The backward hadronic calorimeter (nHCal) of the ePIC experiment at EIC

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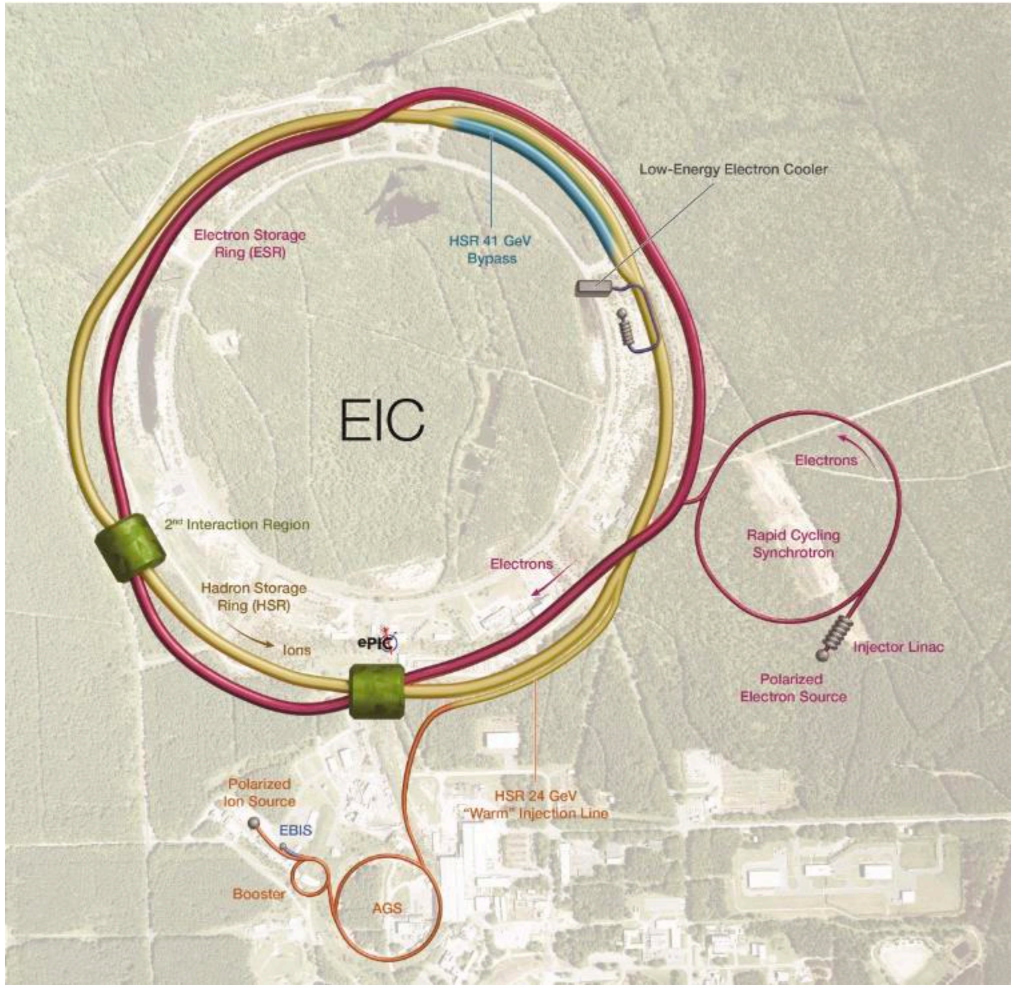
Outline

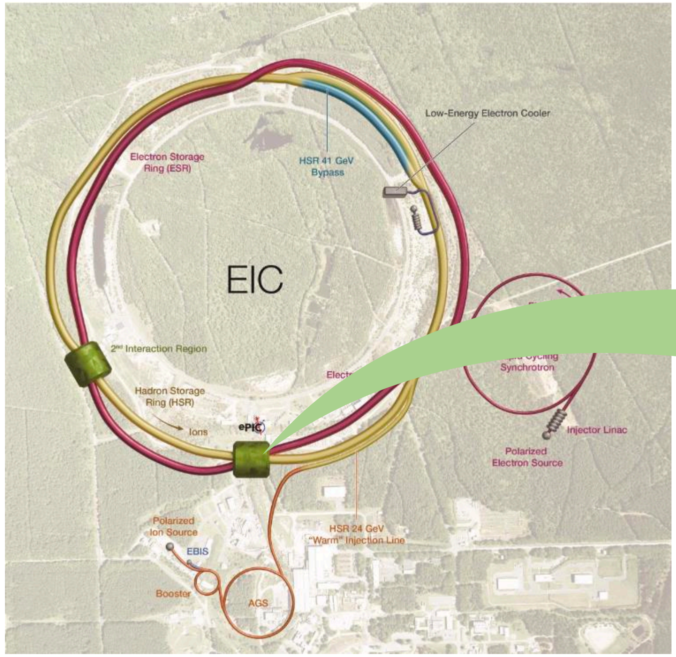
- Introduction
  - Electron-Ion Collider (EIC)
  - The ePIC (electron-Proton/Ion Collider) detector
- Backward Hadronic Calorimeter for ePIC
  - Design
  - Physics Motivation
  - Performance
- Summary

The Electron-Ion Collider (EIC)



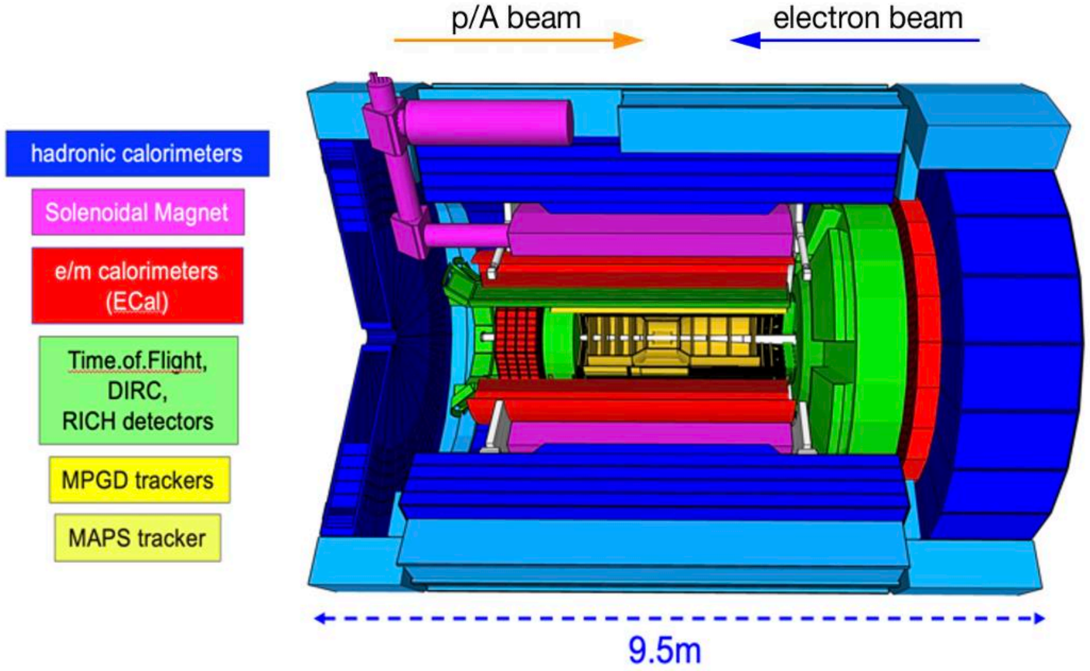
- ❑ Accelerator to be built on the current site of RHIC, BNL to yield e+p/nuclei collision.
- ❑ Variable e+p center-of-mass energies from 28–140 GeV.
- ❑ Ion beams from deuterons to heavy nuclei such as gold, lead, or uranium.
- ❑ High collision electron-nucleon luminosity 10^{33}–10^{34} cm^{-2} s^{-1}.
- ❑ The possibility to have more than one interaction region.

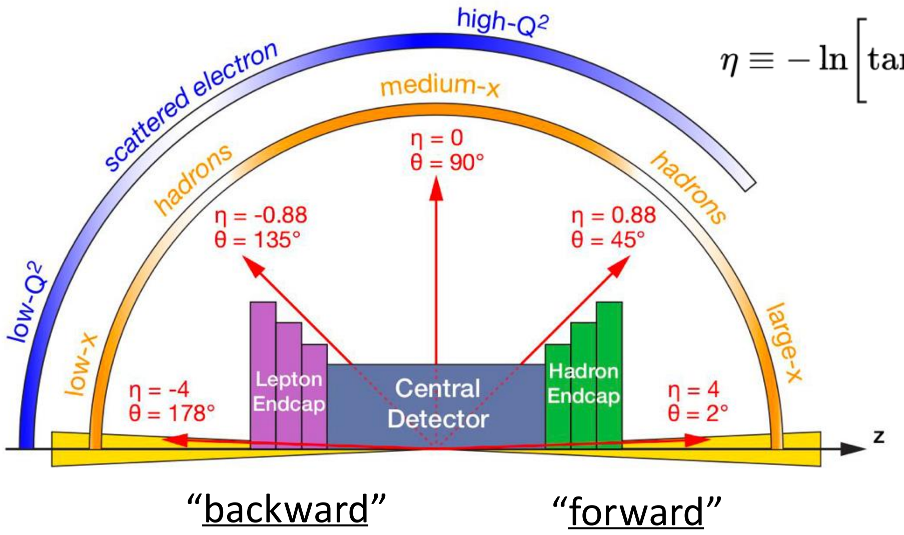
The ePIC detector



- Primary general-purpose detector to be sited at IP6.
- 1.7 T solenoidal superconducting magnet.

https://www.epic-eic.org/public/detector.html

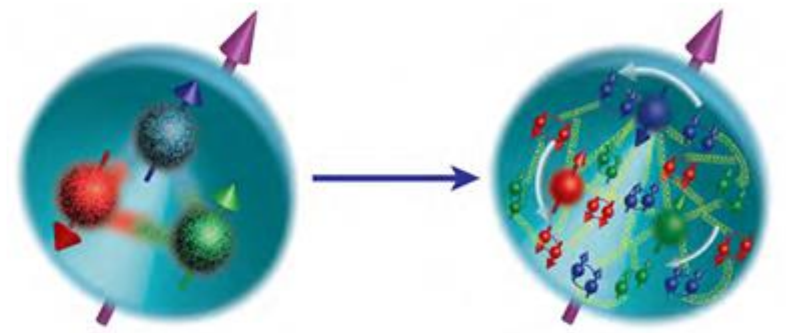




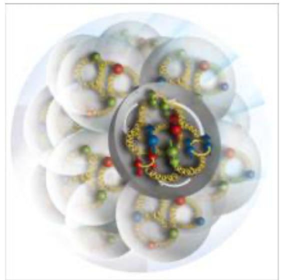
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

A Quick Look into EIC Physics

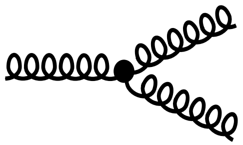
- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?



- How do the nucleon properties (mass & spin) emerge from their interactions?

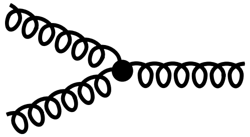


gluon emission



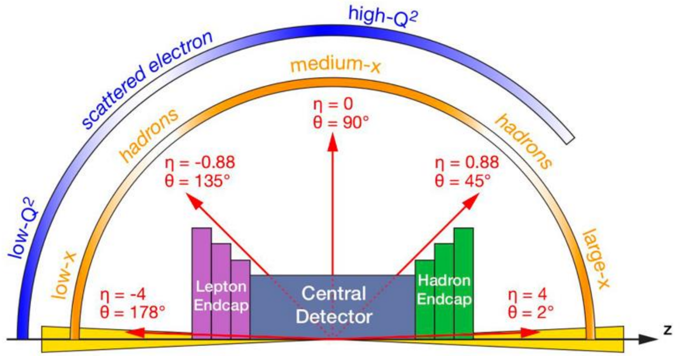
? =

gluon recombination



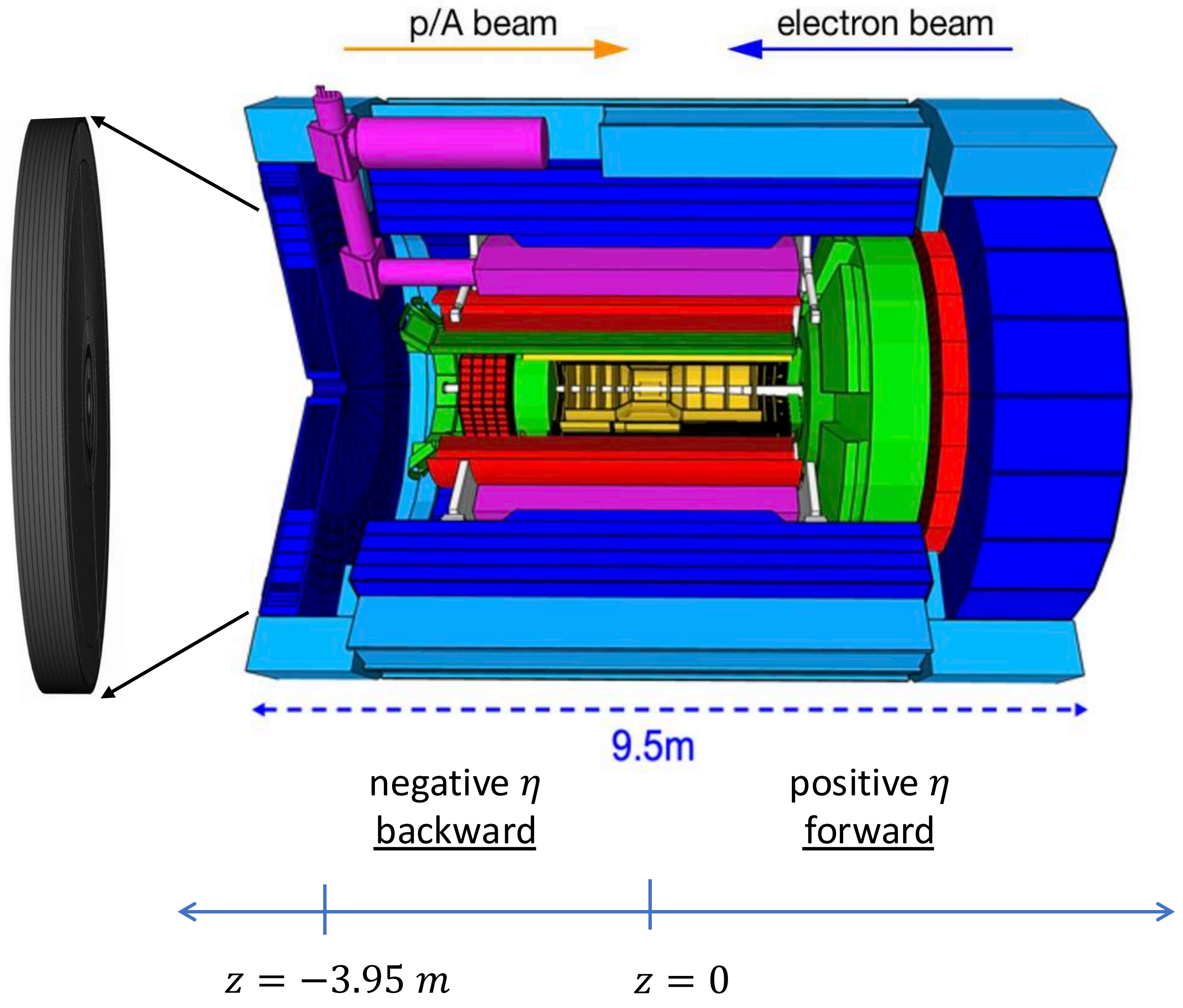
- What happens to the gluon density in nuclei? Does it saturate at high energy (low x), giving rise to a gluonic matter with universal properties in all nuclei (and perhaps even in nucleons)?

Measurements at low-x are essential to the physics objectives of EIC.



The Backward Hadronic Calorimeter for ePIC - nHCal

- Tail catcher sampling calorimeter with alternating Steel/SciTiles layers
- Total of 45 cm (~ 2.4 λ_0)
- Acceptance: $-4.14 < \eta < -1.18$
- Participating institutions: OSU, CTU in Prague, UIUC, UNH, BNL



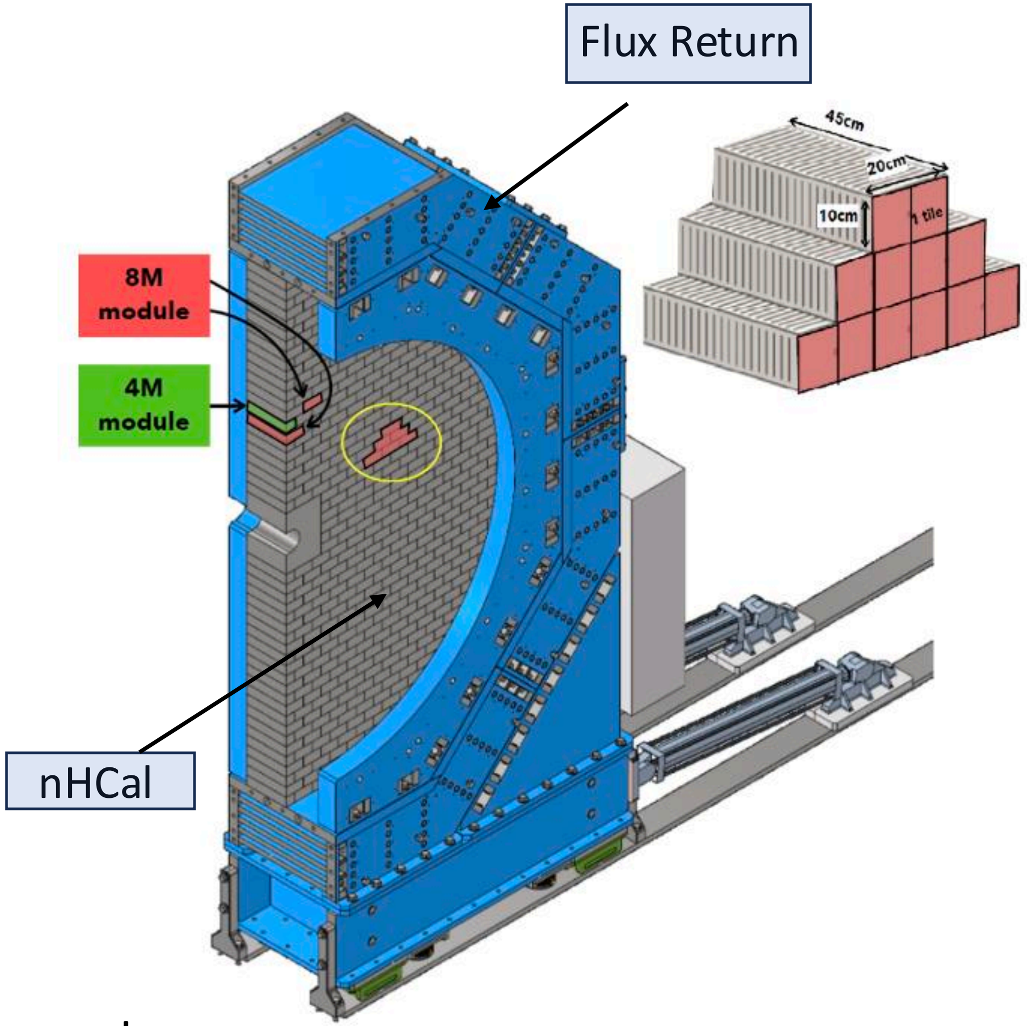
Negative Hadronic Calorimeter (nHCal) - Design

- nHCal is surrounded by an outer collar, backed by a flux return plate and has an oculus ring placed in front.

- Current Design (to be optimized):
  - 10 layers ≈ $2.4\lambda^0$
  - 4 cm non-magnetic steel
  - 4 mm plastic scintillator tiles [10 cm. x 10 cm. or 5 cm. x 5 cm.]
  - SiPM placed on tiles used for light collection

- Tile tests using cosmic ray muons in progress at OSU
  - Light yield, MIP response,
  - efficiency

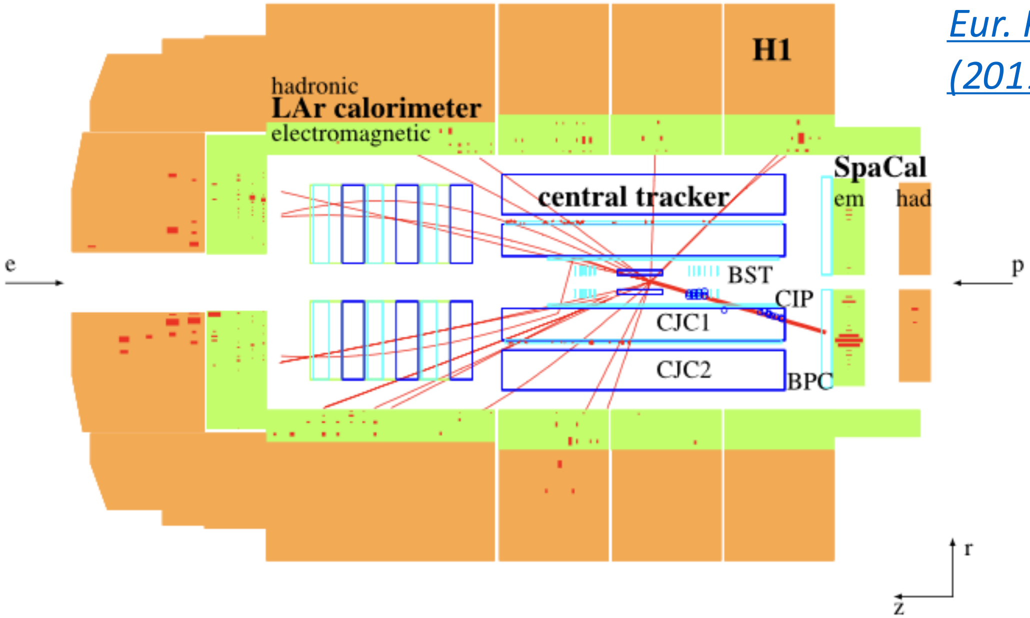
- Low radiation dose expected as compared to the forward region.



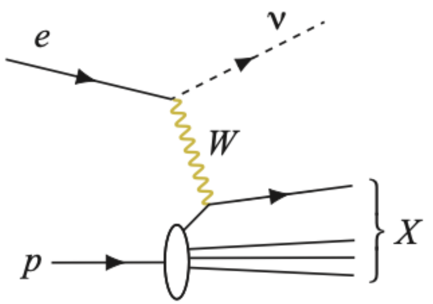
Lessons from HERA H1 detector

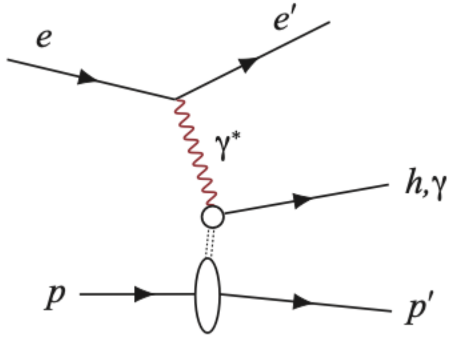
- The backward region of the H1 detector had a **SpaCal** calorimeter upgrade.
  - The difference in energy depositions in the "em" and "had" sections leaded to improved electron-pion separation in low-X.
  - At low energies, "fake electron"s were mitigated from photoproduction events where the scattered electron escapes in the beampipe.
  - Improved hermeticity. Effective in reconstructing events where hadronic energy measurement was crucial (e.g, photoproduction, CC interaction).

[Nucl. Instrum. Meth. A 1997, 386, 2-3]



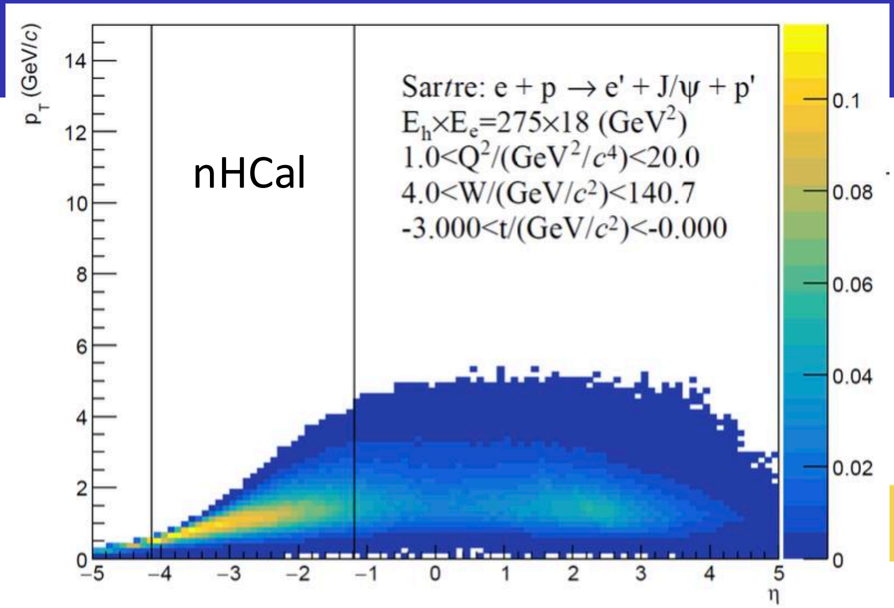
[Eur. Phys. J. C (2011) 71: 1579]





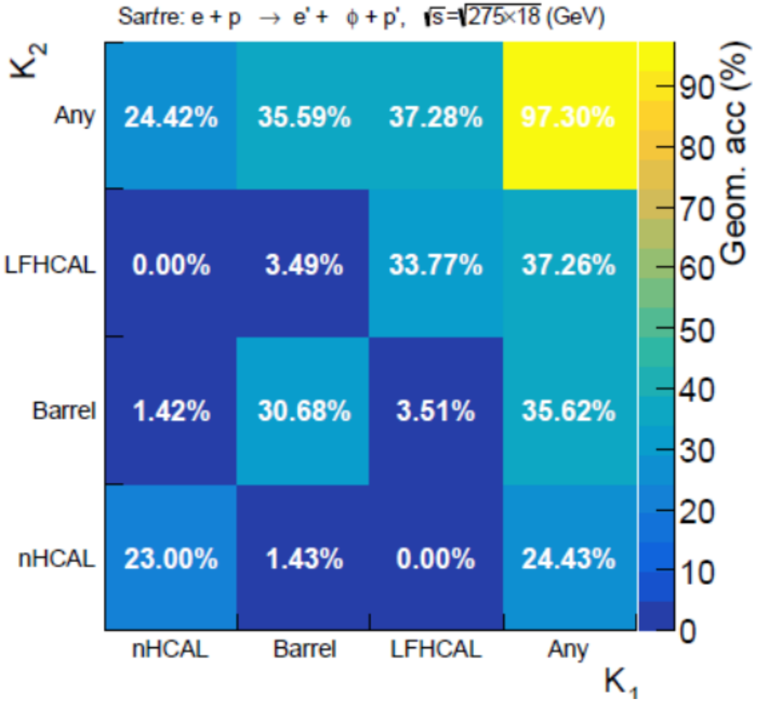
Diffractive Processes

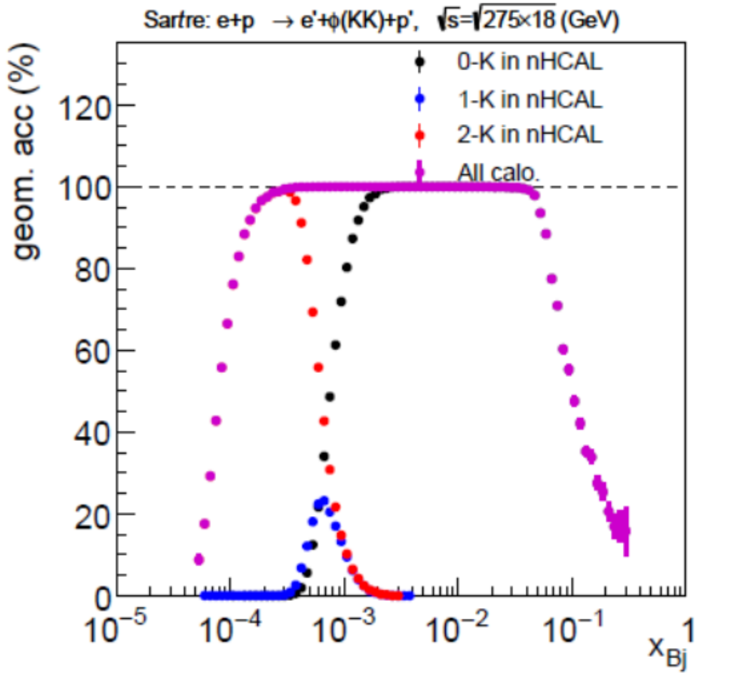
- Diffractive (DDIS) processes made up a significant fraction of the total e+p cross-section.
- Exclusive vector-meson production (e.g. J/ψ, φ) in DDIS will be a powerful tool to explore the structure of hadrons.



Sartre simulation of Diffractive J/ψ production in e+p (18 x275)

Vincent Andrieux (UIUC)





- 24% of φ produce kaons in acceptance of nHCal and any other hadronic calorimeter
- nHCal required to access $x < 10^{-3}$

Neutral Hadrons and Jet Measurement

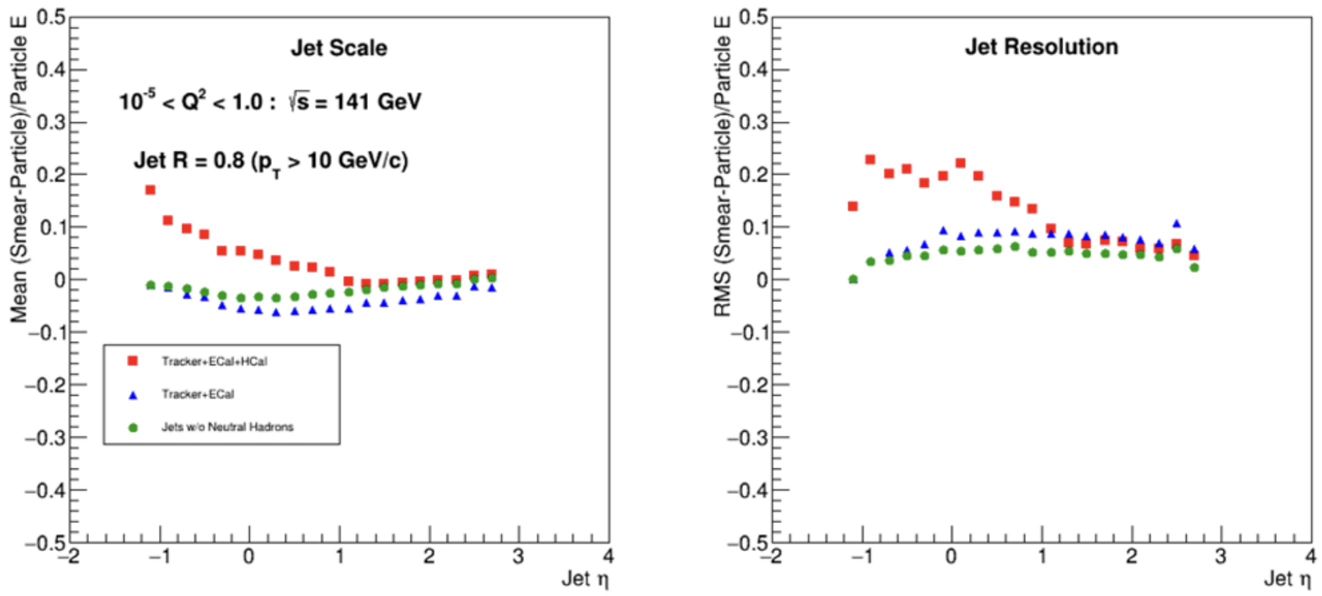
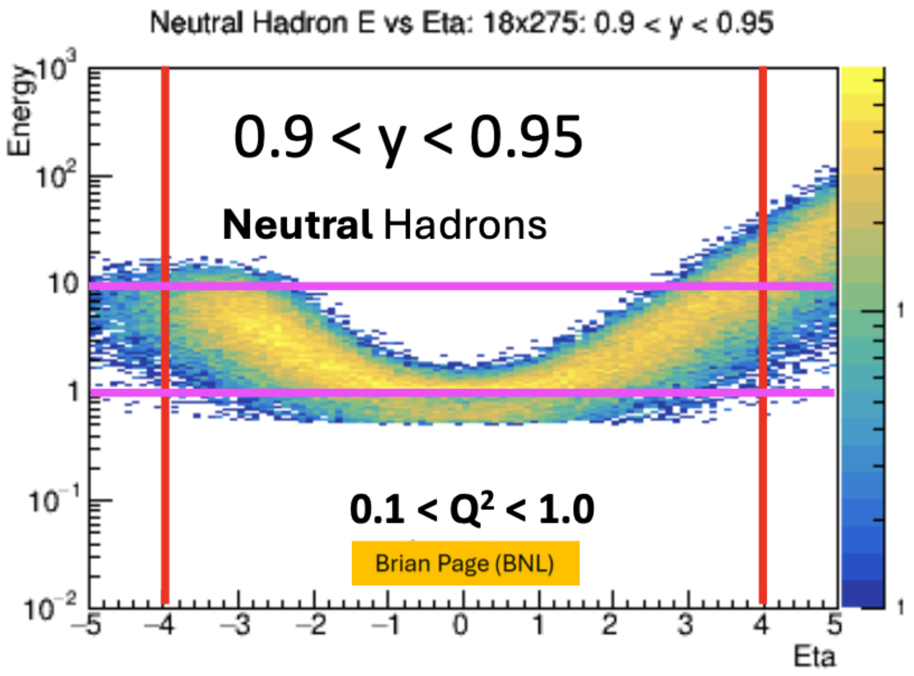


Figure 8.57: Demonstration of the effect of selecting only jets which do not contain a neutral hadron (green circles) on the jet energy scale (left) and resolution (right) as compared to the cases when all subsystems are used in jet finding (red squares) and when HCal information is excluded (blue triangles).



- ❑ Low-x and high-y events produce activity both in backward and forward direction

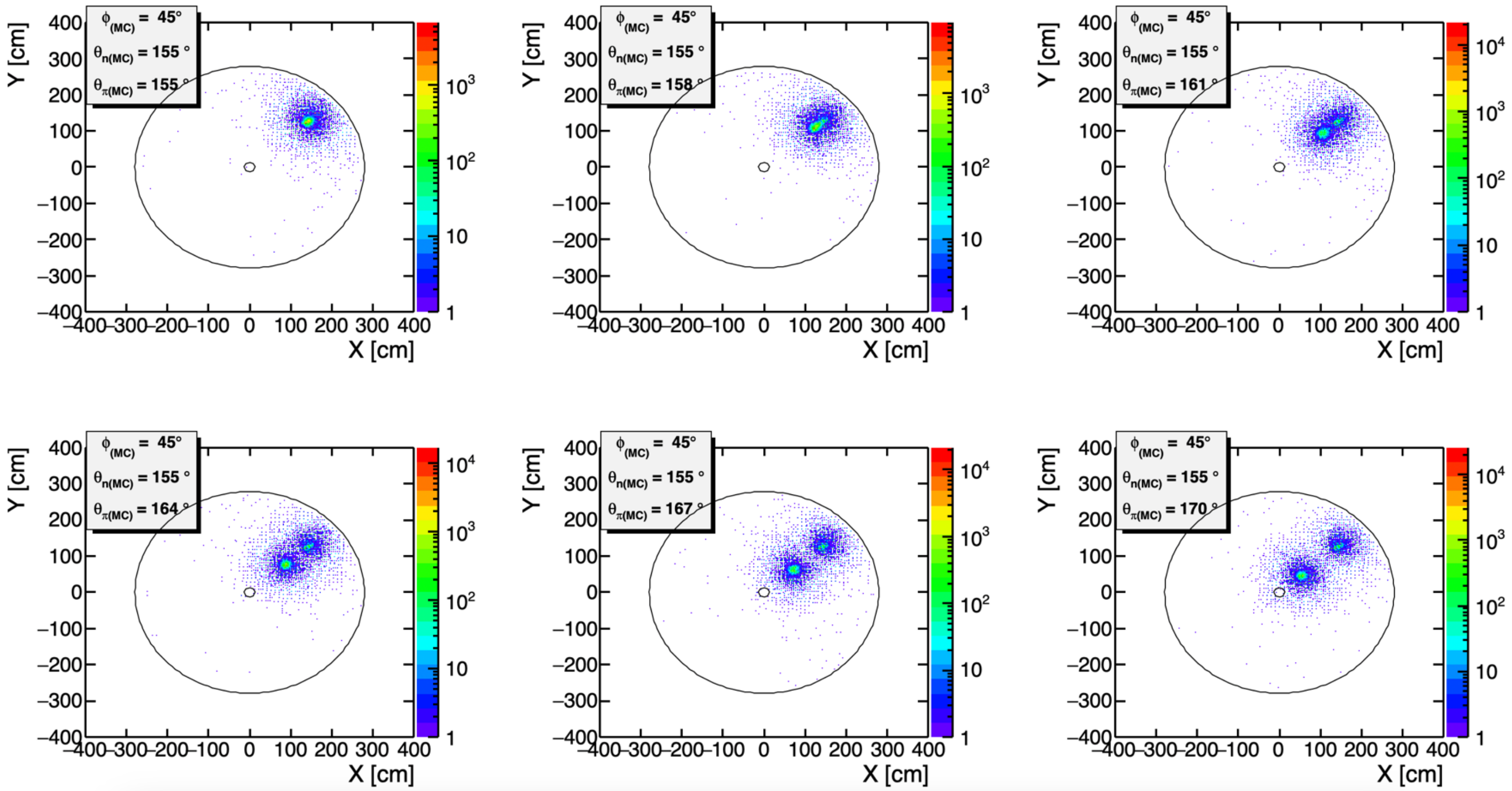
EIC Yellow Report

- ❑ Vetoing jets with neutral hadrons using the nHCal could substantially improve resolution + scale.
- ❑ "This neutral hadron veto capability depends critically on the ability to physically isolate individual showers within the calorimeter ".

Neutral energy reconstruction via charged hadron correction

Objective : *Use two-particle clusters to test the ability to distinguish between neutron/pion shower reconstruction.*

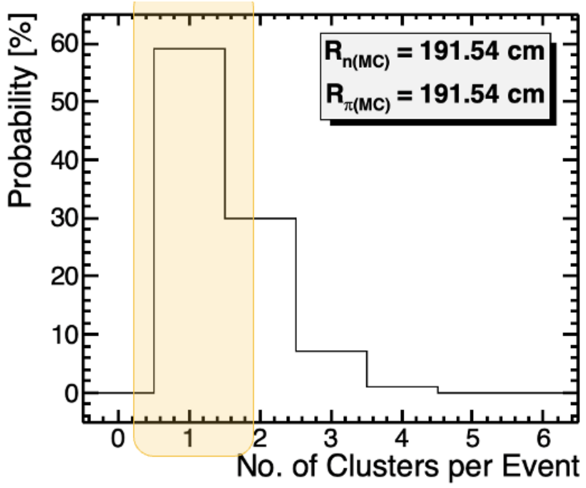
- ❑ (1 n + 1 π^-) / event.
- ❑ $\varphi = 45^\circ$
  - $\theta_n = 155^\circ$ ($\eta = -1.51$) ------ *fixed*
  - $\theta_\pi = 155^\circ$ ($\eta = -1.51$), 158° ($\eta = -1.64$), 161° ($\eta = -1.79$), 164° ($\eta = -1.96$), 167° ($\eta = -2.17$), 170° ($\eta = -2.44$)

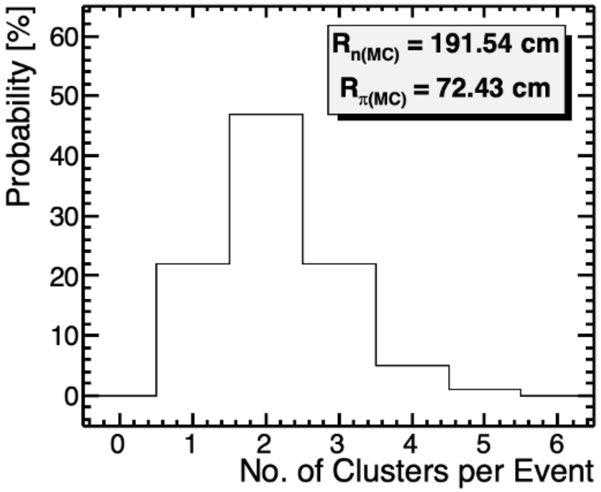


- ❑ Cluster (x,y) are shown in the nHCal plane along with simulated angular coordinates

[neutron showers in outer region; pion showers in inner region]

Charged Hadron Correction





R = Radial Coordinate of the cluster position in the nHCal plane

- ❑ As the showers start to overlap, clusters start to get merged, neutron hits are "hijacked" into pion clusters.

Charged Hadron Correction – Preliminary Approach

If $\left|\frac{E_{charged}^{Reco} - p}{\sigma_E}\right| > 3.0$

$$E_{neutral}^{Reco} = E_{total}^{Reco} - p$$

Else, $E_{neutral}^{Reco} = E_{total}^{Reco} - E_{charged}^{Reco}$

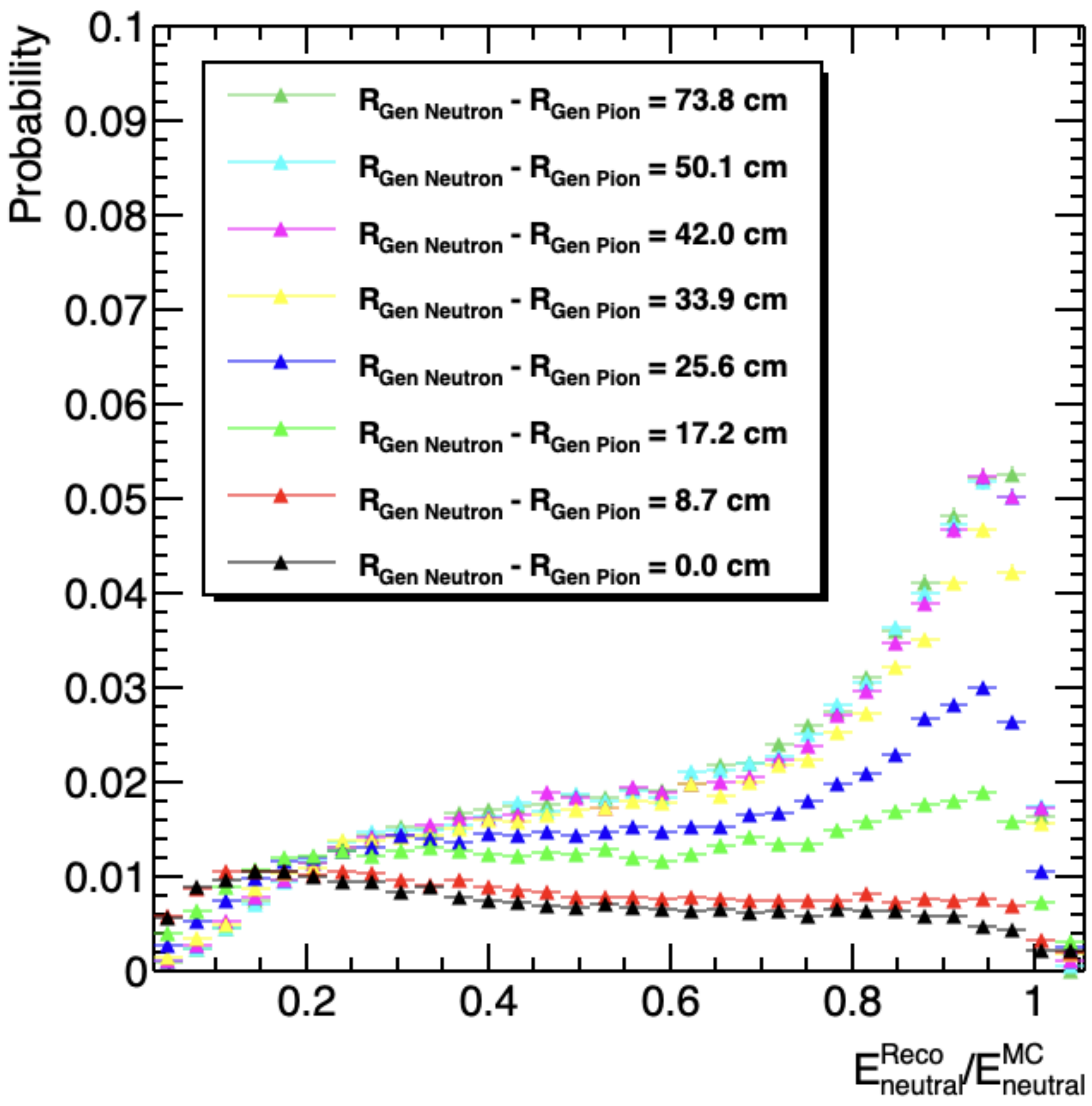
Condition to determine possible reconstruction failure and make charged hadron correction

$E_{charged}^{Reco}$ = Energy of the cluster that is matched to a track

p = Momentum obtained from tracking

σ_E = Energy Resolution

Charged Hadron Correction



When, $|(E^{Reco}_{charged} - p)/\sigma_E| > 3.0$

$$E^{Reco}_{neutral} = E^{Reco}_{total} - p$$

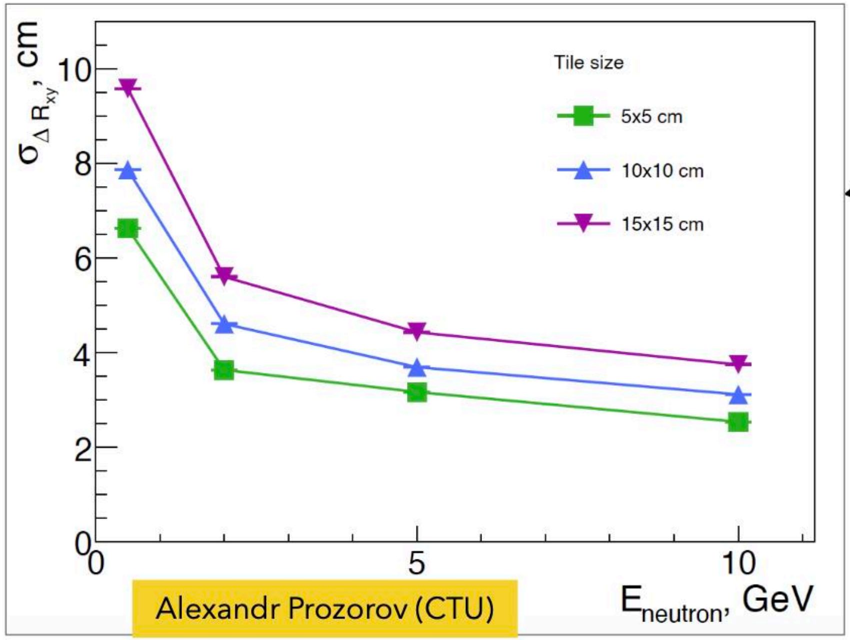
Otherwise,

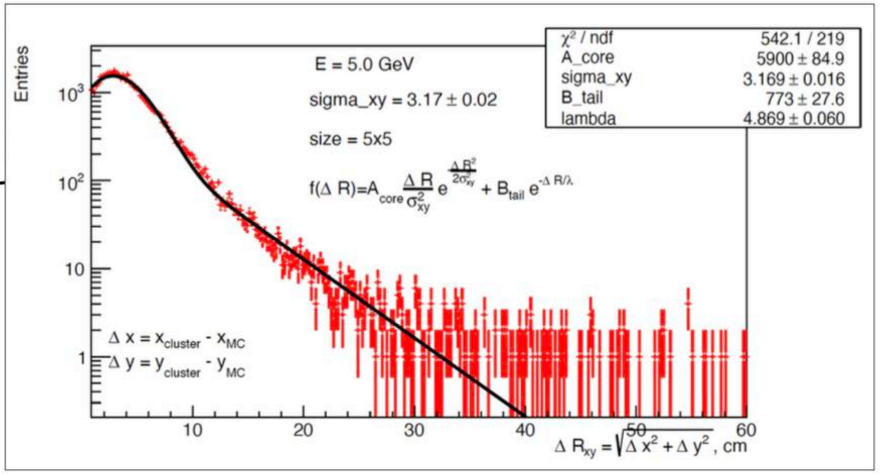
$$E^{Reco}_{neutral} = E^{Reco}_{total} - E^{Reco}_{charged}$$

$E^{MC}_{neutral}$ = MC energy deposition by neutron

- ❑ Good neutral energy separation should be possible from clusters which are ~ 30 cm apart

Single particle position resolution for neutrons



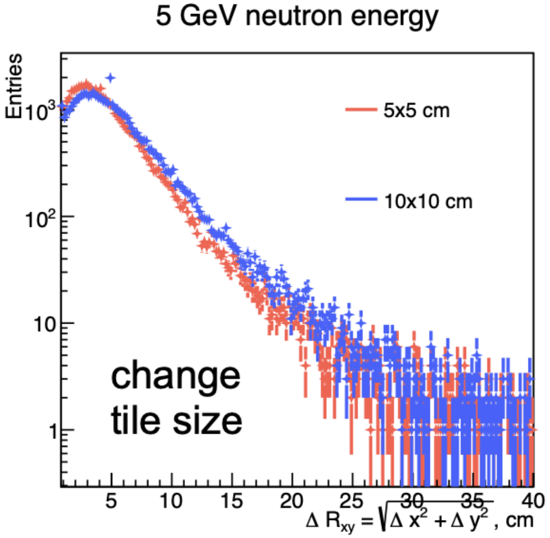


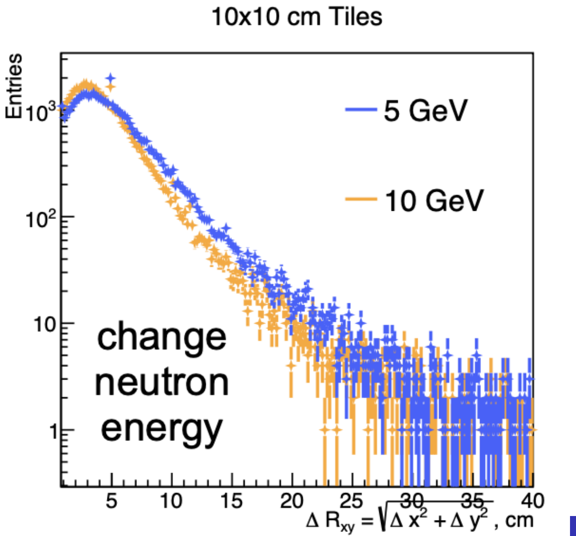
$$\Delta R_{xy} = \sqrt{\Delta x^2 + \Delta y^2}$$

$$\Delta x = x_{cluster} - x_{MC}$$
$$\Delta y = y_{cluster} - y_{MC}$$

- Performed with single-particle neutron simulations and reconstructed clusters for geometry optimization

- Tile size has negligible impact on the transverse position resolution
  - Hadronic showers are much wider than tile size





Summary

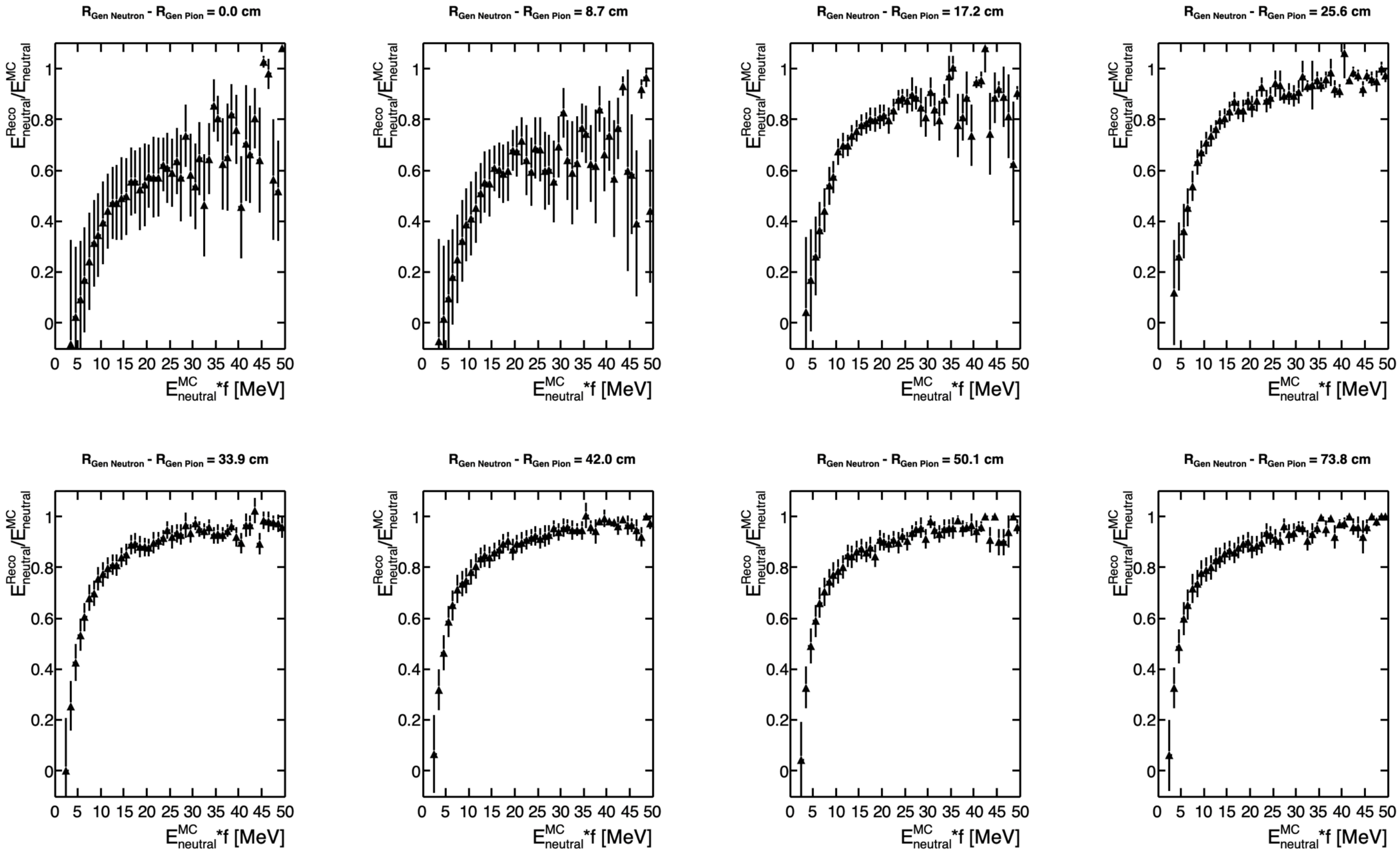
- ❑ nHCal will be crucial for low-x measurements, which is the frontier for proton and nuclear structure and one of the key objectives for EIC physics.
- ❑ Studies of diffractive events will be facilitated from nHCal.
- ❑ It will act as a neutral veto to identify charged jets.

- ❑ Growing collaboration!
- ❑ Opportunities for people to participate!!
  - Simulations, testing, hardware work, reconstruction.

Thank You

Backup

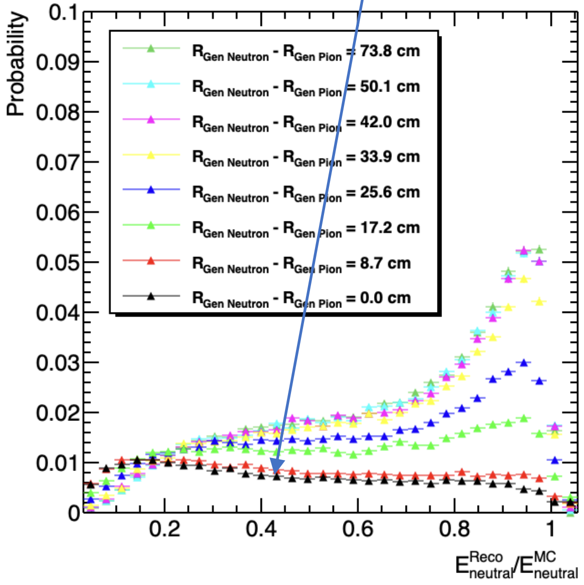
Charged Hadron Correction



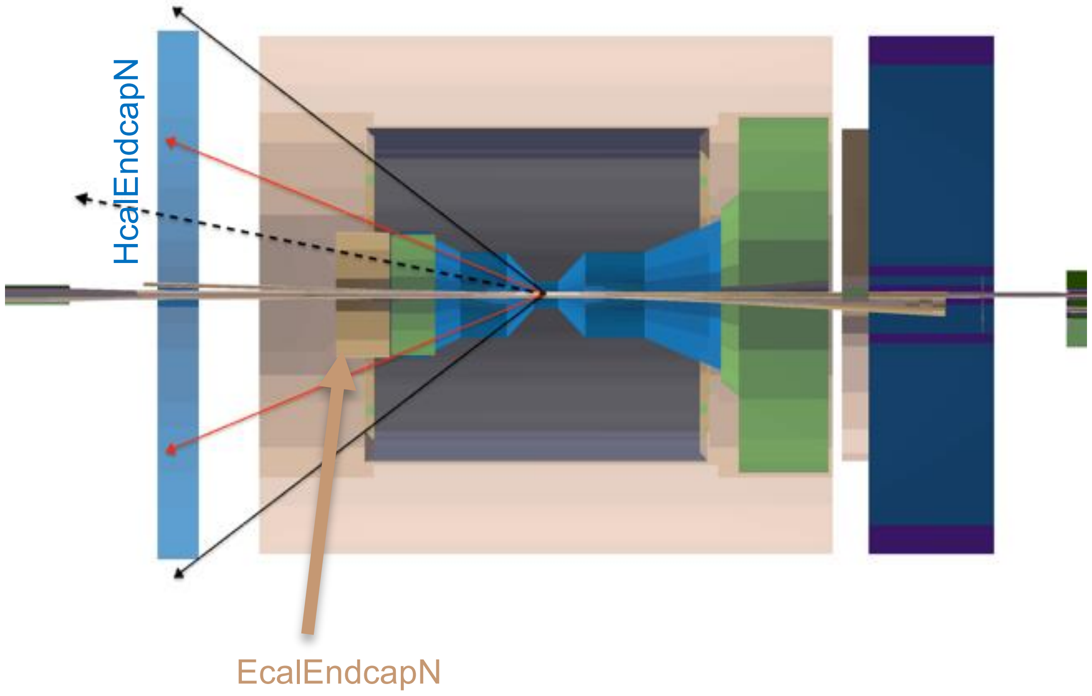
$E^{MC}_{neutral}$*f = the actual (not corrected to sampling fraction) energy deposition on the Sci-tiles

Performance improves with increasing $E^{MC}_{neutral}$*f

Plots with more uncertainty corresponds to flat distributions below

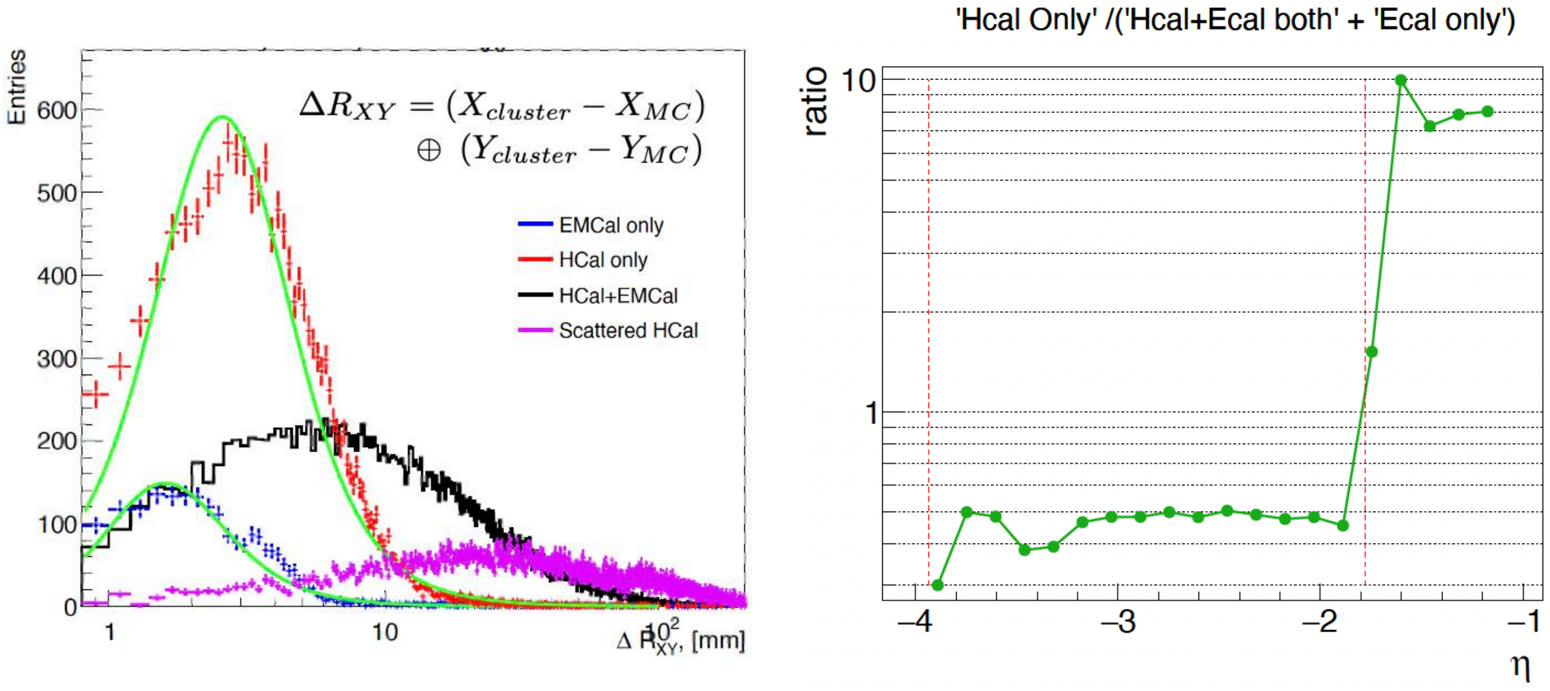


Overlap with EEEMCal



Significant overlap in acceptance with the backward (or Electron-End-cap) EMCal

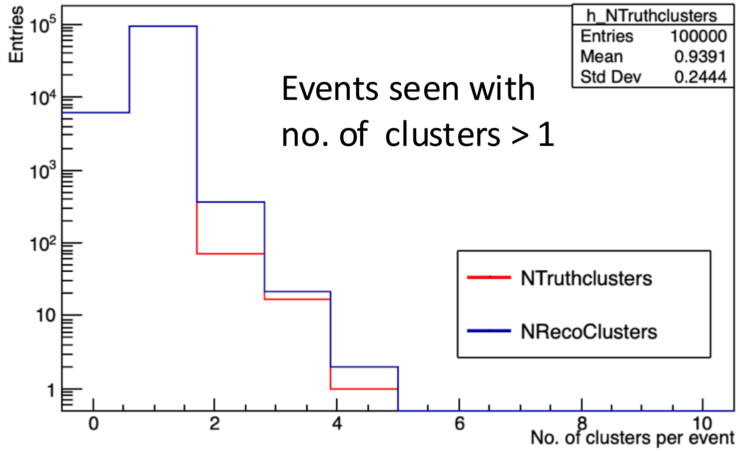
Position Resolution Study - Resolution

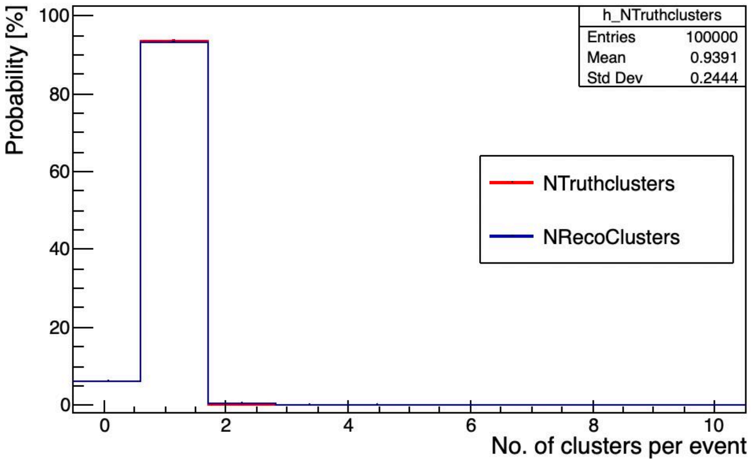


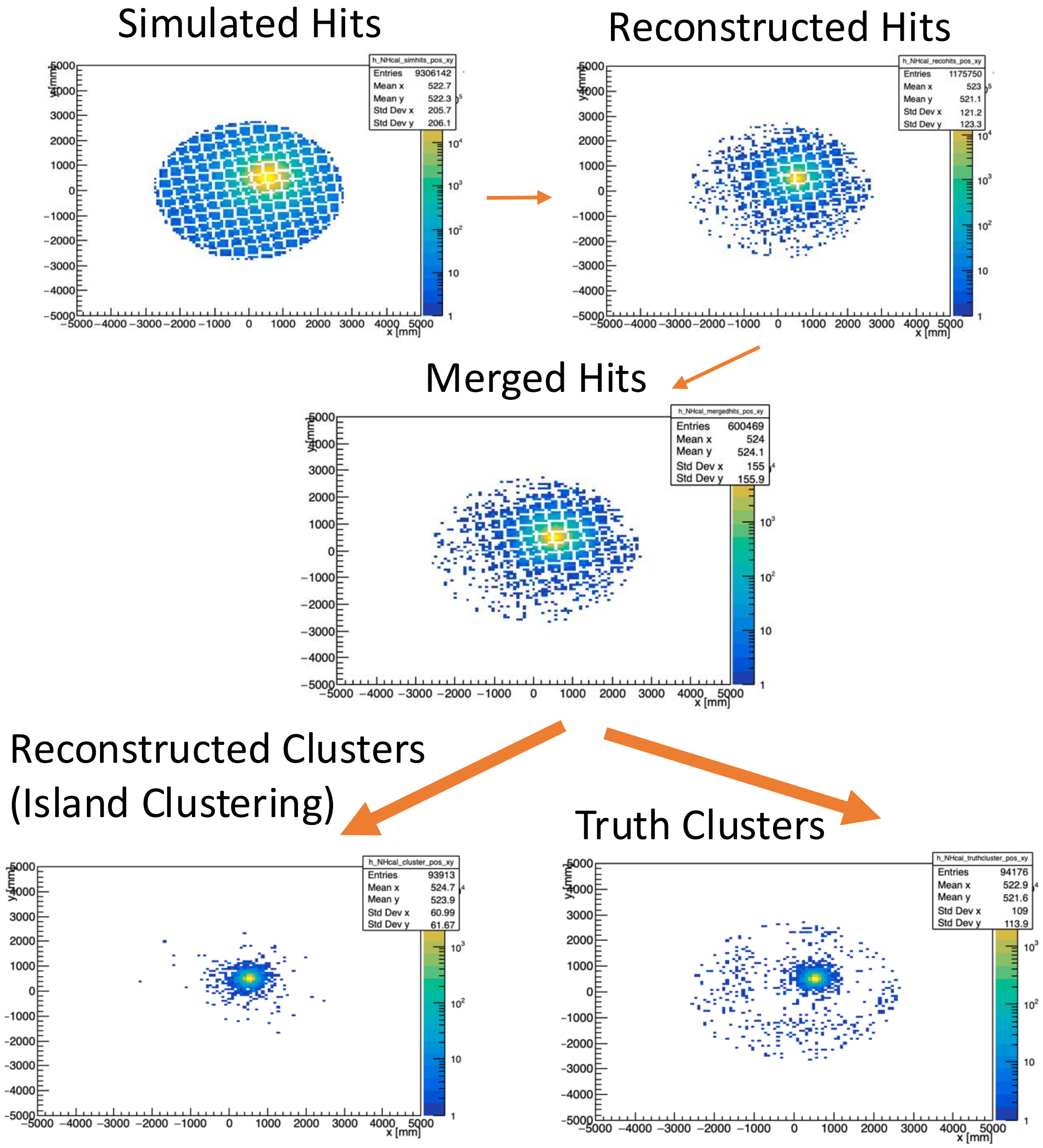
- ~ 68% of neutrons scatter in EEEMCal which might fall out of a jet reconstruction cone. This might be an issue for jet energy reconstruction.
- Scattering in EEMCal affects the ΔR_{XY} resolution.

Hit and Cluster Positions

- 1 neutron/event, 100k events and p = 5 GeV
- θ = 170◦ and φ = 45◦



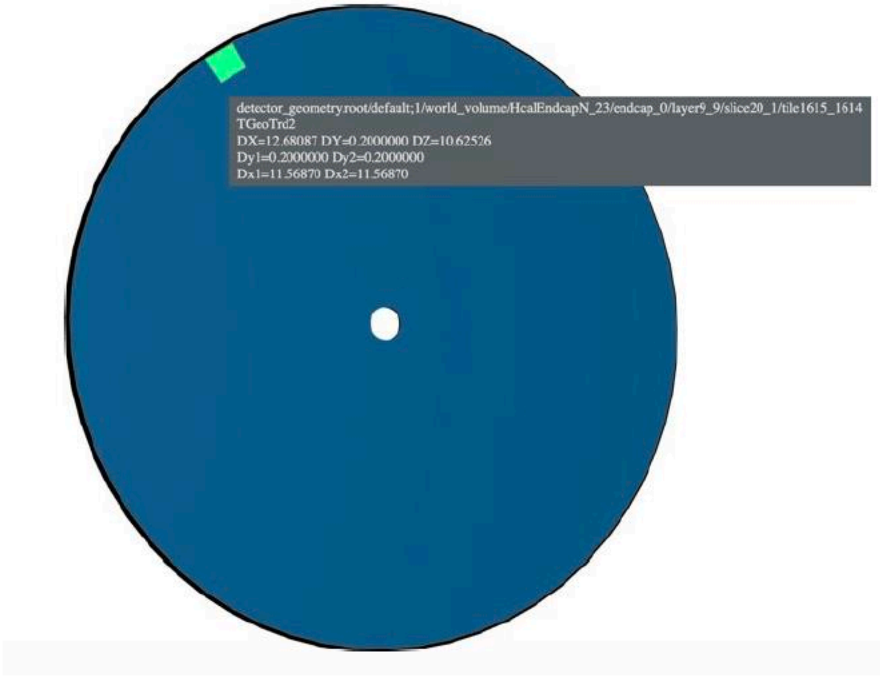




DD4hep – detector description toolkit

- ❑ Works with Geant4 for particle transport
- ❑ Uses ROOT for visualization

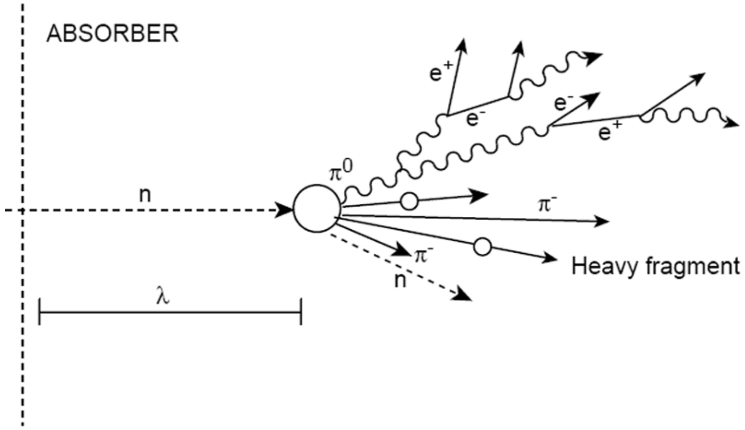
- ➢ Separate detector descriptions from their interpretation
  - • The compact detector description is contained in a .xml file
  - • Interpretation is done by detector Constructors (.cpp file)
    - o Can create one detector element with a given shape.
    - o Make multiple placements to replicate it.



https://dd4hep.web.cern.ch/dd4hep

Hadronic Showers

A hadronic shower is a cascade of secondary particles initiated by the interaction with matter (i.e, energy loss) of an incoming of hadron.

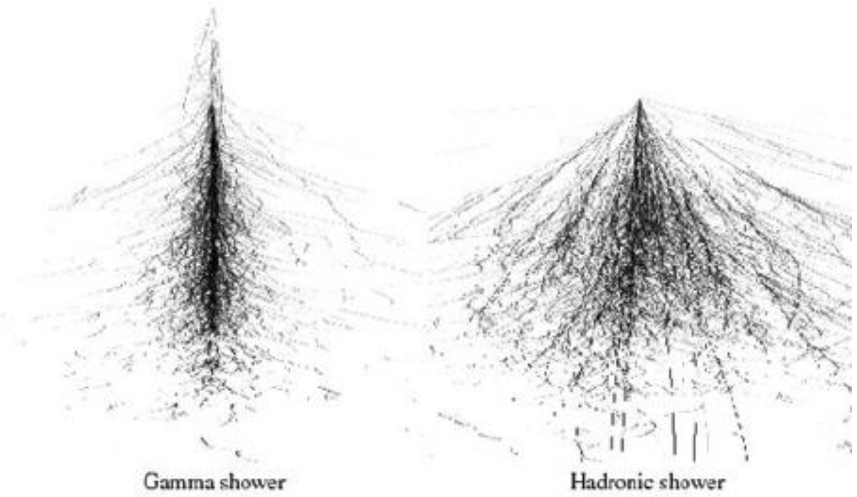


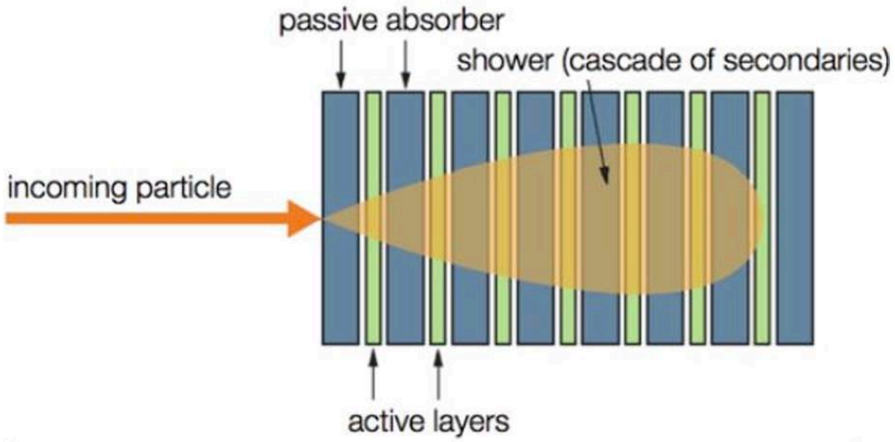
Electromagnetic component:

- Electrons, photons (from excitation, radiation, decay of hadrons, photo-effect, …)
- Neutral pions (eg, $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$)

Hadronic component:

- Charged hadrons $\pi^{\pm}$, $K^{\pm}$, p, …
  - ionization, excitation, nuclei interaction (spallation p/n production, evaporation n, spallation products)
- Neutrons,
  - Elastic collisions, thermalization+capture (=>γ's)
- Break-up of nuclei





- Part of the energy is lost in breaking nuclei (nuclear binding energy)
  - Invisible part of the shower! <u>Only part of the shower energy is sampled!</u>