CHARM PHYSICS AT BESIII

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Published 18 December 2014

We present a selection of recent charm results from the BESIII Collaboration. The topics include measurements of strong phase in $D^0 \rightarrow K\pi$ decay and y_{CP} , decay constant f_{D^+} measurement from $D^+ \rightarrow \mu^+\nu$, form-factors measurement in $D^0 \rightarrow K^-e^+\nu, \pi^-e^+\nu$, Dalitz plot analysis of $D^+ \rightarrow K_S^0\pi^+\pi^0$, search for $D^0 \rightarrow \gamma\gamma$ rare decay and D_s decays.

Keywords: Charmed mesons; leptonic decays; semileptonic decays; hadronic decays.

PACS Numbers: 14.40.Lb, 13.20.Fc, 13.25.Ft

1. Introduction

BESIII has a sample of 2.9 fb^{-1} of $\psi(3770)$ data and 482 pb^{-1} of $\psi(4040)$ data; these resonances dominantly decay to $D^0\bar{D}^0/D^+D^-$ and $D_s^+D_s^-$ pairs, respectively. Since there is no other accompanying particles, the signals are very clean and pure. At the peak, the total $D\bar{D}$ cross-section is about 6.6 nb, while the $D_s^+D_s^-$ cross-section is about 269 pb.

The general technique used for charm physics studies near the $D_{(s)}D_{(s)}$ production threshold is referred as tagging, which means we fully reconstruct one of the $D_{(s)}$ meson and investigate the recoiling side for interest.

In this talk, we will present the highlights from the resent BESIII charm results.

2. Highlights from BESIII

2.1. Measurements of strong phase in $D^0 \rightarrow K\pi$ decay and y_{CP}

We study the process of $D^0\bar{D}^0$ pair production based on 2.9 fb^{-1} $\psi(3770)$ data, and measure the asymmetry $\mathcal{A}_{CP \rightarrow K\pi}$ of the branching fractions of $D^{CP\pm} \rightarrow$

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$K^-\pi^+$ ($D^{CP\pm}$ are the CP -odd and CP -even eigenstates) to be

$$\mathcal{A}_{CP\rightarrow K\pi} = (12.77 \pm 1.31^{+0.33}_{-0.31})\%.$$

Using the quantum-correlated technique, $\mathcal{A}_{CP\rightarrow K\pi}$ can be calculated and help to extract the strong phase difference $\delta_{K\pi}$ between the doubly Cabibbo-suppressed process $\bar{D}^0 \rightarrow K^-\pi^+$ and Cabibbo-favored $D^0 \rightarrow K^-\pi^+$. By taking inputs of other mixing parameters in world-average measurements,¹ we obtain

$$\cos \delta_{K\pi} = 1.03 \pm 0.12 \text{ (stat.)} \pm 0.04 \text{ (syst.)} \pm 0.01 \text{ (ext.)}.$$

This is the world-most accurate result to date, and can improve the world constraints on the mixing parameters and on the γ/ϕ_3 in the CKM matrix.

We have also measured $D^0\bar{D}^0$ mixing parameter y_{CP} using the quantum-correlated technique as well. Here the doubly tagged $\psi(3770) \rightarrow D^0\bar{D}^0$ events, with one D decays to CP eigenstates and the other D decays semileptonically, are used to reconstruct the signals. We get the preliminary result of y_{CP} :

$$y_{CP} = -1.6\% \pm 1.3\% \text{ (stat.)} \pm 0.6\% \text{ (syst.)}.$$

The result is compatible with the previous measurements² and is the most precise measurement of y_{CP} based on $D^0\bar{D}^0$ threshold productions. However, the precision is still statistically limited. In the future, the results can be improved by exploiting global fits method.³

2.2. Precision measurements of $\mathcal{B}(D^+ \rightarrow \mu^+\nu_\mu)$ and the decay constant f_{D^+}

We now present BESIII's precise measurement of the pseudoscalar decay constant f_{D^+} from the decay $D^+ \rightarrow \mu\nu$.⁴ After singly tagged nine D^+ decay modes: $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^+\pi^-$, $K_S^0\pi^+$, $K_S^0\pi^+\pi^+\pi^-$, $K_S^0K^+$, $K^+K^-\pi^+$ and $\pi^+\pi^+\pi^-$, we search for signal via $MM^2 = E_{miss}^2 - p_{miss}^2$, where the missing four-momentum is obtained by subtracting the D tag and signal μ momenta from the known initial-state four-vector. Then we get the branching fractions

$$\mathcal{B}(D^+ \rightarrow \mu^+\nu_\mu) = [3.71 \pm 0.19 \text{ (stat.)} \pm 0.06 \text{ (sys.)}] \times 10^{-4}.$$

This measurement, in conjunction with the CKM matrix element $|V_{cd}|$ value¹ determined from a global Standard Model fit, implies a value for the pseudoscalar decay constant

$$f_{D^+} = (203.4 \pm 5.2 \pm 1.9) \text{ MeV}.$$

Or alternatively, using this branching fraction measurement together with a Lattice QCD prediction for f_{D^+} ,⁵ gives

$$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047.$$

In both cases, they are the most precise results for these quantities to date.

2.3. Form-factors measurement in $D^0 \rightarrow K^- e^+ \nu, \pi^- e^+ \nu$

BESIII has determined the form-factors $f_{\pi, K}(q^2)$ from the semileptonic decays $D^0 \rightarrow K^- e^+ \nu, \pi^- e^+ \nu$.⁶ The four tag modes $K^- \pi^+$, $K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^+ \pi^-$, and $K^- \pi^+ \pi^0 \pi^0$ are used. Our final signal variable is $U = E_{miss} - p_{miss}$; the "miss" quantities representing the unobserved neutrino. For signal U peaks at zero and is similar to a missing-mass-squared. Fits to the U distribution lead to the branching fraction results shown in Table 1.

For the form-factor analysis, we divide the data into bins of q^2 to determine values to $d\Gamma/dq^2$ integrated over these bins. Numerical values of our form factor fit results are given in Table 2 for the three-parameter version of the popular series expansion⁷ prescription for parameterizing the form factor.

In the talk, the results were obtained with about one-third of the full 2.9 fb^{-1} data set; an update using the full data sample is expected soon.

Table 1. Preliminary BESIII branching fractions and PDG 2012 world averages.

Mode	BESIII BF (%)	PDG BF (%)
$D^0 \rightarrow K^- e^+ \nu$	$3.542 \pm 0.030 \pm 0.067$	3.55 ± 0.04
$D^0 \rightarrow \pi^- e^+ \nu$	$0.288 \pm 0.008 \pm 0.005$	0.289 ± 0.008

Table 2. Preliminary BESIII form-factor results. For brevity, only results from the three-parameter series fit are shown.

Mode	$f_+(0) V_{cs(d)} $	r_1	r_2
$D^0 \rightarrow K^- e^+ \nu$	$0.729 \pm 0.008 \pm 0.007$	$-2.179 \pm 0.355 \pm 0.053$	$4.359 \pm 8.927 \pm 1.103$
$D^0 \rightarrow \pi^- e^+ \nu$	$0.144 \pm 0.005 \pm 0.002$	$-2.728 \pm 0.482 \pm 0.076$	$4.194 \pm 3.122 \pm 0.448$

2.4. Dalitz plot analysis of $D^+ \rightarrow K_S^0 \pi^+ \pi^0$

We perform an analysis of the $D^+ \rightarrow K_S^0 \pi^+ \pi^0$ Dalitz plot using 2.9 fb^{-1} $\psi(3770)$ data, in which 166694 candidate events are selected with a background at the level of 15.1%. The Dalitz plot turns out to be well-represented by a combination of six quasi-two-body decay channels ($K_S^0 \rho^+$, $K_S^0 \rho(1450)^+$, $\bar{K}^{*0}$, $\bar{K}_0(1430)^0 \pi^+$, $\bar{K}(1680)^0 \pi^+$, $\bar{\kappa}^0 \pi^+$) plus a small non-resonant components. A model-independent approach has also been considered to confirm an obvious phase shift for the $\bar{\kappa} \pi$ component (shown in Fig. 1). Using the fit fractions from this analysis, partial branching ratios are updated with higher precision than previous measurements.

2.5. Search for $D^0 \rightarrow \gamma \gamma$

Based on the 2.9 fb^{-1} data set taken at $\sqrt{s} = 3.773 \text{ GeV}$, we search for the D^0 rare decay $D^0 \rightarrow \gamma \gamma$. We find no significant signal and set our preliminary upper

Fig. 1. The results of fitting the $D^+ \rightarrow K_S^0 \pi^+ \pi^0$ data with final chosen resonances. (a) Distribution of fitted p.d.f. and projections on (b) $m_{\pi^+ \pi^0}^2$, (c) $m_{K_S^0 \pi^0}^2$ and (d) $m_{K_S^0 \pi^+}^2$. Residuals between data and the total p.d.f. are shown by dots with statistical error bars on the top insets.

limit on

$$B(D^0 \rightarrow \gamma\gamma)/B(D^0 \rightarrow \pi^0 \pi^0) < 5.8 \times 10^{-3}$$

at 90% C.L.. With the known value of $B(D^0 \rightarrow \pi^0 \pi^0)$,¹ this corresponds to $B(D^0 \rightarrow \gamma\gamma) < 4.7 \times 10^{-6}$.

When we are waiting for BESIII to take more data at $\sqrt{s} = 3.773$ GeV, there is an alternate analysis approach that is unique to our data sample. As being mentioned before, the produced $\psi(3770)$ in our sample decays into a pair of $D^0 \bar{D}^0$ mesons. Using the double-tag method, that is reconstruct one of the D^0 mesons with known exclusive modes and look for $D^0 \rightarrow \gamma\gamma$ in the other $\bar{D}^0$ decay, would yield an almost background-free environment, except for the irreducible contamination from $D^0 \rightarrow \pi^0 \pi^0$ for which we have control. Such a study is ongoing currently.

2.6. D_s decays

BESIII has collected $482 \text{ pb}^{-1} e^+e^-$ collision data at 4.009 GeV. At this energy point, the D_s mesons are produced in pair. Compared to the former largest D_s data set (i.e., CLEO-c's $D_s^* D_s$ data taken at 4.17 GeV), we can benefit from the much lower background level as there is no radiative photon in the final states.

Fig. 2. m_{bc} distributions for the singly tagged D_s mesons. Left: $D_s \rightarrow KK\pi$. Right: $D_s \rightarrow K_s^0 K$.

Exploiting the tagging technique, we can tag the D_s meson cleanly. Fig. 2 shows a good example. However, statistics is limited at this energy point as the $D_s D_s$ cross section at 4.009 GeV is only about one-third to $D_s^* D_s$'s at 4.17 GeV. There are several ongoing analysis about D_s physics at BESIII. Results will be coming soon in the near future.

3. Summary

Since the start of running in 2008, BESIII has taken about 2.9 fb^{-1} of data at $\psi(3770)$ and 482 pb^{-1} of data at $\psi(4040)$. In this talk, we have presented several recent BESIII charm results. With the largest $\psi(3770)$ data sample in the world, we have given several competitive results with excellent precision. Meanwhile, BESIII has also started the D_s physics program with the 482 pb^{-1} $\psi(4040)$ data and several analyses are ongoing. Next year, more data will be possibly taken for the charm program and charm physics at BESIII will have a very bright future.

Acknowledgments

I would like to thank the organizers for the successful conference. And thank the colleagues in BESIII for producing nice results.

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