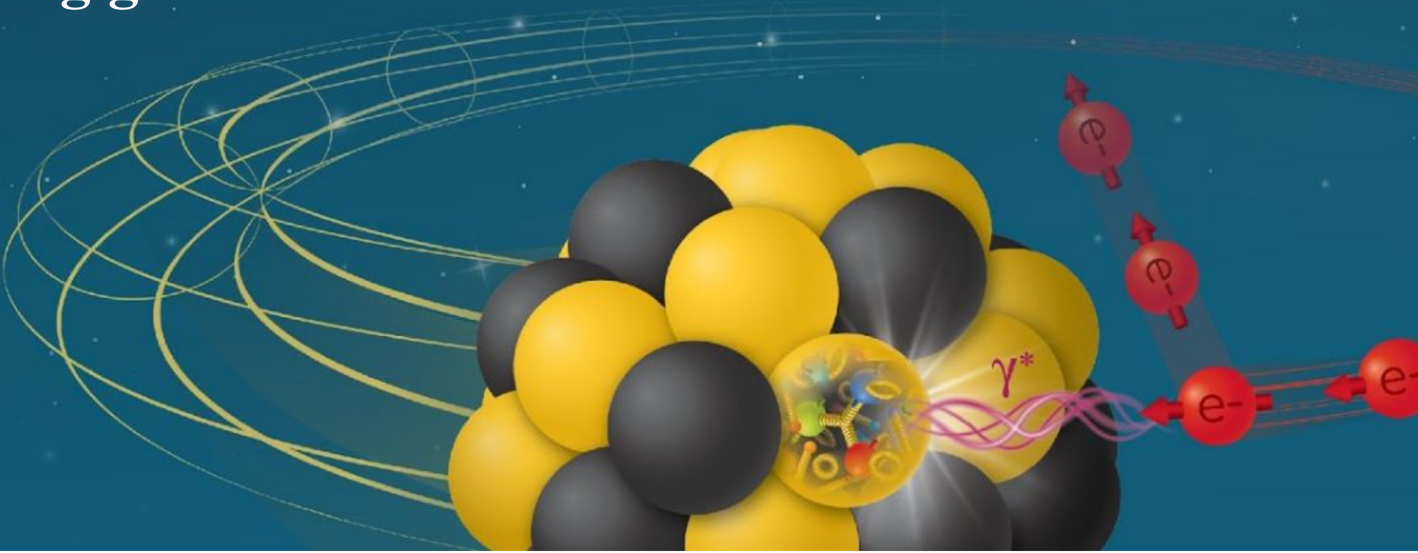
Gluon Saturation, Diffraction and Multihadron Production at the EIC:
Theory, Simulations and Feasibility of Measurements

Center for Frontiers in Nuclear Science

July 15th, 2026 - Stony Brook University

Probing gluon saturation at the future EIC



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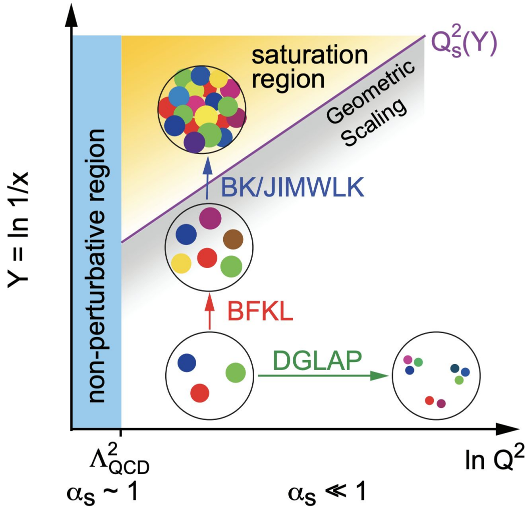
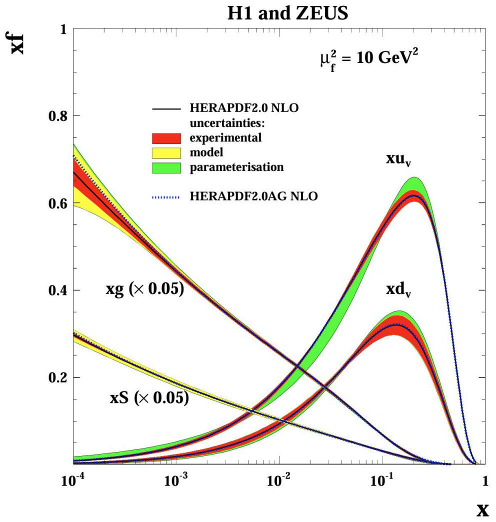
Summary

- ❖ Motivation
  - ➢ Gluon Saturation
- ❖ Observable
  - ➢ Dihadron correlation
  - ➢ STAR measurement and A dependence
- ❖ Methodology
  - ➢ Simulation
  - ➢ Saturation effect on correlation
  - ➢ Dihadron correlation
- ❖ Analysis results
- ❖ Effect of nuclear Fragmentation Functions
- ❖ Conclusion and next steps

Motivation: Gluon Saturation

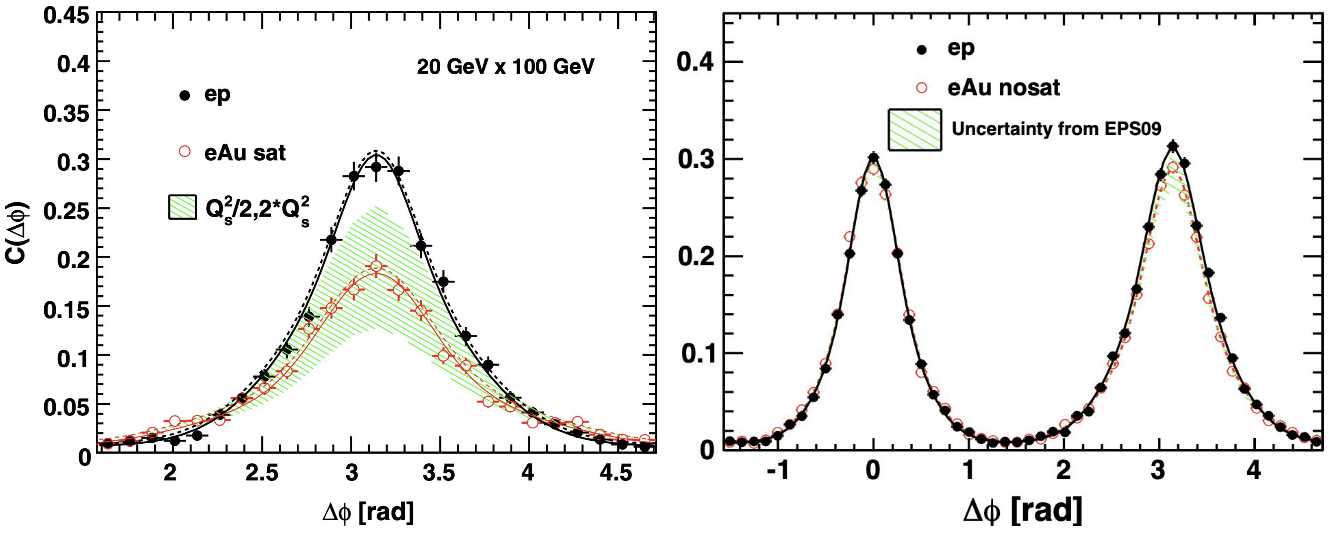
- ❖ Low-x behaviour of PDF threatens unitarity
- ❖ **Nonlinear effects** become relevant
  - ➢ Gluon recombination
  - ➢ Enhanced with nuclear size (Saturation scale $Q_s^{\,2} \sim A^{1/3}$)





Observable: Dihadron correlation

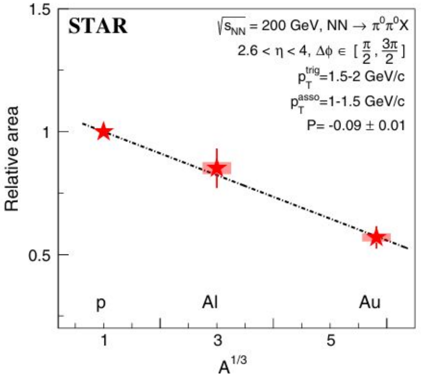
- Dihadron correlation is a key observable in saturation physics
  - Gluons carrying k_T at a scale of $Q_s > Q \rightarrow$ Smear away side

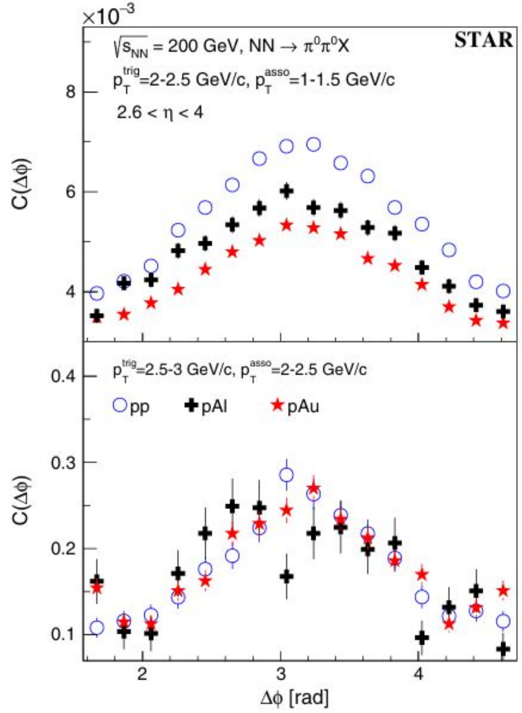


L. Zheng, E.C. Aschenauer, J.H. Lee, Bo-Wen Xiao, Phys. Rev. D 89, 074037 (2014)

Observable: STAR measurement and A dependence

- ❖ Forward di-π^0 correlations in p+p, p+Al, p+Au
- ❖ Away-side peak suppressed in p+A
- ❖ Suppression stronger in heavier nucleus
- ❖ Linear dependence with $A^{1/3}$





STAR, Phys. Rev. Lett. 129, 092501

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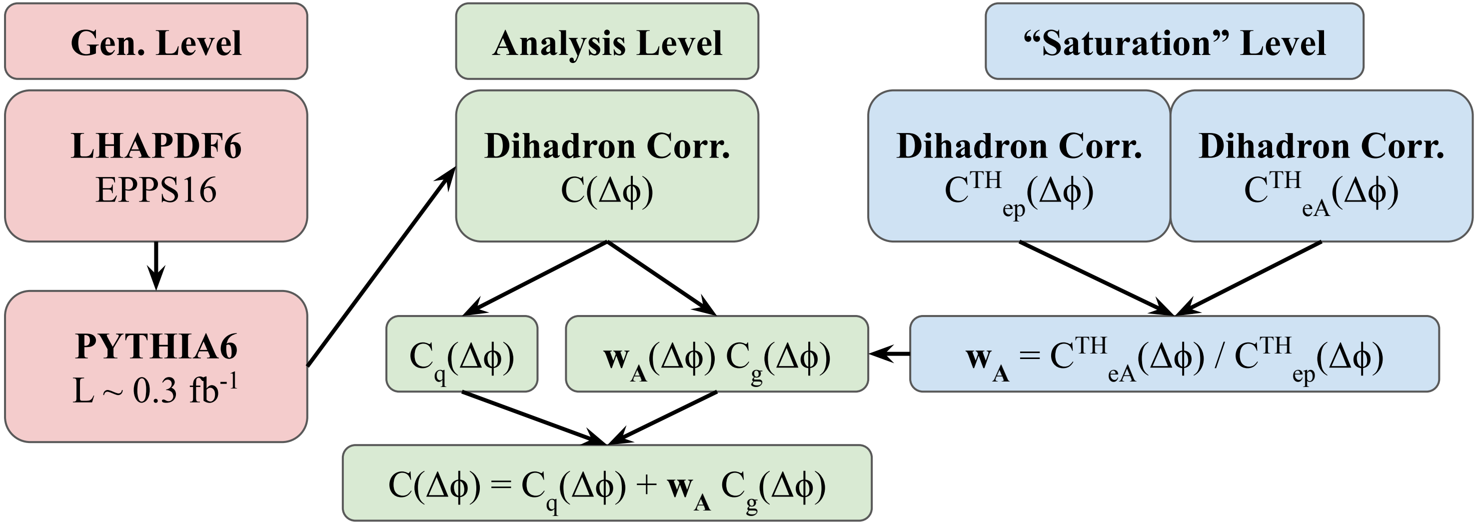
First years of EIC

- Early science matrix (the e+A luminosity is per nucleon)

Species	Beam energy (GeV)	Integrated luminosity (fb^{-1})	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	1.0	NO	N/A
e+D	9×130	1.5	LONG	NO
$e+p$	9×130	1.0	LONG	TRANS and/or LONG
$e+p$	9×275	2.5	LONG	TRANS and/or LONG
e+Au	9×100	1.0	LONG	N/A
$e+{}^3$He	9×166	1.5	LONG	TRANS and/or LONG

- Dihadron correlations identified as an early EIC physics goal
- Observable sensitive to gluon saturation effects
- In this work we compare the dihadron correlation from **e+p**, **e+Ag** and **e+Au**
  - Two different nPDFs: EPPS16 and EPPS21

Methodology



Generation Level

- PYTHIA6 + LHAPDF6:

https://gitlab.com/eic/mceg/PYTHIA-RAD-CORR/-/tree/lhapdf6test?ref_type=heads

- Collision systems: e+p, e+Ag, e+Au
  - Luminosity: **e+p = 0.25 fb^{-1}**, **e+Ag = 0.38 fb^{-1}**, **e+Au = 0.40 fb^{-1}**
  - Energy: 10 x 100 GeV
  - Kinematic range: $1 \leq Q^2 < 9$ GeV^2, $10^{-4} < x < 0.9$
  - Nuclear PDFs: EPPS16 and EPPS21

    https://arxiv.org/pdf/1612.05741, https://arxiv.org/pdf/2112.12462

Saturation Level

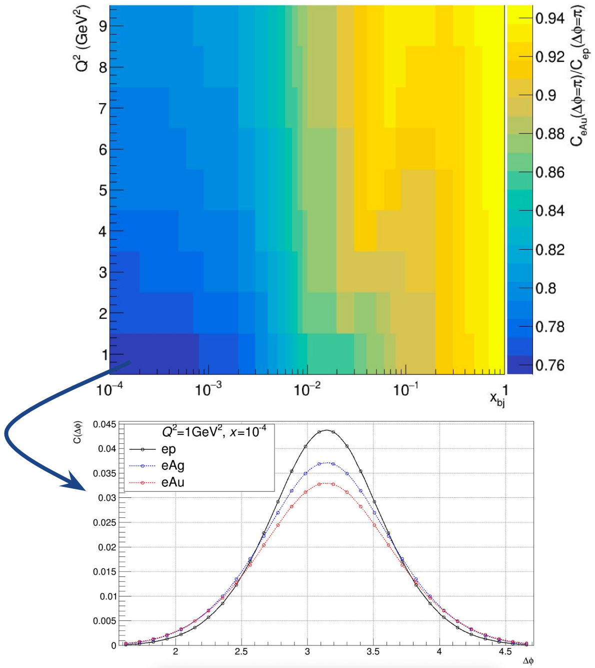
- Coincidence probability calculated within the saturation formalism

$$C(\Delta\phi) = \frac{1}{\frac{d\sigma_{\rm SIDIS}^{\gamma^*+A\to h_1+X}}{dz_{h1}}} \frac{d\sigma_{\rm tot}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d\Delta\phi}$$

- $$\boxed{w_{\rm A}(\Delta\phi) = \frac{C_{\rm eA}(\Delta\phi)}{C_{\rm ep}(\Delta\phi)}}$$

- Weight is calculated across phase space **(Q2, x, z_{h1}, z_{h2})** and applied event by event in the Analysis Level

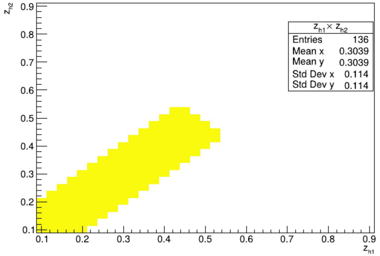
- Fixed parameters: 2.0 GeV/c $\le p_T^{trig}$ and 1.0 GeV/c $\le p_T^{asso} < p_T^{trig}$



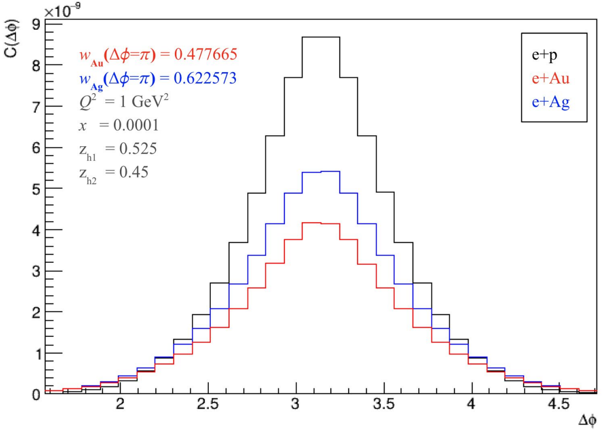
L. Zheng, E.C. Aschenauer, J.H. Lee, Bo-Wen Xiao, Phys. Rev. D 89, 074037 (2014)

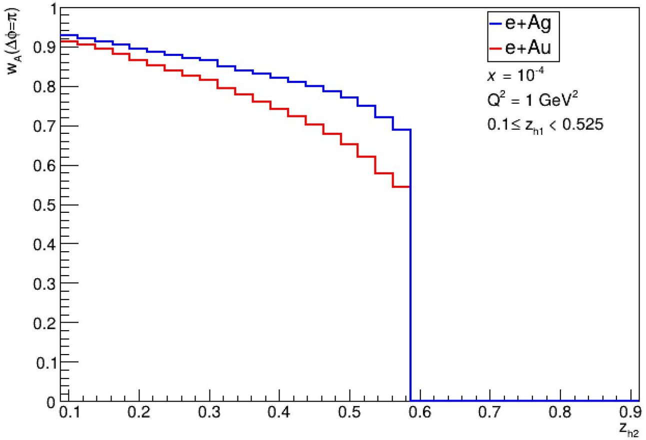
Saturation Level - z_{h1}, z_{h2} dependence

$$\frac{d\sigma_{\rm tot}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d^2p_{h1\perp}d^2p_{h2\perp}} = C\int_{z_{h1}}^{1-z_{h2}} dz_q \frac{z_q(1-z_q)}{z_{h2}^2 z_{h1}^2} d^2p_{1\perp}d^2p_{2\perp}\mathcal{F}(x_g,q_\perp)\mathcal{H}_{\rm tot}(z_q,k_{1\perp},k_{2\perp}) \times \sum_q e_q^2 D_q\left(\frac{z_{h1}}{z_q},p_{1\perp}\right)D_{\bar{q}}\left(\frac{z_{h2}}{1-z_q},p_{2\perp}\right),$$



- Selected region: $z_{h1} + z_{h2} < 1$ and $|z_{h1} - z_{h2}| < 0.1$
- Maximum away side suppression and Saturation weight dependence





Analysis Level

- Events initiated with gluon involving processes (e.g. PGF) have it's dihadron correlation weighted by $w_A(\Delta\phi)$

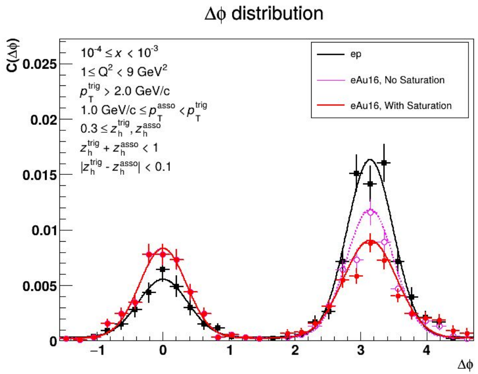
- Analysis cuts:
  - $|\eta| < 4.0$ (ePIC)
  - $1 < Q^2 < 9$ GeV^2
  - $0.3 \leq z_{h1,h2}$ (within $z_{h1} + z_{h2} < 1$ and $|z_{h1} - z_{h2}| < 0.1$)
  - 2.0 GeV/c $\leq p_T^{trig}$
  - 1.0 GeV/c $\leq p_T^{asso} < p_T^{trig}$
  - x bins: $[10^{-4},10^{-3})$, $[10^{-3},10^{-2})$ and $[10^{-2},10^{-1})$

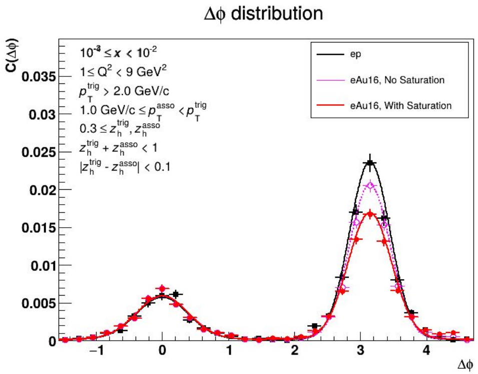
Results: e+Au (EPPS16)

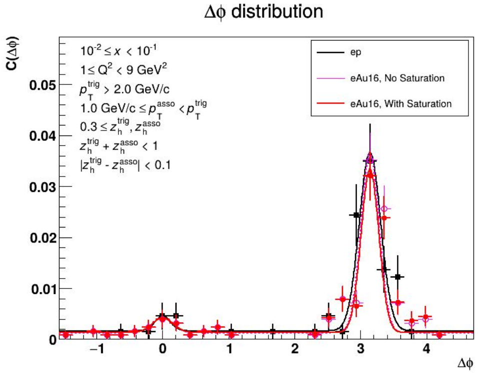
- Suppression of away-side peak observed in e+A *vs* e+p

- Lower *x* more suppressed

- Away-side area **suppression ~40%** in lowest *x* bin of e+Au relative to e+p

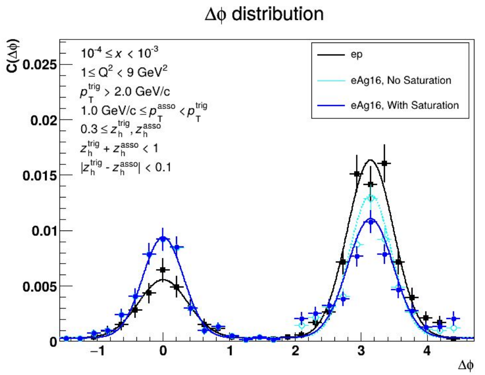


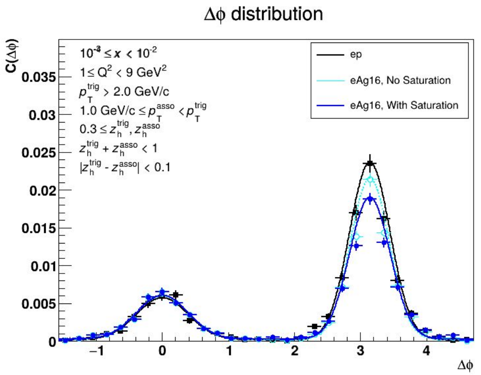


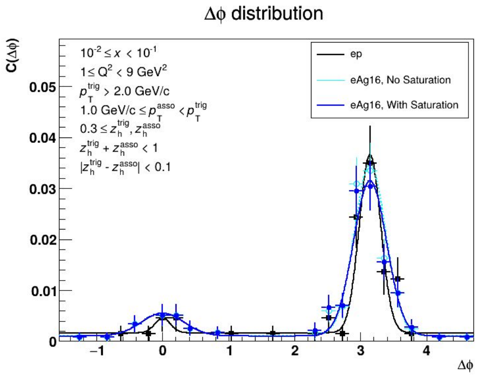


Results: e+Ag (EPPS16)

- ❖ Suppression of away-side peak observed in e+A *vs* e+p
- ❖ Lower *x* more suppressed
- ❖ Difference between Ag and Au reflects nuclear size dependence

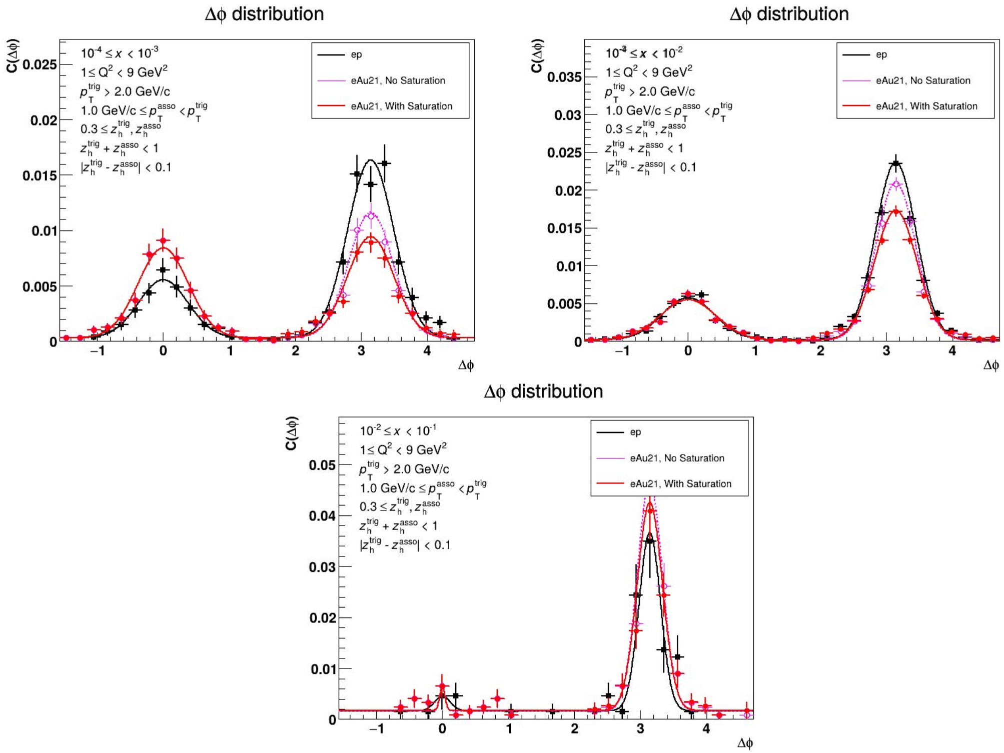






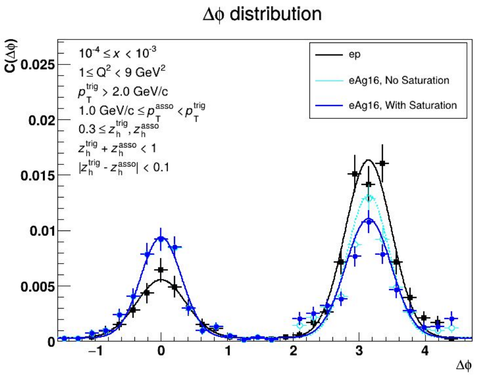
Results: e+Au (EPPS21)

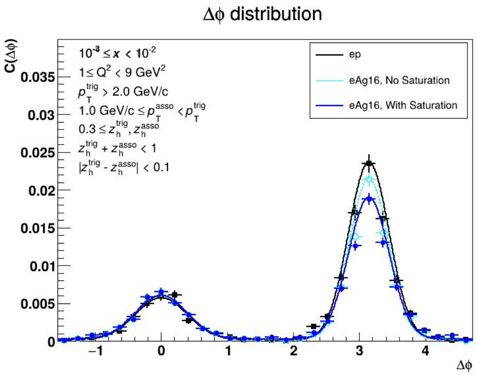
- ❖ Suppression of away-side peak observed in e+A *vs* e+p
- ❖ Lower x more suppressed
- ❖ Difference between Ag and Au reflects nuclear size dependence
- ❖ EPPS16 *vs* EPPS21: results consistent within uncertainties

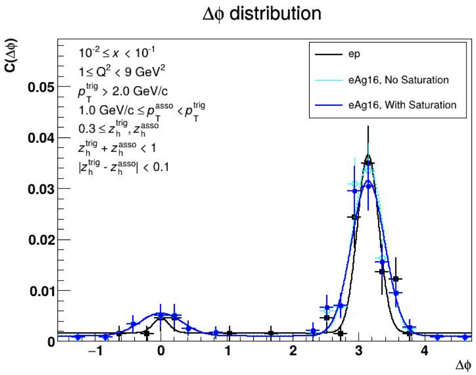


Results: e+Ag (EPPS21)

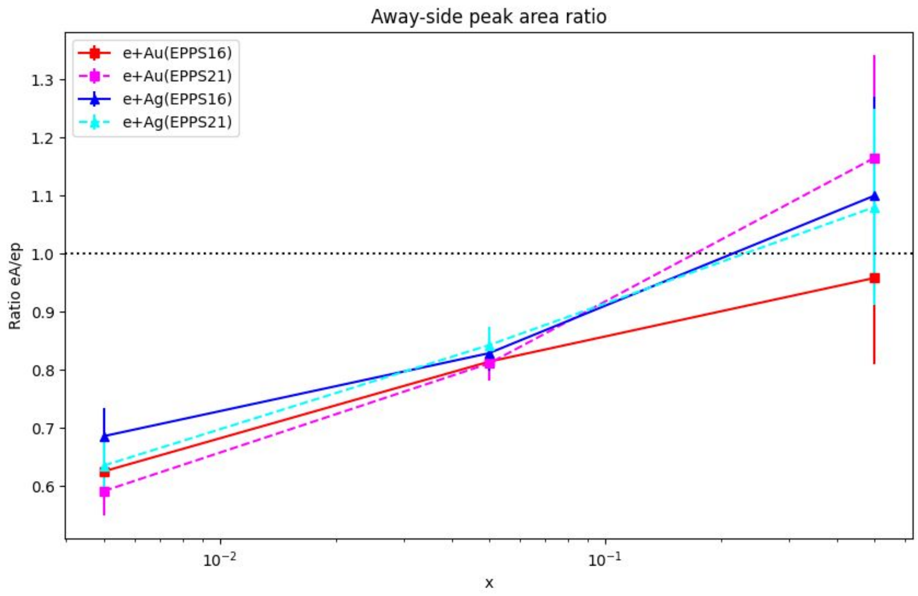
- Suppression of away-side peak observed in e+A *vs* e+p
- Lower x more suppressed
- Difference between Ag and Au reflects nuclear size dependence
- EPPS16 *vs* EPPS21: results consistent within uncertainties







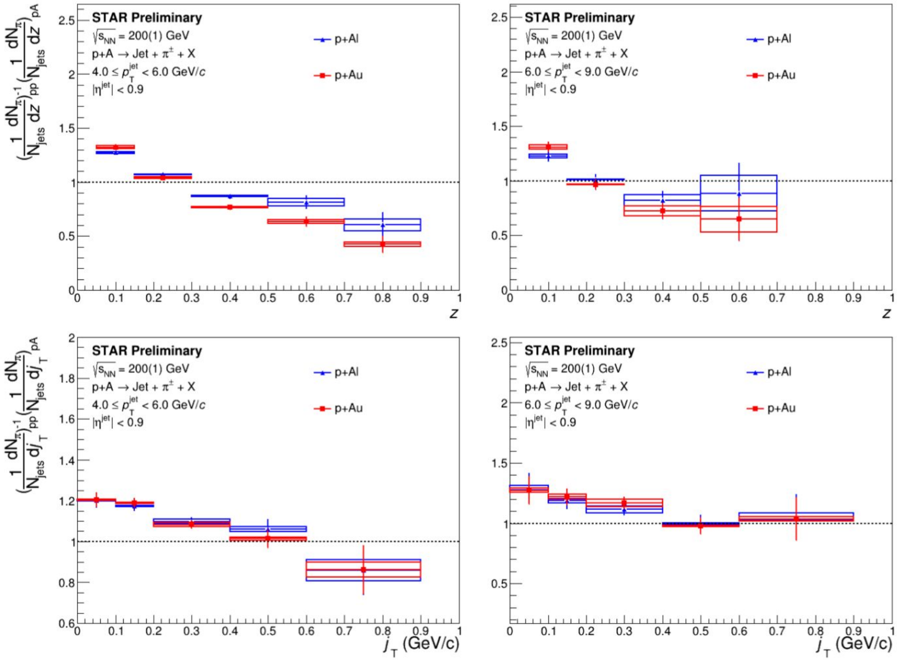
Results: Away-side area



- ❖ Clear away-side suppression in e+A compared to e+p and x dependence
- ❖ Suppression stronger for heavier nuclei

Effect of nuclear Fragmentation Functions

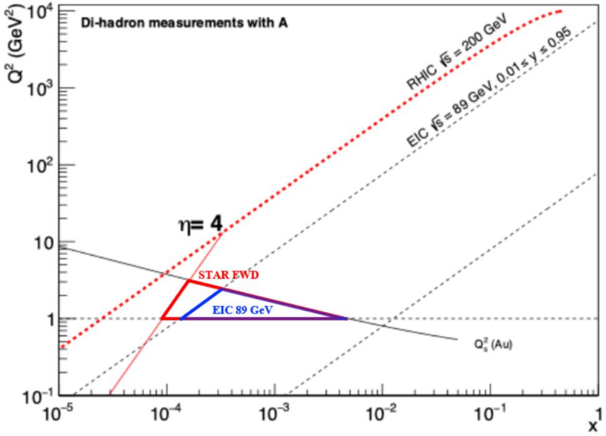
- ❖ Nuclear modification of FF observed in STAR
- ❖ Saturation calculations only used vacuum FF
- ❖ FF can have significant impact in observables that probe saturation



https://agenda.infn.it/event/47074/contributions/289307/attachments/149446/228516/GabrielGarcia_DIS2026_v4.pdf

Conclusion and next steps

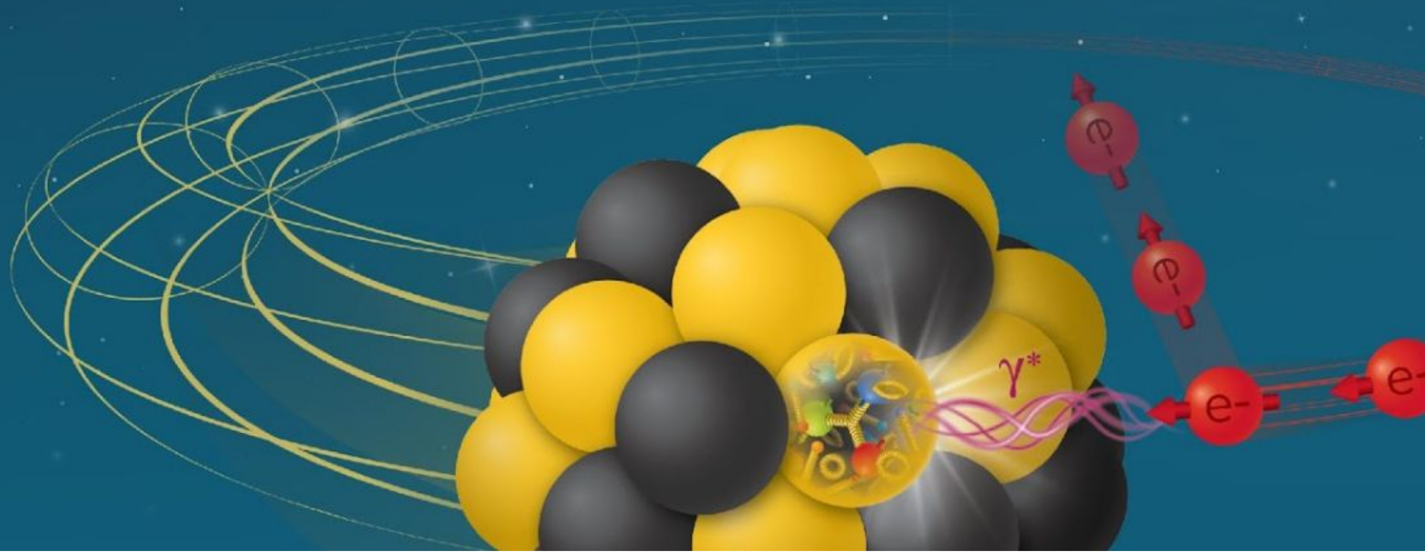
- ❖ We have developed a method that can be used to study observables accounting for saturation processes
- ❖ Dihadron correlations are a clean and sensitive probe of gluon saturation at the EIC
- ❖ This analysis predicts away-side suppression in e+A *vs* e+p
- ❖ Results qualitatively connect STAR p+A observations to futur EIC measurements



Work in progress:

- ❖ Sea quark saturation contribution
- ❖ LHAPDF6 + BeAGLE→ Introduce final state nuclear effects
- ❖ Detector effects

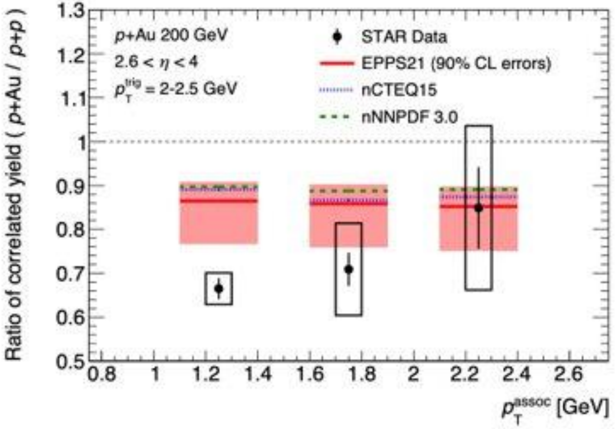
Thank you!



BKP

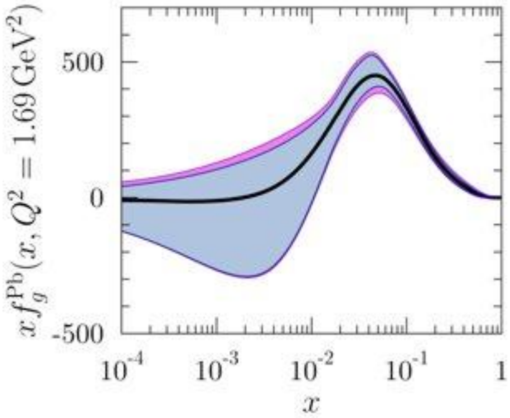
nPDF at small Q^2

D. Perepelitsa, PRC 111 (2025), 054901



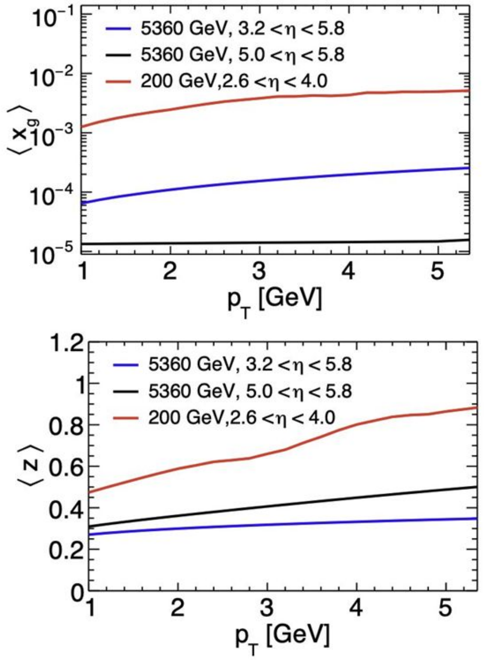
- No p_T dependence, overshoot low p_T data
- The vanishing gluon density at small Q^2 is used

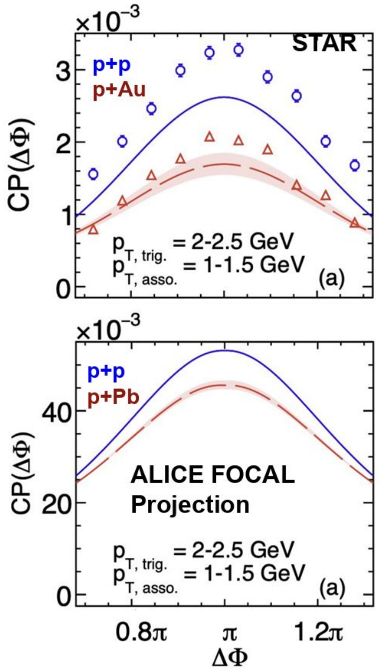
K. Eskola et al., EPJC 82 (2022) 413



- Gluon density is 0 with largely negative error

z impact in $C(\Delta\phi)$





https://arxiv.org/abs/2512.21466 (2025)