Incoherent diffraction and structure fluctuations at small x

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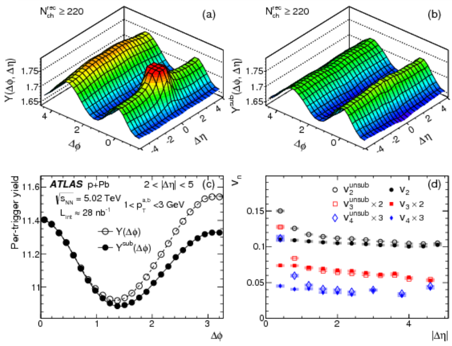
Motivation

Proton structure (key EIC question)

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



ATLAS, arXiv:1409.1792

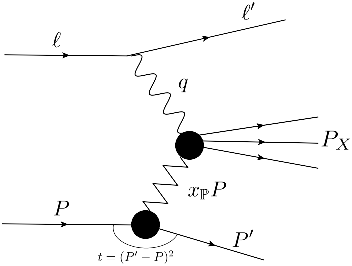
Collective phenomena observed in pA

- Can be caused by initial state geometry

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.

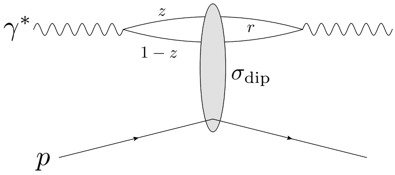
Target: proton or nucleus

Vector mesons from the CGC

CGC: Dipole-proton cross section

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

Universal dipole amplitude N



- Exclusive diffraction:

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

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

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

- Inclusive particle production (pp, pA):

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

- + many other processes

Coherent and incoherent diffraction

Event-by-event fluctuations:

- Coherent diffraction: target remains intact

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

- Incoherent, target breaks up: variance

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

$\langle\rangle =$ Target average.

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Constraining proton fluctuations

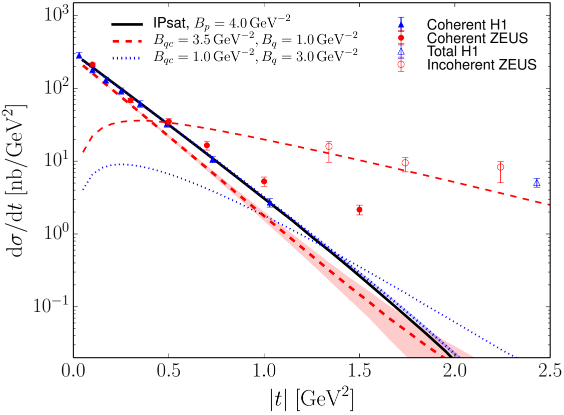
B. Schenke, H.M., arXiv:1603.04349

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 set the degree of geometric fluctuations
- Dipole-target scattering σ_{dip}: IPsat model fit to F_2 data

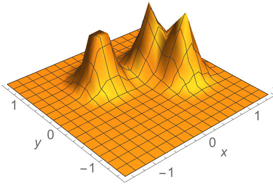
Our proton $=$ 3 overlapping hot spots.

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

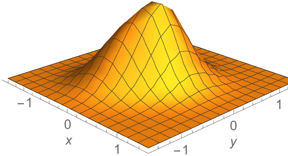


H.M., B. Schenke, arXiv:1603.04349

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



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



- Incoherent data requires large fluctuations

Adding color charge fluctuations: IP-Glasma

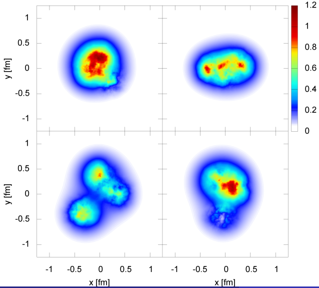
- Obtain saturation scale $Q_s(b_T)$ from IPsat (with constituent quarks)
- Sample color charges $\rho(b_T) \sim Q_s(b_T)$
- Solve Yang-Mills equations to obtain Wilson lines

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

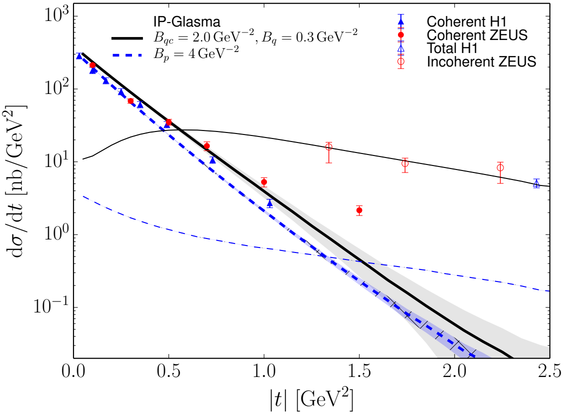
- Dipole amplitude: $N(x_T, y_T) = 1 - \mathrm{Tr}\, V(x_T) V^\dagger(y_T)/N_c$
- Fix parameters B_{qc}, B_q and m with HERA data

Example configurations:
$1 - \mathrm{Re}(\mathrm{Tr}\, V(x_T))/N_c$

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



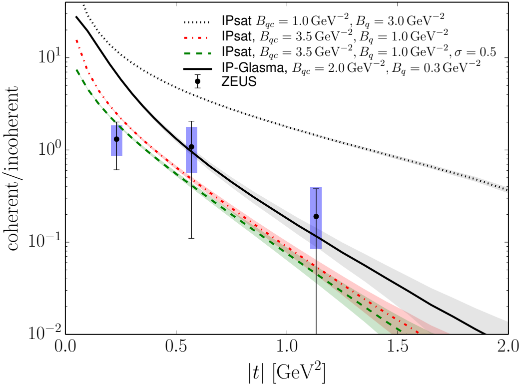
IP-Glasma and HERA data



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

- Color charge fluctuations alone give non-zero incoherent cross section
- HERA data requires additional geometrical fluctuations

Coherent/incoherent ratio, diffractive J/Ψ production

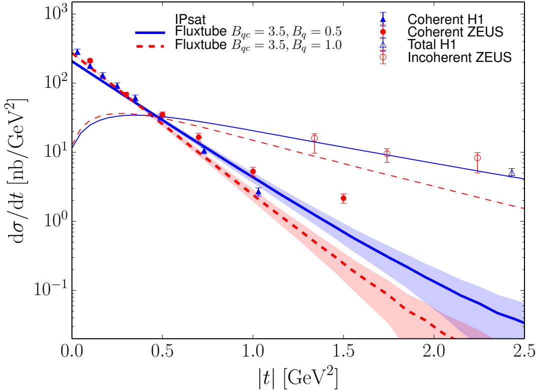


H.M., B. Schenke, arXiv:1603.04349

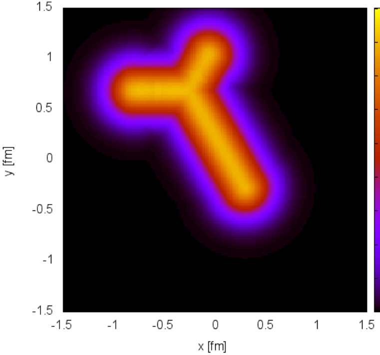
HERA coherent data requires strong fluctuations

- More precise measurements from an EIC can provide tighter constraints

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



Example density profile

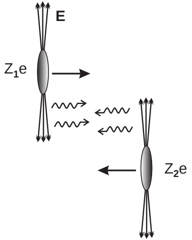


H.M., B. Schenke, in progress

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

More data before EIC: ultraperipheral collisions

$b \gtrsim 2R_A$: strong interactions suppressed, one hadron creates photon flux $n(\omega)$



nucl-ex/0502005

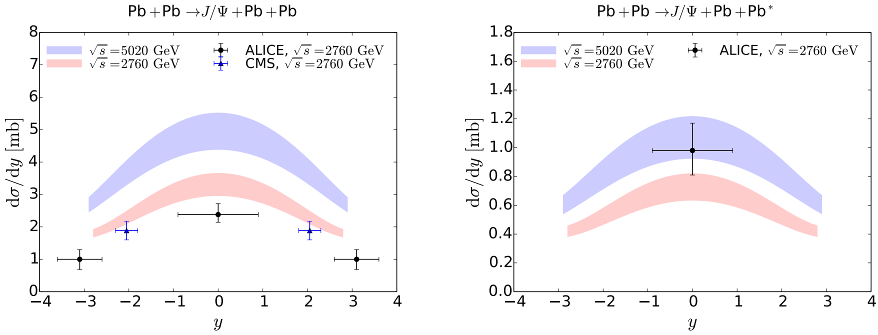
$\sigma \sim n(\omega)\sigma^{\gamma A}(\omega)$

Probes gluons with $x = M_V e^y / \sqrt{s}$

- Forward LHC: $x \sim 0.02$ and $x \sim 10^{-5}$.
- Midrapidity LHC: $x \sim 10^{-3}$

Ultraperipheral pA collisions are dominated by γp scattering!

Predictions for Pb+Pb collisions at $\sqrt{s} = 5020$ GeV



- Normalization has large model dependence (needs J/Ψ wave function)
- $\sqrt{s}$ (or x) evolution (cross section ratios) is more solid prediction
- Incoherent cross section comes from nucleon position fluctuations
- Future: incoherent $\gamma p \to J/\Psi p^*$ from ultraperipheral collisions?

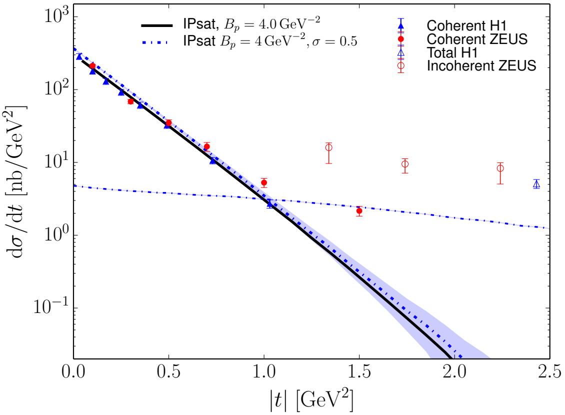
Conclusions

- Coherent and incoherent diffraction combined probe
  - Density profile
  - Density fluctuations
- Color charge fluctuations alone are not enough to describe HERA incoherent J/Ψ production data
  - Large geometric fluctuations of the proton density are needed
- Before EIC exclusive vector meson production can be studied in ultraperipheral heavy ion collisions
  - Relatively good description of the current $\gamma A \to J/\Psi A$ data from CGC

Backups

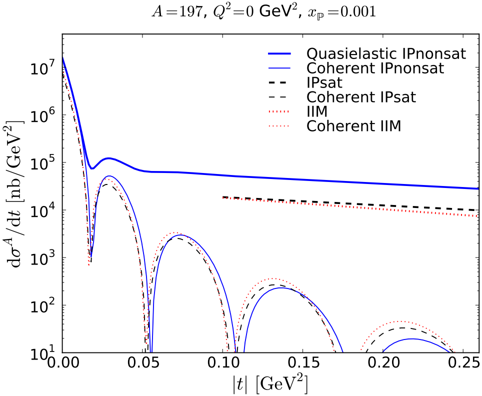
Q_s fluctuations

Q_s fluctuates at length scale $\sim 1/Q_s$



- Amount of fluctuations constrained by LHC multiplicity data
- Q_s fluctuations alone are not enough to describe incoherent data

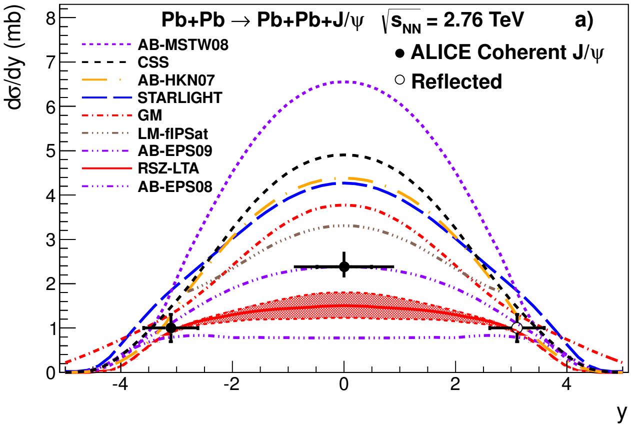
$\gamma A \to J/\Psi A$



T. Lappi, H.M., arXiv:1011.1988

- Coherent spectra $\sim$ FT of average density profile
- Incoherent process dominates at large $|t|$
- Incoherent cross section is also sensitive to saturation effects.

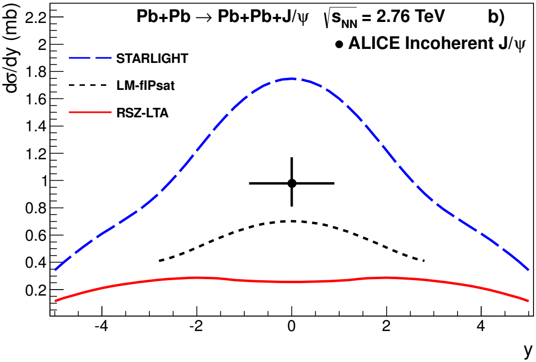
Coherent diffraction, model comparison



ALICE, 1310.7732

Probes average gluon density, models with shadowing/saturation favored.

Comparison of predictions (incoherent diffraction)



Data and other models: ALICE, arXiv:1305.1467

- IPsat calculation: fluctuations from Woods-Saxon distribution
- Simultaneous description of coherent and incoherent data is needed!

Dipole-proton scattering: IPsat model

An impact parameter dependent dipole amplitude

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

- 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

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