

# Incoherent diffraction and proton structure fluctuations

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Based on: B. Schenke, H.M., arXiv:1603.04349, to be published in PRL

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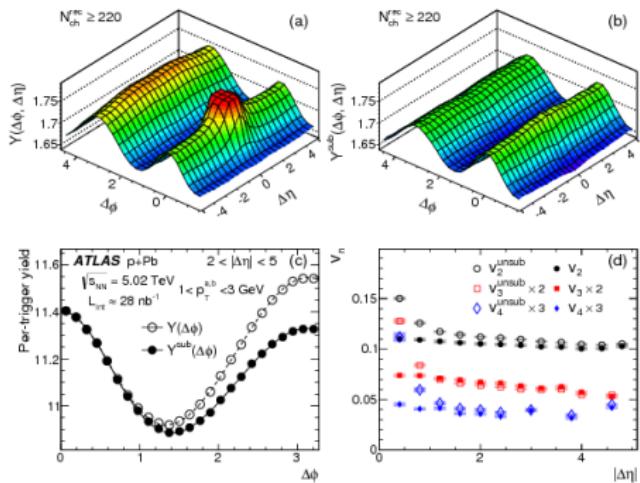
Initial Stages 2016, 25.5.2016

# Motivation

## A fundamental question

How are the quarks and gluons distributed in space inside the nucleon?

Collective phenomena seen in pp&pA



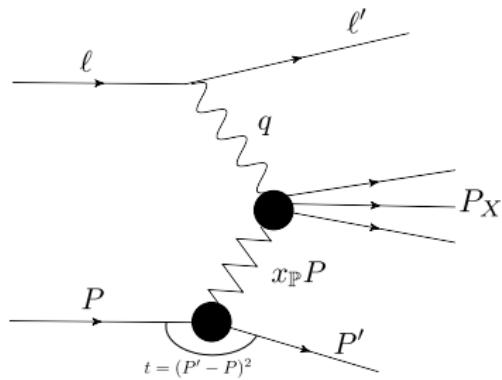
ATLAS, arXiv:1409.1792

- Can be caused by initial state geometry
- Initial state geometry is a necessary input for hydrodynamical calculations

Diffractive processes probe

- Spatial density profile
- Density fluctuations

# Diffractive scattering



Diffractive events: no exchange of color charge

- Target remains intact: *coherent diffraction*, small  $|t|$ .  
Probes average distribution of gluons.
- Target breaks up: *incoherent diffraction*, larger  $|t|$ .  
Sensitive to fluctuations.

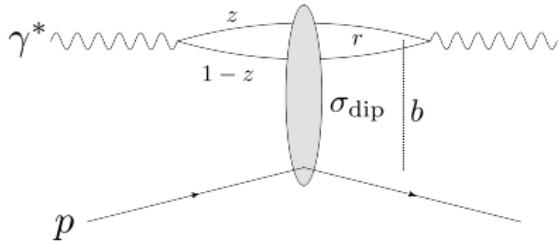
Target: proton or nucleus

# Vector mesons from the CGC

CGC: Dipole-proton cross section

$$\sigma_{\text{dip}}(x, r, \Delta) = 2 \int d^2 b e^{ib \cdot \Delta} N(r, x, b)$$

Universal dipole amplitude  $N$



- Exclusive diffraction:

$$\frac{1}{16\pi} \left| \int d^2 r dz \Psi^* \Psi^V(Q^2, r, z) \sigma_{\text{dip}}(x, r, \Delta) \right|^2$$

- Total  $\gamma^* p$  (DIS):

$$\int d^2 r dz |\Psi^\gamma(Q^2, r, z)|^2 \sigma_{\text{dip}}(x, r, \Delta = 0)$$

- Inclusive particle production (pp, pA):

$$\sim x g(x, Q^2) \int d^2 r e^{ir \cdot p_T} [1 - N(r, x)]$$

- + many other processes

# Coherent and incoherent diffraction

Event-by-event fluctuations:

- Coherent diffraction: target remains intact

$$\frac{d\sigma^{\gamma^* A \rightarrow VA}}{dt} \sim |\langle \mathcal{A}(x, Q^2, t) \rangle|^2$$

- Incoherent, target breaks up: variance

$$\frac{d\sigma^{\gamma^* A \rightarrow VA^*}}{dt} \sim \langle |\mathcal{A}(x, Q^2, t)|^2 \rangle - |\langle \mathcal{A}(x, Q^2, t) \rangle|^2$$

$\langle \rangle$  = Target average.

$\mathcal{A}$  = scattering amplitude for exclusive process

$$\mathcal{A} \sim \int d^2 b dz d^2 r \Psi^* \Psi^V(r, z, Q^2) e^{-ib \cdot \Delta} \mathbf{N}(r, x, b)$$

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# Constraining proton fluctuations

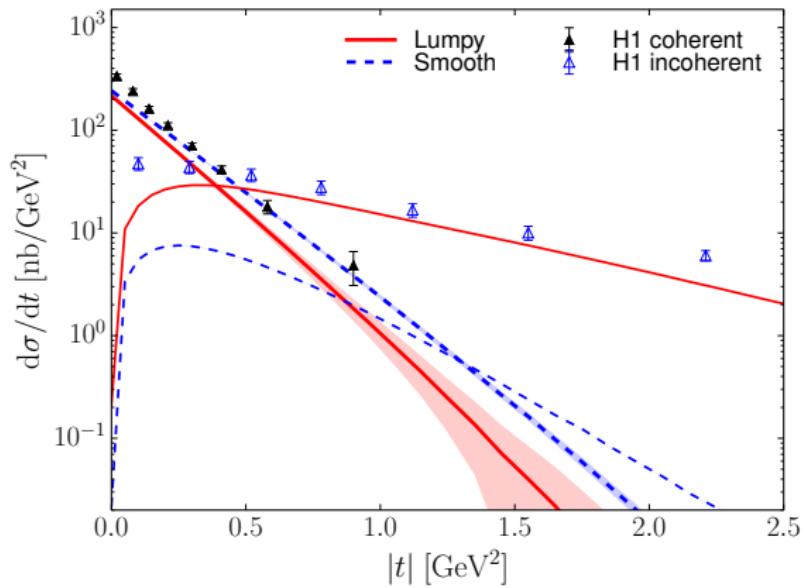
B. Schenke, H.M., arXiv:1603.04349

Start with a simple constituent quark inspired picture:

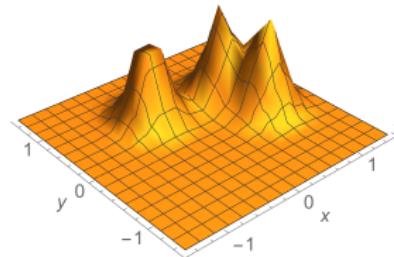
- Small- $x$  gluons are located around the valence quarks (width  $B_q$ ).
- Sample quark positions from a Gaussian distribution, width  $B_{qc}$
- Combination of  $B_{qc}$  and  $B_q$  sets the degree of geometric fluctuations

Our proton = 3 overlapping hot spots.

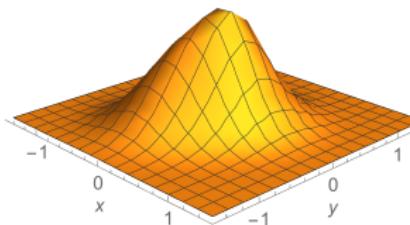
# Constraining proton fluctuations in $\gamma + p \rightarrow J/\Psi + p^*$



Lumpy:  $B_{qc} = 3.5, B_q = 1.0$



Smooth:  $B_{qc} = 1.0, B_q = 3.0$

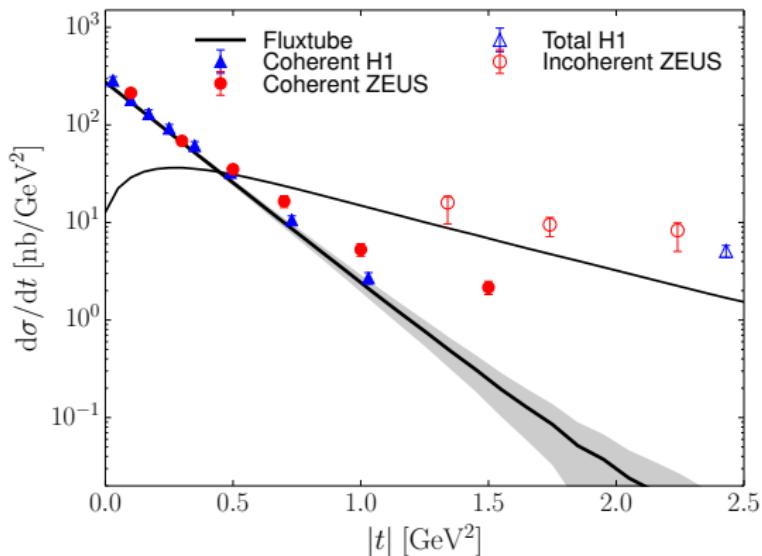


H.M., B. Schenke, in preparation and arXiv:1603.04349

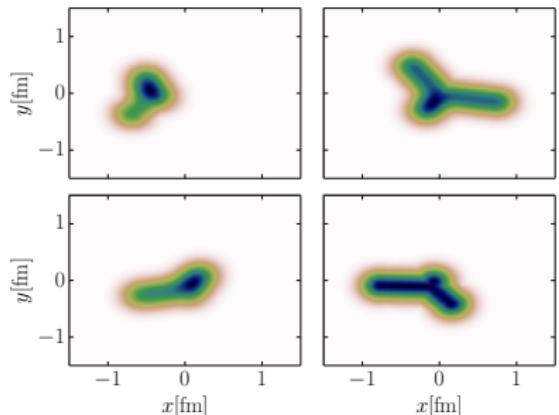
- Incoherent data requires large fluctuations

# Lumpiness matters, not details of the density profile

3 valence quarks that are connected by "color flux tubes" (Gaussian density profile, width  $B_q$ ). Also good description of the data



Example density profiles



H.M., B. Schenke, in preparation

Flux tubes implementation following results from hep-lat/0606016, used also e.g. in 1307.5911

# Saturation scale fluctuations

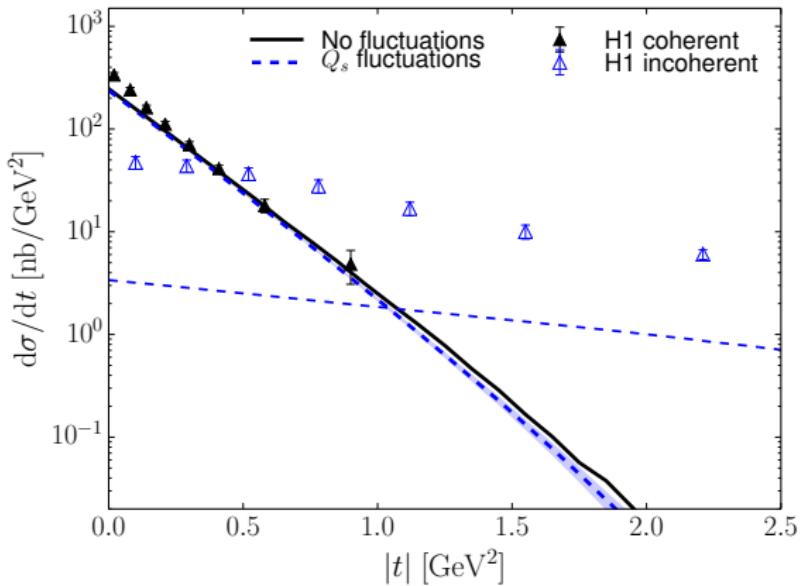
Saturation scale fluctuations ( $p + p$  multiplicity distributions:  $\sigma \sim 0.5$ )

$$P(\ln Q_s^2 / \langle Q_s^2 \rangle) = \frac{1}{\sqrt{2\pi}\sigma} \exp \left[ -\frac{\ln^2 Q_s^2 / \langle Q_s^2 \rangle}{2\sigma^2} \right]$$

McLerran, Tribedy, arXiv:1508.03292:  $p + p$  multiplicity distributions:  
 $\sigma \sim 0.5$

- Shifted to keep average  $Q_s$  unchanged
- Allow  $Q_s^2$  of each constituent quark to fluctuate
- If no geometric fluctuations, divide transverse space to  $\sim 1/Q_s^2$  cells where  $Q_s^2$  fluctuates

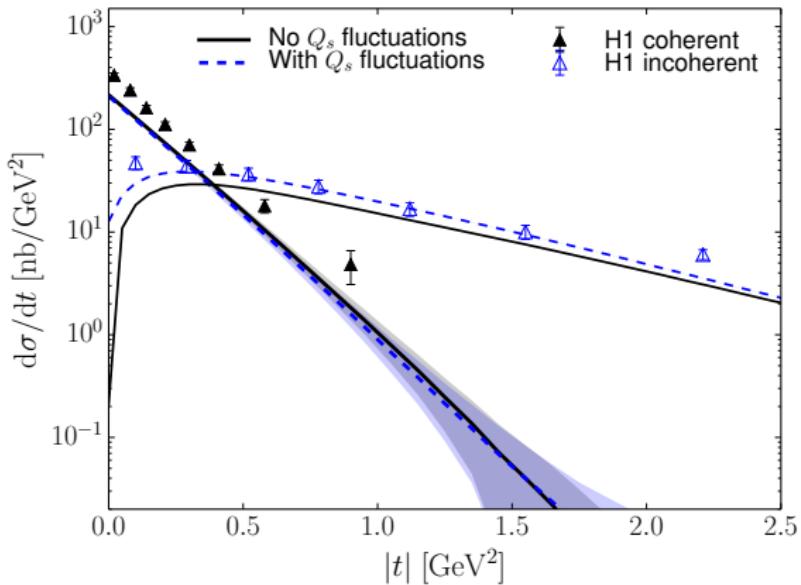
# Only saturation scale fluctuations



H.M., B. Schenke, in preparation and arXiv:1603.04349

- $Q_s$  fluctuations alone are not enough

# Saturation scale fluctuations + geometric fluctuations



H.M., B. Schenke, in preparation and arXiv:1603.04349

- $Q_s$  fluctuations dominate incoherent cross section at small  $|t|$

# Adding color charge fluctuations: IP-Glasma

- Obtain saturation scale  $Q_s(b_T)$  from IPsat (with constituent quarks)
- Sample color charges  $\rho(b_T) \sim Q_s(b_T)$
- Solve Yang-Mills equations to obtain Wilson lines

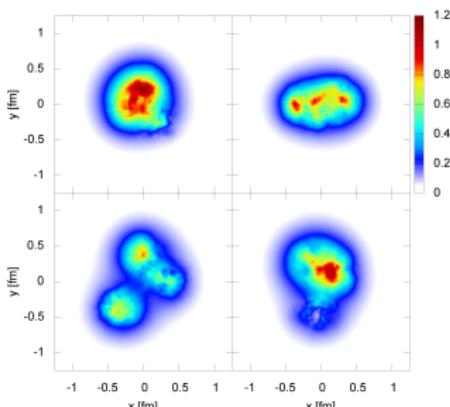
$$V(x_T) = P \exp \left( -ig \int dx^- \frac{\rho(x^-, x_T)}{\nabla^2 + m^2} \right)$$

- Dipole amplitude:  $N(x_T, y_T) = 1 - \text{Tr } V(x_T) V^\dagger(y_T)/N_c$
- Fix parameters  $B_{qc}, B_q$  and  $m$  with HERA data

Example configurations:

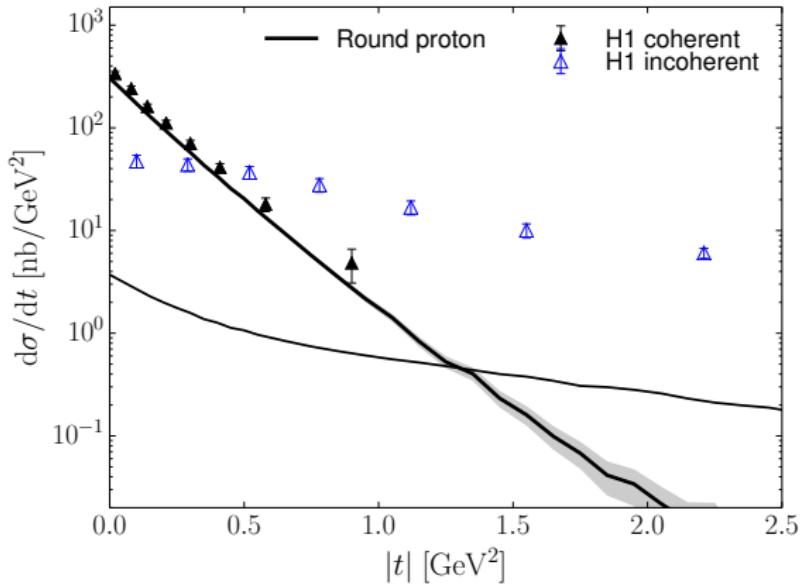
$$1 - \text{Re}(\text{Tr } V(x_T))/N_c$$

H.M., B. Schenke, arXiv:1603.04349



Fluctuations

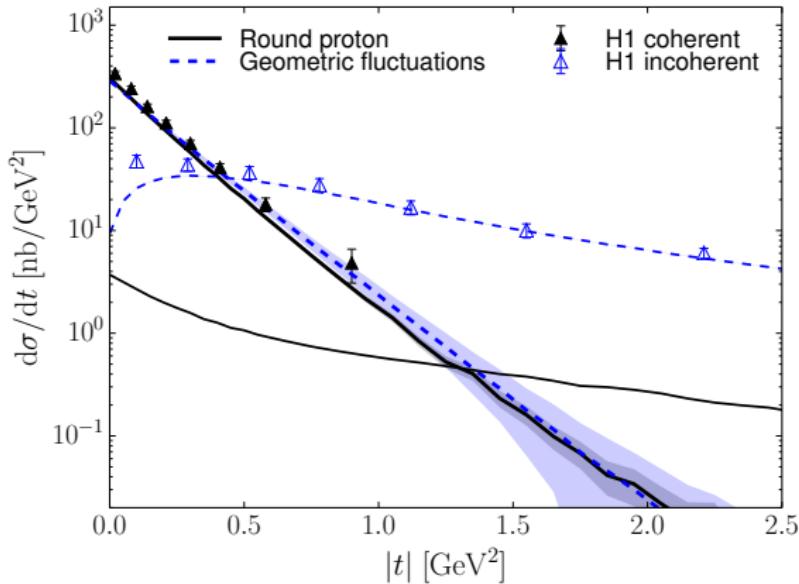
# IP-Glasma and HERA data



H.M., B. Schenke, in preparation and arXiv:1603.04349

- Color charge fluctuations alone are not enough

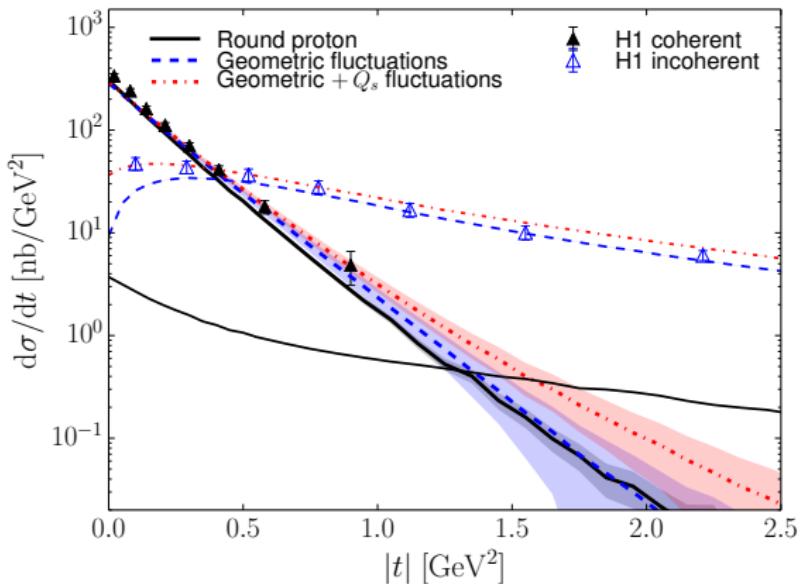
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H.M., B. Schenke, in preparation and arXiv:1603.04349

- Large geometric fluctuations are needed

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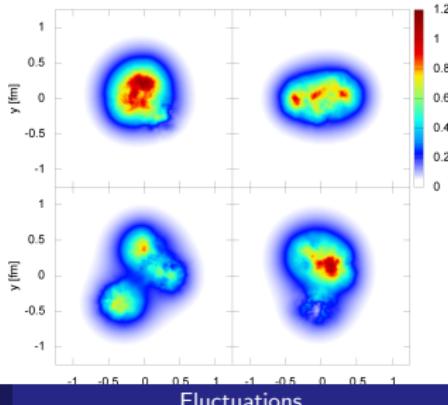


H.M., B. Schenke, in preparation and arXiv:1603.04349

- Large geometric fluctuations are needed
- $Q_s$  fluctuations improve description at small  $|t|$

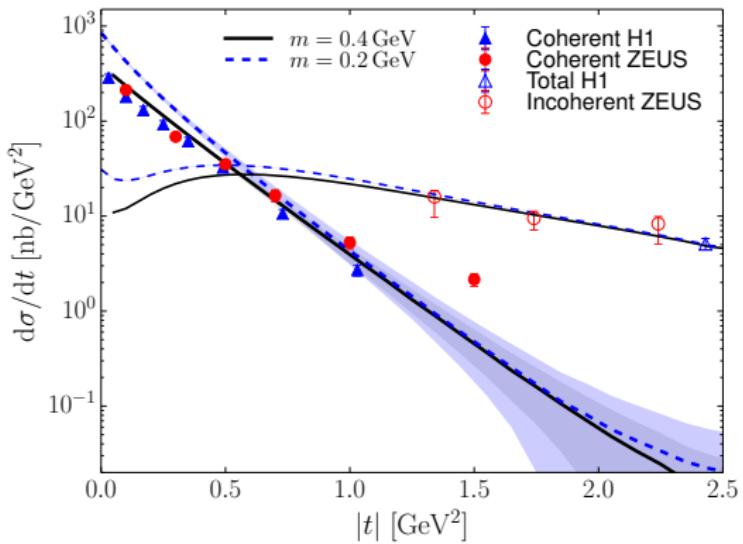
# Conclusions

- Diffractive cross sections calculated from CGC framework
- Coherent and incoherent diffraction combined probe proton
  - Density profile
  - Event-by-event density fluctuations
- Color charge fluctuations alone are not enough to describe HERA incoherent  $J/\Psi$  production data
  - Large geometric fluctuations of the proton density are needed
  - Saturation scale fluctuations improve description at small  $|t|$
- Next step: include small- $x$  evolution in terms of JIMWLK equation



# Backups

# Insensitivity on infrared cutoff



H.M., B. Schenke, in progress

IP-Glasma: IR cutoff  $m \sim \Lambda_{\text{QCD}}$  to regulates long distance coulomb tails

- Proton size depends on  $m$
- No sensitivity at large  $|t|$

# Dipole-proton scattering: IPsat model

An impact parameter dependent dipole amplitude

$$N(r, x, b) = 1 - \exp \left[ -\frac{\pi^2}{2N_c} \alpha_s x g(x, \mu^2) T_p(b) r^2 \right]$$

- Fit to HERA data ( $F_2$ ): initial condition for the DGLAP evolution of  $xg(x, \mu^2)$  (Kowalski, Teaney 2003; Rezaeian et al, 2013)
- Proton profile  $T_p$ : Gaussian, width  $B_p$

$$T_p(b) = -\frac{1}{2\pi B_p} e^{-b^2/2B_p}$$