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Recent results on charmed meson decays at BESIII

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Summary. — The BESIII Experiment at the Beijing Electron Positron Collider (BEPCII) has accumulated the world largest e^+e^- annihilation samples at 3.773 GeV with 2.93 fb^{-1} for $D^{0(\pm)}$ and 4.178 GeV with 3.19 fb^{-1} for $D_s^{\pm}$, which provide a clean background to study charmed meson decays. In this proceeding, we present the recent results of the study of D meson decays at BESIII.

1. – Introduction

The BESIII [1] is a magnetic spectrometer working at a double-ring e^+e^- collider BEPCII operating at center-of-mass energy between 2.0 GeV and 4.6 GeV, located at the Institute of High Energy Physics (IHEP) in Beijing, China. The analysis presented in this report are based on two data samples. One is the e^+e^- annihilation sample taken at 3.773 GeV with 2.93 fb^{-1}, where the main production is $e^+e^- \to \Psi(3770) \to D\bar{D}$. Another one is the e^+e^- annihilation sample taken at 4.178 GeV with 3.19 fb^{-1}, where the main production is $e^+e^- \to D_s^{*\pm}D_s^{\mp}$. In these analyses, double tag method are used. We reconstruct only one of $D\bar{D}$ pair which is called single tag (ST), and reconstruct both of $D\bar{D}$ pair which is called double tag (DT). The absolute branching fraction can be calculated according to the yields and efficiencies of ST and DT by $\mathcal{B} = \frac{N_{DT}}{N_{ST}\cdot\epsilon_{DT}/\epsilon_{ST}}$. Throughout the proceeding, charge conjugate decays are implied unless otherwise noted.

2. – (Semi-)leptonic decays

In SM, the decay rate of $D^+_{(s)} \to \ell^+\nu_\ell$ and $D \to P\ell^+\nu_\ell$ can be parameterized as:

$$(1a)\qquad \Gamma_{D^+_{(s)}\to\ell^+\nu_\ell} = \frac{G_F^2}{8\pi} f^2_{D^+_{(s)}} m_\ell^2 m_D (1-\frac{m_\ell^2}{m_D})|V_{cd(s)}|^2$$

$$(1b)\qquad \frac{\mathrm{d}\Gamma_{\mathrm{D_{(s)}\to P}\ell^+\nu_\ell}}{\mathrm{dq}^2} = \frac{G_F^2|V_{cd(s)}|^2}{8\pi^3 m_D}|\vec{p}_P||f_+^P(q^2)|^2(\frac{W_0-E_P}{F_0})^2[\frac{1}{3}m_D|\vec{p}_P|^2+\mathcal{O}(m_\ell^2)]$$

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where G_F is Fermi coupling constant, m_ℓ and m_D are the masses of the lepton and the $D_{(s)}$ meson, $f_{D^+_{(s)}}$ is the $D^+_{(s)}$ decay constant, $f^P_+(q^2)$ is the form factor, $V_{cd(s)}$ is the CKM matrix element, $W_0 = \frac{m_D^2+m_P^2-m_\ell^2}{2m_D}$ and $F_0 = W_0 - E_p + \frac{m_\ell^2}{2m_D}$. (Semi-)leptonic decays provide a excellent chance to measure the $V_{cd(s)}$ with input $f_{D_{(s)}}$ or $f^P_+(q^2)$ from lattice QCD, and validate lattice QCD (LQCD) by measuring $f_{D^+_{(s)}}$ or $f^P_+(q^2)$ with input $V_{cd(s)}$.

2·1. $D^+_s \to \mu^+\nu_\mu$ *(preliminary)*. – Based on 3.19 fb^{-1} data taken at 4.178 GeV, the branching fraction of $D^+ \to \tau^+\nu_\tau$ is measured to be $(5.28 \pm 0.15_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$ by fitting missing mass square of ν_μ. $|V_{cs}|$ is measured to be $0.974 \pm 0.014_{stat.} \pm 0.016_{syst.}$ by input $f^{LQCD}_{D^+_s}$ [2]. $f_{D^+_s}$ is measured to be $(249.1 \pm 3.6_{stat.} \pm 3.8_{syst.})$ MeV by input $|V_{cs}|^{\mathrm{CKMfitter}}$ [3]. The lepton flavor universality is tested by measuring the ratio $R_{\tau/\mu} = \frac{\mathcal{B}_{D^+_s\to\tau^+\nu_\tau}[this\ work]}{\mathcal{B}_{D^+_s\to\mu^+\nu_\mu}[3]} = 10.2 \pm 0.5$, which is consistent with SM prediction 9.74 ± 0.01 within 1σ.

2·2. $D^0 \to K^-\mu^+\nu_\mu$. – Based on 2.93 fb^{-1} data taken at 3.773 GeV, the branching fraction of $D^0 \to K^-\mu^+\nu_\mu$ is measured to be $(3.413 \pm 0.019_{stat.} \pm 0.035_{syst.})\%$ by fitting $\mathrm{U_{miss}} = \mathrm{E_{miss}} - |\vec{\mathrm{p}}_{\mathrm{miss}}|c$ of ν_μ. Series expansion parameterization [4] to 2nd order of form factor is used in the fit of partial decay rates shown in Fig.1 (a), and $|V_{cs}|$ is measured to be $0.955 \pm 0.006_{exp.} \pm 0.024_{LQCD}$ by input $f^{K,LQCD}_+$ [7], $f^K_+(0)$ is measured to be $0.7327 \pm 0.0039_{stat.} \pm 0.0030_{syst.}$ by input $|V_{cs}|^{\mathrm{CKMfitter}}$ [3]. The lepton flavor universality is tested by measuring the ratio $R^K_{\mu/e}(q^2) = \frac{\mathcal{B}_{D^0\to K^-\mu^+\nu_\mu}[this\ work]}{\mathcal{B}_{D^0\to K^-e^+\nu_e}[5]}$ which is showed in Fig.1 (c) by red dots, and the value is consistent with SM prediction showed by solid line in Fig.1 (c). The details can be found in Ref.[6].

2·3. $D^+_s \to \eta^{(\prime)}e^+\nu_e$ *(preliminary)* . – Based on 3.19 fb^{-1} data taken at 4.178 GeV, the branching fraction of $D^+_s \to \eta^{(\prime)}e^+\nu_e$ are measured to be $(2.32 \pm 0.06_{stat.} \pm 0.06_{syst.})\%$ and $(0.82 \pm 0.07_{stat.} \pm 0.03_{syst.})\%$ by fitting the missing mass square distribution of ν_μ. Series expansion parameterization [4] to 2nd order for form factor is used in the fit of partial decay rates, and $|V_{cs}|$ is measured to be $0.917 \pm 0.094_{stat.} \pm 0.156_{syst.}$ for $D^+_s \to \eta^{\prime}e^+\nu_e$ and $1.032 \pm 0.012_{stat.} \pm 0.080_{syst.}$ for $D^+_s \to \eta e^+\nu_e$ by input $f^{\eta^{(\prime)},LQCD}_+$ [8]. $f^{\eta^{(\prime)}}_+$ are measured to be $0.458 \pm 0.005_{stat.} \pm 0.004_{syst.}$ and $0.490 \pm 0.050_{stat.} \pm 0.011_{syst.}$. The

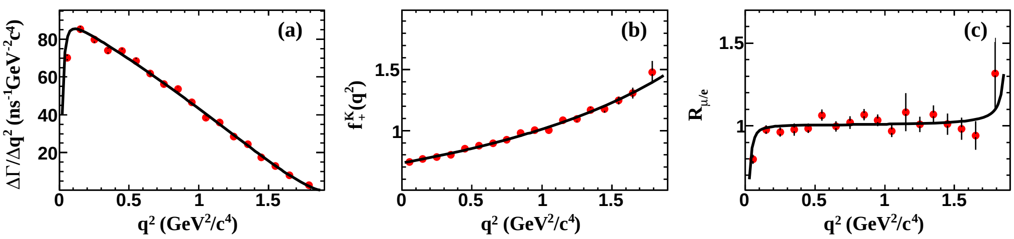

Fig. 1. – (a) Fit to partial decay rates, the red dots are data and solid curve is fit fuction. (b) Projection on form factor of figure (a). (c) The value of measured $R^K_{\mu/e}(q^2)$ (red dots) and SM prediction (solid curve).

TABLE I. – *Fit results of $f_+(0)|V_{cd}|$ with corresponding models. The last value of $f_+(0)$ is extracted by input $|V_{cs}|^{\mathrm{CKMfitter}}$ [3] .*

Model	Parameter	Value (preliminary)	$f_+(0)$ (preliminary)
simple pole	$f_+(0)\|V_{cd}\|$	$0.175 \pm 0.010 \pm 0.001$	$0.778 \pm 0.044 \pm 0.004$
Modified pole model	$f_+(0)\|V_{cd}\|$	$0.163 \pm 0.017 \pm 0.003$	$0.725 \pm 0.076 \pm 0.013$
	α	$0.45 \pm 0.44 \pm 0.02$	
Series two parameters	$f_+(0)\|V_{cd}\|$	$0.162 \pm 0.019 \pm 0.003$	$0.720 \pm 0.084 \pm 0.013$
	r_1	$-2.94 \pm 2.32 \pm 0.14$	

$\eta - \eta'$ mixing angle is calculated to be $\phi_P = (40.2 \pm 1.4_{stat.} \pm 0.5_{syst.})^\circ$ according to the equation $\cot^4\phi_{\mathrm{P}} \simeq \frac{\Gamma_{\mathrm{D_s^+}\to\eta' \mathrm{e}^+\nu_\mathrm{e}}/\Gamma_{\mathrm{D_s^+}\to\eta \mathrm{e}^+\nu_\mathrm{e}}[\text{this work}]}{\Gamma_{\mathrm{D}^+\to\eta' \mathrm{e}^+\nu_\mathrm{e}}/\Gamma_{\mathrm{D}^+\to\eta \mathrm{e}^+\nu_\mathrm{e}}[9]}$.

2·4. *$D_s^+ \to K^{(*)0}e^+\nu_e$ (preliminary)* . – Based on 3.19 fb^{-1} data taken at 4.178 GeV, the branching fraction of $D_s^+ \to K^{(*)0}e^+\nu_e$ are measured to be $(3.25 \pm 0.38_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$ and $(2.38 \pm 0.26_{stat.} \pm 0.12_{syst.}) \times 10^{-3}$ by fitting missing mass square distribution of ν_e. For $D_s^+ \to K^0e^+\nu_e$, three models for form factor are used to extract $f_+(0)|V_{cd}|$, and the fit results with corresponding models are listed in Table.I. For $D_s^+ \to K^{*0}e^+\nu_e$, the formula of differential decay rates given by [10] is used to perform a four dimensional fit, and the form factor is measured to be $r_V = 1.67 \pm 0.34 \pm 0.16$ and $r_2 = 0.77 \pm 0.28 \pm 0.07$.

2·5. *$D \to a_0(980)e^+\nu_e$.* – Based on 2.93 fb^{-1} data taken at 3.773 GeV, the branching fraction $\mathcal{B}_{D^0\to a_0(980)^-e^+\nu_e} \times \mathcal{B}_{a_0(980)^-\to\eta\pi^-}$ and $\mathcal{B}_{D^+\to a_0(980)^0e^+\nu_e} \times \mathcal{B}_{a_0(980)^0\to\eta\pi^0}$ are measured to be $(1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$ and $(1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}$ by performing a two dimensional fit of $\mathrm{M}_{\eta\pi}$ versus $\mathrm{U_{miss}} = \mathrm{E_{miss}} - |\vec{\mathrm{p}}_{\mathrm{miss}}|c$. The significance of first one is 6.4σ, and the second one is 2.9σ. The upper limit for the second one is determined as $< 3.0 \times 10^{-4}$ at the 90% C.L. The decay rates ratio $\frac{\Gamma_{D^0\to a_0(980)^-e^+\nu_e}}{\Gamma_{D^+\to a_0(980)^0e^+\nu_e}}$ is calculated to be $2.03 \pm 0.95 \pm 0.06$, which is consistent with the prediction of isospin symmetry. The details can be found in Ref.[11].

3. – Hadronic decays

For D meson hadronic decays, we focus on the decays via W-annihilation process.

3·1. *$D_s^+ \to p\bar{n}$ (preliminary).* – $D_s^+ \to p\bar{n}$ can proceed only via W-annihilation process. The branching fraction is expected to be $\sim 10^{-6}$ though short-distance process. The long-distance process can enhance the branching fraction to $\sim 10^{-3}$. Based on 3.19 fb^{-1} data taken at 4.178 GeV, the branching fraction of $D_s^+ \to p\bar{n}$ is measured to be $(1.22 \pm 0.10) \times 10^{-3}$ by fitting the missing mass of $\bar{n}$, which is consistent with CLEO's measurement [12] with improved precision and long distance expectation.

3·2. *$D_s^+ \to \omega\pi^+$ and ωK^+ (preliminary).* – $D_s^+ \to \omega\pi^+$ can proceed only via W-annihilation process and $D_s^+ \to \omega K^+$ contains W-annihilation process distribution. Based on 3.19 fb^{-1} data taken at 4.178 GeV, the branching fraction of $D_s^+ \to \omega\pi^+$ and $D_s^+ \to \omega K^+$ are measured to be $(1.85 \pm 0.30_{stat.} \pm 0.19_{syst.}) \times 10^{-3}$ and $(1.13 \pm$

$0.24_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$. The first one is consistent with CLEO's measurement [13], and the second one is the first observation.

3˙3. $D_s^+ \to \pi^+\pi^-\eta$ *(preliminary)*. – Based on 3.19 fb^{-1} data taken at 4.178 GeV, the total branching fraction of $D_s^+ \to \pi^+\pi^-\eta$ is measured to be $(9.50 \pm 0.28_{stat.} \pm 0.41_{syst.})\%$ by double tag method with 7 dominated tag modes. Amplitude analysis is performed for this channel, and the branching fraction of W-annihilation process $D_s^+ \to a_0(980)^+\pi^0$ and $D_s^+ \to a_0(980)^0\pi^+$ are measured to be $(1.46 \pm 0.15_{stat.} \pm 0.22_{syst.})\%$ under isospin symmetry.

4. – Rare decays

4˙1. $D \to h(h^{(')})e^+e^-$. – $D \to X_u\ell^+\ell^-$ are good channels to study FCNC transitions and the branching fraction in SM is less than 10^{-9}. A long-distance effect can enhance this branching fraction to 10^{-6}. The previous upper limit for four body D^0 decays with e^+e^- are $\sim 10^{-4} - 10^{-5}$, and four body D^+ decays with e^+e^- have not been studied before. Based on $2.93 fb^{-1}$ data taken at 3.773GeV, the branching fraction of four body D^0 decays with e^+e^- are measured with an improved precision to $\sim 10^{-5} - 10^{-6}$, and the branching fraction of four body D^+ decays with e^+e^- are measured to be $\sim 10^{-5}$. The details can be found in Ref.[14].

5. – Summary

Based on 2.93 fb^{-1} and 3.19 fb^{-1} e^+e^- annihilation data taken at 3.773 GeV and 4.178 GeV by BESIII, recent analyses of D meson decays performed by BESIII collaboration are presented in this proceeding. In these analyses, $D^0 \to a_0(980)^-e^+\nu_e$, $D_s^+ \to p\bar{n}$, $D_s^+ \to \omega K^+$ and $D_s^+ \to a_0(980)\pi$ are observed for the first time, and the branching fraction or upper limit of other channels are measured with an improved precision. The $|V_{cd(s)}|$, $f_{D_s^+}$ and f_+ are measured in (semi-)leptonic decays which provide important test to LQCD calculation and CKM matrix unitary. More results will be coming in the near future.

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