

Asian ZDC simulation efforts

**EIC Asia meeting on meson structure,
May 1st, 2026**

Ralf Seidl (U Tokyo, QNSI)



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
- Ramaiah University, Bangalore (India): Tapasi Ghoshn

Current status of each group

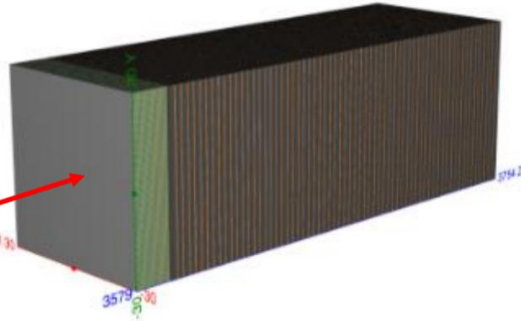
Yeonwoo Park

| 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, $\varphi = 90^\circ$, Crossing Angle = 0, Gun position = (0, 51.567 mm, 14324 mm) γ : 20 GeV, $\theta = 6$ mrad n: 209 GeV, $\theta = 3.6$ mrad Λ : 250 GeV | LSM, CNN -Solid angle |
| Shinshu (Kentaro) | WSi + Hcal 12 layers 3 pixel layers | Common: 10K events, $\theta = 0$ 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

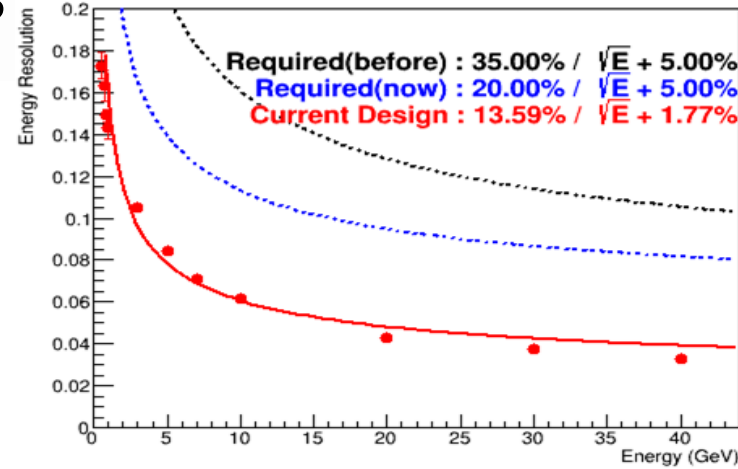
pencil beam



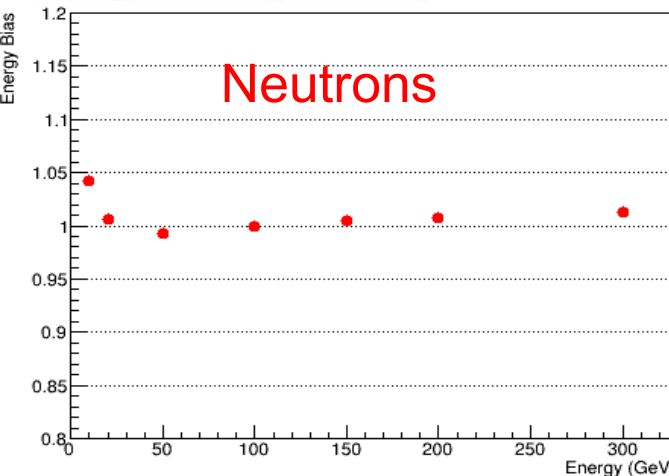
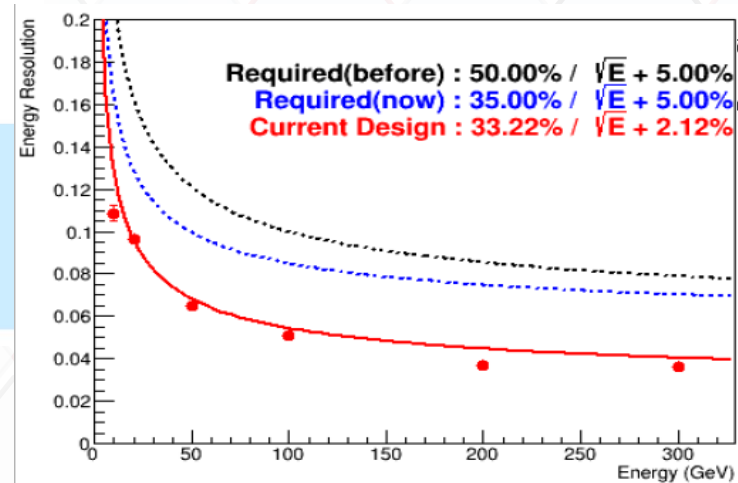
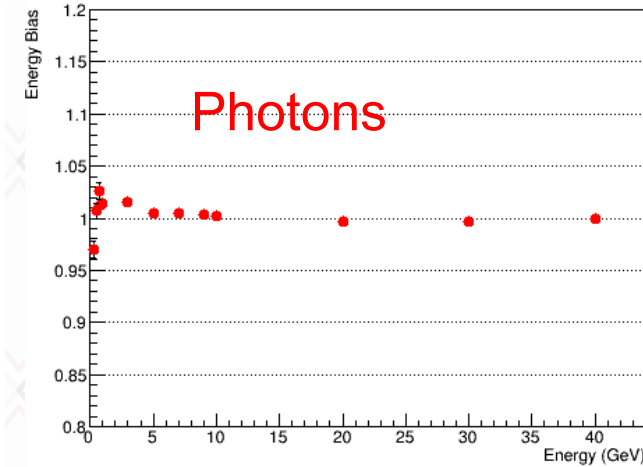
- Put detector straight along z-dir
- Shoot beam along z-dir @ (-15mm, -15mm, z)
- 1GeV - 40GeV gamma (pencil beam)
- 10GeV – 300GeV neutron beam (pencil beam)

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

Energy Resolution(%)



Energy Bias(%)



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.

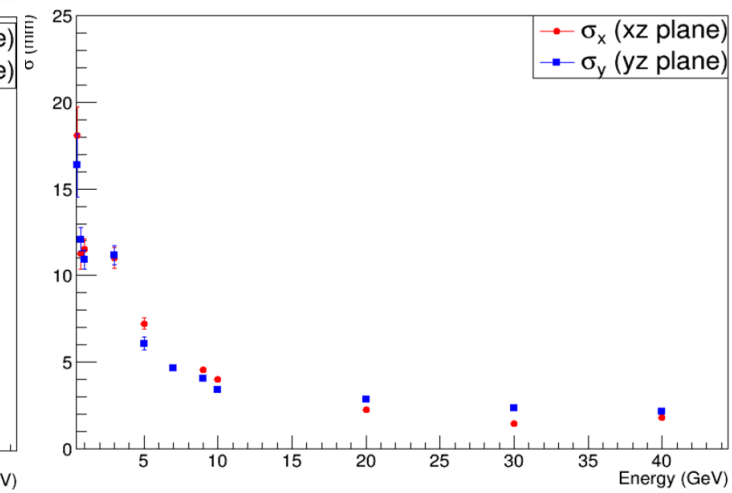
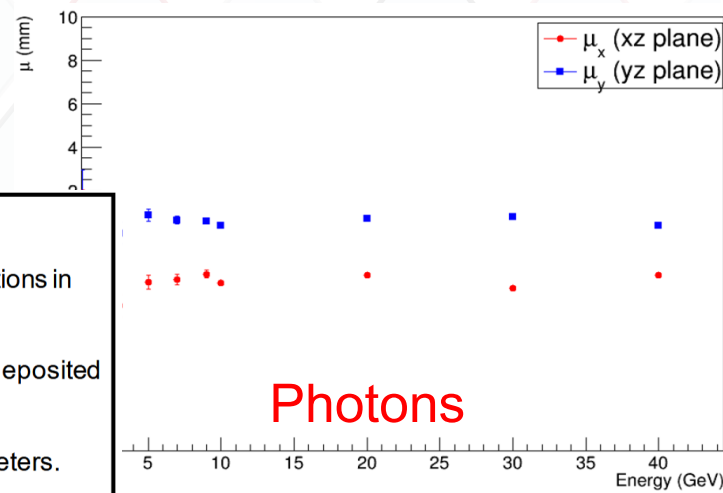
- Step 2 — Energy-weighted layer**

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**

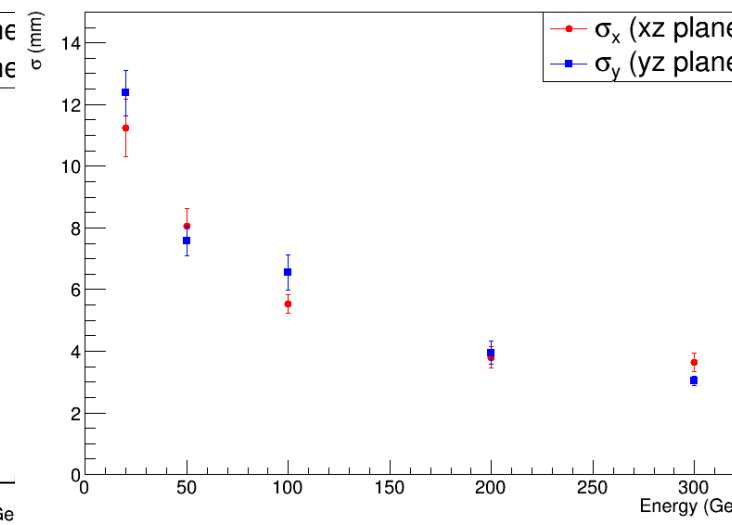
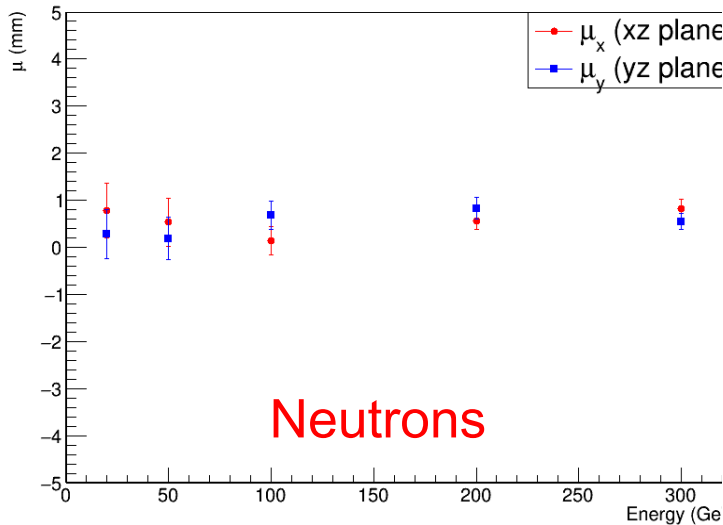
Linear fits (pol1) are performed independently in the XZ and YZ planes to obtain the track parameters.

Only HCAL is included in track reconstruction for now.



- 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

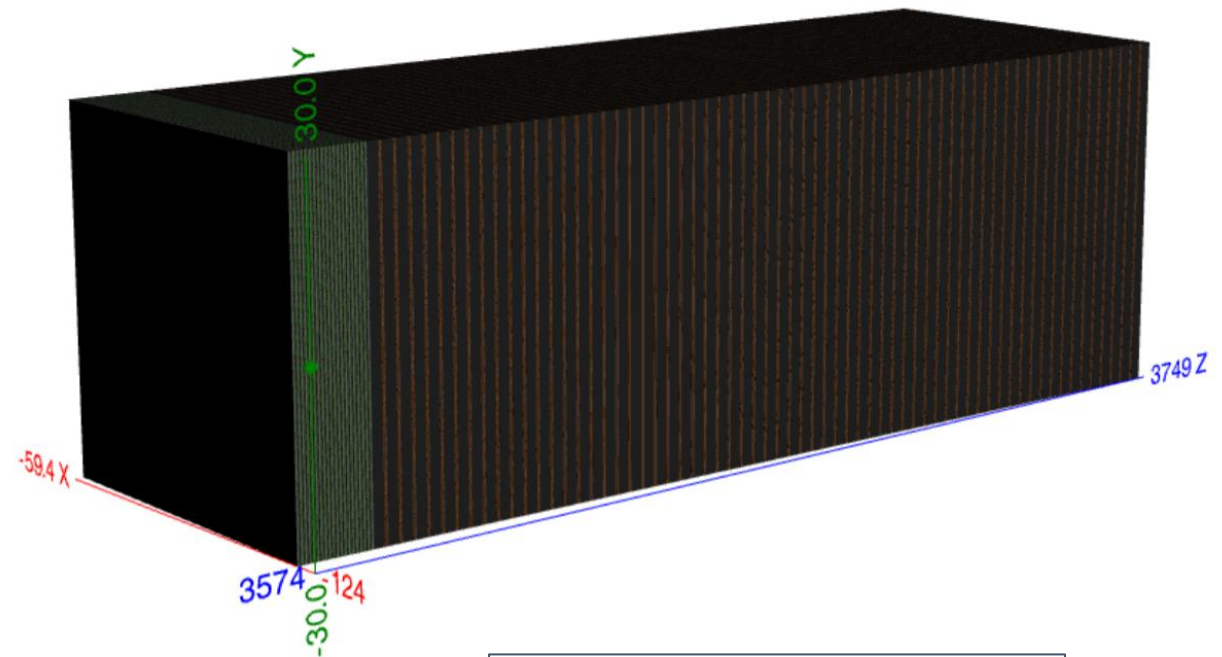
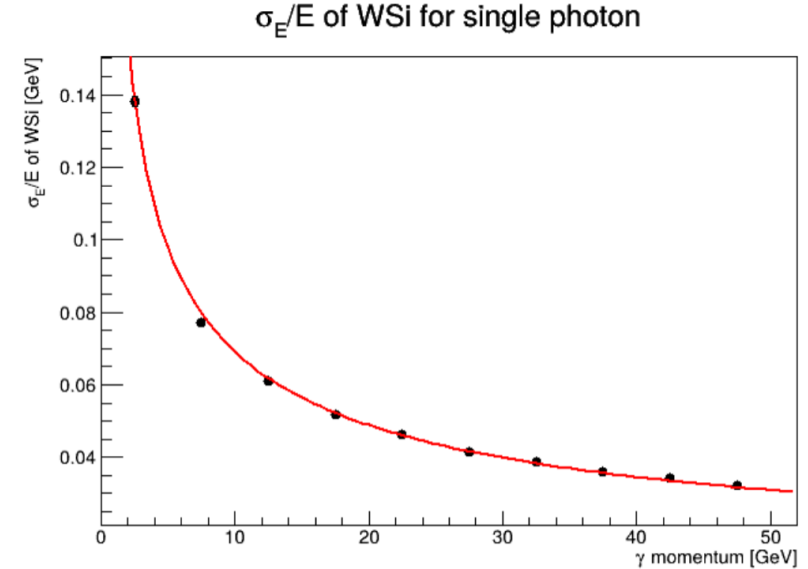


- Only events with energy > 10 GeV are shown.
- A small bias of approximately 0.5 mm is observed in both x and y direction.
- The position resolution is similar in x and y ~ 3 mm with 300GeV neutron beam.

Chia-yu Hsieh

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 cm² 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](#)



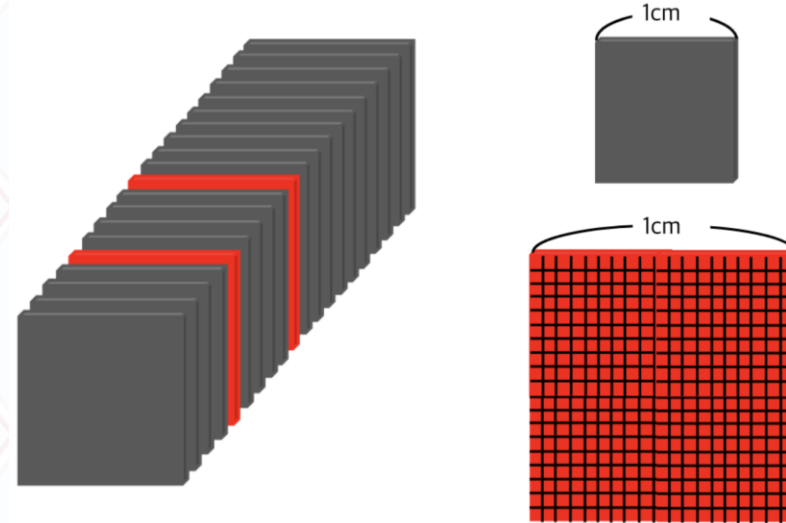
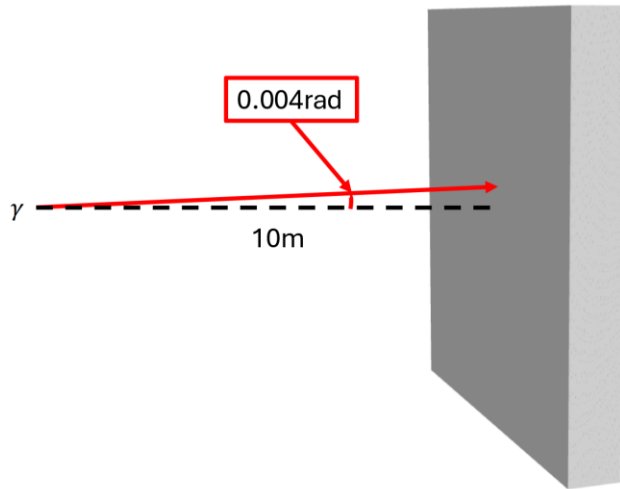
A. Illari, G. Kainth

Sejong simulations

G. Kim, Y. Park

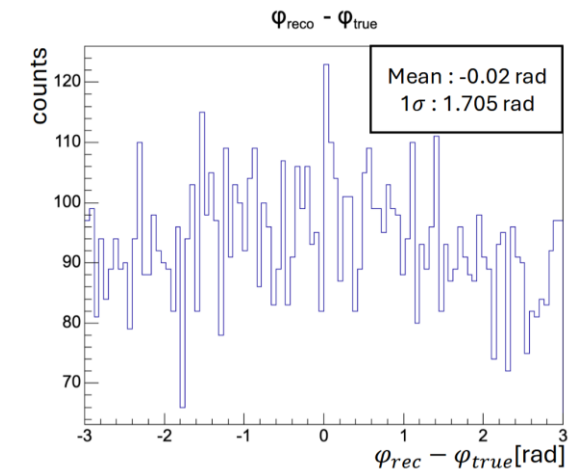
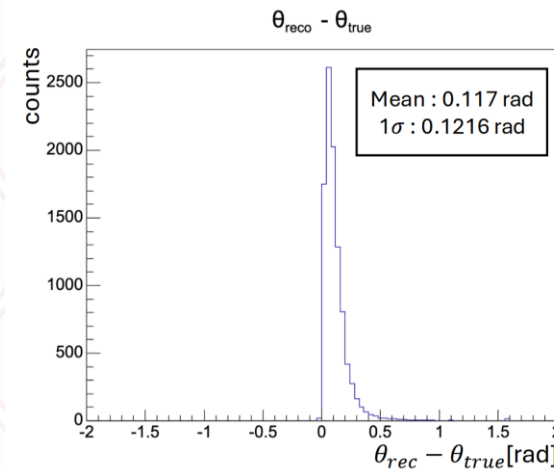
γ particle gun

- 10,000 events
- Fixed E of γ - 10 GeV
- $z = -10\text{m}$
- $\theta = 0.004\text{ rad}$
- $\varphi = 90^\circ$



- 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

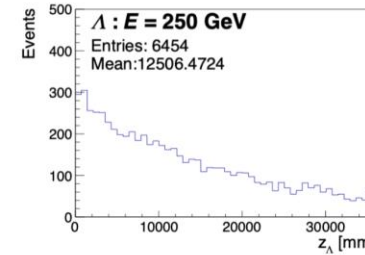


WSi+ HCAL tracking studies

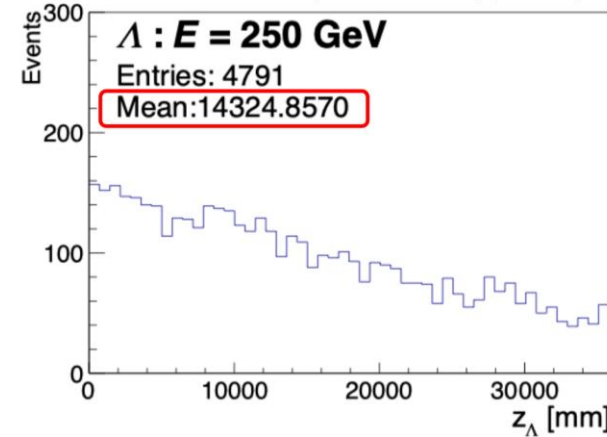
G. Kim, Y. Park

- 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

• Z-vertex distribution



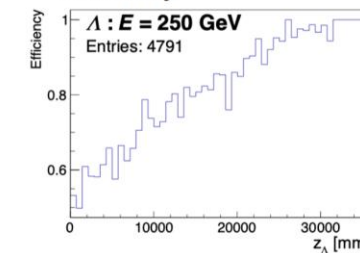
• Z-vertex distribution (detected all decay products)



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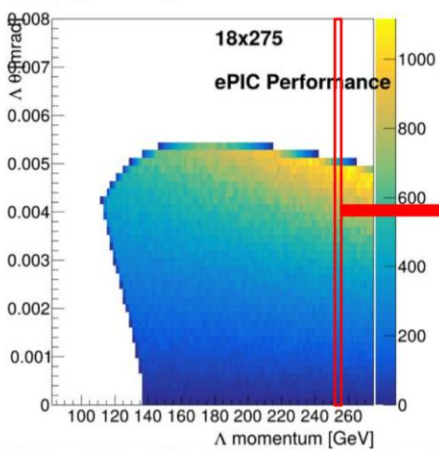
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• Efficiency

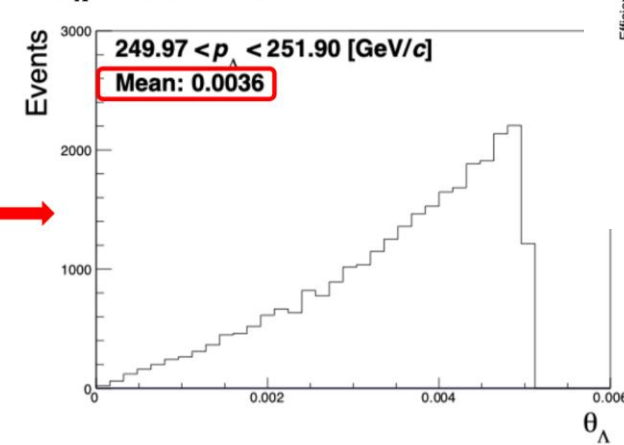


We decided to use Z-vertex 14,324 mm

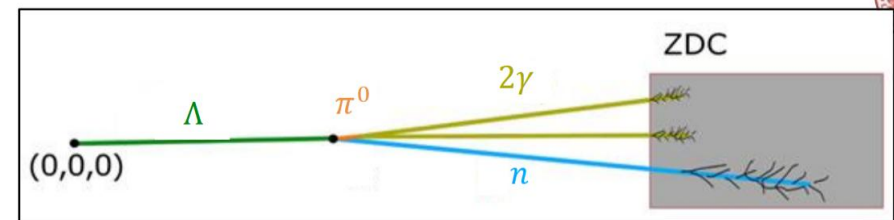
• p_Λ vs θ_Λ



• θ_Λ distribution



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



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

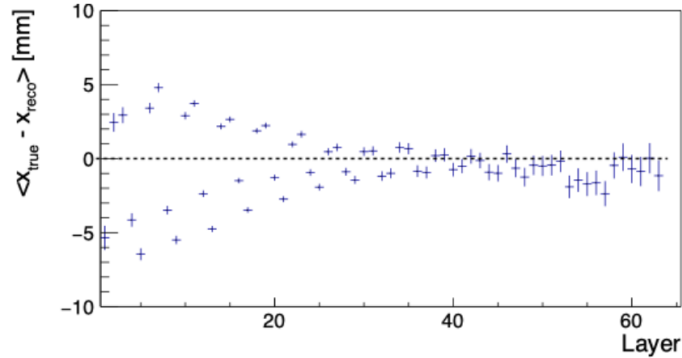
Position resolutions for n and γ

G. Kim, Y. Park

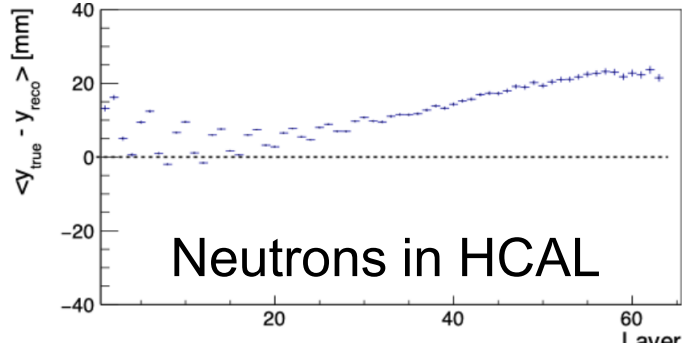
- Early neutron HCAL hits with poor resolution due to staggered siPM tiles
- Large angle causes leakage in γ

Neutron position resolution

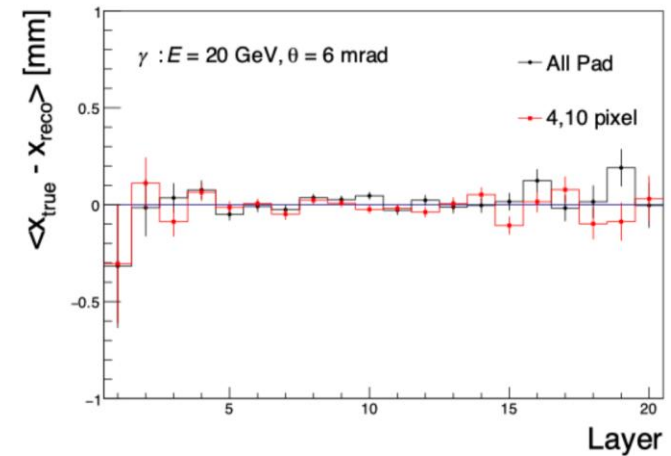
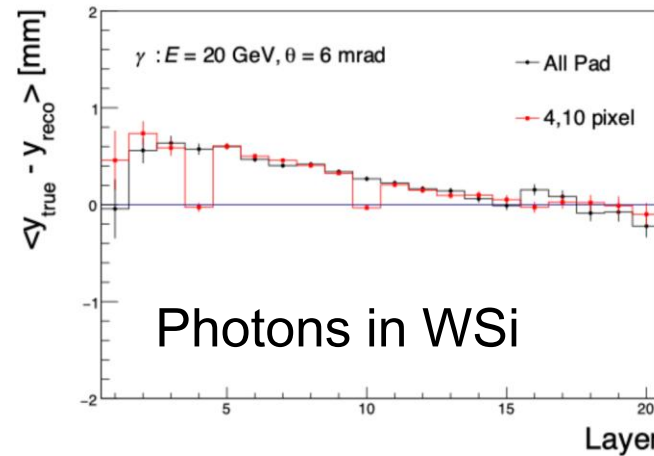
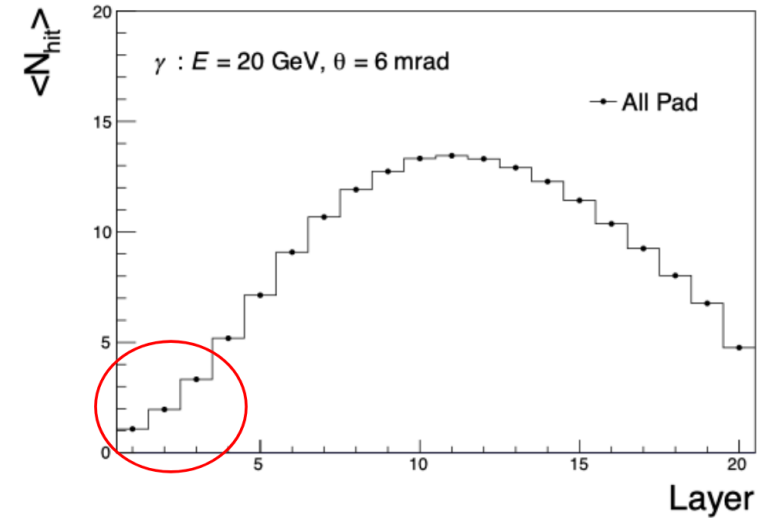
- X_{CM} position resolution vs layer



- y_{CM} position resolution vs layer

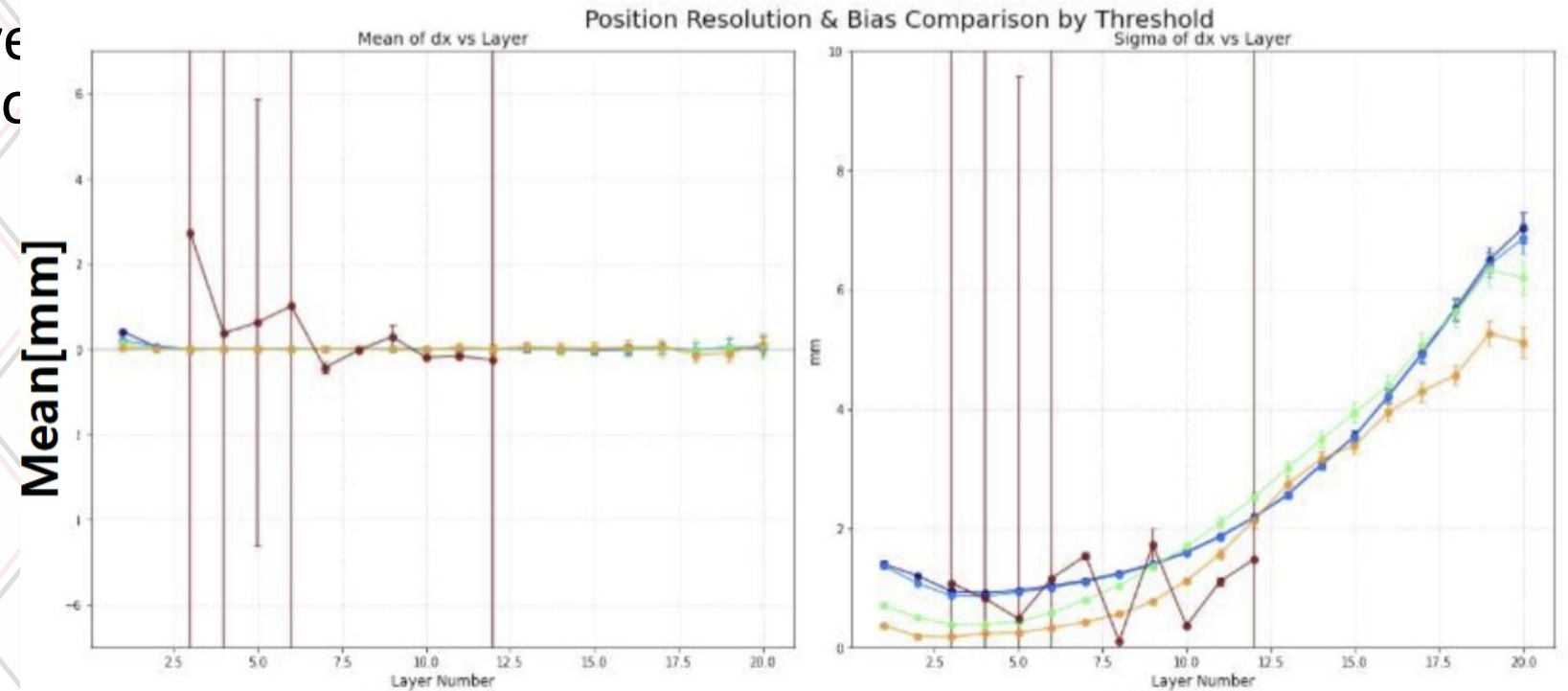
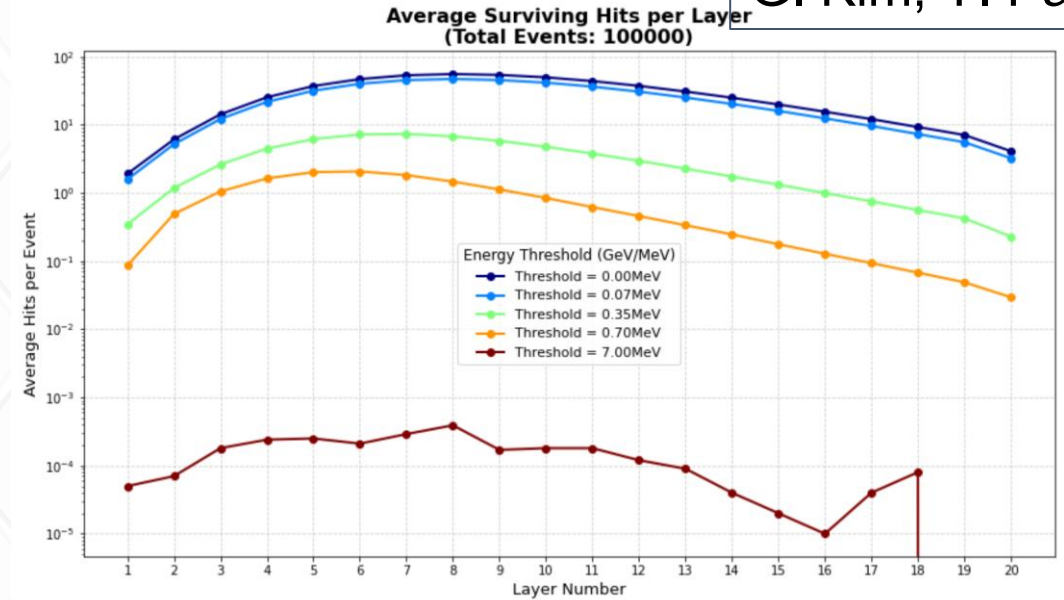


- Center-of-mass position resolutions significantly improve with pixel layers



Threshold dependence

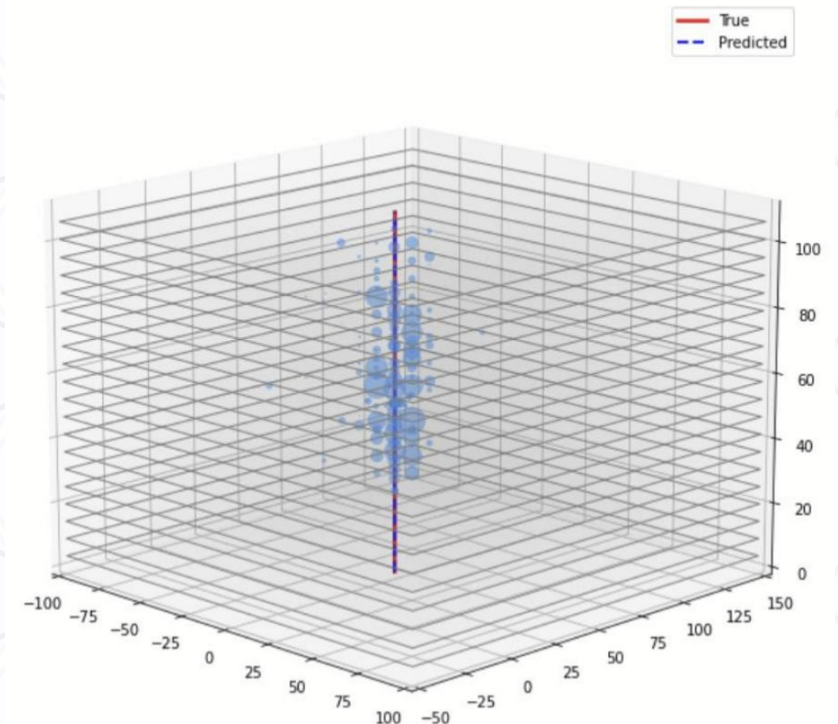
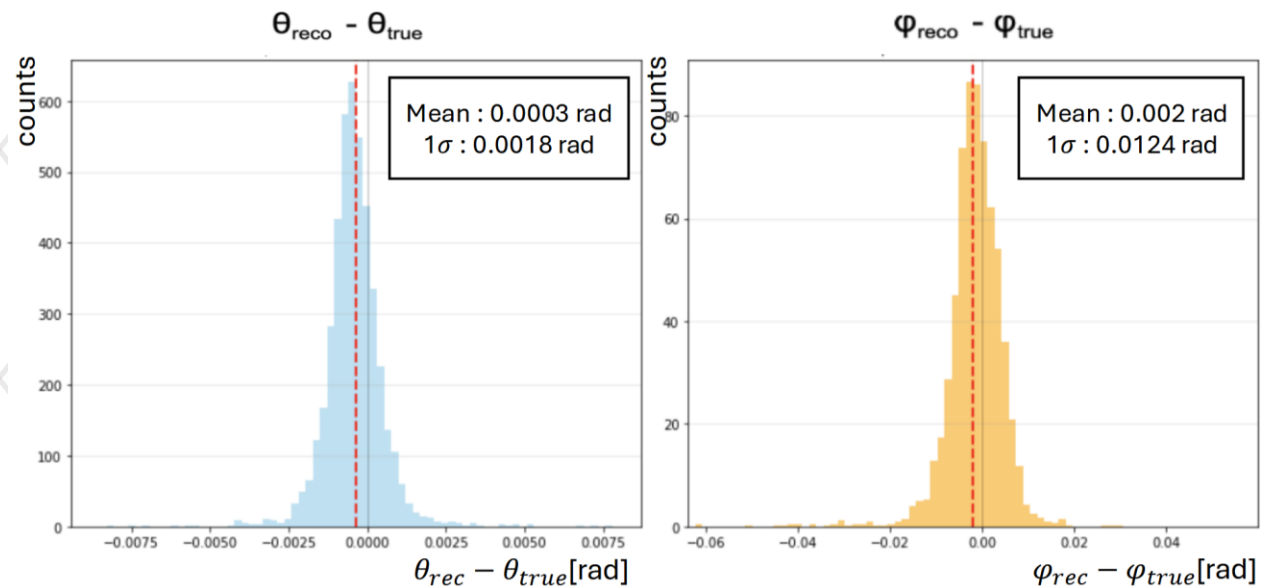
- Test how resolution depends on hit energy threshold (energy weighted mean)
- Too low threshold dominated by noise give poor resolution, need to carefully optimize
- Little dependence on mean position
- However, impact on pointing capabilities limited (not shown)



Try to use ML for better performance

G. Kim, Y. Park

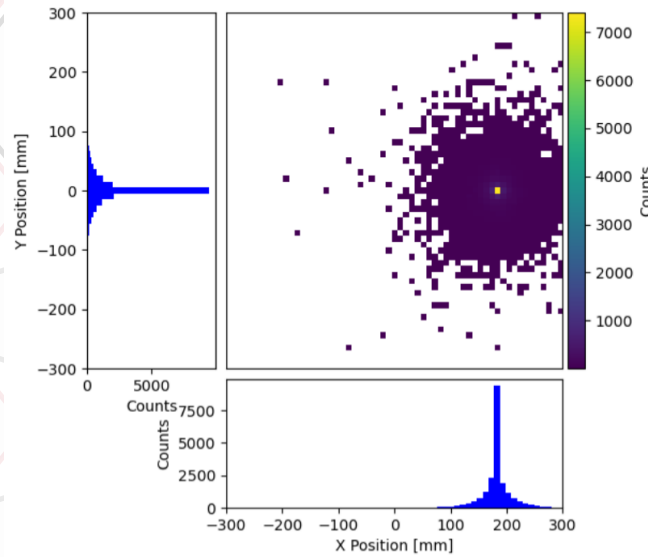
- Use 1D Convolutional Neural Network to improve reconstruction
- True photon angles can be reconstructed well, significantly better than fitting



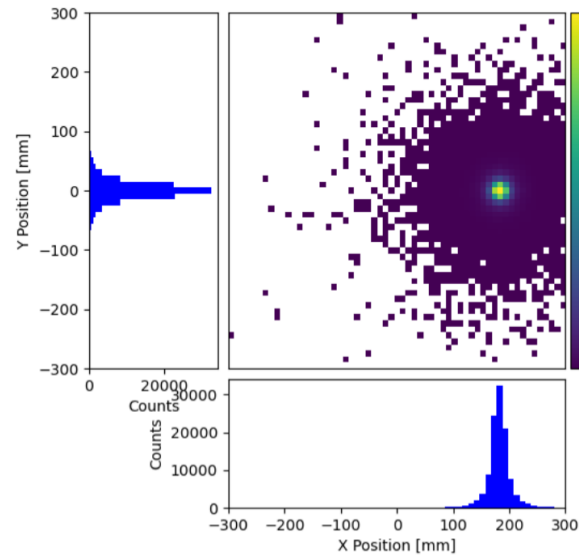
WSi position resolutions using hit average or energy weighted

- 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

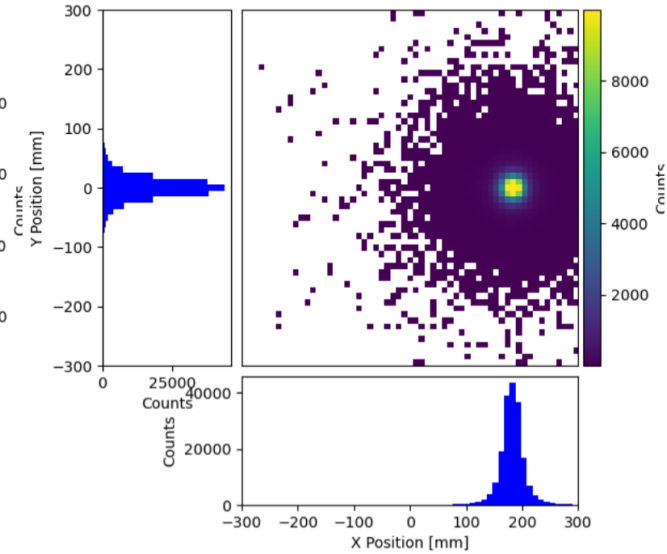
Hit counts for WSi Layer 1



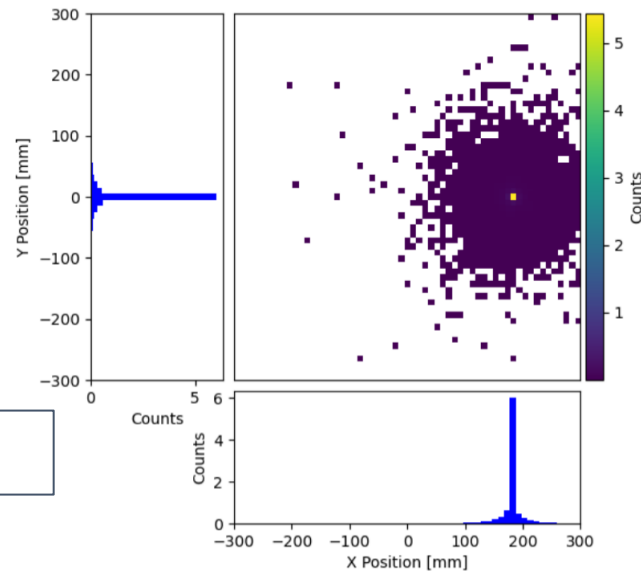
Hit counts for WSi Layer 5



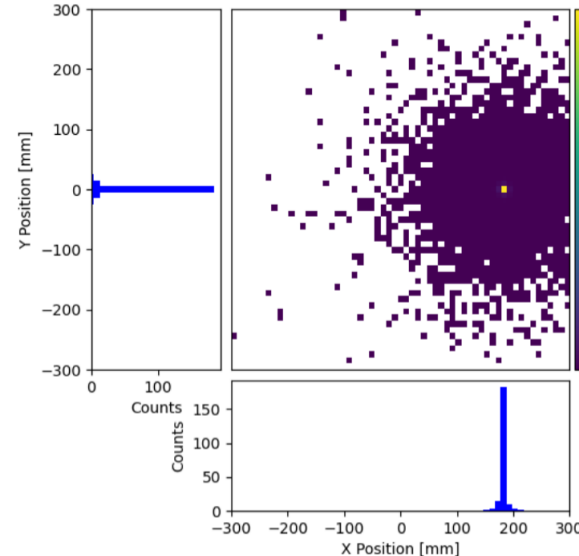
Hit counts for WSi Layer 10



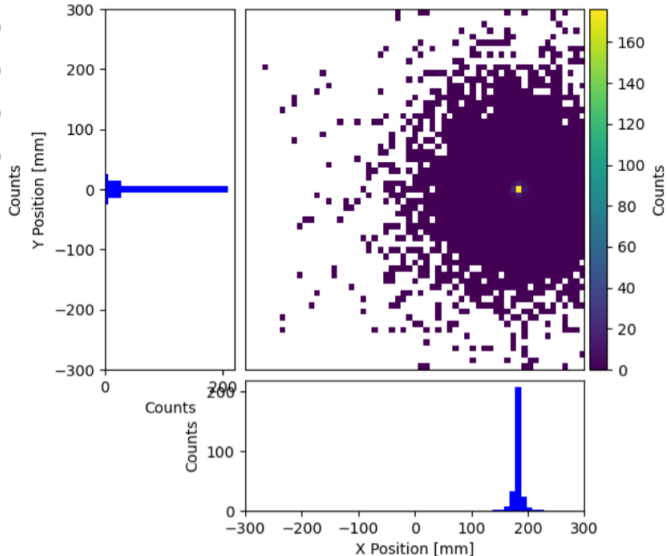
Hit counts for WSi Layer 1



Hit counts for WSi Layer 5



Hit counts for WSi Layer 10



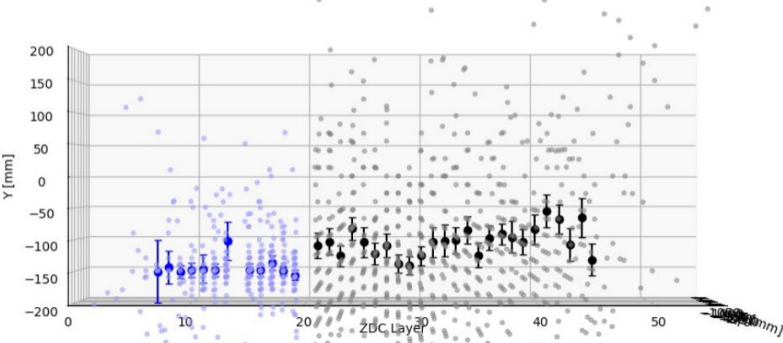
A. Illari, G. Kainth

5/1/2026

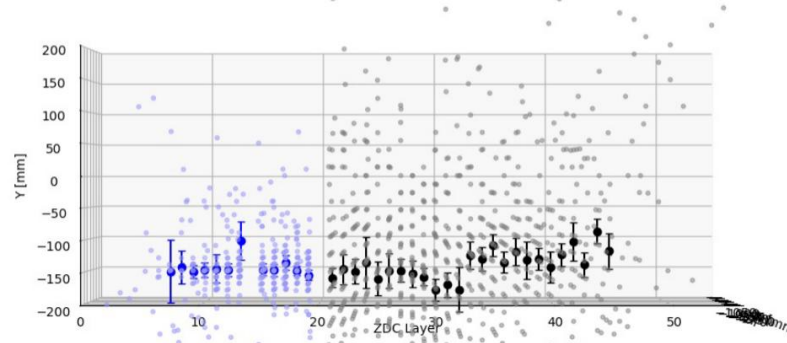
Neutron tracking in WSi and HCal

A. Illari, G. Kainth

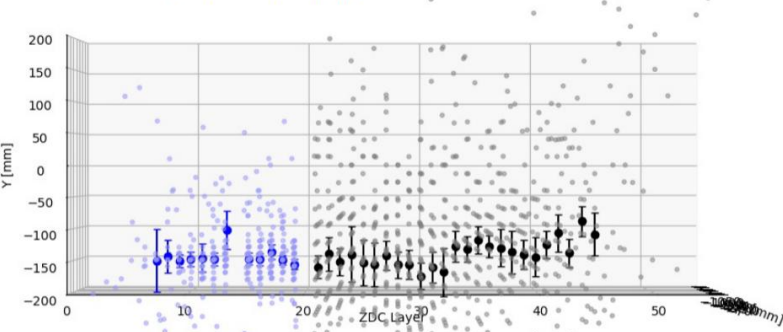
Statistical Average (no energy weight)



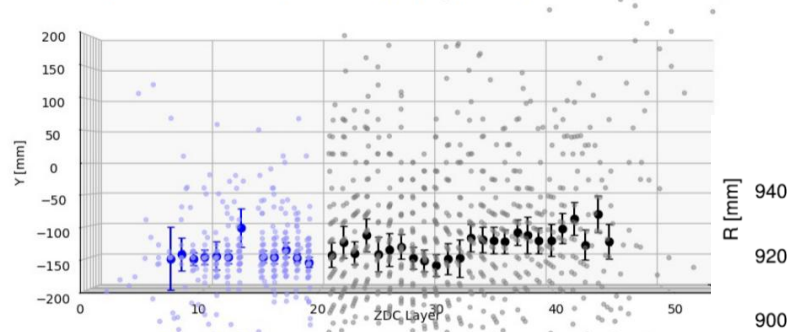
Log ($w_i = (\log(E_i/E_{tot}) + C)/w_{tot}$)



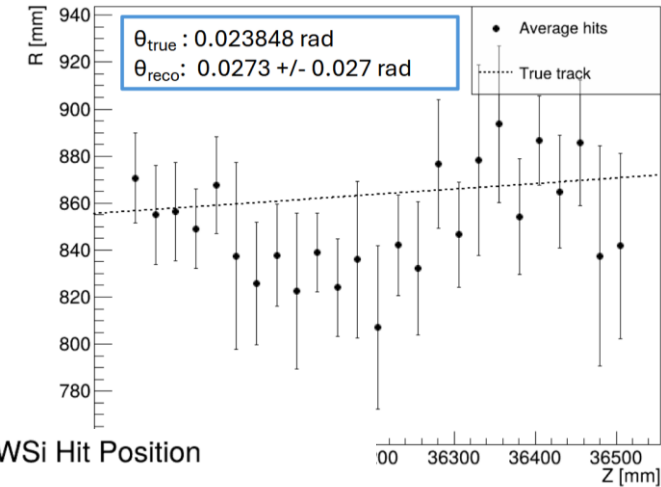
Linear ($w_i = E_i/E_{tot}$)



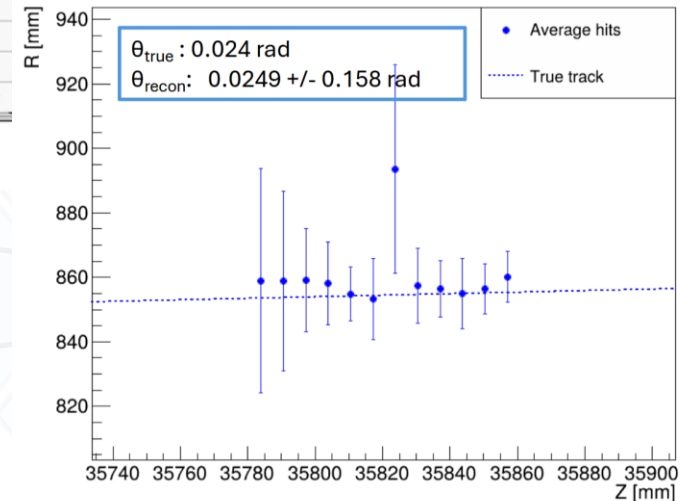
Square root ($w_i = \sqrt{E_i}/E_{tot}$)



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



Average WSi Hit Position

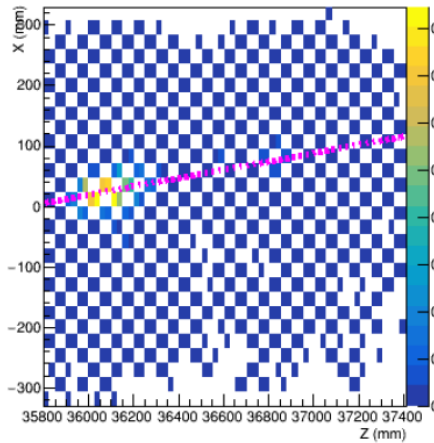


- Best chance of HCal tracking using log E weighted hits
- WSi more reliable after shower is developed even w/o weighting
- Combine both parts in tracking and evaluate overall resolution

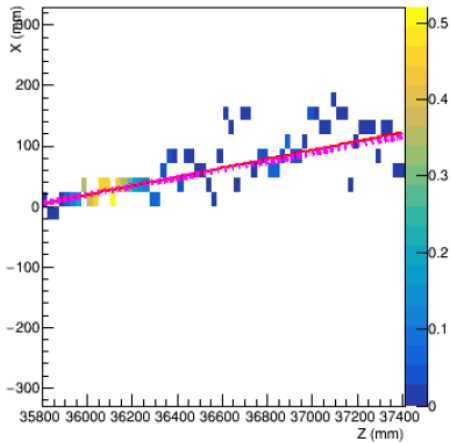
HCAL dependence on layer selection (neutrons)

Chia-yu Hsieh

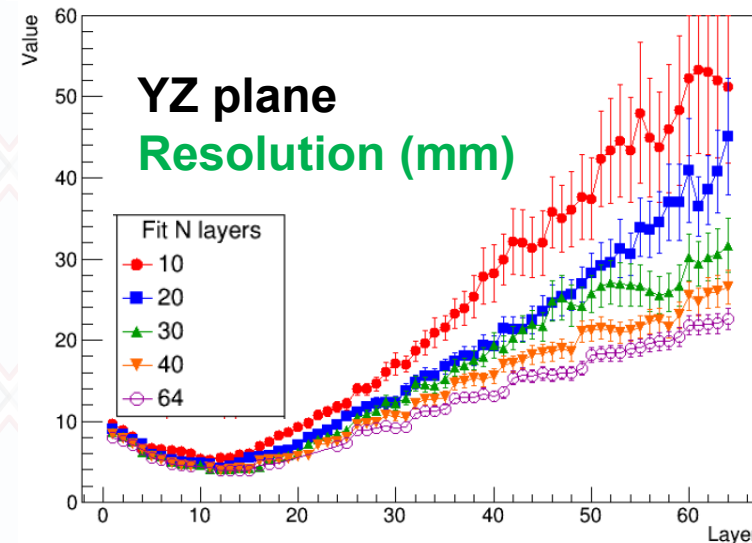
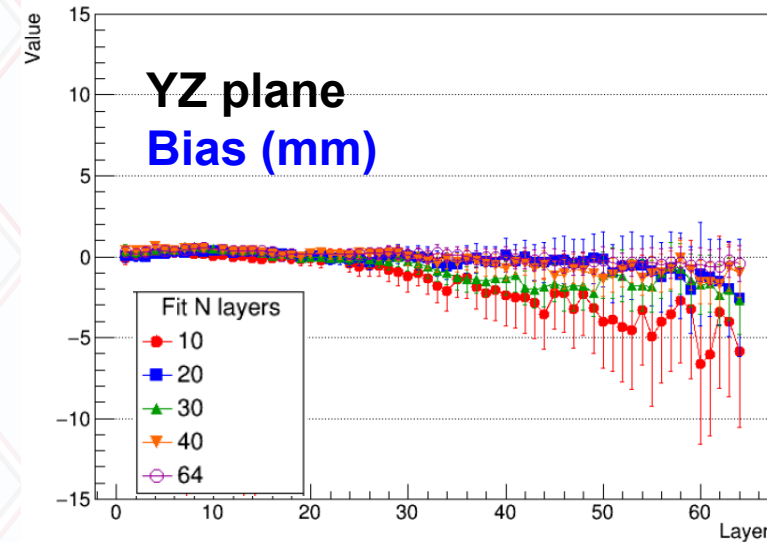
Hit Position
(color = hit energy)



Avg Hit Position in mm
(color = layer energy)

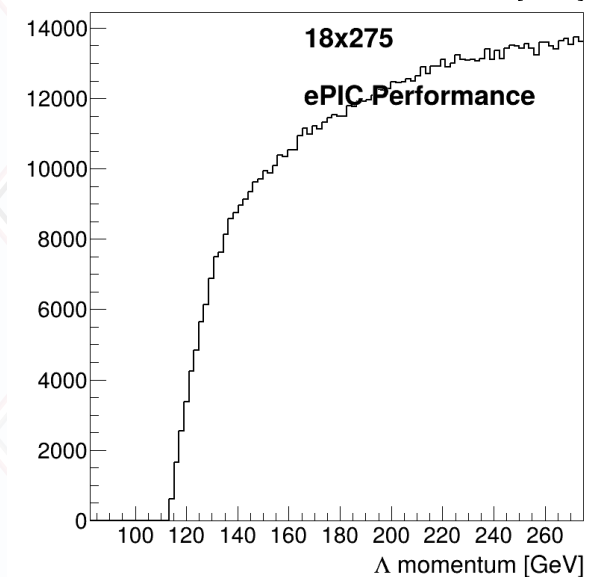
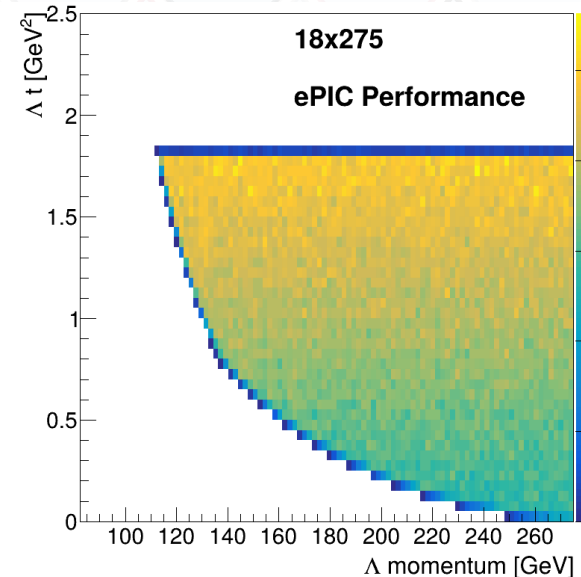
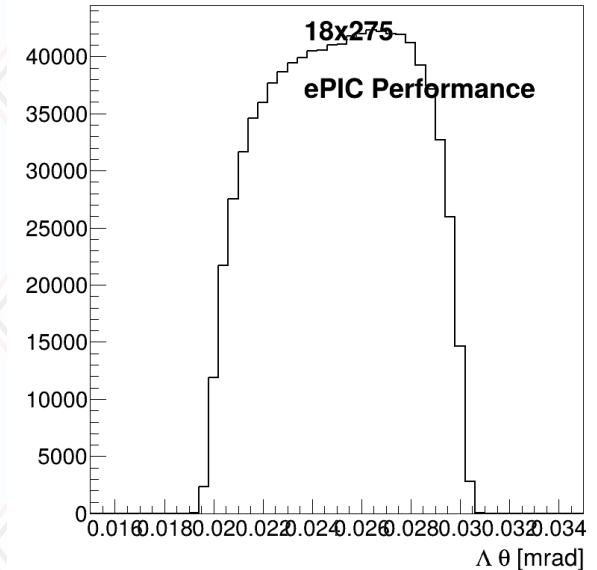
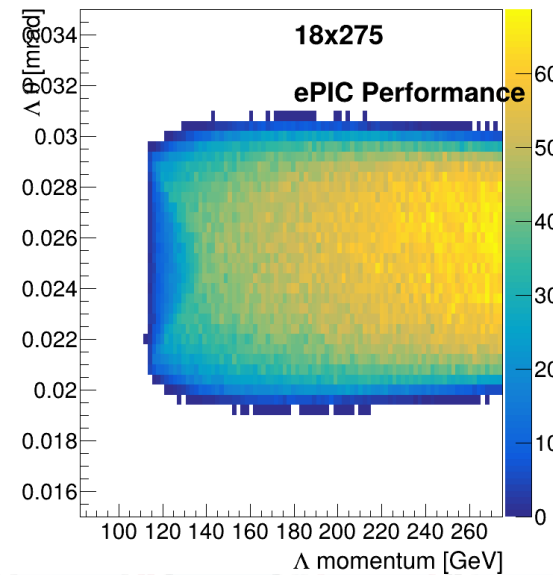


- Test whether restricting track fitting to main shower development improves resolution
- Does not appear to be the case

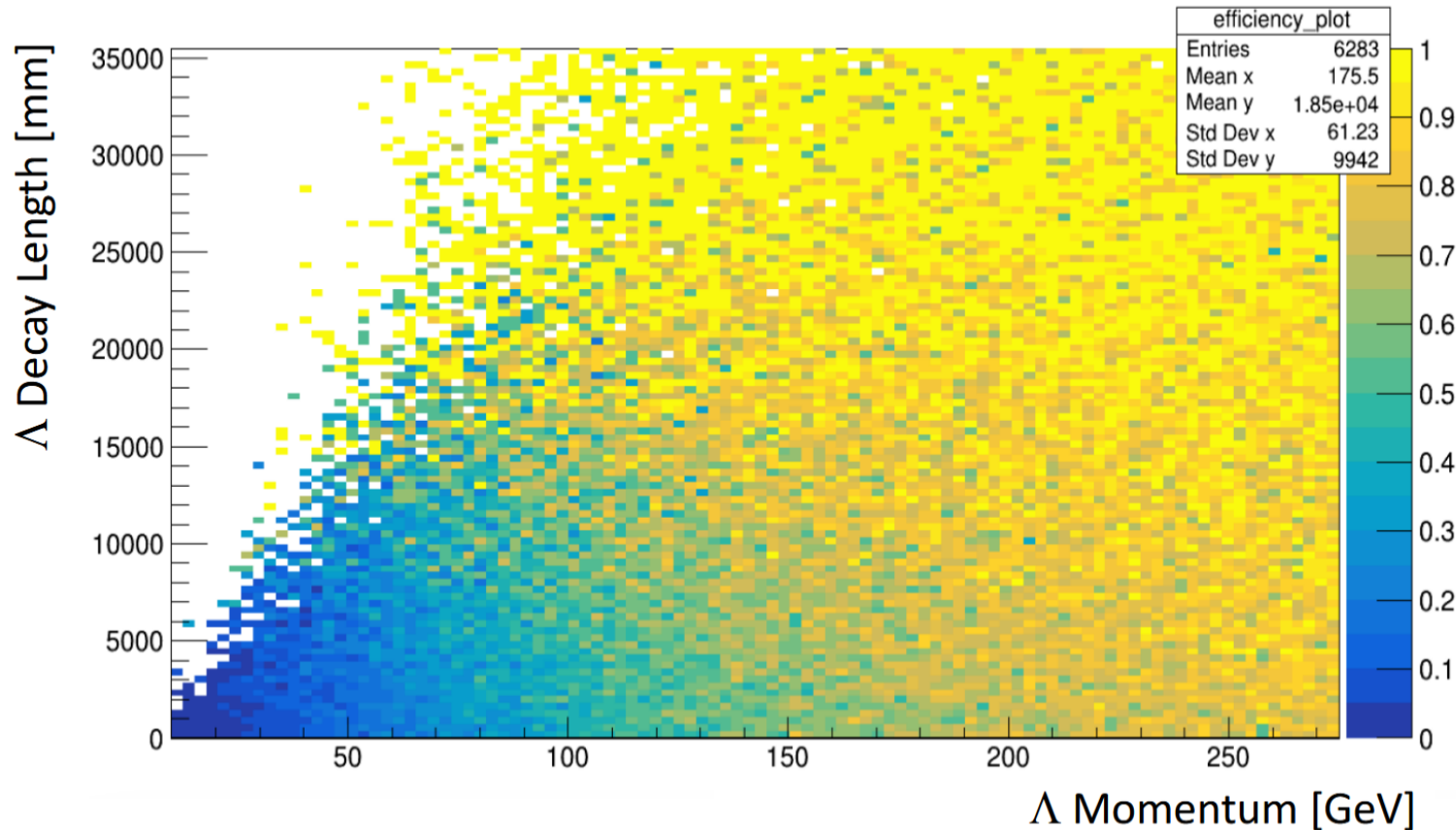


Lambda simulations from meson structure group

- 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 $e+p \rightarrow e'\Lambda K$
- Not yet intensively used by ZDC simulation studies



Efficiency Plot Λ Decay Length vs. Λ Momentum



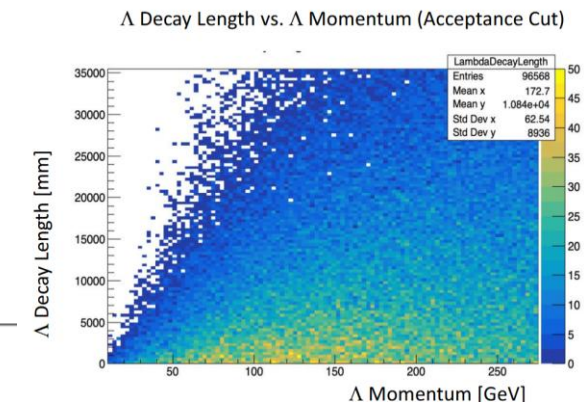
Lambdas pointed at Center of ZDC, no angular distribution included, yet

Highest Efficiency:

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

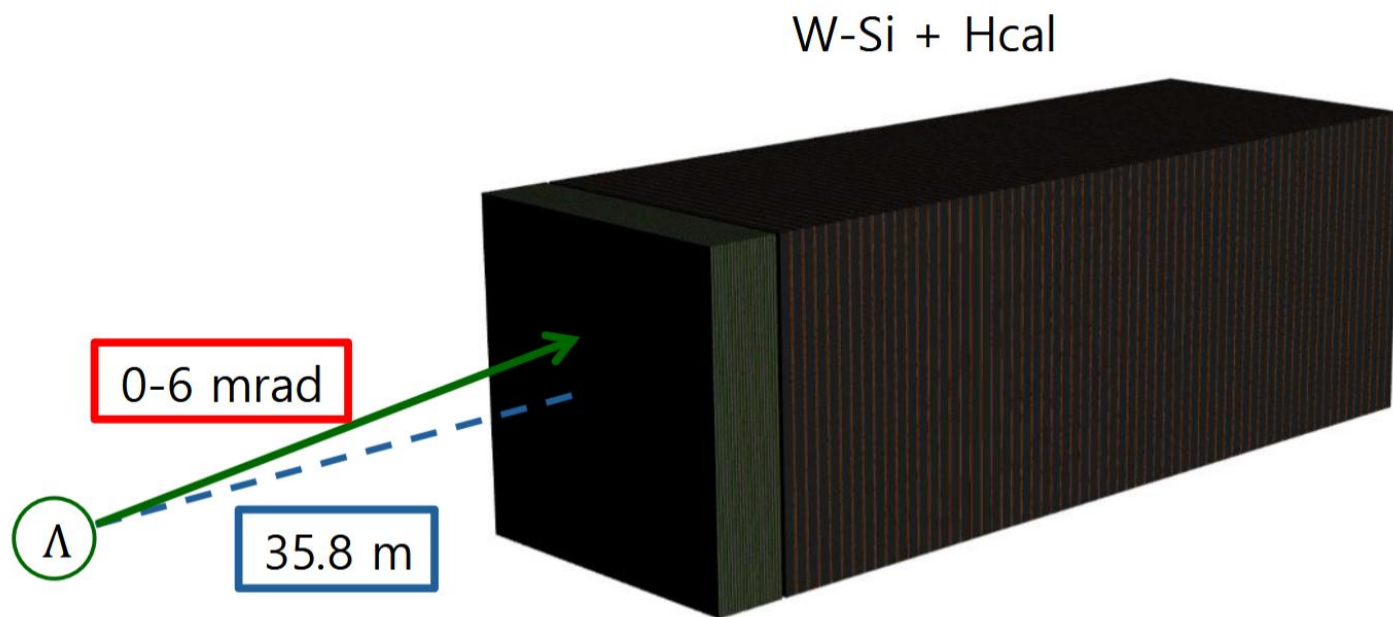
Reconstruction:

- Result in overlapping showers from neutron and photons

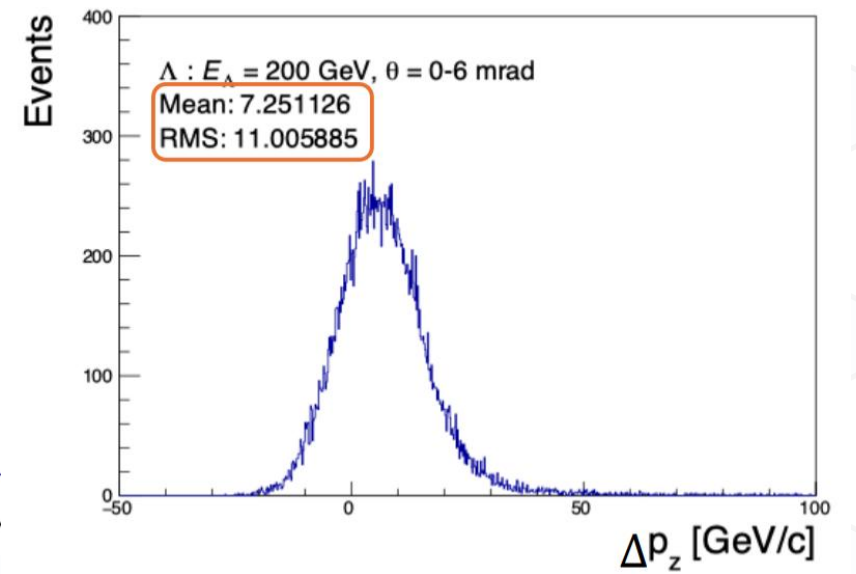
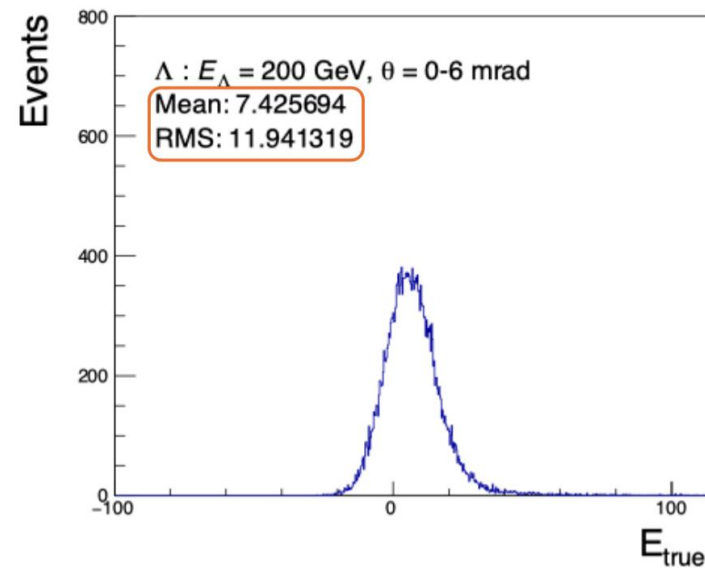
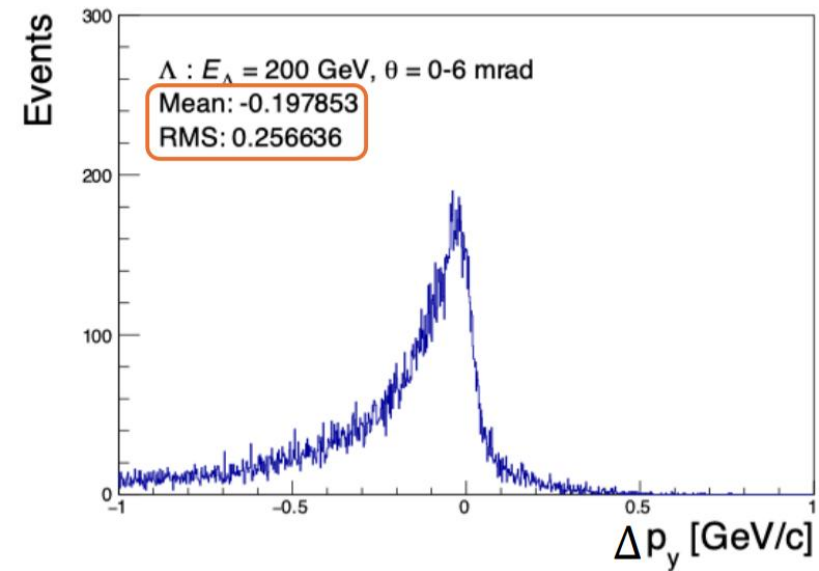
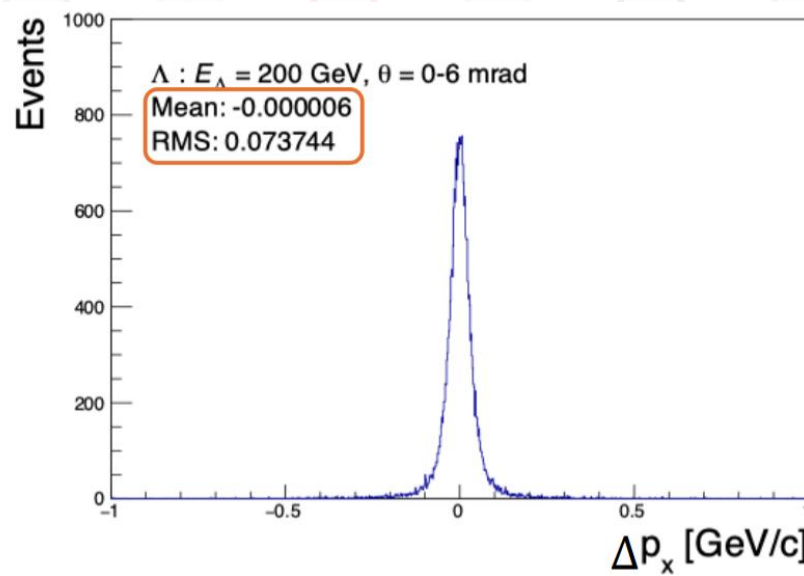


Λ Particle Gun Setup in W-Si + Hcal

- **100,000** events Λ
- $E = 200$ GeV
- $\theta =$ **0-6 mrad**
- $\varphi = 90^\circ$
- Gun position = (0, 0, 0 mm)
- Crossingangle = 0



- PX reconstruction ok, but tails in Py (nonzero h angle) – part is likely due to leakage
- Pz reasonable but larger tail due to decay position uncertainty
- Energy resolution follows Pz uncertainty

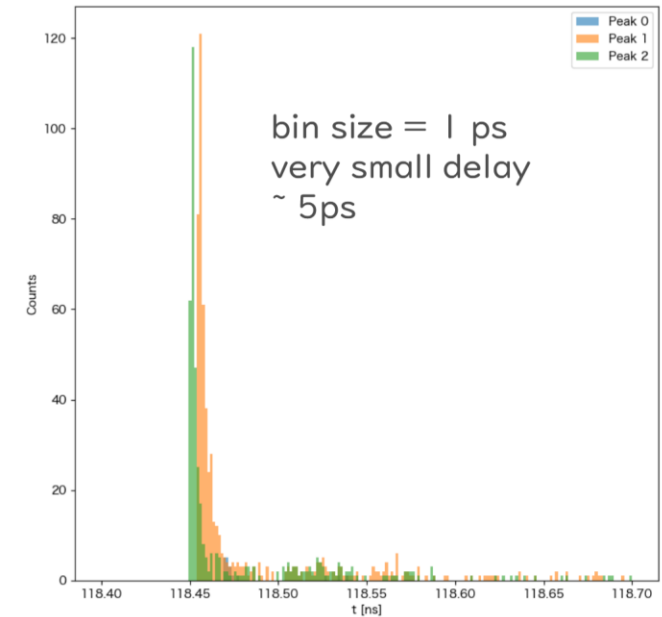
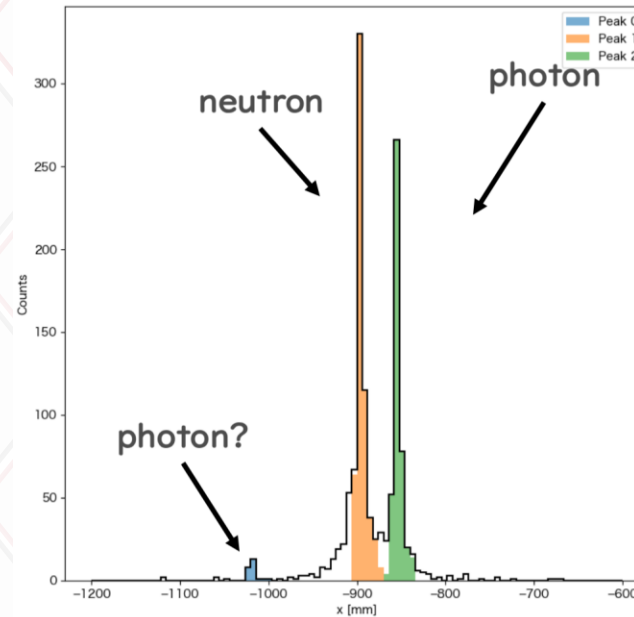


G. Kim, Y. Park

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

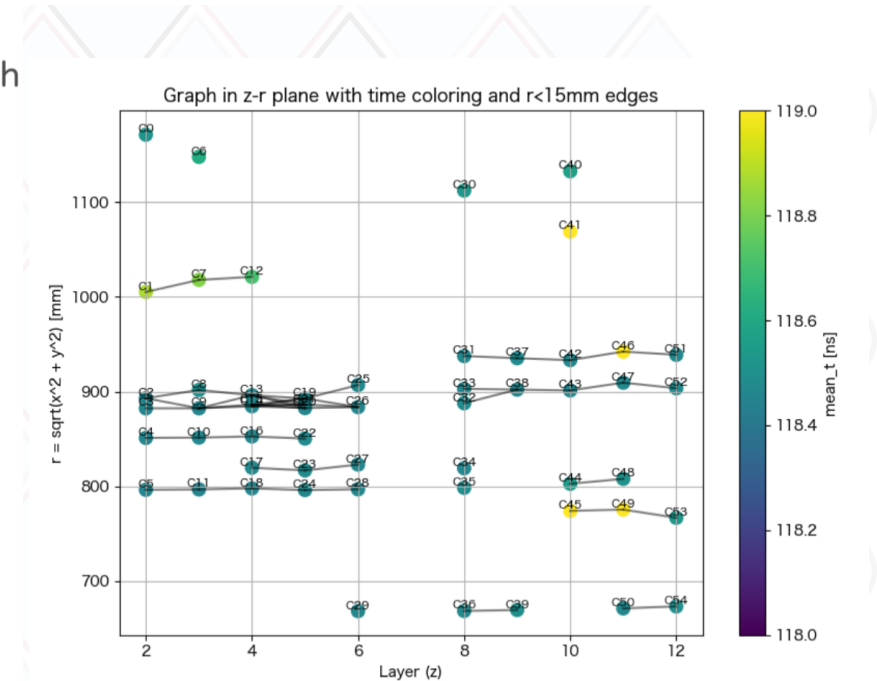


Hit clustering

- 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

R.Seidl: ZDC simulations



Summary

- Various groups working on ZDC simulations
- Substantial progress toward photon and neutron reconstruction, energy and position resolutions
- Angular resolutions for single particles from ZDC not enough to find Λ decay vertex, even when including two photons's in-plane requirement; NN approach may help
- Next steps: move toward Λ reconstruction