Photoproduction of Upsilon states in ultraperipheral collisions at the LHC [1]

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[1]In collaboration with MB Gay Ducati, F Kopp, S Martins [PRD94 (2016) 094023, PRD96(2017)054001]

Outline

- Introduction
  - $\rightarrow$ Ultraperipheral Collisions (UPCs)
  - $\rightarrow$ The photon flux and the photoproduction cross section
  - $\rightarrow$ Exclusive photoproduction $\rightarrow$ Pomeron exchange

- Vector mesons production in pp and PbPb collisions
  - $\rightarrow$ Differential cross section calculation in the dipole formalism
  - $\rightarrow$ Vector mesons wave function
  - $\rightarrow$ Dipole cross section model

- Results for $V = (J/\Psi, \Psi', Y(1S)$ and $Y(2S, 3S))$ production
  - $\rightarrow$ Rapidity distribution of vector meson photoproduction
    - $\rightarrow$ Proton-Proton collisions
    - $\rightarrow$ Pb-Pb collisions

- Summary

Why to Investigate the Quarkonium Production?

• In pp collisions

   $\rightarrow$ Heavy-quark mass acts as a long distance cut-off

      $\rightarrow$ pQCD down to low transverse momenta (p_T).

   $\rightarrow$ Test for both perturbative and non-perturbative aspects of QCD calculations.

• In nuclear collisions

   $\rightarrow$ Open and hidden heavy-flavour production constitutes a sensitive probe of the QGP.

   $\rightarrow$ The in-medium dissociation probability of these states are expected to provide an estimate of the initial temperature reached in the collisions.

   $\rightarrow$ The nuclear modification of the PDFs can also be studied using quarkonium photoproduction in ultra-peripheral nucleus–nucleus collisions.

Quarkonium Production Mechanisms

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- Hadroproduction

    → Colour Singlet Model (CSM).

        → heavy quark pair production with the same quantum numbers as the final-state meson

    → Colour Octet Model (COM).

        → both colorless and colored states of the heavy quark pairs are considered.

        → the relative contribution of the states is parametrized

    → Colour Evaporation Model.

        → cross section of a given quarkonium is proportional to the heavy quark pair cross section.

    → NRQCD combines COM and CSM aspects.

Quarkonium Production Mechanisms

- Photoproduction

  $\rightarrow$ Vector Meson Dominance.

  $\rightarrow$ LO (NLO) perturbative QCD calculations.

  $\rightarrow$ **Colour Dipole Model.**

    $\rightarrow$ Photoproduction cross section is fatorized in photon-meson wave

function and color dipole cross section.

    $\rightarrow$ Meson wavefunction describes dipole-meson transition.

    $\rightarrow$ Dipole cross section describes dipole-target interaction.
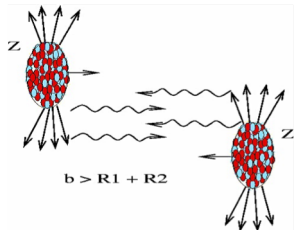
Photoproduction - Theoretical Motivation

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The photoproduction is dominant in ultra-peripheral scattering $\left(b_{\text{impact}} > 2R_A\right)$.
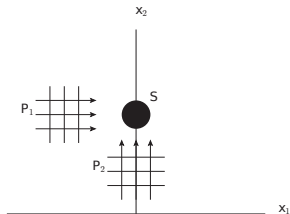

From Weizsäcker-Williams method, the UPC cross section for a given X final state can be given by

$$\sigma_X = \int d\omega \frac{dN(\omega)}{d\omega} \sigma_X^\gamma(\omega)$$
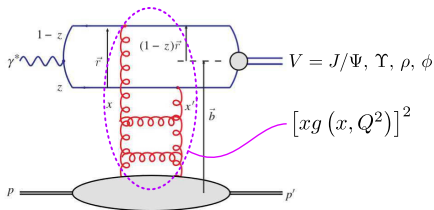
where,

$\frac{dN(\omega)}{d\omega} \rightarrow$ Photon Flux

$\sigma_X^\gamma(\omega) \rightarrow$ Photoproduction Cross Section

Exclusive vector meson photoproduction

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- $\gamma + p \to V + p \to$ has been investigated experimentally and theoretically as it allows to test perturbative Quantum Chromodynamics.

- The quarkonium masses ($\simeq 2m_c$, $2m_b$), give a perturbative scale for the problem even at $Q^2 = 0$.

- The **exclusive** photoproduction of mesons in the high energy regime is a possibility to investigate the Pomeron exchange.


Pomeron $\to$ two gluons (vacuum quantum numbers)

$x(x') \to$ gluon momentum fraction;

$z \to$ quark momentum fraction;

Diffractive production of mesons at $t = 0$

• An important class of diffractive reactions where we can use a perturbative treatment is the exclusive vector meson production in DIS: $\gamma^* p \rightarrow V p$.

• Two gluons exchange diagrams that contribute to the amplitude of the vector meson leptoproduction are shown in the figure below:

(a) (b)
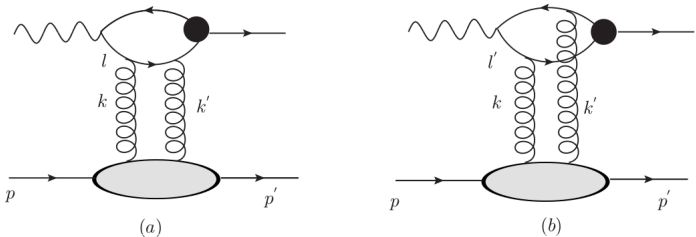
In the color dipole formalism, the amplitude can be written as:

$$A \propto \Psi^\gamma \otimes \sigma^{q\bar{q}} \otimes \Psi^V, \qquad (1)$$

Diffractive production of mesons at $t = 0$ in pQCD approach

Amplitude [2]:

$$A_T(W^2, t=0) = -4\pi^2 i\alpha_s W^2 \int \frac{dk^2}{k^4} \left(\frac{1}{l^2 - m_f^2} - \frac{1}{l'^2 - m_f^2} \right) f(x, k^2) e_c g_V M_V \quad (2)$$

$g_V^2 = 3\Gamma_{ee} M_V / 64\pi\alpha^2 \rightarrow$ specifies the $q\bar{q}$ coupling to the vector meson

$\Gamma_{ee} \rightarrow$ width decay $V \rightarrow e^+ e^-$

$e_c \rightarrow \frac{2}{3}$ for $\psi_{(1S),(2S)}$ and $\frac{1}{3}$ for $Y_{(1S),(2S)}$

$f(x, k^2) \rightarrow$ unintegrated gluons distribution.

$k, l(l') \rightarrow$ gluons transverse momentum and quark (antiquark) momentum

$m_f, m_V \rightarrow$ quark mass (m_c or m_b) and vector meson mass, respectively.

The complete differential cross section (T+L) in the ln $\tilde{Q}^2$ dominant is:

$$\frac{d\sigma^{\gamma^{(*)}p \rightarrow Vp}}{dt}\bigg|_{t=0} = \frac{16\Gamma_{e^+e^-}^V M_V^3 \pi^3}{3\alpha_{em}(Q^2 + M_V^2)^4} \left[\alpha_s(\tilde{Q}^2) x g(x, \tilde{Q}^2) \right]^2 \left(1 + \frac{Q^2}{M_V^2} \right)$$

$xg(x, \tilde{Q}^2) \rightarrow$ grows in small - $x \rightarrow$ undetermined

<u>Dipole formalism</u> $\rightarrow$ can restrict $xg(x, \tilde{Q}^2) \rightarrow$ includes gluon saturation

[2] M. G. Ryskin, Z. Phys. C 57, 89, 1993

Dipole Formalism

• In the LHC energy domain virtual photons can be considered as color dipoles in the light cone representation [3].

• The scattering process is characterized by the color dipole cross section representing their interaction with the target (includes the underlying QCD dynamics).
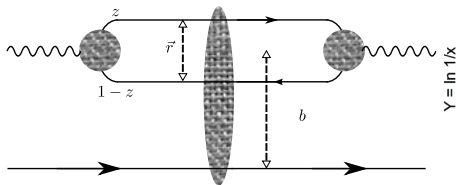
$r \rightarrow$ dipole separation.
$z(1-z) \rightarrow$ quark(antiquark) momentum fraction.
$b \rightarrow$ impact parameter.

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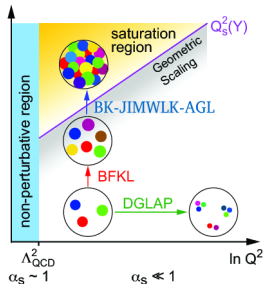
[3] N. N. Nikolaev, B. G. Zakharov, Z. Phys. C 49, 607, 1991

Quarkonium production in pp collisions

The rapidity distribution for exclusive quarkonium photoproduction is given by

$$\frac{d\sigma}{dy}(pp \to p \otimes V \otimes p) = S_{\text{gap}}^2 \left[\omega \frac{dN_\gamma}{d\omega} \sigma(\gamma p \to V + p) + (y \to -y) \right]$$

Photon flux: [4]

$$\frac{dN_\gamma(\omega)}{d\omega} = \frac{\alpha_{em}}{2\pi\,\omega} \left[1 + \left(1 - \frac{2\omega}{\sqrt{s}} \right)^2 \right] \times \left(\ln\xi - \frac{11}{6} + \frac{3}{\xi} - \frac{3}{2\xi^2} + \frac{1}{3\xi^3} \right) \quad (3)$$

$\omega \to$ photon energy

$S_{gap}^2 \sim 0.8$ for J/ψ [5] $\to$ represents the absorptive corrections due to spectator interactions between the two hadrons - Average

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[4] C. A. Bertulani, S. R. Klein and J. Nystrand, Ann. Rev. Nucl. Part. Sci. 55, 271, 2005

[5] W. Schafer and A. Szczurek, Phys. Rev. D 76, 094014, 2007

γp **cross section**

$$\sigma_{\gamma^* p \to Vp}(x, Q^2) = \frac{1}{16\pi B_V} \left| \mathscr{A}\left(x, Q^2, \Delta = 0\right)\right|^2, \qquad (4)$$

where the scattering amplitude is [6]

$$\mathscr{A}\left(x, Q^2, \Delta\right) = \sum_{h,\bar{h}} \int dz\, d^2 r\, \Psi^{\gamma}_{h,\bar{h}}\, \mathscr{A}_{q\bar{q}}(x, r, \Delta)\, \Psi^{V*}_{h,\bar{h}}, \qquad (5)$$

$B_V(W_{\gamma p}) = b_{el}^V + 2\alpha' \log\left(\frac{W_{\gamma p}}{W_0}\right)^2 \to$ diffractive slope parameter

$\alpha' = 0.25\ \text{GeV}^{-2}$

$W_0 = 95\ \text{GeV}$

$b_{el}^{\psi(1S)} = 4.99 \pm 0.41\ \text{GeV}^{-2}$ and $b_{el}^{\psi(2S)} = 4.31 \pm 0.73\ \text{GeV}^{-2}$

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[6] N. N. Nikolaev, B. G. Zakharov, Phys. Lett. B 332, 184, 1994

Light cone wave functions

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The light cone wave functions of the mesons are written as:

$$\Psi_{h,\bar{h}}^{V,L}(r,z) = \sqrt{\frac{N_c}{4\pi}} \delta_{h,-\bar{h}} \frac{1}{M_V z(1-z)} \times [z(1-z)M_V^2 + \delta(m_f^2 - \nabla_r^2)]\phi_L(r,z)$$

where $\nabla_r^2 = (1/r)\partial_r + \partial_r^2$

$$\Psi_{h,\bar{h}}^{V,T(\gamma=\pm)}(r,z) = \pm\sqrt{\frac{N_c}{4\pi}} \frac{\sqrt{2}}{z(1-z)} \{ ie^{\pm i\theta_r}[z\delta_{h\pm,\bar{h}\mp} - (1-z)\delta_{h\mp,\bar{h}\pm}]\partial_r$$

$$+ m_f \delta_{h\pm,\bar{h}\mp} \}\phi_T(r,z)$$

$N_c \rightarrow$ color number.

$h, \bar{h} = \pm\frac{1}{2} \rightarrow$ quarks helicity.

Wave functions: Boosted Gaussian Wavefunction

$\Psi(1S)$ **and** $Y(1S)$**:**

$$\phi_{T,L}^{1S}(r,z) = \mathcal{N}_{T,L} z(1-z) \exp\left\{ -\frac{m_f^2 \mathscr{R}_{1S}^2}{8z(1-z)} - \frac{2z(1-z)r^2}{\mathscr{R}_{1S}^2} + \frac{m_f^2 \mathscr{R}_{1S}^2}{2} \right\}$$

$\Psi(2S)$ and $Y(2S)$:

$$\phi_{T,L}^{2S}(r,z) = \mathcal{N}_{T,L} z(1-z) \exp\left\{ -\frac{m_f^2 \mathscr{R}_{2S}^2}{8z(1-z)} - \frac{2z(1-z)r^2}{\mathscr{R}_{2S}^2} + \frac{m_f^2 \mathscr{R}_{2S}^2}{2} \right\} [1 + \alpha_{2S} g_{2S}(r,z)]$$

$$g_{2S}(r,z) = 2 - m_f^2 \mathscr{R}_{2S}^2 + \frac{m_f^2 \mathscr{R}_{2S}^2}{4z(1-z)} - \frac{4z(1-z)r^2}{\mathscr{R}_{2S}^2}$$

$\mathcal{N}_{T,L}, \mathscr{R}_{nS}^2, \alpha_{2S} \rightarrow$ parameters obtained from the wave functions orthogonality and normalization, relation to dilepton decay width [7], [8]

Meson	m_f (GeV)	$\mathcal{N}_L$	$\mathcal{N}_T$ GeV	$\mathscr{R}^2$ (GeV^{-2})	α_{2S}	M_V (GeV)	$\Gamma_{e^+e^-}^{exp}$ (KeV)	$\Gamma_{e^+e^-}$ (KeV)
J/ψ	1.4	0.57	0.57	2.45	0	3.097	5.55±0.14	5.54
$\psi(2S)$	1.4	0.67	0.67	3.72	-0.61	3.686	2.37±0.04	2.39
$Y(1S)$	4.2	–	0.481	0.567	0	9.46	1.34±0.018	1.34
$Y(2S)$	4.2	–	0.624	0.831	-0.555	10.023	0.612±0.011	0.611

[7] N. Armesto and Amir H. Rezaeian, Phys. Rev. D90, 054003, 2014

[8] B. E. Cox, J. R. Forshaw and R.Sandapen, JHEP06, 034, 2009

Dipole Cross Section - GBW

The GBW (Golec-Biernat and Wusthoff) parametrization is given by: [9]

$$\sigma_{dip}(x, \vec{r}; \gamma) = \sigma_0 \left[1 - \exp\left(-\frac{r^2 Q_{sat}^2}{4} \right)^{\gamma_{\text{eff}}} \right]$$

$\gamma_{\text{eff}} = 1$, $m_c = 1.4$ GeV

Saturation scale $\rightarrow Q_{sat}^2(x) = \left(\frac{x_0}{x}\right)^{\lambda}$

GBW_{old} [9] $\rightarrow Q_{sat}^2(x) = \left(\frac{x_0}{x}\right)^{\lambda}$ $\sigma_0 = 29.12$, $x_0 = 0.41 \times 10^{-4}$ and $\lambda = 0.277$

GBW_{new} [10] (consider the effect of the gluon number fluctuations) $\rightarrow \sigma_0 = 31.85$,

$x_0 = 0.0546 \times 10^{-4}$ and $\lambda = 0.225$

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[9] K. Golec-Biernat and M. Wusthoff, Phys. Rev. D 59, 014017, 1999

[10] M. Kozlov, A. Shoshi and W. Xiang, JHEP 0710, 020, 2007

Dipole cross section - CGC

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Color Glass Condensate parametrization (CGC): [11]

$$\sigma_{q\bar{q}}^{CGC}(x,r) = \sigma_0 \times \begin{cases} N_0 \left(\frac{rQ_s}{2}\right)^{2(\gamma_s + (1/\kappa \lambda Y)\ln(2/rQ_s))}, & rQ_s \leq 2 \\ 1 - e^{-A\ln^2(BrQ_s)}, & rQ_s > 2 \end{cases}$$

$Q_s^{CGC} = (x_0/x)^{\lambda/2} GeV \rightarrow$ saturation scale

$N_0 = 0.7$, $\kappa = 9.9 \rightarrow$ fixed to their LO BFKL values

R, x_0, λ and $\gamma_s \rightarrow$ free parameters of the fit (with $\sigma_0 = 2\pi R^2$)

$A = \frac{-N_0^2 \gamma_s^2}{(1-N_0)^2 \ln(1-N_0)}$, $B = \frac{1}{2}(1-N_0)^{-(1-N_0)/N_0 \gamma_s}$

CGC_{old} ($m_c = 1.4$ GeV)[12] $\rightarrow$ $\sigma_0 = 27.33$, $x_0 = 0.1632 \times 10^{-4}$, $\lambda = 0.2197$ and $\gamma_s = 0.7376$

CGC_{new} ($m_c = 1.27$ GeV)[13] $\rightarrow$ $\sigma_0 = 21.85$, $x_0 = 0.6266 \times 10^{-4}$, $\lambda = 0.2319$ and $\gamma_s = 0.762$

[11] E. Iancu, K. Itakura and S. Munier, Phys. Lett. B 590, 199, 2004

[12] G. Soyez, Phys. Lett. B 655,32, 2007

[13] A.H. Rezaeain and I. Schmidt, Phys. Rev. D 88, 074016, 2013

Dipole cross section - BCGC

Color Glass Condensate parametrization (b-CGC): [14]

$$N_{q\bar{q}}^{bCGC}(x,r) = \begin{cases} N_0 \left(\frac{rQ_s}{2}\right)^{2(\gamma_s + (1/\kappa\lambda Y)\ln(2/rQ_s))}, & rQ_s \leq 2 \\ 1 - e^{-A\ln^2(BrQ_s)}, & rQ_s > 2 \end{cases}$$

$Q_s^{bCGC} = (x_0/x)^{\lambda/2} \left[\exp\left(-\frac{b^2}{2B_{CGC}}\right)\right]^{1/2\gamma_s} GeV \rightarrow$ saturation scale

$B_{CGC} = 7.5 GeV^{-2}$

$\gamma_s = 0.46$ and $\kappa = 9.9 \rightarrow$ fixed to its LO BFKL value

$x_0, \lambda \rightarrow$ free parameters of the fit

$A = \frac{-N_0\gamma_s^2}{(1-N_0)^2 \ln(1-N_0)}, B = \frac{1}{2}(1-N_0)^{-(1-N_0)/N_0\gamma_s}$

$b - CGC_{old}^{14} \rightarrow x_0 = 0.0184 \times 10^{-4}, \lambda = 0.119$ and $\gamma_s = 0.46$

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[14] G. Watt and H. Kowalski, Phys. Rev. D 78, 014016, 2008

$\Psi(1S)$ **and** $\Psi(2S)$ **cross check**
Integrated cross section:

Table: Total cross section in the rapidity region $2.0 < \eta < 4.5$ (in units of *pb*) for photoproduction of the $\psi(1S, 2S)$ (corrected for acceptance) states in *pp* collisions at $\sqrt{s} = 7$ TeV compared to the LHCb data [15].

$\sigma_{pp \to J/\psi \to \mu^+ \mu^-}$	*GBW*	*CGC^{old}*	*CGC^{new}*	*BCGC^{old}*	*GBW^{ksx}*	LHCb measure
$\psi(1s)$	277.60	213.69	199.58	154.57	170.81	291 ± 20.24
$\psi(2s)$	8.40	5.94	5.98	4.13	4.39	6.5 ± 0.98

Cross section ratio (with BG wave function):
$[\psi(2S)/\psi(1S)]_{2<y<4.5} = 0.028 \pm 0.02$
LHCb: $[\psi(2S)/\psi(1S)](2.0 < \eta_\mu < 4.5) = 0.022$

[15] LHCb Collaboration, J. Phys. G 41, 055002, 2014.

$Y(1S)$ **rapidity distribution in** pp **collisions at 7 TeV**

Photoproduction of Y(1S) - LHC - $s^{1/2}$ = 7 T
p + p --> p + Y(1S) + p
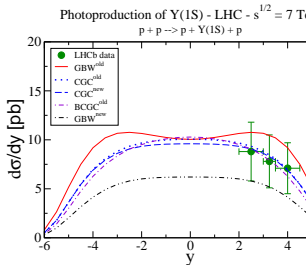
- Predictions to rapidity distribution at LHC ($7\,TeV$) for pp collisions [a];
- The models GBW, CGC and b-CGC were considered for the dipole cross section ($m_b = 4.5$ GeV);

$$B_V(W_{\gamma p}) = b_{el}^V + 2\alpha' \log\left(\frac{W_{\gamma p}}{W_0}\right)^2$$

$\alpha' = 0.164$ GeV^{-2}

$W_0 = 95$ GeV

$b_{el}^{\Upsilon} = 3.68$ GeV^{-2}

[a] LHCb Coll., JHEP 1509, 084 (2015)

Figure: The rapidity distribution of $Y(1S)$ photoproduction at $\sqrt{s} = 7\,TeV$

$Y(1S)$ **and** $Y(2S)$ **rapidity distribution in** *pp* **collisions at 13 TeV**

Photoproduction of Y(1S) - LHC - $s^{1/2}$ = 13 TeV
p + p --> p + Y(1S) + p
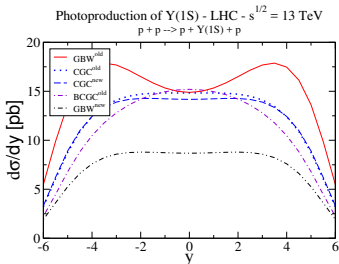
- Predictions to rapidity distribution at LHC (13 *TeV*), for pp collisions;
- The models GBW and CGC were considered for the dipole cross section;

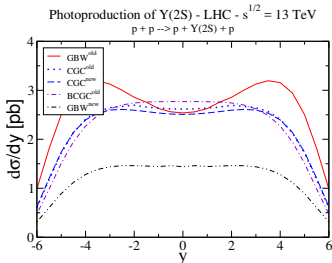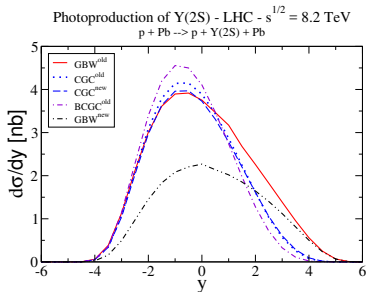Figure: The rapidity distribution of $Y(1S)$ and photoproduction at $\sqrt{s} = 13\,TeV$

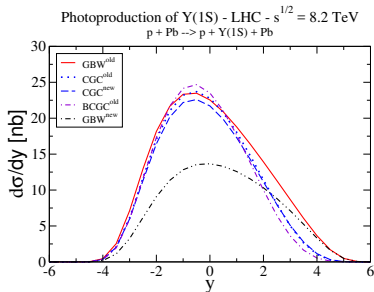# $Y(1S)$ **and** $Y(2S)$ **rapidity distribution in** *pp* **collisions at 13 TeV**

Photoproduction of Y(2S) - LHC - $s^{1/2}$ = 13 TeV
p + p --> p + Y(2S) + p

- Predictions to rapidity distribution at LHC (13 *TeV*), for pp collisions;
- The models GBW and CGC were considered for the dipole cross section;

Figure: The rapidity distribution of $Y(2S)$ and photoproduction at $\sqrt{s} = 13\,TeV$

Prediction for *pA* collisions

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Photoproduction of Y(1S) - LHC - $s^{1/2}$ = 8.2 TeV
p + Pb --> p + Y(1S) + Pb

Photoproduction of Y(2S) - LHC - $s^{1/2}$ = 8.2 TeV
p + Pb --> p + Y(2S) + Pb

- Predictions to rapidity distribution at LHC (8.2 *TeV*) for pA collisions.

$Y(1S)$, $Y(2S)$ **production in AA collisions**

Coherent process:

$$AA \rightarrow AA + V.$$

$\Rightarrow$ nuclei remain intact.

Incoherent process:

$$AA \rightarrow AA^* + V.$$

$\Rightarrow$ involves modification of one of the participating nuclei.

Incoherent cross section: [16]

$$\sigma^{coh}(\gamma A \to VA) = \int d^2b \left\{ | \int d^2r \int dz \Psi_V^*(r,z) \right.$$
$$\left. \times \left(1 - \exp\left[-\tfrac{1}{2}\sigma_{dip}(x,r) T_A(b) \right] \right) \Psi_{\gamma^*}(r,z,Q^2)|^2 \right\}$$

$\sigma_{dip} \to$ dipole cross section.

$\Psi_V \to$ vector meson wave function.

$\Psi_\gamma \to$ photon wave function.

$T_A(b) = \int dz \rho_A(b,z)$

$\rho_A(b,z) \to$ nuclear thickness function.

$b \to$ impact parameter.

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[16] B. Z. Kopeliovich and B. G. Zakharov, Phys. Rev. D 44, 3466, 1991

Rapidity distribution in Pb-Pb collisions for $\Upsilon(1S), \Upsilon(2S)$

Photoproduction of Y(1S) - LHC - $s^{1/2}$ = 5.5 TeV
Pb + Pb --> Pb + Y(1S) + Pb

Photoproduction of Y(2S) - LHC - $s^{1/2}$ = 5.5 TeV
Pb + Pb --> Pb + Y(2S) + Pb
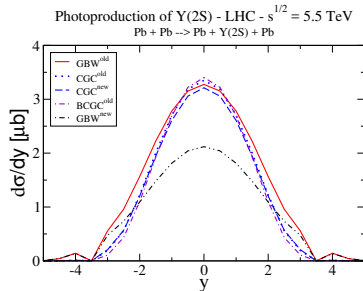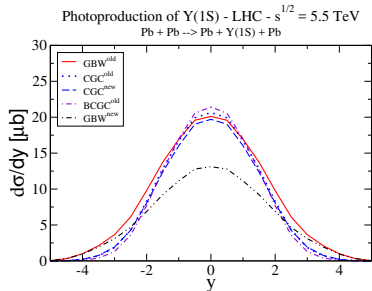
- Predictions to rapidity distribution at LHC (5.5 *TeV*) for AA collisions.

$\Upsilon(3S)$ **rapidity distribution in pPb and PbPb collisions**

GFPAE

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Photoproduction of Y(3S) - LHC - $s^{1/2}$ = 8.2 TeV
p + Pb --> p + Y(3S) + Pb

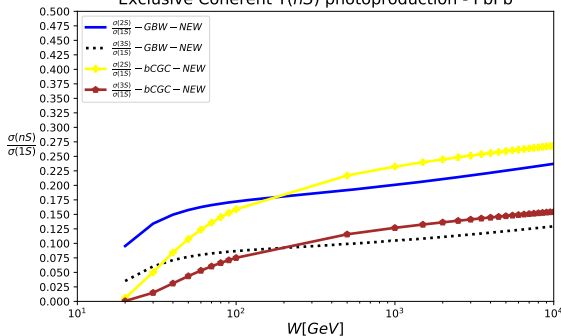Photoproduction of Y(3S) - LHC - $s^{1/2}$ = 5.5 TeV
Pb + Pb --> Pb + Y(3S) + Pb

- Predictions for rapidity distribution of $\Upsilon(3S)$ state in for pA and AA collisions.

Relative contribution od radial states in PbPb

Coherent cross section ratios (for distinct dipole models): [17]

$$\frac{\sigma(nS)}{\sigma(1S)} = \frac{\sigma(\gamma A \to \Upsilon(nS)A)}{\sigma(\gamma A \to \Upsilon(1S)A)}$$

Exclusive Coherent Y(nS) photoproduction - PbPb

[17] Gay Ducati, Kopp, MVTM, Phys. Rev. D 96, 054001, 2017

Incoherent $Y(1S)$, $Y(2S)$ **production in AA collisions**

Inoherent cross section: [18]

$$\sigma^{inc}(\gamma A \to VA^*) = \int d^2 b \frac{T_A(b)}{16\pi B_V} \left\{ \left| \int d^2 r \int dz \Psi_V^*(r,z) \right. \right.$$
$$\left. \left. \times \left[\sigma_{dip}(x,r) \exp\left(-\frac{1}{2}\sigma_{dip}(x,r)T_A(b)\right) \right] \Psi_{\gamma^*}(r,z,Q^2) \right|^2 \right\}$$

$\sigma_{dip} \to$ dipole cross section.

$\Psi_V \to$ vector meson wave function.

$\Psi_\gamma \to$ photon wave function.

$T_A(b) = \int dz \rho_A(b,z)$

$\rho_A(b,z) \to$ nuclear thickness function.

$b \to$ impact parameter.

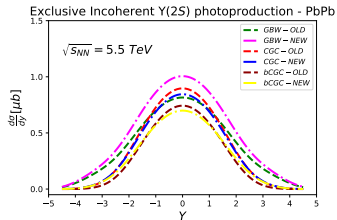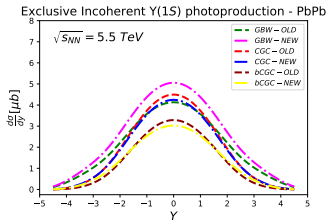[18] B. Z. Kopeliovich and B. G. Zakharov, Phys. Rev. D 44, 3466, 1991

- Predictions to rapidity distribution at LHC ($5.5\,TeV$) for PbPb collisions.

$\Upsilon(3S)$ **rapidity distribution in incoherent PbPb collisions**

Exclusive Incoherent Υ(3S) photoproduction - PbPb

$\sqrt{s_{NN}} = 5.5$ TeV
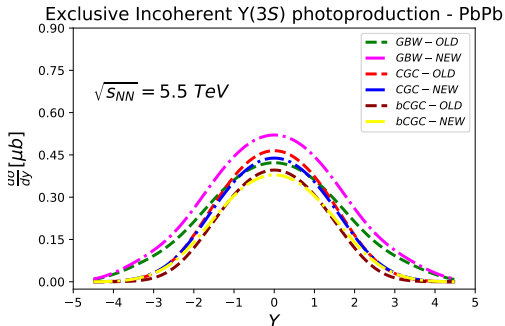
- Predictions for rapidity distribution of $\Upsilon(3S)$ state in incoherent AA collisions.

Summary

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Introduction

Cross
Section
Calculation

Results

Summary

pp:

- The rapidity distributions of mesons $\Psi(1S)$, $\Psi(2S)$, $\Upsilon(1S)$ and $\Upsilon(2S)/\Upsilon(3S)$ production were calculated in pp collisions using the dipole formalism. Focus on the Upsilon states.

- The predictions for $\Psi(1S)$ and $\Psi(2S)$ rapidity distributions and integrated cross sections are consistent with LHCb data.

- The results for $\Upsilon(1S)$ are consistent with LHCb data and predictions to higher energies have been done. Some results for *pA* case were presented.

PbPb:

- The coherent production of mesons $\Upsilon(1S)$ and $\Upsilon(2S,3S)$ has been calculated in Pb-Pb collisions using the dipole formalism (including relative contributions).

- Results for incoherent $\Upsilon(nS)$ production in *PbPb* were presented for sake of completeness.

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Thank You!