Heavy spectroscopy results from LHCb

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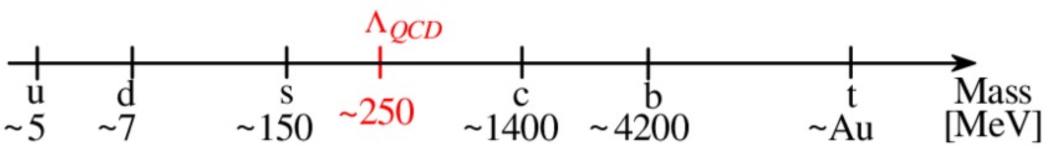
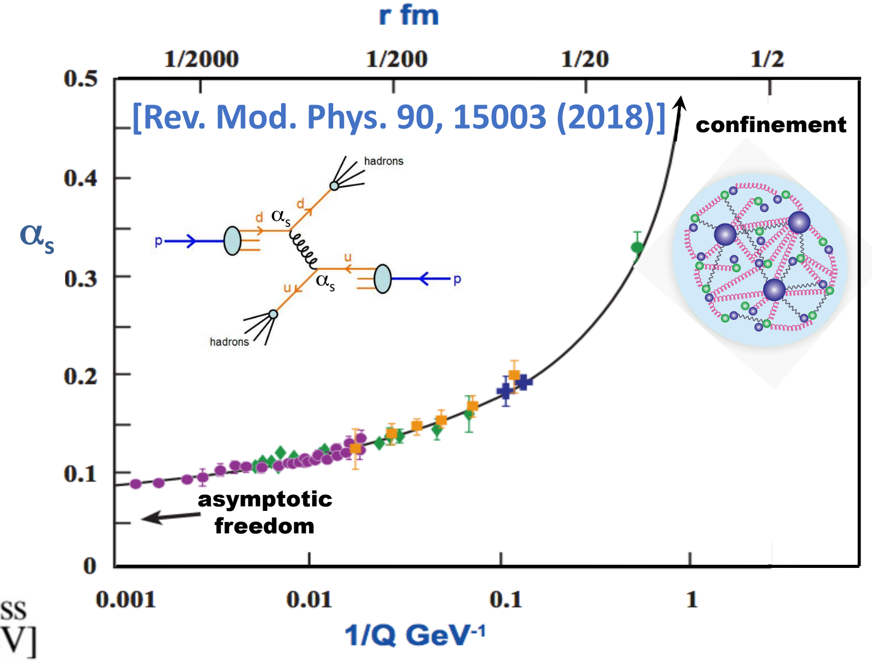
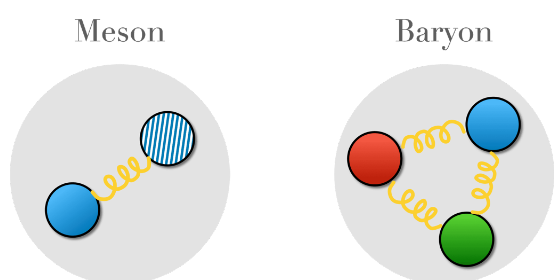
Introduction

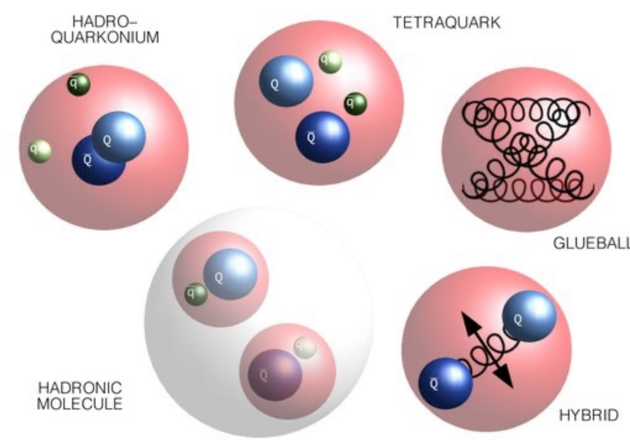
- ➢***QCD dilemma***: understanding the non-perturbative property of QCD at low-energy scale
- ➢***Hadron spectroscopy***: a main tool to probe QCD at low-energy regime
  - ✓***heavy quarks*** bring advances both experimentally and theoretically







conventional hadrons

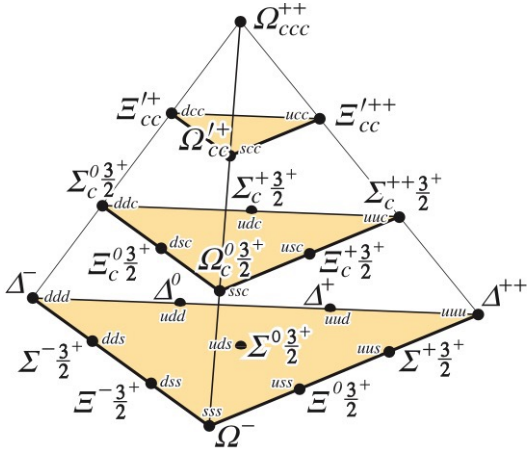


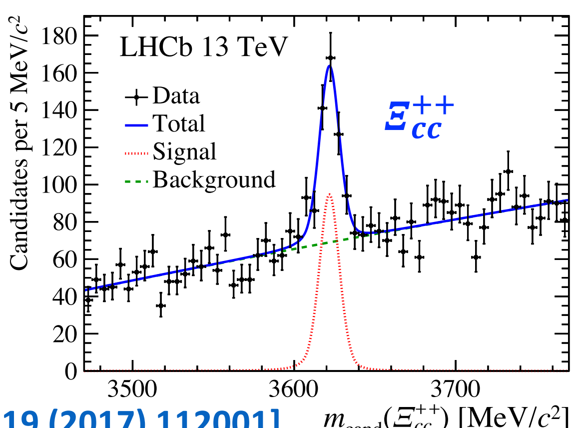
exotic hadrons

Experimental progress

conventional hadrons

- All mesons and baryons have been discovered except for bcq & bbq & $QQ'Q''$

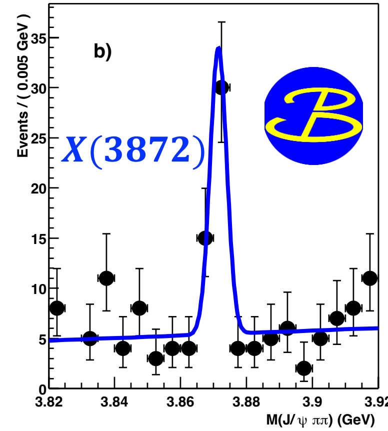




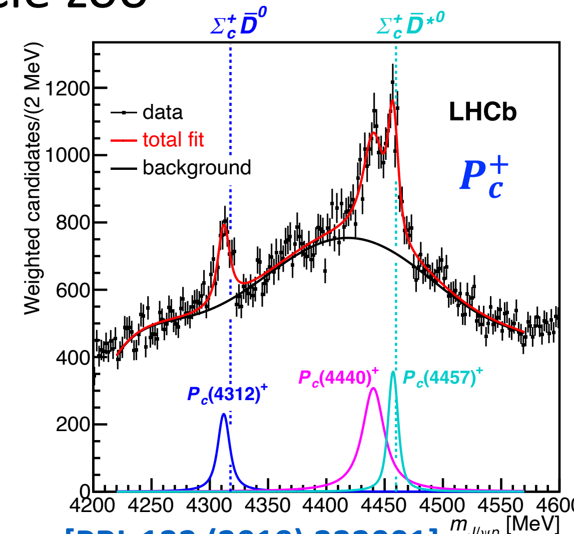
[PRL 119 (2017) 112001]

exotic hadrons

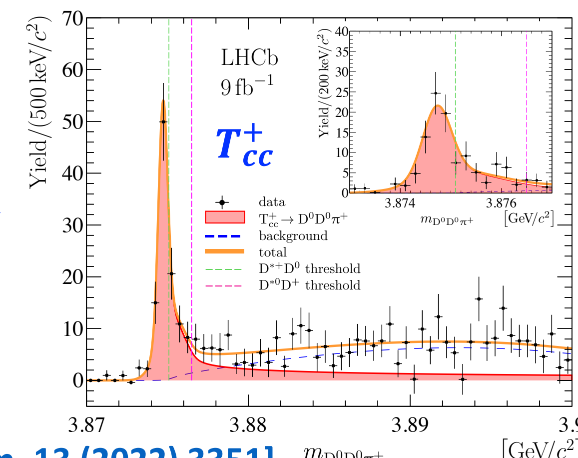
- A new “particle zoo”



[PRL 91 (2003) 262001]



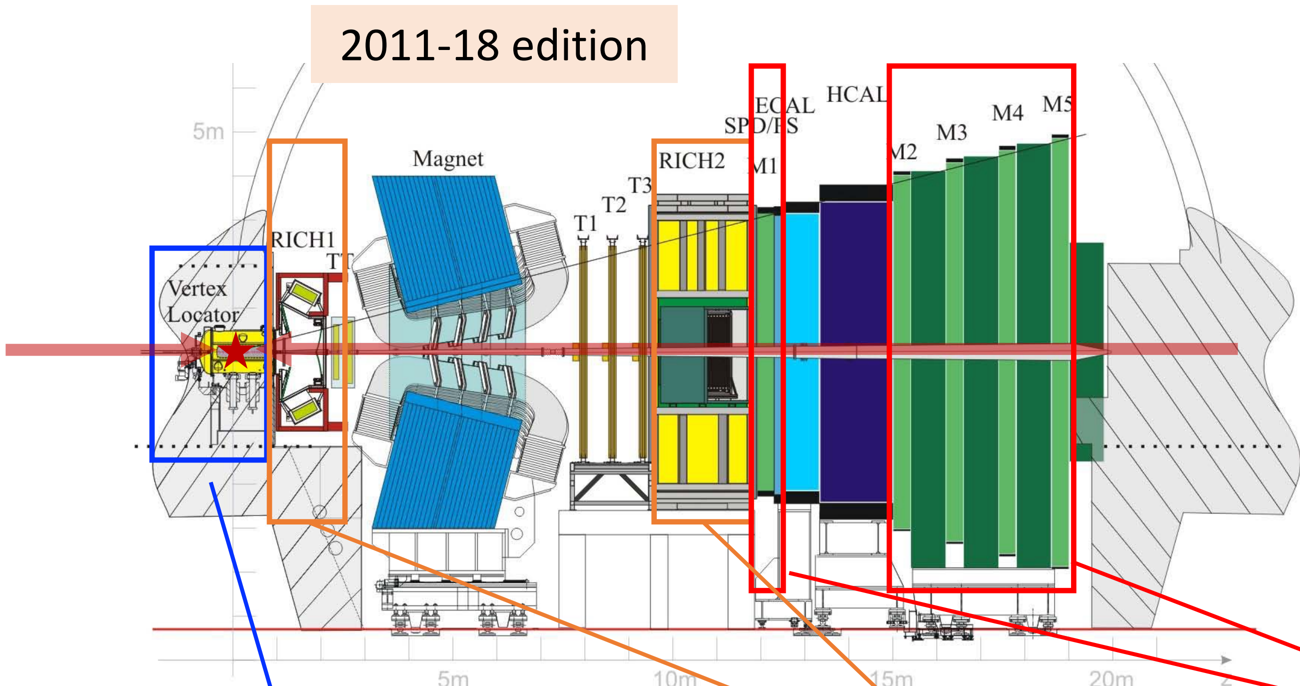
[PRL 122 (2019) 222001]



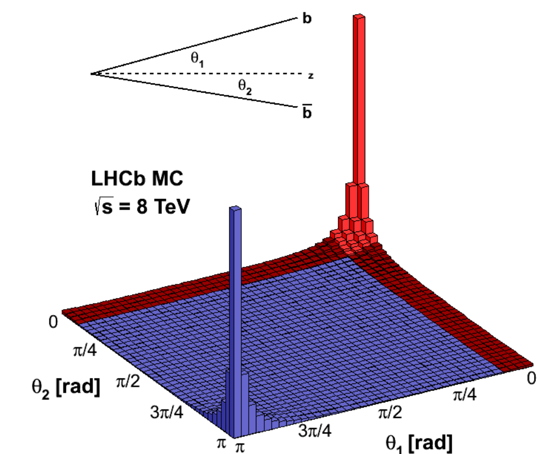
[Nature Comm. 13 (2022) 3351]

The LHCb detector

- LHCb is a single-arm forward region spectrometer covering $2 < \eta < 5$, dedicated to heavy flavor physics at the Large Hadron Collider



2.4% 4π angle
$\Rightarrow 25\%\ b\bar{b}$



Vertex Locator: high precision; capable of separating b/c hadron production and decay vertices

$\sigma_{\mathrm{PV},x/y}\sim 10\ \mu\mathrm{m}$, $\sigma_{\mathrm{PV},z}\sim 60\ \mu\mathrm{m}$

RICHs: efficient identification of pions, kaons and protons

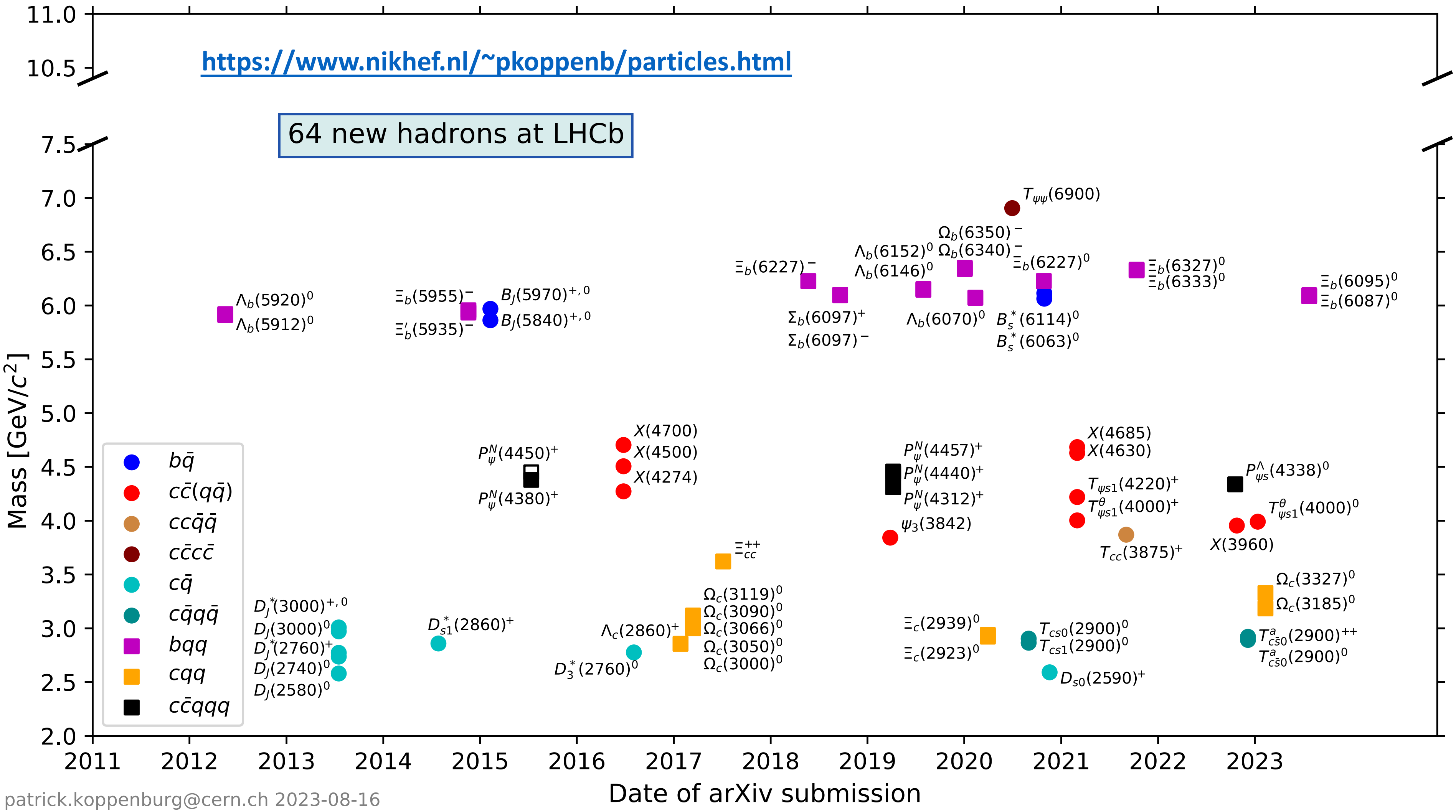
$\varepsilon(K \to K)\sim 95\%$
@ misID rate $(\pi \to K)\sim 5\%$

Muon system (M1-M5): efficient muon identification and trigger

$\varepsilon(\mu \to \mu)\sim 97\%$
@ misID rate $(\pi \to \mu)\sim 1-3\%$

[JINST 3 (2008) S08005]

Hadrons observed at LHCb



Selected new measurements

- **Exotic hadrons**
  - ✓ Search for prompt pentaquarks in open charm final states **[LHCb-PAPER-2023-018]**
  - ✓ Observation of $\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{(*)0} K^-$ and $\Lambda_b^0 \to \Lambda_c^+ D_s^{*-}$ decays **[LHCb-PAPER-2023-034]**
  - ✓ Evidence of $T_{\psi s1}^{\theta}(4000)^0$ in $B^0 \to J/\psi \phi K_S^0$ **[PRL 131 (2023) 131901]**
- **Conventional hadrons**

  New states:
  - ✓ Observation of $\Xi_b^{-/0**} \to \Xi_b^{-/0} \pi^+ \pi^-$ **[PRL 131 (2023) 171901]**
  - ✓ Observation of new $\Omega_c^0 \to \Xi_c^+ K^-$ **[PRL 131 (2023) 131902]**

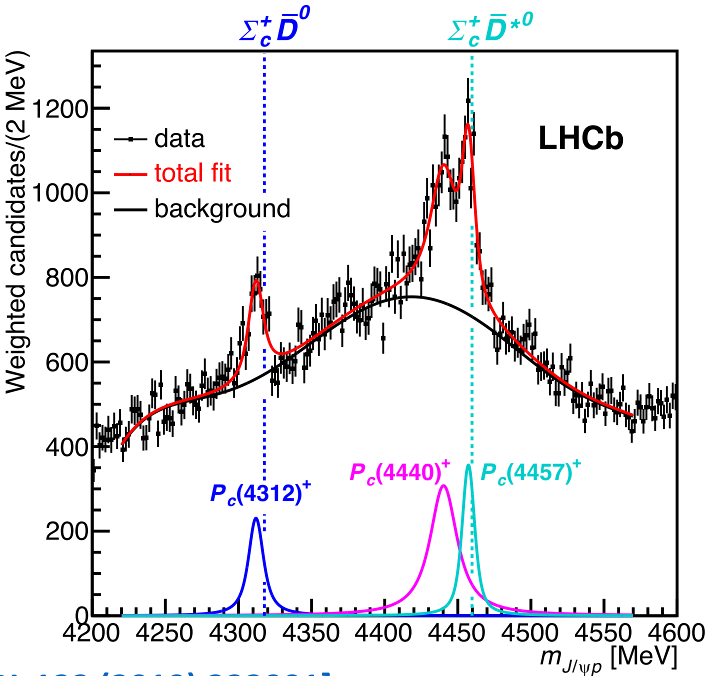
  Particle properties:
  - ✓ Measurement of mass difference of Ω_b^- and Ξ_b^- **[arXiv:2305.15329]**
  - ✓ Study of charmonium states in $B \to \left(K_S^0 K \pi\right) K$ **[PR D108 (2023) 032010]**

  Decays:
  - ✓ Observation of $\Omega_c^0 \to \Omega^- K^+$ and $\Omega_c^0 \to \Xi^- \pi^+$ **[arXiv:2308.08512]**
  - ✓ Observation of $\Xi_b^- \to \Lambda_b^0 \pi^-$ **[PR D108 (2023) 072002]**
  - ✓ Observation of $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$ decays **[arXiv: 2310.13546]**

Exotic hadrons

Background for pentaquark study

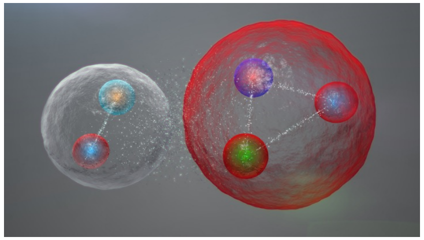
$\Lambda_b^0 \to [J/\psi\, p]K^-$



[PRL 122 (2019) 222001]

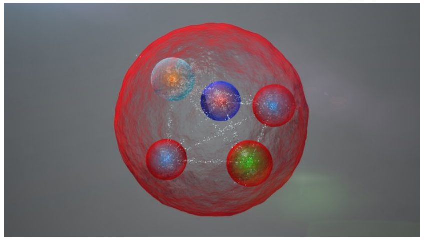
Proximity of $\Sigma_c^+ \bar{D}^0$ and $\Sigma_c^+ \bar{D}^{*0}$ thresholds to the peaks suggests they play an important role in the dynamics

Hadron molecule



- Mass proximity to threshold **natural**
- Fall-apart decay **dominant**

Compact multiquark



- Mass proximity to threshold **accidental**
- No (strong) hierarchy of couplings

➢ The observation of new decay modes can shed light on the binding scheme of the exotic hadrons ⇒ search through open charm modes

Search for pentaquarks via open charm

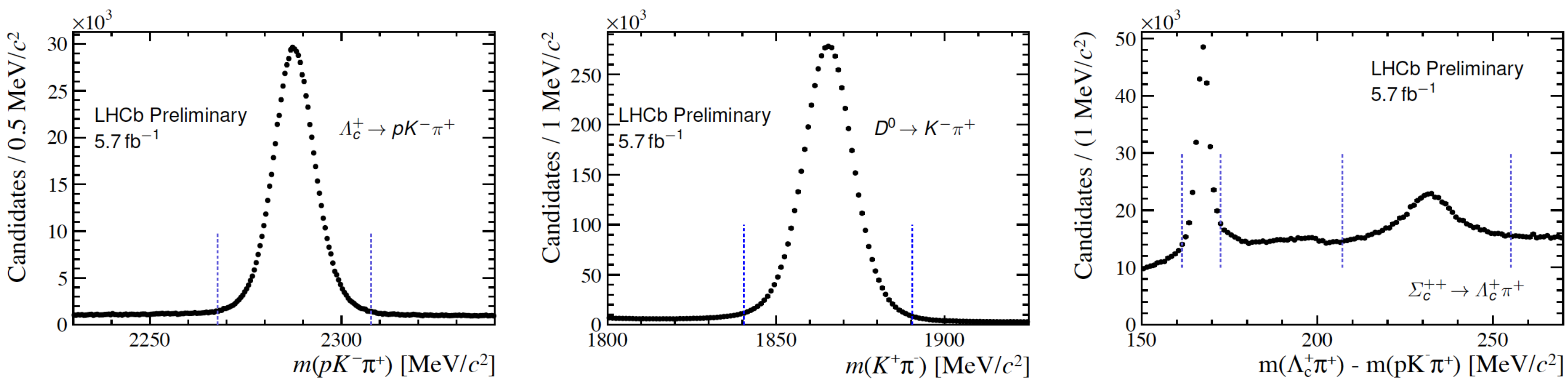
[LHCb-PAPER-2023-018]

- Inclusive search performed using 5.7 fb^{-1} data from 2016-2018
- Reconstruction: $\Lambda_c^+ \to pK^-\pi^+, D^- \to K^+\pi^-\pi^-, D^0 \to K^-\pi^+$

$$\Sigma_c^{++(0)} \to \Lambda_c^+\pi^{+(-)}, D^{*-} \to \bar{D}^0\pi^-$$

$\Sigma_c^{++}\bar{D}^0$ $\Sigma_c^{0}\bar{D}^0$	$\cancel{\Sigma_c^{++}D^0}$ $\cancel{\Sigma_c^{0}D^0}$	$\Sigma_c^{++}D^-$ $\Sigma_c^{0}D^-$	$\cancel{\Sigma_c^{++}D^+}$ $\cancel{\Sigma_c^{0}D^+}$	$\cancel{\Sigma_c^{++}D^{*-}}$ $\cancel{\Sigma_c^{0}D^{*-}}$	$\cancel{\Sigma_c^{++}D^{*+}}$ $\cancel{\Sigma_c^{0}D^{*+}}$
$\Sigma_c^{*++}\bar{D}^0$ $\Sigma_c^{*0}\bar{D}^0$	$\Sigma_c^{*++}D^0$ $\Sigma_c^{*0}D^0$	$\Sigma_c^{*++}D^-$ $\Sigma_c^{*0}D^-$	$\Sigma_c^{*++}D^+$ $\Sigma_c^{*0}D^+$	$\Sigma_c^{*++}D^{*-}$ $\Sigma_c^{*0}D^{*-}$	$\cancel{\Sigma_c^{*++}D^{*+}}$ $\cancel{\Sigma_c^{*0}D^{*+}}$
$\Lambda_c^+\bar{D}^0$	$\Lambda_c^+D^0$	$\Lambda_c^+D^-$	$\Lambda_c^+D^+$	$\Lambda_c^+D^{*-}$	$\Lambda_c^+D^{*+}$
$\Lambda_c^+\bar{D}^0\pi^+$ $\Lambda_c^+\bar{D}^0\pi^-$	$\Lambda_c^+D^0\pi^+$ $\Lambda_c^+D^0\pi^-$	$\Lambda_c^+D^-\pi^+$ $\Lambda_c^+D^-\pi^-$	$\Lambda_c^+D^+\pi^+$ $\Lambda_c^+D^+\pi^-$	$\Lambda_c^+D^{*-}\pi^+$ $\Lambda_c^+D^{*-}\pi^-$	$\Lambda_c^+D^{*+}\pi^+$ $\Lambda_c^+D^{*+}\pi^-$

*10 modes too statistically limited to set upper limits

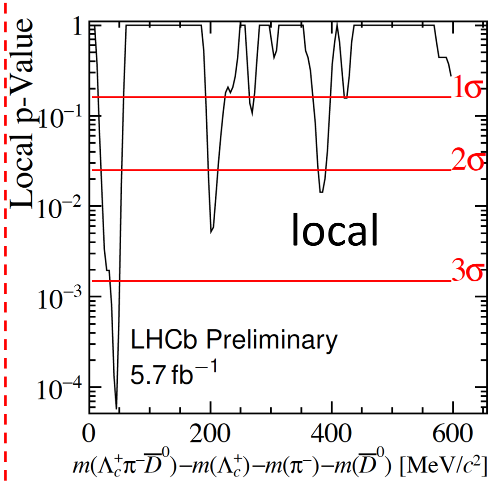


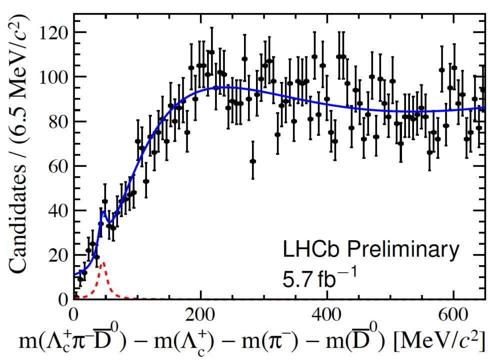
Results

- No significant signals are found

[LHCb-PAPER-2023-018]

- Upper limits set on $R = \frac{N_{P_c}}{N_{\Lambda_c^+}} \times \frac{\varepsilon_{\Lambda_c^+}}{\varepsilon_{P_c}} \rightarrow \frac{\sigma(P_c)\times\mathcal{B}\left(P_c\to\Lambda_c^+ D(\pi)\right)\times\mathcal{B}(D)}{\sigma(\Lambda_c^+)}$





$cc\bar{u}dd$

$M\sim 4335.87$ MeV

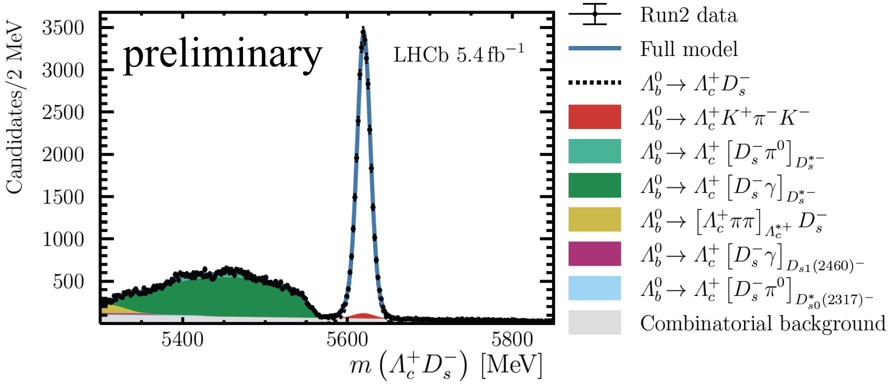
Decay Mode	Significance (σ) Local	Significance (σ) Global	Corresponding Mass (MeV/c^2)	Signal Yield	Upper Limit ($\times10^{-3}$) 90% CL	Upper Limit ($\times10^{-3}$) 95% CL
$\Lambda_c^+\overline{D}^0$	2.85	1.01	349	46.8 ± 23.4	1.16	1.21
$\Lambda_c^+D^{*-}$	2.32	0.00	365	15.0 ± 10.3	2.16	2.39
$\Lambda_c^+\pi^+D^-$	2.82	0.99	225	68.6 ± 13.3	1.95	2.40
$\Sigma_c^0\overline{D}^0$	1.90	0.00	65	4.7 ± 4.2	1.02	1.15
$\Lambda_c^+\pi^-\overline{D}^0$	3.86	2.56	45	60.1 ± 25.9	1.40	1.70
$\Sigma_c^0D^-$	2.03	0.00	261	7.0 ± 2.6	0.71	0.89
$\Lambda_c^+\pi^-D^-$	3.67	2.35	249	82.8 ± 14.3	2.23	2.67
$\Lambda_c^+\pi^-D^{*-}$	2.31	0.00	409	23.6 ± 23.0	2.79	3.28
$\Sigma_c^{*++}D^{*-}$	1.74	0.00	453	3.3 ± 2.4	1.24	1.43
$\Sigma_c^{*0}D^-$	1.86	0.00	109	10.7 ± 29.1	1.32	1.59
$\Lambda_c^+D^+$	2.52	0.59	169	14.9 ± 9.6	1.34	1.50
$\Lambda_c^+\pi^+D^0$	3.21	1.72	45	24.8 ± 39.3	0.98	1.18
$\Lambda_c^+\pi^+D^{*+}$	3.37	1.99	165	13.8 ± 3.5	0.97	1.22
$\Lambda_c^+\pi^-D^{*+}$	2.70	0.58	73	5.8 ± 71.3	1.70	1.94
$\Sigma_c^{*++}D^0$	2.11	0.00	113	3.9 ± 2.8	0.87	0.99
$\Sigma_c^{*0}D^+$	2.18	0.00	69	4.7 ± 4.6	1.13	1.32

✓ Known P_c^+ states tested and yields all agree with 0

$P_c(4312)^+$	$M=4311.9$ MeV, $\Gamma=10$ MeV
$P_c(4440)^+$	$M=4440$ MeV, $\Gamma=21$ MeV
$P_c(4457)^+$	$M=4457.3$ MeV, $\Gamma=6.4$ MeV

$\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{(*)0} K^-$ and $\Lambda_b^0 \to \Lambda_c^+ D_s^{*-}$ [LHCb-PAPER-2023-034]

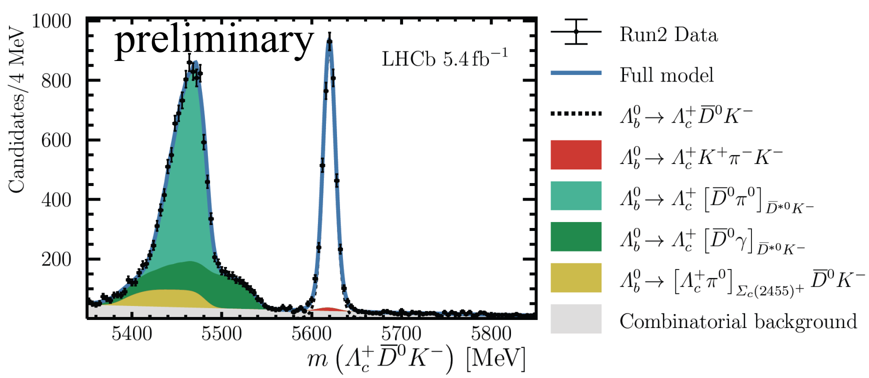
- The observation and branching fraction (BF) measurements of these decays can
  - ✓ pave the way for future P_c^+ search in $\Lambda_c^+ \overline{D}^{(*)0}$ systems, which are open-charm equivalent of $J/\psi p$
  - ✓ probe factorization assumptions in effective QCD theories



$$\frac{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \overline{D}^0 K^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right)} = 0.1908^{+0.0036+0.0016}_{-0.0034-0.0018} \pm 0.0038,$$

$$\frac{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{*0} K^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right)} = 0.589^{+0.018+0.017}_{-0.017-0.018} \pm 0.012,$$

$$\frac{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^{*-}\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right)} = 1.668 \pm 0.022^{+0.061}_{-0.055},$$



$$\boxed{\frac{\mathcal{B}\left(\Lambda_b^0 \to J/\psi p K^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \overline{D}^0 K^-\right)} = 0.152^{+0.032}_{-0.028}, \quad \frac{\mathcal{B}\left(\Lambda_b^0 \to J/\psi p K^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{*0} K^-\right)} = 0.049^{+0.011}_{-0.009},}$$

*Fit fraction of P_c^+ in $\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{(*)0} K^-$

$$\boxed{f_{\Lambda_c^+ \overline{D}^{(*)0}}\left(P_c^+\right)} = \boxed{f_{J/\psi p}\left(P_c^+\right)} \cdot \boxed{\frac{\mathcal{B}\left(\Lambda_b^0 \to J/\psi p K^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \overline{D}^{(*)0} K^-\right)}} \cdot \frac{\mathcal{B}\left(P_c^+ \to \Lambda_c^+ \overline{D}^{(*)0}\right)}{\mathcal{B}\left(P_c^+ \to J/\psi p\right)}$$

future study

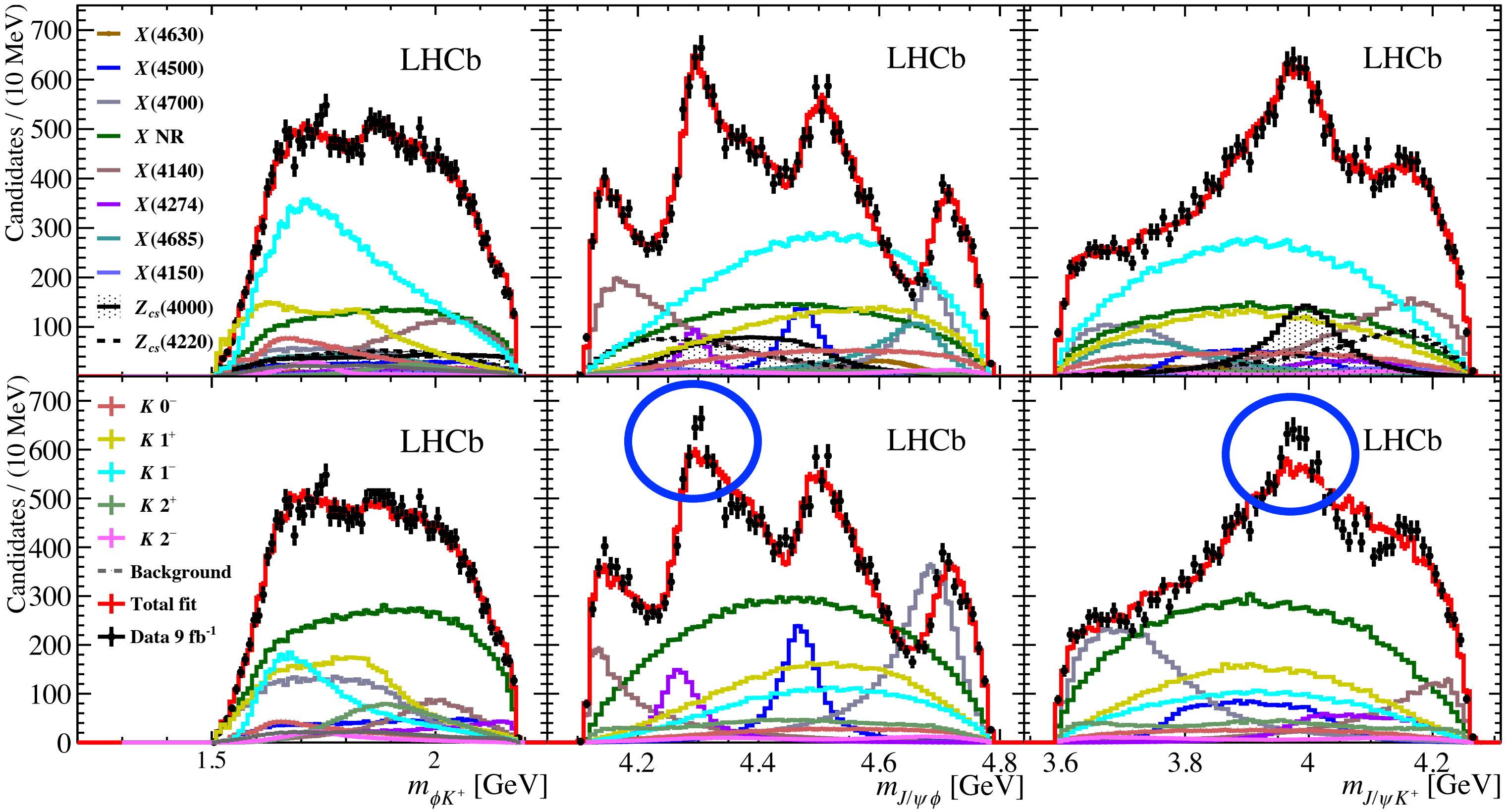
measured

theoretically interesting

$T_{\psi s1}^{\theta}(4000)^+$ in $B^+ \to J/\psi\phi K^+$

Zehua Xu, Liming Zhang

[PRL 127 (2021) 082001]



Updated model

Run 1 model

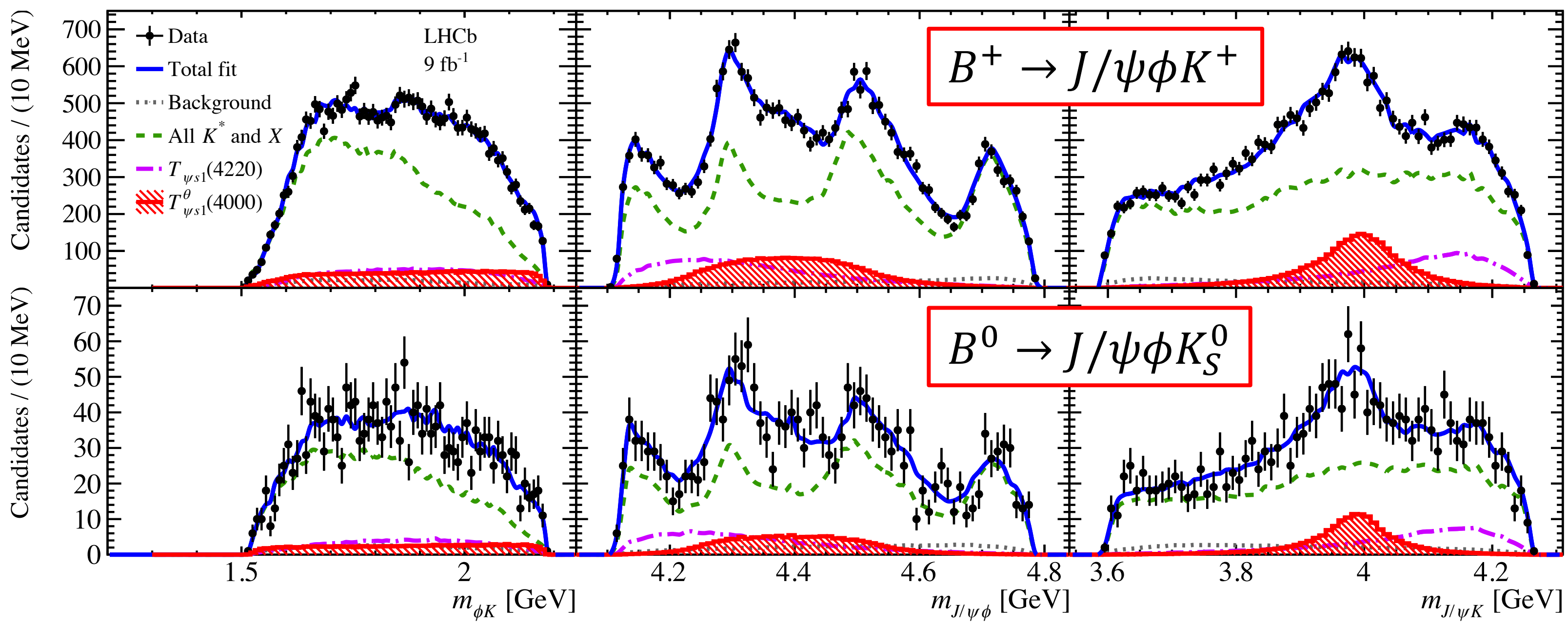
- $Z_{cs}(4000)$ (i.e. $T_{\psi s1}^{\theta}(4000)^+$) was observed with significance $> 10\ \sigma$
- J^P of $Z_{cs}(4000)$ was firmly determined to be 1^+

Evidence of $T_{\psi s1}^{\theta}(4000)^0$ in $B^0 \to J/\psi\phi K_S^0$

Zhihong Shen
Liming Zhang

- ➢ $B^0 \to J/\psi\phi K_S^0$ and $B^+ \to J/\psi\phi K^+$ are related by isospin symmetry
- ➢ Joint amplitude fit performed assuming isospin symmetry except for $T_{\psi s1}^{\theta}(4000)^0$, with significance of 4σ (5.4σ under isospin assumption)

[PRL 131 (2023) 131901]



$$M(T_{\psi s1}^{\theta}(4000)^0) = 3991\,^{+12}_{-10}\,^{+\ 9}_{-17}\ \text{MeV}$$
$$\Gamma(T_{\psi s1}^{\theta}(4000)^0) = 105\,^{+29}_{-25}\,^{+17}_{-23}\ \text{MeV}$$

$$\Delta M\left(T_{\psi s1}^{\theta 0} - T_{\psi s1}^{\theta +}\right) = -12^{+11}_{-10}{}^{+6}_{-4}\ \text{MeV}$$

- ➢ $T_{\psi s1}^{\theta}(4000)^0$ and $T_{\psi s1}^{\theta}(4000)^+$ are likely to be isospin partners

Conventional hadrons

-- New states

Singly-heavy baryons

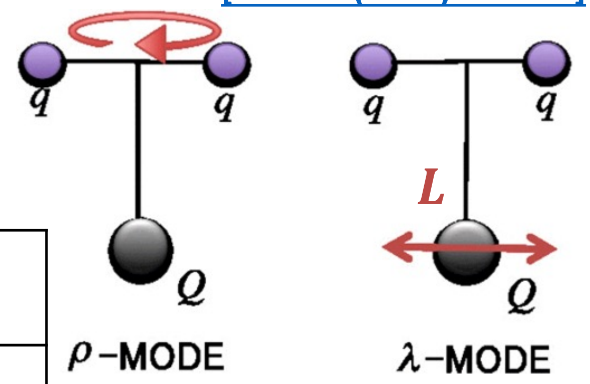
➢Missing resonances problem in baryon physics

⇒ heavy quark-light diquark $Q[qq]$ model is widely used to describe Qqq systems

✓λ-mode: low-lying states well established for most species

✓ρ-mode: no firm assignment yet

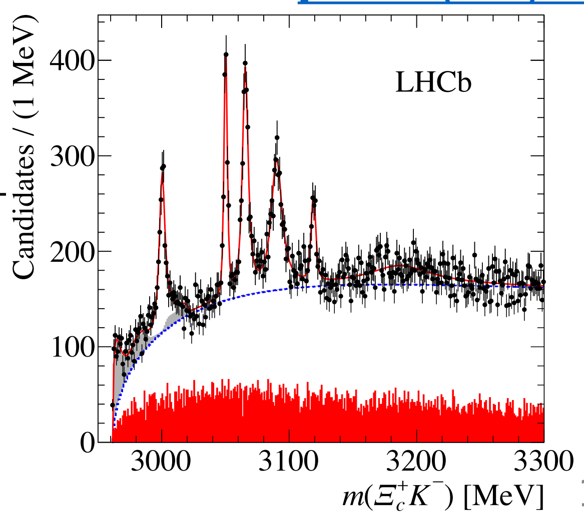
[PRD 92 (2015) 114029]



➢**$\Xi_b^{-/0}$ spectrum** (based on λ-mode)

	$J^P_{[qq]} = 0^+$	$J^P_{[qq]} = 1^+$
$L = 0$	$(1/2)^+$ $\Xi_b^{0,-}$	$(1/2)^+, (3/2)^+$ $\Xi_b'(5935)^-, \Xi_b(5955)^- \to \Xi_b^0\pi^-$ $\Xi_b(5945)^0 \to \Xi_b^-\pi^+$
$L = 1$	$(1/2)^-, (3/2)^-$ $\boldsymbol{\Xi_b(6100)^- \to \Xi_b(5945)^0\pi^-}$ [PRL 126 (2021) 252003] by CMS	……

[PRL 118 (2017) 182001]



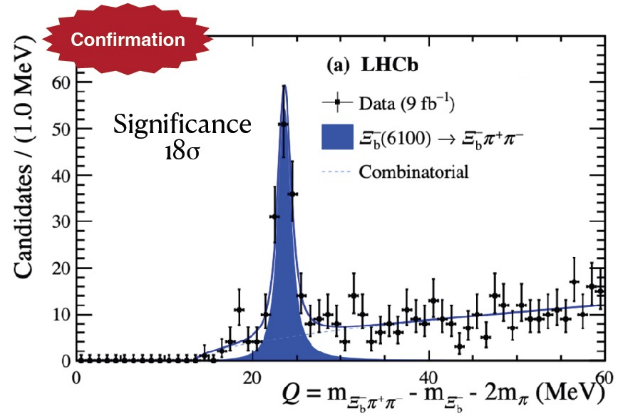
➢**Ω_c^0 spectrum**:
yet no consensus on the interpretation of observed excited states

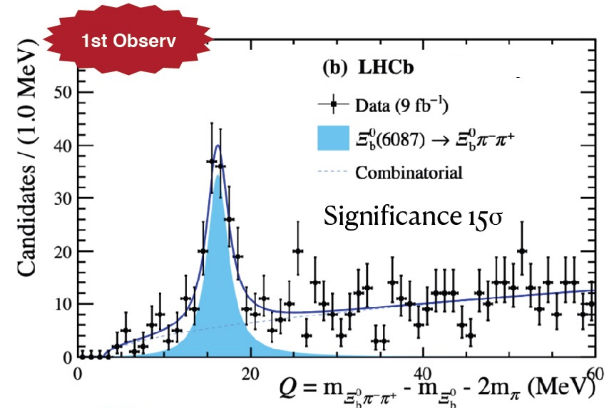
Observation of $\Xi_b^{-/0**} \to \Xi_b^{-/0}\pi^+\pi^-$

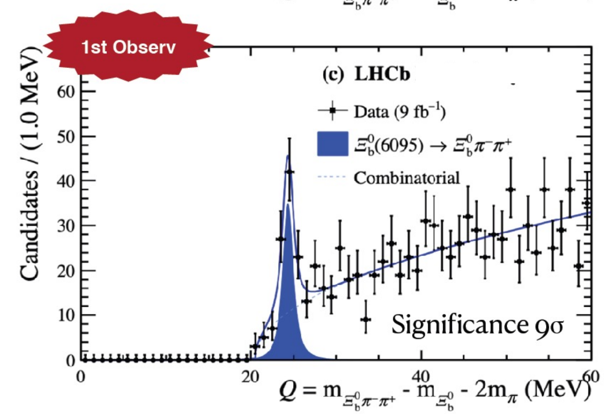
[PRL 131 (2023) 171901]

- $\Xi_b^-\pi^+\pi^-$ with $\Xi_b^- \to \Xi_c^0[pK^-K^+\pi^+]\pi^-$ and $\Xi_b^- \to \Xi_c^0[pK^-K^+\pi^+]\pi^-\pi^+\pi^-$: an LHCb record of 9 tracks!
- $\Xi_b^0\pi^+\pi^-$ with $\Xi_b^0 \to \Xi_c^+[pK^-\pi^+]\pi^-$ and $\Xi_b^0 \to \Xi_c^+[pK^-\pi^+]\pi^-\pi^+\pi^-$

[PRL 126 (2021) 252003] by CMS







	Value [MeV]
$Q_0\ (\Xi_b^-(6100))$	$23.60 \pm 0.11 \pm 0.02$
$\Gamma\ (\Xi_b^-(6100))$	$0.94 \pm 0.30 \pm 0.08$
$m_0\ (\Xi_b^-(6100))$	$6099.74 \pm 0.11 \pm 0.02 \pm 0.6\ (\Xi_b^-)$
$Q_0\ (\Xi_b^0(6087))$	$16.20 \pm 0.20 \pm 0.06$
$\Gamma\ (\Xi_b^0(6087))$	$2.43 \pm 0.51 \pm 0.10$
$m_0\ (\Xi_b^0(6087))$	$6087.24 \pm 0.20 \pm 0.06 \pm 0.5\ (\Xi_b^0)$
$Q_0\ (\Xi_b^0(6095))$	$24.32 \pm 0.15 \pm 0.03$
$\Gamma\ (\Xi_b^0(6095))$	$0.50 \pm 0.33 \pm 0.11$
$m_0\ (\Xi_b^0(6095))$	$6095.36 \pm 0.15 \pm 0.03 \pm 0.5\ (\Xi_b^0)$

Confirmation

1st Observ

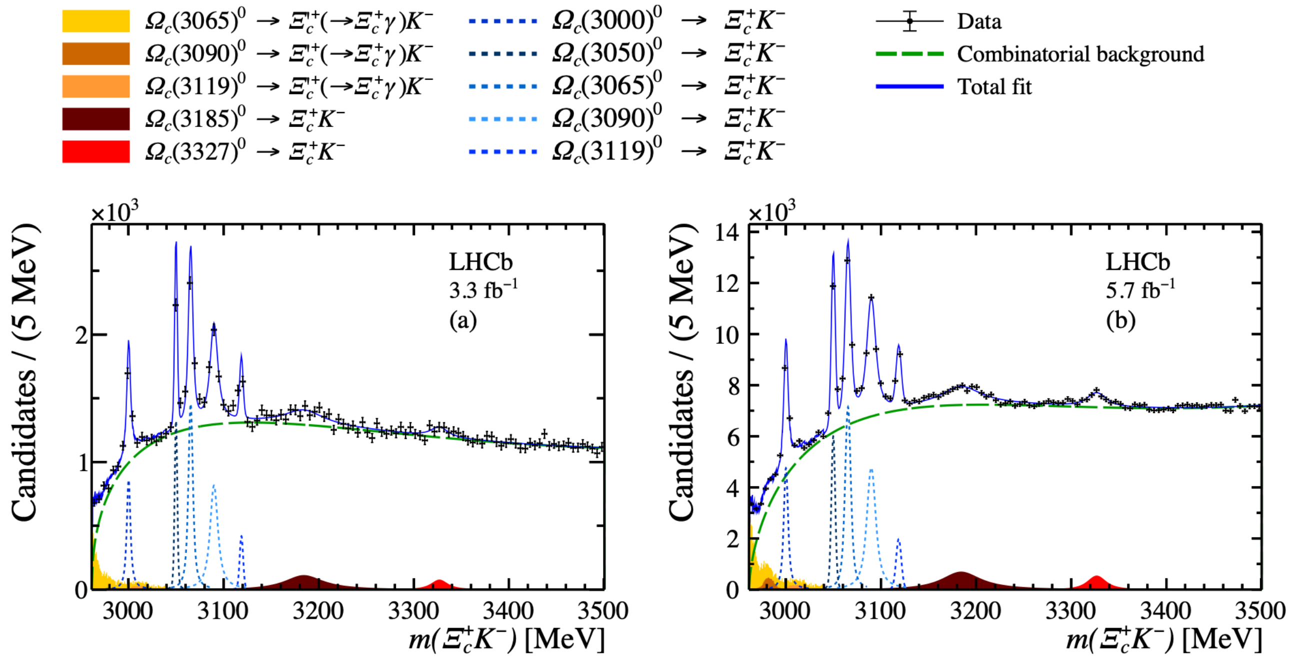
✓ Consistent with naïve expectation for 1P $J^P_{[qq]} = 0^+$ $(1/2)^-, (3/2)^-$ doublet

Observation of new $\Omega_c^0 \to \Xi_c^+ K^-$

Zhihao Xu
Jibo He

[PRL 131 (2023) 131902]

- Using full 9 fb^{-1} Run1+Run2 LHCb data



Resonance	m (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.44 \pm 0.07\ ^{+0.07}_{-0.13} \pm 0.23$	$3.83 \pm 0.23\ ^{+1.59}_{-0.29}$
$\Omega_c(3050)^0$	$3050.18 \pm 0.04\ ^{+0.06}_{-0.07} \pm 0.23$	$0.67 \pm 0.17\ ^{+0.64}_{-0.72}$ < 1.8 MeV, 95% C.L.
$\Omega_c(3065)^0$	$3065.63 \pm 0.06\ ^{+0.06}_{-0.06} \pm 0.23$	$3.79 \pm 0.20\ ^{+0.38}_{-0.47}$
$\Omega_c(3090)^0$	$3090.16 \pm 0.11\ ^{+0.06}_{-0.10} \pm 0.23$	$8.48 \pm 0.44\ ^{+0.61}_{-1.62}$
$\Omega_c(3119)^0$	$3118.98 \pm 0.12\ ^{+0.09}_{-0.23} \pm 0.23$	$0.60 \pm 0.63\ ^{+0.90}_{-1.05}$ < 2.5 MeV, 95% C.L.
$\Omega_c(3185)^0$	$3185.1 \pm 1.7\ ^{+7.4}_{-0.9} \pm 0.2$	$50 \pm 7\ ^{+10}_{-20}$
$\Omega_c(3327)^0$	$3327.1 \pm 1.2\ ^{+0.1}_{-1.3} \pm 0.2$	$20 \pm 5\ ^{+13}_{-1}$

✓ Most precise mass and width measurement

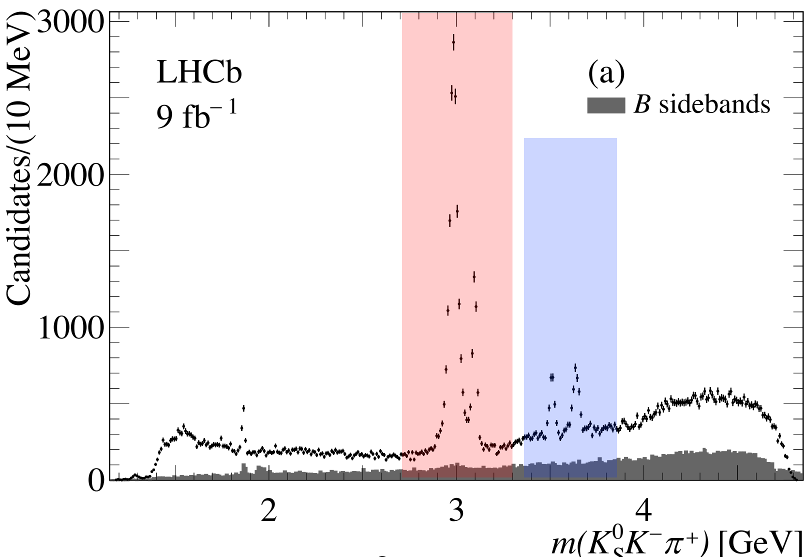
✓ Two new states:

Conventional hadrons

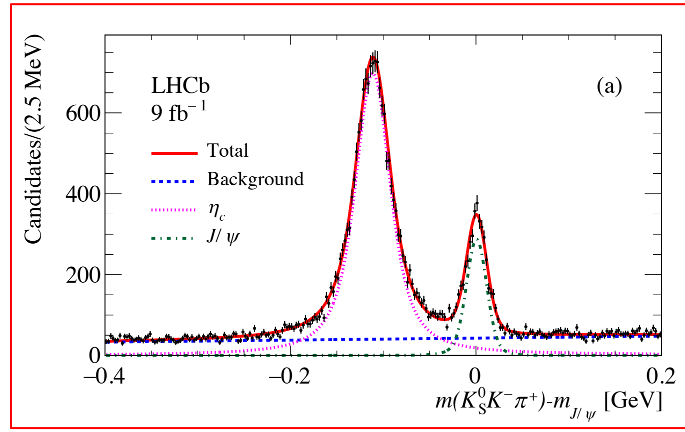
-- Particle properties

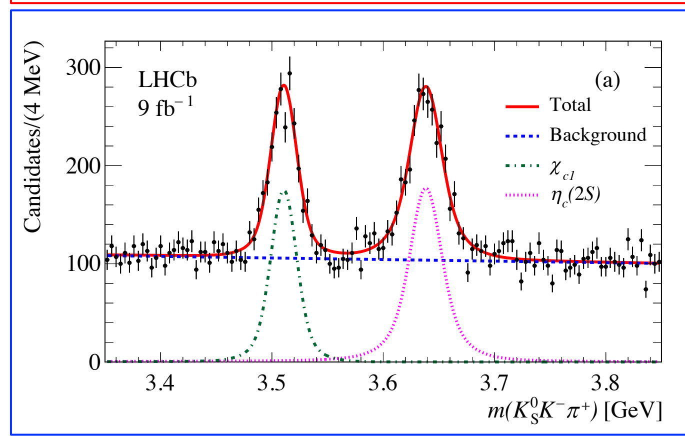
Charmonium in $B \to (K_S^0 K\pi)K$ [PRD 108 (2023) 032010]

➢The $B^+ \to K_S^0 K^+ K^- \pi^+$ and $B^+ \to K_S^0 K^+ K^+ \pi^-$ decays are studied with 9 fb^{-1} data, giving a rich set of results



*similar in $K_S^0 K^+ \pi^-$





Res.	Mass [MeV]	Width [MeV]
η_c	$2985.01 \pm 0.17 \pm 0.89$	$29.7 \pm 0.5 \pm 0.2$
$\eta_c(2S)$	$3637.90 \pm 0.54 \pm 1.40$	$10.77 \pm 1.62 \pm 1.08$
χ_{c1}	$3509.84 \pm 0.69 \pm 0.64$	

best single measurement

Not able to cover

✓Dalitz plot ana. of $\eta_c \& \eta_c(2S) \to K_S^0 K\pi$

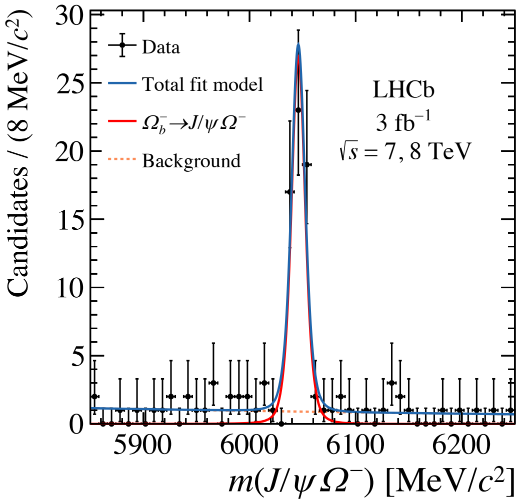
✓First observation of $B^+ \to \chi_{c0} K^0 \pi^+$

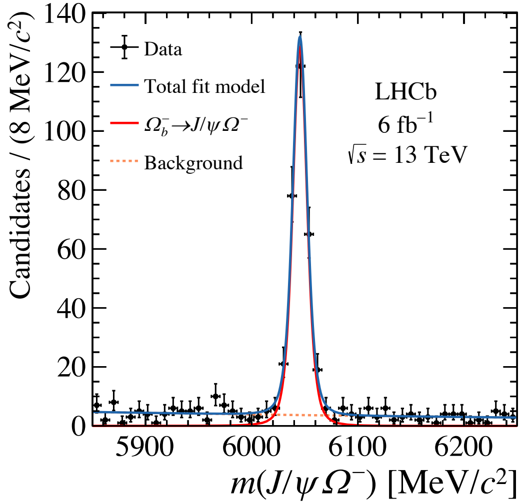
✓A series of BF measurements

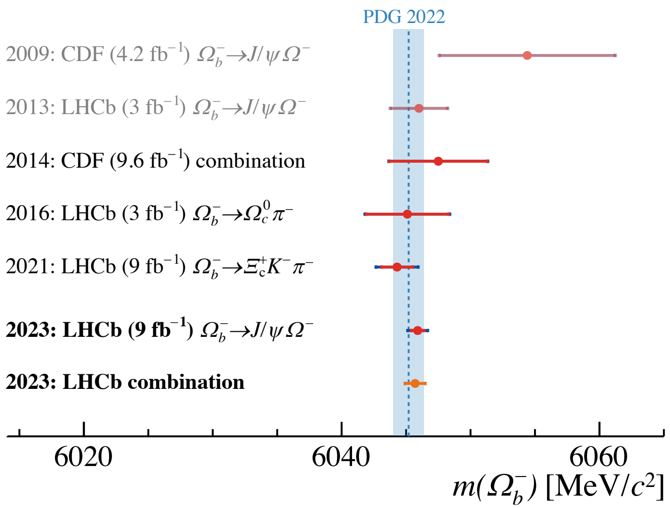
Mass difference of Ω_b^- and Ξ_b^-

[arXiv: 2305.15329]

- Ω_b^- is the least-well studied weakly decaying singly heavy b-baryon
- Ω_b^- mass measured with $\Omega_b^- \to J/\psi\Omega$ using all 9 fb^{-1} data
  - ✓small Q-value
  - ✓clean signal sample with $\Omega \to \Lambda K^-, \Lambda \to p\pi^-$







$$\boxed{m(\Omega_b^-) - m(\Xi_b^-) = 248.54 \pm 0.51\,(\text{stat}) \pm 0.38\,(\text{syst})\ \text{MeV}/c^2}$$

✓mass measured relative to $\Xi_b^- \to J/\psi\Xi^-$ to cancel systematic uncertainty

$$\frac{f_{\Omega_b^-}}{f_{\Xi_b^-}} \times \frac{\mathcal{B}(\Omega_b^- \to J/\psi\Omega^-)}{\mathcal{B}(\Xi_b^- \to J/\psi\Xi^-)} = 0.120 \pm 0.008\,(\text{stat}) \pm 0.008\,(\text{syst})$$

Conventional hadrons

-- Decays

Observation of $\Omega_c^0 \to \Omega^- K^+ \& \Xi^- \pi^+$

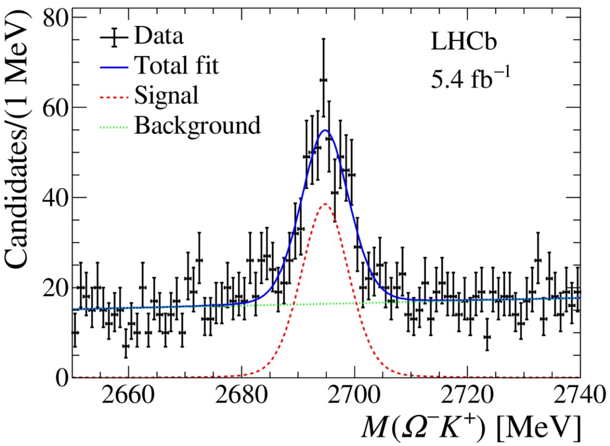
Chuangxin Lin
Miroslav Saur
Ziyi Wang
[arXiv: 2308.08512]

- Current experimental knowledge of Ω_c^0 is very limited
- Predictions of BFs for $\Omega_c^0 \to \Omega^- \pi^+$ and $\Omega_c^0 \to \Xi^- \pi^+$ have significant discrepancies between different models

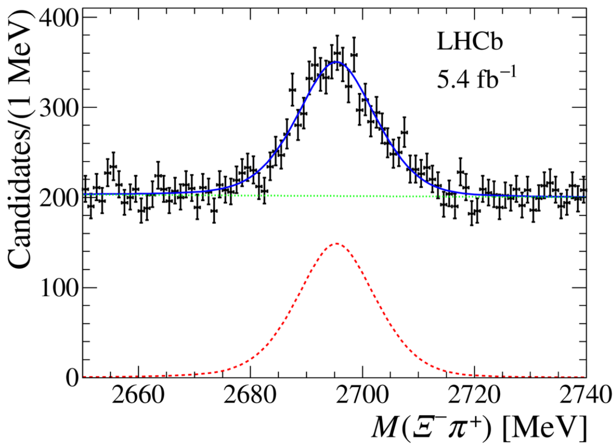
first observation

mass measurement

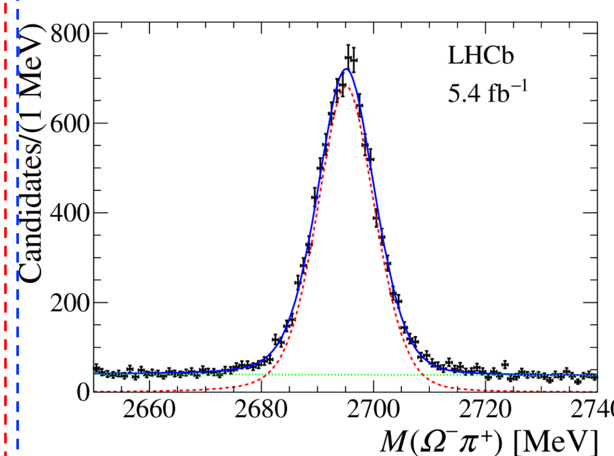
$\Omega_c^0 \to \Omega^- K^+$



$\Omega_c^0 \to \Xi^- \pi^+$



$\Omega_c^0 \to \Omega^- \pi^+$



external W-emission & W-exchange transitions

external W-emission only

$$\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- K^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 0.0608 \pm 0.0051\,(\text{stat}) \pm 0.0040\,(\text{syst}),$$

$$\frac{\mathcal{B}(\Omega_c^0 \to \Xi^- \pi^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 0.1581 \pm 0.0087\,(\text{stat}) \pm 0.0043\,(\text{syst}) \pm 0.0016\,(\text{ext})$$

$$M(\Omega_c^0) = 2695.28 \pm 0.07\,(\text{stat}) \pm 0.27\,(\text{syst}) \pm 0.30\,(\text{ext})\ \text{MeV}/c^2$$

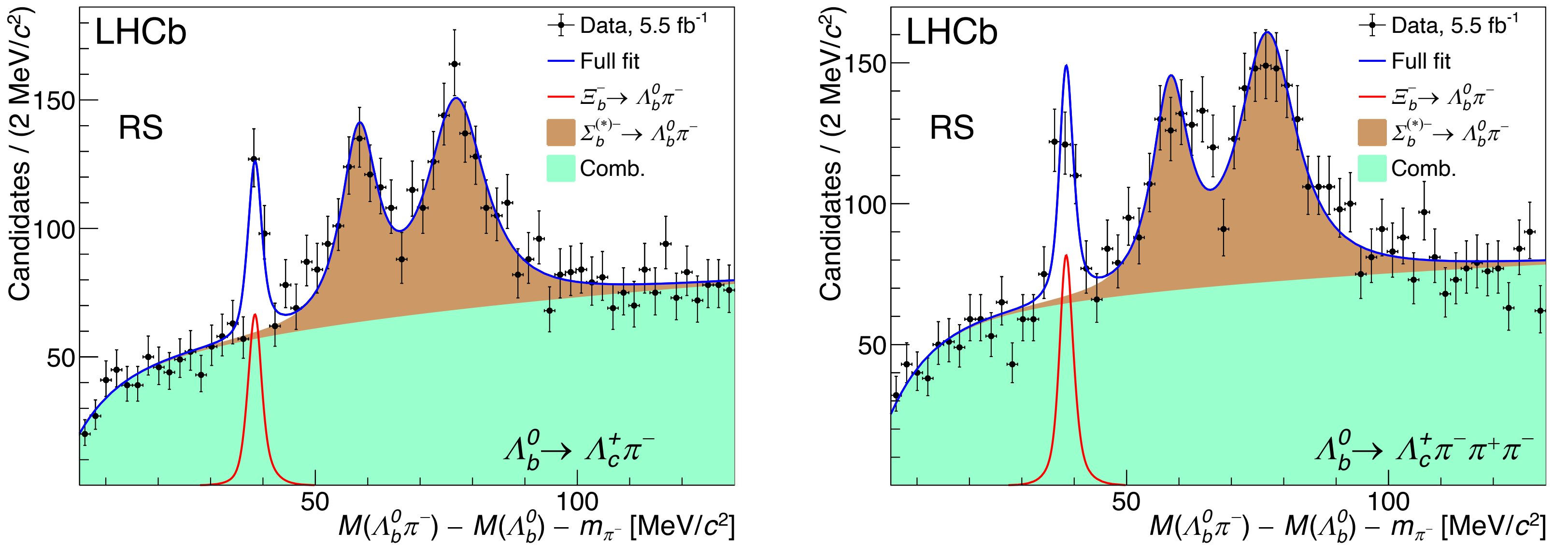
✓Indicating W-exchange contributions are necessary

✓Improving current precision by a factor of four

Observation of $\Xi_b^- \to \Lambda_b^0\pi^-$

[PRD 108 (2023) 072002]

- $\Xi_b^- \to \Lambda_b^0\pi^-$ is a decay process with the b quark as spectator
  - ✓test diquark model and probe possible enhanced short-range correlations within diquarks
  - ✓s-quark decay should be considered in Ξ_b^- decay width calculation



✓First observation

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}}\mathcal{B}(\Xi_b^- \to \Lambda_b^0\pi^-) = (7.3 \pm 0.8 \pm 0.6) \times 10^{-4}$$

$$\mathcal{B}(\Xi_b^- \to \Lambda_b^0\pi^-) = (0.89 \pm 0.10 \pm 0.07 \pm 0.29)\%$$

✓Consistent with diquark model calculation [JHEP 03 (2016) 028]

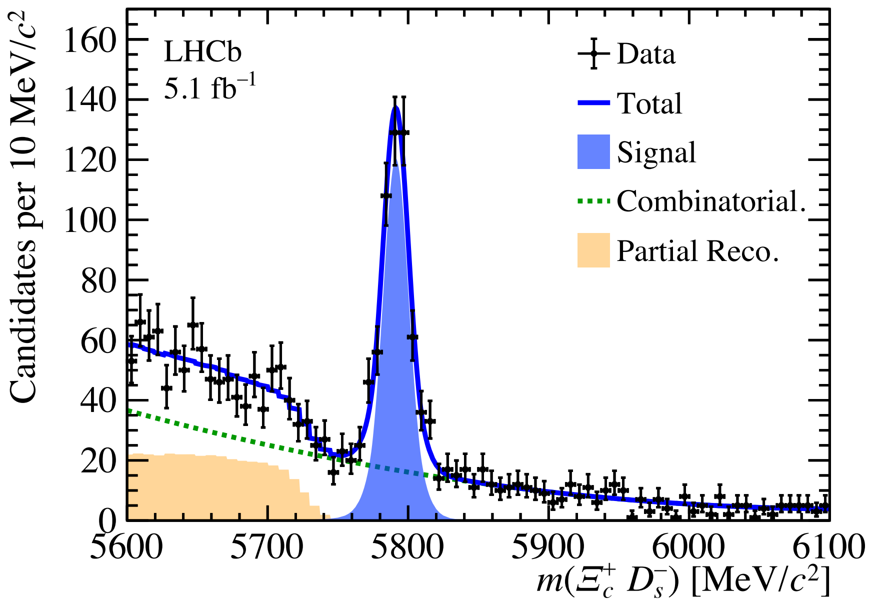
✓No large enhancement [PRD 90 (2014) 033016]

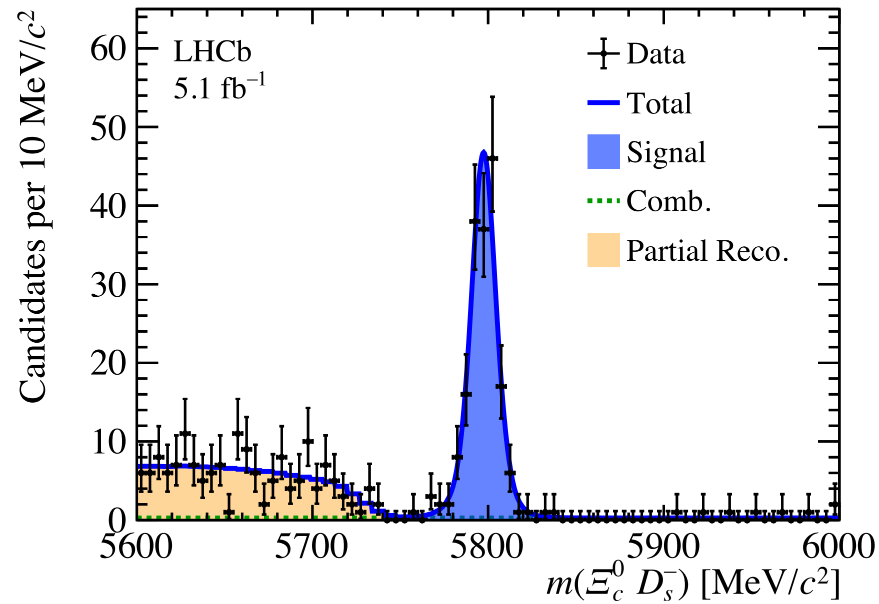
Observation of $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$

- Study on decay modes of $\Xi_b^{0/-}$ is limited
  - ✓ test the *SU(3)* flavor symmetry by comparing to Λ_b^0 decays
  - ✓ give insights into dynamics of beauty-baryon weak decays

[arXiv: 2310.13546]

Yiduo Shang
Yanxi Zhang





✓ First observation

$$\mathcal{R}\left(\frac{\Xi_b^0}{\Lambda_b^0}\right) \equiv \frac{\sigma\left(\Xi_b^0\right)}{\sigma\left(\Lambda_b^0\right)} \times \frac{\mathcal{B}\left(\Xi_b^0 \to \Xi_c^+ D_s^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right)} = (15.8 \pm 1.1 \pm 0.6 \pm 7.7)\%,$$

$$\mathcal{R}\left(\frac{\Xi_b^-}{\Lambda_b^0}\right) \equiv \frac{\sigma\left(\Xi_b^-\right)}{\sigma\left(\Lambda_b^0\right)} \times \frac{\mathcal{B}\left(\Xi_b^- \to \Xi_c^0 D_s^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ D_s^-\right)} = (16.9 \pm 1.3 \pm 0.9 \pm 4.3)\%,$$

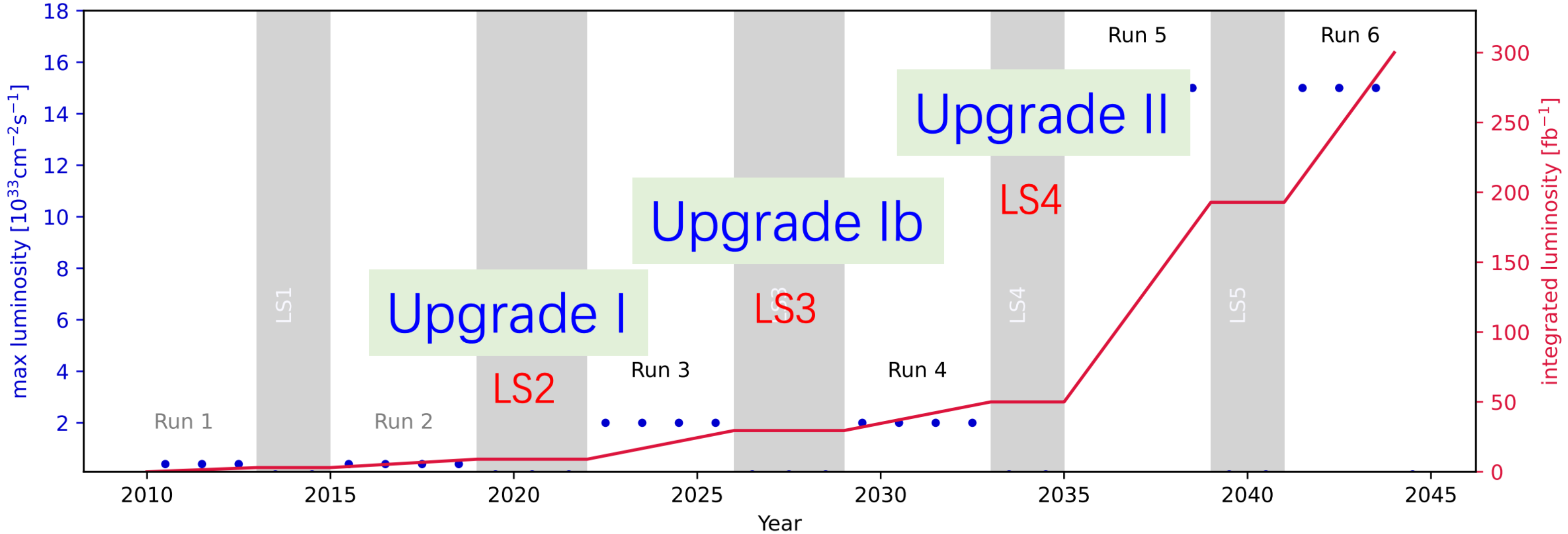
✓ Consistent with *SU(3)* flavor symmetry and phenomenological model predictions

Summary and prospects

- LHCb keeps making important contributions to spectroscopy study
  - ✓**Exotic heavy hadron:** search for pentaquark in open-charm modes; evidence of neutral $T_{\psi s1}^{\theta}(4000)^0$…
  - ✓**Conventional heavy hadron:** new Ξ_b^{**} states; new excited Ω_c^0 states; better mass&width precision; more decays

  ……

- In Run 3, the upgraded LHCb detector and an improved software-only trigger system are implemented



More data, more chances!