Probing gluon saturation with dihadron correlations

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ePIC and EIC Physics
Readiness Workshop
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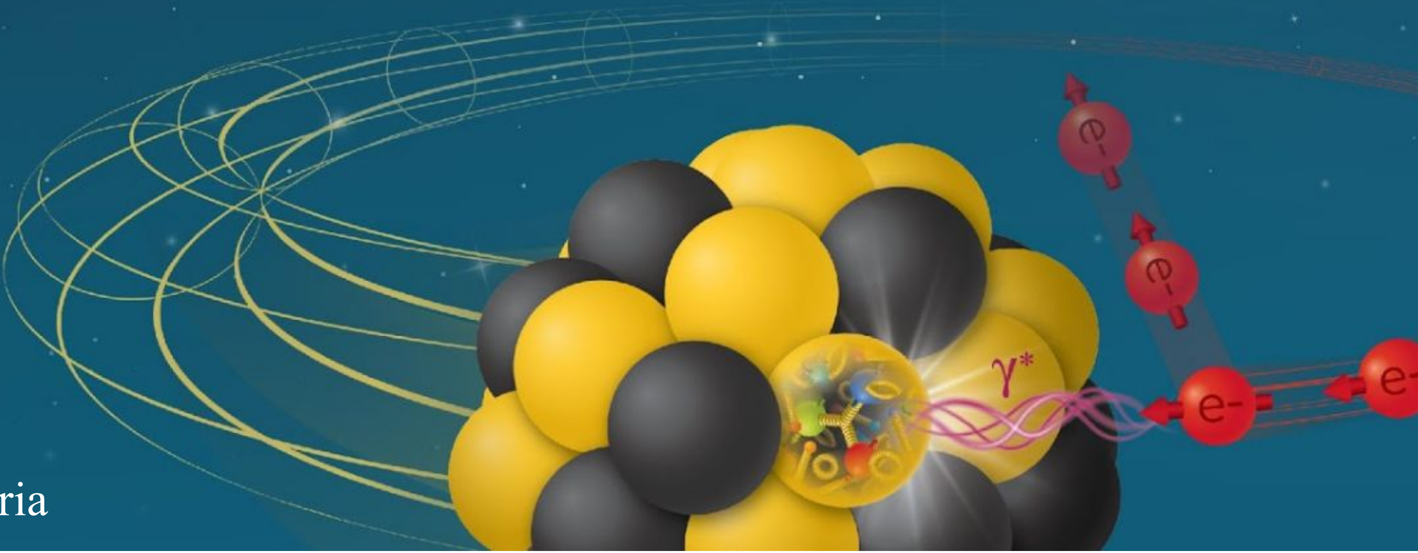

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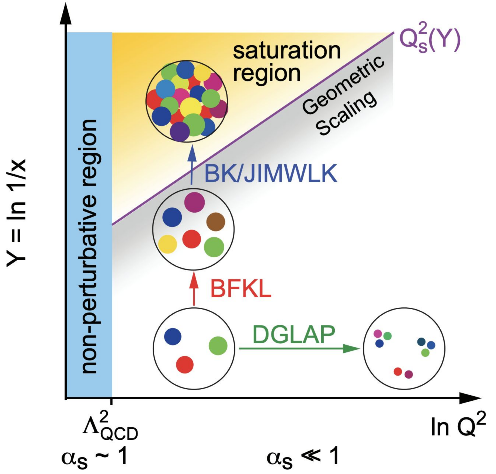
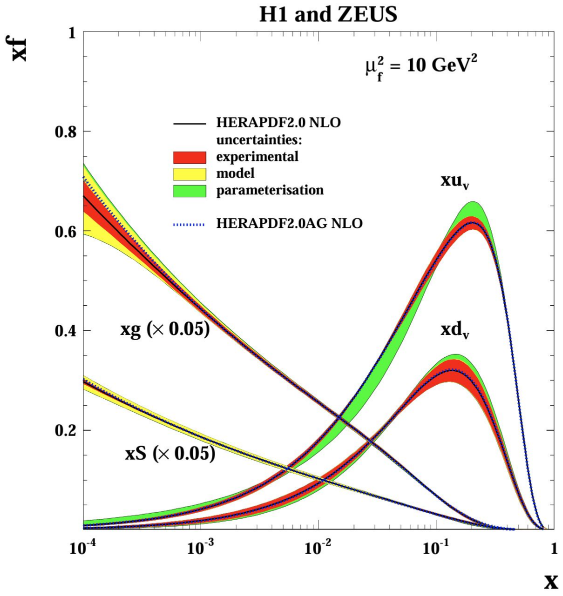
Summary

- Motivation
  - Gluon Saturation
- Observable
  - Dihadron correlation
  - STAR measurement and A dependence
- Analysis setup
  - Simulation
  - Saturation effect on correlation
  - Dihadron correlation
- Analysis results
- Next steps

Motivation: Gluon Saturation

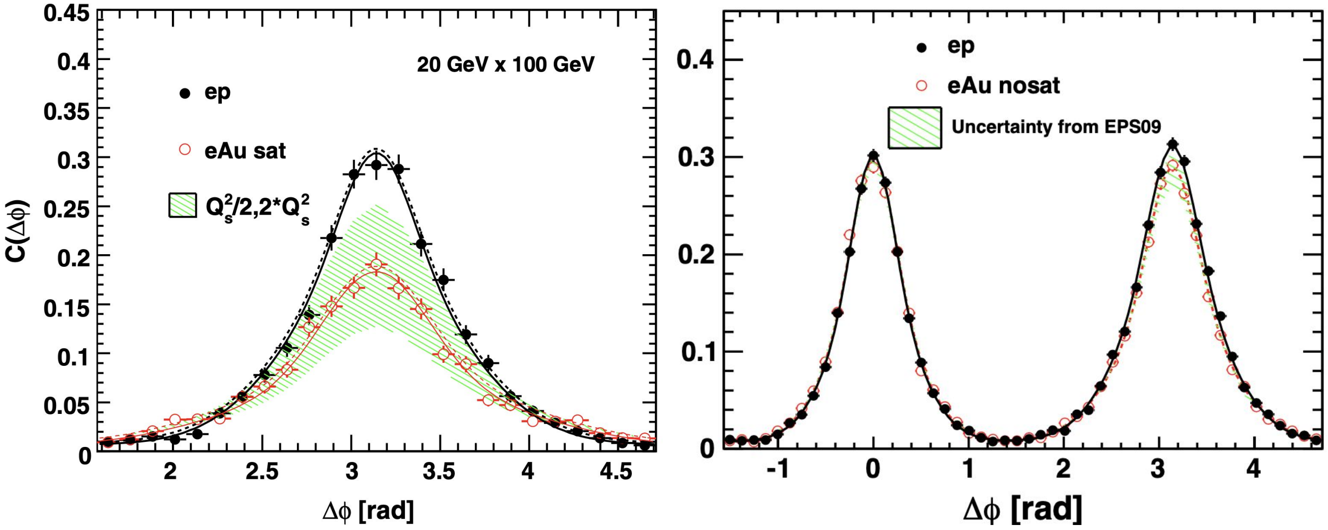
- At small-*x*, gluon density grows rapidly
- Nonlinear effects (gluon recombination) become relevant
- Saturation scale $Q_s^{\,2} \sim A^{1/3}$





Observable: Dihadron correlation

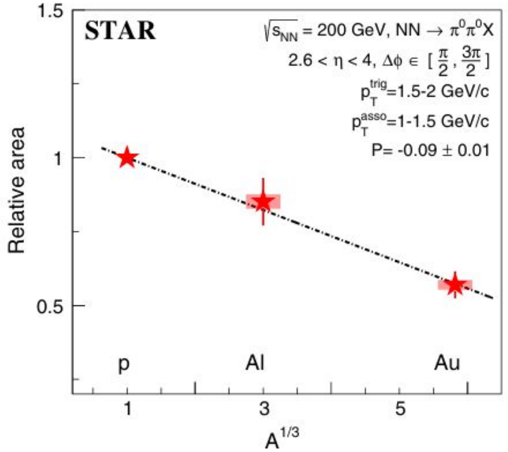
- Dihadron correlation is a key observable in saturation physics
- Gluons carrying k_T at a scale of $Q_s > Q \rightarrow$ Smear away side

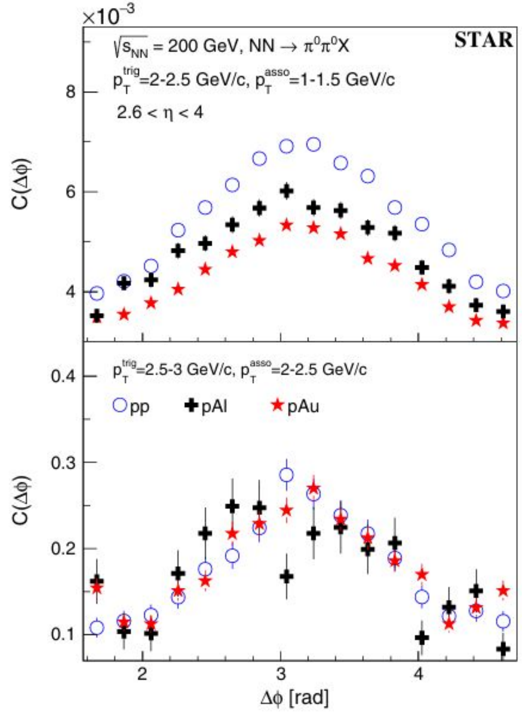


L. Zheng, E.C. Aschenauer, J.H. Lee, Bo-Wen Xiao, Phys. Rev. D 89, 074037 (2014)

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 from April 2025 workshop

  https://indico.cfnssbu.physics.sunysb.edu/event/410

	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

Note: the eA luminosity is per nucleon

- 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

Analysis setup: Simulation

- 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

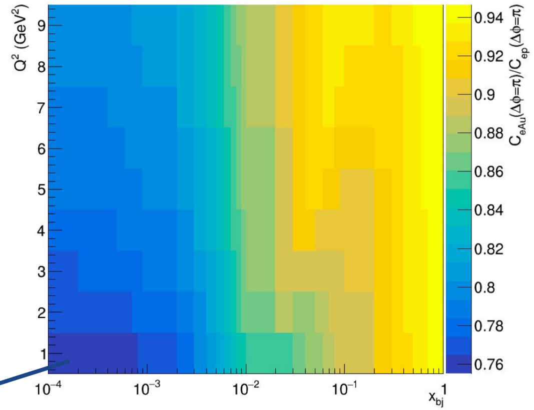
    https://arxiv.org/pdf/1612.05741, https://arxiv.org/pdf/2112.12462

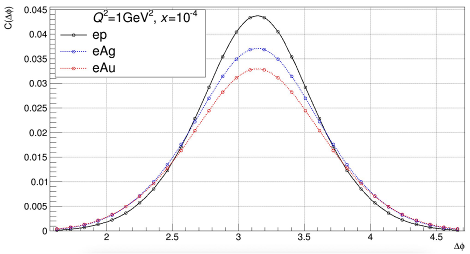
Analysis setup: Saturation effect on correlation

- ❖ Coincidence probability calculated within the saturation formalism

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

- ❖ Fixed parameters:
  - ➢ $z_{\mathrm{h1,h2}} = 0.3$
- ❖ $w_A(\Delta\phi) = \frac{C_{eA}(\Delta\phi)}{C_{ep}(\Delta\phi)}$
- ❖ **Weight is calculated across phase space and applied event by event**

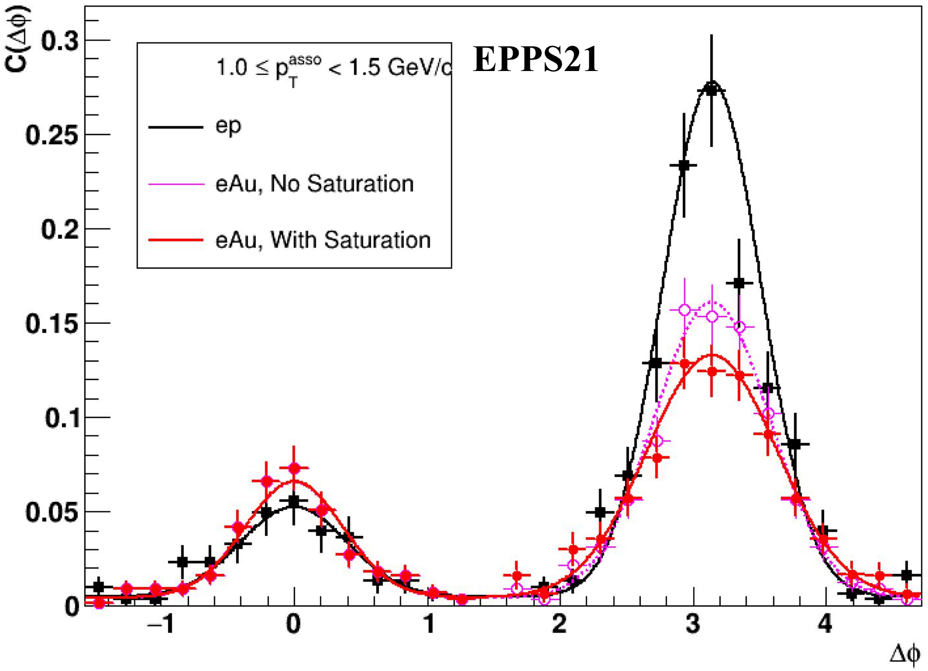




L. Zheng, E.C. Aschenauer, J.H. Lee, Bo-Wen Xiao, Phys. Rev. D 89, 074037 (2014)

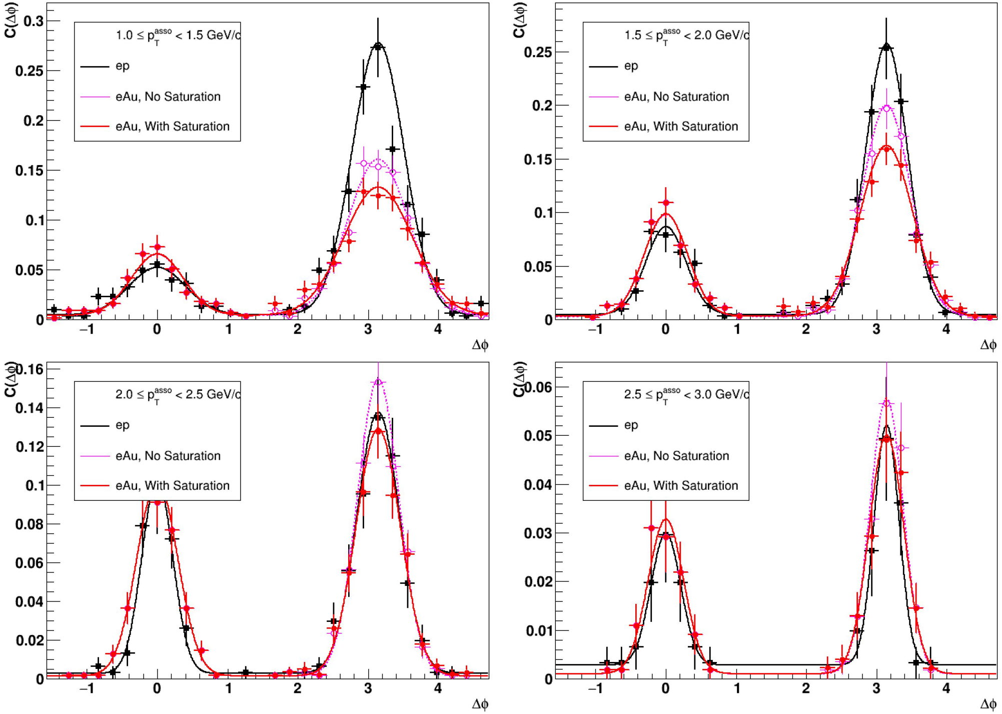
Analysis setup: Dihadron correlation

- Events initiated with gluon involving processes (e.g. PGF) have it's dihadron correlation weighted by $w_A(\Delta\phi)$
- Analysis parameters:
  - $|\eta| < 4.5$ (ePIC)
  - $1 < Q^2 < 9$ GeV^2
  - $10^{-4} < x < 10^{-3}$
  - $0.2 < z_{h1,h2} < 0.4$
  - $2.5 < p_T^{trig} < 3.0$ GeV/c
  - p_T^{asso} bins: 1.0-1.5, 1.5-2.0, 2.0-2.5, 2.5-3.0 GeV/c



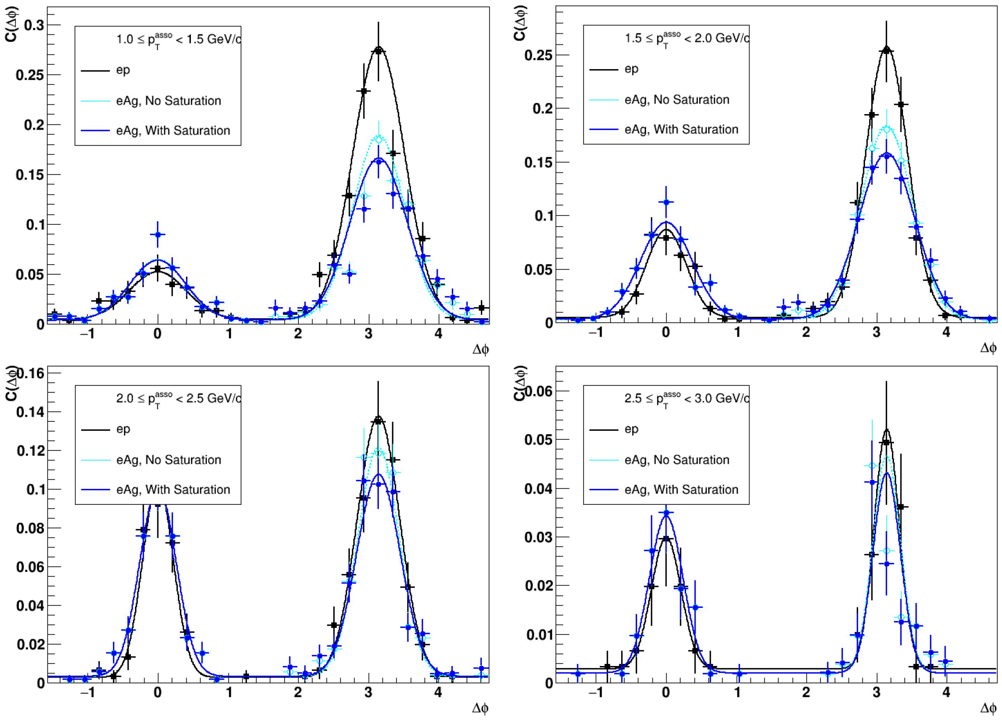
Analysis results: e+Au (EPPS21)

- Suppression of away-side peak observed in e+A *vs* e+p
- Effect decreases with associated hadron p_T
- Away-side area **suppression ~40%** in lowest p_T^{assoc} bin of e+Au (EPPS21) relative to e+p



Analysis results: e+Ag (EPPS21)

- Suppression of away-side peak observed in e+A *vs* e+p
- Effect decreases with associated hadron p_T
- Difference between Ag and Au reflects nuclear size dependence



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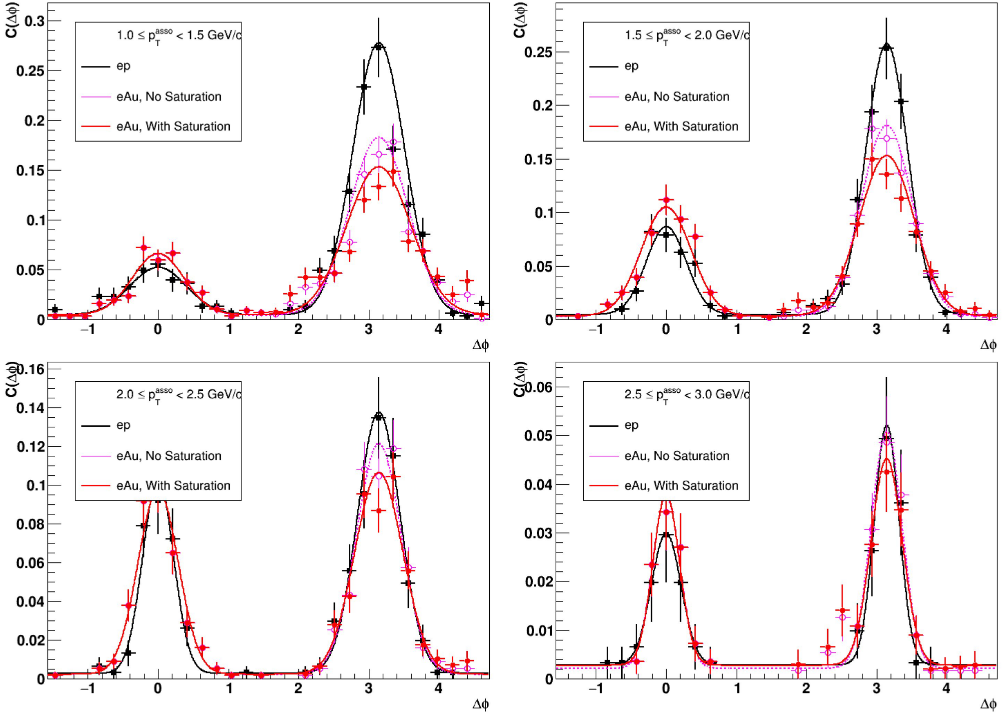
- Difference between Ag and Au reflects nuclear size dependence
- EPPS16 *vs* EPPS21: results consistent within uncertainties



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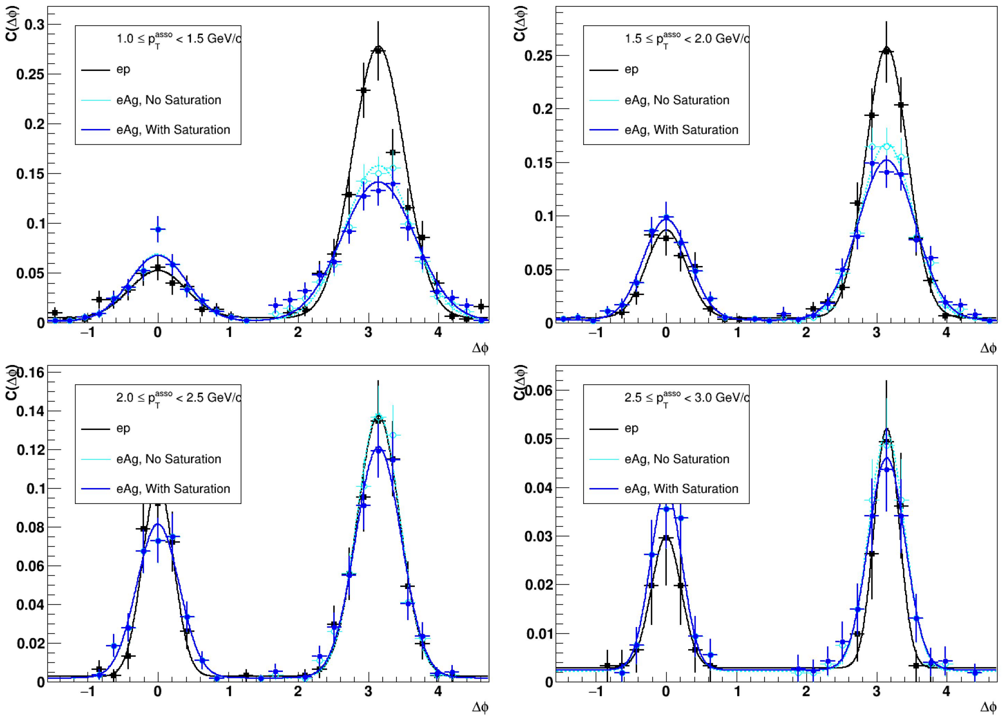
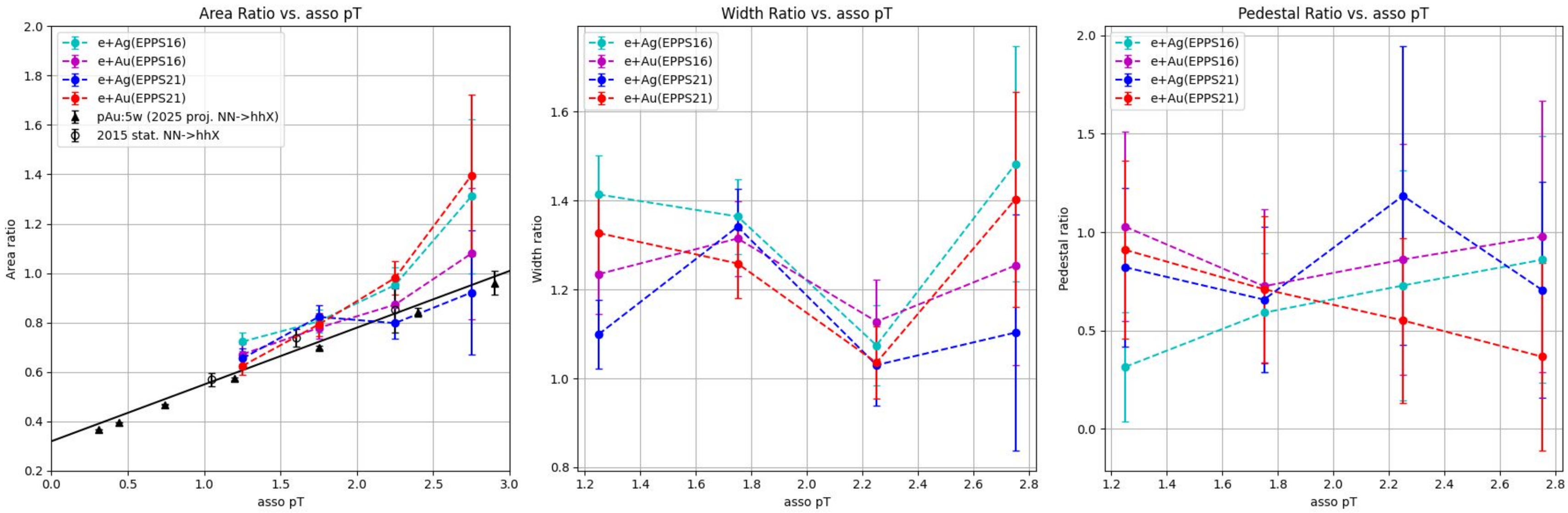


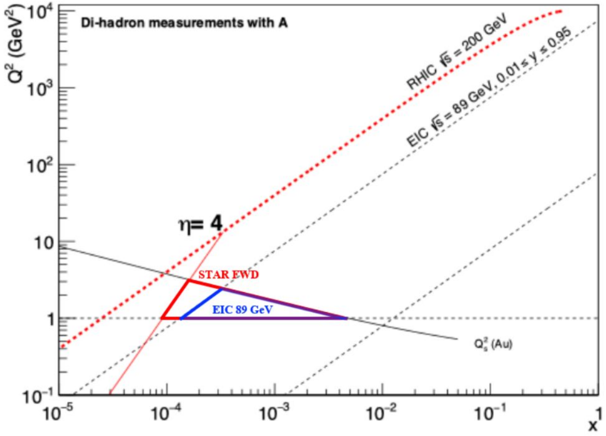
Analysis results



- ❖ Clear away-side suppression in e+A compared to e+p
- ❖ Suppression stronger for heavier nuclei
- ❖ Qualitative agreement with STAR p+A results

Conclusion and next steps

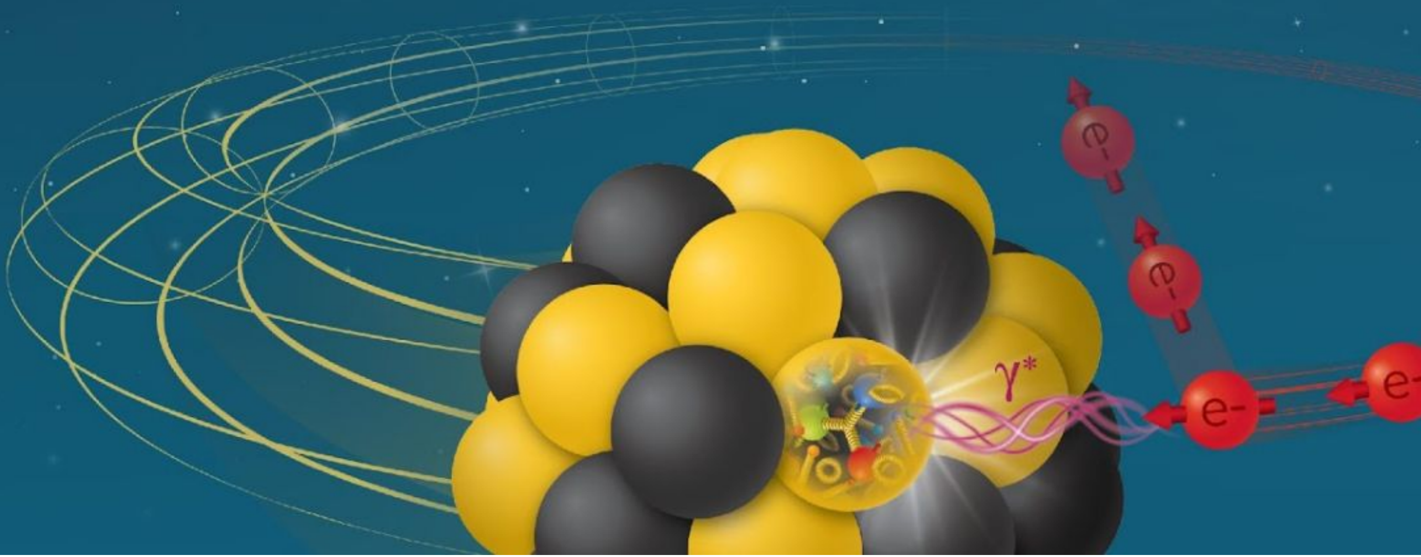
- Dihadron correlations are a clean and sensitive probe of gluon saturation at the EIC
- This analysis predicts away-side suppression in e+A vs e+p
- Results qualitatively connect STAR p+A observations to future EIC measurements



Work in progress:

- Sea quark saturation contribution
- LHAPDF6 + BeAGLE

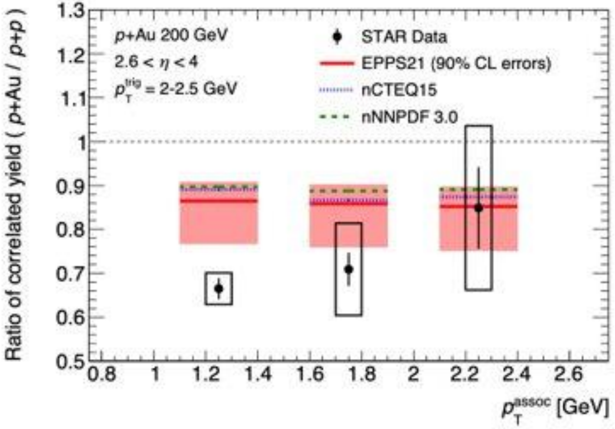
Thank you!



BKP

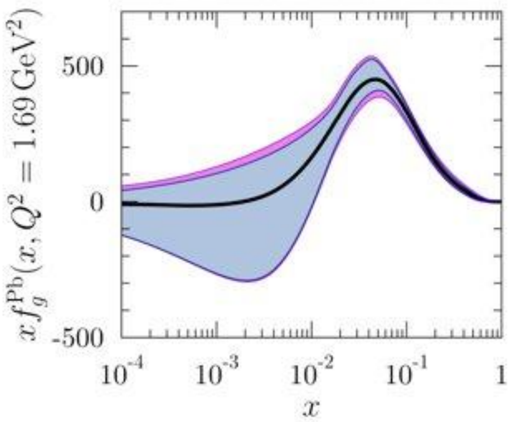
nPDF at small Q^2

D. Perepelitsa, PRC 111 (2025), 054901

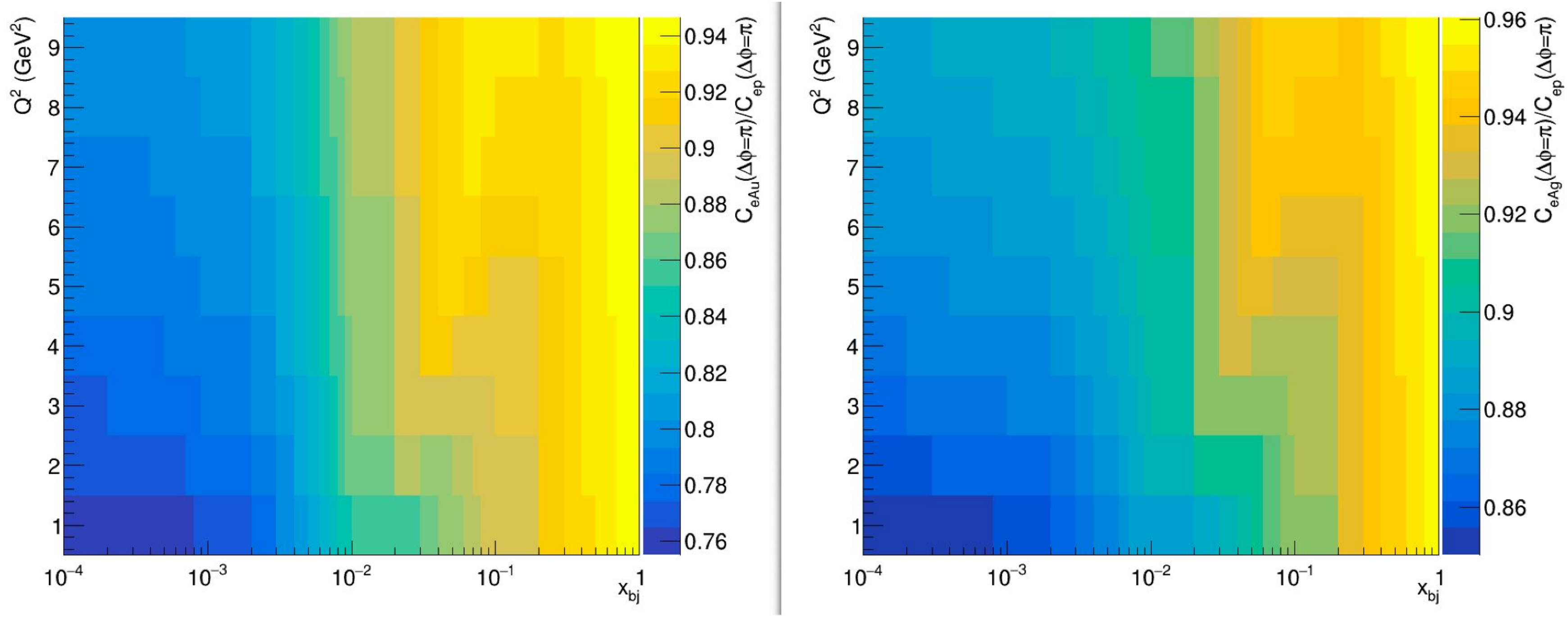


- No p_T dependence, overshoot low p_T data
- The vanishing gluon density at small Q^2 is used

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



- Gluon density is 0 with largely negative error



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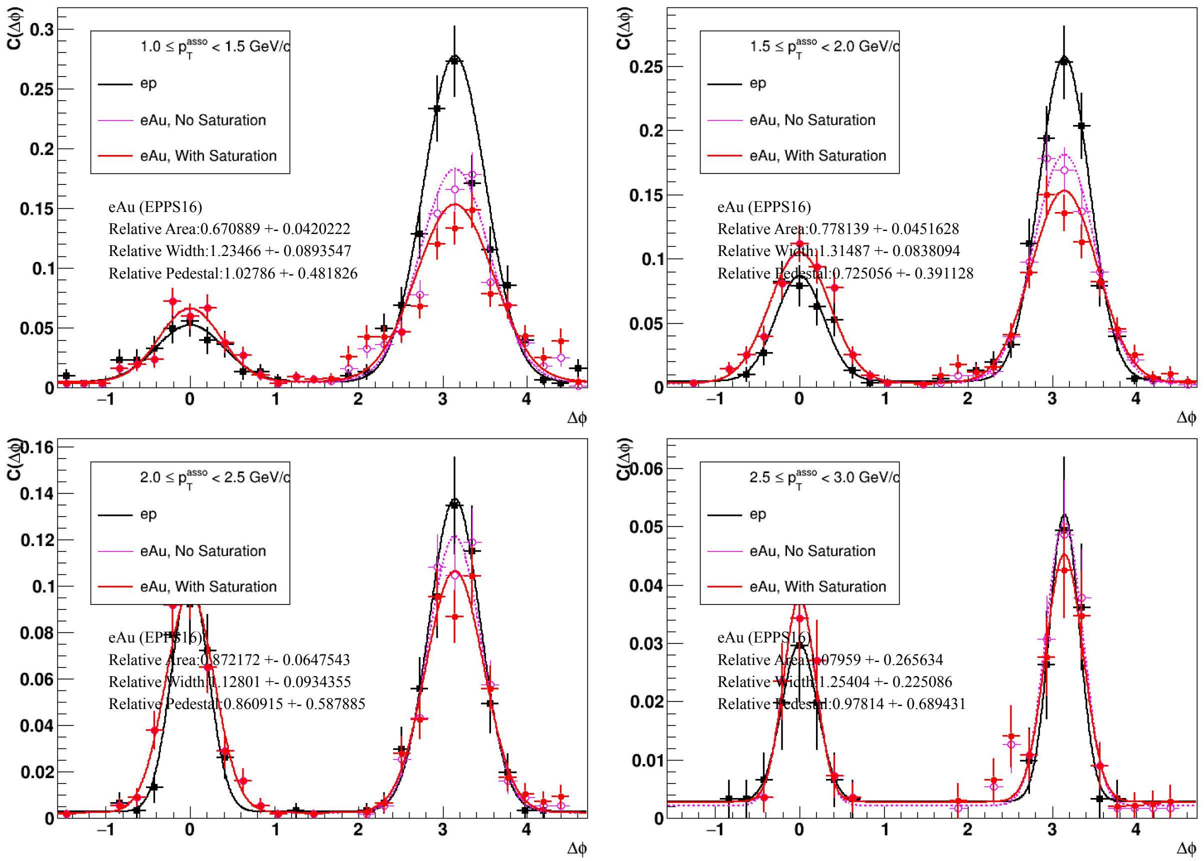
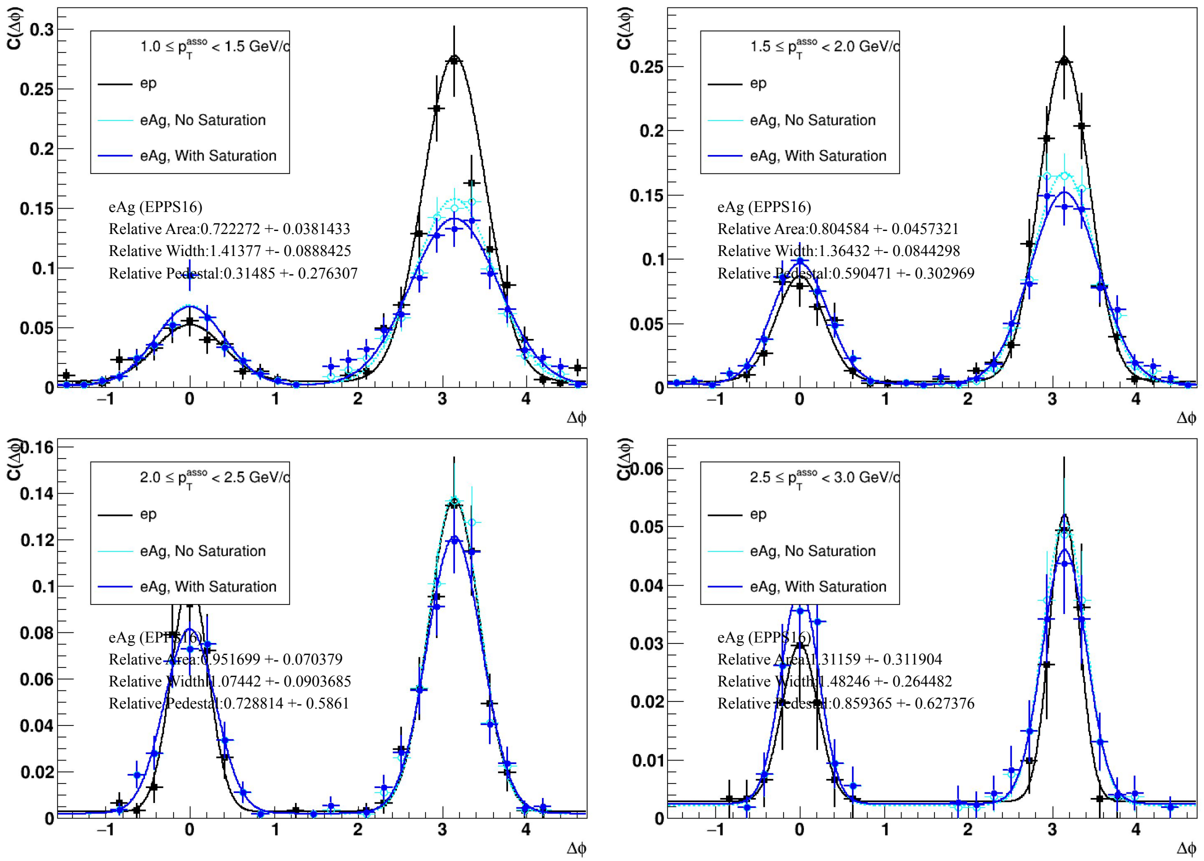
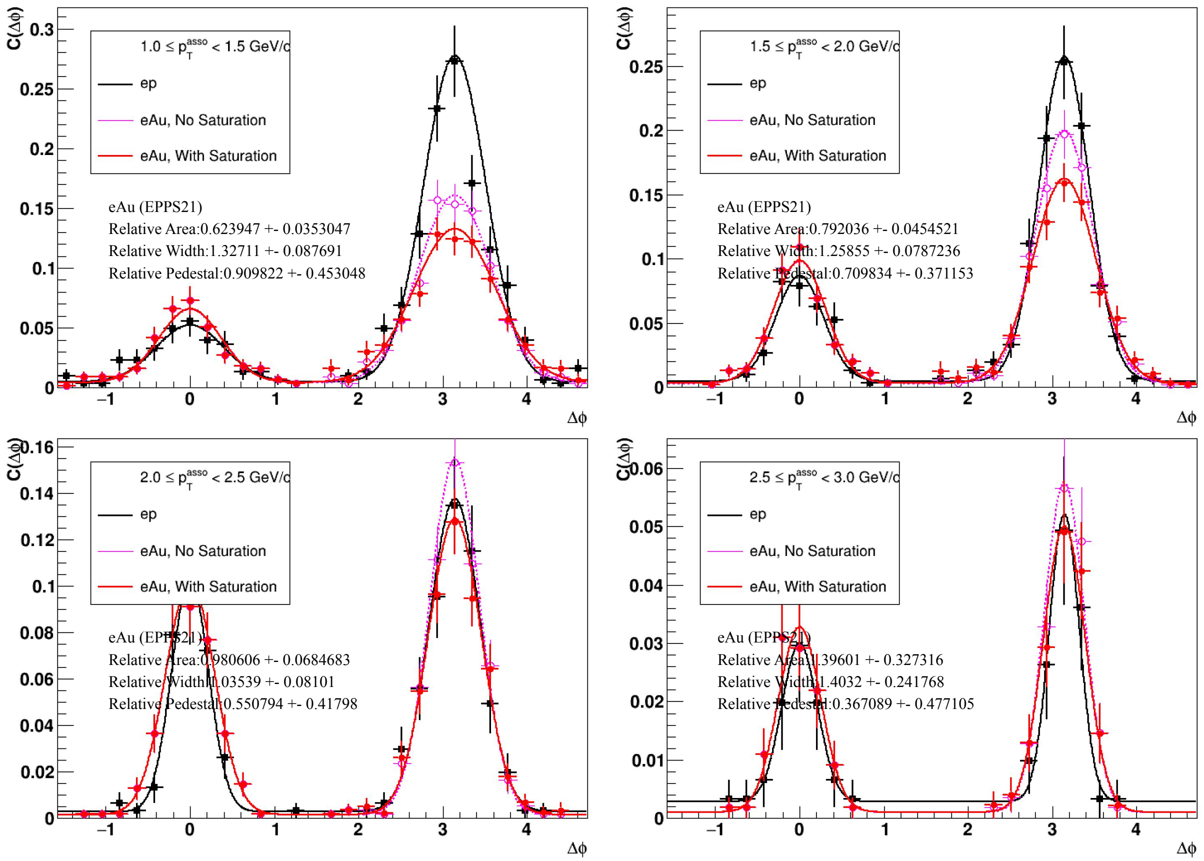


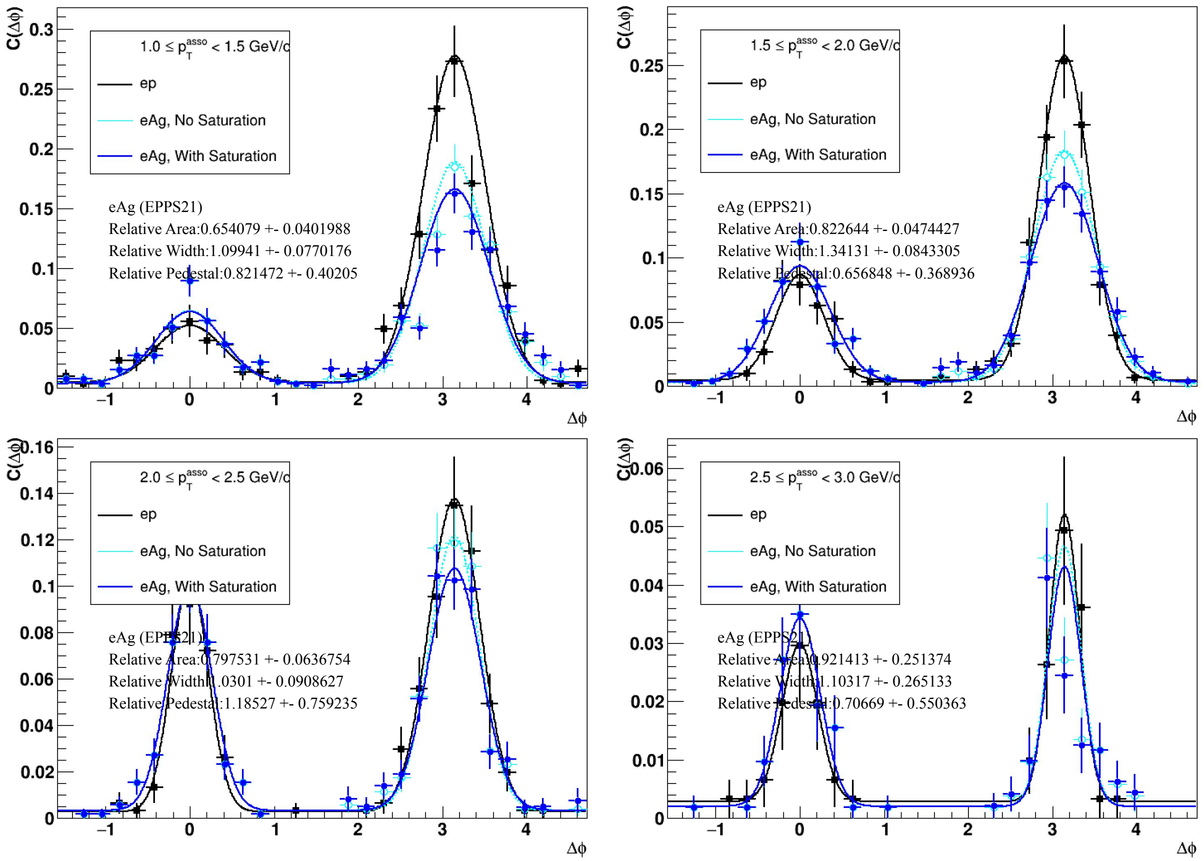
$1.0 \leq p_T^{asso} < 1.5$ GeV/c
ep
eAu, No Saturation
eAu, With Saturation
eAu (EPPS16)
Relative Area:0.670889 +- 0.0420222
Relative Width:1.23466 +- 0.0893547
Relative Pedestal:1.02786 +- 0.481826
$1.5 \leq p_T^{asso} < 2.0$ GeV/c
ep
eAu, No Saturation
eAu, With Saturation
eAu (EPPS16)
Relative Area:0.778139 +- 0.0451628
Relative Width:1.31487 +- 0.0838094
Relative Pedestal:0.725056 +- 0.391128
$2.0 \leq p_T^{asso} < 2.5$ GeV/c
ep
eAu, No Saturation
eAu, With Saturation
eAu (EPPS16)
Relative Area:0.872172 +- 0.0647543
Relative Width:1.12801 +- 0.0934355
Relative Pedestal:0.860915 +- 0.587885
$2.5 \leq p_T^{asso} < 3.0$ GeV/c
ep
eAu, No Saturation
eAu, With Saturation
eAu (EPPS16)
Relative Area:1.07959 +- 0.265634
Relative Width:1.25404 +- 0.225086
Relative Pedestal:0.97814 +- 0.689431
C(Δφ)
Δφ



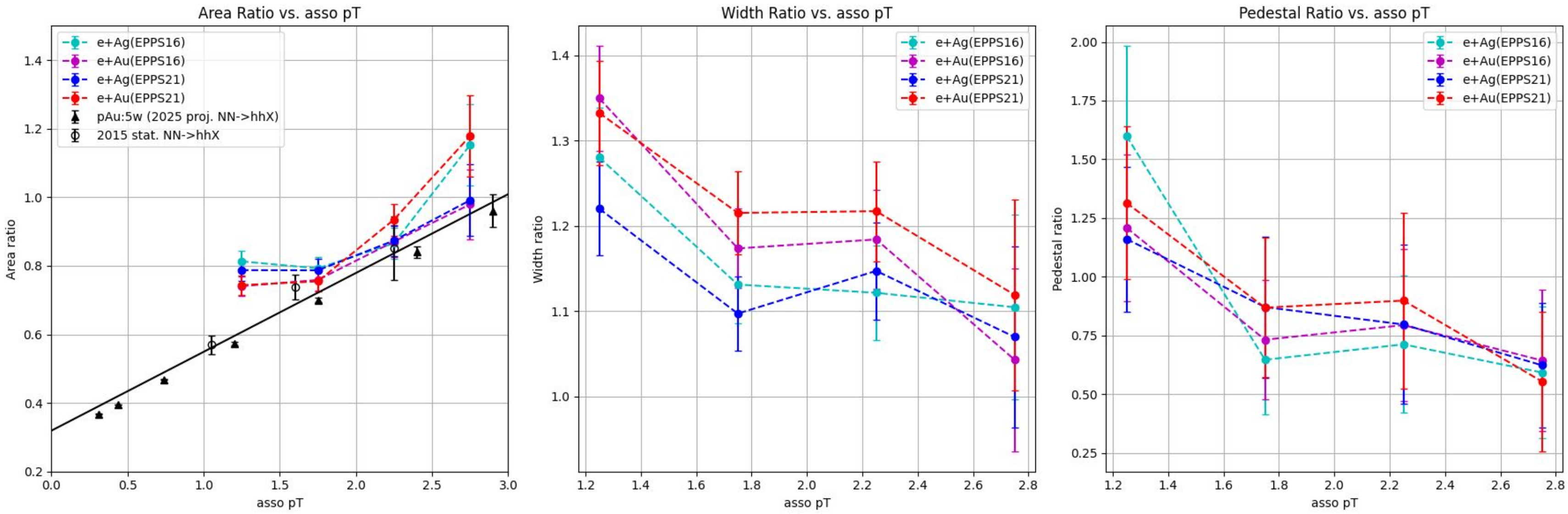
C(Δϕ)
Δϕ
1.0 ≤ p_T^asso < 1.5 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS16)
Relative Area:0.722272 +- 0.0381433
Relative Width:1.41377 +- 0.0888425
Relative Pedestal:0.31485 +- 0.276307
1.5 ≤ p_T^asso < 2.0 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS16)
Relative Area:0.804584 +- 0.0457321
Relative Width:1.36432 +- 0.0844298
Relative Pedestal:0.590471 +- 0.302969
2.0 ≤ p_T^asso < 2.5 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
Relative Area:0.951699 +- 0.070379
Relative Width:1.07442 +- 0.0903685
Relative Pedestal:0.728814 +- 0.5861
2.5 ≤ p_T^asso < 3.0 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
Relative Pedestal:0.859365 +- 0.627376



1.0 ≤ p_T^asso < 1.5 GeV/c
ep
eAu, No Saturation
eAu, With Saturation
eAu (EPPS21)
Relative Area:0.623947 +- 0.0353047
Relative Width:1.32711 +- 0.087691
Relative Pedestal:0.909822 +- 0.453048
1.5 ≤ p_T^asso < 2.0 GeV/c
eAu (EPPS21)
Relative Area:0.792036 +- 0.0454521
Relative Width:1.25855 +- 0.0787236
Relative Pedestal:0.709834 +- 0.371153
2.0 ≤ p_T^asso < 2.5 GeV/c
eAu (EPPS21)
Relative Area:0.980606 +- 0.0684683
Relative Width:1.03539 +- 0.08101
Relative Pedestal:0.550794 +- 0.41798
2.5 ≤ p_T^asso < 3.0 GeV/c
eAu (EPPS21)
Relative Area:1.39601 +- 0.327316
Relative Width:1.4032 +- 0.241768
Relative Pedestal:0.367089 +- 0.477105
C(Δφ)
Δφ


C(Δϕ)
Δϕ
1.0 ≤ p_T^asso < 1.5 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS21)
Relative Area:0.654079 +- 0.0401988
Relative Width:1.09941 +- 0.0770176
Relative Pedestal:0.821472 +- 0.40205
1.5 ≤ p_T^asso < 2.0 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS21)
Relative Area:0.822644 +- 0.0474427
Relative Width:1.34131 +- 0.0843305
Relative Pedestal:0.656848 +- 0.368936
2.0 ≤ p_T^asso < 2.5 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS21)
Relative Area:0.797531 +- 0.0636754
Relative Width:1.0301 +- 0.0908627
Relative Pedestal:1.18527 +- 0.759235
2.5 ≤ p_T^asso < 3.0 GeV/c
ep
eAg, No Saturation
eAg, With Saturation
eAg (EPPS21)
Relative Area:0.921413 +- 0.251374
Relative Width:1.10317 +- 0.265133
Relative Pedestal:0.70669 +- 0.550363

Analysis results: EIC Readiness London



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