New Physics Beryond the SM at BESIII

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Abstract. Numerous astrophysical observations strongly suggest the existence of Dark Matter, which provides a hint of dark sector physics. There could exist many dark candidates predicted by theories BSM, such as dark photons and invisible things, that communicate with the Standard Model sector. The masses and decay modes of these particles are expected to be accessible at the BESIII experiment which is the only currently running tau-charm factory with the largest threshold charm samples and some other unique datasets. We have recently performed searches of dark photons and invisible things in several decay modes. Besides, FCNC processes, BNV/LNV processes are also investigated. This talk will summarize the recent results at BESIII on these searches for new physics BSM.

1 Introduction

The BEPCII is the only running τ-charm factory operating at the energy range of $\sqrt{s}$ =2.0-4.6 GeV, located at Institute of High Energy Physics, CAS, Beijing. This is a lot of unique features in this energy region which benefit greatly the rich physics programs. The BESIII detector has a geometrical acceptance of 93% of 4π and consists a main draft chamber, an electromagnetic calorimeter, a time-of-flight system, a muon chamber system, and a super-conducting solenoid with 1T magentic field. More details of the detector are described in Ref [1] Since data taking from 2009, the BESIII experiment has accumulated 1.3 Billion J/ψ, 0.5 Billion $\psi(3686)$ and 2.9 fb^{-1} $\psi(3770)$, which are the largest threshold charm samples in the world. Based on these data samples, the BESIII collaboration have reported some results of searching for New Physics (NP).

To investigate the possible NP effects, not only high energy hadron colliders and specifically designed experiments are needed, but also electron-positron colliders at low energy regions, they are complementary [2]. For example, if a certain kind of NP is discovered at the energy frontier characterized by the LHC, a detailed study of its profound impacts on flavor physics should be done at the electron-positron collider experiments such as the BESIII. With accumulation of further data set, possible increasing luminosity and center of mass energy, improved understanding of detector performance etc. in the coming years, the BESIII experiment will have great potential in the NP searches.

2 Dark Photon

Many models beyond the Standard Model (SM) predict a new type of weak-interacting degree of freedom [3]. The dark photon (DP, usually denoted as γ' or U) is a new Abelian gauge

group $U(1)$ force carrier, which couples to the SM via kinetic mixing [4] with a mixing strength. It has been proposed to explain the large number of astrophysical anomalies [5], as well as the deviation observed in the anomalous magnetic momentum of muon [6].

With $(1310.6 \pm 7.0) \times 10^6$ J/ψ events collected during 2009 and 2012, we search for dark photon ($\gamma' \to e^+e^-$) firstly in the electromagnetic Dalitz decay $J/\psi \to e^+e^-\eta/\eta'$. For the process of $J/\psi \to e^+e^-\eta$, the values of N_{sig} and signal significance as a function of $m_{\gamma'}$ are shown in Fig. 4 of Ref. [9] . The largest local significance is 2.92σ at $m_{\gamma'} = 0.590$ GeV/c^2 in the $\eta \to \pi^+\pi^-\pi^0$ decay and 2.98σ at $m_{\gamma'} = 2.144$ GeV/c^2 in the $\eta \to \gamma\gamma$ decay, which are less than 3σ. Therefore, we conclude that no evidence of γ' production is found in both the η decay modes.

We compute the upper limits on the product branching fraction $B(J/\psi \to \gamma'\eta) \times B(\gamma' \to e^+e^-)$ at the 90% confidence level (C.L.) as a function of $m_{\gamma'}$ using a Bayesian method after incorporating the systematic uncertainty by smearing the likelihood curve with a Gaussian function with a width of the systematic uncertainty. The combined result is obtained by adding the logarithm likelihoods of two η decays by taking into account their correlated and uncorrelated systematic uncertainties. The combined limits on product branching fraction $B(J/\psi \to \gamma'\eta) \times B(\gamma' \to e^+e^-)$ vary in the range of $(1.9 - 91.1) \times 10^{-8}$ for $0.01 \le m_{\gamma'} \le 2.4$ GeV/c^2 depending on $m_{\gamma'}$ points [7].

To determine the possible dark photon signal yield in the decay $J/\psi \to e^+e^-\eta'$, a series of ML fits are performed in the range $0.07 < m_{\gamma'} < 2.13$ GeV/c^2 with uniform mass steps of 2 MeV/c^2. The results of N_{sig} and the corresponding significance are shown in Fig. 6 of Ref. [7]. The maximum local significance is from $\eta' \to \pi^+\pi^-\eta$, with 3.1σ at 0.204 GeV/c^2. The corresponding global significance is less than 1σ, evaluated by using a large number of pseudo experiments [8]. In conclusion, no significant dark photon signal is observed within the searched range.

We compute the upper limit on the BFs $B(J/\psi \to \gamma'\eta') \times B(\gamma' \to e^+e^-)$ and $B(J/\psi \to \gamma'\eta')$ at the 90% C.L. using a Bayesian method. The values of B^{UP} are plotted as a function of $m_{\gamma'}$ in Fig. 5 (a) and (b) of Ref. [9]. The upper limit at the 90% C.L. on the BF $B(J/\psi \to \gamma'\eta') \times B(\gamma' \to e^+e^-)$ ranges from $(0.2 - 2.0) \times 10^{-7}$ and that on $B(J/\psi \to \gamma'\eta')$ ranges from $(0.6 - 7.4) \times 10^{-7}$ [9]. The mixing strength ϵ coupling γ' and SM photon is determined from the ratio of the BF $B(J/\psi \to \gamma'\eta')$ and that of the radiative process $B(J/\psi \to \gamma\eta')$. The corresponding exclusion limit on the mixing strength ϵ, which is shown in Fig. 5 (c) of Ref. [9], ranges from $(0.3 - 2.6) \times 10^{-2}$ depending on $m_{\gamma'}$ [9].

3 Invisible Decays

Although there is strong evidence from many astrophysical observations for the existence of dark matter, its nature is still mysterious. Dark matter is invisible in the entire electromagnetic spectrum, and its existence is inferred via gravitational effects only. Any information about its interactions with a SM particle would shed light on the nature of dark matter. An invisible decay in which the final state particle is not observable in the detector are not allowed by the Standard Model (SM) except the quarkonium decays to the neutrino-pair. The neutrino (ν) is an elementary fermionic particle that interacts only via the weak interaction within the SM. The branching fraction of quarkonium decays to neutrino-pair is very rare and beyond the scope of the current collider experiment. However, the contribution of the new physics may enhance the branching fraction up to the level of $10^{-4} - 10^{-8}$ [10, 11], making accessible at existing e^+e^- collider experiments including the BESIII experiment.

We perform the first experimental search for invisible decays of a light vector meson ($V = \omega, \phi$) via $J/\psi \to V\eta$ decays. The decay of $\eta \to \pi^+\pi^-\pi^0$ is utilized to tag the V meson decaying into the invisible final state. No evidence for a significant invisible signal is observed, and the

upper limits on the ratio of branching fractions at the 90% confidence level are determined to be $B(\omega \rightarrow invisible)/B(\omega \rightarrow \pi^+\pi^-\pi^0) < 8.1 \times 10^{-5}$ [12] and $B(\phi \rightarrow invisible)/B(\phi \rightarrow K^+K^-) < 3.4 \times 10^{-4}$ [12]. By using the world average values of $B(\omega \rightarrow \pi^+\pi^-\pi^0)$ and $B(\phi \rightarrow K^+K^-)$, the upper limits on the decay branching fractions at the 90% confidence level are set as $B(\omega \rightarrow invisible) < 7.3 \times 10^{-5}$ [12] and $B(\phi \rightarrow invisible) < 1.7 \times 10^{-4}$ [12], respectively. These results can provide complementary information to study the nature of dark matter and constrain the parameters of phenomenological models [13, 14].

4 Baryon Number Violation

The observed matter?antimatter asymmetry in the universe composes a serious challenge to our understanding of nature. The Big Bang theory, the prevailing cosmological model for the evolution of the universe, predicts exactly equal numbers of baryons and antibaryons in the dawn epoch. However, the observed baryon number (BN) exceeds the number of antibaryons by a very large ratio, currently estimated at $10^9 - 10^{10}$ [15]. To give a reasonable interpretation of the baryon-antibaryon asymmetry, Sakharov proposed three principles [16], the first of which is that BN conservation must be violated. Many proposals predict BN violation within and beyond the SM. Among them, proposals that evoke the spontaneous breaking of a large gauge group are especially appealing. In these models, several heavy gauge bosons emerge whose couplings to matter explicitly violate both baryon and lepton number conservation simultaneously.

We search for the process $J/\psi \rightarrow \Lambda_c^+ e^- + c.c.$ for the first time, as shown in Fig. 1 of Ref. [2], two gauge bosons, X and Y, with charges of 4/3 and 1/3, can violate baryon-lepton number conservation. Based on 1.31×10^9 J/ψ events, the candidate events of $J/\psi \rightarrow \Lambda_c^+ e^- + c.c.$ are obtained and by checking the invariant mass of the $pK^-\pi^+ + c.c.$ system, as shown in Fig. 2 of Ref. [2], no signal events are observed in the signal window.

The upper limit on the number of signal events for $J/\psi \rightarrow \Lambda_c^+ e^- + c.c.$ is estimated to be 5.7 at the 90% CL by utilizing a frequentist method [17] with unbounded profile likelihood treatment of systematic uncertainties, where the number of the signal and background events are assumed to follow a Poisson distribution, the detection efficiency is assumed to follow a Gaussian distribution, and the systematic uncertainty, which will be discussed below, is considered as the standard deviation of the efficiency. The upper limit on the branching fraction is determined to be 6.9×10^{-8} [2]. The result is one of the best constraints from meson decays [18?] and is consistent with the conclusion drawn from the proton decay experiment [20]. Even though no any significant signals were observed, the result might hint the theoretical physicists about the scale of new physics.

5 Lepton Number Violation

In the SM, due to the absence of right-handed neutrino component and requirements of $SU(2)_L$ gauge invariance and renormalizability, neutrinos are postulated to be massless. However, the observations of neutrino oscillation phenomena have convincingly shown that neutrinos are of a very tiny mass, which provides the first evidence for physics beyond the SM. Theoretically, the leading model to accommodate the neutrino masses is the so-called ?see-saw? mechanism in which the SM neutrinos turn out to be Majorana particles, who are of its own antiparticle. The effects of Majorana neutrino can be manifest through the process violating the lepton-number (L) conservation by two units ($\Delta L = 2$).

Using the data sample with the integral luminosity of 2.93 fb^{-1} collected at the C.M. energy 3.773 GeV, we perform a search for LNV $\Delta L = 2$ decays of $D \rightarrow K\pi e^+ e^+$. The ULs

on the BFs of Majorana neutrino case are calculated through the profile likelihood method incorporating the systematic uncertainty by implementing the package trolke [17] in root framework, where the numbers of events in the signal and sideband regions are assumed to be the Poisson distributions, and the efficiency is Gaussian distribution. The ULs on the BFs at the 90% CL as a function of m_N is at the level of $10^{-7} - 10^{-6}$, as shown in Fig. 3 (a) and (b) of Ref. [21]. Based on the measured BFs, the mixing matrix element $|V_{eN}|^2$ of a positron with the heavy Majorana neutrino in the charged current interaction as a function of m_N can be obtained [21]. The mixing matrix element $|V'_{eN}(m_N)|^2$ is derived from a reanalysis of neutrinoless double beta decay experimental data [22]. The resultant ULs on the mixing matrix element $|V_{eN}|^2$ as a function of m_N, which are also depicted in Fig. 3 (c) and (d) of Ref. [21], provide the additional and complementary information about the bounds on the $|V_{eN}|^2$ in D meson decays.

6 Flavor Changing Neutral Current

The Flavor Changing Neutral Current decays(FCNC) is forbidden at tree level in the SM due to the Glashow-Iliopoulos-Maiani mechanism, and could only contribute through loops. Any direct observation beyond SM expectations could be a good probe of physics beyond SM.

Based on $(448.1 \pm 2.9) \times 10^6$ $\psi(3686)$ events [23] collected by BESIII. The decay $\psi(3686) \to \Lambda_c^+ p e^+ e^- + c.c.$ with $\Lambda_c^+ \to pK^-\pi^+$ is reconstructed with six charged tracks with zero net charge. The number of signal events is determined by examining the Λ_c^+ signal in the $M_{pK^?\pi^+}$ distribution, which is shown in Fig. 2 of Ref. [24]. No events survive within the signal region ranging from 2.25 to 2.32 GeV/c^2. The potential background in the signal region is estimated using events in the $M_{pK^-\pi^+}$ sideband regions to be 1.5. We also estimate the number of background events to be zero using the inclusive MC sample and the data sample with $\sqrt{s} = 3.773$ GeV. As no candidate events are found in the signal region, the estimated number of background events is determined to be 0.0 ± 1.5 events. The upper limit on the BF of the decay $\psi(3686) \to \Lambda_c^+ p e^+ e^- + c.c.$ is calculated to be 1.7×10^{-6}. The result is within the expectations of the SM, and no evidence for new physics is found.

Based on the dataset taken at $\sqrt{s} = 3.773$ GeV with an integrated luminosity of 2.93 fb^{-1} collected with the BESIII detector, we perform a search for the rare decays of $D \to h(h')e^+e^-$, where $h(')$ are hadrons. Double tagging method is used in the analysis. For each signal mode, ΔE_{sig} is required to be within 3σ of the nominal value, and only the combination with the smallest $|\Delta E_{sig}|$ is kept. No significant excess over the expected backgrounds is observed in M_{BC}^{sig} distributions of the surviving events. The ULs on the signal BFs at the 90% CL are determined. The maximal signal significance is 2.6σ, for $D^0 \to K^-\pi^+e^+e^-$. Its BF is expected to be dominated by the LD Bremsstrahlung and (virtual) resonance decay contributions in the lower and upper regions, so we divide the $M_{e^+e^-}$ distribution into three regions and determine the BFs in the individual regions. All the results are listed in Table 2 of Ref. [?], and are all within the SM predictions. For the four-body D^+ decays, the searches are performed for the first time. The reported ULs of the D^0 decays are improved in general by a factor of 10, compared to previous measurements [25]. All the measured ULs on the BFs are above the SM predictions, which include both LD and SD contributions.

7 summary

BESIII has performed a series of searches for NP processes. Though most of the upper limits are larger than the SM predictions, they may help to discriminate the different new physics models or to constrain the parameters in the different physics models. Additionally,

higher statistics J/ψ, $\psi(3686)$ and D meson samples may help to improve the sensitivity of the measurements. BESIII efforts with more related channels and more coming data will be continued to further test the standard model with higher precision in future.

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References

[1] M.Ablikimetal.(TheBESIIICollaboration),Nucl.Instrum.Meth.A614,345(2010).

[2] M. Ablikim, et. al., Phys. Rev. **D 99**, 072006 (2019)

[3] R. Essig et al., arXiv:1311.0029 and references therein.

[4] B. Holdom, Phys. Lett. B 166, 196 (1986).

[5] N. Arkani-Hamed, D. P. Finkbeiner, T. R. R. Skatyer, and N. Weiner, Phys. Rev. D 79, 015014 (2009); R. Essig, P. Schuster, and N. Toro, Phys. Rev. D 80, 015003 (2009). 5. M. Pospelov, Phys. Rev. D 80, 095002 (2009).

[6] M. Pospelov, Phys. Rev. D 80, 095002 (2009).

[7] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. D 99, 012006 (2019).

[8] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. D 93, 052005 (2016).

[9] M. Ablikim, et. al., Phys. Rev. **D 99**, 012013 (2019)

[10] B. McElrath, Phys. Rev. D 72, 103508 (2005).

[11] B. McElrath, Light Higgses and dark matter at bottom and charm factories, arXiv:0712.00164 (2007)

[12] M. Ablikim, et. al., Phys. Rev. **D 98**, 032001 (2018)

[13] N. Fernandez, J. Kumar, I. Seong, and P. Stengel, Phys. Rev. D 90, 015029 (2014).

[14] P. Fayet, Phys. Rev. D 74, 054034 (2006).

[15] F. C. Adams and G. Laughlin, Rev. Mod. Phys. 69, 337 (1997).

[16] A. D. Sakharov, JETP Lett., 5, 24 (1967).

[17] W. A. Rolke, Angel M. L?opezb and J. Conrad, Nucl. Instrum. Meth. A 551, 493 (2005).

[18] M.E. McCracken et al. (CLAS Collaboration), Phys. Rev. D 92, 072002 (2015).

[19] P. del Amo Sanchez et al. (BABAR Collaboration), Phys. Rev. D 83, 091101(R) (2011).

[20] K. Abe et al. (Super-Kamiokande Collaboration), Phys. Rev. D 95, 012004 (2017).

[21] M. Ablikim, et. al., arXiv: 1902.02450.

[22] P. Benes, A. Faessler, S. Kovalenko and F. Simkovic, Phys. Rev. D 71, 077901 (2005).

[23] M. Ablikim et al. (The BESIII Collaboration), Chin. Phys. C 37, 063001 (2013); M. Ablikim et al. (The BESIII Collaboration), Chin. Phys. C 42, 023001 (2018).

[24] M. Ablikim, et. al., Phys. Rev. **D 97**, 091102(R) (2018)

[25] C. Patrignani et al. (Particle Data Group), Chin. Phys. C 40, 100001 (2016) and 2017 update.