

ON THE $\eta_b \rightarrow J/\psi J/\psi$ DECAY

PIETRO SANTORELLI

Università “Federico II” and INFN - Napoli

- ★ The η_b meson
- ★ The $\eta_b \rightarrow J/\psi J/\psi$ decay
- ★ The $\eta_b \rightarrow D\bar{D}^*$ and the $D\bar{D}^* \rightarrow J/\psi J/\psi$ rescattering
- ★ Conclusions

Based on the paper

Long distance contributions to the $\eta_b \rightarrow J/\psi J/\psi$ decay
hep-ph/0703232

THE η_b MESON

- $\eta_b(1S)$ is the $b\bar{b}$ spin singlet pseudoscalar meson ($J^{PC} = 0^{-+}$)
- $M_{\Upsilon(1S)} - M_{\eta_b} \sim 40 \div 60 \text{ MeV}$
 - Liao and Manke, 2002
 - Recksiegel and Sumino, 2004
 - Ebert, Faustov and Galkin 2003
 - Lengyel et al., 2001
 - Kniel et al., 2004
- ALEPH (2002) observed one event with an expected background of one event in $\gamma\gamma \rightarrow \eta_b \rightarrow 6$ charged particles
- CDF Run II preliminary results

WHY THE $\eta_b \rightarrow J/\psi J/\psi$ DECAY MODE?

Braaten, Fleming and Leibovich, 2001

- If the Branching ratio is large, it can be "easily" detected by looking at $\mu^+ \mu^- \mu^+ \mu^-$ final state
- The process is analogous to the $\eta_c \rightarrow \phi\phi$ except that all the masses are rescaled up by a factor.
- The starting observation is

$$\lim_{m_b \rightarrow \infty, m_c \text{ finite}} \mathcal{Br}[\eta_b \rightarrow J/\psi J/\psi] \sim \left(\frac{1}{m_b}\right)^4 \quad \text{Brodsky and Lepage, 1981}$$

and so

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

using $\mathcal{Br}[\eta_c \rightarrow \phi\phi] = 7 \times 10^{-3}$, $10^{-2} \leq x \leq 1$

$$\begin{aligned} \mathcal{Br}[\eta_b \rightarrow J/\psi J/\psi] &= 7 \times 10^{-4 \pm 1} \\ &\Downarrow \\ \mathcal{Br}[\eta_b \rightarrow J/\psi J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-] &\approx 3 \times 10^{-6 \pm 1} \end{aligned}$$

Using $\sigma(\eta_b) = 0.124 \text{ } \mu b$ at Tevatron's energy and for a $\mathcal{L} = 100 \text{ pb}^{-1}$, the expected number of events is in the range

$$30 \div 3000$$

without taking into account the allowed **rapidity** interval, **acceptance** and **efficiency** for detecting $J/\psi \rightarrow \mu^+ \mu^-$.

IS THE $\mathcal{B}r[\eta_b \rightarrow J/\psi J/\psi]$ SO LARGE ?

Maltoni and Polosa, 2004
Jia, 2006

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

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

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

The larger value is **smaller** than the lower value estimated by scaling law for the exclusive process:

$$\mathcal{B}r[\eta_b \rightarrow J/\psi J/\psi] = 7 \times 10^{-5}$$

Moreover, a direct calculation of the exclusive process by color-singlet model, gives

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

These results suggest to study other decay channels to detect η_b

$$\eta_b \rightarrow D^* \overline{D} (D \overline{D}^*)$$

Maltoni and Polosa, 2004

They evaluated

$$\mathcal{Br}[\eta_b \rightarrow c\bar{c}X] \approx \mathcal{Br}[\eta_b \rightarrow c\bar{c}g] = 1.5_{-0.4}^{+0.8}\%$$

and assumed

$$\mathcal{Br}[\eta_b \rightarrow D^{(*)} \overline{D}^{(*)}] \lesssim \mathcal{Br}[\eta_b \rightarrow c\bar{c}X]$$

↓

$$10^{-3} \leq \mathcal{Br}[\eta_b \rightarrow D \overline{D}^*] \leq 10^{-2}$$

This saturation assumption is questionable

Jia, 2006

$$\mathcal{Br}[\eta_b \rightarrow D \overline{D}^*] \sim 10^{-5}$$

$$\mathcal{Br}[\eta_b \rightarrow D^* \overline{D}^*] \sim 10^{-8}$$

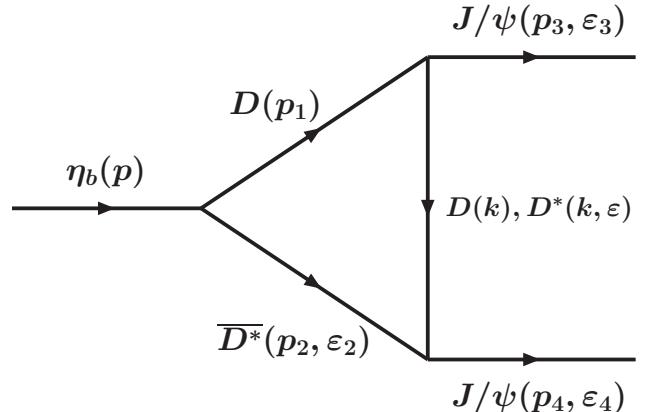
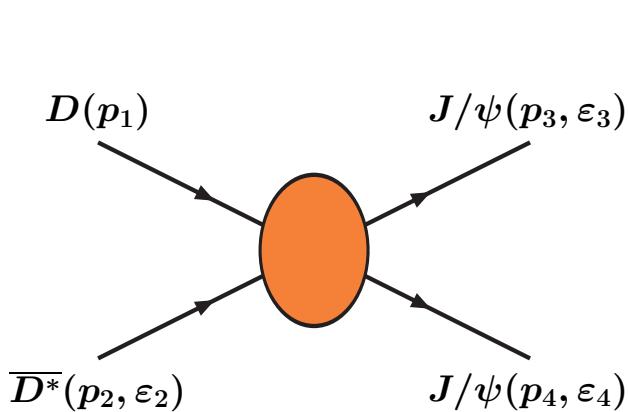
$$\eta_b \rightarrow D^* \overline{D} (D \overline{D}^*) \rightarrow J/\psi J/\psi$$

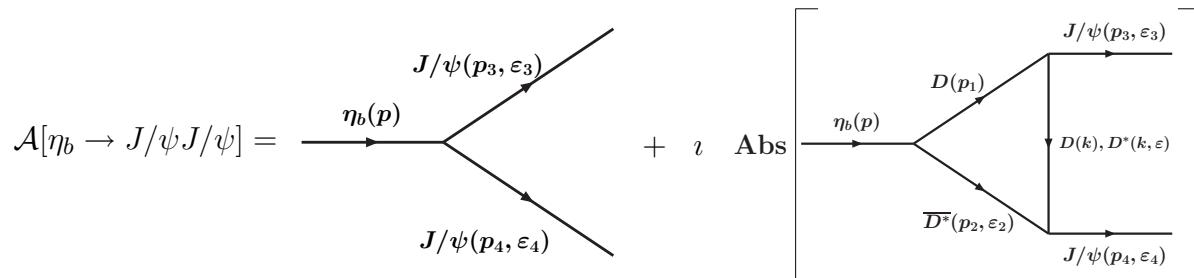
P.S., 2007

We start from the following assumptions:

- a) $\mathcal{Br}[\eta_b \rightarrow D \overline{D}^*] \sim 10^{-4\pm 1}$
- b) $\mathcal{Br}[\eta_b \rightarrow D^* \overline{D}] \ll \mathcal{Br}[\eta_b \rightarrow D \overline{D}^*]$

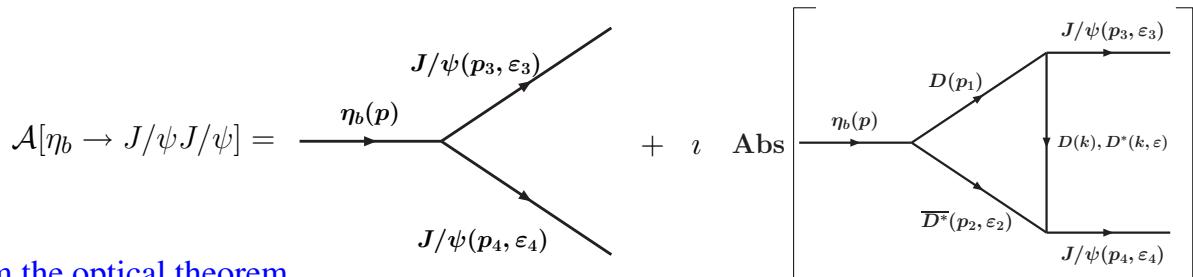
and we will consider the effect of $D \overline{D}^* \rightarrow J/\psi J/\psi$ rescattering



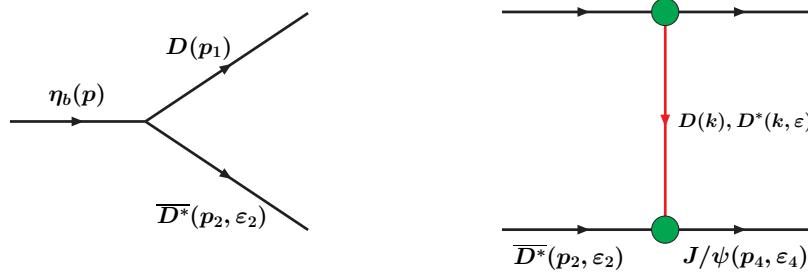


$$\text{---} \xrightarrow{\eta_b(p)} \begin{cases} J/\psi(p_3, \varepsilon_3) \\ J/\psi(p_4, \varepsilon_4) \end{cases} = \frac{i}{m_{\eta_b}} g_{\eta_b JJ} \varepsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \varepsilon_3^{*\gamma} \varepsilon_4^{*\delta}$$

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



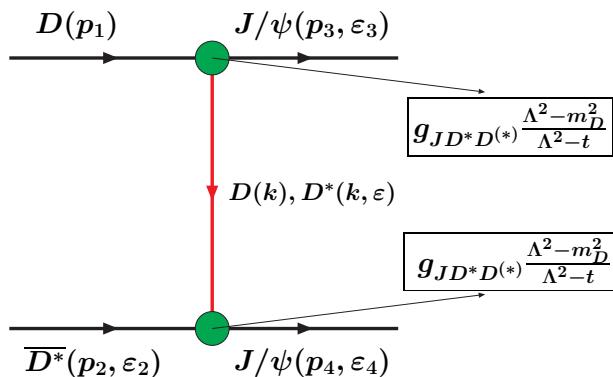
$$\text{Abs} \left[\begin{array}{c} \text{---} \xrightarrow{\eta_b(p)} \begin{cases} D(p_1) \\ D(k), D^*(k, \varepsilon) \end{cases} \xrightarrow{J/\psi(p_3, \varepsilon_3)} \\ \text{---} \xrightarrow{D^*(p_2, \varepsilon_2)} \xrightarrow{J/\psi(p_4, \varepsilon_4)} \end{array} \right] = \frac{1}{32\pi M_{\eta_b} |\vec{p}_3|} \int_{t_{min}}^{t_{max}} dt \mathcal{A}[\eta_b \rightarrow D\bar{D}^*] \mathcal{A}[D\bar{D}^* \rightarrow J/\psi J/\psi]$$



Abs

$$= \frac{1}{32\pi M_{\eta_b} |\vec{p}_3|} \int_{t_{min}}^{t_{max}} dt \mathcal{A}[\eta_b \rightarrow D\bar{D}^*] \mathcal{A}[D\bar{D}^* \rightarrow J/\psi J/\psi]$$

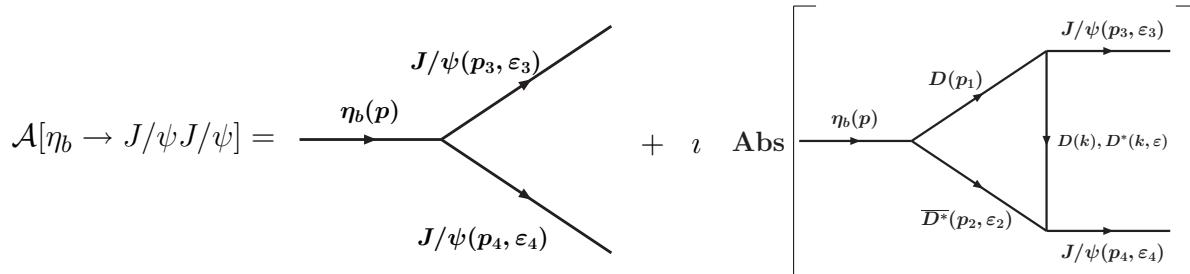
$$\mathcal{A}[\eta_b(p) \rightarrow D(p_1) \bar{D}^*(p_2, \varepsilon_2)] = 2 g_{\eta_b DD^*} (\varepsilon_2^* \cdot p)$$



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

Λ is a free parameter which should not be far from the value of the $D^{(*)}$ mass.

The amplitude, taking into account the Long Distance (rescattering) contribution, can be written as

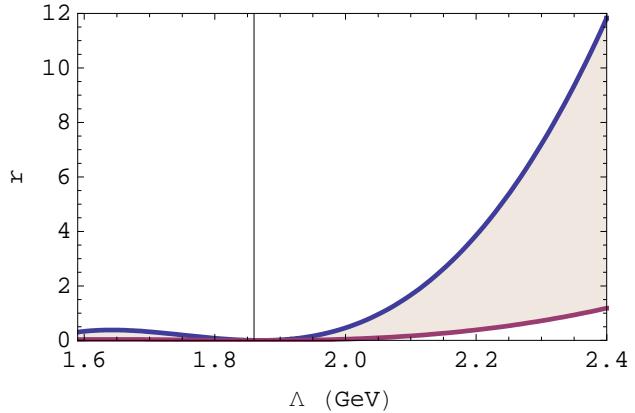


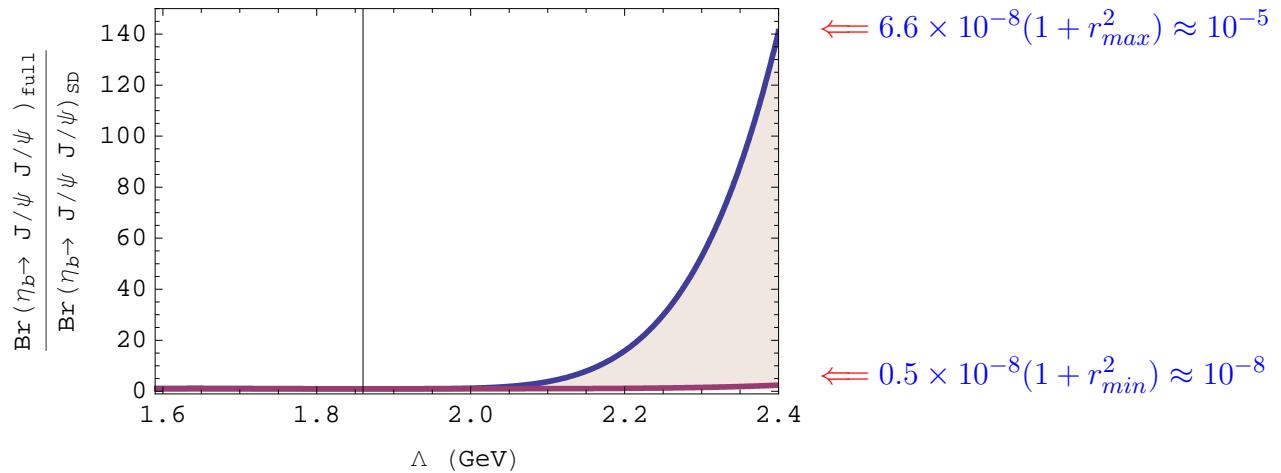
$$\mathcal{A}[\eta_b \rightarrow J/\psi J/\psi] = i \frac{g_{\eta_b JJ}}{m_{\eta_b}} \varepsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \epsilon_3^{*\gamma} \epsilon_4^{*\delta} \left[1 + i \frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}} A_{LD} \right] = i \frac{g_{\eta_b JJ}}{m_{\eta_b}} \varepsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \epsilon_3^{*\gamma} \epsilon_4^{*\delta} [1 - i \mathbf{r}]$$

where

$$\left(\frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}} \right)^2 \propto \frac{\mathcal{B}r[\eta_b \rightarrow D\bar{D}^*]}{\mathcal{B}r[\eta_b \rightarrow J/\psi J/\psi]_{SD}} = 10^{-4 \pm 1}$$

$$4 \leq \frac{g_{\eta_b DD^*}}{g_{\eta_b JJ}} \leq 40$$





	$\mathcal{B}r[\eta_b \rightarrow J/\psi J/\psi]_{SD}$	$\mathcal{B}r[\eta_b \rightarrow J/\psi J/\psi]_{full}$	# Events	# at Tevatron
BFL	$7 \times 10^{-4 \pm 1}$		$677 \div 67700$	$4 \div 400$
J	$(0.5 \div 6.6) \times 10^{-8}$		$0.05 \div 0.6$	$0.0003 \div 0.004$
this work	$(0.5 \div 6.6) \times 10^{-8}$	$1.2 \times 10^{-8} \div 1.0 \times 10^{-5}$	$0.1 \div 93$	$0.0007 \div 0.6$

we used (Run II)

$$\sigma(\eta_b) = 2.5 \text{ } \mu\text{b}$$

$$\mathcal{L} = 1.1 \text{ fb}^{-1}$$

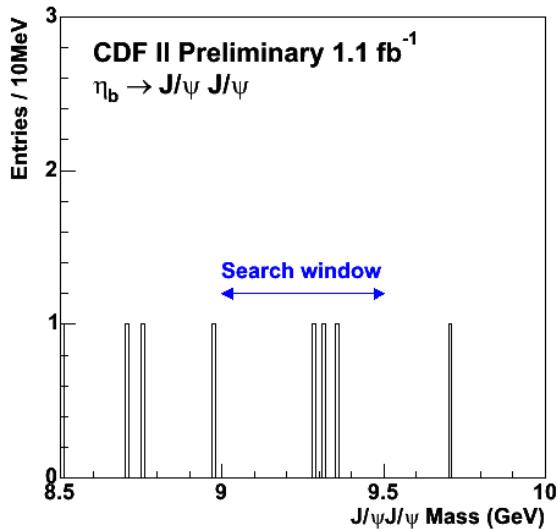
rapidity interval $= \pm 0.6$

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

CDF PRELIMINARY RESULTS

CDF Coll., public note 8448, June 2006

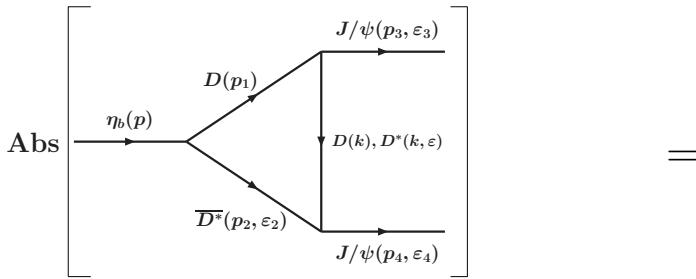
CDF searched for η_b through $\eta_b \rightarrow J/\psi J/\psi$ with both J/ψ decay into a dimuon pair. Using 1.1 fb^{-1} data they observed 3 candidates while expecting 3.6 background events in the search window from 9.0 to 9.5 GeV.



SUMMARY AND CONCLUSIONS

- We have studied the role of the $D\bar{D}^* \rightarrow J/\psi J/\psi$ rescattering in the $\eta_b \rightarrow J/\psi J/\psi$.
- We have shown that this Long Distance contribution may enhance the branching fraction of about two orders of magnitude.
- The large allowed range is a consequence of the not well known $\mathcal{Br}[\eta_b \rightarrow D\bar{D}^*]$ and of the t-dependence of the $g_{J\bar{D}^{(*)}\bar{D}^*}$. Experimental results together with this calculation can be used to put phenomenological constraints on these hadronic quantities.

Backup Slides



$$\begin{aligned}
&= \frac{1}{16\pi m_{\eta_b} \sqrt{m_{\eta_b}^2 - 4m_{J/\psi}^2}} \int_{t_m}^{t_M} dt \mathcal{A}(\eta_b \rightarrow D\bar{D}^*) \mathcal{A}(D\bar{D}^* \rightarrow J/\psi J/\psi) \\
&= \frac{i g_{\eta_b DD^*} \epsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \epsilon_3^{*\gamma} \epsilon_4^{*\delta}}{16\pi m_{\eta_b} \sqrt{m_{\eta_b}^2 - 4m_{J/\psi}^2}} \int_{t_m}^{t_M} \frac{dt}{t - m_D^2} \frac{g_{JDD^*}(t)}{m_{J/\psi}(m_{\eta_b}^2 - 4m_{J/\psi}^2)} \times \\
&\quad \left\{ 2g_{JDD}(t) \left[(m_D^2 - m_{J/\psi}^2)^2 + (m_{\eta_b}^2 - 2m_D^2 - 2m_{J/\psi}^2)t + t^2 \right] \right. \\
&\quad \left. - \frac{g_{JD^*D^*}(t)}{m_D^2} \left[(m_D^2 - m_{J/\psi}^2)^2 (2m_D^2 + m_{\eta_b}^2) - 2m_D^2 (2(m_D^2 + m_{J/\psi}^2) - m_{\eta_b}^2)t + (2m_D^2 - m_{\eta_b}^2)t^2 \right] \right\} \\
&\equiv \left(\frac{A_{LD}}{m_{\eta_b}} g_{\eta_b DD^*} \right) i \epsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \epsilon_3^{*\gamma} \epsilon_4^{*\delta},
\end{aligned}$$

$$[t_m, t_M] \approx [-60, -0.6] \text{ GeV}^2$$

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

M. Ivanov, Körner, P.S., 2004
 Matheus et al., 2005