Exclusive two-charmonium vs. charmonium-glueball production at Belle

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Brodsky, Goldhaber, Lee,	PRL 91, 112001 (2003)
Bodwin, Braaten, Lee,	PRL 90, 162001 (2003)
Bodwin, Braaten, Lee,	PRD 67, 054023 (2003)
Braaten, Lee,	PRD 67, 054007 (2003)

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Outline

Exclusive Two-charmonium Production

- Belle Data $e^+e^- \to J/\psi + \eta_c, \chi_{c0}, \eta_c'$
- $\sigma_{\rm Belle} \sim 10 \times \sigma_{\rm NRQCD}$
- What about $e^+e^- \to J/\psi J/\psi$?

New proposal
$\gamma^*(Q^2) \to J/\psi(\Upsilon) + \mathcal{G}_J,\ J = 0, 2$

- Same order in α_s as $J/\psi + \eta_c, \chi_{c0}, \eta_c'$
- Cross section comparable

  to two-charmonium process

- Discussion

Exclusive Two-Charmonium Production in e^+e^- Annihilation

- Precision measurement

$$R = \frac{\sigma_{J/\psi\eta_c}}{\sigma_{\mu^+\mu^-}} \sim \alpha_s^2 \left(\frac{m_c v}{E_{\text{beam}}}\right)^6$$

$$\sim 4 \times 10^{-7} \ll R_{\text{hadrons}} \sim 3.6$$

- Theory

  Exclusive $\rightarrow$ Color singlet only

  Color-singlet matrix elements are well determined from

  $J/\psi \rightarrow e^+e^-$, $\eta_c \rightarrow \gamma\gamma$, $\chi_{c0,2} \rightarrow \gamma\gamma$

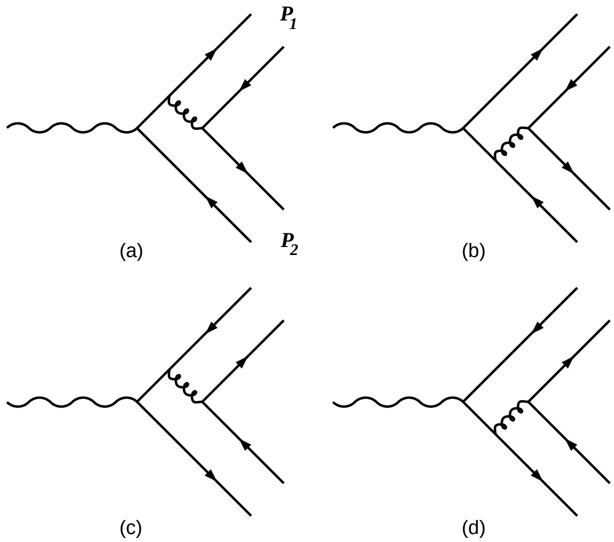
- Belle measured $\sigma_{e^+e^- \rightarrow J/\psi + \eta_c, \eta_c', \chi_{c0}}$

  $\sigma_{\text{Belle}} \sim 10 \times \sigma_{\text{NRQCD}}$

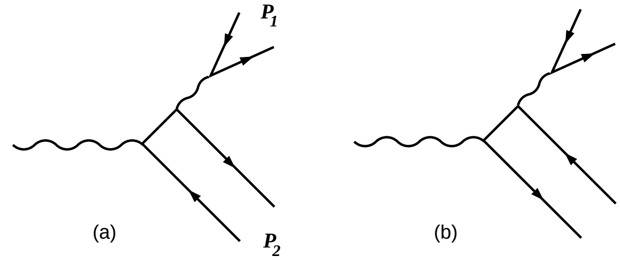
  $\rightarrow$ the largest discrepancy in SM

$$e^+e^- \to \gamma^* \to H_1 H_2,\ C_1 C_2 = -$$

QED+QCD



QED



-21% correction for $J/\psi + \eta_c$

Braaten, Lee, PRD(03)

$$R_{J/\psi \eta_c} \propto \alpha_s^2 (r^2 - Y)^2 \frac{\langle O_1 \rangle_{J/\psi} \langle O_1 \rangle_{\eta_c}}{m_c^6}$$

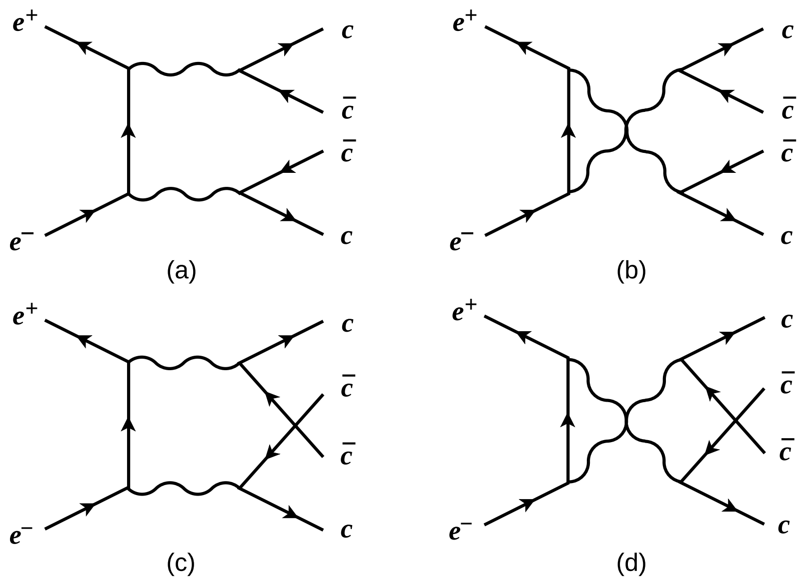
$$Y = \frac{\alpha}{\alpha_s}\left(1 + \frac{\alpha}{3\alpha_s}\right)^{-1},\ r = 2m_c/E_{\rm beam}$$

$$\sigma^{\rm NRQCD}_{J/\psi+\eta_c} = 2.31 \pm 1.09 \text{fb}$$
$$\ll \sigma^{\rm Belle}_{J/\psi+\eta_c} B[\geq 4] = 33^{+7}_{-6} \pm 9 \text{ fb}$$

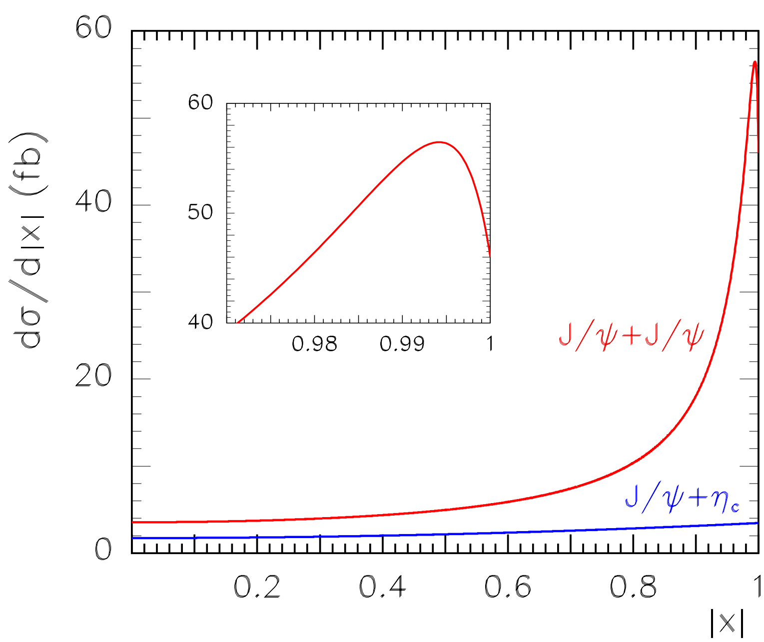
Confirmed by
Liu, He, Chao, PLB(03) [NRQCD]
Brodsky, Ji, Lee [Light Front]

$e^+e^- \to \gamma^*\gamma^* \to H_1H_2,\ C_1C_2 = +$

photon-fragmentation effect



suppressed by
α/α_s^2
enhanced by
$r^{-4}\ln(8/r^4)$
relative to
$J/\psi + \eta_c$



suffers v^2, α_s corrections by a factor 3

$\sigma_{J/\psi\ J/\psi}$ is comparable to $\sigma_{J/\psi\ \eta_c}$

Bodwin, Lee, Braaten, PRL;PRD(03)

Does the $J/\psi\ \eta_c$ signal includes $J/\psi J/\psi$?

- $\sigma_{J/\psi\, J/\psi}$ may be as large as $\sigma_{J/\psi\, \eta_c}$

- Belle resolution = 110 MeV
  $m_{J/\psi[\psi']} - m_{\eta_c[\eta_c(2S)]} = 120[30]$ MeV

- The Belle $J/\psi \eta_c$ signal
  might include $J/\psi J/\psi$

- New Belle analysis :
  Upper limit compatible with theory
  $J/\psi J/\psi$ does not explain Belle's σ
  Problem NOT resolved!!!

QCD predicts the existence of glueballs

J^{PC}	m_G (MeV)	
0^{++}	1730 (50)	(80)
2^{++}	2400 (25)	(120)
0^{-+}	2590 (40)	(130)
0^{*++}	2670 (180)	(130)
1^{+-}	2940 (30)	(140)
2^{-+}	3100 (30)	(150)
3^{+-}	3550 (40)	(170)
0^{*-+}	3640 (60)	(180)
...	(stat.)	(sys.)

Morningstar, Peardon, PRD60 (99)

Some glueballs are in same mass range as charmonium states

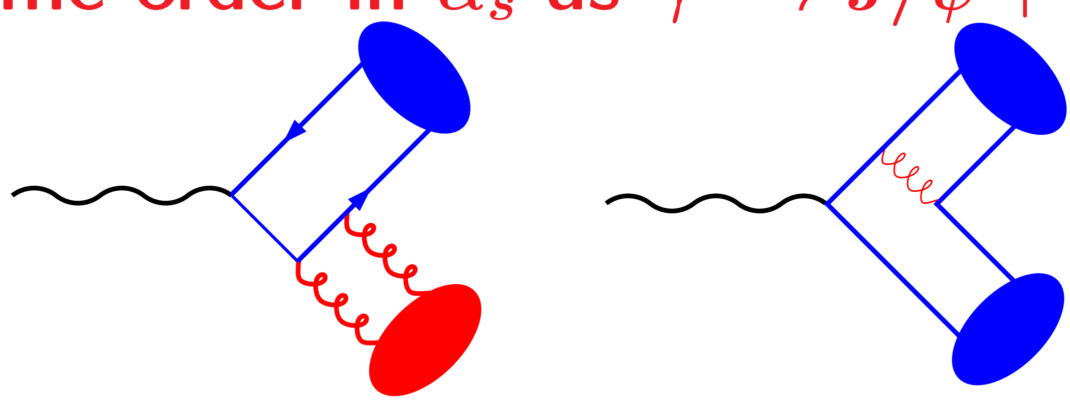
New Proposal
$e^+e^- \to \gamma^* \to \mathcal{G}_J H,\ H = J/\psi, \Upsilon$

Brodsky, Goldhaber, Lee (03)

- Glue-rich process $\gamma^*(Q^2) \to J/\psi + gg$
- Safe Factorization for $Q \gg m_{\mathcal{G}}$.
  Can probe wider glueball mass range at B factories

  pQCD factorization $(\mathcal{G}_J)$
  [Brodsky, Lepage]
  holds if $k_\perp^2/Q^2 \sim m_{\mathcal{G}}^2/Q^2 \ll 1$

  NRQCD factorization $(J/\psi, \Upsilon)$
  [Bodwin, Braaten, Lepage]
  holds if $M_Q v_Q^2 \ll M_Q v_Q \ll M_Q$
  Exclusive→ Color-singlet only
- Same order in α_s as $\gamma^* \to J/\psi + \eta_c$



How to calculate the amplitude

- pQCD factorization($Q^2 \gg k_\perp^2, m_{\mathcal{G}}^2$)

  $\mathcal{M} = \int dxdy\; T_H(x, y, Q)\; \phi_J(x)\; \phi_H(y)$

  Leading-twist calculation

  T_H : the hard scattering amplitude

  $\phi_{J(H)}(x)$: the light-front distribution amplitude for $\mathcal{G}_J(H)$

- Nonperturbative parameters

  $\sqrt{2M_H} \int dy \phi_H(y) \sim \text{NRQCD ME}^{1/2}$

  $I_0 = \int dx \phi_0(x)$

  $I_2 = \int dx \phi_2(x)/[x(1-x)]$

$$\sigma(e^+e^- \to \mathcal{G}_J J/\psi) = R_J \sigma_{\mu^+\mu^-}$$

$$\frac{dR_0}{d\cos\theta^*} \propto \sin^2\theta^* + \frac{r^2}{4}(1+\cos^2\theta^*)$$

$$\frac{dR_2}{d\cos\theta^*} \propto v_c^4 r^2(1+\cos^2\theta^*), \quad r = \frac{4m_c}{\sqrt{s}}$$

- hadron helicity conservation
  as $r \to 0$, $\lambda_H = 0 \to d\sigma \sim \sin^2\theta^*$
- $\mathcal{G}_0$ dominant as $v_c \to 0$
- Only $J_z = \pm 2$ for $\mathcal{G}_2$(leading twist)
- $v_c^4 r^2$ suppression in $\mathcal{G}_2$
- $\int_0^1 dx \frac{\phi_2(x)}{x(1-x)}$ enhancement in $\mathcal{G}_2$

Numerical Result

- From Universality of light-cone amplitudes, $|I_0|^2 \propto$ Br$[\Upsilon \to \mathcal{G}\gamma]$
  Obtain upper bound on $|I_0|^2$ from CUSB resonance-search data
- Apply the bound on $|I_0|^2$
  to $e^+e^- \to \mathcal{G}_0 J/\psi(\Upsilon)$
- Cross section is comparable to that of two-charmonium production

$M_{\mathcal{G}_0} = M_h$	$h = \eta_c$	χ_{c0}	$\eta_c(2S)$
$|I_0|^2_{\text{max}}$ $(10^{-3}$ GeV$^2)$	5.2	5.8	6.2
$\sigma^{\text{max}}_{J/\psi\mathcal{G}_0}$	1.4 fb	1.5 fb	1.6 fb
$\sigma^{\text{max}}_{J/\psi\mathcal{G}_0}/\sigma_{J/\psi h}$	0.63	0.72	1.9

Detectable at B factories?

Discussion

- $e^+e^- \to J/\psi\eta_c$
  - Need independent analysis by BaBar
  - $e^+e^- \to J/\psi J/\psi$ predicted/not seen
  - v^2 corrections are important. Need a better estimate of $\langle v^2\rangle_{J/\psi}$(lattice?)
  - Failure of pQCD factorization???
  - Is a signal of NEW Physics?

- $e^+e^- \to \mathcal{G}_J H$
  - QCD predicts the existence of glueballs
  - Reliable factorization formula
  - Can be used to study heavy glueballs
  - Glueball production rate is comparable to $e^+e^- \to J/\psi\eta_c$
  - How does the light-cone amplitude depend on the glueball mass?
  - Can CLEO provide a better bound on the light-cone amplitude using $\Upsilon \to \gamma X$
  - How do we identify $\mathcal{G}_J$ once produced?