PROCEEDINGS OF SCIENCE

D_s^+ physics at BESIII

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In the year of 2011, the BESIII experiment accumulated 482 pb^{-1} e^+e^- annihilation data taken at 4.009 GeV. We report four analyses based on this sample, including (a) $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu(\tau^+ \to \pi^+\bar{\nu})$, (b) $D_s^+ \to \eta' X$ and $D_s^+ \to \eta'\rho^+$, (c) $D_s^+ \to \eta e^+\nu_e$ and $D_s^+ \to \eta' e^+\nu_e$ and (d) D^{*0} decay branching fractions.

VIII International Workshop On Charm Physics
5-9 September, 2016
Bologna, Italy

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PoS(CHARM2016)083

1. Introduction

D_s^+ meson, which is composed of a charm quark and a strange antiquark, was discovered in 1993. There are rich physics contents in D_s^+ meson decays. For example, the measurements of decay constant $f_{D_s^+}$ can test the unitarity of CKM matrix; the measurements of branching fraction of semileptonic decays can investigate mechanism of $\eta-\eta'$, $\omega-\phi$ and $a0(980)-f0(980)$ mixsing and test the calculation of Lattice QCD; the measurements of hadronic decays can test the calculation of light quark SU(3) symmetry in charm meson system. In the year of 2011, the BESIII experiment accumulated 482 pb^{-1} [1] e^+e^- annihilation data taken at 4.009 GeV. At this energy, D_s mesons are only produced in $D_s^+D_s^-$ pairs and the cross section of $D_s^+D_s^-$ is nearly maximal [2]. As other processes, such as $D_sD_s^*$ and $D_s^*D_s^*$, are not allowed kinematically, we benefit from the exceptional purity of the D_s^+ sample. In this paper, we report the recent BESIII results based on this sample.

2. Measurement of the branching fractions of $D_s^+ \to \mu^+\nu, D_s^+ \to \tau^+\nu(\tau^+ \to \pi^+\bar{\nu})$ and the decay constant $f_{D_s^+}$

The simplest and cleanest decay modes of the D_s^+ meson, both theoretically and experimentally, are the purely leptonic decays. The decay constant $f_{D_s^+}$ can be measured directly via the leptonic decays. Recently, the CLEO [3], *BABAR* [4], and Belle [5] collaborations have published updated measurements of the branching fractions of D_s^+ leptonic decays and the decay constant $f_{D_s^+}$, resulting in the new world average $f_{D_s^+} = (257.5 \pm 4.6)$ MeV [6]. Theoretical predictions of $f_{D_s^+}$ [7, 8, 9, 10, 11, 12] are lower than this value. The most precise predictions are from lattice QCD; the combined $(2+1)$- and $(2+1+1)$-flavor result is (249.0 ± 1.2) MeV. There is an approximately two standard-deviation difference between the experimental average and the lattice QCD calculations. Several models of physics beyond the SM, such as the two-Higgs-doublet model [13] and the *R*-parity-violating model [14], may help to understand this difference. It is important to further investigate this difference both theoretically and experimentally.

In this work, we measure the branching fractions of $D_s^+ \to \mu^+\nu_\mu$ and $D_s^+ \to \tau^+\nu_\tau$ using 482 pb^{-1} of data taken at 4.009 GeV. Our results within the context of the Standard Model (SM) are $\mathscr{B}(D_s^+ \to \mu^+\nu_\mu) = (0.495 \pm 0.067 \pm 0.026)\%$ and $\mathscr{B}(D_s^+ \to \tau^+\nu_\tau) = (4.83 \pm 0.65 \pm 0.26)\%$ (Fig. 1 (left)). Using these branching fractions, the decay constant $f_{D_s^+}$ is determined as $f_{D_s^+} = (241.0 \pm 16.3 \pm 6.6)$ MeV. We have also measured the branching fractions without constraining the $\tau^+\nu_\tau$ and $\mu^+\nu_\mu$ decay rates to the SM prediction, and the results are $\mathscr{B}(D_s^+ \to \mu^+\nu_\mu) = (0.517 \pm 0.075 \pm 0.021)\%$ and $\mathscr{B}(D_s^+ \to \tau^+\nu_\tau) = (3.28 \pm 1.83 \pm 0.37)\%$ (Fig. 1 (right)).

The branching fraction for $D_s^+ \to \mu^+\nu_\mu$ measured in this work is consistent with the experimental world average [6] within one standard deviation, while the branching fraction for $D_s^+ \to \tau^+\nu_\tau$ is about 1.5 standard deviations lower. The measured decay constant $f_{D_s^+}$ is consistent with the average of the lattice QCD calculations [7, 8, 9, 10, 11, 12]. With the pure $D_s^+D_s^-$ sample, we provide an overall competitive result in spite of low statistics.

3. Measurement of the branching fractions of $D_s^+ \to \eta' X$ and $D_s^+ \to \eta'\rho^+$

Hadronic weak decays of charmed mesons provide important information on flavor mixing,

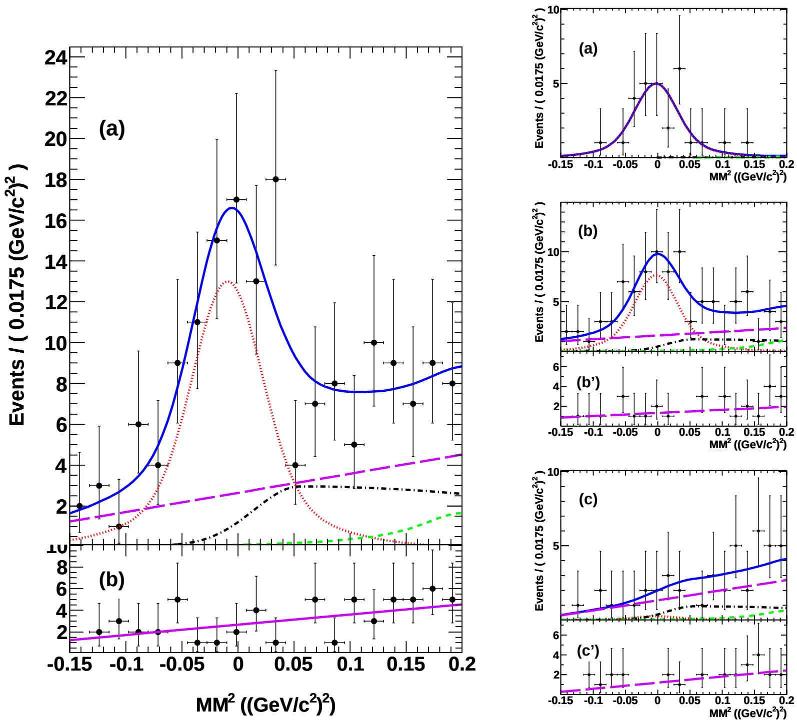

Figure 1: Projections of the simultaneous fit to the MM^2 distributions. The left figure is the fit by require SM constraint, while the right figure is the one without SM constraint. Data are shown as the points with error bars. The red dotted curve shows the $\mu^+\nu_\mu$ signal and the black dot-dashed curve shows the $\tau^+\nu_\tau$ signal. The purple long-dashed line shows the non-D_s^+ background while the green dashed line shows the real-D_s^+ background. The blue curve shows the sum of all these contributions.

CP violation, and strong-interaction effects [15]. There are several proposed QCD-derived theoretical approaches to handle heavy meson decays [16, 17, 18, 19, 20]. However, in contrast to B mesons, theoretical treatment of charmed mesons suffers from large uncertainties since the c quark mass is too light for good convergence of the heavy quark expansion but still much too massive for chiral perturbative theory to be applicable. Currently, theoretical results for the partial decay widths of ground-state charmed mesons agree fairly well with experimental results. However, there exists a contradiction concerning the branching fraction $\mathscr{B}(D_s^+ \to \eta'\rho^+)$. CLEO reported $(12.5\pm2.2)\%$ [21], while a generalized factorization method [22] predicts a factor of four less, $(3.0\pm0.5)\%$. Summing the large experimental value of $\mathscr{B}(D_s^+ \to \eta'\rho^+)$ with other exclusive rates involving η' gives $\mathscr{B}(D_s^+ \to \eta' X) = (18.6\pm2.3)\%$ [6], while the measured inclusive decay rate $\mathscr{B}(D_s^+ \to \eta' X)$ is much lower, $(11.7\pm1.8)\%$ [23], where X denotes all possible combinations of states. Therefore, further experimental study of the η' decay modes is of great importance for resolving this conflict. Recently, CLEO reported an updated measurement of $\mathscr{B}(D_s^+ \to \eta'\pi^+\pi^0) = (5.6\pm0.5\pm0.6)\%$ [24]; this includes the resonant process $\eta'\rho^+$. This is much smaller than the previous result [21].

In this work, we report the measurements of the inclusive rate $\mathscr{B}(D_s^+ \to \eta' X)$ and the exclusive rate $\mathscr{B}(D_s^+ \to \eta'\rho^+)$ at the BESIII experiment. We measure the branching fraction $\mathscr{B}(D_s^+ \to$

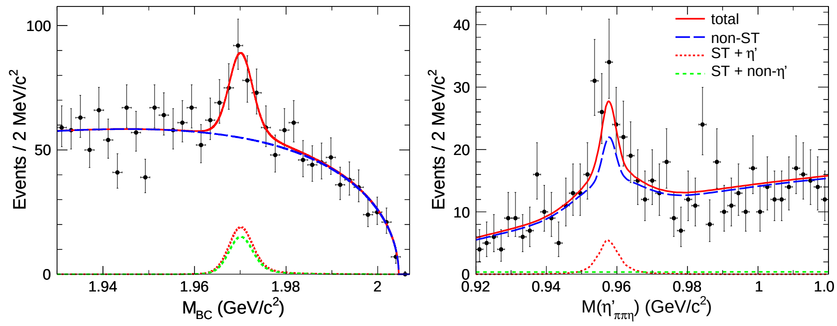

Figure 2: Projections of the two-dimensional unbinned fit to events from data onto $M_{\rm BC}$ (left) and $M(\eta'_{\pi^+\pi^-\eta})$ (right).

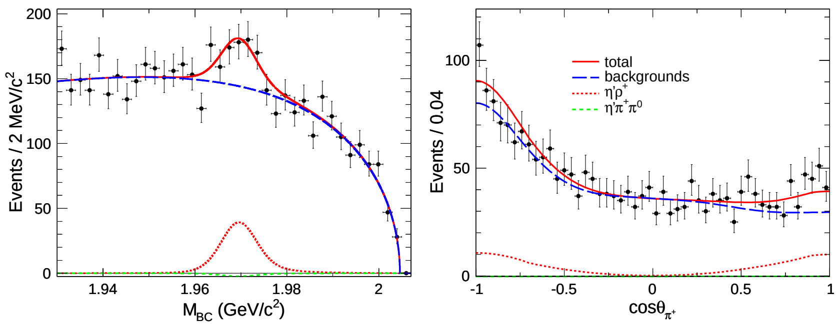

Figure 3: Projection plots of the two dimensional unbinned fit onto $M_{\rm BC}$ (left) and $\cos\theta_{\pi^+}$ (right). The signal events are enriched by requiring $1.955 < M_{\rm BC} < 1.985\,{\rm GeV/c^2}$ in the right plot.

$\eta'X) = (8.8\pm1.8\pm0.5)\%$, which is consistent with CLEO's measurement [23] (Fig. 2). The weighted average of these two results is $\mathscr{B}(D_s^+\to\eta'X) = (10.3\pm1.3)\%$. We also measure the ratio $\mathscr{B}(D_s^+\to\eta'\rho^+)/\mathscr{B}(D_s^+\to K^+K^-\pi^+) = 1.04\pm0.25\pm0.07$, from which we get $\mathscr{B}(D_s^+\to\eta'\rho^+) = (5.8\pm1.4\pm0.4)\%$. This is nearly half of CLEO's older result [21], but compatible with CLEO's newer measurement of $\mathscr{B}(D_s^+\to\eta'\pi^+\pi^0)$ [24], in which the resonant process $\eta'\rho^+$ is believed to dominate. We also report a limit on the non-resonant branching ratio $\mathscr{B}(D_s^+\to\eta'\pi^+\pi^0) < 5.1\%$ at the 90% confidence level (Fig. 3). These results reconcile the tension between experimental data and theoretical calculation [22]. Taking the world average values of other exclusive branching fractions involving η' as input, we obtain the sum of exclusive branching fractions $\mathscr{B}(D_s^+\to\eta'K^+,\eta'\pi^+,\eta'\rho^+,\eta'l\nu_l) = (11.9\pm1.6)\%$, in which l denotes e^+ or μ^+, and where we have assumed that $\mathscr{B}(D_s^+\to\eta'\mu^+\nu_\mu) = \mathscr{B}(D_s^+\to\eta'e^+\nu_e)$. This summed exclusive branching fraction is compatible with the new weighted inclusive result $\mathscr{B}(D_s^+\to\eta'X) = (10.3\pm1.3)\%$.

4. Measurements of the absolute branching fractions for $D_s^+\to\eta e^+\nu_e$ and $D_s^+\to\eta' e^+\nu_e$

The semileptonic decays $D_s^+\to\eta e^+\nu_e$ and $D_s^+\to\eta' e^+\nu_e$ are important channels for the study of heavy quark decays and light meson spectroscopy. The inclusive semileptonic decay widths of the mesons D^0, D^+ and D_s^+ should be equal, up to $SU(3)$ symmetry breaking and non-factorizable components [25]. The measured inclusive semileptonic decay widths of D^0 and D^+ mesons are proven to be consistent with each other. However, they are larger than that of D_s^+ mesons by 20% [26], more than 3σ of the experimental uncertainties. The CLEO Collaboration measured the ratio between the branching fractions for $D_s^+ \to \eta' e^+ \nu_e$ and $D_s^+ \to \eta e^+ \nu_e$ to be $\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)} = 0.35 \pm 0.09 \pm 0.07$ [27] , and the two individual branching fractions to be $B(D_s^+ \to \eta e^+ \nu_e) = (2.48 \pm 0.29 \pm 0.13)\%$ and $B(D_s^+ \to \eta' e^+ \nu_e)$=$(0.91 \pm 0.33 \pm 0.05)\%$ [28]. Recently, these two branching fractions were measured to be $B(D_s^+ \to \eta e^+ \nu_e)$ = $(2.28 \pm 0.14 \pm 0.20)\%$ and $B(D_s^+ \to \eta' e^+ \nu_e)$=$(0.68 \pm 0.15 \pm 0.06)\%$ [29].

In this work, we report measurements of the absolute branching fractions for $D_s^+ \to \eta e^+ \nu_e$ and $D_s^+ \to \eta' e^+ \nu_e$ at the BESIII experiment. We measure the branching fractions for $D_s^+ \to \eta e^+ \nu_e$ and $D_s^+ \to \eta' e^+ \nu_e$ to be $B(D_s^+ \to \eta e^+ \nu_e)$ = $(2.30 \pm 0.31 \pm 0.09)\%$ and $B(D_s^+ \to \eta' e^+ \nu_e)$ = $(0.93 \pm 0.30 \pm 0.05)\%$, and the ratio between $B(D_s^+ \to \eta' e^+ \nu_e)$ and $B(D_s^+ \to \eta e^+ \nu_e)$ to be $0.40 \pm 0.14 \pm 0.02$ (Fig. 4). The branching fractions measured in this work are in good agreement with the previous measurements within uncertainties. The results improve upon the D_s^+ semileptonic branching ratio precision and provide more information for comprehensively understanding the D_s^+ weak decays.

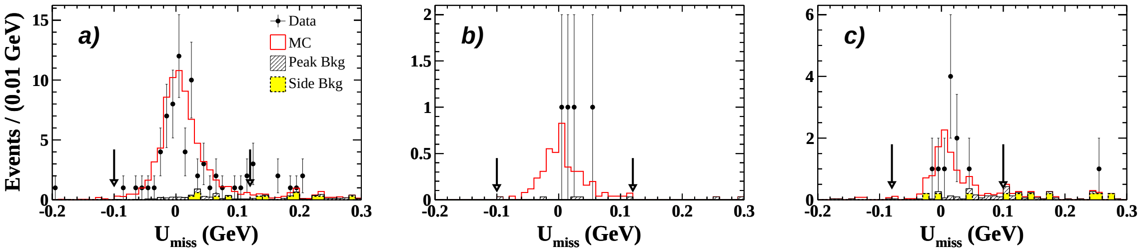

Figure 4: Distributions of $U_{\rm miss}$ of the candidates for (a) $D_s^+ \to \eta e^+ \nu_e$, (b) $D_s^+ \to \eta'(\eta \pi^+ \pi^-) e^+ \nu_e$ and (c) $D_s^+ \to \eta'(\gamma \rho^0) e^+ \nu_e$. The pair of arrows indicates the signal region, points with error bars show the events from data, the solid histograms show the scaled events from inclusive MC, the hatched and dashed histograms show the peaking background ('Peak Bkg') and sideband backgrounds ('Side Bkg'), respectively.

5. Precision measurement of the D^{*0} decay branching fractions

The charmed meson, described as a hydrogen-like hadronic system consisting of a heavy quark (c quark) and a light quark (u, d, or s quark), is a particularly suited laboratory to test the effective models (EMs). A precise measurement of the branching fractions will constrain the model parameters and thereby help to improve the EMs. On the experimental side, these two branching fractions are critical input values for many measurements such as the open charm cross section in e^+e^- annihilation [30] and the semileptonic decays of $B^\pm$ [31]. The data sample used in this analysis of 482 pb^{-1} collected at a center-of-mass (CM) energy $\sqrt{s} = 4.009$ GeV with the BESIII detector can improve previous measurements [32, 33, 34] significantly.

By assuming that there are only two modes of D^{*0}, we measure the branching fractions of D^{*0} to be $\mathscr{B}(D^{*0} \to D^0 \pi^0) = (65.5 \pm 0.8 \pm 0.5)\%$ and $\mathscr{B}(D^{*0} \to D^0 \gamma) = (34.5 \pm 0.8 \pm 0.5)\%$, where the first uncertainties are statistical and the second ones are systematic. It should be noted that both the statistical and the systematic uncertainties of these two branching fractions are fully anti-correlated. Taking the correlations into account, the branching ratio $\mathscr{B}(D^{*0} \to D^0\pi^0)/\mathscr{B}(D^{*0} \to D^0\gamma) = 1.90 \pm 0.07 \pm 0.05$ is obtained. This ratio does not depend on any assumptions in the D^{*0} decays, so it can be used in calculating the D^{*0} decay branching fractions if more decay modes are discovered.

Figure 5 shows a comparison of the measured branching fraction of $D^{*0} \to D^0\pi^0$ with other experiments and the world average value [6]. Our measurement is consistent with the previous ones within about 1σ but with much better precision. These much improved results can be used to update the parameters in the effective models mentioned above, such as the mass of the charm quark [35, 36], the effective coupling constant [37], and the magnetic moment of the charm quark [38]. With these new results as input, the uncertainty in the semileptonic decay branching fraction of $B^\pm$ [31] can be reduced, thus leading to a tighter constraint on the standard model (SM) and its extensions.

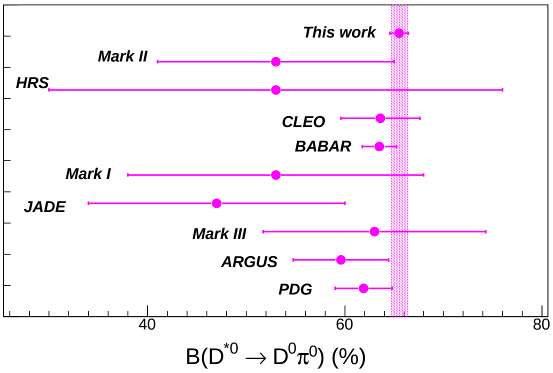

Figure 5: Comparison of the branching fraction of $D^{*0} \to D^0\pi^0$ from this work and from previous experiments. Dots with error bars are results from different experiments, and the band is the result from this work with both statistical and systematic uncertainties.

6. Summary

We report four analyses at BESIII using the 482 pb^{-1} data sample. The results are in good agreement with previous measurements and compatible with the SM predictions. As for the future, BESIII has already taken 3 fb^{-1} data at $\sqrt{s} = 4.18$ GeV, in which $D_sD_s^*$ production is maximal, and we will be able to significantly improve the D_s^+ measurements.

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