Back-to-back di-π^0 correlations at STAR

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(For the STAR Collaboration)

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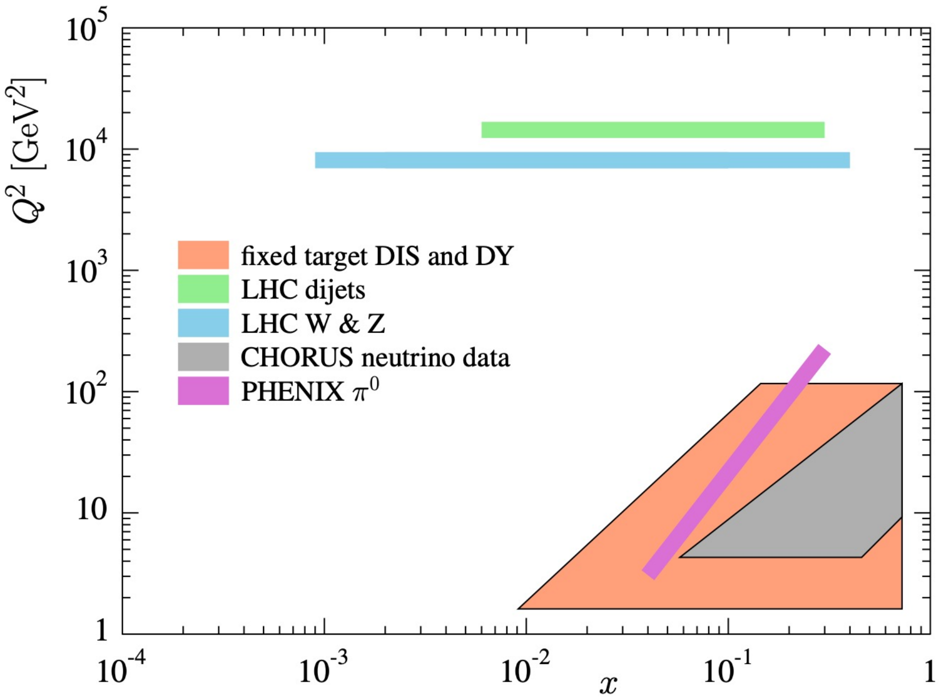
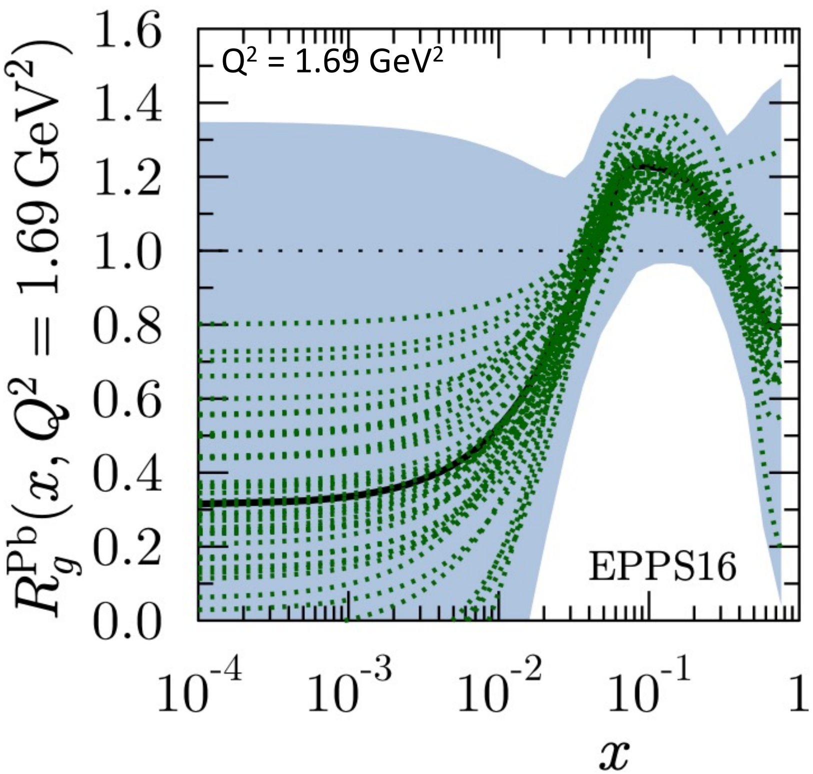
Supported by

Current knowledge of nPDFs

K. Eskola et al., EPJC 77, 163 (2017)



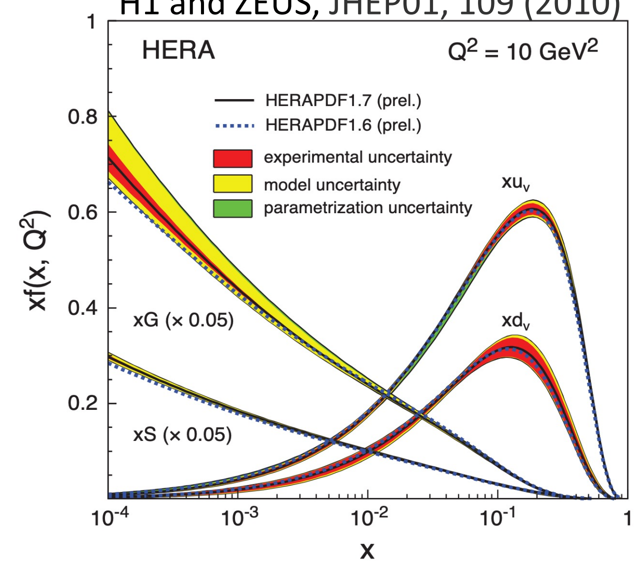


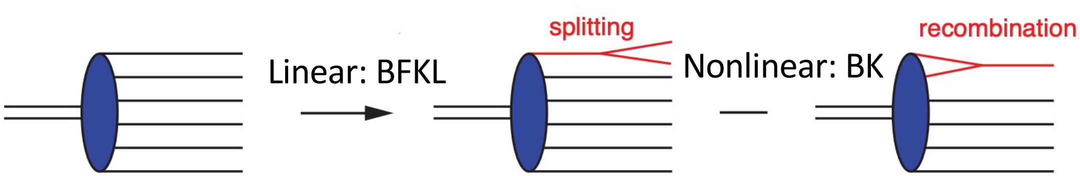
- EPPS16: nuclear gluon distributions have large uncertainties at small x and low Q^2
- RHIC data can probe small x and low/moderate Q^2 where cold nuclear matter (CNM) effect is expected to be strong

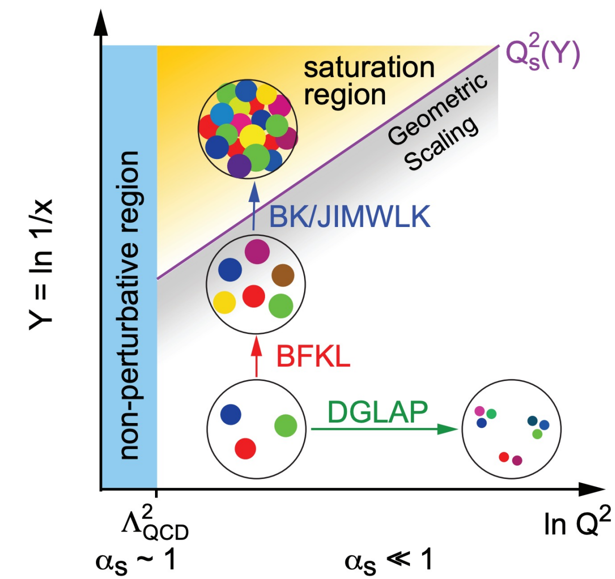
Gluon dynamics at small x

- At small x, nucleon wave function is dominated by gluons; the rise of gluon density has to stop at some point → saturation
- Saturation scale Q_s^2: when $Q^2 < Q_s^2$, gluon splitting and recombination reach a balance
- Gluon dynamics changes from linear to non-linear: DGLAP/BFKL → BK/JIMWLK
- Large Q: small α_s → perturbative QCD calculations under control

H1 and ZEUS, JHEP01, 109 (2010)





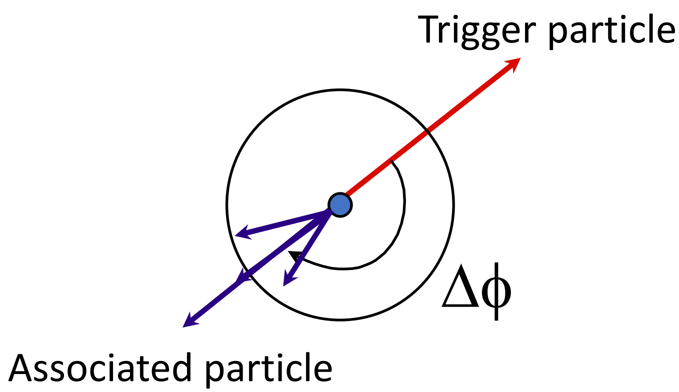


BFKL: $$\frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{\mathrm{BFKL}} \otimes N(x,r_T). \quad N \sim (1/x)^\lambda$$

BK: $$\frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{\mathrm{BFKL}} \otimes N(x,r_T) - \alpha_s [N(x,r_T)]^2$$

Di-hadron production to probe multiple scattering

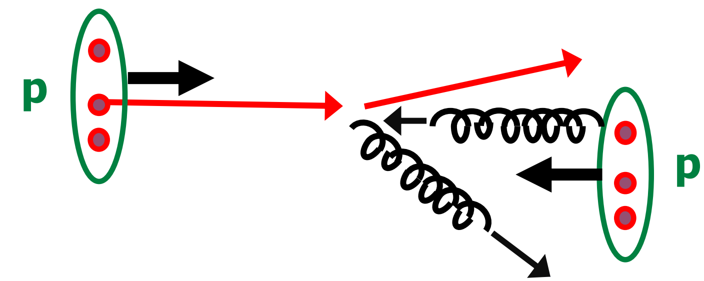
beam-view

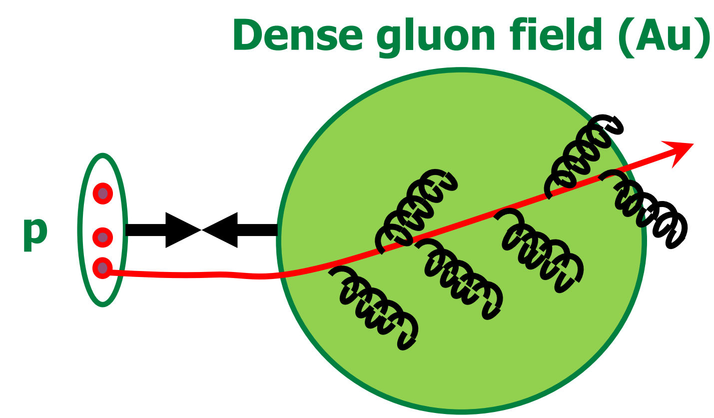


$$C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi}$$

- **Why forward**: two final state particles at forward rapidity provide access to small x regime
- **Method**: measure the azimuthal correlation between two final hadrons in pp and pA
- **pp**: 2→2 process ⇒ back-to-back di-hadron
- **pA**: back-to-back configuration is smeared by multiple gluon interactions

side-view



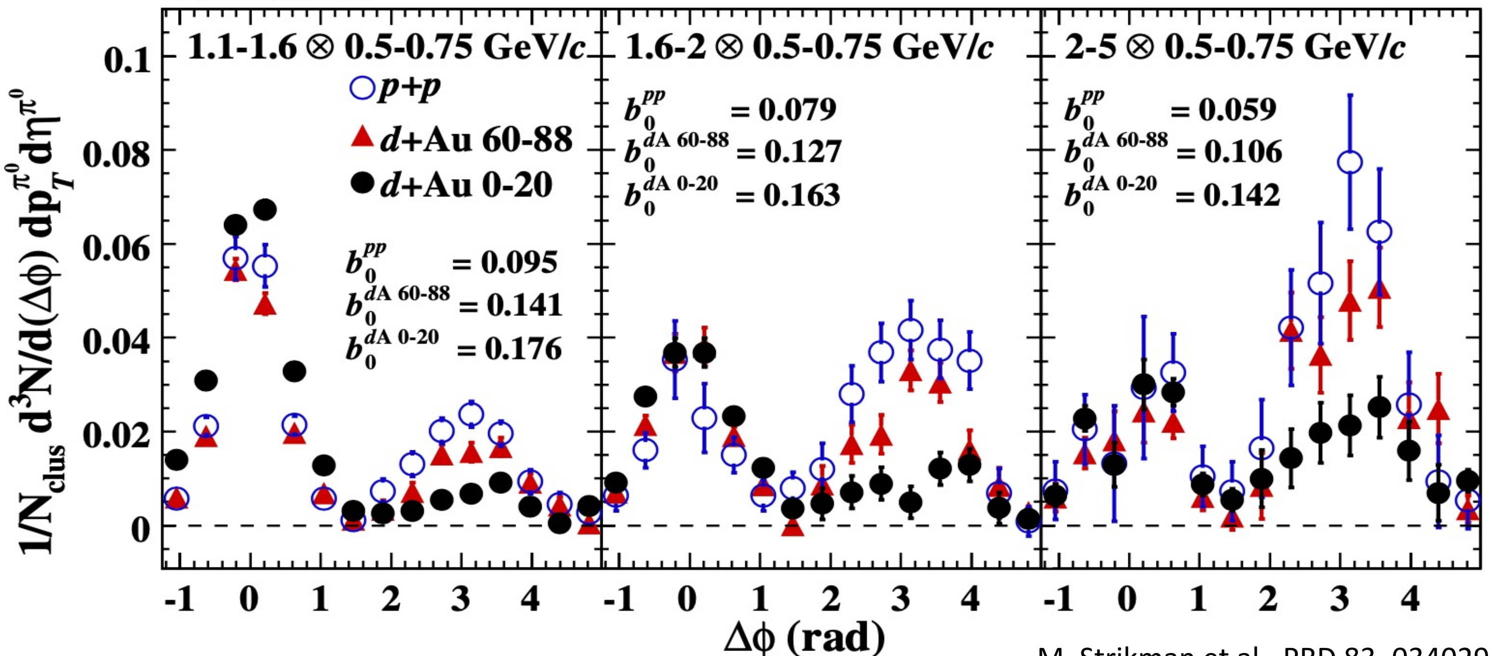


P_T is balanced by many gluons

$$x_p \sim \frac{p_{T1}e^{\eta_1} + p_{T2}e^{\eta_2}}{\sqrt{s}} \gg x_A \sim \frac{p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}}{\sqrt{s}}$$

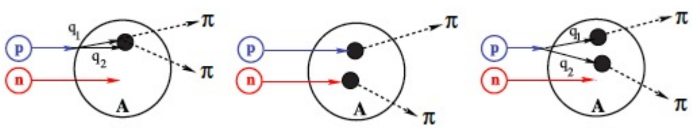
Di-π^0 correlations in dAu

PHENIX p+p/d+Au: 3.0 < η < 3.8 PHENIX Collaboration, PRL 107, 172301 (2011)



M. Strikman et al., PRD 83, 034029 (2011)

Possible contribution from double parton interaction to the cross section? →



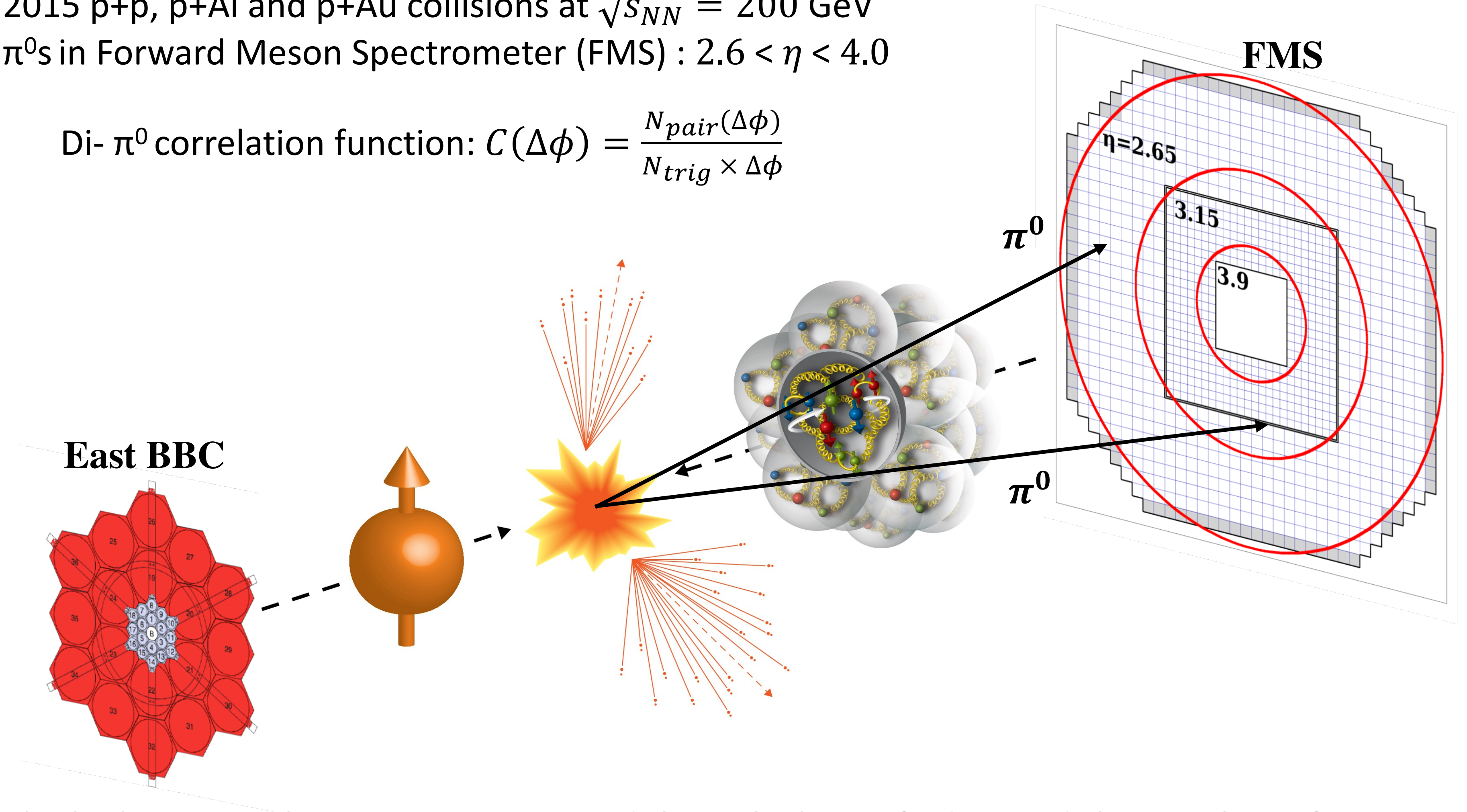
- dAu: interpretation of the suppression complicated by alternative explanation; much higher pedestal in dAu than in pp

→ **pAu collisions are theoretically and experimentally cleaner**

STAR measurement

- 2015 p+p, p+Al and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
- π^0s in Forward Meson Spectrometer (FMS) : $2.6 < \eta < 4.0$

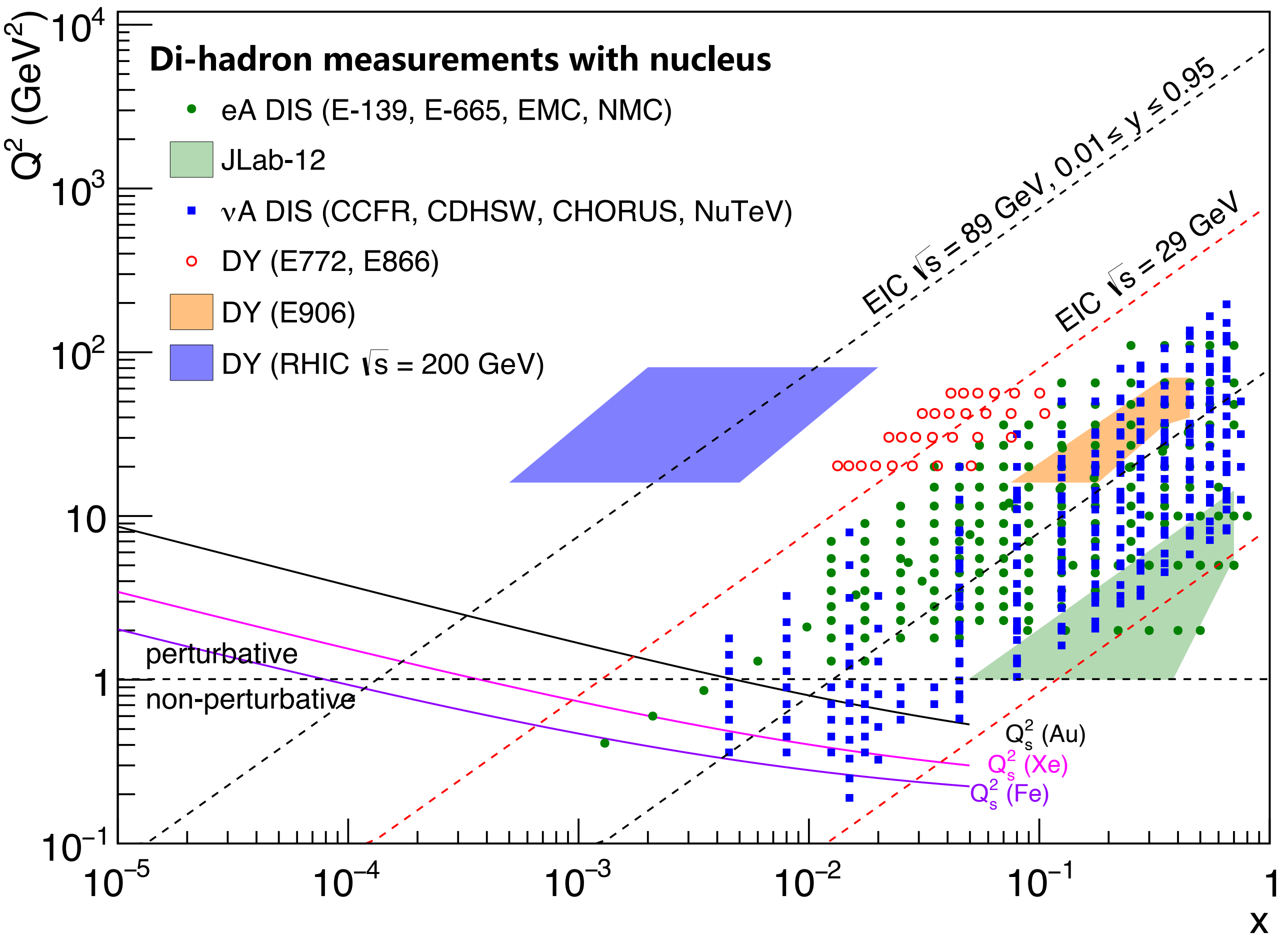
Di- π^0 correlation function: $C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi}$



- The high energy photon is reconstructed through cluster finding and shower shape fitting
- π^0, decaying into two photons, is constructed from a pair of photon candidates

x-Q^2 phase space and Q_s^2

R. Abdul Khalek et al., arXiv:2103.05419

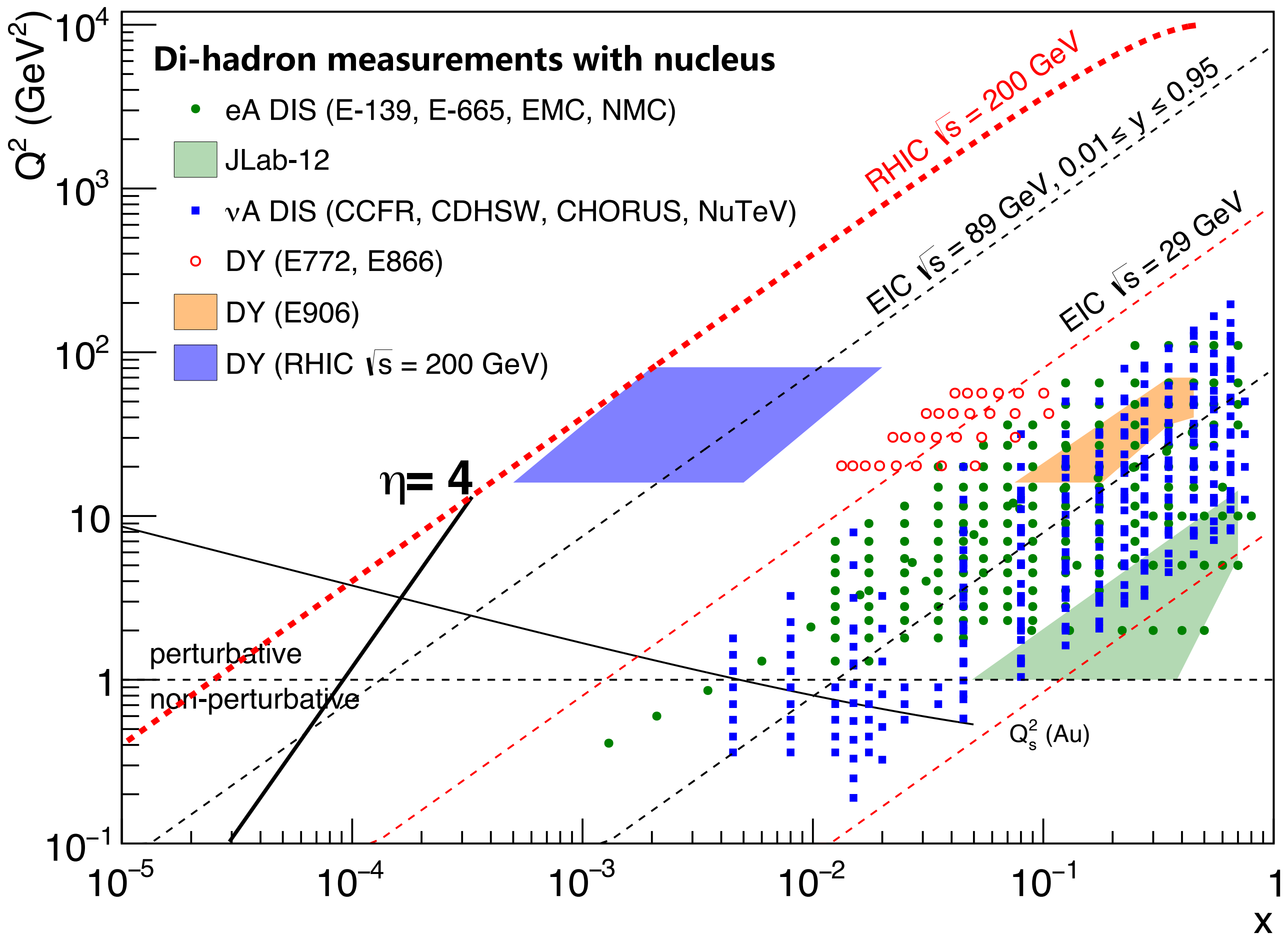


- Saturation scale Q_s: the inverse of transverse distance between partons; grows with A and decreases with x

$$Q_s^2(x) \sim A^{\frac{1}{3}}\left(\frac{1}{x}\right)^{\lambda}$$

x-Q^2 phase space and Q_s^2

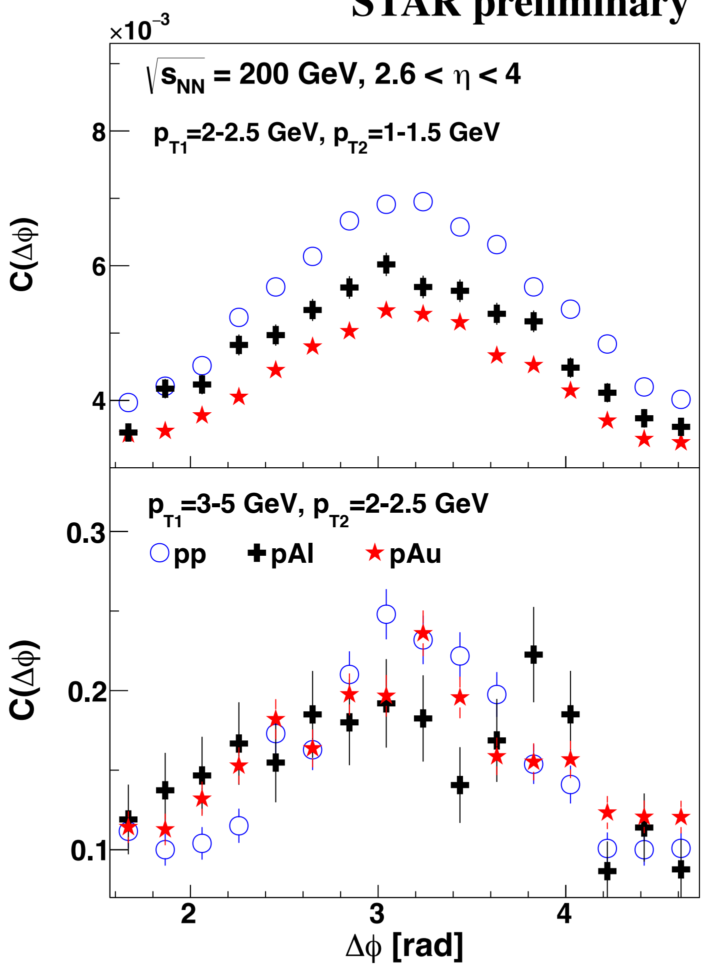
R. Abdul Khalek et al., arXiv:2103.05419

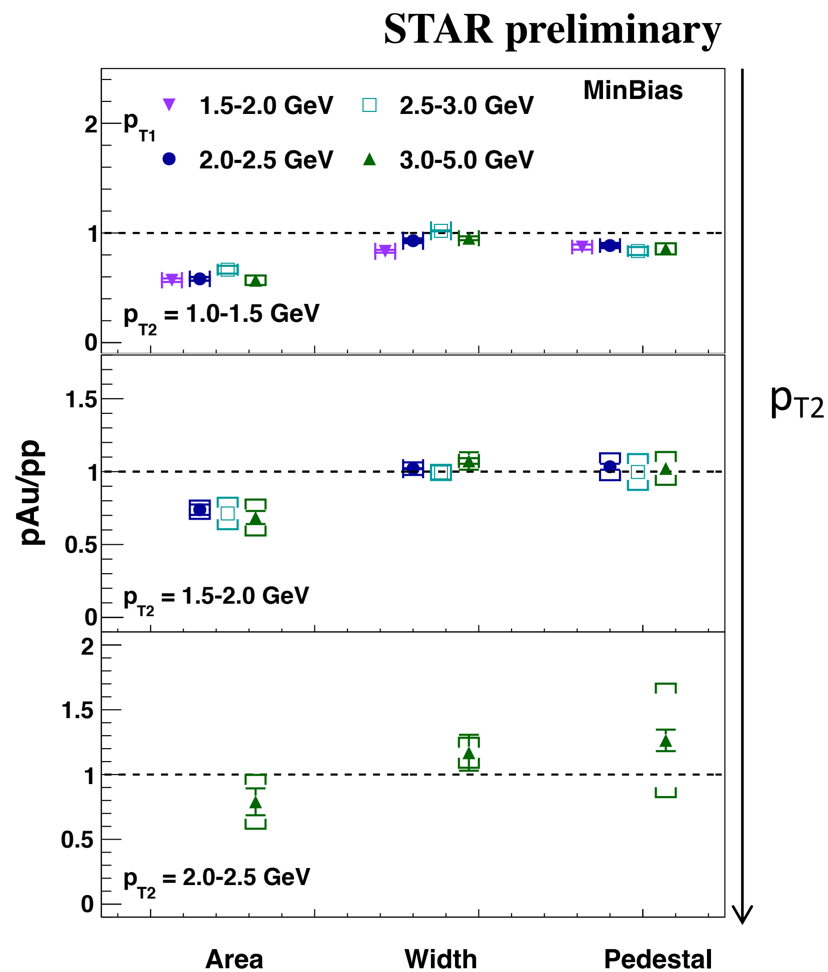


- STAR FMS data ($\sqrt{s_{NN}} = 200$ GeV) can probe the saturation region
- One can study the evolution on x and Q^2 through scanning p_T

Di-π^0 correlations at STAR

Area (integral from $\frac{\pi}{2}$ to $\frac{3\pi}{2}$), Width (σ) and Pedestal from fit

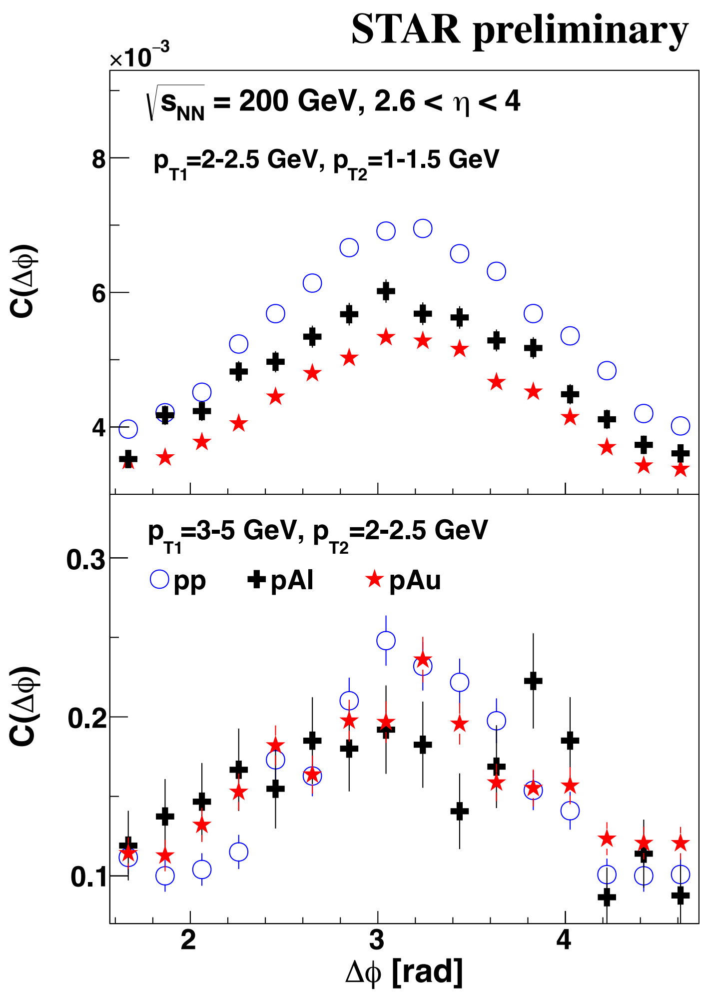


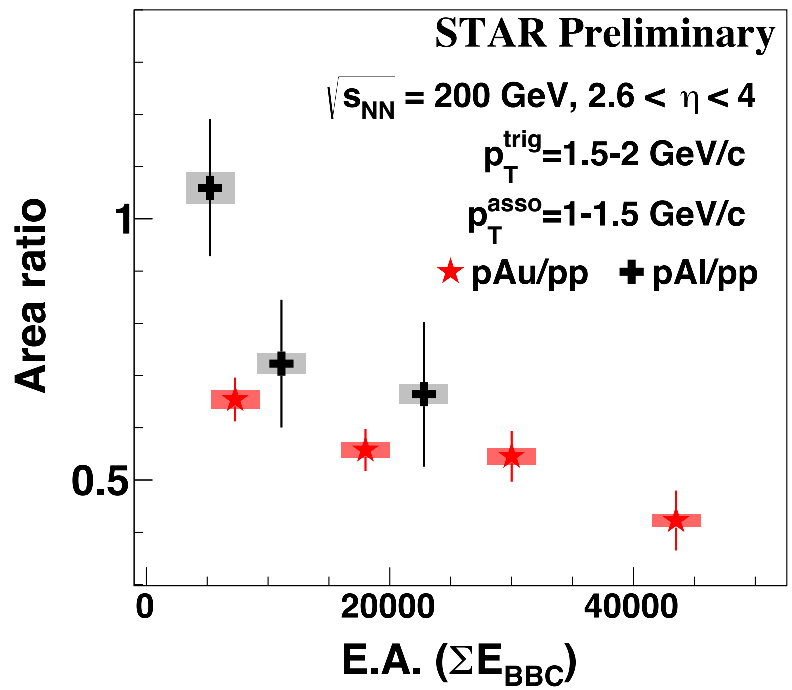


- p_T dependence: suppression observed at low p_T in pA but not high p_T
- Pedestal and width unchanged between pp and pAu collisions

Di-π^0 correlations at STAR

Area (integral from $\frac{\pi}{2}$ to $\frac{3\pi}{2}$), Width (σ) and Pedestal from fit

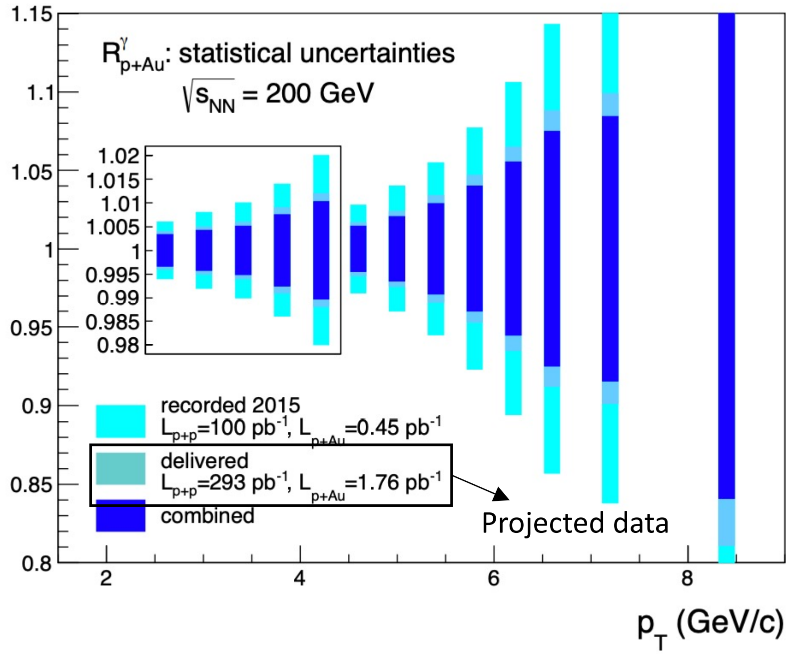


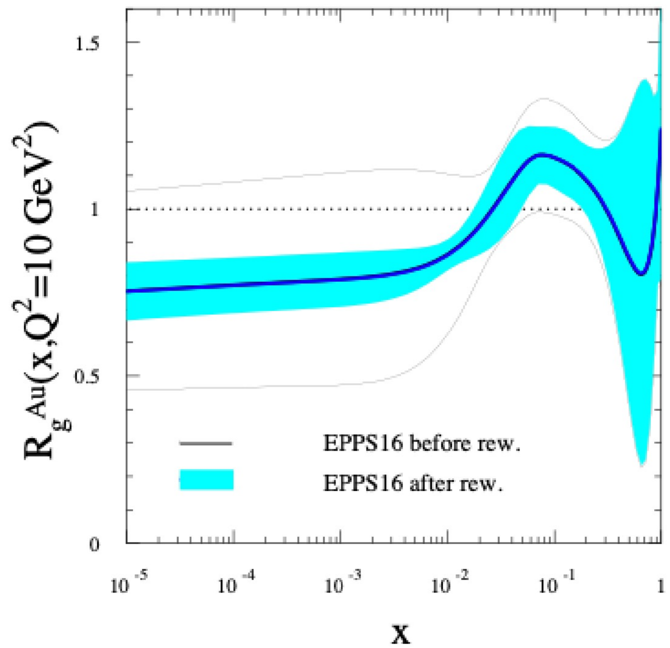


- Similar trend of event activity dependence in pAu and pAl: enhanced suppression at high E.A.
- Nucleus dependence: enhanced suppression in pAu collisions with respect to pAl collisions

Future measurements on direct photon at STAR

RHIC Cold QCD Plan, arxiv:1602.03922



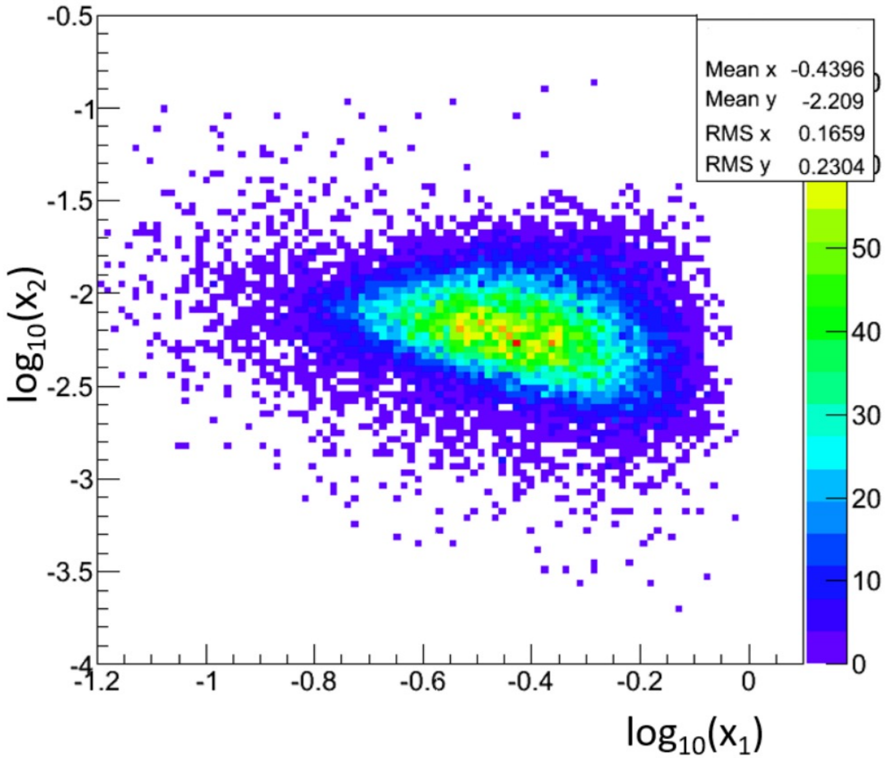


2024 pAu data with STAR forward upgrade + 2015 pAu data:

- R^{γ}_{pAu} of direct photons from q+g→q+γ, free from the final state effects
- Larger luminosity data improve the constraints on gluon distributions
- Challenge: background photons from fragmentation and hadron decays; small cross section of direct photon at forward rapidity

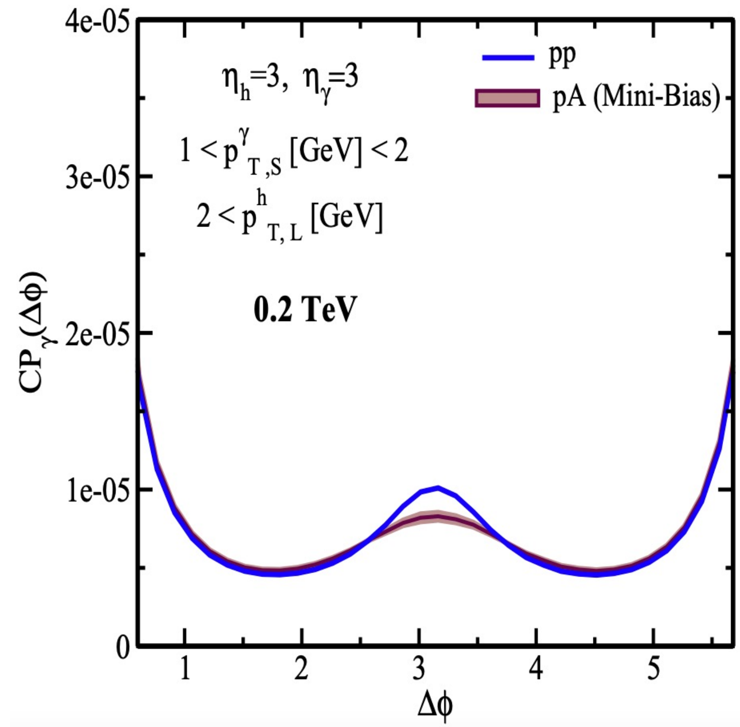
Other future measurements at STAR

γ-jet



RHIC Cold QCD Plan, arxiv:1602.03922

γ-hadron



PRD 86 (2012) 094016

2024 pAu with STAR forward upgrade, sensitive to the gluon density at small x

- Jets are better proxies of initial parton kinematics than hadrons:
  - $\frac{p_{T1}\, e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}} < x_A$ for di-hadron
  - $\frac{p_{T1}\, e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}} \sim x_A$ for γ-jet

Summary and outlook

- The evidence of a novel universal regime of non-linear gluon dynamics in nuclei is very important to help us understand QCD processes in Cold Nuclear Matter:
  - Understand the collective dynamics of gluons
  - Investigate inner landscape of nuclei: initial state input to eA/pA/AA

- Di-hadron correlation is a key measurement in the pA physics program at STAR
  - STAR shows a clear signature of non-linear gluon dynamics with di-hadron correlation measurement
  - First measurement of nuclear effect dependence on A: stronger suppression in pAu than pAl
  - Event activity dependence: suppression enhanced in “high activity” collisions at low p_T

- Future high precision measurements at STAR with forward upgrade for more observables: direct γ, γ-hadron/jet, di-charged hadron, di-jet…