Highlight of LHCb results in 2025

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On behalf of LHCb

The 2025 International Workshop on CEPC
Guangzhou SCNU
2025.11.05-11.11

Outline

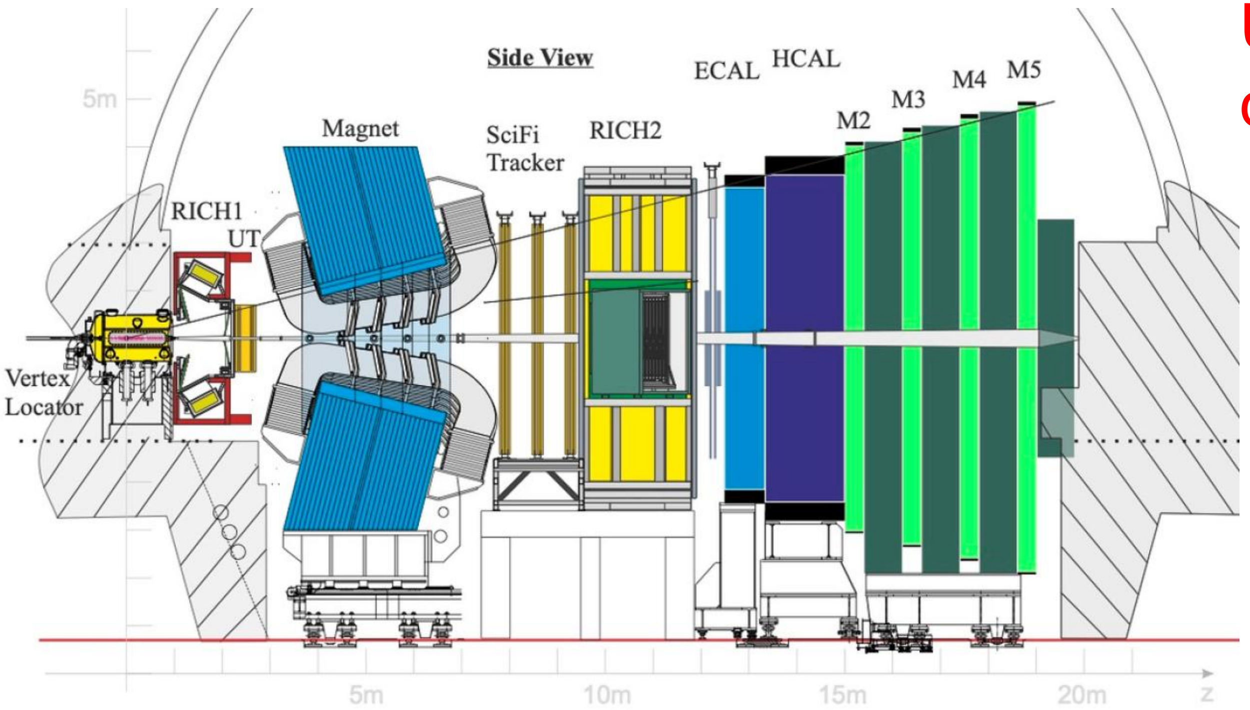
- Introduction of LHCb

- Highlight of LHCb results in 2025
  - CPV
  - Rare decays
  - Hadron spectroscopy
  - Electroweak and heavy-ion

- Prospects and conclusion

LHCb experiment

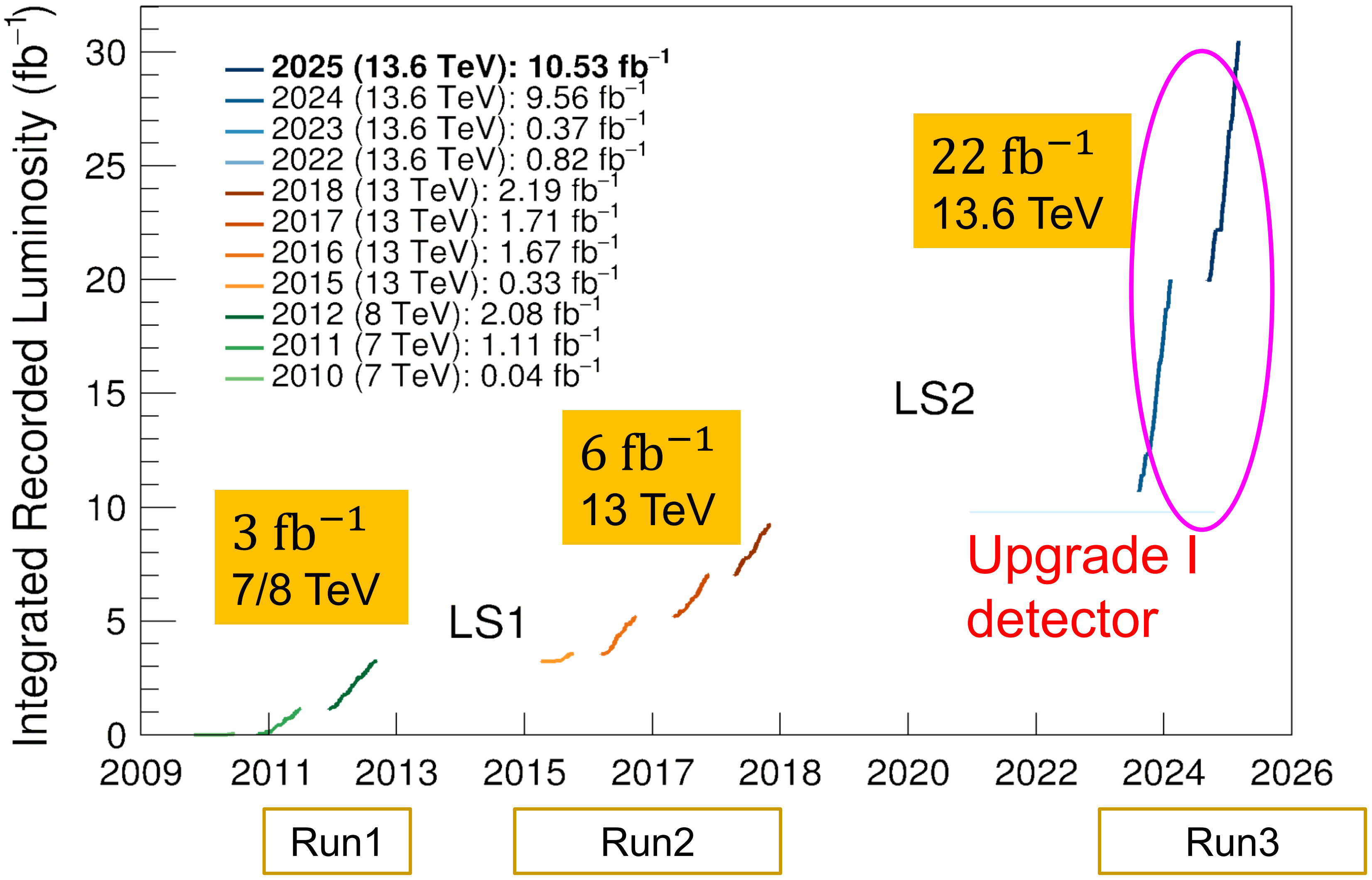
LHCb collaboration： 26 counties, 107 institutes, 1812 members



Upgrade I detector

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

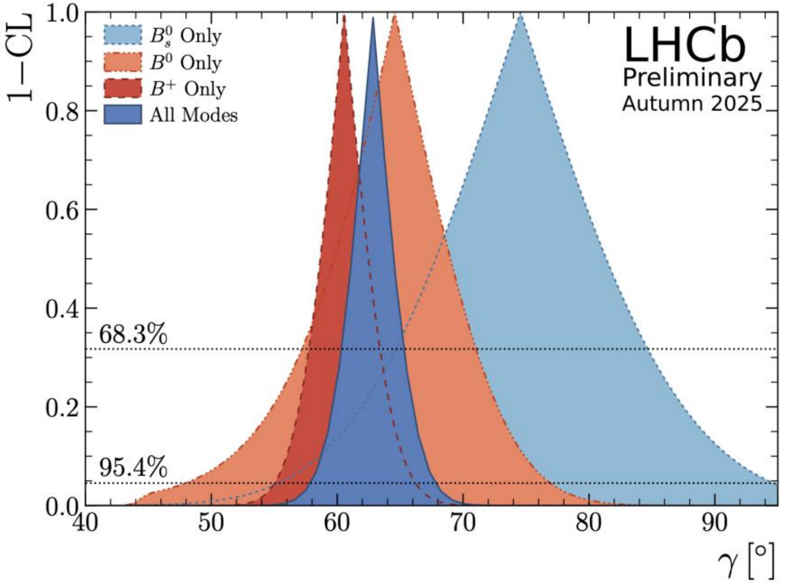
LHCb data samples



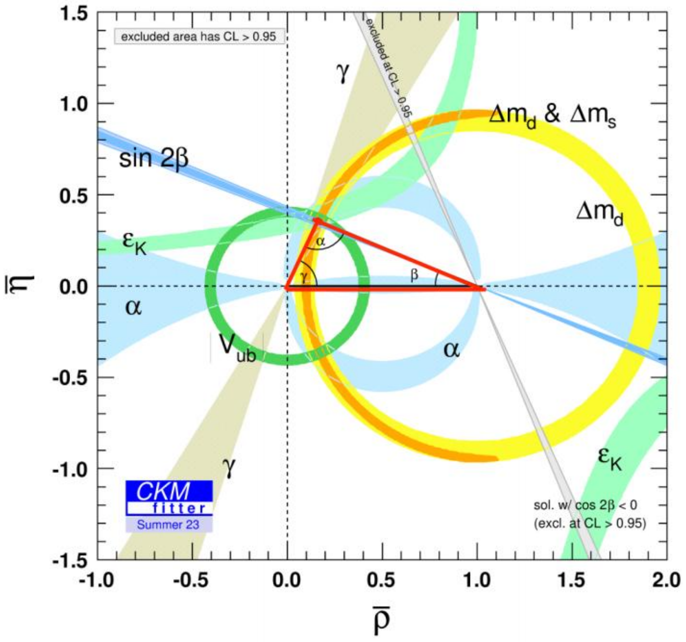
Highlights of CPV

- CKM matrix
- CP violation measurements in baryon decays

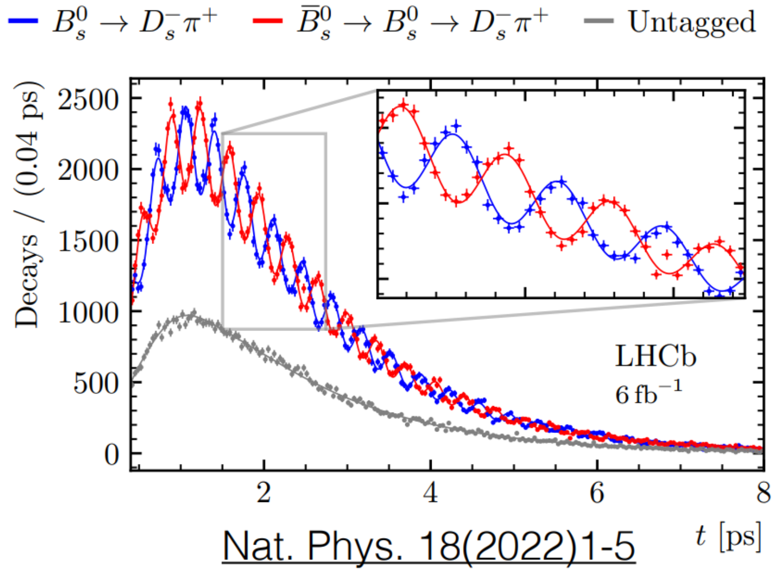
CKM matrix



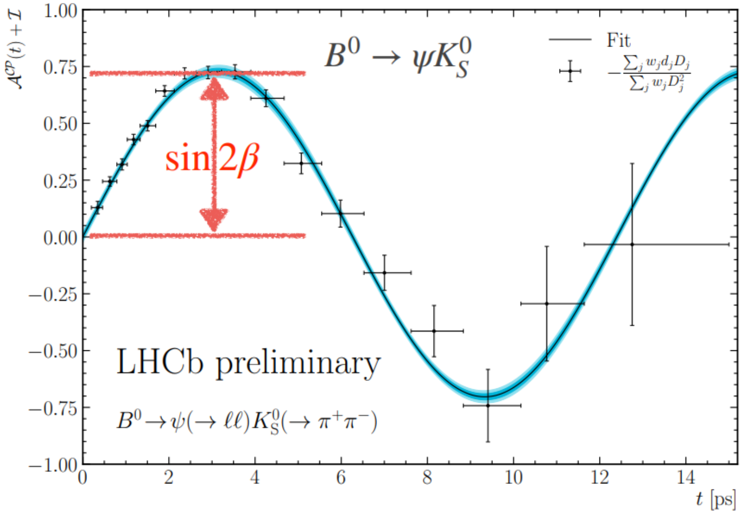
LHCb-CONF-2025-003



Still space for New Physics?

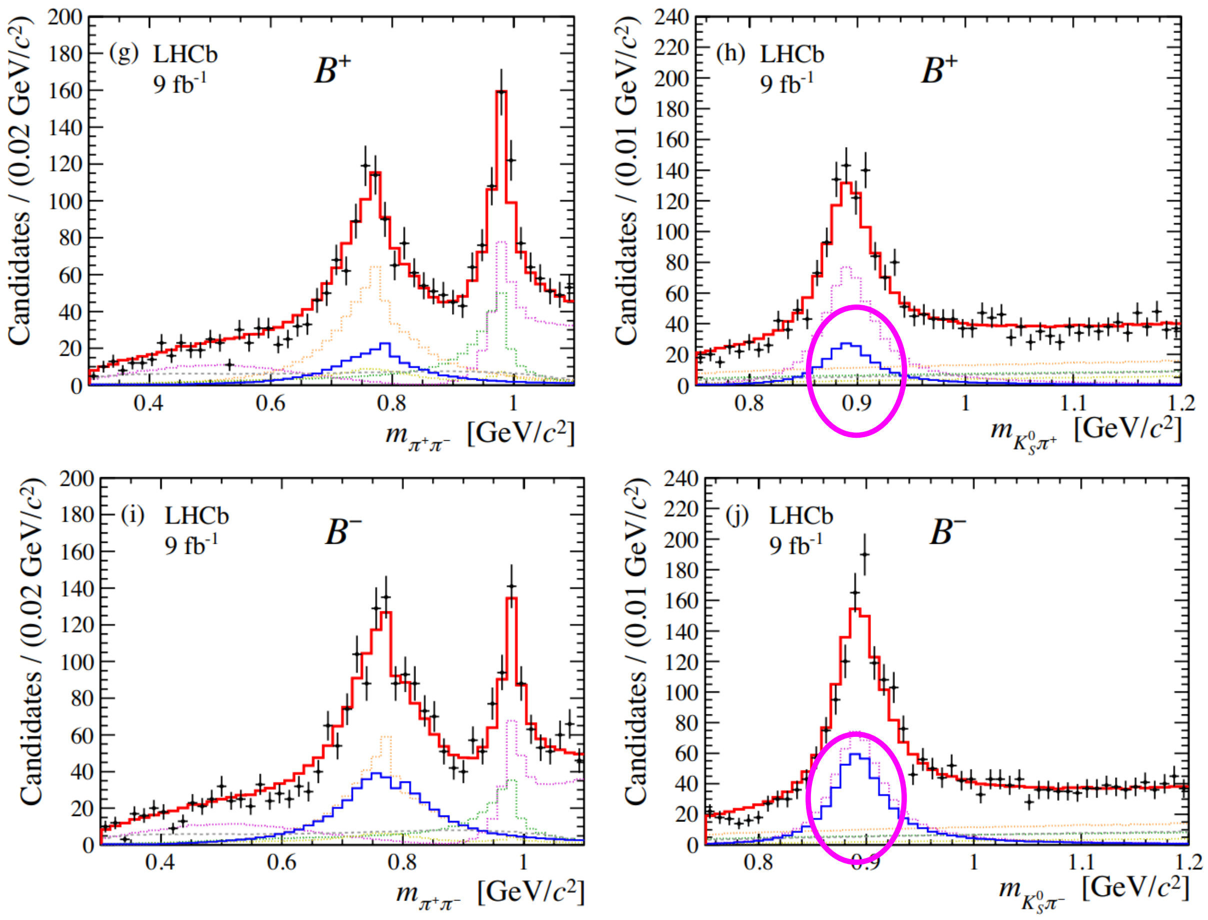


Nat. Phys. 18(2022)1-5



PRL132(2024)021801

First observation of CPV in $B^0 \to \rho(770)^0 K^*(892)^+$



$$\mathcal{A}_{CP} \equiv \frac{\sum_\lambda (|\bar{A}_\lambda|^2 - |A_\lambda|^2)}{\sum_\lambda (|\bar{A}_\lambda|^2 + |A_\lambda|^2)} = 0.507 \pm 0.062 \pm 0.017.$$

- CPV significance: 9σ

$$f_L \equiv \frac{|A_0|^2 + |\bar{A}_0|^2}{\sum_\lambda (|A_\lambda|^2 + |\bar{A}_\lambda|^2)} = 0.720 \pm 0.028 \pm 0.009,$$

$$f_L^+ \equiv \frac{|A_0|^2}{\sum_\lambda |A_\lambda|^2} = 0.491 \pm 0.083 \pm 0.025,$$

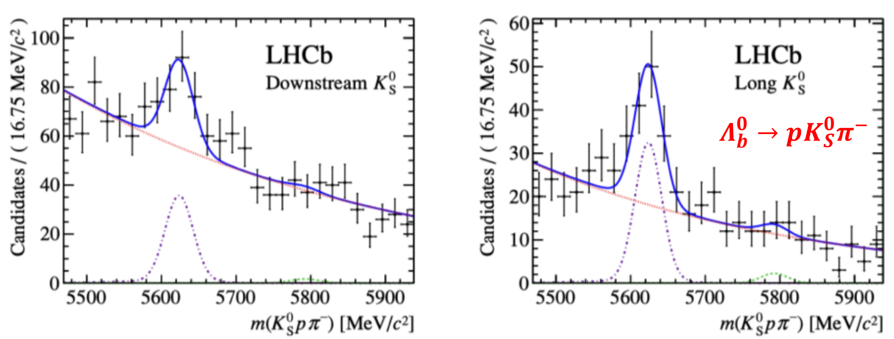
$$f_L^- \equiv \frac{|\bar{A}_0|^2}{\sum_\lambda |\bar{A}_\lambda|^2} = 0.794 \pm 0.025 \pm 0.007$$

arXiv:2508.13563

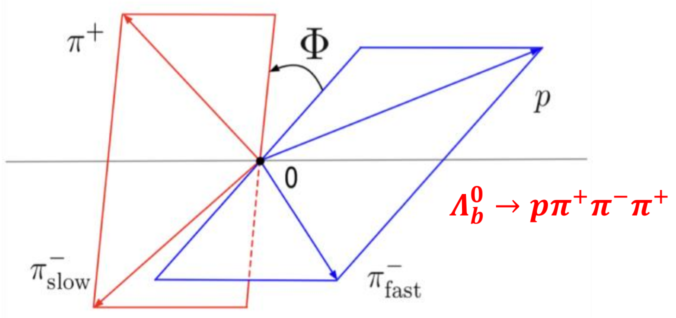
CP violation in baryons

- Baryons crucial for asymmetries in Universe, no CP violation in baryons observed yet
- CPV: b baryons $\mathcal{O}(1-10\%)$, c baryons $\mathcal{O}(0.1\%)$, hyperon $\mathcal{O}(0.001-0.01\%)$

Direct CP violation ($\propto \sin(\Delta\delta_{ST})\sin(\Delta\phi_{EW})$)

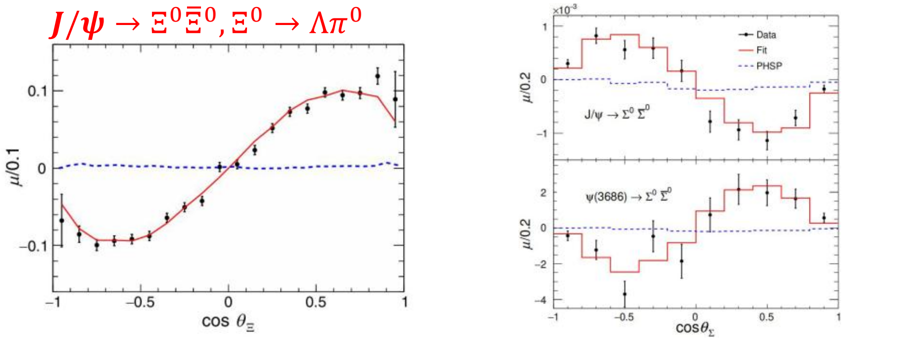


Triple-product asymmetry ($\propto \cos(\Delta\delta_{ST})\sin(\Delta\phi_{EW})$)



Decay parameters asymmetry

$J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \Lambda\pi^0$



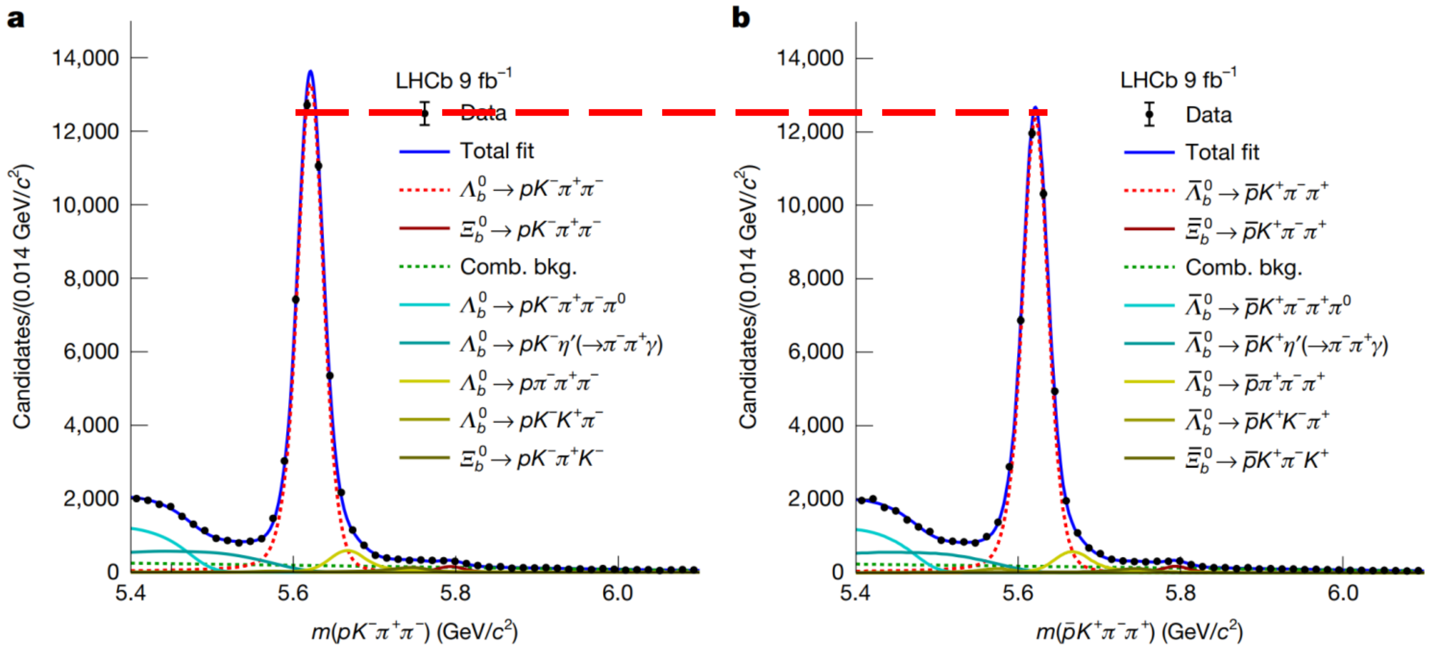
- Puzzling situation: similar Λ_b^0 production as B^+, huge significance of CPV in B^+, none in Λ_b^0?

10 years of searches

Decay	Methods	Data	References
$\Lambda_b^0 \to pK_S^0\pi^-$	A_{CP}	1 fb^{-1}	JHEP 04 (2014) 087
$\Lambda_b^0 \to \Lambda hh'$	A_{CP}	3 fb^{-1}	JHEP 05 (2016) 081
$\Lambda_b^0 \to p\pi^-\pi^+\pi^-$	TPA, energy test	3 fb^{-1} 6.6 fb^{-1}	Nature Physics 13 (2017) 391 PRD 102 (2020) 051101
$\Lambda_b^0 \to pK^-\mu^+\mu^-$	A_{CP}	3 fb^{-1}	JHEP 06 (2017) 108
$\Lambda_c^+ \to ph^-h^+$	A_{CP}	3 fb^{-1}	JHEP 03 (2018) 182
$\Lambda_b^0 \to pK^-/p\pi^-$	A_{CP}	3 fb^{-1}	PLB 787 (2018) 124
$\Lambda_b^0 \to ph^-h^+h^-$	TPA	3 fb^{-1}	JHEP 08 (2018) 039
$\Lambda_b^0 \to ph^-h^+h^-$	A_{CP}	3 fb^{-1}	EPJC 79 (2019) 745
$\Xi_b^- \to pK^-K^-$	Amplitude	5 fb^{-1}	PRD 104 (2020) 052010
$\Xi_c^+ \to pK^-\pi^+$	kNN	3 fb^{-1}	EPJC 80 (2020) 986
$\Lambda_b^0 \to pD^0K^-$	Miranda S_{CP}^i	9 fb^{-1}	PRD104 (2021) 112008
$\Lambda_b^0 \to \Lambda\gamma$	photon polarization	3 fb^{-1}	PRD105 (2022) L051104
$\Lambda_b^0 \to \Lambda_c^+h^-$	Decay parameter	9 fb^{-1}	PRL 133 (2024) 261804
$\Lambda_b^0 \to ph^-$	A_{CP}	9 fb^{-1}	PRD 111(2025) 092004
$\Lambda_b^0 \to \Lambda hh'$	A_{CP}	9 fb^{-1}	PRL 134 (2025) 101802
$\Lambda_b^0 \to pK^-\pi^+\pi^-$	A_{CP}	9 fb^{-1}	Nature 643 (2025) 1223
$\Lambda_b^0, \Xi_b^0 \to pK_S^0h^-$	A_{CP}	9 fb^{-1}	JHEP 10 (2025) 169
$\Lambda_b^0 \to J/\psi ph^-$	A_{CP}, TPA	6 fb^{-1}	LHCb-PAPER-2025-021

First observation CPV in Λ_b^0 decays

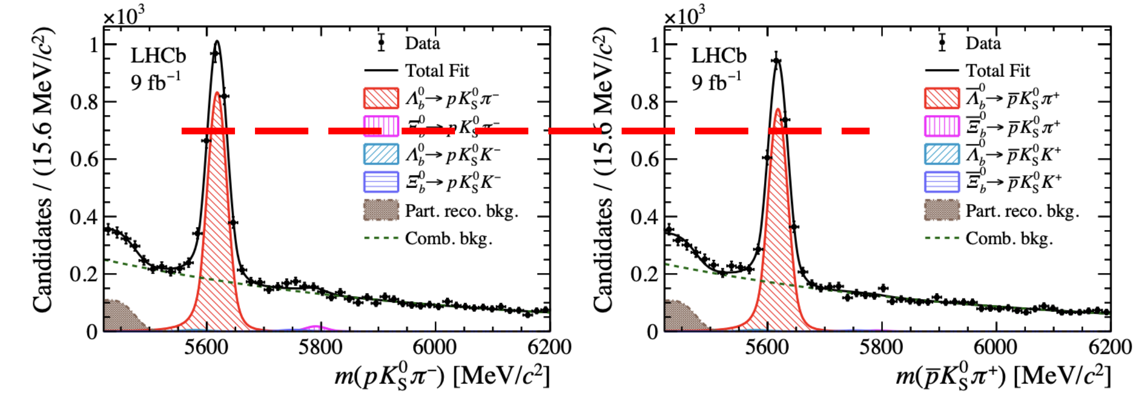
Nature 643 (2025) 1223



- $\Lambda_b^0 \to pK^-\pi^+\pi^-$ CPV significance $> 5\sigma$

$$\boxed{A_{CP} = (2.45 \pm 0.46 \pm 0.10)\%}$$

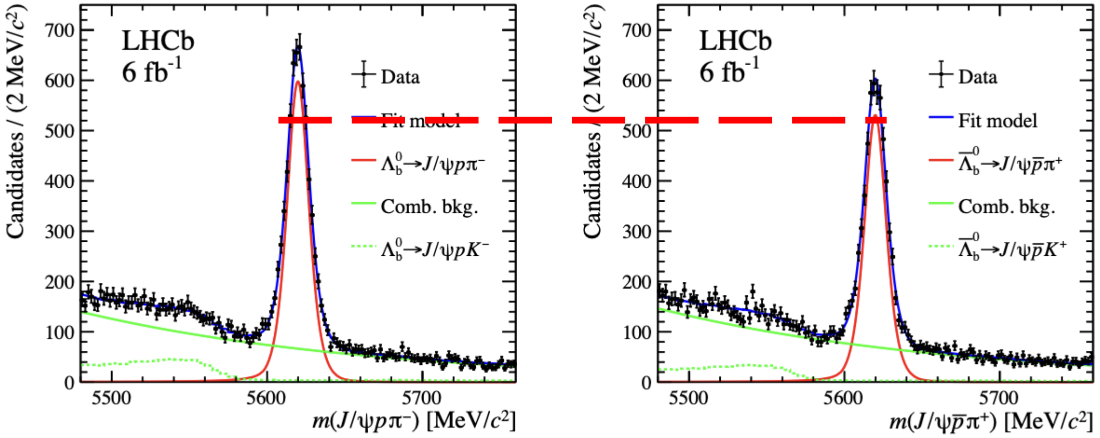
Other CPV measurements of Λ_b^0 decay



- No CPV

JHEP10(2025)169

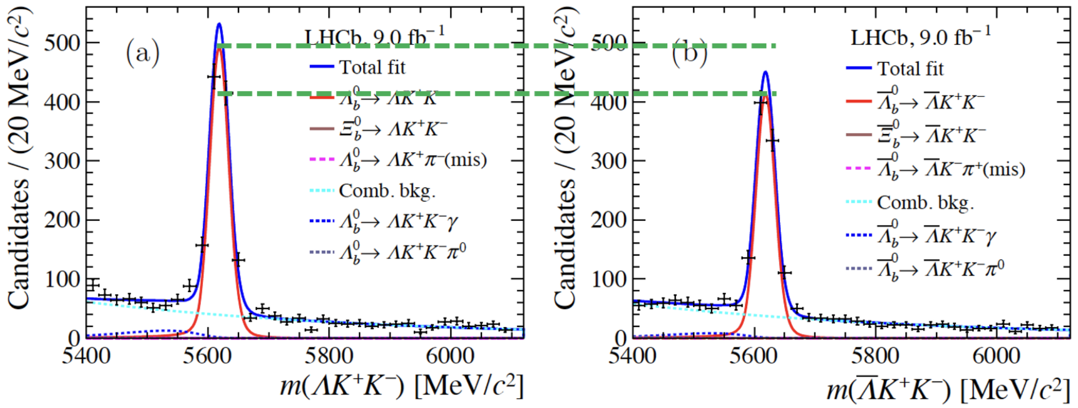
$$A^{CP}\left(\Lambda_b^0 \to pK_S^0\pi^-\right) = (3.4 \pm 1.9 \pm 0.9)\%$$



arXiv:2509.16103

- CPV significance: 3.3σ

$$\Delta\mathcal{A}_{CP} = \mathcal{A}_{CP}(\Lambda_b^0 \to J/\psi p\pi^-) - \mathcal{A}_{CP}(\Lambda_b^0 \to J/\psi pK^-)$$
$$= (4.03 \pm 1.18 \pm 0.23)\%,$$



- CPV significance: 3.1σ

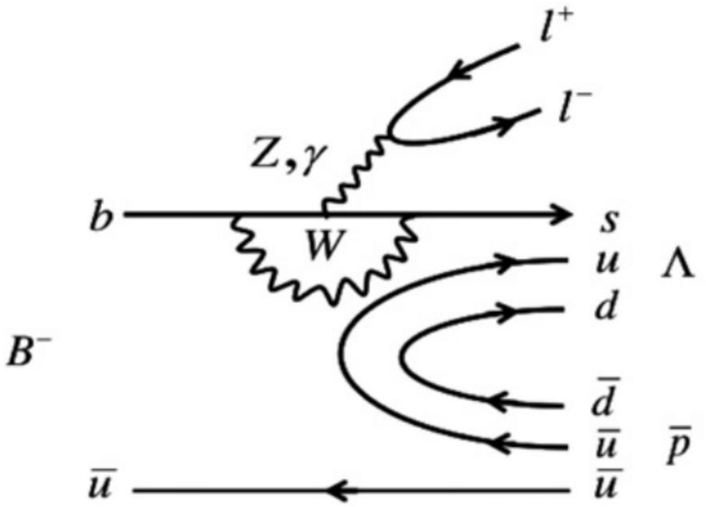
PRL 134 (2025) 101802

$$\Delta A_{CP}(\Lambda_b^0 \to \Lambda K^+K^-) = 0.083 \pm 0.023 \pm 0.016$$

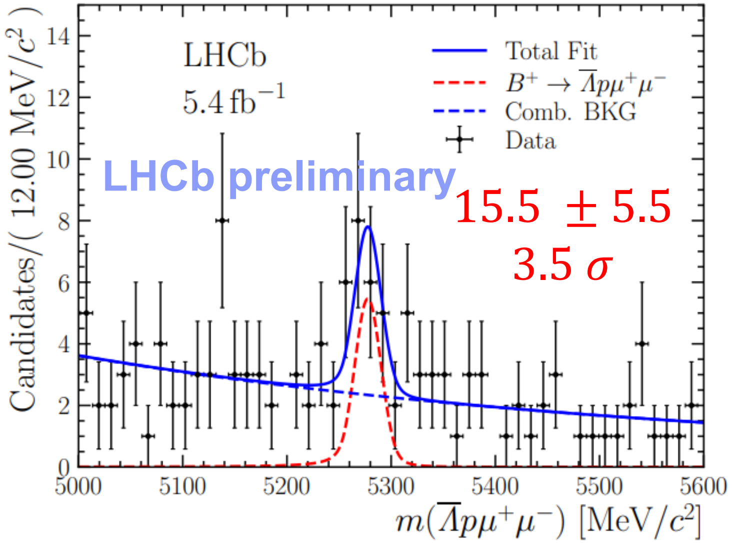
Highlights of rare decays

- Baryonic decays
  - FCNC B decays
  - Others

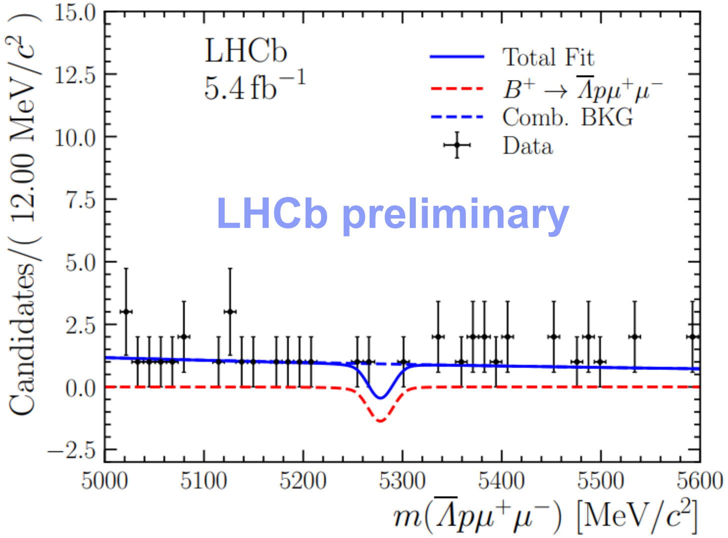
Evidence of $B^+ \to p\bar{\Lambda}\mu^+\mu^-$ with Run2 data



LHCb-PAPER-2025-051



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

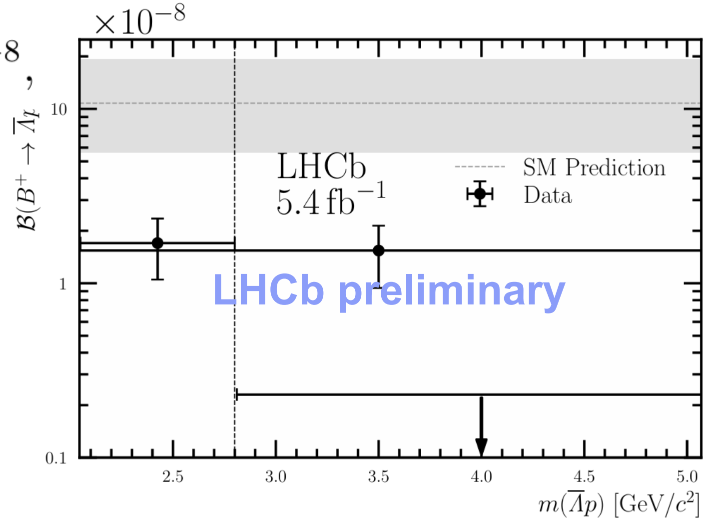


$m(\bar{\Lambda}p) > 2.8\,\mathrm{GeV}/c^2$

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

$$\mathcal{B}(B^+ \to \bar{\Lambda}p\mu^+\mu^-)|_{m(\bar{\Lambda}p)>2.8\,\mathrm{GeV}/c^2} < 2.4\,(3.2) \times 10^{-9} \text{ @ } 90\%\ (95\%)$$

LHCb preliminary



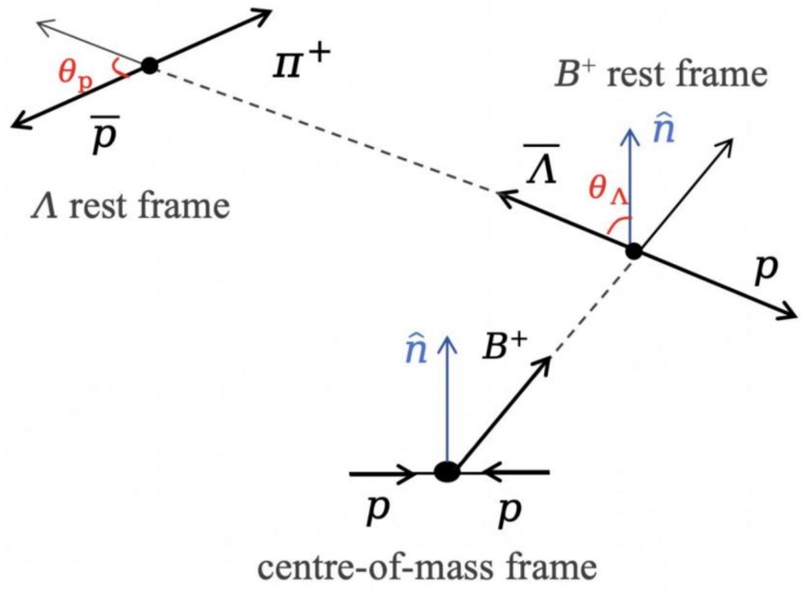
- ➢ Hint a threshold enhancement
- ➢ Improved understanding of baryonic form factors

Study of decays $B^+ \to p\Lambda$

- Anomaly in $\Lambda_b^0 \to pK^-$ CP asymmetry
  - May be due to partial-wave cancellation

[PRL. 134290 (2025) 221801](#)

- A theoretical prediction for the CP asymmetry in $B^+ \to p\Lambda$ is up to 10% [JHEP 03 (2021) 075]
  - Could be suppressed by S-P wave cancellation?



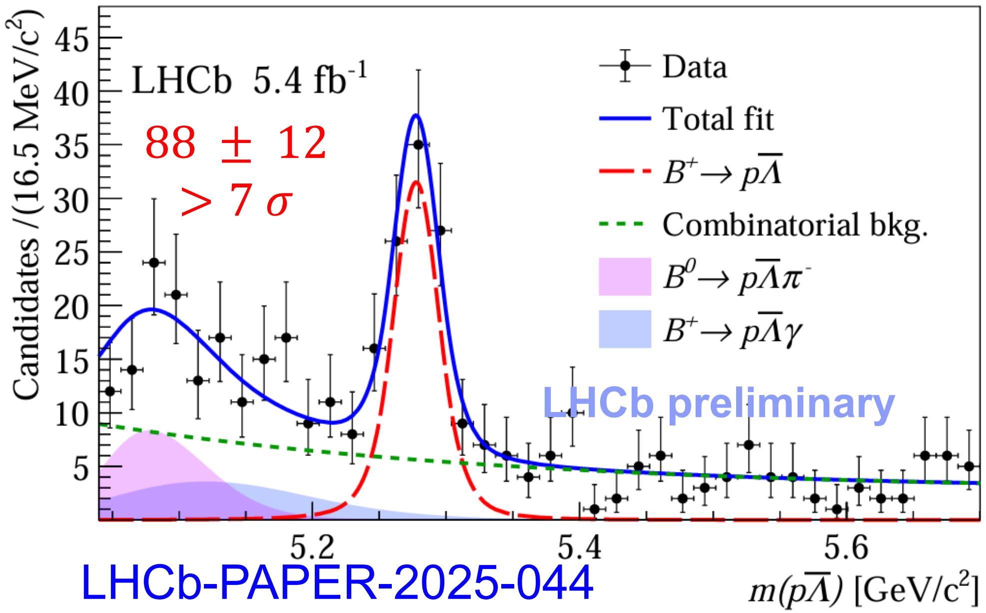
- Investigation of CP violation in the $B^+ \to p\Lambda$ decay rate and angular distribution

$$\alpha_B = \frac{|H_{+1/2}|^2 - |H_{-1/2}|^2}{|H_{+1/2}|^2 + |H_{-1/2}|^2} = \frac{2Re(S \cdot P)}{|S|^2 + |P|^2} \approx 0.6$$

[arxiv.2204.11058]

$$\frac{d\Gamma}{dcos\theta_p} \propto 1 - \alpha_\Lambda\, \alpha_B cos\theta_p, \text{ here } \alpha_\Lambda^{avg} = 0.755 \pm 0.003$$

First observation of $B^- \to \Lambda\bar{p}$ with Run2 data



LHCb-PAPER-2025-044

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

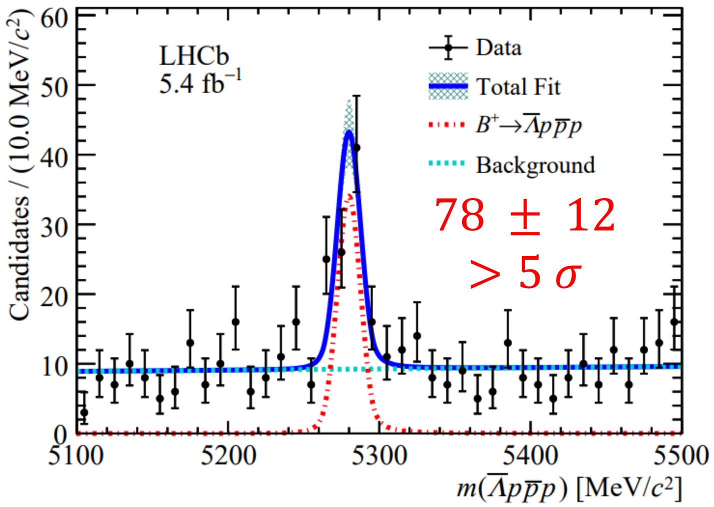
- Consistent with theoretical prediction
- Lower than the corresponding 3-body decay:
  - $\mathcal{B}(B^+ \to p\bar{\Lambda}^0\pi^0) = (3.0^{+0.7}_{-0.6}) \times 10^{-6}$,
  - $\mathcal{B}(B^0 \to p\bar{\Lambda}^0\pi^-) = (3.16 \pm 0.24) \times 10^{-6}$

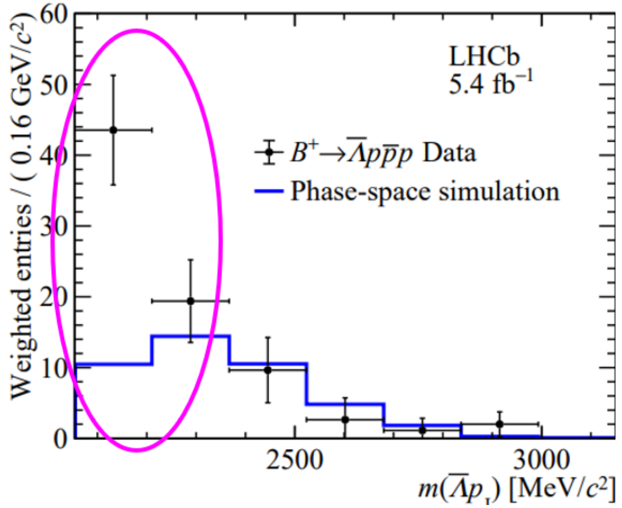
- Decay parameter

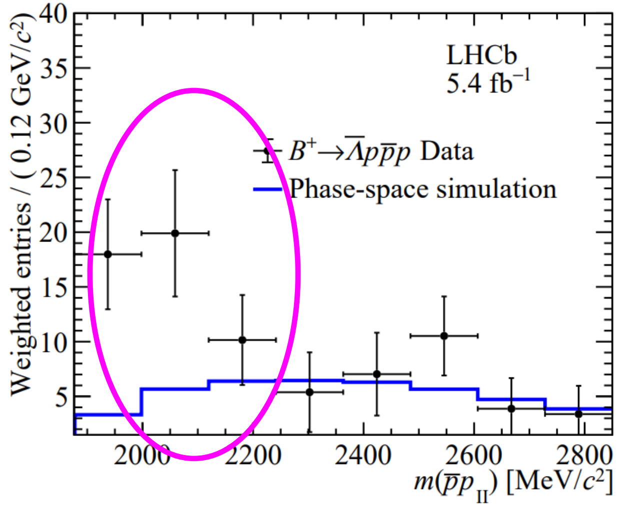
$$\alpha_B = 0.87^{+0.26}_{-0.29} \pm 0.09,$$

- Indicating the presence of comparable S-wave and P-wave decay amplitudes

First observation of $B^+ \to \bar{\Lambda} p \bar{p} p$ with Run2 data





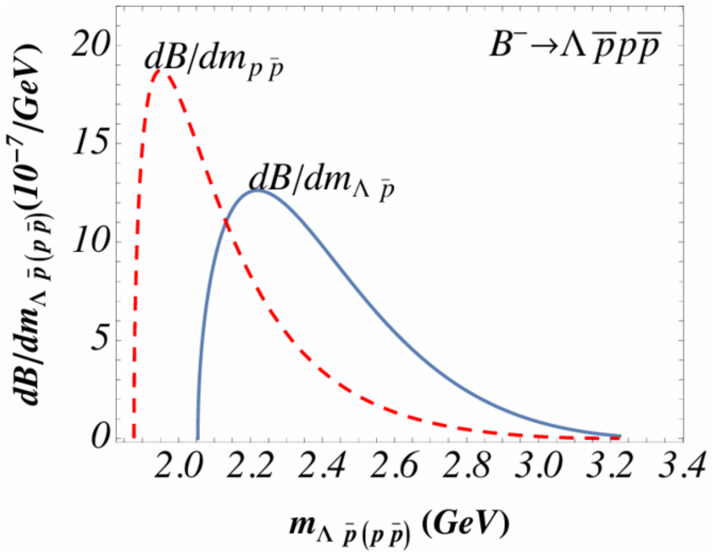


arxiv:2508.16259

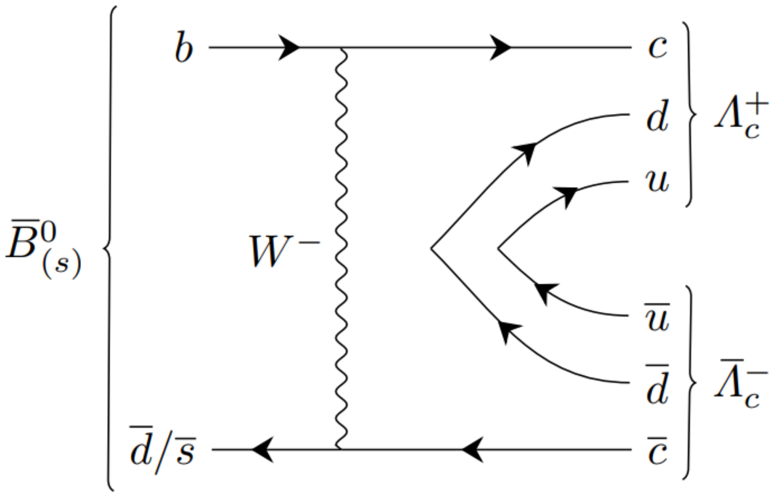
$$\mathcal{B}(B^+ \to \bar{\Lambda} p \bar{p} p) = (2.08 \pm 0.34 \pm 0.12 \pm 0.26) \times 10^{-7}$$

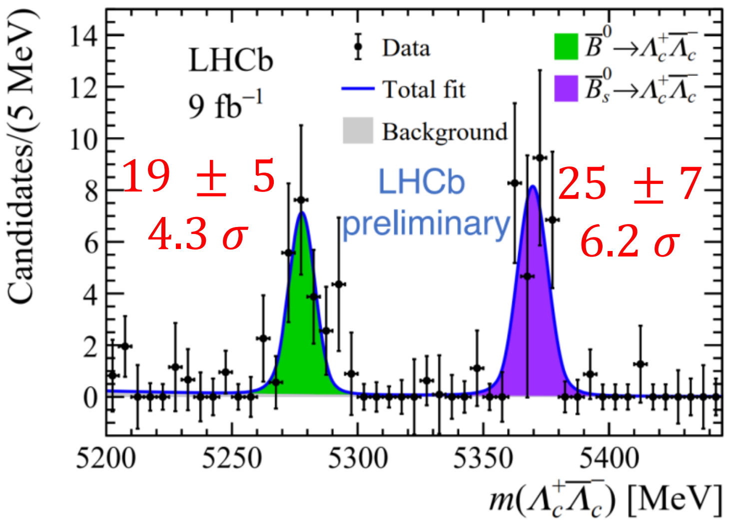
$$\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%.$$

- A clear double-threshold enhancement in both the baryon–antibaryon invariant mass distributions
  - $X(1835)$ and $X(2085)$?



First observation of $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$





LHCb-PAPER-2025-053

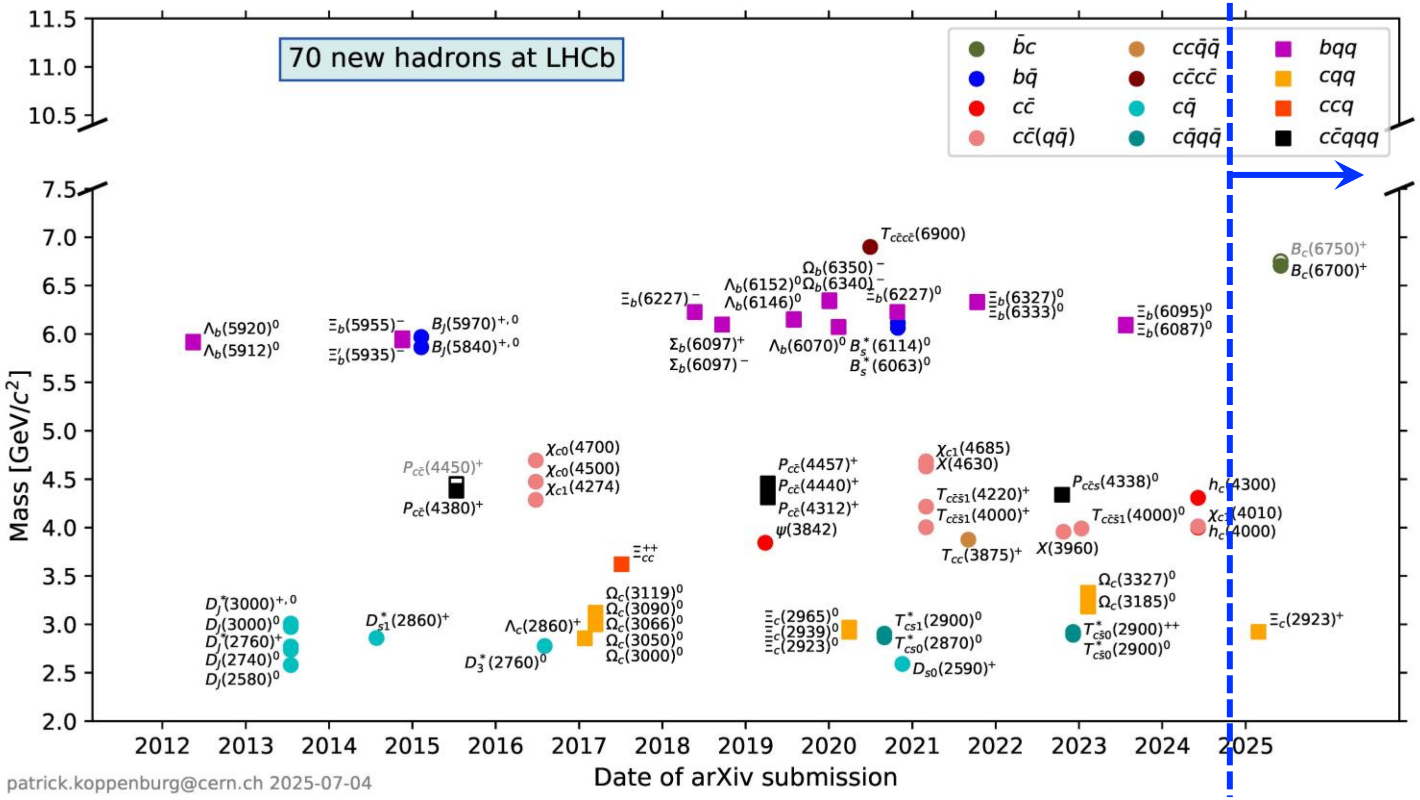
- Before this work, the only observed decays are $B^0 \to \Lambda_c^+ \Xi_c^-$ and $B^+ \to \Lambda_c^+ \Xi_c^0$ PRD 100 (2019) 3, 031101 , PRL 122 (2019) 8, 082001
  - Both are dominated by W-emission topology
- LHCb measured the upper limits on $B_{(s)}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ with Run1 data PRL112 (2014) 202001
- First observation of $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$ and first evidence of $B^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = (1.0077^{+0.2672}_{-0.2784}(\text{stat}) \pm 0.0841(\text{syst}) \pm 0.1462(\mathcal{B})) \times 10^{-5},$$

$$\mathcal{B}(\overline{B}_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) = (5.0182 \pm 1.3152(\text{stat}) \pm 0.4943(\text{syst}) \pm 0.7503(\mathcal{B})) \times 10^{-5}$$

- The first experimental verification of the W-exchange process in baryonic B decays

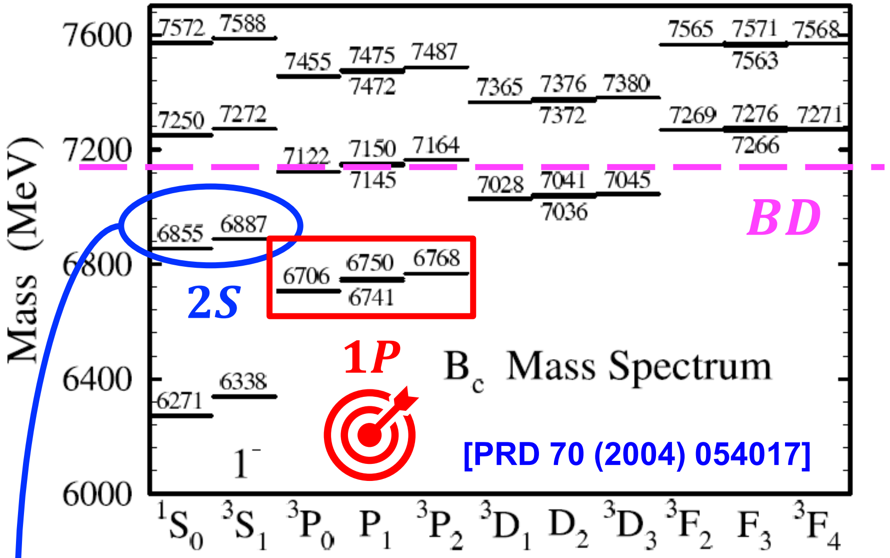
QCD and hadron spectroscopy



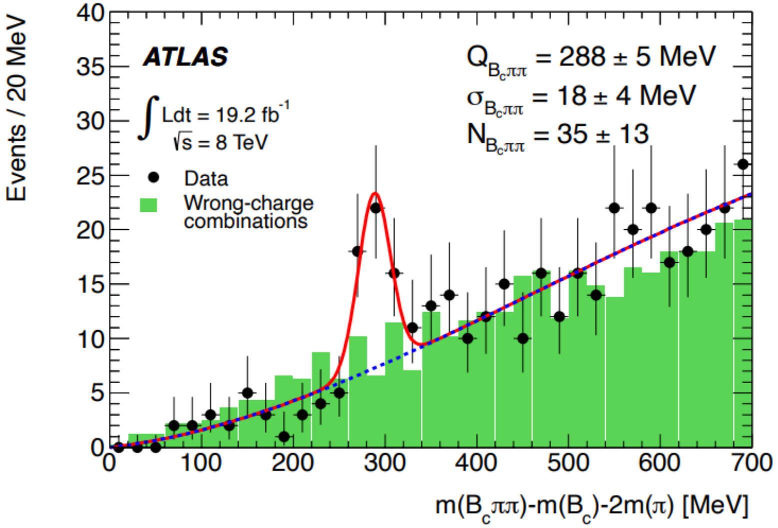
- Observation of $B_c(1P)^+ \to B_c^+\gamma$
- Observation of $\Xi_c^{**+} \to \Xi_c^+\pi^+\pi^-$

B_c spectroscopy

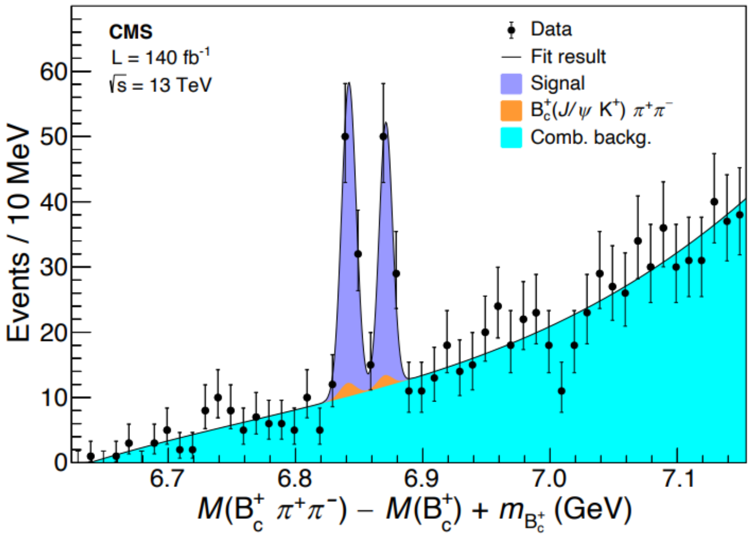
- ➢ B_c meson is a **unique and ideal tool to study QCD**
  - ☐ the only meson consisting of heavy quarks of different flavors
  - ☐ intermediate of the charmonium and bottomonium systems
- ➢ Excited B_c^+ states below BD threshold can only undergo radiative or pionic transitions to the ground state B_c^+ ⇒ $\mathbf{\Gamma \sim \mathcal{O}(100\ keV)}$



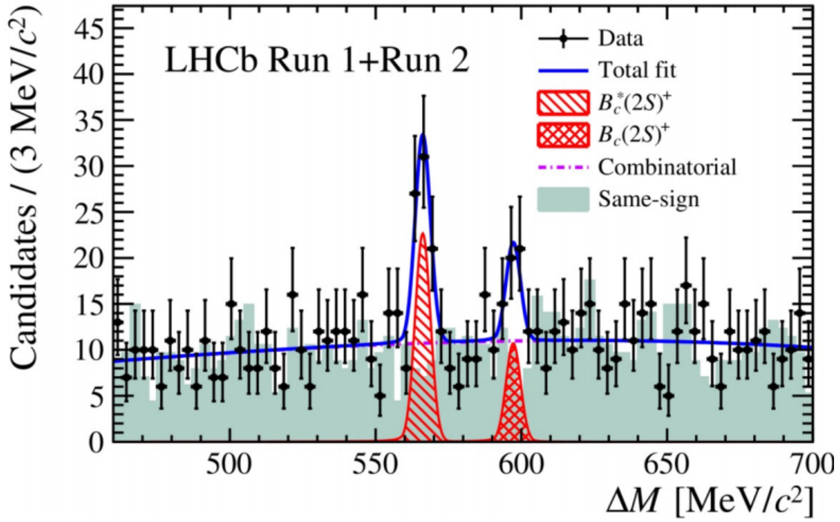
[PRL 113 (2014) 12004]



[PRL 122 (2019) 132001]



[PRL 122 (2019) 232001]



Observation of $B_c(1P)^+$ states

➢ **Photon energy correction is applied to the simulation to eliminate the mismatch to data**

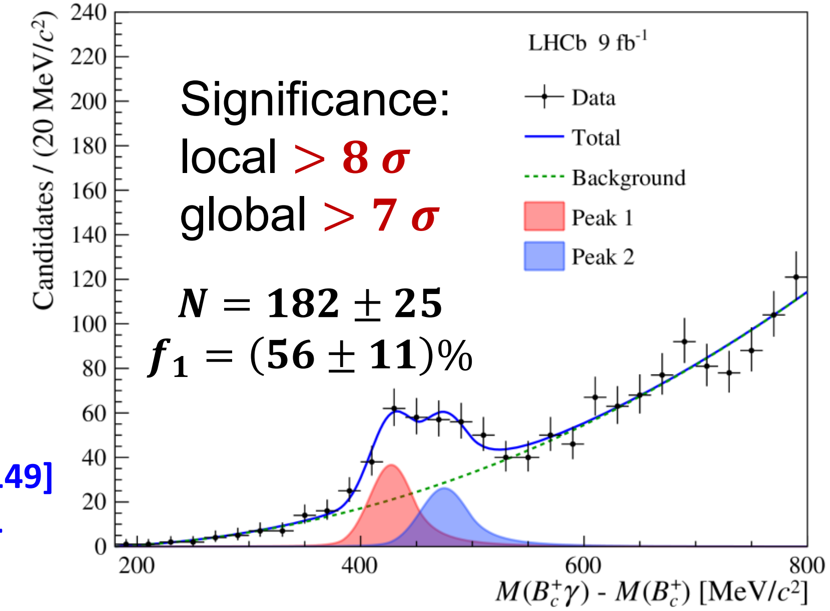
➢ Theory-independent fit

➢ The visible width is $\sim 37\ \mathrm{MeV}/c^2$

➢ Width of a single peak is $\sim 20\ \mathrm{MeV}/c^2$

$\Rightarrow$ a **minimal effective two-peak model**

*$\Gamma(B_c(1P)^+) \sim \mathcal{O}(100\ \mathrm{keV})$ negligible



Significance:
local $> 8\ \sigma$
global $> 7\ \sigma$

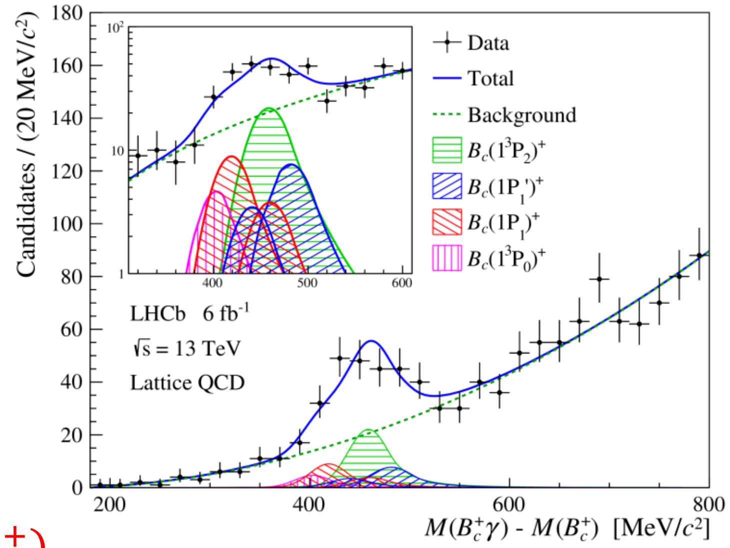
$N = 182 \pm 25$
$f_1 = (56 \pm 11)\%$

[arXiv: 2507.02149] accepted by PRL

$M_1 = 6704.8 \pm 5.5(\mathrm{stat.}) \pm 2.8(\mathrm{syst.}) \pm 0.3(B_c^+)\ \mathrm{MeV}/c^2$
$M_2 = 6752.4 \pm 9.5(\mathrm{stat.}) \pm 3.1(\mathrm{syst.}) \pm 0.3(B_c^+)\ \mathrm{MeV}/c^2$

➢ Theory-constrained fit

➢ masses and relative yields of six peaks fixed according to predictions
$\Rightarrow$ verification of various QCD models



[arXiv: 2507.02142] accepted by PRD

$$\frac{\sigma(B_c(1P)^+)}{\sigma(B_c^+)} = 0.20 \pm 0.03(\mathrm{stat.}) \pm 0.02(\mathrm{syst.}) \pm 0.03(\mathrm{theo.})$$

for $p_T(B_c^+) < 20\ \mathrm{GeV}/c, 2.0 < y(B_c^+) < 4.5$ at $\sqrt{s} = 13\ \mathrm{TeV}$

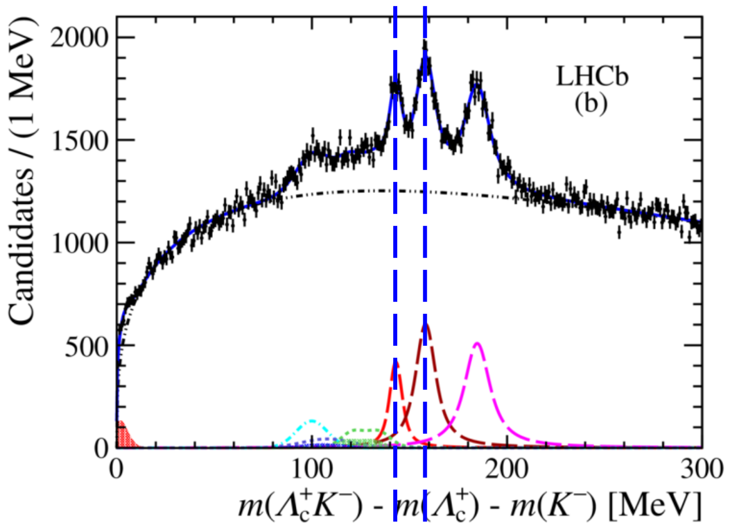
[Comput. Phys. Commun. 197 (2015) 335]

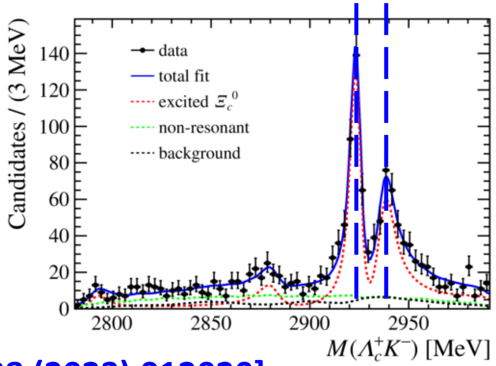
➢ consistent with BcVegPy calculations

$\Xi_c^{0,+}$ spectroscopy

➢ $\Xi_c^{0,+}$ baryons offer
- a crucial testbed for **Heavy Quark Effective Theory**
- verification of **diquark model** with profound implications also for exotic hadrons

[PRL 124 (2020) 222001]





[PRD 108 (2023) 012020]

➢ $\Lambda_c^+K^-$ mass spectrum

Resonance	Mass [MeV]	Γ [MeV]
$\Xi_c(2923)^0$	$2923.04 \pm 0.25 \pm 0.20 \pm 0.14$	$7.1 \pm 0.8 \pm 1.8$
$\Xi_c(2939)^0$	$2938.55 \pm 0.21 \pm 0.17 \pm 0.14$	$10.2 \pm 0.8 \pm 1.1$
$\Xi_c(2965)^0$	$2964.88 \pm 0.26 \pm 0.14 \pm 0.14$	$14.1 \pm 0.9 \pm 1.3$

first observation

☐ $\Xi_c(2965)^0$ inconsistent with the known $\Xi_c(2970)^0$:

$$M = 2967.8^{+0.9}_{-0.7}\ \text{MeV}, \Gamma = 28.1^{+3.4}_{-4.0}\ \text{MeV}$$

➢ $\Lambda_c^+K^-$ in $B^- \to \Lambda_c^+\overline{\Lambda}_c^-K^-$

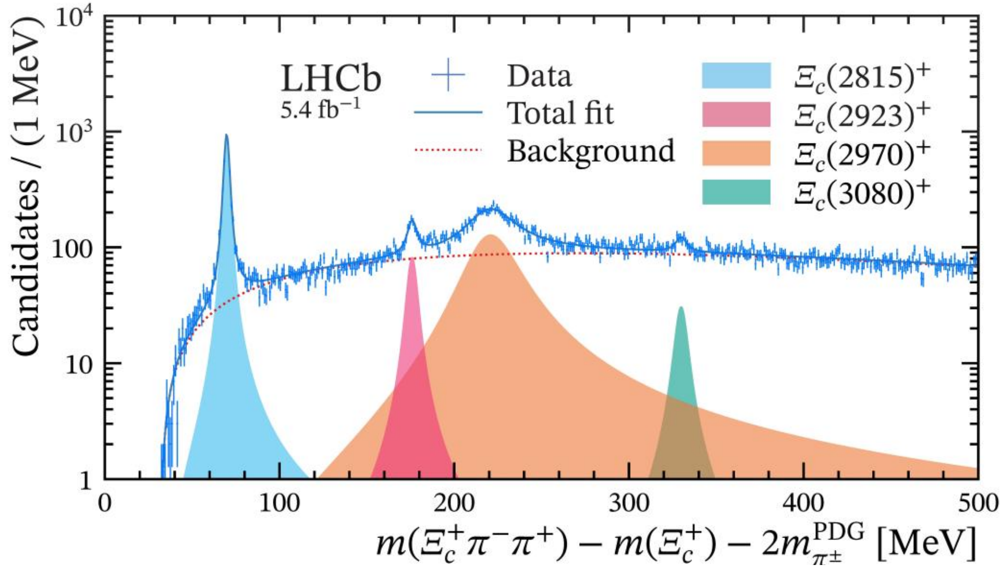
State	Mass (MeV)	Width (MeV)	Significance
$\Xi_c(2880)^0$	$2881.8 \pm 3.1 \pm 8.5$	$12.4 \pm 5.2 \pm 5.8$	3.8σ
$\Xi_c(2923)^0$	$2924.5 \pm 0.4 \pm 1.1$	$4.8 \pm 0.9 \pm 1.5$	$> 10\sigma$
$\Xi_c(2939)^0$	$2938.5 \pm 0.9 \pm 2.3$	$11.0 \pm 1.9 \pm 7.5$	$> 10\sigma$

confirmation

☐ Isospin partners Ξ_c^{**+} can help elucidate their properties

Observation of $\Xi_c^{**+} \to \Xi_c^+\pi^+\pi^-$

- Decay chain: $\Xi_c^{**+} \to \Xi_c(2645)^0(\to \Xi_c^+\pi^-)\pi^+, \Xi_c^+ \to pK^-\pi^+$



[PRL 132 (2025) 161901]

$$m[\Xi_c(2815)^+] = 2816.65 \pm 0.03 \pm 0.03 \pm 0.23\,\text{MeV},$$
$$\Gamma[\Xi_c(2815)^+] = 2.07 \pm 0.08 \pm 0.12\,\text{MeV},$$
$$m[\Xi_c(2923)^+] = 2922.8 \pm 0.3 \pm 0.5 \pm 0.2\,\text{MeV},$$
$$\Gamma[\Xi_c(2923)^+] = 5.3 \pm 0.9 \pm 1.4\,\text{MeV},$$

first observation

$$m[\Xi_c(2970)^+] = 2968.6 \pm 0.5 \pm 0.5 \pm 0.2\,\text{MeV},$$
$$\Gamma[\Xi_c(2970)^+] = 31.7 \pm 1.7 \pm 1.9\,\text{MeV},$$
$$m[\Xi_c(3080)^+] = 3076.8 \pm 0.7 \pm 1.3 \pm 0.2\,\text{MeV},$$
$$\Gamma[\Xi_c(3080)^+] = 6.8 \pm 2.3 \pm 0.9\,\text{MeV},$$

observation of new decay mode

- $\Lambda_c^+K^-$ @ LHCb

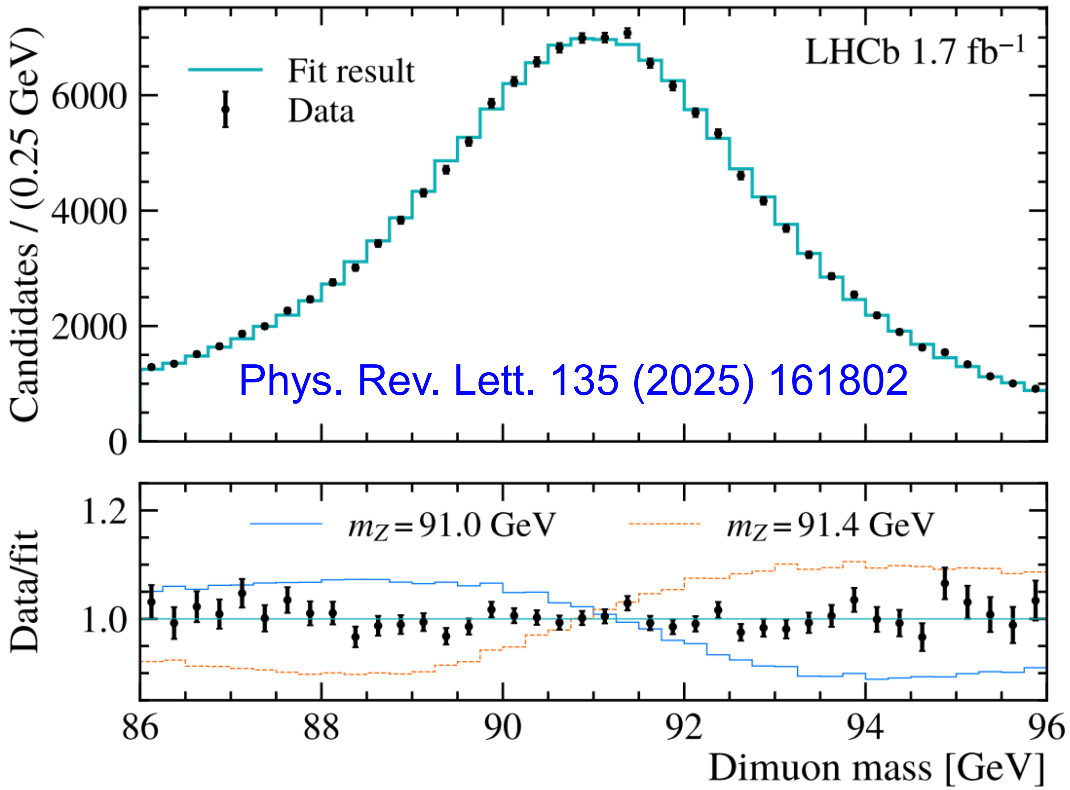
$\Xi_c(2923)^0$ $\xrightarrow{\text{isospin partner}}$

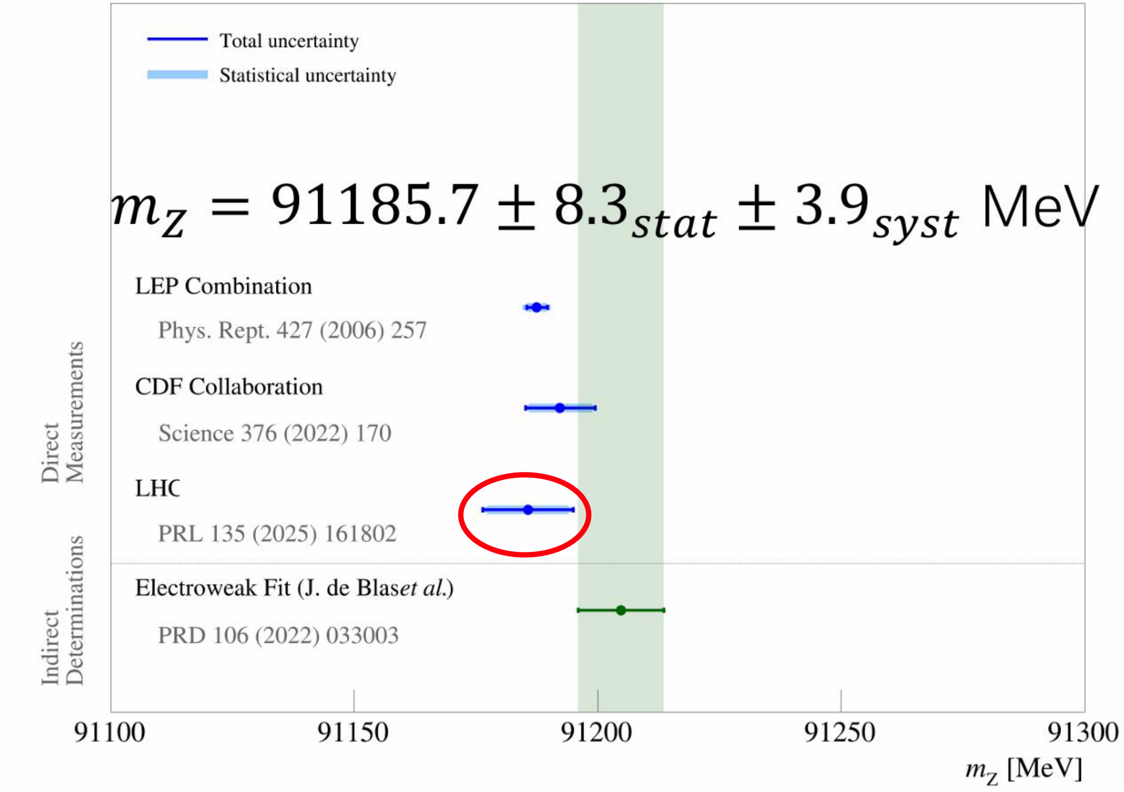
$\Xi_c(2939)^0$ $\dashrightarrow$ not seen

$\Xi_c(2965)^0$ $\dashrightarrow$ inconsistent width

Electroweak and heavy-ion

Z mass measurement in LHC

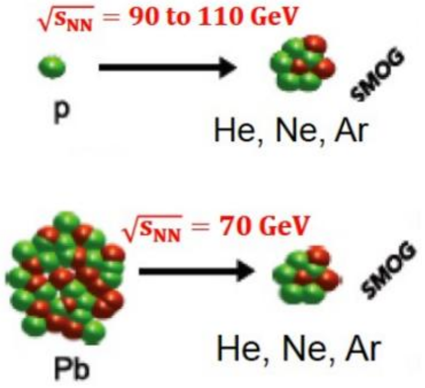


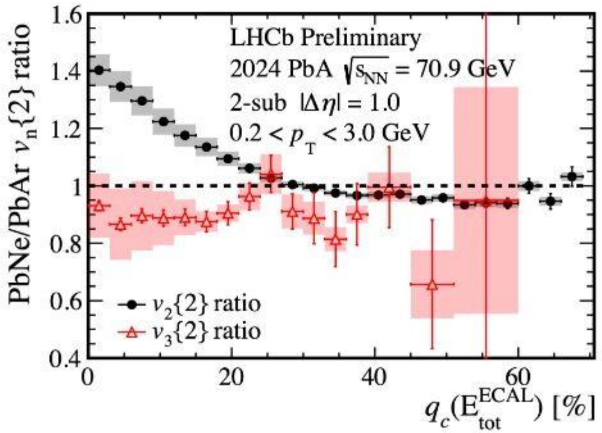


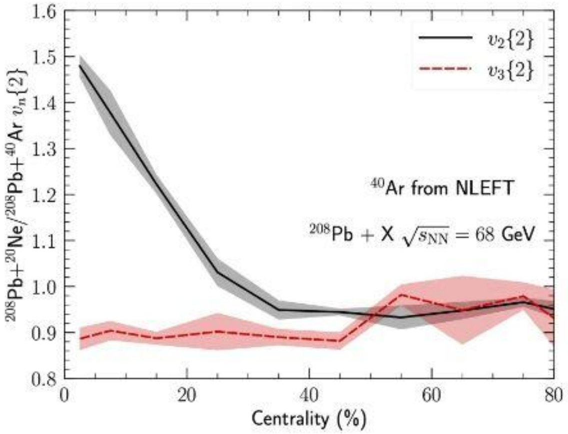
- The new momentum calibration method enables LHCb to potentially challenge the precision of LEP's measurement of the Z boson mass in the future

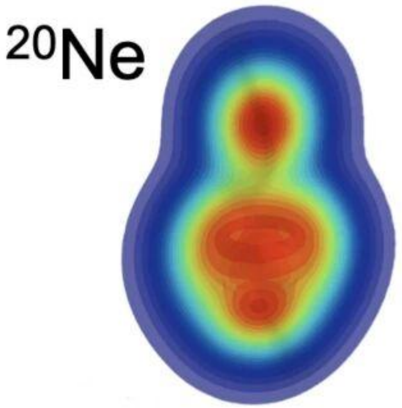
Unveiling the shape of the Neon-20 nucleus

气体固定靶模式









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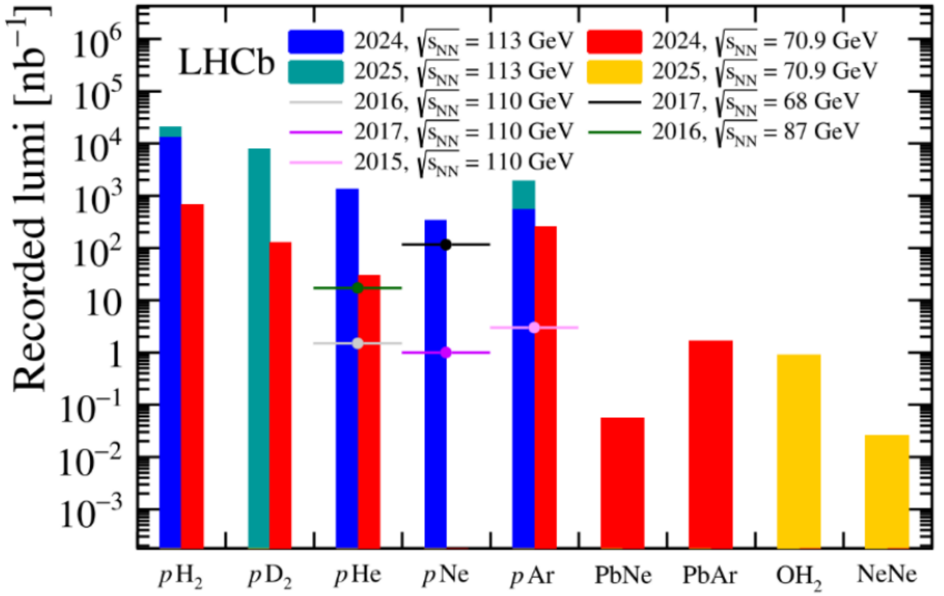
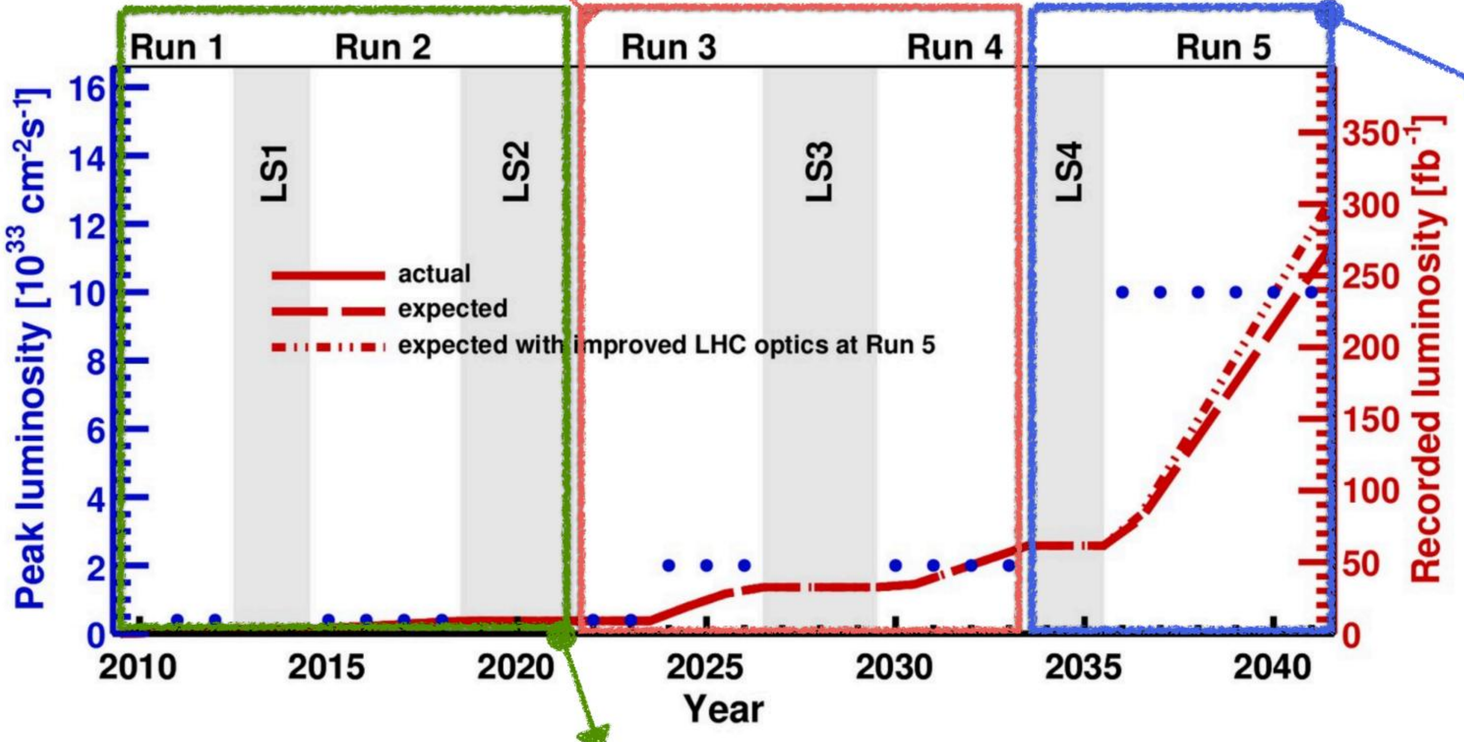


- Observe a significant Pb+Ne/Pb+Ar $v\{2\}$ ratio greater than unity in central collisions, qualitatively consistent with 3+1D hydro prediction with ab-initio nuclear structure (PGCM and NLEFT)

Prospects and conclusion

LHCb Upgrade II

- Currently Run 3 data taking, same luminosity in Run 4
- $\mathscr{L}_{max} \sim 2 \times 10^{33}$ cm$^{-2}s^{-1}$, ~5 visible interactions (aimed for 23 fb^{-1}, >22 fb^{-1} **collected**)



- Upgrade II planned for LS4
- Peak luminosity: $(1.0 \sim 1.5) \times 10^{-34}$ cm^{-2}s^{-1}
- $\sim$ 40 invisible interactions
- Aiming for ~300 fb^{-1}

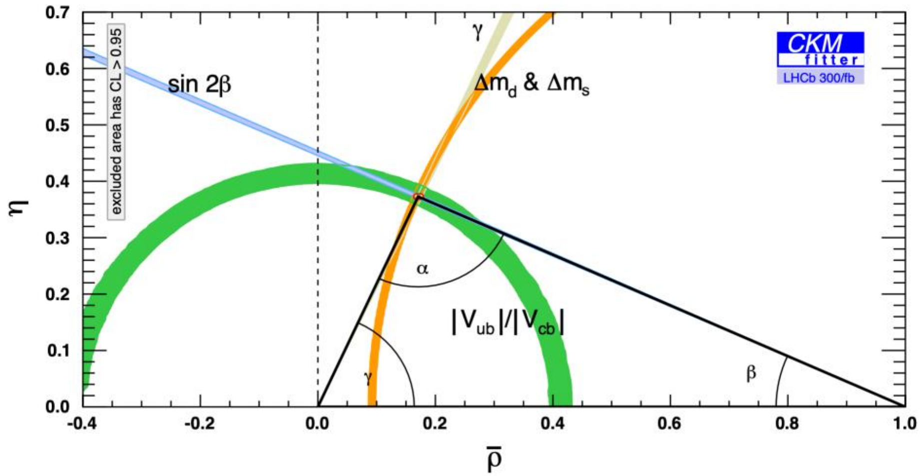
LHCb-TDR-026 UII Scoping document

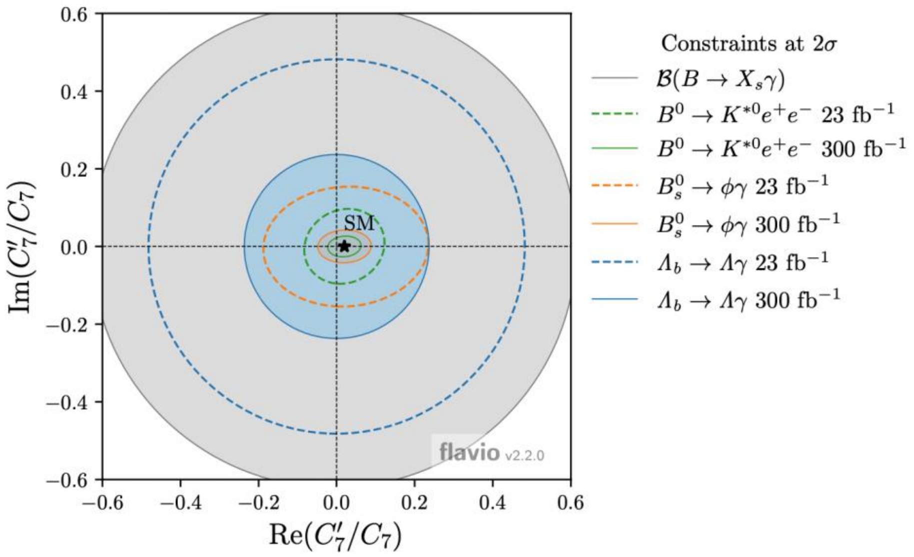
- Runs 1-2: $\mathscr{L}_{max} \sim 4 \times 10^{32}$ cm$^{-2}s^{-1}$ (9 fb^{-1})
- ~1 visible interaction/bunch-crossing

Physics potential

LHCb-PUB-2025-001

Observable	Current LHCb (up to 9 fb^{-1})	Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests				
γ ($B \to DK$, *etc.*)	2.8°	1.3°	0.8°	0.3°
ϕ_s ($B_s^0 \to J/\psi\phi$)	20 mrad	12 mrad	8 mrad	3 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	3%	2%	1%
Charm				
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare decays				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—	—	—	0.2
$A_T^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	0.060	0.043	0.016
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	0.148	0.097	0.038

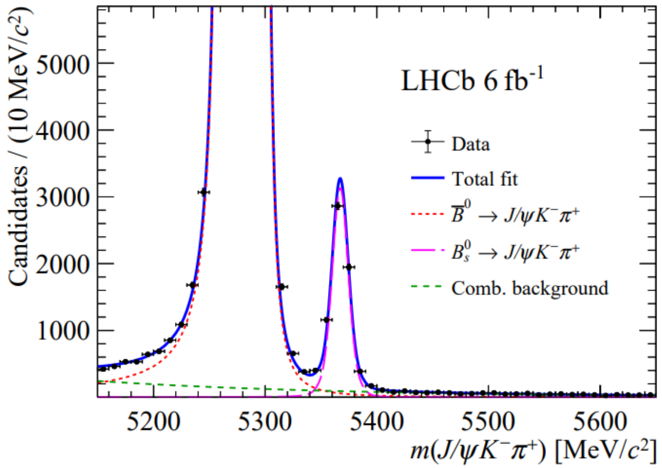


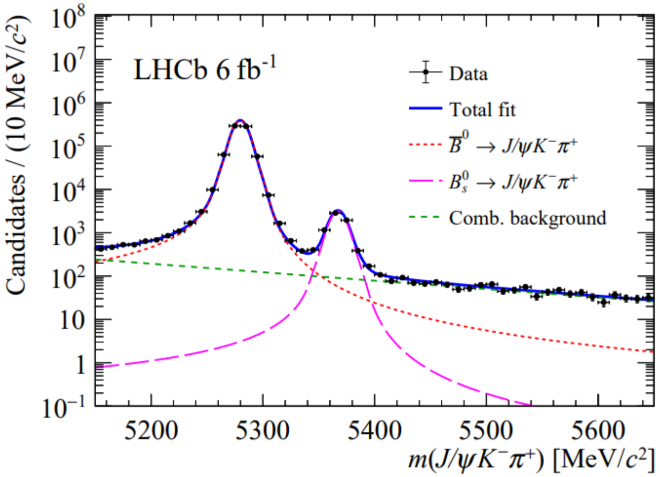


- 1% level precision for CKM elements
- Great opportunities for many new discoveries and NP searches

Back up

CPV of $B^0 \to J/\psi K^*(892)^0$





$$\begin{aligned}
f_0 &= 0.528 \pm 0.011\,(\text{stat}) \pm 0.009\,(\text{syst}),\\
f_\parallel &= 0.205 \pm 0.012\,(\text{stat}) \pm 0.005\,(\text{syst}),\\
A_0^{CP} &= 0.021 \pm 0.026\,(\text{stat}) \pm 0.007\,(\text{syst}),\\
A_\parallel^{CP} &= -0.073 \pm 0.060\,(\text{stat}) \pm 0.007\,(\text{syst}),\\
A_\perp^{CP} &= 0.057 \pm 0.049\,(\text{stat}) \pm 0.014\,(\text{syst}).
\end{aligned}$$

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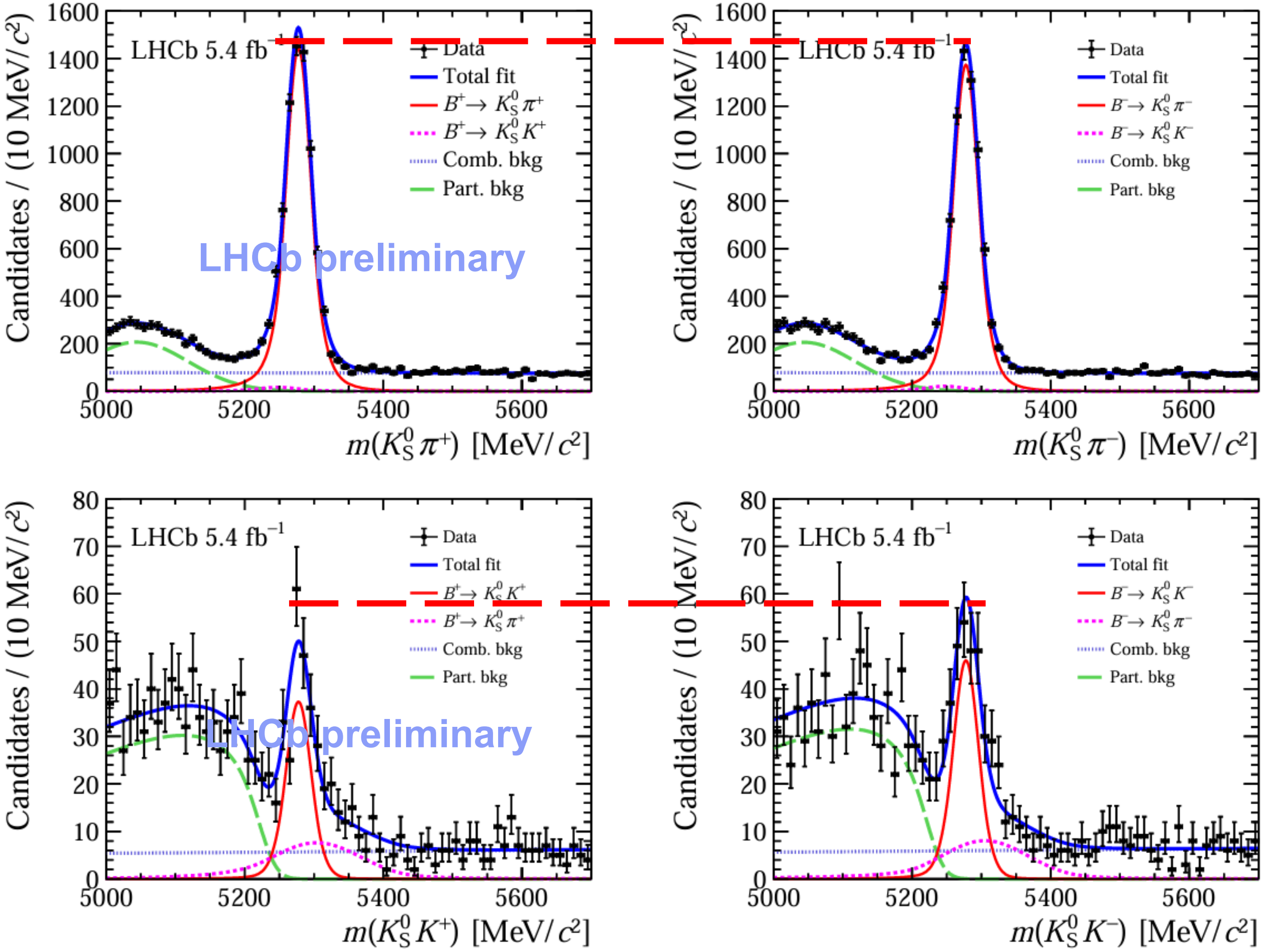
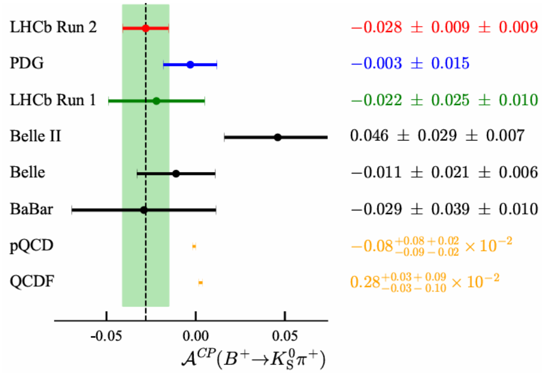
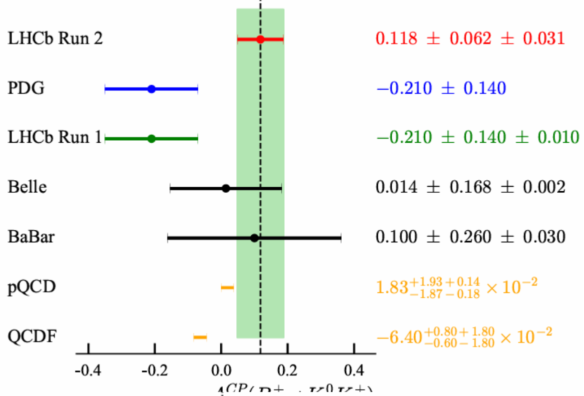
$$\frac{\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0})}{\mathcal{B}(B^0 \to J/\psi K^{*0})} = (3.12 \pm 0.09\,(\text{stat}) \pm 0.06\,(\text{syst}) \pm 0.10\,(\frac{f_d}{f_s}))\%.$$

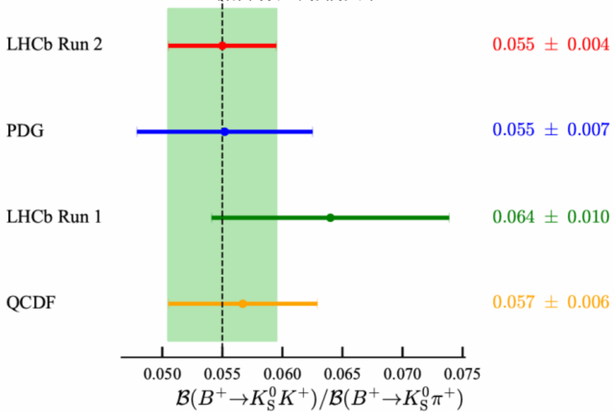
$$\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0}) = (4.13 \pm 0.12\,(\text{stat}) \pm 0.07\,(\text{syst}) \pm 0.14\,(\frac{f_d}{f_s}) \pm 0.45\,(\mathcal{B}_{B^0})) \times 10^{-5}.$$

CPV of $B^+ \to K^0_S\pi^+, K^0_S K^+$









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