Inclusive Hadron production in $e^+e^-$ collision at B-Factories

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Abstract

Inclusive hadron production in $e^+e^-$ collision has been investigated for hadron spectroscopy, production mechanisms and the decay branch. In this article, we report recent results on the production rates of hyperons and charmed baryons, the search for excited $\Xi_c$ states and the absolute branching fraction of $\Lambda_c^+ \rightarrow pK^-\pi^+$. 

1 Introduction

Hadron production from $e^+e^-$ collision is a powerful tool for spectroscopy. Recent discoveries of exotic mesons at B-factories have opened a new field beyond the constituent quark model. One of the most important topics in the hadron physics is to understand the internal structure of the hadrons. For example, in the case of exotic mesons, whether these are meson-meson molecules or consist of colored diquarks is in question. The color magnetic interaction (CMI) gives a strong attraction to a spin-singlet diquark, so-called a good diquark, which plays an important role to understand the structure of exotic hadrons. The CMI is proportional to the inverse quark mass, thus it becomes weaker for the heavier quark. Charmed baryons which consist of one charm quark and two light quarks are suitable object to study diquark correlation between light quarks since the CMI between the charm quark and the light quark is suppressed due to the heavy mass of the charm quark. Experimental issues are precise measurement of spectroscopy, the spin-parity assignment, the production rate and the decay branch. In this article, recent results on the production rates of hyperons and charmed baryons, excited charmed strange baryons and the absolute branching fraction of $\Lambda_c^+ \rightarrow pK^-\pi^+$ are described.

2 Production rates of hyperons and charmed baryons

The production rates of baryons near the $\Upsilon(4S)$ energy were measured by ARGUS\(^1\,^2\) and CLEO\(^3\) collaborations. The production cross sections divided by the spin multiplicity show a clear mass dependence of $\exp(-\alpha m)$. S.B. Chun and C.D. Buchanan succeeded to describe this tendency qualitatively in the wide energy region of $\sqrt{S} = 10, 29, 91$ GeV using a relativistic string model\(^4\). In the ARGUS measurement, the $\Lambda$ and $\Lambda(1520)$ hyperons seemed to have higher production rates by factors. The $\Lambda$ hyperon is a spin-flavor singlet object, and the $ud$-diquark is correlated. R.L. Jaffe pointed out that a diquark correlation in $\Lambda$ may explain these anomalies\(^6\). Namely, a good diquark is light and easy to be created. The charmed baryons have much stronger diquark correlation since the CMI with charm quark is suppressed due to its mass. Thus, it is interesting to measure production rates of charmed baryons. The analysis procedure and preliminary results are described bellow.
The production rates of hyperons have been measured using data taken at Belle at 50 MeV below the Υ(4S) energy with an integrated luminosity of 79 fb$^{-1}$. For the measurement of charmed baryons, we have used an additional data sample collected at the Υ(4S) energy with an integrated luminosity of 562 fb$^{-1}$, which has higher statistics but contains significant $B$-meson decay contribution. Charmed baryons produced by $B$ decay have low momenta due to the limited kinetic energy, and thus these are eliminated by selecting high momentum particles. The total cross sections are then obtained using a fragmentation model by Peterson$^7$. The feed-down contributions to $\Lambda$, $\Sigma$, $\Sigma(1385)^+$, $\Omega^-$, $\Lambda_c^+$ from heavier states are subtracted. Fig. 1 shows the baryon production rates obtained from preliminary$^{10}$ and previous$^{8,9}$ measurements by Belle collaboration. The production cross sections were normalized by the total hadronic cross section (Belle collaboration). The production rates were normalized by the total hadronic cross section (Belle collaboration). The production rates of hyperons lie on a straight line except for $\Omega^-$. Thus, the enhancements of $\Lambda$ and $\Lambda(1520)$ reported by ARGUS experiment are not confirmed. The suppression of $\Omega^-$ can be explained by the suppression of $g \rightarrow ss$ process or the lack of the "good diquark" in $J^P = 3/2^+$ baryon. The production rates of charmed baryons are significantly higher than the extrapolation of the hyperon line due to the large $Q$-value for $c\bar{c}$ creation at 10 GeV. The production rates of $\Lambda_c^+$, $\Sigma_c^0$ and $\Sigma_c^-$ resonances lie on a straight line, however, one can see clear deviations of $\Lambda_c(2625)^+$ and $\Omega_c^0$ baryons. The absolute branching ratio of $\Omega_c^0 \rightarrow \Omega^- \pi^+$ is unknown, and thus, a phenomenological calculation of 0.25$\pm$0.12 % was used by following PDG’s method for the $\Lambda_c^+ \rightarrow pK^-\pi^+$ decay. This value may not be correct and further theoretical study is necessary. Another peculiar state is $\Lambda_c(2625)^+$ with $J^P = 3/2^-$ which shows higher rate than the line by factors. This high rate may be due to the large "good diquark" content in $\Lambda_c$ resonances than $\Sigma_c$’s, or another scenario is that $\Lambda_c$ with orbital excitation is favored. In order to understand the mechanisms, further study on other $\Lambda_c$ members, $\Lambda_c(2595)^+$ and $\Lambda_c(2880)^+$, is underway.

3 Study of charmed strange baryons

The charmed strange baryons are suitable for studying $us$ or $ds$ diquark system. Such a diquark correlation may appear in the mass spectra and/or branching fractions of excited states. Recently, a number of excited states, $\Xi_c^*$, has been observed at B-factories. Two excited states, $\Xi_c(2980)$ and $\Xi_c(3080)$, were reported by the Belle collaboration in the $\Lambda_c^+K^-\pi^+$ and $\Lambda_c^+K_0^0\pi^-$ final states$^{11}$. These states were confirmed by BaBar later$^{12}$. In the same paper, BaBar reported evidence of two resonances, $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$, in the $\Sigma_c(2455)^+K^-$ and $\Sigma_c(2520)^+K^-$...
final states, respectively. An independent search for these two states is necessary to confirm the
existences. Among a number of possible decay modes of the charmed strange baryons, the
$\Lambda D^{+(0)}$ mode has not been studied well. In this section, we report recent results on charmed
strange baryons in the $\Lambda D^{+(0)}$ and $\Lambda D^{+(0)}$ final states by Belle collaboration using a data
sample with an integrated luminosity of $980 \text{ fb}^{-1}$.

Fig. 2 shows invariant mass spectra of $\Lambda^+_c K^- \pi^+$ system measured at Belle (a,c) and BaBar
(b,d) collaborations\(^{13,12}\). The top two plots show with $\Sigma^+_c(2455)^{++} K^-$ selection and bottom
two are with $\Sigma^+_c(2520)^{++} K^-$ selection. One can see clear peaks of $\Xi^+_c(3055)^+$ and
$\Xi^+_c(3080)^+$ as shown in Fig. 2 (a) and (b). Thus, $\Xi^+_c(3055)^+$ is confirmed by Belle with 6.6 $\sigma$
significance. A prominent peak of $\Xi^+_c(3080)^+$ is seen in invariant mass spectra of $\Sigma^+_c(2520)^{++} K^-$
both in Belle and BaBar results as shown in Fig. 2 (c) and (d). However, a signal of $\Xi^+_c(3123)^+$
is not visible in the Belle results in Fig. 2 (c). Belle collaboration obtained the upper limit
on the production rate, $\sigma \times \text{BR}(\Lambda^+_c \rightarrow p K^- \pi^+)$, to be $0.34 \text{ fb}$ with 95% C.L, compared with
$1.6 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.}) \text{ fb}$ by BaBar collaboration. In order to confirm these results further
and search for neutral partners, $\Lambda D^+$ and $\Lambda D^0$ final stats have been investigated. Fig. 3 shows invariant
mass spectra of $\Lambda D^+$ (a) and $\Lambda D^0$ (b)\(^{14}\). Clear peaks of $\Xi^+_c(3055)^+$ and $\Xi^0_c(3080)^+$ can be seen.
These results show further confirmation of $\Xi^+_c(3055)^+$ and the first observation of $\Xi^0_c(3055)^0$.

4 Absolute branching fraction of $\Lambda^+_c \rightarrow p K^- \pi^+$

The absolute branching fractions of hyperons are well established, however, little is known for
carried baryons. The Particle Data Group estimated absolute branching fraction of $\Lambda^+_c \rightarrow$
pK−π+ to be 5.0 ± 1.3% model-dependently using measurements by ARGUS and CLEO collaborations. The Belle collaboration has performed the first model-independent measurement\textsuperscript{15}. We have used a data sample, corresponding to an integrated luminosity of 978 fb\textsuperscript{−1}, collected at or near the Υ(nS) (n = 1, 2, 3, 4, 5) resonances. The inclusive Λ\textsuperscript{+} production is identified in the missing mass of the e\textsuperscript{+}e\textsuperscript{−} → c\bar{c} → D(∗)−pπ+X reaction. A clear peak is seen in Fig. 4 (a) on the combinatorial background. The exclusive Λ\textsuperscript{+} → pK−π+ events are reconstructed in these events as shown in Fig. 4 (b). The absolute branching fraction is obtained after the correction for the detection efficiency and bias due to selecting the specific final state to be 6.84 ± 0.24\textsuperscript{+0.21}_{−0.27} \%.

This value is slightly higher than the current PDG value with much higher precision.

5 Summary

We have reported recent results on the baryon production at B-factories. The production rates of hyperons and charmed baryons have been measured at Belle. The enhancements of Λ and Λ(1520) reported by ARGUS collaboration are not confirmed. The production rate of Λ\textsubscript{c}(2625)\textsuperscript{+} is a factor higher than the line on which Σ\textsubscript{c}'s lie. Further study on other Λ\textsubscript{c} members is underway. Recent results on excited Ξ\textsubscript{c} by Belle and BaBar have been described. The previous observation of Ξ\textsubscript{c}(3055)\textsuperscript{+} by BaBar is confirmed by Belle collaboration but not for Ξ\textsubscript{c}(3123). The neutral Ξ\textsubscript{c}(3055)\textsuperscript{0} state is observed in ΛD\textsubscript{0} decay mode for the first time. A model-independent measurement of the absolute branching fraction of Λ\textsubscript{c}→pK−π+ has been performed by Belle. This measurement significantly improves the current PDG value.

References