A search for baryon- and lepton-number violating decays of Λ hyperons using the CLAS detector at Jefferson Laboratory

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The Standard Model (SM) of particle physics has had great success in interpreting and predicting experimental results since its conception in the late 1960s. There are, however, features of our universe that are inconsistent with the SM framework. Astronomical observations suggest that our Universe is dominated by matter over antimatter, however cosmological models assume an early universe with no such asymmetry (*i.e.*, matter and antimatter in equal proportions). The *de facto* assumption of the high-energy physics community is that this indicates a failing of the SM. In the SM, baryon number (B) is used to quantify the amount of matter and antimatter that participate in a reaction. With one rare exception, all SM processes conserve B, meaning that any reaction would begin and end with the same amounts of matter and antimatter. A possible explanation for the asymmetry in our Universe is that there are yet-unobserved particle interactions, outside of the SM framework, that voilate B conservation.

Other experiments have been performed to search for baryon-number-violating (BNV) processes in decays of the nucleon, τ leptons, top quarks, hadrons with bottom and charm quarks, and the Z boson, but no signal has yet been observed. Missing from this list, however, are analyses of processes involving strange quarks in the initial state. This paper presents a search for BNV decays of the Λ hyperon (a bound state of u, d, and s quarks) as a direct probe of couplings of BNV interactions to the strange quark. Though this type of analysis was perhaps not one of their initial physics goals, the CLAS and CEBAF are well suited for this search for several reasons, including observed energy range, photon energy tagging, and optimization for charged-particle detection. In addition, previous analyses of the Λ production have demonstrated that CLAS provides impressive signal/background separation, a feature crucial to searches for rare reactions. The data used in this analysis are part of the g11 run period, gathered in the Summer of 2004.

We investigated eight potential BNV decay modes in which the Λ decays to a charged meson and a charged lepton (the meson being either a $\pi^{\pm}$ or $K^{\pm}$, the lepton being either a $e^{\mp}$ or a $\mu^{\mp}$) or to a K_S^0 meson and a neutrino. These decay modes are motivated by several theoretical models that rely on a novel class of particles, the so-called *leptoquarks*, to generate baryon number violation. In addition, we searched for the decay of a Λ to an anti-proton and a π^+. This is an example of a baryon-antibaryon oscillation reaction, in which a neutral matter state spontaneously oscillates into its antimatter counterpart. Such reactions would have far-reaching implications and are often highlighted as consequences of high-energy theories ranging from see-saw models to extra dimensions.

For all channels, the analysis proceeded in three steps. We first used the charged SM decay mode $\Lambda \to p\pi^-$ to determine the total number of $K^+\Lambda$ events produced during the run period. We then developed a set of background separation cuts for each BNV channel, based on timing information for all charged final-state particles and event-based kinematic observables. We assessed the signal efficiency using a Monte Carlo technique and the background size using side-bands of blinded signal regions. After optimizing BNV channel cuts, we unblinded the data to determine whether BNV signal was present.

Though similar studies have been performed with much higher sensitivities for decays of the nucleon, this study offers the first direct probe of BNV processes involving strange quarks in the initial state. We found no BNV signal in any of the ten decay channels investigated, and set upper limits on the branching fraction for each decay mode in the range 7×10^{-7} to 2×10^{-5}, values competitive with upper limits on BNV processes in heavy-quark, lepton, and boson decays at performed at facilities such as SLAC, the Tevatron, and the LHC.

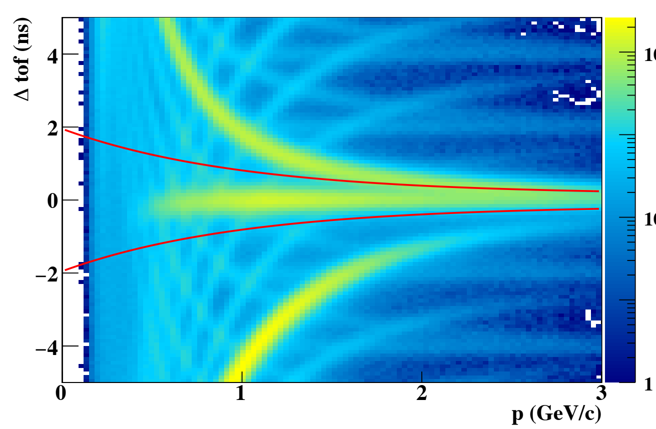

FIG. 1. Δtof versus momentum (p) for K^+ candidate tracks for all data events that pass a cut on missing mass squared centered at zero. This plot demonstrates the excellent background separation afforded by the CLAS, one of the key features of this analysis. The red curves show the upper and lower bounds of a cut selecting SM $K^+\Lambda$ photoproduction events. Several background structures are present in this distribution. The majority of these background events are removed by later analysis cuts. After all analysis cuts, we are left with a clean Λ sample of roughly 1.8×10^6 events.