Beauty-hadron spectroscopy at LHCb

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On behalf of the LHCb collaboration

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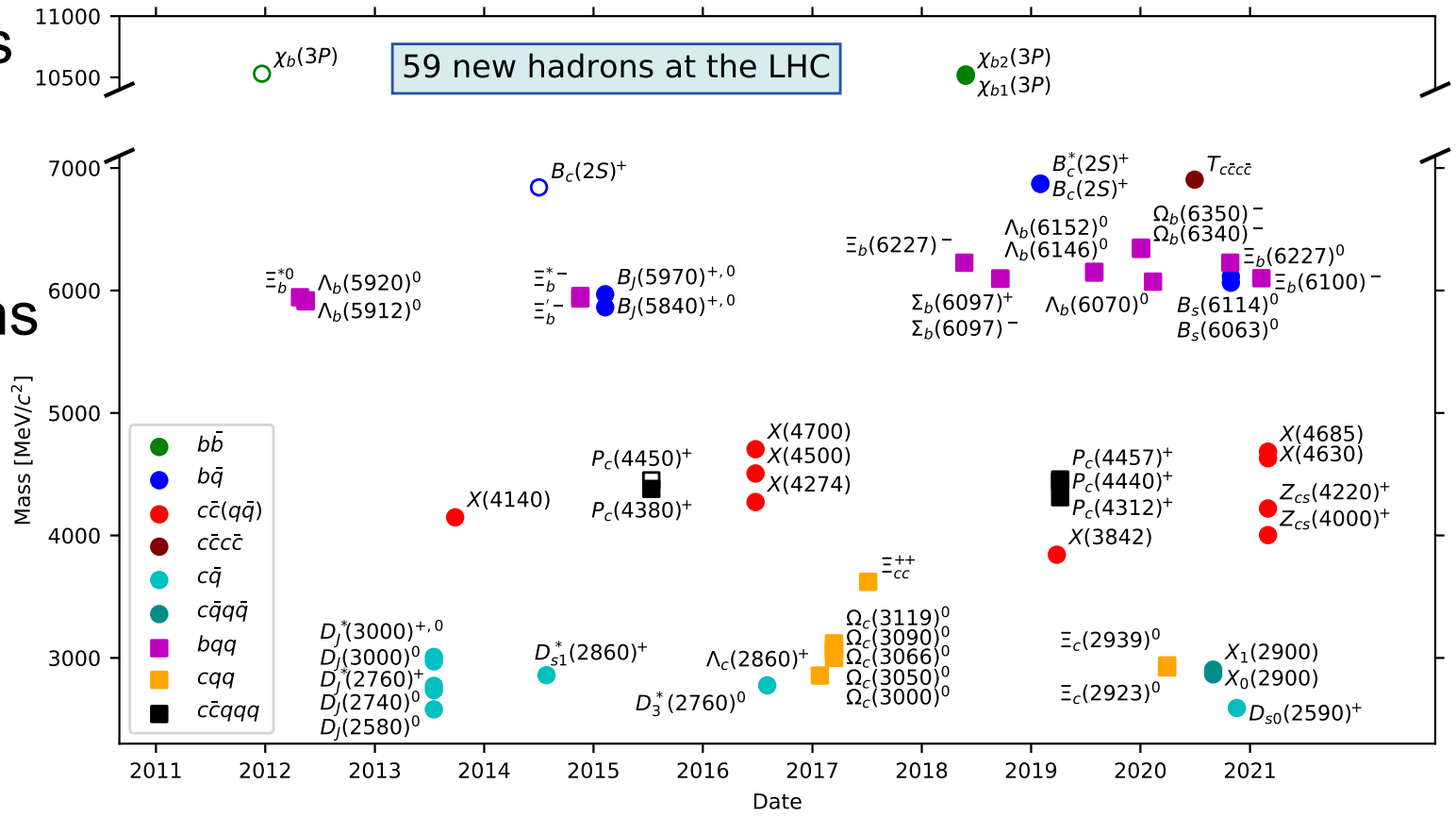
Introduction

- Study of heavy-hadron spectroscopy helps to understand the hadronic structure and how QCD works
- LHC observed 59 new hadrons
  - Mainly from LHCb



[LHCB-FIGURE-2021-001]

Recent results of beauty-hadron spectroscopy

- Observation of new excited B_s^0 states in B^+K^-

  [EPJC 81 (2021) 7, 601]

- Observation of a new Ξ_b^0 state in $\Xi_b^-\pi^+$

  [PRD 103 (2021) 012004]

- Observation of two new excited Ξ_b^0 states in $\Lambda_b^0 K^-\pi^+$ **New!**

  [LHCb-PAPER-2021-025, in preparation]

- Search for Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$

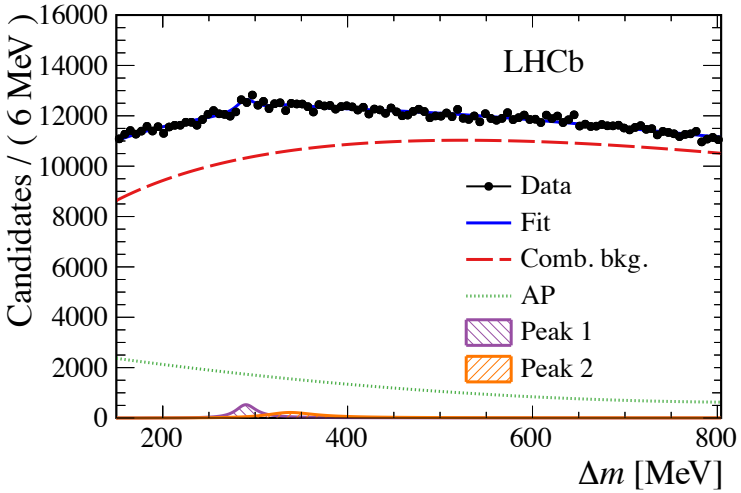
  [arXiv:2104.04759]

Observation of new excited B_s^0 states in B^+K^-

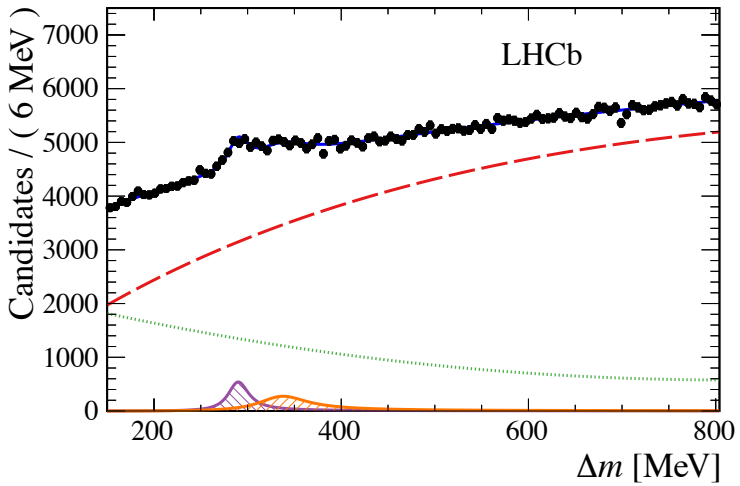
[EPJC 81 (2021) 7, 601]

Observation of new excited B_s^0 states in B^+K^-

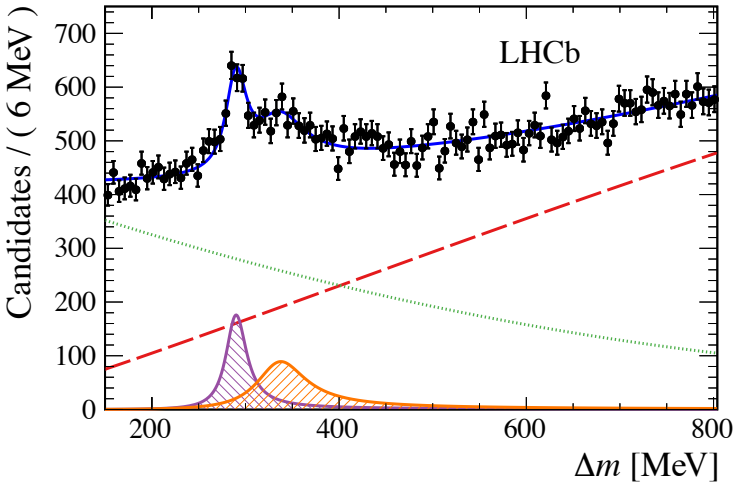
- Data sample in 2011-2018
  - $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
  - $B^+ \to \overline{D}^0(\to K^+\pi^-)\pi^+$
- Peaks in B^+K^- mass spectrum
- Simultaneous fit in $p_T(K^-)$ bins
  - $0.5 < p_T < 1$ GeV
  - $1 < p_T < 2$ GeV
  - $p_T > 2$ GeV
- Local significance
  - 20σ for one-peak vs background-only hypothesis
  - 7.7σ for two-peak vs one-peak hypothesis



$0.5 < p_T < 1$ GeV



$1 < p_T < 2$ GeV



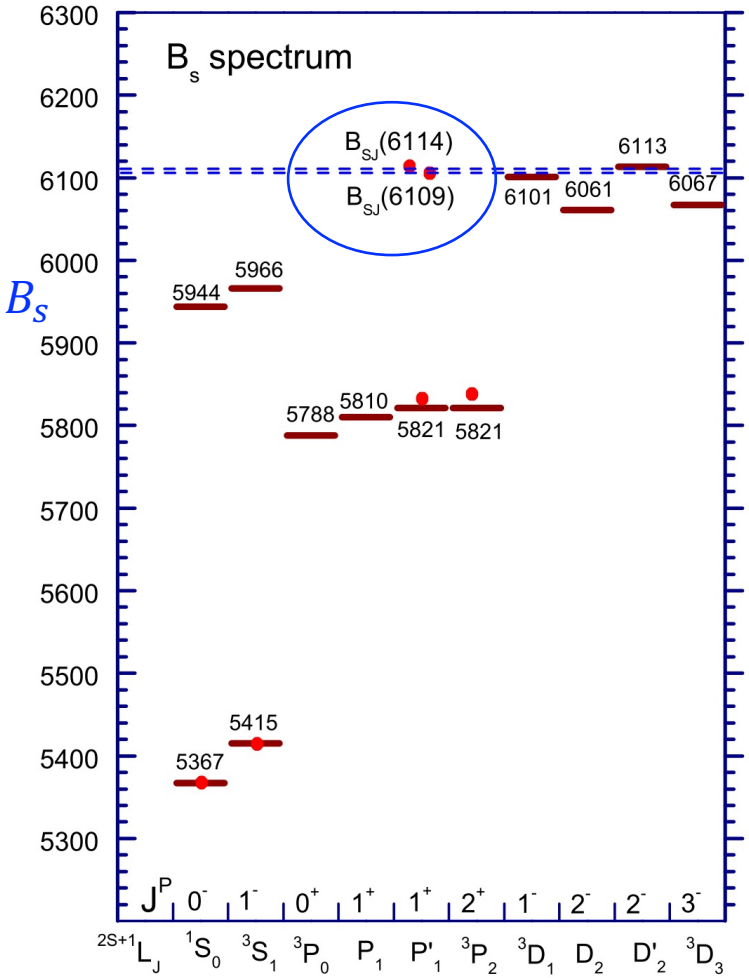
$p_T > 2$ GeV

$$\Delta m \equiv m_{B^+K^-} - m_{B^+} - m_{K^-}$$

Observation of new excited B_s^0 states in B^+K^-

- Two models
  - $B_s^{**0} \to B^+K^-$
    $m_1 = 6063.5 \pm 1.2(\text{stat}) \pm 0.8(\text{syst})$ MeV
    $\Gamma_1 = 26 \pm 4(\text{stat}) \pm 4(\text{syst})$ MeV
    $m_2 = 6114 \pm 3(\text{stat}) \pm 5(\text{syst})$ MeV
    $\Gamma_2 = 66 \pm 18(\text{stat}) \pm 21(\text{syst})$ MeV
  - $B_s^{**0} \to B^{*+}[B^+\gamma]K^-$, with γ missed
    $m_1 = 6108.8 \pm 1.1(\text{stat}) \pm 0.7(\text{syst})$ MeV
    $\Gamma_1 = 22 \pm 5(\text{stat}) \pm 4(\text{syst})$ MeV
    $m_2 = 6158 \pm 4(\text{stat}) \pm 5(\text{syst})$ MeV
    $\Gamma_2 = 72 \pm 18(\text{stat}) \pm 25(\text{syst})$ MeV

Consistent with D-wave B_s



[PRD 103 (2021) 116010]

- Ratio of resonance decays to B^+K^- and $B^{*+}K^-$ is disfavored but cannot be excluded

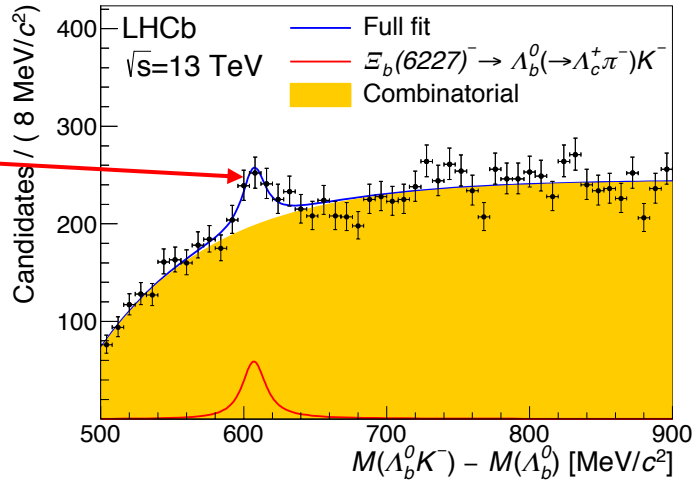
- Production ratio relative to B_{s2}^{*0} :
  - $R \equiv \frac{\sum\sigma(B_s^{**0})\times\mathcal{B}(B_s^{**0}\to B^{(*)+}K^-)}{\sigma(B_{s2}^{*0})\times\mathcal{B}(B_{s2}^{*0}\to B^+K^-)} = 0.87 \pm 0.15(\text{stat}) \pm 0.19(\text{syst})$

Observation of a new Ξ_b^0 state in $\Xi_b^- \pi^+$

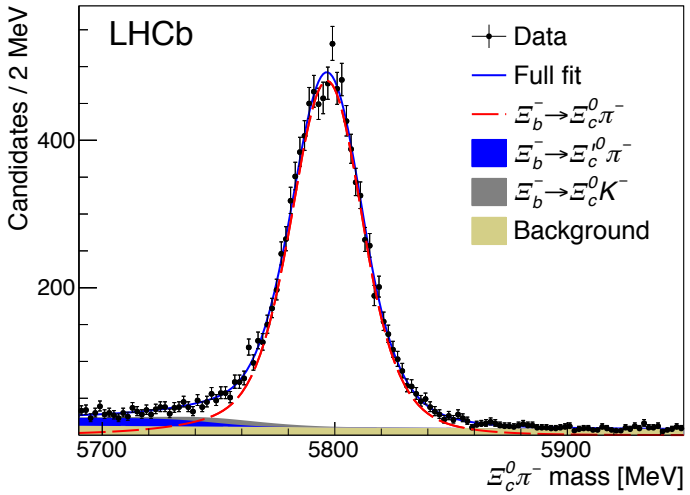
[PRD 103 (2021) 012004]

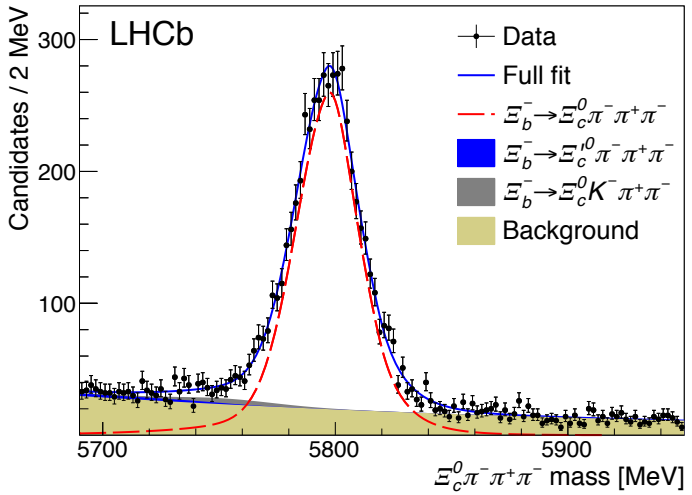
Observation of a new Ξ_b^0 state in $\Xi_b^-\pi^+$

- Search for isospin partner of $\Xi_b(6227)^-$
  - $\Xi_b(6227)^-$ observed in $\Lambda_b^0 K^-$ and $\Xi_b^0\pi^-$
- Data sample in 2011-2018
  - $\Xi_b^- \to \Xi_c^0(\to pK^-K^-\pi^+)\pi^-$
  - $\Xi_b^- \to \Xi_c^0(\to pK^-K^-\pi^+)\pi^-\pi^+\pi^-$
- Improved measurement of Ξ_b^- mass (only $\Xi_b^- \to \Xi_c^0\pi^-$)
  - $m(\Xi_b^-) = 5797.33 \pm 0.24 \pm 0.29$ MeV



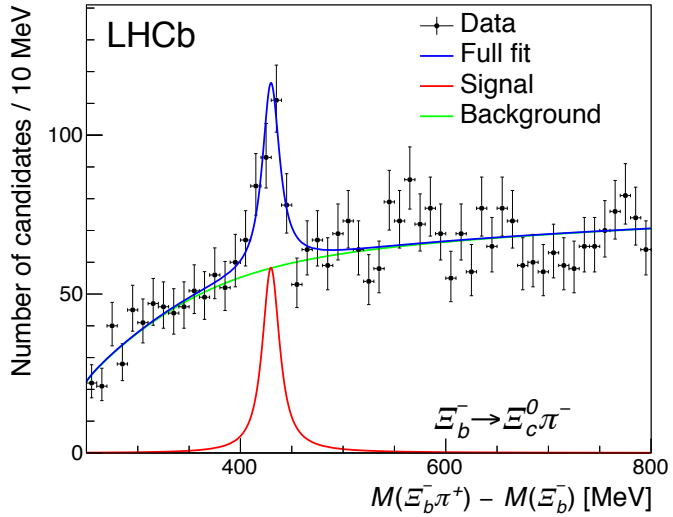
[PRL 121 (2018) 072002]

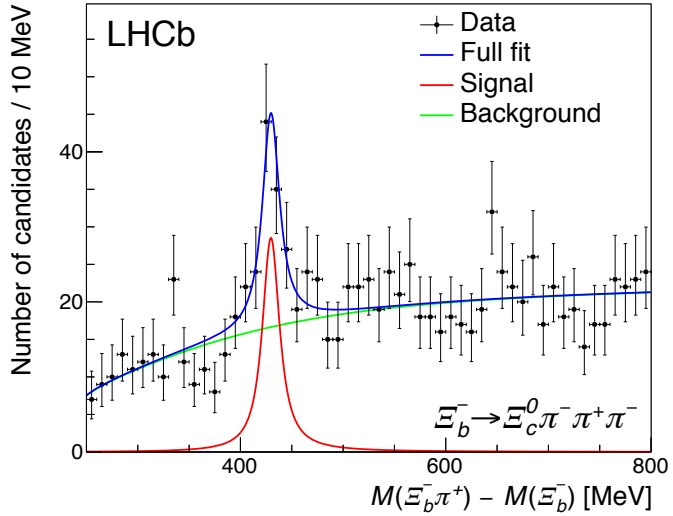




Observation of a new Ξ_b^0 state in $\Xi_b^-\pi^+$

- Peak in $\Xi_b^-\pi^+$ mass spectrum (10σ)
  - $m(\Xi_b(6227)^0) - m(\Xi_b^-) = 429.8\,^{+1.4}_{-1.5} \pm 0.3$ MeV
  - $m(\Xi_b(6227)^0) = 6227.1\,^{+1.4}_{-1.5} \pm 0.5$ MeV
  - $\Gamma(\Xi_b(6227)^0) = 18.6\,^{+5.0}_{-4.1} \pm 1.4$ MeV
- Improved results of charged isospin partner in $\Lambda_b^0 K^-$
  - $m(\Xi_b(6227)^-) - m(\Lambda_b^0) = 608.3 \pm 0.8 \pm 0.3$ MeV
  - $m(\Xi_b(6227)^-) = 6227.9 \pm 0.8 \pm 0.5$ MeV
  - $\Gamma(\Xi_b(6227)^-) = 19.9 \pm 2.1 \pm 1.5$ MeV
- Relative production rate at $\sqrt{s} = 13$ TeV
  - $\frac{f_{\Xi_b(6227)^0}}{f_{\Xi_b^-}} \mathcal{B}(\Xi_b(6227)^0 \to \Xi_b^-\pi^+) = 0.045 \pm 0.008 \pm 0.004$





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

[LHCb-PAPER-2021-025, in preparation]

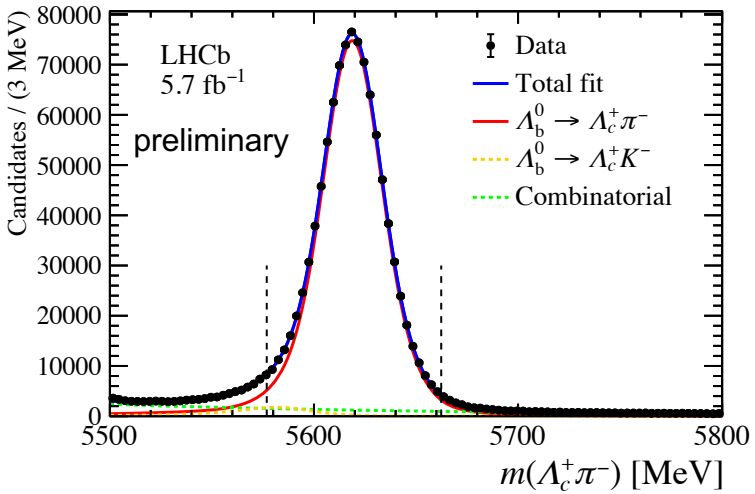
Observation of two new excited Ξ_b^0 states in $\Lambda_b^0 K^- \pi^+$

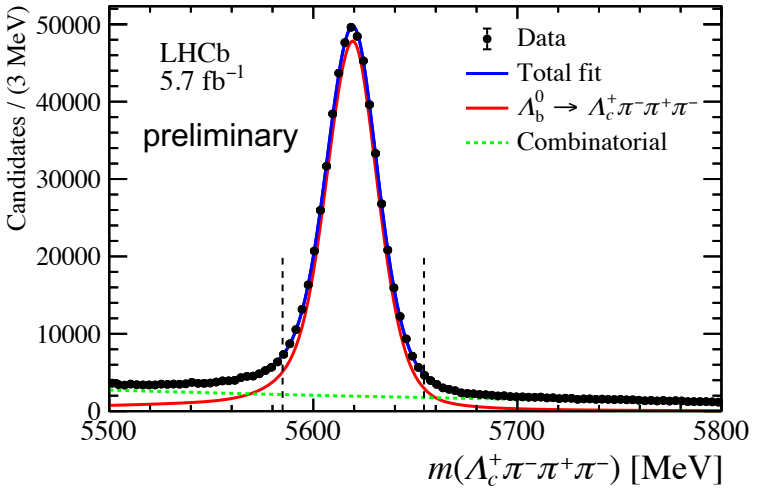
- Two narrow 1D Ξ_b^0 states predicted by theory
- Data sample in 2015-2018
  - $\Lambda_b^0 \to \Lambda_c^+ (\to pK^-\pi^+)\pi^-$
  - $\Lambda_b^0 \to \Lambda_c^+ (\to pK^-\pi^+)\pi^-\pi^+\pi^-$
- Redefine mass for better resolution
  - $m(\Lambda_b^0 K^-\pi^+) \equiv m_{\Lambda_b^0 K^-\pi^+} - m_{\Lambda_b^0} + \boxed{5619.62}\,\text{MeV}$

Λ_b^0 mass [PRL 119 (2017) 062001]

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]





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

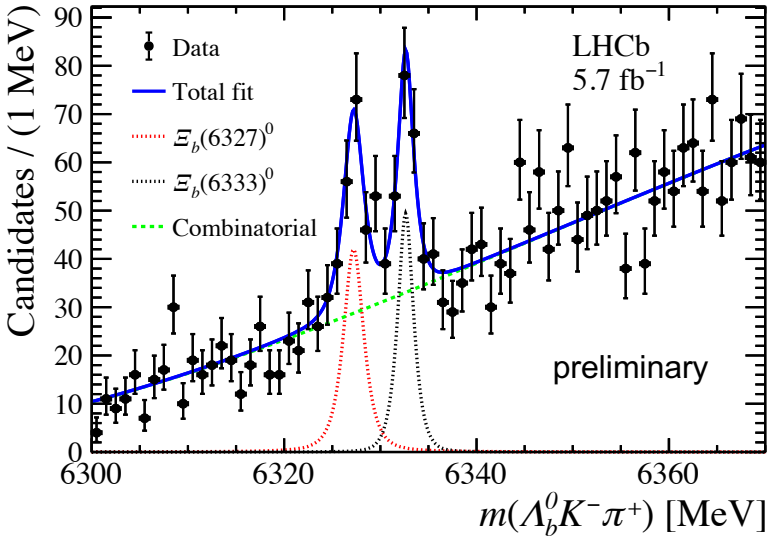
- No peaks in $\Lambda_b^0 K^+ \pi^-$ (Wrong-Sign) mass spectrum
- Two peaks in $\Lambda_b^0 K^- \pi^+$ (Right-Sign) mass spectrum
  - $m_{\Xi_b(6327)^0} = 6327.28\,^{+0.23}_{-0.21}(\text{stat}) \pm 0.08(\text{syst}) \pm 0.24(m_{\Lambda_b^0})$ MeV
  - $m_{\Xi_b(6333)^0} = 6332.69\,^{+0.17}_{-0.18}(\text{stat}) \pm 0.03(\text{syst}) \pm 0.22(m_{\Lambda_b^0})$ MeV
  - $\Gamma_{\Xi_b(6327)^0} < 2.20\ (2.56)$ MeV at 90% (95%) CL
  - $\Gamma_{\Xi_b(6333)^0} < 1.55\ (1.85)$ MeV at 90% (95%) CL
  - $\Delta m \equiv m_{\Xi_b(6333)^0} - m_{\Xi_b(6327)^0} = 5.41\,^{+0.26}_{-0.27}(\text{stat}) \pm 0.06(\text{syst})$ MeV

Consistent with 1D Ξ_b^0

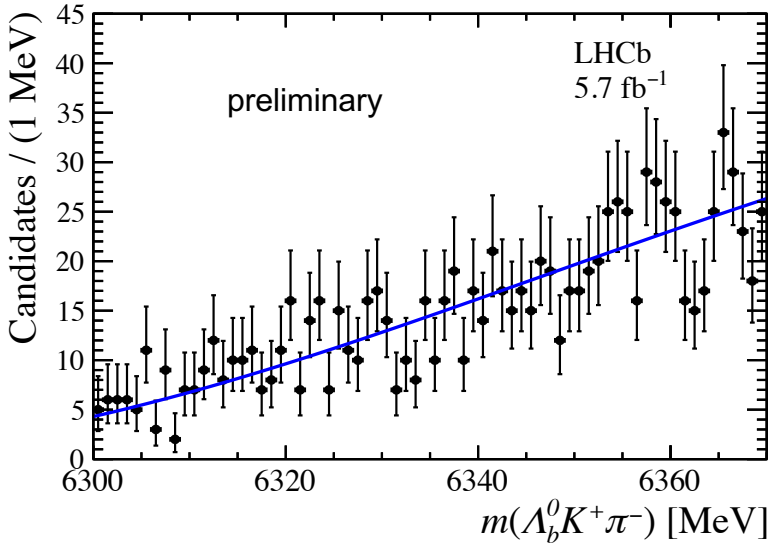
Decay mode	$\Xi_b(6327)$ $[3/2^+\ (1D)]$	$\Xi_b(6330)^0$ $[5/2^+\ (1D)]$
$\Xi_b'(5935)\,\pi$	0.39^p	0.09^f
$\Sigma_b(5815)\,K$	1.73^p	0.00^f
$\Xi_b^*(5955)\,\pi$	0.09^p, 0.15^f	0.51^p, 0.07^f
$\Sigma_b^*(5835)\,K$	0.02^p, 0.00^f	0.09^p, 0.00^f
Total width	2.38	0.76

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

- Significance considering systematic uncertainty
  - 9.9σ for two-peak vs background-only hypothesis
  - 5.8σ for two-peak vs one-peak hypothesis



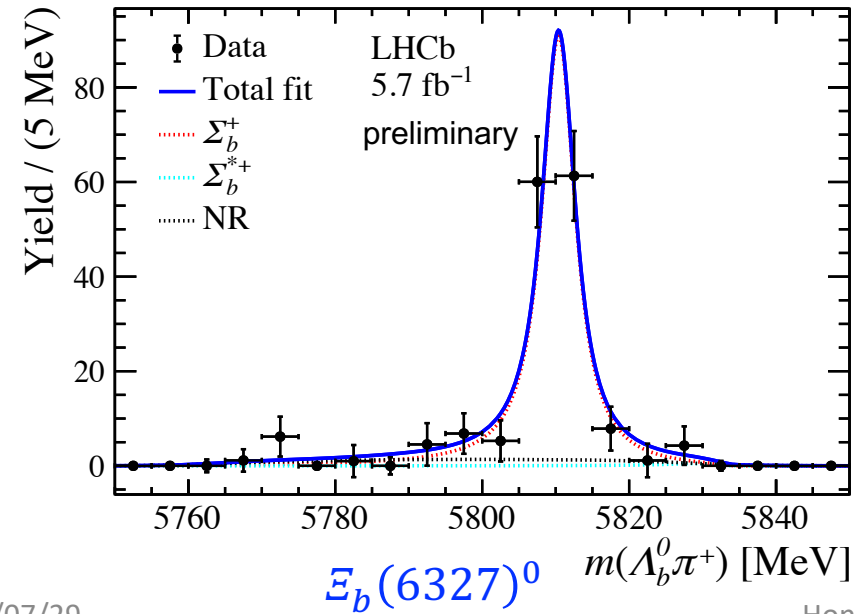
RS

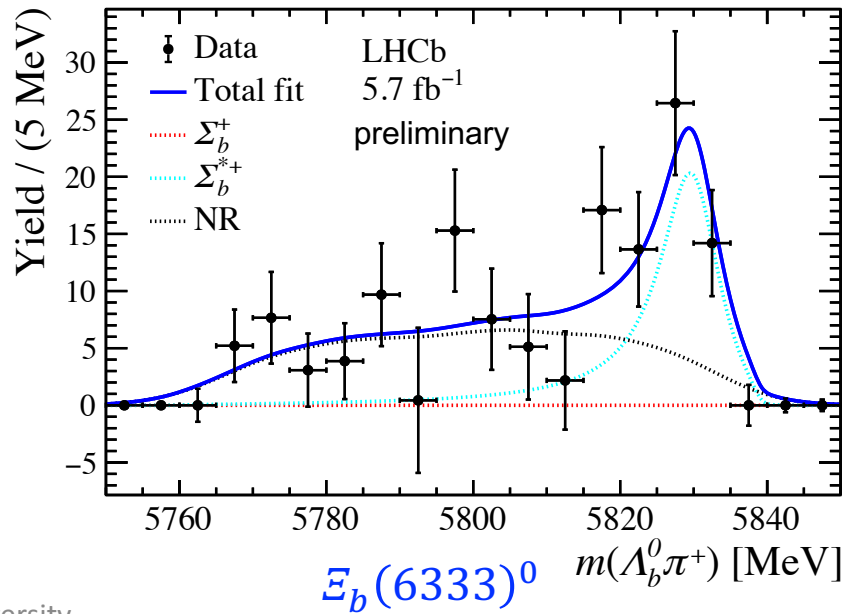


WS

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

- Resonant structure in $\Lambda_b^0 \pi^+$ mass spectrum
  - $\Xi_b(6327)^0$ predominantly decays to $\Sigma_b^+ K^-$
  - About half of $\Xi_b(6333)^0$ decay without $\Lambda_b^0 \pi^+$ resonances, the rest decay through Σ_b^{*+} intermediate structure
  - Consistent with 1D Ξ_b^0 doublets [Bing Chen *et. al*. PRD 100 (2019) 094032]



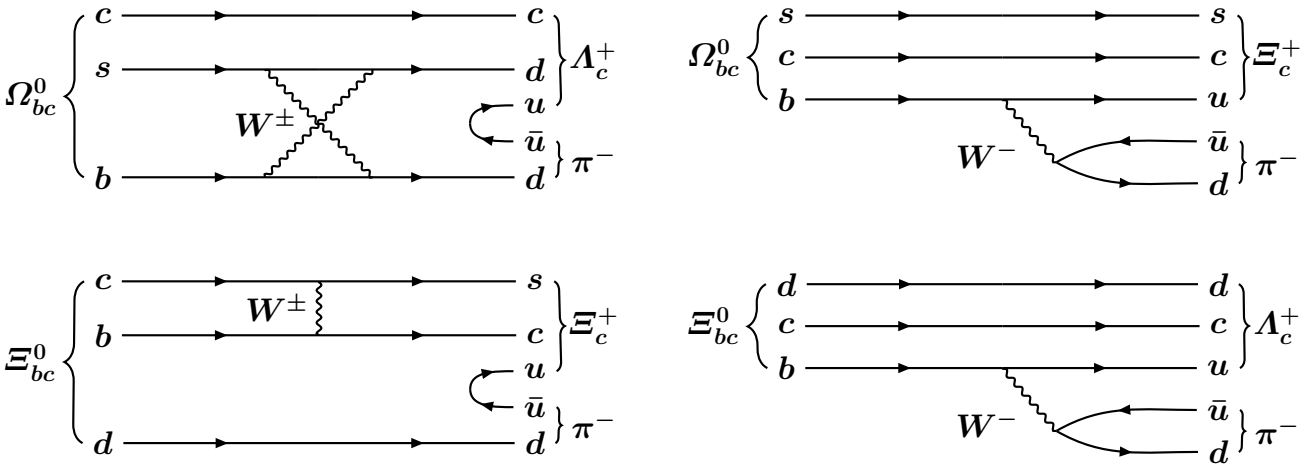


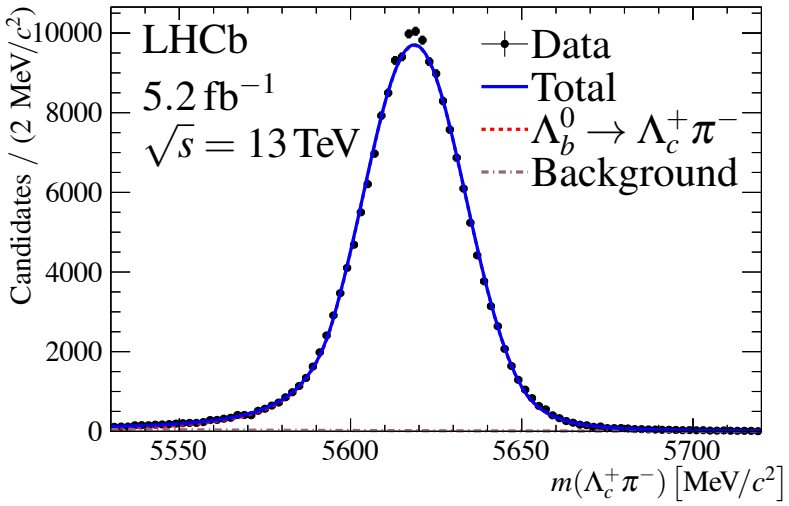
Search for Ξ_{bc}^{0} and Ω_{bc}^{0} decaying to $\Lambda_{c}^{+}\pi^{-}$ and $\Xi_{c}^{+}\pi^{-}$

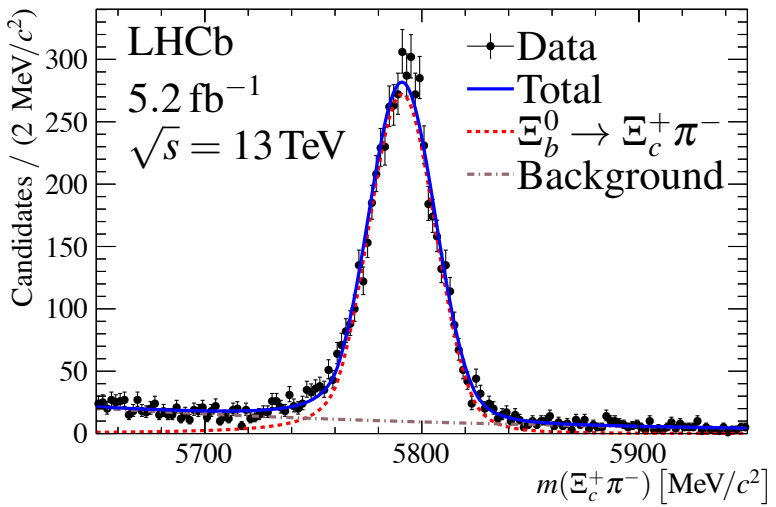
[arXiv:2104.04759]

Search for Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$

- Data sample
  - $\Lambda_c^+ \to pK^-\pi^+$
  - $\Xi_c^+ \to pK^-\pi^+$
- Control channel
  - $\Lambda_b^0 \to \Lambda_c^+\pi^-$
  - $\Xi_b^0 \to \Xi_c^+\pi^-$

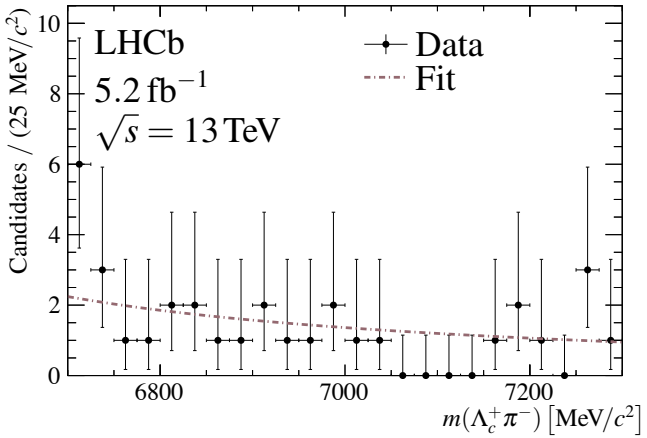


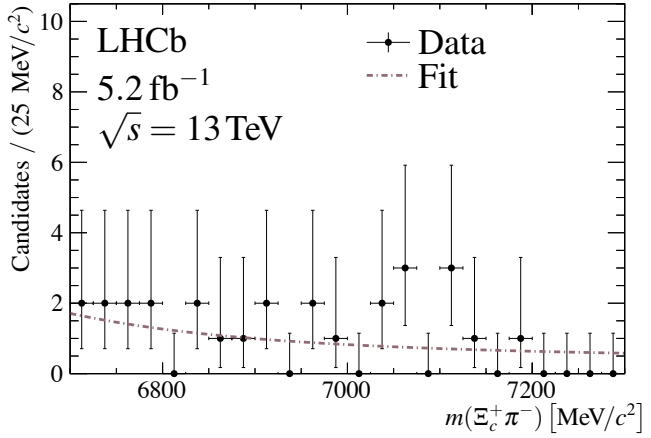




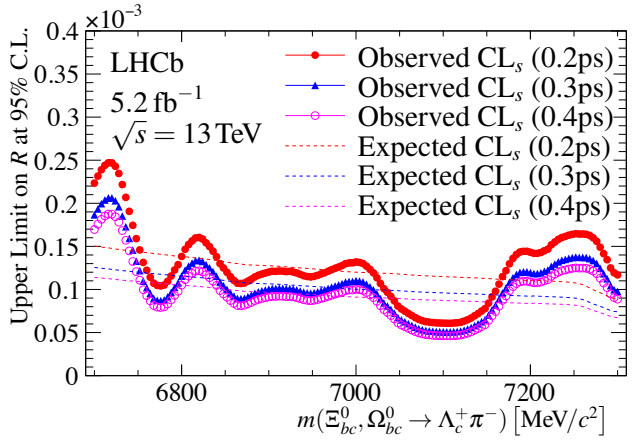
Search for Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$

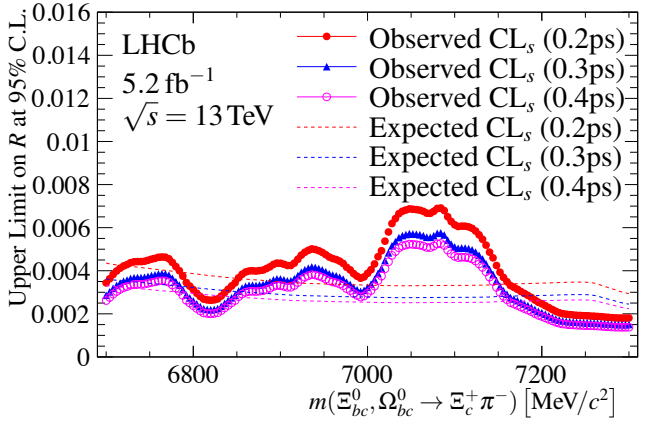
- No significant excess





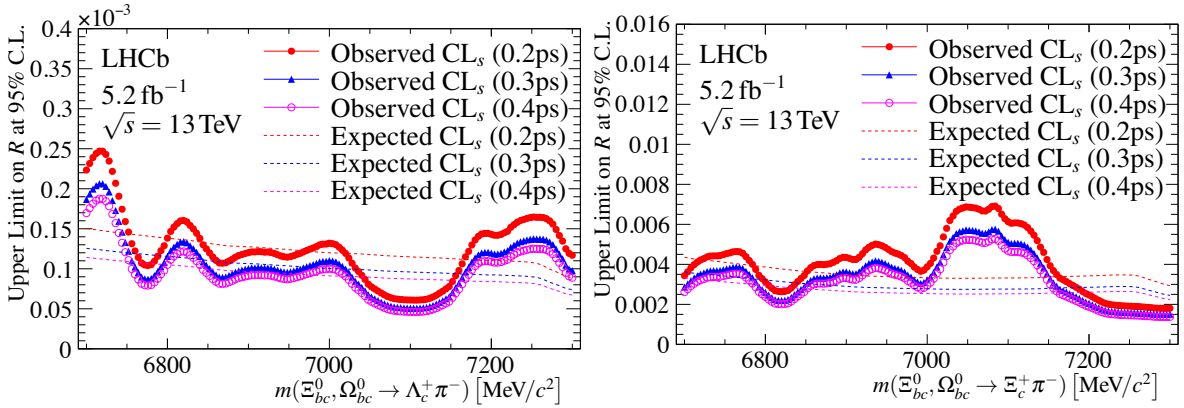
- Upper limits (95% CL) on production ratio relative to $\Lambda_b^0 \to \Lambda_c^+\pi^-$ ($\Xi_b^0 \to \Xi_c^+\pi^-$)
  - $\Lambda_c^+\pi^-$: 0.5×10^{-4} to 2.5×10^{-4}
  - $\Xi_c^+\pi^-$: 1.4×10^{-3} to 6.9×10^{-3}



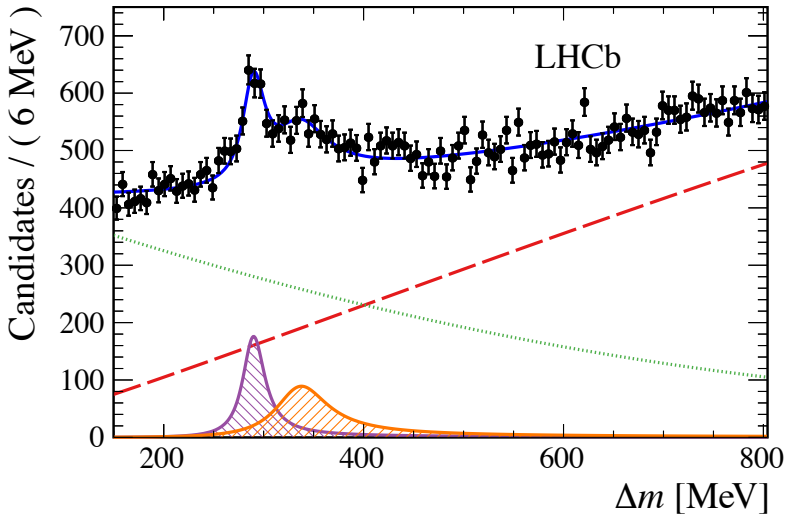


Summary

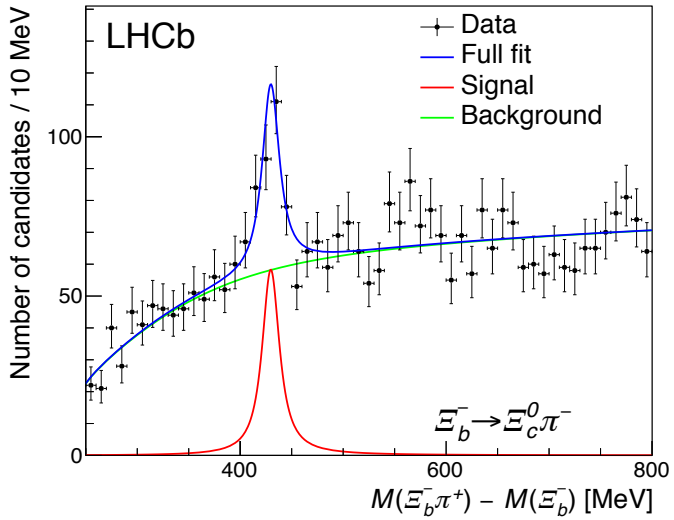
- Lots of new beauty hadrons observed at LHCb
- Upper limits on production ratio set for Ξ_{bc}^0 and Ω_{bc}^0



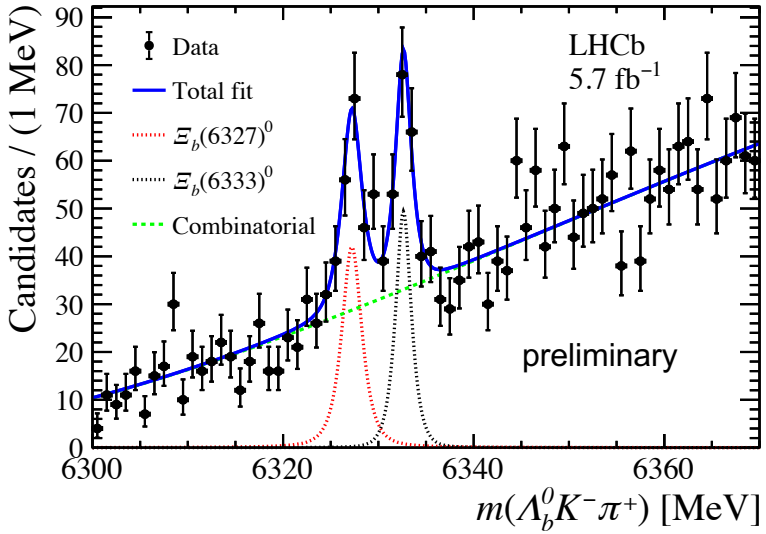
[arXiv:2104.04759]



[EPJC 81 (2021) 7, 601]



[PRD 103 (2021) 012004]



[LHCb-PAPER-2021-025, in preparation]

New!

Thank you!

Backup

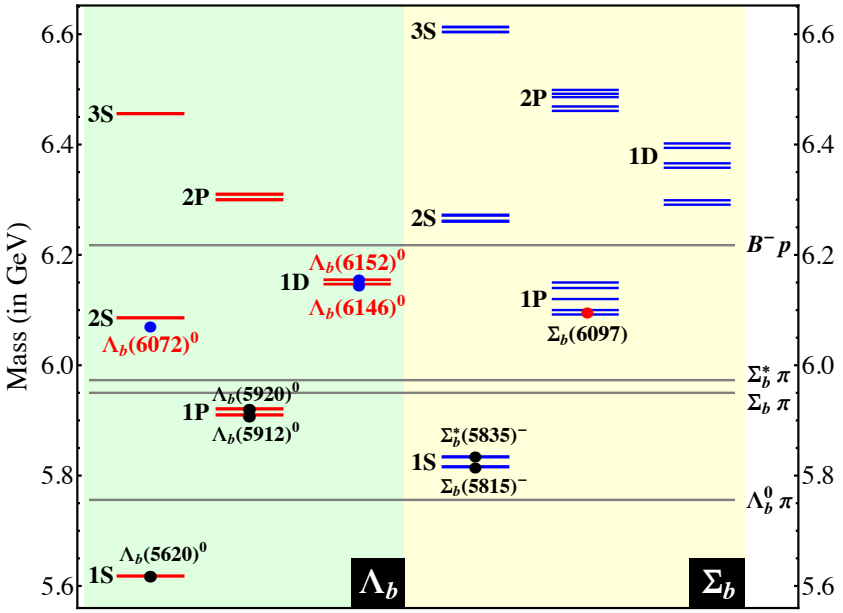
Beauty-baryon spectroscopy

[LHCb-PAPER-2021-025, in preparation]

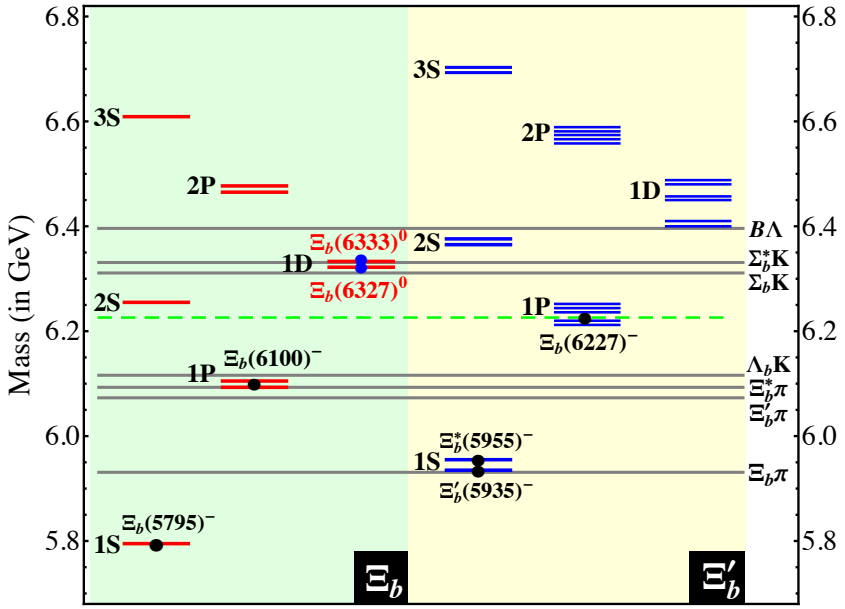
[PRL 126 (2021) 252003]

[JHEP 06 (2020) 136]

- Beauty baryon (bqq')
  - Light diquark spin $j_{qq'} = 0\ (1)$: $\Lambda_b^0\ (\Sigma_b)$
- Beauty baryon contains one s quark (bsq)
  - Light diquark spin $j_{sq} = 0\ (1)$: $\Xi_b\ (\Xi_b')$



[PRD 98 (2018) 074032]



[PRD 98 (2018) 031502]

Search for Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$

[arXiv:2104.04759]

➢Production ratio relative to $\Lambda_b^0 \to \Lambda_c^+\pi^-$ ($\Xi_b^0 \to \Xi_c^+\pi^-$)

- $R(\Lambda_c^+\pi^-) \equiv \frac{\sigma(pp\to H_{bc}^0 X)\mathcal{B}(H_{bc}^0\to\Lambda_c^+\pi^-)}{\sigma(pp\to\Lambda_b^0 X)\mathcal{B}(\Lambda_b^0\to\Lambda_c^+\pi^-)} = \frac{N(H_{bc}^0\to\Lambda_c^+\pi^-)}{N(\Lambda_b^0\to\Lambda_c^+\pi^-)}\cdot\frac{\varepsilon(\Lambda_b^0)}{\varepsilon(H_{bc}^0)}$
- $R(\Xi_c^+\pi^-) \equiv \frac{\sigma(pp\to H_{bc}^0 X)\mathcal{B}(H_{bc}^0\to\Xi_c^+\pi^-)}{\sigma(pp\to\Xi_b^0 X)\mathcal{B}(\Xi_b^0\to\Xi_c^+\pi^-)} = \frac{N(H_{bc}^0\to\Xi_c^+\pi^-)}{N(\Xi_b^0\to\Xi_c^+\pi^-)}\cdot\frac{\varepsilon(\Xi_b^0)}{\varepsilon(H_{bc}^0)}$
- H_{bc}^0 represents Ξ_{bc}^0 or Ω_{bc}^0
- Different H_{bc}^0 mass varied from 6700 to 7300 MeV, with a step size of 4 MeV
- Considered lifetime: 0.2 ps, 0.3 ps, 0.4 ps