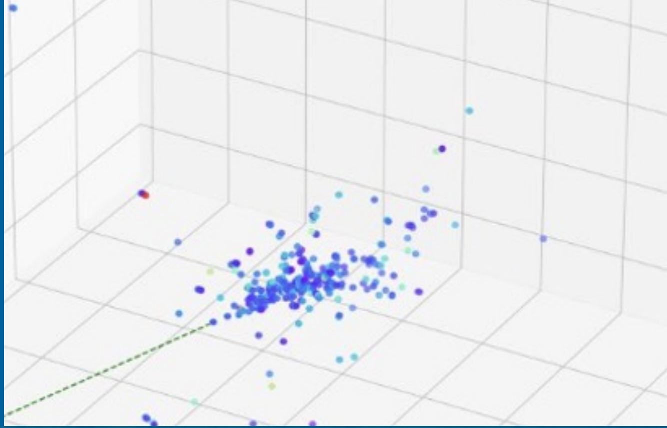
CPAD WORKSHOP 2022 @ STONY BROOK UNIVERSITY

NOV 29 - DEC 2, 2022

DESIGN CONCEPT OF IMAGING BARREL ELECTROMAGNETIC CALORIMETER FOR THE ELECTRON-ION COLLIDER



JIHEE KIM
Argonne National Laboratory
(jihee.kim@anl.gov)

for the EIC Imaging Calorimetry Collaborators

Argonne NATIONAL LABORATORY
University of Regina
UNIVERSITY OF CALIFORNIA SANTA CRUZ
University of Manitoba

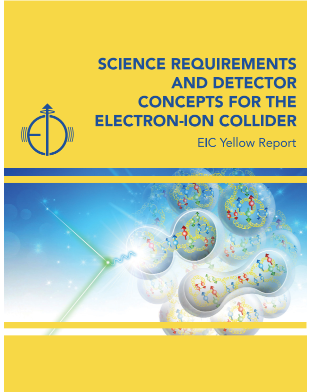
OUTLINE

- Introduction/Motivation
- Imaging Barrel Calorimetry
- Detector Performance Simulation Study
- Outlook of the Upcoming R&D Program
- Summary

INTRODUCTION

Electron-Ion Collider (EIC) – Barrel ECAL requirements

- Ultimate experimental facility to explore the gluon-dominated regime in nucleons and nuclei, shedding light on their structure and interactions within
- 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 $(10-12)\%/\sqrt{E} \oplus (1-3)\%$
  - Require electron-pion separation up to 10^4 at low particle momenta
  - Discriminate between $\pi^0 \to \gamma\gamma$ decays and single photons from DVCS processes
- Detector Technologies:
  - lead tungstate, tungsten SPACAL, lead-scintillating fiber sandwich



eicug.org

MOTIVATION

Detector Technology - Barrel ECAL

- Main role for physics goals:
  - Good energy/position resolutions (3D imaging info)
- Desired detector features:
  - Compact (in limited space), low power, reduced cooling needs
- Among technologies of well-demonstrated in various HEP/particle physics
  - Silicon detector
    - Multiple layers for high precision tracking (pixelated)
  - Lead-scintillating fiber sandwich
    - Excellent Energy resolution
- Based on features discussed, can we combine into one detector concept to fulfill EIC Yellow Report - barrel ECAL requirement?

IMAGING BARREL CALORIMETRY

Hybrid Concept

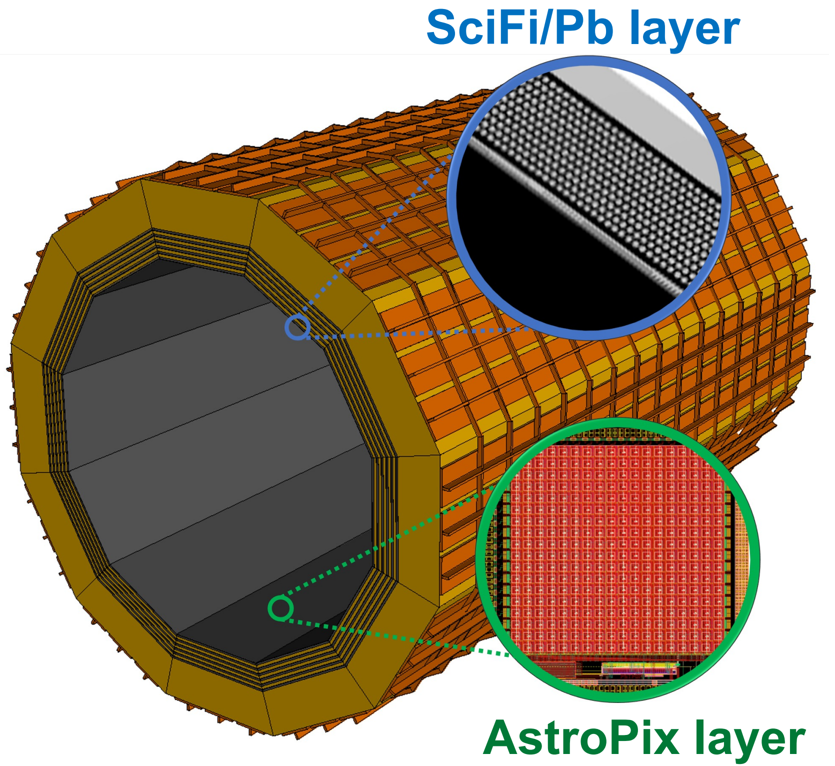
- 6 layers of AstroPix
  - Monolithic silicon sensors AstroPix (NASA's AMEGO-X mission)
  - Thickness ~ 0.155 cm per layer

NIM, A 1019 (2021) 165795

- 5 "sandwich" layers and 1 outer layer of SciFi/Pb
  - Scintillating fibers embedded in Pb (SciFi/Pb – Similar to GlueX Barrel Ecal at JLab)
  - Thickness ~ 2 cm per layer
  - Outer layer ~ 24.5 cm

NIM, A 896 (2018) 24-42

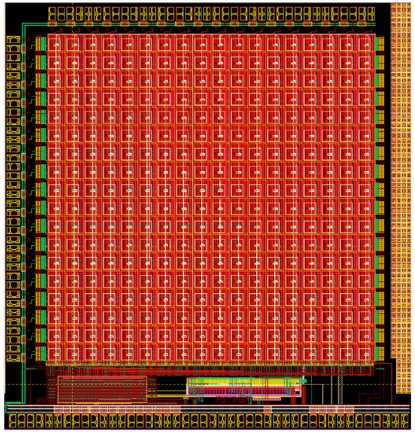
- Length ~435 cm and Inner radius ~ 78 cm
- Total depth ~ 38 cm
- Total radiation thickness of 21 X_0



IMAGING BARREL CALORIMETRY

Imaging layer – AstroPix Monolithic CMOS active pixel silicon sensors

- Main role: position measurement
- Designed for future γ-rays space-based telescope
- 6 layers of imaging silicon sensor
  - Electronics, cooling plates, glue, and support structure
  - Noise suppression of 4 σ (here, σ ~ 5 keV)
- Pixel size (0.5 mm × 0.5 mm)
- Thickness of the chip ~ 0.5 mm
- Low power consumption ~ 1.44 mW/cm^2
- Time resolution ~ 50 ns
- ~ 80M channels per each layer



AstroPix v1

IMAGING BARREL CALORIMETRY

SciFi/Pb layer – GlueX

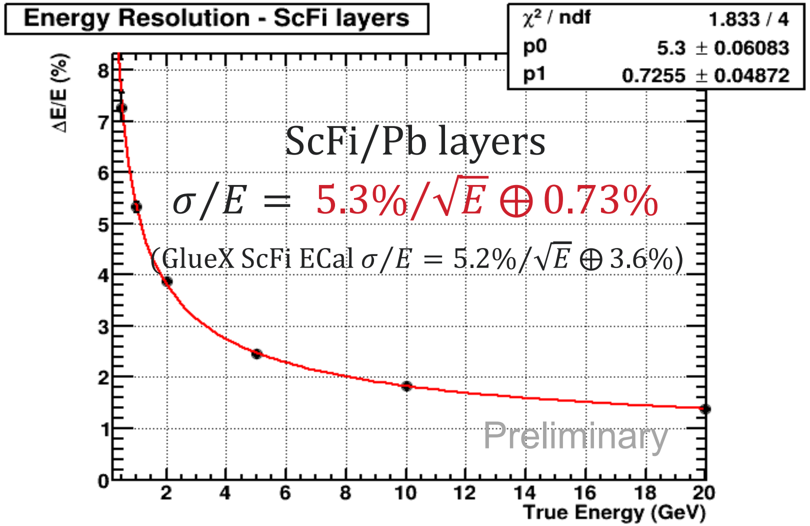
- Main role: energy measurement
- 5 “sandwich” layers and 1 outer layer of SciFi/Pb which can be extended to inner HCAL
- Fiber radius ~ 0.5 mm
- Displacement between fibers ~ 1.35 mm
- 2-side readout with SiPMs
- E_γ < 2.5 GeV tested
- In simulation: built geometry for each fiber
  - Energy deposit sum in each fiber
  - Signal sum of fibers in ~ 2×2 cm^2 grid in digitization

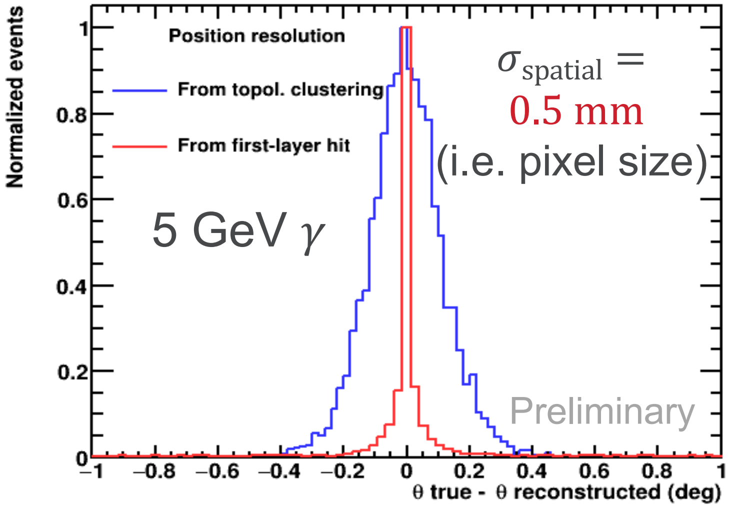
SciFi/Pb prototype

DETECTOR PERFORMANCE STUDY

Energy and Position Resolution

EIC YR Requirement:
Energy and position with moderate energy resolution $(10-12)\%/\sqrt{E} \oplus (1-3)\%$





Excellent Energy and Spatial resolution

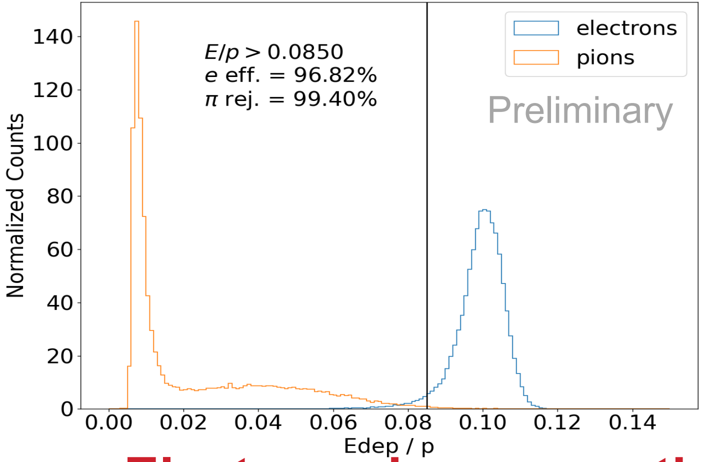
DETECTOR PERFORMANCE STUDY

Electron Identification

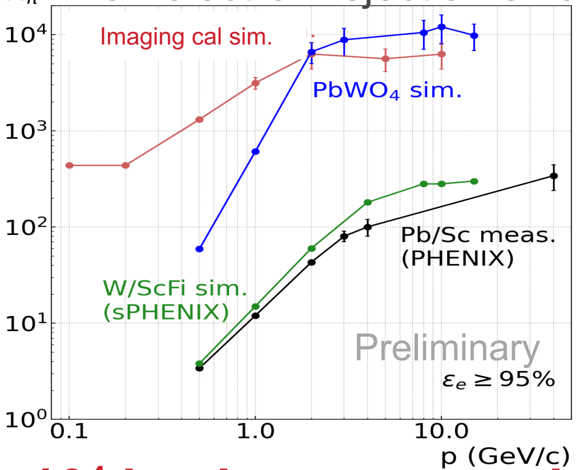
EIC YR Requirement:

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

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



Pion-electron rejection efficiency



Used ML algorithm

Standalone Calorimeter (no material/no magnetic field)

Other calorimeter technologies from EIC Yellow Report

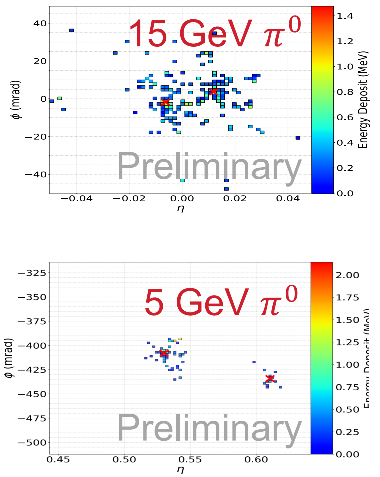
Electron-pion separation up to 10^4 in pion suppression at low particle-momenta

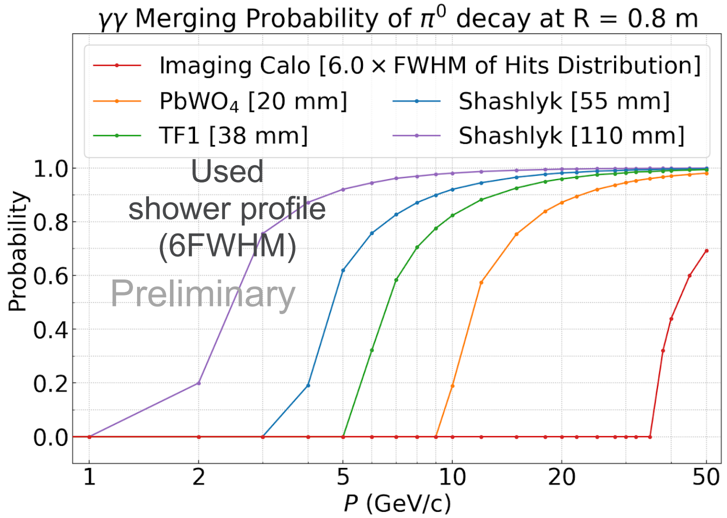
DETECTOR PERFORMANCE STUDY

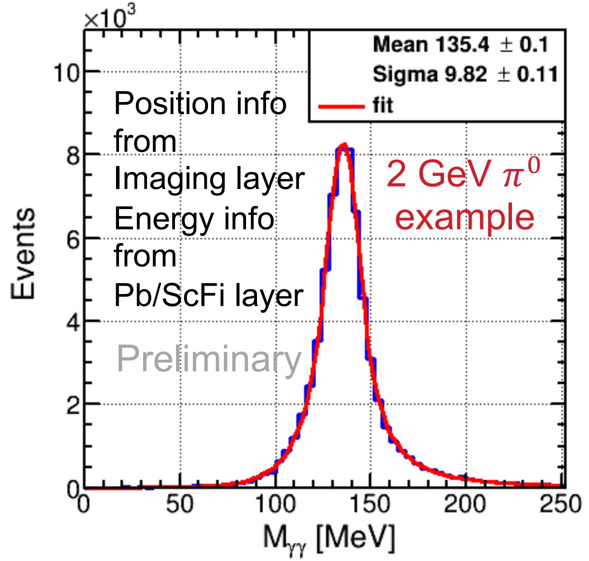
Neutral Pion Reconstruction

EIC YR Requirement:

Discriminate between π^0 decays and single γ from Deeply Virtual Compton Scattering (DVCS)







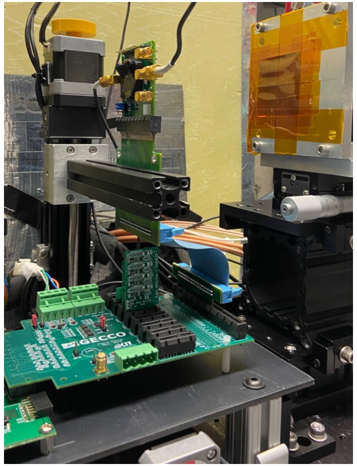
Able to separate two gammas from neutral pion above 20 GeV

TESTING OF AstroPix AND Scifi/Pb

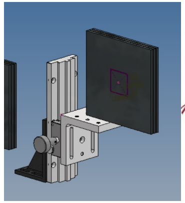
Investigation of SciFi/Pb and AstroPix Technologies (and Integration)

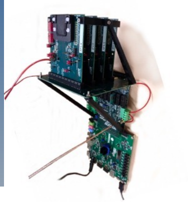
AstroPix

- Preliminary testing campaign at the Fermilab Test Beam Facility (120 GeV proton beam) Feb 2023
- Study response to electromagnetic shower with multilayer of AstroPix sensor (interleaved with tungsten radiator)



AstroPix test setup





SciFi/Pb

- Utilize a GlueX barrel ECAL prototype at JLab Hall D
- Energy measurement for higher energy up to 6.2 GeV
- Primary tests with the SiPM readout option
- Used to optimize detector design

SciFi/Pb prototype

SUMMARY AND OUTLOOK

- Hybrid Imaging 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/Position resolution, Electron identification, Separation of two gammas
- Argonne LDRD and EIC generic detector R&D are approved: prototyping on each technologies and further their integration in the EIC environment.
- R&D program towards prototyping the generic imaging calorimetry for EIC in FY23
  - Tests of AstroPix sensor in the EM calorimetry environment
  - Multilayer chip tests at FNAL with tungsten radiator and readout of multilayer chips with the Felix board
  - With a GlueX barrel ECAL prototype at JLab Hall D, high energy measurement and readout aspects

Imaging Calorimetry Collaborators

Whitney Amstrong, Manoj Jadhav, Sylvester Joosten, Simran Kaur, Jihee Kim, Jessica Metcalfe, Zein-Eddine Meziani, Tom O'Connor, Chao Peng, Paul E. Reimer, Marshall Scott, Junqi Xie, Maria Żurek

Stjepan Orešić, Zisis Papandreou, Jonathan Zrling

Tony Affolder, Vitaliy Fadeyev

Wouter Deconinck

THANK YOU!

This work is supported by Laboratory Directed Research and Development (LDRD) funding, "Tomography at an Electron-Ion Collider: Unraveling the Origin of Mass and Spin" and "Towards Prototyping the Design of a Generic Imaging Barrel Electromagnetic Calorimeter" from Argonne National Laboratory, provided by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-06CH11357.