SiPM-on-tile ZDC update

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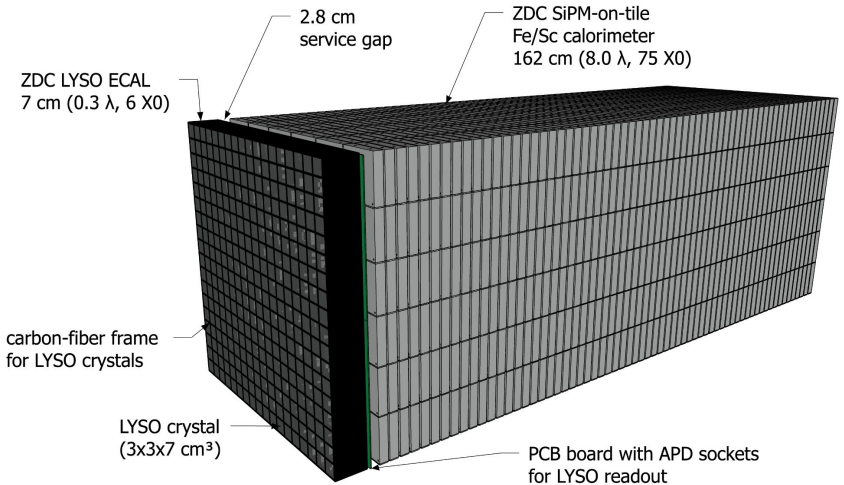
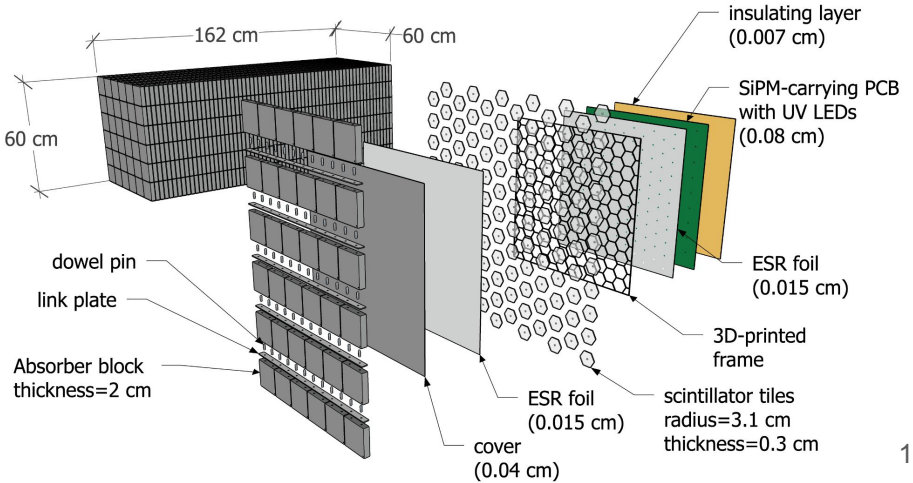




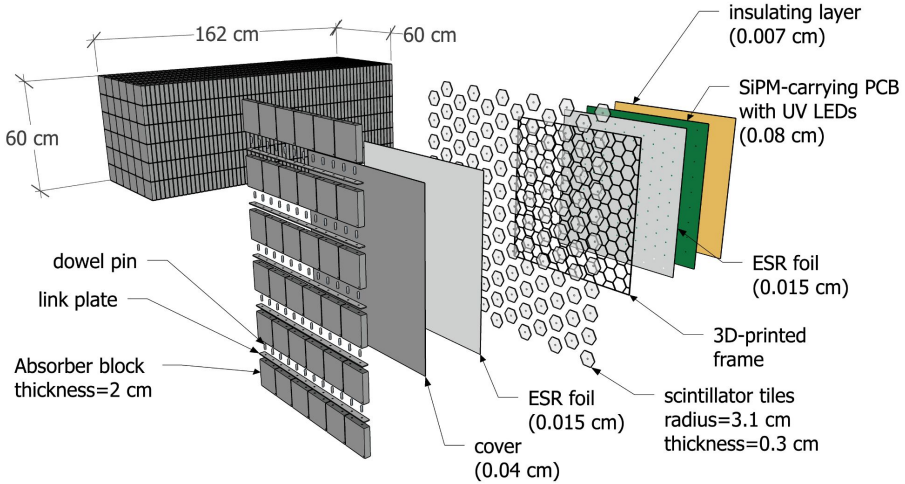
ePIC TIC meeting 12/18/2023

Outline

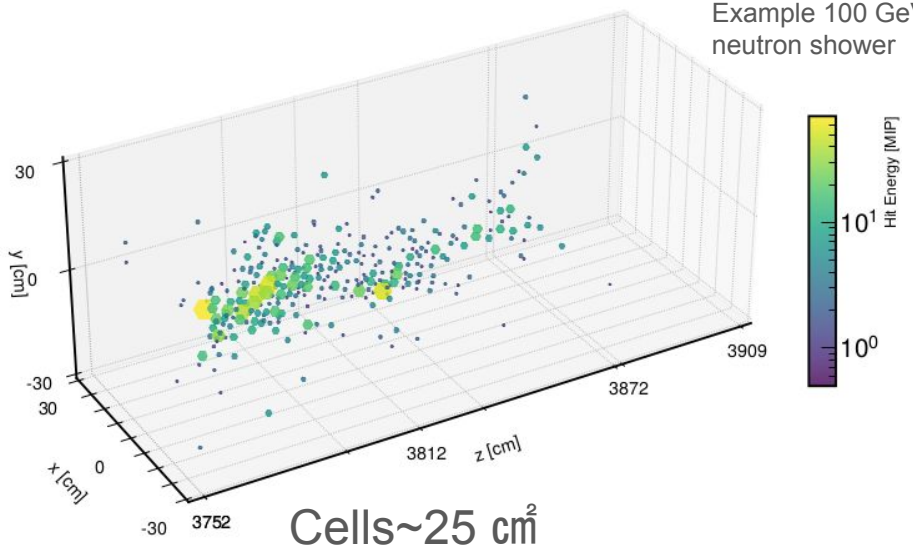
New results relative to Nov 20th and Oct. 9th presentations

1) Updates on standalone γ/π0 performance studies.
2) Updated combined system (LYSO + Fe/Sc) performance for neutrons
3) Updates related to software in ePIC and physics benchmark

Reminder: SiPM-on-tile Fe/Sc ZDC

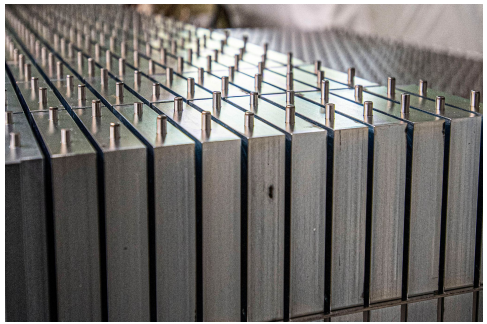


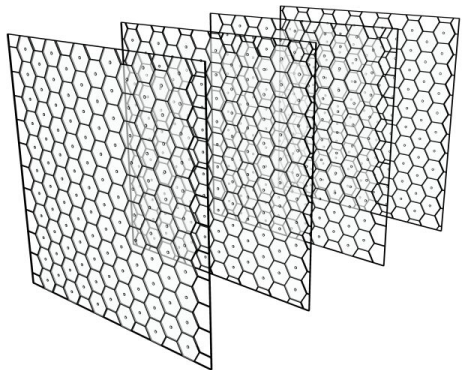
Example 100 GeV neutron shower

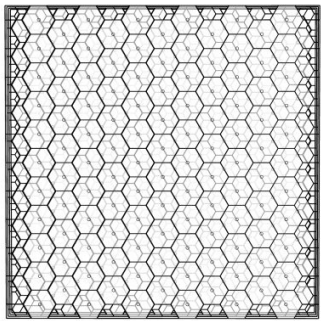


Cells~25 cm^2

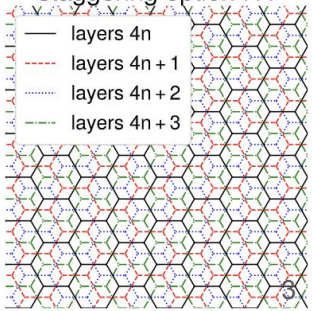
Fe blocks from STAR





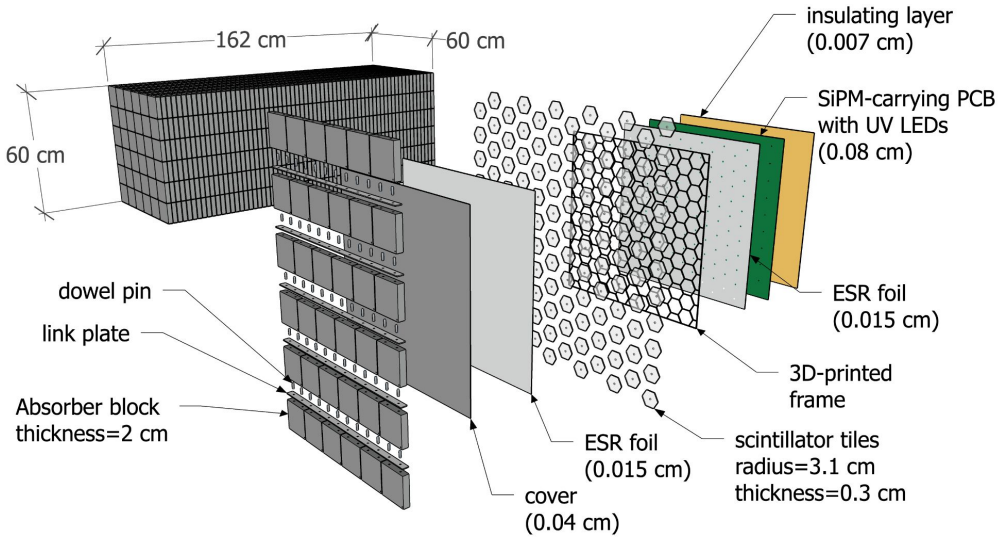


staggering option H4



Recipe for Fe/SiPM-on-tile option

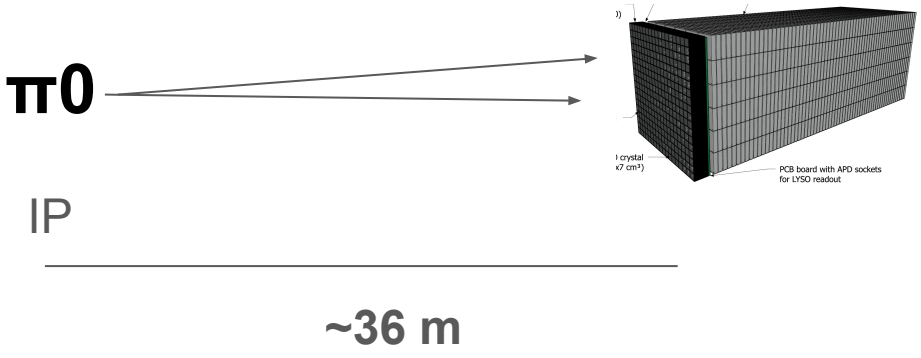
- **Fe blocks:** 2304 units of 10x10x2 cm3
  Cost: **0$** (reused from STAR HCAL)
  Not even shipping cost!
- **7.5k SiPM-on-tile channels**, each of which is:
  1 **SiPMs:** 3 mm size. Cost: **11.5$/unit**
  (same as fHCAL, vendor: HPK)
  1 **Tile:** ~25 cm2 size. Cost: **2$/unit**
  (same as fHCAL, vendor: Fermilab)
  1 **Readout & bias:** HGROC **2$/ch**
  (same as fHCAL)



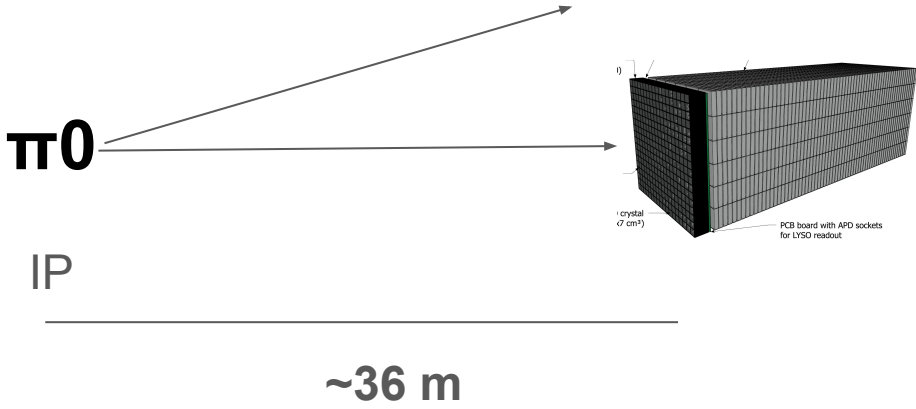
Total material costs would be ~0.1 $M

On the issue of π0/ɣ separation

Case A)
Two photons hit ZDC



Case B)
One photon hits ZDC, other misses

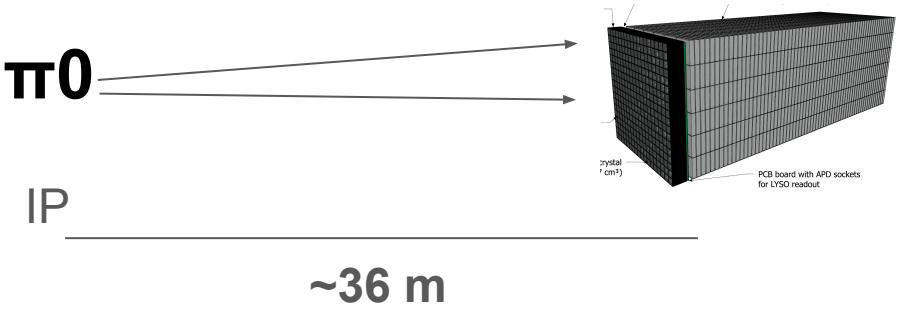


- ZDC granularity is only relevant for case A).
- The case B) can be reduced with missing energy cut, and 20%/√E resolution is enough for that (see Zach's presentation)

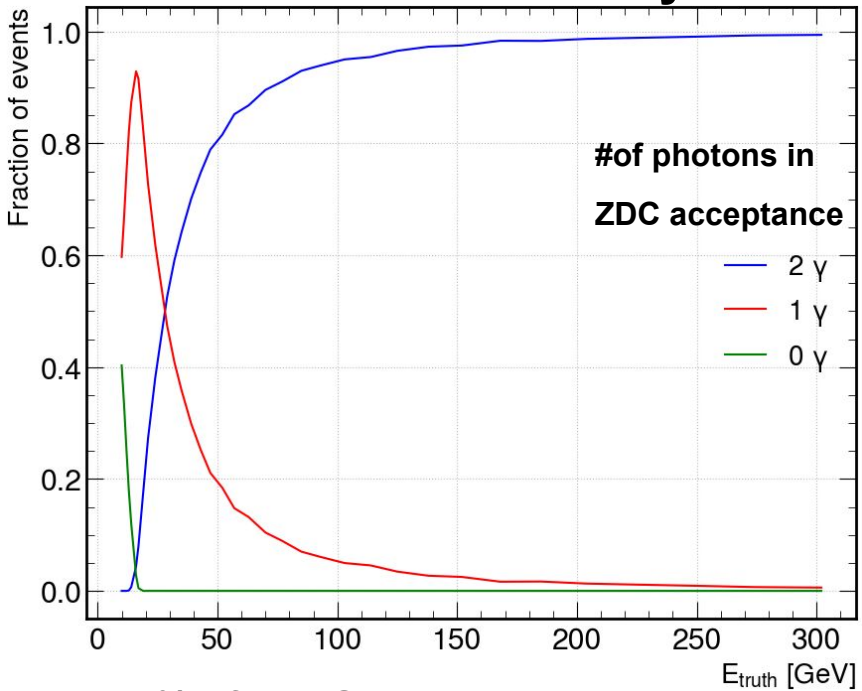
Simple kinematics of π0 decay

Simple exercise:
Generated π0 decays over the nominal, unobstructed ZDC acceptance (θ<4 mrad) full azimuth over a range of energies.

Determined how many events have photons from the decay fall within ZDC acceptance.

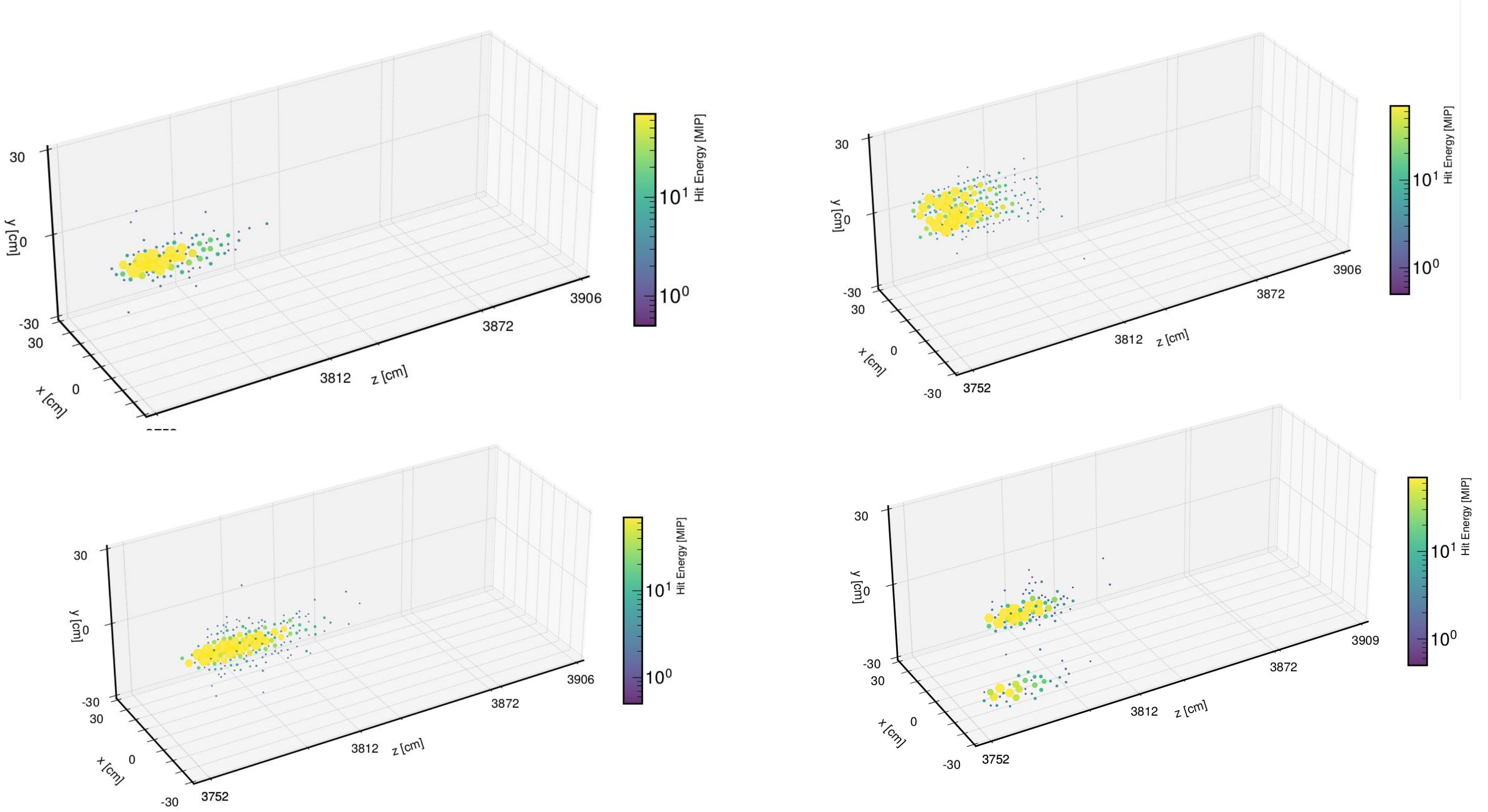


Fraction of π0 decays



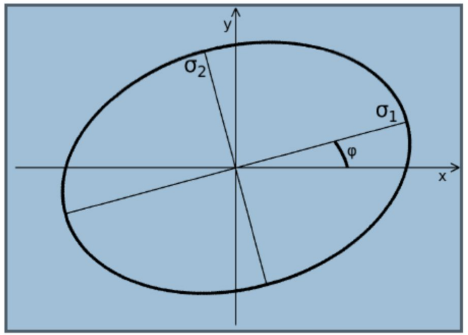
~10% of 100 GeV π0 decays yield only 1 photon in ZDC! This is irreducible background with shower-shapes only

Example one and two photon showers

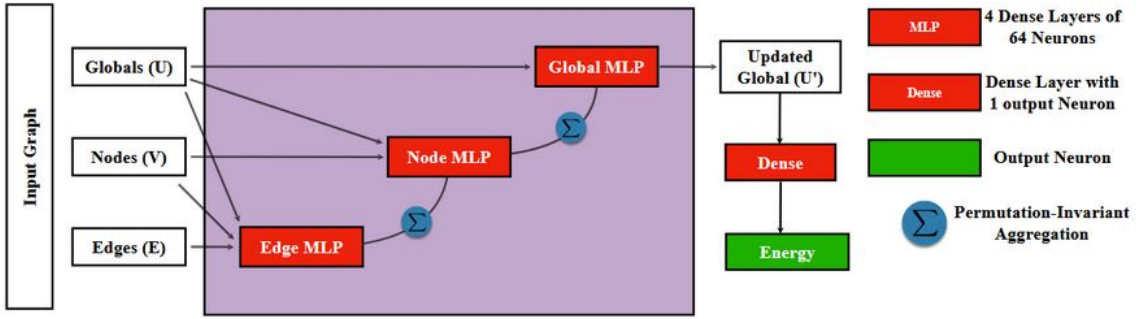


Methods used in π0/ɣ separation studies

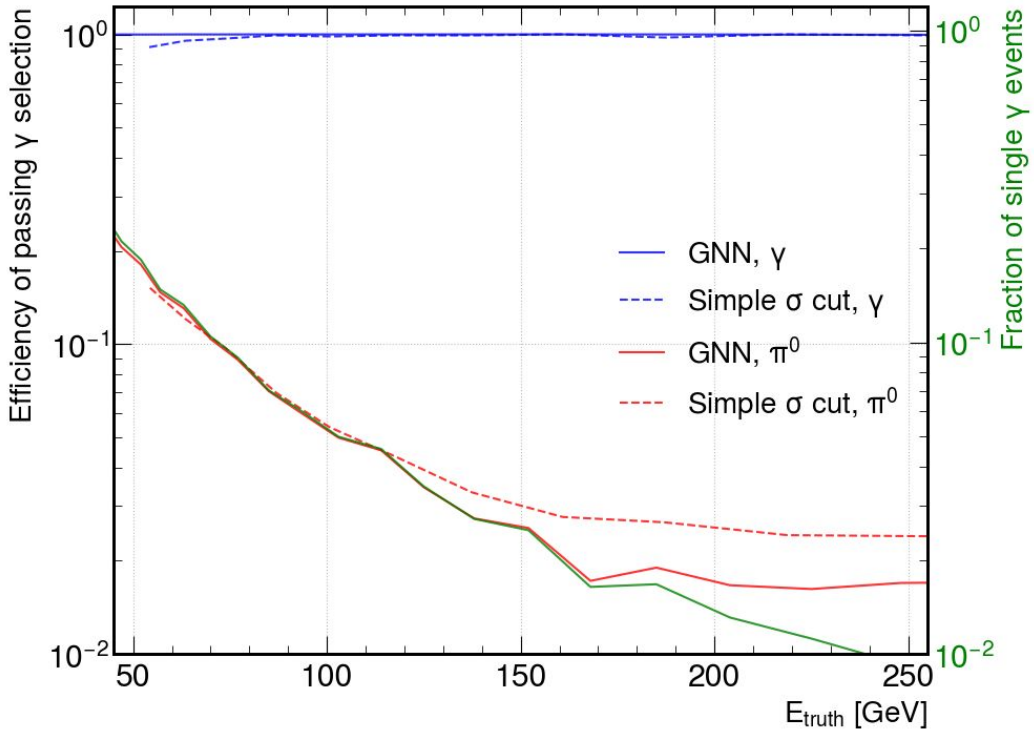
Method A)
Simple shower shape
Presented on Nov 20th



New: Method B)
Graph Neural Network
Simultaneous classification & regression



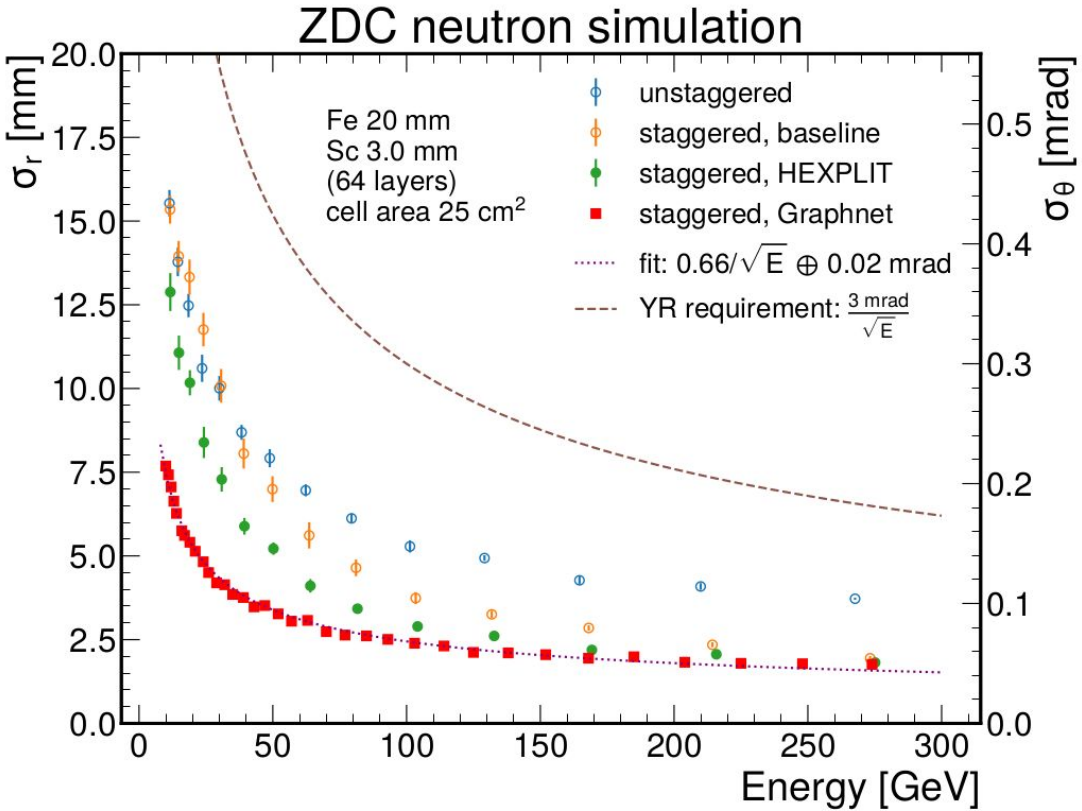
SiPM-on-tile standalone performance on π0/γ separation



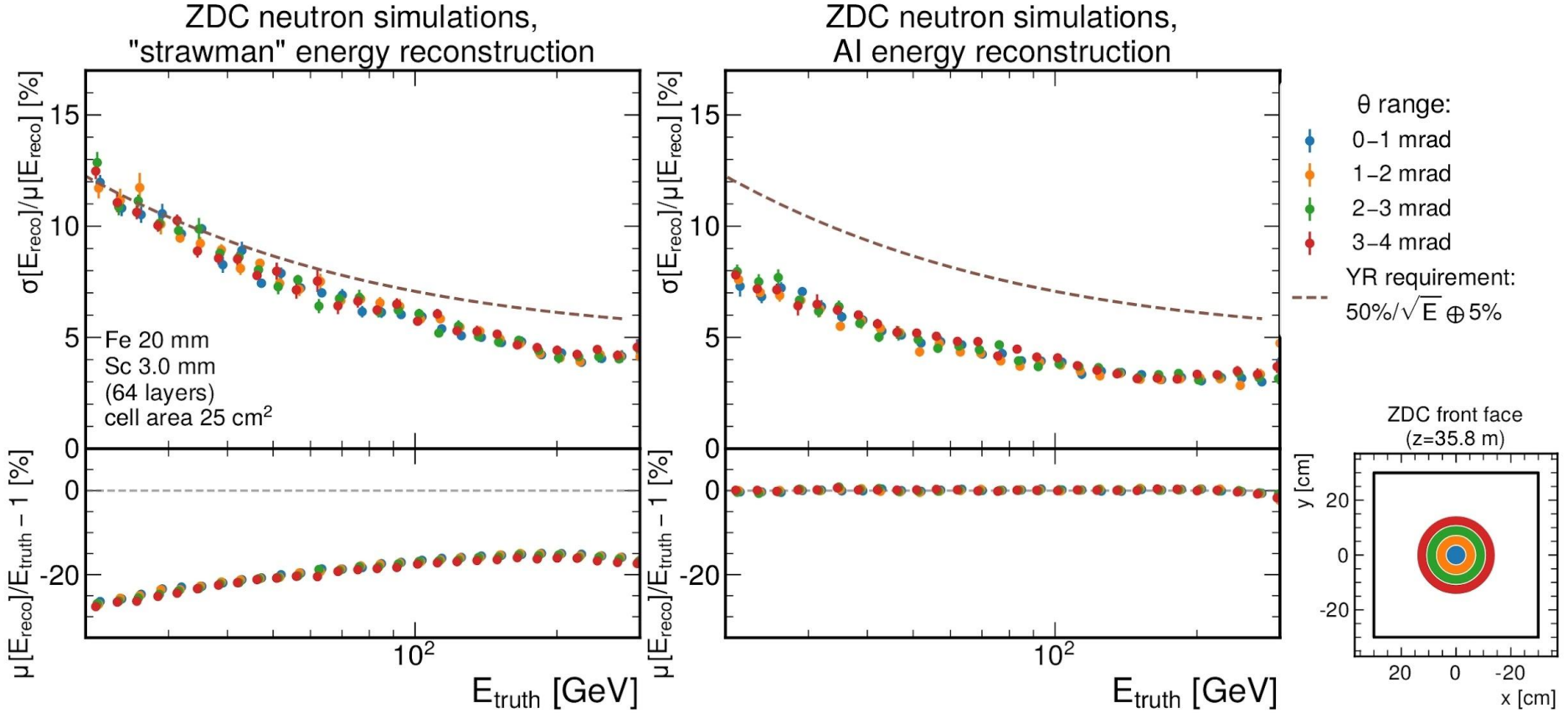
- GNN (solid red) improves simple shower-shape cut above ~120 GeV
- GNN reaches ~2% misclassification rate above 150 GeV
- For reference, a perfect detector would yield a performance shown in green (true fraction of π0 that yield only on photon in acceptance).
- Simple shower shape close to perfect case until ~120 GeV, GNN close to perfect until ~170 GeV.

Take home message: SiPM-on-tile granularity good enough for this application.
Higher granularity would yield insignificant gains, which are neither required nor justified by physics.

Reminder: standalone neutron performance



Reminder: Standalone Neutron-performance

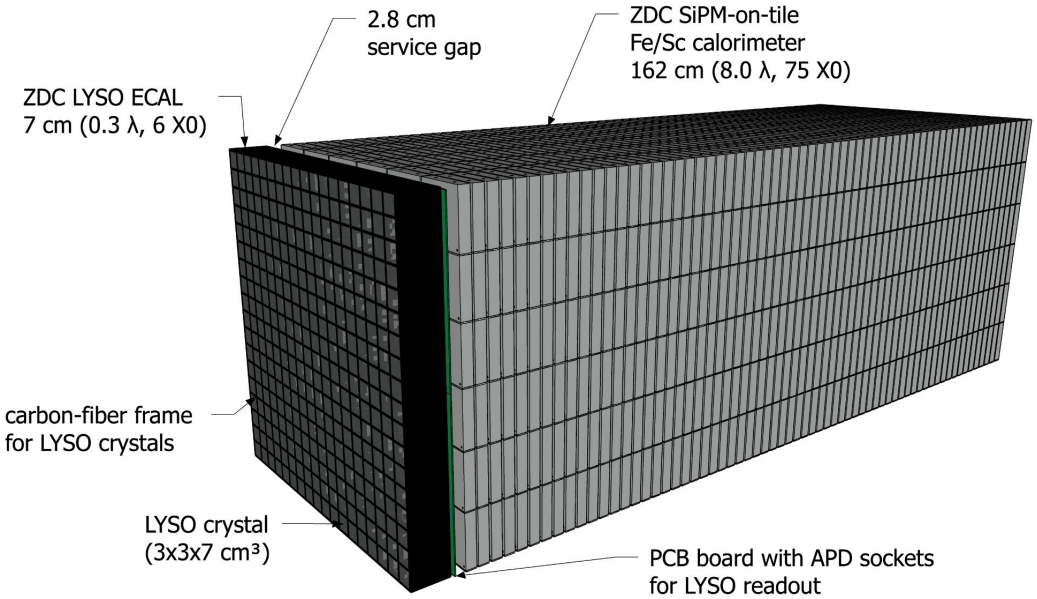


Summary of SiPM-on-tile Fe/Sc calorimeter standalone performance

	Energy resolution	Angular resolution [mrad]	π^0 rejection
Neutron	$54\%/\sqrt{E} \oplus 2\%$ (strawman)	$0.79/\sqrt{E} \oplus 0.02$ (HEXPLIT)	—
	$35\%/\sqrt{E} \oplus 2\%$ (GNN)	$0.66/\sqrt{E} \oplus 0.02$ (GNN)	—
Photon	$20\%/\sqrt{E} \oplus 1\%$ (strawman)	$0.19/\sqrt{E} \oplus 0.01$ (baselin)	$> 97\%$ for $E > 150$ GeV (σ cut)
			$> 98\%$ for $E > 150$ GeV (GNN)

- Meets yellow report requirements
- At 100 GeV, the neutron angular resolution is 2.5 mm or 80 μrad, which added in quadrature with beam divergence in the high-acceptance configuration (56 μrad) yields a pT resolution of 10 MeV

Reminder: Combined system could be LYSO crystal ECAL (Oct 9th design) and SiPM-on-tile Fe/Sc

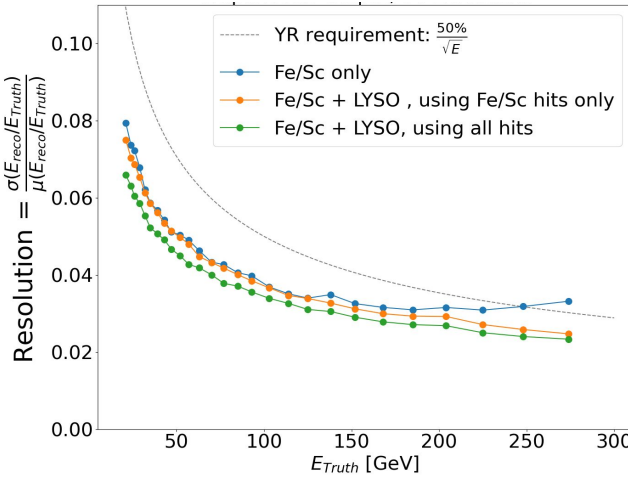


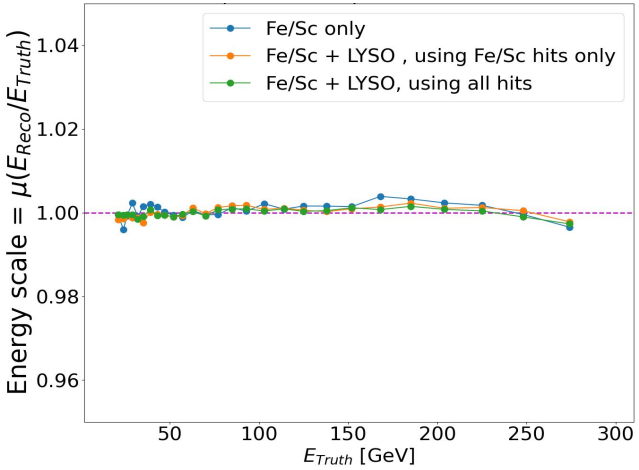
Meets all physics requirements while maximizing synergies with other ePIC subsystems, reducing cost and risks.

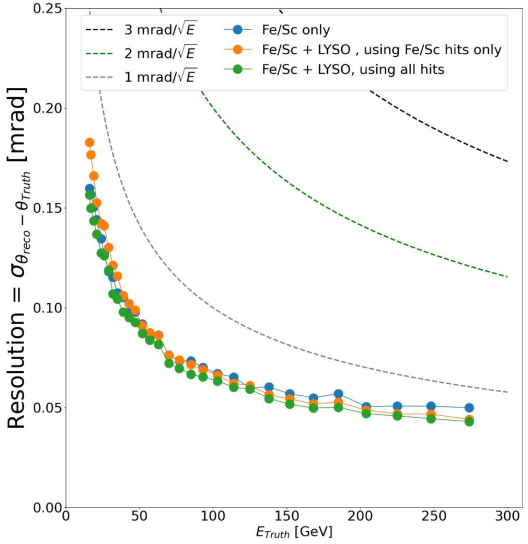
Low-energy γ→ LYSO
High-energy γ and π0→ Fe/Sc
High-energy neutrons → Fe/Sc

Combined LYSO + Fe/Sc neutron performance with GNNs

GNN yields optimal reconstruction, software compensated linear response







- Adding LYSO slightly improves energy resolution.
- No significant impact on the angular resolution

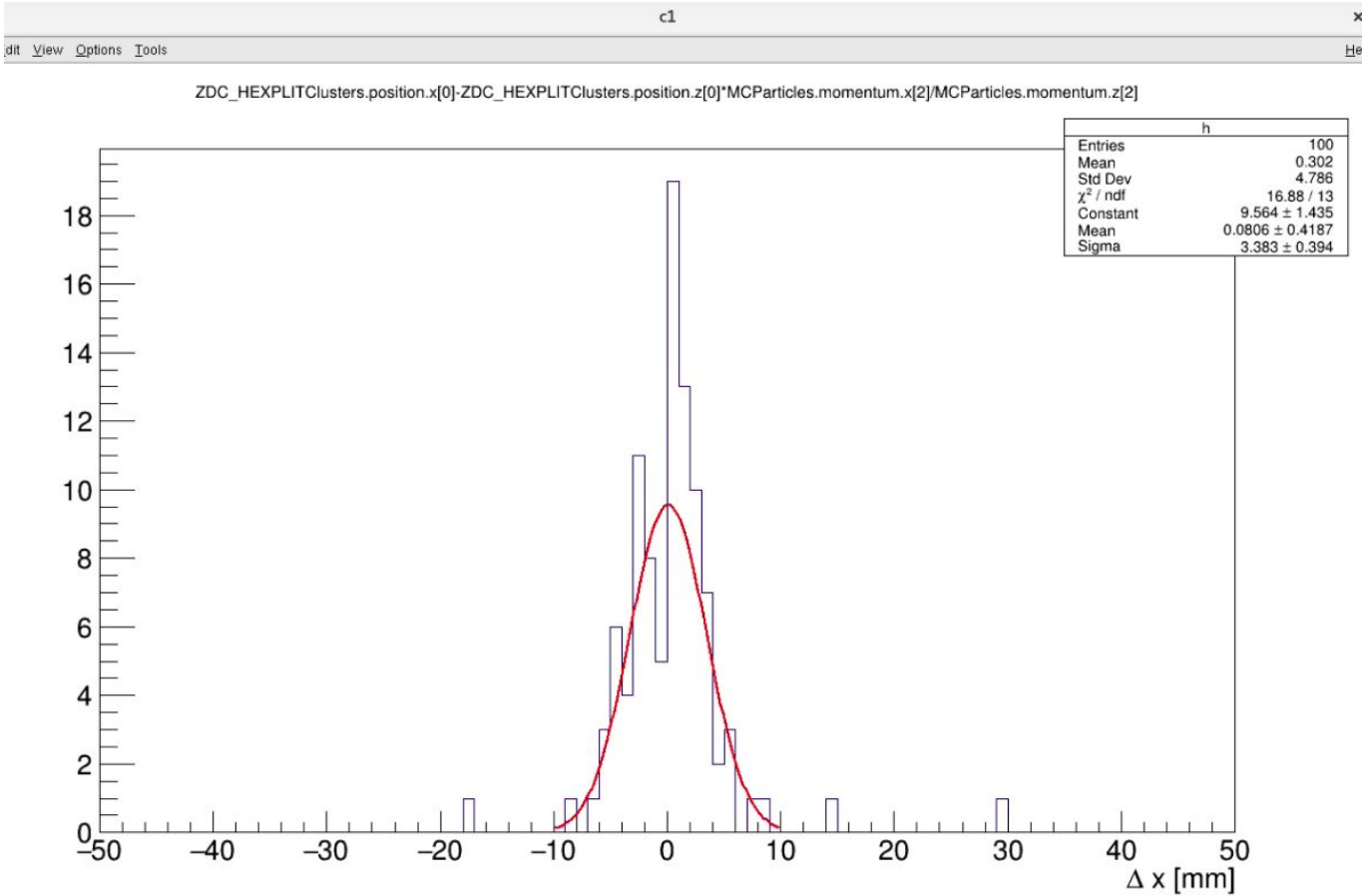
Credit: Bishnu Karki, Sebastian Moran, Ryan Milton

ZDC SiPM-on-tile software in DD4HEP and ePIC

- DD4hep plugin for hexagonal segmentation and staggering was added to official DD4HEP core software
  https://github.com/AIDASoft/DD4hep/pull/1161
- ZDC Fe/SiPM-on-tile was added to official ePIC sim DD4HEP geometry model
- **New:** Digitization parameters tuned and added to EICrecon:
  https://github.com/eic/EICrecon/blob/sipmzdc/src/detectors/ZDC/ZDC.cc
- **New:** Fe/Sc + LYSO configuration added to dedicated branch of ePIC sim:
  https://github.com/eic/epic/tree/ZDC_LYSO
- **New:** new branch of EICRecon for ZDC SiPM-on-tile algorithms:
  https://github.com/eic/EICrecon/tree/sipmzdc
- **New:** HEXPLIT algorithm C++ version is on EICrecon:
  https://github.com/eic/EICrecon/blob/sipmzdc/src/algorithms/calorimetry/HEXPLIT.cc
- **New:** LogWeighting 3D position reco algorithm is on EICrecon:
  https://github.com/eic/EICrecon/blob/sipmzdc/src/algorithms/calorimetry/LogWeightReco.cc
- **New:** ZDC Physics Benchmark with Deeply-exclusive meson events created
  https://github.com/eic/physics_benchmarks/tree/demp_zdc/benchmarks/demp/analysis
- **New:** 3D Topological clustering algorithm deployed for ZDC benchmark:
  https://github.com/eic/EICrecon/blob/sipmzdc/src/algorithms/calorimetry/ImagingTopoClusterConfig.h

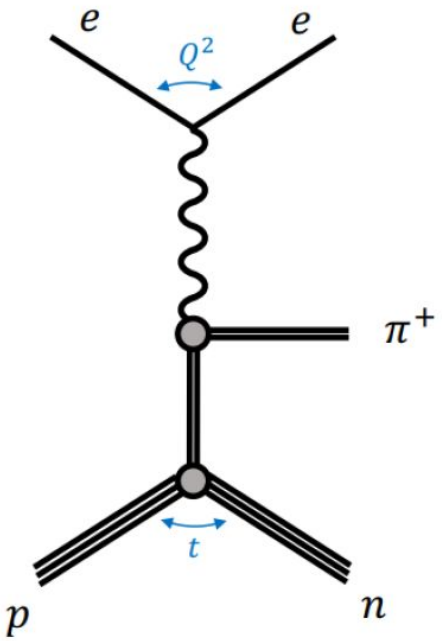
Credit: Seboh Paul, Barak Schmookler, Weibin Zhang, Bishnu Karki, Ryan Milton

Complete neutron reconstruction is now built in (part of EICrecon output)



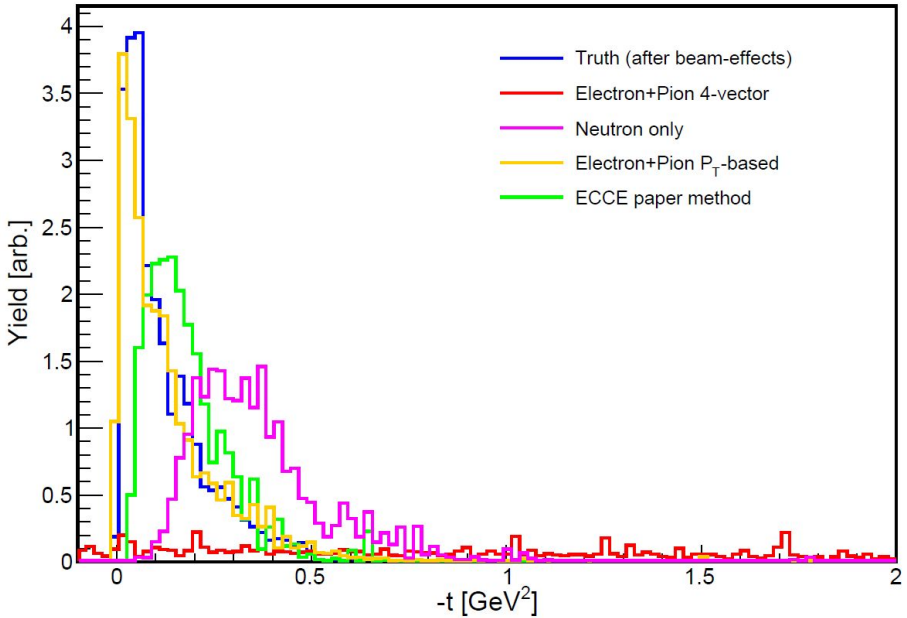
ZDC Physics Benchmark

https://github.com/eic/physics_benchmarks/tree/demp_zdc/benchmarks/demp/



Events from DEMPgen read from S3

Includes full neutron reconstruction in ZDC

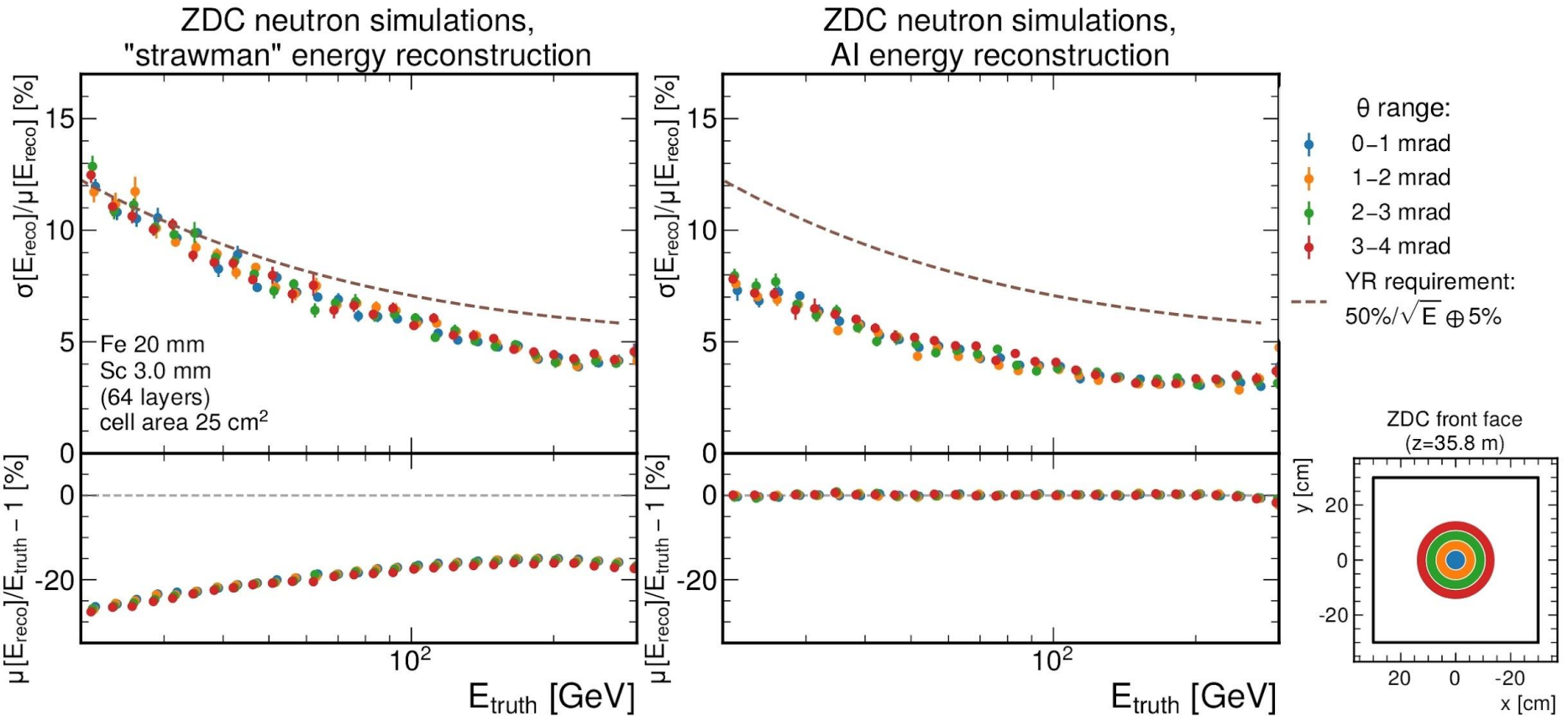


Credit, Barak Schmookler, Sebouh Paul

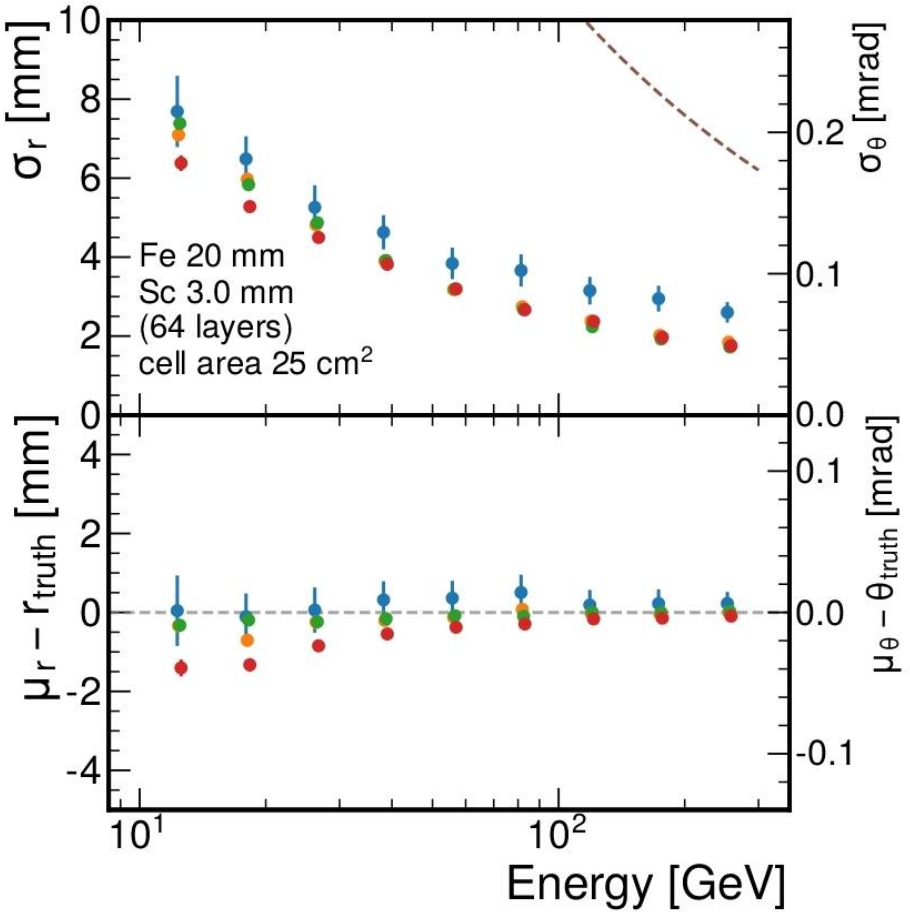
Summary

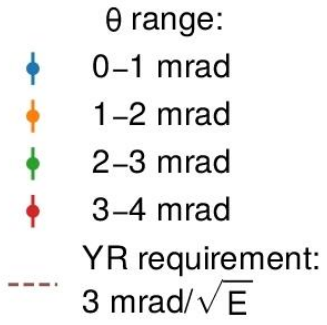
1) Updates on standalone γ/π0 performance studies
   → Fe/Sc SiPM-on-tile performance is close to be dominated by “irreducible” background of π0 yielding only 1 photon in ZDC acceptance.
2) Updated combined system studies
   → Adding LYSO slightly improves energy resolution and does not impact much the angular resolution for neutron showers.
3) Updates related to software and physics benchmarks
   → Entire chain of algorithms is in ePIC software now
   → Flagship benchmark is in place up and running

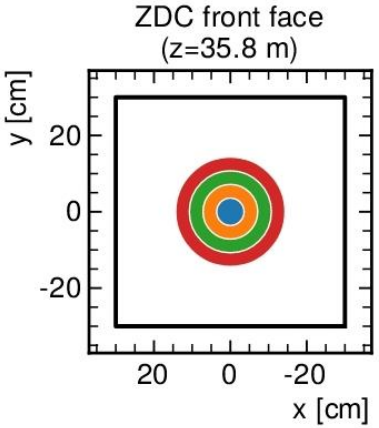
BACKUP


ZDC neutron simulations,
"strawman" energy reconstruction
σ[E_reco]/μ[E_reco] [%]
Fe 20 mm
Sc 3.0 mm
(64 layers)
cell area 25 cm²
μ[E_reco]/E_truth − 1 [%]
E_truth [GeV]
ZDC neutron simulations,
AI energy reconstruction
θ range:
0–1 mrad
1–2 mrad
2–3 mrad
3–4 mrad
YR requirement:
50%/√E ⊕ 5%
ZDC front face
(z=35.8 m)
y [cm]
x [cm]

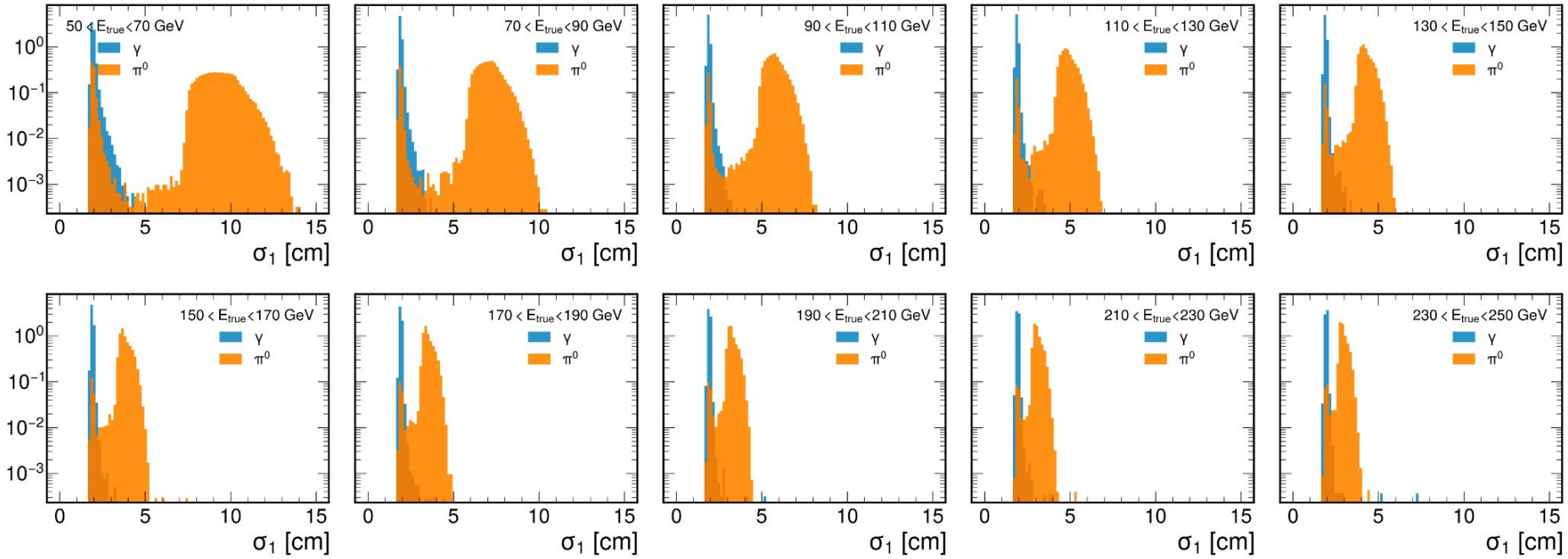
ZDC neutron simulations, Graphnet reconstruction







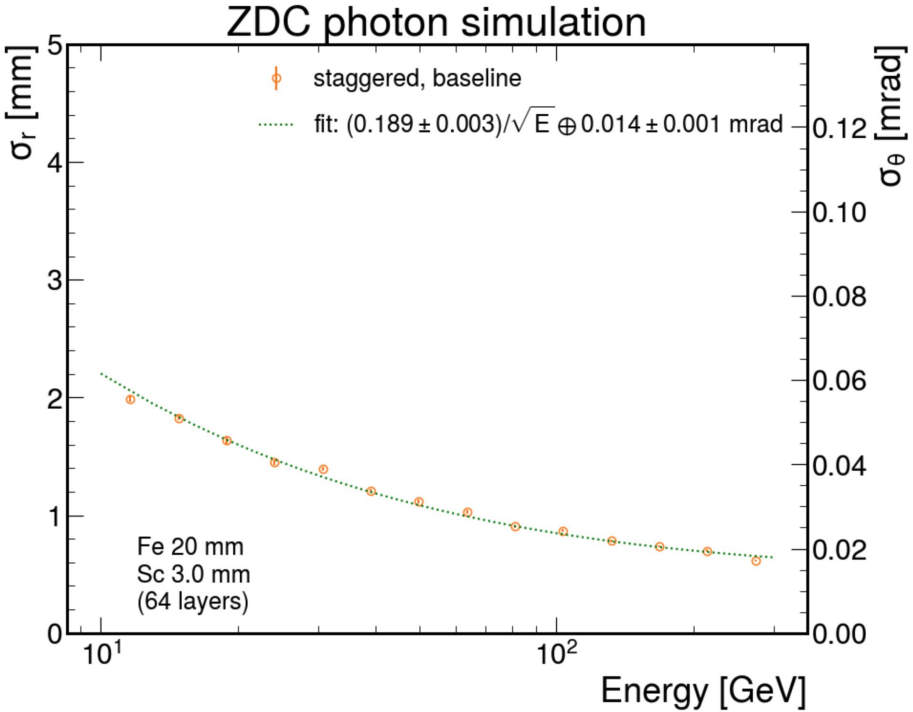
Preliminary performance plots for γ/π0 identification

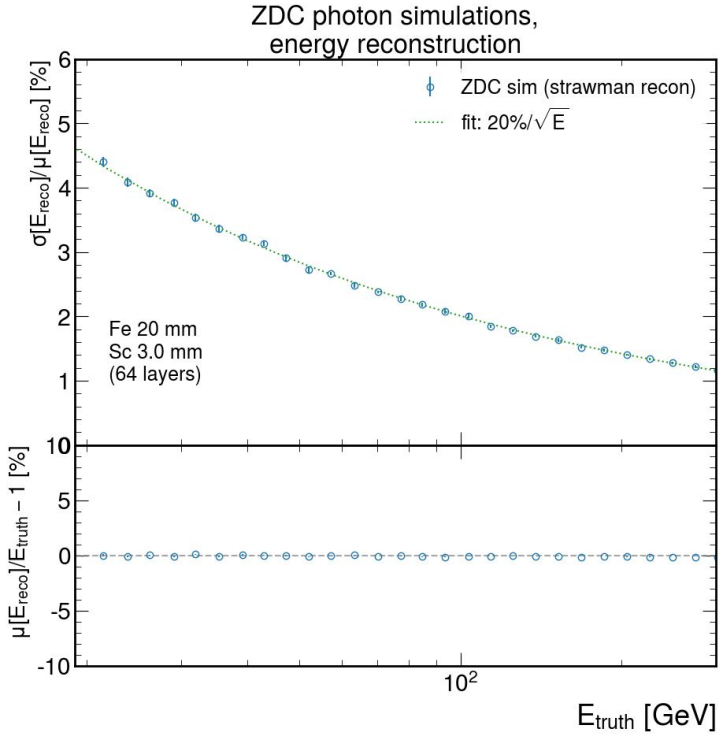


Single photon peak well separated from diphoton distribution.

The single photon peak in pi0 (other photon missing ZDC acceptance) is “irreducible” with shower shape only

Fe/Sc SiPM-on-tile photon performance





Credit: Sebouh Paul

Fe/Sc SiPM is adequate for high-energy photons