Charm spectroscopy in BaBar

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Abstract. The high luminosity of PEP-II in combination with the vertexing and particle identification capabilities of the BaBar detector offer unique opportunities for hadron spectroscopy. The recent results of the search for new resonances and the precise measurement of known open charm states are presented.

1. Charm-strange Mesons
For a complete understanding of the \(c\bar{s}\) meson spectrum, a precise experimental knowledge of all states is mandatory. The current classification of states remains controversial since the measured masses of the \(D_{s0}^{*}(2317)^{+}\) and \(D_{s1}(2460)^{+}\) resonances [1] are lying well below the expected values [2].

An inclusive study of the \(D^0K^+\) and \(D^+K^0_s\) final states using 240 fb\(^{-1}\) of BaBar [3] data has been performed [4]. Three decay modes of the \(D\) meson have been reconstructed: \(D^0 \rightarrow K^-\pi^+\), \(D^0 \rightarrow K^-\pi^+\pi^0\) and \(D^+ \rightarrow K^-\pi^+\pi^+\). All three \(DK\) mass spectra in figure 1 show similar features: The single bin peak at 2.4 GeV/\(c^2\) is a reflection from the decay \(D_{s1}(2536)^+ \rightarrow D^{*0}K^+\) or \(D^+K^0_s\) where either the \(\pi^0\) or the \(\gamma\) from the \(D^* \rightarrow D\pi(\gamma)\) decay is not reconstructed. Next is a large signal from the \(D_{s2}(2573)^+\). A structure around 2860 MeV/\(c^2\) has been found in all three mass spectra and is interpreted as the new \(c\bar{s}\) state \(D_{sJ}(2860)^+\). Furtheron, a broad structure is visible peaking around 2700 MeV/\(c^2\). Monte Carlo simulations have been used to investigate if the latter two structures are due to reflections from other charmed states. Also, candidates from \(D\) sideband regions have been studied. In both cases there are no peaks visible in the 2700 and in the 2860 MeV/\(c^2\) mass regions. Kaon misidentification as well as wrong sign \(DK\) combinations have been examined with no signal found in the regions of interest. A simultaneous fit with relativistic Breit-Wigner lineshapes and an exponential background function to all three mass spectra yields the following numbers for the \(D_{s2}(2573)^+\) which are an improvement over existing measurements [1]: \(m = 2572.2 \pm 0.3 \pm 1.0\) MeV/\(c^2\) and \(\Gamma = 27.1 \pm 0.6 \pm 5.6\) MeV/\(c^2\), where the first error denotes the statistical and the second error the systematic uncertainty. For the \(D_{sJ}(2860)^+\), a mass of 2856.6 \(\pm 1.5 \pm 5.0\) MeV/\(c^2\) and a width of 47 \(\pm 7 \pm 10\) MeV/\(c^2\) are obtained. The decay into two pseudoscalar mesons implies natural spin parity: \(J^P = 0^+, 1^-, 2^+ \ldots\) This state may be the radial excitation of \(D_{s0}^{*}(2317)^+\) \((J^P = 0^+\)) but other explanations are not ruled out. The structure at 2700 MeV/\(c^2\) is best described by a Gaussian with a mean of 2688 \(\pm 4 \pm 3\) MeV/\(c^2\) and a sigma of 112 \(\pm 7 \pm 36\) MeV/\(c^2\). The assignment of this structure to a possible resonance remains inconclusive, but it is not associated with any known reflection or background. Furtheron, there has been an observation by Belle, showing a structure with similar mass and width in \(B^+ \rightarrow D^0\bar{D}^0K^+\) decays with \(J^P = 1^-\) [5].
2. Charmed Baryons

2.1. Discovery of $\Omega_c^*$

The production of charmed baryons provides an environment to study the internal quark-gluon interactions. A rich spectrum is predicted for these baryons, but up to now only few states have been experimentally detected [1].

The $\Omega_c^*$ ($J^P = \frac{3}{2}^+$) was the last remaining css state with no orbital or radial excitation to be discovered. Using 231 fb$^{-1}$ of BABAR data, the inclusive production of $\Omega_c^*$ is observed for the first time with the $\Omega_c^*$ decaying into $\Omega_c^0 \gamma$ [6]. Four different decay modes for the $\Omega_c^0$ have been reconstructed: $\Omega_c^- \pi^+$, $\Omega_c^- \pi^+ \pi^0$, $\Omega_c^- \pi^- \pi^+ \pi^-$, and $\Xi^- K^- \pi^+ \pi^-$. A clear signal is visible in the combined mass spectra, with no peak visible in the mass distribution from the $\Omega_c^0$ sideband regions (figure 2a). A fit to the combined mass spectra yields a value for the mass difference of $m(\Omega_c^*) - m(\Omega_c^0) = 70.8 \pm 1.0 \pm 1.1$ MeV/c$^2$, which is consistent with predictions. Moreover, the ratio of the inclusive production cross sections for $\Omega_c^*$ and $\Omega_c^0$ has been measured with a result of $1.01 \pm 0.23 \pm 0.11$.

2.2. Discovery of $\Lambda_c(2940)^+$

The search for charmed baryons decaying into $D^0 p$, based on 287 fb$^{-1}$ of BABAR data, reveals two states in figure 2b: the narrow $\Lambda_c(2880)^+$, a state first observed by CLEO [7], and also a new signal at 2940 MeV/c$^2$ [8]. This is the first observation of charmed baryons decaying into $D$ and a light baryon. The $D^0$ is reconstructed via the decays $K^- \pi^+$ and $K^- \pi^+ \pi^- \pi^-$. No signals are observed when examining wrong-sign $D^0$ combinations and proton misidentification, and there is no structure either when using candidates from $D^0$ sidebands. Reflections from hypothetical heavier baryons are also strongly disfavored. A fit taking the detector resolution into account yields for the $\Lambda_c(2940)^+$ a mass of $2939.8 \pm 1.3 \pm 1.0$ MeV/c$^2$ and a width of $17.5 \pm 5.2 \pm 5.9$ MeV/c$^2$ is obtained. Analyzing the $D^+ p$ final state shows no signal of a doubly charged partner state of the $\Lambda_c(2940)^+$, confirming it to be an isospin 0 state with $cdu$ quark content.
2.3. Search for excited charm-strange baryons

Using 384 fb$^{-1}$ of BABAR data, six different decay modes are analyzed for the search of excited charm-strange baryons [9]: $\Lambda_c^+ K^0_S$, $\Lambda_c^+ K^-$, $\Lambda_c^+ K^-\pi^+$, $\Lambda_c^+ K^0\pi^-$, $\Lambda_c^+ K^-\pi^+\pi^-$, $\Lambda_c^+ K^0\pi^+\pi^-$, with five different final states of the $\Lambda_c$. The intermediate resonances $\Sigma_c(2455)^{++0}$ and $\Sigma_c(2520)^{++0}$, decaying into $\Lambda_c\pi$, are incorporated into the analysis. Statistically significant signals are only observed in the three-body final states (figure 3). The baryon resonances $\Xi_c(2980)^+$, $\Xi_c(3077)^+$ and $\Xi_c(3077)^0$ [10] are confirmed with an improved measurement of the mass and width for the $\Xi_c(2980)^+$ (table 1). Evidence for two new states $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ is found only in decays via the intermediate resonances through $\Sigma_c(2455)^{++}K^-$ and $\Sigma_c(2520)^{++}K^-$.

| $\Xi_c$ | Mass (MeV/$c^2$) | Width (MeV/$c^2$) | Significance |
|---------|------------------|------------------|-------------|
| $\Xi_c(2980)^+$ | 2969.3 ± 2.2 ± 1.7 | 27 ± 8 ± 2 | > 9.0$\sigma$ |
| $\Xi_c(3077)^+$ | 3077.0 ± 0.4 ± 0.2 | 5.5 ± 1.3 ± 0.6 | > 9.0$\sigma$ |
| $\Xi_c(3077)^0$ | 3079.3 ± 1.1 ± 0.2 | 5.9 ± 2.3 ± 1.5 | 4.5$\sigma$ |
| $\Xi_c(3055)^+$ | 3054.2 ± 1.2 ± 0.5 | 17 ± 6 ± 11 | 6.4$\sigma$ |
| $\Xi_c(3123)^+$ | 3122.9 ± 1.3 ± 0.3 | 4.4 ± 3.4 ± 1.7 | 3.6$\sigma$ |
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