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Prague, Czech Republic, 26-30 June 2017

Investigating Saturation Effects in Ultra - Peripheral Heavy Ion Collisions

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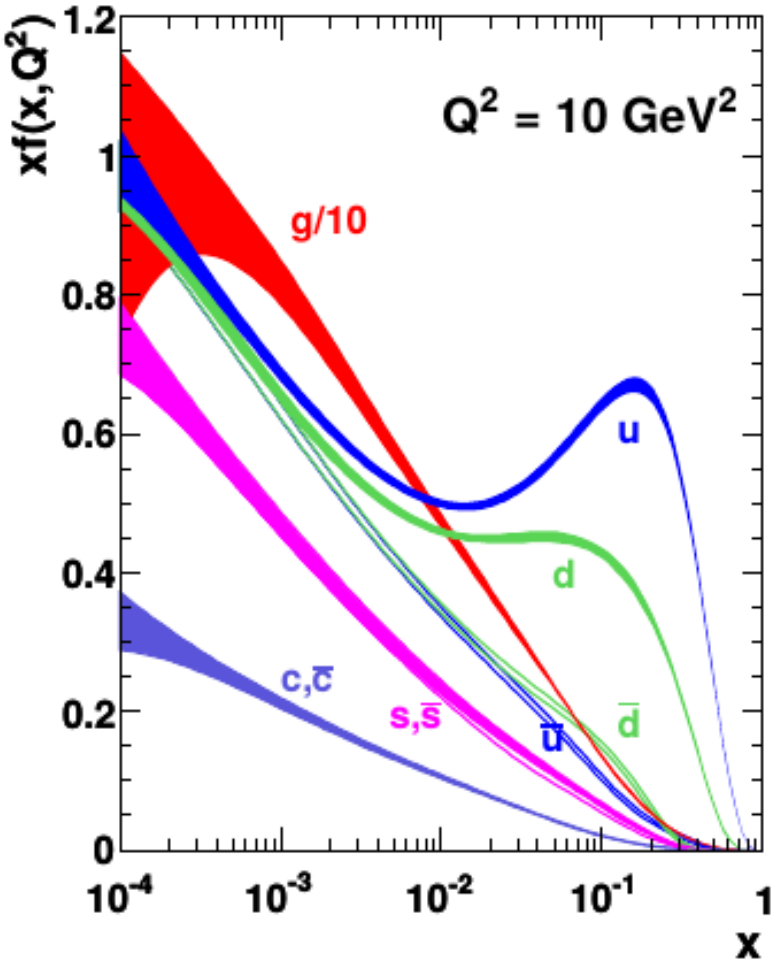
Prague
30 June 2017

Outline

- Hadronic structure and QCD dynamics at high energies
- Photon – induced interactions in hadronic collisions
- Color dipole formalism for the vector meson photoproduction
- Impact of saturation effects
- Comparison with the LHC data

Hadronic structure at high energies

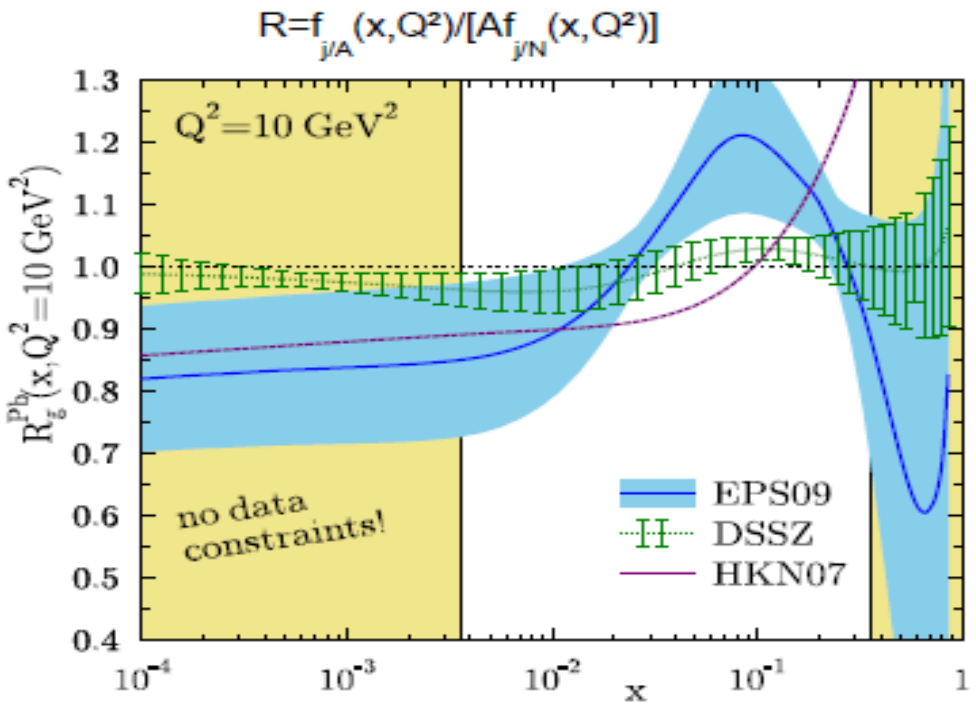


- Proton structure at high energies (small values of x) is dominated by gluons;
- Linear QCD Evolution equations (DGLAP/BFKL) predict a power growth of gluon distribution at small −x;
- Large uncertainty on the behaviour at small −x;
- The current data included in the global analysis does not constrain the gluon distribution at high energies.

Hadronic structure at high energies

$$R_g \equiv \frac{x g_A(x, Q^2)}{A \cdot x g_p(x, Q^2)}$$

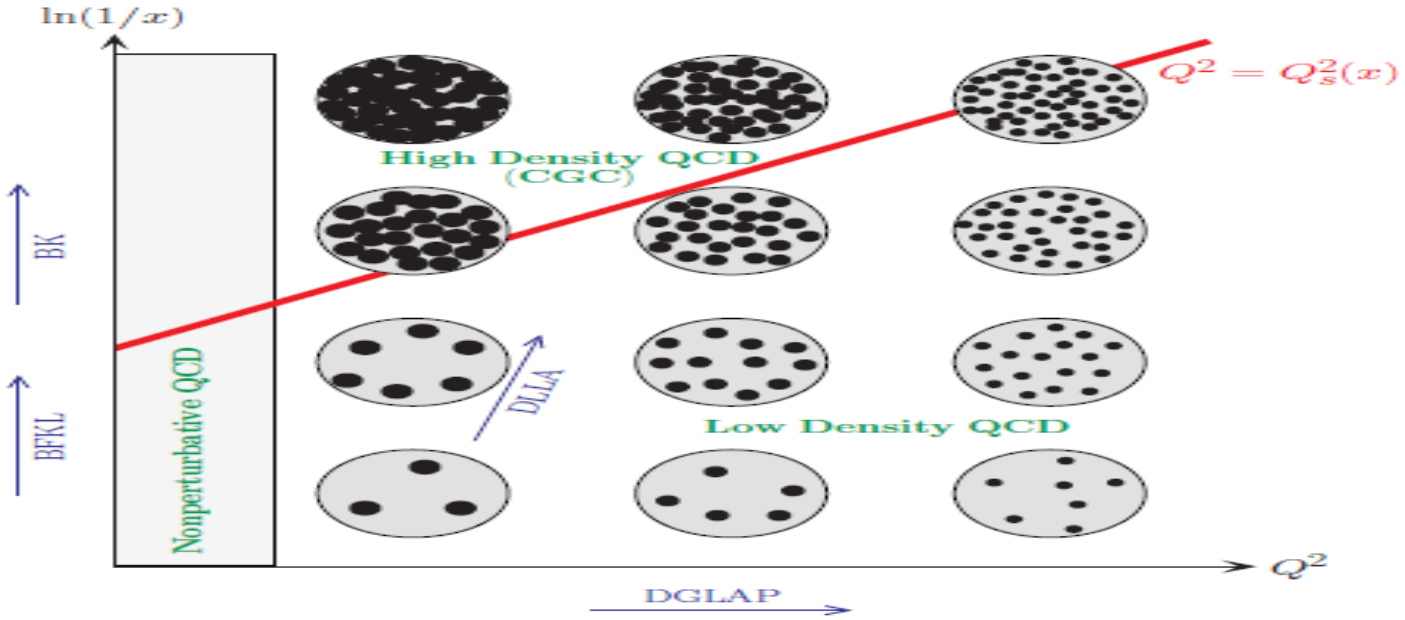
- No nuclear effects $\Rightarrow R_g = 1$.



Eskola, Puukkunen, arXiv:1401.2345

- The current electron – ion experimental data does not constrain the small –x behaviour;
- Large theoretical uncertainty present in the kinematical range probed by LHC.

QCD dynamics at high energies



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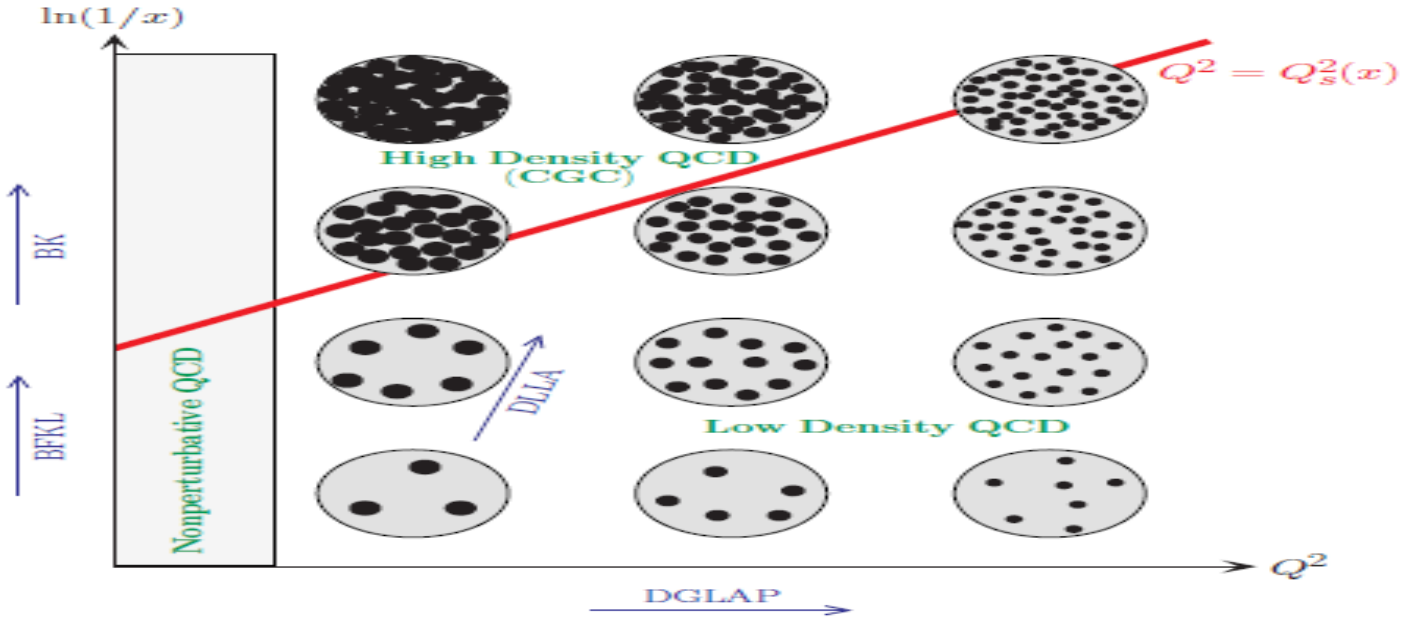

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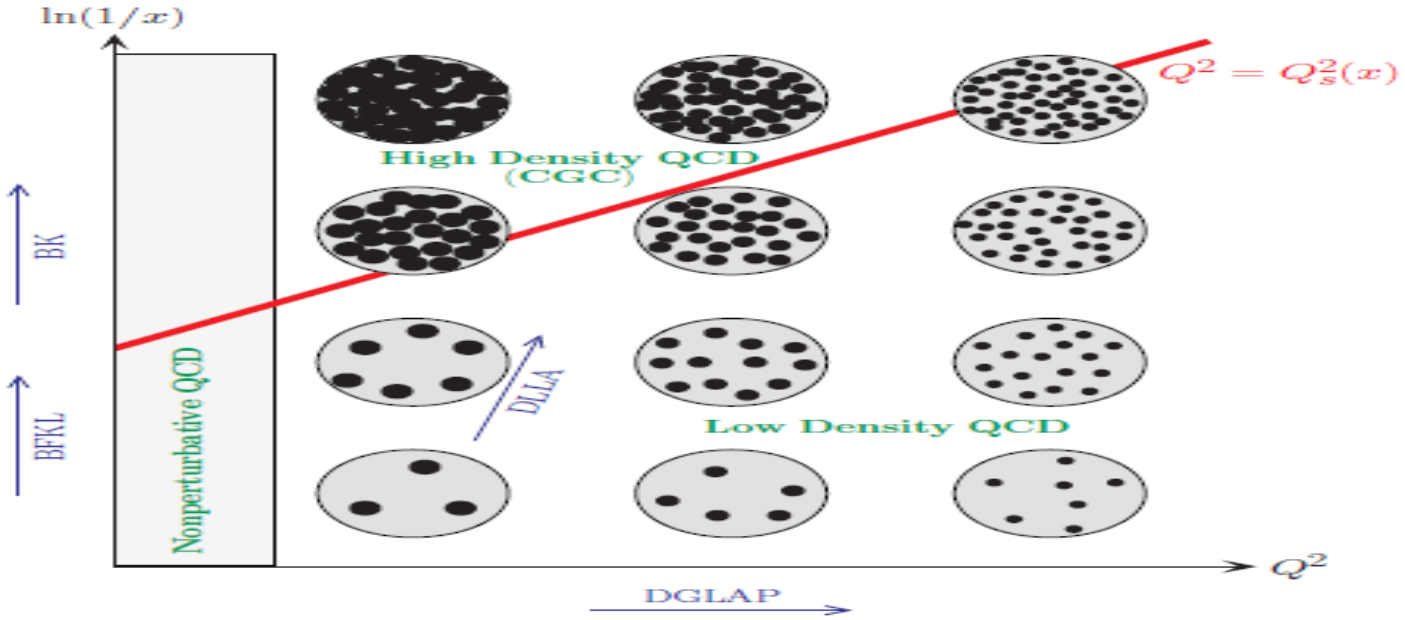

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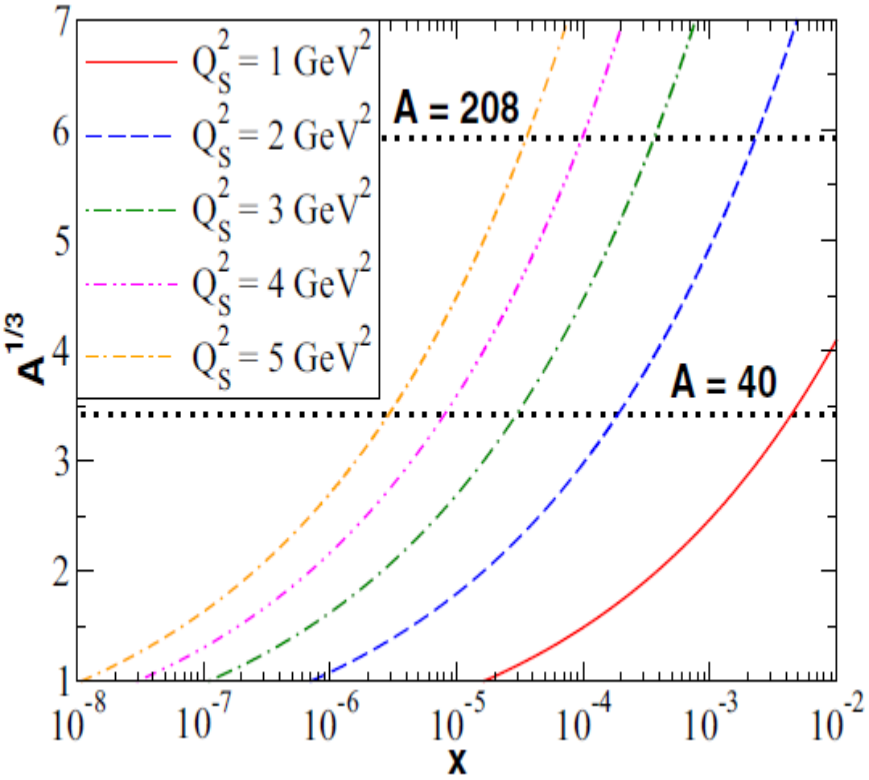

- Saturation scale Qs [proportional to $(1/x)^{\lambda/2}A^{\beta}$] defines the onset of nonlinear QCD dynamics (Gluon saturation effects);
- Nuclei are an efficient amplifier of the gluon saturation effects.

How to probe the QCD dynamics at high energies ?

- In the last decades, several observables have been proposed and experimentally analyzed;
- Best scenario: Observables measured in ep and eA collisions. (FUTURE!)
- Alternative: Photon - induced interactions in hadronic collisions.

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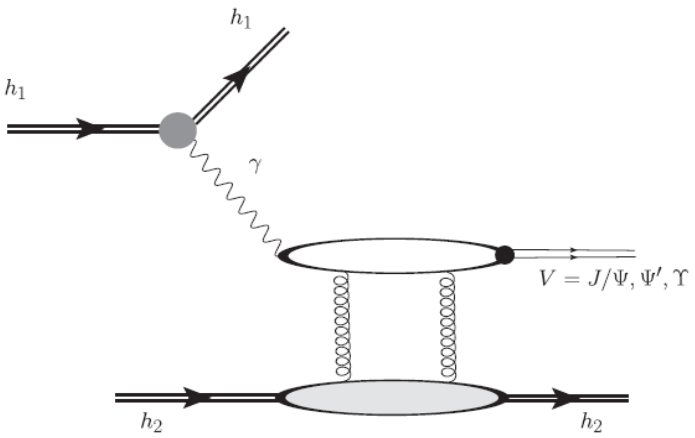

[a] VPG, Bertulani, PRC65, 054905 (2002)

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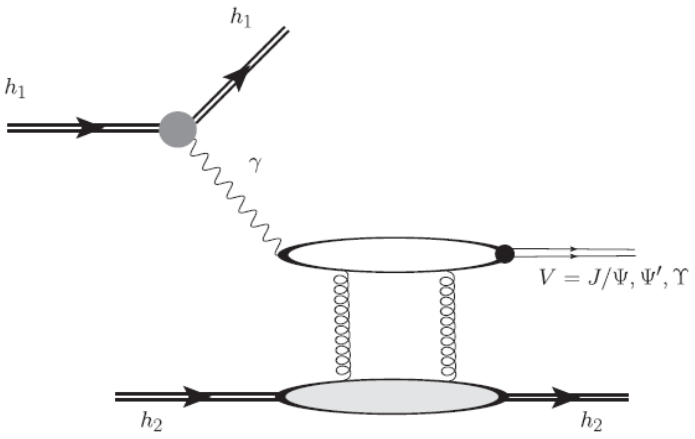

At leading order in LL(1/x) approx.:

$$\left.\frac{d\sigma^{\gamma h \to V h}}{dt}\right|_{t=0} = \mathcal{N} \frac{\pi^3 \Gamma_{e^+e^-} M_V^3}{48 \alpha_{\rm em}} \left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g_h(x, \bar{Q}^2)\right]^2$$

Cross section is proportional to the square of the hadron gluon distribution at $x = 4\overline{Q}^2/W^2$

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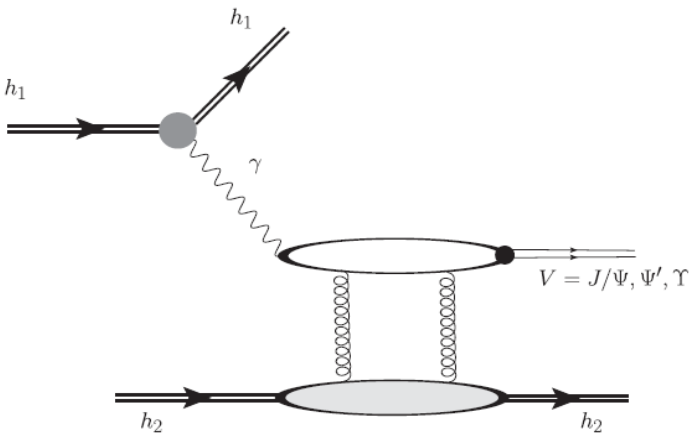

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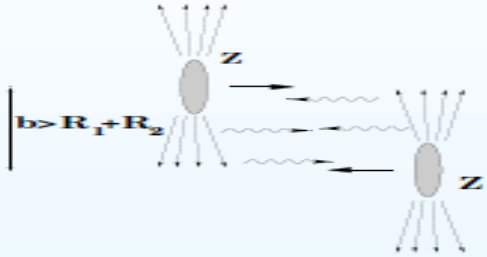

1. γh Processes: $\sigma(h_1 h_2 \to X) = n_h(\omega) \otimes \sigma^{\gamma h \to X}(W_{\gamma h})$
2. $\gamma\gamma$ Processes: $\sigma(h_1 h_2 \to X) = n_1(\omega) \otimes n_2(\omega) \otimes \sigma^{\gamma\gamma \to X}(W_{\gamma\gamma})$

Center of mass energies

LHC	pp	$W_{\gamma p} \lesssim 8390$ GeV	$W_{\gamma\gamma} \lesssim 4504$ GeV
LHC	$pPb(Ar)$	$W_{\gamma A} \lesssim 1500\,(2130)$ GeV	$W_{\gamma\gamma} \lesssim 260\,(480)$ GeV
LHC	$PbPb$	$W_{\gamma A} \lesssim 950$ GeV	$W_{\gamma\gamma} \lesssim 160$ GeV
HERA	ep	$W_{\gamma p} \lesssim 200$ GeV	–

Photoproduction in pp collisions at LHC probes photon - hadron center - of - mass energies one order of magnitude larger than HERA.

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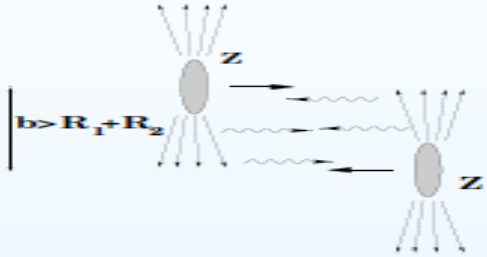

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Photoproduction in pA and AA collisions at LHC probes a unexplorated regime of photon - nucleus center of mass energies.

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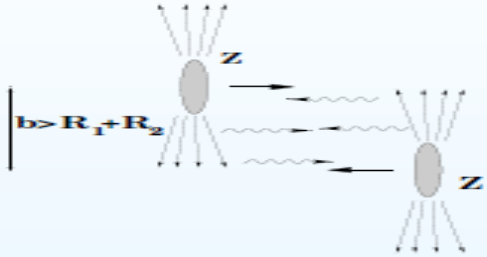

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Photon - induced interactions at LHC allows to study the high energy regime of QCD (Small - x Physics).

Diffractive vector meson photoproduction in UPHIC: Color Dipole Formalism

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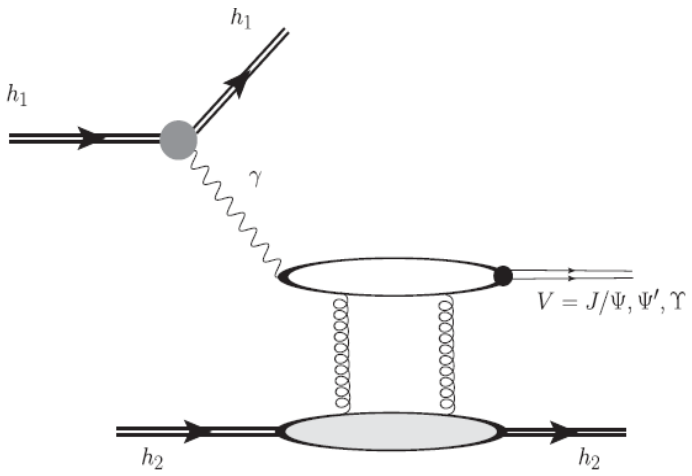

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[a] VPG, Machado, EPJC 40, 519 (2005)

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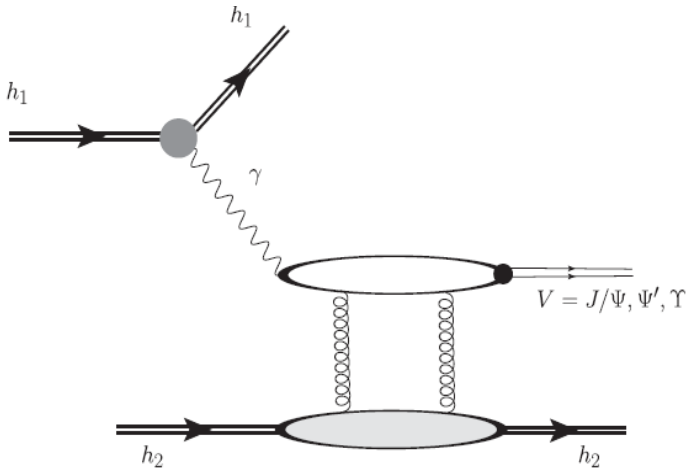

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Overlap function for Vector Mesons

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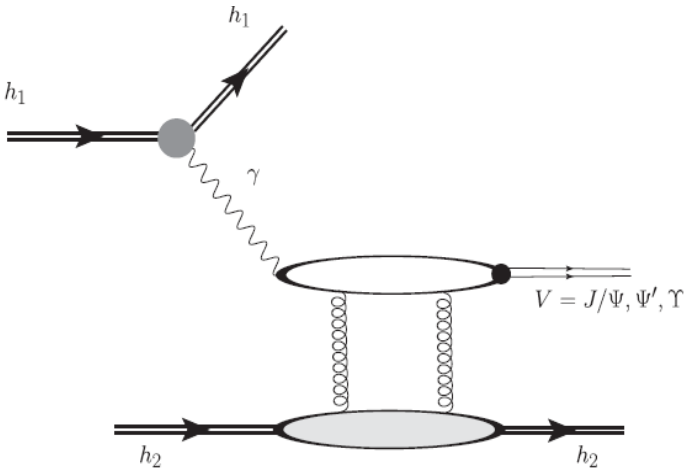

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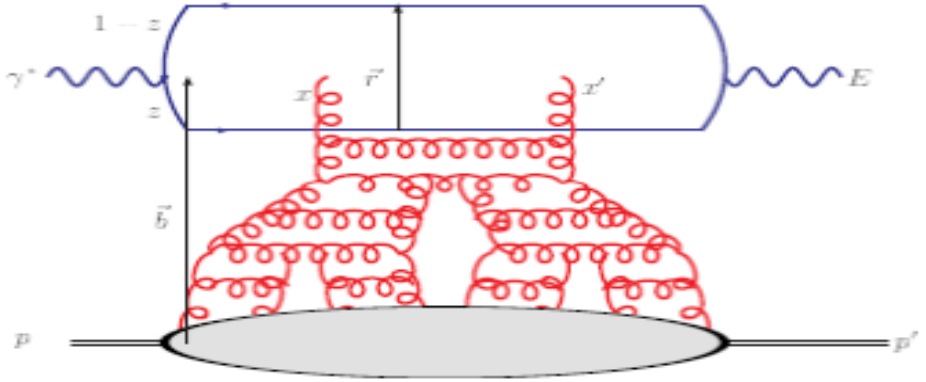
Forward dipole - hadron scattering amplitude: Determined by the QCD dynamics

[a] VPG, Machado, EPJC 40, 519 (2005)

Diffractive vector meson photoproduction in UPHIC: Color Glass Condensate Formalism

Dipole - proton scattering amplitude:



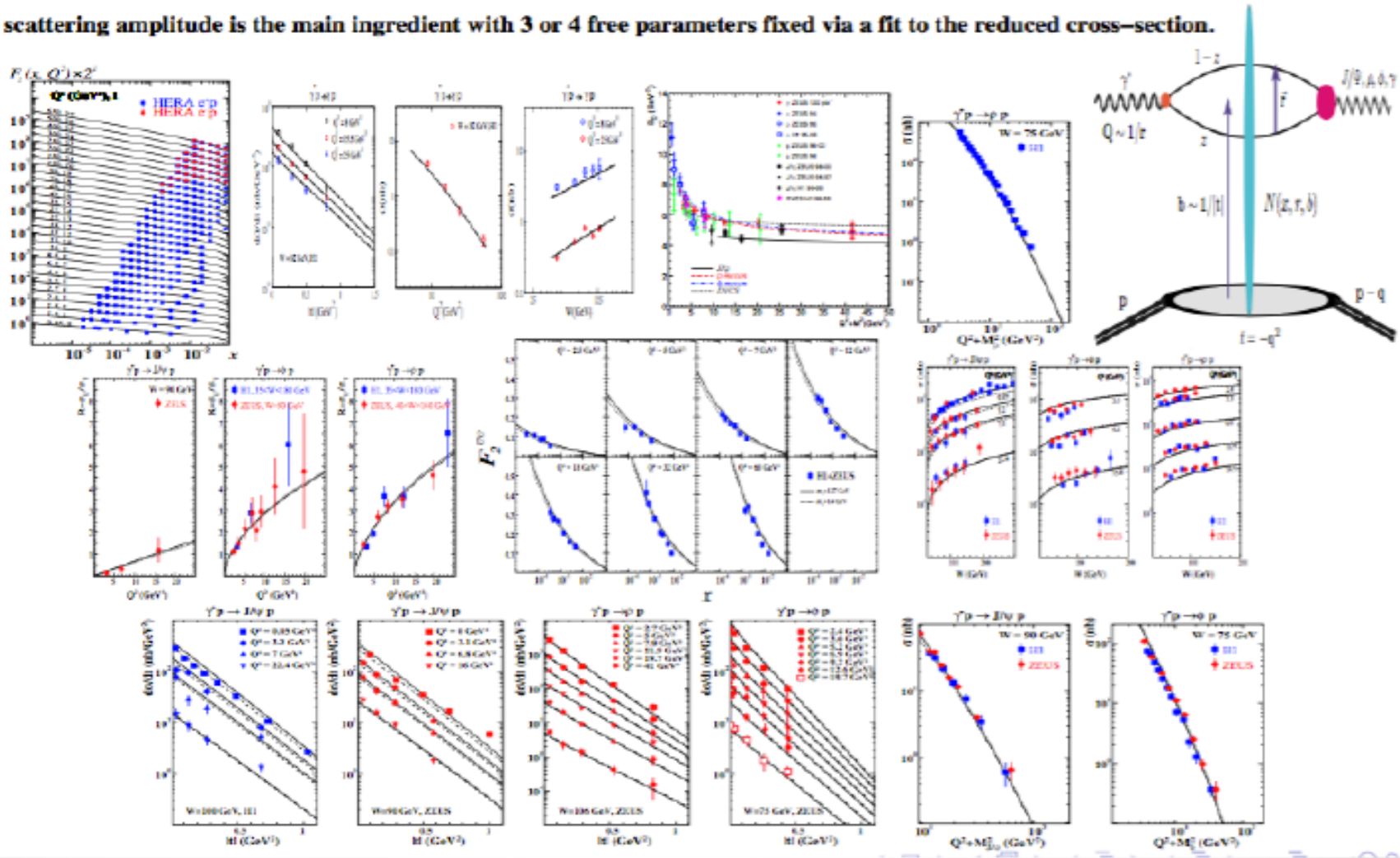
- bCGC : $$\mathcal{N}^p(\hat{x}, \boldsymbol{r}, \boldsymbol{b}) = \begin{cases} \mathcal{N}_0 \left(\frac{rQ_s(b)}{2}\right)^{2\left(\gamma_s + \frac{\ln(2/rQ_s(b))}{\kappa\lambda Y}\right)} & rQ_s(b) \leq 2 \\ 1 - e^{-A\ln^2(BrQ_s(b))} & rQ_s(b) > 2 \end{cases}$$

  - Proposed originally by Kowalski, Motyka and Watt (06)
  - Parameters of the model updated considering the high precision combined HERA data (Rezaeian, Schmidt, 13)

A unified description of combined inclusive HERA data & diffractive data in CGC

Rezaeian, Siddikov, Van de Klundert, Venugopalan, arXiv:1212.2974; Rezaeian, Schmidt, arXiv:1307.0825

The dipole scattering amplitude is the main ingredient with 3 or 4 free parameters fixed via a fit to the reduced cross–section.



Rezaeian, INT workshop '17

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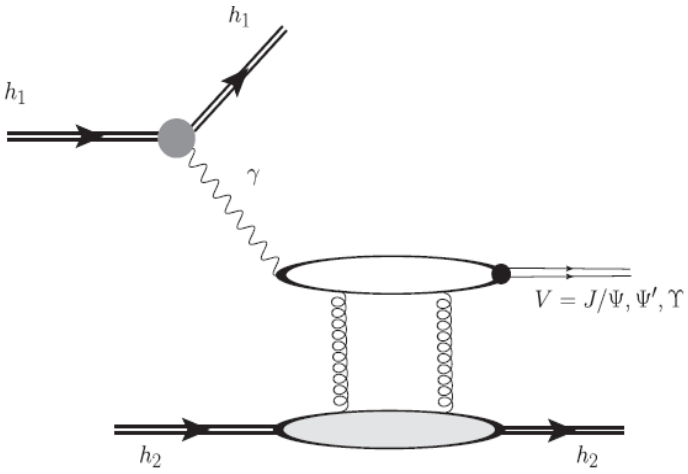

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- Nucleus: $\mathcal{N}_A(x, \boldsymbol{r}, \boldsymbol{b}_A) = 1 - \exp\left[-\frac{1}{2}\sigma_{dp}(x, \boldsymbol{r}^2)\, T_A(\boldsymbol{b}_A)\right]$ → Sums all multiple elastic rescatterings of the dipole.

$$\sigma_{dp}(x, \boldsymbol{r}^2) = 2 \int d^2\boldsymbol{b}_p\, \mathcal{N}_p(x, \boldsymbol{r}, \boldsymbol{b}_p)$$

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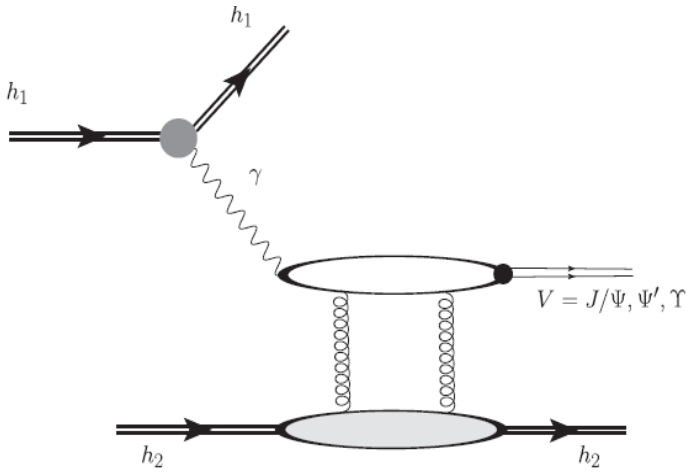

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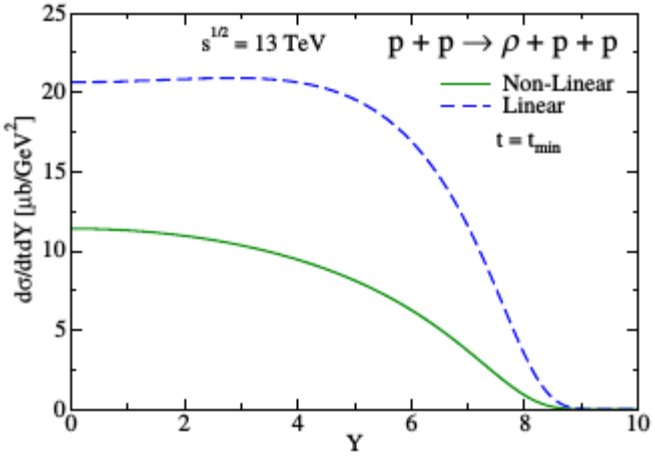
In the dipole picture, all free parameters have been constrained by HERA data. Predictions for UPHIC are parameter free!

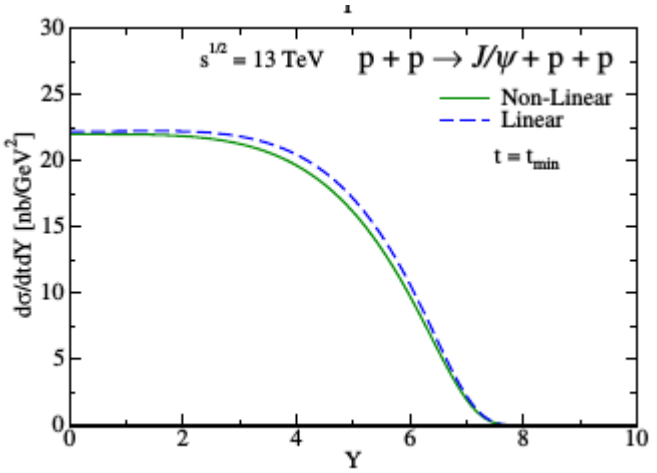
Diffractive vector meson photoproduction in UPHIC: Impact of the gluon saturation effects

VPG, Spiering, Navarra, PLB 768, 299 (2017)

Diffractive vector meson photoproduction in UPHIC: Impact of the gluon saturation effects

pp Collisions:





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VPG, Spiering, Navarra, PLB 768, 299 (2017)

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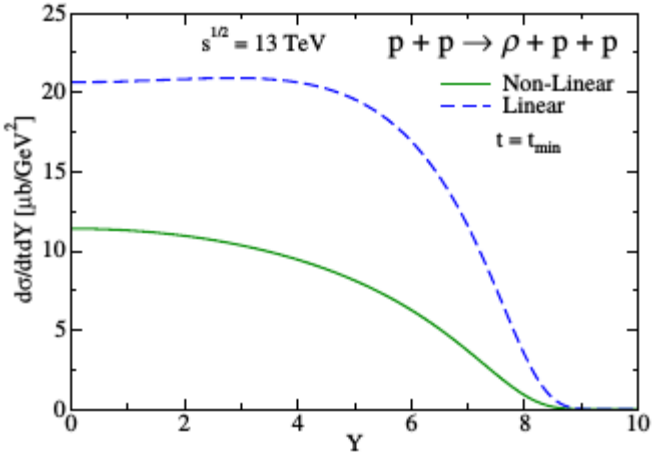
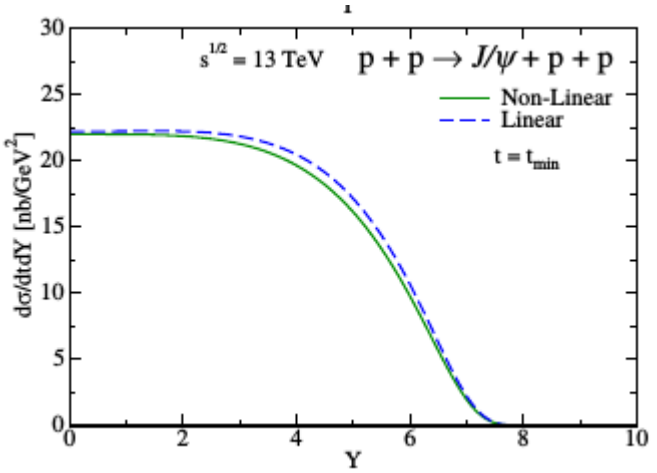
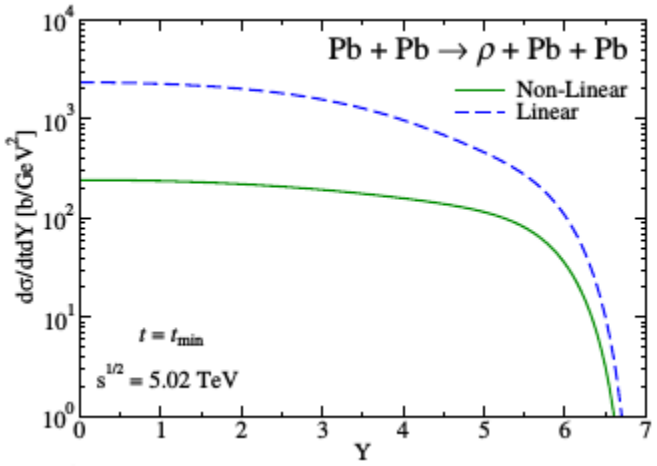
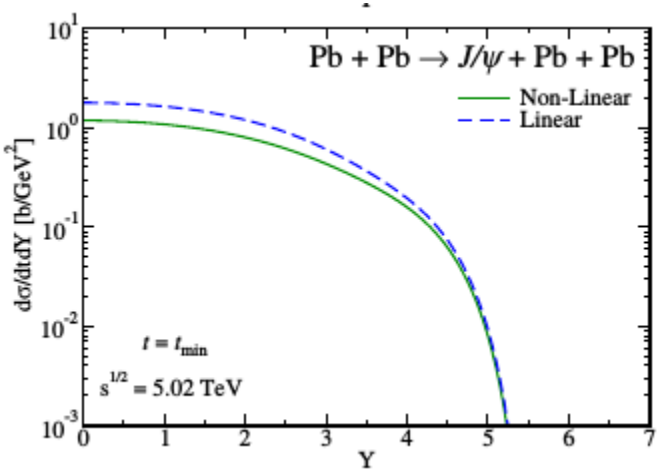




PbPb Collisions:





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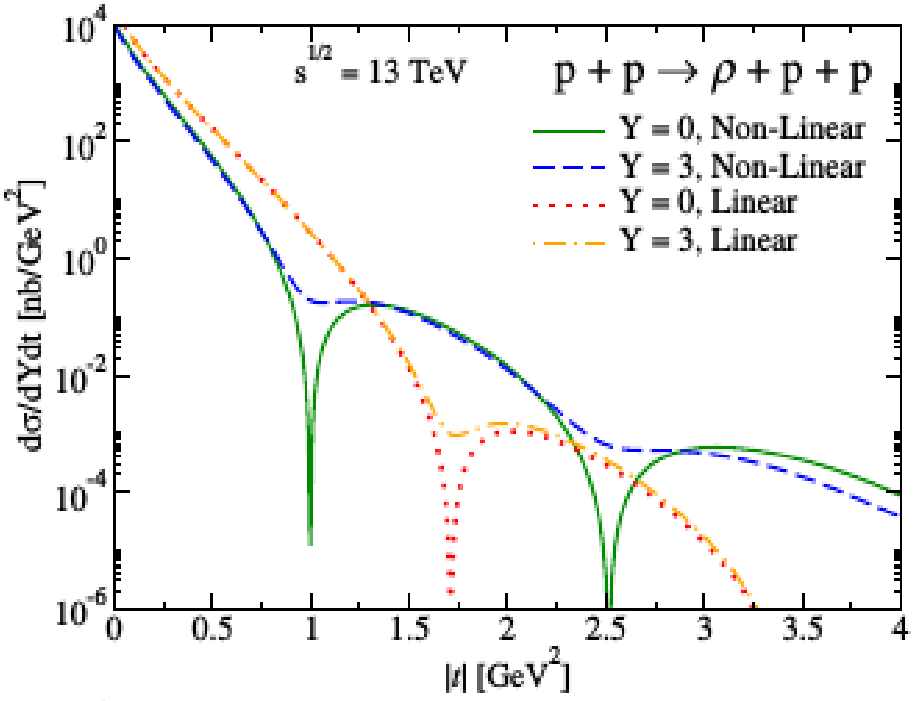
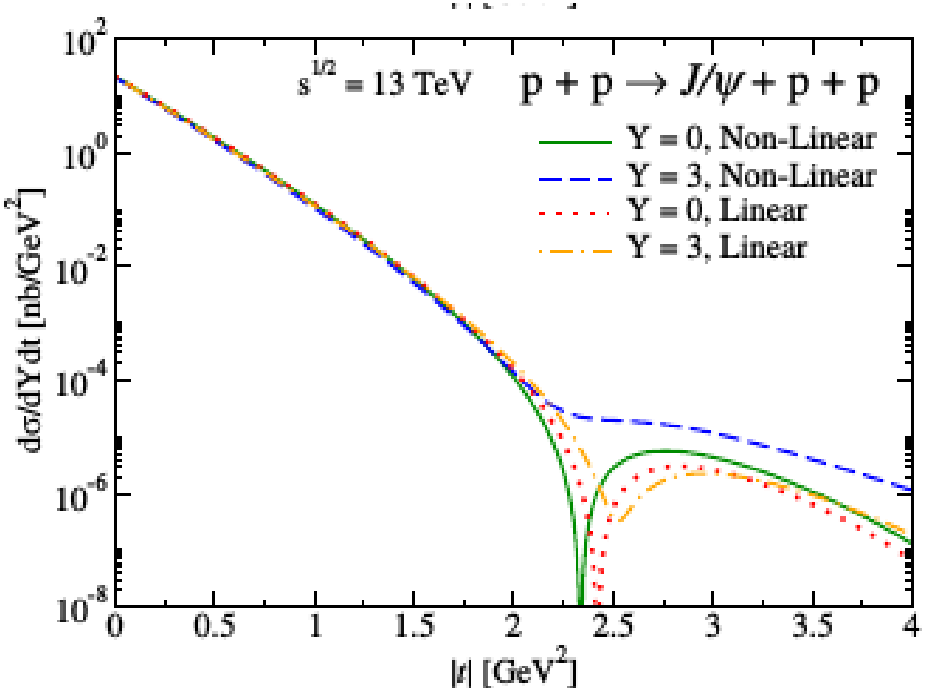




Linear model:

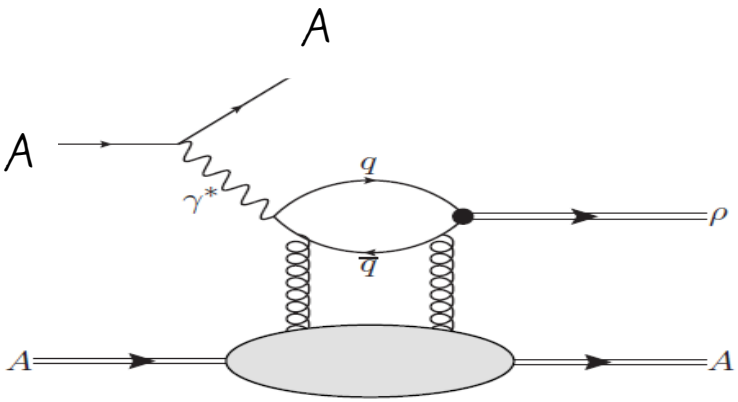
$$\mathcal{N}^p(x, \boldsymbol{r}, \boldsymbol{b}_p) = \mathcal{N}_0 \left(\frac{r\, Q_s(b_p)}{2} \right)^{2\left(\gamma_s + \frac{\ln(2/r\, Q_s(b_p))}{\kappa\, \lambda\, Y}\right)}$$

VPG, Spiering, Navarra, PLB 768, 299 (2017)

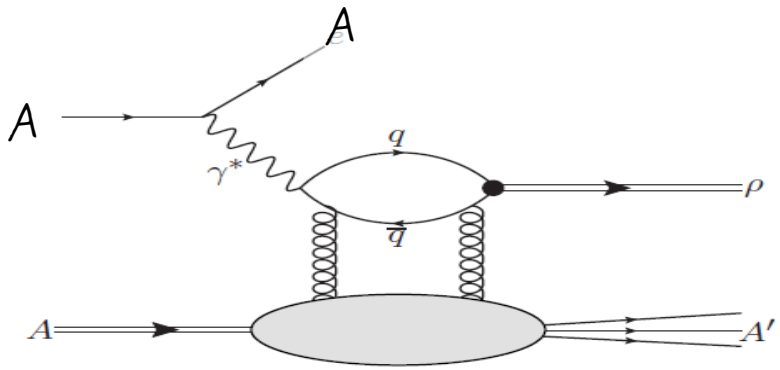
Diffractive vector meson photoproduction in UPHIC: Impact of the gluon saturation effects

PbPb Collisions:

Coherent production:



Incoherent production:



VPG, Spiering, Navarra, PLB 768, 299 (2017)

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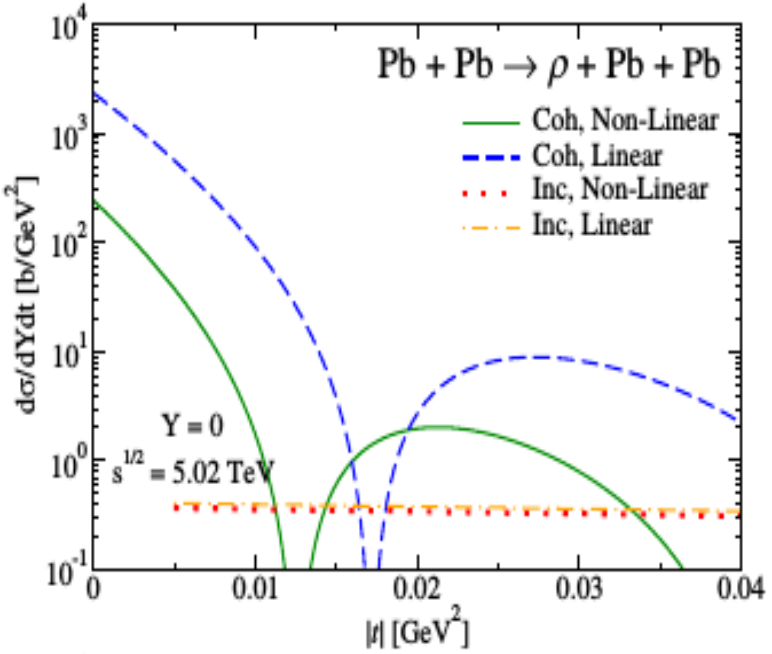
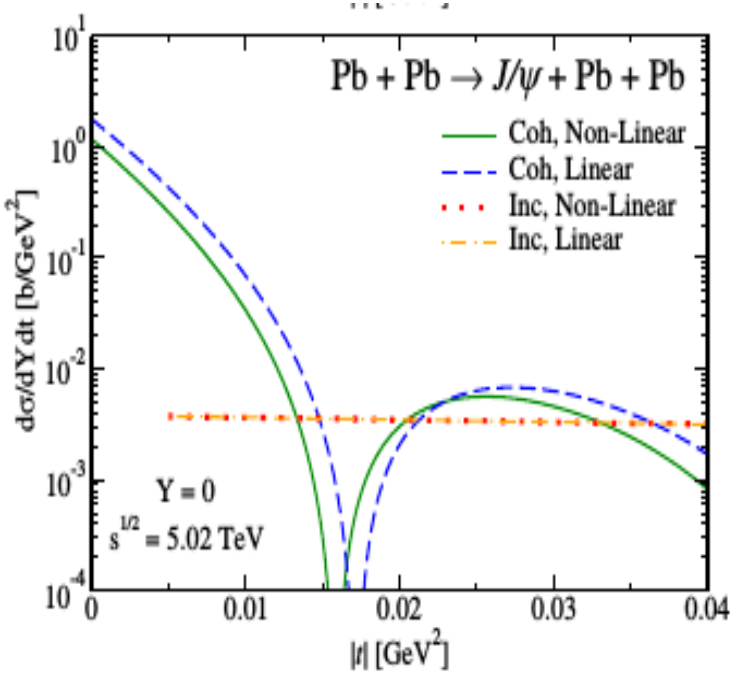




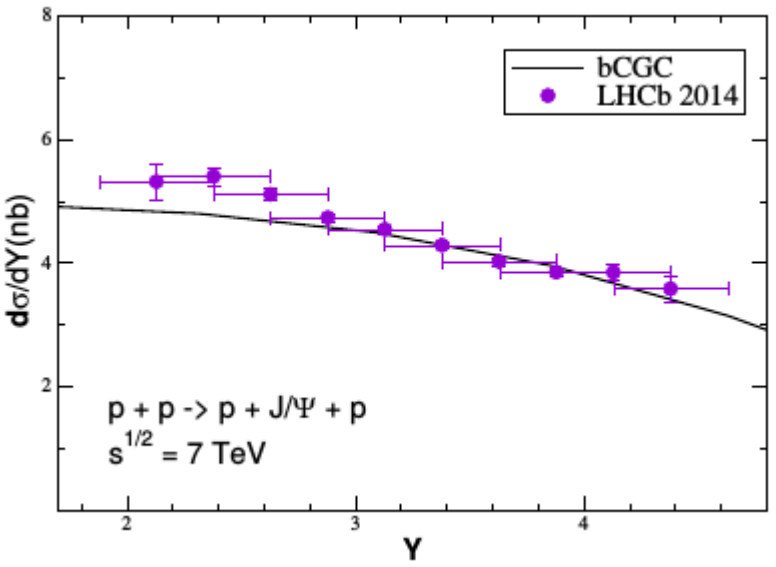
Linear model: $\mathcal{N}^A(x, r, \boldsymbol{b}_A) = \frac{1}{2}\sigma_{dp}(x, r) A T_A(\boldsymbol{b}_A)$

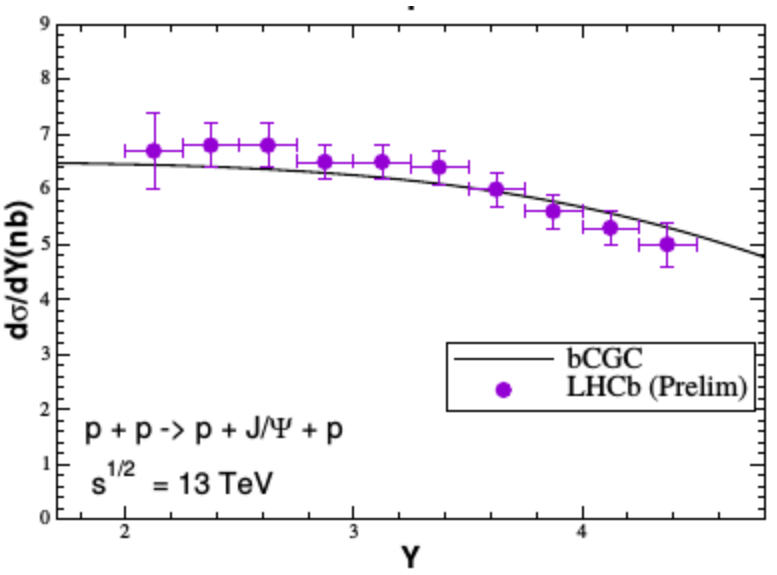
VPG, Spiering, Navarra, PLB 768, 299 (2017)

Comparison with the LHC data

Comparison with the LHC data

Diffractive J/Psi photoproduction in pp collisions:

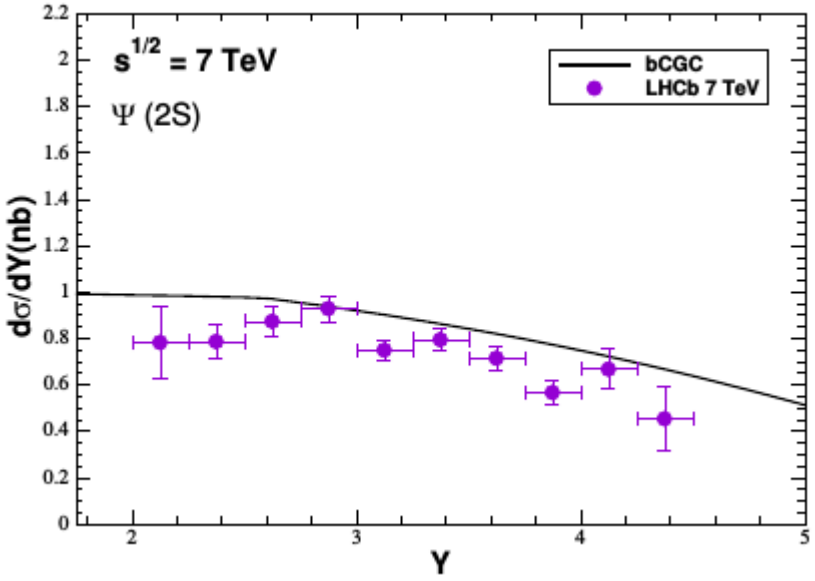


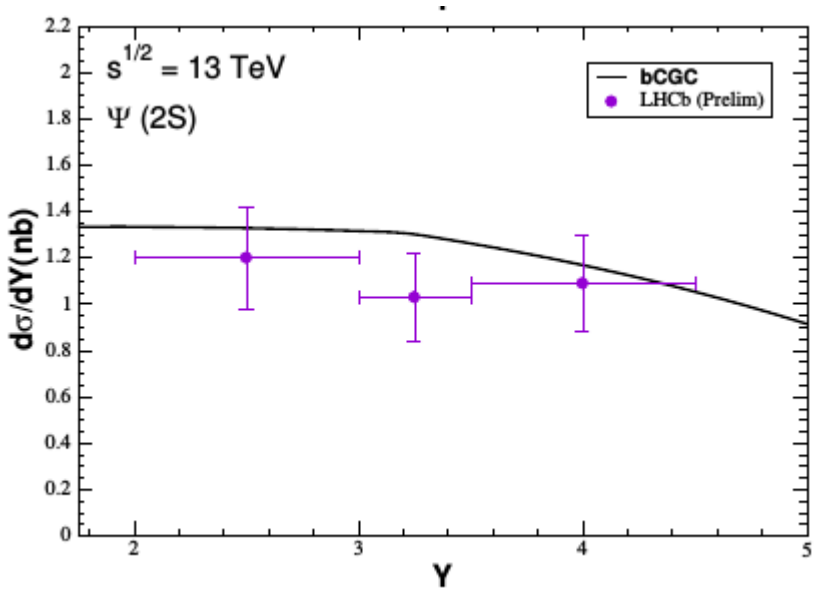


VPG, Moreira, Navarra, PRD95, 094024 (2016)

Comparison with the LHC data

Diffractive Psi(2S) photoproduction in pp collisions:

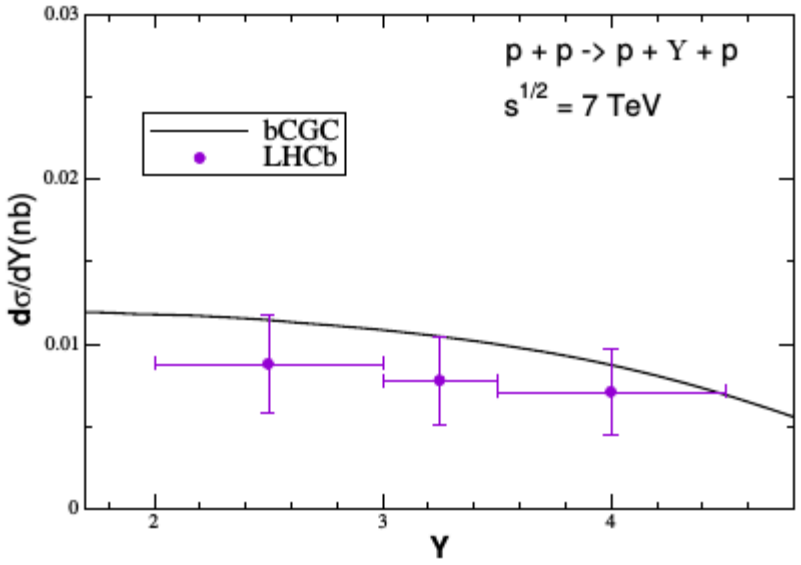


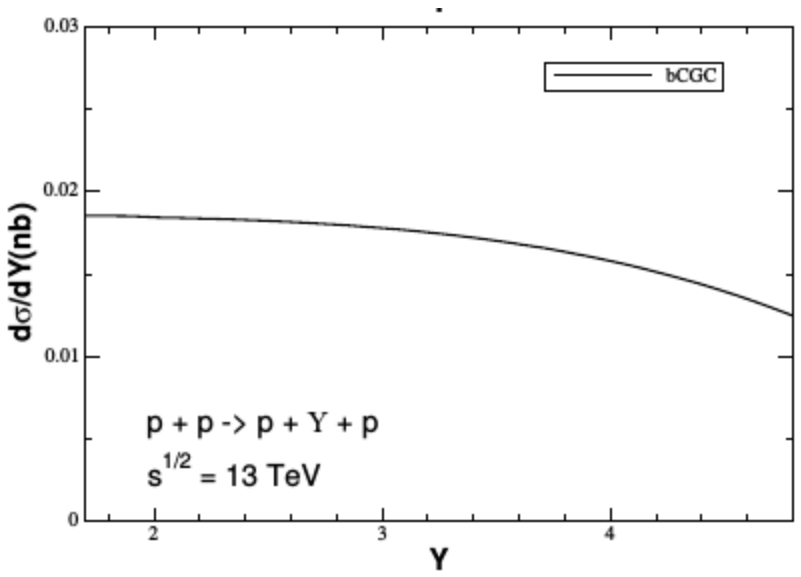


VPG, Moreira, Navarra, PRD95, 094024 (2016)

Comparison with the LHC data

Diffractive Upsilon photoproduction in pp collisions:

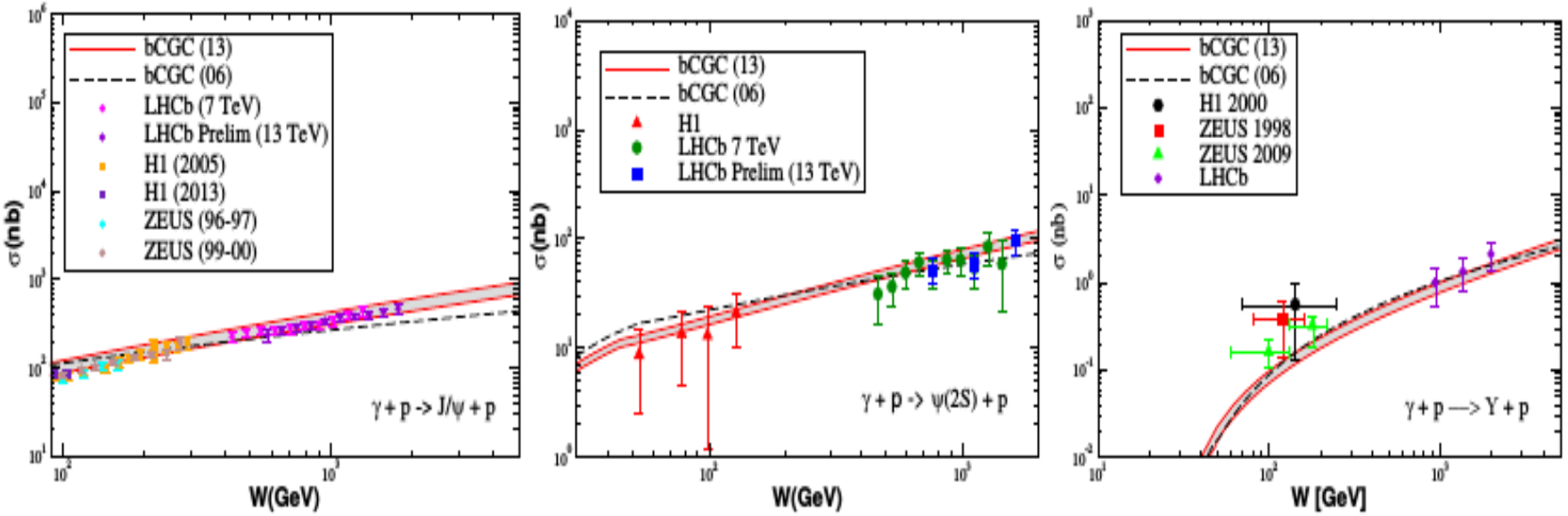




VPG, Moreira, Navarra, PRD95, 094024 (2016)

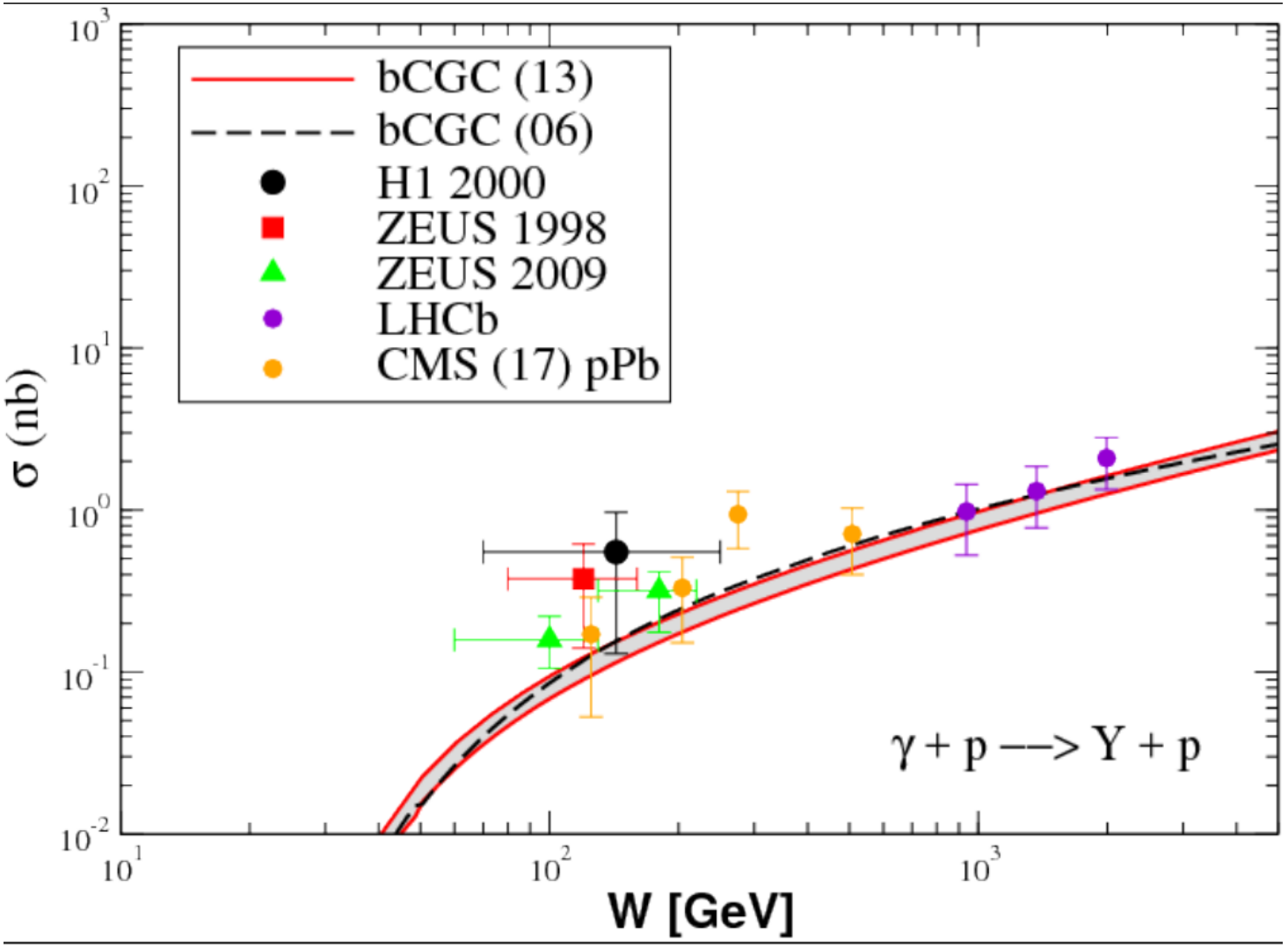
Comparison with the LHC data

Energy dependence of the photon - proton cross section:

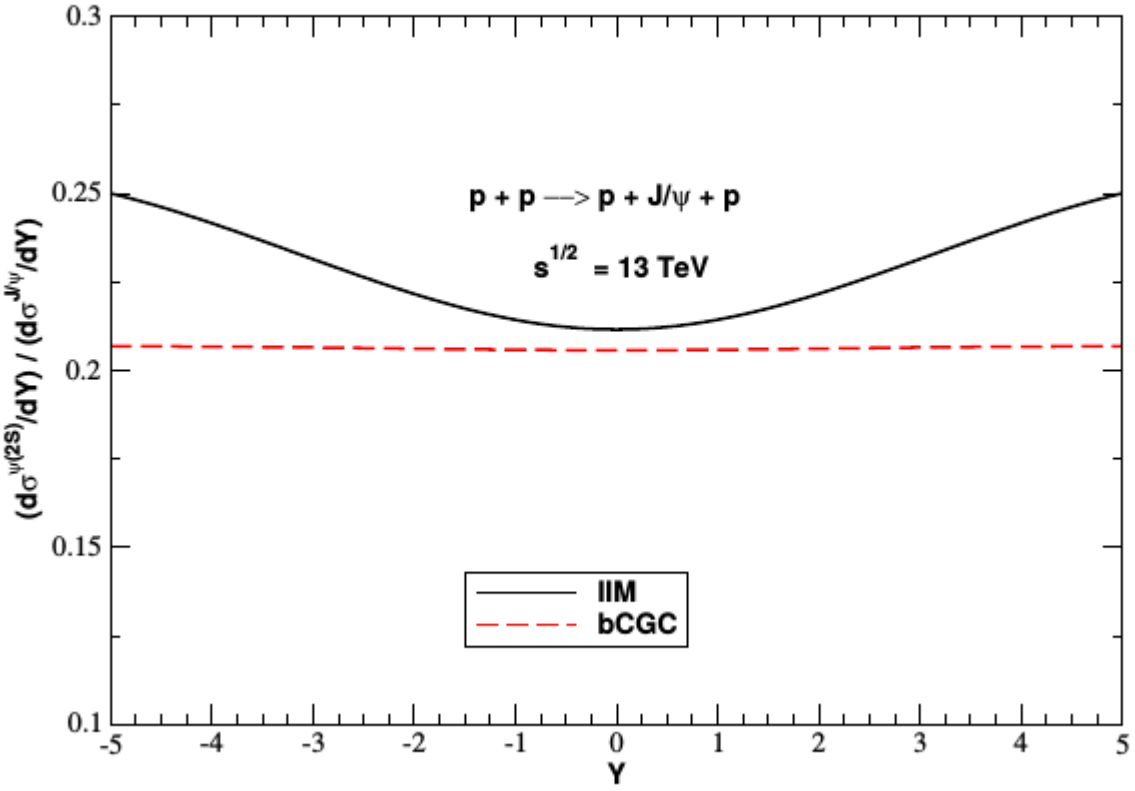


VPG, Moreira, Navarra, PRD95, 094024 (2016)

Comparison with preliminary CMS pPb data



Ratio between charmonium cross sections



Summary

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- ✓ The diffractive vector meson photoproduction in photon – induced interactions at the LHC is an important probe of the QCD dynamics at high energies.
- ✓ The Run I data can be sucessfully described by the color dipole formalism taking into account the nonlinear effects in the QCD dynamics.
- ✓ The Run II data can be used to constrain the description of the dipole – hadron scattering amplitude and the vector meson wave function
- ✓ Complementary studies can be performed by analysis of the double vector meson production and the vector meson production associated to a leading neutron.

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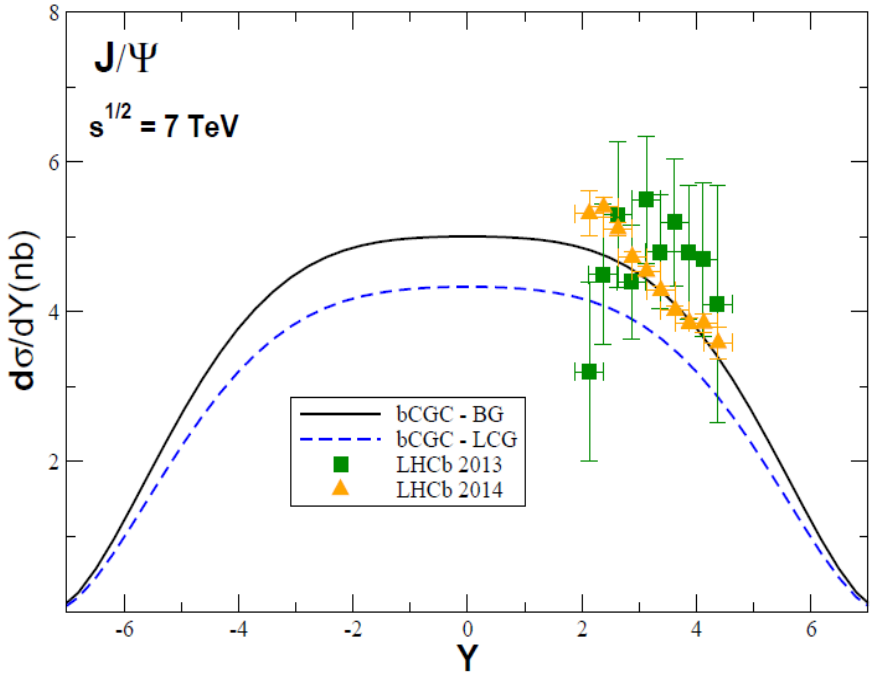
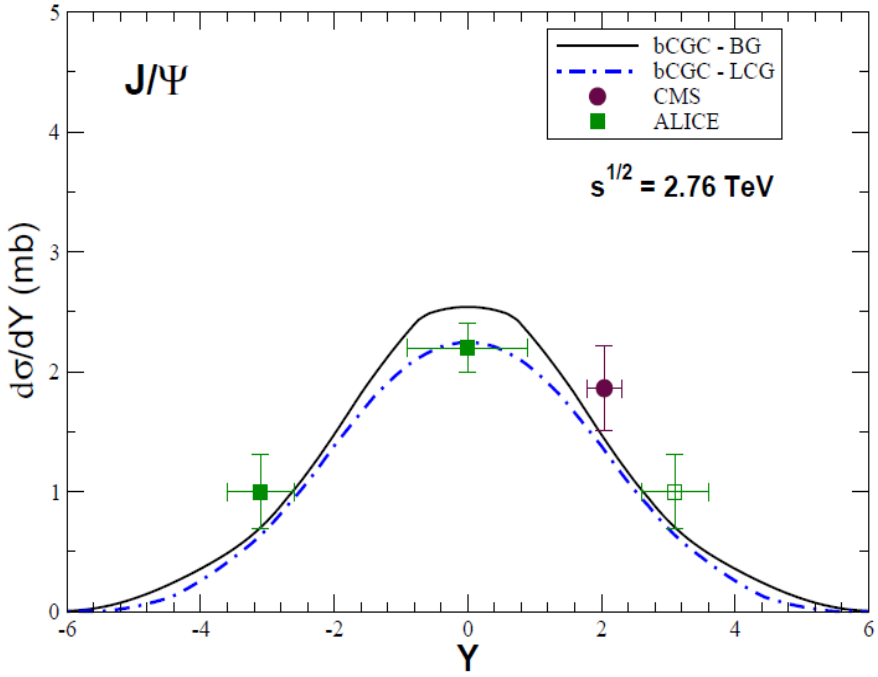
Thank you for your attention!

Extras

Comparison with the Run I data

- Diffractive J/Ψ photoproduction in hadronic collisions [a]

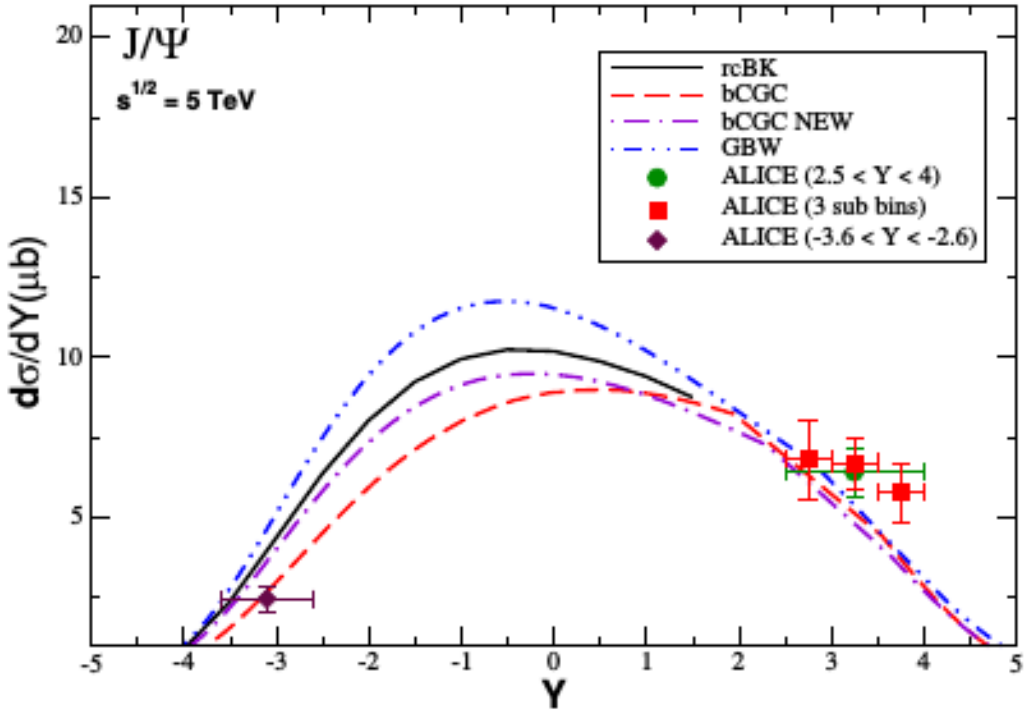




([a]) VPG, Moreira, Navarra, PRC90, 015203 (2014)

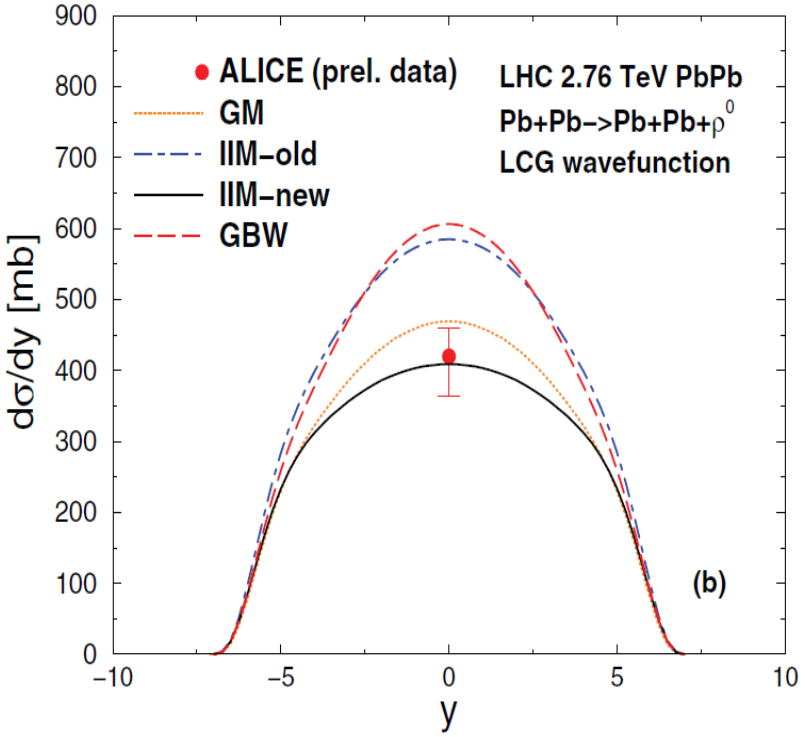
Comparison with the Run I data

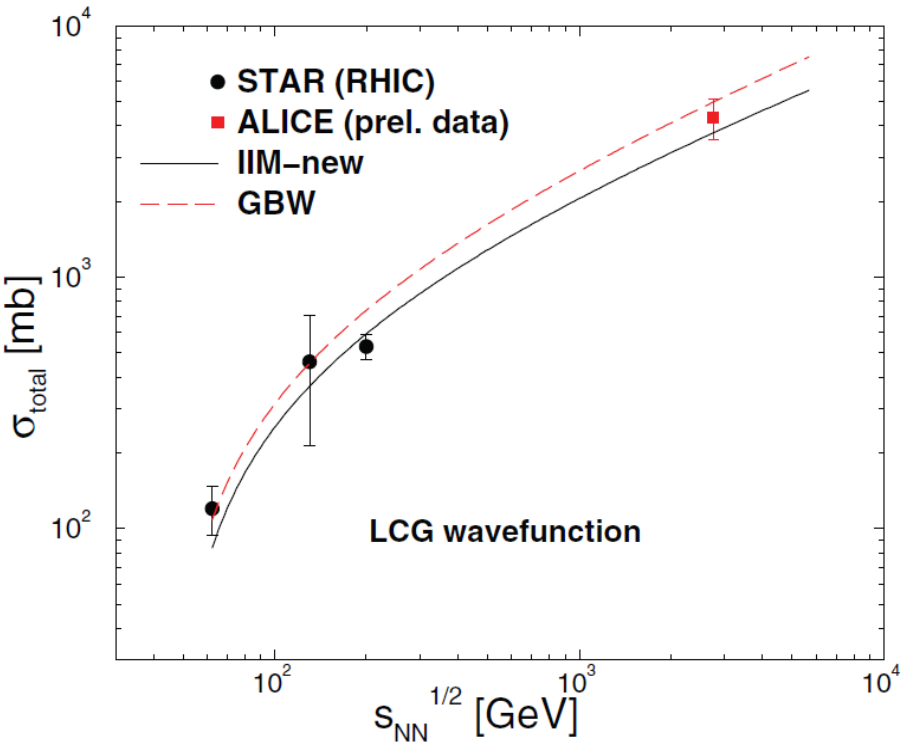
- Diffractive J/Ψ photoproduction in hadronic collisions [a]



Comparison with the Run I data

- Diffractive ρ photoproduction in hadronic collisions [c]

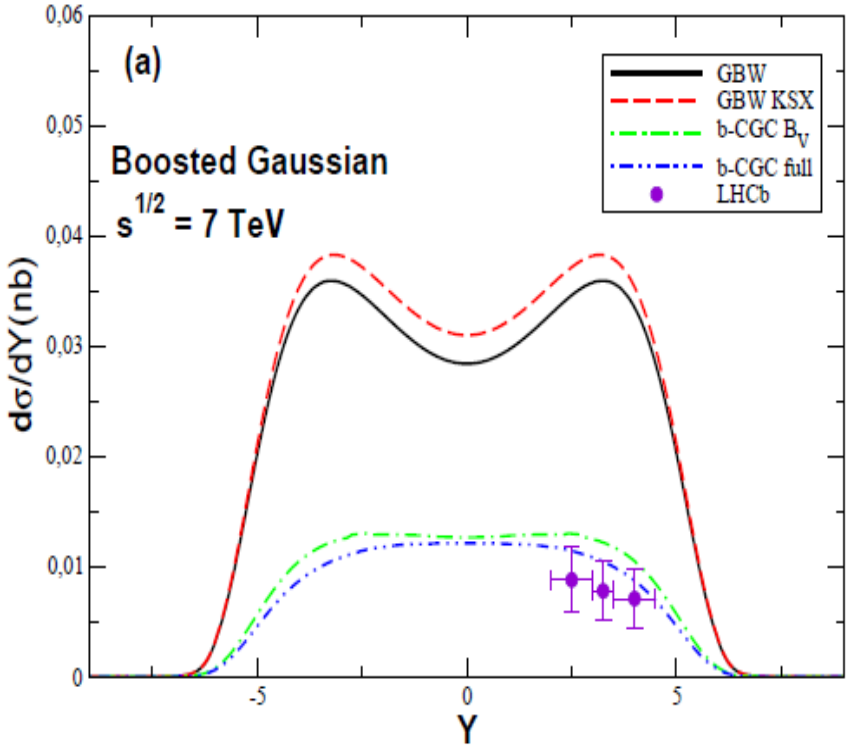


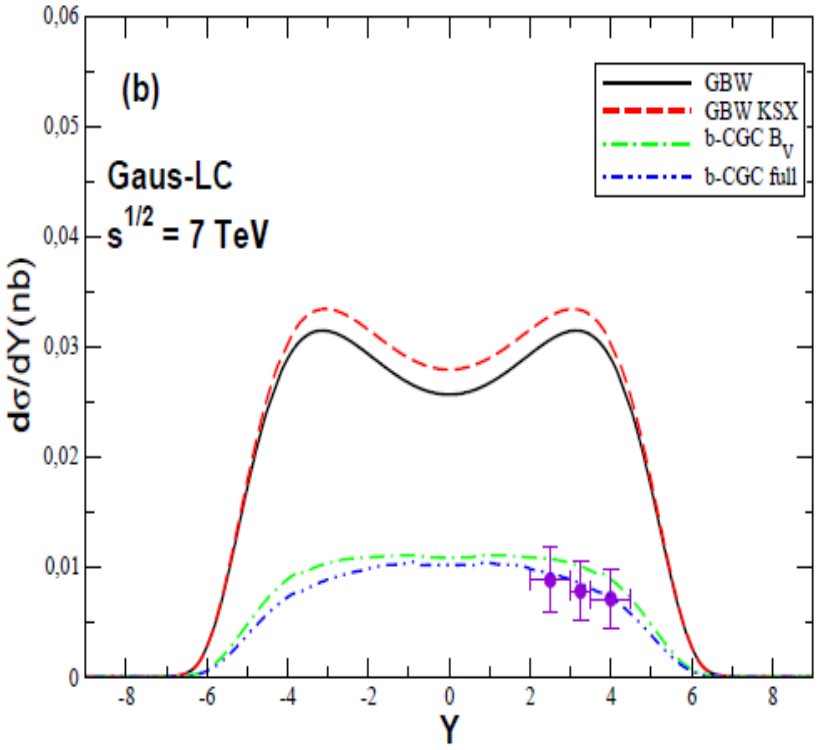


(c) VPG, Machado, EPJC 40, 519 (2005); PRC80, 054901 (2009); PRC84, 011902 (2011); Machado, dos Santos, PRC91, 025203 (2015)

Comparison with the Run I data

- Diffractive Υ photoproduction in hadronic collisions [b]





[b] VPG, Moreira, Navarra, PLB 472, 172 (2015)