ePIC Electromagnetic Calorimetry

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EIC physics

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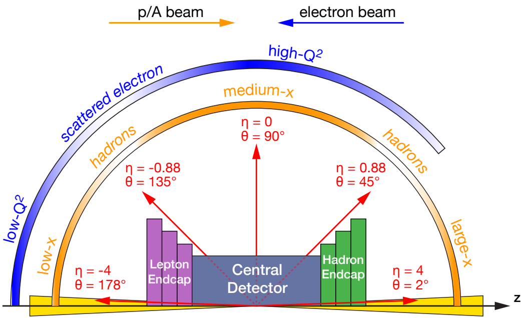
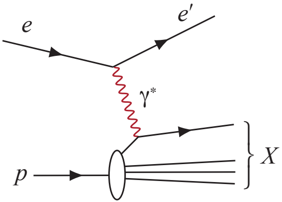
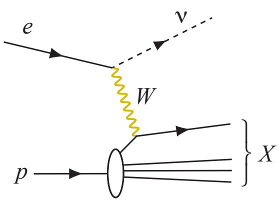
- Red particles are measured.
- Lepton endcap is important to reconstruct the kinematics of the scattered electron.
- Hadron endcap is important to measure hadrons in SIDIS and exclusive DIS.

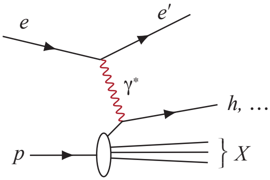




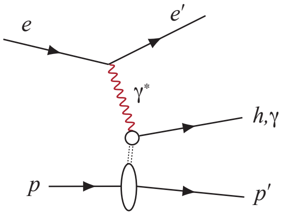
NC DIS: $e + p/\mathrm{A} \longrightarrow e' + X$



CC DIS: $e + p/\mathrm{A} \longrightarrow \nu + X$

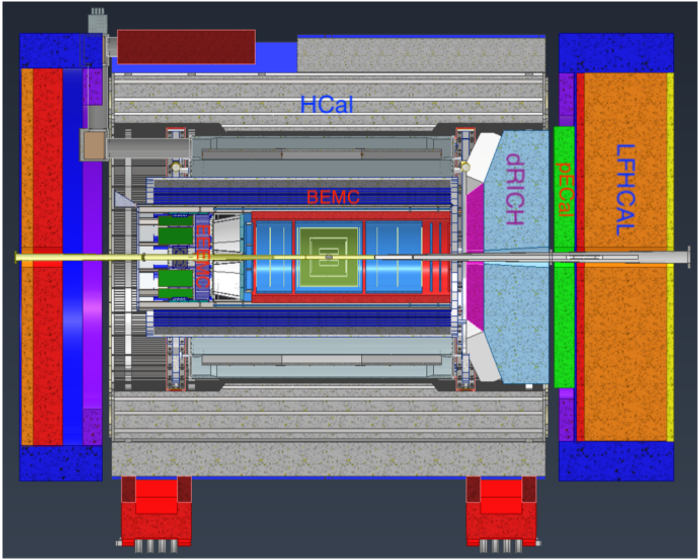


SIDIS:
$e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} + X$



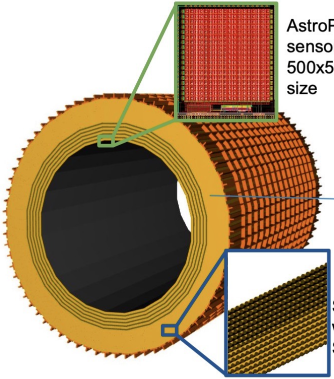
Exclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$

ePIC detector

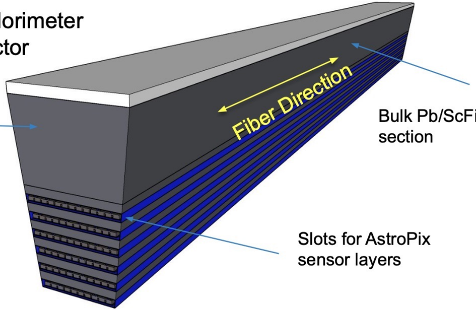


Barrel ECal

Geometry of barrel ECal



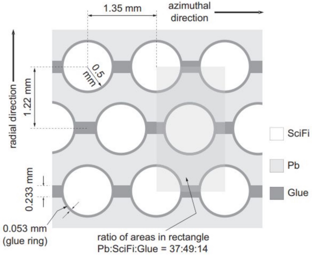
- **4(+2) layers of imaging Si sensors** interleaved with **5 Pb/ScFi layers**
- Followed by a **bulk section of Pb/ScFi section**

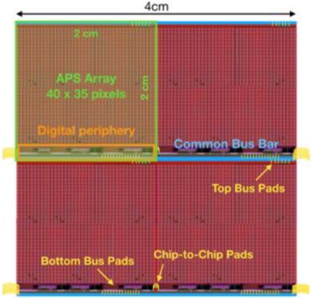


Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-side Pb/ScFi readout and radial segmentation)

Technology of barrel ECal

- Pb/SciFi layers follow the GlueX Barrel Calorimeter:
  - Energy resolution: $\sigma = 5.2\%/\sqrt{E} \oplus 3.6\%$
  - 15.5 X0, extracted for low energy photons $<\sim$1 GeV
  - Position resolution in z: 1.1 cm$/\sqrt{E}$
  - 2-side SiPM readout, Δt measurement
- Imaging layers based on AstroPix sensors
  - Very low power dissipation
  - Good energy resolution
  - 500 μm pixel size
  - Time resolution $\sim$3.25 ns (V4)





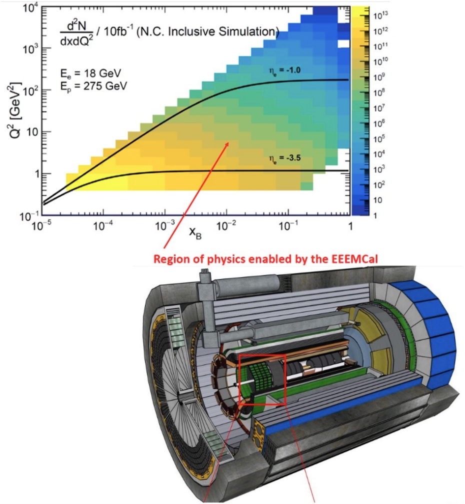
Summary of Barrel ECal

- Identify the scattered electrons and measures their energy.
- Space-constrained to very limited space inside the solenoid ($\sim$40 cm and 17.1 X0).
- Excellent energy resolution ($5.2\%/\sqrt{E} \oplus 1.0\%$).
- Unrivaled low-energy electron-pion separation by combining the energy measurement with shower imaging.
- Fine granularity for good π^0/γ separation up to 10 GeV/c.
- Unrivaled position resolution due to the silicon layers.
- Longitudinal shower profile from the Pb/ScFi layers.
- Deep enough to serve as inner HCal.
- Measuring low energy photons down to 100 MeV, while having the range to measure energies well above 10 GeV.
- Wealth of information enables new measurements, ideally suited for particle-flow.

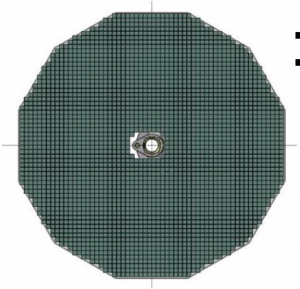
Backward ECal

Goals and requirements of backward ECal

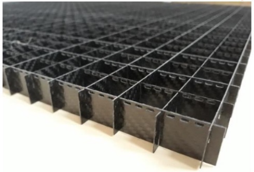
- Goals:
  - Measure scattered electrons at $-3.5 < \eta < -1$
  - Electron/pion separation
  - Improve electron resolution at large $|\eta|$
  - Measure photons with good resolution
  - Separate $\pi^0 \rightarrow \gamma\gamma$ at high energy
- Requirements:
  - Energy resolution: $2\%/\sqrt{E} \oplus (1-3)\%$
  - Pion suppression: 1:104
  - Minimum detection energy: > 50 MeV

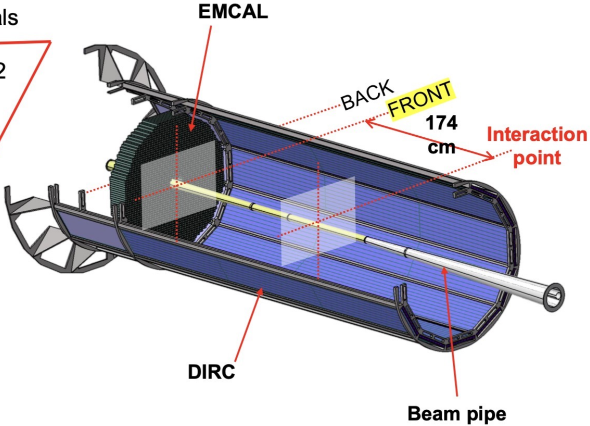


Mechanical design



- 2x2x20 cm^3 PWO crystals
- 0.5-mm-thick C-fiber between crystals along 2 cm in the front & back; 0.5 mm of air elsewhere





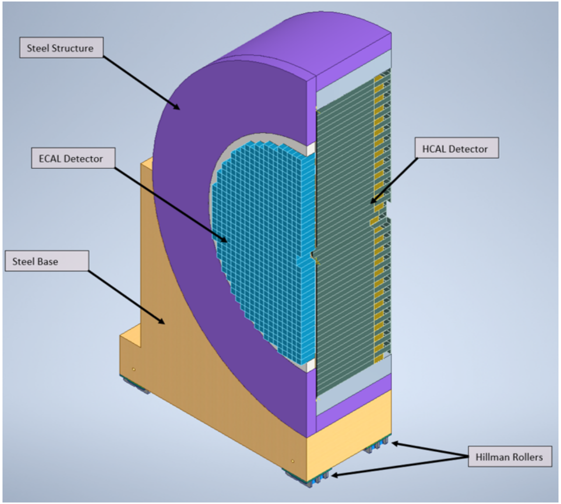
Specifications:

PWO:	8,28g/cm3
Dimension:	20x20x200 mm
Mass:	0,662 Kg
Nb:	≈ 2850 crystals
Total mass:	≈ 1900 Kg
External diameter:	≈ 123 cm
Space max:	0,5 mm (carbon plate)

Forward ECal

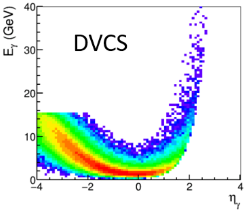
pEcal designs

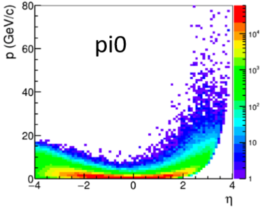
- Sampling ECal:
  - Measure photons and hadrons at the forward region.
  - Good energy resolution $[(10–12)\%/\sqrt{E} \oplus (1–3)\%]$.
- pECal with W/ScFi structure:
  - Beehive with fibers of radius 0.235 mm.
  - Absorber: 97% Tungsten + 3% epoxy.
  - Fiber: 100% polystyrene.

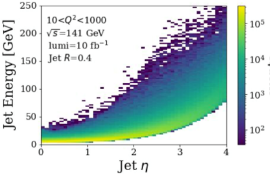


High-level input of pECal

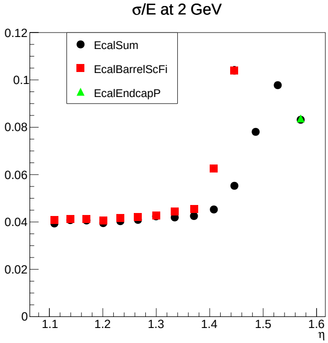
- η coverage: 1.4 to 4.
- Radius: $R_{in} = 14$ cm, $R_{out} = 173$ cm.
- Integration length along z-axis: 30 cm.
- Total weight: $\sim$20 tons.
- Number of readout channels: $\sim$15k.
- Readout must work in magnetic field, neutron fluxes up to 10^{12} n/cm^2.
- Fit in limited space (small X0).
- Hadron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

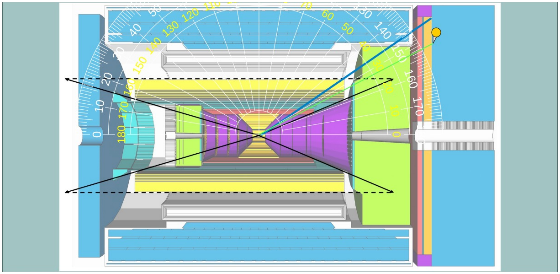


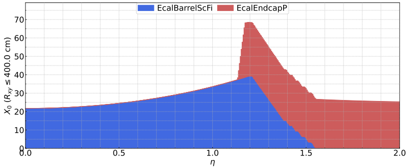




Barrel and endcap ECal overlapping optimization



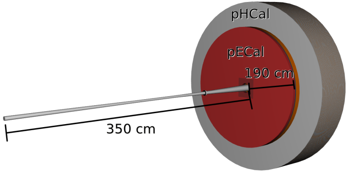




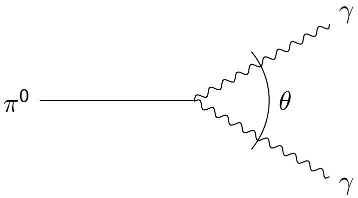
The green line corresponds to $\eta = 1.4$. For $\eta < 1.4$, the barrel Ecal dominates the resolutions. Only for $\eta > 1.4$, we need the fEcal.

$\pi^0 \to \gamma\gamma$ separation

$\pi^0 \to \gamma\gamma$ separation



- "Usual" criteria: $\pi^0 \to \gamma\gamma$ distinguished if photons are separated by one tower size.
- pECal: 2.5×2.5 cm at z = 350 cm.
- $\theta_{min} = \frac{2.5\ cm}{350\ cm} = 0.007 \Rightarrow E_{\pi^0} = 38\ GeV$.



$$\theta_{min} = \frac{2m_{\pi^0}}{E_{\pi^0}}$$

Shower profile *vs* neural networks

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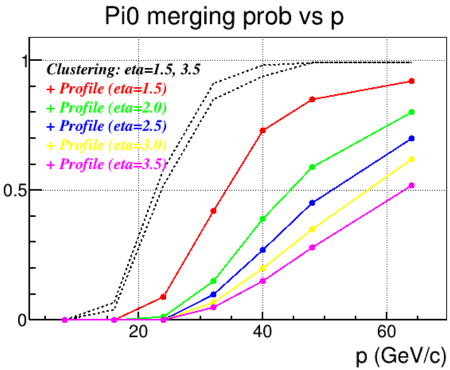
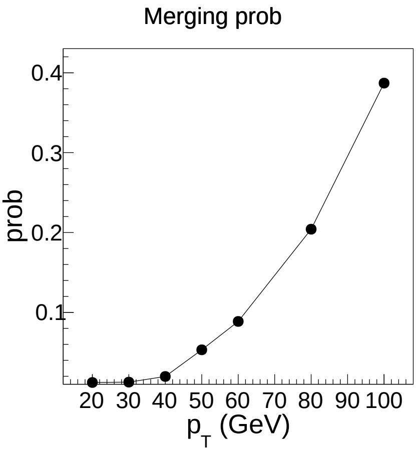
- Shower profile: $\chi^2 = \sum_i \left(\frac{E_i^{meas} - E_i^{pred}}{\sigma_i} \right)^2$
- EIC YR Fig. 11.46: pECal with granularity $\sim$0.008 (2.5$\times$2.5 cm^2 at z=3m).



- Neural networks input ($\eta = 2$): 5$\times$5 central tower energies; pECal x and y positions.



HF jets identification

Energy resolutions for $b/\bar{b}$ jets

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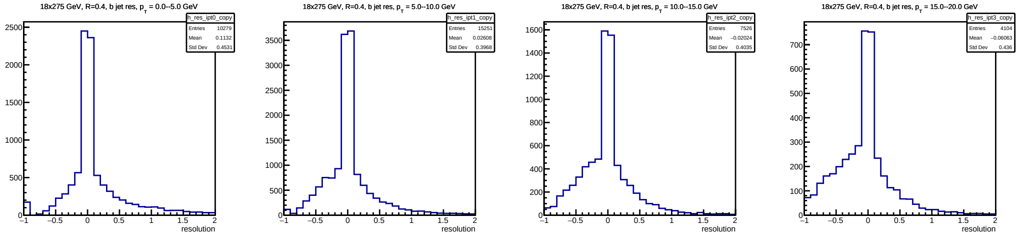
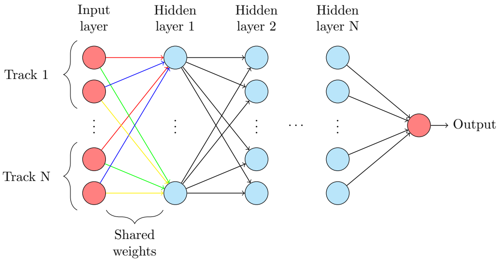
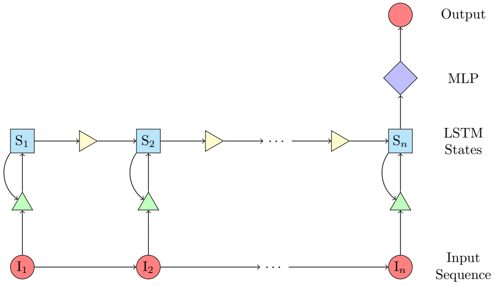
- Pythia events: $e(\gamma) + p(g) \rightarrow b + \bar{b}$.
- Find the truth and reco jets closest to b and $\bar{b}$.
- Resolution $= \frac{E_{reco} - E_{truth}}{E_{truth}}$.
- Good resolution up to $p_T^{jet} = 20$ GeV for 18x275 GeV beams.



HF jet identification

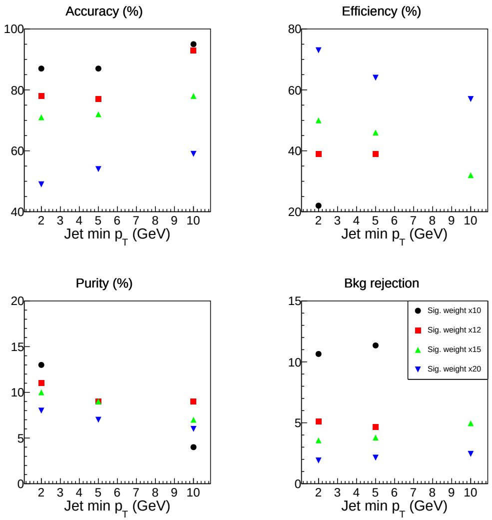
- Purposes:
  - Identify HF jets.
  - Use HF decay electrons as the jet axis.
- Input:
  - Four momenta of jet constituents.
  - Tracking momentum, pECal and pHCal energy.
  - ~~dRICH PID.~~
  - ~~Vertex and DCA.~~
- NN methods: BDT, LSTM.
- Figures from [PRD 94, 112002].





Performance of jet HF ID

- Pythia DIS events: $e + p \rightarrow q(jet) + X$, $Q^2_{min} > 10$ 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

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- The technology choices for all ECals in ePIC were defined.
- Performance of calorimeters were extensively verified with realistic simulations to meet YR requirements.
- Detector consortia formed and are working hard to advanced designs to TDR level.

Backup

Energy resolution: W/ScFi

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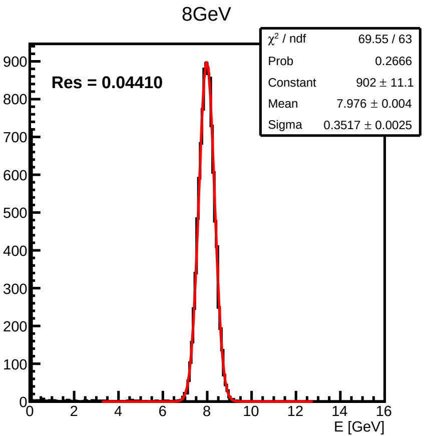
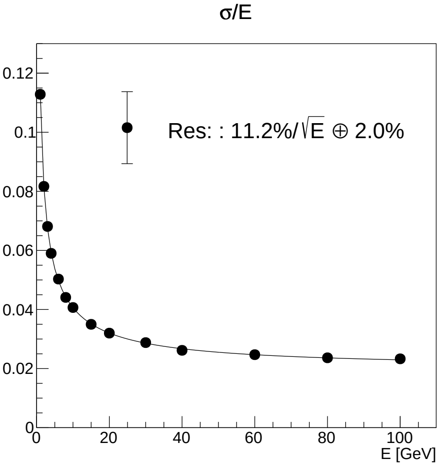


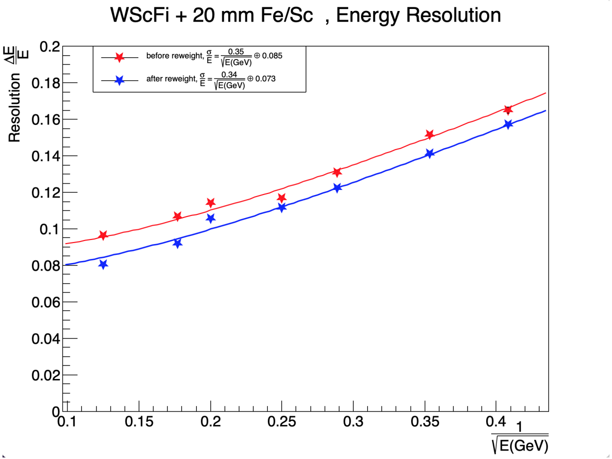
Single photon input at 8 GeV

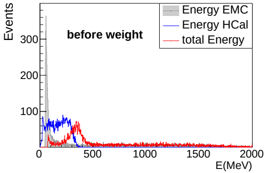


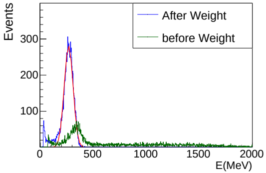
W/ScFi ECal: 17 cm ($\sim 1.1\lambda_{int}$)

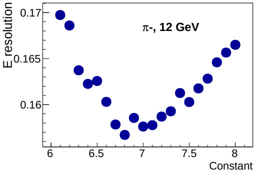
Energy weighting

- Weight energy by: $E_{tot} = E_{ECal}/C + E_{HCal}$.









e/h ratios

- Sandwich: $\lambda_{eff} = \frac{1}{\frac{x_i}{x_{tot}}\frac{1}{\lambda_i} + \frac{x_j}{x_{tot}}\frac{1}{\lambda_j}}$.
- Beehive: $\lambda_{eff} = \frac{1}{\frac{A_i}{A_{tot}}\frac{1}{\lambda_i} + \frac{A_j}{A_{tot}}\frac{1}{\lambda_j}}$.
- Use detector length: $9\lambda_{eff}$.
- λ_{eff} (in mm) $= 153$ (W/ScFi), 398 (Shashlyc), 187 (HCal).