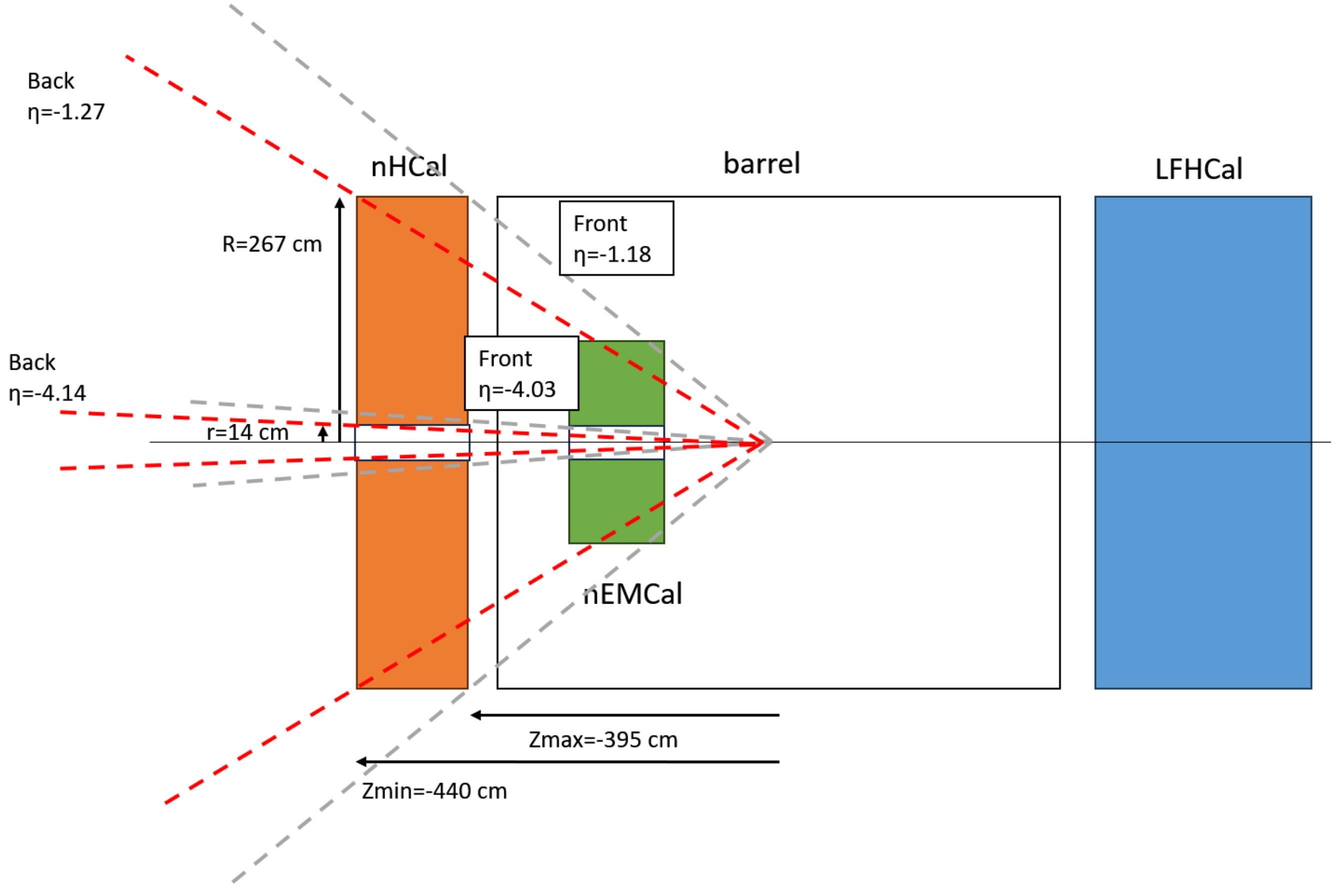
Physics Motivation for the Backward Hadronic Calorimetry in ePIC

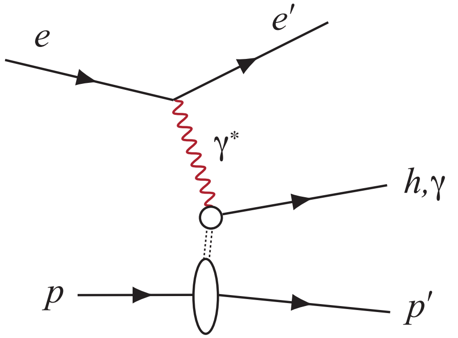
Daniel Brandenburg (OSU)
for the ePIC nHCAL DSC

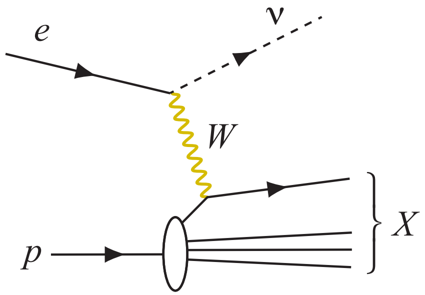
Oct 24, 2025
ePIC General Meeting



Electron Ion Collider Mission

- How do the nucleonic properties such as mass and spin emerge from partons and their underlying interactions?
- How are partons inside the nucleon distributed in both momentum and position space?
- How do color-charged quarks and gluons, and jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?
- How does a dense nuclear environment affect the dynamics of quarks and gluons, their correlations, and their interactions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to gluonic matter or a gluonic phase with universal properties in all nuclei and even in nucleons?





Low-x measurements are crucial to the EIC physics mission

Physics central to EIC Mission

- Key question: Why put hadronic calorimetry in the electron going direction (backward)?
- Answer: Low-x physics

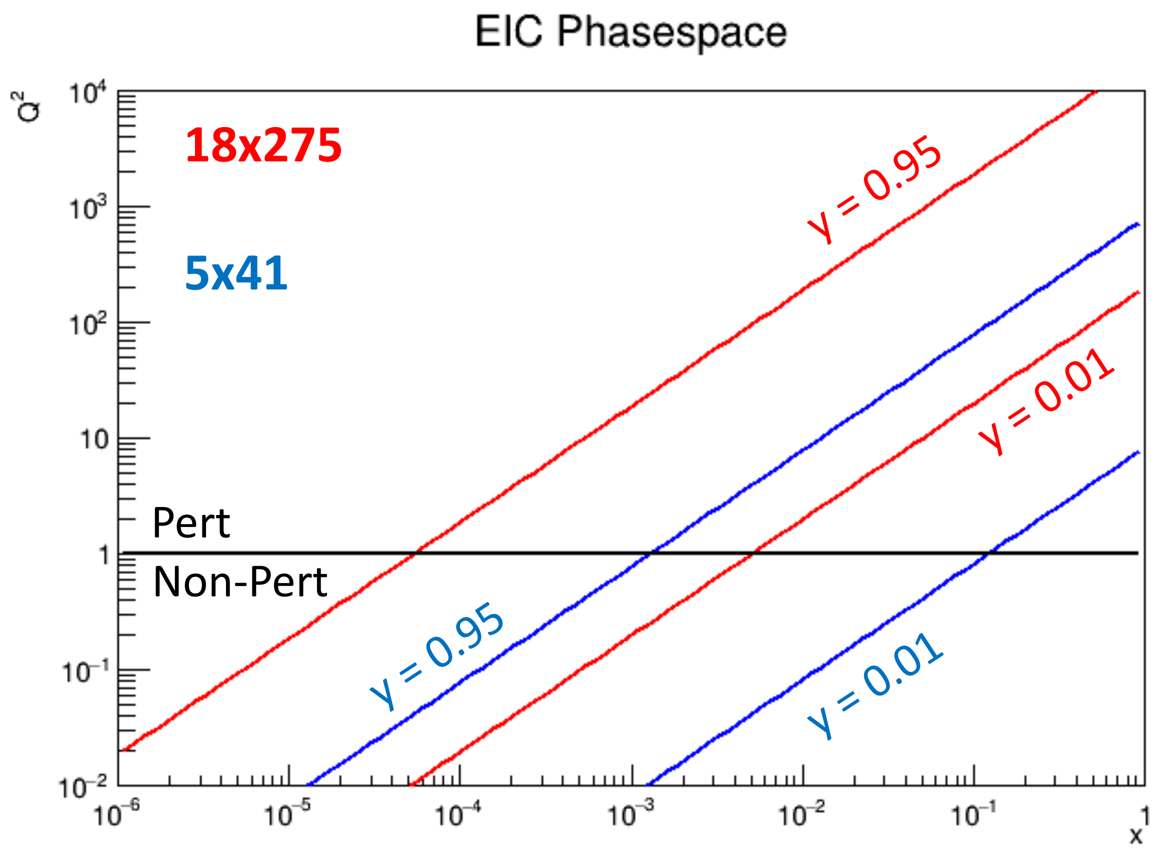
- Backward region = high gluon densities

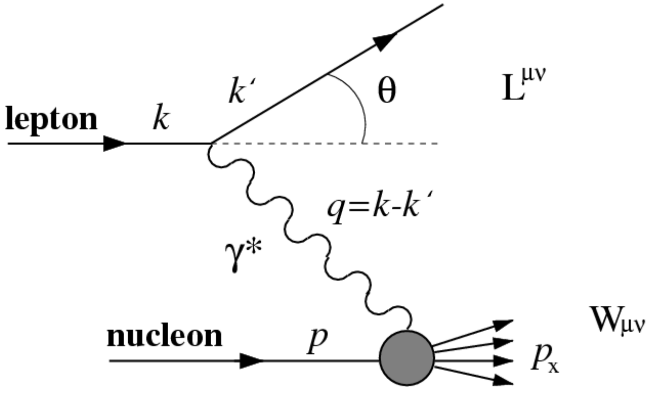
“the EIC will be the first experimental facility capable of exploring the internal 3-dimensional sea quark and gluon structure of a nucleus at low x” – EIC White paper

Backward (negative Eta) HCAL Coverage

For leading order processes event kinematics determine the final state

nHCAL = low-x, low-Q^2, ~mid to high-y





$$Q^2 = -q^2 = -(k - k')^2$$

$$W^2 = (q + P)^2$$

$$y = \frac{q \cdot P}{k \cdot P}$$

Bjorken scaling variable $x = \frac{Q^2}{2p \cdot q}$

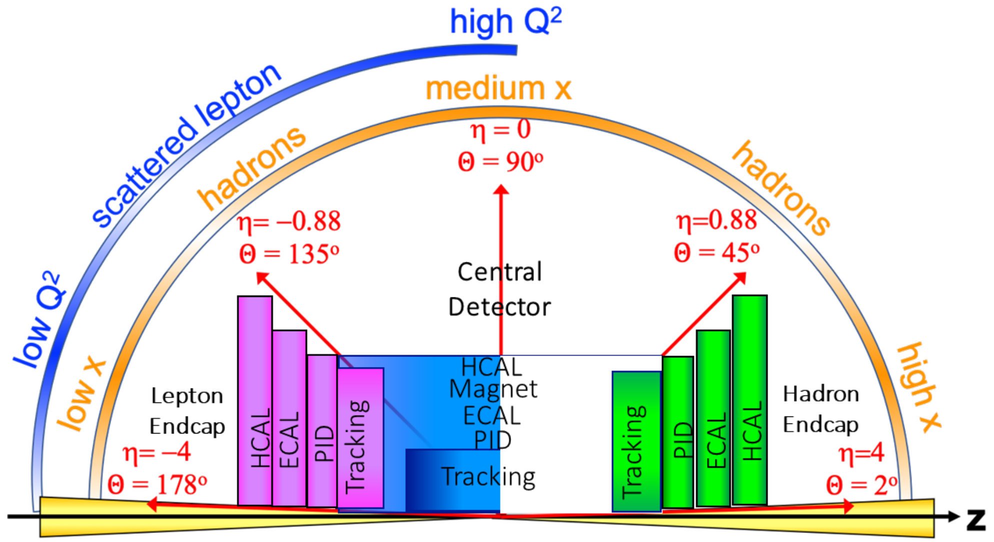


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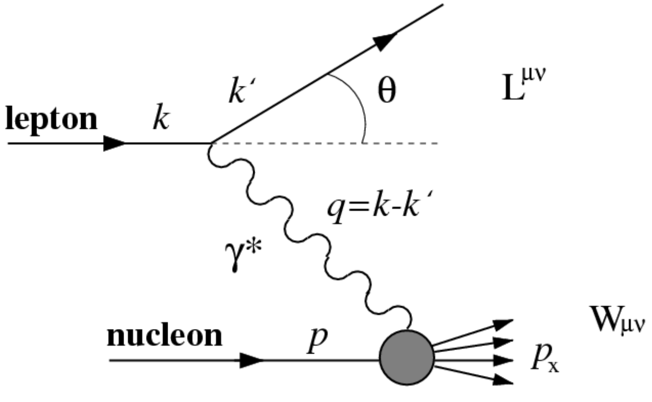
Table: Summary of EIC Scientific Goals Dependent on Low x Measurements

Goal	Description	Relevance at Low x
Three-Dimensional Structure	Map gluon and sea quark distribution in momentum and position space	Gluons dominate, essential for low x PDFs
Proton's Mass and Spin	Determine gluon contribution to mass and spin	Polarized gluons at low x crucial for spin studies
Nuclear Structure Functions	Study nuclear modifications and gluon saturation	Low x probes shadowing, saturation effects
QCD Non-Perturbative Regime	Study QCD at low Q^2, often correlated with low x	Insights into gluon dynamics at small scales
Search for CGC	Look for high gluon density state, expected at very low x	Exclusive to low x, potential new physics



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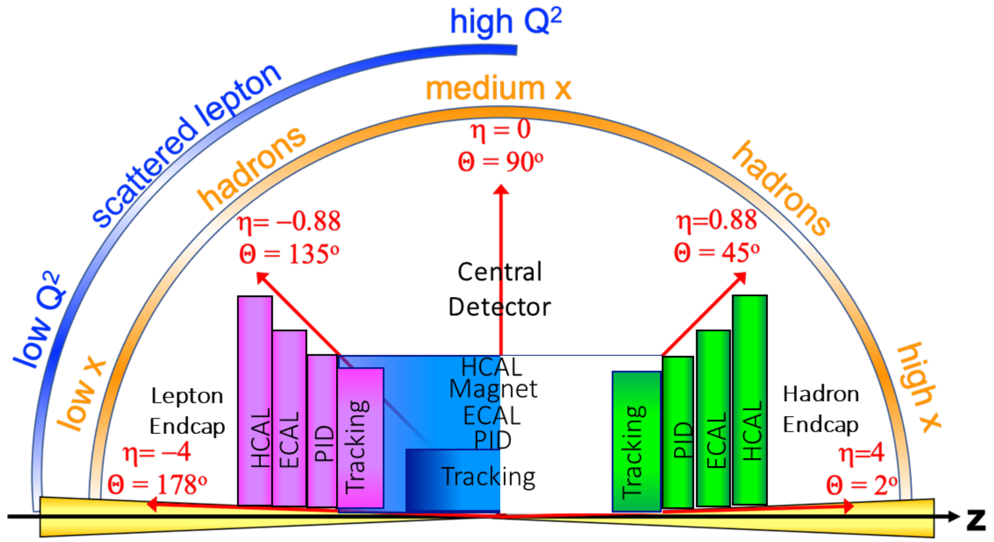

Physics central to EIC Mission

- Key question: Why put hadronic calorimetry in the electron going direction (backward)?
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- Specifically, nHCAL improves/allows:
  - Hermiticity + Electron tagging +event kinematics in low-x
  - Diffractive Processes (Vector Mesons + Dijets + uniqueness)
  - Neutron detection and neutral veto

- Backward region = high gluon densities

"the EIC will be the first experimental facility capable of exploring the internal 3-dimensional sea quark and gluon structure of a nucleus at low x" – EIC White paper

Lessons from HERA : Hermiticity + Electron Tagging

H1 upgrade to include SPACAL (1995) in the backward region

- Purpose: Enhanced capability to study low Q² physics, improved trigger efficiency for low-energy electrons, and better background rejection, enabling precise measurements of structure functions and diffractive processes at low x.
- Current understanding of low-x proton structure functions are based on HERA measurements
- Hermiticity improved with nHCAL

Determination of event kinematics – especially for photoproduction and CC where we rely on hadronic reconstruction

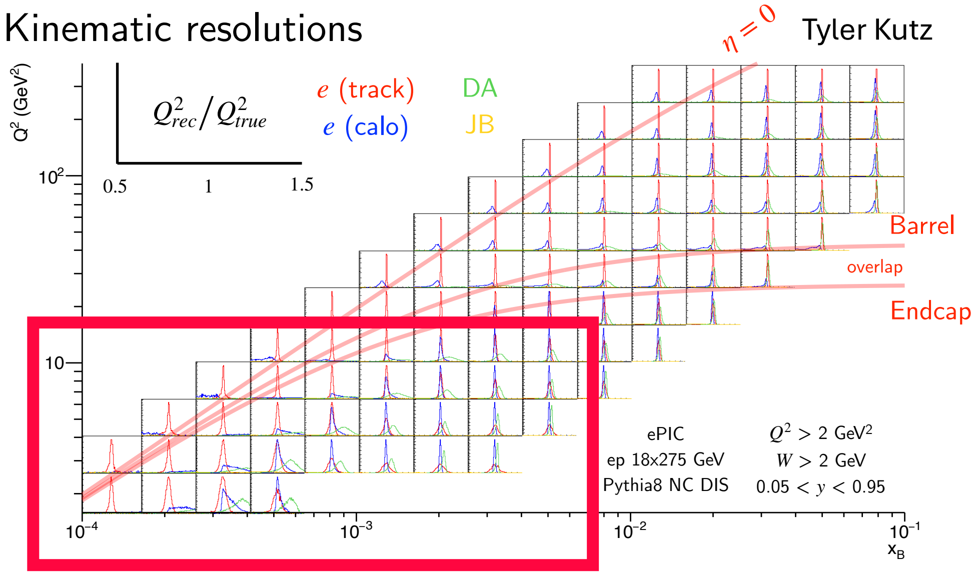
+ Precision event shape measurements

- e/pi separation and background rejection are key challenges at low-x.

→ nHCAL allows hadronic veto in most challenging cases

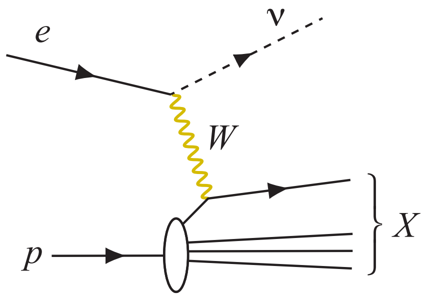
Hadronic response and e/π separation with the H1 lead/fibre calorimeter

H1 SPACAL group



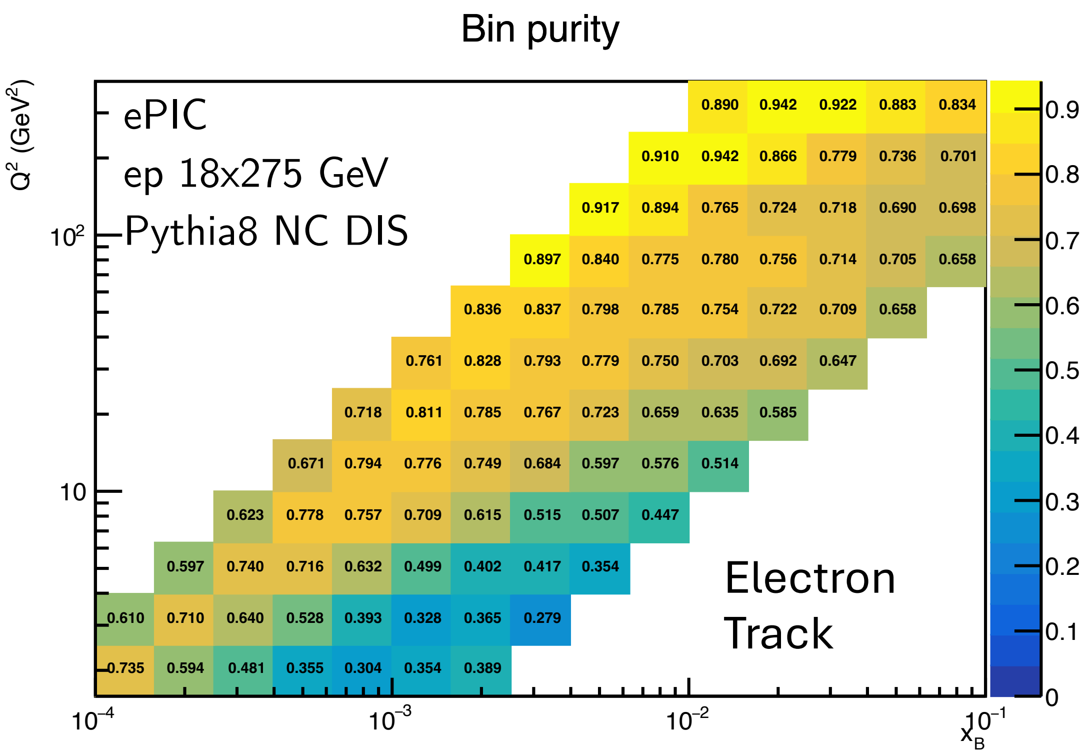
Potential benefit with nHCAL

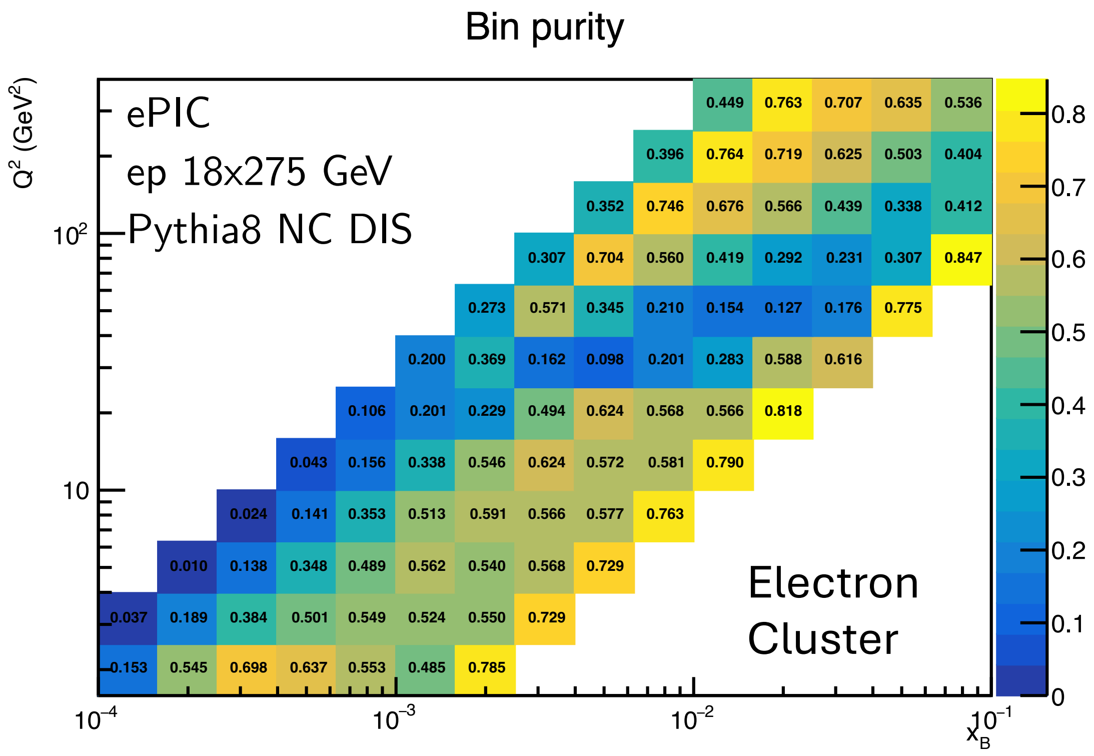
<u>Low-x and low-Q^2</u>



Event Kinematics & Reconstruction

We have tracking and an EMCAL for electron tagging





$$P = \frac{N_{gen+rec}}{N_{rec}}$$

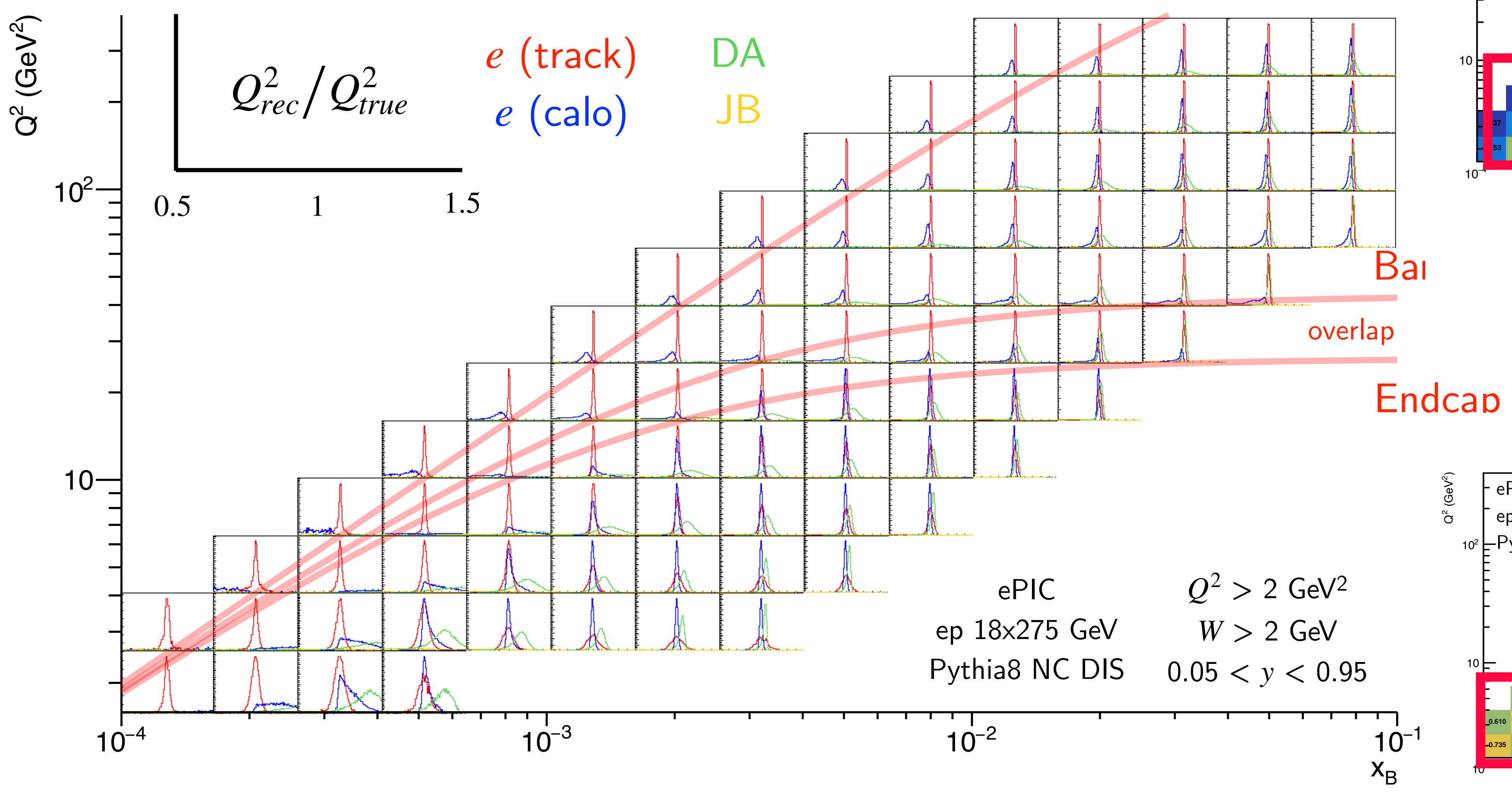
Low-x, Low Q^2 events are most difficult to tag cleanly with tracking & EMCAL. Neutral & Hadronic veto is crucial in this region

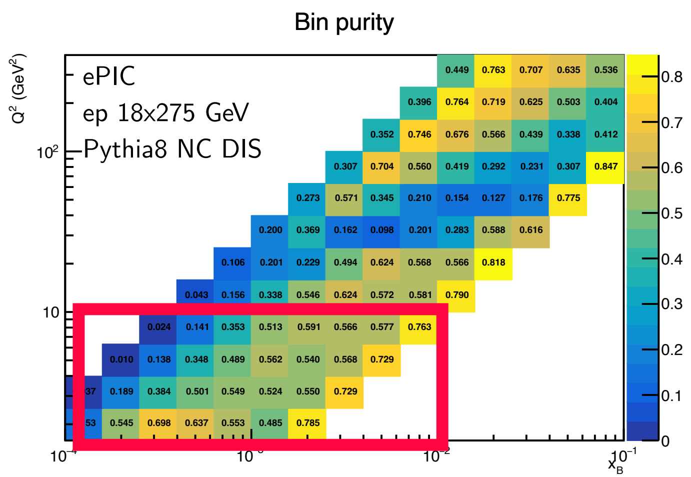
$$P = \frac{N_{gen+rec}}{N_{rec}}$$

Study by Tyler Kutz

Event Kinematics & Reconstruction

Kinematic resolutions





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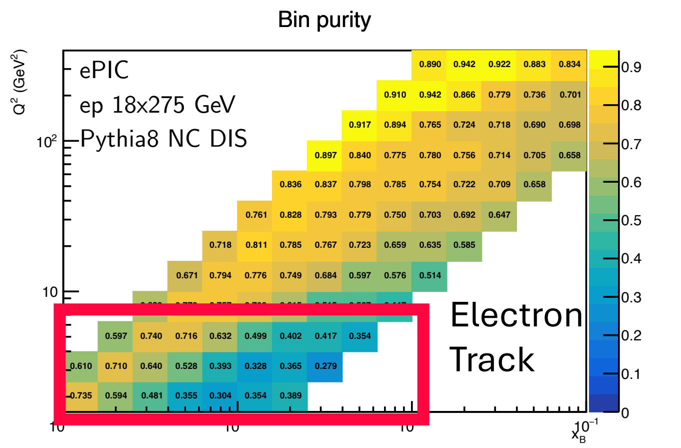

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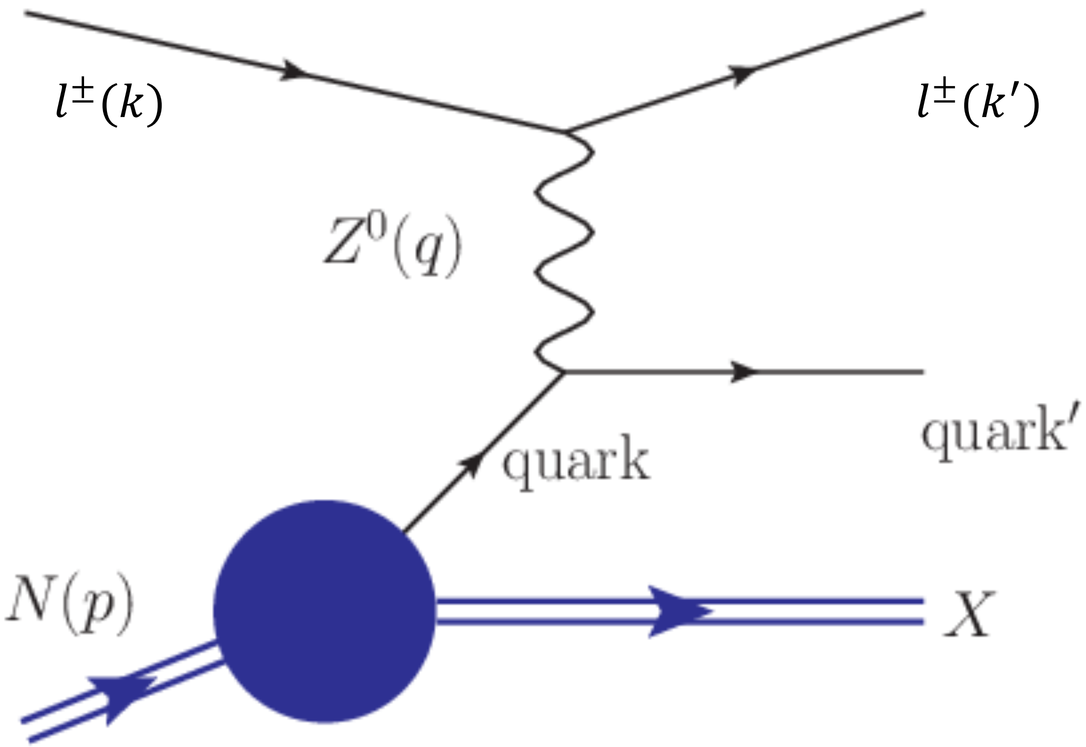
Event Kinematics & Reconstruction

- Event inelasticity (y):
- $y \equiv \frac{p \cdot q}{p \cdot k}$
- Need scattered electron kinematics
  - Not guaranteed, and not possible for charged current
- Or estimate it with the hadronic final states y_{JB} where:
- $y_{JB} \approx \sum_h \frac{E_h - p_{z,h}}{2E_e}$



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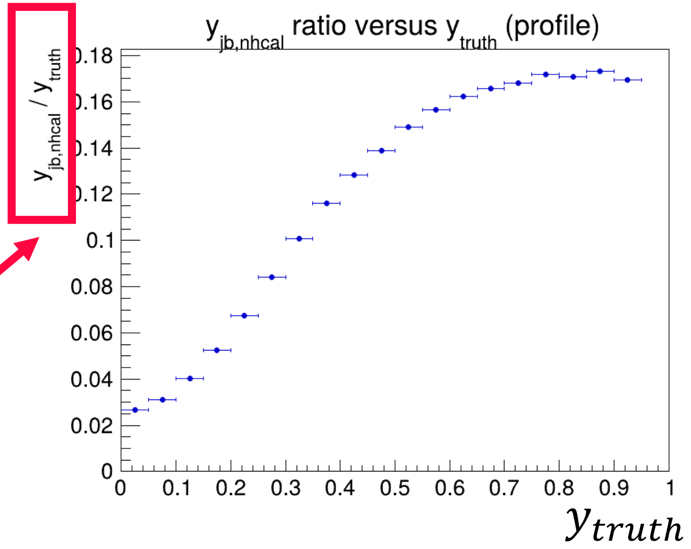
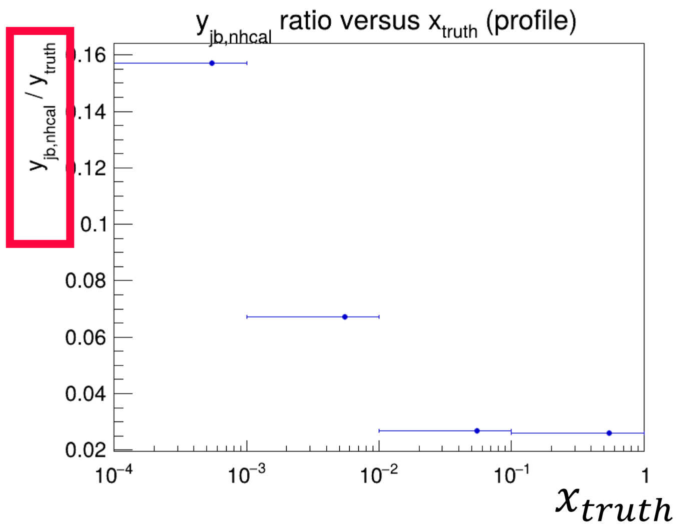
eAu DIS 10x100 BeAGLE 1<=Q^2<=10

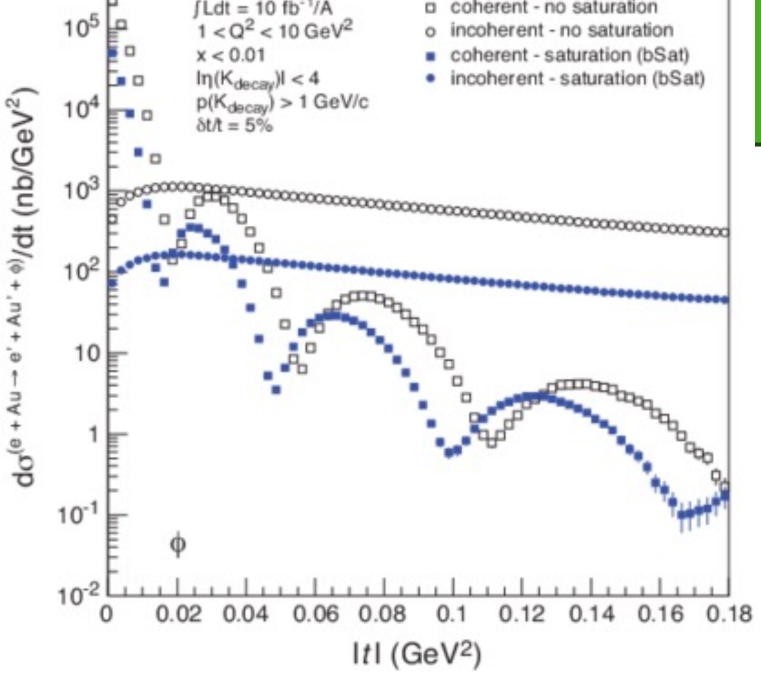


Fraction of hadronic final state (contributing to y_{JB}) from neutrals in nHCAL acceptance



~10% (and growing) effect on y_{JB} for $x < 10^{-2}$

Diffractive Events

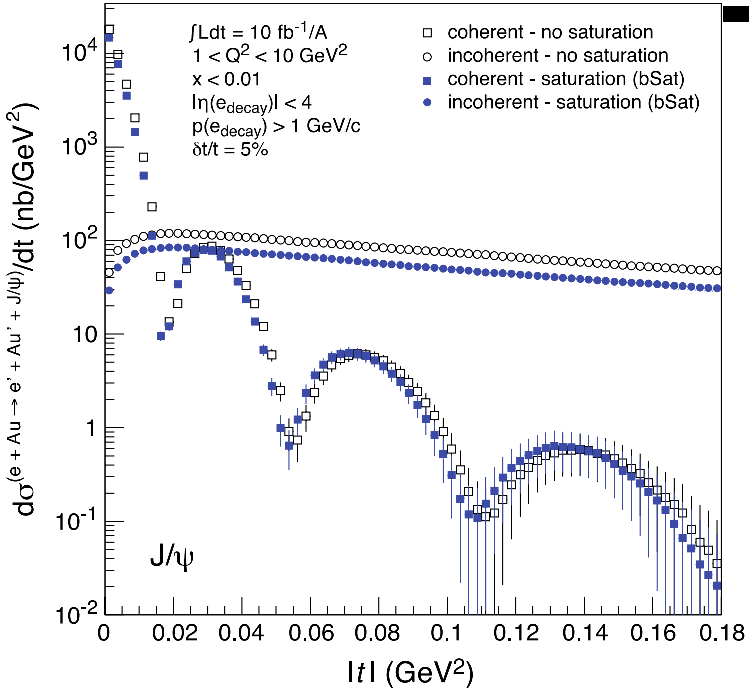


At HERA, diffractive events made up a large fraction of the total e+p cross-section (10–15%). Saturation models predict that at **the EIC, more than 20% of the cross section will be diffractive**

- Diffractive processes are directly proportional to square of gluon distribution – **"very sensitive to the onset of non-linear dynamics in QCD"**
- Exclusive diffractive production of the ϕ and J/ψ was featured in the EIC White Paper
- **Consider as motivation only the impact of an nHCAL on $J/\psi \to \mu\mu$ and $\phi \to KK$**
- But other cases for μ, K acceptance also

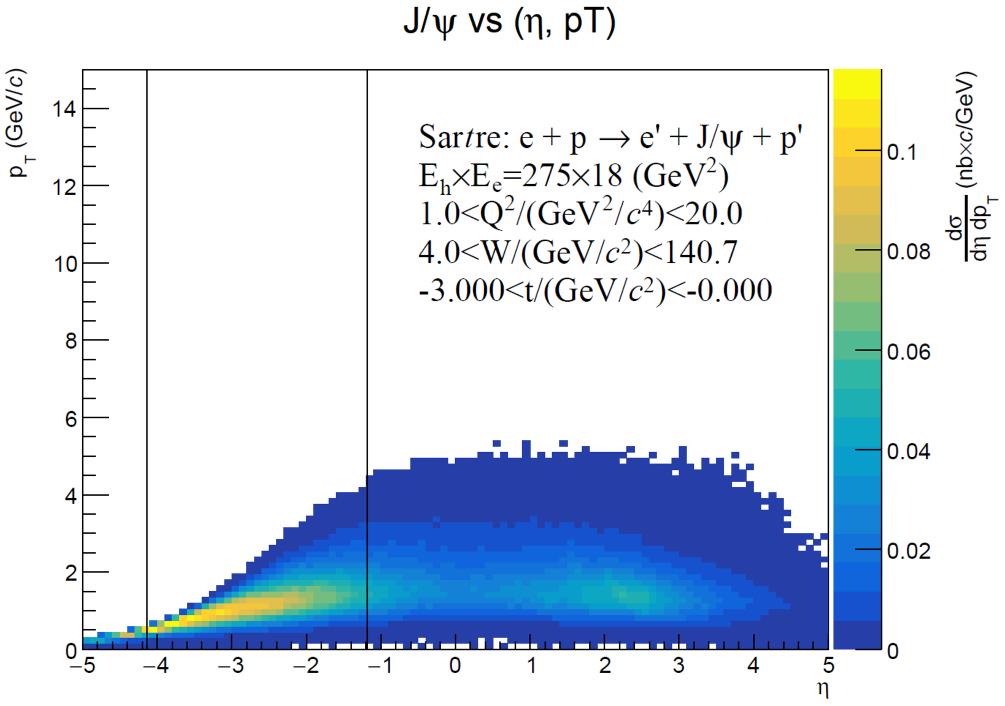
H.Mantysaari,B.Schenke PRC 101 (2020) 015203

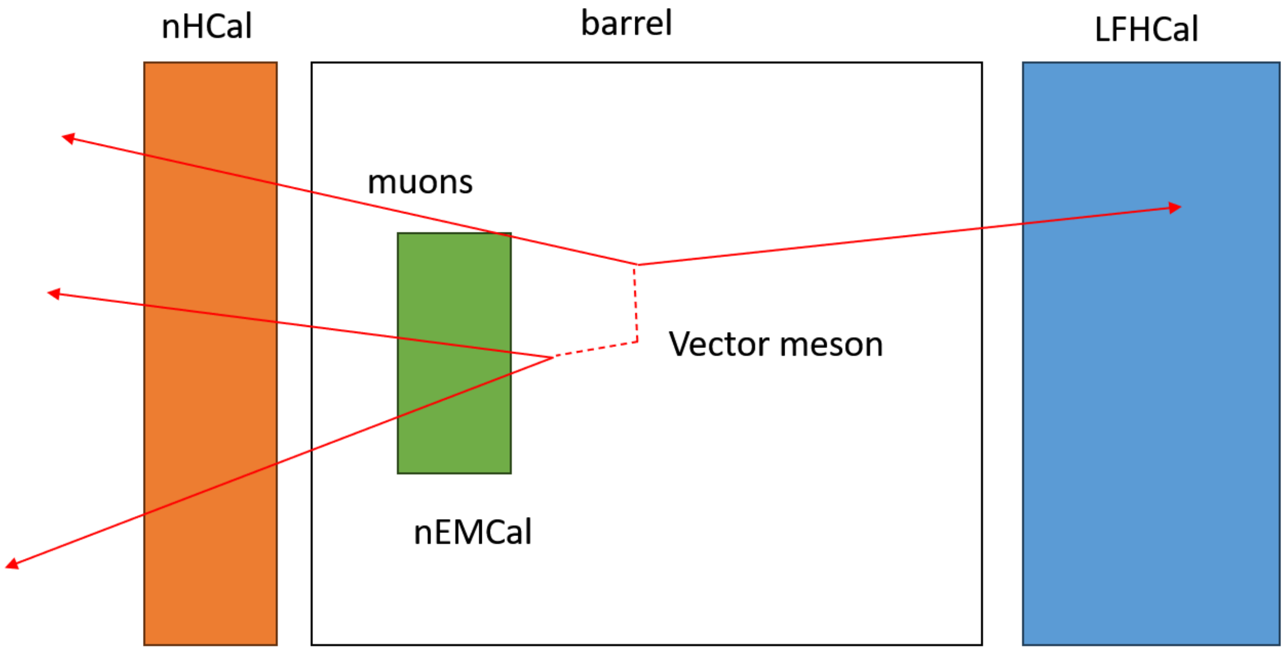
https://arxiv.org/pdf/2103.05419



VM Kinematic Distributions

- Sartre (275x18) simulation of Diffractive J/ψ in ep





Backward acceptance is crucial for accessing fully available diffractive cross section

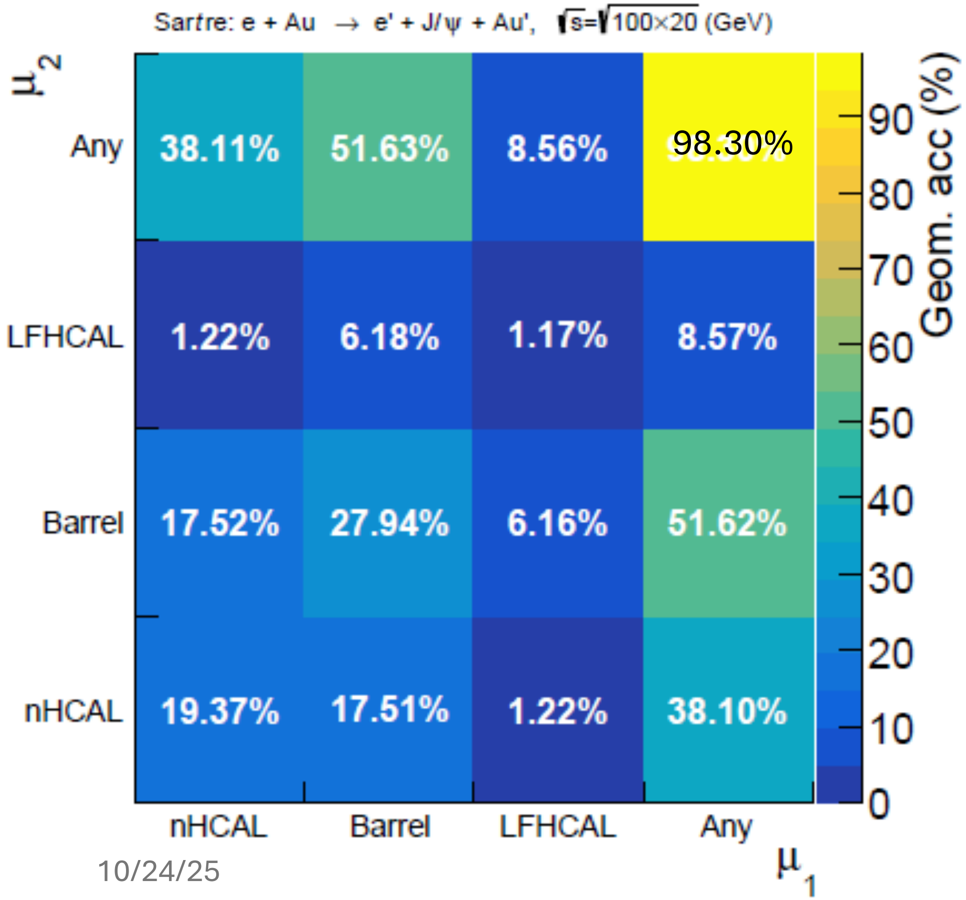
-4.05 < eta < -1.2

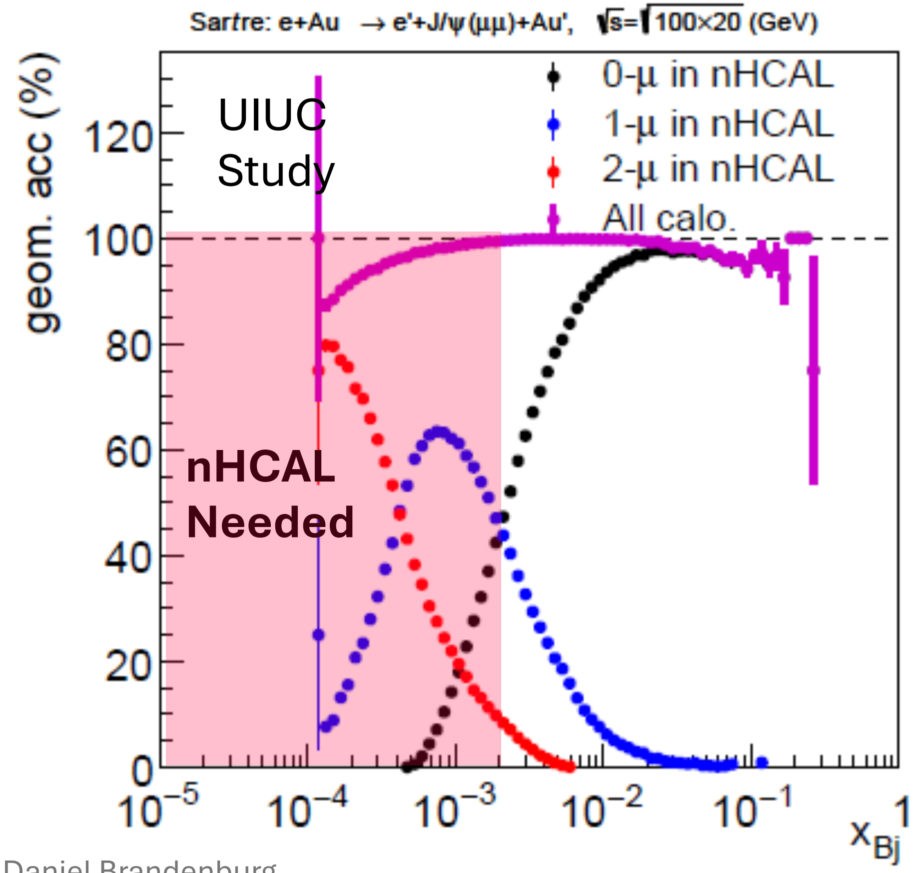
Additional backward acceptance has a <u>multiplicative</u> effect. Access to various VM decay topologies:

- nHCAL x nHCAL
- nHCAL x Barrel
- nHCAL x LFHCAL

nHCAL Impact for $J/\psi \to \mu\mu$

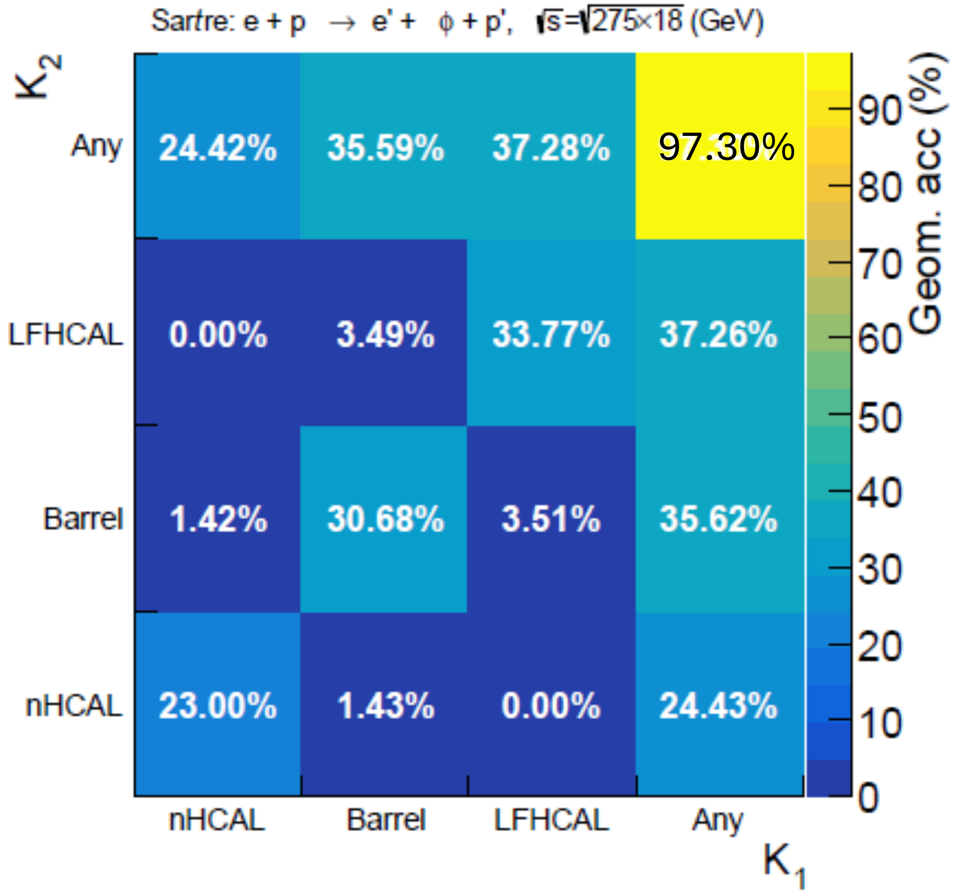
- **40% = nHCAL + any:** J/psi send one or both muons into backward HCAL acceptance
- Virtually all $x < \sim 10^{-3}$ events require nHCAL acceptance
- **Bonus: muon channel compliments electron channel, reduced Bremsstrahlung + Sudakov**

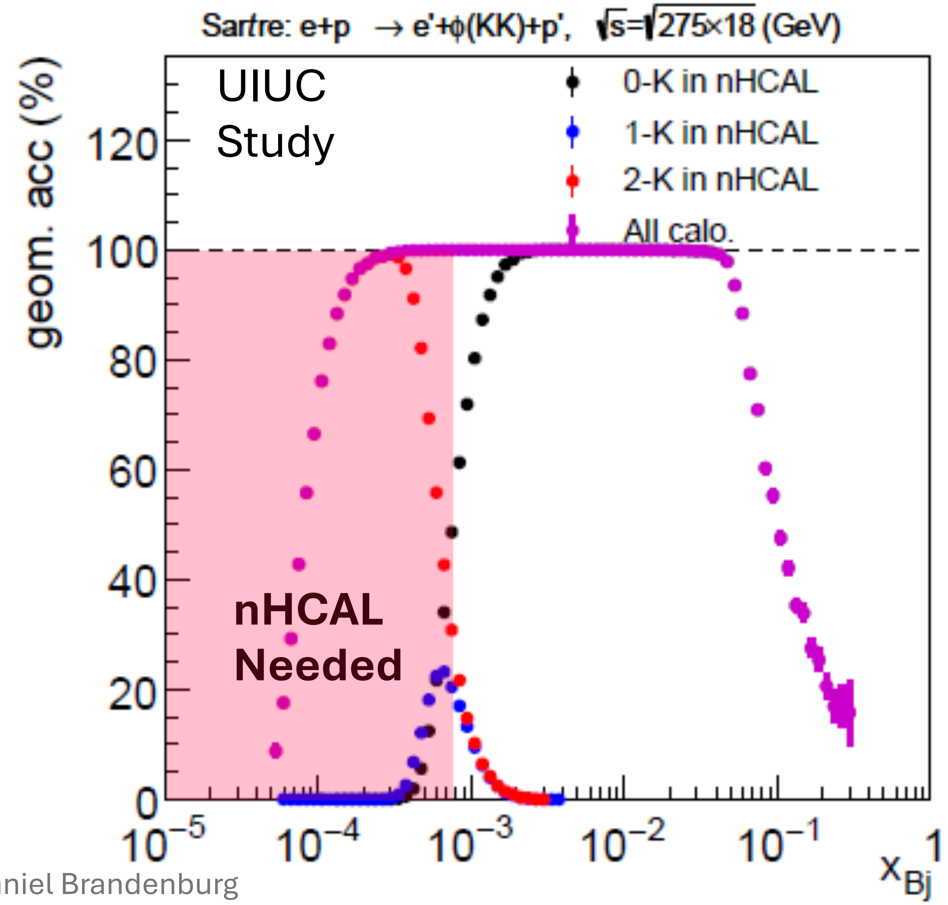




nHCAL Impact on $\phi \to KK$

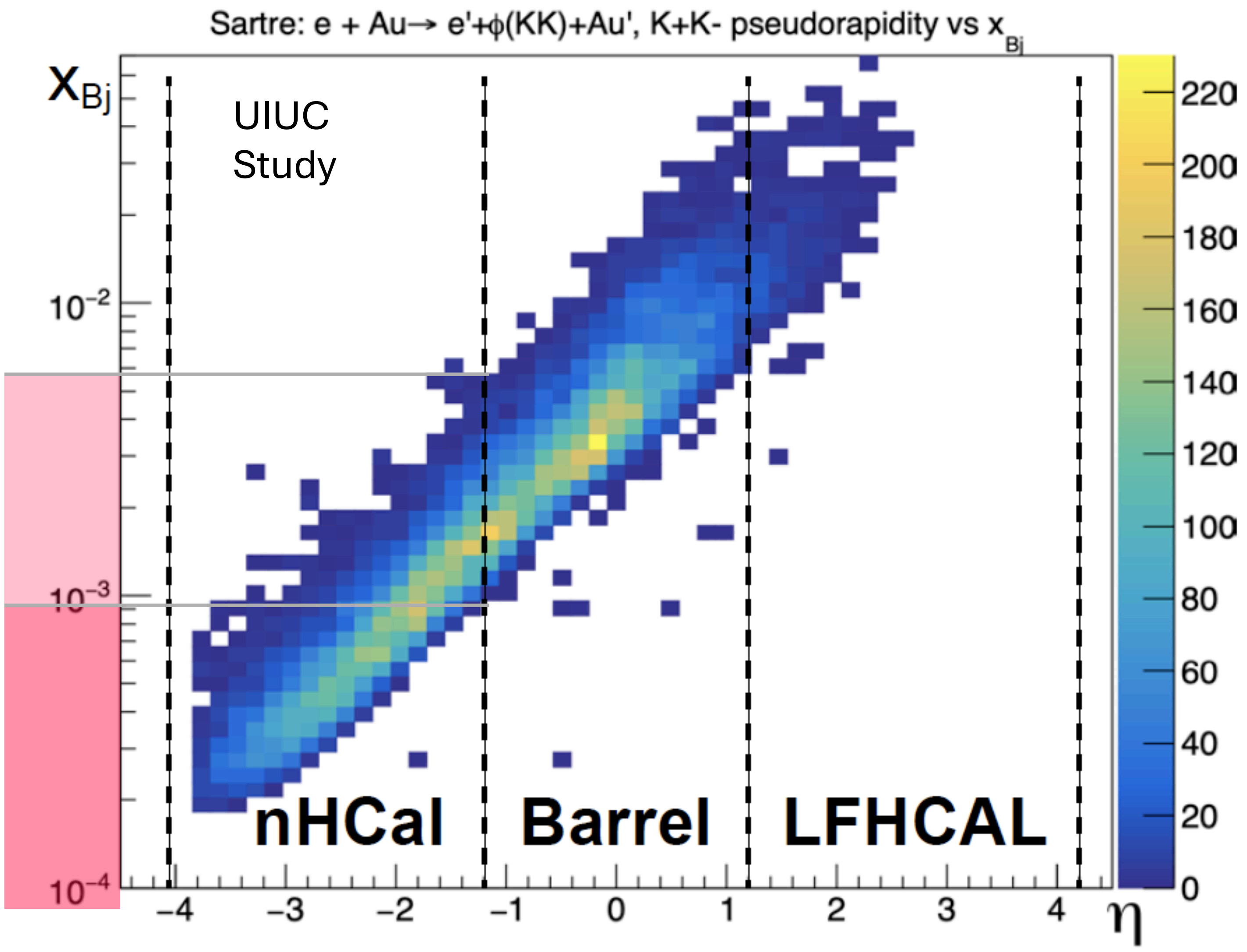
- **25% = nHCAL + any: ϕ** sends one or both Kaon into backward HCAL acceptance
- Virtually all $x < \sim 10^{-3}$ events require nHCAL acceptance
- **Bonus: muon channel compliments electron channel, reduced Bremsstrahlung + Sudakov**





nHCAL for Low-x VM Production

- Exact fraction and x threshold depend on details of nHCAL design (η coverage)
- <u>Message is clear:</u>
  - nHCAL crucial for **low-x**
- VM studies could be discovery measurements, but backgrounds are challenging
- We have also studied $\gamma\gamma \rightarrow \mu^+\mu^-$, same story

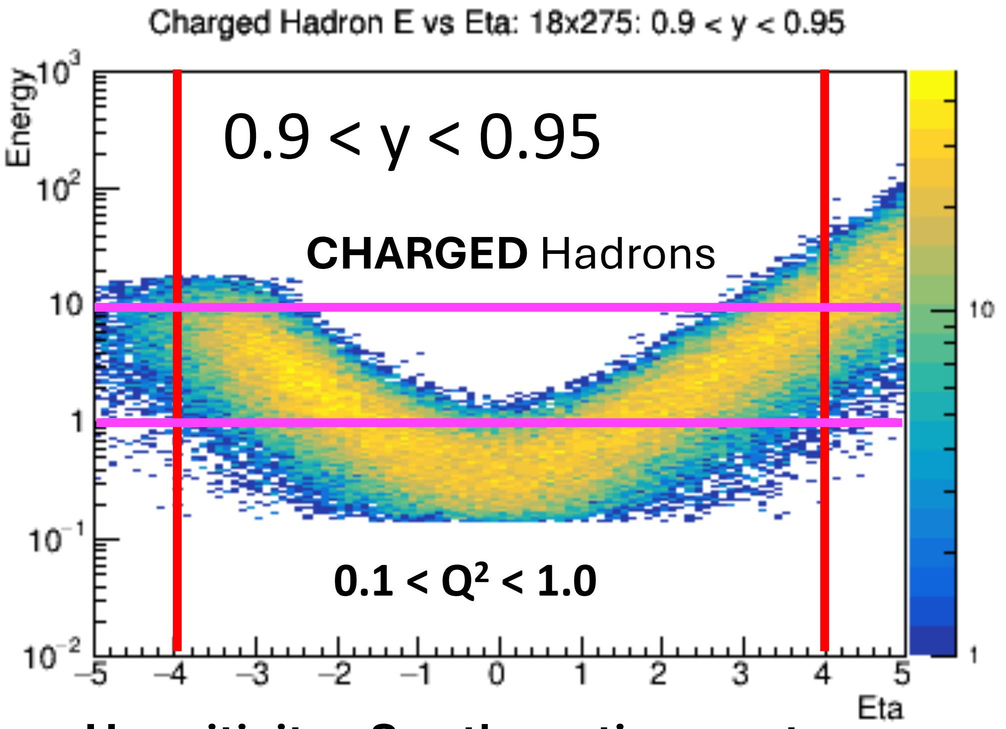


Phys. Rev. D **104**, 114030

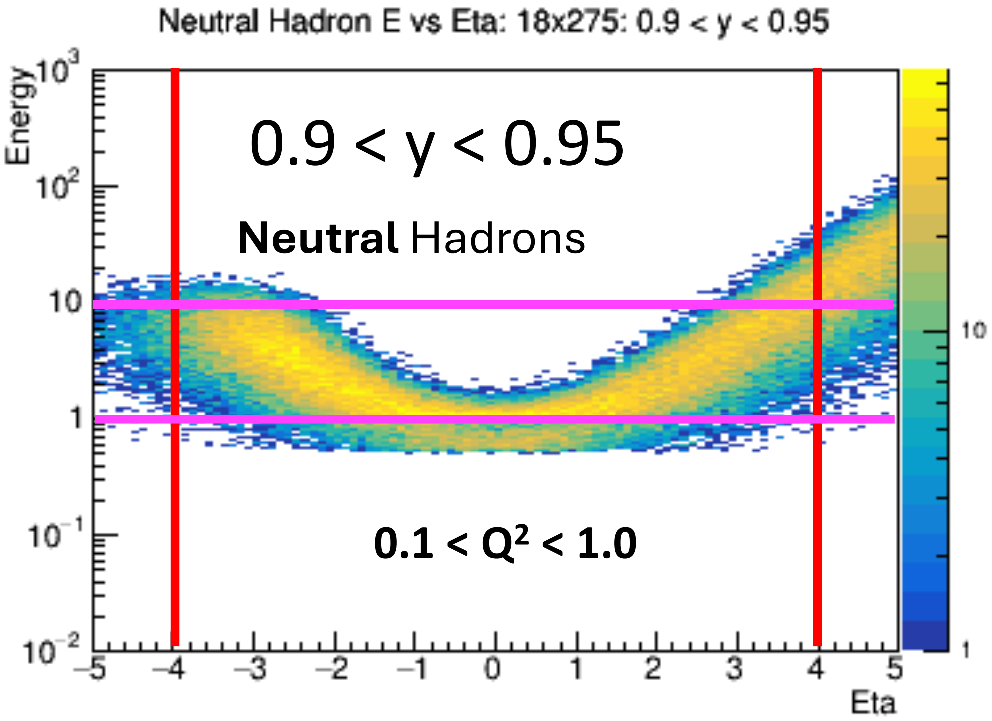
Difractive Dijets – Another Crucial Component

- "Studies of (dijet) diffraction in high-energy electron-proton scattering is one of the highlights of the HERA heritage"
- Low-x, high-y processes -> Jets in negative eta
- Hi inelasticity events = activity BOTH forward & backward
  https://arxiv.org/pdf/1911.00657

"The importance of jet probes was reflected in the EIC Yellow Report where they touched on nearly every major physics topic (Nucl. Phys. A, Vol 1026, 122447)"



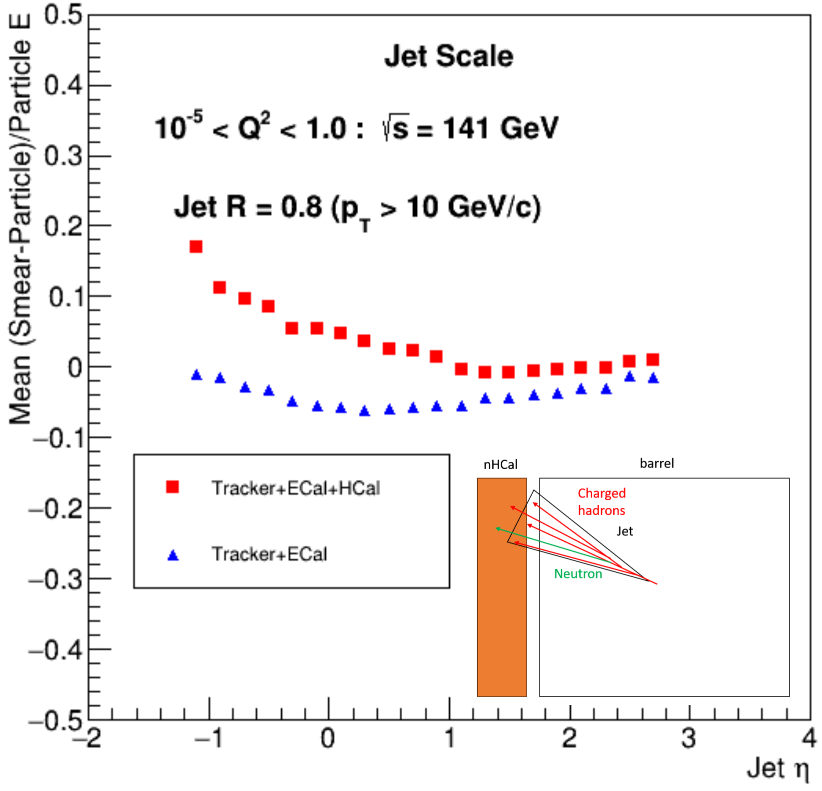
Hermiticity – See the entire event (forward & backward)



nHCAL – improve Jet Energy Resolution + Jet energy scale for large range of low-x measurements

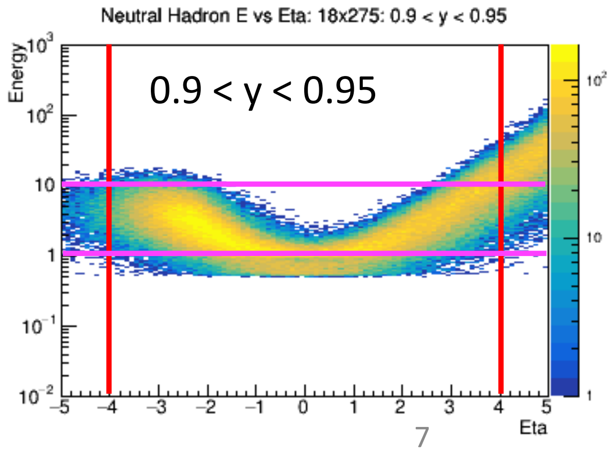
Neutral Hadrons

- nHCAL – improve Jet Energy Resolution (JER) + Jet Energy Scale (JES) for large range of low-x measurements



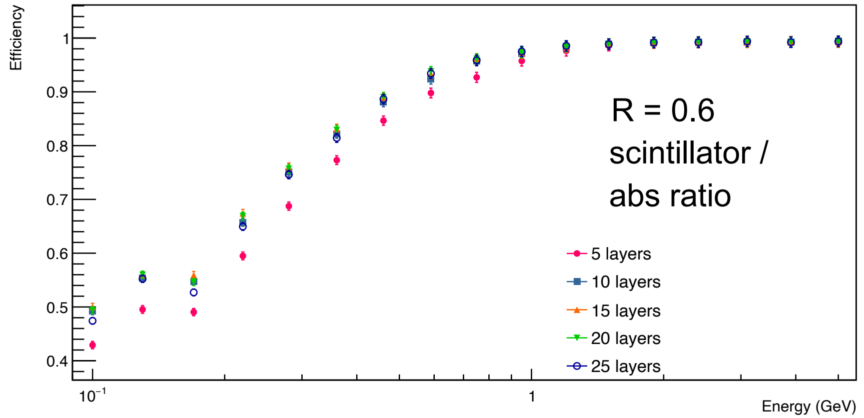
EIC Yellow Report Fig. 8.57

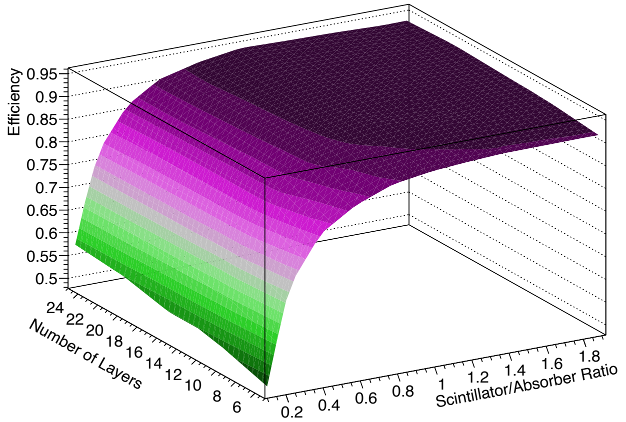
Vetoing jets with neutral hadrons using the nHCal could substantially improve resolution + scale



$$< E >= 2.38\ \mathrm{GeV},\ \text{lowest}\ E = 1\ \mathrm{GeV}$$

$$< p >= 2.12\ \mathrm{GeV/c},\ \text{lowest}\ p = 0\ \mathrm{GeV}$$





nHCAL design optimized for low energy neutron detection

ePIC nHCAL: Physics → Detector Requirements

We want to do this physics + crucial to EIC Mission	=	Detector Requirements

nHCAL Crucial for:

- Low-x & Q^2, high y

Diffraction

- Vector Mesons
- Dijets

Muon ID (dis-ambiguation)

Charged Jet Measurements

Neutral Jet / Neutral VETO

Scattered Electron ID (h VETO)

Improved Hermiticity (benefit kinematic resolution in CC)

- Coverage in backward direction
- Good μ / π separation via MIP signal
- High efficiency low-energy neutron efficiency
- Good spatial resolution to distinguish clusters (neutral vs. charge)
- Good timing resolution

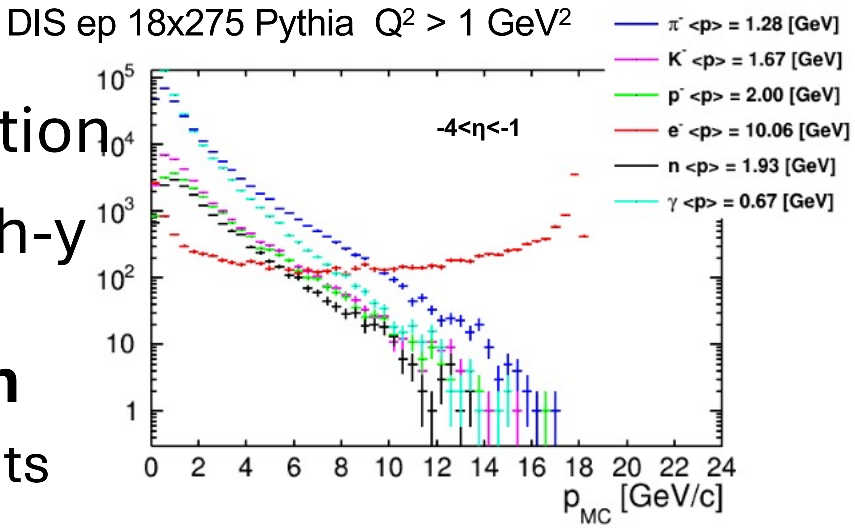
nHCAL: crucial for core aspects of EIC Physics Mission

Main purpose of nHCal

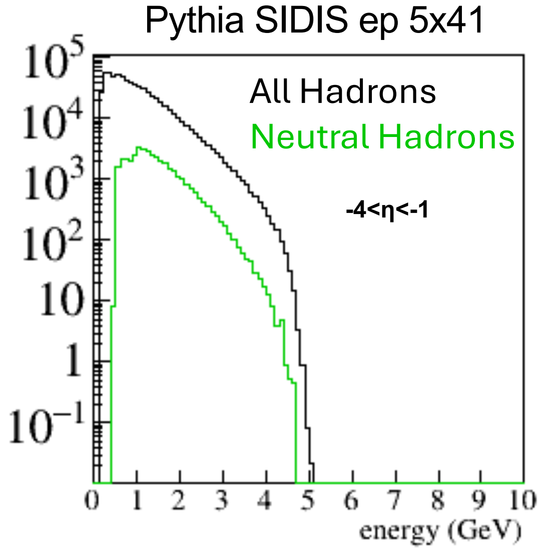
- Tail catcher calorimeter in the backward (electron-going) direction
- Important for low-x and -Q2, high-y (high gluon densities) - **core aspects of EIC physics mission**
  - Diffraction, neutral and charged jets
  - Neutron detection and muon ID
- Lessons learned from HERA / H1 backward SPACAL [NIMA 386 (1997), 397-408](#) [PLB 665 (2008), 139-146](#)
- Tail-catcher: design optimized for particles in the few to 10s of GeV range

neutrons in nHCal:
<p>=1.9 GeV/c
<E>=2.2 GeV

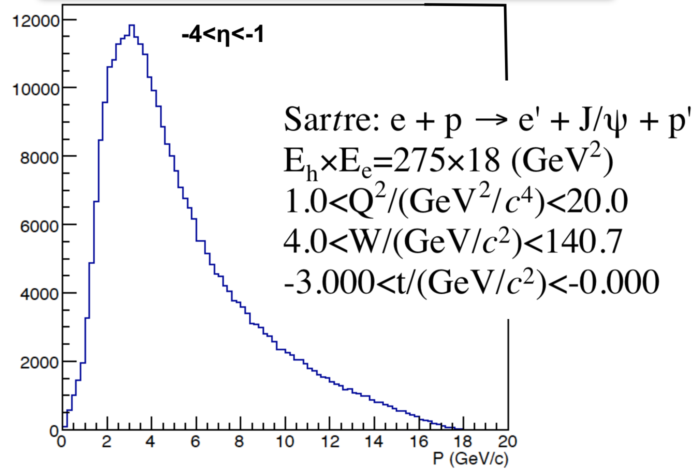
muons in nHCal:
<p>=5.3 GeV/c
<E>=5.3 GeV



neutrons and charged particles



muons from diffractive J/ψ decay



nHCal design optimization via simulations - overview

Readout:

- Utilize CALOROC (36ch) along with other HCALs
- (1058 (full) x 2 + 72 (half)) * 10 layers = 21,880 channels
- Each CALOROC has 36 ch.
  - CALOROC can handle 1 full module (20 channels) or 2 half modules

Design optimization

- Parameters: transverse tile size, number of layers, scintillator & absorber thickness
- nHCAL: 1st layer (nearest IP) is scintillator
  - ➢ Improve neutral vs. charged hadron separation
- Dedicated simulations:
  - ➢ Single particle, DIS, Diffractive events
- Absorber material fixed by external constraints
  - Non-magnetic material (magnet system)
  - Risk + cost prohibit use of e.g. W, depleted U

Physics impact ➡ Design parameter ⬇	σE/E	Eff	μ/π sep.	λint
Gross length	X	X		
Tile configuration	X	X		
Z-layer readout	X		X	
Sampling fraction, absorber/scintillator ratio				X
Absorber material	X			X

5x5 or 10x10	scintillator thickness	0.4				0.6	2.4	1.2
[cm]	absorber thickness	4	3	2	1.5 2	2	4	2
10 layers		45					64	
12 layers		54						
13 layers			46					
15 layers		68						
20 layers				50		54	58	64
28 layers					57			

gross length

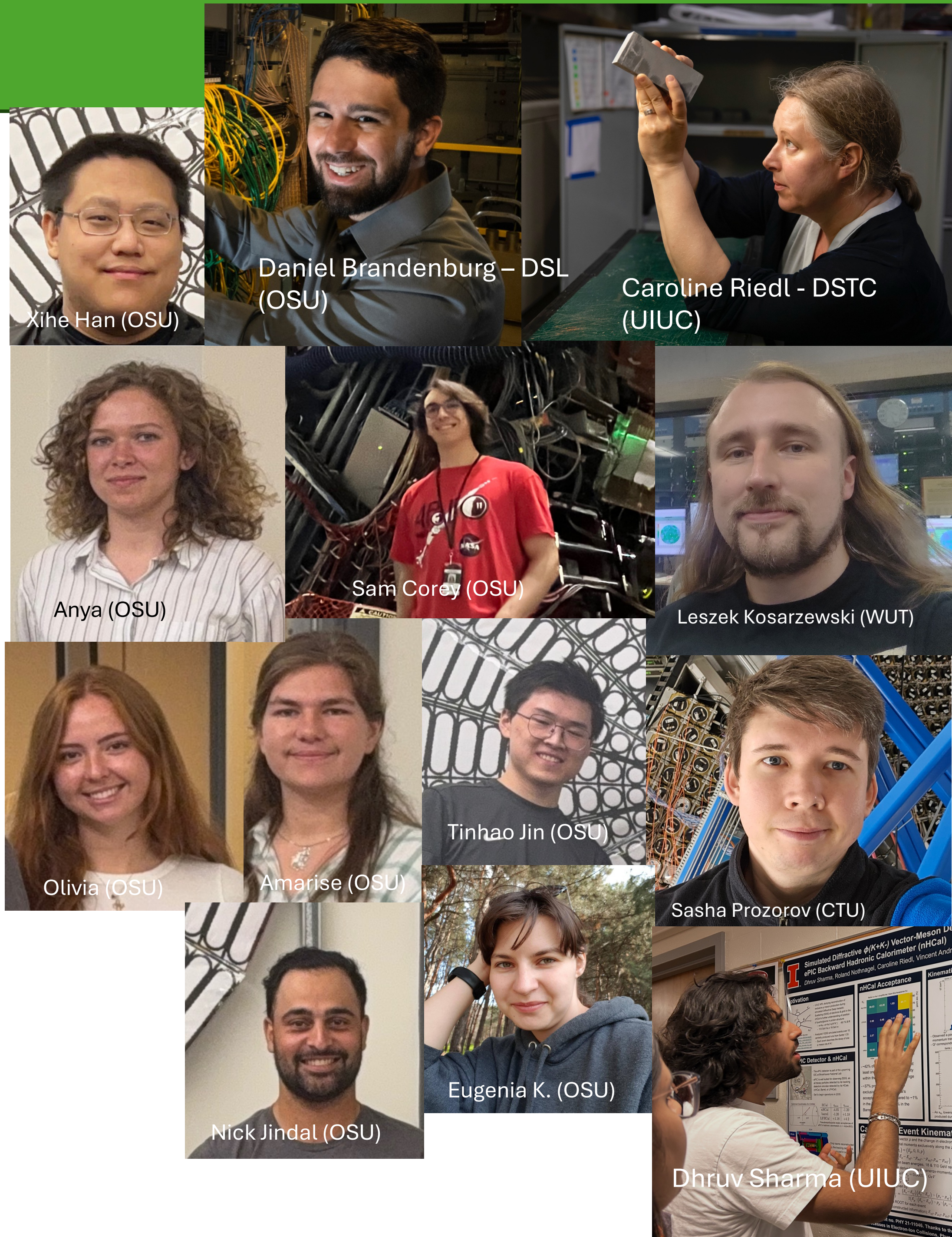
nHCal configuration (10x10 tiles)

LFHCal configuration (5x5 tiles)

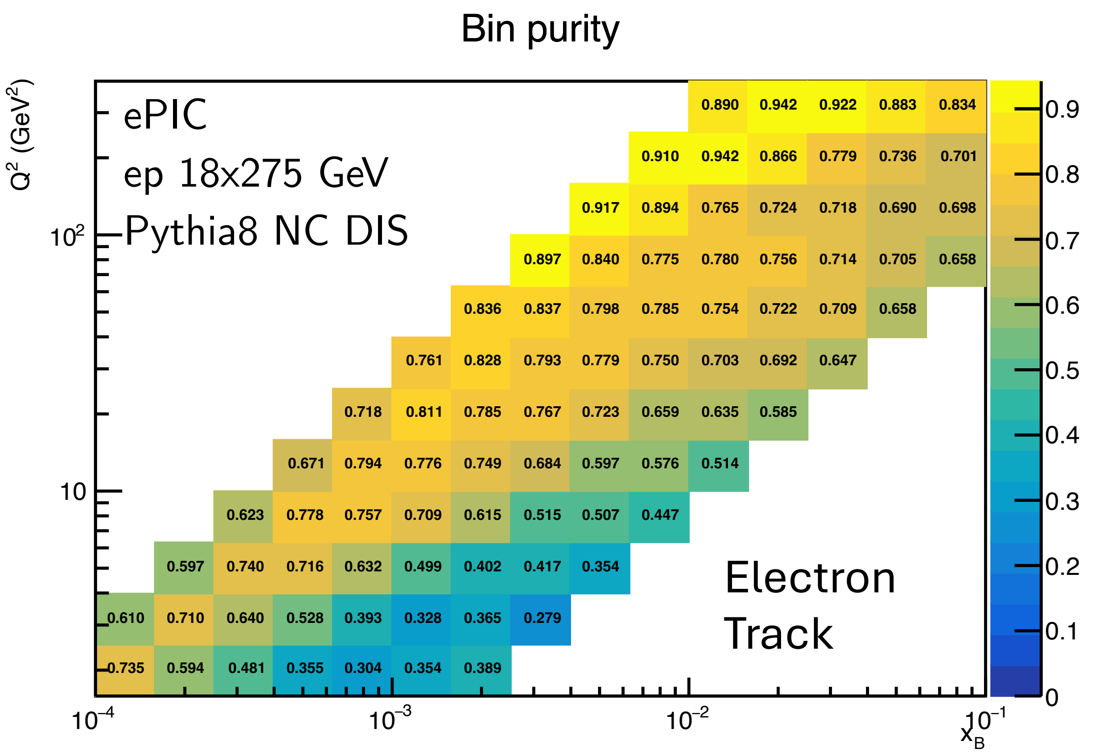
nHCAL Summary

Status:

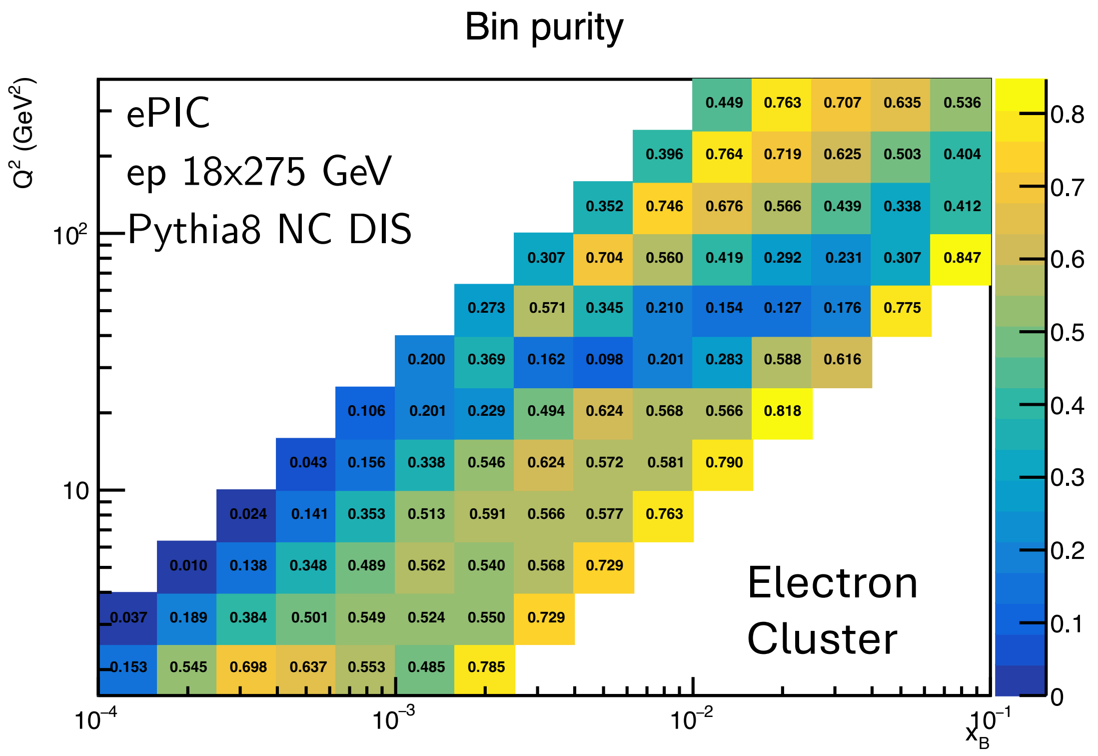
- Synergy with LFHCAL technology, with design of nHCAL optimized for ‘tail-catcher’ role in ePIC
- Involved institutions: OSU, UIUC, CTU, BNL, WUT
- Design optimization for Tail-Catcher role in ePIC
  - Neutron efficiency at low energy
  - Charged particle detection at low energy
  - Muon and Kaon Identification
  - **Crucial for low-x, low Q^2, and high y events**
- The nHCal can be delivered later than most other detectors because it is decoupled from the magnetic flux return
- Baseline configuration determined & plan for CD-2 and beyond outlined with milestones



Summary nHCAL



$$P = \frac{N_{gen+rec}}{N_{rec}}$$

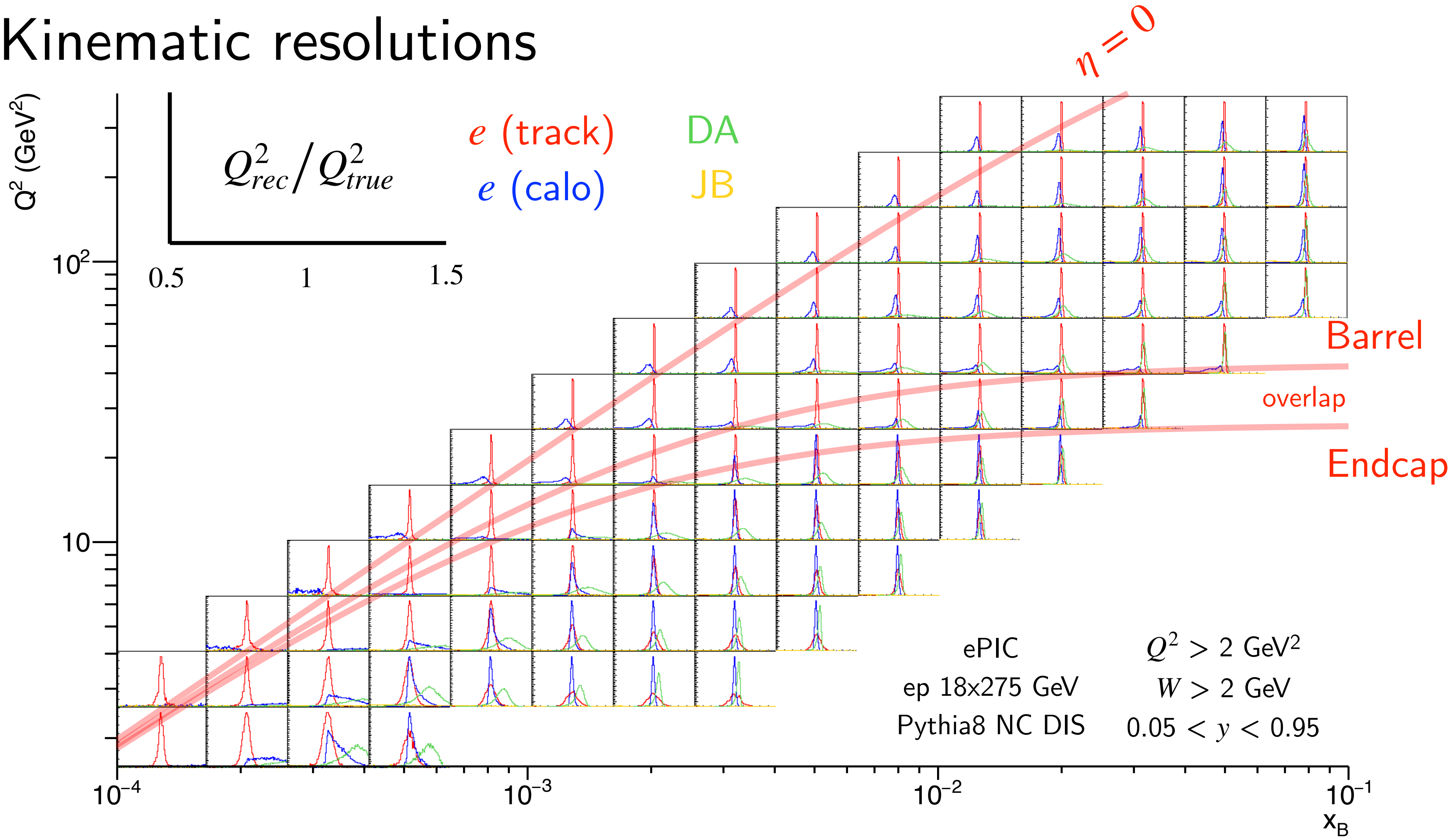


$$P = \frac{N_{gen+rec}}{N_{rec}}$$

Tyler Kutz

Kinematic Resolution

Kinematic resolutions



Tyler Kutz

- Low x physics:
  - Proton structure
  - Nuclear structure

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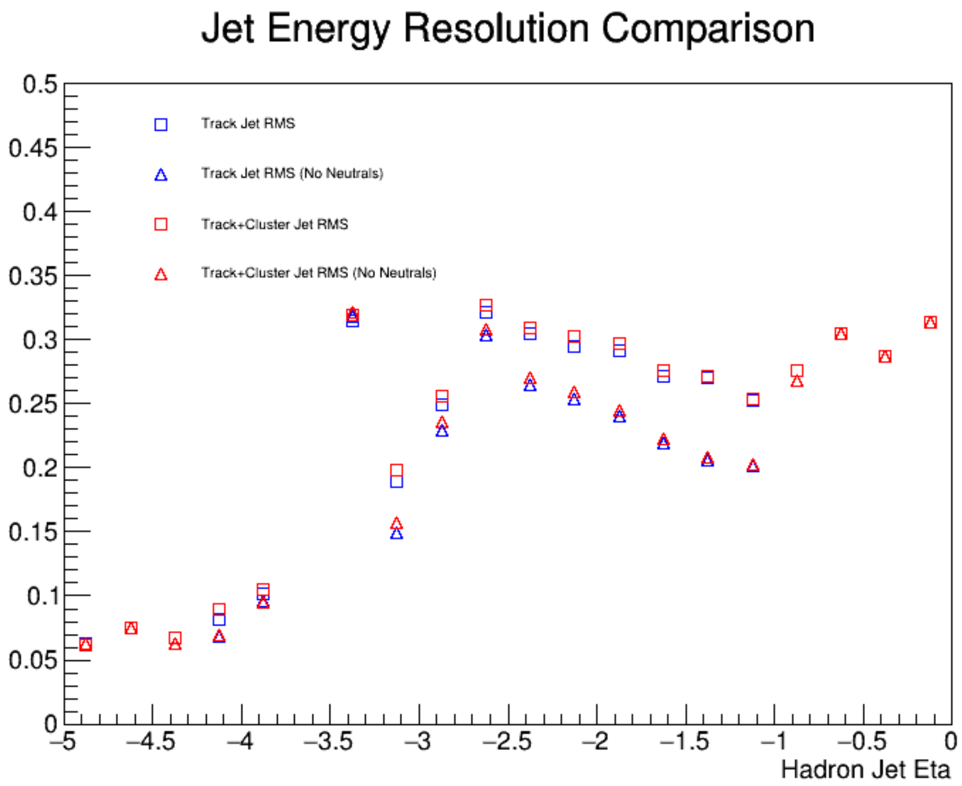
Search for CGC	Look for high gluon density state, expected at very low x	Exclusive to low x, potential new physics

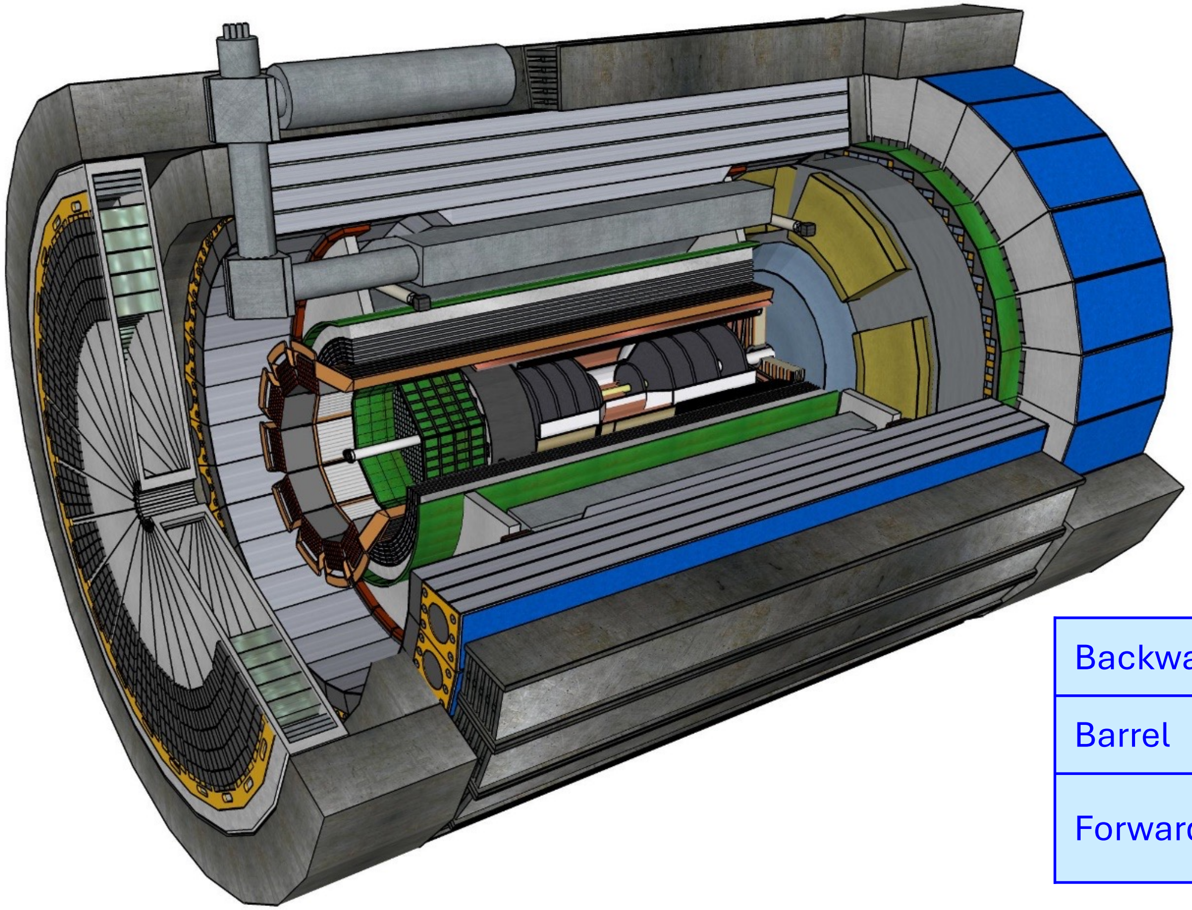
Neutral jets impact



- RMS of the full distribution of jet $(E_{reco} - E_{generated})/E_{generated}$ vs. η_{jet}
- Isolating neutral $(20 - 25\%$ of all jets) and charged jets already improves the resolution by $\sim 20\%$
- Unavoidable deterioration of resolution when adding clusters
  - Tracking offers better resolution in this kinematic range
  - However hadron measurements still needed for neutrals!
- Need track projections and cluster matching in DIS events for a realistic study

Hadronic Calorimetry

- **Energy resolution:** particle flow reconstruction (combined with tracking and em-calorimetry)
- **Granularity:** neutral cluster isolation and jet substructure measurements
- **Flux return** for solenoid magnet



Backward	**NHCal**	Steel/scintillator calorimeter
Barrel	**BHCal**	Refurbished from sPHENIX
Forward	**LFHCal**	Longitudinally segmented steel/scintillator

Main purpose of nHCal

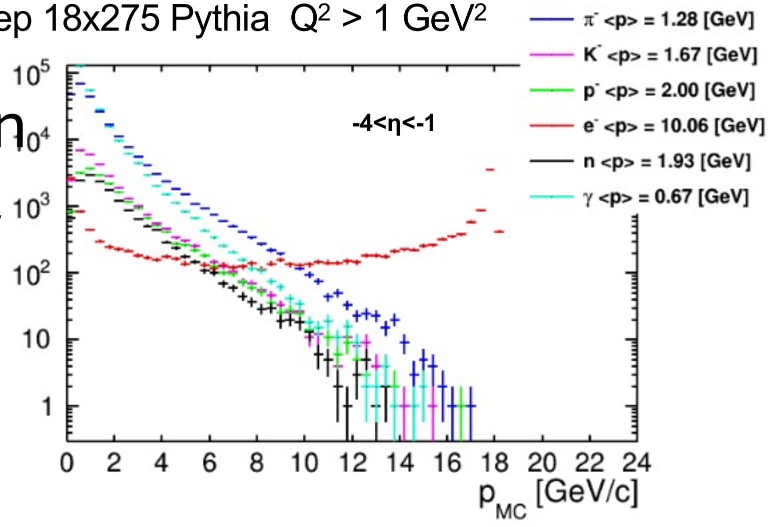
Charge 1

- Tail catcher calorimeter in the backward (electron-going) direction
- Important for low-x and -Q2, high-y (high gluon densities) - **core aspects of EIC physics mission**
  - Diffraction, neutral and charged jets
  - Neutron detection and muon ID
- Lessons learned from HERA / H1 backward SPACAL [NIMA 386 (1997), 397-408](#) [PLB 665 (2008), 139-146](#)
- Tail-catcher: design optimized for particles in the few to 10s of GeV range

neutrons in nHCal:
<p>=1.9 GeV/c
<E>=2.2 GeV

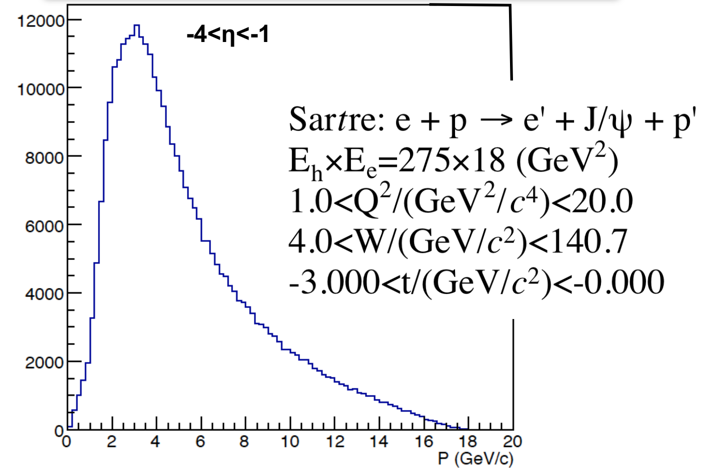
muons in nHCal:
<p>=5.3 GeV/c
<E>=5.3 GeV

DIS ep 18x275 Pythia $Q^2 > 1$ GeV^2

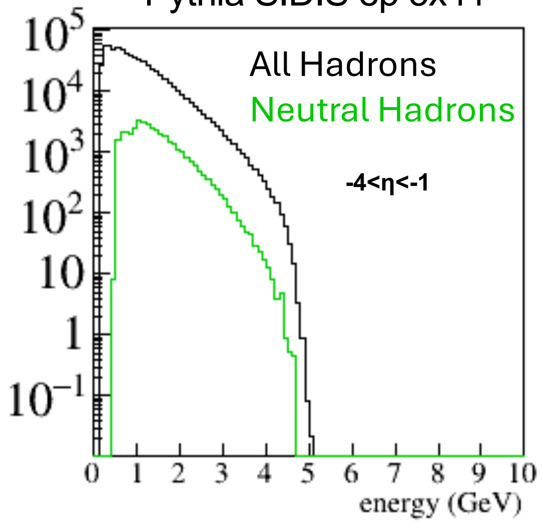


neutrons and charged particles

muons from diffractive J/ψ decay



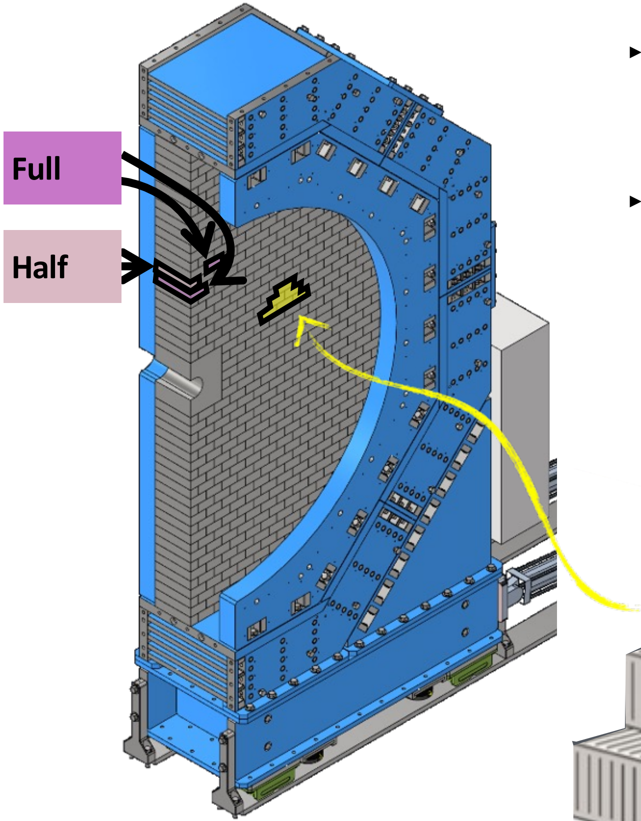
Pythia SIDIS ep 5x41



Backward (electron-going) hadronic calorimeter - **nHCal**

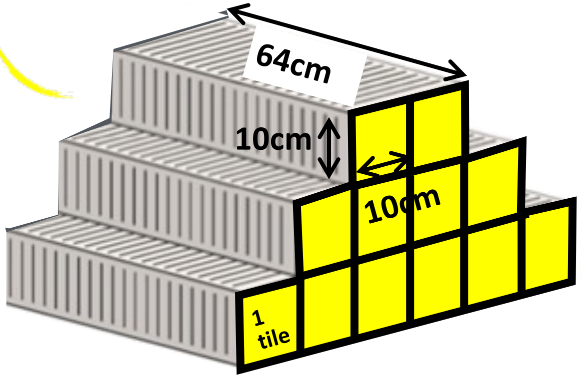
Charge 1

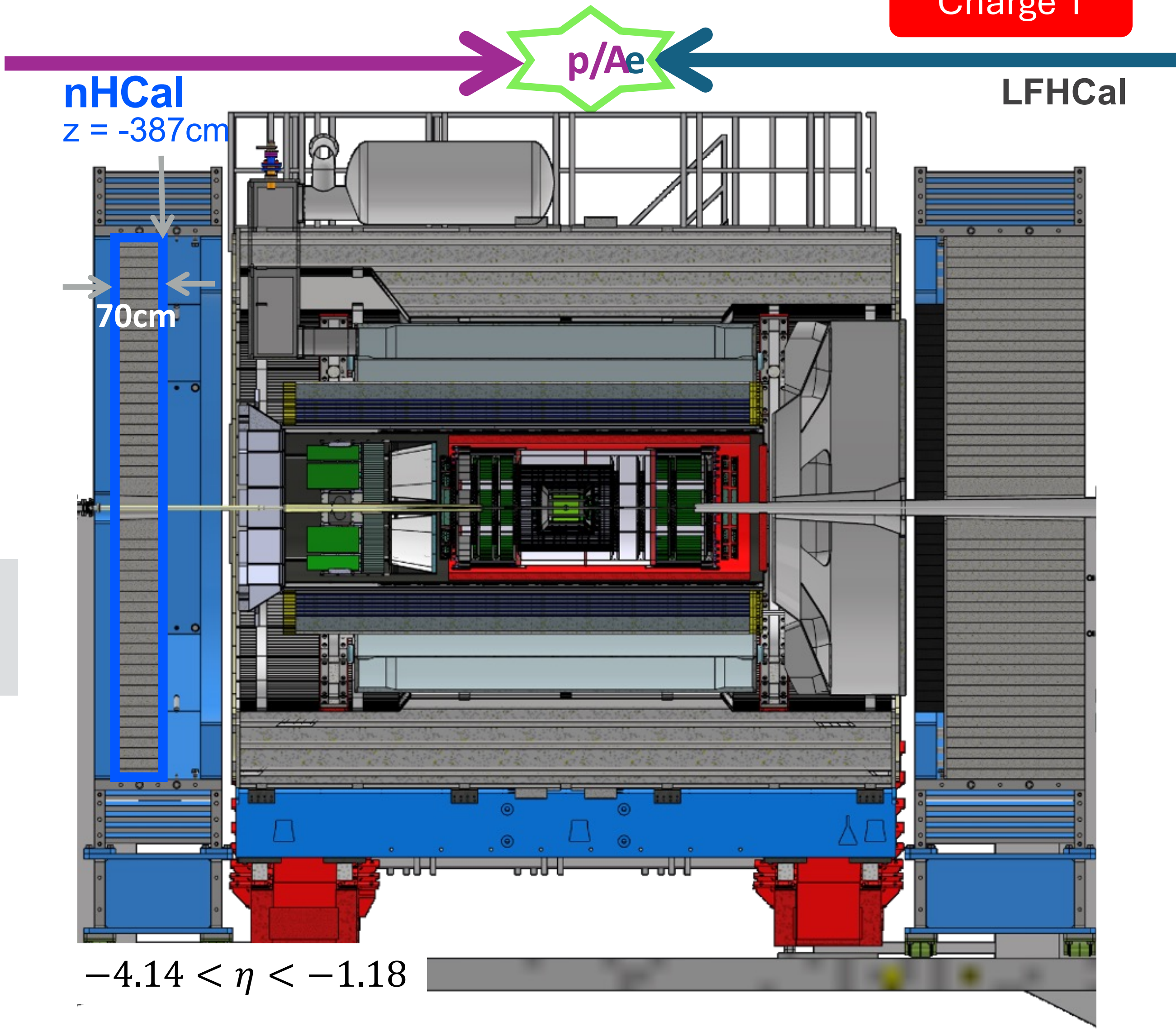
- Tail catcher calorimeter with sampling approach, alternating Fe / Sci Tiles layers
  - Synergies with LFHCal (choice of technology)



- Interaction lengths: ~2.4 (LFHCal: 6)
- up to ~70cm available (including electronics)

10 layers of each: 4 cm steel + 2.4 **cm scintillator**
+ Initial scintillator layer (2.4 cm)





$-4.14 < \eta < -1.18$

nHCal design optimization via simulations - overview

Charge 1/2

Readout:

- Utilize CALOROC (36ch) along with other HCALs
- (1058 (full) x 2 + 72 (half)) * 10 layers = 21,880 channels
- Each CALOROC has 36 ch.
    - CALOROC can handle 1 full module (20 channels) or 2 half modules

Design optimization

- Parameters: transverse tile size, number of layers, scintillator & absorber thickness
- nHCAL: 1st layer (nearest IP) is scintillator
    - ➢ Improve neutral vs. charged hadron separation
- Dedicated simulations:
    - ➢ Single particle, DIS, Diffractive events
- Absorber material fixed by external constraints
    - Non-magnetic material (magnet system)
    - Risk + cost prohibit use of e.g. W, depleted U

Physics impact ➡ Design parameter ⬇	$\sigma E/E$	Eff	μ/π sep.	λ_{int}
Gross length	X	X		
Tile configuration	X	X		
Z-layer readout	X		X	
Sampling fraction, absorber/scintillator ratio				X
Absorber material	X			X

5x5 or 10x10	scintillator thickness	0.4				0.6	2.4	1.2
[cm]	absorber thickness	4	3	2	1.5 2	2	4	2
10 layers		45					64	
12 layers		54						
13 layers			46					
15 layers		68						
20 layers				50		54	58	64
28 layers					57			

gross length

nHCal configuration (10x10 tiles)

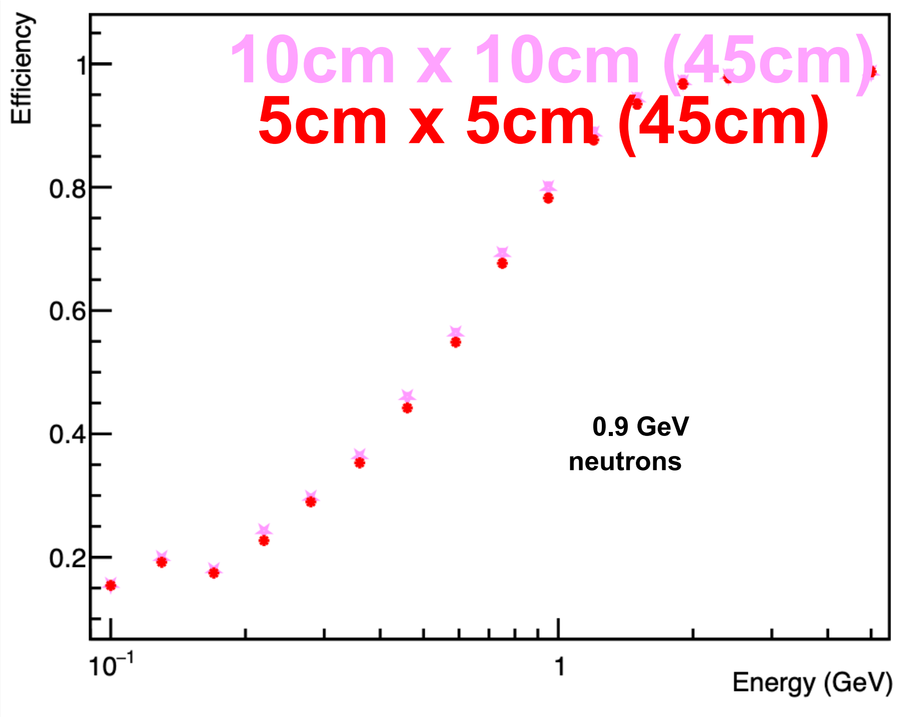
LFHCal configuration (5x5 tiles)

Design Optimization: Efficiency for neutrons

Charge 2

As a tail-catcher, low energy neutron detection is key design metric for the nHCAL

- Tile size has negligible impact
- Efficiency increases with
  - Number of layers (⇒ length of calorimeter): 10 → 15 layers increases efficiency by about 5% for 1 GeV neutrons
  - Scintillator / absorber ratio: scintillator 4mm → 8mm increases efficiency by nearly 20% for 0.5 GeV neutrons



Constraints on gross length, tile configuration, absorber/scintillator ratio

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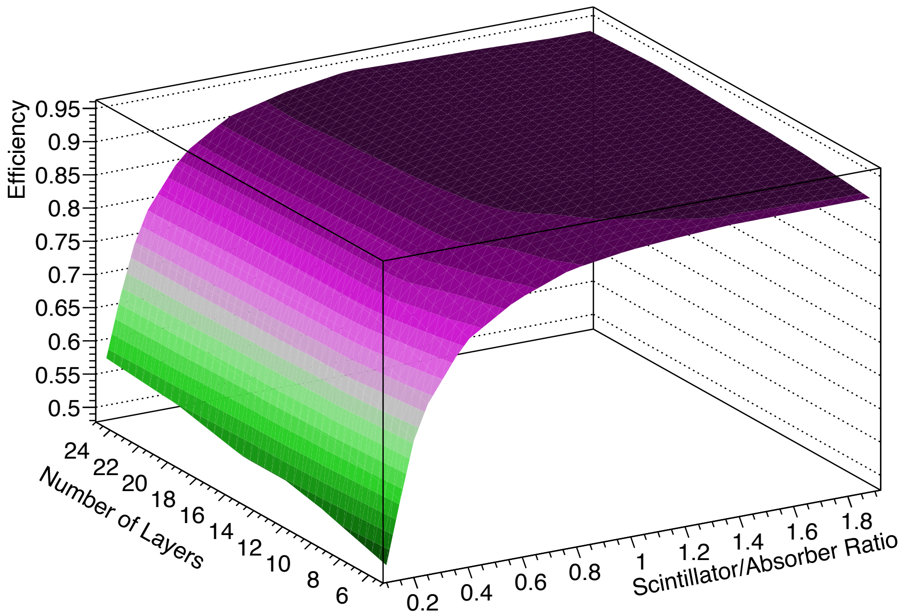

0.9 GeV neutrons

R=0.6 gives optimal efficiency for designs with >10 layers

Constraints on gross length, tile configuration, absorber/scintillator ratio

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  - Number of layers (⇒ ~length of calorimeter): >5 layers increases efficiency by about 5% for ~1 GeV neutrons
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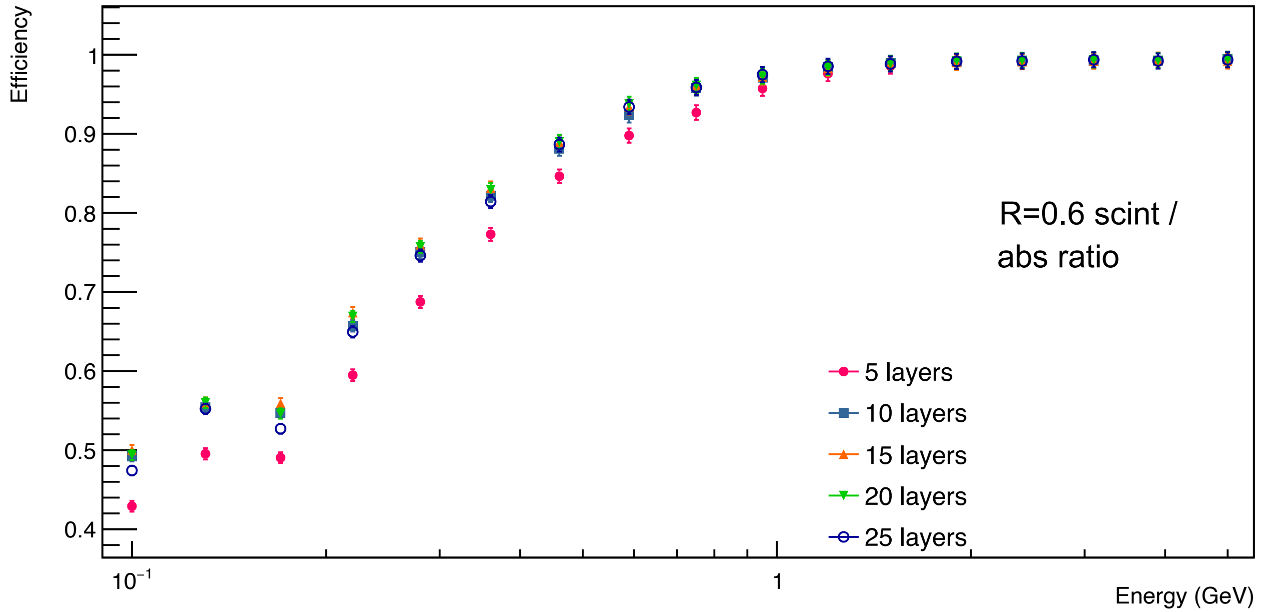

Constraints on gross length, tile configuration, absorber/scintillator ratio

Design Optimization: Efficiency for neutrons

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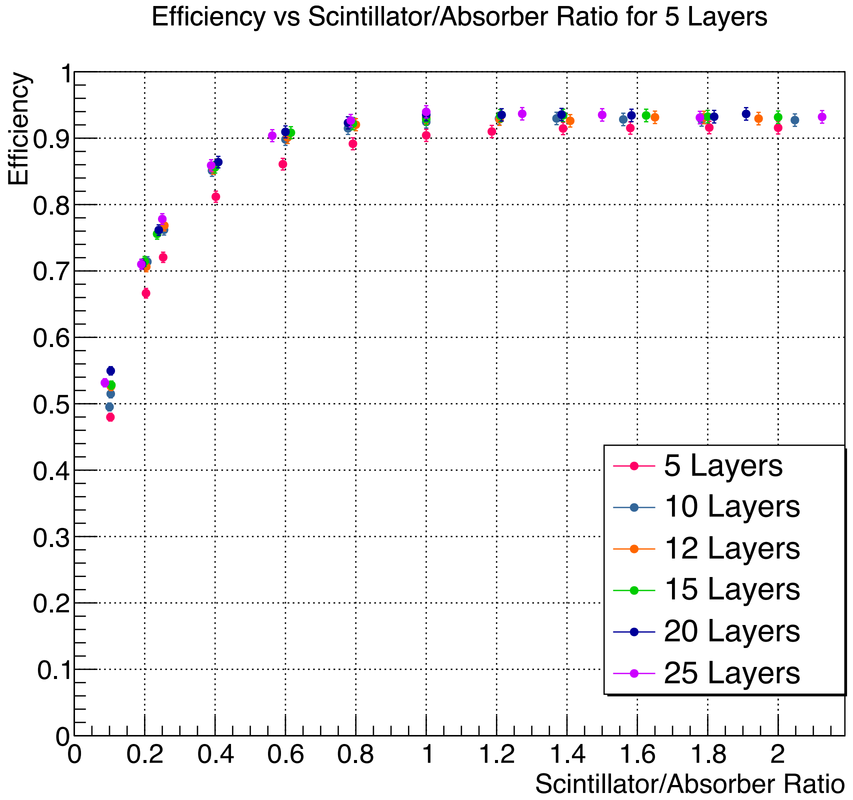
  - Scintillator / absorber ratio: scintillator 4mm → 8mm increases efficiency by nearly 20% for 0.5 GeV neutrons.
  - Optimal for >=10 layers R> ~0.6



0.9 GeV neutrons

R=0.6 gives optimal efficiency for designs with >10 layers

Constraints on gross length, tile configuration, absorber/scintillator ratio

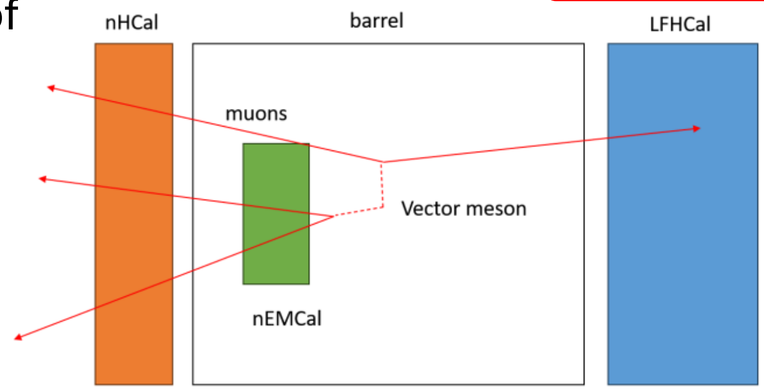
VM decays & Muon Identification

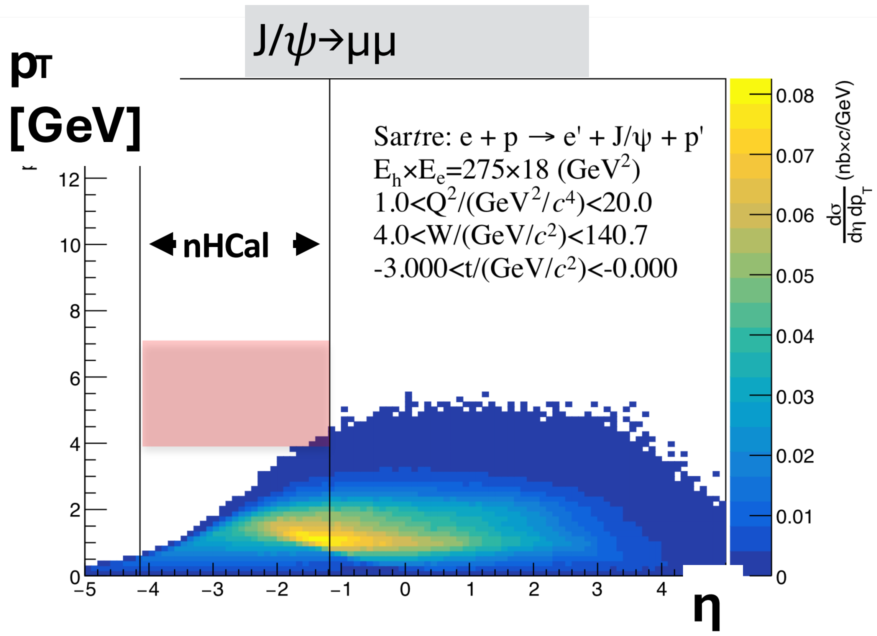
- Additional backward acceptance provides access to a more complete set of vector-meson decay topologies
  - nHCal crucial for low-x
  - Non-ambiguous channels (vs. e^+e^- final states)
- <u>nHCAL: significant at low-x</u>

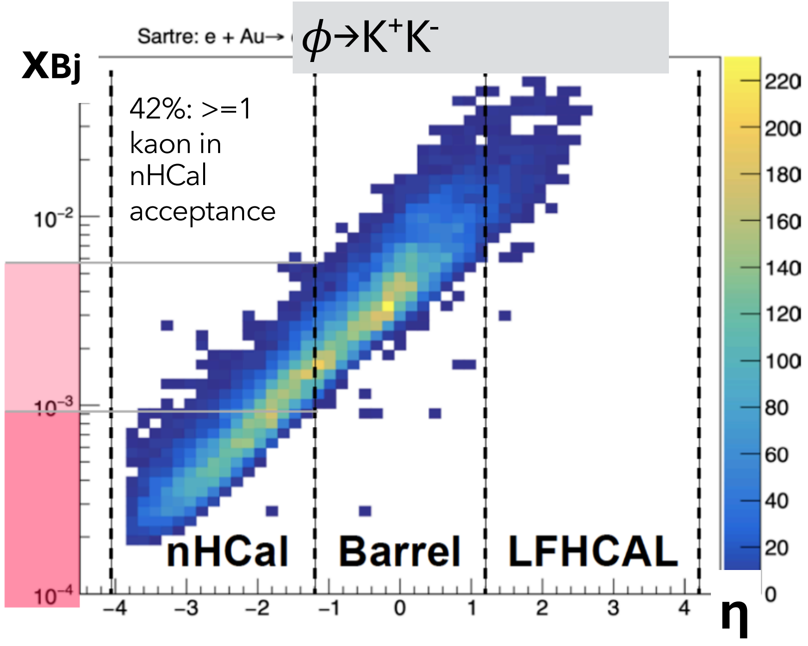
Charge 5

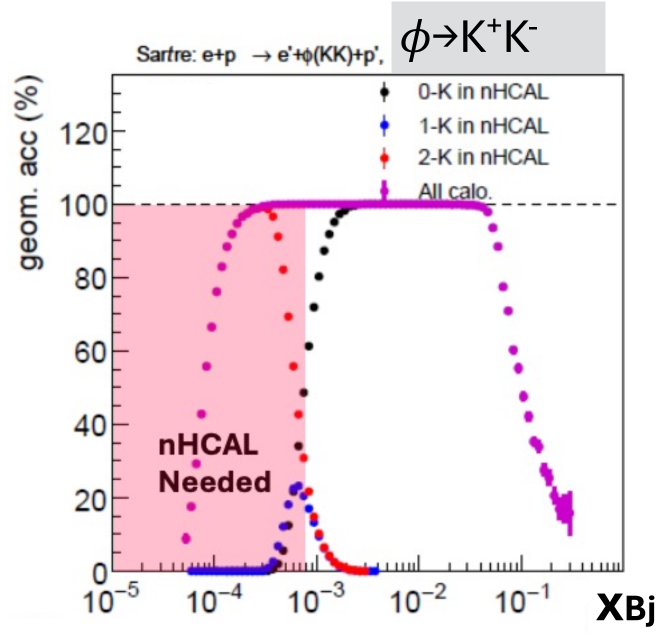
Constraints on <u>gross length</u>, <u>tile configuration</u>, <u>readout</u>

Charge 2









VM decays & Muon Identification

Charge 2

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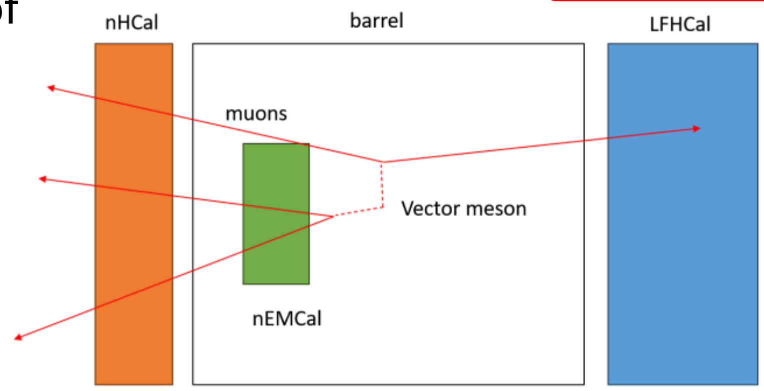


Constraints on gross length, tile configuration, readout

Charge 5

Design Optimization for Muon ID

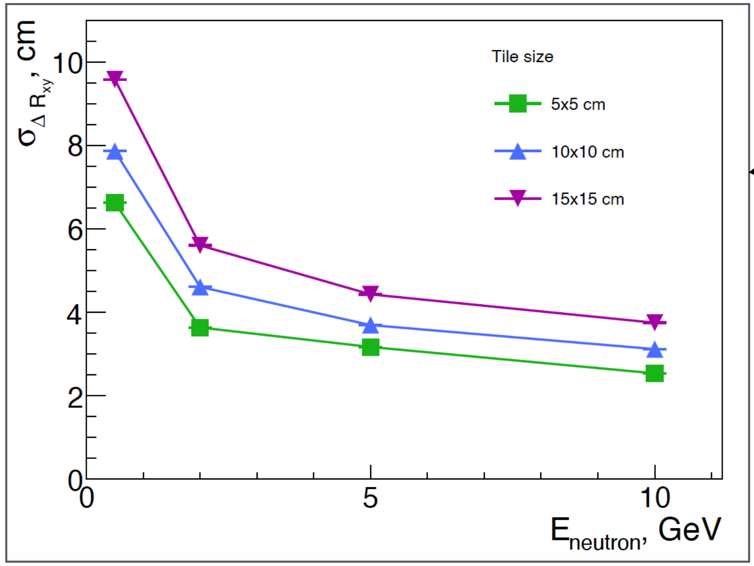
- Muon optimization metric = $\varepsilon_\mu(p,\eta) / \sqrt{\alpha_{h\to\mu}}$
  - With ε_μ = muon efficiency, $\alpha_{h\to\mu}$ = hadron mis-id rate
  - MIP efficiency can be ~100%, so design configuration primarily driven by hadron mis-id rate
  - Studies on-going in single particle events, diffractive events, DIS

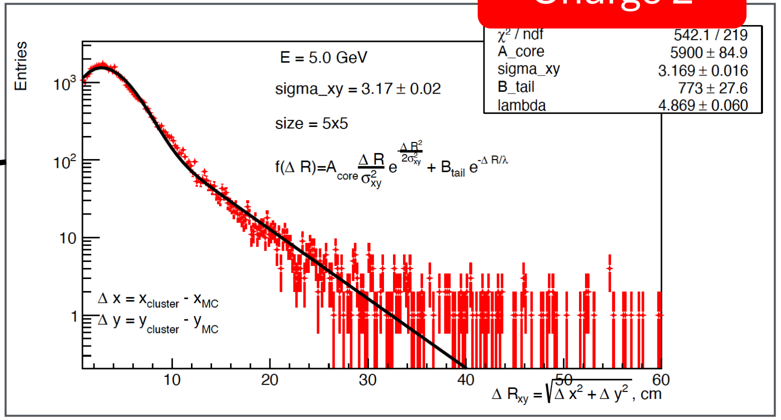
Position resolution for neutrons

Constraints on tile configuration, readout

Charge 2

- Transverse position resolution
  - Test position resolution varying tile size
- Neutron position resolution insensitive to tile size
  - As expected due to large transverse size of c
- Neutron and pion clusters can be distinguished when separated by ~30cm

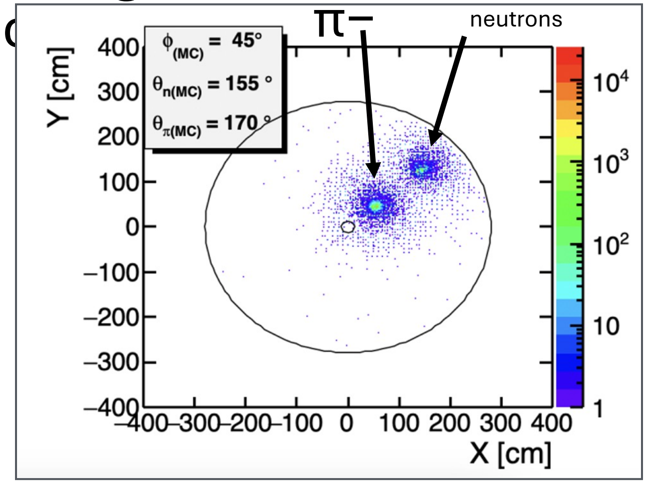




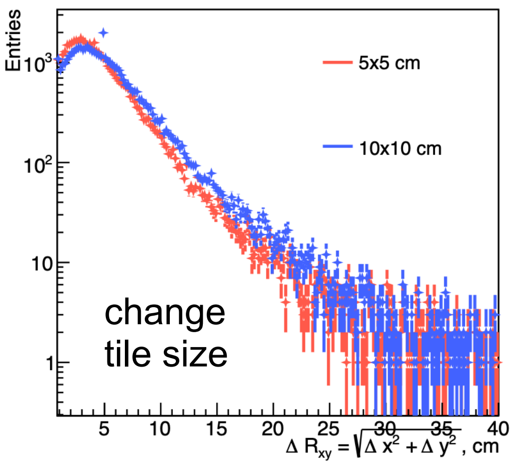
$$\Delta R_{xy} = \sqrt{\Delta x^2 + \Delta y^2}$$

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

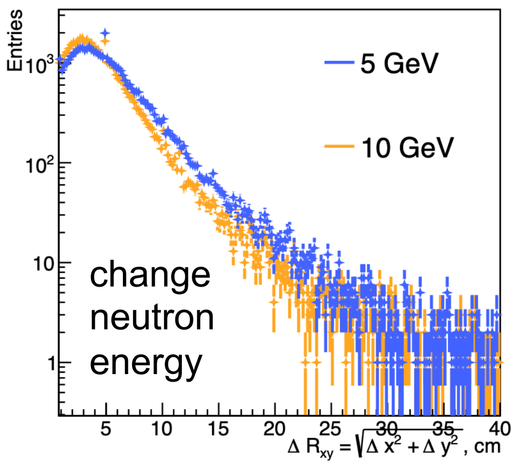
$\Delta y = y_{cluster} - y_{MC}$



5 GeV neutron energy



10x10 cm Tiles

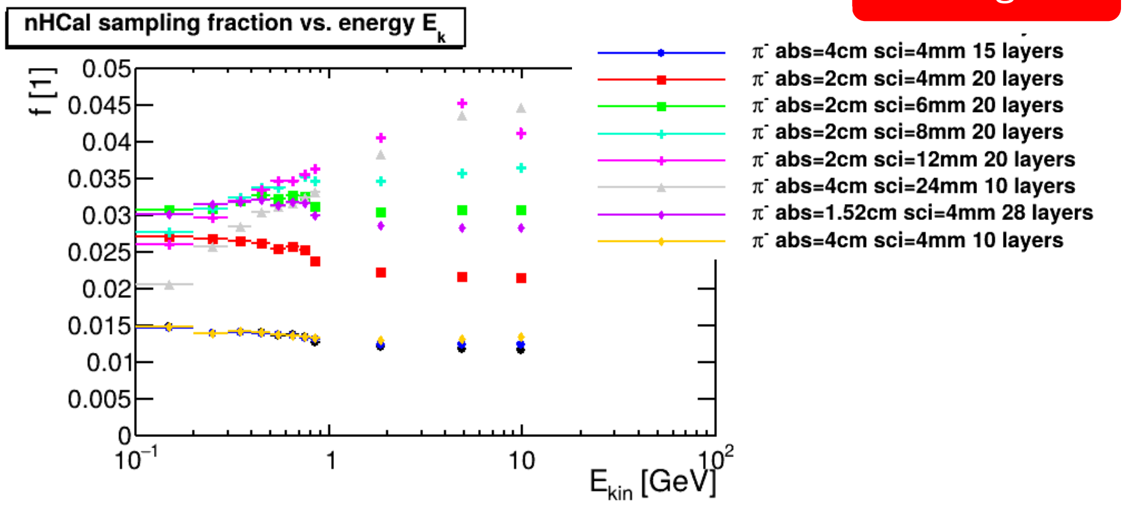


Sampling fractions and gross detector length

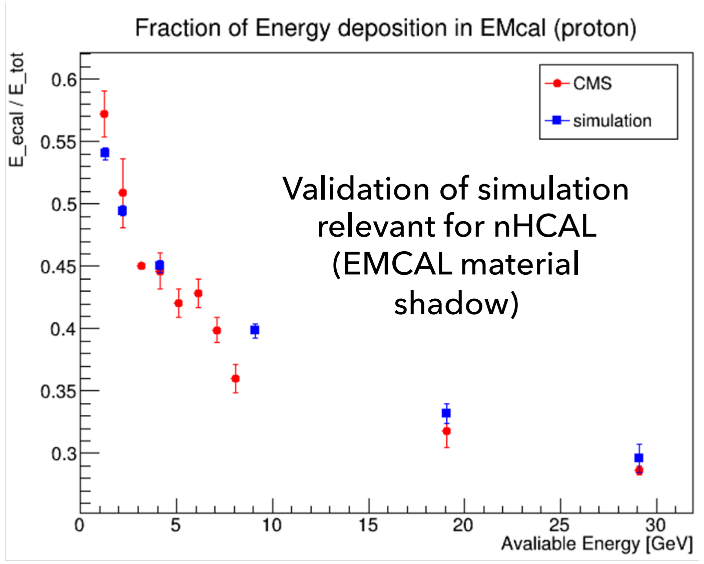
Charge 2

Sampling fraction = energy deposit in active material / incident energy

- ~ 3-4.5% for optimal design (10x10, 10 layers, 4cm absorber, 2.4cm scintillator)
- Not dependent on particle species (n or π^-) - reflects how much of a particle shower can be sampled
- Not dependent on tile size (10x10, 5x5) but ratio abs/sci
- Design optimization driven by other parameters for tail-catcher (i.e. neutron eff, muon id, etc.)



- Also validated understanding and simulation uncertainty of the material budget upstream of nHCal (primarily backward EMCAL)



CMS EMCal + HCal beamtest
https://cds.cern.ch/record/1046333

Charge 5

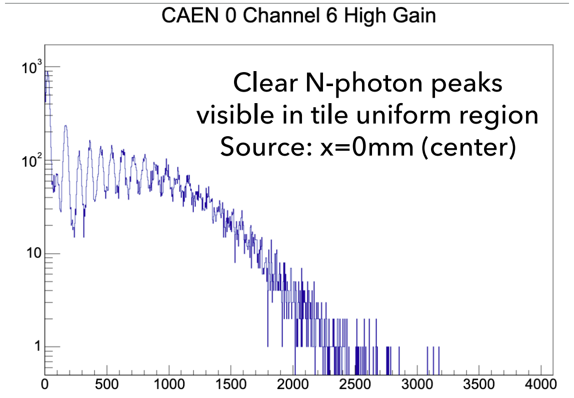
Constraints on gross length

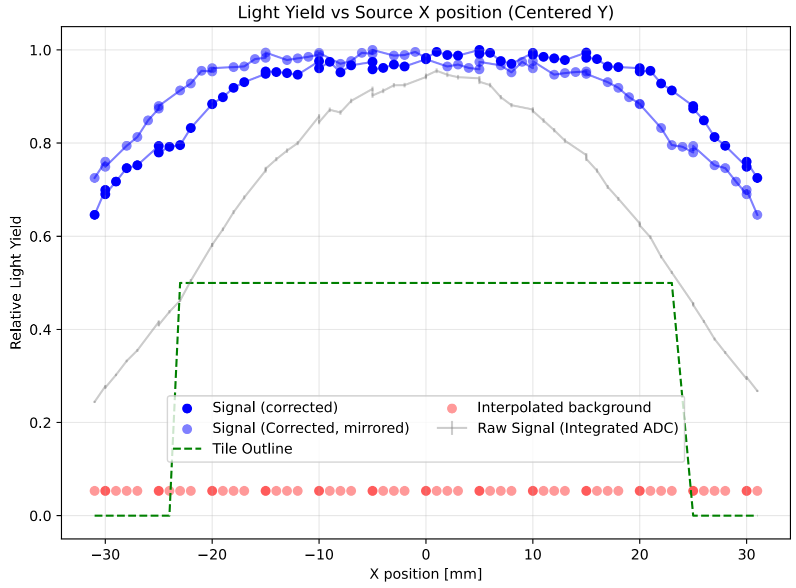
nHCal performance evaluation

Charge 2

Scintillator tile testing

- Cosmics and Sr source
  - Vary tile size (2x2, 5x5, 10x10)
  - Vary tile thickness (4, 6, 8, 12mm)
  - Vary SiPM placement (center, corner, edge)
- Performance evaluation
  - Light yield per MIP,



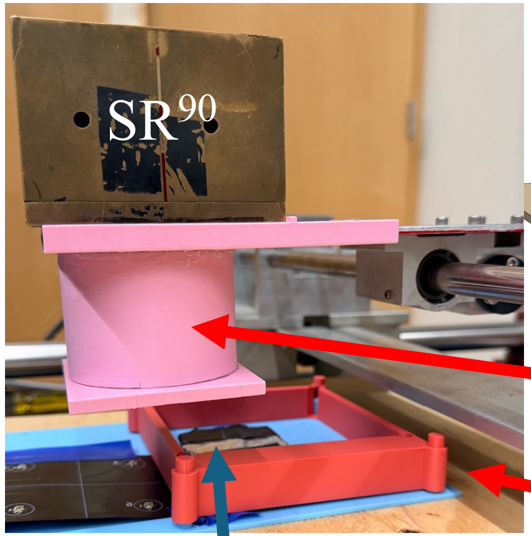


Light uniformity study:
4.7 x 4.7 cm (LFHCAL) wrapped tile

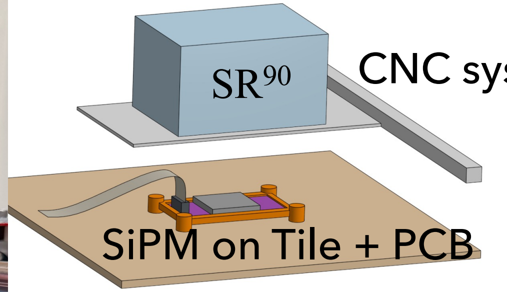
Work in progress

GOAL: verification of 10x10 cm tile configuration

Fully automated (CNC driven) tile-testing apparatus



Tile being tested



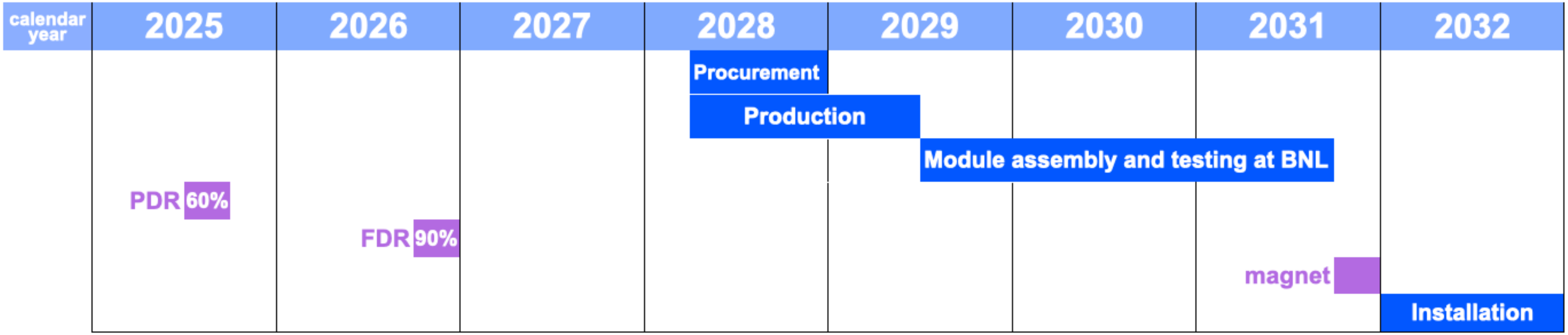
Pb collimator provides ~5mm beam profile FWHM

3D printed custom flexible PCB holder & light shield

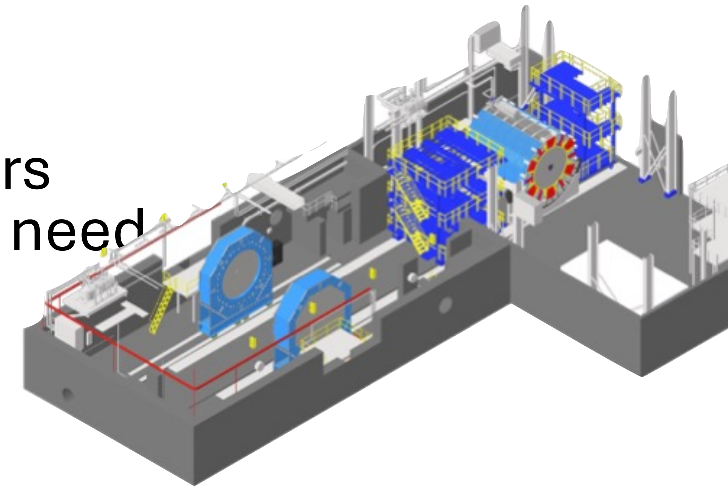
CAEN module for SiPM bias and DAQ

nHCal baselining and start of construction

Charge 3



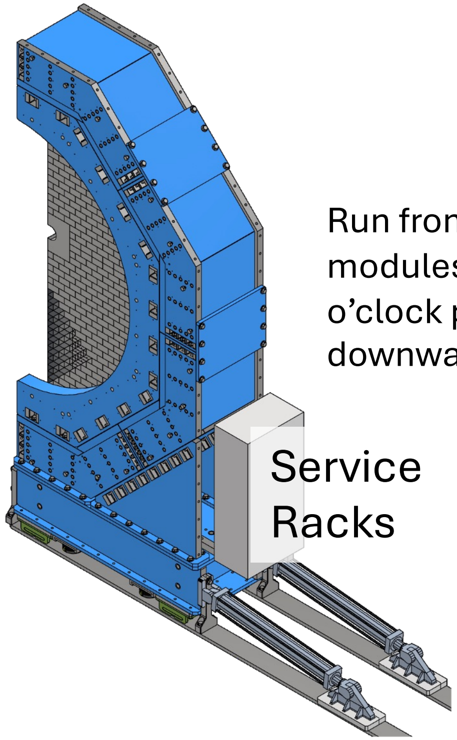
- Majority of design parameters have been optimized by simulation-based studies (TBD: readout layer integration)
- Detector studies, optimization, and physics impact documented in preTDR
- The nHCal can be delivered later than most other detectors because it is decoupled from the flux return and does not need to be in place for the solenoid field mapping



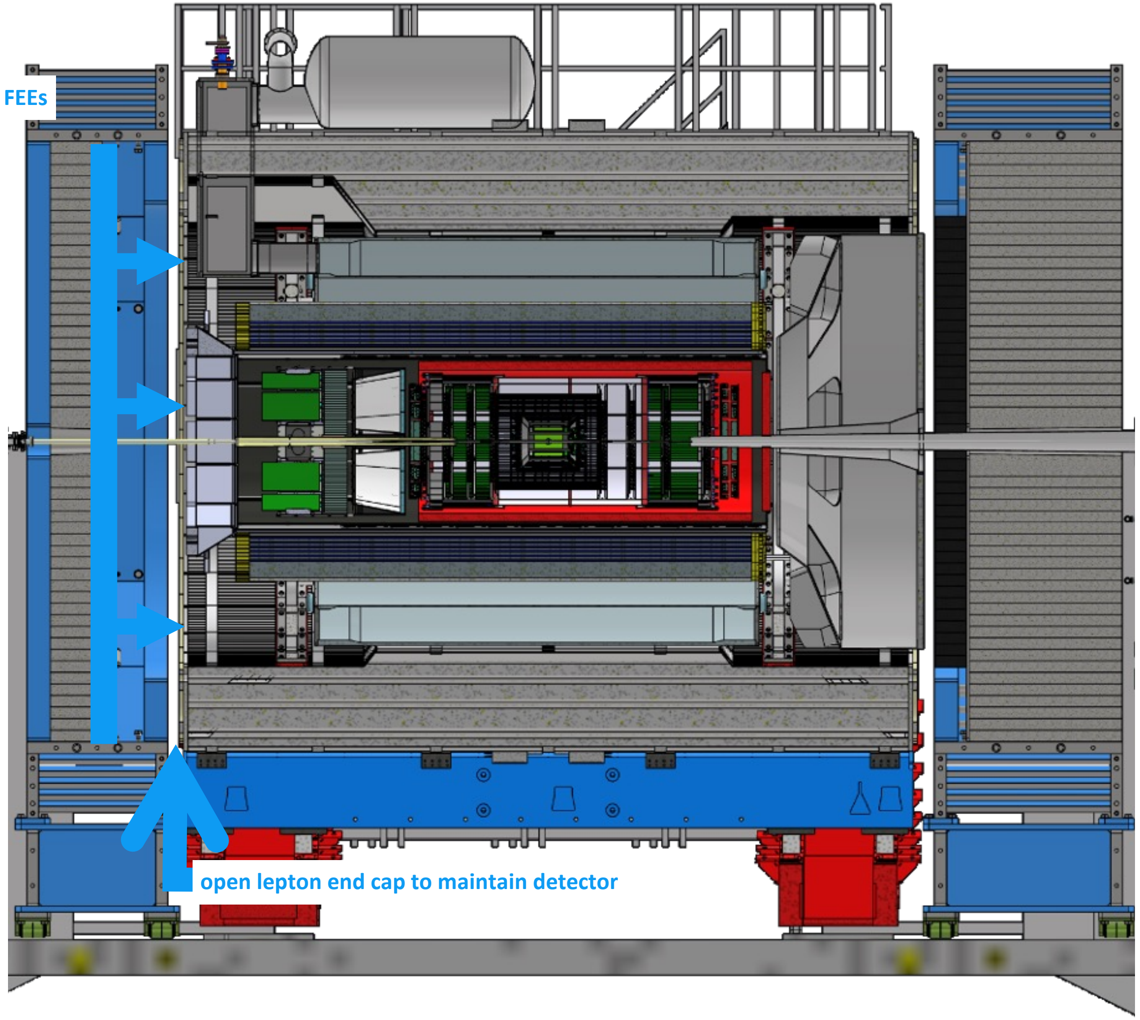
nHCal integration and planning for installation & maintenance

Charge 3

- Integration: services (LV, signal, slow control cables) and possibly cooling
  - Total dissipated heat: 0.5-2.4 kW (10cmx10cm tiles)
  - **FEEs** towards the IP ⇒ nHCal has to be serviced and maintained from the front (unlike LFHCal)



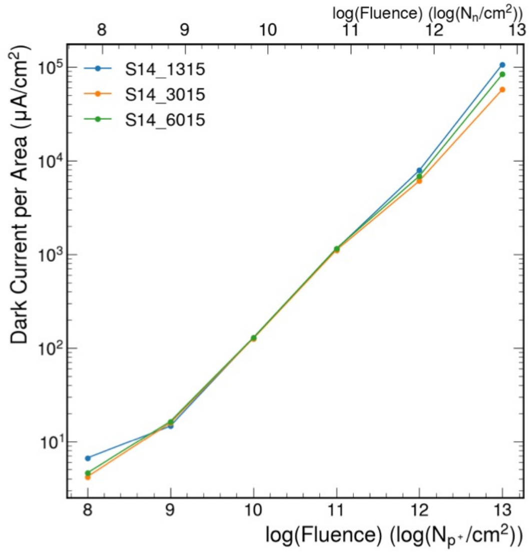
Run from the front face of the HCAL modules near the 3 o'clock and 9 o'clock positions and are routed downward to service racks.

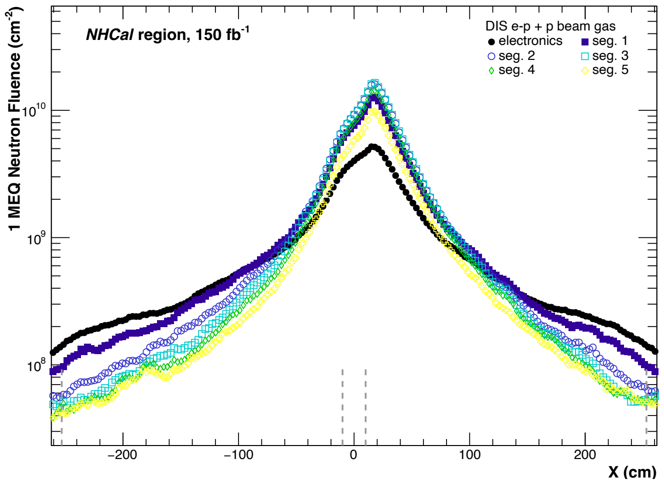


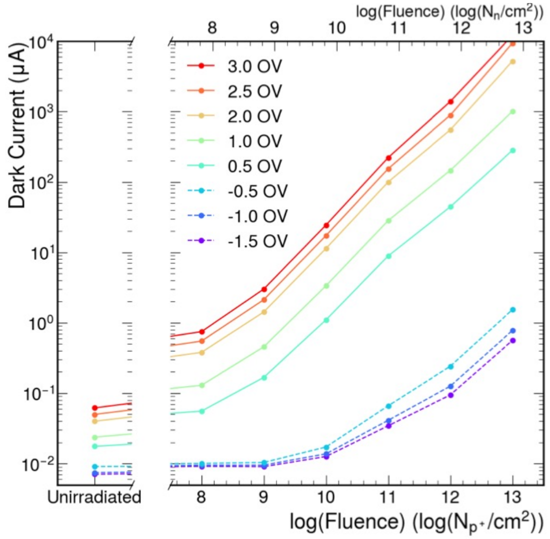
SiPM ES&H and QA Considerations

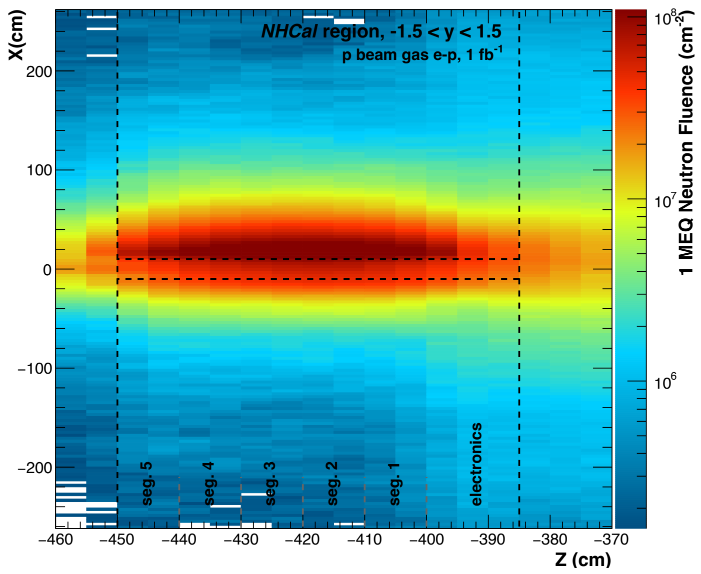
Charge 4

- Degradation of SiPMs due to radiation damage has been studied[1]
- Expected SiPM lifetime sufficient for anticipated dosage in backward direction over > 15 years ($\mathcal{L}$ = 150 fb^{-1}) of running









[1] https://arxiv.org/pdf/2503.14622

SiPM ES&H and QA Considerations

Charge 4

- Procurement includes 1% margin for possible production and assembly process losses
- SiPM & module assembly testing process foreseen:
  - SiPM vendor testing and V_{op} classification within 0.1 V per batch
  - Flex PCB vendor to test PCB connectivity
  - V_{op} spot checks for 5% of the SiPMs
  - Tile assembly testing connectivity after assembly (also verifies vendor QA process)
  - Cosmics module testing prior to installation
  - Cosmics data taking after installation

Synergy with LFHCAL

- Procurement includes property assessment of material:
  - Inspection of dimensional tolerances according to technical drawings, including nickel-plating
- Calorimeter absorber chosen for safety, magnetic constraints, physics motivations.
- Use of radioactive sources for testing follow all local & institutional guidelines

Path to CD-2 and beyond

Well defined plan

- Continue to utilize technologic synergy with LFHCAL
- Detector optimization based on tail-catcher role and lessons learned from H1 SPACAL

Milestones

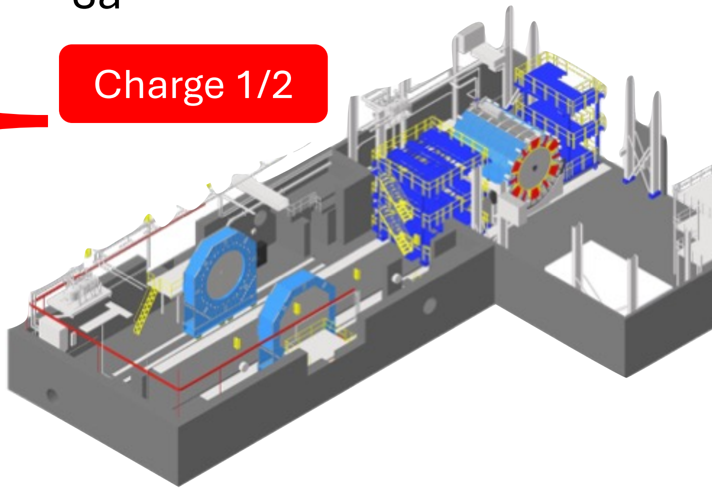
- Incorporation of muon identification and acceptance into HCAL system design
- Develop MIP/muon identification utilities in the ePIC software
- Explore benefits of AI/ML for energy resolution/scale corrections
- Study impact on vector meson acceptance
- Full simulation studies with backgrounds
  - preTDR will be based on October ePIC simulation campaign which includes beam backgrounds
- Study nHCAL impact on event kinematic reconstruction and background rejection
- Prototype development and testing
- Finalize readout configuration and DAQ to determine channel count
- Investigate cost saving alternatives to electron beam welding

Motivated/encouraged by past feedback

Charge 5

Readiness for CD-2 / CD-3a

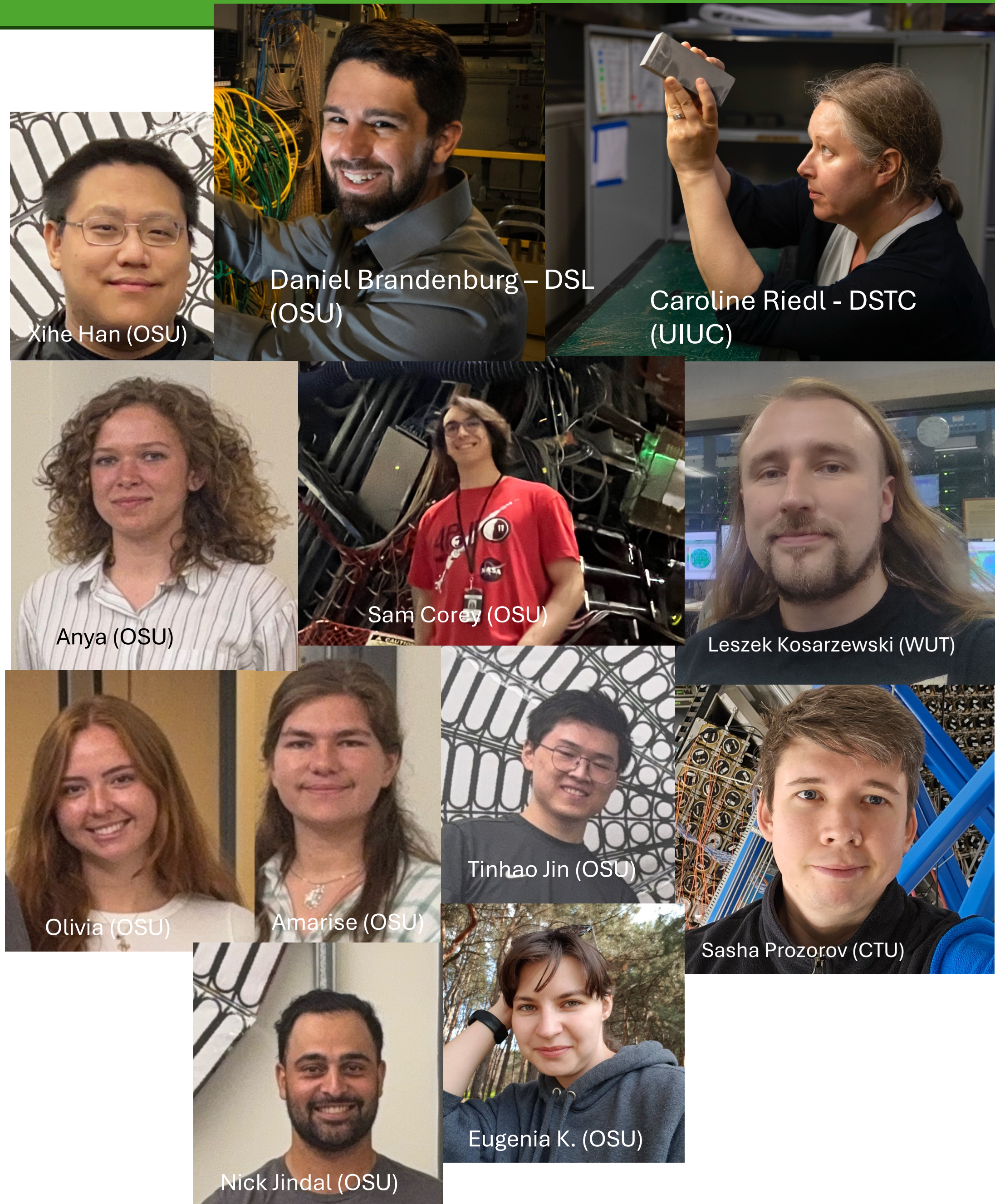
Charge 1/2



nHCal summary

Status:

- Synergy with LFHCAL technology, with design of nHCAL optimized for 'tail-catcher' role in ePIC
- Involved institutions: OSU, UIUC, CTU, BNL, WUT
- Design optimization for Tail-Catcher role in ePIC
  - Neutron efficiency at low energy
  - Charged particle detection at low energy
  - Muon and Kaon Identification
  - Impacts on low-x, low Q^2, and high y events
- October campaign including full simulations with beam backgrounds will be used for preTDR
- The nHCal can be delivered later than most other detectors because it is decoupled from the magnetic flux return
- Baseline configuration determined & plan for CD-2 and beyond outlined with milestones



nHCal performance evaluation

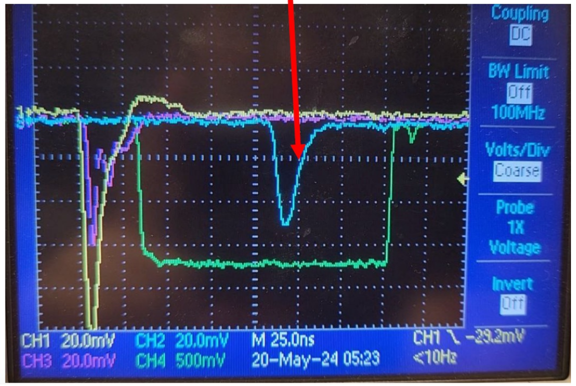
Charge 2

Scintillator tile testing

- Cosmics and Sr source
  - Vary tile size (2x2, 5x5, 10x10
  - Vary tile thickness (4, 6, 8, 12mm)
  - Vary SiPM placement (center, corner, edge)
- Performance evaluation
  - Light yield per MIP, uniformity, cross-talk

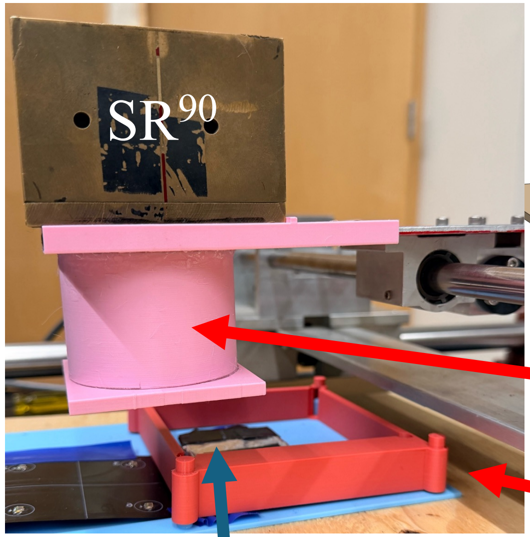
GOAL: verify 10x10 cm tile configuration

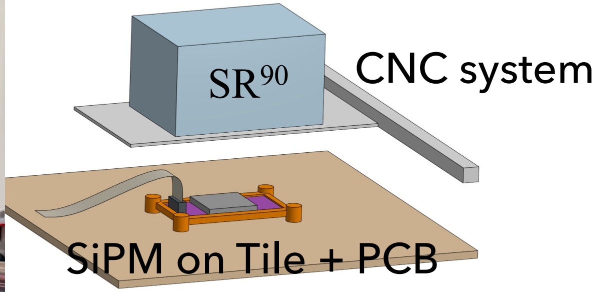
signal from SiPM-on-tile



CAEN module for SiPM bias and DAQ

Fully automated (CNC driven) tile-testing apparatus





Pb collimator provides ~5mm beam profile FWHM

3D printed custom flexible PCB holder & light shield

Tile being tested