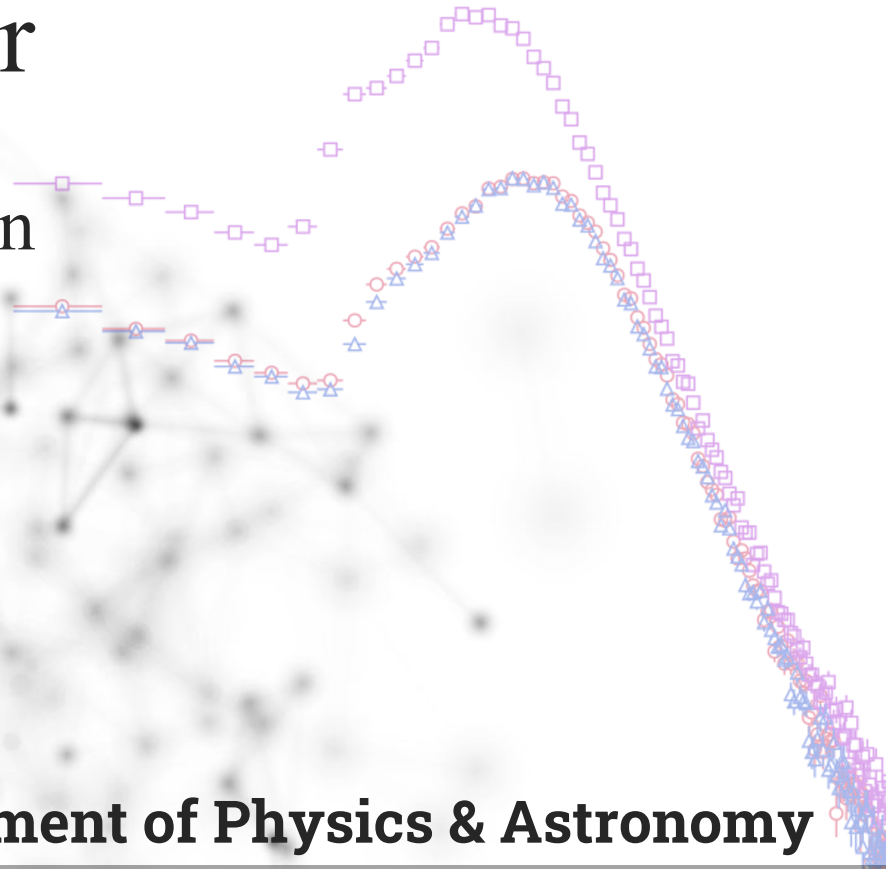
Energy Deposition on Scintillating Tiles of the Barrel Hadronic Calorimeter at the Electron-Ion-Collider

HUGS Seminar Presentation

by

Olaiya A. Olokunboyo



Date: June 12th, 2025

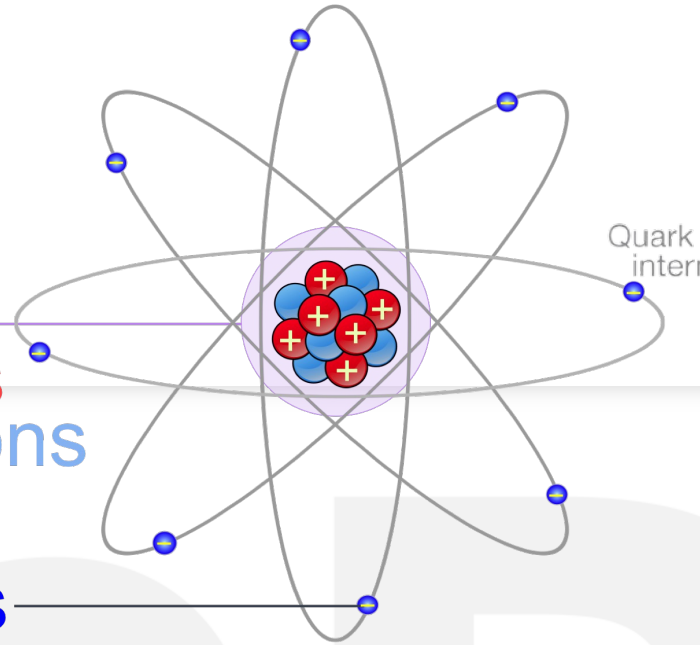
Department of Physics & Astronomy

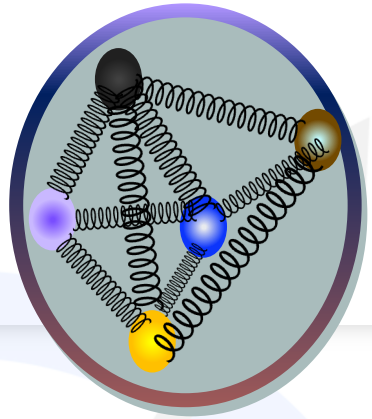
U.S. DEPARTMENT OF ENERGY

HUGS 40 years!

University of New Hampshire

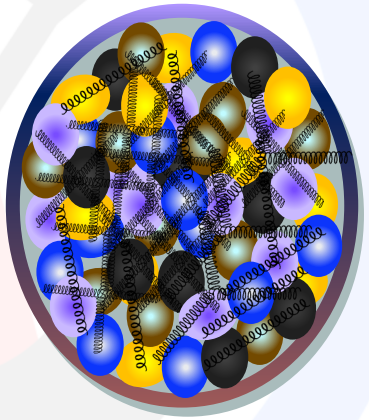
Scientific Imaging Curiosity - The Electron-Ion Collider (EIC)





Low Energy

Growth in gluons density



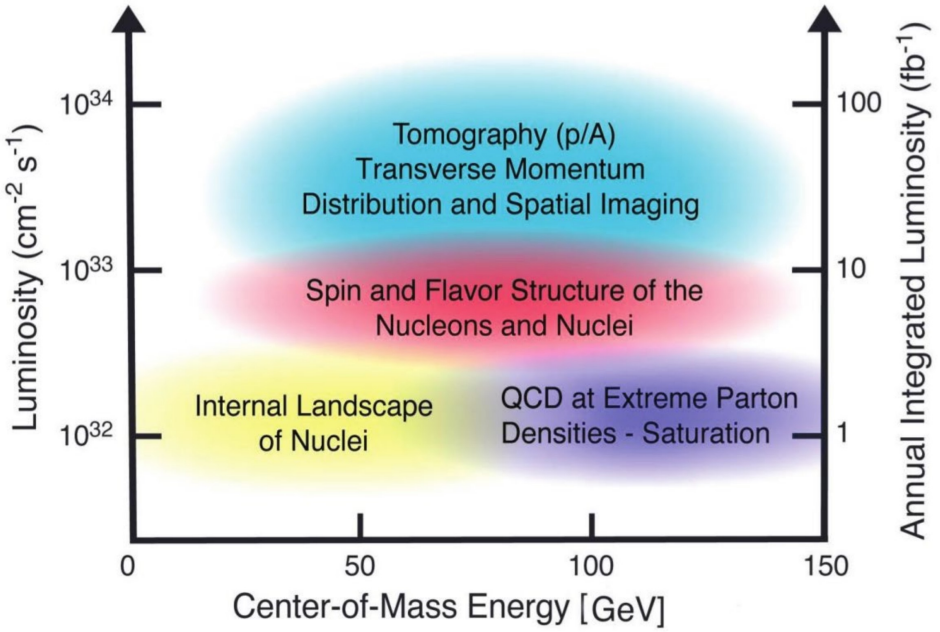
High Energy

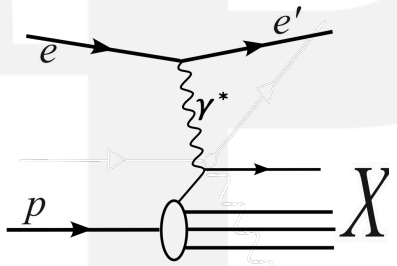
Brookhaven National Laboratory. (2020, March 25). *Electron-Ion Collider (EIC) at Brookhaven National Laboratory* [Photo album]. Flickr
Maria ŻUREK, Argonne National Laboratory, Oct. 2024 slide

EIC Physics Program

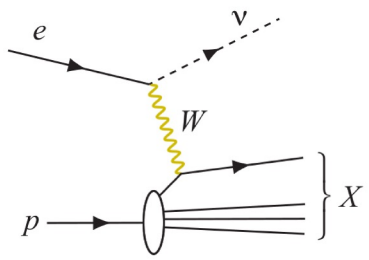
- **EIC purpose-built to study internal structure of nuclei and the emergent dynamics of QCD**

- **Right:** major topics to be explored at EIC vs. required luminosities & CoM energy
  - **(n)PDFs**
  - **Spin/flavor structure of nuclei**
  - **Saturation/extreme parton density**
  - **TMDs/GPDs**
- Accessed via wide variety of channels:
  - NC DIS
  - CC DIS
  - SIDIS
  - Exclusive

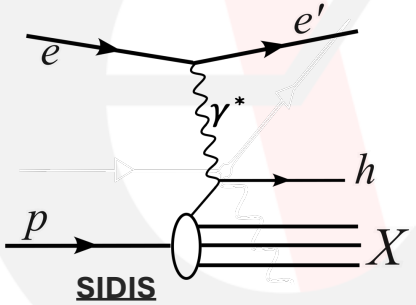




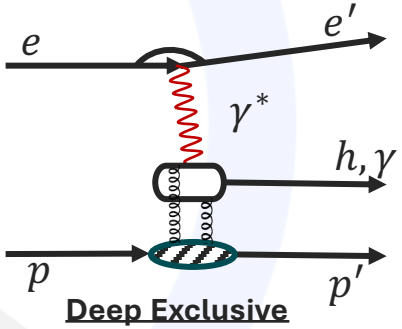
NC DIS
(n)PDFs



CC DIS
(n)PDFs
spin/flavor structure
tomography



SIDIS
spin/flavor structure
Tomography, TMDs



Deep Exclusive
Tomography, TMDs
extreme parton density

Nuclear Physics News, 31(4), pp. 15–19. doi: 10.1080/10619127.2021.1954435
Nucl.Phys.A 1026 (2022) 122447

The Central ePIC Detector

Tracking

Provides high-precision essential for mapping charged particle trajectories

PID

Identification of charged particles and the time-of-flight measurements

EM Calorimetry

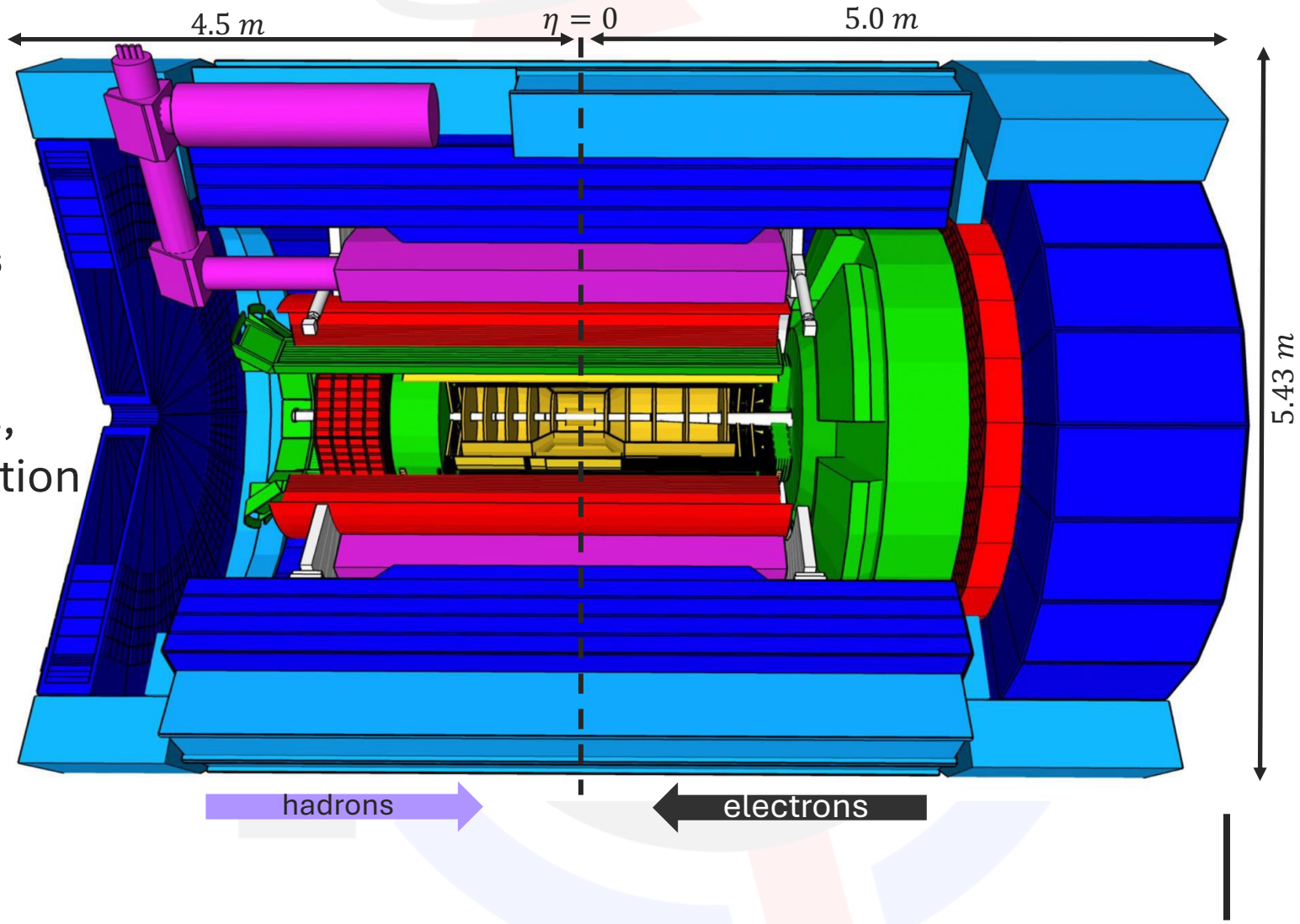
Measures the energy of electrons, photons, and pions with high resolution

Magnet

Provides magnetic field for particle trajectories and momentum measurements

Hadron Calorimetry

For detecting hadrons and measuring their energies



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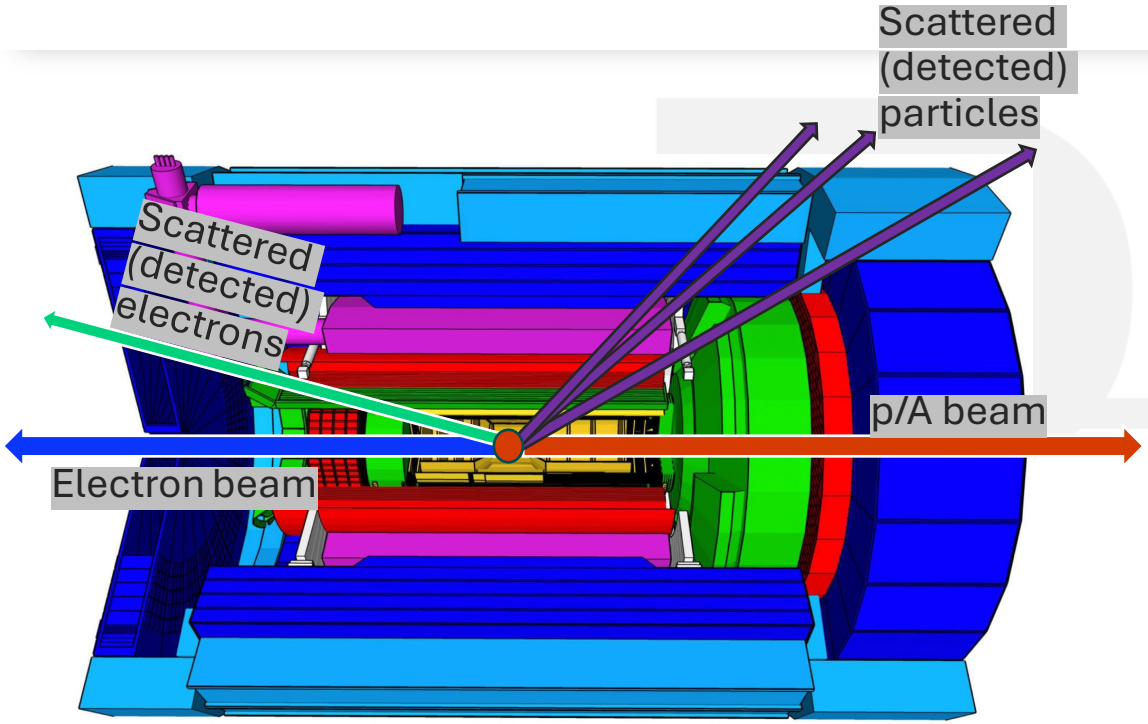
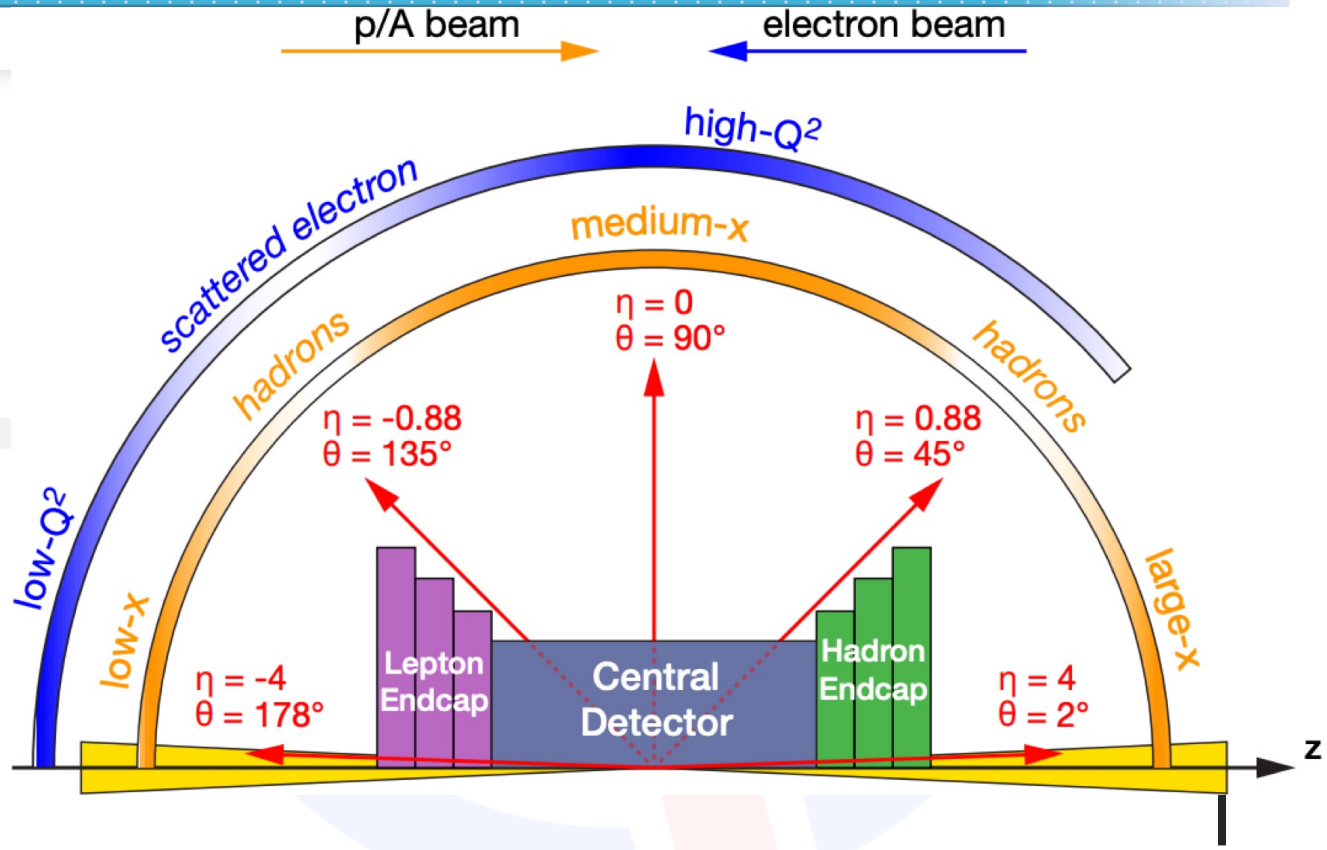
Eur.Phys.J.A 52 (2016) 9, 268

The Central ePIC Detector

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right) = \frac{1}{2}\ln\left(\frac{p + p_z}{p - p_z}\right), \qquad -4 < \eta < 4;$$





Nucl.Phys.A 1026 (2022) 122447
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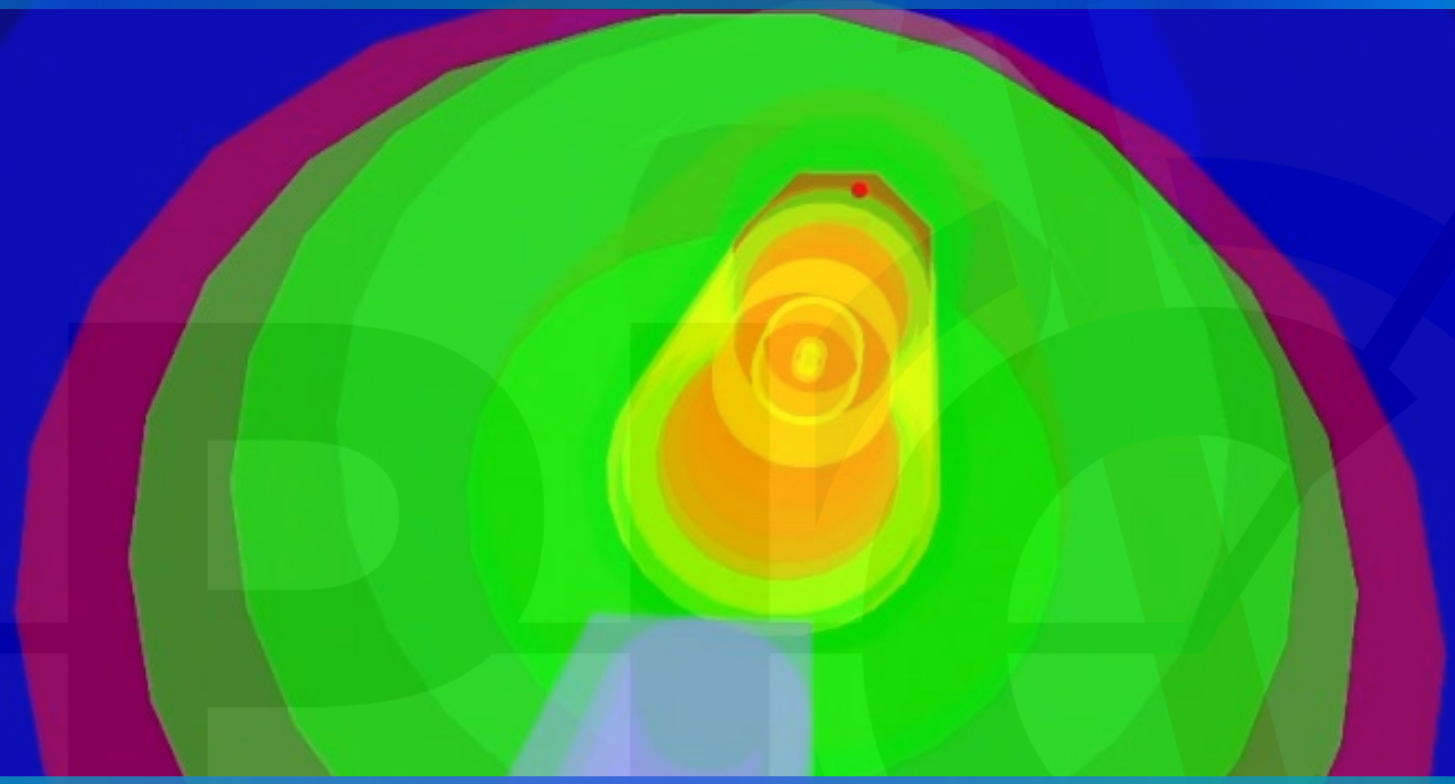
Barrel Hadronic Calorimeter (BHCal)

A measure of the energy and momentum properties of the final-state hadrons in the central pseudorapidity $-1.1 < \eta < 1.1$

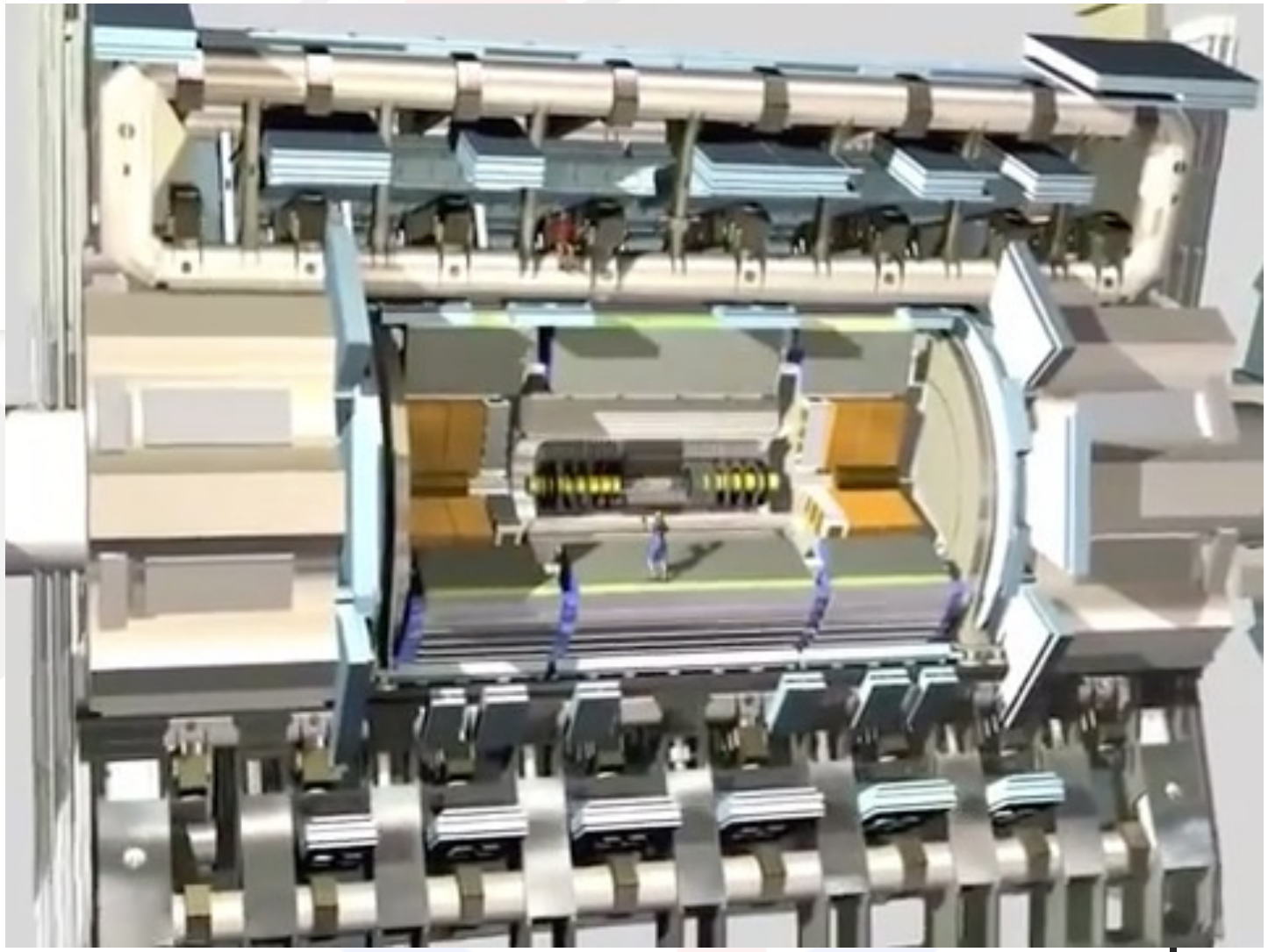


BHCal aims to constrain the jet-energy scale and resolution by capturing the long-lived neutral component of jets, while also measuring the hadronic final state, tagging charged-current DIS events, and contributing to muon identification.

Brookhaven National Laboratory. (n.d.). *ePIC experiment at the Electron-Ion Collider*

BHCal Energy Deposition - Scintillation Tiles

- When a particle passes through the tile, it excites the scintillator material.
- The material then emits light, which is collected by wavelength-shifting silicon photomultipliers (SiPMs).
- The intensity of the light is proportional to the energy deposited by the particle.



One of the physics goals with the BHCal is to aid in the reconstruction of muons.

CERN. *ePIC Barrel HCal DSC Review.* YouTube, 15 June 2023, https://www.youtube.com/watch?v=6KEB21_ngCE

Muons Measurement with BHCal

Why muons?

- **Distinguish signal**: separating signal processes from hadronic backgrounds is important for studying rare or clean electroweak and heavy-flavor processes.
- **Charged Current DIS**: where final-state hadrons and muons may appear help in charm and beauty decays, quarkonia production

How can muons be measured?

- **Energy Deposition & penetration depth**: muons penetrate more deeply than hadrons and deposit minimal energy compared to hadronic showers. We can exploit this by looking for low-energy deposition and deep penetration.
- **Machine learning**: train classifiers using energy patterns, timing, and tracking to identify muons probabilistically.

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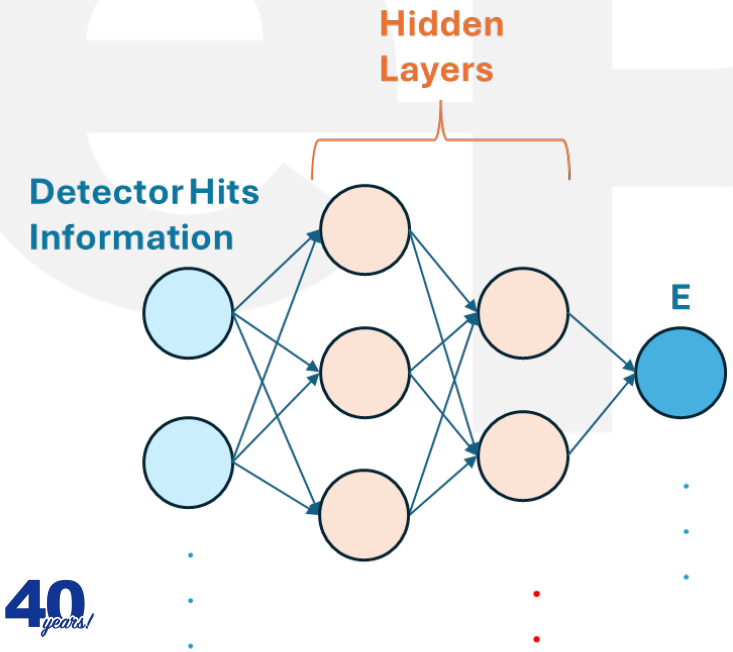
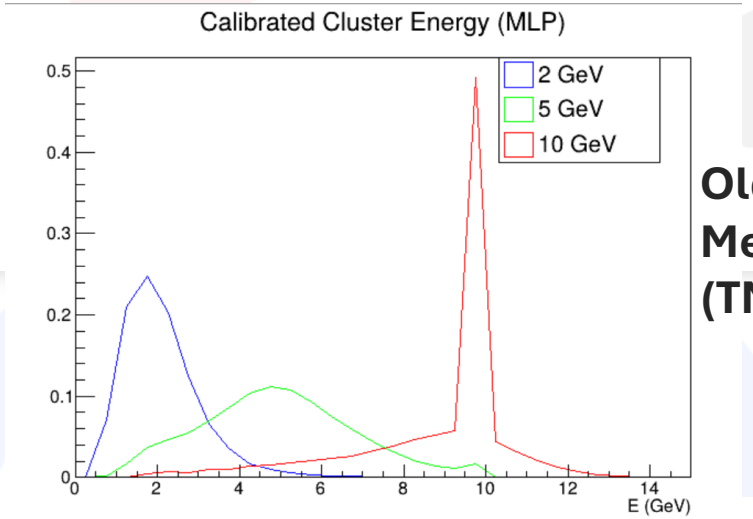
New neural network currently in development to perform BHCal energy calibration

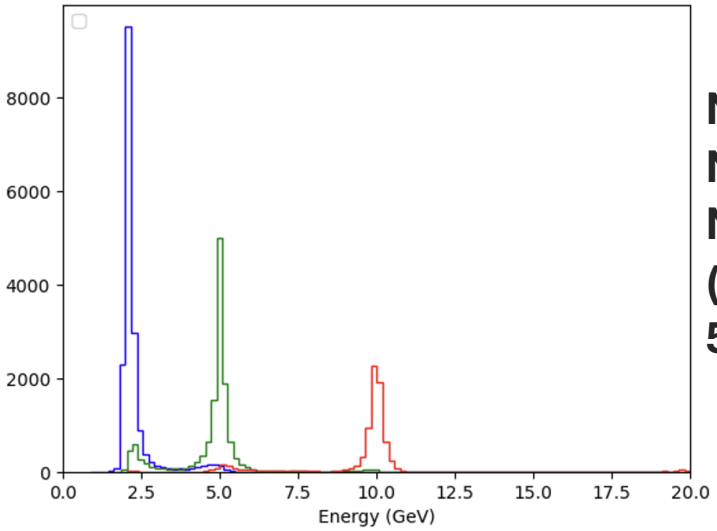
- **Framework:** PyTorch
- **Architecture:** Multi-Layer Perceptron
- **Details:** 3 Hidden Layers, 256 Neurons

- Initially designed by D. Ruth
- **Hyperparameters currently being optimized by O. Olokunboyo, N. Santiesteban, D. Ruth**





Old Method (TMVA)

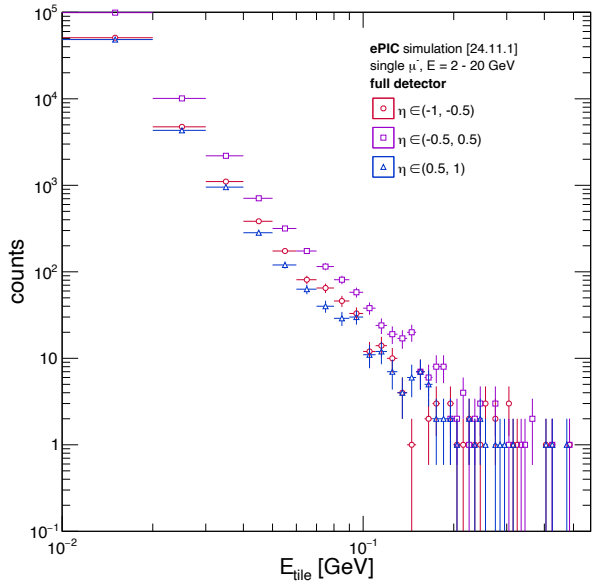


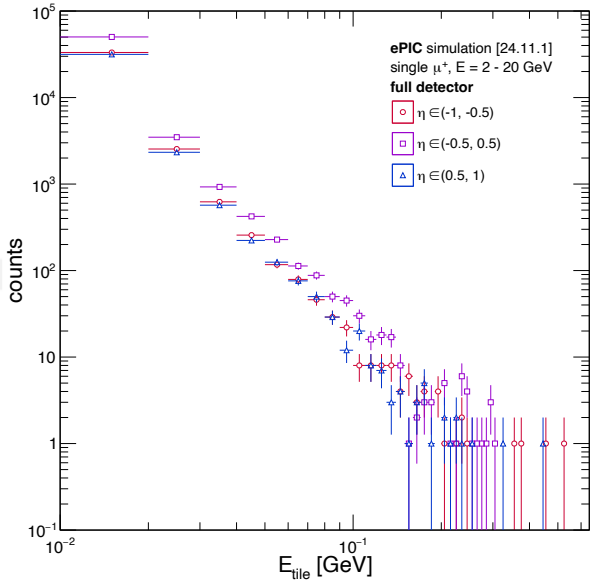
New Neural Network (Trained 5 minutes)

BHCal Energy Deposition Simulation Studies

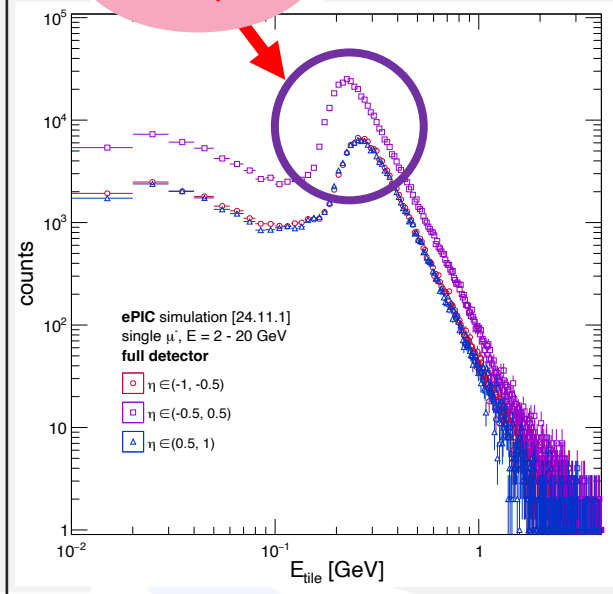
μ energies deposited on tiles: the sum of energy deposited on a scintillator tile by single μ^- and μ^+ with energies between 2 and 20 GeV/c as a function of η.

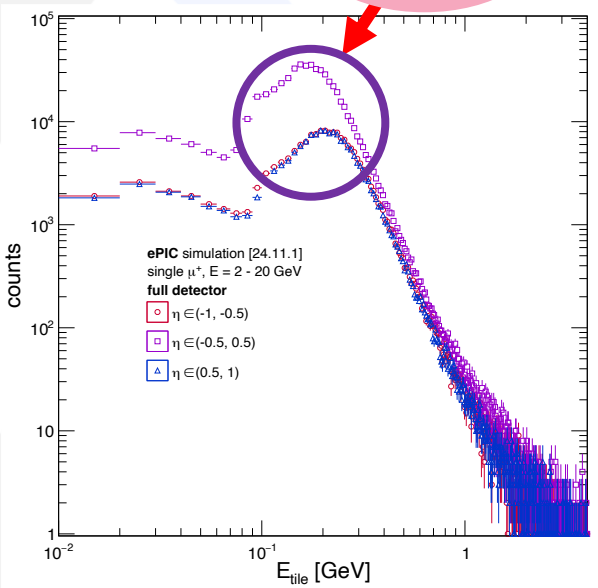
Simulated





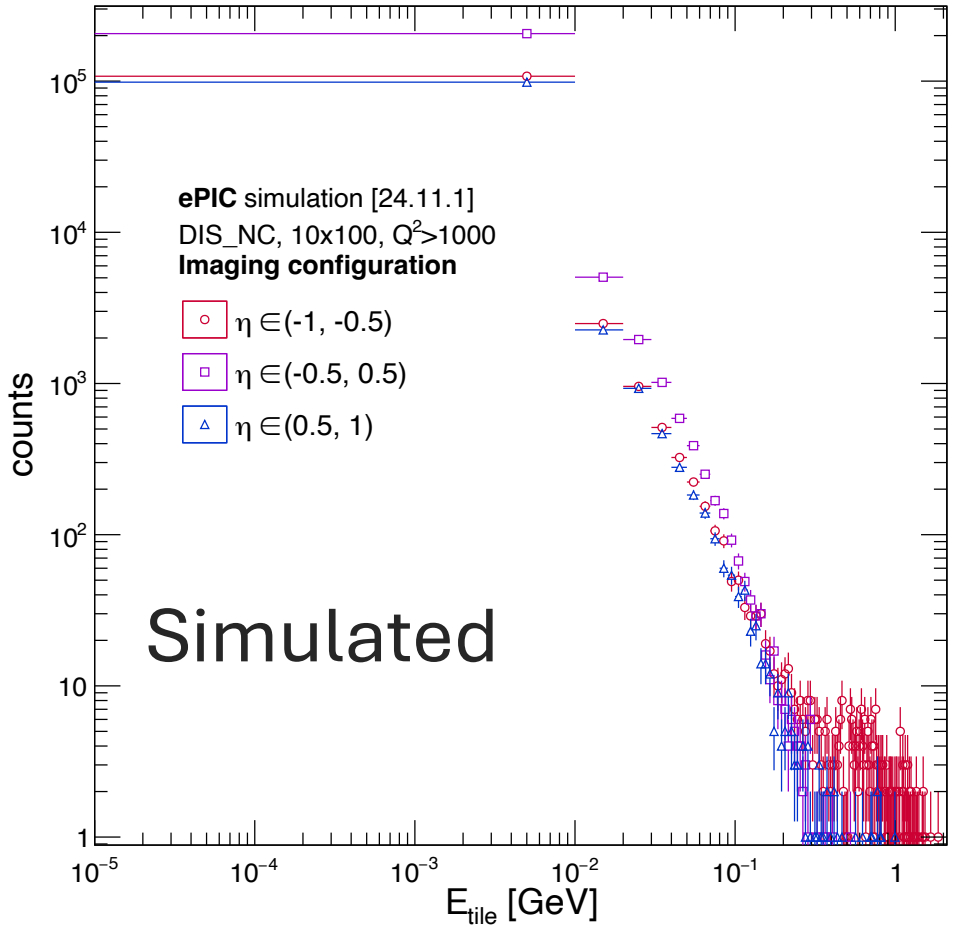
Reconstructed

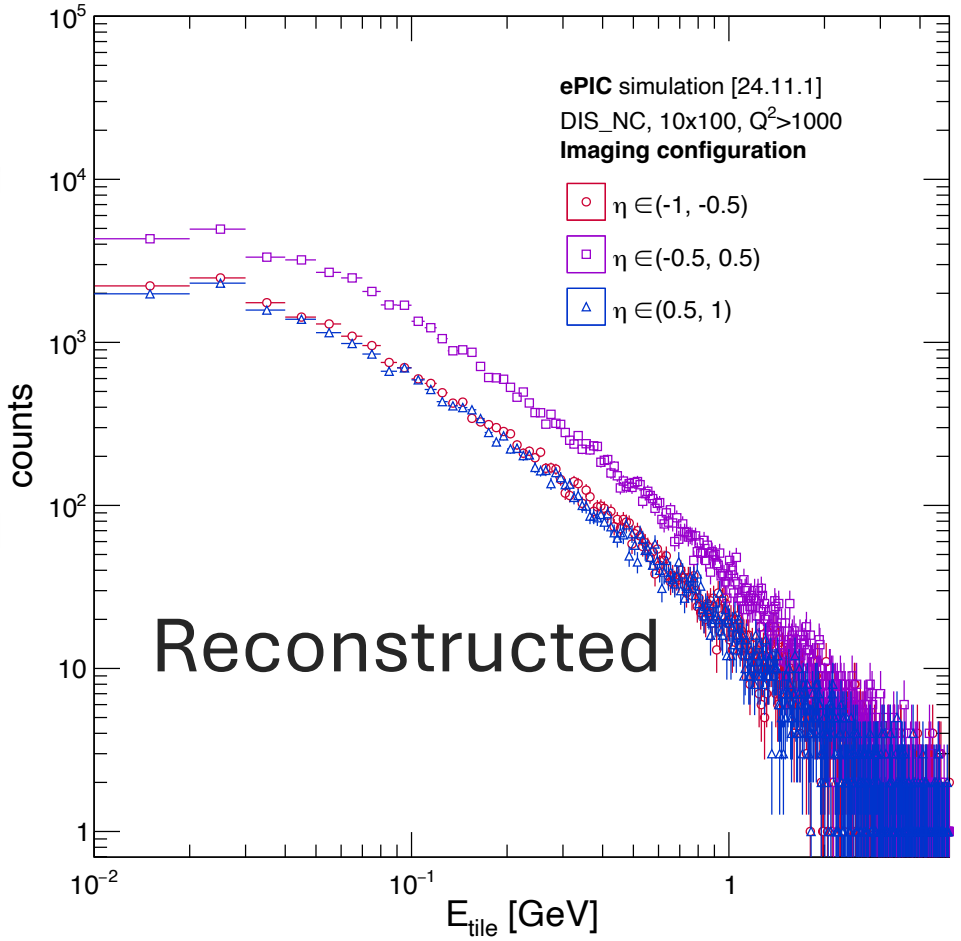




BHCal Energy Deposition Simulation Studies

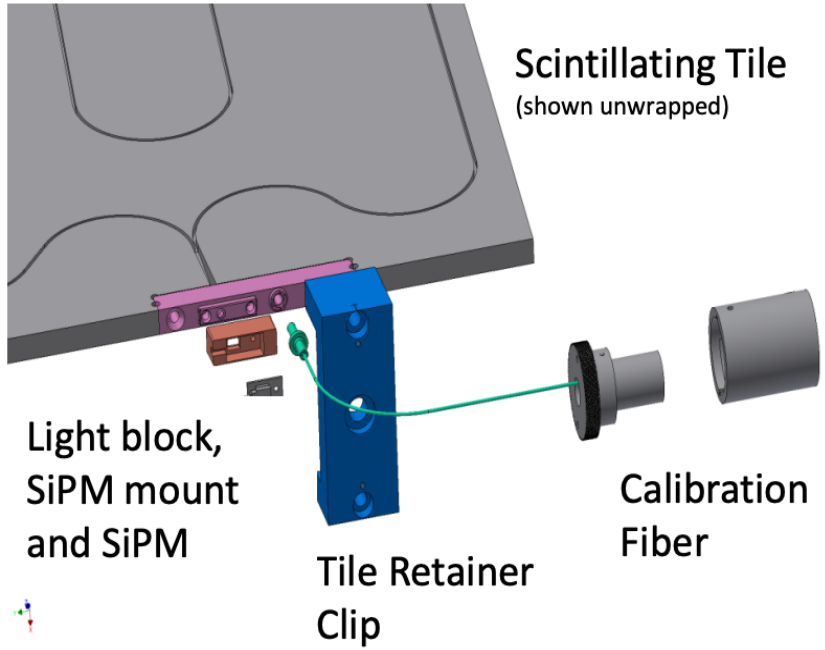
μ DIS NC energy on tiles: the distribution energy of "hits" (i.e. the simulated and reconstructed energy of individual tiles) in BHCal with beams 10×100 DIS events for $Q^2 > 1000\ GeV^2$ for all particles in the events as a function of their η.

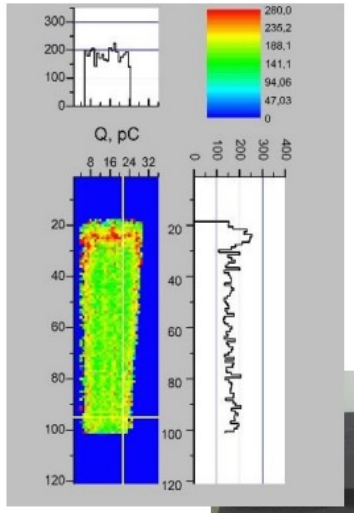


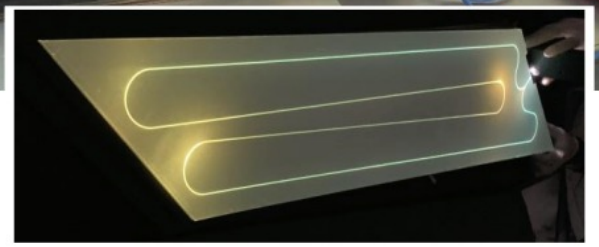


Next: Going Technical - BHCal Tiles testing

- **Setting up and optimizing the test stand for the tiles**
- **Using SiPM electronics to perform cosmic ray measurements and calibration**
- **Repeat sector – level cosmic calibration**







J. G. Lajoie, “ePIC Barrel HCal DSC Review,” presented at CERN Indico, 2023. [Online]. Available: https://indico.cern.ch/event/1238718/contributions/5431984/attachments/2692321/4672270/3%20lajoie%20ePIC%20Barrel%20HCal%20DSC%20rev1.pdf

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