New $X_{0,1}(2900)$-like exotic states in b-baryon decays

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Outline:

1. Introduction
2. Formalism
3. Results
4. Summary

Open-charm exotic states: tetraquark candidates

- In $B^+ \to D^+ D^- K^+$,

$X_{0,1}(2900)^0 \to D^- K^+$ in the $D^- K^+$ invariant mass spectrum,

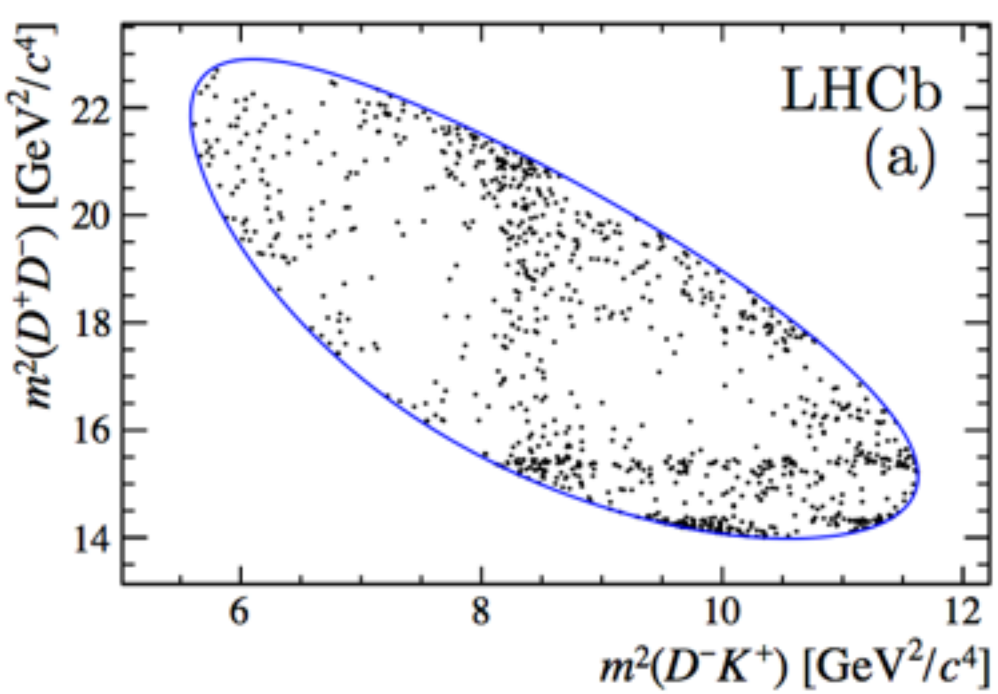
LHCb: PRL125, 242001 (2020); PRD102, 112003(2020)

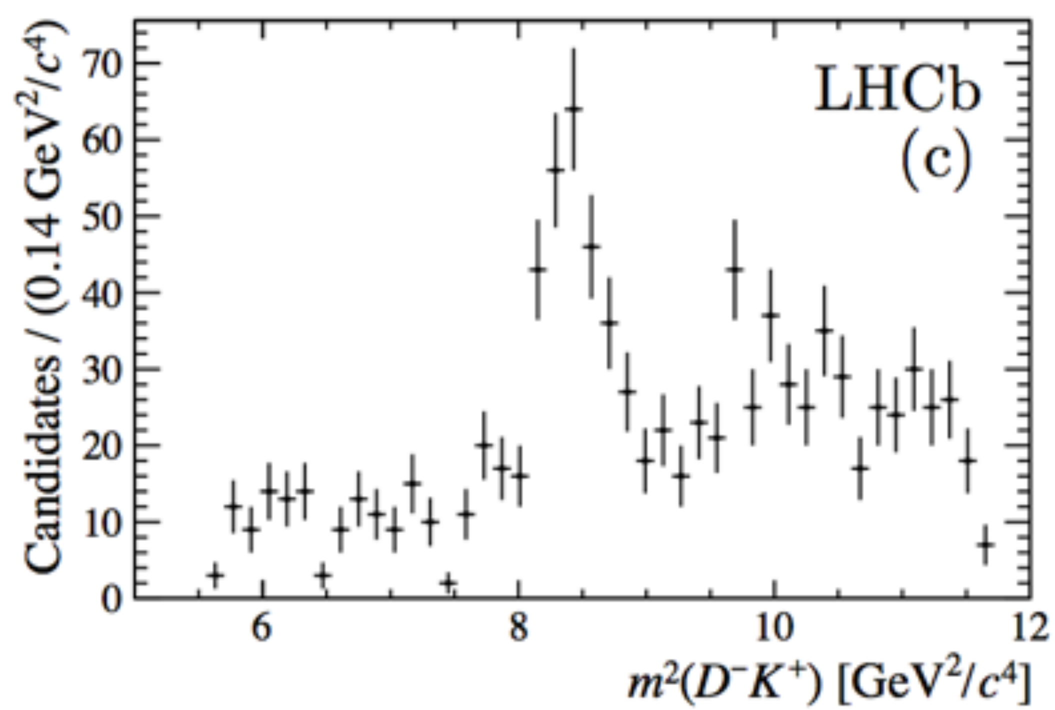
- $X_{0,1}(2900)^0$, $(\bar{c}d\bar{s}u)$, four different quark flavors.

$(m_{X_0(2900)^0}, m_{X_1(2900)^0}) =$

$(2.866 \pm 0.007 \pm 0.002, 2.904 \pm 0.005 \pm 0.001)$ GeV

$(\Gamma_{X_0(2900)^0}, \Gamma_{X_1(2900)^0}) = (57 \pm 12 \pm 4, 110 \pm 11 \pm 4)$ MeV





Theoretical interpretation

Final state interaction, Triangle rescattering

- X.H. Liu, M.J. Yan, H.W. Ke, G. Li and J.J. Xie,

"Triangle singularity as the origin of $X_0(2900)$ and $X_1(2900)$ observed in $B^+ \to D^+ D^- K^+$," EPJC80, 1178 (2020).

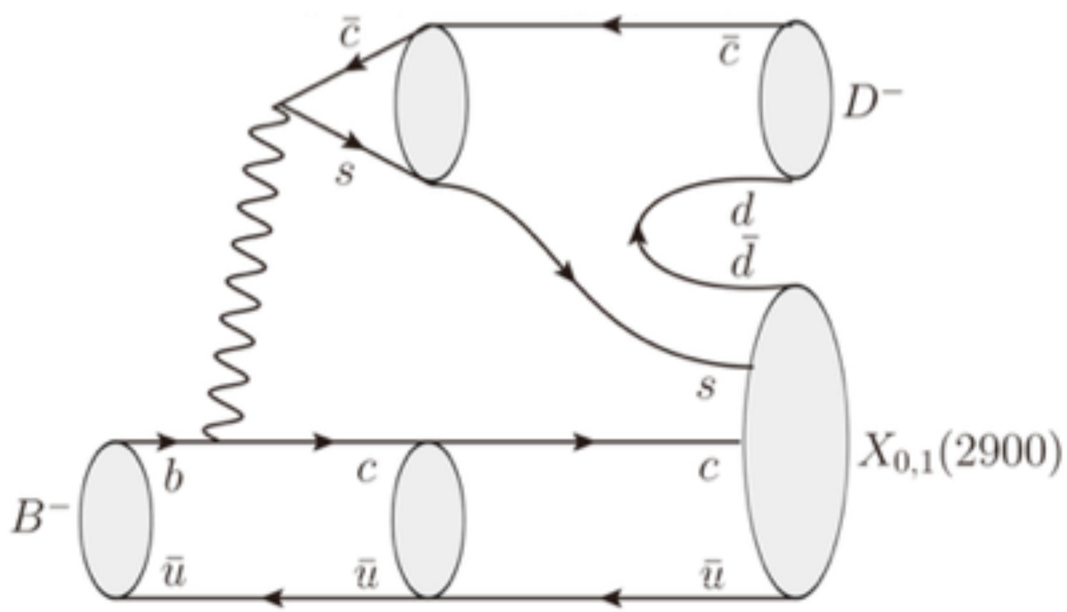
- T.J. Burns and E.S. Swanson,

"Kinematical cusp and resonance interpretations of the $X(2900)$," PLB813, 136057 (2021).

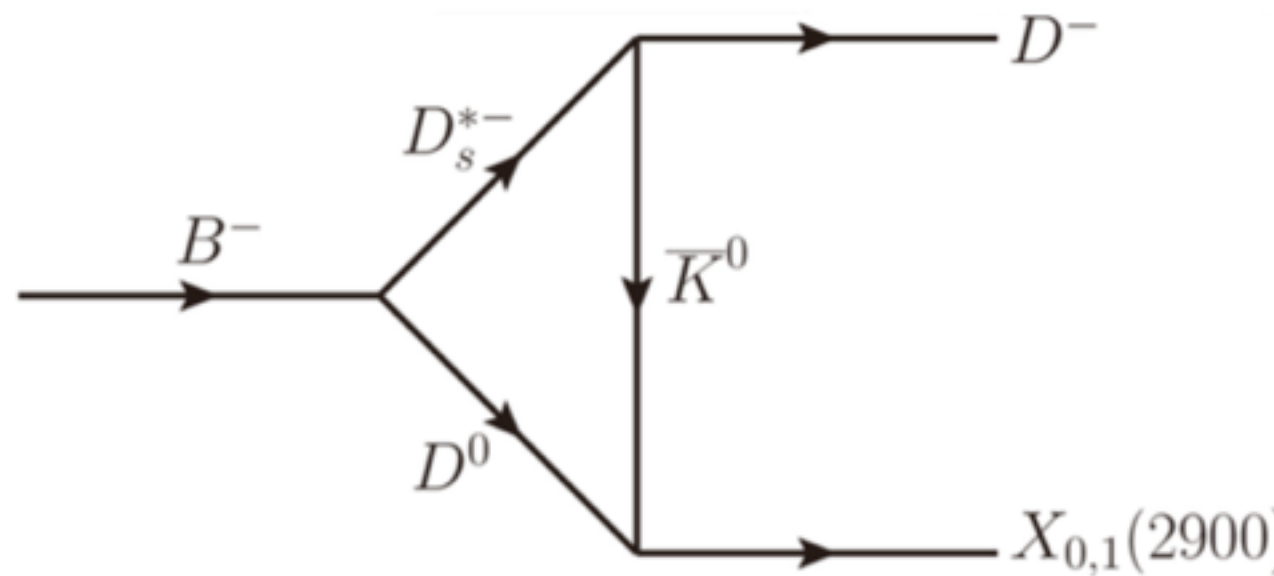
"Discriminating among interpretations for the $X(2900)$ states," PRD103, 014004 (2021).

- Y.K. Chen, J.J. Han, Q.F. Lu, J.P. Wang and F.S. Yu,

"Branching fractions of $B^- \to D^- X_{0,1}(2900)$ and their implications," EPJC81, 71 (2021).



(a)



(b)

- Diagrams from

Y.K. Chen, J.J. Han, Q.F. Lu, J.P. Wang and F.S. Yu, EPJC81, 71 (2021).

Theoretical interpretation

- $X_c \sim (q_1q_2 - q_2q_1)\bar{q}_3\bar{c}$ and $(q_1q_2 + q_2q_1)\bar{q}_3\bar{c}$

$\bar{6}$ and 15 in the irreducible $SU(3)_f$.

X.G. He, W. Wang and R. Zhu,

"Open-charm tetraquark X_c and open-bottom tetraquark X_b,"

EPJC80, 1026 (2020). Masses calculated in 2-body

Coulomb and chromomagnetic interactions model

- Firstly proposing to hunt for X_c in $B_{(c)}$ decays

J. Phys. G44, 014003 (2017).

- $\bar{6}$, 1st radially excited state (2S):

$X'_{ud\bar{s}\bar{c}}$, $J^P = 0^+$, identified as $X_0(2900)^0$

$X'_{ds\bar{u}\bar{c}}$, $X'_{su\bar{d}\bar{c}}$, $Y'_{sn\bar{n}\bar{c}}$, $J^P = 0^+$, $n = u$ or d

$X_0'^{--}$, $X_0'^{0}$, $Y_0'^{-}$

- 15, orbitally excited state (1P):

$X_{ud\bar{s}\bar{c}}$, $J^P = 1^-$, identified as $X_1(2900)^0$

$X_{ds\bar{u}\bar{c}}$, $X_{su\bar{d}\bar{c}}$, $Y_{sn\bar{n}\bar{c}}$, $J^P = 1^-$, $n = u$ or d

X_1^{--}, X_1^{0}, Y_1^{-}

“Open-beauty” exotic state $X(5568)$

$X(5568)^{\pm} \to B_s^0 \pi^{\pm}$

4 different quark flavors $\bar{b}s\bar{d}u$ $(\bar{b}s\bar{u}d)$

Observed by D0 Collaboration

Not confirmed by LHCb and other experiments

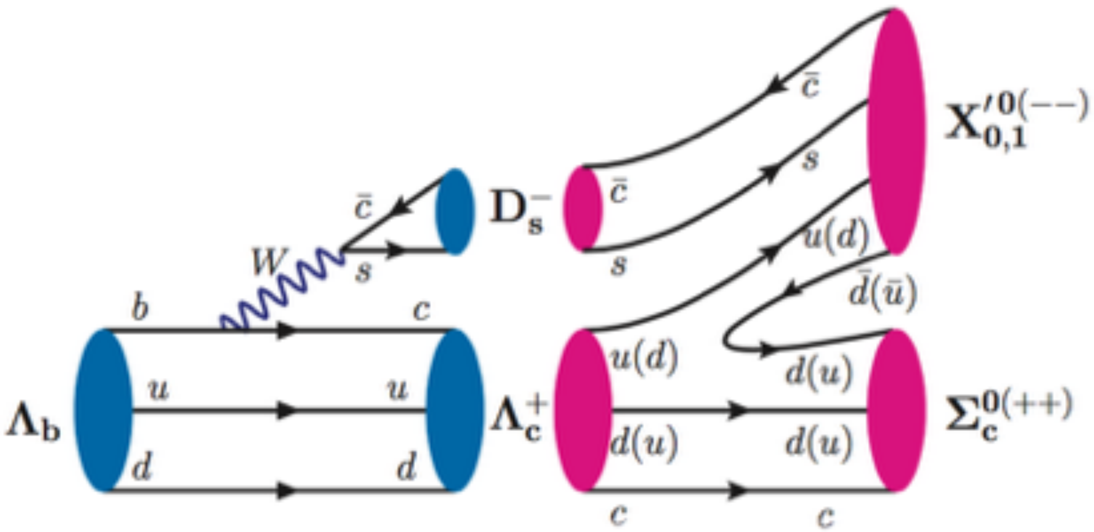
• A confirmation of $X_{0,1}(2900)$-like exotic state

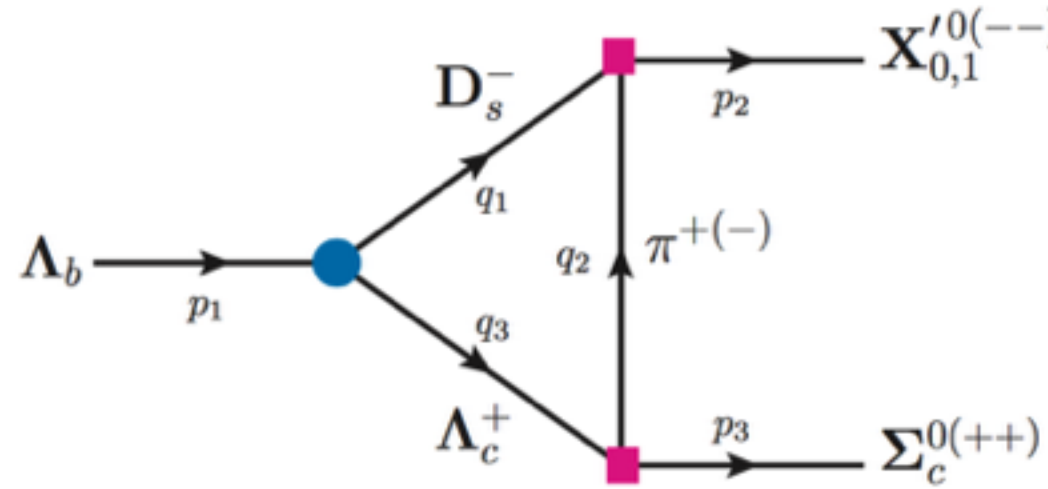
from a different decay channel

• We propose $\Lambda_b \to \Sigma_c^{0(++)} X_0'^{0(--)}, \Sigma_c^{0(++)} X_1^{0(--)}$

$X_0'^0$ (X_1^0) and $X_0'^{--}$ (X_1^{--}),

consisting of $su\bar{d}\bar{c}$ and $sd\bar{u}\bar{c}$.





$$\mathcal{M}_b(\Lambda_b \to \Lambda_c^+ D_s^-) = \bar{u}_{\Lambda_c}(F_b^+ - F_b^- \gamma_5) u_{\Lambda_b}$$

$$F_b^+ = C_{\mathrm{w}} m_- \left[f_1 + \left(\frac{m_{D_s}^2}{m_+ m_-} \right) f_3 \right]$$

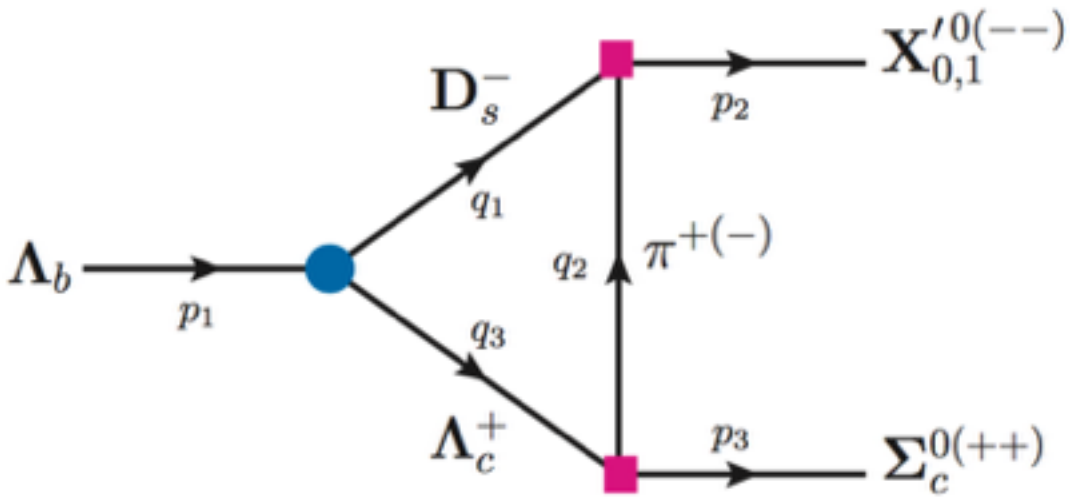
$$F_b^- = C_{\mathrm{w}} m_+ \left[g_1 + \left(\frac{m_{D_s}^2}{m_+^2} \right) g_3 \right]$$

$$m_\pm = m_{\Lambda_b} \pm m_{\Lambda_c}$$

$$C_{\mathrm{w}} = i(G_F/\sqrt{2})\, a_1 V_{cb} V_{cs}^* f_{D_s}$$

$$\mathcal{B}(\Lambda_b \to \Lambda_c^+ D_s^-) = (1.10 \pm 0.10)\%$$

$$a_1 = 0.93 \pm 0.04$$



$$\mathcal{M}_0(X'_0 \to D_s^-\pi) = g_0$$
$$\hat{\mathcal{M}}_1(X_1 \to D_s^-\pi) = g_1\epsilon \cdot (p_{D_s} - p_\pi)$$
$$\mathcal{M}_c(\Sigma_c \to \Lambda_c^+\pi) = g_c\bar{u}_{\Lambda_c}\gamma_5 u_{\Sigma_c}$$

- $B(\Sigma_c \to \Lambda_c\pi) \simeq 100\%$, leading to $g_c = 19.1$
- $SU(3)_f$:

$X_{0,1}(2900)^0 \to D^-K^+$

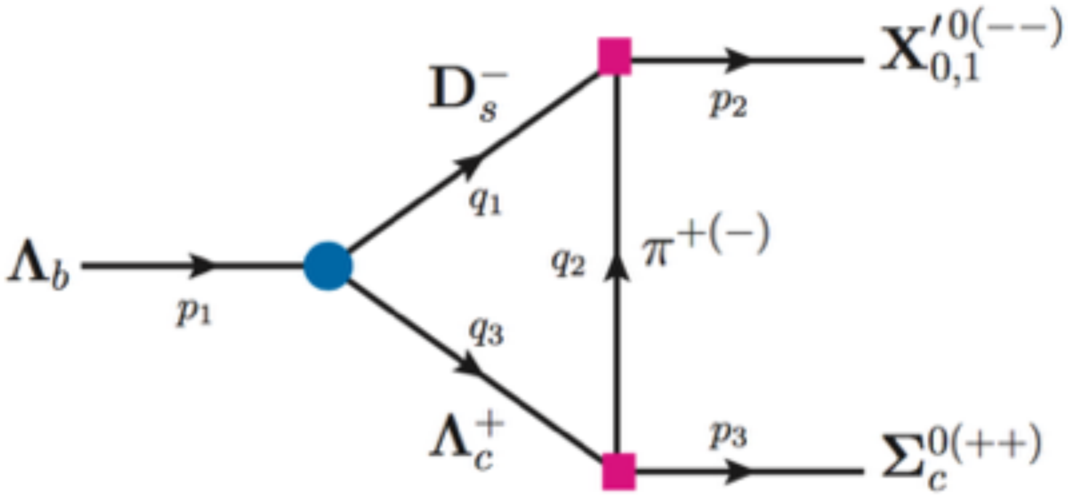
$X'^{0(--)}_0(X^{0(--)}_1) \to D_s^-\pi^{+(-)}$

$g_0 = (2.85 \pm 0.32)$ GeV

$g_1 = 4.63 \pm 0.25$

X.G. He, W. Wang and R. Zhu,

EPJC80, 1026 (2020)



$$\mathcal{M}(\Lambda_b \to \Sigma_c X_0', \Sigma_c X_1) = \int \frac{d^4 q_3}{(2\pi)^4} \frac{\mathcal{M}_b \mathcal{M}_c^\dagger \mathcal{M}_{0,1}}{(q_1^2 - m_{D_s}^2)(q_2^2 - m_\pi^2)(q_3^2 - m_{\Lambda_c}^2)},$$

$$\mathcal{M}_1 \equiv \hat{\mathcal{M}}_1 F_{\Lambda_1}(q_2^2)$$

$$F_{\Lambda_1}(q_2^2) \equiv (\Lambda_1^2 - m_\pi^2)/(\Lambda_1^2 - q_2^2)$$

$$\{C_0; C^\mu; C^{\mu\nu}\} = \int \frac{d^4 q_3}{i\pi^2} \frac{\{1; q_3^\mu; q_3^\mu q_3^\nu\}}{(q_3^2 - m_{\Lambda_c}^2)[(q_3 - p_1)^2 - m_{D_s}^2][(q_3 - p_3)^2 - m_\pi^2]},$$

By replacing m_π with Λ_1, we obtain $\{C_0'; C'^\mu; C'^{\mu\nu}\}$.

$$C^\mu = -p_1^\mu C_1 - p_3^\mu C_2,$$

$$C^{\mu\nu} = g^{\mu\nu} C_{00} + p_1^\mu p_1^\nu C_{11} + p_3^\mu p_3^\nu C_{22} + (p_1^\mu p_3^\nu + p_1^\nu p_3^\mu) C_{12},$$

$$\tilde{C}_{i(ij)} = C_{i(ij)} - C'_{i(ij)},$$

[28] G. 't Hooft and M.J.G. Veltman, Nucl. Phys. B **153**, 365 (1979).

[29] T. Hahn and M. Perez-Victoria, Comput. Phys. Commun. **118**, 153 (1999).

[30] A. Denner and S. Dittmaier, Nucl. Phys. B **734**, 62 (2006).

$$(C_0, C_1, C_2) = (0.37 - 0.32i, -1.50 - 2.30i, -0.91 - 0.55i)\ \mathrm{GeV}^{-2}\,.$$

$$\tilde{C}_0 = (0.26 + 0.17i, 0.36 + 0.10i, 0.41 + 0.05i)\ \mathrm{GeV}^{-2}\,,$$

$$\tilde{C}_1 = (0.95 - 2.15i, 0.35 - 2.75i, -0.11 - 2.94i)\ \mathrm{GeV}^{-2}\,,$$

$$\tilde{C}_2 = (0.06 - 0.24i, 0.08 - 0.35i, 0.05 - 0.45i)\ \mathrm{GeV}^{-2}\,,$$

$$\tilde{C}_{00} = (-1.02 - 0.51i, -1.62 - 0.45i, -2.17 - 0.25i)\,,$$

$$\tilde{C}_{11} = (-0.52 + 1.85i, -0.01 + 2.19i, 0.33 + 2.23i)\ \mathrm{GeV}^{-2}\,,$$

$$\tilde{C}_{12} = (-0.02 + 0.19i, 0.00 + 0.26i, 0.03 + 0.31i)\ \mathrm{GeV}^{-2}\,,$$

$$\tilde{C}_{22} = (0.01 + 0.06i, 0.02 + 0.08i, 0.02 + 0.11i)\ \mathrm{GeV}^{-2}\,.$$

$$\Lambda_1 = (1.25 \pm 0.25)\ \mathrm{GeV}$$

[32] N.A. Tornqvist, Z. Phys. C **61**, 525 (1994).

[33] X.Q. Li, D.V. Bugg and B.S. Zou, Phys. Rev. D **55**, 1421 (1997).

[34] Q. Wu, D.Y. Chen, X.J. Fan and G. Li, Eur. Phys. J. C **79**, 265 (2019).

$$\mathcal{M}(\Lambda_b \to \Sigma_c X_0') = \bar{u}_{\Sigma_c}(F_0^+ - F_0^- \gamma_5) u_{\Lambda_b} ,$$

$$\mathcal{M}(\Lambda_b \to \Sigma_c X_1) = \bar{u}_{\Sigma_c}[(F_1^+ \gamma^\mu - F_1^- \gamma^\mu \gamma^5) + (G_1^+ p_3^\mu - G_1^- p_3^\mu \gamma^5)] u_{\Lambda_b} \epsilon_\mu .$$

$$F_0^\pm = \frac{\mp i g_c g_0}{16\pi^2} F_b^\mp (m_{\Lambda_c} C_0 \pm m_{\Lambda_b} C_1 + m_{\Sigma_c} C_2) , F_1^\pm = \frac{i g_c g_1}{8\pi^2} F_b^\mp \tilde{C}_{00} ,$$

$$G_1^\pm = \frac{-i g_c g_1}{8\pi^2} F_b^\mp [m_{\Lambda_c}(\tilde{C}_0 + \tilde{C}_1 + \tilde{C}_2) \pm m_{\Lambda_b}(\tilde{C}_1 + \tilde{C}_{11} + \tilde{C}_{12}) + m_{\Sigma_c}(\tilde{C}_2 + \tilde{C}_{12} + \tilde{C}_{22})] .$$

Our calculations:

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{0(++)} X_0'^{0(--)}) = (2.3 \pm 0.6) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{0(++)} X_1^{0(--)}) = (4.3^{+3.3}_{-2.5}) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{++} X_0'^{--}, X_0'^{--} \to D^- K^-)$$

$$\simeq (1.1 \pm 0.3) \times 10^{-4}$$

Other decay channels

$b \to c\bar{c}s$

$\Lambda_b \to \Lambda_c^+ D_s^- \to \Sigma_c^+ Y_1^-$

$\Xi_b^{0(-)} \to \Xi_c^{+(0)} D_s^- \to \Xi_c^{+(0)}(2645) Y_1^-$

(with π^0 exchange)

$\Xi_b^0 \to \Xi_c^+ D_s^- \to \Xi_c^0(2645) X_0'^0,\ \Xi_c^0(2645) X_1^0$

$\Xi_b^- \to \Xi_c^0 D_s^- \to \Xi_c^+(2645) X_0'^{--},\ \Xi_c^+(2645) X_1^{--}$

(with $\pi^\pm$ exchange)

$b \to c\bar{c}d$

$\Lambda_b \to \Lambda_c^+ D^- \to \Xi_c'^0 X_{0,1}(2900)^0, \Xi_c'^0 X_{0,1}(2900)^0$

(with $K^\pm$ exchange)

$b \to c\bar{u}d$

$\Lambda_b \to \Lambda_c^+ \pi^- \to \Lambda^{(*)} \bar{X}_0'^0, \Lambda^{(*)} \bar{X}_1^0$

$\Lambda_b \to \Lambda_c^+ \pi^- \to \Sigma^{(*)0} \bar{X}_0'^0, \Sigma^{(*)0} \bar{X}_1^0$

$\Xi_b^{0(-)} \to \Xi_c^{+(0)} \pi^- \to \Xi^{(*)0(-)} \bar{X}_0'^0, \Xi^{(*)0(-)} \bar{X}_1^0$

(with $D_s^\pm$ exchange)

$\mathcal{B}(\Lambda_b \to \Sigma_c^+ Y_1^-) \sim 10^{-4}$

$\mathcal{B}(\Xi_b^{0(-)} \to \Xi_c^{0(+)}(2645) X_0'^{0(--)}) \sim 10^{-5}$

$\mathcal{B}(\Lambda_b \to \Xi_c'^0 X_{0,1}(2900)^0) \sim 10^{-5}$

$\Xi_c(2645) \to \Xi_c \pi$, $\Xi_c'^0 \to \Xi_c^0 \gamma$

Summary

- We have proposed b-baryon decay channels

to confirm the discovery of $X_{0,1}(2900)$-like exotic states.

- Particularly, we have predicted that

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{0(++)} X_0'^{0(--)}) = (2.3 \pm 0.6) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{0(++)} X_1^{0(--)}) = (4.3^{+3.3}_{-2.5}) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b \to \Sigma_c^{++} X_0'^{--}, X_0'^{--} \to D^- K^-)$$

$$\simeq (1.1 \pm 0.3) \times 10^{-4},$$

accessible to the LHCb experiment.

Thank You