

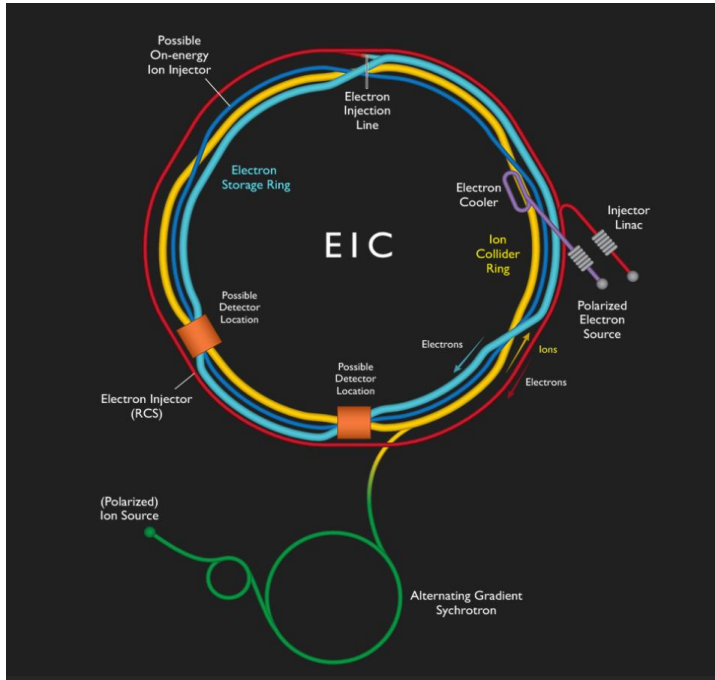
Probing Gluon Saturation with Dijets at the Electron-Ion Collider

Sasha Lempert, Stony Brook University

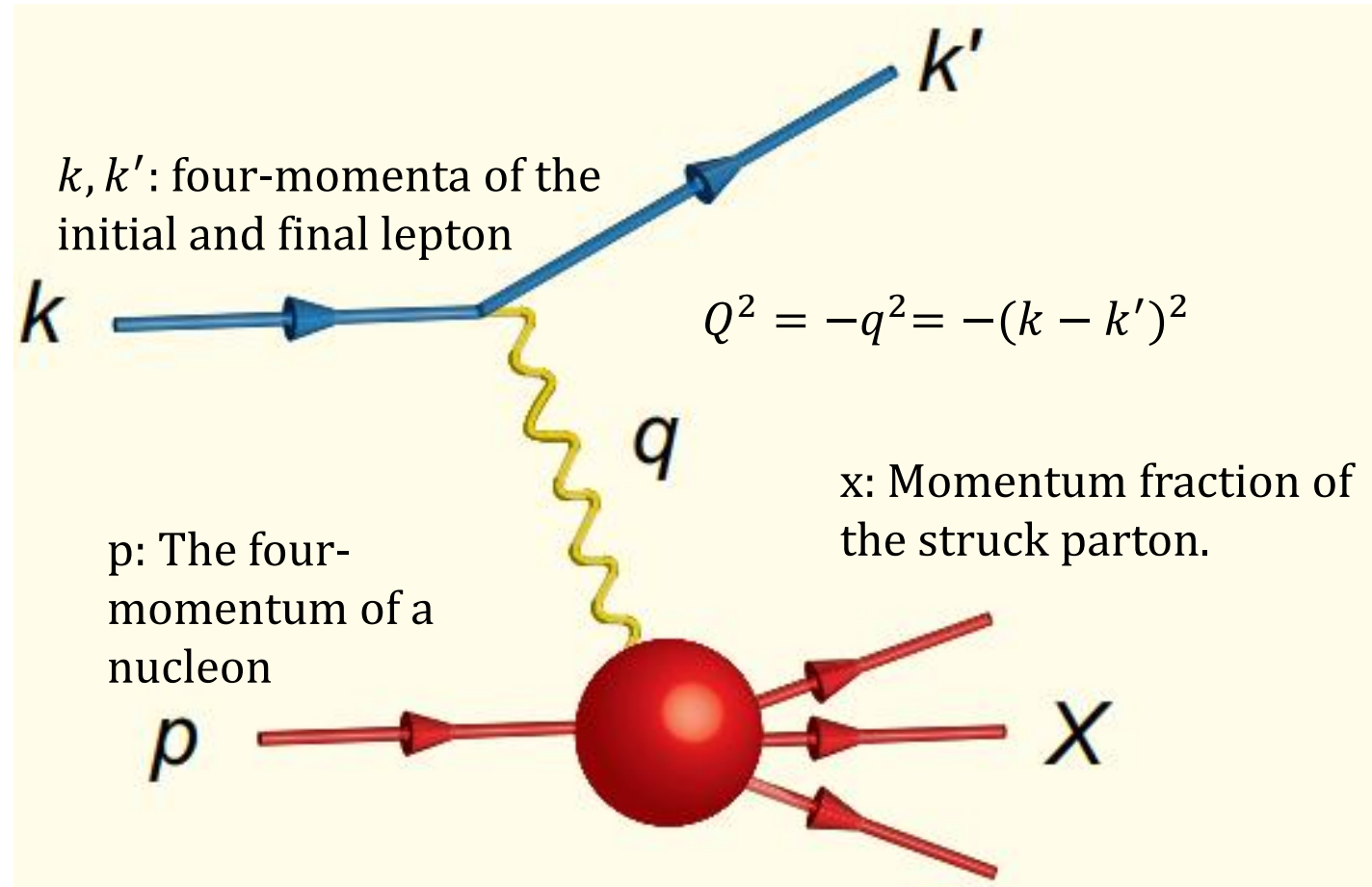
Xiaoxuan Chu, Brookhaven National Laboratory

10/22/26

The purpose of the EIC



- Explore gluon saturation at small x
- Map proton and nuclear structure
- Trace the origin of quark and gluon spin
- Study how quarks and gluons form hadrons
- Explore how nuclear binding emerges.



$$Q^2 = xys$$

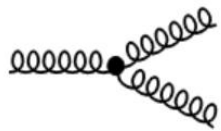
s : Center-of-mass energy squared
 y : Inelasticity

Gluon Saturation

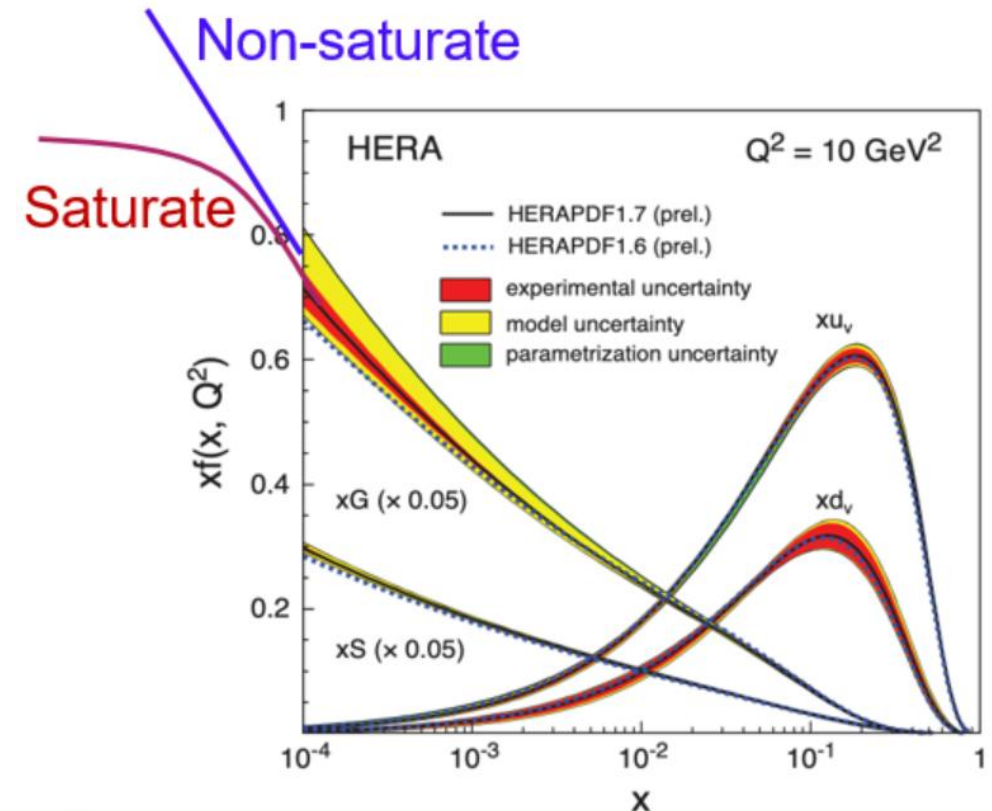
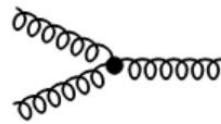
One of the key goals of the EIC is to understand the gluon saturation

- Gluons dominate the proton and nucleus at high energies.
- At sufficiently small x , gluon recombination competes with gluon splitting, leading to gluon saturation.

Gluon splitting

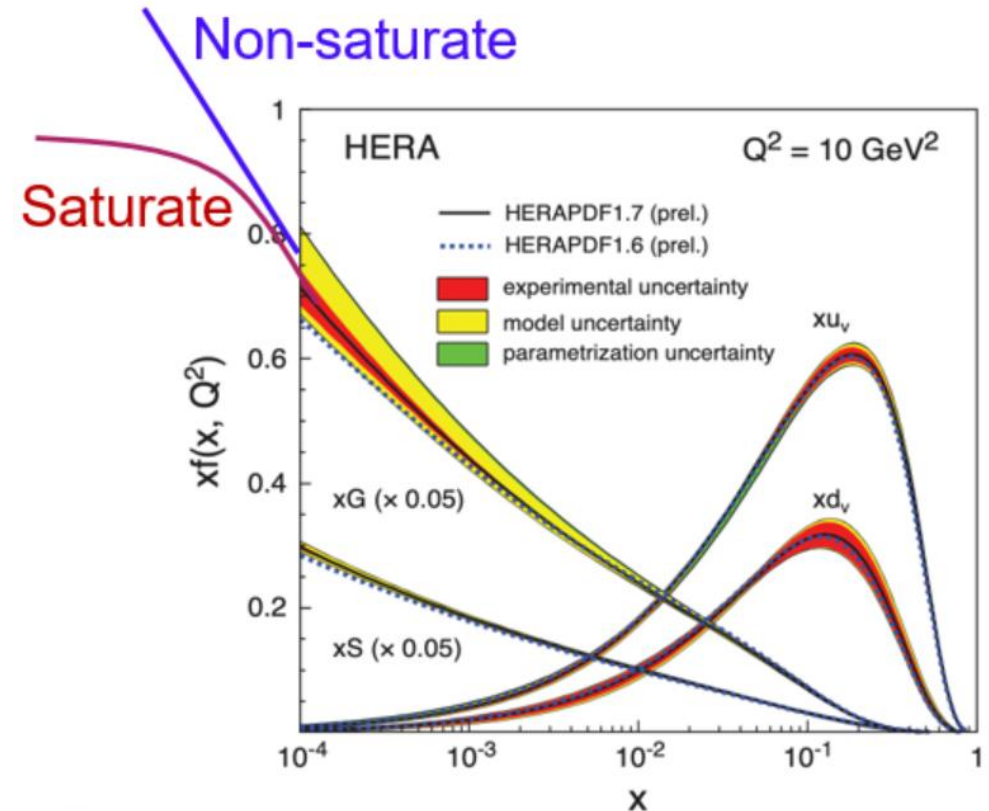
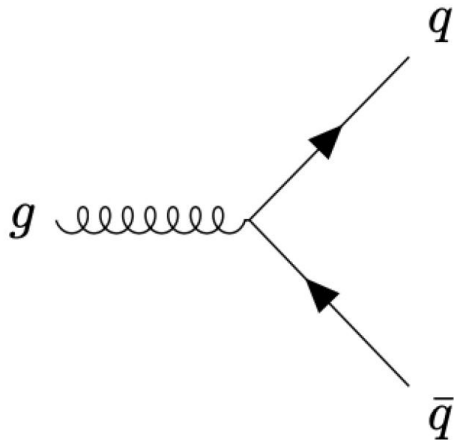


Gluon recombination

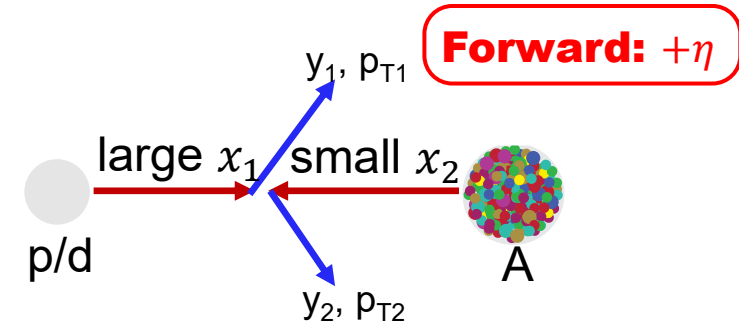
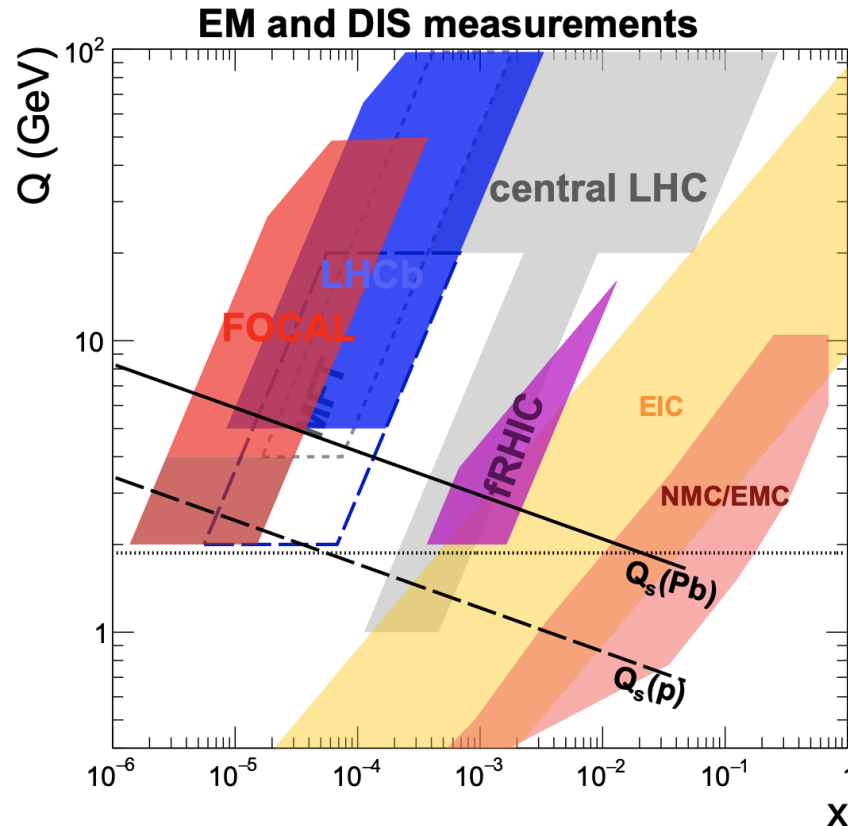


Sea Quark Saturation

- Sea quarks can arise from gluon splitting, $g \rightarrow q\bar{q}$.
- Quarks interact with the dense gluon field inside nuclei.
- Quark-sensitive observables can reveal nuclear saturation effects.



Saturation with di-hadron correlation



$$Q_s \propto A^{\frac{1}{3}} \cdot x^{-\lambda} \cdot \frac{1}{b}$$

$$x_2 \sim \frac{p_{T1} e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}}$$

For a larger Q_s :

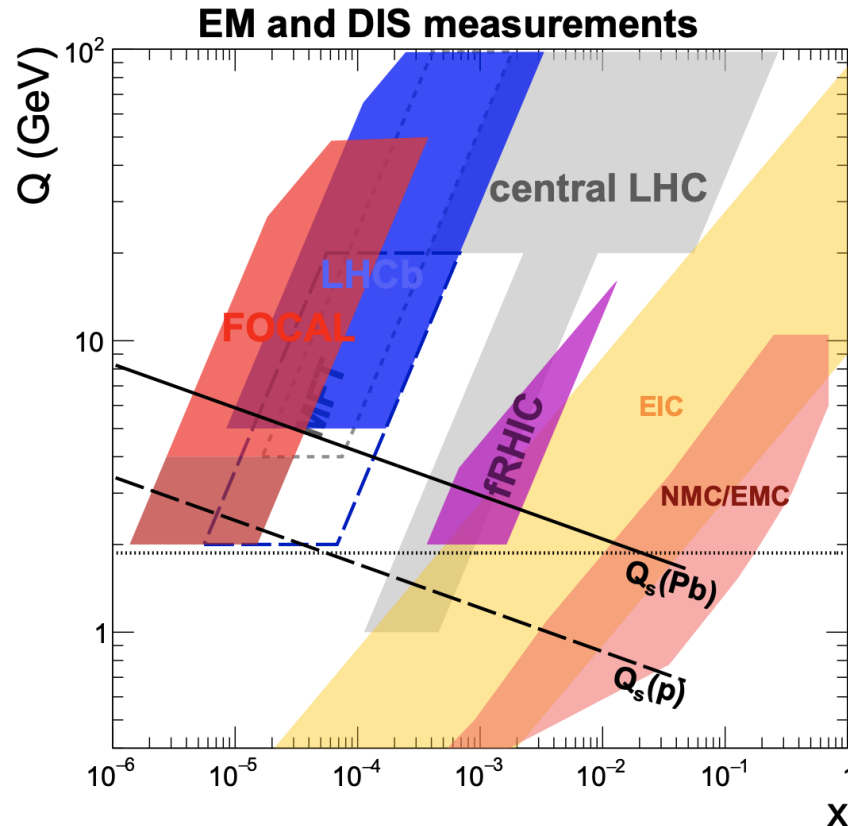
- Larger A
- Smaller x : $+\eta$ and lower p_T
- Smaller b : central collisions

$$Q \propto \frac{p_{T1} + p_{T2}}{2}$$

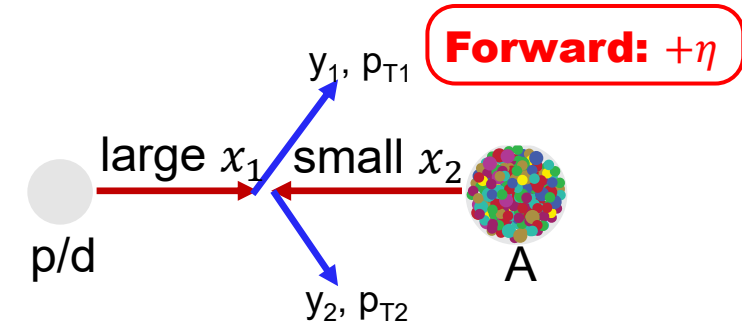
Smaller Q : lower p_T

Gluon saturation: $Q^2 < Q_s^2$

Saturation with di-hadron correlation



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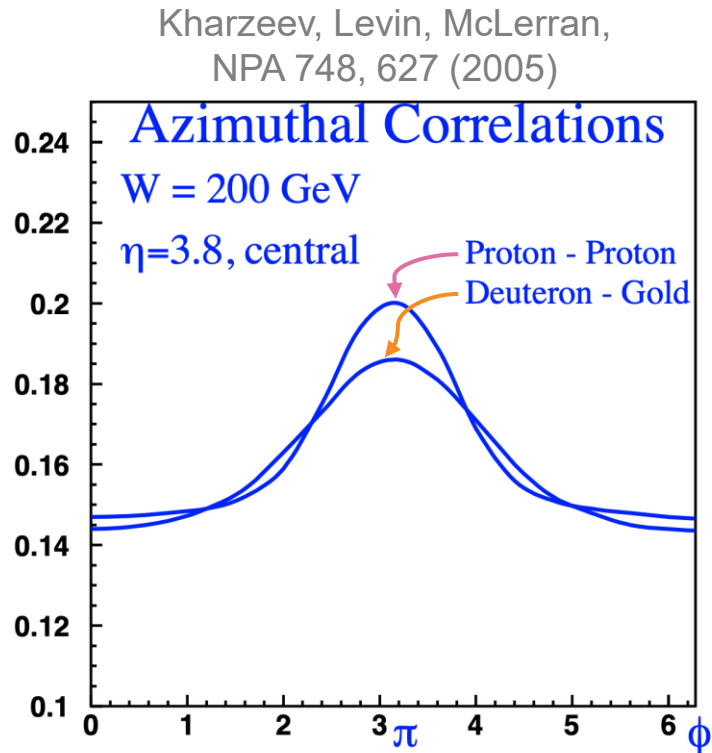
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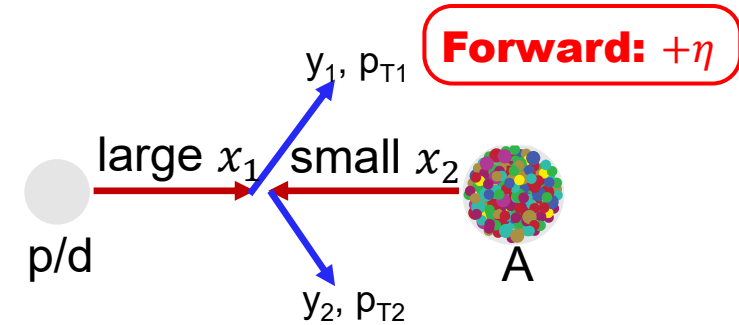
Smaller Q : lower p_T

We can explore different saturation regions by varying p_T , y , b , and A

Saturation with di-hadron correlation



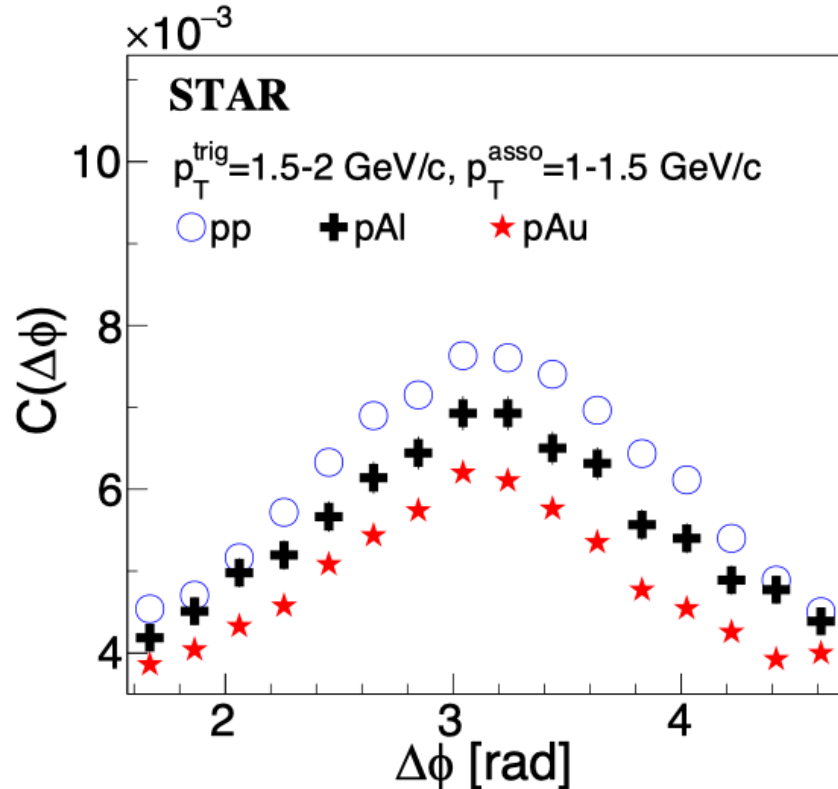
Suppression and Broadening is expected with Saturation



dAu vs pp collisions:

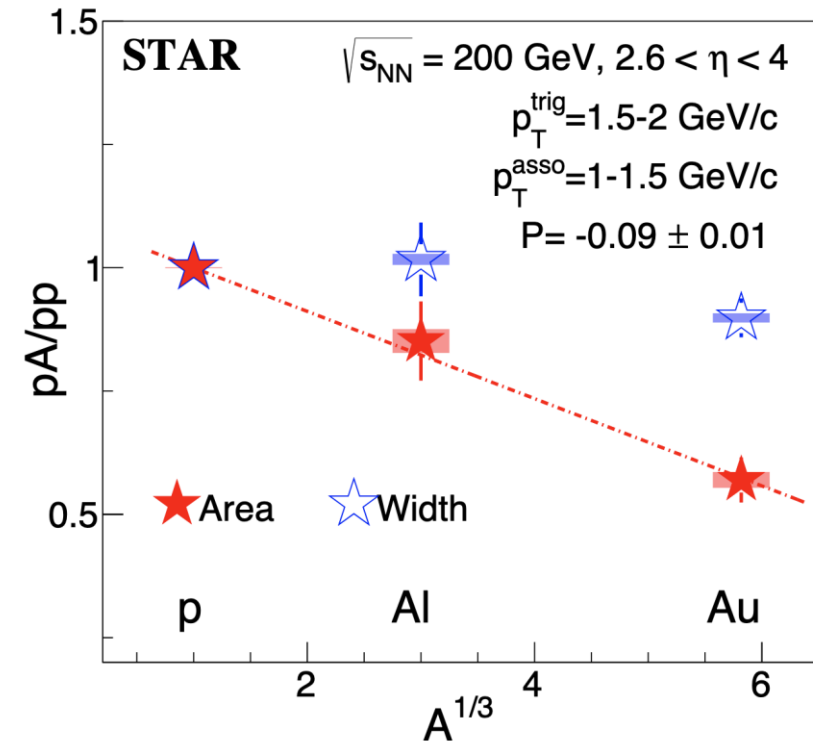
- Suppressed back-to-back peak due to gluon saturation → the **area** under the curve signifies **suppression**
- The **width** of the plot represents **broadening**

STAR pp and pA data



Gluon radiation and higher-order interactions modify scattering.

Additional quark and gluon emissions modify momentum correlations and can broaden the peak.

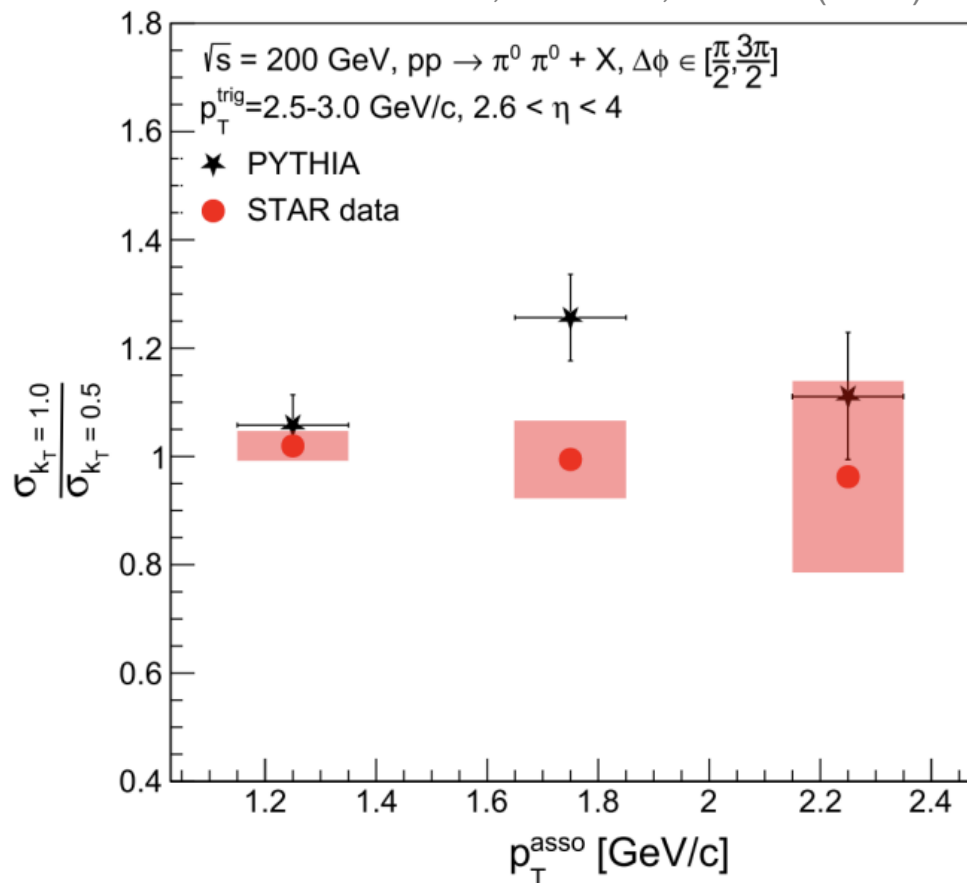


Suppression (area ratio <1) was observed in p+Au.

No significant broadening (width ratio~1) was measured, contrary to expectations.

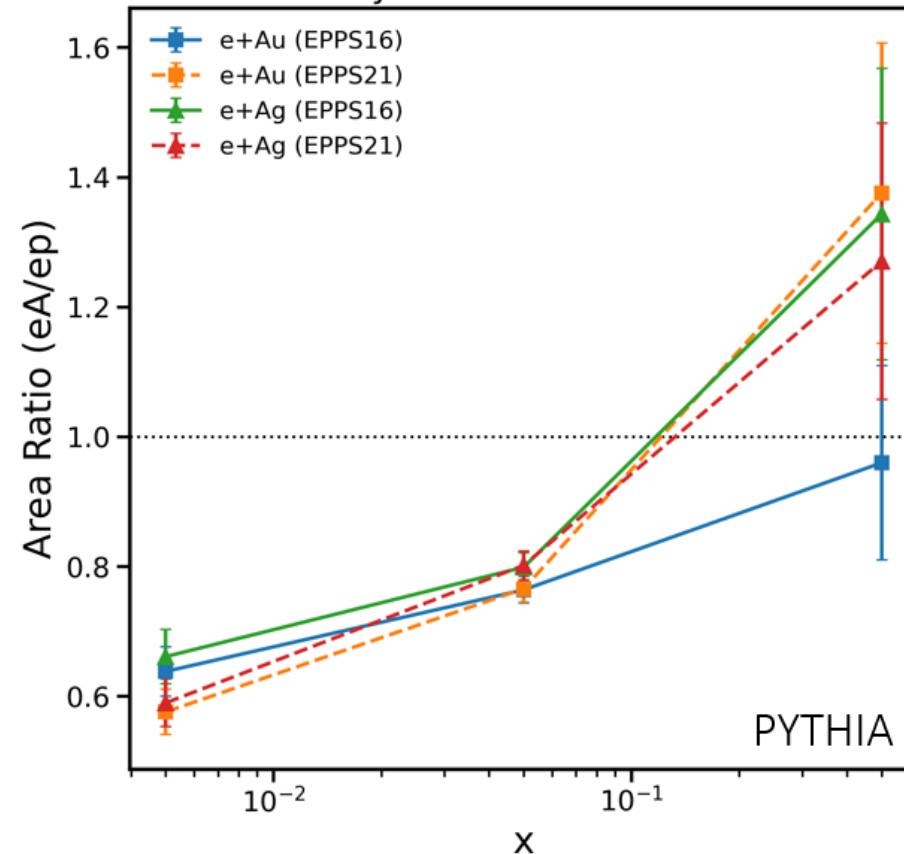
Studies of Gluon Saturation

K. Cassar et al., PRD 112, 034034 (2025)



Results and the NLO framework are **consistent** with PYTHIA. NLO contributions cannot be ignored.

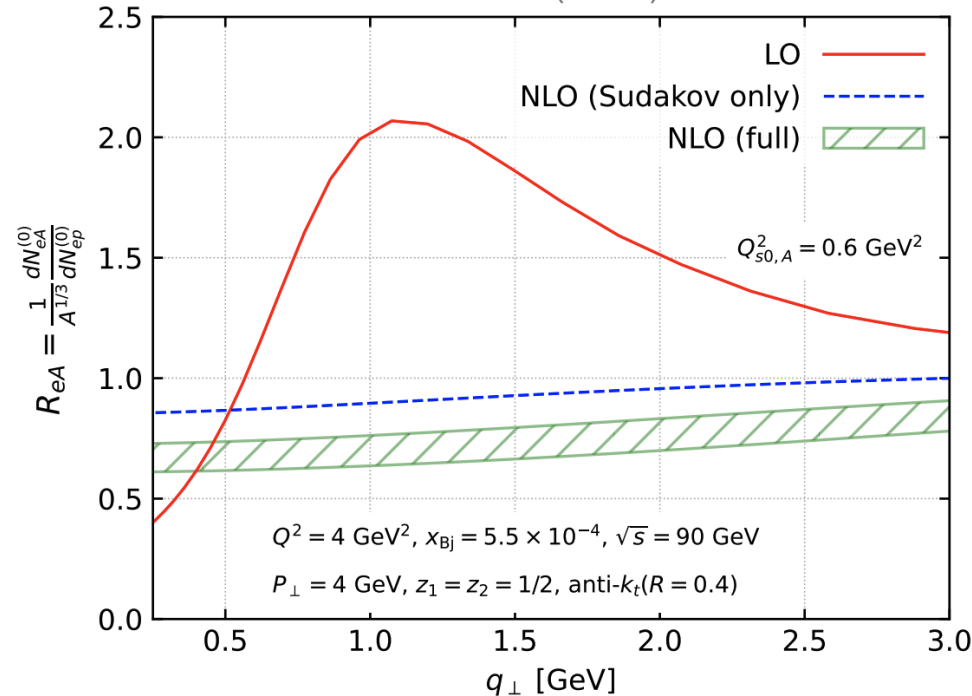
G. Garcia (2026)
Away-side Peak Area Ratio



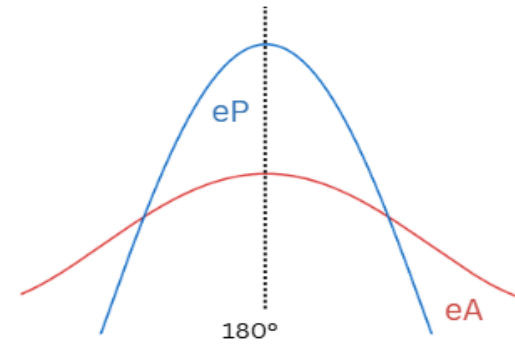
Searching for saturation at the EIC from di-hadron correlation under NLO.
This work will use dijet observables under NLO.

Studies of Gluon Saturation

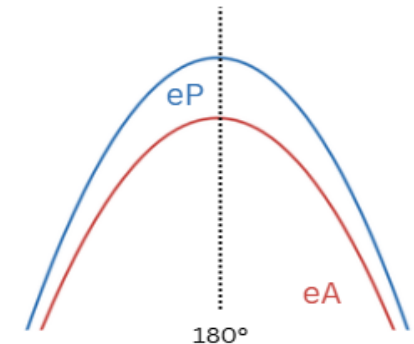
P. Caucal et al., PRL 132,
081902 (2024)



Leading Order (LO)
Broadening + Suppression



Next Leading
Order (NLO)
Suppression



$$\text{Observable: } R_{eAu} = \left(\frac{d\sigma_{eAu}}{dq_{\perp}} \right) / \left(\frac{d\sigma_{ep}}{dq_{\perp}} \right)$$

$q_{\perp}$: Transverse momentum imbalance of the dijets
 σ : Measures how many particles are produced for a given integrated luminosity.

NLO theory prediction agrees with our simulation work, no broadening is predicted under NLO.

Simulation for ep, eA

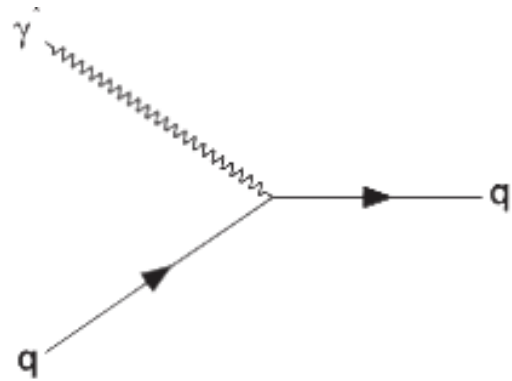
ep and eAu simulation:

- PYTHIA-generated e+p and e+Au (EPPS 16) collisions, 9×100 GeV
- $\sqrt{s} = 60$ GeV
- $10^{-4} < x < 0.9$
- $1 < Q^2 < 9 \text{ GeV}^2$

Dijet Channel:

- Anti- k_T jet reconstruction
- Two leading jets with $p_t^{trig} > 5 \text{ GeV}$ and $p_t^{associate} > 4.5 \text{ GeV}$
- $\eta \leq 4.5$
- $p_t^{track} \geq 0.250 \text{ GeV}$

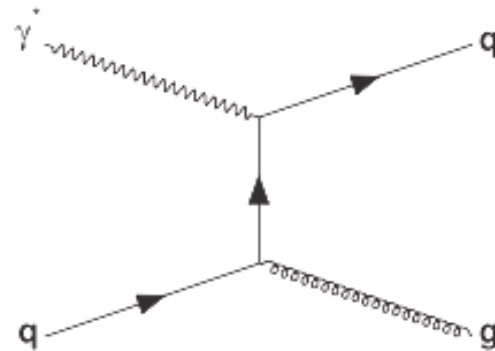
Hard Scattering Processes in DIS



Leading Order Deep Inelastic Scattering (LO DIS)

$$\gamma^* q \rightarrow q$$

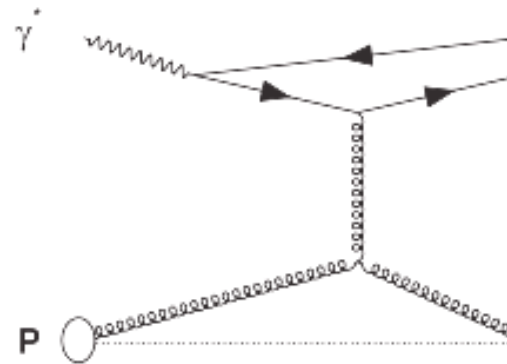
- Virtual photon scatters from a quark.
- Produces one outgoing parton.



QCD Compton Scattering (QCDC)

$$\gamma^* q \rightarrow qg$$

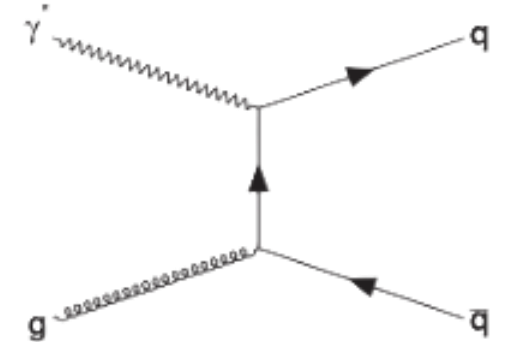
- Virtual photon scatters off a target quark.
- Produces an outgoing quark and gluon.



Resolved

$$qg \rightarrow qq$$

- Virtual photon develops a quark and gluon structure.
- A photon constituent scatters off a target parton.

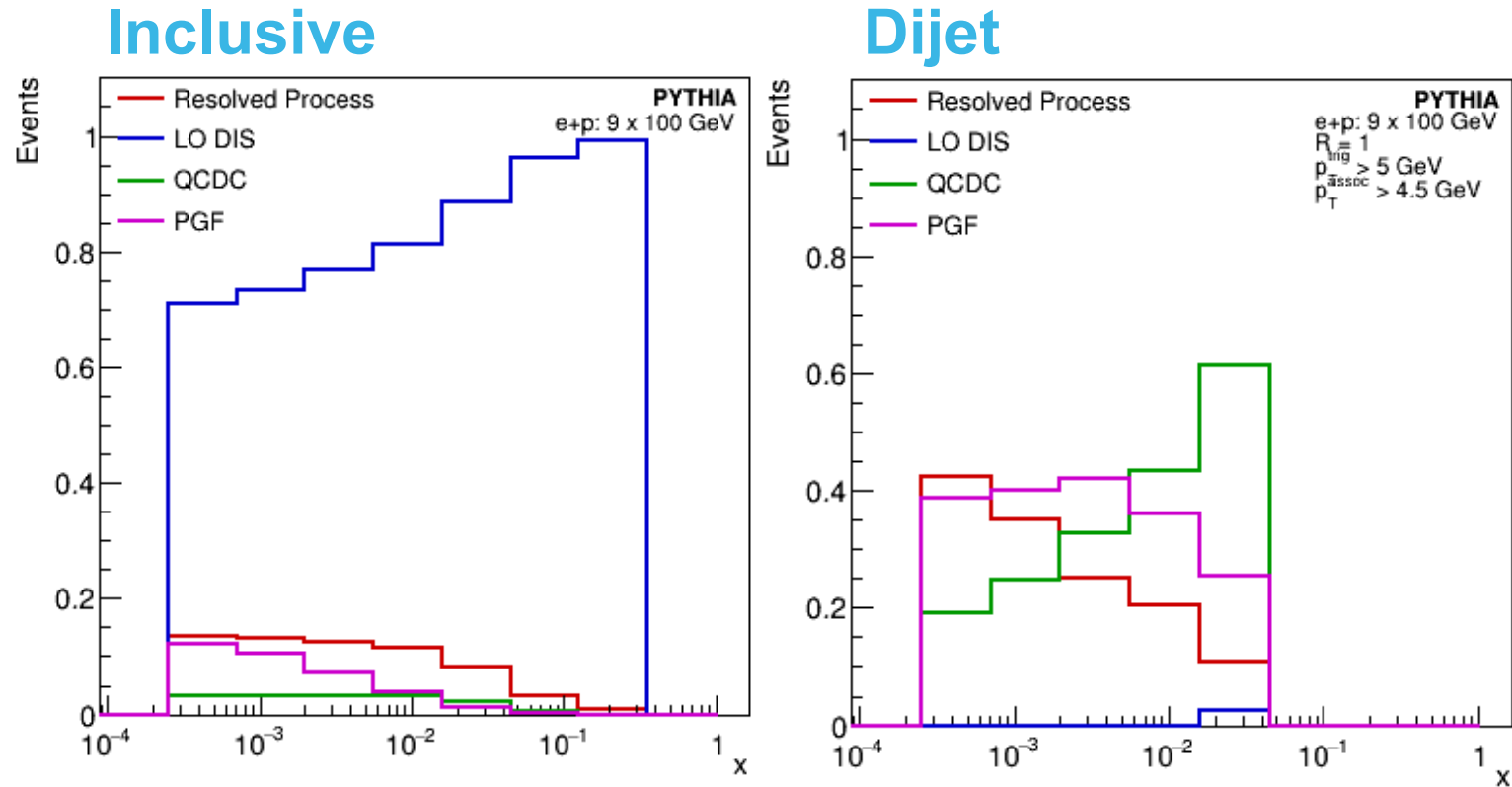


Photon Gluon Fusion (PGF)

$$\gamma^* g \rightarrow q\bar{q}$$

- Virtual photon interacts with a gluon.
- Directly probes the target gluon distribution.

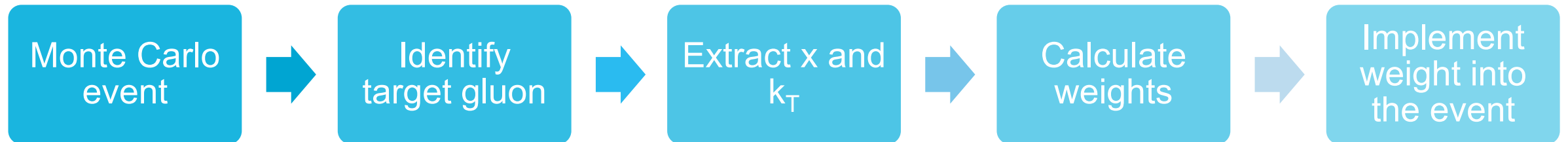
Selecting Dijet events



By selecting Dijets, LO DIS events are suppressed, and we can analyze PGF events

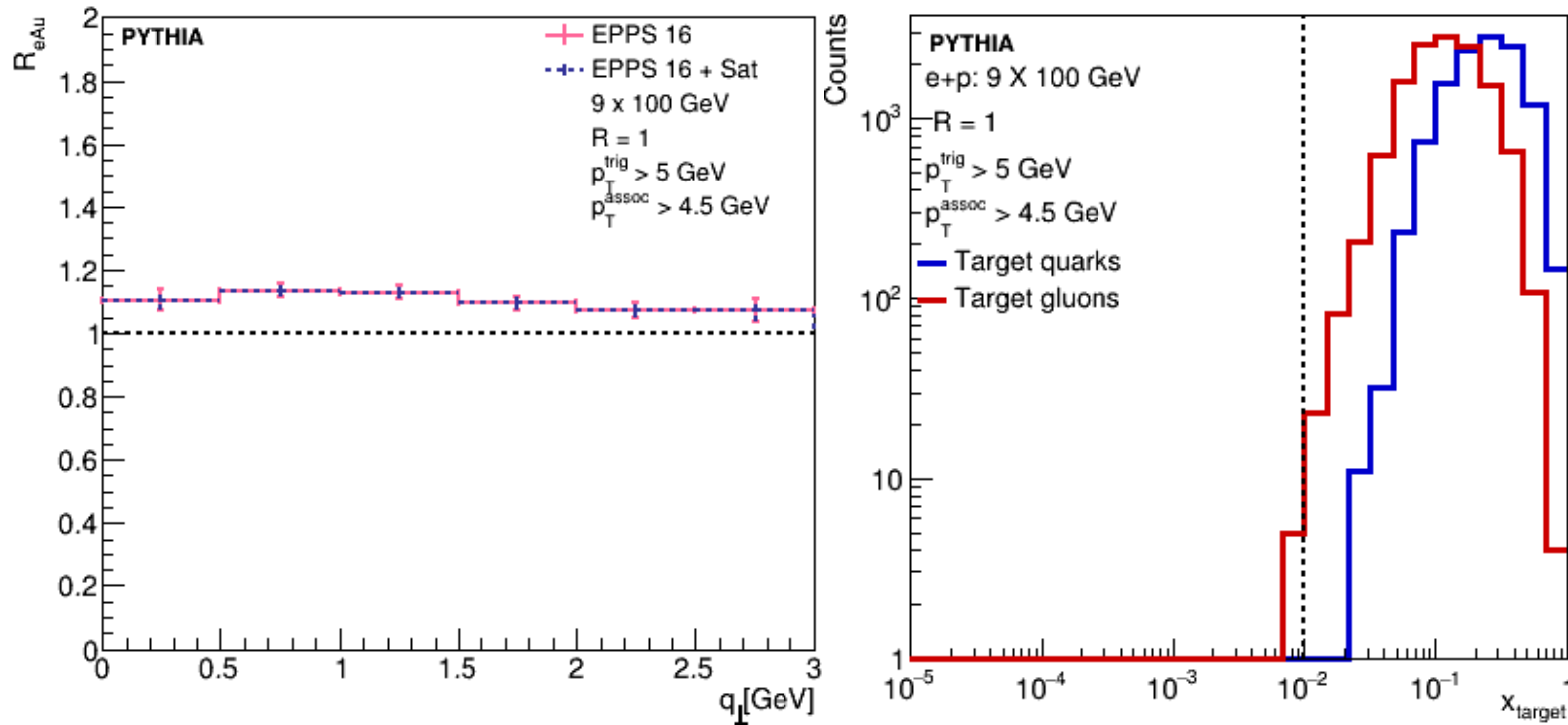
Implementing Sat. Effect (NLO TMD)

- Identify the target gluon in each generated event.
- Extract the gluon x and k_T
- Match the event's (x, k_T) to the nearest entry in the TMD lookup table.
- Assign the corresponding saturation weights $= \frac{eAu_{TMD}}{ep_{TMD}}$ P. Caucal et al., PRL 132, 081902 (2024)

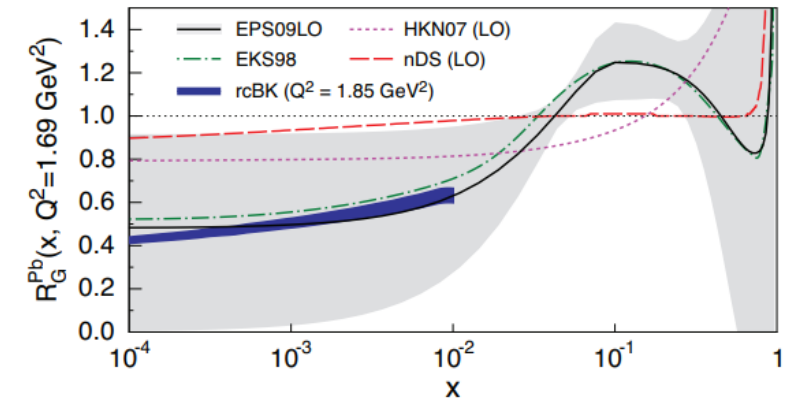


Results

Observable: $R_{eAu} = \left(\frac{d\sigma_{eAu}}{dq_{\perp}} \right) / \left(\frac{d\sigma_{ep}}{dq_{\perp}} \right)$



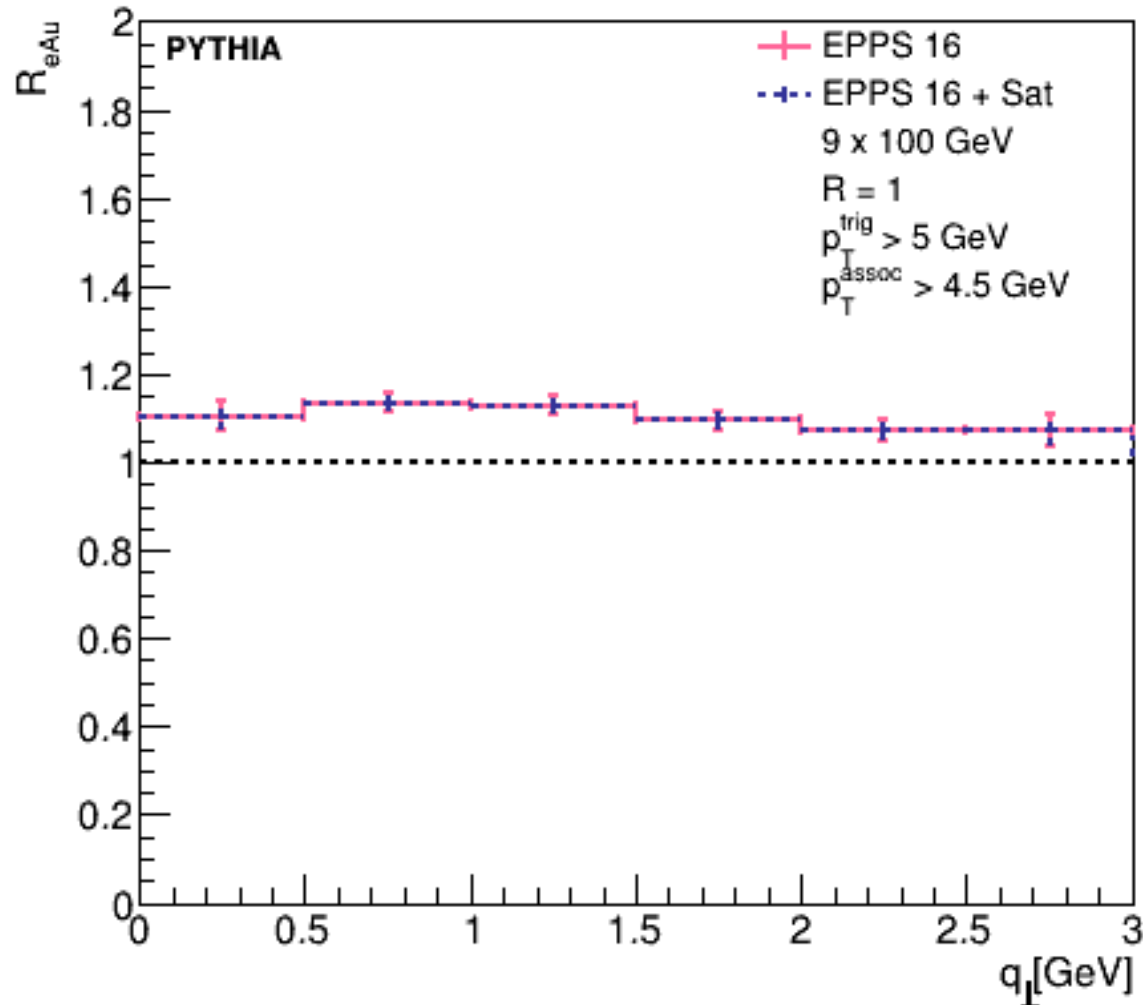
A. Accardi et al., Eur. Phys. J. A 52, 268 (2016)



Results tell us that the nPDF R_{eAu} is enhanced, while the R_{eAu} with saturation remains the same with no effect from the weighting because the probed x region doesn't reach saturation region yet.

Summary

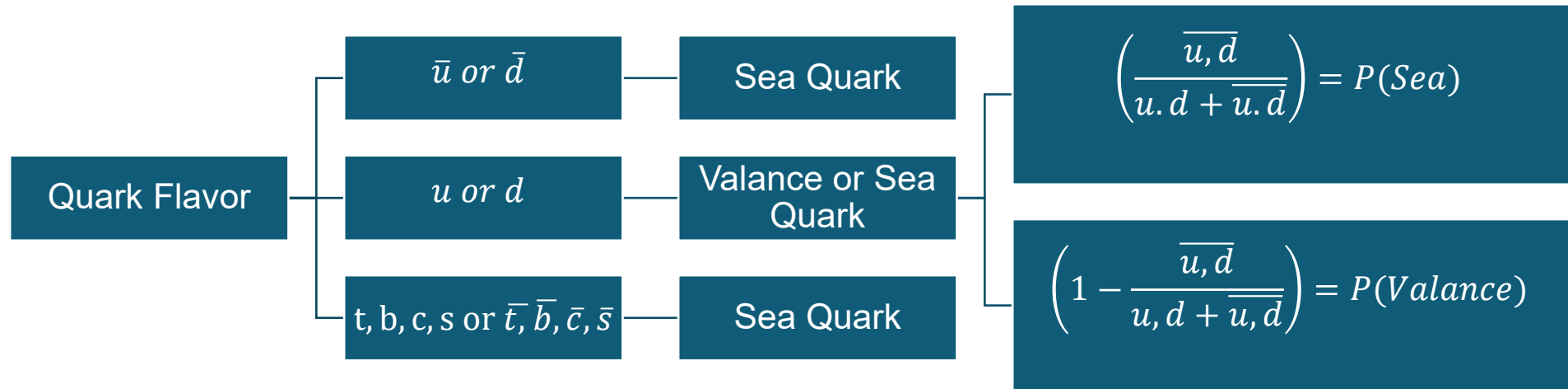
Observable: $R_{eAu} = \left(\frac{d\sigma_{eAu}}{dq_{\perp}} \right) / \left(\frac{d\sigma_{ep}}{dq_{\perp}} \right)$



- Investigated gluon saturation signals using dijet observables at the EIC.
- Using PYTHIA simulations of 9 GeV $\times$ 100 GeV electron–gold collisions, we found that dijet observables have limited sensitivity to gluon saturation.
- This is because the average probed momentum fraction is $x \approx 10^{-1}$ which lies outside the small- x saturation regime, limiting our ability to observe saturation effects.

Back up

Determining Sea Quark or Valance Quark



- Sea quarks are all antiquarks and quarks other than valence up/ down quarks.
- Up and down quarks are classified probabilistically as sea or valence.
- Sea up and anti-up quarks have equal distributions.
- To classify an up or down quark: if a random number is below $P(Sea)$, classify the quark as sea and apply the TMD weight.