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 $Σ_b^{**±}$ states is also expected with similar rates. For $Σ_b^{**}$ states, two decay modes are possible, $Σ_b^{**} → Λ_b^0 π^-$ and $Σ_b^{**} → Λ_b^0 ππ$ with the $ππ$ pair in an isovector ($I = 1$) state. The sum of partial decay widths should be equal to the total decay width, $Γ_{tot} = Γ_{Λ_b^0 π^-} + Γ_{Λ_b^0 π}$, and possible contributions from radiative decays are expected to be negligible. The partial decay widths of exited $Σ_b^{**}$ states into the $Λ_b^0 (ππ)_{I=1}$ 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 $Λ_b^0 π^±$ final state from the isospin partners $Σ_b^{**±}$ states can be estimated as

$$\frac{N_{Λ_b^0 π^±}}{N_{Λ_b^0 π^+ π^-}} = \frac{Γ_{Λ_b^0 π}}{Γ_{Λ_b^0 ππ}} \frac{ε_{Λ_b^0 π^±}}{ε_{Λ_b^0 π^+ π^-}},$$

where $ε$ denotes the corresponding efficiency. Conservatively taking $Γ_{Λ_b^0 π^±} = 4$ MeV and rescaling the expectation to the Run 1 dataset for comparison with Ref. [2], the expected yield is

$$N_{Λ_b^0 π^±} = 8.5 × 10^3 \left( \frac{ε_{Λ_b^0 π^±}}{ε_{Λ_b^0 π^+ π^-}} \right).$$

(1)

It is natural to expect that the ratio of efficiencies is $\frac{ε_{Λ_b^0 π^±}}{ε_{Λ_b^0 π^+ π^-}} > 1$. If the newly observed peak corresponds to a neutral component of the excited $Σ_b^{**}$ isotriplet, then very large signals from the decays of the corresponding charged components of the isotriplet, $Σ_b^{**±} → Λ_b^0 π^±$ should be observed in Run 1 analysis of $Λ_b^0 π^±$ spectra [2]. Figures 1 and 2 show the $Λ_b^0 π^±$ mass spectra from Ref. [2] with the expected signals from $Σ_b^{**±}$ 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 $\Sigma^{*+}\rightarrow\Lambda_b^0\pi^-$ decays superimposed.
Figure 2: The \( \Lambda_0^b \pi^+ \) mass spectrum from Ref. [2] with the expected signal from the \( \Sigma^{**+}_b \rightarrow \Lambda_0^b \pi^+ \) decays superimposed.
Is it a neutral component of the $\Sigma_b(6097)$ triplet?

Is the new baryon a neutral member of the $\Sigma_b(6097)$ triplet? The parameters are summarised in Table 1:

- The mass difference between $\Lambda_b^{**}$ and $\Sigma_b(6097)^\pm$ 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 $\Sigma_b(6097)^\pm$ 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 $\frac{\epsilon_{\Lambda_b^{***}}}{\epsilon_{\Lambda_b^{**}}}$ should be around 0.1 instead of exceeding unity.

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

Table 1: Masses and widths of $\Sigma_b^\pm$ states from Ref. 2.

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<tr>
<td>$\Sigma_b(6097)^+$</td>
<td>6095.8 ± 1.7 ± 0.4</td>
<td>28.9 ± 4.2 ± 0.9</td>
<td>900 ± 110</td>
</tr>
<tr>
<td>$\Sigma_b(6097)^-$</td>
<td>6098.0 ± 1.7 ± 0.5</td>
<td>31.0 ± 5.5 ± 0.7</td>
<td>880 ± 100</td>
</tr>
<tr>
<td>$\Lambda_b^{**}$</td>
<td>6071.3 ± 2.9 ± 0.6</td>
<td>72 ± 11 ± 2</td>
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Mass spectra of $\Lambda_b^0 \pi^\pm$ combinations from the $\Lambda_b^{*0}$ decays

The $\Lambda_b^0 \pi^\pm$ mass spectra from $\Lambda_b^0 \pi^+ \pi^-$ and $\Lambda_b^0 \pi^\mp \pi^\pm$ combinations with $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ from the $\Lambda_b^{*0}$ signal-enhanced region $6.00 < m_{\Lambda_b^0 \pi \pi} < 6.14$ GeV are shown in Fig. 3. The $\Lambda_b^0 \pi^\pm$ mass spectrum from the signal $\Lambda_b^{*0}$ decays is obtained assuming that the $\Lambda_b^0 \pi^\pm$ spectra from the same-sign $\Lambda_b^0 \pi^+ \pi^- \pi^\pm$ 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.

![Figure 3](image-url)

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 $\Lambda_b^0 \pi^\mp \pi^\pm$ combinations (open blue histogram). (Bottom) Difference between $\Lambda_b^0 \pi^\pm$ mass spectra from $\Lambda_b^0 \pi^+ \pi^-$ and $\Lambda_b^0 \pi^\mp \pi^\pm$ combinations. A fit with the $\Sigma_b^\pm \to \Lambda_b^0 \pi^\mp$ and $\Sigma_b^{*\pm} \to \Lambda_b^0 \pi^\pm$ contributions and a smooth nonresonant component is superimposed.
References


[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