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Semileptonic D decays

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In 2010 and 2011, BESIII collected 2.93 and 0.482 fb^{-1} data at the center-of-mass energies $\sqrt{s} = 3.773$ and 4.009 GeV, respectively. Herein, we report results on the semileptonic decays $D^+ \to \bar{K}^0(\pi^0)e^+\nu_e$, $D^+ \to K^-\pi^+e^+\nu_e$, and $D^+ \to \bar{K}^0\mu^+\nu_\mu$. The absolute branching fractions for these decays, the form factors of the $D^+ \to \bar{K}^0(\pi^0)e^+\nu_e$, $D^+ \to K^-\pi^+e^+\nu_e$ decays and the CKM matrix element $|V_{cs(d)}|$ are reported. Measurements of the leptonic decay $D_s^+ \to \ell^+\nu_\ell$ and the decay constant of $f_{D_s^+}$ are also reported.

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1. Introduction

D semileptonic decay rates can be parameterized by the quark mixing matrix element and the form factor of hadronic weak current in theory. Consequently, they open an window to probe for the weak and strong effects. Among of them, the simplest case is $D \to K(\pi)\ell^+\nu_\ell$, which differential decay rate can be simply written as

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2 p_{K(\pi)}^3 |f_+^{K(\pi)}(q^2)|^2, \tag{1.1}$$

where G_F is the Fermi coupling constant, $|V_{cs(d)}|$ is the quark mixing matrix element between the two quarks $c\bar{s}(\bar{d})$, $p_{K(\pi)}$ is the kaon(pion) momentum in the D rest frame, $f_+^{K(\pi)}(q^2)$ is the form factor of hadronic weak current depending on the square of the four momentum transfer $q = p_D - p_{K(\pi)}$. $X = 1/2$ for $D^+ \to \pi^0\ell^+\nu_\ell$, $X = 1$ for $D^0 \to K^-(\pi^-)\ell^+\nu_\ell$ and $D^+ \to \bar{K}^0\ell^+\nu_\ell$.

In the Standard Model (SM), the $D^+_{(s)}$ mesons decay into $\ell\nu_\ell$ via a virtual W^+ boson. The decay rate of the leptonic decay $D^+_{(s)} \to \ell^+\nu_\ell$ can be parameterized by the $D^+_{(s)}$ decay constant $f_{D^+_{(s)}}$ via

$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2}{8\pi}|V_{cd(s)}|^2 f^2_{D^+_{(s)}} m_\ell^2 m_{D^+_{(s)}}(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}), \tag{1.2}$$

where G_F is the Fermi coupling constant, $|V_{cd(s)}|$ is the quark mixing matrix element between the two quarks $c\bar{d}(\bar{s})$, m_ℓ and $m_{D^+_{(s)}}$ are the lepton and $D^+_{(s)}$ masses.

From experimental studies of semileptonic decays and leptonic decays of charmed mesons, one can determine the decay constant $f_{D^+_{(s)}}$, or the form factors in D semi-leptonic decays and the CKM matrix elements $|V_{cs(d)}|$, which are important to calibrate the theoretical calculations and the CKM matrix unitarity test. In recent ten years, extensive studies of semileptonic decays and leptonic decays of charmed mesons have been performed at BESII and CLEO-c [1], by analyzing data samples of 33 pb^{-1} taken around $\psi(3770)$, 818 pb^{-1} taken at $\psi(3770)$ and about 600 pb^{-1} taken around $\sqrt{s} = 4.17$ GeV, respectively, which are near to the production thresholds of the $D\bar{D}$ ($D^0\bar{D}^0$, D^+D^-) and $D_s^{*+}D_s^- + c.c.$ pairs. Meanwhile, Belle and Babar also performed studies on $D^0 \to K^-\ell^+\nu_\ell$, $D^0 \to \pi^-\ell^+\nu_\ell$, $D^+ \to K^-\pi^+e^+\nu_e$, $D^+ \to K^+K^-e^+\nu_e$ and $D_s^+ \to \ell^+\nu_\ell$ with data samples up to 913 and 521 fb^{-1} taken at $\sqrt{s} = 10.58$ GeV, respectively [1].

In 2010 and 2011, BESIII [2] accumulated 2.93 fb^{-1} data at $\sqrt{s}$ = 3.773 GeV [3] and 0.482 fb^{-1} data at $\sqrt{s}$ = 4.009 GeV [4]. Based on the data sample taken at $\sqrt{s}$ = 3.773 GeV, BESIII have reported the studies of the leptonic decay $D^+ \to \mu^+\nu_\mu$ [5], and the semileptonic decays $D^0 \to K^-(\pi^-)e^+\nu_e$ [6], $D^+ \to K^0_L e^+\nu_e$ [7], $D^+ \to \omega e^+\nu_e$ and $D^+ \to \phi e^+\nu_e$ [8]. Improved measurements of the decay constant f_{D^+} and the form factors in D semileptonic decays as well as the CKM matrix elements $|V_{cs(d)}|$ have been extracted. This proceeding reports recent results on the semileptonic decays $D^+ \to \bar{K}^0(\pi^0)e^+\nu_e$, $D^+ \to K^-\pi^+e^+\nu_e$, $D^+ \to \bar{K}^0\mu^+\nu_\mu$ as well as the leptonic decay $D_s^+ \to \ell^+\nu_\ell$ with the two data samples mentioned above. Throughout the proceeding, charge conjugate is implied.

2. $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$

For the purpose of studying the semileptonic decays $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$, we reconstruct the singly tagged D^- mesons using 9 hadronic decays. Fig. 1 shows the fits to the beamenergy-constrained mass ($M_{\rm BC}$) spectra of the $K^+\pi^-\pi^-$, $K^0_S\pi^-$, $K^0_SK^-$, $K^+K^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $\pi^-\pi^-\pi^+$, $K^0_S\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^-\pi^+$ and $K^0_S\pi^-\pi^-\pi^+$ combinations selected from data. Throughout the proceeding, the K^0_S and π^0 mesons are reconstructed by the $K^0_S \to \pi^+\pi^-$ and $\pi^0 \to \gamma\gamma$ decays, respectively, unless otherwise mentioned. From the fits to these $M_{\rm BC}$ spectra, we obtain $(170.31\pm0.34)\times10^4$ singly tagged D^- mesons.

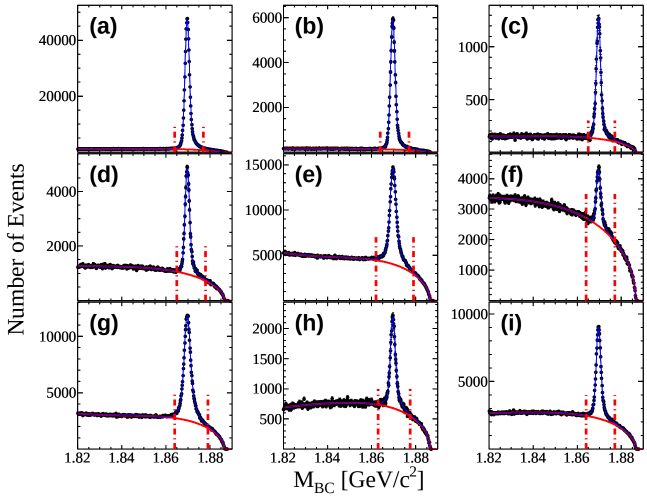

Figure 1: Fits to the $M_{\rm BC}$ spectra for the singly tagged D^- candidates (the $M_{\rm BC}$ signal region is marked by the pair of dashed lines in each sub-figure). The error bars are data. The blue curves are the best fits. The red curves are the fitted backgrounds.

Fig. 2 shows the fits to the $U_{\rm miss}$ distributions of the candidates for $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$, which are selected in the systems against the singly tagged D^- mesons. Here, the $\bar{K}^0$ mesons are reconstructed by the $\bar{K}^0 \to K^0_S \to \pi^+\pi^-$ decays. From the fits, we obtain 26008 ± 168 and 3402 ± 70 signals of $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$. With these events, we obtain preliminary results on the absolute branching fractions

$$\mathscr{B}(D^+ \to \bar{K}^0e^+\nu_e) = (8.60\pm0.06_{\rm stat.}\pm0.15_{\rm sys.})\times10^{-2}$$

and

$$\mathscr{B}(D^+ \to \pi^0e^+\nu_e) = (3.63\pm0.08_{\rm stat.}\pm0.05_{\rm sys.})\times10^{-3},$$

respectively. These are consistent within errors with previous measurements but with better precisions.

We also fit to the differential partial widths of $D^+ \to \bar{K}^0e^+\nu_e$ and $D^+ \to \pi^0e^+\nu_e$, with results shown in Fig. 3. Here, the Simple Pole model [9], the Modified Pole model [9], the ISGW2 model [10], the two-parameter series expansion (Series.2.Par.) [11] and the three-parameter series expansion (Series.3.Par.) [11] have been tried. From these fits, we obtain preliminary results on the extracted parameters of different models, as summarized in Tab. 1.

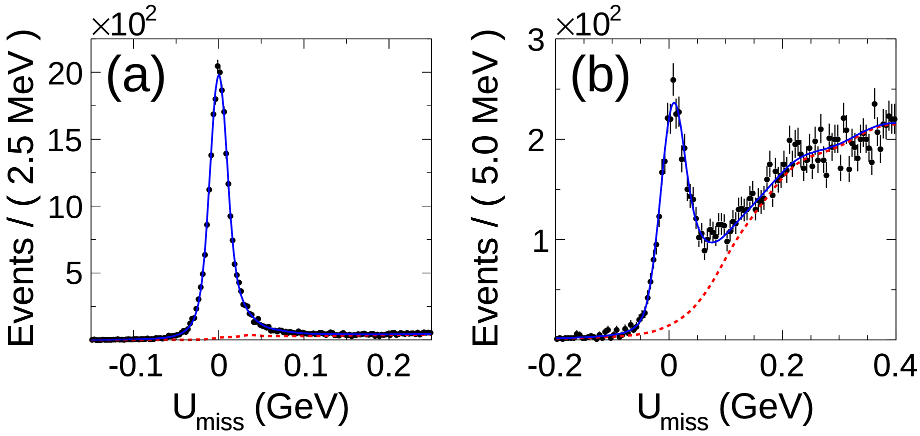

Figure 2: Fits to the $U_{\rm miss}$ distributions for the selected (a) $D^+ \to \bar{K}^0 e^+ \nu_e$ and (b) $D^+ \to \pi^0 e^+ \nu_e$ candidates with fit projections overlaid. The error bars are data. The blue solid curves are the best fits. The red dashed curves are the fitted backgrounds.

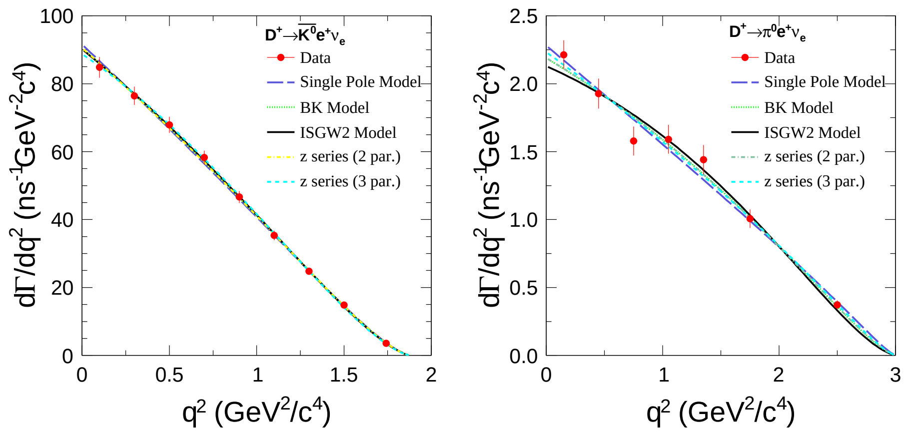

Figure 3: Fits to the differential partial widths of (a) $D^+ \to \bar{K}^0 e^+ \nu_e$ and (b) $D^+ \to \pi^0 e^+ \nu_e$.

3. $D^+ \to \bar{K}^0 e^+ \nu_e$ via $\bar{K}^0 \to \pi^0 \pi^0$

Good photon resolution of the BESIII detector allows us to try to measure the absolute branching fraction for $D^+ \to \bar{K}^0 e^+ \nu_e$ via $\bar{K}^0 \to \pi^0 \pi^0$. To do so, we reconstruct the singly tagged D^- mesons using 6 hadronic decays of $K^+\pi^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $K^0_S\pi^-$, $K^0_S\pi^-\pi^0$, $K^0_S\pi^-\pi^-\pi^+$ and $K^+K^-\pi^-$. About 1.5 millions of singly tagged D^- mesons are accumulated [12].

Fig. 4 shows the fit to the $U_{\rm miss}$ distribution of the accepted candidates for $D^+ \to \bar{K}^0 e^+ \nu_e$ with $\bar{K}^0 \to \pi^0 \pi^0$. The fit gives the number of the $D^+ \to \bar{K}^0 e^+ \nu_e$ decays to be 5013 ± 78. Based on this, we determine the absolute branching fraction to be

$$\mathscr{B}(D^+ \to \bar{K}^0 e^+ \nu_e) = (8.59 \pm 0.14_{\rm stat.} \pm 0.21_{\rm sys.})\%.$$

This result is well consistent with the other measurements within uncertainties and has a precision comparable to the PDG value [1].

Table 1: Summary of the extracted parameters from the fits to the partial widths, where the first errors are statistical and the second systematic.

	Single pole model		
Decay mode	$f_+(0)\lvert V_{cq}\rvert$	$m_{\rm pole}$ (GeV/c^2)	
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.7094 \pm 0.0035 \pm 0.0111$	$1.935 \pm 0.017 \pm 0.006$	
$D^+ \to \pi^0 e^+ \nu_e$	$0.1429 \pm 0.0020 \pm 0.0009$	$1.898 \pm 0.020 \pm 0.003$	
	Modified pole model		
Decay mode	$f_+(0)\lvert V_{cq}\rvert$	α	
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.7052 \pm 0.0038 \pm 0.0112$	$0.294 \pm 0.031 \pm 0.010$	
$D^+ \to \pi^0 e^+ \nu_e$	$0.1400 \pm 0.0024 \pm 0.0010$	$0.285 \pm 0.057 \pm 0.010$	
	ISGW2 model		
Decay mode	$f_+(0)\lvert V_{cq}\rvert$	r (GeV^{-1})	
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.7039 \pm 0.0037 \pm 0.0111$	$1.587 \pm 0.023 \pm 0.007$	
$D^+ \to \pi^0 e^+ \nu_e$	$0.1381 \pm 0.0023 \pm 0.0007$	$2.078 \pm 0.067 \pm 0.011$	
	Two-parameter series expansion		
Decay mode	$f_+(0)\lvert V_{cq}\rvert$	r_1	
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.7053 \pm 0.0040 \pm 0.0112$	$-2.18 \pm 0.14 \pm 0.05$	
$D^+ \to \pi^0 e^+ \nu_e$	$0.1400 \pm 0.0026 \pm 0.0007$	$-2.01 \pm 0.13 \pm 0.02$	
	Three-parameter series expansion		
Decay mode	$f_+(0)\lvert V_{cq}\rvert$	r_1	r_2
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.6983 \pm 0.0056 \pm 0.0112$	$-1.76 \pm 0.25 \pm 0.06$	$-13.4 \pm 6.3 \pm 1.4$
$D^+ \to \pi^0 e^+ \nu_e$	$0.1413 \pm 0.0035 \pm 0.0012$	$-2.23 \pm 0.42 \pm 0.06$	$1.4 \pm 2.5 \pm 0.4$

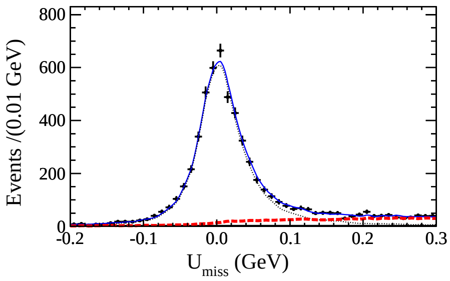

Figure 4: Fit to the $U_{\rm miss}$ distribution of the candidates for $D^+ \to \bar{K}^0(\pi^0\pi^0)e^+\nu_e$. The dots with error bars are data, the blue solid curve is the fit result, the black dotted and the red dashed curves are the fitted signal and background.

Combining the PDG values for $\mathcal{B}(D^0 \to K^- e^+ \nu_e)$, $\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e)$, and the lifetimes of D^0 and D^+ mesons (τ_{D^0} and τ_{D^+}) [1] with the measured value of $\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e)$, we determine

$$\frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\bar{\Gamma}(D^+ \to \bar{K}^0 e^+ \nu_e)} = \frac{\mathcal{B}(D^0 \to K^- e^+ \nu_e) \times \tau_{D^+}}{\bar{\mathcal{B}}(D^+ \to \bar{K}^0 e^+ \nu_e) \times \tau_{D^0}} = 0.969 \pm 0.025,$$

where $\bar{\mathcal{B}}(D^+ \to \bar{K}^0 e^+ \nu_e)$ is the uncertainty averaged branching fraction based on the PDG value and the measured value of $\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e)$. This ratio supports isospin conservation holding in the two semileptonic decays of $D^0 \to K^- e^+ \nu_e$ and $D^+ \to \bar{K}^0 e^+ \nu_e$ within about 1.2σ.

4. $D^+ \to \bar{K}^0 \mu^+ \nu_\mu$

Using the same singly tagged D^- mesons as mentioned in section 3, we also study the semimuonic decays of $D^+ \to \bar{K}^0\mu^+\nu_\mu$. In the selection of the signal side, we reconstruct $\bar{K}^0$ mesons with two decays $\bar{K}^0 \to K^0_S \to \pi^+\pi^-$ and $\bar{K}^0 \to K^0_S \to \pi^0\pi^0$ [13].

Fig. 5 shows simultaneous fits to the two $U_{\rm miss}$ distributions of the $D^+ \to \bar{K}^0\mu^+\nu_\mu$ candidate events. In the fits, we constrain the numbers of the efficiency and branching fraction corrected doubly tagged events and $D^+ \to \bar{K}^0\pi^+\pi^0$ peaking backgrounds, respectively, under the assumption that K^0_S contributes to half of the neutral kaon decays. From the fits, we obtain the observed numbers of the semileptonic decays to be 16516 ± 130 or 4198 ± 33 for the $+-$ or 00 modes, respectively. Based on these, we obtain the absolute branching fraction

$$\mathscr{B}(D^+ \to \bar{K}^0\mu^+\nu_\mu) = (8.72 \pm 0.07 \pm 0.18)\%.$$

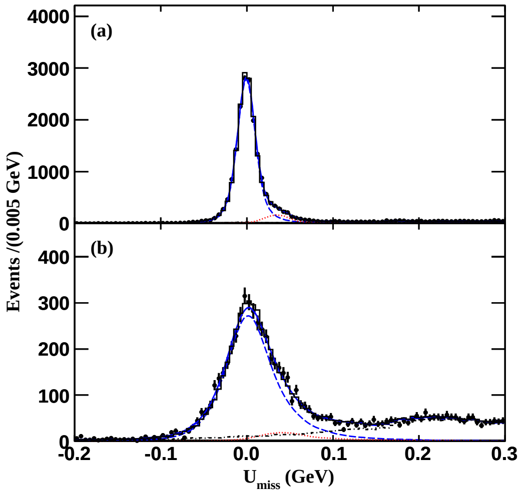

Figure 5: Fits to the $U_{\rm miss}$ distributions of the (a) $D^+ \to \bar{K}^0(\pi^+\pi^-)\mu^+\nu_\mu$ and (b) $D^+ \to \bar{K}^0(\pi^0\pi^0)\mu^+\nu_\mu$ candidates, where the histograms are the inclusive MC sample, the dots with error bars are data, the blue solid curves are the fit results, the blue dashed curves are the $D^+ \to \bar{K}^0\mu^+\nu_\mu$ signals, the red dotted curves are the $D^+ \to \bar{K}^0\pi^+\pi^0$ peaking backgrounds and the black dot-dashed curves are from other backgrounds.

Combining the measured $\mathscr{B}(D^+ \to \bar{K}^0\mu^+\nu_\mu)$ with the τ_{D^0}, τ_{D^+}, $\mathscr{B}(D^0 \to K^-\mu^+\nu_\mu)$ and $\mathscr{B}(D^+ \to \bar{K}^0e^+\nu_e)$ taken from PDG [1], we determine the ratios of the partial widths $\Gamma(D^0 \to K^-\mu^+\nu_\mu)/\Gamma(D^+ \to \bar{K}^0\mu^+\nu_\mu) = 0.963 \pm 0.044$, which supports isospin conservation holding in the two decays, and $\Gamma(D^+ \to \bar{K}^0\mu^+\nu_\mu)/\Gamma(D^+ \to \bar{K}^0e^+\nu_e) = 0.988 \pm 0.033$, which is consistent with the predicted value in Ref. [14] within uncertainties.

5. $D^+ \to K^-\pi^+e^+\nu_e$

Using the similar singly tagged D^- mesons as mentioned in section 3, we study the semileptonic decay $D^+ \to K^-\pi^+e^+\nu_e$ [15]. Based on 18262 signals of $D^+ \to K^-\pi^+e^+\nu_e$, we determine the absolute branching fraction

$$\mathscr{B}(D^+ \to K^-\pi^+e^+\nu_e) = (3.71 \pm 0.03 \pm 0.08)\%.$$

A partial wave analysis (PWA) is performed on the selected candidates, with results shown in Fig. 6. The PWA results show that the dominant $\bar{K}^{*0}$ component is accompanied by an S-wave contribution accounting for $(6.05 \pm 0.22 \pm 0.18)\%$ of the total rate, and other components can be negligible. We obtain the mass and width of $\bar{K}^{*0}(892)$ $M_{\bar{K}^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)$ MeV/c^2 and $\Gamma_{\bar{K}^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)$ MeV/c^2, the Blatt-Weisskopf parameter $r_{\rm BW} = 3.07 \pm 0.26 \pm 0.11$ (GeV$/c)^{-1}$, as well as the parameters of the hadronic form factors $r_V = \frac{V(0)}{A_1(0)} = 1.411 \pm 0.058 \pm 0.007$, $r_2 = \frac{A_2(0)}{A_1(0)} = 0.788 \pm 0.042 \pm 0.008$, $m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)$ MeV/c^2, $m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)$ MeV/c^2, $A_1(0) = 0.585 \pm 0.011 \pm 0.017$. Here, the first errors are statistical and the second systematic.

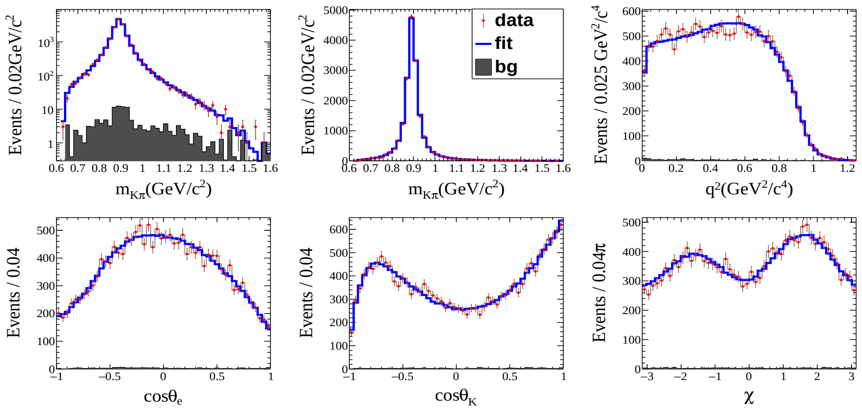

Figure 6: Projections of the kinematic variables of PWA for $D^+ \to K^-\pi^+e^+\nu_e$, where $m_{K\pi}$ is the $K\pi$ mass, q^2 is the $e\nu_e$ mass square, θ_K is the angle between π and D momenta in the $K\pi$ rest frame, θ_e is the angle between ν_e and D momenta in the $e\nu_e$ rest frame and χ is the angle between the two decay planes. The dots with error bars are data, the blue curves are the weighted signal MC and the hatched histograms are the simulated backgrounds.

In the PWA process, the phase of the non-resonant background $\delta_S(m_{K\pi})$ is factorized by the LASS parameterizations, and the helicity form factors $H_+(q^2, m_{K\pi})$, $H_-(q^2, m_{K\pi})$ and $H_0(q^2, m_{K\pi})$ are parameterized by the spectroscopic pole dominance (SPD) model. We also make model-independent measurements of the $\delta_S(m_{K\pi})$, and the helicity form factors, respectively. The results are consistent with the expectations of the corresponding models and previous measurements.

6. $D_s^+ \to \ell\nu_\ell$ at 4.009 GeV

To investigate the leptonic decay $D_s^+ \to \ell^+\nu_\ell$, we reconstruct the singly tagged D_s^- mesons using 9 hadronic decays. Fig. 7 shows the $M_{\rm BC}$ spectra of the $K_S^0K^-$, $K^+K^-\pi^-$, $K^+K^-\pi^-\pi^0$, $K_S^0K^+\pi^-\pi^-$, $\pi^+\pi^-\pi^-$, $\pi^-\eta$, $\pi^-\eta'_{\pi^+\pi^-\eta}$, $\pi^-\eta'_{\gamma\rho^0}$ and $\rho^-\eta$ combinations. The η mesons are reconstructed by the $\eta \to \gamma\gamma$ decays. By fitting to these spectra, as shown in Fig. 7, we obtain 15127 ± 312 singly tagged D_s^- mesons.

Fig. 8 shows the fit to the $M^2_{\rm miss}$ distribution of the candidates for $D^+ \to \mu^+\nu_\mu$, which are selected in the systems against the singly tagged D_s^- mesons. In the fits, the signal yields of $D_s^+ \to \mu^+\nu_\mu$ and $D_s^+ \to \tau^+\nu_\tau$ has been constrained by the SM prediction. We obtain 69.3 ± 9.3

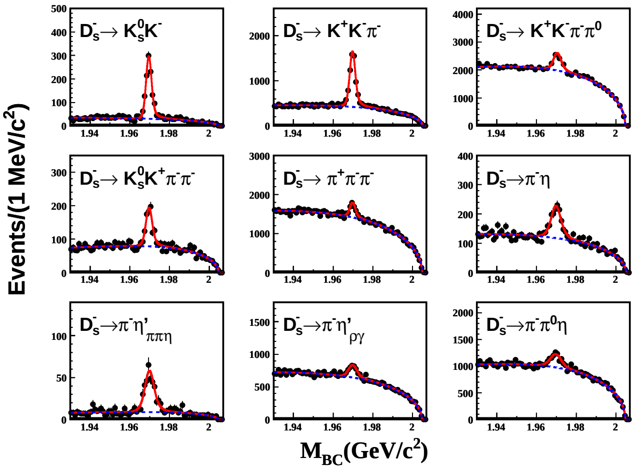

Figure 7: Fits to the $M_{\rm BC}$ spectra for the singly tagged D_s^- candidates. The error bars are data. The red curves are the best fits. The blue dashed curves are the fitted backgrounds.

signals of $D_s^+ \to \mu^+\nu_\mu$ or 32.5 ± 4.3 signals of $D_s^+ \to \tau^+\nu_\tau$. These give preliminary results on the absolute branching fractions to be

$$\mathscr{B}(D_s^+ \to \mu^+\nu_\mu) = (0.495 \pm 0.067_{\rm stat.} \pm 0.026_{\rm sys.})\%$$

and

$$\mathscr{B}(D^+ \to \tau^+\nu_\tau) = (4.83 \pm 0.65_{\rm stat.} \pm 0.26_{\rm sys.})\%.$$

Here, the measured $\mathscr{B}(D_s^+ \to \mu^+\nu_\mu)$ has been corrected by 1% to considering the $\gamma\mu^+\nu_\mu$ final state. Using the measured $B(D_s^+ \to \ell^+\nu_\ell)$ and the quark mixing matrix element $|V_{ud}|$ from a global SM fit [1], we obtain preliminary result on the D_s^+ decay constant

$$f_{D_s^+} = 241.0 \pm 16.3_{\rm stat.} \pm 6.6_{\rm sys.}\ \text{MeV}.$$

7. Summary

Based on 2.93 and 0.482 fb^{-1} data samples taken at $\sqrt{s} = 3.773$ and 4.009 GeV with the BESIII detector, we report recent studies on the semileptonic decays $D^+ \to \bar{K}^0(\pi^0)e^+\nu_e$, $D^+ \to K^-\pi^+e^+\nu_e$, $D^+ \to \bar{K}^0\mu^+\nu_\mu$ and the leptonic decay $D_s^+ \to \ell^+\nu_\ell$. The absolute branching fractions for these decays, the decay constant of $f_{D_s^+}$, the form factors of the $D^+ \to \bar{K}^0(\pi^0)e^+\nu_e$ and $D^+ \to K^-\pi^+e^+\nu_e$ decays, as well as the CKM matrix element $|V_{cs(d)}|$ are reported.

In 2016, BESIII have collected a data sample of about 3 fb^{-1} at $\sqrt{s} = 4.18$ GeV. Measurements of the decay constant of $f_{D_s^+}$, the CKM matrix element $|V_{cs}|$ and the D_s^+ semileptonic decays are expected to be further improved in the near future.

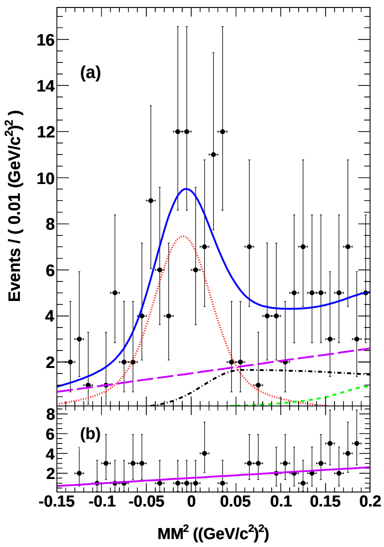

Figure 8: Simultaneous fits to the $M^2_{\rm miss}$ distribution of the $D_s^+ \to \ell^+\nu_\ell$ candidates. The error bars are data. The blue curves are the best fits. The red dotted curve is the $D_s^+ \to \mu^+\nu_\mu$ signal shape. The black dot-dashed curve is the $D_s^+ \to \tau^+\nu_\tau$ signal shape. The purple curve is the non-D_s^+ background. The green curve is the D_s^+ backgrounds.

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