East Asian ZDC simulation efforts

Far forward meeting, Feb 3, 2026

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Starting point and aim

- Test different geometries: Baseline, HCAL only, various WSi+HCAL settings
- calculate angular and position resolutions for photons and neutrons, find best way to extract it (energy weighting, 3d image recognition, other algorithms, etc).
- classify clustering efficiency for Lambda decays as a function of closest gamma-neutron separation at ZDC front, or closest endpoint distance and as a function of Lambda energy and decay position, etc.
- calculate overall Lambda reconstruction efficiency
- calculate Lambda decay position, energy resolution and corresponding t or Δ resolution (initially use just single Lambda energies and angles to obtain t for different proton beam energies, then reweight using actual pion Sullivan MC distributions)
- try to reproduce UCR Lambda study: Confirm their findings given their assumptions and critically check these assumptions (especially use of π^0 mass for photon pair). Explicitly show why inclusion of Si Pad/Pixel layers improve the Lambda reconstruction, efficiency and resolutions
- neutron early showers (already in EMCAL part): how much does this affect clustering, neutron energy resolution, neutron direction?
- timing possibility with AC-LGADs: neutron identification using time-of-flight, for which neutron energies could this be used? This is likely only possible for early showers with high imaging layer hit multiplicity (rare). Could that help in the clustering?
- longer term: move from hits to more realistic reconstruction (digitization,etc), add Lambda reconstruction and all steps (clustering, etc) to eicrecon.

Participants

- Academia Sinica (Taiwan): Chia-Yu Hsieh
- Sejong University (Korea): Saehanseul Oh, Yongsun Kim, Gyeongjun Kim, Yeonwoo Park
- Shinshu University (Japan): Kentaro Kawade, Koki Nakamoto
- Uconn (US): Alessio Illari, Gursimran Kainth
- RIKEN (Japan): Yuji Goto
- Kobe University(Japan): Yuji Yamazaki
- Tokyo City University (Japan): Marco Meyer-Conde

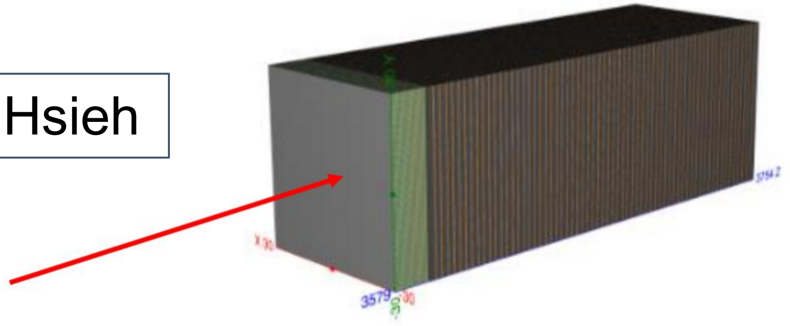
Current status of each group

Yeonwoo Park

Group	Configuration	Setup	Observable
Taiwan (Chia-Yu)	Ecal + Hcal	Common: 10K events, Shot beam along z-dir (-15mm, -15mm, z) γ: 0.1 - 40 GeV n: 10 - 300 GeV	Analyze MC to get position resolution - Fit pol1
Korea	Hcal WSi + Hcal 20 layers 2 pixel layers	Common: 10K events, φ = 90 °, Crossing Angle = 0, Gun position = (0, 51.567 mm, 14324 mm) γ: 20 GeV, θ = 6 mrad n: 209 GeV, θ = 3.6 mrad Λ: 250 GeV	LSM, CNN -Solid angle
Shinshu (Kentaro)	WSi + Hcal 12 layers 3 pixel layers	Common: 10K events, θ = 0 rad γ: 25 - 100 GeV n: 50 - 200 GeV Λ: 200 GeV	GNN -x, y position resolution
Uconn (Alessio)	WSi + Hcal 20 layers Pad layers	Common: 10k events, shot at varying angles γ: 30 GeV n: 80 - 260 GeV	fit the angular resolution distributions

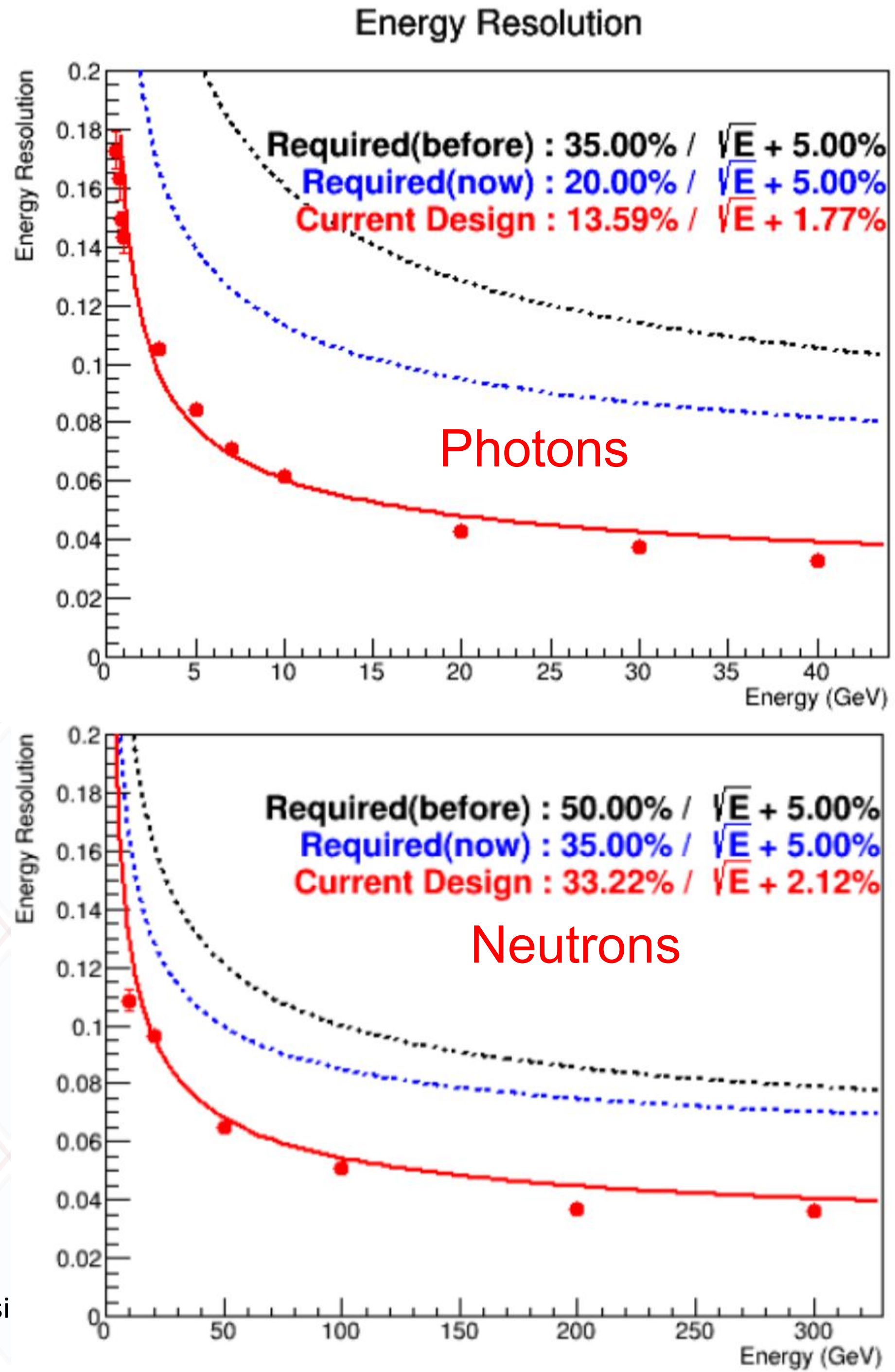
Baseline detector resolutions

Chia-yu Hsieh



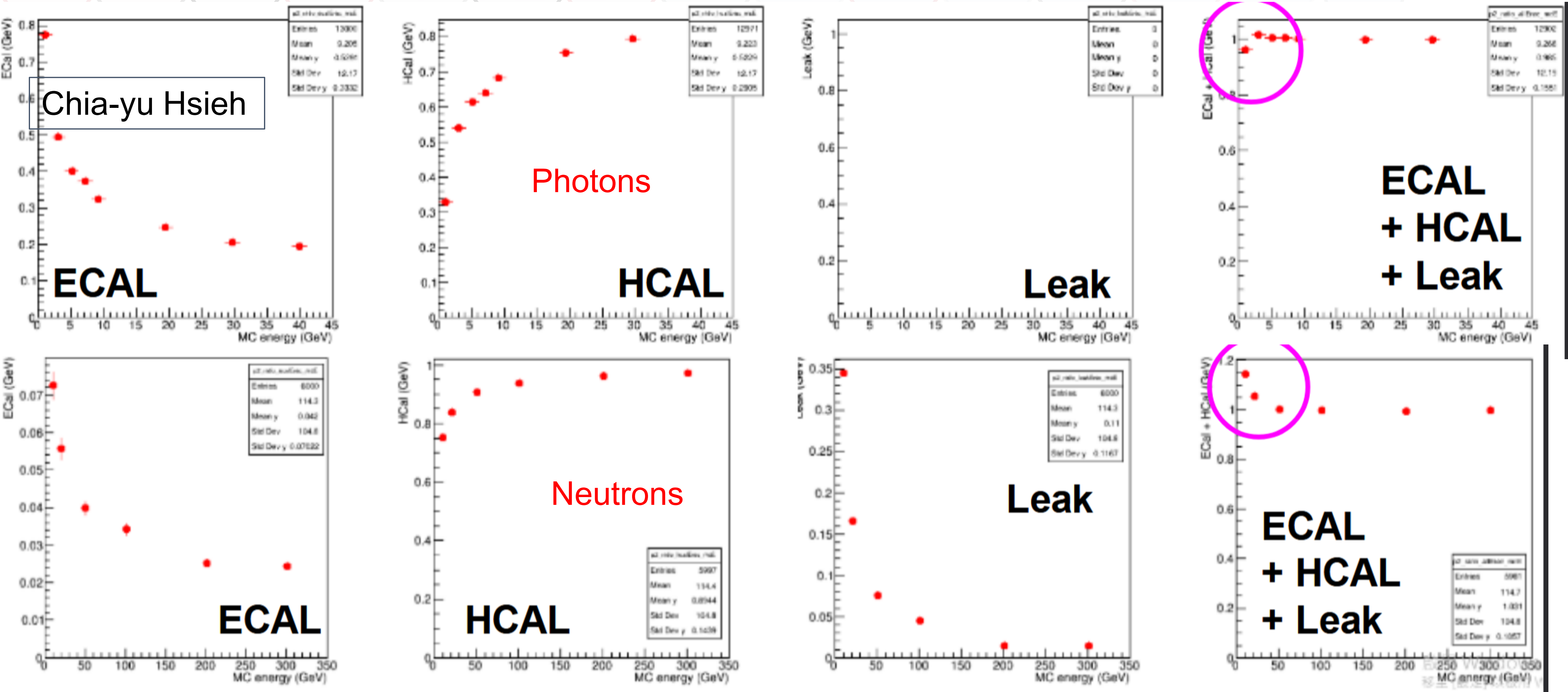
pencil beam

- Put detector straight along z-dir
- Shoot beam along z-dir @ (-15mm, -15mm, z)
- **1GeV - 40GeV gamma (pencil beam)**
- **10GeV – 300GeV neutron beam (pencil beam)**



- In Baseline configuration: good energy resolutions in ECAL+HCAL (currently based on raw hits w/o digitization)

Energy reconstruction in Baseline detector



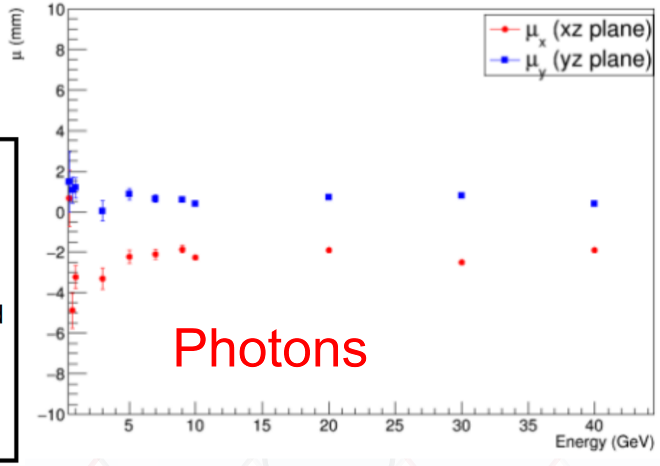
Energy not well reconstructed for neutron<50GeV

Position/angular resolutions

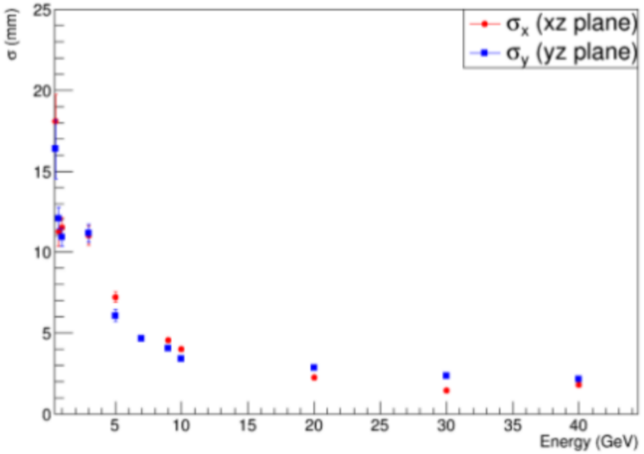
- **Steps**

Step 1 — Layer by layer weighted position
For each detector layer, a single representative hit position is calculated by averaging all hit positions in that layer, weighted by their deposited energy.
Step 2 — Energy-weighted layer
Each layer contributes one position to the track fit, with a weight proportional to the total energy deposited in that layer. As a result, layers with larger energy deposition have a stronger influence on the fit.
Step 3 — Fitting xz and yz planes
Linear fits (pol1) are performed independently in the **XZ** and **YZ** planes to obtain the track parameters.
Only HCAL is included in track reconstruction for now.

Mean/Bias VS Energy



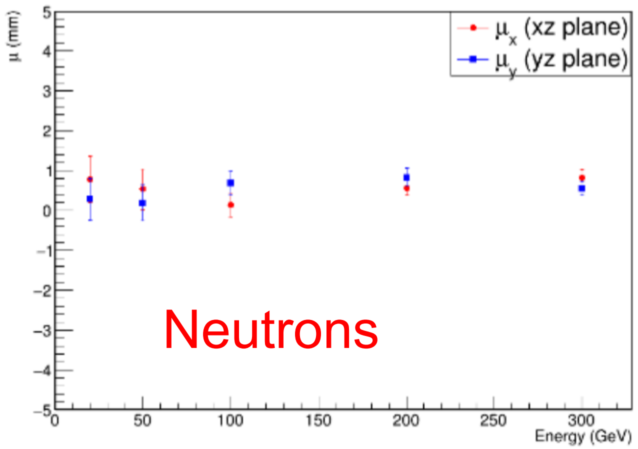
Sigma/Resolution VS Energy



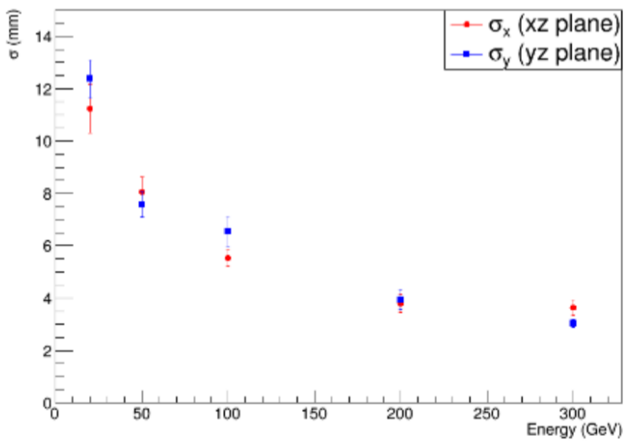
- **Only events with energy > 0.5 GeV are shown.**
- A small bias of approximately **2 mm** is observed in the **x** direction, while **no significant bias** is seen in **y**.
- The position resolution is **similar in x and y**, at about **2 mm**.

- Results comparable to the UCR studies

Mean/Bias VS Energy



Sigma/Resolution VS Energy

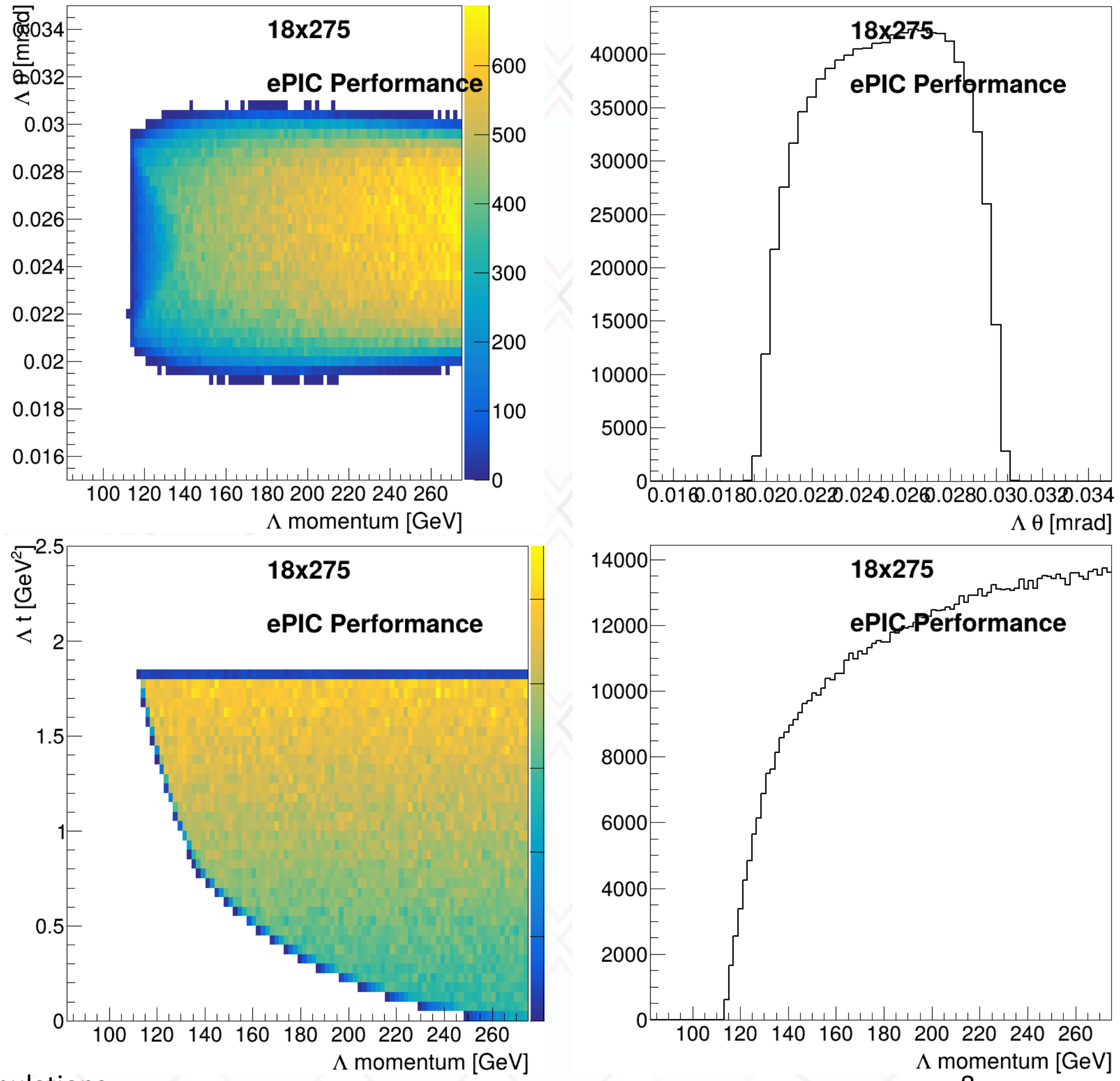


- **Only events with energy > 10 GeV are shown.**
- A small bias of approximately **0.5 mm** is observed in both **x and y** direction.
- The position resolution is **similar in x and y ~ 3 mm with 300GeV neutron beam.**

Chia-yu Hsieh

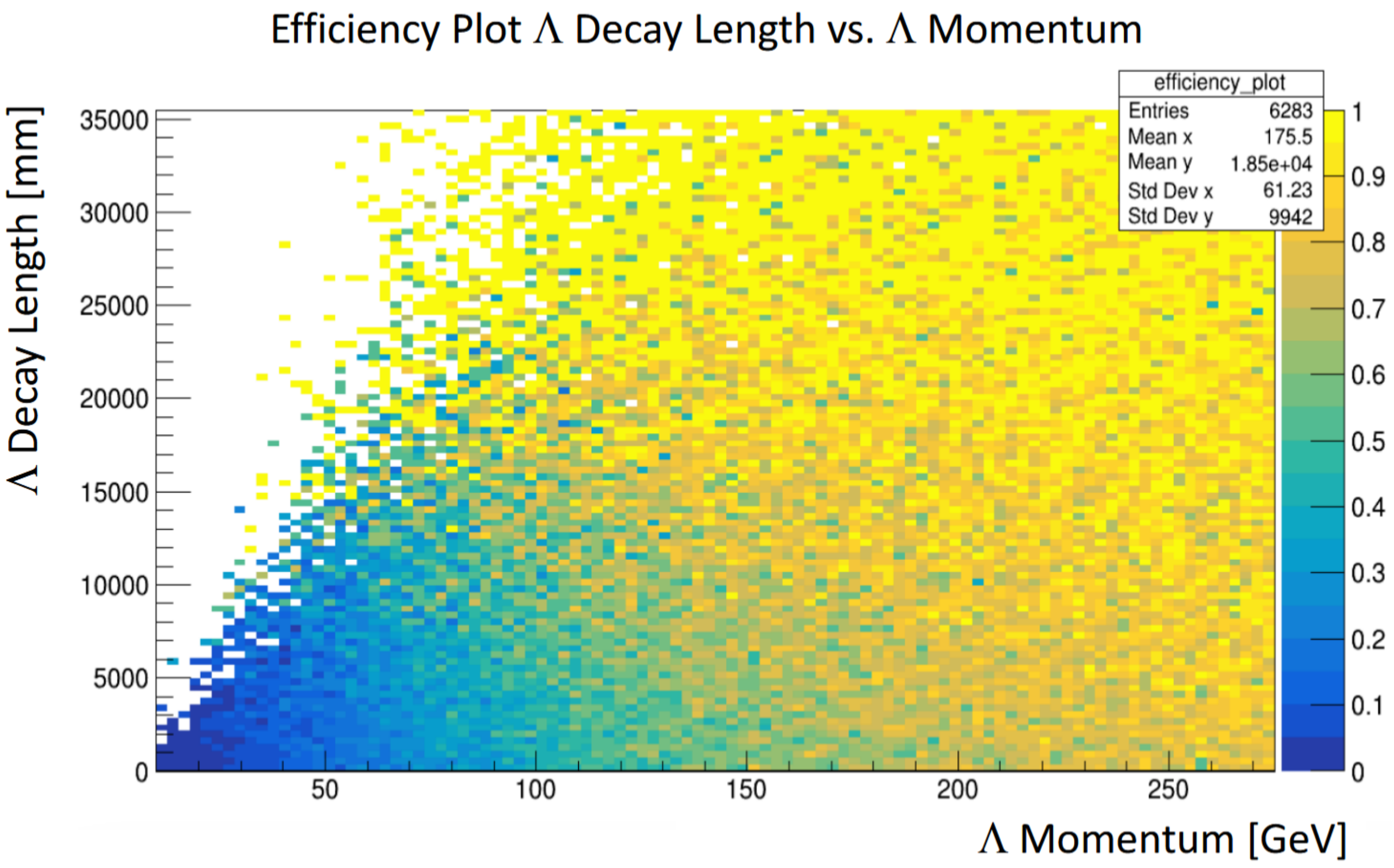
Lambda simulations from meson structure group

- Meson structure group information and simulations https://jeffersonlab.github.io/meson-structure/data.html
- HepMC files like root://dtn-eic.jlab.org//volatile/eic/romanov/meson-structure-2025-10/afterburner/18x275-priority/k_lambda_18x275_5000evt_0001.afterburner.hepmc can be read via xrdfs or copied via xrdcp and input into dd4sim
- MC files seem to be elastic Kaon scattering e+p→e'ΛK
- Not yet intensively used by ZDC simulation studies



ZDC Acceptance Studies

A.Illari, G. Kainth

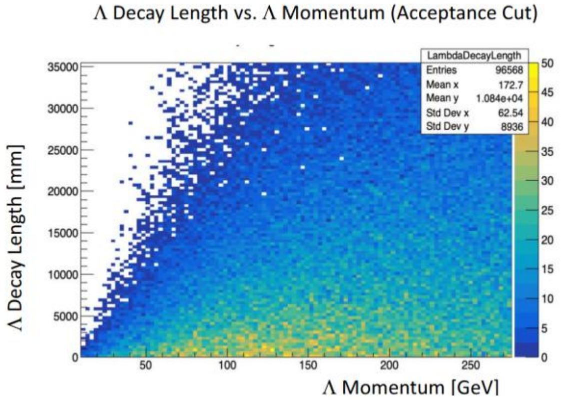


Highest Efficiency:

- Lambda baryons with higher momentum and later decays have a higher change of reaching the ZDC

Reconstruction:

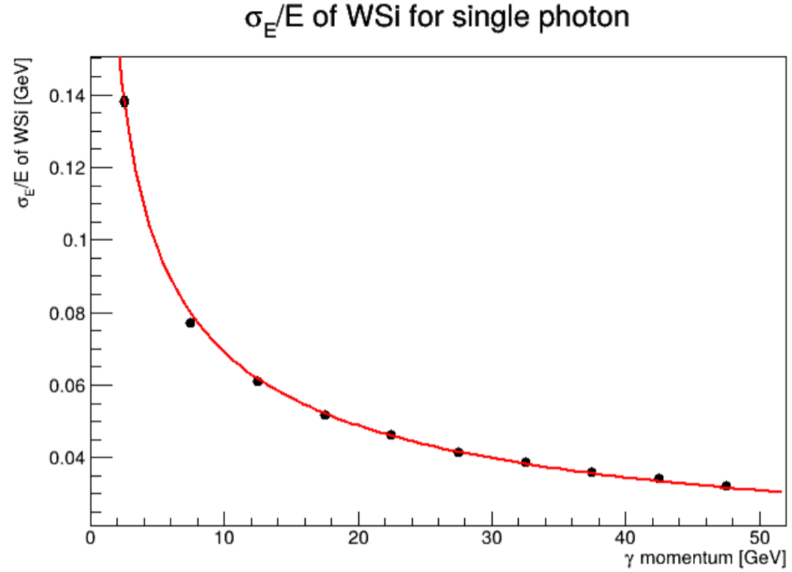
- Result in overlapping showers from neutron and photons

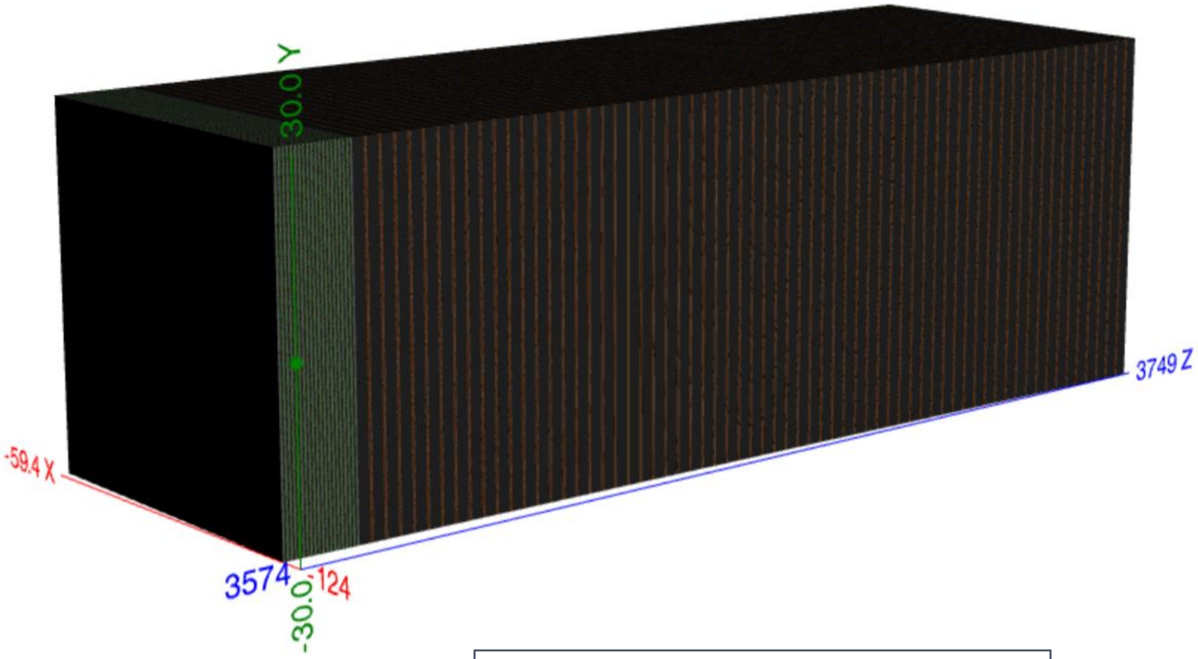


Lambdas pointed at Center of ZDC, no angular distribution included, yet

WSi Geometries

- Common Design
  - Moved SiPM HCal back
  - Reduced airgap from 5mm to 1mm
  - 20 layers of 3.5 mm W layers
  - WSi Geometric Length 120mm
  - Removed air facing Si
- 4 Designs so far:
  - Design 0: Only 1 cm^2 pads
  - Design 1: HG layers 3, 6, 9
  - Design 2: HG layers 4, 8, 12
  - Design 3: HG layers 5, 10, 15
- Available here:
  - Github link





A.Illari, G. Kainth

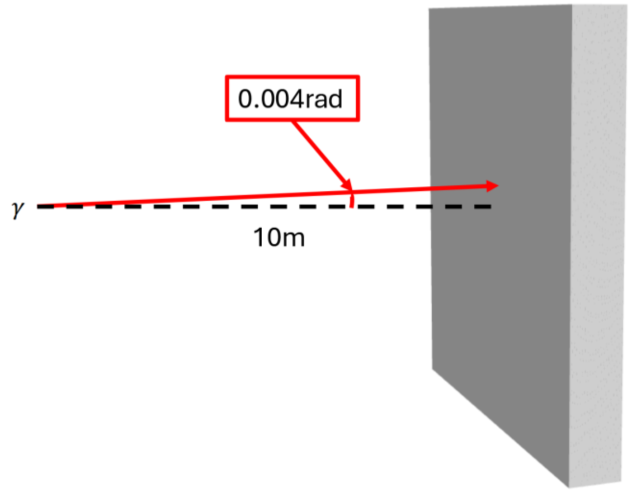
UCONN
UNIVERSITY OF CONNECTICUT

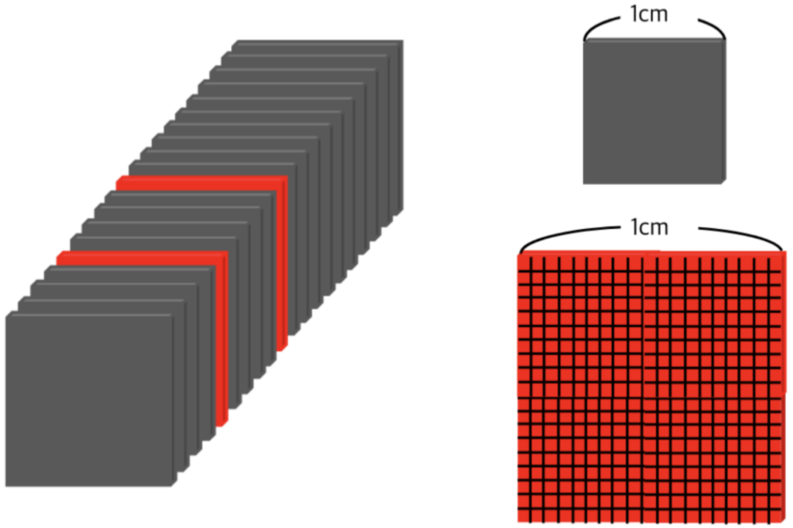
Sejong simulations

G. Kim, Y. Park

γ particle gun

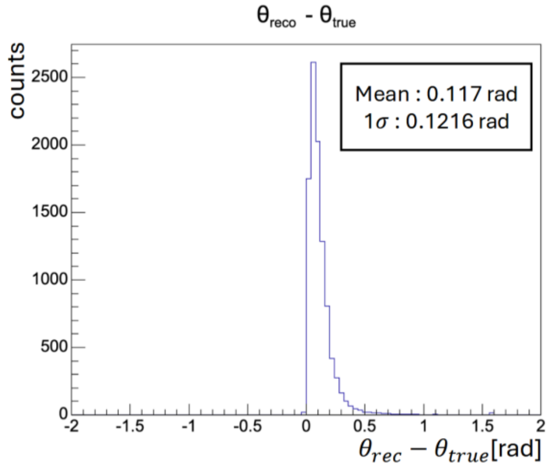
- 10,000 events
- Fixed E of γ - 10 GeV
- z = -10m
- θ = 0.004 rad
- φ = 90°

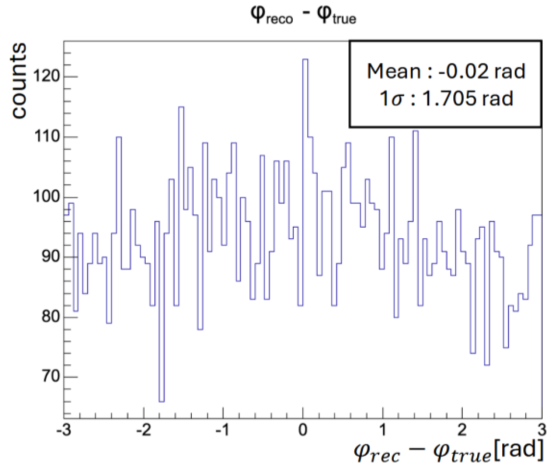




- Pad layer : 1cm*1cm
- Pixel layer : 0.5mm*0.5mm
- 5th, 10th layers are pixel + other layers are pads

- Concentrate on ALICE FoCal-type ECAL
- Tracking using least squares not working well, but choice of variables, especially ϕ at small angles not optimal



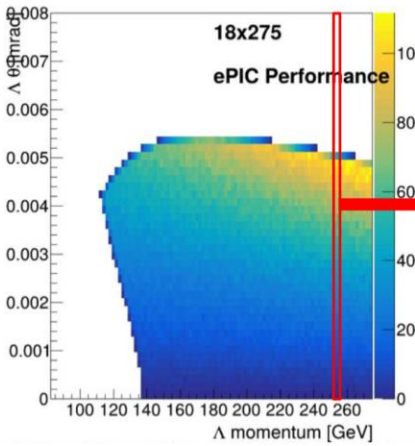


WSi+ HCAL tracking studies

G. Kim, Y. Park

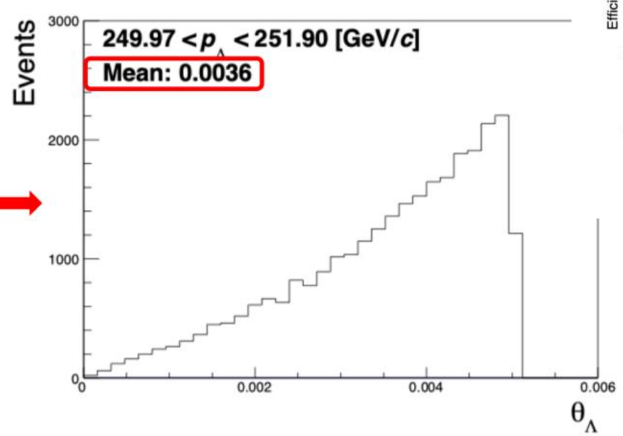
- Sejong strategy: Take average kinematics from meson-structure group simulations for particle gun simulations of neutrons and photons. Results in fairly large polar angles wrt to center of ZDC – substantial leakage for neutrons
- Will look at more energies/angles

- p_Λ vs θ_Λ

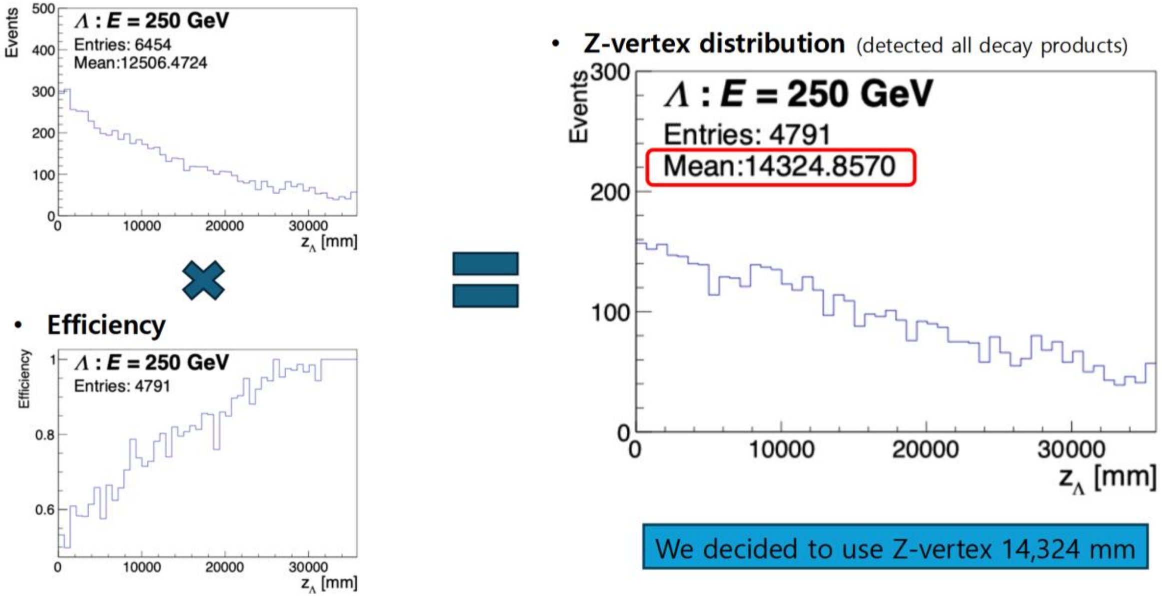


Meson structure group information and simulations - https://jeffersonlab.github.io/meson-structure/data.html

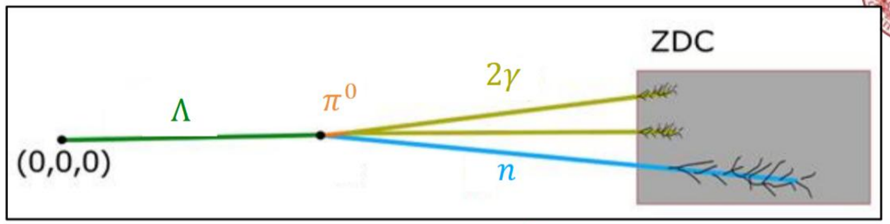
- θ_Λ distribution



We decided to use 250 GeV as a representative value of Λ momentum, with its typical $\theta_\Lambda = 0.0036$ rad



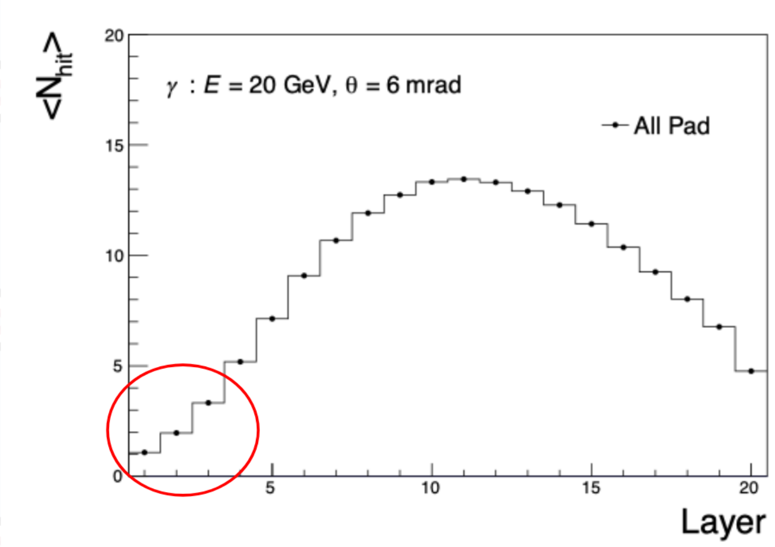
We decided to use Z-vertex 14,324 mm



Position resolutions for n and γ

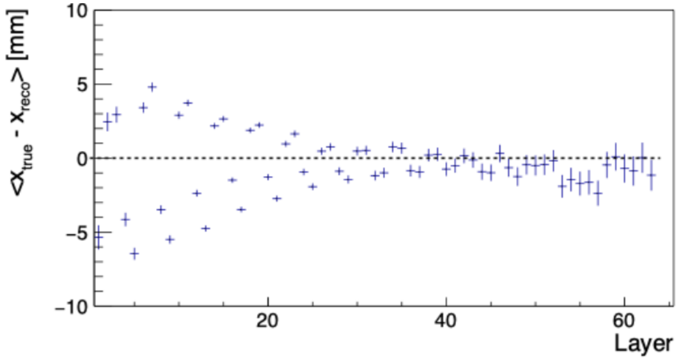
G. Kim, Y. Park

- Early neutron HCAL hits with poor resolution due to staggered siPM tiles
- Large angle causes leakage in y

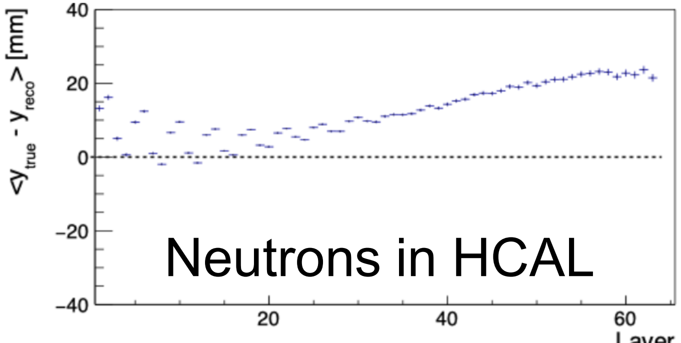


Neutron position resolution

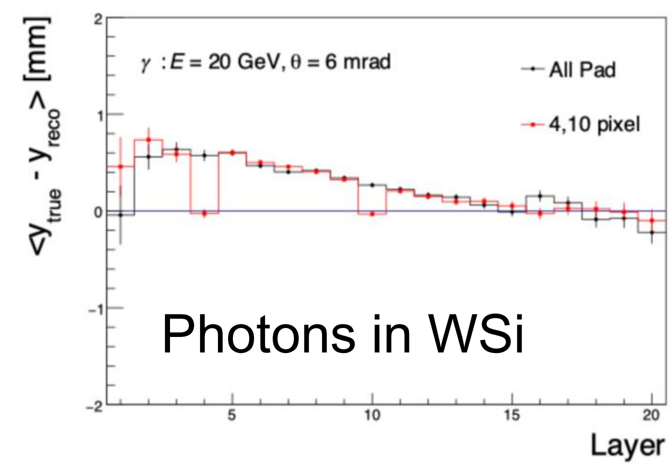
- x_{CM} position resolution vs layer

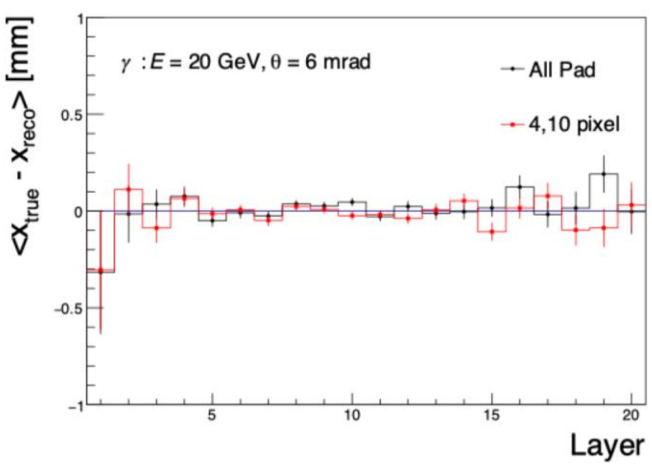


- y_{CM} position resolution vs layer



- Center-of-mass position resolutions significantly improve with pixel layers

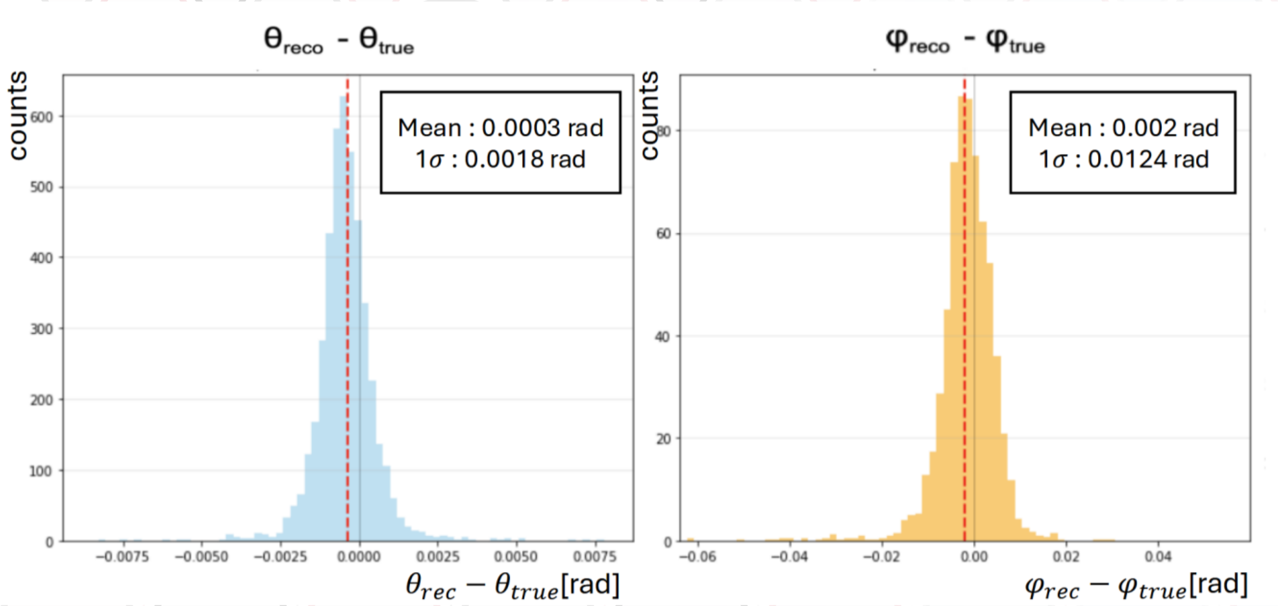


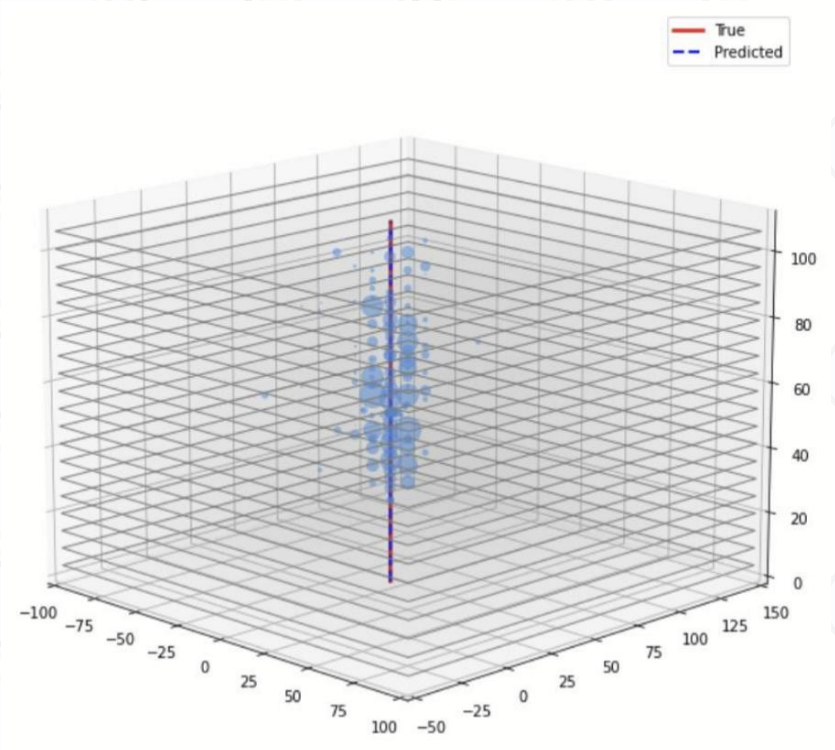


Try to use ML for better performance

G. Kim, Y. Park

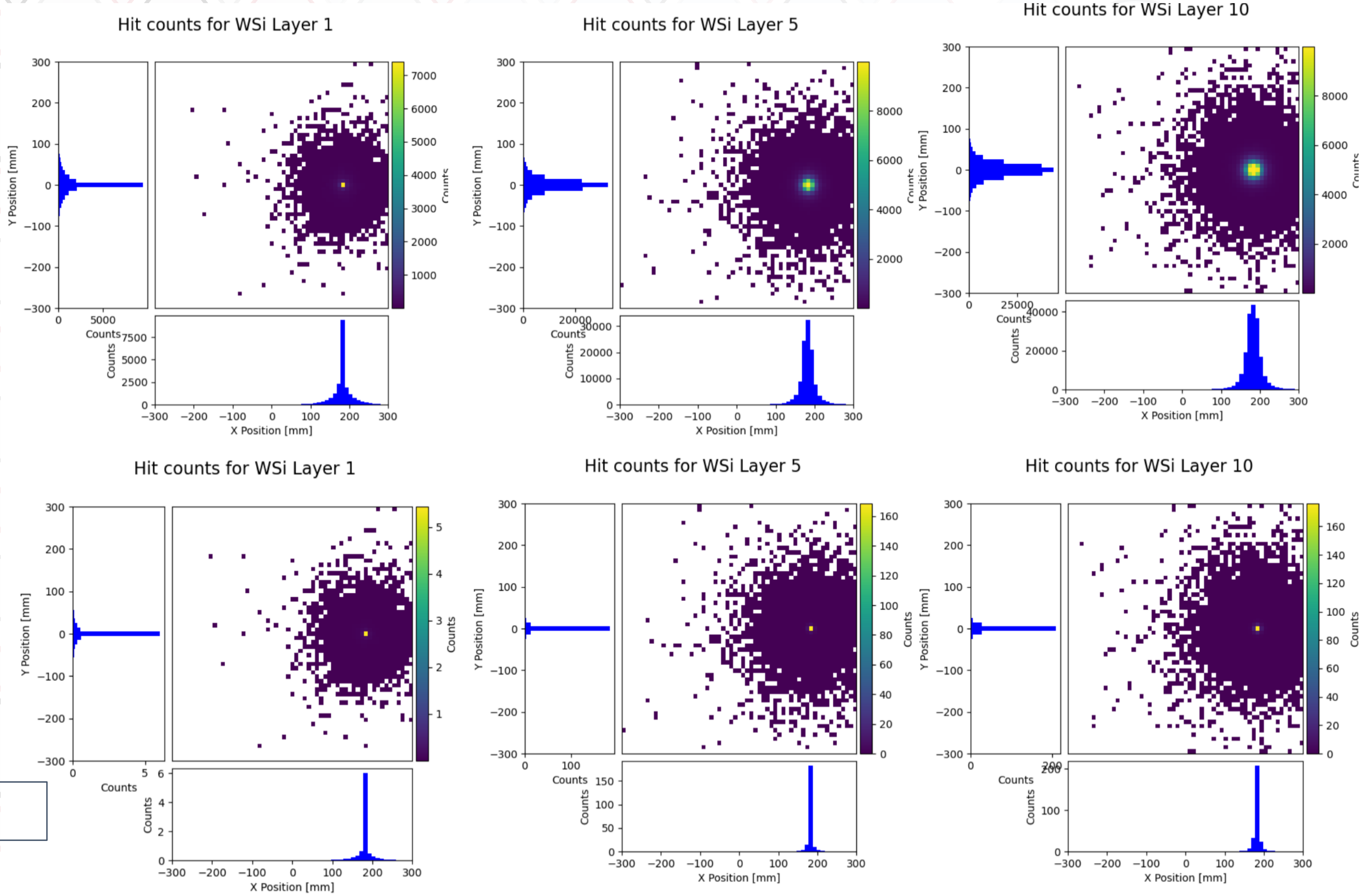
- Use 1D Convolutional Neural Network to improve reconstruction
- True photon angles can be reconstructed well





WSi position resolutions using hit average or energy weighted averag

- Only WSi Pad layers, no pixels
- 10k events of 30 GeV photons, (30m, 5 mrad rotation in x)
- Clearly better to use energy weighting in WSi

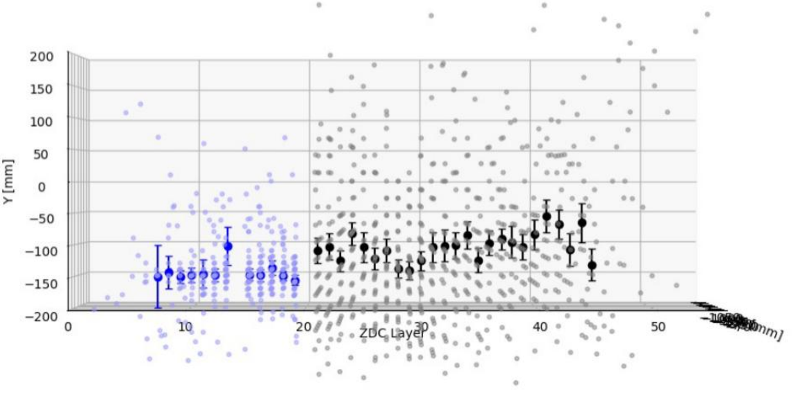


A.Illari, G. Kainth

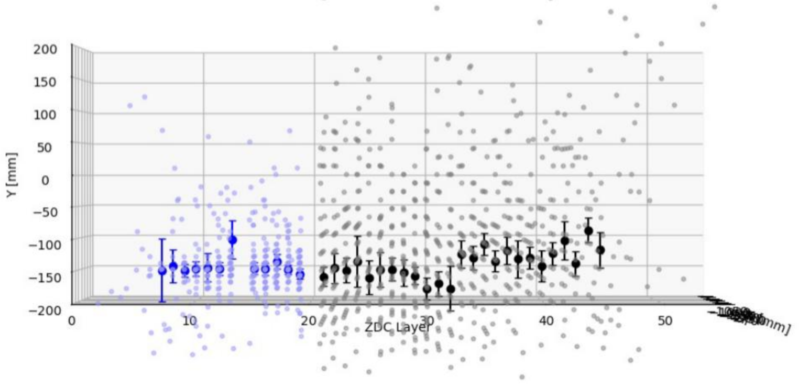
Neutron tracking in WSi and HCAL

A.Illari, G. Kainth

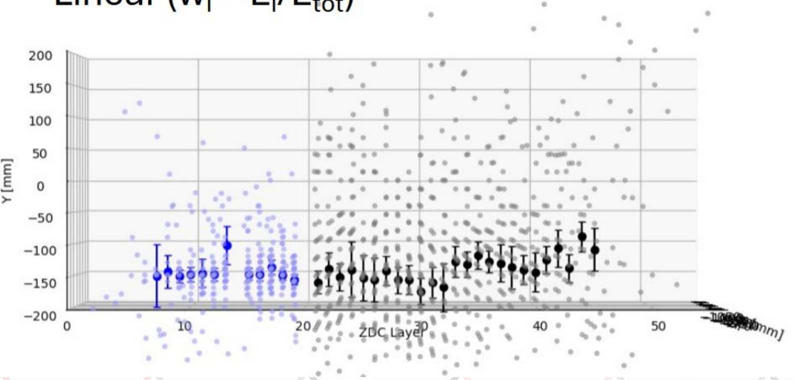
Statistical Average (no energy weight)



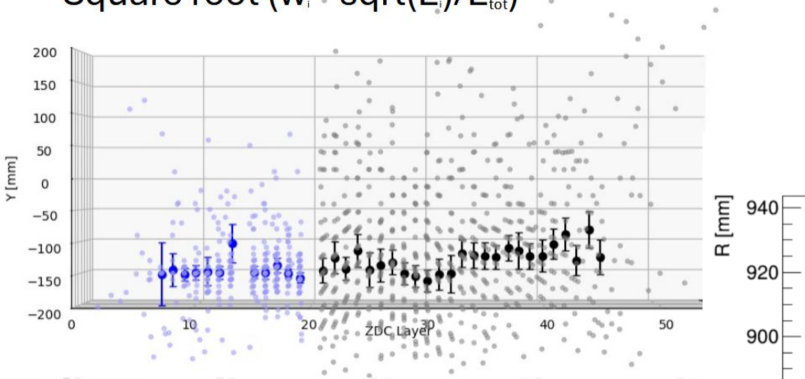
Log ($w_i = (\log(E_i/E_{tot})) + C)/w_{tot}$)

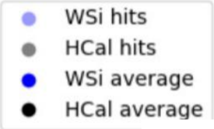


Linear ($w_i = E_i/E_{tot}$)

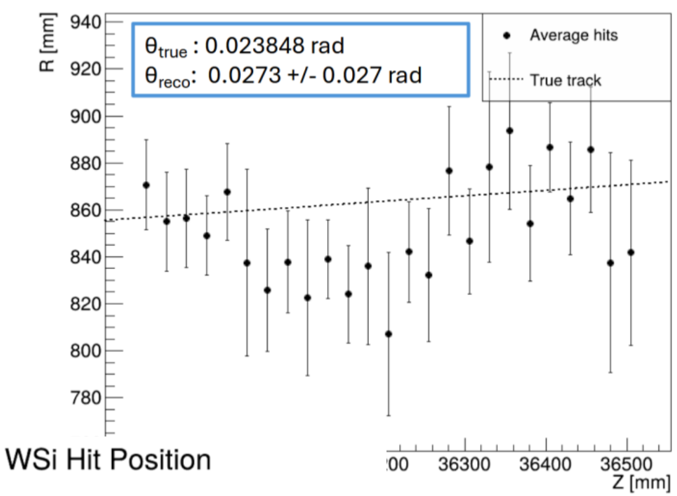


Square root ($w_i = \mathrm{sqrt}(E_i)/E_{tot}$)

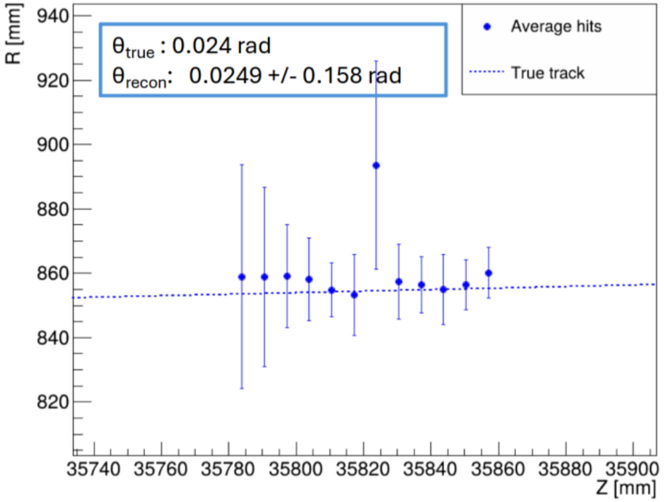




Log ($w_i = (\log(E_i/E_{tot})) + C)/w_{tot}$)



Average WSi Hit Position



- Best chance of HCAL tracking using log E weighted hits
- WSi more reliable after shower is developed even w/o weighting
- Combine both parts in tracking and evaluate overall resolution

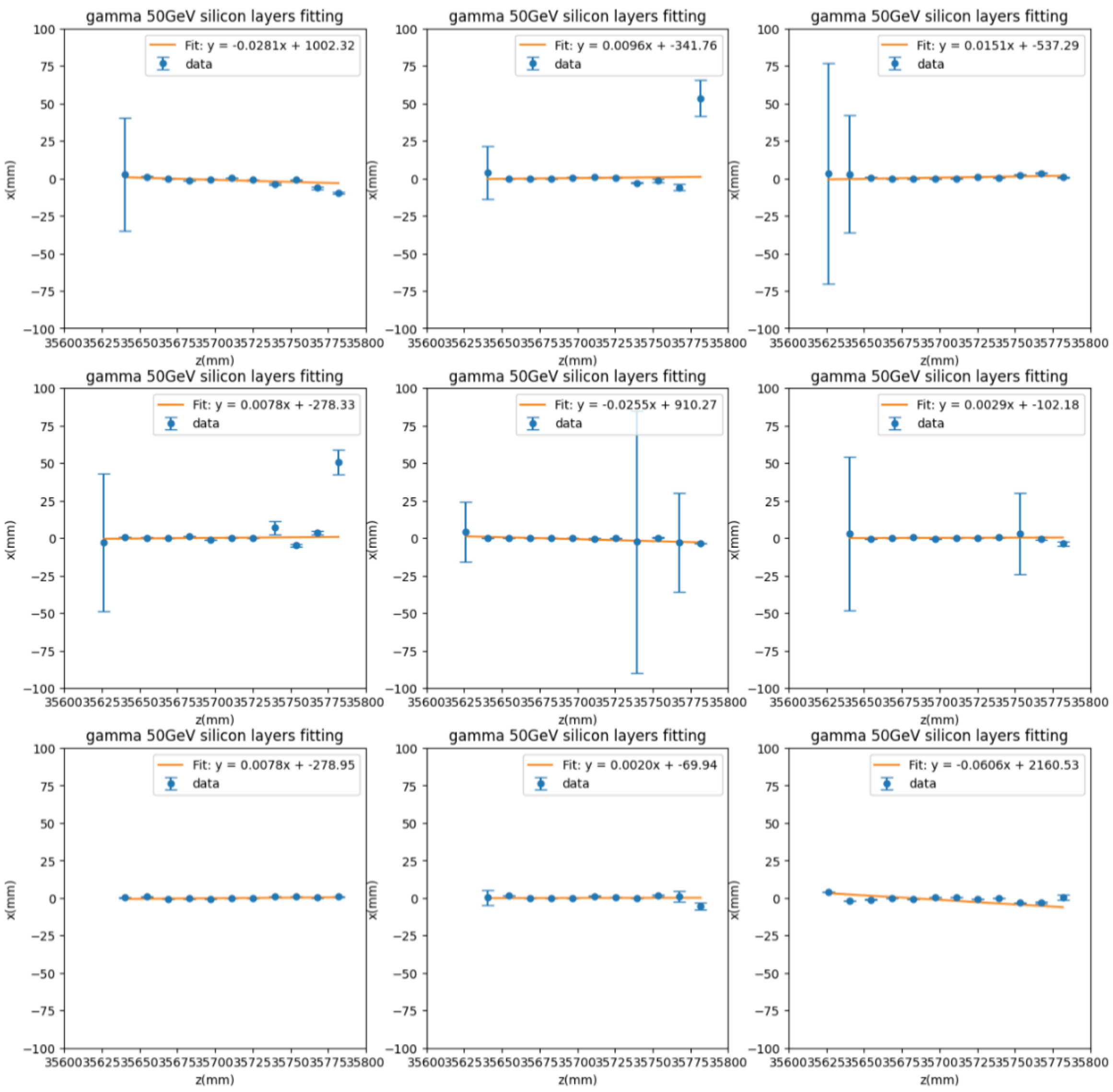
Hit position from mult. layers

Koki Nakamoto

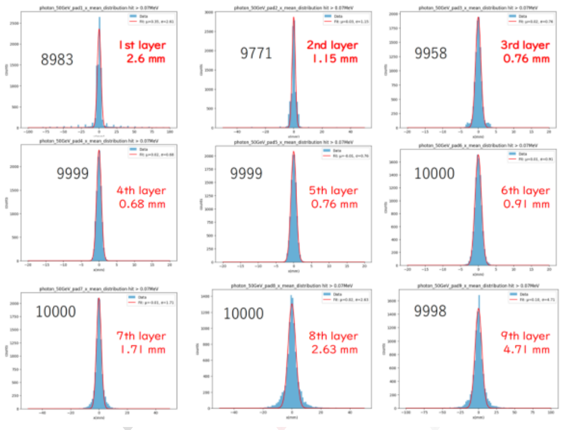
- Test line fitting for several events
  - Point: Hit center position determined by gaussian fitting
  - Error: Fitting error

Todo

- Angle determination performance
- Vertex reconstruction performance
- Generate Lambda MC simulation



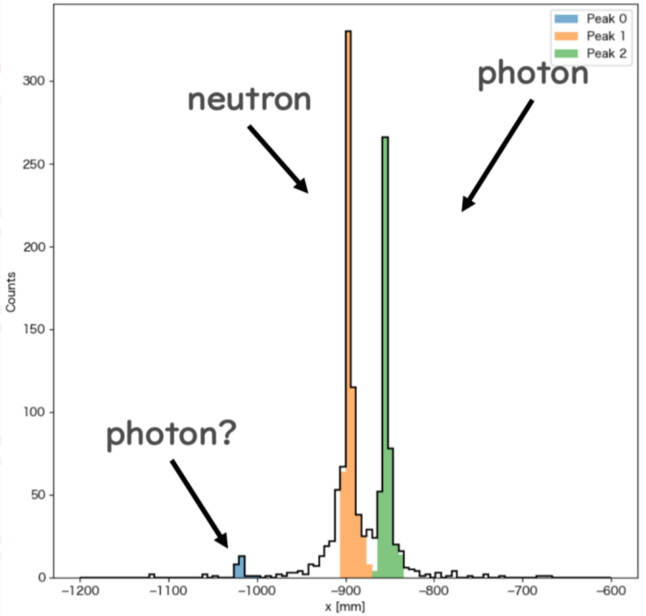
Position resolution (Pad x)

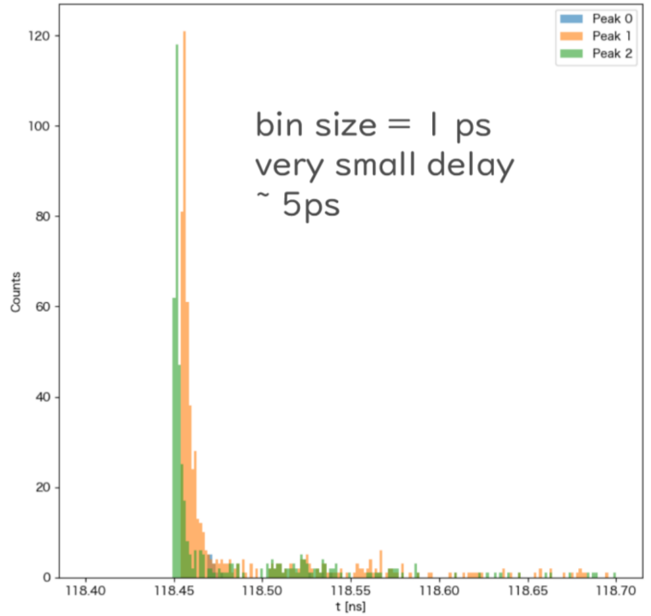


Timing studies

- Can one identify the neutron based on timing differences
- 5ps delay and many WSi hits suggest possibility for n ID
- Try GraphNN to reconstruct clusters, energy, position and ID

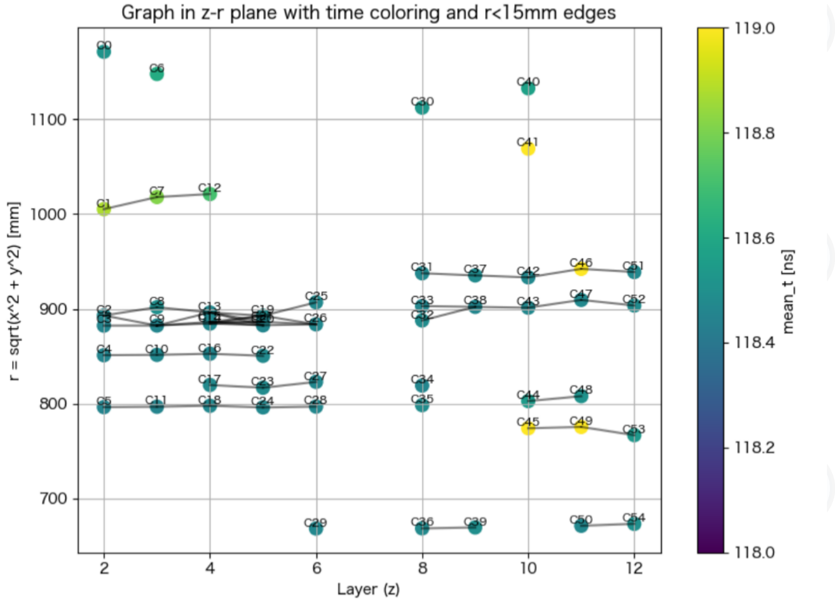
Kawade





Hit clustering

- 2D x-y (weight=eDep) map for each pad layer
- Get node features
  - hit center (x-y)
  - number of hits in cluster
  - mean x, y, z
  - mean timing
  - rms of them
- Edges are connected only between neighboring layers
  - distance for edge feature



Reconstruct energy, position, PID

Summary

- Various groups working on ZDC simulations
- Substantial progress toward photon and neutron reconstruction, energy and position resolutions
- Next steps: move toward Λ reconstruction