PROCEEDINGS OF SCIENCE

Charm semileptonic physics at BESIII

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Recent measurements on the semileptonic decays of $D_{(s)}$ meson and Λ_c baryon at the BESIII experiment are reviewed. The measurements of absolute branching fractions of $D \to K e^+ \nu_e$, $D \to \pi e^+ \nu_e$, $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$ and $\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$ decays are presented. The experimental results of the $D \to K \ell \nu$ and $D \to \pi \ell \nu$ form factors as well as the Cabibbo-Kobayashi-Maskawa matrix elements $|V_{cs}|$ and $|V_{cd}|$ are also discussed.

The 15th International Conference on Flavor Physics & CP Violation
5-9 June 2017
Prague, Czech Republic

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PoS(FPCP2017)001

1. Introduction

Studies of charm semileptonic physics play a crucial role in understanding the weak and strong interactions. In the recent few years, the impressive experimental progresses are taking place in the determination of charm properties, which lead us into the era of the precision charm physics and allow us probe new physics (NP). In the following we present the recent studies on the semileptonic decays of $D_{(s)}$ meson and Λ_c baryon at the BESIII experiment.

2. Semileptonic D Decays

In the Standard Model (SM), neglecting the lepton mass, the differential decay rate for $D^+ \to Pe^+\nu_e$ ($P = K^-$, π^-, $\bar{K}^0$ or π^0) is given by

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2 p^3 |f_+(q^2)|^2, \tag{2.1}$$

where p is the momentum of the pseudoscalar meson P in the rest frame of the D meson, q^2 is the squared four momentum transfer, i.e., the invariant mass of the electron and neutrino system, and $f_+(q^2)$ is the form factor which describes the strong interaction between the final state quarks and is usually parameterized in data analysis. In Eq. (2.1), X is a multiplicative factor due to isospin, which equals to 1 for modes $D^0 \to K^-e^+\nu_e$, $D^0 \to \pi^-e^+\nu_e$, $D^+ \to \bar{K}^0e^+\nu_e$ and $1/2$ for mode $D^+ \to \pi^0e^+\nu_e$. These semileptonic decays provide an excellent chance to validate the lattice QCD calculations by measuring the form factors at $q^2 = 0$, and to measure the magnitudes of Cabibbo-Kobayashi-Maskawa (CKM) matrix elements V_{cs} and V_{cd}.

Based on 2.93 pb^{-1} $\psi(3770)$ data, BESIII well study the dynamics of the $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$ decays [1]. Using five hadronic modes $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^+\pi^-\pi^-$, $K^+\pi^+\pi^-\pi^-\pi^0$ and $K^+\pi^-\pi^0\pi^0$, $(279.33 \pm 0.37) \times 10^4$ $\bar{D}^0$ tags are accumulated. In this huge sample of $\bar{D}^0$ tags, 70727 ± 278 and 6297 ± 87 signal events for $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$ decay channels are observed, respectively. By analyzing these events, the branching fraction are measured to be $\mathscr{B}(D^0 \to K^-e^+\nu_e) = (3.505 \pm 0.014_{\rm stat} \pm 0.033_{\rm syst})\%$ and $\mathscr{B}(D^0 \to \pi^-e^+\nu_e) = (0.295 \pm 0.004_{\rm stat} \pm 0.003_{\rm syst})\%$, which are consistent with the previous measurements and are the most precise at present. To study the $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$ decays, $(170.31 \pm 0.34) \times 10^4$ single D^- tags are accumulated using nine hadronic modes. In this sample of D^- tags, 26008 ± 168 and 3402 ± 70 signal events of $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$ are found, respectively. With these events, the branching fractions are measured to be $\mathscr{B}(D^+ \to \bar{K}^0e^+\nu_e) = (8.60 \pm 0.06_{\rm stat} \pm 0.15_{\rm syst})\%$ and $\mathscr{B}(D^+ \to \pi^0e^+\nu_e) = (0.363 \pm 0.008_{\rm stat} \pm 0.005_{\rm syst})\%$, which are consistent within errors with previous measurements but with better precisions [2].

In addition to the measurements of the branching fractions, we also studied the differential decay rates of these two processes. We first divided the semileptonic events into several q^2 bins and measure the partial decay rates in each q^2 bin. We then fit these partial decay rates using different form factor models. In the fits, single pole model, modified pole model and series expansion are tried. Figures 1 and 2 show the fit resulsts. From the fits, we extract the product $f_+(0)|V_{cs(d)}|$ and other form factor parameters.

Since the CKM matrix elements are fundamental parameters of the SM, precise determinations of $|V_{cs(d)}|$ are very important in testing the SM and searching for NP. The recent experimental

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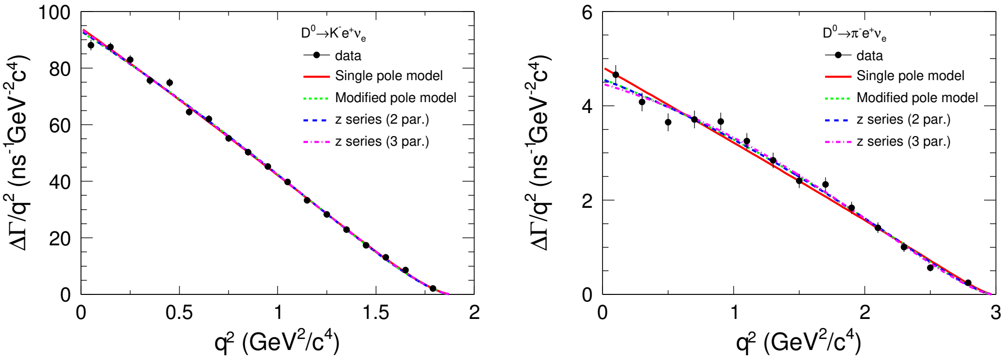

Figure 1: The differential decay rates for $D^0 \to K^- e^+ \nu_e$ (left) and $D^0 \to \pi^- e^+ \nu_e$ (right) decays with the fit results overlaid.

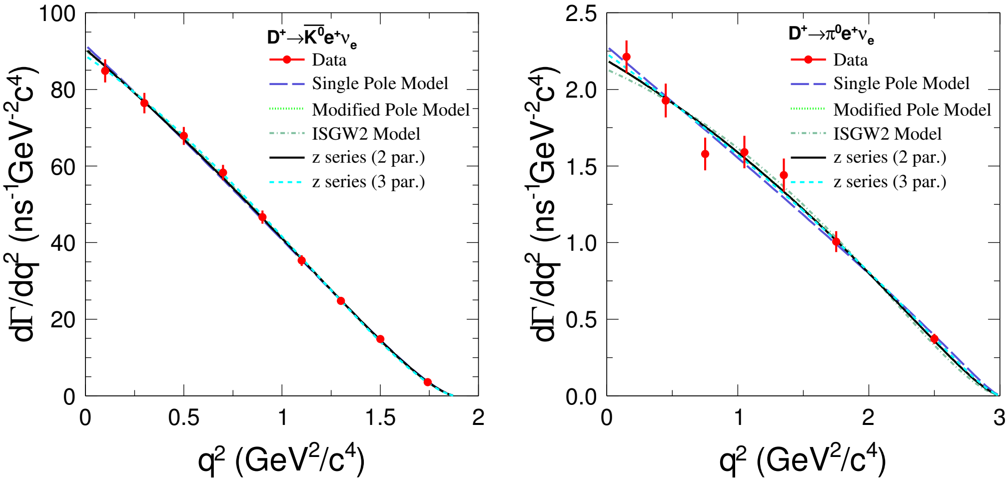

Figure 2: The differential decay rates for $D^+ \to \bar{K}^0 e^+ \nu_e$ (left) and $D^+ \to \pi^0 e^+ \nu_e$ (right) decays with the fit results overlaid.

results of $f_+^{D\to K}(0)|V_{cs}|$ and $f_+^{D\to\pi}(0)|V_{cd}|$ are compared in Fig. 3. Averaging these measurements and using the latest lattice QCD results of form factors, one can obtain $|V_{cs}| = 0.958 \pm 0.004_{\rm expt} \pm 0.024_{\rm LQCD}$ and $|V_{cd}| = 0.214 \pm 0.002_{\rm expt} \pm 0.009_{\rm LQCD}$, where the uncertainties are still dominated by lattice QCD uncertainties on form factors. If averaging the determinations from leptonic and semileptonic decays, one can find $|V_{cs}| = 0.988 \pm 0.14$ and $|V_{cd}| = 0.216 \pm 0.004$. Using the V_{cs} and V_{cd} extracted from leptonic and semileptonic decays, we examined the unitarity of the CKM matrix. One can find $|V_{us}|^2 + |V_{cs}|^2 + |V_{ts}|^2 = 1.029 \pm 0.028$ and $|V_{ud}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1.025 \pm 0.028$ for the second column and second row, respectively, which are consistent with the SM expectations. For the first column, we have $|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 0.996 \pm 0.002$, which is 2σ deviations from unity and indicates that there may be some NP.

3. Semileptonic D_s Decays

By analyzing the data taken at 4.009 GeV, BESIII investigates the semileptonic $D_s^+ \to \eta e^+ \nu_e$

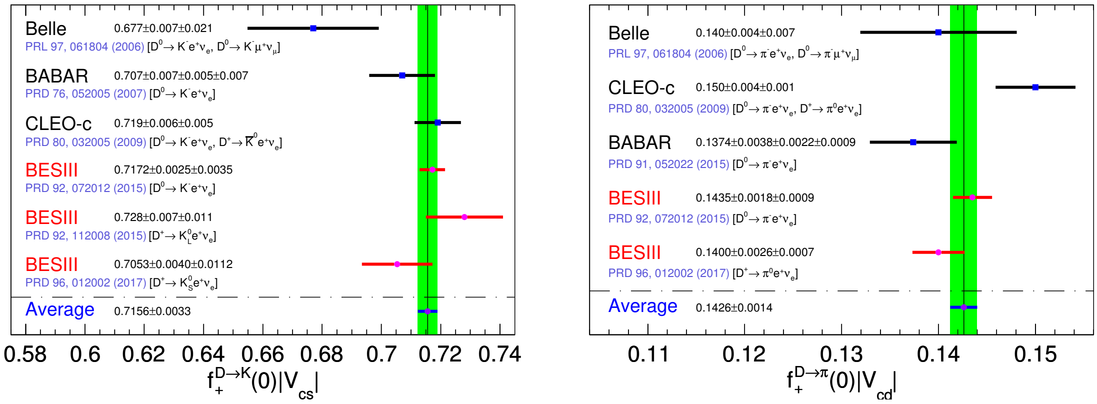

Figure 3: Compilations of $f_+^{D\to K}(0)|V_{cs}|$ (left) and $f_+^{D\to\pi}(0)|V_{cd}|$ (right).

and $D_s^+ \to \eta' e^+\nu_e$decays [3]. Using ten hadronic modes 13157 ± 240 D_s^- mesons are singly tagged. The $D_s^+ \to \eta^{(\prime)} e^+\nu_e$ decays are selected in the recoil side of D_s^- tags by requiring there are no extra tracks except a $\eta^{(\prime)}$ and a positron. The information of the neutrino is inferred from the variable $U_{\rm miss}$, which is the difference between the missing energy and missing momentum of the event. Figure 4 shows the distributions of $U_{\rm miss}$, where the signal is peaked around 0. After subtracting the backgrounds, 58.5 ± 8.0 signals of $D_s^+\to\eta e^+\nu_e$, 3.8 ± 2.0 signals of $D_s^+\to\eta'(\eta\pi^+\pi^-)e^+\nu_e$ and 8.2 ± 3.8 signals of $D_s^+\to\eta'(\gamma\rho^0)e^+\nu_e$ are retained, respectively. These yield the branching fractions $\mathscr{B}(D_s^+\to\eta e^+\nu_e) = (2.30\pm0.31_{\rm stat}\pm0.08_{\rm syst})\%$ and $\mathscr{B}(D_s^+\to\eta' e^+\nu_e) = (0.93\pm0.30_{\rm stat}\pm0.05_{\rm syst})\%$, which are consistent with previous measurements within uncertainties. Combining the branching fraction measurements, we obtain the ratio $\mathscr{B}(D_s^+\to\eta' e^+\nu_e)/\mathscr{B}(D_s^+\to\eta e^+\nu_e) = 0.40\pm0.14_{\rm stat}\pm0.02_{\rm syst}$, which provides complementary information to understand η-η' mixing.

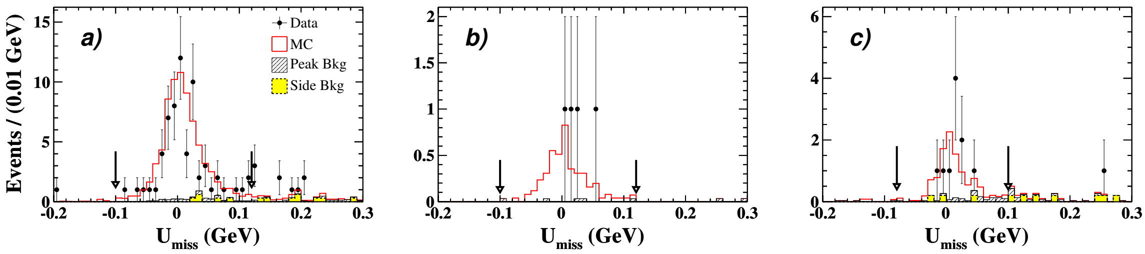

Figure 4: The $U_{\rm miss}$ distributions of the selected (a) $D_s^+\to\eta e^+\nu_e$, (b) $D_s^+\to\eta'(\eta\pi^+\pi^-)e^+\nu_e$ and (c) $D_s^+\to\eta'(\gamma\rho^0)e^+\nu_e$ candidates, where the arrows denote the signal regions.

4. Semileptonic Λ_c Decays

Based on 567 pb^{-1} data taken at 4.599 GeV, the branching fractions of $\Lambda_c\to\Lambda\ell^+\nu_\ell$ ($\ell = e,\mu$) decays are measured at the BESIII experiment [4, 5]. Using eleven hadronic modes, 14415 ± 159 $\bar\Lambda_c^+$ tags are accumulated. In this sample, 103.5 ± 10.9 and 78.7 ± 10.5 signal events for $\Lambda_c\to\Lambda e^+\nu_e$ and $\Lambda_c\to\Lambda\mu^+\nu_\mu$ semileptonic decays are extracted from the fits to the $U_{\rm miss}$ distributions as shown in Fig. 5. By analyzing these events, the branching fraction are measured to be $\mathscr{B}(\Lambda_c \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38_{\rm stat} \pm 0.20_{\rm syst})\%$ and $\mathscr{B}(\Lambda_c \to \Lambda \mu^+ \nu_\mu) = (3.49 \pm 0.46_{\rm stat} \pm 0.27_{\rm syst})\%$, which are the first absolute measurements. The branching fraction results provide stringent tests on different theoretical models which vary over a wide range from 1.4% to 9.2%.

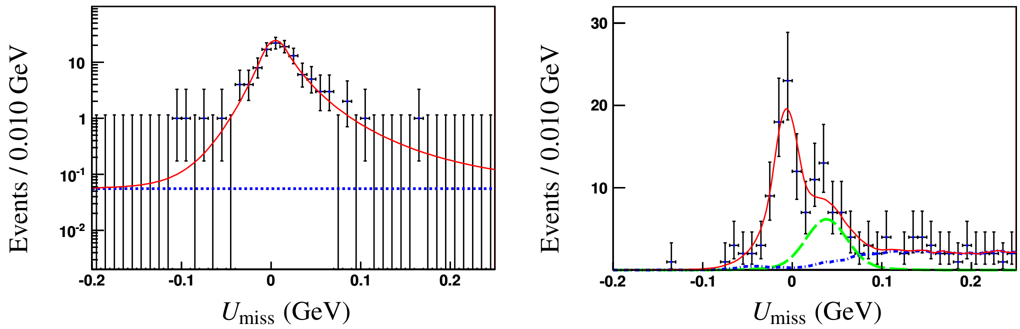

Figure 5: The $U_{\rm miss}$ distributions of the selcted $\Lambda_c^+ \to \Lambda e^+ \nu_e$ (left) and $\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$ (right) candidates (dots with error bars). The result of the fit is overlaid (red solid line).

5. Summary

In summary, many important results on semileptonic charm physics including the improved measurements of branching fractions, form factors and determination of CKM matrix elements are produced at the BESIII experiment.

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