Energy dependence of the proton geometry in exclusive vector meson production

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Arjun Kumar, TT: arXiv:2202.06631
Exclusive diffraction

Dipole model with bSat and bNonSat

\[
\frac{d\sigma_{q\bar{q}}}{d^2b} = 2 \left[ 1 - \exp \left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) xg(x, \mu^2) T(b) \right) \right]
\]

\[
\frac{d\sigma_{q\bar{q}}^{\text{nosat}}}{db} = \frac{\pi^2}{N_C} r^2 \alpha_s(\mu^2) xg(x, \mu^2) T(b)
\]

\[
xg(x, \mu_0^2) = A_g x^{-\lambda_s} (1 - x)^6 \quad \mu^2 = \mu_0^2 + \frac{C}{r^2}
\]
Incoherent Scattering

Good, Walker (Phys. Rev. 120 (1960) 1857–1860):

Proton dissociates \((f \neq i)\):

\[
\sigma_{\text{incoherent}} \propto \sum_{f \neq i} \langle i | \mathcal{A} | f \rangle^\dagger \langle f | \mathcal{A} | i \rangle \quad \text{complete set}
\]

\[
= \sum_{f} \langle i | \mathcal{A} | f \rangle^\dagger \langle f | \mathcal{A} | i \rangle - \langle i | \mathcal{A} | i \rangle^\dagger \langle i | \mathcal{A} | i \rangle
\]

\[
= \langle i | |\mathcal{A}|^2 | i \rangle - |\langle i | \mathcal{A} | i \rangle|^2 = \langle |\mathcal{A}|^2 \rangle - |\langle \mathcal{A} \rangle|^2
\]

The incoherent CS is the variance of the amplitude!!

\[
\frac{d\sigma_{\text{total}}}{dt} = \frac{1}{16\pi} \langle |\mathcal{A}|^2 \rangle
\]

\[
\frac{d\sigma_{\text{coherent}}}{dt} = \frac{1}{16\pi} |\langle \mathcal{A} \rangle|^2
\]
Incoherent Scattering in $ep$

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\frac{d\sigma_{qq}}{d^2 b} = 2 \left[ 1 - \exp \left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) T(b) \right) \right]
\]

\[T_p(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}}\]

\[T_p(b) = \frac{1}{2\pi N_q B_q} \sum_{i=1}^{N_q} e^{-\frac{(|\vec{b} - \vec{b}_i|^2)}{2B_q}}\]

$\vec{b}_i$ with a Gaussian distribution of width $B_{qc}$

Also: large scale (small $|t|$) saturation scale fluctuations.
Incoherent Scattering in $ep$

$$\frac{d\sigma_{qq}^\text{nosat}}{db} = \frac{\pi^2}{N_C} r^2 \alpha_S(\mu^2)xg(x, \mu^2)T(b)$$

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For $b_{\text{NonSat}}$, $\langle A \rangle \propto \langle T(b) \rangle$

$$T_p(b) = \frac{1}{2\pi N_q B_q} \sum_{i=1}^{N_q} e^{-\frac{(\vec{b} - \vec{b}_i)^2}{2B_{q\text{c}}}}$$

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Modified profile:

$$T_q(b) = \frac{1}{2\pi B_q} \frac{1}{\exp \left( \frac{b^2}{2B_q} \right) - S_g}$$

$\vec{b}_i$ with a Gaussian distribution of width $B_{qc}$

Also: large scale (small $|t|$) saturation scale fluctuations.
Modelling x-dependence:
1. The Proton’s Size

\[ T_p(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}} \]

\[ B_G(x_{IP}) = B_p x_{IP}^{\lambda_p} \]

\[ r_{rms} = \sqrt{2B_G(x_{IP})} \]
$$T_p(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}}$$

$$B_G(x_{IP}) = B_p x_{IP}^{\lambda_p} \quad B_p = 2.3 \text{ GeV}^{-2} \quad \lambda_p = -0.062$$
Modelling x-dependence:

2. The Hotspot Size

\[ T_p(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}} \]

\[ B_G(x_{IP}) = B_p x_{IP}^{\lambda_p} \]

\[ r_{rms} = \sqrt{2B_G(x_{IP})} \]

Variable Hotspot Width (VHW):

\[ T_p(b) = \frac{1}{2\pi N_q B_q} \sum_{i=1}^{N_q} e^{-\frac{(b - \bar{b}_i)^2}{2B_q}} \]

\[ B_q(x_{IP}) = B_{hs} x_{IP}^{\lambda_{hs}} \]

\[ r_{rms} = \sqrt{2(B_{qc} + B_q(x_{IP}))} \]
Modelling x-dependence:  

2. The Hotspot Size

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Variable Hotspot Width (VHW):

\[ B_q(x_{IP}) = B_{hs} x_{IP}^{\lambda_{hs}} \]

Logarithmic model:

\[ B_q(x_{IP}) = b_0 \ln^2 \frac{x_0}{x_{IP}} \]

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F. Salazar, B. Schenke, A. Soto-Ontoso,
Accessing subnuclear fluctuations and saturation with multiplicity dependent J/ψ production in p+p and p+Pb collisions, Phys. Lett. B 827 (2022) 136952. arXiv:2112.04611
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\[ r_{rms} = \sqrt{2(B_{qc} + B_q(x_{IP}))} \]
\[ B_q(x_{IP}) = B_{hs} x_{IP}^{\lambda_{hs}} \]

\[ B_{hs} = 0.256 \pm 0.009 \text{ GeV}^{-2} \quad \lambda_{hs} = -0.198 \pm 0.0045 \]

\[ B_q(x_{IP}) = b_0 \ln^2 \frac{x_0}{x_{IP}} \]

\[ b_0 = 0.075 \pm 0.004 \text{ GeV}^{-2} \quad x_0 = 6.7 \pm 1.2 \]
Modelling x-dependence:

3. Number of Hotspots

\[ T_p(b) = \frac{1}{2\pi N_q B_q} \sum_{i=1}^{N_q} e^{-\frac{(\vec{b} - \vec{b}_i)^2}{2B_q}} \]

\[ N_q \rightarrow N_q(x_P) = p_0 x_P^{p_1} (1 + p_2 \sqrt{x_P}) \]

J. Cepila, J. G. Contreras, J. D. Tapia Takaki, 
Energy dependence of dissociative J/ψ photoproduction as a signature of gluon saturation at the LHC.
Phys. Lett. B 766 (2017) 186–191.

\[ p_0 = 0.011, \ p_1 = -0.56, \ p_2 = 165 \]
Elastic $J/\psi$ photoproduction

- $B_q = 0.94 \text{ GeV}^{-2}$, $N_q = 3$
- $B_q = B_{hs} \chi_{hs} \text{ GeV}^{-2}$, $N_q = 3$
- $B_q = b_q \ln^2 \left( \frac{x_0}{x} \right) \text{ GeV}^{-2}$, $N_q = 3$
- $B_q = 0.94 \text{ GeV}^{-2}$, $N_q = N_q(x)$
- $B_G = 4.0 \text{ GeV}^{-2}$ (no fluctuations)
- $B_G = B_G(x) \text{ GeV}^{-2}$ (no fluctuations)

- H1 ($Q^2 = 0.05 \text{ GeV}^2$)
- ZEUS ($Q^2 = 0 \text{ GeV}^2$)
\[ B_{hs} = 0.462 \text{ GeV}^{-2} \]
\[ \lambda_{hs} = -0.182 \]
\[ b_0 = 0.117 \pm 0.004 \text{ GeV}^{-2} \]
\[ x_0 = 20 \pm 6 \]
Conclusions and Outlook

Presented a few modified hotspot models to take energy dependence into account.

Data shows preferences for models where the hotspot width varies with $x_{IP}$.

Currently not great discriminating power in the data.

EIC can significantly improve these measurements.

Would be nice to see $\frac{\sigma_{\text{inelastic}}(y)}{\sigma_{\text{elastic}}}$ in pA UPC.

At some point we need a new fit of all model parameters.
