Branching fractions of $B^- \to D^- X_{0,1}(2900)$ and their implications

Yan-Ke Chen

Lanzhou University

Based on work collaborated with Jia-Jie Han, Qi-Fang Lü, Jian-Peng Wang, Fu-Sheng Yu.

arXiv:2009.01182

September 9, 2020

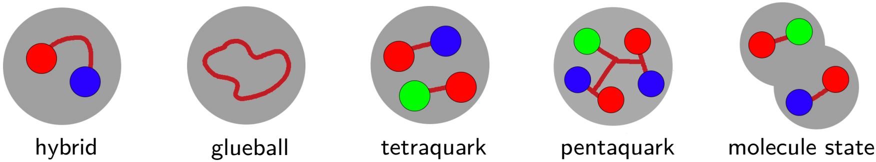
Overview

1. Motivation
2. Theoretical framework
3. Numerical results
   - $B^- \to D^- X_{0,1}(2900)$ decays
   - $B^- \to \bar{\Lambda}_c^- \Xi_c^{(\prime)0}$ and $\Lambda_b^0 \to P_c^+ K^-$ decays
   - $B^- \to \pi^- X_{0,1}(2900)$ decays
4. Isospin analysis on $B \to D X_{0,1}$
5. Summary

Motivation(I)

Exotic hadrons: states beyond conventional mesons ($q\bar{q}$) and baryons (qqq).

- Predicted by M. Gell-Mann and G. Zweig in 1964
- Different models: hybrid, glueball, multiquark state, molecular state....



Study of exotic hadrons can provide new insights into:

- internal structure and dynamics of hadrons
- non-perturbative behaviour of QCD

Future experimental discoveries and theoretical advances are needed.

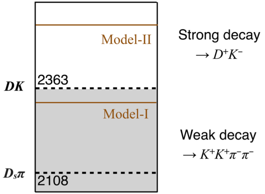
Motivation(II)

States requiring > 3 valence quarks are manifestly exotic.

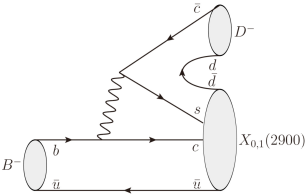
- $X(5568)(bs\bar{u}\bar{d})$ was observed by D0 Collaboration, though the existence was not confirmed by other collaborations.

$(cs\bar{u}\bar{d})$ is a promising detectable tetraquark in$B^- \to D^- X$ decays.

- The lowest-lying ground state may below the $D\bar{K}$ threshold. [arXiv:1709.02571]
- The topological diagram is an W-emission diagram with large V_{CKM} elements.



$M_{cs\bar{u}\bar{d}}$ predicted under $SU(3)$ symmetry



The topological diagram of $B^- \to D^- X$

Motivation(III)

The exotic states $X_{0,1}(2900)$ are observed in mass spectrum of D^+K^- in $B^- \to D^-D^+K^-$ by the LHCb collaboration.
[arXiv:2009.00025],[arXiv:2009.00026]

- Their masses are much higher than the $D\overline{K}$ threshold.
- They are produced in the $B^- \to D^-X_{0,1}$.
- The relatively large branching fractions are the key point in the observation.

	$M_X(\mathrm{MeV})$	$\Gamma_X(\mathrm{MeV})$	Fit fraction(%)	$Br_{\mathrm{exp}}(10^{-5})$
$B^- \to D^-X_0$	2866 ± 7	57 ± 13	5.6 ± 0.5	1.23 ± 0.41
$B^- \to D^-X_1$	2904 ± 5	110 ± 12	30.6 ± 3.2	6.73 ± 2.26

It is necessary to understand the production mechanism of $X_{0,1}(2900)$ in the weak decays of B mesons and the corresponding branching fractions.

Theoretical framework(I)

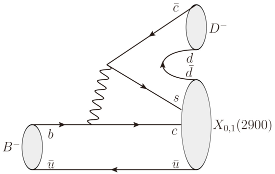
The topological diagram of $B^- \to D^- X_{0,1}(2900)$:

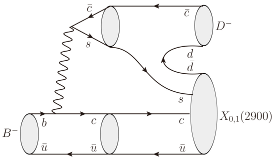
- non-factorizable.
- not easy to caculate in QCD-inspired methods.
- dominated by the long-distance contributions.

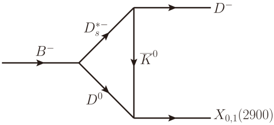
The final-state-interaction(FSI) effects:

- has been successfully applied to the $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$.
  [Chin. Phys. C **42** (2018) 051001]
- has been tested in the $B \to \pi\pi, K\pi$ and $D\pi$ modes.
  [Phys. Rev. D **71** (2005) 014030]

We calculate the long-distance contributions by FSIs effects.

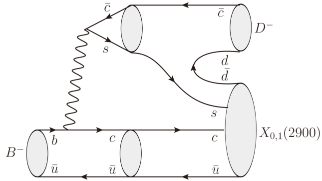


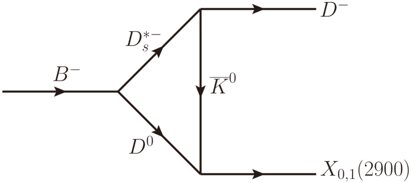




Theoretical framework(II)

Rescattering mechanism: $B^- \to D_s^{*-} D^0 \to D^- X_{0,1}(2900)$ via exchanging one intermediate state $\overline{K}^0$.





The weak-decay vertex:

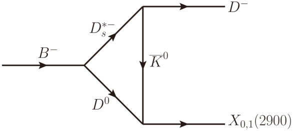
$$\left\langle D_s^{*-} D^0 \left| \mathcal{H}_{eff} \right| B^- \right\rangle = \frac{G_F}{\sqrt{2}} V_{cb} V_{cs}^{*} a_1 f_{D_s^*} m_{D_s^*} F_1^{B\to D}\left(m_{D_s^*}^2\right) \left(2\epsilon_{D_s^{*-}}^{*} \cdot p_{B^-}\right)$$

The effective Lagrangian of the strong interaction

$$\mathcal{L} = \mathcal{L}_{VPP} + \mathcal{L}_{SPP} = i g_{VPP} V^{\mu} \left(P \overleftrightarrow{\partial}_{\mu} P\right) - g_{SPP} m_s SPP$$

Theoretical framework(III)

The absorptive part of the decay amplitude is:



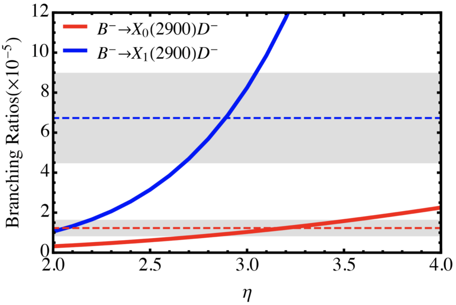
$$\begin{aligned}\mathcal{A}bs(B^- \to D^- X_0(2900)) =& -2i\frac{G_F}{\sqrt{2}} V_{CKM} a_1 \int \frac{|\vec{p}_{D_s^{*-}}| d\cos\theta d\phi}{32\pi^2 m_B} g_{D_s^* DK} g_{DKX_0} m_{X_0} \frac{F^2(t, m_K)}{t - m_K^2} \\ & \cdot f_{D_s^{*-}} m_{D_s^{*-}} F_1^{B\to D}(M^2_{D_s^{*-}})(p_{D^0}\cdot p_{D^-} - \frac{(p_{D_s^{*-}}\cdot p_{D^-})(p_{D_s^{*-}}\cdot p_{D^0})}{m^2_{D_s^{*-}}}),\end{aligned}$$

$$\begin{aligned}\mathcal{A}bs(B^- \to D^- X_1(2900)) =& 2i\frac{G_F}{\sqrt{2}} V_{CKM} a_1 \int \frac{|\vec{p}_{D_s^{*-}}| d\cos\theta d\phi}{32\pi^2 m_B} g_{D_s^* DK} g_{DKX_1} m_{X_0} \frac{F^2(t, m_K)}{t - m_K^2} \\ & \cdot f_{D_s^{*-}} m_{D_s^{*-}} F_1^{B\to D}(M^2_{D_s^{*-}})(p_{D^0}\cdot p_{D^-} - \frac{(p_{D_s^{*-}}\cdot p_{D^-})(p_{D_s^{*-}}\cdot p_{D^0})}{m^2_{D_s^{*-}}}) \\ & \cdot (p_K \cdot \epsilon_{X_1}),\end{aligned}$$

$$F(t, m_K) = \frac{\Lambda^2 - m_K^2}{\Lambda^2 - t}, \quad \Lambda = m_{exc} + \eta\Lambda_{QCD}$$

$B^- \to D^- X_{0,1}(2900)$ decays

$g_{DKX_0} = 1.0$, $g_{DKX_1} = 9.3$ are be extracted from the widths of $X_{0,1}(2900)$



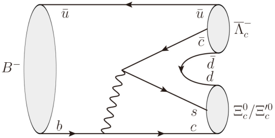
Consistent with the experimental measurements when $\eta \approx 3.0$.

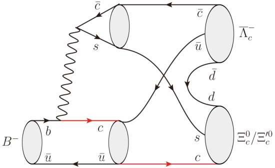
[arXiv:2009.00025],[arXiv:2009.00026]

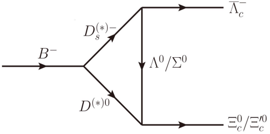
The prodcution of $X_{0,1}(2900)$ in $B^- \to D^- X_{0,1}(2900)$ can be understood by rescattering mechanism.

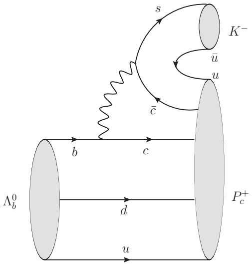
$B^- \to \bar{\Lambda}_c^- \Xi_c^{(\prime)0}$ and $\Lambda_b^0 \to P_c^+ K^-$ decays(I)

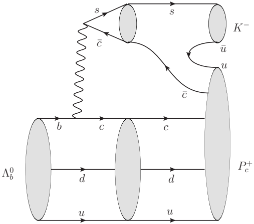
They have similar topological diagrams with those of $B^- \to D^- X_{0,1}(2900)$

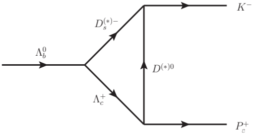






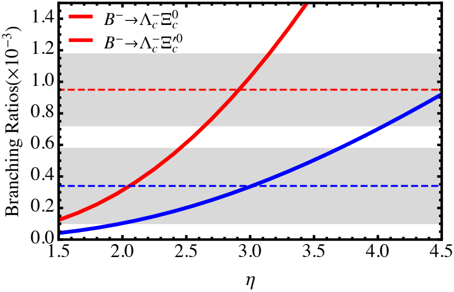






$B^- \to \bar{\Lambda}_c^- \Xi_c^{(\prime)0}$ and $\Lambda_b^0 \to P_c^+ K^-$ decays(II)

The strong couplings based on [Eur. Phys. J. C **80** (2020) 22].

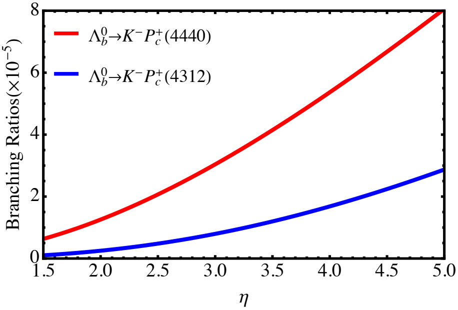


Consisten with the experiment when $\eta \approx 3.0$.

[Prog. Theor. Exp. Phys. 2020, 083C01 (2020)],[Phys. Rev. D **100** (2019) 112010]

$B^- \to \bar{\Lambda}_c^- \Xi_c^{(\prime)0}$ and $\Lambda_b^0 \to P_c^+ K^-$ decays(III)

The strong couplings based on [Phys. Rev. D **100** (2019) 056005].



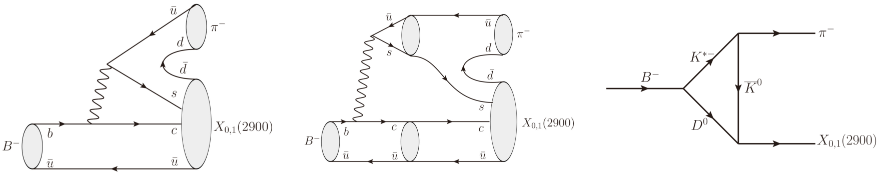
It can be expected that $\Lambda_b^0 \to K^- P_c^+$ and $B^- \to D^- X_{0,1}$ have similar branching fractions at 10^{-5}.

- The difference is the spectors.
- $Br\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right) \approx Br\left(B^- \to D^0 D_s^-\right)$
  [Prog. Theor. Exp. Phys. 2020, 083C01 (2020)]

$B^- \to \pi^- X_{0,1}(2900)$ decays(I)

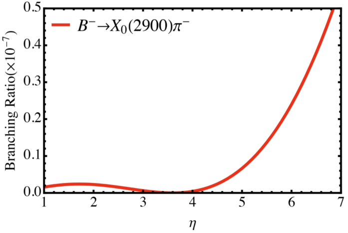
The $B^- \to \pi^- X_{0,1}$ decays are similar to the $B^- \to D^- X_{0,1}$ decays.

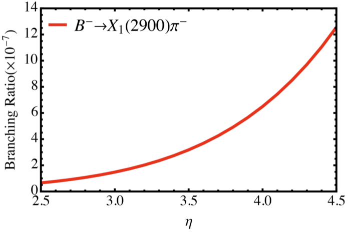
- A charm anti- quark replaced by an up anti-quark.
- suppressed by CKM factor for $|V_{us}| / |V_{cs}| \approx 0.225$.
- D^- meson has to be reconstructed by $D^- \to K^+\pi^-\pi^-$ process in the experiments.



$B^- \to \pi^- X_{0,1}$ are good alternative processes to check the results in $B^- \to D^- X_{0,1}$ decays.

$B^- \to \pi^- X_{0,1}(2900)$ decays(II)





The results are much smaller than naively expectation.

- $Br(B^- \to \pi^- X_0)$ is around $10^{-9} \sim 10^{-8}$.
- $Br(B^- \to \pi^- X_1)$ is at the order of 10^{-7}.
- $Br(B^- \to \pi^- X_{0,1})/Br(B^- \to D^+ K^- \pi^-)$ smaller than few percent.

The main reason is the lack of relatively large rescattering contribution. There is no significant enhancement or peak in the $D^+ K^-$ mass spectrum in the amplitude analysis of $B^- \to D^+ K^- \pi^-$ by the LHCb collaboration. [Phys. Rev. D **91** (2015) 092002]

Isospin analysis on $B \to DX_{0,1}$(I)

The quark flovors of $X_{0,1}(2900)$ are $cs\bar{u}\bar{d}$, but their isoapin are not determined, it could either be isospin singlet or triplet.

If X_i is an isospin singlet state:

$$\mathcal{A}\left(\bar{B}^0 \to \bar{D}^0 X_i^0\right) = \mathcal{A}\left(B^- \to D^- X_i^0\right)$$

then we have

$$Br\left(\bar{B}^0 \to \bar{D}^0 X_0^0\right) / Br\left(\bar{B}^0 \to \bar{D}^0 D^+ K^-\right) = (1.15 \pm 0.38)\%$$
$$Br\left(\bar{B}^0 \to \bar{D}^0 X_1^0\right) / Br\left(\bar{B}^0 \to \bar{D}^0 D^+ K^-\right) = (6.29 \pm 2.11)\%$$

Isospin analysis on $B \to DX_{0,1}$(II)

If X_i is an isospin triplet state:

$$\mathcal{A}\left(B^- \to \bar{D}^0 X_i^-\right) = -\sqrt{2}\mathcal{A}\left(B^- \to D^- X_i^0\right) = -\mathcal{A}\left(\bar{B}^0 \to D^- X_i^+\right) = \sqrt{2}\mathcal{A}\left(\bar{B}^0 \to \bar{D}^0 X_i^0\right)$$

then we have the fractions

$$Br\left(B^- \to \bar{D}^0 X_0^-\right)/Br\left(B^- \to D^0 \bar{D}^0 K^-\right) = (1.7 \pm 0.6)\%$$
$$Br\left(\bar{B}^0 \to D^- X_0^+\right)/Br\left(\bar{B}^0 \to D^+ D^- \bar{K}^0\right) = (3.3 \pm 1.3)\%$$

and

$$\mathrm{Br}\left(B^- \to \bar{D}^0 X_1^-\right)/\mathrm{Br}\left(B^- \to D^0 \bar{D}^0 K^-\right) = (9.3 \pm 3.7)\%$$
$$Br\left(\bar{B}^0 \to D^- X_1^+\right)/Br\left(\bar{B}^0 \to D^+ D^- \bar{K}^0\right) = (17.9 \pm 7.0)\%$$

Summary

1. We calculate $Br(B^- \to D^- X_{0,1})$ using rescattering mechanism, which are consistant with experimental measurements.
2. The rescattering mechanism is tested by the processes $B^- \to \bar{\Lambda}_c^- \Xi_c^{(\prime)0}$ and $\Lambda_b^0 \to P_c^+ K^-$.
3. $Br(B^- \to \pi^- X_{0,1})$ are predicted with large uncertainties.
4. The isopins of $X_{0,1}(2900)$ are discussed.

Thanks for your attention