Progress of Reconstruction for Long Crystal Bar ECAL

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on behalf of CEPC ECAL software group

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Outline

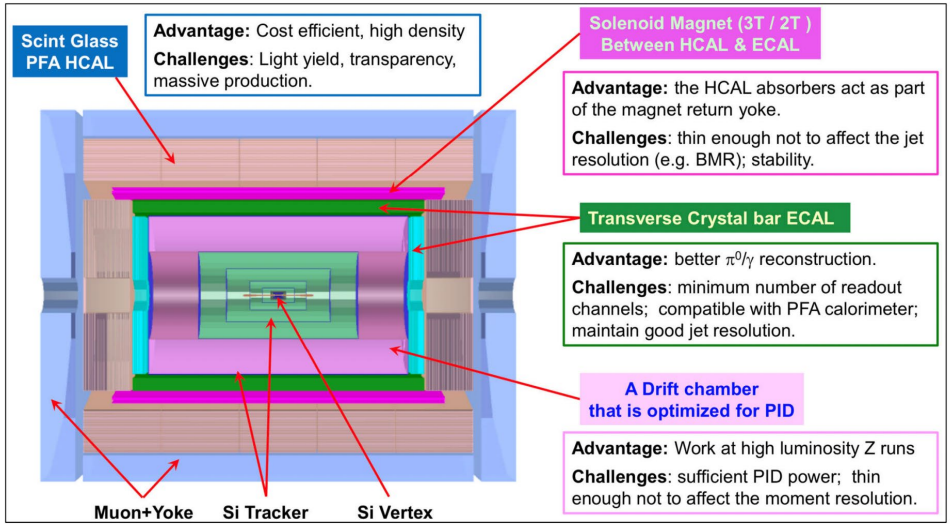
- Introduction
- Long crystal bar electromagnetic calorimeter
- Update of clustering algorithm
- Update of photon recognition
- Summary and Plan

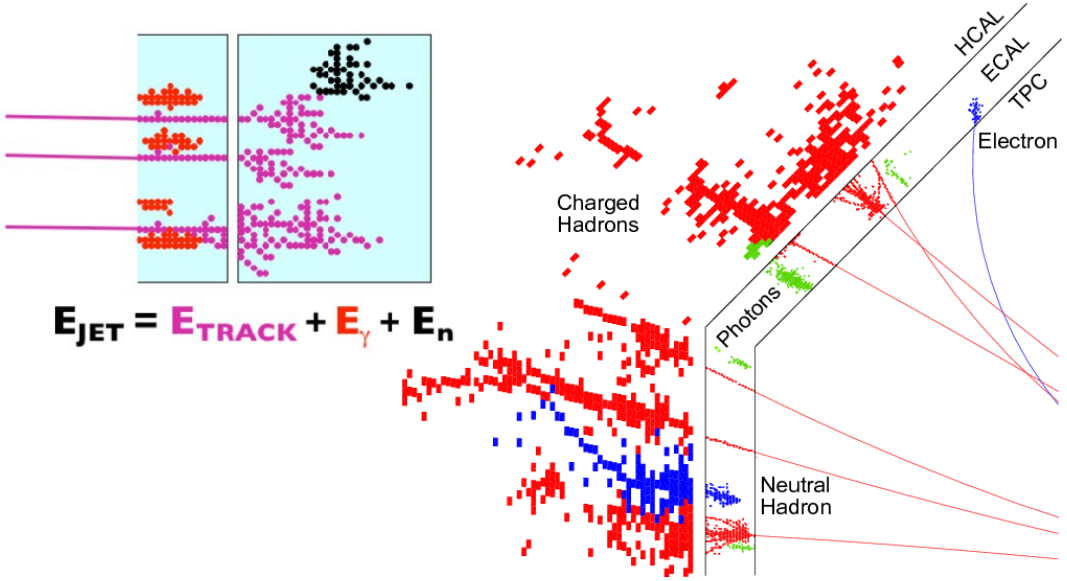
Introduction

- 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.
- PFA: "confusion" determines jet energy resolution
  - Avoid double counting of energy from same particle
  - Separate energy deposits from different particles

PFA = Hardware + Software

Natural Idea: High granularity & Compact EM showers



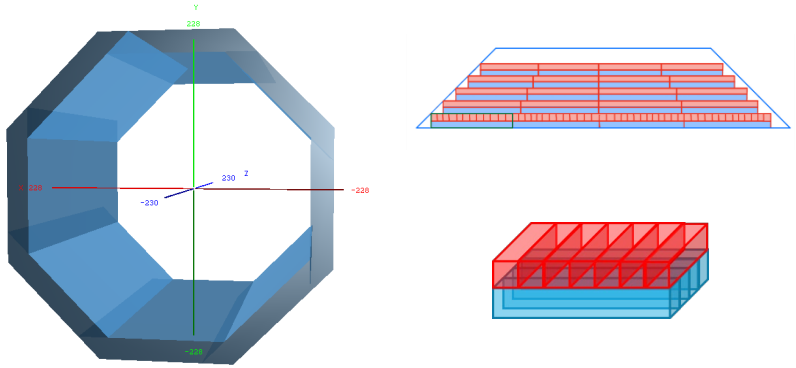


$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{EM} + \sigma^2_{Had} + \sigma^2_{Confusion}}$$

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 of readout channels (15%)
- ✓ Time measurements
- ➢ 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

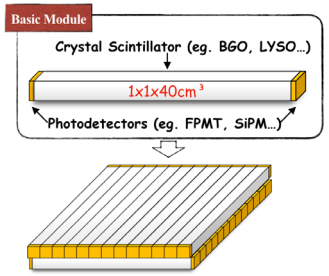
Challenges for reconstruction algorithm:

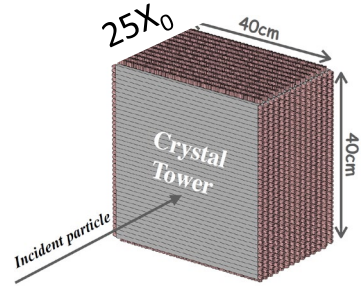
- ✓ Ambiguity caused by matching of horizontal and vertical bars.
- ✓ Identification of energy deposits from each individual particle.
- Specific software:

  2D measurements in each layer ➔ Equivalent high granularity calorimeter (imaging calorimeter)
- Generic software:

  Explore the potential of the detector / characteristics of EM showers

Detector description and digitization





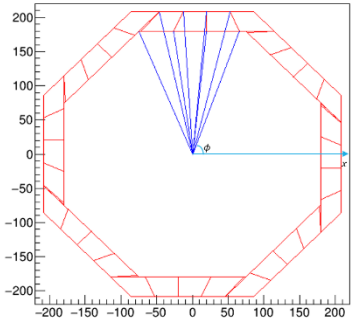
A BGO crystal barrel ECAL:

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:

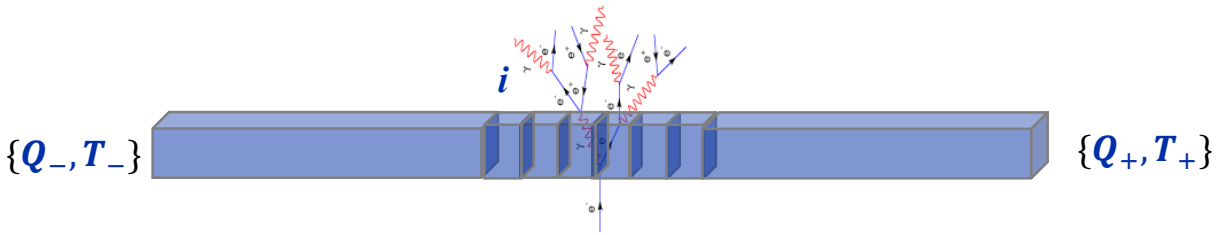
Contribution of each G4step $\boldsymbol{i}$

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

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

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

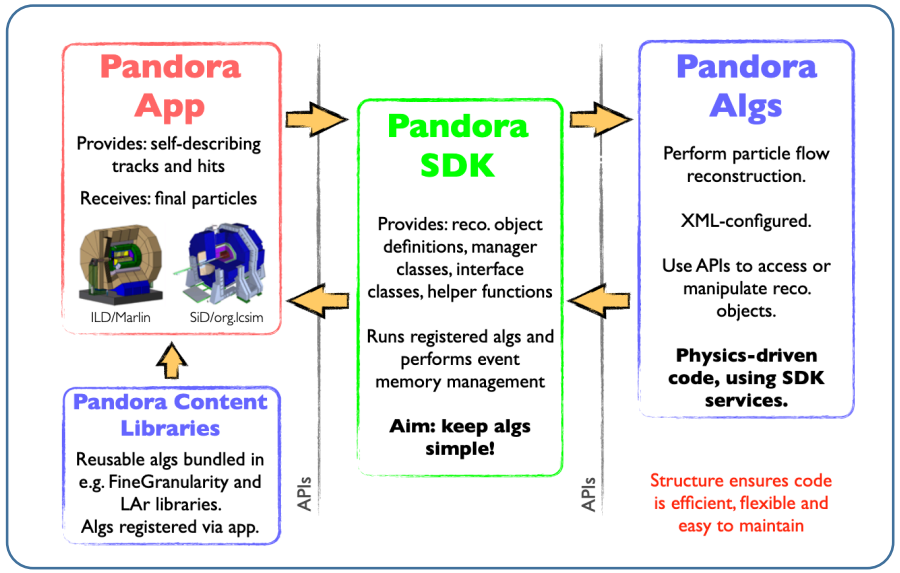
Simplified Conditions: $L_{Atten} = \infty$



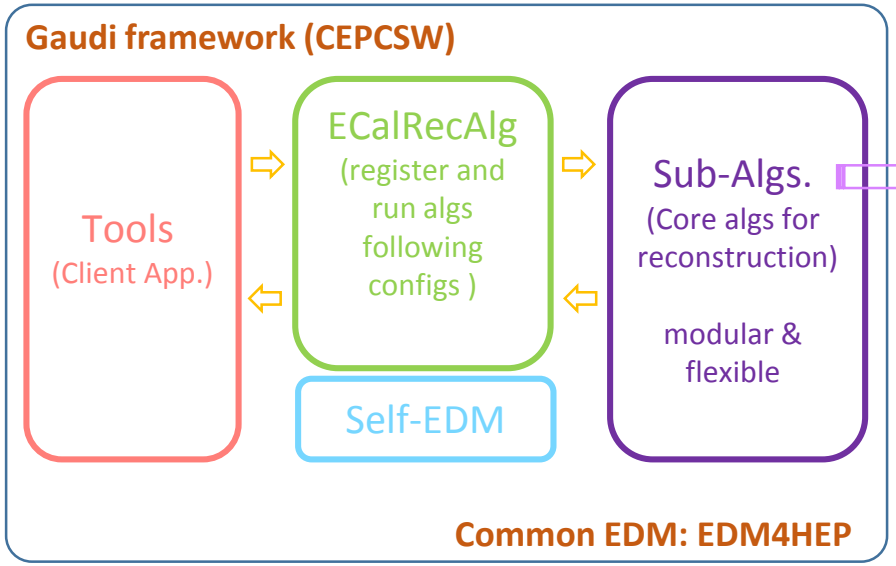
Reconstruction software

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



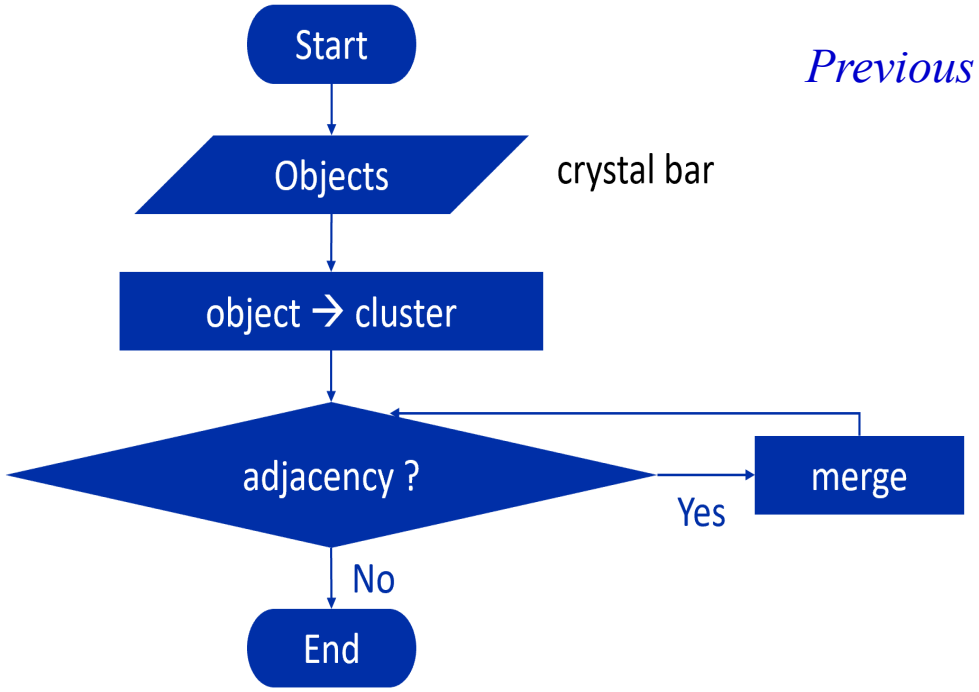
1. Clustering
2. Particle recognition
3. Energy splitting

Reconstruction algorithm

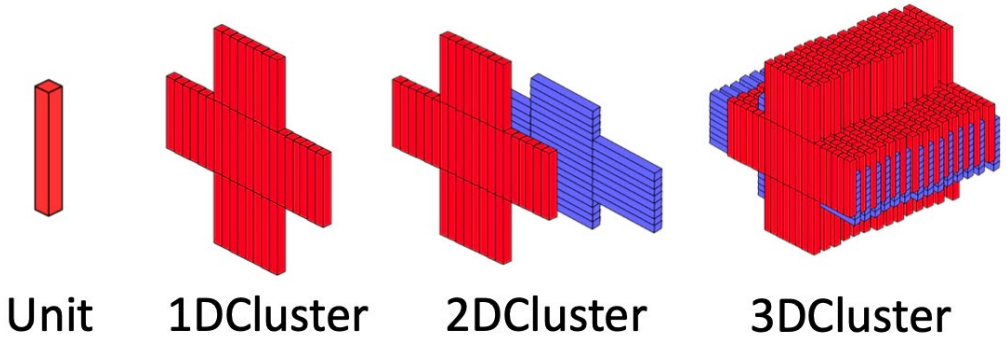
Clustering algorithm for long crystal bar ECAL

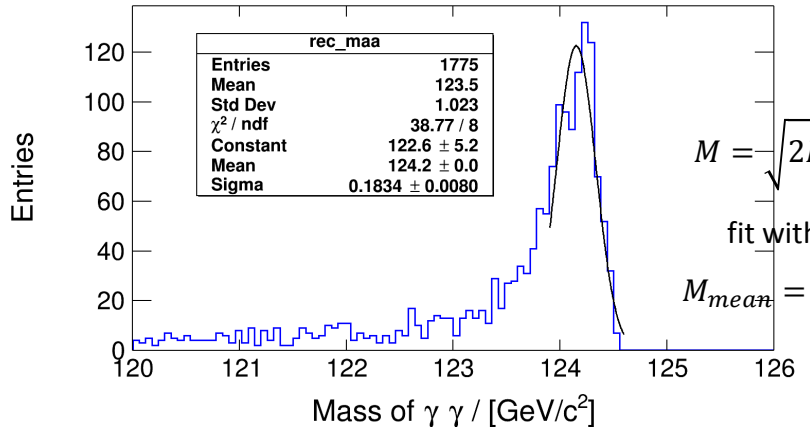
A cluster is a group of adjacent units whose energy is greater than noise threshold

Clustering based on identification of adjacency or not



Previous Algorithm:





$H \to \gamma\gamma$

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

fit with gaussian function

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

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

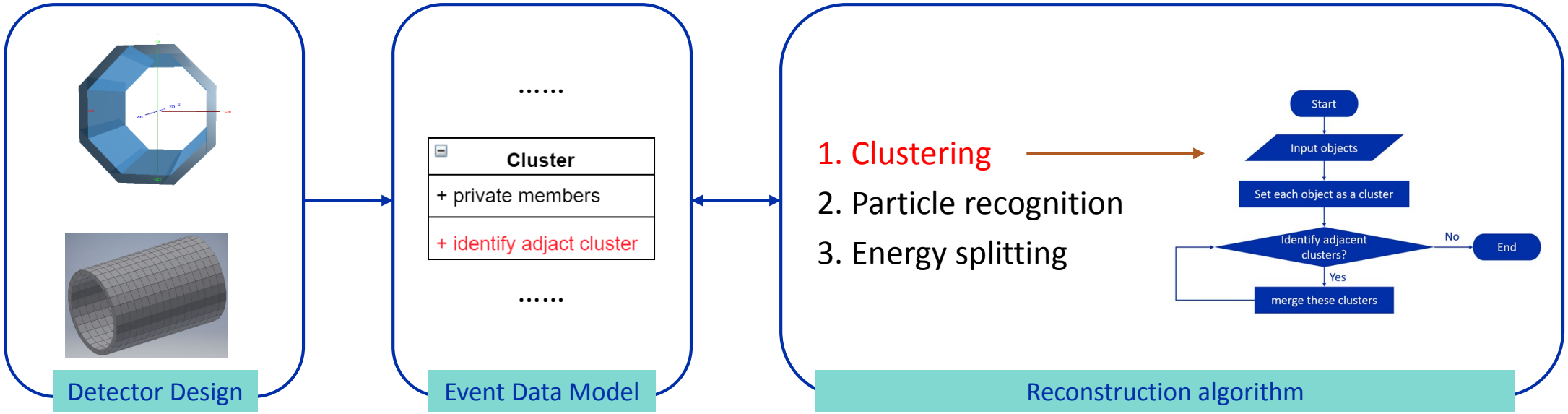
Feature of clustering algorithm

1. Abstract concept

   clustering function template is used from units to 3D cluster

2. Modularization

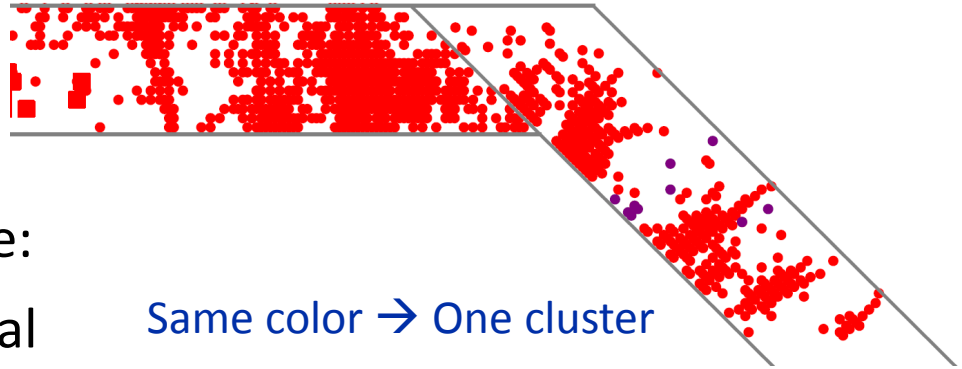
   easy to migrate, adapted to different detector design, such as endcap ECAL and HCAL



Update of clustering algorithm

Performance check using $H -> gg$:

Problem: a cluster contains many particles

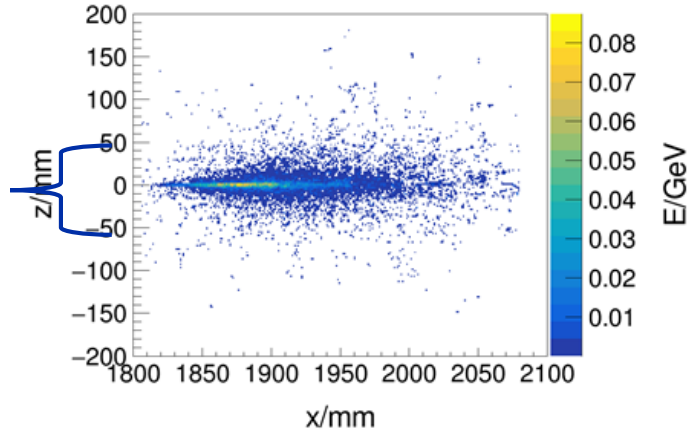


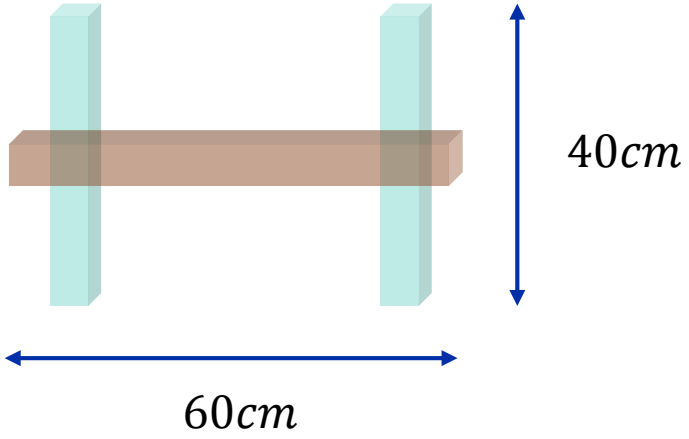
Same color → One cluster

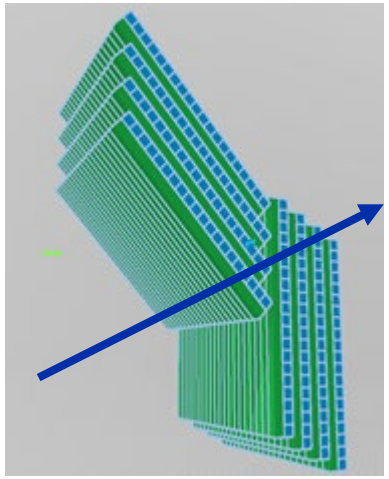
Identification of energy deposits from each individual particle:

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

$2R_m$





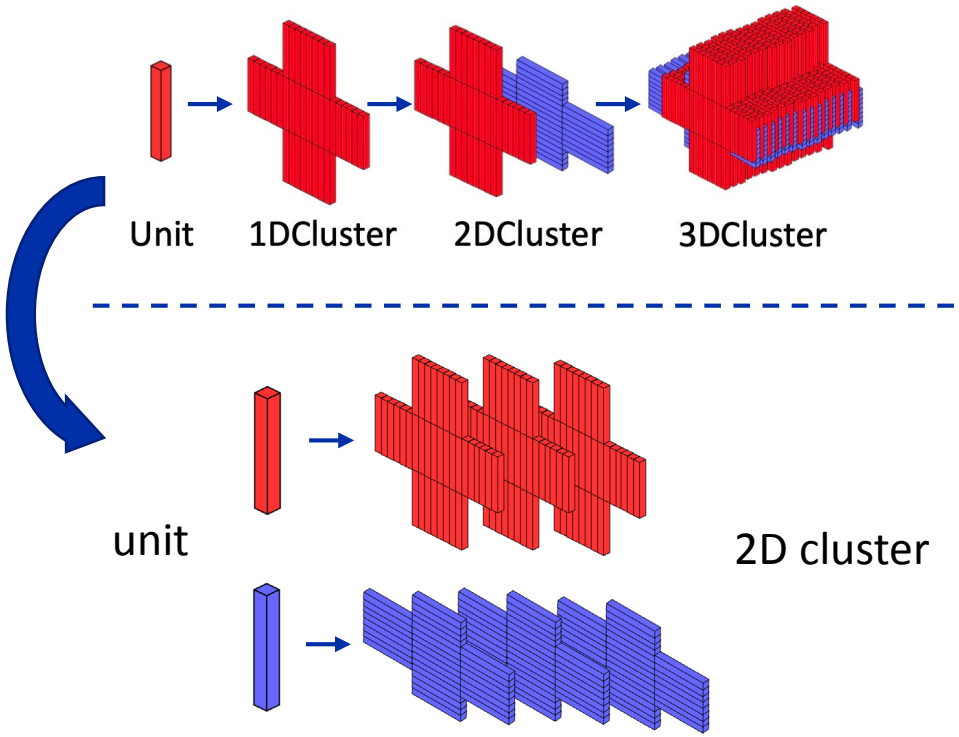


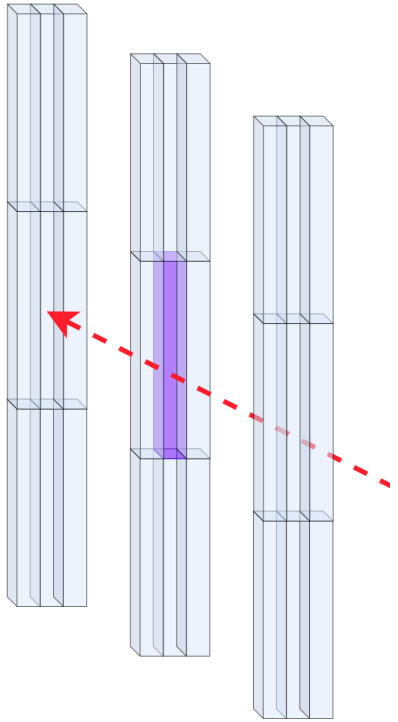
Design of clustering algorithm

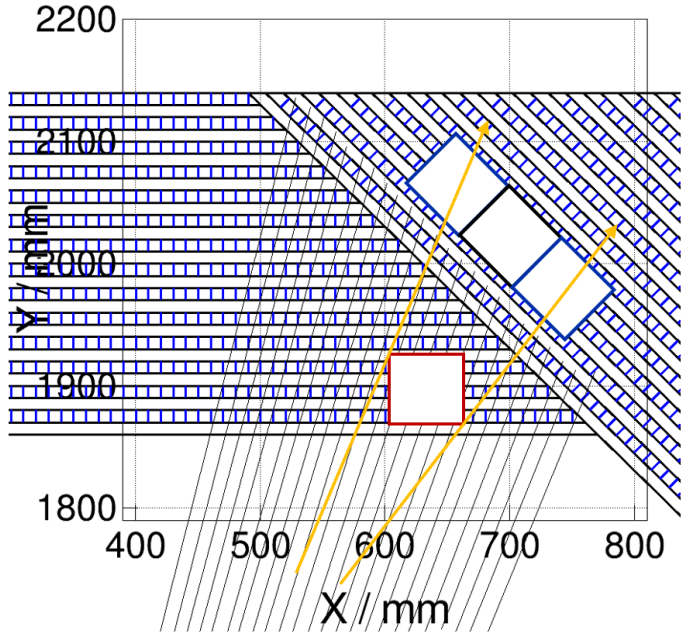
1. Vertical and horizontal units are clustered respectively
2. More strict criteria of adjacency
3. Adjacent two modules: dictionary lookup method

PFA need an imaging calorimeter

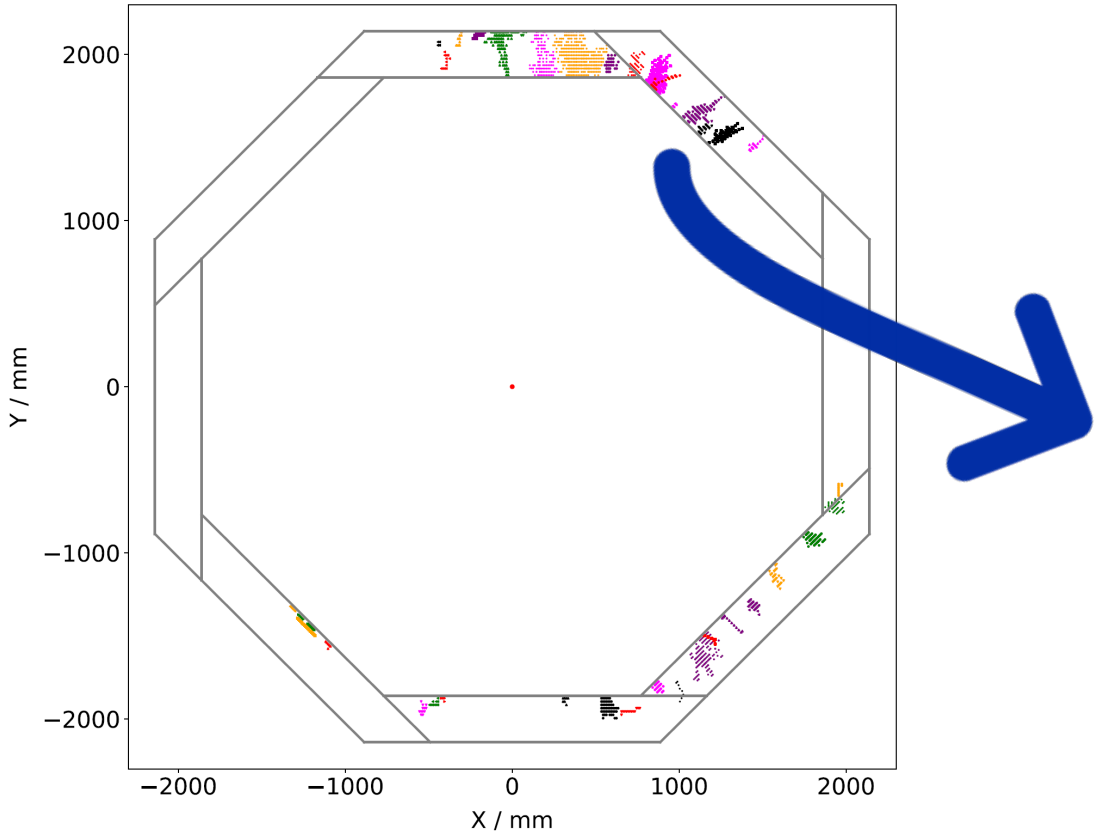
Projection of vertical and horizontal units make it possible!



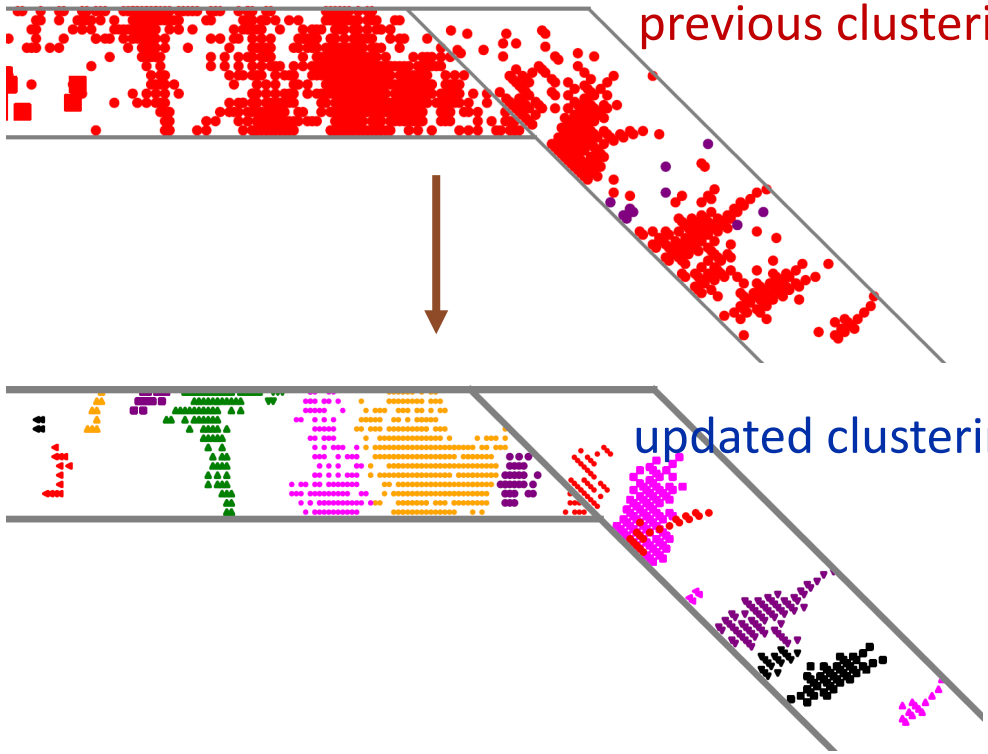




Clustering results for $H \rightarrow gg$ event



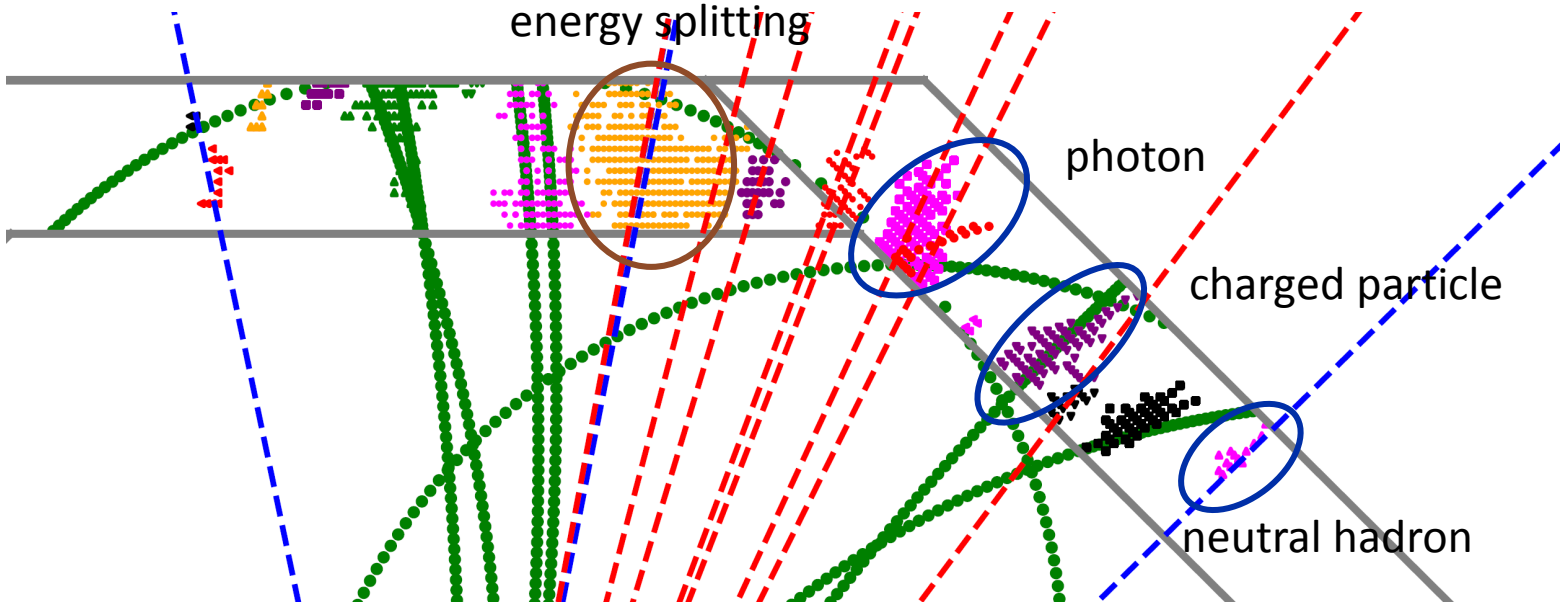
Different colors ➔ Different clusters



Separation power is improved significantly

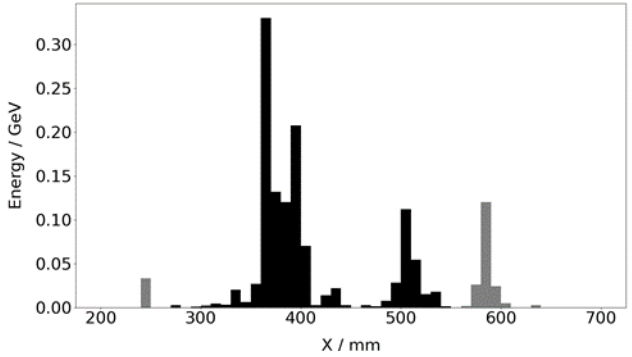
Crystal bar ECAL behavior close to an imaging calorimeter

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

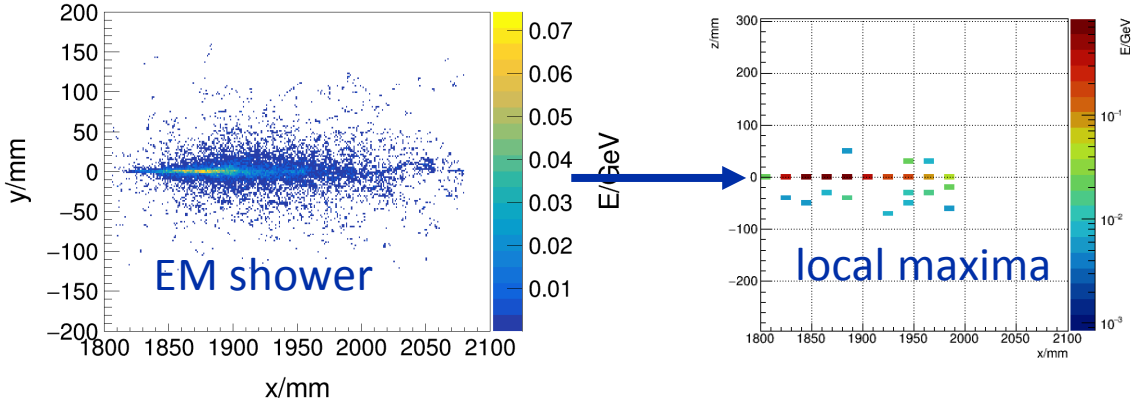


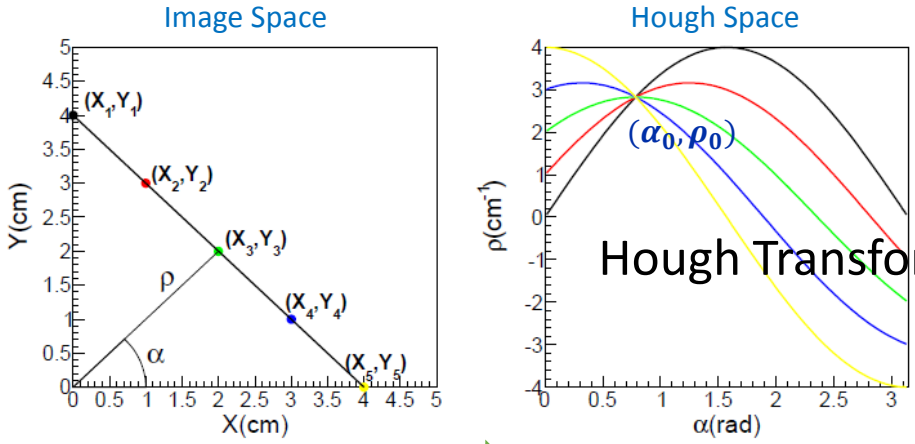
There is a clear relationship between individual cluster and single particle.

Waiting to particle recognition and energy splitting!

Photon recognition

Photon recognition → Energy "Core" recognition





Hough Transformation

(x_i, y_i)

Series of Points

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

Series of Curves

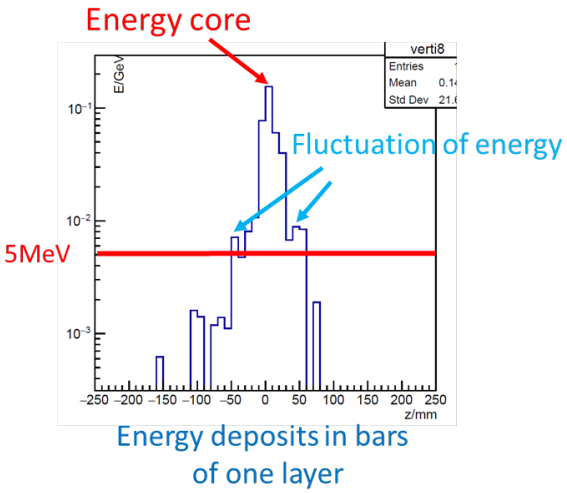
(α_0, ρ_0)

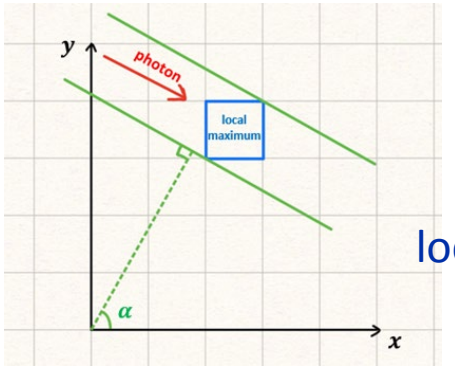
Point

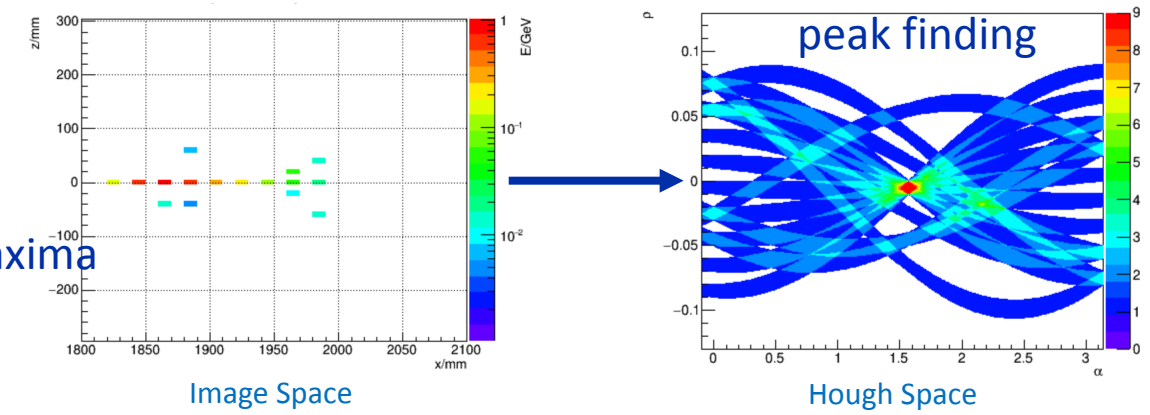
$\rho_0 = x \cos\alpha_0 + y \sin\alpha_0$

Line

Hough Transformation in ECAL: cube, not a point





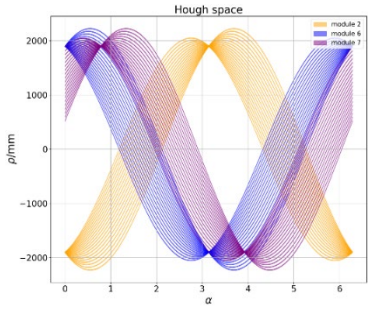


Generalization of photon recognition algorithm

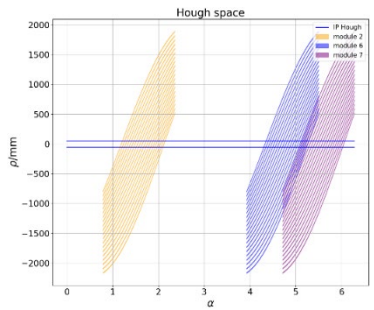
Identify photons in jets:

1.Much larger Hough space

→ Much larger memory & more computation required



Original Hough space



After limitation

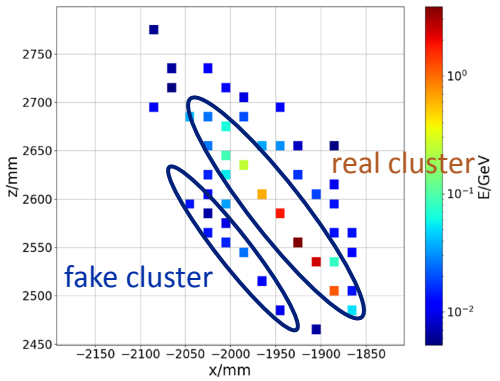
0	0	0	1	0
0	1	0	1	0
0	0	2	0	0
0	0	3	0	0
0	1	0	0	0
0	1	0	0	0

Original 2D matrix

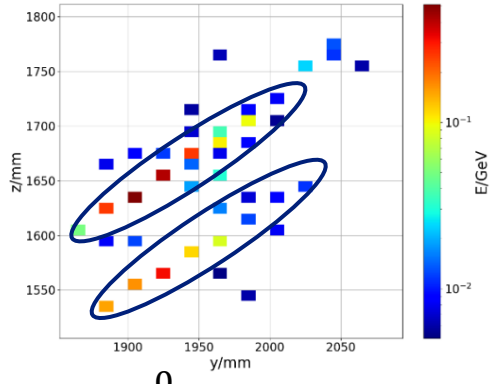
Row	Column	Value
1	4	1
2	2	1
2	4	1
3	3	2
4	3	3
5	2	1
6	2	1

Sparse matrix

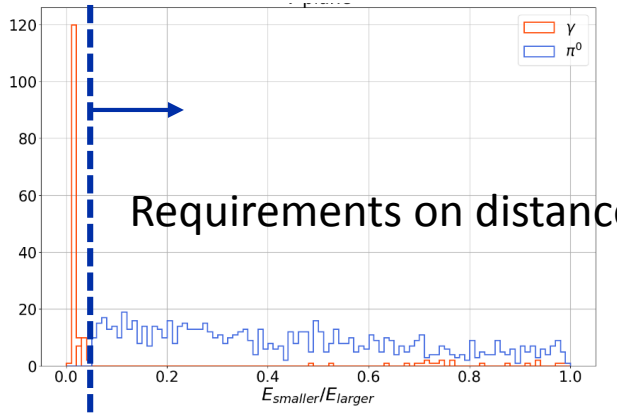
2.Fluctuations may be recognized as fake clusters



High energy photons



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



Requirements on distance and energy fraction

Single photon recognition

Single photon events:

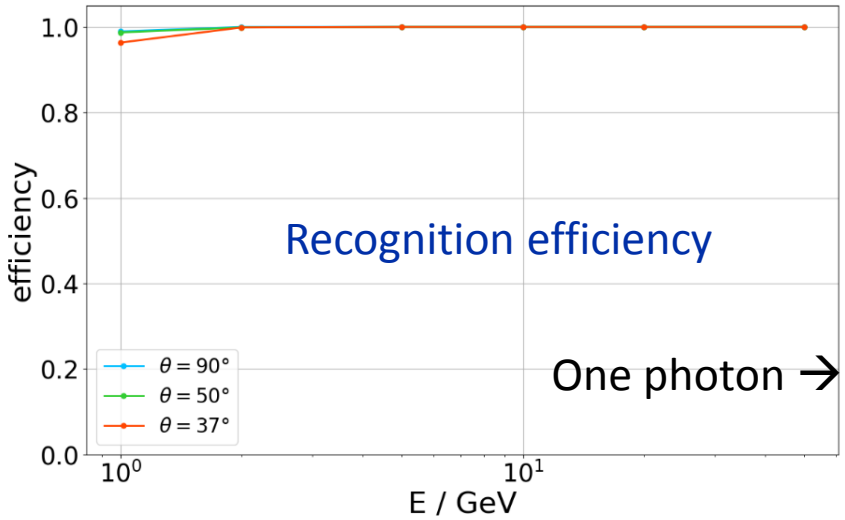
$E = 1, 2, 5, 10, 20, 50\ GeV$

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

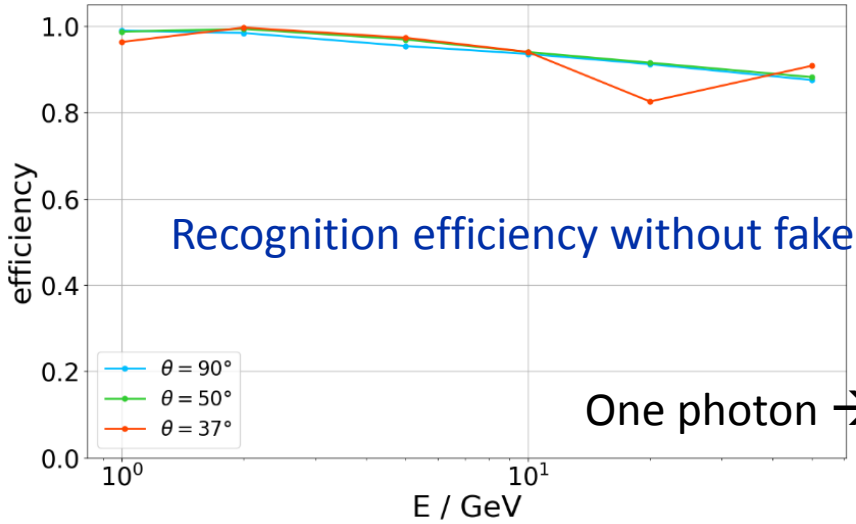
$\phi = 0^{\circ} \sim 360^{\circ}$

Photon recognition efficiency $\sim 100\%$

Gamma conversions are NOT counted

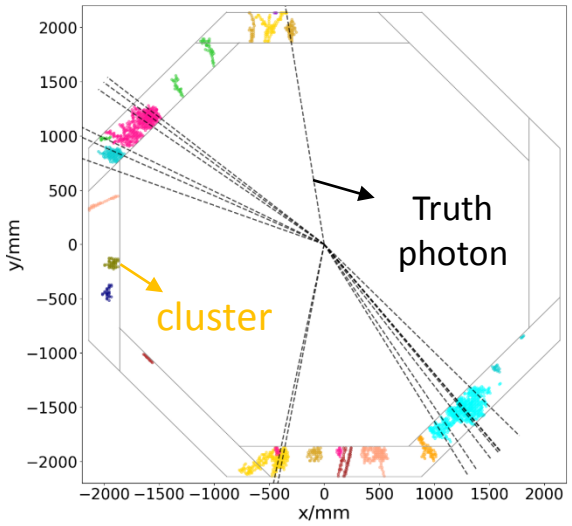


One photon → ≥ 1 shower

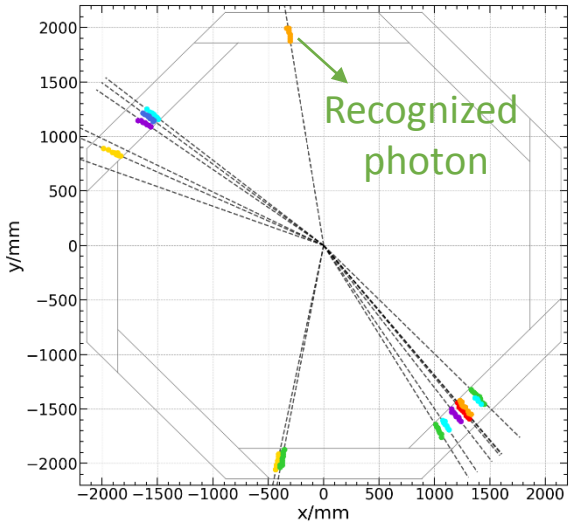


One photon → One shower

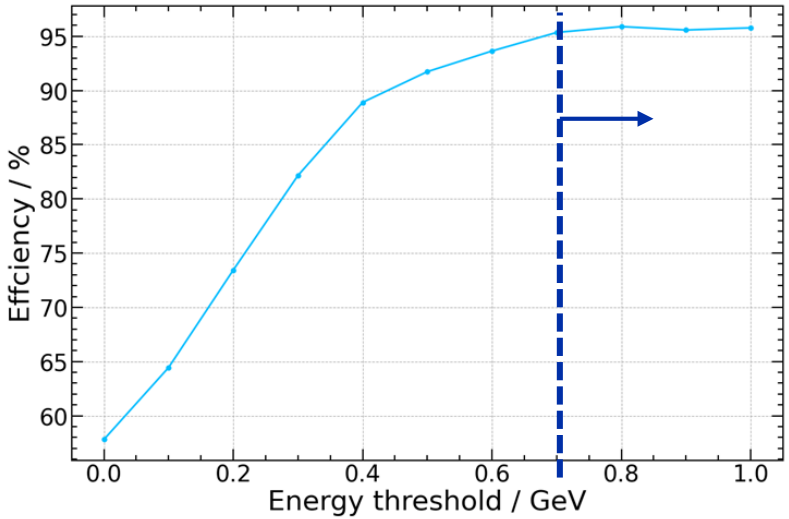
Photon recognition in $H \to b\bar{b}$ event



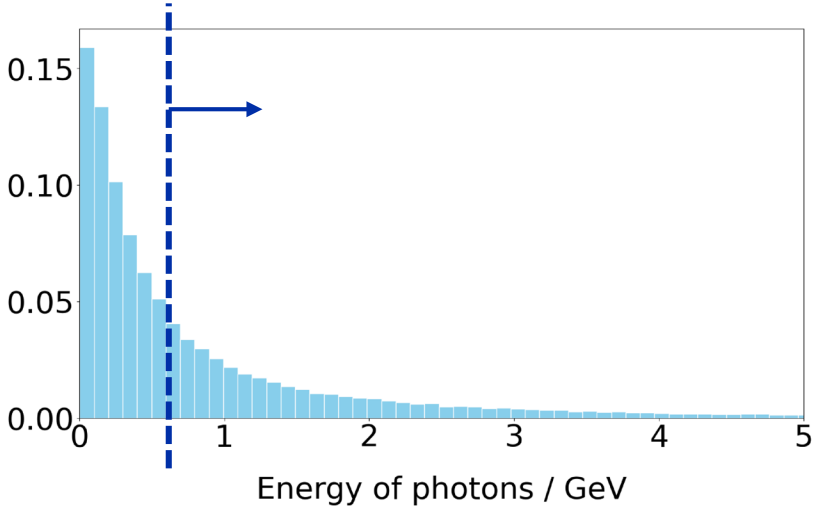
Clustering



Photon recognition



Recognition efficiency

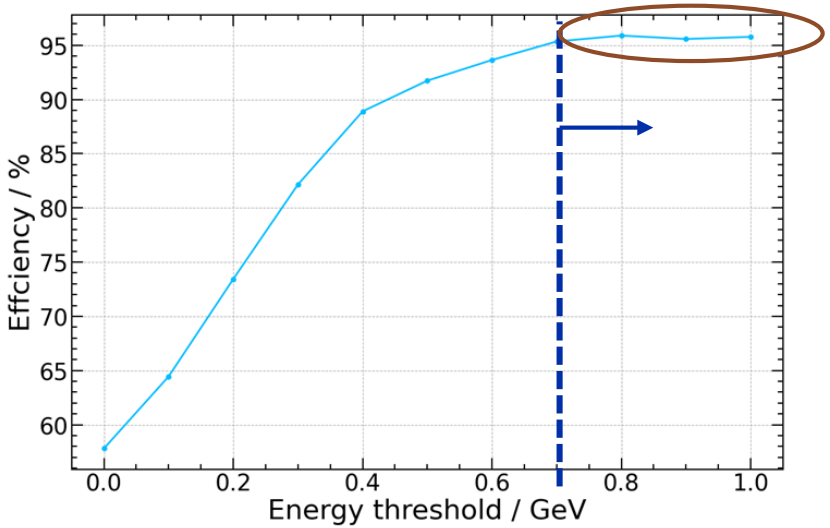


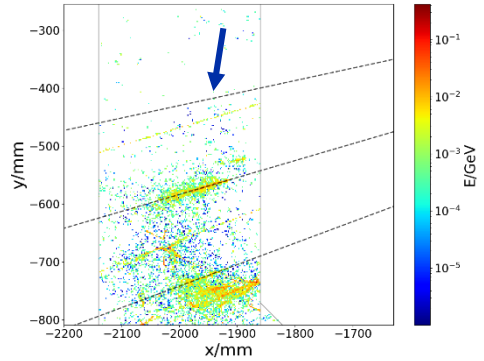
Recognition efficiency for photons in jet with E>0.7 GeV is >95%

Photons with lower energy will be recognized using other method

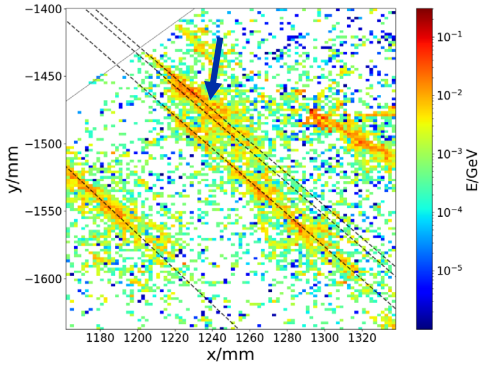
Gamma conversions are counted

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

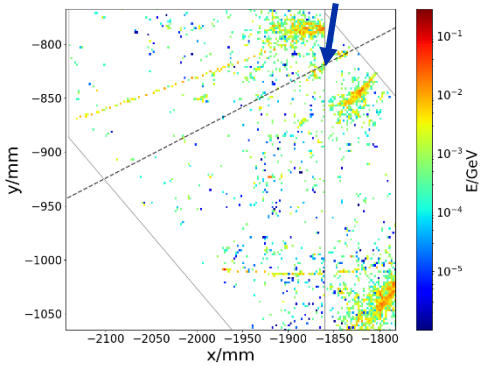




gamma conversion



two very close photons



energy leakage

Summary

- Long crystal bar ECAL detector design has better energy resolution and can save cost. Many challenges for the perpendicular crystal bars design concept, including software.
- Update of clustering algorithm:
  - ✓ Application of abstract concept and modularization in the software development.
  - ✓ two 2-dimensional clustering explore clear relationship between cluster and individual particle.
- Update of photon recognition:
  - ✓ From local coordinate to global coordinate, optimization for 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:

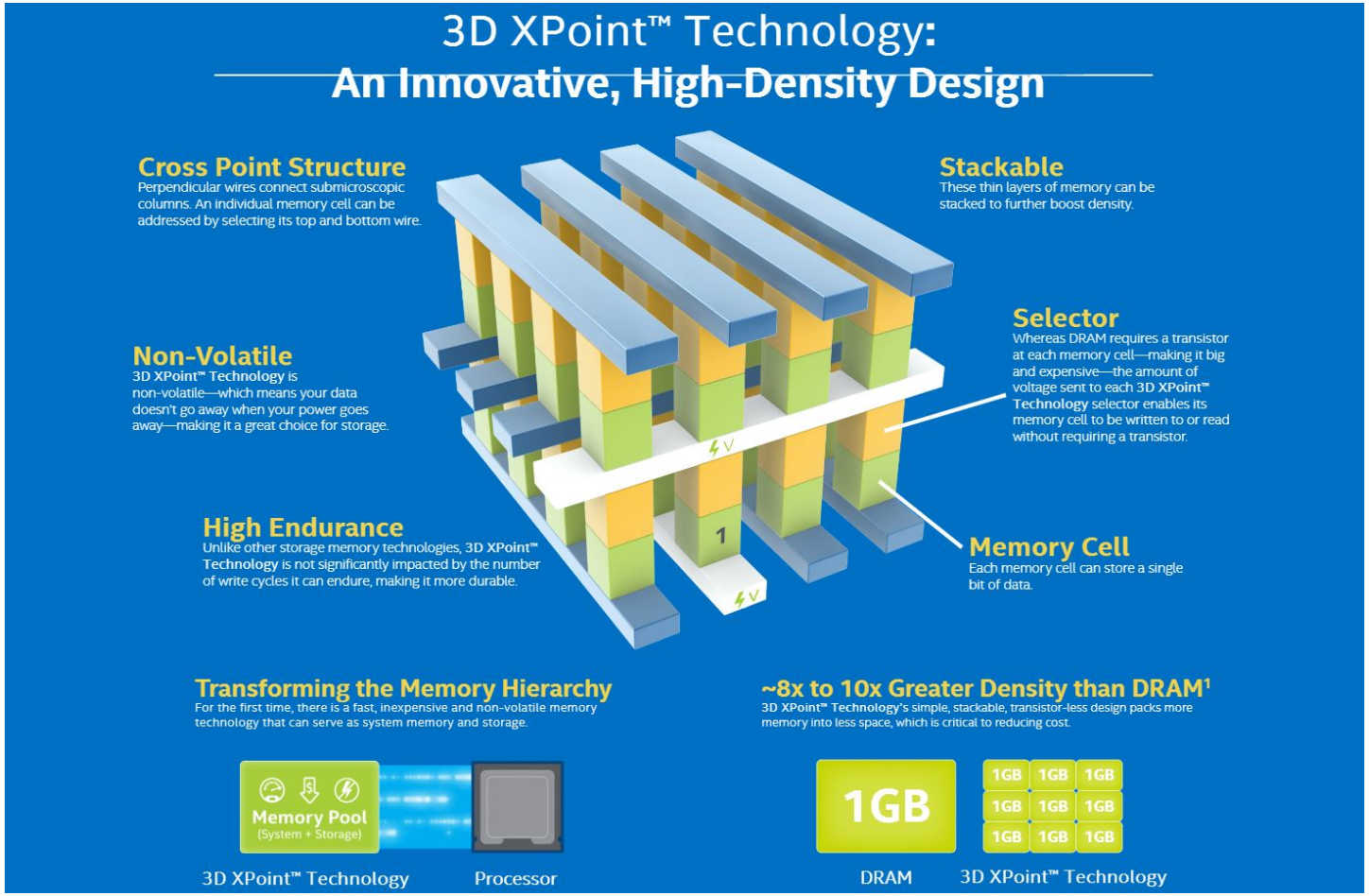
- ➢ Match of extrapolated charged track and cluster.
- ➢ Match of perpendicular crystal bars and energy splitting.
- ➢ Optimization of detector design, ……

1. Clustering
2. Particle recognition
3. Energy splitting

Reconstruction algorithm

Thanks!

Name of long crystal bar ECAL?



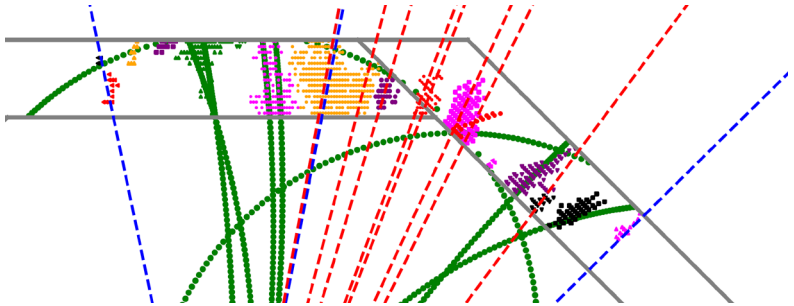
Cross-Point ECAL

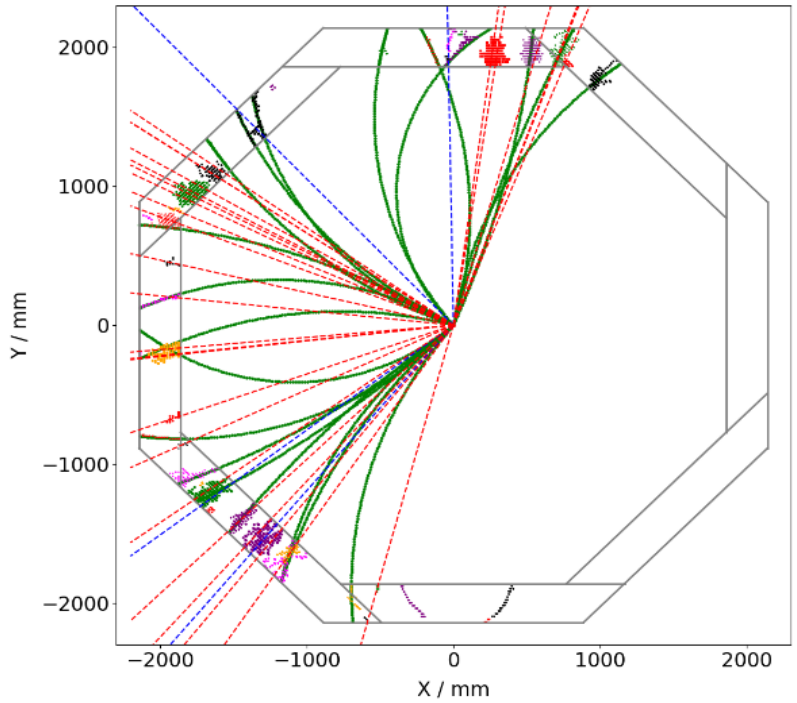
or

XPoint ECAL

Thanks!

back up

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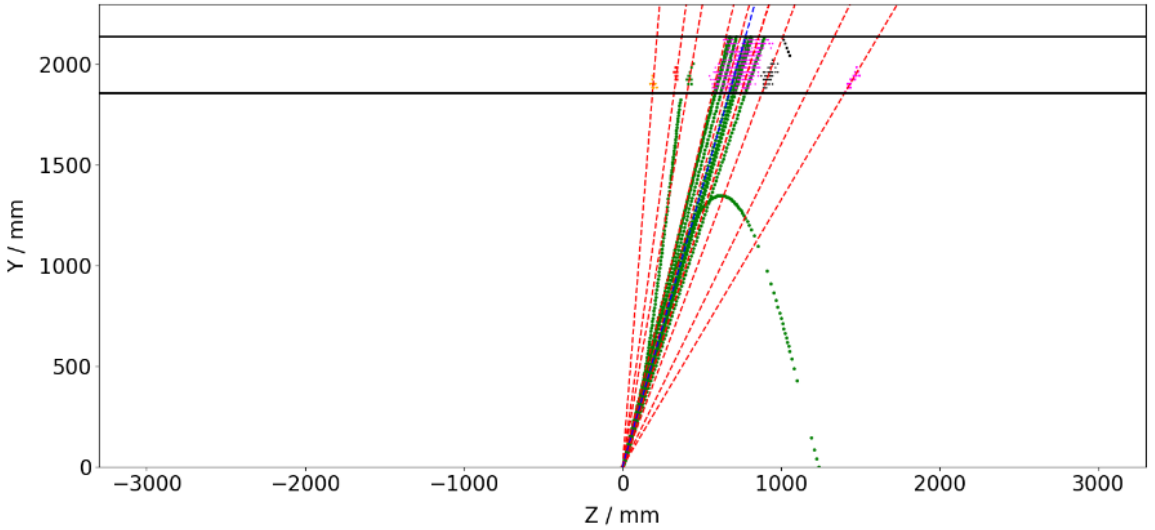
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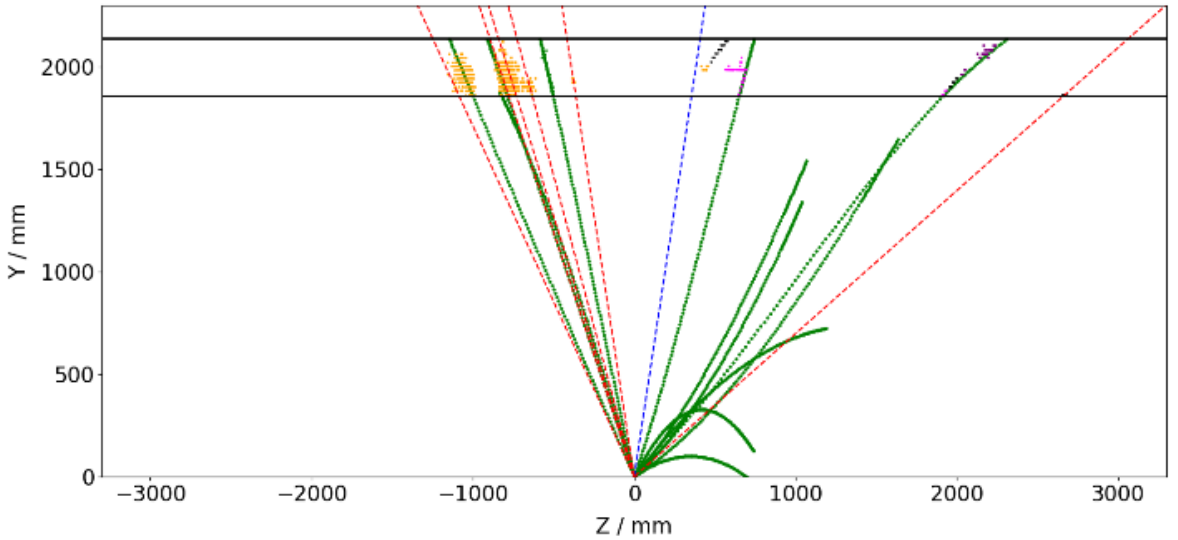
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