Pseudoscalar Quarkonium Exclusive Decays to Vector Meson Pair

Cong Feng Qiao

Graduate University Chinese Academy of Sciences

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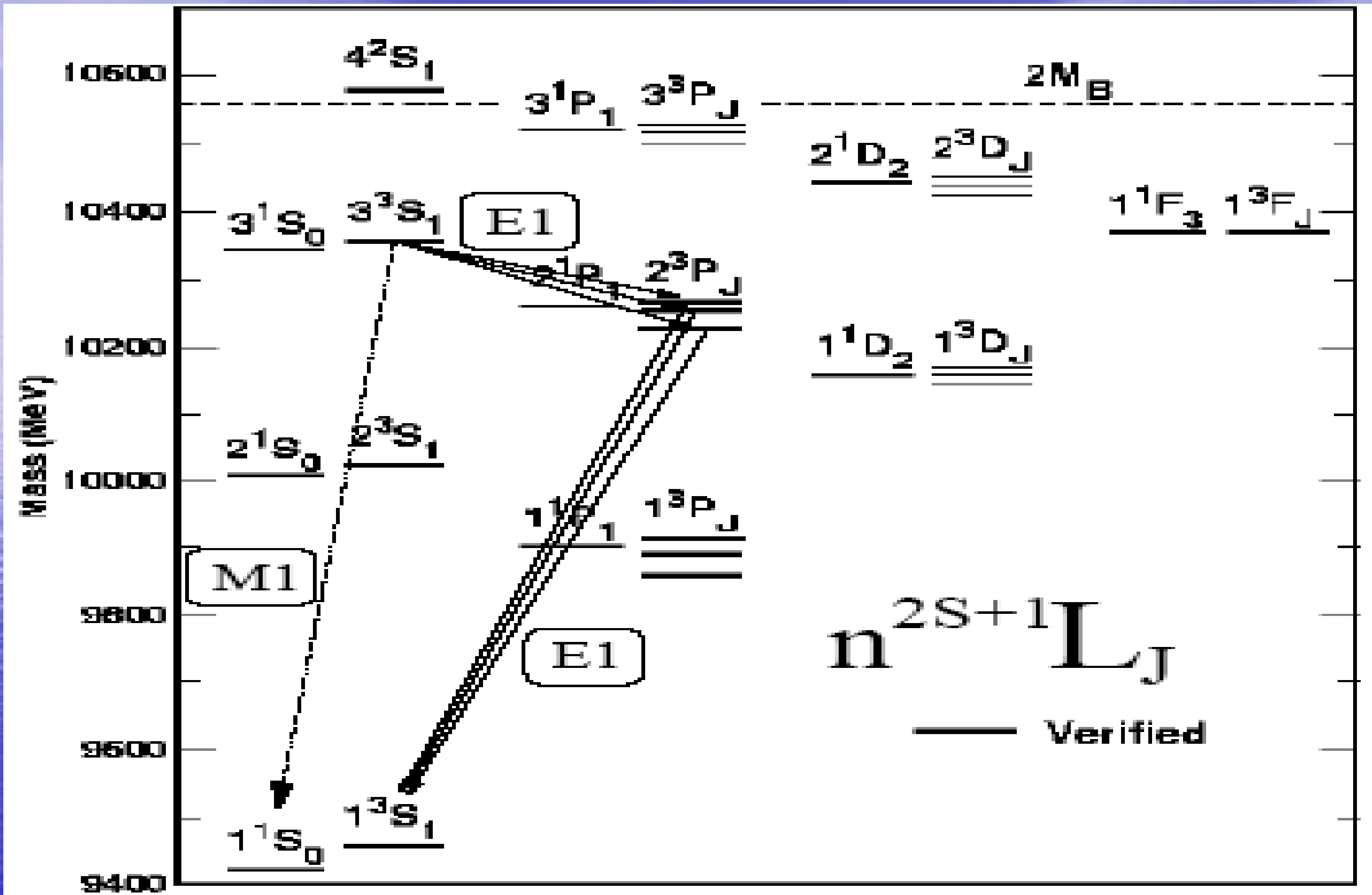
I. η_b Exclusive Decays to J/Ψ Pair

- The lowest energy state in Υ family, the η_b, is very elusive. The existence of the η_b is a solid prediction of the quark model

- About thirty year after it spin triplet partner being found, recently it was observed for the first time by Babar through Υ (3s) --> η_b γ

[Aubert, et al., Babar Collaboration, 2008]



10600
10400
10200
10000
9800
9600
9400
Mass (MeV)
4²S₁
3¹P₁
3³P_J
2M_B
2¹D₂
2³D_J
3¹S₀
3³S₁
E1
1¹F₃
1³F_J
2¹P₁
2³P_J
1¹D₂
1³D_J
2¹S₀
2³S₁
1¹P₁
1³P_J
M1
E1
$n^{2S+1}L_J$
Verified
1³S₁
1¹S₀

- In recent years, the search for η_b has been conducted at CLEO, LEP, and CDF, B-factories, using both inclusive and exclusive methods

- It is worth noting that both Babar and CLEO-c measurements are indirect ones. For further study on η_b physics, direct measurements on its decay products are necessary

Direct Search for η_b at CDF

[Tseng, CDF, 2002]

$\eta_b \rightarrow J/\psi\ J/\psi$

- A small cluster of 7 events can be seen, where 1.8 events are expected from background
- If this cluster is due to η_b decay, then the product of its production cross-section and decay branching fractions are near the lower limit of expectation from Braaten et al.

- According Braaten, Fleming and Leibovich (hep-ph/0008091) , though helicity suppressed,

$$Br[\eta_b \to J/\psi + J/\psi] = 7\times 10^{-3} \sim 7\times 10^{-5}$$

- Which seems to be overestimated, since

$$Br[\eta_b \to C + C + \overline{C} + \overline{C}] \sim 10^{-5}$$

[Maltoni and Polosa,hep-ph/0405082]

- A recent analysis shows:

[Jia, hep-ph/0611130]

$$Br[\eta_b \to \phi + \phi] \approx (0.9 - 1.4) \times 10^{-9}$$

$$Br[\eta_b \to J/\psi + J/\psi] = 2.4^{+4.2}_{-1.9} \times 10^{-8}$$

- If so, such a rare decay mode perhaps will not be observed in the foreseeable future in experiment

- More recently, the $\eta_b \to J/\psi\ J/\psi$ process was calculated at the next-to-leading order accuracy and find the NLO correction many enhance the branching fraction to the same level of relativistic correction

[Bin Gong, Yu Jia, and J.X.Wang, PLB, 2009]

- However, there exists a disagreement in this result

[Braguta & Kartvelishvili, arXiv:0907.2772]

- The radiative correction to $\eta_b \rightarrow J/\psi\ J/\psi$ process is recalculated by a third party. Result shows there is no agreement with either initial calculation or with the criticism

- Nevertheless, numerical results are all in a similar order

[Sun, Hao, QCF, PLB, 2011]

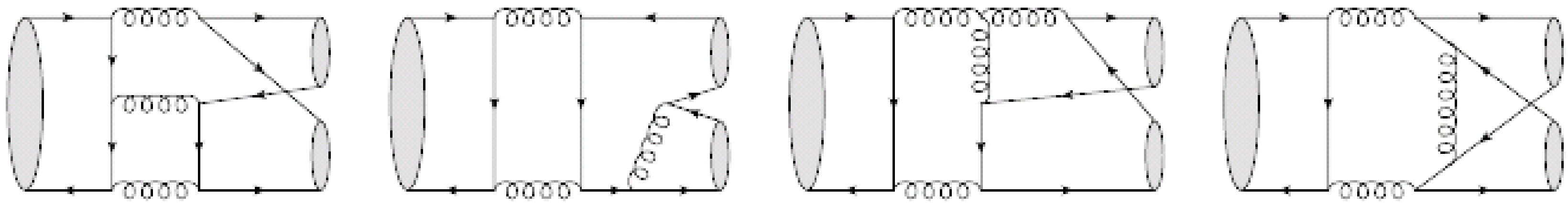


FIG. 1: Typical Feynman diagrams of the exclusive process $\eta_b(P_{\eta_b}) \to J/\psi(P_{J/\psi_1}) + J/\psi(P_{J/\psi_2})$ at the one-loop level.

Because of parity and Lorentz invariance, the decay amplitude possesses the following unique tensor structure

$$\mathcal{M}(\lambda_1, \lambda_2) = \mathcal{A}\, \varepsilon_{\mu\nu\rho\sigma} \varepsilon^{*\mu}_{J/\psi_1}(\lambda_1) \varepsilon^{*\nu}_{J/\psi_2}(\lambda_2) P^{\rho}_{J/\psi_1} P^{\sigma}_{J/\psi_1} .$$

- After a lengthy calculation, we obtain:

[Sun, Hao, QCF, 2010]

$$\mathcal{A} = \frac{512\sqrt{2}\pi\alpha_s^3 m_c \psi_{\eta_b}(0)\psi_{J/\psi}^2(0)}{9\sqrt{3}m_b^{9/2}(m_b^2 - 4m_c^2)} F\left(m_c^2, m_b^2\right)$$

with the real and imaginary parts reading as

$$\begin{aligned}\mathrm{Re}(F\left(m_c^2, m_b^2\right))_{asy} = \quad & \frac{19}{32}\log^2(a) - \frac{1}{8}\log(2)\log(a) + \frac{5}{4}\log(a) + \frac{5}{16}\log^2(2) \\ & + \frac{1}{2}\log(2) + \frac{29\pi^2}{96} - \frac{3\sqrt{3}}{8}\pi + \frac{3}{4}\end{aligned}$$

$$\mathrm{Im}(F(m_c^2, m_b^2))_{asy} = \frac{19\pi}{16}\log(a) + \frac{7\pi}{16}\log(2) + \pi$$

in small m_c limit

- The double and single logarithmic terms agree with Gong et al. result, but not the finite terms

- With the following in puts

$$\psi_{J/\psi}(0) = 0.263\ \mathrm{GeV}^{3/2},\ m_c = 1.5\ \mathrm{GeV},\ m_b = 4.7\ \mathrm{GeV},\ \alpha_s = 0.18 \sim 0.26$$

we have

$$Br[\eta_b \to J/\psi J/\psi] = 5.93 \times 10^{-8} \sim 2.58 \times 10^{-7}$$

Higher twist contributions

- In the light-cone formalism, the leading twist term has no contribution to the $\eta_b \to J/\psi\, J/\psi$ process

- We expand the LCDA projector in momentum space given by Beneke and Feldmann(2001) to twist-4, which yields more terms than what employed by Braguta et al.

- With the asymptotic form for twist-2 distribution amplitudes, i.e.

$$\phi_\perp(u) = \phi_\parallel(u) = \phi_{AS}(u) = 6u(1-u)$$

The analytical decay amplitude turns out to be pretty simple, it reads

$$\begin{aligned}\mathcal{M}_{\perp\perp} =\ & T_0 \varepsilon_{\mu\nu\rho\sigma} \varepsilon_{1\perp}^{*\mu} \varepsilon_{2\perp}^{*\nu} n_-^\rho n_+^\sigma \frac{9}{256 E_1^2 E_2^2} \times \Big[(\pi^2 - 4) m_{V_1} m_{V_2} (f_{V_1} \tilde{f}_{V_2} + f_{V_1} \tilde{f}_{V_2}) \\ & + 2\pi^2 (m_{V_2}^2 f_{V_1}^T \tilde{f}_{V_2}^T + m_{V_1}^2 f_{V_2}^T \tilde{f}_{V_1}^T) \Big] .\end{aligned}$$

- Here,

$$\tilde{f}_V = f_V - f_V^T \frac{m_1 + m_2}{m_V} , \quad \tilde{f}_V^T = f_V^T - f_V \frac{m_1 + m_2}{m_V}$$

and decay constants $f_{J/\psi}$ and $f^T_{J/\psi}$ can be obtained through experiment and NRQCD

$$f_{J/\psi} = 416 \text{ MeV} \; , \; f^T_{J/\psi} = 379 \text{ MeV}$$

- Then the numerical result reads

$$Br[\eta_b \to J/\psi J/\psi] = (1.1 \sim 2.3) \times 10^{-6} \, .$$

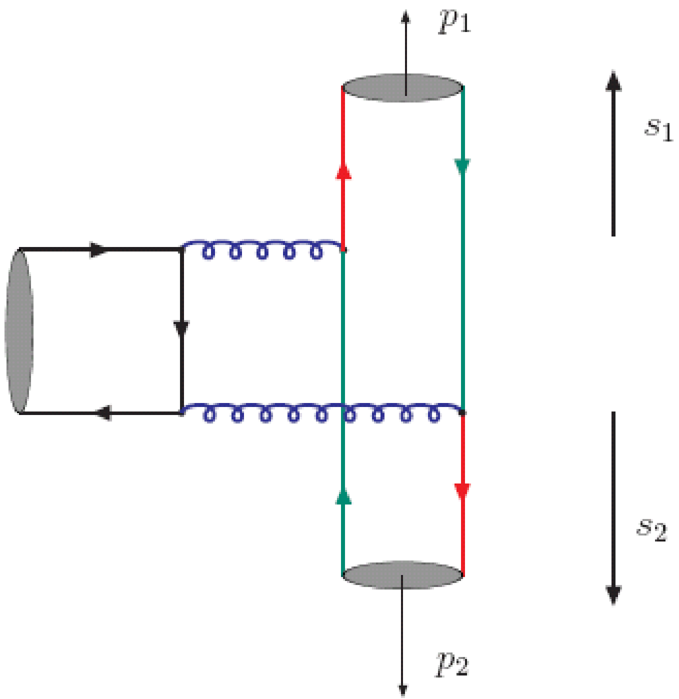
II. η_c Exclusive Decays to Vector Meson Pair

- Theoretically, the description of $\eta_c \rightarrow V V$ process is a long-standing unsolved problem

- Perturbatively, this process is helicity suppressed

- HSR prediction: $\lambda_1 + \lambda_2 = 0$;
- Parity conservation $\Rightarrow \mathcal{M} \sim \mathcal{A}\epsilon_{\mu\nu\rho\sigma}\varepsilon_1^\mu \varepsilon_2^\nu p_1^\rho p_2^\sigma$

$\boxed{\varepsilon_L = ap_1 + bp_2}$ $\Rightarrow$ No longitudinal polarization!



$P \to VV$ decay:

$\boxed{L = 1,\ S = 1}$

$\Downarrow$

$\boxed{\lambda_1 + \lambda_2 = \pm 2}$

$\Downarrow$

$\eta_c \to VV$ decays should be suppressed!

Experiment measurement on $\eta_c \rightarrow VV$ processes

- BES Collaboration, Phys.Rev.D72:072005,2005.

Final state	Branching ratio(Br)	Br/κ_{12}^3
$\rho^0\rho^0$	4.15×10^{-3}	6.6×10^{-3}
$K^{*0}\overline{K}^{*0}$	5.2×10^{-3}	5.0×10^{-3}
$\phi\phi$	2.5×10^{-3}	6.0×10^{-3}
$\omega\omega$	$< 4 \times 10^{-3}$	$< 6.4 \times 10^{-3}$
$\omega\phi$	$< 7.1 \times 10^{-3}$	$< 6.8 \times 10^{-3}$

K_{12} is a kinematical factor

- There were lots of theoretical investigations on this issue in the literature, e.g.

- η_c-glueball mixing
  Anselmino et al., PRD42(1990)3218,PRD50(1994)595.
- three-particle wave functions for light vectors
  Chernyak et al., NPB348(1991)327.
- Bethe-Salpeter wave functions
  Jia and Chao, HEP&NP.23(1995)765.
- $\eta_c - \eta' - \eta$ mixing
  Feldmann and Kroll, PRD62(2000)074006.
- $^3P_0$ quark-creation mechanism
  B.S.Zou et al., PRD71(2005)114002.
- intermediate meson exchange model
  Q.Zhao, PLB636(2006)197.

- In light-cone distribution formalism we calculate this process, up to the next-to-leading order in twist expansion

- In addition to the asymptotic form, the LCDA form in terms of Gegenbauer polynomials is also taken into account in our calculation

$$\phi_{\parallel,\perp}(u,\mu^2) = 6u(1-u)\left(1+\sum_{n=1}^{\infty} a_n^{\parallel,\perp}(\mu^2)C_n^{3/2}(2u-1)\right)$$

- We find

Final state	Br[ex]	Br[AS]	Br[GP]
$\rho\rho$	$(2.0 \pm 0.7) \times 10^{-2}$	2.0×10^{-4}	2.8×10^{-4}
$K^* \bar{K}^*$	$(9.2 \pm 3.4) \times 10^{-3}$	7.2×10^{-4}	9.0×10^{-4}
$\omega\omega$	$< 3.1 \times 10^{-3}$	9.1×10^{-5}	1.3×10^{-4}
$\phi\phi$	$(2.7 \pm 0.9) \times 10^{-3}$	6.6×10^{-4}	8.1×10^{-4}

- The results are in disagreement with the experiment measurements

[Sun, Hao, QCF, 2010]

III. Brief Summary

- To further study the nature of recently observed state η_b direct measurement of its decay products is necessary

- With in the pQCD and factorization scheme, we have calculated the helicity suppressed process $\eta_c \to J/\psi\ J/\psi$ to next-to-leading order

- Our result confirms the existence of double logarithm, however, others terms differs from what in the literature, though numerical difference is not big

- In the light cone formalism, expanding the LCDAs of final vector mesons to twist-4, we find that the higher twist terms contribute more to the η_b decay width than what from the NLO corrections
- According to our twist-4 calculation, the branching fraction of $\eta_b \rightarrow J/\psi\ J/\psi$ process can be as large as 10^{-6}, which enables the direct search of η_b in Tevatron Run II or LHC

- In the light cone formalism we have calculated the process $\eta_c \rightarrow VV$ in next-to-next-leading order in twist expansion

- Result shows that the higher twist DAs indeed violate the helicity conservation rules, however it still deviate a lot from the experimental measurement

- This means that the perturbative description of $\eta_c \rightarrow VV$ is not enough, and some non-perturbative mechanism may play important roles

Thank you for your attention