Finalizing 2024 FNAL Beam Test Results of EIC fEMCal

Yunshan Cheng

UCLA

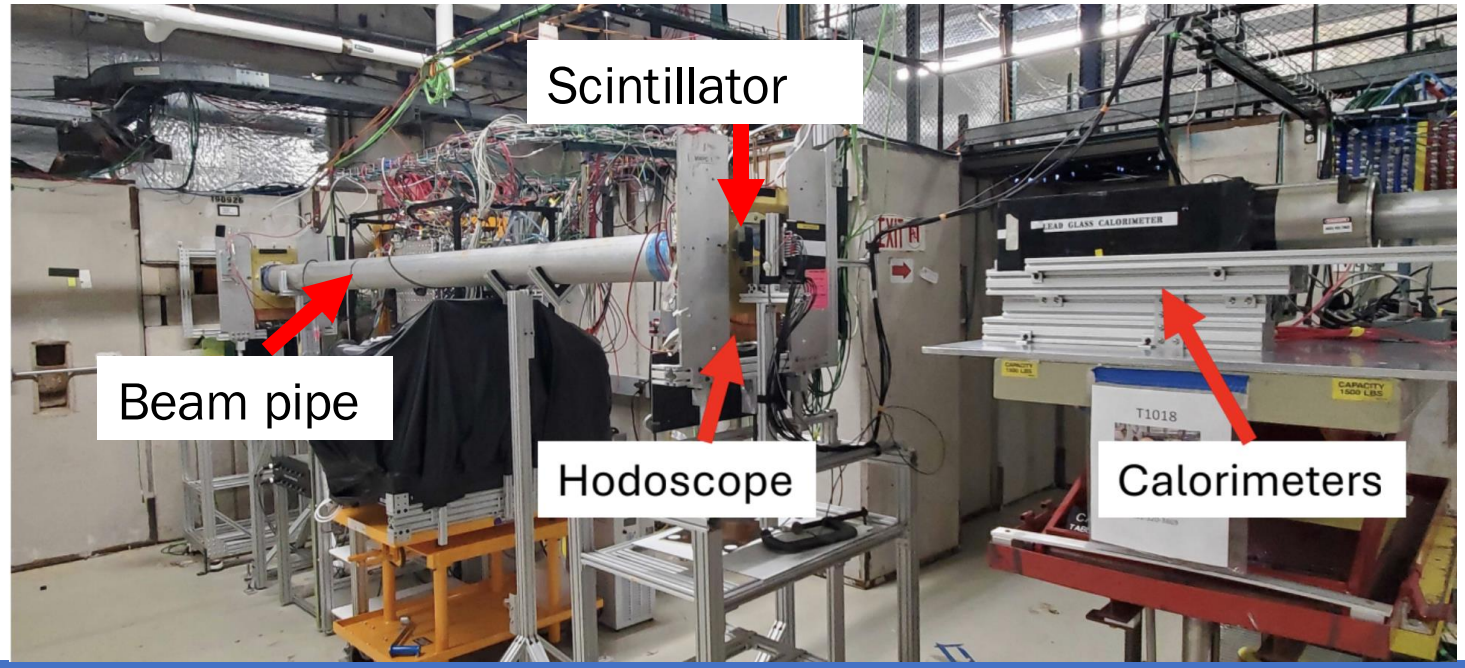
Jan 9, 2025

Introduction

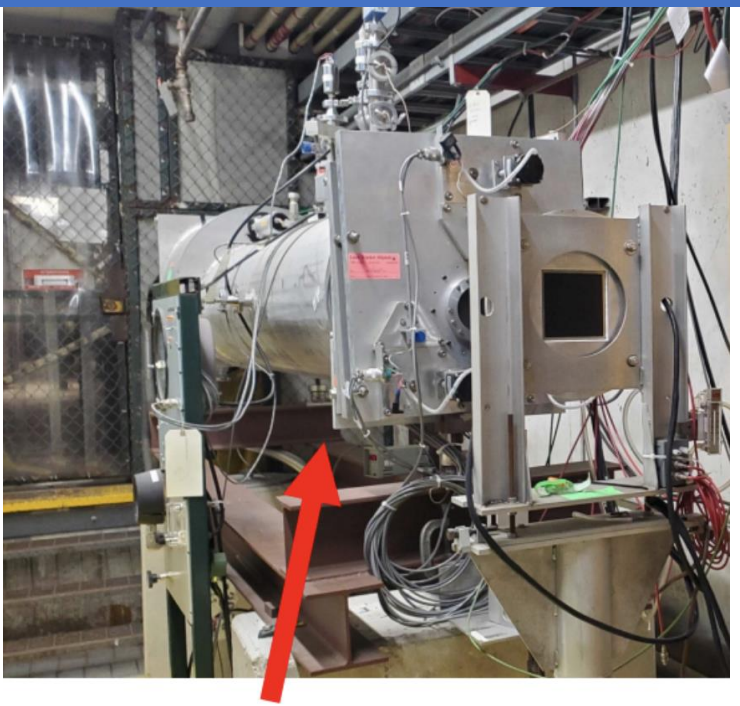
- **Objective of eRD106: Develop readout of fEMCal with**
  - **improved uniformity**

    Directly relates to the constant term of energy resolution, when at highest energies $\frac{1}{\sqrt{E}}$ vanishes.
  - **improved light collection efficiency**

    It is important to meet ePIC required lowest energies of 50 MeV, and to have good S/N ratio after SiPM's radiation damage.
- **Measured uniformity and energy resolutions as a function of energies (2-10 GeV e-) and impact angles, spanning the acceptance of the forward fEMCal in ePIC.**

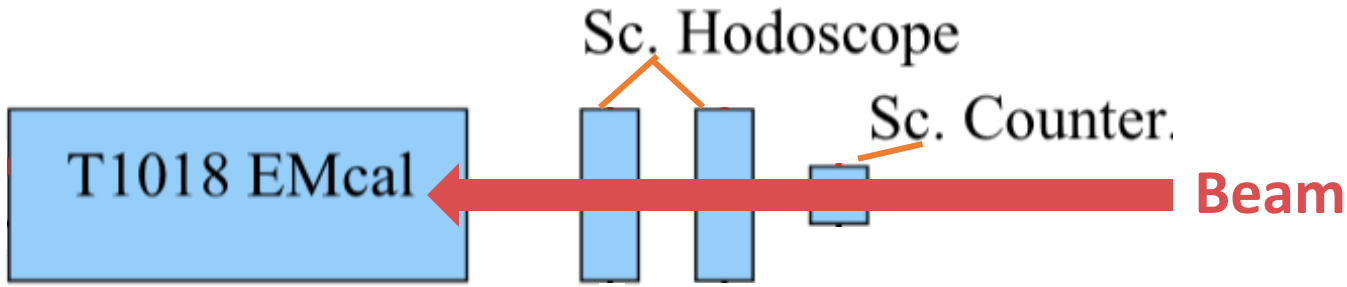


Detector Setup

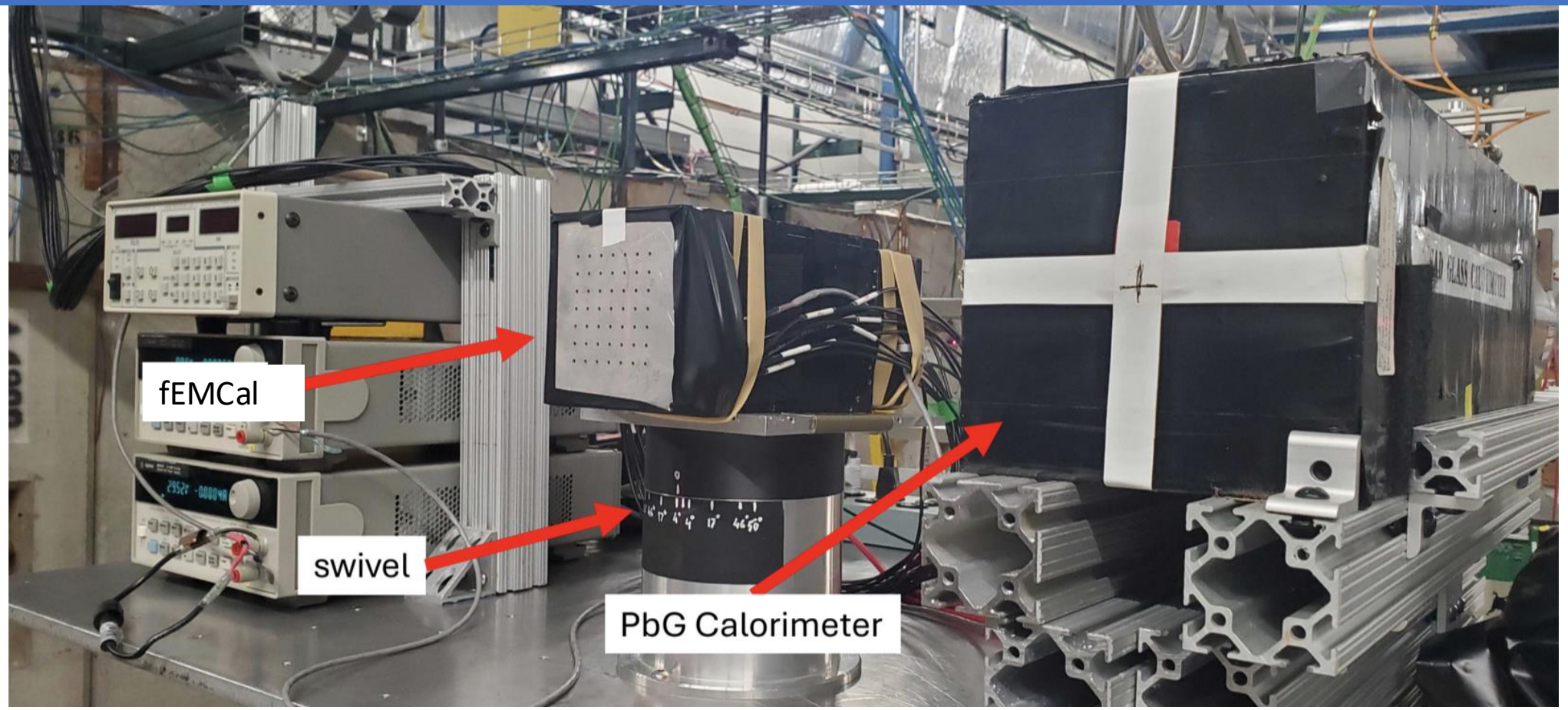


Available channels:

- **16 channel hodoscope (4x4 cm^2, 8 vertical + 8 horizontal bars)**
- **1 Scintillator (4x4 cm^2)**
- **1 Cherenkov counter**
- **1 PbGl channel**
- **16 fEMCal channels (10x10 cm^2)**

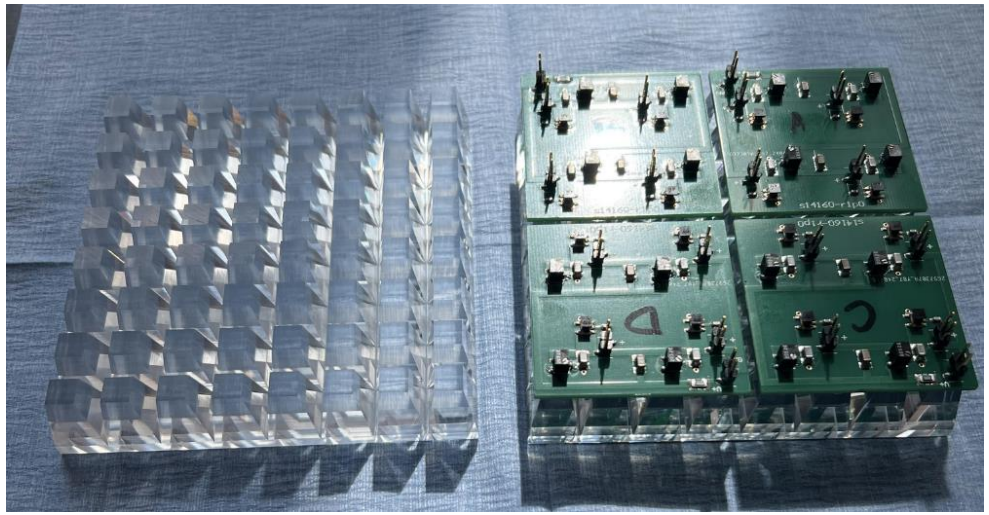


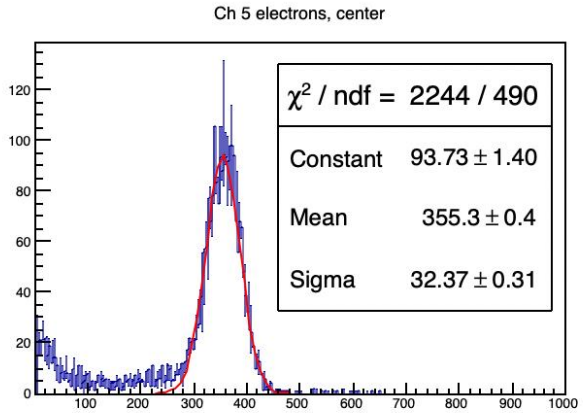
Detector Setup

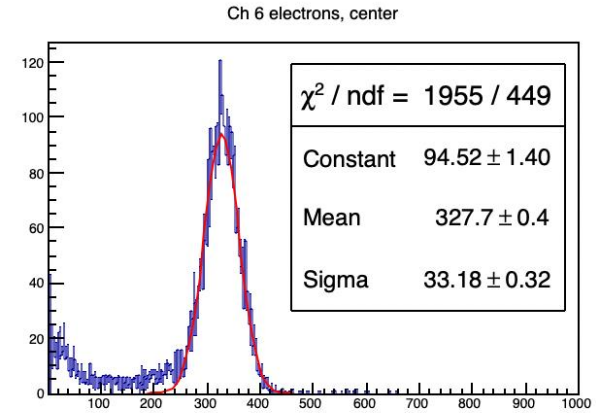


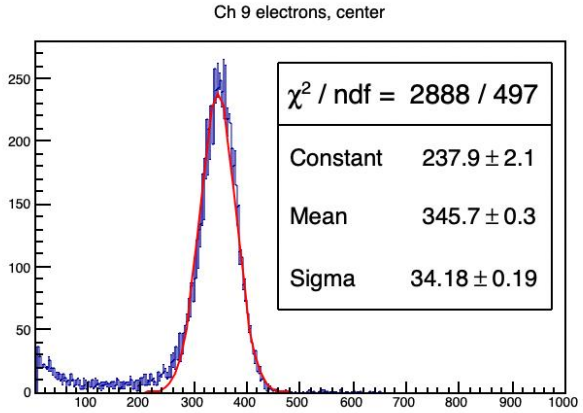
- **The PbGl Calorimeter and fEMCal can be swapped to be in front of the beam line.**
- **The fEMCal was placed on a swivel to change the angle of incidence.**

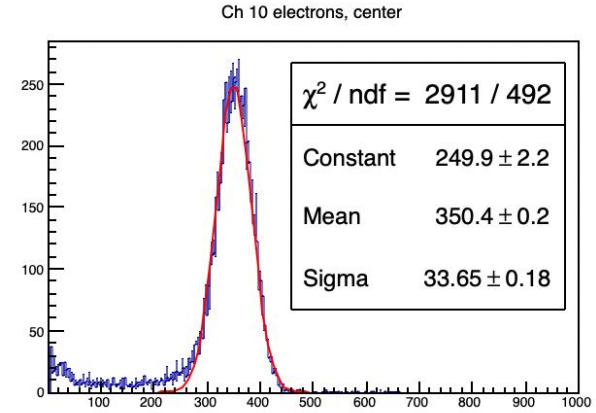
Updates from preliminary results: Calibration





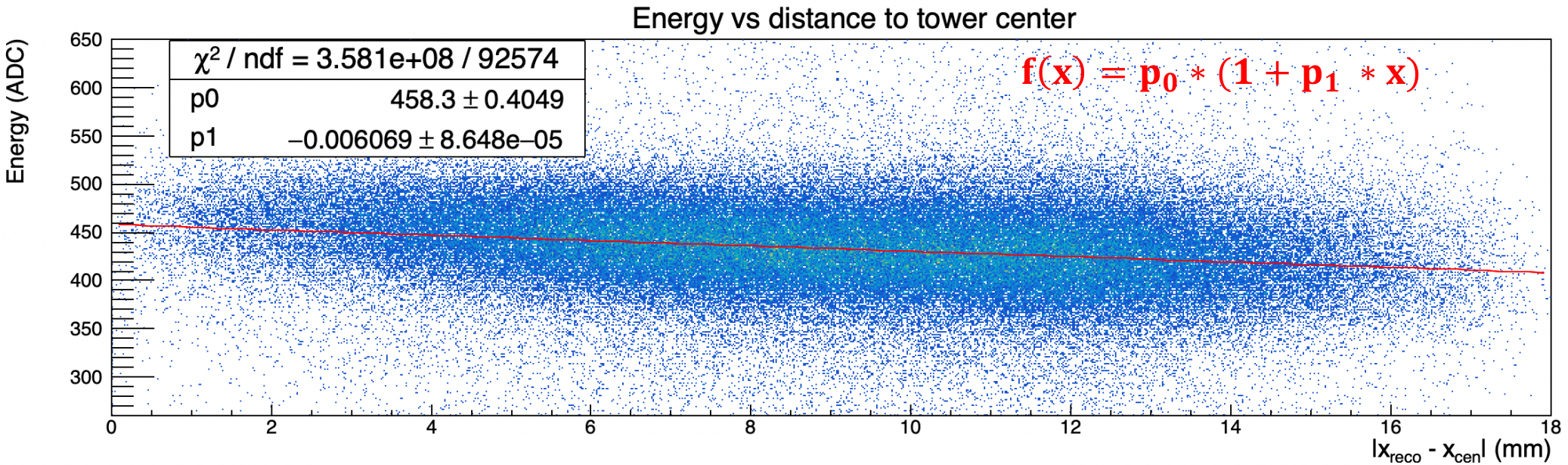




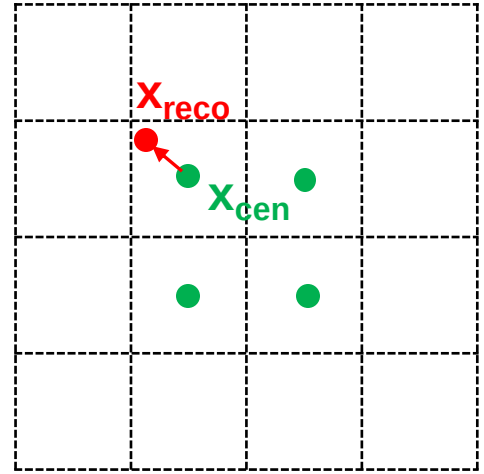


- **SiPM boards were assembled from mixed SiPMs with slightly different operation voltages.**
- **Calibration factors of 16 channels:**
  - **Fit histogram of energy deposition of each channel.**
  - **Find scale factors that align these energy peak positions.**
  - {1.07, 1.02, 1.06, 0.97, 0.98, 1.032, 0.95, 1.01, 0.95, 1.005, 1.018, 1, 1.0, 1, 1.02, 1.}

Updates from preliminary results: falloff at periphery of the towers



$$x_{\text{reco}} = \frac{\sum_i w_i \cdot x_i}{\sum_i w_i}, \quad w_i = \frac{\max(\ln(\text{ADC}_i) + 3.8, 0)}{\sum_j w_j}$$



- **Total energy decreases as the reconstructed position gets farther from the closest center of towers.**
- **It is a systematic effect near the tower boundaries, and is independent of energies.**
- **Add correction factor $\frac{1}{1+p_1 * |x_{reco} - x_{cen}|}$ to mitigate position-dependent effects.**

Uniformity

- **Definition:**
  8 x 8 hodoscopes with 4.8 mm width

➔ **64 position bins, each with mean ADC**

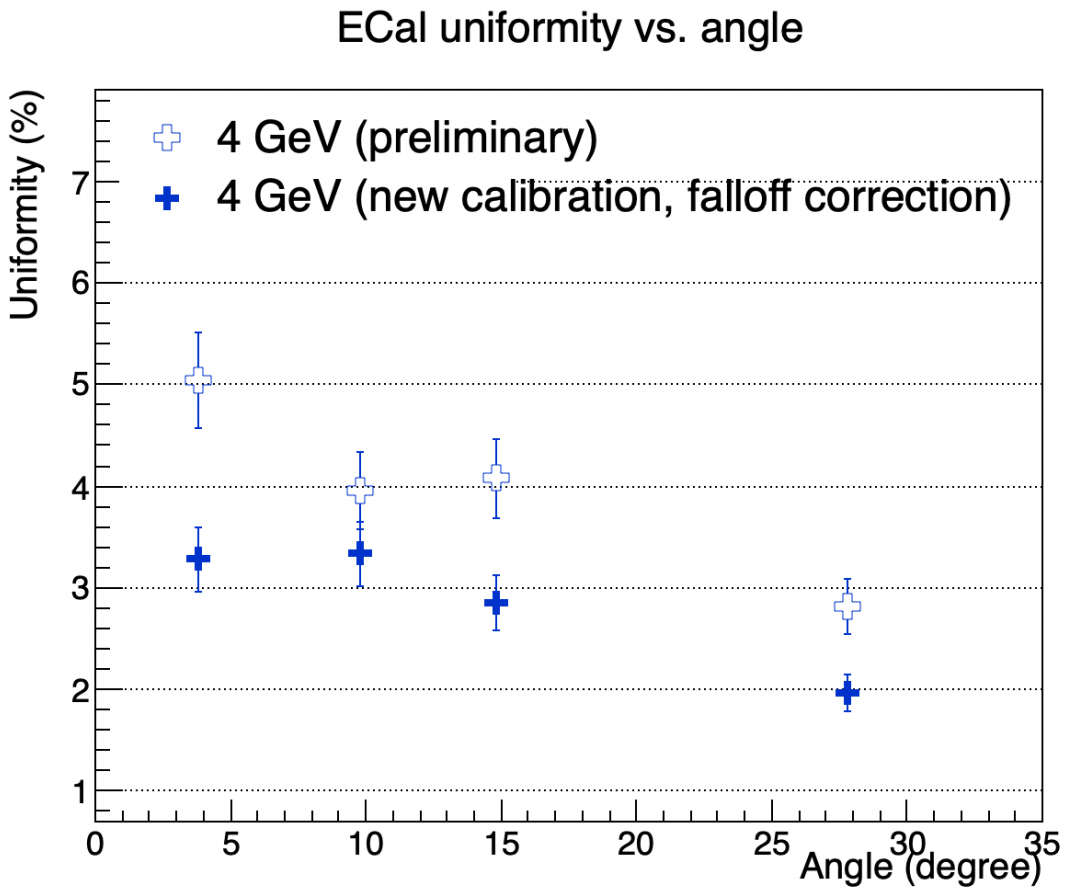
➔ **64 mean ADC values**

➔ **Get the average and standard deviation of mean ADC**

- **Uniformity =** $\frac{sigma\ of\ mean\ ADC}{average\ of\ mean\ ADC}$

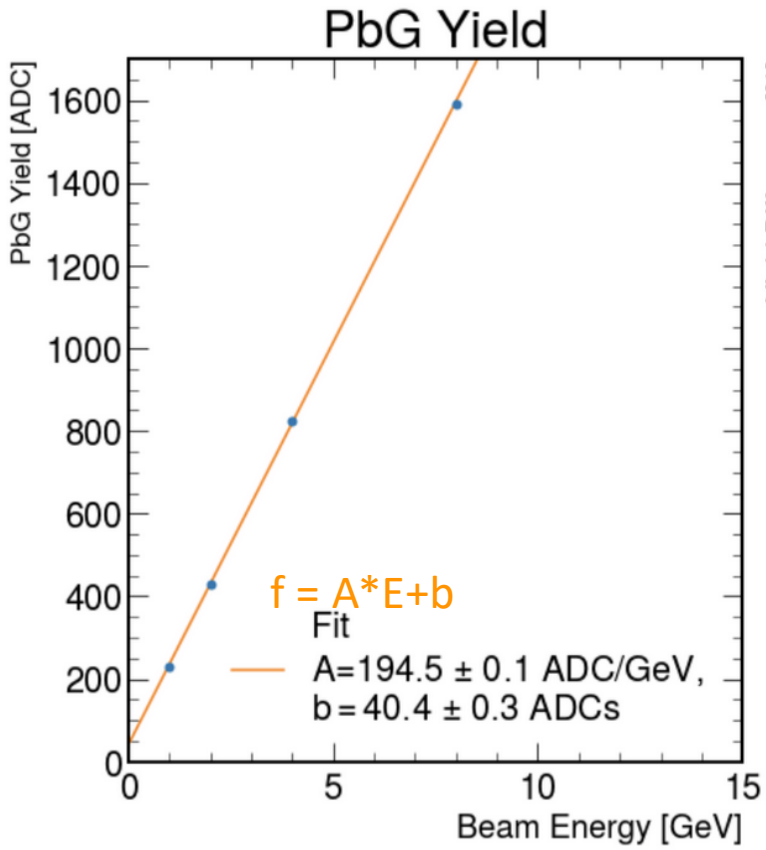
- **It describes position variations of energy deposition.**

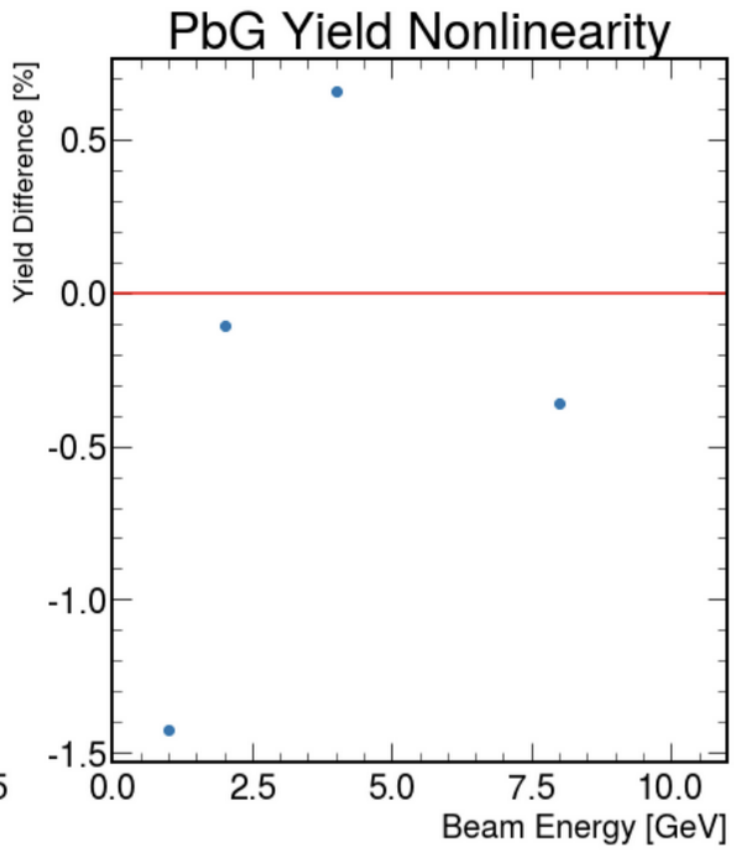
- **Updated calibration and corrections of systematic falloff effect at tower boundaries improves uniformity.**
- **fEMCal's non-uniformity is 2%-4% at 4 GeV, and it improves with increased impact angle.**

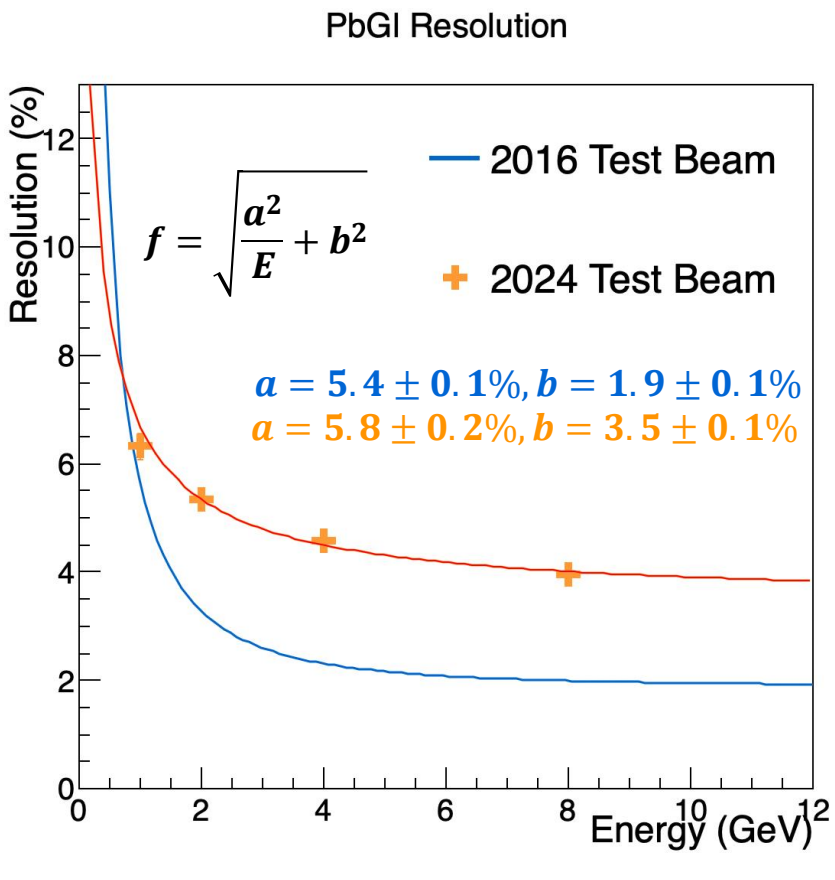


e- Beam Test with PbGl

Credit to Sean Preins





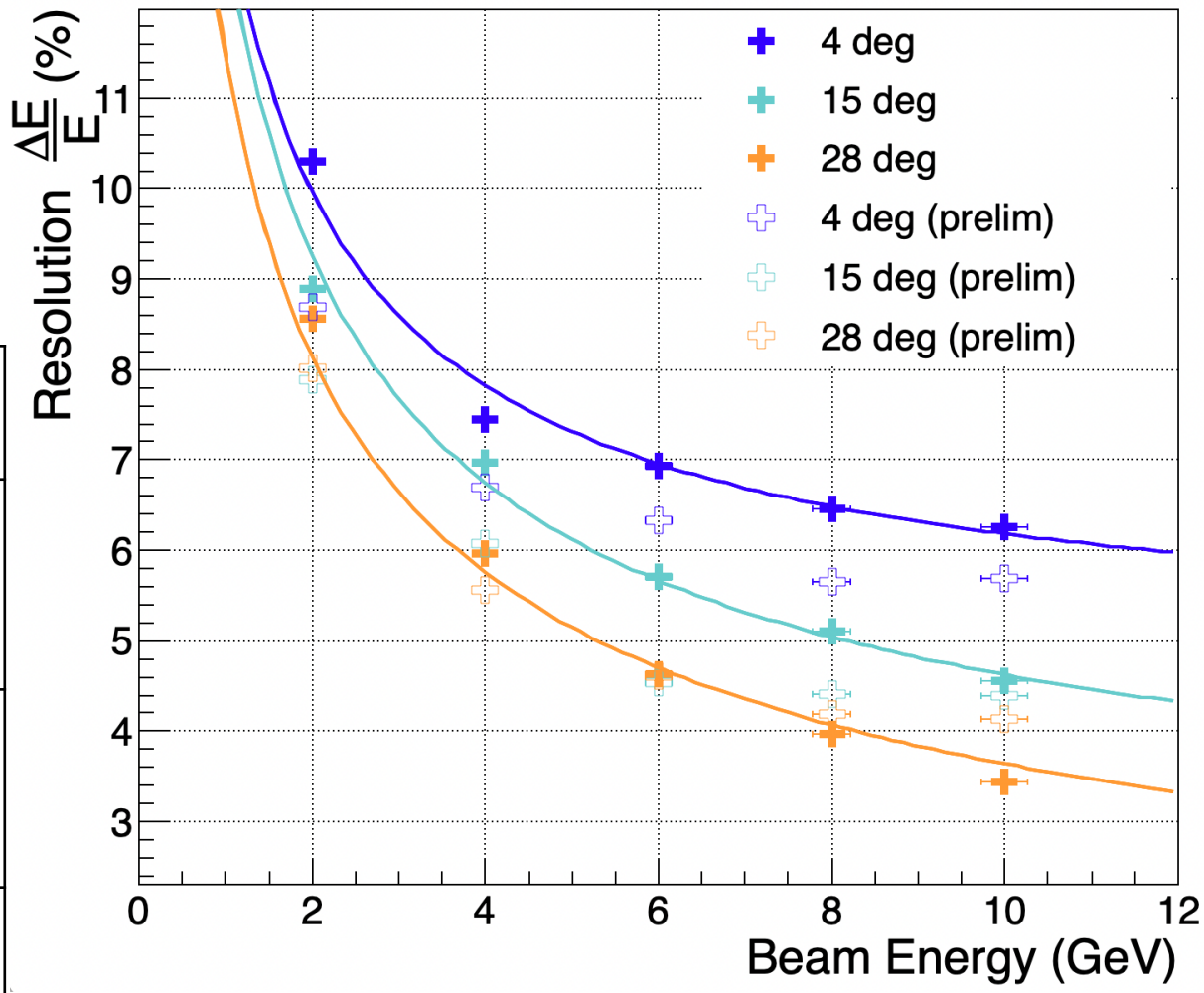


- **Constant term of e- beam resolution is 3.5%, and FNAL website suggests 2.7%.**
- **Due to less beam time and limited energy range (1-8 GeV) of 2024 test beam, the beam condition was unclear to us.**

Energy resolutions of fEMCal

- **2.7% beam momentum spread are deducted.**
- **Constant term of resolution gets smaller with increased beam incident angle.**
- **The constant terms of resolutions are not consistent with non-uniformities.**

Incident angle	Resolution	Nonuniformity (4 GeV)
4 deg	$f(E) = \sqrt{\frac{12.36 \pm 0.18^2}{E}} + 4.79 \pm 0.07^2$	3.28 ± 0.31
15 deg	$f(E) = \sqrt{\frac{12.68 \pm 0.18^2}{E}} + 2.30 \pm 0.15^2$	2.86 ± 0.27
28 deg	$f(E) = \sqrt{\frac{11.52 \pm 0.07^2}{E}} + 0.00 \pm 0.19^2$	1.97 ± 0.19

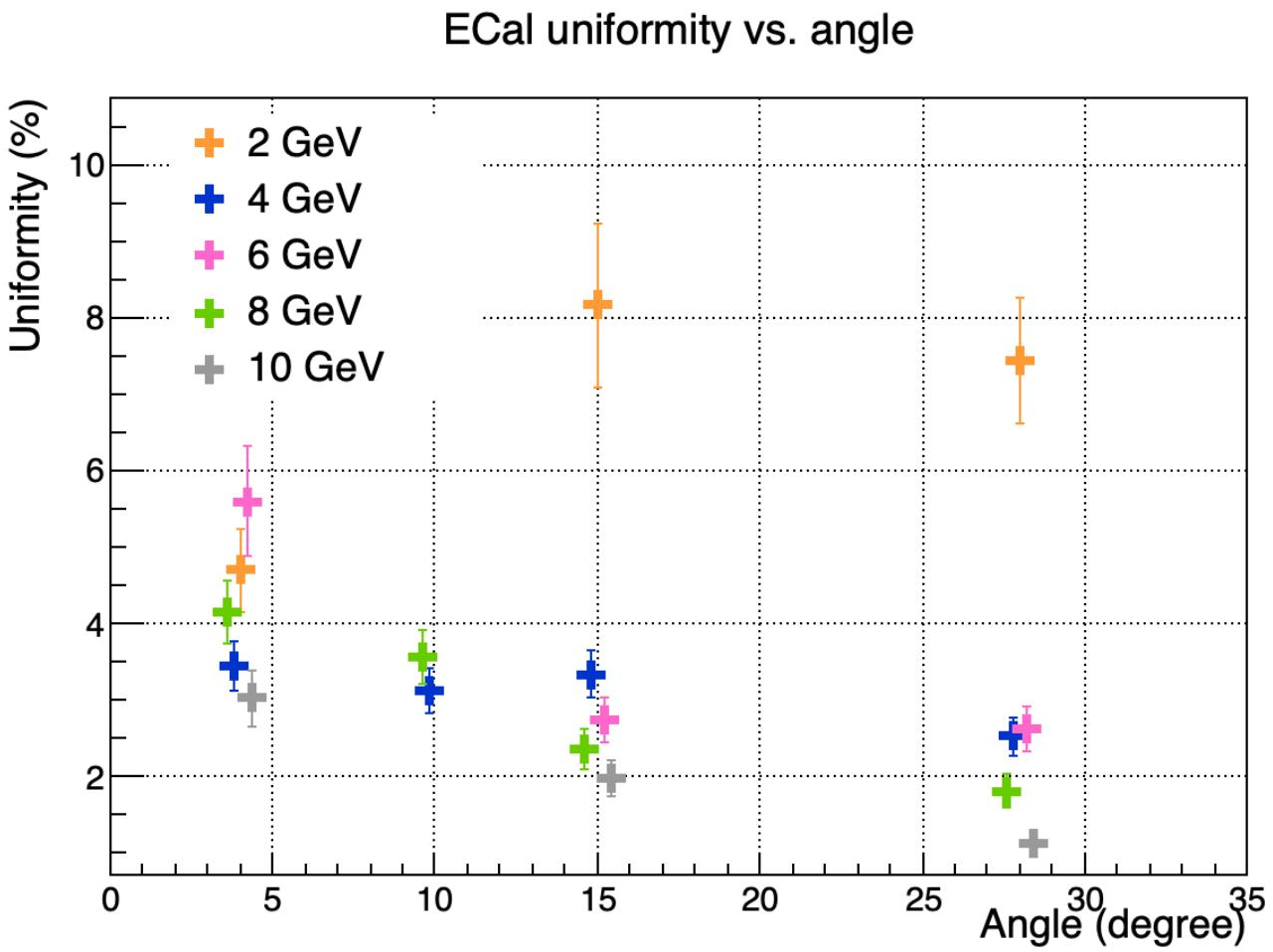


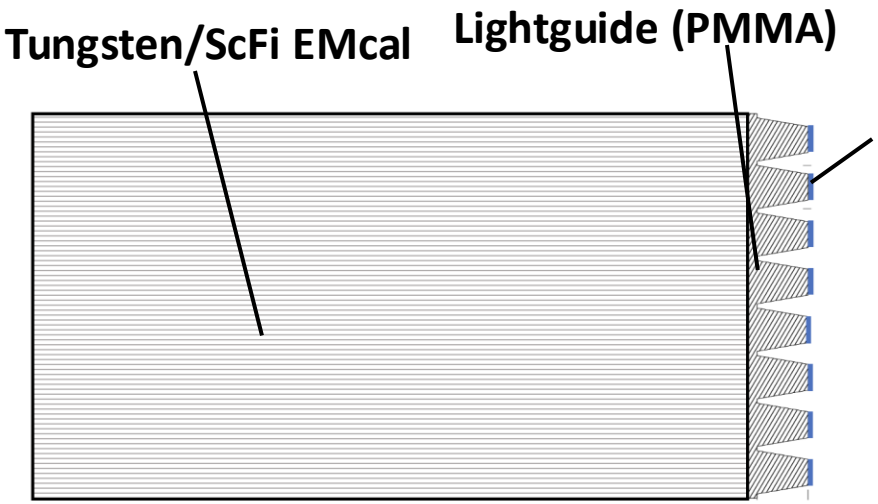
Conclusions

- **With updated calibrations and falloff corrections, nonuniformity of fEMCal prototype improves. It is 2-4% at 4 GeV, which is close to ePIC requirements.**

- **Absolute light yield of SiPM at FNAL is 2470 pixels/GeV, scaling to SiPMs that will be used for ePIC is 1580 pixels/GeV. It is close to our expectation and it satisfies ePIC requirements.**

Backups


ECal uniformity vs. angle
Uniformity (%)
2 GeV
4 GeV
6 GeV
8 GeV
10 GeV
Angle (degree)


Tungsten/ScFi EMcal
Lightguide (PMMA)