Strangeness Nuclear Physics Results from FINUDA

Monica Bertani

Laboratori Nazionali di Frascati dell'INFN, Via E.Fermi 40, I-00044 Frascati, Italy

Abstract. From the analysis of the first data set collected by the FINUDA experiment new results on strangeness nuclear physics have been obtained, stimulating deeper investigation, both experimental and theoretical. The main results obtained up to now concern ${}^{12}_{\Lambda}C$ spectroscopy, search for neutron-rich hypernuclei and for $\overline{K}$-nuclear states.

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INTRODUCTION

FINUDA is a non focusing magnetic spectrometer installed in the ϕ-factory DAΦNE in Frascati. The main idea of the experiment is to stop the flux of slow and monochromatic K^- (127 MeV/c) coming from the main ϕ decay $\phi \to K^+K^-$ (49%) in thin nuclear targets ($0.1 \div 0.3\,\mathrm{g\,cm^{-2}}$) with minimum straggling, thus producing Λ-hypernuclei ${}^{A}_{\Lambda}Z$ through the strangeness exchange reaction: $K^-_{stop} + {}^{A}Z \to {}^{A}_{\Lambda}Z + \pi^-$. The spectroscopy of hypernuclear states can be performed by measuring the momentum of the isotropically emitted π^-. The detector, whose details and performances are described in ref.[1, 2], is designed as a typical collider experiment and provides a full event multi-tracking reconstruction with large acceptance and high momentum resolution for charged particles. Therefore it is possible to study a wide-range physics program from the formation and decay of strange hadronic systems to the features of strange nuclear matter systems. Latest results from FINUDA experiment are reviewed here.

HYPERNUCLEAR SPECTROSCOPY

The raw momentum spectrum of the π^- coming from the ${}^{12}C$ targets is shown in fig.1a) where the two main peaks from the ground state and first excited states are evident. Several background processes from K^- absorption producing π^- have been simulated and reconstructed in the apparatus. The size of the apparatus and the magnetic field value (B=1.1 T) determine a momentum acceptance cut for long tracks of about 180MeV/c. Therefore the contributing background processes left are quasi-free Λ decay ($\Lambda \to p\pi^-$) where Λ are produced from $K^-n \to \Lambda\pi^-$, and the nucleon absorption $K^-NN \to \Sigma^-N$, $\Sigma^- \to n\pi^-$. The background processes are subtracted from the experimental spectrum, momenta are converted in binding energy (B_Λ) and the resulting ${}^{12}_{\Lambda}C$ excitation spectrum is shown in fig.1b). The resulting energy resolution is 1.29 MeV/c FWHM which improves the previous measurement obtained at KEK with a 1.45MeV FWHM

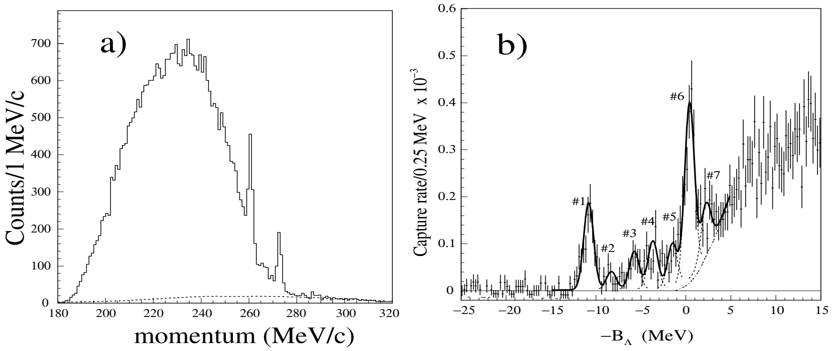

FIGURE 1. a) Spectrum of the momentum of the π^- emitted from the interaction vertex of a K^- into a carbon target. The dashed line represents the contribution from K^- absorption by two nucleons (see details in the text). b) Λ binding energy spectrum of ${}^{12}_{\Lambda}$C. The solid line represents the result of a fit with 7 gaussian functions. The dot-dashed line starting at $B_\Lambda = -1$ MeV represents the contribution from the quasi-free Λ production. The dotted lines represent the result of a gaussian fit on every single peak.

resolution. The two prominent peaks, numbered 1 and 6, correspond to the ground state formation s_Λ and first excited state p_Λ of ${}^{12}_{\Lambda}C$. With respect to the previously observed levels, peak #5 is a newly observed state that was interpreted as the positive-parity excited state of the ${}^{11}C$ core [3]. Details of the analysis and discussion can be found in [2].

SEARCH FOR NEUTRON RICH HYPERNUCLEI

Neutron-rich Λ hypernuclei with a large neutron excess (N/Z ratio more than double the typical ordinary nuclei values) have been theoretically predicted [4] but never observed up to now. The search of such hypernuclei is an intriguing challenge in the attempt to expand our knowledge on nuclear systems toward the limits of stability in the S=-1 plane and to study their structure at high N/Z ratio. Furthermore relation with nuclear astrophysics exists, mainly in the study of very high-density matter in neutron stars [5]. Neutron rich Λ-hypernuclei can be produced by means of different reactions based on the double charge-exchange mechanism, such as (K^-, π^+), studied in FINUDA. The overall production reaction is $K^-_{stop} +^A (Z) \rightarrow^A_\Lambda (Z-2) + \pi^+$. The residual Λ-hypernucleus has two protons less and one neutron more than the target nucleus.

On the target nuclei ^{6}Li, ^{7}Li and ^{12}C employed by FINUDA, the above reaction should produce the neutron-rich hypernuclei ${}^{6}_{\Lambda}$H, ${}^{7}_{\Lambda}$H and ${}^{12}_{\Lambda}$Be together with a π^+ which characterizes their signature. The inclusive momentum spectra of the selected π^+ is shown in fig.2. No significant structure at minimum 90% C.L. either in the region of interest (where neutron rich hypernuclei are expected to be) nor in the whole Λ bound region is shown. Upper limits for the production rate of ${}^{6}_{\Lambda}$H and ${}^{7}_{\Lambda}$H at 90% C.L., in (K^-_{stop}, π^+) reactions, are $(2.5\pm0.4_{stat}{}^{+0.4}_{-0.1}{}_{syst}) \times 10^{-5}/\mathrm{K}^-_{stop}$ and $(4.5\pm0.9_{stat}{}^{+0.4}_{-0.1}{}_{syst}) \times 10^{-5}/\mathrm{K}^-_{stop}$ respectively. These are the first experimental data ever extracted for these nuclei. For ${}^{12}_{\Lambda}$Be the upper limit estimated by FINUDA is $(2.0\pm0.4_{stat}{}^{+0.3}_{-0.1}{}_{syst}) \times 10^{-5}/\mathrm{K}^-_{stop}$ which improves the previous measurement [6]. Details on the analysis and

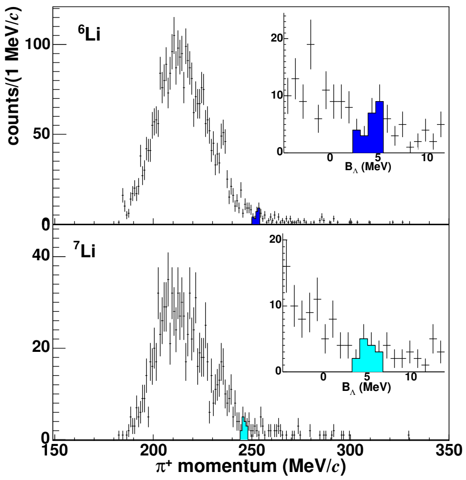

FIGURE 2. Inclusive π^+ momentum spectra after the background reduction. The region of interest are highlighted and enlarged views of the same spectra around the region of interest, with the Λ binding energy axis, are shown in the insets.

systematic errors can be found in [7].

SEARCH FOR $\overline{K}$-BOUND NUCLEAR STATES

The existence of the so-called deeply bound $\overline{K}$-nuclear systems [8] is highly debated. These states consist of few-body strange (S=–1) systems composed of nucleons strongly bound to a $\overline{K}$. The strength of the $\overline{K}N$ attractive interaction, in the I=0 configuration, allows for the stability of the system, as well as for its compactness [9]. The binding energies predicted for these states are rather sizeable, and their widths are very narrow. On the other hand, plenty of theoretical evaluations exist that predict much shallower trends [10] for the $\overline{K}$-nucleus potential depth and substantially exclude the possibility of observing such states. Further criticism is coming from [11], which criticizes the first theoretical approach explaining the observed signals in terms of few body K^- absorption reactions and their elementary kinematics. The quest for the existence of such states is open and experimental answers are needed.

Experimental signatures compatible with deeply bound states have been found by KEK-PS E471 experiment [12, 13] for the (K^--three nucleon) system by exploiting the missing mass method: they claimed the existence of two states $S^0(3115)$ and $S^+(3140)$, observed in the inclusive proton and neutron spectra respectively.

FINUDA has observed [14] a signal for a (K^-pp) bound state decaying into Λp by studying the invariant mass of the system. On the other side, from the study of inclusive proton spectra following the capture of K^- in ^{6}Li, and ^{12}C [15] no signal is found compatible with a $\overline{K}$-nuclear state as seen by [12]. The momenta spectra of protons following the capture of K^- in ^{6}Li and ^{12}C have been measured with 1% resolution, the inclusive distributions are shown in fig 3a) for ^{6}Li (two targets) and in fig.3b) for ^{12}C (three targets), not acceptance corrected. The ^{12}C spectrum is smooth, whereas for ^{6}Li

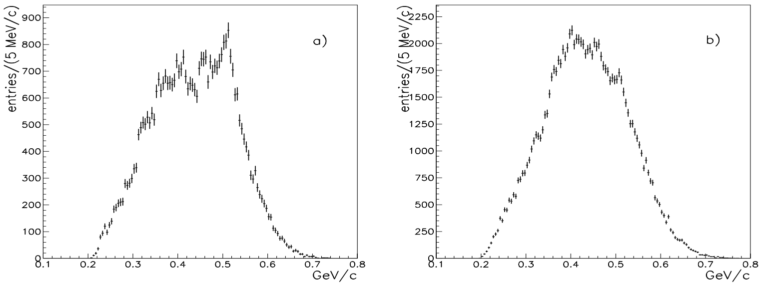

FIGURE 3. Inclusive proton spectra measured following K^- capture at rest from ^{6}Li (a) and ^{12}C (b).

a well defined peak appears at about 500 MeV/*c*. The first observation of a structure of this kind in the same region [12] was identified as a strange tribaryon or, possibly, a $\overline{K}$-nuclear state: $K^- + ^4He \to S_0 + p$. The full reconstruction of the kinematics of the events in the peak allows FINUDA to explain (for details see ref.[15]) the structure as due to the interaction of the K^- with a "quasi"-deuteron cluster in the ^6Li nucleus, leading to the two body final state $\Sigma^- + p$. The protons in the peak are in fact correlated with π^- coming from Σ^- decay in flight, with momenta larger than 275 MeV/*c*. The capture rate for such a reaction is $(1.62 \pm 0.23_{stat}\ ^{+0.71}_{-0.44}(sys))\%/K^-_{stop}$, in agreement with the existing observations on ^{4}He targets and with the hypothesis that the ^{6}Li nucleus can be interpreted as a $(d+\alpha)$ cluster. This explanation rules out the quest for a deeply bound state in this channel and a warning is coming that selective capture by nuclei can be the source of ambiguities in missing mass measurements.

More experimental data is needed and FINUDA is going to take a five-fold data starting October 2006.

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