Physics Motivation for the Backward Hadronic Calorimetry in ePIC

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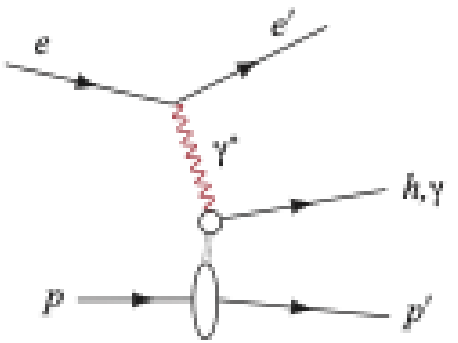
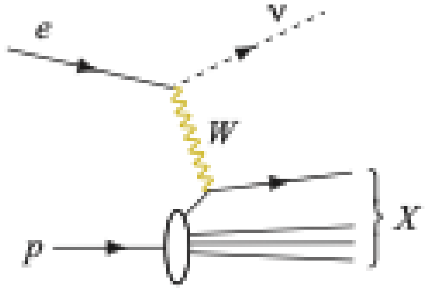
for the ePIC nHCAL Group

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

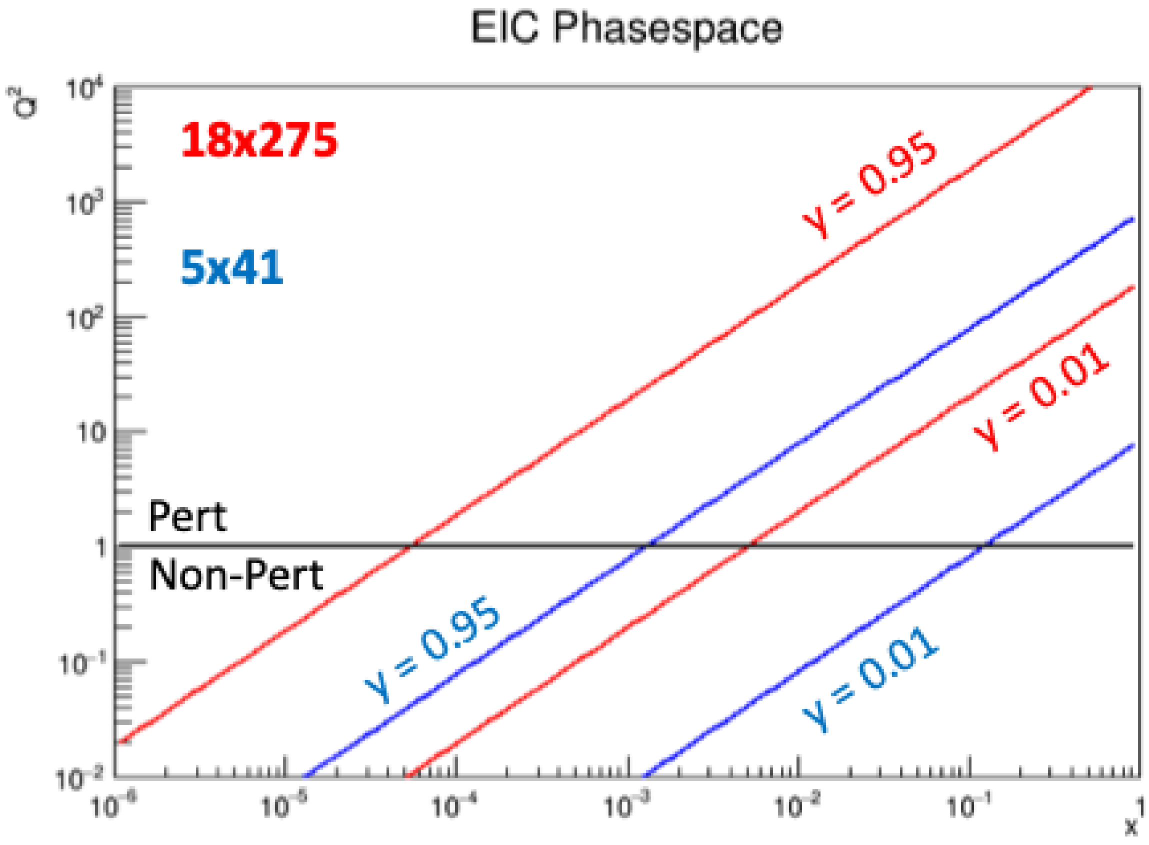
- Backward region = high gluon densities

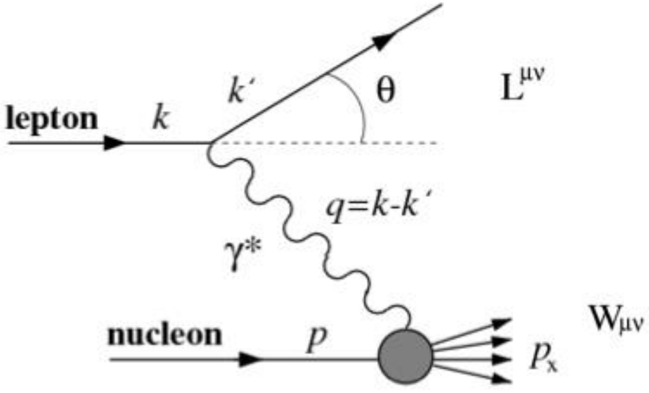
“the EIC will be the first experimental facility capable of exploring the internal 3-dimensional sea quark and gluon structure of a nucleus at low x” – EIC White paper

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



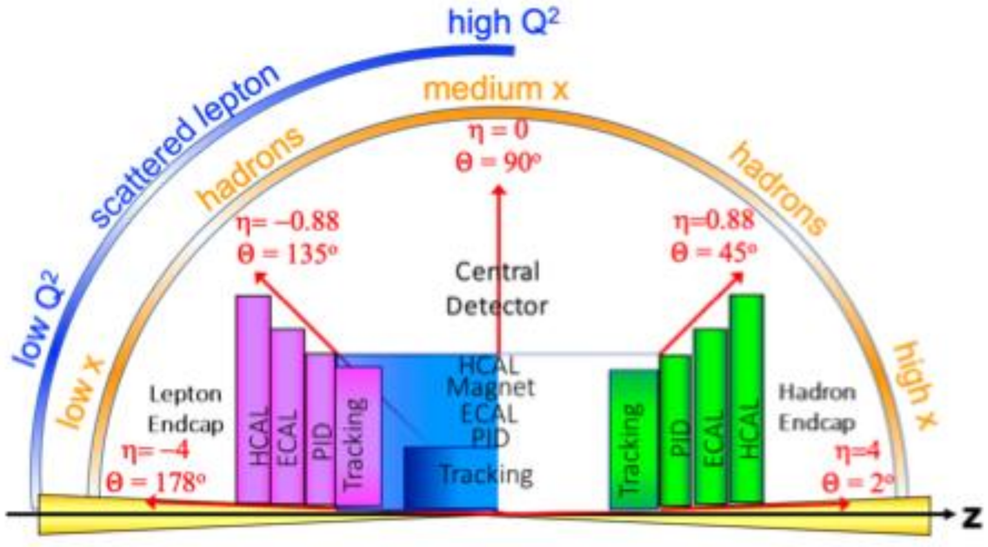


$$Q^2 = -q^2 = -(k - k')^2$$

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

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

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



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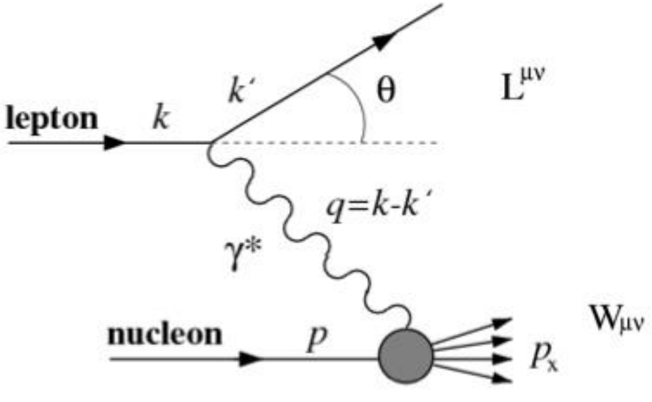

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Table: Summary of EIC Scientific Goals Dependent on Low x Measurements

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
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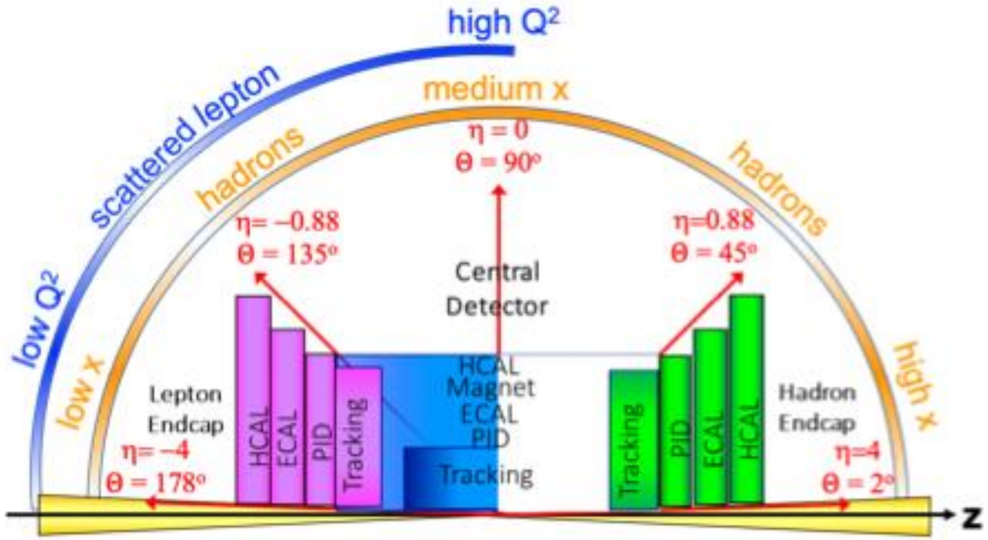


Physics central to EIC Mission

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

- Specifically, nHCAL improves/allows:
  - Hermiticity + Electron tagging in low-x
  - Diffractive Processes (Vector Mesons + Dijets)
  - 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

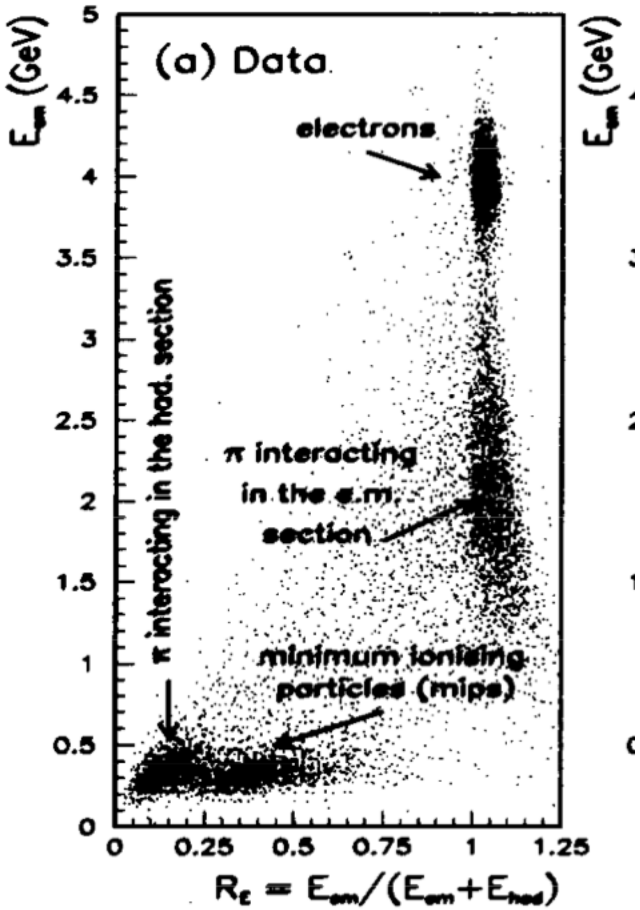
- H1 upgrade to include SPACAL (1995) in the backward region
  - Purpose: Enhanced capability to study low Q^2 physics, improved trigger efficiency for low-energy electrons, and better background rejection, enabling precise measurements of structure functions and diffractive processes at low x.
  - Current 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

  - e/pi separation and background rejection are key challenges at low-x. nHCAL allows hadronic veto

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

H1 SPACAL group

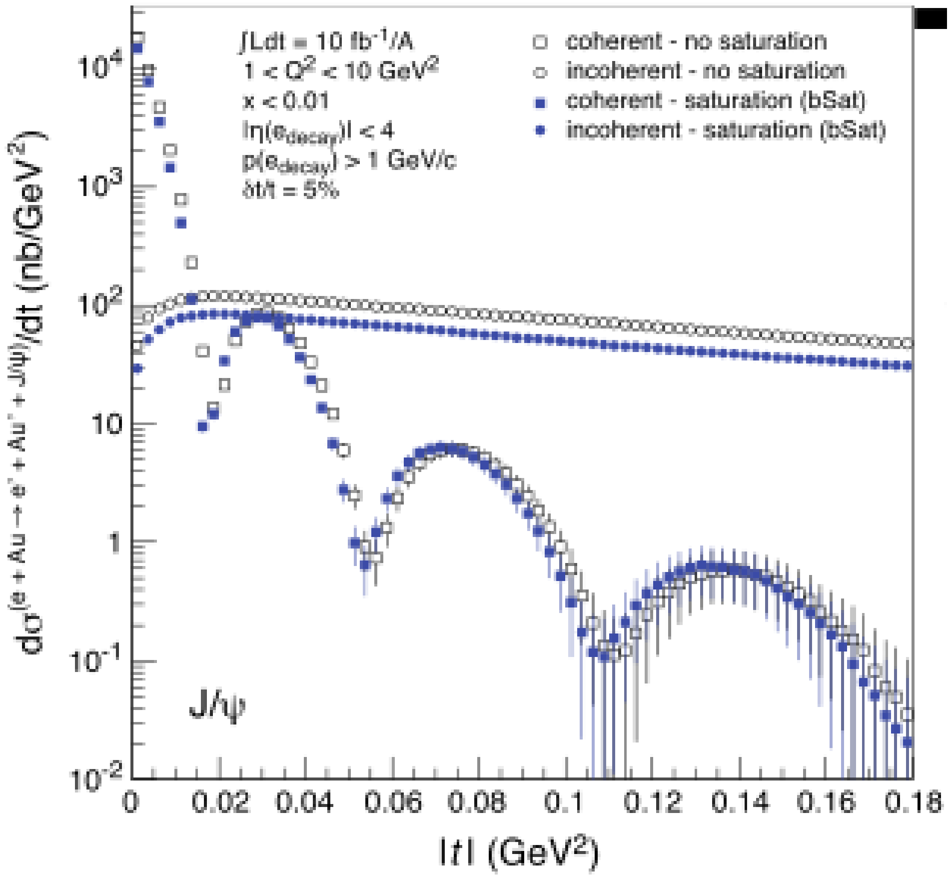


Background Rejection

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**

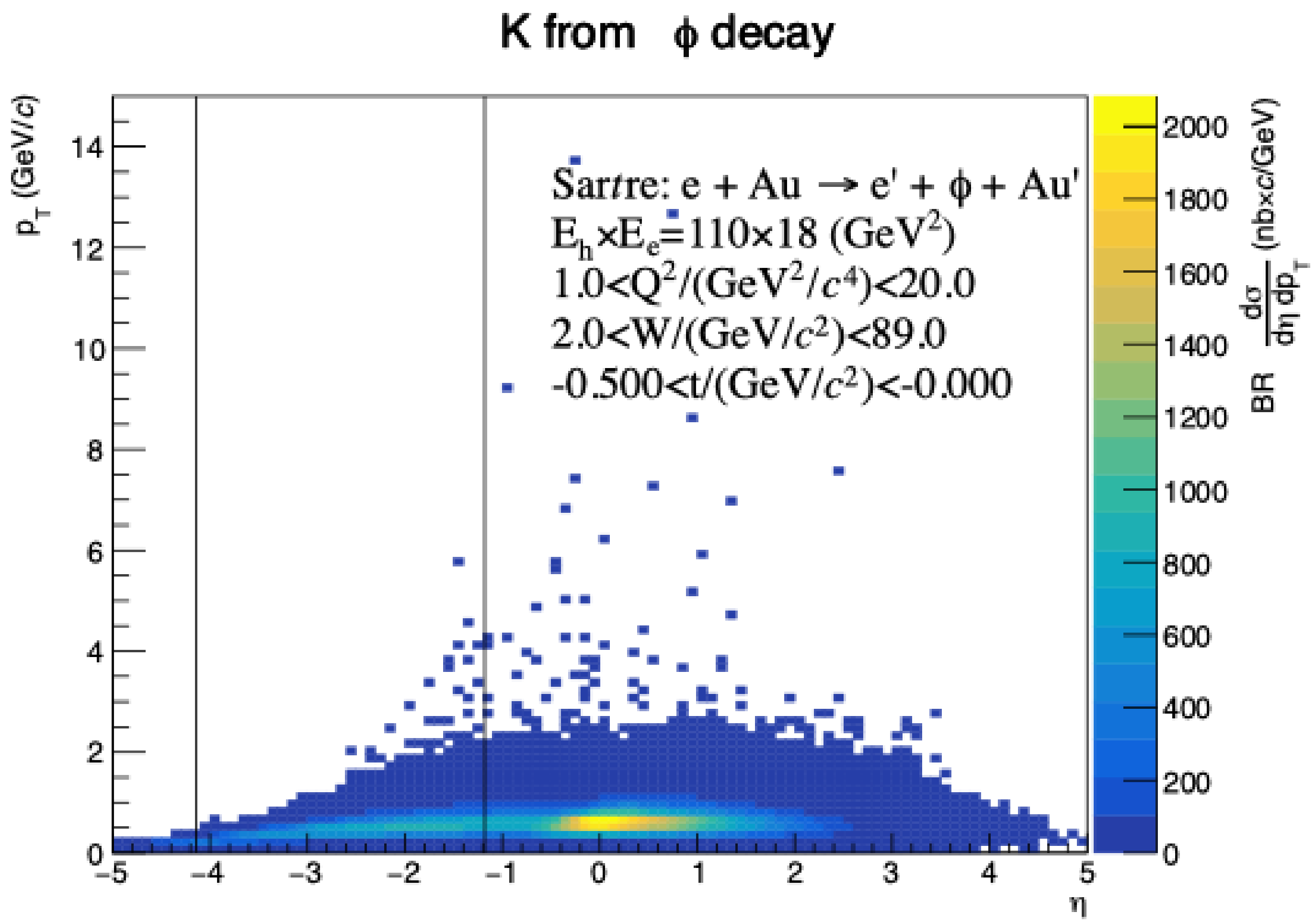
- Diffractive processes are directly proportional to square of gluon distribution – **“very sensitive to the onset of non-linear dynamics in QCD”**
- Exclusive production of the φ was one of the featured reactions in the EIC White Paper
- **Consider as motivation only the impact of an nHCAL on j/psi->mumu and phi->KK**



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

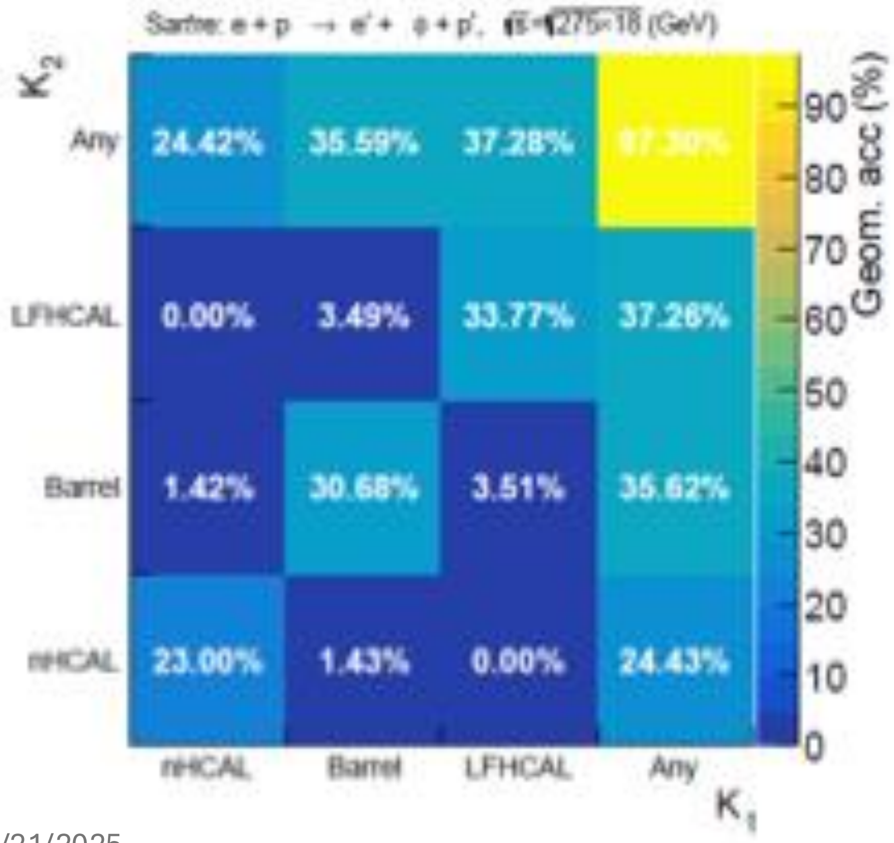
https://arxiv.org/pdf/2103.05419

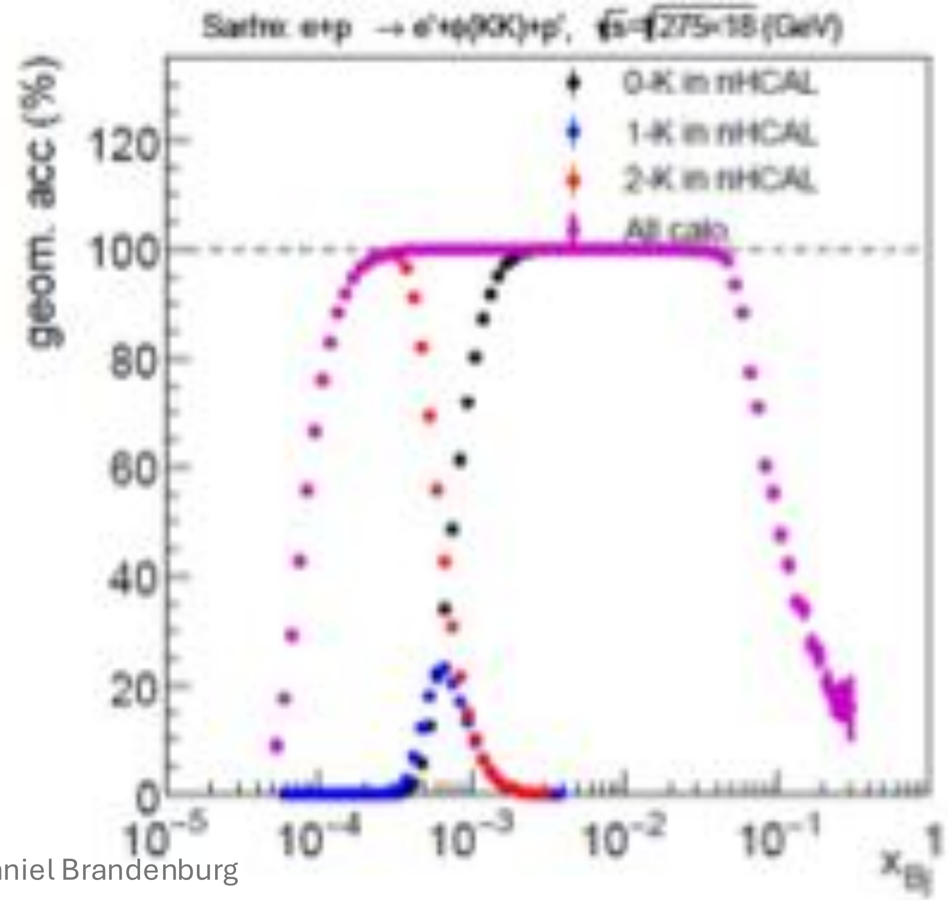
- I am confused by this, lets discuss



nHCAL IMPACT: Phi->KK

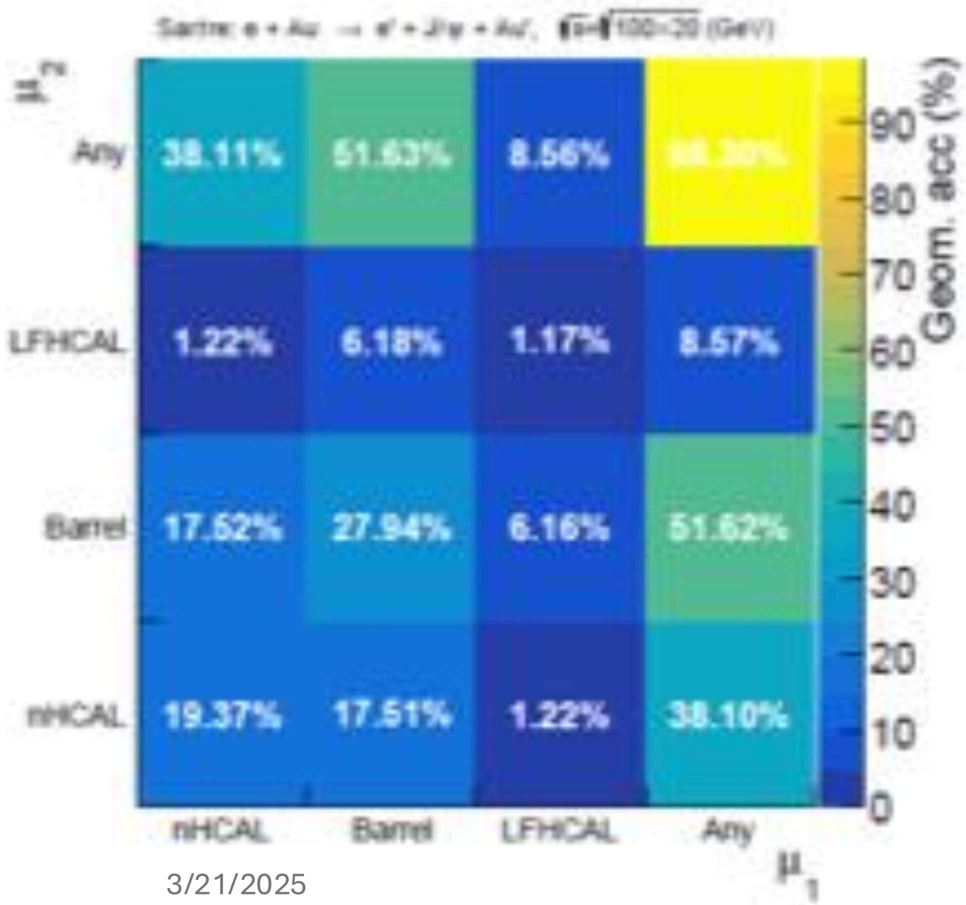
- Example, assuming acceptance in
- nHCAL necessary for accessing low-x production

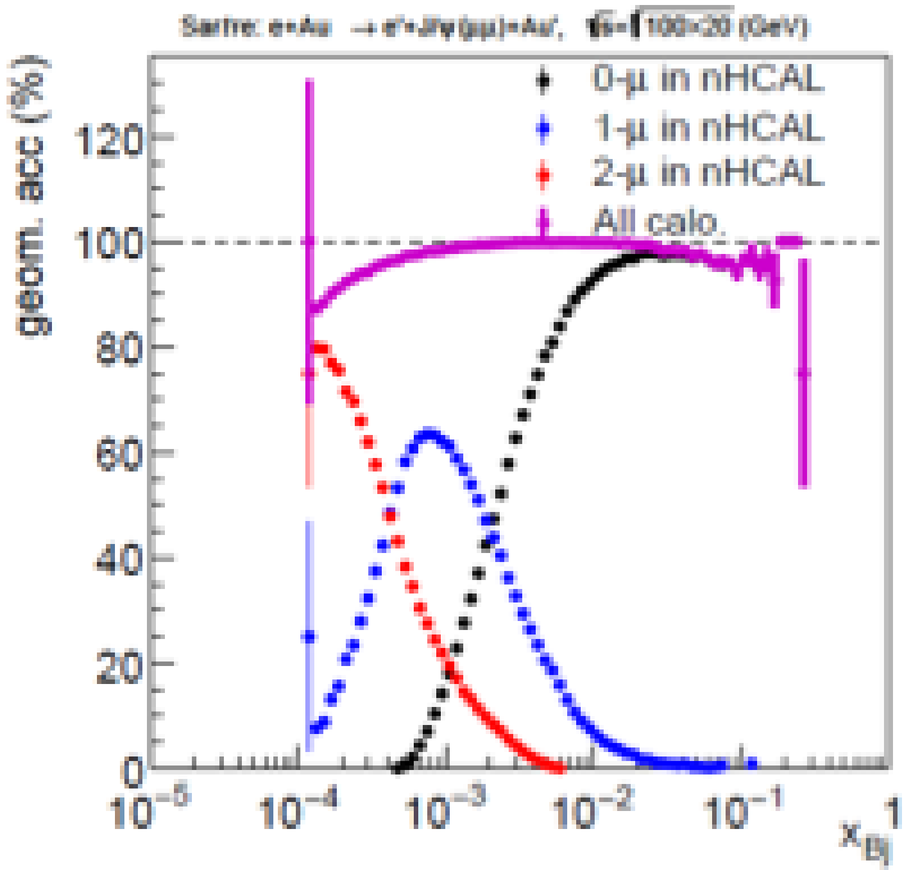




J/psi->mumu

- Majority fraction of low-x diffractive J/psi send one or both muons into backward HCAL acceptance – **40% = nHCAL + any**

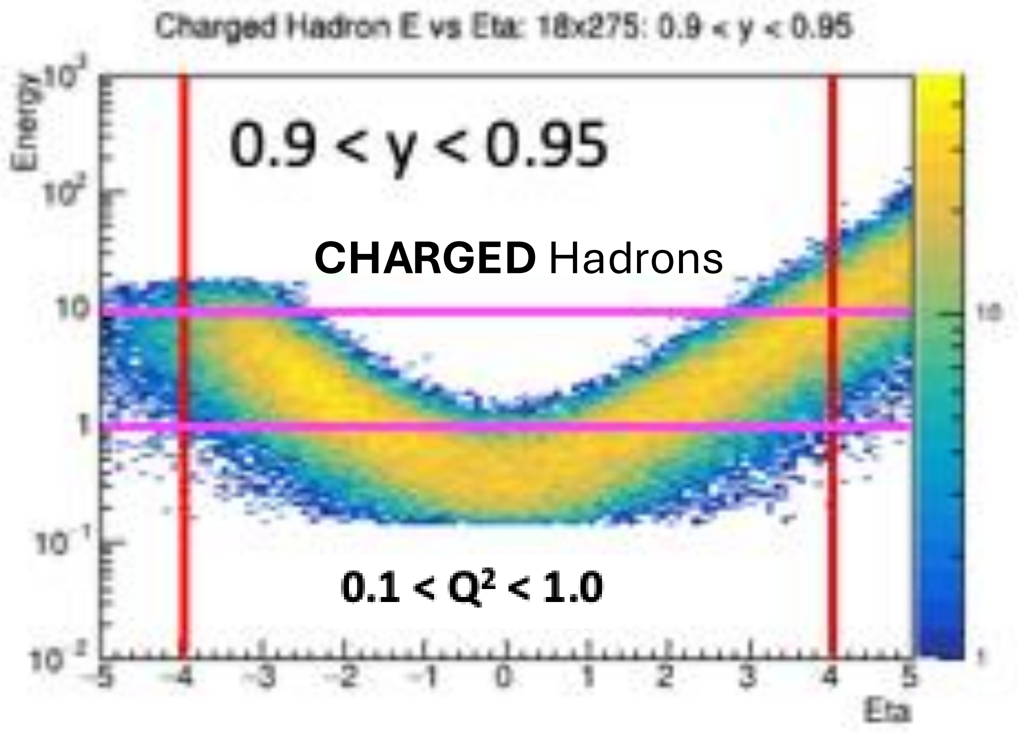


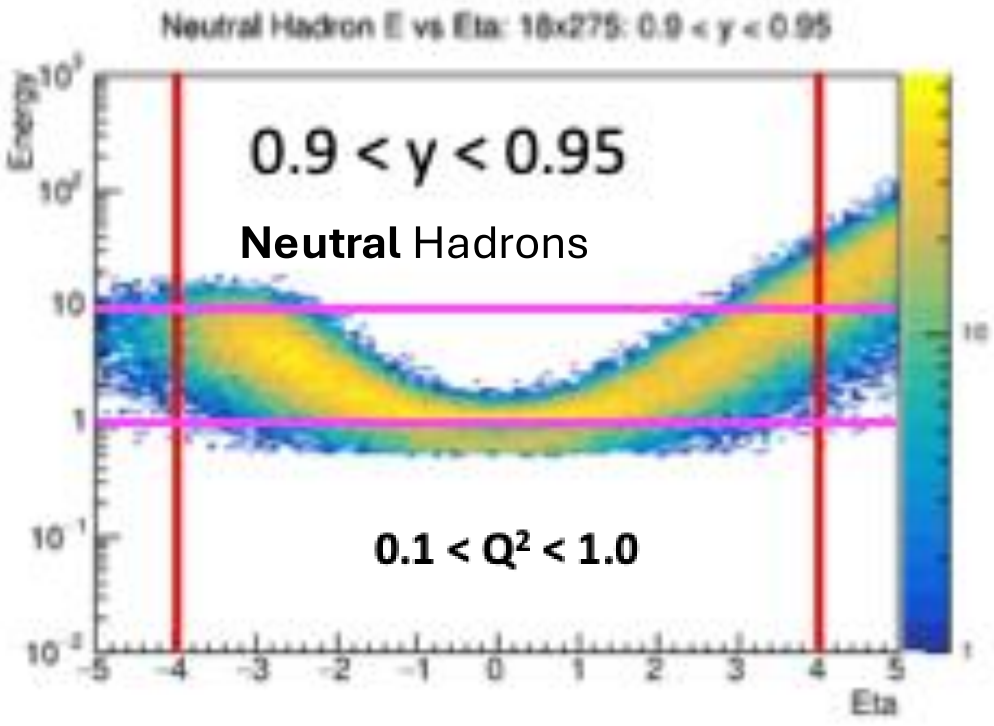


Jets and Neutron detection

- "Studies of (dijet) diffraction in high-energy electron-proton scattering is one of the high-lights of the HERA heritage"
- Low-x, high-y processes -> Jets in negative eta
- Hi inelasticity events = activity BOTH forward & backward

"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)"





https://arxiv.org/pdf/1911.00657

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

ePIC nHCAL: Physics and Requirements

We want to do this physics
+ crucial to EIC Mission

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Detector Requirements

nHCAL Needed for:
- **Low-x & Q^2, high y**

Diffraction
- **Vector Mesons**
- **Dijets**

Charged Jet Measurements
Scattered Electron ID
Hadron-beam background mitigation

- Good μ/π separation of tracks with MIP signal
- Good spatial resolution to distinguish neutral/charged hadrons
- High efficiency for low-energy neutron detection (track-cluster matching)
- Good timing resolution

Summary nHCAL

- Low x physics:
  - Proton structure
  - Nuclear structure

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