New Physics Opportunities in Photon Induced interactions at the LHC

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High and Medium Energy Group

Physics and Mathematics Institute

UFPel - Brazil

Photon 2015 – BINP - Novosibirski
15 June 2015

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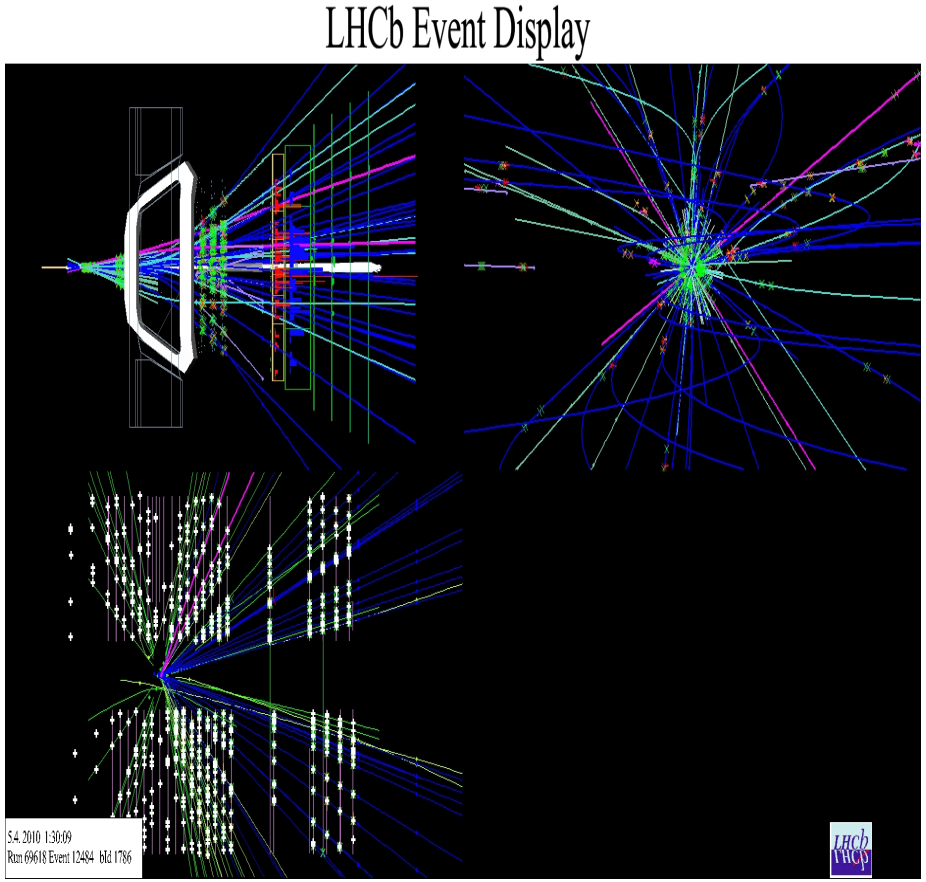
Typical *pp* events:



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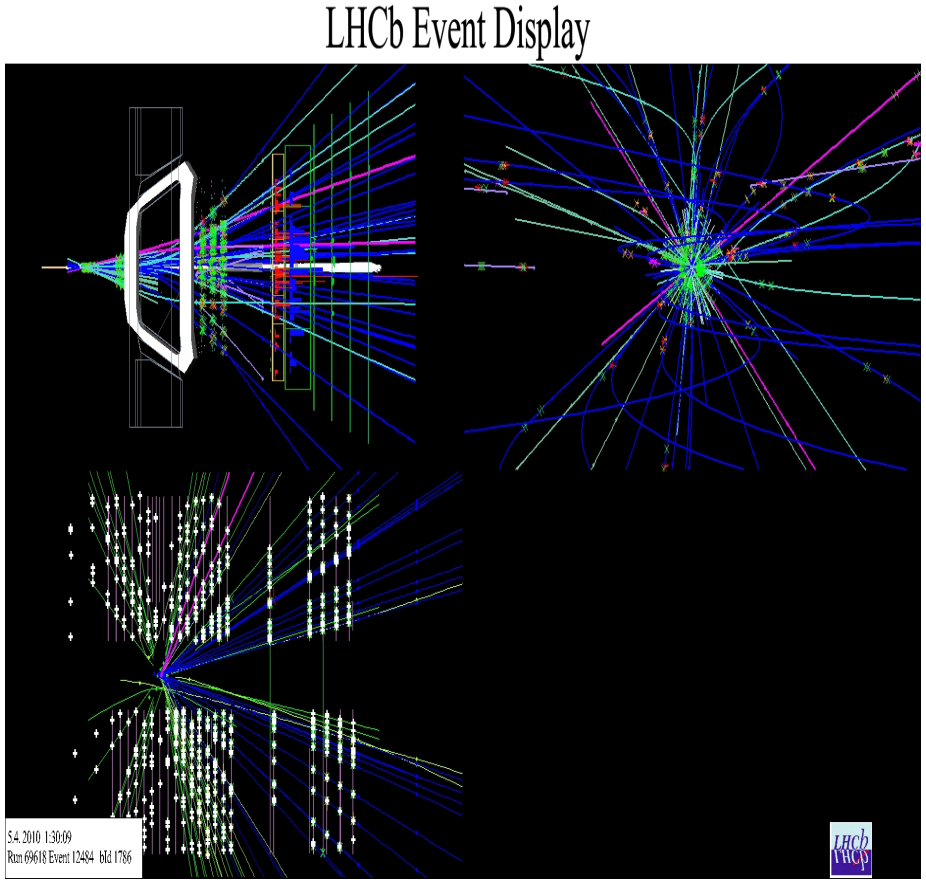

Many tracks + high pT particles

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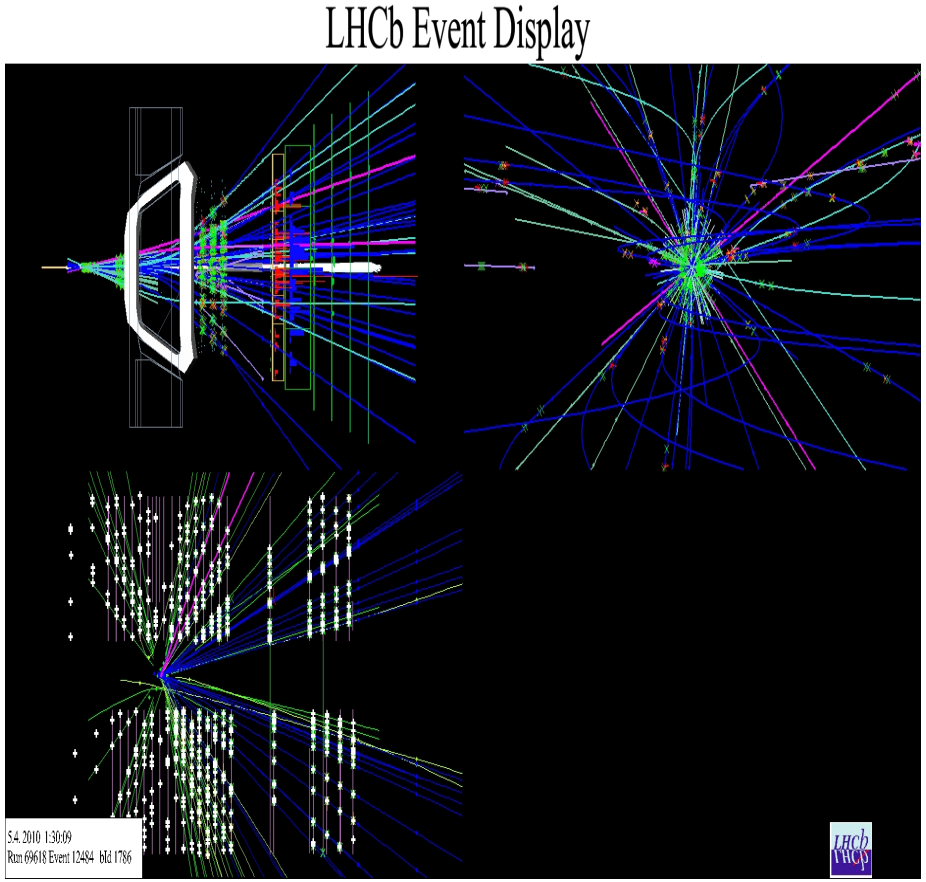

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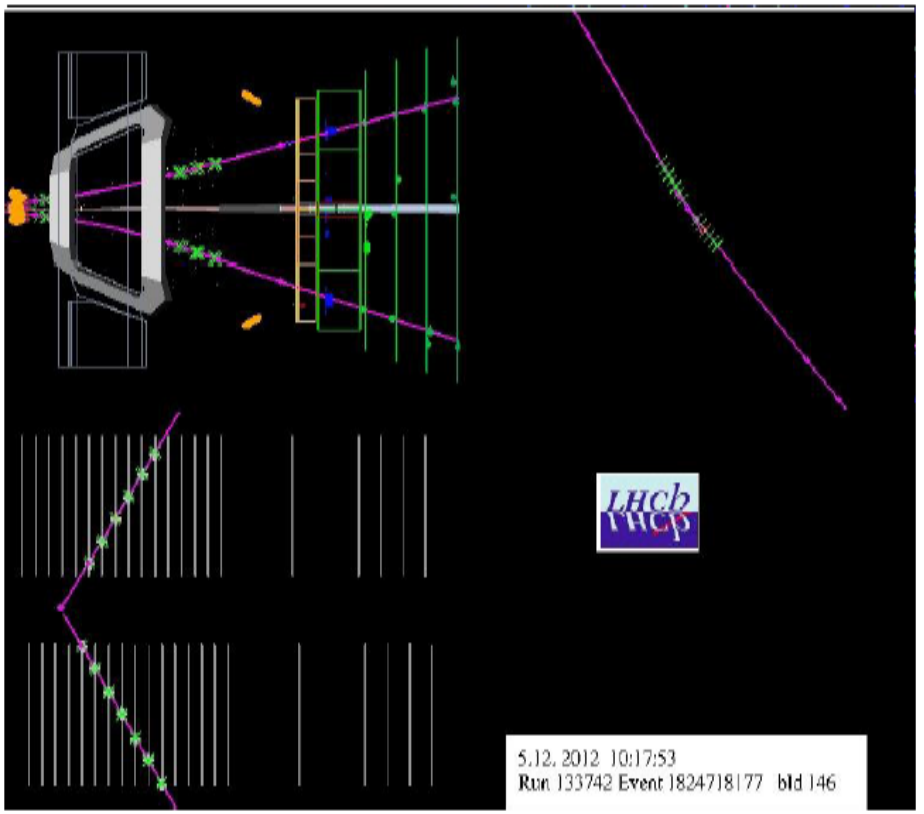

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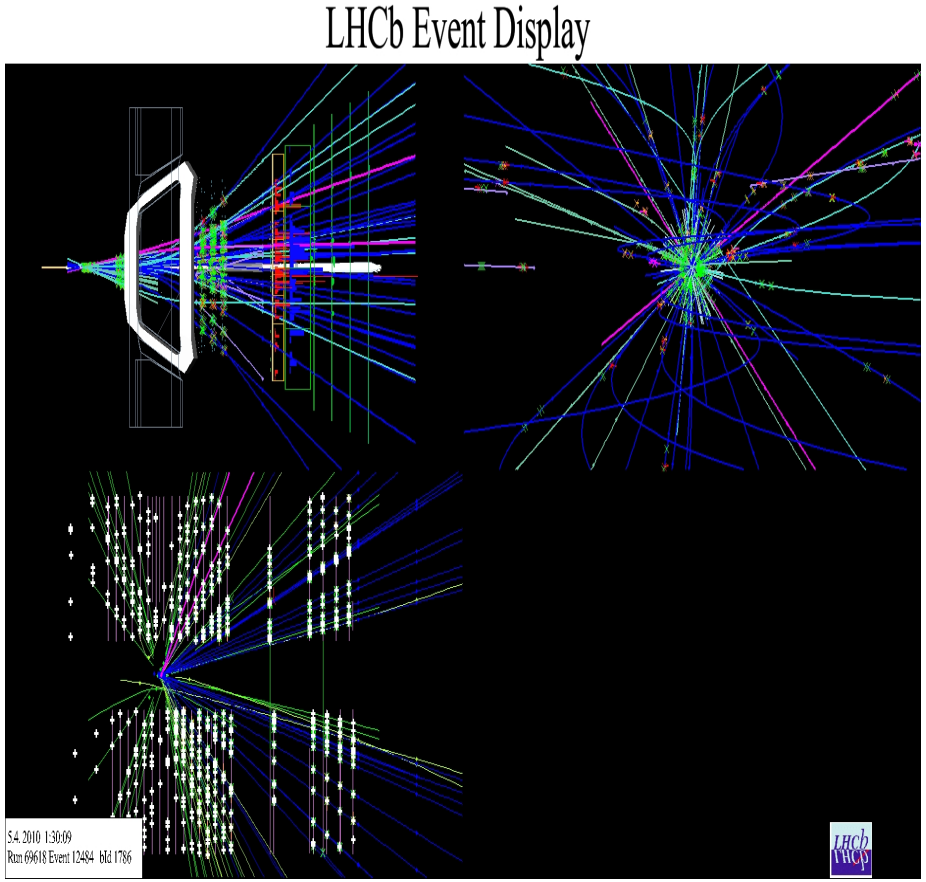

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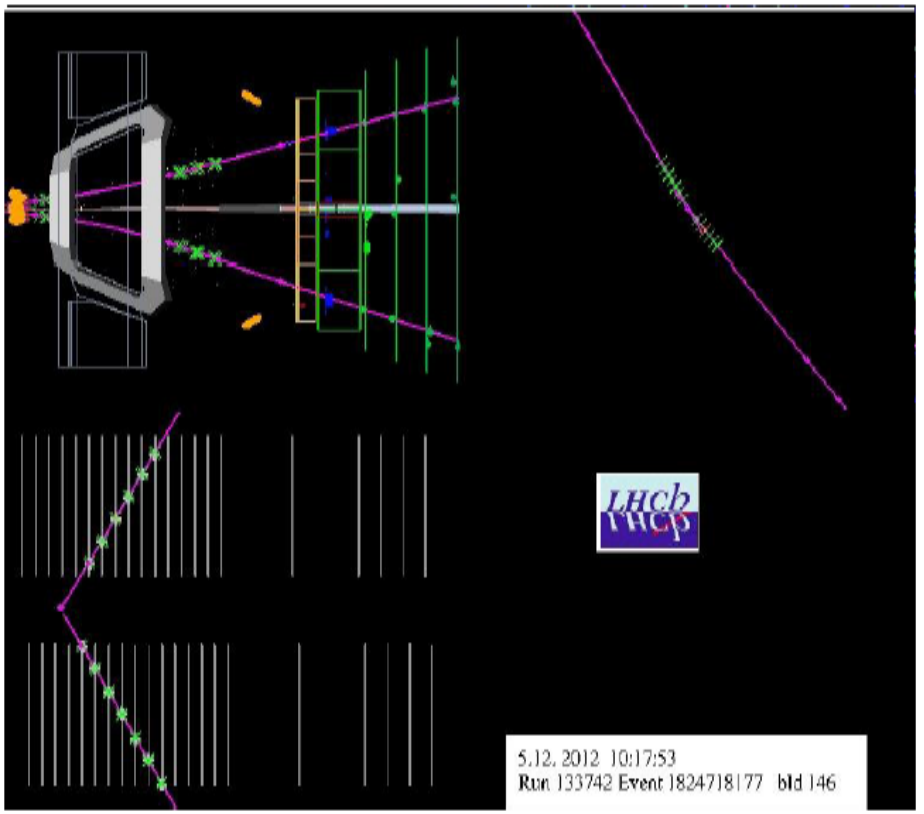

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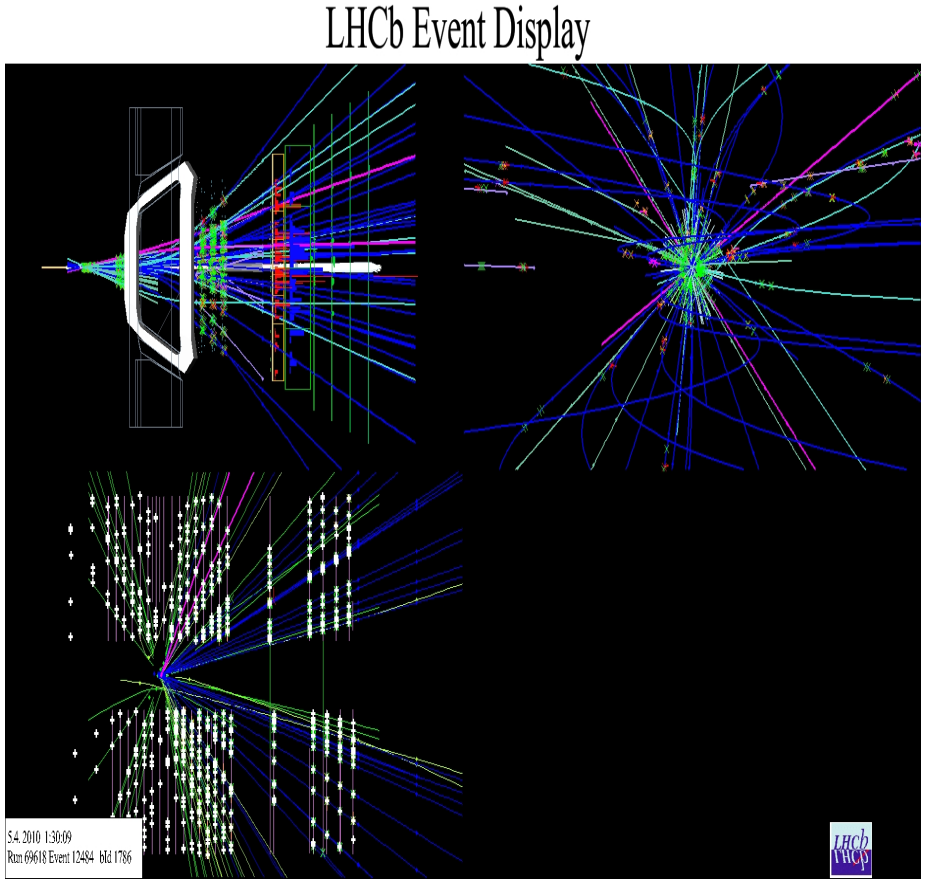

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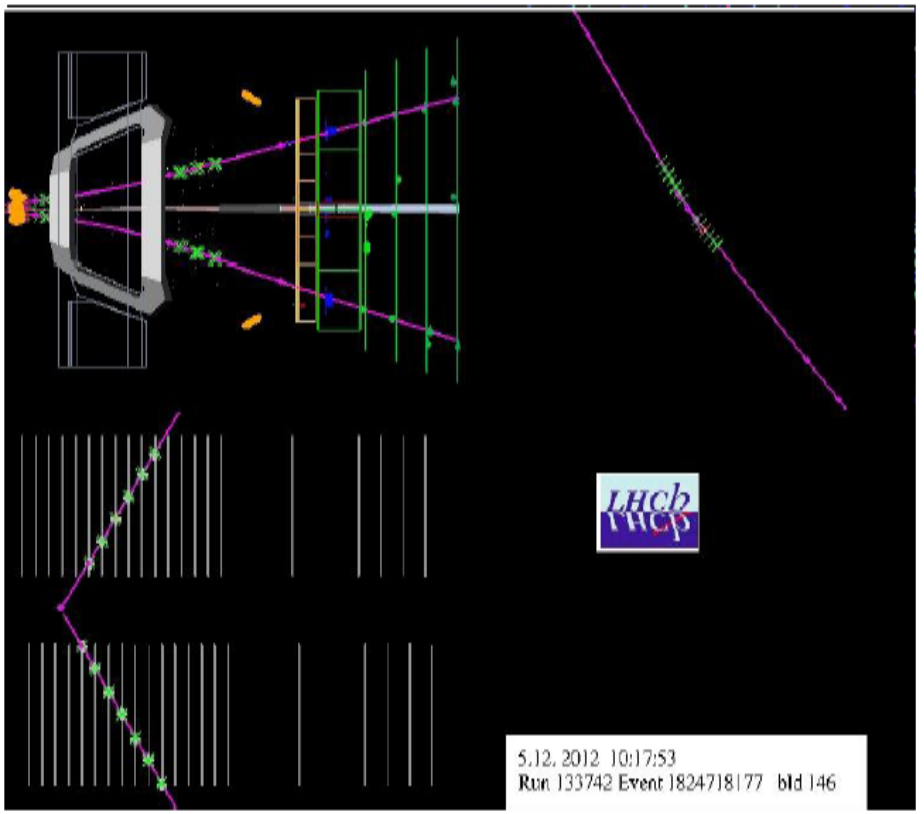
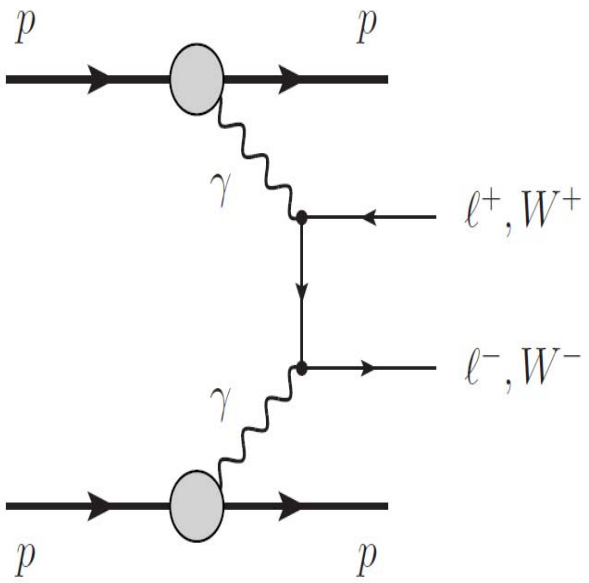


Central Exclusive Process (CEP)

Central Exclusive Processes

Two-photon interactions:



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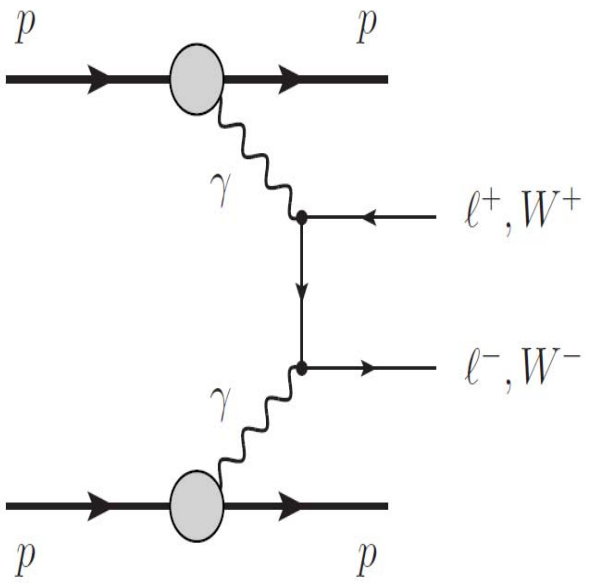

- Very clean processes: Central production with forward hadrons
- Accessible measurements:

1. Luminosity via dilepton production ($\gamma\gamma \to \mu^+\mu^-$);
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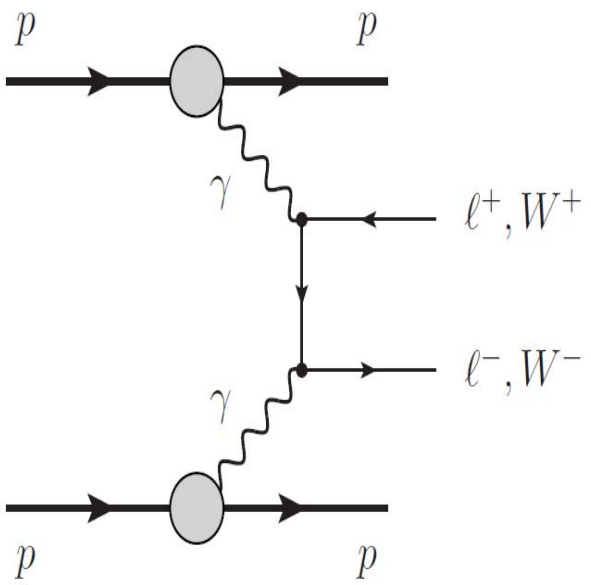

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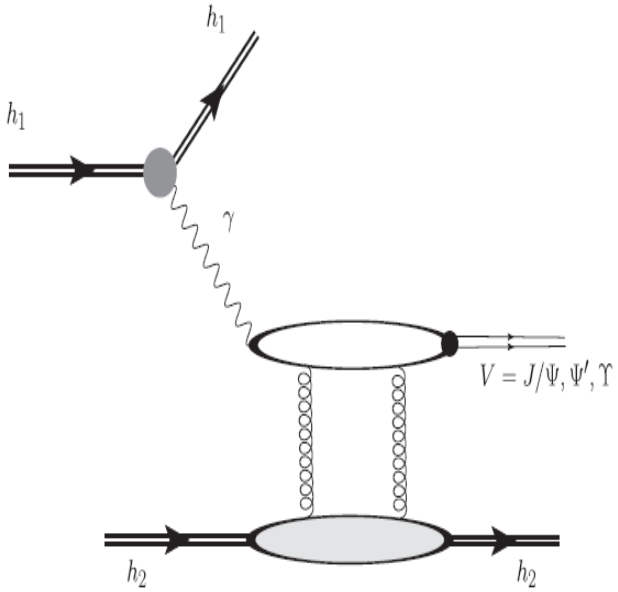

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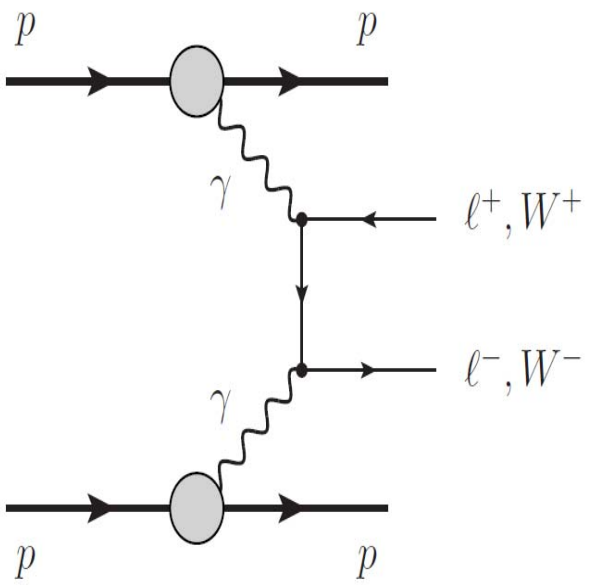

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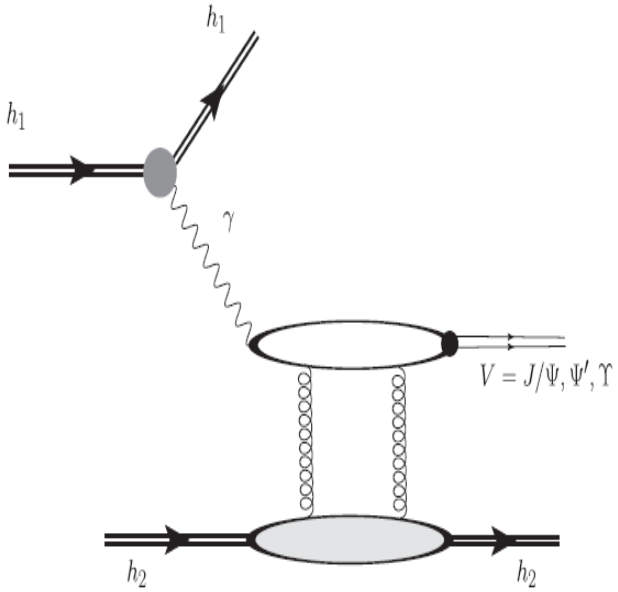

- Allow us to study the QCD dynamics at small-x.
- Sensitive to the description of diffraction.
- Determination of the gluon distribution and the magnitude of the shadowing effects.
- Search for saturation effects.
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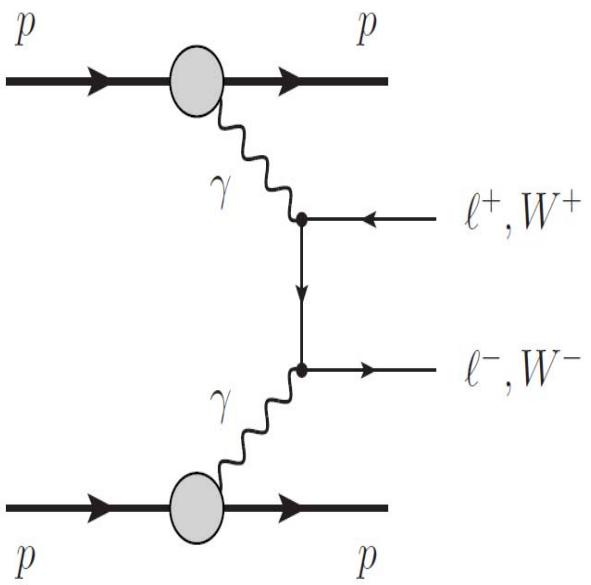

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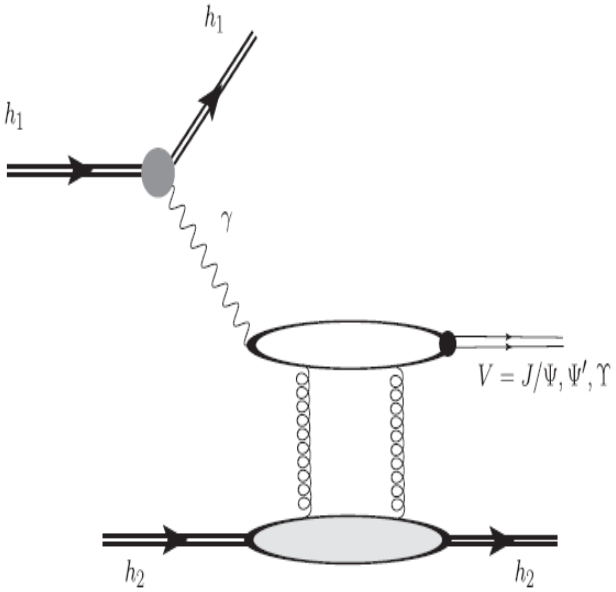

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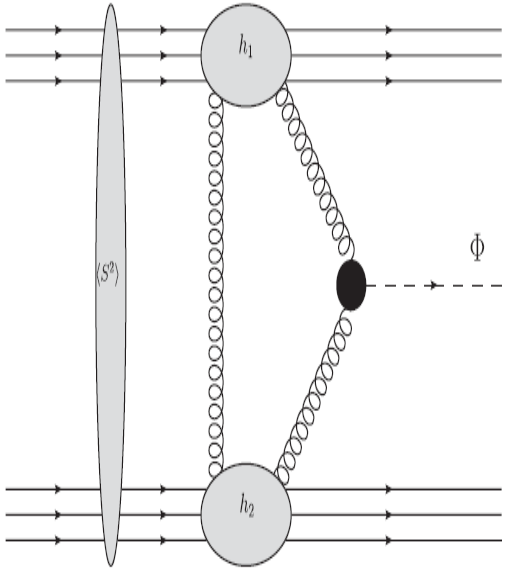

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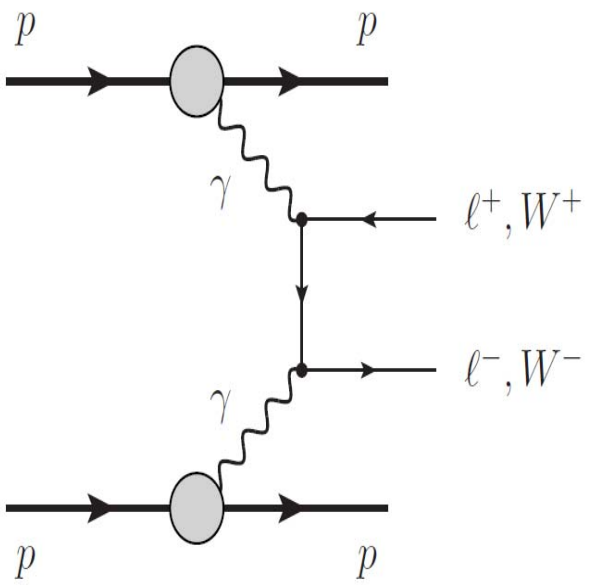

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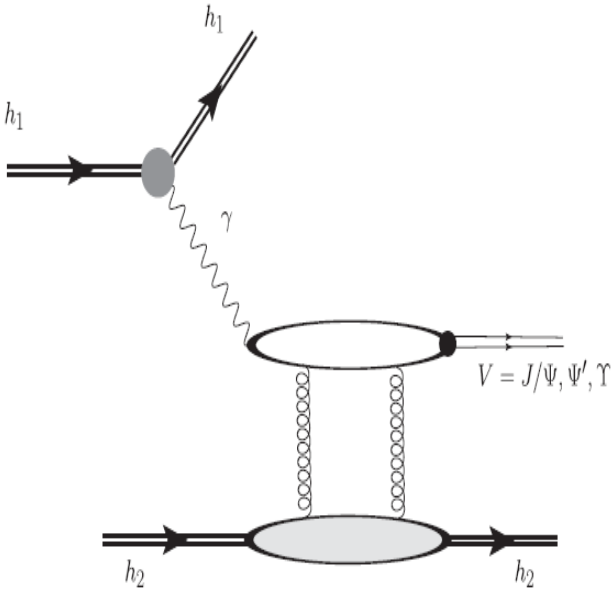

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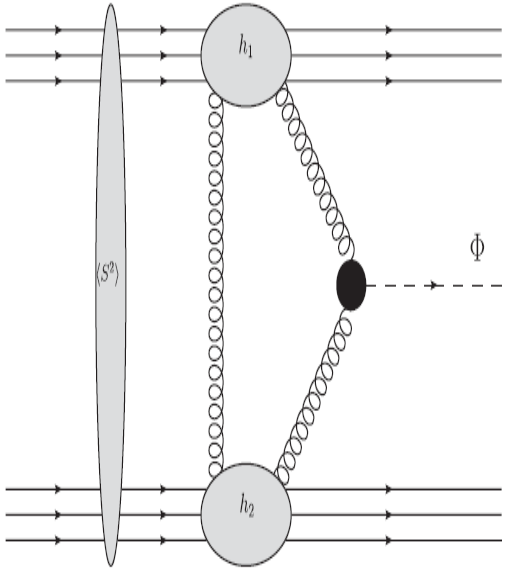

- Spin - parity analyser: only a subset of resonant states can be produced. In particular 0^{++} but not, for example, 1^{++}.
- Sensitive to the description of diffraction.
- Very sensitive to beyond Standard Model Physics.

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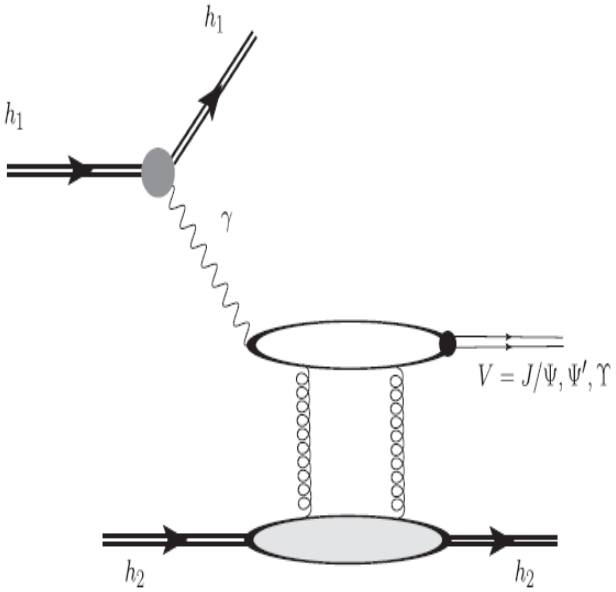

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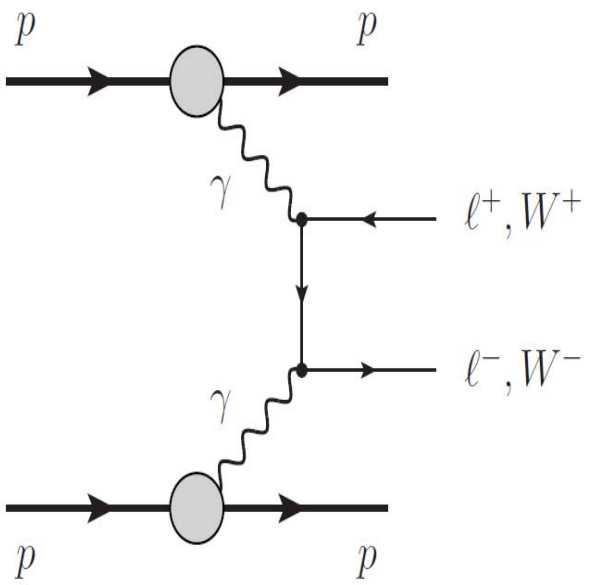

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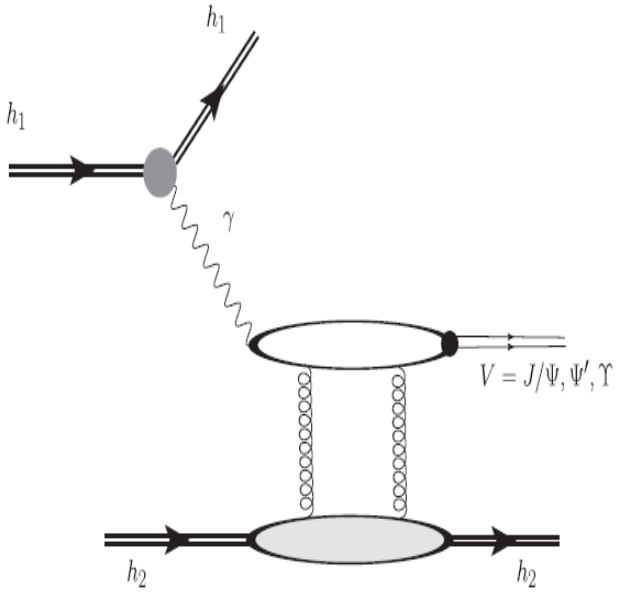

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Photon – Induced Interactions:

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The Equivalent Photon Approximation

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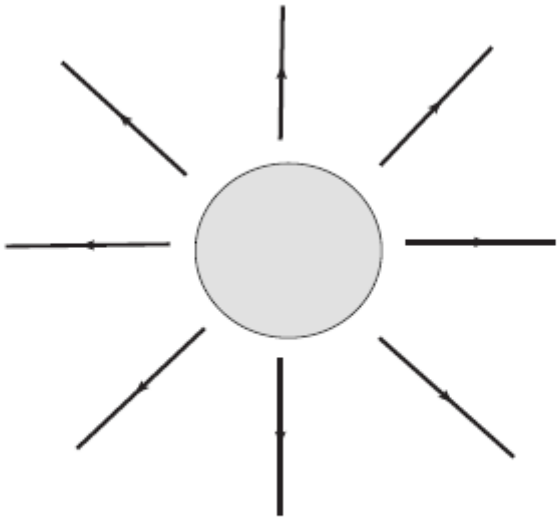
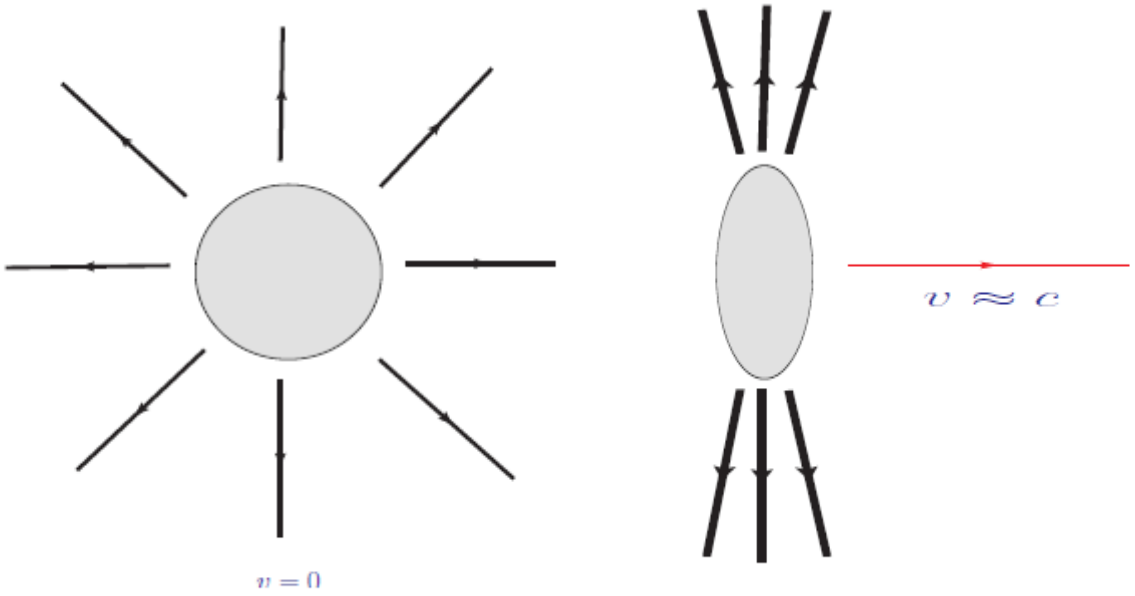
- Consider a charged nucleus at rest. The associated electromagnetic field can be represented by:



$v = 0$

Photon – Induced Interactions:
The Equivalent Photon Approximation

- As a charged nucleus moves with nearly the speed of light, the electromagnetic field becomes transverse to its velocity.



Photon – Induced Interactions:
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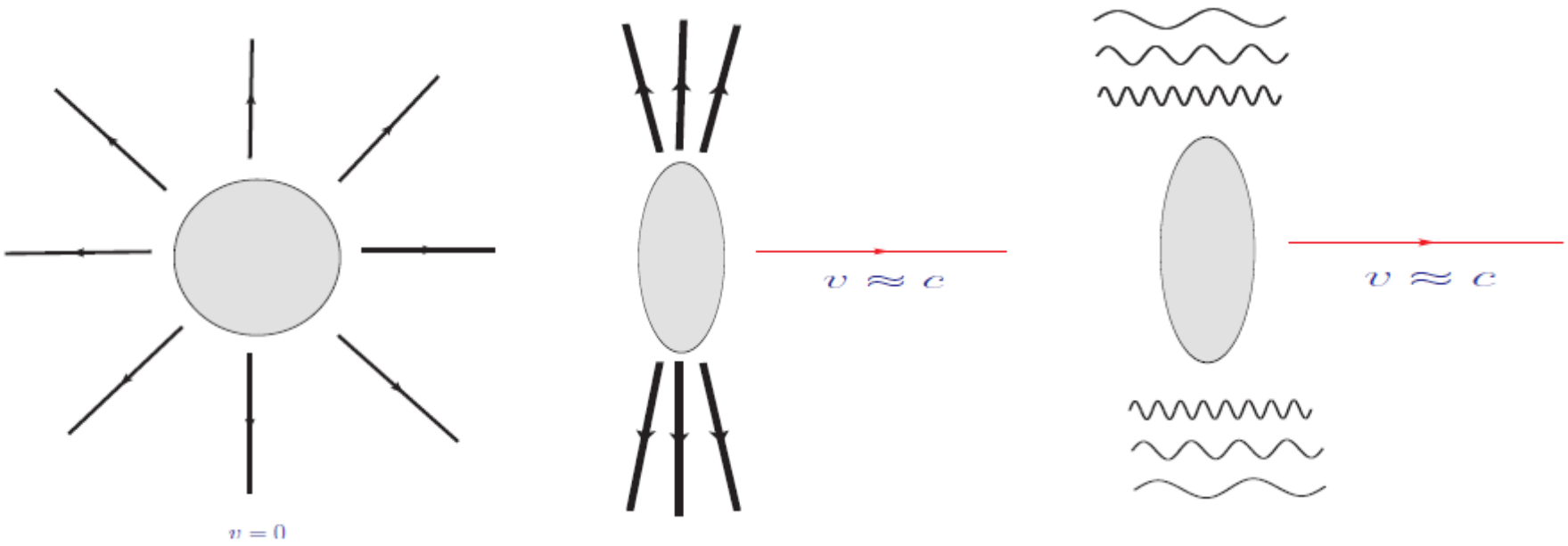
- Since the electric and magnetic field associated to the nucleus take on the same absolute value, this transverse electromagnetic field can be simulated by an equivalent swarm of photons [a].



[a] E. Fermi (1924), E. J. Williams (1933), C. F. Von Weizacker (1934)

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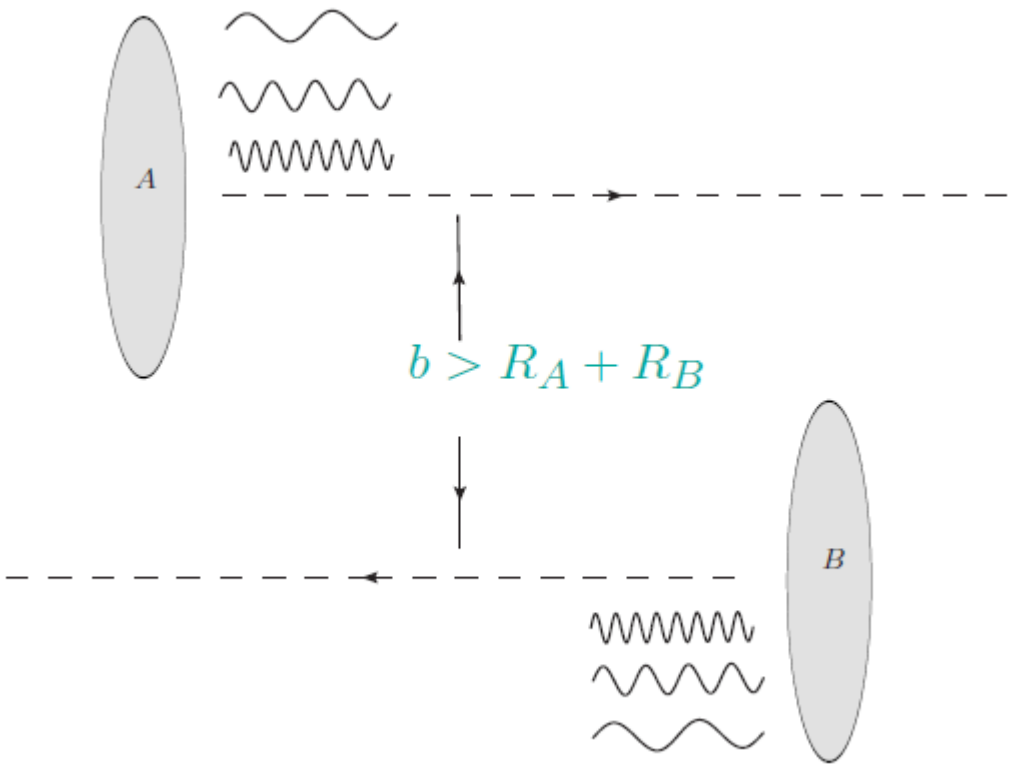
- Thus the collision of two charged nuclei at large impact parameter can be described as the collision of two equivalent swarms of photons.



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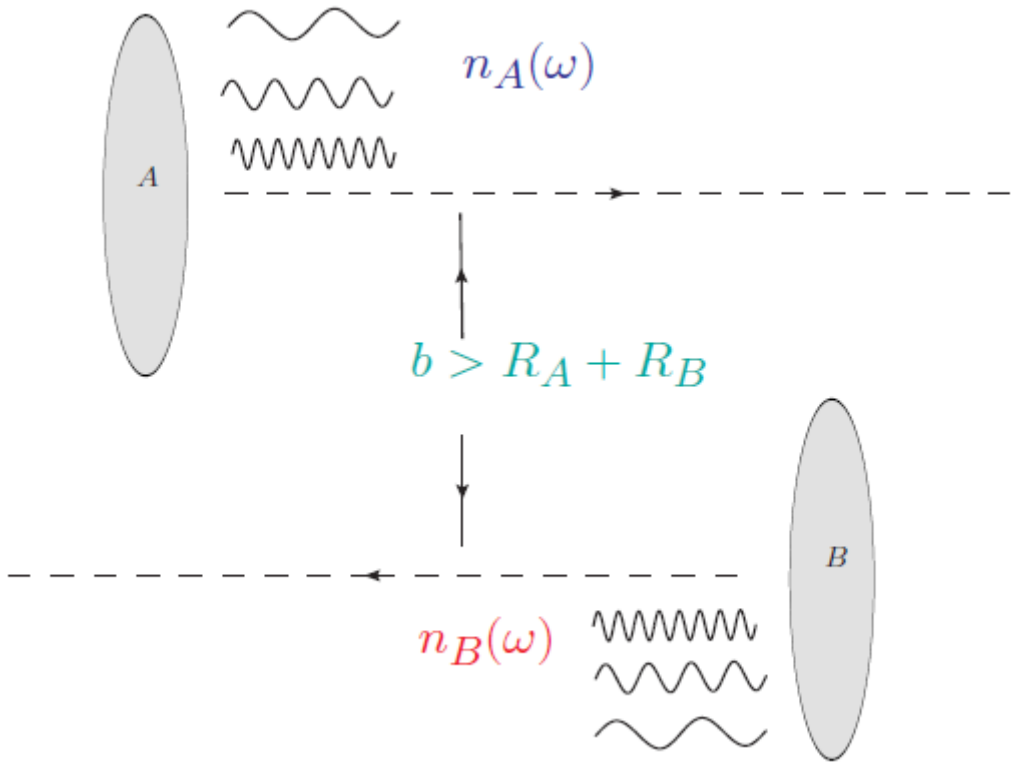

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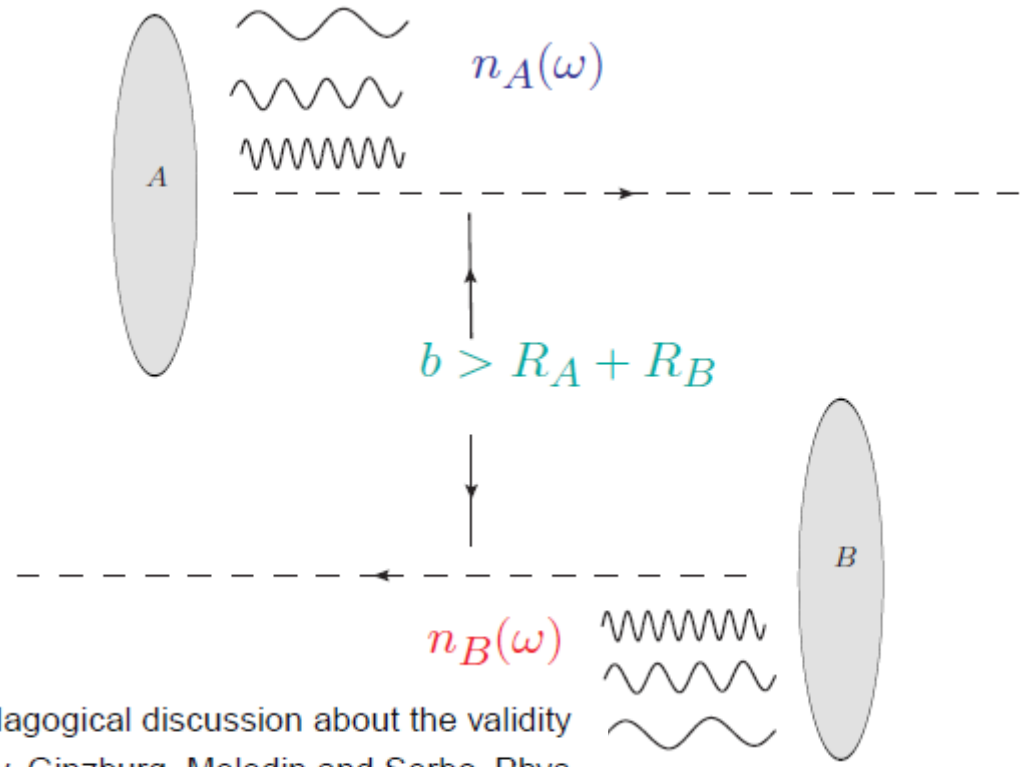
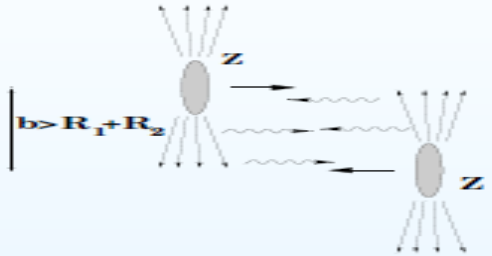


- For a detailed and pedagogical discussion about the validity of the EPA see Budnev, Ginzburg, Meledin and Serbo, Phys. Rep. 15, 181 (1975).

Photon – Induced Interactions:
Center of mass energies



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Center of mass energies

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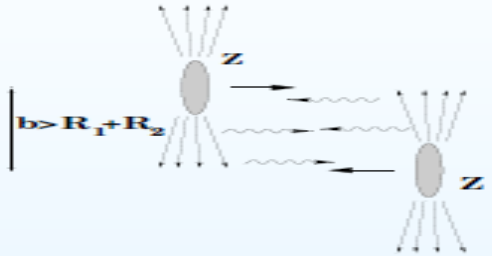

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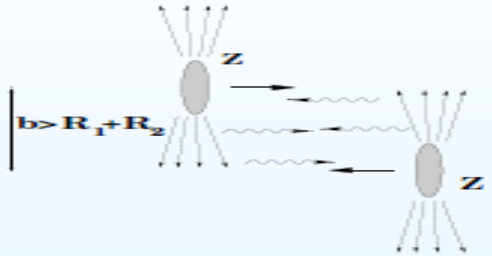

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- Photoproduction in pp collisions at LHC probes energies one order of magnitude larger than HERA.

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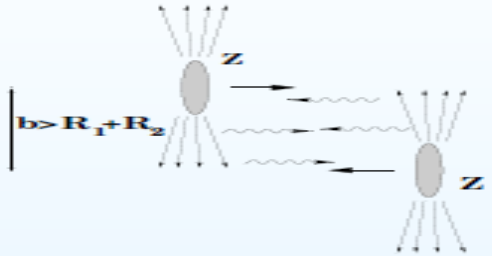

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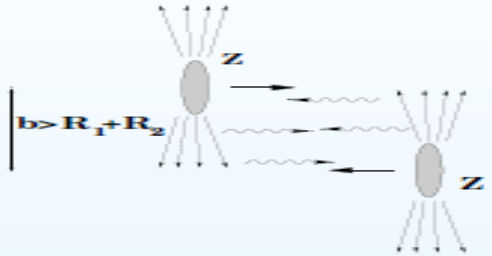

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- Photoproduction in pA and AA collisions probes an unexplored regime of center of mass energies.

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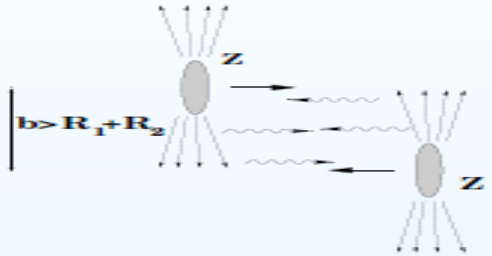

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- $\gamma\gamma$ interactions with center of mass energies larger than those obtained at LEP - CERN.

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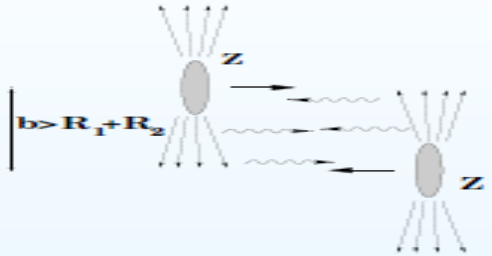

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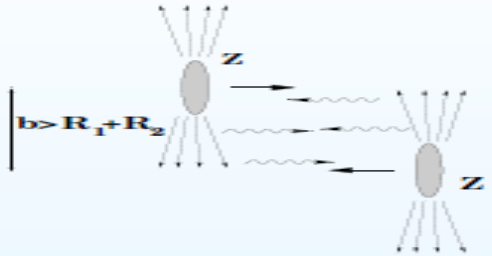
LHC	$PbPb$	$W_{\gamma A} \lesssim 950$ GeV	$W_{\gamma\gamma} \lesssim 160$ GeV
HERA	ep	$W_{\gamma p} \lesssim 200$ GeV	–

- $\gamma\gamma$ interactions with center of mass energies larger than those expected in the future ILC.

Photon – Induced Interactions:
Center of mass energies



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- The LHC is the world's most powerful collider not only for protons and lead ions but also for $\gamma\gamma$ and γh collisions.

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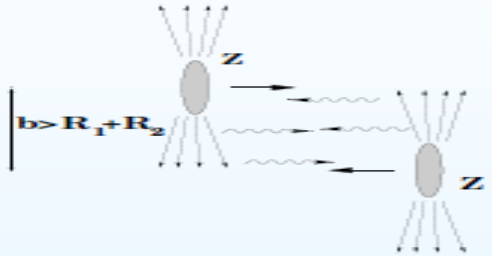

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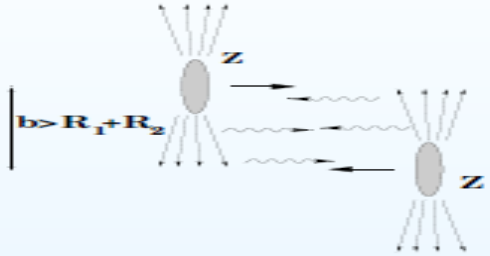
- Photon - induced interactions at LHC allows to study Quantum Chromodynamics in an unexplored regime of center of mass energies.

Photon – Hadron Interactions at the LHC:
Typical processes



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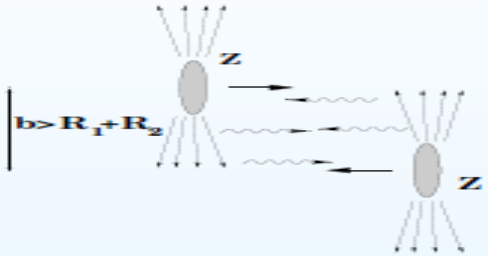

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- Inclusive processes: $\gamma p \to XY$

$\Rightarrow$ Heavy quark photoproduction ($X = c\bar{c},\ b\bar{b}$)

The final state is characterized by one rapidity gap due to the dissociation of the hadron target ($pp \to p \otimes XY$).

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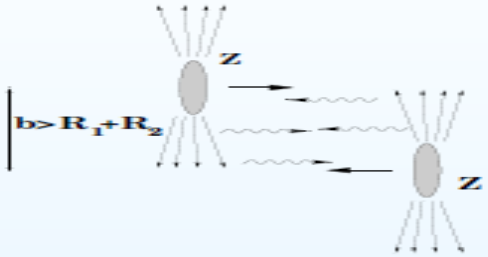

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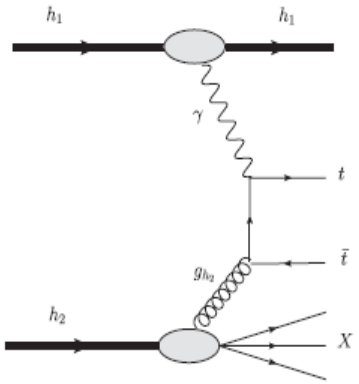

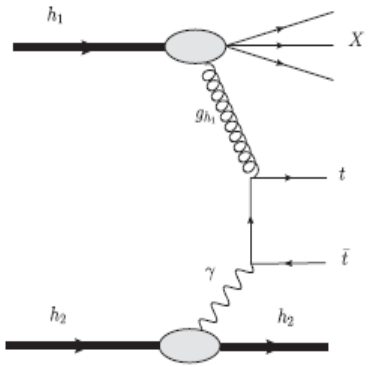

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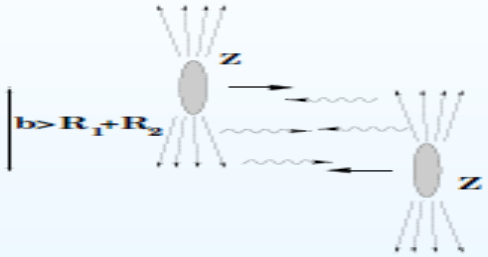

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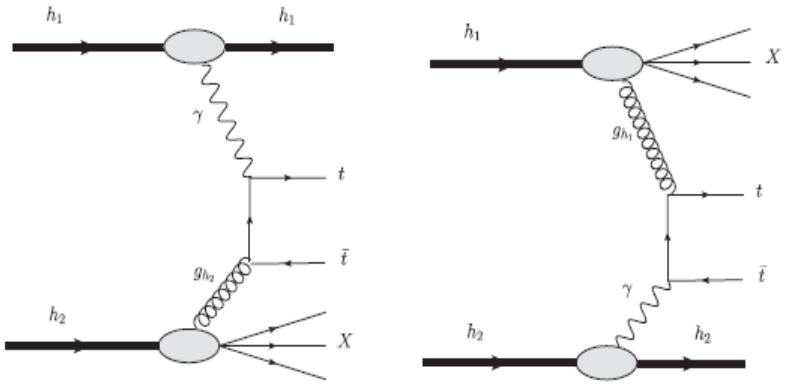

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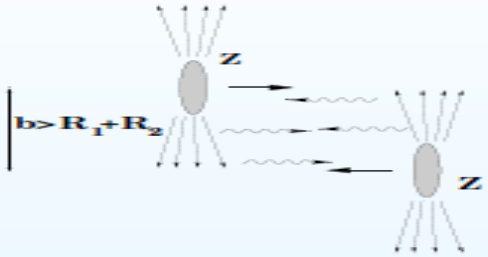

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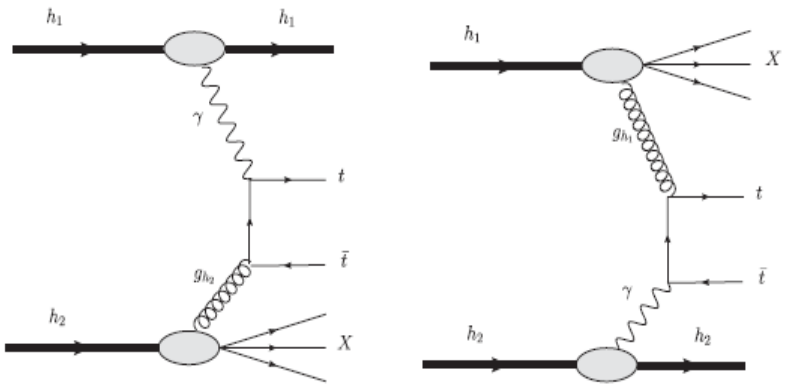

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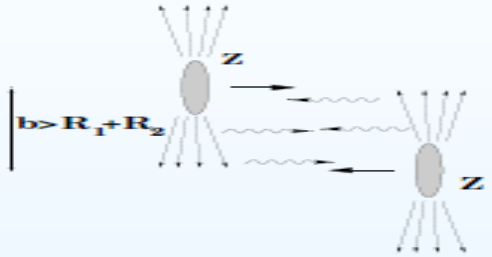
TABLE I. The integrated cross section (events rate) for the photoproduction of top quarks in pp, pPb, and $PbPb$ collisions at LHC energies.

pp	MRST	CT10
$\sqrt{s} = 8$ TeV	0.739 pb (73900)	0.764 pb (76400)
$\sqrt{s} = 14$ TeV	2.50 pb (250000)	2.53 pb (253000)

pPb	MRST	MRST + EPS09
$\sqrt{s} = 5.5$ TeV	0.036 nb (5.4/3600)	0.038 nb (5.7/3800)
$\sqrt{s} = 8.8$ TeV	0.159 nb (23.85/15900)	0.165 nb (24.75/16500)

PbPb	MRST	MRST + EPS09
$\sqrt{s} = 5.5$ TeV	0.42 nb (0.18)	0.40 nb (0.17)

Photon – Hadron Interactions at the LHC:
Typical processes



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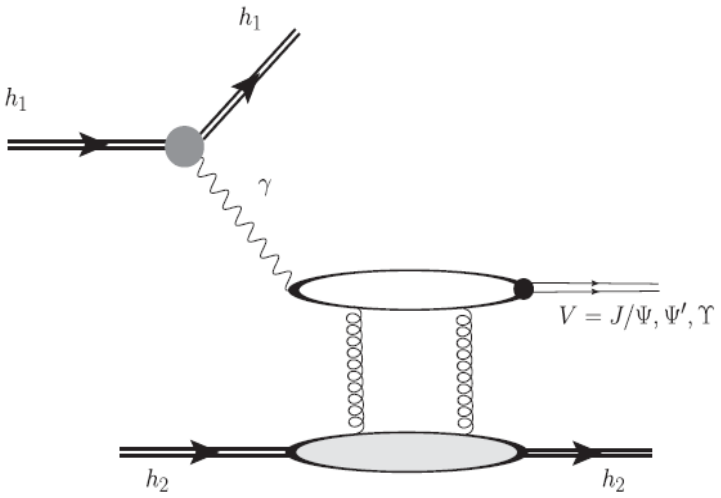

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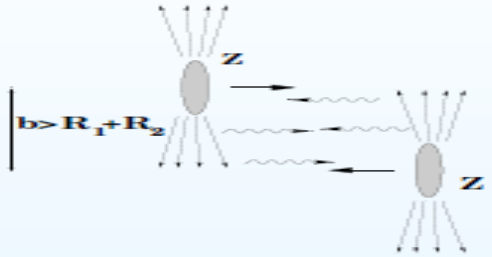

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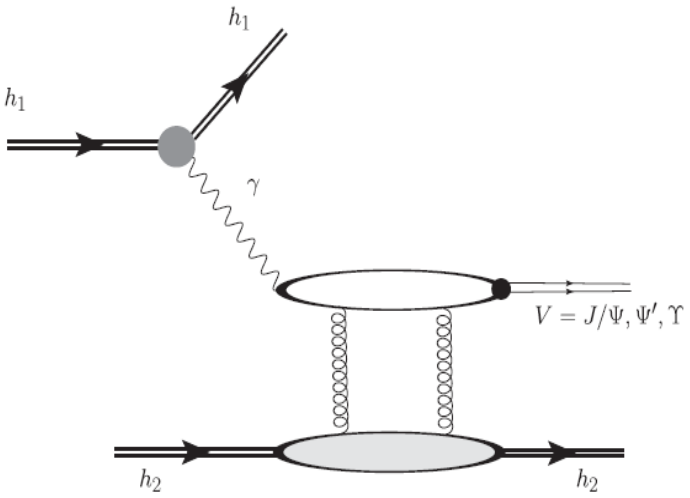

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Photon – Hadron Interactions at the LHC:
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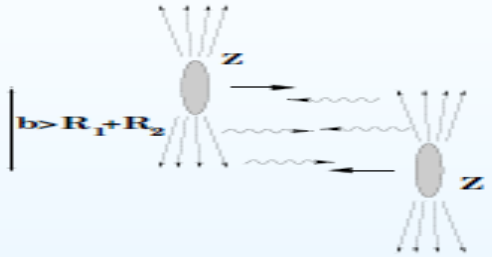

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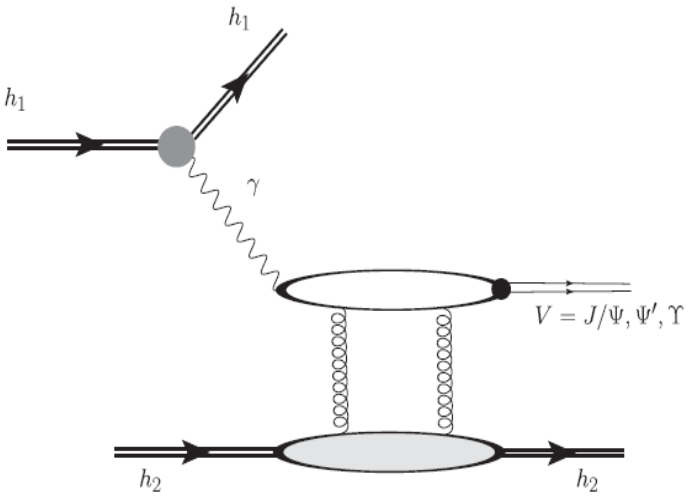

- Cross section is proportional to the square of the proton/nuclear gluon distribution.
- Diffractive vector meson photoproduction in UPHIC is a probe of the gluon distribution [a]

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

Photon – Hadron Interactions at the LHC:
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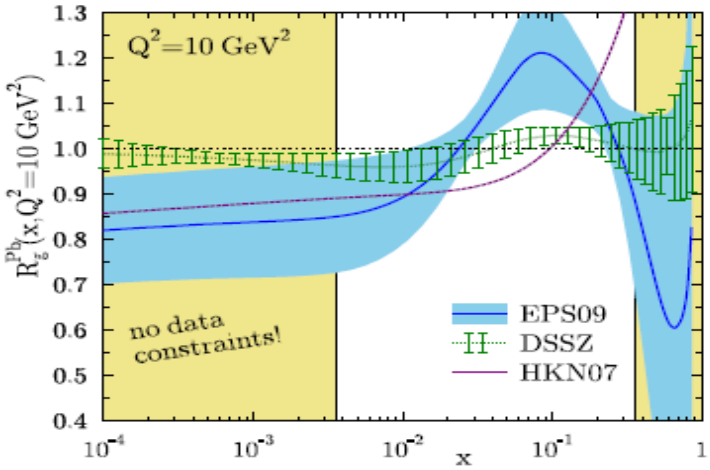

Eskola, Puukkunen, arXiv:1401.2345

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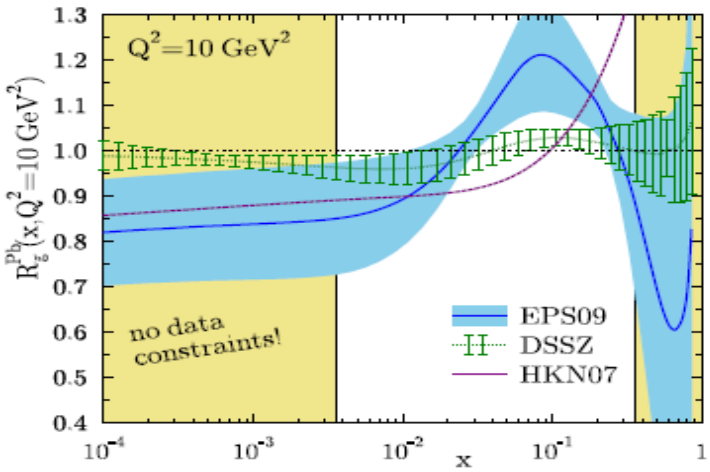

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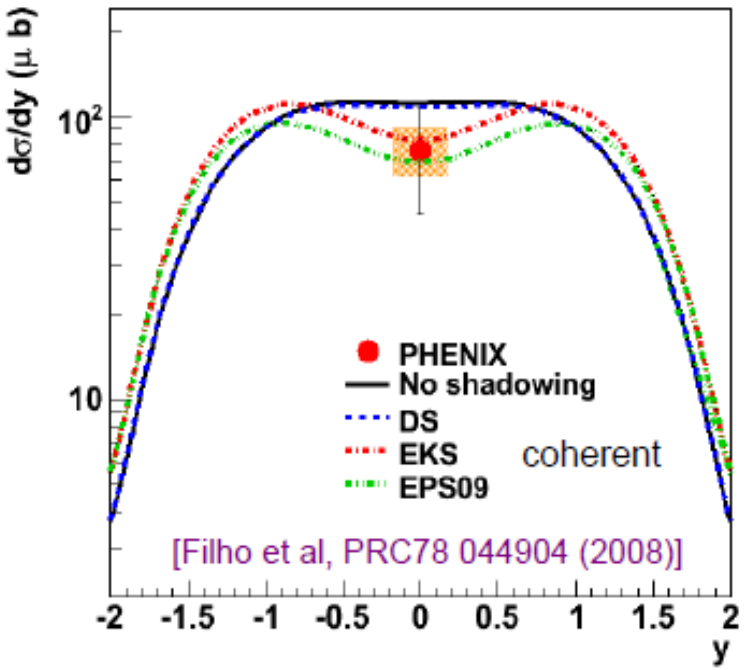

Photon – Hadron Interactions at the LHC: Constraining the nuclear gluon distribution

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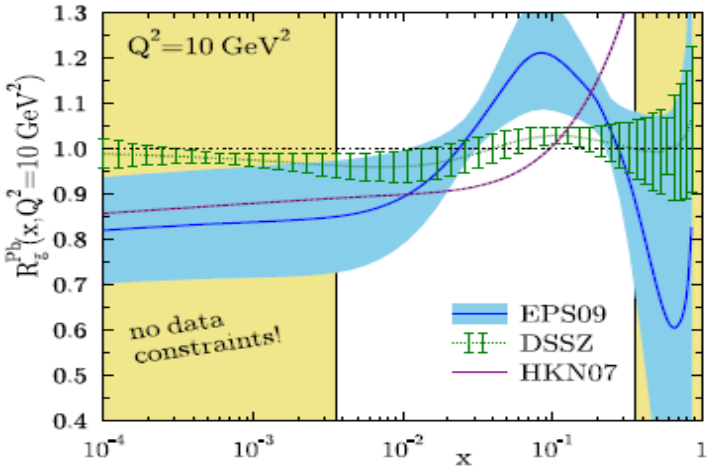

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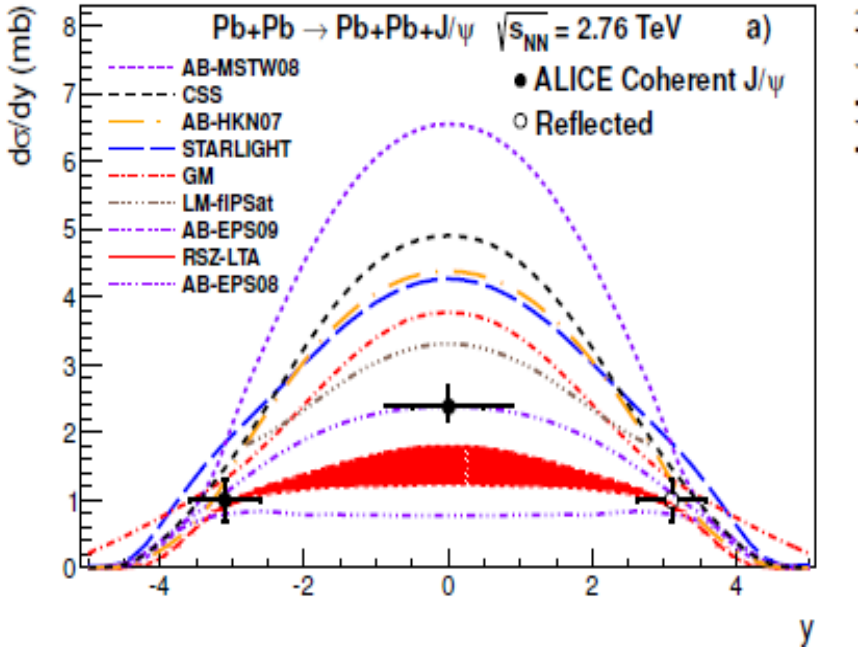

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$$y = -3 \Rightarrow x = 0.02$$

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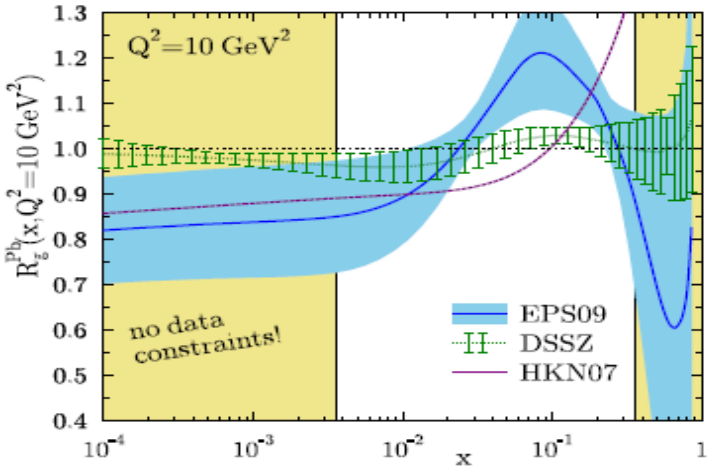

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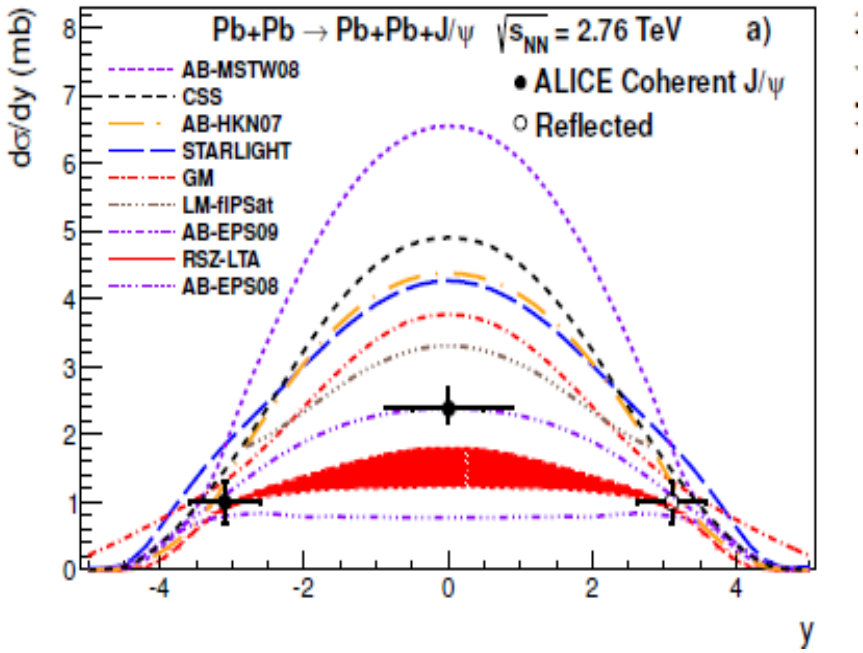

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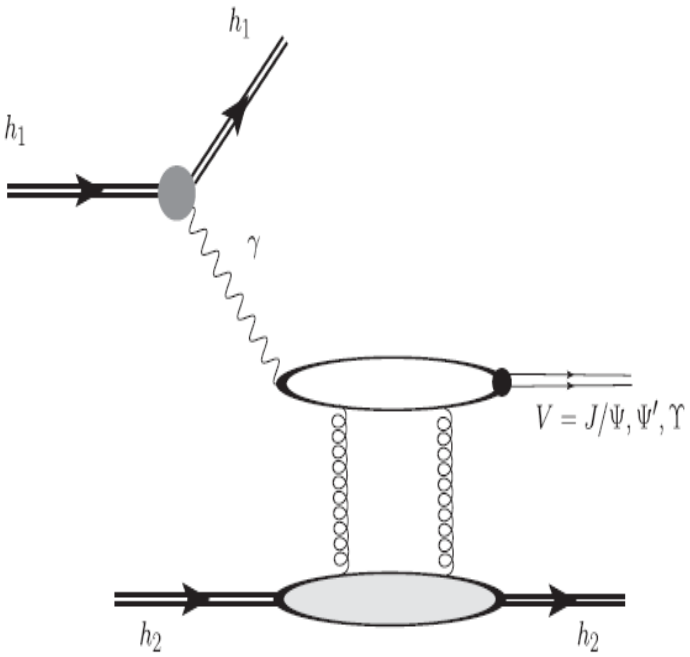
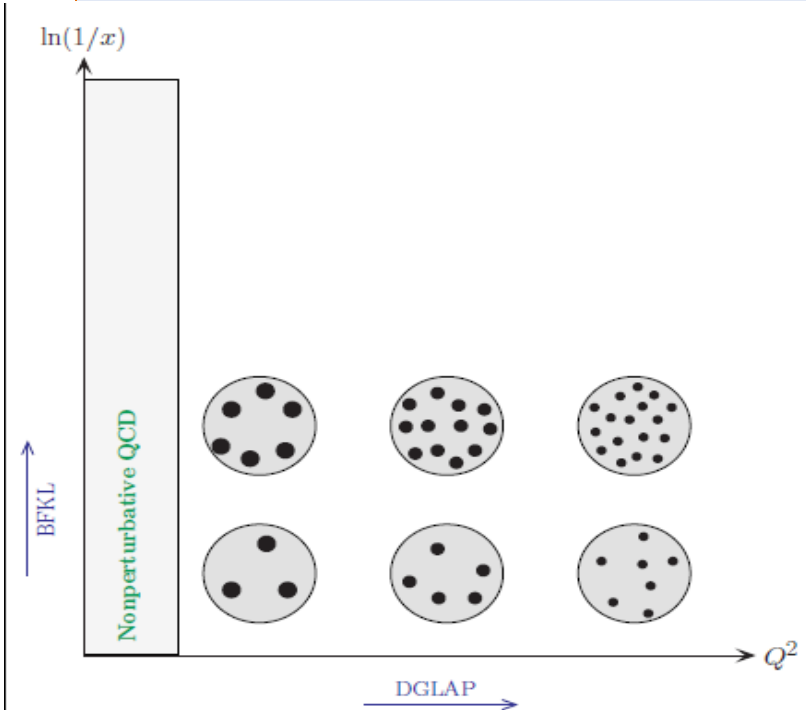
Photon – Hadron Interactions at the LHC: Probing the QCD dynamics



- Diffractive vector meson photoproduction in photon - induced interactions is a probe of the **nonlinear effects** in the QCD dynamics at high energies and the **vector meson wave function** [a].

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

Photon – Hadron Interactions at the LHC:
Probing the QCD dynamics



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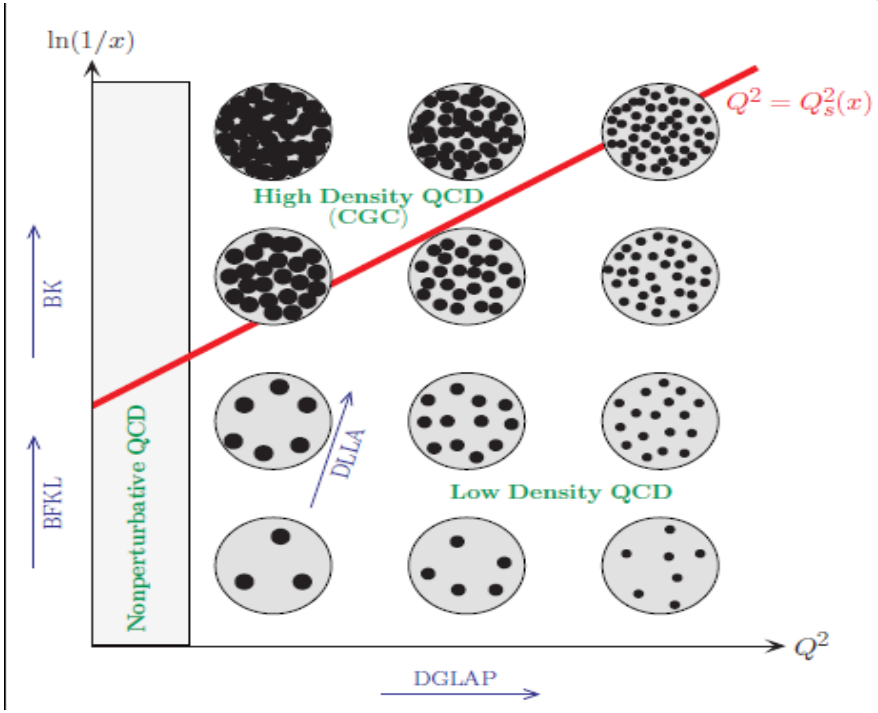

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- Saturation scale Q_s (energy and atomic number dependent) defines the onset of nonlinear QCD dynamics.

- Open questions: Are present at RHIC/LHC/Cosmic Rays? What is the magnitude of these effects? What is the more adequate description of the nonlinear effects?

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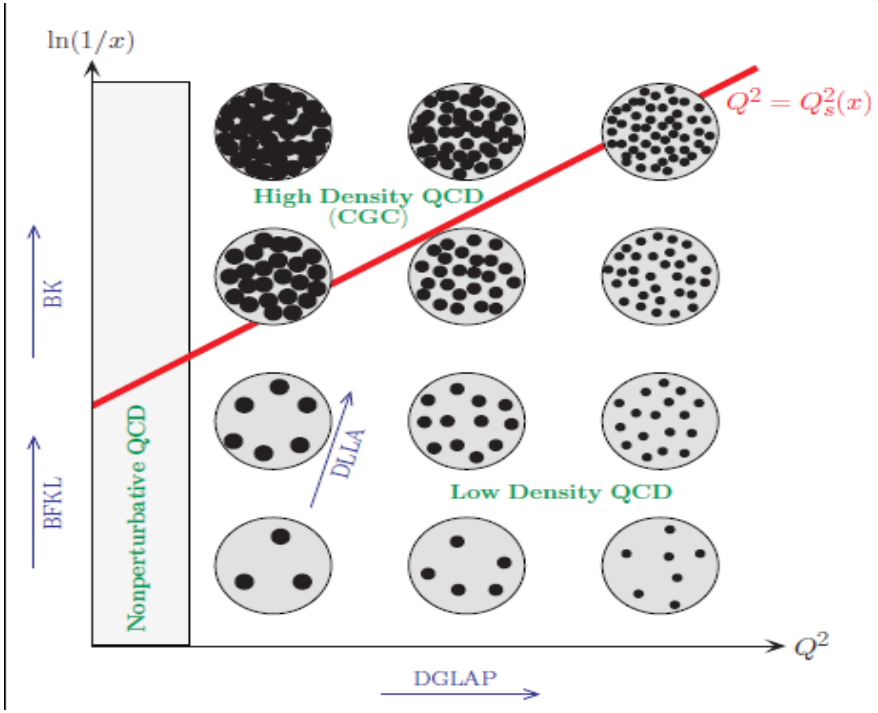

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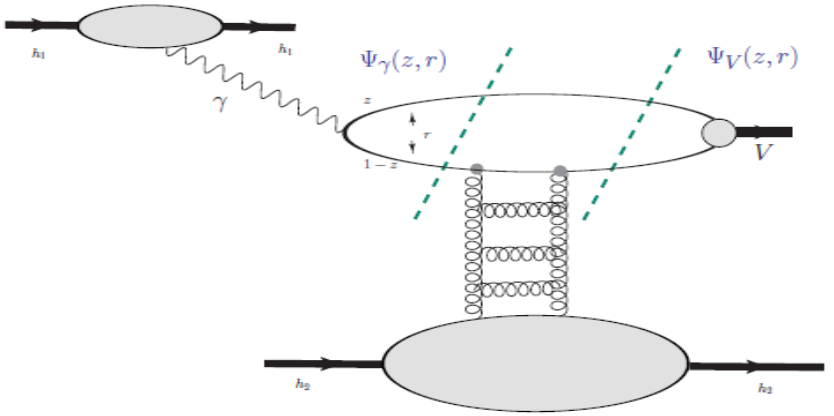

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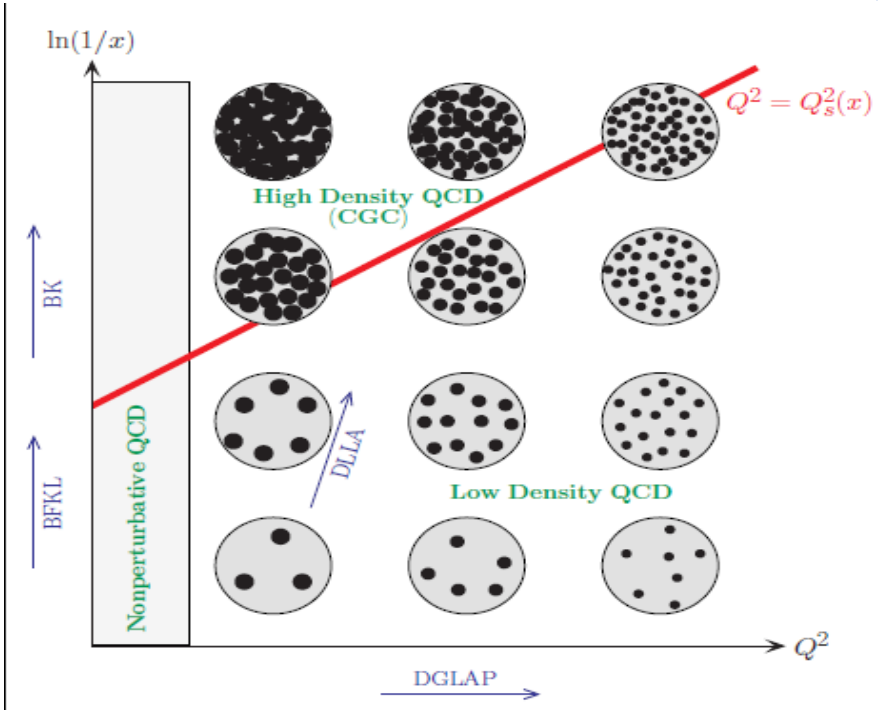

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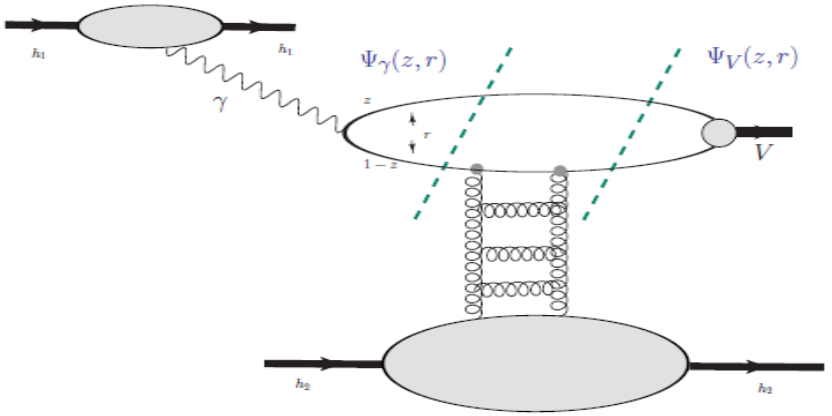

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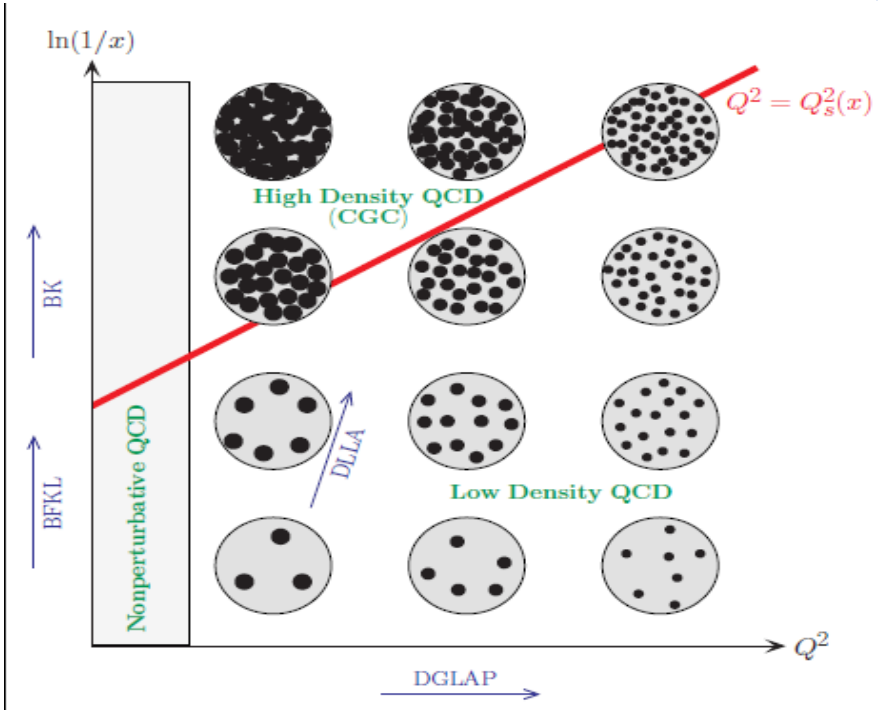

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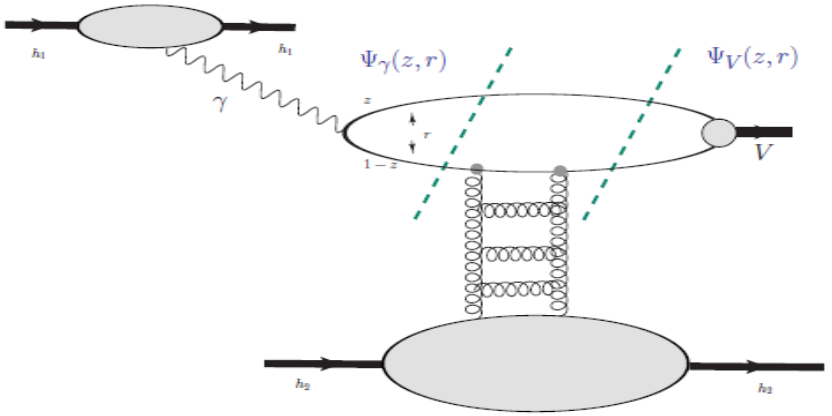

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Photon – Hadron Interactions at the LHC: Probing the QCD dynamics

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

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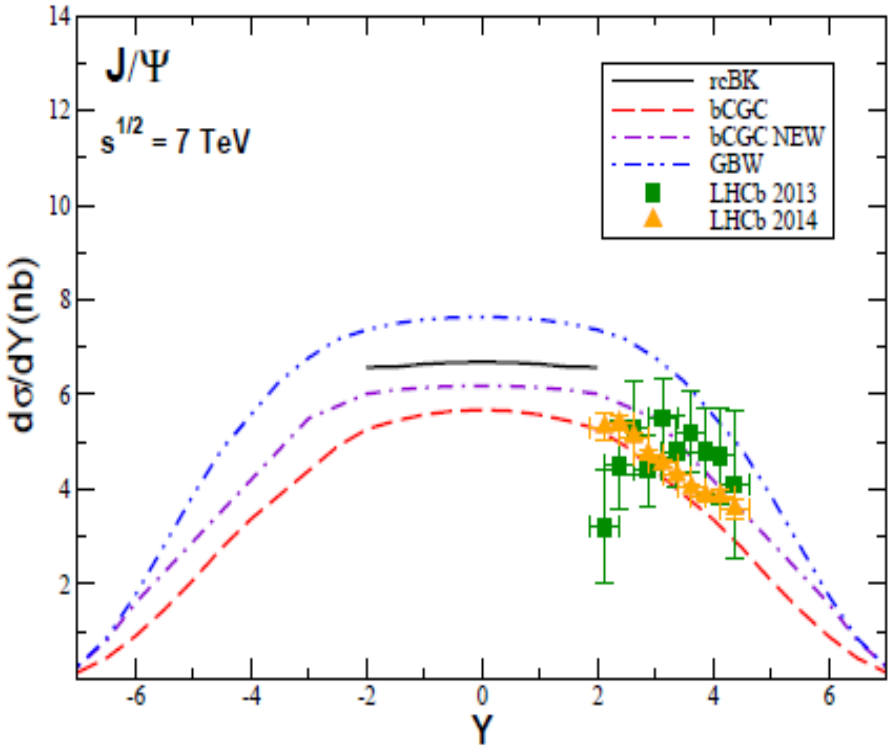

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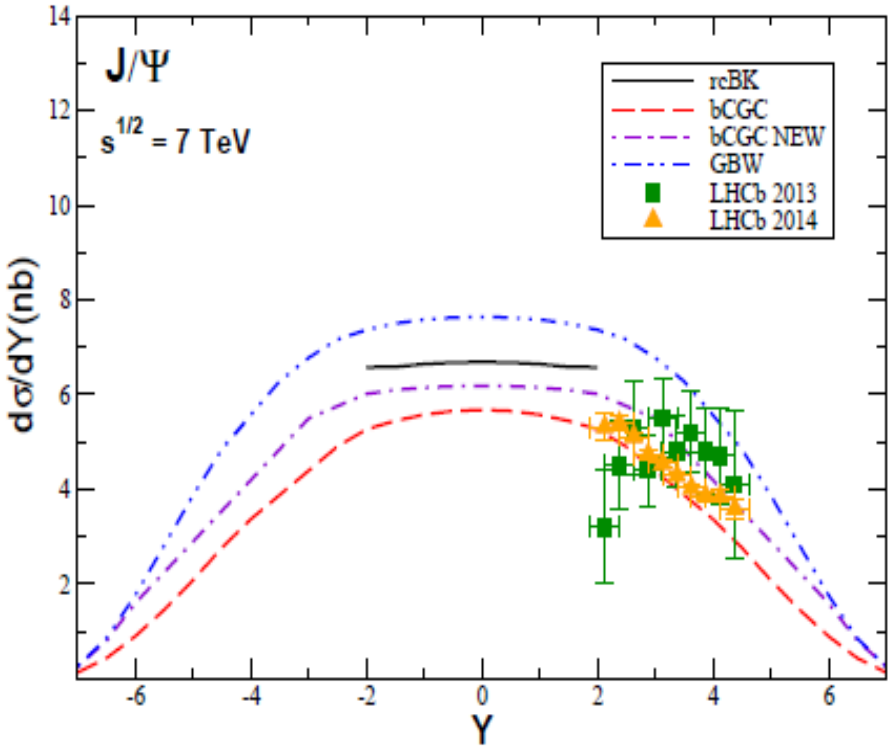

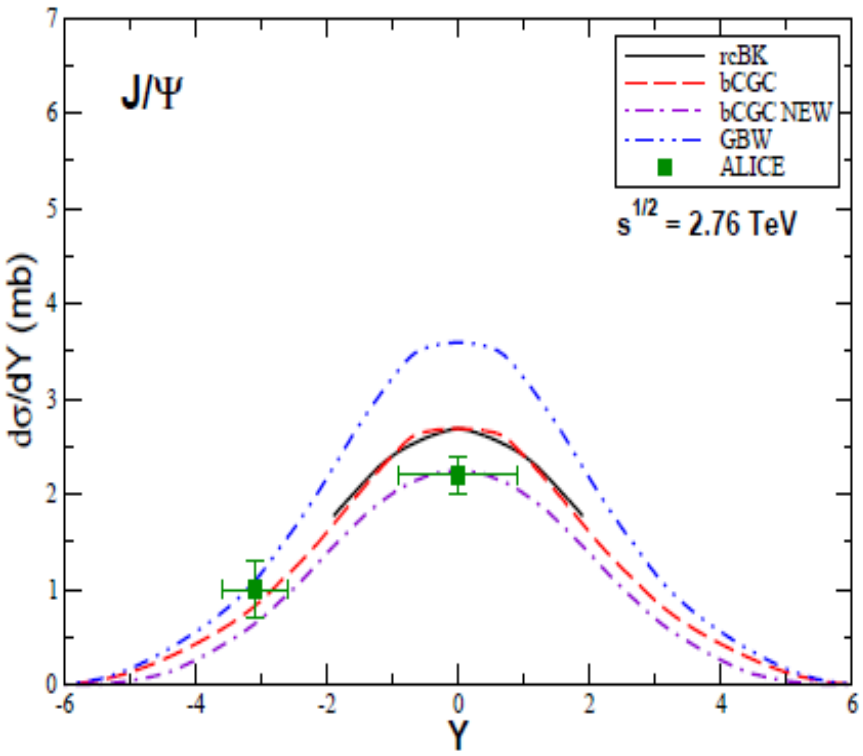

[a] VPG, Moreira, Navarra, PRC90, 15203 (2014)

Photon – Hadron Interactions at the LHC: Probing the QCD dynamics

- Diffractive Υ photoproduction in hadronic collisions [b]

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

Photon – Hadron Interactions at the LHC: Probing the QCD dynamics

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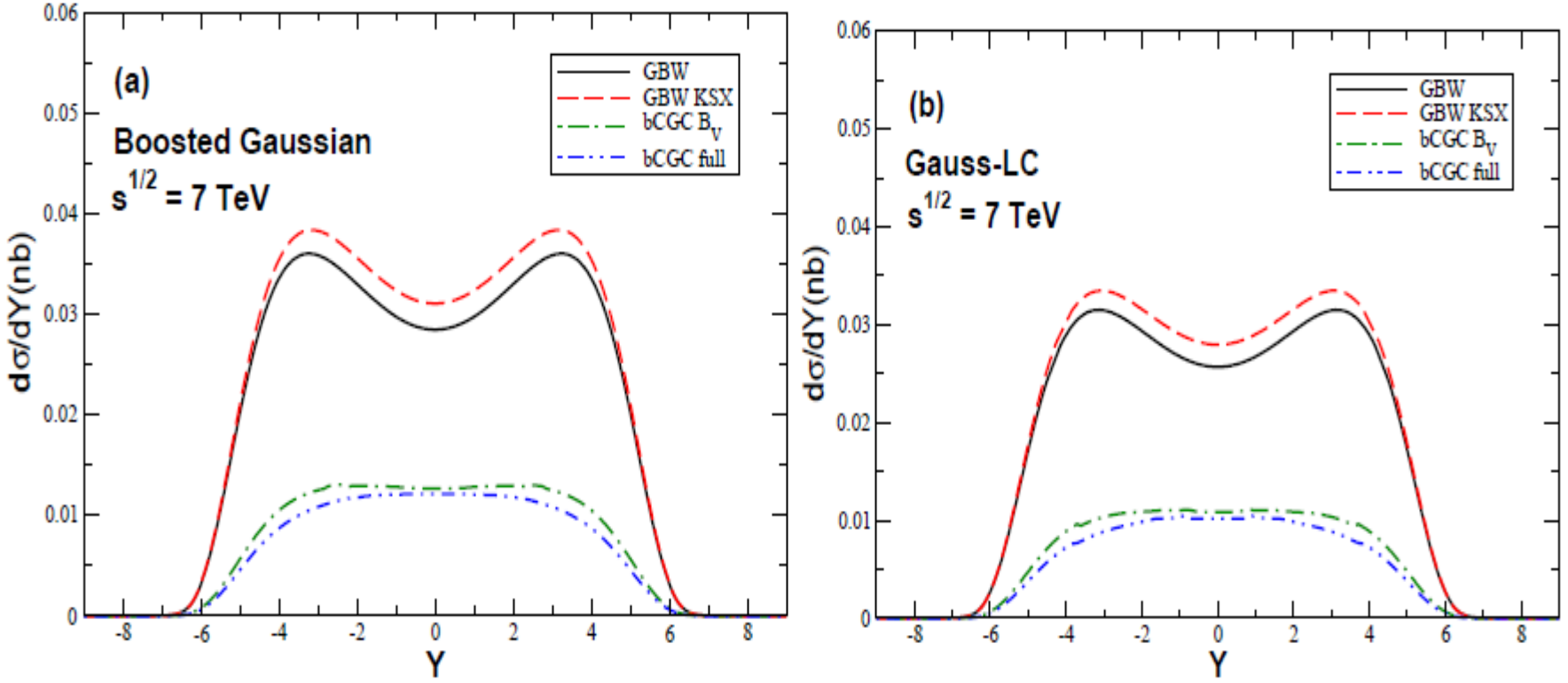

[b] VPG, Moreira, Navarra, PLB 472, 172 (2015)

Photon – Hadron Interactions at the LHC: Probing the QCD dynamics

- Diffractive ρ photoproduction in hadronic collisions [c]

[c] VPG, Machado, PRC80, 054901 (2009); PRC84, 011902 (2011)

Photon – Hadron Interactions at the LHC: Probing the QCD dynamics

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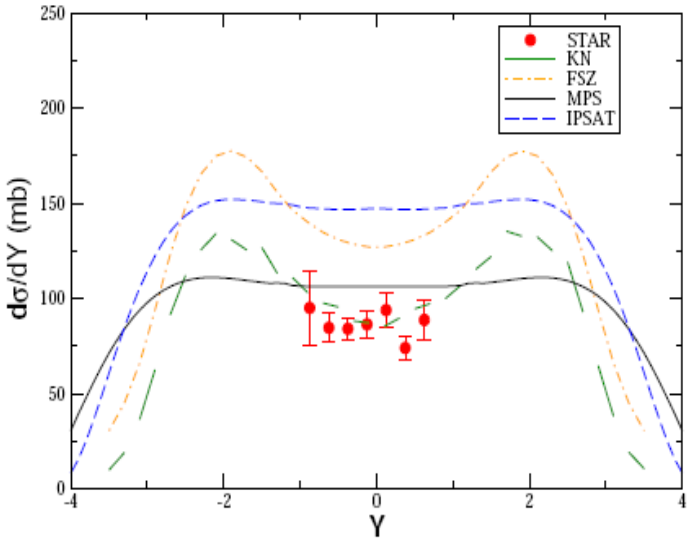

FIG. 1: (Color online) Predictions for the rapidity distribution of ρ^0 photoproduction at RHIC energy considering distinct theoretical approaches. Data from STAR Collaboration [24].

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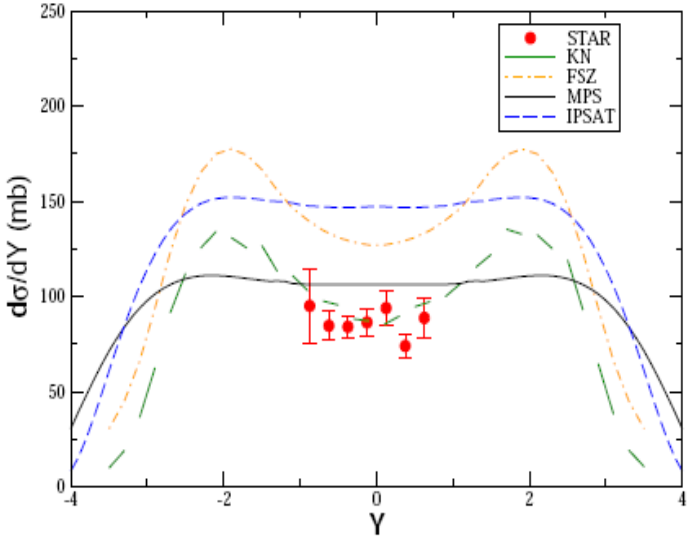

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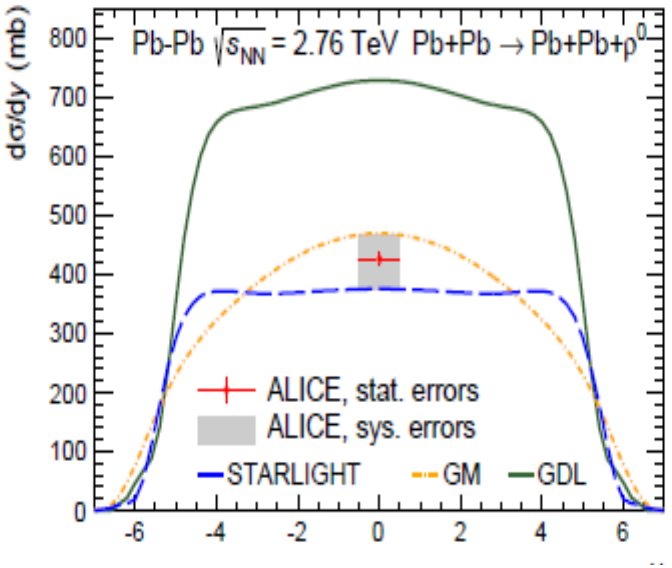

arXiv:1503.09177v1 [nucl-ex]

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Photon – Hadron Interactions at the LHC:
Probing the Odderon

Photon – Hadron Interactions at the LHC: Probing the Odderon

- In pQCD the Pomeron corresponds to a C - even parity (C being the charge conjugation) compound state of two t-channel reggeized gluons, which determines the high energy behaviour of the total hadronic cross sections.

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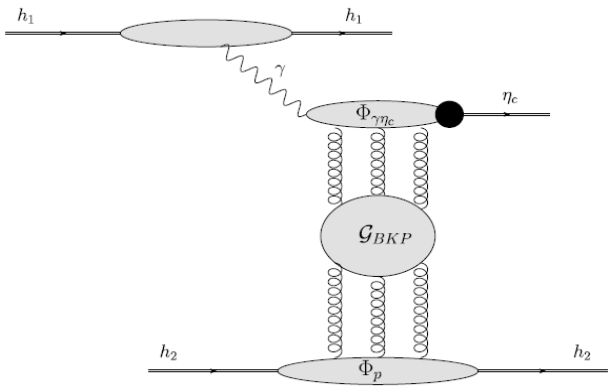

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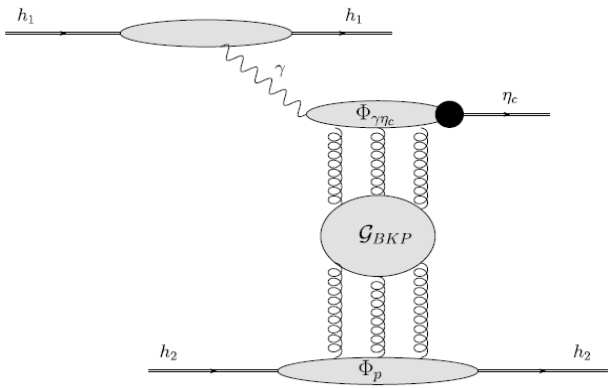

- Basic idea: As the photon carries negative C parity, its transformation into a diffractive final state system of positive C parity requires the t - channel exchange of an object of negative C parity.

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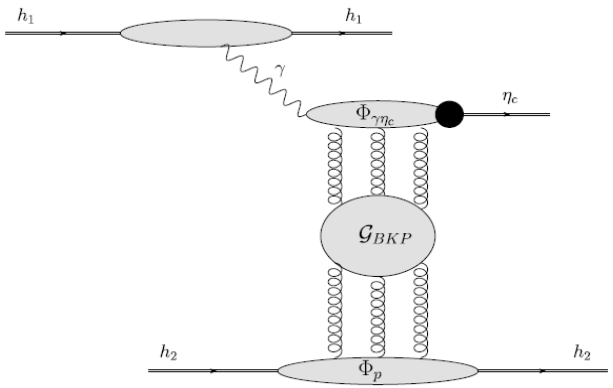

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Photon – Hadron Interactions at the LHC: Probing the Odderon

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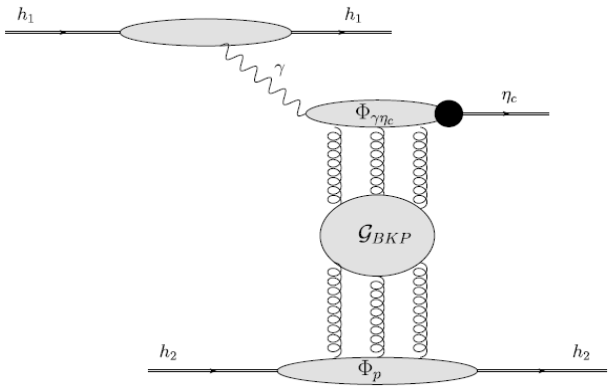

- We have considered two different models for the Odderon exchange:

Czyzewski, Kwiecinski, Motyka, Sadzikowski (CKMS) model: simplified three non interacting gluon exchange.

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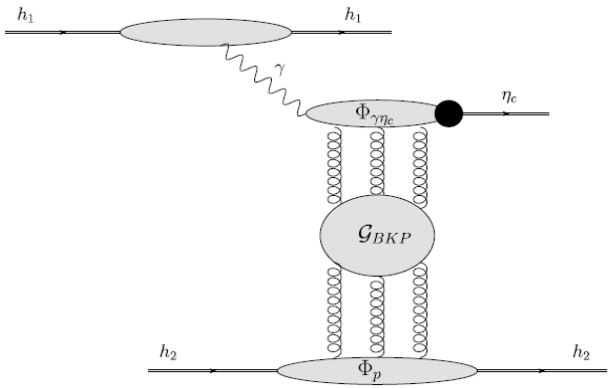

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- Predictions:

Table 1
Cross sections (event rates/year) for the diffractive η_c photoproduction in pp collisions at LHC energies.

$\sqrt{s_{NN}}$	CKMS	BBCV
8 TeV	0.55 pb (55 000)	10.10 pb (1×10^6)
14 TeV	0.65 pb (65 000)	13.90 pb (1.4×10^6)

Table 2
Cross sections (event rates/year) for the diffractive η_c photoproduction in PbPb collisions at LHC energies.

$\sqrt{s_{NN}}$	CKMS	BBCV
2.76 TeV	0.30 μb (126)	14.25 μb (5985)
5.5 TeV	0.40 μb (168)	23.59 μb (9912)

[a] VPG, NPA 902, 32 (2013)

Photon – Hadron Interactions at the LHC: Probing the Odderon

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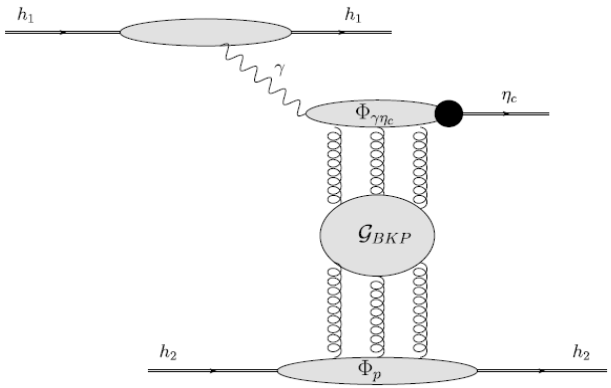

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- Predictions for the AFTER@LHC experiment [b].

h_1h_2	CKMS	BBCV
pp ($\sqrt{s} = 115$ GeV)	0.05 pb (1000.0)	0.30 pb (6000.0)
Pbp ($\sqrt{s} = 72$ GeV)	28.1 pb (31.0)	356.6 pb (393.0)
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TABLE I: Cross sections (event rates/year) for the exclusive η_c photoproduction in $pp/Pbp/PbPb$ collisions at AFTER@LHC experiment.

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[b] VPG, Sauter, PRD 91, 094014 (2015)

Photon – Hadron Interactions at the LHC: Probing the Odderon

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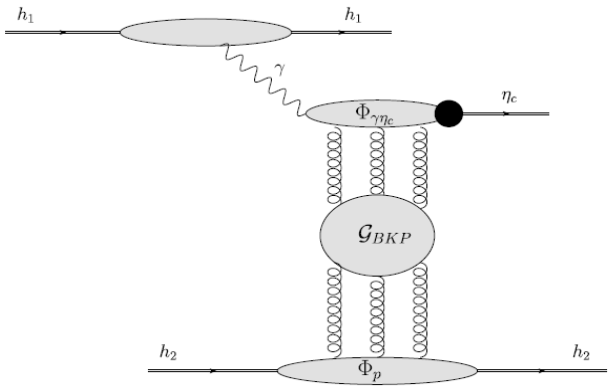

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TABLE I: Cross sections (event rates/year) for the exclusive η_c photoproduction in $pp/Pbp/PbPb$ collisions at AFTER@LHC experiment.

- Background is only present in pp collisions, which makes the observation of the exclusive η_c production in Pbp and $PbPb$ collisions a signature of the Odderon.

[a] VPG, NPA 902, 32 (2013)

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Photon – Hadron Interactions at the LHC:
Probing the Charmoniumlike Exotic states

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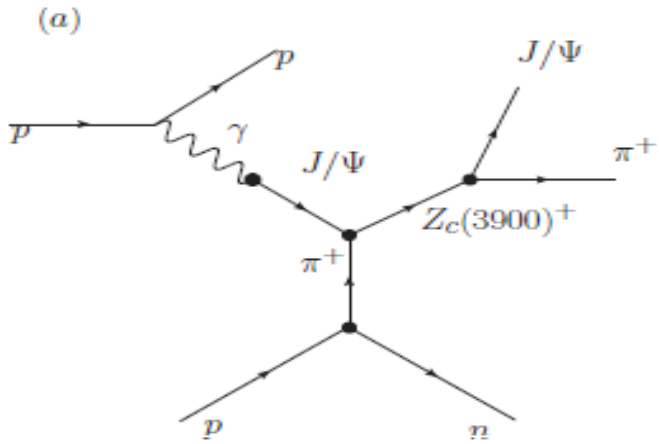

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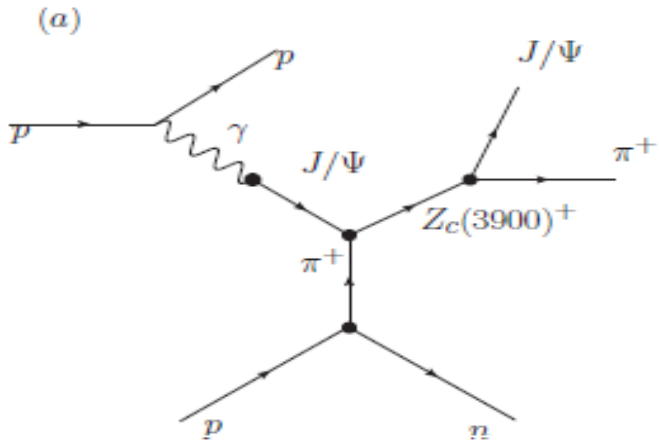

- Basic idea: the photon stemming from one of the incident protons fluctuates into a J/Ψ which interacts with the other proton through the π - exchange producing a n and a $Z_c^+(3900)$ state which decays in the $J/\Psi + \pi$ system.

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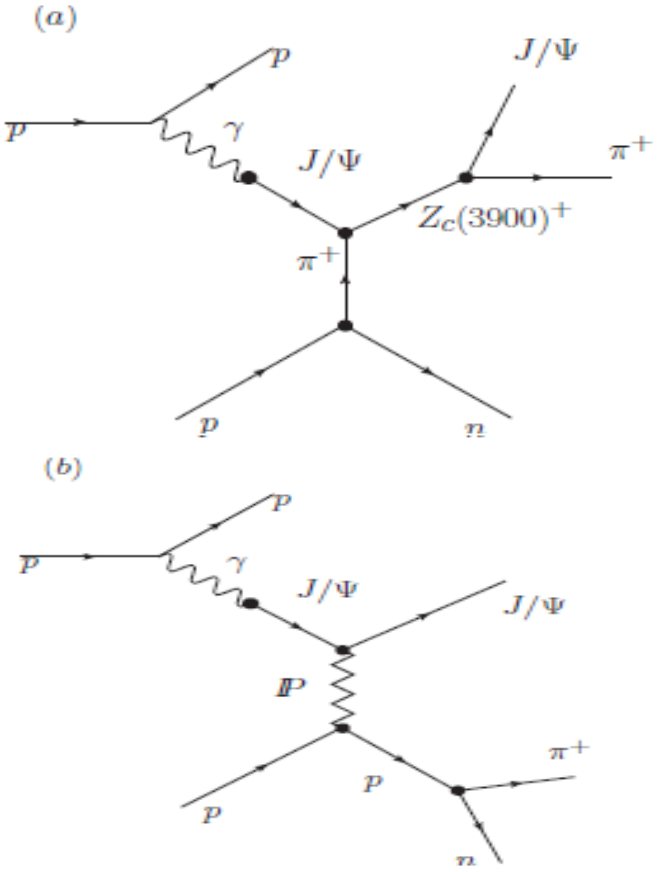

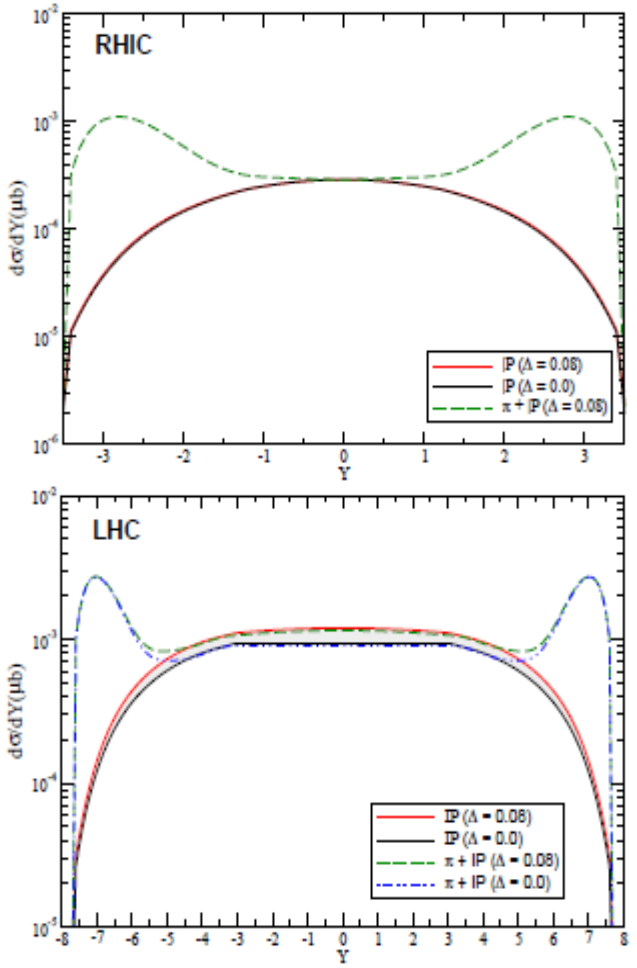

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Photon – Hadron Interactions at the LHC:
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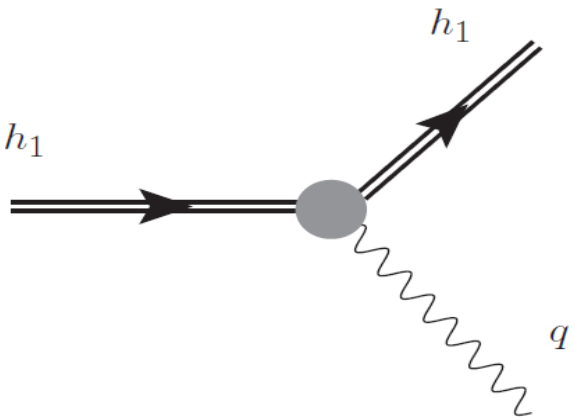

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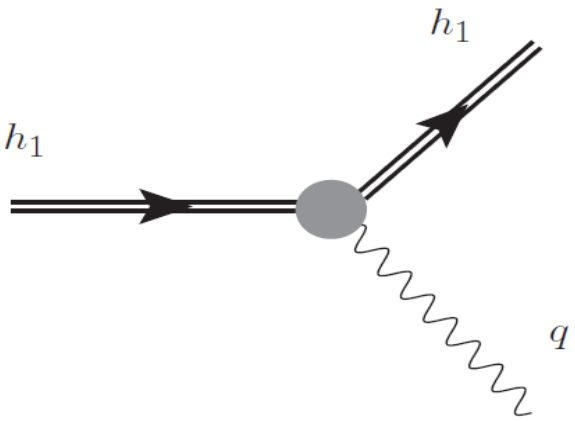

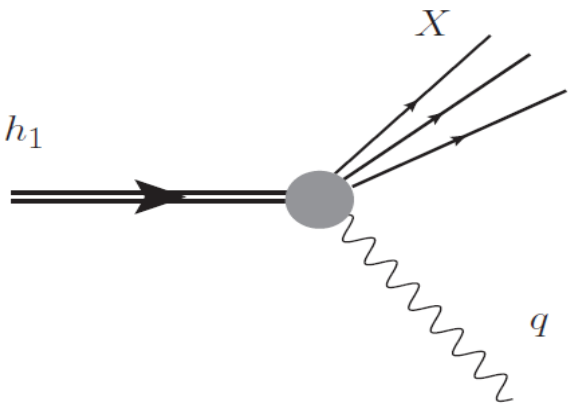

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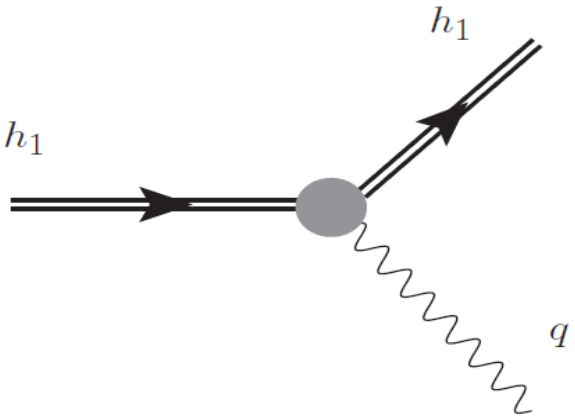

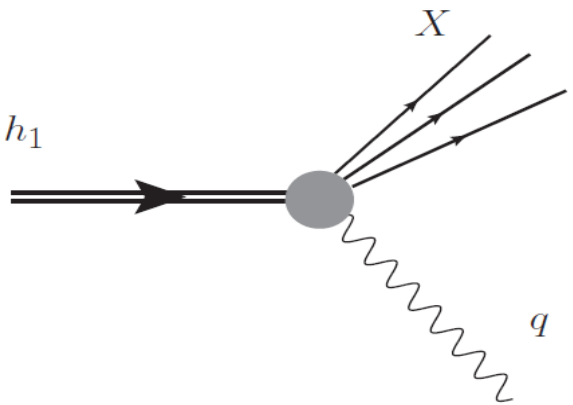

$$\gamma(x,\mu^2) = \gamma_{\rm el}(x) + \gamma_{\rm inel}(x,\mu^2)$$

where x is the fraction of the nucleon energy carried by the photon and μ is a momentum scale of the photon - induced subprocess.

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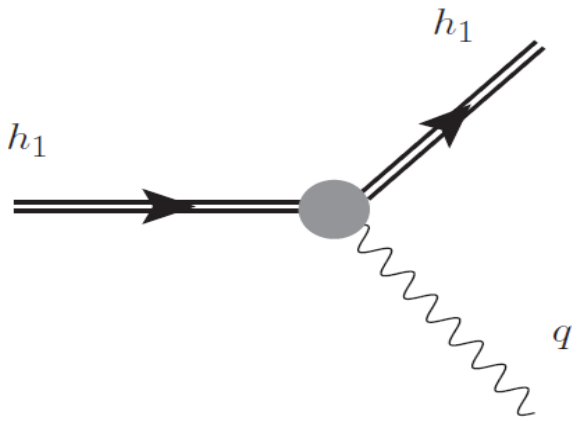

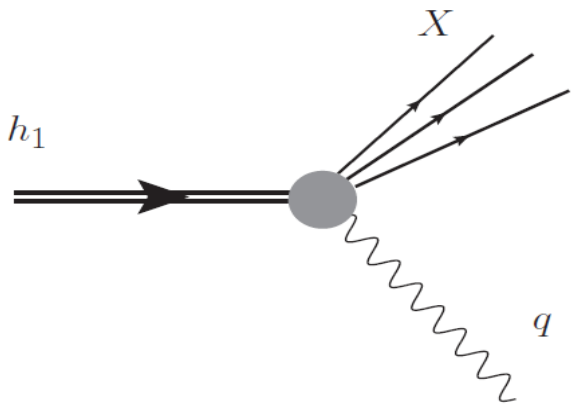

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- Several groups (MRST, NNPDF, CTEQ) have proposed to treat the photon as one of the point-like partons inside the nucleon and to account for this QED effect explicitly in the global analysis.

Photon – Hadron Interactions at the LHC:
Probing the Photon Distribution of the Proton

- The inclusion of the QED effects implies that the quark, gluon and photon distributions satisfy QED-modified DGLAP equations, which are given at leading order in both α_s and α by:

$$\begin{aligned}
\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{qq}(y)\; q_i(\frac{x}{y},\mu^2) + P_{qg}(y)\; g(\frac{x}{y},\mu^2)\Big\} \\
&+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{\tilde{P}_{qq}(y)\; e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\; e_i^2\gamma(\frac{x}{y},\mu^2)\Big\} \\
\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{gq}(y)\; \sum_j q_j(\frac{x}{y},\mu^2) + P_{gg}(y)\; g(\frac{x}{y},\mu^2)\Big\} \\
\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{\gamma q}(y)\; \sum_j e_j^2\; q_j(\frac{x}{y},\mu^2) + P_{\gamma\gamma}(y)\; \gamma(\frac{x}{y},\mu^2)\Big\}\;,
\end{aligned}$$

where

$$\begin{aligned}
\tilde{P}_{qq} &= C_F^{-1}P_{qq}, \qquad & P_{\gamma q} &= C_F^{-1}P_{gq}, \\
P_{q\gamma} &= T_R^{-1}P_{qg}, \qquad & P_{\gamma\gamma} &= -\frac{2}{3}\sum_i e_i^2\;\delta(1-y)
\end{aligned}$$

and momentum is conserved:

$$\int_0^1 dx\; x\;\Big\{\sum_i q_i(x,\mu^2) + g(x,\mu^2) + \gamma(x,\mu^2)\Big\} = 1\;.$$

Photon – Hadron Interactions at the LHC:
Probing the Photon Distribution of the Proton

- Initial condition $\gamma(x, Q_0^2)$:

  MRST: Naive model

  NNPDF: Freely parametrized

  CTEQ: Similar to that proposed by MRST, but with arbitrary normalization.

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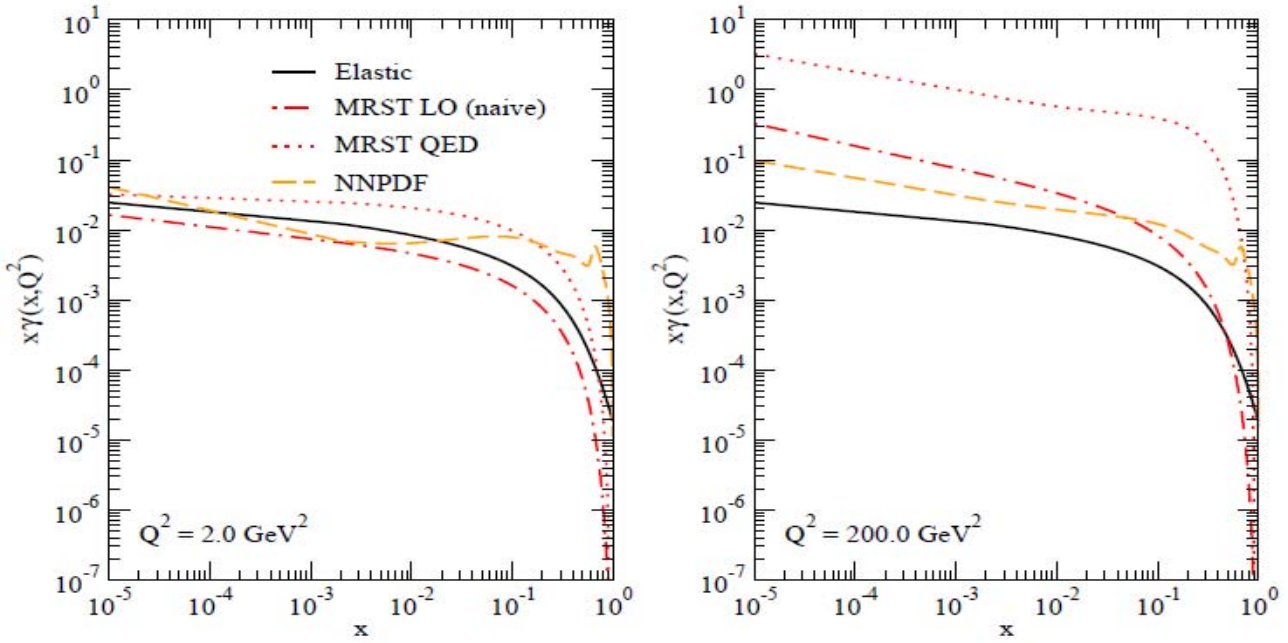
  MRST: Naive model

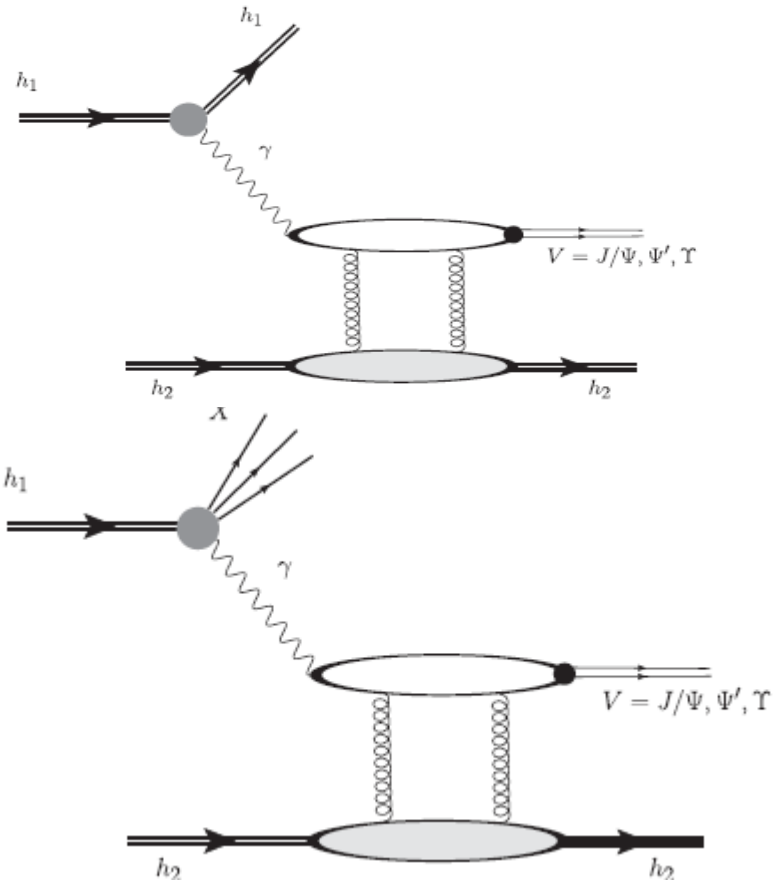
  NNPDF: Freely parametrized

  CTEQ: Similar to that proposed by MRST, but with arbitrary normalization.



Photon – Hadron Interactions at the LHC:
Probing the Photon Distribution of the Proton

- Diffractive Quarkonium Photoproduction in Hadronic Collisions as a probe of the photon flux [a].



[a] VPG, da Silveira, PRD 91, 054013 (2015)

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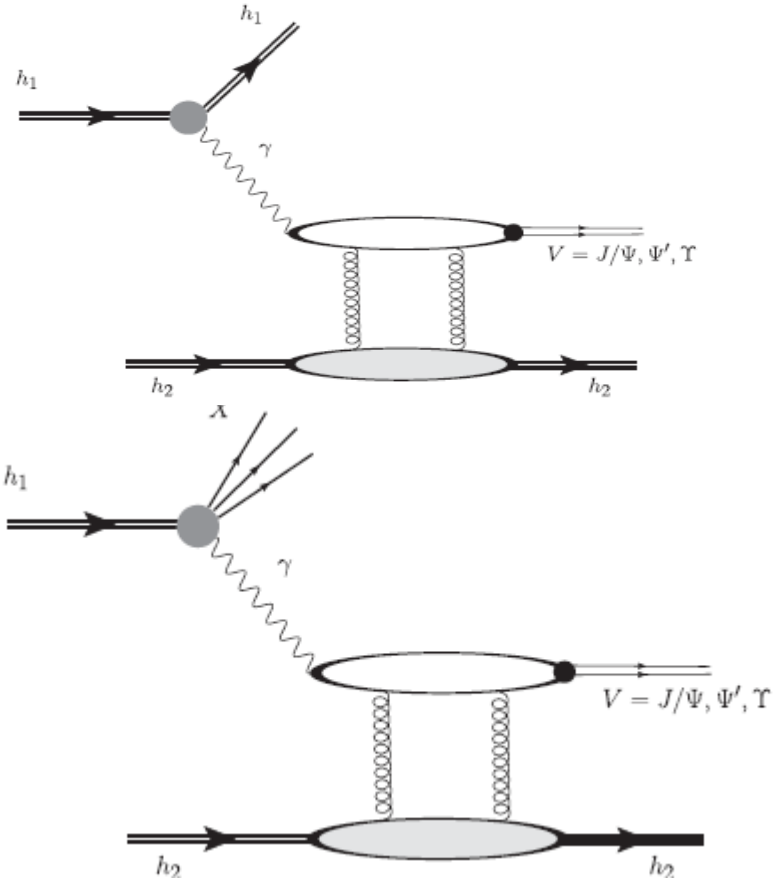

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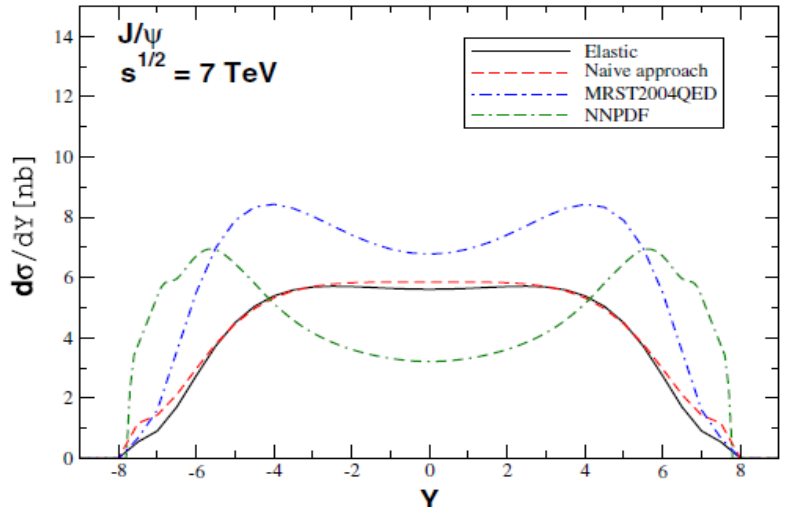

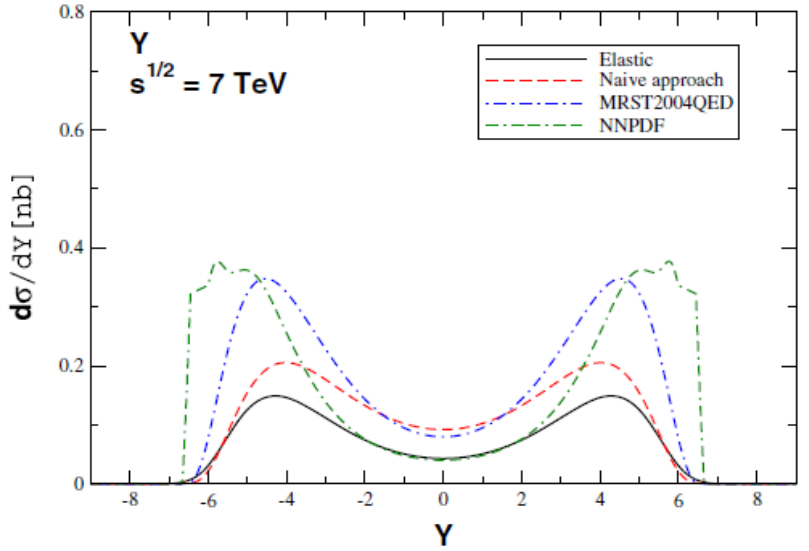

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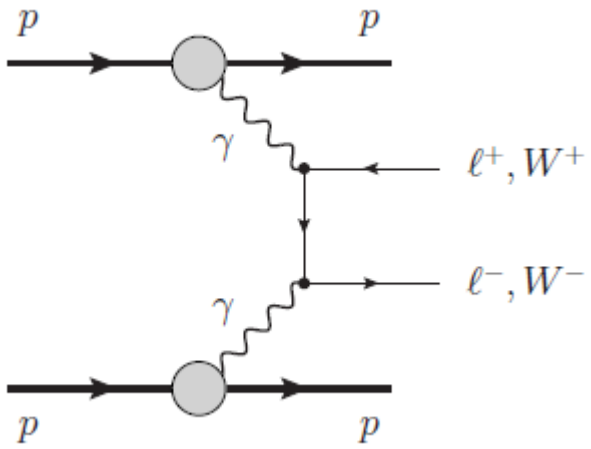

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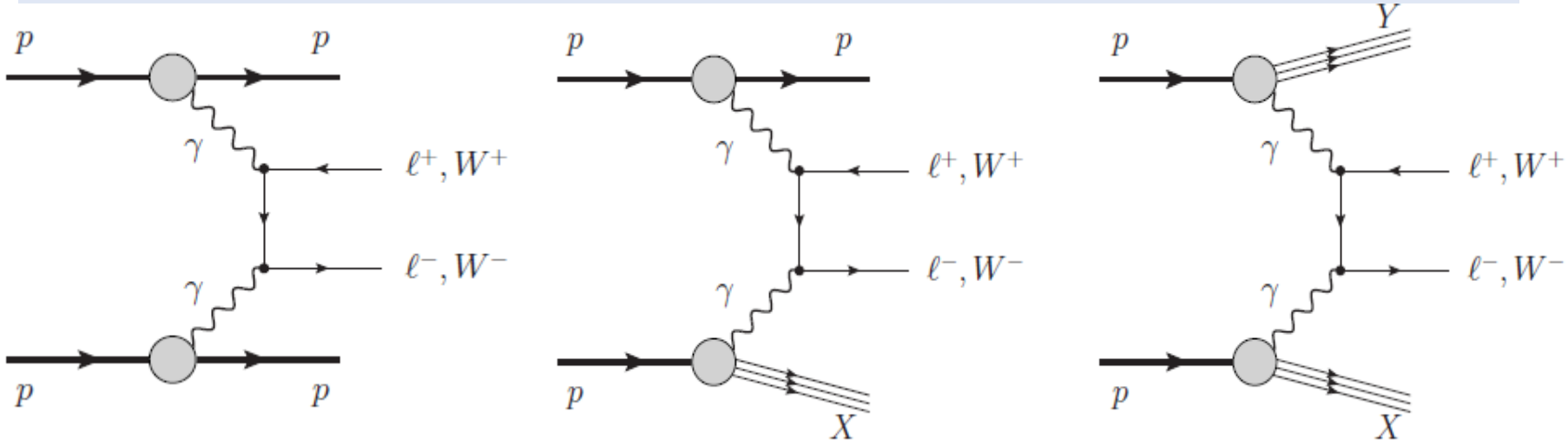

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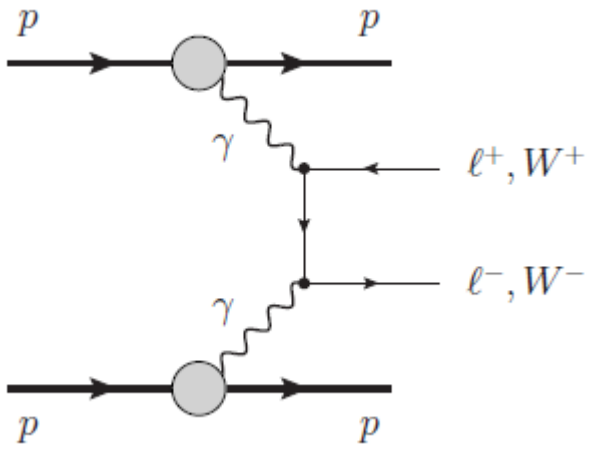

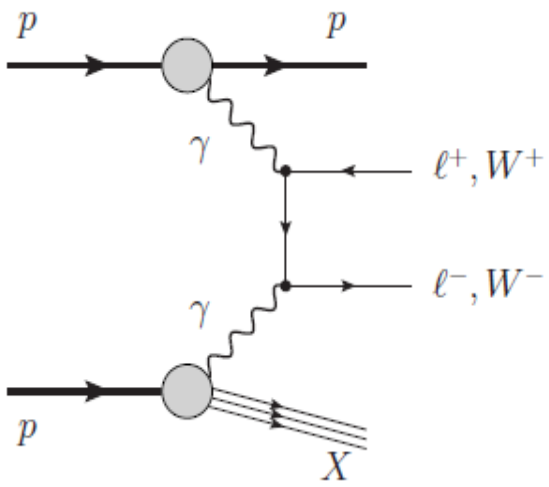

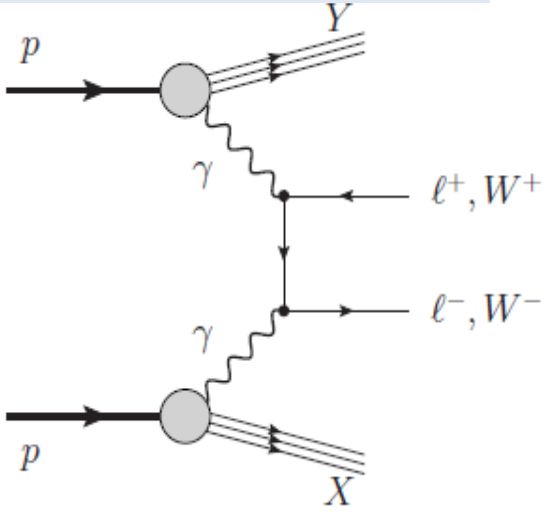

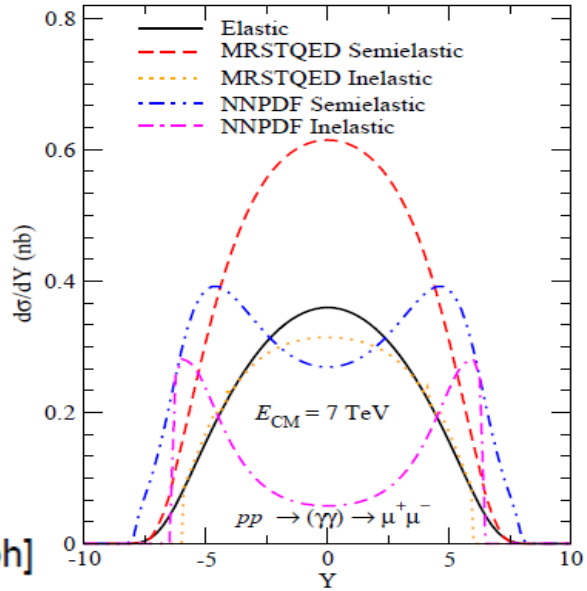

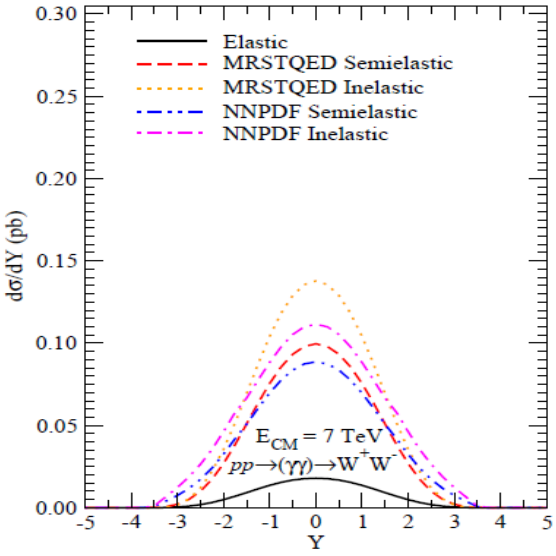

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Thank you for your attention !

Extras

Probing Quarkonium Production in photon – induced interactions

Quarkonium + Photon production in photon – induced interactions (*)

$$\frac{d\sigma[p+p\to p\otimes H+\gamma+X)]}{dY} = \omega\frac{dN_{\gamma/h_1}(\omega)}{d\omega}\sigma_{\gamma h_2\to H+\gamma+X}(\omega) + \omega\frac{dN_{\gamma/h_2}(\omega)}{d\omega}\sigma_{\gamma h_1\to H+\gamma+X}(\omega),$$

$$\sigma(\gamma+p\to H+\gamma+X) = \int dz\,dp_\perp^2\,\frac{xg(x,Q^2)}{z(1-z)}\,\frac{d\sigma}{dt}(\gamma+g\to H+\gamma)$$

$$\frac{d\sigma}{dt}(\gamma+g\to H+\gamma) = \frac{64\pi^2}{3}\,\frac{e_Q^4\alpha^2\alpha_s m_Q}{s^2}\left(\frac{s^2s_1^2+t^2t_1^2+u^2u_1^2}{s_1^2t_1^2u_1^2}\right)\langle O_8^V(^3S_1)\rangle$$

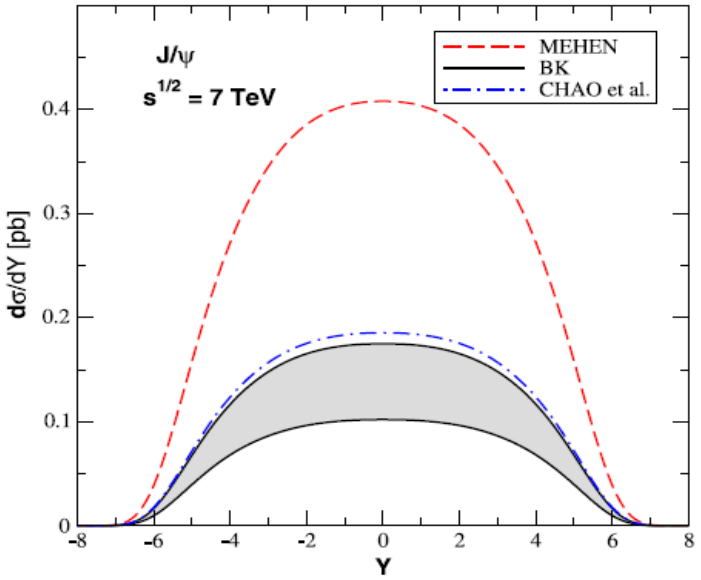
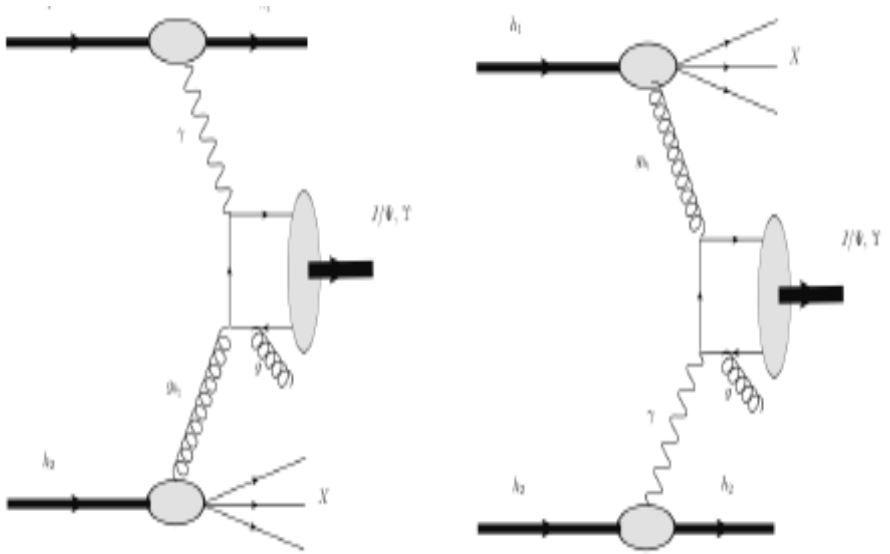


Table 1 The total cross section for the $H+\gamma$ photoproduction in coherent hadron–hadrons collisions at LHC energies

$J/\Psi+\gamma$	MEHEN	BK
LHC (7 TeV)	3.62 pb	1.23 ± 0.50 pb
LHC (14 TeV)	5.60 pb	1.90 ± 0.32 pb
$\Upsilon+\gamma$	BFL	BSV
LHC (14 TeV)	5.46 fb	1.45 ± 0.13 fb

(*) VPG, M. M. Machado, EPJC 72, 2231 (2012)

Inelastic Quarkonium production in photon – induced interactions (*)



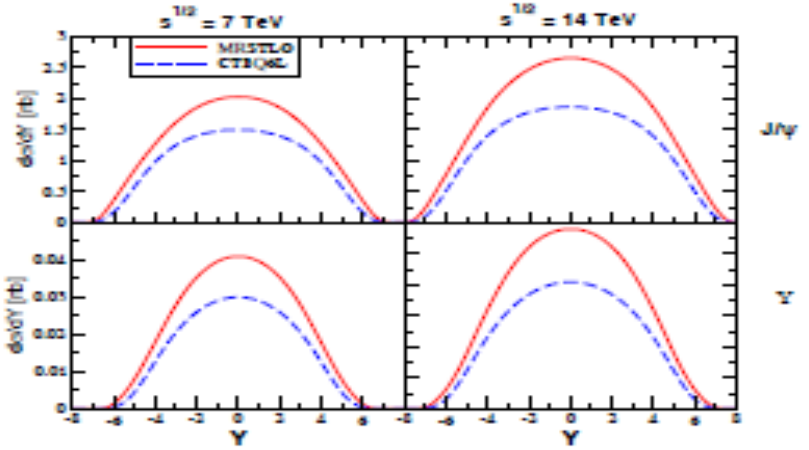


Fig. 4. Rapidity distribution for the J/Ψ and Υ production in coherent pp collisions at $\sqrt{s} = 7\,\text{TeV}$ (left panels) and $14\,\text{TeV}$ (right panels) considering two different parametrizations for

Table 1. The total cross section (event rates) for the inelastic quarkonium photoproduction in coherent pp collisions at LHC energies.

J/Ψ	MRSTLO	CTEQ6L
$\sqrt{s} = 7\,\text{TeV}$	$18.0\,\text{nb}$ (1.8×10^9)	$13.0\,\text{nb}$ (1.3×10^9)
$\sqrt{s} = 14\,\text{TeV}$	$25.0\,\text{nb}$ (2.5×10^9)	$18.0\,\text{nb}$ (1.8×10^9)
Υ	MRSTLO	CTEQ6L
$\sqrt{s} = 7\,\text{TeV}$	$0.30\,\text{nb}$ (30×10^6)	$0.21\,\text{nb}$ (21×10^6)
$\sqrt{s} = 14\,\text{TeV}$	$0.47\,\text{nb}$ (47×10^6)	$0.33\,\text{nb}$ (33×10^6)

(*) VPG, M. M. Machado, EPJA 50, 72 (2014)