Charm Physics at *BABAR*

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Abstract. Large production of the $c\bar{c}$ pairs and high integrated luminosity make the PEP-II B Factory an excellent place for studying the charm hadrons. In this paper, we present a few of the most recent results from the *BABAR* collaboration in the charm sector.

INTRODUCTION

The *BABAR* detector [1] is a general purpose detector designed to collect data at PEP-II asymmetric e^+e^- collider, operating at the center-of-mass energy corresponding to the $\Upsilon(4S)$ resonance or ~ 40 MeV below it. With copious production of $c\bar{c}$ pairs from the continuum and high integrated luminosity, *BABAR* is not only a B Factory, it is also an excellent laboratory to study the charm production and decays. In this paper, we present a few of the most recent charm analysis results from *BABAR*.

$\mathbf{D^0 - \bar{D}^0}$ MIXING

Charm mixing is characterized by two dimensionless parameters, $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$, where Δm ($\Delta\Gamma$) is the mass (width) difference between the two neutral D mass eigenstates, and Γ is the average width. If either x or y is nonzero, then the $D^0 - \bar{D}^0$ mixing will occur. In the Standard Model (SM), $D^0 - \bar{D}^0$ mixing rate is heavily suppressed by the Glashow-Iliopoulos-Maiani (GIM) mechanism[2]. However, the SM mixing rate can be enhanced by the non-perturbative effects and possible new physics beyond SM.

Based on a sample of 87 fb^{-1} data, *BABAR* performed a search of $D^0 - \bar{D}^0$ mixing [3] to measure the overall time-integrated mixing rate $R_{mix} = (x^2 + y^2)/2$ using the decay chain $D^{*+} \to D^0\pi^+$, $D^0 \to K^{\pm}e^{\mp}\nu$ [4]. The charge of the pion daughter of the charged D^* identifies the production flavor of the neutral D, while the charge of the electron identifies the decay flavor. These charges are equal for unmixed decays and opposite for mixed decay. Using event selection and reconstruction based on neural networks and charged kaon and electron particle identification, we obtained 49620 ± 265 unmixed events and 114 ± 61 mixed events. This results in

$$\begin{aligned} R_{mix} &= 0.0024 \pm 0.0012(\text{stat}) \pm 0.0004(\text{syst}) \\ R_{mix} &< 0.0042 \text{ at } 90\,\% \text{ CL.} \end{aligned} \quad (1)$$

SEARCH FOR $D^0 \to \ell^+\ell^-$

In the SM, the flavor-changing neutral current (FCNC) decays $D^0 \to e^+e^-$ and $D^0 \to \mu^+\mu^-$ are highly suppressed by the GIM mechanism. The lepton-flavor violating (LFV) decay $D^0 \to e^\pm\mu^\mp$ is strictly forbidden in the SM. Some extensions to the Standard Model [5], such as the *R*-parity violating supersymmetry, can enhance the FCNC processes by many orders of magnitude and can also permit the LFV decays.

BaBar performed a search for the decays of $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, and $D^0 \to e^\pm\mu^\mp$ based on a sample of $122\,\mathrm{fb}^{-1}$ data [6]. To ensure as clean a sample as possible, the reconstructed $D^0 \to \ell^+\ell^-$ candidate is required to originate from a $D^{*+} \to D^0\pi^+$ decay. A minimum value of $2.4\,\mathrm{GeV}/c$ is imposed on the center-of-mass momentum of each D^0 candidate to further reduce the combinatorial background involving the decay products of B mesons. Tight particle selection criteria are also applied to the daughters of $D^0 \to \ell^+\ell^-$ decays.

We observed no significant signals in all three decay modes. As a result, the branching fraction upper limits (UL) have been calculated using the $D^0 \to \pi^+\pi^-$ decay as the normalization mode. We obtain

$$\begin{aligned} \mathrm{Br}(D^0 \to e^+e^-) &< 1.2\times10^{-6} \text{ at } 90\,\%\text{ CL.,} \\ \mathrm{Br}(D^0 \to \mu^+\mu^-) &< 1.3\times10^{-6} \text{ at } 90\,\%\text{ CL.,} \\ \mathrm{Br}(D^0 \to \mu^\pm e^\mp) &< 8.1\times10^{-7} \text{ at } 90\,\%\text{ CL..} \end{aligned} \qquad (2)$$

These results represent significant improvements on the previous limits [7, 8].

SEARCH FOR $D_{SJ}(2632)^+$

The SELEX Collaboration at FNAL has recently reported the observation of a narrow state [9] at a mass of 2632 MeV/c^2 that decays to $D_s^+\eta$. Evidence for the same state in the D^0K^+ mass spectrum was also presented. BaBar has searched for this resonance in the final states $D_s^+\eta$, D^0K^+ and $D^{*+}K_S^0$ [10] produced in $e^+e^- \to c\bar{c}$ events, using $125\,\mathrm{fb}^{-1}$ data. As shown in Fig. 1, no signal is observed in $D_s^+\eta$ decay channel; similarly, no evidence of $D_{sJ}(2632)^+$ was found in the D^0K^+ and $D^{*+}K_S^0$ final states, although large and clean signals for the decay $D_{s2}(2573)^+ \to D^0K^+$ and $D_{s1}(2536)^+ \to D^{*+}K_S^0$ are seen.

Ξ_C^0 PRODUCTION AND DECAYS

Using a sample of $116\,\mathrm{fb}^{-1}$ data, *BABAR* has performed a branching fraction ratio measurement of the Ξ_c^0 decaying to Ω^-K^+ and $\Xi^-\pi^+$ [11]. The result

$$\frac{\mathrm{Br}(\Xi_c^0 \to \Omega^-K^+)}{\mathrm{Br}(\Xi_c^0 \to \Xi^-\pi^+)} = 0.294 \pm 0.018\,(\mathrm{stat}) \pm 0.016\,(\mathrm{syst}) \qquad (3)$$

is a significant improvement over the previous measurement by CLEO [12] and is consistent with a spectator quark model prediction [13].

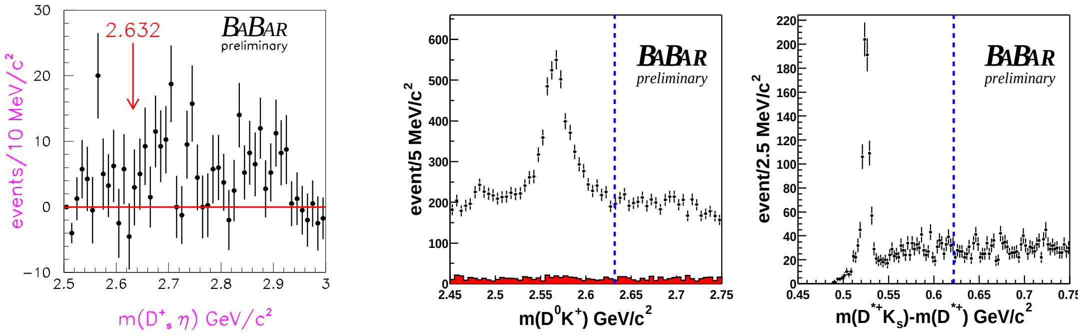

FIGURE 1. (Left:) The $D_s^+\eta$ invariant mass distribution after background subtraction. The arrow indicates the mass location of the expected $D_{sJ}(2632)^+$ state. (Middle:) The D^0K^+ invariant mass distribution. The red histogram is the invariant mass distribution of D^0K^- combinations, and the blue line indicates the mass location of the expected $D_{sJ}(2632)^+$ state. (Right:) The distribution of the difference in invariant mass of the $D^{*+}K_S^0$ combination and D^{*+} candidate. The blue line indicates the mass location of the expected $D_{sJ}(2632)^+$ state.

Although copious production of Ξ_c^0 in B decays has been predicted, such process has been only observed by CLEO [14] with a significance of $\sim 3\sigma$ in the $\Xi_c^0 \to \Xi^-\pi^+$ decay mode and $\sim 4\sigma$ in the $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ decay mode. We studied the Ξ_c^0 production by measuring the spectrum of the Ξ_c^0 momentum p^* in the e^+e^- center-of-mass frame. The Ξ_c^0 produced by the B decays tends to have a smaller momentum; its p^* distribution peaks below 1.5 GeV/c and has a kinematic limit of $p^* = 2.135$ GeV/c at *BABAR*. As for the Ξ_c^0 from continuum production, its momentum distribution peaks at a much higher p^* value. By examining the p^* distribution of the Ξ_c^0 from on-resonance and off-resonance sample, we found

$$\mathrm{Br}(B \to \Xi_c^0 X) \times \mathrm{Br}(\Xi_c^0 \to \Xi^-\pi^+) = 2.11 \pm 0.19\,(\mathrm{stat}) \pm 0.25\,(\mathrm{syst}) \times 10^{-4}, \quad (4)$$

and

$$\sigma(e^+e^- \to \Xi_c^0 X) \times \mathrm{Br}(\Xi_c^0 \to \Sigma^-\pi^+) = 388 \pm 39\,(\mathrm{stat}) \pm 41\,(\mathrm{syst})\,\mathrm{fb}, \quad (5)$$

where both Ξ_c^0 and $\bar{\Xi}_c^0$ are included in the cross-section.

MEASUREMENT OF Λ_C^+ MASS

The invariant masses of the charm hadron ground states are currently reported by the Particle Data Group (PDG) with a precision of about 0.5–0.6 MeV/c^2 [15]. The best individual measurements have a statistical and systematic precision of about 0.5 MeV/c^2 and use data samples of a few hundred events. The *BABAR* data sample contains a large amount of different charm hadron decays and, due to the excellent momentum and vertex resolution in *BABAR*, many of the decay modes can be reconstructed with an event-by-event mass uncertainty of a few MeV/c^2. We can therefore provide significantly improved estimate of the charm hadron masses.

With a sample of $232\,\text{fb}^{-1}$ data, *BABAR* performed a precision measurement of the Λ_c^+ mass. The measurement is based on the reconstruction of the decay modes $\Lambda_c^+ \to \Lambda\bar{K}^0 K^+$ and $\Lambda_c^+ \to \Sigma^0 \bar{K}^0 K^+$. Because almost all of the Λ_c^+ invariant mass in these decays tied to the well-known rest masses of the Λ_c^+ decay products, the systematic uncertainty in the reconstructed mass is significantly reduced compared to the measurements that try to use the more common decay modes. Combining the results from those two modes, the measured Λ_c^+ mass is

$$m(\Lambda_c^+) = 2286.46 \pm 0.14\,\text{MeV}/c^2. \tag{6}$$

This result is in agreement with the mass values measured in other much large sample of Λ_c^+ decays, including $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to pK_S^0$ decays, although these are subject to large systematic uncertainties.

This Λ_c^+ mass measurement is the most precise measurement of an open charm hadron mass to date and is an improvement in precision by more than a factor of four over the current PDG value of $2284.9 \pm 0.6\,\text{MeV}/c^2$. Our result is about 2.5σ higher than the PDG value, which is based on several high Q-value decay modes, mainly $\Lambda_c^+ \to pK^-\pi^+$ decays.

CONCLUSION

BABAR has a very rich and active charm physics program. In this paper we discussed only a few most recent results from *BABAR*. Given the excellent luminosity achieved by PEP-II, much more high precision charm physics results are expected in the near future.

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