Fluctuations of the inner structure of the proton and the dissociative production of vector mesons

Evidence of strong proton shape fluctuations from incoherent diffraction

H. Mantysaari and B. Schenke
Phys. Rev. Lett. 117 (2016) 052301

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

J. Cepila, J. G. Contreras and J. D. Tapia Takaki
Phys. Lett. B 766 (2017) 186-191

Dagmar Bendová
Workshop on Diffraction and UPC in Děčín

Workshop supported by grant SVK30/19/F4

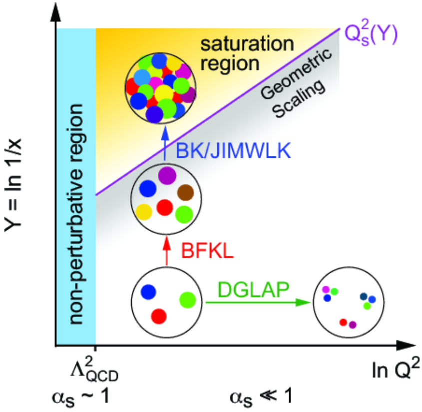

Figure: C. Marquet, Nucl.Phys. A904-905 (2013) 294c-301c.

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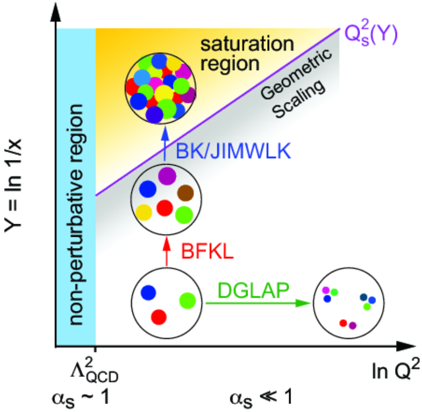

Figure: C. Marquet, Nucl.Phys. A904-905 (2013) 294c-301c.

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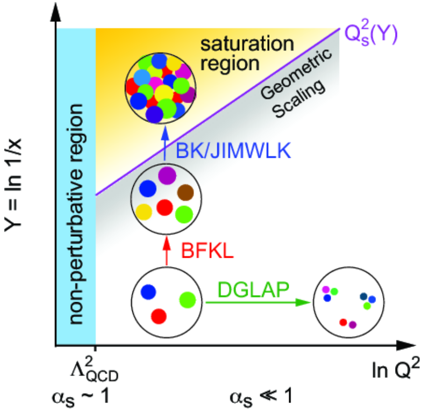
Evolution of the partonic structure of the proton



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- Evolution of parton densities with increasing energy.
- By fixing the scale of the process, one can fix the position in ln Q^2.
- Growth of gluon densities with increasing energy (descreasing Bjorken-x).
- Going to smaller x (higher E), one can reach the saturation scale $Q_S^2(x)$
  - Below $Q_S^2(x) \rightarrow$ dilute regime, linear evolution of the gluon density (BFKL).
  - Above $Q_S^2(x) \rightarrow$ dense regime, non-linear evolution of the gluon density (JIMWLK, BK) – **gluon saturation**.

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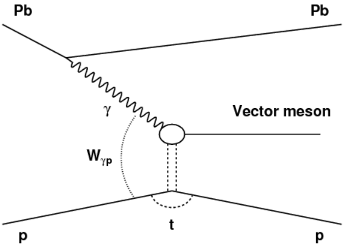

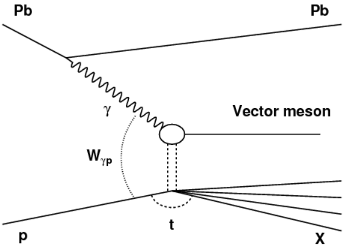

Theoretical approach

- Color dipole approach
  - Incoming particle ($e^{\pm}$, Pb nucleus) emits a (virtual) photon γ^*
  - Photon interacts with the proton in its rest frame via one of its Fock states - $q\bar{q}$ dipole
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  - $(\psi_V^* \psi_{\gamma^*})_{T,L}$ — photon and vector meson wave functions

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- Dipole amplitude $N(x, \vec{r}, \vec{b})$ can be obtained as a solution of BK/JIMWLK evolution equations or from various parametrizations.
- Various groups apply different approach to the dipole-proton cross section and subnucleonic fluctuations in the transverse (IP) plane.

- **Impact-parameter dependent saturation model (IP-Sat)**

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}\vec{b}} = 2\left[1 - \exp\left(-\vec{r}^2 F(x, \vec{r}) T_p(\vec{b})\right)\right]$$

  - Proton profile function

$$T_p(\vec{b}) = \frac{1}{2\pi B_p} \exp\left(\frac{-\vec{b}^2}{2B_p}\right)$$

  - B_p is related to the transverse size of the proton.
  - DGLAP evolved gluon distribution

$$F(x, \vec{r}^2) = \frac{\pi^2}{2N_c} \alpha_S(\mu^2) xg(x, \mu^2), \qquad \mu^2 = \mu_0^2 + \frac{4}{\vec{r}^2}$$

- **IP-Glasma model**
  - Dipole amplitude N at given x calculated from the Wilson lines of the proton.
  - Sampling of color charges from the IP-Sat (propotional to the saturation scale $Q_s(x)$).
  - Calculations performed on the lattice.

Approach of Mantysaari et al. – a constituent quark model

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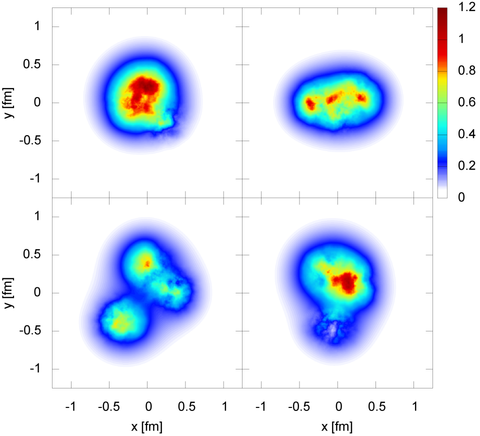
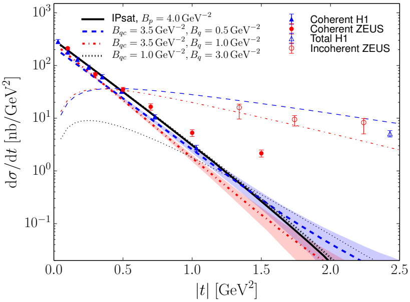
- Positions of valence quarks can fluctuate event by event.
- Proton saturation scale $Q_s(x)$ can also fluctuate event by event, independently for each constituent quark.
- $Q_s(x)$ fluctuations can be implemented by modifying the T_q normalization.

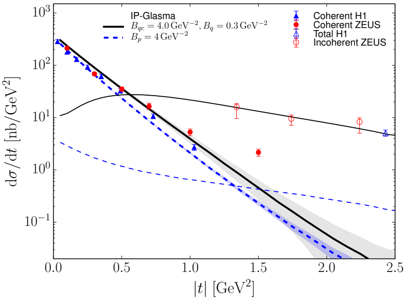
- Example of four configurations of the proton in the IP-Glasma model at $x \approx 10^{-3}$.



Results of Mantysaari et al. – $|t|$-distribution of J/ψ cross section

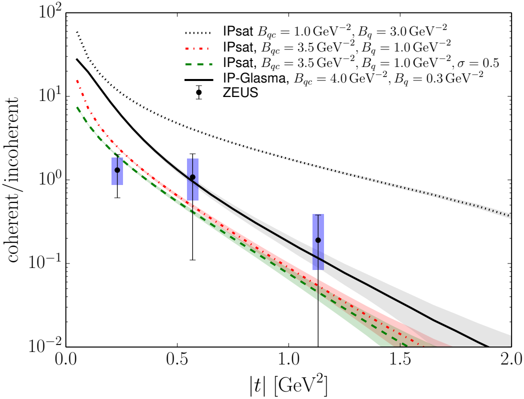
- Coherent cross section dominates at low values of $|t|$.
- Incoherent cross section has a large contribution at large $|t|$‘s.
- Both models provide good description of the coherent process independently on inclusion of subnucleonic fluctuations.
- Without large fluctuations, incoherent cross section is considerably underestimated.
- Q_s fluctuations only don‘t result in description of the incoherent cross section.
- **By including both subnucleonic and Q_s fluctuations in the proton structure, a good description of incoherent process is obtained.**





Results of Mantysaari et al. – ratio of total J/ψ cross sections

- Prediction with smoother proton is not in agreement with the data.
- Strongly fluctuating proton provides a good description of the data.
- Fluctuations of Q_s have only small effect on the result.
- Future EIC should provide more precise measurements.



Approach of Čepila et al. – Energy-dependent hot-spot model

- Factorize out the b-dependence into a separate function

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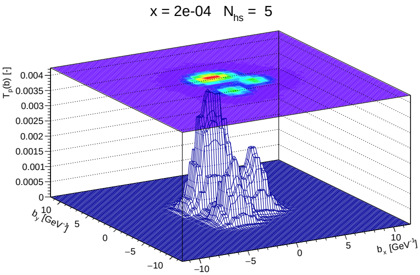
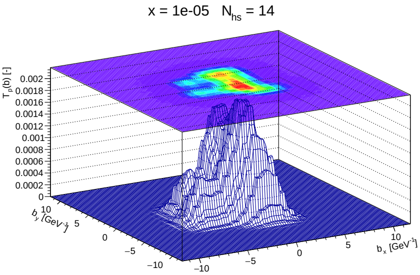
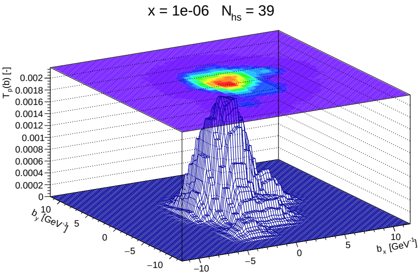
  - **Number of hot spots grows with decreasing** $x \to N_{hs} = p_0 x^{p_1}\left(1+p_2\sqrt{x}\right)$
  - The positions and number of the hot spots fluctuate event-by-event.

Approach of Čepila et al. – Examples of proton profiles

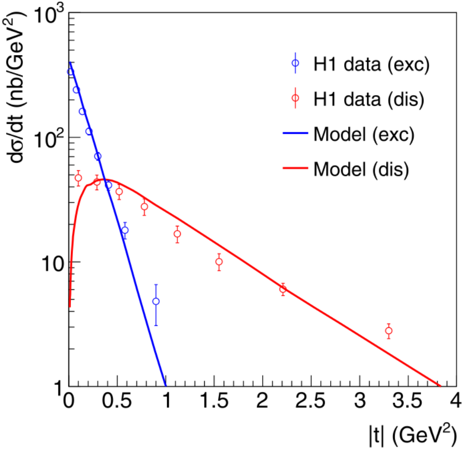






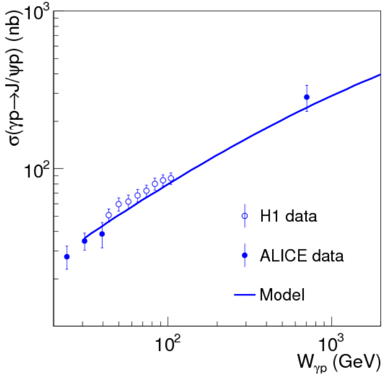
Results of Čepila et al. – $|t|$ distribution of J/ψ cross section

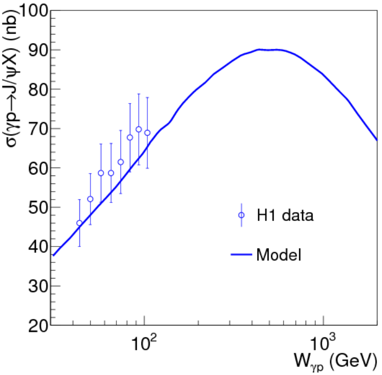
- Comparison of the model to the H1 data for J/ψ photoproduction at $W_{\gamma p} = 78\ \mathrm{GeV}$
- Exclusive cross section dominates at low $|t|$.
- Dissociative cross section has a large contribution at high values of $|t|$.



Results of Čepila et al. – total J/ψ cross section

- Exclusive cross section grows with increasing photon-proton CMS energy $W_{\gamma p}$.
- Dissociative cross section shows striking behavior in dependence on $W_{\gamma p}$
  - Cross section reaches a maximum at a certain energy and decreases afterwards
  - With decreasing x available area in the proton is filled with hot spots
  - At even lower x hot spots start to overlap $\rightarrow$ all the possible configurations look alike $\rightarrow$ variance decreases.
  - **Saturation of gluon densities in the impact-parameter plane.**





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- These measurements can be improved at future EIC.

BACKUP SLIDES

Dissociative cross section at ALICE

- Hot-spot model – maximum of the dissociative cross section at $W_{\gamma p} \approx 500\ \mathrm{GeV}$
- These conditions can be reached at LHC
  - Dissocitive contribution populates large $|t|$ region
  - $|t|$ is related to transverse momentum p_T of J/ψ at ALICE