Exclusive Vector Meson Photoproduction at Run 2 LHC energies: Color dipole predictions

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Based on arXiv:1710.10070, PRD96 (2017) 094027

In collaboration with M. Machado, B. Moreira, F. Navarra and G. dos Santos

Kobe
18 April 2018

Outline

- Photon - induced interactions in hadronic collisions
- Exclusive vector meson photoproduction at the LHC - The color dipole model
- Comparison with the LHC data and predictions for the Run 2 energies

LHC = Photon collider

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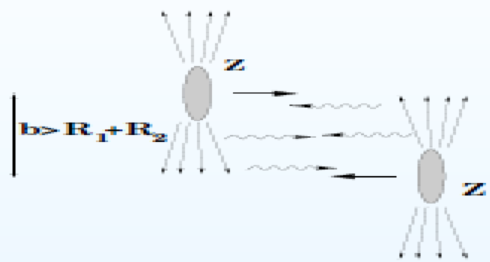


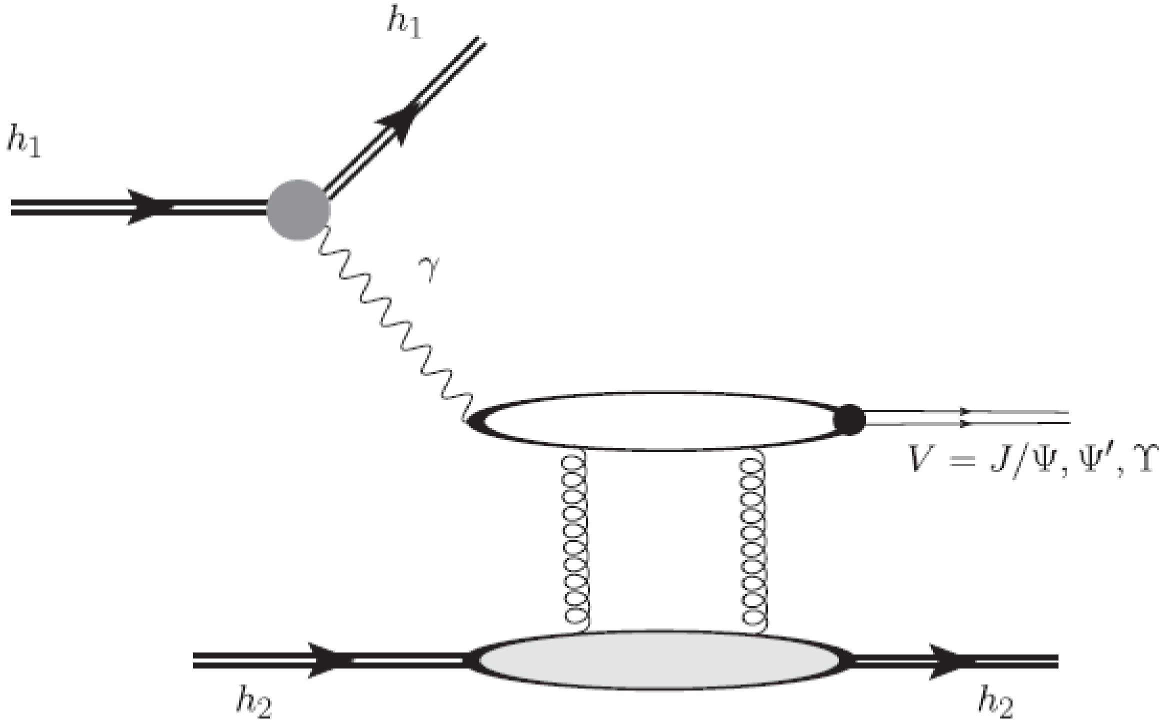
1. γh Processes: $\sigma(h_1 h_2 \to X) = n_h(\omega) \otimes \sigma^{\gamma h \to X}(W_{\gamma h})$
2. $\gamma\gamma$ Processes: $\sigma(h_1 h_2 \to X) = n_1(\omega) \otimes n_2(\omega) \otimes \sigma^{\gamma\gamma \to X}(W_{\gamma\gamma})$

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.

Exclusive vector meson photoproduction at the LHC



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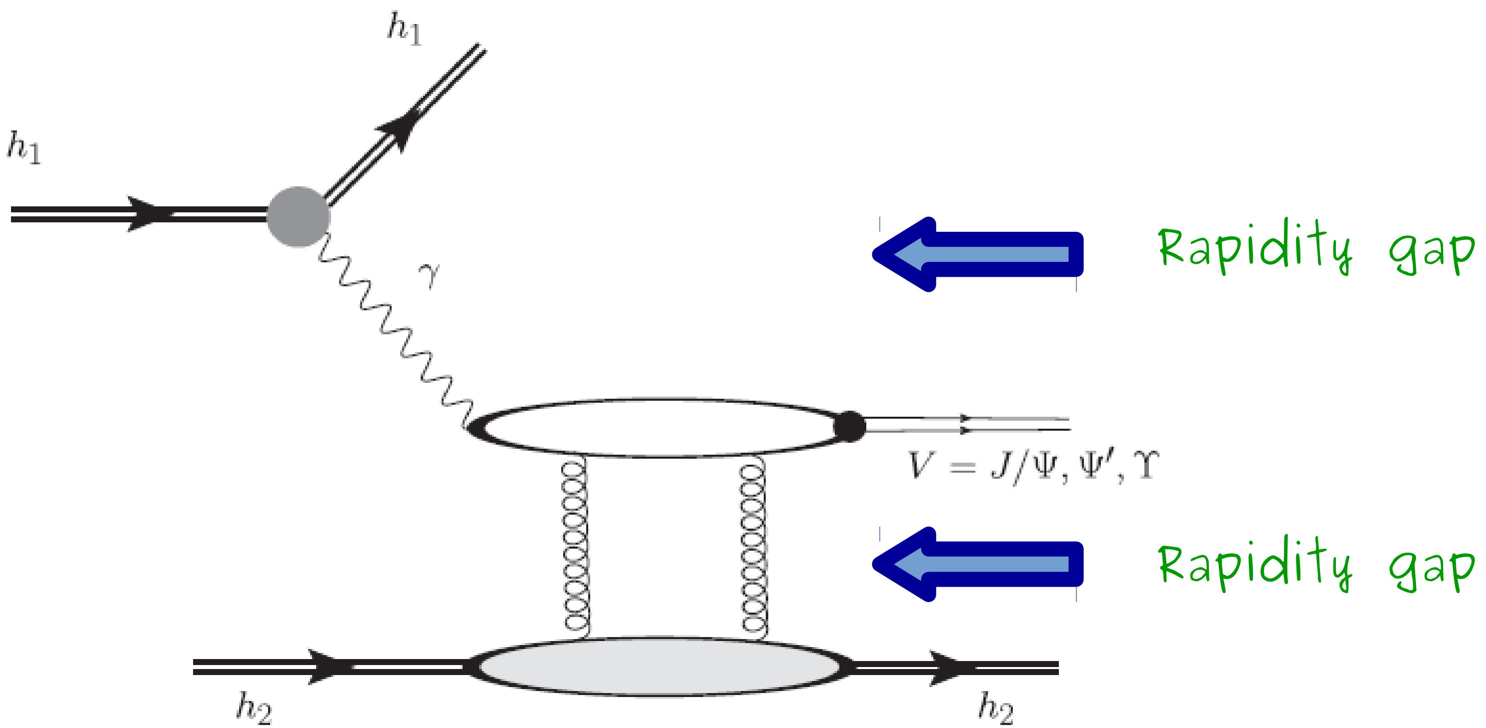

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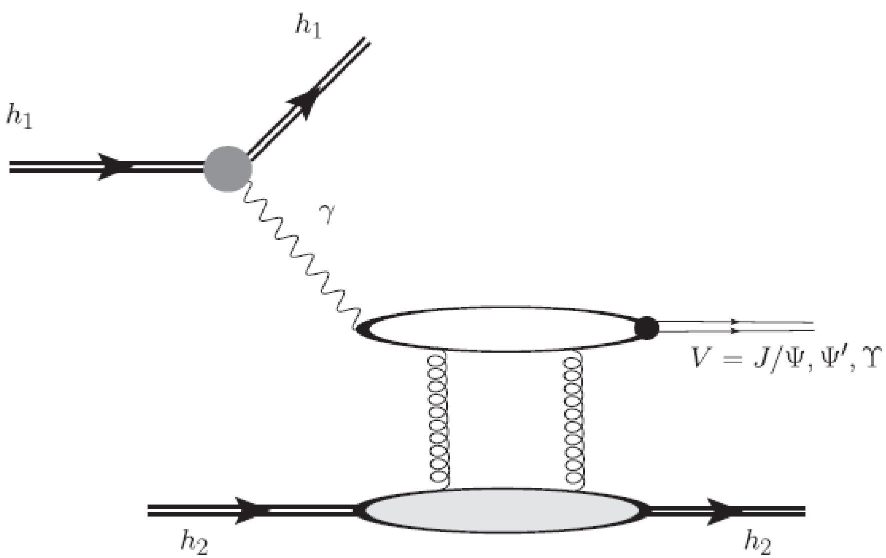


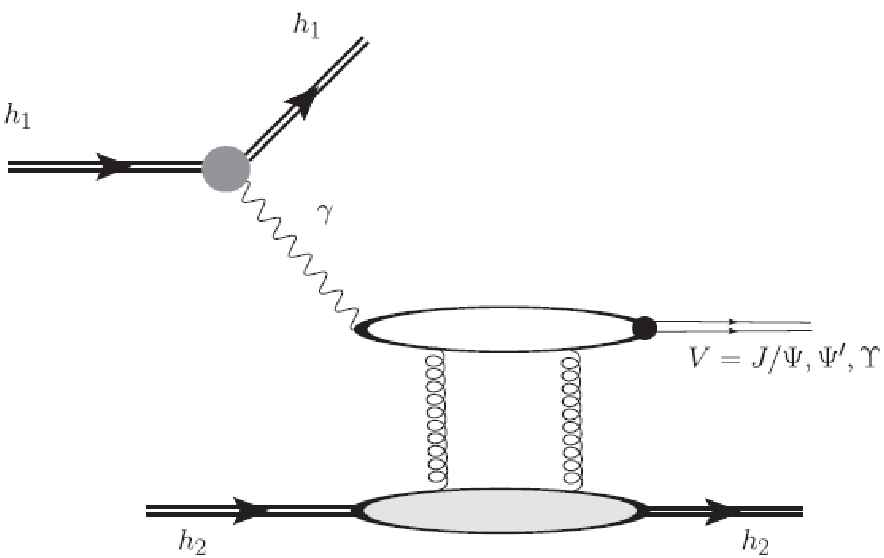
At leading order in LL(1/x) approx.:

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

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

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

Exclusive vector meson photoproduction at the LHC



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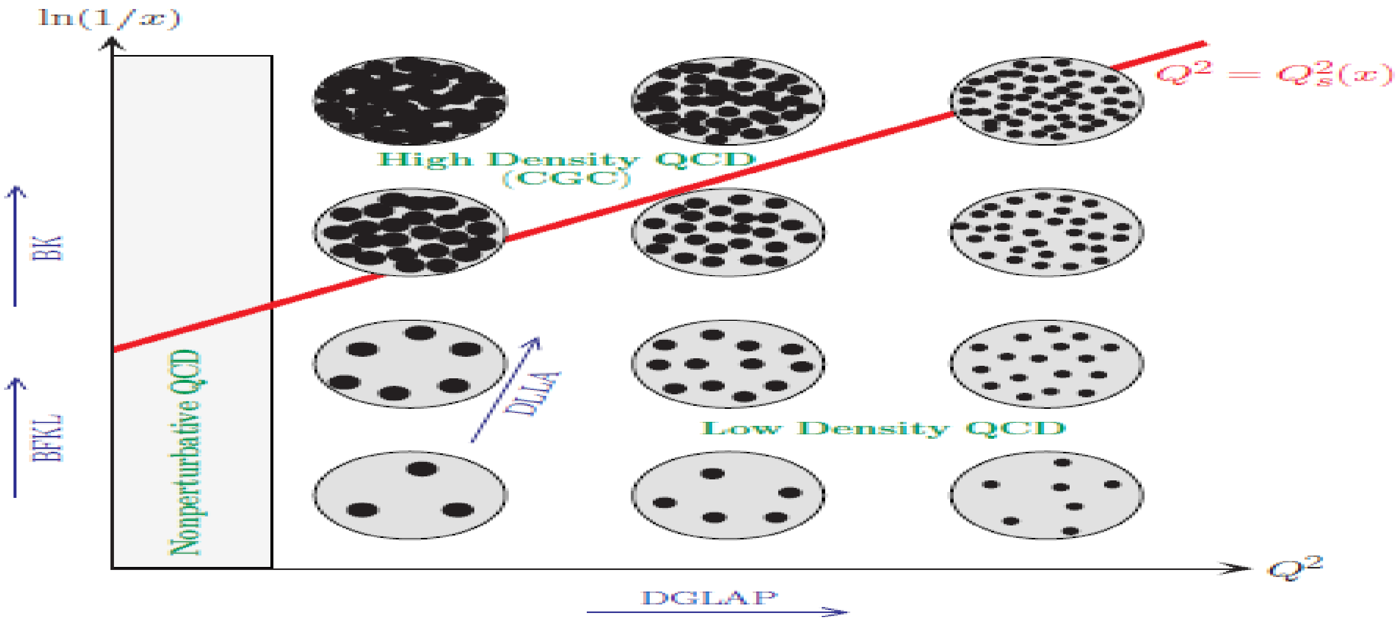
Important probe of the QCD dynamics at high energies!

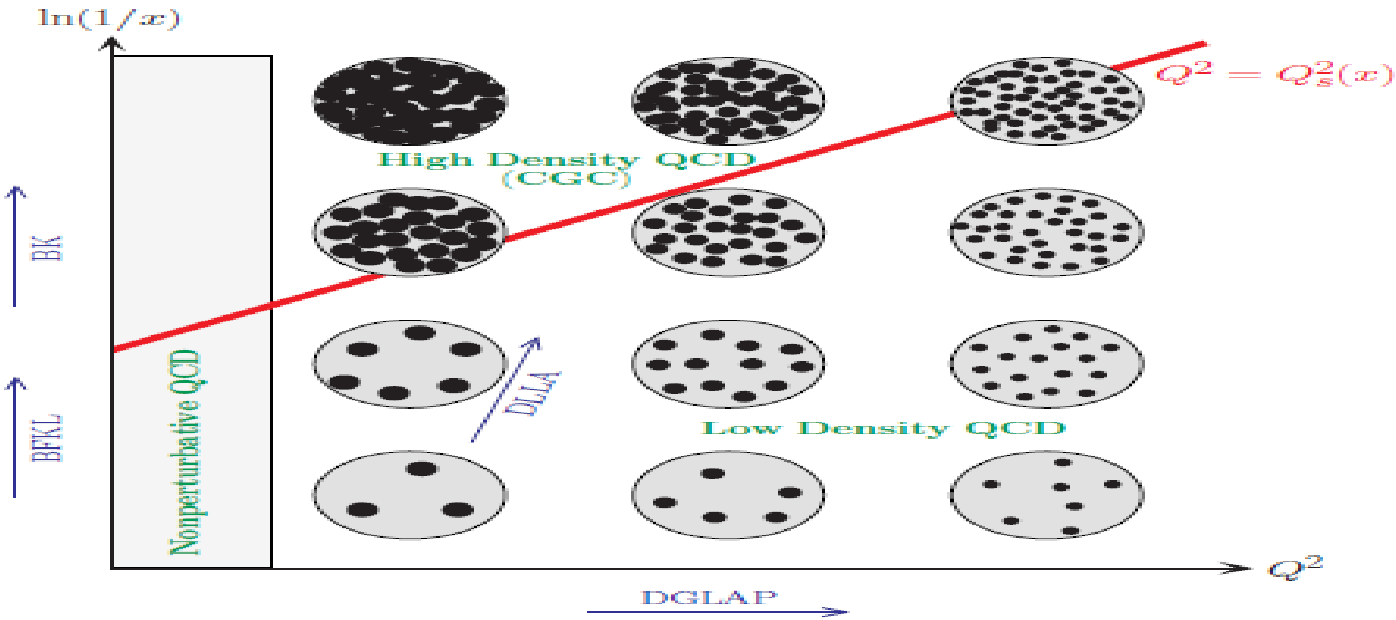
[a]VPG, Bertulani, PRC65, 054905 (2002)

QCD dynamics at high energies



- Linear QCD Evolution equations predict a power growth of gluon distribution at small $-x$;

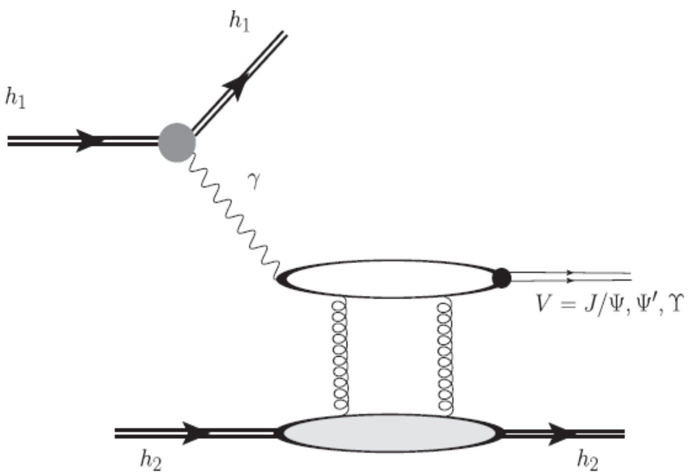
QCD dynamics at high energies



- Linear QCD Evolution equations predict a power growth of gluon distribution at small −x;
- Number of gluons in the hadron becomes só large that gluon recombine. Nonlinear effects should be taken into account.

Exclusive vector meson photoproduction in UPHIC: Color Dipole Formalism

$$\frac{d\sigma\,[h_1 + h_2 \to h_1 \otimes V \otimes h_2]}{d^2b dy} = \left[\omega N_{h_1}(\omega, b)\, \sigma_{\gamma h_2 \to V \otimes h_2}(\omega)\right]_{\omega_L} + \left[\omega N_{h_2}(\omega, b)\, \sigma_{\gamma h_1 \to V \otimes h_1}(\omega)\right]_{\omega_R}$$



$$\sigma(\gamma h \to V h) = \int_{-\infty}^{0} \frac{d\sigma}{dt}\, dt = \frac{1}{16\pi} \int_{-\infty}^{0} |\mathcal{A}_T^{\gamma h \to V h}(x, \Delta)|^2\, dt$$

$$\mathcal{A}_T^{\gamma h \to V h}(x, \Delta) = i \int dz\, d^2\boldsymbol{r}\, d^2\boldsymbol{b}_h e^{-i[\boldsymbol{b}_h - (1-z)\boldsymbol{r}].\boldsymbol{\Delta}}\ (\Psi^{V*}\Psi)_T\ 2\mathcal{N}_h(x, \boldsymbol{r}, \boldsymbol{b}_h)$$

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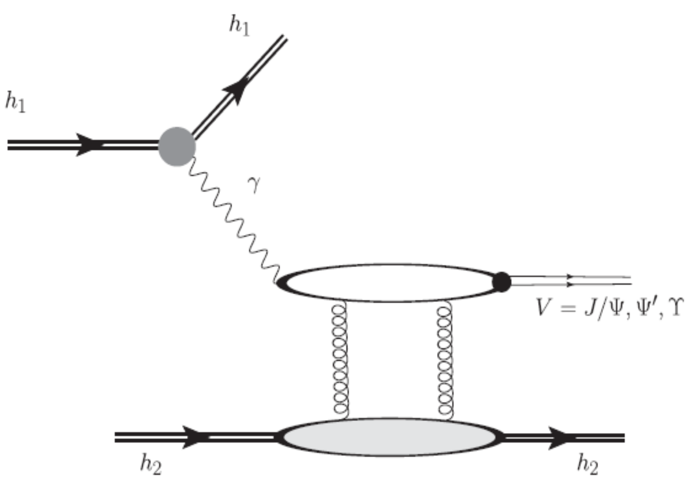

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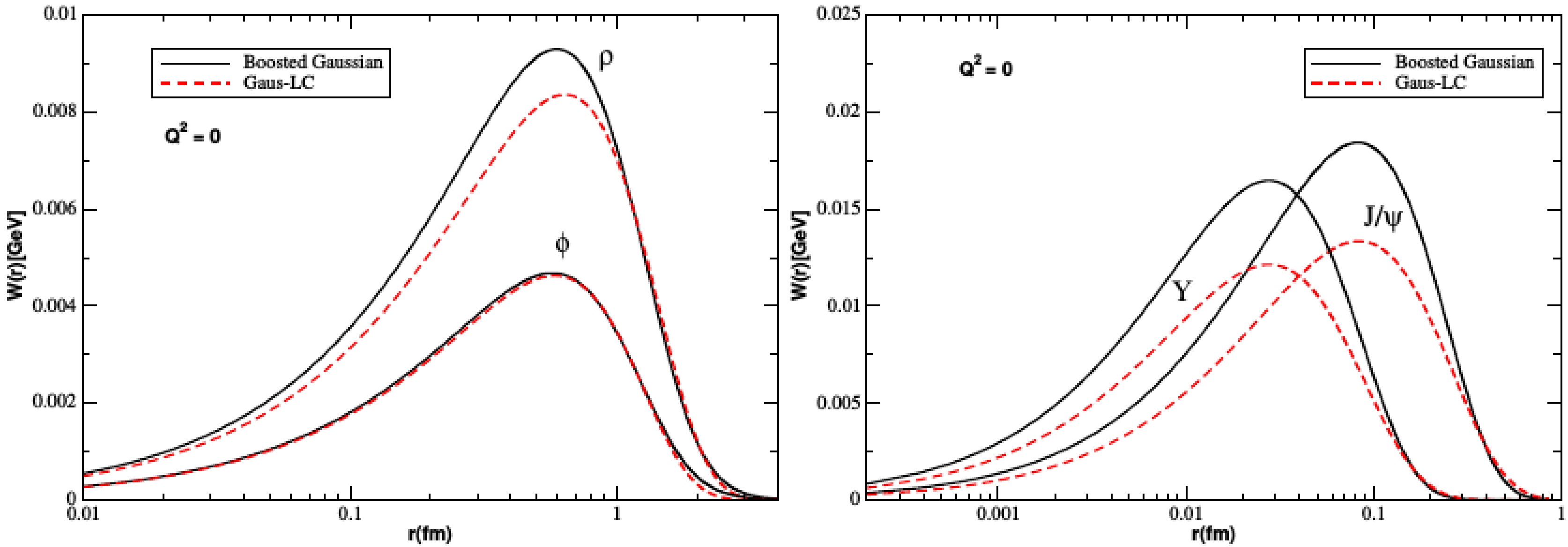
Overlap function for Vector Mesons

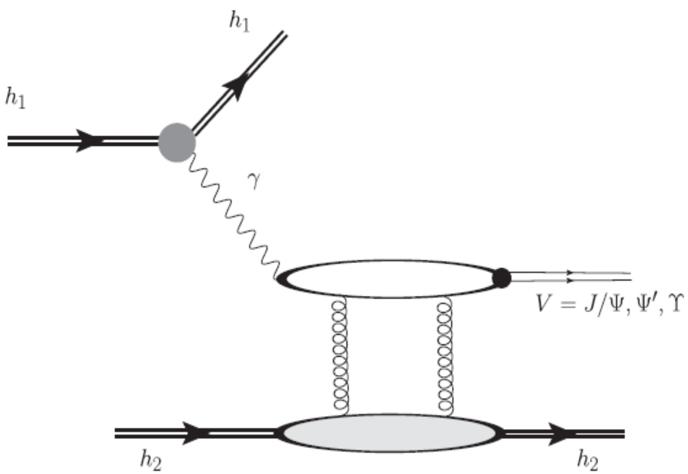
Exclusive vector meson photoproduction in UPHIC: Color Dipole Formalism

$$W(\boldsymbol{r}) = 2\pi r \int_0^1 dz \left[\Psi^{V*}(\boldsymbol{r}, z)\Psi(\boldsymbol{r}, z)\right]$$



Exclusive vector meson photoproduction in UPHIC: Color Dipole Formalism

$$\frac{d\sigma\left[h_1+h_2\to h_1\otimes V\otimes h_2\right]}{d^2bdy}=\left[\omega N_{h_1}(\omega,b)\,\sigma_{\gamma h_2\to V\otimes h_2}\left(\omega\right)\right]_{\omega_L}+\left[\omega N_{h_2}(\omega,b)\,\sigma_{\gamma h_1\to V\otimes h_1}\left(\omega\right)\right]_{\omega_R}$$



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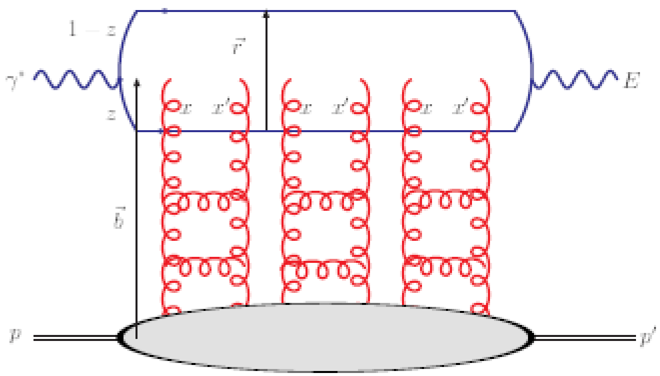
Forward dipole - hadron scattering amplitude: Determined by the QCD dynamics

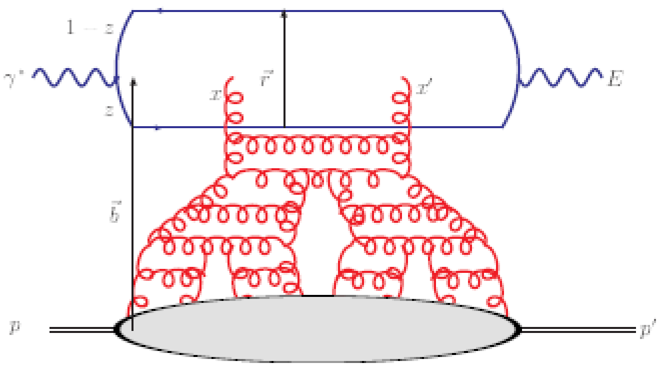
Diffractive vector meson photoproduction in UPHIC: Color Dipole Formalism

* IP – SAT model:



"Classical" CGC model.

* bCGC model:



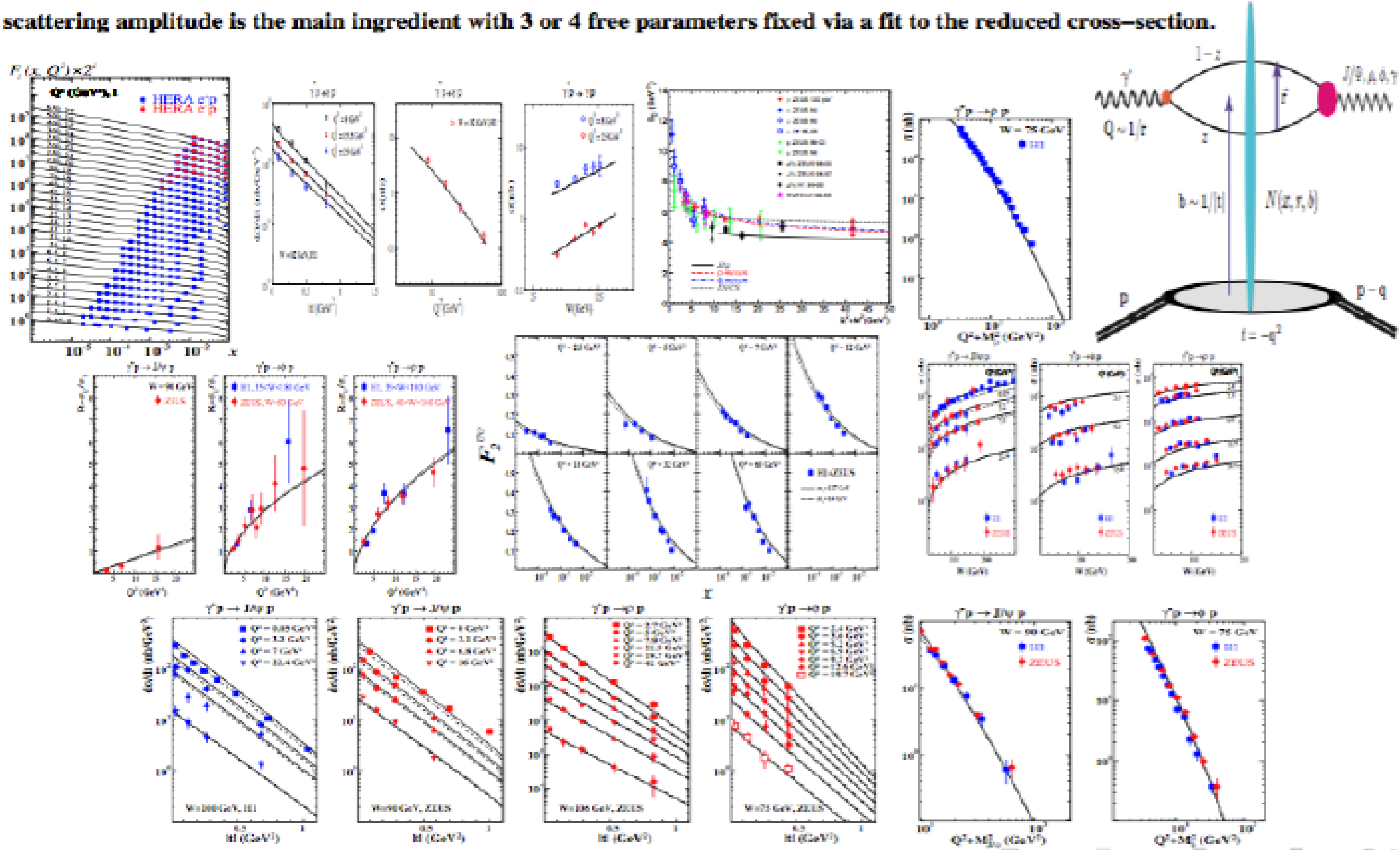
"Quantum" CGC model.

Important: Both models describe quite well the HERA ep data.

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

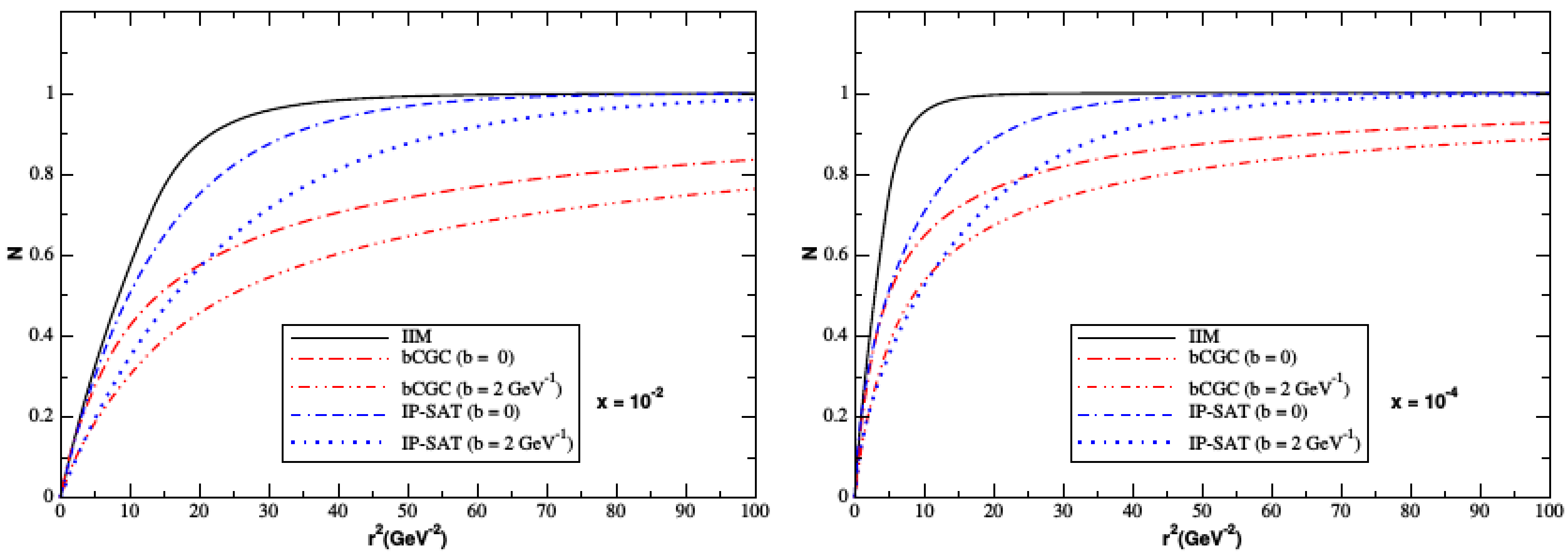
The dipole scattering amplitude is the main ingredient with 3 or 4 free parameters fixed via a fit to the reduced cross–section.



Rezaeian, INT workshop '17

Diffractive vector meson photoproduction in UPHIC: Color Dipole Formalism

Dipole - proton scattering amplitude:



The transition between the linear (small - r) and nonlinear (large - r) is distinct in the different models.

Diffractive vector meson photoproduction in UPHIC: Color Dipole Formalism

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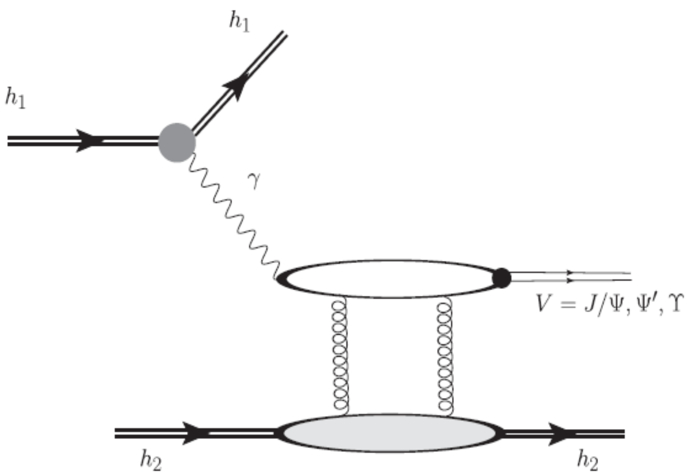

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- Nucleus: $\mathcal{N}_A(x, \boldsymbol{r}, \boldsymbol{b}_A) = 1 - \exp\left[-\frac{1}{2}\sigma_{dp}(x, \boldsymbol{r}^2)\, T_A(\boldsymbol{b}_A)\right]$ Sums all multiple elastic rescatterings of the dipole.

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

Diffractive vector meson photoproduction in UPHIC: Color Dipole Formalism

Dipole - nucleus scattering amplitude:

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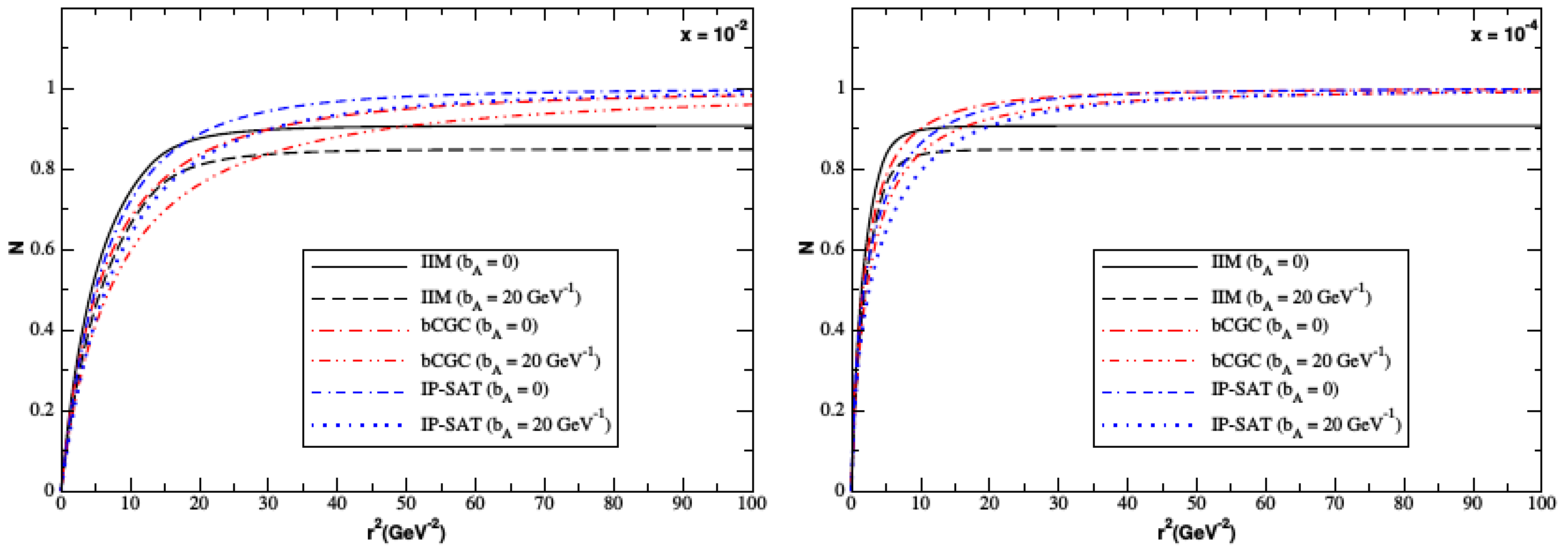

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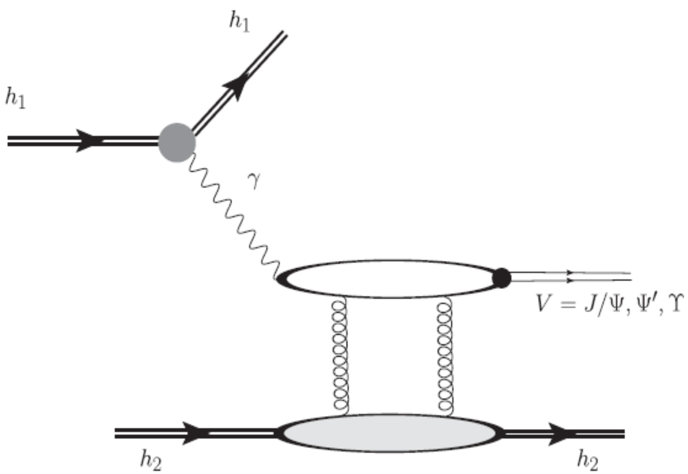

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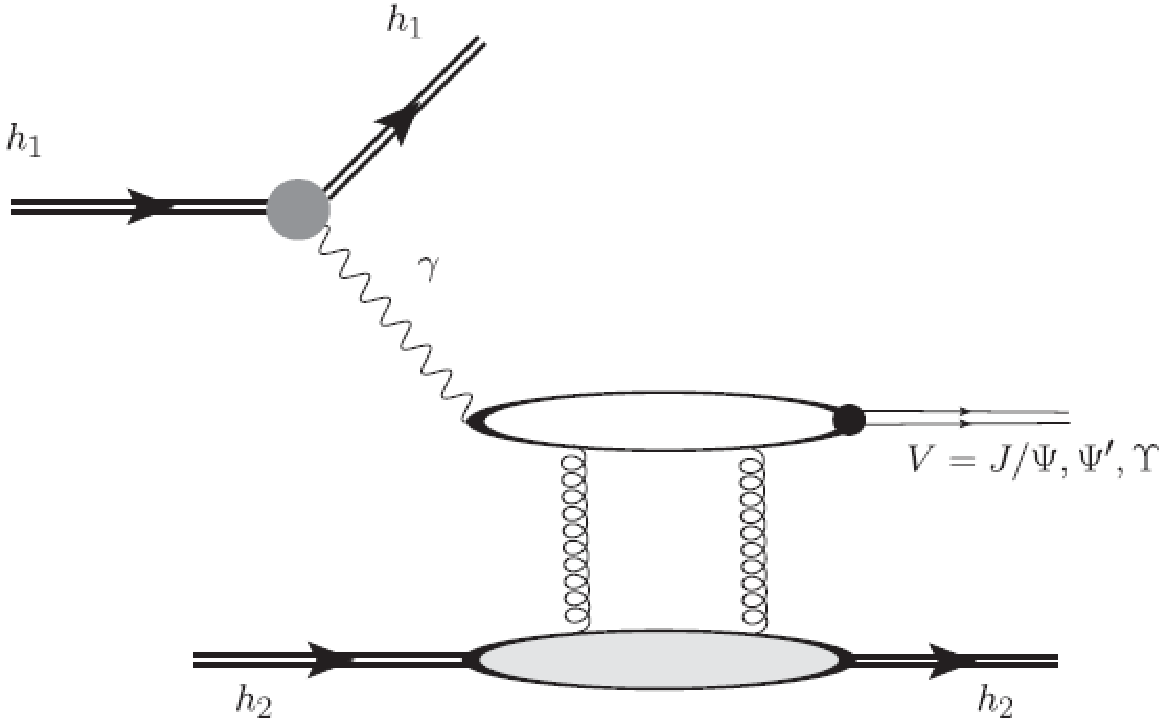
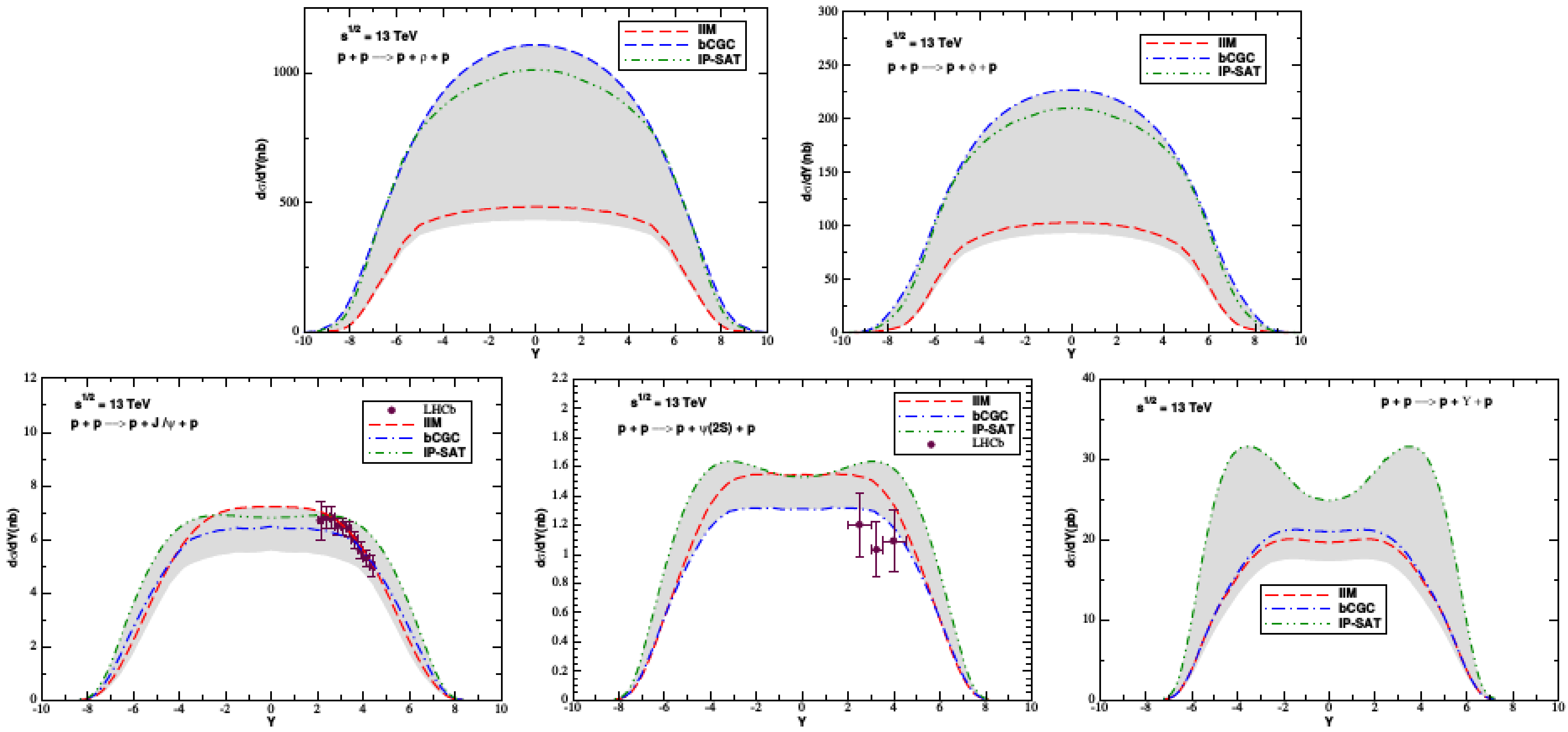
In the dipole picture, all free parameters have been constrained by HERA data. Predictions for UPHIC are parameter free!

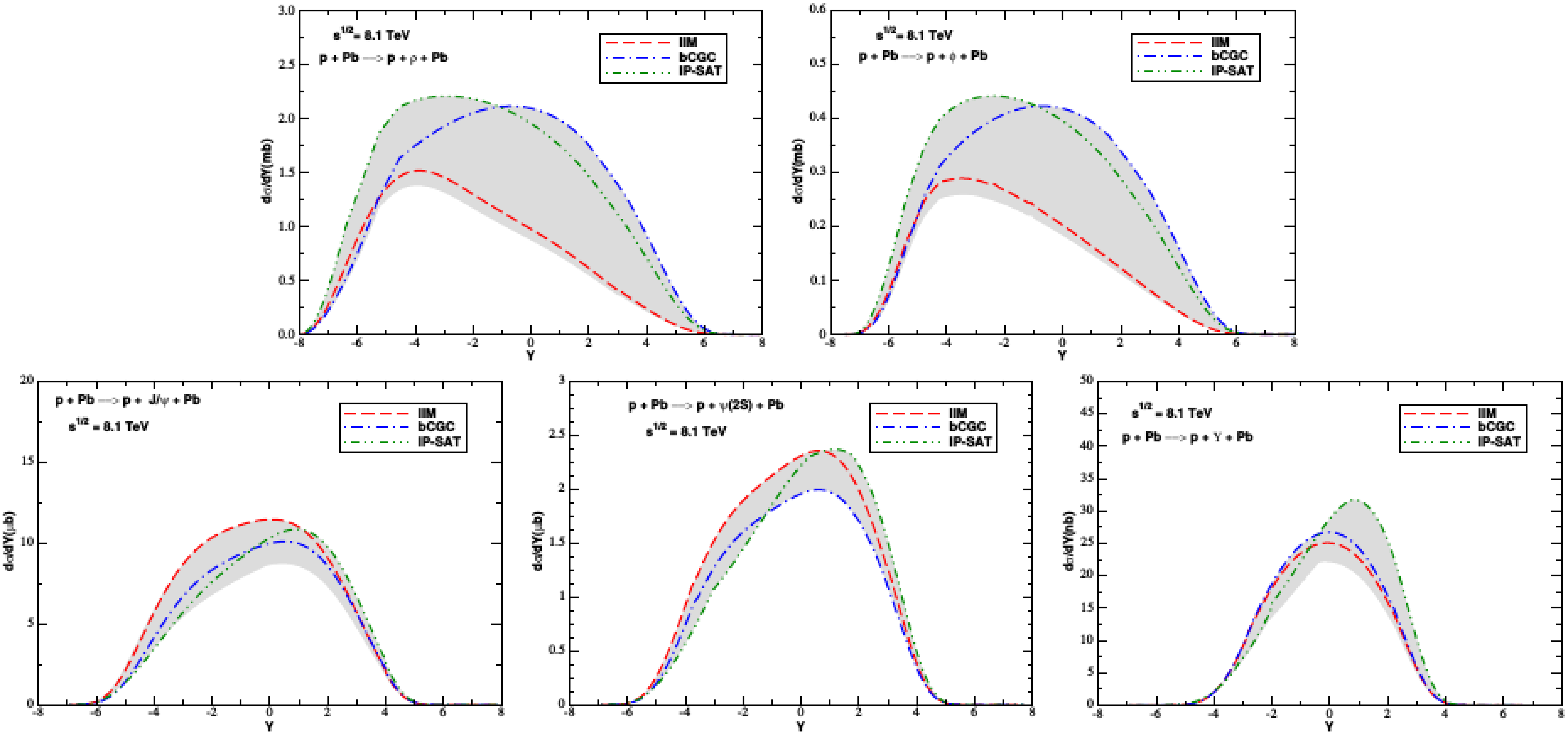
Exclusive vector meson photoproduction at the LHC: Comparison to the data and predictions for the Run 2



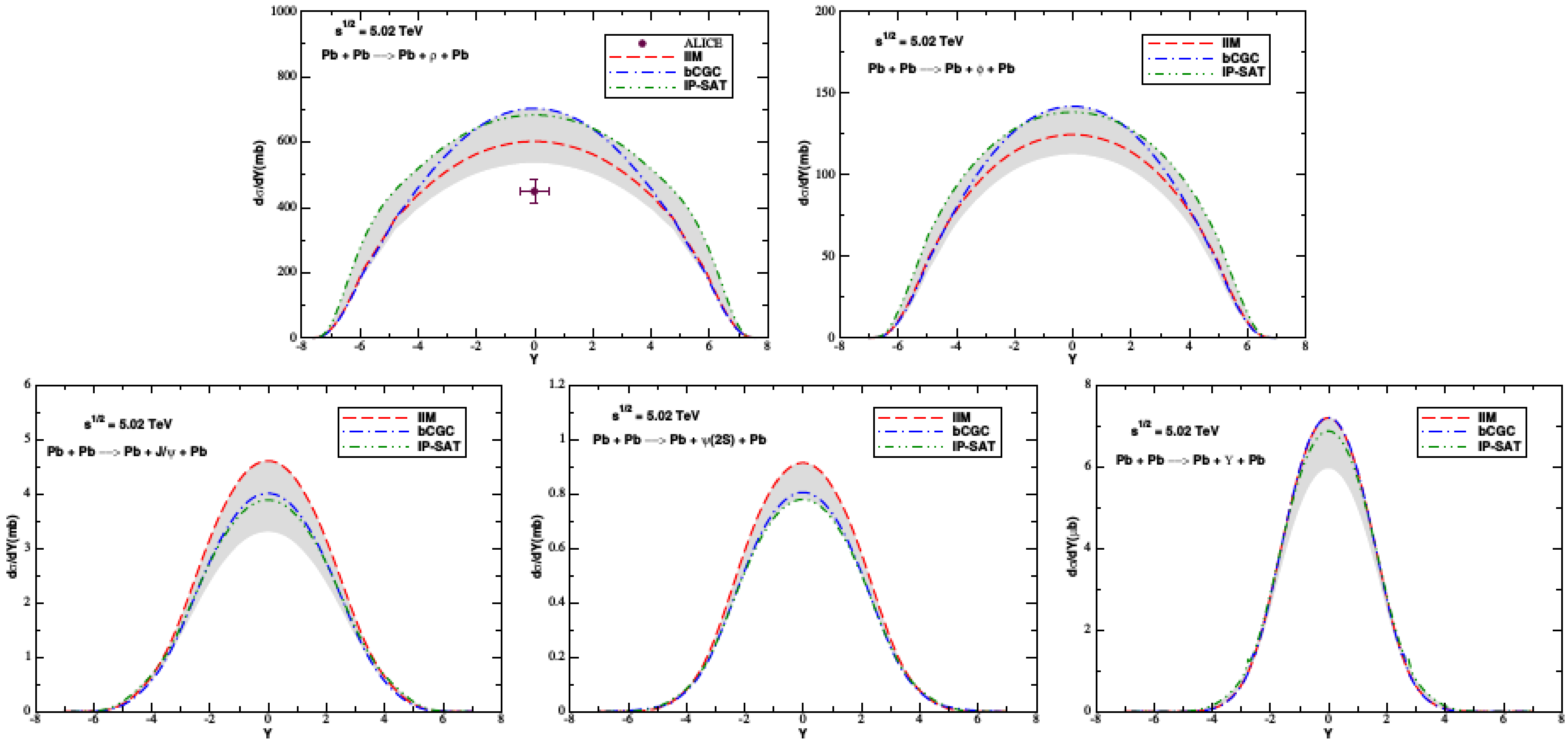
Predictions for pp collisions



Predictions for pPb collisions



Predictions for PbPb collisions



Open questions:

- ✓ Validity of the dipole picture for the light meson photoproduction;
- ✓ Modelling of the gap survival probability for the exclusive vector meson photoproduction;
- ✓ Treatment of the skeweness in the nucleon and nuclear case;
- ✓ Inclusion of QCD evolution in the nuclear scattering amplitude;
- ✓ Inclusion of the next – to – leading order corrections for the vector meson wave functions and nonlinear evolution;

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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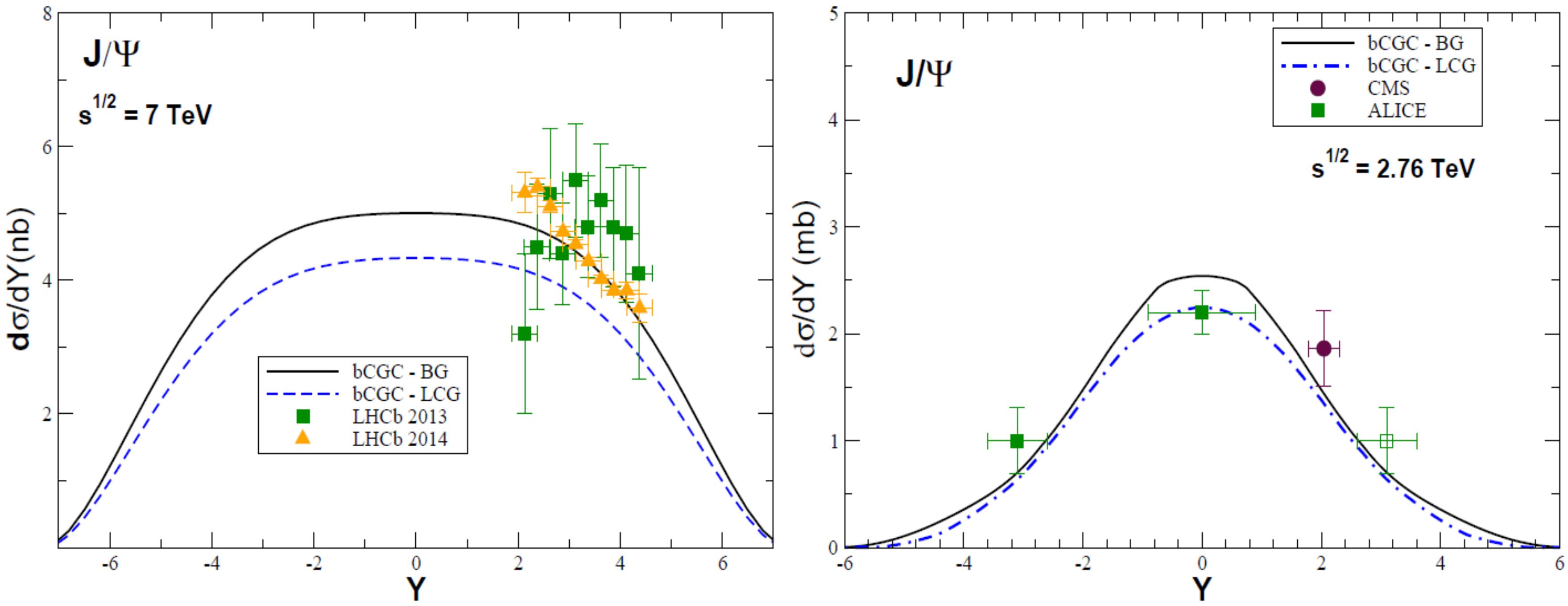
Thank you for your attention!

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

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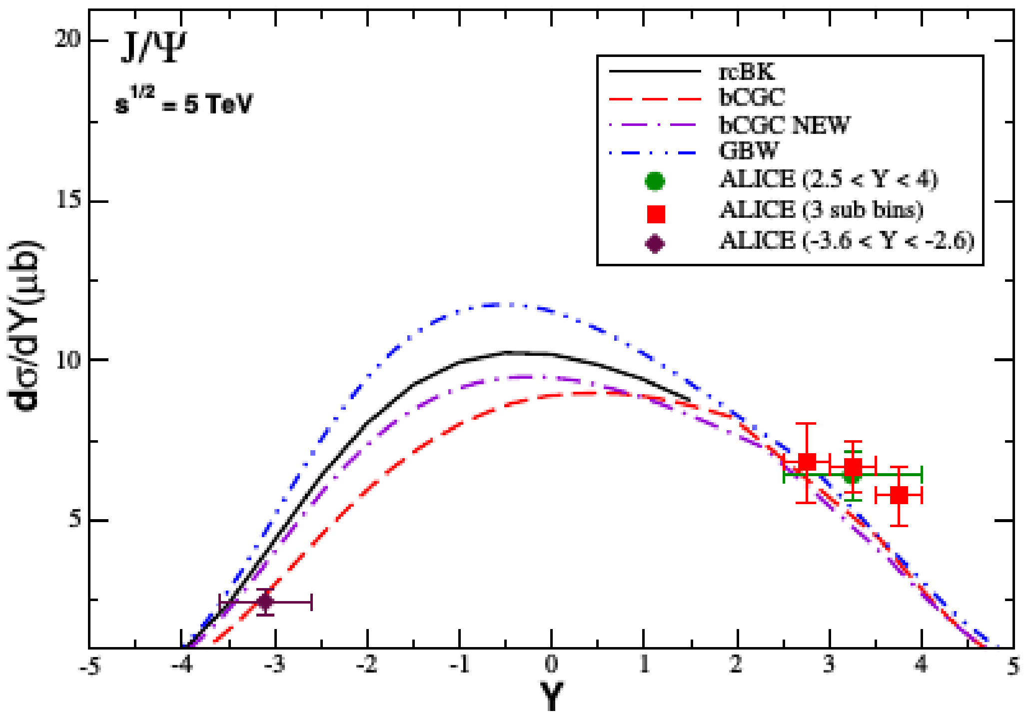
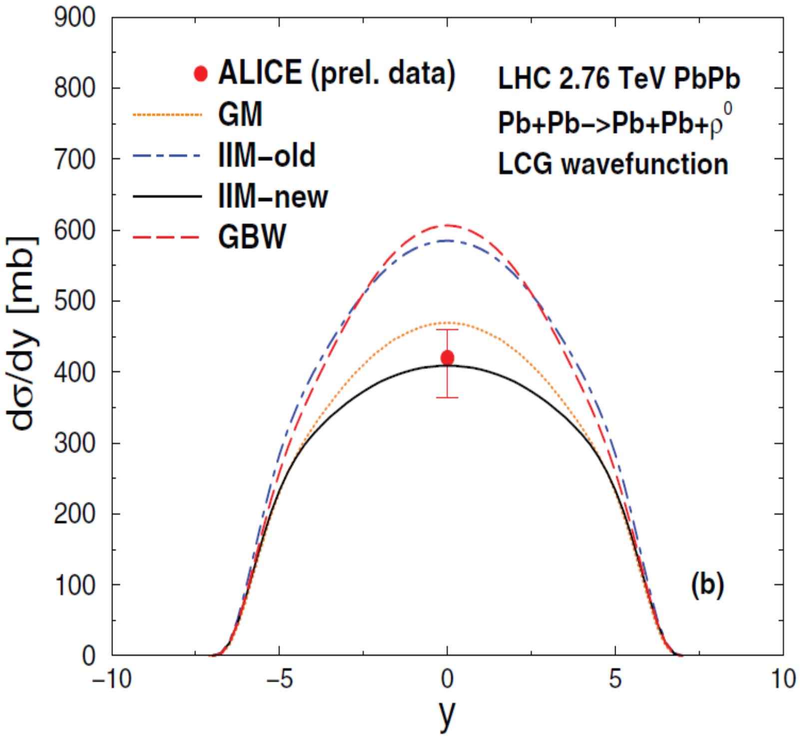
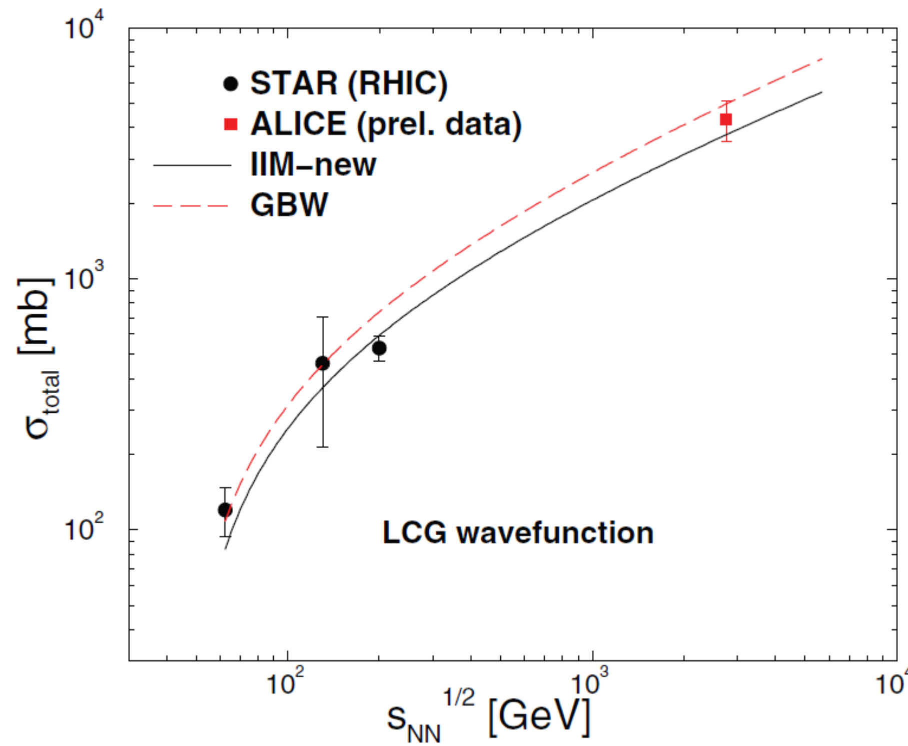


Comparison with the Run I data

- Diffractive ρ photoproduction in hadronic collisions [c]

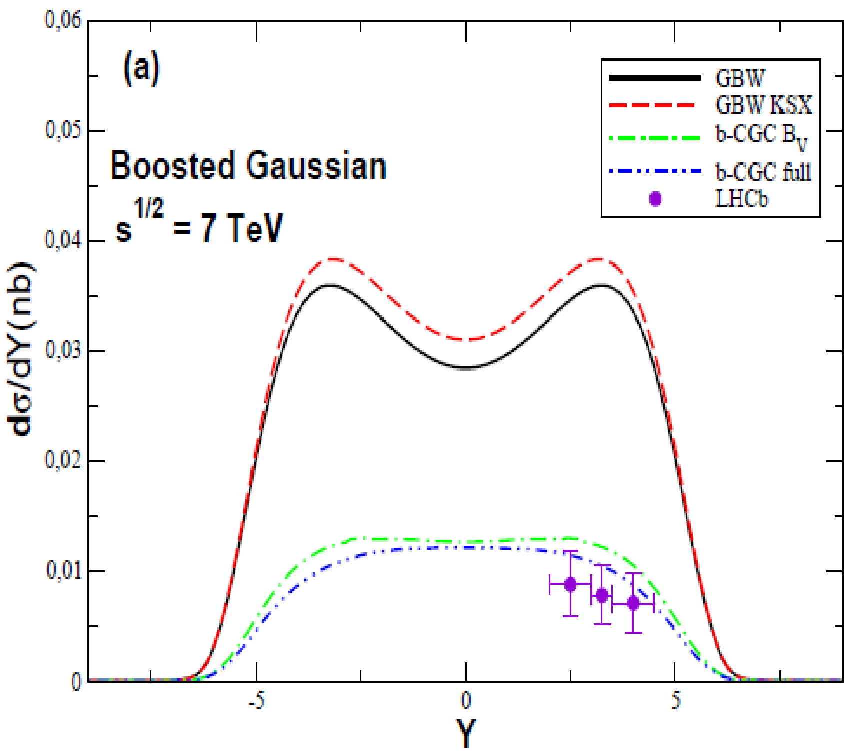


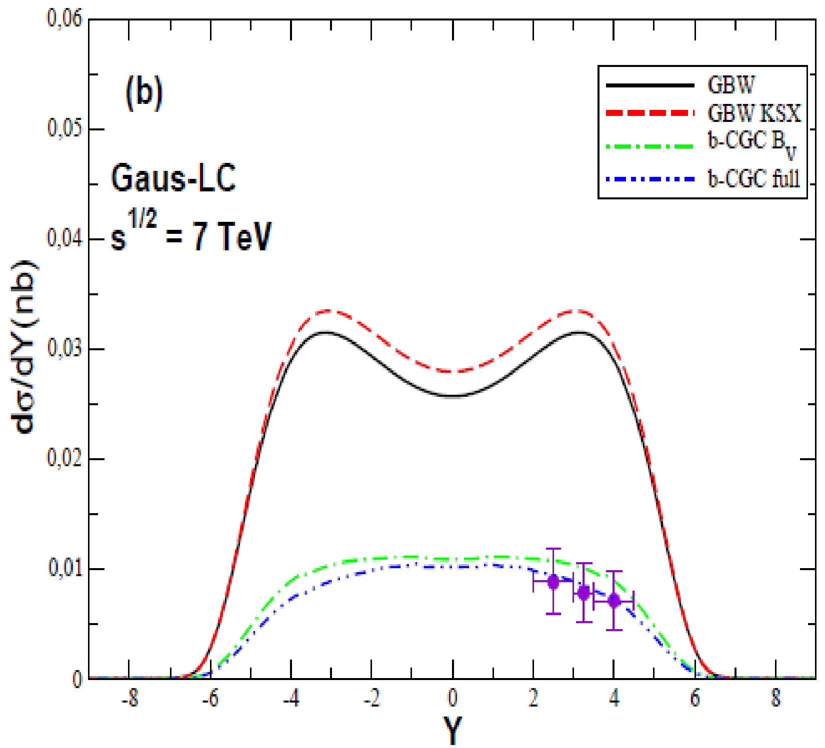


(c) VPG, Machado, EPJC 40, 519 (2005); PRC80, 054901 (2009); PRC84, 011902 (2011); Machado, dos Santos, PRC91, 025203 (2015)

Comparison with the Run I data

- Diffractive Υ photoproduction in hadronic collisions [b]





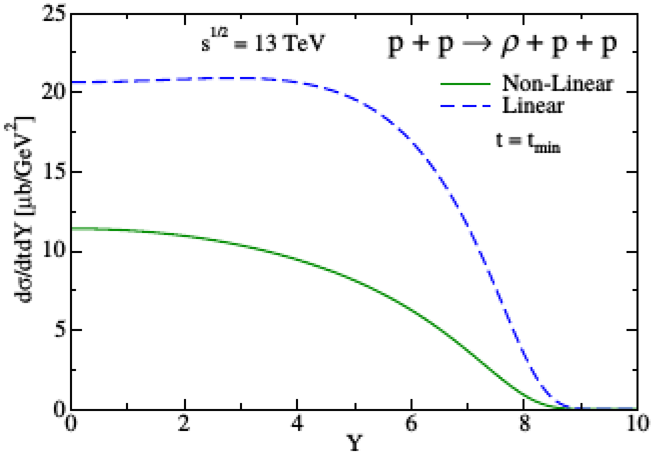
[b] VPG, Moreira, Navarra, PLB 472, 172 (2015)

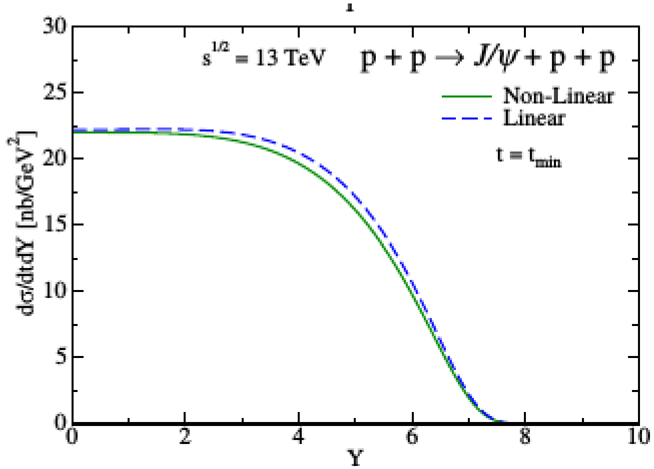
Diffractive vector meson photoproduction in UPHIC: Impact of the gluon saturation effects

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

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

pp Collisions:





$$t_{min} = -m_N^2 M_V^4 / W^4$$

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

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

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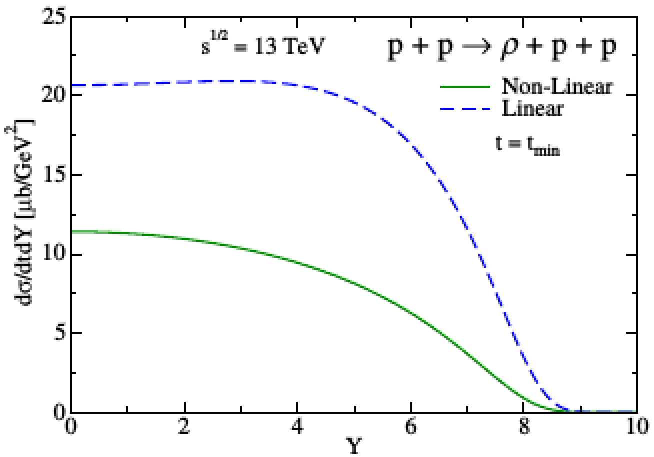
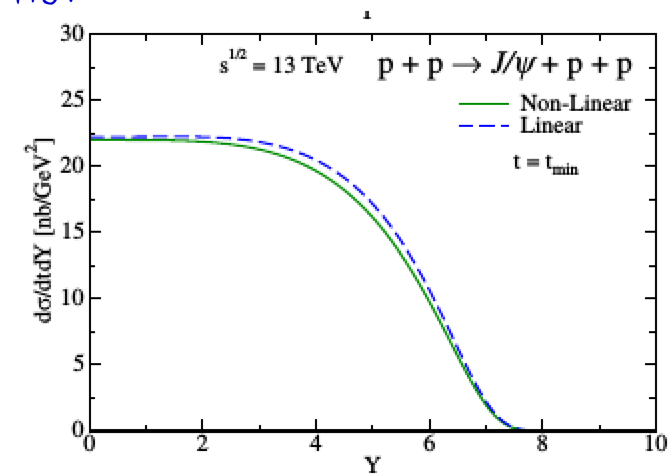
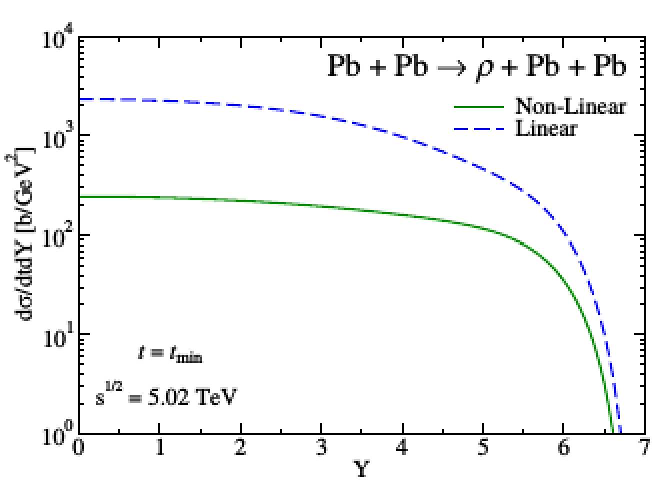
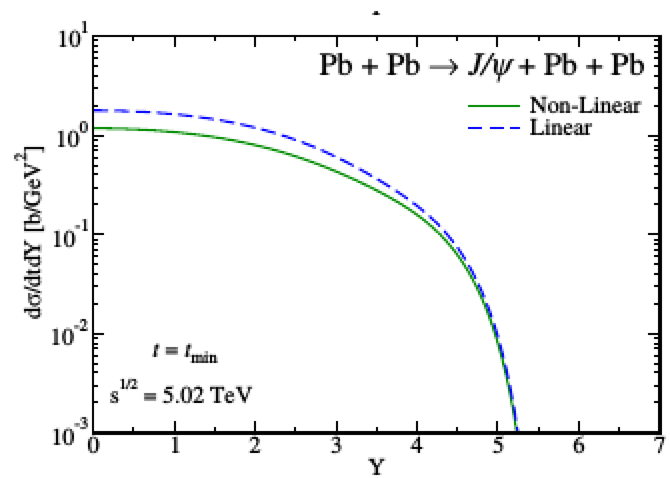




PbPb Collisions:





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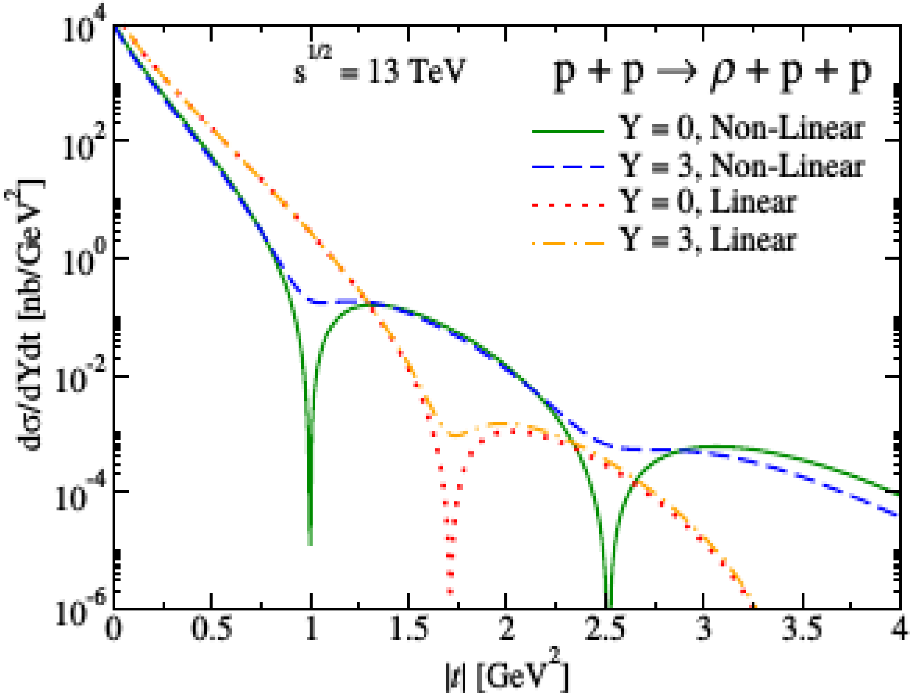
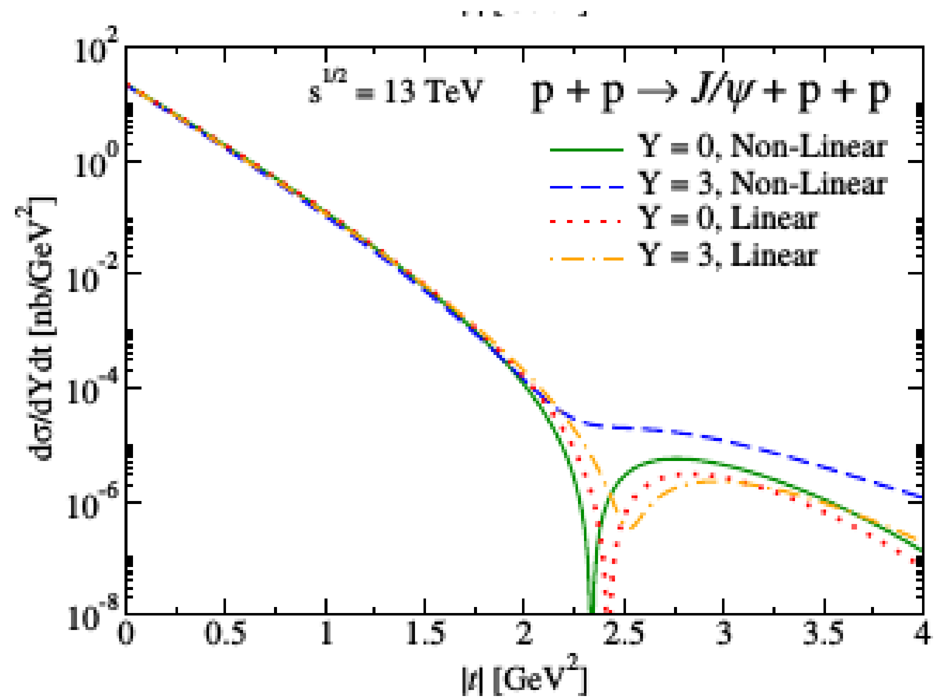




Linear model:

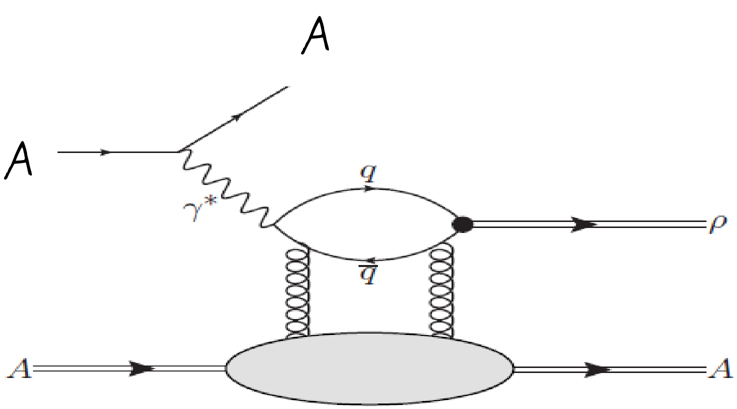
$$\mathcal{N}^p(x, \boldsymbol{r}, \boldsymbol{b}_p) = \mathcal{N}_0 \left(\frac{r\, Q_s(b_p)}{2}\right)^{2\left(\gamma_s + \frac{\ln(2/r\, Q_s(b_p))}{\kappa\, \lambda\, Y}\right)}$$

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

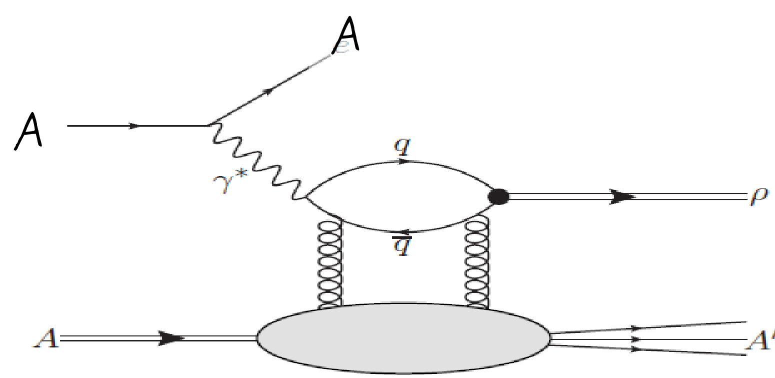
Diffractive vector meson photoproduction in UPHIC: Impact of the gluon saturation effects

PbPb Collisions:

Coherent production:



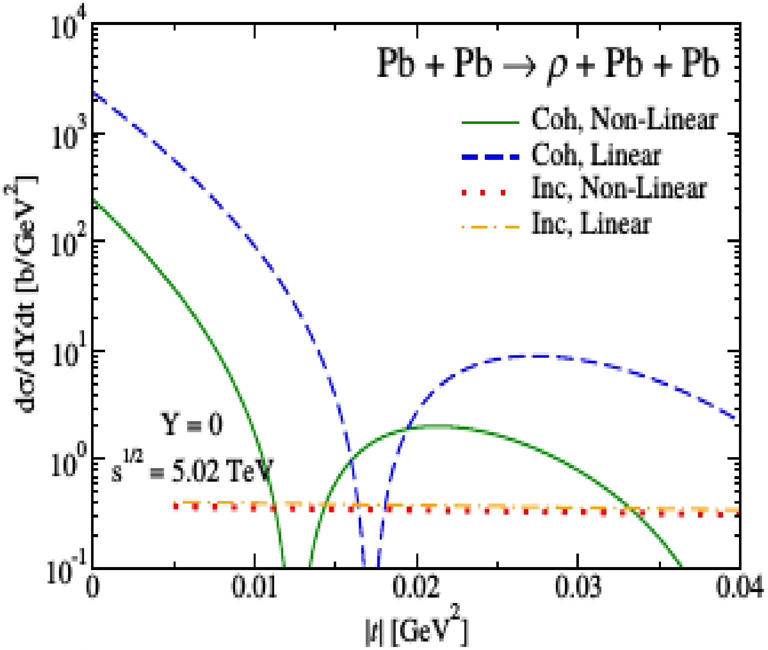
Incoherent production:

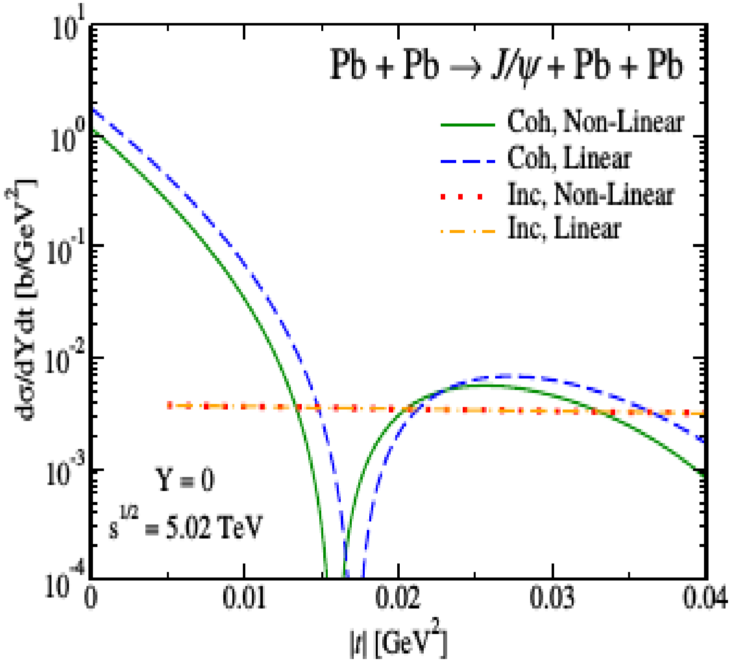


VPG, Spiering, Navarra, PLB 768, 299 (2017)

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

PbPb Collisions:





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)