Recent searches for new physics and rare decays at LHCb

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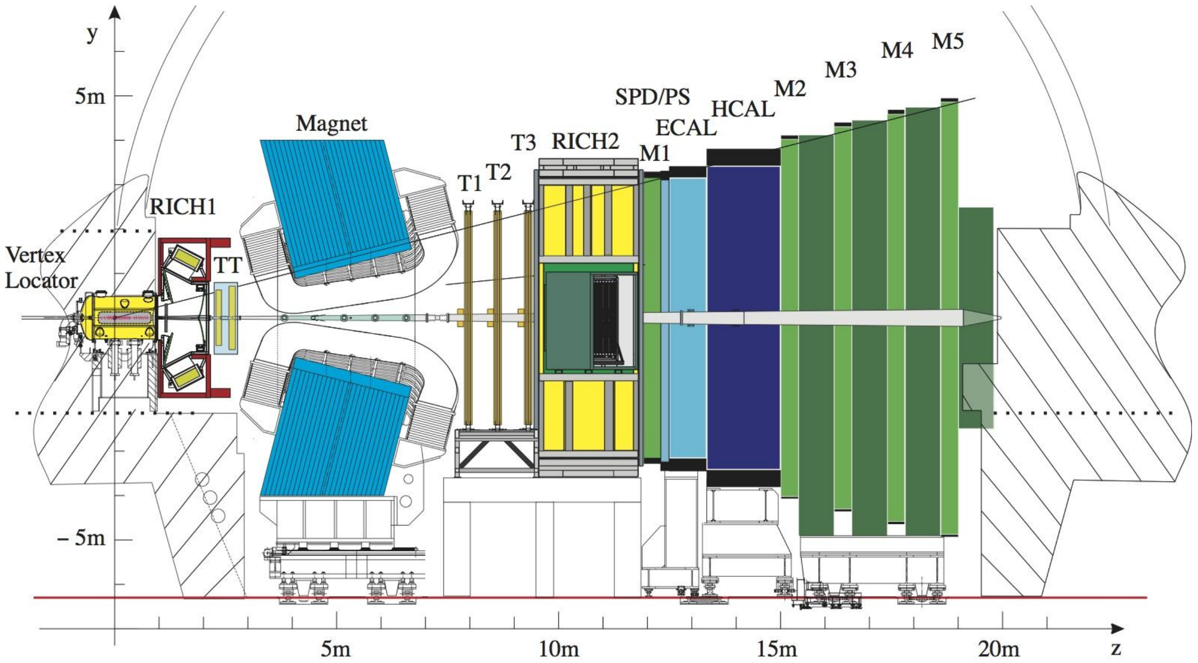
Outline

- Introduction
- Rare decays
  - FCNC
  - Pure charmless baryonic decays
- Prospects and summary

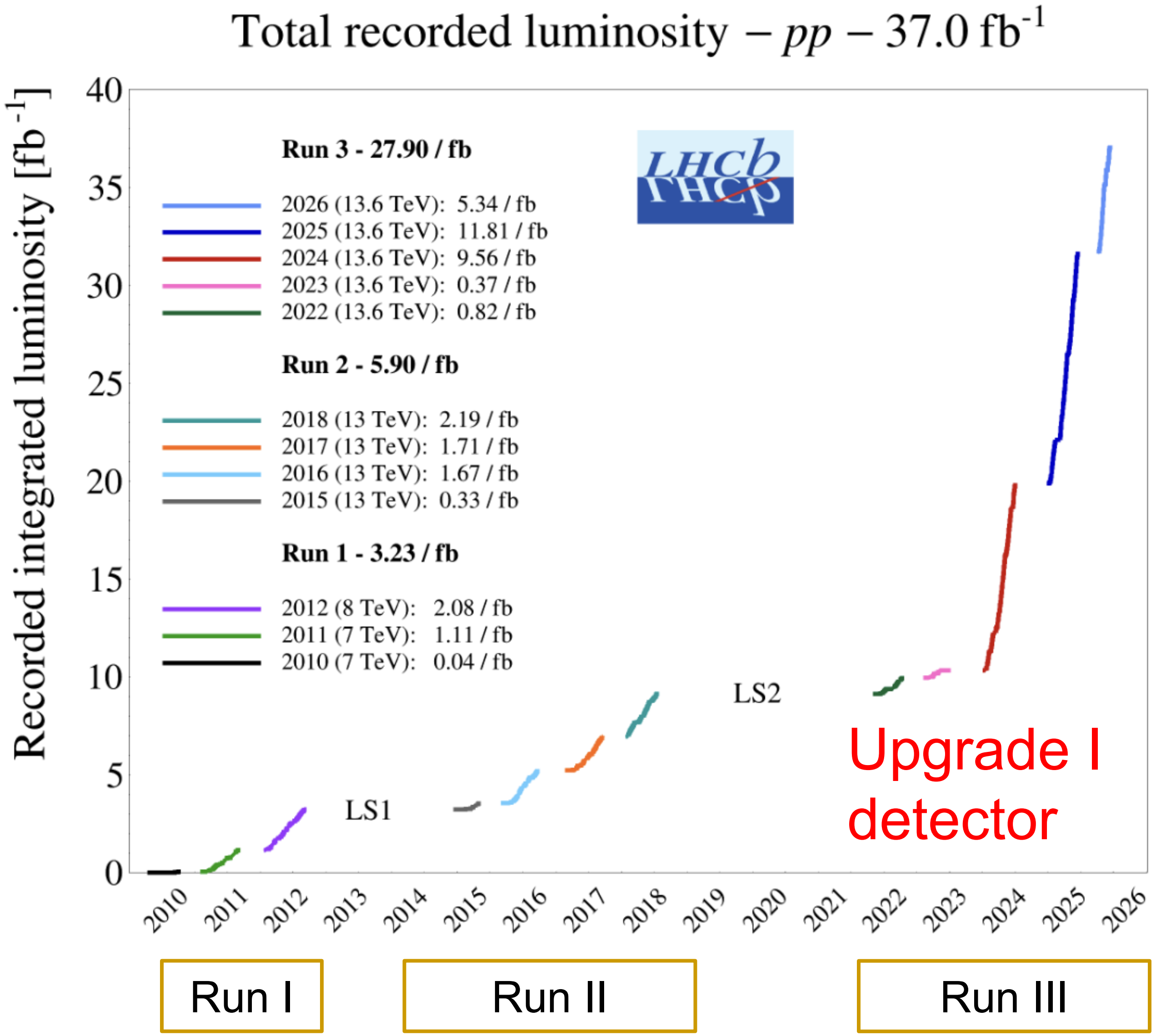
LHCb experiment

LHCb collaboration： 21 counties, 96 institutes, 1812 members



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

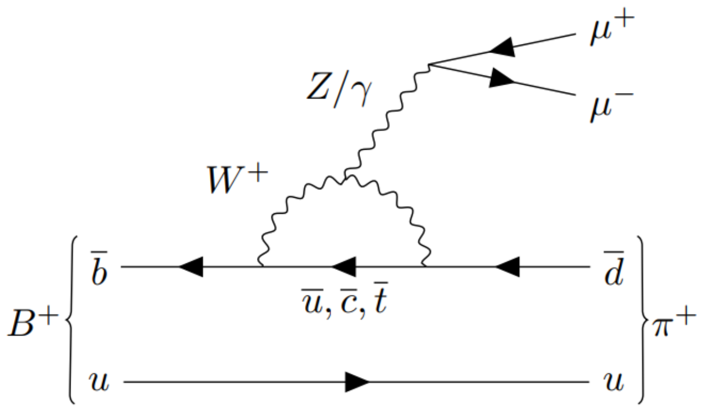
LHCb data



- A new LHCb detector for Run 3 operates at $\times 5$ higher instantaneous luminosity
- Similar performance, while efficiency for hadron final states increased by a factor of 2

FCNC $b \to s/d\gamma(l^+l^-)$ decays

- $B^0 \to K^{*0}\mu^+\mu^-$, (all q^2)
- $B^+ \to \pi^+\mu^+\mu^-,\ B^+ \to \pi^+e^+e^-$
- $B^+ \to p\bar{\Lambda}\mu^+\mu^-$



$b \to s l^+ l^-$ decays

- $b \to s l^+ l^-$ **decays described by effective Hamiltonian**

$$H = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i\, O_i + \frac{K}{\Lambda_{NP}^2} O_j^{(6)}$$

New physics can affect Wilson coefficients C_i or add new operators O_j

Wilson Coefficients: C_i

→ Perturbative, short distance physics

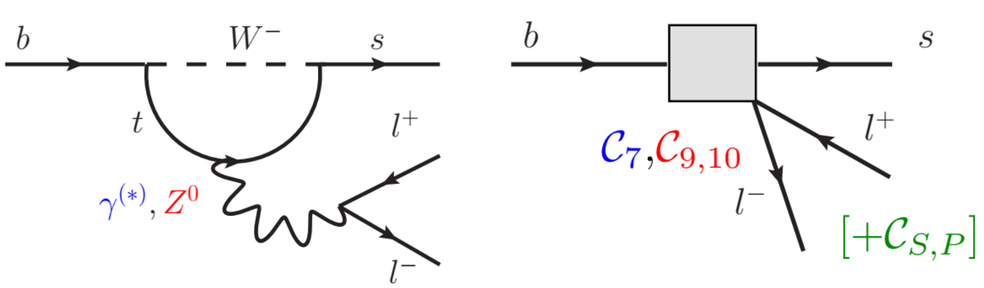
→ Describes heavy SM+NP effects

Operators: $\mathcal{O}_i$

→ Non-perturbative, long distance physics

→ Strong interactions, difficult to calculate

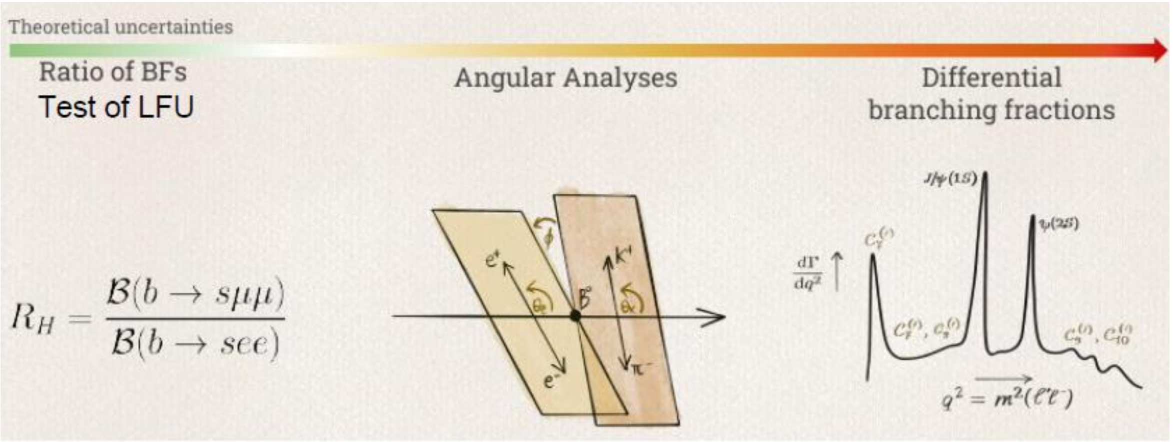
- **Sensitivity to Wilson coefficients**



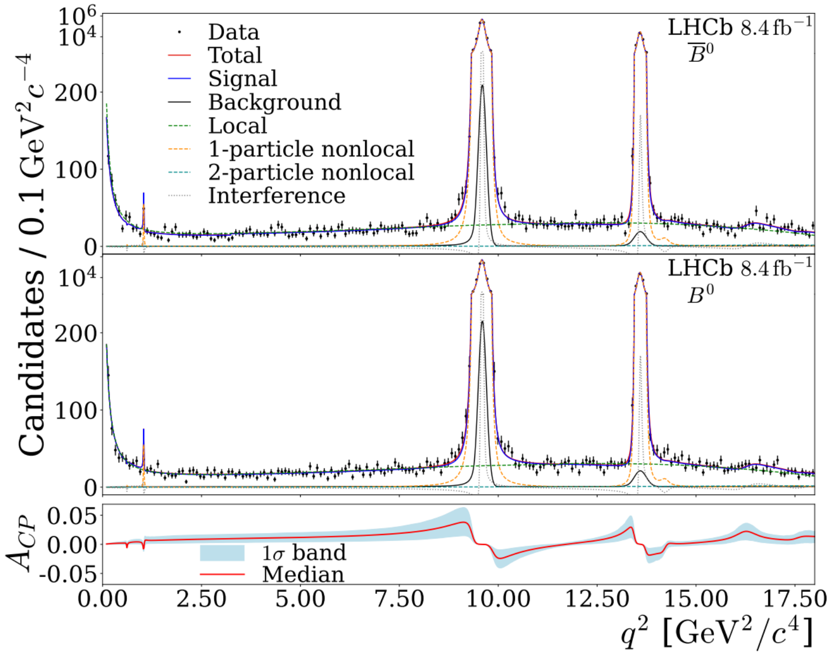
- $B^0_{(s)} \to l^+ l^-$
  $[\mathcal{C}_{10}, \mathcal{C}_S, \mathcal{C}_P]$
- $b \to s l^+ l^-$
  $[\mathcal{C}_7, \mathcal{C}_9, \mathcal{C}_{10}]$

7: photon penguin; 9,10: EW penguin; S,P: (pseudo-) scalar penguin

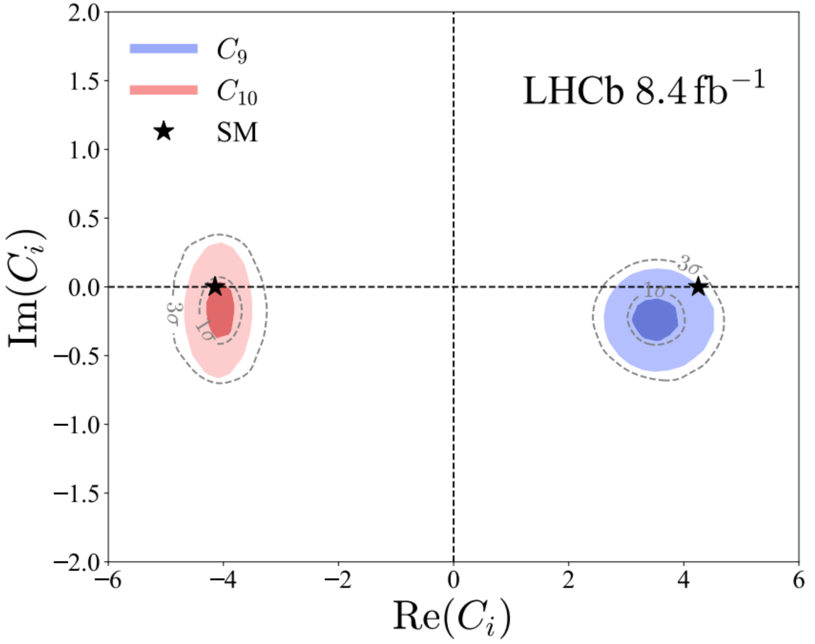
- **Theoretically clean probes of NP**
  - Pure leptonic decays
  - Ratio between $e/\mu/\tau$
  - Special angular observables
  - Differential BF



CPV of $B^0 \to K^{*0}\mu^+\mu^-$



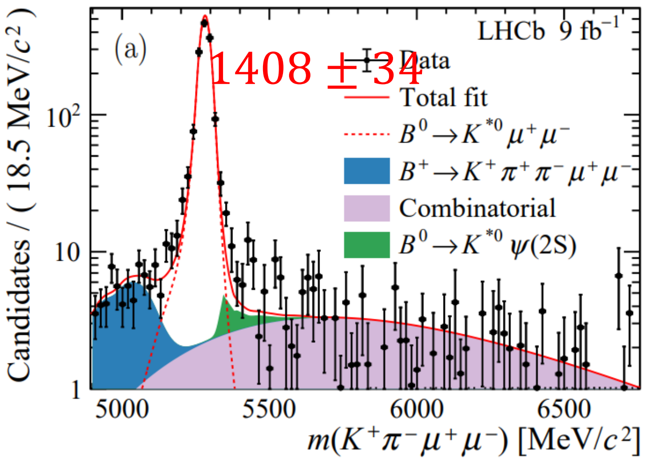
arXiv:2605.07582v1

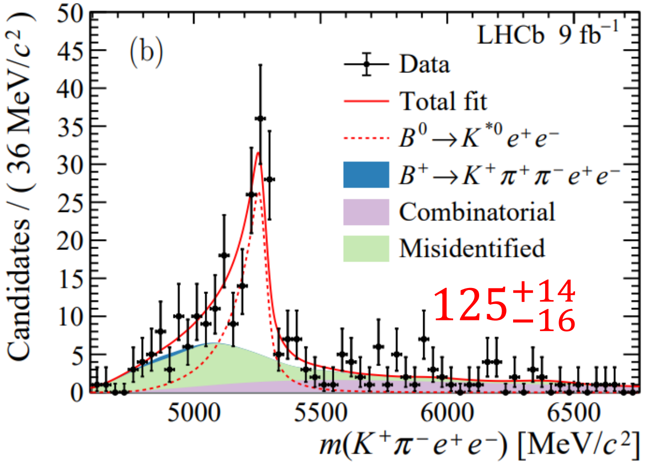


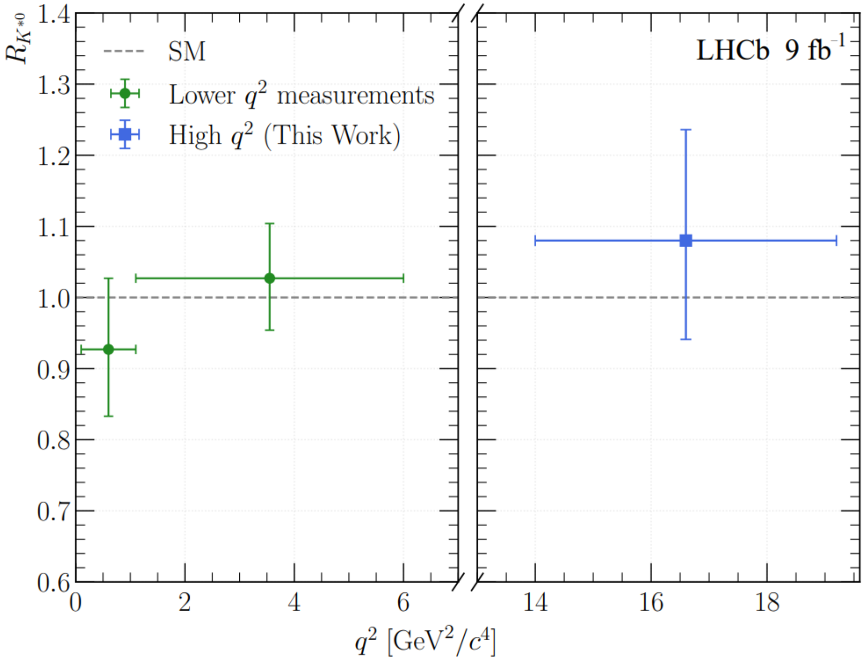
Wilson coefficient results		
$\lVert\mathcal{C}_9\rVert$	3.50 ± 0.30	± 0.15
$\lVert\mathcal{C}_{10}\rVert$	4.04 ± 0.18	± 0.15
$\delta\phi_{\mathcal{C}_9}$	-0.067 ± 0.032	± 0.011
$\delta\phi_{\mathcal{C}_{10}}$	0.043 ± 0.035	± 0.010
$\mathcal{R}e(\mathcal{C}_9)$	3.50 ± 0.30	± 0.15
$\mathcal{I}m(\mathcal{C}_9)$	-0.23 ± 0.11	± 0.04
$\mathcal{R}e(\mathcal{C}_{10})$	-4.04 ± 0.18	± 0.15
$\mathcal{I}m(\mathcal{C}_{10})$	-0.17 ± 0.14	± 0.04
$\mathcal{R}e(\mathcal{C}'_9)$	0.39 ± 0.46	± 0.21
$\mathcal{R}e(\mathcal{C}'_{10})$	-0.12 ± 0.21	± 0.06

- No CPV
- First direct measurements C_9 and C_{10}
  - 1 σ with SM (the imaginary parts more precisely than real parts)
  - The resolution is improved one order

LFU of $B^0 \to K^{*0} l^+ l^-$ in high-q^2 region





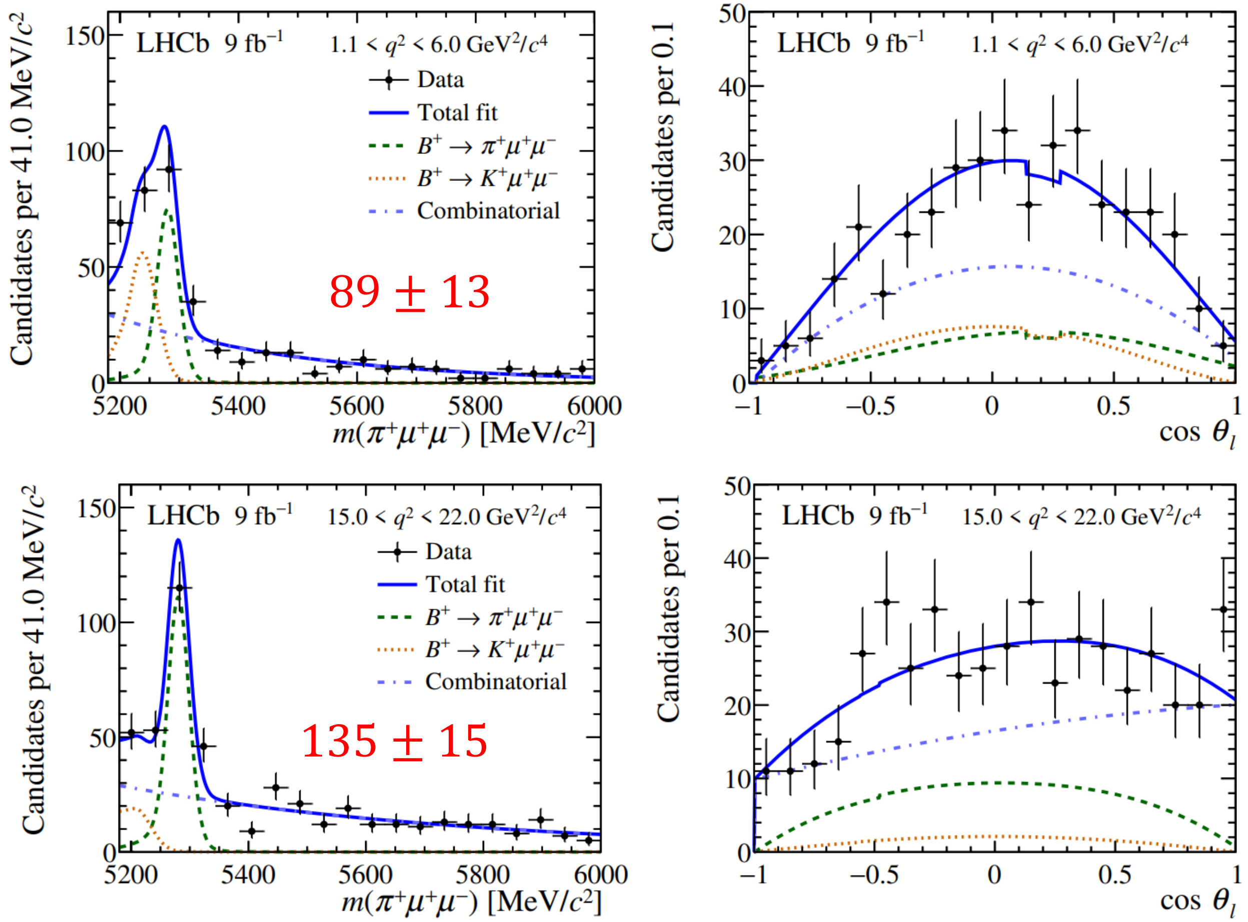


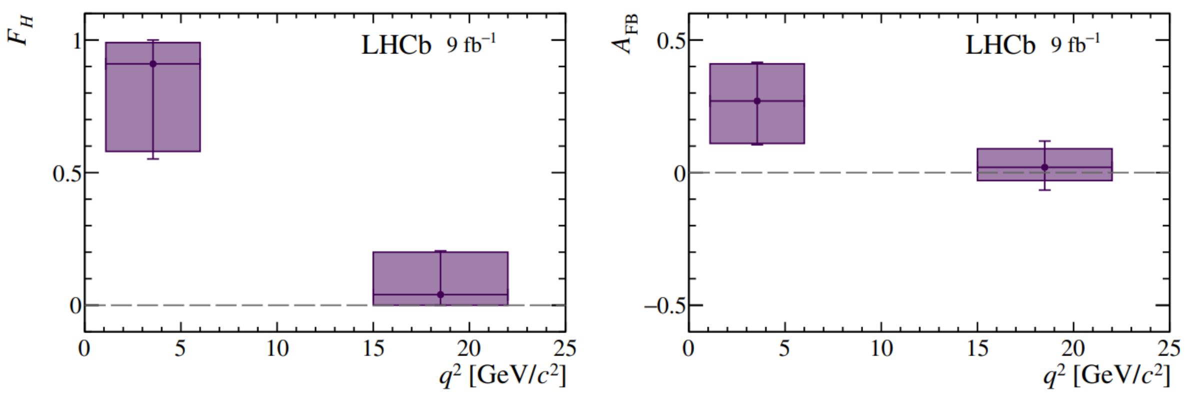
arXiv:2604.08631v1

$$R_{K^{*0}} = 1.08\ ^{+0.14}_{-0.12}\,(\text{stat}) \pm 0.07\,(\text{syst}),$$

- A stringent test of LFU in high-q^2 region
- Consistent with the previous result reported by Belle
- A threefold improvement in precision

Angular analysis of $B^+ \to \pi^+\mu^+\mu^-$



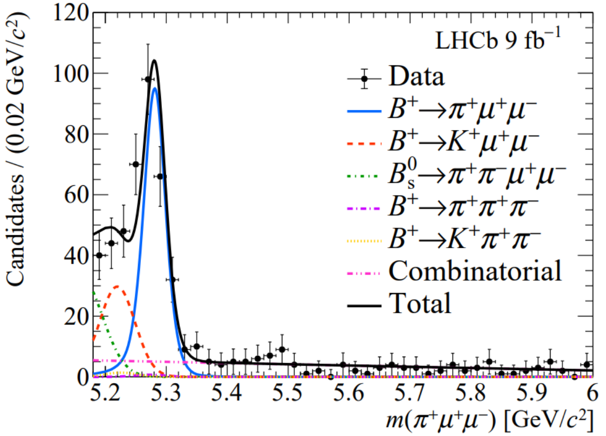


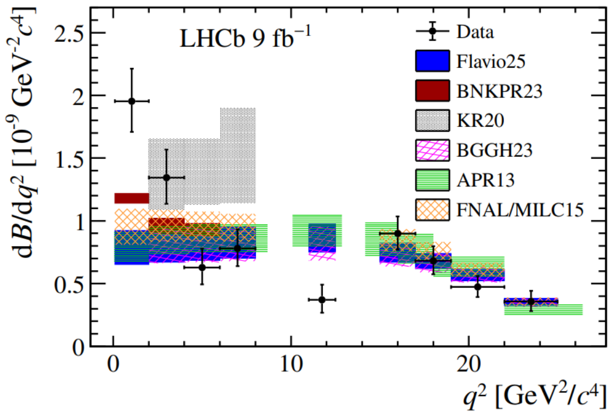
	F_H	F_H interval	$A_{\rm FB}$	$A_{\rm FB}$ interval
$1.1 < q^2 < 6.0\,\text{GeV}^2/c^4$	0.91	[0.60, 0.99]	0.27	[0.11, 0.42]
$15.0 < q^2 < 22.0\,\text{GeV}^2/c^4$	0.04	[0.00, 0.20]	0.02	[−0.02, 0.09]

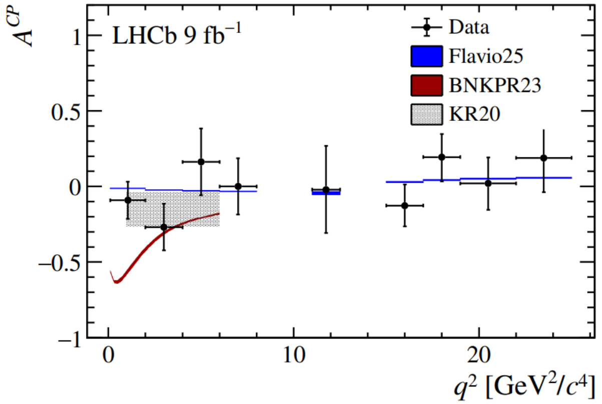
- First measurement of A_{FB} and flat term F_H

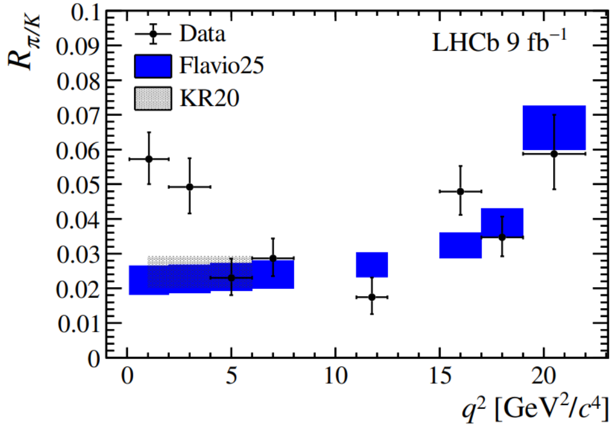
arXiv:2604.21987v1

Differential BF and CPV of $B^+ \to \pi^+\mu^+\mu^-$







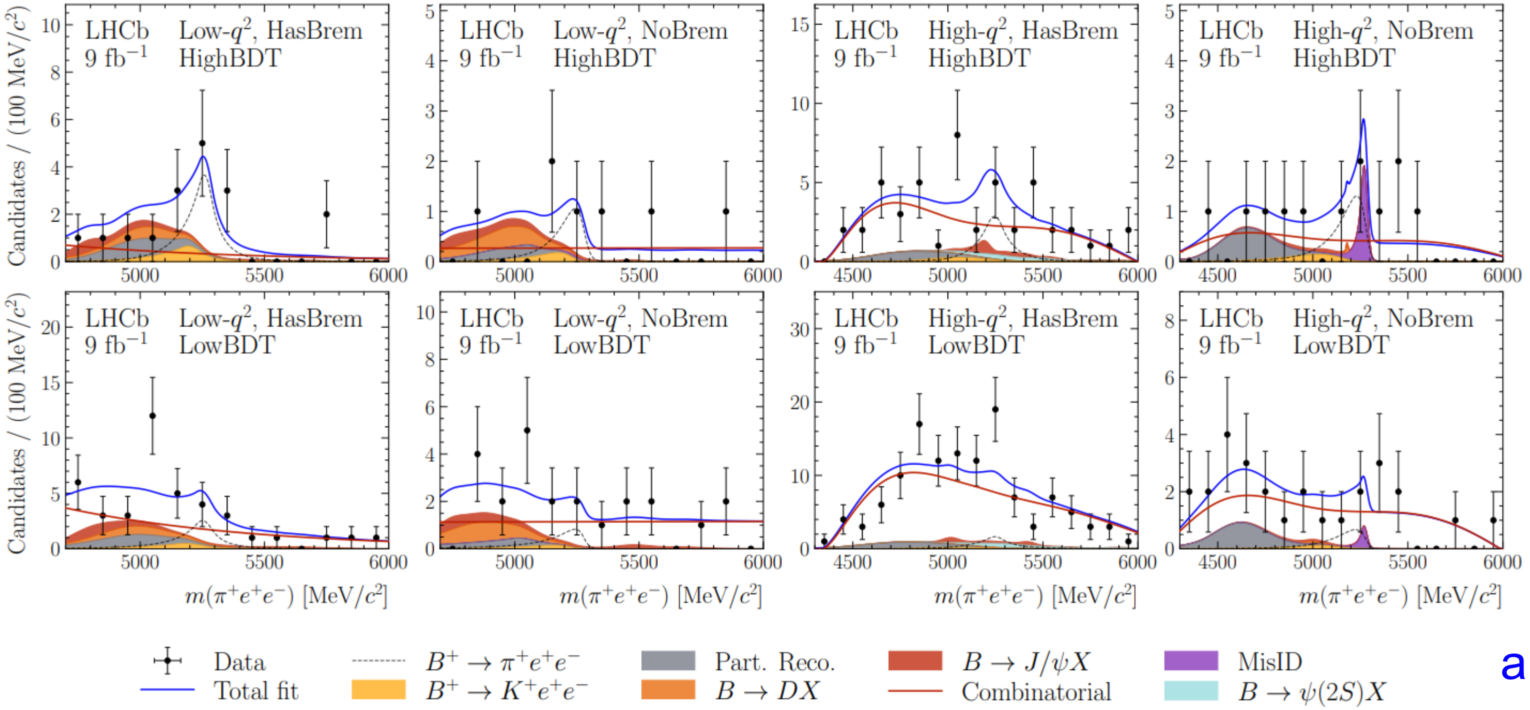


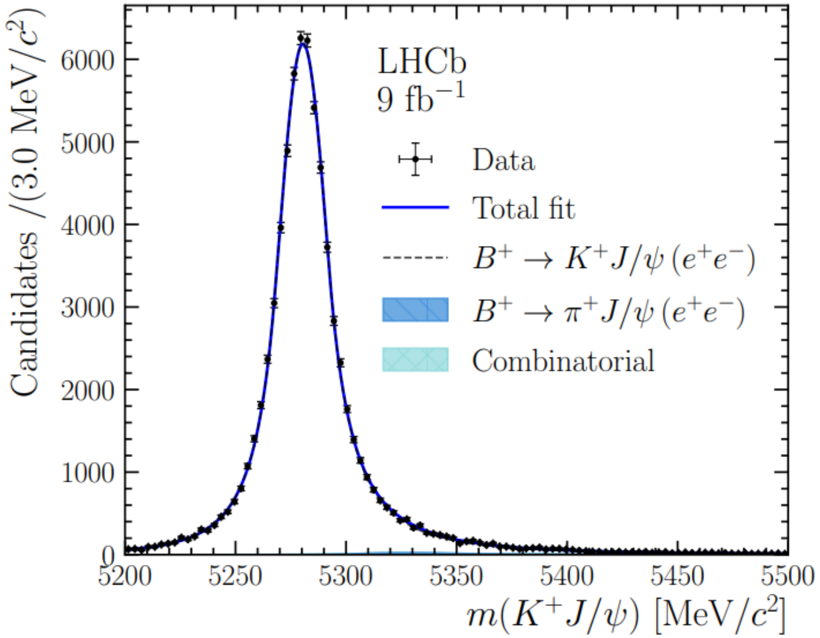
arXiv:2606.23646v1

- First time for differential BF and CPV
- Some localised deviations >3 σ
- Flavio25 do not model the effect of light-quark and charmonia resonances

Prediction	q^2 range [GeV$^2/c^4$]	Compatibility (σ)
BGGH23 [24]	$[2,8]\cup[11,12.5]\cup[15,25]$	1.35
KR20 [21, 22]	$[2,8]$	2.03
FNAL/MILC15 [19]	$[0.1,8]\cup[15,25]$	2.45
BNKPR23 [23]	$[0.1,6]$	3.14
Flavio25 [65]	$[0.1,8]\cup[11,12.5]\cup[15,25]$	3.78

First evidence of $B^+ \to \pi^+ e^+ e^-$





arXiv:2604.26784v2

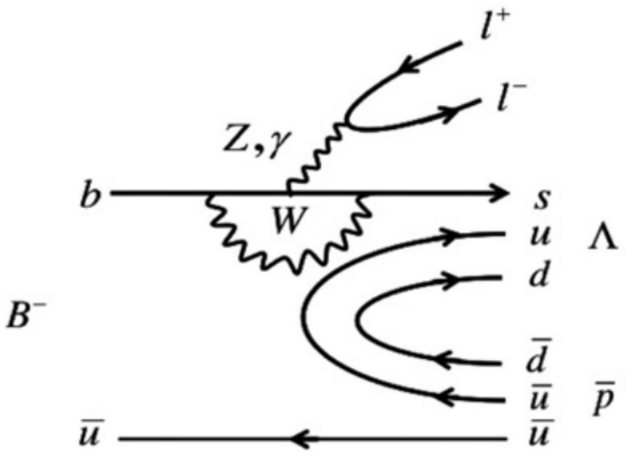
$$\mathcal{B}(B^+ \to \pi^+e^+e^-) = (2.4\,^{+0.9}_{-0.8}\,^{+0.4}_{-0.2}) \times 10^{-8},$$

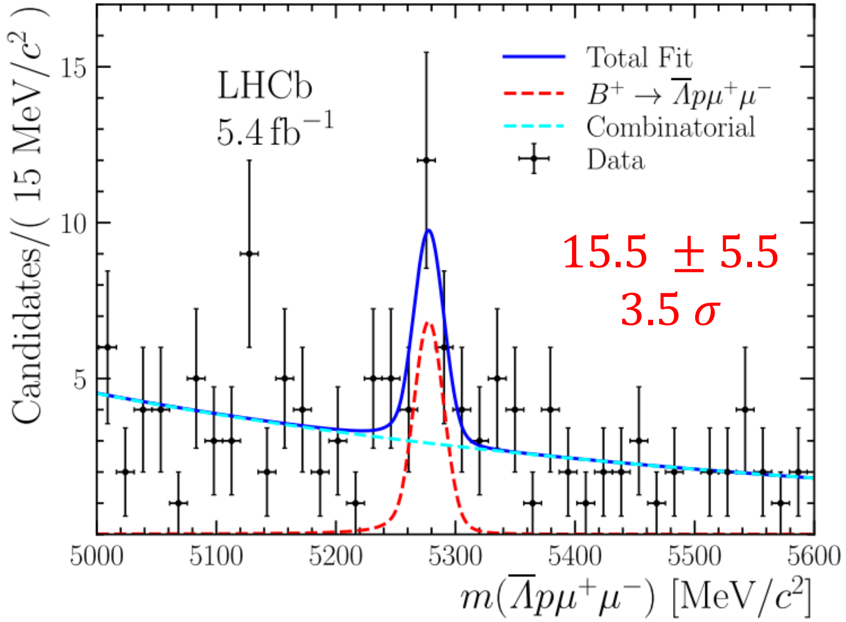
$$\mathcal{B}(B^+ \to \pi^+e^+e^-)^{[0.045,6]\,\mathrm{GeV}^2/c^4} = (0.76\,^{+0.30}_{-0.27}\,^{+0.14}_{-0.08}) \times 10^{-8},$$

$$\mathcal{B}(B^+ \to \pi^+e^+e^-)^{[15,25]\,\mathrm{GeV}^2/c^4} = (0.40\,^{+0.52}_{-0.45}\,^{+0.24}_{-0.22}) \times 10^{-8}.$$

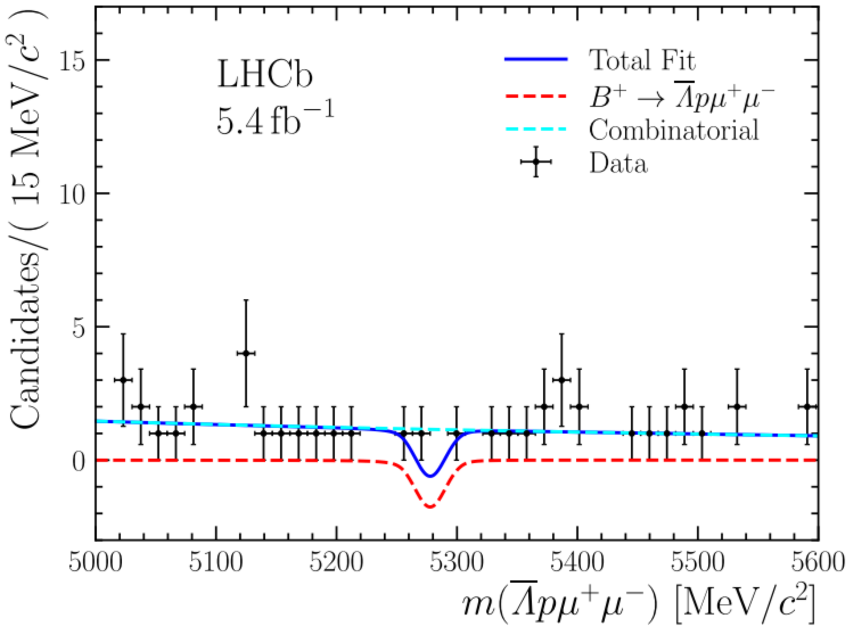
- 3.2 σ signifince
- Agreement with the lattice QCD (Phys. Rev. Lett. 115 (2015) 152002)

Evidence for the rare decay $B^+ \to p\bar{\Lambda}\mu^+\mu^-$





$m(\bar{\Lambda}p) < 2.8\,\mathrm{GeV}/c^2$



$m(\bar{\Lambda}p) > 2.8\,\mathrm{GeV}/c^2$

arXiv:2601.06878v1 accepted by PRL

- $B^+ \to J/\psi\Lambda p$ as normalization mode

$$\mathcal{B}(B^+ \to \bar{\Lambda}p\mu^+\mu^-)|_{m(\bar{\Lambda}p)<2.8\,\mathrm{GeV}/c^2} = (1.70 \pm 0.60_{\mathrm{stat}} \pm 0.19_{\mathrm{syst}} \pm 0.14_{\mathrm{ext}}) \times 10^{-8},$$

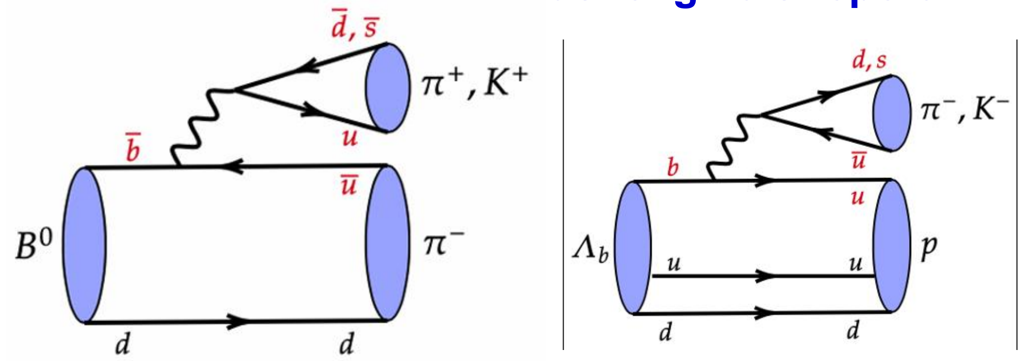
Pure charmless baryonic decays of B meson

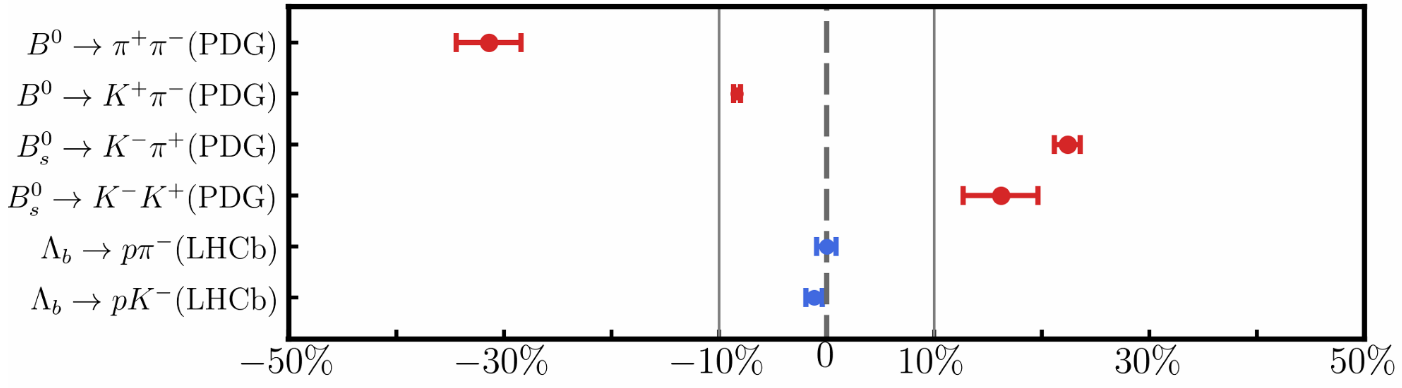
$$B^+ \to p\bar{\Lambda},\ B^0_{(s)} \to p\bar{p}p\bar{p},\ B^+ \to \bar{\Lambda}p\bar{p}p$$

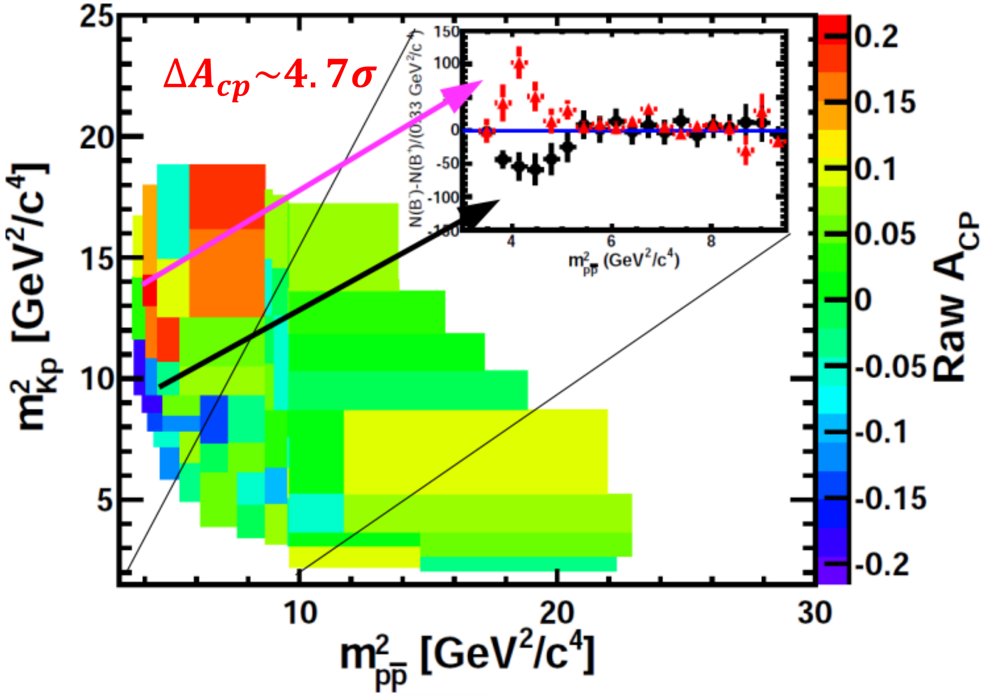
CP asymmetry

- CPV in some B-meson decays are **10%**, but b-baryon CPV only reach **1%**
- Provide a crucial bridge to understanding this puzzle
- CPV of multi-body decays: richer interference structures, more precise constraints on strong phases, more efficient utilization of statistics, and higher sensitivity to new physics

Fusheng Yu's report

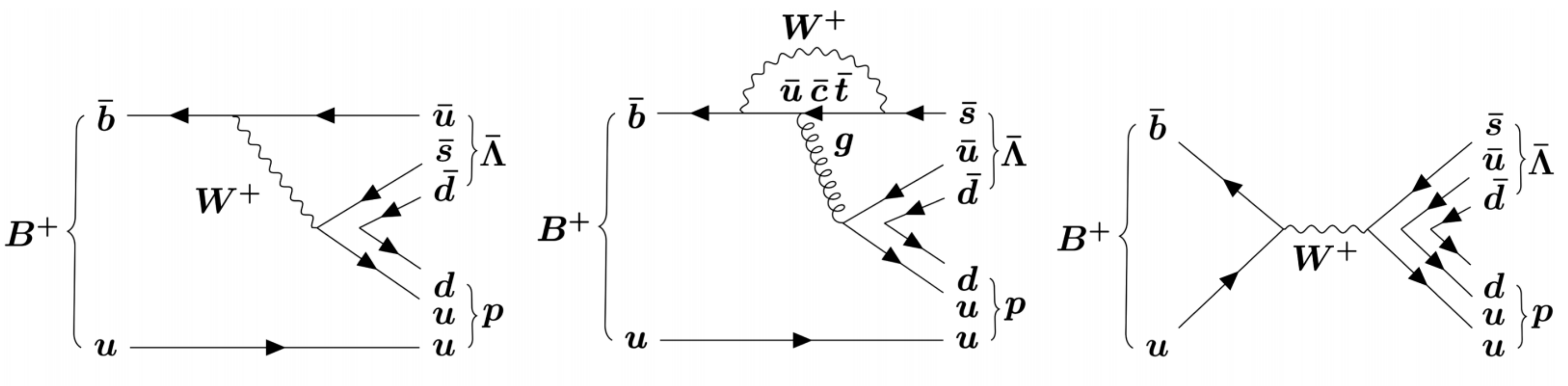




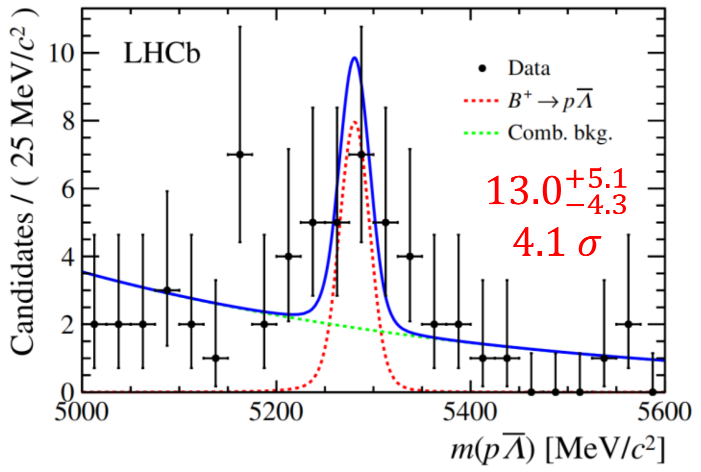


PRL 113, 141801 (2014)

Search for $B^- \to \Lambda\bar{p}$ decay



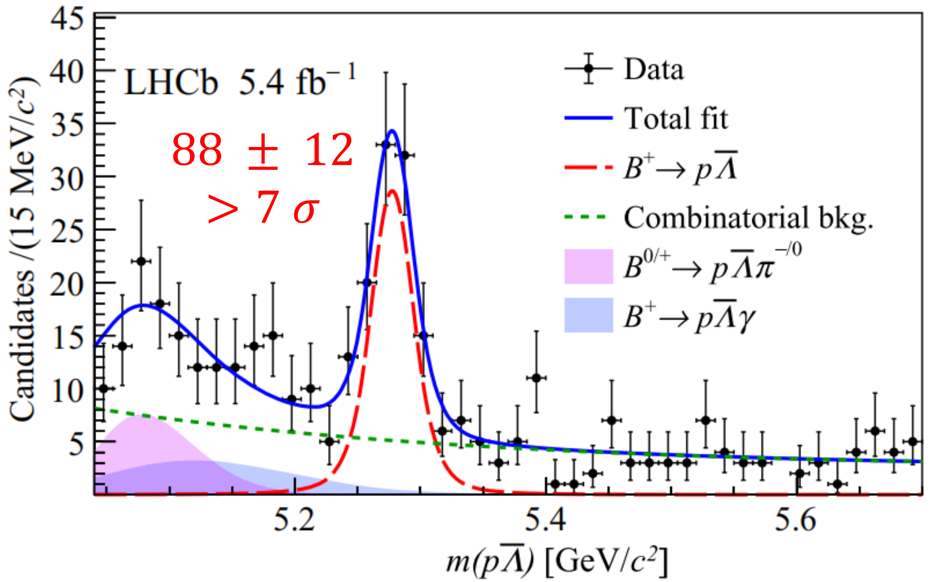
(a) (b) (c)

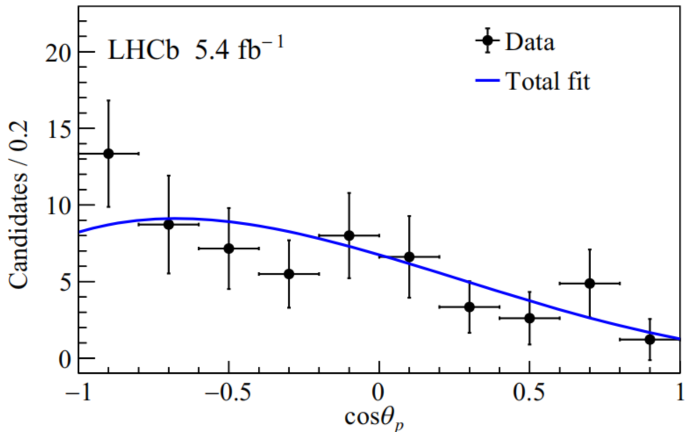


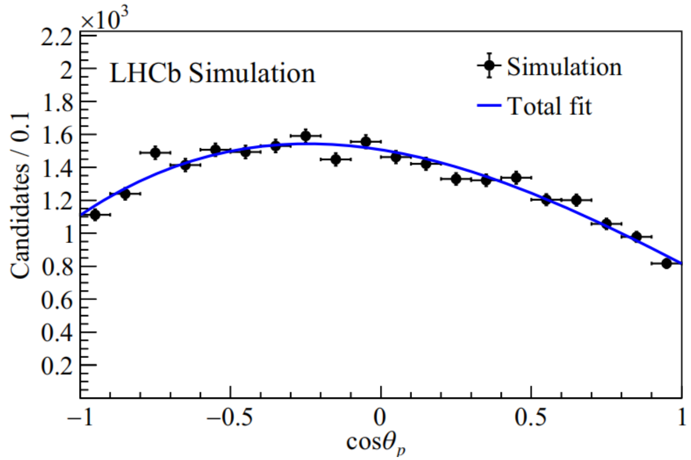
JHEP04(2017)162

- CP-violation of $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$ $\sim 10\%$
- Why $A_{cp}(\Lambda_b^0 \to pK^-) = (-1.14 \pm 0.17)\%$
- Theoretical studies for $A_{cp}(B^- \to \Lambda\bar{p})$ could reach 10%, but S-wave and P-wave amplitudes cancellation could suppress CPV
- LHCb have searched this decay mode with Run I data

First observation of the $B^+ \to p\bar{\Lambda}$ decay







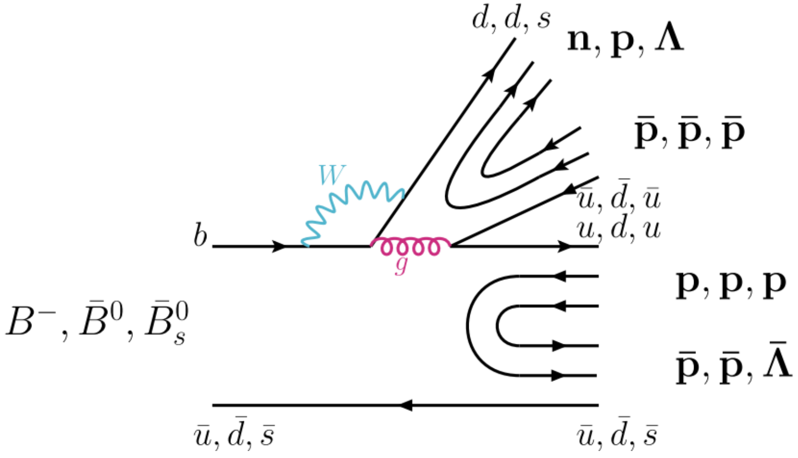
PRL 136, 051802 (2026)

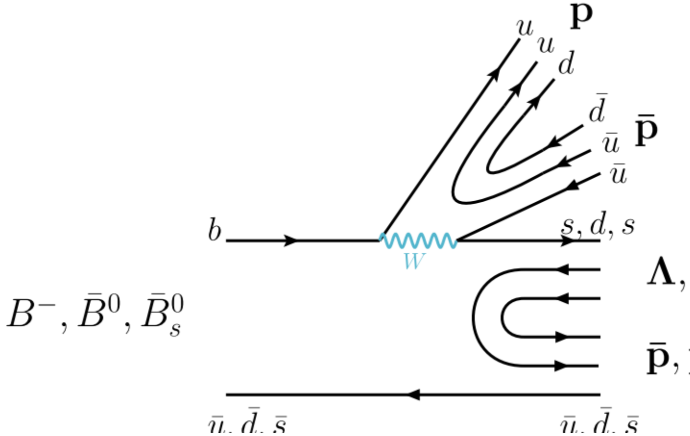
$$\alpha_B = 0.87^{+0.26}_{-0.29} \pm 0.09,$$

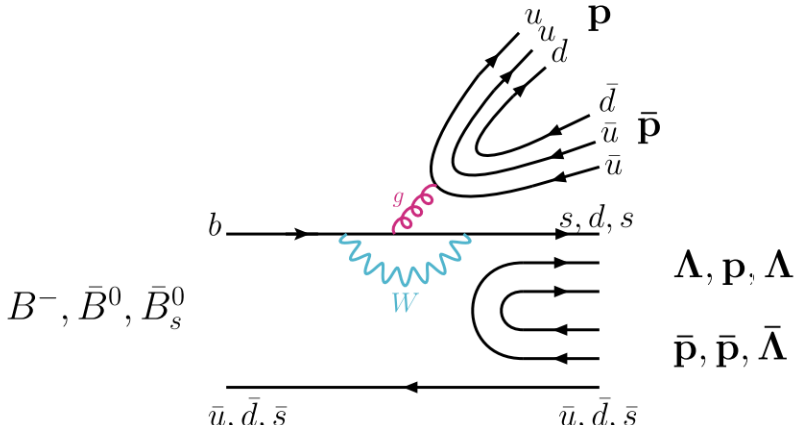
$$\mathcal{B}(B^+ \to p\bar{\Lambda}) = (1.24 \pm 0.17 \pm 0.05 \pm 0.03) \times 10^{-7}$$

- Consistent with available theoretical predictions
- $\alpha_B \neq 0$ indicates a strong interference between the competing S-wave and P-wave amplitudes
- $\mathcal{B}(B^+ \to p\bar{\Lambda}) \sim 10 \times \mathcal{B}(B^0 \to p\bar{p})$ →like mesonic two-body B-meson decays
- CPV of $B^+ \to p\bar{\Lambda}$ will become feasible

Four-body baryonic decays： $B^0_{(s)} \to p\bar{p}p\bar{p}$， $B^+ \to \bar{\Lambda}p\bar{p}p$

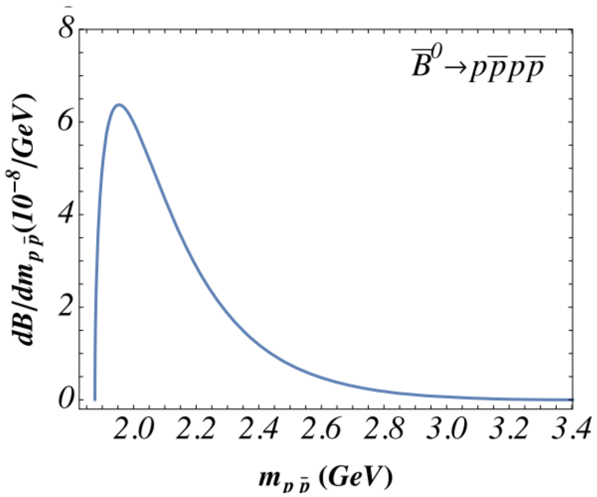


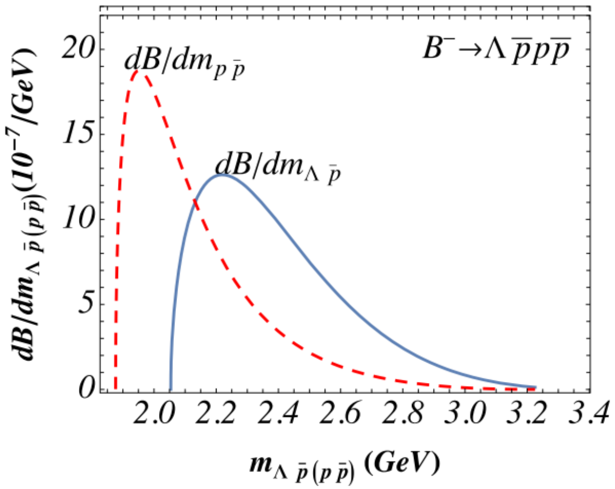




Physics Letters B 845 (2023) 138158

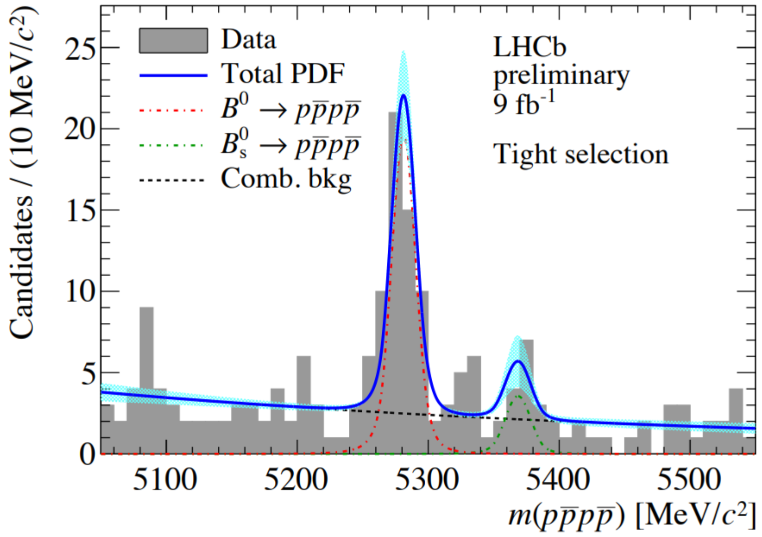
Decay mode	Our work	Data
$10^8\mathcal{B}(\bar{B}^0 \to p\bar{p}p\bar{p})$	$2.2 \pm 0.4 \pm 0.1 \pm 0.4$	2.2 ± 0.4 [10]
$10^7\mathcal{B}(B^- \to n\bar{p}p\bar{p})$	$1.7^{+0.4}_{-0.2} \pm 0.1^{+0.7}_{-0.4}$	--
$10^7\mathcal{B}(B^- \to \Lambda\bar{p}p\bar{p})$	$7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}$	--
$10^7\mathcal{B}(\bar{B}^0_s \to \Lambda\bar{\Lambda}p\bar{p})$	$1.9^{+0.3}_{-0.1} \pm 0.01^{+1.1}_{-0.6}$	--



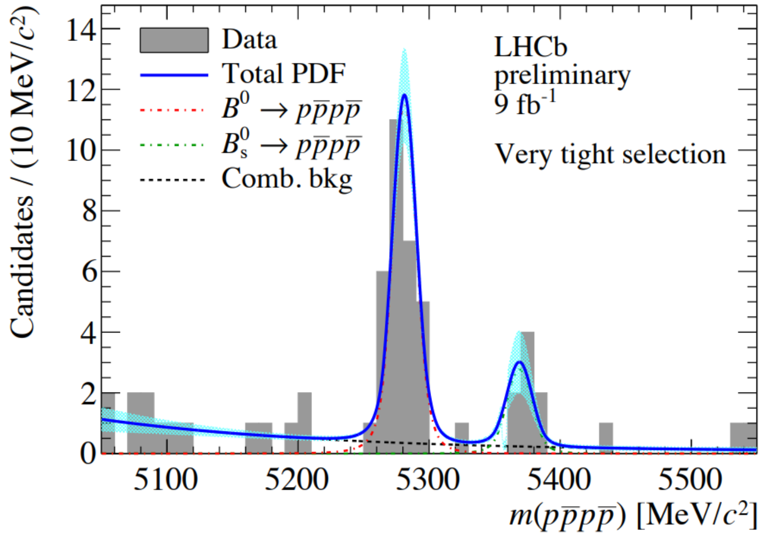


First observation of $B_s^0 \to p\bar{p}p\bar{p}$

Tight selection



Very tight selection



PRL 131, 091901 (2023)

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

Significance: > 9σ

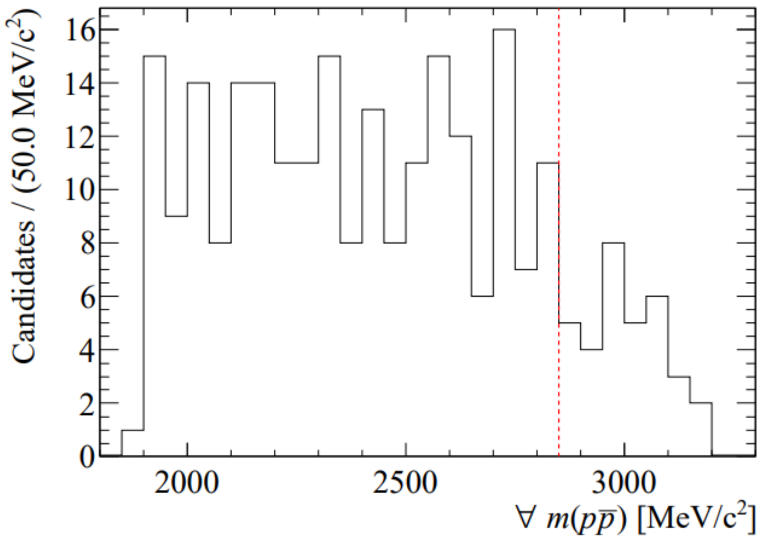
N($B_s^0 \to p\bar{p}p\bar{p}$) = 7 ± 3

Significance: 4σ

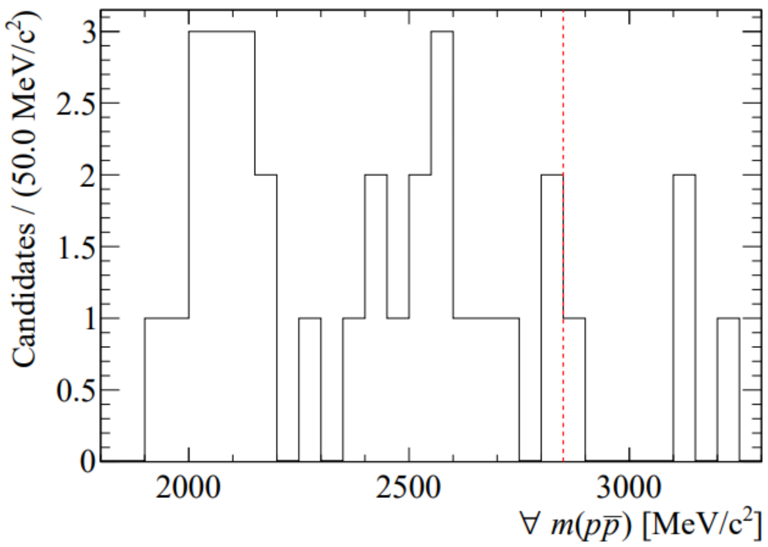
- $B^0 \to J/\psi(\to p\bar{p})K^{*0}(\to K^+\pi^-)$ and $B_s^0 \to J/\psi(\to p\bar{p})\phi(\to K^+K^-)$ as normalization channel
- $\mathcal{B}\left(B^0 \to p\bar{p}p\bar{p}\right) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$
- $\mathcal{B}\left(B_s^0 \to p\bar{p}p\bar{p}\right) = (2.3 \pm 1.0 \pm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

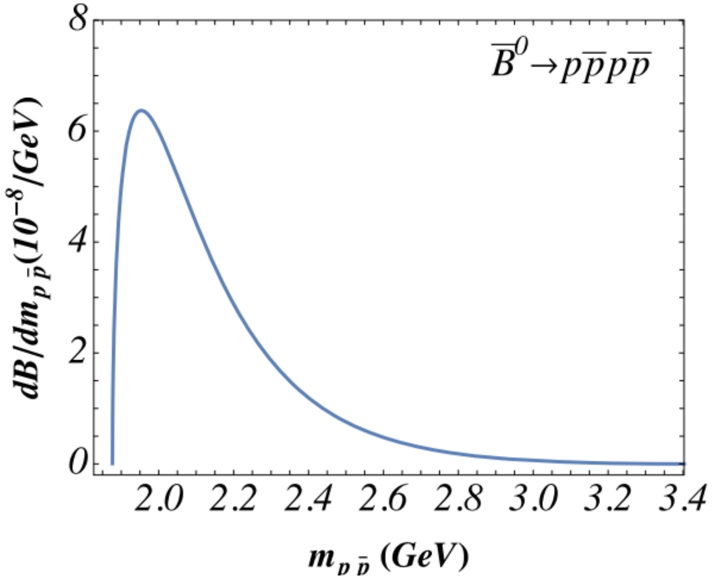
Mass distributions of $p\bar{p}$

Tight selection



Very Tight selection

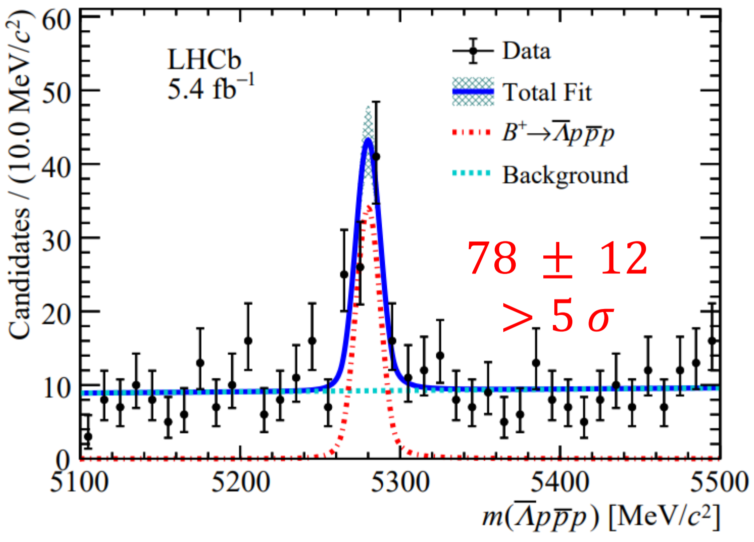




Data above the red-dashed line are excluded by the $c\bar{c}$ veto.

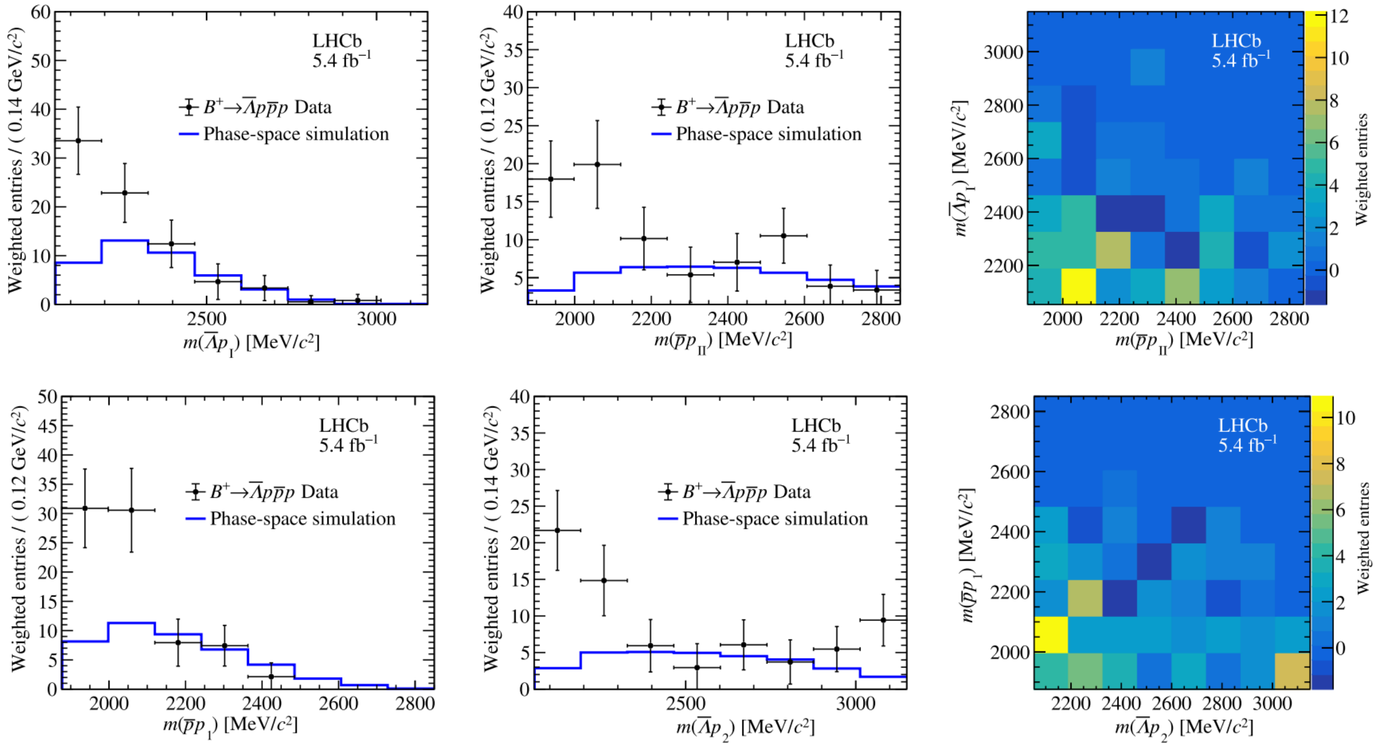
- To avoid $J/\psi \to p\bar{p}$, require $m(p\bar{p}) < 2.85\mathrm{GeV}/c^2$
- Branching fractions with $c\bar{c}$ veto (only stat. uncertainty)
  - $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (1.6 \pm 0.4) \times 10^{-8}$
  - $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 1.2) \times 10^{-8}$

First observation of $B^+ \to \bar{\Lambda} p \bar{p} p$



PRL 135, 261901 (2025)

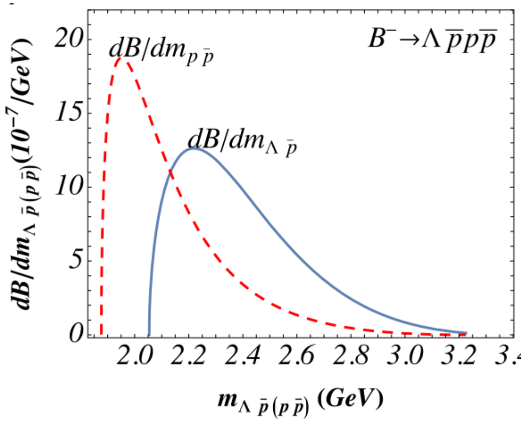
$$\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%.$$



$m(\bar{\Lambda} p_1) < m(\bar{\Lambda} p_2)$

$m(\bar{p} p_1) < m(\bar{p} p_2)$

- LHCb result: $\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p) = (2.08 \pm 0.34 \pm 0.12 \pm 0.26) \times 10^{-7}$
- Theoretical result: $\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p) = (7.4^{+0.6}_{-0.2} \pm 0.03^{+3.6}_{-2.6}) \times 10^{-7}$
- A clear double-threshold enhancement in both baryon-antibaryon invariant-mass distributions



Prospects

- **Upgrade (Upgrade-II: 300 fb^{-1})**

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [606]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [607]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [608]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$B_s^0, B^0 \to \mu^+\mu^-$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [609]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$b \to c\ell^-\bar{\nu}_l$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [610]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

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Summary

- **There is no sign of beyond the SM source yet**
  - Many first searches, angular analyses, Differential BF and LFU

- **Opportunities in future**
  - Higher precision in rare decay measurements: Angular distributions and LFU tests in $b \to sl^+l^-$ decays, …
  - More B meson charmless baryonic decays are on the way: $B_s^0 \to p\bar{p}$, $B_{(s)}^0 \to \Lambda\bar{\Lambda}$, $B_{(s)}^0 \to \Xi^+\bar{\Xi}^-$, $B_{(s)}^0 \to \Omega\bar{\Omega}$, $B_s^0 \to p\bar{p}p\bar{p}$ …

谢 谢！