Results of J/ψ weak decay searching at BESIII

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It is a tremendous opportunity to study the rare weak decay of J/ψ using the largest J/ψ data samples in the world produced by the Beijing Electron Positron Collider (BEPCII) at a center-of-mass energy $\sqrt{s}$ = 3.097 GeV and collected with the BESIII detector. In this proceeding, I summarize the BESIII results which have been published in 4 papers of about 6 reaction channels on the weak rare decays of J/ψ in last eight years.

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1. Introduction

The decays of J/ψ are dominated by hadronic and electromagnetic interaction, which have been extensively studied. By contrast, there are few rare weak decays studied in detail. For the J/ψ particle, lying below $D\bar{D}$ threshold, decays to $D\bar{D}$ is forbidden. However, the J/ψ decays into a single D meson accompanied by light hadrons or leptons via weak decay is kinematically allowed. Searching for the J/ψ weak decays can provide an experimental check of the standard model (SM) which predicts the branching fraction (BF) of J/ψ decays to single D meson up to the order of 10^{-8} [1, 2] and may offer a unique opportunity to probe new physics beyond the SM, including the Top Color models [3], the minimal supersymmetric standard model with or without R-parity [4], and the two-Higgs doublet model [5].

The BESIII experiment has searched for several weak decays of J/ψ and set upper limit (UL) for BFs at the order of $10^{-5} \sim 10^{-8}$ using different statistics sample [6–9]. In the following sections of this proceeding, I will elaborate those results, where the charge conjugation is implied unless otherwise specified.

2. Recent searches on the weak decay of J/ψ

2.1 $J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

With the prospect of high-statistics J/ψ samples, theoretical calculations of the BFs of two-body hadronic weak decays of $J/\psi \to DP/DV$, where D represents a charmed meson and P and V the pseudoscalar and vector mesons, respectively, have been performed. The BFs of $J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$ are predicted to be higher than those of $J/\psi \to D_s^- \pi^+$ and $J/\psi \to \bar{D}^0 \bar{K}^0$ [10]. In this analysis [6], the D_s^- and $\bar{D}^0$ mesons are identified by their semileptonic decays $D_s^- \to \phi e^- \bar{\nu}_e$ and $\bar{D}^0 \to K^+ e^- \bar{\nu}_e$ to avoid large background contamination from conventional J/ψ hadronic decays. Due to the undetectable neutrinos in semileptonic decays, D_s^- and $\bar{D}^0$ mesons could be identified by the distribution of mass recoiling against the ρ^+ and $\bar{K}^{*0}$, respectively, rather than directly by their invariant mass of the decay products.

Using a sample of $(225.3 \pm 2.8) \times 10^6$ J/ψ events collected at the BESIII detector, the search for two Cabibbo-favored decay modes $J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$ has been performed. The ULs for the observed number of events at the 90% C.L. are determined to be 2.5 for $J/\psi \to D_s^- \rho^+$ and 2.7 for $J/\psi \to \bar{D}^0 \bar{K}^{*0}$ using a series of unbinned extended maximum likelihood fits. Since no evident signal is observed, ULs at the 90% C.L. are set on the BFs, $\mathcal{B}(J/\psi \to D_s^- \rho^+) < 1.3 \times 10^{-5}$ and $\mathcal{B}(J/\psi \to \bar{D}^0 \bar{K}^{*0}) < 2.5 \times 10^{-6}$, for the first time. These ULs exclude new physics predictions which allow flavor-changing processes to occur with BFs around 10^{-5} and are still consistent with the predictions of the SM.

2.2 $J/\psi \to D_s^{(*)-} e^+ \nu_e$

The BFs of $J/\psi \to D_s^{(*)} l \nu$ could be enhanced when new interaction couplings are considered, such as in the beyond SM models [4, 11, 12]. In this analysis [7], the D_s^- meson is reconstructed via four hadronic decay modes $KK\pi$, $KK\pi\pi$, $K_S^0 K$ and $K_S^0 K\pi\pi$ and the D_s^* candidate is reconstructed from its radiative transitions to D_s. For the $J/\psi \to D_s^{(*)} l \nu$ candidate, the J/ψ semileptonic decay

events are extracted using the variable $U_{\text{miss}} = E_{\text{miss}} - |\vec{p}_{\text{miss}}|$. A simultaneous unbinned maximum likelihood fit is used to determine the event yields of the four D_s decay modes.

With a sample of $(225.3 \pm 2.8) \times 10^6$ J/ψ events collected with the BESIII detector, we have searched for the weak decays $J/\psi \rightarrow D_s^- e^+ \nu_e$ and $J/\psi \rightarrow D_s^{*-} e^+ \nu_e$. No significant excess of signal is observed. At the 90% C.L., the ULs of the BFs are $\mathcal{B}(J/\psi \rightarrow D_s^- e^+ \nu_e) < 1.3 \times 10^{-6}$ and $\mathcal{B}(J/\psi \rightarrow D_s^{*-} e^+ \nu_e) < 1.8 \times 10^{-6}$. The UL on the $\mathcal{B}(J/\psi \rightarrow D_s^{*-} e^+ \nu_e)$ is set for the first time, and the UL on the $\mathcal{B}(J/\psi \rightarrow D_s^- e^+ \nu_e)$ is 30 times more strict than the previous result [13]. The results are within the SM prediction.

2.3 $J/\psi \rightarrow D^0 e^+ e^-$

In the SM, decays of J/ψ induced by flavor changing neutral currents (FCNCs) are forbidden at the tree level due to the Glashow-Iliopoulos-Maiani (GIM) mechanism, but can occur via a $c \rightarrow u$ transition at the loop level. For $J/\psi \rightarrow D^0 e^+ e^-$ decay, its BF can be enhanced by 2 or 3 orders of magnitude in many new physics models compared with the SM. It offers an ideal opportunity to study non-perturbative QCD effects and their underlying dynamics by searching for experimental evidence for these FCNC processes. In this work [8], the D^0 meson is reconstructed by its three prominent exclusive hadronic decay modes $K^- \pi^+$, $K^- \pi^+ \pi^0$ and $K^- \pi^+ \pi^+ \pi^-$, which have relatively large BFs, and suffer from relatively low background. Signal yields are estimated by a simultaneous unbinned maximum likelihood fit on the distributions of invariant mass of three decay modes of D^0.

Finally, the rare decay of $J/\psi \rightarrow D^0 e^+ e^-$ is searched for using samples of $(1310.6 \pm 7.2) \times 10^6$ J/ψ events collected with the BESIII detector. No significant signal is observed and UL at the 90% C.L. for the BF is determined to be $\mathcal{B}(J/\psi \rightarrow D^0 e^+ e^-) < 8.5 \times 10^{-8}$. And the limit is more stringent by 2 orders in magnitude compared to the previous result [14]. Though the ULs are larger than the SM predictions, they may help to discriminate between the different new physics models and constrain their parameters.

2.4 $J/\psi \rightarrow D^- e^+ \nu_e$

In weak semi-leptonic J/ψ decays, the hadronic transition form factor between the initial and final-state mesons can be cleanly decoupled from the weak current [15–19]. The theoretical predictions for the BF of the rare semi-leptonic decay $J/\psi \rightarrow D^- e^+ \nu_e$ within the SM are of the order of 10^{-11} [15–19]. To further test the SM predictions and constrain the contributions from new physics models, a new measurement of $\mathcal{B}(J/\psi \rightarrow D^- e^+ \nu_e)$ with greater sensitivity is required. In this work [9], we reconstruct the D^- meson through its hadronic decay mode $K^+ \pi^- \pi^-$. An unbinned extended maximum likelihood fit on U_{miss} distribution is used to estimate the signal yield.

Based upon a sample of 10.1×10^9 J/ψ events collected with the BESIII detector, the BF of the rare semi-leptonic decay $J/\psi \rightarrow D^- e^+ \nu_e$ is studied with a semi-blind analysis. No excess of events is observed over the background. The resulting UL on the BF at 90% C.L. is $\mathcal{B}(J/\psi \rightarrow D^- e^+ \nu_e) < 7.1 \times 10^{-8}$. This is the most sensitive search for the $J/\psi \rightarrow D^- e^+ \nu_e$ decay. This measurement is compatible with the SM theoretical predictions, and puts a stringent constraint on the parameter spaces for different new physics models predicting BFs of the order of 10^{-5} [19].

3. Summary

The rare decays of J/ψ have been a minority science field for both theoretical and experimental studies in the world. Up to now BESIII has only published 4 papers of about 6 decay modes in last eight years. J/ψ resonance is forbidden to decay into a pair of charmed mesons, but can decay into a single D meson accompanied by light hadrons or leptons via weak decay. The BFs of those weak decays are predicted to be at the order of 10^{-8} or below in the SM. We investigate several searches of weak decay modes of J/ψ performed by BESIII. These measurements on UL are roughly compatible with SM prediction, but more data will be helpful to put a stronger constraint on the parameter spaces of some beyond SM models.

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