Incoherent and coherent vector meson production in ultraperipheral heavy ion collisions from the Color Glass Condensate

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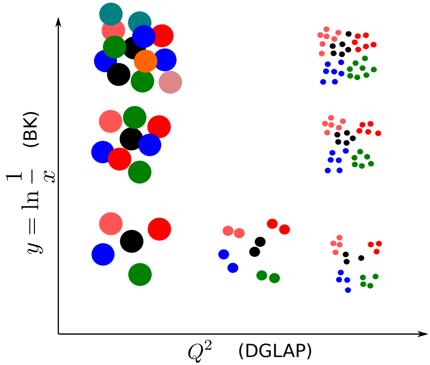
Introduction



Saturation effects $\sim$ gluon recombination

- The Color Glass Condensate framework describes many small-x processes accurately
- Necessary input: gluon density at $x = x_0$ (from DIS)
- There is very little small-x nuclear DIS data

eA collisions would be ideal, but before eRHIC/LHeC have to use something else
$\Rightarrow$ ultraperipheral AA

CGC: a universal framework

Input

- Dipole-target amplitude $N(r, x = x_0)$ at initial x (non-perturbative)
- BK evolution equation to get $N(r, x < x_0)$ (peturbative)

Can compute

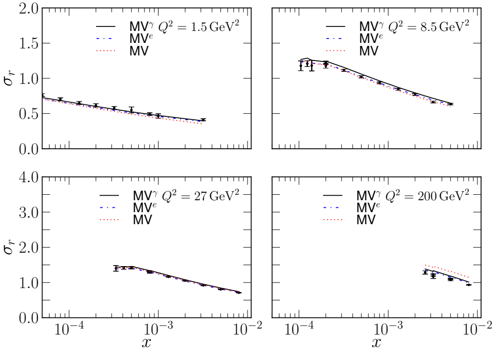
- Deep inelastic scattering
- Diffractive vector meson production
- Single inclusive hadron production
- Double inclusive hadron production (correlations)
- ...

DIS as a baseline for CGC

Total $\gamma^* p$ cross section is

$$\sigma^{\gamma^* p} = \sigma_0 \int \mathrm{d}z \, |\Psi_{\gamma^* \to q\bar{q}}|^2 \, N(r, x)$$

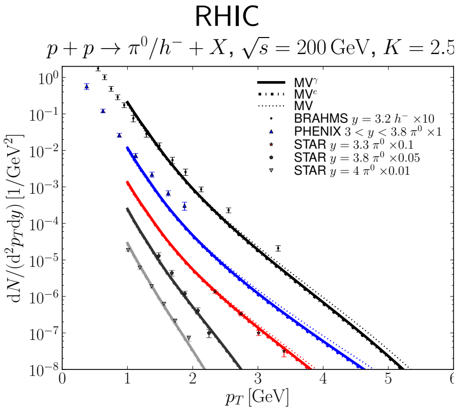
Parametrise initial condition for the BK evolution and fit to HERA structure function data $\Rightarrow$ excellent description, $\chi^2/N \sim 1$

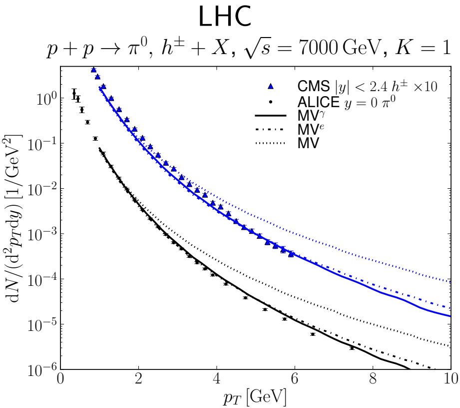


T.Lappi, H.M, 1309.6963

Application: single inclusive hadron production

Using the fitted dipole amplitude we can compute π^0 yield at RHIC and the LHC (T.Lappi, H.M, 1309.6963)



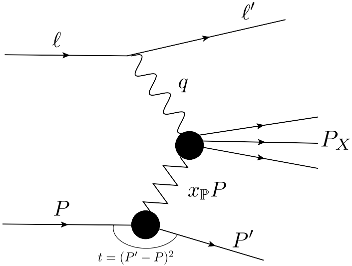


$\sigma \sim \int \mathrm{d}^2 b N(r, x)$, impact parameter dependence not needed.

A way to probe impact parameter dependence: diffraction

(Lepton-proton) Diffraction

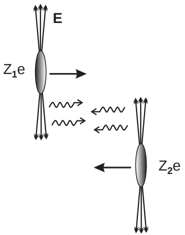
Diffractive deep inelastic scattering (DDIS) = DIS with no exchange of quantum numbers (color).



- $e + p \to e + p + X$, proton interacts via "pomeron exchange"
- $x_{\mathbb{P}}$: fraction of proton momentum carried by the pomeron.
- $Q^2 = -q^2$: virtuality of the photon.

Ultraperipheral AA collision

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



J. Nystrand et al, nucl-ex/0502005

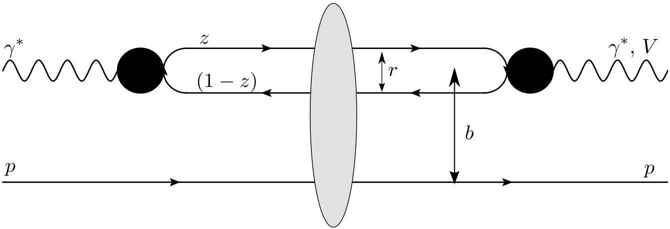
$$\sigma^{AA \to AA+V} \sim n(\omega)\sigma^{\gamma A \to VA}(\omega)$$

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

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

Dipole model is valid only at $x \lesssim 10^{-2} \Rightarrow$ at LHC limit $|y| \lesssim 2 \dots 3$.

Diffraction in dipole model



Diffractive DIS in dipole model:

1. $\gamma^* \to q\bar{q}$ (QED)
2. $q\bar{q}$ scatters elastically
3. $q\bar{q} \to J/\Psi$

1&3 combined: wave function overlap $(\Psi^* \Psi^{J/\Psi})_{T,L}$

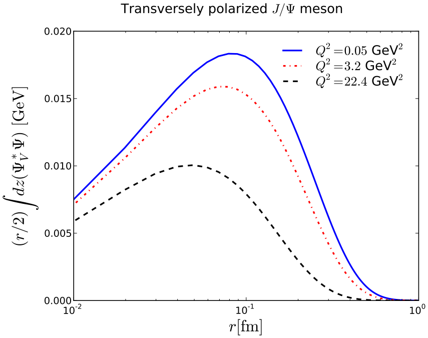
$$\mathcal{A}^{\gamma^* p \to J/\Psi p} = 2i \int \mathrm{d}^2 r \mathrm{d}^2 b \mathrm{d}z (\Psi^* \Psi^{J/\Psi})_{T,L} e^{-ib\cdot\Delta} N(r, x, b)$$

$\Rightarrow$ amplitude $\sim$ Fourier transform of the b profile.

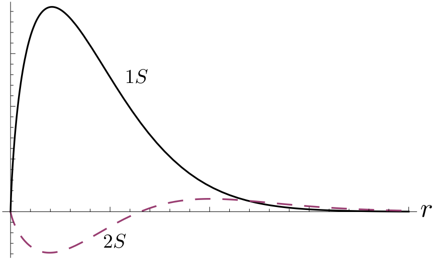
Vector meson wave functions

$\gamma^* \to q\bar{q}$ can be computed from QED, but $q\bar{q} \to$ vector meson requires some modelling, parameters fit to reproduce decay width.

Excited states: $\Psi(2S)$ wave function has a node (orthogonal to J/Ψ). Cross section $\sim \int \mathrm{d}^2 r \Rightarrow$ large suppression compared to J/Ψ



Radial overlap:



Corrections

Total cross section for quasielastic diffraction:

$$\frac{\mathrm{d}\sigma^{\gamma^* p \to Vp}}{\mathrm{d}t} = \frac{R_g^2(1+\beta^2)}{16\pi} |\mathcal{A}^{\gamma^* p \to Vp}|^2$$

Here

- β^2: correction from the real part
- R_g^2: Skewedness (the gluons in the target are probed at different x)

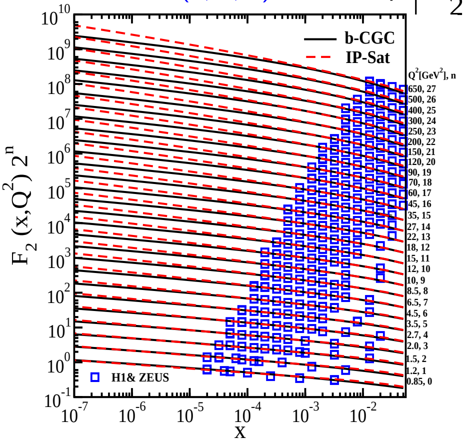
Large corrections are needed to reproduce HERA data.

In ultraperipheral events especially skewedness correction becomes $\sim 100\%$

IPsat model

No satisfactory b-dependent BK evolved N with heavy quarks (yet):
Use IPsat (Kowalski, Motyka, Watt, 2006; Rezaeian et al, 2012):

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



Rezaeian et al, 1307.0825

- Fit to HERA data: initial condition for DGLAP evolution of $xg(x,\mu^2)$
- Proton profile T_p gaussian (fit width to HERA)
- Very good agreement with structure function data

Generalization for nuclei

S matrix $\sim$ probability not to scatter [recall: $S = 1 - N$]:

$$S_A(r, b, x) = \prod_{i=1}^{A} S_p(r, b - b_i, x)$$

Average over nucleon configurations

$$\langle \mathcal{O}(\{b_i\}) \rangle_N = \int \prod_{i=1}^{A} \left[\mathrm{d}^2 b_i \, T_A(b_i) \right] \mathcal{O}(\{b_i\})$$

Coherent and incoherent diffraction

Diffraction off the nucleus:

- Coherent diffraction: nucleus remains intact

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

- Quasielastic = coherent + incoherent

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

- Incoherent, nucleus is allowed to break up (dominates at $-t \gtrsim 1/R_A^2$)

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

$\langle\rangle_N$ = Average over nucleon positions.

Factorized IPsat

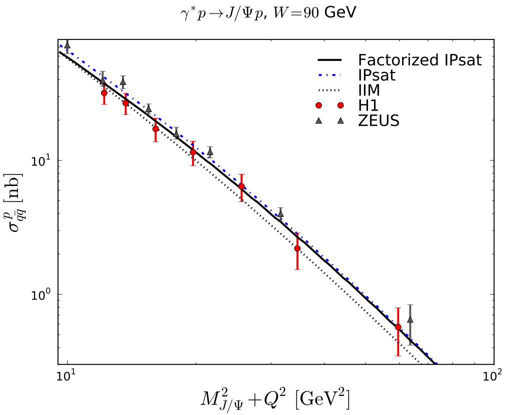
Quasielastic cross section can be computed using a factorized approximation (T. Lappi, H.M, 1011.1988)

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

- Compare different dipole models to study model dependence
  - fIPsat06: IPsat fit to HERA F_2 data (Kowalski, Motyka, Watt, 2006)
  - fIPsat12: IPsat fit to HERA combined σ_r data (Rezaeian et al, 2012)
  - IIM fit to HERA F_2 data (Iancu, Itacura, Munier, 2004)

Comparison with the HERA data

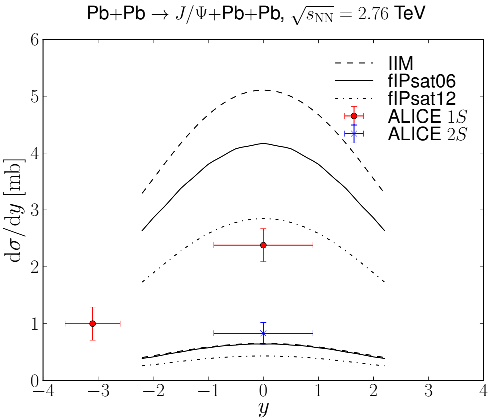
Compare with HERA $\gamma^* p \to J/\Psi p$ data:



T. Lappi, H. Mäntysaari, 1011.1988

Also a good description of the F_2 data.

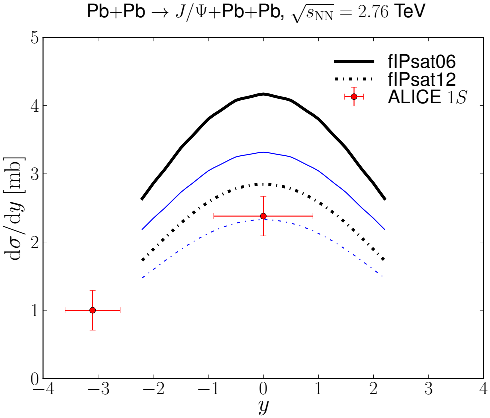
Comparison with the ALICE data: coherent diffraction



T. Lappi and H. Mäntysaari, 1301.4095; Data: ALICE 1310.7732

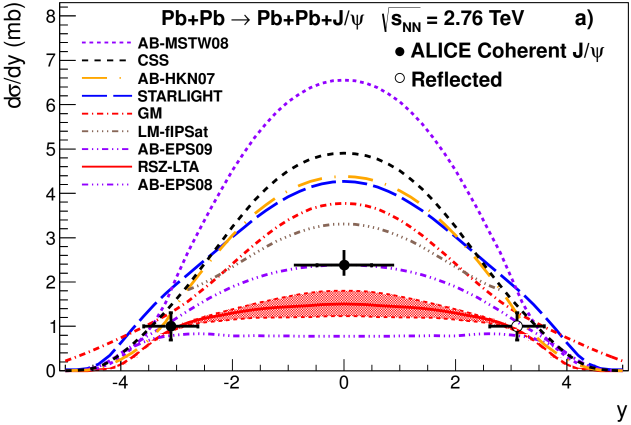
Different dipole models: change overall normalization, but shape is very similar.

Wave function dependence



Data: ALICE 1310.7732

Thin lines: Boosted-Gaussian; thick: Gaus-LC
Different wavefunction models affect overall normalization



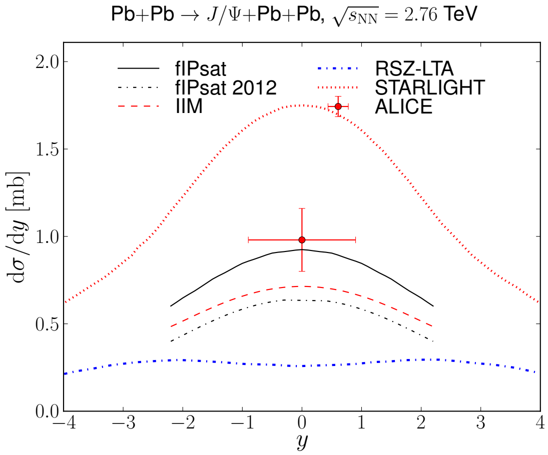
ALICE, 1310.7732

Unshadowed models (e.g. AB-MSTW08) disagree with the data

⇒ saturation effects seen

Comparison of predictions (incoherent diffraction)

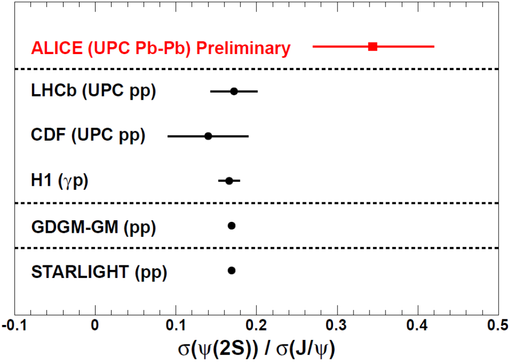
Incoherent scattering: absolute normalization has large model dependence



Data and other models: ALICE, 1305.1467

$\Psi(2S)/\Psi(1S)$

For nuclear targets the $\Psi(2S)/\Psi(1S)$ ratio increases.



Poster by M. Broz, QM14

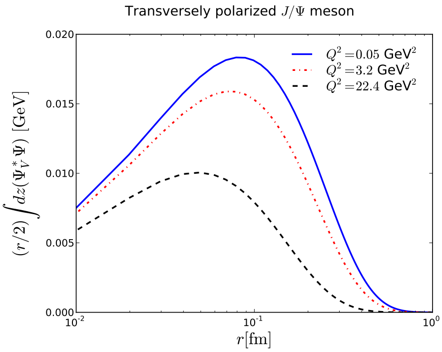
Qualitative agreement with dipole model: node effect is damped at large Q_s^2 (contribution from large dipoles is suppressed).
fIPsat06+boosted Gaussian: 0.13 (HERA) $\to$ 0.15 (ALICE)

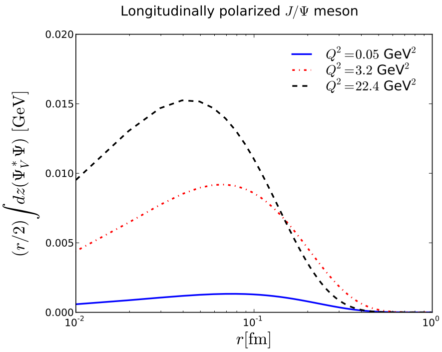
Conclusions

- Ultraperipheral heavy ion collisions make it possible to study γA diffraction at high energy
- Coherent and incoherent photoproduction measurements provide independent model constraints
- Dipole model description of incoherent and coherent diffraction in $\gamma^* A$
    - Absolute normalization has largish model dependence
    - Rapidity evolution of $\mathrm{d}\sigma/\mathrm{d}y$ is more precise prediction
- Work in progress: use BK-evolved dipole amplitude consistently with the HERA F_2 and F_{2c} data

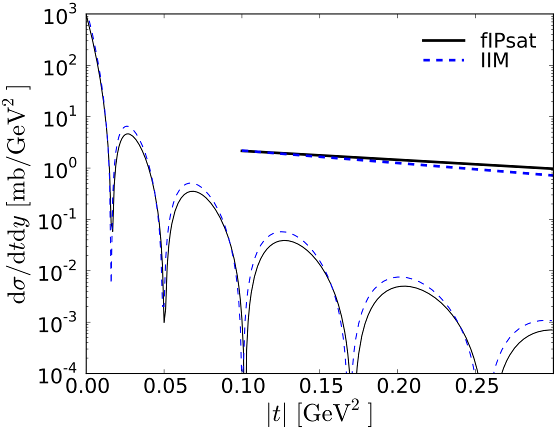
BACKUPS

Wave function overlap in J/Ψ production:





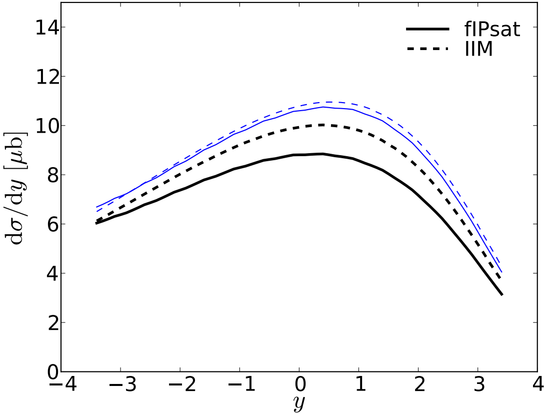
Differential cross section



T. Lappi, H. Mäntysaari, 1301.4095

Assuming proton profile function $T_p(b) \sim e^{b^2/(2B_p)} \Rightarrow$ incoherent cross section $\sim e^{-B_p t}$: probes spatial distribution of gluons in proton!

pA prediction



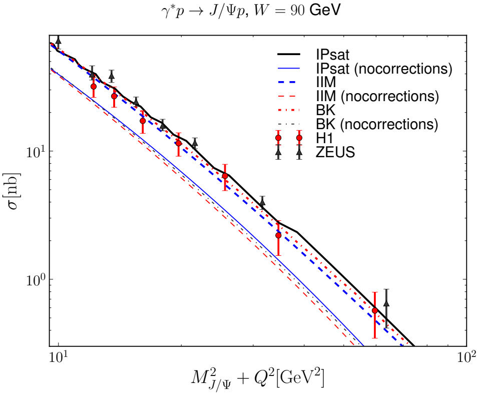
T. Lappi, H. Mäntysaari, 1301.4095 CMS frame

As the photon flux $\sim Z^2$, dominant process is the one where the nucleus emits the photon $\Rightarrow$ probes mostly proton structure.

BK evolved dipole amplitude

Preliminary

Fit HERA σ_r: get automatically good description of σ_r^{charm}. Assume factorized impact parameter profile and $\sigma = \frac{1}{B_p}\mathrm{d}\sigma/\mathrm{d}t|_{t=0}$



Problem: large $\sigma_0 \sim 50$ mb