



Observation of two new excited Ξ_b^0 states decaying to $\Lambda_b^0 K^- \pi^+$

[arXiv: 2110.04497]

牟宏杰 (Hongjie Mu)

Tsinghua University

CLHCP2021

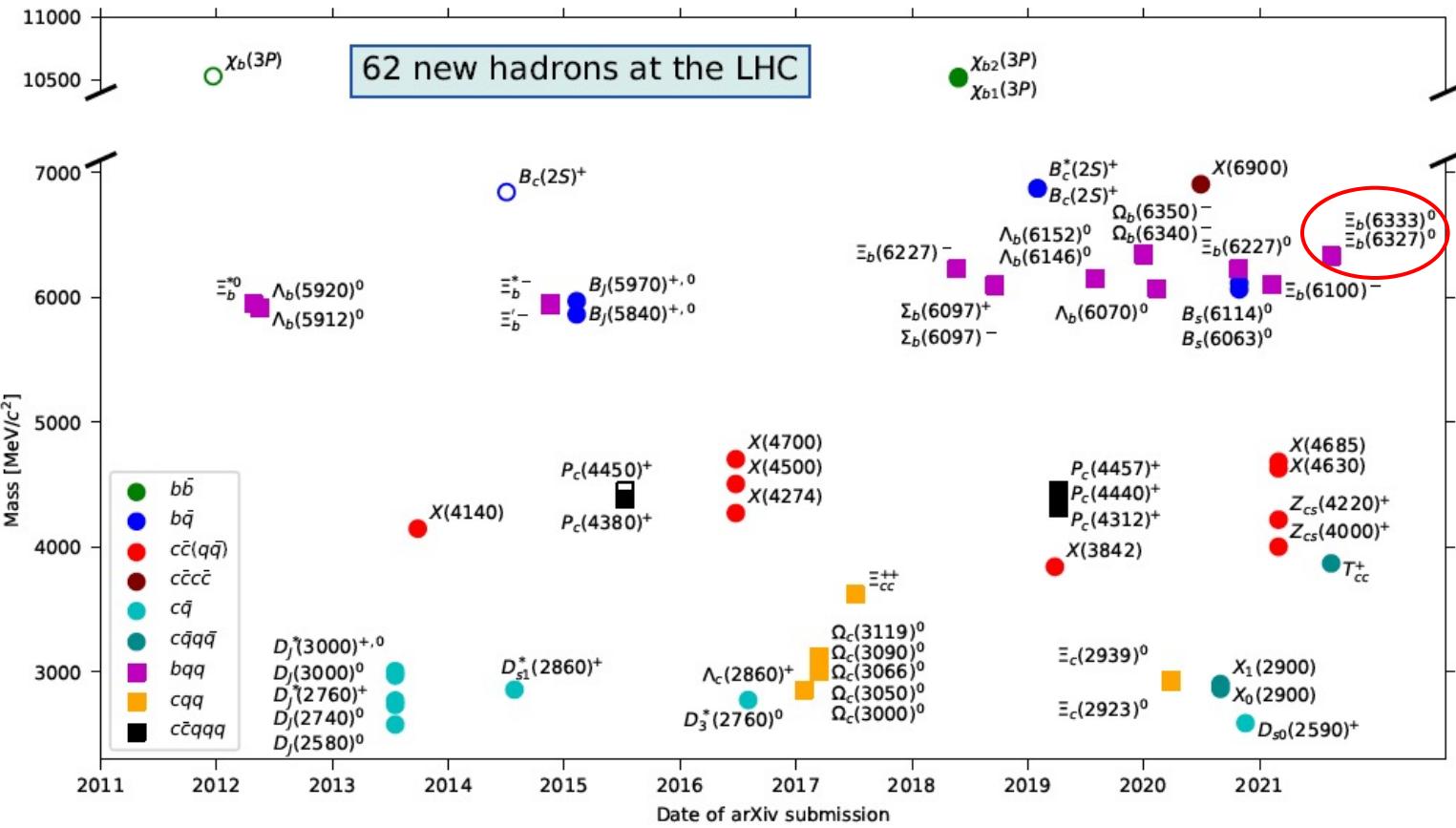
November 25-28, 2021

Introduction

- Study of heavy-hadron spectroscopy
helps to understand the hadron structures and how QCD works

- LHC observed 62 new hadrons
 - 55 new hadrons at LHCb

- Experimental results could provide more inputs and constraints to tune models



From [Patrick Koppenburg](#)

The LHCb detector

[JINST 3 (2008) S08005]

[Int. J. Mod. Phys A 30 (2015) 1530022]

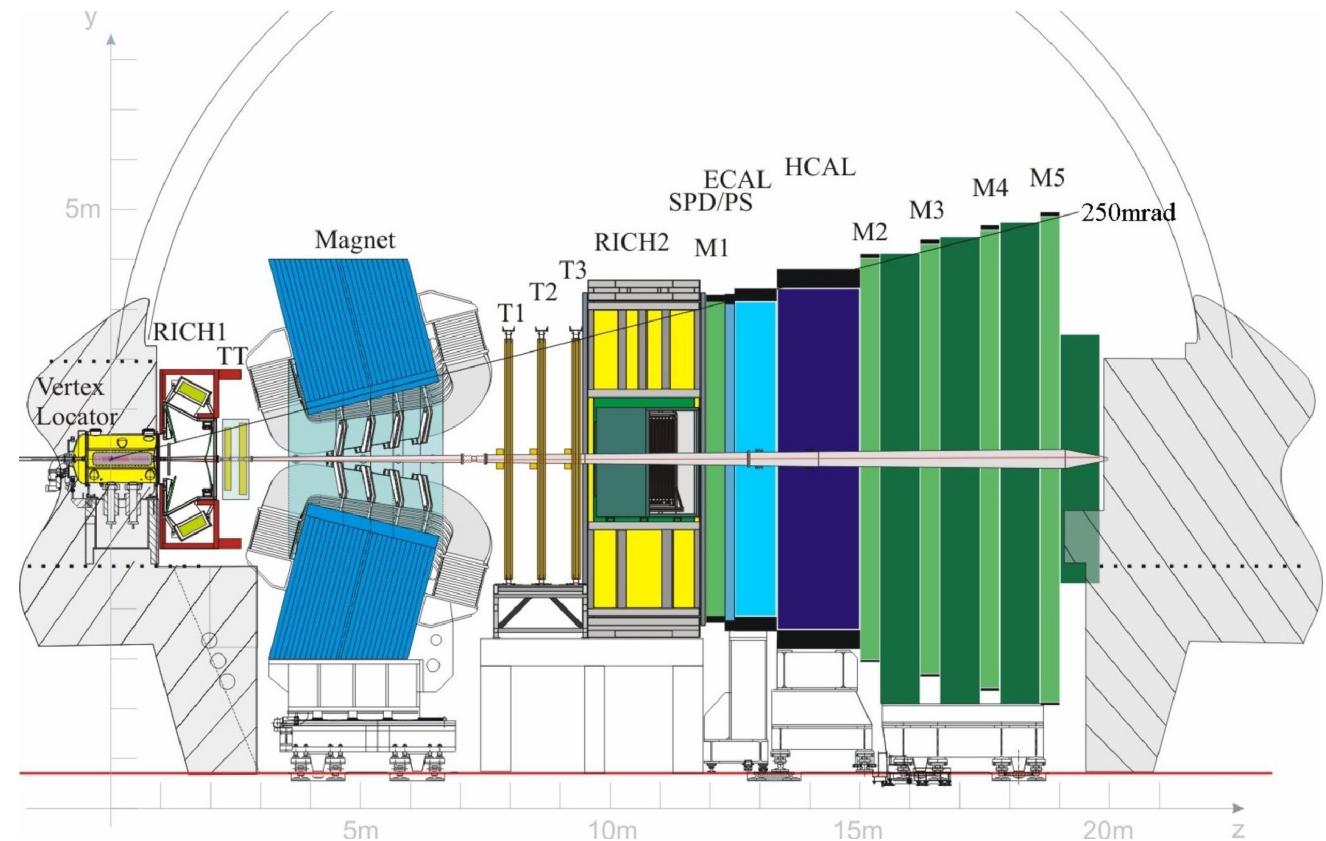
- Single-arm forward spectrometer covering $2 < \eta < 5$
- Designed for heavy flavour physics

Vertex Locator: $\sigma_{\text{IP}} \sim 20\mu\text{m}$

RICHs: $\varepsilon_{\text{PID}}(K) \sim 95\%$
mis-ID: $\varepsilon_{\text{PID}}(\pi \rightarrow K) \sim 5\%$

Tracking stations:
 $\varepsilon_{\text{tracking}} \sim 96\%$
 $\sigma_p/p \sim 0.5\% - 1\% (5 - 200\text{GeV})$

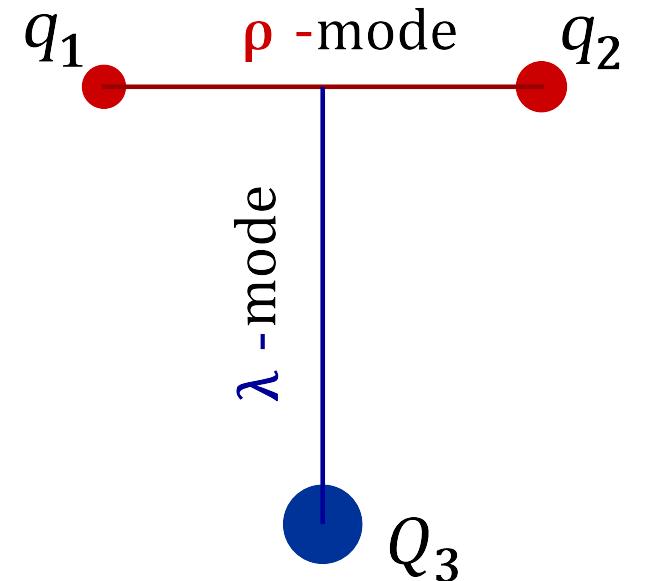
Muon system:
 $\varepsilon_{\text{PID}}(\mu) \sim 97\%$
mis-ID: $\varepsilon_{\text{PID}}(\pi \rightarrow \mu): 1 - 3\%$



Singly heavy baryon

➤ Modeled by diquark-quark system

- ρ -model: orbital excitations between two light quarks (q_1, q_2)
- λ -model: orbital excitations (\vec{L}) between heavy quark (Q_3) and diquark system
 - Almost all observed states can be explained as λ -model excited states
 - \vec{s}_{qq} : diquark spin, $\vec{s}_{qq} = \vec{s}_{q_1} + \vec{s}_{q_2}$ (0 or 1), $q = u, d, s$
 - \vec{j}_{qq} : total angular momentum of diquark system, $\vec{j}_{qq} = \vec{L} + \vec{s}_{qq}$
 - \vec{s}_Q : spin of heavy quark (1/2), $Q = b, c$
 - \vec{J} : total angular momentum of the heavy baryon, $\vec{J} = \vec{j}_{qq} + \vec{s}_Q$
 - Parity: $(-1)^L$
- Example: 1D Ξ_b^0 (bsu)
 - $L = 2$ (D wave), $s_{qq} = 0$, $s_Q = \frac{1}{2}$
 - $J^P = \left(\frac{3}{2}\right)^+, \left(\frac{5}{2}\right)^+$



[Bing Chen et. al. PRD 100 (2019) 094032]

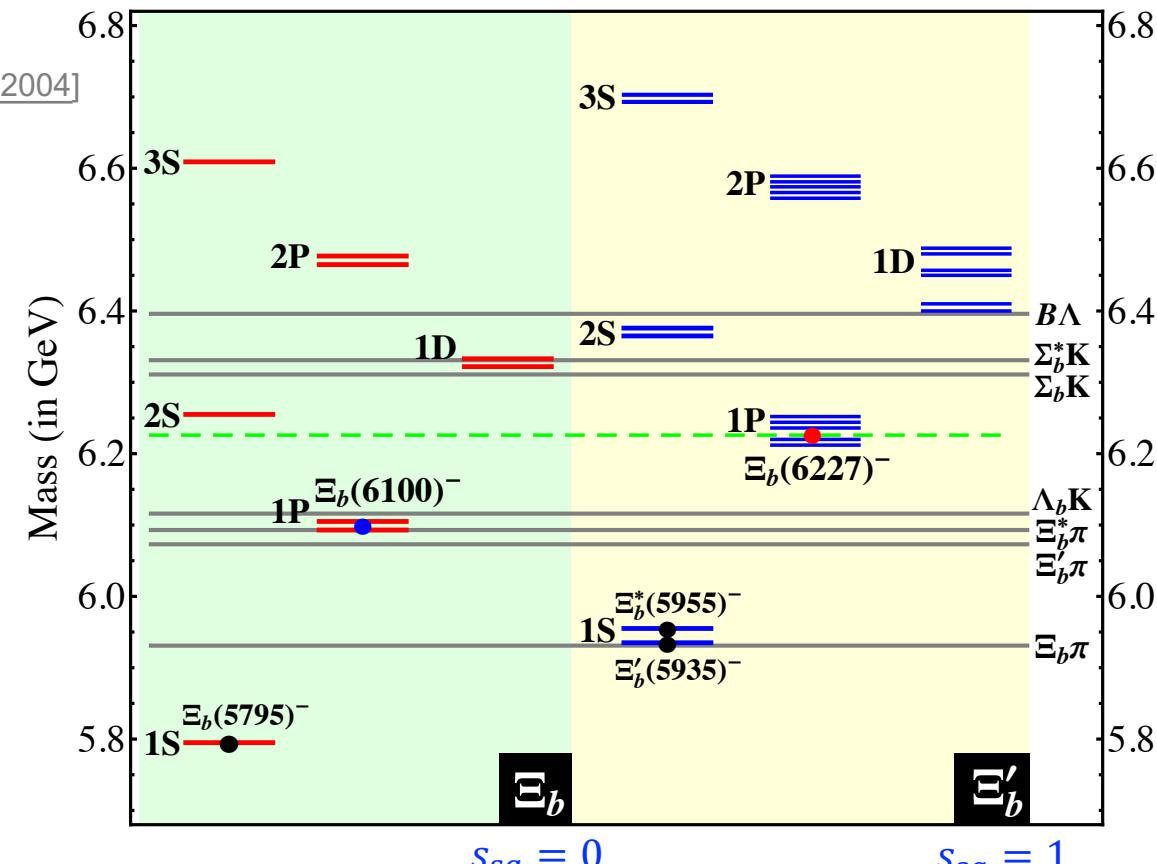
Status of Ξ_b spectroscopy

➤ Latest results

- $\Xi'_b(5935)^-$ and $\Xi_b^*(5955)^-$ in $\Xi_b^0\pi^-$ [PRL 114 (2015) 062004]
- $\Xi_b(6227)^-$ in $\Lambda_b^0 K^-$ and $\Xi_b^0\pi^-$ [PRL 121 (2018) 072002]
- $\Xi_b(6227)^0$ in $\Xi_b^-\pi^+$ [PRD 103 (2021) 012004]
 - Isospin partner of $\Xi_b(6227)^-$
- $\Xi_b(6100)^0$ in $\Xi_b^-\pi^+\pi^-$ [PRL 126 (2021) 252003]

➤ High-mass states still missing

- Theory predictions: lines
- Experiment observed: points



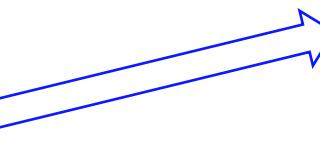
[Bing Chen et. al. PRD 98 (2018) 031502]

[PRL 126 (2021) 252003]

Search for excited Ξ_b^0 in $\Lambda_b^0 K \pi$ decays

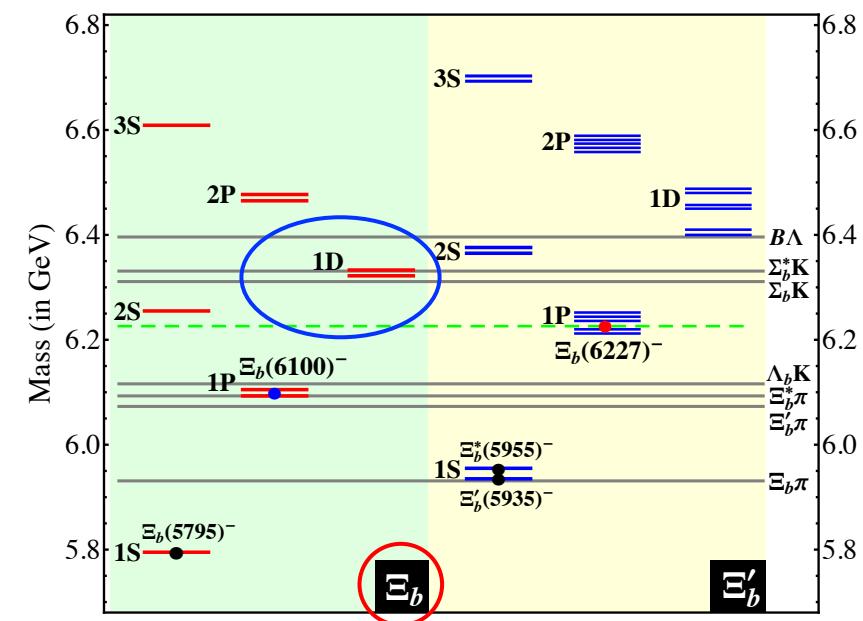
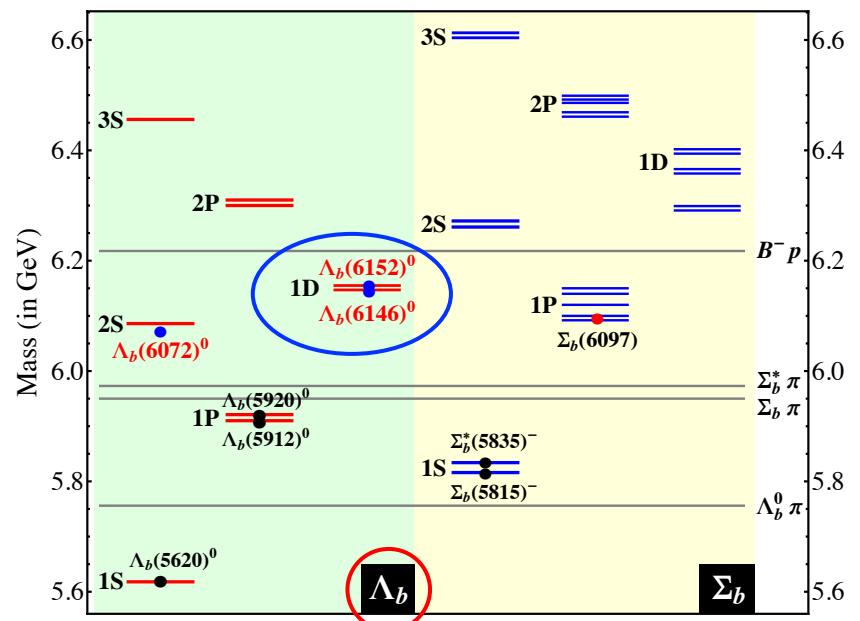
- LHCb observed $\Lambda_b(6146)^0$ and $\Lambda_b(6152)^0$ in $\Lambda_b^0 \pi^- \pi^+$
 - Consistent with 1D $\Lambda_b^0 [ud\bar{b}]$
- [PRL 123 (2019) 152001]

- Two 1D Ξ_b^0 states are predicted
 - Search for 1D $\Xi_b^0 [us\bar{b}]$ states in $\Lambda_b^0 K^- \pi^+$



Decay mode	$\Xi_b(6327) [3/2^+ (1D)]$	$\Xi_b(6330)^0 [5/2^+ (1D)]$
$\Xi_b'(5935) \pi$	0.39 ^p	0.09 ^f
$\Sigma_b(5815) K$	1.73 ^p	0.00 ^f
$\Xi_b^*(5955) \pi$	0.09 ^p , 0.15 ^f	0.51 ^p , 0.07 ^f
$\Sigma_b^*(5835) K$	0.02 ^p , 0.00 ^f	0.09 ^p , 0.00 ^f
Total width	2.38	0.76

[Bing Chen et. al. PRD 100 (2019) 094032]



Λ_b^0 candidate selections

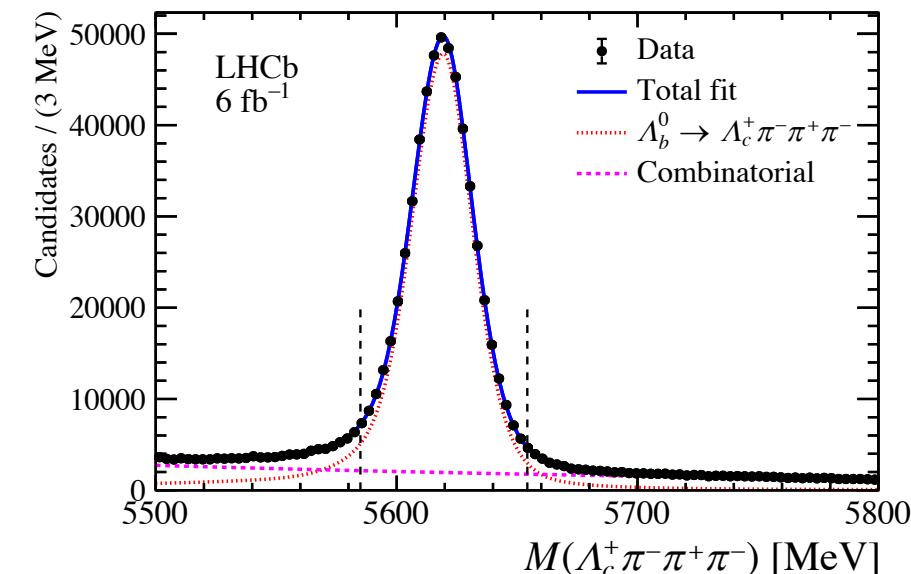
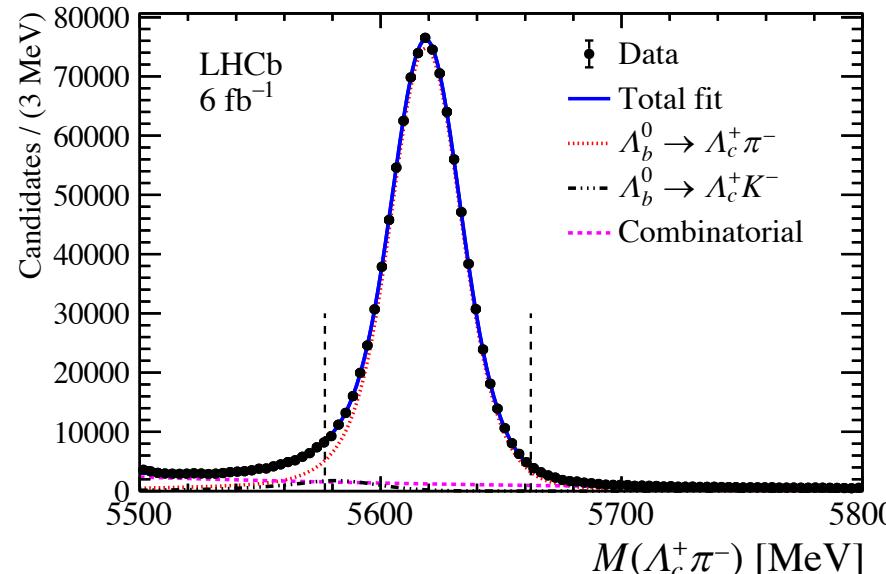
➤ Collected by LHCb experiment in 2015-2018

➤ Decay modes

- $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) \pi^-$
- $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) \pi^- \pi^+ \pi^-$

➤ Cut-based preselection + BDT

➤ Signals within mass window: 966k ($\Lambda_c^+ \pi^-$) + 533k ($\Lambda_c^+ \pi^- \pi^+ \pi^-$)



$\Lambda_b^0 K\pi$ candidates

➤ Λ_b^0 combined with kaon and pion

- Right-sign (RS)

- $\Lambda_b^0 K^- \pi^+$

- Contain the predicted Ξ_b^0 states

- Wrong-sign (WS)

- $\Lambda_b^0 K^+ \pi^-$

- Background study

- Cut-based selection

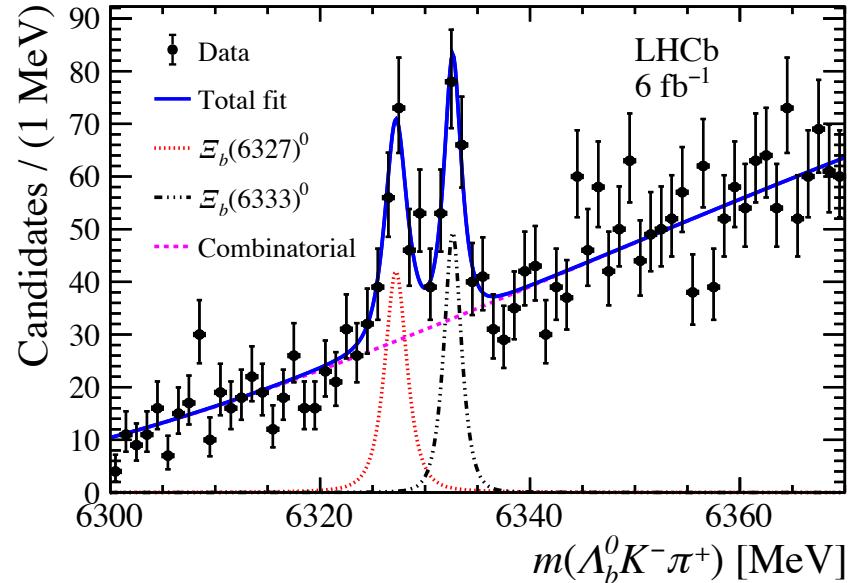
- Especially optimize p_T and PID cuts of prompt K and π
 - Based on simulation and WS sample

- Redefine mass for better resolution

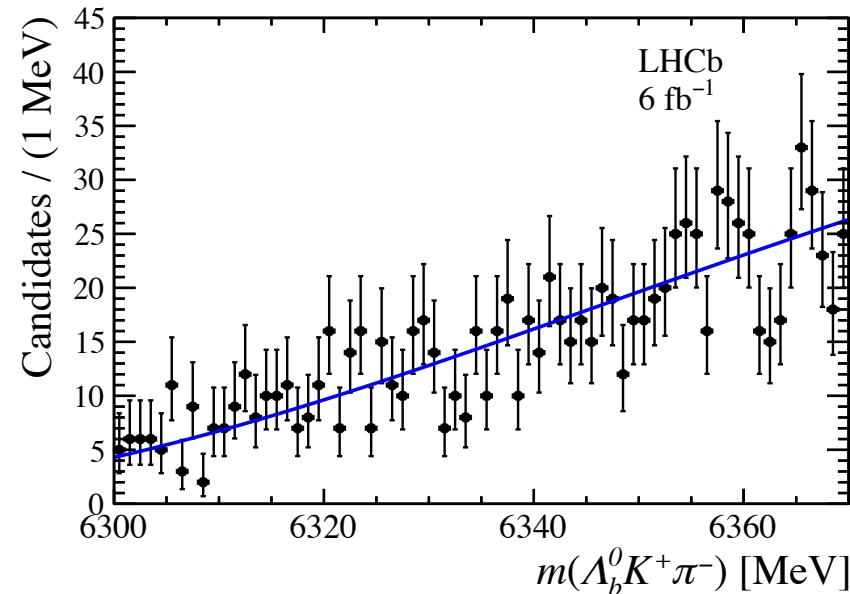
- $m(\Lambda_b^0 K\pi) \equiv M(\Lambda_b^0 K\pi) - M(\Lambda_c^+ \pi^- (\pi^+ \pi^-)) + 5619.62 \text{ MeV}$

Λ_b^0 mass

[PRL 119 (2017) 062001]



RS



WS

$\Lambda_b^0 K\pi$ mass fit

➤ Simultaneous fit (RS+WS)

- Signal

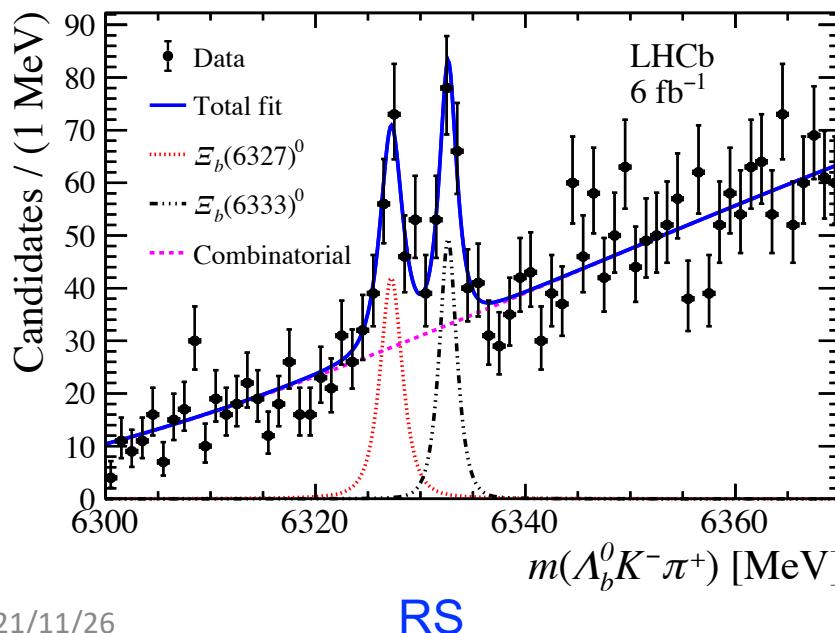
- RBW with constant width
- Convolved with a resolution function, fixed to simulation

- Background

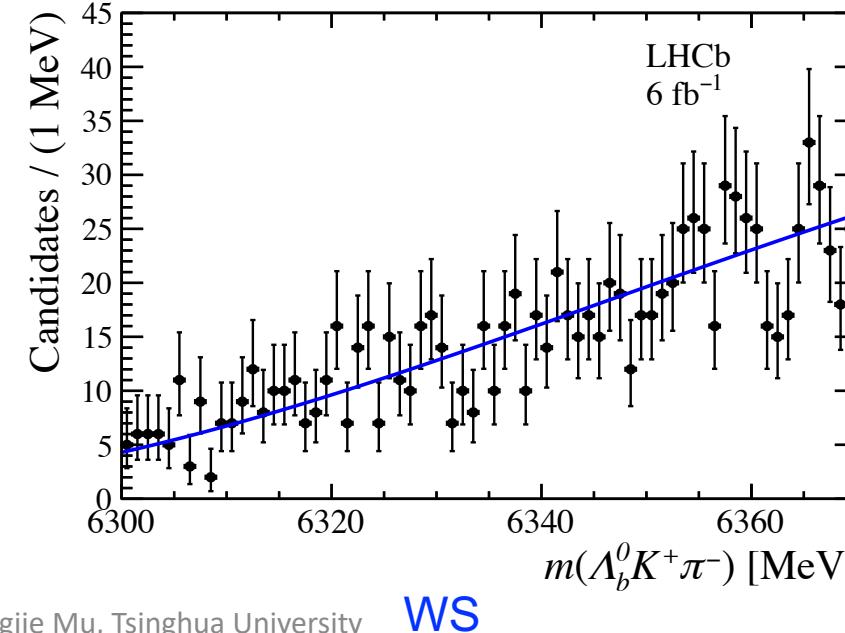
- A threshold function
- RS and WS samples share the same background shape parameters

$$f_{\text{sig}}(m(\Lambda_b^0 K\pi)) = \frac{c_{\text{sig}}}{(m^2 - m^2(\Lambda_b^0 K\pi))^2 + m^2 \Gamma^2}$$

$$f_{\text{bkg}}(\Lambda_b^0 K\pi) = c_{\text{bkg}}(m(\Lambda_b^0 K\pi) - m_t)^{a_0} e^{-a_1(m(\Lambda_b^0 K\pi) - m_t)}$$



RS



WS

Statistical significance:
 10.2 σ vs background-only
 6.6 σ vs one-peak

Systematic uncertainties on mass and width measurements

- Systematic uncertainties are smaller than statistical uncertainties

Statistical uncertainties

State	Mass [MeV]	Width [MeV]
$\Xi_b(6327)^0$	$6327.28^{+0.23}_{-0.21}$	$0.93^{+0.74}_{-0.60}$
$\Xi_b(6333)^0$	$6332.69^{+0.17}_{-0.18}$	$0.25^{+0.58}_{-0.25}$

Systematic uncertainties on mass (MeV) and width (MeV)

Source	$\Xi_b(6327)^0$		$\Xi_b(6333)^0$		
	m	Γ	m	Γ	Δm
Momentum scale	0.06	0.06	0.03	0.04	0.03
Signal shape	0.01	0.12	0.00	0.25	0.01
Background shape	0.01	0.17	0.01	0.15	0.00
Resolution model	0.05	0.20	0.01	0.25	0.05
Total systematic uncertainty	0.08	0.29	0.03	0.39	0.06
Λ_b^0 mass (syst, momentum scale)	0.12	-	0.12	-	-
Λ_b^0 mass (syst, excl. momentum scale)	0.05	-	0.05	-	-
Λ_b^0 mass (stat)	0.16	-	0.16	-	-
Total uncertainty from $m_{\Lambda_b^0}$	0.24	-	0.22	-	-

Results

➤ Masses and widths

$$m_{\Xi_b(6327)^0} = 6327.28^{+0.23}_{-0.21}(\text{stat}) \pm 0.08(\text{syst}) \pm 0.24(m_{\Lambda_b^0}) \text{ MeV}$$

$$m_{\Xi_b(6333)^0} = 6332.69^{+0.17}_{-0.18}(\text{stat}) \pm 0.03(\text{syst}) \pm 0.22(m_{\Lambda_b^0}) \text{ MeV}$$

$$\Delta m \equiv m_{\Xi_b(6333)^0} - m_{\Xi_b(6327)^0} = 5.41^{+0.26}_{-0.27}(\text{stat}) \pm 0.06(\text{syst}) \text{ MeV}$$

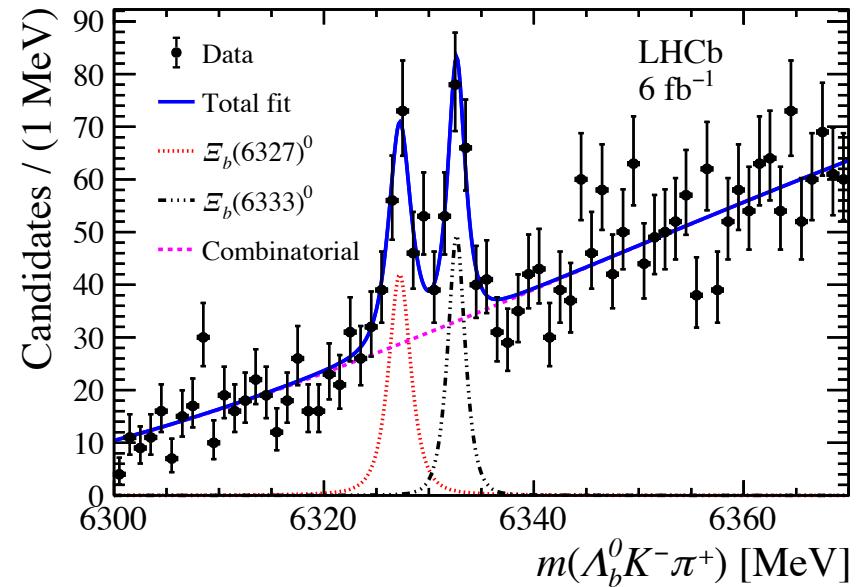
$$\Gamma_{\Xi_b(6327)^0} < 2.20 \text{ (2.56) MeV at 90% (95%) CL}$$

$$\Gamma_{\Xi_b(6333)^0} < 1.55 \text{ (1.85) MeV at 90% (95%) CL}$$

- Masses are consistent with 1D Ξ_b^0

➤ Significance considering systematic uncertainty

- 9.9σ for two-peak vs background-only hypothesis
- 5.8σ for two-peak vs one-peak hypothesis



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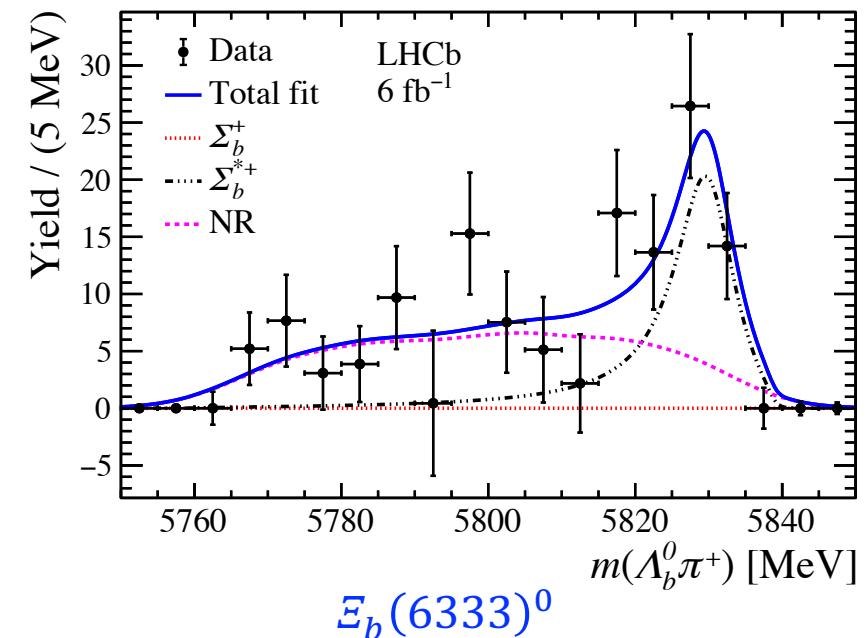
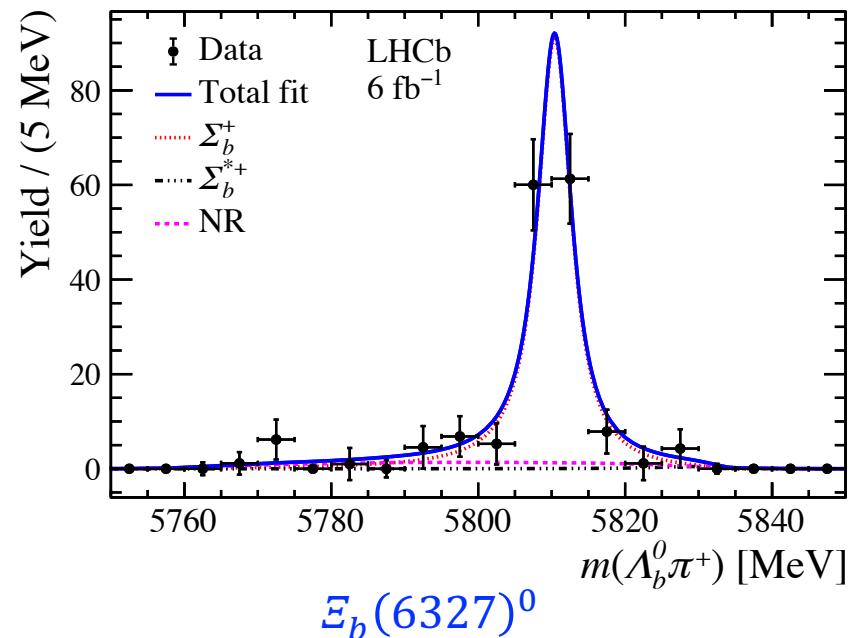
[Bing Chen et. al. PRD 100 (2019) 094032]

Resonant structure in $\Lambda_b^0\pi^+$ mass spectrum

- $\Xi_b(6327)^0$: predominantly decays into $\Sigma_b^+ K^-$
- $\Xi_b(6333)^0$: about a half decays into $\Sigma_b^{*+} K^-$,
the rest decay without $\Lambda_b^0\pi^+$ resonances
- Consistent with 1D Ξ_b^0 doublets

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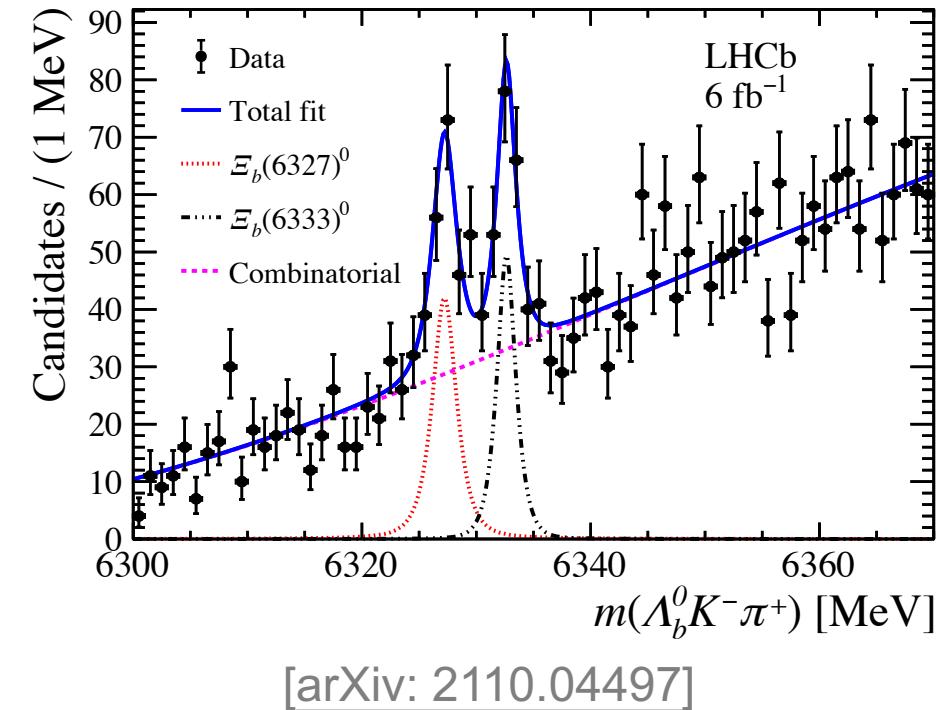
Summary

➤ Observation of two new excited Ξ_b^0 states decaying to $\Lambda_b^0 K^- \pi^+$

- Consistent with expectations for 1D Ξ_b^0 states

➤ LHCb upgrade

- Opportunities for new hadrons



Thank you!

Backup

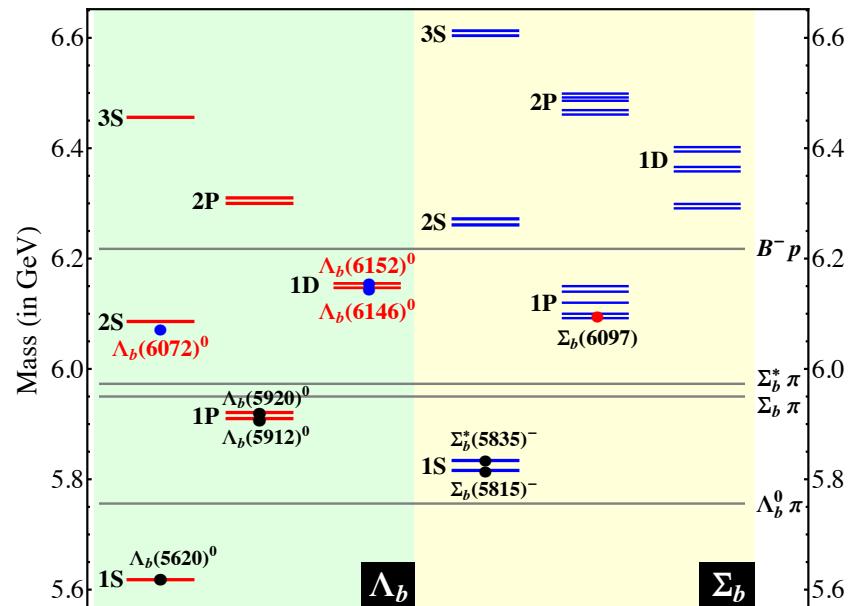
Beauty baryons with quark content bqq' and bsq

➤ Can be classified by light diquark spin $s_{qq'}$ or s_{sq}

- q and q' are u or d quarks

➤ Quark content: bqq'

- Λ_b^0 family: $s_{qq'} = 0$
- Σ_b family: $s_{qq'} = 1$



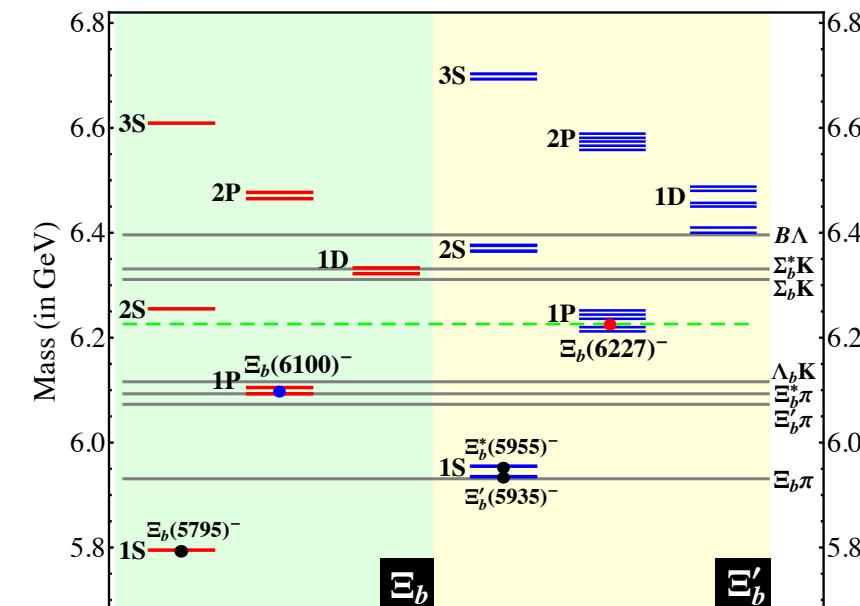
[Bing Chen et. al. PRD 98 (2018) 074032]

[JHEP 06 (2020) 136]

2021/11/26

Quark content: bsq

- Ξ_b family: $s_{sq} = 0$
- Ξ'_b family: $s_{sq} = 1$



[Bing Chen et. al. PRD 98 (2018) 031502]

[PRL 126 (2021) 252003]

Hongjie Mu, Tsinghua University

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