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A study of the ΔI = 1/2 rule in the weak decay of S-shell hypernuclei: BNL E931.

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It is empirically observed that the non-leptonic decay of strange hadrons is enhanced when the change in isospin is 1/2. This is generalized in the "ΔI = 1/2 rule" that states that all such decays proceed predominately through ΔI = 1/2 amplitudes. However, there is no definitive explanation for this apparently universal rule. Non-mesonic decay of Λ-hypernuclei can occur through a weak decay process $\Lambda N \to nN$. By measuring the relative decay widths (Γ_n/Γ_p) in the full set of s-shell hypernuclei, a sensitive test of the ΔI = 1/2 rule, and the determination of its applicability to non-mesonic decays can be made. In addition, information about the spin-isospin dependence of the weak decay process can be extracted. A measurement of Γ_n/Γ_p to an accuracy of even 50% will be sufficient to address important issues relating to the ΔI = 1/2 rule and to the weak decay process. AGS experiment 931 will measure the ratio Γ_n/Γ_p following the decay of ${}^4_\Lambda$H which is produced by a stopped K^- beam in a liquid Helium target. Arrays of charged particle and neutron detectors will measure the relative neutron and proton emission probabilities.

1. INTRODUCTION

A particle stable Λ hypernucleus normally decays electromagnetically to its ground state before undergoing a weak decay to an ordinary nucleus. The mesonic decay widths

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are characterized by the decays:

$$\begin{array}{ll} \Lambda \rightarrow p + \pi^- & \Gamma_{\pi^-} \\ \Lambda \rightarrow n + \pi^0 & \Gamma_{\pi^0} \end{array} \tag{1}$$

The non-mesonic decay widths, where the decay is stimulated by the interaction of the Λ with a nucleon are given by:

$$\begin{array}{ll} \Lambda + p \rightarrow n + p & \Gamma_p \\ \Lambda + n \rightarrow n + n & \Gamma_n \end{array} \tag{2}$$

where the total non-mesonic decay width is $\Gamma_{nm} = \Gamma_p + \Gamma_n$. Since both mesonic and non-mesonic decays contribute in s-shell Λ hypernuclear decay, all of the decay widths are important to describe the decay process. In particular, mesonic decay is Pauli blocked in heavy hypernuclei and non-mesonic decay dominates. Thus, s-shell Λ hypernuclei provide an ideal testing ground to examine the weak decay process.

The total non-mesonic width seems to be relatively insensitive to the details of the weak interaction model, but the ratio, Γ_n/Γ_p is strongly dependent. If treated by a meson exchange interaction, this ratio is sensitive to specific mesonic exchange components (π, ρ, K, etc.) and to the imposition of the ΔI = 1/2 rule [1]. This rule simply states that transitions where the isospin changes by 1/2 are favored over those where isospin changes by 3/2. There is no universal explanation [2] for the ΔI = 1/2 rule. The relation between the partial decay rates and the nuclear densities for all s-shell hypernuclei can be expressed as:

$$\begin{aligned} \Gamma_{nm}({}^3_\Lambda\mathrm{H}) &= \tfrac{1}{8}\rho_3(R_{p1} + 3R_{p0} + R_{n1} + 3R_{n0}) \\ \Gamma_{nm}({}^4_\Lambda\mathrm{H}) &= \tfrac{1}{6}\rho_4(2R_{p0} + 3R_{n1} + R_{n0}) \\ \Gamma_{nm}({}^4_\Lambda\mathrm{He}) &= \tfrac{1}{6}\rho_4(3R_{p1} + R_{p0} + 2R_{n0}) \\ \Gamma_{nm}({}^5_\Lambda\mathrm{He}) &= \tfrac{1}{8}\rho_5(3R_{p1} + R_{p0} + 3R_{n1} + R_{n0}) \end{aligned} \tag{3}$$

where the ρ-factors are the mean nucleon densities at the position of the Λ in each nucleus. For ΔI = 1/2 decays, $R_{n0} = 2R_{p0}$, since only I = 1 final states are allowed. In particular, the Δ I = 1/2 rule predicts $\Gamma({}^4_\Lambda\mathrm{H}) = 2\Gamma({}^4_\Lambda\mathrm{He})$.

The total decay width can be *naively* considered to be proportional to the overlap of Λ and nucleon wave functions. Thus, it is very sensitive to the Λ-nucleus potential. Determining the partial decay widths for each process for the complete set of s-shell hypernuclei will fully determine (over determine) the nuclear densities and wave functions. Although there are no direct measurements on the non-mesonic decay of ${}^4_\Lambda$H, it can be estimated from other existing data (the total lifetime is known, for example). KEK results [3] based on measurements of $\Gamma_{Tot}({}^4\mathrm{H})$ and $\Gamma_p/\Gamma_n({}^4\mathrm{He})$ suggest that $\Gamma({}^4_\Lambda\mathrm{H}) \approx \Gamma({}^4_\Lambda\mathrm{He})$. But these estimates are very sensitive to the theoretical assumptions about the mesonic widths.

The mesonic widths may also have an impact on our understanding of QCD. It is suggested that ΛN$\rightarrow$NN amplitudes may be dominated by direct quark processes [4,5] with no intermediate meson. Such processes would not be expected to follow the ΔI =

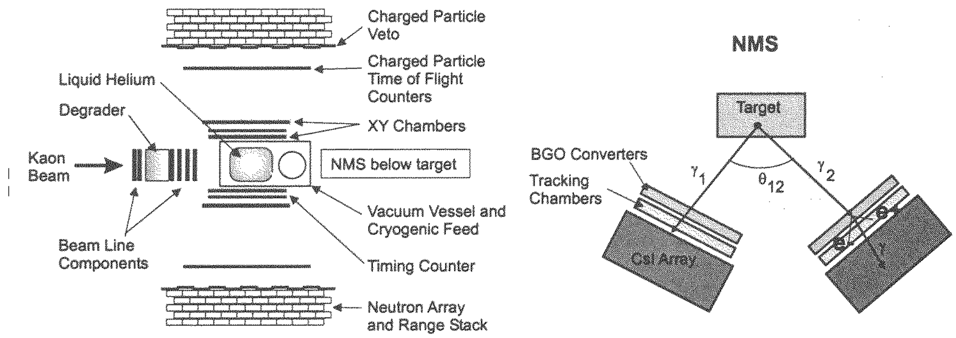

Figure 1. AGS E931 experimental layout, with the NMS shown on the right side. In the experiment it is located under the target.

1/2 rule. However, violation of the $\Delta I = 1/2$ rule would not, by itself, provide sufficient evidence to confirm this mechanism.

It is the purpose of this paper to describe an experiment that will provide a sufficiently precise measurement of Γ_n/Γ_p for ${}^4_\Lambda$H that will complete the relevant data for s-shell hypernuclei and address some of these issues.

2. EXPERIMENT DESCRIPTION

Experiment 931 will produce ${}^4_\Lambda$H by using the kaon beam available at the AGS, using the reaction

$$^4\mathrm{He}(K^-_{stopped}, \pi^0)^4_\Lambda\mathrm{H} \quad \longrightarrow \quad \begin{array}{l} \Lambda n \to n + n \\ \Lambda p \to n + p \end{array} \tag{4}$$

on a 20 cm long × 20 cm diameter liquid He target. Events that result in the formation of a ${}^4_\Lambda$H hypernucleus are tagged by detecting the photons from the decay $\pi^0 \to \gamma + 256.9$ MeV (total) in the Neutral Meson Spectrometer (NMS) [6]. After a ${}^4_\Lambda$H hypernucleus is formed and tagged, its weak decay modes can be characterized by measuring the emission of protons and neutrons using appropriate detectors located away from the target, as shown in Fig. 1. The proton stimulated decay emits a p and n, whereas the neutron stimulated decay emits two neutrons. The experimental goal is to measure the ratio $\alpha = \Gamma_n/\Gamma_p$ for ${}^4_\Lambda$H by directly measuring the number of $p - n$ and $n - n$ coincidences. In order to test the $\Delta I = 1/2$ rule, it is necessary to measure α to an accuracy of only ~50%. By combining this result with ${}^5_\Lambda$He, the partial decay widths can be extracted for each process, independent of assumptions regarding the nuclear density.

The AGS kaon beam provides 2.5×10^5 kaons per spill (1000 spills/hour) at 650 MeV/c with a 4% momentum range. Time of Flight (TOF) techniques are used with the beam line counters to distinguish kaons from pions in the incident beam. The experiment will use a non-dispersed tune, allowing ~27% of the kaons incident on the target to be stopped.

Other in-flight interactions cause an additional factor of 2 loss, thus a ~13% kaon stopping power is taken as a conservative value for estimating production rates.

In order to tag the formation of a ${}^4_\Lambda$H hypernucleus, the decay of the π^0 must be unambiguously identified. This requires sufficient energy resolution in the NMS to separate the ${}^4_\Lambda$H ground state from quasi-free Λ production. This requires an energy resolution of about 10 MeV FWHM. The NMS is capable of achieving a resolution better than 3 MeV FWHM for such processes by measuring the angle between the pair of photons emitted by the π^0 decay. The BGO layer of detectors convert, through pair production, the incident γ to e^+ and e^- pairs and a residual photon. The measurement of the opening angle gives, to first order, the energy resolution of the spectrometer by utilizing the kinematical relation

$$E_{\pi^0}^2 = \frac{2m_{\pi^0}^2}{(1-x)^2(1-\cos\theta)}, \text{ where } \quad x = |\frac{E_1 - E_2}{E_1 + E_2}| \tag{5}$$

and θ is the angle between the emitted photons. This requires determining the decay vertex. A live target has been used in other experiments where maximal resolution was the goal. The resolution necessary for this experiment can be achieved without a live target, using calorimetery and determining the reaction vertex to a few cm. The energy sharing ratio x is an adjustable parameter in the analysis (the "x_{cut}") that is found to have a nearly linear relationship to the resolution and tagging rate. Thus, energy resolution can be improved at the cost of statistics, and vice versa.

Charged particle counters and multi-wire proportional counters, located on both sides of the target are combined with TOF to provide a proton emission trigger. Neutral particles (neutrons) are identified by time of flight of an event detected in the neutron arrays that did not deposit energy in the veto scintillators. Each neutron array has an efficiency of ~22%.

The ${}^4_\Lambda$H production rate can be estimated using the information that is summarized in Table 1. The estimate is based on 1000 beam spills/hour, and utilizes simulations as well as known correction factors. The π^0 tagging efficiency is known from other experiments that used the NMS, and is based on an x_{cut} that simulations predict will yield a resolution of ~5 MeV. The two-arm BGO geometrical efficiency is ~37%, but in practice there is an additional 10% loss. The 65 tagged ${}^4_\Lambda$H production/hour translates into ~40,000 ${}^4_\Lambda$H for the 600 hour experiment. Correcting for detector and coincidence efficiency, approximately 100 $n-n$ or $p-n$ coincidences will be detected.

Table 1
${}^4_\Lambda$H production rate estimate.

	Target Eff.		NMS Trig. Eff.			
Beam/hr	Stops	${}^4_\Lambda$H	x_{cut} Tag	BGO	DAQ Eff.	Tags/hr
2.5×10^8	13%	0.73%	13 msr	33%	80%	65

3. CONCLUSIONS

The proposed experiment will have sufficient resolution and statistics to succeed. The detection system is already in place and is being improved based on experience gained during an engineering run. The experiment will address the question of the validity of the $\Delta I = 1/2$ rule for non-mesonic weak decays and will complete the measurement of the decay widths for the full set of s-shell hypernuclei. This should reveal the spin/isospin dependence of the weak decay process, and will impact nuclear models and potentials.

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REFERENCES

1. J. Cohen, Phys. Rev. C 42 (1990) 2724.
2. L. Okun, Leptons and Quarks (North Holland, The Netherlands, 1982) and N. Isgur, et al., Phys. Rev. Lett. 64 (1990) 161.
3. H. Outa, et al., Nucl. Phys. A 639 (1998) 251c.
4. K. Maltman and M. Shmatikov, AIP Conf. Proc. 338, ed. S. J. Seestrom (Amer. Inst. of Phys., Woodbury, New York, 1995), p. 601.
5. M. Oka, et al., Nuclear and Particle Physics with Meson Beams in the 1 GeV/c Region, eds. S. Sugimoto and O. Hashimoto (Universal Academy Press, Tokyo, 1995), p. 237.
6. H. A. Thiessen and Jen-Chieh Peng, Investigation of Light Hypernuclei Using the $(K^-_{stopped}, \pi^0)$ Reaction. AGS Proposal E907, 1994.