On the issue of Insert Granularity

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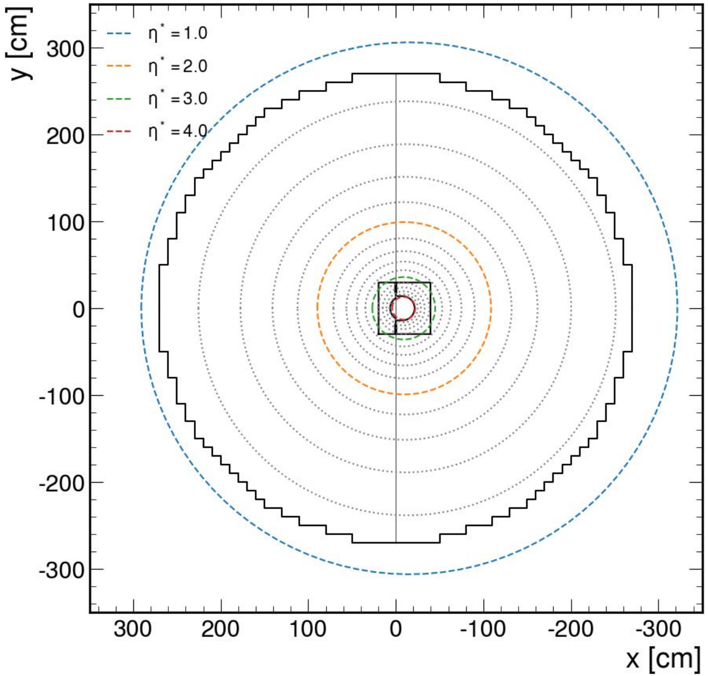
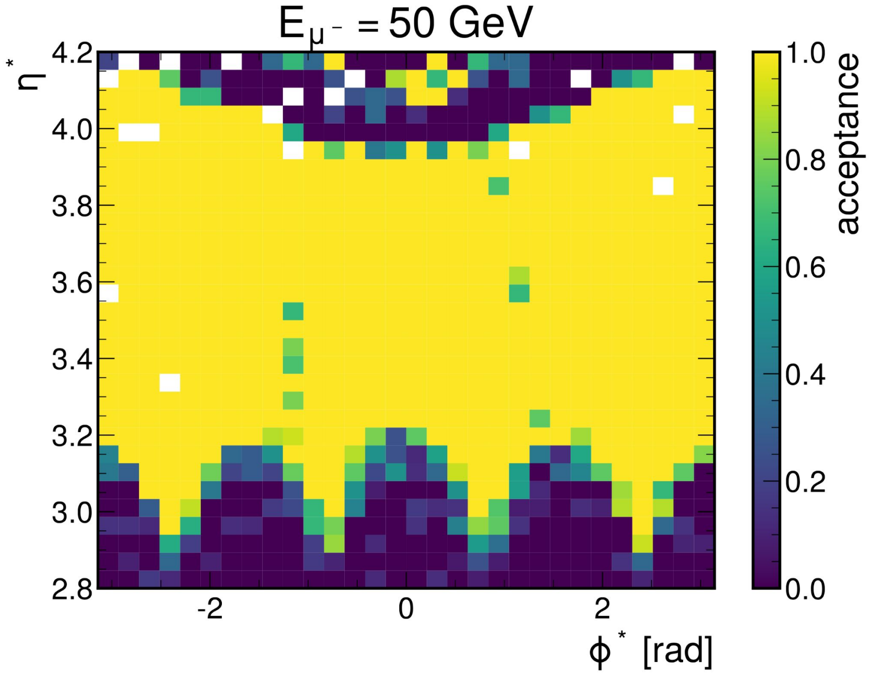
This work was carried out by Ryan Milton

What is the insert? (phasespace)

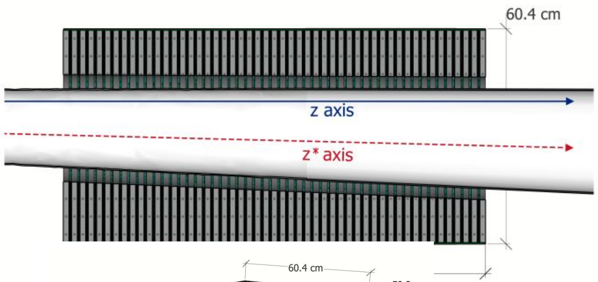
- It is the inner most part of LFHCAL, covering 3.0<eta<4.0
- It covers more than ⅓ of the eta/phi phasepace of LHFCAL with <1% of its volume/cost.

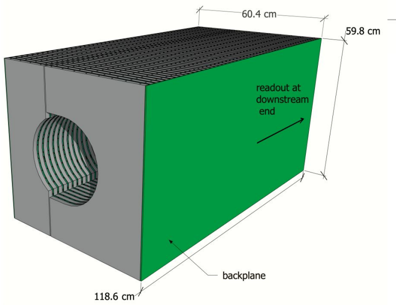


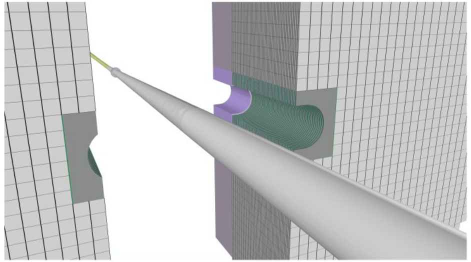


What is the insert? (mechanically)

- Its mechanical concept uses layers that optimizes acceptance in presence of crossing angle. This enables acceptance up to eta=4.0, which is a key requirement of the EIC yellow report.



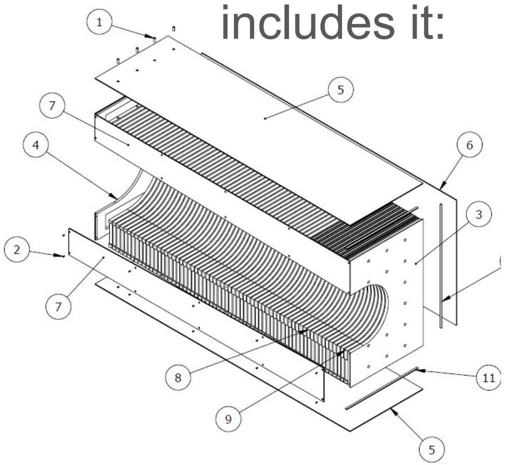


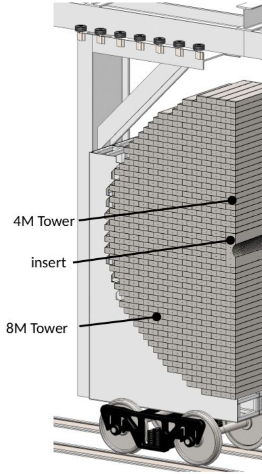


M. Arratia et al. *NIMA 1047 (2023) 167866*

[*https://linkinghub.elsevier.com/retrieve/pii/S0168900222011585*](https://linkinghub.elsevier.com/retrieve/pii/S0168900222011585)

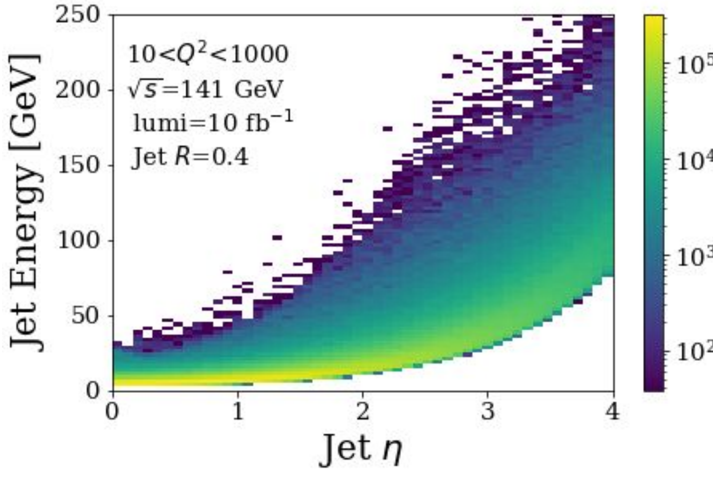
LHFCAL design includes it:

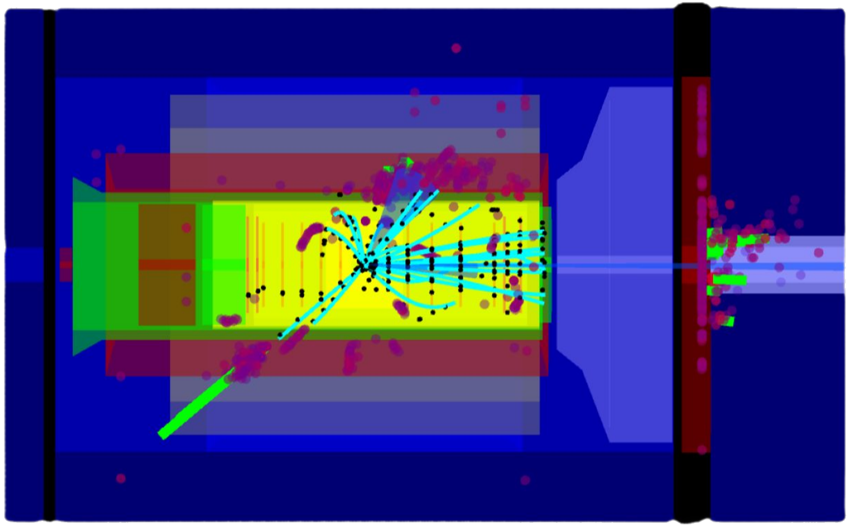


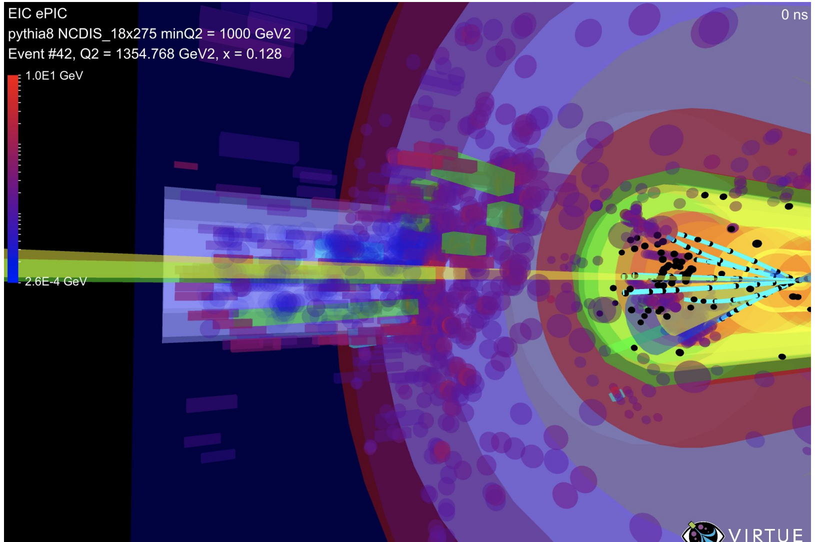


What is the insert? (granularity)

- Its granularity is motivated for better measurements of the highest energy jets at EIC, which cover the energy 50-250 GeV with high statistics.



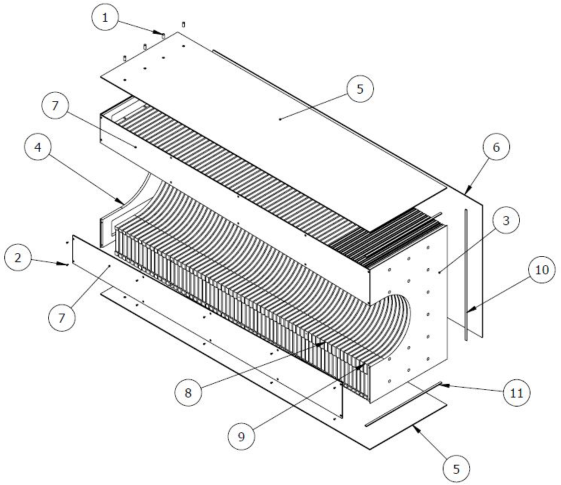




The mechanical concept of the Insert is in the final design of LFHCAL, so it is frozen.

But, the granularity of the insert has been a matter of extensive debate and very strong/surprising interest, in the context of the upcoming 60% readiness review.

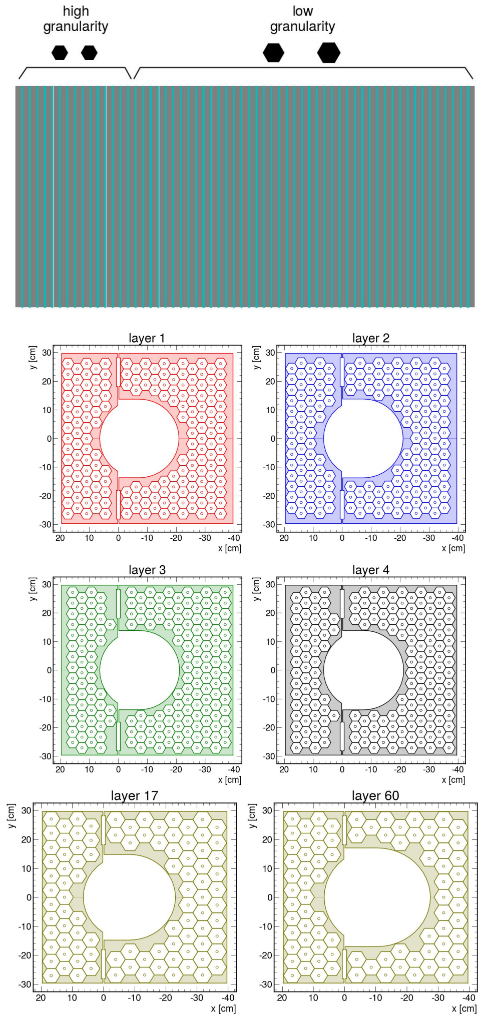
What is more, this 1% matter somehow made it to the list of the ePIC collaboration priorities in Summer mtg.



LFHCAL	Insert motivation	We have no plots really motivating, we could also continue the std LFHCAl design fully to the beam pipe.

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



What are we comparing?

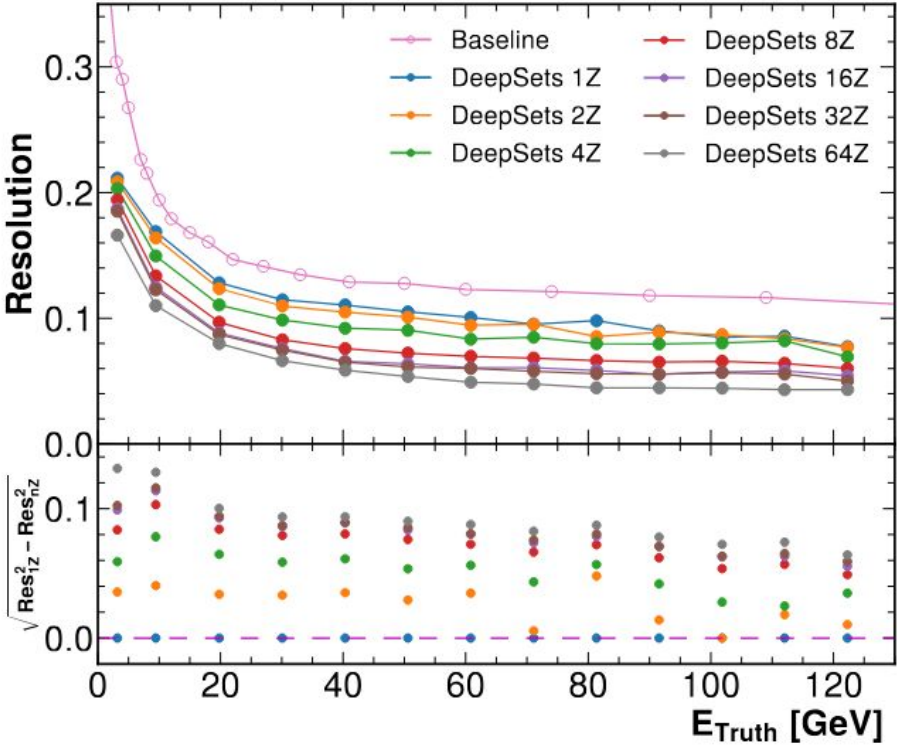
“High granularity” insert (current)	“LHFCAL-like” granularity insert (strongly suggested)
6710 SiPMs and 210 CALOROC Number of channels: 6710.	5280 SiPMs and 24 CALOROC Number of channels: 754.
“Problem”: <10% cross talk. Unclear whether this is a real issue	“Solution”: Likely a bit less cross talk by ~25% decrease in SiPM count.
Con: need to “motivate in review”	Pro: being same granularity as LHFCAL makes it less likely to stick out in review

- Note, some misinformation/miscommunication lead to claims that “LHFCAL-like” configuration would be a x4 decrease in SiPM count and would be a solution the cross-talk issue. That is just fake.
- As a side note, the high-granularity is marginally more expensive, with negligible impact on cost. In particular, extra 1.4k SiPM and ~190 CALOROC → small money <O(0.1%) of LHFCAL cost.

Other differences

“High granularity” insert (current)	“LHFCAL-like” granularity insert (strongly suggested)
Calibration: Trivially calibrated channel-by-channel with MIPs. Important when radiation dose is not homogeneous	**Calibration** MIP calibration of summed 7-channels will likely be likely degraded and/or lost
Timing: Good timing performance channel by channel. Could serve as “tag” for other detectors	**Timing**: Timing performance for summed-7 channels will likely be greatly degraded
Acceptance Dead area is minimal by construction, every layer is optimized for acceptance. This is important in the insert region where each layer is different because of the beampipe	**Dead area:** tower-like structure (summing of 7 layers) will lead to inefficient tessellation, gaps in acceptance.

Our previous studies showed that longitudinal granularity improved energy resolution



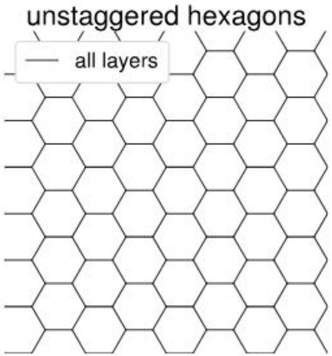
The optimal use of segmentation for sampling calorimeters, F. Torales Acosta et al., JINST 19 P06002 (2024)

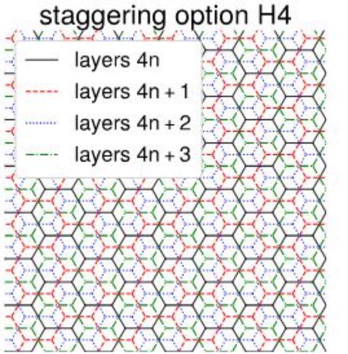
Single-pion performance, With ECAL in front

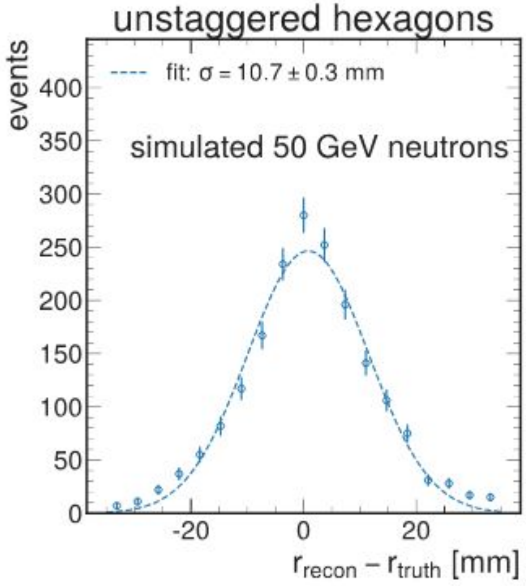
Our previous studies showed
Staggering of layers (possible
Only if reading out every layer)
Improves angular resolution
By a factor of 2

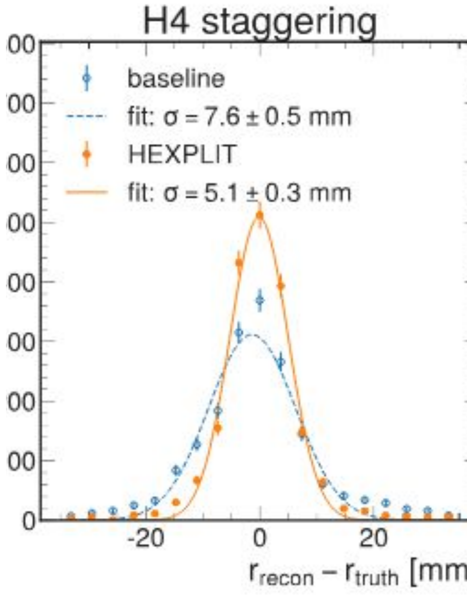
- [Leveraging staggered tessellation for enhanced spatial resolution in high-granularity calorimeters]()

  S. J Paul and M. Arratia Nucl.Instrum.Meth.A 1060 (2024) 169044





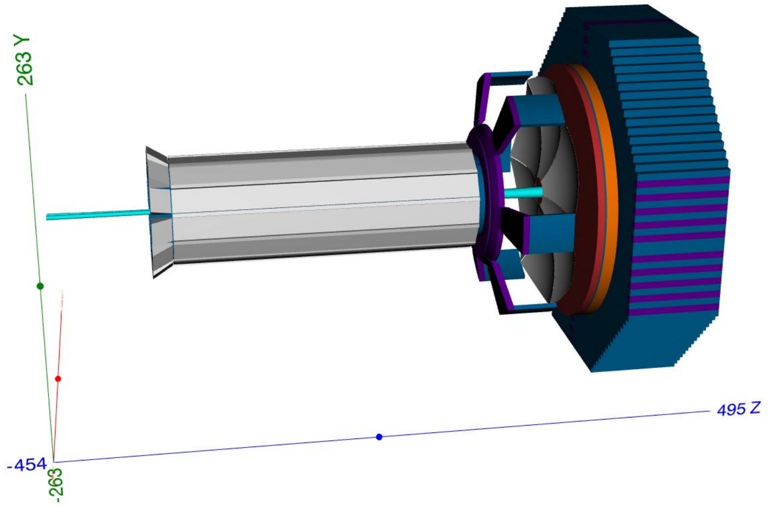




New studies

Data generation

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



Graph-Neural Network

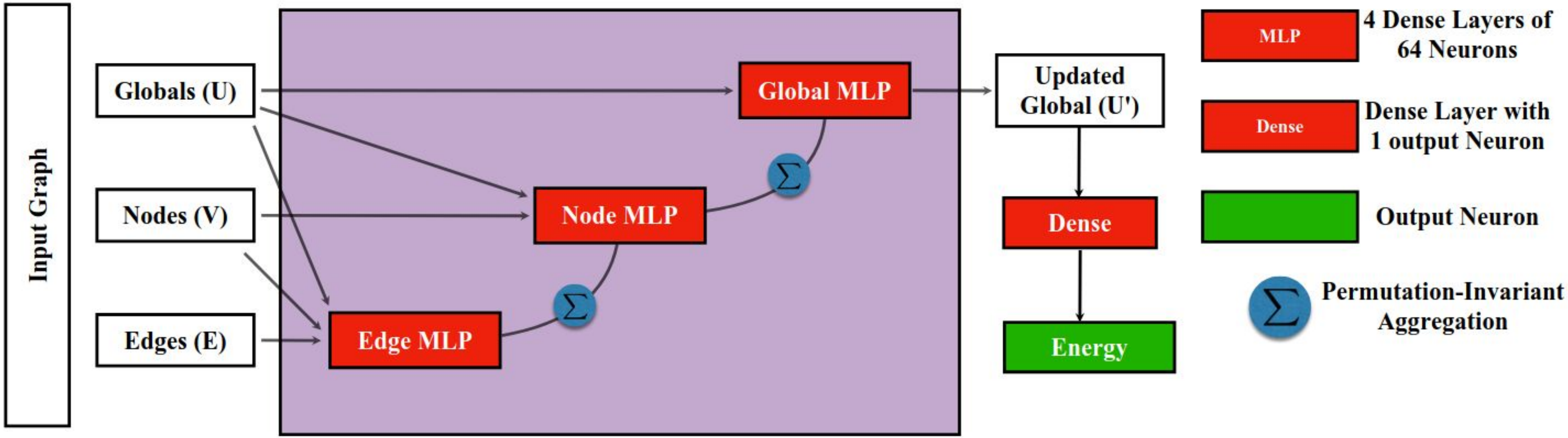


Figure 2. A schematic of the GNN model.

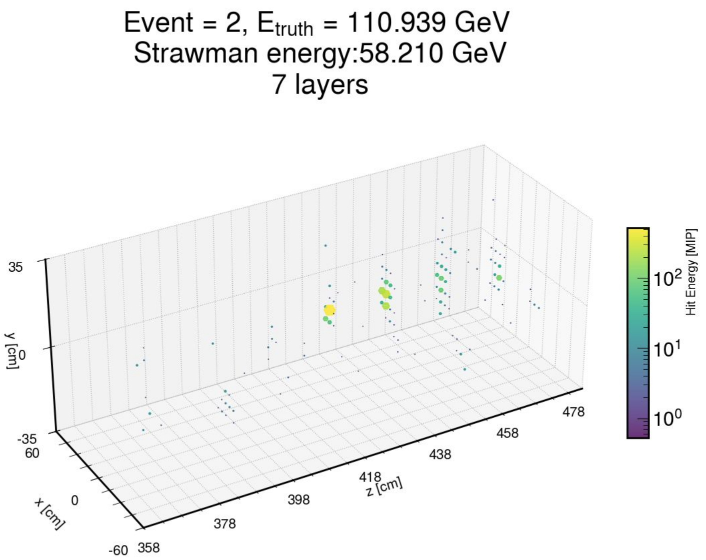
State of the art method to reconstruct high-granularity detector, implements software-compensation thus optimal reconstruction.

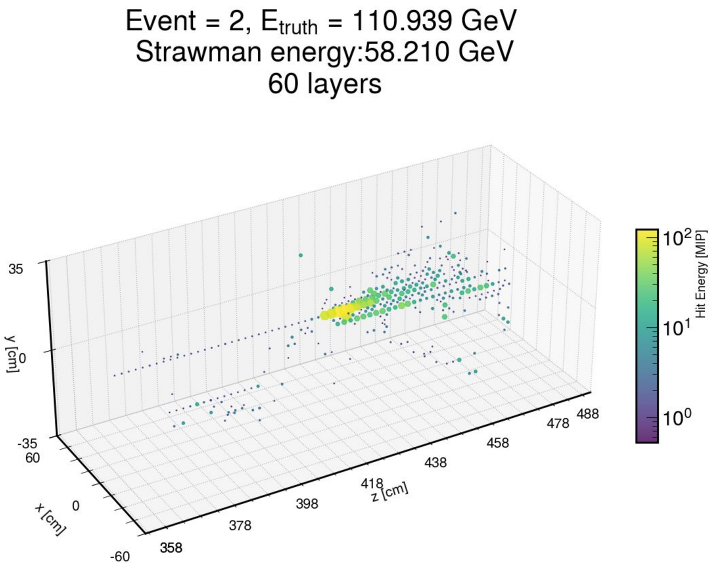
See for more details:

R. Milton et al., *Nucl.Instrum.Meth.A* **1079** 170613 (2025),

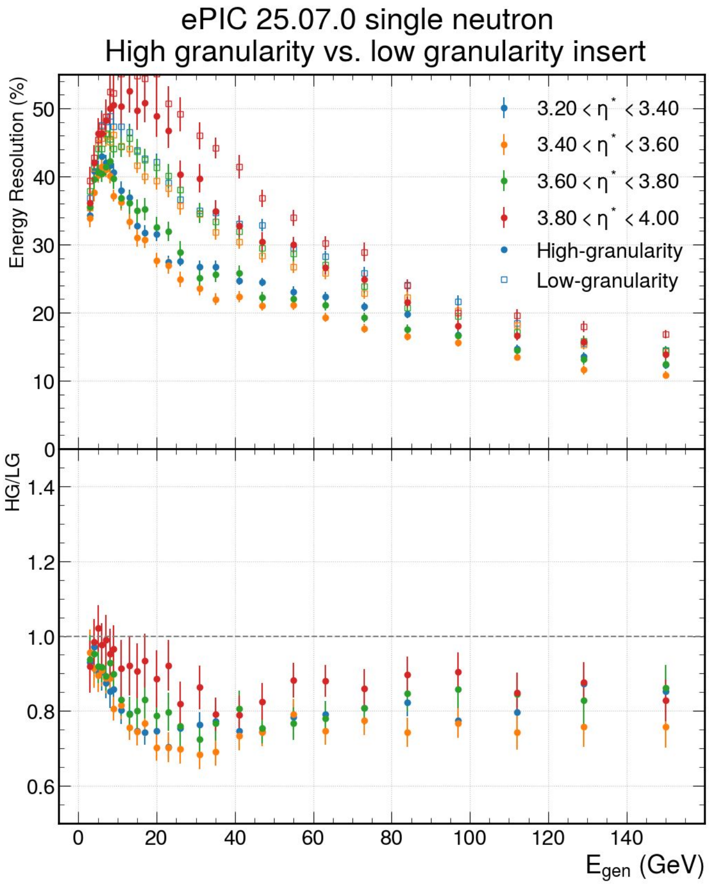
S. Paul et al., *Phys. Rev. D* **111**, 092013 (2025)

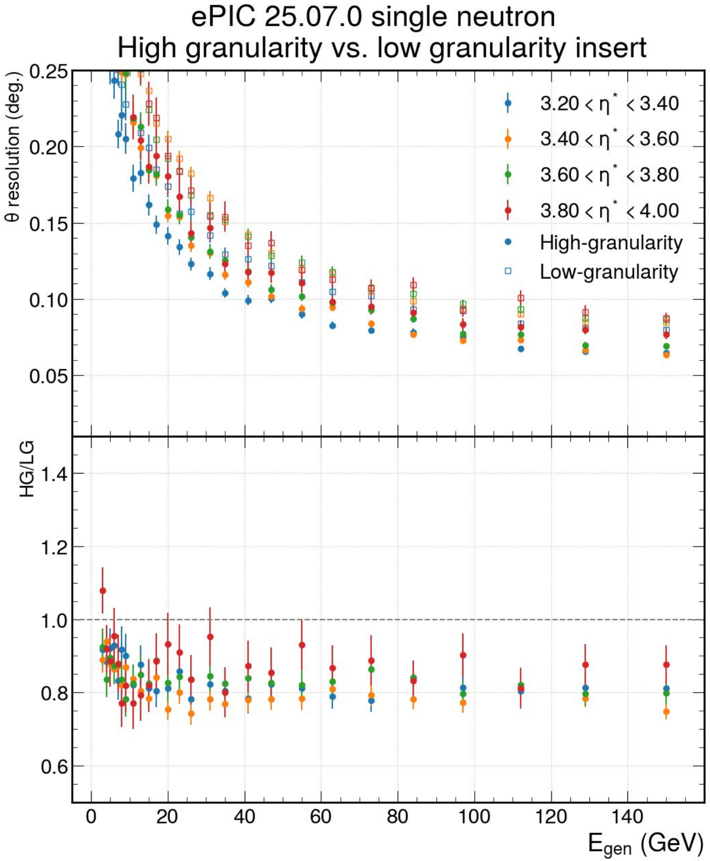
Event display comparisons



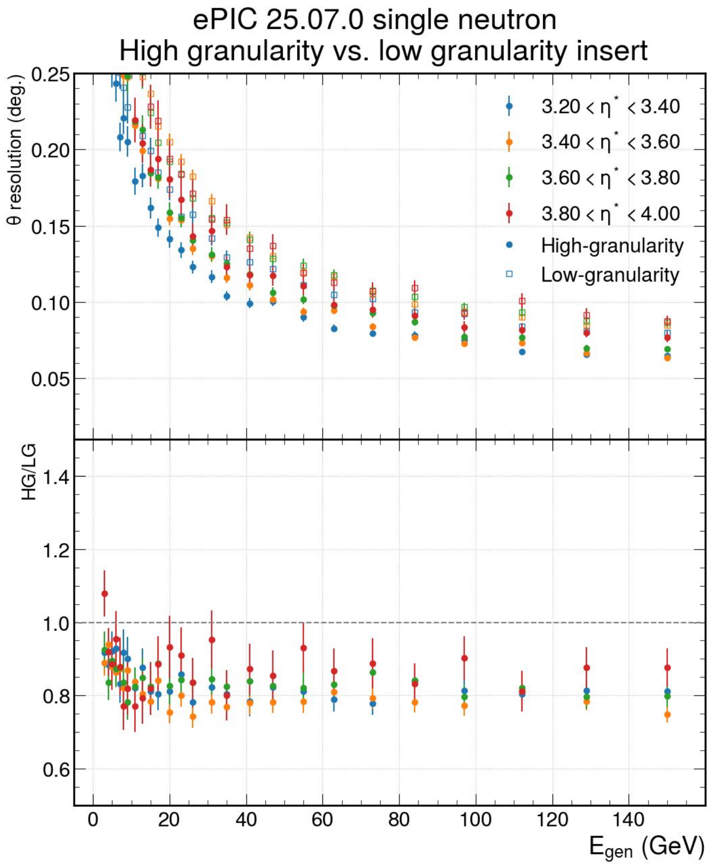


GNN Insert Standalone

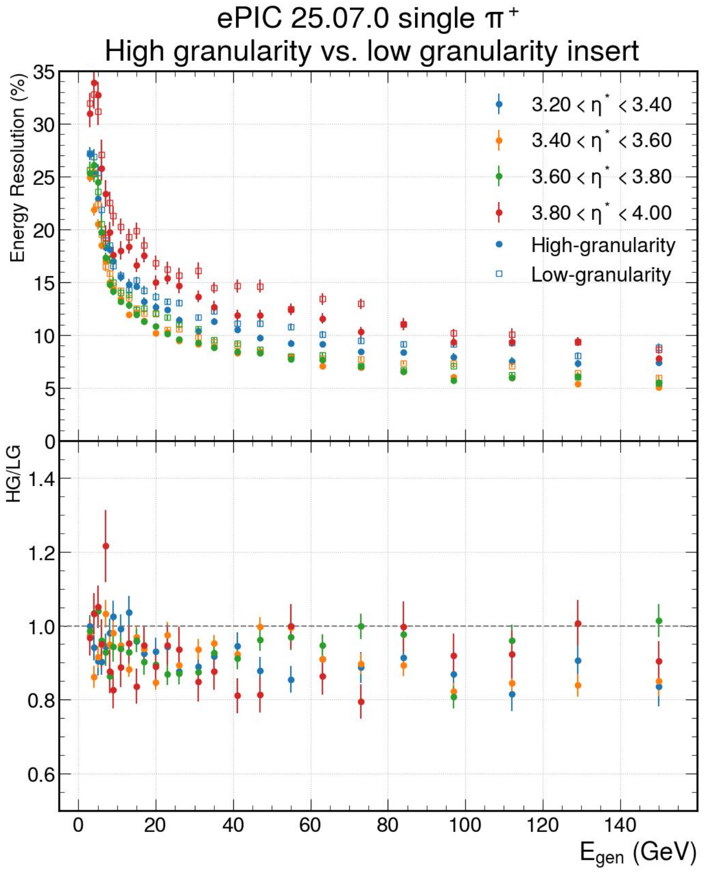


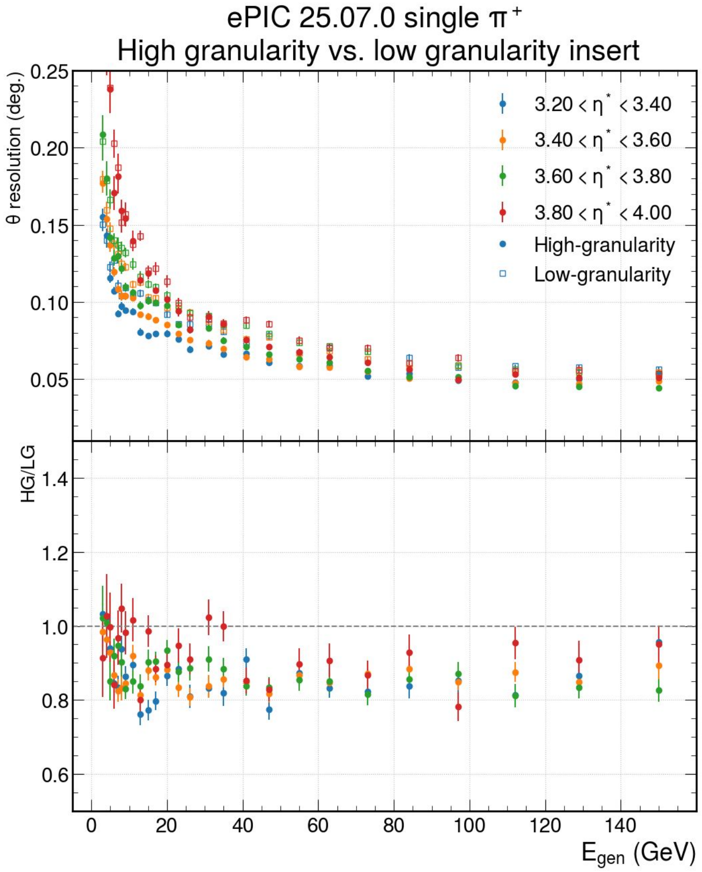


GNN Insert Standalone



GNN performance for pions with MIP-like deposition in ECAL



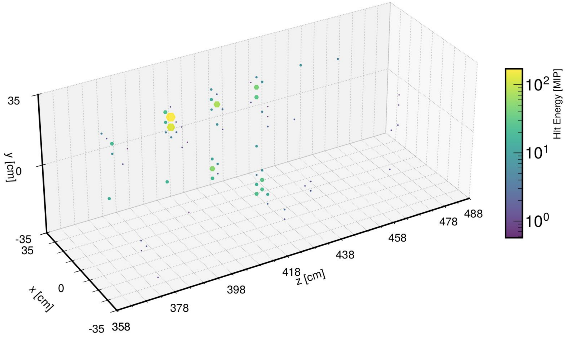


Two-shower separation using $\rho^0 \rightarrow \pi^+\pi^-$ As proxy

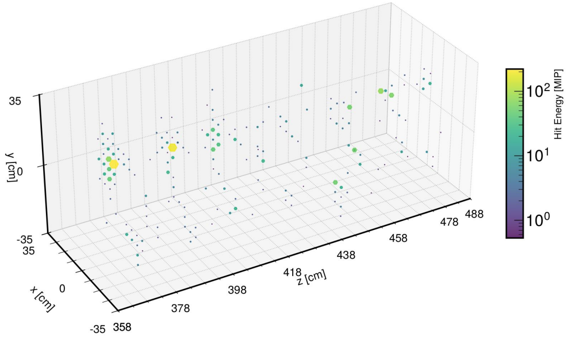
- Having two-shower separation would open up new capabilities for EIC jet physics program, as well as background rejection (beam gas, etc)
- Asymmetry = $(E_{high} - E_{low})/(E_{high} + E_{low})$
- E_{high} = energy of high-energy pion in event, E_{low} = energy of low-energy pion

$\rho^0 \rightarrow \pi^+\pi^-$ Event displays: $0 < \text{Asymmetry} \leq 0.2$

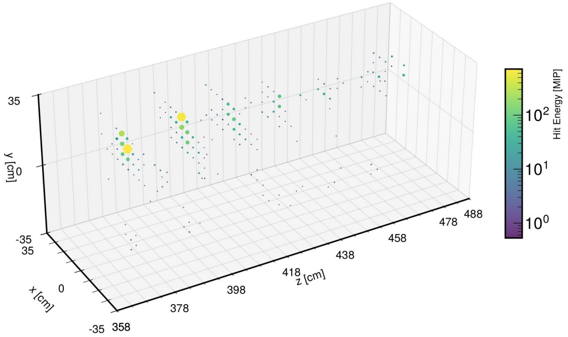
$E_{truth,\,high}$ = 14.1 GeV, $E_{truth,\,low}$ = 11.9 GeV
Asym. = 0.09
7 layers



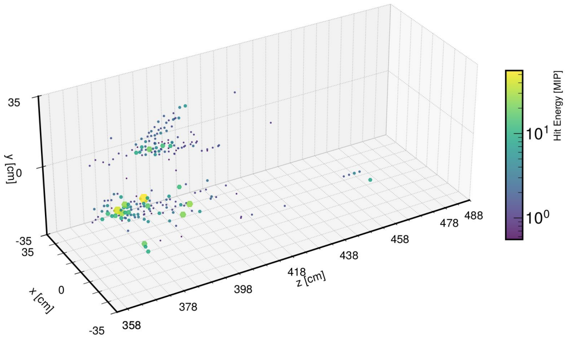
$E_{truth,\,high}$ = 49.3 GeV, $E_{truth,\,low}$ = 34.7 GeV
Asym. = 0.17
7 layers



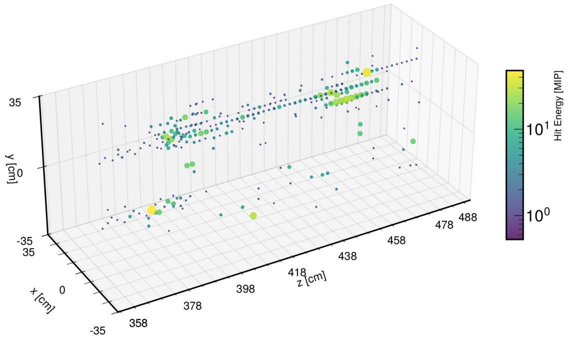
$E_{truth,\,high}$ = 75.4 GeV, $E_{truth,\,low}$ = 53.6 GeV
Asym. = 0.17
7 layers



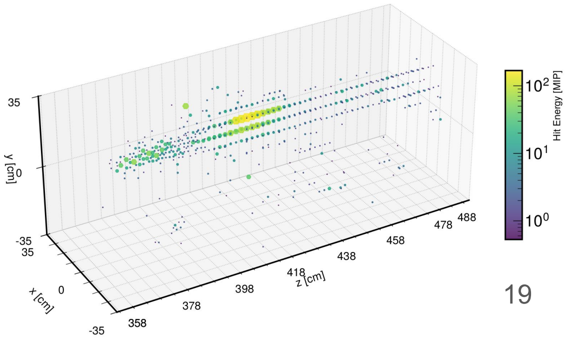
$E_{truth,\,high}$ = 12.0 GeV, $E_{truth,\,low}$ = 8.0 GeV
Asym. = 0.20
60 layers



$E_{truth,\,high}$ = 42.8 GeV, $E_{truth,\,low}$ = 30.2 GeV
Asym. = 0.17
60 layers

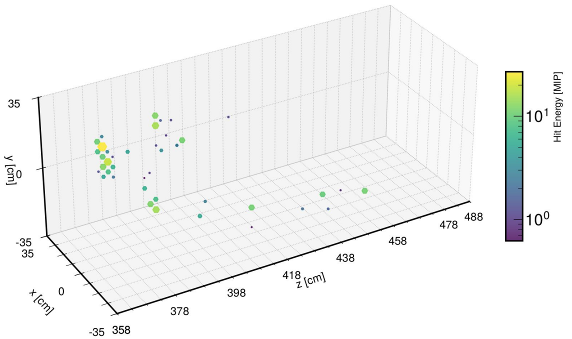


$E_{truth,\,high}$ = 71.2 GeV, $E_{truth,\,low}$ = 57.8 GeV
Asym. = 0.10
60 layers

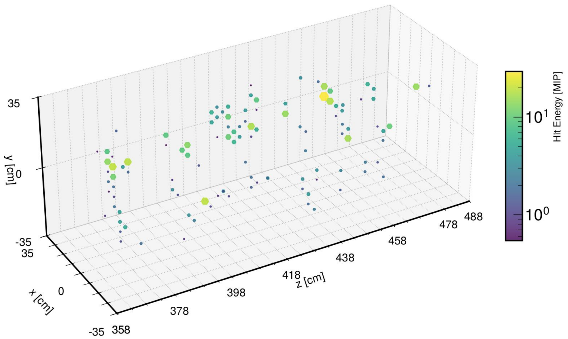


$\rho^0 \to \pi^+\pi^-$ Event displays: 0.2 < Asymmetry ≤ 0.4

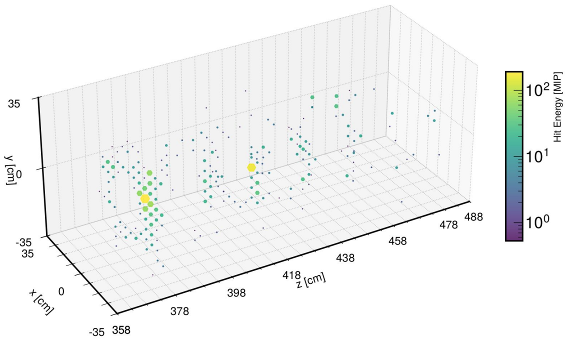
$E_{truth,\,high}$ = 11.2 GeV, $E_{truth,\,low}$ = 5.8 GeV
Asym. = 0.32
7 layers



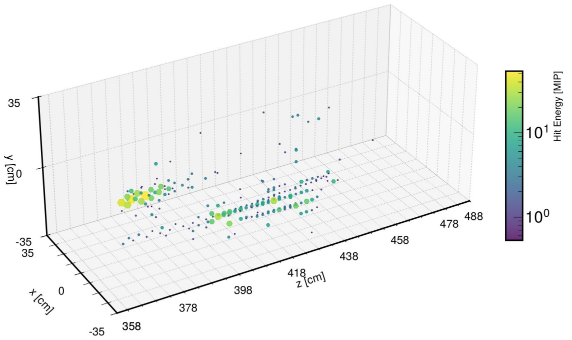
$E_{truth,\,high}$ = 21.5 GeV, $E_{truth,\,low}$ = 9.6 GeV
Asym. = 0.38
7 layers



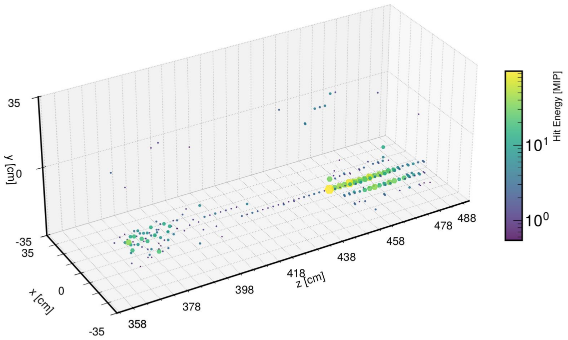
$E_{truth,\,high}$ = 77.5 GeV, $E_{truth,\,low}$ = 34.5 GeV
Asym. = 0.38
7 layers



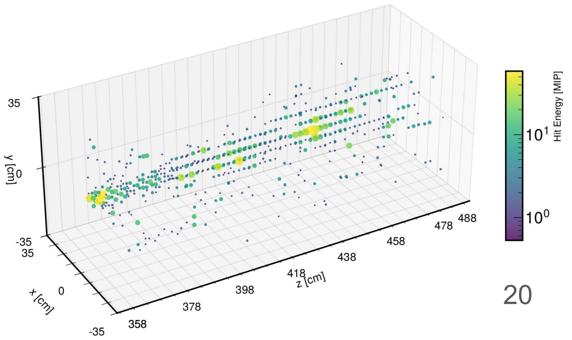
$E_{truth,\,high}$ = 17.7 GeV, $E_{truth,\,low}$ = 8.3 GeV
Asym. = 0.36
60 layers



$E_{truth,\,high}$ = 27.5 GeV, $E_{truth,\,low}$ = 13.5 GeV
Asym. = 0.34
60 layers

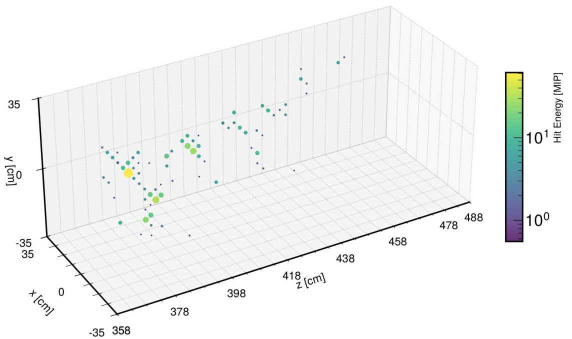


$E_{truth,\,high}$ = 89.8 GeV, $E_{truth,\,low}$ = 39.3 GeV
Asym. = 0.39
60 layers

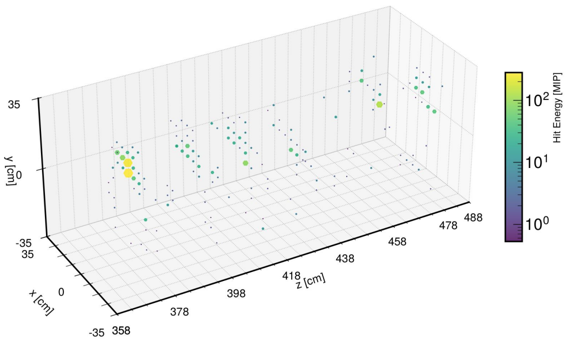


$\rho^0 \to \pi^+\pi^-$ Event displays: 0.4 < Asymmetry ≤ 0.6

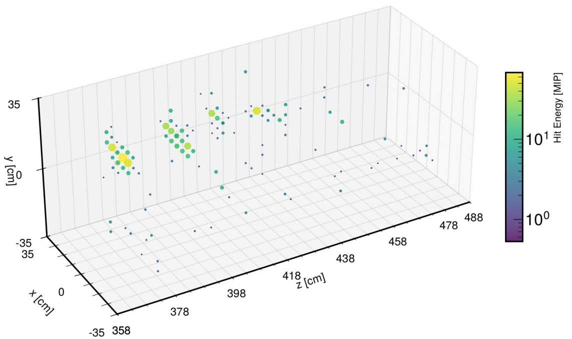
$E_{truth, high}$ = 19.1 GeV, $E_{truth, low}$ = 6.9 GeV
Asym. = 0.47
7 layers



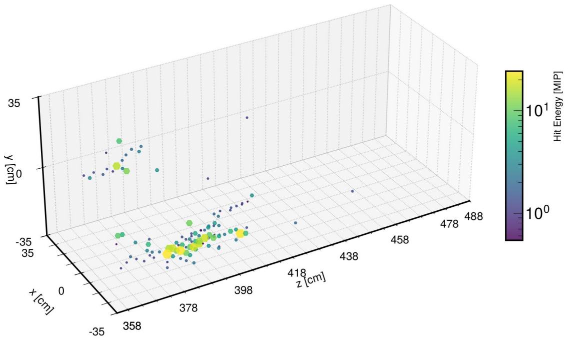
$E_{truth, high}$ = 38.5 GeV, $E_{truth, low}$ = 16.5 GeV
Asym. = 0.40
7 layers



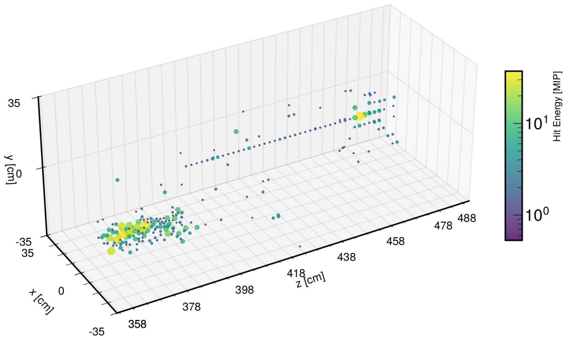
$E_{truth, high}$ = 89.1 GeV, $E_{truth, low}$ = 22.9 GeV
Asym. = 0.59
7 layers



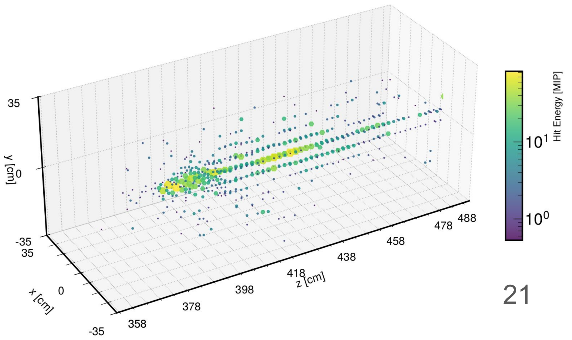
$E_{truth, high}$ = 11.5 GeV, $E_{truth, low}$ = 3.5 GeV
Asym. = 0.53
60 layers



$E_{truth, high}$ = 26.1 GeV, $E_{truth, low}$ = 8.9 GeV
Asym. = 0.49
60 layers

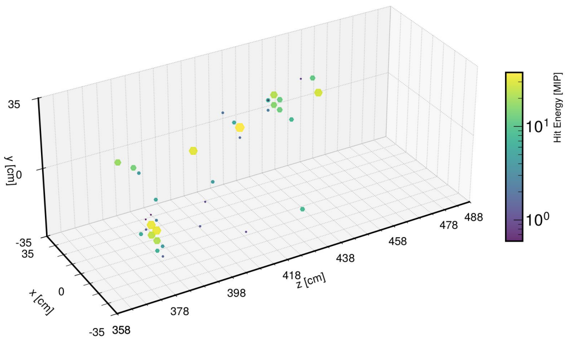


$E_{truth, high}$ = 75.6 GeV, $E_{truth, low}$ = 21.4 GeV
Asym. = 0.56
60 layers

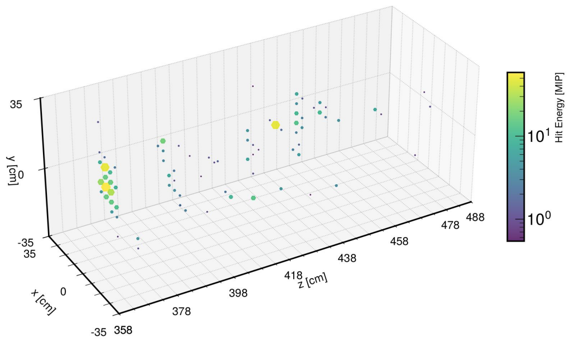


$\rho^0 \rightarrow \pi^+\pi^-$ Event displays: 0.6 < Asymmetry ≤ 0.8

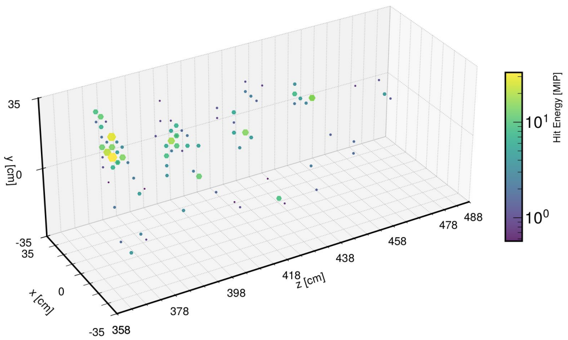
$E_{truth, high}$ = 18.9 GeV, $E_{truth, low}$ = 4.1 GeV
Asym. = 0.64
7 layers



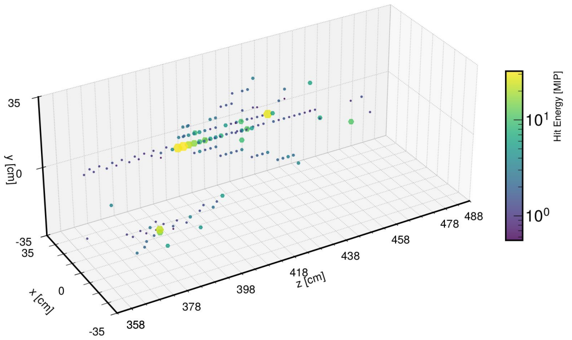
$E_{truth, high}$ = 51.4 GeV, $E_{truth, low}$ = 11.6 GeV
Asym. = 0.63
7 layers



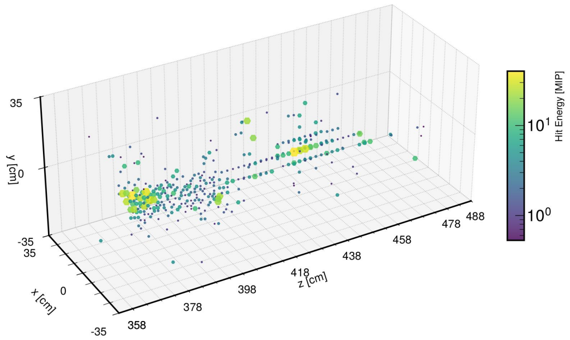
$E_{truth, high}$ = 92.8 GeV, $E_{truth, low}$ = 19.2 GeV
Asym. = 0.66
7 layers



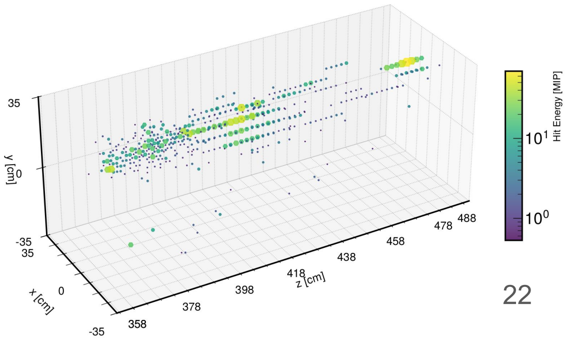
$E_{truth, high}$ = 12.1 GeV, $E_{truth, low}$ = 2.9 GeV
Asym. = 0.61
60 layers



$E_{truth, high}$ = 63.7 GeV, $E_{truth, low}$ = 9.3 GeV
Asym. = 0.74
60 layers

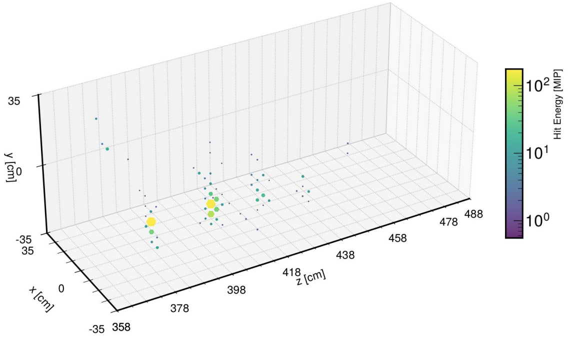


$E_{truth, high}$ = 95.1 GeV, $E_{truth, low}$ = 16.9 GeV
Asym. = 0.70
60 layers

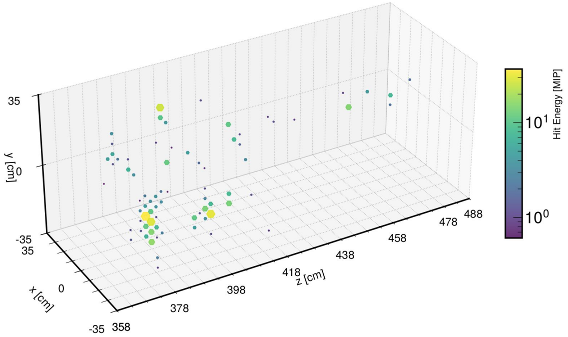


$\rho^0 \to \pi^+\pi^-$ Event displays: 0.8 < Asymmetry ≤ 1.0

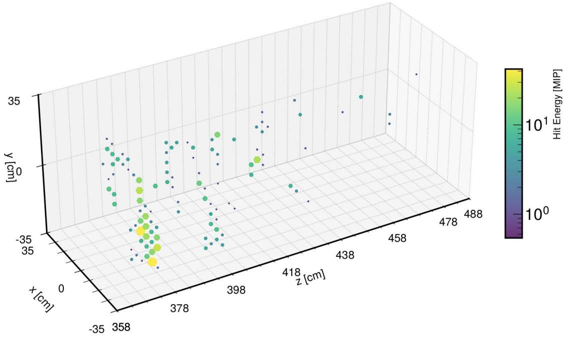
$E_{truth,\,high}$ = 21.4 GeV, $E_{truth,\,low}$ = 1.6 GeV
Asym. = 0.86
7 layers



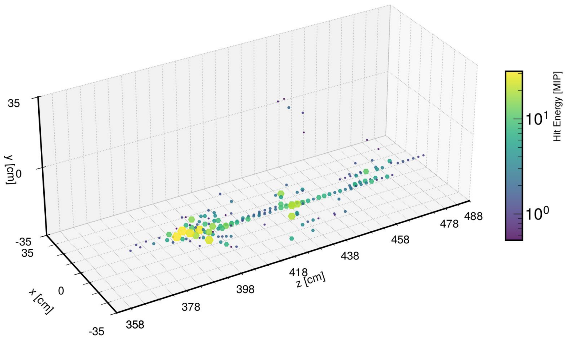
$E_{truth,\,high}$ = 60.8 GeV, $E_{truth,\,low}$ = 2.2 GeV
Asym. = 0.93
7 layers



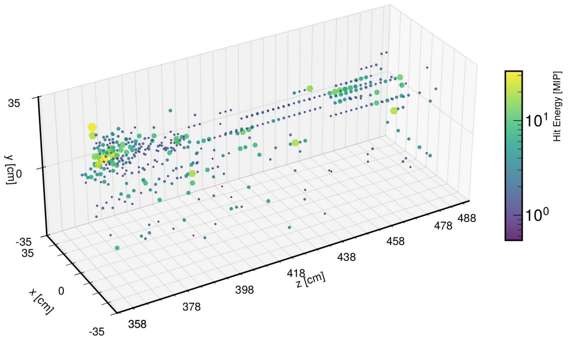
$E_{truth,\,high}$ = 90.9 GeV, $E_{truth,\,low}$ = 6.1 GeV
Asym. = 0.87
7 layers



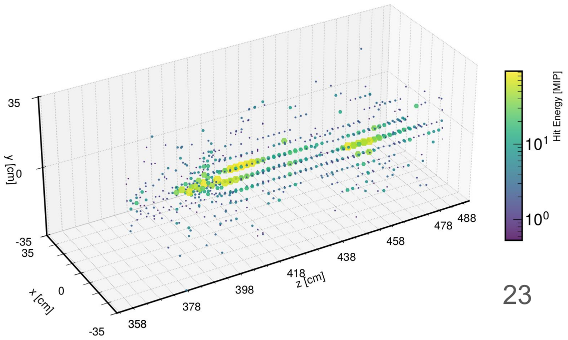
$E_{truth,\,high}$ = 21.1 GeV, $E_{truth,\,low}$ = 1.9 GeV
Asym. = 0.83
60 layers



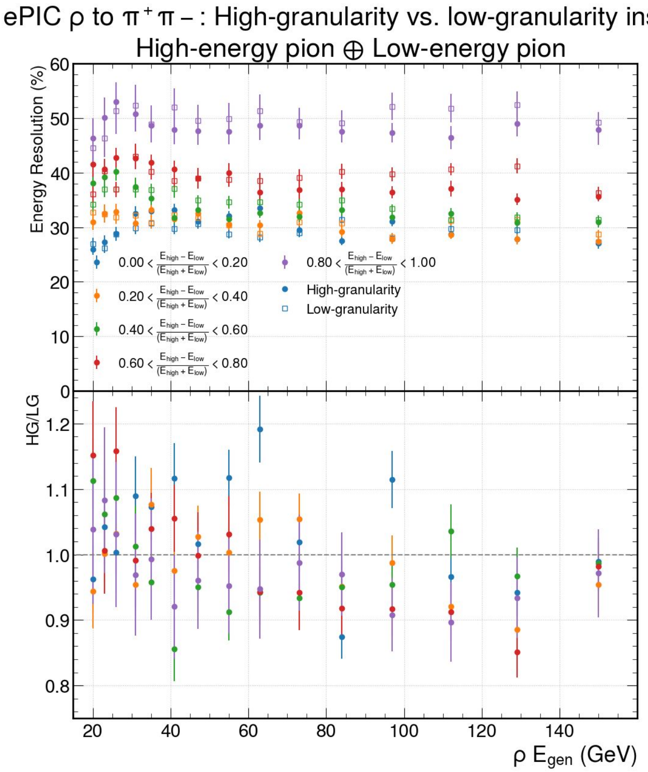
$E_{truth,\,high}$ = 68.3 GeV, $E_{truth,\,low}$ = 4.7 GeV
Asym. = 0.87
60 layers

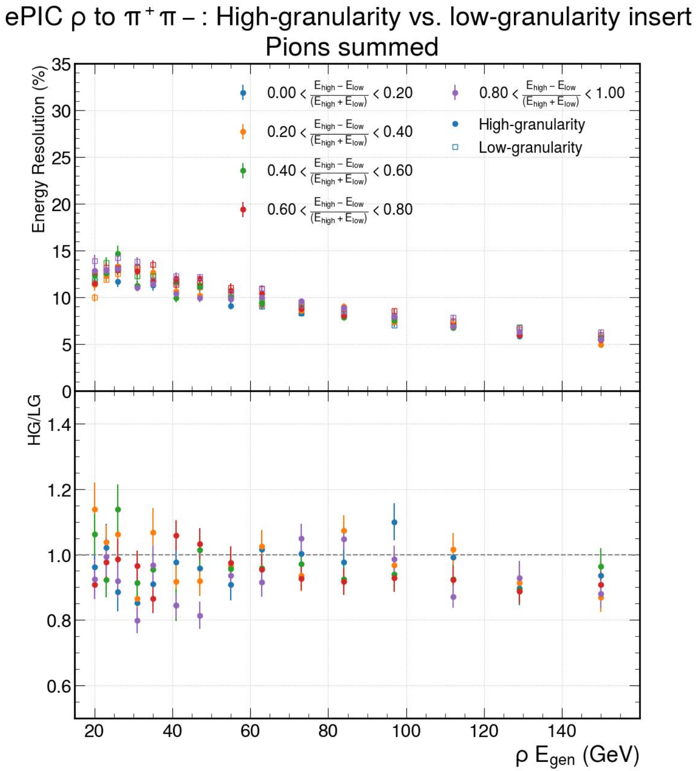


$E_{truth,\,high}$ = 121.0 GeV, $E_{truth,\,low}$ = 8.0 GeV
Asym. = 0.88
60 layers



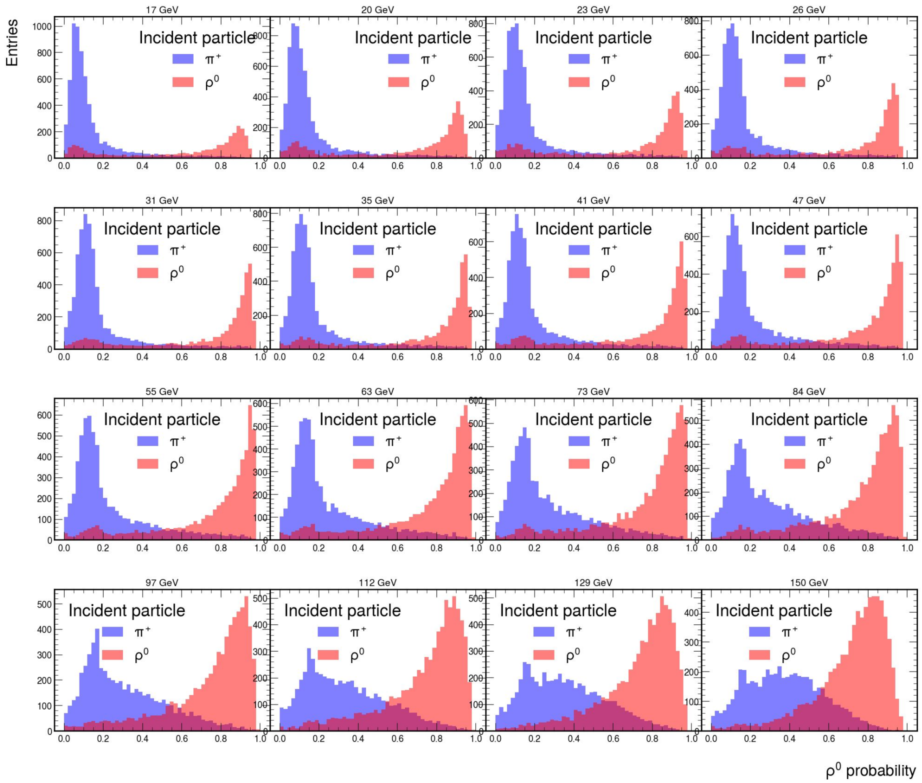
Two-shower Energy performance (showers in Insert)



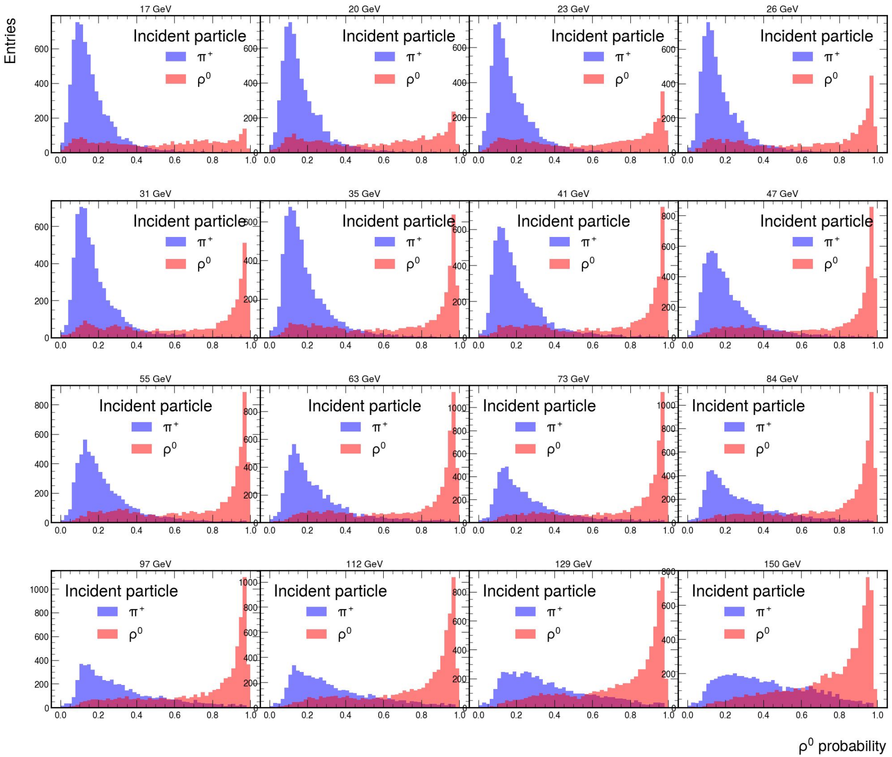


Classification one shower vs two shower

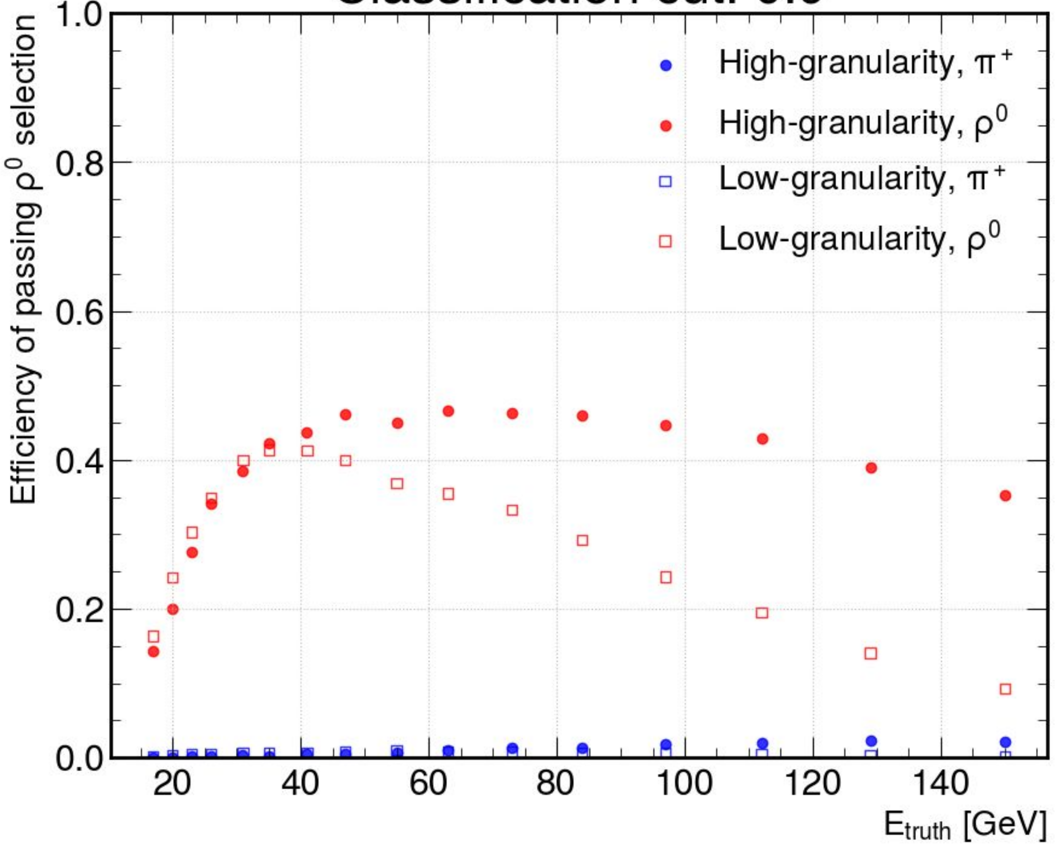
Low granularity insert



High granularity insert



ePIC 25.07.0 $\rho^0 + \pi^+$
High granularity vs. low granularity insert
Classification cut: 0.9



Final word

- We prefer the high-granularity option since we think that changing Insert current granularity to "LHFCAL-like" granularity:
  - Would not fix anything (despite fake claims on the contrary).
  - Would not save any money.
  - Would be a lost of performance for no reason.
  - Would be a missed opportunity to deploy the maximum power of SiPM-on-tile for 50-250 GeV jet range (for which it was designed for), in ⅓ of phasespace of LFHCAL.

- Our studies have shown improved performance in single particle and two-shower separation. This is truly great bang per buck because the cost is peanuts (<10% of insert which is in turn <1% of LFHCAL)

- But, in the interest of converging and cutting our losses (time, student salaries, group morale and soul), we would gladly yield rather than continuing arguing.

  Our studies are complete, so this is our very last presentation on the subject.

  Gracias totales!

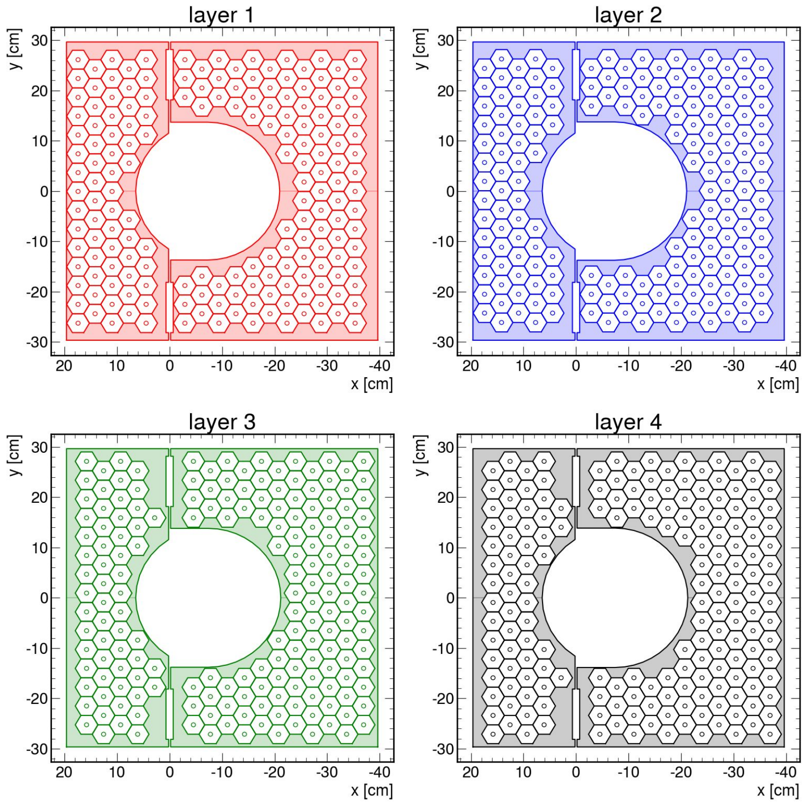
Backup

More detail of “high-granularity” Cell Layout

First 16 layers:

- High granularity: ~12 cm^2
- Staggering offsets repeat every 4 layers
- Purpose: determining the position of the start of the showers

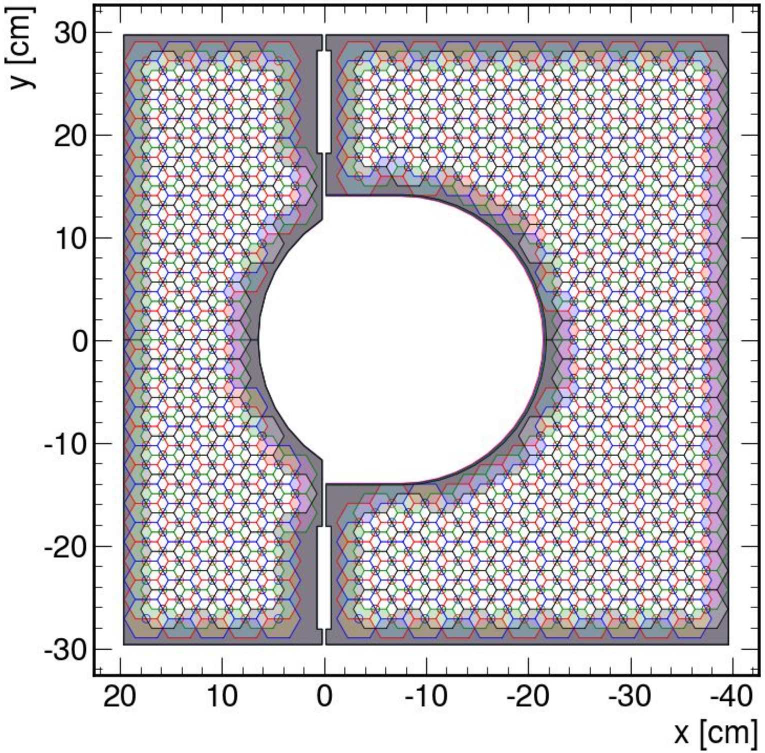
*https://doi.org/10.1016/j.nima.2023.169044

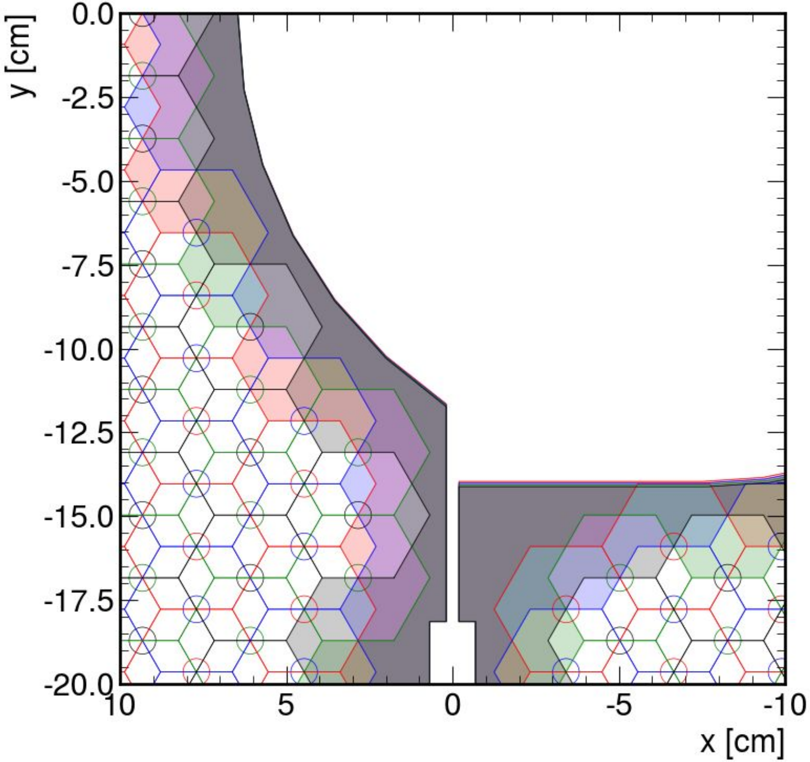


https://github.com/sebouh137/staggered_tesselations/blob/main/GenerateLayersH4.ipynb

https://github.com/eic/epic/pull/771
(merged into main)

Deadspace in one layer is covered (partially) by cells in other layers through staggering





High-granularity cell Layout (continued)

Remaining layers (17-60) are low-granularity layers. 21 cm^2 cells on left side, 25 cm^2 cells on right side