PROCEEDINGS OF SCIENCE

Baryon/Lepton number violation searches at BESIII

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Based on 2.93 fb^{-1} of e^+e^- collision data taken at $\sqrt{s}$ = 3.773 GeV and 1.31×10^9 J/ψ events taken at $\sqrt{s}$ = 3.097 GeV, we present the searches for baryon number and lepton number violation in $D^0 \to pe^-(\bar{p}e^+)$, $D^+ \to \bar{\Lambda}(\bar{\Sigma^0})e^+$, $D^+ \to \Lambda(\Sigma^0)e^+$, $D^\pm \to n(\bar{n})e^\pm$, $J/\psi \to \Lambda_c^+ e^- + c.c$, and $J/\psi \to pK^-\bar{\Lambda} + c.c$ decays. No obvious signals are found and the upper limits on the branching fractions of these decays are set to be $\sim 10^{-8} - 10^{-6}$ at 90% confidence level. Those results are the most stringent ones to date for these processes but are still far above the prediction of the higher generation model.

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

*Speaker

https://pos.sissa.it/

PoS(ICHEP2022)702

1. Introduction

As demonstrated by the stability of ordinary matter, baryon (B) number is empirically known to be conserved to a very high degree. However, the absolute conservation of B has been questioned by theory for many years. For example, the fact that there is an excess of baryons over anti-baryons in the universe implies the existence of baryon number violating (BNV) processes. Therefore, various Standerd Model (SM) extensions with BNV processes have been proposed. Under dimension six operators, BNV processes can happen with $\Delta(B-L)=0$, where $\Delta(B-L)$ is the change of baryon number minus lepton number between initial and final states [1]. Another class of BNV operators is the dimension seven operators allowing $\Delta(B-L)=2$ processes [2]. Some of the SM extensions, e.g., SU(5), SO(10), E6 and flipped SU(5) models, predict BFs for these kinds of decays at the level of 10^{-39} to 10^{-27} [4–6], which is compatible with the experimental limits from proton decay experiments. Over decades, the decay of the proton, the lightest baryon, has been searched for without success. An alternative probe is to look for the BNV decays of a heavy quark. Thus, experimental searches for these BNV decays probe new physics effects and test different models beyond the SM. Various BNV processes were searched for in τ, Λ, D and beauty hadrons decays by the CLEO [7], CLAS [8] and BaBar [9] experiments, but no evidence was found. With the large data samples accumulated by the BESIII experiment, several searches for BNV D^0, D^+ and J/ψ decays are reported. Throughout this paper, the presence of charge-conjugated processes are implied unless explicitly stated otherwise.

2. $\Delta(B-L)=0$

2.1 Search for $D^0 \to pe^-$ and $D^0 \to \bar{p}e^+$

The $D^0 \to pe^-$ and $D^0 \to \bar{p}e^+$ decays can be mediated by heavy hypothetical gauge bosons X and Y which have electric charge $\frac{4}{3}e$ or $\frac{1}{3}e$ and can couple a quark to a lepton. In 2009, the CLEO collaboration searched for the decays of $D^0(\bar{D}^0) \to \bar{p}e^+$ and $D^0(\bar{D}^0) \to pe^-$ [10] and set the upper limits (ULs) of the branching fractions (BFs) to be $\mathcal{B}(D^0(\bar{D}^0) \to \bar{p}e^+) < 1.1\times10^{-5}$ and $\mathcal{B}(D^0(\bar{D}^0) \to pe^-) < 1.0\times10^{-5}$ at 90% confidence level (CL), respectively. Note that this result did not tag the initial flavor (D^0 vs. $\bar{D}^0$) of the charm meson. By analyzing 2.93 fb^{-1} of e^+e^-

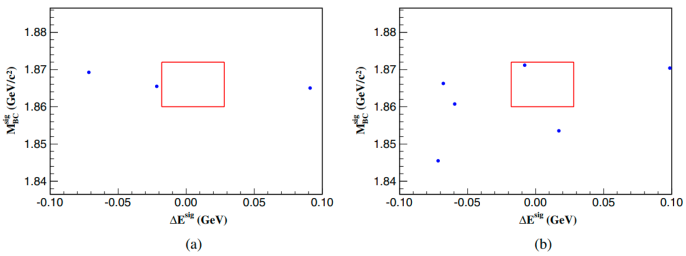

Figure 1: Distributions of $M_{\rm BC}^{\rm sig}$ vs $\Delta E^{\rm sig}$ of the candidate events for (a) $D^0 \to \bar{p}e^+$ and (b) $D^0 \to pe^-$ in data. The red rectangles denote the signal region.

collision data taken at $\sqrt{s}=3.773$ GeV, we have searched for the SM forbidden decays $D^0 \to \bar{p}e^+$ and $D^0 \to pe^-$. Figures 1(a) and 1(b) show the distributions of $M_{\rm BC}^{\rm sig}$ vs $\Delta E^{\rm sig}$ of the candidate events for $D^0 \to \bar{p}e^+$ and $D^0 \to pe^-$ selected from the data sample, respectively. No obvious signals have been observed. The ULs on $\mathcal{B}(D^0 \to \bar{p}e^+)$ and $\mathcal{B}(D^0 \to pe^-)$ at 90% CL are set to be 1.2×10^{-6} and 2.2×10^{-6} [12], respectively. These ULs are still far above the prediction of the higher generation model.

2.2 Search for $J/\psi \to \Lambda_c^+ e^-$

Although there are some searches for BNV processes in charm or bottom baryons decay [13] at the collider experiments, which might provide different and complementary information from the proton decay experiments, searching for the processes in quarkonium decay opens a new avenue to study the BNV. With the huge J/ψ data sample collected at BESIII, it is possible to study the process $J/\psi \to \Lambda^+ e^-$, and expect the first constraint of BNV from charmonium decay. By analyzing $1.31 \times 10^9 J/\psi$ events , the decay of $J/\psi \to \Lambda^+ e^-$ has been investigated for the first time. Figure 2 shows the invariant mass of the $pK^-\pi^+$ system.

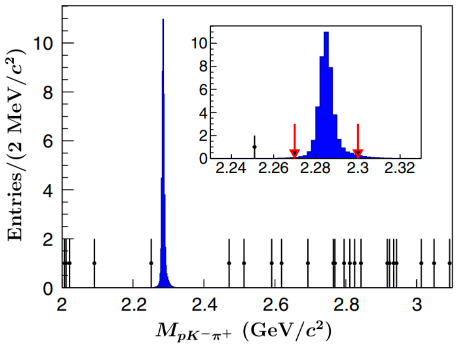

Figure 2: Distributions of $M_{pK^-\pi^+}$ for the $J/\psi \to \Lambda_c^+ e^-$ candidate events for signal MC simulation (shaded histogram) and data (dots with error bars), where the signal MC sample is normalized arbitrarily. The inset plot shows a narrow mass range within $(2.23, 2.33)$ GeV/c^2, where the arrows represent the signal mass window.

No signal event has been observed and thus the UL on the BF is set to be 6.9×10^{-8} at 90% CL [14], which is more than two orders of magnitude more strict than that of CLEO's measurement in the analogous process. The result is one of the best constraints from meson decays and is consistent with the conclusion drawn from the proton decay experiment.

3. $\Delta(B - L) = 2$

3.1 Search for $\Lambda - \bar{\Lambda}$ oscillation in $J/\psi \to pK^-\bar{\Lambda}$

The negative results from $\Delta(B - L) = 0$ decay experiments almost rule out the total parameter space of the simplest $\Delta(B - L) = 0$ GUTs. Therefore, it is very important to carry out a $\Delta(B - L)$ un-conserving exploration in both theory and experiment. The discovery of neutrino oscillations have made $N - \bar{N}$ [15] oscillation to be quite plausible theoretically if small neutrino masses are to be understood as a consequence of the seesaw mechanism, which indicates the existence of $\Delta(B - L) = 2$ interactions. Since 1980 [16], there have been many experiments searching for BNV through $n - \bar{n}$ oscillation with UL results, while few results from other baryons. X. W. Kang and H. B. Li gave a prospect of searching for $\Lambda - \bar{\Lambda}$ oscillation at the BESIII experiment [17]. The LHCb experiment presented a constraint on $\Xi_b^0\bar{\Xi}_b^0$ oscillation. The theoretical advantage for using $\Lambda - \bar{\Lambda}$ is it has a second generation quark, which can give further searches with the result of proton decay which only have the first generation quark.

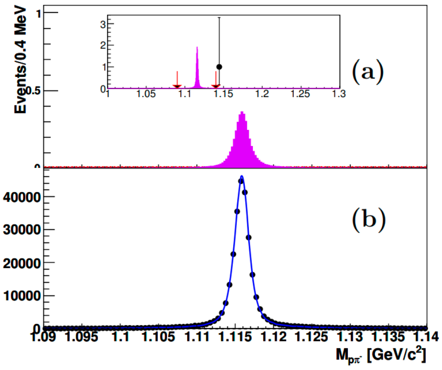

Figure 3: The $M_{p\pi^-}$ distribution of (a) WS events in the signal region and full span, where the dot with error bar is from data, the pink filled histogram which is normalized arbitrarily is from simulated WS signal events, the arrows in the inset figure show the edges of signal region, (b) RS events from data, where the dots with error bars are from data and the blue line represents the fitting result.

Based on 1.31×10^9 J/ψ events, the $\Lambda\bar{\Lambda}$ oscillation process is investigated in $J/\psi \to pK^-\bar{\Lambda}$ for the first time. And it is an alternative way to search for BNV process with $\Delta(B-N) = 2$ in addition to neutron oscillation experiments. Figure 3 (b) shows the fitted $M_{p\pi^-}$ distribution of wrong sign (WS) signal events and Fig. 3 (a) shows the $M_{p\pi^-}$ distribution of right sign (RS) signal events, where WS and RS represents the events from $J/\psi \to pK^-\bar{\Lambda} \to pK^-\Lambda$ and $J/\psi \to pK^-\bar{\Lambda}$ decays, respectively. No evidence for the baryon oscillation is observed. The UL of the oscillation rate is set to be $\mathcal{P} = \mathcal{B}(J/\psi \to pK^-\Lambda)/\mathcal{B}(J/\psi \to pK^-\bar{\Lambda}) = (N^{\rm obs}_{\rm WS}/\varepsilon_{\rm WS})/(N^{\rm obs}_{\rm RS}/\varepsilon_{\rm RS}) = 4.4\times10^{-6}$ at 90% CL [18]. Based on this constraint, the oscillation parameter is calculated to be $\delta m_{\Lambda\bar{\Lambda}} < 3.8\times10^{-15}$ MeV at 90% CL [18] corresponding to an oscillation time lower limit of 1.7×10^{-7} s. This result is comparable with the predicted one in Kang and Li's prospect with only about one-tenth data sample. Although the UL of the oscillation period is much larger than the lifetime of Λ, in some special condition such as a potential well in some kind of hypernuclei, the Λ might exist for much longer time , representing an opportunity an opportunity to obtain better constraint.

4. $\Delta(B-L) = 0, 2$

4.1 Search for $D^+ \to \bar{\Lambda}(\bar{\Sigma}^0)e^+$ and $\Lambda(\Sigma^0)e^+$

Under dimension six operators, BNV processes $D^+ \to \bar{\Lambda}(\bar{\Sigma}^0)e^+$ can happen with $\Delta(B-L) = 0$. Under dimension seven operators, BNV processes $D^+ \to \Lambda(\Sigma^0)e^+$ can happen with $\Delta(B-L) = 2$. Reference [2] argues that the decay amplitudes of these two kinds of BNV processes may be comparable. A higher-generation supersymmetry (SUSY) model predicts that the BF of $D^+ \to \bar{\Lambda}\ell^+$ is no more than 10^{-29} with the experimental limit of proton decay, where ℓ^+ represents e^+ or μ^+. The D^+ BNV decays to the $\bar{\Sigma}^0$ baryon should have a BF at similar magnitude.

By analyzing 2.93 fb^{-1} of e^+e^- collision data taken at $\sqrt{s} = 3.773$ GeV, we report the first searches for the BNV decays $D^+ \to \bar{\Lambda}e^+$ and $D^+ \to \bar{\Sigma}^0e^+$ with $\Delta(B-L) = 0$, as well as $D^+ \to \Lambda e^+$

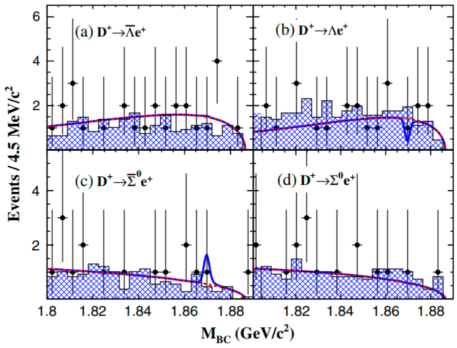

Figure 4: Fits to the $M_{\rm BC}$ distributions of the accepted candidate events in data, where the dots with error bars are data, the solid curves are the best fits, and the red dashed curves are the background shapes. The blue hatched histograms are the MC-simulated backgrounds scaled to data according to the luminosity.

and $D^+ \to \Sigma^0 e^+$ with $\Delta(B-L) = 2$. Figure 4 shows the $M_{\rm BC}$ distributions of the accepted candidate events in data and inclusive MC samples. No signals are found, and the ULs on the BFs of these decays are set at 90% CL [3]. The ULs on BFs are determined to be $\mathcal{B}(D^+ \to \Lambda e^+) = 1.1 \times 10^{-6}$, $\mathcal{B}(D^+ \to \bar{\Lambda} e^+) = 6.5 \times 10^{-7}$, $\mathcal{B}(D^+ \to \Sigma^0 e^+) = 1.7 \times 10^{-6}$, and $\mathcal{B}(D^+ \to \bar{\Sigma}^0 e^+) = 1.3 \times 10^{-6}$, respectively. These limits are far above the prediction of the higher generation model.

4.2 Search for $D^\pm \to n(\bar{n})e^\pm$

A higher-generation SUSY model predicts the BF of $D^0 \to \bar{p}\ell^+(\ell^+ = e^+, \mu^+)$ to be less than 4.0×10^{-39}, thus the decay $D^+ \to n\ell^+$ is also expected to be of a comparable magnitude because it differs only by the change of a spectator quark. In this paper, we report the first search for the BNV process $D^{+(-)} \to \bar{n}(n)e^{+(-)}$ with $\Delta(B-L) = 0$ and $D^{+(-)} \to n(\bar{n})e^{+(-)}$ with $\Delta(B-L) = 2$, by analyzing 2.93 fb^{-1} of e^+e^- collision data taken at $\sqrt{s} = 3.773$ GeV. An unbinned maximum-likelihood fit is performed to each $M_{n/\bar{n}}$ distribution as shown in Fig. 5.

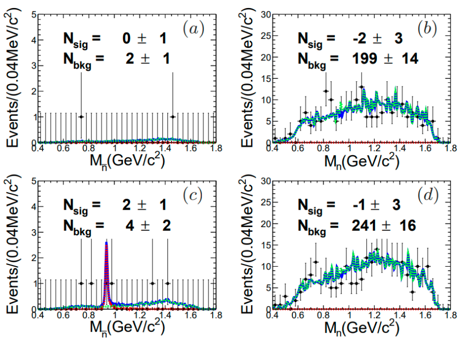

Figure 5: Fits to the $M_{n/\bar{n}}$ distributions for processes (a) $D^+ \to \bar{n}e^+$, (b) $D^- \to ne^-$, (c) $D^- \to \bar{n}e^-$ and (d) $D^+ \to ne^+$. The black dots with error bar are data. The red dotted, green dotted and blue solid lines are signal, background, and the sum of signal and background, respectively.

No signal is found and the ULs on BF at 90% CL are determined to be $\mathcal{B}(D^+ \to \bar{n}e^+) < 1.43 \times 10^{-5}$ and $\mathcal{B}(D^+ \to ne^+) < 2.91 \times 10^{-5}$ for the processes with $\Delta(B-L) = 0$ and $\Delta(B-L) = 2$ [19], respectively.

5. Summary

With 2.93 fb^{-1} of $\psi(3770)$ data and $1.31 \times 10^9 J/\psi$ events, BESIII have studied the BNV and LNV D^0, D^+ and J/ψ decays. No obvious signals are found and the ULs on these decay are set to be $\sim 10^{-8} - 10^{-6}$ at 90% CL. Those results are the most stringent ones to date for these processes but are still far above the prediction of the higher generation model. With larger data samples, and assuming no signal, it will be possible to improve the ULs of these decays.

6. Acknowledgement

The author would like to thank all the colleagues in BESIII Collaboration for their great effort to make the mentioned results available, and of course thank the organiser of ICHEP2022 conference to make the extraordinary event happen.

References

[1] S. Weinberg, Phys. Rev. Lett. **43**, 1566 (1979).

[2] F. Wilczek and A. Zee, Phys. Rev. Lett. **88**, 311 (1979).

[3] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **101**, 031102 (2020).

[4] H. Georgi and S. L. Glashow, Phys. Rev. Lett. **32**, 438 (1974).

[5] E. Kearns, Talk presented at the ISOUP Symposium, Asilomar, CA, May (2013).

[6] W. S. Hou, M. Nagashima, and A. Soddu, Phys. Rev. D **72**, 095001 (2005).

[7] R. Godang *et al.* (CLEO Collaboration), Phys. Rev. D **59**, 091303(1999).

[8] M. E. McCracken *et al.*, Phys. Rev. D**92**, 072002 (2015).

[9] P. del Amo Sanzhez *et al.* (BaBar Collaboration), Phys.Rev.D **83**, 091101(2011).

[10] P. Rubin *et al.* (CLEO Collaboration), Phys. Rev. D **79**, 097101 (2009).

[11] K. Biswal, L. Maharana and S. P. Misra, Phys. Rev. D **25** 266 (1982).

[12] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **105**, 032006 (2022).

[13] C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C 40, 100001 (2016).

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

[15] B. Dutta, Y. Mimura and R. N. Mohapatra, Phys. Rev. Lett. **96**, 061801 (2006)

[16] R. N. Mohapatra and R. E. Marshak, Phys. Rev. Lett. **44**, 1316-1319 (1980)

[17] X. W. Kang, H. B. Li and G. R. Lu, Phys. Rev. D **81**, 051901 (2010)

[18] M. Ablikim *et al.* (BESIII Collaboration), Search for $\Lambda - \bar{\Lambda}$ oscillation in $J/\psi \to pK^-\bar{\Lambda} + c.c$ (BESIII preliminary result)

[19] M. Ablikim *et al.* (BESIII Collaboration), arXiv:2209.05787.