



Rare B -meson baryonic decays at LHCb

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Outline

➤ *B*-meson charmless pure baryonic decays

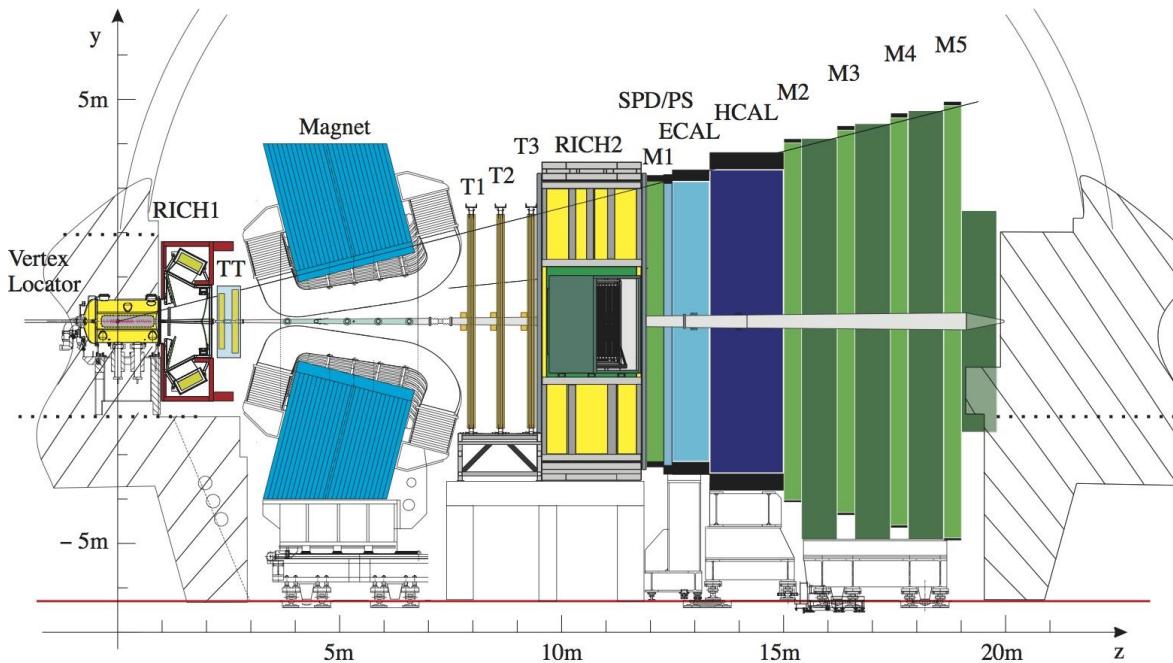
$$\square B_s^0 \rightarrow p\bar{p}, B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$$

➤ Baryon- and lepton-number violating decays

$$\square B_{(s)}^0 \rightarrow p\mu^-$$

LHCb experiment

LHCb collaboration: 21 counties, 96 institutes, 1600 members

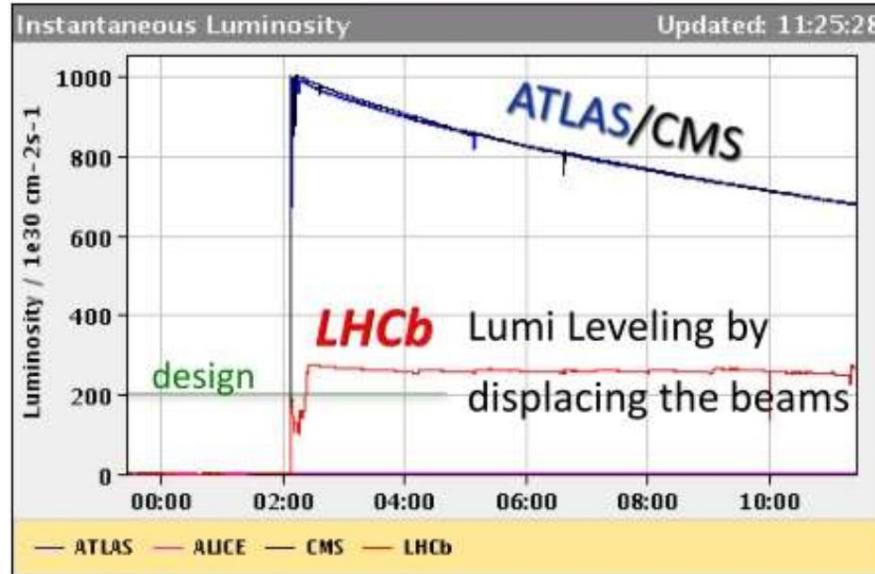


中国单位(9个):
清华大学
华中师范大学
中国科学院大学
武汉大学
高能物理研究所
华南师范大学
湖南大学
北京大学
兰州大学

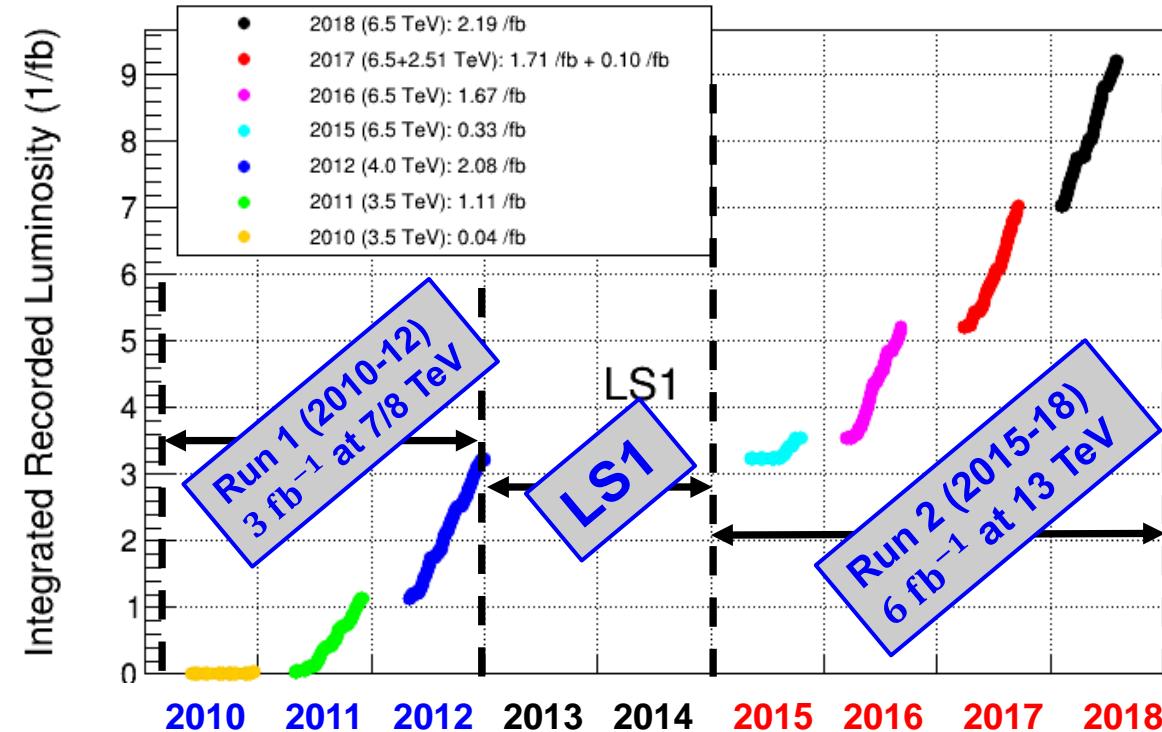
- Understand matter-antimatter imbalance (CP violation)
- Search for new physics (Rare decays)
- Explore and understand QCD (Hadron properties, exotic hadrons)

LHCb data samples

Luminosity levelling $L \sim 3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$



Run-I: 3 fb^{-1} , Run-II: 6 fb^{-1}



Large $b\bar{b}$ and $c\bar{c}$ production cross sections:

$$\sigma(b\bar{b}X) \sim 0.5\% \times \sigma_{pp}^{\text{inelas}}, \quad \sigma(c\bar{c}X) \sim 10\% \times \sigma_{pp}^{\text{inelas}}$$

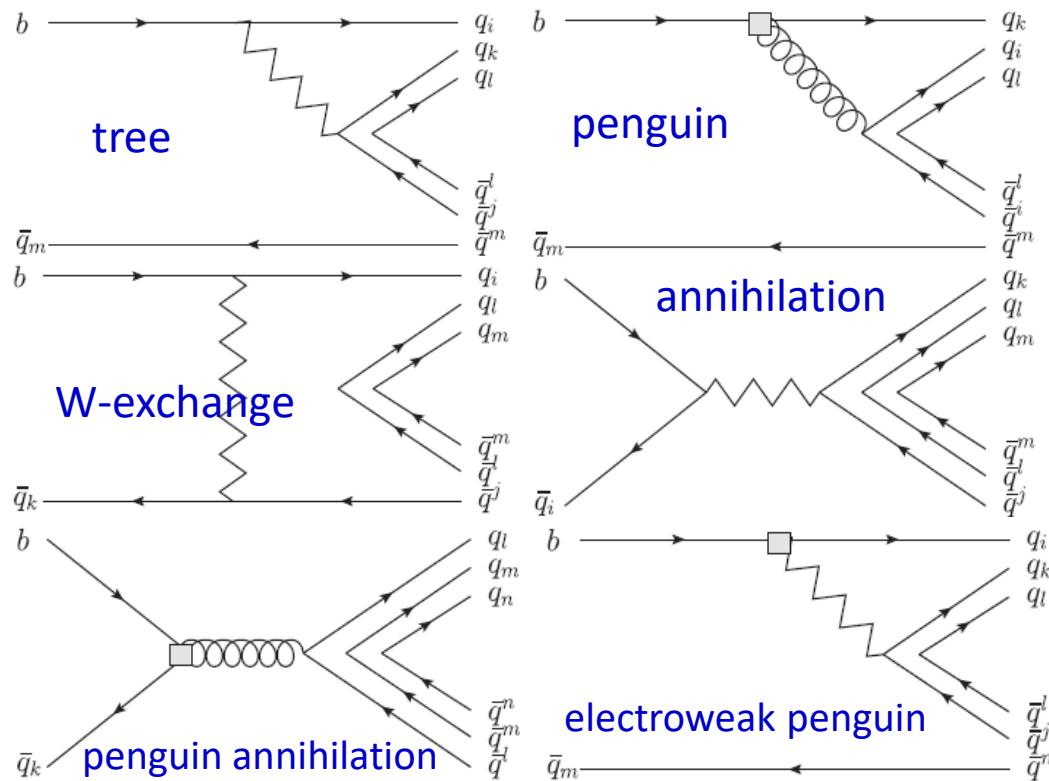
***B*-meson charmless pure baryonic decays**

$$B_s^0 \rightarrow p\bar{p}, B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$$

Two-body charmless 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)

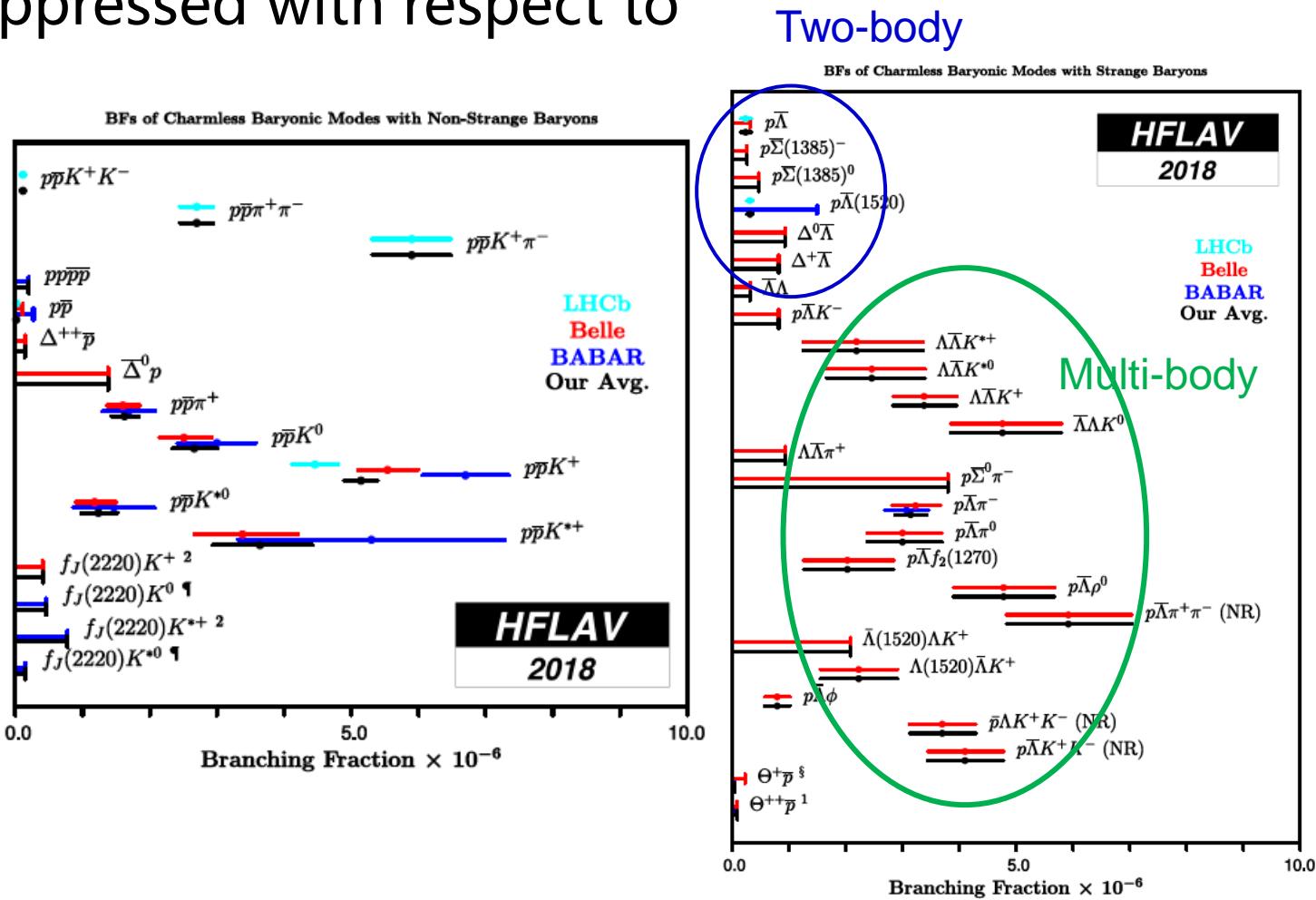


- $B^0 \rightarrow p\bar{p}$ and $B^+ \rightarrow p\bar{\Lambda}$ as inputs to predict other $B \rightarrow \mathcal{B}_1 \mathcal{B}_2$
- Baryonic B decays are also interesting in the study of CP violation
- Pure penguin modes are expected to be sensitive to new physics contributions

The charmless baryonic decays of B

- 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

Patterns in charmless decays of B

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

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

[\[arXiv:2206.06673\]](#)

PRL 119, 232001

[\[PRD 98 \(2018\) 7, 071102\]](#)

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

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

[\[arXiv:2206.06673\]](#)

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

Search for $B_{(s)}^0 \rightarrow p\bar{p}$

- First observation of $B^0 \rightarrow p\bar{p}$ with Run 1 data

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

$$\text{➤ } \mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 1.5 \times 10^{-8} \text{ @90% CL}$$

- Some predictions expect $B_s^0 \rightarrow p\bar{p}$ to be further suppressed (negligible penguin-level gluon-exchange and annihilation contributions)

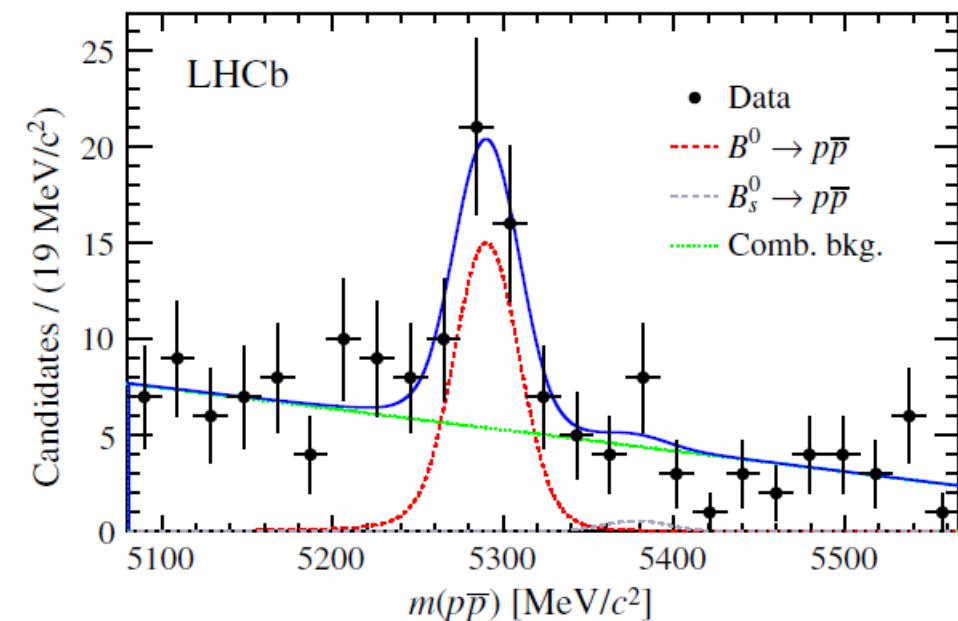
[PRD 89, 056003 (2014), PRD 95, 096004 (2017)]

- Other predictions expect $B_s^0 \rightarrow p\bar{p}$ rates similar to that of $B^0 \rightarrow p\bar{p}$ (penguin-level gluon-exchange and annihilation contributions can't be neglected)

[JHEP2004, 035 (2020)]

- Updated search for $B_s^0 \rightarrow p\bar{p}$ decay is needed

PRL 119, 232001 (2017)



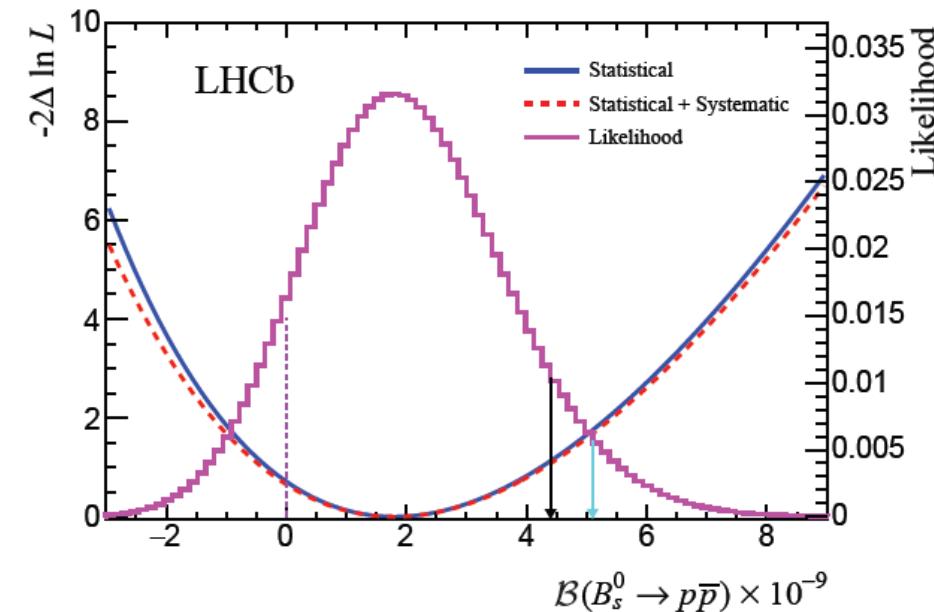
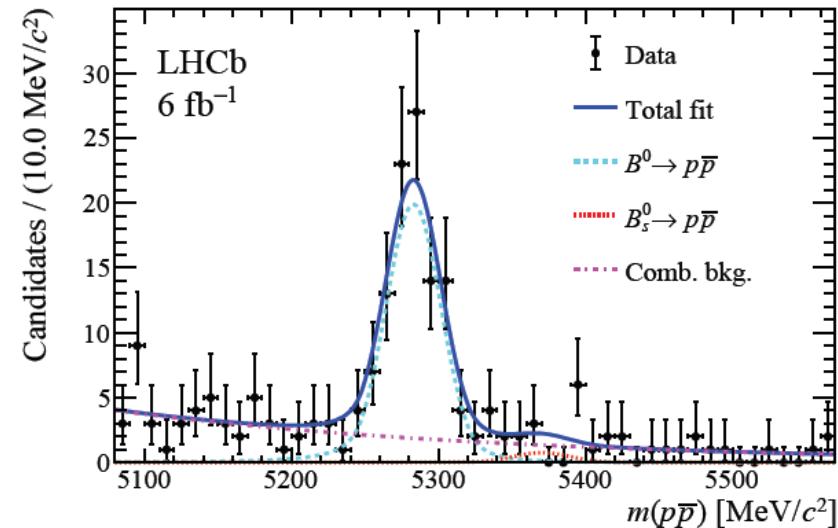
Search for $B_s^0 \rightarrow p\bar{p}$ with Run 2 data

(by LHCb-China members)

- $N(B^0 \rightarrow p\bar{p}) = 98 \pm 11(16.2\sigma)$
- $N(B_s^0 \rightarrow p\bar{p}) = 4 \pm 5(0.9\sigma)$
- $B^0 \rightarrow K^+ \pi^-$ and $B_s^0 \rightarrow K^+ \pi^-$ as normalization channel
- $\mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8}$
Consistent with Run 1
- Upper Limit on $\mathcal{B}(B_s^0 \rightarrow p\bar{p})$ improved by factor 3
 - $\mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 15 \times 10^{-9}$ @ 90% CL (RUN-I)

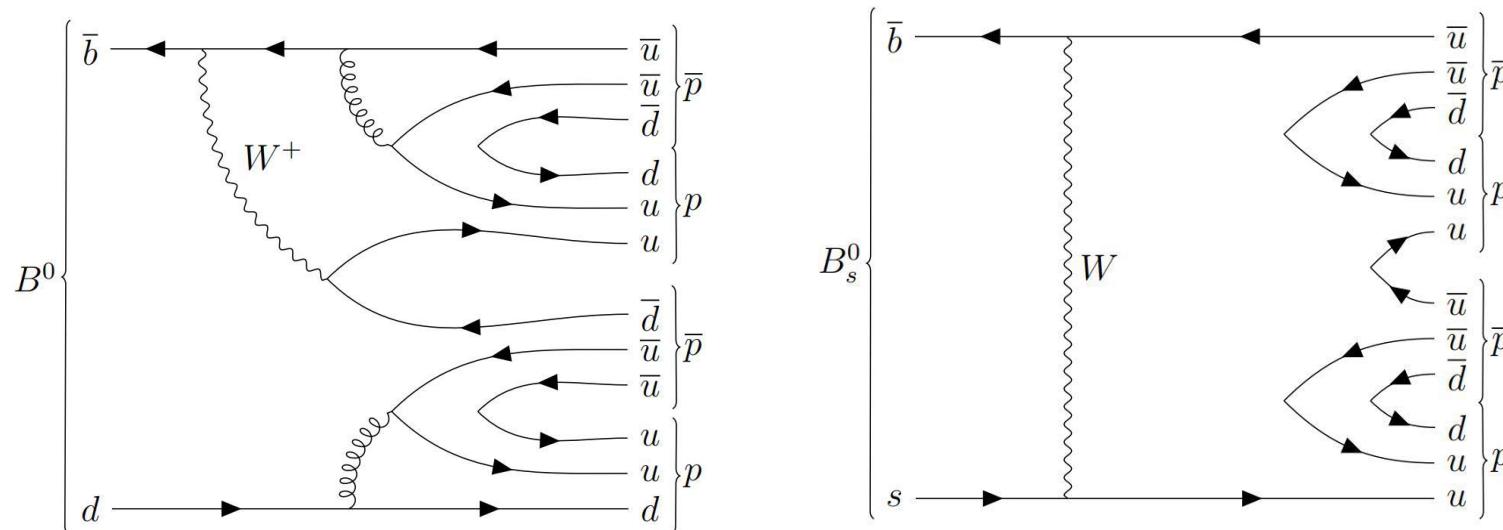

 - $\mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 4.5(5.1) \times 10^{-9}$ @ 90%(95%) CL (New)

arXiv:2206.06673, accepted by PRD



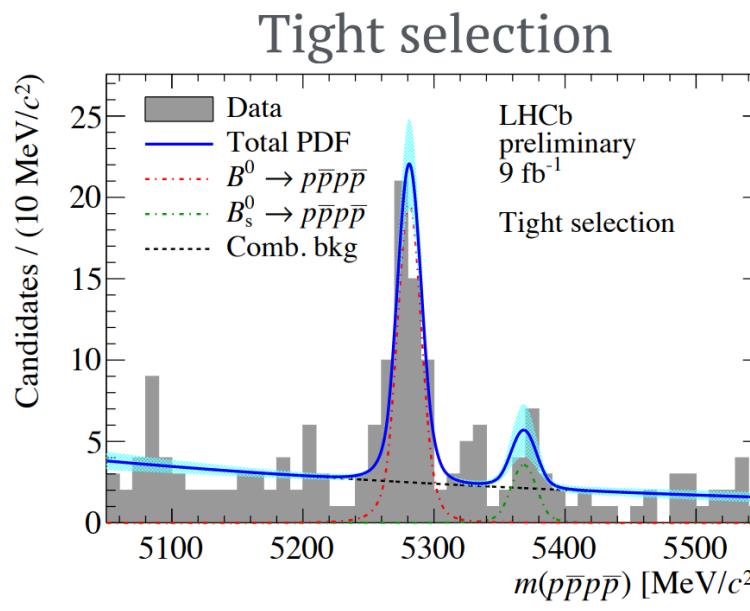
Search for $B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$

- B meson decay to 4 baryons was never observed
 - $B^0 \rightarrow p\bar{p}p\bar{p}$ (2.9σ) [Phys. Rev. D 98, 071102 \(2018\)](#)
- $B_s \rightarrow p\bar{p}p\bar{p}$ (**no study reported**) is expected to be further suppressed with respect to B^0
 - Hadronisation fraction $f_s/f_d \sim 25\%$, and $\left| \frac{V_{us}}{V_{ud}} \right|^2 \sim 5\%$



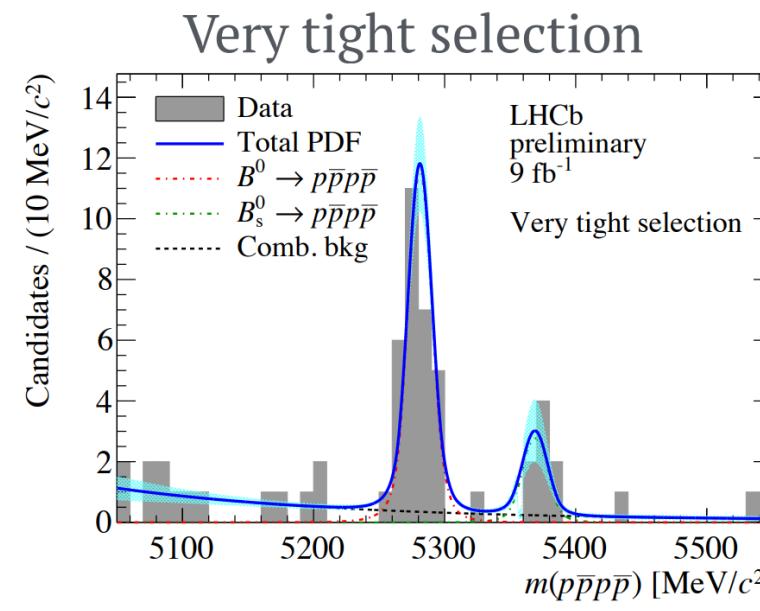
Search for $B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$ with Run 1&2 data

(by LHCb-China members)



$$N(B^0 \rightarrow p\bar{p}p\bar{p}) = 48 \pm 8$$

Significance: $> 9\sigma$



$$N(B_s^0 \rightarrow p\bar{p}p\bar{p}) = 7 \pm 3$$

Significance: 4σ

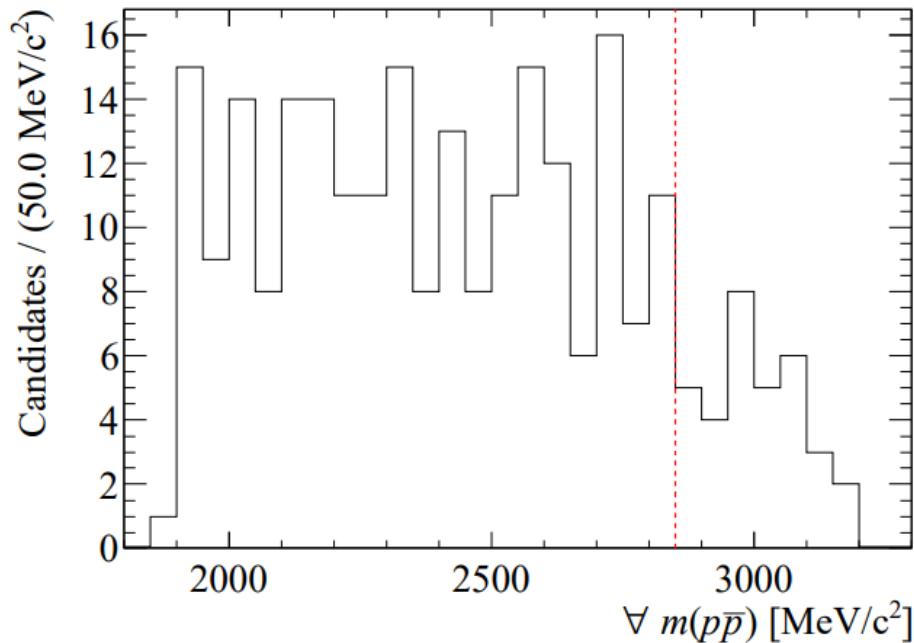
- $B^0 \rightarrow J/\psi(\rightarrow p\bar{p})K^{*0}(\rightarrow K^+\pi^-)$ and $B_s^0 \rightarrow J/\psi(\rightarrow p\bar{p})\phi(\rightarrow K^+K^-)$ as normalization channel
- $\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$
- $\mathcal{B}(B_s^0 \rightarrow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

[arXiv:2211.08847](https://arxiv.org/abs/2211.08847)

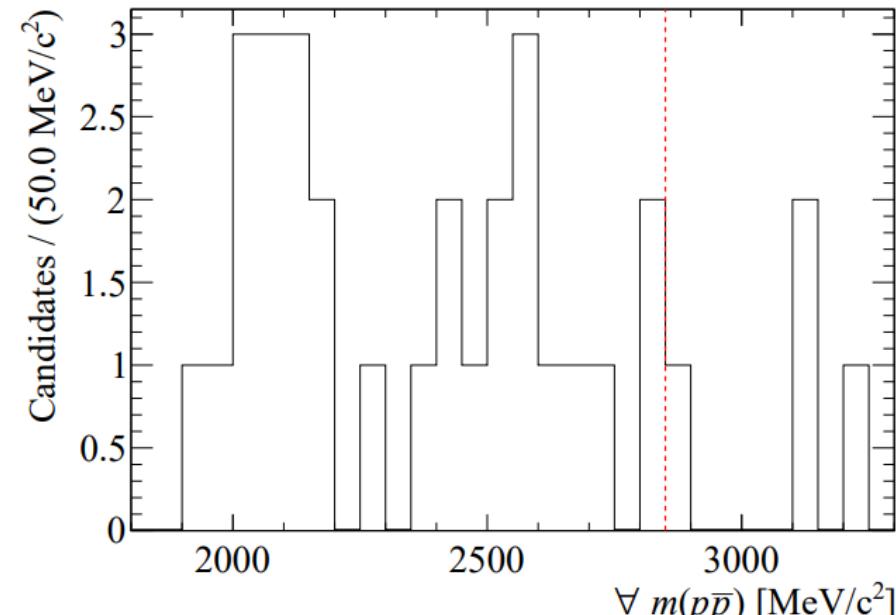
Accepted by PRL

Mass distributions of $p\bar{p}$

Tight selection



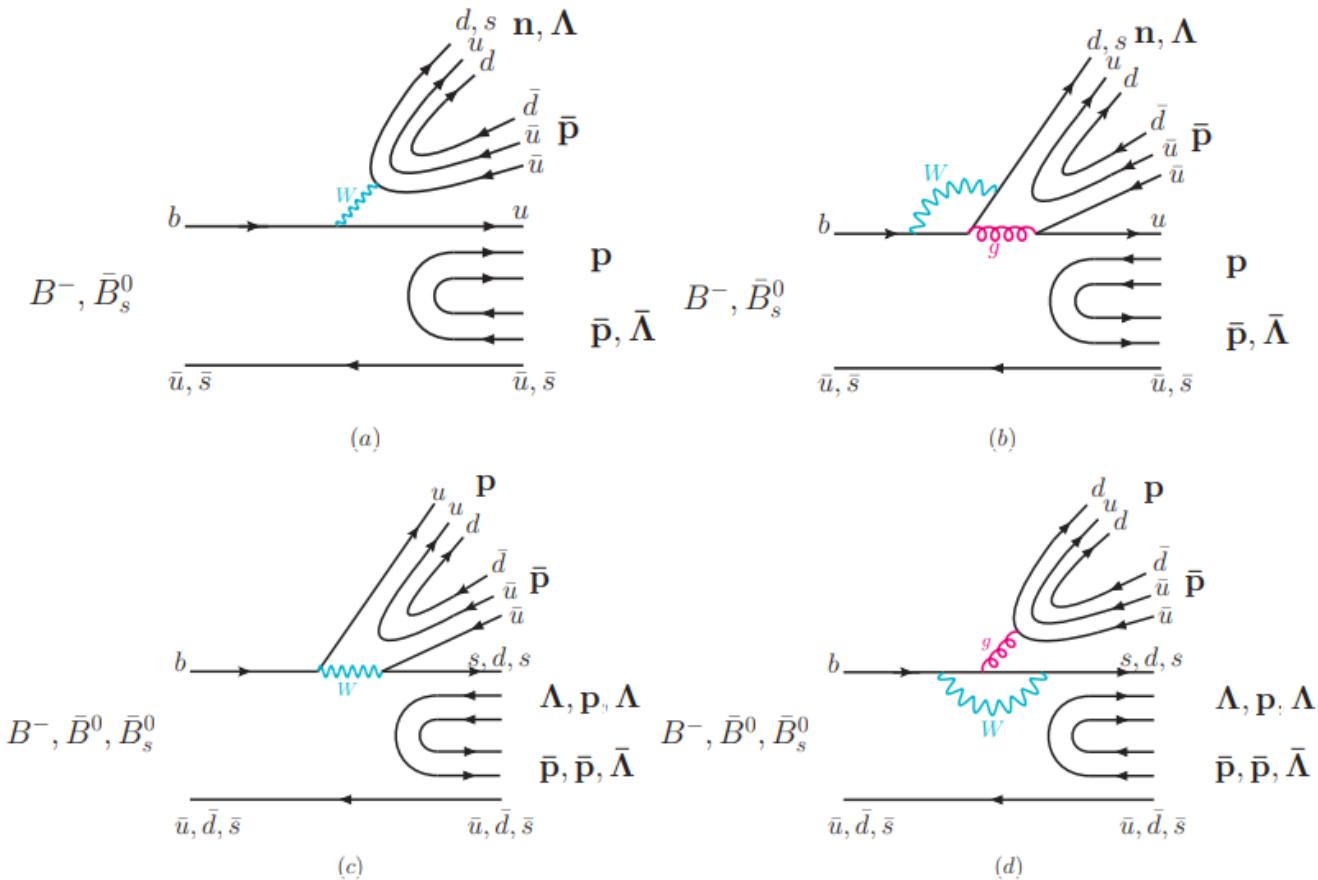
Very Tight selection



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

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

Some theoretical researches



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

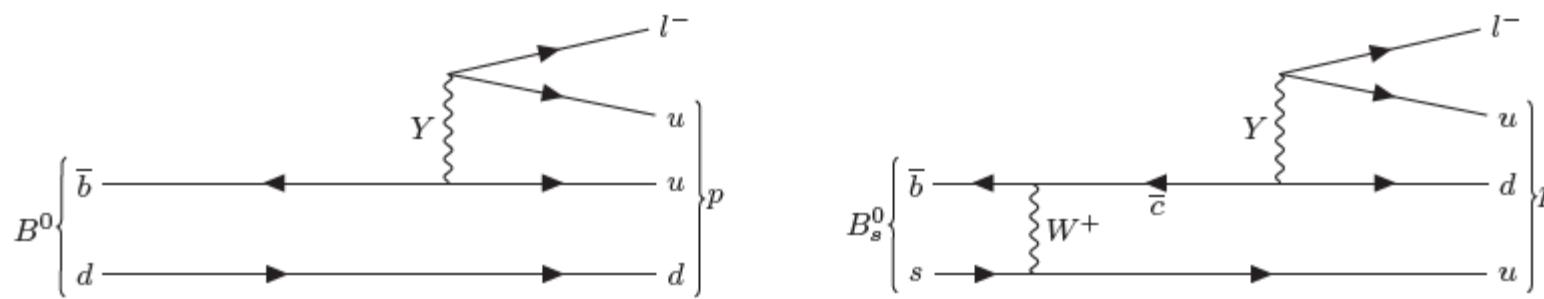
arXiv:2212.01954

Baryon- and lepton-number violating decays

$$B_{(s)}^0 \rightarrow p\mu^-$$

Search for $B_{(s)}^0 \rightarrow p\mu^-$

- **Fact:** Matter anti-matter asymmetry in the Universe
- **Solution:** baryon number must be violated
- **SM prediction:** $\mathcal{B}(\bar{b} \rightarrow uul^-) < 2.4 \times 10^{-27}$ Phys. Rev. D72 (2005) 095001



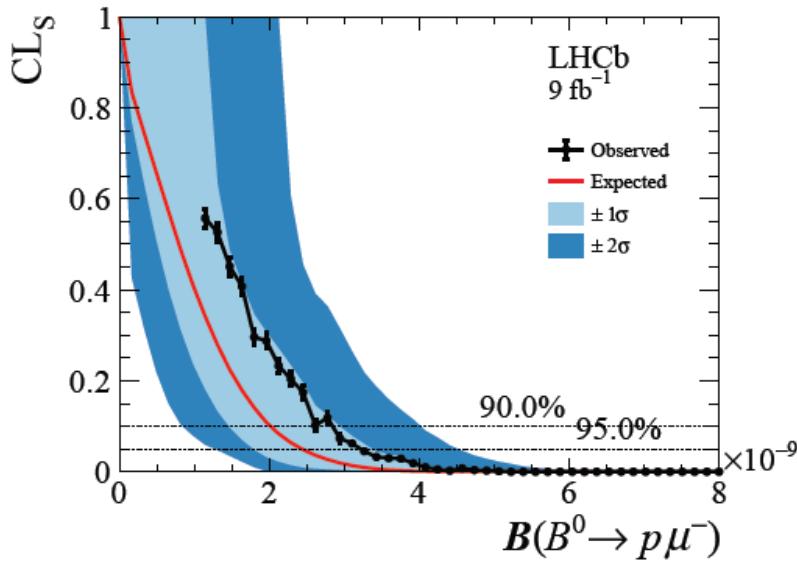
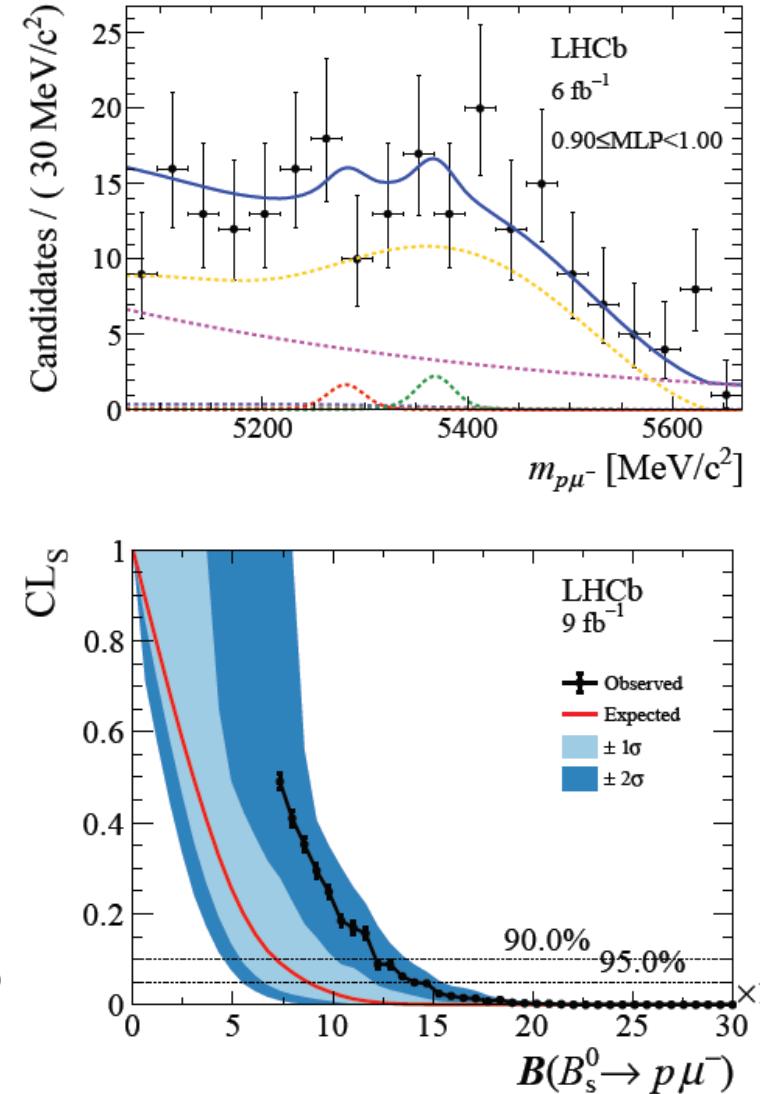
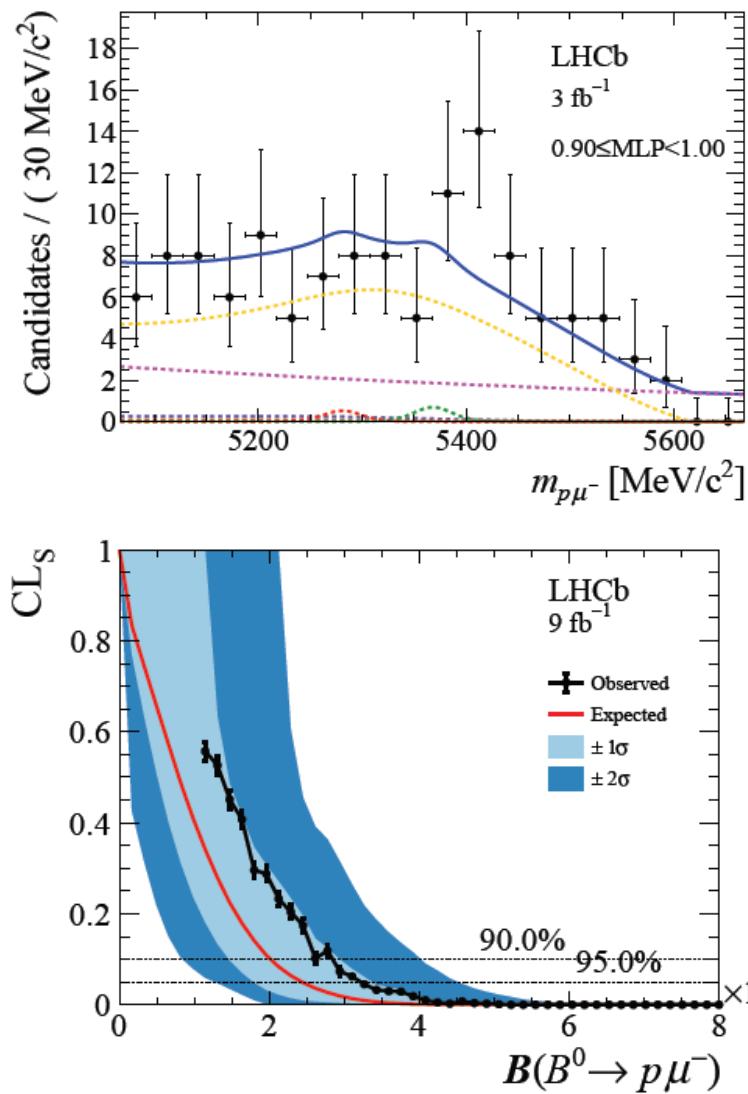
Feynman diagrams of $B^0 \rightarrow pl^-$ decay mediated by a hypothetical Y boson.

arXiv:2210.10412

Search for $B_{(s)}^0 \rightarrow p\mu^-$ with Run 1&2 data

(by LHCb-China members)

- $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow J/\psi(\rightarrow \mu^+\mu^-)K^+$ as normalization channel
- No significant signals observed
- $\mathcal{B}(B^0 \rightarrow p\mu^-) < 2.6(3.1) \times 10^{-9}$ @ 90%(95%) CL
- $\mathcal{B}(B_s^0 \rightarrow p\mu^-) < 12.1(14.0) \times 10^{-9}$ @ 90%(95%) CL
- First upper limits



Summary and prospects

➤ LHCb provides ideal environment for searching for rare baryonic decays of B mesons

- B meson charmless baryonic decay: $B_s^0 \rightarrow p\bar{p}$, $B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$
- More results are on the way: $B^- \rightarrow \Lambda\bar{p}p\bar{p}$, $B_{(s)}^0 \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$, $B_{(s)}^0 \rightarrow \Lambda_c^+\bar{\Xi}_c^-$, $B_{(s)}^0 \rightarrow \Xi_c\bar{\Xi}_c$
- Baryon- and lepton-number violating: $B_{(s)}^0 \rightarrow p\mu^-$

➤ Opportunities with Run 3&4 (50 fb^{-1})

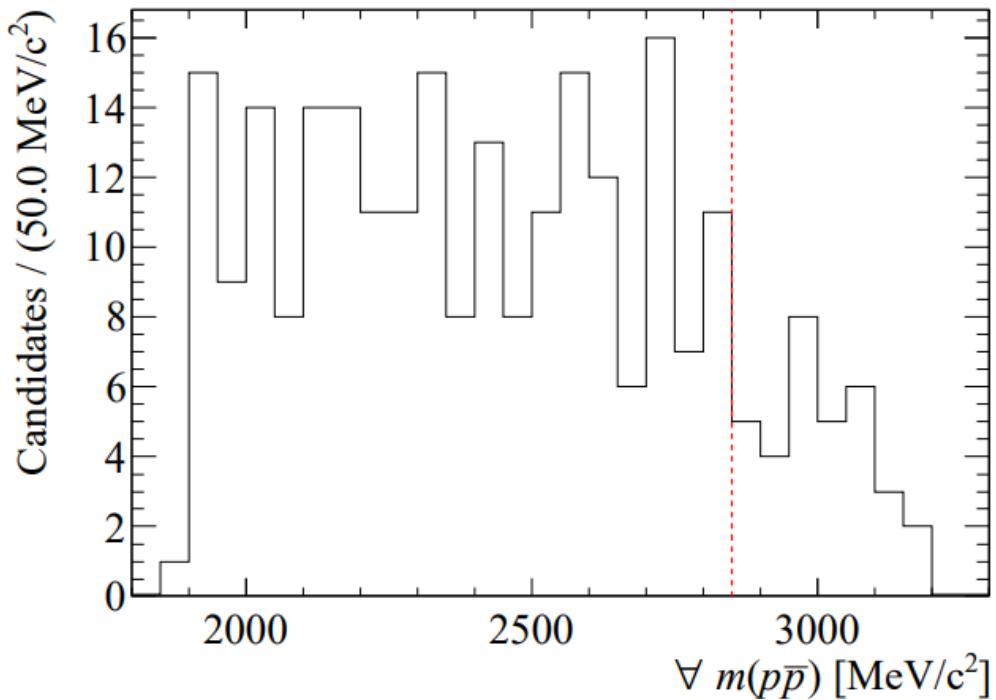
- Higher precision in rare decay measurements
- Wider scope for exploitation

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

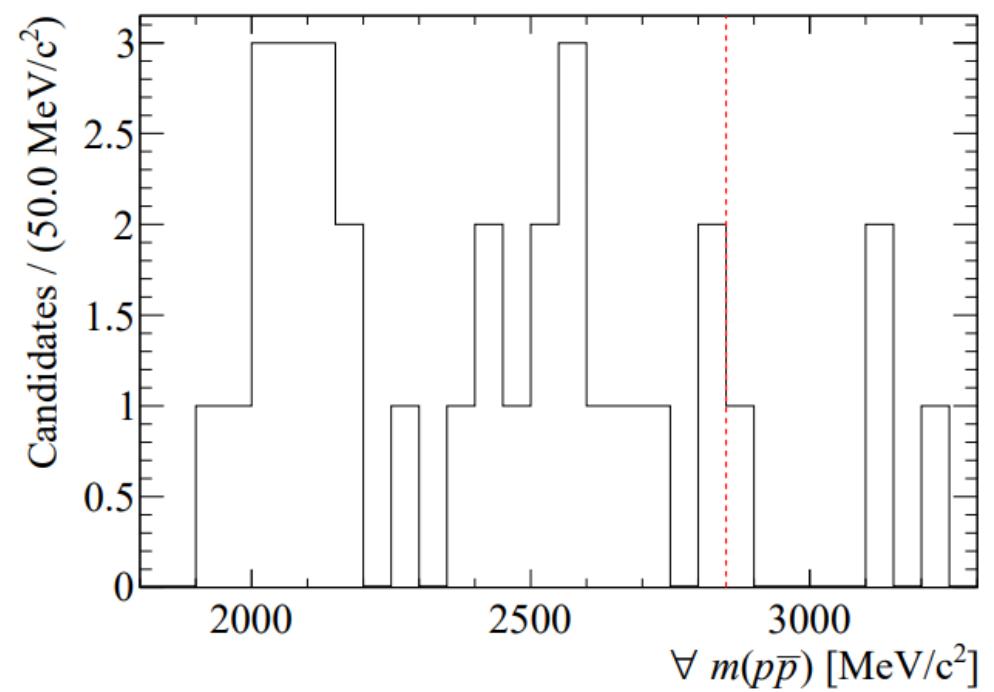
Backup

Mass distributions of $p\bar{p}$

Tight selection



Very Tight selection



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