Search for Baryon and Lepton Number Violation in $J/\psi \to \Lambda^{+}\pi^{-}e^{-} + c.c.$
Using 1.31 \times 10^9 J/\psi events collected by the BESIII detector at the Beijing Electron Positron Collider, we search for the process \( J/\psi \to \Lambda^+_c e^- + \text{c.c.} \) for the first time. In this process, both baryon and lepton number conservation is violated. No signal is found and the upper limit on the branching fraction \( B(J/\psi \to \Lambda^+_c e^- + \text{c.c.}) \) is set to be 6.9 \times 10^{-8} at the 90% Confidence Level.

The observed matter–antimatter asymmetry in the universe poses 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 \( 10^9 \sim 10^{10} \). To give a reasonable interpretation of the baryon-antibaryon asymmetry, Sakharov proposed three principles, 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. The SU(5) grand unification theory (GUT) \[ 3 \], which covers the SM gauge group \( SU_L(3) \times SU_L(2) \times U_Y(1) \), was first proposed as a minimal extension of the SM. In that scenario, two extra gauge bosons, \( X \) and \( Y \), with charges of \( 4/3 \) and \( 1/3 \), the so-called leptoquarks, exist and can violate baryon-lepton number conservation. In the unification picture, their masses are about \( 10^{15} \text{ GeV}/c^2 \). Unfortunately, this simplest SU(5) model is ruled out because its prediction of the proton lifetime is several orders of magnitude smaller than the experimental lower limits. However, this does not rule out the need to search for grand unification theories that allow for BN violation. For example, the SO(10), the E6 and the flipped SU(5) models all predict a longer proton lifetime that is not in conflict with the present data.

In this Letter, we analyze the \( J/\psi \) data sample collected with the BESIII detector operating at the BEPCII storage ring \[ 8 \] to search for the SM forbidden baryon-lepton number violating decay \( J/\psi \to \Lambda^+_c e^- \) (charge conjugation is implied throughout this Letter). Based on this analysis, we set an upper bound on the rate of \( J/\psi \to \Lambda^+_c e^- \).

The BESIII detector has a geometric acceptance covering 93% of the 4\pi solid angle and consists of the following main components. (1) A small-celled main drift chamber (MDC) with 43 layers is used to track charged particles. The average single-wire resolution is 135 \( \mu \text{m} \), the momentum resolution for 1 GeV/c charged particles in a 1 T magnetic field is 0.5%, and the specific energy loss (dE/dx) resolution is better than 6%. (2) An electromagnetic calorimeter (EMC) is used to measure photon energies. The EMC is made of 6240 CsI(Tl) crystals arranged in a cylindrical shape (barrel) plus two endcaps. For 1.0 GeV photons, the energy resolution is 2.5% in the barrel and 5% in the endcaps, and the position resolution is 6 mm for the barrel and 9 mm for the endcaps. (3) A time-of-flight (TOF) system is used for particle identification (PID). It is composed of a barrel made of two layers, each consisting of 88 pieces of 5 cm thick and 2.4 m long plastic scintillators, as well as two endcaps each with 96 fan-shaped 5 cm thick plastic scintillators. The time resolution is 80 ps in the barrel and 110 ps in the endcaps, providing a \( K/\pi \) separation of more than
is defined to be $(2.27, 2.30)$ GeV/$c^2$ in the $pK^-\pi^+$ invariant mass distribution. This corresponds to a range of $\pm 4$ times the mass resolution around the $\Lambda_c^+$ nominal mass. The detection efficiency is determined to be $(35.43 \pm 0.02)\%$ based on simulated $J/\psi \rightarrow \Lambda_c^+ e^- \rightarrow pK^-\pi^+ e^-$ events, where the $\Lambda_c^+$ decay is modeled by a dedicated generator according to the result of a Partial Wave Analysis (PWA) of the decay $\Lambda_c^+ \rightarrow pK^-\pi^+$ [16]. Besides the non-resonant 3-body decay process, processes with intermediate states (such as $\Delta^+\pi^+$, $\Delta(1600)^+\pi^+$, excited $\Lambda$ states, excited $\Sigma$ states), as well as the corresponding interferences, are also included in the helicity amplitudes. Parity conservation is not required since this is a weak decay. The data and MC simulation for the decay $\Lambda_c^+ \rightarrow pK^-\pi^+$ are compared and found to be in good agreement, based on $567 \mathrm{pb}^{-1}$ of experimental data taken at $\sqrt{s} = 4.599$ GeV, just above the threshold for $\Lambda_c$ pair production [16]. This consistency leads to a negligible systematic uncertainty due to the generator.

The background from $J/\psi$ decays is investigated using an inclusive MC sample which has the same size as the $J/\psi$ data sample. No background events are found in the signal window. The background from QED processes is studied with other simulated MC samples of $e^+ e^- \rightarrow q\bar{q}$, $e^+ e^- \rightarrow (\gamma) e^+ e^-$ and $e^+ e^- \rightarrow (\gamma) \mu^+ \mu^-$ which correspond to 40, 1.5 and 30 times the $J/\psi$ data, respectively. Most of these backgrounds are rejected by the PID requirements and the kinematic fit. The normalized number of surviving background events is 0.03, which is from wrong PID in the process $e^+ e^- \rightarrow K^+ K^- \pi^+ \pi^-$. The background from QED processes is also verified by using experimental data samples taken away from the $J/\psi$ and $\psi(3686)$ mass regions, including data taken at 3.08 GeV, 3.65 GeV, and scan data sets covering the energy range from 2.23 to 4.59 GeV. No events are found in the signal window after taking into account the differences in the integrated luminosities, the cross sections, the particle momenta, and the beam energies [17].

The candidate events of $J/\psi \rightarrow \Lambda_c^+ e^-$ are studied by examining the invariant mass of the $pK^-\pi^+$ system, $M_{pK^-\pi^+}$, as shown in Fig. 2. Since no events are observed in the signal window, the upper limit on the number of signal events $s_{90}$ for $J/\psi \rightarrow \Lambda_c^+ e^-$ is estimated to be 5.7 at the 90% CL by utilizing a frequentist method [18] 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 of $J/\psi \rightarrow \Lambda_c^+ e^-$ is determined by

$$B(J/\psi \rightarrow \Lambda_c^+ e^-) < \frac{s_{90}}{N_{j/\psi}^{\text{tot}} \times B(\Lambda_c^+ \rightarrow pK^-\pi^+)}$$

where $N_{j/\psi}^{\text{tot}} = (1310.6 \pm 7.0) \times 10^6$ is the total number of $J/\psi$ decays [19], and $B(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.35 \pm 0.33)\%$.
is the decay branching fraction taken from Ref. [20]. Inserting the numbers of $s_0$, $N_j^{\text{tot}}$, and $\mathcal{B}(\Lambda^+_c \to pK^-\pi^+)$ into the above equation, the upper limit on the branching fraction of $J/\psi \to \Lambda^+_c e^-$ is determined to be

$$\mathcal{B}(J/\psi \to \Lambda^+_c e^-) < 6.9 \times 10^{-8}.$$  

![Graph](image)

**FIG. 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 $(2.23, 2.33)\text{ GeV}/c^2$, where the arrows represent the signal mass window.

Systematic uncertainties in the measurement of $\mathcal{B}(J/\psi \to \Lambda^+_c e^-)$ mainly originate from the total number of $J/\psi$ events, the tracking efficiency, the PID efficiency, the kinematic fit, the MC modeling, and the quoted branching fraction for $\Lambda^+_c \to pK^-\pi^+$. The uncertainty in the total number of $J/\psi$ determined via inclusive hadronic events is 0.5% [19]. The uncertainty due to tracking efficiency is 1.0% for each track, as determined from a study of the control samples $J/\psi \to pK^-\Lambda$ and $\psi(3686) \to \pi^+\pi^- J/\psi$ [23]. The uncertainties arising from the differences of PID efficiencies between data and MC simulation for electron, pion, kaon, and proton are determined with the control samples $e^+e^- \to \gamma e^+e^-$ (at 3.097 GeV), $J/\psi \to K^+K^-\pi^0$, $J/\psi \to \pi^+\pi^-\pi^0$ and $J/\psi \to \pi^+\pi^-p\bar{p}$, respectively. They are 0.3%, 1.0%, 0.5% and 0.6% for electron, pion, kaon and proton, respectively. The uncertainty of the kinematic fit is estimated using a control sample of $J/\psi \to \pi^+\pi^-p\bar{p}$, where a selection efficiency is defined by counting the number of events with and without the kinematic fit requirement. The difference of the selection efficiencies between data and MC simulation, 0.2%, is assigned as the corresponding systematic uncertainty. The uncertainty due to MC modeling is negligible [16]. In the calculation of the upper limit, the branching fraction $\mathcal{B}(\Lambda^+_c \to pK^-\pi^+) = (6.35 \pm 0.33)\%$ is quoted from Ref. [20], yielding a systematic uncertainty of 5.2%. The total systematic uncertainty is 7.0%, obtained by adding all of the above uncertainties in quadrature.

In summary, by analyzing $1.3106 \times 10^9 J/\psi$ events collected at $\sqrt{s} = 3.097$ GeV with the BESIII detector at the BEPCII collider, the decay of $J/\psi \to \Lambda^+_c e^- + c.c.$ has been investigated for the first time. No signal events have been observed and thus the upper limit on the branching fraction is set to be $6.9 \times 10^{-8}$ at the 90% CL, which is more than two orders of magnitude more strict than that of CLEO's measurement in the analogous process [6]. The result is one of the best constraints from meson decays [22, 23] and is consistent with the conclusion drawn from the proton decay experiment [24].

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