PROCEEDINGS OF SCIENCE

Search for rare decays at BESIII

Yunxuan Song (on behalf of the BESIII Collaboration)[a,b,*]

[a] *School of Physics, Peking University, Beijing 100871, People's Republic of China*

[b] *State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People's Republic of China*

E-mail: songyx.hep@pku.edu.cn

Based on 10 billion J/ψ events accumulated by the BESIII detector, we show the searches for the rare process of J/ψ weak decays. We also search for other rare decay process, such as the FCNC process $D^0 \to \pi^0 \nu\bar{\nu}$. Using J/ψ decay, BESIII also produce millions of Hyperon, which can be used to search for the rare decay process $\Xi^- \to \Xi^0 e\nu$.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)957

1. Introduction

BESIII [1] is an e^+e^- collider experiment running at τ-charm energy region with peak luminosity at $10^{33}\text{cm}^{-2}\text{s}^{-1}$ located at the Beijing Electron Positron Collider (BEPCII) [2]. In the last more than 10 years running period, BESIII has accumulated huge data sample, including world largest J/ψ, $\psi^{'}$, $\psi^{''}$ data set by direct e^+e^- annihilation. With these huge clean data samples, BESIII has performed several work to explore the boundaries of Standard Model (SM). This report summaries three recent results at BESIII related to rare decays.

2. Search for the decay $D^0 \to \pi^0 \nu\bar{\nu}$

The Flavor Changing Neutral Current decays (FCNC) are forbidden at tree level in the Standard Model due to the Glashow-Iliopoulos-Maiani mechanism [3]. GIM suppression is more effective for the charm sector compared to the down-type quarks in the bottom and strange sectors. FCNC processes involving D decays into charged lepton pairs are often totally overshadowed by long distance contributions [4, 5]. However, for D FCNC decays into final states involving dineutrinos, such as $D^0 \to \pi^0\nu\bar{\nu}$, long-distance contributions become insignificant and the short-distance contributions from Z-penguin and box diagrams dominate, resulting in the branching fraction at the level of 10^{-15} in SM [6]. That makes D FCNC decay involving dineutrinos a unique and clean probe to search for new physics beyond SM [7].

The BESIII Collaboration presented a search for neutrino pair in the final state of charm decays for the first time [8], taking advantage of 2.93fb^{-1} of data collected at the energy of 3.773 GeV. The final state was reconstructed by means of the double-tag technique: the single-tag $\bar{D}^0$ was reconstructed in three different hadronic channels ($K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$), then the D^0 decay signal was reconstructed recoilling against the single-tag $\bar{D}^0$, finding two photons from π^0 decay. The signal was searched in the energy deposited in the electromagnetic calorimeter. In order to be able to investigate the $D^0 \to \pi^0\nu\bar{\nu}$ decay, a data-driven method was used: the data-driven analysis procedure was validated by means of one third of the full data sample. Since no obvious signal is observed over the background, the branching ratio upper limit for the $D^0 \to \pi^0\nu\bar{\nu}$ decay was calculated to be 2.1×10^{-4} at 90% confidence level.

The result is lower than the upper limit predicted in Ref. [9], hence, providing constrains on the fermionic coupling strength of leptoquarks to the sterile neutrinos. In the future, more stringent results will be available based on an anticipated larger $\psi(3770)$ data set of about 20 fb^{-1} at BESIII [10, 11].

3. Search for the rare semi-leptonic decay $J/\psi \to D^- e^+ \nu_e$

The hadronic and electromagnetic decays of J/ψ have been studied extensively. However, there are few weak decays studied in details. Although the J/ψ weak decays into a charmed meson accompanied by light hadrons or leptons are kinematicaly allowed, but never observed experimentally. In the SM, J/ψ weak decays are highly suppressed, which offers a unique opportunity to probe new physics beyond the SM.

In the weak semi-leptonic J/ψ decays, the hadronic transition form factor between the initial and final-state mesons can be clearly decoupled from the weak current [12–16]. The theoretical predictions for the branching fraction of the rare semi-leptonic decay $J/\psi \to D^- e^+ \nu_e$ within the SM are of the order of 10^{-11} [12–16]. To further test the SM predictions and constrain the contributions from new physics models, a new measurement of $\mathcal{B}(J/\psi \to D^- e^+ \nu_e)$ with greater sensitivity is required. In this work [17], we reconstruct the D^- meson through its hadronic decay mode $K^+\pi^-\pi^-$. Due to conservation of energy and momentum, the undetected neutrino ν_e carries a missing-energy $E_{\rm miss} = E_{J/\psi} - E_{D^-} - E_{e^+}$ and a missing-momentum $\vec{p}_{\rm miss} = \vec{p}_{J/\psi} - \vec{p}_{D^-} - \vec{p}_{e^+}$, where E_{D^-} (E_{e^+}) and $\vec{p}_{D^-}$ ($\vec{p}_{e^+}$) are the energy and momentum of the D^- (e^+) in the rest frame of the initial e^+e^- collision. The yield of the signal decays is extracted by examining the variable $U_{\rm miss} = E_{\rm miss} - c|\vec{p}_{\rm miss}|$, in which the signal candidates are expected to peak around zero.

Based upon a sample of 10 billion J/ψ events collected with BESIII, the branching fraction of the rare semi-leptonic decay $J/\psi \to D^- e^+ \nu_e$ is studied with a semi-blind analysis. No excess of events is observed over the background. The resulting upper limit on the branching fraction at the 90% confidence level is $\mathcal{B}(J/\psi \to D^- e^+ \nu_e) < 7.1 \times 10^{-8}$. This is the most sensitive search for the $J/\psi \to D^- e^+ \nu_e$ 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 branching fractions of the order of 10^{-5} [16].

4. Search for the hyperon semileptonic decay $\Xi^- \to \Xi^0 e^- \bar{\nu}_e$

Hyperon semileptonic decays play an important role in understanding the interplay between weak and strong interactions, where the former determines quark flavor transitions and the latter determines hadronic structures. Some fundamental issues in the particle physics field such as the flavor SU(3) symmetry [18], the CKM unitarity [19] and the lepton flavor asymmetry [20] can be examined through hyperon semileptonic decays.

On the experimental side, there is much room for the measurements of hyperon semileptonic decays to be improved. So far the decay of $\Xi^- \to \Xi^0 e^- \bar{\nu}_e$ has not been observed. The previous search [21] was performed at Brookhaven National Laboratory (BNL) in 1974, which set an upper limit of 2.3×10^{-3} on the branching fraction $\mathcal{B}(\Xi^- \to \Xi^0 e^- \bar{\nu}_e)$ at 90% C. L. based on 8150 Ξ^- events. BESIII has collected about 10 billion J/ψ events and could produce over 10^6 hyperon pairs via J/ψ decays [22], allowing it to study many rare and forbidden hyperon decays sensitively.

Using 10 billion J/ψ events collected with BESIII, the decay of $\Xi^- \to \Xi^0 e^- \bar{\nu}_e$ is studied with double-tag technique. The single-tag $\bar{\Xi}^+$ is reconstructed from its dominant hadronic channel $\bar{\Xi}^+ \to \bar{\Lambda}(\bar{p}\pi^+)\pi^-$. The Ξ^0 baryon in signal is then reconstructed via $\Xi^0 \to \Lambda(p\pi^-)\pi^0(\gamma\gamma)$ recoiling against the single-tag $\bar{\Xi}^+$. Due to the very limited phase space and the small momentum of Ξ^-, the electron in signal is treated as a missing particle. The invariant mass squared of the lepton-neutrino system is taken as the fitting observable, where no obvious signal is found over the background. The resulting upper limit on the branching fraction at the 90% confidence level is determined to be 2.59×10^{-4}, which is one order of magnitude stricter then the previous search.

5. Summary and Outlook

BESIII has produced a large amount of results on rare decays based on the world's largest samples at J/ψ, ψ' and ψ'' resonances. Many interesting investigations to the boundaries of SM are expected to be coming soon.

References

[1] M. Ablikim *et al.* (BESIII Collaboration), Nucl. Instrum. Meth. A **614**, 345-399 (2010)

[2] C.H. Yu, Z. Duan, S. Gu, Y.Y. Guo, X.Y. Huang, D. Ji, *et al.*, in *Proc. IPAC2016*, pp. 1014–1018.

[3] S. L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D **2**, 1285-1292 (1970)

[4] L. Cappiello, O. Cata and G. D'Ambrosio, JHEP **04**, 135 (2013)

[5] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **119**, no.18, 181805 (2017)

[6] G. Burdman, E. Golowich, J. L. Hewett and S. Pakvasa, Phys. Rev. D **66**, 014009 (2002)

[7] A. Paul, I. I. Bigi and S. Recksiegel, Phys. Rev. D **83**, 114006 (2011)

[8] M. Ablikim *et al.* [BESIII], Phys. Rev. D **105**, no.7, L071102 (2022) doi:10.1103/PhysRevD.105.L071102 [arXiv:2112.14236 [hep-ex]].

[9] G. Faisel, J. Y. Su and J. Tandean, JHEP **04**, 246 (2021)

[10] H. B. Li and X. R. Lyu, Natl. Sci. Rev. **8**, no.11, nwab181 (2021)

[11] M. Ablikim *et al.* (BESIII Collaboration), Chin. Phys. C **44**, no.4, 040001 (2020)

[12] Y. M. Wang, H. Zou, Z. T. Wei, X. Q. Li and C. D. Lu, Eur. Phys. J. C **54**, 107-121 (2008)

[13] Y. L. Shen and Y. M. Wang, Phys. Rev. D **78**, 074012 (2008)

[14] R. Dhir and R. C. Verma, Adv. High Energy Phys. **2013**, 706543 (2013)

[15] M. A. Ivanov and C. T. Tran, Phys. Rev. D **92**, no.7, 074030 (2015)

[16] T. Wang, Y. Jiang, H. Yuan, K. Chai and G. L. Wang, J. Phys. G **44**, no.4, 045004 (2017)

[17] M. Ablikim *et al.* (BESIII Collaboration), JHEP **06**, 157 (2021)

[18] G. S. Yang and H. C. Kim, Phys. Rev. C **92** (2015), 035206

[19] N. Cabibbo, E. C. Swallow and R. Winston, Phys. Rev. Lett. **92** (2004), 251803

[20] H. M. Chang, M. González-Alonso and J. Martin Camalich, Phys. Rev. Lett. **114** (2015) no.16, 161802

[21] N. Yeh, A. Gaigalas, W. D. Smith, H. Zendle, C. Baltay, A. Bridgewater, S. Csorna, W. A. Cooper, L. K. Gershwin and M. Habibi, *et al.* Phys. Rev. D **10** (1974), 3545

[22] H. B. Li, Front. Phys. (Beijing) **12** (2017) no.5, 121301 [erratum: Front. Phys. (Beijing) **14** (2019) no.6, 64001]