Charm Physics at B Factories

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We review of the experimental status in charm mixing, charm semileptonic decays, charm baryon spectroscopy and charmonium production at Belle and BaBar.

1 Charm Mixing

After the discovery by Tevatron of $B_s^0 - \overline{B}_s^0$-oscillations D^0 and $\overline{D}^0$ remains the last flavor neutral meson system with unobserved mixing. Neutral meson mixing is characterized by parameters $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$, where ΔM and $\Delta\Gamma$ are the mass and width difference between the two CP eigenstates. The SM box diagram in $D^0 \leftrightarrow \overline{D}^0$ transitions is strongly GIM and CKM suppressed. However, D mixing can be enhanced by long distance effects, involving on- or off-shell $D^0 \leftrightarrow \overline{D}^0$ transitions through intermediate states accessible to both mesons, that contribute both to x and y. New Physics contribution to loops can enhance x only, and observation of $x \gg y$ would be a signal of New Physics. Observation of CP violating effects in D would be another unambiguous signature of New Physics as the SM predicts tiny CP violation beyond the present experimental sensitivity.

Experimentally one of the following techniques is exploited to search for D mixing: study of wrong-sign (WS) hadronic decays, search for WS D^0 semileptonic decays, a time-dependent Dalitz plot analysis or direct measurement of the lifetime difference between opposite CP eigenstates. The first method provides the restrictive mixing constraints, in spite of a complication due to presence of doubly-Cabibbo suppressed (DCS) contribution to the same WS final state. The interference of the mixing and DCS amplitudes results in rotation of measured $x' = x\cos\delta + y\sin\delta$ and $y' = -x\sin\delta + y\cos\delta$ by the strong phase difference δ between the mixing and DCS amplitudes. This year BaBar [2] has presented a strong evidence for D mixing in $D^0 \to K^+\pi^-$ decays. The WS decay rate is a function of proper decay-time:

$$R(t) = e^{-\Gamma t}(R_D + \sqrt{R_D}y'\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2),$$

where R_D is the DCS decay rate (Fig. 1). The mixing and DCS contributions are thus discriminated in the fit to the time-dependent rate of WS decays. The fit yields the mixing parameters to be $x'^2 = (-0.22 \pm 0.30 \pm 0.21) \cdot 10^{-3}$ and $y' = (9.7 \pm 4.4 \pm 3.3) \cdot 10^{-3}$ and a correlation between them -0.94. This result is inconsistent with the no-mixing hypothesis with a significance of 3.9σ. Belle [3] has observed an evidence for D mixing by comparing the apparent lifetime when a D^0 meson decays to the CP eigenstates K^+K^- and $\pi^+\pi^-$, and when it decays to the final state $K^-\pi^+$ (Fig. 1). They find $y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$, 3.2σ from zero. Using a time-dependent Dalitz plot analysis Belle [4] has also reported a measurement of D mixing in $D^0 \to K_s^0\pi^+\pi^-$ decays. Assuming negligible CP violation, the mixing parameters were found to be $x = (0.80 \pm 0.29^{+0.09+0.15}_{-0.07-0.14})\%$ and $y = (0.33 \pm 0.24^{+0.07+0.08}_{-0.12-0.09})\%$. Both Belle and BaBar have found no evidence for CP asymmetry in D decays.

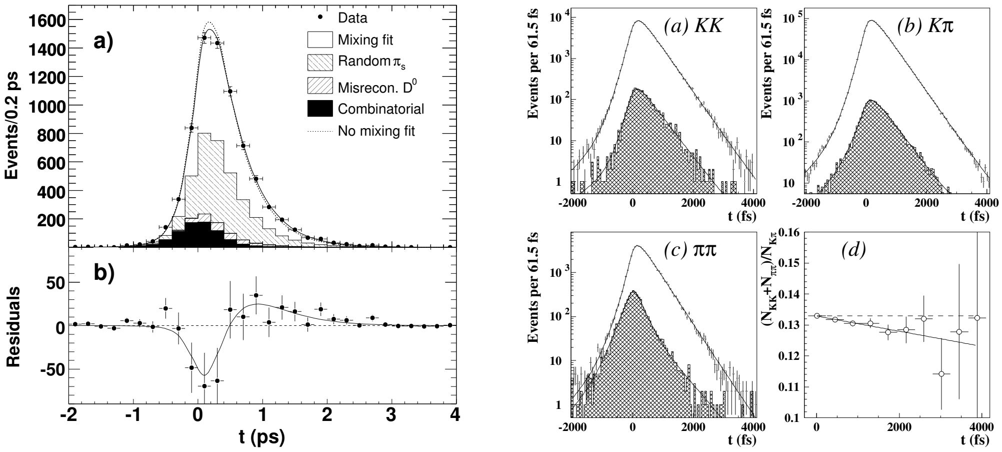

Figure 1: Left plot: (a) BaBar's the proper decay-time distribution of combined D^0 and $\overline{D}^0$ WS candidates; (b) the difference between the data and the no-mixing fit. Right plot: Belle results of the simultaneous fit to decay-time distributions of (a) $D^0 \to K^+K^-$; (b) $D^0 \to \pi^+\pi^-$; (c) $D^0 \to K^-\pi^+$ decays; (d) ratio of decay-time distributions between $D^0 \to K^+K^-/\pi^+\pi^-$ and $D^0 \to K^-\pi^+$.

2 Charm semileptonic decays

The measurements of charm semileptonic decay form factors provide a precise tests of LQCD calculations with high statistics and an important inputs for B physics. Belle [5] has measured $D^0 \to K^-\ell^+\nu$ and $D^0 \to \pi^-\ell^+\nu$ decays. The D^0 momentum was tagged through a full reconstruction of the recoiling charm meson and mesons from fragmentation in the $e^+e^- \to c\bar{c}$ events. This technique provides an excellent q^2 resolution and a low level of backgrounds though with considerably reduced statistics. Normalizing to the total number of D^0 tags, Belle has measured the absolute branching fractions to be $\mathcal{B}(D^0 \to K^-\ell^+\nu) = (3.45 \pm 0.07 \pm 0.20)\%$ and $\mathcal{B}(D^0 \to \pi^-\ell^+\nu) = (0.255 \pm 0.019 \pm 0.016)\%$ and the semileptonic form factors (within the modified pole model) $f_+^K(0) = 0.695 \pm 0.007 \pm 0.022$ and $f_+^\pi(0) = 0.624 \pm 0.020 \pm 0.030$. BaBar [6] has presented a model independent measurements of the hadronic form factor $f_+(q2)$ in the decay $D^0 \to K^-\ell^+\nu$ and the normalization of the form factor at $q^2 = 0$ determined to be $f_+(0) = 0.727 \pm 0.007 \pm 0.005 \pm 0.007$.

3 Charm baryon spectroscopy

Recently the progress in charmed-baryon spectroscopy is evident with a growing number of observed new states and decays modes. BaBar [7] has observed a new charmed baryon in the continuum events in the D^0p final state. Fig. 2 shows the D^0p invariant mass spectrum with two prominent structures: one near a mass 2880 MeV/c^2 that is consistent with the known state $\Lambda_c(2880)$, the other at a mass of $2939.8 \pm 1.3 \pm 1.0$ MeV/c^2 and with an intrinsic width of $17.5 \pm 5.2 \pm 5.9$ MeV. As there is no evidence in the D^+p spectrum of doubly-charged partners, one can conclude that this state is excited Λ_c, temporary called $\Lambda_c(2940)$. Belle [8] reported the first observation of $\Lambda_c(2940) \to \Sigma_c(2455)\pi$ decay and measured $\Lambda_c(2880)$ and

$\Lambda_c(2940)$ parameters. An analysis of angular distributions in $\Lambda_c(2880) \to \Sigma_c(2455)\pi$ decays strongly favors a $\Lambda_c(2880)$ spin assignment of 5/2 over 3/2 or 1/2.

Belle [9] has analyzed the $\Lambda_c^+ K^- \pi^+$ final state searching for the doubly-charmed $\Xi_{cc}^+(3520)$, reported by SELEX [10]. No evidence for this state is found with the Belle data, while two new charmed strange baryons, $\Xi_{cx}^+(2980)$ and $\Xi_{cx}^+(3077)$, are clearly seen near the threshold (Fig. 2) with mass of $2978.5 \pm 2.1 \pm 2.0\,\mathrm{MeV}/c^2$ ($3076.7 \pm 0.9 \pm 0.5\,\mathrm{MeV}/c^2$) and width of $43.5 \pm 7.5 \pm 7.0\,\mathrm{MeV}$($6.2 \pm 1.2 \pm 0.8\,\mathrm{MeV}$), respectively. A significant signal at the mass of $3082.8 \pm 1.8 \pm 1.5\,\mathrm{MeV}/c^2$ for the isospin partner state decaying into $\Lambda_c^+ K_S^0 \pi^-$ is also observed. Babar [11] has confirmed observation of $\Xi_{cx}^+(2980)$ and $\Xi_{cx}^+(3077)$ baryons, with the parameters consistent with the Belle measurement. The high mass of new states suggests that they can be $L = 2$ excitations, but no direct measurements of quantum numbers are made so far. Belle [12] has reported a precise measurement of masses of the $\Xi_c(2645)$ and

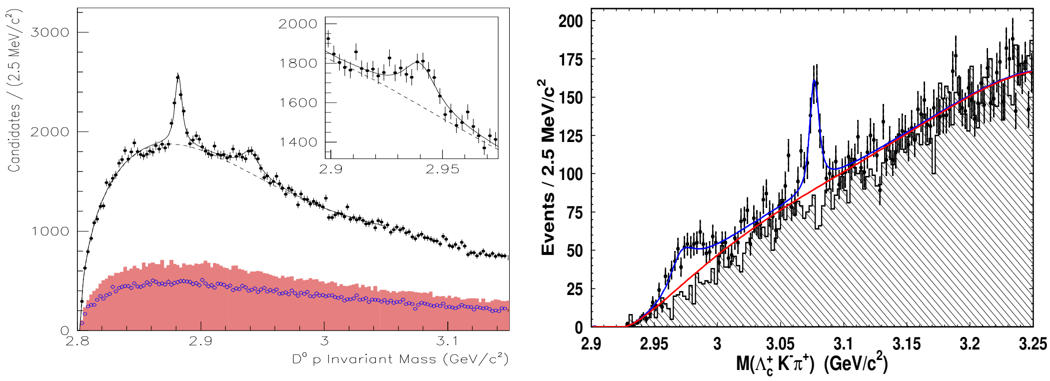

Figure 2: a) The $D^0 p$ invariant mass distribution and the contribution from false D^0 candidates estimated from D^0 mass sidebands and (open points) the mass distribution from WS $\overline{D}^0 p$ candidates. b) $\Lambda_c^+ K^- \pi^+$ invariant mass spectrum. The shaded area shows the WS combinations.

$\Xi_c(2815)$ baryons. The states $\Xi_c(2645)^{0,+}$ are observed in the $\Xi_c^{+,0}\pi^{-,+}$ decay modes, while the $\Xi_c(2815)^{0,+}$ are reconstructed in the $\Xi_c(2645)^{+,0}\pi^{-,+}$ decay modes.

Finally, the family of predicted $J^P = 3/2^+$ states was completed with the first observation by BaBar [13] of an excited singly-charmed baryon Ω_c^* (css) in the radiative decay $\Omega_c^0\gamma$. The mass difference between the Ω_c^* and the Ω_c^0 baryons has been measured to be $70.8 \pm 1.0 \pm 1.1\,\mathrm{MeV}/c^2$ in good agreement with the QCD predictions. From the momentum spectrum of the Ω_c^0 baryons in the e^+e^- center-of-mass frame Ω_c^0 production from B decays and in $e^+e^- \to c\bar{c}$ events was observed [14].

4 Measurement of the near-threshold $\sigma(e^+e^- \to D^{(*)}\overline{D}^{(*)})$ using ISR

Exclusive e^+e^- hadronic cross sections to final states with charm meson pairs are of special interest because they provide information on the spectrum of $J^{PC} = 1^{--}$ charmonium states above the open-charm threshold, which is poorly understood. To measure the e^+e^- hadronic cross section at $\sqrt{s}$ smaller than the initial e^+e^- center-of-mass (CM) energy (E_{CM}) at B-factories, initial-state radiation (ISR) can be used. ISR allows a measurement of cross sections in a broad energy range while the high luminosity of the B-factories compensates for the suppression associated with the emission of a hard photon. BaBar [15] has performed a study of exclusive production of the $D\overline{D}$ system through ISR in a search for charmonium states, where $D = D^0$ or D^+. The $D\overline{D}$ mass spectrum shows a clear $\psi(3770)$ signal. Further structures appear in the 3.9 and 4.1 GeV/c^2 regions. No evidence is found for $Y(4260)$ decays to $D\overline{D}$, implying an upper limit $\frac{\mathcal{B}(Y(4260)\to D\bar{D})}{\mathcal{B}(Y(4260)\to J/\psi\pi^+\pi^-)} < 7.6$ (95% CL). Recently Belle [16] has reported the first measurements of exclusive $e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^+D^{*-}$ cross sections at $\sqrt{s}$ around the $D^{*+}D^{*-}$ and D^+D^{*-} thresholds with ISR. A partial reconstruction technique was used to increase the efficiency and to suppress background. The shape of the $e^+e^- \to D^{*+}D^{*-}$ cross section is complicated with several local maxima and minima (Fig. 3). The minimum near 4.25 GeV/c^2 — in the $Y(4260)$ region — could be due to $D_s^*D_s^*$ (DD^{**}) threshold effects or due to destructive interference of this state with other $\psi(nS)$ states. Aside from a prominent excess near the $\psi(4040)$, the $e^+e^- \to D^+D^{*-}$ cross section is relatively featureless. The measured cross sections are compatible within errors with the $D^{(*)}\overline{D}^*$ exclusive cross section in the energy region up to 4.260 GeV measured by CLEO-c [17].

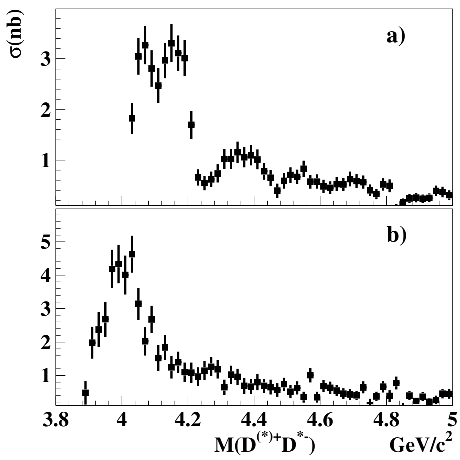

Figure 3: The exclusive cross sections for a) $e^+e^- \to D^{*+}D^{*-}$ and b) $e^+e^- \to D^+D^{*-}$.

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