Energy dependent hot spots model

Energy dependence of dissociative J/ψ photoproduction as a signature of gluon saturation at the LHC

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Introduction

- Gluon density in hadrons grows with energy (with decreasing Bjorken-x)
- At some point non-linear effects tame this growth = **gluon saturation**
- Vector meson photoproduction is sensitive to the gluon distribution in the impact parameter b plane
  - Exclusive processes given as an average over the configurations of the target
  - Dissociative processes are given by the variance over the configurations

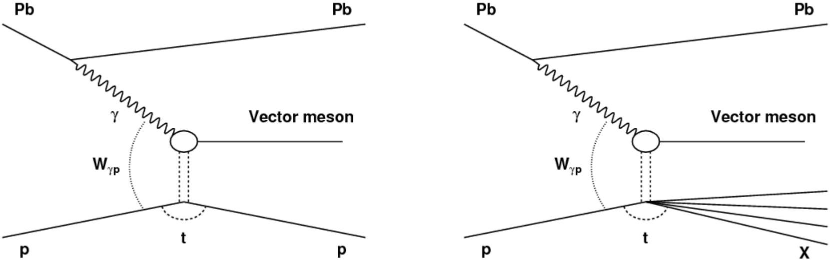


Figure: Diagrams for exclusive (left) and dissociative (right) vector meson photo-production.

Theoretical approach (1)

- Color dipole approach
  - Incoming particle ($e^{\pm}$, Pb nucleus) emits a virtual photon γ^*
  - Photon interacts with the proton via one of its Fock states - $q\bar{q}$ dipole
  - Dipole forms a vector meson
- The amplitude of the process

$$\mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) = i \int \mathrm{d}\vec{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} (\psi^*_{VM}\psi_{\gamma^*})_{T,L} \int \mathrm{d}\vec{b} e^{-i[\vec{b}-(1-z)\vec{r}]\vec{\Delta}} \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}\vec{b}} \tag{1}$$

  - $\vec{\Delta}^2 = -t$
  - $\vec{r}$ - transverse distance between the q and $\bar{q}$
  - z - longitudinal momentum fraction of γ^* carried by the quark
  - $(\psi^*_{VM}\psi_{\gamma^*})_{T,L}$ - overlap of the photon and vector meson wave functions
  - T,L - transverse and longitudinal polarisation of γ^*
  - $\vec{b}$ - impact parameter

Theoretical approach (2)

- Dipole-proton cross section related to the dipole scattering amplitude N via the optical theorem

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}\vec{b}} = 2N(x, \vec{r}, \vec{b}) \tag{2}$$

- Factorised form of the dipole amplitude:

$$2N(x, r, \vec{b}) = \sigma_0 N(x, r) T_p(\vec{b}) \tag{3}$$

  - $r \equiv |\vec{r}|$
  - σ_0 - normalization constant
  - $T_p(\vec{b})$ describes the transverse structure of the proton

- Dipole amplitude $N(x, r)$ from the Golec-Biernat–Wusthoff model

$$N(x, r) = 1 - \exp\left[-\frac{r^2 Q_s^2(x)}{4}\right], \qquad Q_s^2(x) = Q_0^2 \left(\frac{x_0}{x}\right)^{\lambda} \tag{4}$$

Theoretical approach (3) - Hot spots model

- Proton structure fluctuates from interaction to interaction - many possible configurations
- Fluctuations included in $T_p(\vec{b})$
- Proton profile as a sum of N_{hs} regions of high gluonic density (hot spots)

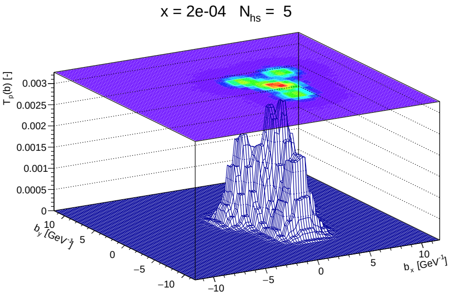
$$T_p(b) = \frac{1}{N_{hs}} \sum_{j=1}^{N_{hs}} T_{hs}\left(\vec{b} - \vec{b}_j\right) \tag{5}$$

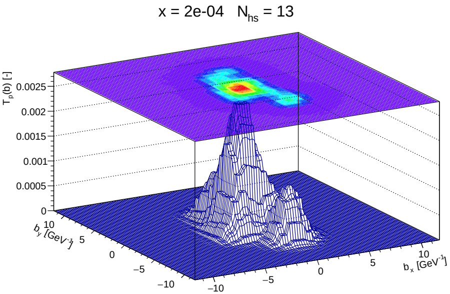
$$T_{hs}(b) = \frac{1}{2\pi B_{hs}} \exp\left(-\frac{b^2}{2B_{hs}}\right). \tag{6}$$

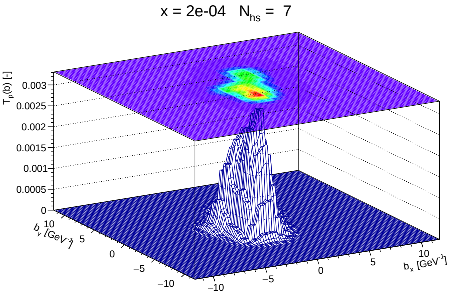
  - Each $\vec{b}_j$ is obtained from 2-D Gaussian distribution centered at $\vec{0}$ with the width B_p
  - B_p, B_{hs} - average of the squared transverse radius of the proton, resp. hot spot
- Indirect energy dependence of the $T_p(\vec{b})$ - number of hot spots $N_{hs} = N_{hs}(x)$

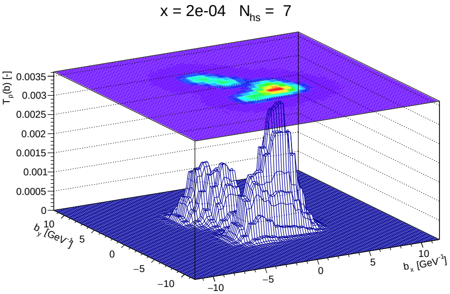
$$N_{hs} = p_0 x^{p_1}\left(1 + p_2\sqrt{x}\right) \tag{7}$$

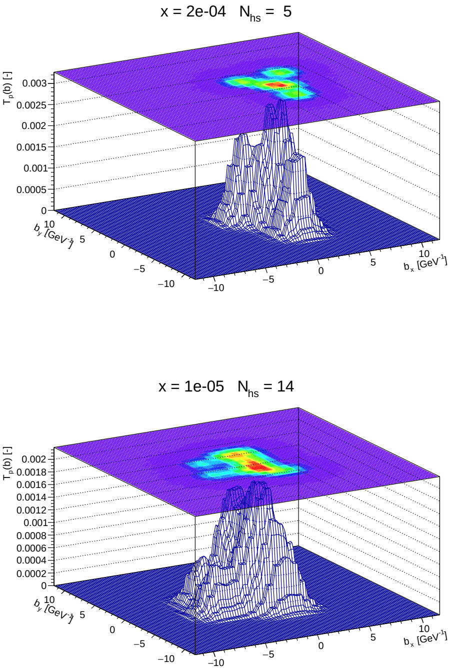
$$p_0 = 0.011,\ p_1 = -0.58,\ p_2 = 300 \rightarrow N_{hs}(x = 2 \cdot 10^{-4}) \doteq 6.0802$$


x = 2e-04 N_{hs} = 5
$T_p(b)$ [-]
b_y [GeV^{-1}]
b_x [GeV^{-1}]


x = 2e-04 N_{hs} = 13
$T_p(b)$ [-]
b_y [GeV^{-1}]
b_x [GeV^{-1}]


x = 2e-04 N_{hs} = 7
$T_p(b)$ [-]
b_y [GeV^{-1}]
b_x [GeV^{-1}]


x = 2e-04 N_{hs} = 7
$T_p(b)$ [-]
b_y [GeV^{-1}]
b_x [GeV^{-1}]


x = 2e-04 N_{hs} = 5
x = 2e-04 N_{hs} = 14
x = 1e-05 N_{hs} = 14
x = 1e-06 N_{hs} = 39
$T_p(b)$ [-]
b_x [GeV^{-1}]
b_y [GeV^{-1}]

Theoretical approach (4)

- The amplitude can be rewritten as

$$\mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) = iA_b(\vec{\Delta})A_r(x, Q^2, \vec{\Delta})_{T,L} \tag{8}$$

$$A_b \equiv \int \mathrm{d}\vec{b}e^{-i\vec{b}\cdot\vec{\Delta}} T_p(\vec{b}) = e^{-\frac{B_{hs}\Delta^2}{2}} \cdot \frac{1}{N_{hs}} \sum_{j=1}^{N_{hs}} e^{-i\vec{b}_j\cdot\vec{\Delta}}$$

- The exclusive cross section

$$\left(\frac{\mathrm{d}\sigma^{\gamma^* p\to J/\psi p}}{\mathrm{d}|t|}|\right)_{T,L} = \frac{(R_g)^2_{T,L}}{16\pi} | \left\langle \mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) \right\rangle |^2 \tag{9}$$

- The dissociative cross section

$$\left(\frac{\mathrm{d}\sigma^{\gamma^* p\to J/\psi X}}{\mathrm{d}|t|}|\right)_{T,L} = \frac{(R_g)^2_{T,L}}{16\pi} \left(\left\langle |\mathcal{A}_{T,L}(x, Q^2, \vec{\Delta})|^2 \right\rangle - | \left\langle \mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) \right\rangle |^2\right) \tag{10}$$

- The skewedness correction to the amplitude

$$R_g(\lambda_{T,L}) = \frac{2^{2\lambda_{T,L}+3}}{\sqrt{\pi}} \frac{\Gamma\left(\lambda_{T,L} + \frac{5}{2}\right)}{\Gamma(\lambda_{T,L} + 4)}, \qquad \lambda_{T,L} \equiv \frac{\partial \ln\left(\mathcal{A}_{T,L}\right)}{\partial \ln\left(\frac{1}{x}\right)} \tag{11}$$

Results

- Parameters:

$$\lambda = 0.21, \qquad x_0 = 2 \cdot 10^{-4}, \qquad Q_0^2 = 1\ \mathrm{GeV}^2$$
$$B_p = 4.7\ \mathrm{GeV}^{-2}, \qquad \sigma_0 = 4\pi B_p, \qquad B_{hs} = 0.8\ \mathrm{GeV}^{-2}$$
$$p_0 = 0.011, \qquad p_1 = -0.58, \qquad p_2 = 250 \rightarrow p_2 = 300$$

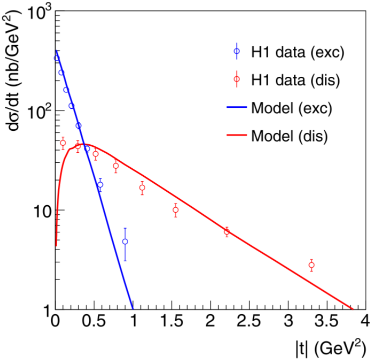


Figure: Comparison of the model to H1 data of the $|t|$ distribution for exclusive (blue) and dissociative (red) differential cross section of J/ψ at $< W >= 78$ GeV.

Results

- At some energy value - the dissociative cross section starts to decrease
  - N_{hs} grows $\rightarrow$ at some point hot spots overlap
  - Configurations are similar when saturation is reached and variance $\rightarrow 0$

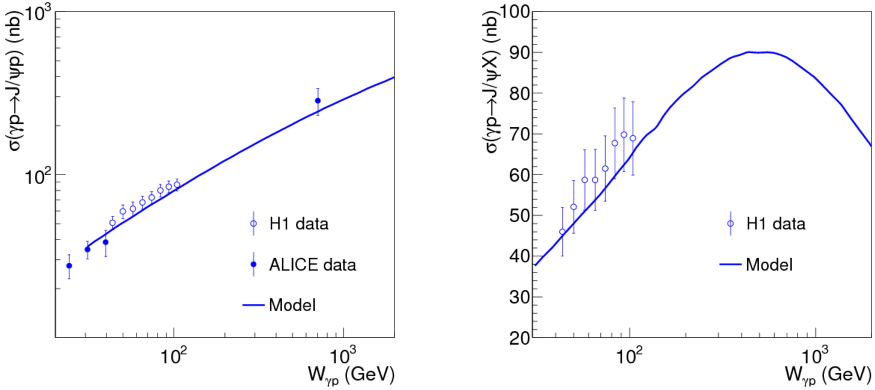


Figure: Comparison of the model to H1 and ALICE data of the W dependence for exclusive (left) and dissociative (right) cross section of J/ψ.

Conclusions and discussion

- Maximum of the dissociative cross section at $W_{\gamma p} \approx 500\ \mathrm{GeV}$
  - $N_{hs} \approx 10 - 11$
  - Sizeable overlap of hot spots
  - Cross section decreases with increasing energy
- These conditions can be reached at LHC
  - Dissocitive contribution populates large $|t|$ region
  - $|t|$ is related to transverse momentum of J/ψ at ALICE