Supplementary material for LHCb-PAPER-2019-045

Excited Λ_b^{**0} or Σ_b^{**0}?

The new observed baryon state can be either an excited isosinglet Λ_b^{**0} state or a neutral component of the excited Σ_b^{**} isotriplet. If it corresponds to the Σ_b^{**0} state, the production of two charged $\Sigma_b^{**\pm}$ states is also expected with similar rates. For Σ_b^{**} states, two decay modes are possible, $\Sigma_b^{**} \to \Lambda_b^0\pi$ and $\Sigma_b^{**} \to \Lambda_b^0\pi\pi$ with the $\pi\pi$ pair in an isovector ($\mathrm{I}=1$) state. The sum of partial decay widths should be equal to the total decay width, $\Gamma_{\mathrm{tot}} = \Gamma_{\Lambda_b^0\pi\pi} + \Gamma_{\Lambda_b^0\pi}$, and possible contributions from radiative decays are expected to be negligible. The partial decay widths of exited Σ_b^{**} states into the $\Lambda_b^0\,(\pi\pi)_{\mathrm{I}=1}$ final state are calculated in Ref. [1], and they do not exceed 3.6 MeV for any P-wave or low-mass D-wave excitations.

The expected signal in the $\Lambda_b^0\pi^\pm$ final state from the isospin partners $\Sigma_b^{**\pm}$ states can be estimated as

$$\frac{N_{\Lambda_b^0\pi^\pm}}{N_{\Lambda_b^0\pi^+\pi^-}} = \frac{\Gamma_{\Lambda_b^0\pi}}{\Gamma_{\Lambda_b^0\pi\pi}}\frac{\epsilon_{\Lambda_b^0\pi^\pm}}{\epsilon_{\Lambda_b^0\pi^+\pi^-}}\,,$$

where ϵ denotes the corresponding efficiency. Conservatively taking $\Gamma_{\Lambda_b^0\pi\pi} = 4\,\mathrm{MeV}$ and rescaling the expectation to the Run 1 dataset for comparison with Ref. [2], the expected yield is

$$N_{\Lambda_b^0\pi^\pm} = 8.5\times10^3\left(\frac{\epsilon_{\Lambda_b^0\pi^\pm}}{\epsilon_{\Lambda_b^0\pi^+\pi^-}}\right). \tag{1}$$

It is natural to expect that the ratio of efficiencies is $\frac{\epsilon_{\Lambda_b^0\pi^\pm}}{\epsilon_{\Lambda_b^0\pi^+\pi^-}} > 1$. If the newly observed peak corresponds to a neutral component of the excited Σ_b^{**} isotripet, then very large signals from the decays of the corresponding charged components of the isotriplet, $\Sigma_b^{**\pm} \to \Lambda_b^0\pi^\pm$ should be observed in Run 1 analysis of $\Lambda_b^0\pi^\pm$ spectra [2]. Figures 1 and 2 show the $\Lambda_b^0\pi^\pm$ mass spectra from Ref. [2] with the expected signals from $\Sigma_b^{**\pm}$ states superimposed. The ratio of efficiencies is conservatively taken to be 1. Since no such large signals are observed, the interpretation of the new state as neutral member of Σ_b^{**} isotriplet is disfavoured.

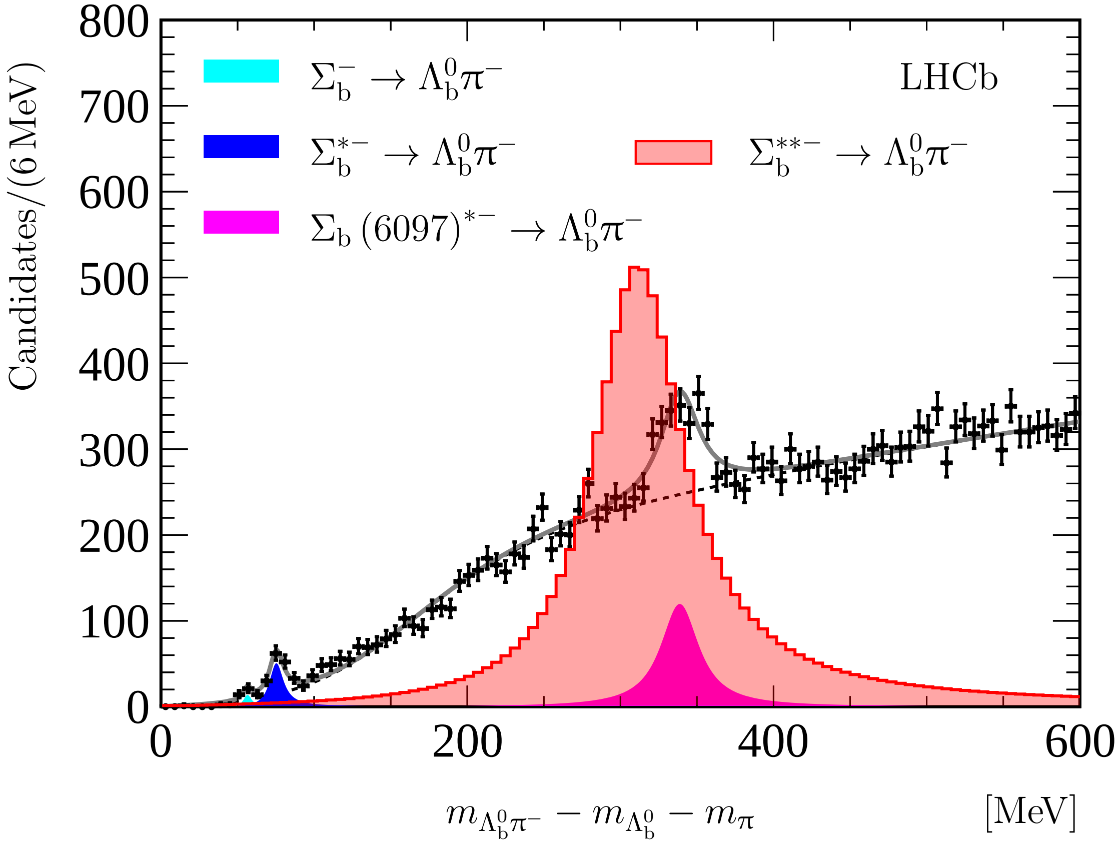

Figure 1: The $\Lambda_b^0\pi^-$ mass spectrum from Ref. [2] with the expected signal from the $\Sigma_b^{**-} \to \Lambda_b^0\pi^-$ decays superimposed.

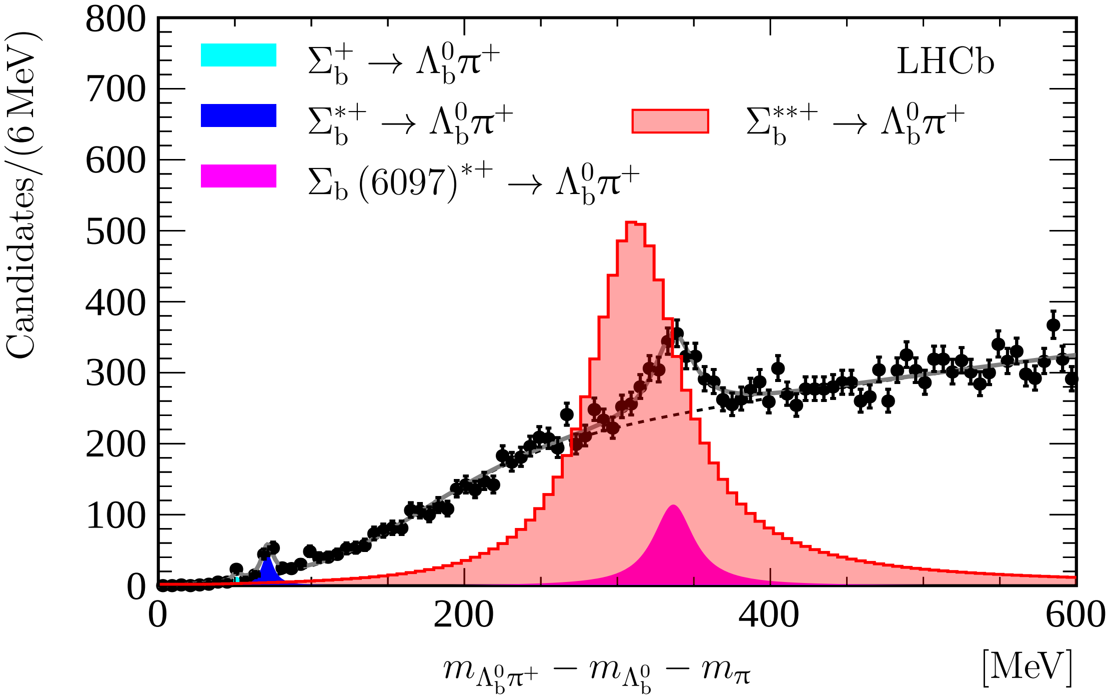

Figure 2: The $\Lambda_b^0\pi^+$ mass spectrum from Ref. [2] with the expected signal from the $\Sigma_b^{**+} \to \Lambda_b^0\pi^+$ decays superimposed.

Is it a neutral component of the $\Sigma_{\mathrm{b}}(6097)$ triplet?

Is the new baryon a neutral member of the $\Sigma_{\mathrm{b}}(6097)$ triplet? The parameters are summarised in Table 1.

- The mass difference between $\Lambda_{\mathrm{b}}^{**}$ and $\Sigma_{\mathrm{b}}(6097)^{\pm}$ is hardly compatible with the hypothesis of isotopic partners.
- The difference in the widths is even larger, close to a factor of two. The different multiplet component indeed can have different widths, *e.g.*, if due to mass splitting certain decay modes are forbidden for some multiplet components, but in this case there are no forbidden modes and thus all the widths must be similar.
- The observed yields of the $\Sigma_{\mathrm{b}}(6097)^{\pm}$ states for the Run 1 dataset are significantly smaller than the projected yield from Eq. (1). To make the yields compatible, the ratio of efficiencies $\frac{\epsilon_{\Lambda_{\mathrm{b}}^0\pi}}{\epsilon_{\Lambda_{\mathrm{b}}^0\pi\pi}}$ should be around 0.1 instead of exceeding unity.

Considering the differences in mass, width and yields, the interpretation of the newly observed $\Lambda_{\mathrm{b}}^{**}$ state as a neutral member of the $\Sigma_{\mathrm{b}}(6097)$ triplet is unlikely.

Table 1: Masses and widths of $\Sigma_{\mathrm{b}}^{\pm}$ states from Ref. [2].

	Mass [MeV]	Width [MeV]	Run 1 yield
$\Sigma_{\mathrm{b}}(6097)^{+}$	$6095.8 \pm 1.7 \pm 0.4$	$28.9 \pm 4.2 \pm 0.9$	900 ± 110
$\Sigma_{\mathrm{b}}(6097)^{-}$	$6098.0 \pm 1.7 \pm 0.5$	$31.0 \pm 5.5 \pm 0.7$	880 ± 100
$\Lambda_{\mathrm{b}}^{**}$	$6071.3 \pm 2.9 \pm 0.6$	$72 \pm 11 \pm 2$	

Mass spectra of $\Lambda_b^0\pi^\pm$ combinations from the Λ_b^{**0} decays

The $\Lambda_b^0\pi^\pm$ mass spectra from $\Lambda_b^0\pi^+\pi^-$ and $\Lambda_b^0\pi^\pm\pi^\pm$ combinations with $\Lambda_b^0 \to \Lambda_c^+\pi^-$ from the Λ_b^{**0} signal-enhanced region $6.00 < m_{\Lambda_b^0\pi\pi} < 6.14\,\mathrm{GeV}$ are shown in Fig. 3. The $\Lambda_b^0\pi^\pm$ mass spectrum from the signal Λ_b^{**0} decays is obtained assuming that the $\Lambda_b^0\pi^\pm$ spectra from the same-sign $\Lambda_b^0\pi^\pm\pi^\pm$ combinations represent the background. The background-subtracted spectrum is consistent with the presence of relatively small contributions from $\Lambda_b^{**0} \to \Sigma_b^\pm\pi^\mp$ and $\Lambda_b^{**0} \to \Sigma_b^{*\pm}\pi^\mp$ decays and a dominant contribution from nonresonant $\Lambda_b^{**0} \to \Lambda_b^0\pi^+\pi^-$ decays.

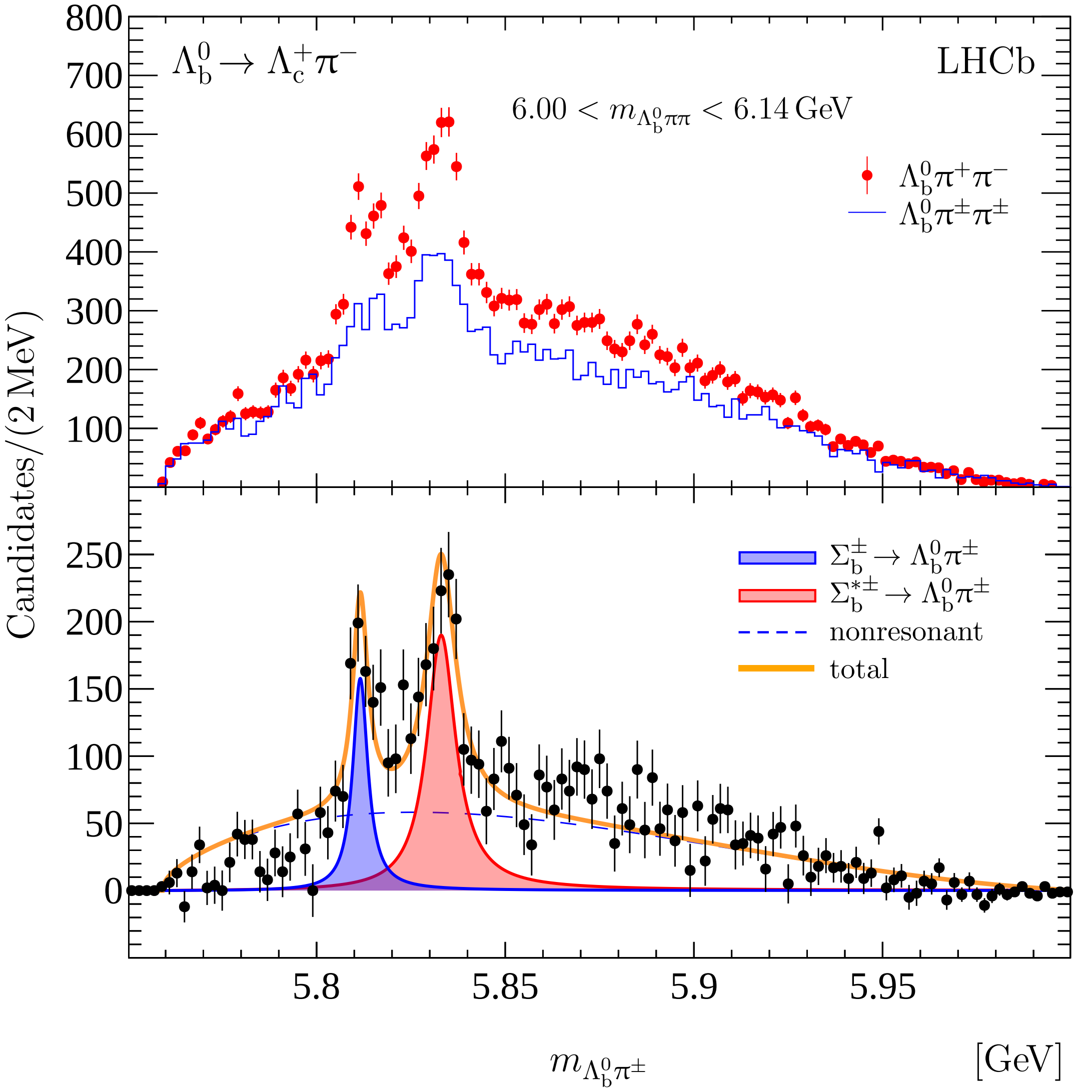

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Figure 3: (Top) Spectra of $\Lambda_b^0\pi^\pm$ mass with $\Lambda_b^0 \to \Lambda_c^+\pi^-$ for $\Lambda_b^0\pi^+\pi^-$ combinations (red points with error bars) and $\Lambda_b^0\pi^\pm\pi^\pm$ combinations (open blue histogram). (Bottom) Difference between $\Lambda_b^0\pi$ mass spectra from $\Lambda_b^0\pi^+\pi^-$ and $\Lambda_b^0\pi^\pm\pi^\pm$ combinations. A fit with the $\Sigma_b^\pm \to \Lambda_b^0\pi^\pm$ and $\Sigma_b^{*\pm} \to \Lambda_b^0\pi^\pm$ contributions and a smooth nonresonant component is superimposed.

References

[1] C. Mu *et al.*, *Dipion decays of heavy baryons*, Chin. Phys. **C38** (2014) 113101, `arXiv:1405.3128`.

[2] LHCb collaboration, R. Aaij *et al.*, *Observation of two resonances in the $\Lambda_b^0\pi^{\pm}$ systems and precise measurement of $\Sigma_b^{\pm}$ and $\Sigma_b^{*\pm}$ properties*, Phys. Rev. Lett. **122** (2019) 012001, `arXiv:1809.07752`.