Inclusive diffractive heavy quarkonium photoproduction in pp, pA and AA collisions

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Outline

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Motivation

◆ The heavy quarkonium through photoproduction processes provide a unique way to test QCD.

- probing the generalized gluon density at small x

◆ The heavy quarkonium production mechanism has been studied by various approaches:

- NRQCD factorization Phys. Rev. D 51 (1995) 1125
- pQCD fragmentation function factorization Phys. Lett. B 613 (2005) 45
- Color dipole model Phys. Rev. D 88 (2013) 074016
- VMD model Phys. Rev. C 95 (2017) 025204.
- …

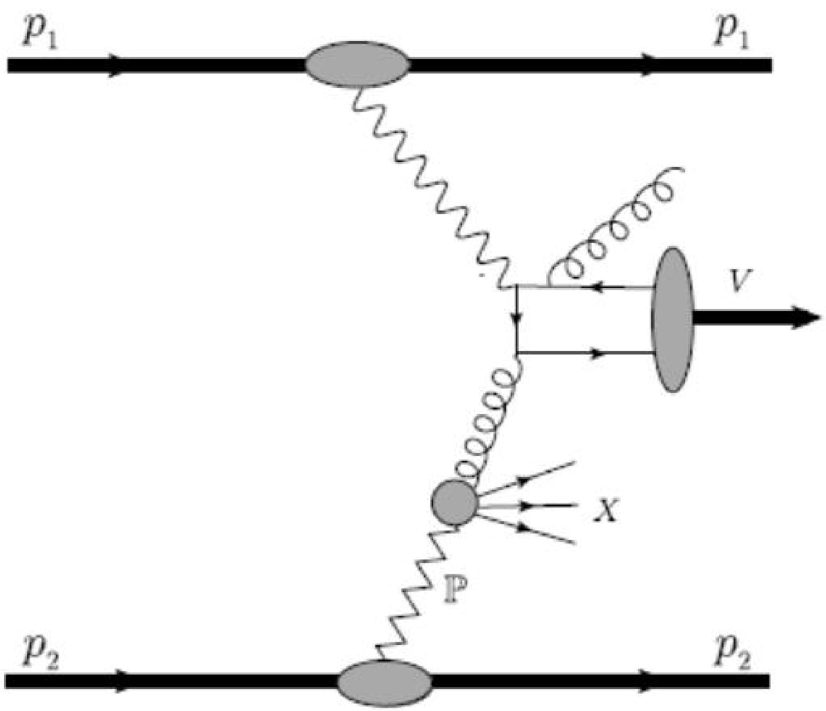
We would like to enhance the precision of the NRQCD factorization through including the resolved photoproduction processes.

We focus on the Inclusive diffractive heavy quarkonium photoproduction.

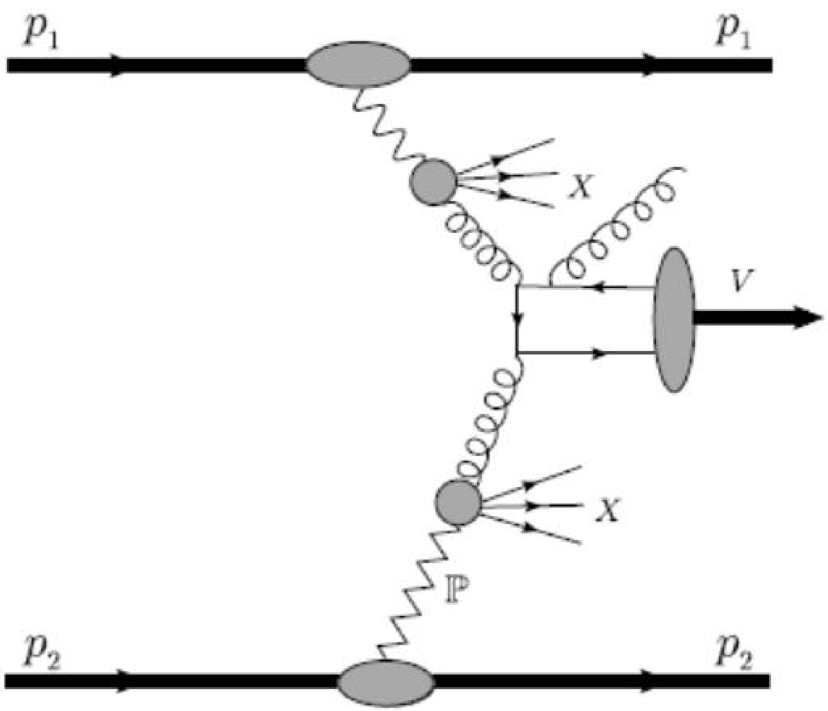
1. The inclusive events
2. The exclusive events
3. The diffractive events

The inclusive diffractive events refer to the fact that the heavy quarkonium is produced by pomeron breakup in the proton, while the proton itself is still intact.

The schematic diagram of inclusive diffractive heavy quarkonium photoproduction.



The direct photoproduction processes



The resolved photoproduction processes

Inclusive diffractive heavy quarkonium photoproduction in NRQCD

The total cross section for the heavy quarkonium photoproduction is given by

$$\sigma(p_1 + p_2 \to p_1 \otimes V + X \otimes p_2) = \int d\omega \frac{dN_{\gamma/p_1}(\omega)}{d\omega} \sigma_{\gamma p_2 \to VX \otimes p_2}(W_{\gamma p_2}) + \int d\omega \frac{dN_{\gamma/p_2}(\omega)}{d\omega} \sigma_{\gamma p_1 \to VX \otimes p_1}(W_{\gamma p_1}),$$

$$W_{\gamma p} = \sqrt{2\omega\sqrt{s}}, \quad \omega = \frac{M}{2} exp(\pm y),$$

The equivalent photon flux of the relativistic proton is given by

$$\frac{dN_{\gamma/p}(\omega)}{d\omega} = \frac{\alpha_{em}}{2\pi\omega}\left[1 + (1 - \frac{2\omega}{\sqrt{s}})^2\right] \times \left(\ln\eta - \frac{11}{6} + \frac{3}{\eta} - \frac{3}{2\eta^2} + \frac{1}{3\eta^3}\right)$$ Phys. Rev. D 50 (1994) 2335

The rapidity distribution of heavy quarkonium inclusive diffractive photoproduction is given by

$$\frac{d\sigma(p_1 + p_2 \to p_1 \otimes V + X \otimes p_2)}{dy} = \omega \frac{dN_{\gamma/p_1}(\omega)}{d\omega} \sigma_{\gamma p_2 \to VX \otimes p_2}(\omega) + \omega \frac{dN_{\gamma/p_2}(\omega)}{d\omega} \sigma_{\gamma p_1 \to VX \otimes p_1}(\omega),$$

The total cross section for direct heavy quarkonium photoproduction can be written as

$$\sigma(\gamma + p \to V + X \otimes p) = \int dz dp_T^2 \frac{x_1 g_h(x_1, Q^2)}{z(1-z)} \frac{d\sigma}{dt}(\gamma + g \to V + g).$$

$$z = (p_q \cdot p_h)/(p_\gamma \cdot p_h)$$

$$x_1 = \frac{p_T^2 + M^2(1-z)}{W_{\gamma p} z(1-z)}$$

dσ/dt is partonic differential cross section

g_h is the diffractive gluon distribution

$$g_h(x, Q^2) = \int_x^1 \frac{dx_{\mathbb{P}}}{x_{\mathbb{P}}} f_{\mathbb{P}/p}(x_{\mathbb{P}}) g_{\mathbb{P}}\left(\frac{x}{x_{\mathbb{P}}}, Q^2\right)$$

Phys. Lett. B 152 (1985) 256

Resolved photoproduction processes

The total cross section for resolved heavy quarkonium photoproduction can be written as

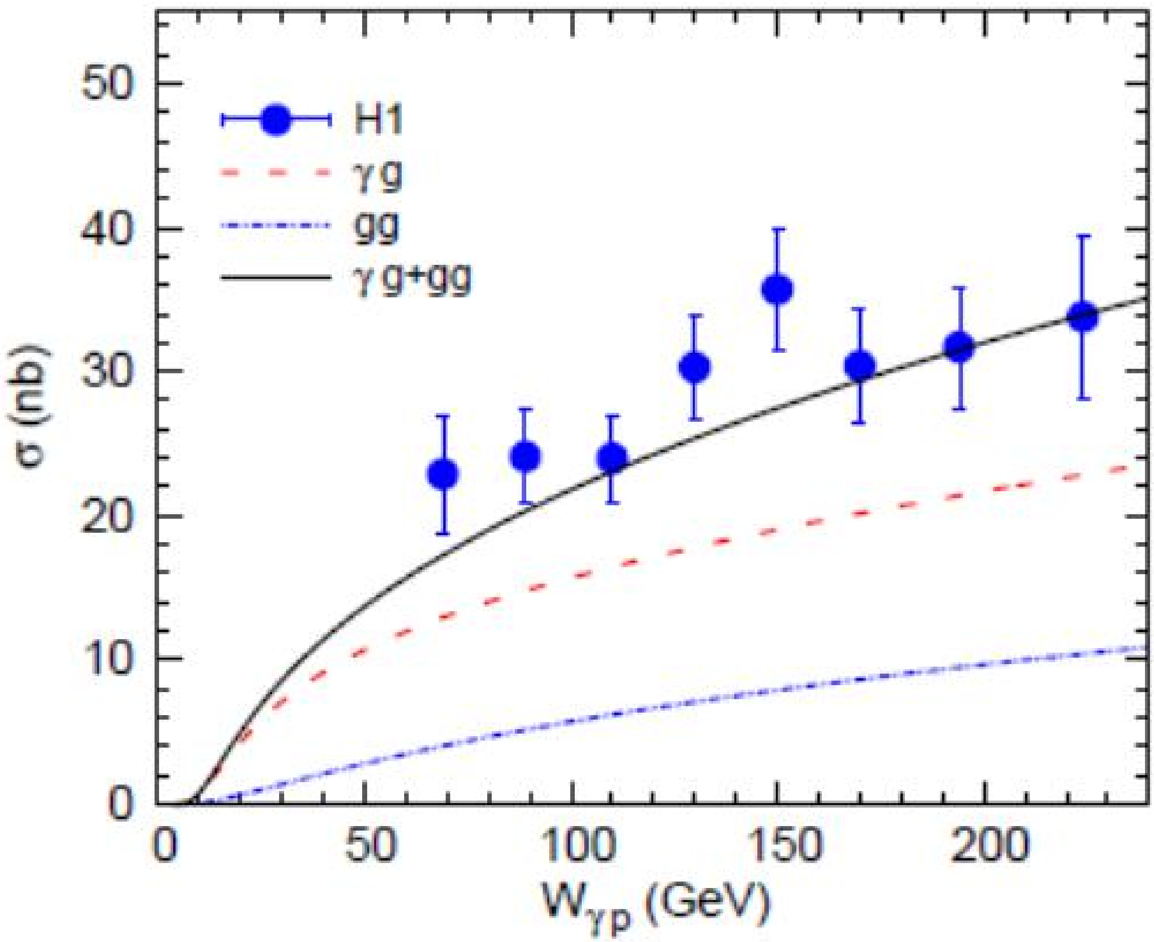
$$\sigma(g_\gamma + p \to V + X \otimes p) = \int dz dp_T^2 dx_3 \frac{x_2 g_h(x_2, Q^2) x_3 g_\gamma(x_3, Q^2)}{z(1 - \frac{z}{x_3})} \frac{d\sigma}{dt}(g + g \to V + g),$$

$$x_2 = \frac{x_3 p_T^2 + M^2(x_3 - z)}{W_{\gamma p} z(1 - \frac{z}{x_3})}$$

$g_\gamma(x_3, Q^2)$ is the photon structure function

Phys. Rev. D 60 (1999) 054019

Results for inclusive processes



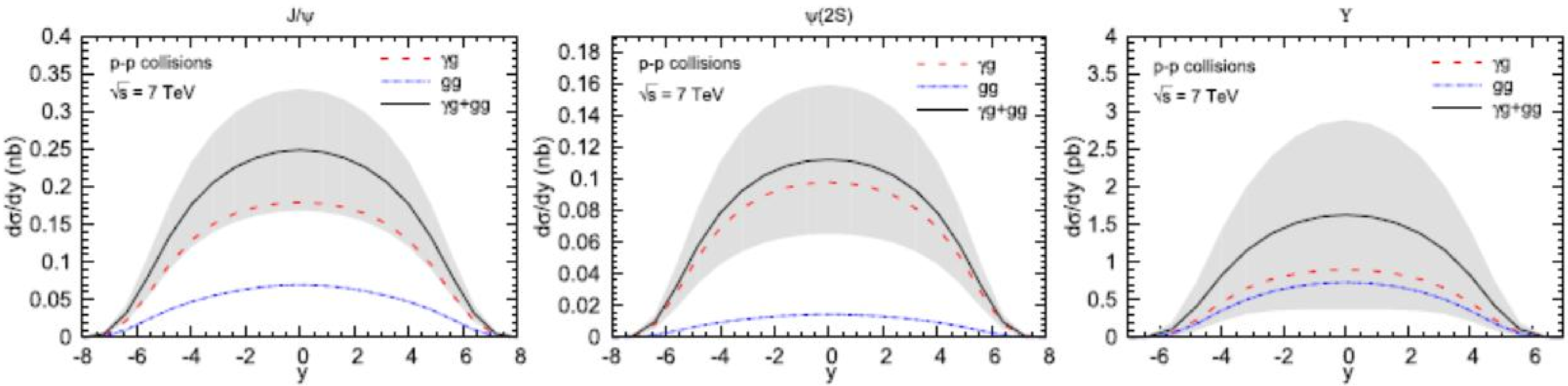
$$Q^2 = p_T^2$$

$$0.3 \leq z \leq 0.9$$

$$p_{T,\mathrm{min}} = 1\,\mathrm{GeV}$$

The contribution from resolved photoproduction processes in the region of larger Wγp can reach to about 28%.

Results for inclusive diffractive processes--------pp collisions



The contribution of resolved photoproduction processes can reach to 28%, 13% and 44%.

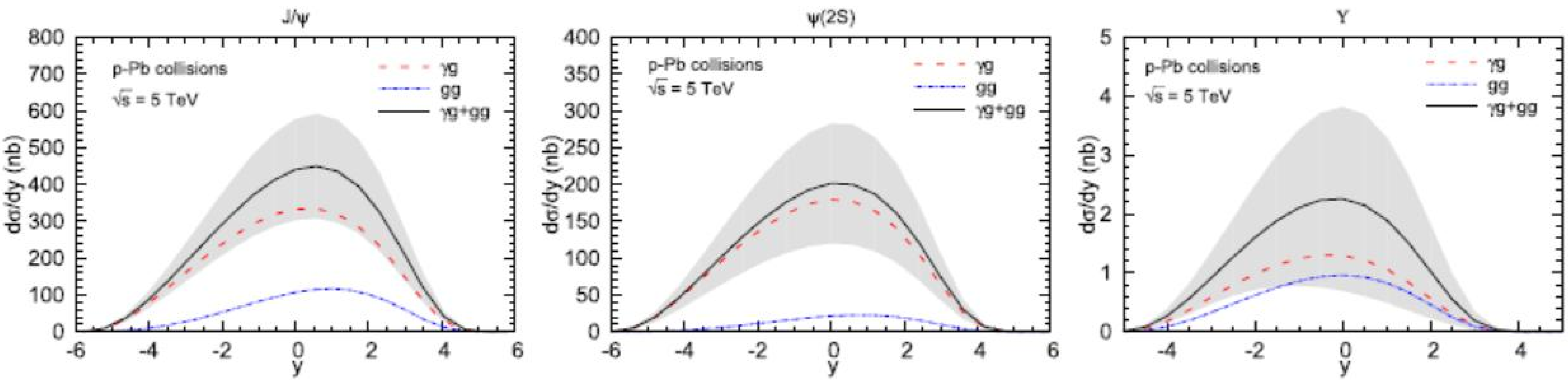
Results for inclusive diffractive processes--------pPb collisions

The equivalent photon flux of nucleus becomes

$$\frac{dN_{\gamma/A}(\omega)}{d\omega} = \frac{2Z^2\alpha_{em}}{\pi\,\omega}\left[\xi K_0(\xi) K_1(\xi) - \frac{\xi^2}{2}\left(K_1^2(\xi) - K_0^2(\xi)\right)\right],$$ Phys. Rep. 458 (2008) 1

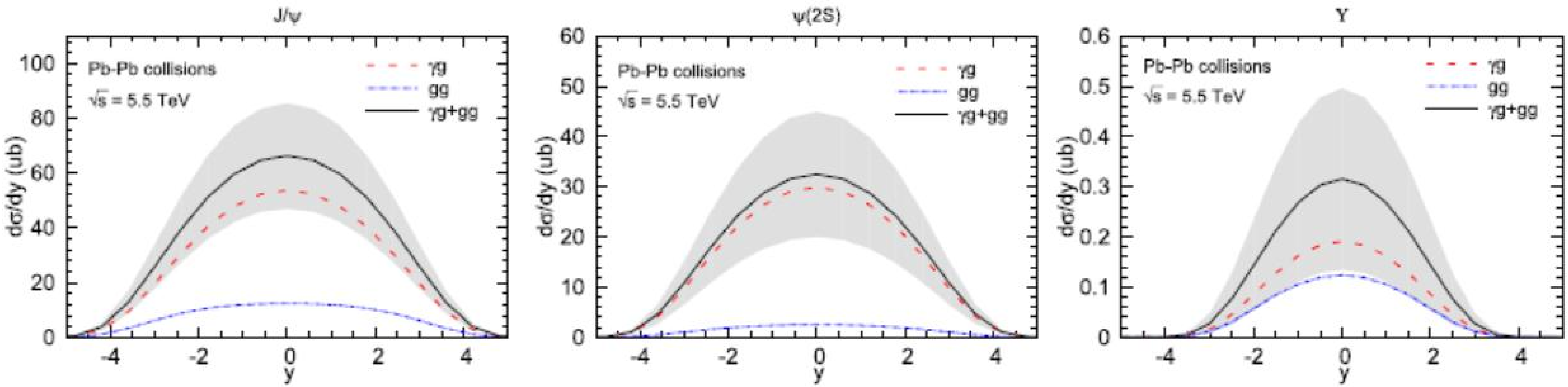
In nucleus processes, the diffractive gluon distribution can be expressed as

$$g_A(x, Q^2) = R_g A^2 \int_x^1 \frac{dx_{\mathbb{P}}}{x_{\mathbb{P}}}\left[f_{\mathbb{P}/p}(x_{\mathbb{P}}) \cdot F_A^2(t)\right] g_{\mathbb{P}}\left(\frac{x}{x_{\mathbb{P}}}, Q^2\right),$$ Eur. Phys. J. C 77(9) (2017) 600



The contribution of resolved photoproduction processes can reach to 27%, 12% and 44%.

Results for inclusive diffractive processes--------PbPb collisions



The contribution of resolved photoproduction processes can reach to 21%, 8% and 40%.

Results for inclusive diffractive processes

	pp ($\sqrt{s}=7$ TeV)		pPb ($\sqrt{s}=5$ TeV)		$PbPb$ ($\sqrt{s}=5.5$ TeV)	
	γg	gg	γg	gg	γg	gg
J/Ψ	1.70 nb	0.65 nb	1.86 μb	0.69 μb	0.27 mb	0.072 mb
$\Psi(2S)$	0.91 nb	0.13 nb	0.93 μb	0.13 μb	0.15 mb	0.014 mb
Υ	6.98 pb	5.53 pb	4.76 nb	3.73 nb	0.72 μb	0.48 μb

1. The differential cross sections of ϒ photoproduction is smaller than the J/ψ and ψ(2S).
2.The contributions from resolved photoproduction processes for upsilon production are larger than J/ψ and ψ(2S).

Summary

1. Using the NRQCD factorization formalism, we have studied the distributions of total cross sections of inclusive J/ψ production. It shows that the resolved photoproduction processes has a significant effect in heavy quarkonium photoproduction.

2. We predict the rapidity distributions of J/ψ, $\psi(2S)$ and Υ inclusive diffractive photoproduction in pp, pPb and PbPb collisions at LHC energies. We found that the contributions from resolved photoproduction processes for upsilon production are larger than J/ψ and $\psi(2S)$.

Thank you for your attention

Backup

The photon-gluon processes

$$\frac{d\sigma}{dt}\left[{}^3S_1^{(1)}\right] = \frac{Me^2e_c^2g^4\,\langle 0|\,\mathcal{O}({}^3S_1^{(1)})\,|0\rangle}{27\pi s^2}\frac{s^2(s-M^2)^2+t^2(t-M^2)^2+u^2(u-M^2)^2}{(s-M^2)^2(t-M^2)^2(u-M^2)^2}$$

$$\frac{d\sigma}{dt}\left[{}^{2S+1}L_J^{(8)}\right] = \frac{(ee_cg^2)^2}{16\pi s^2}\frac{\langle 0|\,\mathcal{O}^{J/\psi}({}^{2S+1}L_J^{(1,8)})\,|0\rangle}{m(2J+1)} \times f({}^{2S+1}L_J^{(8)})$$

Backup

The gluon-gluon processes

$$\frac{d\sigma}{dt}\left[{}^3S_1^{(1)}\right] = \frac{5g_s^6\langle 0|\mathcal{O}^{J/\psi}({}^3S_1^{(1)})|0\rangle M}{216\pi s^2(s+t)^2(s+u)^2(t+u)^2} \times[t^2u^2+stu(t+u)+s^2(t^2+tu+u^2)]$$

$$\frac{d\sigma}{dt}\left[{}^1S_0^{(8)}\right] = \frac{5g_s^6\langle 0|\mathcal{O}^{J/\psi}({}^1S_0^{(8)})|0\rangle}{1024\pi M s^3 t(s+t)^2 u(s+u)^2(t+u)^2}$$
$$\times[t^2u^2(4t^4+8t^3u+13t^2u^2+8tu^3+4u^4)$$
$$+2stu(t+u)(2t^4+8t^3u+15t^2u^2+8tu^3+2u^4)$$
$$+s^2(4t^6+20t^5u+71t^4u^2+108t^3u^3+71t^2u^4+20tu^5+4u^6)$$
$$+2s^3(t+u)(4t^4+19t^3u+35t^2u^2+19tu^3+4u^4)$$
$$+s^4(13t^4+46t^3u+71t^2u^2+46tu^3+13u^4)$$
$$+4s^5(t+u)(2t^2+3tu+2u^2)$$
$$+4s^6(t^2+tu+u^2)]$$