Performance and Calibration of the ePIC Barrel HCal

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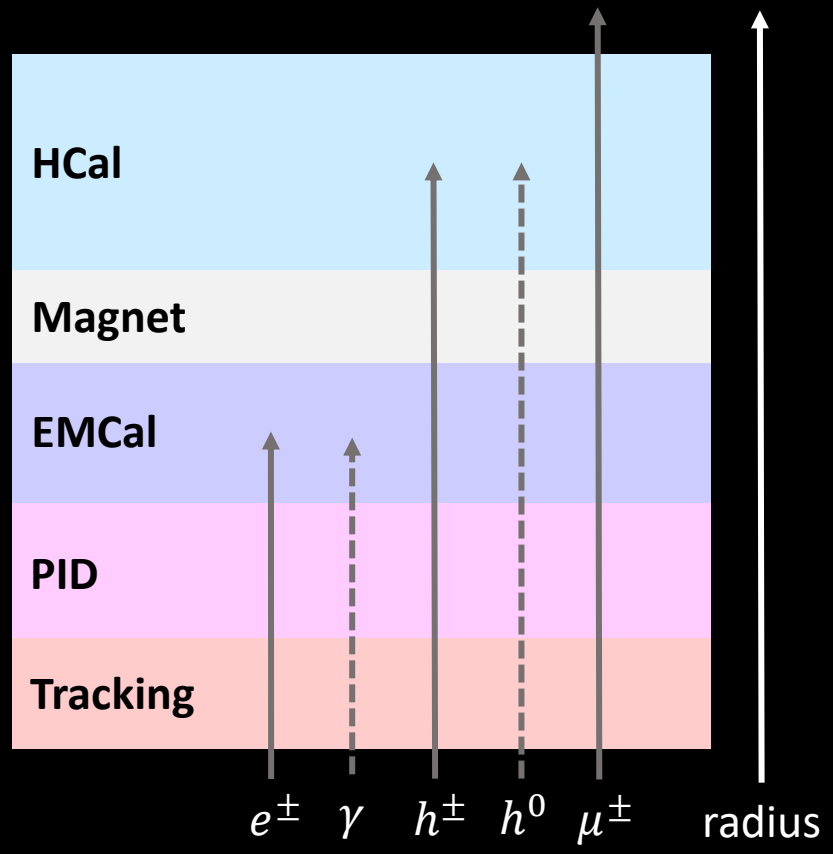
Overview | introduction

- In barrel region ($|\eta| < 1$), jets are relatively soft
  - Tracker provides best momentum determination
  - But hadronic calorimeter would provide measurement of h^0

∴ The Barrel Hadronic Calorimter **(BHCal)** will serve several roles at ePIC
  a) Precise jet energy reconstruction
  b) Additional determination of e^- kinematics
  c) Solenoid flux return
  d) Possible $\mu^\pm$ identification

- **Right:** schematic diagram of a typical particle experiment

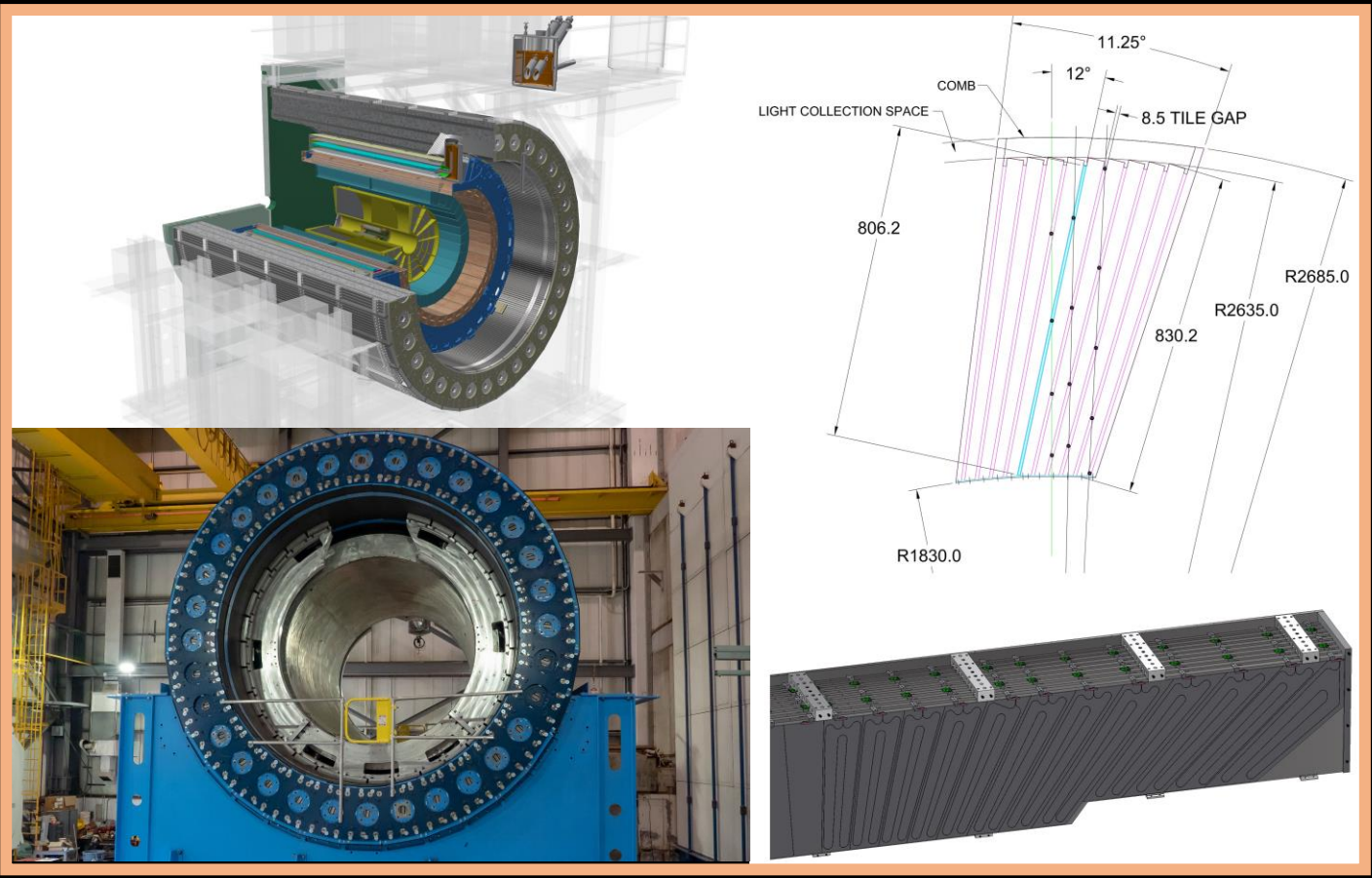


Overview | the sPHENIX Barrel Hadronic Calorimeter

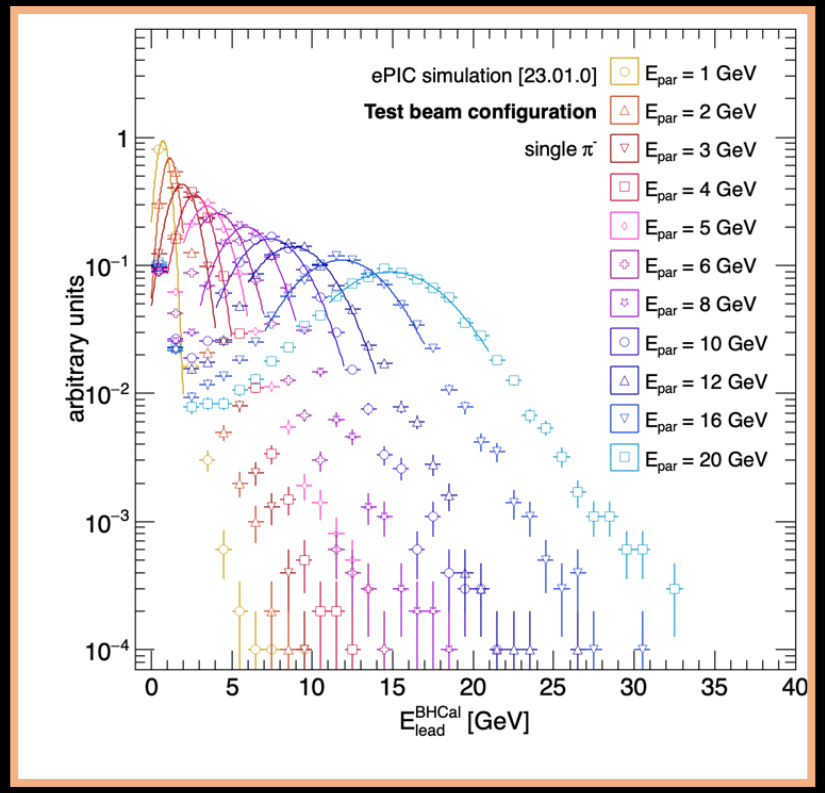
- **ePIC will utilize the (outer) sPHENIX BHCal**

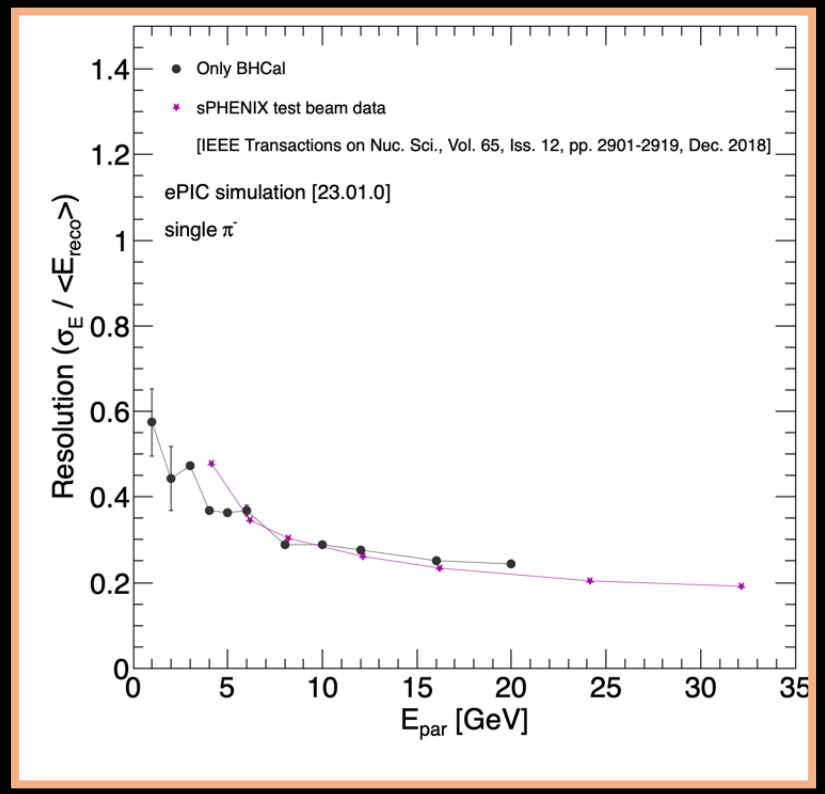
- Consists of alternating steel and scintillating tile (+ WLS fibers)
  - $|\eta| < 1.1$, 2π coverage
    - 48 towers/sector, 32 sectors
    - 5 tiles/tower
  - $\Delta\eta \times \Delta\varphi \sim 0.1 \times 0.1$
  - Uses SiPM readouts
    - 1536 channels

- sPHENIX gangs each signal from tile into 1 preamp per tower
  - ☞ **ePIC will read out each tile using HGCROCs**
  - (same chip as LFHCal)



Overview | implementation & plans for ePIC



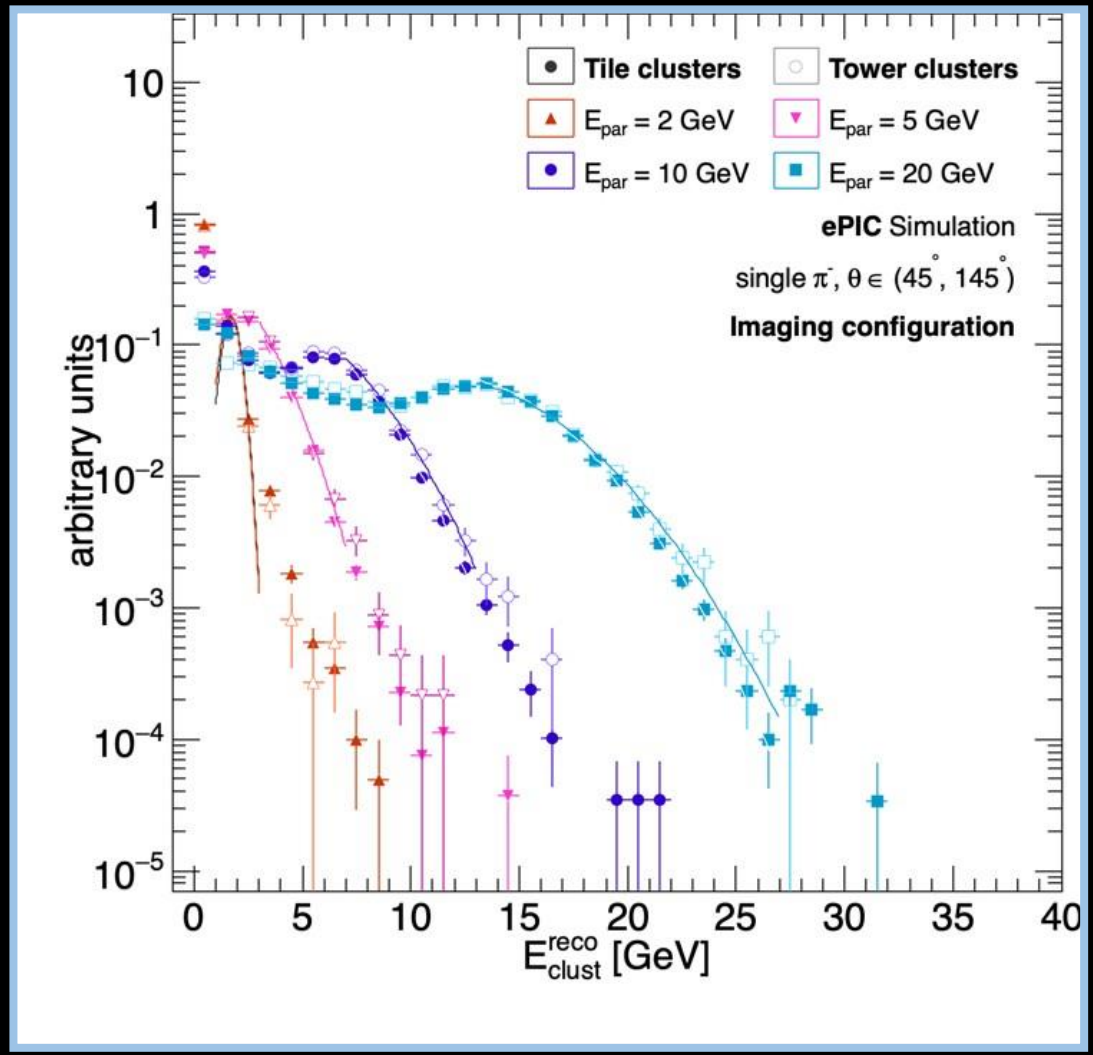


- BHCal implemented in DD4hep by John Lajoie
  - **Left:** reconstructed energies in BHCal for single π^-
- **Right:** calculated resolutions from ePIC simulation **(black circles)** vs. sPHENIX test beam data **(purple stars)**

Calibration

- Energy measured by BHCal degraded for several reasons
  - Inefficiencies in clustering
  - Fluctuations in hadronic and EM parts of shower
  - Energy loss in inactive material
  - Loss due to nuclear-binding energies
  - Etc.
- ∴ **Measured energy has to be calibrated!**

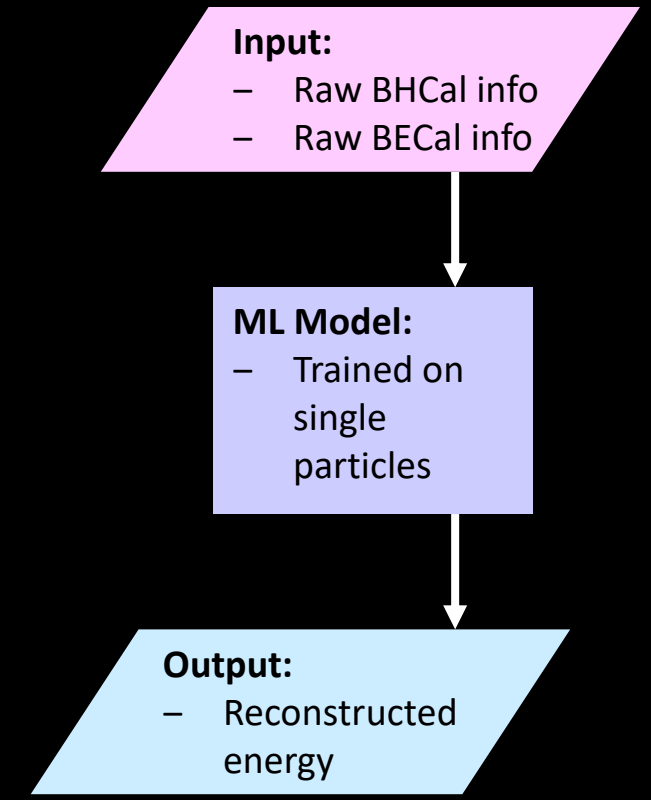
- **Right:** energy of leading BHCal cluster for single π^- events with full ePIC simulation
  - More on tile vs. tower clusters in following slides



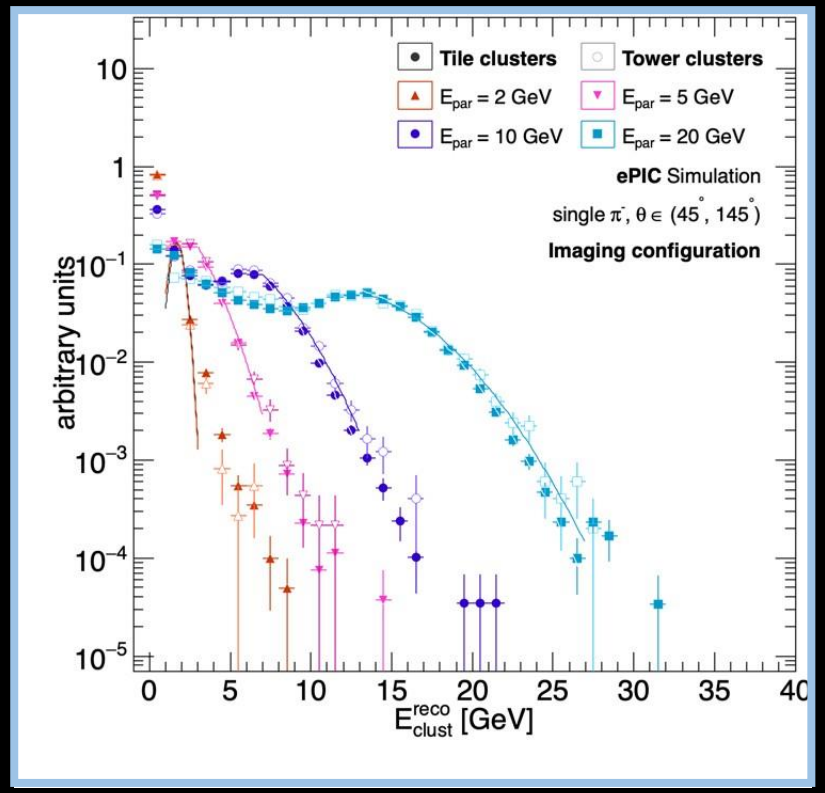
Calibration | strategy

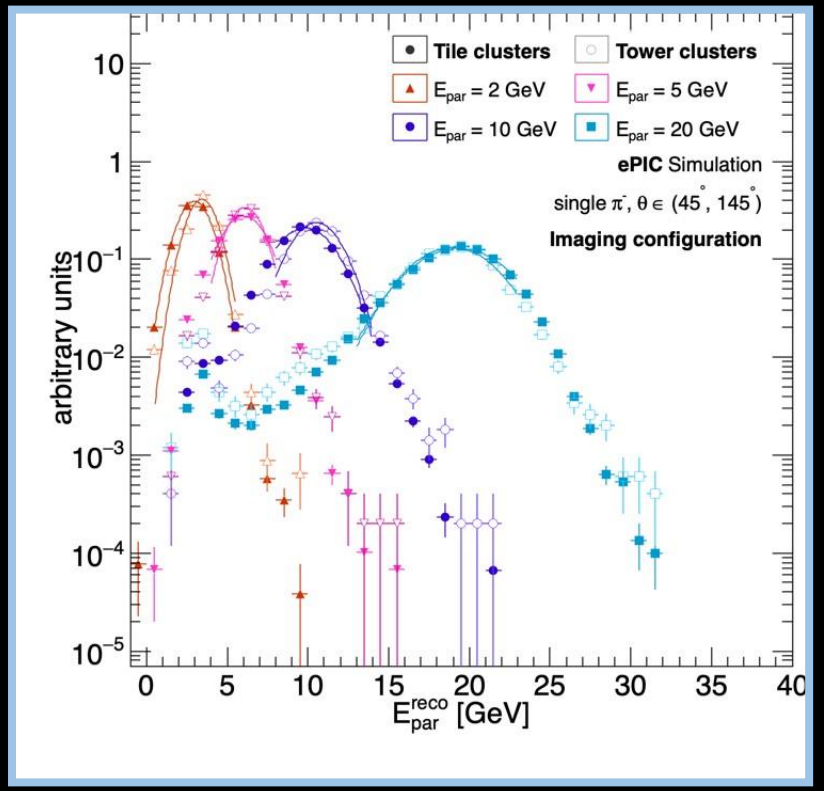
- Start at **EM Scale:**
  - EM part of shower corrected for
    - i.e. Sampling fraction applied
  - Things like nuclear binding energy still need to be corrected for
  - ☞ **Good target for Maching Learning!**

- **Used TMVA:**
  - Trained on single particle events
  - Regression analysis particle energy as target
  - (More details in backup)



Calibration | output

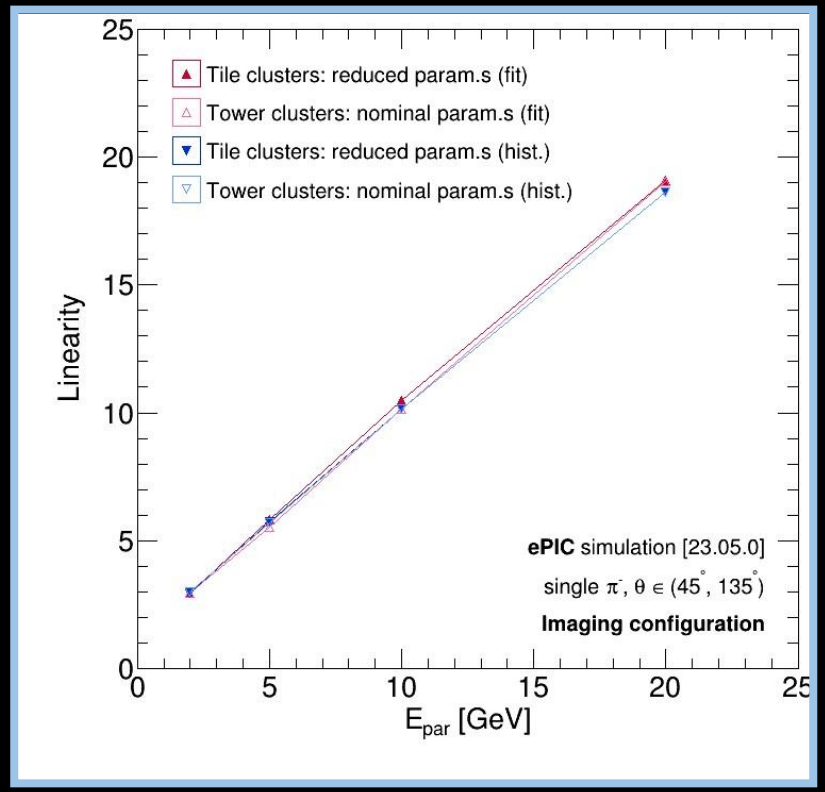


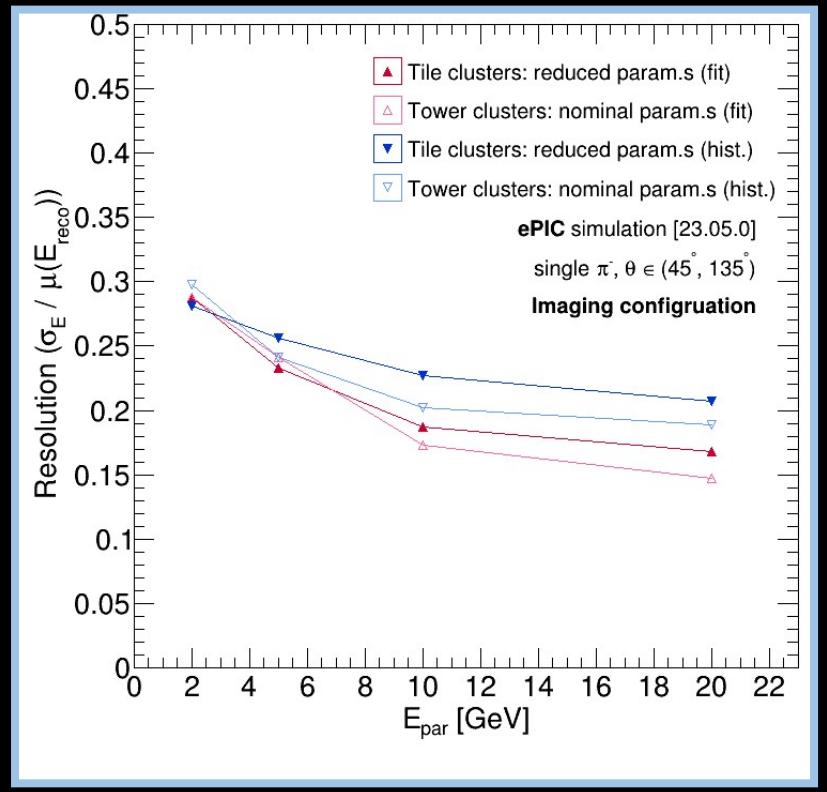


- **Left:** uncalibrated energy of lead BHCal clusters in single π^- events
  Right: calibrated energy
  - ☞ i.e. particle energy in this scenario

- **Calibrated energies still show significant tails**
  - Under investigation now…
  - One source could be (unwanted) cluster splitting?

Calibration | using tiles rather than towers

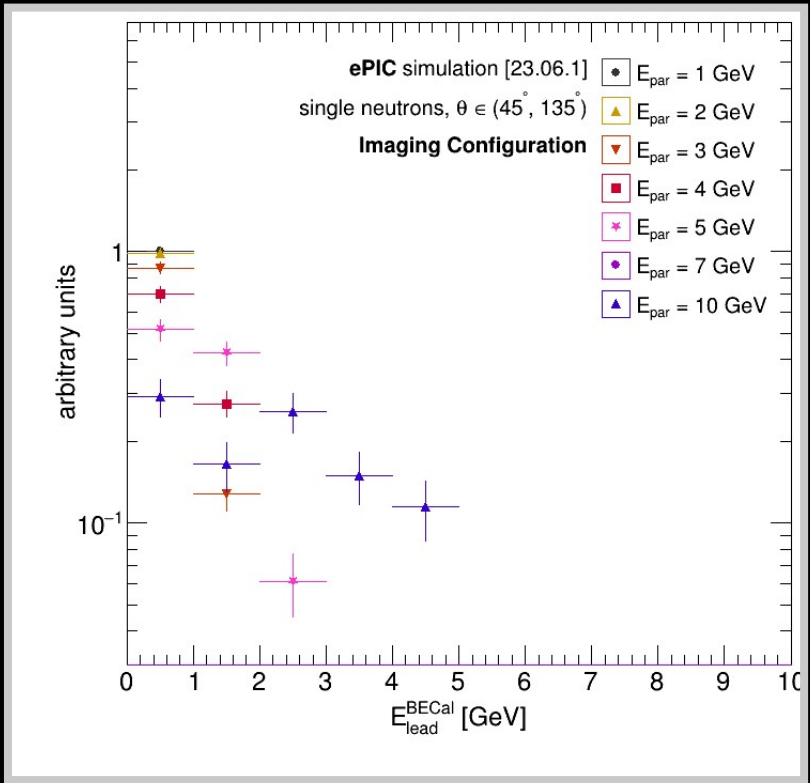


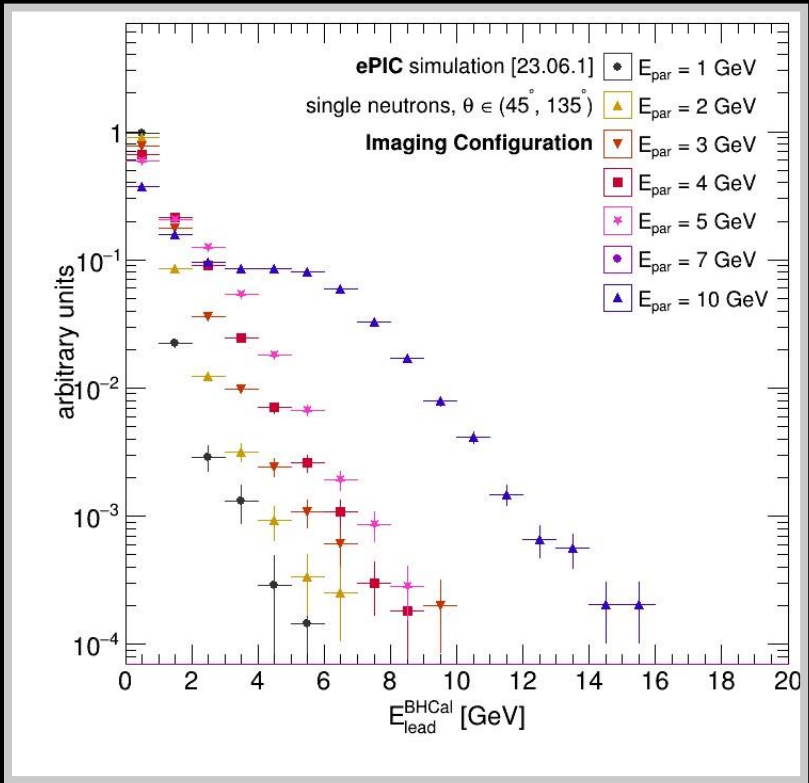


- How does using tiles vs. towers as readout impact resolution?
  - **Left:** calculated linearity
  - **Right:** calculated resolution

- Tower-based cluster resolution a little better than tile-based using this model
  - Under investigation now…

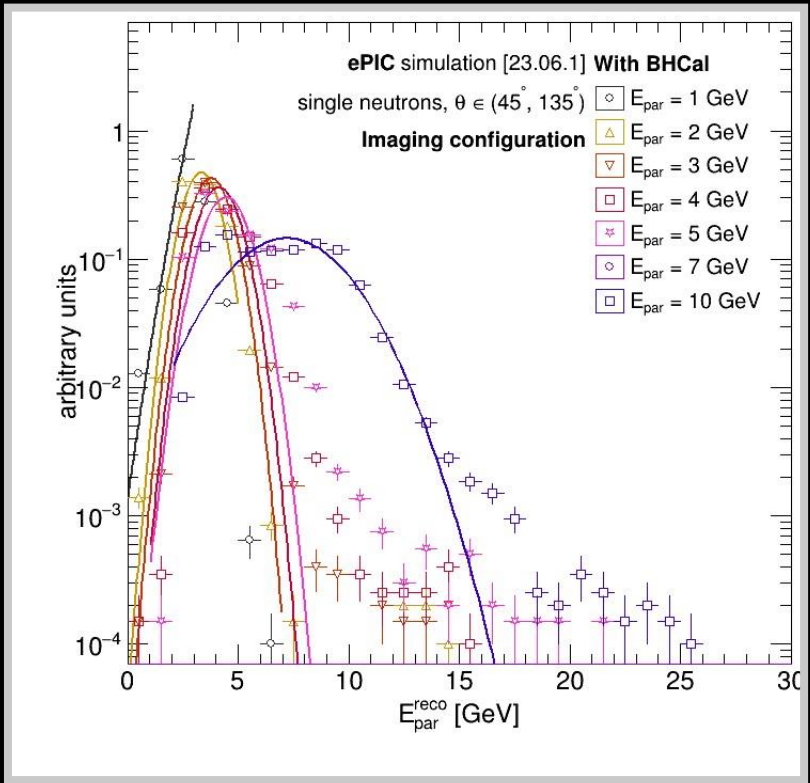
Performance | neutrons

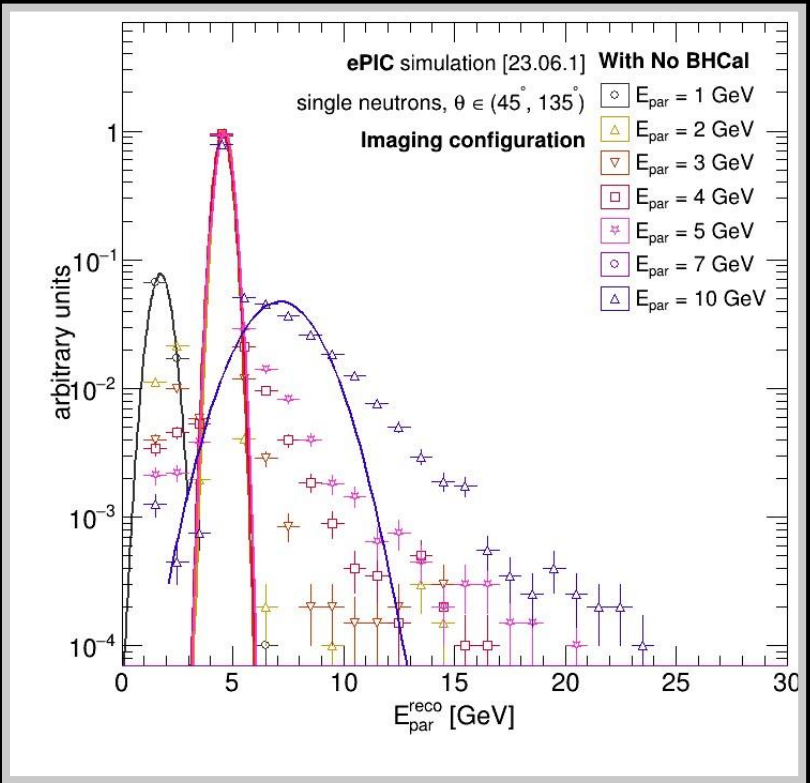




- Now exploring performance of BHCal
  - Extending calibration studies to include other particles such as neutrons
  - ☞ **How much h^0 energy makes it to the BHCal?**
- Raw lead cluster energies from BECal **(left)** and BHCal **(right)** for single neutrons

Performance | neutrons





- First attempts at calibrating neutrons:
  - **Left:** calibration with BHCal info
  - **Right:** calibration without BHCal info
  - **How does BHCal impact measurement of neutral energy?**
- **Needs work!**
  - Cluster splitting (see backup) could be negatively impacting calibration

Summary & Next Steps

Summary

- The BHCal will be a valuable part of jet measurements at ePIC
- Performance and calibration studies are early, but off the ground!

Calibration Studies

- Questions to answer:
  - How do individual BECal layers affect π^- calibration?
  - How does calibration vary with η/φ?
- Improve calibration model
  - Hyperparameter scan
  - Extend ML model to split clusters?
- Integrate workflow into EICrecon

Performance Studies

- Continue studying neutron response
- Study response to $\mu^{\pm}$
- Study BHCal impact on JES in realistic DIS events
- Implementation of benchmarks

ePIC

STATE

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Thanks!

Backup | tile and SiPM/chip information

Tiles

- Scintillating tiles manufactured by Uniplast
  - sPHENIX integrated into simulations detailed cosmic ray response maps from MEPHI
    - ☞ Uruguyan telescope
- Not expecting significant radiation damage to tiles
  - But will replace SiPMs and readout
  - Will need to remove tiles
    - ☞ Could remeasure cosmics

Chips

- Plan to piggy-back on HGCROC development for LFHCal
- BHCal Designed for 40K 15 µm pixels

Backup | TMVA parameters

Parameters

- Regression analysis
- Trained on 1000 events
- 3 methods (all out-of-the-box):
  a) Linear Discriminant (shown)
  b) MLP (neural network)
  c) Boosted Decision Tree

Training Variables

- Energy of leading BHCal and BEMC clusters
- Eta, phi of leading BHCal and BEMC clusters
- No. of hits in lead BHCal and BEMC clusters
- Sum of energy in imaging and SciFi layers
  - To-Do: add in individual imaging layers

Target

- particle energy

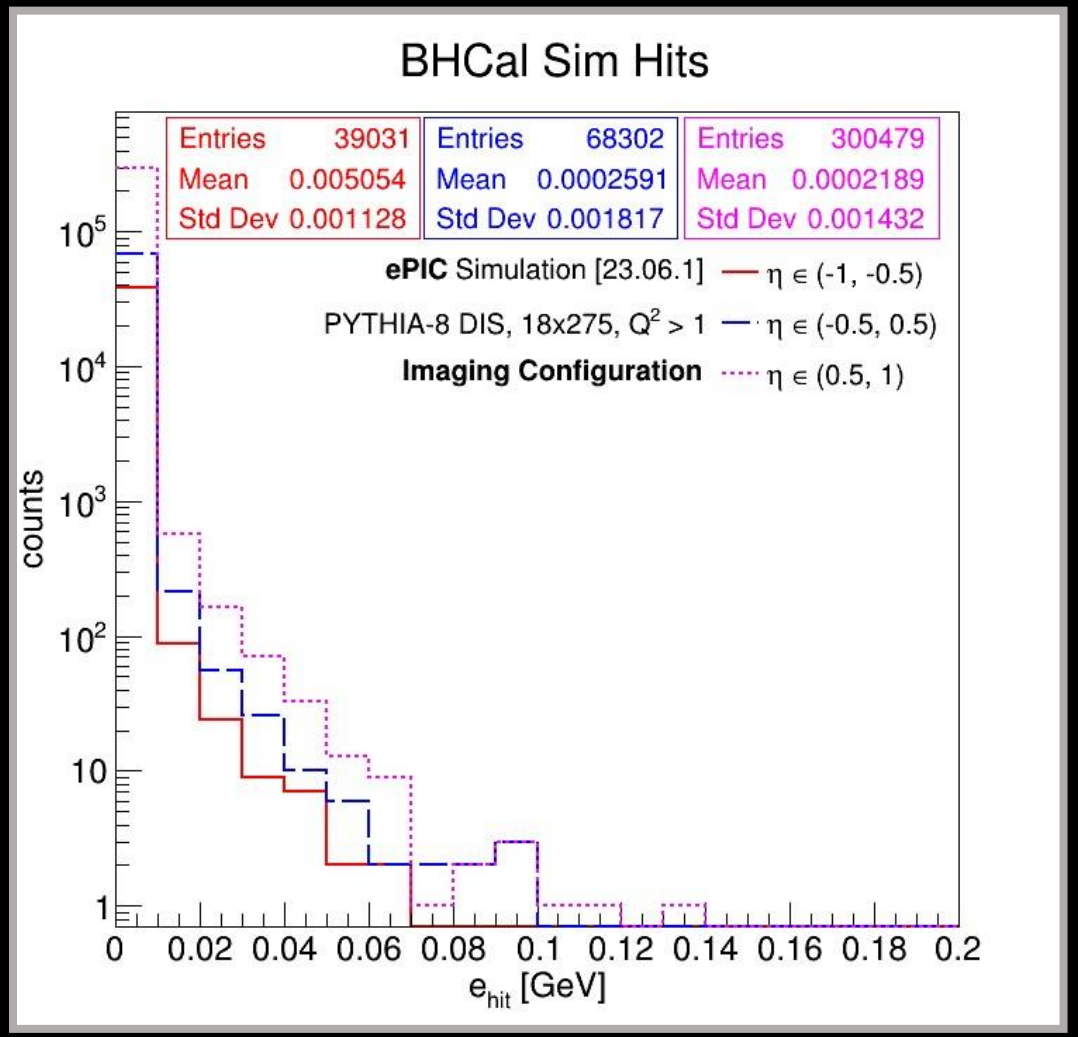
Backup | dynamic range

- **Right:** distribution of visible energy deposited in BHCal scintillating tiles in DIS events
  - 18x275 GeV, $Q^2 > 1$ (10K evt.s)
  - Distributions binned in η

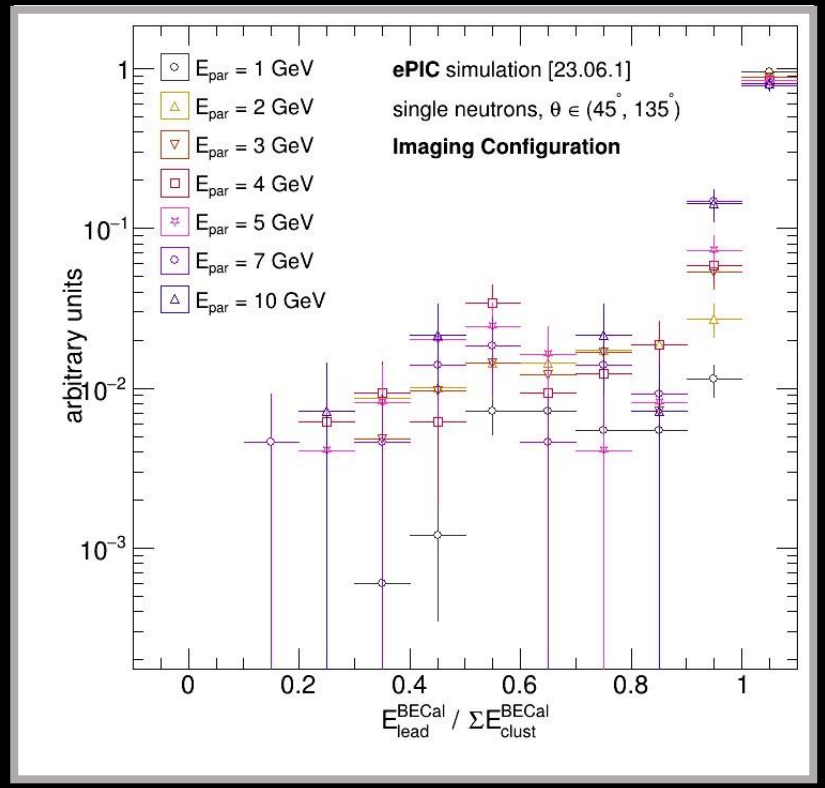
- How does this compare to sPHENIX?
  - sPHENIX had 50 GeV total energy/tower
    - ⇒ **300 MeV/tile** (correcting for sampling frac.)
  - sPHENIX sees ~16000 pixels/GeV of visible energy
    - ⇒ ~960 SiPM pixels firing per 300 MeV
    - ⇒ Or about 96 firing for a 1 GeV μ (MIP)
    - ∴ **Want a range of 20 ~ 10K pixels for ePIC**

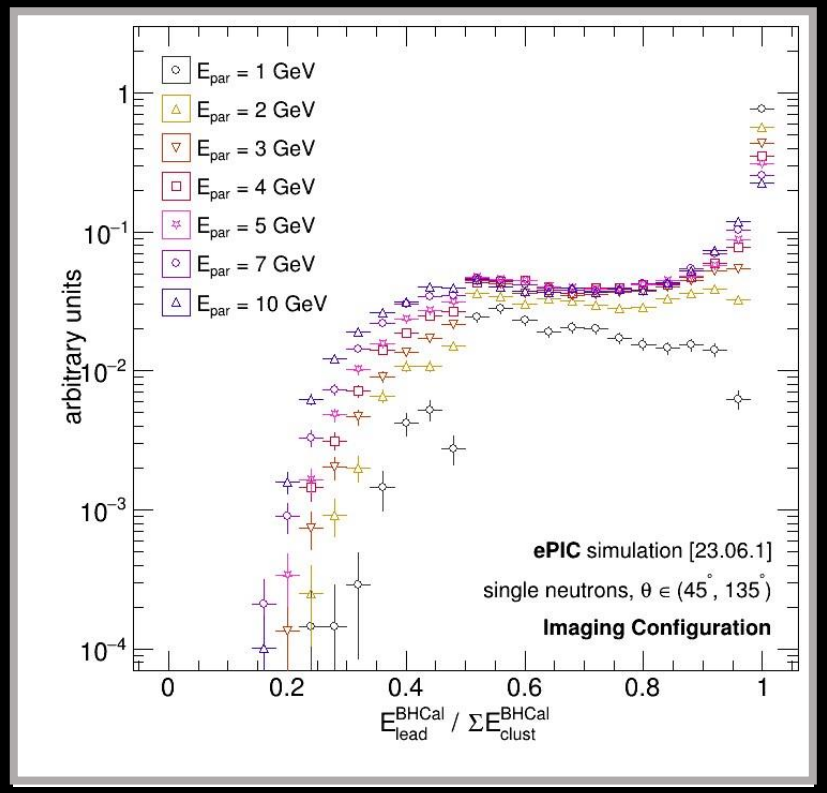
- Using specs for Hamamatsu S12572-O15P-02 (sPHENIX) and S14160-3015PS (ePIC):
  - **Single pixel charge output is 52 fC for ePIC**
  - (24 fC for sPHENIX)

- **In good shape to read out individual tiles with HGCROCs being used for LFHCal will!**
  - ☞ All calculations by John LaJoie



Backup | cluster splitting in neutrons





- Ratio of lead BECal **(left)** and BHCal clusters **(right)** energies to sum of energy in BECal, BHCal respectively
  - **Note:** y-axis ranges differ
  - Pretty significant rate of (unwanted) cluster splitting!