Probing gluon saturation with dihadron correlation at the EIC

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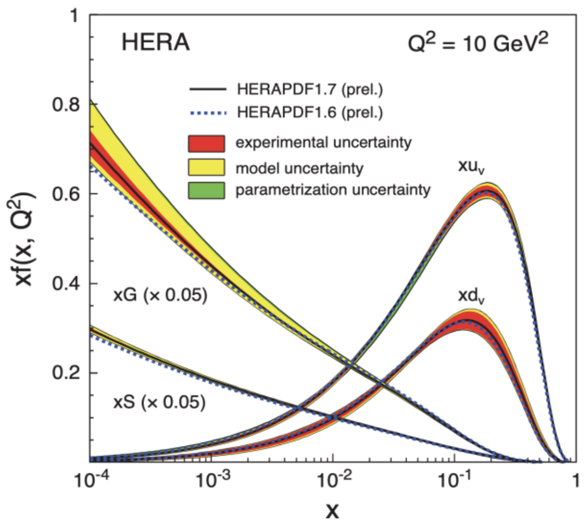
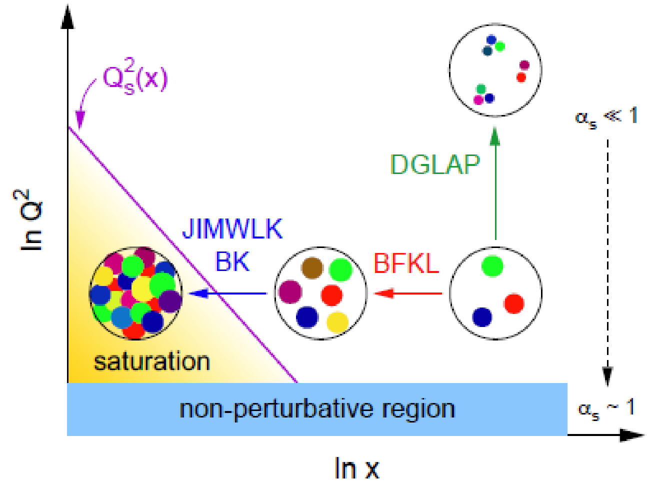
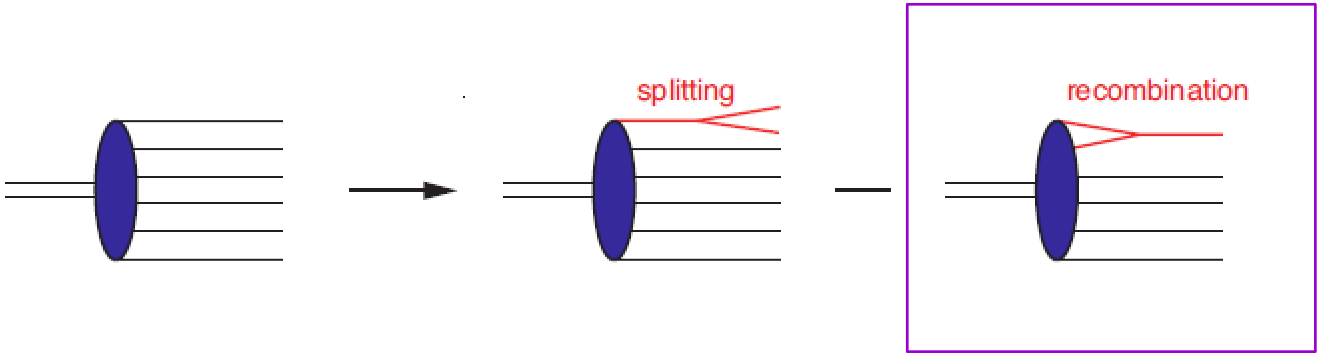
Exploring gluon saturation regime

- Linear evolution causes the explosive growth of gluon density at small x.
- Nonlinear evolution arises as JIMWLK/BK alternative to DGLAP, BFKL due to **gluon recombination**.
- Saturation regime, $Q^2<Q^2_s(x)$

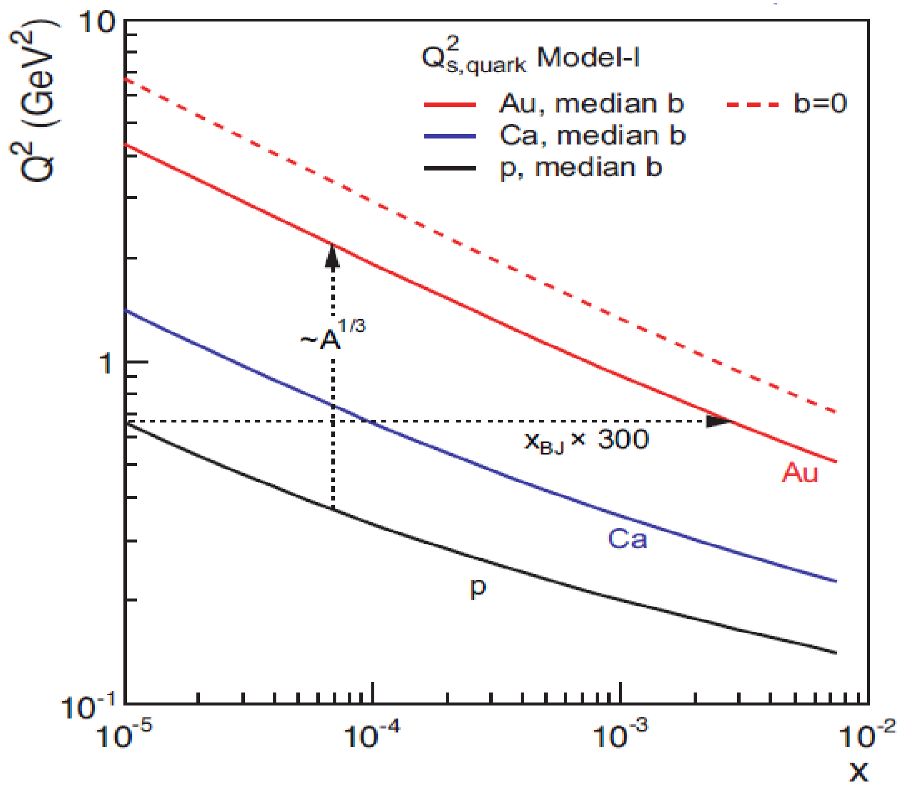


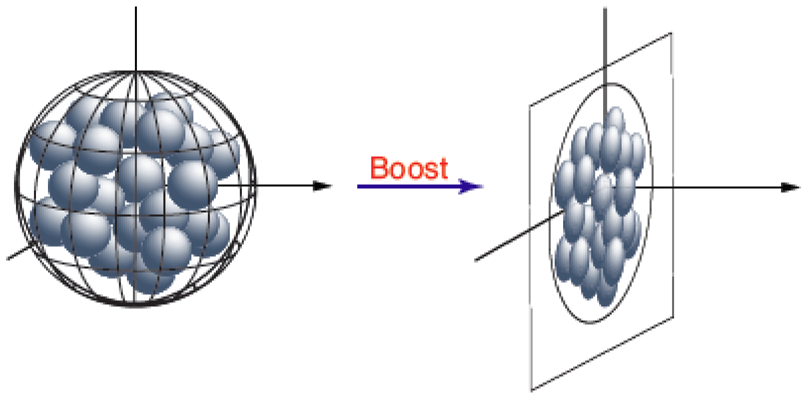




Nuclear amplification of saturation

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

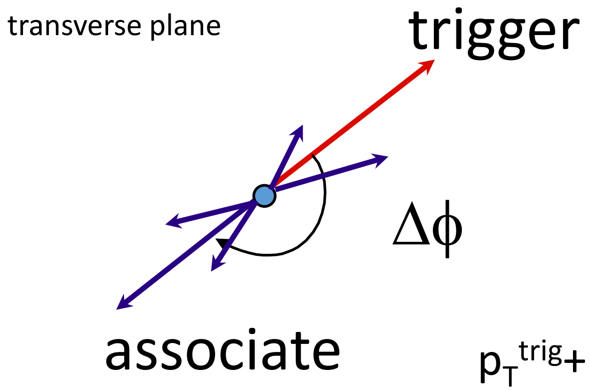




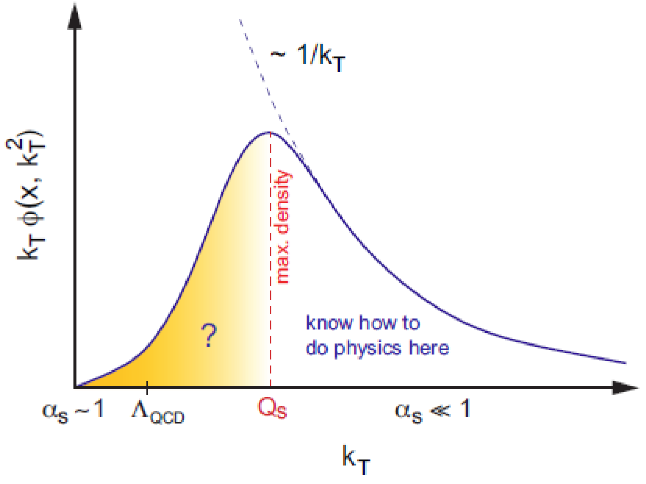
- Gluon density scales as nuclear size.
- Effective x much smaller in a nucleus.
- Saturation regime reached at lower energy in nuclei.

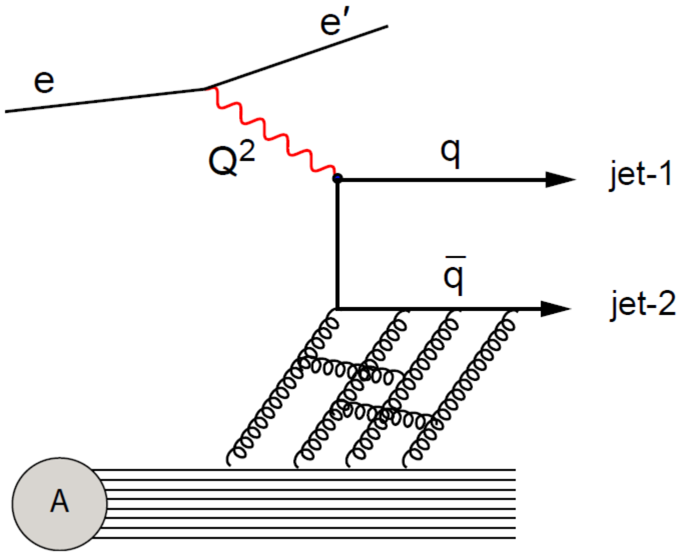
Saturation and dihadron correlation

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



$p_T^{trig} + p_T^{asso} \sim Q_s$



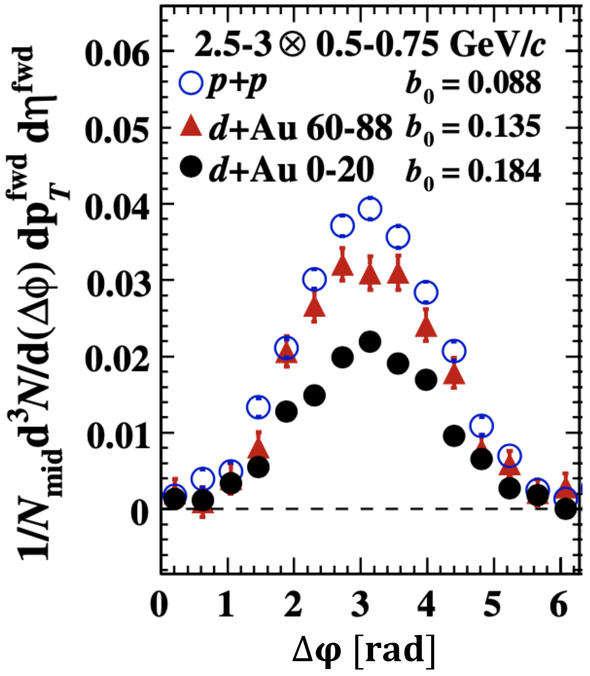


- Back to back hadron pairs decorrelate
- Strong suppression at away side predicted by saturation
- Probe nuclei in k_T space.

Current experimental results

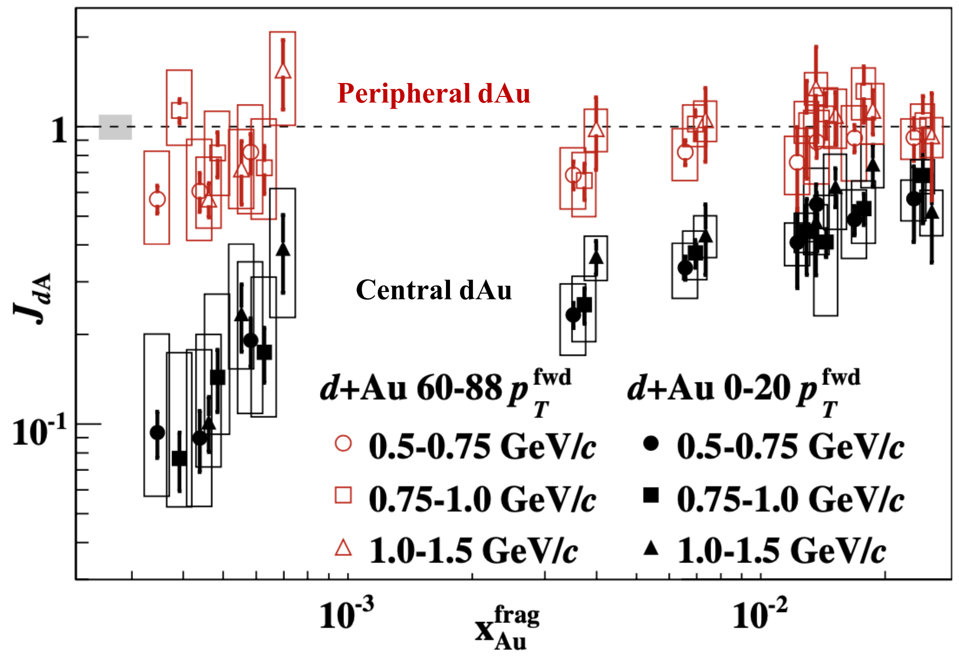
Middle-forward

|η|<0.35, 3.0 < η < 3.8



$$J_{dA} = \frac{1}{\langle N_{coll} \rangle} \frac{\sigma_{dA}^{pair} / \sigma_{dA}}{\sigma_{pp}^{pair} / \sigma_{pp}}$$

Forward-forward ← Middle-forward



PRL 107 (2011) 172301

$$x_{Au}^{frag} = \frac{p_{T1} e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}}$$

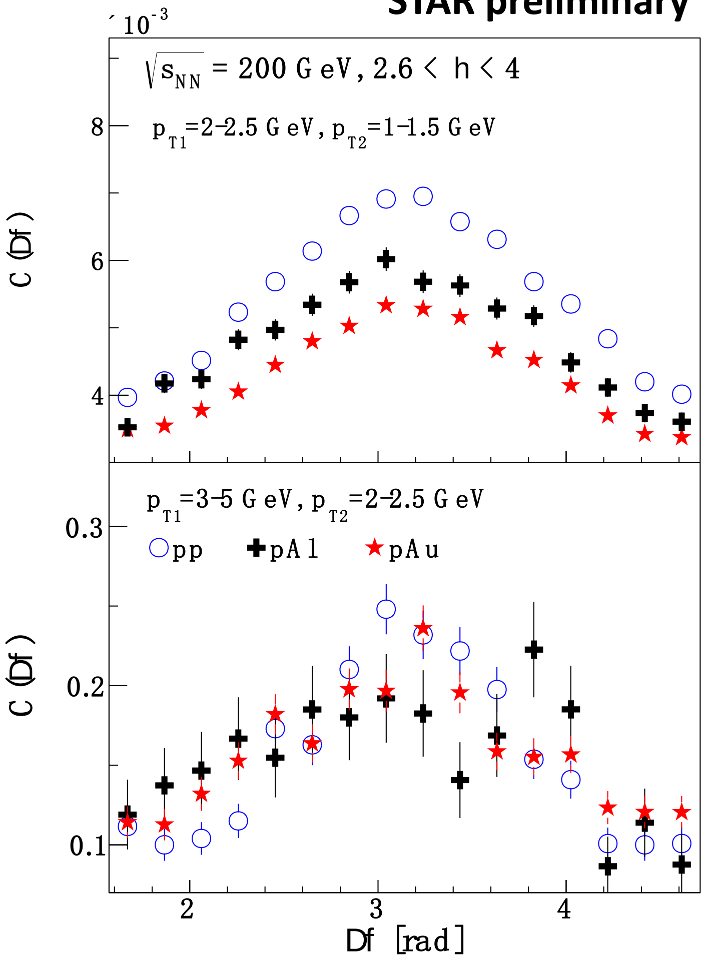
- Suppression observed in central dAu collisions
- Smaller x probed with forward rapidity: stronger suppression in forward-forward correlation

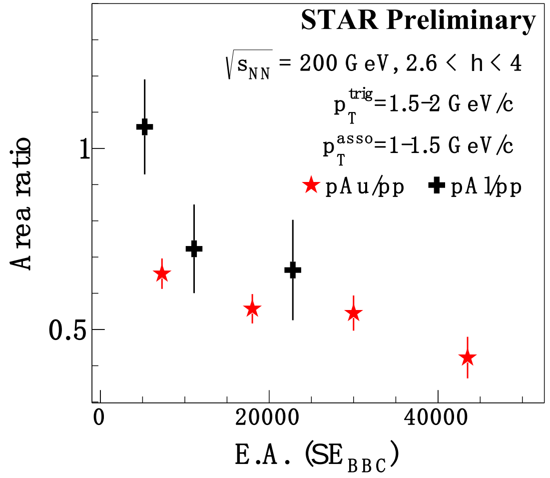
Current experimental results

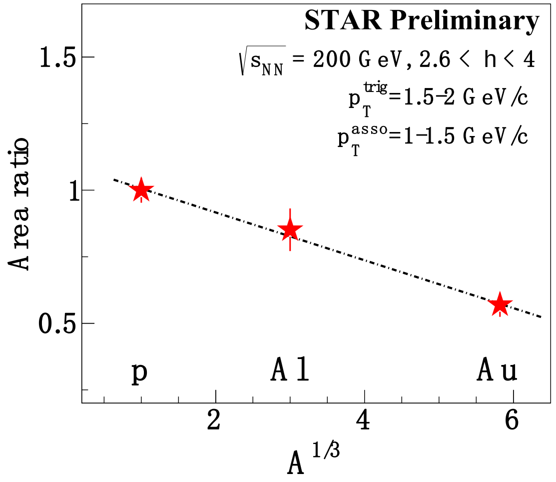
Xiaoxuan Chu 2021 CFNS talk

- Suppression in pA varying with p_T
- Enhanced suppression with event activity for both pAl and pAu
- Suppression scales with $A^{1/3}$

STAR preliminary







Study saturation in eA

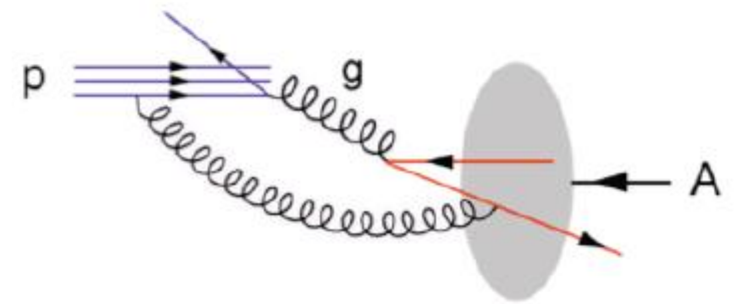
– Point-like probe in DIS

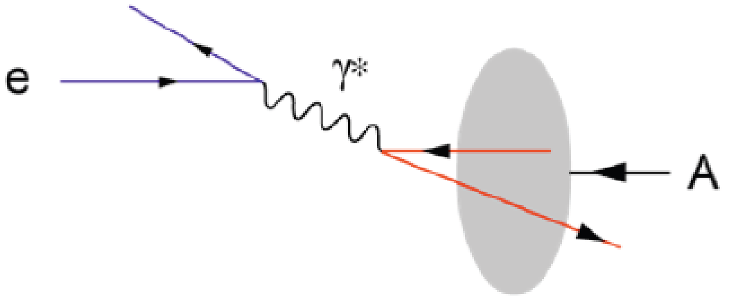
– Control initial/final state

– eA experimentally much cleaner, no pedestal

  - no “spectator” background to subtract

– Access to the exact kinematics of the DIS process (x, Q^2)





eA dihadron correlation in saturation formalism

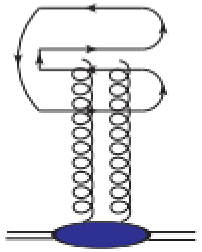
PRD 83 105005 (2011) F. Dominguez, C. Marquet, B. Xiao, F. Yuan

Correlation function

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

Pair cross-section (Weizsäcker-Williams gluon distribution $G^{(1)}$)

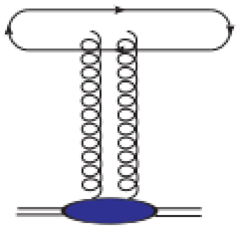
$$\frac{d\sigma_{\text{tot}}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d^2p_{h1\perp}d^2p_{h2\perp}} \sim xG^{(1)}(x_g,q_\perp) \sim \mathcal{F}(x_g,q_\perp) = \frac{1}{2\pi^2}\int d^2r_\perp e^{-iq_\perp r_\perp}\frac{1}{r_\perp^2}[1-\exp(-\frac{1}{4}r_\perp^2 Q_s^2)]$$



Gauge link for large nucleus at small-x using MV model

Trigger particle cross-section (color dipole gluon distribution $G^{(2)}$)

$$\frac{d\sigma_{\text{SIDIS}}^{\gamma^*+A\to h_1+X}}{dz_{h1}d^2p_{h1\perp}} \sim xG^{(2)}(x_g,q_\perp) \sim F_{x_g}(q_\perp) = \int\frac{d^2r}{2\pi^2}e^{iq_\perp\cdot r_\perp}\frac{1}{N_c}Tr\langle U(r_\perp)U^\dagger(0)\rangle_\rho \simeq \frac{1}{\pi Q_{sA}^2}\exp[-\frac{q_\perp^2}{Q_{sA}^2}],$$



Unique process to probe WW gluon distribution

	DIS and DY	SIDIS	hadron in pA	photon-jet in pA	Dijet in DIS	Dijet in pA
$G^{(1)}$ (WW)	×	×	×	×	√	√
$G^{(2)}$ (dipole)	√	√	√	√	×	√

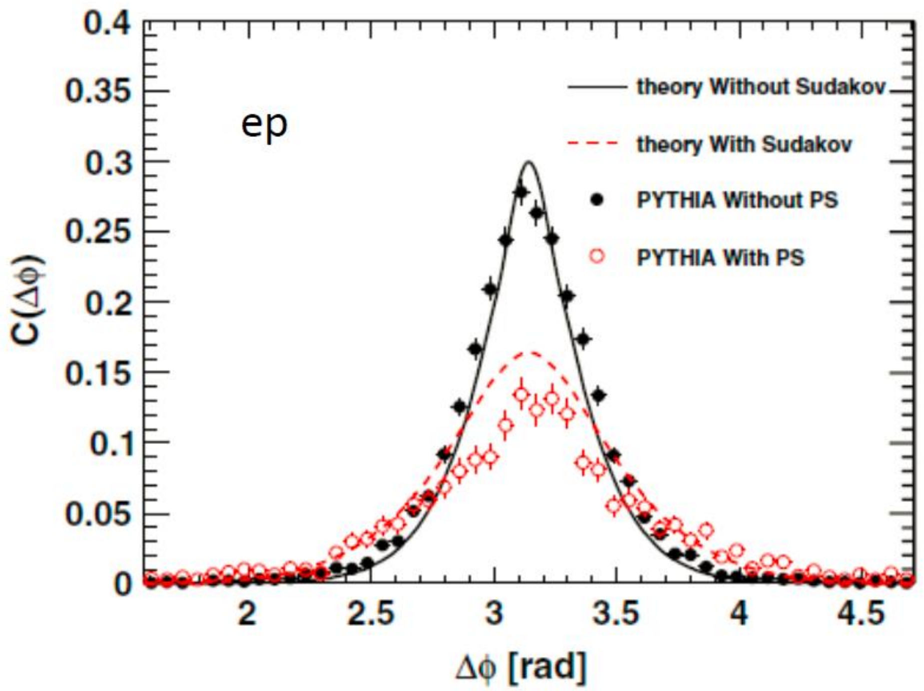
Sudakov effect in dihadron correlation

PRD 88 114010 (2013), A. Mueller, B. Xiao, F. Yuan

$$\mathcal{F}(x_g, q_\perp) = \frac{1}{2\pi^2}\int d^2r_\perp e^{-iq_\perp r_\perp}\frac{1}{r_\perp^2}\left[1-\exp\left(-\frac{1}{4}r_\perp^2 Q_s^2\right)\right]$$
$$\times \exp\left[-\frac{\alpha_s N_c}{4\pi}\ln^2\frac{K^2 r_\perp^2}{c_0^2}\right]$$

$K^2 = P_T^2$ or $K^2 = Q^2$, $C_0=2e$

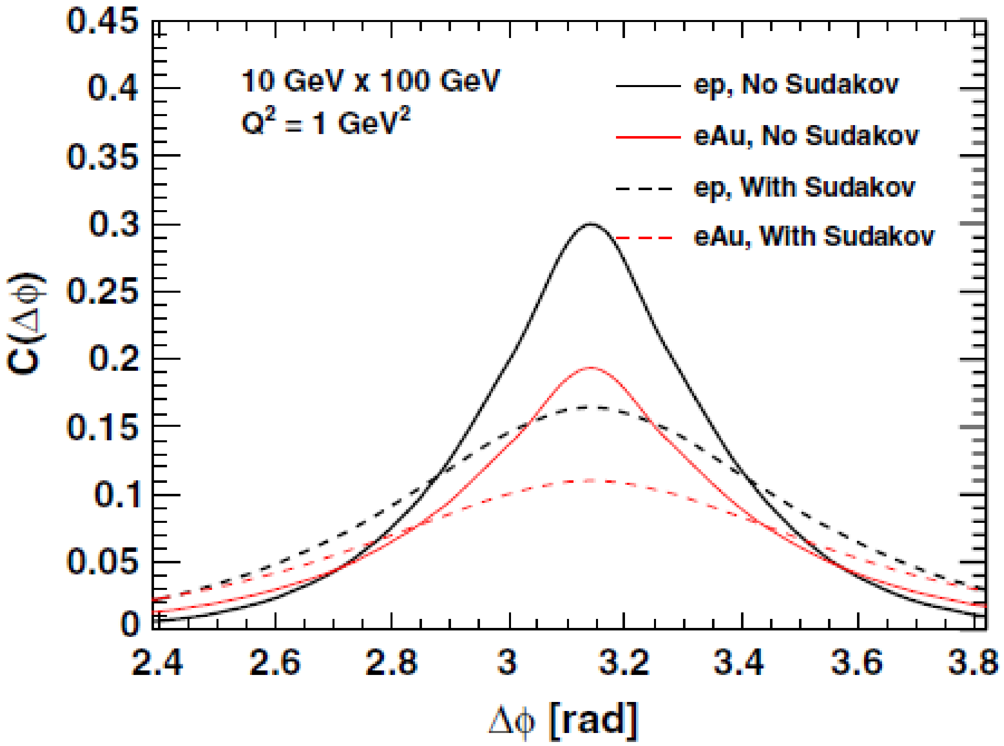
- Beyond leading order calculation achieved by inclusion of Sudakov factor in WW gluon distribution
- Parton shower effectively cast into Sudakov factor in saturation formalism for dihadron correlation



PRD 89 (2014) 074037

Saturation with Sudakov factor

- Strong suppression expected at away side of the correlation function
- Away side suppression is due to a combination of Sudakov factor and saturation effects
- No nuclear dependence in this Sudakov factor



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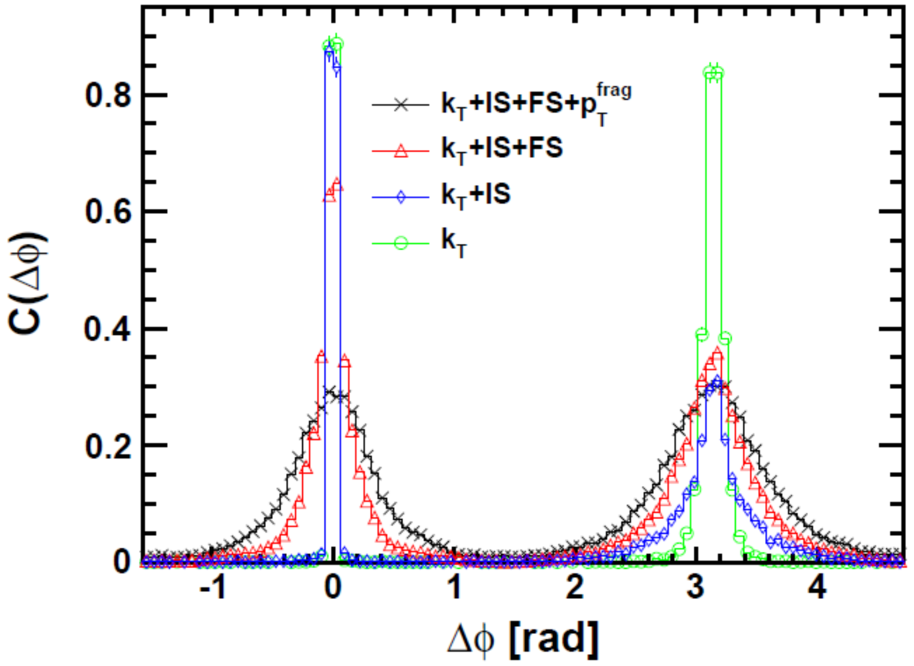
Study to distinguish the contribution from Sudakov and saturation can be achieved by running with different target types or utilizing the near side peak scanned with different Q^2

Disentangle different effects with near/away side peaks

- Near side peak width mainly affected by final state parton shower and fragmentation pt
- Away side peak width dominated by initial state parton shower



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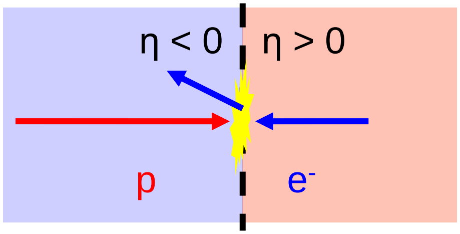
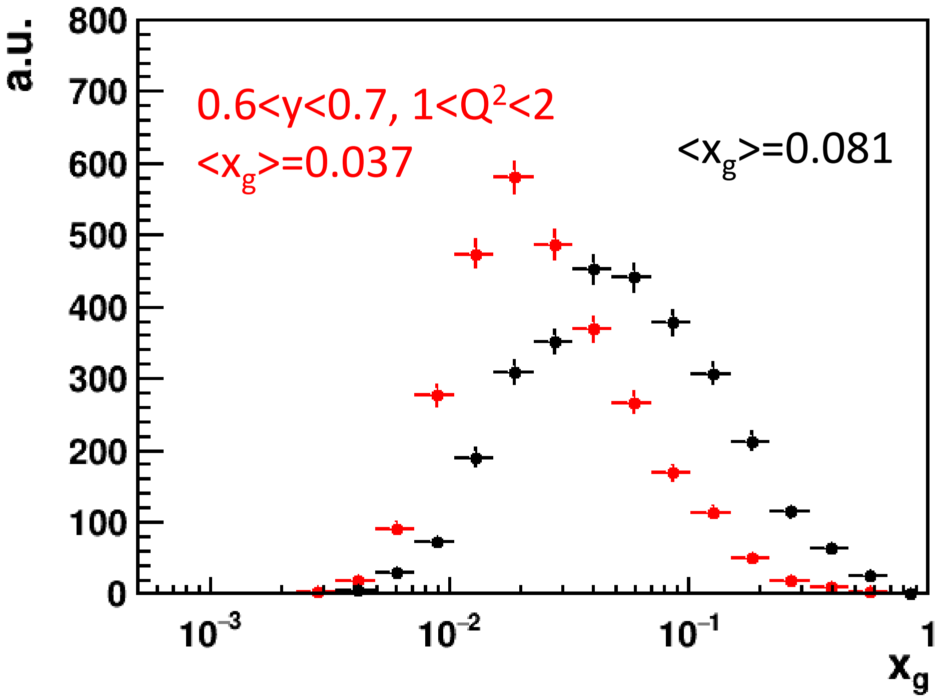
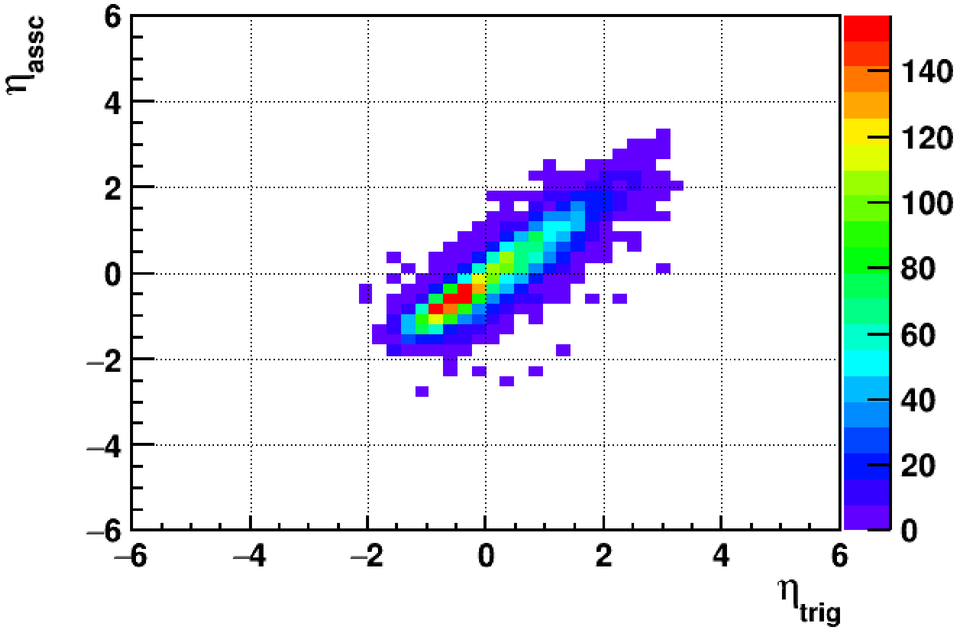
	Near-side $\Delta\phi$ RMS	Away-side $\Delta\phi$ RMS
k_T	0.21	0.25
$k_T + \mathrm{IS}$	0.30	0.72
$k_T + \mathrm{IS} + \mathrm{FS}$	0.65	0.81
$k_T + \mathrm{IS} + \mathrm{FS} + p_T^{\mathrm{frag}}$	1.00	1.00

Kinematic coverage

ep/Au 18x110 GeV
charged hadron,
$0.01<y<0.95$, $Q2>1$ GeV^2,
$p_{T\,trig}^{*}>2$ GeV, $p_{T\,assc}^{*}>1$ GeV,
$0.2<z_h<0.4$,
* indicates γ^{*}p c.m.s frame



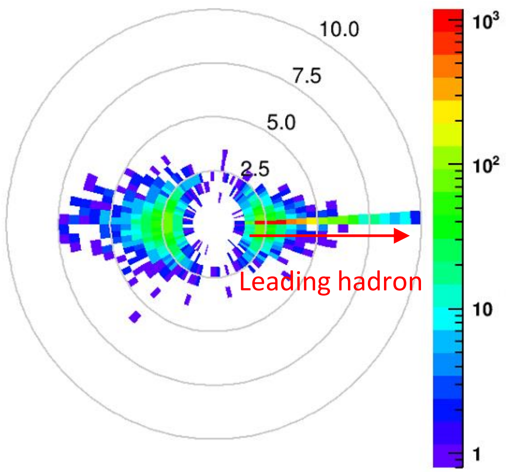




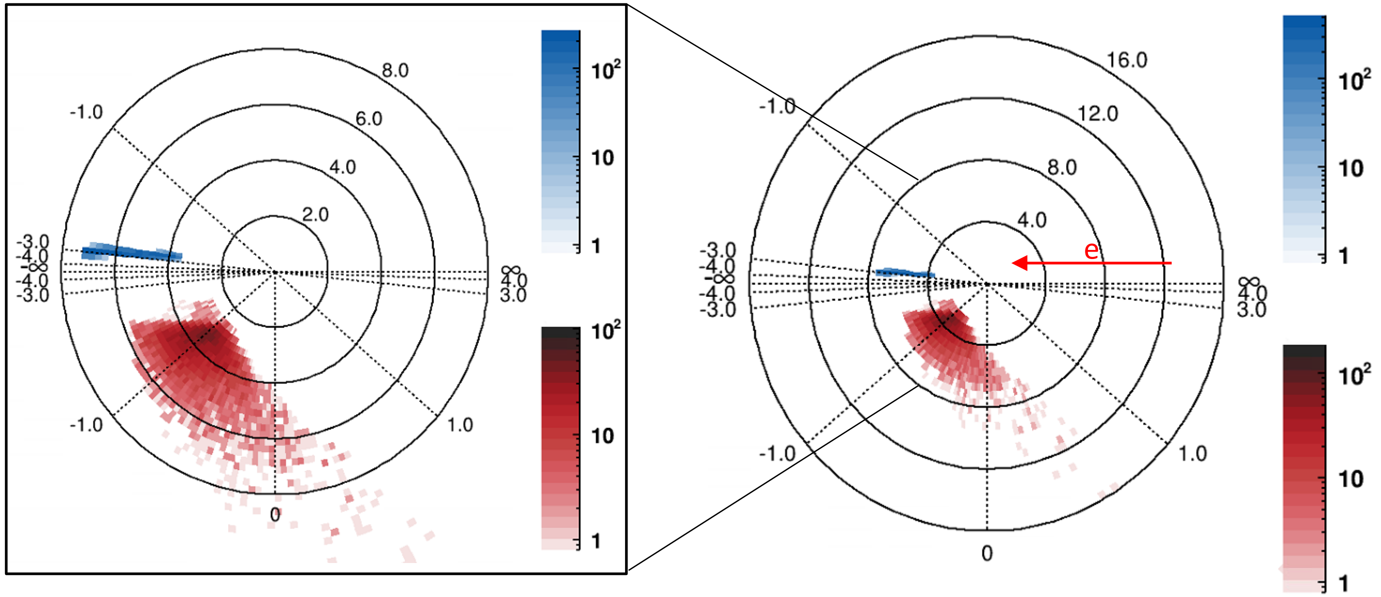
Kinematic map for dihadron pairs

ep/Au 18x110 GeV
0.6<y<0.8, $1<Q^2<2$ GeV^2
charged hadron, |η|<4.5, $p_{T\ trig}^*>2$ GeV, $p_{T\ assc}^*>1$ GeV, $0.2<z_h<0.4$,
* indicates γ^*p c.m.s frame

p_T vs $\Delta\phi$ for associate hadron relative to leading hadron in Lab frame



p vs η for scattered electron and charged hadron pairs (blue for e-, red for hadron)

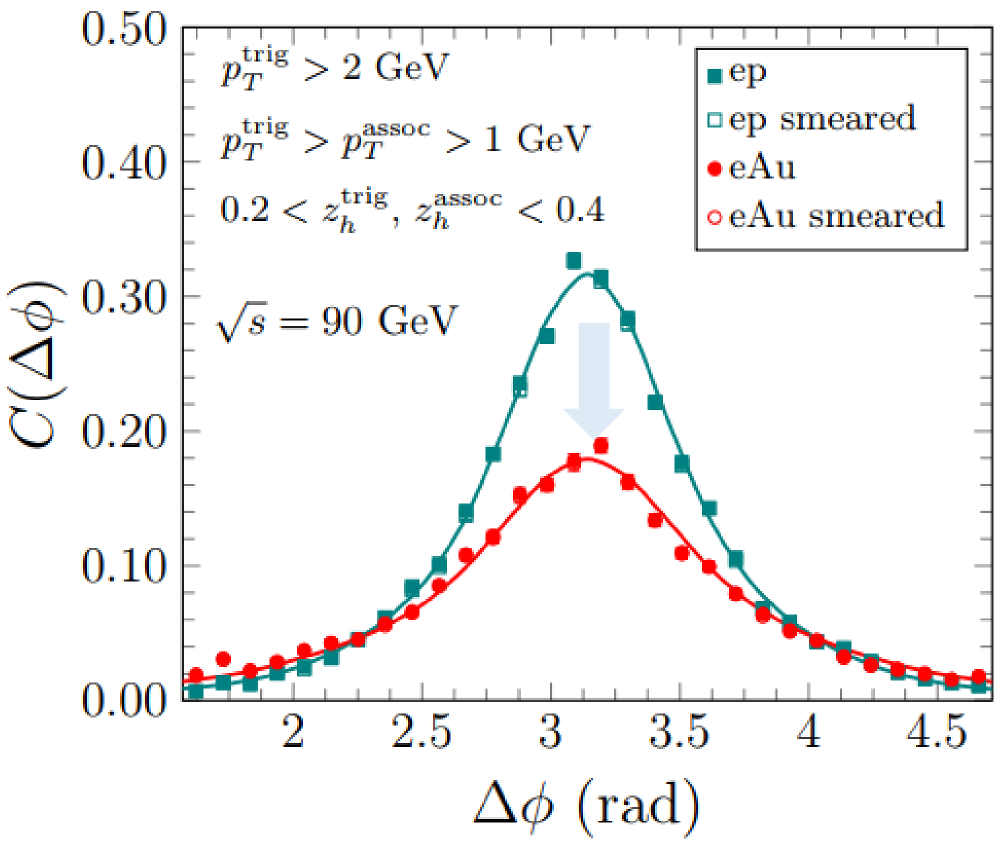


- Scattered e^- : p range 3.5~7 GeV, η range: -around -3
- Hadron pair: p range: 3~8 GeV, η range: backward rapidity

Projection on the saturation effect

ep/eAu 18x110 GeV
0.6<y<0.8, 1<Q^2<2 GeV^2
All charge, |η|<3.5, 0.2<z<0.4
p_T^{trig}>2 GeV, 1<p_T^{assc}< p_T^{trig}
in γ^*p c.m.s frame
L_{int}=10 fb^{-1}/A

- Sizable suppression to uncover the gluon saturation at the EIC



Summary and outlook

- Dihadron correlation is a sensitive to the underlying gluon dynamics.
- Sudakov effects are important to understand the dihadron correlations.
- The proposed luminosity and the detector setup is suitable to precisely measure the gluon saturation at EIC through dihadron correlations.
- Dijet estimations and rcBK type calculations are still under investigation.