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Subnuclear fluctuations in vector meson photoproduction: a window to saturation

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April 18, 2018, Kobe

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Contents and bottom line

- News from J/ψ production in γp collisions:
  - The energy dependence of dissociative J/ψ photoproduction provides a striking signature for saturation.

Čepila, JGC, Tapia , PLB 766 (2017) 186

- News from J/ψ production in γPb collisions:
  - Fluctuations of subnuclear degrees of freedom also leave an imprint in the photoproduction of J/ψ off nuclear targets.

Čepila, JGC, Křelina, PRC 97 (2018), 024901

- News from other vector mesons:
  - The mass dependence of vector meson photoproduction privides a new handle in the search for saturation effects.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508

Introduction

Introduction

See Heikki's talk on Monday!

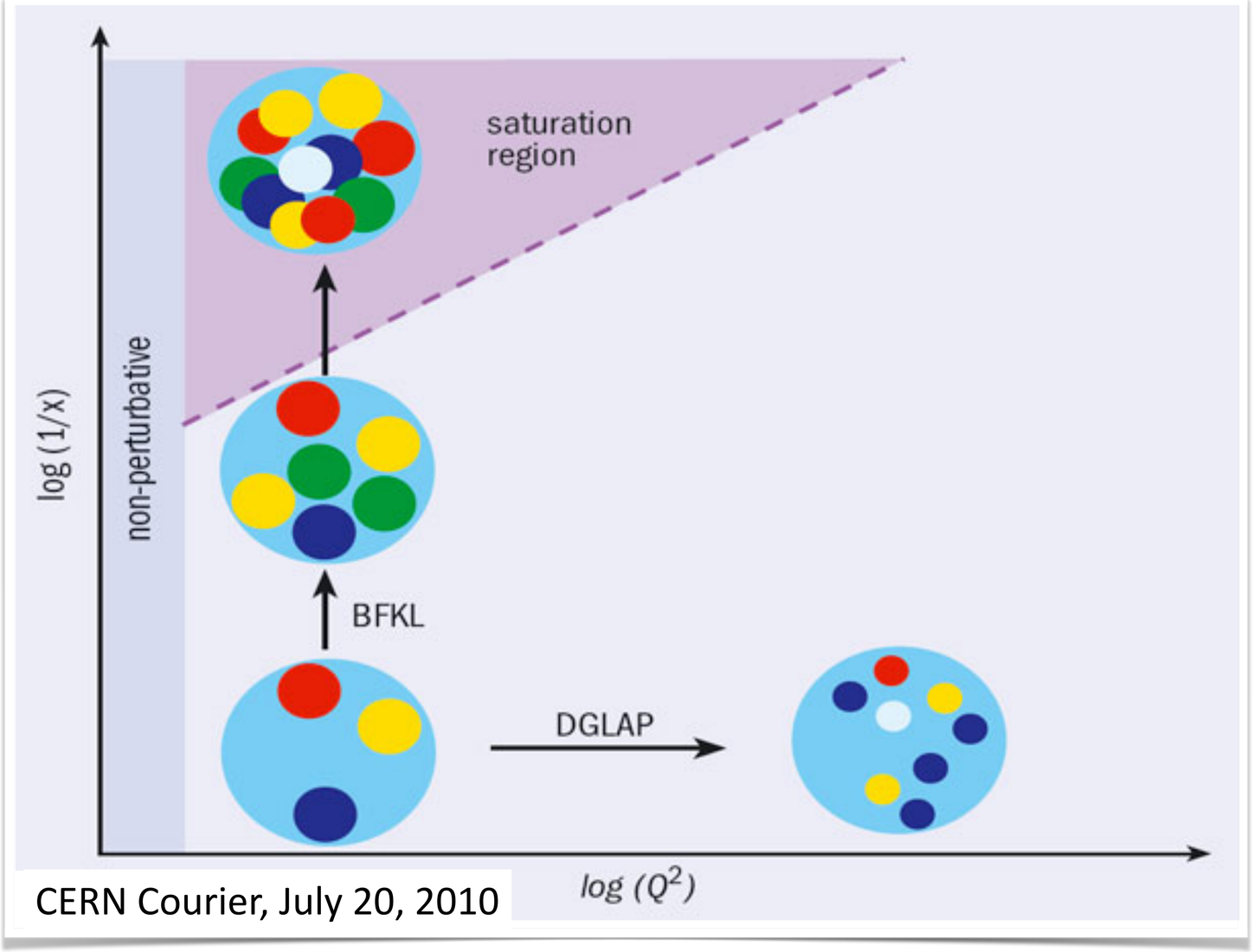
- Fluctuations of subnuclear degrees of freedom in the impact-parameter plane, may yield signatures of saturation.

- Full formal treatment of this problem is difficult.
  - From the theory side there are open problems; e.g., how to deal with contribution form large dipoles.
  - The calculations need sizeable computational resources.

- Try to extract the main broad behaviour in a simple model.
  - Simple, but guided by pQCD.
  - Parameters, with reasonable values, fixed by as little data as possible to have some predictive power.
  - Agreement with data is comforting, but should not be overemphasised,

News from J/ψ production in γp collisions

High-energy limit of pQCD



CERN Courier, July 20, 2010

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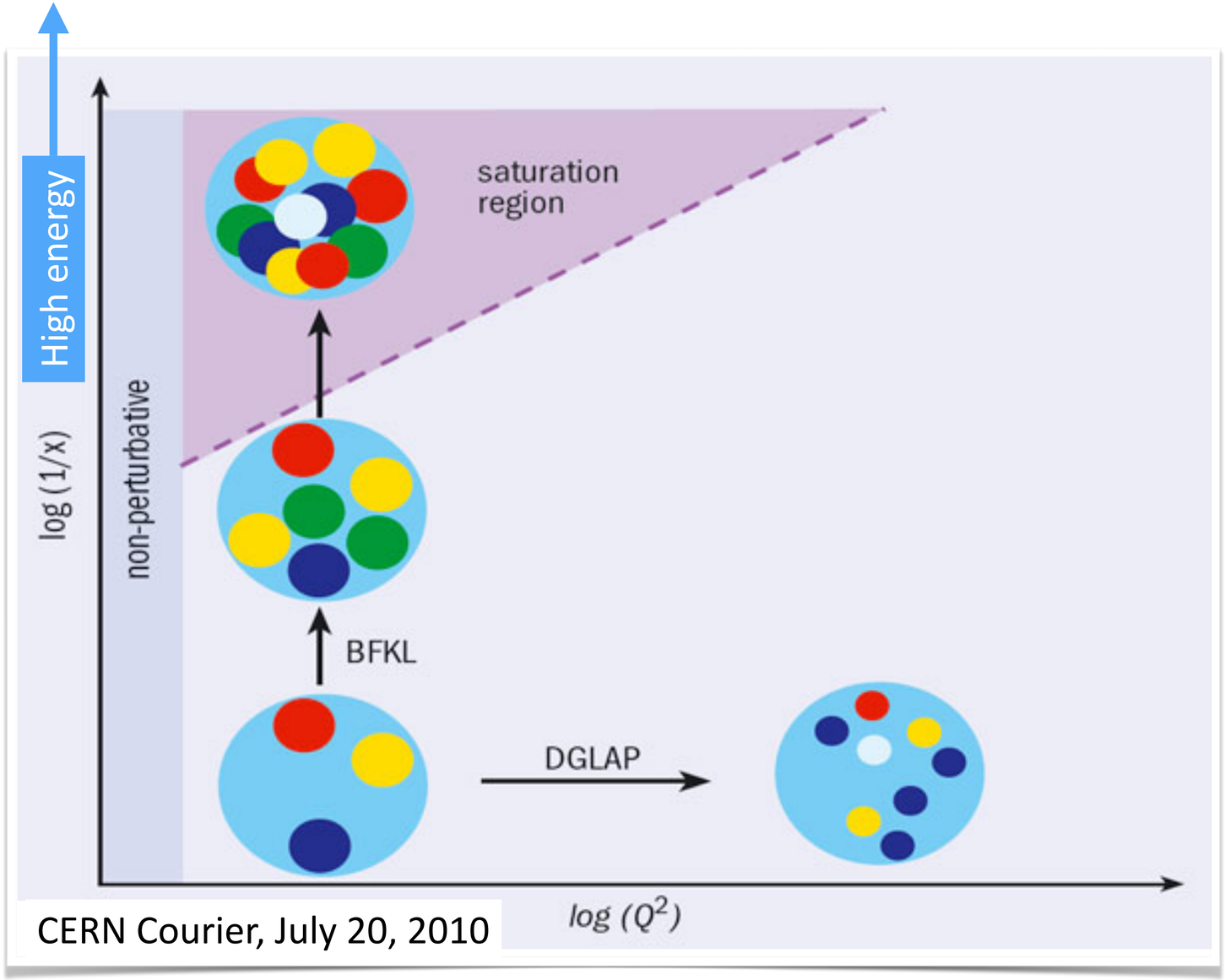

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$$x = M^2/W^2$$

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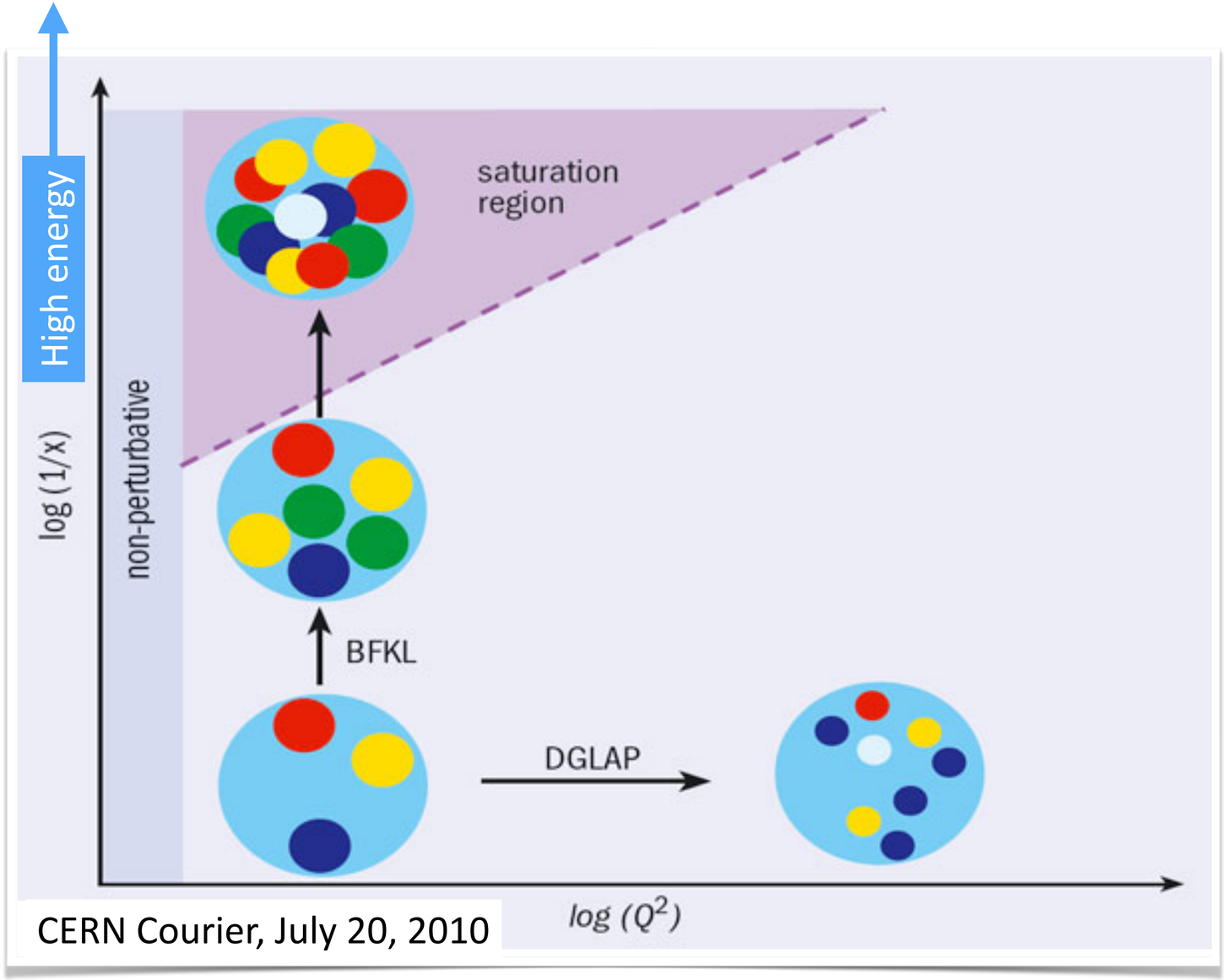

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For photoproduction of J/ψ:

- there is only one hard scale, the mass of the J/ψ, which fixes a point in the $\log(Q^2)$ axis of this diagram,
- the position along the log(1/x) axis is given by the rapidity of the J/ψ.

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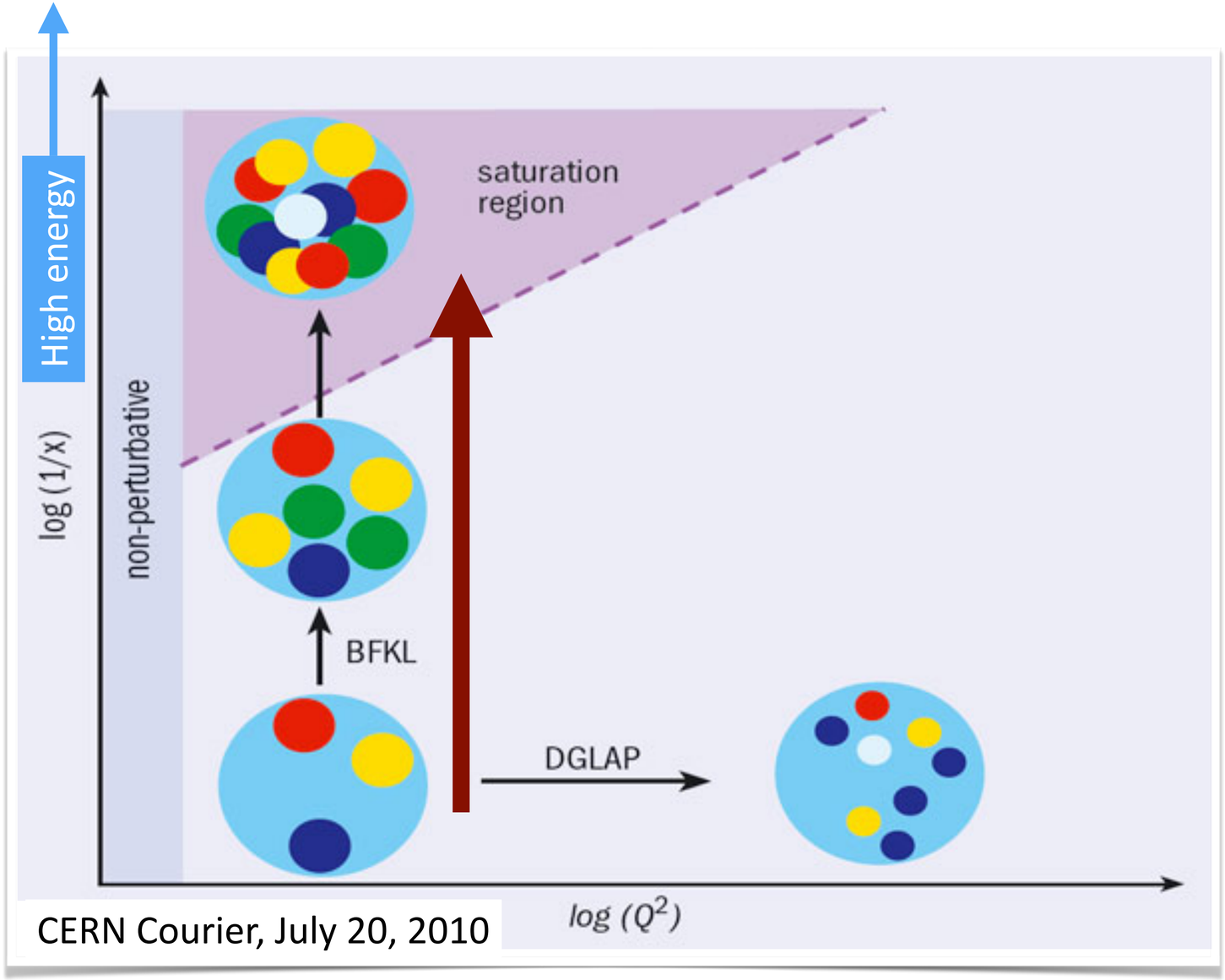

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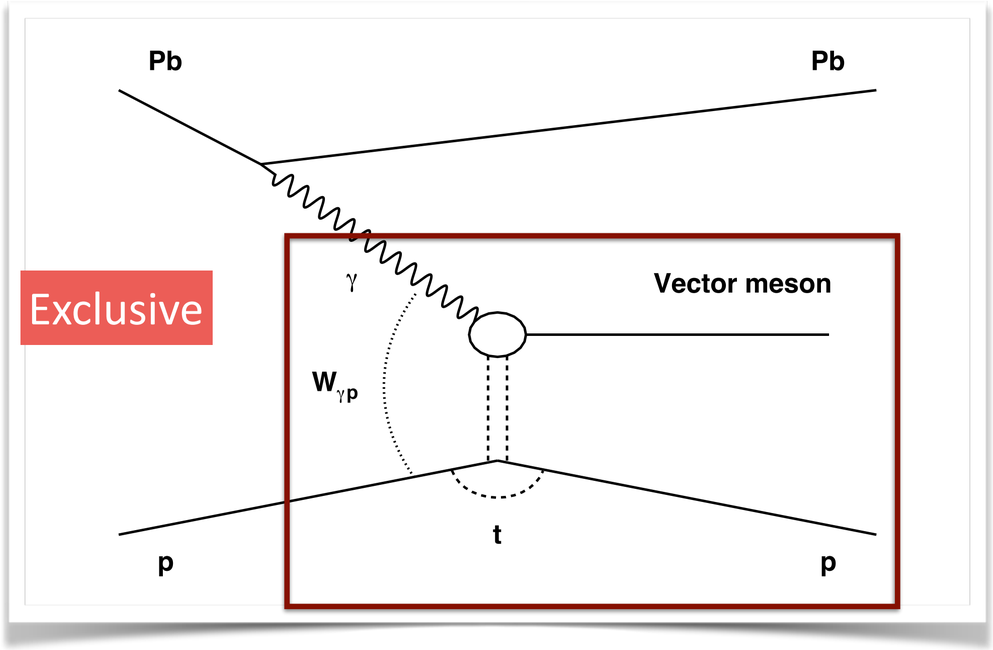
The rapidity dependence of J/ψ photoproduction take us upwards in this diagram and may allow us to search for the region labelled **saturation**.

Exclusive and dissociative J/ψ production



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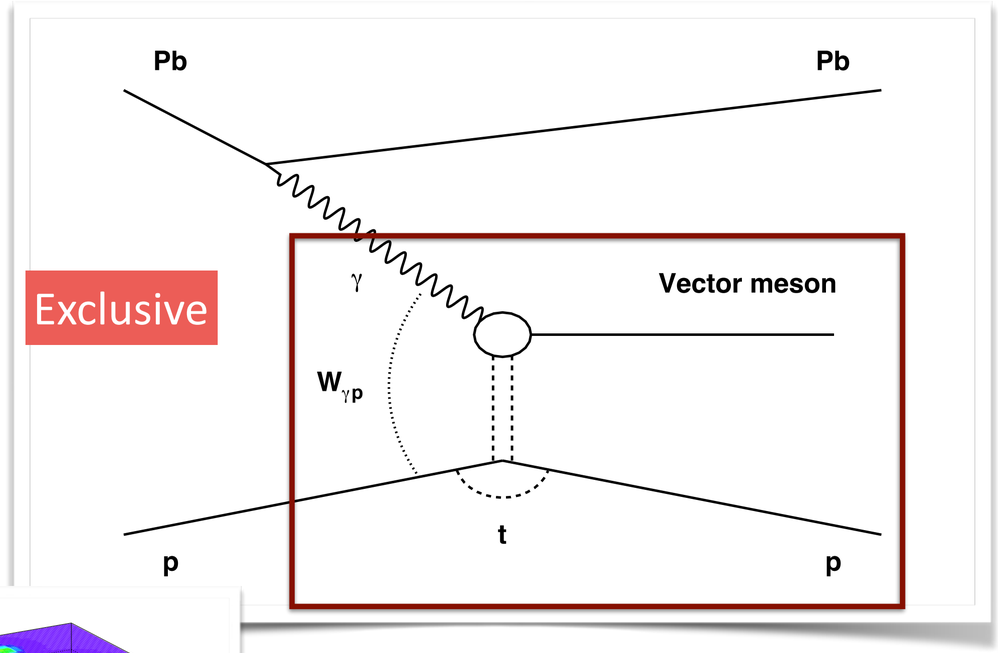

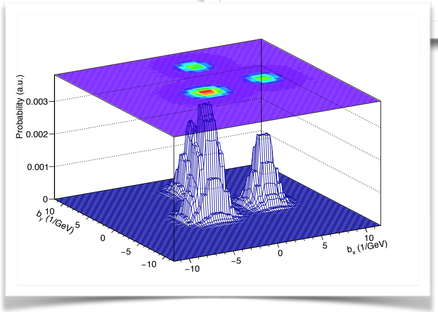

Mantysaari, Schenke, PRL 117 (2016) 052301

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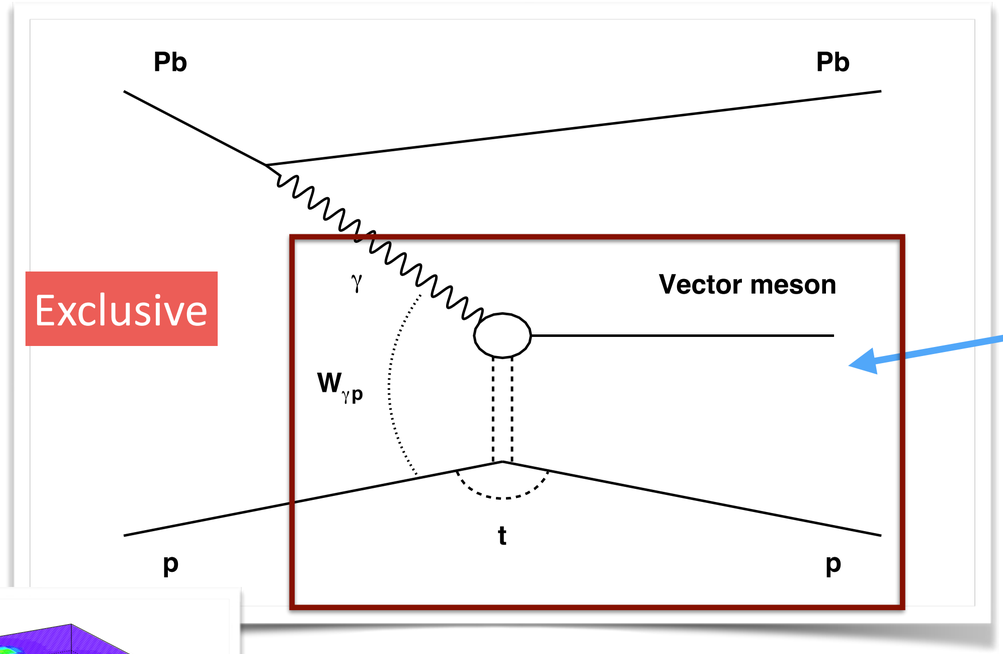
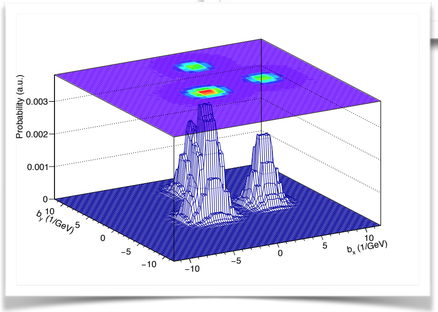


$$\frac{d\sigma(\gamma p \to \mathrm{J}/\psi p)}{dt} = \frac{R_g^2}{16\pi}\left|\left\langle A(x, Q^2, \vec{\Delta})\right\rangle\right|^2$$

Average over configurations



Good,Walker , PR 120 (1960) 1857

Miettinen, Pumplin, PRD18 (1978) 1696

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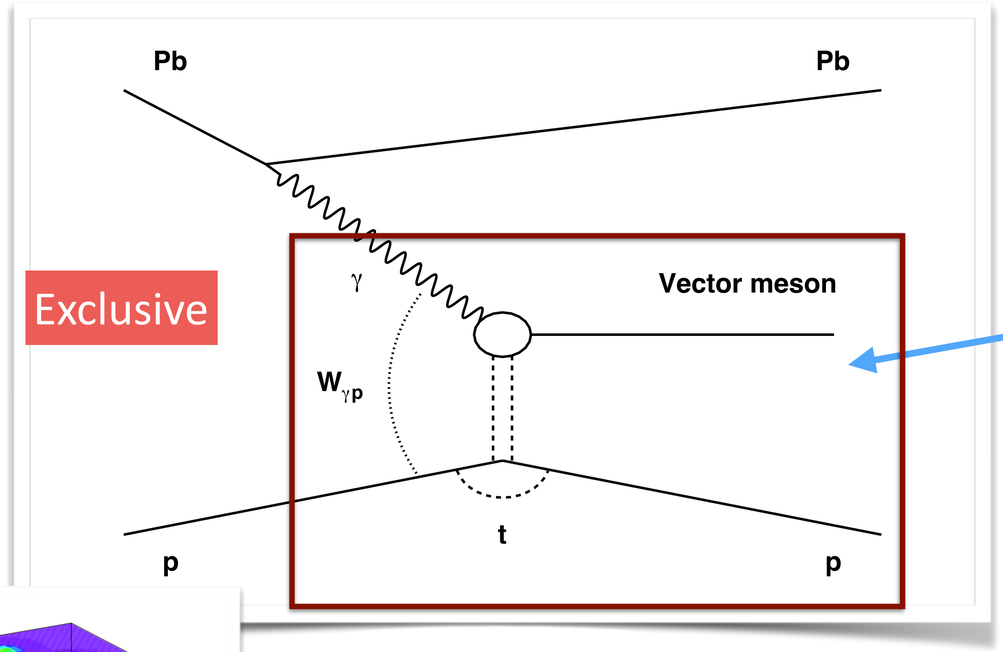

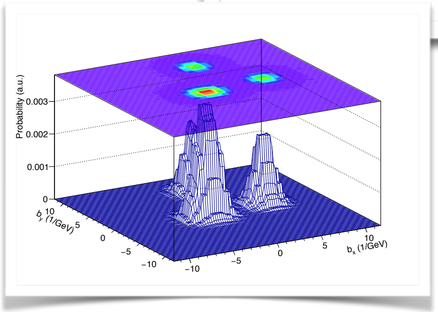

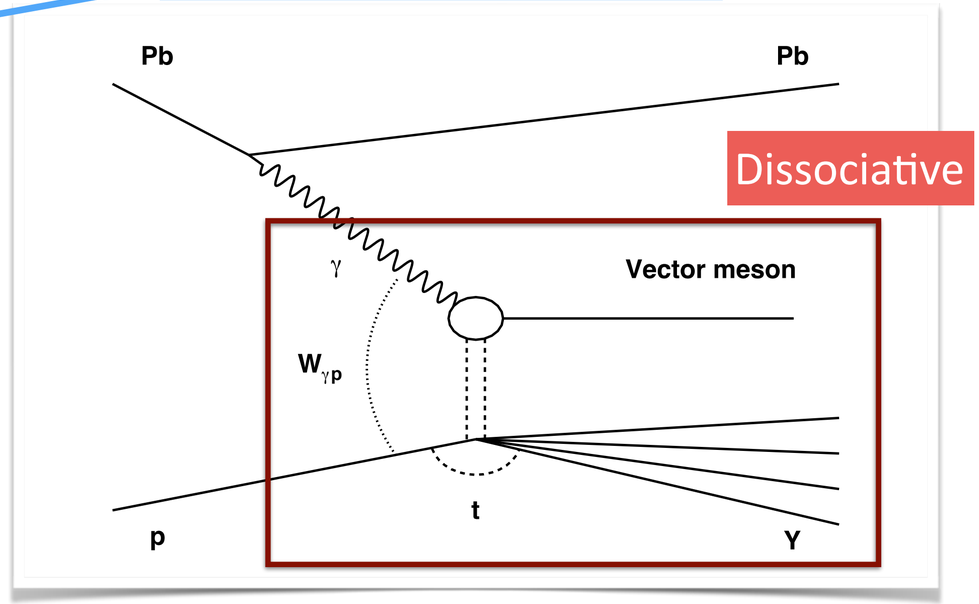

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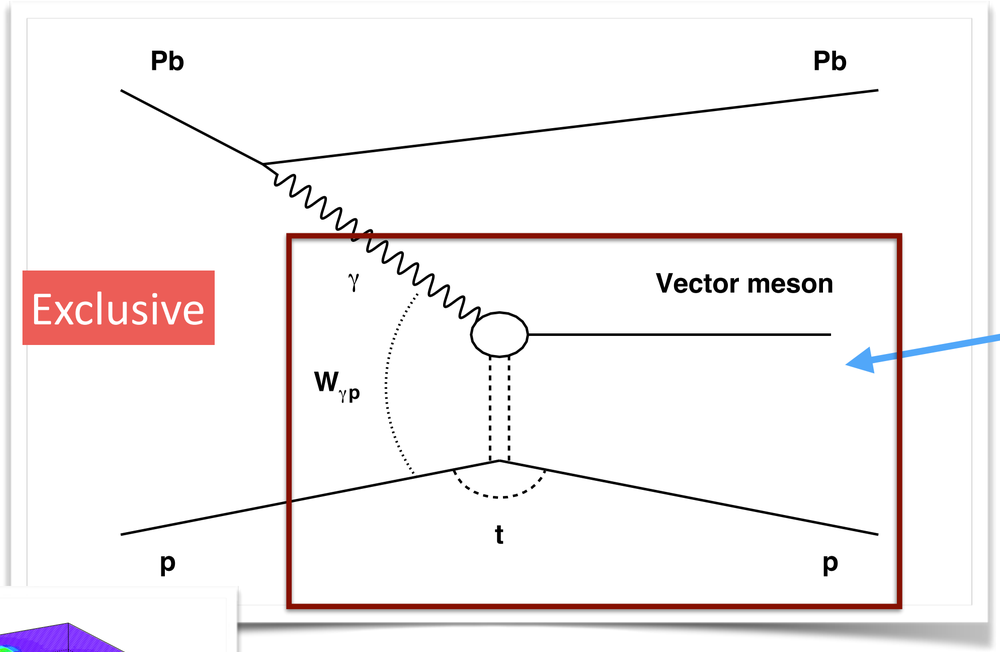
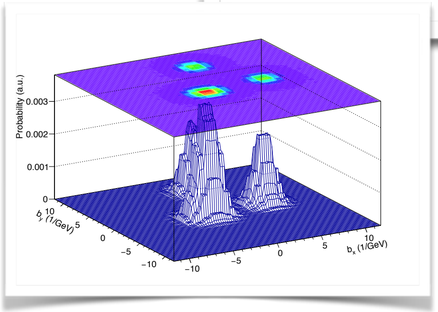
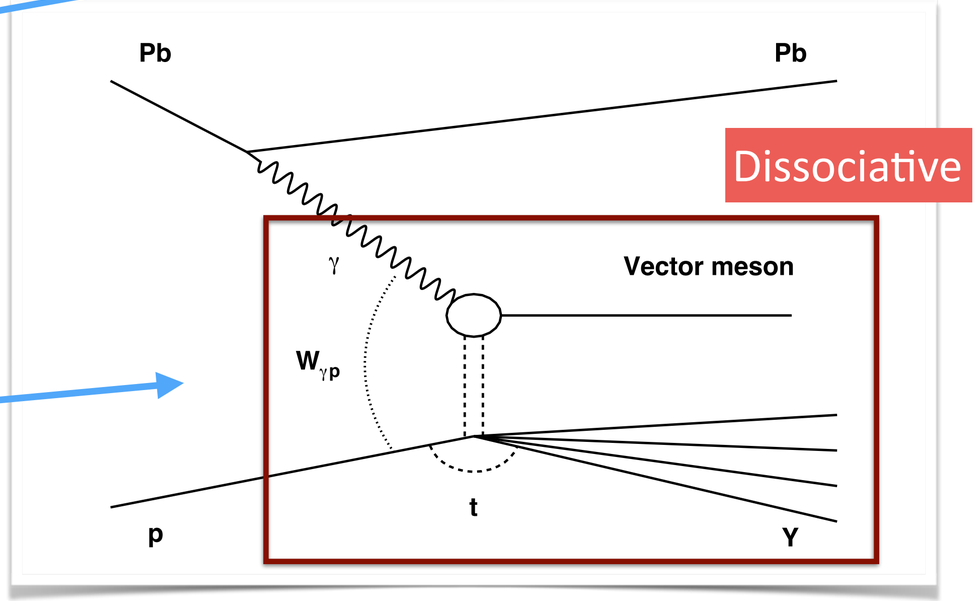




Variance over configurations



$$\frac{d\sigma(\gamma p \to \mathrm{J}/\psi Y)}{dt} = \frac{R_g^2}{16\pi}\left(\left\langle\left|A(x,Q^2,\vec{\Delta})\right|^2\right\rangle - \left|\left\langle A(x,Q^2,\vec{\Delta})\right\rangle\right|^2\right)$$

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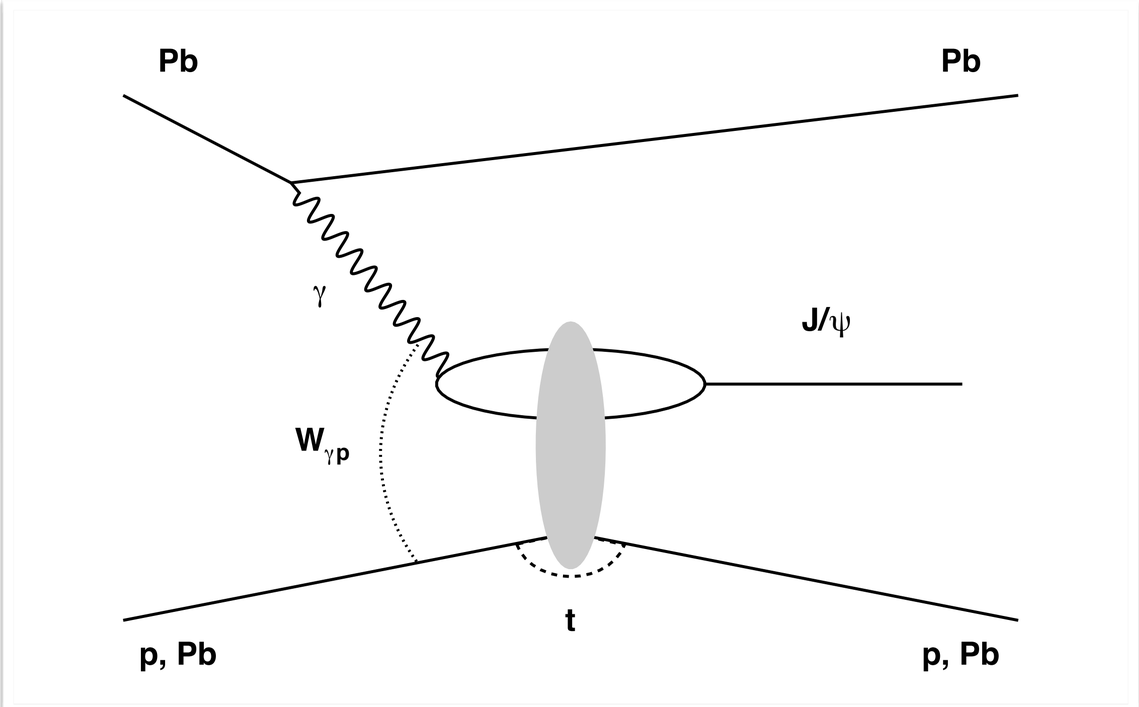
The amplitude in the dipole picture

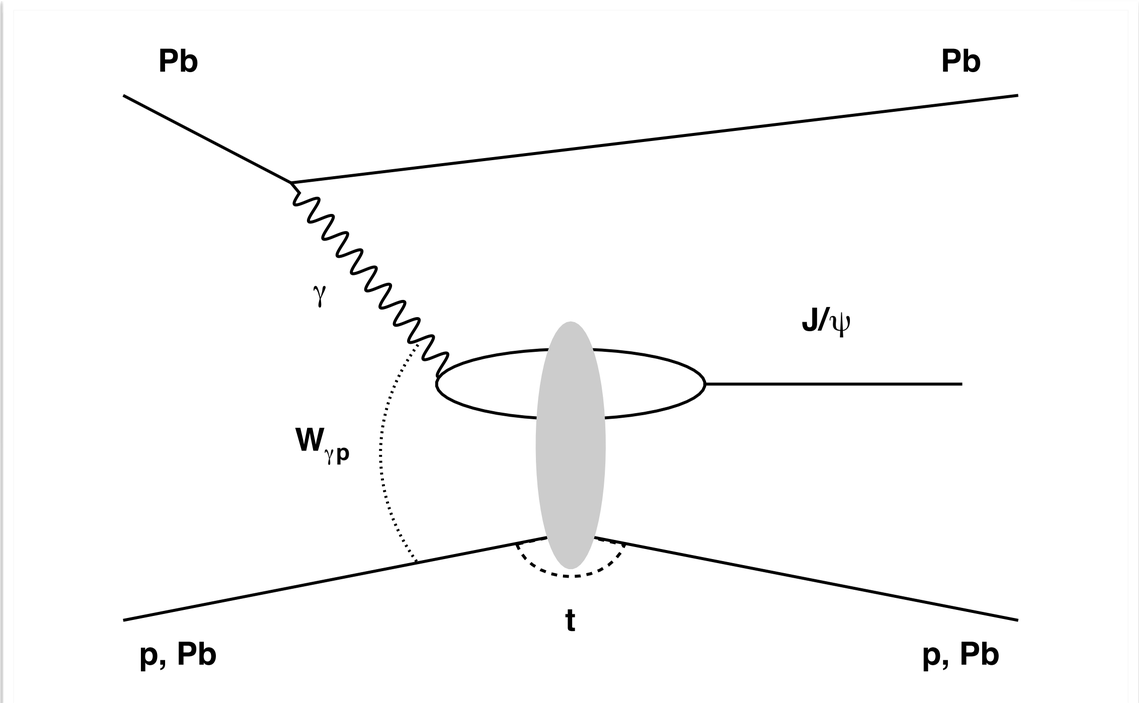


e.g., Kowalski, Motyka, Watt, PRD74 (2006) 074016

The amplitude in the dipole picture

x related to Wγp which is related to the rapidity of the vector meson

$$A(x, Q^2, \vec{\Delta})_{T,L} = i \int d\vec{r} \int_0^1 \frac{dz}{4\pi} (\Psi^* \Psi_V)_{T,L} \int d\vec{b}\, e^{-i(\vec{b}-(1-z)\vec{r})\cdot\vec{\Delta}} \frac{d\sigma_{\rm dip}}{d\vec{b}}$$



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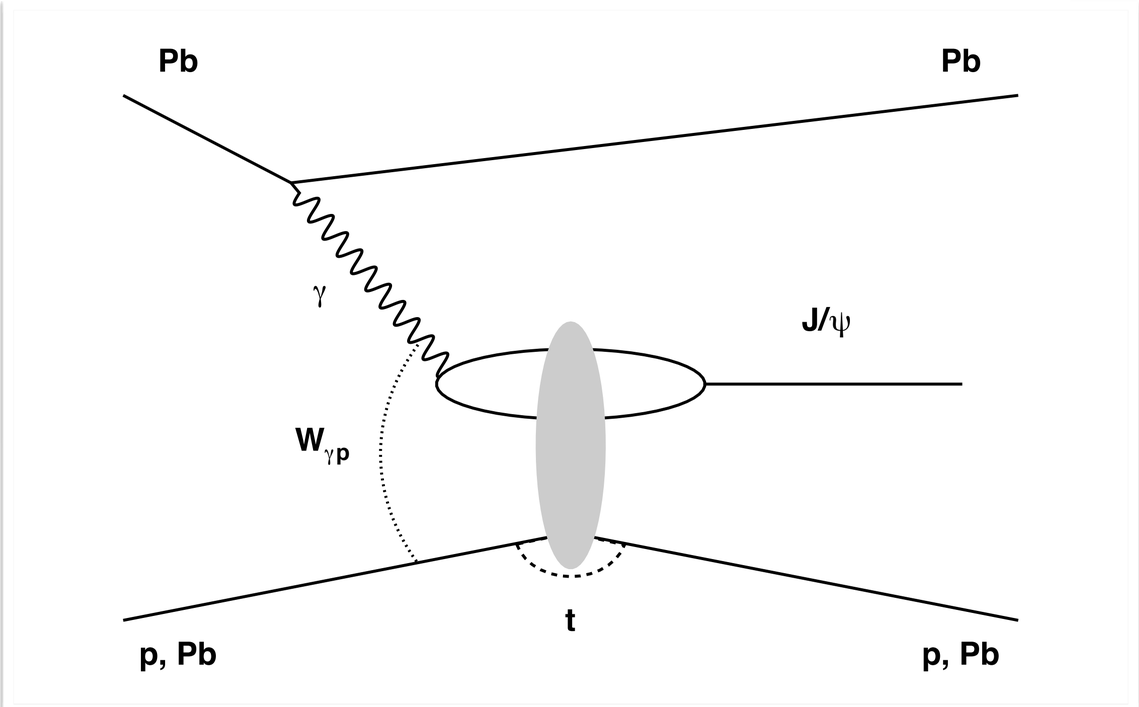

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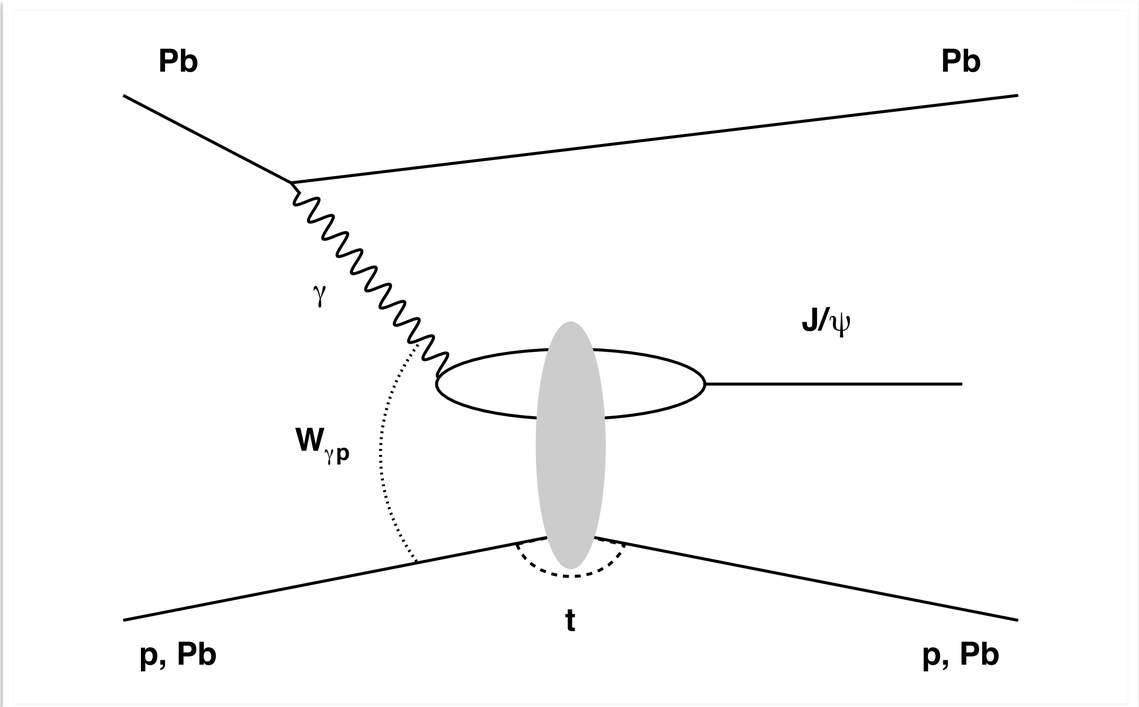

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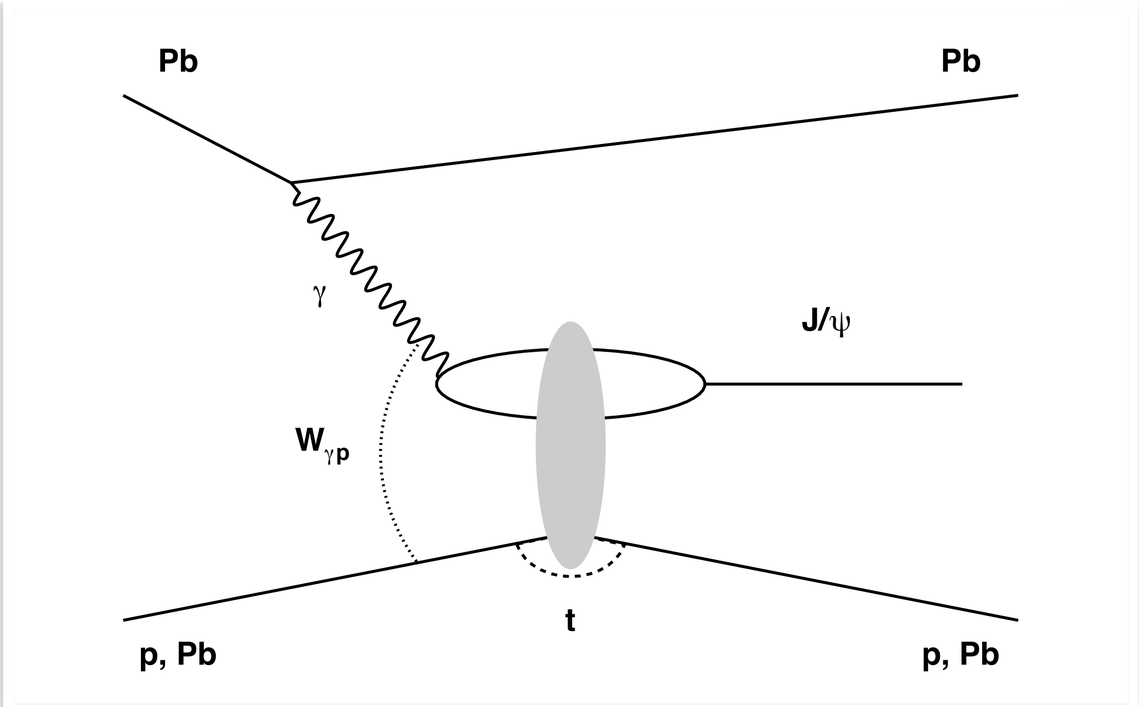

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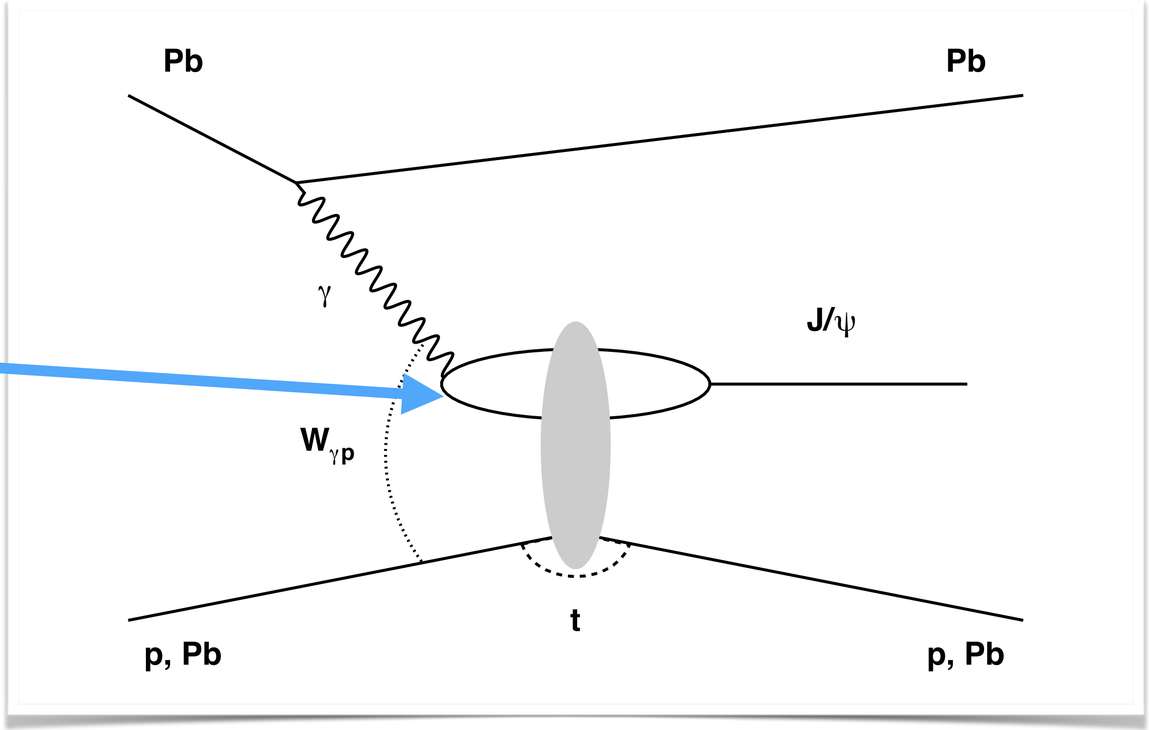
Transverse, Longitudinal photons

Photon virtuality

Photon-dipole wave function



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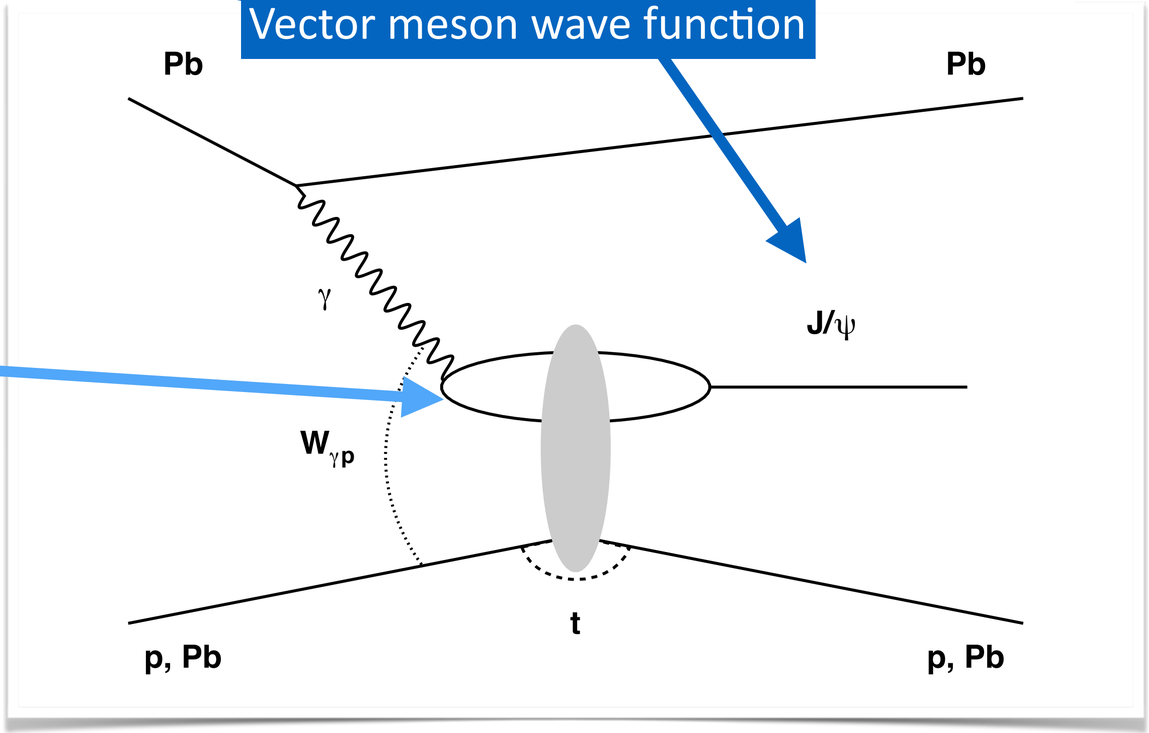

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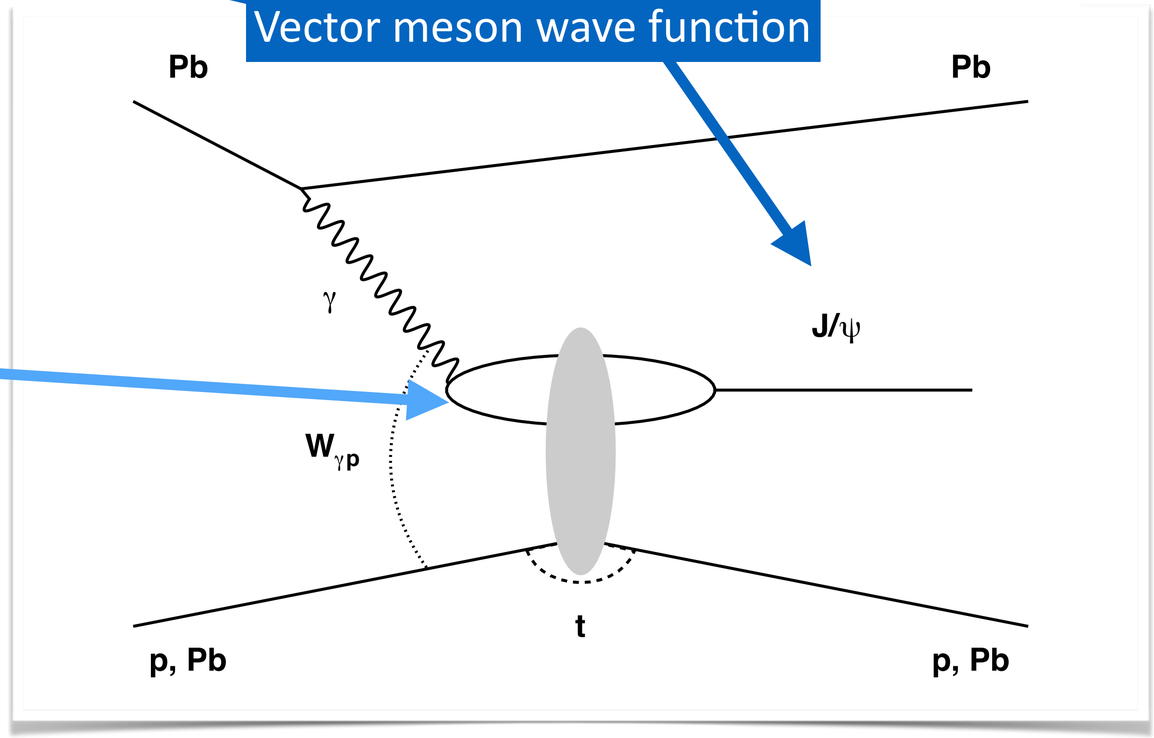

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Dipole-Target cross section
pQCD physics gets here!

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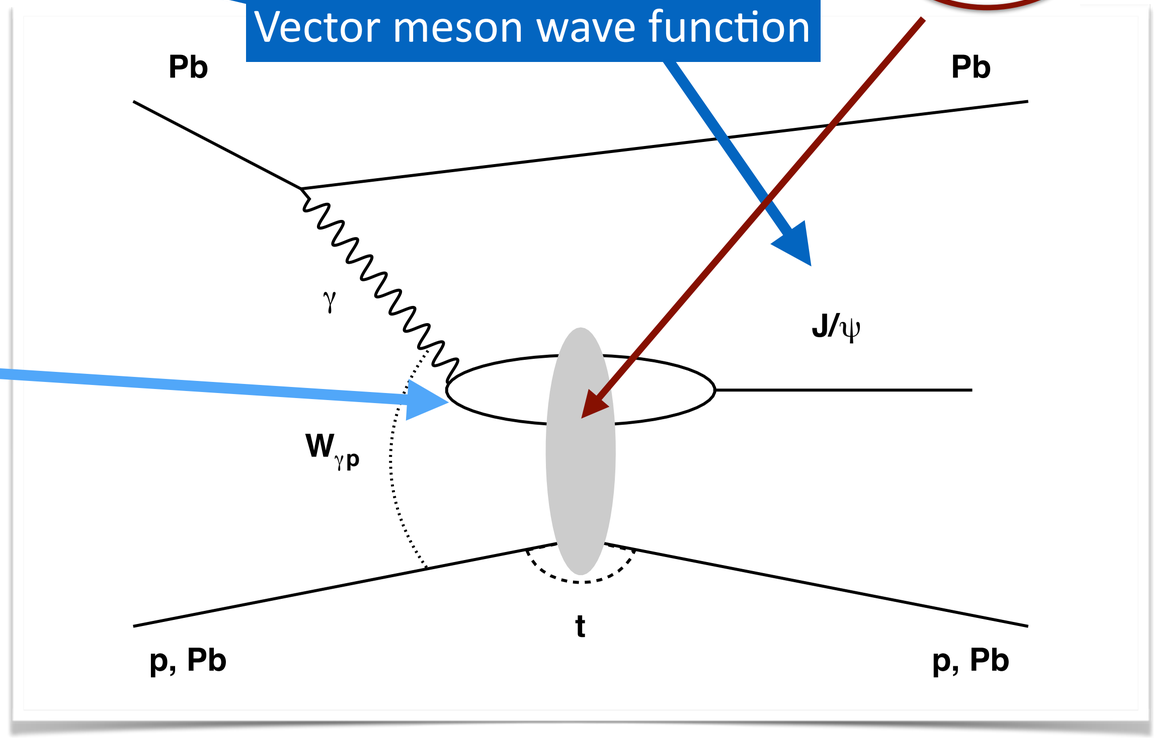

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The dipole-target cross section

Dipole target amplitude

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

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$$N^{\rm GBW}(x, r) = \left(1 - e^{-r^2 Q_s^2(x)/4}\right)$$

$$Q_s^2(x) = Q_0^2 (x_0/x)^\lambda$$

Golec-Biernat, Wusthoff, PRD59 (1998) 014017

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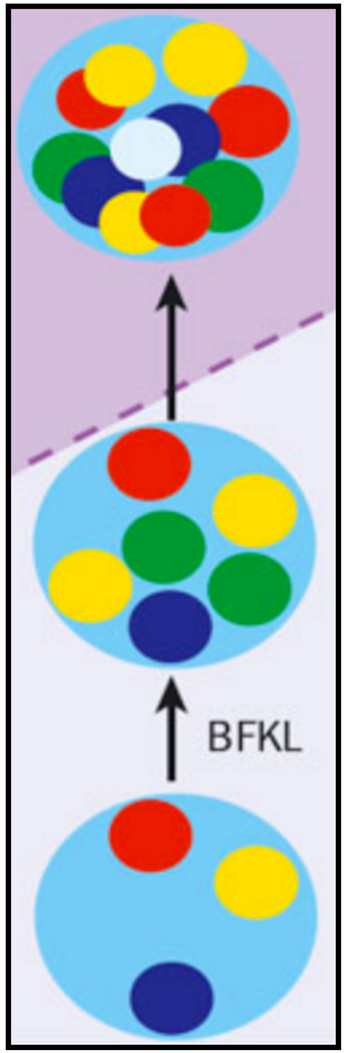
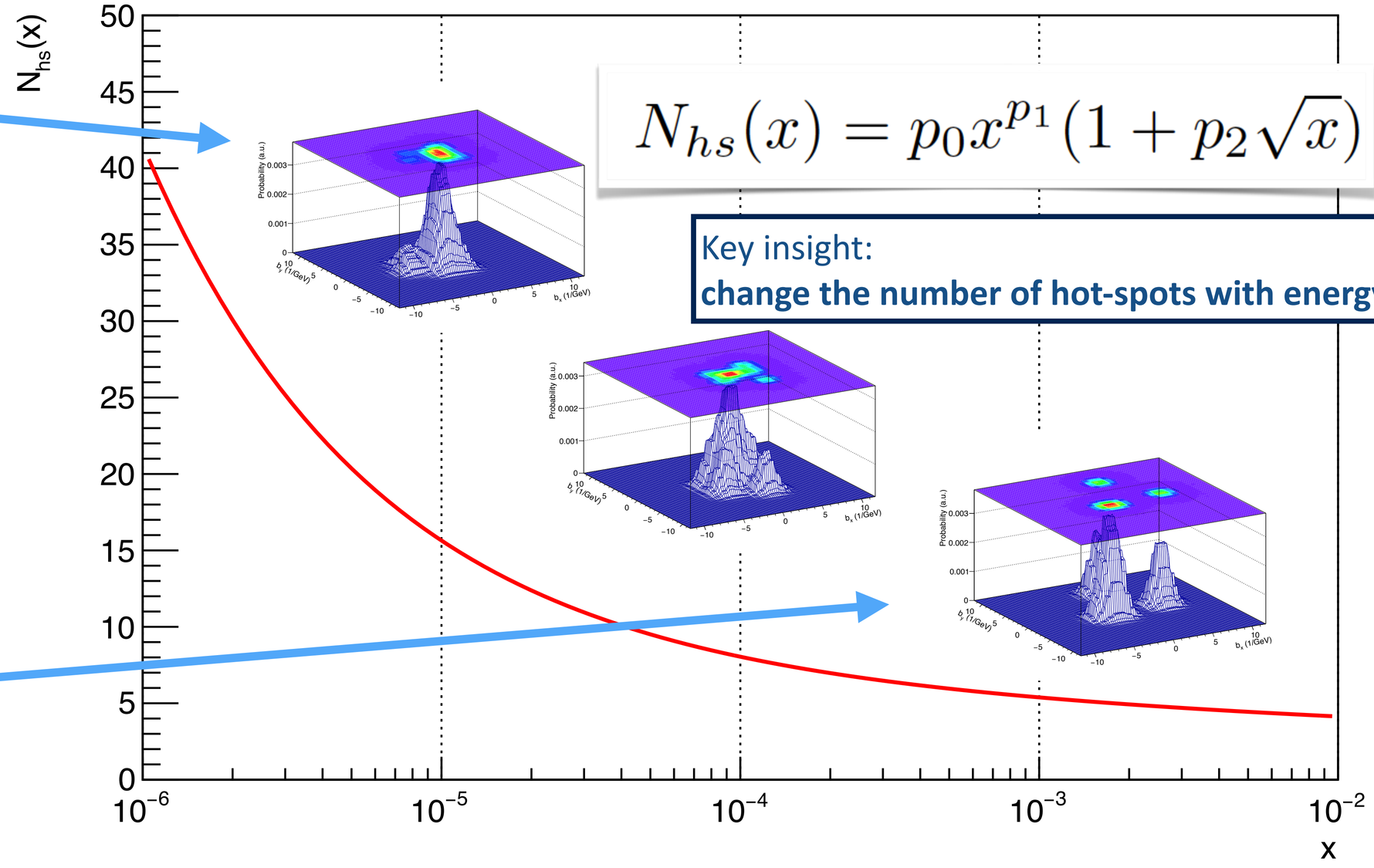
Number of hot spots

Key insight:
change the number of hot-spots with energy!

Number of hot spots





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

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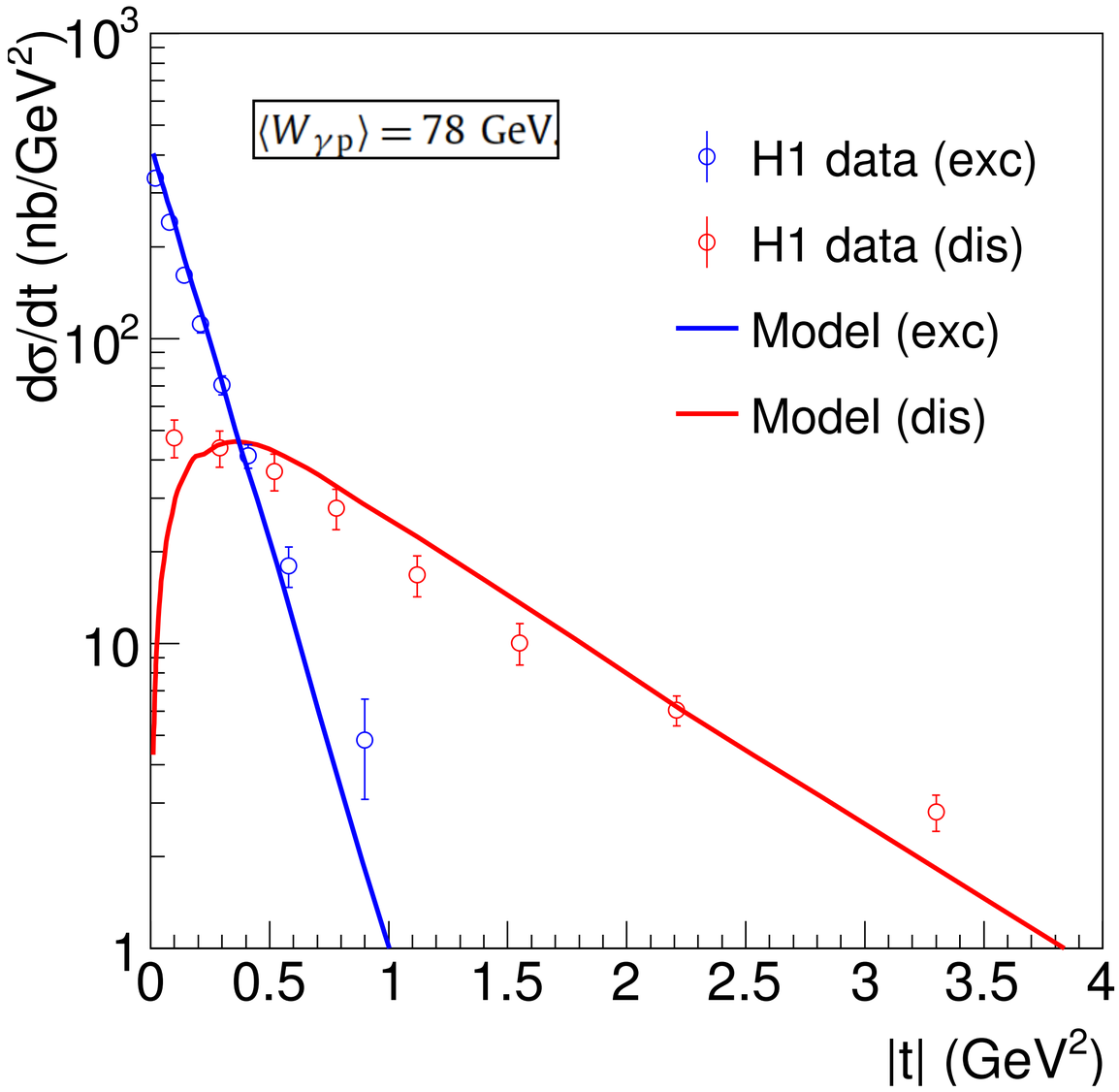
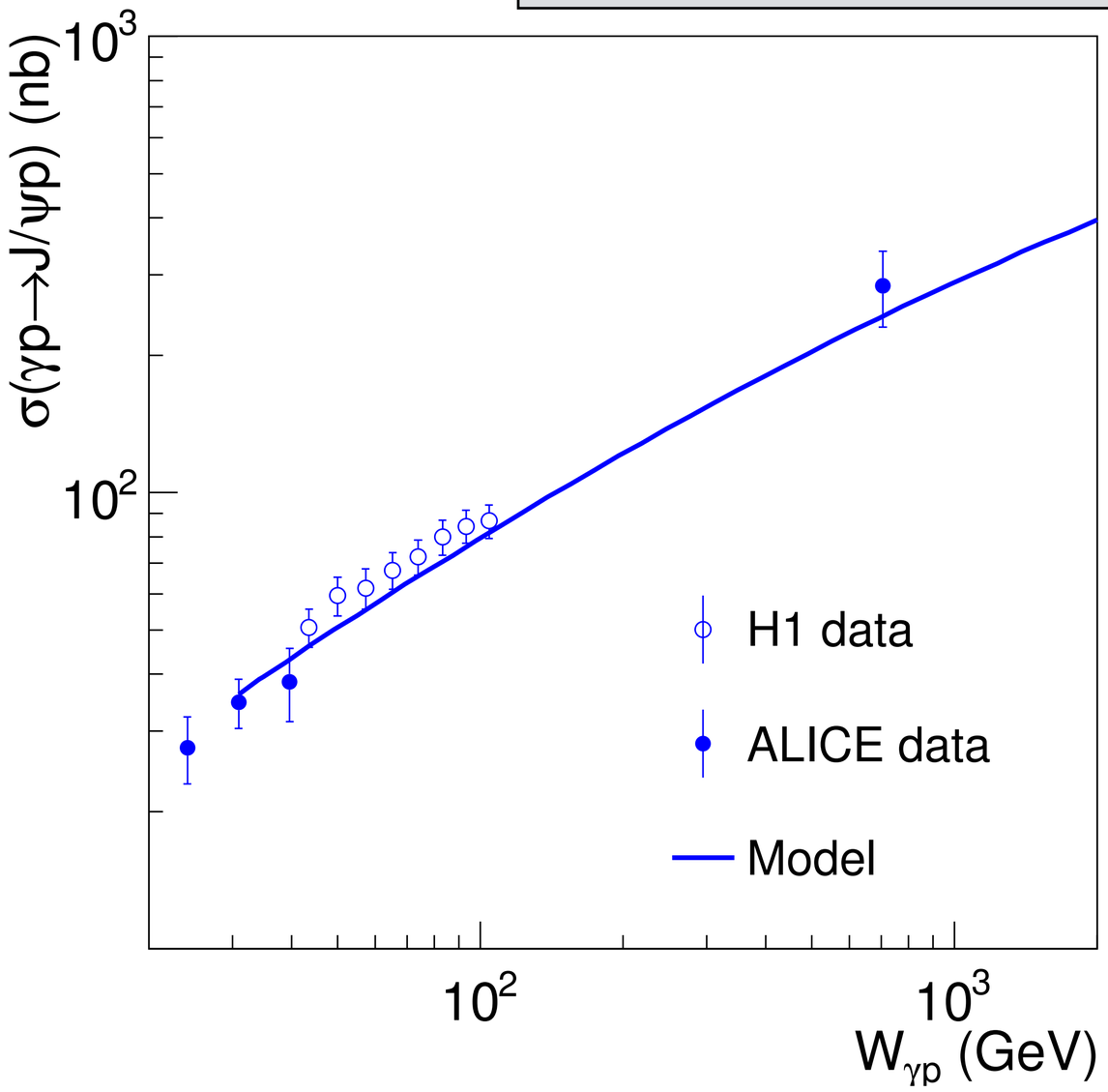
Comparison to J/ψ data

Čepila, JGC, Tapia , PLB 766 (2017) 186





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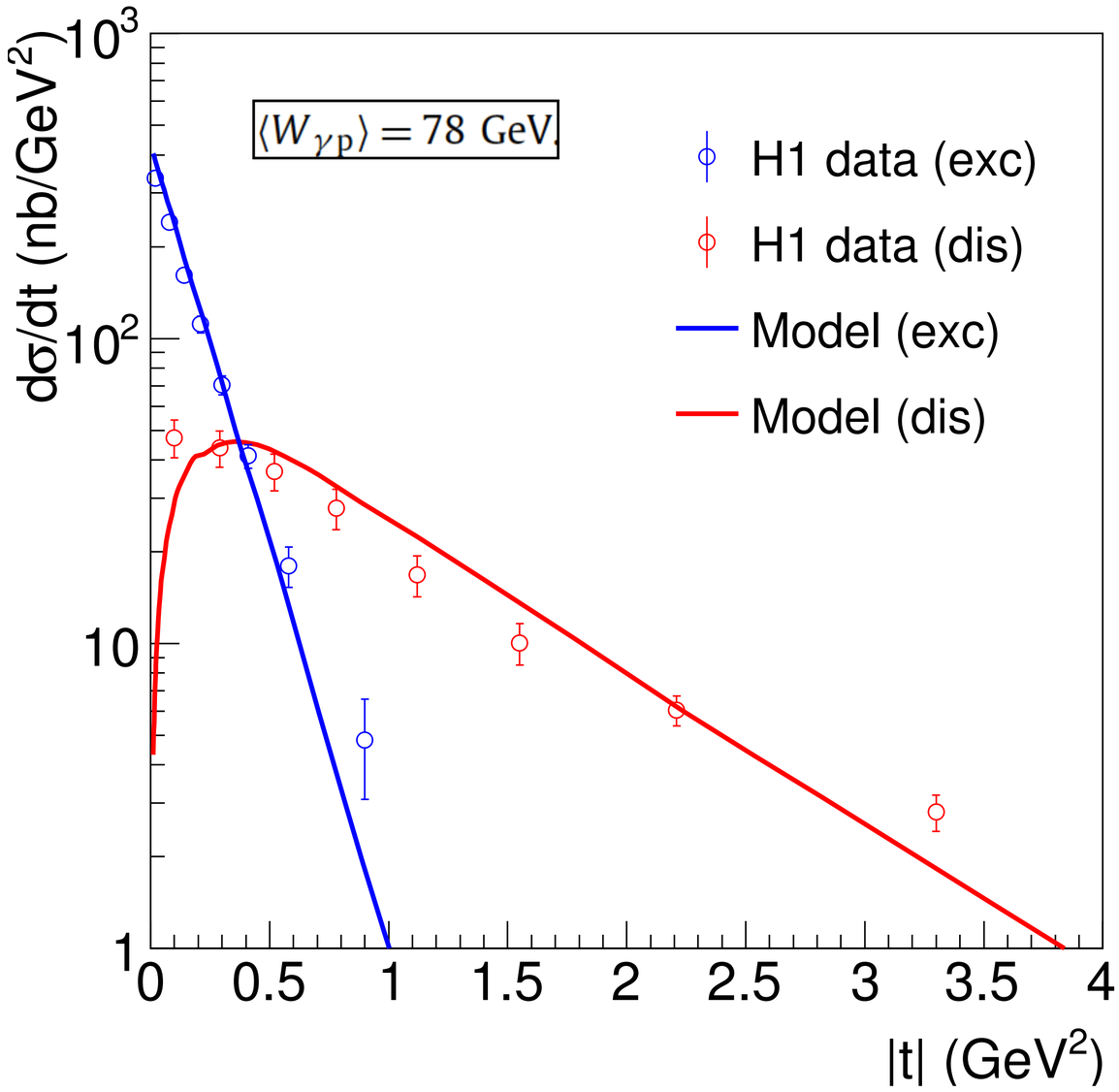

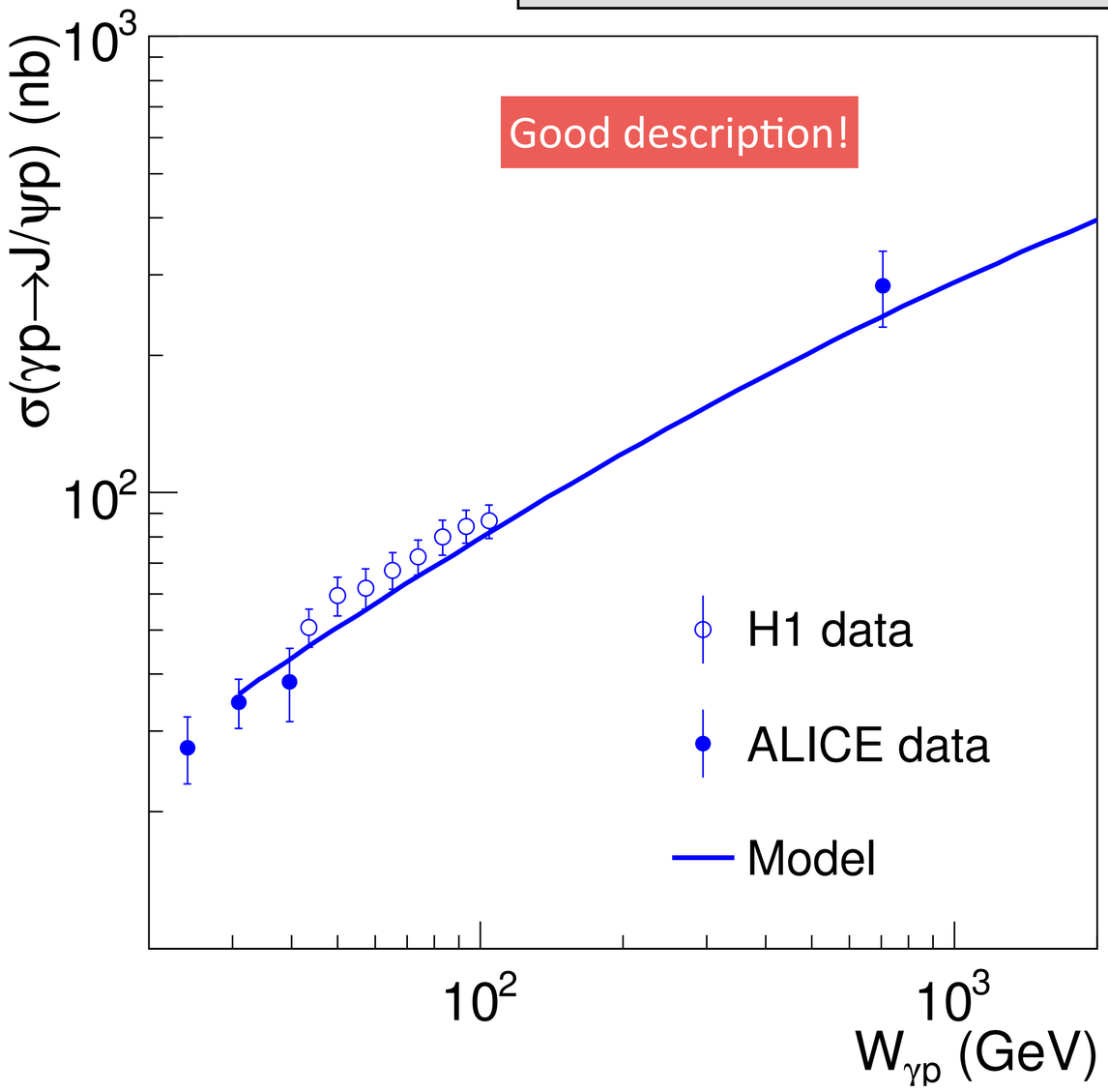

Comparison to inclusive data

$$F_2(x,Q^2) = \frac{Q^2}{4\pi^2\alpha_{em}}\left(\sigma_T^{\gamma^* p}(x,Q^2) + \sigma_L^{\gamma^* p}(x,Q^2)\right)$$

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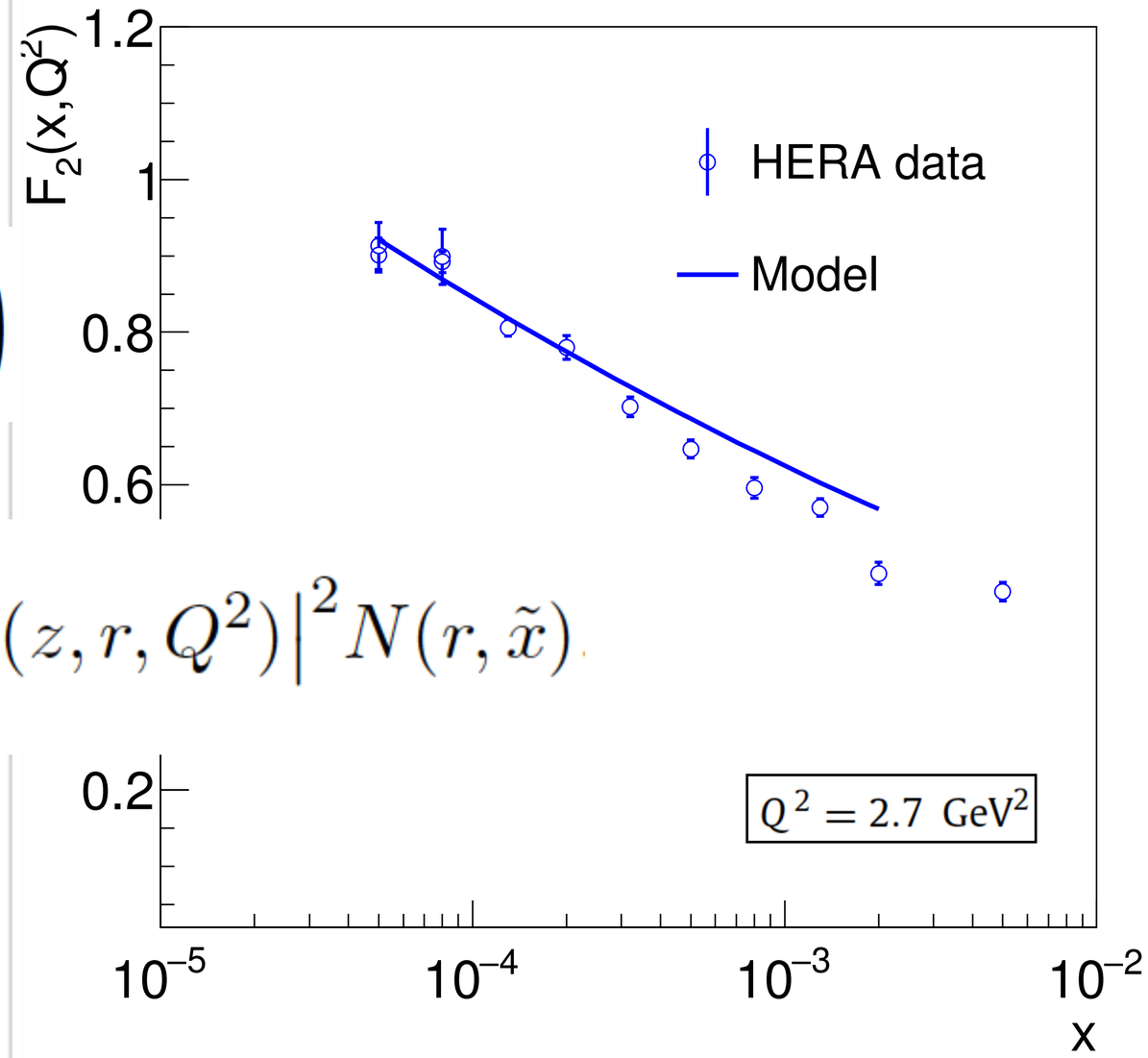
Čepila, JGC, Tapia , PLB 766 (2017) 186



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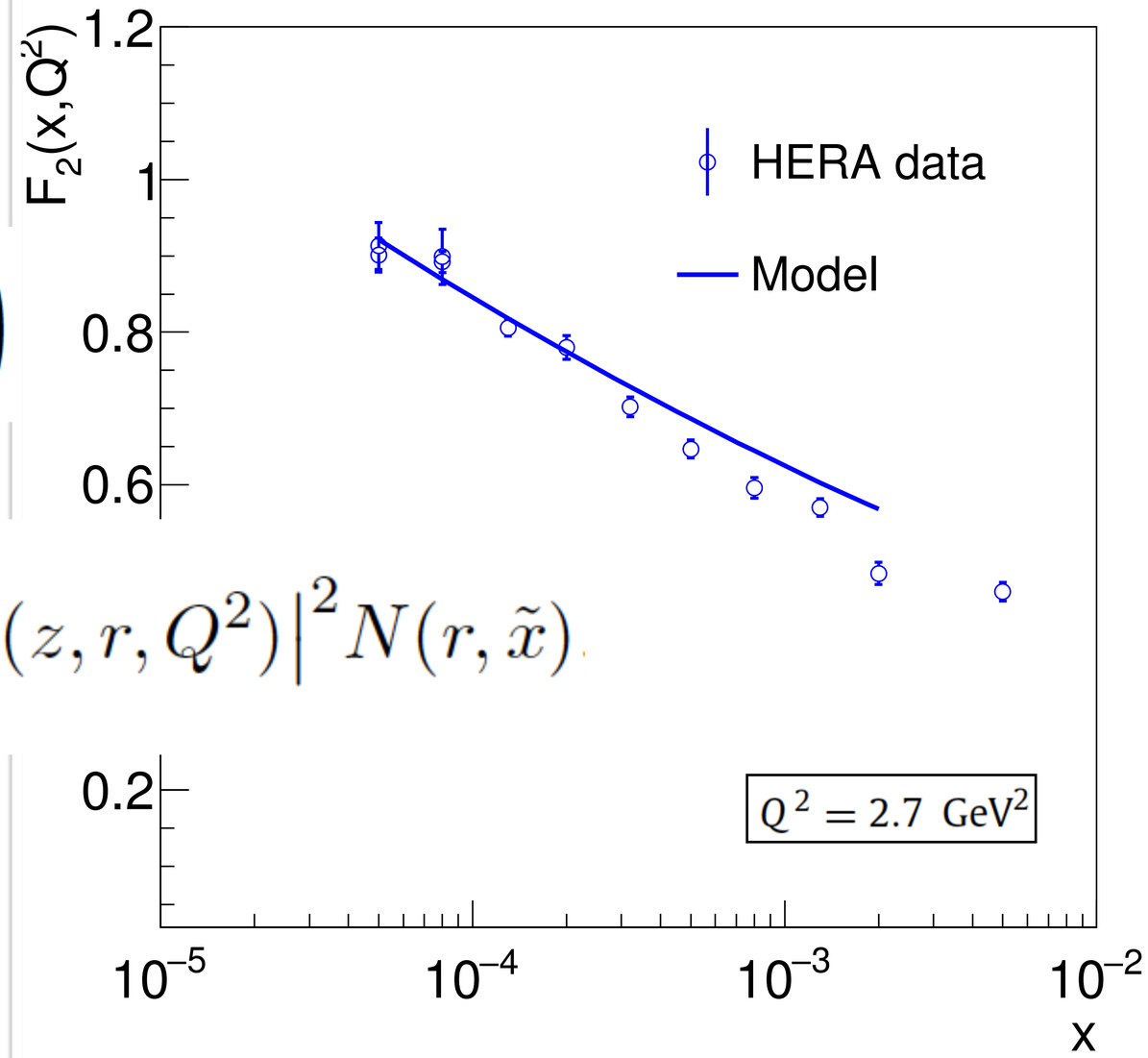
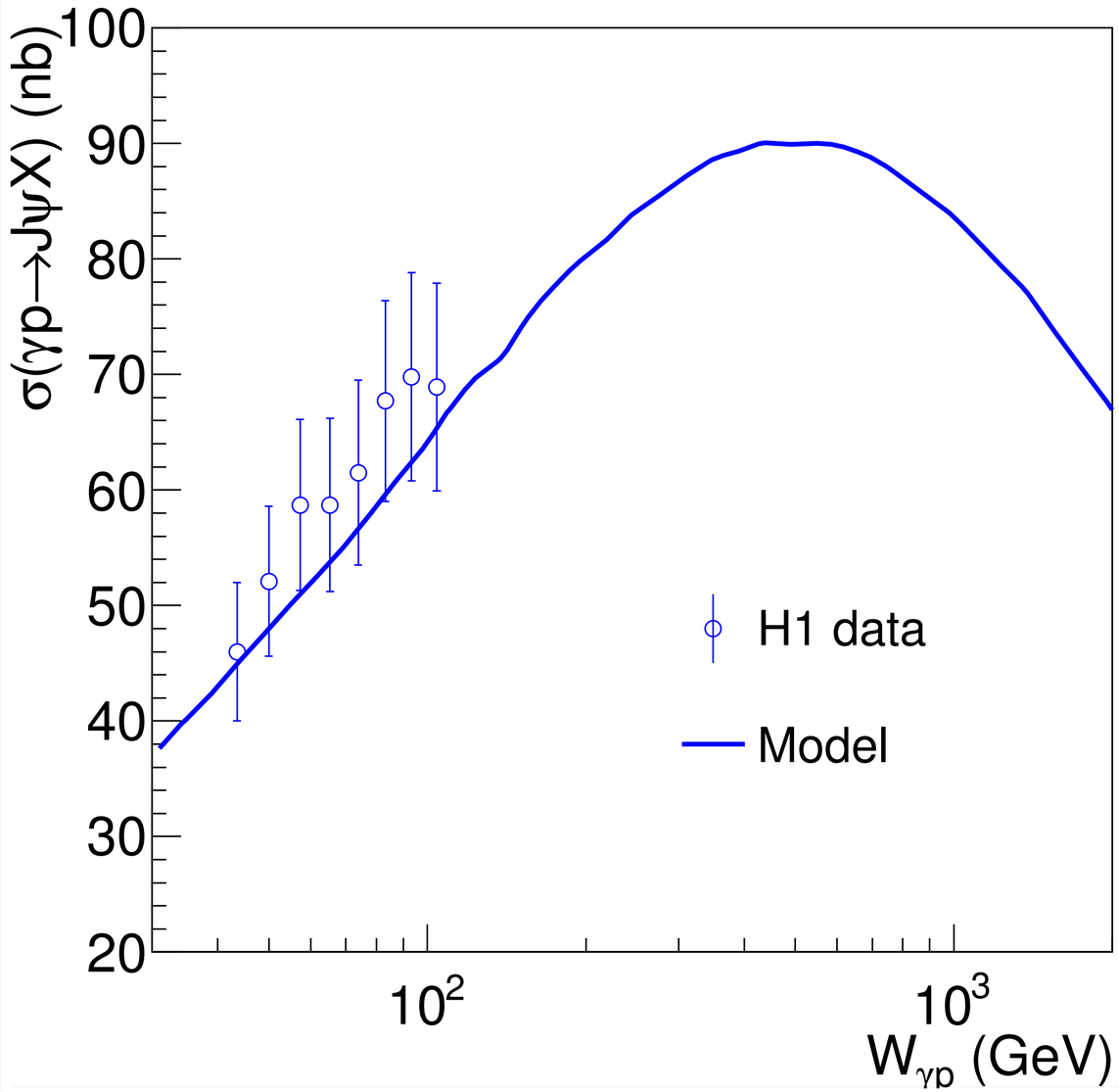


Good description even though the model was developed for vector meson production.

Prediction for the energy dependence of dissociative production

Čepila, JGC, Tapia , PLB 766 (2017) 186



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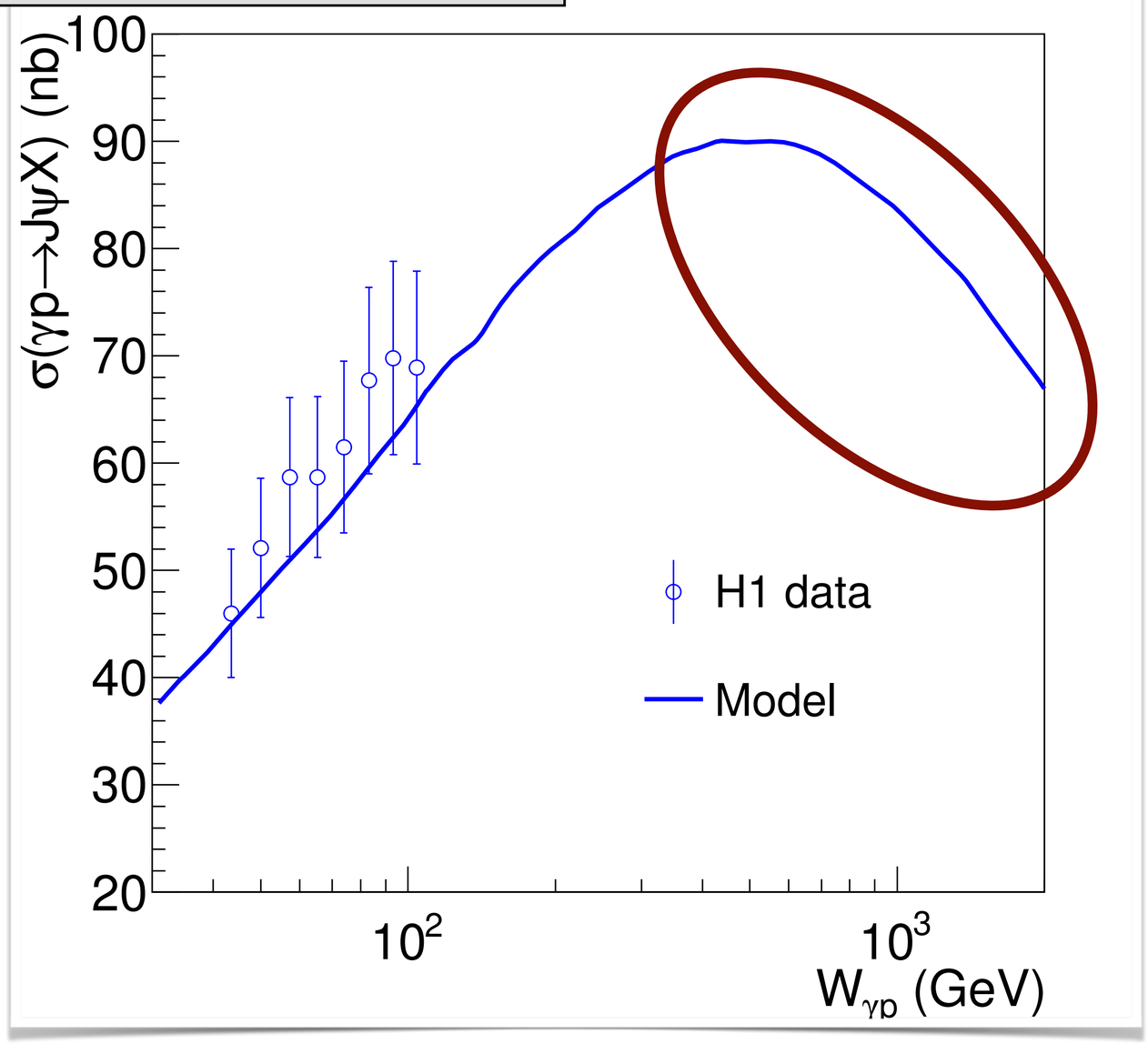

- The model predicts an **striking signature** for saturation:
  - As the number of hot spot grows, the hot spots fill up the proton.
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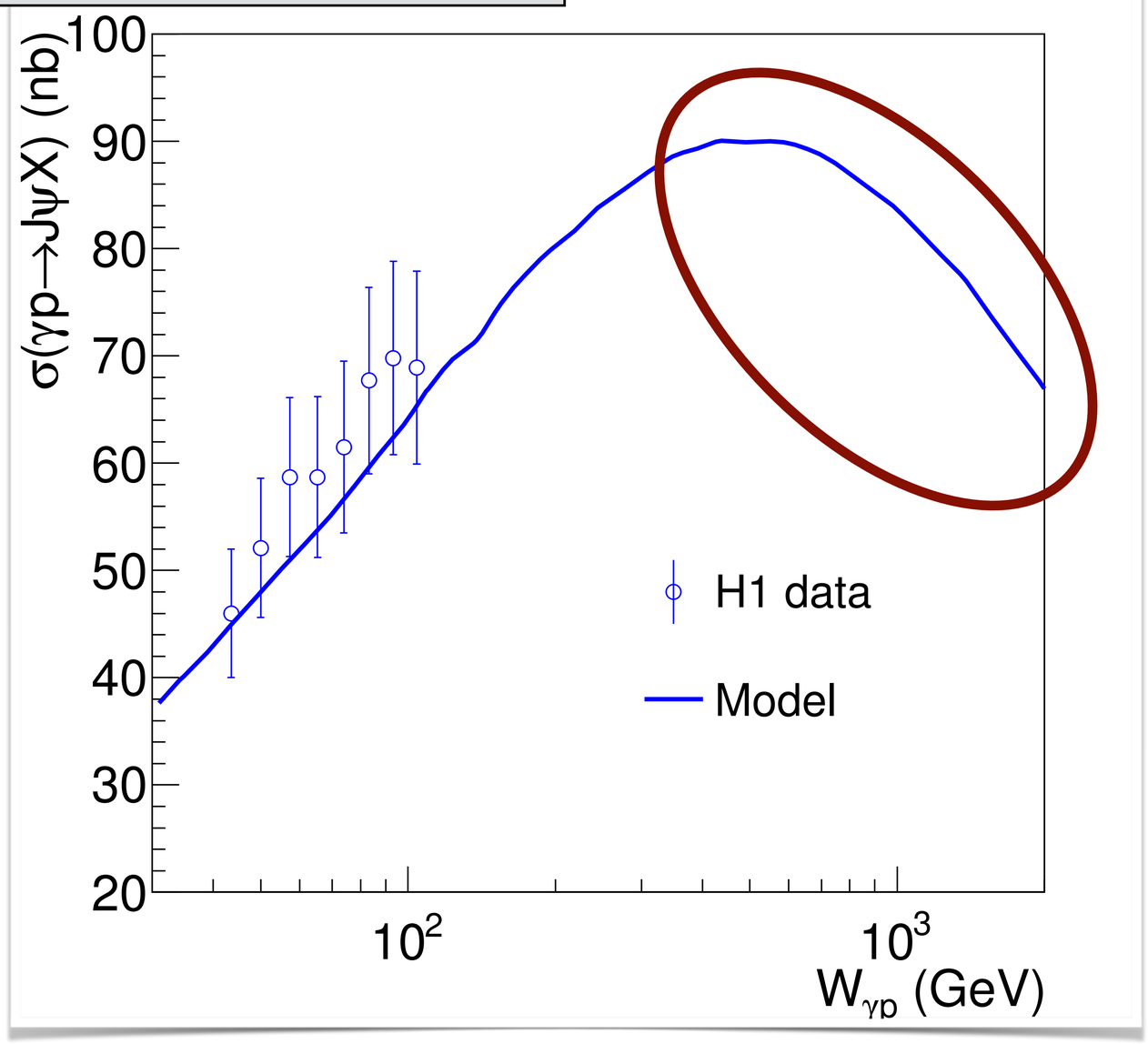

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At the LHC we can measure J/ψ production accompanied by proton dissociation in this energy range!

News from J/ψ production in γPb collisions

Extension of the model to the case of nuclear targets

Glauber-Gribov approach:

$$\left(\frac{d\sigma_{dA}}{d\vec{b}}\right)_j = 2\left[1 - \exp\left(-\frac{1}{2}\sigma_{dp}(x,r)T_A^j(\vec{b})\right)\right],$$

Position of nucleons from a Woods-Saxon distribution, position of hot spots as before.

Armesto, EPJC26 (2002) 35-43

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Nuclear saturation scale from geometric scaling arguments

$$\left(\frac{d\sigma_{dA}}{d\vec{b}}\right)_j = \sigma_0^A\left[1 - \exp\left(-r^2 Q_{A,s}^2(x)/4\right)\right]T_A^j(\vec{b}).$$

$$Q_{s,A}^2(x) = Q_s^2(x)\left(\frac{A\pi R_p^2}{\pi R_A^2}\right)^{\frac{1}{\delta}},$$

Armesto, Salgado, Wiedemann, PRL94 (2005) 022002

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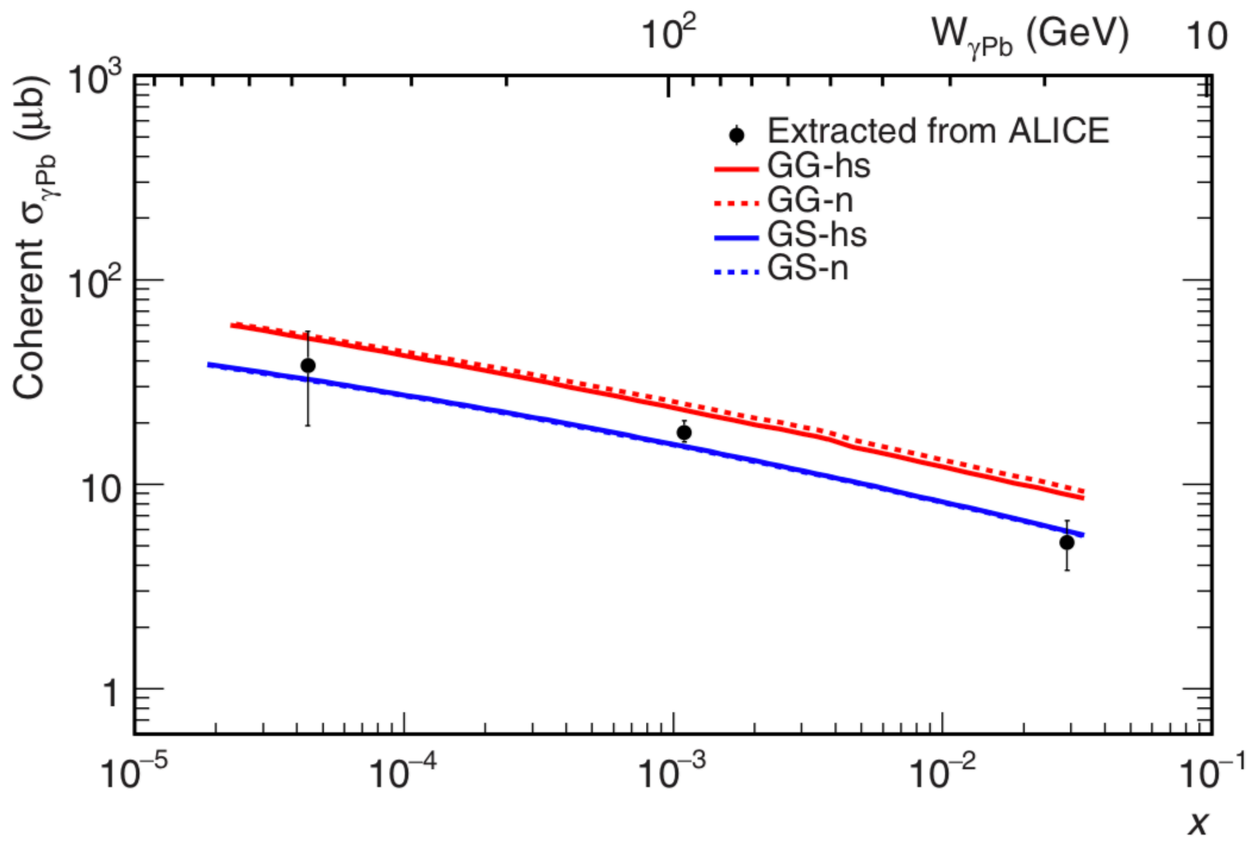
Čepila, JGC, Křelina, PRC 97 (2018), 024901



Good description of available data!

Ratio of incoherent to coherent cross sections

If the photon interact only with one nucleon in the nucleus, the process is called incoherent and the cross section is given by the variance over configurations as in the case for dissociative production.

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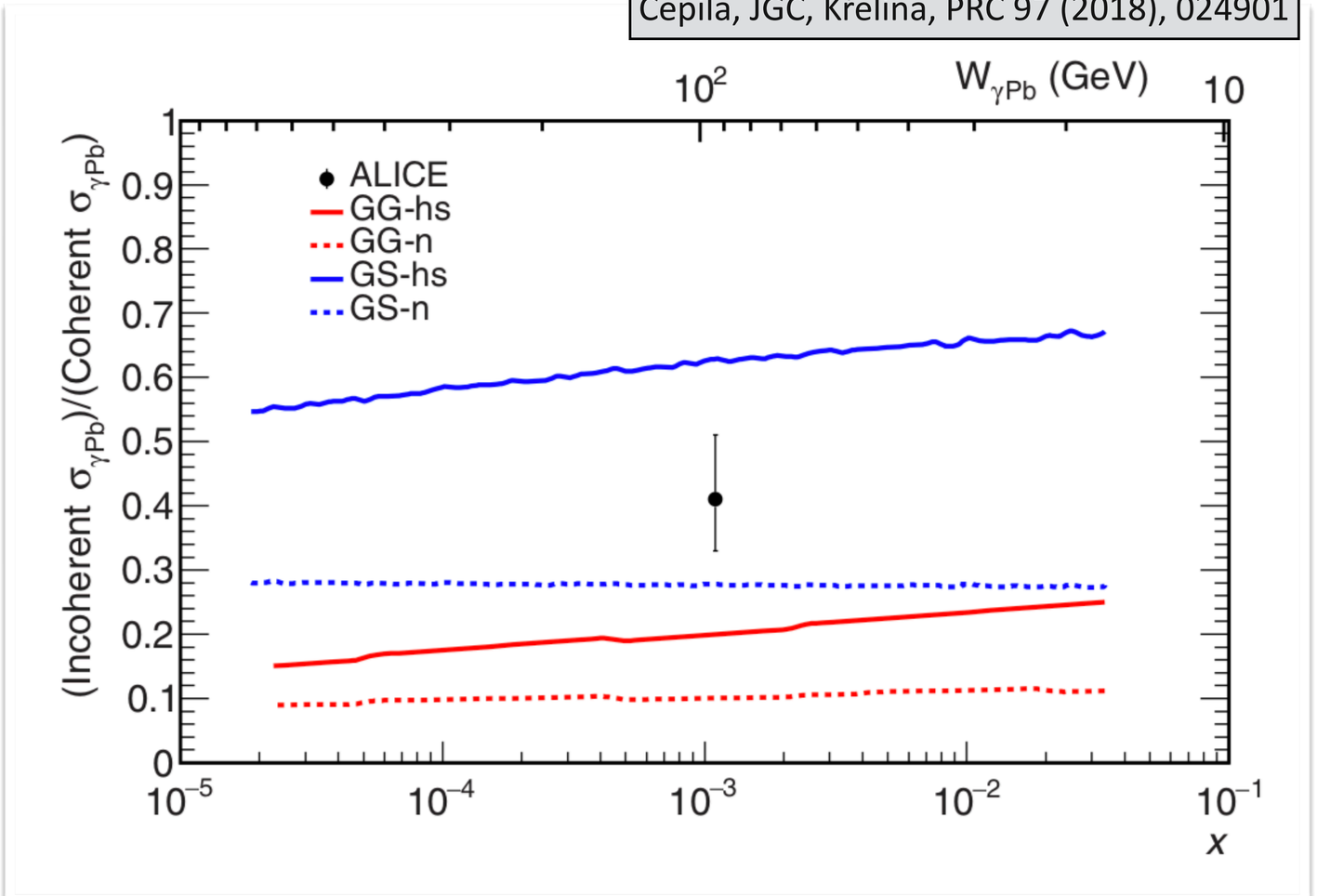
The energy dependence on the number of the subnuclear degrees of freedom produces and energy dependence on the ratio of incoherent to coherent cross section.

Čepila, JGC, Křelina, PRC 97 (2018), 024901



News from other vector mesons

Extension of the model to other vector mesons

Only change needed is for the ρ^0, where the positions of the hot spots within the proton are sampled from a Gaussian of width Bp = 8 GeV^{-2} instead of 4.7 GeV^{-2}.

Extension of the model to other vector mesons

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508

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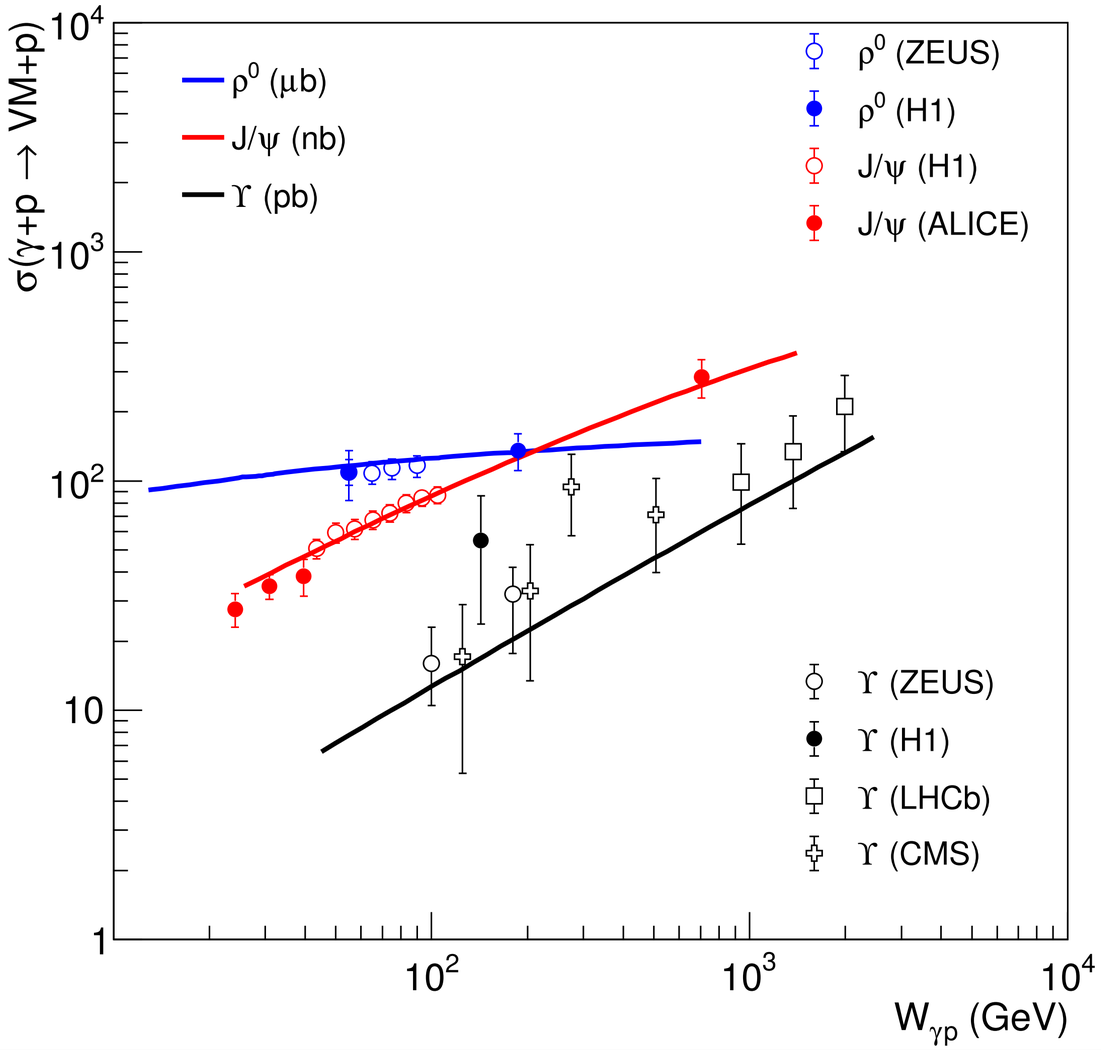
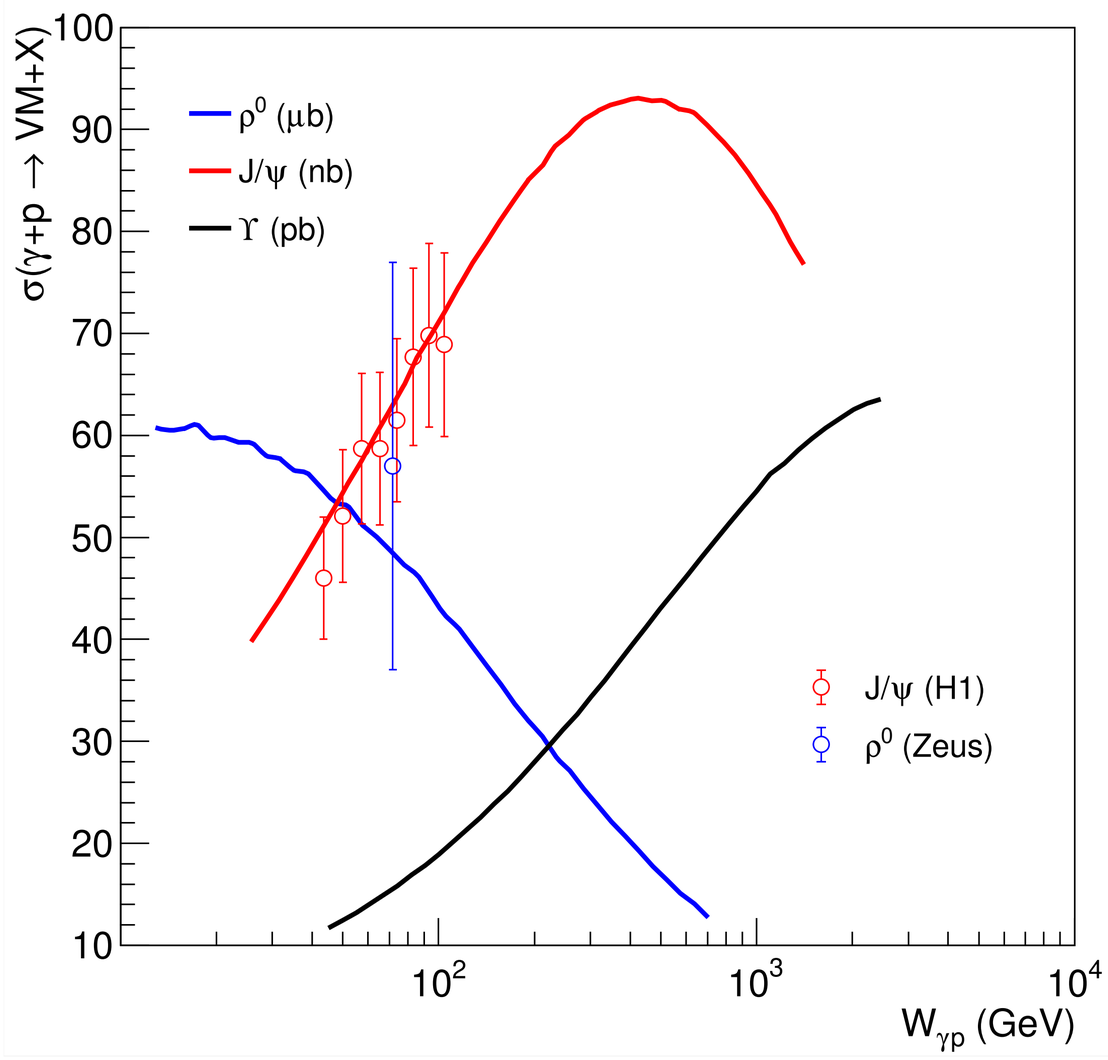


Good description of available data for excusive production!

Extension of the model to other vector mesons: γp

- The position of the maximum of the dissociative cross section shifts with the mass of the vector meson.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508



Extension of the model to other vector mesons: γp

- The position of the maximum of the dissociative cross section shifts with the mass of the vector meson.
- The decrease of the cross section is given by the decrease in the variance over configurations; i.e., saturation.
- This shift on the maximum with the mass of the vector meson is related to the average dipole size from the convolution of the wave functions for the transitions of the photon to the diquark and from the diquark to vector meson.

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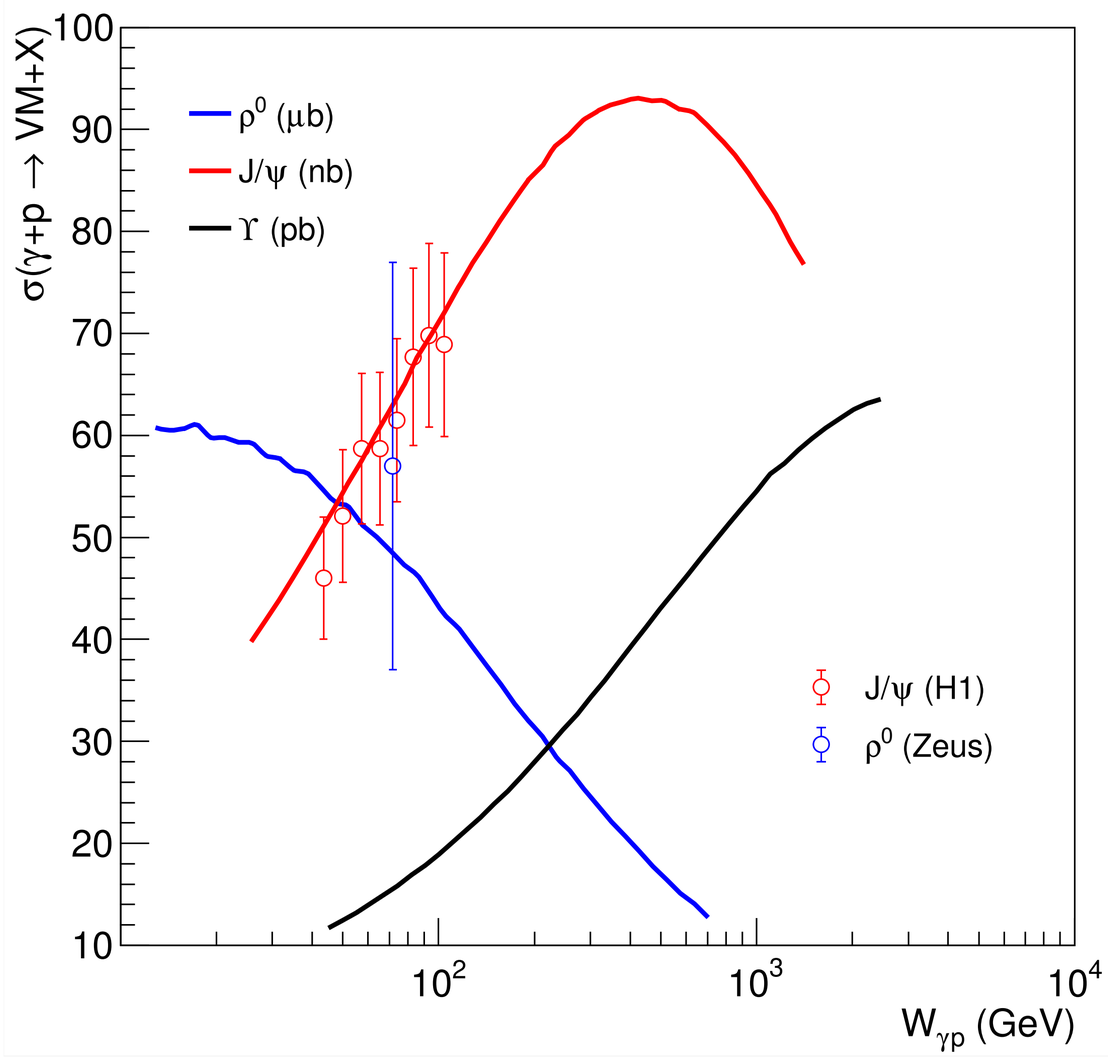

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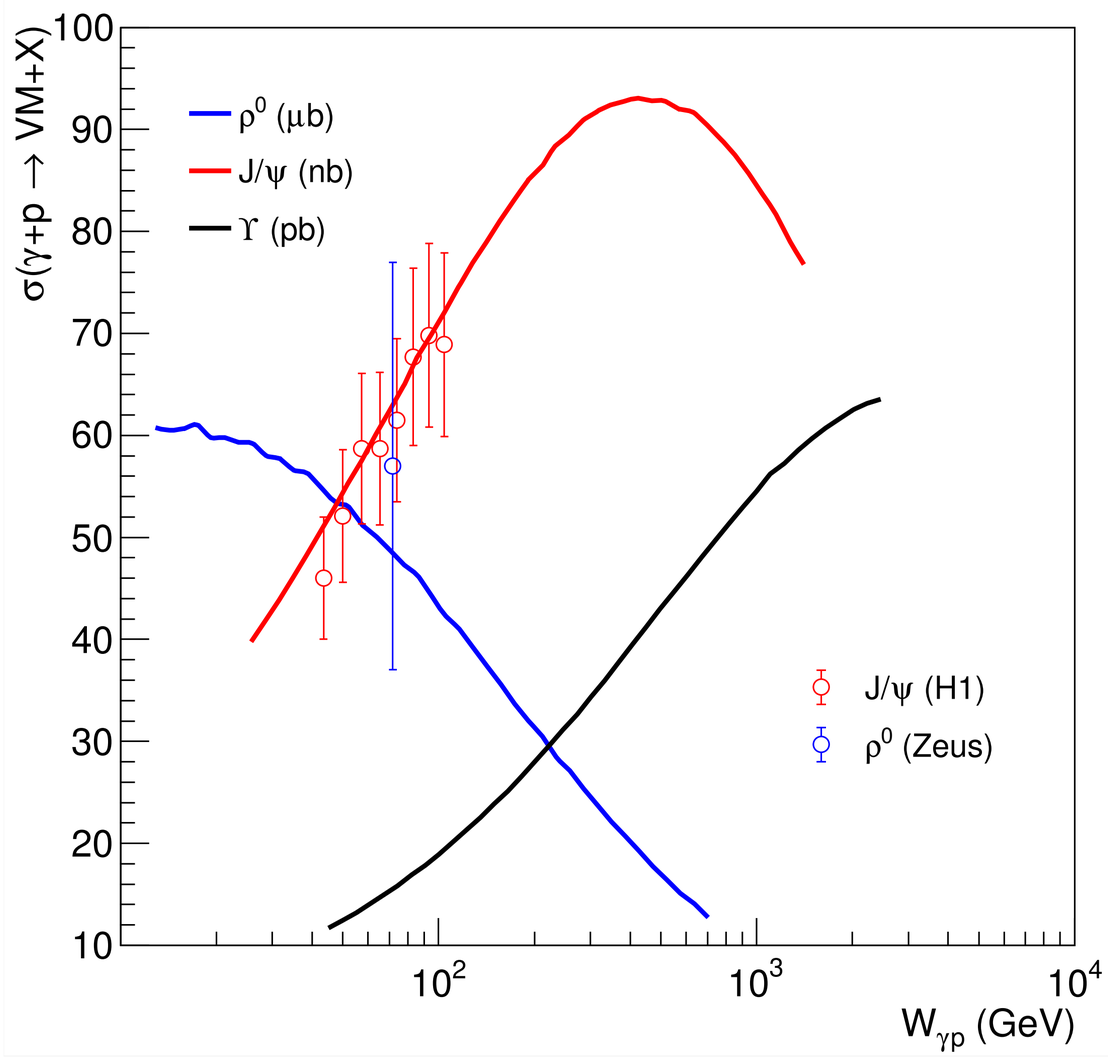
Measuring at the LHC all three vector meson would provide a new handle to look for saturation effects.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508



Extension of the model to other vector mesons: γPb

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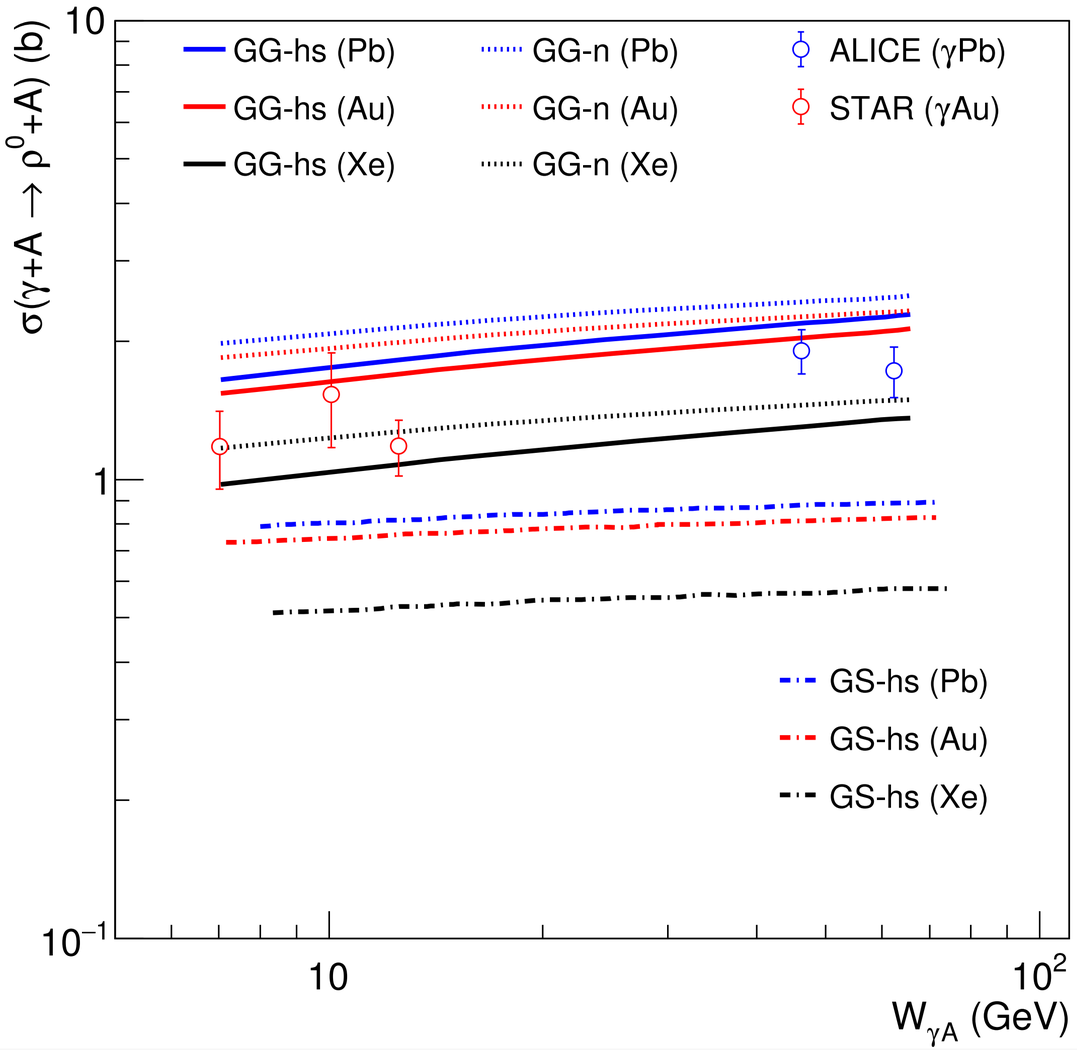
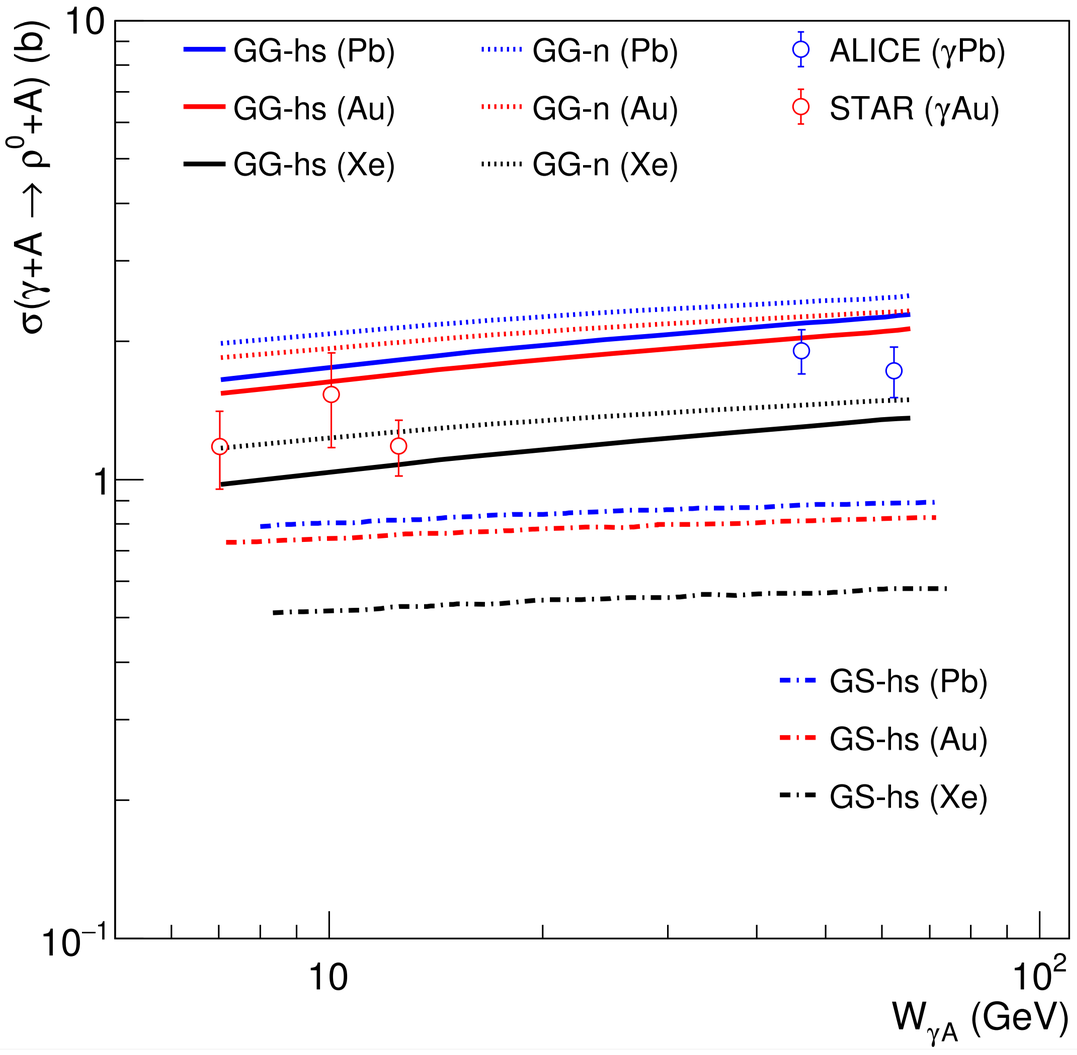


Extension of the model to other vector mesons: γPb

- The model based on geometric scaling ideas predicts a cross section for coherent production of ρ^0 about a factor of 2 smaller than data.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508



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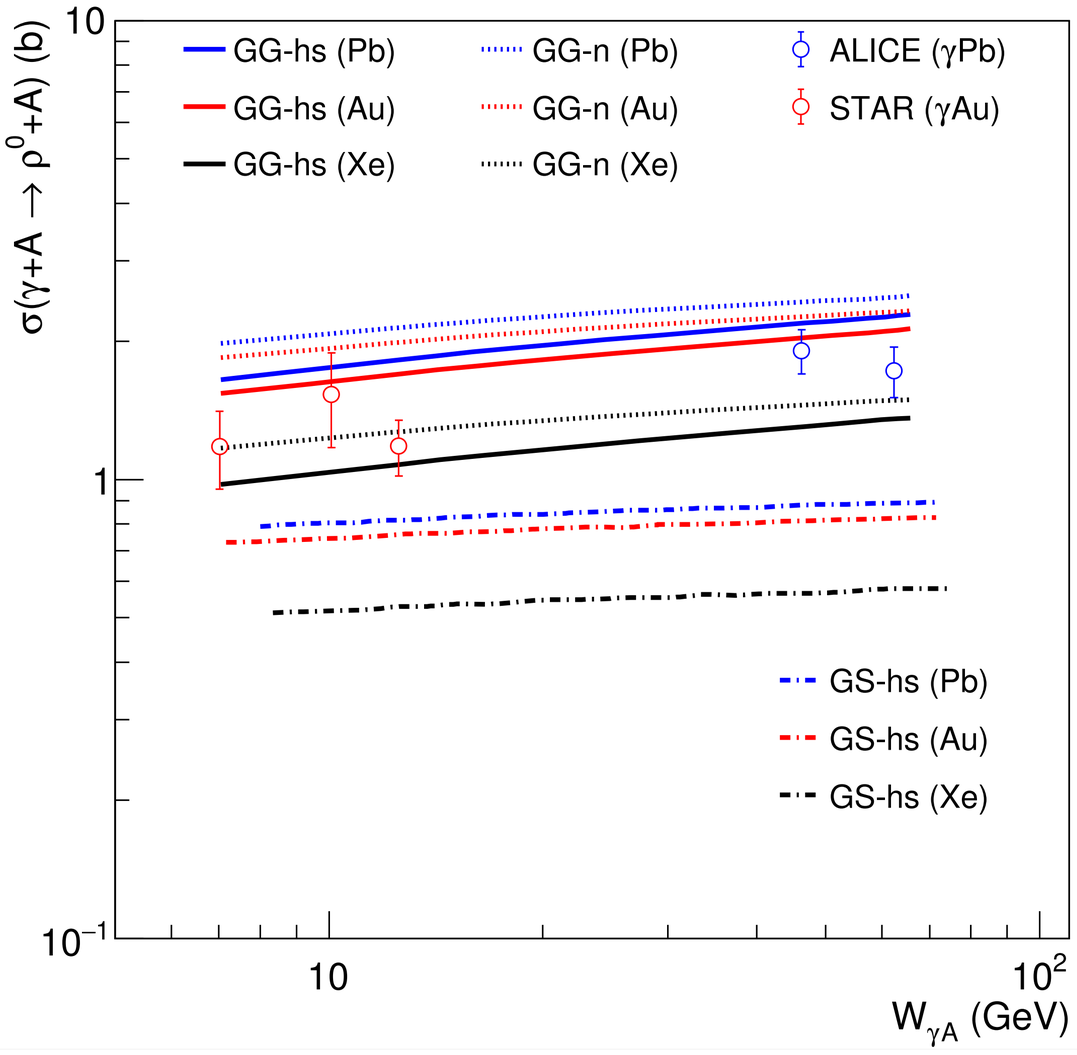

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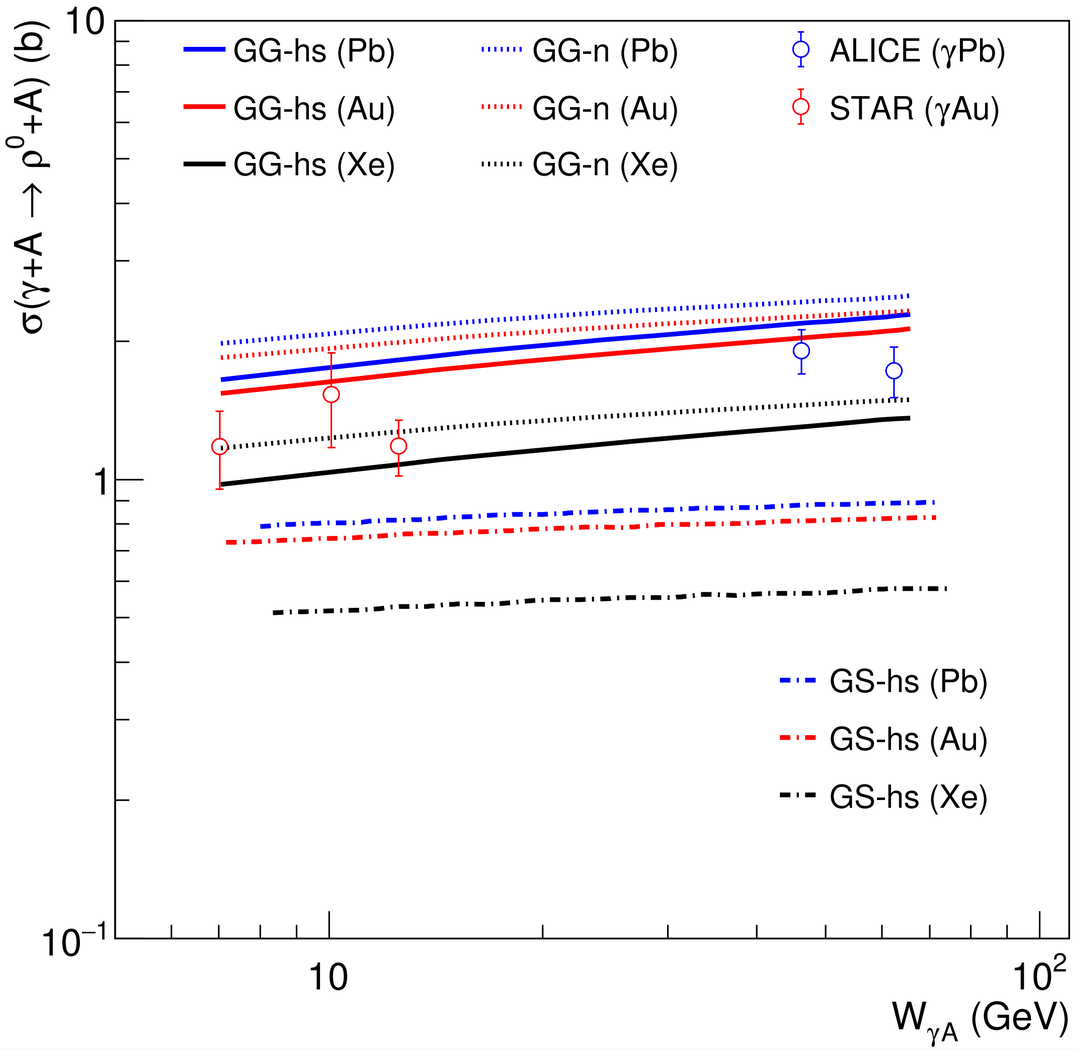
- The model based on Gribov-Glauber ideas overshoots data by a bit more than one sigma.

- In this model, there is a **difference** in the energy evolution of the coherent cross section **when adding subnucleon degrees of freedom**.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508



Summary and outlook

Summary and outlook

- News from J/ψ production in γp collisions:
  - The energy dependence of dissociative J/ψ photoproduction provides a striking signature for saturation.

Čepila, JGC, Tapia , PLB 766 (2017) 186

- News from J/ψ production in γPb collisions:
  - Fluctuations of subnuclear degrees of freedom also leave an imprint in the photoproduction of J/ψ off nuclear targets.

Čepila, JGC, Křelina, PRC 97 (2018), 024901

- News from other vector mesons:
  - The mass dependence of vector meson photoproduction privides a new handle in the search for saturation effects.

Čepila, JGC, Křelina, Tapia, arXiv 1804.05508

Eagerly awaiting new data on photoproduction of vector mesons off protons and off nuclei!