Frascati Physics Series Vol. XXXVI (2004), pp.
DAΦNE 2004: Physics at meson factories – Frascati, June 7-11 , 2004
Selected Contribution in Plenary Session

FIRST EXCLUSIVE MEASUREMENT OF THE NON-MESONIC WEAK DECAY OF THE ${}^{12}_{\Lambda}$C

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ABSTRACT

We have measured the emitted pair nucleons from the nonmesonic weak decay (NMWD) of ${}^{12}_{\Lambda}$C for the first time in coincidence measurement in order to identify each decay channel exclusively without ambiguity of final state interaction (FSI) and two-nucleon (2N) induced NMWD contribution. The ${}^{12}_{\Lambda}$C hypernuclei were produced via the(π^+, K^+) reaction. The obtained pair yield ratio of the neutron- to ptroton- induced NMWD, N_{nn}/N_{np}, is about 0.5, which is close to that of ${}^{5}_{\Lambda}$He [1, 2].

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1 Introduction

When a Λ hyperon bound in the nucleus, it will decay via the mesonic weak decay ($\Gamma_{\pi^-}; \Lambda \rightarrow p\pi^-$, $\Gamma_{\pi^0}; \Lambda \rightarrow n\pi^0$) or one-nucleon (1N) induced NMWD ($\Gamma_n; \Lambda n \rightarrow nn$, $\Gamma_p; \Lambda p \rightarrow np$) process. 2N incduced NMWD ($\Gamma_{2N}; \Lambda NN \rightarrow nNN$), which is not confirmed experimentally yet, has been predicted in theoretical calculations.

There has been a long standing puzzle on the Γ_n/Γ_p ratio of NMWD of Λ hypernuclei. Until recently experimental values were close to or larger than unity [3)] but the theoretical ones much smaller than unity. Very recently there have been important progresses with which both experimental [4, 5)] and theoretical [6)] ratios approached to 0.5. However the experimental values are still subjected to the ambiguities due to the FSI effects and 2N NMWD contribution. To resolve this problem we have measured the two emitted pair nucleons in the NMWD in coincidence method. In order to observe the ratio Γ_n/Γ_p of $\Lambda N \rightarrow nN$ channel clearly without FSI effects and 2N induced contribution, back-to-back pair events were selected (for example, $cos\theta_{NN} < -0.8$, θ_{NN} is the opening angle of pair). The yields of pair coincidences, Y_{np} and Y_{nn}, are

$$Y_{nn} = Y_{hyp} b_{nm} r_n \epsilon_{nn} {f_n}^2, \;\; Y_{np} = Y_{hyp} b_{nm} r_p \epsilon_{np} f_n f_p \qquad (1)$$

where Y_{hyp},b_{nm} and $r_{n(p)}$ are the number of ${}^{12}_{\Lambda}$C produced, the branching ratio for NMWD of ${}^{12}_{\Lambda}$C and $\Gamma_{n(p)}/\Gamma_{nm}$, respectively. Then r_n/r_p , which is Γ_n/Γ_p ratio, is obtained from the ratio Y_{nn}/Y_{np} as

$$\frac{r_n}{r_p}(=\frac{\Gamma_n}{\Gamma_p}) \;\; = \frac{\{Y_{nn}/Y_{hyp}b_{nm}\epsilon_{nn}\}}{\{Y_{np}/Y_{hyp}b_{nm}\epsilon_{np}\}} \cdot \frac{f_n f_p}{f_n^2} \;\; = \frac{N_{nn}}{N_{np}} \cdot \frac{f_p}{f_n}. \qquad (2)$$

Since $Y_{hyp}b_{nm}$ is the total number of the NMWD, Y_{nm}, N_{nn} and N_{np} of the bracket are the normalized pair yields per NMWD for full solid angle and unit efficiency. If we assume same FSI effects on neutrons and protons, *i.e.*, $f_n \approx f_p$, the ratio Γ_n/Γ_p is simply become the N_{nn}/N_{np} ratio as shown in eq.(2). The similar spectral shapes of the neuton and proton singles spectra observed in this experiment support the same FSI effect on neutrons and protons [5)]. Thus, the Γ_n/Γ_p ratio can be directly determined from the measured pair number ratio, N_{nn}/N_{np}, without much ambiguity of FSI and 2N induced NMWD.

2 Experimental Method and Analysis

The experiment was carried out at K6 beam line of the KEK-PS with 1.05 GeV/c π^+ beam which maximizes the cross section of the (π^+, K^+) reaction. The mass spectrum of produced hypernuclei were calculated by reconstructing momenta of incoming π^+ and outgoing K^+ using a beam line spectrometer and the Superconducting Kaon Spectrometer(SKS) , respectively. The segmented plastic scintillator(BC408) was used as the ^{12}C target. Proton energy loss inside target material was corrected thanks to the good vertex resolution.

Fig.1(left) shows the decay particle detection system. The decay counter system has three coincidence counter sets, top,bottom and side arms. The top and bottom decay arms were placed symmetrically from the center of the experimental target optimized for the back-to-back coincidence and one at the side to measure the angular correlation for non-back-to-back events. Each of top and bottom coincidence counter sets consists of a fast timing counters (T2), a particle drift chamber (PDC), veto or stop timing counters (T3) and neutron counter arrays (T4), while the same set for the side counter but without PDC.

Fig.1(right up) shows the $1/\beta$, the inverse of velocity, spectra of neutral particles with 2MeVee threshold for particle identification(PID). Fig.1(right down) shows PID function of charged particles, which is derived by ΔE, E and TOF which denote the light output(ADC) in T2, the total light output of T3 and T4 counters and time-of-flight between T2 and T3, respectively. Neutrons and protons were well seperated. The neutron kinetic energy calculated from $1/\beta$ and proton kinetic energy calculated from the range information which is obtained from light output and birks's law. If particles have large decay angle, we can not well distinguish between stop particles and passing through particles in side parts of detectors. Therefore, charged particles case, we selected the events which fired the central part of T2 and T3 detectors. The detection threshold were about 10MeV for neutrons and 30MeV for protons. The pair acceptance is calculated with energy dependent event-by-event Monte Carlo simulation, which takes into consideration the detector geometry, energy dependent efficiency and real vertex distribution.

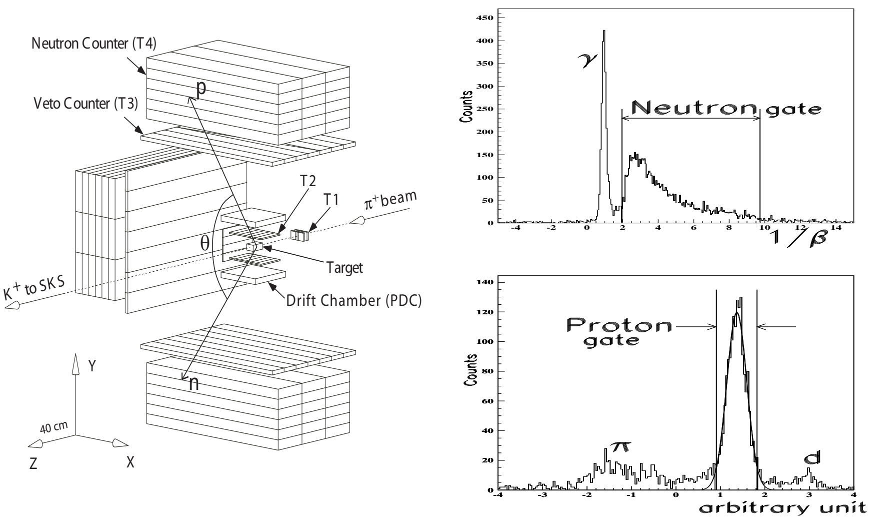

Figure 1: *Schematic view of the decay particle detection system(left) and Particle identification for neutral(right up) and charged(right down) particles.*

3 Results and Discussion

The ${}^{12}_{\Lambda}$C excitation energy spectra in different conditions are shown in Fig.2(left), the inclusive spectrum (a), those with a *np*-pair coincidence(b), and with a *nn*- pair coincidence(c), respectively. The vertical lines shows the gate for the ground state for the decay particle measurement. The coincident *np*- and *nn*- pair nucleons from the decay of ${}^{12}_{\Lambda}$C were measured. Fig.2(right) show the energy sum and opening angle distribution depicted in Fig.1(left). Because observed protons have no sensitivity below 30MeV, the same energy threshold, $E_n = 30MeV$, was applied to both nucleons. The hatched histogram in right figures show the contamination due to the absorption of π^- from the mesonic decay. The amount of the contamination was estimated referring to the π^- absorption from the mesonic decay of quasi-free Λ.

In Fig.2(d,e), the energy sum distribution of *np*-(d), *nn* -pair(e) nucleons of ${}^{12}_{\Lambda}$C are shown. The energy sum resolution for *np*- and *nn*- pair, $\sigma_{E_{np}}$ and $\sigma_{E_{nn}}$, were estimated to 9 MeV and 11 MeV at Q-value($\sim$ 150MeV), respectively. In the *np*-pair, the energy sum distribution have broad peak around Q-value. This

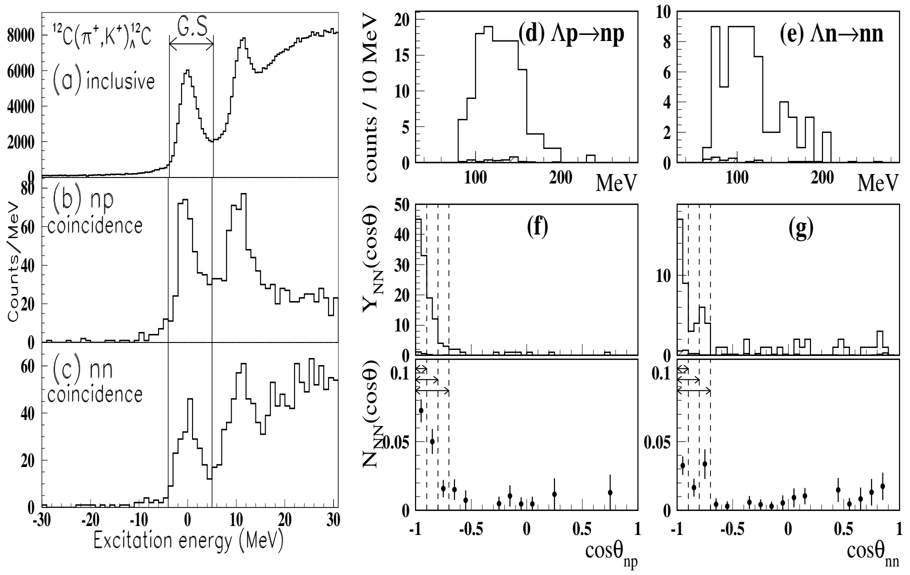

Figure 2: *Excitation energy spectra(a,b,c) of $^{12}_{\Lambda}C$, inclusive (a), with np-pair coincidence (b), and with a nn-pair coincidence (c), respectively. (d,e): Measured energy sum correlation of np- and nn- pairs, respectively without correction of efficiency. (f,g): Upper figure shows the measured angular correlations of np-, nn- pairs without correction of efficiency Lower figure shows the normalized number of np-, nn- pairs per NMWD of $^{12}_{\Lambda}C$.*

might be considered due to the FSI and 2N induced contribution. These effects are severer in the *nn* -pair spectrum than in that of *np*-pair. The upper two figure in Fig.2(f,g) show openging angle distribution of *np*-pair and *nn* -pair respectively. They are not normalized for the acceptance and efficiency yet. The angular resolution were estimated to be $\sigma_{cos_{\theta_{np}}} = 0.018$ and $\sigma_{cos_{\theta_{nn}}} = 0.029$ at cosθ= -0.9. The lower two figures in Fig.2(f,g) show the normalized pair yields per NMWD for full solid angle and unit efficiency introduced in eq.(2). The b_{nm} value was derived from the π^- and π^0 branching ratios measured in the present experiment and its error bar was drastically reduced compared to the previous ones [7, 8]. The three vertical dashed lines in Fig.2(f,g) indicated the back-to-back angular regions of $cos\theta_{NN}(< -0.7/0.8/0.9)$. Table.1 shows the obtained N_{nn}/N_{np} ratio for 3 back-to-back angular regions and they are compared with those of $^{5}_{\Lambda}$He [1, 2] where N_{nn} and N_{np} are the simple sum

Table 1: $N_{nn}/N_{np}(\sim \Gamma_n/\Gamma_p)$ *of* ${}^{12}_{\Lambda}C$*(Preliminary results) and* ${}^{5}_{\Lambda}He$

back-to-back condition	$N_{nn}/N_{np}(\sim \Gamma_n/\Gamma_p)$ ${}^{12}_{\Lambda}$C	$N_{nn}/N_{np}(\sim \Gamma_n/\Gamma_p)$ ${}^{5}_{\Lambda}$He
$cos\theta_{NN} < -0.90$	$0.45 \pm 0.11 \pm 0.04$	
$cos\theta_{NN} < -0.80$	$0.40 \pm 0.09 \pm 0.04$	$0.45 \pm 0.11 \pm 0.03$
$cos\theta_{NN} < -0.70$	$0.60 \pm 0.12 \pm 0.04$	

of $N_{NN}(cos\theta)$ of Fig.2(f,g) in the back-to-back angular region. The obtained $N_{nn}/N_{np}(\sim \Gamma_n/\Gamma_p)$ of NMWD of ${}^{12}_{\Lambda}$C is ~ 0.5 which is close to that of ${}^{5}_{\Lambda}$He. The systematic error are mainly from the neutron detection efficiency, 6% .

We have measured the emitted pair nucleons in the NMWD of ${}^{12}_{\Lambda}$C in coincidence. We clearly identified Λ N $\rightarrow$ nN decay channel and determined the pair yield ratio per NMWD, N_{nn}/N_{np}, without much ambiguity of FSI and 2N NMWD contribution. The obtained $N_{nn}/N_{np}(\sim \Gamma_n/\Gamma_p)$ of NMWD of ${}^{12}_{\Lambda}$C is ~ 0.5 which is almost free from the effects of FSI and 2N induced contribution. This value is consistent well with recent theoretical calculation results [6].

We are grateful to K.Nakamura and KEK-PS staff for the support of our experiment and stable operation of KEK-PS. Authors, MK and HB, acknowledge the support from KOSEF(R01-2000-000-00019-0)and KRF(2003-070-C00015).

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