

First Measurement of the Absolute Branching Fraction of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$ 

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The absolute branching fraction of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  is reported for the first time based on an  $e^+e^-$  annihilation sample of  $10 \times 10^9 J/\psi$  events collected with the BESIII detector at  $\sqrt{s} = 3.097$  GeV. The branching fraction is determined to be  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu) = [1.48 \pm 0.21(\text{stat}) \pm 0.08(\text{syst})] \times 10^{-4}$ , which is improved by about 30% in precision over the previous indirect measurements. Combining this result with the world average of  $\mathcal{B}(\Lambda \rightarrow pe^-\bar{\nu}_e)$ , we obtain the ratio  $\{\Gamma(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)/\Gamma(\Lambda \rightarrow pe^-\bar{\nu}_e)\}$  to be  $0.178 \pm 0.028$ , which agrees with the standard model prediction assuming lepton flavor universality. The asymmetry of the branching fractions of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  and  $\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu$  is also determined, and no evidence for  $CP$  violation is found.

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The standard model (SM) of particle physics provides precise predictions for the properties and interactions of fundamental particles, which have been confirmed by numerous experimental results (e.g., the discovery of the

Higgs boson [1,2]). However, recently there have been indications of tensions between theory and experiment, in particular in the lepton sector [3].

Semileptonic (SL) hyperon decays provide a benchmark to test the SM and complement direct searches for physics beyond the SM, especially for muonic modes which are very sensitive to nonstandard scalar and tensor contributions [4]. In the SM, the SL hyperon decays are described by SU(3) flavor symmetry, which enables systematic expansions and accurate predictions with a simplified dependence on hadronic form factors [4]. Therefore, a

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comparison of the branching fraction (BF)  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$  between its experimental measurement and its SM expectation provides an important probe of physics beyond the SM. Besides, a more precise measurement of  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$  is welcome to provide better constraints on the tensor coupling in the general analysis provided by the SM effective field theory [4].

Lepton flavor universality (LFU), which is an accidental feature of the SM [5], has been tested in recent years using a variety of different probes, and there are hits for a possible violation of LFU in semileptonic  $b$ -quark decays. The measurements are obtained from experiments at the  $B$  factories (*BABAR* [6,7] and *Belle* [8–11]), as well as at the LHC (LHCb) [12–15]. According to the results from the Heavy Flavor Averaging Group, a combined discrepancy at the level of 3 standard deviations is observed in  $b \rightarrow c\ell\bar{\nu}_\ell$  decays [16]. A similar comprehensive analysis of exotic effects in  $s \rightarrow u$  transitions has not yet been done, especially for SL hyperon decays, which can be denoted as  $B_1 \rightarrow B_2\ell^-\bar{\nu}_\ell$ . For the SL hyperon decays, the LFU test observable is the ratio between decay rates of the semi-muonic decay and the semielectronic decay  $R^{\mu e} \equiv \{\Gamma(B_1 \rightarrow B_2\mu^-\bar{\nu}_\mu)/\Gamma(B_1 \rightarrow B_2e^-\bar{\nu}_e)\}$  which is not only sensitive to LFU violation but is also linearly sensitive to the contributions of (pseudo)scalar and tensor operators [4].

In theory, working at next-to-leading order, the LFU test observable  $R^{\mu e}$  of  $\Lambda \rightarrow p$  decay is predicted to be  $0.153 \pm 0.008$  [4], while the current experimental measurement is  $0.189 \pm 0.041$  [3]. The large experimental uncertainty is dominated by the BF  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$ . So far, experimental information for  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$  has only come from fixed-target experiments [17–20], which were performed about fifty years ago. The most precise measurement was performed in 1972 [20] and was reported as a relative BF  $\{\Gamma(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)/\Gamma(\Lambda \rightarrow N\pi)\} = (1.4 \pm 0.5) \times 10^{-4}$  based on 14 signal events which were selected from about 0.6 million bubble chamber pictures. With the current level of precision, the experimental  $R^{\mu e}$  result agrees with the SM prediction. A more accurate measurement of  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$  will provide a more stringent test of LFU.

In addition, it is possible to test for  $CP$  violation, which has been observed only in  $K$  [21] and  $B$  meson decays [22,23] and in 2019 in neutral charm meson decays [24,25]. However, all effects observed so far of  $CP$  violation in particle decays cannot explain the observed matter-antimatter asymmetry in the Universe [3,26]. This motivates further searches for new sources of  $CP$  violation, which has not yet been observed in the decays of any baryon. Hence, it is vital to search for  $CP$  violation in hyperon decays. Besides, within the SM,  $CP$  violation for down-type quarks ( $s$  or  $b$ ) is expected to be larger than for up-type quarks ( $c$ ) [27], which motivates us to search for  $CP$  violation in hyperon decays as well. In 2019, the BESIII Collaboration reported the most precise direct test of  $CP$  violation in  $\Lambda$  hyperon nonleptonic decays  $\Lambda \rightarrow p\pi^-$  and

$\bar{\Lambda} \rightarrow \bar{p}\pi^+, \bar{n}\pi^0$  [28]. In comparison, no search for  $CP$  violation in SL hyperon decays has yet been reported. Hence, a search for  $CP$  violation in SL hyperon decays offers complementary information in the hyperon sector.

In this Letter, we report the first measurement of the absolute BF  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$ , by analyzing  $\Lambda\bar{\Lambda}$  hyperon pairs in  $10 \times 10^9$   $J/\psi$  meson decay events collected with the BESIII detector at  $\sqrt{s} = 3.097$  GeV. We use the double-tag (DT) technique [29], which provides a clean and straightforward BF measurement without requiring knowledge of the total number of  $\Lambda\bar{\Lambda}$  events produced. Based on the measured absolute branching fraction,  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)$ ,  $R^{\mu e}$  for  $\Lambda$  semileptonic decays is determined. In addition, the  $CP$  asymmetry of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  and  $\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu$  is also presented for the first time.

Details about the design and performance of the BESIII detector are given in Refs. [30,31]. Simulated data samples produced with a GEANT4-based [32] Monte Carlo (MC) software, which includes the geometric description of the BESIII detector and the detector response, are used to determine the detection efficiencies and to estimate backgrounds. The simulation includes the beam energy spread and initial state radiation in the  $e^+e^-$  annihilations modeled with the generator KKMC [33]. For the simulations of both of the decays  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  and  $\Lambda \rightarrow pe^-\bar{\nu}_e$ , we use the model reported in Ref. [34], and use the form factors of  $\Lambda \rightarrow pe^-\bar{\nu}_e$  obtained from experimental measurements, which are summarized in Ref. [35]. The generator constructed in Ref. [28] is used to simulate the dominant background  $\Lambda \rightarrow p\pi^-$  decay. An “inclusive” MC sample of generic events includes both the production of the  $J/\psi$  resonance and the continuum processes incorporated in KKMC [33]. The known decay modes are modeled with EvtGen [36] using BFs taken from the Particle Data Group [3], and the remaining unknown charmonium decays are modeled with LundCharm [37]. Final state radiation from charged final state particles is incorporated with PHOTOS [38].

Using the DT technique, we obtain the BF by reconstructing signal  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  decays in events with  $\bar{\Lambda}$  decays reconstructed in its dominant hadronic decay mode,  $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ . If a  $\bar{\Lambda}$  hyperon is found, it is referred to as a single-tag (ST) candidate. An event in which a signal  $\Lambda$  decay and a ST  $\bar{\Lambda}$  are simultaneously found is referred as a DT event. The BF of the signal decay is given by

$$\mathcal{B}_{\text{sig}} = \frac{N_{\text{DT}}/\epsilon_{\text{DT}}}{N_{\text{ST}}/\epsilon_{\text{ST}}}, \quad (1)$$

where  $N_{\text{DT}}$  is the DT yield,  $\epsilon_{\text{DT}}$  is the DT selection efficiency, and  $N_{\text{ST}}$  and  $\epsilon_{\text{ST}}$  are the ST yield and the ST selection efficiency. Throughout this Letter, charge-conjugated channels are always implied.

Good charged tracks detected in the main drift chamber (MDC) must satisfy  $|\cos\theta| < 0.93$ , where  $\theta$  is the polar angle with respect to the  $z$  axis, which is the axis of the MDC. Events with at least two good charged tracks are selected. Combinations of any pair of oppositely charged tracks are assigned as ST  $\bar{\Lambda}$  candidates without imposing further particle identification (PID) criteria. The pairs are constrained to originate from a common vertex by requiring the  $\chi^2$  of the vertex fit to be less than 100. The decay length of the  $\bar{\Lambda}$  candidate is required to be greater than twice the vertex resolution away from the interaction point. At least one  $\bar{\Lambda}$  hyperon is required to be reconstructed successfully via the vertex fits. The tagged  $\bar{\Lambda}$  hyperons are selected using two variables, the energy difference

$$\Delta E_{\text{tag}} \equiv E_{\bar{\Lambda}} - E_{\text{beam}}, \quad (2)$$

and the beam-constrained mass

$$M_{\text{BC}}^{\text{tag}} c^2 \equiv \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\bar{\Lambda}} c|^2}, \quad (3)$$

where  $E_{\text{beam}}$  is the beam energy, and  $\vec{p}_{\bar{\Lambda}}$  and  $E_{\bar{\Lambda}}$  are the momentum and the energy of the  $\bar{\Lambda}$  candidate in the  $e^+e^-$  rest frame. If there are multiple combinations, the one giving the minimum  $|\Delta E_{\text{tag}}|$  is retained for further analysis. The tagged  $\bar{\Lambda}$  are required to satisfy  $\Delta E_{\text{tag}} \in [-17, 13]$  MeV.

The yield of ST  $\bar{\Lambda}$  hyperons is obtained from a maximum likelihood fit to the  $M_{\text{BC}}^{\text{tag}}$  distribution of the accepted ST candidates, where we use the MC-simulated signal shape convolved with a double-Gaussian resolution function to represent the signal shape and a third-order Chebyshev function to describe the backgrounds. The signal yield is estimated in the mass region  $[1.089, 1.143]$  GeV/ $c^2$ . The fit result is shown in Fig. 1, and the total ST  $\bar{\Lambda} + \text{c.c.}$  yield is  $N_{\text{ST}} = 14,609,800 \pm 7,117(\text{stat})$ .

Candidate events for  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  decays are selected from the remaining tracks recoiling against the ST  $\bar{\Lambda}$  candidates. We require the total number of all good charged tracks to be 4 ( $N_{\text{track}} = 4$ ) with the criteria for additional good charged tracks the same as those used in the ST selection. We further identify a charged track as a  $\mu^-$  by requiring the PID likelihoods calculated by combining the MDC ionization energy loss, time-of-flight and electromagnetic calorimeter information satisfy  $\mathcal{L}_\mu > 0.001$  and  $\mathcal{L}_\mu > \mathcal{L}_e$ , where the  $\mathcal{L}_\mu$  and  $\mathcal{L}_e$  are likelihoods calculated based on the muon and electron hypotheses, respectively. The other track is assumed to be a proton. As the neutrino is not detected, we employ the kinematic variable

$$U_{\text{miss}} \equiv E_{\text{miss}} - c|\vec{p}_{\text{miss}}| \quad (4)$$

to obtain information on the neutrino, where  $E_{\text{miss}}$  and  $\vec{p}_{\text{miss}}$  are the missing energy and momentum carried by the neutrino, respectively.  $E_{\text{miss}}$  is calculated by

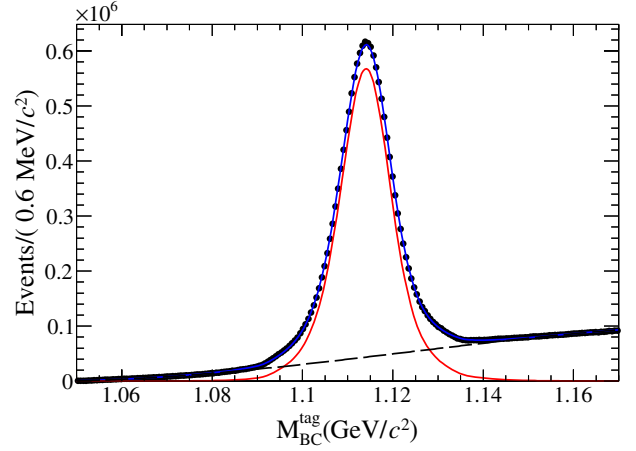


FIG. 1. Fit to the  $M_{\text{BC}}^{\text{tag}}$  distribution of the ST  $\bar{\Lambda} + \text{c.c.}$  candidates. Data are shown as dots with error bars. The solid blue, solid red, and dashed black curves are the fit result, signal shape, and the background shape, respectively.

$$E_{\text{miss}} = E_{\text{beam}} - E_p - E_{\mu^-}, \quad (5)$$

where  $E_p$  and  $E_{\mu^-}$  are the measured energies of  $p$  and  $\mu^-$ , respectively. We use the magnitude of the constrained  $\Lambda$  momentum to calculate  $p_{\text{miss}}$

$$p_{\text{miss}} = |\vec{p}_{\Lambda} - \vec{p}_p - \vec{p}_{\mu^-}|, \quad (6)$$

where  $\vec{p}_{\Lambda}$ ,  $\vec{p}_p$ , and  $\vec{p}_{\mu^-}$  are the momenta of  $\Lambda$ ,  $p$ , and  $\mu^-$ , respectively, in which  $\vec{p}_{\Lambda}$  is given by

$$\vec{p}_{\Lambda} = -\frac{\vec{p}_{\bar{\Lambda}}}{c|\vec{p}_{\bar{\Lambda}}|} \sqrt{E_{\text{beam}}^2 - m_{\Lambda}^2 c^4}, \quad (7)$$

where  $m_{\Lambda}$  is the nominal  $\Lambda$  mass. For signal events,  $U_{\text{miss}}$  is expected to peak around zero.

For the accepted signal candidates of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  decay, there is still background from the dominant hadronic decay  $\Lambda \rightarrow p\pi^-$ , because of misidentification between  $\mu^-$  and  $\pi^-$  and  $\pi^-$  decay which leads to  $\Lambda \rightarrow p\pi^- \rightarrow p\mu^-\bar{\nu}_\mu$  background. To suppress this background, we first impose a four-constraint energy momentum conservation (4C fit) kinematic fit with the  $J/\psi \rightarrow \Lambda\bar{\Lambda}$  hypothesis. Before the 4C fit, a  $\Lambda$  is reconstructed based on the  $p\pi^-$  hypothesis of obtaining the momentum vector of the  $\Lambda$ . The  $\chi^2$  of the 4C fit is required to be larger than 20. Second, for this background, the mass recoiling against  $\bar{\Lambda}p$ , i.e.,  $M_{\bar{\Lambda}p}^{\text{recoil}}$ , is expected to be the  $\pi^-$  mass. Therefore, we require that the signal candidates satisfy  $M_{\bar{\Lambda}p}^{\text{recoil}} > 0.170$  GeV/ $c^2$ . This requirement can effectively suppress the  $\Lambda \rightarrow p\pi^-$  background, resulting in the relative signal efficiency being 34 times larger than that of the background. Third, after the 4C fit, if we assign the  $\pi^-$  mass to  $\mu^-$  candidates when calculating the invariant mass of  $p\mu^-$ , i.e.,  $M_{p\mu^-}^{\text{sig}}$ , the

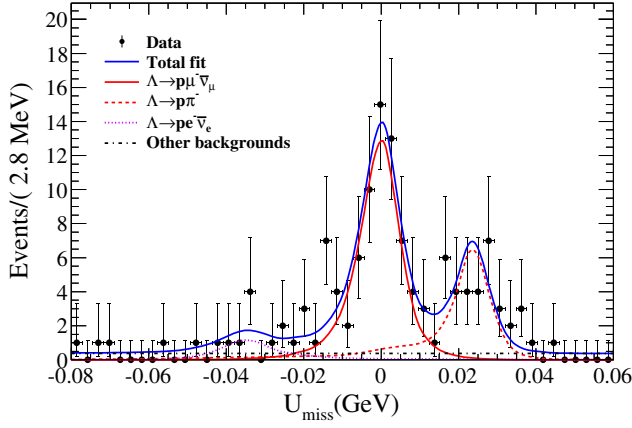


FIG. 2. Fit to the  $U_{\text{miss}}$  distribution of the DT candidates. Data are shown as dots with error bars. The solid blue and red curves are the fit result and signal shape, respectively. The dashed red and dotted violet curves are background shapes for  $\Lambda \rightarrow p\pi^-$  and  $\Lambda \rightarrow pe^-\bar{\nu}_e$  decays, respectively. The dash-dotted black curve represents the other backgrounds.

$\Lambda$  mass is expected for the background. Therefore, we can eliminate background by only retaining the events with  $M_{p\mu(4C)}^{\text{sig}} \in [1.075, 1.100] \text{ GeV}/c^2$ , which leads the relative signal efficiency to be twofold larger than that of the background. To verify the reliability of these requirements, ten cross-checks varying the criteria above and below the nominal requirements have been performed using the method reported in Ref. [39].

The inclusive MC sample is analyzed using TopoAna [40] to study potential backgrounds. After imposing the above selection criteria, there is no peaking background in the signal region, and the dominant backgrounds are  $\Lambda \rightarrow p\pi^-$  and  $\Lambda \rightarrow pe^-\bar{\nu}_e$  decays that are included in the determination of the signal yield. For the potential backgrounds that include an extra photon,  $J/\psi \rightarrow \gamma\Lambda\bar{\Lambda}$  and  $\Lambda \rightarrow p\pi^-\gamma$  decays, which are studied with corresponding exclusive MC simulation, the  $J/\psi \rightarrow \gamma\Lambda\bar{\Lambda}$  decay background is negligible. The  $\Lambda \rightarrow p\pi^-\gamma$  decay background is small but will be taken into consideration as a systematic uncertainty.

To determine the signal yield, an unbinned extended maximum likelihood fit is performed to the  $U_{\text{miss}}$  distribution. The signal is modeled by the MC-simulated signal shape convolved with a Gaussian resolution function to account for imperfect simulation of the detector resolution.

The main backgrounds are modeled by the MC-simulated shapes obtained from the exclusive MC samples. Other backgrounds are described by a first-order polynomial. The parameters of the Gaussian, the first-order polynomial, and all yields are left free in the fit. The fit to the data is shown in Fig. 2. The numbers of  $N_{\text{ST}}$ ,  $\epsilon_{\text{ST}}$ ,  $N_{\text{DT}}$ ,  $\epsilon_{\text{DT}}$ , and the BF of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu + \text{c.c.}$  are summarized in the first row of Table I.

The systematic uncertainties due to the requirements for  $N_{\text{track}} = 4$  (2.71%),  $\Lambda$  reconstruction through the vertex fit (0.05%), the 4C fit (0.57%), and the  $M_{\Lambda p}^{\text{recoil}} > 0.170 \text{ GeV}/c^2$  and  $M_{p\mu(4C)}^{\text{sig}} \in [1.075, 1.100] \text{ GeV}/c^2$  (1.04%) are studied with the control sample  $J/\psi \rightarrow \Lambda(\rightarrow p\pi^-\bar{\Lambda}(\rightarrow \bar{p}\pi^+))$  using the method reported in Ref. [28]. For the simulation of the signal MC model (2.80%), it is estimated by varying the input values of form factors [35] by 1 standard deviation. Other sources of systematic uncertainty include the following items: the MC statistics (0.01%); the proton tracking (1.00%), muon tracking (1.00%) and the muon PID (2.00%), which are cited from Refs. [41,42]; and the fits to the  $U_{\text{miss}}$  (1.87%) and  $M_{\text{BC}}^{\text{tag}}$  (2.17%) distributions estimated by using alternative fit procedures, i.e., changing the signal and background shapes for both of these fits and changing the bin size for the fit to the  $M_{\text{BC}}^{\text{tag}}$  distribution. For the fit to  $U_{\text{miss}}$ , the signal shape is changed by removing the Gaussian resolution function, and the background shapes are changed in three ways. First, we convolve the background shapes with the Gaussian resolution function which is the same as the one for the signal shape. Then, the  $\Lambda \rightarrow p\pi^-\gamma$  MC-simulated shape is added. Finally, we change the input parameters [28] by 1 standard deviation to determine the  $\Lambda \rightarrow p\pi^-$  MC-simulated shape. The total systematic uncertainty is estimated to be 5.55% by adding all these uncertainties in quadrature.

Finally, we obtain the BF,  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu) = (1.48 \pm 0.21 \pm 0.08) \times 10^{-4}$ , where the first uncertainty is statistical and the second is systematic. Combining with the well-measured BF of the decay  $\Lambda \rightarrow pe^-\bar{\nu}_e$ ,  $\mathcal{B}(\Lambda \rightarrow pe^-\bar{\nu}_e) = (8.32 \pm 0.14) \times 10^{-4}$  [3], we determine the ratio  $R^{\mu e} \equiv \{\Gamma(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)\}/\{\Gamma(\Lambda \rightarrow pe^-\bar{\nu}_e)\}$  to be  $R^{\mu e} = 0.178 \pm 0.028$ . This result is consistent within uncertainties with the value  $0.153 \pm 0.008$  that is expected from LFU in the SM [4].

The BFs of the charge-conjugated decays  $\Lambda \rightarrow p\mu^+\nu_\mu$  and  $\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu$ ,  $\mathcal{B}_{\Lambda \rightarrow p\mu^+\nu_\mu}$ , and  $\mathcal{B}_{\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu}$ , are measured

TABLE I. The  $N_{\text{ST}}$ ,  $N_{\text{DT}}$ ,  $\epsilon_{\text{ST}}$ ,  $\epsilon_{\text{DT}}$  and the obtained BFs. The uncertainties are statistical only.

Decay mode	$N_{\text{ST}}(\times 10^3)$	$N_{\text{DT}}$	$\epsilon_{\text{ST}}(\%)$	$\epsilon_{\text{DT}}(\%)$	$\mathcal{B}_{\text{sig}}(\times 10^{-4})$
$\Lambda \rightarrow p\mu^-\bar{\nu}_\mu + \text{c.c.}$	$14,609.8 \pm 7.1$	$64 \pm 9$	$55.36 \pm 0.05$	$1.65 \pm 0.01$	$1.48 \pm 0.21$
$\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$	$7,385.9 \pm 5.1$	$31 \pm 7$	$55.21 \pm 0.06$	$1.64 \pm 0.01$	$1.43 \pm 0.30$
$\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu$	$7,391.0 \pm 5.0$	$33 \pm 6$	$55.50 \pm 0.08$	$1.66 \pm 0.01$	$1.49 \pm 0.29$

separately. The asymmetry of these two BFs is determined as

$$\mathcal{A}_{CP} \equiv \frac{\mathcal{B}_{\Lambda \rightarrow p\mu^-\bar{\nu}_\mu} - \mathcal{B}_{\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu}}{\mathcal{B}_{\Lambda \rightarrow p\mu^-\bar{\nu}_\mu} + \mathcal{B}_{\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu}}. \quad (8)$$

The corresponding  $N_{ST}$ ,  $N_{DT}$ ,  $\epsilon_{ST}$ ,  $\epsilon_{DT}$ , and the BFs are summarized in the last two rows of Table I. The asymmetry is determined to be  $\mathcal{A}_{CP} = 0.02 \pm 0.14(\text{stat}) \pm 0.02(\text{syst})$ , where the systematic uncertainties of  $N_{\text{track}} = 4$ ,  $\Lambda$  reconstruction through the vertex fit, the  $4C$  fit, the  $M_{\Lambda p}^{\text{recoil}} > 0.170 \text{ GeV}/c^2$ , the  $M_{p\mu(4C)}^{\text{sig}} \in [1.075, 1.100] \text{ GeV}/c^2$ , and the signal MC model cancel. Other systematic uncertainties are estimated separately as above. No evidence for  $CP$  violation is found.

In summary, using  $10 \times 10^9 J/\psi$  decay events collected with the BESIII detector at  $\sqrt{s} = 3.097 \text{ GeV}$ , the semi-leptonic hyperon decay  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  is studied at a collider experiment for the first time. Based on the double-tag method, we report the first measurement of the absolute BF of  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  as  $\mathcal{B}(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu) = [1.48 \pm 0.21(\text{stat}) \pm 0.08(\text{syst})] \times 10^{-4}$  which improves the precision of the world average value by about 30%. The BF is consistent with theoretical predictions that incorporate quark SU(3) flavor symmetry without symmetry breaking [34], and predictions based on the factorization of the contribution of valence quarks and chiral effects [43].

Using the well-measured branching fraction of the decay  $\Lambda \rightarrow pe^-\bar{\nu}_e$ , we determine the ratio  $R^{\mu e} \equiv \{[\Gamma(\Lambda \rightarrow p\mu^-\bar{\nu}_\mu)]/[\Gamma(\Lambda \rightarrow pe^-\bar{\nu}_e)]\}$  to be  $R^{\mu e} = 0.178 \pm 0.028$  which is in agreement with the previous results but is the most precise to date. The  $R^{\mu e}$  result agrees with LFU, and the higher precision can aid in the study of the (pseudo) scalar and tensor operator contributions in theory [4]. The asymmetry of the BFs of charge-conjugated decays  $\Lambda \rightarrow p\mu^-\bar{\nu}_\mu$  and  $\bar{\Lambda} \rightarrow \bar{p}\mu^+\nu_\mu$  is also determined. No evidence for  $CP$  violation is found.

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