

$\eta_b \rightarrow J/\psi J/\psi$ DECAY: THE LONG DISTANCE CONTRIBUTIONS

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

Based on the paper

Long distance contributions to the $\eta_b \rightarrow J/\psi J/\psi$ decay
[hep-ph/0703232](https://arxiv.org/abs/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

Experimental searches

- **ALEPH (2002)** observed one event with an expected background of one event in $\gamma\gamma \rightarrow \eta_b \rightarrow 6$ charged particles
- **L3 (2004)** no evidence for $\eta_b \rightarrow$ charged particles
- **CLEO (2005)** studied $\Upsilon(2S) \rightarrow \eta_b\gamma$, $\Upsilon(3S) \rightarrow \eta_b\gamma$: no evidence.
- **DELPHI (2006)** $\gamma\gamma \rightarrow \eta_b \rightarrow (4, 6, 8)$ charged particles
- **CDF Run II dataset**, preliminary results

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

Braaten, Fleming and Leibovich, 2001

- It can be “easily” detected by looking at the $\mu^+ \mu^- \mu^+ \mu^-$ 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 point is

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

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

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



$$\mathcal{Br}[\eta_b \rightarrow D^* \overline{D}^*] \sim 0$$

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

This saturation assumption is questionable

Jia, 2006

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

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

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

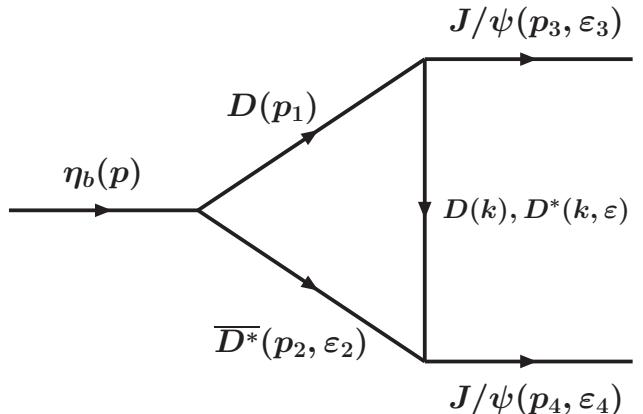
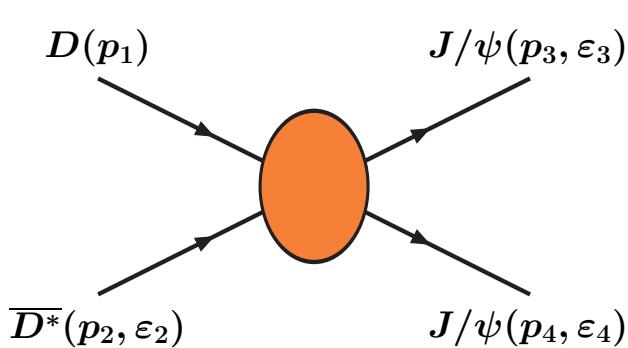
P.S., 2007

We take into account all the previous considerations:

a) $\mathcal{Br}[\eta_b \rightarrow D\overline{D}^*] \sim 10^{-5} \div 10^{-2}$

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



We will neglect the dispersive contribution and we shall evaluate

$$\mathcal{A}[\eta_b \rightarrow J/\psi J/\psi] = \text{tree diagram} + i \text{ Abs} \left[\text{Feynman diagram} \right]$$

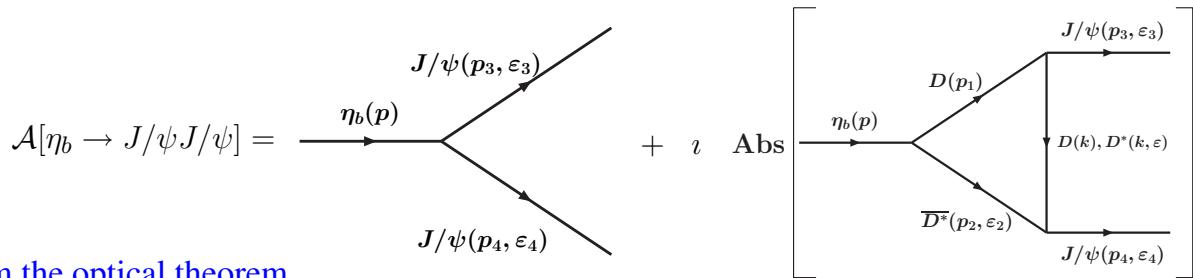
The tree diagram shows an incoming $\eta_b(p)$ particle splitting into two J/ψ particles, labeled $J/\psi(p_3, \varepsilon_3)$ and $J/\psi(p_4, \varepsilon_4)$.

The enclosed Feynman diagram shows an incoming $\eta_b(p)$ particle splitting into a $D(p_1)$ particle and a $\overline{D}^*(p_2, \varepsilon_2)$ particle. The $D(p_1)$ particle then splits into a $J/\psi(p_3, \varepsilon_3)$ particle and a $D(k, D^*(k, \varepsilon))$ particle. The $\overline{D}^*(p_2, \varepsilon_2)$ particle then splits into a $J/\psi(p_4, \varepsilon_4)$ particle and a $D(k, D^*(k, \varepsilon))$ particle.

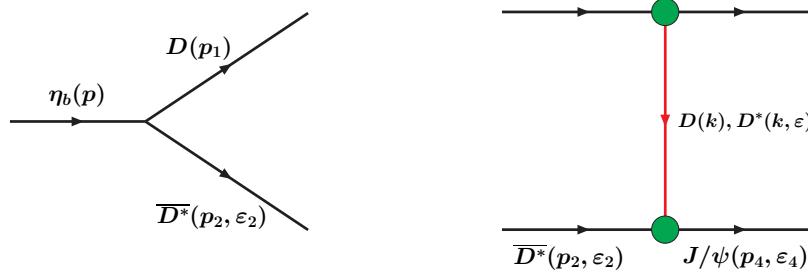
$$\text{tree diagram} = \frac{i}{m_{\eta_b}} g_{\eta_b JJ} \varepsilon_{\alpha\beta\gamma\delta} p_3^\alpha p_4^\beta \varepsilon_3^{*\gamma} \varepsilon_4^{*\delta}$$

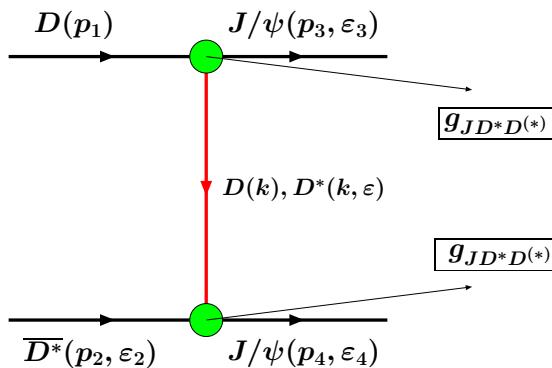
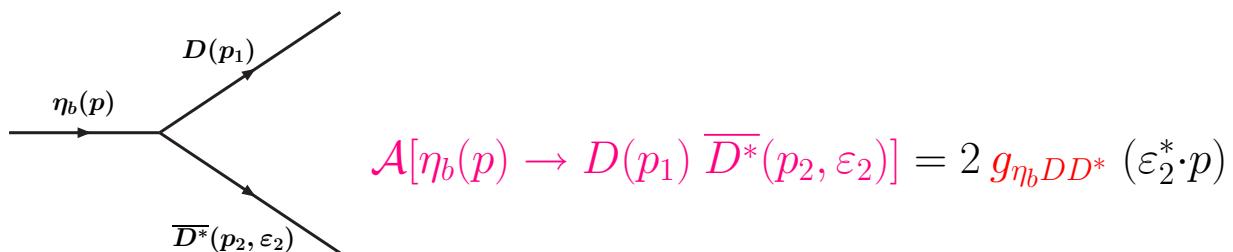
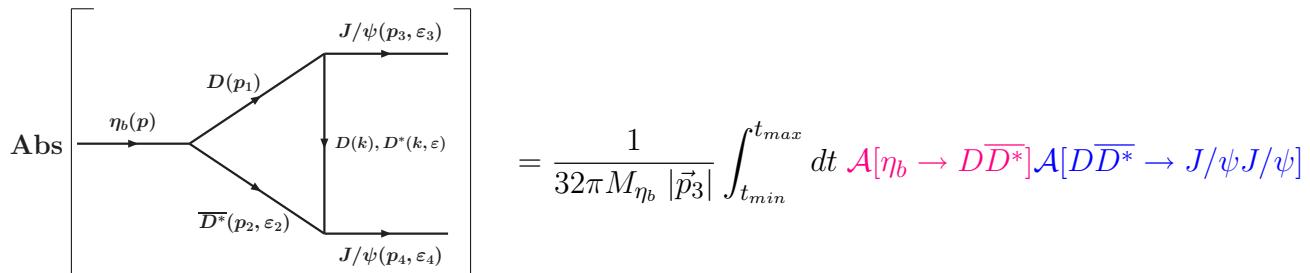
The tree diagram shows an incoming $\eta_b(p)$ particle splitting into two J/ψ particles, labeled $J/\psi(p_3, \varepsilon_3)$ and $J/\psi(p_4, \varepsilon_4)$.

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



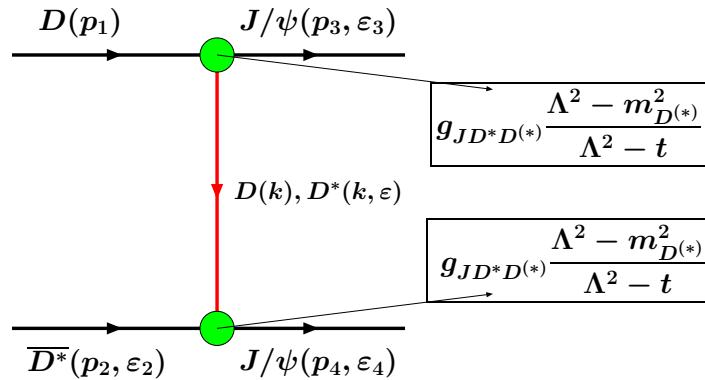
$$\text{Abs} \left[\begin{array}{c} \text{---} \xrightarrow{\eta_b(p)} \begin{cases} D(p_1) \\ D(k), D^*(k, \varepsilon) \end{cases} \xrightarrow{J/\psi(p_3, \varepsilon_3)} \\ \text{---} \xrightarrow{D^*(p_2, \varepsilon_2)} \xrightarrow{J/\psi(p_4, \varepsilon_4)} \end{array} \right] = \frac{1}{32\pi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





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

Matsui and Satz, '86



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

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

We choose the function

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

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, 2004) we put

$$\Lambda = m_{D^{(*)}} + \Lambda_{QCD} \alpha \quad \Lambda_{QCD} = 0.22 \text{ GeV} \quad \text{and} \quad \alpha \approx 2.2$$

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

$$\mathcal{A}[\eta_b \rightarrow J/\psi J/\psi] = \text{---} \xrightarrow{\eta_b(p)} \begin{cases} J/\psi(p_3, \varepsilon_3) \\ J/\psi(p_4, \varepsilon_4) \end{cases} + i \text{ Abs} \left[\text{---} \xrightarrow{\eta_b(p)} \begin{cases} D(p_1) \\ \overline{D^*}(p_2, \varepsilon_2) \end{cases} \xrightarrow{J/\psi(p_3, \varepsilon_3)} \boxed{J/\psi(p_4, \varepsilon_4)} \right]$$

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

where

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



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



$$0.31 \pm 0.06 \leq r \leq 10 \pm 2 \quad \text{with } 2.0 \leq \alpha \leq 2.4$$

Assuming that (**Jia**)

$$\mathcal{Br}(\eta_b \rightarrow J/\psi J/\psi)_{SD} = 2.4^{+4.2}_{-1.9} \times 10^{-8},$$

we identify two possible scenarios:

1°: $\mathcal{Br}[\eta_b \rightarrow D \bar{D^*}] \sim 10^{-5} \Rightarrow$ Negligible FSI

2°: $10^{-3} \leq \mathcal{Br}[\eta_b \rightarrow D \bar{D^*}] \leq 10^{-2} \Rightarrow$ Large FSI

	$\mathcal{Br}[\eta_b \rightarrow J/\psi J/\psi]_{SD}$	$\mathcal{Br}[\eta_b \rightarrow J/\psi J/\psi]_{full}$	# Events	# at Tevatron	# at LHC
BFL	$7 \times 10^{-4 \pm 1}$		$677 \div 67700$	$4 \div 400$	
J	$(0.5 \div 6.6) \times 10^{-8}$		$0.05 \div 0.6$	$0.0003 \div 0.004$	$0.5 \div 6$
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

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

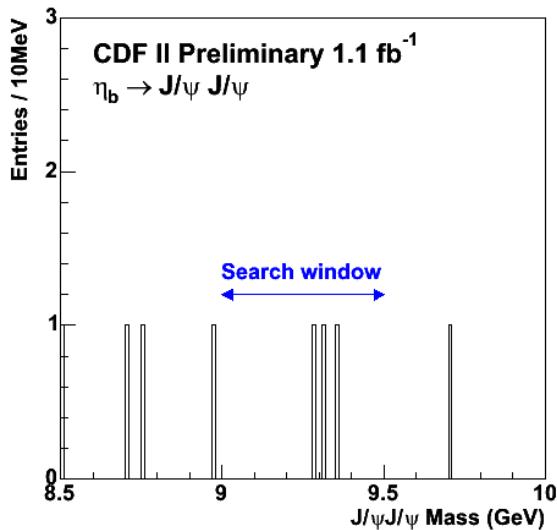
LHC $\sigma(\eta_b) = 15 \mu\text{b}$ $\mathcal{L} = 300 \text{ fb}^{-1}$ rapidity interval $= \pm 0.6$

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

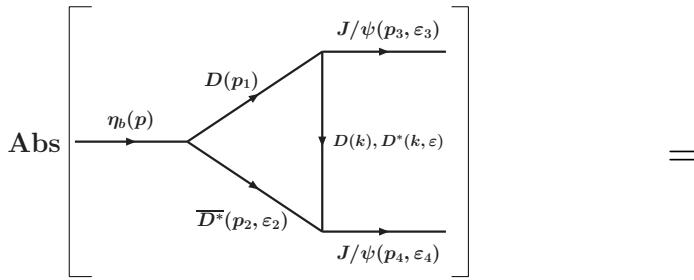
CDF searched for η_b through $\eta_b \rightarrow J/\psi J/\psi$ with both J/ψ decay into a dimuon pair. Using 1.1 fb^{-1} data they observed 3 candidates while expecting 3.6 background events in the search window from 9.0 to 9.5 GeV.



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.
- Experimental results together with this calculation can be used to put phenomenological constraints on the hadronic quantities: $g_{J D^{(*)} D^{(*)}}$ and $g_{\eta_b D\bar{D}^*}$.

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