GNN regression of single neutrons and rho-decay in the insert

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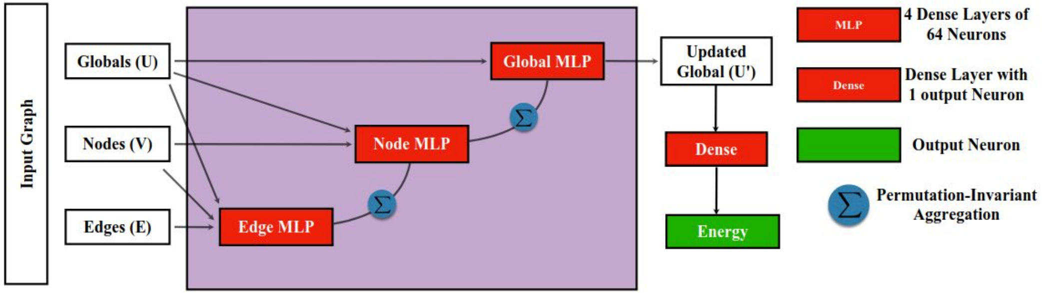
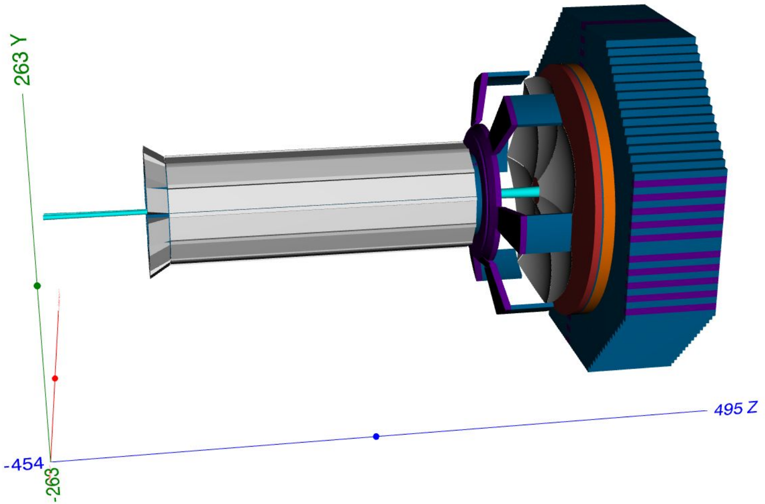
Motivation

- In previous studies, we have seen that neural networks improve the energy and angular resolutions of our detectors
  - Impact of segmentation using DeepSets and GNNs: F. Torales Acosta *et al.*, *JINST* **19** P06002 (2024)
  - Neutrons in ZDC: R. Milton et al., *Nucl.Instrum.Meth.A* **1079** 170613 (2025)
  - $\Lambda^0 \rightarrow n+\gamma+\gamma$ in ZDC: S. Paul et al., *Phys. Rev. D* ***111****, 092013 (2025)*
- How do GNNs perform for the insert? And how do different readout configurations impact the performance?



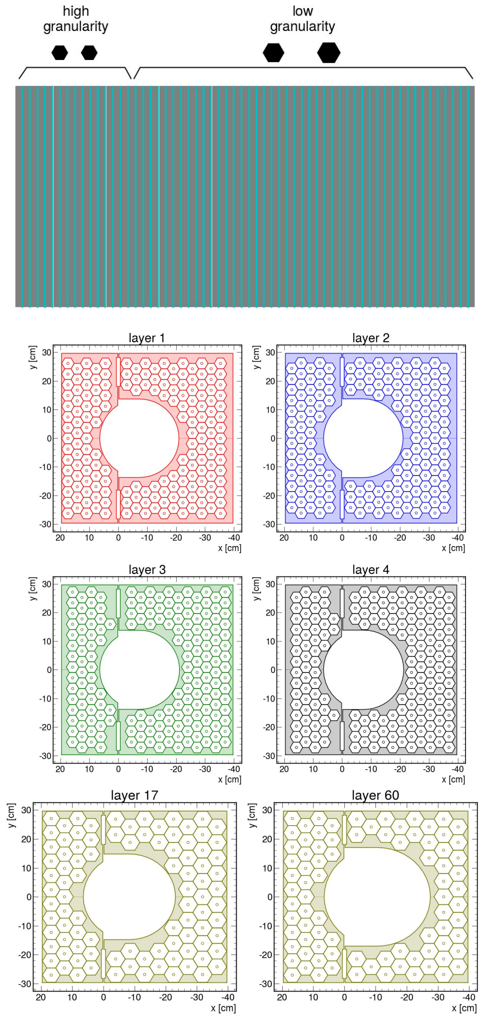
Data generation

- forward_detectors_with_insert.xml from epic-25.07.0, and EICrecon v1.26.1
- Single neutrons 1-150 GeV, 2.3° <θ^*<4.25°
- Two insert configurations:
  - High granularity: Default design in epic
  - Low granularity (LFHCAL-like): Larger cells, fewer z segmentations



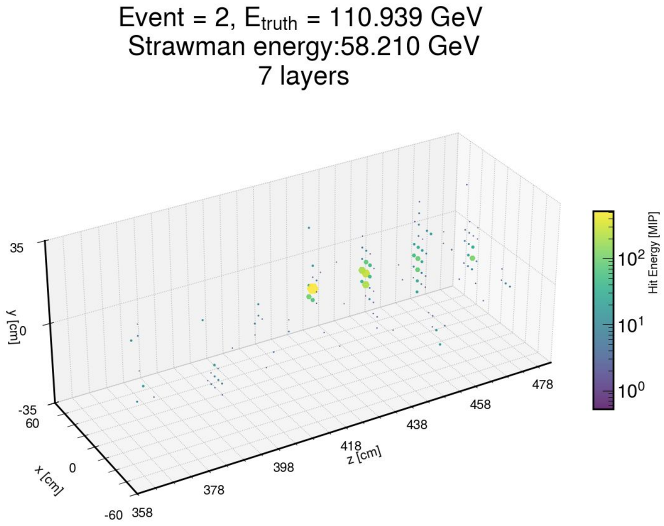
Detector configurations

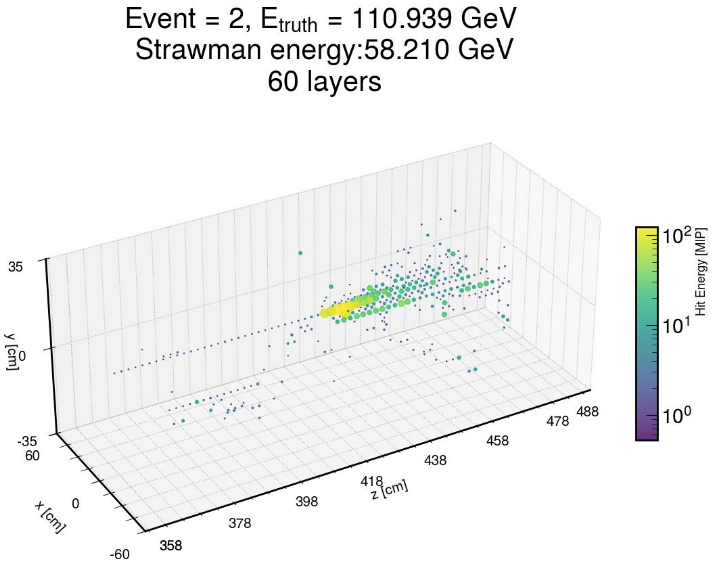
- High granularity configuration (default, [epic code here](), made in Sept. 2024):
  - 16 staggered, high-granularity layers with 14 cm^2 hexagons
  - 44 unstaggered, low-granularity layers. 21 cm^2 cells on left side, 25 cm^2 cells on right side
  - Total channels: 6710
  - Motivated for: makes channel-by-channel MIP-calibration, better timing response, better separation of showers.
- Low granularity (LFHCAL-like) configuration:
  - 60 unstaggered layers of 25 cm^2 square cells, with final readout integrated into 7 z segmentations
  - Total channels: 5280



Event display comparisons

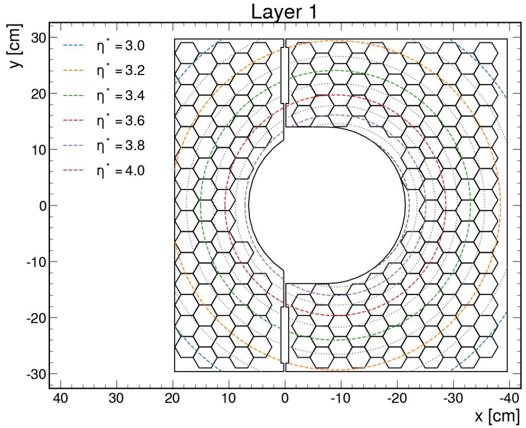
- Difficult to make out shower in low granularity case
- For these event displays, strawman energy = E_{insert} / SF_{insert}

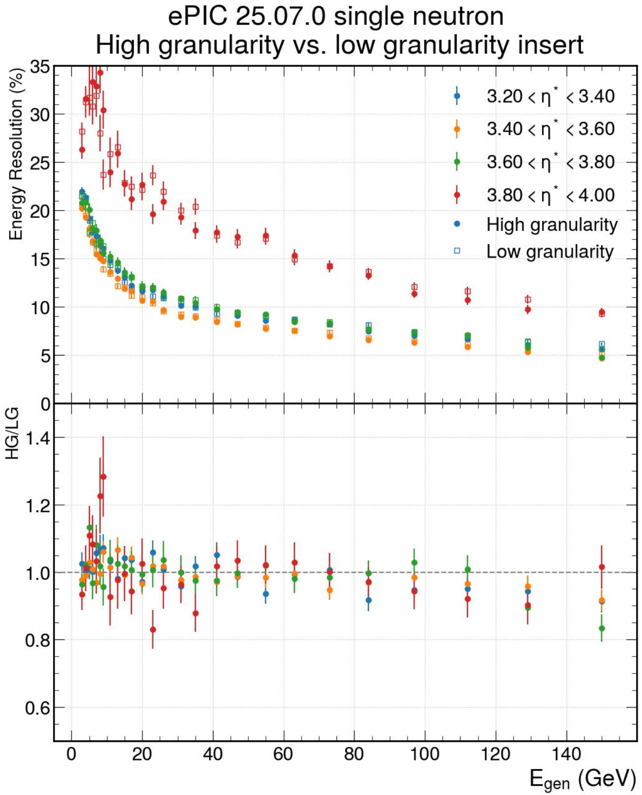




Comparing energy resolutions for single particles

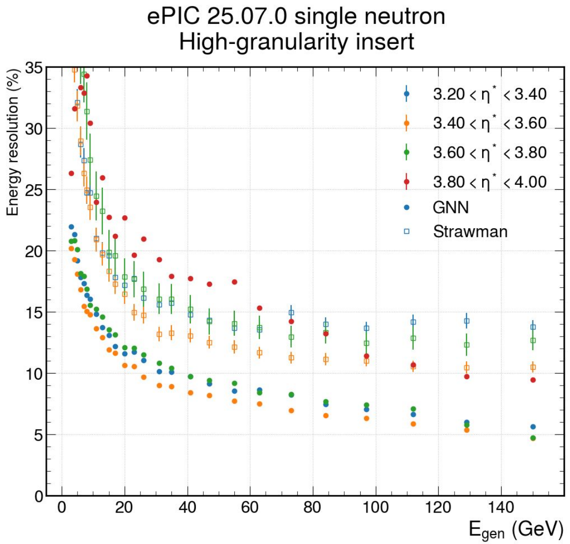
- Energy resolution = σ/μ from fit of E_{GNN}/E_{gen}
- See little difference between the two granularity configurations. This is not unexpected.

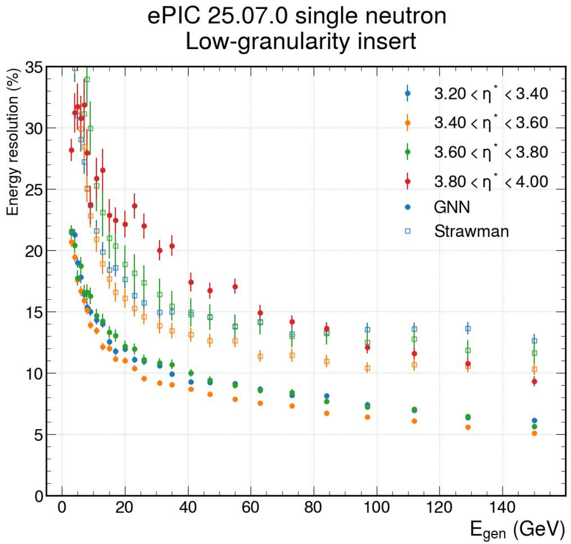




Comparison to strawman reconstruction (single particles)

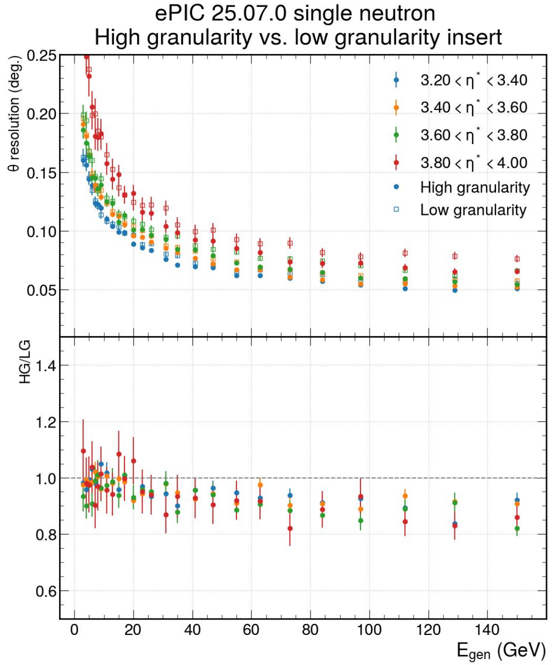
- Compare the GNN output to a “strawman” approach
- $E_{strawman} = E_{Ecal,\, 3<\eta^*<4} + E_{insert} / SF_{insert}$

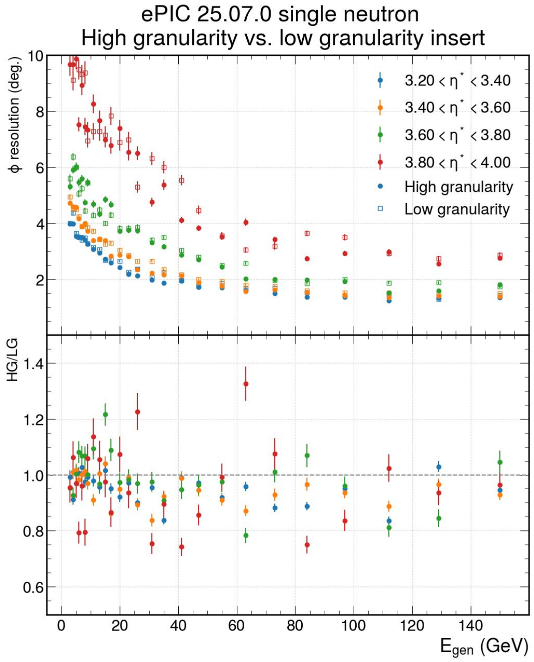




Angular resolutions for single particles

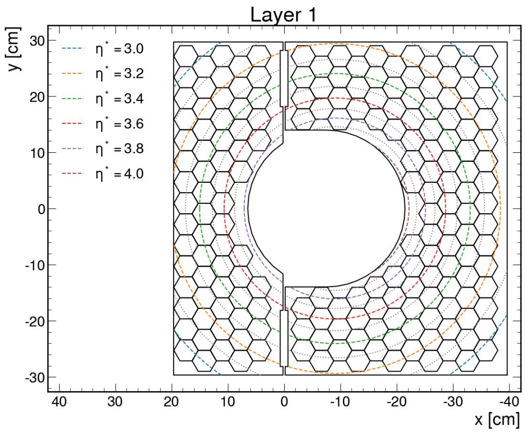
- See about 10% better performance for HG with θ resolution
- Little difference in ϕ resolution

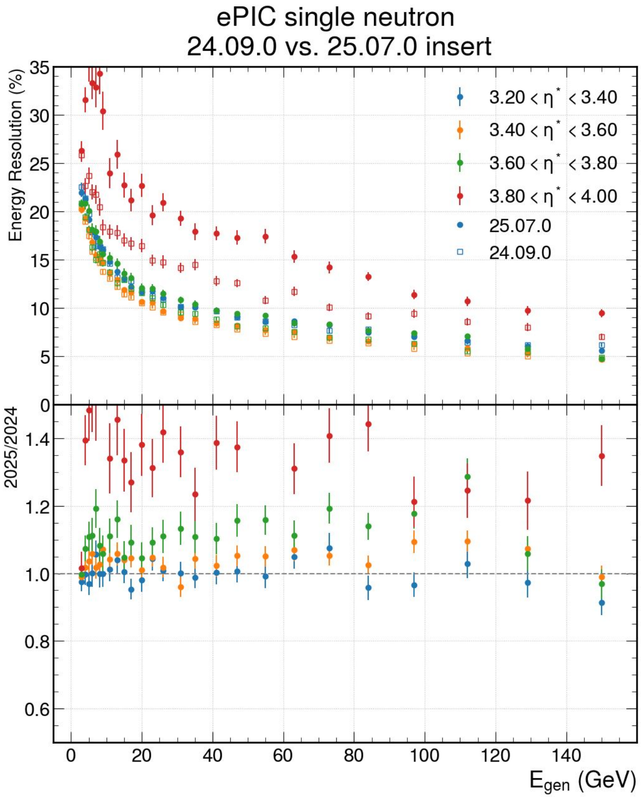




Comparison to previous results

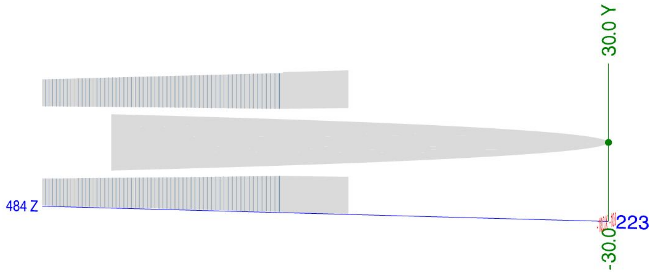
- When we compare to previous results from September 2024, see a big difference in the $3.8<\eta^*<4.0$ bin
- What's causing this difference?



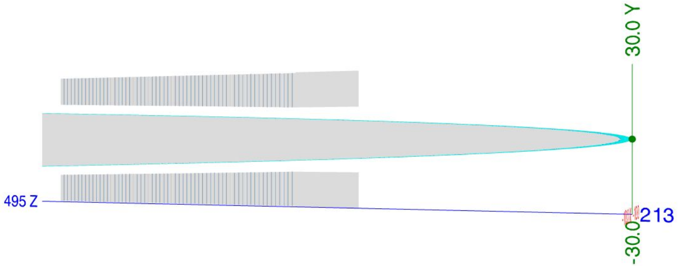


Changes to the beampipe

- In May 2025, the beampipe was overhauled in the epic simulations to be more realistic (Github link)
- Many changes were made, including the beampipe extending through the insert



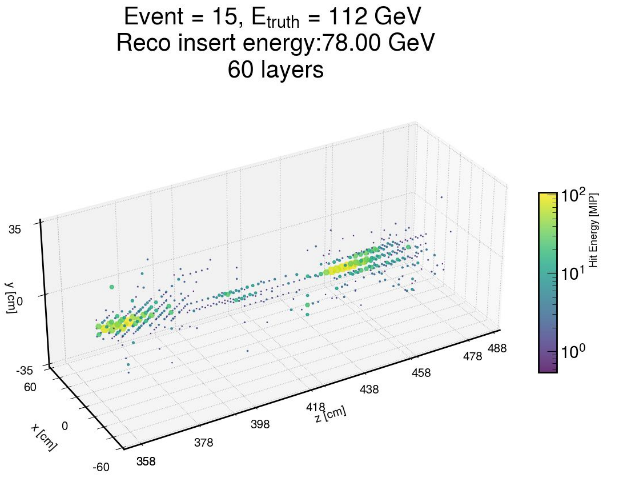
ePIC 24.09.0: insert with beampipe x-projection

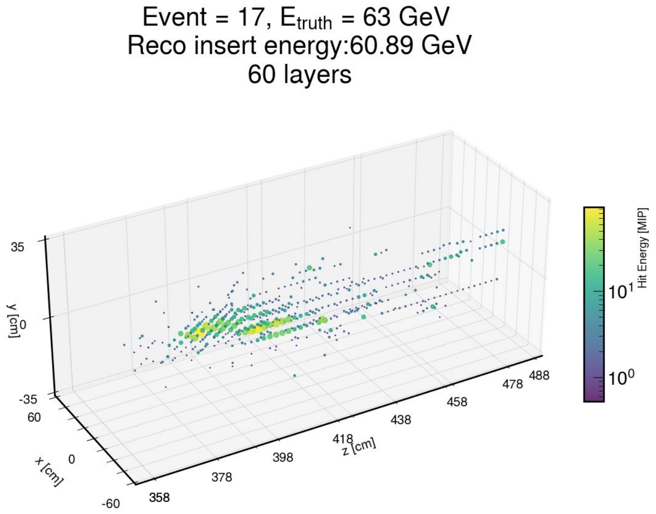


ePIC 25.07.0: insert with beampipe x-projection

ρ^0-decay

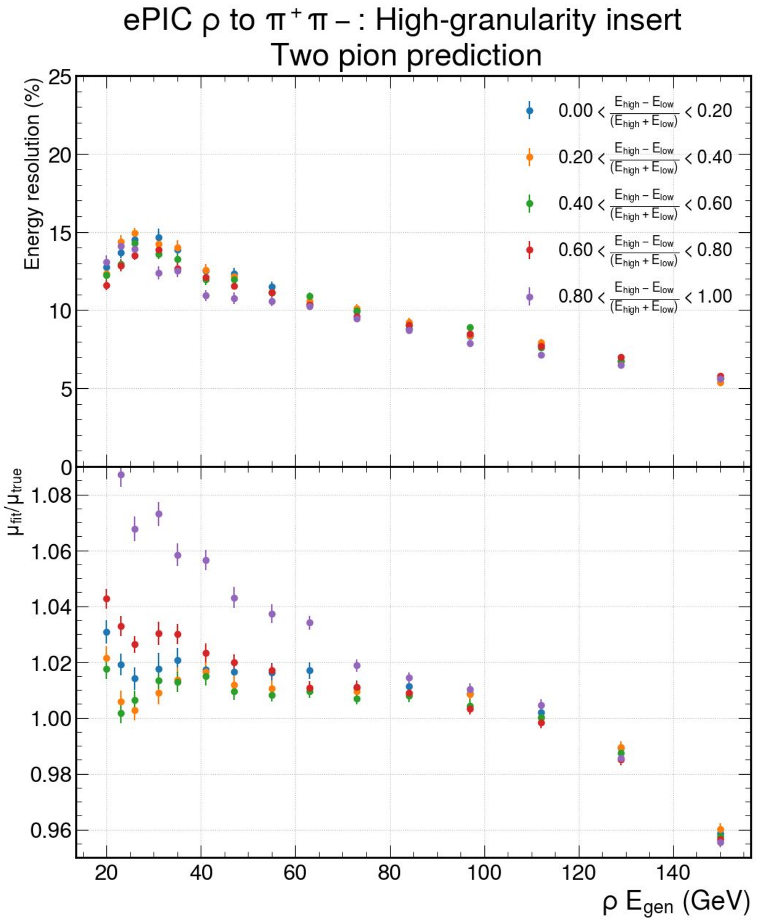
- Now simulate $\rho^0 \rightarrow \pi^+\pi^-$
- Using this as a proxy for multiple shower performance
- ρ^0, 1-150 GeV, $2.3° < \theta^* < 4.25°$
    - Demand that both pions hit the ECal in region $3 < \eta^* < 4$
- Train GNN to predict the energies and angles of the two pions
- Only have high granularity results currently





Energy resolutions

- Divide into bins of asymmetry
- See a drop in energy scales as asymmetry increases
- Next step is to see how the low granularity configuration performs

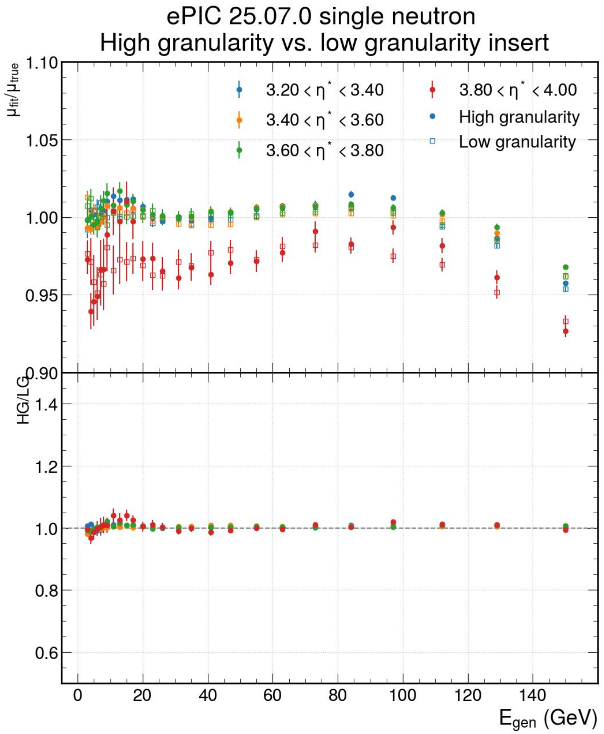


Conclusions

- From previous studies, GNNs reconstruct single particle energies and angles well
- See little difference in GNN results when using insert configuration with larger cells and 7 readout layers, compared to smaller cells and 60 readout layers for single particles.
- This was a starting point, since we need more complicated final states to stress possible configurations. Currently working on 2-shower overlap using the proxy $\rho^0 \rightarrow \pi^+\pi^-$,

Thank you!

Backup: Energy scales



Backup: Angle comparisons from 2024/2025