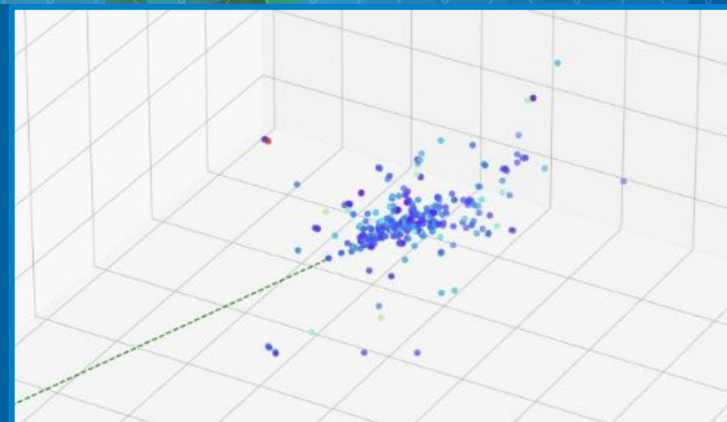
APRIL 27, 2022

BARREL CALORIMETER II



Maria ŻUREK, Argonne National Laboratory

EIC Calorimetry Requirements
Barrel CAL in EIC Yellow Report

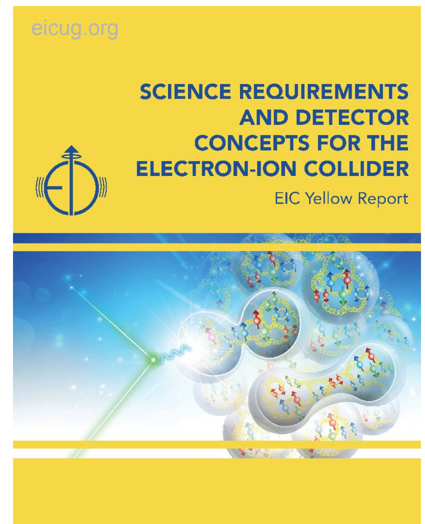
EIC Community outlined physics, detector requirements, and evolving detector concepts in the EIC Yellow Report.

EIC Yellow Report requirements for barrel ECal

- Detection of electrons/photons to measure **energy and position**
- Require **moderate energy resolution** $(10 - 12)\ \%/\sqrt{E} \oplus (1 - 3)\%$
    - But! With high electron-pion separation at low momenta.
- Require **electron-pion separation up to 10^4** at low particle momenta
- Discriminate between **π^0 decays and single photons** from DVCS
- **Low energy photon** reconstruction ~100 MeV

The main functionality of barrel and negative hadron calorimeters

- In the mid-rapidity region, the functionality of hadron calorimeters is driven by a single jet measurements.
- Neutral hadron isolation could also be important for jet energy scale and resolution
- Assist in **detection and isolation** of neutral hadrons, in combination with information from EMCals, tracking and PID detectors.

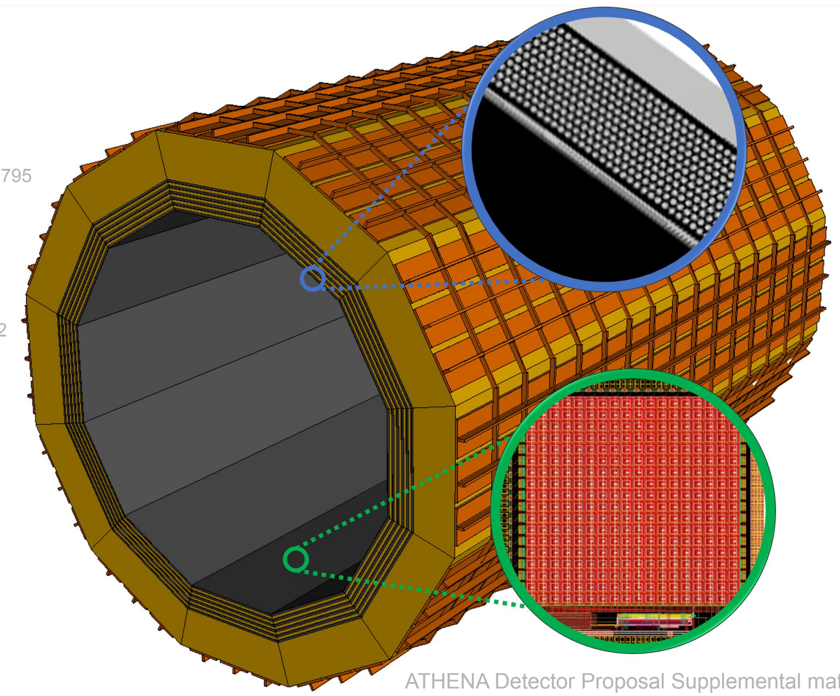


DETECTOR GEOMETRY
ATHENA Barrel ECal

https://anl.box.com/s/w5i3e7cmzgznnl1qyjukuhspsn87zwhe

- **Hybrid concept**
  - Imaging calorimetry based on monolithic silicon sensors AstroPix (NASA's AMEGO-X mission) Nuclear Inst. and Methods in Physics Research, A 1019 (2021) 165795
  - Scintillating fibers embedded in Pb (Pb/ScFi – Similar to GlueX Barrel ECal) 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
- Total radiation thickness of 20 X_0
- Detector coverage: $-1.5 < \eta < 1.2$ which overlaps with "electron-going" side endcap

Imaging layer – Position info
Pb/ScFi layer – Energy info

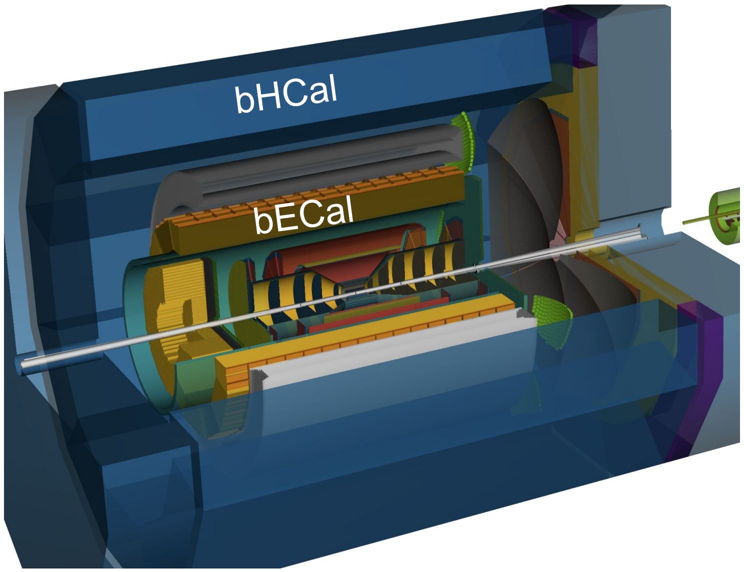


ATHENA Detector Proposal Supplemental material

Hadronic calorimetry in the ATHENA barrel

Combined approach: bECal Pb/SciFi and Fe/Scint tail catcher

- **Outer region of bECal serves as inner HCal** (inside the magnet), with decent energy resolutions for hadrons from the BECAL Pb/ScFi layers
- **Dedicated bHCal tail catcher sits outside the magnet**:
  - Five-layer steel and scintillator sandwich, re-using the scintillation mega-tiles from the STAR bECal
  - Design for the backward HCal similar to the barrel HCal
  - Re-using STAR components (steel, cradles, mega-tiles) significantly reduces cost
- **bHCal is relatively shallow**, only needed to instrument ~2 interaction lengths (λ_I):
  - ATHENA magnet ~ $1.3\lambda_I$ precludes good energy measurement of hadrons
  - ATHENA bECal ~ $1\text{-}1.7\lambda_I$ deep
  - $2\lambda_I$ contains 95% of hadronic showers
  - remaining space used for flux-return steel bars from the STAR magnet



Hadronic calorimetry in the ATHENA barrel

Combined approach: bECal Pb/SciFi and Fe/Scint tail catcher

What is the efficiency of **neutron detection** for

- one interaction length EMcal,
- 1.3 interaction length magnet between EMCal and HCal
- sandwich Fe/Sc HCal tail catcher.

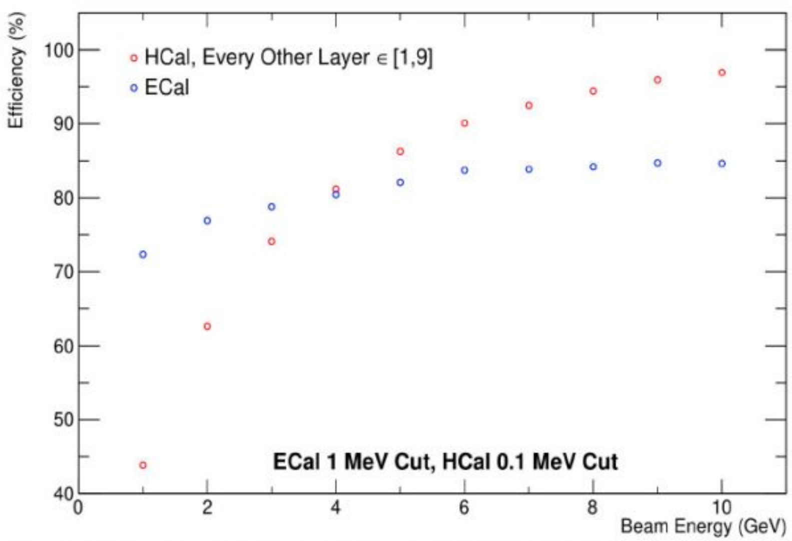


Figure 6. Efficiency of registration of neutrons in bECal and bHCal as a function of neutron energy.

Energy resolution of combined EMCal+HCal systems for pions in the energy range 1-10 GeV for different thickness of EMcal with and without dead material

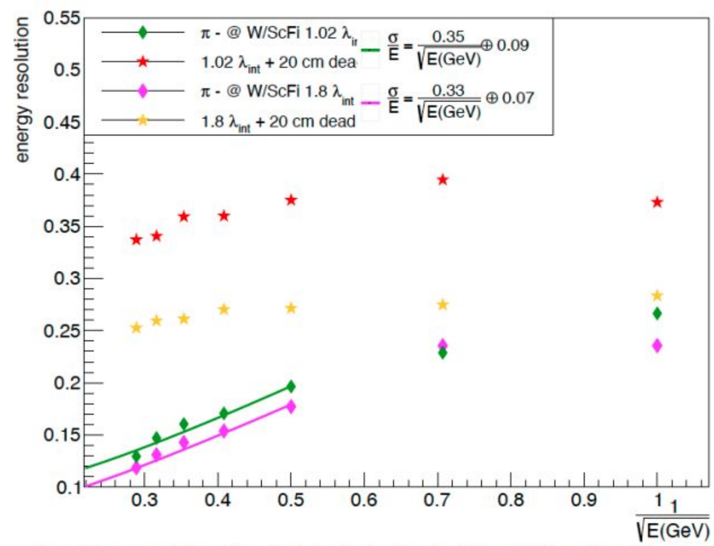


Figure 8 Energy resolution of barrel calorimeters for pions for different configurations of the detectors.

Imaging Layers in Barrel ECAL

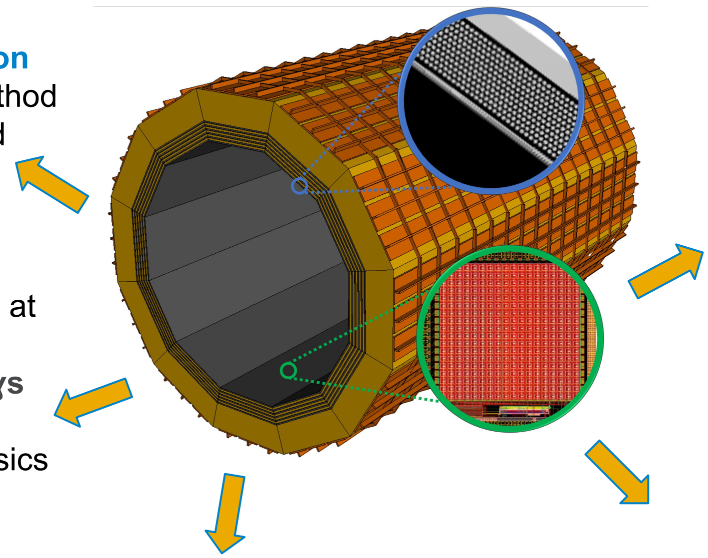
Excellent position resolution allowing precise 3D shower imaging

Significantly improved **electron/pion separation** with respect to E/p method

- Impact on DIS cross section and asymmetries

Separation of ɣs from π^0 decays at high momenta up to ~40 GeV/c. Precise position reconstruction of **ɣs** (below 1 mm at 5 GeV).

- Impact on DVCS and photon physics



Provides a **space coordinate for DIRC** reconstruction (no need for additional large-radius tracking detector)

- Improving PID for SIDIS and beyond
- Improved tracking resolution for high-momentum particles

Tagging **final state radiative photons** from nuclear/nucleon elastic scattering at low x to **benchmark QED internal corrections**

Imaging layers provide:

- precise measurement of photon coordinates and the angle between electron and photon

Allowing PID of **low energy muons** that curl inside the barrel ECal (< 1.5 GeV with 3T MF)

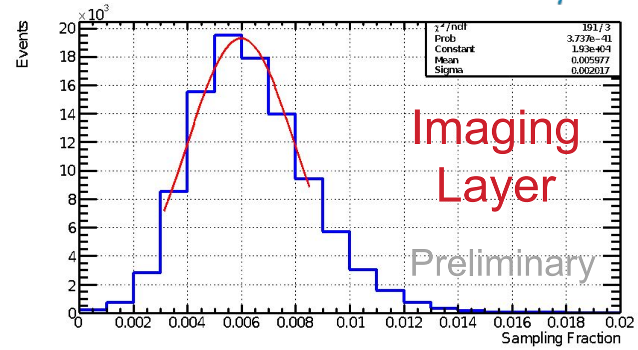
- Impact on J/psi reconstruction, TCS

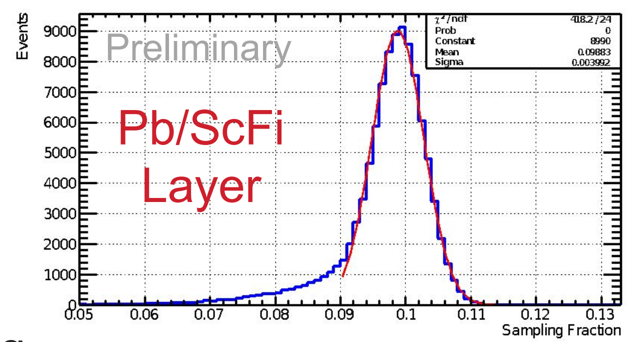
PERFORMANCE STUDIES

Detector Setup and Reconstruction

- Full simulations within the ATHENA detector geometry
  - R_{Calo} = 103 cm
- Single particle generators (Geant4)
- Full reconstruction process
  - Digitization
  - Reconstruction
  - Clustering
- In simulations: we explore the possibility of using the AstroPix sensor off-the-shelf

Used 5 GeV γs



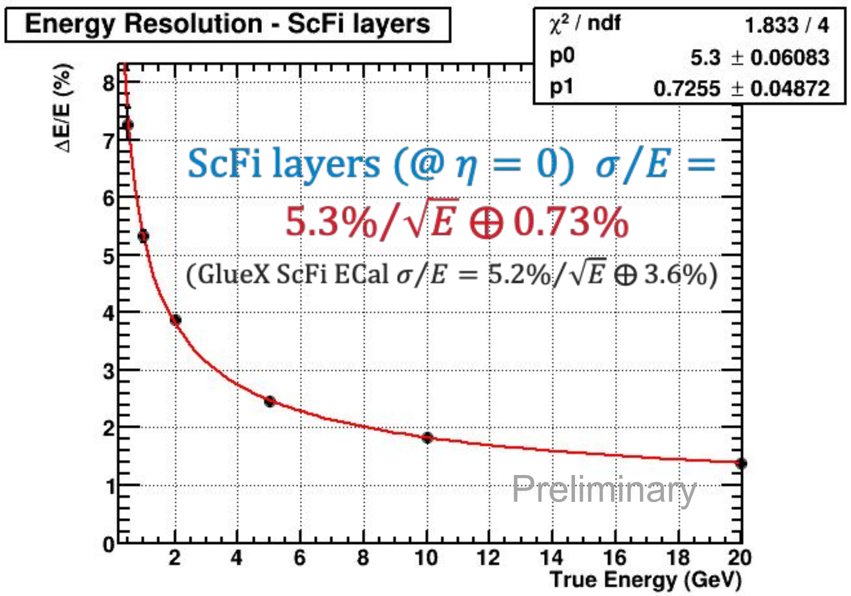


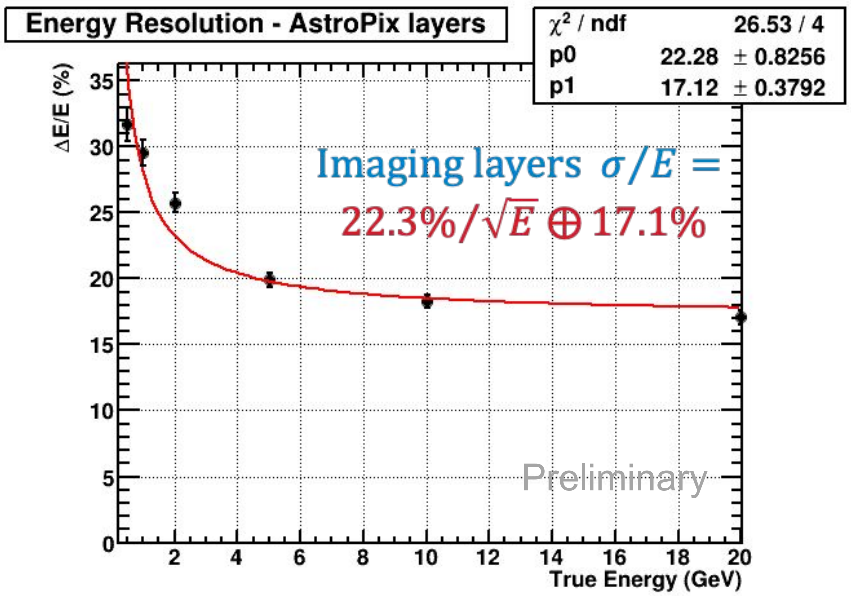
$$\text{Sampling Fraction} = \frac{\sum E_{\text{active layer}}}{E_{\text{thrown}}}$$

Imaging Layer ~0.6%
Pb/ScFi Layer ~10%

ENERGY RESOLUTION

The main role of the Pb/ScFi Layers





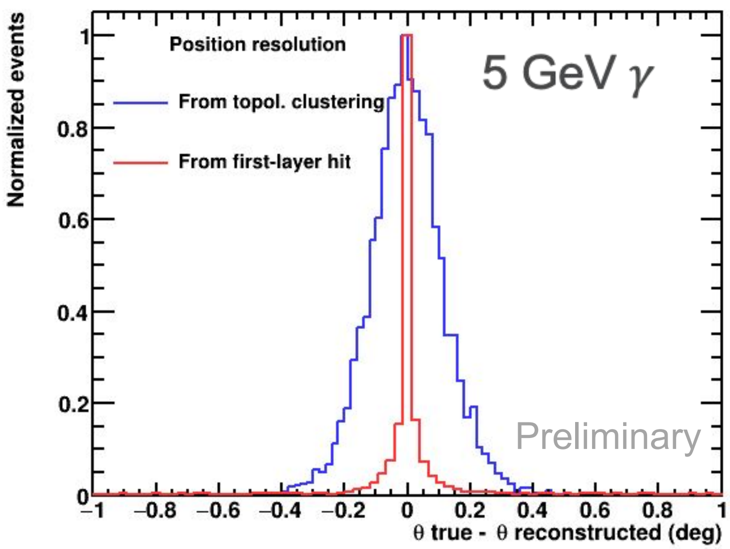
ATHENA Detector Proposal Supplemental material

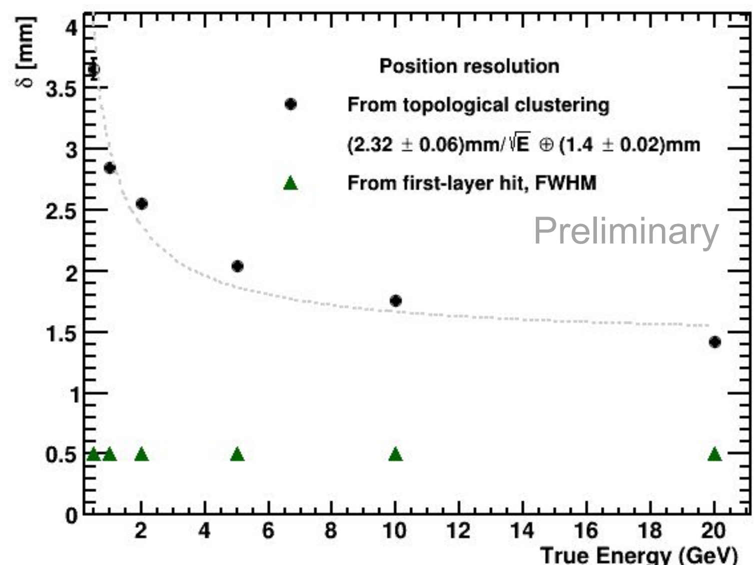
SPATIAL RESOLUTION

The main role of the Imaging Layers

Cluster level: $\sigma_{\text{spatial}} = (2.32 \pm 0.06)\text{mm}/\sqrt{E} \oplus (1.4 \pm 0.02)\text{mm} \quad @\, \eta = 0$

With first layer hit position on top of cluster level: $\sigma_{\text{spatial}} = 0.5\text{mm}$ (i.e. pixel size)





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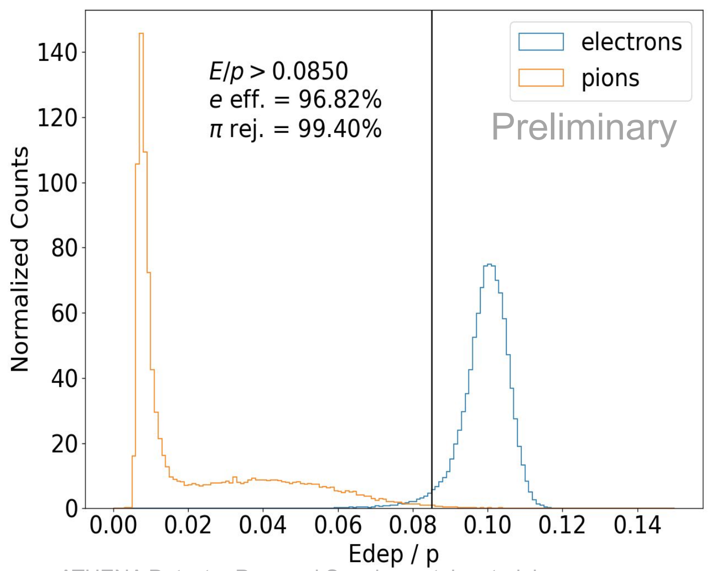
ELECTRON IDENTIFICATION

$e - \pi$ separation

- Separation of electrons from background π in Deep Inelastic Scattering (DIS) processes

E/p cut on $e - \pi$ samples



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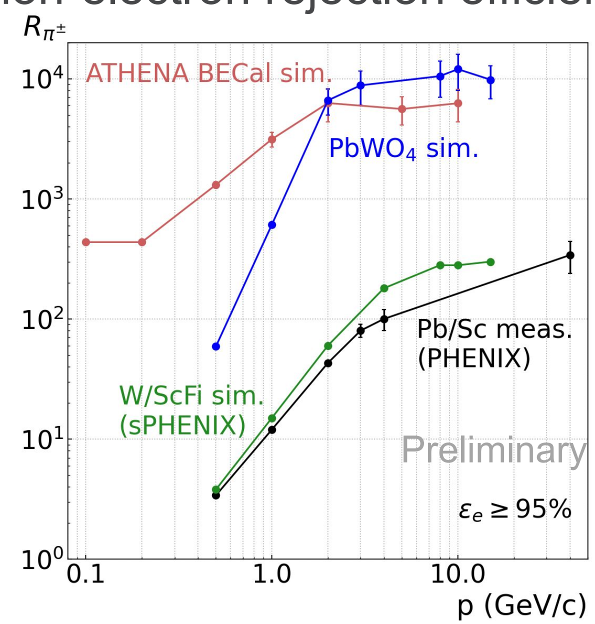
Pion-electron rejection efficiency



Used
ML algorithm

Standalone Calorimeter (no material/no magnetic field)

With MF and material in front of Calo: ~ 3 x 10^3 with el. eff ~ 91%

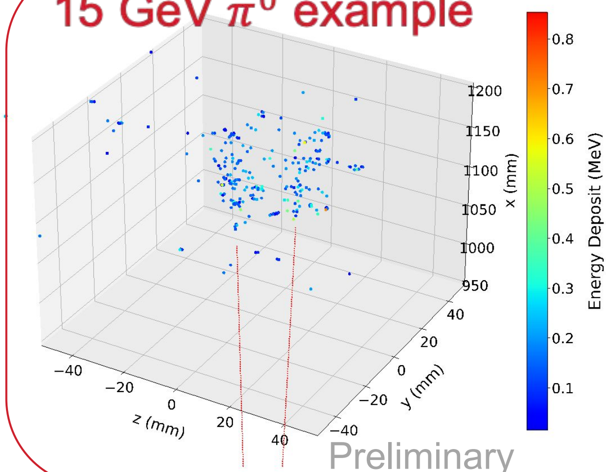
Other calorimeter technologies from EIC Yellow Report

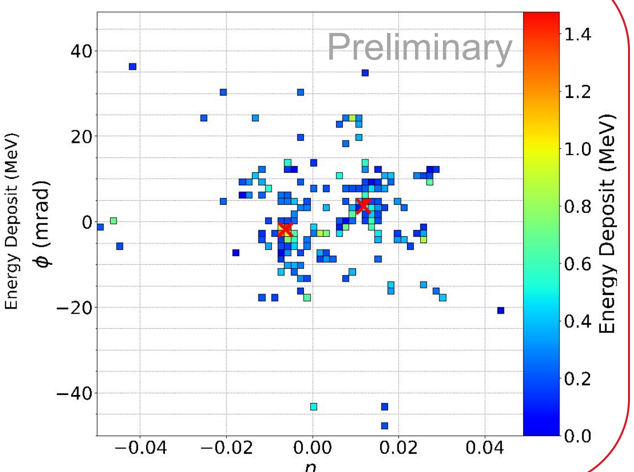
DVCS SINGLE PHOTON AND $\pi^0 \rightarrow \gamma\gamma$ DECAY

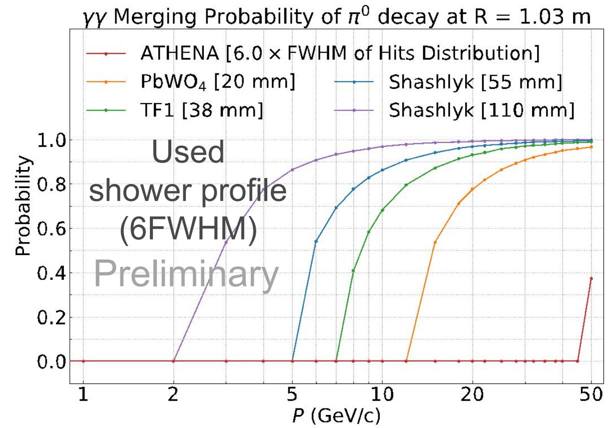
π^0 reconstruction

- π^0 background to Deeply Virtual Compton Scattering (DVCS)
  - High momentum $\pi^0 \rightarrow \gamma\gamma$ can not be distinguished from each other
  - Detector can miss the low energy photon coming from π^0 decay

15 GeV π^0 example





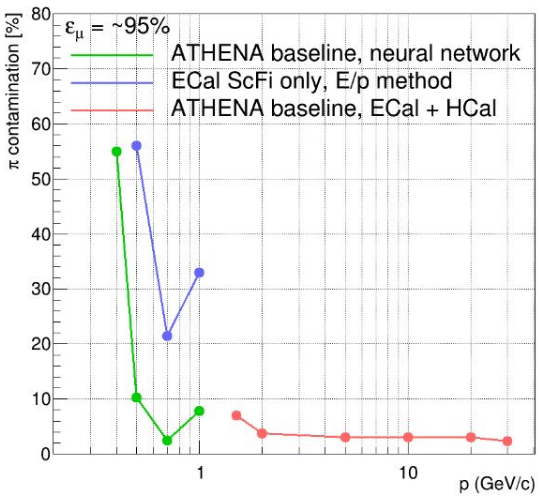


ATHENA Detector Proposal Supplemental material

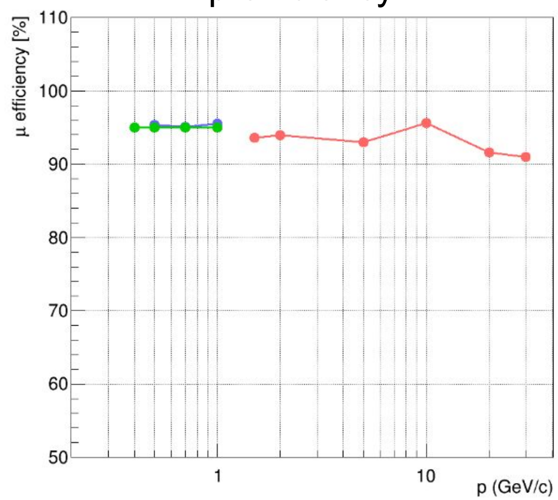
MUONS IN BARREL

- Muon/pion separation in **central region** determined from information from the **Barrel ECal** and **HCal**
- Results for single particle simulation, **see details in the following slides**

π contamination



μ efficiency



- **At η = 0: muons >~1.5 GeV/c reach HCal, and <~1.5 GeV/c curl inside the BCal** (different approach to analysis)
  - ➢ This discontinuity (in reaching HCal) is rapidity dependent
- Neural Network studies in ECal done for η = (-1,1), ECal+HCal studies and E/p studies in ECal done for η = 0
- Further improvements to muon/pion separation from PID detectors expected (DIRC)

SUMMARY AND OUTLOOK

Hybrid Imaging ECAL calorimeter proposed for the future Electron-Ion Collider

- Scintillating fibers embedded in Pb and imaging calorimetry based on silicon sensors (AstroPix)

- Meets and further improves EIC Yellow Report requirements
  - Excellent Energy and Spatial resolution
  - Electron-pion separation at low particle-momenta
  - Separation of two gammas from neutral pion up to 45 GeV
- **Beamtests and prototyping**
  - AstroPix v2 sensor beamtests in Fermilab (in Feb and planned in April 2022)
  - A few AstroPix v2 sensors in multilayer configuration tested as a tracker
  - **Plans for calorimeter prototype with radiator/ScFi/Pb layers**

Hadronic calorimetry in the ATHENA barrel

- Combined approach: bECal Pb/SciFi and Fe/Scint tail catcher
- Re-using STAR components (steel, cradles, mega-tiles)