Neutral Hyperon and H-Dibaryon Results from KTeV

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Abstract. Results from the KTeV experiment at Fermilab using Ξ⁰ hyperons are presented, especially the first form-factor (FF) measurement from its semi-leptonic decay. This decay, which is an important test of the Standard Model, was observed for the first time using the 1997 KTeV experiment. We also report on the analysis of a large samples of Ξ⁰ weak radiative decays, and a search for the decay of a lightly bound \( H^0 \) dibaryon.

INTRODUCTION

The KTeV experiment is a neutral beam experiment produced by protons from the Tevatron accelerator at 800 GeV/c impinging on a target at a 4.8 mrad angle. The fiducial decay volume starts 90 m down stream of a target because of the space needed to collimate the neutral beam which is where most of the neutral particles decay and is also the location of the sweeping magnetics that eliminate the charged particles. The decay volume from 90 to 160 m from the target is an ultra high vacuum to reduce interactions and has scintillator ring counters to veto those events where the particles have left the fiducial volume. A spectrometer consisting of tracking chambers, an analysis magnet, electromagnetic calorimetry (CsI) [1], particle identification by transition radiation detectors (TRD) [2], and a muon counter system with 5 m of iron filter directly follows the decay volume.

Data was collected in 16 triggers for two different experimental configurations in 1997 and 1999. A rare kaon decay program E799 [3,4], and the search for direct CP violation E832 [5] are presented elsewhere in these proceedings. Presented here are part of the results from a neutral hyperon program that had three triggers in the E799 experiment configuration, and limited to the results from the 1997 run.

PHYSICS ANALYSIS

Physics results from the KTeV hyperon program are:
Semi-leptonic Decays: Neutral hyperon semi-leptonic decays accessible in KTeV are the beta-decay $\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e$, and muon decay $\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu$. They are important to study for their weak decay FF which give an understanding of their underlying structure. In the V-A formulation the transition amplitude for the beta decay is:

$$M = \frac{G}{\sqrt{2}} < \Sigma|J^\lambda|\Xi > \bar{u}_e \gamma_\lambda (1 + \gamma_5) u_\nu$$  \hspace{1cm} (1)$$

The V-A hadronic current can be written as:

$$< \Sigma|J^\lambda|\Xi > = C i \bar{u}(\Sigma) \left[ f_1 \gamma^\lambda \sigma_{\mu \nu}^\lambda \gamma_\nu + f_2 \frac{M_\Xi}{M_\Sigma} \lambda M_\Xi + g_1 \gamma^\lambda + g_2 \frac{M_\Xi}{M_\Sigma} \lambda M_\Xi \right] \gamma_5 \bar{u}(\Xi)$$  \hspace{1cm} (2)$$

where $C$ is the CKM matrix element, and $q$ is the momentum transfer. There are 3 vector FF: $f_1$ (vector), $f_2$ (weak magnetism) and $f_3$ (an induced scaler); plus 3 axial-vector FF: $g_1$ (axial vector), $g_2$ (weak electricity) and $g_3$ (an induced pseudo-scaler). All six FF are real if time reversal invariance is valid. The quark model predicts a nonzero but small $g_2$ FF if SU(3) breaking is sizable, but the standard model assumes this FF is zero. The FF $f_3$ and $g_3$ for the beta decay, are expected to be large (i.e. $\frac{q_3}{g_1} \sim 8$), but it is multiplied by $\frac{M_\Xi}{M_\Sigma}$ making this term negligibly small so as not to contribute any noticeable effect, but for the muon decay this may no longer be assumed. Furthermore, neither of these decays had previously been observed so measuring their branching ratio was also important as a test of the standard model, and in the case of the muon decay this could be the first place to look for a $g_3$ FF. The final results for the beta decay are a branching ratio of $(2.60 \pm 0.11 \pm 0.16) \times 10^{-4}$, based on 626 events where the first error is statistical and the second systematic, and the theoretical expected is $2.6 \times 10^{-4}$. For the muon decay its preliminary branching ratio is $(3.5 \pm 2.0 \pm 0.5) \times 10^{-6}$ based on 5 events, again the first error is statistical and the second systematic, while the asymmetric error bars are from the small number of events and poisson statistics at the 68% C.I. [6]; theoretical expected is $2.6 \times 10^{-6}$.

A very clean sample of $\Xi^0$ beta decays, see figure 1 left, was obtained by using the TRD detector. The decays of the $\Sigma^+$ has a 98% analyzing power, and this fact makes its equivalent to a fully polarized beam. However, spin alignment magnetics gave the ability to control this and then test the technique on the much bigger normal mode decays: $\Xi^0 \rightarrow \Lambda^0 \pi^0$. By working in the $\Sigma^+$ reference frame all of the FF could be devised by measuring the angular distribution of the proton relative to the electron, neutrino (we typically use the reconstructed transverse neutrino direction) see figure 1 right, as well as test the technique by comparing the proton direction relative to the reconstructed $\Xi^0$. The final four FF are: $f_1 = 0.99 \pm 0.14$, $\frac{q_1}{f_1} = 1.24 \pm 0.27$, $\frac{q_2}{f_1} = 2.3 \pm 1.3$, and $\frac{q_3}{f_1} = -1.4 \pm 2.1$; here this analysis used the previously quoted branching ratio, and permitted the $g_2$ FF to float. The $g_2$ FF is
FIGURE 1. On the left is the $\Xi^0$ beta decay compared to its normalized MC and possible backgrounds, and on the right is the angular distribution in the $\Sigma^+$ reference frame of the angular asymmetry of the proton to electron, reconstructed neutrino and between the reconstructed neutrino and the electron.

consistent with zero and in another analysis it was constrained to be zero and the FF reanalyzed and they essentially remained unchanged.

**Radiative Decays:** Neutral hyperon radiative decays accessible in KTeV are: $\Xi^0 \rightarrow \Sigma^0 \gamma$ and $\Xi^0 \rightarrow \Lambda^0 \gamma$. Although these decays are not simple first-order processes but actually proceed through complicated diagrams, they are important to study because they are difficult to calculate, but yet have high branching ratios. Furthermore, the angular emission of the high energy gamma relative to the hyperon polarization can be related to the underlying mechanism of its decay as a test of various theories. The decay $\Xi^0 \rightarrow \Sigma^+ \gamma$ in KTeV is identified when a second radiative decay of $\Sigma^0 \rightarrow \Lambda^0 \gamma$ and then for both radiative decays of the $\Xi^0$ through the charged particle decay of $\Lambda^0 \rightarrow p^+\pi^-$. As with the semi-leptonic decays the self analyzing power with hyperon decays permits the polarization to be determined relative to the gamma angular distribution. The final results for the radiative decay $\Xi^0 \rightarrow \Sigma^0 \gamma$ is a branching ratio of $(3.34 \pm 0.05 \pm 0.11) \times 10^{-3}$, based on 4048 events, shown in figure 2 left, where the first error is statistical and the second systematic. The angular distribution of the gamma relative to the $\Xi^0$ polarization vector is $-0.65 \pm 0.13$, see figure 2 right. The radiative decay $\Xi^0 \rightarrow \Lambda^0 \gamma$ preliminary branching ratio is $(0.95 \pm 0.03 \pm 0.09) \times 10^{-3}$ based on 1105 events.

**Dibaryon Search:** The KTeV hyperon data was used to search for a six quark neutral hadron state which has two strange, two up and two down quarks that decays $H^0 \rightarrow \Lambda^0 p^+ \pi^-$. The data used for normalizing the decay was $\Xi^0 \rightarrow \Lambda^0 \pi^0$ with the decay of the $\Lambda^0 \rightarrow p^+ \pi^-$ and $\pi^0 \rightarrow e^+e^-\gamma$. These two decays share
FIGURE 2. On the left is the $\Xi^0 \to \Sigma^0\gamma$ decay signal compared to its normalized MC, and on the right the determination of the gamma angular asymmetry.

similar technical details for their analysis: two different charged particle vertices, a reconstructible $\Lambda^0$ mass peak and a stiff proton. Using the 1997 data from KTeV E799 run we have ruled out the existence of a $H^0$ dibaryon in the mass range from 2.194 to 2.231 GeV/c$^2$ for long lifetimes of $5 \times 10^{-10}$ to $1 \times 10^{-3}$ seconds at the 90% CI [7].

CONCLUSIONS

The results quoted here are the final measurements for these decays from the 1997 KTeV run. Three times more data exists from the 1999 run which is in the process of being analyzed. Future results are planned to make improvements in all decay modes, and some decays previously excluded by trigger requirements, such as: $\Xi^0 \to \Lambda^0\pi^0$ where the decay $\pi^0 \to e^+e^-\gamma$ will provide a sample of decays where the $z$ vertex can be measured from the two electrons for use in a $\Xi^0$ mass and lifetime improved measurement, the decay $\Xi^0 \to \Sigma^0\gamma$ with the special decay $\Sigma^0 \to \Lambda^0e^+e^-$, or the radiative decay $\Xi^0 \to \Lambda^0\pi^0\gamma$. All of these decays are especially well suited for the excellent abilities of $\pi^0$ and $\gamma$ measurements with our high precession CsI electromagnetic calorimeter, and our unmatched $\pi^\pm/e^\pm$ rejection obtained with the TRD system.

REFERENCES

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