THE UNIVERSITY OF TENNESSEE KNOXVILLE

# Opportunities at EIC for testing baryon number carrier


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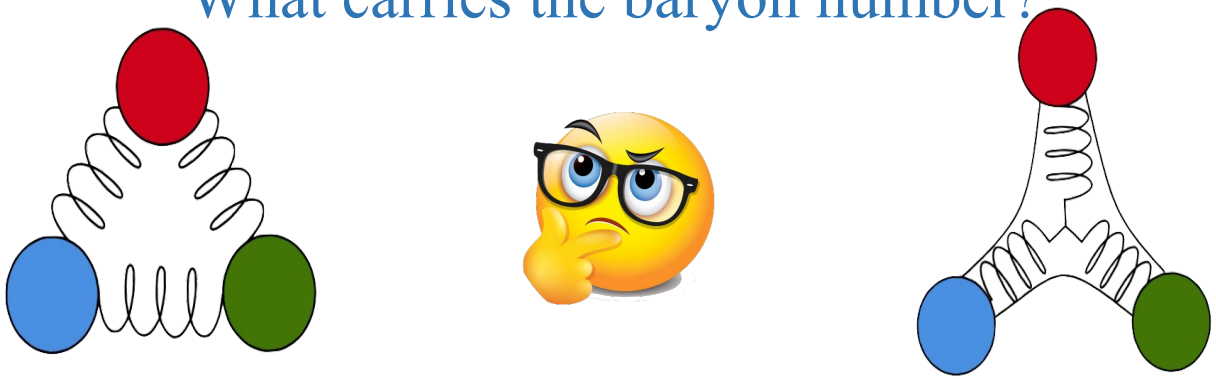
What carries the baryon number?




N.Magdy, et al, Opportunities at EIC for testing baryon number carrier, in preparation

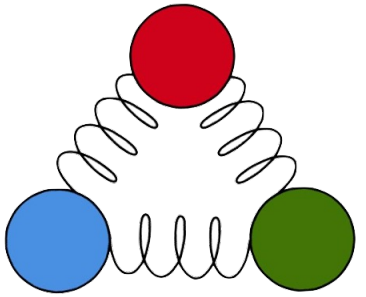
# ❖ Motivation

## What carries the baryon number?

**Baryon number:** carried by the valence quarks? This is an assumption

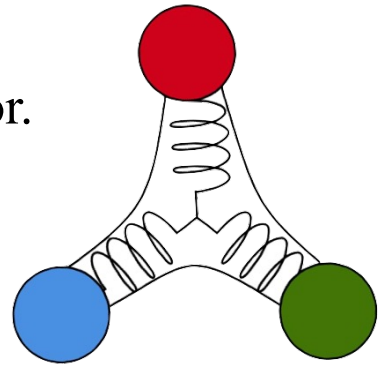
$$B = \frac{1}{3}(n_q - n_{\bar{q}})$$

- ✓ $\pm\frac{1}{3}B$ to each quark and antiquark cannot be inferred from QCD's first principles for baryons!
- ✓ Valence quarks carry most of the momentum and are contracted into thin "pancakes" at high energy.
- ✓ Quarks have less time to interact due to contracted longitudinal length



**The string junction?**

- ✓ Non-perturbative configuration of gluons represented by a locally gauge-invariant state vector.
- ✓ Carries lower momentum and is less contracted
- ✓ Made of low-x gluons and has more time to interact with other partons
- ✓ Enhanced baryon transport to mid-rapidity



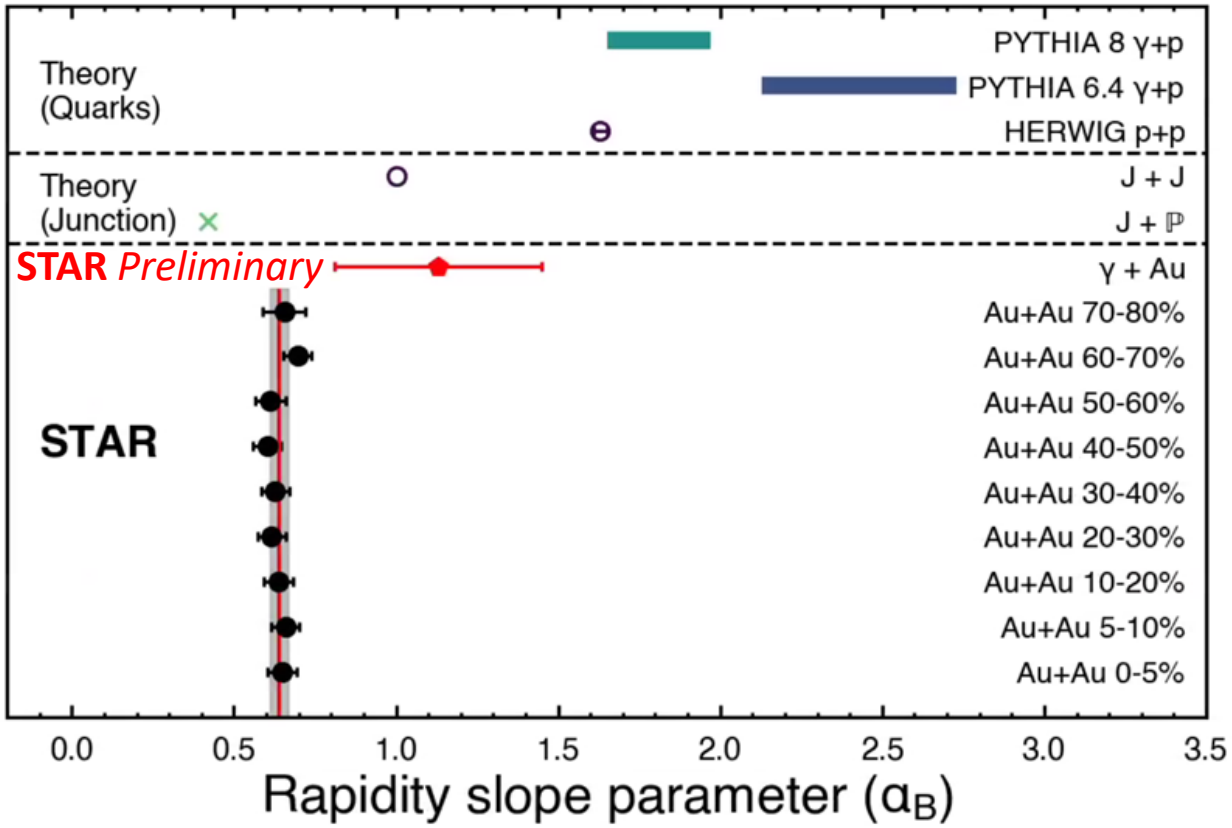
Has neither of these scenarios been verified experimentally?

# ❖ Motivation

**Several methods are suggested to test the hypothesis:**

- ➢ Net-Baryon in e+A collisions
  - ✓ The photon excepted has almost zero virtuality
  - ✓ Probes the nucleus at low-$x$

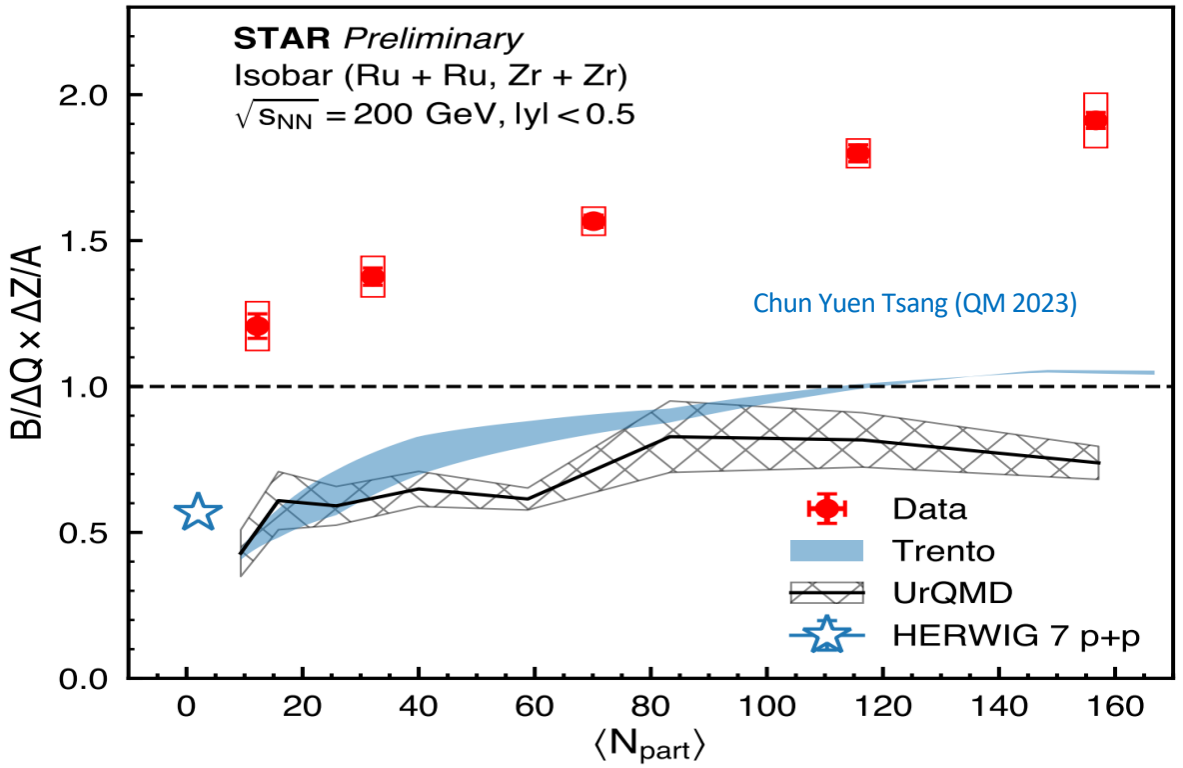
Chun Yuen Tsang (QM 2023)



# ❖ Motivation

**Several methods are suggested to test the hypothesis:**

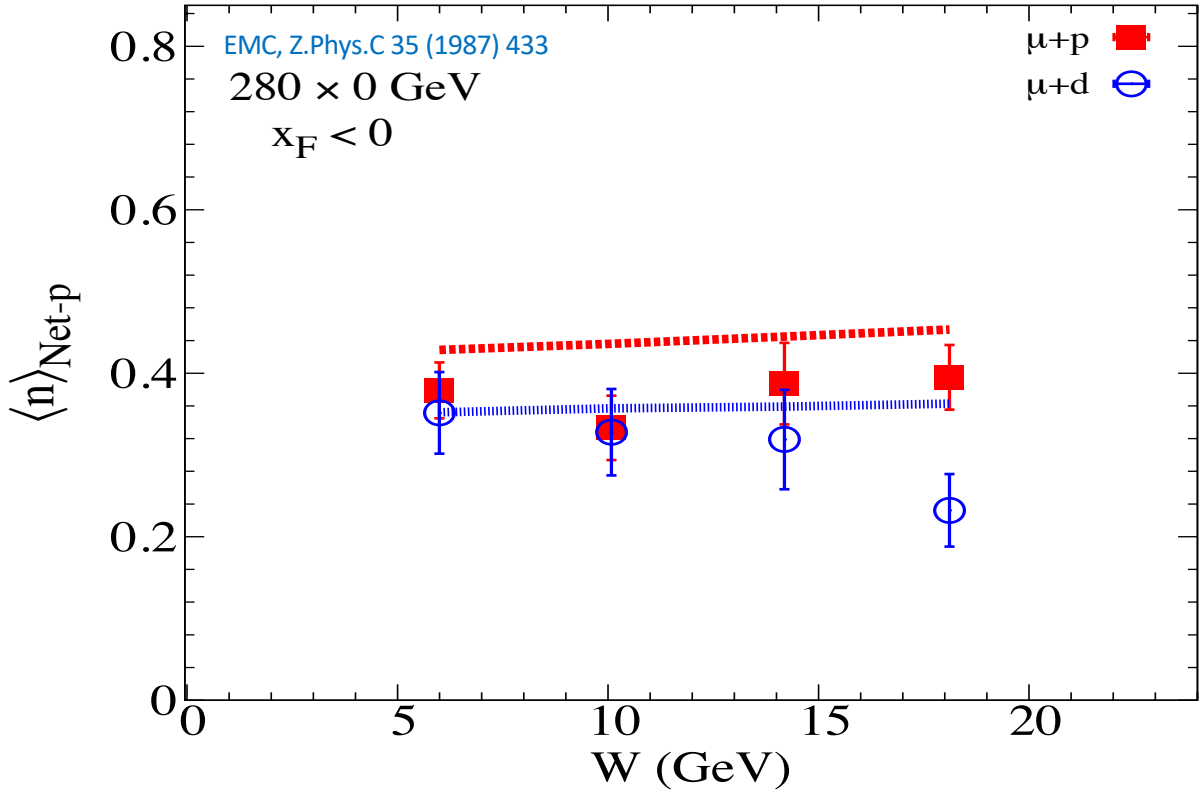
- ➢ Net-Baryon vs. Net-Electric charge in Isobar collisions
  - ✓ The ratio B/Δ$Q$*ΔZ/A can be used to differentiate different carriers
    - Valence quarks carry B and Q if (B/Δ$Q$*ΔZ/A) = 1
    - Junction carry B (i.e., B is enhanced) if B/Δ$Q$*ΔZ/A > 1

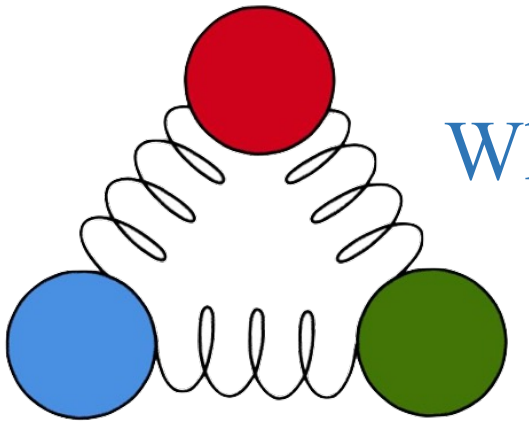


# ❖ Motivation

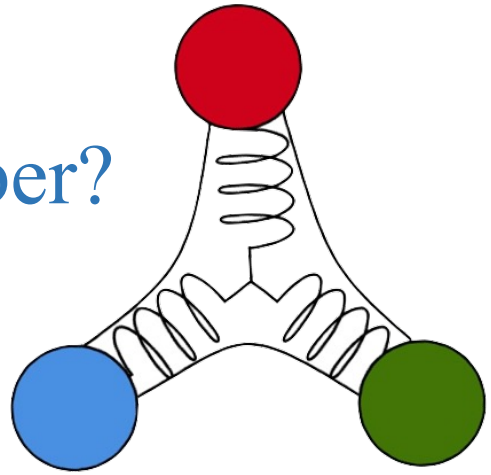
**Several methods are suggested to test the hypothesis:**

- ➢ Net-Proton differences between $\mu + p$ and $\mu + d$
  - ✓ EMC, minor (if any) difference
  - ✓ Diquark Lund model shows a 20% difference





# What carries the baryon number?



## At RHIC:

- RHIC nuclear energy is at a sweet spot but has limited acceptance in rapidity, $Q^2$ and x

## At EIC:

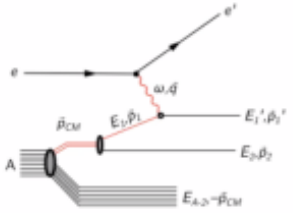
- Suitable energy range, good acceptance in rapidity (extended from 2.5 to 6.0) $Q^2$ and x
  - ✓ Low-$p_T$ PID is needed to study the charge and baryon transports

**Can EIC answer such a question?**

# The BeAGLE Model

# ❖ The BeAGLE model:

Wan Chang et al., PRD 106, 012007 (2022)



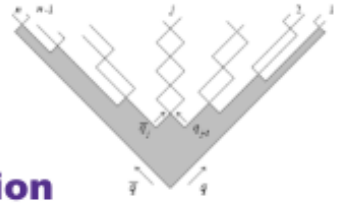
Primary interaction treated by **PYTHIA6** for the hard collision.

Glauber handled by BeAGLE

**PyQM:** Nuclear Geometry + optional gluon radiation in medium.

Hadronization handled by **PYTHIA6.**

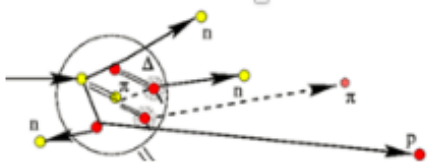
**Primary interaction**



**Hadronization**

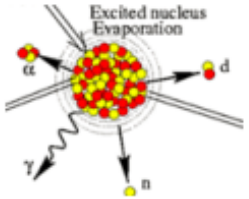
Cascade process handled by **DPMJET.**

**Formation time. Stochastic.**



**Intra-nuclear cascade**

Nuclear remnant evaporation and break up by **FLUKA.**




**Nuclear remnant evaporation & breakup**

## Some Nuclear Effects

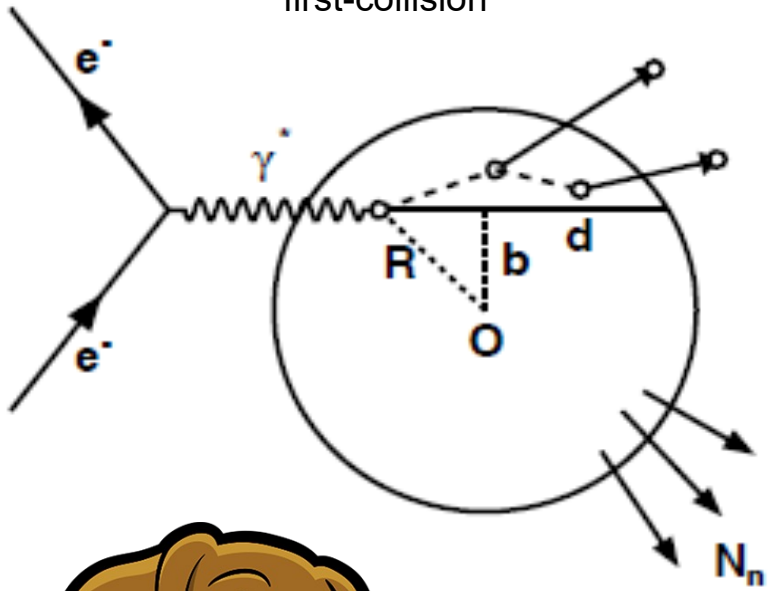
| | In BeAGLE |
|---|---|
| • Parton distribution functions | ✅ |
| • Parton saturation (CGC etc.) | |
| • Short-range correlations | ✅ (GCF) |
| • "Fermi motion" | ✅ |
| • Partonic (or "dipole") MS | ✅ |
| • Partonic gluon radiation | ✅ |
| • Medium-modified hadronization | |
| • Formation times | ✅ |
| • Hadronic Cascade | ✅ |
| • Nuclear evaporation, breakup | ✅ |
| • Photonic de-excitation of A* | ✅ |

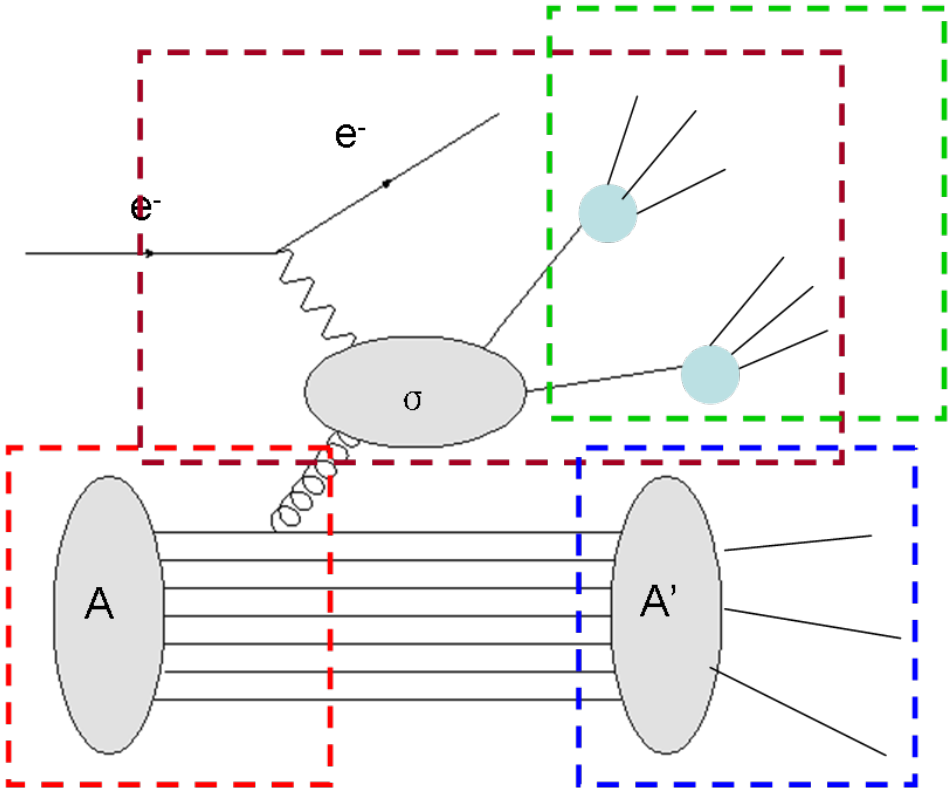
# ❖ The BeAGLE model:

$d \equiv \int dz\ \rho/\rho_0$

from $Z_{\text{first-collision}} \rightarrow \infty$

Wan Chang et al., PRD 106, 012007 (2022)




A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation ( gamma dexcitation/nuclear fission/fermi break up ) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

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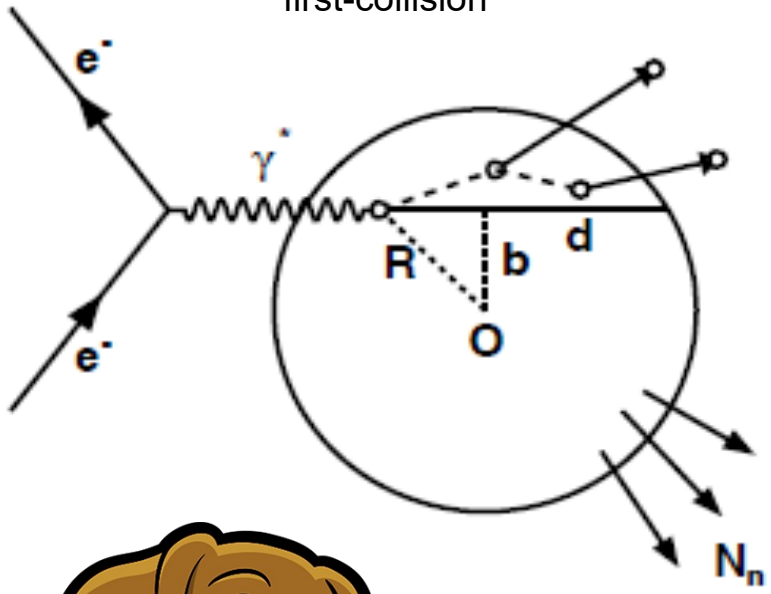


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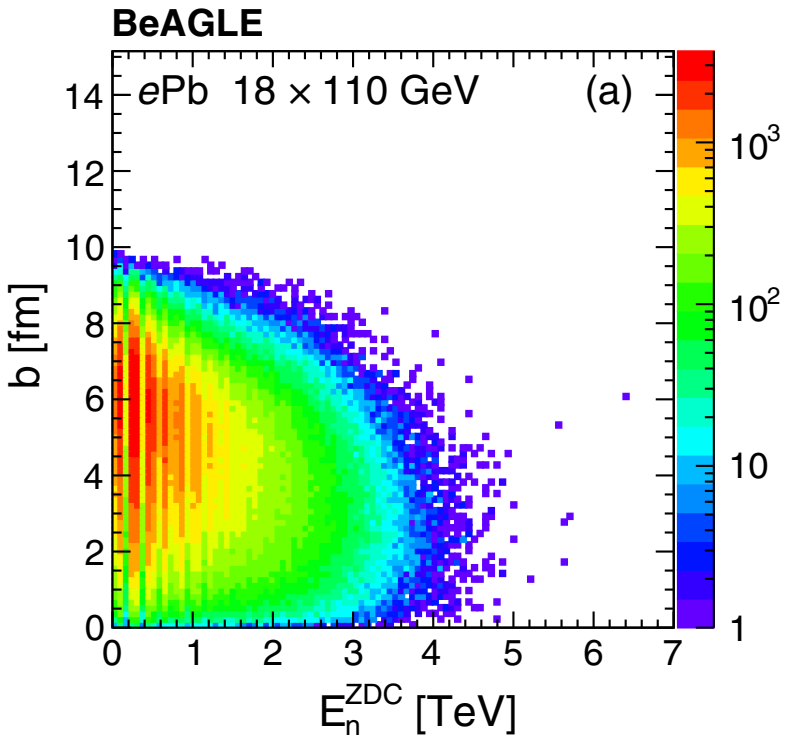
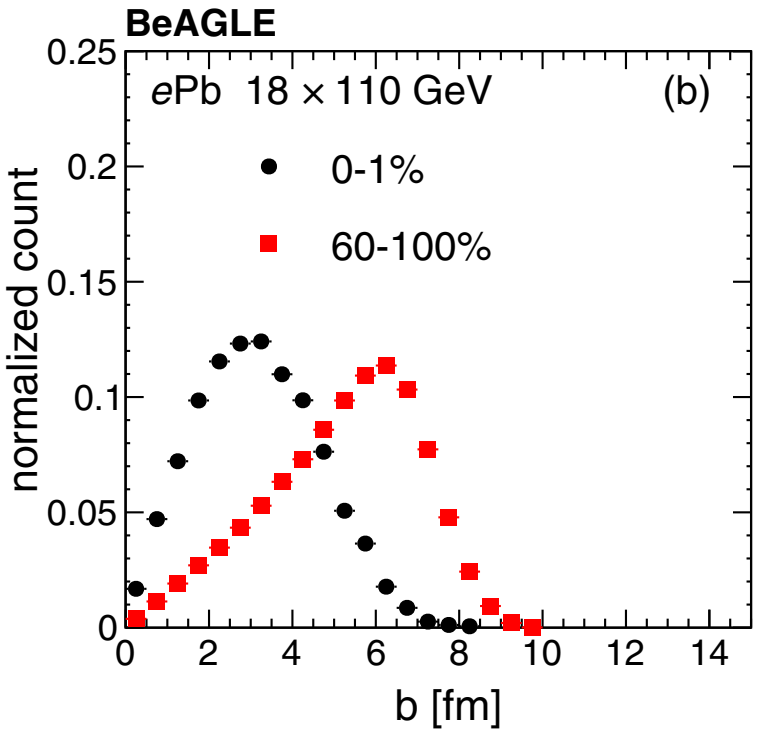


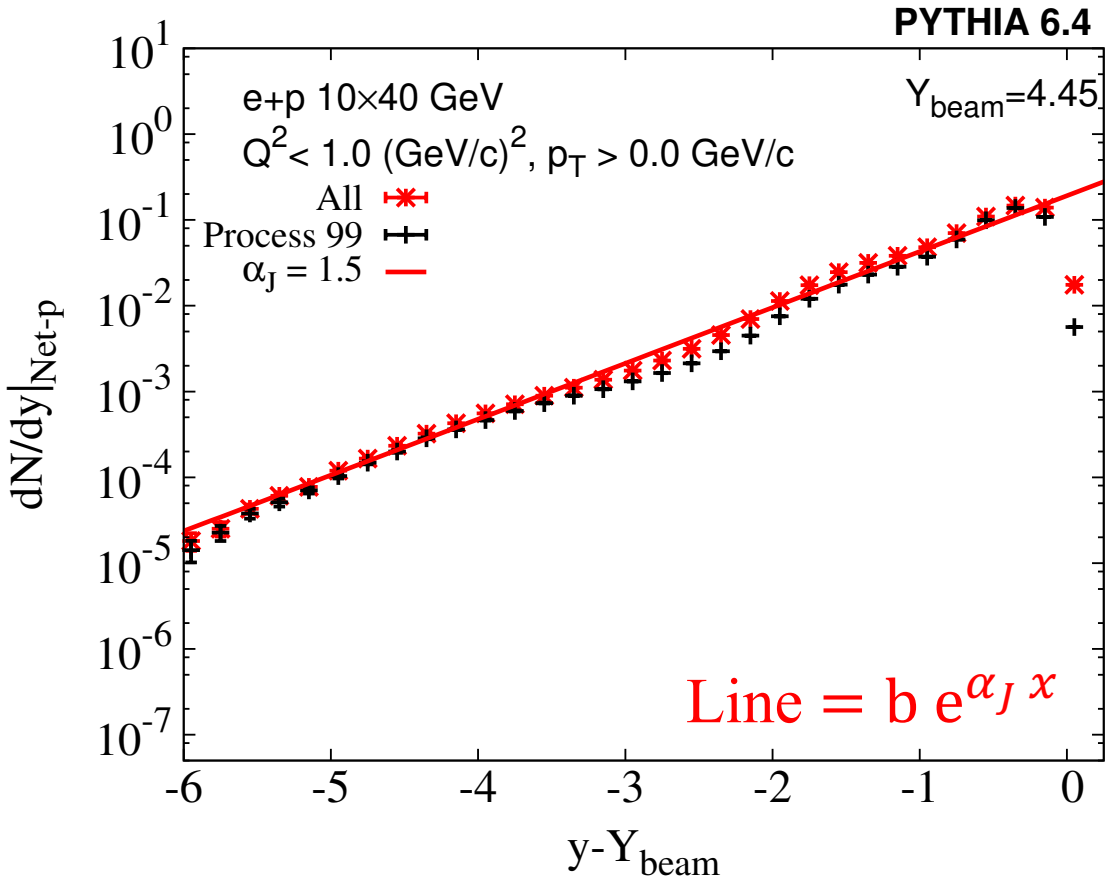

Neutrons in ZDC can be used for centrality definition?

# ❖ At the EIC

## The $dN/dy|_{Net-p}$

**If the junction hypothesis is true:**

- Interact with a junction in the target nucleus
- Enhanced creation of mid-rapidity baryons
  - ✓ Junction interaction time > quark interaction time
  - ✓ More baryons are stopped in the junction picture
- Regge theory prediction:
  - ✓ $\frac{dN}{dy} \propto e^{\alpha_B (y - y_{beam})}$
  - ✓ $\alpha_B$ is related to Regge intercept of junctions ($\alpha_B \sim 0.5$)




$\alpha_B$ from PYTHIA is larger than the prediction for the junction expectation

99 is LO DIS

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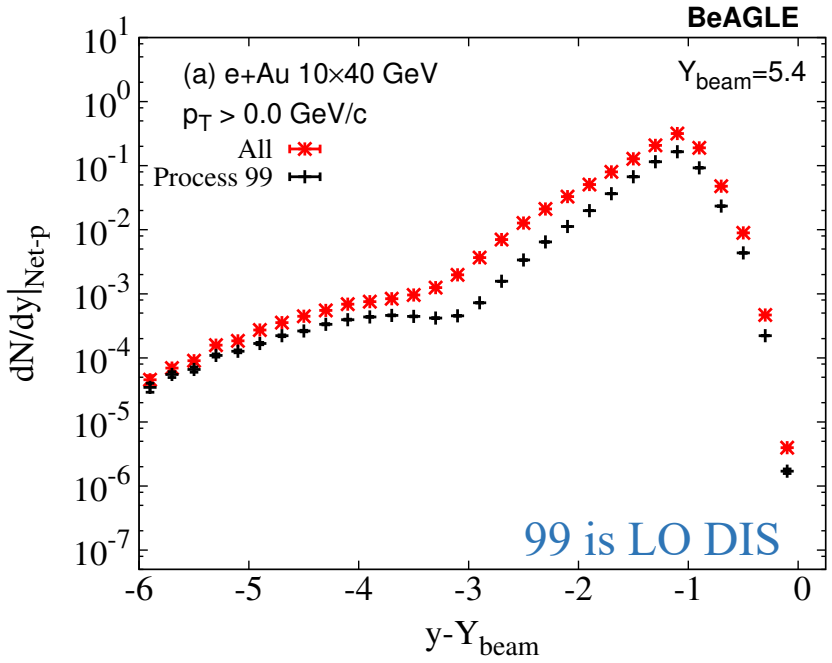
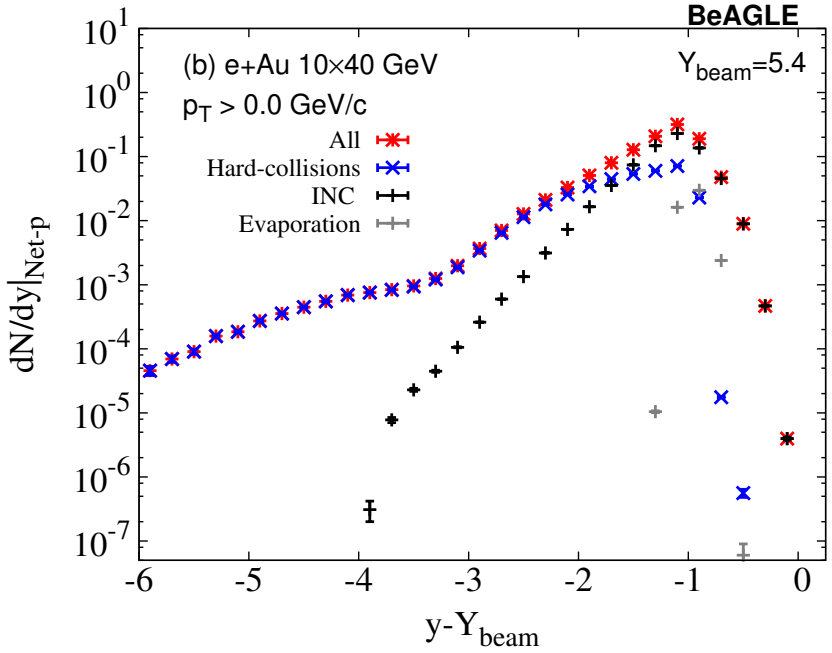
BeAGLE results suggest two slopes (larger than 1.0) depending on the rapidity range



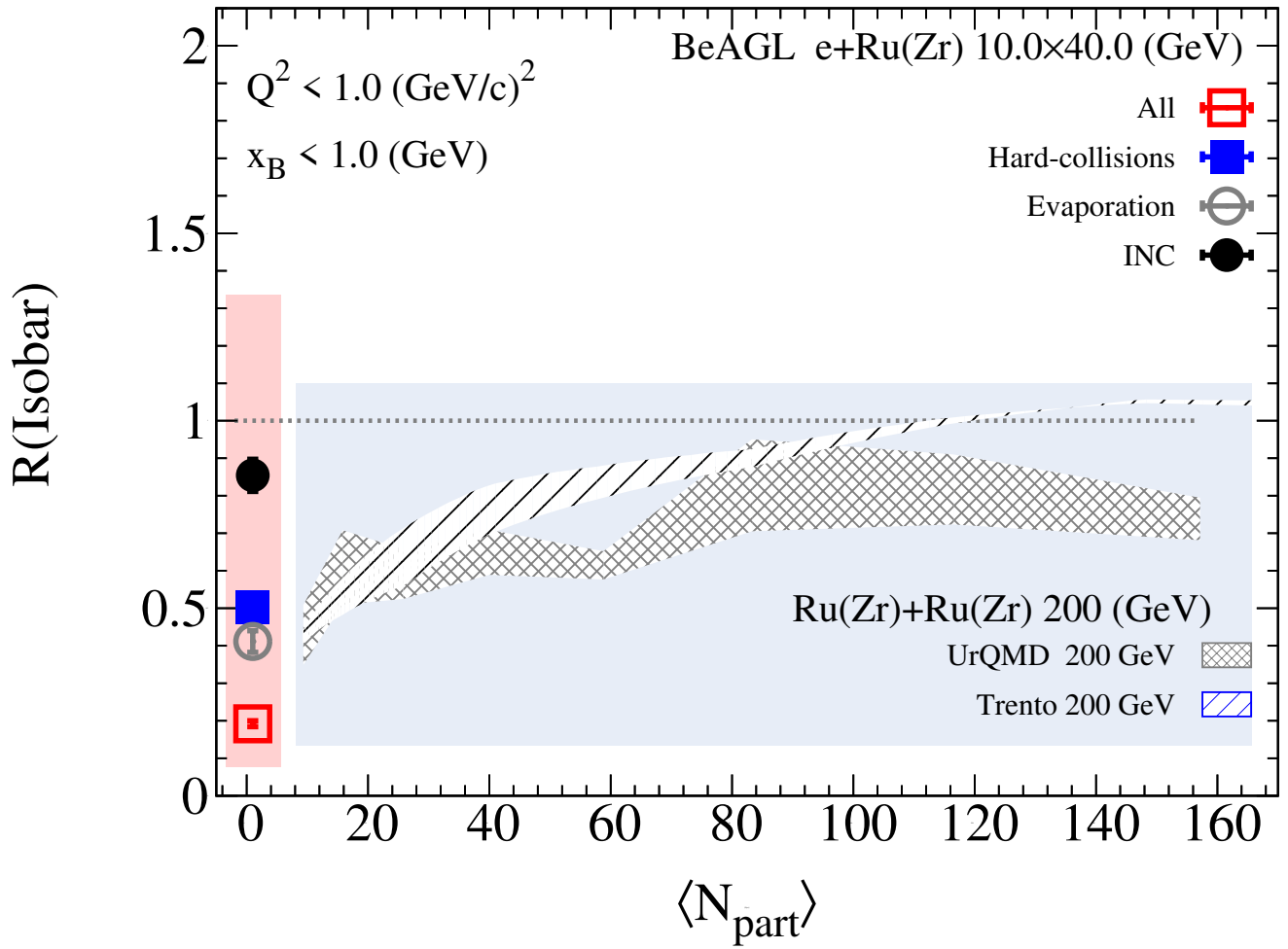
❖ At the EIC

# Isobaric ratio

- Net-Baryon vs. Net-Electric charge in Isobar collisions
  - ✓ The ratio B/Δ$Q$*ΔZ/A can be used to differentiate different carriers
    - Valence quarks carry B and Q if (B/Δ$Q$*ΔZ/A) <= 1
    - Junction carry B (i.e., B is enhanced) if B/Δ$Q$*ΔZ/A > 1

- R(Isobar) shows dependence on the BeAGLE processes

BeAGLE shows value consistent with the quark's scenario



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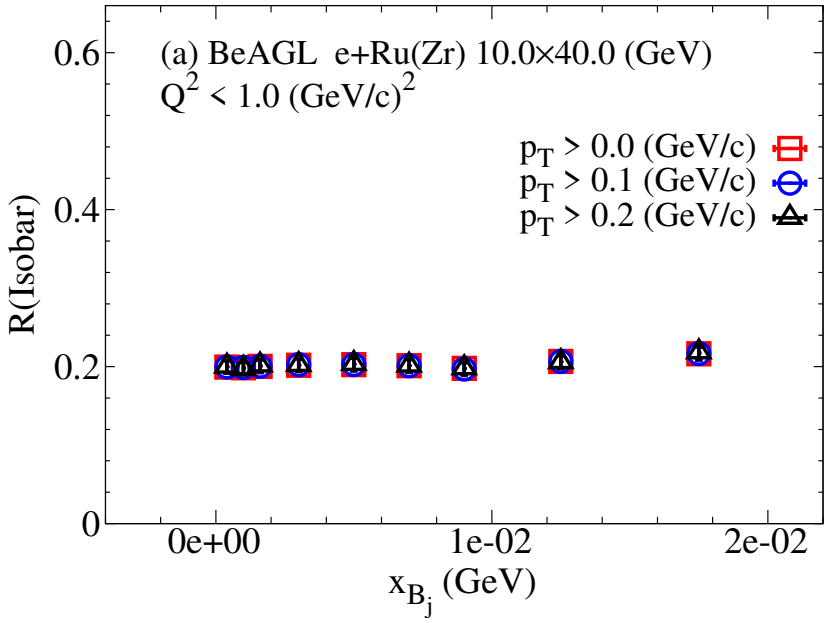
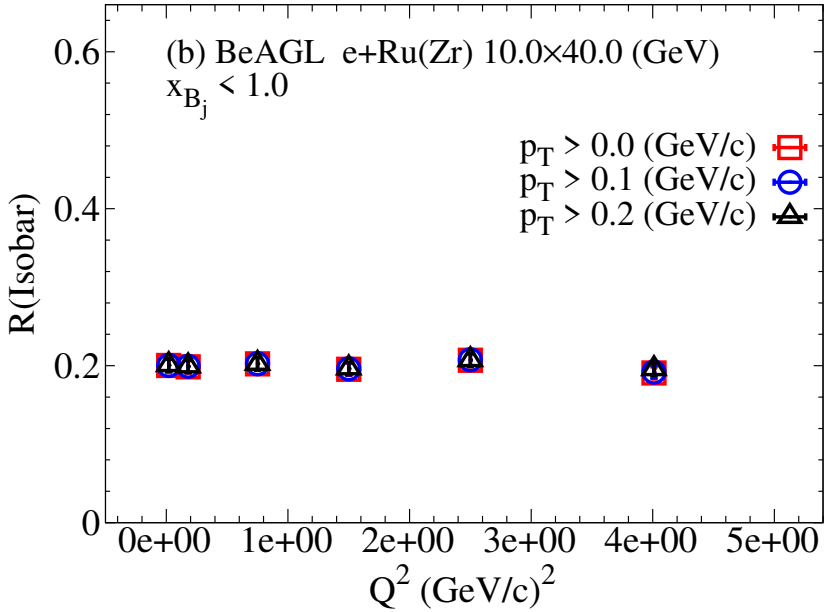
- $R(Isobar)$ is independent of $Q^2, x_{B_j}$ and $p_T$

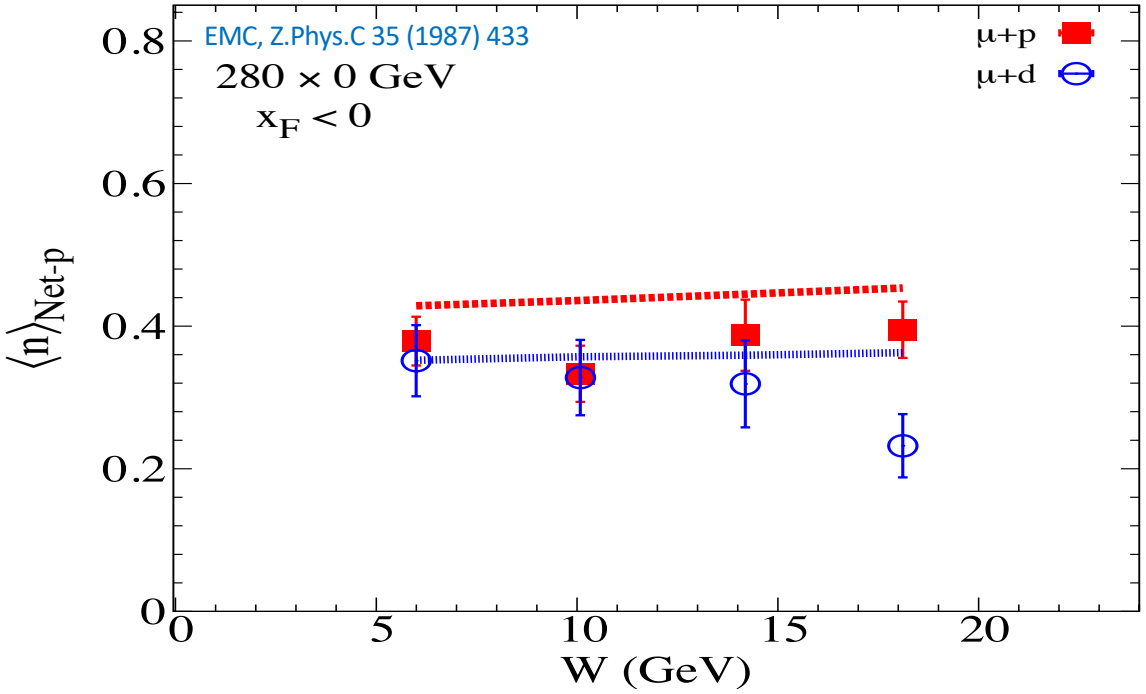
BeAGLE shows value consistent with the quark's scenario

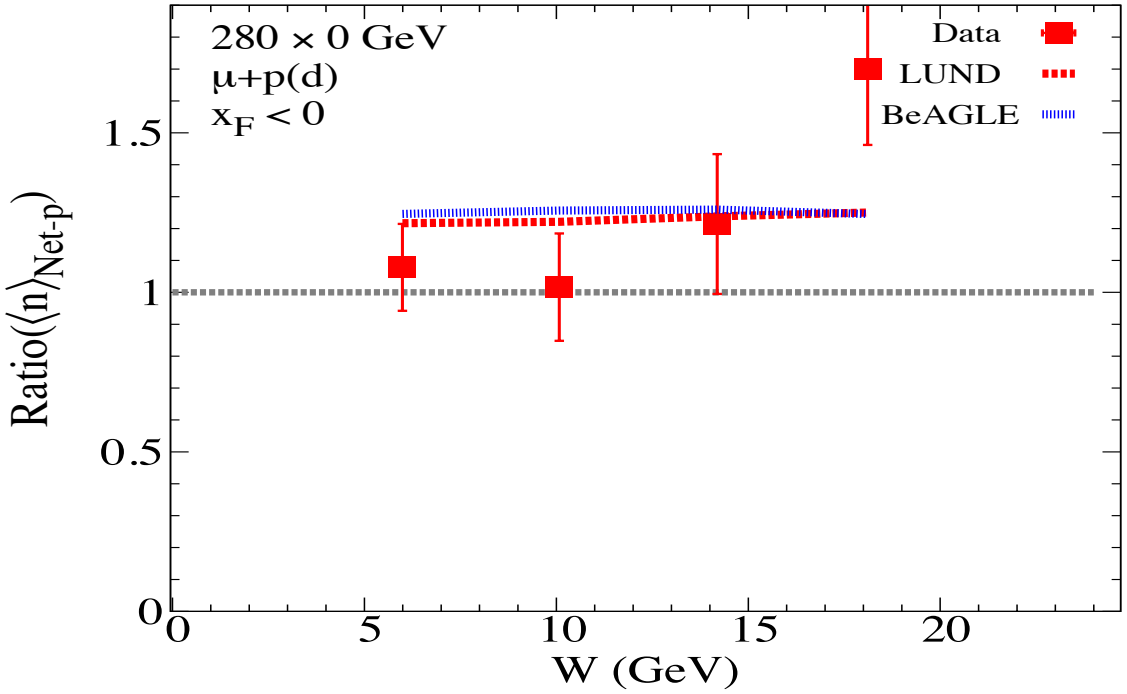


❖ At the EIC

➢ Net-Proton of $\mu(e) + p(d)$




Within uncertainty, EMC measurements show minor differences between $\mu + p$ and $\mu + d$

Diquark Lund model shows a ~20% difference

BeAGLE shows value consistent with the Diquark Lund model

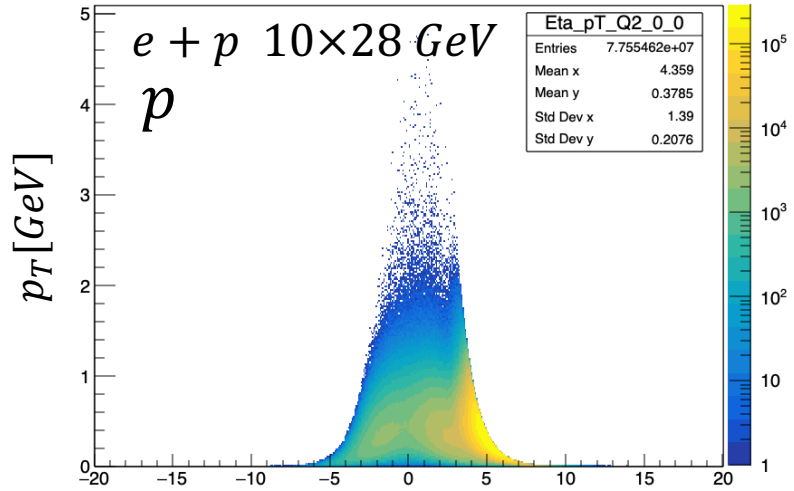
Can EIC do better?

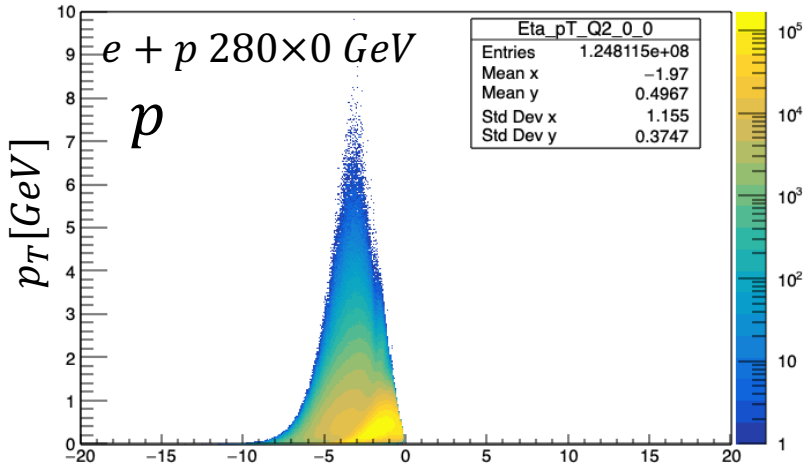
❖ At the EIC

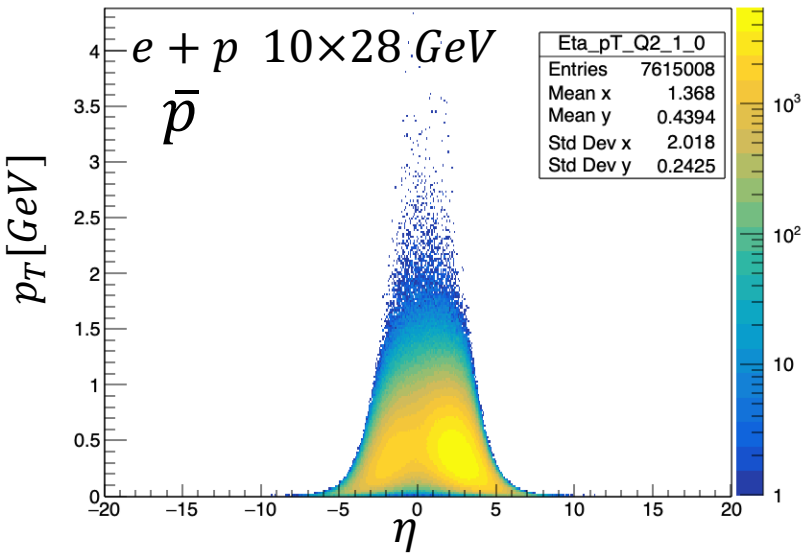
➢ Net-Proton of $\mu(e) + p(d)$

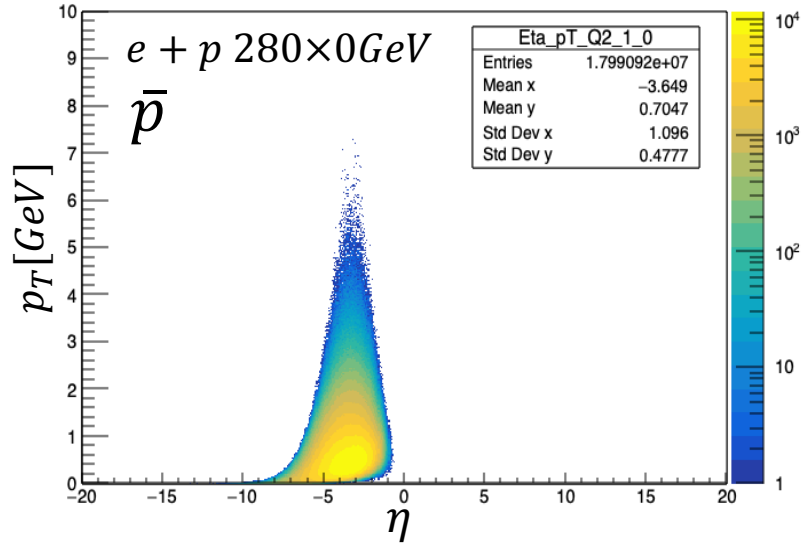
Can EIC do better?

# The $p_T$ $vs$ $\eta$ selections



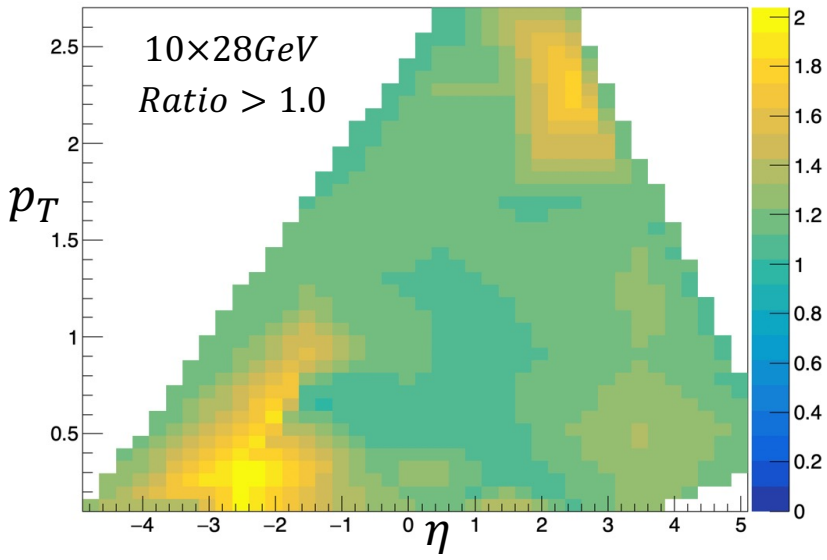



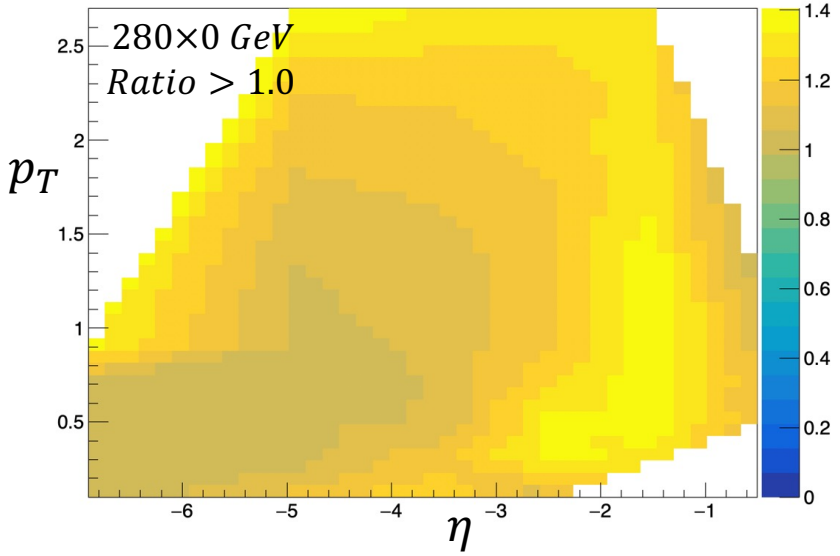
❖ At the EIC

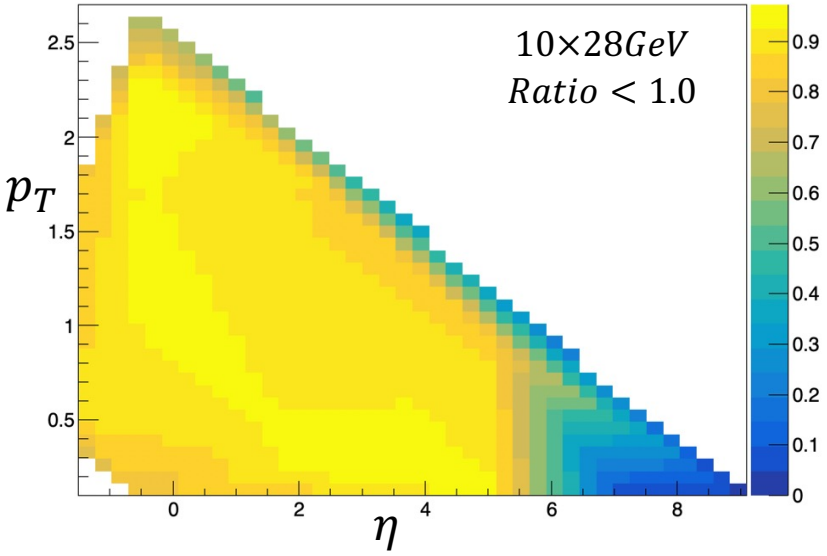
➢ Net-Proton of $\mu(e) + p(d)$

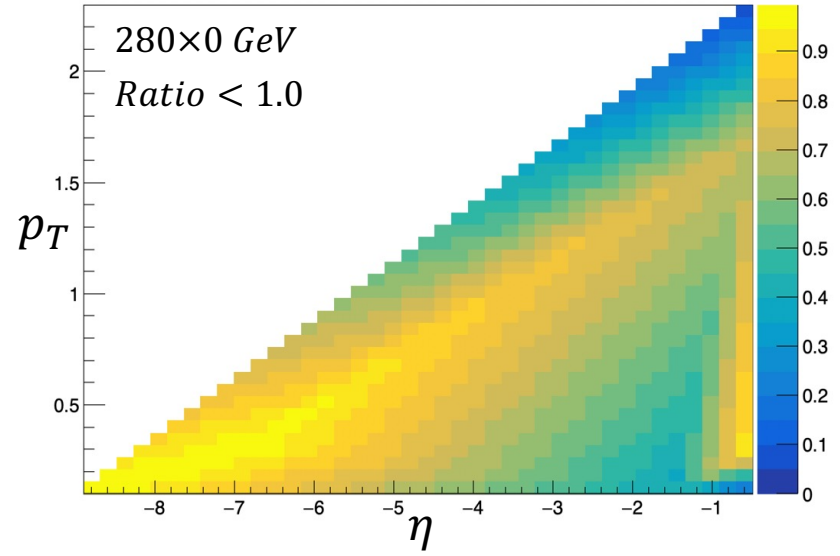
The ratio of net proton [e+p/e+d]

Can EIC do better?



# Conclusions

**We investigated the ability to use the EIC to study baryon junctions in e+A and the isobar collisions:**

- The net-baryon yield slopes from PYTHIA and BeAGLE simulations are much steeper than expected from the baryon junction picture

- The isobaric ratios in BeAGLE are shown to be less than 1.0
  - ✓ Independent of $x_B$
  - ✓ Independent of $Q^2$

- Net-Proton of $\mu(e) + p(d)$
  - ✓ BeAGLE shows value consistent with the Diquark Lund model

Consistent with the quark's scenario.

Thank You