Recent theoretical progress in hypernuclear decay

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Abstract. Some progress experienced recently in the field of hypernuclear weak decay is briefly summarized. Theoretical analyses of the double–coincidence nucleon spectra measured at KEK points towards a solution of the long–standing puzzle on the ratio Γ_n/Γ_p between the neutron–($\Lambda n \to nn$) and proton–induced ($\Lambda p \to np$) decay rates. Despite this improvement, the reaction mechanism for the hypernuclear non–mesonic weak decay seems to be not fully understood. Indeed, an intriguing problem, of more recent origin, is open: it concerns the asymmetry of the angular emission of non–mesonic weak decay protons from polarized hypernuclei. The important role played by final state interactions and two–nucleon induced decay channels, $\Lambda NN \to nNN$, in the determination of Γ_n/Γ_p and the decay asymmetries is pointed out.

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INTRODUCTION

Diversified efforts have been devoted to the study of hypernuclear weak decay in the latest years. Theoretical reviews on the subject can be found in Ref. [1]. For recent, related experiments, performed at KEK, see Refs. [2, 3]. Forthcoming data are expected from FINUDA, while new experiments are planned at J–PARC and HypHI.

Strong evidences for a solution of the longstanding problem on the ratio Γ_n/Γ_p between the widths for the weak processes $\Lambda n \to nn$ and $\Lambda p \to np$ originated from theoretical analyses [4] of KEK nucleon coincidence data [3]. The main results of these analyses are briefly discussed in the present contribution. The lately extracted Γ_n/Γ_p values turn out to be in agreement with previous, pure theoretical estimates [5, 6].

Despite this progress, the reaction mechanism for the hypernuclear non–mesonic weak decay (NMWD) is not fully understood. Indeed, an intriguing problem, of more recent origin, is open: it concerns the asymmetry of the angular emission of protons from the NMWD of polarized hypernuclei. Predictions for the angular asymmetries are discussed here in the light of data.

The results have been obtained with a one–meson–exchange model for the $\Lambda N \to nN$ processes in finite nuclei [6], combined with an intranuclear cascade code [7], which takes into account the nucleon final state interactions (FSI). The $\Lambda NN \to nNN$ process is included by treating the nuclear finite size effects via a local density approximation scheme. For details on the models employed see Ref. [4].

TABLE 1. Predictions for $R_2 \equiv N_{nn}/N_{np}$ in ${}^5_\Lambda$He and ${}^{12}_\Lambda$C. The data are from KEK [3].

Model	${}^5_\Lambda$He N_{nn}/N_{np}	Γ_n/Γ_p	${}^{12}_\Lambda$C N_{nn}/N_{np}	Γ_n/Γ_p
OPE	0.25	0.09	0.24	0.08
OMEa	0.51	0.34	0.39	0.29
OMEf	0.61	0.46	0.43	0.34
EXP	0.45 ± 0.11		0.40 ± 0.09	

THE RATIO Γ_n/Γ_p

The ratio, $N^{\rm wd}_{nn}/N^{\rm wd}_{np}$, between the number of weak decay nn and np pairs equals Γ_n/Γ_p. Due to FSI and two–body induced decays, one predicts:

$$\frac{\Gamma_n}{\Gamma_p} \equiv \frac{N^{\rm wd}_{nn}}{N^{\rm wd}_{np}} \neq \frac{N_{nn}}{N_{np}} \equiv R_2\left[\Delta\theta_{12}, \Delta T_n, \Delta T_p\right], \tag{1}$$

when the observable numbers N_{nn} and N_{np} are determined by employing particular pair opening angle and nucleon kinetic energy intervals. The results of Ref. [4] clearly show the dependence of N_{nn}/N_{np} on $\Delta\theta_{12}$, ΔT_n and ΔT_p; N_{nn}/N_{np} turns out to be much less sensitive to FSI effects and variations of energy cuts and angular restrictions than N_{nn} and N_{np} separately.

In Table 1 the ratios N_{nn}/N_{np} predicted by the one–pion–exchange (OPE) and one–meson–exchange models (OMEa and OMEf, using NSC97a and NSC97f potentials, respectively) for ${}^5_\Lambda$He and ${}^{12}_\Lambda$C are given for the back–to–back kinematics ($\cos\theta_{NN} \leq -0.8$) and nucleon kinetic energies $T_n, T_p \geq 30$ MeV. The OMEa and OMEf results are in agreement with the KEK data.

A weak–decay–model independent analysis [4] of these data allowed us to determine:

$$\frac{\Gamma_n}{\Gamma_p}({}^5_\Lambda\mathrm{He}) = 0.40 \pm 0.11 \text{ if } \Gamma_2 = 0\,,\ \frac{\Gamma_n}{\Gamma_p}({}^5_\Lambda\mathrm{He}) = 0.27 \pm 0.11 \text{ if } \frac{\Gamma_2}{\Gamma_1} = 0.2, \tag{2}$$

$$\frac{\Gamma_n}{\Gamma_p}({}^{12}_\Lambda\mathrm{C}) = 0.38 \pm 0.14 \text{ if } \Gamma_2 = 0\,,\ \frac{\Gamma_n}{\Gamma_p}({}^{12}_\Lambda\mathrm{C}) = 0.29 \pm 0.14 \text{ if } \frac{\Gamma_2}{\Gamma_1} = 0.25. \tag{3}$$

These values are substantially smaller than those obtained from single–nucleon spectra analyses and are in agreement with pure theoretical predictions [5, 6]. This result represents a strong evidence for a solution of the long–standing puzzle on Γ_n/Γ_p.

ASYMMETRIES

An intriguing open problem concerns an angular asymmetry in the emission of NMWD protons from polarized hypernuclei. While theory predicts a negative intrinsic Λ asymmetry a_Λ, with a moderate dependence on the hypernucleus, the measurements seem to favor $a^{\rm M}_\Lambda({}^5_\Lambda\vec{\mathrm{He}}) > 0$ and $a^{\rm M}_\Lambda({}^{12}_\Lambda\vec{\mathrm{C}}) < 0$. However, while one predicts $a_\Lambda({}^5_\Lambda\vec{\mathrm{He}}) \simeq a_\Lambda({}^{12}_\Lambda\vec{\mathrm{C}})$,

TABLE 2. Results for the proton intensities from the NMWD of ${}^{5}_{\Lambda}\vec{\mathrm{He}}$ and ${}^{12}_{\Lambda}\vec{\mathrm{C}}$. Data are from KEK [9].

Model	${}^{5}_{\Lambda}\vec{\mathrm{He}}$ I_0^{M}	a_Λ^{M}	${}^{12}_{\Lambda}\vec{\mathrm{C}}$ I_0^{M}	a_Λ^{M}
Without FSI	0.69	-0.68	0.75	-0.73
FSI and $T_p^{\mathrm{th}} = 0$	1.27	-0.30	2.78	-0.16
FSI and $T_p^{\mathrm{th}} = 30$ MeV	0.77	-0.46	1.05	-0.37
FSI and $T_p^{\mathrm{th}} = 50$ MeV	0.59	-0.52	0.65	-0.51
FSI and $T_p^{\mathrm{th}} = 70$ MeV	0.39	-0.55	0.38	-0.65
EXP		0.12 ± 0.10		-0.44 ± 0.32

there is no known reason to expect this approximate equality to be valid for the observable asymmetry, a_Λ^{M}. To overcome this problem, we evaluated [8] the effects of the nucleon FSI on the NMWD of polarized hypernuclei.

In table 2 we show OMEf results for the weak decay and observable proton intensities, $I(\theta) = I_0(1 + p_\Lambda a_\Lambda \cos\theta)$ and $I^{\mathrm{M}}(\theta) = I_0^{\mathrm{M}}(1 + p_\Lambda a_\Lambda^{\mathrm{M}} \cos\theta)$, respectively, for ${}^{5}_{\Lambda}\vec{\mathrm{He}}$ and ${}^{12}_{\Lambda}\vec{\mathrm{C}}$. As a result of the nucleon FSI, $|a_\Lambda| \gtrsim |a_\Lambda^{\mathrm{M}}|$ for any value of the proton kinetic energy threshold: when $T_p^{\mathrm{th}} = 0$, $a_\Lambda/a_\Lambda^{\mathrm{M}} \simeq 2$ for ${}^{5}_{\Lambda}\vec{\mathrm{He}}$ and $a_\Lambda/a_\Lambda^{\mathrm{M}} \simeq 4$ for ${}^{12}_{\Lambda}\vec{\mathrm{C}}$; $|a_\Lambda^{\mathrm{M}}|$ increases with T_p^{th} and $a_\Lambda/a_\Lambda^{\mathrm{M}} \simeq 1$ for $T_p^{\mathrm{th}} = 70$ MeV in both cases. The KEK data quoted in the table correspond to a T_p^{th} varying between 30 and 50 MeV: our corresponding predictions agree (disagree) with the ${}^{12}_{\Lambda}\vec{\mathrm{C}}$ (${}^{5}_{\Lambda}\vec{\mathrm{He}}$) datum.

FSI turn out to be an important ingredient also when studying the NMWD of polarized hypernuclei, but they cannot explain the present asymmetry data. In our opinion, new and improved experiments more clearly establishing the sign and magnitude of a_Λ^{M} for s– and p–shell hypernuclei are necessary to disclose the origin of the asymmetry puzzle.

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