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The Color Octet Effect from $e^+e^- \to J/\psi + X + \gamma$ at B Factory

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Contents

Abstract

We study the initial state radiation process $e^+e^- \to J/\psi + X + \gamma$ for J/ψ production at B factory, and find the cross section is 61% larger than it's Born one for color octet part and is about half as it's Born one for color singlet part. Furthermore, the color singlet and color octet signal are very clearly separated in it's E_γ spectra due to kinematics difference. We suggest to measure this E_γ spectra at B factory to determine the color octet effect.

1 Motivation

1. Color singlet mechanism: $\psi[^3S_1^1]$

2. Color-octet mechanism: $\psi[^3S_1^8]$, $\psi[^3P_J^8]$, $\psi[^1S_0^8]$,.....

   the high-p_T J/ψ production measurement by the CDF collaboration at the Tevatron in 1992.

   === non-relativistic QCD(NRQCD). The factorization formalism of NRQCD provides a theoretical framework to the treatment of heavy-quarkonium production.

   Although it seems to show qualitative agreements with experimental data, but .....

3. The eveidence support color octet:

   $\gamma + \gamma \to J/\psi + X$ on LEP II,

4. The eveidence do not support color octet:

   The current experimental results on inelastic J/ψ phtonproduction at HEAR, Full NLO QCD correction

   The QCD higher order process $\gamma + \gamma \to J/\psi c\bar{c}$ and other higher order process give large contributions.

5. The eveidence support color octet or not ????:

   The measurement of the J/ψ production at B factory in BaBar and Belle: $p^*_{J/\psi}$ spectra did not agree with experimental results, and gives the total cross section $\sigma(e^+e^- \to J/\psi + X) = 0.72 \pm 0.08 + 0.13(-0.17)pb$.

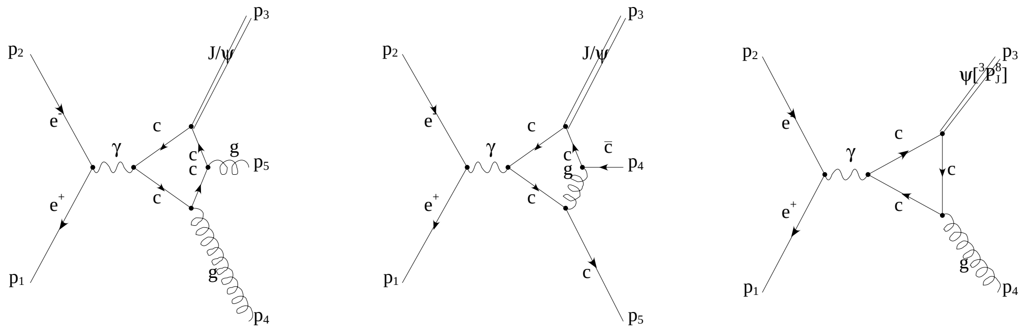

Figure 1: The typical Feynman diagrams for the $e^+e^- \to J/\psi X$, there are 6 diagrams for the $e^+e^- \to J/\psi gg$, 4 diagrams for $e^+e^- \to J/\psi c\bar{c}$ and 2 diagrams for each $e^+e^- \to \psi[^3P_J^8]g,\ J = 0, 1, 2$

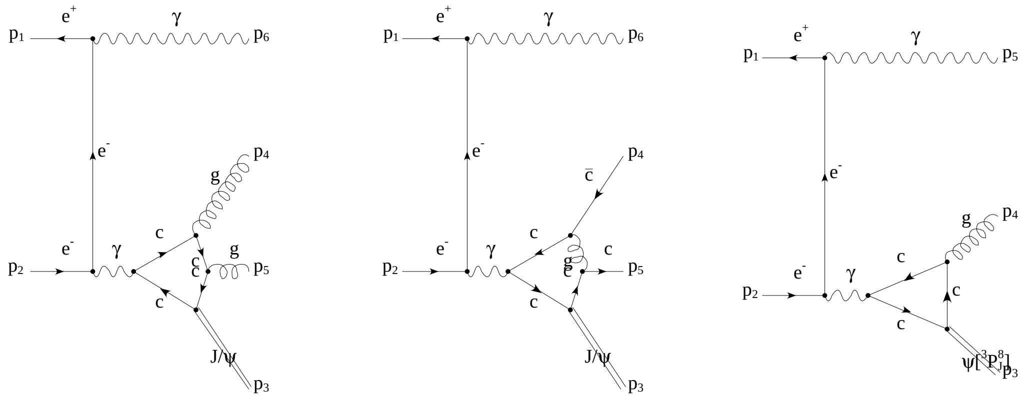

Figure 2: The typical Feynman diagrams for the $e^+e^- \to J/\psi X\gamma$, there are 12 diagrams for the $e^+e^- \to J/\psi gg\gamma$, 8 diagrams for $e^+e^- \to J/\psi c\bar{c}\gamma$ and 4 diagrams for each $e^+e^- \to \psi[^3P_J^8]g\gamma,\ J = 0, 1, 2$

2 Uncerntainty in the theoretical treatment of J/ψ production

1. the QCD correction: the QCD correction effect up to a few times in various leading order calculation for J/ψ production.

2. the hadronization of the color octet $J/\psi^{(8)}$ to the color singlet J/ψ and hadrons.

In the measurement of the spectra of $p^*_{J/\psi}$ in J/ψ production at B factory in Belle experiments, The spectra show that the theoretical predication for color octet does not appear.

The ref[**?**] addressed on the problem, but the results is not predictive since the introduced shape function for $J/\psi^{(8)}$ is unknown.

Due to the above two kinds of uncertainty, the $p^*_{J/\psi}$ spectra from color octet $J/\psi^{(8)}$ is unknown, and meanwhile the higher order QCD effect for the color singlet J/ψ production is also unknown. So to confirm, to extract $J/\psi^{(8)}$ information from the measurement in B factory experiment become unavailable.

3 $e^+e^- \to J/\psi + X + \gamma$ and the results

QED higher order process is small???, Examples in which QED higher order process could be very lager.

1. $e^+e^- \to J/\psi\gamma$

2. $e^+e^- \to J/\psi e^+e^-$

3. $e^+e^- \to J/\psi + J/\psi$

Our numerical results show $e^+e^- \to J/\psi + X + \gamma$ is even 61% larger than it' Born process.

A universal formula is easily obtained for the virtual correction plus soft photon emitted one. It is:

$$\sigma^{Soft+Virtul} = \sigma_0\{\frac{2\alpha}{\pi}[(\ln\frac{s}{m_e^2} - 1)(\ln\frac{2\delta\epsilon}{\sqrt{s}} + \frac{3}{4}) + \frac{\pi^2}{6} - \frac{1}{4}]\}. \tag{1}$$

3.1 The parameters used in the numercial calculation

$$m_c = 1.5,\ m_{J/\psi} = 3.0,\ \alpha = 1/137,\ \alpha_s^{(n_f=3)}(\mu).$$

J/ψ matrix elements and the universal NRQCD matrix elements for color octet J/ψ are chosen as:

$$< J/\psi >= 1.4,\ < J/\psi^{(8)}(^1S_0) >= 0.015,\ < \psi^{(8)}(^3P_J) >= (2J+1)0.0043{m_c}^2.$$

The renormalization scale μ dependent:

$$\begin{array}{ll} \alpha_s = \alpha_s^{(3)}(10.6) = 0.188 & for\ Born\ processes \\ \alpha_s = \alpha_s^{(3)}(\sqrt{(p_1+p_2-p_\gamma)^2}) & for\ hard\ photon\ processes. \end{array}$$

The following cut condition is applied to all the radiation processes.

$$\sqrt{(p_1+p_2-p_\gamma)^2} > m_{J/\psi} + 3m_\pi.$$

beam direction, t-channel enhancement effect the color singlet processes: $E_\gamma < 1.0GeV$, the color octet processes: $E_\gamma > 4.0GeV$.

Table 1: The numerical results for the color singlet and color-octet J/ψ production. The $p^*_{J/\psi} = \sqrt{p^2 - m^2_{J/\psi}}$ is the 3-momentum of J/ψ. $\delta\epsilon = 0.1$ is used. The cut $p^*_{J/\psi} > 2.0GeV$ is used by the experiment to suppress the J/ψ from B decay. The result for color octet with cut condition $p^*_{J/\psi} > 2.0GeV$ is not presented since it does not make sense in the case that the detail of $J/\psi^{(8)}$ hadronization procedure is unknown

	Born	Virtual+Soft	hard photon (unit: pbar)
$p^*_{J/\psi} > 2.0GeV$			
$e^+e^- \to J/\psi gg(\gamma)$	0.158	-0.044	0.072
$e^+e^- \to J/\psi c\bar{c}(\gamma)$	0.102	-0.028	0.022
In total	0.270	-0.072	0.094
$p^*_{J/\psi} > 0GeV$			
$e^+e^- \to J/\psi gg(\gamma)$	0.203	-0.056	0.099
$e^+e^- \to J/\psi c\bar{c}(\gamma)$	0.119	-0.033	0.029
In total	0.322	-0.089	0.128
$e^+e^- \to \psi[^3P^8_J]g(\gamma)$	0.143	-0.039	0.351
$e^+e^- \to \psi[^1S^8_0]g(\gamma)$	0.133	-0.037	0.094
In total	0.276	-0.076	0.445

Table 2: The same one but the cut for the $0.8 > cos(\gamma\ and\ beam) > -0.8$

	Born	Virtual+Soft	hard photon (unit: pbar)
$p^*_{J/\psi} > 0GeV$			
$e^+e^- \to J/\psi gg(\gamma)$	0.203	-0.056	0.011
$e^+e^- \to J/\psi c\bar{c}(\gamma)$	0.119	-0.033	0.003
In total	0.322	-0.089	0.014
$e^+e^- \to \psi[^3P_J^8]g(\gamma)$	0.143	-0.039	0.032
$e^+e^- \to \psi[^1S_0^8]g(\gamma)$	0.133	-0.037	0.010
In total	0.276	-0.076	0.042

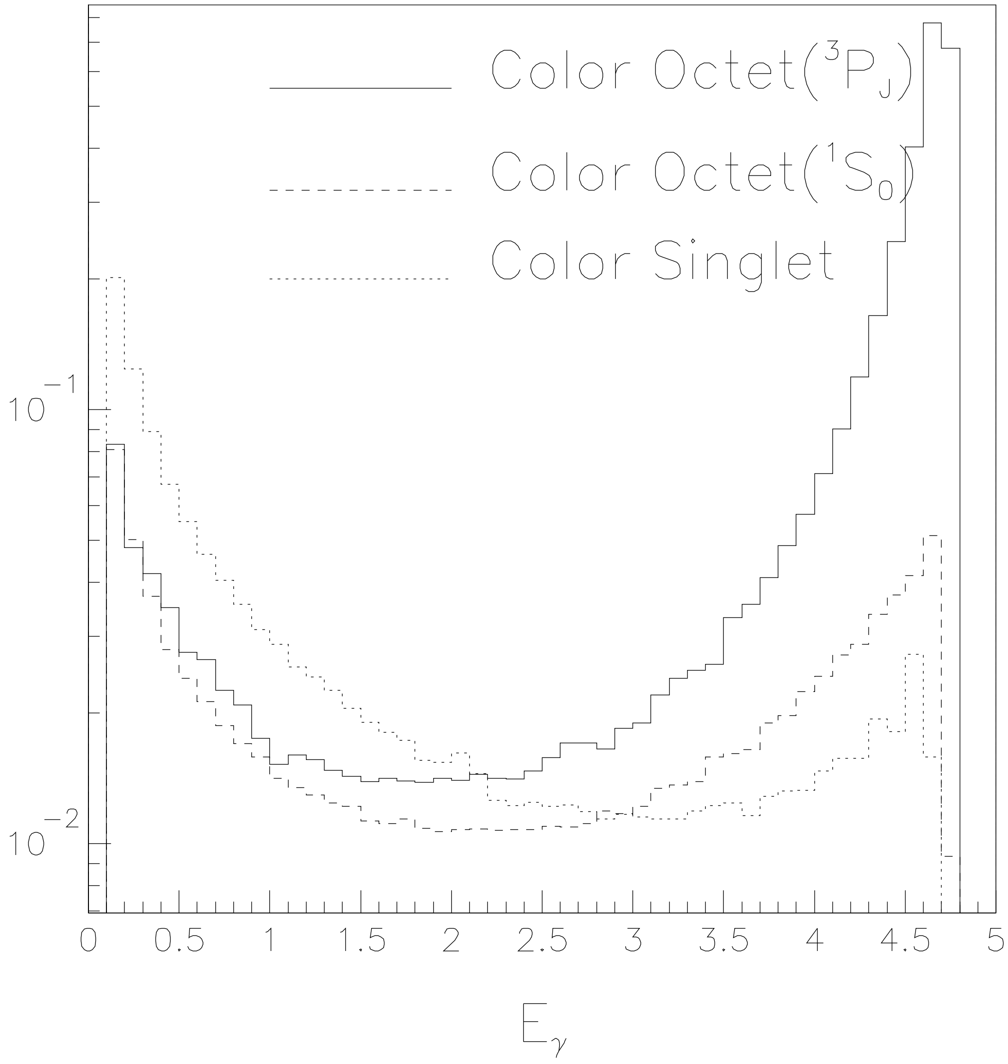

Figure 3: The differential cross section distribution vs the energy of emitted hard photon

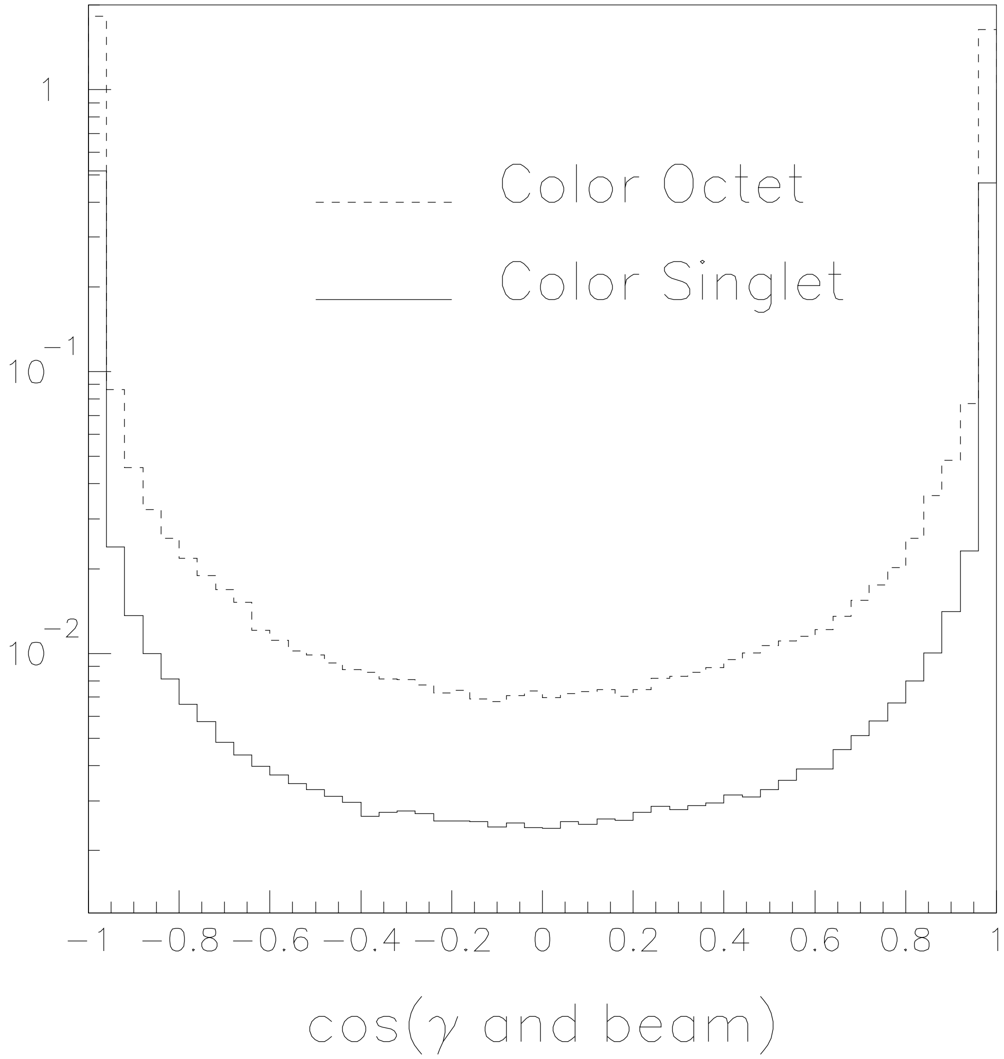

Figure 4: The differential cross section distribution vs the $cos(\theta)$ of the emitted hard photon and the beam

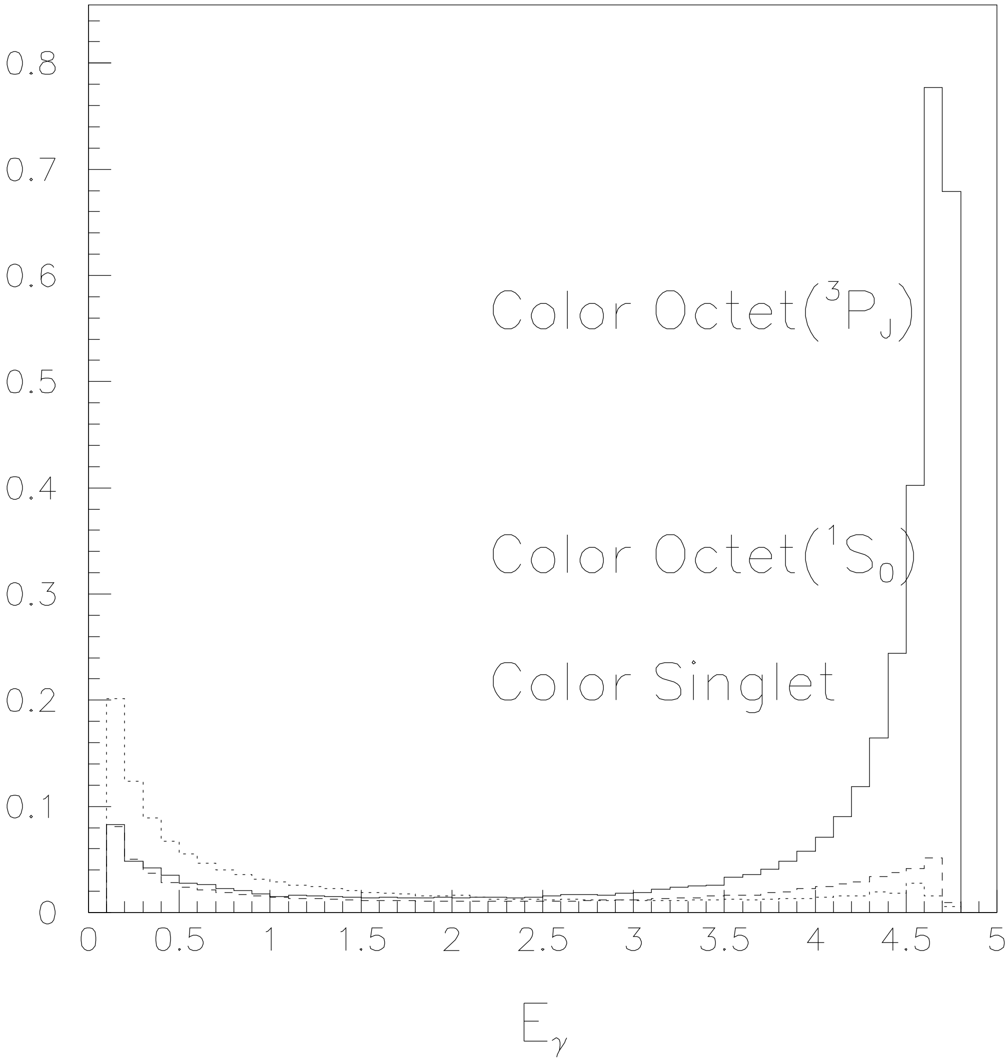

Figure 5: The differential cross section distribution vs the energy of emitted hard photon

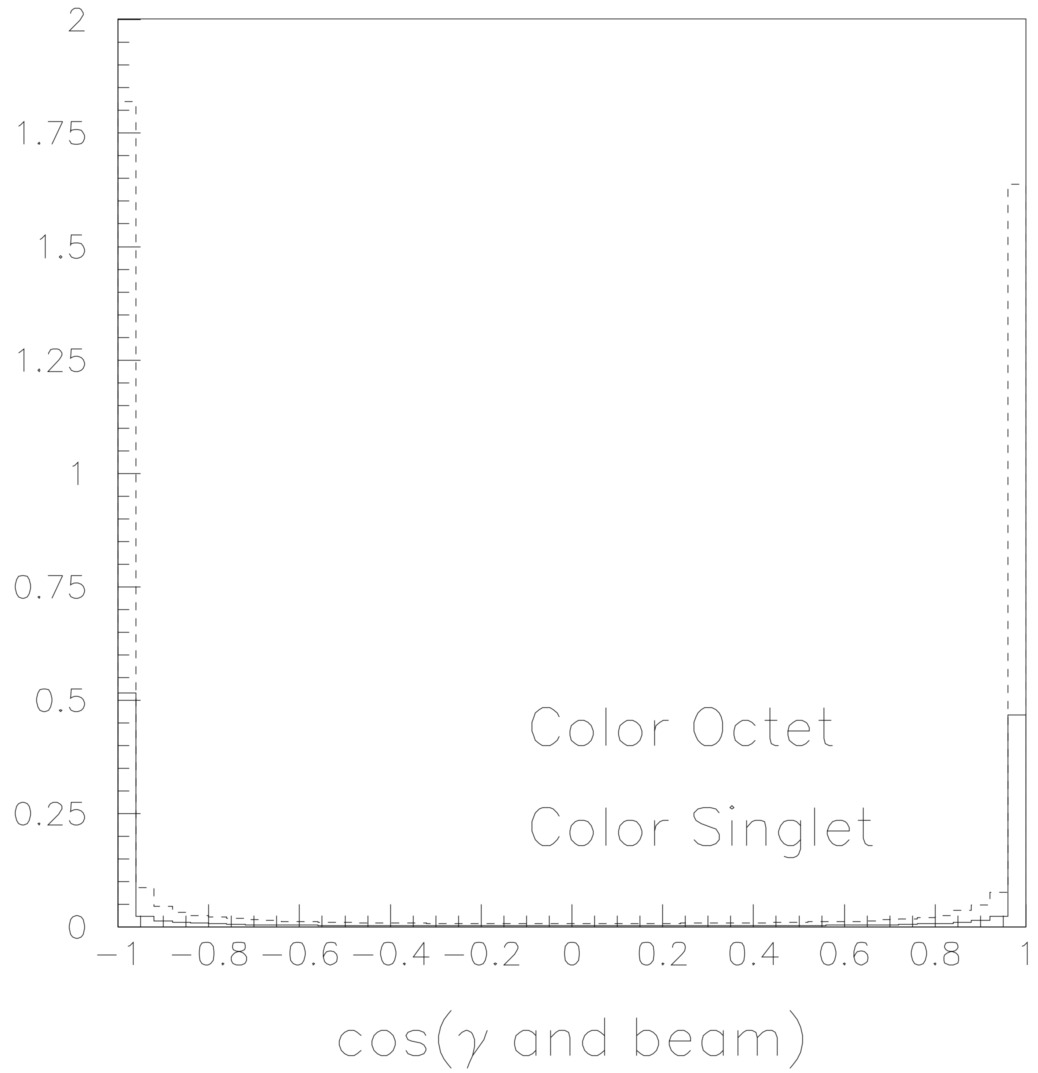

Figure 6: The differential cross section distribution vs the $cos(\theta)$ of the emitted hard photon and the beam

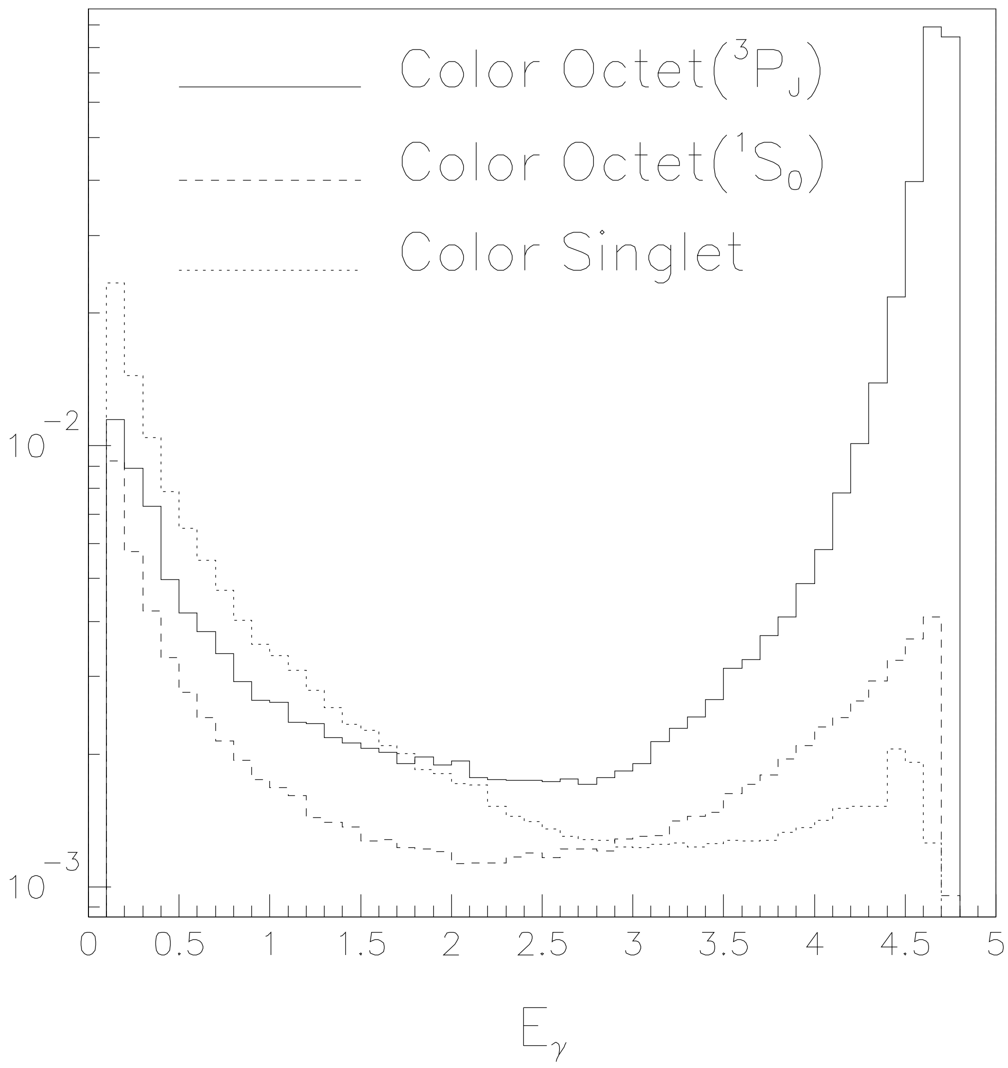

Figure 7: The differential cross section distribution vs the energy of emitted hard photon

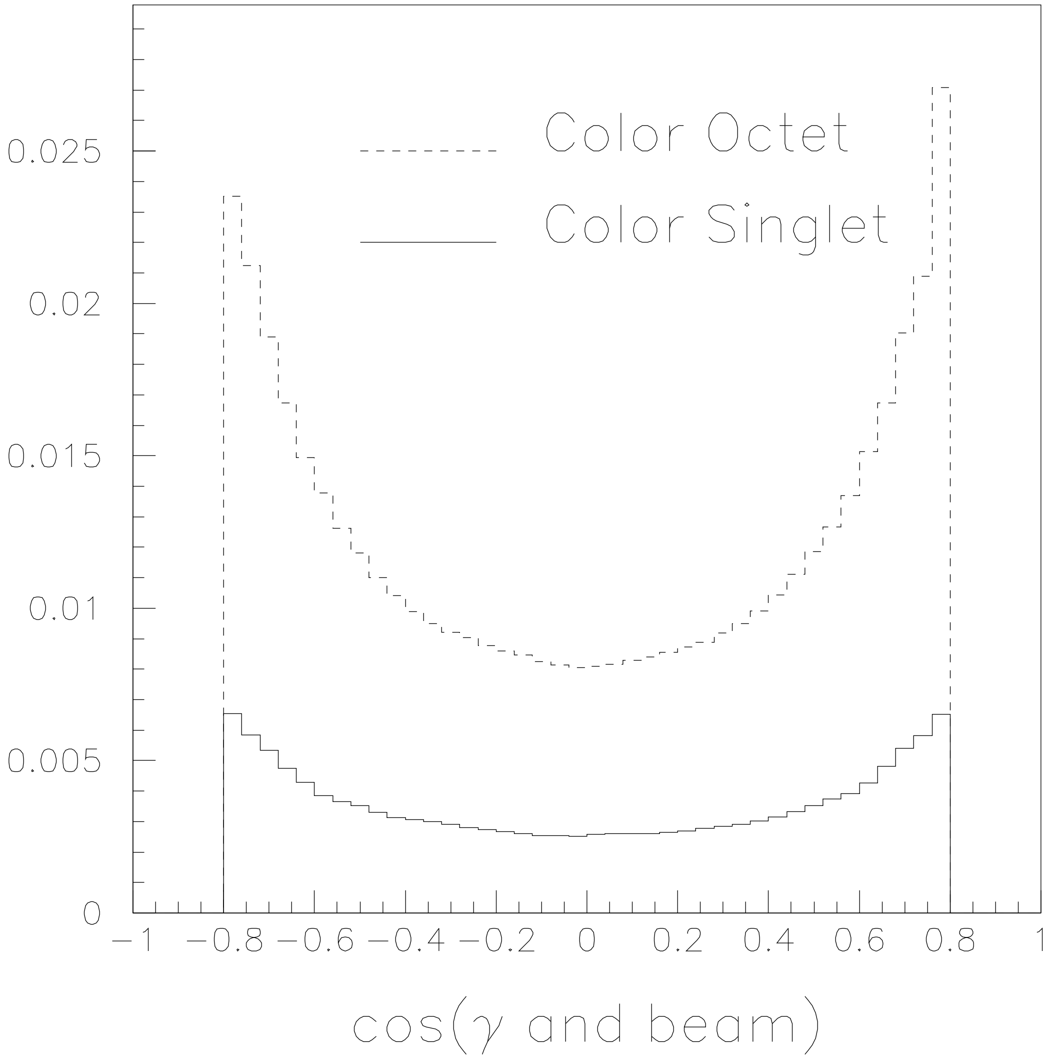

Figure 8: The differential cross section distribution vs the $cos(\theta)$ of the emitted hard photon and the beam

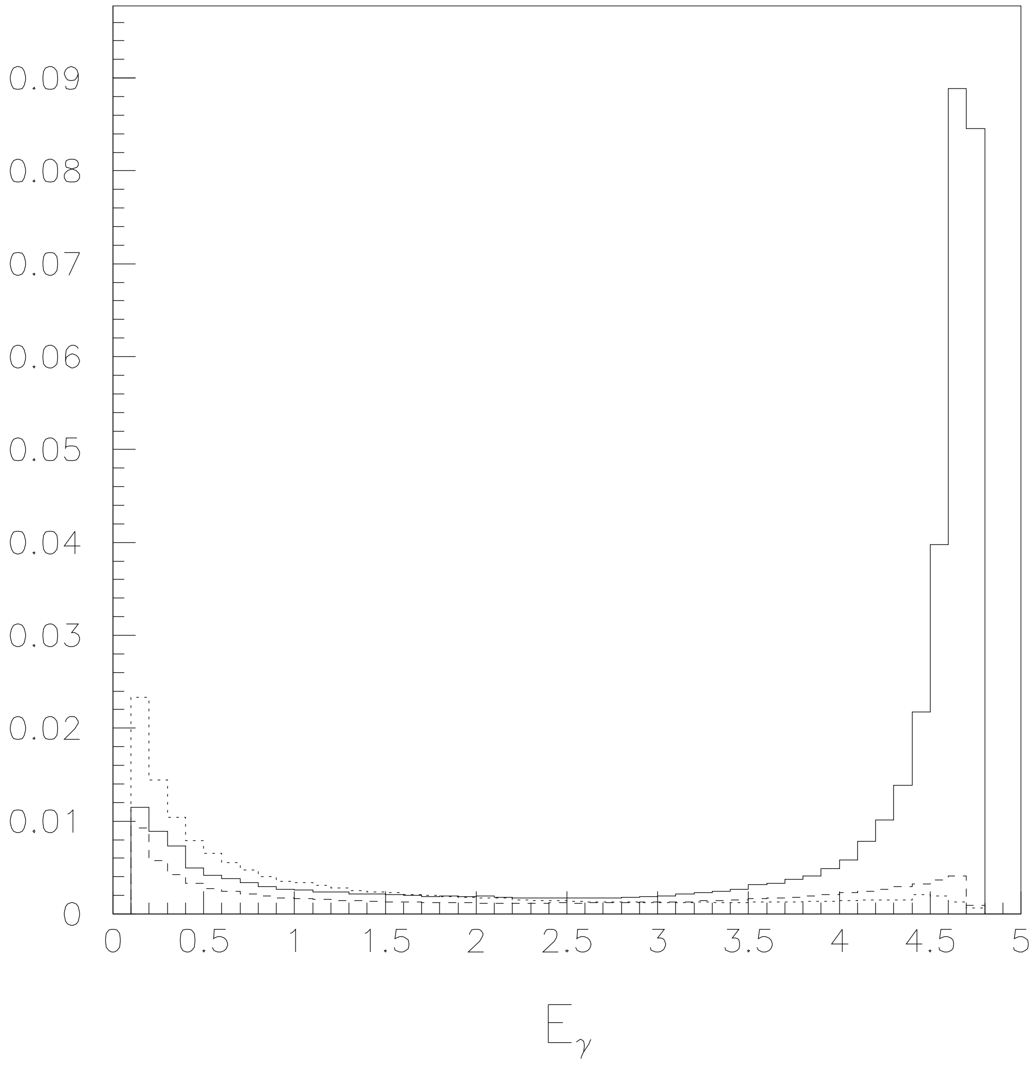

Figure 9: The differential cross section distribution vs the energy of emitted hard photon

3.2 The reason for this distribution is completely form the kinematics structure

When the center mass energy go down from 10.6Gev to 5GeV, the cross section will increase

1. $e^+e^- \to J/\psi gg$, about 4 times
2. $e^+e^- \to \psi[^3P_J^8]g$ about 51 times
3. $e^+e^- \to \psi[^1S^0]g$, about 17 times and $e^+e^- \to J/\psi c\bar{c}$ will be closed.

3.3 The property of this E_γ spectrum

1. It is hardly be changed even if there is large QCD correction effects.
2. It can not be changed by the procedure of $J/\psi^{(8)}$ and gluon hadronization into J/ψ and hadrons
3. It very clearly separate the color singlet and color octet signal.
4. Another advantage is that the color octet cross section in the hard photon process is even 61% large than it's Born one.

As approximation, we have

$$\begin{gathered}
\sigma(e^+e^- \to J/\psi + X) = 0.233x + 0.2y, \\
\sigma(e^+e^- \to J/\psi + X + \gamma) = 0.128x + 0.445y, \\
\sigma(e^+e^- \to J/\psi + X, color\ singlet) = 0.233x, \\
\sigma(e^+e^- \to J/\psi + X, color\ octet) = 0.2y.
\end{gathered} \tag{2}$$

where x and y represent the effects of QCD correction and uncertainty from the NRQCD matrix elements, and all the numerical values from the Table.2.

4 The checkment for the calculation

For both the Born processes and the hard photon emitted processes, We obtain the formula and Fortran source of the cross section, including the kinematics, by using our automatic Feynman diagram calculation program FDC[**?**]. The FDC was used in the calculation of $e^+e^- \to J/\psi\gamma$ and $e^+e^- \to J/\psi e^+e^-$ [**?**]. In ref[**?**] it was used in the calculation of $\gamma + \gamma \to J/\psi c\bar{c}$, and many other processes to repeat the calculation by ref[**?**]. In the Fortran source generated by FDC, it is very easily to check the gauge invariance by replacing the polarization vector of gluon or γ to it's momentum. All the possible gauge invariance are checked to be satisfied numerically in our calculation. Our analytic formula generated by FDC for $e^+e^- \to \psi[^3P_J^8]g,\ J = 0, 1, 2;\ \psi[^1S_0^8]g$ are checked with ref[**?**].

5 Summary and Conclusion

A good way to determine color octet effect:

To measure the E_γ spectra in the initial state radiation process $e^+e^- \to J/\psi + X + \gamma$.

It could avoid the uncertainties from $J/\psi^{(8)}$ hadronization and QCD correction.