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

Pietro Santorelli

Università "Federico II" & INFN, Napoli, Italy

International Workshop on Heavy Quarkonium 2007

Outline

- The $\eta_c \to \phi\phi$ and the $\eta_b \to J/\psi\ J/\psi$ decays
- The $\eta_b \to D\overline{D^*}$ and the $D\overline{D^*} \to J/\psi\ J/\psi$ rescattering
- Conclusions

Based on the paper
P.S., *Long distance contributions to the $\eta_b \to J/\psi\ J/\psi$ decay*, hep-ph/0703232

Outline

- The $\eta_c \to \phi\phi$ and the $\eta_b \to J/\psi\ J/\psi$ decays
- The $\eta_b \to D\overline{D^*}$ and the $D\overline{D^*} \to J/\psi\ J/\psi$ rescattering
- Conclusions

Based on the paper
P.S., *Long distance contributions to the $\eta_b \to J/\psi\ J/\psi$ decay*,
hep-ph/0703232

Outline

- The $\eta_c \to \phi\phi$ and the $\eta_b \to J/\psi\ J/\psi$ decays
- The $\eta_b \to D\overline{D^*}$ and the $D\overline{D^*} \to J/\psi\ J/\psi$ rescattering
- Conclusions

Based on the paper
P.S., *Long distance contributions to the $\eta_b \to J/\psi\ J/\psi$ decay*,
hep-ph/0703232

$\eta_c \to \phi\phi$ and $\eta_b \to J/\psi J/\psi$

Braaten, Fleming and Leibovich, 2001

$$\lim_{m_b\to\infty, m_c\ \mathit{finite}} \mathcal{B}r[\eta_b \to J/\psi J/\psi] \sim \left(\frac{1}{m_b}\right)^4$$

Brodsky and Lepage, 1981

$$\frac{\mathcal{B}r[\eta_b \to J/\psi J/\psi]}{\mathcal{B}r[\eta_c \to \phi\phi]} \sim \left(\frac{m_c}{m_b}\right)^4 \equiv x \approx 10^{-2}$$

$$\mathcal{B}r[\eta_b \to J/\psi J/\psi] = 7 \times 10^{-4\pm1}$$

$$x \ \in \ [10^{-2}, 1] \quad \& \quad \mathcal{B}r[\eta_c \to \phi\phi] = 7 \times 10^{-3}$$

A lot of events are predicted at Tevatron run II

$$\eta_b \to J/\psi\, J/\psi \ \to \mu^+\ \mu^-\ \mu^+\ \mu^-$$

$\eta_c \to \phi\phi$ and $\eta_b \to J/\psi J/\psi$

Maltoni and Polosa, 2004; Jia, 2006

Maltoni & Polosa calculations

- A direct calculation, at LO, of the inclusive process has been done

$$\mathcal{B}r[\eta_b \to c\bar{c}c\bar{c}\,] = 1.8^{+2.3}_{-0.8} \times 10^{-5}$$

- In NRQCD $\Gamma[\eta_b(\eta_c) \to VV] = 0$ at LO in α_s and v^2. Rescaling non-perturbative and higher order contributions by the same factor is not reliable.

Jia estimate

- $\mathcal{B}r[\eta_b \to J/\psi\ J/\psi] = (0.5\ \div\ 6.6)\ \times\ 10^{-8}$

$\eta_c \to \phi\phi$ and $\eta_b \to J/\psi J/\psi$

Maltoni and Polosa, 2004; Jia, 2006

Maltoni & Polosa calculations

- A direct calculation, at LO, of the inclusive process has been done

$$\mathcal{B}r[\eta_b \to c\bar{c}c\bar{c}\,] = 1.8^{+2.3}_{-0.8} \times 10^{-5}$$

- In NRQCD $\Gamma[\eta_b(\eta_c) \to VV] = 0$ at LO in α_s and v^2. Rescaling non-perturbative and higher order contributions by the same factor is not reliable.

Jia estimate

- $\mathcal{B}r[\eta_b \to J/\psi\ J/\psi] = (0.5\ \div\ 6.6)\ \times\ 10^{-8}$

Note that

Jia,2006

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{th} = (0.3 \div 1.5) \times 10^{-5}$$

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{exp} = (2.7 \pm 0.5) \times 10^{-3}$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^*}$

$10^{-3} \leqslant \mathcal{B}r[\eta_b \to D\overline{D^*}] \leqslant 10^{-2}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 0$ $\quad$ *Maltoni Polosa*

$\mathcal{B}r[\eta_b \to D\overline{D^*}] \sim 10^{-5}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 10^{-8}$ $\quad$ *Jia*

Note that

Jia,2006

$$\mathcal{B}r[\eta_c \to \phi\ \phi]\Big|_{th} = (0.3 \div 1.5) \times 10^{-5}$$

$$\mathcal{B}r[\eta_c \to \phi\ \phi]\Big|_{exp} = (2.7 \pm 0.5) \times 10^{-3}$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^{*}}$

$$10^{-3} \leqslant \mathcal{B}r[\eta_b \to D\overline{D^{*}}] \leqslant 10^{-2} \qquad \mathcal{B}r[\eta_b \to D^{*}\overline{D^{*}}] \approx 0$$

Maltoni Polosa

$$\mathcal{B}r[\eta_b \to D\overline{D^{*}}] \sim 10^{-5} \qquad \mathcal{B}r[\eta_b \to D^{*}\overline{D^{*}}] \approx 10^{-8}$$

Jia

Note that

Jia,2006

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{th} = (0.3 \div 1.5) \times 10^{-5}$$

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{exp} = (2.7 \pm 0.5) \times 10^{-3}$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^*}$

$10^{-3} \leqslant \mathcal{B}r[\eta_b \to D\overline{D^*}] \leqslant 10^{-2}$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 0$ Maltoni Polosa

$\mathcal{B}r[\eta_b \to D\overline{D^*}] \sim 10^{-5}$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 10^{-8}$ Jia

Note that

Jia,2006

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{th} = (0.3 \div 1.5) \times 10^{-5}$$

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{exp} = (2.7 \pm 0.5) \times 10^{-3}$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^*}$

$10^{-3} \leqslant \mathcal{B}r[\eta_b \to D\overline{D^*}] \leqslant 10^{-2}$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 0$ *Maltoni Polosa*

$\mathcal{B}r[\eta_b \to D\overline{D^*}] \sim 10^{-5}$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 10^{-8}$ *Jia*

Note that

Jia,2006

$$
\begin{aligned}
\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{th} &= (0.3 \div 1.5) \times 10^{-5} \\
\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{exp} &= (2.7 \pm 0.5) \times 10^{-3}
\end{aligned}
$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^{*}}$

$10^{-3} \lesssim \mathcal{B}r[\eta_b \to D\overline{D^*}] \lesssim 10^{-2}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 0$ $\quad$ Maltoni Polosa

$\mathcal{B}r[\eta_b \to D\overline{D^*}] \sim 10^{-5}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 10^{-8}$ $\quad$ Jia

Note that

Jia,2006

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{th} = (0.3 \div 1.5) \times 10^{-5}$$

$$\mathcal{B}r[\eta_c \to \phi\,\phi]\Big|_{exp} = (2.7 \pm 0.5) \times 10^{-3}$$

Is the case of $\eta_b \to J/\psi J/\psi$ similar to $\eta_c \to \phi\phi$?

What kind of mechanisms could be responsible for the enhancement?

Final State Interactions?

- J/ψ has large coupling to $(D^{(*)}\overline{D^{(*)}})$
- η_b couples to $D\overline{D^*}$

$10^{-3} \leqslant \mathcal{B}r[\eta_b \to D\overline{D^*}] \leqslant 10^{-2}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 0$ $\quad$ Maltoni Polosa

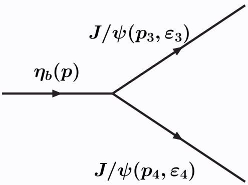
$\mathcal{B}r[\eta_b \to D\overline{D^*}] \sim 10^{-5}$ $\quad$ $\mathcal{B}r[\eta_b \to D^*\overline{D^*}] \approx 10^{-8}$ $\quad$ Jia

$\eta_b \to J/\psi J/\psi$: the Full Amplitude

The full amplitude

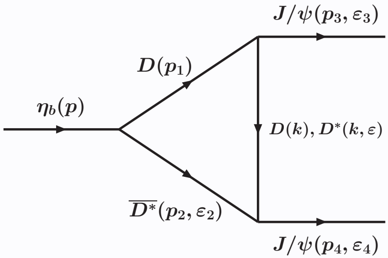
$$\mathcal{A}[\eta_b \to J/\psi J/\psi] =$$

Short Distance



+

Long Distance



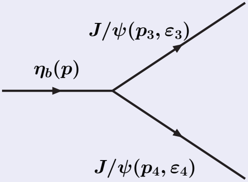
$\eta_b \to J/\psi J/\psi$: the Full Amplitude

P.S., 2007

The full amplitude

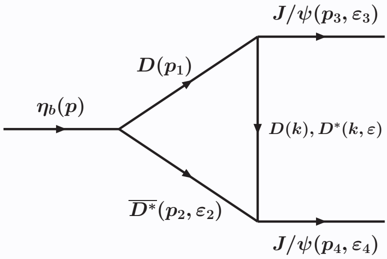
$$\mathcal{A}[\eta_b \to J/\psi J/\psi] =$$

Short Distance



+

Long Distance



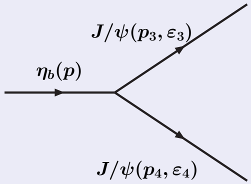
$\eta_b \to J/\psi J/\psi$: the Full Amplitude

P.S., 2007

The full amplitude

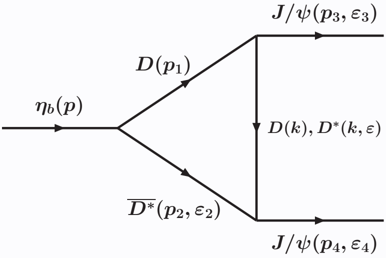
$$\mathcal{A}[\eta_b \to J/\psi J/\psi] =$$

Short Distance



$+$

Long Distance



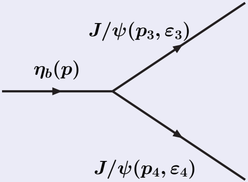
$\eta_b \to J/\psi J/\psi$: the Full Amplitude

P.S., 2007

The full amplitude

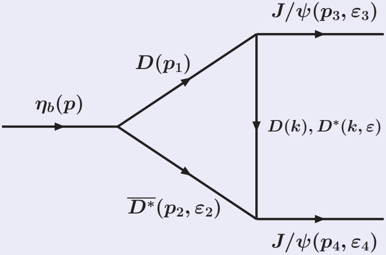
$$\mathcal{A}[\eta_b \to J/\psi J/\psi] =$$

Short Distance

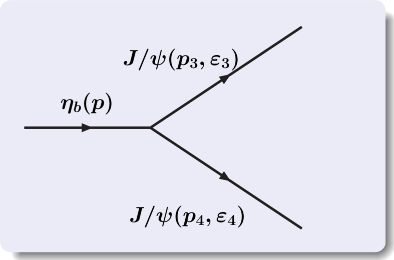


$+$

Long Distance



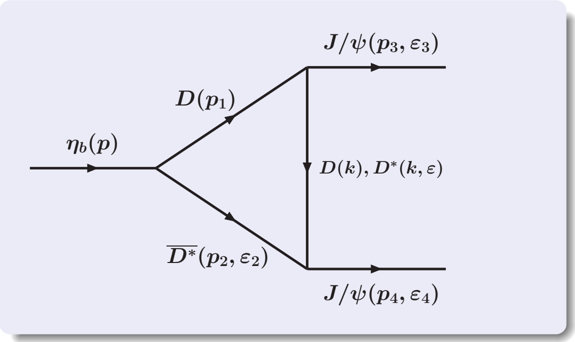
The *Short Distance* Contribution



$$= \frac{\imath}{m_{\eta_b}} g_{\eta_b JJ}\, \varepsilon_{\alpha\beta\gamma\delta}\, p_3^\alpha p_4^\beta \varepsilon_3^{*\gamma} \varepsilon_4^{*\delta}$$

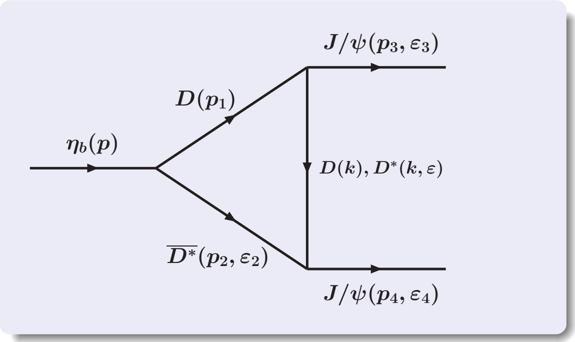
$g_{\eta_b JJ}$ can be obtained by evaluating the $\eta_b \to J/\psi J/\psi$ rate (NRQCD, quark models, etc.)

The Contribution of Hadron Loops



- we evaluate the Absorbitive part
- the Dispersive part, for which the theoretical evaluation is more difficult, would imply even a larger branching ratio

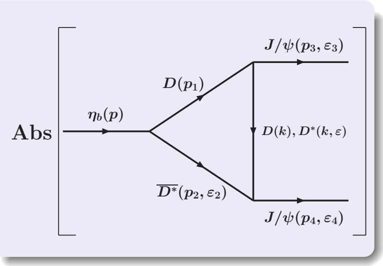
The Contribution of Hadron Loops



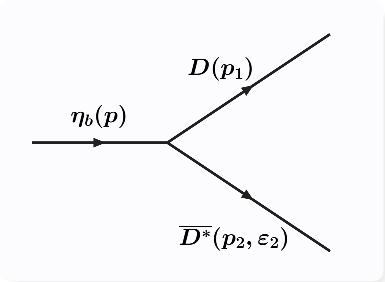
- we evaluate the Absorbitive part
- the Dispersive part, for which the theoretical evaluation is more difficult, would imply even a larger branching ratio

The Absorbitive Part of Hadron Loops

By using optical theorem



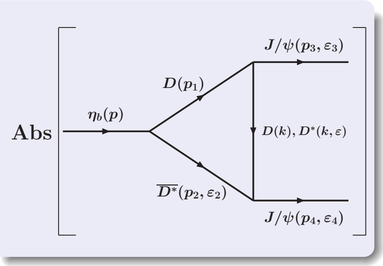
$$\propto \int_{t_{min}}^{t_{max}} dt\, \mathcal{A}[\eta_b \to D\overline{D^*}]\mathcal{A}[D\overline{D^*} \to J/\psi J/\psi]$$



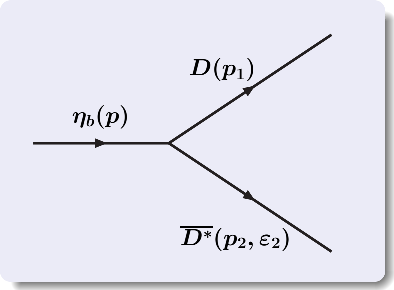
$$\mathcal{A}[\eta_b \to D\,\overline{D^*}] = 2\, g_{\eta_b D D^*}\, (\varepsilon_2^* \cdot p)$$

The Absorbitive Part of Hadron Loops

By using optical theorem



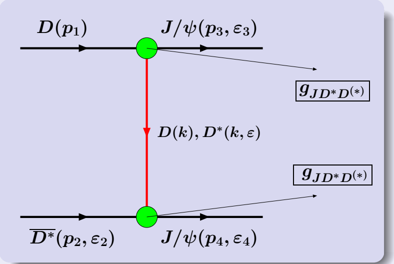
$$\propto \int_{t_{min}}^{t_{max}} dt\ \mathcal{A}[\eta_b \to D\overline{D^*}]\mathcal{A}[D\overline{D^*} \to J/\psi J/\psi]$$



$$\mathcal{A}[\eta_b \to D\ \overline{D^*}] = 2\ g_{\eta_b D D^*}\ (\varepsilon_2^* \cdot p)$$

The Absorbitive Part of Hadron Loops (cont')

The scattering amplitude $\mathcal{A}[D\overline{D^*} \to J/\psi J/\psi]$

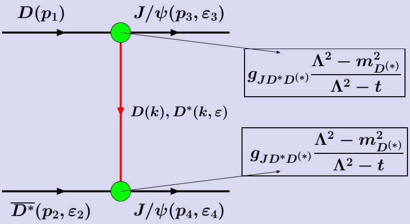


These couplings are relevant to the calculation of the $\sigma(J/\psi\ \pi \to D^{(*)}\ \overline{D^{(*)}})$: the "standard" mechanism of J/ψ suppression in heavy ion collisions. However, the J/ψ suppression is also an indication of the quark-gluon plasma formation.

Matsui and Satz, '86

The Absorbitive Part of Hadron Loops (cont’)

The scattering amplitude $\mathcal{A}[D\overline{D^*} \to J/\psi J/\psi]$



Off-shellness of the exchanged charmed mesons is taken into account by writing the couplings as functions of the variable $t = k^2 = (p_1 - p_3)^2$.

There are many calculations of these couplings and of their dependence on the variable **t**

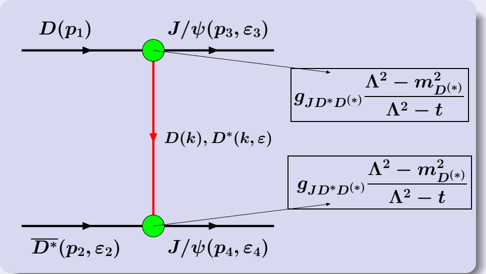
Deandrea, Nardulli and Polosa, 2003
Ivanov, Korner and P.S., 2004
Matheus, et al., 2005

We use

$$(g_{JDD},\ g_{JDD^*},\ g_{JD^*D^*}) = (6, 12, 6)$$

The Absorbitive Part of Hadron Loops (cont')

The scattering amplitude $\mathcal{A}[D\overline{D^*} \to J/\psi J/\psi]$



We choose the function

$$F(t) = \frac{\Lambda^2 - m^2_{D^{(*)}}}{\Lambda^2 - t} .$$

to parametrize the t-dependance. Λ is a free parameter which should not be far from the value of the $D^{(*)}$ mass. Following H. Y Cheng , Chua and Soni, (2005) we use

$$\Lambda = m_{D^{(*)}} + \Lambda_{QCD}\ \alpha$$

$$\Lambda_{QCD} = 0.22\ GeV \quad \text{and} \quad \alpha \approx 2.2$$

Results

$$\mathcal{A}[\eta_b \to J/\psi J/\psi] \;=\; \imath\,\frac{g_{\eta_b JJ}}{m_{\eta_b}}\,\varepsilon_{\alpha\beta\gamma\delta}\,p_3^{\alpha}p_4^{\beta}\epsilon_3^{*\gamma}\epsilon_4^{*\delta}\left[1-\imath\;\underbrace{\frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}}A_{LD}}\right]$$

$$\left(\frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}}\right)^2 \propto \frac{\mathcal{B}r[\eta_b \to D\overline{D^*}]}{\mathcal{B}r[\eta_b \to J/\psi\;J/\psi]_{SD}} \in [10^2, 10^5]$$

$$\Downarrow$$

$$\mathbf{1} \leq \frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}} \leq \mathbf{35}$$

$$\Downarrow$$

$$\mathbf{0.31 \pm 0.06} \leq \frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}}A_{LD} \leq \mathbf{10 \pm 2}$$

with $2.0 \leq \alpha \leq 2.4$

Results

	$\mathcal{B}r[\eta_b \to J/\psi J/\psi]_{SD}$	$\mathcal{B}r[\eta_b \to J/\psi J/\psi]_{full}$	# Events	# at Tevatron	# at LHC
BFL	$7 \times 10^{-4\pm1}$		$677 \div 67700$	$4 \div 400$	
J	$(0.5 \div 6.6) \times 10^{-8}$		$0.05 \div 0.6$	$0.0003 \div 0.004$	$0.5 \div 6$
this work	$(0.5 \div 6.6) \times 10^{-8}$	$(0.28 \div 6.7) \times 10^{-6}$	$3 \div 65$	$0.02 \div 0.4$	$26 \div 640$

we used

$$\text{TEVATRON(RunII)} \quad \sigma(\eta_b) = 2.5\ \mu\text{b} \quad \mathcal{L} = 1.1\ \text{fb}^{-1} \quad \text{rapidity interval } = \pm\, 0.6$$

$$\text{LHC} \quad \sigma(\eta_b) = 15\ \mu\text{b} \quad \mathcal{L} = 300\ \text{fb}^{-1} \quad \text{rapidity interval } = \pm\, 0.6$$

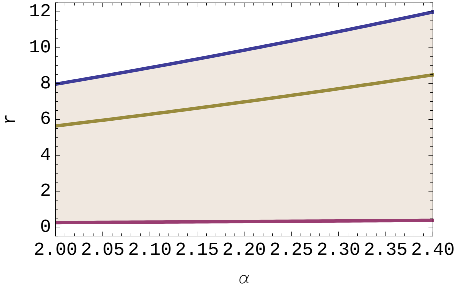
and a 10% of the product of acceptance and efficiency for detecting each $J/\psi \to \mu^+\mu^-$

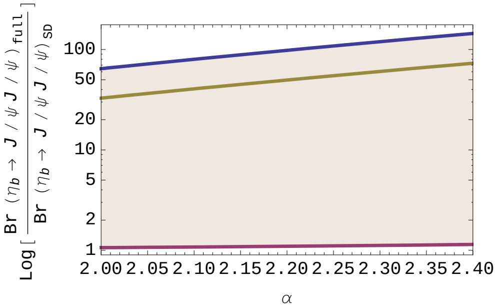
Summary and Conclusions

- We have studied the role of the $D\,\overline{D^*} \to J/\psi J/\psi$ rescattering in the $\eta_b \to J/\psi J/\psi$.
- We have shown that this contribution may enhance the branching fraction of about two orders of magnitude which would imply a measurable effect in LHC.
- To give a firm prediction of the $\mathcal{B}r[\eta_b \to J/\psi\ J/\psi]$ a direct calculation of the $\mathcal{B}r[\eta_b \to D\,\overline{D^*}]$ is in order.
- However, experimental results together with this calculation can be used to put phenomenological constraints on the hadronic quantities: $g_{\eta_b D D^*}$ and $g_{J D^{(*)} D^{(*)}}$.

Summary and Conclusions

- We have studied the role of the $D\,\overline{D^*} \to J/\psi J/\psi$ rescattering in the $\eta_b \to J/\psi J/\psi$.
- We have shown that this contribution may enhance the branching fraction of about two orders of magnitude which would imply a measurable effect in LHC.
- To give a firm prediction of the $\mathcal{B}r[\eta_b \to J/\psi\ J/\psi]$ a direct calculation of the $\mathcal{B}r[\eta_b \to D\,\overline{D^*}]$ is in order.
- However, experimental results together with this calculation can be used to put phenomenological constraints on the hadronic quantities: $g_{\eta_b D D^*}$ and $g_{J D^{(*)} D^{(*)}}$.


r
12
10
8
6
4
2
0
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
α


$\mathrm{Log}\left[\frac{\mathrm{Br}\,(\eta_b \to J/\psi\, J/\psi)_{\mathrm{full}}}{\mathrm{Br}\,(\eta_b \to J/\psi\, J/\psi)_{\mathrm{SD}}}\right]$
100
50
20
10
5
2
1
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
α