Update on Tungsten and software compensation question

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Outline

- Brief reminder of validation studies against with CALICE data
- Update on tungsten vs no tungsten: angular resolutions
- Update on insert tungsten vs no tungsten

Goal:

- Compare two HCAL configurations: one has 4 W layers in front (default) and the other has no W layers (and instead more it has more Fe layers)

- The question we want to pursue is: how does the performance compare <u>after</u> software compensation?

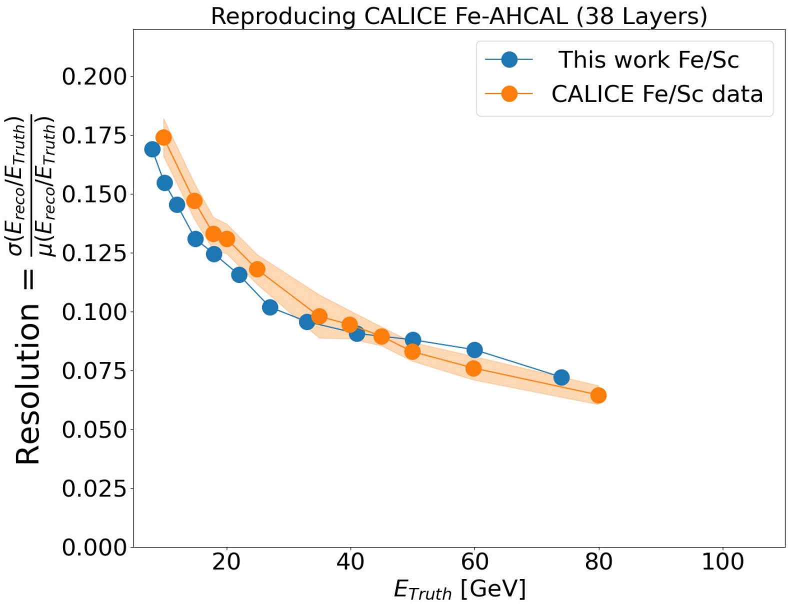
- We seek to address the comment from recent final-design review:
"Implement software compensation as soon as possible and re-assess the benefits of the tungsten section."

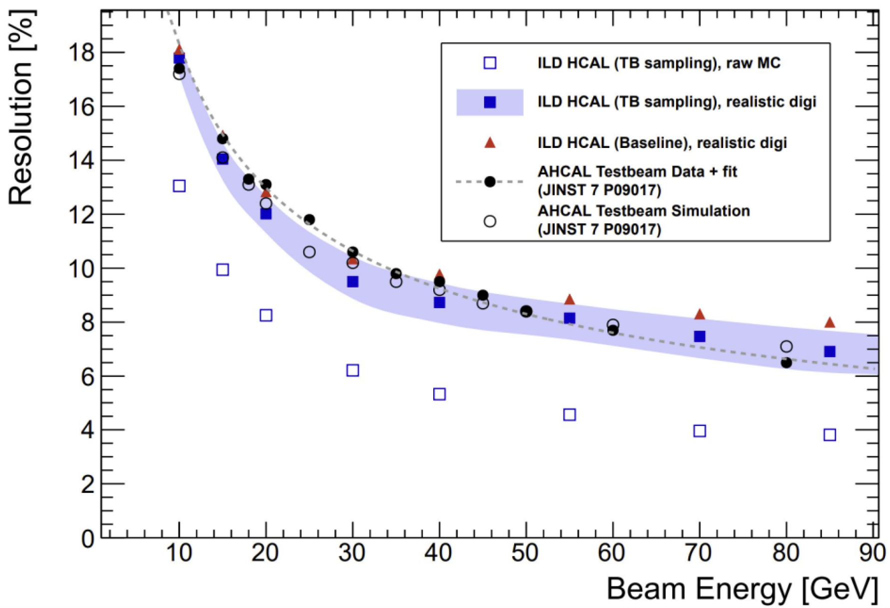
First, on the issue of validation of simulation

Validation of simulation

Comparison with CALICE Fe-AHCAL

CALICE Fe/Sc Calo result from Ref.



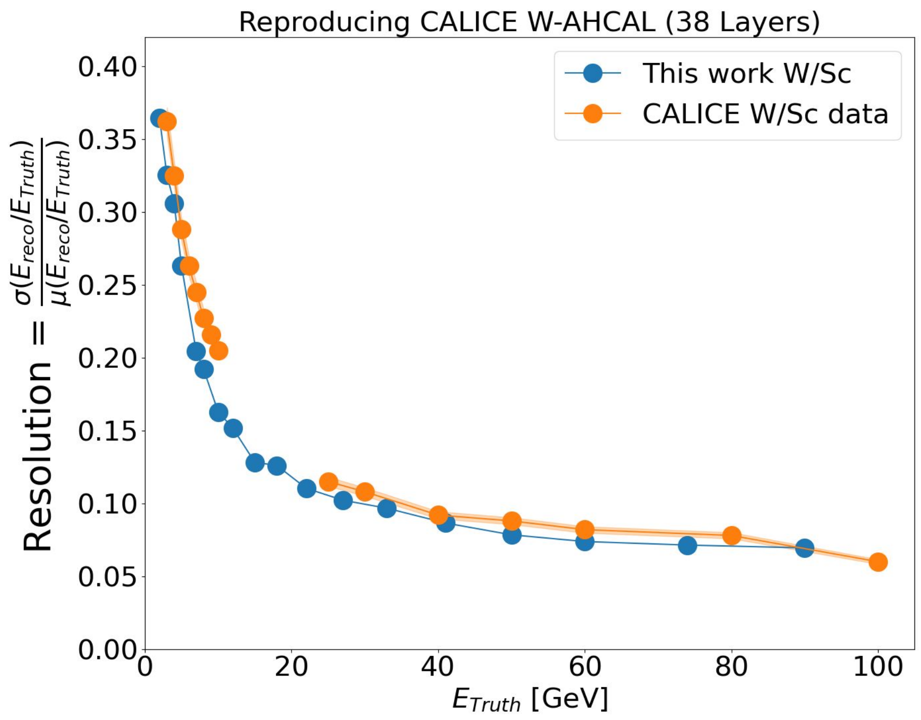


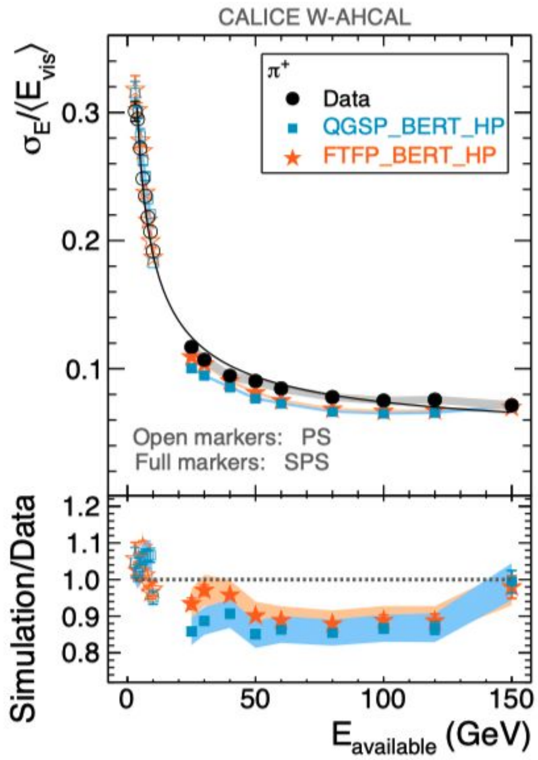
- We simulated CALICE Fe-HCAL geometry for this study.
  Good agreement with CALICE test-beam data. Validates simulation to within a high degree.
- Key drivers to get resolution right: time and energy cuts. Other stuff like optical photons or SiPM saturation, etc is marginal. Oskar pointed us to studies showing that.

Validation of simulation

Comparison W-AHCAL

CALICE W/Sc Calo results from Ref.





Some disagreement between data and simulation is reported by CALICE group

Methodology for software compensation studies

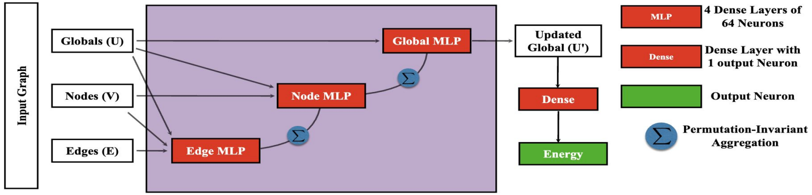
- What we mean by **"software compensation"** is described in the following:

  "for intrinsically non-compensating calorimeters, compensation can be achieved by so-called "off-line weighting" or "software compensation" techniques. These techniques assign different weights to electromagnetic and hadronic energy deposits on an event-by event basis. The differing spatial structure of the electromagnetic and hadronic components of particle showers can be used to characterise the origin of energy deposits…",

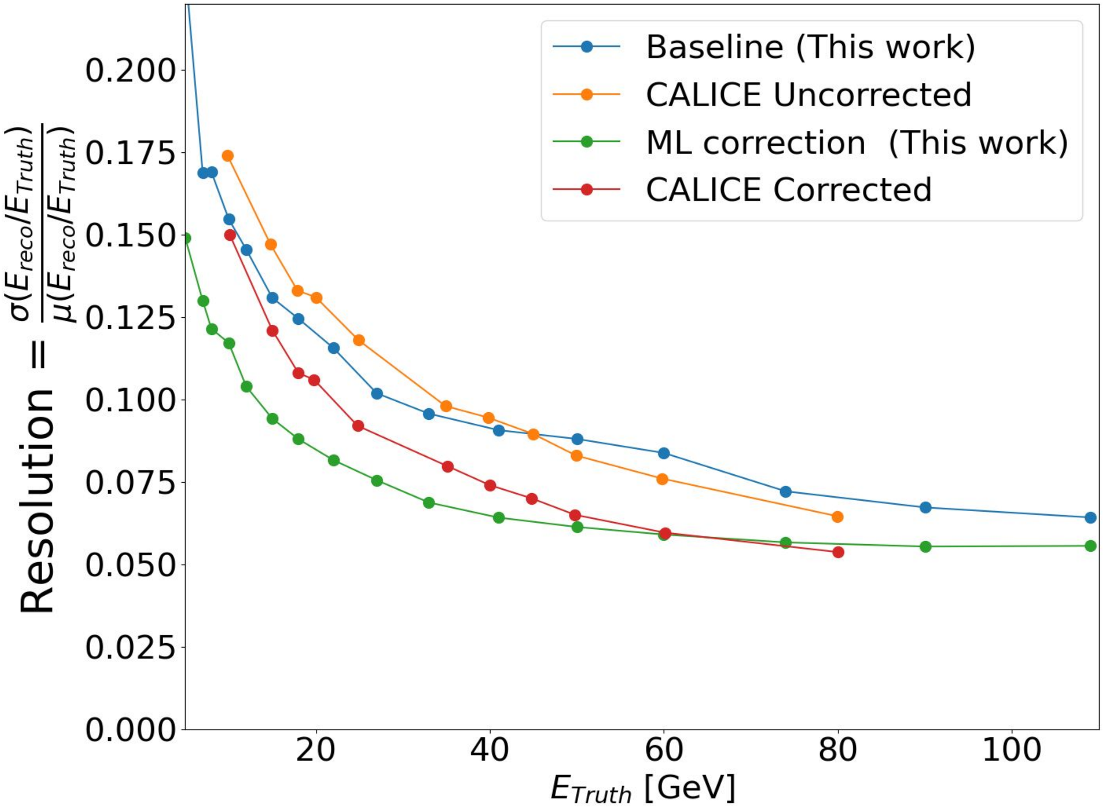
  [*CALICE Collaboration 2012 JINST 7 P09017*]

- Rather than do it "by hand" like what was done by CALICE (very time consuming), we implement software compensation using Graph-Neural Networks as described in https://arxiv.org/abs/2310.04442.

  Using GNNs is more efficient, optimal way to find the *"weights"* that minimize the resulting energy resolution but is the same principle than the traditional CALICE method (nothing mysterious).
- **Simultaneous energy and angular regression**



Validation of simulation and ML based software compensation against CALICE test-beam data

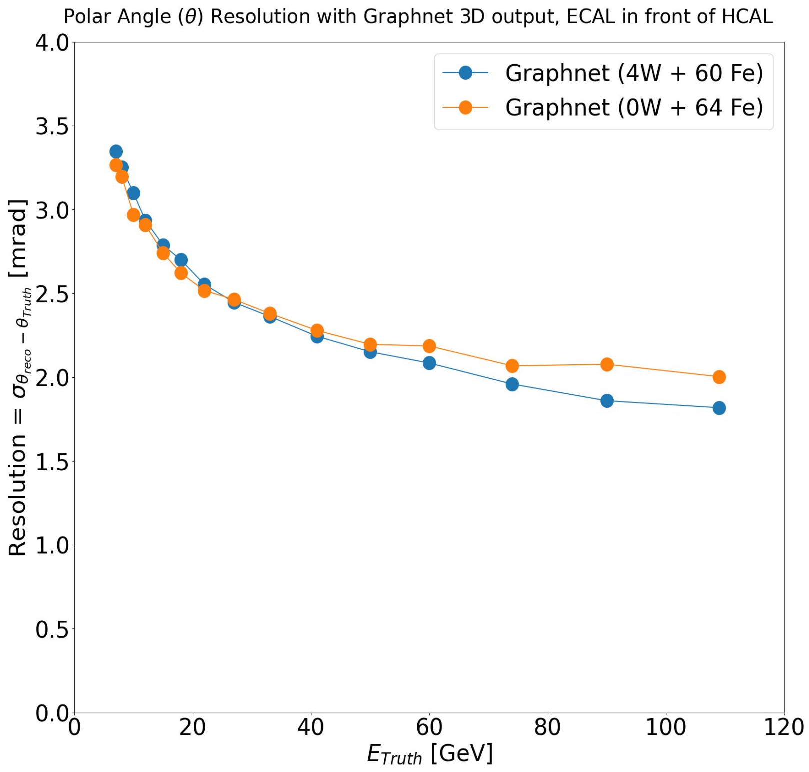


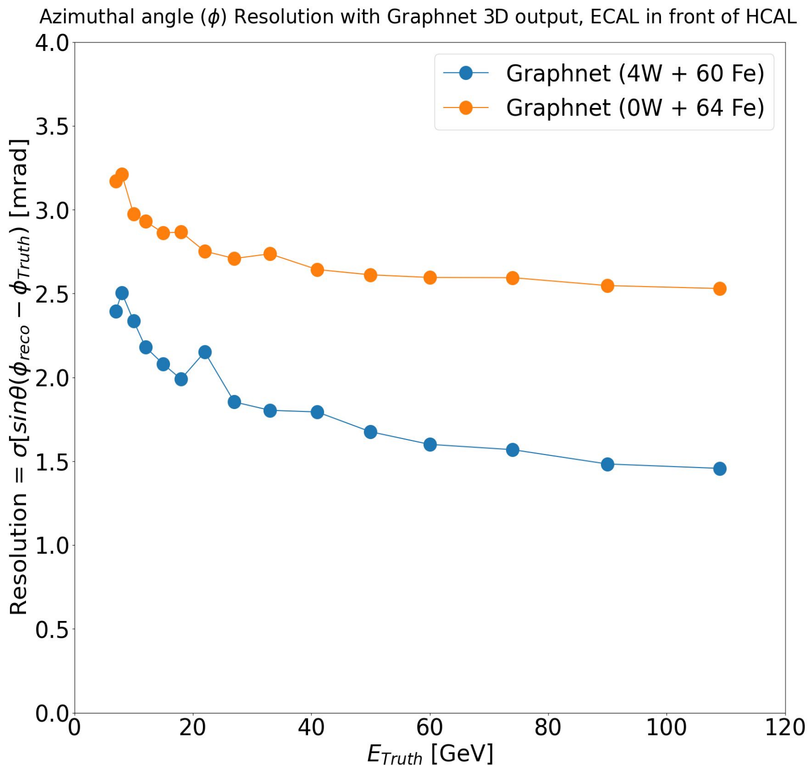
ML based software compensation shows some improvement over traditional software compensation at low energies.

Overall ML predicts something not so far from what has demonstrated in tst beams with traditional (non ML) methods.

[CALICE Result]

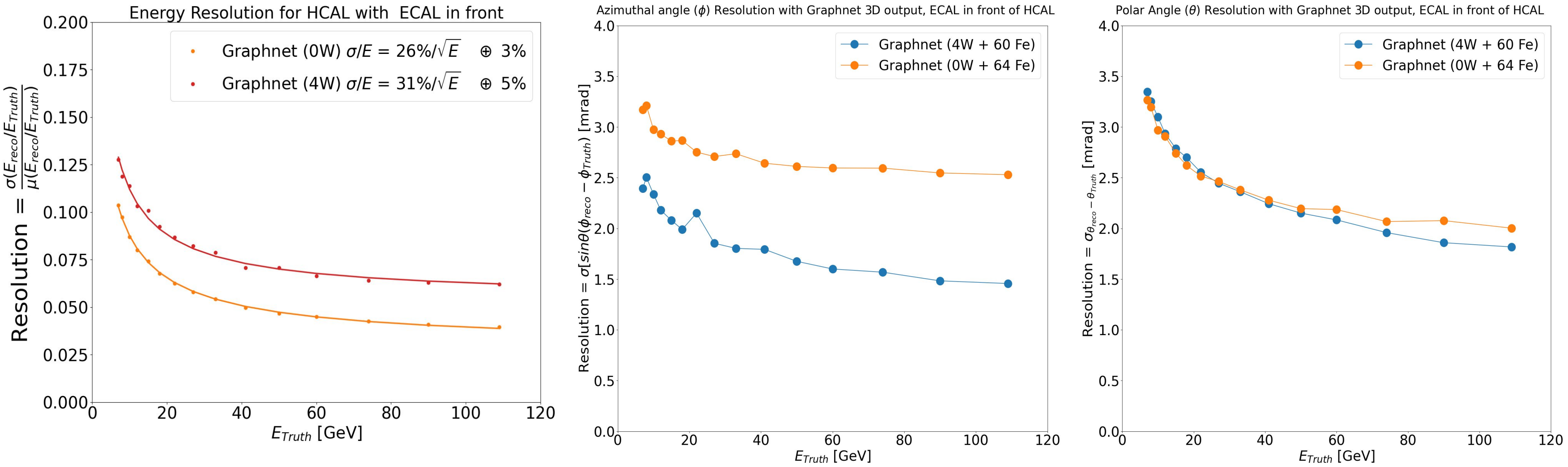
Angular resolution study





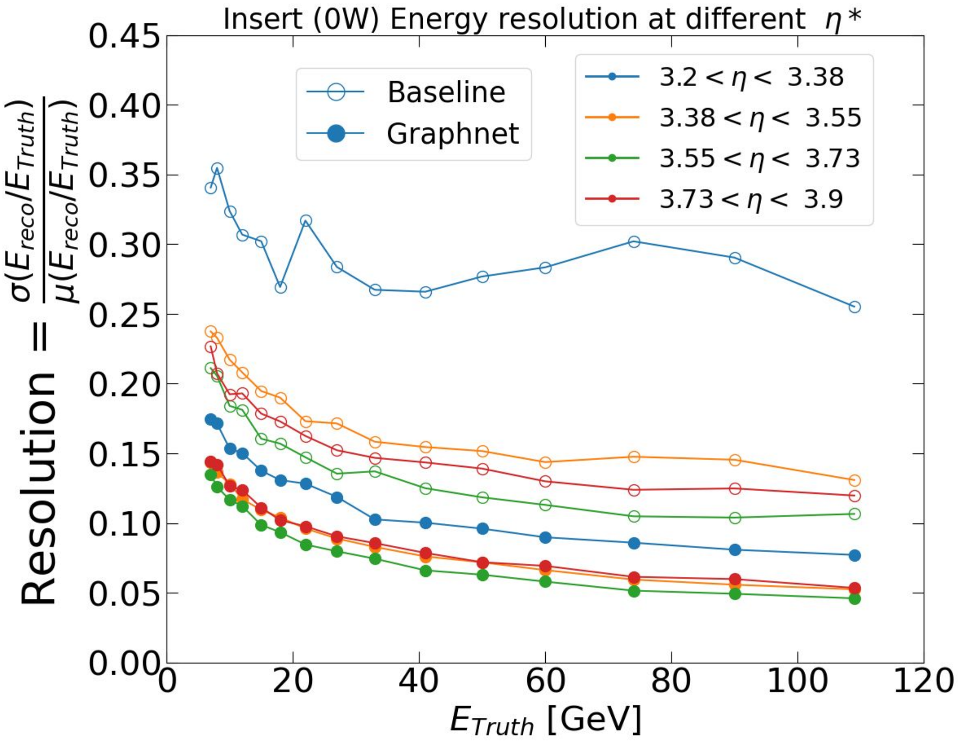
Addition of W layers improves azimuthal angular resolution for azimuthal angle (transverse plane)
But not much for polar angle (longitudinal)

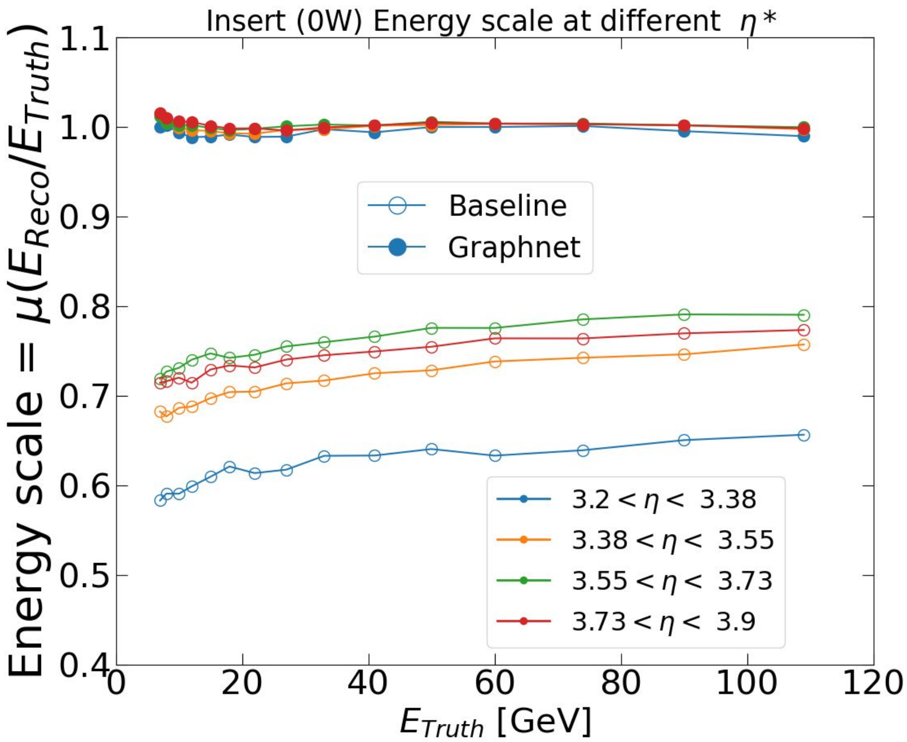
Summary of performance with optimal reconstruction (software compensated)



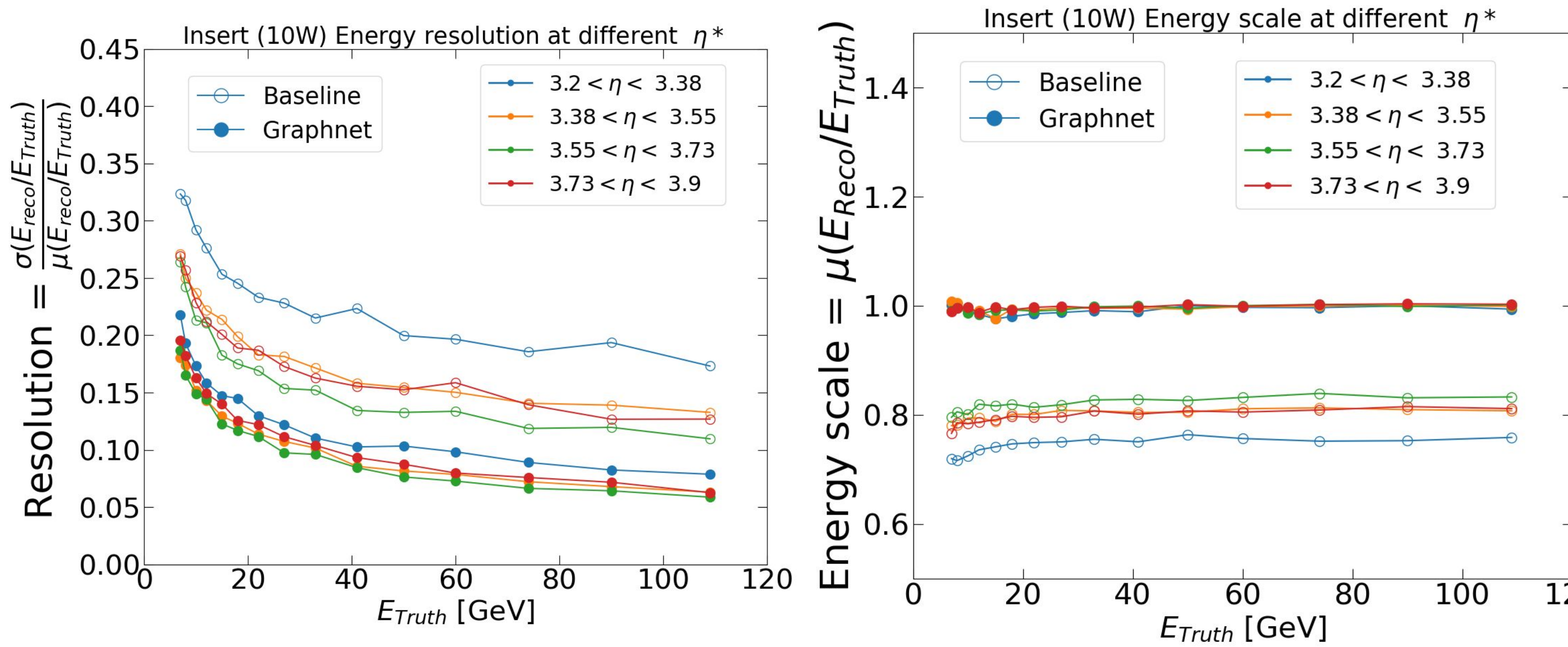
The inclusion of W leads to better azimuthal angle resolution but significantly worse energy resolution. No significant effect on shower containment observed. The overall calorimeter system is deep enough and changes due to W are marginal. ECAL + HCAL (4W + 60Fe), total=7.7 λ ECAL + HCAL (0W + 64Fe), total=7.5λ

Energy resolution and scale for standalone Insert (0W - 64 Fe) at different η*





Energy resolution and scale for standalone Insert (10W - 54 Fe) at different η*



Standalone Insert 0W + 64 Fe

η range	Stochastic (a) (%)	Constant (c) (%)
3.20 - 3.38	58 44	27 7
3.38 - 3.55	55 38	13 4
3.55 - 3.73	52 35	9 4
3.73 - 3.90	51 38	11 5

Baseline
Graphnet

Standalone Insert 10W + 54 Fe

η range	Stochastic (a) (%)	Constant (c) (%)
3.20 - 3.38	74 52	17 6
3.38 - 3.55	64 47	12 5
3.55 - 3.73	63 47	10 4
3.73 - 3.90	63 50	12 5

Baseline
Graphnet

Conclusion

- We simulated forward ePIC forward calorimeters (ECal + HCal) using DD4HEP.

  Implemented AI/ML based software compensation technique on HCal
  - Fixes the energy scale, same energy response for electron and hadron
  - Improves the energy resolution
  - Optimal reconstruction for energy, polar and azimuthal angle.

- Case study for two different combinations of Fe/W mixture was presented
  - Energy resolution for “0W_64Fe” is about 25% better relative to “4W_60Fe”
  - Angular resolution in transverse plane (azimuth) improves by about 30%, no improvement

Bottom line: W inclusion is a tradeoff between angular resolution and energy resolution.

Performance with pure Fe is likely a better option.

Enhanced longitudinal granularity has bigger upsides than W layer.