# Forward ECal desgin and simulations

Zhongling Ji

UCLA

California EIC Consortium Collaboration Meeting

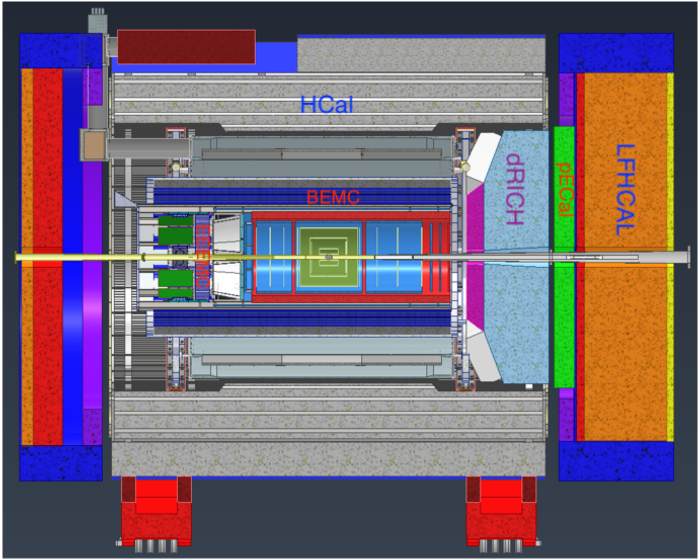
February 29, 2024

# Outline

1. Overview
2. pECal design
3. $\pi^0 \to \gamma\gamma$ separations
4. Heavy-flavor jet identifications
5. Summary

# ePIC detector

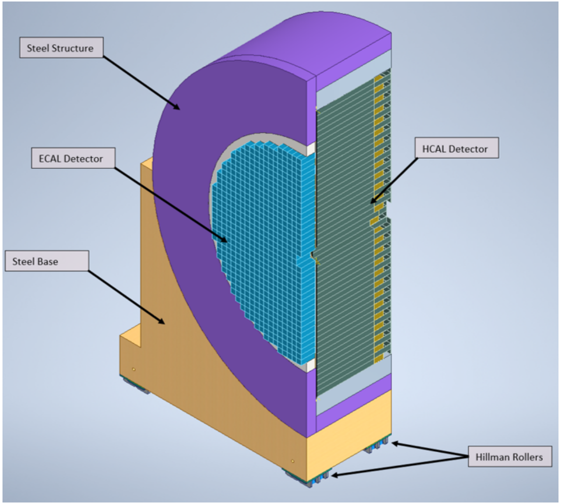
UCLA



# Forward ECal (pECal) designs

UCLA

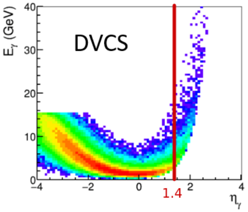
- Sampling ECal:
  - Measure photons and hadrons at the forward region.
  - Good energy resolution $[(10\text{–}12)\%/\sqrt{E} \oplus (1\text{–}3)\%]$.
- pECal with W/ScFi structure:
  - Beehive with fibers of radius 0.235 mm.
  - Absorber: 97% Tungsten + 3% epoxy.
  - Fiber: 100% polystyrene.

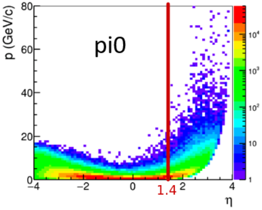


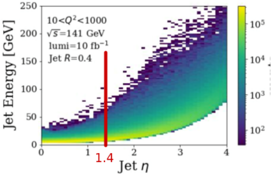
# High-level input of pECal

UCLA

- $\eta$ coverage: 1.4 to 4.
- Radius: $R_{in} = 14$ cm, $R_{out} = 173$ cm.
- Integration length along z-axis: 30 cm.
- Total weight: $\sim$20 tons.
- Number of readout channels: $\sim$15k.
- Readout must work in magnetic field, neutron fluxes up to $10^{12}$ n/cm$^2$.
- Fit in limited space (small X0).
- Hadron compensation with e/h ratio $\sim$1.
- Good $\pi^0/\gamma$ separation up to $\sim$50 GeV.
- Optimal reconstruction of jets.
- Ability to identify heavy-flavor jets.

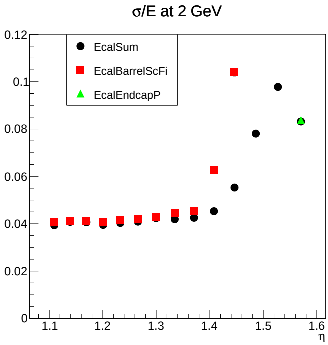


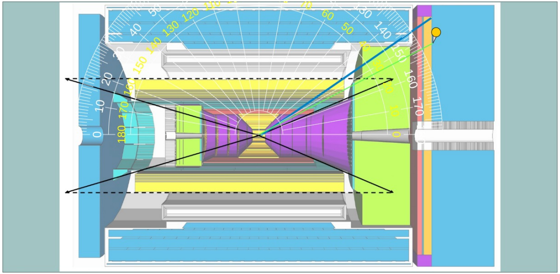



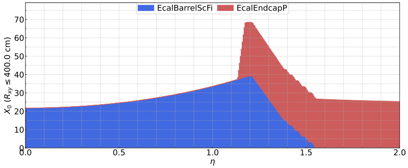



# Acceptance: barrel and endcap overlapping

UCLA

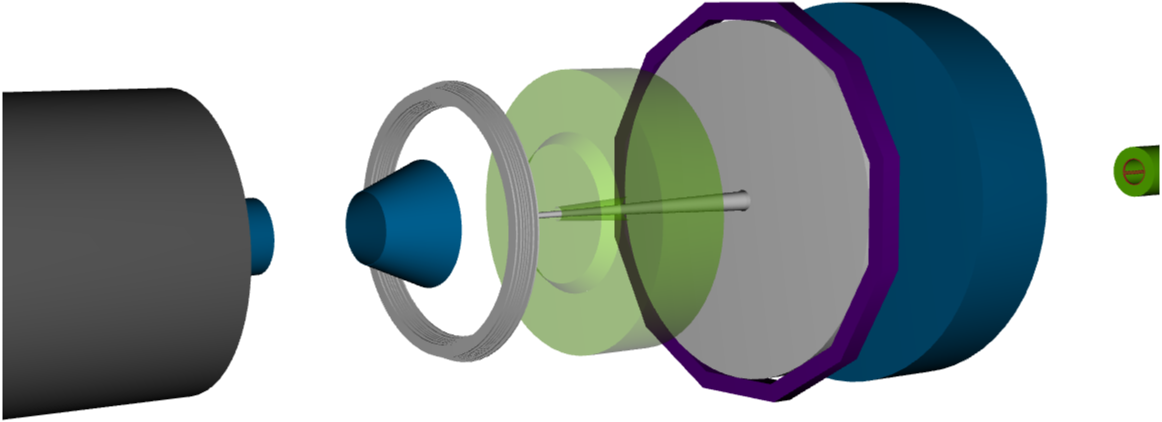




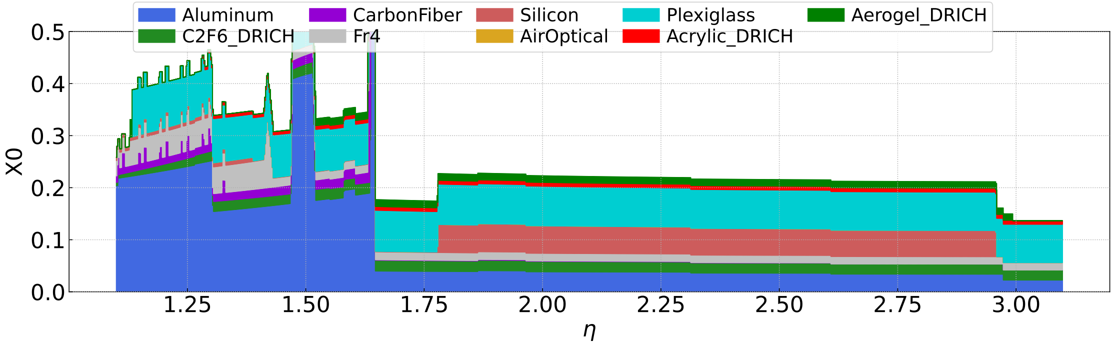

The green line corresponds to $\eta = 1.4$. For $\eta < 1.4$, the barrel Ecal dominates the resolutions. Only for $\eta > 1.4$, we need the fEcal.

# Materials before pECal



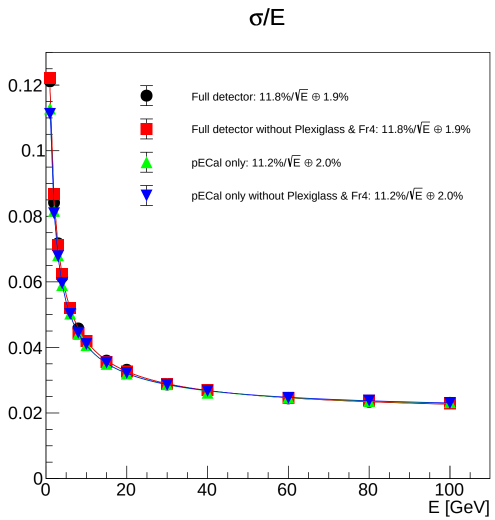
# Material scan

```
<slice name="Cover_slice" material="Aluminum"/>
<slice name="Air_slice" material="Air"/>
<slice name="PCB_slice" material="Fr4"/>
<slice name="LightGuide_slice" material="Plexiglass"/>
<slice name="Scintillator_slice" material="AvgTungstenScFi"/>
```



# Comparison of pECal resolutions

- Full detector: *epic_full.xml*
- pECal only: *compact/ecal/forward_homogeneous.xml*
- With & without Plexiglass & Fr4.



# Dynamic range and SiPM size

UCLA

- Question: Low average energy in pECal $\rightarrow$ 50 $\mu m$ SiPM at low $\eta$?
- Requirement to avoid saturation: Number of SiPM pixels $\gtrsim$ 3 $\times$ Highest light yield.
- Counting of SiPM pixels:
  - Each tower has four 6$\times$6 $mm^2$ SiPMs.
  - 50 $\mu m$ SiPM has $\sim$57k pixels.
  - 15 $\mu m$ SiPM has $\sim$638k pixels.
- Conclusions:
  - $\gtrsim$96k light yield at $\eta \sim 1.5$ for 100 GeV $\pi^0$.
  - Need 15 $\mu m$ SiPM for all $\eta$ ranges.
  - CD3A for SiPMs we chose S14160-6015PS as SiPMs for pECal.

# DD4hep fiber implementation

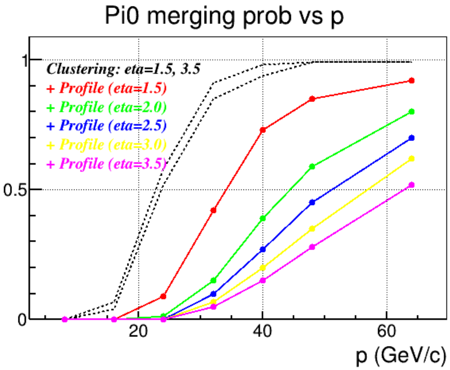
UCLA

- Problem: pEClal with fibers uses $\sim$6 GB memory in DD4hep and will use more memory when other detectors are included.
- Reason: storing *PlacementPath–VolumeID* mapping in *m_geo.g4Paths* uses large memory.
- Solution: group fibers in each module as a single readout channel.
- Result: reduce memory usage to $<$700 MB, which is the same as that without fibers.
- ~~Method I~~: Change DD4hep to let it only store the *VolumeID* for each module instead of each fiber.
  - Pros: Easy to build fibers.
  - Cons: Need to change DD4hep code.
- Method II: Set the whole module as a sensitive detector and cover the insensitive areas by daughter radiators.
  - Pros: No need to change DD4hep code.
  - Cons: More coding to build the fibers.

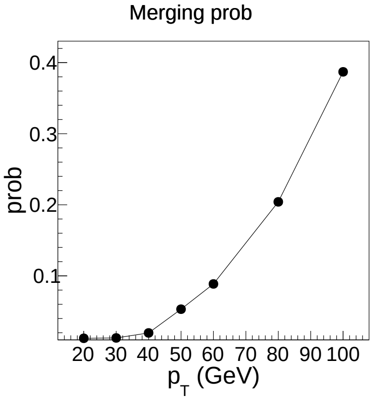
# $\pi^0 \to \gamma\gamma$ separations

UCLA

- Shower profile: $\chi^2 = \sum_i \left(\frac{E_i^{meas} - E_i^{pred}}{\sigma_i}\right)^2$
- EIC YR Fig. 11.46: pECal with granularity $\sim$0.008 (2.5×2.5 cm$^2$ at z=3m).



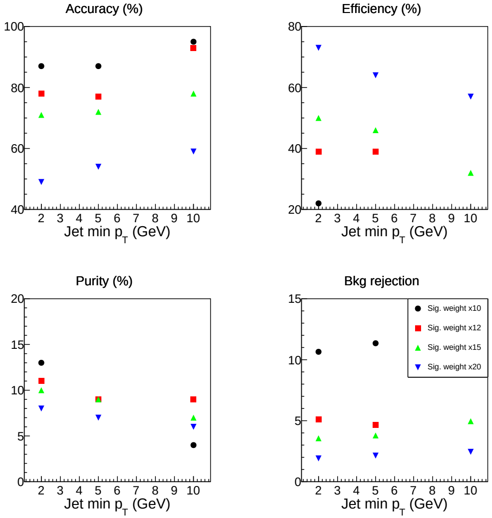

- Neural networks input ($\eta = 2$): 5×5 central tower energies; pECal x and y positions.
- For 60 GeV at $\eta = 2$, reduced merging prob from 80% to 10%.



# Heavy-flavor jet identifications

UCLA

- Pythia DIS events: $e + p \to q(jet) + X$, $Q^2_{min} > 10$ GeV$^2$.
- Jet flavor ID: Only consider the jet closest to the hard-scattered quark q, identify the quark flavor q as the jet flavor.
- Signal: HF jets; Bkg: LF jets.
- $N_{LF} : N_{HF} = 169619 : 9685 \approx 17.5 : 1$.
- Training: Use LSTM, large weight on signal.
- Best overall performance: Weight signal by factor 15.
- 70% accuracy, 50% efficiency, 10% purity, 4 times bkg rejection.



# Summary

UCLA

- The technology choices for all ECals in ePIC were defined.
- Performance of calorimeters were extensively verified with realistic simulations to meet YR requirements.
- Ready to implement fibers for fECal in DD4hep after fixing its geometry.
- Using a neural network improves the $\pi^0 \rightarrow \gamma\gamma$ separation.
- Tracking, pECal, and LFHCAL provide good energy resolutions for the HF jets in the forward direction.
- LSTM gives reasonable performance for heavy-flavor jet identification.
- Including vertex and dRICH PID will give better jet ID in the future.