TOWARDS A SOLUTION OF THE $\Gamma_n/\Gamma_p$ PUZZLE IN THE WEAK DECAY OF $\Lambda$–HYPERNUCLEI

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Introduction — For many years, a theoretical explanation of the large experimental values of the ratio, $\Gamma_n/\Gamma_p$, between the neutron– and proton–induced non–mesonic decay widths, $\Gamma(\Lambda n \rightarrow nn)$ and $\Gamma(\Lambda p \rightarrow np)$, of $\Lambda$–hypernuclei has been missing.

In this contribution we discuss some results of a calculation 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 $\Gamma_n/\Gamma_p$ from data than single–nucleon observables. Moreover, coincidence experiments have been performed recently at KEK.

A one–meson–exchange model for the $\Lambda N \rightarrow nN$ processes in finite nuclei has been combined with an intranuclear cascade code, which takes into account the nucleon final state interactions (FSI). The $\Lambda NN \rightarrow nNN$ 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 $\Lambda$–hypernuclei are also presented.

Coincidence observables and determination of $\Gamma_n/\Gamma_p$ — The ratio, $N_{nn}^{wd}/N_{np}^{wd}$, between the number of weak decay $nn$ and $np$ pairs equals $\Gamma_n/\Gamma_p$. Due to FSI and two–body induced decays, one predicts:

$$\frac{\Gamma_n}{\Gamma_p} = \frac{N_{nn}^{wd}}{N_{np}^{wd}} \neq \frac{N_{nn}}{N_{np}} = R_2 [\Delta \theta_{12}, \Delta T_n, \Delta T_p] ,$$

(1)

when the observable numbers $N_{nn}$ and $N_{np}$ are determined by employing par-
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.

| Model | $^5\Lambda$He | | $^{12}\Lambda$C | |
|-------|---------------|----------|-----------------|----------|
| OPE   | 0.24          | 0.08     |                  |          |
| OMEa  | 0.39          | 0.29     |                  |          |
| OMEf  | 0.43          | 0.34     |                  |          |
| EXP   | 0.44 ± 0.11   | 0.40 ± 0.09 |              |          |

The particular pair opening angle and nucleon kinetic energy intervals. The results of Ref. 2 clearly show the dependence of $N_{nn}/N_{np}$ on $\Delta \theta_{12}$, $\Delta T_n$ and $\Delta T_p$; $N_{nn}/N_{np}$ 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 ($N_{NN}^{1Bn}$) proton ($N_{NN}^{1Bp}$) and two–nucleon ($N_{NN}^{2B}$) induced processes by:

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

(2)

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

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

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

(3)
from appropriate $\Gamma_2/\Gamma_1$ values. By using the KEK data of Table II we obtain:

$$\frac{\Gamma_n}{\Gamma_p}(^5_\Lambda\text{He}) = 0.39 \pm 0.11 \text{ if } \Gamma_2 = 0, \quad \frac{\Gamma_n}{\Gamma_p}(^5_\Lambda\text{He}) = 0.26 \pm 0.11 \text{ if } \Gamma_2 = 0.2, \quad (4)$$

$$\frac{\Gamma_n}{\Gamma_p}(^{12}_\Lambda\text{C}) = 0.38 \pm 0.14 \text{ if } \Gamma_2 = 0, \quad \frac{\Gamma_n}{\Gamma_p}(^{12}_\Lambda\text{C}) = 0.29 \pm 0.14 \text{ if } \Gamma_2 = 0.25. \quad (5)$$

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

Forthcoming data from KEK and FINUDA could be directly compared with the results reported here and in Ref. 2. This will permit to achieve better determinations of $\Gamma_n/\Gamma_p$ and to establish the first constraints on $\Gamma_2/\Gamma_1$.

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 $\Lambda$ asymmetry $a_{\Lambda}$, with a moderate dependence on the hypernucleus, the measurements seem to favor $a_{\Lambda}(^{5}_\Lambda\text{He}) > 0$ and $a_{\Lambda}(^{12}_\Lambda\text{C}) < 0$. However, while one predicts $a_{\Lambda}(^{5}_\Lambda\text{He}) \simeq a_{\Lambda}(^{12}_\Lambda\text{C})$, there is no known reason to expect this approximate equality to be valid for the observable asymmetry, $a_{\Lambda}^M$. To overcome this problem, we are evaluating the effects of the nucleon FSI on the NMWD of polarized hypernuclei and performing the first calculation of $a_{\Lambda}^M$.

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 $I^M(\theta) = I^M_0(1 + p_{\Lambda} a_{\Lambda}^M \cos \theta)$, respectively, for $^{5}_\Lambda\text{He}$ and $^{12}_\Lambda\text{C}$. As a result of the nucleon FSI, $|a_{\Lambda}| \gtrsim |a_{\Lambda}^M|$ for any value of the proton kinetic energy threshold: when $T_{p}^{th} = 0$, $a_{\Lambda}/a_{\Lambda}^M \approx 2$ for $^{5}_\Lambda\text{He}$ and $a_{\Lambda}/a_{\Lambda}^M \approx 4$ for $^{12}_\Lambda\text{C}$; $|a_{\Lambda}^M|$ increases with $T_{p}^{th}$ and $a_{\Lambda}/a_{\Lambda}^M \approx 1$ for $T_{p}^{th} = 70$ 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 $^{12}_\Lambda\text{C}$ ($^{5}_\Lambda\text{He}$) 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 $a_{\Lambda}^M$ for $s$– and $p$–shell hypernuclei are necessary to disclose the origin of the asymmetry puzzle.
Table 2: Results for the proton intensities from the NMWD of $^5\Lambda$He and $^{12}\Lambda C$.

| Model                  | $^5\Lambda$He | $^{12}\Lambda C$ |
|------------------------|---------------|-----------------|
| Without FSI            | $I^M_0$ 0.69  | $I^M_0$ 0.75    |
|                        | $a^M_0$ −0.68 | $a^M_0$ −0.73  |
| FSI and $T^th_p = 0$   | 1.27          | 2.78            |
|                        | −0.30         | −0.16           |
| FSI and $T^th_p = 30$ MeV | 0.77          | 1.05            |
|                        | −0.46         | −0.37           |
| FSI and $T^th_p = 50$ MeV | 0.59          | 0.65            |
|                        | −0.52         | −0.51           |
| FSI and $T^th_p = 70$ MeV | 0.39          | 0.38            |
|                        | −0.55         | −0.65           |
| KEK                    | 0.11 ± 0.44   | −0.44 ± 0.32   |

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