The ePIC Forward Hadronic Calorimeter

- design and performance -

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Particle Flow with HCals at the EIC

Particle flow:

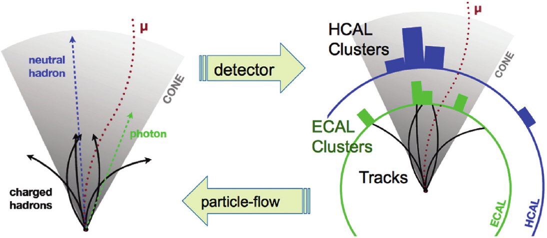
- Combination of all available detector information for particle reconstruction
  → e.g. tracking and ECals for electrons, tracking and all calorimeters for hadrons
- Reconstructed energy or lack of energy deposit provide valuable information

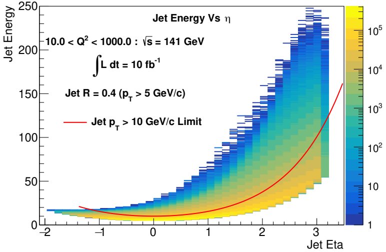
Jet reconstruction:

- Large physics program with inclusive jets at EIC
  → high energetic jets in forward region $\eta > 1.5$
- Jet energy scale and resolution rely on full particle flow
  → high energetic hadrons constrained by HCals (focus on neutral hadrons)

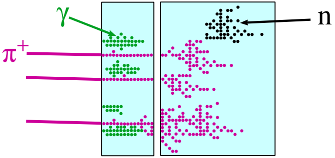
Hadron/Lepton PID:

- Hadrons on average only leave MIP energy in ECals
  → energy/momentum constrained by tracking and HCals
- Neutron detection only possible with HCals in ePIC
- Muon PID possible depending on HCal design



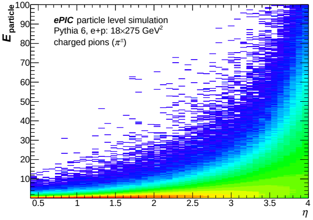


Forward HCal - considerations

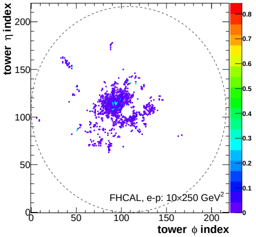


$$E_{\mathrm{JET}} = E_{\mathrm{Track}} + E_{\mathrm{ECal}} + E_{\mathrm{HCal}}$$

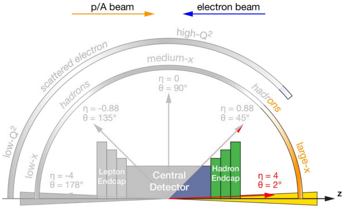
Optimization for particle flow

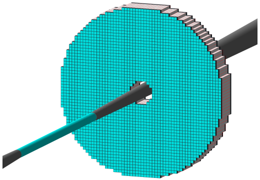


Expected energy range

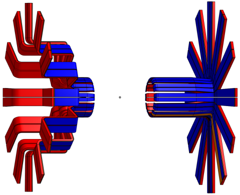


Shower separation at high η





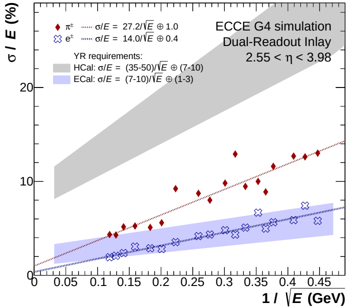
Acceptance limitations



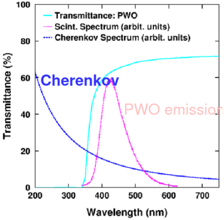
Integration and services

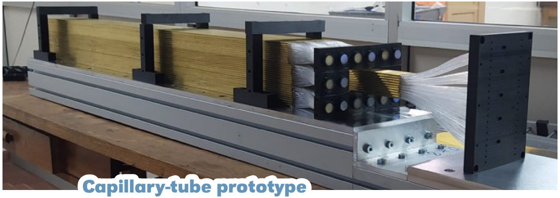
HCal technology catalogue

- **Sampling calorimeter**
  - → Zeus Uranium-Sci calorimeter best-in-class with $\sigma_E/E \propto 35\%/\sqrt{E}$
  - → performance depending on material Z (more is better)
  - → typically 3–20mm thick absorbers with 2.5–4mm thick scintillator plates
- **Dual readout calorimeter**
  - → projective approach similar to IDEA ($\sigma/E = 11\%/\sqrt{E} \oplus 0.8\%$)
  - → various absorber and fiber arrangements possible
  - → option as possible high η inlay
  - → machine learning approach necessary for high granularity clusterization
- **CherenkovScintillation (CS) Glass**
  - → Dual-readout alternative with separate readout of C and S light
  - → R&D necessary for sufficient UV C-light transparency
  - → low production cost



CSGlass prototypes



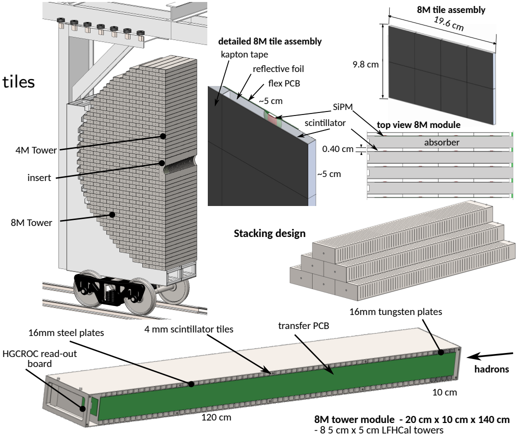


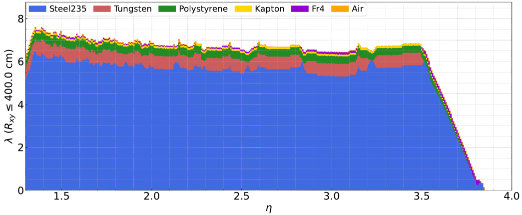
Capillary-tube prototype

ePIC LFHCAL design

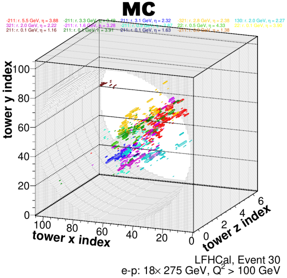
LFHCAL = Longitudinally-separated Forward Hadronic CALorimeter

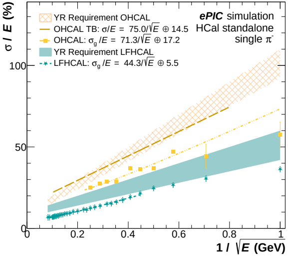
- Module structure containing 8 tower segments each
  - $\rightarrow$ $5 \times 5 \times 140\text{cm}^3$ tower dimensions
  - $\rightarrow$ approximately 6–7λ/λ_0 depth
- Longitudinal separation into 7 segments
  - $\rightarrow$ each containing 10 absorber (1.6cm) and 10 scintillator (4mm) tiles
  - $\rightarrow$ pre-shower segment with tungsten absorber instead of steel
- Acceptance of $1.1 < \eta < 3.2$
  - $\rightarrow$ $z_{\text{min}} = 3.6\text{m}$, $20 < R < 270\text{cm}$
- Readout via SiPM on tile and small flex PCB
  - $\rightarrow$ summing signals in each longitudinal segment
- Flux return for magnet and support structure for forward ECal
- Upgrade path with individual tile readout



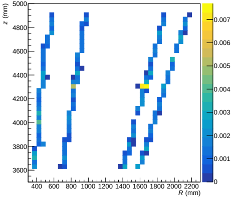


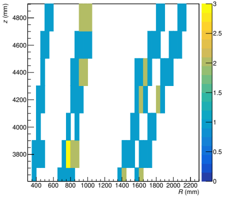
ePIC LFHCAL performance and PID

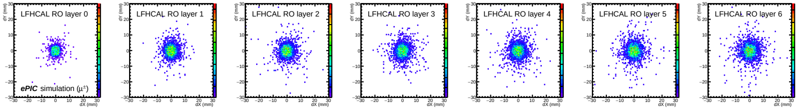




- High granularity eventually allows for detailed shower studies
  → ML-based approach for shower separation being studied
- LFHCAL fulfills YR performance requirements:
  → ePIC simulation $\sigma/E = 44\%/\sqrt{E} \oplus 5.5\%$
  → testbeam of prototype planned within FY24
- Good position resolution due to granularity
  → matching of tracks to individual z-segments possible
- Muon PID as application of segmentation:
  → muons generate MIP signal in crossed scintillator tiles
  → PID performance improves with increasing z-segmentation
  → requirement of more than 80% matched segments provides strong muon PID

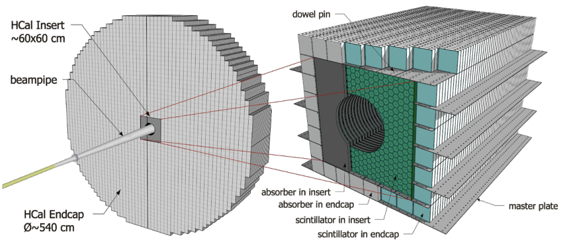


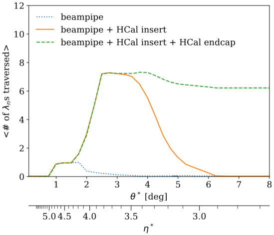


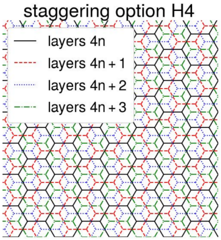


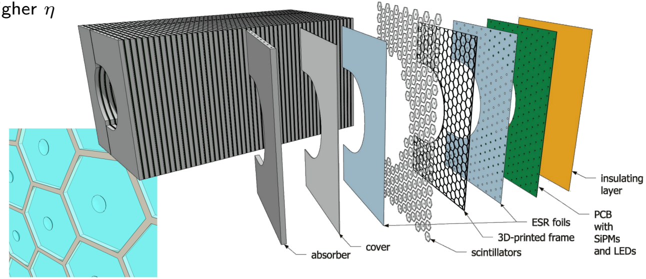
ePIC HCal Insert design

- Design inspired by CALICE calorimeter at the future ILC
  → SiPM on tile and high granularity approach
  → idea to provide 5D shower information (position, energy, and time)
- Hexagonal scintillator plates sandwiched between steel absorbers plates
  → layer-dependent granularity (1–7: 9cm^2, 8–14: 25cm^2, 15–50: 36cm^2)
- Staggering of layers for improved resolution
- Distance to beampipe minimized for largest possible acceptance
  → $3.2 < \eta < 4.0$ ($14.6 < R < 30$cm), tail to even higher η



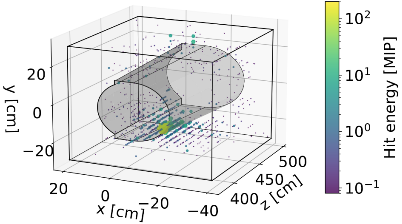


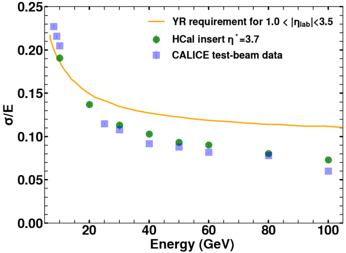


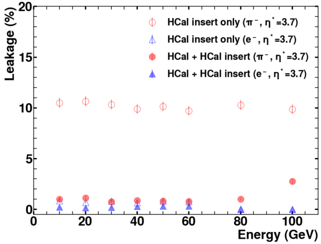


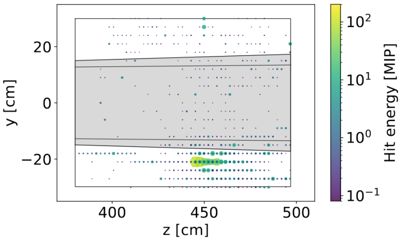
ePIC HCal Insert performance

- Clusterizer not yet developed
  → performance studies based on summed hit information
  → ML-based approach being studied
- Fulfills YR performance requirements
  → in agreement with CALICE test-beam data
- Strong shower leakage reduction at high η compared to standalone LFHCAL
- Further performance improvements with timing information possible
  → to be studied in combination with ML-clusterizer

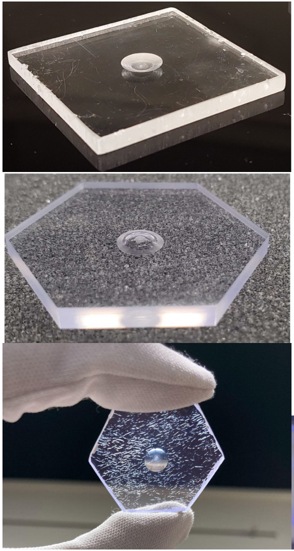




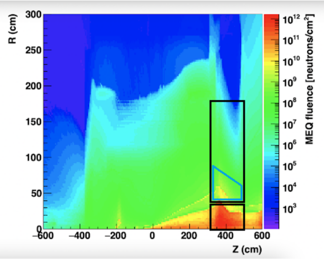


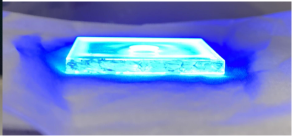


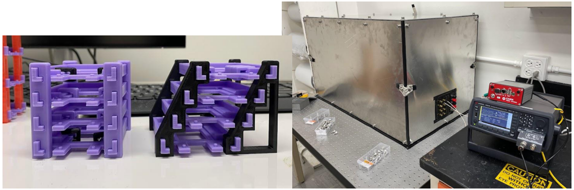
R&D efforts towards prototype manufacturing



- Significant efforts for scintillator tile manufacturing
  → machining difficulties with chipped edges or crazing
  → uneven tiles from injection molding
  → several challenges already overcome
- Light yield of various tile prototypes being studied
  → dark box construction and cosmic data taking employed
  → different SiPM's being tested
- Strong radiation environment in forward region
  → irradiation tests for tiles and sensors planned

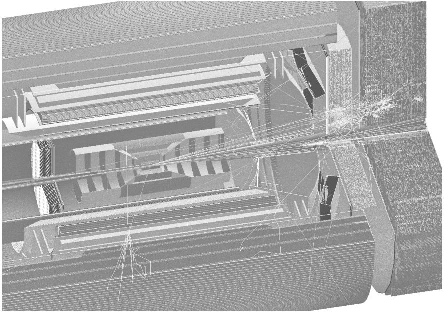






Summary

- Overview of forward HCal systems in ePIC shown
  → LFHCAL and high-η inlay
- Detailed detector design of both systems presented
- First performance results of simulation and test beams
  → Yellow Report requirements met by both systems
- Path forward and R&D efforts presented with current challenges



Forward hadronic calorimeter detector systems on track for ePIC!