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TOWARDS A SOLUTION OF THE $\Gamma_{\rm n}/\Gamma_{\rm p}$ PUZZLE IN THE WEAK DECAY OF Λ–HYPERNUCLEI

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1 Introduction

For many years, a theoretical explanation of the large experimental values of the ratio, Γ_n/Γ_p, between the neutron– and proton–induced non–mesonic decay widths, $\Gamma(\Lambda n \to nn)$ and $\Gamma(\Lambda p \to np)$, of Λ–hypernuclei has been missing [1]. In this contribution we discuss some results of a calculation [2] of nucleon–nucleon coincidence distributions for the hypernuclear non–mesonic weak decay (NMWD). The work is motivated by the fact that correlation observables are expected to allow a cleaner extraction of Γ_n/Γ_p from data than single–nucleon observables. Moreover, coincidence experiments have been performed recently at KEK [3].

A one–meson–exchange model for the $\Lambda N \to nN$ processes in finite nuclei has been combined with an intranuclear cascade code, 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. [2].

Preliminary results for the angular asymmetries in the NMWD of polarized Λ–hypernuclei are also presented.

2 Coincidence observables and determination of Γ_n/Γ_p

The ratio, $N_{nn}^{\rm wd}/N_{np}^{\rm wd}$, 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:

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

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. [2] 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.

The numbers of nucleon pairs N_{NN} —which we consider to be normalized per NMWD— are related to the corresponding quantities for the neutron ($N_{NN}^{\rm 1Bn}$) proton ($N_{NN}^{\rm 1Bp}$) and two–nucleon ($N_{NN}^{\rm 2B}$) induced processes by:

$$N_{NN} = \frac{N_{NN}^{\rm 1Bn}\,\Gamma_n + N_{NN}^{\rm 1Bp}\,\Gamma_p + N_{NN}^{\rm 2B}\,\Gamma_2}{\Gamma_n + \Gamma_p + \Gamma_2} \equiv N_{NN}^{\Lambda n\to nn} + N_{NN}^{\Lambda p\to np} + N_{NN}^{\Lambda np\to nnp}, \tag{2}$$

where $N_{NN}^{\rm 1Bn} \equiv N_{NN}^{\Lambda n\to nn}(\Gamma_n + \Gamma_p + \Gamma_2)/\Gamma_n$, etc.

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 preliminary KEK data: this comparison provides an indication for a ratio $\Gamma_n/\Gamma_p \simeq 0.3$ in both hypernuclei.

Table 1: *Predictions for* $R_2 \equiv N_{nn}/N_{np}$ *in* ${}^{5}_{\Lambda}$*He and* ${}^{12}_{\Lambda}$*C. The (preliminary) data are from KEK–E462 and KEK–E508* [3].

	${}^{5}_{\Lambda}$He		${}^{12}_{\Lambda}$C	
Model	N_{nn}/N_{np}	Γ_n/Γ_p	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	0.44 ± 0.11		0.40 ± 0.09	

We have then performed a weak–decay–model independent analysis of KEK coincidence data. The 6 weak–decay–model independent quantities $N^{\rm 1Bn}_{nn}$, $N^{\rm 1Bp}_{nn}$, $N^{\rm 2B}_{nn}$, $N^{\rm 1Bn}_{np}$, $N^{\rm 1Bp}_{np}$ and $N^{\rm 2B}_{np}$ of Eq. (2) are used to evaluate Γ_n/Γ_p as:

$$\frac{\Gamma_n}{\Gamma_p} = \frac{N^{\rm 1Bp}_{nn} + N^{\rm 2B}_{nn}\dfrac{\Gamma_2}{\Gamma_1} - \left(N^{\rm 1Bp}_{np} + N^{\rm 2B}_{np}\dfrac{\Gamma_2}{\Gamma_1}\right)\dfrac{N_{nn}}{N_{np}}}{\left(N^{\rm 1Bn}_{np} + N^{\rm 2B}_{np}\dfrac{\Gamma_2}{\Gamma_1}\right)\dfrac{N_{nn}}{N_{np}} - N^{\rm 1Bn}_{nn} - N^{\rm 2B}_{nn}\dfrac{\Gamma_2}{\Gamma_1}}, \tag{3}$$

from appropriate Γ_2/Γ_1 values. By using the KEK data of Table 1 we obtain:

$$\frac{\Gamma_n}{\Gamma_p}\left({}^{5}_{\Lambda}\mathrm{He}\right) = 0.39 \pm 0.11 \;\text{ if }\; \Gamma_2 = 0\;, \;\frac{\Gamma_n}{\Gamma_p}\left({}^{5}_{\Lambda}\mathrm{He}\right) = 0.26 \pm 0.11 \;\text{ if }\; \frac{\Gamma_2}{\Gamma_1} = 0.2, \tag{4}$$

$$\frac{\Gamma_n}{\Gamma_p}\left({}^{12}_{\Lambda}\mathrm{C}\right) = 0.38 \pm 0.14 \;\text{ if }\; \Gamma_2 = 0\;, \;\frac{\Gamma_n}{\Gamma_p}\left({}^{12}_{\Lambda}\mathrm{C}\right) = 0.29 \pm 0.14 \;\text{ if }\; \frac{\Gamma_2}{\Gamma_1} = 0.25. \tag{5}$$

These values are substantially smaller than those obtained from single–nucleon spectra analyses and are in agreement with pure theoretical predictions [4]. In our opinion, this represents an important progress towards the solution of the Γ_n/Γ_p puzzle.

Forthcoming data from KEK and FINUDA [5] could be directly compared with the results reported here and in Ref. [2]. This will permit to achieve better determinations of Γ_n/Γ_p and to establish the first constraints on Γ_2/Γ_1.

3 The asymmetry puzzle

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,

Table 2: *Results for the proton intensities from the NMWD of* ${}^{5}_{\Lambda}\vec{\mathrm{He}}$ *and* ${}^{12}_{\Lambda}\vec{\mathrm{C}}$.

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
KEK [7]		0.07 ± 0.08		-0.44 ± 0.32

the measurements seem to favor $a_\Lambda^{\mathrm{M}}({}^{5}_{\Lambda}\vec{\mathrm{He}}) > 0$ and $a_\Lambda^{\mathrm{M}}({}^{12}_{\Lambda}\vec{\mathrm{C}}) < 0$. However, while one predicts $a_\Lambda({}^{5}_{\Lambda}\vec{\mathrm{He}}) \simeq a_\Lambda({}^{12}_{\Lambda}\vec{\mathrm{C}})$, 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 are evaluating [6] the effects of the nucleon FSI on the NMWD of polarized hypernuclei and performing the first calculation of a_Λ^{M}.

In table 2 we show preliminary 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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