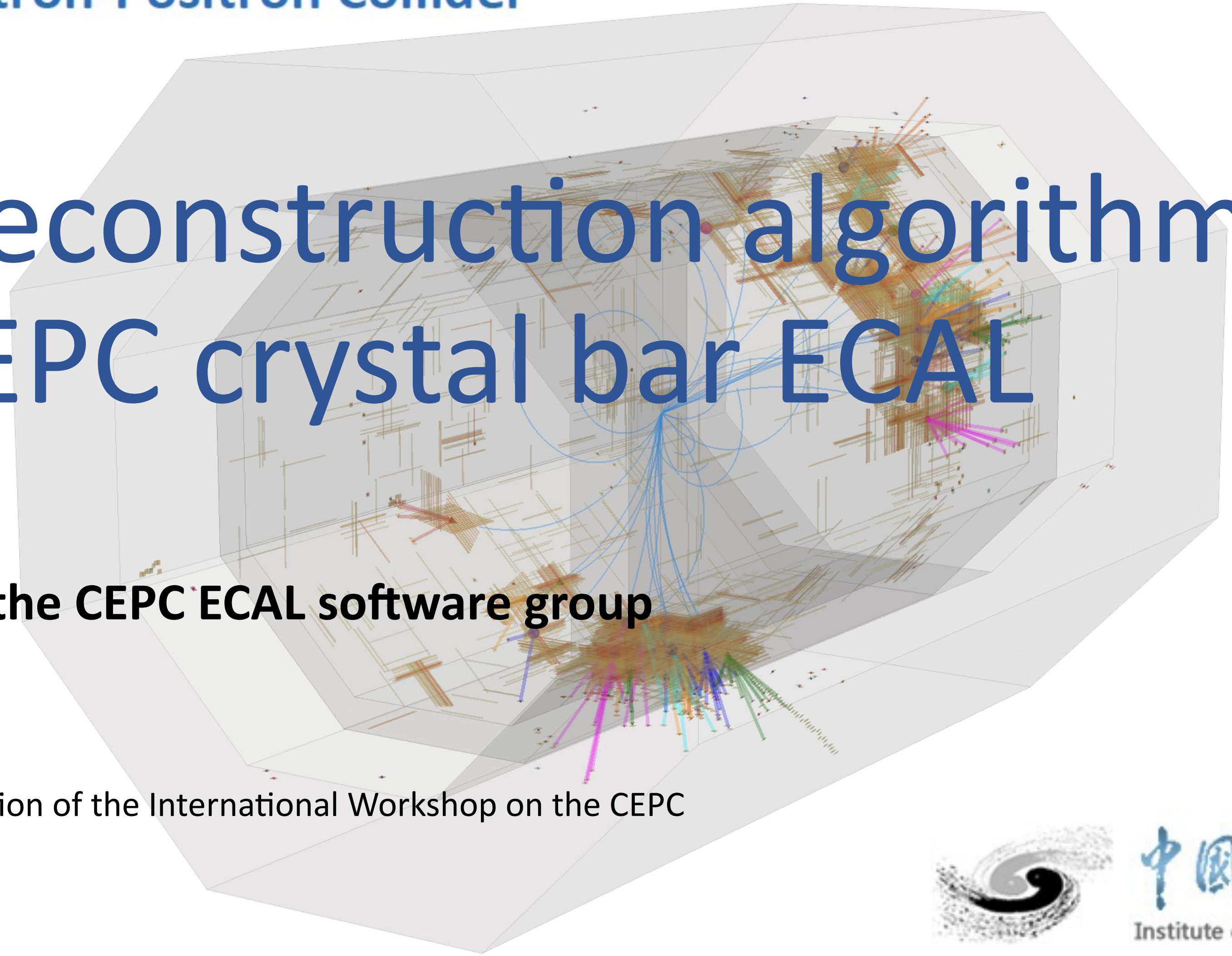
2024 European Edition of the International Workshop on the Circular Electron-Positron Collider

PFA reconstruction algorithm for CEPC crystal bar ECAL



Fangyi Guo
on behalf of the CEPC ECAL software group
IHEP, CAS

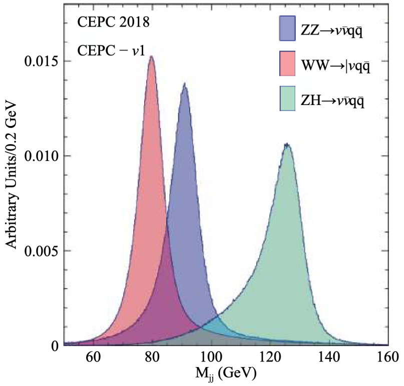
2024 European Edition of the International Workshop on the CEPC
Marseille, France
April 8-11, 2024

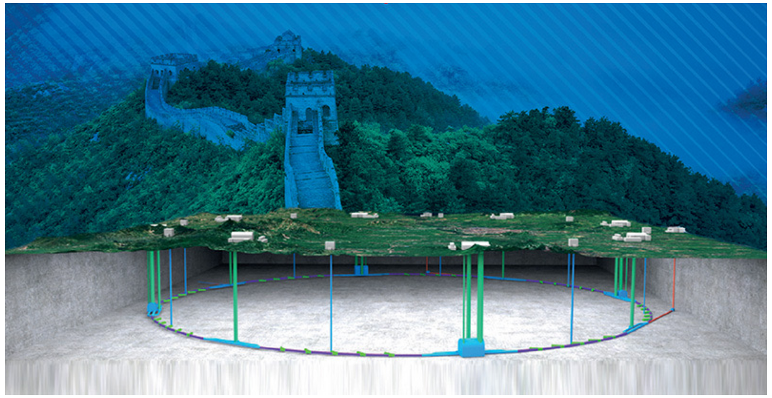
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Introduction

- **CEPC: Future circular e^+e^- collider experiment**
  - Aiming the precise measurement of Higgs/EW/top/flavor physics & BSM search.
  - Detector requirement:
    - Jet energy resolution $< 30\%/\sqrt{E}$.
    - $W/Z \rightarrow qq$ separation: BMR$\sim 4\%$.

➡ **Particle flow approach**





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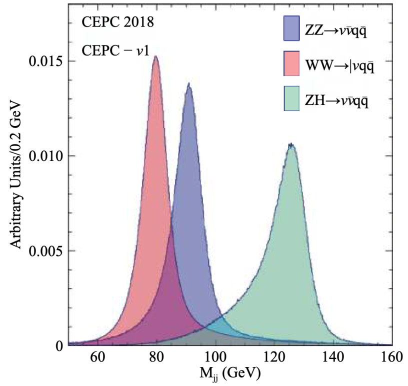
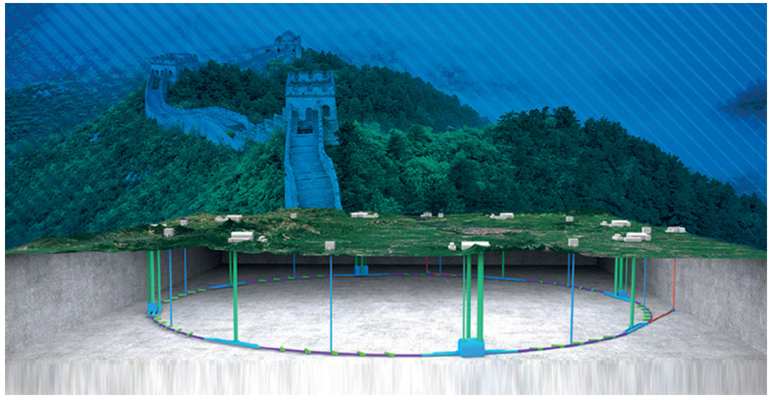
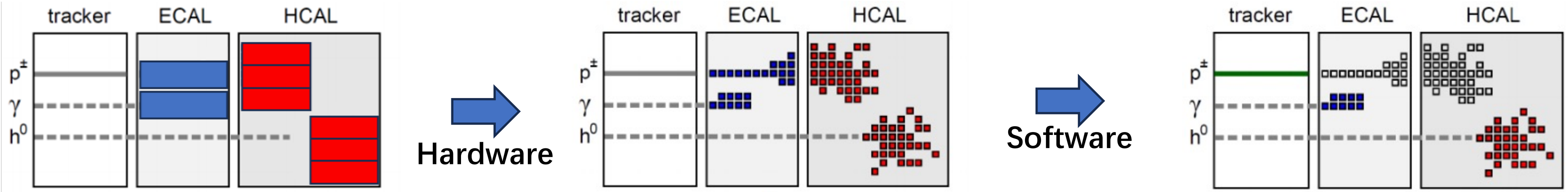




- **PFA and current PFA-originated calorimetry: hardware + software**

Hardware: separate clusters from different particles.
- High granularity.
- Compact sampling structure.

Software: correctly assign calorimeter energy deposits to the particles.
- Clustering
- Pattern recognition.



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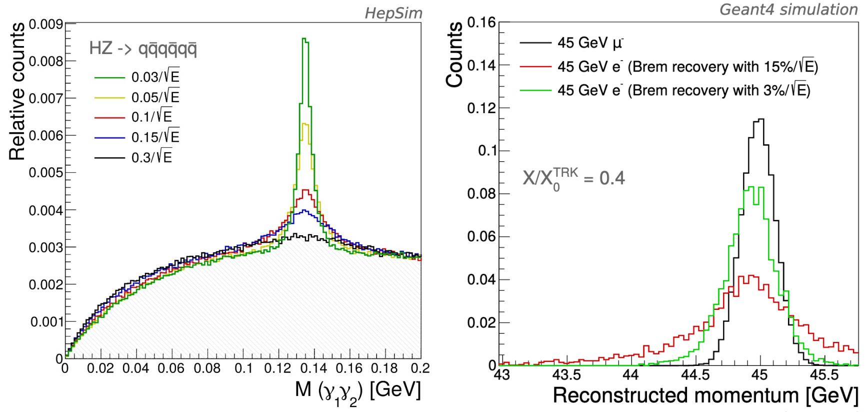
- **Homogeneous crystal ECAL for CEPC**
  - A 5D detector for PFA: spatial + energy + time.
  - Better EM resolution $\sigma_E/E \sim 3\%/\sqrt{E}$ for:
    - π^0 reconstruction in flavor physics
    - Photon recovery from bremsstrahlung



[*JINST* **15** P11005 (2020)]

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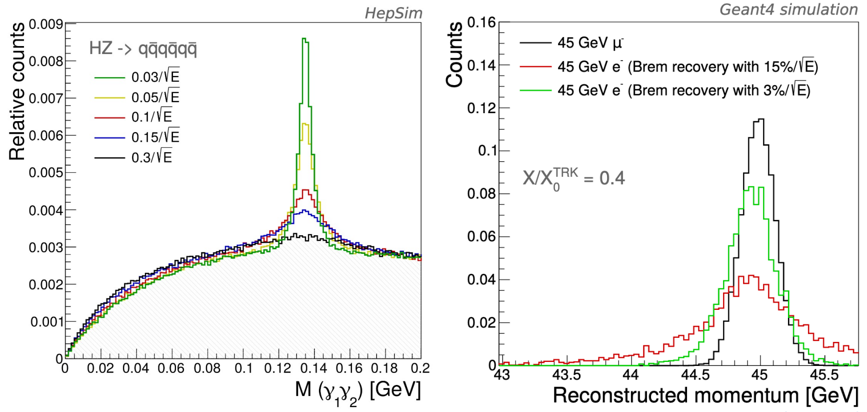

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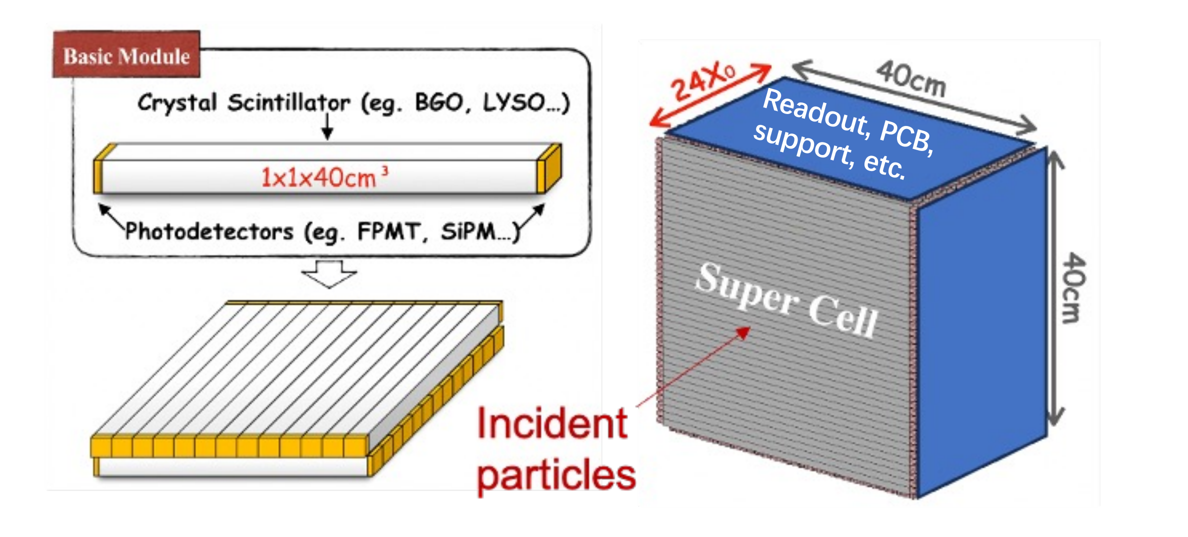
- **A novel concept: orthogonal arranged crystal bars**
  - Minimized dead material in the module.
  - O(10) less readout channels than HG ECAL.



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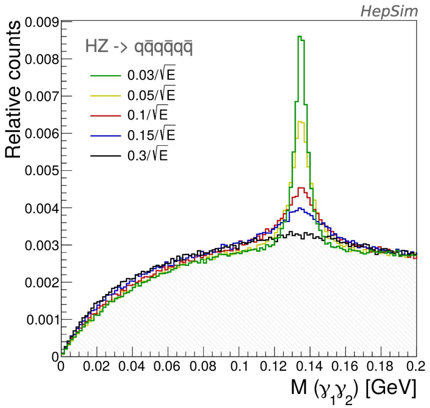

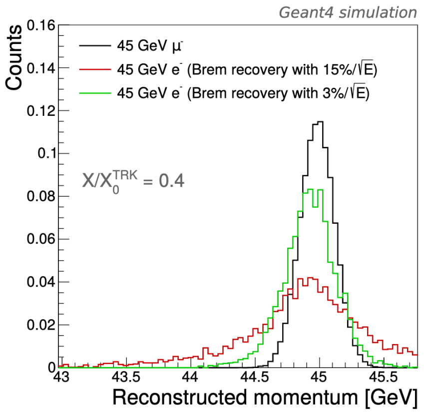

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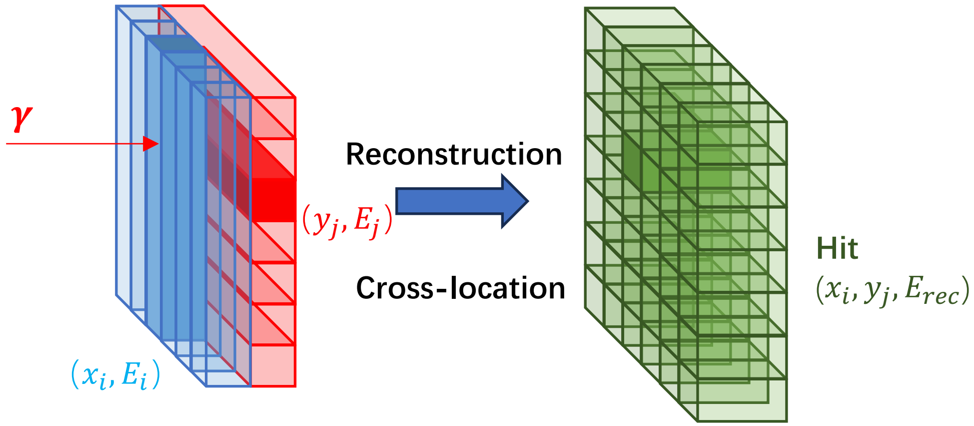

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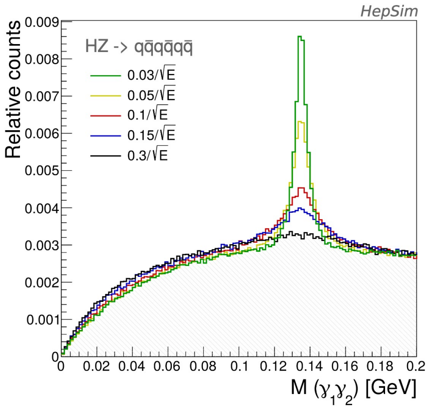

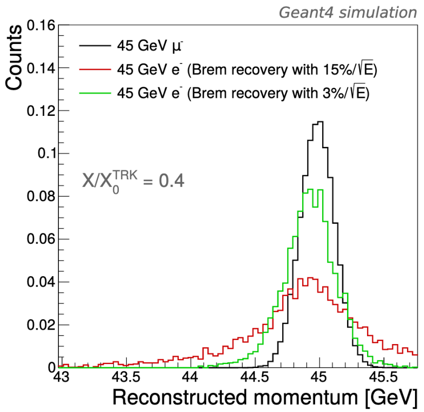

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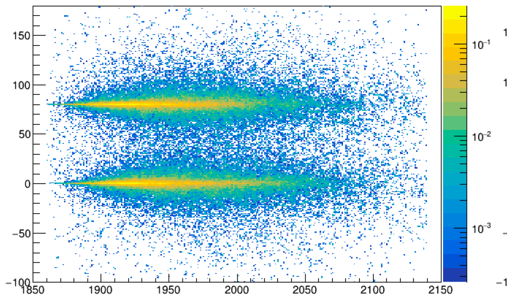
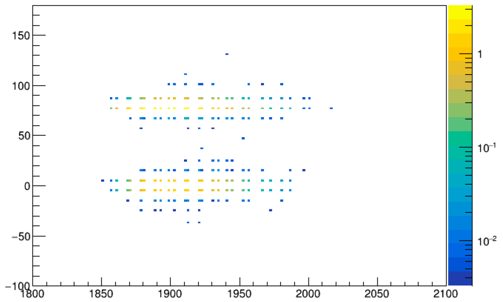


Homogeneous BGO ECAL



Sampling SiW ECAL (with threshold)

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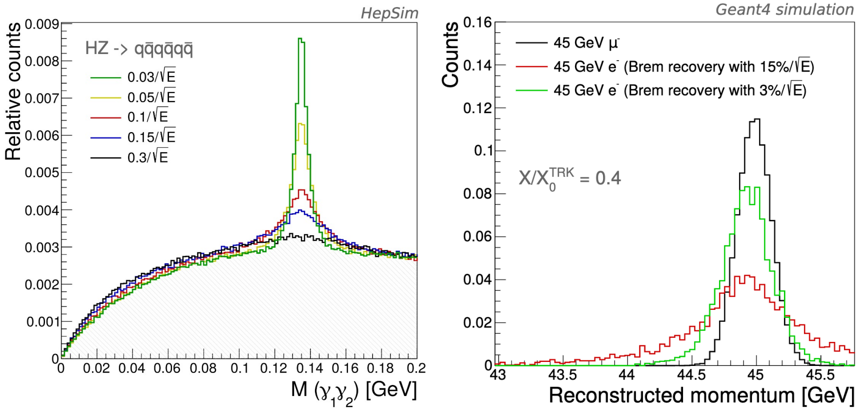

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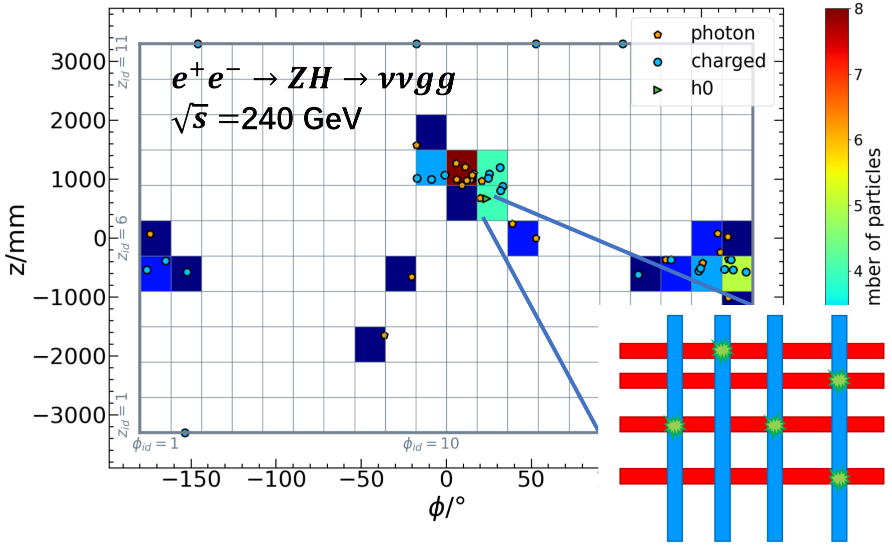
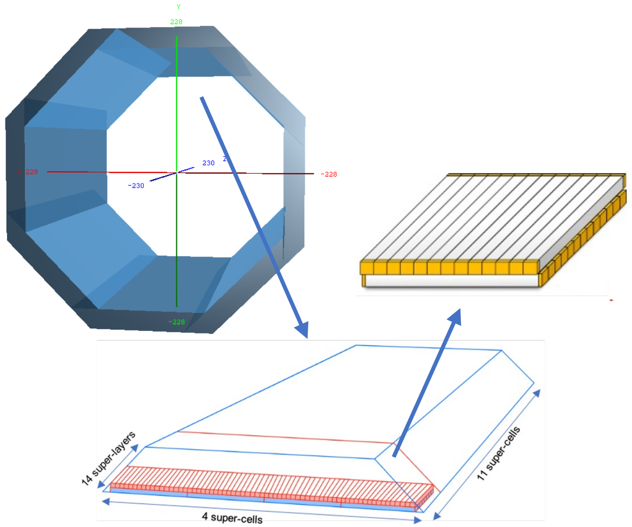
    - Multi-particle ambiguity in jet event



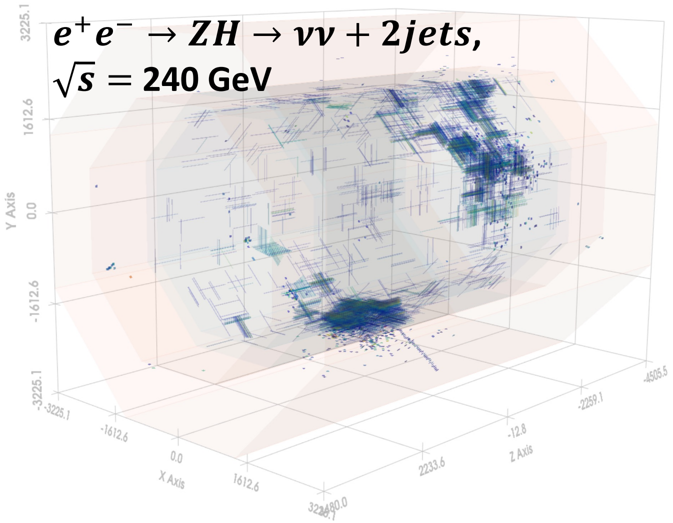
A dedicated PFA is needed for this crystal bar ECAL

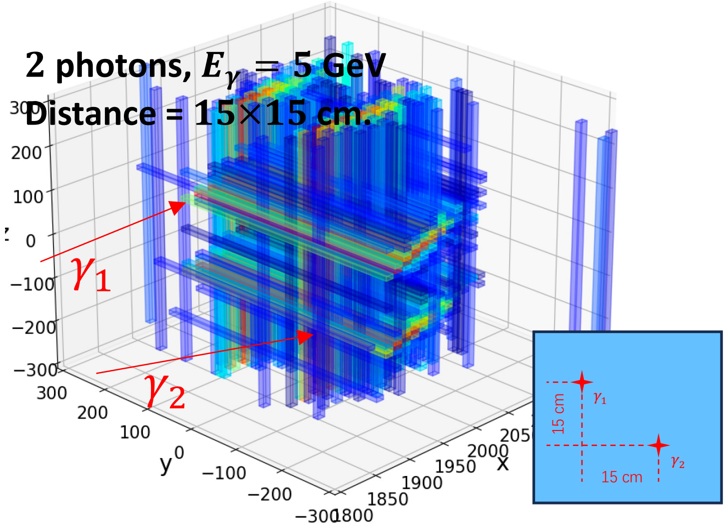
Simulation

- **Detector geometry**
  - Global: octagonal ECAL, $R = 1.86\ \mathrm{m}, L = 6.6\ \mathrm{m}, H = 28\ \mathrm{cm}$
  - Crystal Bar: $1{\times}1{\times}40{\sim}60\ \mathrm{cm}^3$
  - Super Cell: 2 layers of perpendicular crossing bars $\sim40{\times}{\sim}60{\times}2\ \mathrm{cm}^3$
  - Ideal geometry: no dead area, supporting, mechanics, etc.
  - Ideal digitization for energy and time.



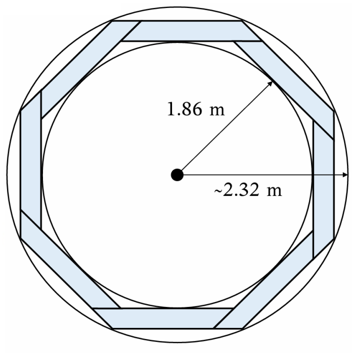
- **Event display:**

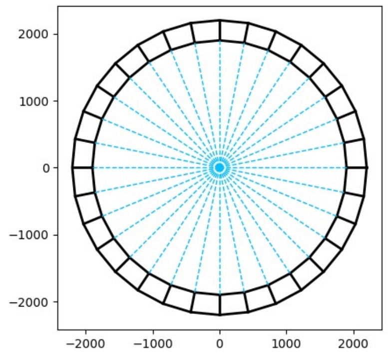


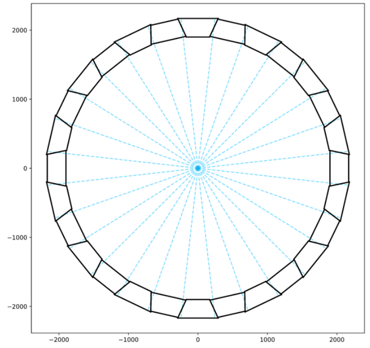


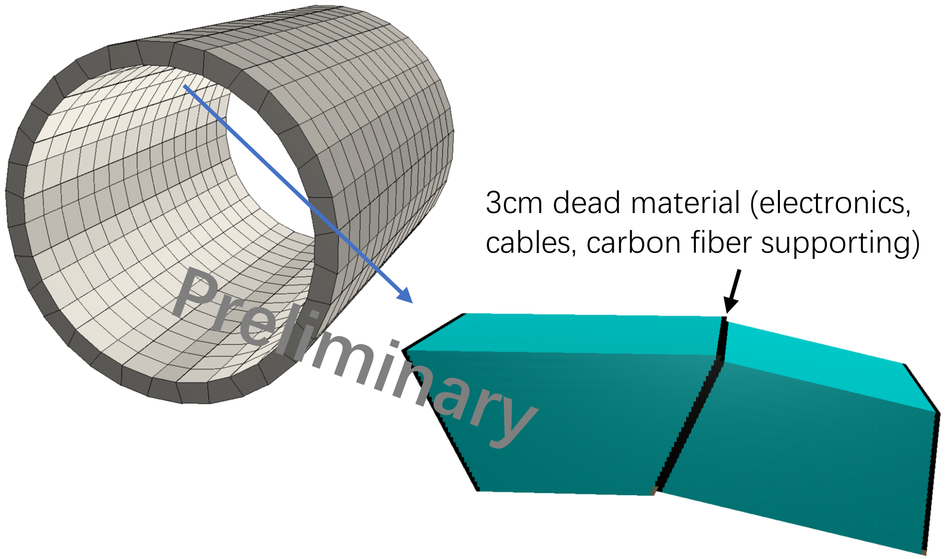
Simulation

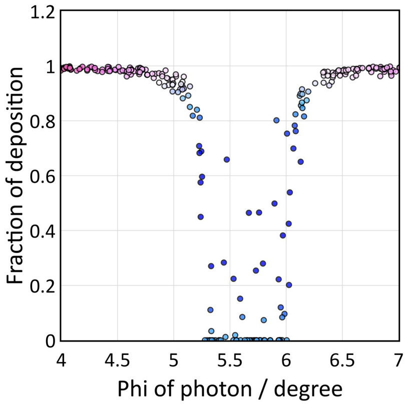
- **Optimized geometry: 32-side trapezoid ECAL**
  - More compact structure, smaller HCAL R_{in}.
  - Minimized cracks between modules.

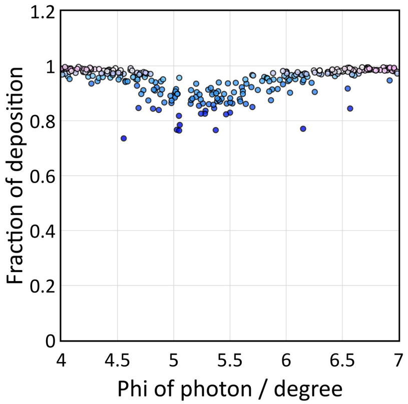








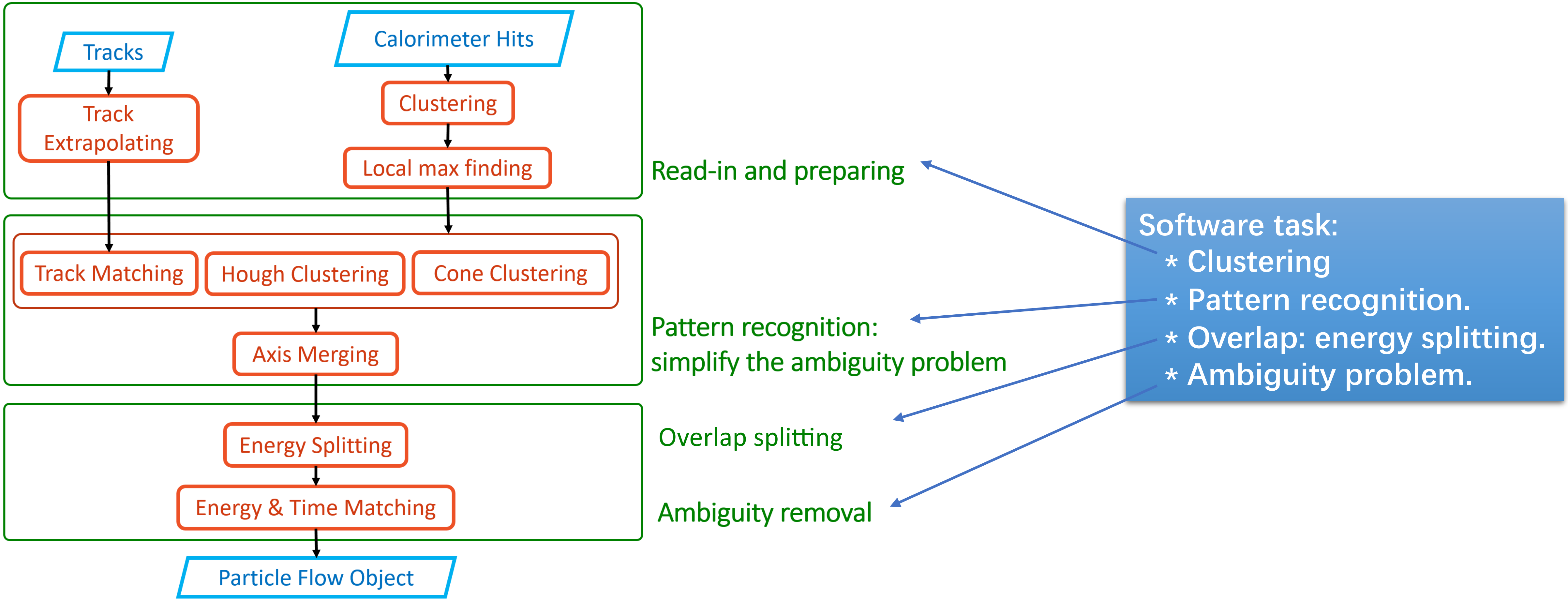




Photon energy leakage in crack region: <20%.
An energy correction is expected.

Reconstruction algorithm

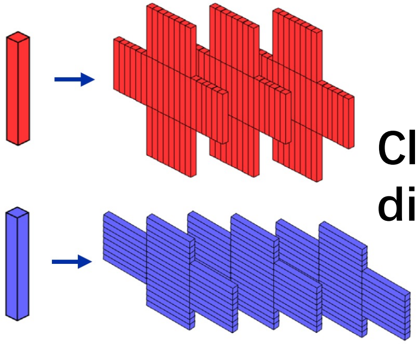
- **A pattern recognition PFA**



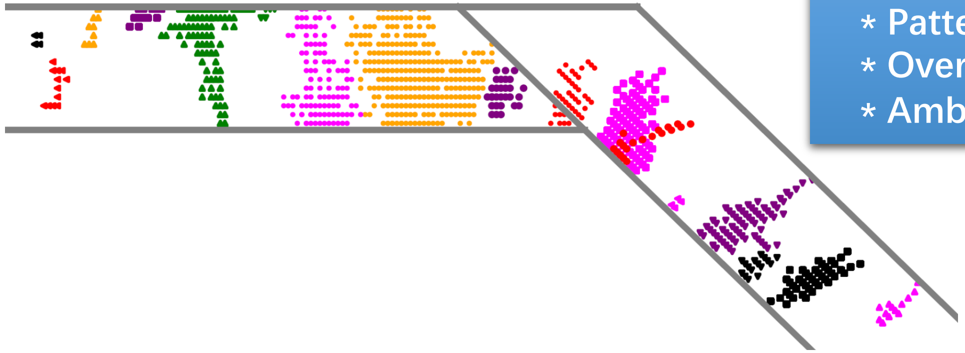
Reconstruction algorithm

- **Global neighbor clustering for pre-processing.**

Crystal bars

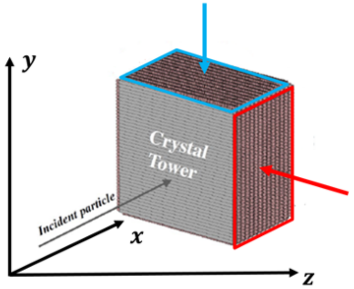


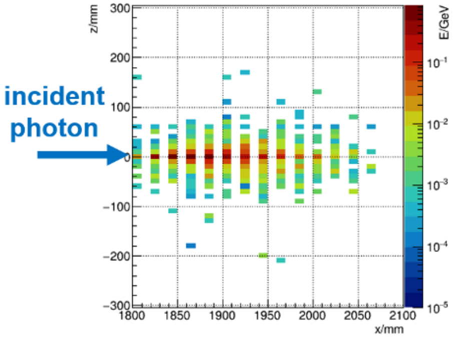
Cluster in 2 directions.



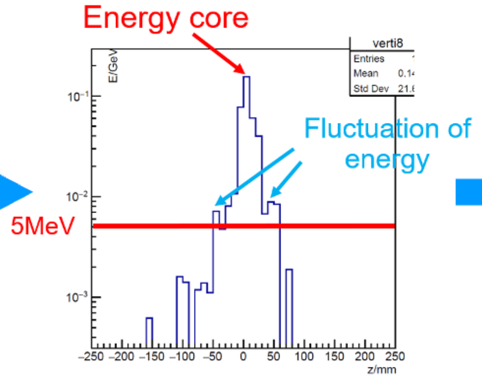
Software task:
✓ * Clustering
* Pattern recognition.
* Overlap: energy splitting.
* Ambiguity problem.

- **Shower recognition:**
  - Use the local maximum to simplify the pattern in homogeneous ECAL

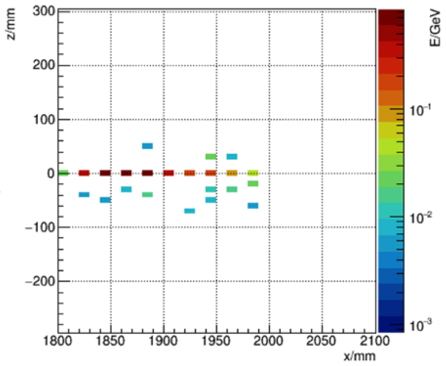




Energy deposits in crystals



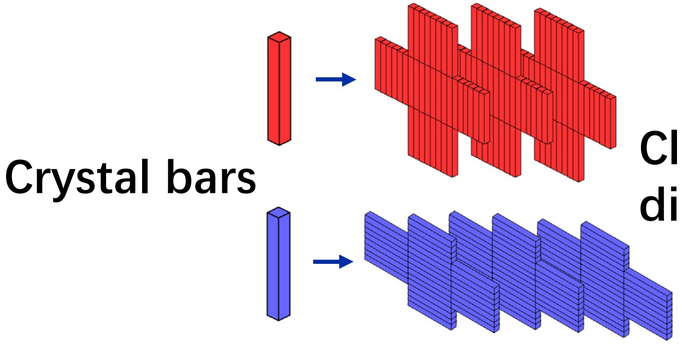
Picking out local-max in each layer

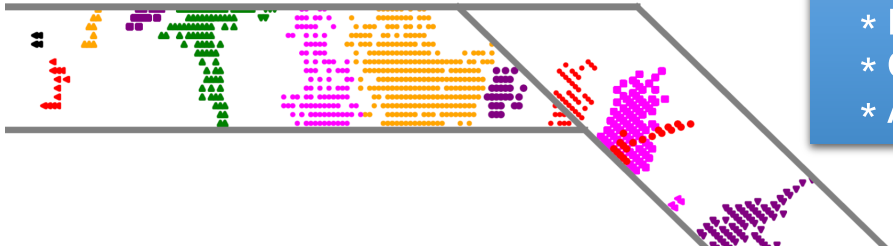


Local Maximum Distribution

Reconstruction algorithm

- **Global neighbor clustering for pre-processing.**





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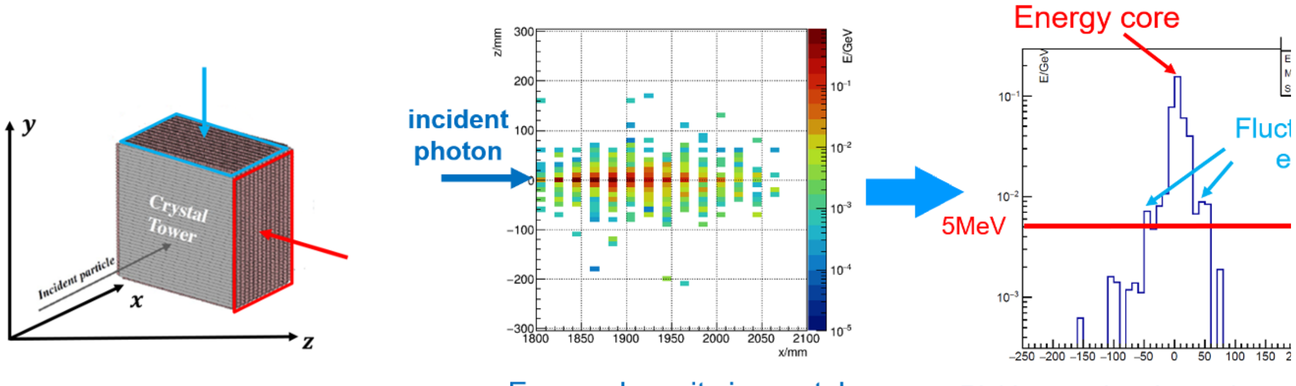
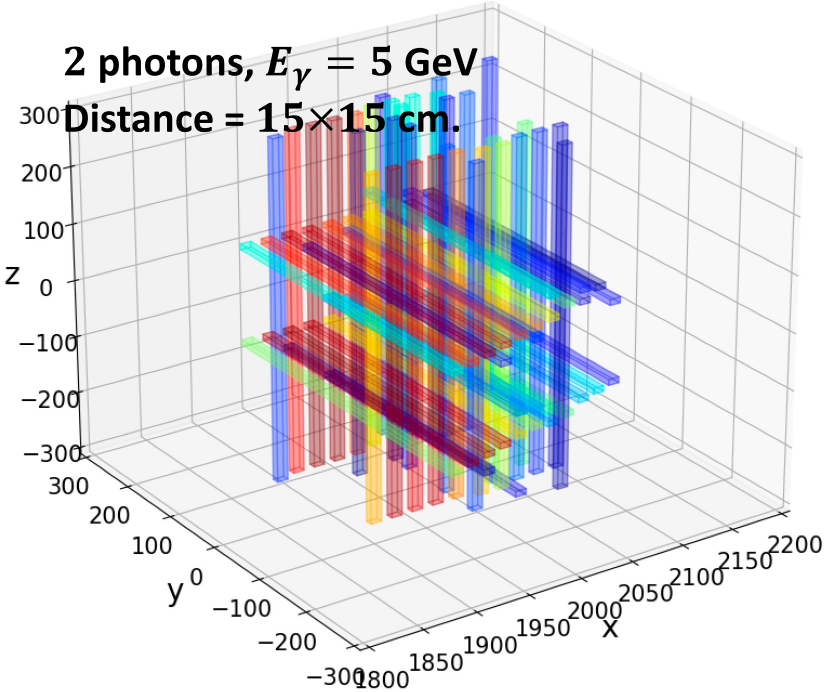


Energy deposits in crystals

Picking out local-max in ea



Reconstruction algorithm

- **Shower recognition:**
  - 3 individual algorithms for different type: track-match, Hough, Cone-clustering.
  - A set of topological cluster merging.

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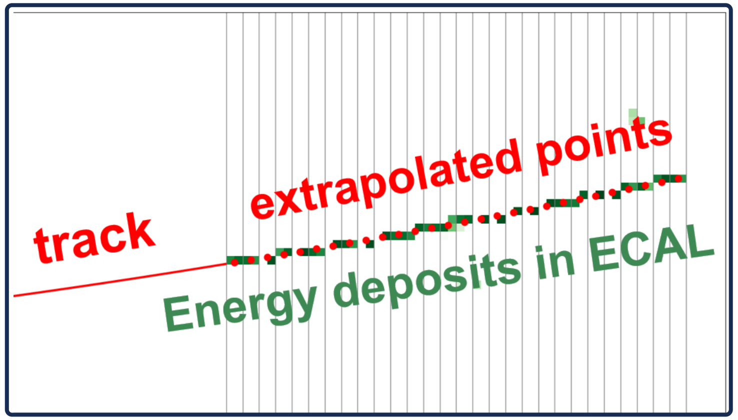

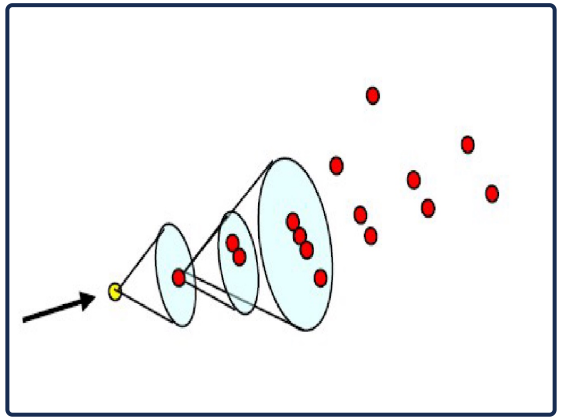

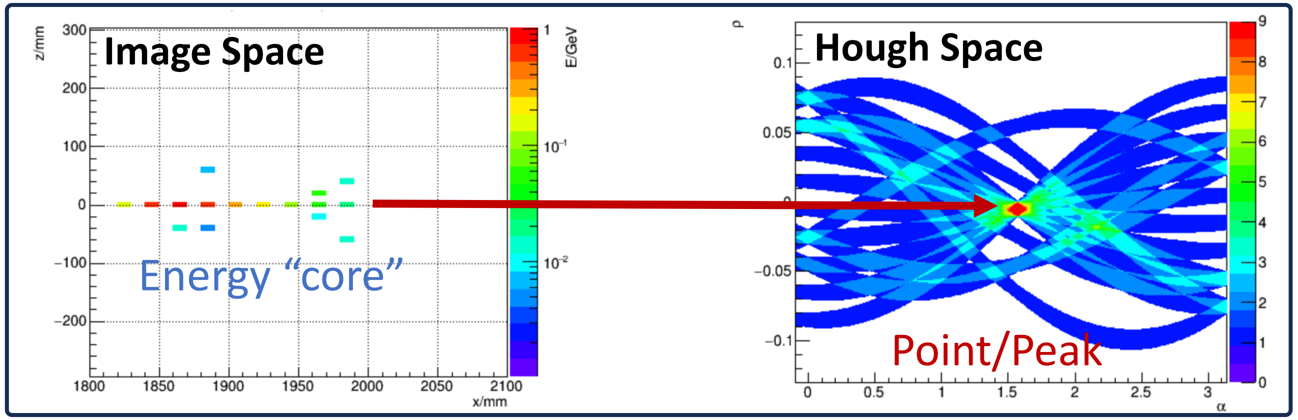

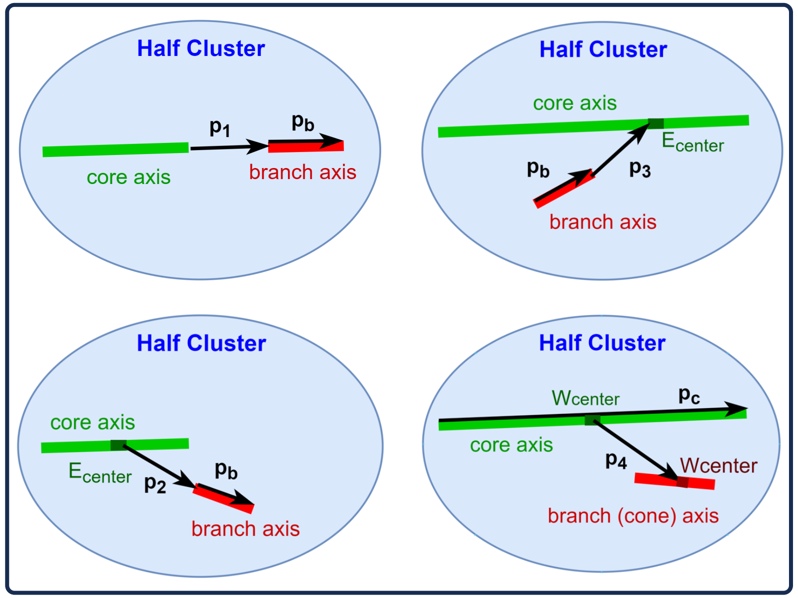

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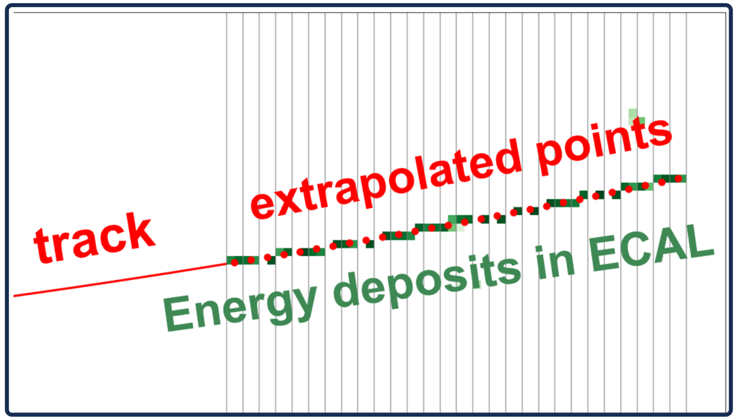
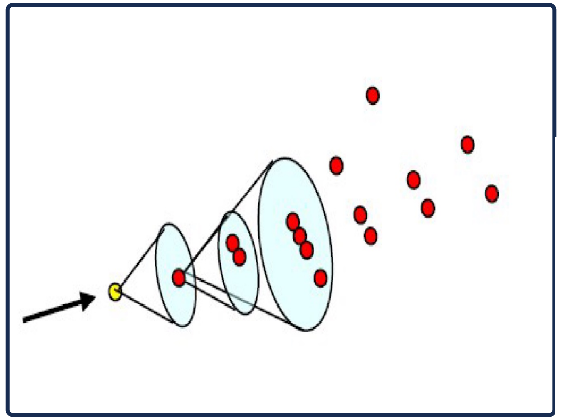
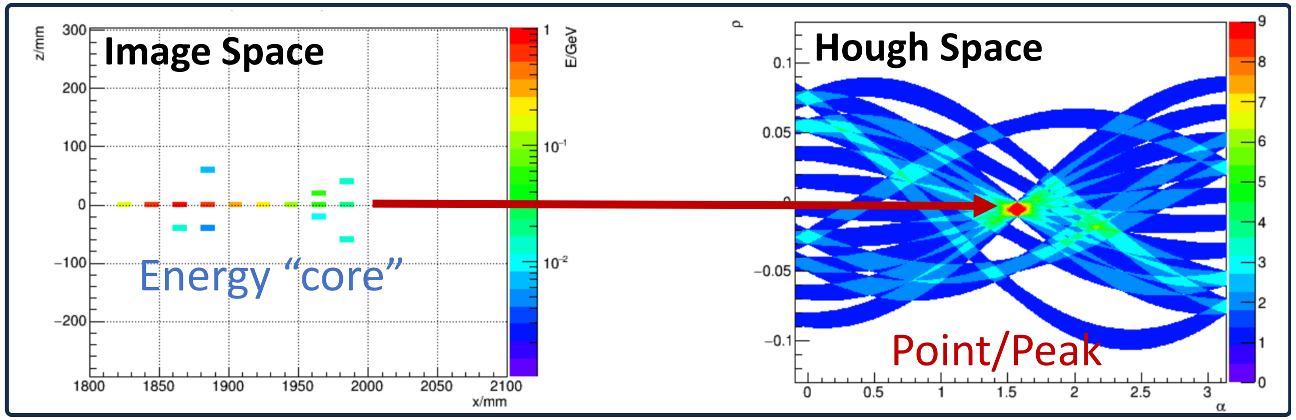
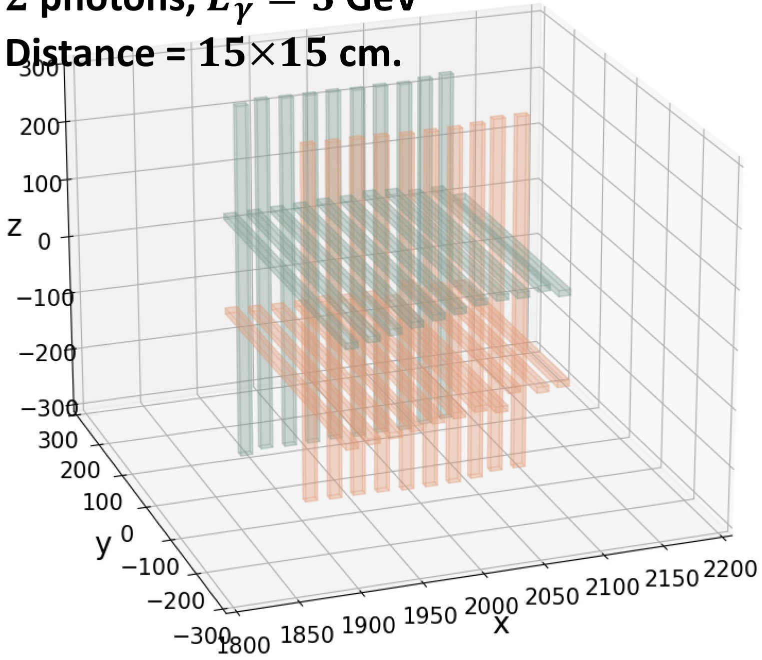






2 photons, $E_\gamma = 5$ GeV
Distance = 15×15 cm.



Reconstruction algorithm

- **Splitting for the overlapped shower:**
  - Calculate the expected energy deposition from EM profile.
    - Expected energy : $E_{i\mu}^{exp} = E_{\mu}^{seed} \times f(|x_i - x_c|)$
    - Assigned weight: $w_{i\mu} = \frac{E_{i\mu}^{exp}}{\sum_{\mu} E_{i\mu}^{exp}}$

Software task:
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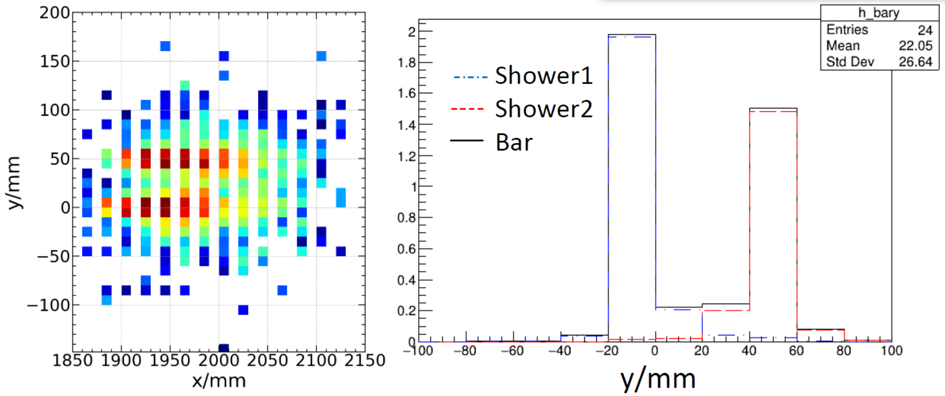
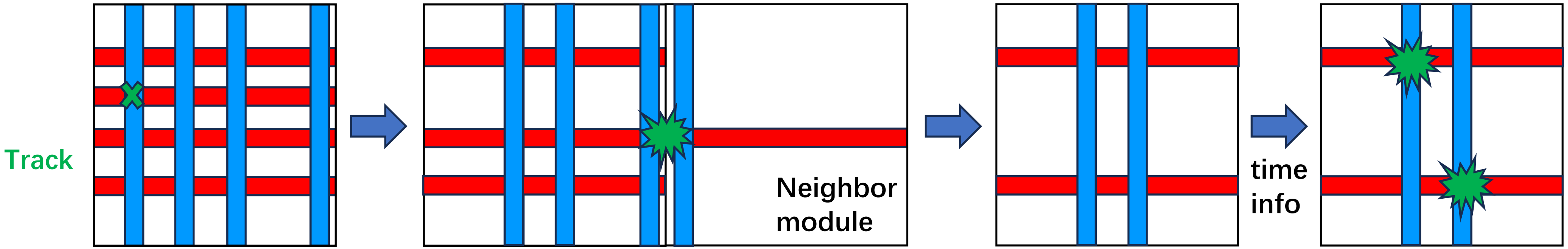
✓ * Overlap: energy splitting.
✓ * Ambiguity problem.



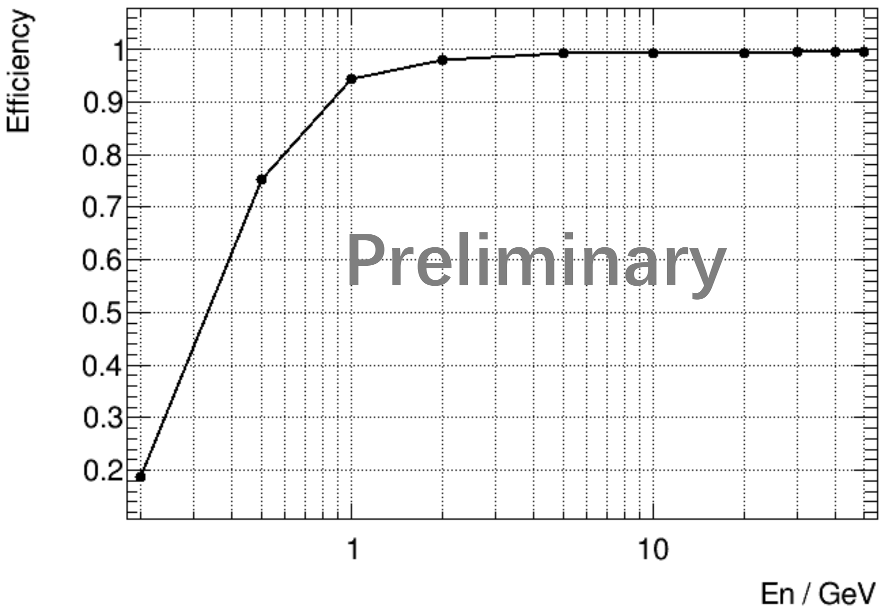
- **Ambiguity removal:**
  - Information from: track, neighbor tower, time.

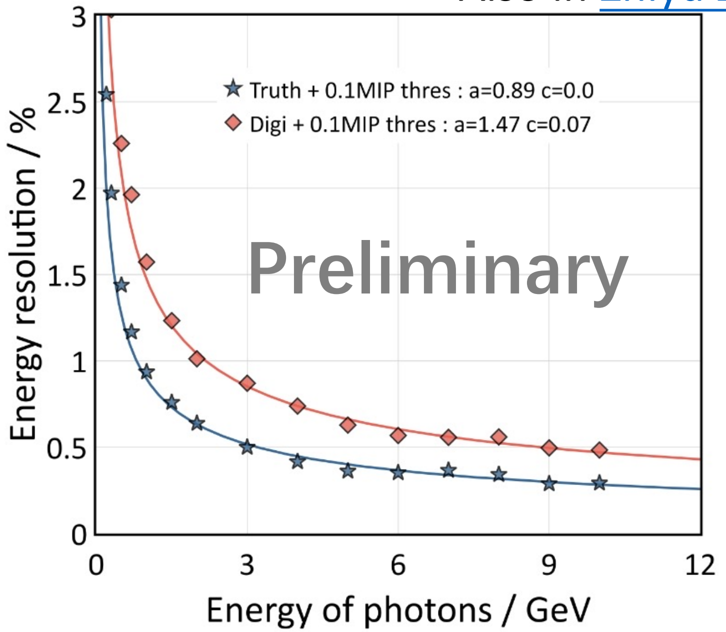


Preliminary performance

- **Single photon reconstruction**
  - Efficiency: ~100% for >1 GeV photons.
  - Energy resolution: related to digitization model.
    - A realistic model is under development, including crystal scintillation ⊕ ADC digitization and gain modes.
    - Parameters in the model comes from lab experiments.

Also in Zhiyu Zhao's talk

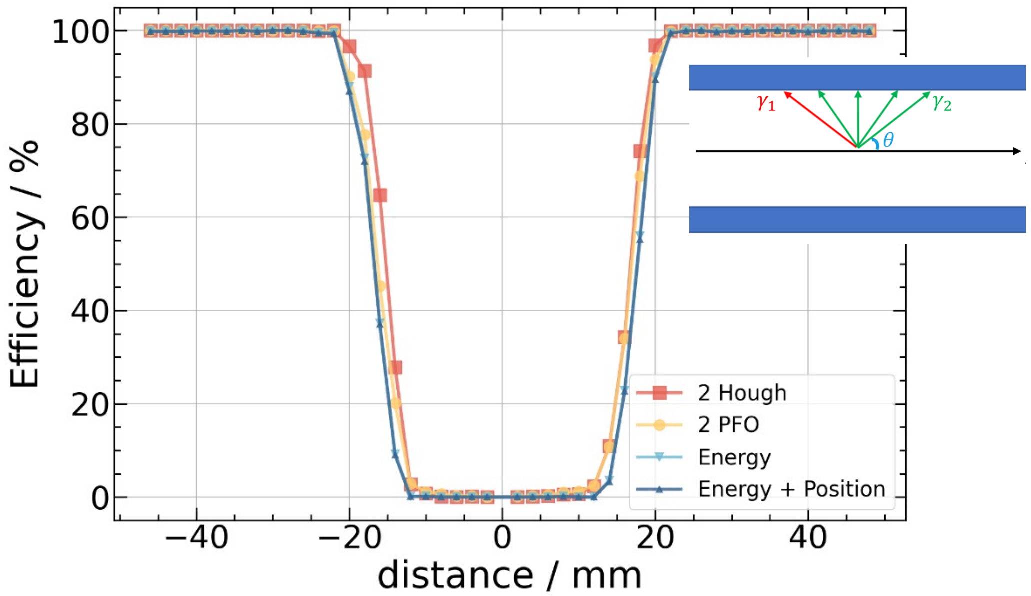




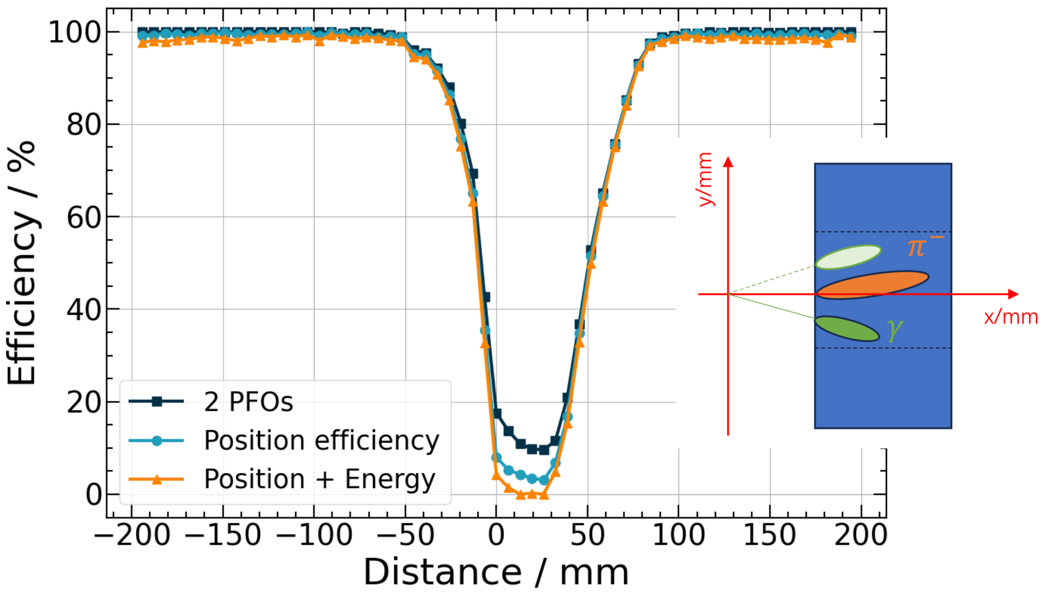
Preliminary performance

- **Close-by particle separation**
  - Key performance in PFA reconstruction.
  - $\gamma - \gamma$ separation: 2.2 cm @ 100% efficiency.
  - $\gamma - \pi$ separation: 10 cm @ 100% efficiency.

$\gamma - \gamma$ separation for 5 GeV photons

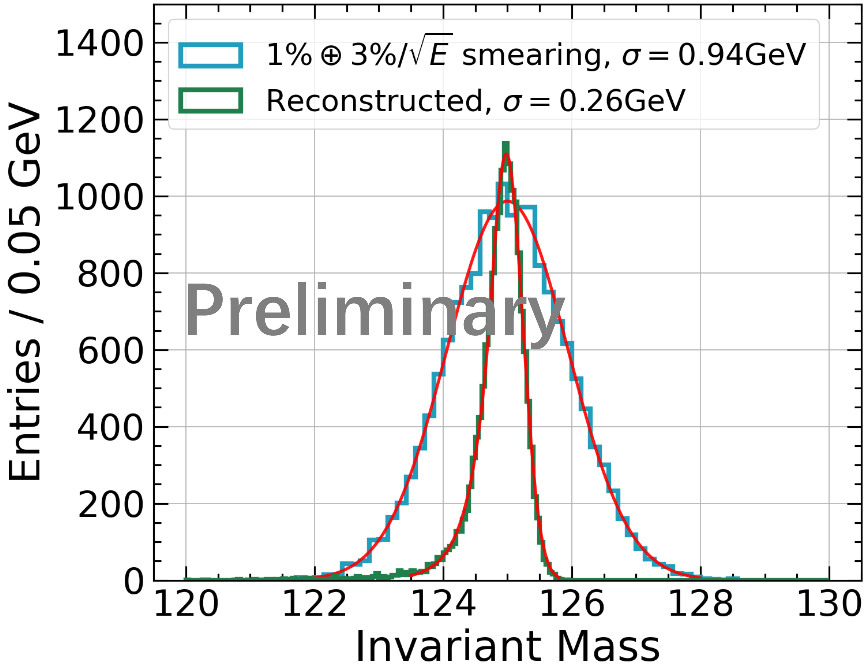


$\gamma - \pi$ separation for 5 GeV γ and π^-



Preliminary performance

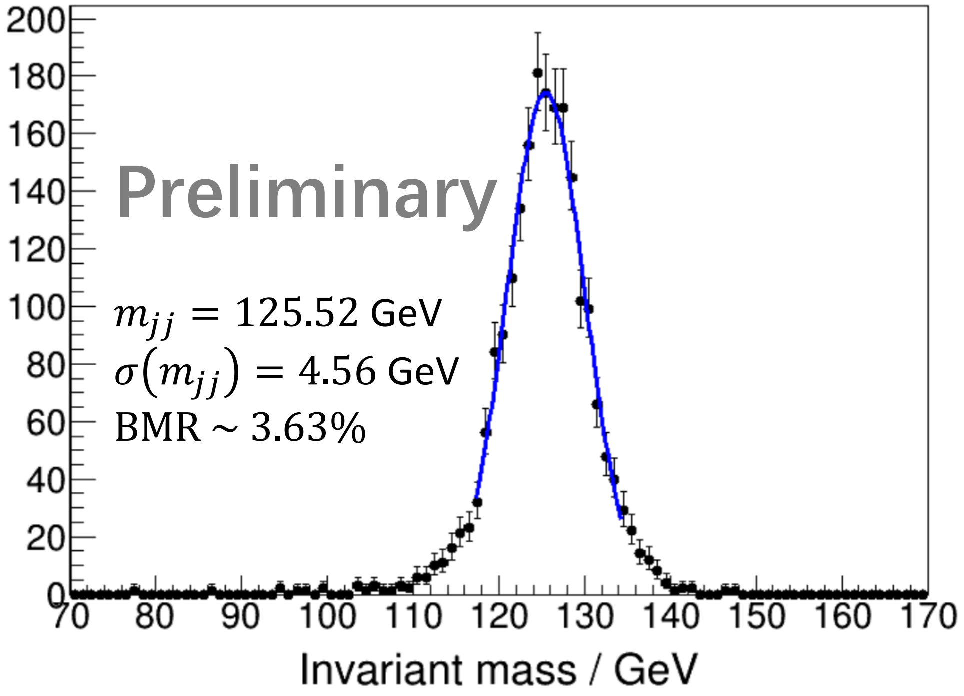
- **Physics performance: $H \rightarrow \gamma\gamma$**
  - Pure channel for ECAL performance, a benchmark channel for physics.
  - The preliminary digitization model is considered.
  - An energy correction for longitudinal leakage: $\frac{E_{dep}}{E_{inc}} = p_0 + p_1 \cdot CoreEneRatio + p_2 \cdot T_{max}Ratio$. Crack regions are excluded.



Preliminary performance

- **Physics performance: $e^+e^- \rightarrow ZH \rightarrow \nu\nu gg$**
  - Boson mass resolution (BMR) of di-jet event is essential for CEPC detector.
  - Only consider ECAL reconstruction: truth tracker + rec. ECAL + truth HCAL.

$$m_{Higgs} = \sqrt{\left(p_{mc\ charged\ particles} + p_{ECAL\ neutral\ clusters} + p_{truth\ HCAL\ neutral\ clusters}\right)^2}$$



Already included:
- Intrinsic energy resolution of ECAL and HCAL.
- Reconstruction efficiency in ECAL.
- Confusion and ambiguity in ECAL.
- Track mis-matching.

Missing for a full PFA:
- Track efficiency and resolution.
- HCAL efficiency and confusion.

Summary and prospects

- **A novel crystal ECAL design for CEPC Reference detector**
  - Optimal EM resolution, excellent low energy sensitivity, lower cost.
  - R&D progresses in hardware are introduced in Zhiyu's talk.
- **A dedicated pattern recognition PFA**
  - Main challenges are the shower overlapping and ambiguity.
  - Very promising separation power and a preliminary BMR are derived.
- **Next step: a full PFA with:**
  - Optimized 32-side ECAL geometry.
  - Realistic digitization model.
  - Energy correction for the cracks between modules.
  - Full tracker and HCAL reconstruction.
  - For better understanding: decouple the contributions in current BMR / JER.

Thank you for your attention!