Exclusive charmonium $+\gamma$ and bottomonium $+\gamma$ production in a potential scheme

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Introduction

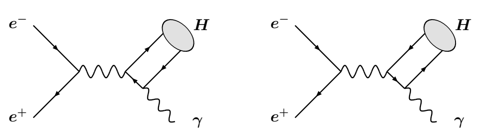
In recent years the new experimental results from Belle, BaBar, CLEO, CDF and D0 collaboration [1] have induced renewed theoretical interest in understanding the mass spectrum, decay and production mechanisms of charmonium and bottomonium states.

The charmonium production has been studied in various processes, such as in hadron-hadron collision, electron-proton collision, fixed target experiments, B meson decays, as well as Z^0 decays[2, 3].

The BaBar[4] and Belle[5] have been studied the double charmonium production in e^+e^- annihilation is particularly interesting in testing the quarkonium production mechanisms of the color-singlet model and the color-octet model in the nonrelativistic QCD (NRQCD) factorization approach.

Methodology

The Feynman diagrams for the exclusive process $e^+(k_2)\,e^-(k_1) \rightarrow H(P, \lambda_H) + \gamma(k, \lambda)$ at order $\alpha^3\alpha_s^0$ are shown in Figure.



Here, k_1, k_2, P, and k are the momenta for the e^-, e^+, H, and γ, respectively. The helicities of the H and γ are denoted by λ_H and λ, respectively. The S-matrix element for the process is given by

$$\mathcal{M}_H(\lambda_H, \lambda) = \frac{e}{s} L_\mu \mathcal{A}_H^{\mu\nu}(\lambda_H)\epsilon^*_{\gamma\nu}(\lambda), \quad (1)$$

where ϵ_γ is the polarization four-vector of the photon.
The leptonic current L_μ in Eq. (1) is defined by

$$L_\mu = \bar{v}(k_2)\gamma_\mu u(k_1). \quad (2)$$

factor $\mathcal{A}_H^{\mu\nu}\epsilon^*_{\gamma\nu}$ in Eq. (1) corresponds to the amplitude for $\gamma^*(Q) \rightarrow H(P, \lambda_H) + \gamma(k, \lambda)$, where Q is the momentum of the virtual photon γ^*. The NRQCD factorization formula for the exclusive process $e^+e^- \rightarrow H + \gamma$ at leading order in both α_s and v, where H is a heavy quarkonium of charge-conjugation parity $C = +1$. The quarkonia H that we consider are the S-wave spin-singlet $(^1S_0)$ state.
The differential cross section for the $e^+e^- \rightarrow H(^1S_0) + \gamma(\pm1)$ is given by H. S. Chung *et al.*[2]

$$\frac{d\sigma}{dx}\left[e^+e^- \rightarrow H(^1S_0) + \gamma(\pm1)\right] = \frac{\pi^2 e_Q^4 \alpha^3 r}{2s} \left(1 - \frac{m_H^2}{s}\right)(1 + x^2)\frac{\langle O_1\rangle_s}{m^3} \quad (3)$$

The total cross section for the processes $e^+e^- \rightarrow H(^1S_0) + \gamma(\pm1)$ by integrating the diffrential is given by H. S. Chung *et al.*[2]

$$\sigma[e^+e^- \rightarrow H(^1S_0) + \gamma] = \frac{8\pi^2 e_Q^4 \alpha^3 r}{3s} \left(1 - \frac{m_H^2}{s}\right)\frac{\langle O_1\rangle_S}{m^3} \quad (4)$$

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TABLE I: The production cross sections of the processes $e^+e^- \to H + \gamma$ $H = \eta_c, \eta_c^{'}, \eta_b$

CPP_ν	$\sigma(e^+e^- \to \eta_c + \gamma)(fb)$		$\sigma(e^+e^- \to \eta_c^{'} + \gamma)(fb)$		$\sigma(e^+e^- \to \eta_b + \gamma)(fb)$	
	Ours	Others	Ours	Others	Ours	Others
0.1	16.9	41.6 ± 14.1[6]	4.25	24.2 ± 14.5[6]	0.73	
0.3	31.8	$82.0^{+21.4}_{-19.8}$[2]	11.5	$49.2^{+9.4}_{-7.4}$[2]	1.22	$2.5^{+0.2}_{-0.2}$[2]
0.5	44.5	$42.5 - 53.7$[3]	19.8	$27.7 - 35.1$[3]	1.63	2.19[3]
0.7	55.4	$68.0^{+22.2}_{-20.3}$[7]	29.0	$42.6^{+10.9}_{-8.8}$[7]	1.98	
0.8	60.1		33.9		2.14	
0.9	64.5		38.8		2.28	
1.0	68.6		43.9		2.41	
1.1	72.3		49.0		2.54	
1.3	78.9		59.4		2.76	
1.5	84.6		69.8		2.94	
2.0	95.6		95.7		3.31	

Results and Discussion

We have calculated the cross section for the $H = \eta_c(1S, 2S)$ and $\eta_b(1S)$ produced exclusively with a photon from e^+e^- annihilation into a virtual photon at leading order in α_s and v. The NRQCD factorization formulas for the differential distributions with respect to the scattering angle of the photon and the total cross sections for $H = \eta_c, \eta_b$ have been obtained [2]. The production cross sections of $H = \eta_c(1S, 2S), \eta_b(1S)$, exclusively with a photon , calculated using the spectroscopic parameters[8, 9] for the potential exponent lying between $1.0 \leq \nu \leq 1.5$ are found to be in the range 68 - 84 fb for $\eta_c(1S)$,43 - 69 fb for $\eta_c(2S)$ and 2.1 -2.5 fb for $\eta_b(1S)$ with the predictions of other theoretical results.

These values are significantly greater than those for $J/\psi + \eta_c$ and $J/\psi + \eta_c(2S)$ measured at the B factories. We hope that high precision measurement with lesser uncertainties will be reported in near future at different heavy flavour production high luminosity experiments.

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