

Diffraction Structure Functions from JIMWLK Evolution

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Small-x, Diffraction and Vector Mesons



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Outline

1. Introduction

2. Setup

3. Results

4. Conclusions

Introduction

- Goal: predict $x_{\mathbb{P}}$ dependence of diffractive structure functions F_{λ}^D from JIMWLK
- Compare to HERA data for baseline
- Main result: nuclear modification in EIC kinematics

Diffractive DIS: $\ell + A \rightarrow \ell + A + X$

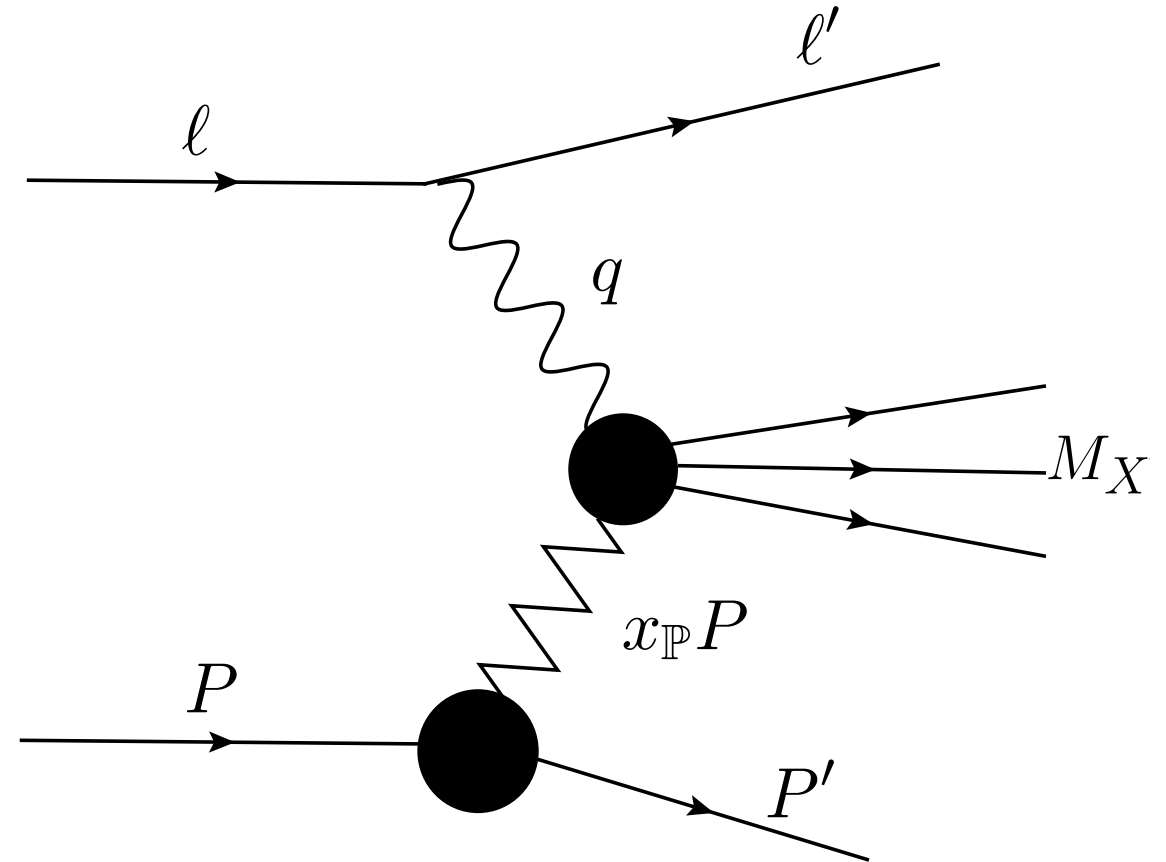
- Relevant kinematical variables:

- β : controls the mass of the final state X
- $Q^2 = -q^2$: virtuality of the photon
- $x_{\mathbb{P}}$: fraction of target momentum carried by the pomeron

$$\beta \equiv \frac{Q^2}{2q \cdot (P - P')} \approx \frac{Q^2}{M_X^2 + Q^2}$$

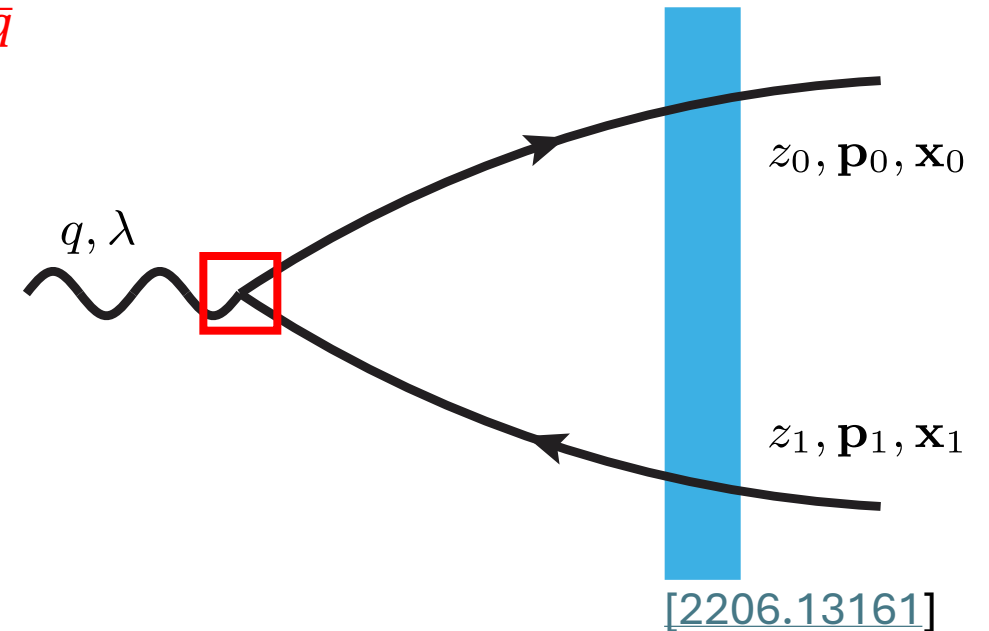
$$x_{\mathbb{P}} \equiv \frac{(P - P') \cdot q}{P \cdot q}$$

$$x_{\mathbb{P}} F_{\lambda}^{D(4)} = \frac{Q^2}{4\pi^2 \alpha_{em}} \frac{Q^2}{\beta} \frac{d\sigma_{\gamma_{\lambda}^* + A}^D}{dM_X^2 dt}$$



Diffractive Cross Section in the Dipole Picture

- LO: virtual photon $\rightarrow q\bar{q}$ dipole wave function $\psi_{\gamma_\lambda^* \rightarrow q\bar{q}}$
- $q\bar{q}g$ contribution is small at $\beta > 0.5$
- Color Glass Condensate (CGC) framework
- Target classical color fields: Wilson lines $V(\mathbf{x})$
- Start from general form for cross section:



$$\sigma_{\gamma_\lambda^* \rightarrow q\bar{q}}^D = \int \frac{d^2\mathbf{p}_0 dp_0^+ d^2\mathbf{p}_1 dp_1^+}{2p_0^+ (2\pi)^3 2p_1^+ (2\pi)^3} 2q^+ 2\pi \delta(p_0^+ + p_1^+ - q^+) N_c$$

$$\int d^2\mathbf{x}_0 \int d^2\mathbf{x}_1 \int d^2\bar{\mathbf{x}}_0 \int d^2\bar{\mathbf{x}}_1 e^{-i\mathbf{x}_{0\bar{0}}(\mathbf{p}_0 - z_0\mathbf{q})} e^{-i\mathbf{x}_{1\bar{1}}(\mathbf{p}_1 - z_1\mathbf{q})}$$

$$\sum_{f, h_0, h_1} \left(\psi_{\gamma_\lambda^* \rightarrow q_0 \bar{q}_1} \right)^\dagger \left(\psi_{\gamma_\lambda^* \rightarrow q_0 \bar{q}_1} \right) \left[S_{0\bar{1}}^\dagger - 1 \right] \left[S_{01} - 1 \right]$$

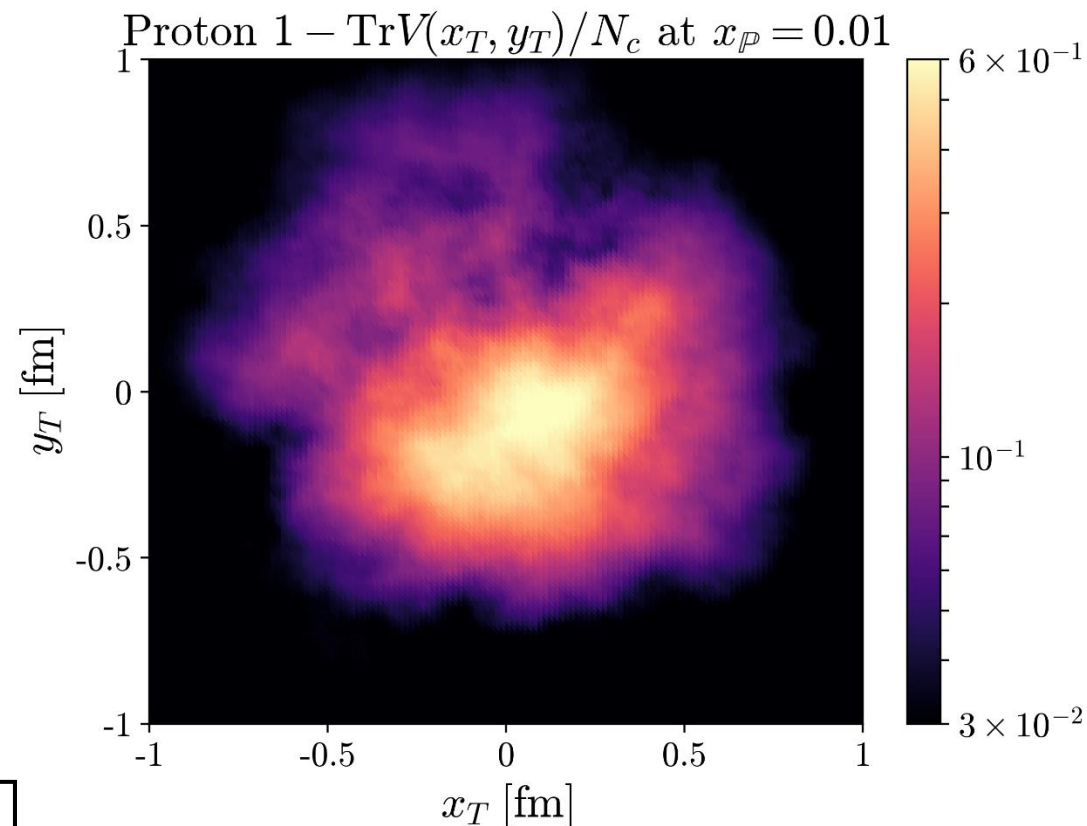
$$S_{01} = \frac{1}{N_c} \text{Tr}[V(\mathbf{x}_0)V^\dagger(\mathbf{x}_1)]$$

The Setup

- MV model initial condition + JIMWLK evolution on a transverse lattice
- Initial geometry IP-Glasma, evolution JIMWLK
- JIMWLK initial condition fitted to exclusive J/ψ [[2207.03712](#)]
- There are no free parameters

$$\frac{d}{dy} V(\mathbf{x}) = V(\mathbf{x}) it^a \left[\int d^2\mathbf{z} \varepsilon_{\mathbf{x},\mathbf{z}}^{ab,i} \xi_{\mathbf{z}}^{b,i}(y) + \sigma^a(\mathbf{x}) \right]$$

$$y = \ln(1/x_{\mathbb{P}})$$



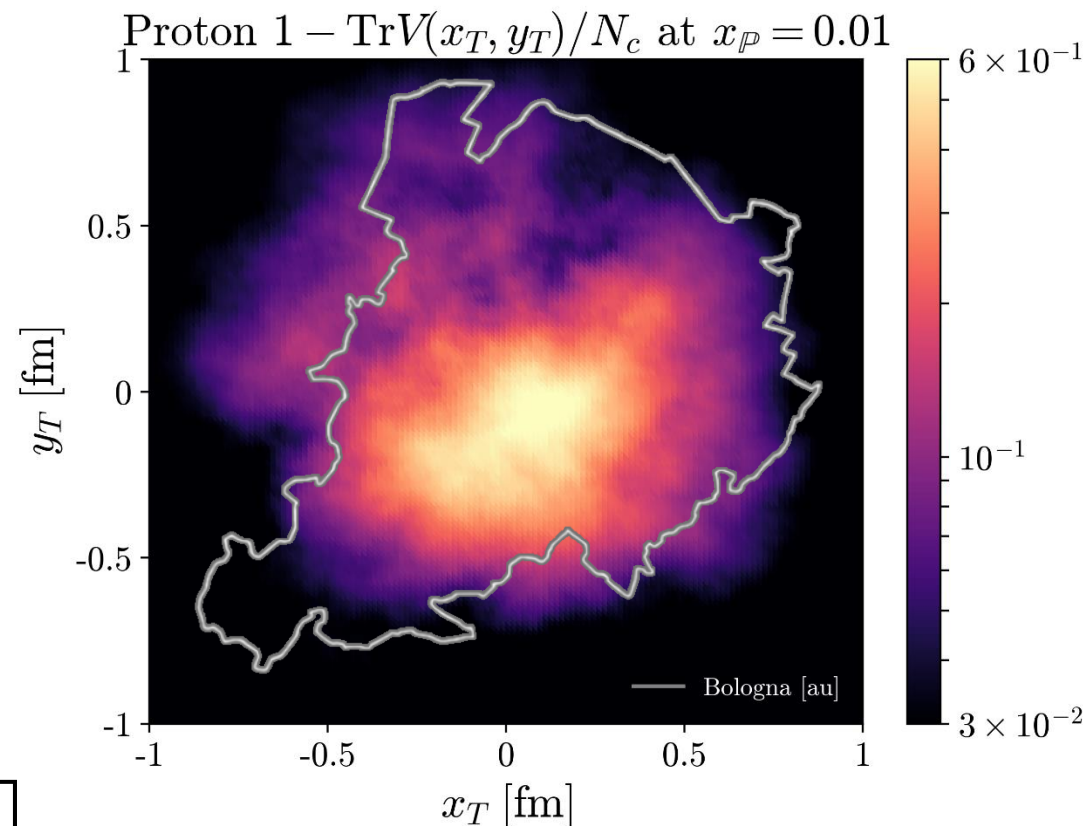
github.com/chunshen1987/ipglasma/
Schenke et al.

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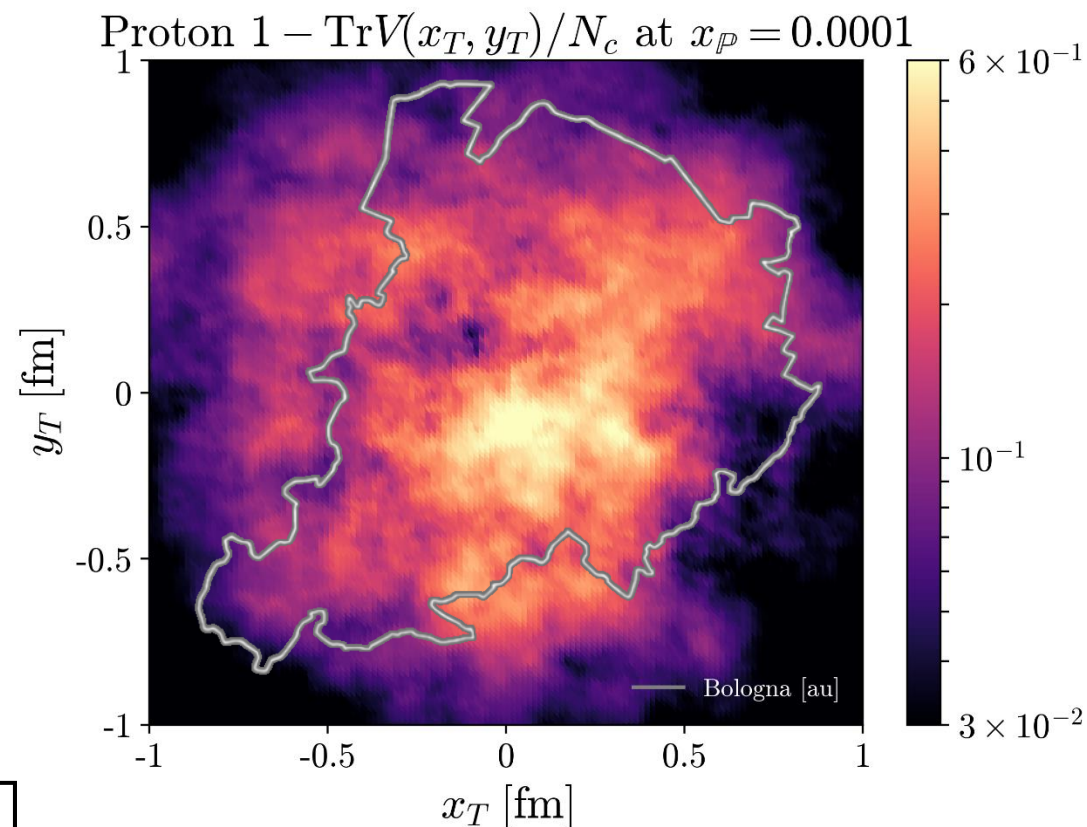
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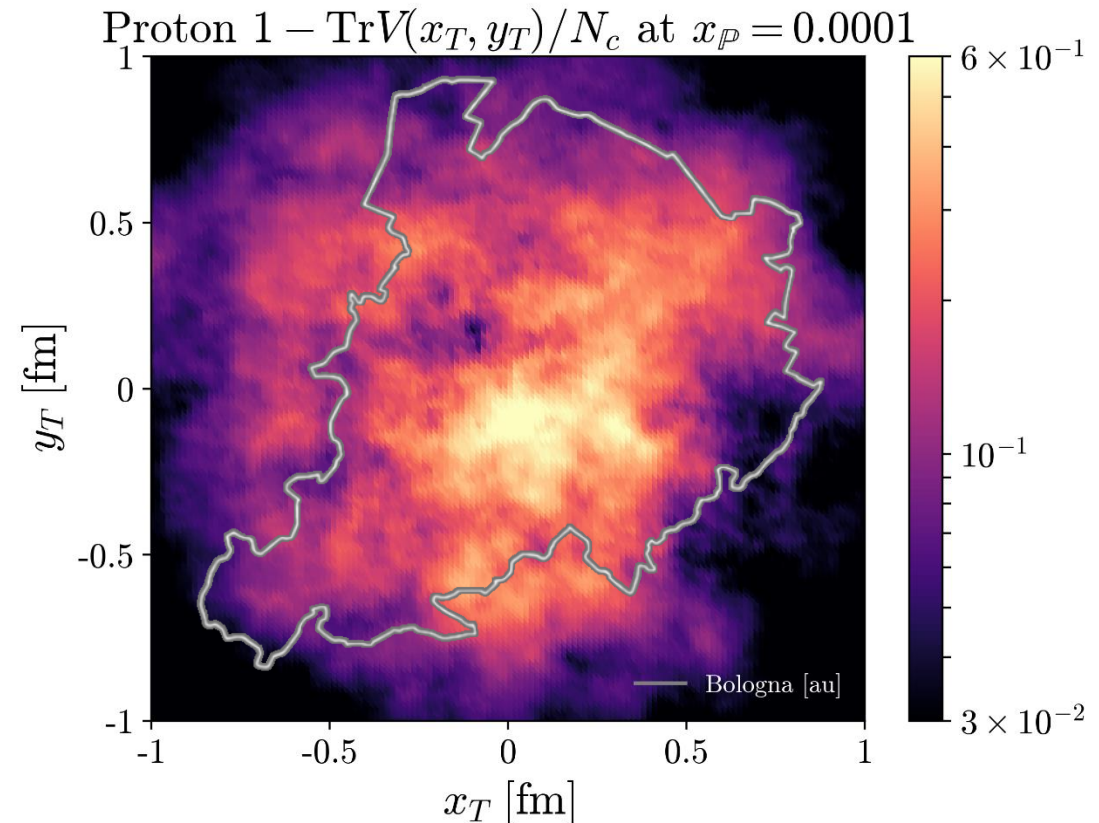
Diffractive Cross Section on a Lattice

- Wilson lines on a 2D lattice in the transverse plane
- Discretized integrals in cross section
- Coherent cross section is computed via **ensemble average** of scattering amplitude

$$\frac{d\sigma_{\lambda, q\bar{q}}^D}{dM_X^2 d|t|} = \frac{N_c}{4\pi} \frac{1}{4(2\pi)^3} \sum_{z_i} dz_i \sum_{\theta_{l\Delta, i}} d\theta_{l\Delta} \left| \left\langle \sum_{\substack{n, m, \\ v, w}}^N a^4 \psi_{\gamma_\lambda^* \rightarrow q\bar{q}} \right. \right.$$

$$\times \left[1 - \frac{1}{N_c} \text{Tr} [V(\mathbf{x}_{n, m}) V^\dagger(\mathbf{x}_{v, w})] \right] e^{i(|\mathbf{l}| \hat{\mathbf{i}} \cdot (\mathbf{x}_{n, m} - \mathbf{x}_{v, w}) + \Delta \cdot (z_i \mathbf{x}_{n, m} + (1 - z_i) \mathbf{x}_{v, w}))} \left. \right|^2$$

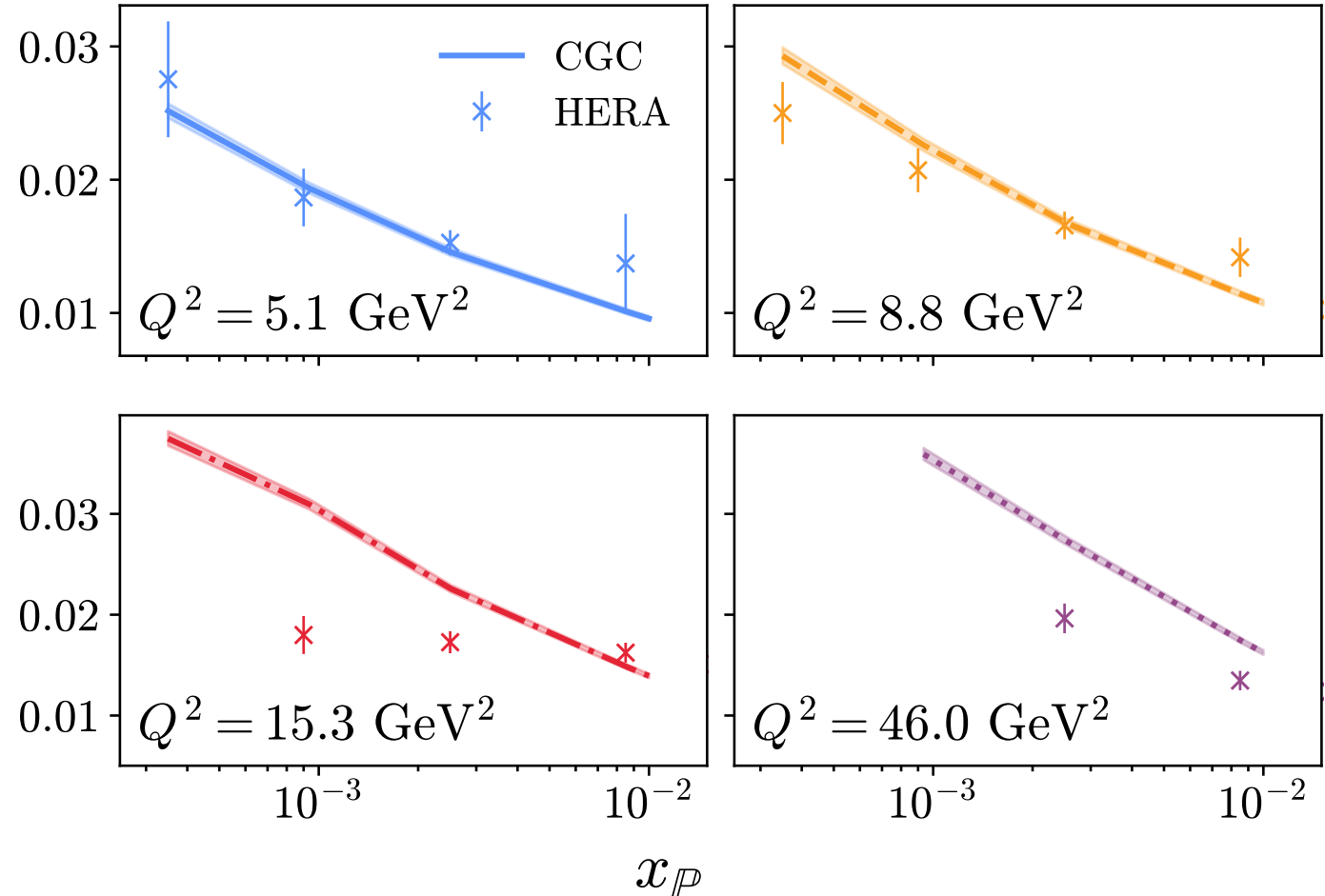
$$\mathbf{l}^2 = z_0 z_1 M_X^2 - m_f^2 \quad \Delta^2 = |t|$$



Proton Reduced Cross Section

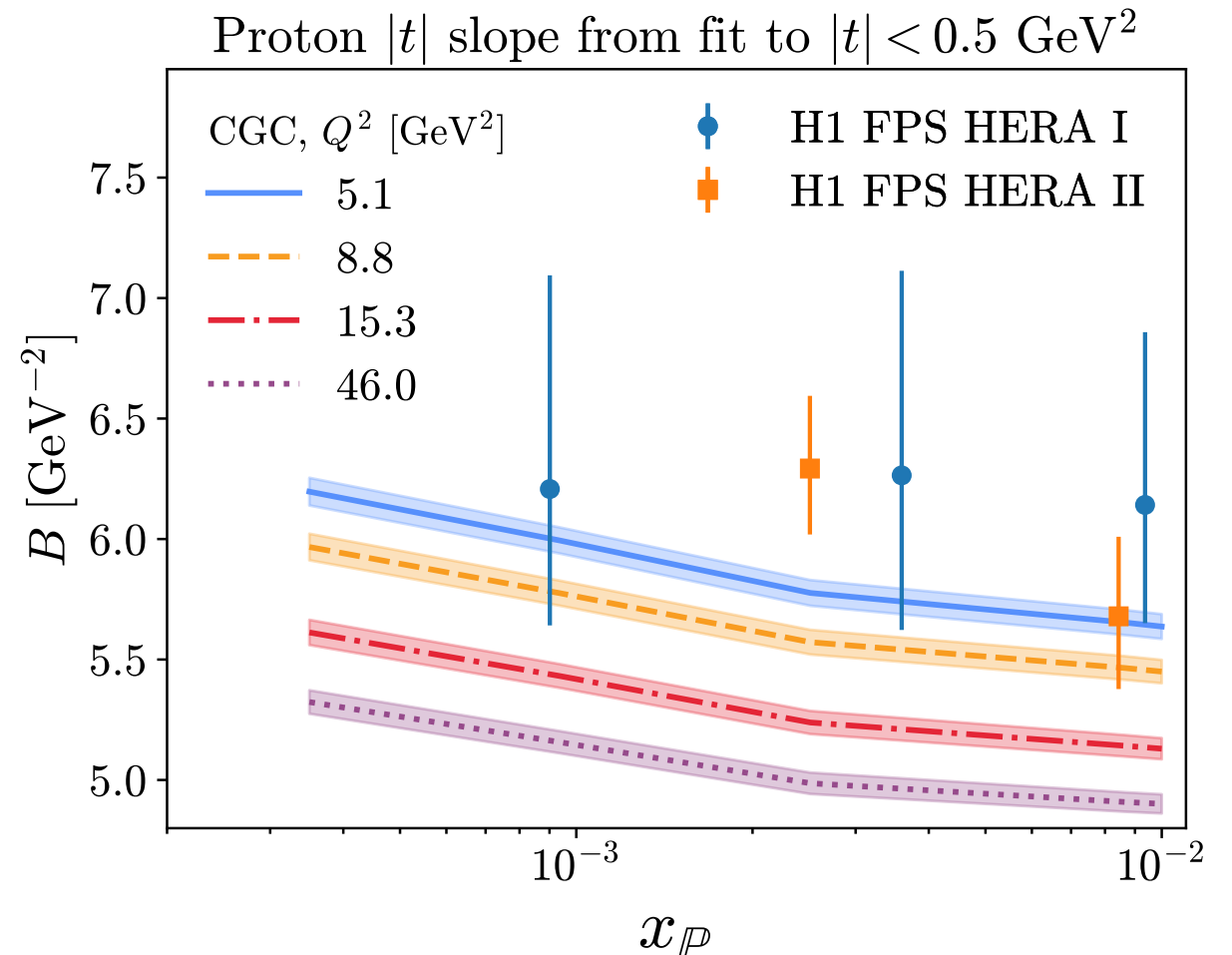
- $x_{\mathbb{P}}$ dependence from JIMWLK, compatible with HERA [[1207.4864](#)]
- No free parameters
- Agreement at low Q^2 is good
- Faster Q^2 evolution than in data, similar systematics previously seen in inclusive F_2 computed using the MV model [[1309.6963](#)]
- Successful benchmark, starting point for predictions

Proton $x_{\mathbb{P}}\sigma_r^{D(3)}(\beta = 0.56, Q^2, x_{\mathbb{P}})$ at $\sqrt{s} = 318$ GeV



Proton Slope Parameter $\frac{d\sigma}{d|t|} \sim e^{-B|t|}$

- Measures the target–probe system size
- HERA data from [1010.1476](#) with no measurable Q^2 dependence
- Results & data in the same ballpark
- Proton transverse size increases at smaller $x_{\mathcal{P}}$ due to radiated gluons
- Probe size increases at smaller Q^2 where $q\bar{q}$ dipoles are typically larger



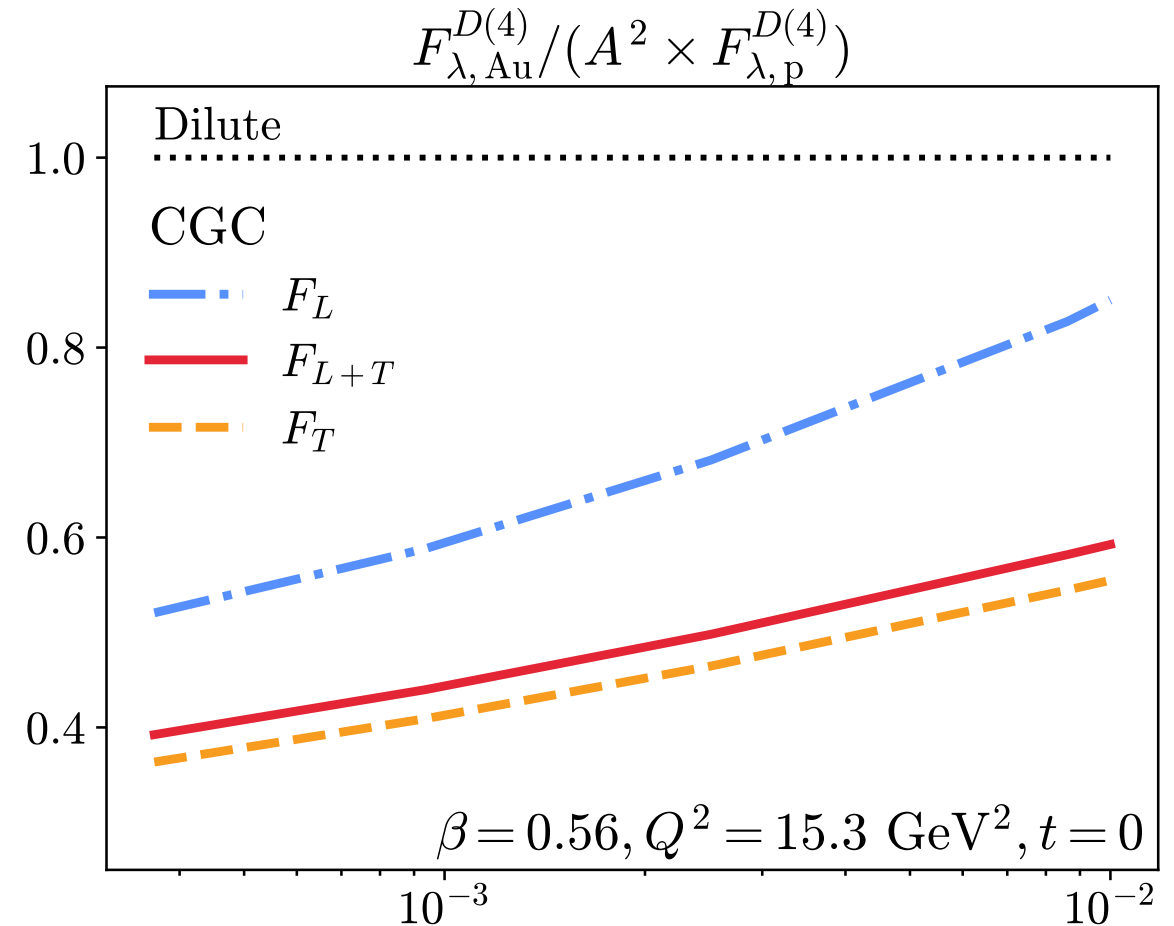
Nuclear Modification of $F_{\lambda}^{D(4)}$ at $t = 0$

- This prediction is the goal of this work
- Ratio is 1 at $t = 0$ in the absence of non-linear effects i.e., without saturation
- Strong nuclear suppression predicted
- Transverse photon typically splits into larger dipoles, leading to non-linear multiple scattering
- Transverse polarization dominates the cross section in these kinematics

$$\text{amplitude} \sim 1 - \exp(-r_T^2 Q_s^2)$$

r_T : dipole size

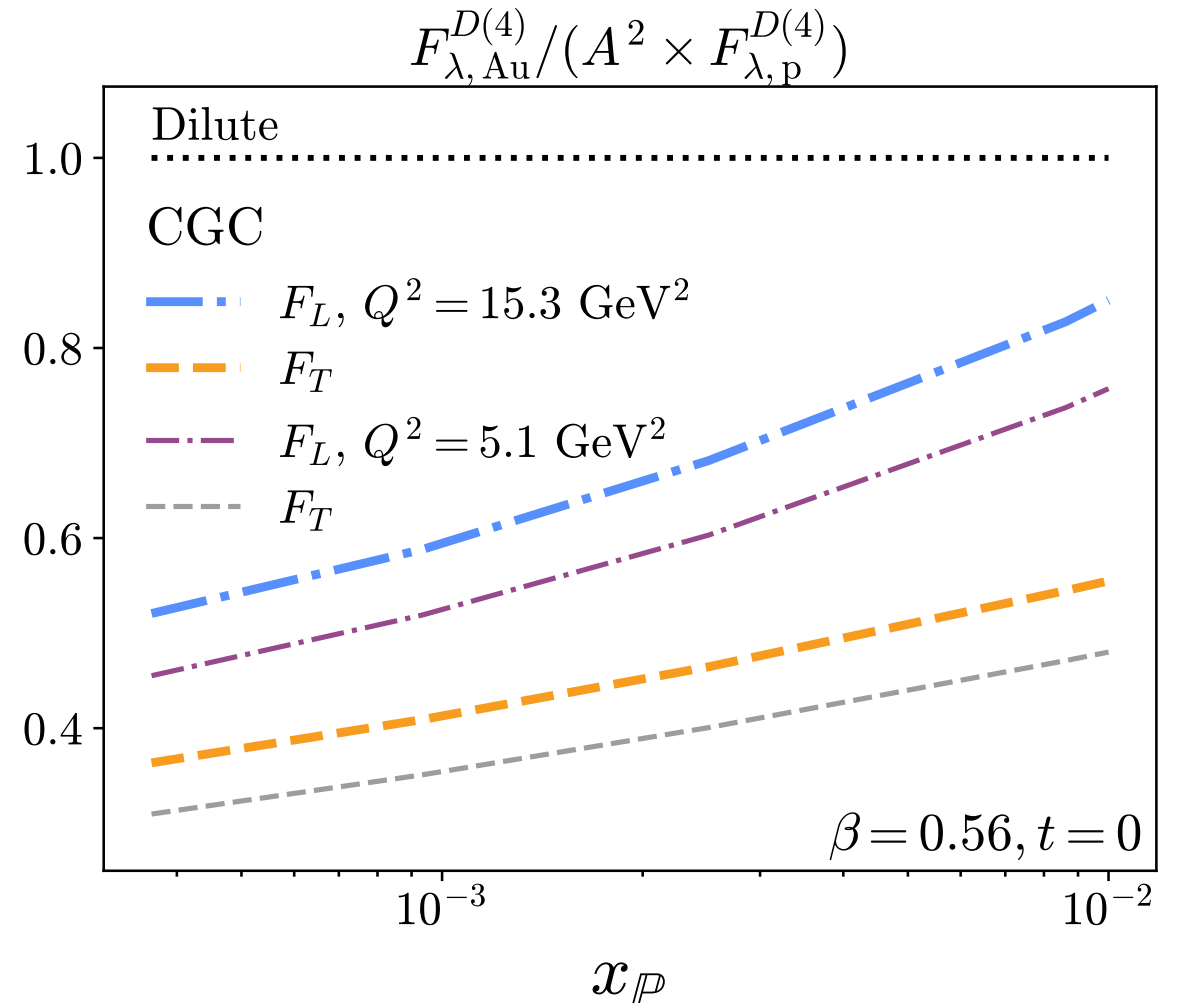
Q_s : saturation scale



$x_{\mathbb{P}}$

Q^2 Dep. Nuclear Modification of $F_{\lambda}^{D(4)}$ at $t = 0$

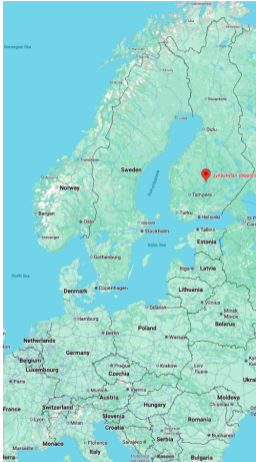
- This prediction is the goal of this work
- Ratio is 1 at $t = 0$ in the absence of non-linear effects i.e., without saturation
- Strong nuclear suppression predicted
- Transverse photon typically splits into larger dipoles, leading to non-linear multiple scattering
- Transverse polarization dominates the cross section in these kinematics
- Stronger suppression towards lower Q^2



Conclusions

- Setup constrained by exclusive J/ψ data
- $x_{\mathbb{P}}$ dependence from JIMWLK evolution
- Good description of HERA diffractive structure function data
- Predict slope parameter B with $x_{\mathbb{P}}$ & Q^2 evolution
- Predict strong nuclear suppression for the diffractive cross section in EIC kinematics
- Can be compared to future EIC measurements

Initial Stages 2027 at Jyväskylä



- The 9th Initial Stages 2027 conference (IS2027)
- **June 7-11, 2027**, Jyväskylä Finland
- International flights to Helsinki + domestic connection
- Organized by Jyväskylä QCD theory + ALICE groups
- <https://indico.global/event/15638/>

