Hadronic Calorimetry in ePIC

- design and performance -

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Particle Flow with HCals at the EIC

Particle flow:

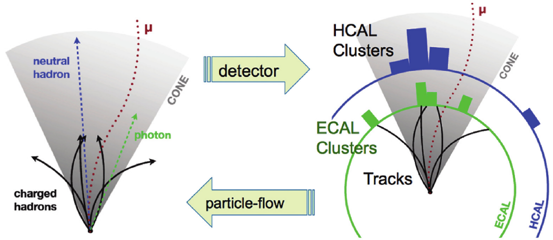
- Combination of all available detector information for particle reconstruction
  → e.g. tracking and ECals for electrons, tracking and all calorimeters for hadrons
- Reconstructed energy or lack of energy deposit provide valuable information

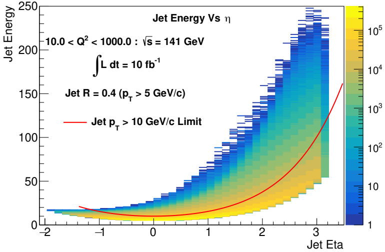
Jet reconstruction:

- 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)

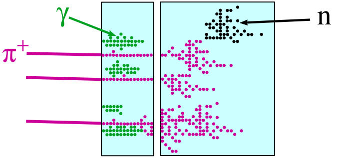
Hadron/Lepton PID:

- 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



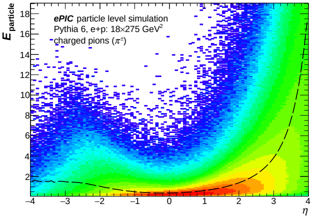


HCal design considerations

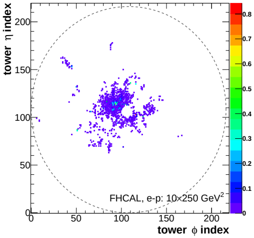


$E_{\mathrm{JET}} = E_{\mathrm{Track}} + E_{\mathrm{ECal}} + E_{\mathrm{HCal}}$

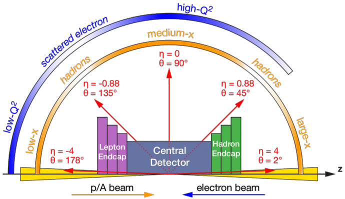
Optimization for particle flow

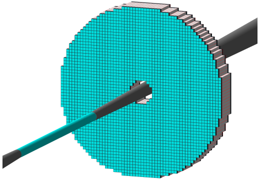


Expected energy range

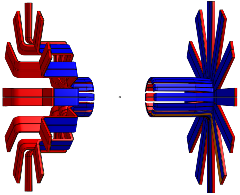


Shower separation at high η





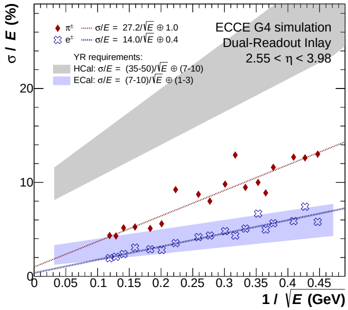
Acceptance limitations



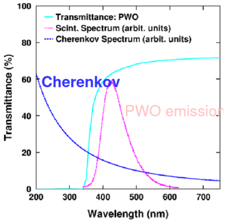
Integration and services

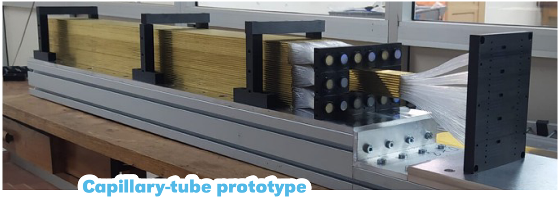
HCal technology catalogue

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



CSGlass prototypes



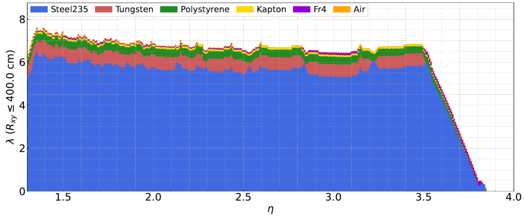


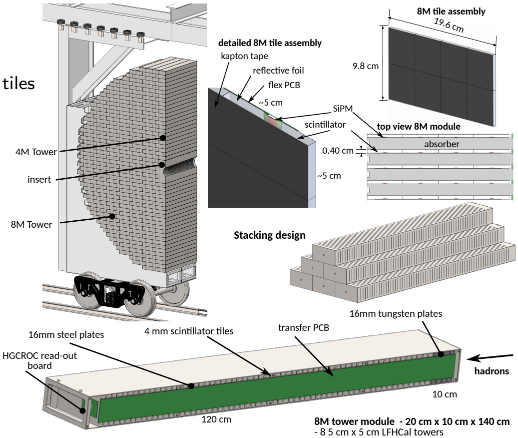
Capillary-tube prototype

ePIC Forward (p-going) HCal design

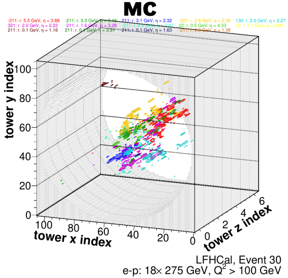
LFHCAL = Longitudinally-separated Forward Hadronic CALorimeter

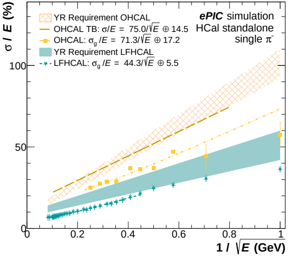
- Module structure containing 8 tower segments each
  → $5 \times 5 \times 140\text{cm}^3$ tower dimensions
  → approximately 6–7λ/λ_0 depth
- Longitudinal separation into 7 segments
  → each containing 10 absorber (1.6cm) and 10 scintillator (4mm) tiles
  → pre-shower segment with tungsten absorber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



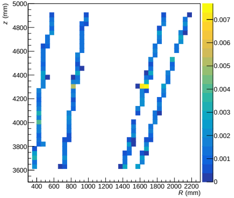


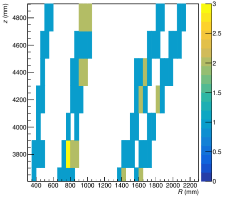
ePIC LFHCAL performance and PID

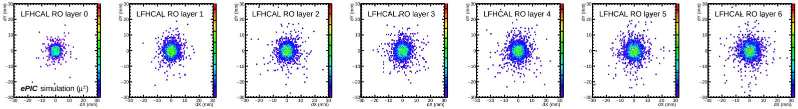




- High granularity eventually allows for detailed shower studies
  → ML-based approach for shower separation being studied
- LFHCAL fulfills YR performance requirements:
  → ePIC simulation $\sigma/E = 44\%/\sqrt{E} \oplus 5.5\%$
  → testbeam of prototype planned within FY24
- Good position resolution 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

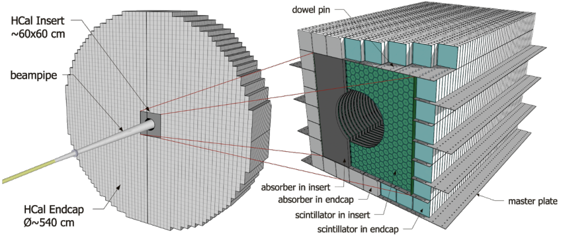


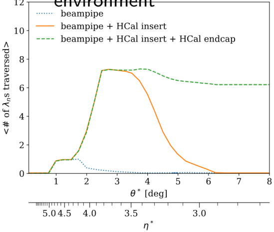


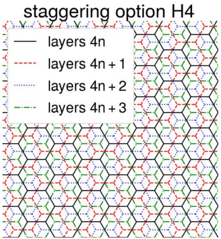


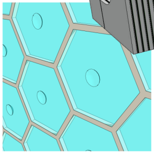
ePIC Forward HCal Insert design

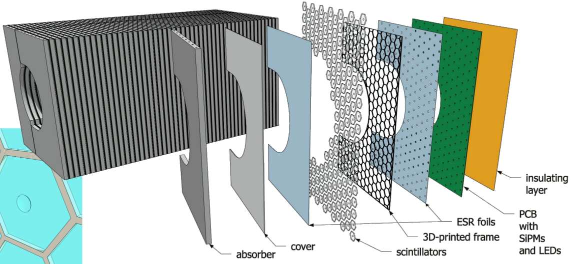
- Design inspired by CALICE calorimeter at the future ILC
  $\rightarrow$ SiPM on tile and high granularity approach
  $\rightarrow$ idea to provide 5D shower information (position, energy, and time)
- Hexagonal scintillator plates sandwiched between steel absorbers plates
  $\rightarrow$ layer-dependent 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
  $\rightarrow 3.2 < \eta < 4.0$ ($14.6 < R < 30$cm), tail to even higher η
- Accessibility of SiPMs for annealing due to high radiation environment





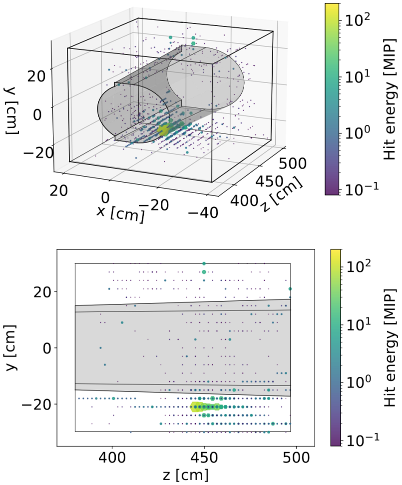


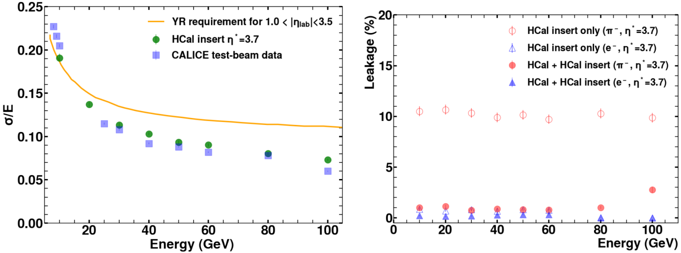




ePIC HCal Insert performance

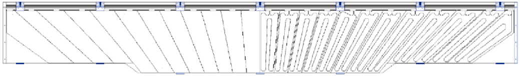
- Clusterizer not yet developed
  → performance studies based on summed hit information
  → ML-based approach being studied
- Fulfills YR performance requirements
  → in agreement with CALICE test-beam data
- Strong shower leakage reduction at high η compared to standalone LFHCAL
- Further performance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

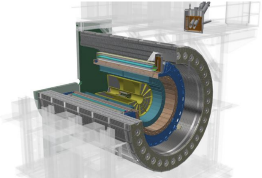


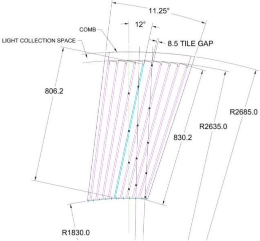


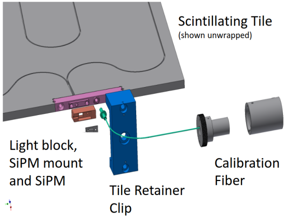
ePIC Barrel HCal design

- Repurpose of sPHENIX outer barrel HCal for ePIC
  → serves as part of solenoid flux return
- 32 sectors with 240 tiles per sector
  → tiles tilted by 12° in ϕ
  → 8mm thick scint. tiles with 26.1–42.4mm tapered steel plates
- Readout by $3 \times 3\text{mm}^2$ SiPMs
  → grouping of 5 tiles or individual readout
  → existing SiPMs likely to be replaced by Hamamatsu S14160-3015PS
  → H2GCROC3 used as front-end board



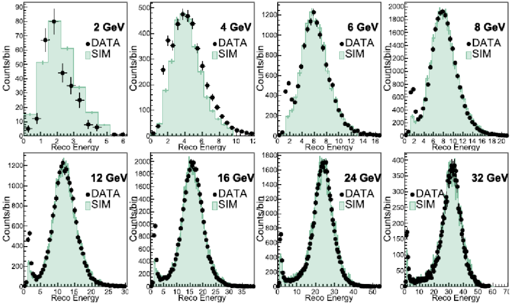


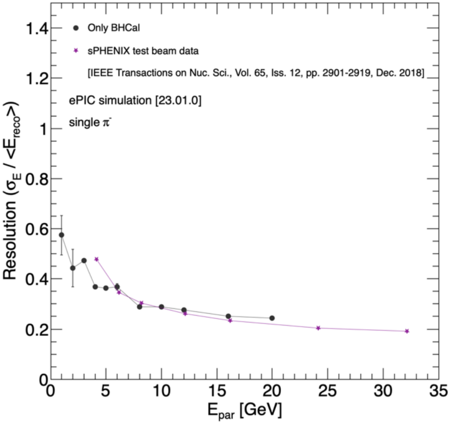




ePIC Barrel HCal performance

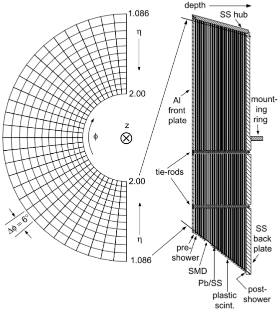
- YR requirement of 85-100%$/\sqrt{E}\oplus$7–10%
- Energy resolution determined in sPHENIX test beam
  $\rightarrow$ meets YR requirements
  $\rightarrow$ ePIC simulation reproduces resolution nicely
- Multiple calibration steps performed
  $\rightarrow$ cosmic ray telescope maps for each tile
  $\rightarrow$ temperature calibration for SiPMs

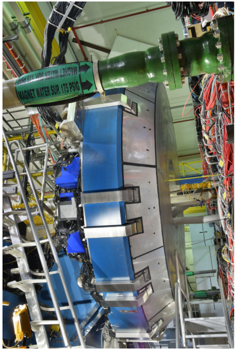


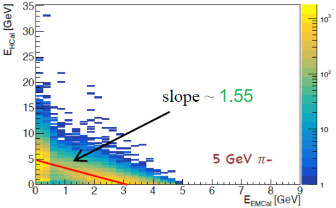


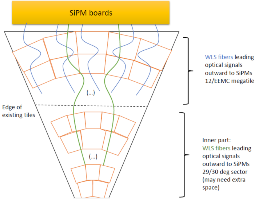
ePIC Backward HCal design and performance

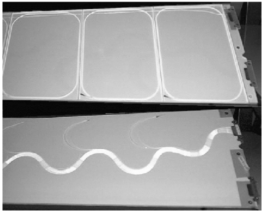
- Purpose: A future backward HCal shall provide functionality of a tail catcher for the high resolution e/m calorimeter in electron identification, as well as for jet kinematics measurement at small Bjorken x
- Repurpose and extension of STAR EEMC megatiles
  $\rightarrow$ ePIC HCal has larger radius
  $\rightarrow$ special construction of outer tile pieces
- Sampling HCal with 10 layers ($2.4\lambda/\lambda_0$)
  $\rightarrow$ 4cm steel and 4mm scintillator plates
- Light guided by WLS fibers and collected by SiPMs
- Readout based on HGCROC/EICROC
- Performance to be studied
  $\rightarrow$ energy sharing with EEEMC, position and angular resolution studies being performed





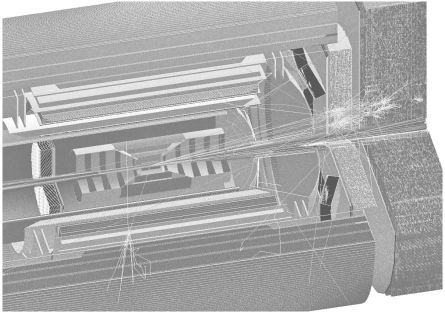






Summary

- Overview of HCal systems in ePIC shown
  → backward: repurposed and extended from STAR EEMC
  → barrel: repurposed from sPHENIX outer barrel HCal
  → forward: new detectors with SiPM-on-tile technology
- First performance results of simulation and test beams
  → Yellow Report requirements met by all systems



Hadronic calorimeter detector systems on track for ePIC!