Charmonium Production In The B Factory

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Introduction

- Since the discovery of charm quark in 1974, a great deal of works on it have been done. It plays a central role in heavy quark physics
- Basic parameter
  1. Mass $1.25 \pm 0.09 GeV$
  2. Charm number $c = 1$
  3. $I(J^P) = 0(\frac{1}{2})^+$
- the mass scale of such region play a central role in test both perturbation and Non-perturbative region.

Charmonium

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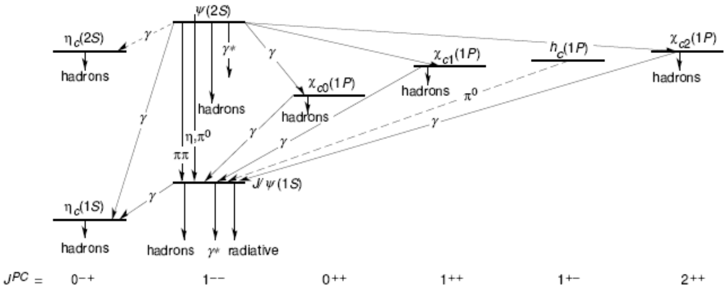
- $p\bar{p}$ collider and CLEO also obtain charmonium result. we have a great deal of datas

Brief outline of charm quark and charmonium family

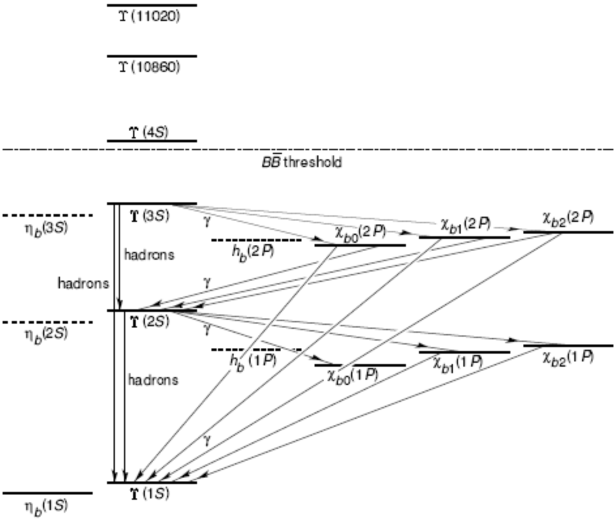
- Charmonium Family



from hep-ph/0602091

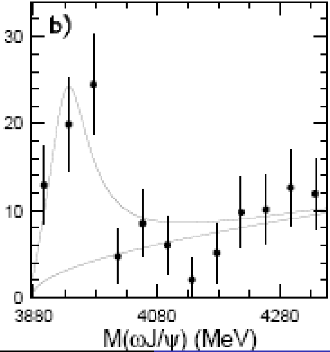
Brief outline of charm quark and charmonium family

- $b\bar{b}$ quarkonium has similar family struture as well



New results from B factories

- In this part I list only the new results from BaBar and Belle
- B factory including BaBar and Belle collaborations, making using of e^+e^- collider, at the center energy of 10.6 GeV, just 40 MeV below the mass of $\Upsilon(4s)$
  - observation for exclusive $B \to K\omega J/\psi$, signal of Y(3940).(Phys. Rev. Lett94, 182002 2005)



$\psi(4323)$

- $e^+e^- \to \pi^+\pi^-\psi(2S)$,and then $\psi(2S) \to \pi^+\pi^- J/\psi$Phys. Rev. Lett98.212001, 2007

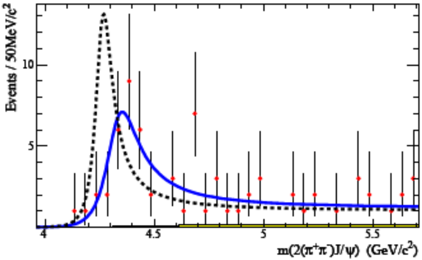


FIG. 3: The $2(\pi^+\pi^-)J/\psi$ invariant mass spectrum up to 5.7 GeV/c^2 for the final sample. The shaded histogram represents the fixed background and the curves represent the fits to the data (see text).

Mesurement from CDF (Phys. Rev. Lett 98, 132002)

- X(3872) was analyzed in the exclusive mode $X(3872) \to J/\psi\pi^+\pi^-$,and with $J/\psi \to \mu^+\mu^-$
  - $J^{PC} = 1^{++}$ or $J^{PC} = 2^{-+}$

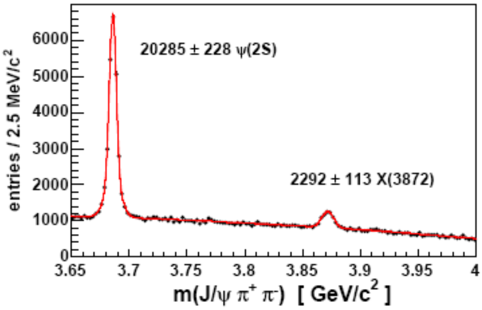


FIG. 1: The $J/\psi\,\pi^+\pi^-$ mass spectrum after optimizing the selection cuts, fitted by a double Gaussian function for the $\psi(2S)$ (left), a Gaussian function for the $X(3872)$ particle (right), and a second order polynomial for the combinatorial background.

Large cross section $e^+e^- \to J/\psi\eta_c$ measurement

- Both inclusive and exclusive cross section from BaBar and Belle are much larger than theoretical prediction almost an order
  $\sigma(J/\psi\eta_c) = 33fb$ (Phys. Rev. Lett89 142001)
  $\sigma(J/\psi\eta_c) = 25.6fb$ (Phys. Rev. D70 071102)
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- while for inclusive process
  $\sigma[e^+e^- \to J/\psi + c\bar{c} + X] = 0.87pb$

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Question

The theoretical predictions are **not** consist to those results, and now let us look at some theoretical calculation based on NRQCD, which is a great challenge to NRQCD.

early model assumption

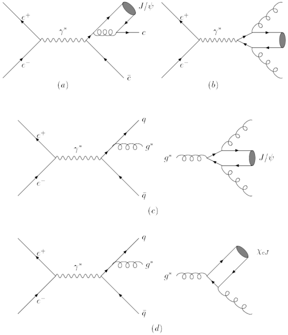
- $Q\bar{Q}$ production is based on several approxmations
- $Q\bar{Q}$ are heavy quarks, creation of two on-shell quark pairs, then their binding to make meson.
- its creation is perturbative and is computable with Feynman diagram.
- as we consider bound states of heavy quark(charmonium and bottomonium) their relative velocity in the meson must be small, so we can use NRQCD, expanded with power of v^2. one suppose that the meson must be created with two quarks at rest in the meson frame. this is static approximation.
- one suppose the quark pairs produced in a colour singlet(CSM)

$e^+e^- \to J/\psi\eta_c$ LO

- In order to resolve the puzzle many works had been done in the framework of NRQCD and different mechanism
- Kühn and other authors' works
- some author proposed color-octet maybe dominant.
- most calculation are based on NRQCD
- NRQCD only use $R(0)$ as input. at present NLO input was considered. The ${}^3S_1$ states have quantum numbers of a virtual photon $J^{PC} = 1^{--}$ and can annihilate into lepton pairs.
- two photon annihilation of C-even states. with $J \neq 1$ can annihilate into two photon states.
- in order to compare different input, ${}^3S_1 \to 3\gamma$ decay was also used.
- $v(p/2)\bar{u}(p/2) \propto \varepsilon(p+m)R(0)$

other contributions

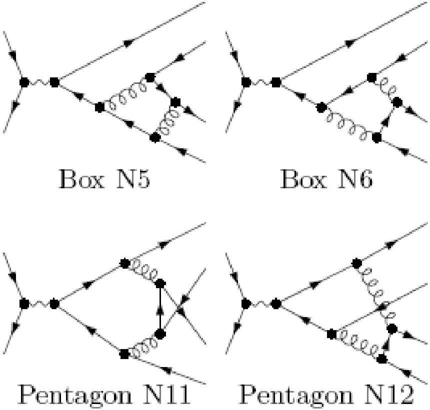
- C.H.Chang, C.F.Qiao and J.X.Wang Phys.Rev D57 4035 1998,
  F.Yuan, C.F.Qiao and K.T.Zhao Phys.Rev D56 321 1997,



- $e^+e^- \to J/\psi J/\psi$ was proposed, but the experiment result ruled out this process.

exclusive $e^+e^- \to J/\psi\eta_c$ NLO

- Y.J.Zhang and K.T.Zhao, Phys.Rev.Lett 96, 092001 (2006)



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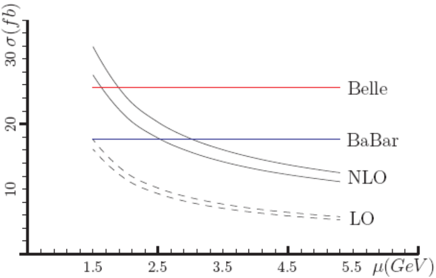
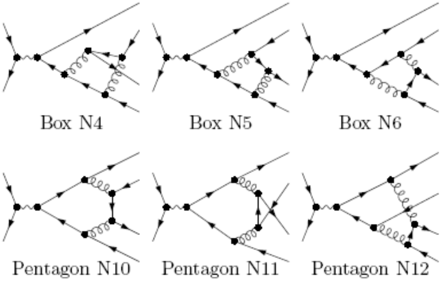


- NLO result form this figure we can see NLO cross section reach to the lower bound of experiment.

$$e^+e^- \to J/\psi\eta_c = 15.7pb \text{ or } 18.9pb$$

inclusive $e^+e^- \to J/\psi + c\bar{c}$ NLO

- Y.J.Zhang and K.T.Zhao, Phys.Rev.Lett 98, 092003 (2007)
- the inclusive J/ψ production cross section via double $c\bar{c}$ measured by Belle (Phys.Rev.Lett 89, 142002 (2002))
  $\sigma[e^+e^- \to J/\psi + c\bar{c} + X] = 0.87pb$
  when NLO is considered
  $\sigma[e^+e^- \to J/\psi + c\bar{c} + X] = 0.33pb$ or $0.47pb$ in different parameter.



Relativistic corrections

- Z.G.He, Y.Fan, K.T.Zhao Phys.Rev.D75,074011 (2007)
- For exclusive $e^+e^- \to J/\psi\eta_c$

$\sigma_{LO(\alpha_s,v^2)} = 2.26fb$
$\sigma_{NLO(\alpha_s)} = 10.92fb$
$\sigma_{NLO(v^2)} = 3.87fb$
$\sigma_{NLO(\alpha_s,v^2)} = 20.04fb$

conclusion

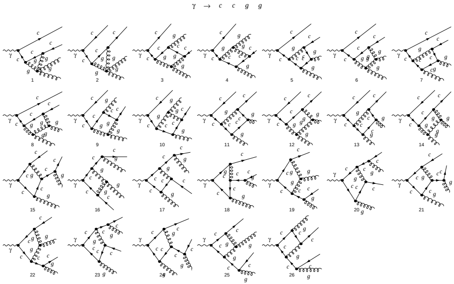
The results indicate that both Relativistic corrections and QCD correction give much enhancement to cross section.

NRQCD and Application

- Some authors suggest that the dominant mechanism for charmonium production in e^+e^- annihilation is color-singlet process $e^+e^- \to J/\psi gg$
- we calculate $e^+e^- \to J/\psi gg$ NLO
- we make use of FeynArt to generate all Feynman diagrams involved to this process and create Feynman Amplitudes
- we then isolate all divergence including UV and IR
- numerical calculation

NRQCD and Application

- $e^+e^- \to J/\psi gg$
  - contain both soft and collinear infrared divergence



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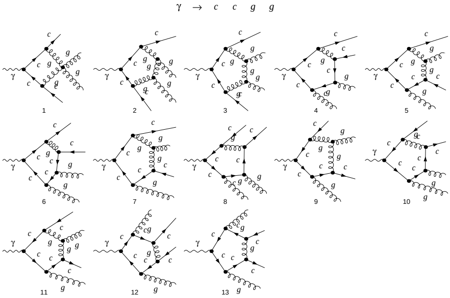

NRQCD and Application and loop integral

- General Form we will treat the loop integral as

$$L = \int \frac{d^n q}{(2\pi)^n} \frac{1}{(q^2 - m_1^2)((q+p_1)^2 - m_2^2)...((q+p_{n-1})^2 - m_n^2)} \quad (3.1)$$

- define $Y_{ij} = (m_i^2 + m_j^2) - (k_{i-1} - k_{j-1})^2$
- Inverse the above matrix

$$L^n = c_i L_i^{n-1} \quad (3.2)$$

- $C_0[0, m^2 + 2.s46, m^2 + 2.(s45 + s46 + s56), 0, 0, m^2]$
  $C_0[m^2, 0, m^2 + 2.s46, m^2, 0, 0]$
  $C_0[0, 0, 2.s56, 0, 0, 0]$

Summarization and Prospect

- up to now theoretical prediction have difference with experiment data about charmonium states.
- data from B factory have a challenge to NQDCD
- we have seen NLO calculation give much enhancement to LO

Thank you!