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NON-MESONIC WEAK DECAY OF ${}^{5}_{\Lambda}$He and ${}^{12}_{\Lambda}$C and THE EFFECT OF FSI ON ITS OBSERVABLES

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ABSTRACT

We have measured the emitted pair nucleons in the nonmesonic weak decay (NMWD) of ${}^{5}_{\Lambda}$He and ${}^{12}_{\Lambda}$C for the first time in coincidence method in the KEK-PS E462 and E508 experiments. We have clearly identified the prominent feature of back-to-back kinematics of NMWD and shown the Γ_n/Γ_p ratio close to 1/2. We still have to identify the contribution of two nucleon induced one in order to understand the NMWD. However, it is often mixed in with the effect of nuclear final state interaction (FSI). We have estimated the FSI effect on the singles nucleon number ratio and coincidence nucleon pair number ratio.

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1 Introduction

The nonmesonic weak decay (NMWD) of Λ hypernuclei has attracted much attention during last couple of decades, since it provides an unique opportunity to study the strangeness changing baryonic weak interaction $\Lambda N \rightarrow NN$, namely $\Lambda p \rightarrow np$ (Γ_p) and $\Lambda n \rightarrow nn$ (Γ_n). It also involves many important current issues, such as the long standing Γ_n/Γ_p ratio puzzle, the existence and the strength of the predicted two-nucleon ($2N$) induced NMWD components, $\Lambda NN \rightarrow nNN$ (Γ_{2N}), and the effect of nuclear final state interaction (FSI) on NMWD etc. All these are crucial issues in order to understand the weak decay mechanism of Λ hypernuclei and the strangeness changing baryonic weak interaction.

There has been a long standing concern on the Γ_n/Γ_p ratio of NMWD of Λ hypernuclei. Until a few years ago the experimental ratios have shown the ratio close to or greater than unity, implying the dominance of the neutron-induced channel while theoretical models for the $\Delta S=1$ baryonic weak interaction predicted values much smaller than unity. We refer the details of the various models and their results on NMWD widths to the recent review article [1)]. However more recently there has been an important developement finding the incorrect sign between pion and kaon exchange amplitude whose correction significantly increased the values of Γ_n/Γ_p [2)]. Since then the direct quark interaction model calculation has produced the ratio for ${}^{5}_{\Lambda}\mathrm{He}$ up to 0.70. The heavy meson exchange model calculation of Jido *et al.* also reproduced the increased ratio of ${}^{12}_{\Lambda}\mathrm{C}$ reaching to 0.57 [1)].

Important progresses have been made in the experimental studies of NMWD of Λ hypernuclei in a series of experiments at KEK. In the following sections, they will be introduced and discussed in terms of the effects of FSI on Γ_n/Γ_p ratio.

2 Experimental Progress

The accurate measurement of proton (E307) and neutron spectra (E369) of NMWD of ${}^{12}_{\Lambda}\mathrm{C}$ were reported [3, 4)]. The quality of neutron spectrum of NMWD obtained in the experiment E369 was improved drastically both in the statistics and the signal to background (S/B) ratio over those of the previous one. With both proton and neutron spectra measured, Γ_n/Γ_p ratio was derived to

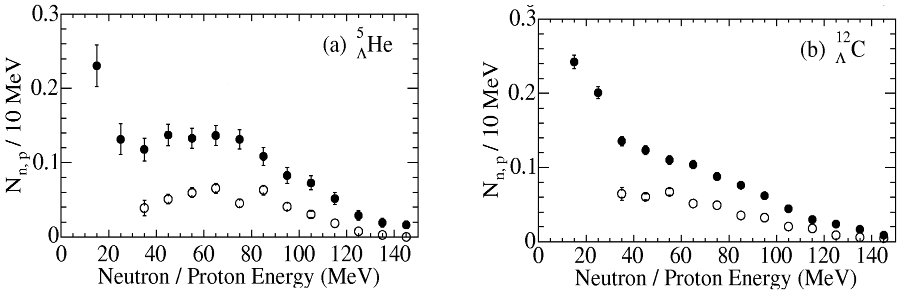

Figure 1: *Proton (open circle) and neutron (dark circle) spectra of the NMWD of ${}^{5}_{\Lambda}He$ (a) and ${}^{12}_{\Lambda}C$(b) are shown* [5].

be about 0.5 directly from the measured neutron-to-proton number ratio cancelling out most of the FSI effect and considering NMWD 1N induced process. Recently we have reported the simultaneously measured spectra of neutrons and protons emitted in NMWD of ${}^{5}_{\Lambda}$He and ${}^{12}_{\Lambda}$C with much higher statistics than those of the previous experiments as shown in the fig.1 [5]. The neutron to proton yield ratios for both hypernuclei obtained with a much higher threshold energy (60 MeV) than that of the E307/E369 (40 MeV) were about two which suggests Γ_n/Γ_p ratios again about 0.5. However, the results still contained uncertainties due to the residual FSI effects and a possible large 2N induced NMWD contribution. Therefore, it was important and urgent to confirm the proton channel dominance and to establish the Γ_n/Γ_p ratio of NMWD unambiguously.

In order to remove such ambiguities, we have measured the emitted pair nucleons from the NMWD of ${}^{5}_{\Lambda}$He (E462) and ${}^{12}_{\Lambda}$C (E508) in coincidence method and determined the nucleon pair number ratio, N_{nn}/N_{np}, from the events of back-to-back opening angles which is the characteristics of two body kinematics of 1N NMWD [6, 7].

Fig.2 shows the normalized pair numbers, $N_{np(n)}(cos\theta)$, per NMWD in $cos\theta$ for ${}^{5}_{\Lambda}$He (left side) and ${}^{12}_{\Lambda}$C (right side). Upper figures show np pair distributions and lower ones nn pair distributions. Back to back peaking at $cos(\theta) = -1$ which is the signature of two body final state is clearly observed in both *np* and *nn* pair angular correlation. This is the first experimental observation of the Λp→np and Λn→nn 1N induced NMWD processes. N_{nn}/N_{np} ratios in the back-to-back kinematic region are shown in the tab.1 where N_{nn}

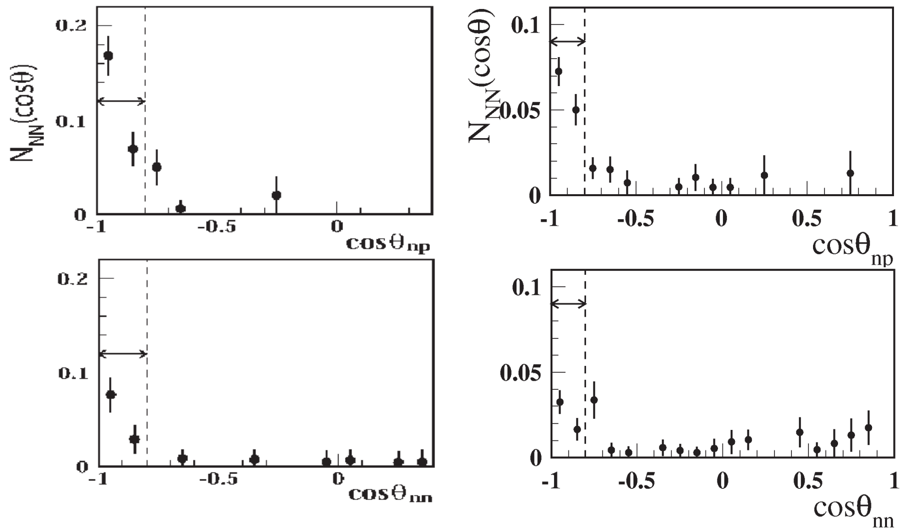

Figure 2: *Left side shows the Nnp(x)(above) and Nnn(x)(below) for* $^{5}_{\Lambda}He$ *and right side for those of* $^{12}_{\Lambda}C$*. x indicates* $cos\theta$*.*

Table 1: N_n/N_p *and* N_{nn}/N_{np} *values from E462 and E508*

	Region	$^{5}_{\Lambda}$He	$^{12}_{\Lambda}$C
N_n/N_p	$E \geq 60MeV$	$2.17 \pm 0.15 \pm 0.16$	$2.00 \pm 0.09 \pm 0.14$
N_{nn}/N_{np}	$cos\theta \leq -0.9$		$0.45 \pm 0.11 \pm 0.04$
	$cos\theta \leq -0.8$	$0.45 \pm 0.11 \pm 0.04$	$0.40 \pm 0.09 \pm 0.04$
	$cos\theta \leq -0.7$		$0.60 \pm 0.12 \pm 0.04$

and N_{np} are the sum of $N_{NN}(cos\theta_i)$ over the back-to-back kinematic regions.

3 Effects of FSI on Γ_n/Γ_p

3.1 Inclusive nucleon number ratio of proton and neutron, N_n/N_p

Next we consider the effect of FSI on the Γ_n/Γ_p ratio. If we consider NMWD consisted of one nucleon induced ones only, namely proton- and neutron-induced channels, the normalized emitted neutron (proton) numbers per NMWD, $N_{n(p)}$, whose energies above a certain threshold energy can be written as

$$N_n = (2r_n + r_p)f_{nn} + r_p f_{pn}, \tag{1}$$

$$N_p \quad = \quad (2r_n + r_p)f_{np} + r_p f_{pp} \tag{2}$$

where r_p the branching ratio of the proton stimulated channel out of the NMWD so that r_n, that of neutron, is $1 - r_p$. f_{nn}(or f_{pp}) is the survival factor staying in the concerned range after the FSI with the residual nucleons while f_{np}(or f_{pn}) those due to the secondaries crossed over from the other channel. The crossed over contribution is not expected large in the high energy region. Considering the isospin independence of the strong interaction and the isospin symmetric propagating medium of carbon, we may assume $f_{nn} = f_{pp} = f$ and $f_{np} = f_{pn} = g$. Then the ratio of the neutron to proton number per NMWD can be expressed as

$$\frac{N_n}{N_p} = \frac{(2 - r_p) + r_p\beta}{(2 - r_p)\beta + r_p}. \tag{3}$$

When we apply $N_n/N_p = 0.69/0.4 = 1.73$ for the region of $E_N \geq 40$MeV from E307 and E369 spectra and β = g/f = (0.076, 0.11) extracted from the two currently available INC calculations, $\mathbf{\Gamma_n/\Gamma_p}(=r_n/r_p)$ becomes ($\mathbf{0.45}$, $\mathbf{0.51}$) for ${}^{12}_{\Lambda}$C. It is noted that these values are almost FSI model independent result and the first experimental result to show the proton channel dominance in the NMWD of Λ hypernuclei. Now this agrees very well with the recent theoretical predictions [1].

Similarly, we apply eq.3 to the N_n/N_p ratios shown in the tab.1 derived from the high statistics inclusive spectra of ${}^{5}_{\Lambda}$He (E462) and ${}^{12}_{\Lambda}$C (E508) shown in the fig.2 with a higher threshold energy, 60 MeV. Then we get $\mathbf{\Gamma_n/\Gamma_p}$ **0.61**(${}^{\mathbf{5}}_{\mathbf{\Lambda}}$**He**) and **0.58**(${}^{\mathbf{12}}_{\mathbf{\Lambda}}$**C**) when we use the β values of 60 MeV threshold energy 0.02 for ${}^{5}_{\Lambda}$He and 0.05 for ${}^{12}_{\Lambda}$C.

3.2 Coincidence nn and np nucleon pair number ratio, N_{nn}/N_{np}

In order to derive the Γ_n/Γ_p ratio from the N_n/N_p ratio of the singles spectra, we have made an assumption of 1N process of NMWD which cause the result some ambiguity due to 2N NMWD process. This ambiguity is removed when we measure both emitted nucleons, apply the back-to-back kinematics of 1N process and derive the Γ_n/Γ_p ratio from the pair number ratio, N_{nn}/N_{np}.

We can obtain the effect of FSI on the the nucleon pair number ratio similarly,

$$\frac{N_{nn}}{N_{np}} = \frac{r_n + r_p\beta'}{r_p + 2r_p\beta'}, \tag{4}$$

where N_{nn}/N_{np} values are shown in the tab.1 and β' is the reduced β due to the back-to-back opening angle selection. Here the assumption of $r_p + r_n = 1$ is removed. β' adopted for ${}^{12}_{\Lambda}$C were 0.059 ($cos\theta$ $\leq$ -0.9), 0.066 ($cos\theta$ $\leq$ -0.8) and 0.073 ($cos\theta$ $\leq$ -0.7) while those for ${}^{5}_{\Lambda}$He 0.4$\cdot\beta'$(${}^{12}_{\Lambda}$C). Then we get $\mathbf{\Gamma_n/\Gamma_p (= r_n/r_p)}$ **0.43** for $\mathbf{{}^{5}_{\Lambda}He}$ and **0.41** ($\mathbf{cos\theta \leq -0.9}$), **0.35** ($\mathbf{cos\theta \leq -0.8}$) and **0.59** ($\mathbf{cos\theta \leq -0.7}$) for $\mathbf{{}^{12}_{\Lambda}C}$.

Recent experimental results on NMWD at KEK-PS, of both singles and coincidence measurements, have shown the proton channel dominance with the Γ_n/Γ_p values close to 1/2. FSI effect have been estimated for N_n/N_p and N_{nn}/N_{np} ratio and Γ_n/Γ_p values are derived. The Γ_n/Γ_p from N_n/N_p tend to show about 20-30% bigger values than those from N_{nn}/N_{np}. We consider this difference due to the 2N NMWD contribution.

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