Evidence of a new excited charmed baryon decaying to \( \Sigma_c(2455)^0,^+^+^\pi^\pm \)

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We present the study of \( \bar{B}^0 \to \Sigma_c(2455)^0,^+^+^\pi^\pm \) decays based on 772 \( \times 10^6 \) \( B\bar{B} \) events collected with the Belle detector at the KEKB symmetric-energy \( e^+ e^- \) collider. The \( \Sigma_c(2455) \) candidates are reconstructed via their decay to \( \Lambda_c^+ \pi^\pm \) and \( \Lambda_c^0 \) decays to \( pK^-\pi^+ \), \( pK^0_S \), and \( \Lambda^+ \) final states. The corresponding branching fractions are measured to be \( B(\bar{B}^0 \to \Sigma_c(2455)^0,^+^+^\pi^\pm) = (1.09 \pm 0.06 \pm 0.15) \times 10^{-4} \) and \( B(\bar{B}^0 \to \Sigma_c(2455)^0,^+^+^\pi^\pm) = (1.84 \pm 0.11 \pm 0.06) \times 10^{-4} \), which are consistent with the world average values with improved precision. A new structure is found in the \( M_{\Sigma_c(2455)}(\Lambda^+_c, \pi^\pm) \) spectrum with a significance of 2.6 including systematic uncertainty. The structure is possibly an excited \( \Lambda_c^+ \) and is tentatively named \( \Lambda_c(2910)^+ \). Its mass and width are measured to be \( (2913.8 \pm 5.6 \pm 3.8) \) MeV/c\(^2\) and \( (51.8 \pm 20.0 \pm 18.8) \) MeV, respectively. The products of branching fractions for the \( \Lambda_c(2910)^+ \) are measured to be \( B(\bar{B}^0 \to \Lambda_c(2910)^+ \pi^\pm) \times B(\Lambda_c(2910)^+ \to \Sigma_c(2455)^0\pi^\pm) = (9.5 \pm 3.6 \pm 1.6) \times 10^{-6} \) and \( B(\bar{B}^0 \to \Lambda_c(2910)^+ \pi^\pm) \times B(\Lambda_c(2910)^+ \to \Sigma_c(2455)^0\pi^\pm) = (1.24 \pm 0.35 \pm 0.10) \times 10^{-5} \). Here, the first and second uncertainties are statistical and systematic, respectively.

Due to the numerous degrees of freedom of the internal structure of charmed baryons, their spectroscopy provides an excellent laboratory for studying the dynamics of light quarks in the environment of a heavy quark and testing heavy-quark symmetry and chiral symmetry of light quarks [1–3]. Although many excited charmed baryons have been discovered by the BaBar, Belle, CLEO, and LHCb in the past two decades [4], there are still missing states in the predicted spectra [5] and properties of known particles are still poorly understood [4]. Currently, there is no unified phenomenological model that can fully describe the charmed baryon sector. Theoretically, the mass spectrum of excited charmed baryons has been studied with numerous approaches, such as a Quantum Chromodynamics (QCD) based quark model [6], the QCD sum rule [7–11], Reggie phenomenology [12], a relativistic quark potential model [13], quark potential models [14–18], the relativistic flux tube models [19, 20], the coupled channel model [21], the constituent quark models [22–24], and lattice QCD [25, 26]. More experimental measurements

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are required to validate these theoretical models.

Among the observed excited $\Lambda^+_c$ family, the highest state $\Lambda_c(2940)^+$ presents many mysteries. It was discovered by BaBar via its decay to $D^0\bar{p}$ [27], and confirmed by LHCb [28], and its decay to $\Sigma_c(2455)^{0,+}+\pi^\pm$ was observed by Belle [29]. Though the quantum number $J^P = \frac{3}{2}^+$ is favored for $\Lambda_c(2940)^+$ according to the LHCb measurement, other spin-parity assignments are also proposed [5, 30]. Besides that, the mass of $\Lambda_c(2940)^+$ is lower than the expected $\Lambda_c(\frac{3}{2}^+, 2P)$ state in the quark models [13, 18, 19, 23], in which its mass is expected to be above 3 GeV/$c^2$ and the mass of the undiscovered $\Lambda_c(\frac{3}{2}^+, 2P)$ state is slightly lighter than that of $\Lambda_c(\frac{3}{2}^-, 2P)$ by not more than 25 MeV/$c^2$. Such a low-mass puzzle for $\Lambda_c(2940)^+$ can be explained by introducing the $D^*N$ channel contribution [31], while the mass of $\Lambda_c(\frac{3}{2}^-, 2P)$ state is higher than that of $\Lambda_c(\frac{3}{2}^-, 2P)$ by around 40 MeV/$c^2$ in this scenario, which leads to an interesting mass inversion. Thus, it is important to verify the quantum number of $\Lambda_c(2940)^+$ or search for other candidates of $\Lambda_c(2P)$.

Compared to the previous inclusive analyses [27–29], the study of $\Lambda_c(2P)$ can be performed in $B^0 \to \Lambda^+_c(2P)\to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}$ exclusive decays, which can constrain the spin and parity of the possible excited $\Lambda^+_c(2P)$ and provide a simpler background environment. The $B^0 \to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}$ decay has been previously studied by CLEO [32], Belle [33, 34], and BaBar [35] based on 9.17 fb$^{-1}$, 357 fb$^{-1}$ and 426 fb$^{-1}$ $\Upsilon(4S)$ data samples, respectively, with $\Lambda^+_c$ reconstructed via the $pK^-\pi^+$ mode. The average branching fractions are $B(B^0 \to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}) = (1.08 \pm 0.16) \times 10^{-4}$ and $B(B^0 \to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}) = (1.88 \pm 0.24) \times 10^{-4}$. The invariant mass spectra of $M_{\Sigma_c(2455)^{0,+}+\pi^\pm}$ and $M_{pK^+\pi^-}$ are found to be inconsistent with phase-space distributions. In particular, Belle’s analysis in Ref. [34] suggested that there could be a structure or overlap of several known excited $\Lambda^+_c$ near the threshold of the $M_{\Sigma_c(2455)^{0,+}}$ spectrum, which needs further study.

In this Letter, we present a study of the $B^0 \to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}$ decays [36] and study the possible resonance in the $M_{\Sigma_c(2455)^{0,+}+\pi^\pm}$ spectrum using the full data sample of 711 fb$^{-1}$ collected at the $\Upsilon(4S)$ resonance by the Belle detector [37] at the KEKB asymmetric energy electron-positron collider [38]. Simulated signal events with $B^0$ meson decays are generated using EVTGEN [39]. These events are processed by a detector simulation based on GEANT3 [40]. The generic Monte Carlo (MC) samples of $\Upsilon(4S) \to BB$ ($B = B^+$ or $B^0$) and $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) events at $\sqrt{s} = 10.58$ GeV are used to check the backgrounds [41], corresponding to five times the integrated luminosity of the data.

For charged track identification, information from different detector subsystems is combined to form the likelihood $L_i$ for species $i$, where $i = \pi, K$, or $p$ [42]. Except for the charged tracks from $\Lambda \to p\pi^-$ and $K^0_S \to \pi^+\pi^-$ decays, a track with a likelihood ratio $R^L_K = L_K/(L_K + L_{\pi^+}) > 0.6$ ($< 0.4$) is identified as a kaon (pion) [42]. With this selection, the kaon (pion) identification efficiency is about 93% (97%). A track with $R^L_K = L_p/(L_p + L_{\pi^+}) > 0.6$ is identified as a proton with an efficiency above 90%. The $K^0_S$ and $\Lambda$ candidates are reconstructed from pairs of oppositely charged tracks, treated as $\pi^+\pi^-$ and $p\pi^-$, with the similar method used in Ref. [43]. The $p\pi^-$ invariant mass should be within 3.5 MeV/$c^2$ ($\sim 3\sigma$, where $\sigma$ denotes the mass resolution) of the $\Lambda$ nominal mass [4]. The $\Sigma_c(2455)^{0,+}$ candidates are reconstructed via their decay to $\Lambda^+_c\pi^+$, while the $\Lambda^+_c$ are reconstructed with the $\Lambda^+_c \to pK^-\pi^+$, $pK^{0}_S$, and $\Lambda\pi^+$. The mass windows of $\Sigma_c(2455)^{0,+}$ and $\Lambda^+_c$ are within 10 MeV/$c^2$ and 14 MeV/$c^2$ of their nominal masses [4], respectively, which retain more than 94% of the signal events. About 8% of events have multiple candidates that are all used for further analysis.

Figure 1 shows the scatter plot of $\Delta M_B$ versus $M_{bc}$ of the selected $B^0 \to \Sigma_c(2455)^{0,+}+\pi^\pm\bar{p}$ candidates from data after applying the selection criteria above. The $M_{bc}$ is defined as $\sqrt{E_{\text{beam}}^2/c^2 - (\sum p_i)^2/c}$, where $E_{\text{beam}}$ and $p_i$ are the beam energy and the three-momenta of the $B^0$-meson decay products in the center-of-mass system of the $e^+e^-$ collision. The $\Delta M_B$ is defined as $M_B - m_B$, where $M_B$ is the invariant mass of the $B^0$ candidate and $m_B$ is the nominal $B^0$-meson mass [4]. The $B^0$ signal region is $|\Delta M_B| < 0.023$ GeV/$c^2$ ($\sim 2.5\sigma$) and $M_{bc} > 5.272$ GeV/$c^2$ ($\sim 2.5\sigma$), which is illustrated by the green box in Fig. 1.
\[ \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \] are extracted by unbinned two-dimensional (2D) extended maximum likelihood fits to the \( M_{bc} \) and \( M_{\Lambda^+_c\pi^+} \) distributions of the selected \( \bar{B}^0 \rightarrow \Lambda^+_c\pi^-\pi^+\bar{p} \) candidates. The 2D fitting function is parameterized as

\[
f(M_1, M_2) = N_{bg} s(M_1) s(M_2) + N_{bg} s(M_1) b'(M_2) + N_{bg} b(M_1) s(M_2) + N_{bg} g(M_1) g'(M_2),
\]

where \( s(M_1) \) and \( S(M_2) \) are the 1D signal function in \( M_{bc} \) and \( M_{\Lambda^+_c\pi^+} \), respectively, while \( b(M_1), g(M_1), b'(M_2) \) and \( g'(M_2) \) are the background functions for the same arguments. Here, \( s(M_1) \) is a Gaussian function, \( S(M_2) \) is a non-relativistic Breit-Wigner (BW) function with the phase space factor \( p_{\pi\pi}/M_{\Lambda^+_c\pi^+} \) considered, convoluted with a triple-Gaussian function whose parameters determined by MC simulation. Moreover, \( p_{\pi\pi} \) is the momentum of the selected \( \pi^+ \) in the rest frame of \( \Lambda^+_c\pi^+ \) system. Here, \( b \) and \( g \) are ARGUS functions [44] while \( b' \) and \( g' \) are second-order Chebyshev polynomial. All the parameters of the fitting functions are free to float except for those of triple-Gaussian functions. The projections of the 2D fits to the selected \( \bar{B}^0 \rightarrow \Lambda^+_c\pi^-\pi^+\bar{p} \) candidates from data are shown in Fig. 2 with the contribution from each component indicated in the legends.

In calculating the branching fractions of \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \), the \( M_{\Lambda^+_c\pi^+\pi^-} \) versus \( M_{\bar{p}\pi^\mp} \) planes are divided uniformly into 4 \( \times 4 \) bins. The \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) signal yield, \( N_{bc}(\Sigma_c(2455)^{0,++}) \), where \( i \) represents each \( M_{\Lambda^+_c\pi^+\pi^-} \) versus \( M_{\bar{p}\pi^\mp} \) bin, is extracted by the simultaneous fit to all the bins with the same method used in Fig. 2, where the signal functions share the same set of parameters. The total yields of \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) and \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) are 767 ± 44 and 1213 ± 73, respectively, obtained by summing the corresponding signal yield in each bin. The total yields are consistent with the overall fit results shown in Fig. 2.

The branching fractions of \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) are calculated from

\[
\frac{1}{\epsilon^B} \times \frac{B(\bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p}) \times B_{\bar{p}\pi^\mp}}{\Sigma_{bc}(\Sigma_c(2455)^{0,++})},
\]

where \( N_{BB} = 772 \times 10^6 \) is the number of \( B\bar{B} \) pairs and \( B(\bar{B}(4S) \rightarrow \bar{B}^0 B^0) = 0.486 \pm 0.006 \) [4]. Furthermore, \( \epsilon_i = \Sigma_i \left( \epsilon^B \times B(\Lambda^+_c \rightarrow f_j) \right) \) is the reduced detection efficiency in each \( M_{\Lambda^+_c\pi^+\pi^-} \) versus \( M_{\bar{p}\pi^\mp} \) bin, where \( f_j \) represents \( pK^-\pi^+ \), \( pK^0\bar{\pi} \), and \( \Lambda^+\pi^- \) for \( j = 1, 2, \) and 3, respectively; \( \epsilon^B \) is the detection efficiency of \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) with \( \Lambda_c \rightarrow f_j \) in the corresponding bin; \( B(\Lambda^+ \rightarrow f_j) \) is the branching fraction of \( \Lambda^+_c \rightarrow f_j \) including the decay branching fractions of \( K_S \) to \( \pi^+\pi^- \) and \( \Lambda \rightarrow p\pi^- \). Then, the branching fractions of \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) are calculated to be \( B(\bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p}) = (1.84 \pm 0.11) \times 10^{-4} \) and \( B(\bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p}) = (1.09 \pm 0.06) \times 10^{-4} \). The uncertainties here are statistical only.

We combine the spectra of \( M_{\Sigma_c(2455)^{0,++}} \) and \( M_{\Sigma_c(2455)^{0,++}} \) (denoted hereafter as the \( M_{\Sigma_c(2455)} \) spectrum) to search for a possible resonance. We estimate the background contributions from non-\( M_{bc} \) peaking backgrounds using the events in the three blue sideband regions minus the events in the two red sideband regions in Fig. 1, which are denoted as \( B \) sidebands, and the sidebands of \( \Sigma_c(2455)^{0,++} \), defined as 2.470 MeV/\( c^2 < M_{\Lambda^+_c\pi^+\pi^-} < 2.491 \) MeV/\( c^2 \) or 2.425 MeV/\( c^2 < M_{\Lambda^+_c\pi^+\pi^-} < 2.437 \) MeV/\( c^2 \), to estimate the non-\( \Sigma_c(2455)^{0,++} \) backgrounds. The distributions of the (a) \( M_{\Sigma_c(2455)^{0,++}M_{bc}} \), (b) \( M_{\Sigma_c(2455)^{0,++}M_{bc}} \), and (c) \( M_{\Sigma_c(2455)^{0,++}} \) of the selected \( \bar{B}^0 \rightarrow \Sigma_c(2455)^{0,++}\pi^\mp \bar{p} \) candidates in the \( \bar{B}^0 \) signal region and the corresponding \( \Sigma_c(2455) \) signal region are shown in Fig. 3, where a structure around 2.91 GeV/\( c^2 \) can be seen in all plots that cannot be well described by any known resonance. The filled histograms in plots (a), (b), and (c) are from the normalized \( B \) sidebands, \( \Sigma_c(2455) \) sidebands, and \( \Sigma_c(2455)^{0,++} \) sidebands, respectively. There is no peaking contribution from any sideband.

To determine the parameters of the structure, an unbinned extended maximum likelihood fit is performed to the \( M_{\Sigma_c(2455)^{0,++}} \) spectrum. The signal shape is a non-relativistic BW convoluted with a Gaussian function (whose width equals to 5.3 MeV/\( c^2 \) determined from
MC simulation) with the detection efficiency curve considered. The background is represented with a second-order Chebyshev polynomial. The corresponding fitted signal yield of the structure is 150 ± 40; its mass and width are determined to be (2913.8 ± 5.6) MeV/c^2 and (51.8 ± 20.0) MeV, respectively. For the mass measurement, the −1.5 MeV/c^2 shift between the output and input mass determined by MC simulation has been corrected (“mass correction factor”). The uncertainties here are statistical only. The statistical significance of the structure is 6.1σ, estimated from the difference of the logarithmic likelihoods of the fits without and with a signal component with the difference in the number of degrees of freedom, 3, considered [45]. Alternative fits to the M_{Σ_c(2455)π} spectrum are performed: (a) using a first or third-order polynomial as the background shape; (b) changing the mass resolution by 10%; and (c) using an energy-dependent relativistic BW function as the shape function. The statistical significances of the structure are larger than 5.8σ in all cases. When only taking the contributions of Λ_c(2880)^+ and Λ_c(2940)^+ as the signal shapes in the fit with their parameters constrained to be within 1σ of their world average values [4], their significances are 1.5σ and 2.6σ, respectively. However, when introducing Λ_c(2880)^+ and Λ_c(2940)^+ as additional background components into the above fit with the new structure, their yields are consistent with zero and the significance of the new structure decreases to 4.2σ. Therefore, we take the fit with only one signal component as nominal result, and take 4.2σ as the signal significance of the new structure with the systematic uncertainty included.

The known particle with the closest mass and width to the structure is Λ_c(2940)^+. However, the mass of the structure differs from that of Λ_c(2940)^+ [4] by 3.8σ with systematic uncertainty described below considered. Since the mass difference between the structure and Λ_c(2940)^+ agrees with the expected mass gap between Λ_c(\frac{3}{2}^-, 2P) and Λ_c(\frac{1}{2}^-, 2P) state in quark models [13, 18, 19, 23], the structure is a good candidate for the Λ_c(\frac{1}{2}^-, 2P) state and is tentatively named as Λ_c(2910)^+. The \( B^0 \rightarrow Λ_c(2910)^+\bar{p} \) and Λ_c(2940)^+ → Σ_c(2455)^0π^+ are S-wave decays under this assumption. However, further study is needed to confirm whether this state is an excited Λ_c or Σ_c.

To determine the signal yields of \( B^0 \rightarrow Λ_c(2910)^+\bar{p} \) with Λ_c(2910)^+ → Σ_c(2455)^0π^+, a simultaneous unbinned extended maximum-likelihood fit to the M_{Σ_c(2455)^0π^+} and M_{Σ_c(2455)^+π^-} spectra is performed, where the signal function is the same to both spectra. The fit functions are the same as those used in the nominal fit to M_{Σ_c(2455)π} spectrum above with all the parameters free to float. The fit results are shown in panels (b) and (c) of Fig. 3. The fitted signal yields are \( N_{Σ_c(2455)^0π^+} = 63 \pm 24 \) and \( N_{Σ_c(2455)^+π^-} = 83 \pm 23 \) for \( Λ_c(2910)^+ \rightarrow Σ_c(2455)^0π^+ \) and \( Λ_c(2910)^+ \rightarrow Σ_c(2455)^+π^- \), respectively. The fitted mass and width of \( Λ_c(2910)^+ \) are (2914.7 ± 5.6) MeV/c^2 and (50.1 ± 20.5) MeV, respectively, which are consistent with those from the fit to the M_{Σ_c(2455)π} spectrum.

The branching fraction product of \( B(\bar{B}^0 \rightarrow Λ_c(2910)^+\bar{p}) \times B(Λ_c(2910)^+ \rightarrow Σ_c(2455)^0π^+/π^-) \) is calculated with \( N_{Σ_c(2455)^0π^+/π^-} = (2 × N_{B\bar{B}} \times B(Γ(4S) \rightarrow B^0\bar{B}^0) \times Σ_i(B(Λ_i^+ \rightarrow f_i) × e_i^A(2910)^+)) \), where \( e_i^A(2910)^+ \) is the detection efficiency of \( B^0 \rightarrow Λ_c(2910)^+\bar{p} \) with \( Λ_c(2910)^+ \rightarrow Σ_c(2455)^0π^+/π^- \), \( Σ_c(2455)^0π^+ \rightarrow Λ^+_cπ^± \), \( Σ_c(2455)^0π^- \rightarrow Λ^+_cπ^- \), and \( Λ^+_c \rightarrow f_i \), which is 10.60%, 12.14%, and 11.24% for \( Λ^+_c \rightarrow pK^-π^+ \), \( pK_S^0 \), and \( Λ^+_cπ^+ \), respectively. The detection efficiencies here include the particle identification (PID) correction factors described below and the decay branching fractions of \( K_S^0 \rightarrow π^+π^- \) and \( Λ \rightarrow ππ^- \). The detection efficiencies are the same for \( Σ_c(2455)^0π^+ \) and \( Σ_c(2455)^0π^- \) intermediate states, according to the MC simulations. The branching fraction products are calculated to be \( B(\bar{B}^0 \rightarrow Λ_c(2910)^+\bar{p}) \times B(Λ_c(2910)^+ \rightarrow Σ_c(2455)^0π^+) = (9.5 ± 3.6) × 10^{-6} \) and \( B(\bar{B}^0 \rightarrow Λ_c(2910)^+\bar{p}) \times B(Λ_c(2910)^+ \rightarrow Σ_c(2455)^+π^-) = (1.24 ± 0.35) \times 10^{-5} \). The errors here are statistical only.

There are several sources of systematic uncertainties in the branching fraction measurements. Using \( D^+ \rightarrow D^0π^+ \), \( D^0 \rightarrow K^-π^+ \), and \( Λ \rightarrow ππ^- \) samples, the efficiency ratios between data and MC simulations are 0.998 ± 0.013, 0.970 ± 0.006, 0.900 ± 0.005, and 0.987 ± 0.005 for kaon, pion, proton from Λ_c^+, and proton directly from \( B^0 \), respectively, whose central values are taken as the efficiency correction factors and the errors are taken as the systematic uncertainties due to PID. The uncertainties on the branching fractions of \( Λ_c^+ \) decay chains are 5.1%, 5.1%, and 5.4% for \( Λ_c^+ \rightarrow pK^-π^- \), \( pK_S^0 \), and \( Λ_c^+π^+ \) modes [4], respectively. The uncertainties on the detection efficiency include those from PID, the branching fractions of Λ_c^+ decays, tracking efficiency (0.35%/track), as well as Λ (2.95%) and \( K_S^0 \) (0.5%) selection efficiencies. Assuming all the sources of the above systematic uncertainties are independent, the uncertainties from the same sources are summed linearly weighted by the expected signal yields over the three Λ_c^+ decay modes. Then, the uncertainties from different sources are added in quadrature to yield the total uncertainties on detection efficiency, which are listed in Table I.

We estimate the systematic uncertainties on the fitting procedure by changing the order of the background polynomial, the range of the fit, and the mass resolution (enlarged by 10%). The deviations from the nominal fitted results are taken as systematic uncertainties. For \( B(\bar{B}^0 \rightarrow Σ_c(2455)^0π^+/π^-) \), the fitting uncertainties in \( M_{Λ_c^+π^±π^±} \) versus \( M_{ππ^±} \) bins are summed in quadrature.
I am independent,

Table I: Summary of the systematic uncertainties on the branching fraction measurements (%). Here, $B_i$ means $B(\bar{B}^0\to \Sigma_c(2455)^0\pi^0\bar{p})$, $B(\bar{B}^0\to \Sigma_c(2455)^0\pi^-\bar{p})$, $B(\bar{B}^0\to \Lambda_c(2910)^+\bar{p})\times B(\Lambda_c(2910)^+\to \Sigma_c(2455)^0\pi^+)$, and $B(\bar{B}^0\to \Lambda_c(2910)^+\bar{p})\times B(\Lambda_c(2910)^+\to \Sigma_c(2455)^0\pi^-)$ for $i = 1, 2, 3,$ and 4, respectively.

| $B_i$ | Detection efficiency | Fit | $N_B$ | Sum |
|-------|----------------------|-----|-------|-----|
| $B_1$ | 5.9                  | 1.6 | 1.8   | 6.4 |
| $B_2$ | 5.9                  | 1.9 | 1.8   | 6.5 |
| $B_3$ | 5.6                  | 16  | 1.8   | 17  |
| $B_4$ | 5.8                  | 5.6 | 1.8   | 8.2 |

weighted by $1/\varepsilon_i$. These uncertainties are added in quadrature to yield the total uncertainties due to fit.

The uncertainties on the average value of $B(\Upsilon(4S)\to B^0\bar{B}^0)$ and $N_{\Upsilon(4S)}$ are 1.2% and 1.37%, respectively. Thus, the uncertainty of the $B^0$ count is 1.8%.

Assuming all sources listed in Table I are independent, the uncertainties from different sources are added in quadrature to yield the total systematic uncertainties.

The following systematic uncertainties are considered for the mass and width of $\Lambda_c(2910)^+$. Half of the mass correction factor is taken as a systematic uncertainty. By changing the order of the background polynomial and fit region, the differences in the fitted $\Lambda_c(2910)^+$ mass (3.42 MeV/$c^2$) and width (18.3 MeV) are taken as systematic uncertainties. By replacing the non-relativistic BW function by a relativistic BW function with a mass-dependent width of $\Gamma_{\pi} = P/M_{\pi}$, where $\Gamma_{\pi}$ is the width of the resonance, $\Phi(M_{\pi}) = P/M_{\pi}$ is the S-wave phase space factor ($P$ is the $\pi$ momentum in the $\Sigma_c\pi$ or $\Lambda_c(2910)^+$ center-of-mass frame), the difference in the measured $\Lambda_c(2910)^+$ mass (1.2 MeV/$c^2$) is taken as a systematic uncertainty. When considering the background contributions from $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$, by changing their masses and widths by $\pm1\sigma$, the differences in mass and width of $\Lambda_c(2910)^+$ are 1.0 MeV/$c^2$ and 4.3 MeV, respectively, which are taken as systematic uncertainties.

Assuming all the sources are independent, we add them in quadrature to obtain the total systematic uncertainties on the $\Lambda_c(2910)^+$ mass and width, which are 3.8 MeV/$c^2$ and 18.8 MeV, respectively.

In summary, based on $772 \times 10^6$ pairs of $B\bar{B}$ data samples collected with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider, we analyze the $B^0 \to \Sigma_c(2455)^0\pi^0\bar{p}$ decays with the branching fractions measured to be $B(\bar{B}^0\to \Sigma_c(2455)^0\pi^0\bar{p}) = (1.84\pm0.11\pm0.12) \times 10^{-4}$ and $B(\bar{B}^0\to \Sigma_c(2455)^0\pi^-\bar{p}) = (1.09 \pm 0.06 \pm 0.07) \times 10^{-4}$, which are consistent with the previous measurements [4, 32–35] with improved precision. A structure around 2.91 GeV/$c^2$ is found in the $\Sigma_c(2455)^0$ spectrum with a statistical significance of 6.1σ. The significance changes to 4.2σ when introducing possible background contributions from $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$. The mass and width of the state are measured to be $(2933.8 \pm 5.6 \pm 3.8)$ MeV/$c^2$ and $(51.8 \pm 20.0 \pm 18.8)$ MeV, respectively. This state is possibly a good candidate for $\Lambda_c(2940)^+$ and is tentatively named as $\Lambda_c(2910)^+$ with its nature needing more investigation. The products of branching fractions concerning the $\Lambda_c(2910)^+$ are measured to be $B(\bar{B}^0\to \Lambda_c(2910)^+\bar{p}) \times B(\Lambda_c(2910)^+\to \Sigma_c(2455)^0\pi^-) = (1.24 \pm 0.35 \pm 0.10) \times 10^{-5}$, and $B(\bar{B}^0\to \Lambda_c(2910)^+\bar{p}) \times B(\Lambda_c(2910)^+\to \Sigma_c(2455)^0\pi^+) = (9.5 \pm 3.6 \pm 1.6) \times 10^{-6}$. Here, the first and second uncertainties are statistical and systematic, respectively. The $B(\bar{B}^0\to \Sigma_c(2455)^0\pi^0\bar{p})$ measurements in this analysis supersede the previous Belle measurements [33].

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