B-meson pure baryonic decays at LHCb

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烟台大学

Outline

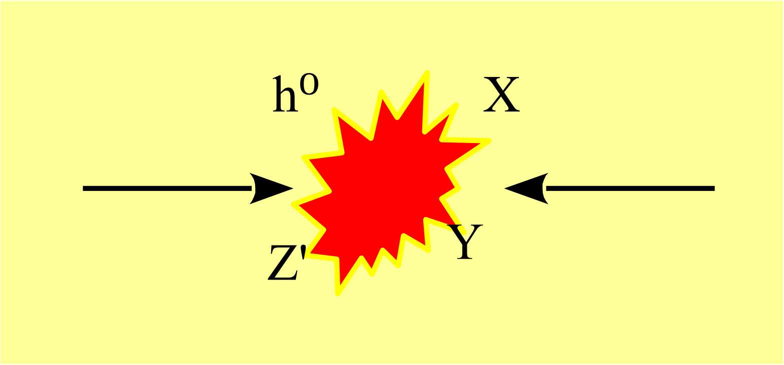
- Introduction
- B-meson charmless pure baryonic decays
  - □ $B_s^0 \to p\bar{p}$, $B_{(s)}^0 \to p\bar{p}p\bar{p}$, $B^+ \to p\bar{\Lambda}$
- Outlook

Two ways of study new physics in LHC

High energy frontier

- ATLAS and CMS

  Search new particles in collision directly



High precision frontier

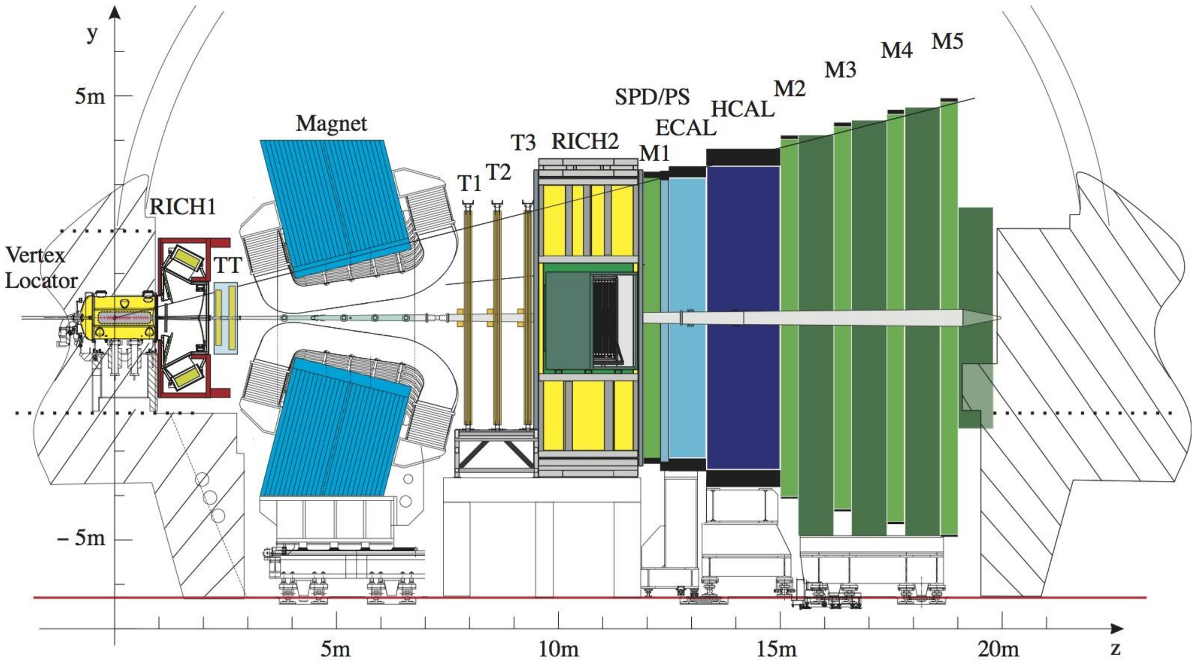
- LHCb

  Precisely measurement loop diagram for searching new particles that appear in the loop diagram

  - Search new physics far above the accelerator collision energy
  - Test new physics models, determining coupling constants and phases

LHCb experiment

LHCb collaboration： 21 counties, 96 institutes, 1600 members

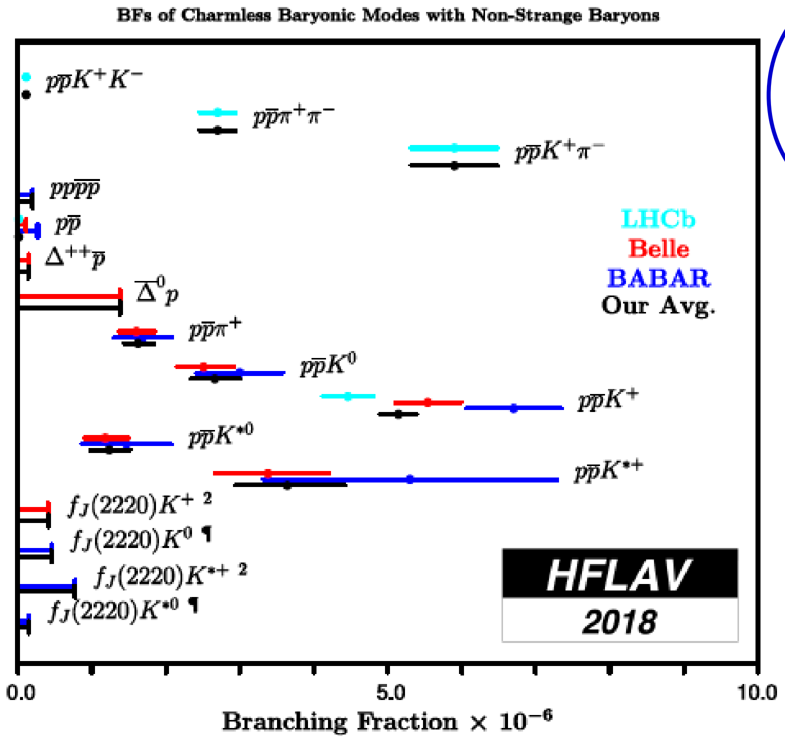


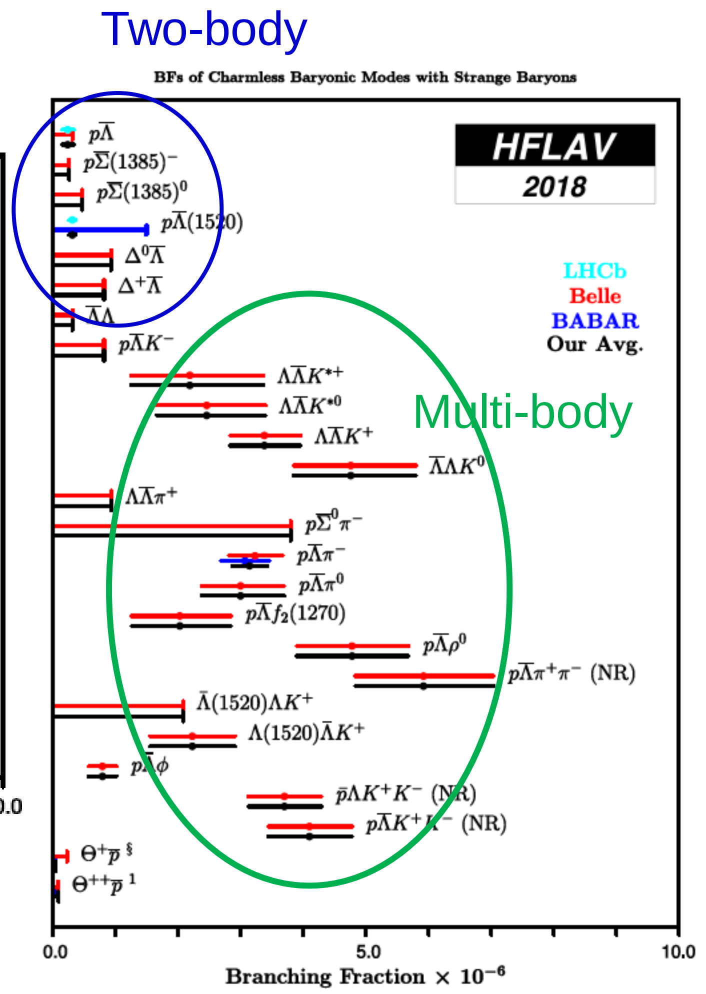
中国单位(9个)：
清华大学
华中师范大学
中国科学院大学
武汉大学
高能物理研究所
华南师范大学
北京大学
湖南大学
兰州大学

- Understand matter-antimatter imbalance (CP violation)
- Search for new physics (Rare decays)
- Explore and understand QCD (Hadron properties, exotic hadrons)

The feature of B baryonic decays

- Two-body baryonic decays suppressed with respect to multibody decays
- Decays of B mesons into multiple baryons still far from being fully understood





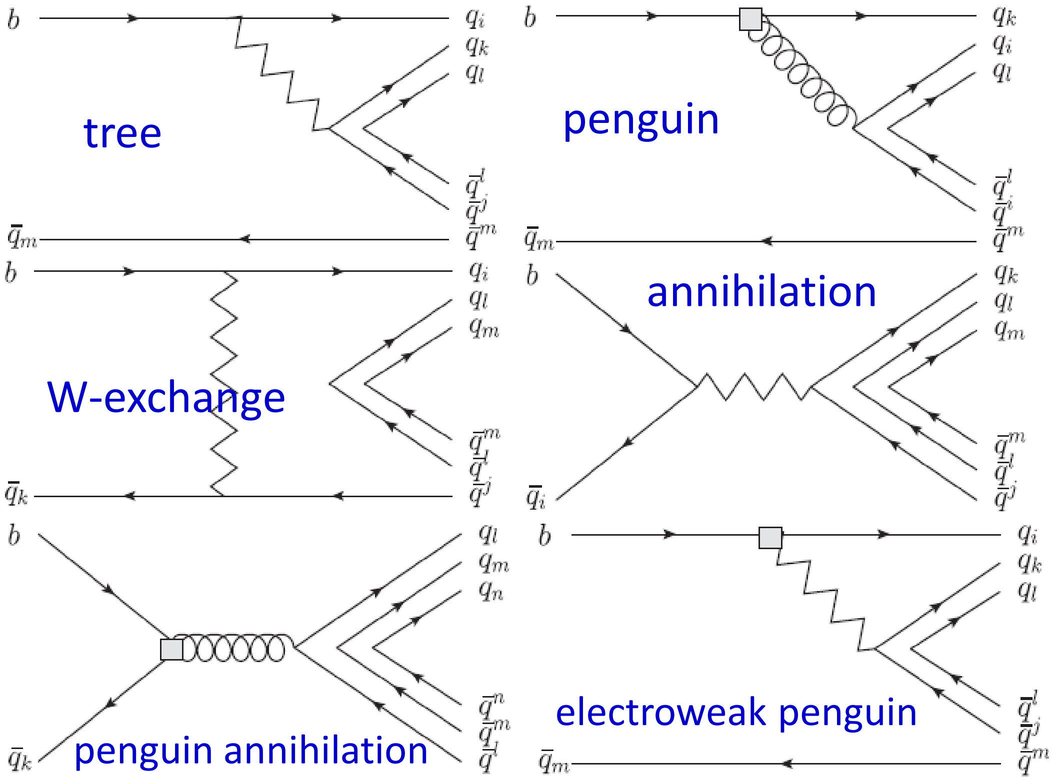
Charmless baryonic $B^+$and B^0 modes branching fractions reported by HFLAV

Two−body baryonic decays of B

- Provides information on the dynamics of B decays and tests QCD based models of the hadronization process

- Discriminate models and extract both tree and penguin amplitudes of charmless two-body baryonic decays

Phys. Rev. D 95, 096004 (2017)



- $B^0 \to p\bar{p}$ and $B^+ \to p\bar{\Lambda}$ as inputs to predict other $B \to \mathfrak{B}_1\mathfrak{B}_2$

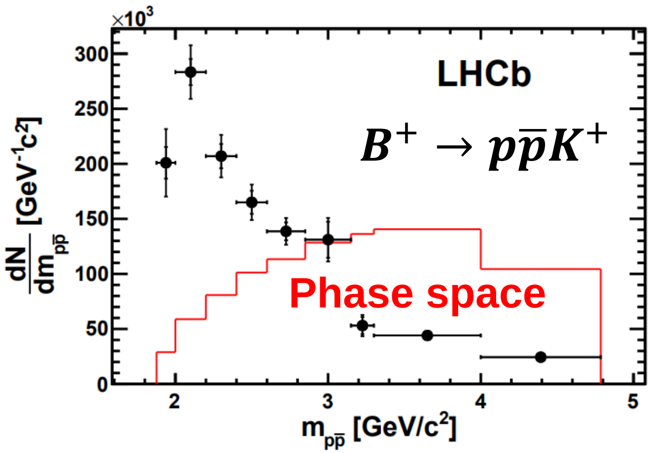
- Baryonic B decays are also interesting in the study of CP violation

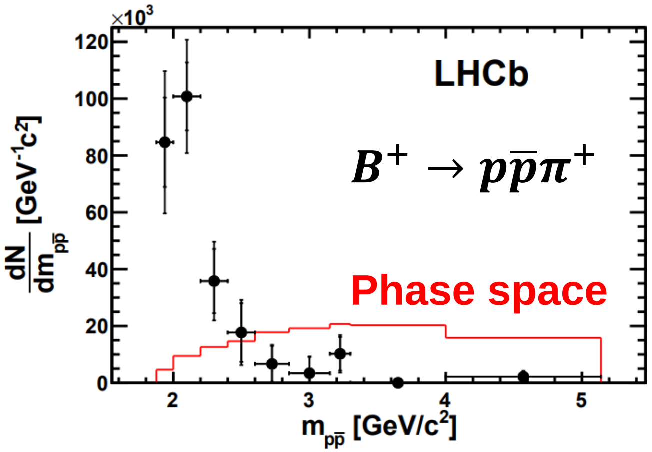
- Pure penguin modes are expected to be sensitive to new physics contributions

Threshold enhancement

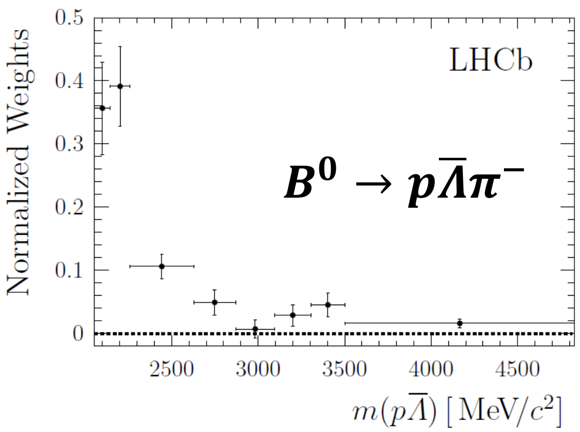
➢ Many channels have the special feature: baryon-antibaryon pair peaks near threshold

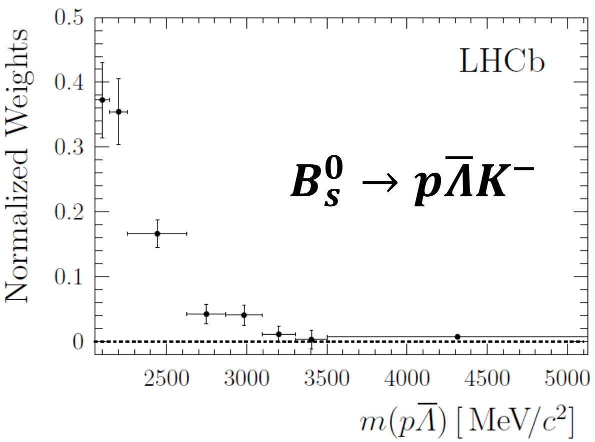
PRD 88, 052015 (2013)

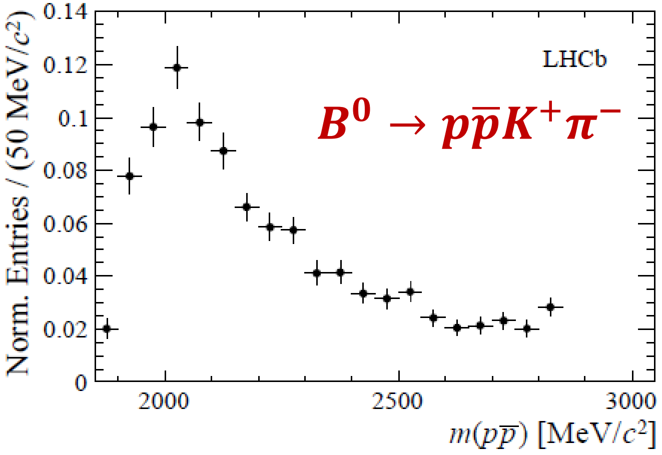


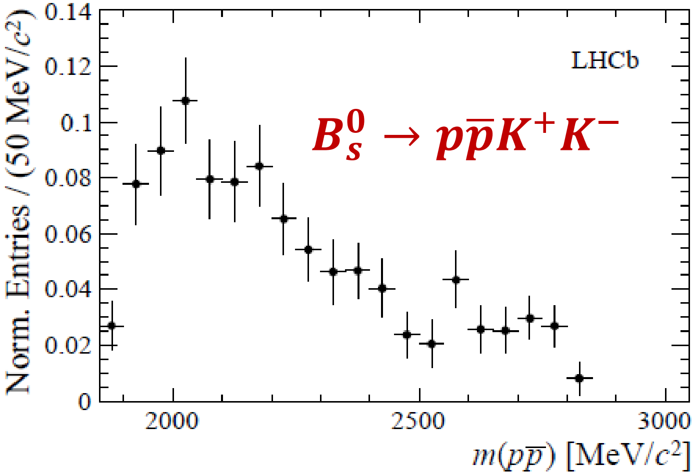


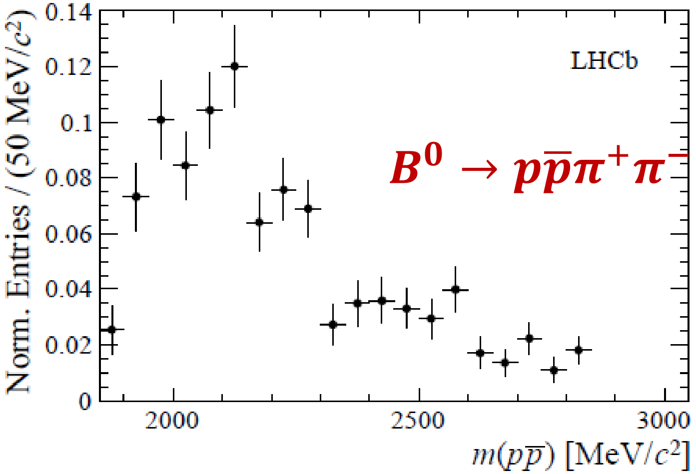
Phys. Rev. Lett. 119 (2017) 041802







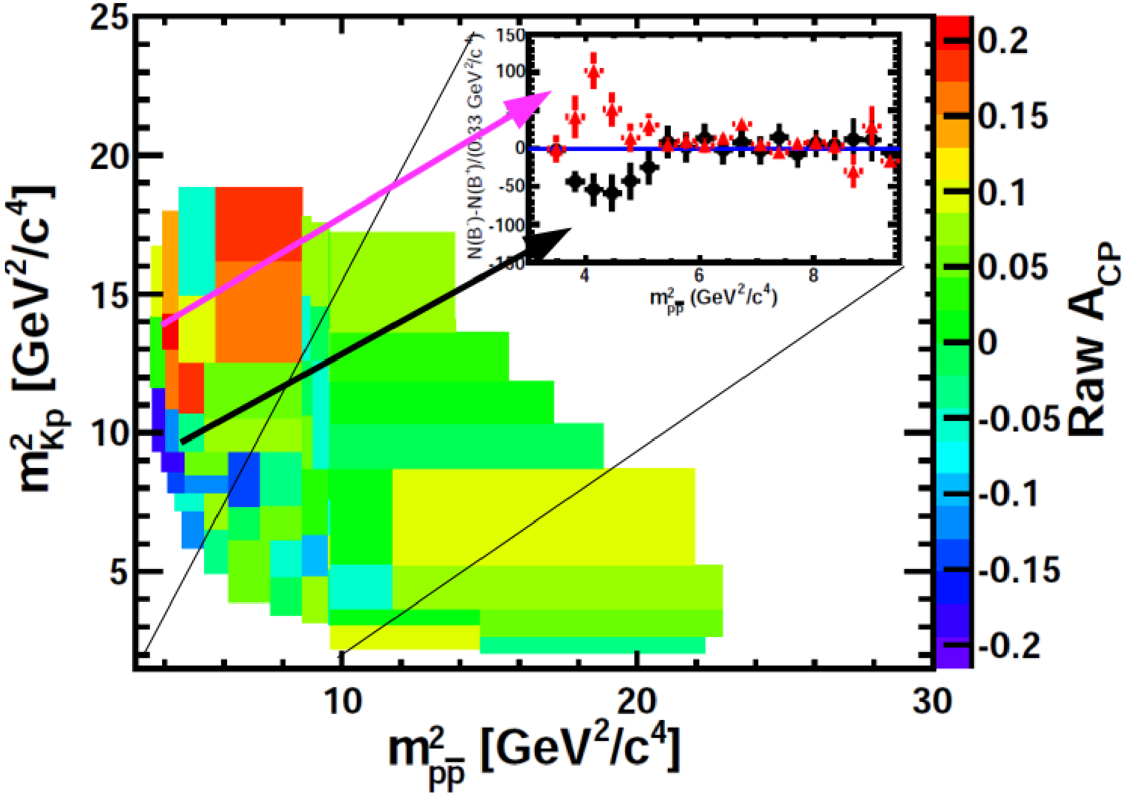




Phys. Rev. D 96 (2017) 051103

CP asymmetry

- 4σ CP asymmetry effect near-threshold with sign-flip near the zero crossing of the cosine of the light meson angle in $p\bar{p}$ frame (ΔA_{cp}~4.7σ), pointing to interfering J=0 and J=1 type waves



PRL 113, 141801 (2014)

B-meson charmless pure baryonic decays

$B_s^0 \to p\bar{p}, B_{(s)}^0 \to p\bar{p}p\bar{p}, B^+ \to p\bar{\Lambda}$

Patterns in charmless decays of B

- Interesting patterns in rates with or without $p\bar{p}$ pairs in final state

B^0

- ✓ $\mathcal{B}(B^0 \to \pi^+\pi^-) = (5.1 \pm 0.2) \times 10^{-6}$ $\sim$ $\mathcal{B}(B^0 \to p\bar{p}\pi^+\pi^-) = (2.9 \pm 0.2) \times 10^{-6}$
- ✓ $\mathcal{B}(B^0 \to K^+\pi^-) = (2.0 \pm 0.1) \times 10^{-6}$ $\sim$ $\mathcal{B}(B^0 \to p\bar{p}K^+\pi^-) = (6.3 \pm 0.5) \times 10^{-6}$
- ✓ $\mathcal{B}(B^0 \to K^+K^-) = (7.8 \pm 0.5) \times 10^{-8}$ $<$ $\mathcal{B}(B^0 \to p\bar{p}K^+K^-) = (1.2 \pm 0.3) \times 10^{-7}$
- ✓ $\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.16) \times 10^{-8}$ $\sim(?)$ $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) < (2.0) \times 10^{-7}$

[arXiv:2206.06673] PRL 119, 232001 [PRD 98 (2018) 7, 071102]

Threshold enhancement at $\mathrm{m}(p\bar{p}) = \mathrm{m}(p) + \mathrm{m}(\bar{p})$

B_s^0

- ✓ $\mathcal{B}(B_s^0 \to \pi^+\pi^-) = (7.0 \pm 1.0) \times 10^{-7}$ $\sim$ $\mathcal{B}(B_s^0 \to p\bar{p}\pi^+\pi^-) = (4.3 \pm 2.0) \times 10^{-7}$
- ✓ $\mathcal{B}(B_s^0 \to K^+\pi^-) = (5.8 \pm 0.7) \times 10^{-6}$ $\sim$ $\mathcal{B}(B_s^0 \to p\bar{p}K^+\pi^-) = (1.4 \pm 0.3) \times 10^{-6}$
- ✓ $\mathcal{B}(B_s^0 \to K^+K^-) = (2.7 \pm 0.2) \times 10^{-5}$ $>$ $\mathcal{B}(B_s^0 \to p\bar{p}K^+K^-) = (4.5 \pm 0.5) \times 10^{-6}$
- ✓ $\mathcal{B}(B_s^0 \to p\bar{p}) < (5.1) \times 10^{-9}$ $\sim(?)$ $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = ?$

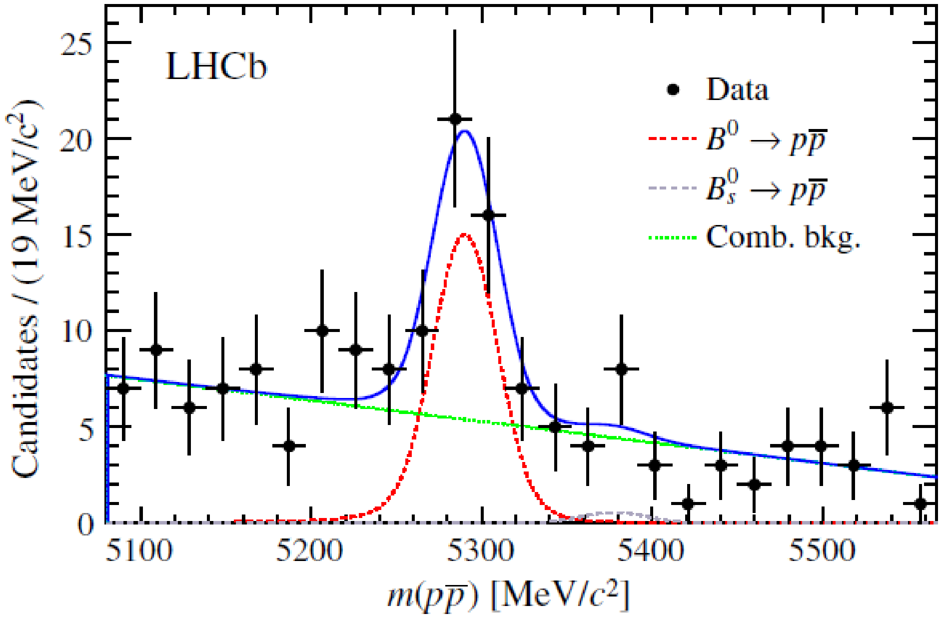
[arXiv:2206.06673]

- New measurements of pure baryonic B decays would provide new insights in the understanding of the non-trivial processes involved

Search for $B^0_{(s)} \to p\bar{p}$

- First observation of $B^0 \to p\bar{p}$ with Run 1 data
  - $\mathcal{B}(B^0 \to p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$
  - $\mathcal{B}(B^0_s \to p\bar{p}) < 1.5 \times 10^{-8}$@90% CL

PRL 119, 232001 (2017)



- Some predictions expect $B^0_s \to p\bar{p}$ to be further suppressed (negligible penguin-level gluon-exchange and annihilation contributions)
  [PRD 89, 056003 (2014), PRD 95, 096004 (2017)]

- Other predictions expect $B^0_s \to p\bar{p}$ rates similar to that of $B^0 \to p\bar{p}$ (penguin-level gluon-exchange and annihilation contributions can’ t be neglected)
  [JHEP2004, 035 (2020)]

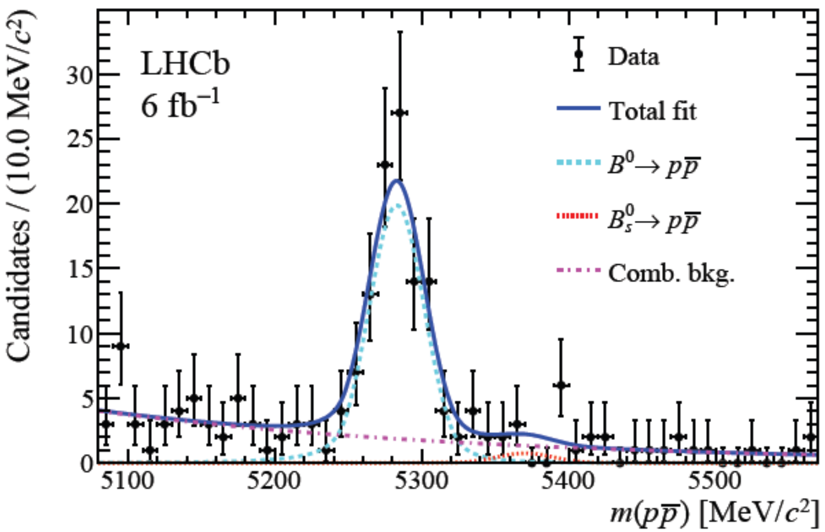
- Updated search for $B^0_s \to p\bar{p}$ decay is needed

Search for $B_s^0 \to p\bar{p}$ with Run 2 data

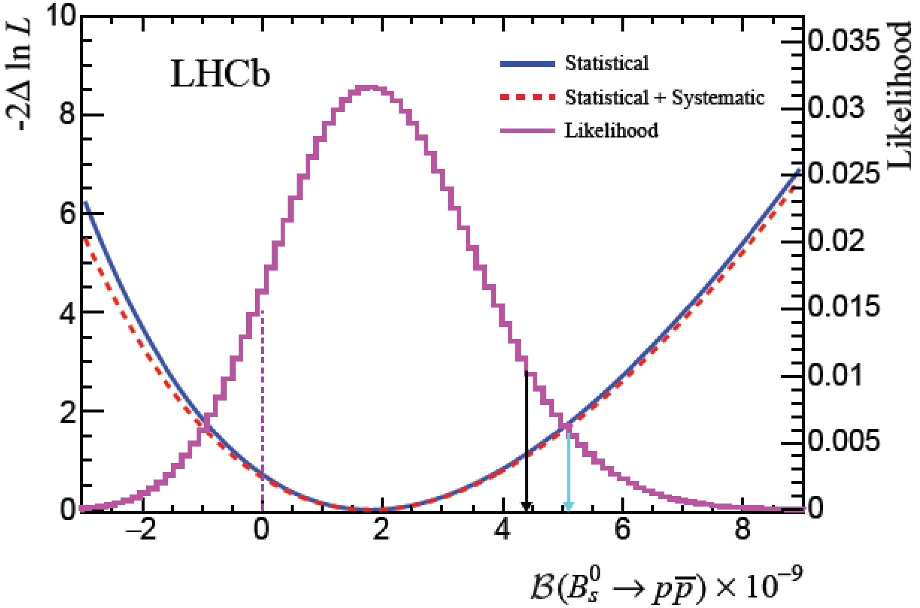
(by LHCb-China members)

Phys. Rev. D 108, 012007

- $N(B^0 \to p\bar{p}) = 98 \pm 11(16.2\sigma)$
- $N(B_s^0 \to p\bar{p}) = 4 \pm 5(0.9\sigma)$
- $B^0 \to K^+\pi^-$ and $B_s^0 \to K^+\pi^-$ as normalization channel
- $\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8}$
  Consistent with Run 1



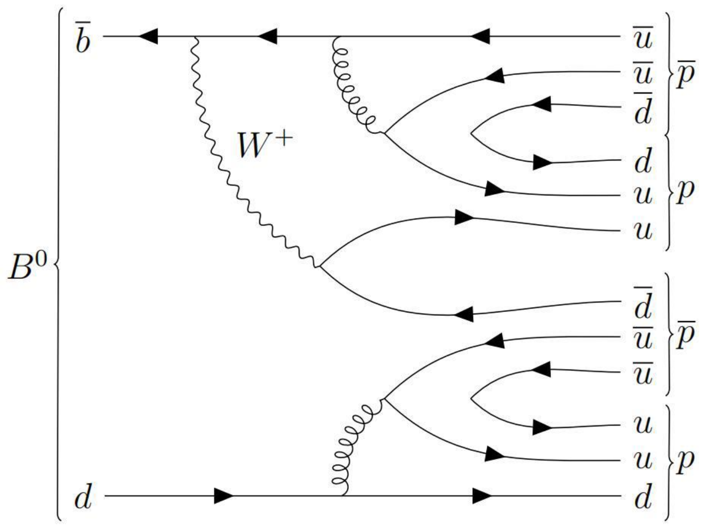
- Upper Limit on $\mathcal{B}(B_s^0 \to p\bar{p})$ improved by factor 3
  - $\mathcal{B}(B_s^0 \to p\bar{p}) < 15 \times 10^{-9}$@90% CL (RUN-I)
  - $\mathcal{B}(B_s^0 \to p\bar{p}) < 4.5(5.1) \times 10^{-9}$@90%(95%) CL (New)

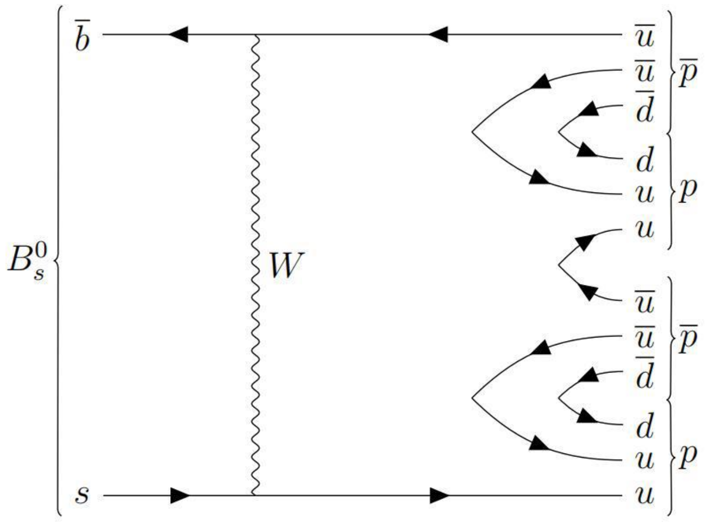


Search for $B^0_{(s)} \to p\bar{p}p\bar{p}$

- B meson decay to 4 baryons was never observed
  - $B^0 \to pppp$ (2.9σ) **Phys. Rev. D 98, 071102 (2018)**

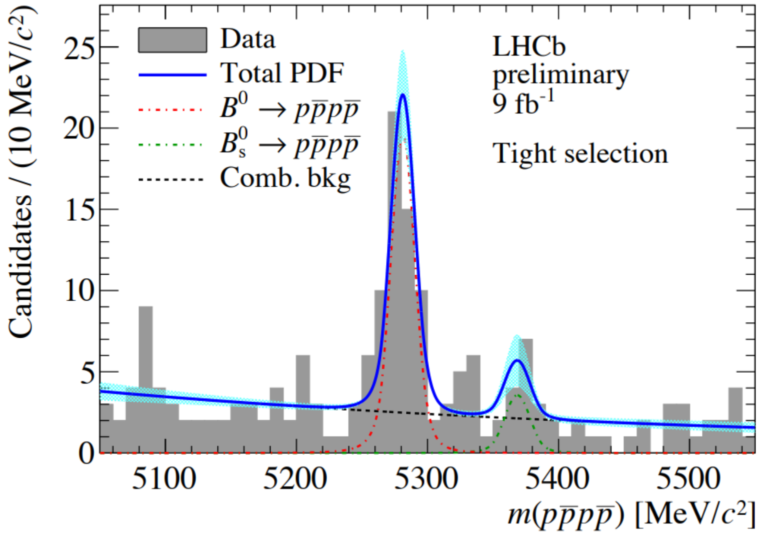
- $B_s \to pppp$ (**no study reported**) is expected to be further suppressed with respect to B^0
  - Hadronisation fraction f_s/f_d~25%, and $\left|\frac{V_{us}}{V_{ud}}\right|^2$ ~5%

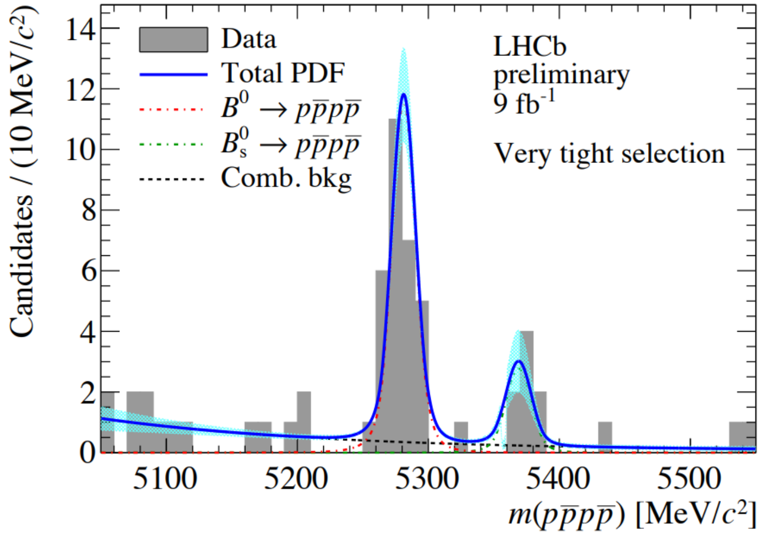




Search for $B^0_{(s)} \to p\bar{p}p\bar{p}$ with Run 1&2 data

(by LHCb-China members)





arXiv:2211.08847

Accepted by PRL

N($B^0 \to p\bar{p}p\bar{p}$) = 48 ± 8

Significance: > 9σ

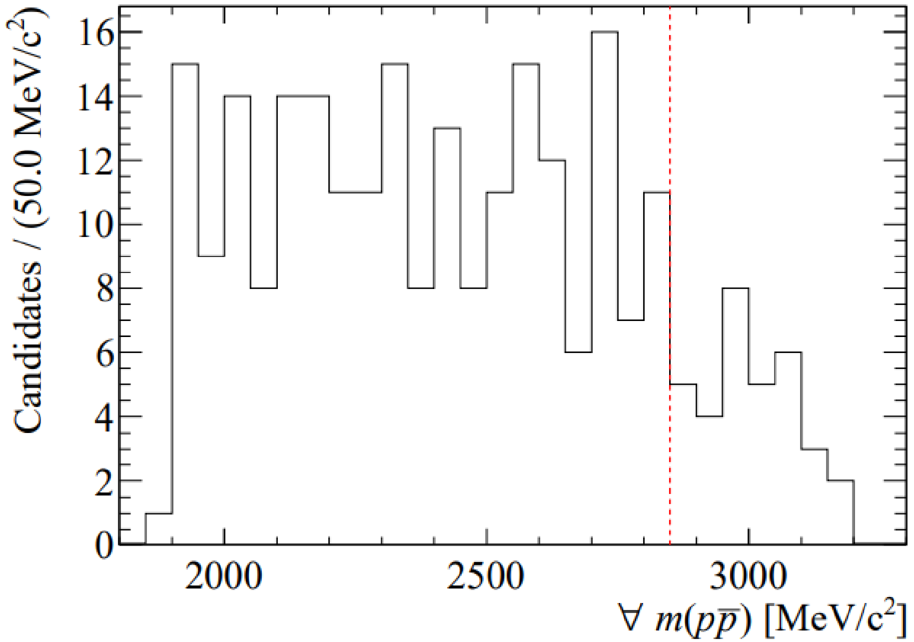
N($B^0_s \to p\bar{p}p\bar{p}$) = 7 ± 3

Significance: 4σ

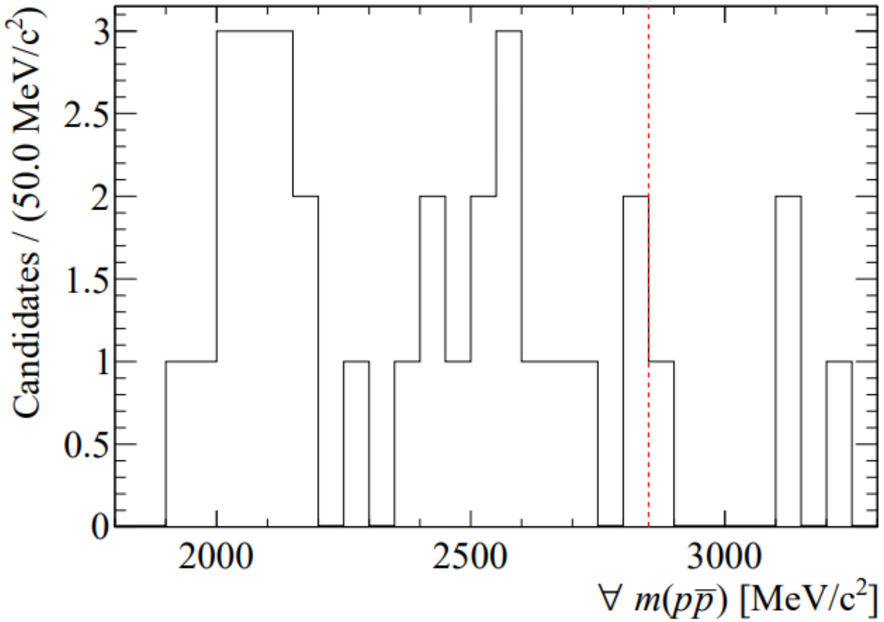
- $B^0 \to J/\psi(\to p\bar{p})K^{*0}(\to K^+\pi^-)$ and $B^0_s \to J/\psi(\to p\bar{p})\phi(\to K^+K^-)$ as normalization channel
- $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$
- $\mathcal{B}(B^0_s \to p\bar{p}p\bar{p}) = (2.3 \pm 1.0 \pm 0.2 \pm 0.1) \times 10^{-8}$
- $B^0_s \to p\bar{p}p\bar{p}$ is not consistent with expected Cabibo suppression: $\left|\frac{V_{us}}{V_{ud}}\right|^2 \sim 5\%$
- Expect other theoretical explanations

Mass distributions of $p\bar{p}$

Tight selection



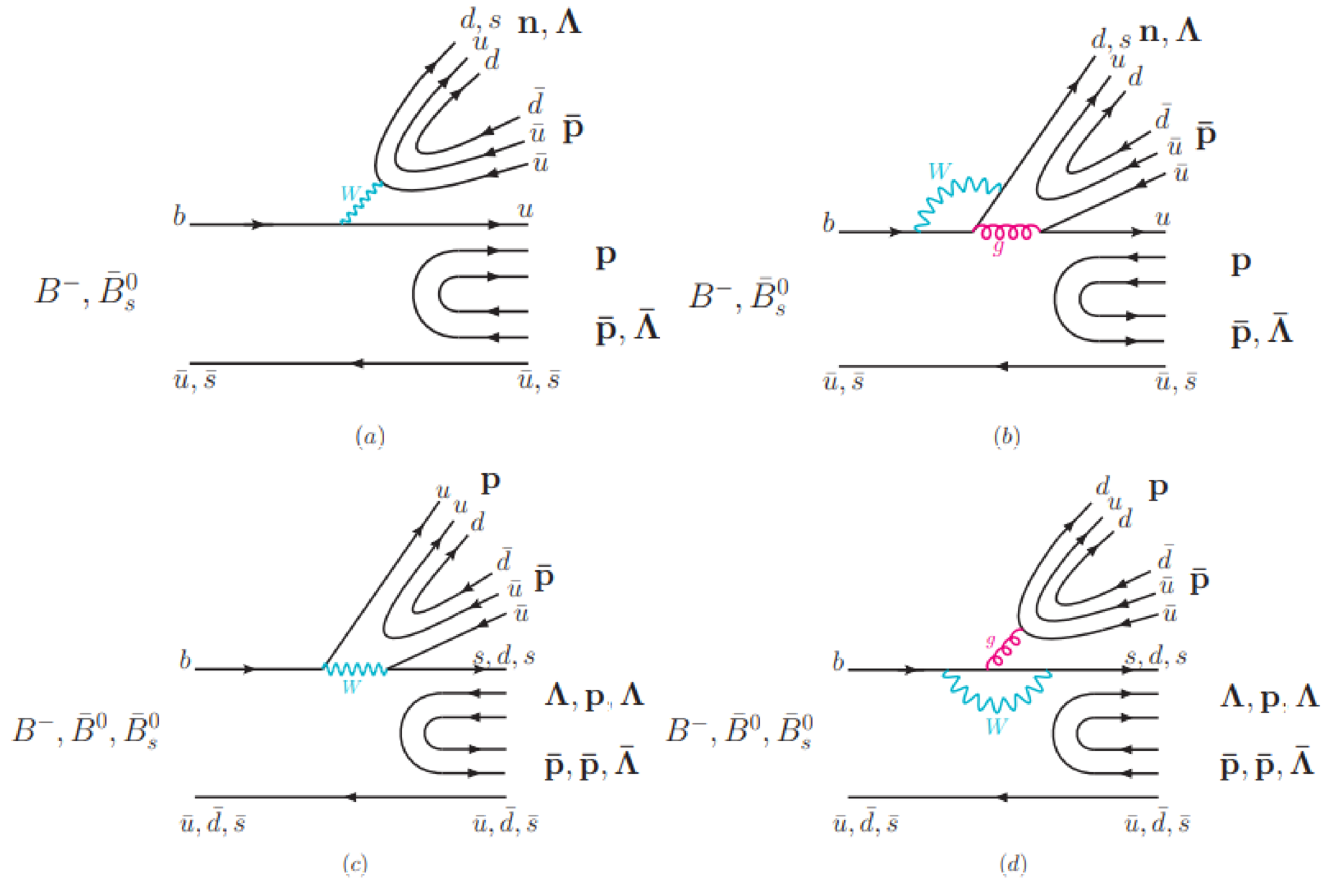
Very Tight selection



Data above the red-dashed line are excluded by the $c\bar{c}$ veto.

- To avoid $J/\psi \to p\bar{p}$, require $m(p\bar{p}) < 2.85\mathrm{GeV}/c^2$
- Branching fractions with $c\bar{c}$ veto (only stat. uncertainty)
  - $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (1.6 \pm 0.4) \times 10^{-8}$
  - $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 1.2) \times 10^{-8}$

Some theoretical researches



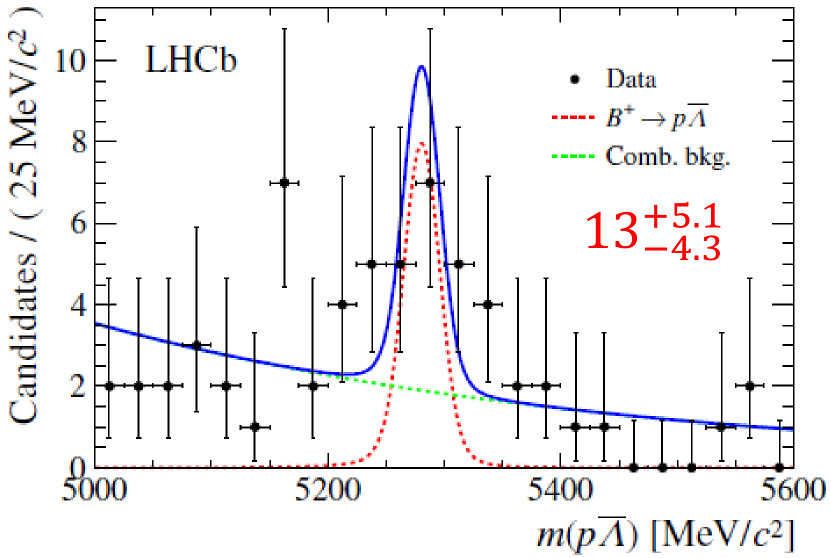
PLB (2023)138158

decay mode	our work	data
$10^8\mathcal{B}(\bar{B}^0 \to p\bar{p}p\bar{p})$	$2.2 \pm 0.4 \pm 0.1 \pm 0.4$	2.2 ± 0.4 [10]
$10^8\mathcal{B}(B^- \to n\bar{p}p\bar{p})$	$8.4^{+2.1}_{-1.0} \pm 0.4^{+3.4}_{-1.9}$	—
$10^7\mathcal{B}(B^- \to \Lambda\bar{p}p\bar{p})$	$3.7^{+0.3}_{-0.1} \pm 0.02^{+1.8}_{-1.3}$	—
$10^7\mathcal{B}(\bar{B}_s^0 \to \Lambda\bar{\Lambda}p\bar{p})$	$1.9^{+0.3}_{-0.1} \pm 0.01^{+1.1}_{-0.6}$	—

Evidence for $B^+ \to p\bar{\Lambda}$ with RUN-I data

JHEP 04(2017)162

- $B^+ \to K_S^0 \pi^+$ as a normalization mode
- $\mathcal{B}(B^+ \to p\bar{\Lambda}) = (2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-7}$
- The first evidence for this decay process (4.1σ)



$$\mathcal{B}(B^+ \to p\bar{\Lambda}) = \frac{N(B^+ \to p\bar{\Lambda})}{N(B^+ \to K_S^0\pi^+)} \frac{\epsilon_{B^+\to K_S^0\pi^+}}{\epsilon_{B^+\to p\bar{\Lambda}}} \frac{\mathcal{B}(K_S^0 \to \pi^+\pi^-)}{\mathcal{B}(\Lambda \to p\pi^-)} \mathcal{B}(B^+ \to K_S^0\pi^+)$$

- Compatible with the theoretical predictions
  - **Phys. Rev. D 66 (2002) 014020, , Phys. Rev. D 89 (2014) 056003**
- In tension with calculations based on QCD sum rules (**Nucl. Phys. B 345 (1990) 137**) and factorization (**Phys. Rev. D 91 (2015) 077501**)

Summary and prospects

- **LHCb provides ideal environment for searching for rare baryonic decays of B mesons**
  - B meson charmless baryonic decay: $B_s^0 \to p\bar{p}$, $B_{(s)}^0 \to p\bar{p}p\bar{p}$
  - More results are on the way: $B^- \to \Lambda\bar{p}p\bar{p}$, $B_{(s)}^0 \to \Lambda_c^+\overline{\Lambda}_c^-$, $B_{(s)}^0 \to \Lambda_c^+\bar{\Xi}_c^-$, $B_{(s)}^0 \to \Xi_c\bar{\Xi}_c$

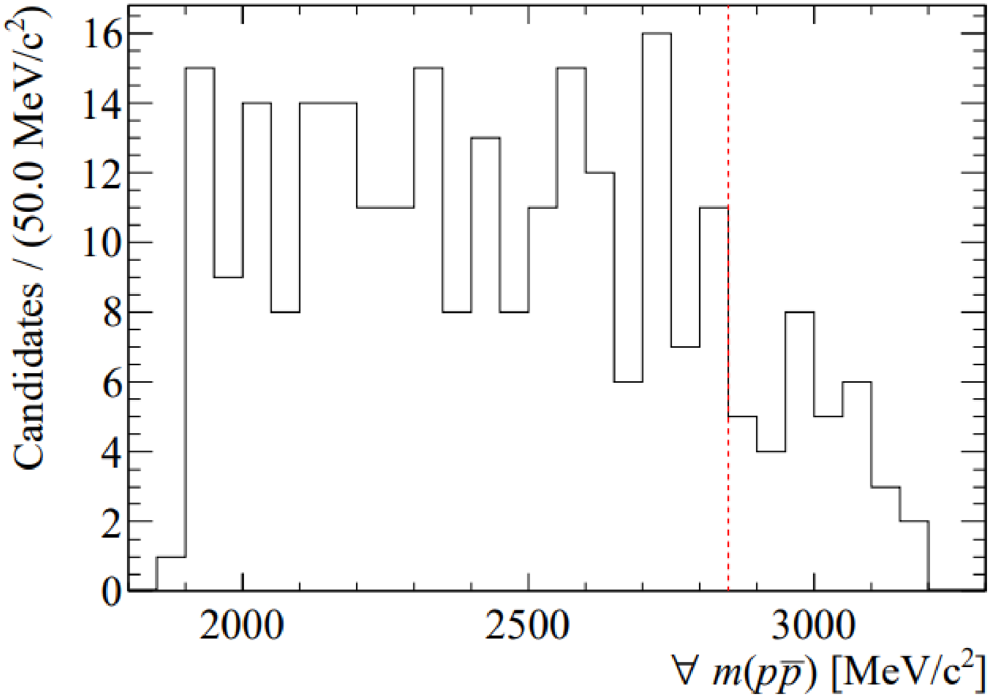
- **Opportunities with Run 3&4 (50 $\mathbf{fb^{-1}}$)**
  - Higher precision in rare decay measurements
  - Wider scope for exploitation

LHCb-China team is currently focusing on these rare decay measurements

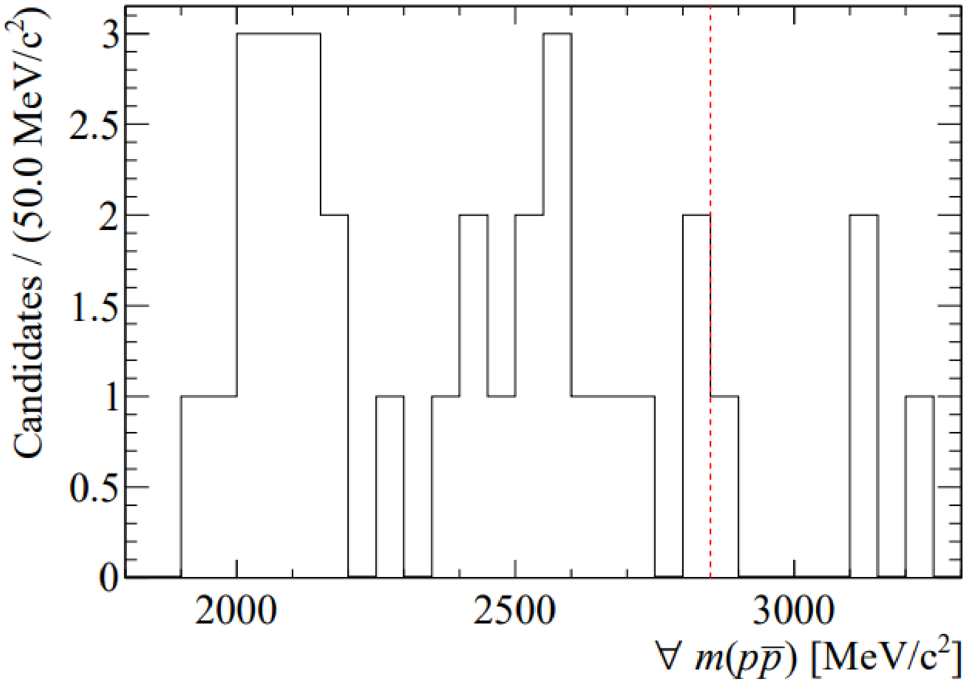
Backup

Mass distributions of $p\bar{p}$

Tight selection



Very Tight selection



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