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# Charm physics at BESIII

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**Abstract**: Based on 2.93 and 0.567 fb$^{-1}$ data taken at the center-of-mass energies $\sqrt{s}=3.773$ and 4.599 GeV with the BESIII detector, we report the precise measurements of the decay constant $f_{D^+}$, the form factors of $D$ semileptonic decays, the Dalitz plot analysis of $D^+\to K_S^0\pi^+\pi^0$, the strong phase differences in $D\to K_{S/L}^0\pi^+\pi^-$ and $K^-\pi^+$, the $D^0\overline{D}^0$ mixing parameter $y_{CP}$, the searches for 2-body hadronic decays $D^{0(+)}\to\omega\pi^{0(+)}$, rare decays of $D^0\to\gamma\gamma$ and $D^+\to K(\pi)^\pm e^\mp e^+$ as well as the significant improved measurements of the absolute branching fractions for $\Lambda_c^+\to\Lambda e^+\nu_e$ and 12 hadronic final states.

**Key words**: charmed meson and baryon; leptonic and semileptonic decays; hadronic decay; rare decay; decay constant; form factor; strong phase; quark mixing matrix element

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# BESIII 粲物理

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**摘要**:分析 BESIII 探测器在质心系能量 3.773 和 4.599 GeV 采集的 2.93 和 0.567 fb$^{-1}$数据,报道了衰变常数 $f_{D^+}$ 和 $D$ 介子半轻子衰变的形状因子,$D^+\to K_S^0\pi^+\pi^0$ 的 Dalitz 图分析,$D\to K_{S/L}^0\pi^+\pi^-$ 和 $K^-\pi^+$ 强相差,$D^0\overline{D}^0$ 混合参数 $y_{CP}$ 的测量;2 体强子衰变 $D^{0(+)}\to\omega\pi^{0(+)}$,稀有衰变 $D^0\to\gamma\gamma$ 和 $D^+\to K(\pi)^\pm e^\mp e^+$ 的寻找以及 $\Lambda_c^+\to\Lambda e^+\nu_e$ 和 12 个强子衰变绝对分支比的测量.

**关键词**:粲介(重)子;纯轻和半轻子衰变;强子衰变;稀有衰变;衰变常数;形状因子;强相角;夸克混合矩阵

## 0 Introduction

Precision measurements of charm decays provide rich information to better understand strong and weak effects. Firstly, the (deferential) decay rates of the $D$ leptonic and semileptonic decays can be simply functioned as decay constant $f_{D^+}$ or form factors and CKM matrix element $|V_{cs(d)}|$. From an analysis of the $D$ leptonic and semileptonic decays, we can determine these elementary constants, thus calibrating the LQCD calculation on $f_{D^+}$ and the form factors and testing

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the CKM matrix unitarity.

Secondly, studies of $D$ hadronic decays are important due to several aspects. At $\psi(3770)$, the quantum correction property of $D^0$ meson production provides an access to CP asymmetry in $D^0\overline{D}^0$ mixing and strong phase parameters which can be used to constrain $\gamma/\phi_3$ and to further test the CKM matrix unitarity. Improved knowledge of 2-body decays is helpful for understanding $U$-spin and $SU(3)$ flavor symmetry breaking effects. Datlitz plot analysis of 3-body decays can provide rich information about the parameters of sub-resonances and strong phases.

Thirdly, in the Standard Model (SM), the Flavor Changed Neutral Current (FCNC) process and the Leptonic Number Violation (LNV) process are highly suppressed. However, some new dynamics beyond the SM may enhance these kinds of processes to observable level at BESIII. So, search for these rare decays can be used to probe for New Physics beyond the SM. Any evidence of rare decay and CP violation in charm decays or significant deviation of CKM unitarity may indicate New Physics beyond the SM.

Finally, compared to charmed meson decays, the knowledge of charmed baryon $\Lambda_c^+$ decays is still very poor. It is desired to improve the measurements of the known decays and search for new decay modes. Significantly improved knowledge of the decay rates or dynamics of charm decays can also provide better inputs for beauty physics.

Herein, we report recent results on the studies of the leptonic, semileptonic and hadronic decays of $D^0$, $D^+$ and $\Lambda_c^+$. These are based on 2.93[1] and 0.567[2] $\mathrm{fb}^{-1}$ data at $\sqrt{s} = 3.773$ and 4.599 GeV, where $D^0\overline{D}^0$, $D^+D^-$ and $\Lambda_c^+\overline{\Lambda}_c^-$ are produced in pairs, taken with the BESIII detector[3]. Throughout the proceeding, charge conjugate is implied.

## 1 *D* leptonic and semileptonic decay

In the Standard Model, the $D^+$ mesons decay into $l\nu_l$ via a virtual $W^+$ boson. The decay rate of the leptonic decays $D^+\to l^+\nu_l$ can be parameterized by the $D^+$ decay constant $f_{D^+}$ via

$$\Gamma(D^+\to l^+\nu_l) = \frac{G_F^2}{8\pi}|V_{cd}|^2 f_{D^+}^2 m_l^2 m_{D^+}\left(1-\frac{m_l^2}{m_{D^+}{}^2}\right) \tag{1}$$

where $G_F$ is the Fermi coupling constant, $|V_{cd}|$ is the quark mixing matrix element, $m_l$ and $m_{D^+}$ are the lepton and $D^+$ masses. To investigate the leptonic decay $D^+\to\mu^+\nu_\mu$[4], the singly tagged $D^-$ mesons are reconstructed using 9 hadronic decays $K^+\pi^-\pi^-$, $K_S^0\pi^-$, $K_S^0K^-$, $K^+K^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $\pi^+\pi^-\pi^-$, $K_S^0\pi^-\pi^0$, $K^+\pi^+\pi^-\pi^-\pi^-$ and $K_S^0\pi^+\pi^-\pi^-$. From these, we accumulate $(170.31\pm0.34)\times10^4$ singly tagged $D^-$ mesons. Fig. 1 (a) shows the $M_{\mathrm{miss}}^2$ distribution of the $D^+\to\mu^+\nu_\mu$ candidates, which are selected in the systems against the singly tagged $D^-$ mesons. We obtain $409\pm21$ $D^+\to\mu^+\nu_\mu$ signals after background subtraction, which leads to the branching fraction $\mathcal{B}(D^+\to\mu^+\nu_\mu)=(3.71\pm0.19_{\mathrm{stat.}}\pm0.06_{\mathrm{sys.}})\times10^{-4}$. Using the measured $\mathcal{B}(D^+\to\mu^+\nu_\mu)$ and the quark mixing matrix element $|V_{cd}|$ from a global Standard Model fit[5], we determine the $D^+$ decay constant $f_{D^+}=203.2\pm5.3_{\mathrm{stat.}}\pm1.8_{\mathrm{sys.}}$ MeV. Fig. 1(b) compares the $f_{D^+}$ measured at BESIII and CLEO[6] as well as those calculated by recent theories. The $\mathcal{B}(D^+\to\mu^+\nu_\mu)$ and $f_{D^+}$ measured at BESIII are consistent within errors with previous measurements, but with the best precision. By using the measured $\mathcal{B}(D^+\to\mu^+\nu_\mu)$ and the LQCD calculation on $f_{D^+}$[7], we determine

$$|V_{cd}| = 0.2210\pm0.058_{\mathrm{stat.}}\pm0.047_{\mathrm{sys.}},$$

which has the best precision in the world to date.

On the other hand, the $D$ semileptonic decays can be parameterized by the quark mixing matrix element and the form factor of hadronic weak current simply, thus providing an ideal window to probe for the weak and strong effects. For example, the differential decay rates of $D\to K(\pi)e^+\nu_e$ can be simply written as

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

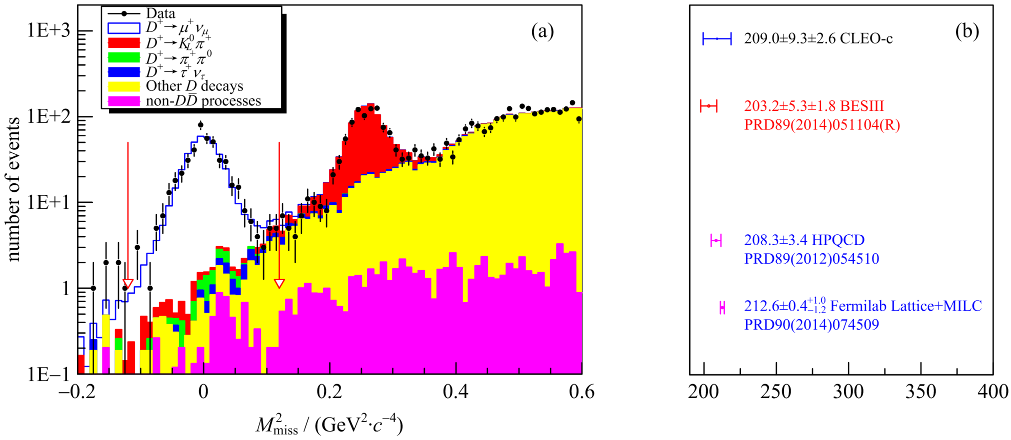


**Fig. 1** (a) $M^2_{\rm miss}$ distribution of the $D^+\to\mu^+\nu_\mu$ candidates. (b) Comparison of $f_{D^+}$

where $G_F$ is the Fermi coupling constant, $|V_{cs(d)}|$ is the quark mixing matrix element, $p_{K(\pi)}$ is the kaon (pion) momentum in the $D^0$ rest frame, $f_+^{K(\pi)}(q^2)$ is the form factor of hadronic weak current depending on the square of the four momentum transfer $q = p_D - p_{K(\pi)}$. To investigate the semileptonic decays $D^0 \to K(\pi)^- e^+ \nu_e$[8], we reconstruct the singly tagged $\bar{D}^0$ mesons using 5 hadronic decays of $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^+$, $K^+\pi^-\pi^-\pi^+\pi^0$ and $K^+\pi^-\pi^0\pi^0$, which give $(279.33\pm0.37)\times10^4$ singly tagged $\bar{D}^0$ mesons. Based on 70 727±278 $D^0\to K^-e^+\nu_e$ and 6297±87 and $D^0\to\pi^-e^+\nu_e$ signals, we determine the branching fractions

$$\mathscr{B}(D^0\to K^-e^+\nu_e) = (3.505\pm0.014_{\rm stat.}\pm0.033_{\rm sys.})\%$$

and

$$\mathscr{B}(D^0\to\pi^-e^+\nu_e) = (0.2950\pm0.0041_{\rm stat.}\pm0.0026_{\rm sys.})\%,$$

respectively. The branching fractions measured at BESIII are consistent within errors with previous measurements, but with the best precision. Fig. 2 shows the fits to the partial widths for $D^0\to K^-e^+\nu_e$ and $D^0\to\pi^-e^+\nu_e$ using the Simple Pole model[9], the Modified Pole model[9], the two-parameter series expansion (Series. 2. Par.)[10] and the three-parameter series expansion (Series. 3. Par.)[10]. From the fits, we obtain the parameters of different models. With the extracted $f_+^{K(\pi)}(0)|V_{cs(d)}|$ based on two-parameter series expansion and the expected $f_+^{K(\pi)}(0)$ by LQCD[11-12], we determine the quark mixing matrix elements $|V_{cs(d)}|$. Fig. 3 compares the $|V_{cs(d)}|$ extracted at BESIII with the ones from different experiments.

To study the semileptonic decays $D^+\to K_L^0e^+\nu_e$, $D^+\to K^-\pi^+e^+\nu_e$ and $D^+\to\omega(\phi)e^+\nu_e$, we use 6 hadronic decays of $K^+\pi^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $K_S^0\pi^-$, $K_S^0\pi^-\pi^0$, $K_S^0\pi^+\pi^-\pi^-$ and $K^+K^-\pi^-$. With about 24 thousands of $D^+\to K_L^0e^+\nu_e$ signals[13], we make

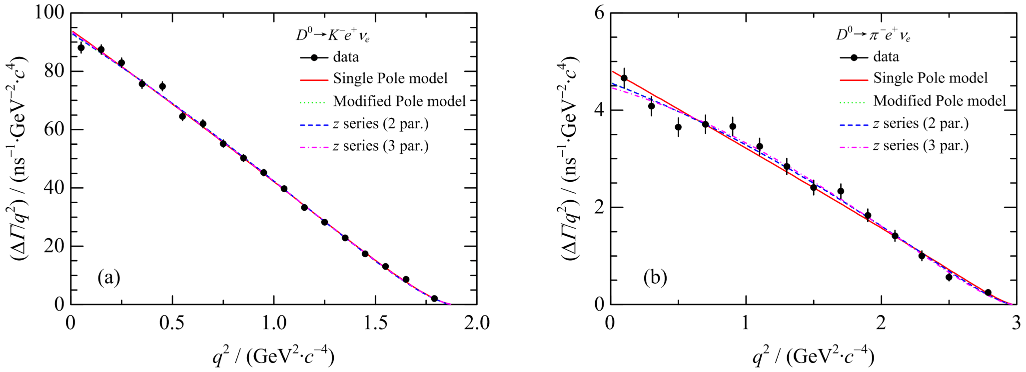


**Fig. 2** Fits to the partial widths of (a) $D^0\to K^-e^+\nu_e$ and (b) $D^0\to\pi^-e^+\nu_e$

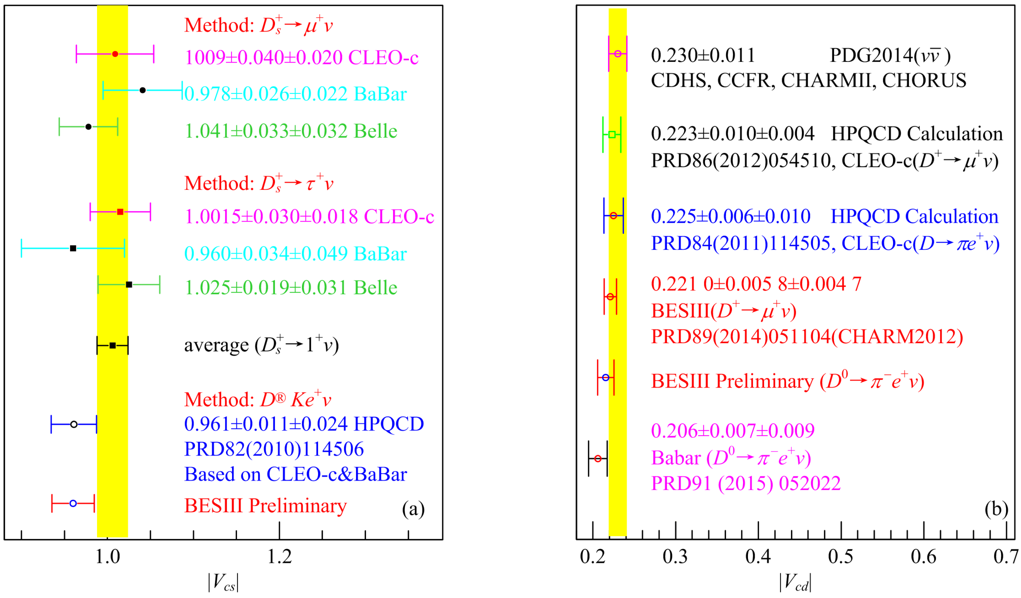


**Fig. 3 Comparison of the extracted (a) $|V_{cs}|$ and (b) $|V_{cd}|$ based on different experiments**

first measurement of the branching fraction

$$\mathscr{B}(D^+\to K_L^0 e^+\nu_e) = (4.482\pm0.027_{\text{stat.}}\pm0.103_{\text{sys.}})\%$$

and the CP asymmetry

$$A_{\text{CP}}^{D^+\to K_L^0 e^+\nu_e} = (-0.59\pm0.60_{\text{stat.}}\pm1.50_{\text{sys.}})\%,$$

supporting that there is no CP asymmetry in this decay. In addition, we perform simultaneous fit to the event density $I(q^2)$ for different tag modes with the two-parameter series expansion and obtain the product of

$$f_+^K(0)\,|V_{cs}| = 0.728\pm0.006_{\text{stat.}}\pm0.011_{\text{sys.}}.$$

Using 18 262 $D^+\to K^-\pi^+e^+\nu_e$ candidates[14] which is almost background free, we determine the branching fraction

$$\mathscr{B}(D^+\to K^-\pi^+e^+\nu_e) = (3.71\pm0.03\pm0.08)\%.$$

A partial wave analysis (PWA) is performed on the selected candidates, with results shown in Fig. 4. The PWA results show that the dominant $\bar{K}^{*0}$ component is accompanied by an $S$-wave

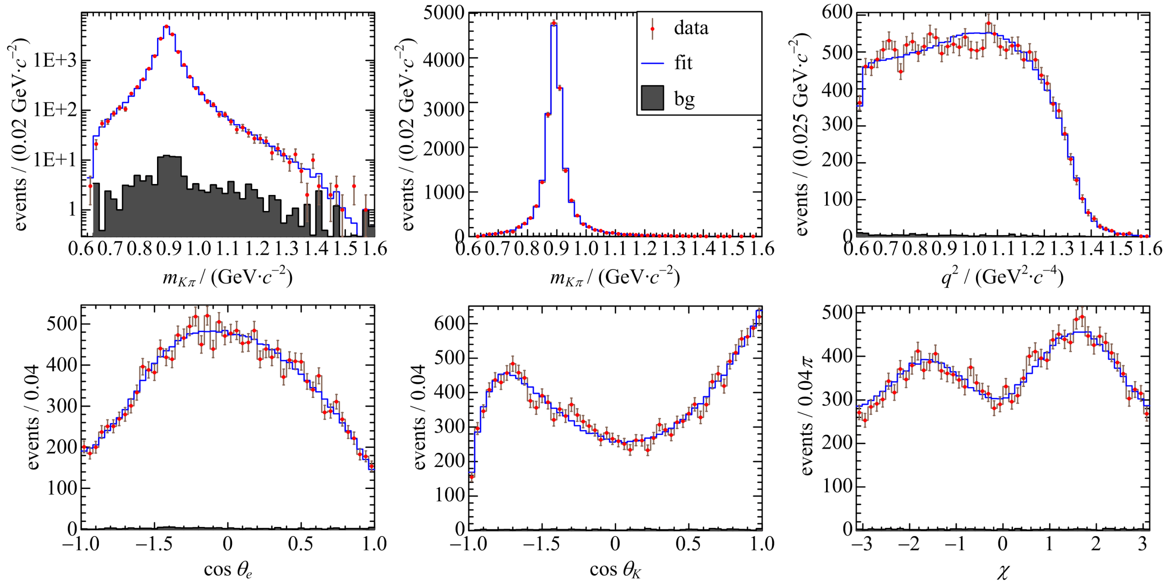


**Fig. 4 Projections of the kinematic variables of PWA for $D^+\to K^-\pi^+e^+\nu_e$, where $m_{K\pi}$ is the $K\pi$ mass, $q^2$ is the $e\nu_e$ mass square, $\theta_K$ is the angle between $\pi$ and $D$ momenta in the $K\pi$ rest frame, $\theta_e$ is the angle between $\nu_e$ and $D$ momenta in the $e\nu_e$ rest frame and $\chi$ 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**

contribution accounting for $(6.05\pm0.22\pm0.18)\%$ of the total rate, and other components can be negligible. We obtain the mass and width of $\overline{K}^{*0}(892)$ $M_{\overline{K}^{*0}(892)}=(894.60\pm0.25\pm0.08)$ MeV/$c^2$ and $\Gamma_{\overline{K}^{*0}(892)}=(46.42\pm0.56\pm0.15)$ MeV/$c^2$, the Blatt-Weisskopf parameter $r_{\mathrm{BW}}=3.07\pm0.26\pm0.11\ (\mathrm{GeV}/c)^{-1}$, as well as the parameters of the hadronic form factors $r_V=\frac{V(0)}{A_1(0)}=1.411\pm0.058\pm0.007$, $r_2=\frac{A_2(0)}{A_1(0)}=0.788\pm0.042\pm0.008$, $m_V=(1.81^{+0.25}_{-0.17}\pm0.02)$ MeV/$c^2$, $m_A=(2.61^{+0.22}_{-0.17}\pm0.03)$ MeV/$c^2$, $A_1(0)=0.585\pm0.011\pm0.017$. In the above 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[15-17]. 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.

Based on $491\pm32$ $D^+\to\omega e^+\nu_e$ signals[18], we determine the branching fraction $\mathscr{B}(D^+\to\omega e^+\nu_e)=(1.63\pm0.11_{\mathrm{stat.}}\pm0.08_{\mathrm{sys.}})\times10^{-3}$, which is consistent with previous measurements but with better precision. We perform amplitude analysis of $D^+\to\omega e^+\nu_e$ for the first time, and obtain the ratios of the hadronic form factors to be $r_V=\frac{V(0)}{A_1(0)}=1.24\pm0.09_{\mathrm{stat.}}\pm0.06_{\mathrm{sys.}}$ and $r_2=\frac{A_2(0)}{A_1(0)}=1.05\pm0.15_{\mathrm{stat.}}\pm0.05_{\mathrm{sys.}}$. Also, we search for $D^+\to\phi e^+\nu_e$, but do not find obvious signal. So, we set the upper limit on the branching fraction for $D^+\to\phi e^+\nu_e$ to be $1.3\times10^{-5}$ at 90% confidence level, which is significantly better than previous searches.

## 2 *D* hadronic decays

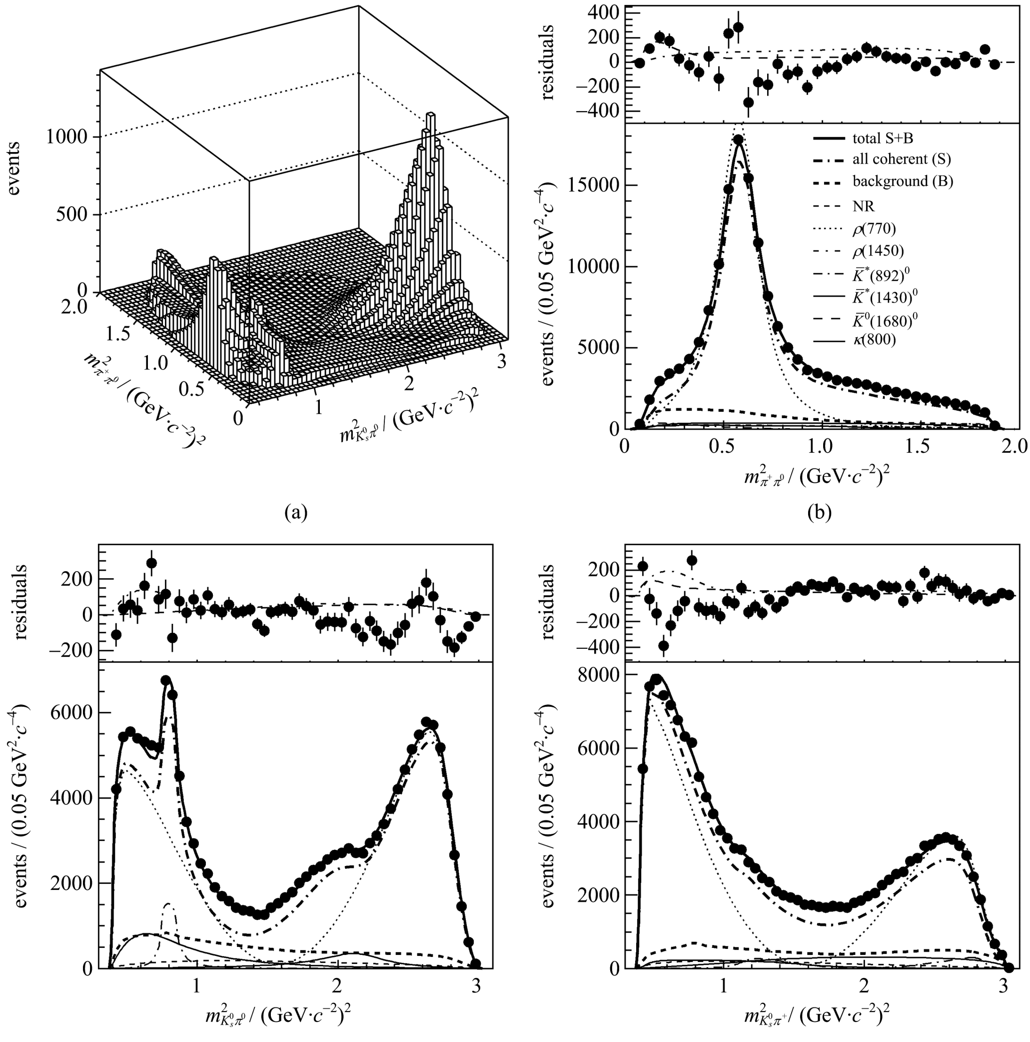
We perform Dalitz plot analysis on the 3-body decay $D^+\to K_S^0\pi^+\pi^0$[19]. Based on 166 694 candidate events with a background of about 15%, we fit the distribution of data to a coherent sum of six intermediate resonances plus a nonresonant component with a low mass scalar resonance $\bar{\kappa}$ included, with results shown in Fig. 5. From the analysis, we obtain the fitted fraction for each component.

Combining the fitted fractions and the world averaged branching fraction for $D^+\to K_S^0\pi^+\pi^0$ $(6.99\pm0.27)\%$[20], we obtain the partial branching fractions as summarized in Tab. 1.

**Tab. 1 Summary of the partial branching fractions, where the uncertainties are statistical, experimental systematic and modeling systematic, respectively**

| $D^+\to$ | partial $\mathscr{B}(\%)$ |
|---|---|
| $K_S^0\pi^+\pi^0$ nonresonance | $0.32\pm0.05\pm0.25^{+0.28}_{-0.25}$ |
| $\rho^+K_S^0, \rho^+\to\pi^+\pi^0$ | $5.83\pm0.16\pm0.30^{+0.45}_{-0.15}$ |
| $\rho(1450)^+K_S^0, \rho(1450)^+\to\pi^+\pi^0$ | $0.15\pm0.02\pm0.09^{+0.07}_{-0.11}$ |
| $\overline{K}^*(892)^0\pi^+, \overline{K}^*(892)^0\to K_S^0\pi^0$ | $0.250\pm0.012\pm0.015^{+0.025}_{-0.024}$ |
| $\overline{K}_0^*(1430)^0\pi^+, \overline{K}_0^*(1430)^0\to K_S^0\pi^0$ | $0.26\pm0.04\pm0.05\pm0.06$ |
| $\overline{K}^*(1680)^0\pi^+, \overline{K}^*(1680)^0\to K_S^0\pi^0$ | $0.09\pm0.01\pm0.05^{+0.04}_{-0.08}$ |
| $\bar{\kappa}^0\pi^+, \bar{\kappa}^0\to K_S^0\pi^0$ | $0.54\pm0.09\pm0.28^{+0.36}_{-0.19}$ |
| $NR+\bar{\kappa}^0\pi^+$ | $1.30\pm0.12\pm0.12^{+0.12}_{-0.30}$ |
| $K_S^0\pi^0$ $S$-ware | $1.21\pm0.10\pm0.16^{+0.19}_{-0.27}$ |

At present, among the 3 angles of CKM triangle, $\alpha/\phi_2$, $\beta/\phi_1$ and $\gamma/\phi_3$, the $\gamma/\phi_3$ is the least precisely measured. The $\gamma/\phi_3$ can be constrained by the phase differences $c_i$ and $s_i$ of $D^0$ and $\overline{D}^0$. Here, $c_i$ and $s_i$ denote the weighted average of $\cos\Delta\delta_D$ and $\sin\Delta\delta_D$, where $\Delta\delta_D$ is the phase difference of $D^0$ and $\overline{D}^0$. We perform binned Dalitz plot analysis of $D^0\to K_{S/L}^0\pi^+\pi^-$ by using the flavored tags $K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$, the CP even tags $K^+K^-$, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$ and $K_L^0\pi^0$, as well as the CP odd tags $K_S^0\pi^0$, $K_S^0\eta(\gamma\gamma)$, $K_S^0\eta(\pi^+\pi^-\pi^0)$, $K_S^0\omega(\pi^+\pi^-\pi^0)$ and $K_S^0\eta'$[21]. The extracted $c_i$ and $s_i$ with only statistical uncertainties are compared to the CLEO measurement[22-23] and the model prediction in Fig. 6. Our results represent a significant statistical improvement over previous measurements, which will allow for increased precision in the measurement of the unitarity triangle $\gamma/\phi_3$ using the decay $B^\pm\to D(K_S^0\pi^+\pi^-)K^\pm$ through the GGSZ method[24].



(a)　(b)

(c)　(d)

**Fig. 5　The results of fitting the $D^+\to K_S^0\pi^+\pi^0$ data (a). Distribution of fitted p. d. f. and projections on (b) $m^2_{\pi^+\pi^0}$, (c) $m^2_{K_S^0\pi^0}$ and (d) $m^2_{K_S^0\pi^+}$. Residual between the data and total p. d. f are shown by dots with statistical error bars in the top insets with minor contributions from $\rho(1450)^+$ and $\overline{K}^*(1680)^0$**

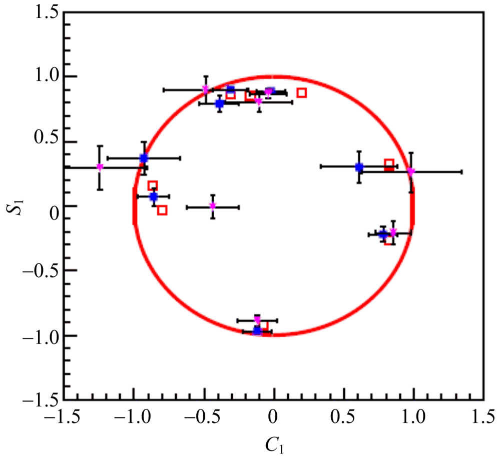


**Fig. 6　The extracted $s_i$ versus $c_i$ from $D\to K^0_{S/L}\pi^+\pi^-$. The blue dot, pink triangle and red rectangle represent BESIII, CLEO and model prediction, respectively**

We determine the $D^0\overline{D}^0$ mixing parameter $y_{CP}=(-2.1\pm1.3_{\text{stat.}}\pm0.7_{\text{sys.}})\%$, by analysis of $D^0\to K^- l^+\nu_l\,(l=e$ and $\mu)$ using the CP even tags $K^+K^-$, $\pi^+\pi^-$ and $K_S^0\pi^0\pi^0$, and the CP odd tags $K_S^0\pi^0$, $K_S^0\eta$ and $K_S^0\omega$[25]. This result is compatible with the previous measurement with about two standard deviations. However, the precision is still statistically limited and less precise than the current world average.

Measurement of the strong phase difference between $D^0$ and $\overline{D}^0$ is important to relate to the $D^0\overline{D}^0$ mixing parameters $x$ and $y$ from $x'$ and $y'$. We measure the $D\to K^-\pi^+$ strong phase difference based on analysis of $D^0\to K^-\pi^+$ and $K^+\pi^-$ using the CP even tags $K^+K^-$, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$, $\pi^0\pi^0$ and $\rho^0\pi^0$, and the CP odd tags $K_S^0\pi^0$, $K_S^0\eta$ and $K_S^0\omega$[26]. We determine the asymmetry of $\mathcal{A}_{K\pi}^{CP}$ of the branching fraction of $D\to K^-\pi^+$ in CP-odd and CP-even eigensates to be $(12.7\pm1.3\pm0.7)\%$. With external inputs of $r^2=(3.50\pm0.04)\times10^{-3}$, $y=(6.7\pm0.9)\times10^{-3}$ from HFAG[27] and $R_{WS}=(3.80\pm0.05)\times10^{-3}$ from PDG[20]. The $\cos\delta_{K\pi}$ is determined to be $1.02\pm0.11_{\text{stat.}}\pm0.06_{\text{sys.}}\pm0.01_{\text{input}}$.

It is expected that $\mathcal{B}(D^{0(+)}\to\omega\pi^{0(+)})$ is at $10^{-4}$ level[28]. CLEO searched for and did not observe the $D^0\to\omega\pi^0$ and $D^+\to\omega\pi^+$ signals using single tag method[29]. They set the upper limits on these two decay branching fractions to be $2.6\times10^{-4}$ and $3.4\times10^{-4}$ at 90% confidence level, respectively. We search for $D^0\to\omega\pi^0$ and $D^+\to\omega\pi^+$ by using double tag method[30] with the fitted $\pi^+\pi^-\pi^0$ invariant mass spectra shown in Fig. 7. The significance of the $D^0\to\omega\pi^0$ and $D^+\to\omega\pi^+$ signals are $4.1\sigma$ and $5.4\sigma$, respectively. These two branching fractions are determined to be $\mathcal{B}(D^0\to\omega\pi^0)=(1.05\pm0.41_{\text{stat.}}\pm0.09_{\text{sys.}})\times10^{-4}$ and $\mathcal{B}(D^+\to\omega\pi^+)=(2.74\pm0.58_{\text{stat.}}\pm0.17_{\text{sys.}})\times10^{-4}$. Also, we confirm that the $\omega$ helicity angle of the $D^{0(+)}\to\omega\pi^{0(+)}$ candidates follow the expected $H_\omega^2=\cos^2\theta_{\text{helicity}}$ formalism.

## 3 D rare decays

Search for the FCNC and LNV rare decays of charmed mesons can shed some lights on New Physics beyond the SM. At BESIII, we have searched for the rare decays of $D^0\to\gamma\gamma$[31] and $D^+\to K(\pi)^\pm e^\mp e^+$[32] with double and single tag methods, respectively. No significant signals are observed, thus we set the upper limits of their branching fractions to be $\mathcal{B}(D^0\to\gamma\gamma)<3.8\times10^{-6}$, $\mathcal{B}(D^+\to K^+e^+e^-)<1.2\times10^{-6}$, $\mathcal{B}(D^+\to K^-e^+e^+)<0.6\times10^{-6}$, $\mathcal{B}(D^+\to K^+e^+e^-)<0.3\times10^{-6}$, $\mathcal{B}(D^+\to K^-e^+e^+)<1.2\times10^{-6}$ at 90% confidence level. Some of them are improved compared to previous measurements.

## 4 $\Lambda_c^+$ decays

The $\Lambda_c^+$ was observed in $e^+e^-$ annihilation at Mark II in 1979[33]. Thereafter, many works have been done to study the $\Lambda_c^+$ decay properties. However, the knowledge of $\Lambda_c^+$ physics are still very poor[5]. The sum of the branching fractions of the known $\Lambda_c^+$ decays is not more than 60% and their uncertainties are large. So, significantly improved measurements of these decay branching fractions are important to comprehensively understand the $\Lambda_c^+$ decay properties. By analyzing 567 $\text{pb}^{-1}$ data taken at 4.559 GeV with the BESIII detector, we study 12 hadronic decays of $\Lambda_c^+$, which are $\Lambda_c^+\to pK_S^0$, $pK^-\pi^+$, $pK_S^0\pi^0$, $pK_S^0\pi^+\pi^-$, $\Lambda\pi^+$, $\Lambda\pi^+\pi^0$, $\Lambda\pi^+\pi^+\pi^-$, $pK^-\pi^+\pi^0$, $\Sigma^0\pi^+$,

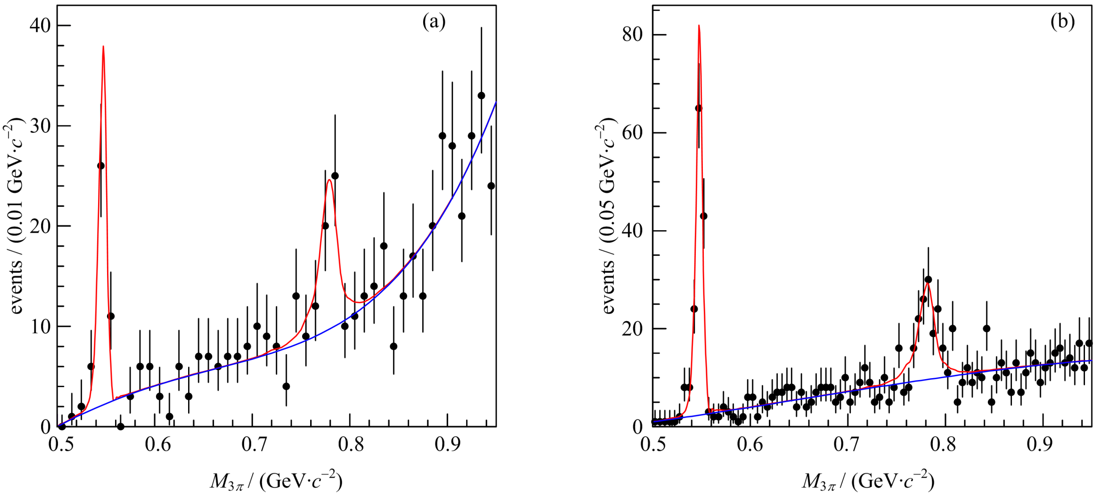


**Fig. 7 Fits to the $\pi^+\pi^-\pi^0$ invariant mass spectra of the selected (a) $D^0\to\omega\pi^0$ and (b) $D^+\to\omega\pi^+$. The blue hatched histograms are the sideband background events**

$\Sigma^+\pi^0$，$\Sigma^+\pi^+\pi^-$ and $\Sigma^+\omega$[34]. Fig. 8 shows the fits to the $M_{\mathrm{BC}}$ spectra of the accepted single tag candidates. From these，we obtain about 15 thousand of the singly tagged $\Lambda_c^+$ baryons.

At the recoil systems of the singly tagged $\Lambda_c^+$ baryons，we select the candidates for the doubly tagged $\Lambda_c^+\bar{\Lambda}_c^-$ baryon pairs. Fig. 9 shows the fits to the $M_{\mathrm{BC}}$ spectra of the accepted candidates. From these，we obtain about one thousand of the doubly tagged $\Lambda_c^+\bar{\Lambda}_c^-$ baryon pairs.

By combining the singly tagged $\Lambda_c^+$ baryons and the doubly tagged $\Lambda_c^+\bar{\Lambda}_c^-$ baryon pairs，we determine the absolute branching fractions of these twelve decays，which are

$\mathscr{B}(\Lambda_c^+\to pK_S^0)=(1.48\pm0.08)\%$，
$\mathscr{B}(\Lambda_c^+\to pK^-\pi^+)=(5.77\pm0.27)\%$，
$\mathscr{B}(\Lambda_c^+\to pK_S^0\pi^0)=(1.77\pm0.12)\%$，
$\mathscr{B}(\Lambda_c^+\to pK_S^0\pi^+\pi^-)=(1.43\pm0.10)\%$，
$\mathscr{B}(\Lambda_c^+\to pK^-\pi^+\pi^0)=(4.25\pm0.10)\%$，
$\mathscr{B}(\Lambda_c^+\to \Lambda\pi^+)=(1.20\pm0.67)\%$，
$\mathscr{B}(\Lambda_c^+\to \Lambda\pi^+\pi^0)=(6.70\pm0.35)\%$，
$\mathscr{B}(\Lambda_c^+\to \Lambda\pi^+\pi^+\pi^-)=(3.67\pm0.23)\%$，
$\mathscr{B}(\Lambda_c^+\to \Sigma^0\pi^+)=(1.28\pm0.68)\%$，
$\mathscr{B}(\Lambda_c^+\to \Sigma^+\pi^0)=(1.18\pm0.11)\%$，
$\mathscr{B}(\Lambda_c^+\to \Sigma^+\pi^+\pi^-)=(3.58\pm0.22)\%$，
$\mathscr{B}(\Lambda_c^+\to \Sigma^+\omega)=(1.47\pm0.18)\%$，

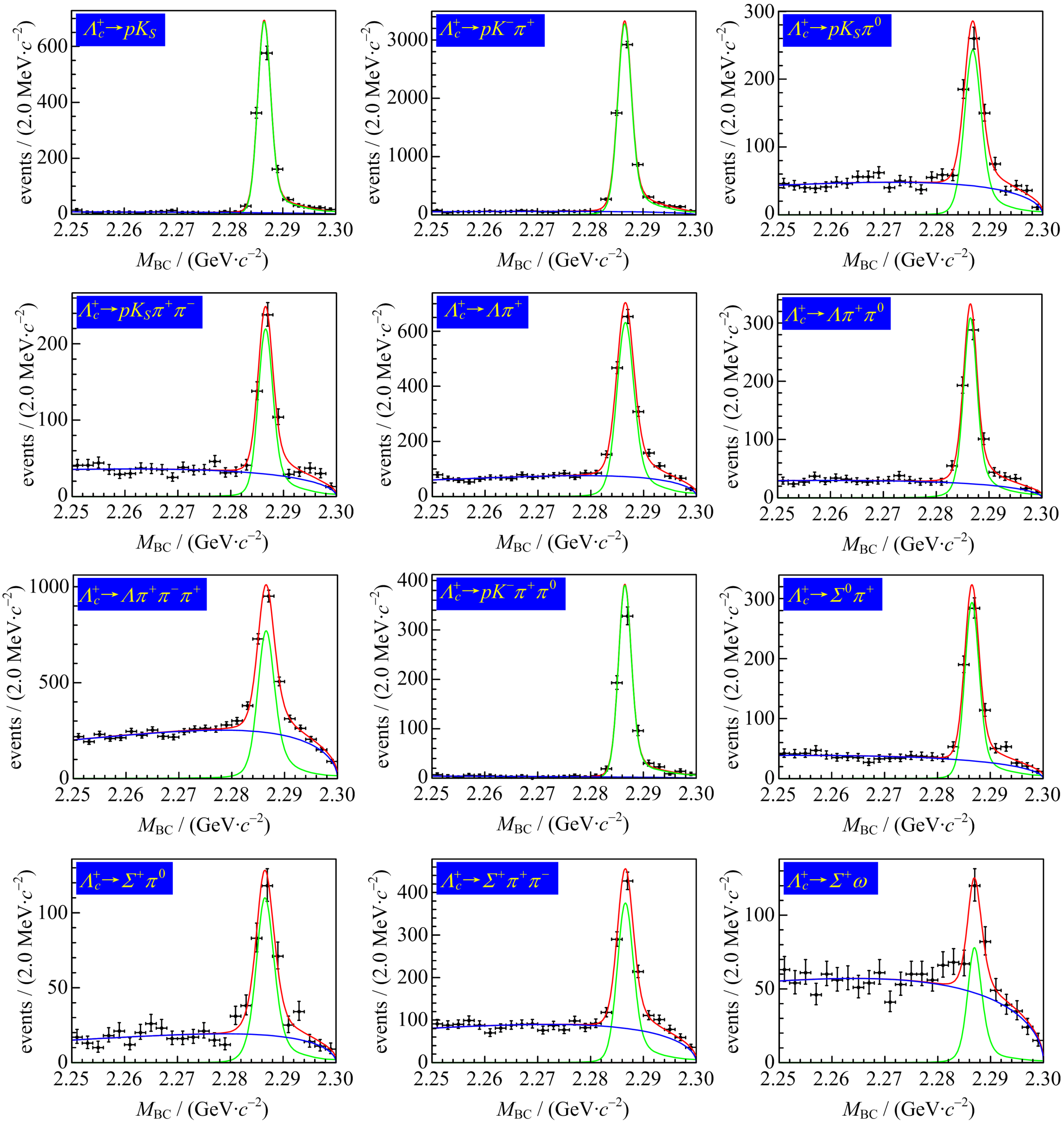


**Fig. 8** Fits to the $M_{\mathrm{BC}}$ spectra of singly tagged $\Lambda_c^+$ candidate events

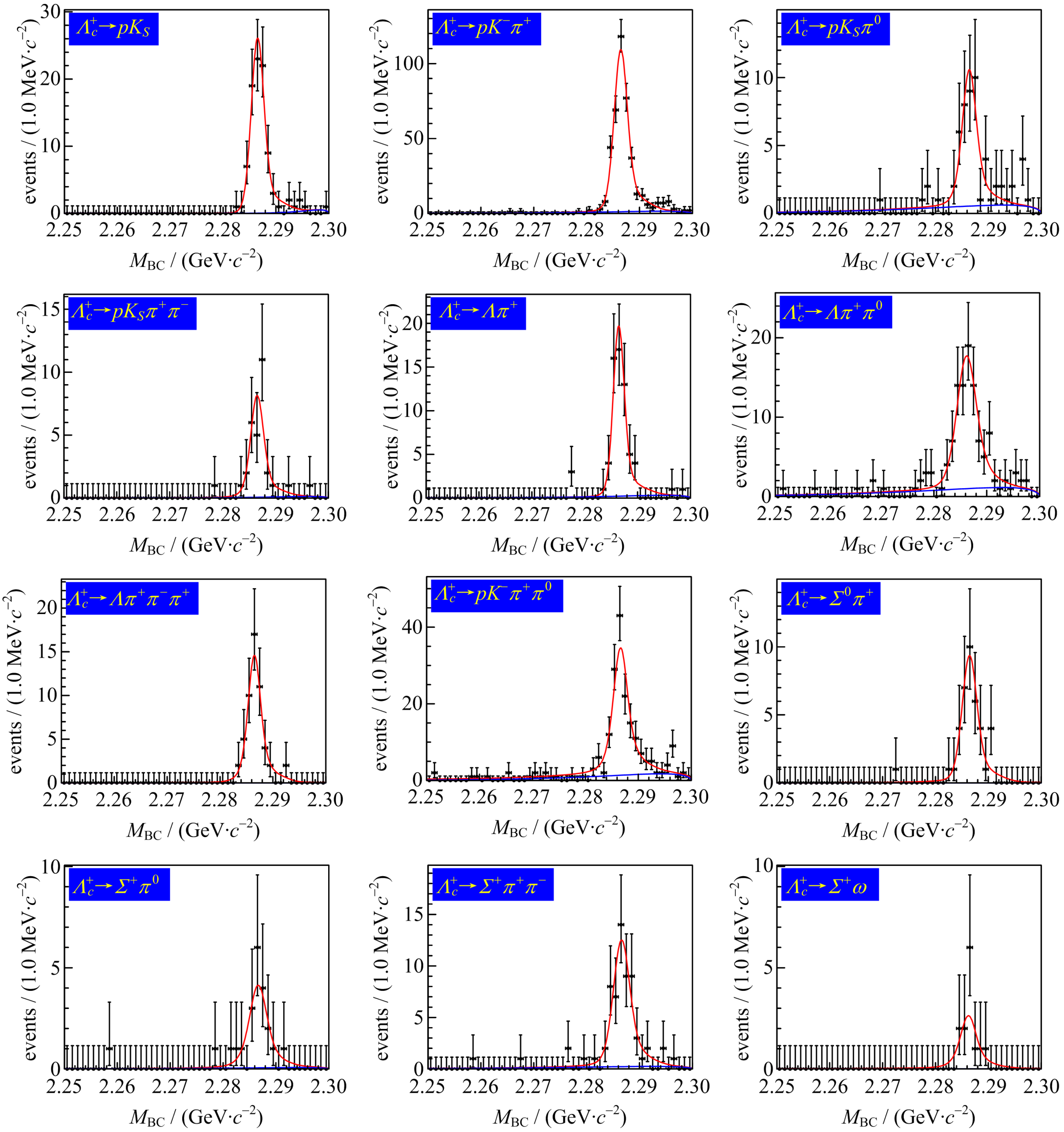


**Fig. 9**　Fits to the $M_{\mathrm{BC}}$ spectra of doubly tagged $\Lambda_c^+$ candidate events

where the uncertainties are only statistical. These results are more precise than the PDG values[5]. The $\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)$ measured in this wok and the one measured at BELLE[35] will calibrate other decay rates of $\Lambda_c^+$ with much better precision.

We also perform the first absolute measurement of the semileptonic decay of $\Lambda_c^+\to\Lambda e^+\nu_e$[36]. The $U_{\mathrm{miss}}$ distribution of the selected candidates is shown in Fig. 10. After subtracting background，we obtain 103.5±10.9 signal events of $\Lambda_c^+\to\Lambda e^+\nu_e$. This leads to the absolute branching fraction to be $\mathcal{B}(\Lambda_c^+\to\Lambda e^+\nu_e)=(3.63\pm0.38\pm0.20)\%$. This work improves the precision of the world average value[5] more than two fold. As the theoretical predictions on this rate vary in a

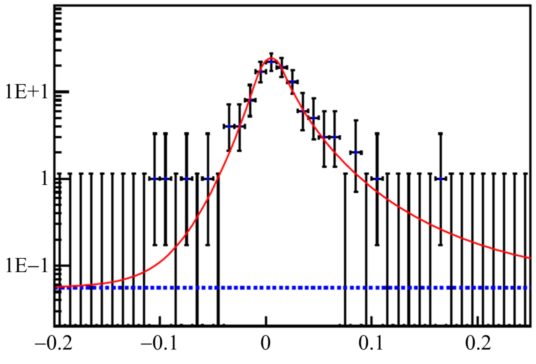


**Fig. 10**　$U_{\mathrm{miss}}$ distribution of the selected $\Lambda_c^+\to\Lambda e^+\nu_e$ candidates

large range of (1.4～9.2)%, this measurement provides a stringent test on these models.

## 5 Conclusion

By analyzing 2.93 and 0.567 fb$^{-1}$ data taken at $\sqrt{s}=3.773$ and 4.599 GeV with the BESIII detector, we report the precise measurements of the decay constant $f_{D^+}$, the form factors of $D$ semileptonic decays, the Dalitz plot analysis of $D^+\to K_S^0\pi^+\pi^0$, the strong phase differences in $D\to K_{S/L}^0\pi^+\pi^-$ and $K^-\pi^+$, the $D^0\overline{D}^0$ mixing parameter $y_{CP}$, the searches for 2-body hadronic decays $D^{0(+)}\to\omega\pi^{0(+)}$, rare decays of $D^0\to\gamma\gamma$ and $D^+\to K(\pi)^{\pm}e^{\mp}e^+$ as well as the significant improved measurements of the absolute branching fractions for $\Lambda_c^+\to\Lambda e^+\nu_e$ and 12 hadronic final states. These are important to test the LQCD calculations on $f_{D^+}$ and the form factors of $D$ semileptonic decays, to test the CKM matrix unitarity, to search for New Physics beyond the SM, and to comprehensively understand the $\Lambda_c^+$ decay property. In 2016, BESIII will collect 3 fb$^{-1}$ data at 4.18 GeV. More interesting physics based on charmed mesons and charmed baryons will hopefully be achieved at BESIII in the near future.

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