



# The precision frontier for gluon saturation

$\Delta t \propto 1/\Delta E$

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Jefferson Lab

momentum

# Outline

- Gluon saturation: review, status, and challenges
- Precision frontier for gluon saturation
- Two-particle azimuthal correlations in the CGC at NLO

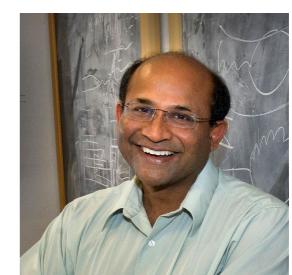
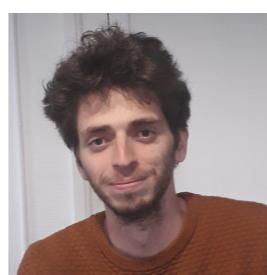
P. Caucal, FS, R. Venugopalan. [2108.06347](#) [[JHEP 11 \(2021\) 222](#)]

PC, FS, B. Schenke ,RV. [2208.13872](#) [[JHEP 11 \(2022\) 169](#)]

PC, FS, BS, T. Stebel, RV. [2304.03304](#) [[JHEP 08 \(2023\) 062](#)]

[2308.00022](#) [preprint]

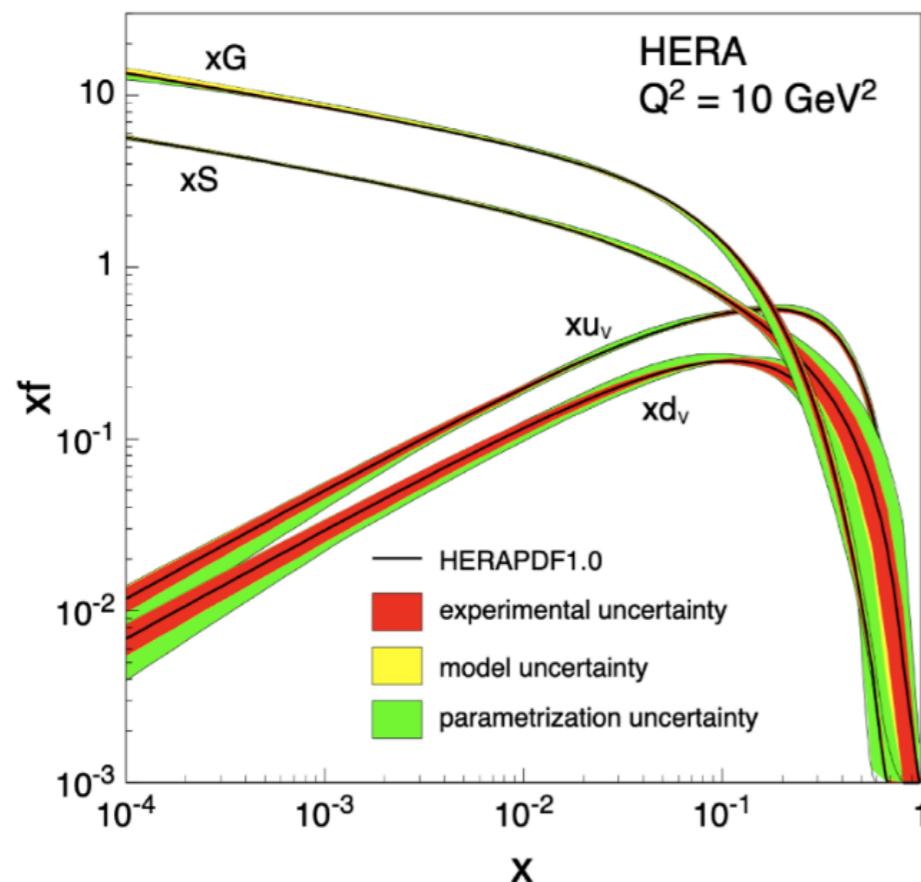
- Outlook



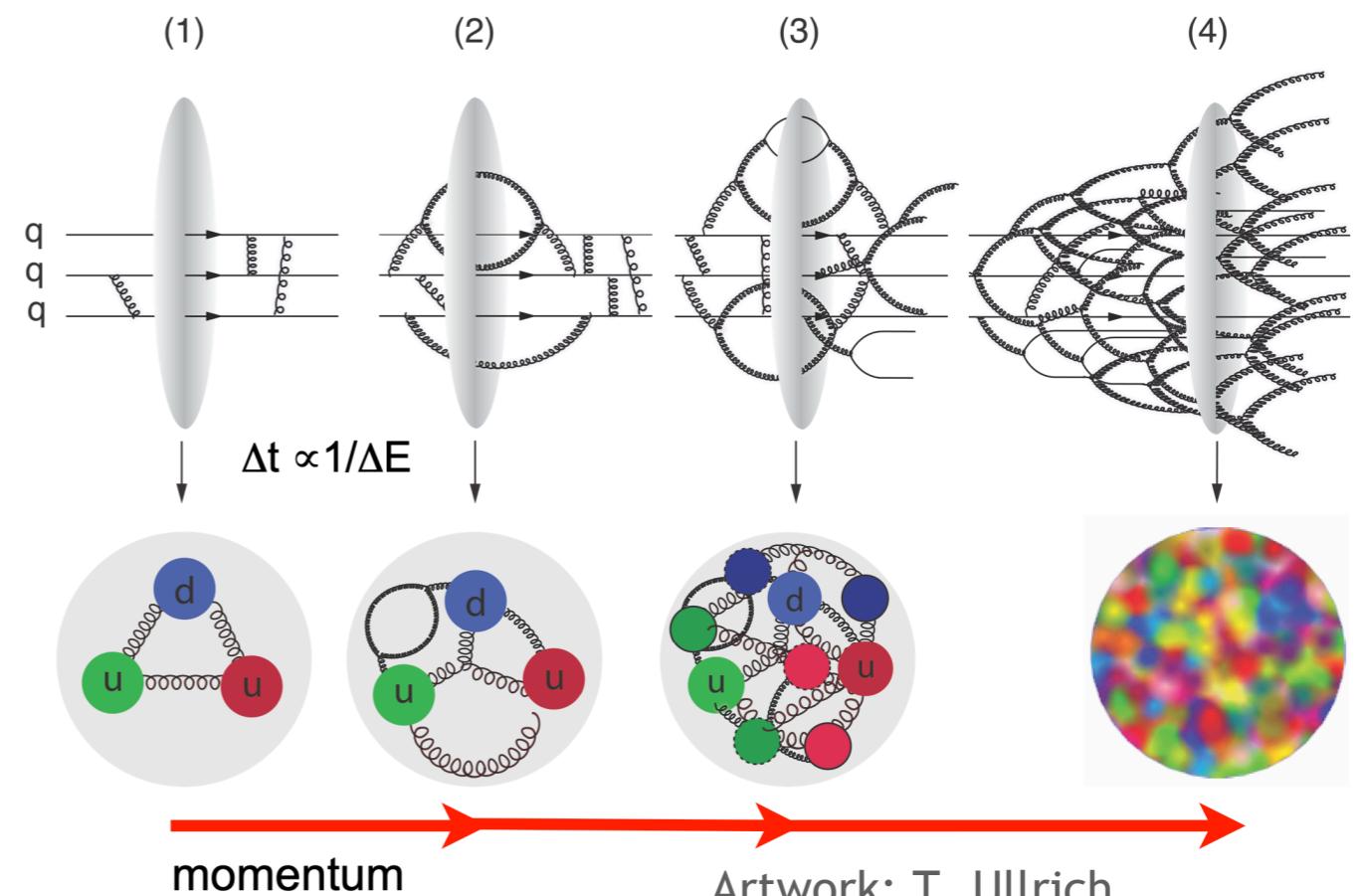
Paul Caucal Björn Schenke Tomasz Stebel Raju Venugopalan

# Gluon saturation: review, status and challenges

## Anatomy of QCD at high-energies



gluon density must saturate at high-energies/small- $x$

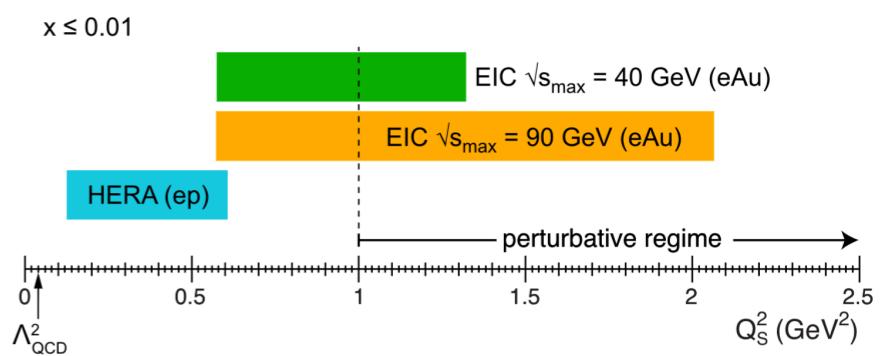


Partonic picture superseded by **strong highly occupied fields**

Emergence of an energy and nuclear species dependent momentum scale  $Q_s^2 \propto A^{1/3} s^{1/3}$

Multiple scattering (higher twist effects)

Non-linear evolution equations



# Why gluon saturation?

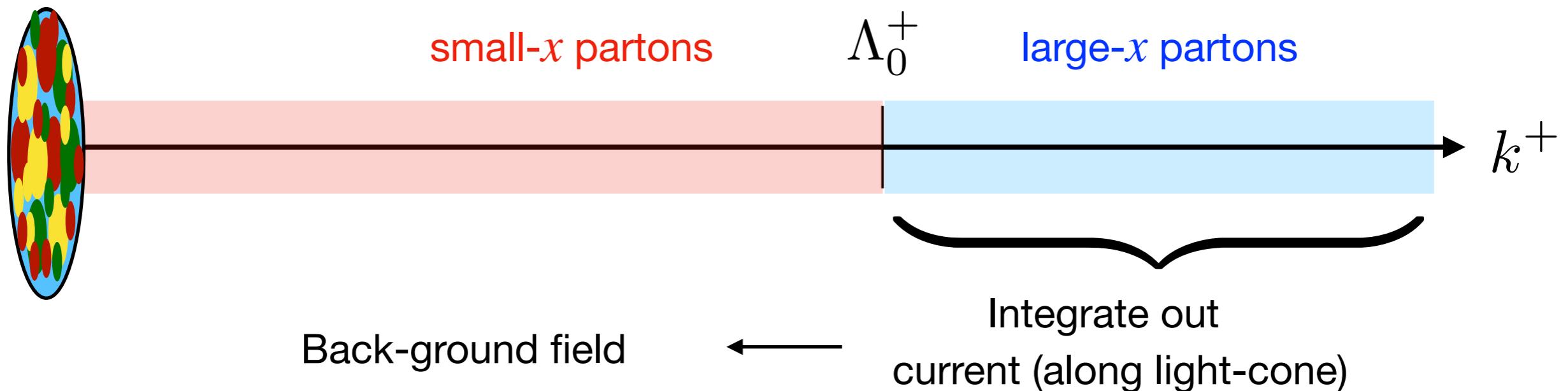
- Search of gluon saturation is one of the major goals of the future EIC.
- The **Color Glass Condensate** is an EFT for this **gluon saturated regime**.
- A wide variety of observables are available to search for gluon saturation: **structure functions, diffractive processes, and semi-inclusive measurements**.
- Competing physical mechanisms might lead to similar signatures. Need sharper predictions (NLO era for gluon saturation).

# The Color Glass Condensate

## Sources and fields

L. McLerran, R. Venugopalan (1993)

Color (QCD)  
Glass (separation slow vs fast modes)  
Condensate (highly occupied system)



A double average:

$$\langle\langle \mathcal{O} \rangle\rangle = \underbrace{\int [\mathcal{D}\rho] W_{\Lambda_0}[\rho]}_{\text{CGC average for } \rho} \underbrace{\frac{\int^{\Lambda_0} [\mathcal{D}A] \mathcal{O} e^{iS[A,\rho]}}{\int^{\Lambda_0} [\mathcal{D}A] e^{iS[A,\rho]}}}_{\text{Path integral in the presence of } \rho}$$

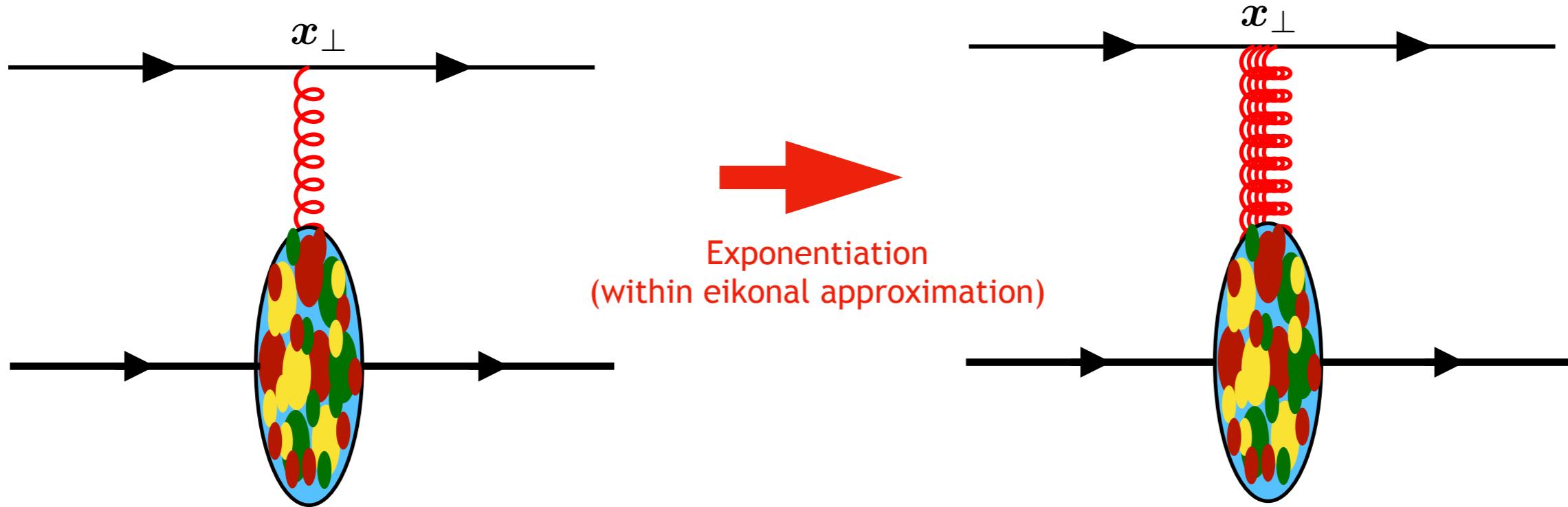
At leading order:

$$\langle\langle \mathcal{O} \rangle\rangle = \int [\mathcal{D}\rho] W_{\Lambda_0}[\rho] \mathcal{O}[A_{\text{cl}}]$$

Classical solution  
in presence of  $\rho$

# The Color Glass Condensate

## Multiple scattering and Wilson lines



Light-like Wilson line

$$V_{ij}(\mathbf{x}) = P \exp \left\{ ig \int dx^- A_{cl}^{+,a}(\mathbf{x}, x^-) t^a \right\}$$

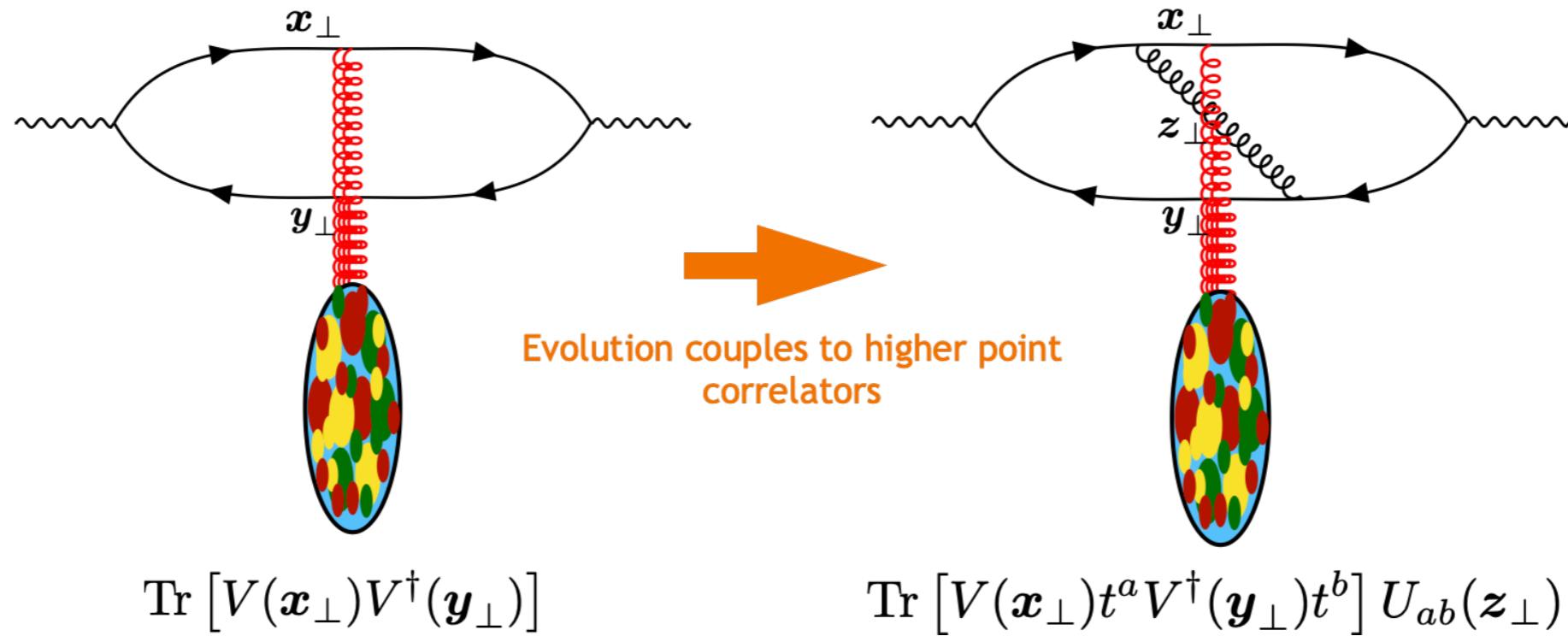
Observables built from Wilson lines, derivatives, etc... convoluted with perturbative factor (splitting functions)

$$\langle \mathcal{O} \rangle = \langle VV^\dagger \dots \rangle$$

# Gluon saturation: review, status and challenges

## Color Glass Condensate in a nutshell

- Non-linear renormalization group evolution (BK-JIMWLK)



I. Balitsky (1995), Y. Kovchegov (1999)  
J. Jalilian-Marian, E. Iancu, L. McLerran,  
H. Weigert, A. Leonidov, A. Kovner (1996-2002)

- Fast fields are non-perturbative, slow fields evolve perturbatively
- **Probing CGC with dilute projectile**  
= pQCD embedded in strong gluon (non-perturbative) background field

# The Color Glass Condensate

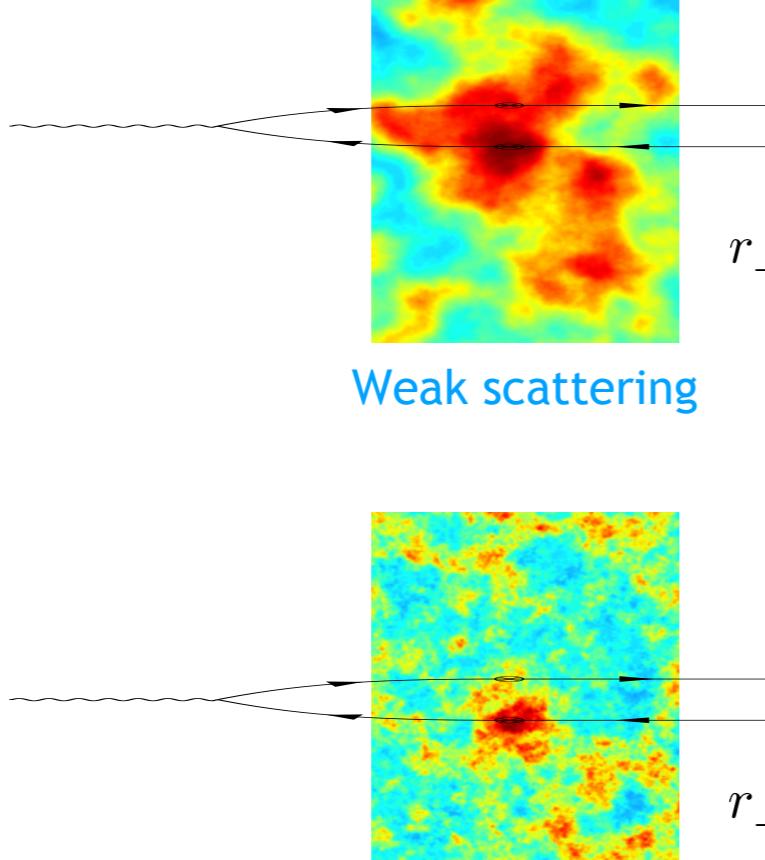
## Saturation scale

Dipole amplitude:  $1 - \frac{1}{N_c} \langle \text{Tr} [V(\mathbf{x}_\perp) V^\dagger(\mathbf{y}_\perp)] \rangle$

$Q_s$  “correlation length”

$$Q_s^2 \propto A^{1/3} x^{-0.3}$$

Energy Evolution/smaller-x

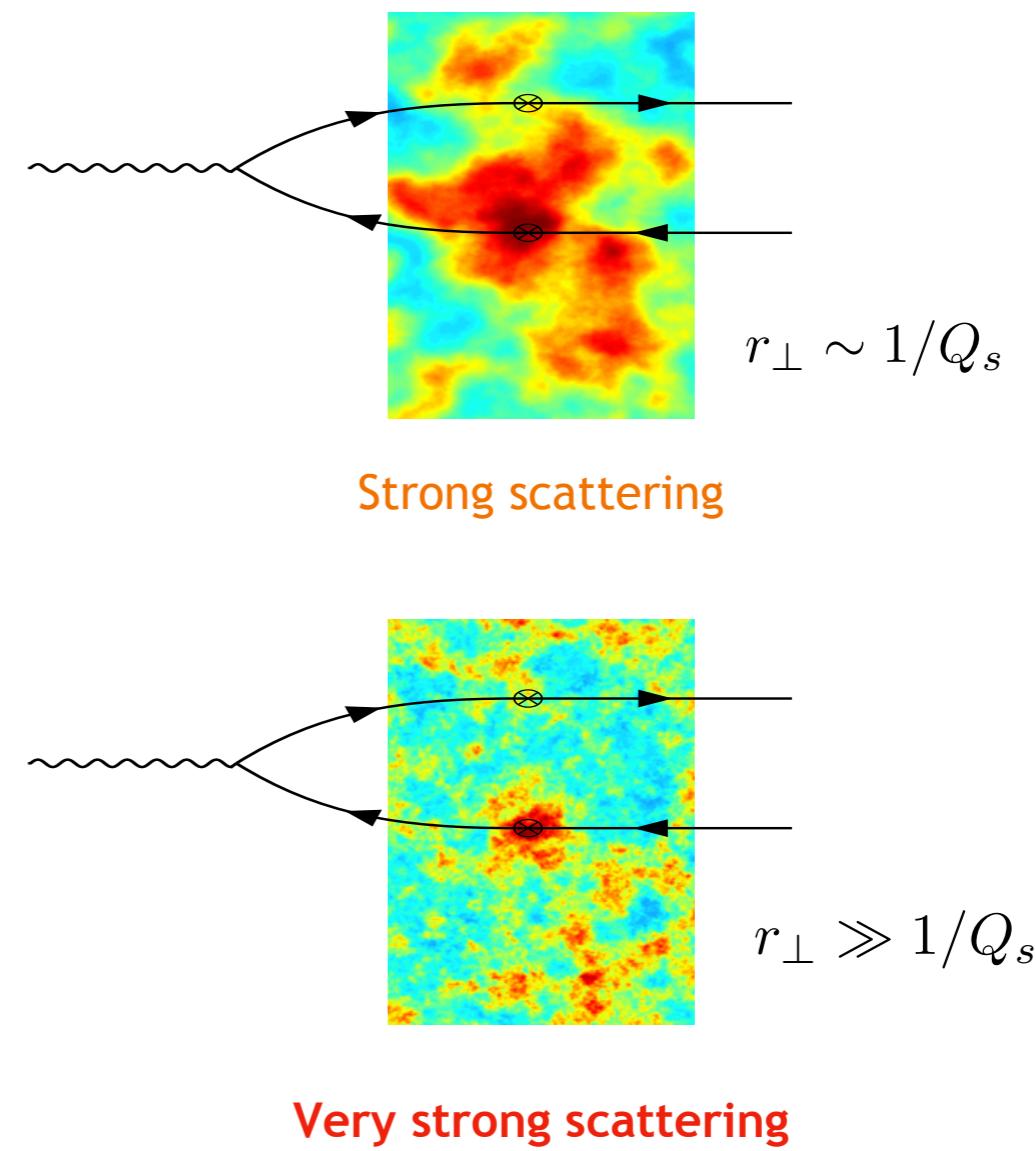


$$r_\perp \ll 1/Q_s$$

Weak scattering

$$r_\perp \sim 1/Q_s$$

Strong scattering



Strong scattering

$$r_\perp \sim 1/Q_s$$

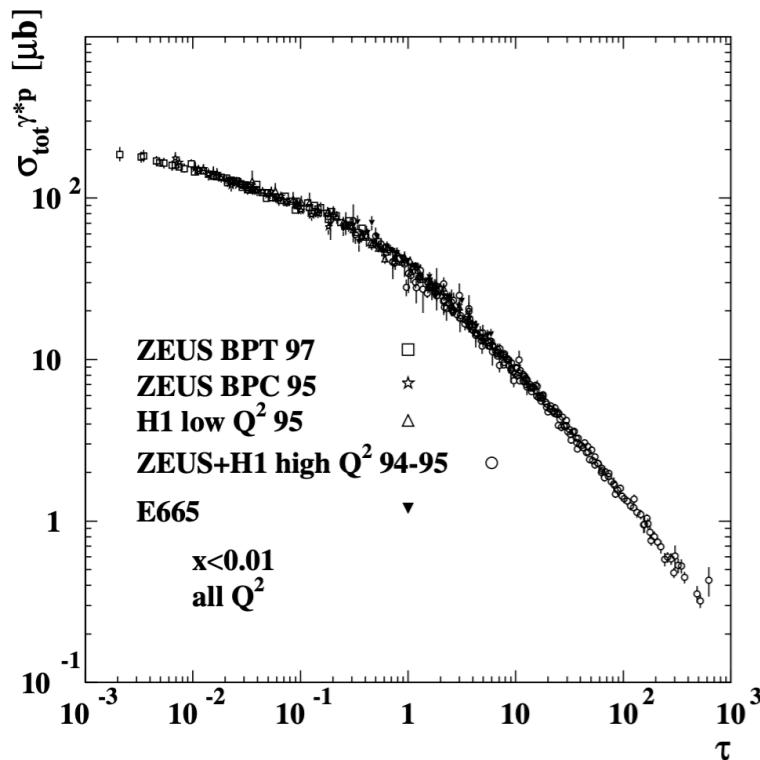
$$r_\perp \gg 1/Q_s$$

Very strong scattering

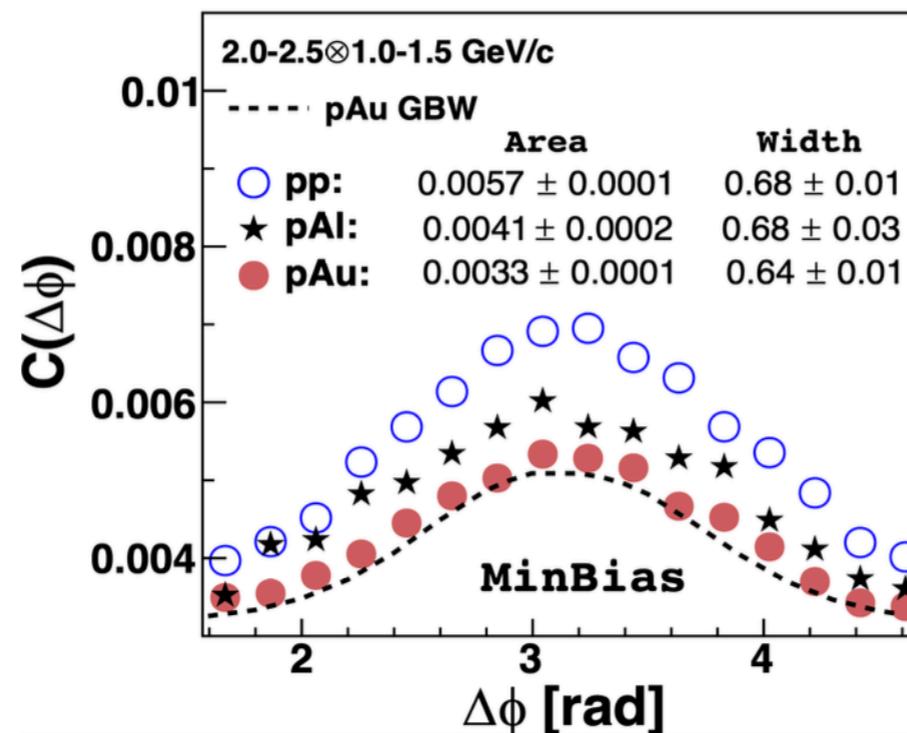
# Gluon saturation: review, status and challenges

## Experimental status

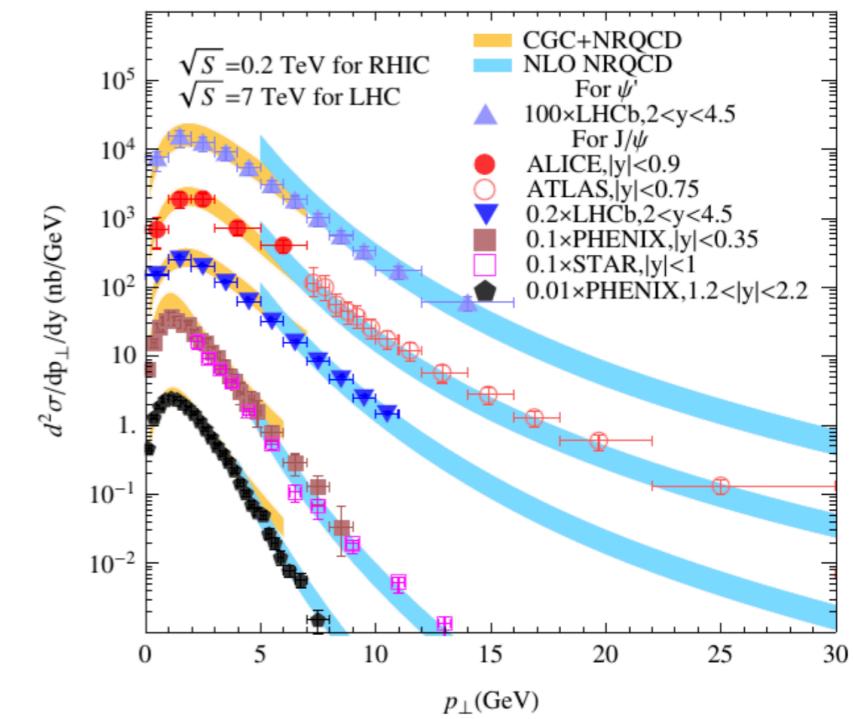
- Heavy-ion collisions, hadronic collisions, UPCs (e.g. RHIC and LHC)
- Deep-inelastic scattering (at HERA and future EIC)
- Inclusive, semi-inclusive, diffractive processes



Geometric scaling at RHIC



Dihadron suppression at RHIC



Quarkonium production at RHIC and LHC

**universe** For a recent review see:

Review  
Mining for Gluon Saturation at Colliders

Astrid Morreale <sup>1,\*</sup>,<sup>†</sup> and Farid Salazar <sup>2,3,4</sup>,<sup>†</sup>

Compelling but not definitive evidence yet!

# Gluon saturation: review, status and challenges

## Outstanding challenges

- Higher-order calculations for precision
- Identification of novel observables
- Modeling of initial conditions
- Spin Physics and saturation
- Event generators and global analysis
- Unification of dilute and dense QCD  
(beyond CGC)



recently funded SURGE Topical Collaboration supported by DOE

**Discovery and characterization of gluon saturation principal goals  
of the future Electron-Ion Collider**

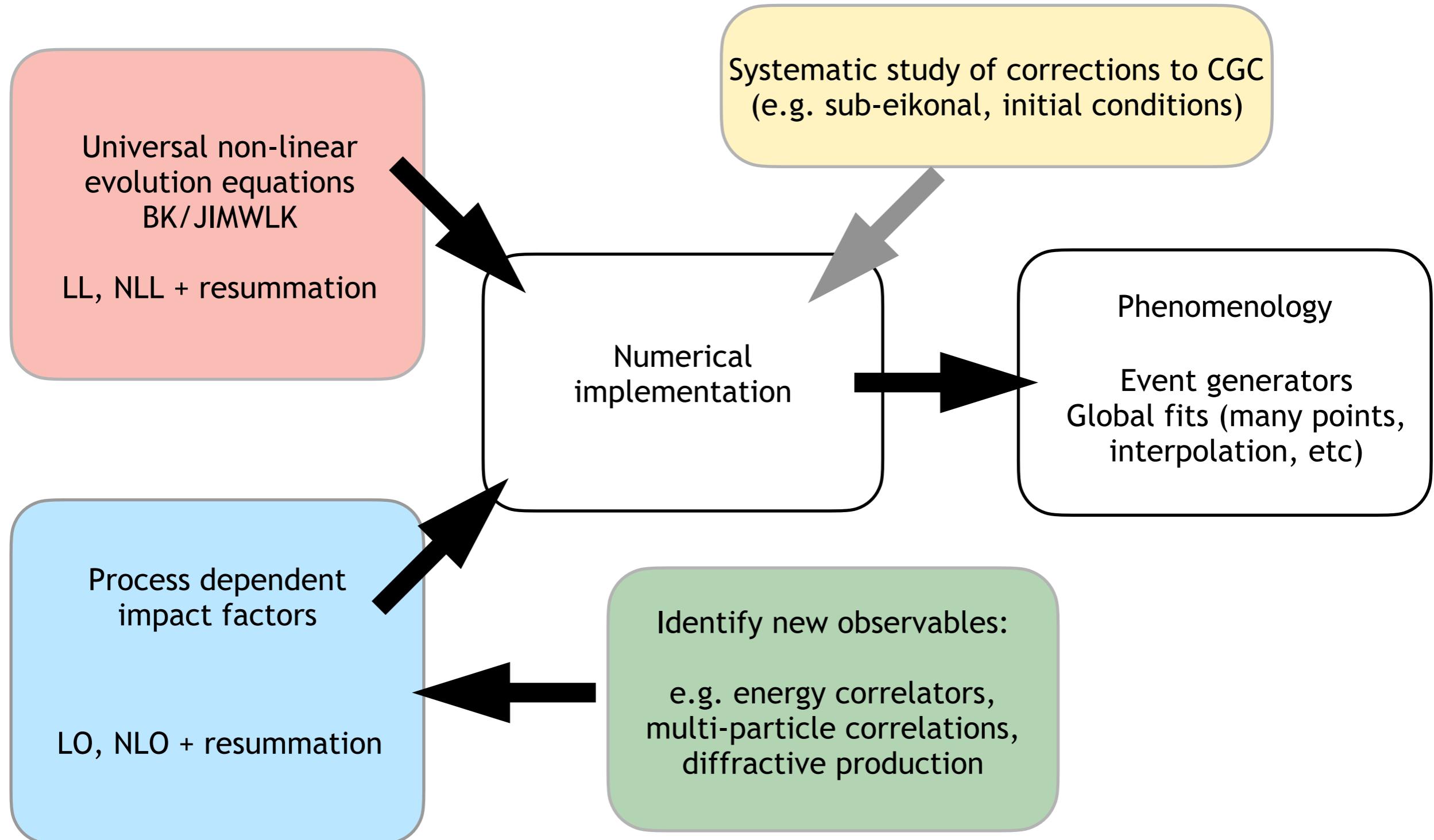
Other novel directions:

- Entanglement entropy and saturation, space-like and time-like correspondence, CGC-blackhole correspondence, color memory effect

For a short review see: *section 6 in Snowmass 2021 White Paper (arXiv: 2203.13199)*

# Precision frontier for gluon saturation

End-to-end precision analysis for saturation physics



# Precision frontier for gluon saturation

## Evolution equations at NLL accuracy

The evolution of the BK equation through the years

running coupling

Y. Kovchegov, H. Weigert (2007)  
I. Balitsky (2007)

NLL

I. Balitsky, G. Chirilli (2008)

NLL is unstable

T. Lappi, H. Mäntysaari (2015)

NLL with resummation

B. Ducloue, E. Iancu, A. Mueller,  
G. Soyez, D. Triantafyllopoulos  
(2015)

NLL with resummation  
is stable

T. Lappi, H. Mäntysaari (2016)

and the JIMWLK equation

running coupling

T. Lappi, H. Mäntysaari  
(2013)

NLL

I. Balitsky, G. Chirilli (2013)  
A. Kovner, M. Lublinsky, Y. Mulian (2014)

NLL with resummation

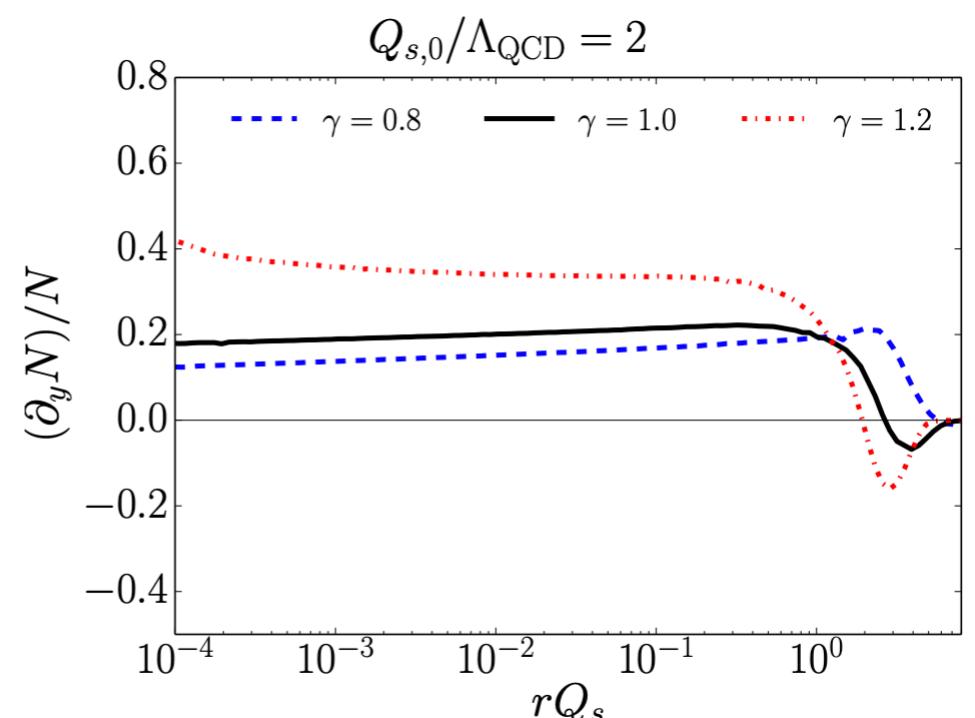
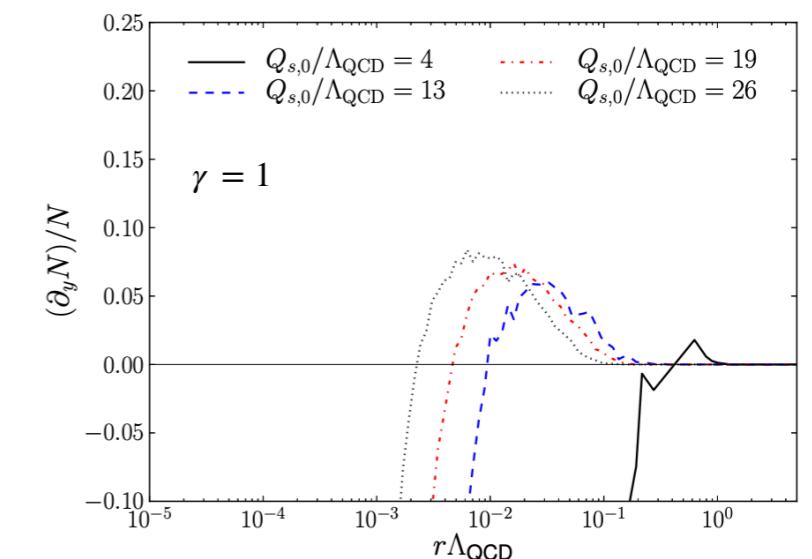
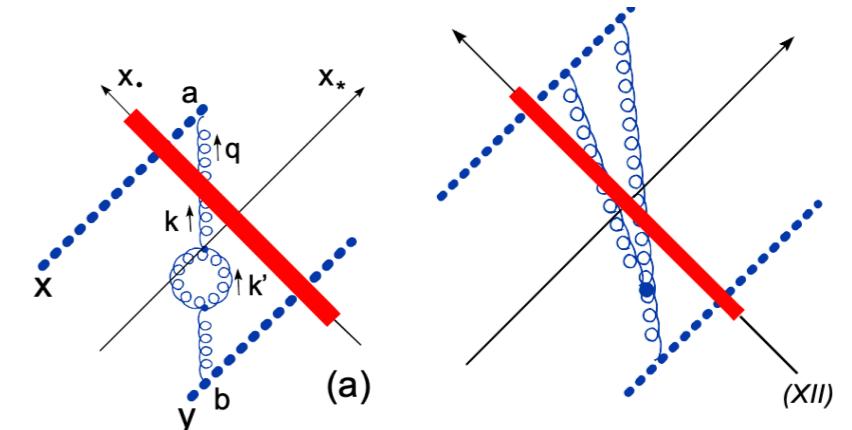
Y. Hatta, E. Iancu (2016)

NLL with massive quarks

L. Dai, M. Lublinsky (2022)

running coupling revisited

T. Altinoluk, G. Beuf, A. Kovner,  
M. Lublinsky, V. Skokov (2023)



# Precision frontier for gluon saturation

## Impact factors at NLO

### Structure functions

- |                |  |
|----------------|--|
| light quarks   | I. Balitsky, G. Chirilli (2011)<br>G. Beuf (2017) H. Hänninen, T. Lappi, R. Paatelainen (2017) |
| massive quarks | G. Beuf, T. Lappi, R. Paatelainen (2021,2022)  |

### Diffractive processes in DIS

- |                               |   |
|-------------------------------|---|
| dijets and light vector meson | R. Boussarie, A. Grabovsky, D. Ivanov, L. Szymanowski, S. Wallon (2016) |
| vector meson                  | H. Mäntysaari, J. Penttala (2021, 2022)                                 |
| single hadron                 | M. Fucilla, A. Grabovsky, E. Li, L. Szymanowski, S. Wallon (2023)       |

### Semi-inclusive processes in DIS

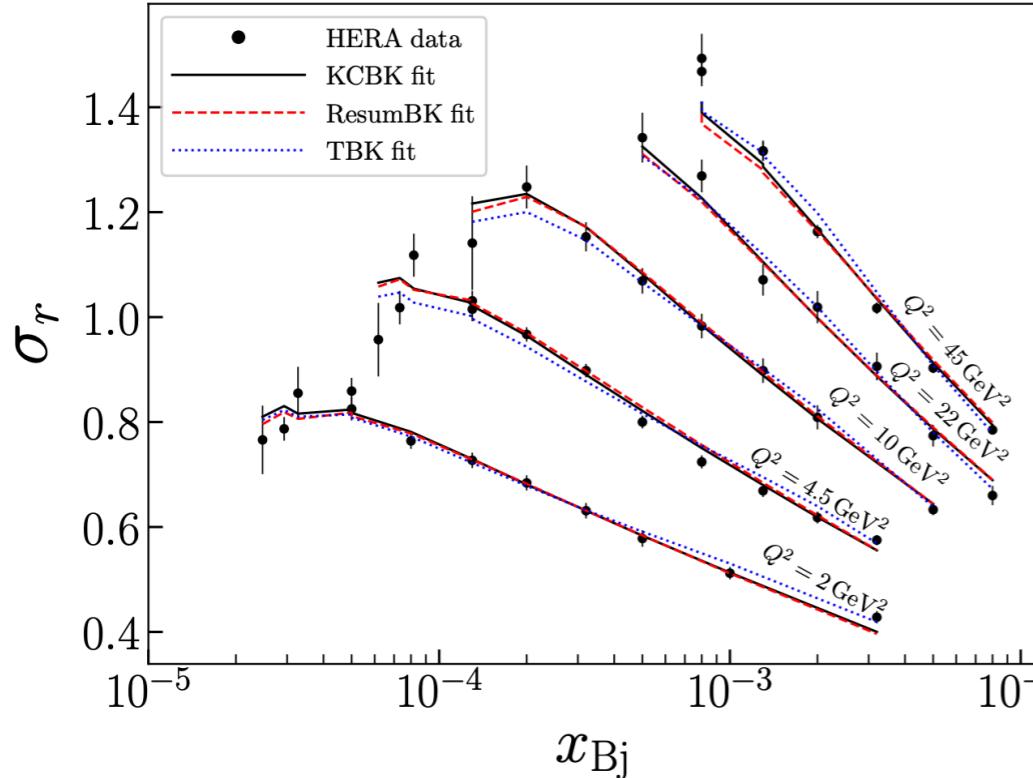
- |                                 |  |
|---------------------------------|--|
| dijet+photon                    | K. Roy, R. Venugopalan (2019)                      |
| dijets                          | P. Caucal, FS, R. Venugopalan (2021)               |
| dijets (photo-production limit) | P. Taels, T. Altinoluk, G. Beuf, C. Marquet (2022) |
| dihadron, and SIDIS             | F. Bergabo, J. Jalilian-Marian (2022)              |

### Semi-inclusive processes in pA

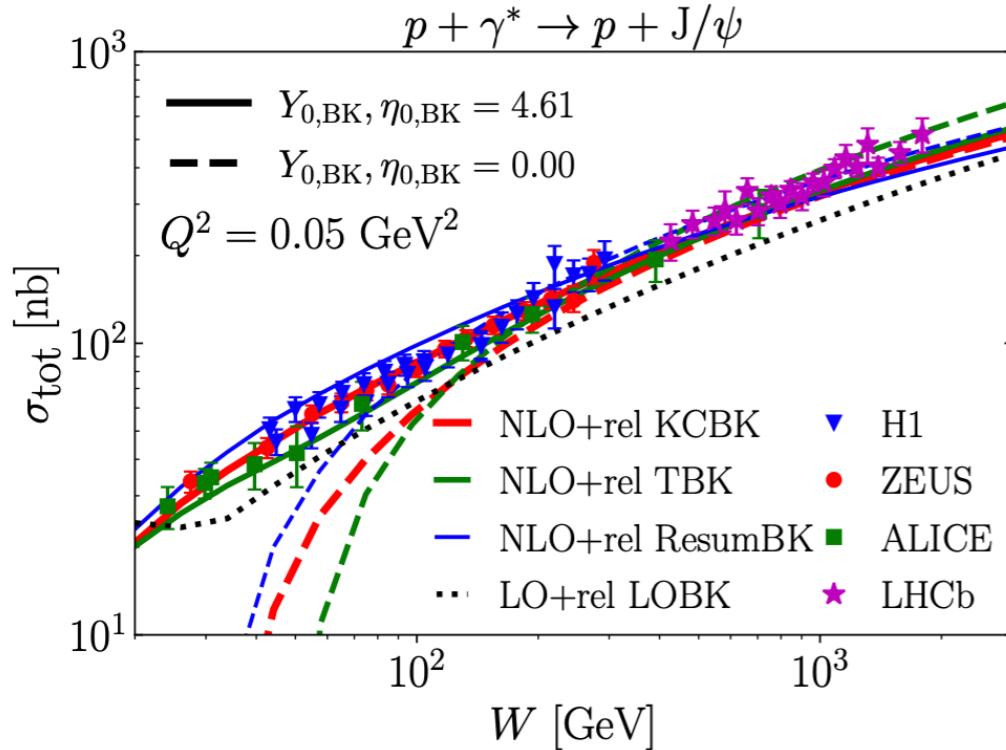
- |               |  |
|---------------|--|
| single hadron | G. Chirilli, B. Xiao, F. Yuan (2012)     |
| single jet    | H.Y. Liu, K. Xie, Z. Kang, X. Liu (2022) |

# Precision frontier for gluon saturation

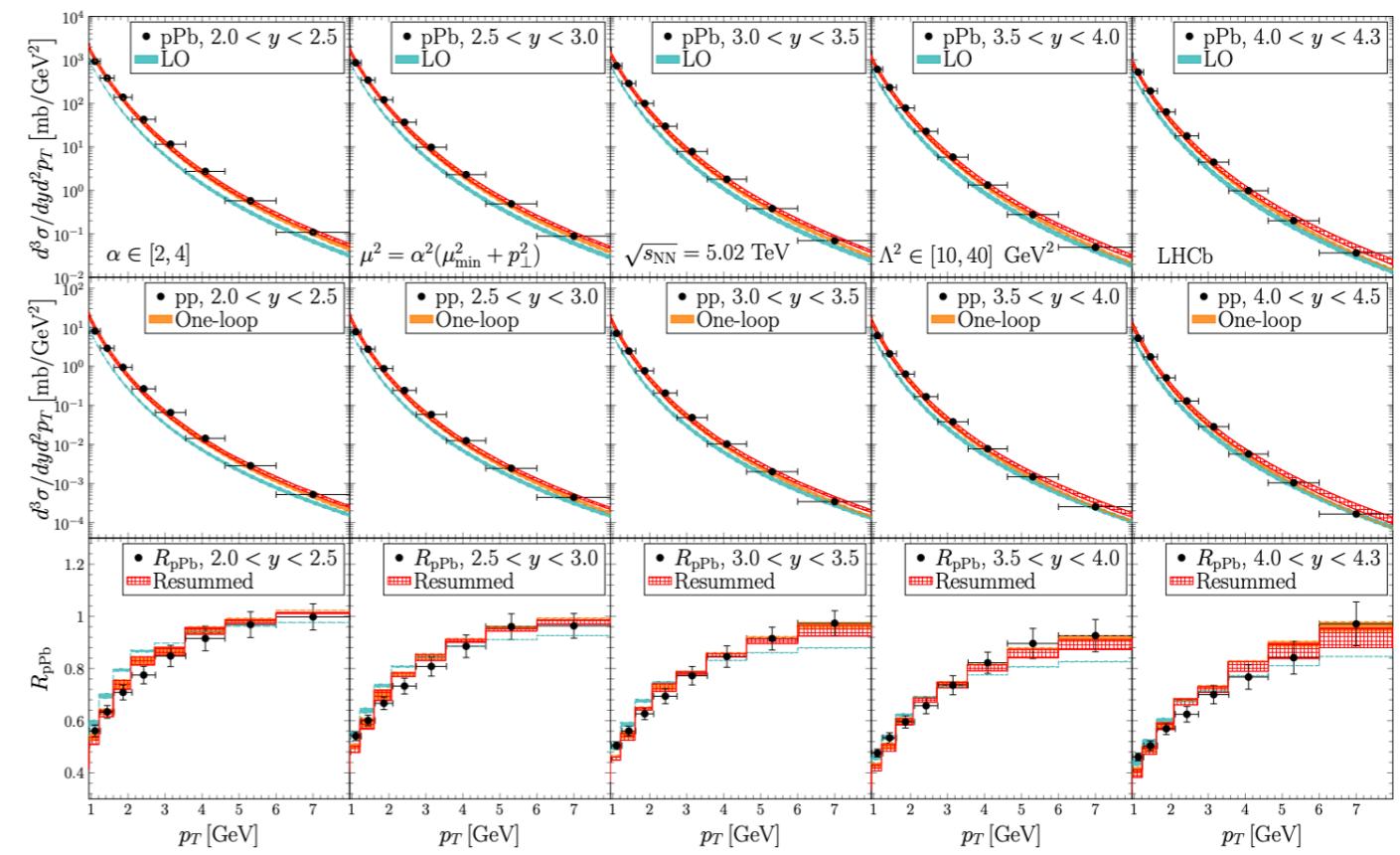
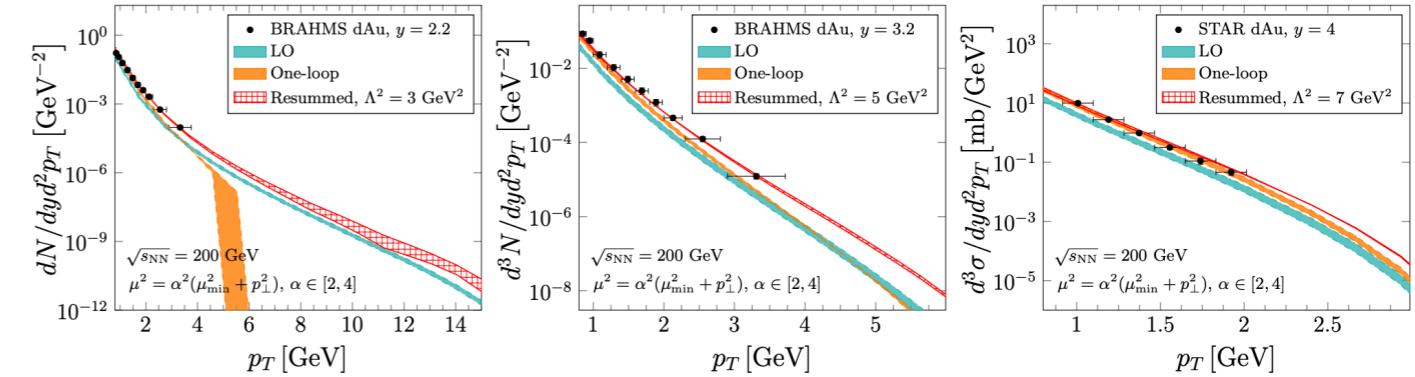
## Saturation physics at NLO



Beuf, Lappi, Hänninen, Mäntysaari (2020)



Mäntysaari, Penttala (2022)



Shi, Wang, Wei, Xiao (2021)

# Precision frontier for gluon saturation

Lots of recent progress in understanding saturation physics in the precision era (NLO) with focus on fully inclusive process or one-particle production

The more differential the process (e.g. two-particle correlations) the harder the calculations (both analytically and numerically)

Our goal:

Promote two-particle observables in saturation to NLO

Observable:

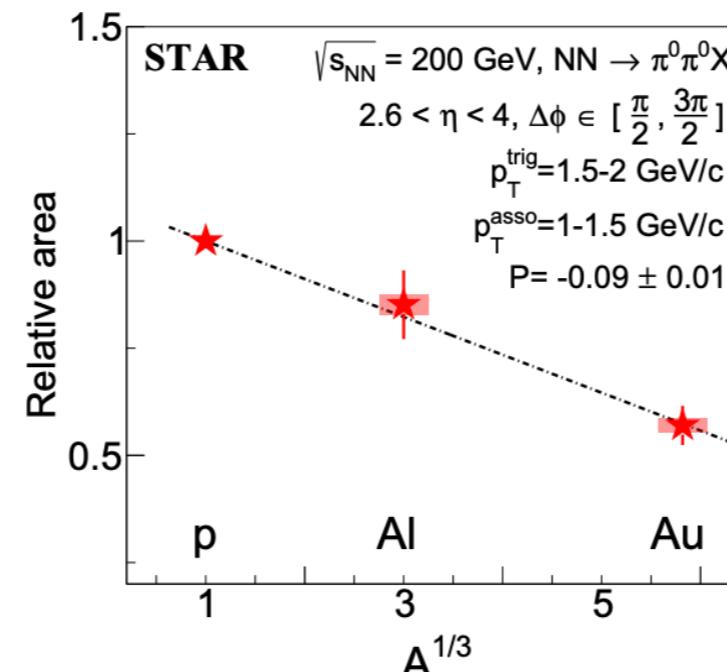
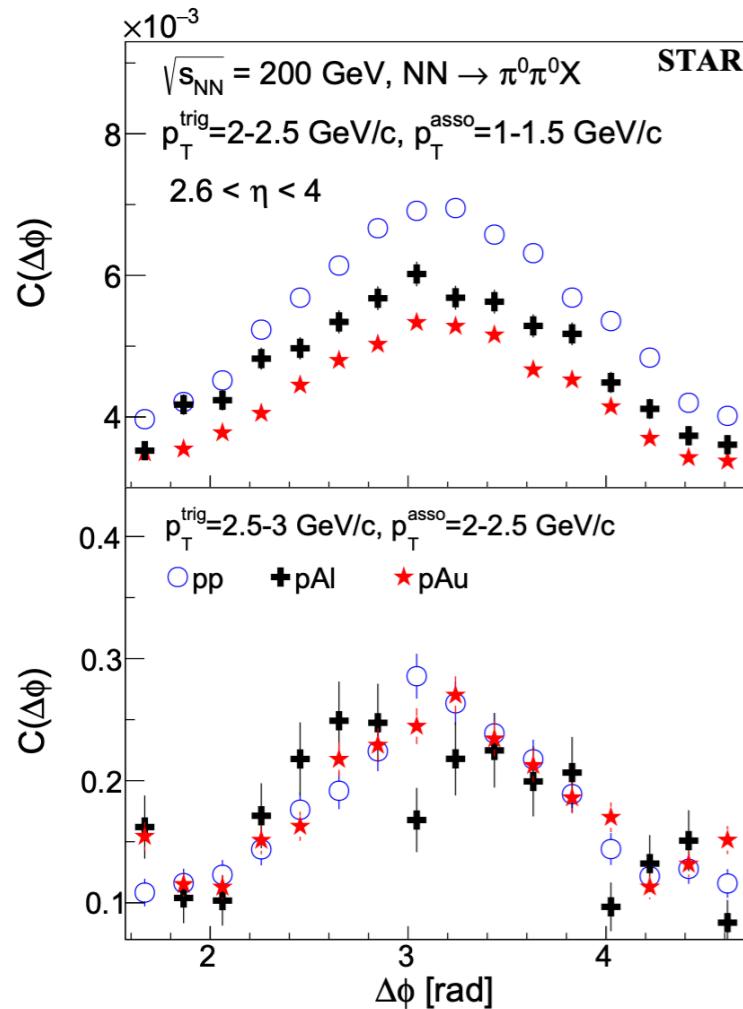
Inclusive Dijet production in DIS

Why?

Will be measured at EIC and theoretically clean

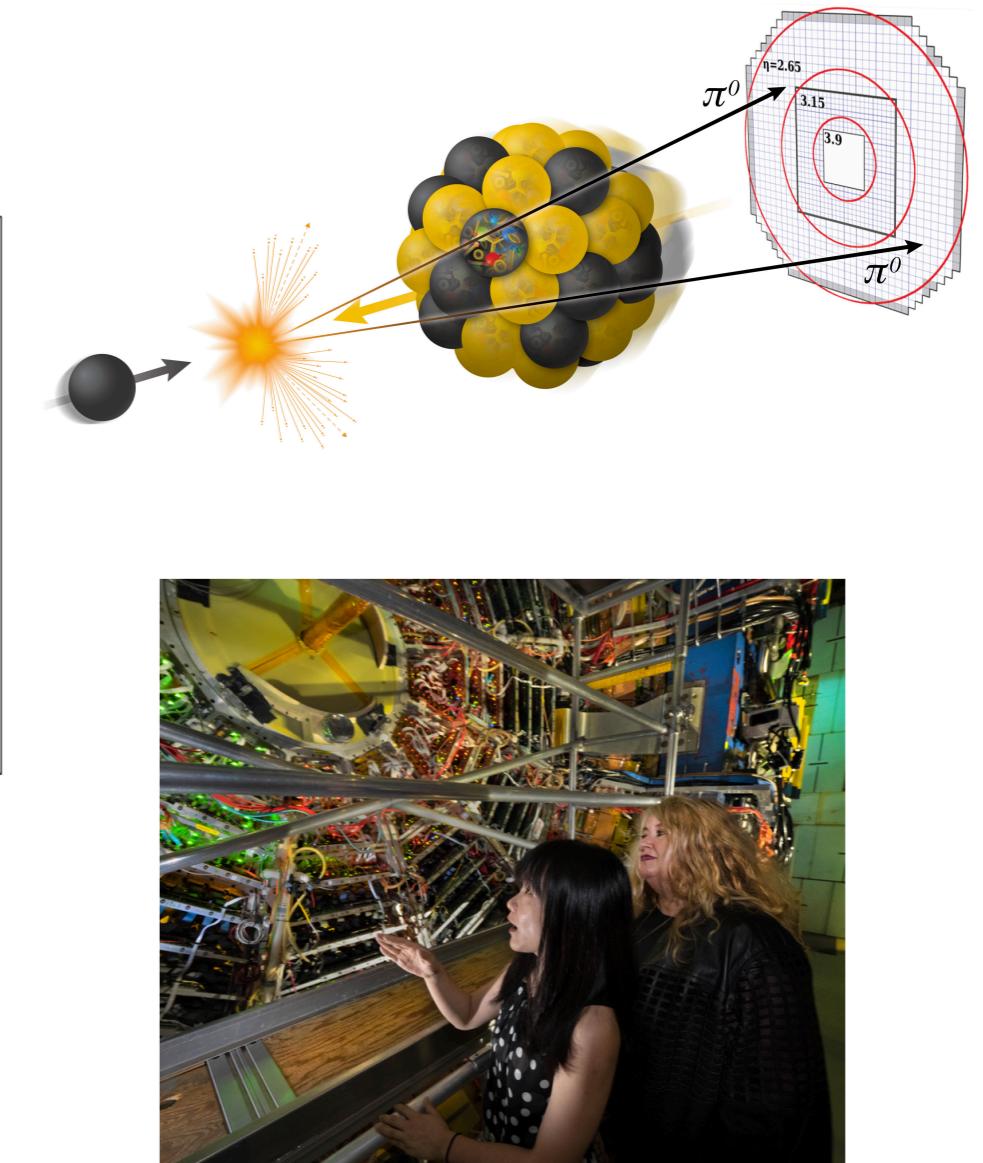
# Azimuthal correlations a window to gluon saturation

Evidence for Nonlinear Gluon Effects in QCD and Their Mass Number Dependence at STAR



Suppression characteristic  
of saturation

$$Q_s^2 \propto A^{1/3}$$



STAR Collaboration  
*Phys. Rev. Lett.* 129, 092501 (2022)

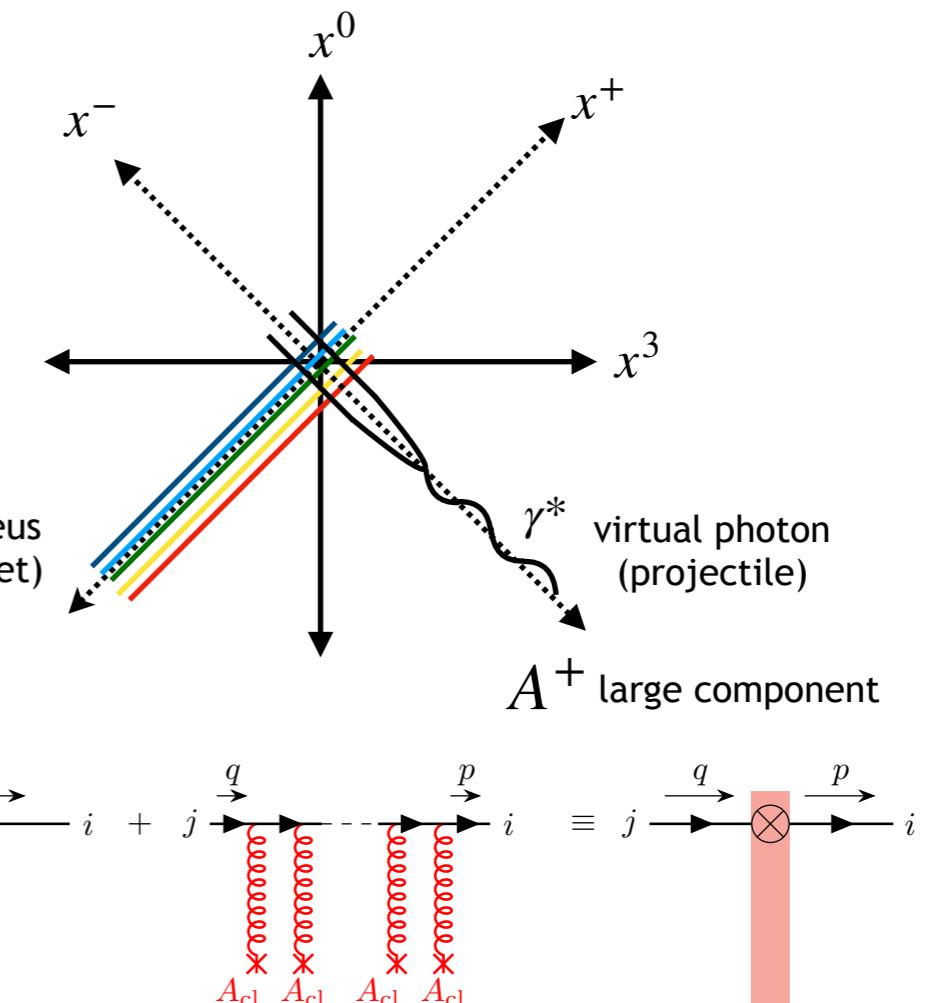
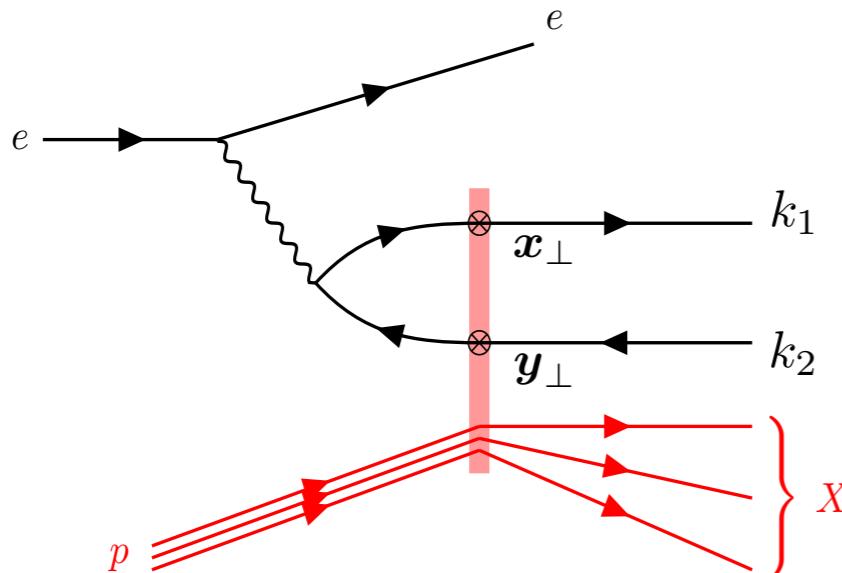
Xiaoxuan Chu and Elke Aschenauer

What about dihadron production at the EIC?

# Dijet production in DIS at LO

## Dijet azimuthal correlations in DIS

Jalilian-Marian, Gelis (2003)



Unpolarized differential cross-section:

$$d\sigma_{\text{LO}} = \boxed{\mathcal{H}(Q, P_\perp; l_\perp, l'_\perp)} \otimes_{l_\perp, l'_\perp} \boxed{\mathcal{G}(q_\perp; l_\perp, l'_\perp)}$$

Perturbatively calculable

$q\bar{q}$  interaction with nucleus

First numerical evaluation of dijet production in DIS within CGC:

PHYSICAL REVIEW LETTERS 124, 112301 (2020)

Multigluon Correlations and Evidence of Saturation from Dijet Measurements at an Electron-Ion Collider

Heikki Mäntysaari<sup>1,2,\*</sup>, Niklas Mueller,<sup>3,†</sup>, Farid Salazar<sup>1,3,‡</sup>, and Björn Schenke<sup>3,§</sup>

# Dijet production in DIS at NLO



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## Dijet impact factor in DIS at next-to-leading order in the Color Glass Condensate

Paul Caucal,<sup>a</sup> Farid Salazar<sup>a,b,c</sup> and Raju Venugopalan<sup>a</sup>

- Divergences: UV, soft and collinear

Dimensional regularization + longitudinal momentum cut-off + small-R cone algorithm

$$\int_{\Lambda^-} \frac{dk_g^-}{k_g^-} \mu^\varepsilon \int \frac{d^{2-\varepsilon} k_{g\perp}}{(2\pi)^{2-\varepsilon}} f_{\Lambda^-}(k_g^-, k_{g\perp})$$

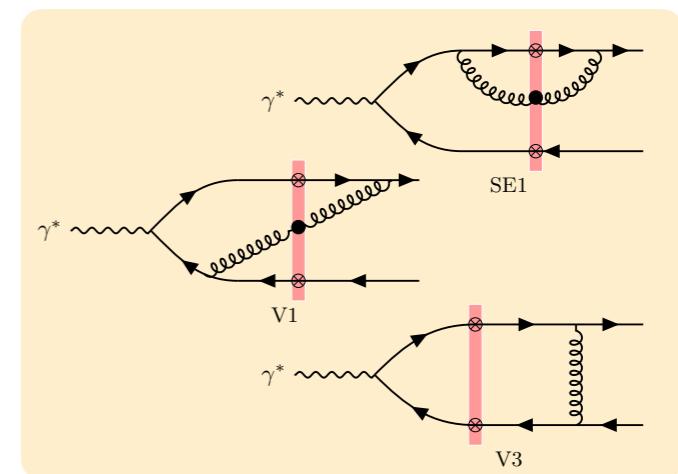
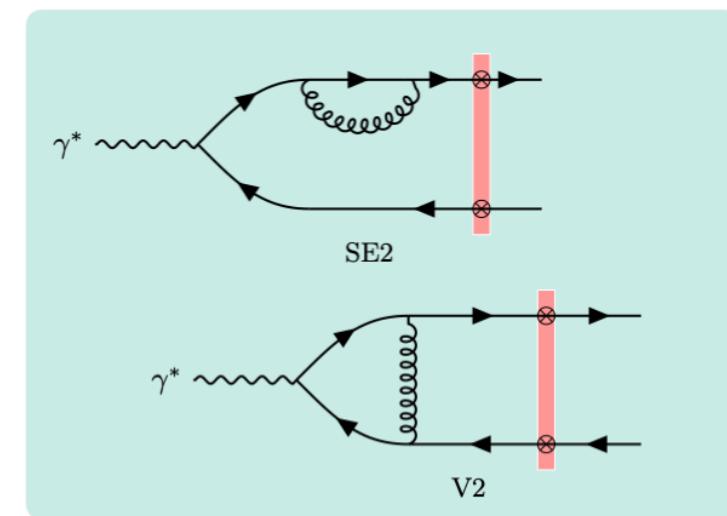
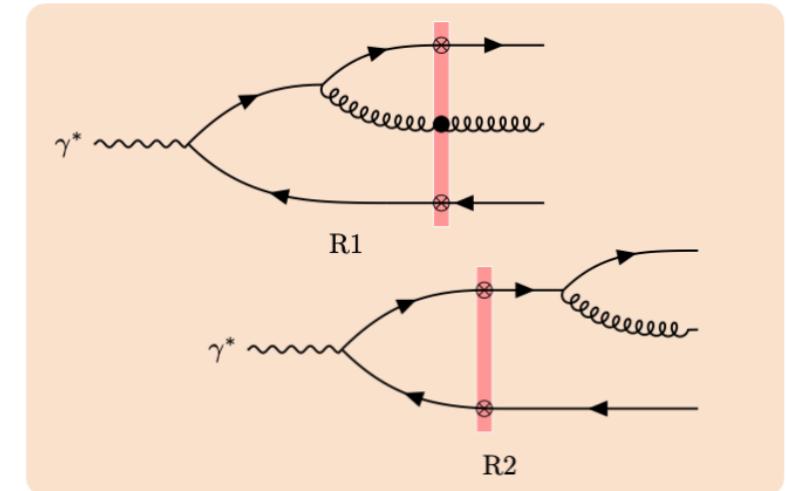
- Large rapidity (high-energy) logs

Resummed via JIMWLK renormalization

- Impact factor

Finite piece (free of large rapidity logs), but might contain other (potentially) large logs!

- We showed cancellation of UV, soft and collinear divergences
- Absorbed large energy/rapidity logs into JIMWLK resummation
- Isolated genuine  $\mathcal{O}(\alpha_s)$  contributions (aka impact factor)



# Dijet production in DIS at NLO

Evolution and impact factor

$$d\sigma_{\text{NLO}} = \int_{z_0} \frac{dz_g}{z_g} d\tilde{\sigma}_{\text{NLO}}(z_g)$$

$$d\sigma_{\text{NLO}} = \boxed{\int_{z_0} \frac{dz_g}{z_g} d\tilde{\sigma}_{\text{NLO}}(0)} + \boxed{\int_{z_0} \frac{dz_g}{z_g} [d\tilde{\sigma}_{\text{NLO}}(z_g) - d\tilde{\sigma}_{\text{NLO}}(0)]}$$

Impact factor

JIMWLK factorization

$$d\tilde{\sigma}_{\text{NLO}}(0) = H_{\text{LL}} d\sigma_{\text{LO}} = \mathcal{H} \otimes H_{\text{LL}} \mathcal{G}$$

$$d\sigma_{\text{LO+LL}} = \mathcal{H}(Q, P_\perp; \mathbf{l}_\perp, \mathbf{l}'_\perp) \otimes_{\mathbf{l}_\perp, \mathbf{l}'_\perp} \mathcal{G}_Y(\mathbf{q}_\perp; \mathbf{l}_\perp, \mathbf{l}'_\perp)$$

$$Y = \ln(z_g) \quad \frac{\partial \mathcal{G}}{\partial Y} = H_{\text{LL}} \mathcal{G} \quad \text{JIMWLK RG evolution}$$

Explicit expression for impact factor provided in Caucal, Salazar, Venugopalan (2021)

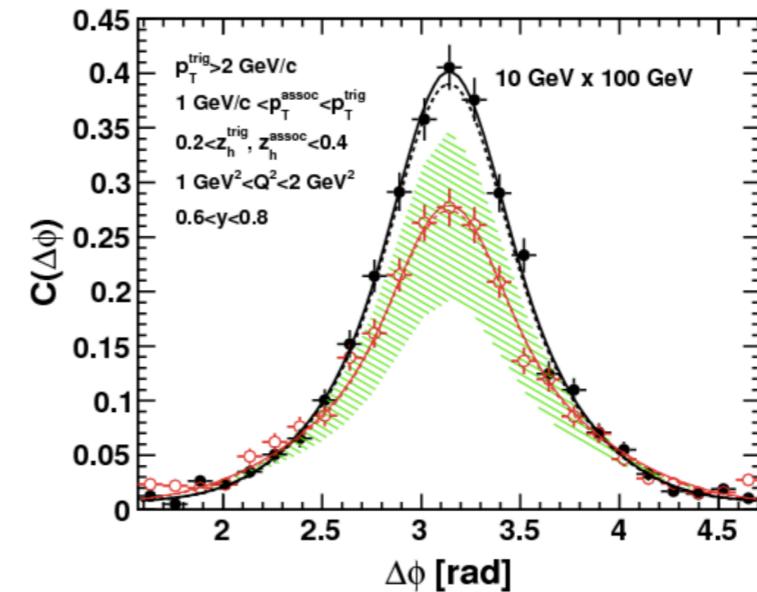
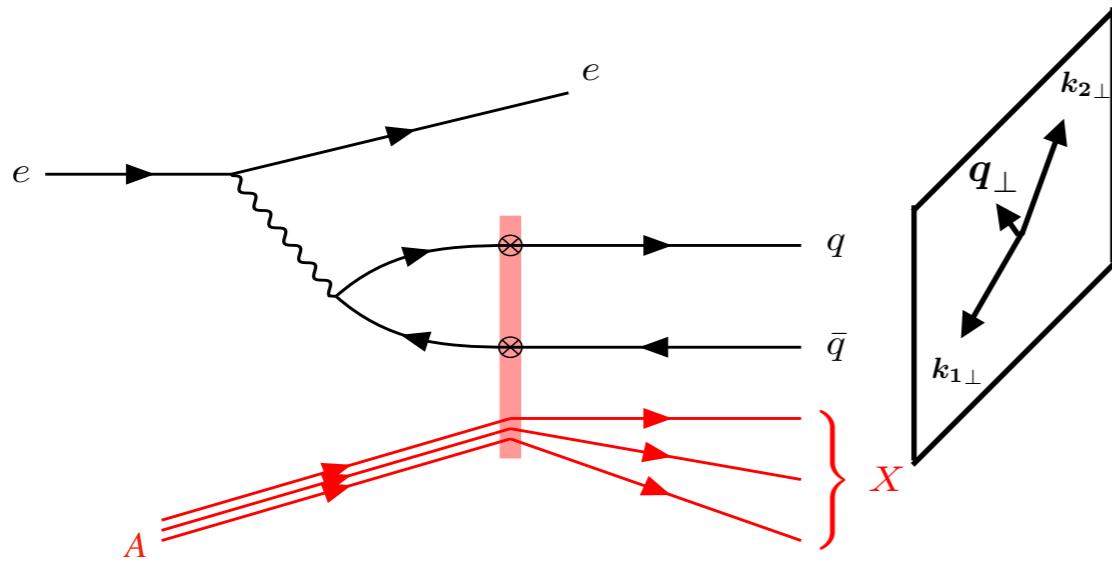
# Back-to-back dijets at LO

Small-x TMD factorization from CGC

F. Dominguez, C. Marquet, B-W. Xiao, F. Yuan (2011)

In the “correlation limit”  $q_\perp, Q_s \ll P_\perp$  and high-energy limit  $P_\perp \ll W$

↳ Forward-jets (photon direction) but close to back-to-back in the transverse plane



Zheng, Aschenauer,  
Lee, Xiao (2014)

Perturbatively calculable

$$d\sigma_{\text{LO}} = \mathcal{H}^{ij}(Q, P_\perp) G_Y^{ij}(q_\perp)$$

$$G_Y^{ij}(q_\perp) = \frac{-2}{\alpha_s} \int \frac{d^2 b_\perp d^2 b'_\perp}{(2\pi)^4} e^{-i q_\perp \cdot (b_\perp - b'_\perp)} \left\langle \text{Tr} \left[ V(b_\perp) \partial_\perp^i V^\dagger(b_\perp) V(b'_\perp) \partial_\perp^j V^\dagger(b'_\perp) \right] \right\rangle_Y$$

“Bare” TMD built from Wilson lines correlators, saturation scale  $Q_s$  implicitly built-in

Nuclear dependence  $Q_s^2 \propto A^{1/3}$

# Back-to-back dijets at NLO

Interplay of small- $x$  & soft gluon resummation

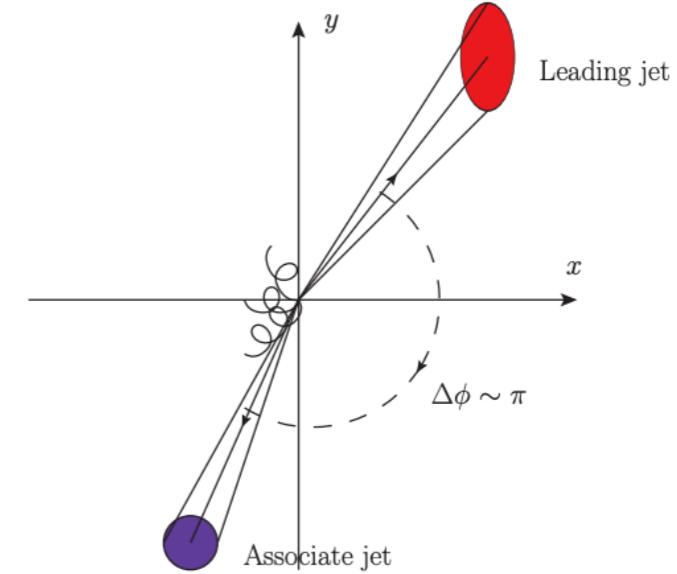
A.H. Mueller, B-W. Xiao, F. Yuan (2013)

$$q_\perp^2 \ll P_\perp^2 \ll s$$

$$\ln(s/P_\perp^2)$$

$$\ln^2(P_\perp^2/q_\perp^2)$$

Joint small- $x$  + Sudakov resummation



$$d\sigma = \mathcal{H}(Q, \mathbf{P}_\perp) \int \frac{d^2 \mathbf{r}_{bb'}}{(2\pi)^2} e^{-i\mathbf{q}_\perp \cdot \mathbf{r}_{bb'}} \tilde{G}_Y^0(\mathbf{r}_{bb'}) e^{-S_{\text{Sud}}(\mathbf{r}_{bb'}, \mathbf{P}_\perp)}$$

Sudakov factor:

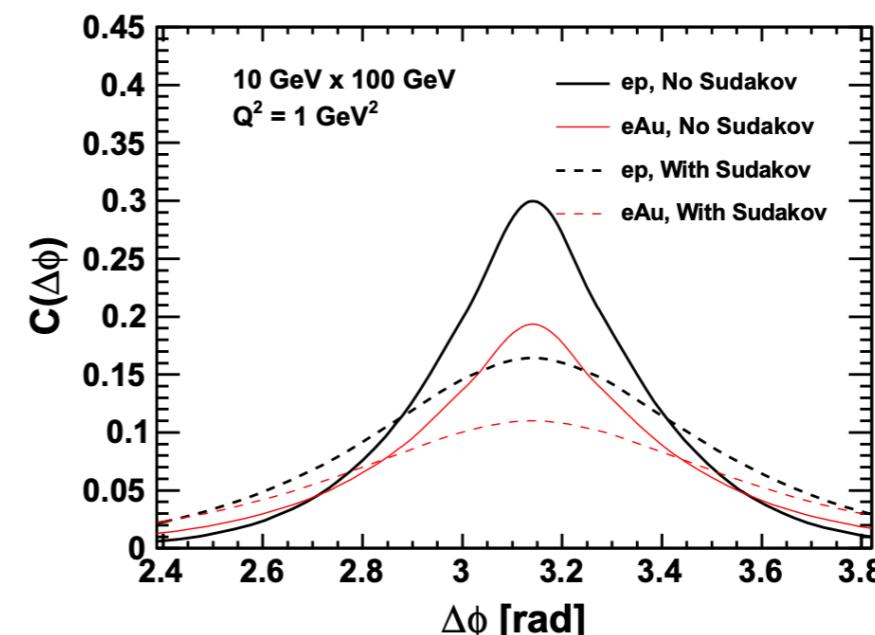
$$S_{\text{Sud}}(\mathbf{r}_{bb'}, P_\perp) = \frac{\alpha_s N_c}{\pi} \int_{c_0^2/\mathbf{r}_{bb'}^2}^{P_\perp^2} \frac{1}{2} \ln \left( \frac{P_\perp^2}{\mu^2} \right)$$

$\tilde{G}_Y$  obeys JIMWLK equation (non-linear)

(see also Dominguez, Mueller, Munier, Xiao 2013)

Soft gluon emissions change profile  
of azimuthal correlations

Zheng, Aschenauer, Lee, Xiao 2013



# Our goal:

Does the CGC/TMD correspondence hold at NLO?

$$d\sigma_{\text{NLO}} = \mathcal{H}_{\text{LO+NLO}}^{ij}(Q, \mathbf{P}_\perp) \int \frac{d^2 b_\perp}{(2\pi)^2} e^{-i \mathbf{q}_\perp \cdot \mathbf{r}_{bb'}} \tilde{G}_Y^{ij}(\mathbf{r}_{bb'}) e^{-S_{\text{Sud}}(\mathbf{r}_{bb'}, \mathbf{P}_\perp)}$$

- i) Is this evolution equation related to non-local RG equation known in small-x literature?
- ii) Is it possible to pin down the Sudakov double and single logs?
- iii) Is it possible to express the finite pieces in terms of a factorizable NLO coefficient function and the WW gluon TMD? Or do we expect factorization-breaking contributions?
- iv) Can we account both for unpolarized and linearly polarized contributions?

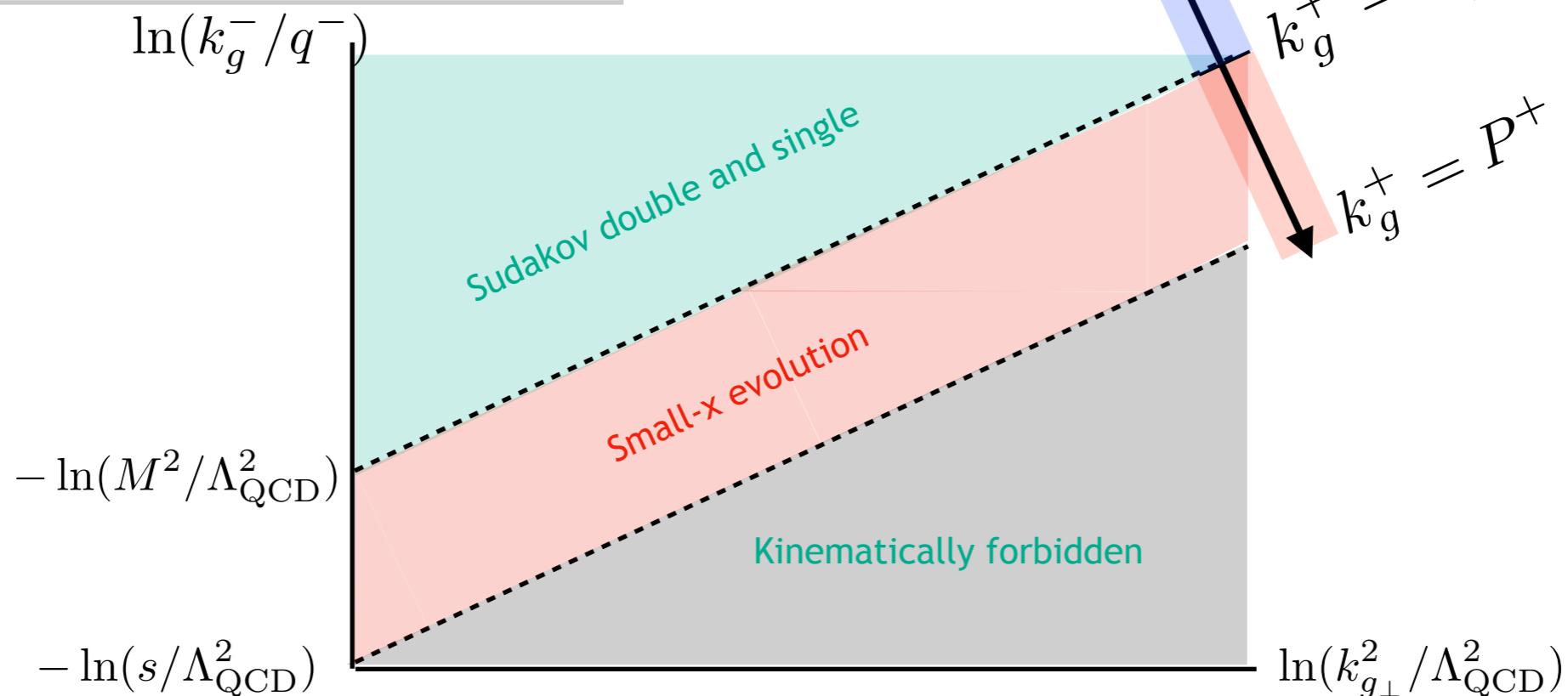
Ian Balitsky has worked extensively in this direction within “rapidity-only factorization” at operator level

# Phase space for small- $x$ resummation



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**Back-to-back inclusive dijets in DIS at small  $x$ :  
Sudakov suppression and gluon saturation at NLO**  
Paul Caucal,<sup>a</sup> Farid Salazar,<sup>b,c,d,e</sup> Björn Schenke<sup>a</sup> and Raju Venugopalan<sup>a</sup>

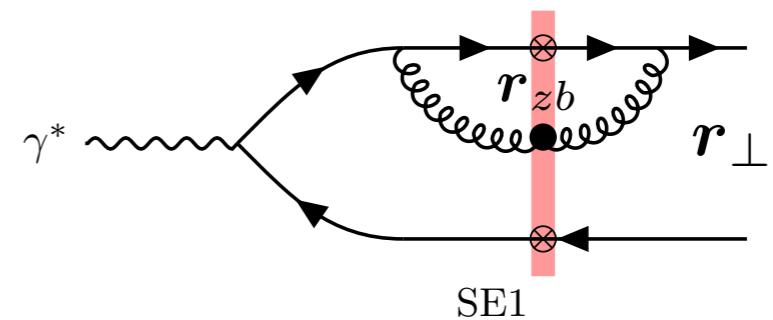


Examining “rapidity divergent term ”more closely

$$d\tilde{\sigma}_{\text{NLO}}(z_g) = H_{\text{LL}} d\sigma_{\text{LO}} \quad \text{if} \quad z_g r_{zb}^2 \lesssim z_1 z_2 r_\perp^2 \longrightarrow k_f^+ = \frac{Q_f^2}{2k_f^-} \sim \frac{M^2}{2q^-}$$

Kinematically constrained JIMWLK

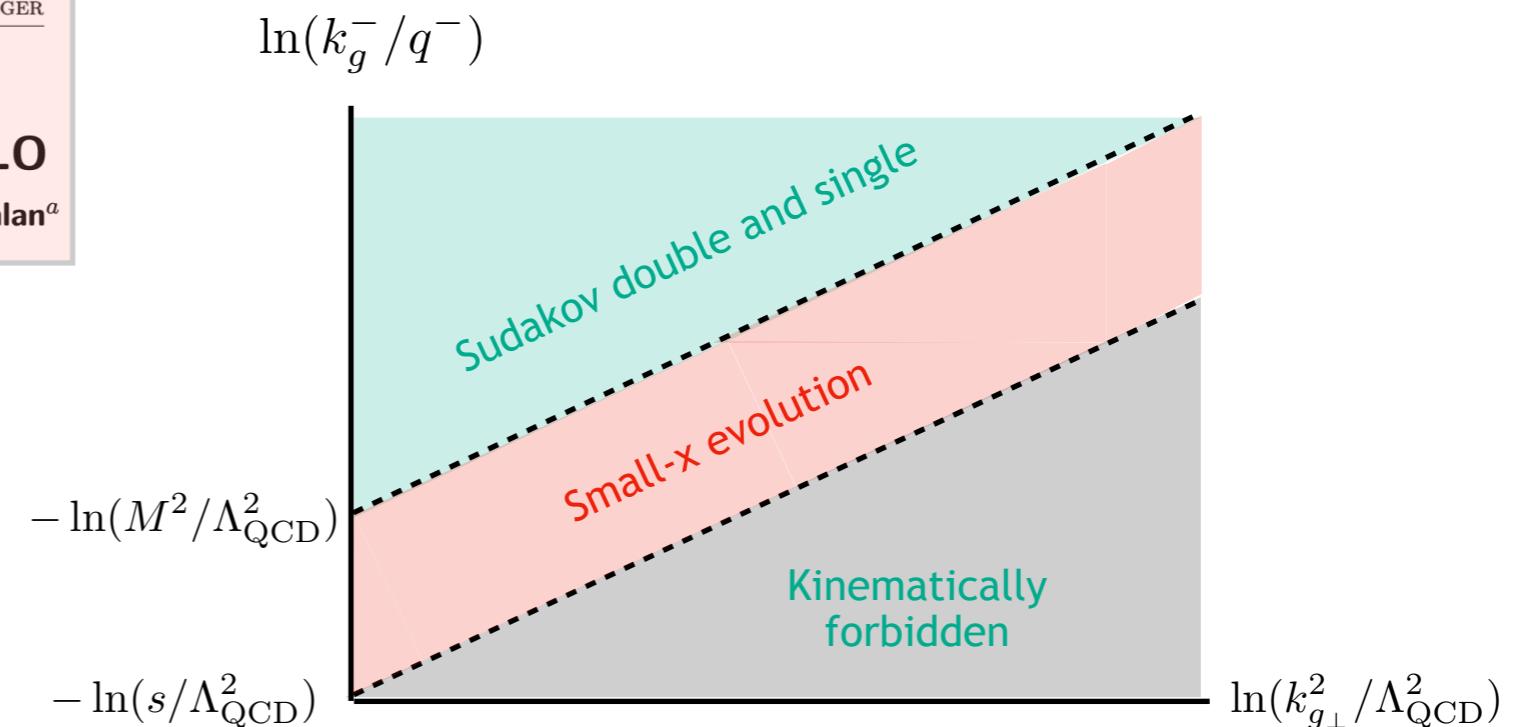
$$\frac{\partial \mathcal{G}}{\partial Y} = H_{\text{LL}} \Theta \left( 1/(z_g Q_f^2) - r_<^2 \right) \mathcal{G}$$



# Sudakov and small-x resummation I

**Back-to-back inclusive dijets in DIS at small  $x$ :  
Sudakov suppression and gluon saturation at NLO**  
Paul Caucal,<sup>a</sup> Farid Salazar,<sup>b,c,d,e</sup> Björn Schenke<sup>a</sup> and Raju Venugopalan<sup>a</sup>

**Small-x evolution for WW**  
follows well-known BK-JIMWLK  
equations amended with a  
**kinematic constrain** to separate  
**small-x** and **soft gluons**



$$d\sigma_{\text{NLO}} = \mathcal{H}(Q, \mathbf{P}_\perp) \int \frac{d^2 \mathbf{r}_{bb'}}{(2\pi)^2} e^{-i \mathbf{q}_\perp \cdot \mathbf{r}_{bb'}} \tilde{G}_Y^0(\mathbf{r}_{bb'}) [1 - S_{\text{Sud}}(\mathbf{r}_{bb'}, \mathbf{P}_\perp)] + \mathcal{O}(\alpha_s^2)$$

$$\frac{\partial G}{\partial Y} = H_{\text{LL}} \Theta \left( 1/(z_g Q_f^2) - r_<^2 \right) G$$

$$S_{\text{Sud}}(\mathbf{r}_{bb'}, P_\perp) = \frac{\alpha_s N_c}{\pi} \int_{c_0^2/\mathbf{r}_{bb'}^2}^{P_\perp^2} \frac{d\mu^2}{\mu^2} \left[ \frac{1}{2} \ln \left( \frac{P_\perp^2}{\mu^2} \right) + B_0 \right]$$

$$B_0 = \frac{C_F}{N_c} \ln \left( \frac{1}{z_1 z_2 R^2} \right) + \ln \left( \frac{P_\perp^2 + z_1 z_2 Q^2}{P_\perp^2} \right) - 1$$

Finite results apparently involve complicated convolution including operators beyond WW,  
but **needed for precision!**

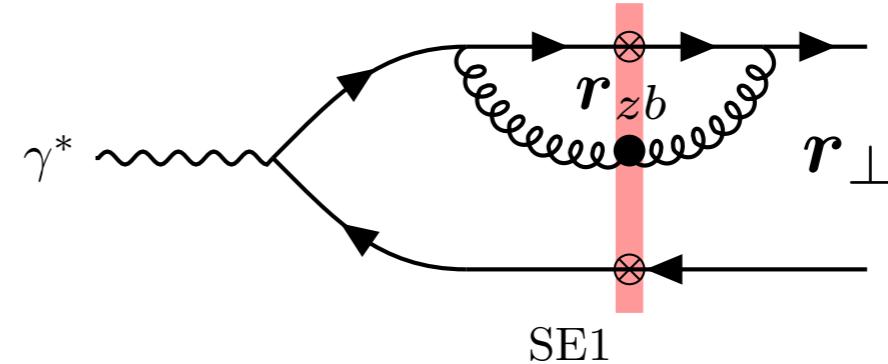
Discrepancy with expected single log from CSS

# Factorization of finite pieces



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**Back-to-back inclusive dijets in DIS at small  $x$ : gluon Weizsäcker-Williams distribution at NLO**  
 Paul Caucal,<sup>a</sup> Farid Salazar,<sup>b,c,d,e</sup> Björn Schenke,<sup>f</sup> Tomasz Stelzel<sup>g</sup>  
 and Raju Venugopalan<sup>f</sup>



Leading power Expansion of all finite pieces  
 can be cast in terms of the WW gluon TMD

Finite contributions can be absorbed into NLO impact factor

$$d\sigma_{\text{NLO}} = \mathcal{H}_{\text{NLO}}(Q, P_\perp; Y, R) \int \frac{d^2 b_\perp}{(2\pi)^2} e^{-i q_\perp \cdot b_\perp} \tilde{G}_Y^0(b_\perp) [1 - S_{\text{Sud}}(b_\perp, P_\perp)] + \mathcal{O}(\alpha_s^3)$$

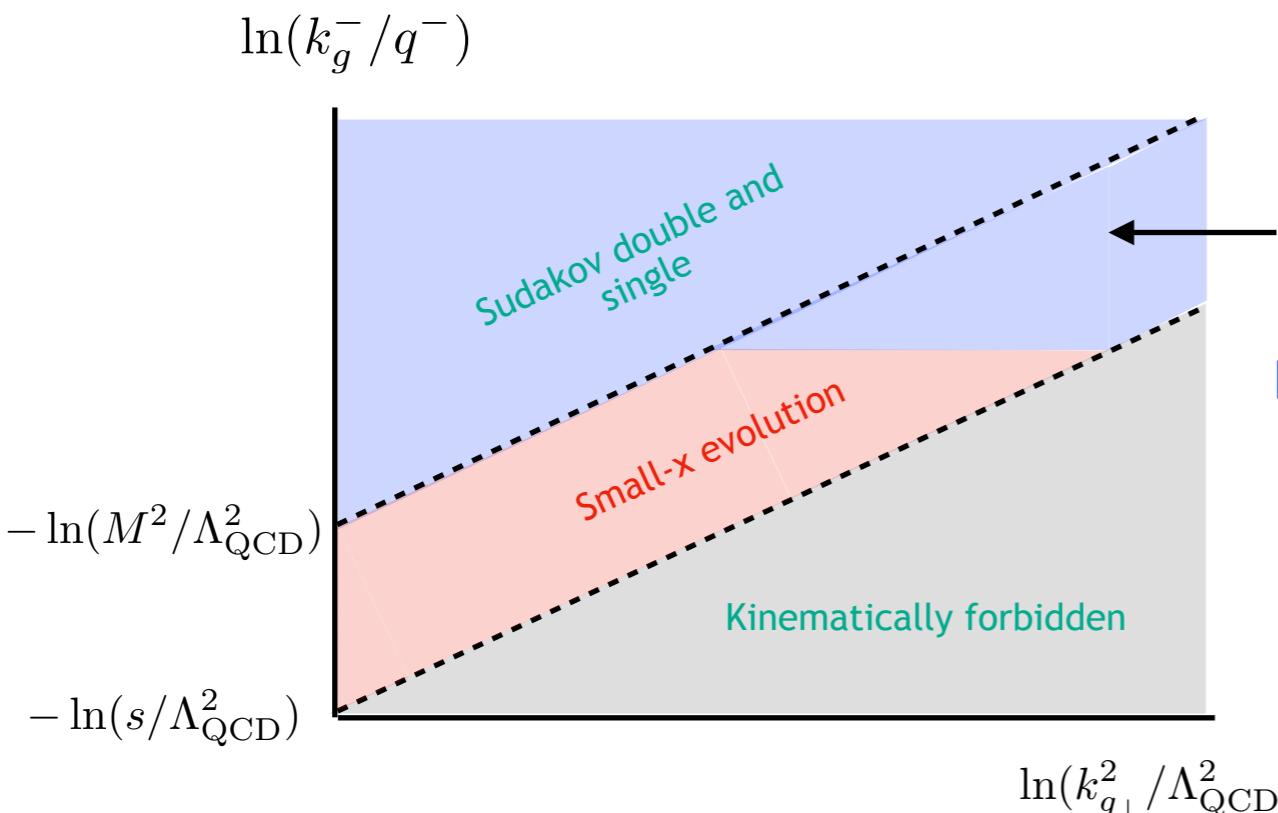
fully analytic result

- TMD-like factorization at NLO in small- $x$  kinematics

Paves the road for

- Efficient numerical implementation and phenomenology

# Sudakov and small-x resummation II



This region contains a Sudakov single log, which exactly cancels the term that caused discrepancy with CSS

Furthermore, it is convenient to formulate the evolution in terms of “target momentum fraction”  $\eta = \ln(k_g^+/P^+)$

The resulting small-x equation (ordered in  $\eta$ ) is the JIMWLK analog of the non-local BK equation found by Ducloué, Ian, Mueller, Soyez, Triantafyllopoulos (2019)

$$d\sigma_{\text{NLO}} = \mathcal{H}_{\text{NLO}}(Q, P_\perp; R) \int \frac{d^2 \mathbf{b}_\perp}{(2\pi)^2} e^{-i \mathbf{q}_\perp \cdot \mathbf{b}_\perp} \tilde{G}_\eta^0(\mathbf{b}_\perp) [1 - S_{\text{Sud}}(\mathbf{b}_\perp, P_\perp)]$$

$$S_{\text{Sud}}(\mathbf{r}_{bb'}, P_\perp) = \frac{\alpha_s N_c}{\pi} \int_{c_0^2/\mathbf{r}_{bb'}^2}^{P_\perp^2} \frac{d\mu^2}{\mu^2} \left[ \frac{1}{2} \ln \left( \frac{P_\perp^2}{\mu^2} \right) + B_0 \right]$$

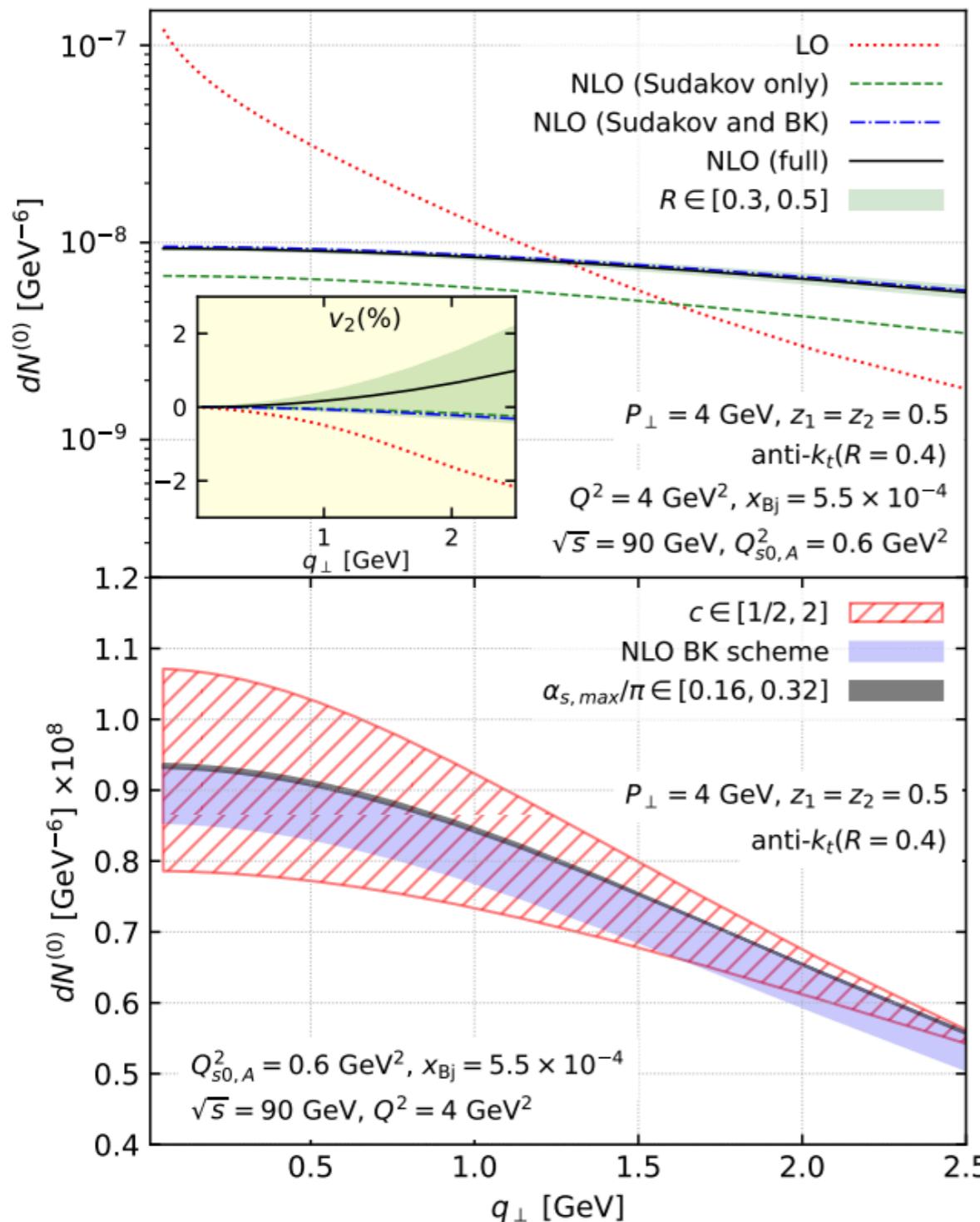
$$B_0 = \frac{C_F}{N_c} \ln \left( \frac{1}{z_1 z_2 R^2} \right) + \ln \left( \frac{P_\perp^2 + z_1 z_2 Q^2}{P_\perp^2} \right) - \frac{\pi}{N_c} \beta_0$$

For phenomenology we will exponentiate Sudakov logs ala CSS

$$[1 - S_{\text{Sud}}(\mathbf{b}_\perp, P_\perp)] \rightarrow \exp(-S_{\text{Sud}}(\mathbf{b}_\perp, P_\perp))$$

Caucal, FS, Schenke, Stebel, Venugopalan  
(preprint 2308.00022)

# Numerical results for the differential cross-section



$dN$  min-bias differential yield

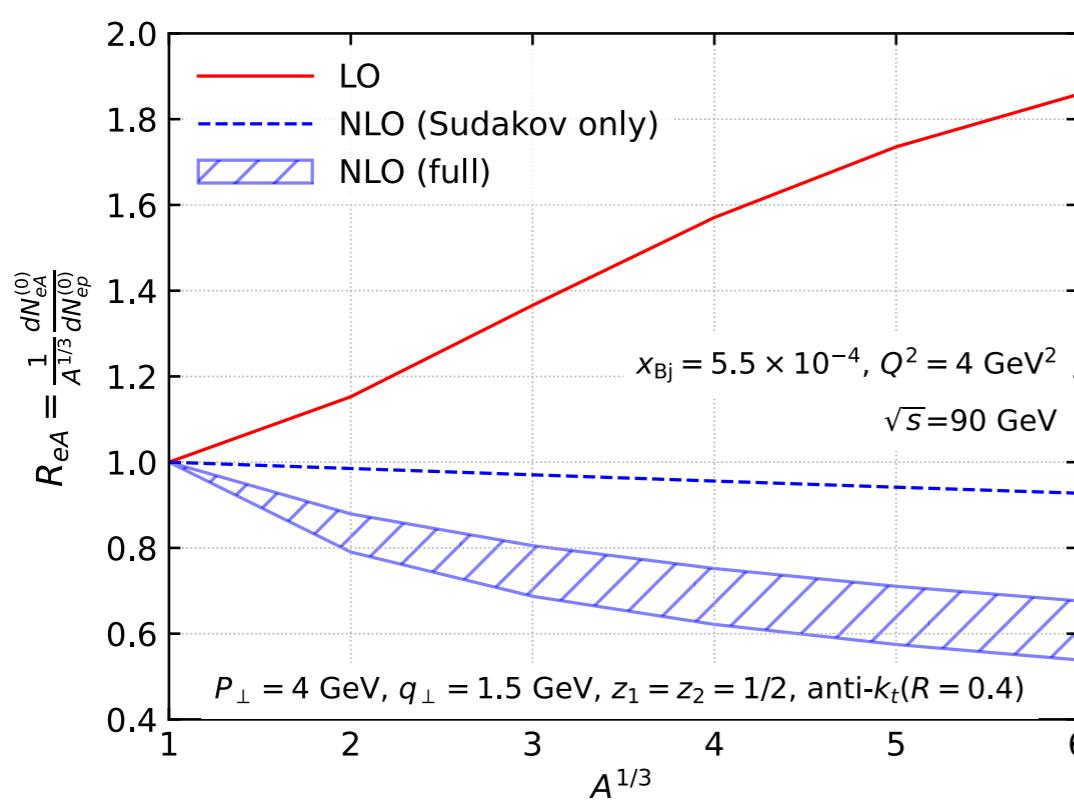
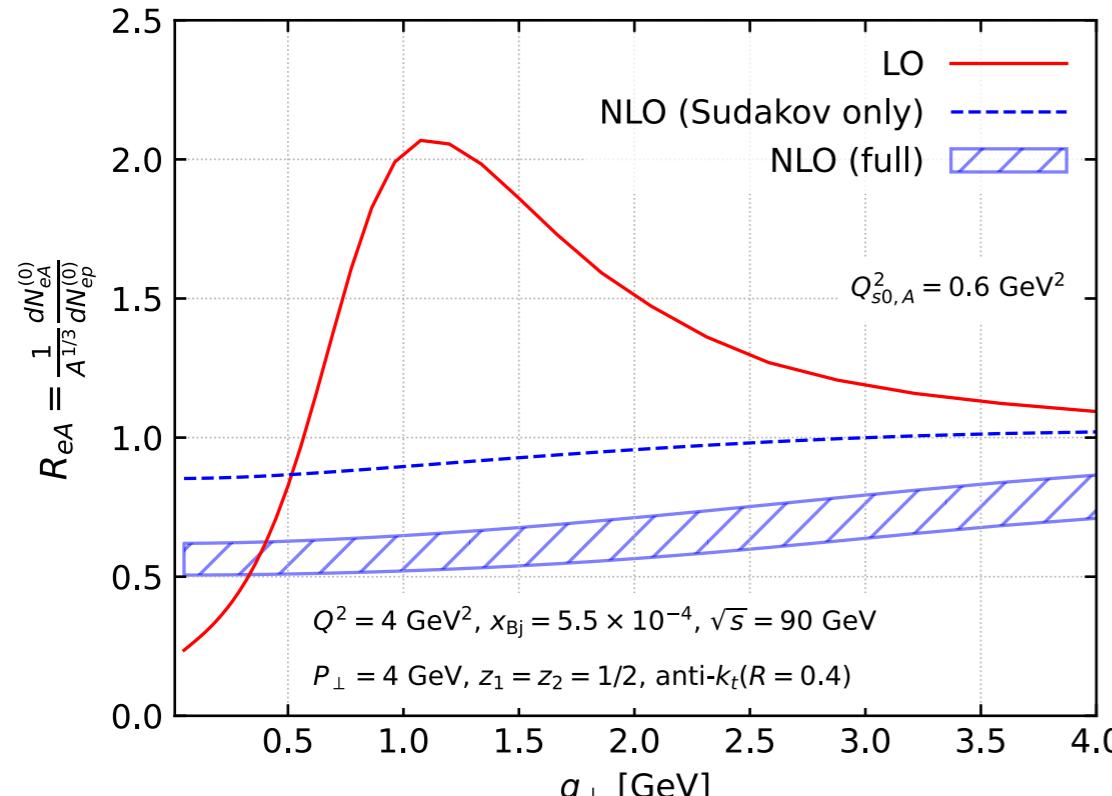
- Sudakov significantly suppresses the yield when  $q_\perp$  is small (back-to-back)
- Small- $x$  evolution results in the growth of the yield (slower at smaller  $q_\perp$   $\rightarrow$  saturation)
- NLO corrections to hard function have a very small effect (at this kinematics)
- Uncertainties:  
Running of the coupling in hard function and Sudakov factor

$$\alpha_s(cP_\perp) \quad \alpha_s(c\mu)$$

NLO BK scheme with or without collinear single log resummation

$\alpha_{max}$ : freezing of the coupling

# Numerical results for nuclear modification ratio



$dN$  min-bias differential yield

$$R_{eA} = \frac{1}{A^{1/3}} \frac{dN_{eA}}{dN_{ep}}$$

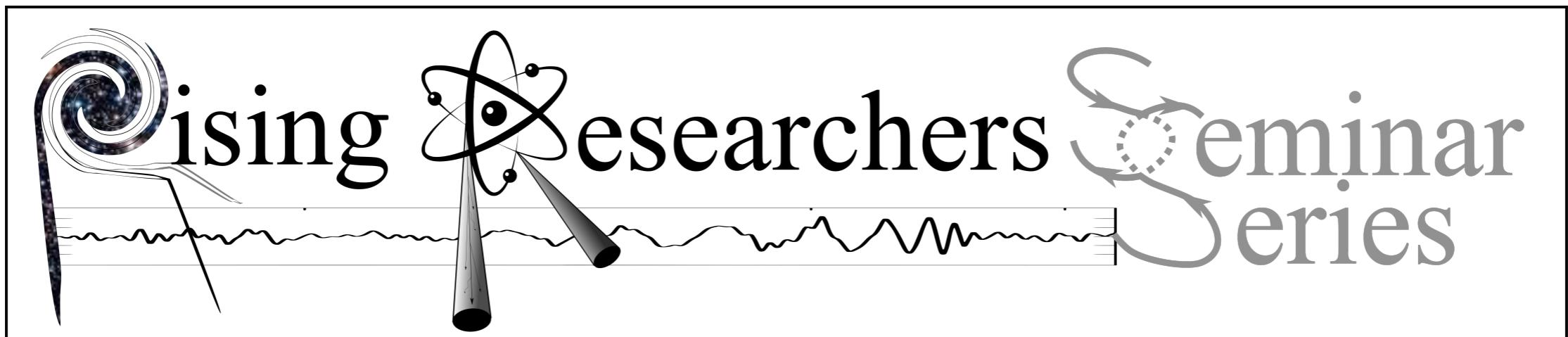
- LO shows suppression and a Cronin peak (broadening)
- NLO (Sudakov only) displays a slight suppression but is close to unity
- Full NLO (Sudakov + small-x evolution) shows a significant A-dependent suppression

# Summary

- Search for **gluon saturation** is one of the **major goals** of the future EIC and upcoming upgrades of the LHC (e.g. Focal)
- The **Color Glass Condensate** is an **EFT** for this **saturated regime** that has been applied to calculate a **variety of processes**.
- We performed a **complete NLO calculation** for dijet production in DIS within the CGC
- We showed **TMD factorization (1-loop)** at small-x holds when jets are back-to-back in the transverse plane
- Provide **numerical predictions** for EIC

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