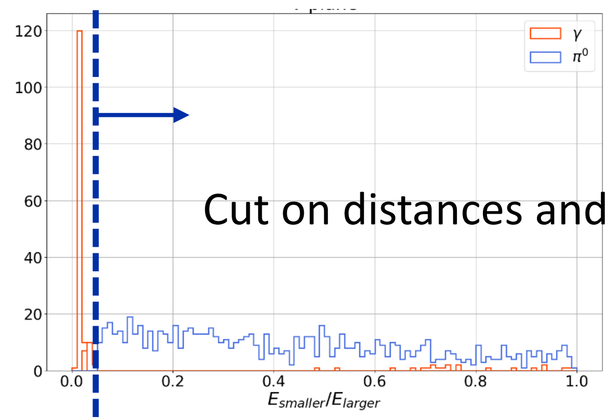
2.Fluctuations may be recognized as fake clusters



High energy photons



$\pi^0 \to \gamma\gamma$



Cut on distances and energy ratio

Single photon recognition

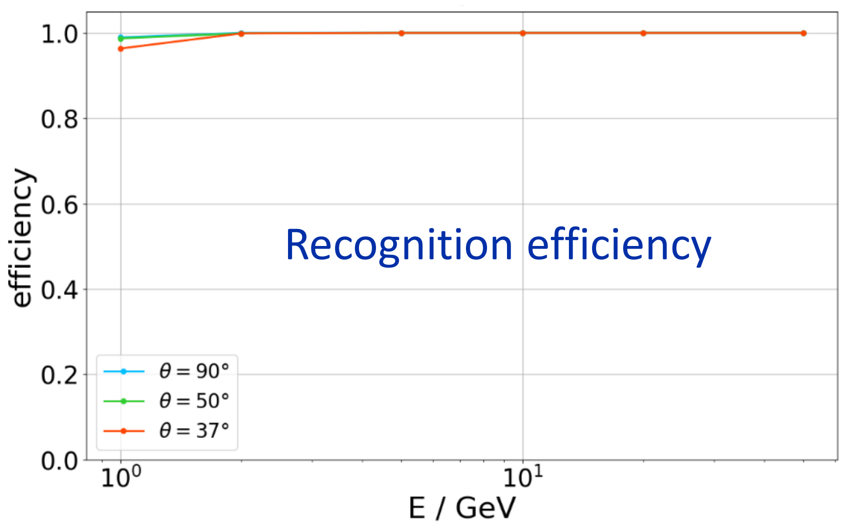
Single photon events:

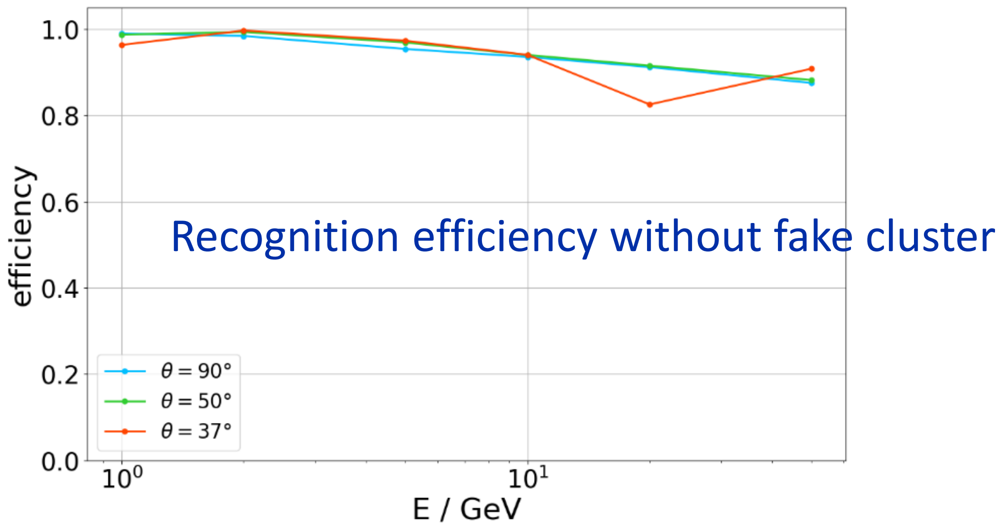
$$E = 1, 2, 5, 10, 20, 50\ GeV$$

$$\theta = 90^{\circ}, 50^{\circ}, 37^{\circ}$$

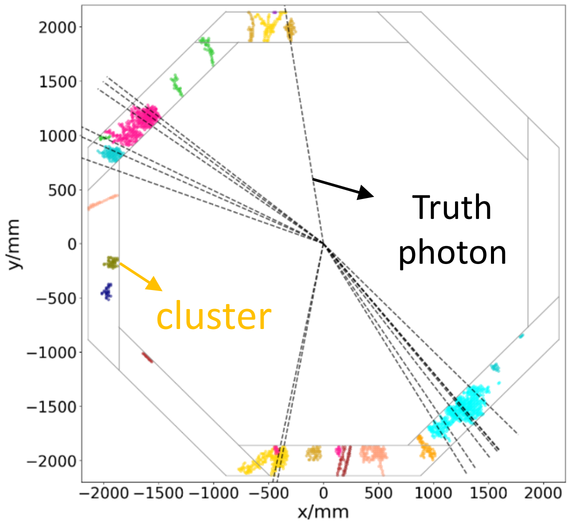
$$\phi = 0^{\circ} \sim 360^{\circ}$$

Photon recognition efficiency $\sim 100\%$

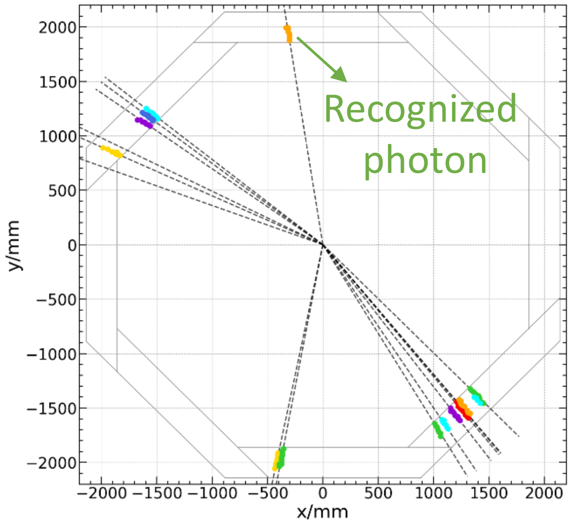




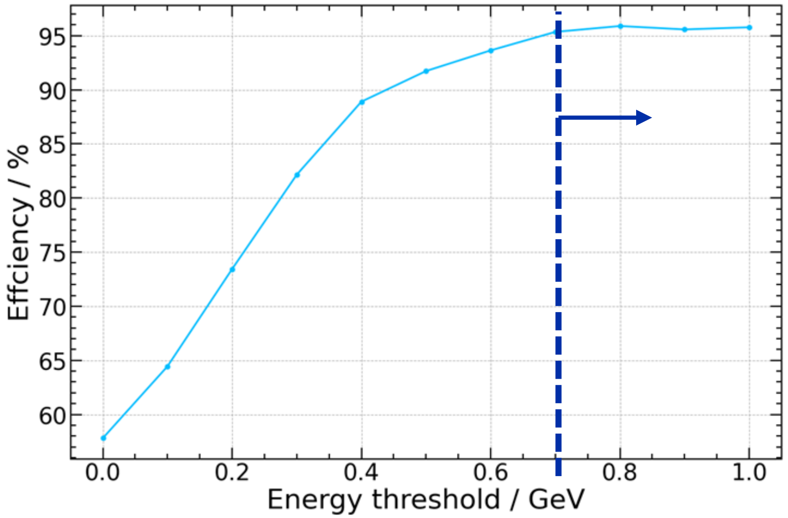
Photon recognition in $H \rightarrow b\bar{b}$ event



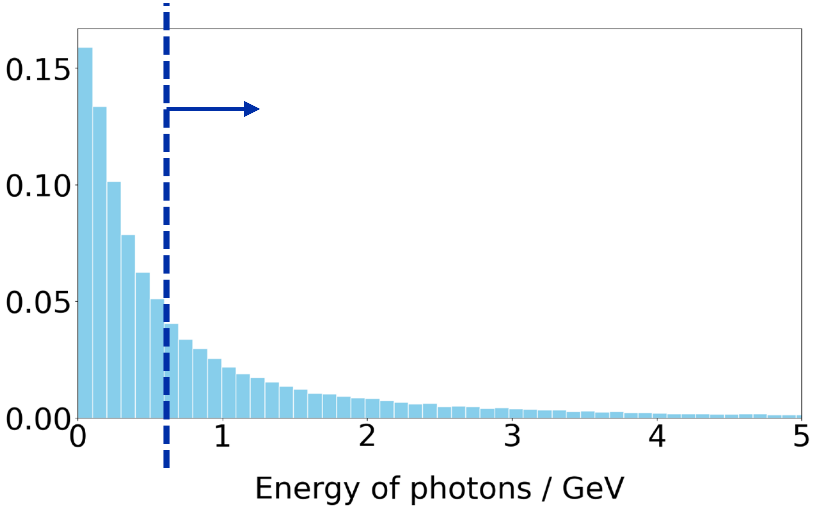
Clustering



Photon recognition



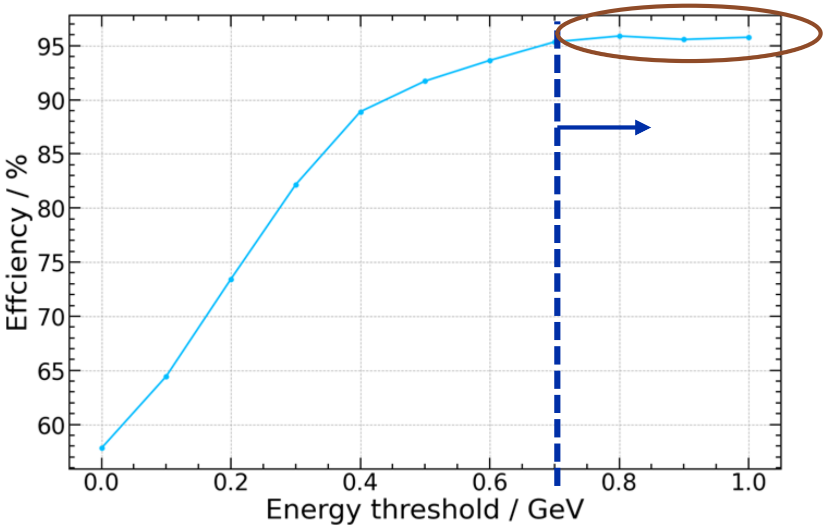
Recognition efficiency

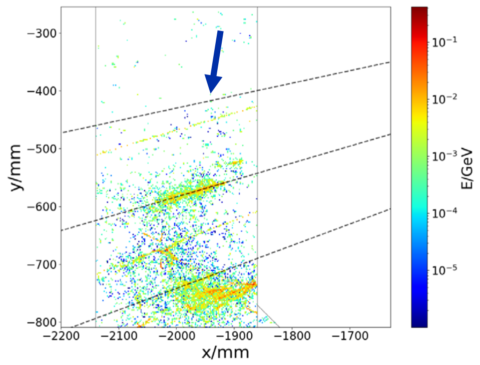


Recognition efficiency $> 95\%$ for photons with $E > 0.7\ GeV$

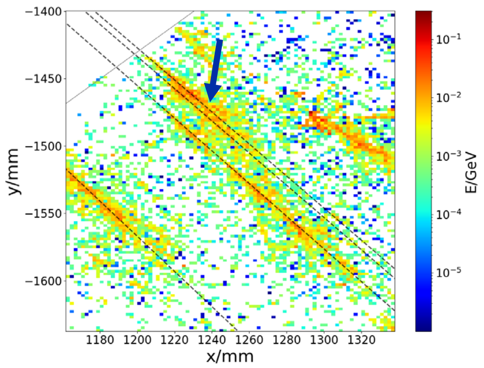
Photons with lower energy will be recognized using other method

Photon recognition in $H \to b\bar{b}$ event

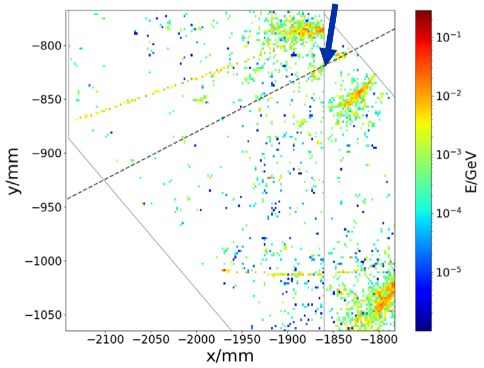




photon conversion



two very close photons



energy leakage

Summary

- Long crystal bar ECAL detector design has better energy resolution and can save cost. Reconstruction is a big challenge for the perpendicular crystal bars design concept.
- Update of clustering algorithm:
  - ✓ Application of abstract concept and modularization in the software development.
  - ✓ two 2-dimensional clustering explore clear relationship between individual cluster and single particle.
- Update of photon recognition:
  - ✓ From local coordinate to global coordinate, optimization of memory and CPU time.
  - ✓ Recognition efficiency of single photon $\sim 100\%$; recognition efficiency for photons in jet with $E > 0.7\ GeV$ is $> 95\%$

➢ Plan of reconstruction algorithm:
  - ➢ Match of extrapolated charged track and cluster.
  - ➢ Match of perpendicular crystal bars and energy splitting.
  - ➢ optimization of detector design, ……

Thanks!

back up