Electromagnetic Calorimeters at the EIC

- lessons from the 1st detector -

Nicolas Schmidt (ORNL)

Oak Ridge National Laboratory

Yellow Report: DIS Physics with ECals

Inclusive DIS:

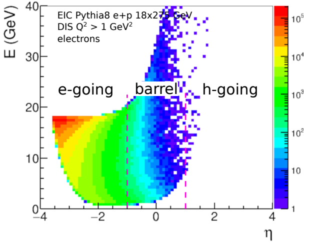
- scattered **electron** mostly backwards and in barrel
- electron energy ranges up to beam energy in backward and even higher in barrel
- electrons in barrel correspond to high Q^2 events
- electron **PID needed** due to γ and $\pi^{\pm}$ BG at low energies

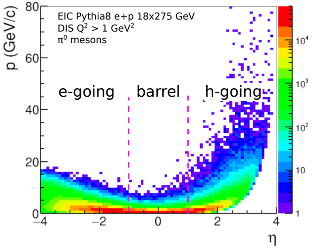
Semi-inclusive DIS:

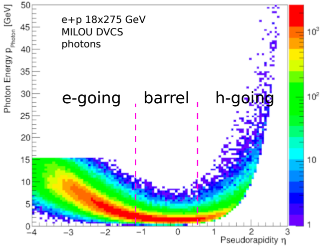
- $\pi^0 \rightarrow \gamma\gamma$ reconstruction needed
- momenta up to 10 GeV$/c$ in barrel (higher in forward)
- **granularity requirement** to prevent merging of photon showers

Exclusive DIS:

- measurement of **DVCS photons**, J/Ψ →ee, and more
- signal over wide rapidity range
- **hermetic coverage** necessary



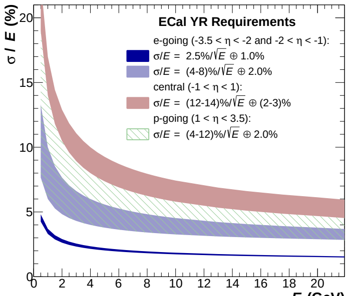




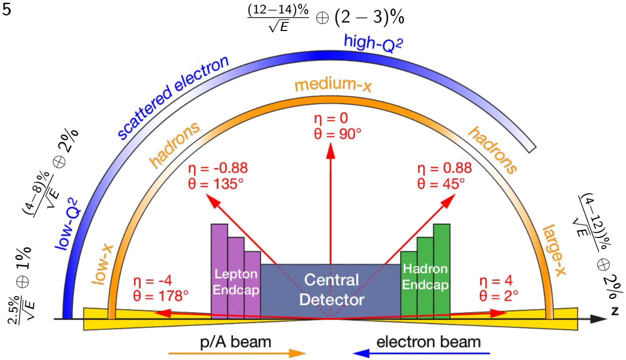
Yellow Report: Requirements for ECals

- YR outlines **energy and position resolution requirements** to fulfill physics program
  $\rightarrow$ strong resolution requirement for e-going side
  $\rightarrow$ lowest requirement in barrel with $(12\text{–}14)\%/\sqrt{E} \oplus (2\text{–}3)\%$
- Strong **PID requirements**:
  $\rightarrow$ π suppression up to factor 1e4 in e-going and at least 3σ e/π elsewhere
- **Hermetic coverage** required from $-3.5 < \eta < 3.5$

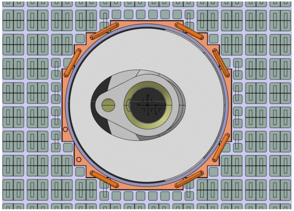
- **Integration** with other detectors crucial
  $\rightarrow$ low inner material budget needed
  $\rightarrow$ routing of services to be considered



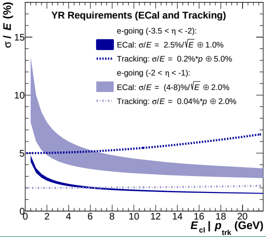
EIC Yellow Report [Link]



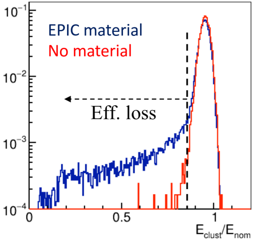
e-going direction - considerations



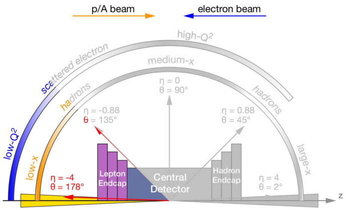
acceptance beyond $\eta < -3.5$ difficult

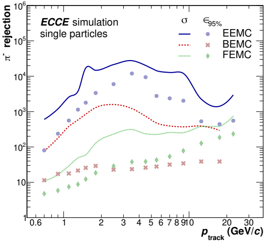


e^- energy reco. largely based on tracking

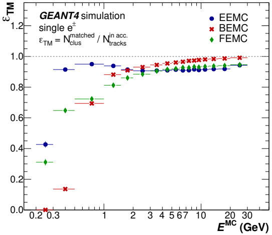


Energy losses from detector material



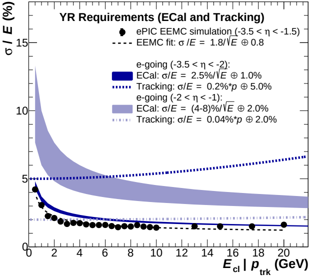


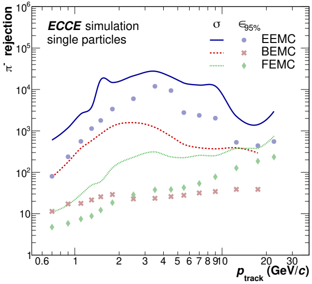
Electron PID crucial



High track matching efficiency needed

e-going direction - ePIC



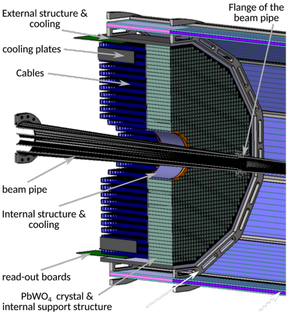


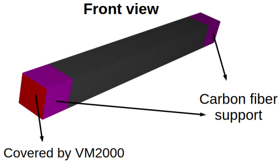
- **PbWO$_4$ crystal calorimeter**
  → $2 \times 2 \times 20\text{cm}^3$ dimension, 2932 crystals in total
  → light yield strongly temperature dependent
  → readout on both crystal ends for higher light yield

- Calorimeter at $z = -166$cm and covers $8.5 < R < 64.1$ cm
  → acceptance of $-3.6 < \eta < -1.6$

- Performance based on simulations **exceeds YR requirements**
  → energy reso of $\sigma/E = 1.8\%/\sqrt{E} \oplus 0.8\%$
  → pion rejection up to 10^4

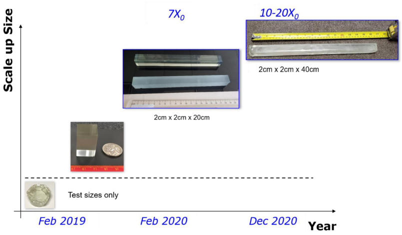
- Approximate **cost of $10 M**
  → dominated by cost of crystals



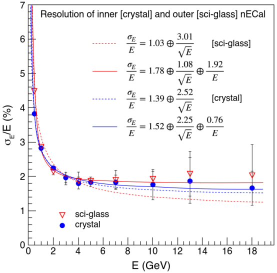


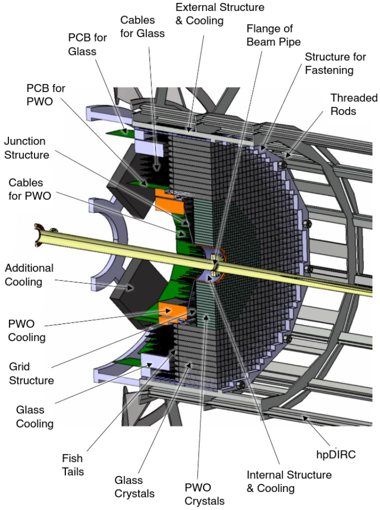
e-going direction - alternatives

- **Sci-Glass or hybrid** $PbWO_4$ and Sci-Glass calorimeter
  → cost-effective alternative with comparable performance
  → risk associated with Sci-Glass as further R&D is needed
  → challenging cluster finding at crossover region in hybrid case
- Magnitude of Sci-Glass utilization depending on calorimeter size
- Homogeneous calorimeter most likely only feasible option in this region

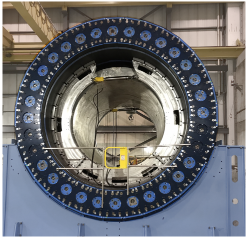


Sci-Glass R&D timeline

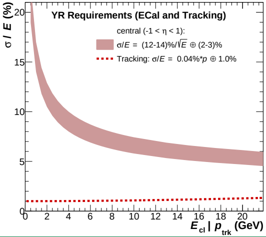




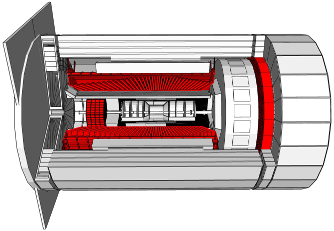
barrel region - considerations



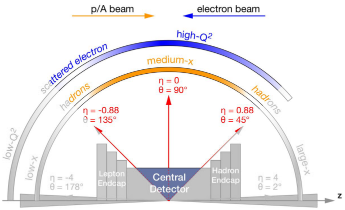
Magnet bore limits size

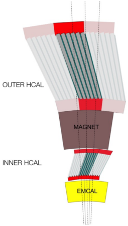


e^- energy reco. dominated by tracking

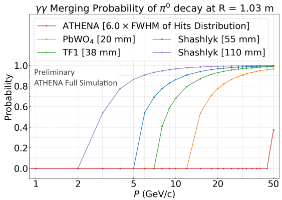


Crucial for hermetic ECal coverage





Possible integration with HCal

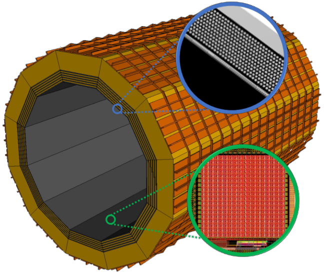


Shower separation/merging

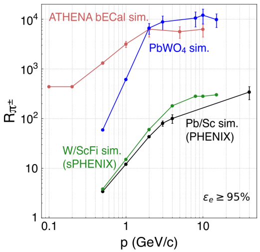
barrel region - ePIC (after internal review)

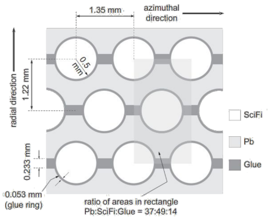
- Hybrid concept
  → **Imaging calorimetry** based on AstroPix monolithic silicon sensors ($500\mu m \times 500\mu m$)
  → Scintillating fibers embedded in Pb **(Pb/ScFi)** similar to GlueX ECal
- Imaging of showers via six layers of silicon interleaved with five Pb/ScFi layers
  → also provides space point for DIRC cherenkov reconstruction
  → **spatial resolution** $\sigma = (2.32 \pm 0.06)\mathrm{mm}/\sqrt{E} \oplus (1.4 \pm 0.02)\mathrm{mm}$ or $\sigma = 0.5mm$
- Total radiation length of 20 X_0
- **AI approach** for pattern recognition of 3D shower images
  → fine pixelation allows for tagging of radiative photons
- Acceptance of $-1.8 < \eta < 1.5$ and full azimuth
- Energy resolution GlueX $\sigma/E = 5.2\%/\sqrt{E} \oplus 3.6\%$ (ePIC sim. slightly better)
- Good pion rejection with hybrid information

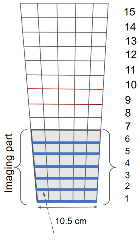
Pb/ScFi layer – Energy info



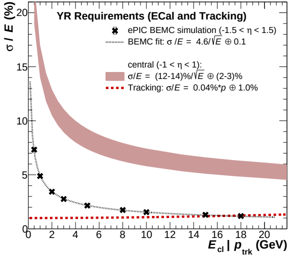
Imaging layer – Position info





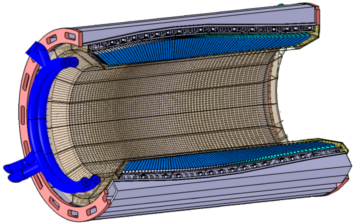


Imaging layers

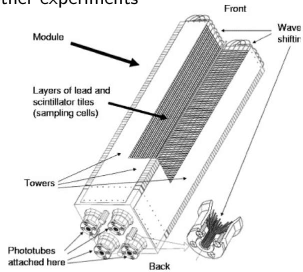


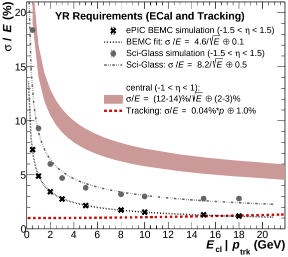
barrel region - alternatives

- **PANDA-style crystal calorimeter**
  → slight acceptance gaps due to module effects
  → offset projective geometry to avoid channeling
  - **$PbWO_4$ crystals**
    → expensive but excellent performance
  - **Sci-Glass crystals**
    → R&D for long crystals necessary
    → cost-effective with comparable performance to Imaging Calorimeter
  - **Cesium Iodide crystals**
    → used in BaBar calorimeter [link]
    → high performance: $\sigma/E \approx 2.3\%/\sqrt{E} \oplus 1.35\%$

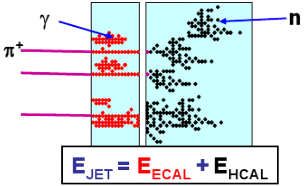


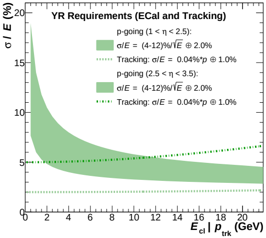
- **Shashlik ECal** like ALICE EMCal or PHENIX EMC
  → most cost effective alternative with option of re-use from other experiments
  → good performance mainly for larger radii
- **W/ScFi ECal** like sPHENIX EMC [link]
  → high granularity and low moliere radius
  → barely sufficient performance: $\sigma/E \approx 13.3\%/\sqrt{E} \oplus 3.5\%$
- **Dual Readout** IDEA
  → requires significant space
  → could be combined with endcap (see later)

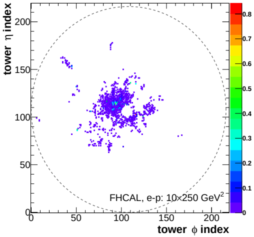




p-going direction - considerations



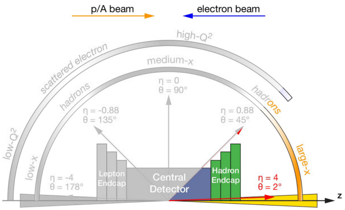


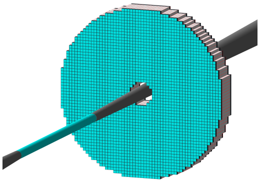


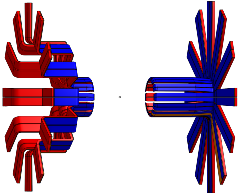
Optimization for particle flow

High energy γ reco. crucial

Shower separation at high η



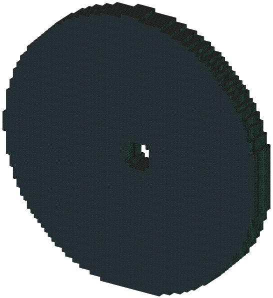




Acceptance limitations

Integration and services

p-going direction - ePIC



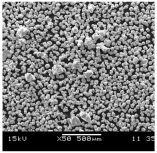
- **W/SciFi calorimeter**
  → matrix of tungsten powder, expoxy and embedded ScFi
  → 0.47mm diam. fibers, 1mm spacing, SF $\approx$ 2%
  → $2.5 \times 2.5 \times 17\text{cm}^3$ tower dimensions

- Design based on **STAR forward prototype** [link] and **sPHENIX EMCal** [link]
  → fiber readout via light guide to $3 \times 3\text{mm}^2$ SiPMs

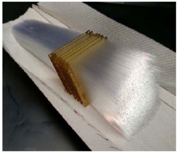
- Acceptance of $1.3 < \eta < 3.5$ $(20 < R < 170\text{cm})$

- Fulfills YR performance requirements:
  → ePIC simulation $\sigma/E = 7.1\%/\sqrt{E} \oplus 0.1\%$
  → sPHENIX TB $\sigma/E = 11.4\%/\sqrt{E} \oplus 1.5\%$

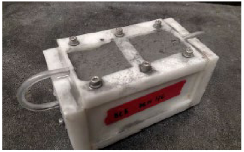
W Powder ~ 50 µm

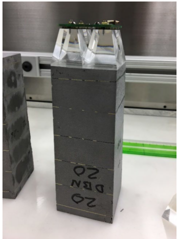


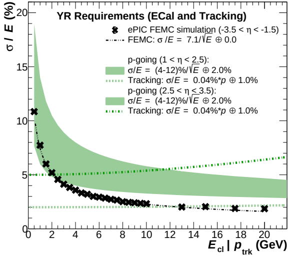
Fiber Assembly



Mold with W powder, fibers + epoxy

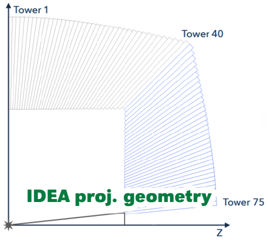






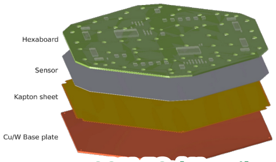
p-going direction - alternatives

- **Re-use** PHENIX Pb-scintillator shashlik ECal
  - $\rightarrow$ cost-effective option with good performance ($\sigma/E = 8.1\%/\sqrt{E} \oplus 2.1\%$)
  - $\rightarrow$ requires refinement of segmentation with SiPMs ($5.535 \times 5.535\text{cm}^2$)
- **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
  - $\rightarrow$ barrel coverage possible depending on magnet bore
  - $\rightarrow$ machine learning approach necessary for high granularity clusterization
- **FoCal-E or CMS HGCAL technology** [link]
  - $\rightarrow$ silicon layers to resolve shower development
  - $\rightarrow$ excellent PID performance
  - $\rightarrow$ ML necessary for clusterization

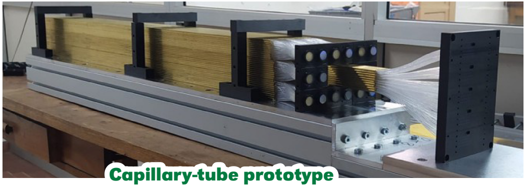


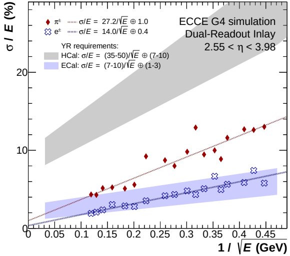
IDEA proj. geometry

ECal choice highly depends on 2nd detector physics objectives!



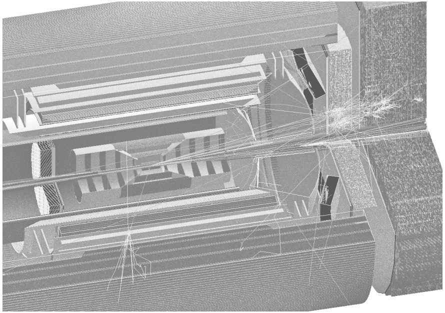
HGCAL ECal Hex Tile


Capillary-tube prototype



Summary

- Overview of general ECal considerations for each detector region
- Technology choices, acceptance and performance of ePIC detector presented
- **Large pool of alternative approaches possible**
  → re-use of traditional technologies
  → more novel approaches like dual readout calorimetry
- EMCal system choice depends on many external factors
  → physics, material budgets, tracking detectors, magnet bore, ...



Electromagnetic calorimetry in 2nd detector a problem with many solutions!