

Baryonic B decays

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Outline:

1. Introduction
2. Formalism
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Introduction

- $m_B > m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}$ for $\mathbf{B}\bar{\mathbf{B}}'$

$(D_s^+ \rightarrow p\bar{n}, \mathcal{B} \text{ of order } 10^{-3})$

$(D_s^+ \rightarrow p\bar{p}e^+\nu_e, \text{ Cheng and Kang, [PLB780, 100 (2018)]})$

1. $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M$

$\mathcal{B}(\bar{B}^0 \rightarrow n\bar{p}D^{*+}) \simeq 10^{-3}$ observed in 2001 (CLEO)

$\mathcal{B}(B^- \rightarrow p\bar{p}K^-) \simeq 10^{-6}$ observed in 2002 (BELLE)

2. $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'$, 1st observation in 2017 (LHCb)

$\mathcal{B}(\bar{B}^0 \rightarrow p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$

$\mathcal{B}(\bar{B}_s^0 \rightarrow p\bar{p}) < 1.5 \times 10^{-8}$

[PRL119, 232001 (2017)]

Introduction

3. First observation of a baryonic $\bar{B}_s^0$ decay (LHCb)

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \Lambda \bar{p} K^+ + \bar{\Lambda} p K^-)$$
$$= (5.46 \pm 0.61 \pm 0.57 \pm 0.50 \pm 0.32) \times 10^{-6}$$

[PRL119, 232001 (2017)]

4. $B_{(s)} \rightarrow \mathbf{B} \bar{\mathbf{B}}' M M'$

$$\mathcal{B}(B^- \rightarrow \Lambda \bar{p} \pi^+ \pi^-) = (5.92_{-0.84}^{+0.88} \pm 0.69) \times 10^{-6} \text{ (BELLE, 2009)}$$

$$\mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^+ \pi^-) = (3.0 \pm 0.2 \pm 0.2 \pm 0.1) \times 10^{-6} \text{ (LHCb, 2017)}$$

$$\mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} K^\mp \pi^\pm) = (6.6 \pm 0.3 \pm 0.3 \pm 0.3) \times 10^{-6} \text{ (LHCb, 2017)}$$

Review: “17.12 B decays to baryons”

in “The Physics of the B Factories” (Cheng, EPJC)

• The threshold effect in the $m_{B\bar{B}'}$ spectrum

Peak near the threshold area of

$$m_{B\bar{B}'} \simeq m_B + m_{\bar{B}'}$$

as the difference between

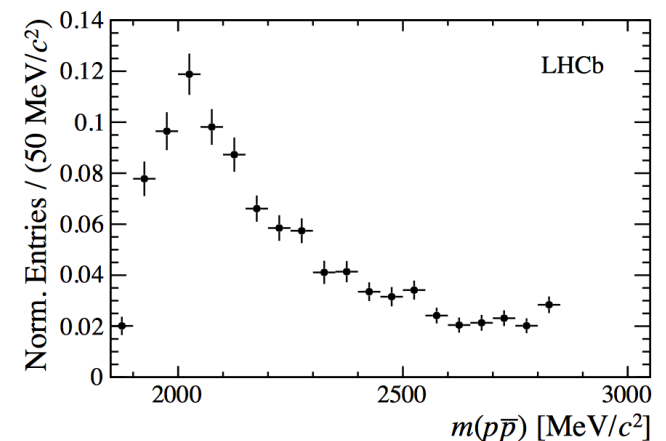
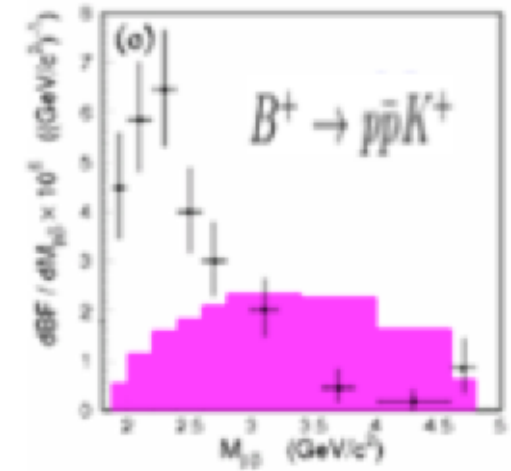
$$B \rightarrow B\bar{B}' \text{ and } B \rightarrow B\bar{B}'M.$$

1. Accessibility of charmless cases

2. Smallness of $\mathcal{B}(\bar{B}_{(s)}^0 \rightarrow p\bar{p}, \Lambda\bar{\Lambda}, B^- \rightarrow \Lambda\bar{p})$

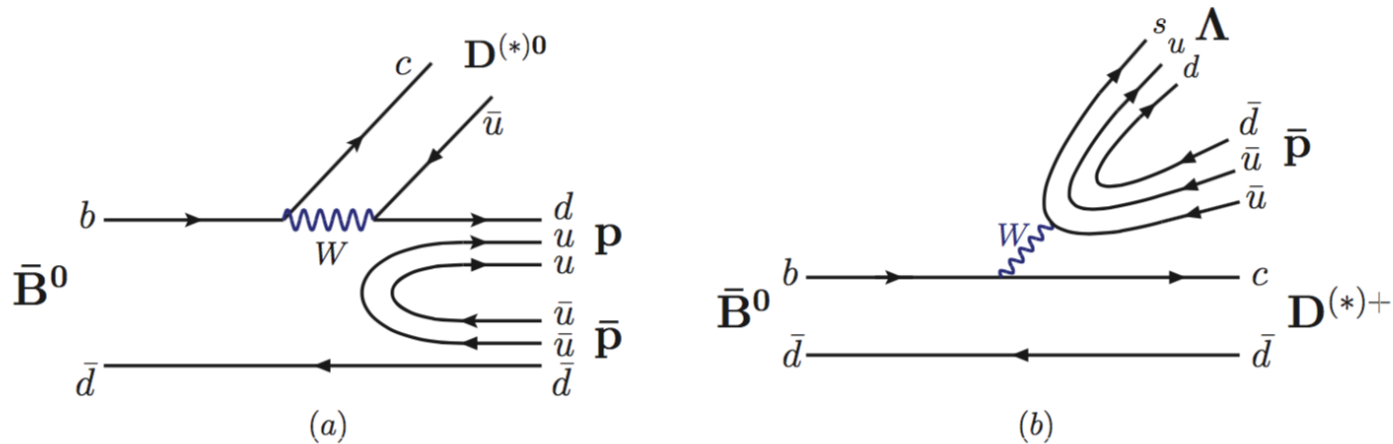
Conjecture by Hou and Soni, PRL86, 4247 (2001)

(Inspired by $\bar{B} \rightarrow D^*p\bar{n}$ and $\bar{B} \rightarrow D^*\pi p\bar{p}$)



• Factorization

$$\mathcal{A}_T \propto \langle M | (\bar{q}_1 q_2) | 0 \rangle \langle \mathbf{B} \bar{\mathbf{B}}' | (\bar{q}_3 b) | \bar{B} \rangle \quad \mathcal{A}_C \propto \langle \mathbf{B} \bar{\mathbf{B}}' | (\bar{q}_1 q_2) | 0 \rangle \langle M | (\bar{q}_3 b) | \bar{B} \rangle$$



A. matrix elements of the $\mathbf{B} \bar{\mathbf{B}}'$ formation

$0 \rightarrow \mathbf{B} \bar{\mathbf{B}}'$: timelike baryonic form factors ($ee \rightarrow p \bar{p}$)

$B \rightarrow \mathbf{B} \bar{\mathbf{B}}'$: B meson transition form factors, new term

$B^- \rightarrow \Lambda \bar{p} \gamma$ (2005, BELLE), $B^- \rightarrow p \bar{p} \ell^- \bar{\nu}_\ell$ (2014, BELLE)

B. approaches under factorization

1. pole model:

H.Y. Cheng, K.C. Yang, PRD66, 014020; 094009 (2002)

2. parameterization of $B \rightarrow \mathbf{BB} + \text{pQCD}$ counting rules:

W.S. Hou, A. Soni, PRL86, 4247 (2001);

C.K. Chua, W.S. Hou, S.Y. Tsai, PRD66, 054004 (2002);

C.K. Chua, W.S. Hou, EPJC29, 27 (2003).

- Timelike baryonic form factors

$$\langle \mathbf{B}\bar{\mathbf{B}}' | V_\mu | 0 \rangle = \bar{u} \left\{ F_1 \gamma_\mu + \frac{F_2}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} i \sigma_{\mu\nu} q_\nu \right\} v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | A_\mu | 0 \rangle = \bar{u} \left\{ g_A \gamma_\mu + \frac{h_A}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} q_\mu \right\} \gamma_5 v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | S | 0 \rangle = f_S \bar{u} v, \quad \langle \mathbf{B}\bar{\mathbf{B}}' | P | 0 \rangle = g_P \bar{u} \gamma_5 v$$

- pQCD counting rules (Lepage and Brodsky, 1979)

$$F_1 = \frac{C_{F_1}}{t^2} [\ln(\frac{t}{\Lambda_0^2})]^{-\gamma}, \quad g_A = \frac{C_{g_A}}{t^2} [\ln(\frac{t}{\Lambda_0^2})]^{-\gamma}$$

The $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'$ transition form factors

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}' b)_V | \bar{B} \rangle =$$

$$i \bar{u}(p_{\mathbf{B}}) [g_1 \gamma_\mu + g_2 i \sigma_{\mu\nu} p^\nu + g_3 p_\mu + g_4 q_\mu + g_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] \gamma_5 v(p_{\bar{\mathbf{B}}'})$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}' b)_A | \bar{B} \rangle =$$

$$i \bar{u}(p_{\mathbf{B}}) [f_1 \gamma_\mu + f_2 i \sigma_{\mu\nu} p^\nu + f_3 p_\mu + f_4 q_\mu + f_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] v(p_{\bar{\mathbf{B}}'})$$

$$q = p_{\mathbf{B}} + p_{\bar{\mathbf{B}}'}, \quad p = p_{\bar{B}} - p_{\mathbf{B}} - p_{\bar{\mathbf{B}}'},$$

$$f_i = \frac{D f_i}{t^n}, \quad g_i = \frac{D g_i}{t^n}$$

$n = 3$ for 3 gluon propagators

• Predictions to be consistent with data.

decay modes	predictions	data
$10^6 \mathcal{B}(B^- \rightarrow \Lambda \bar{\Lambda} K^-)$	2.8 ± 0.2	$3.38_{-0.36}^{+0.41} \pm 0.41$
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{\Lambda} \bar{K}^0)$	2.5 ± 0.3	$4.76_{-0.68}^{+0.84} \pm 0.61$
$10^7 \mathcal{B}(B^- \rightarrow \Lambda \bar{\Lambda} \pi^-)$	1.7 ± 0.7	< 9.4
$10^5 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} D^0)$	1.14 ± 0.26	$1.43_{-0.25}^{+0.28} \pm 0.18$
$10^5 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} D^{*0})$	3.23 ± 0.32	$1.53_{-0.85}^{+1.12} \pm 0.47 (< 4.8)$
$10^5 \mathcal{B}(\bar{B}^0 \rightarrow \Sigma^0 \bar{\Lambda} D^0)$	1.8 ± 0.5	$1.5_{-0.8}^{+0.9}$
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} \phi)$	1.5 ± 0.3	$0.818 \pm 0.215 \pm 0.078$

• Challenge from observations

Predictions (Cheng, Geng and Hsiao, 2008)

$$\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+, \Lambda \bar{p} D^{*+}) = (3.4 \pm 0.2, 11.9 \pm 2.7) \times 10^{-6}$$

Observations [PRL115, 221803 (2015), BELLE]

$$\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+) = (25.1 \pm 2.6 \pm 3.5) \times 10^{-6}$$

$$\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+}) = (33.6 \pm 6.3 \pm 4.4) \times 10^{-6}$$

$$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+) = -0.08 \pm 0.10$$

$$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+}) = +0.55 \pm 0.17$$

- Comment from BELLE:

“The measured branching fractions are clearly incompatible with the theoretical predictions ...

This indicates that the model parameters used in the calculation need to be revised and, perhaps, some modification of the theoretical framework is required.”

- Underestimation of the baryonic form factors

due to the information of $ee \rightarrow p\bar{p}$
(electromagnetic interaction only)

- With the new extractions of BFFs from baryonic B decays, we obtain

decay mode	data	our results
$10^5 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+)$	2.51 ± 0.44	1.85 ± 0.30
$10^5 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+})$	3.36 ± 0.77	2.75 ± 0.24
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+)$	-0.08 ± 0.10	-0.030 ± 0.002
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+})$	$+0.55 \pm 0.17$	$+0.150 \pm 0.000$

1. The data of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)+}$ are not involved in the extractions.
2. Factorization still works.

Extractions of the baryonic form factors

1. Timelike baryonic form factors:

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}q')_V | 0 \rangle = \bar{u} \left[F_1 \gamma_\mu + \frac{F_2}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} i \sigma_{\mu\nu} q^\nu \right] v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}q')_A | 0 \rangle = \bar{u} \left[g_A \gamma_\mu + \frac{h_A}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} q_\mu \right] \gamma_5 v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}q')_S | 0 \rangle = f_S \bar{u} v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{q}q')_P | 0 \rangle = g_P \bar{u} \gamma_5 v$$

$$F_1 = \frac{\bar{C}_{F_1}}{t^2}, \quad g_A = \frac{\bar{C}_{g_A}}{t^2}, \quad f_S = \frac{\bar{C}_{f_S}}{t^2}, \quad g_P = \frac{\bar{C}_{g_P}}{t^2}$$

$$\bar{C}_i = C_i [\ln(t/\Lambda_0^2)]^{-\gamma} \text{ with } \gamma = 2.148 \text{ and } \Lambda_0 = 0.3 \text{ GeV.}$$

$$(C_{F_1}, C_{g_A}, C_{f_S}, C_{g_P}) = \sqrt{\frac{3}{2}} (C_{||}, C_{||}^*, -\bar{C}_{||}, -\bar{C}_{||}^*) \quad (\text{for } \langle \Lambda \bar{p} | (\bar{s}u)_{V,A,S,P} | 0 \rangle)$$

$$\text{with } C_{||(\bar{||})}^* \equiv C_{||(\bar{||})} + \delta C_{||(\bar{||})} \text{ and } \bar{C}_{||}^* \equiv \bar{C}_{||} + \delta \bar{C}_{||}.$$

$$\chi^2/d.o.f \simeq 2.3 \text{ (20 data points)}$$

$$(C_{||}, \delta C_{||}) = (154.4 \pm 12.1, 19.3 \pm 21.6) \text{ GeV}^4$$

$$(C_{\bar{||}}, \delta C_{\bar{||}}) = (18.1 \pm 72.2, -477.4 \pm 99.0) \text{ GeV}^4$$

$$(\bar{C}_{||}, \delta \bar{C}_{||}) = (537.6 \pm 28.7, -342.3 \pm 61.4) \text{ GeV}^4$$

2. $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'$ transition form factors:

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{s}b)_V | B \rangle = i\bar{u}[g_1\gamma_\mu + g_2i\sigma_{\mu\nu}p^\nu + g_3p_\mu + g_4q_\mu + g_5(p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu]\gamma_5 v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{s}b)_A | B \rangle = i\bar{u}[f_1\gamma_\mu + f_2i\sigma_{\mu\nu}p^\nu + f_3p_\mu + f_4q_\mu + f_5(p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu]v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{s}b)_S | B \rangle = i\bar{u}[\bar{g}_1\not{p} + \bar{g}_2(E_{\bar{\mathbf{B}}_2} + E_{\mathbf{B}_1}) + \bar{g}_3(E_{\bar{\mathbf{B}}_2} - E_{\mathbf{B}_1})]\gamma_5 v$$

$$\langle \mathbf{B}\bar{\mathbf{B}}' | (\bar{s}b)_P | B \rangle = i\bar{u}[\bar{f}_1\not{p} + \bar{f}_2(E_{\bar{\mathbf{B}}'} + E_{\mathbf{B}}) + \bar{f}_3(E_{\bar{\mathbf{B}}'} - E_{\mathbf{B}})]v$$

$$f_i = \frac{D_{f_i}}{t^3}, \quad g_i = \frac{D_{g_i}}{t^3}, \quad \bar{f}_i = \frac{D_{\bar{f}_i}}{t^3}, \quad \bar{g}_i = \frac{D_{\bar{g}_i}}{t^3}$$

$$\langle \Lambda\bar{p} | (\bar{s}b)_{V,A} | B^- \rangle:$$

$$D_{g_1} = D_{f_1} = \sqrt{\frac{3}{2}}D_{||}, \quad D_{g_{4,5}} = -D_{f_{4,5}} = -\sqrt{\frac{3}{2}}D_{||}^{4,5}$$

$$\chi^2/d.o.f \simeq 0.8 \text{ (28 data points)}$$

$$D_{||} = (45.7 \pm 33.8) \text{ GeV}^5, \quad (D_{||}^4, D_{||}^5) = (6.5 \pm 18.1, -147.1 \pm 29.3) \text{ GeV}^4$$

$$(\bar{D}_{||}, \bar{D}_{||}^2, \bar{D}_{||}^3) = (35.2 \pm 4.8, -22.3 \pm 10.2, 504.5 \pm 32.4) \text{ GeV}^4$$

$$C_{F_1} = \frac{5}{3}C_{\parallel} + \frac{1}{3}C_{\parallel\bar{\parallel}}, \quad C_{g_A} = \frac{5}{3}C_{\parallel}^* - \frac{1}{3}C_{\parallel\bar{\parallel}}^*, \quad (\text{for } \langle p\bar{p}|\bar{u}\gamma_{\mu}(\gamma_5)u|0\rangle)$$

$$C_{F_1} = \frac{1}{3}C_{\parallel} + \frac{2}{3}C_{\parallel\bar{\parallel}}, \quad C_{g_A} = \frac{1}{3}C_{\parallel}^* - \frac{2}{3}C_{\parallel\bar{\parallel}}^*, \quad (\text{for } \langle p\bar{p}|\bar{d}\gamma_{\mu}(\gamma_5)d|0\rangle)$$

$$C_{f_S} = \frac{1}{3}\bar{C}_{\parallel}, \quad C_{g_P} = \frac{1}{3}\bar{C}_{\parallel}^*, \quad (\text{for } \langle p\bar{p}|\bar{d}(\gamma_5)d|0\rangle)$$

$$C_{F_1} = \sqrt{\frac{3}{2}}C_{\parallel}, \quad C_{g_A} = \sqrt{\frac{3}{2}}C_{\parallel}^*, \quad (\text{for } \langle \Lambda\bar{p}|\bar{s}\gamma_{\mu}(\gamma_5)u|0\rangle)$$

$$C_{f_S} = -\sqrt{\frac{3}{2}}\bar{C}_{\parallel}, \quad C_{g_P} = -\sqrt{\frac{3}{2}}\bar{C}_{\parallel}^*, \quad (\text{for } \langle \Lambda\bar{p}|\bar{s}(\gamma_5)u|0\rangle)$$

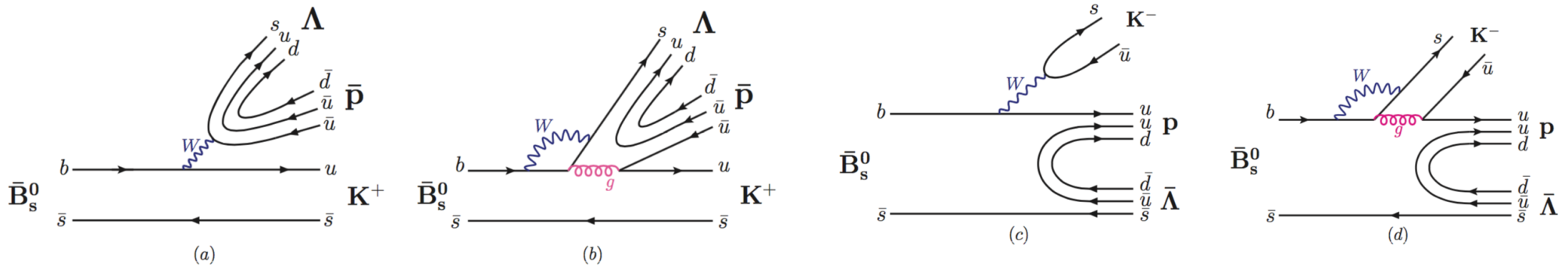
- Baryonic $\bar{B}_s^0$ decay

First observation of a baryonic $\bar{B}_s^0$ decay (LHCb)

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \Lambda \bar{p} K^+ + \bar{\Lambda} p K^-)$$

$$= (5.46 \pm 0.61 \pm 0.57 \pm 0.50 \pm 0.32) \times 10^{-6}$$

[PRL119, 232001 (2017)]



- Naive inference

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \bar{p} \Lambda K^+) \simeq \mathcal{B}(\bar{B}^0 \rightarrow \bar{p} \Lambda \pi^+), 3.1 \times 10^{-6}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow p \bar{\Lambda} K^-) \simeq \mathcal{B}(B^- \rightarrow p \bar{p} K^-), 5.9 \times 10^{-6}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow p \bar{\Lambda} \pi^-) \simeq \mathcal{B}(B^- \rightarrow p \bar{p} \pi^-), 1.6 \times 10^{-6}$$

- our results [PLB767, 205 (2017)]

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \bar{p}\Lambda K^+) = (3.75 \pm 0.81_{-0.31}^{+0.67} \pm 0.01) \times 10^{-6}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow p\bar{\Lambda}K^-) = (1.31 \pm 0.32_{-0.10}^{+0.22} \pm 0.01) \times 10^{-6}$$

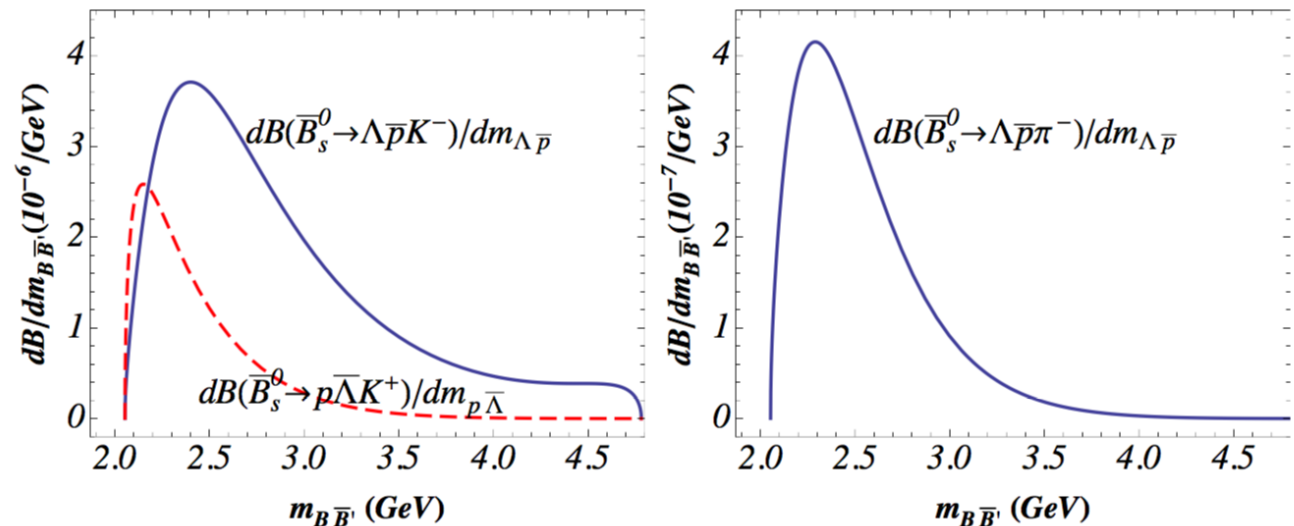
$$\mathcal{B}(\bar{B}_s^0 \rightarrow p\bar{\Lambda}\pi^-) = (2.79 \pm 1.37_{-0.30}^{+0.64} \pm 0.17) \times 10^{-7}$$

errors: the form factors, non-factorizable effects, and CKM matrix elements.

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \bar{p}\Lambda K^+ + p\bar{\Lambda}K^-) = (5.1 \pm 1.1) \times 10^{-6}, \text{ to agree with the data of } (5.46 \pm 0.61 \pm 0.57 \pm 0.50 \pm 0.32) \times 10^{-6}.$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow \bar{p}\Lambda K^+) \simeq (f_K/f_\pi)^2 (\tau_{B_s^0}/\tau_{B^0}) \mathcal{B}(\bar{B}^0 \rightarrow \bar{p}\Lambda\pi^+)$$

$$\frac{\mathcal{B}(\bar{B}_s^0 \rightarrow p\bar{\Lambda}\pi^-)}{\mathcal{B}(\bar{B}_s^0 \rightarrow p\bar{\Lambda}K^-)} \simeq \frac{\mathcal{B}(B^- \rightarrow p\bar{p}\pi^-)}{\mathcal{B}(B^- \rightarrow p\bar{p}K^-)}$$

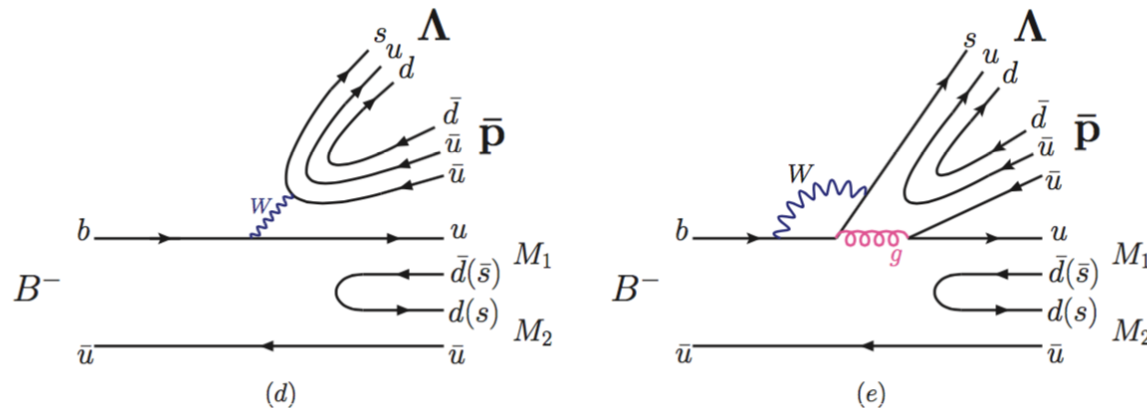
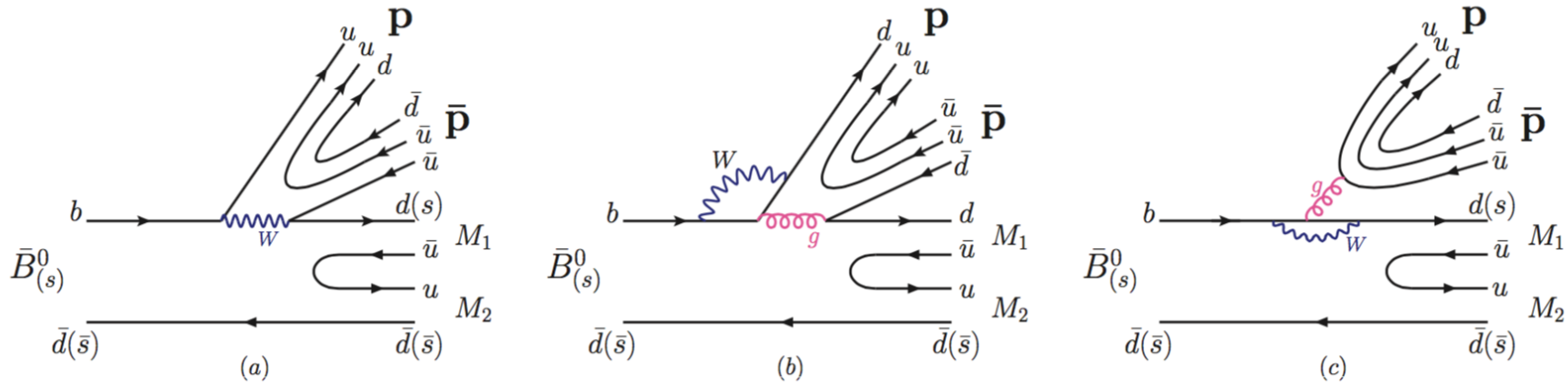


• Four-body Baryonic $B_{(s)}$ decays

$$\mathcal{B}(B^- \rightarrow \Lambda \bar{p} \pi^+ \pi^-) = (5.92^{+0.88}_{-0.84} \pm 0.69) \times 10^{-6} \text{ (BELLE, 2009)}$$

$$\mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^+ \pi^-) = (3.0 \pm 0.2 \pm 0.2 \pm 0.1) \times 10^{-6} \text{ (LHCb, 2017)}$$

$$\mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} K^\mp \pi^\pm) = (6.6 \pm 0.3 \pm 0.3 \pm 0.3) \times 10^{-6} \text{ (LHCb, 2017)}$$



- $B \rightarrow M_1 M_2$ transition form factors

$$\langle M_1 M_2 | \bar{q}_1 \gamma_\mu (1 - \gamma_5) b | B \rangle =$$
$$h \epsilon_{\mu\nu\alpha\beta} p_B^\nu p^\alpha (p_{M_2} - p_{M_1})^\beta + i r q_\mu + i w_+ p_\mu + i w_- (p_{M_2} - p_{M_1})$$
$$h = \frac{C_h}{t^2}, \quad w_- = \frac{D_{w_-}}{t^2}$$

Chua, Hou, Shiao and Tsai,

“Evidence for factorization in three-body anti- $B \rightarrow D^{(*)} K^- K^0$ decays,”

PRD67, 034012 (2003); EPJC33, S253 (2004).

$$(C_h, C_{w_-})|_{B \rightarrow \pi\pi} = (3.6 \pm 0.3, 0.7 \pm 0.2) \text{ GeV}^3$$

$$(C_h, C_{w_-})|_{B \rightarrow KK(K\pi)} = (-38.9 \pm 3.3, 14.2 \pm 2.3) \text{ GeV}^3$$

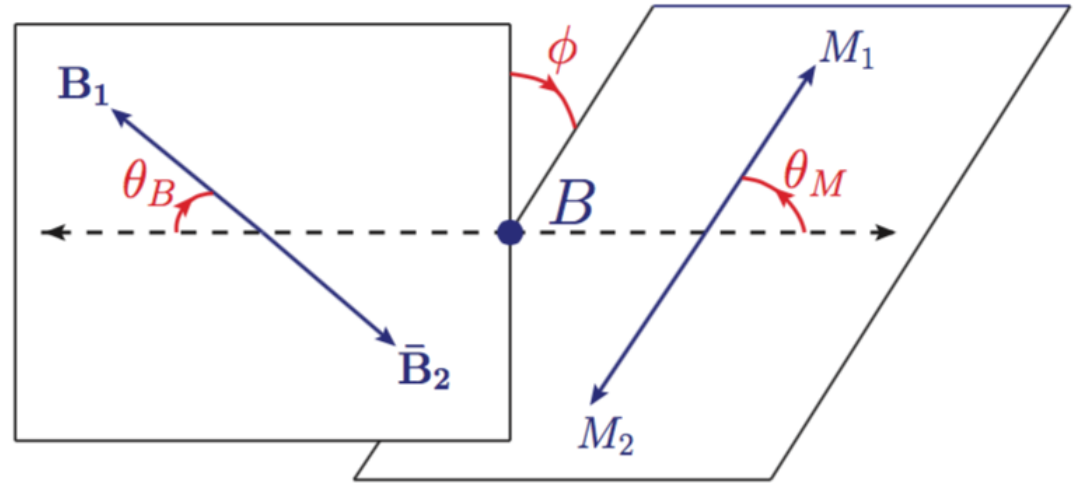
phase space

$$d\Gamma = \frac{|\bar{\mathcal{A}}|^2}{4(4\pi)^6 m_B^3} X \alpha_{\mathbf{B}} \alpha_{\mathbf{M}} ds dt d\cos\theta_{\mathbf{B}} d\cos\theta_{\mathbf{M}} d\phi$$

$$X = \left[\frac{1}{4} (m_B^2 - s - t)^2 - st \right]^{1/2},$$

$$\alpha_{\mathbf{B}} = \frac{1}{t} \lambda^{1/2}(t, m_{\mathbf{B}_1}^2, m_{\bar{\mathbf{B}}_2}^2),$$

$$\alpha_{\mathbf{M}} = \frac{1}{s} \lambda^{1/2}(s, m_{M_1}^2, m_{M_2}^2),$$

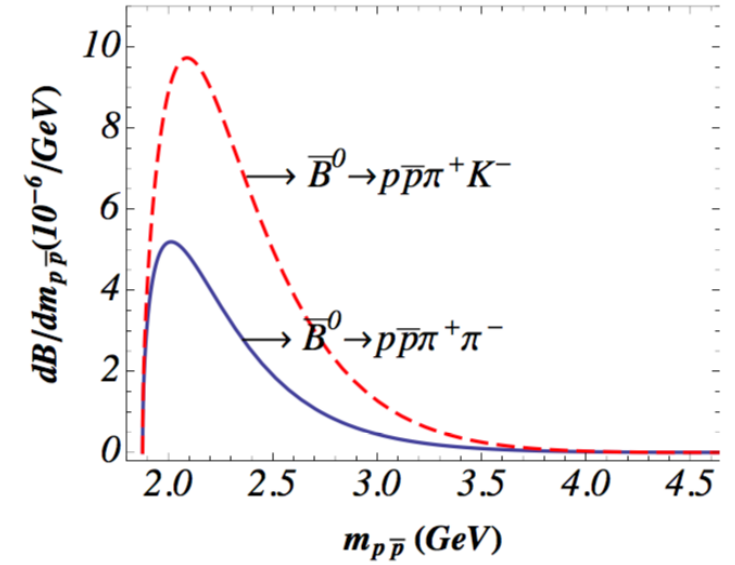


$$\lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2bc - 2ca,$$

$$(m_{M_1} + m_{M_2})^2 \leq s \leq (m_B - \sqrt{t})^2, \quad (m_{\mathbf{B}_1} + m_{\bar{\mathbf{B}}_2})^2 \leq t \leq (m_B - m_{M_1} - m_{M_2})^2,$$

$$0 \leq \theta_{\mathbf{B}}, \theta_{\mathbf{M}} \leq \pi, \quad 0 \leq \phi \leq 2\pi.$$

branching ratios	our results	data
$10^6 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} \pi^+ \pi^-)$	$3.7_{-0.5}^{+1.2} \pm 0.1 \pm 0.9$	5.9 ± 1.1
$10^6 \mathcal{B}(B^- \rightarrow \Lambda \bar{p} K^+ K^-)$	$3.0_{-0.5}^{+1.1} \pm 0.1 \pm 0.7$	—
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^+ \pi^-)$	$3.0_{-0.3}^{+0.5} \pm 0.3 \pm 0.7$	3.0 ± 0.3
$10^6 \mathcal{B}(\bar{B}^0 \rightarrow p \bar{p} \pi^\pm K^\mp)$	$6.6 \pm 0.5 \pm 0.0 \pm 2.3$	6.6 ± 0.5

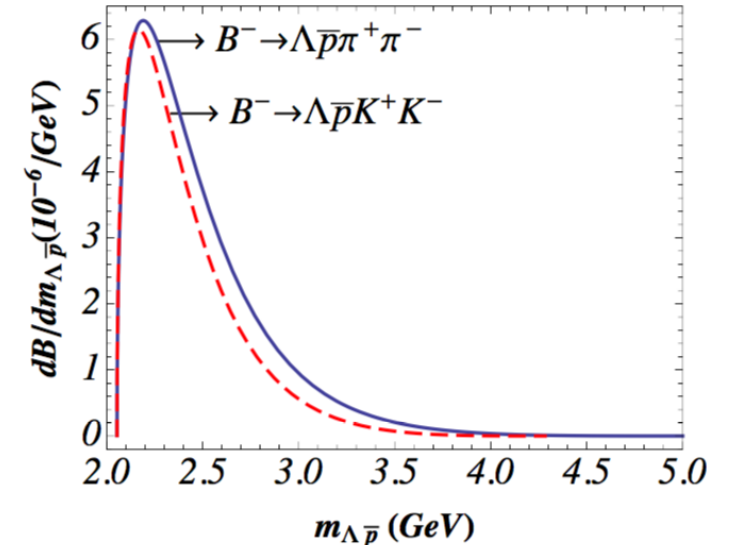


The errors come from the non-factorizable effects,
CKM matrix elements, and form factors, respectively.

arXiv:1807.10503 [hep-ex], [Belle]

$$\mathcal{B}(B^+ \rightarrow p \bar{\Lambda} K^+ K^-)$$

$$= (4.22_{-0.44}^{+0.45} \pm 0.51) \times 10^{-6}$$



Summary

- The factorization, together with the determination of the baryonic form factors, can be used to study the baryonic B decays.

- Particularly, we have explained

$$\bar{B}_s^0 \rightarrow \bar{p}\Lambda K^+ + p\bar{\Lambda}K^-,$$

$$B \rightarrow \mathbf{B}_1\mathbf{B}_2M_1M_2.$$

Thank You