Diffractive vector meson production in ultraperipheral heavy ion collisions from the Color Glass Condensate

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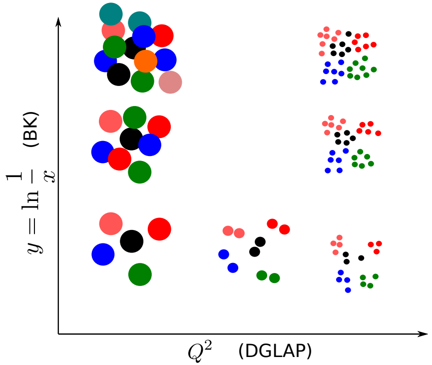
Introduction



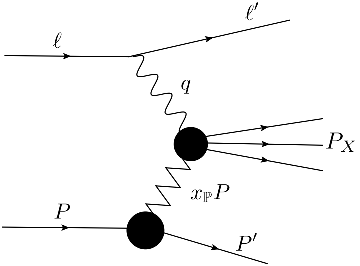
Saturation effects $\sim$ gluon recombination

- 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*

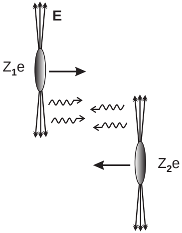
(Lepton-proton) Diffraction

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



nucl-ex/0502005

$b \gtrsim 2R_A$: strong interactions suppressed, nucleus creates photon flux $n(\omega)$
$\sigma \sim n(\omega)\sigma^{\gamma A}(\omega)$
Probes gluons with $x = M_V e^y / \sqrt{s}$

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

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

Coherent and incoherent diffraction

Diffraction off the nucleus:

- Coherent diffraction: nucleus remains intact

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

- Quasielastic = coherent + incoherent

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

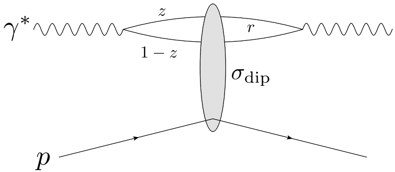
- Incoherent, nucleus is allowed to break up

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

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

Dipole cross section

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



- Total $\gamma^* p$:

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

- Total diffraction:

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

- Exclusive diffraction:

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

- Inclusive particle production (pp, pA):

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

- $+$ Correlations, ...

IPsat model

Impact parameter dependent BK evolution is problematic (work in progress), use IPsat model (Kowalski, Teaney 2003; Rezaeian et al, 2013):

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

- Fit to HERA data: initial condition for DGLAP evolution of $xg(x,\mu^2)$
- Proton profile T_p gaussian

Generalize for nuclei:

- $T_p(b) \to \sum_{i=1}^A T_p(b - b_i)$
- Average over different nucleon configurations from Woods-Saxon $\Rightarrow$ coherent/incoherent diffraction

Factorized IPsat

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

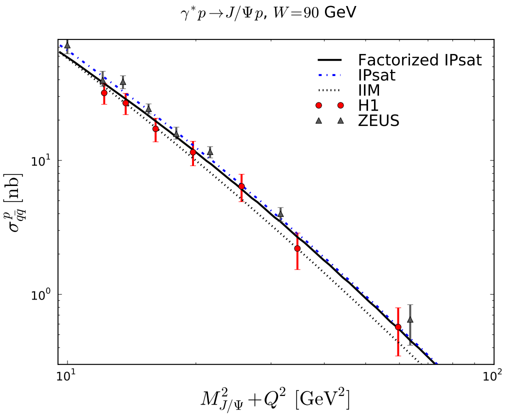
$$N(r,x,b) \approx T(b)N(r,x)$$

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

- Also large corrections from real part and skewness
- Compare "fIPsat" to IIM (Iancu, Itacura, Munier) model: study dependence on dipole model

Comparison with the HERA data

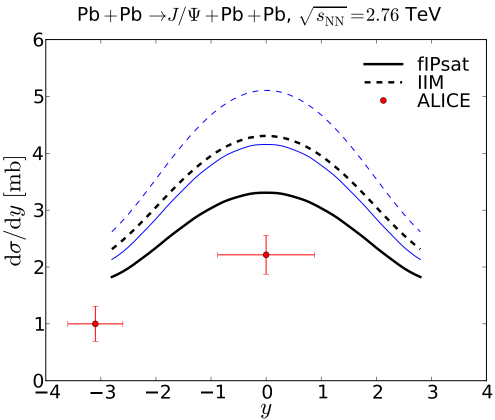
Compare with HERA $\gamma^* p \to J/\Psi p$ data:



T. Lappi, H. Mäntysaari, 1011.1988

Also a good description of the F_2 data.

Comparison with the ALICE data: coherent diffraction

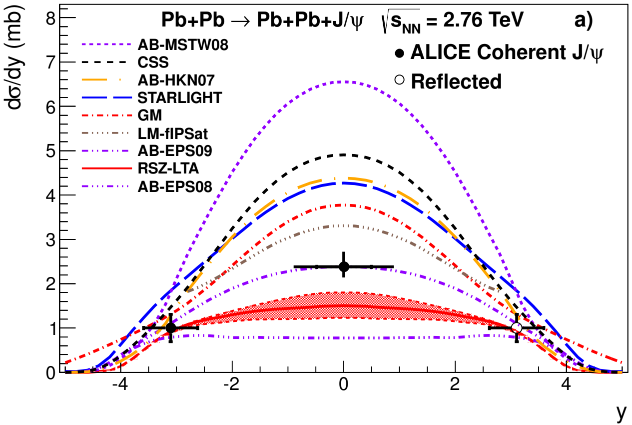


T. Lappi and H. Mäntysaari, 1301.4095; Data: ALICE 1310.7732

Different dipole and vector meson wavef models: change overall normalization, but shape is very similar.

RHIC midrapidity: $\mathrm{d}\sigma/\mathrm{d}y = 109\mu\mathrm{b}$, experimental $76 \pm 34\mu\mathrm{b}$.

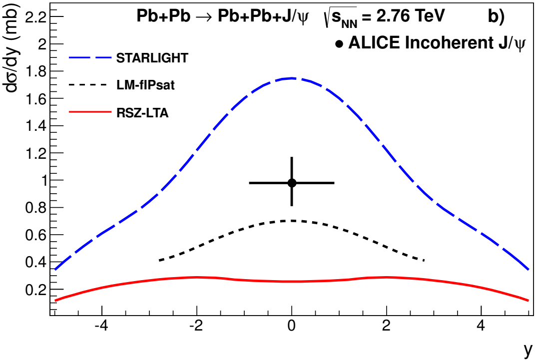
Coherent diffraction, model comparison



ALICE, 1310.7732

Unshadowed model (AB-MSTW08) clearly fails ⇒ saturation effects seen

Comparison of predictions (incoherent diffraction)



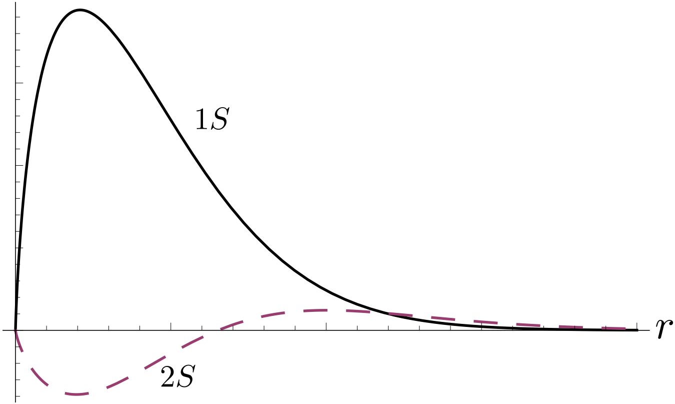
ALICE, 1305.1467

Normalization dependence on the J/Ψ wave function model: $\sim 25\%$

$\Psi(2S)$ production

$\Psi(2S)$ wave function has a node $\Rightarrow$ large suppression compared to J/Ψ

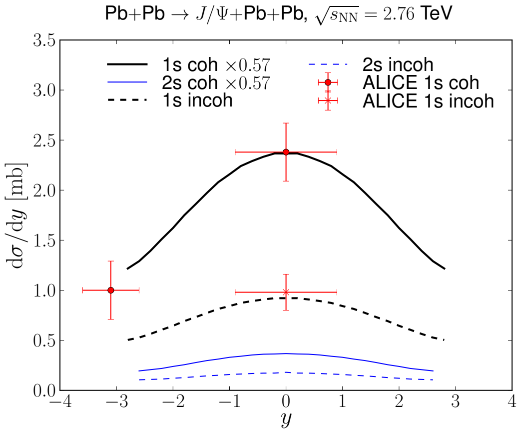
- Meson-photon wave function overlap, $z = 0.5$:



$\Psi(2S)$ production

$\Psi(2S)$ wave function has a node $\Rightarrow$ large suppression compared to J/Ψ

- 2S/1S Ratio depends on event type:
  $\gamma p <$ coherent $\gamma A <$ incoherent γA



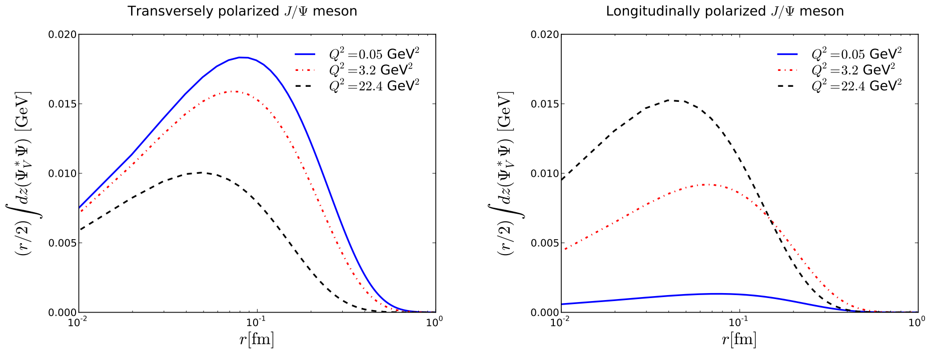
Data: ALICE, 1310.7732, 1305.1467

Conclusions

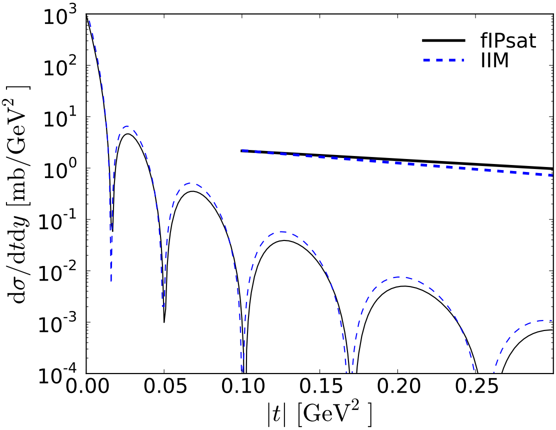
- Ultraperipheral heavy ion collisions make it possible to study γA diffraction at high energy
- Coherent and incoherent photoproduction measurements provide independent model constraints
- Dipole model description of incoherent and coherent diffraction in $\gamma^* A$
  - Here used IPsat parametrization fit to HERA
  - Absolute normalization has largish model dependence
  - Rapidity evolution of $\mathrm{d}\sigma/\mathrm{d}y$ is more precise prediction
- Prediction for $\Psi(2S)$ production and $\Psi(2S)\Big/\mathrm{J}/\Psi$ ratio
- 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:



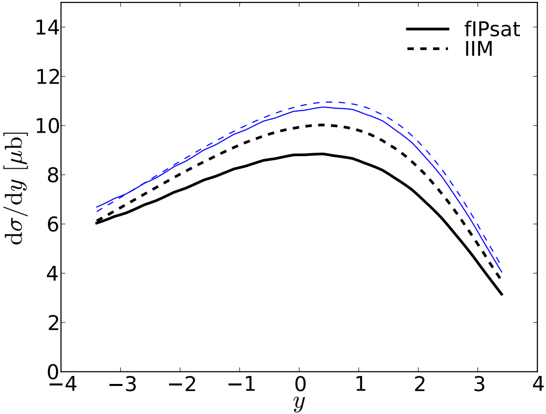
Differential cross section



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!

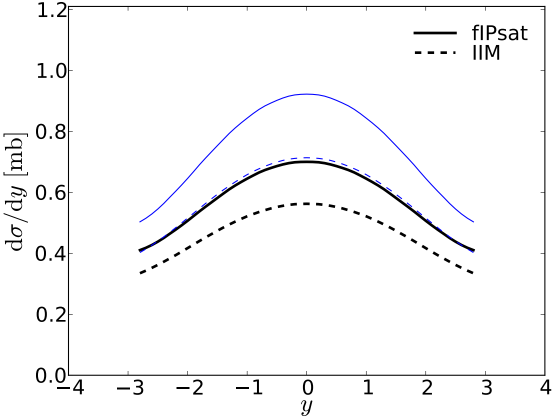
pA prediction



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.

Prediction for incoherent diffraction

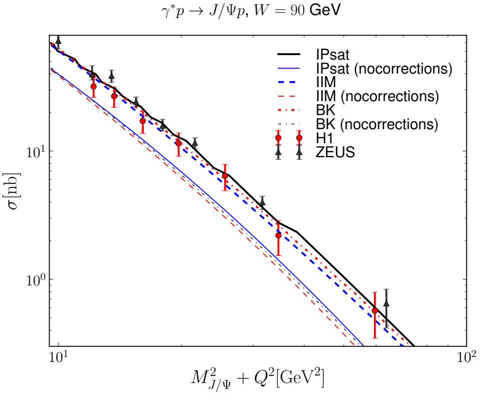


T. Lappi, H. Mäntysaari, 1301.4095

Again overall normalization uncertainty, but $\sigma(y = 0)/\sigma(y = 2) = 1.4$ more precise prediction.

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