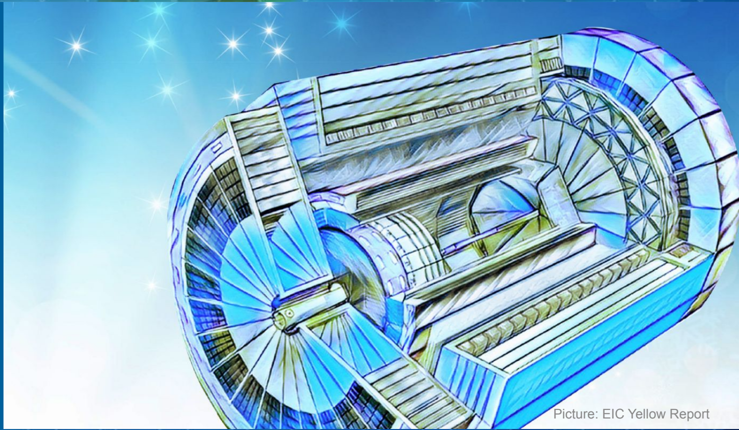
June 8, 2022

2022 RHIC/AGS Annual Users' Meeting

Calorimetry

Session: EIC Detector

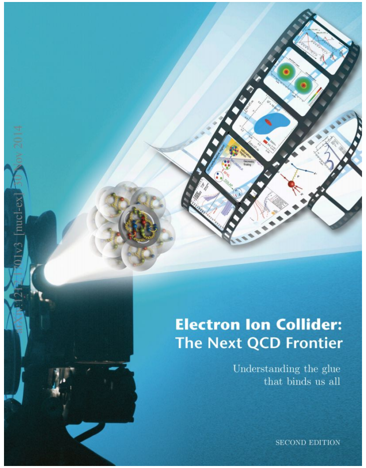
Detector 1 Calo WG conveners: Friederike Block, Carlos Muñoz Camacho, Oleg Tsai, Paul E Raimer

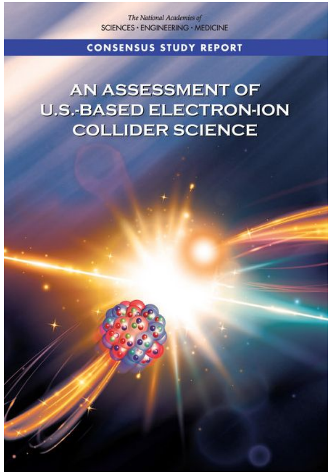


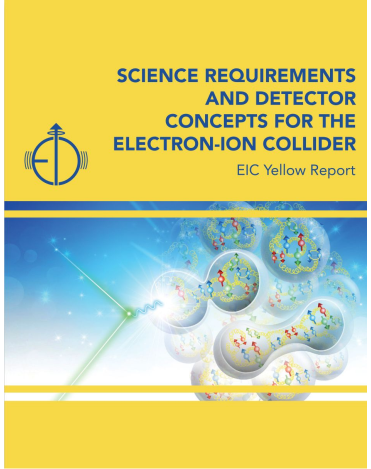
Picture: EIC Yellow Report

Maria ŻUREK, Argonne National Laboratory

EIC Physics Case







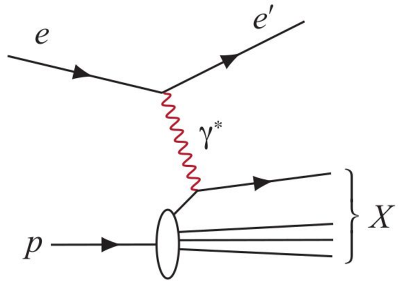
NAS Finding 1: An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

EIC Physics Case

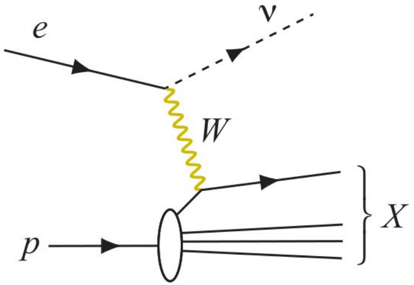
Calorimetry Role

DIS event kinematics - scattered electron or final state particles (CC DIS, low y)



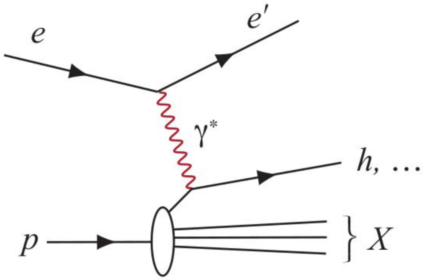
Neutral Current DIS

- Detection of scattered electron with high precision - event kinematics
- Excellent e/h separation needed



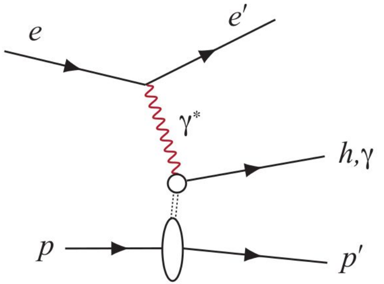
Charged Current DIS

- Event kinematics from the final state particles (Jacquet-Blondel method)
- Jet measurement capabilities



Semi-Inclusive DIS

- Precise detection of scattered electron in coincidence with at least 1 hadron
- Measurement of SIDIS π^0, decay electrons (e.g. HF)

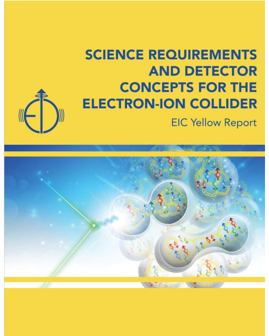


Deep Exclusive Processes

- Detection of all particles in event
- Detection of DVCS γ, exclusive π^0, decay electrons (e.g. VM)
- Separation of γ/π^0 for DVCS

→ See talk by A. Jentsch about far-forward (exclusivity) and far-backward region (Low Q^2, luminosity)

EIC Calorimetry Requirements



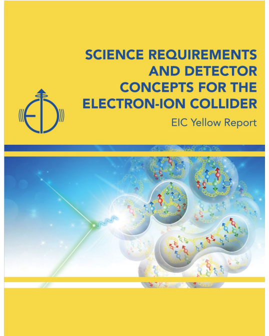
EIC Community outlined physics, detector requirements, and evolving detector concepts in the EIC Yellow Report.

Main tasks of the ECAL

- Detect the scattered **e and separate them from π.**
- Improve the electron **momentum resolution at backward rapidities**.
- **Detect neutral particles (photons, π^0)**, and measure the energy and the coordinates of the impact.
- Separate **secondary electrons and positrons from charged hadrons**.
- Provide **spatial resolution of two photons sufficient to identify decays π^0 → γγ** at high energies.

Challenges: e/π PID, ɣ/π^0 discimination, high energy resolution at large |η| and momentum, dynamic range of sensors, available space

EIC Calorimetry Requirements



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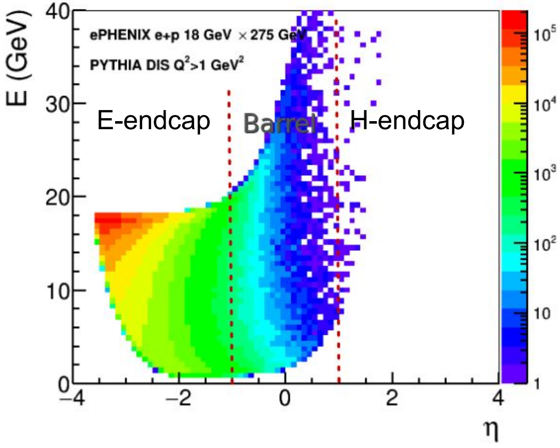
	-4 < η < -2	**-2 < η < -1**	**|η| < 1**	**1 < η < 4**
E resolution	$2\%/\sqrt{E} \oplus (1-3)\%$	$7\%/\sqrt{E} \oplus (1-3)\%$	$(10-2)\ \%/\sqrt{E} \oplus (1-3)\%$	$(10\text{-}12)\ \%/\sqrt{E} \oplus (1-3)\%$
e/π separation	up to 10^{-4}	up to 10^{-4}	up to 10^{-4}	3σ e/π
Min E [GeV]	0.1	0.1	0.1	0.1

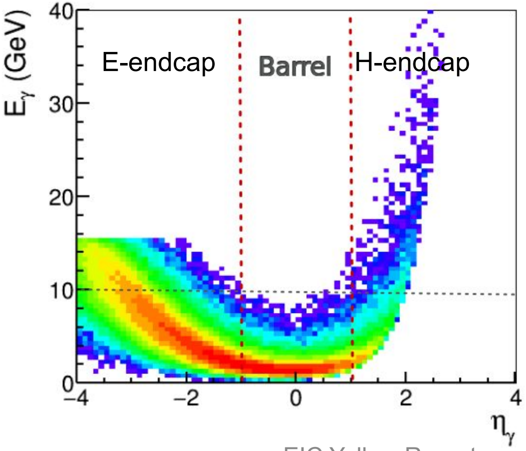
EIC Calorimetry Requirements

EIC Yellow Report

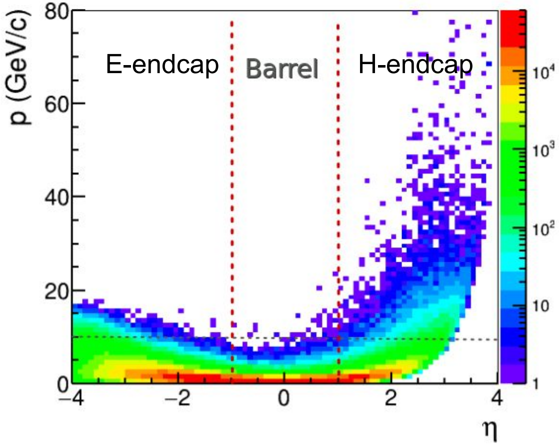
DIS electrons



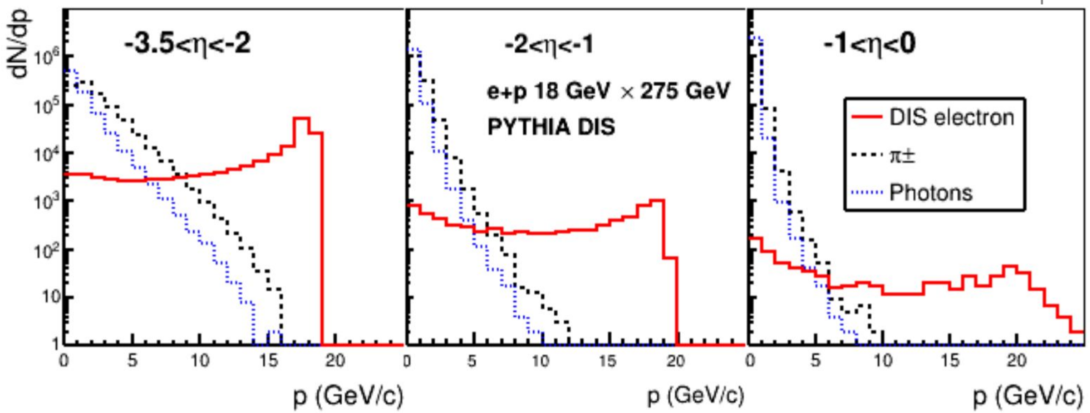
DVCS photons



SIDIS π^0



EIC Yellow Report



e/π separation:

- Depends on momentum and η
- Tightest constrain from parity violating asymmetries 10^{-4}
- ΔG requires ~ 10^{-3}

EIC Calorimetry Requirements

Main tasks of HCAL

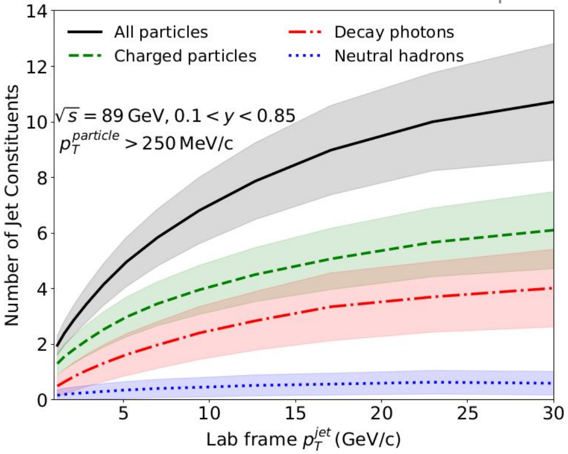
- **Precise reconstruction of the jet energy**
  - **Detection and isolation** of neutral hadrons, in combination with information from EMCals, tracking and PID detectors.
  - **Neutral/charged cluster discrimination** with help of tracking
  - Complementing tracking at high η
- Detection of all the **final state hadrons** (Jaquet-Blondel method)
  - Proton fragmentation products in the forward area (n and K_L only in HCal)

Challenges: available space, energy resolution at high η

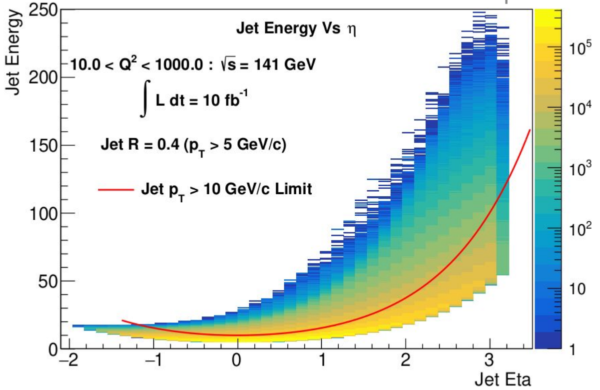
η	EIC Specifications		Conservative option	
	σ_E/E, %	E_{min}, MeV	σ_E/E, %	E_{min}, MeV
-3.5 to -1.0	$45/\sqrt{E}+7$	500	$50/\sqrt{E}+10$	500
-1.0 to +1.0	$85/\sqrt{E}+7$	500	$100/\sqrt{E}+10$	500
+1.0 to +3.5	$35/\sqrt{E}$	500	$50/\sqrt{E}+10$	500

EIC Yellow Report

EIC Yellow Report

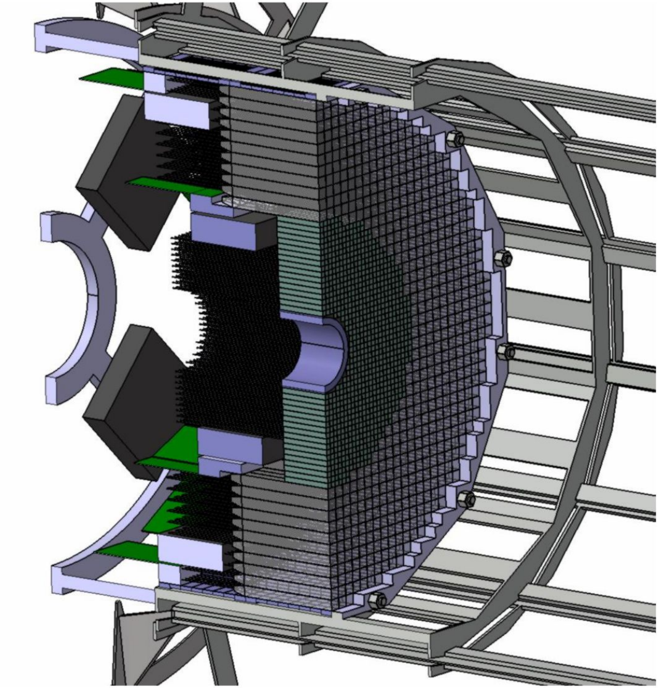


EIC Yellow Report



Detector I Calorimetry

Backward Calorimetry



Backward EMCAL

- Non-projective **PbWO calorimeter** (EEEMC-Consortium)
  - 2 × 2 × 20 cm^3 crystals
  - Length ~$20X/X_0$, transverse size ~Molière radius
  - Located inside the inner DIRC frame
  - Preferred readout: SiPMs of pixel size 10μm or 15μm
  - Cooling to keep temperature stable within ± 0.1 ◦C
- Ongoing efforts advancing the design to increase coverage in η (−3.7 < η < −1.5) with inlay around beampipe

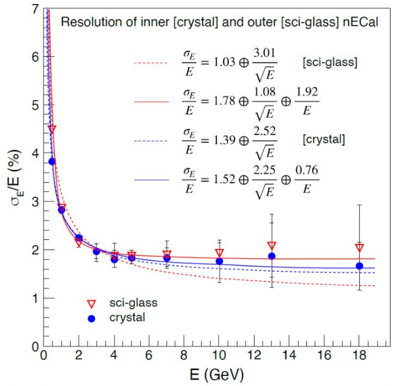
Backward HCAL in consideration

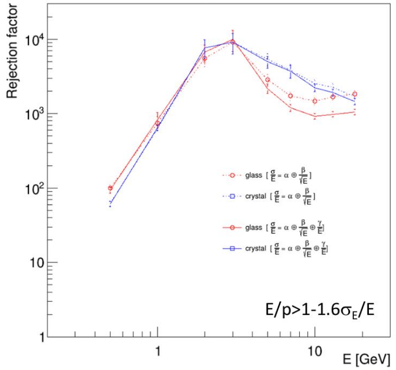
- Possible upgrade path

→ See C. Muñoz Camacho for EEEMCal, https://indico.bnl.gov/event/15493/
→ See B. Page, https://indico.bnl.gov/event/15686/

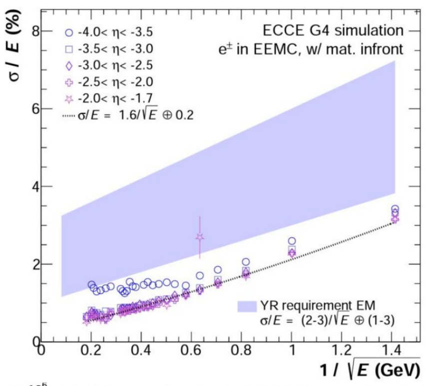
Backward EM Calorimetry

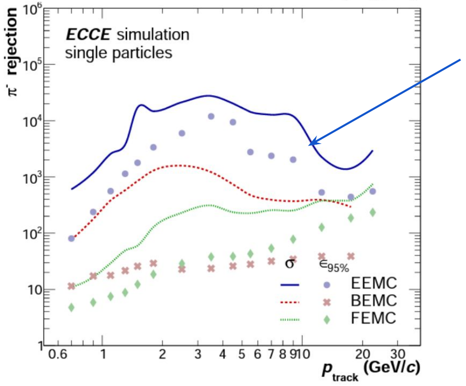
ATHENA



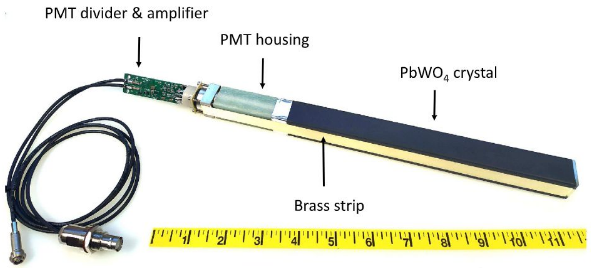


ECCE



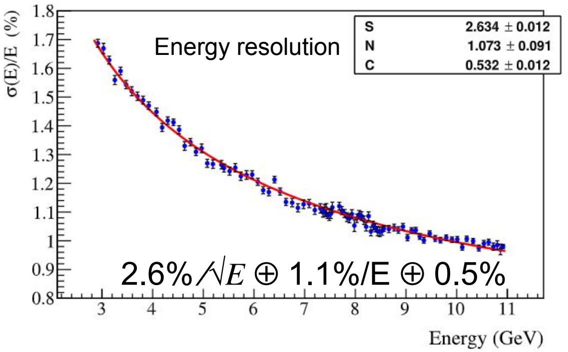


→ C. Muñoz Camacho for EEEMCal, https://indico.bnl.gov/event/15493/



Compton calorimeter / NPS prototype beam test

- 12x12 PWO modules (SICCAS crystals)
- Tested in JLab Hall-D

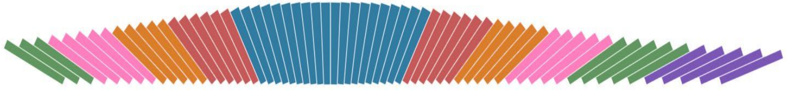


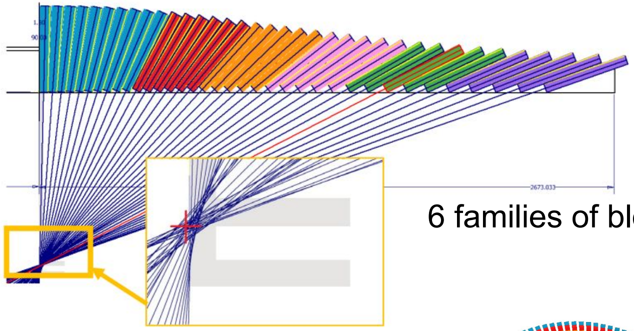
$2.6\%/\sqrt{E} \oplus 1.1\%/E \oplus 0.5\%$

→ V. Berdnikov, https://indico.bnl.gov/event/15615/
→ Nucl. Inst. Meth. A 1013 (2021) 165683

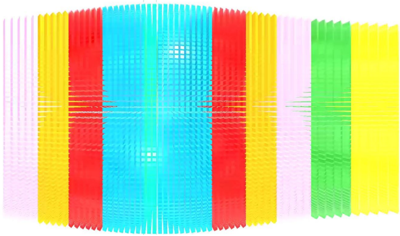
Barrel EM Calorimetry

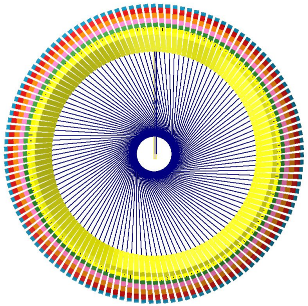
Technology I





6 families of blocks

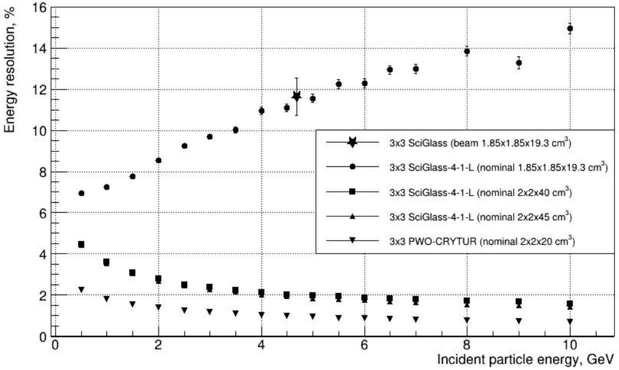




→ See T. Horn, https://indico.bnl.gov/event/15802/

8000 homogeneous blocks of SciGlass

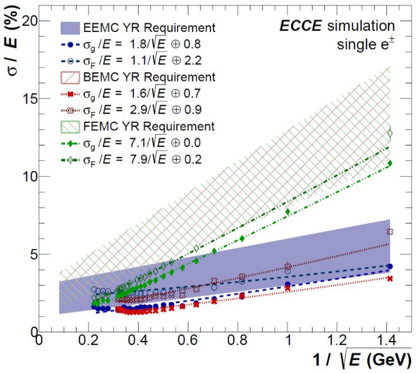
- 45.5 cm length (18 X_0)
  + ~10 cm radial readout space, read by SiPMs
- Coverage: $-1.7 < \eta < 1.3$
- SciGlass
  - Ongoing R&D EEEMCAL consortium
    → *See Talk by T. Horn*
  - Alternative to high resolution (expensive) crystal EMCal
  - 3 x 3 20 cm (~ 7X_0) SciGlass prototype detector tested in beam



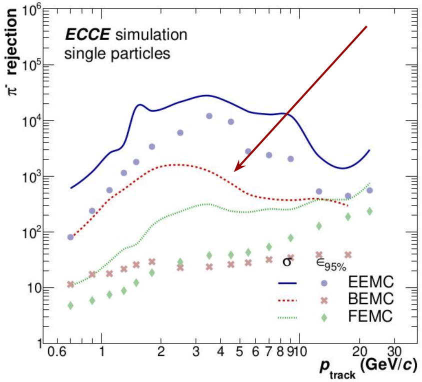
Barrel EM Calorimetry

Technology I

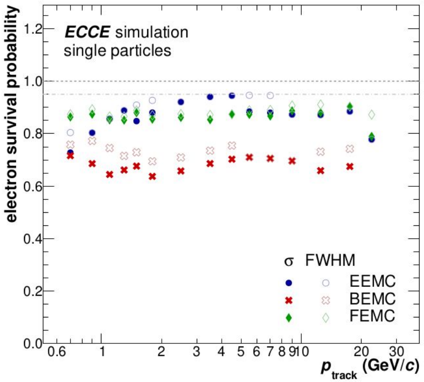
Energy resolution



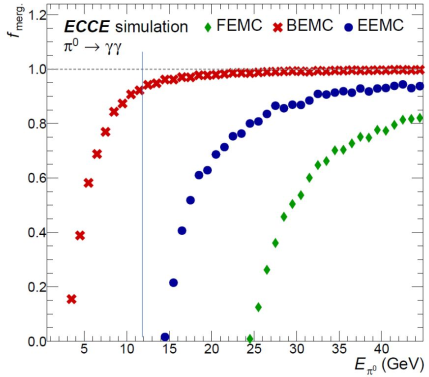
Pion rejection

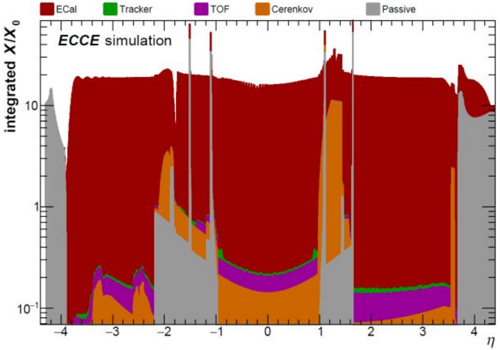


Electron efficiency



Separation of γ/π^0





Geant4 Simulations

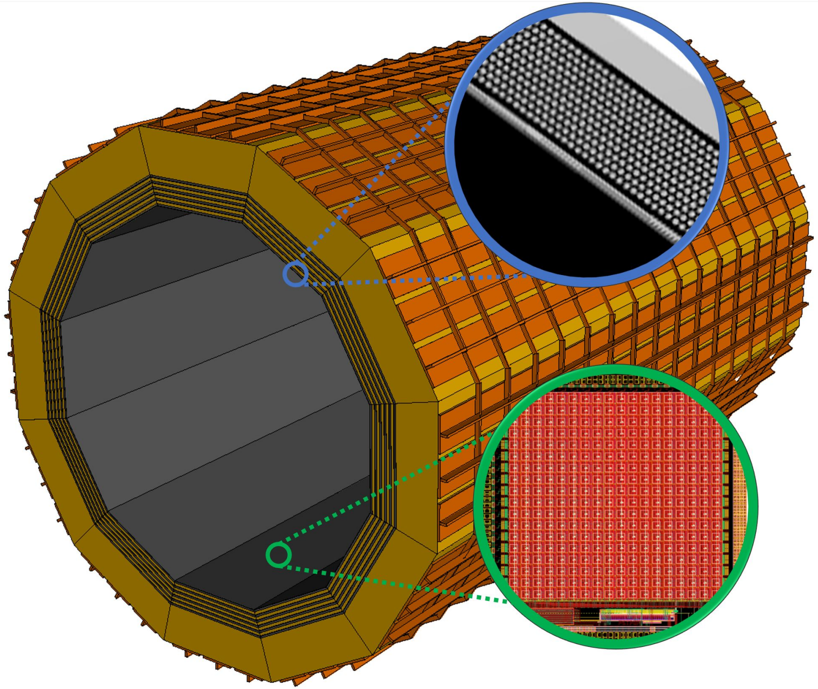
- Implemented with the active components and support structures
- Materials in front of the EM calorimeter considered
- 1.5 T Magnetic Field

→ See T. Horn, https://indico.bnl.gov/event/15802/

Barrel EM Calorimetry

Technology II

- **Hybrid concept**
  - Imaging calorimetry based on monolithic silicon sensors AstroPix (NASA's AMEGO-X mission) - 500 μm x 500 μm pixels Nuclear Inst. and Methods in Physics Research, A 1019 (2021) 165795
  - Scintillating fibers in Pb (Similar to GlueX Barrel ECal, 2-side readout w/ SiPMs) Nuclear Inst. and Methods in Physics Research, A 896 (2018) 24-42
- 6 layers of imaging Si sensors interleaved with 5 Pb/ScFi layers and followed by a large chunk of Pb/ScFi section (can be extended to inner HCAL)
- Total radiation thickness for EMCAL of ~20 X_0
- Detector coverage: $-1.7 < \eta < 1.3$ which overlaps with "electron-going" side endcap



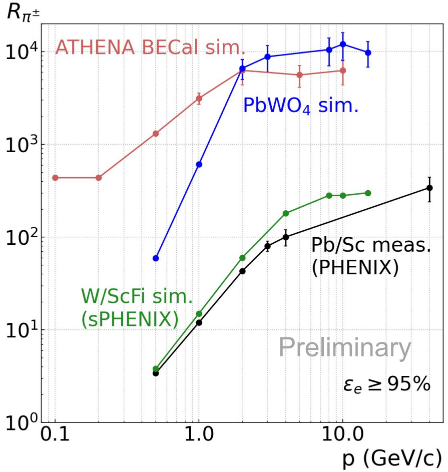
Energy resolution - SciFi/Pb Layers: $5.3\% / \sqrt{E} \oplus 1.0\%$

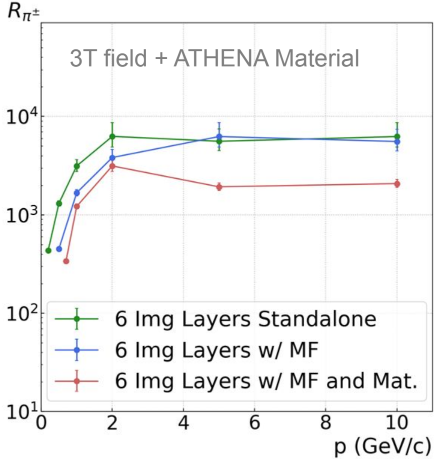
Position resolution - Imaging Layers (+ 2-side SciFi readout): with 1st layer hit information ~ pixel size

Barrel EM Calorimetry

Technology II

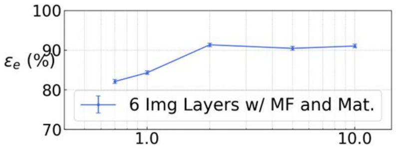
Pion rejection





- Standalone Calorimeter (no material/no magnetic field) → for apple-to-apple comparison with technologies presented in YR
- 2 step method: E/p cut + NN based on 3D position and energy information from imaging layers

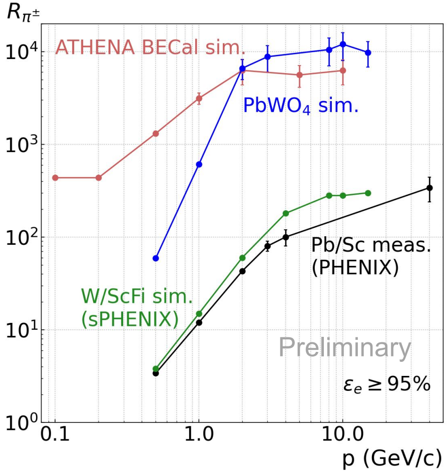
- Impact of material and 3T field
- The lowest *p* point at 0.7 GeV/c significantly affected by the high magnetic field
  - The rejection factor will go up with lower field

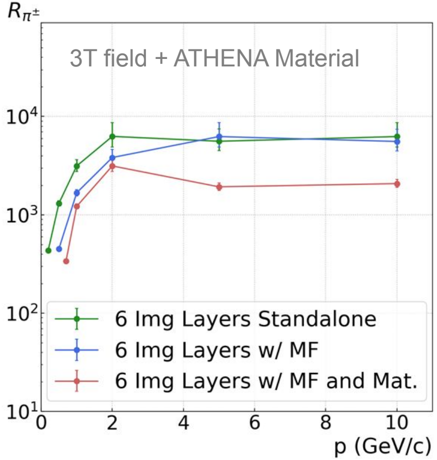


Barrel EM Calorimetry

Technology II

Pion rejection





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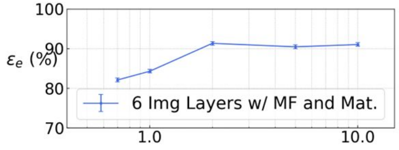
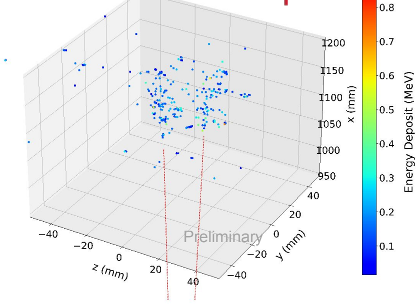
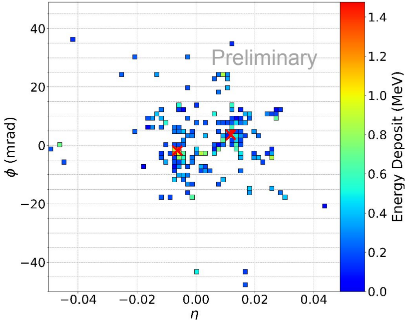
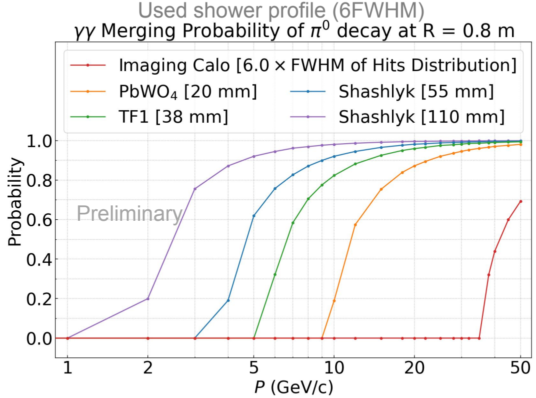


Separation of γ/π^0

15 GeV π^0 example

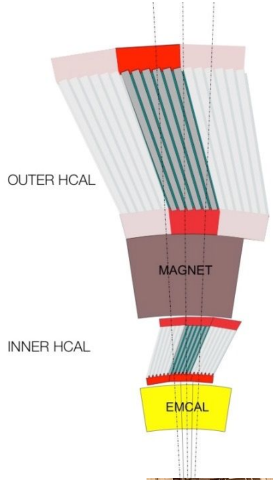


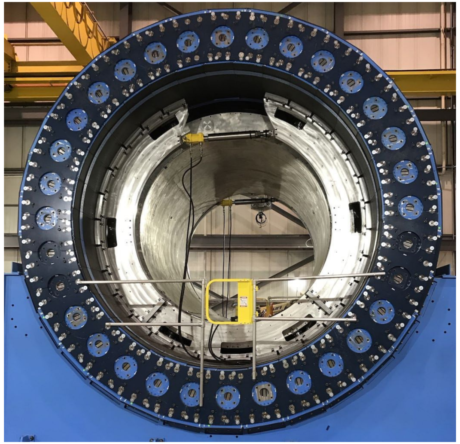




Shower profile from ATHENA simulation w/ 3T field. First check at r = 80 cm.

Barrel Hadronic Calorimetry

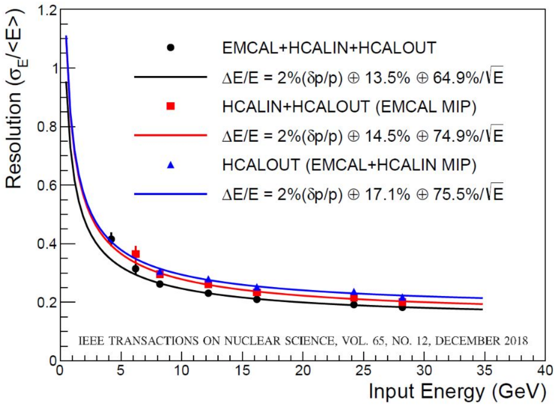




Reuse of sPHENIX outer (outside of the Solenoid) HCal ≈ $3.5\lambda_I$

- Steel and scintillating tiles with wavelength shifting fiber
- $\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$ (1,536 readout channels, SiPMs)

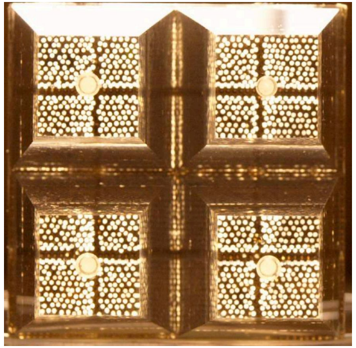
sPHENIX Test Beam

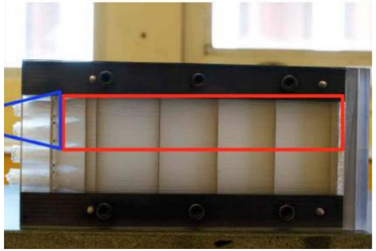


- Necessity and feasibility of inner HCal under development, depends on EMCAL choice

⟶ See: J. Lajoie, https://indico.bnl.gov/event/15493/

Forward EM Calorimetry





4 SiPMs / tower

R&D: Improvement of light collection eff. and uniformity

Simulations:

- Expected E resolution ~ 11%/√E ⊕ 2%
- Can effectively separate γ/π^0 (z = 3.5 m) with ML methods

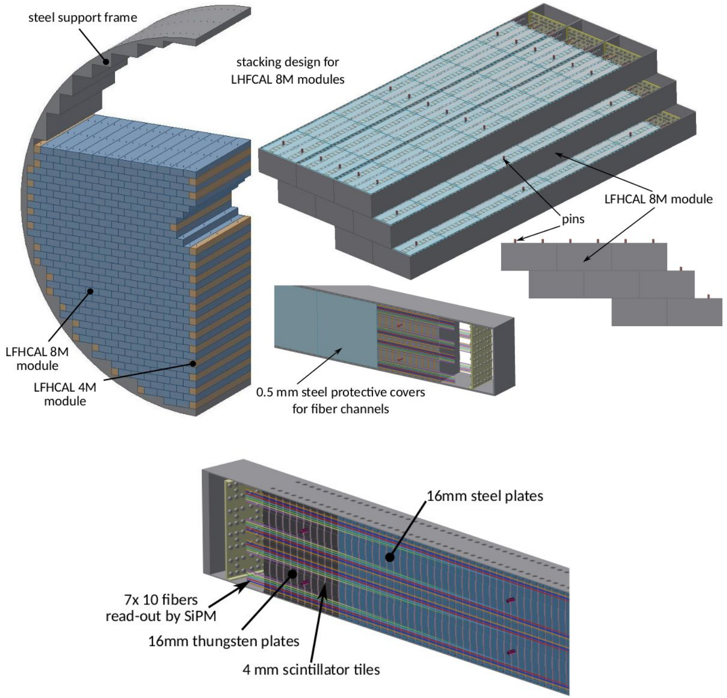
→ See F. Bock, N. Schmidt, https://indico.bnl.gov/event/15686/

→ See O. Tsai, https://indico.bnl.gov/event/15686/

Two mature sampling EMCal designs considered:

- Pb-Scintillator Shashlik: scintillating tiles; light transported through the WLS fibers
  - Single towers smaller than R_M (~5.2 cm), use shower maxima to separate close particles
  - X/X_0 = 18.5 (37.5 cm + 5 cm readout)
- W/SciFi: scintillating fibers embedded in W/epoxy mix
  - Similar to sPHENIX W/SciFi
  - X/X_0 = 23 (17 cm + 10 cm readout), 2.5 x 2.5 cm towers (R_M=~2.3 cm)
  - Easier construction for WSciFi calorimeter
  - Compactness and higher EM-shower containment

Forward Hadronic Calorimetry



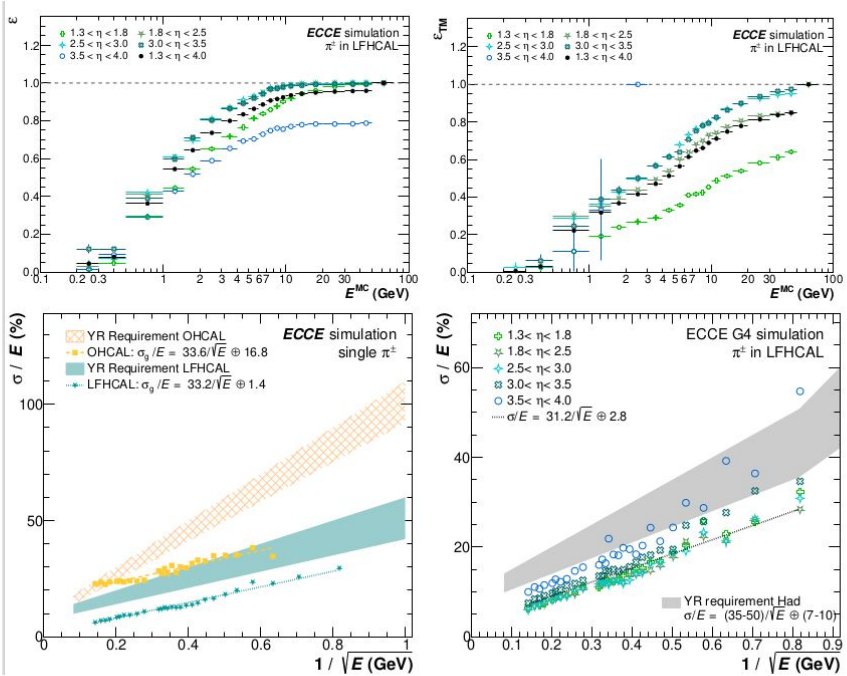
→ See F. Bock, https://indico.bnl.gov/event/15810/
→ See O. Tsai, https://indico.bnl.gov/event/15810/

Two designs based on longitudinally separated steel and scintillator tiles

- Inspired by STAR Forward Calorimeter
  - Fe/Scint (20 mm / 3 mm) sandwich
  - 4 longitudinal segments (scintillation tiles with two different time constants)
  - λ/λ_0 = 7 (ECAL + HCAL)
- Inspired by Projectile Spectator Detector (CBM)
  - 60 layers of steel-sci plates + 10 layers of W-Sci plates (5 x 5 cm towers)
  - 7 signals per tower (from 10 plates)
  - λ/λ_0 = 6.9 (HCAL only, larger shower containment)

- Ongoing efforts to explore granular inlay around beampipe

Forward Hadronic Calorimetry

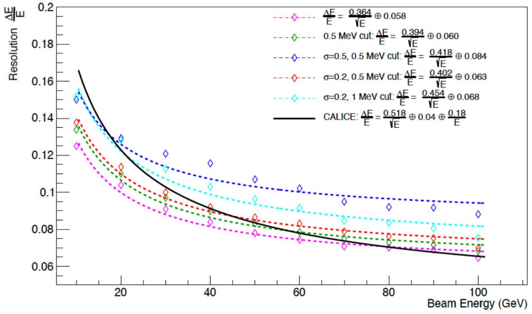


Performance on energy resolution and matching

- Cluster finding and track matching efficiencies good in center of LFHCAL, losses towards edges (further ML optimization in progress)
- Small η dependence for energy resolution (fulfills YR requirements)

In general, our **MC requires validation**

- Validation for high Z absorbers
  - J. Adam, A. Jentsch (BNL), studies with Pb/Sc hcal eRD1/STAR
- Work in progress to tune MC for Fe absorber



Fe/Sc, CALICE Model R.Milton (UCLA)

→ See F. Bock, https://indico.bnl.gov/event/15810/
→ See O. Tsai, https://indico.bnl.gov/event/15810/

Summary and Outlook

- Electron-Ion Collider physics case requires a detector with unique capabilities
  - Detector requirements summarized in the EIC Yellow Report (YR)

- This talk summarizes the needs and proposed technology choices to fulfill the YR requirements for the EIC Electromagnetic and Hadronic Calorimetry in the Central Detector
  - *See the talk about the Far-Forward and Far-Backward regions by A. Jentsch*
- Active R&D efforts for different technologies
  - *See the talks in the next 2 sessions*

- Final Detector I technology choices for calorimetry under evaluation
  - Ongoing performance, risk, and cost studies and integration evaluations