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MEASUREMENT WITH HIGH RESOLUTION OF THE PROTON SPECTRA FROM THE NON-MESONIC WEAK DECAY OF $^{5}_{\Lambda}$He, $^{7}_{\Lambda}$Li AND $^{12}_{\Lambda}$C

FINUDA Collaboration

Abstract

The aim of this work is to present the latest experimental results obtained with the FINUDA experiment, istalled at the collider DAΦNE at Laboratori Nazionali di Frascati, from the study of the NMWD for ^{6}Li, ^{7}Li and ^{12}C targets. Proton spectra will be presented for the NMWD of $^{5}_{\Lambda}$He, $^{7}_{\Lambda}$Li and $^{12}_{\Lambda}$C hypernuclei. In particular the proton spectrum following the weak decay of $^{7}_{\Lambda}$Li has been never studied before.

1 Introduction

The importance of the non-mesonic weak decays (NMWD) of Hypernuclei has been recognized from the early days of hypernuclear physics [1], but for several decades the item was scarcely studied experimentally, due to the hardness of obtaining rasonable event rates. Only in the last few years a considerable effort was performed at KEK by the SKS Collaboration and measurements of several observables, like lifetimes, neutron and proton spectra, coincidence spectra and polarization were measured with reasonable precision. A quite recent experimental review is due to Outa [2]. Also from the theoretical side a clever effort has been performed, in close correlation with the flow of the experimental data coming out. Reviews on the theoretical progress are due to Alberico and Garbarino [3].

As a result of these efforts, a reasonable qualitative agreement between theory and experiment was achieved on some items, but not on others. In particular Bauer *et. al* [4] noticed a strong disagreement concerning the partial proton decay widths Γ_p for the $\Lambda n \rightarrow np$ process in nuclei. These considerations lead us to analyze carefully the proton spectra following the NM decay of Hypernuclei in the data collected with the FINUDA spectrometer at DAΦNE [5]. In a previous paper [6] we presented our results concerning ${}^{12}_{\Lambda}$C, obtained from the analysis of the data collected in the 2003-2004 run; we present here preliminary results from the analysis of the above data on ${}^{12}_{\Lambda}$C with an improved code of analysis, as well as of new data collected in the 2006-2007 run on targets of ^{6}Li and ^{7}Li.

2 Experimental method and analysis techniques

The FINUDA detector has been described in a previous pubblication [7], and we recall here only a few relevant features. Hypernuclei are produced by the reaction

$$K^-_{stop} + ^A Z \rightarrow ^A_\Lambda Z + \pi^- \qquad (1)$$

induced by the low-energy (16 MeV) K^- from the $\phi(1020)$-decay produced at the DAΦNE ϕ-factory. FINUDA consists of several subdetectors (Si-microstrip detectors, low mass drift chambers, straw tubes, scintillators) arranged to provide the hypernucleus formation vertex, with a spatial resolution of 30 μm, and the tracking of the charged particles from the vertex, with a resolution of $\sim$0.6% FWMH for pions and 1.2% for protons. The detectors are arranged in a cylindrical geometry centered around the colliding beams (e^+,e^-) axis, in a magnetic field provided by a superconducting solenoid of 1 T, homogeneous within 1% and the total solid angle of detection is 2π sr. Compared with the analysis performed in [6], the more significant improvements are:

1. the reconstruction of the trajectories of the charged particles, previously done by requiring 4 hits in the tracking detectors (*long tracks*), now is done also requiring 3 hits (*short tracks*). This improvement allowed to recover the losses in statistics (inefficiencies of the detectors), as well as to lower the low energy cut on the proton spectra from 25 to 15 MeV.

2. the particle identification was performed not only taking into account the information from the Si-microstrip detectors but also using the drift chambers information.

3. the distance between the K^- interaction vertex of reaction (1) and the π^- extrapolated track point was required to be less than 3 mm, allowing a powerful cleaning of the spectra from the background due to the physical processes, mainly Σ^- decay in flight from the reactions:

$$K^- + (np) \rightarrow \Sigma^- + p \qquad\qquad \Sigma^- \rightarrow p + \pi^- \tag{2}$$

   which is one of the limiting feature to the use of reaction (1).

4. the acceptance, whose precise knowledge is of paramount importance for the determination of the proton spectra in particular near the threshold of 15 MeV, was evaluated passing the simulated events (protons emitted isotropically from 100 to 600 MeV/c, from the nuclear targets) through the full reconstruction chain used for the real events. Geometrical effects, efficiency of the FINUDA pattern recognition, trigger requests and quality cuts were then taken into proper account. We remark that in the analysis reported previously only geometrical effects were taken into account.

3 Experimental results

3.1 ^6Li *targets*

The results reported here correspond to a total of $\sim$21$\times$ 10^6 K^- stopped in the two ^{6}Li targets used in the 2006-2007 run. ^{6}Li is the only nuclear target for which reaction (1) does not lead to a bound hypernucleus. As a matter of fact $^6_\Lambda$Li is unbound and decays immediately into $^5_\Lambda$He + p.

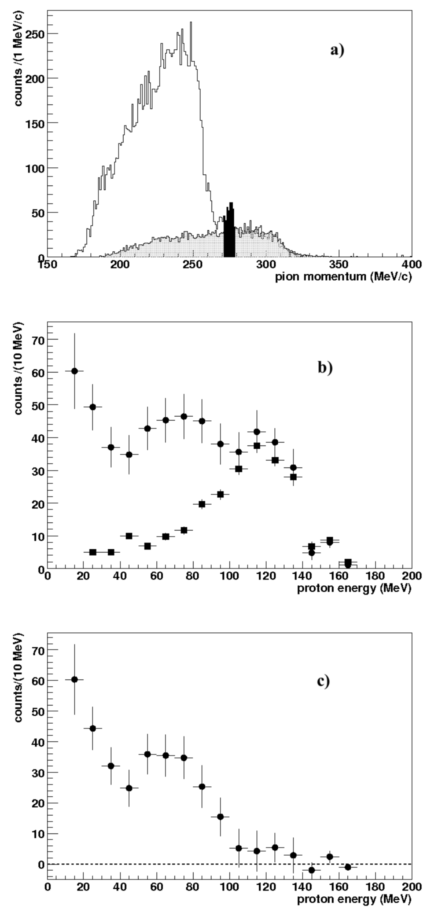

Figure 1: a): π^- spectrum for events with an additional proton track, from the two ^{6}Li targets; the region selected in black evidences the *g.s.* region and superimposed (hatched histogram) the contribution to the spectrum from the K^-np channel. b): Energy spectrum of the proton coming from the background absorption process (squares) superimposed to the acceptance corrected proton spectrum obtained from the data (dots) for the $^5_\Lambda$He. c): Proton energy spectrum coming from the NMWD of $^5_\Lambda$He after the background subtraction.

In the spectrum of π^- from (1) on a ^{6}Li target, a peak appears at 275

MeV/c and it is the signature of the ${}^{5}_{\Lambda}$He formation. Fig.1(a) shows the π^- momentum spectrum in coincidence with a proton. By selecting the π^- in the range from 272 to 278 MeV/c (black area in Fig.1(a)) we obtain the proton spectrum shown in Fig.1(b) (dots). It exhibits a double humped camel-back shape; the hump at 80 MeV is due to the protons from the NM weak deacy of ${}^{5}_{\Lambda}$He, that one at 120 MeV to reaction (2). A similar structure, but with a less pronounced second hump was observed for ${}^{12}_{\Lambda}$C, and will be reported for ${}^{7}_{\Lambda}$Li. The case of ${}^{6}_{\Lambda}$Li is special, since it exhibits a peculiar (α+d) cluster structure. We observed clearly such an effect in a previous analysis on the (K^-np) absorption process on ^{6}Li [8]. For ^{6}Li we modeled the (K^-np) absorption process contribution by using the quasi-d momentum distributions calculated by [10]. The hatched histogram in Fig1(a) shows the π^- spectrum from such a simulation; the two π^- spectra of Fig1(a) are normalized to the same area beyond 278 MeV/c. The black squares in Fig.1(b) indicate the spectrum of the protons from reaction (2) emitted in coincidence with a π^- in the range 272-278 MeV/c, i.e. the background. The second hump is nicely reproduced. Fig.1(c) shows the difference between the two spectra of Fig.1(b). We will discuss such a spectrum after the discussion on the ^{7}Li targets, which is related.

3.2 ^{7}*Li targets*

The results discussed here correspond to a total of $\sim$13 $\times$ 10^6 K^- stopped in the two ^{7}Li targets used in the 2006-2007 run. Fig. 2(a) shows the π^- spectrum in coincidence with a proton. By selecting the π^- in the range from 272 to 278 MeV/c (hatched area in Fig.2(a)) corresponding to the formation of ${}^{7}_{\Lambda}$Li in the ground state, we obtain the proton spectrum of Fig2(b) (black dots) which shows a maximum at 80 MeV, with a shoulder around 120 MeV. In order to subtract the contribution from the reaction (2), we used an approach similar to that adopted for ^{6}Li, apart the modeling of the internal motion of the (np) pair, taken from conventional models of the nucleon internal momenta and not from a peculiar cluster structure.

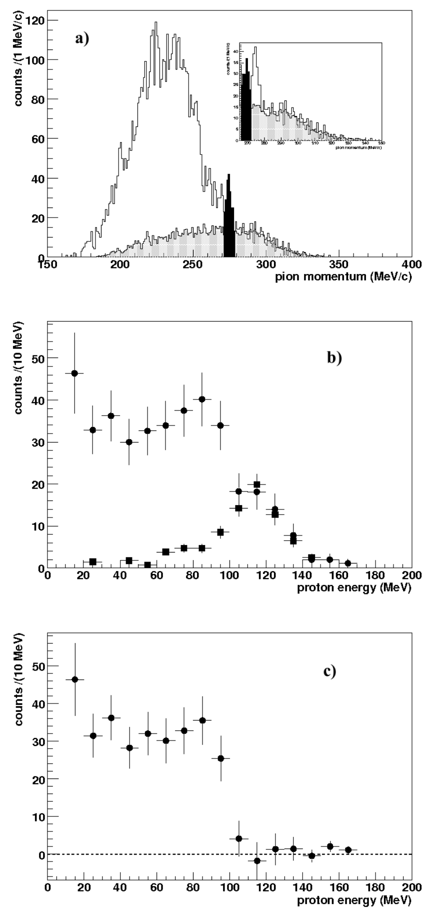

Figure 2: a): π^- spectrum for events with an additional proton track, from the two ^{7}Li targets; the black region correspond to the interval choosen for the *g.s.* and superimposed (hatched histogram) the contribution to the spectrum from the $K^- np$ absorption reaction. b): Energy spectrum of the proton coming from the background (squares) superimposed to the acceptance corrected proton spectrum obtained from the data (dots) for the $^7_\Lambda$Li. c):Proton energy spectrum coming from the NMWD of $^7_\Lambda$Li after the background subtraction.

The hatched histogram in Fig2(a) shows the π^- spectrum from this source, normalized at the same area beyond 278 MeV/c. The dots in Fig. 2(b) indicate the spectrum of the protons from reaction (1) emitted in coincidence with a π^- in the momentum range 272-278 MeV/c. Fig. 2(c) shows the difference between the two spectra. The spectrum looks like a peak centered at 80 MeV, as expected from NM decays, with a low enegy tail that can be attribuited to final state interaction and/or two nucleons $\Lambda + (np) \rightarrow nnp$ induced decays [9].

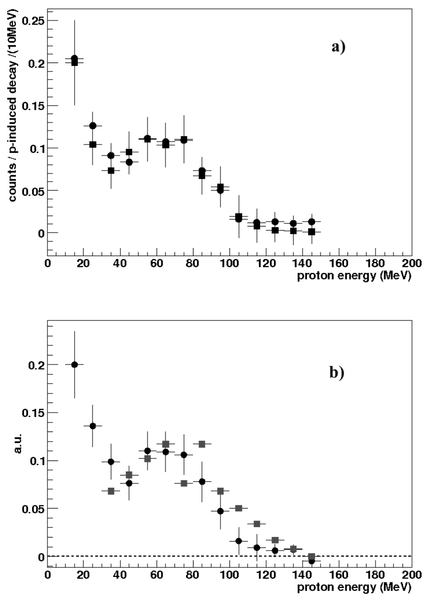

Figure 3: a): Proton energy spectrum of ${}^5_\Lambda$He obtained from ^{7}Li targets analysis (squares) and the one obtained with the analysis of ^{6}Li targets (dots). The two spectra are normalized to area beyond 15 MeV. b): (black dots) FINUDA proton spectrum from induced proton non mesonic weak decay for ${}^5_\Lambda$He; squares: result achieved for the${}^5_\Lambda He$ at the KEK experiments; the two spectra are normalized to area beyond 35 MeV.

A closer inspection to Fig.2(a) indicate a hint for a peak at 269 MeV/c (inset of Fig.2(a)), which does not show up in the inclusive π^- spectrum, but

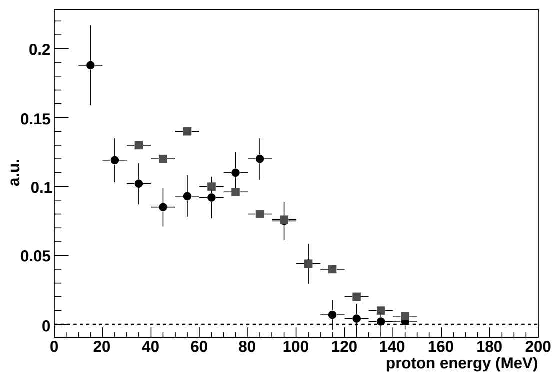

Figure 4: Black dots: FINUDA proton spectrum from induced proton non mesonic weak decay for ${}^{12}_{\Lambda}C_{g.s.}$; squares: result achieved for ${}^{12}_{\Lambda}C_{g.s.}$ at the KEK experiments; the two spectra are normalized to area beyond 35 MeV.

only if a proton in coincidence is required. It corresponds to the formation of the (${}^{5}_{\Lambda}$He+d) system. If true the proton spectrum should be that measured for the ^{6}Li targets. By selecting the π^- from 267 to 271 MeV/c we obtain a final spectrum which is very same, within the errors, of that measured for ^{6}Li, and reported in Fig3(a), superimposed. We have omitted all the intermediate steps of the analysis, fully similar to the previous one. By adding the two spectra we obtain the final spectrum of protons from ${}^{5}_{\Lambda}$He NM decays, represented in Fig.3(b).

3.3 ${}^{12}C$ *targets*

The analysis of the spectra of protons emitted from ${}^{12}_{\Lambda}$C in the ground state was carried out as in Ref. [6], but with the improvements of the reconstruction code described in Sec.2. We omitt for sake of brevity the intermediate analysis steps, and we present only the final result, shown by Fig.4.

3.4 Results and Discussion

The partial decay rates Γ_p we measured and reported in Tab. 1 and are calculated for protons of energy greater than 15 MeV. Then they must be considered only as lower bounds for the Γ_p. The comparison with previous existing data by SKS [11] is reported in Fig.3(b) and 4. The grey squares repesent the KEK data. In order to compare the shapes of the spectra, we have normalized to area the spectra by FINUDA and by SKS beyond 35 MeV. Whereas there is a consistency for the spectra from ${}^{5}_{\Lambda}$He (the Kolmogorov-Smirnov test provides a confidence level of 75%), the spectra for ${}^{12}_{\Lambda}$C are fully inconsistent (the Kolmogorov-Smirnov test provides a confidence level of 5%). Work is in progress in order to compare the experimental results with the theoretical predictions. At present our conclusion is that the proton spectra show the " memory of the free reaction $\Lambda + p \rightarrow np$ " (peak at 80 MeV); a result which is naively expected on simple grounds. The low energy tail can be attibuited to FSI or two nucleon absorption processes [3].

Target material	**Hypernucleus**	Γ_p (units of Γ_Λ)
^{7}Li and ^{6}Li	${}^{5}_{\Lambda}$He	0.26±0.1
^{7}Li	${}^{7}_{\Lambda}$Li	0.37±0.09
^{12}C	${}^{12}_{\Lambda}$C	0.43±0.07

Table 1: Γ_p values calculated for the proton induced decay of the studied hypernuclei. The errors reported in the table are statistical only.

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