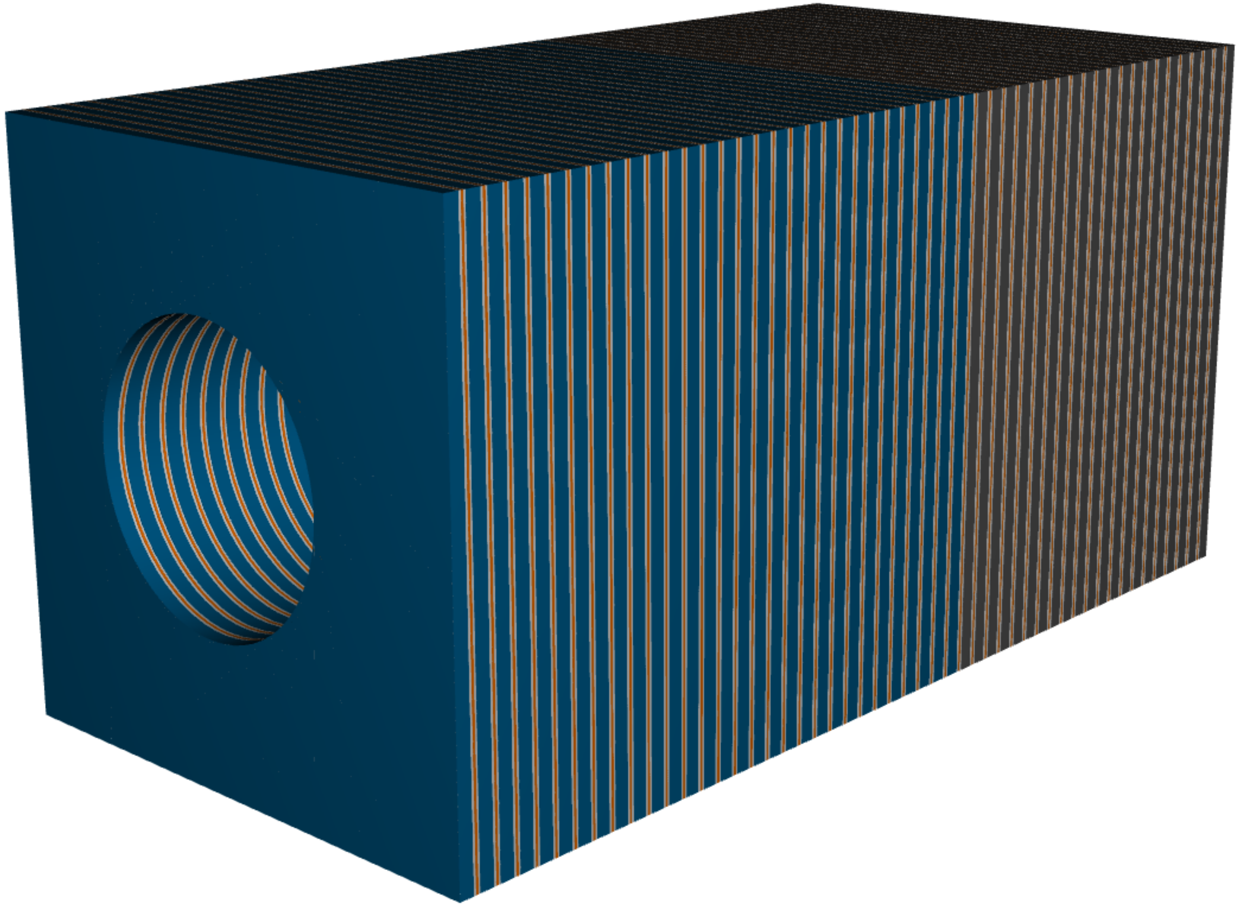
Summary of calorimeter insert design and performance

Ryan Milton

UCR

California EIC Consortium Meeting,

Jan. 27-28, 2023



Since last meeting

- Joint UCLA/UCR NIMA paper on forward HCal insert design and simulation performance
    - [Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167866]
- Insert implemented in ePIC simulations (Bryce Canyon)
- Numerous studies ongoing:
    - Machine learning (UCR, LLNL, Ben Nachman)
    - SiPMs and scintillators
    - Prototype and beam test
    - Jet studies in ePIC

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

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A high-granularity calorimeter insert based on SiPM-on-tile technology at the future Electron-Ion Collider

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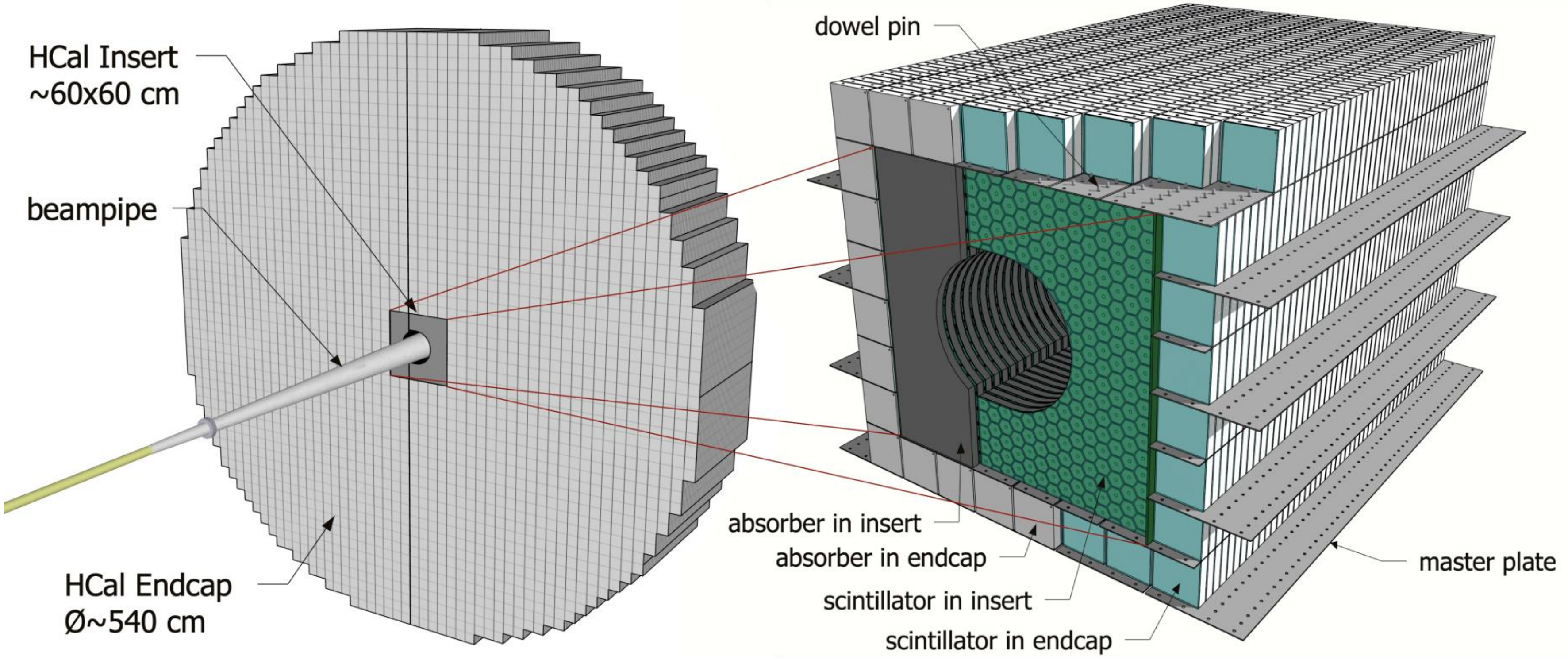
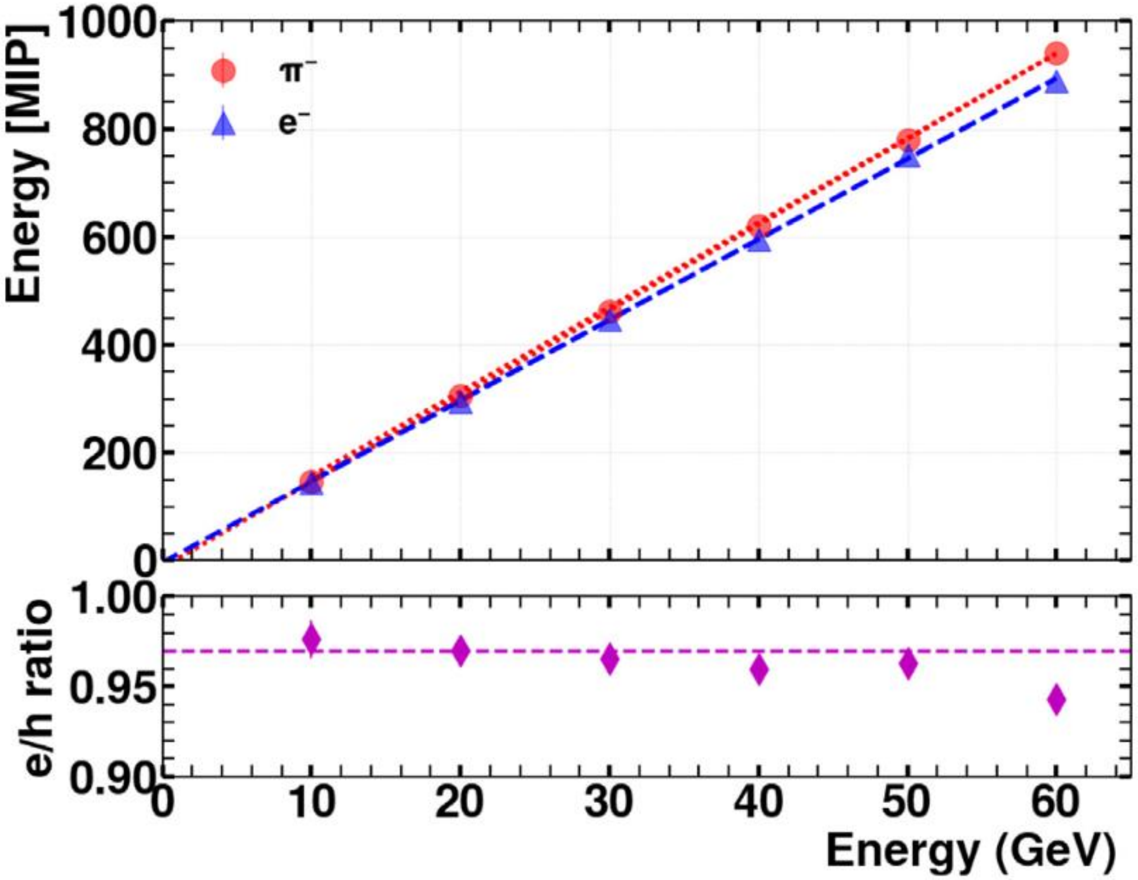
Insert recap

- Instruments near the beampipe in forward region, $3 < \eta < 4$ or $2.1^\circ < \theta < 5.7^\circ$
- High-granularity to yield a good angular resolution
  - Allows measurements of jets and hadronic final states in DIS reactions
- Fully integrated into the hadron endcap and solves mechanical issues in complex region

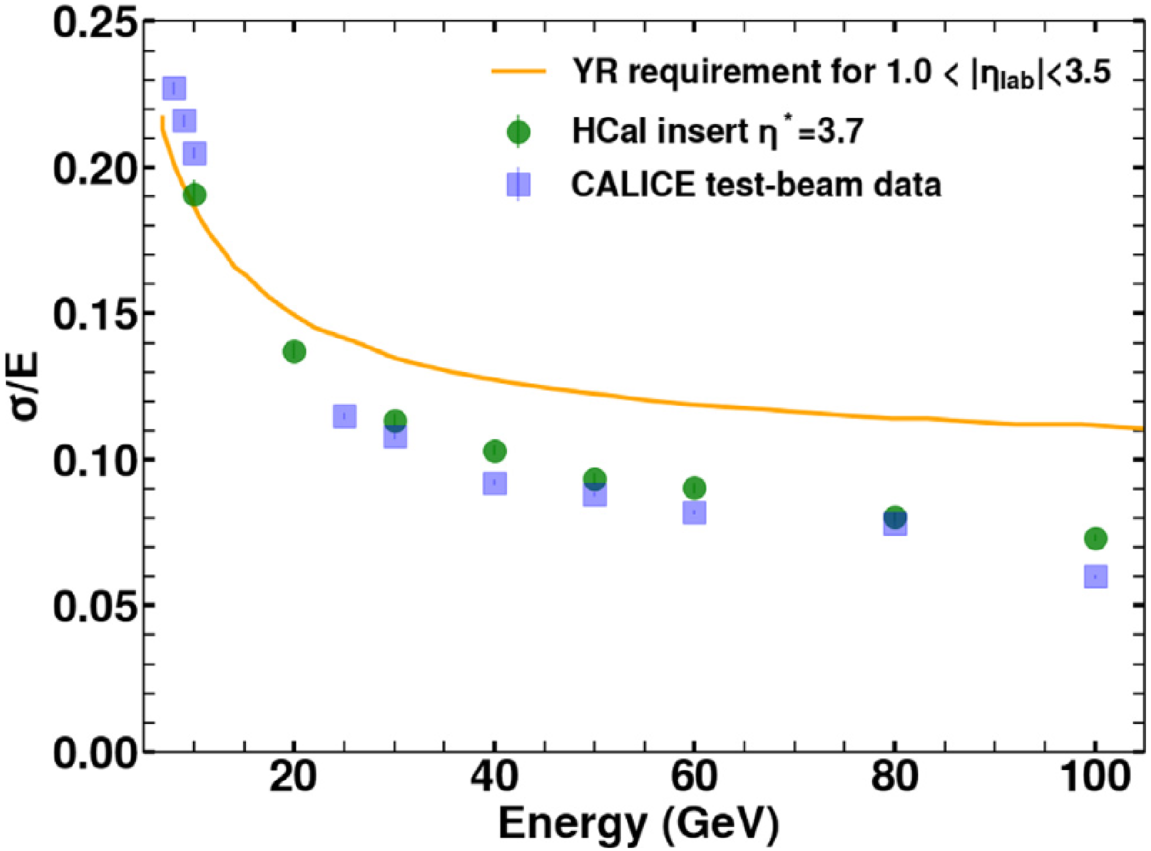


Performance metrics recap

- Good energy linearity and e/h close to 1
  - Don't need extra compensation techniques for hadronic showers
- Energy resolutions validated against CALICE W/Sc sampling calorimeter



$\eta^* = 3.7$



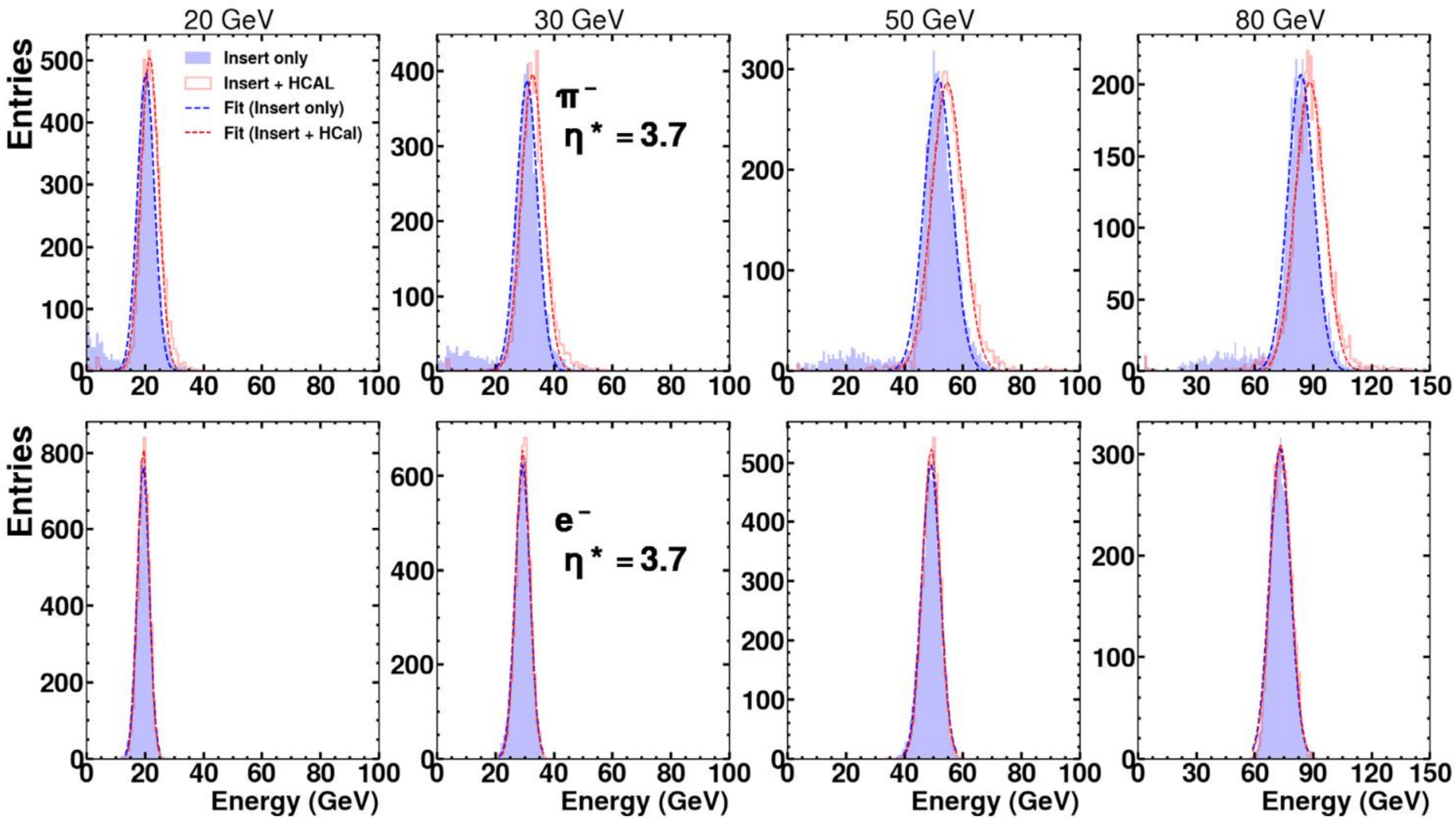
Resolutions of π^-, $\eta^* = 3.7$

Handling leakage

- Combine insert + HCal energies with: $E_{total} = \frac{E_{insert}}{SF_{insert}} + \frac{E_{HCal}}{SF_{HCal}}$
- Low energy tails indicate leakage out of insert into HCal

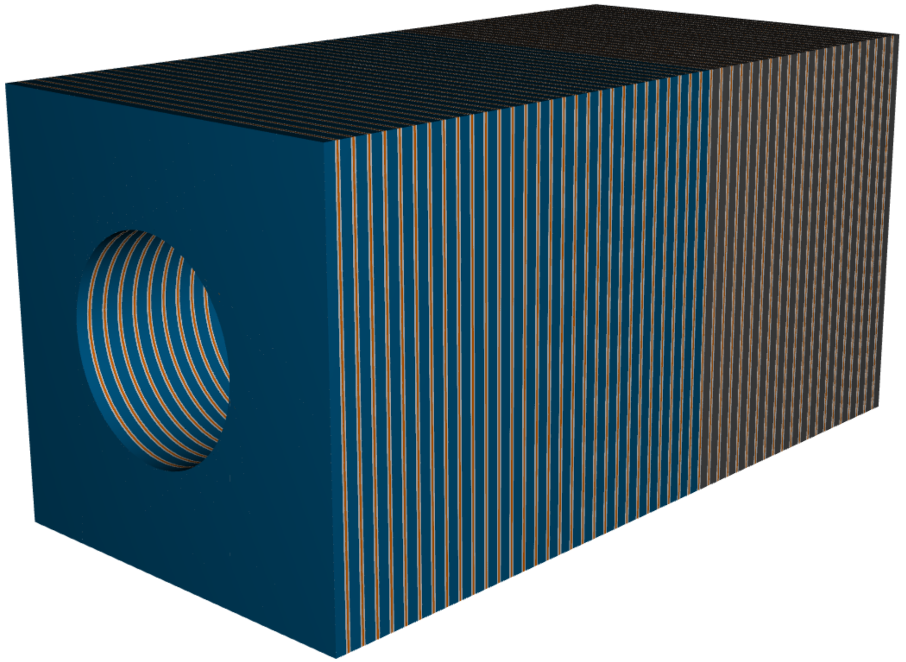
Top:
$\pi^-, \eta^* = 3.7$

Bottom:
$e^-, \eta^* = 3.7$

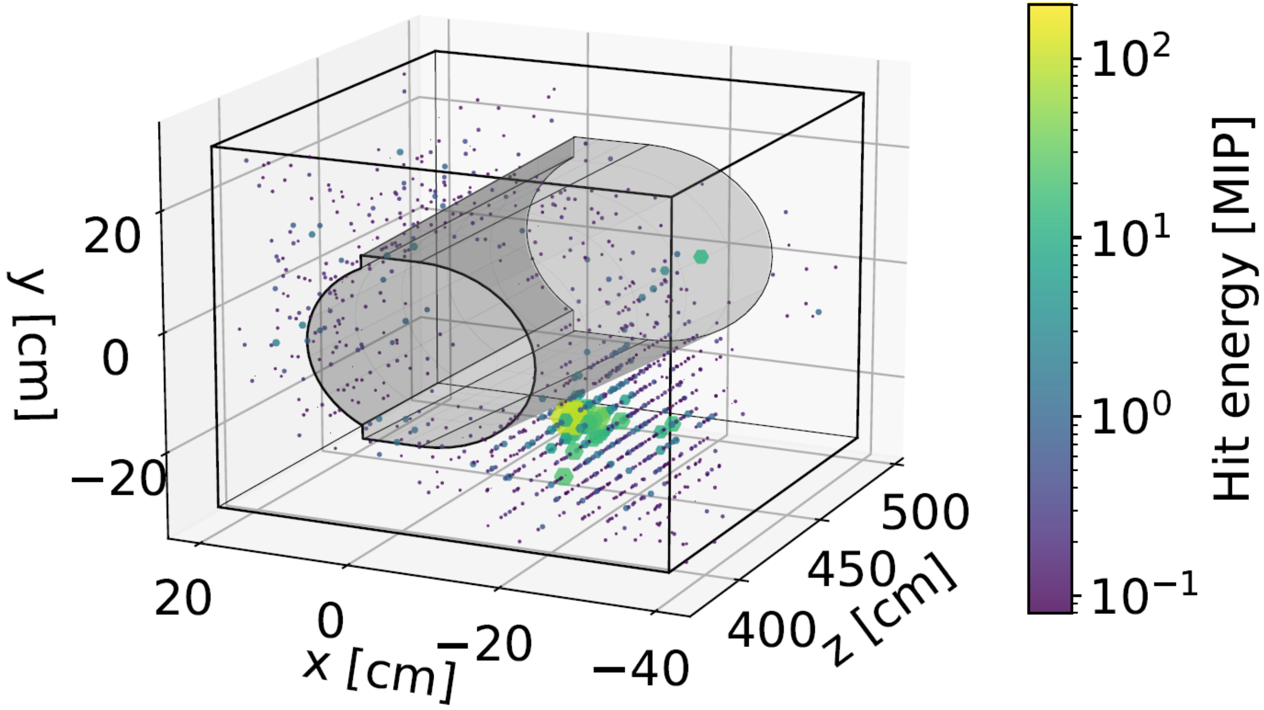


Studying absorber materials

- Original design: 30 layers W/Sc (.17 λ_n each) + 21 layers Fe/Sc (.107 λ_n each), 7.3 λ_n total
- Steel necessary to contain the magnetic flux
- Tungsten desirable for compact showers and compensated response
- What is the optimal splitting between tungsten and steel?



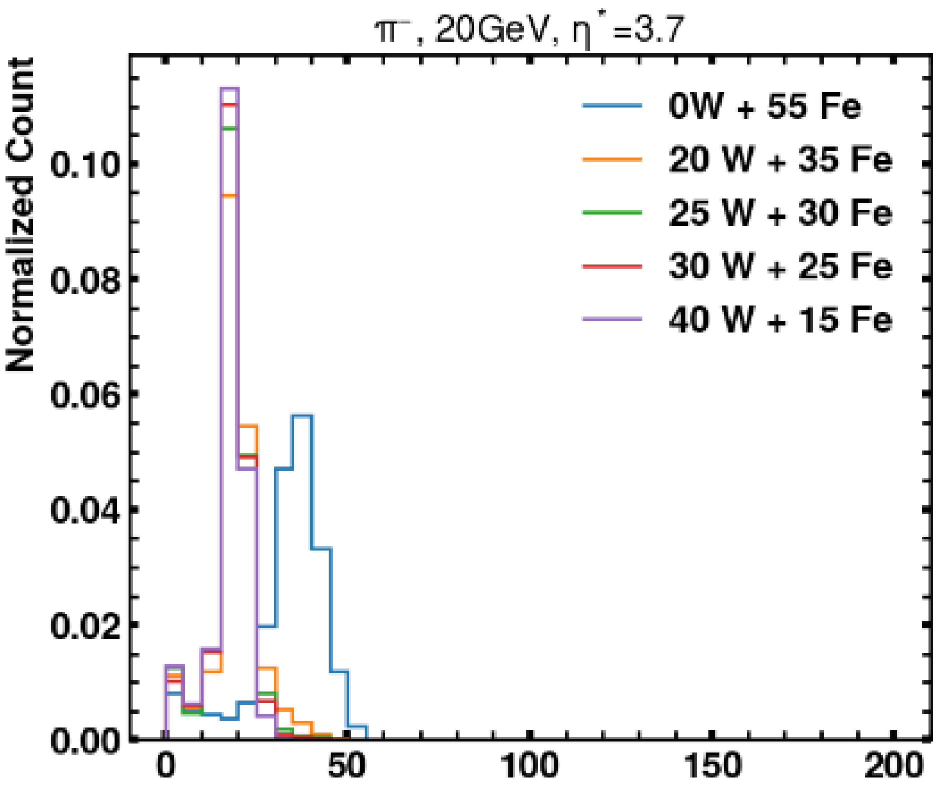
Blue: Tungsten, Gray: Steel

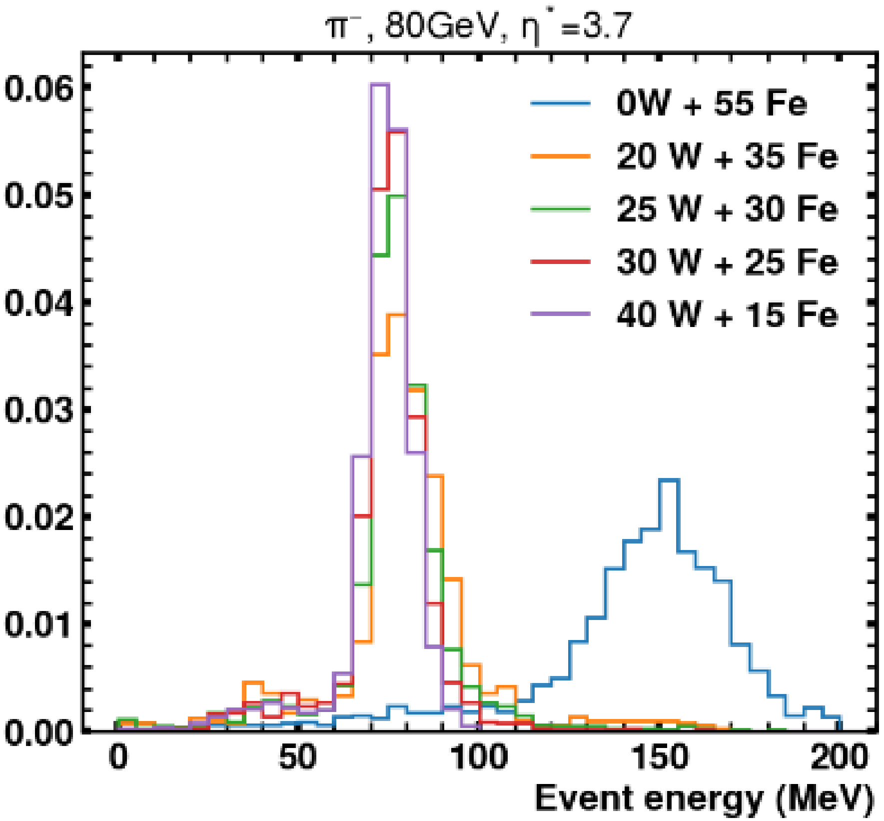


50 GeV π^- at $\eta^* = 3.7$

Hadronic response to layer numbers

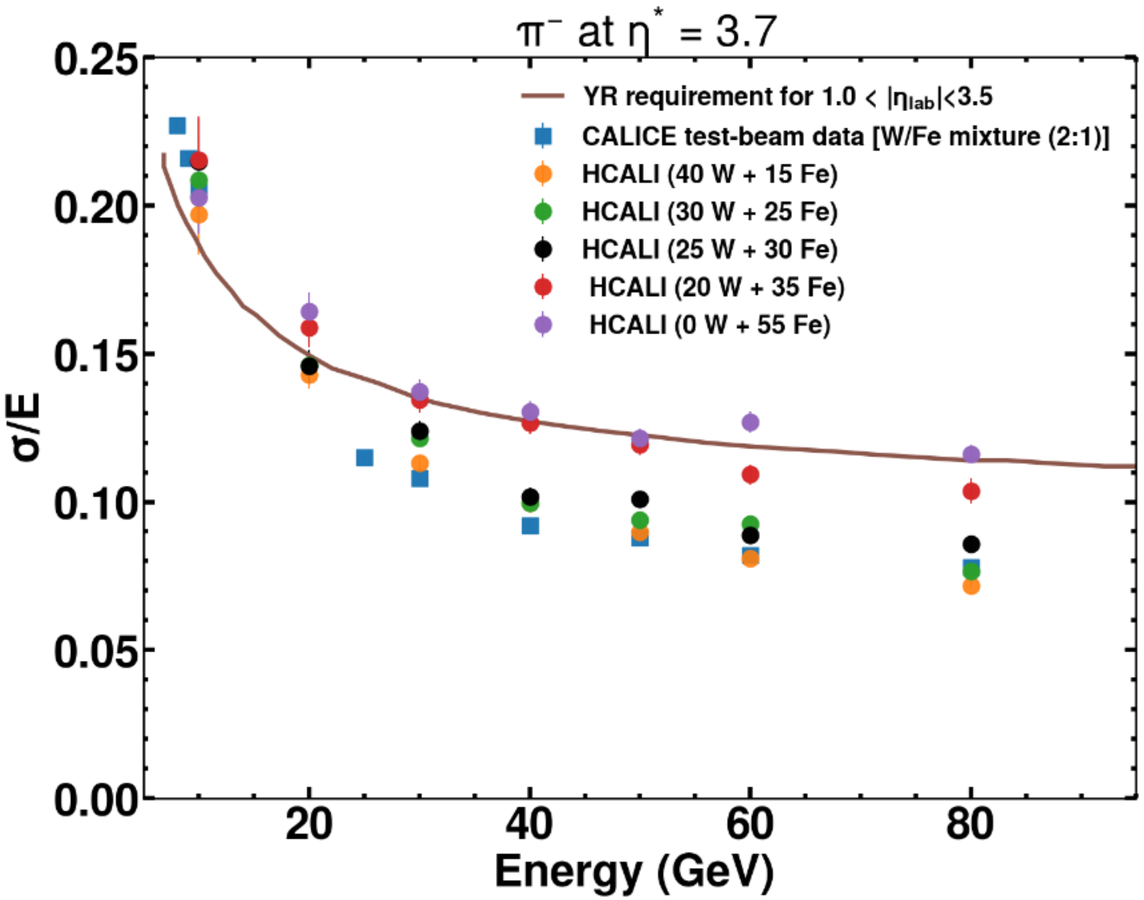
- Higher average energy with all steel, but much wider distribution
  - Large low energy tail as well
- Even just a little bit of tungsten narrows the distribution

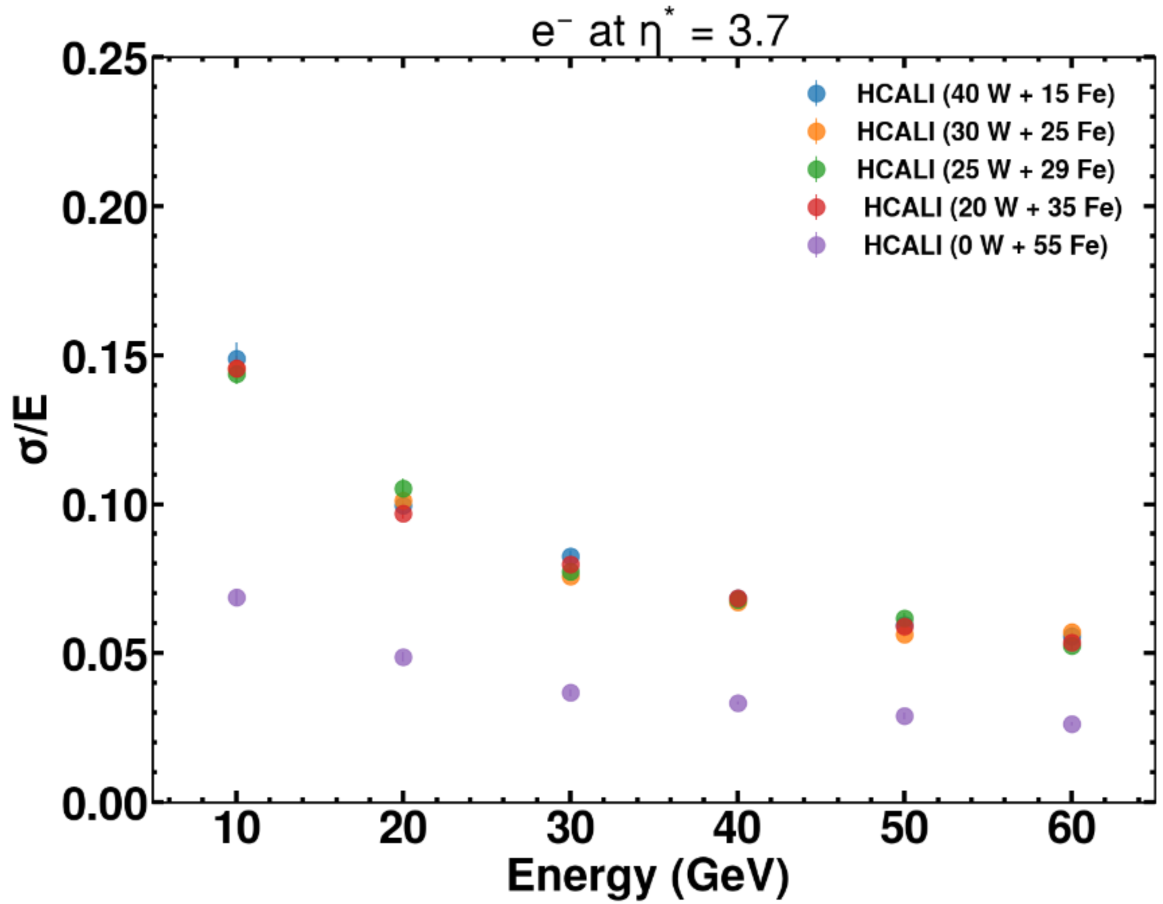




Energy resolutions

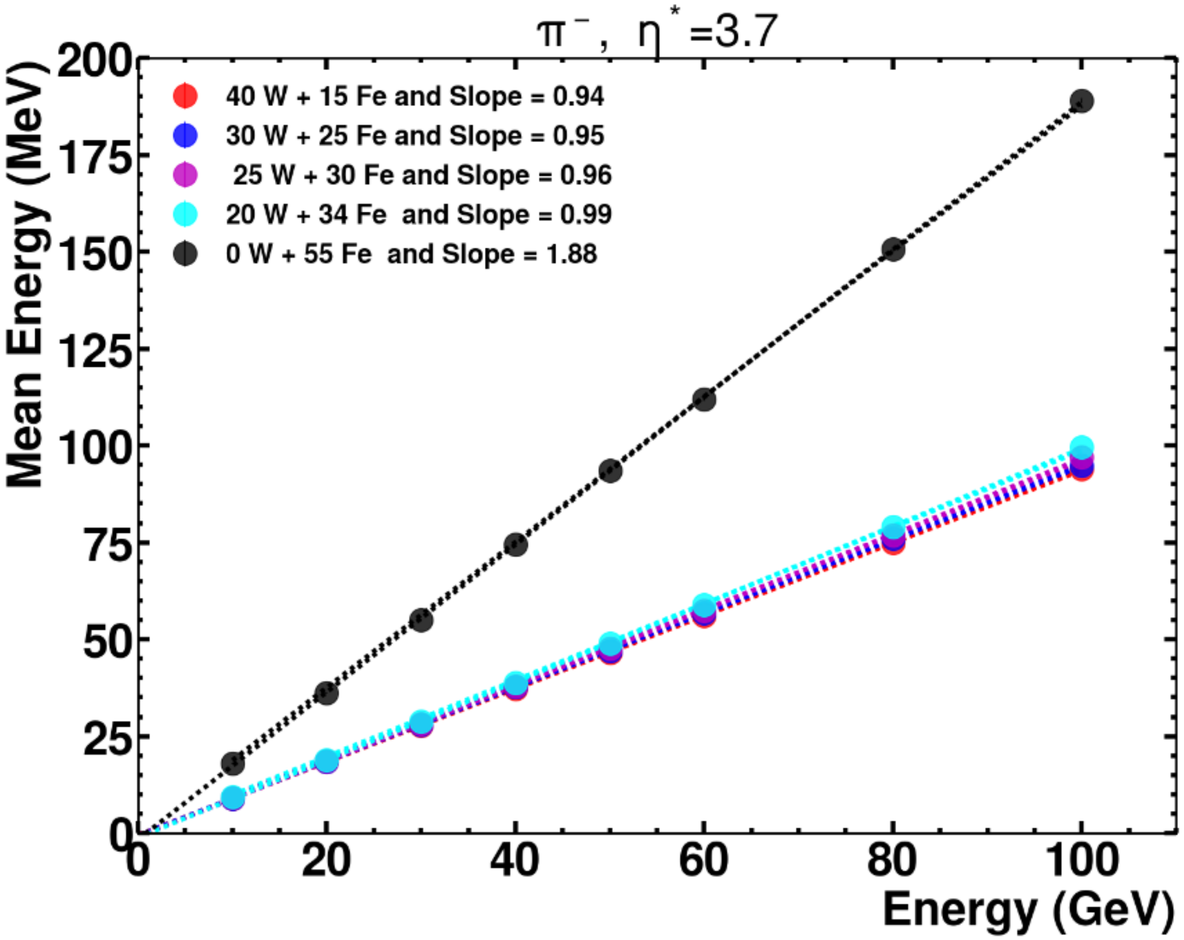
- Tungsten improves hadronic resolution but with diminishing returns
- Steel has better energy resolutions with electromagnetic showers

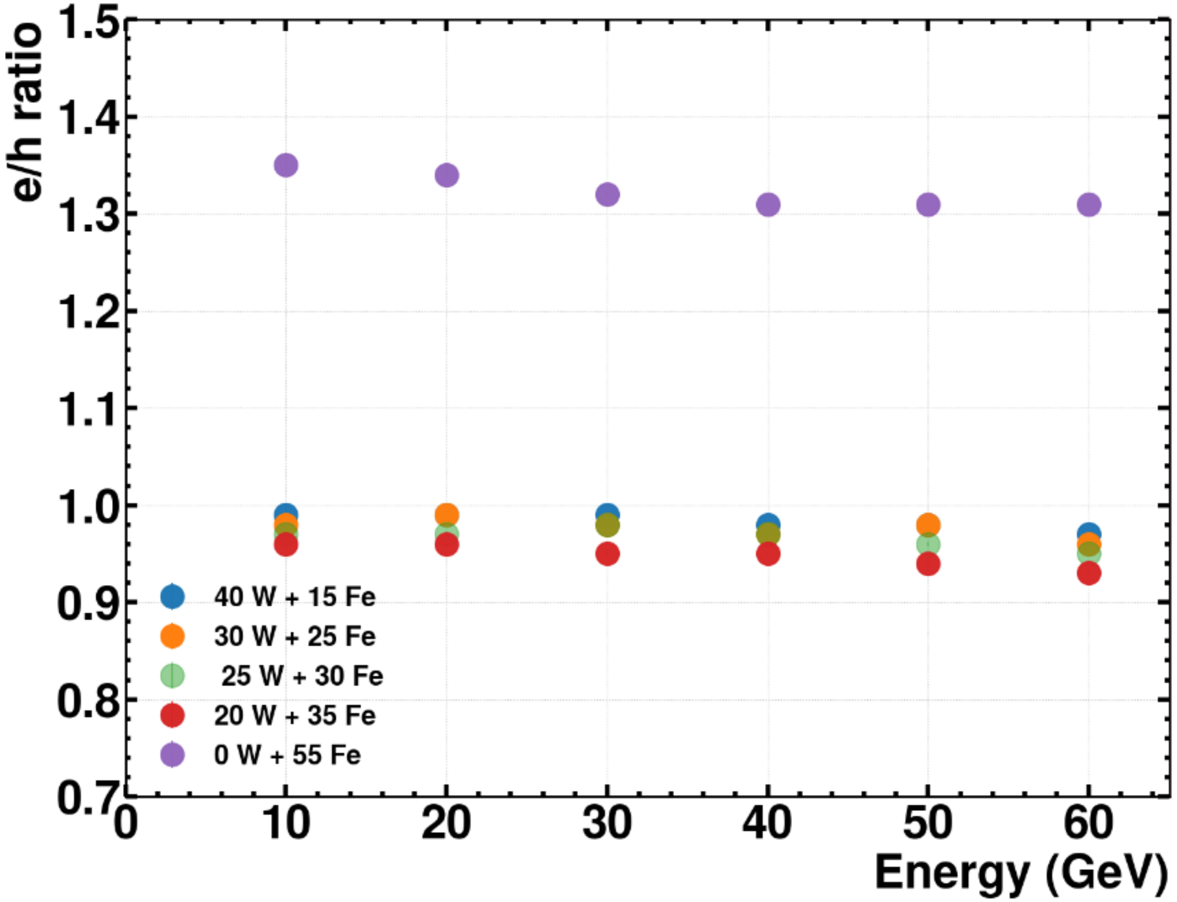




Tungsten perks

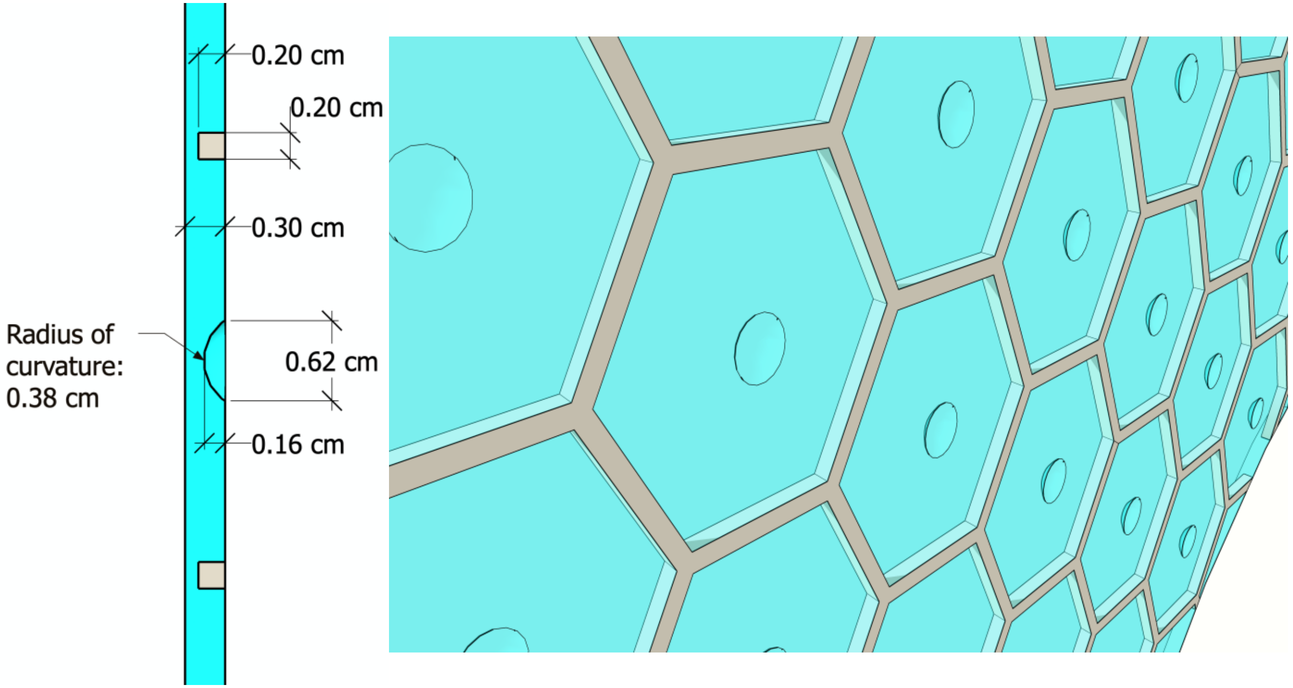
- Improved energy linearity with tungsten
- Significantly improved e/h ratio

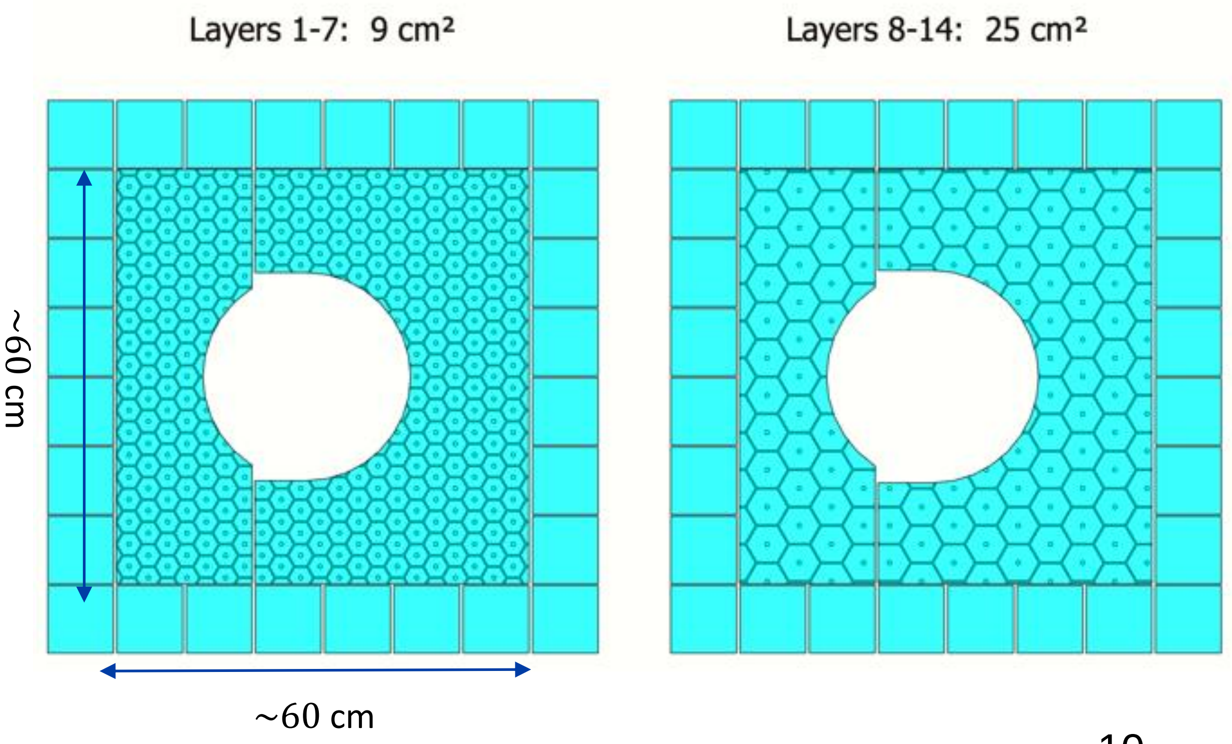




Scintillator design

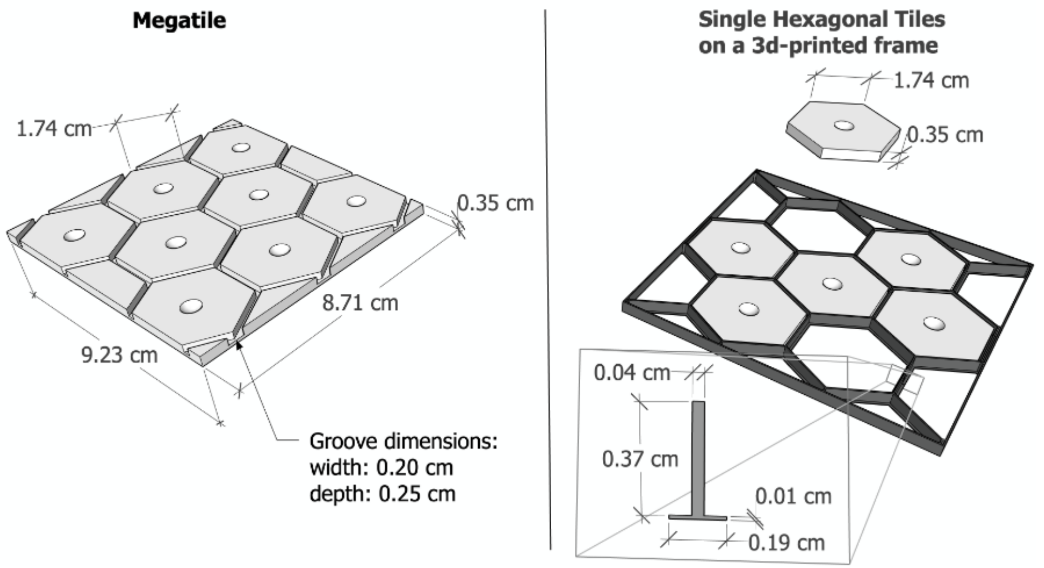
- Hexagonal cells to easily tessellate the area
- SiPM-on-tile design
  - SiPMs hosted on PCBs fit into hemispherical dimples
- Epoxy in grooves between cells to reduce optical crosstalk
- Potentially changing granularity throughout insert

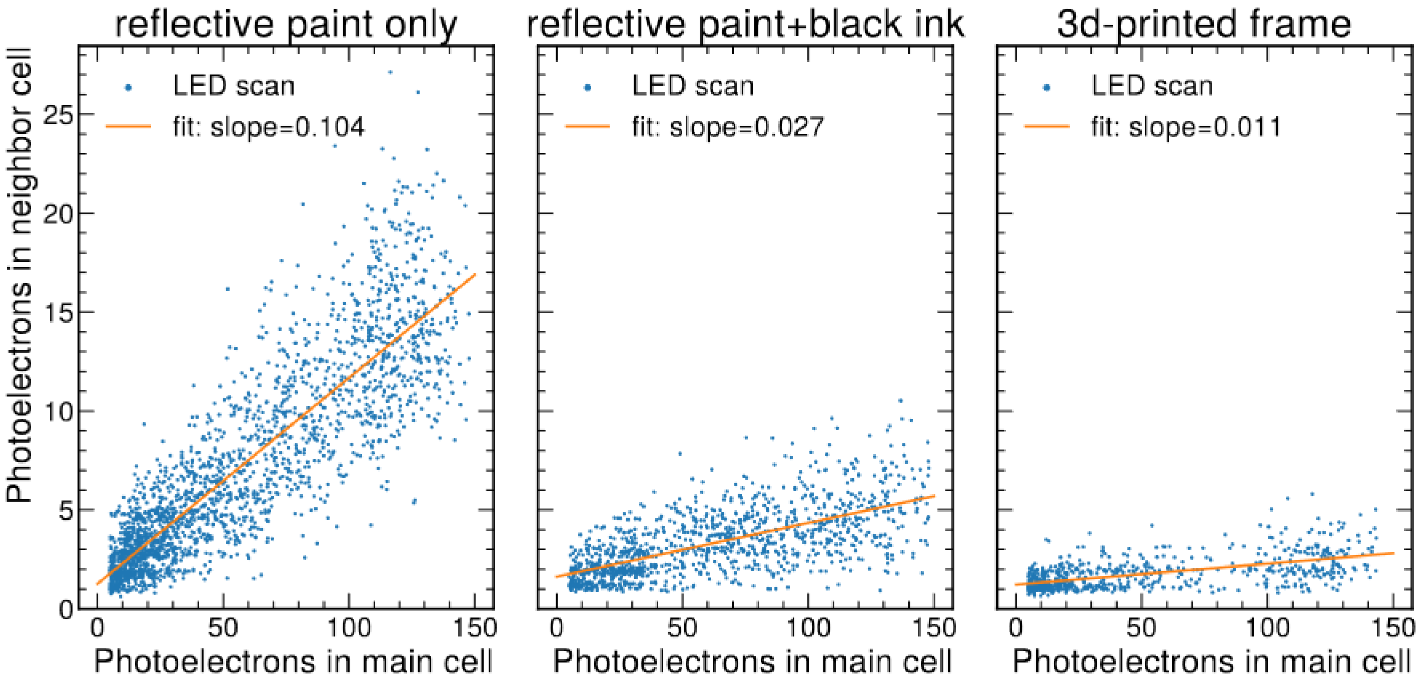




Optimizing scintillator cells

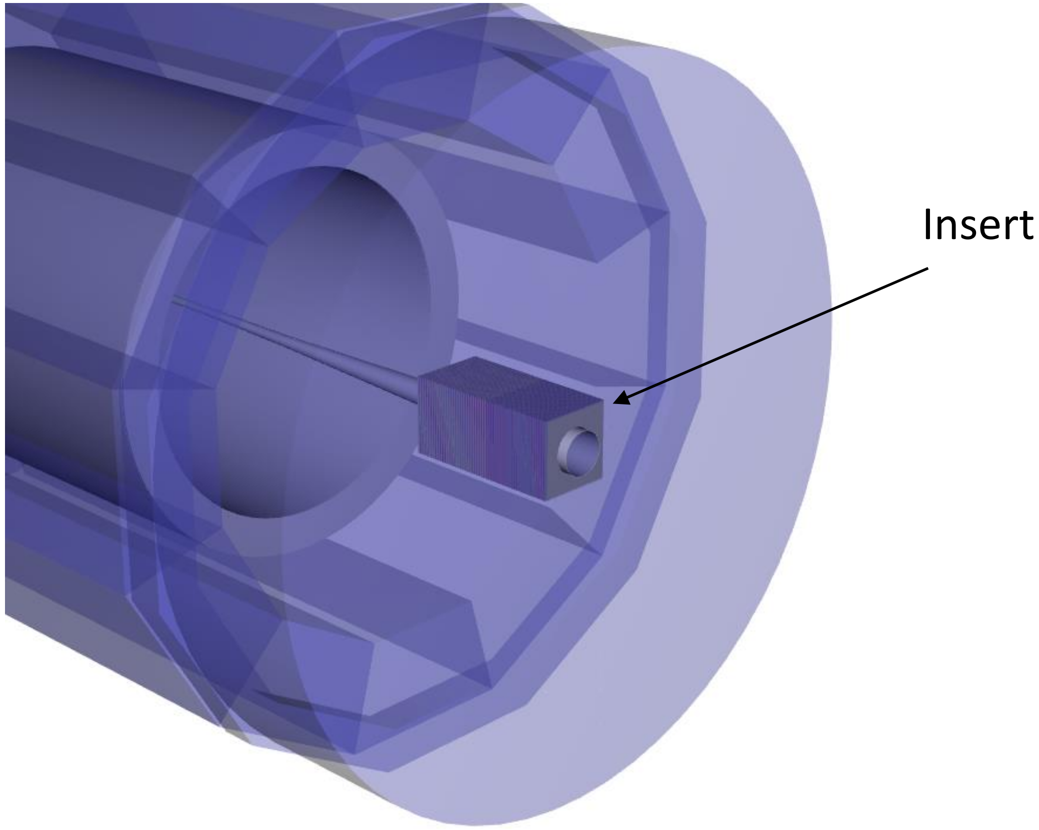
- Moving away from megatiles to 3D-printed frames with individual cells
- 3D-printed frames reduce optical crosstalk between cells
- Frame size and shapes can be adjusted
- Will hear more about scintillator efforts in later talks



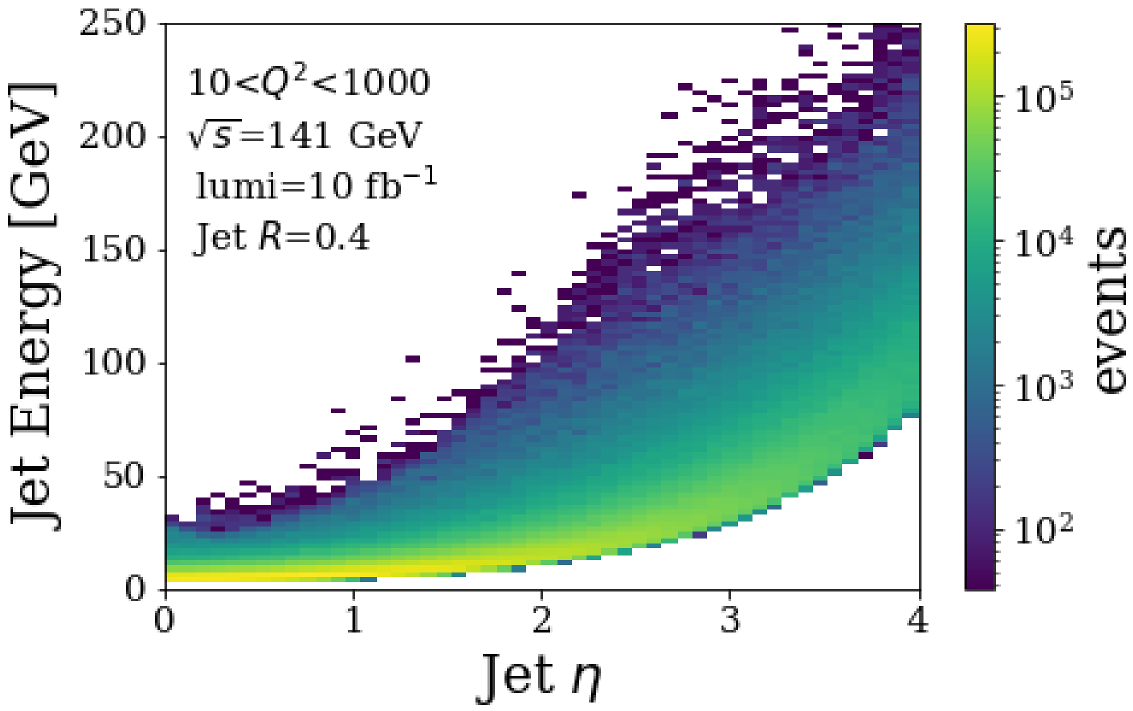


Jet studies in ePIC simulations

- ECal insert and HCal insert implemented in Bryce Canyon ePIC simulations
- Highest energy jets produced in the $3 < \eta < 4$ range
    - Calorimeters in this range critical for measurement



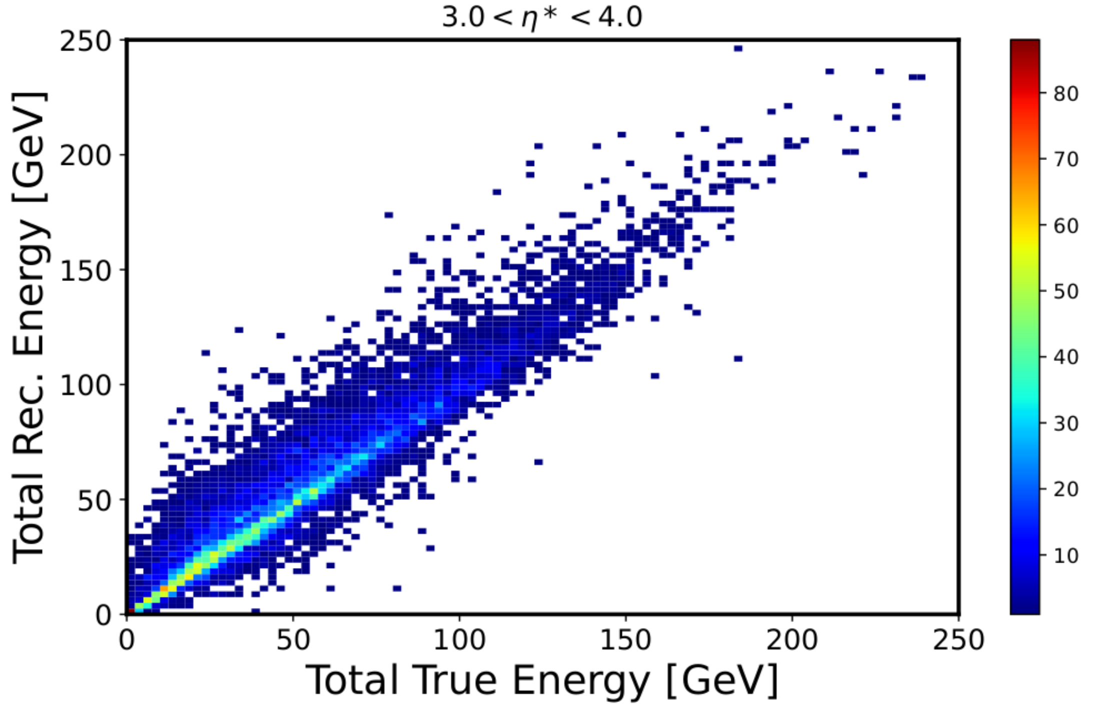
ECal insert and HCal insert in ePIC simulation

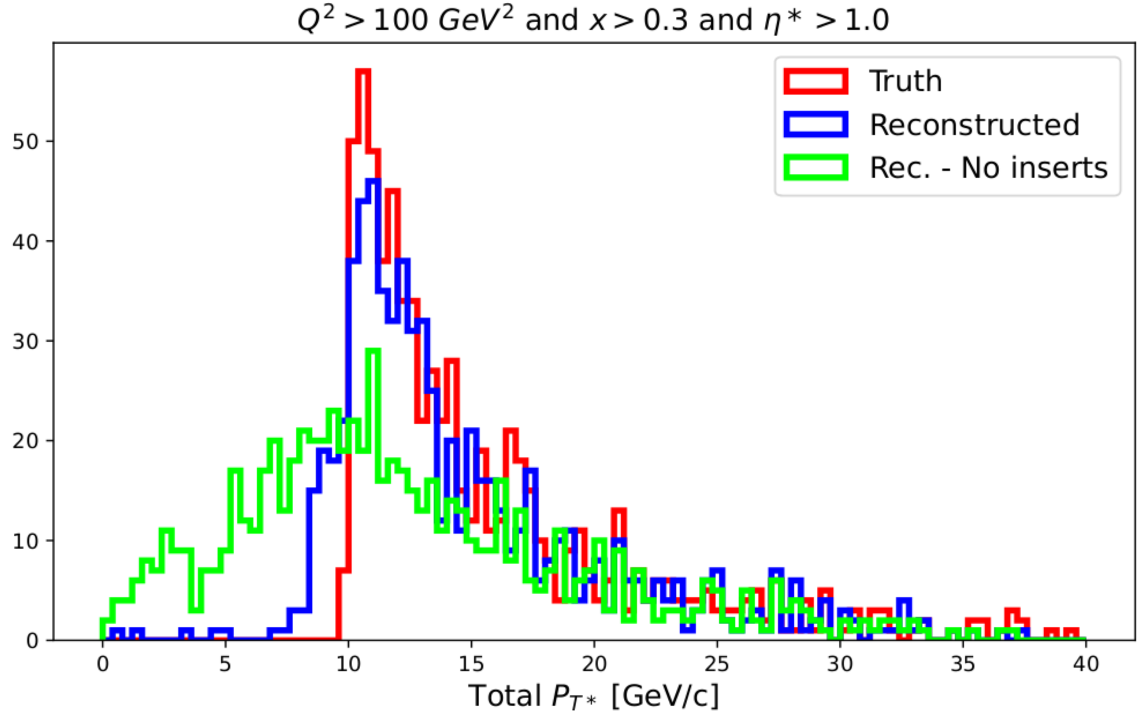


Pythia8 simulation

Jet metrics in forward endcap

- Linear response of truth energy vs reconstructed energy
- Total P_t measured agrees with the truth values
  - Worse agreement without the insert (Arches) and only using HCal
  - Critical for reconstruction of Q^2
- These studies used both the ECal insert and HCal insert





Studies by Barak Schmookler

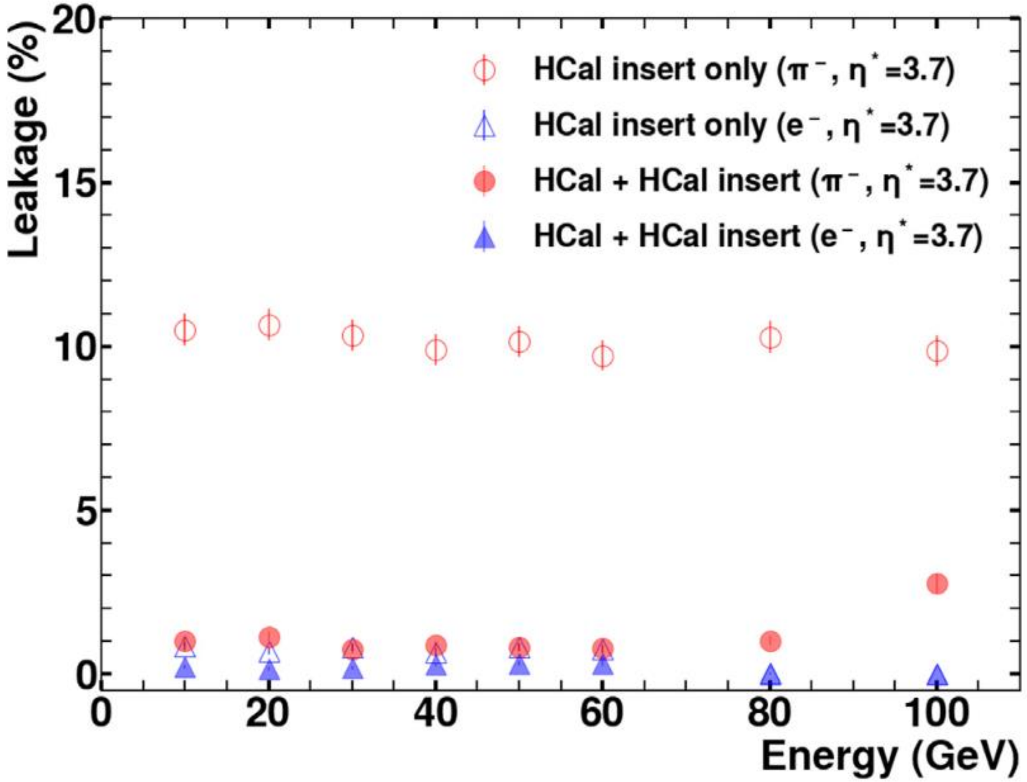
Summary and future plans

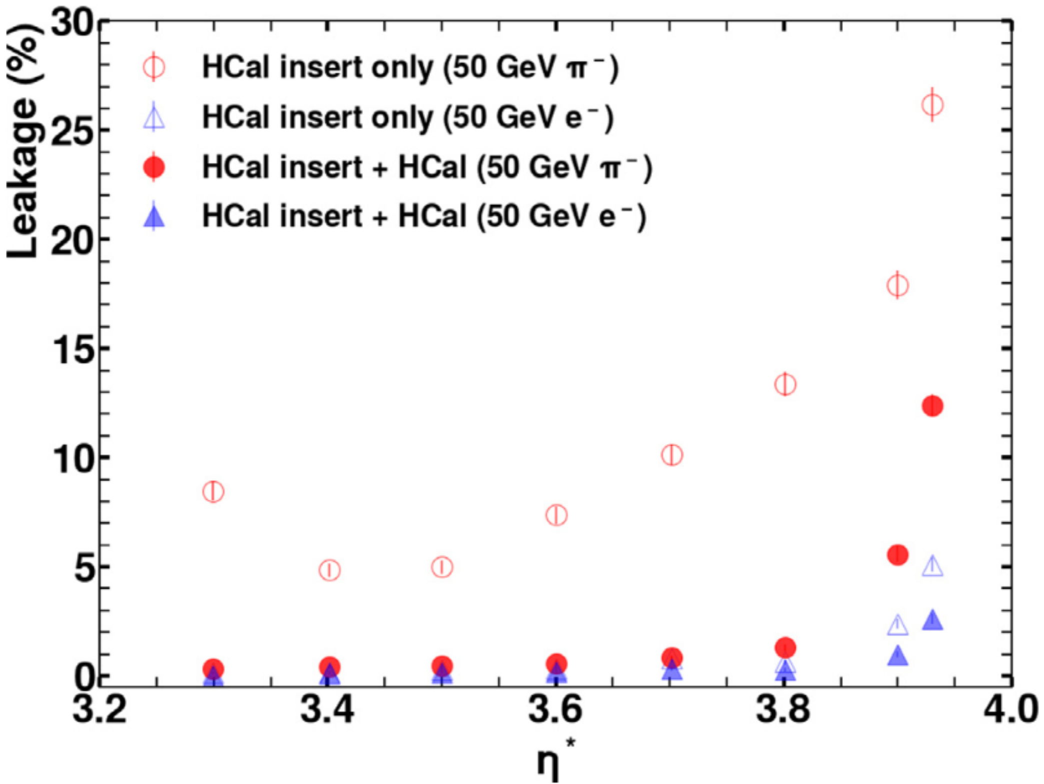
- HCal insert enables detection near beampipe in forward region with validated energy resolutions and controlled leakage
- HCal insert design is being optimized for W/Steel layers and scintillating cell designs
- Future plans:
  - Further jet studies within forward calorimeters from ePIC simulations
  - Papers on scintillators and potentially ECal insert
  - Turning my attention to machine learning efforts for hadron endcap
    - With Consortium members from UCR, LLNL, and Ben Nachman

Thank you!

Backup: Quantifying leakage

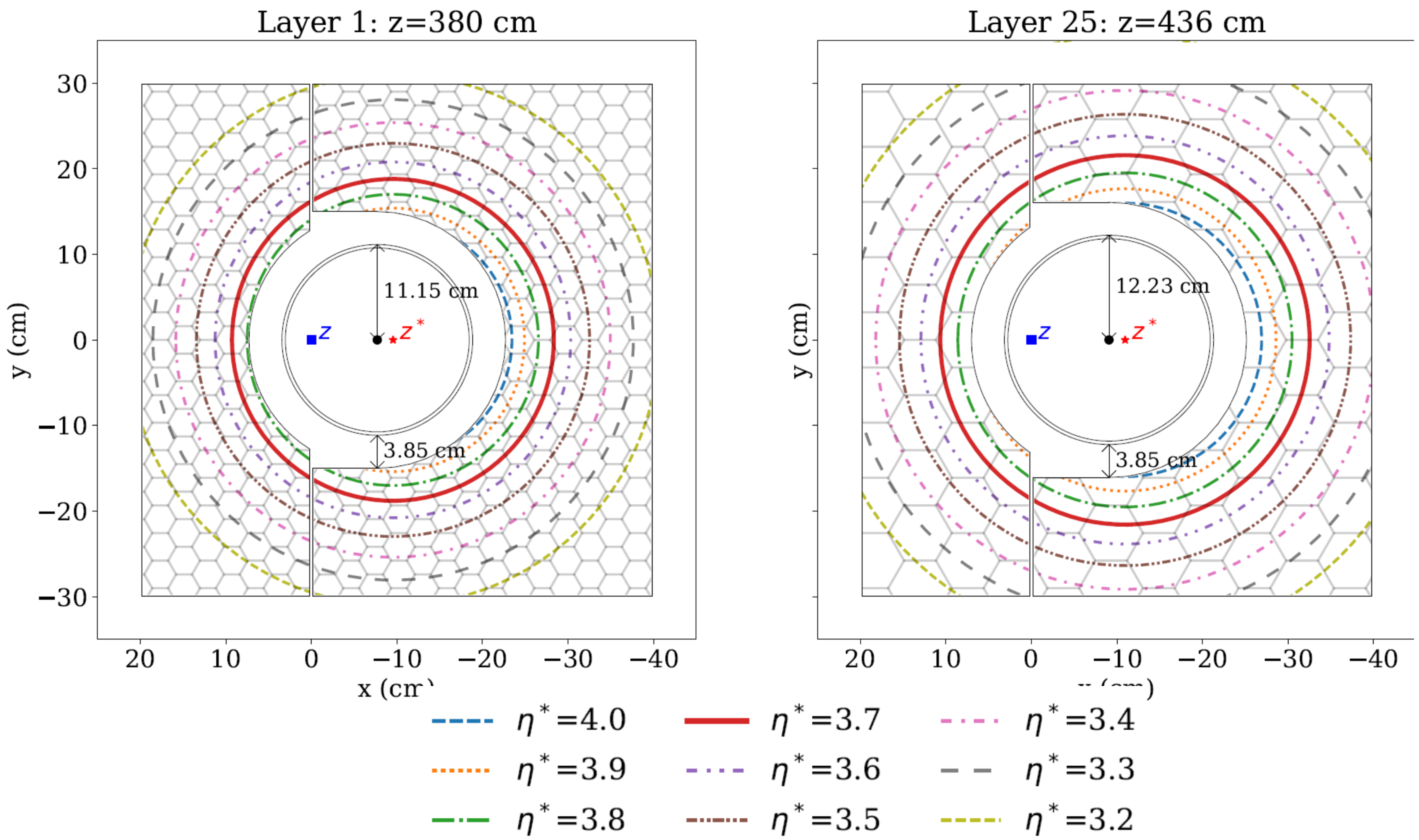
- Leakage: Energy that escapes from the detector
  - Will result in events with lower energy deposition
- $\text{Leakage} = \frac{\#\ events\ with\ E_{total} < \mu - 3\sigma}{\#\ events}$
  - μ, σ from Gaussian fits of energy distributions
- Some transverse leakage out of insert, mostly captured by HCal

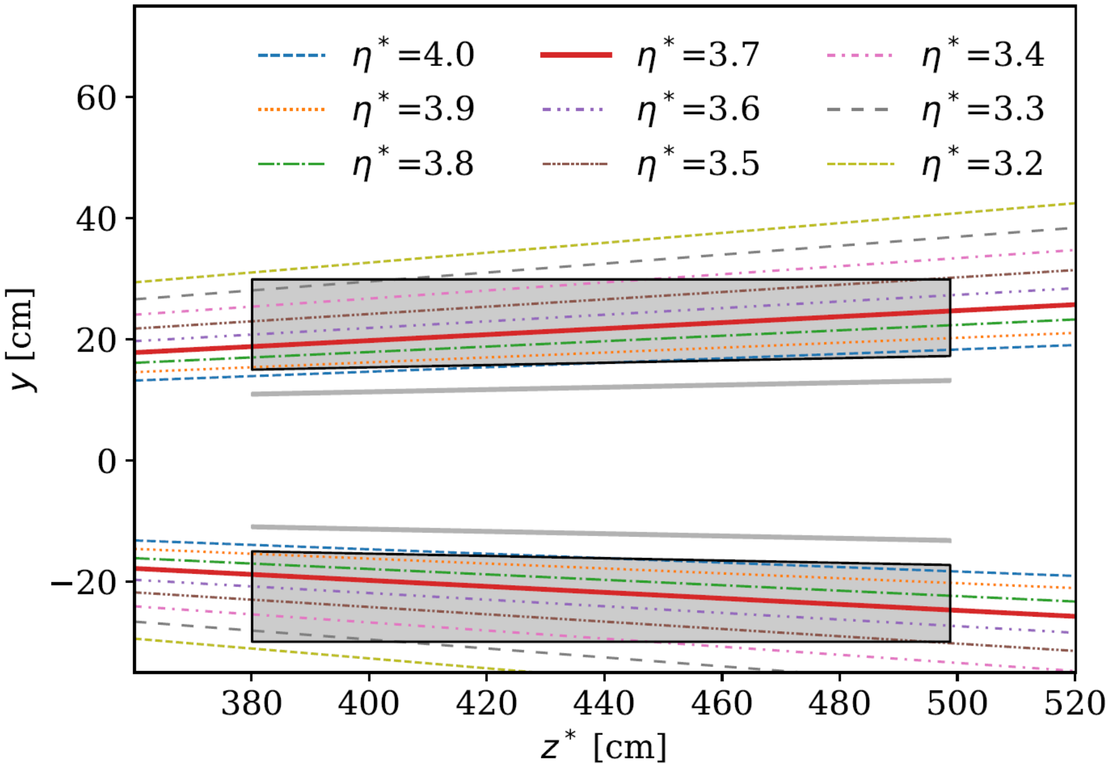




Backup: Geometric acceptance

- Consistent acceptance between $3.5 \leq \eta^* \leq 3.8$ throughout entire insert
- For $3.2 \leq \eta^* \leq 3.4$, some acceptance but still captured by HCal
    - For $3.0 \leq \eta^* < 3.2$, mainly captured by HCal
- $z^*$and η^* are with respect to proton beam axis

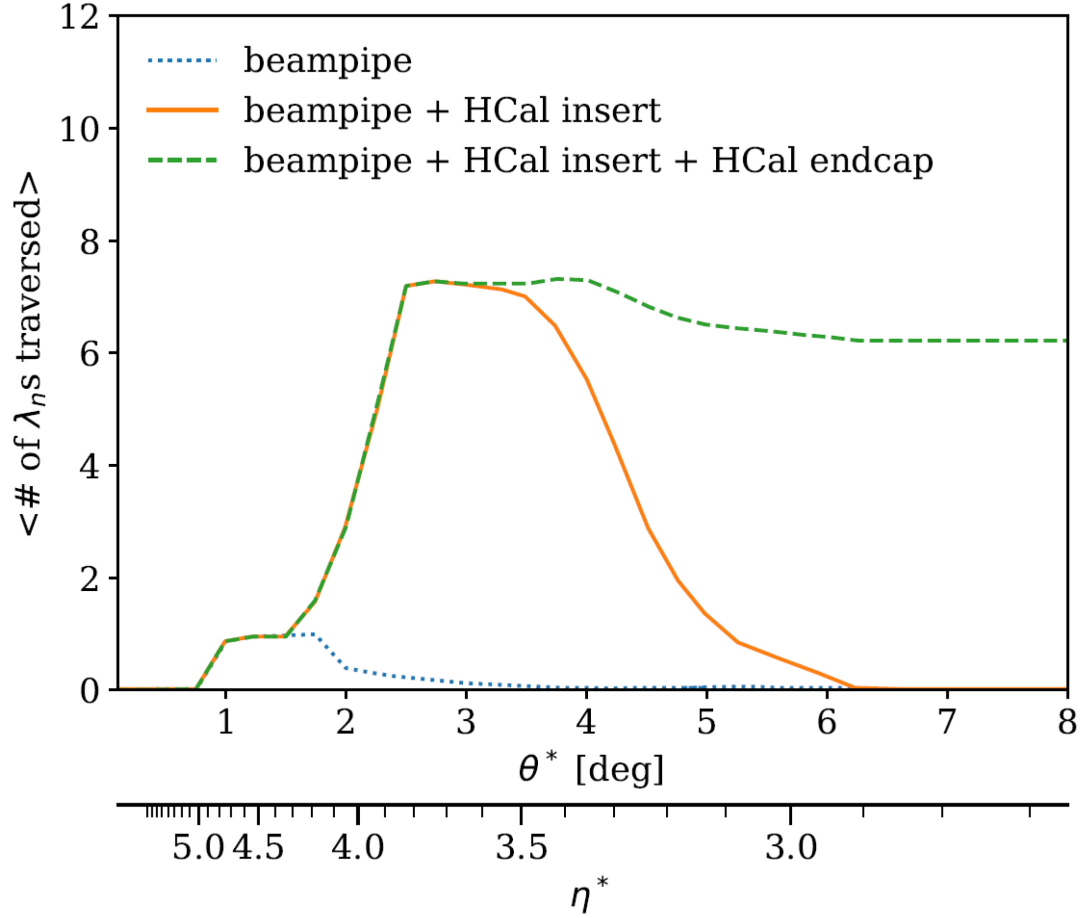




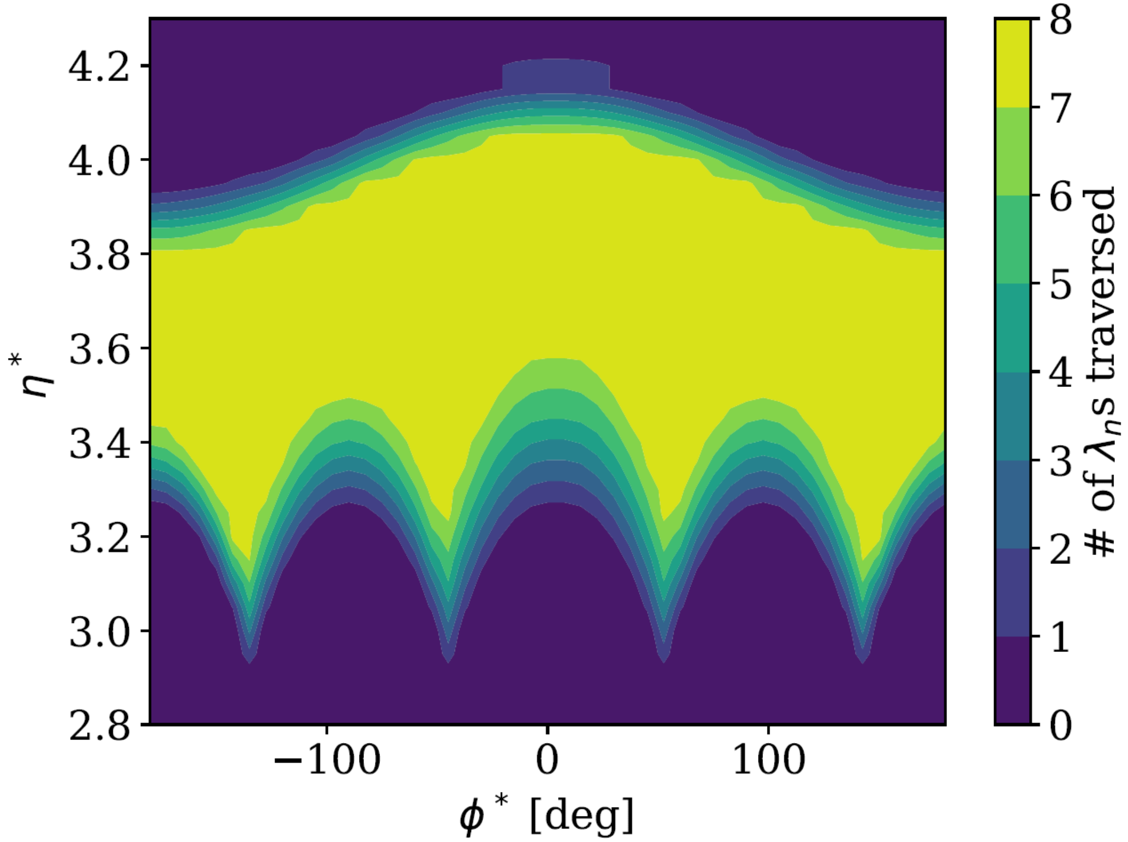
η^* acceptance for yz^*cross section

Backup: Quantifying geometric acceptance and containment

- Can quantify how well the insert accepts and contains particles at different angles
  - Number of interaction lengths (λ_n) traversed
  - Insert is about 7.3 λ_n long

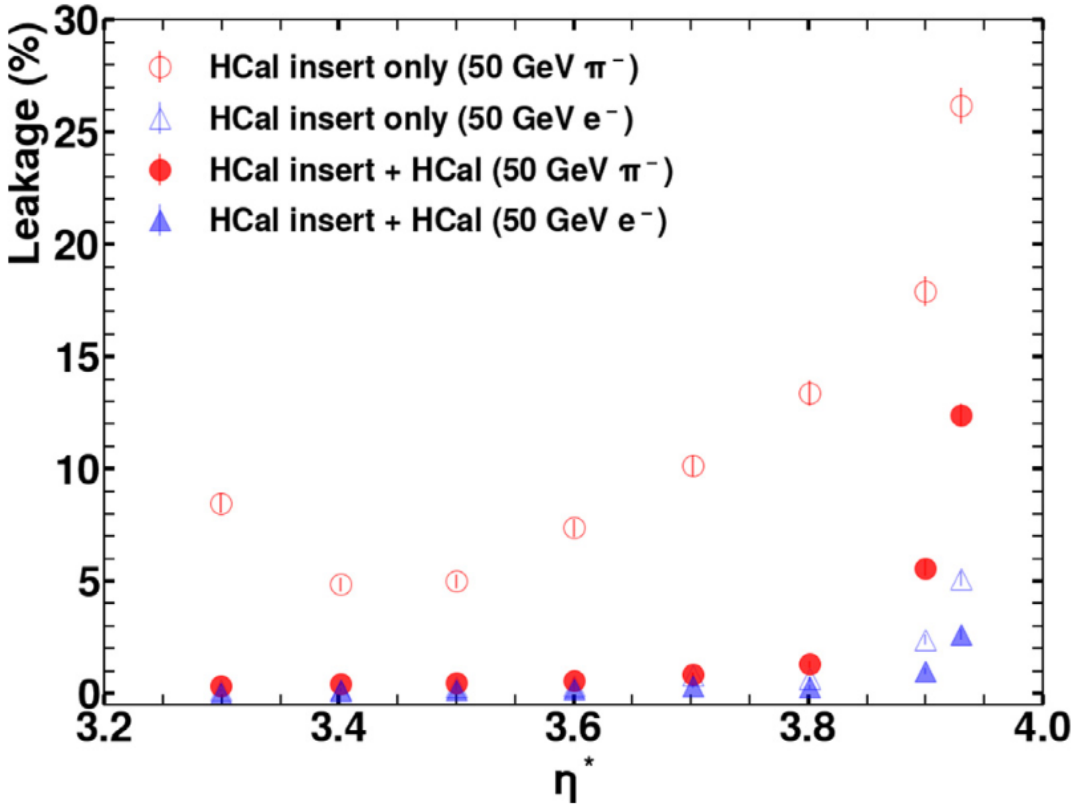


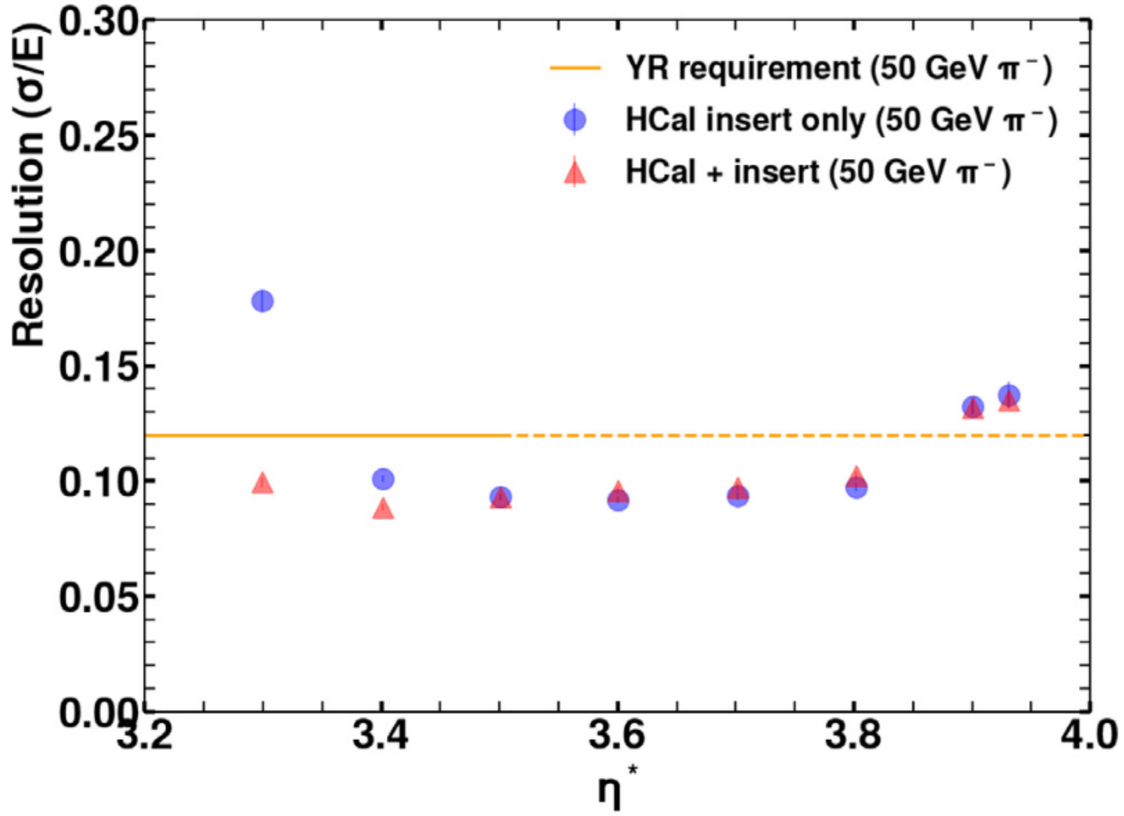
Number of λ_n's traversed averaged over ϕ



Number of λ_n's traversed in insert alone

Backup: Performance against η^*





Resolutions of π^- vs η^*

Backup: Insert readout

- PCBs will plug into PCB backplanes on either side of the insert
- Readouts are at the downstream end of the backplanes