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Results on Λp emission from K^- absorption at rest on light nuclei

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Abstract

The analysis of the first FINUDA paper on the emission of Λp pairs following the K^- absorption at rest on ^{6}Li, ^{7}Li, ^{12}C nuclei has been revised by using a much larger data set and an updated analysis techniques. The preliminary results regarding the $^9\text{Be}(K^-_{stop}, \Lambda p)X$ reaction are discussed.

Keywords: Kaon absorption; Kaon-induced reactions and scattering; Kaon nuclear bound states; Kaonic nuclear bound clusters

1. Introduction

When the FINUDA Collaboration observed for the first time Λp correlated pairs following K^- absorption at rest on ^{6}Li, ^{7}Li, ^{12}C targets [1], a strong back-to-back correlation was observed. Such an angular correlation is expected for the quasi-free two nucleon absorption; however, the invariant mass spectra showed that only a little fraction of it belongs to the quasi-free signal at ~ 2340 MeV/c^2. The largest part of the Λp data features a bump at $M_{\Lambda p} = 2255$ MeV/c^2, 67 MeV/c^2 wide. The strong angular correlation suggested to the authors of Ref. [1] that the dynamics between K^- and the two protons could be affected by a strong attractive potential. In order to get rid of the background contamination the first analysis was based on the exclusive selection of the back-to-back Λp pairs. Such a selection inspired an alternative interpretation, provided by [2], who explained the Λp bump in terms of Final State Interaction of Λ and p with the residual nucleus. A bump-like structure can be obtained thanks to an angular cut, as applied to the FINUDA data.

Some concern was also arisen about the role of heavier nuclear cluster formation and $\Sigma\Lambda$ conversion reaction, as well as $\Sigma^0 \to \Lambda\gamma$ decay.

In order to clarify the experimental situation, an analysis was performed on the data coming from the second FINUDA data-taking, which could rely on a statistics ~ 8 times higher than that collected during the first run. Accordingly, each target could be examined separately, instead of dealing with a mixture of light targets as in [1]. Moreover, to improve the tracking reconstruction performance a new pattern recognition and fitting algorithm was implemented, that allowed to lower the momentum threshold and to reconstruct pions with momentum as low as 60–70 MeV/c. This achievement was crucial to study the mesonic weak decay of Lambda hypernuclei [3] and to detect the $\pi^\pm$ spectra in coincidence with a $\Sigma^\mp$ formation [4]. A further improvement was applied to the vertex finding algorithm, which allows to determine the secondary vertex, for instance the $\Lambda \to \pi^- p$ decay, with ~ 200 μm resolution and the kaon stop position with ~ 800 μm resolution, being the latter mainly due to the multiple scattering suffered by the low momentum kaons.

The present analysis actually deals only with protons and Λ's with momentum larger than 300 MeV/c, to discard events with large acceptance correction weights. This study differs from the previous one [1] in the selection cuts, in the type of analyzed targets and in the track reconstruction code. In the former analysis the background was mainly rejected by applying strong cuts, on the contrary in the present analysis the cuts were relaxed, so it basically deals with all reactions involved in Λp spectra produced in K^-_{stop} absorption reactions.

2. Results

The reactions induced by the absorption at rest of negative kaons with Λ and p in the final state come from the absorption on proton pairs or proton–neutron pairs. The latter are more probable even because of the statistical ratio $2N/(Z-1)$ (in a nucleus with Z protons and N neutrons [5]), but to have a Λ and p in the final state a two step reaction is required. Therefore, the final Λp yield from proton–neutron absorption is comparable with the one from proton–proton.

The following ten reactions participating to Λp production were considered, which are grouped in 5 sets for a practical representation:

a) $K^-_{stop}pp[A-pp] \to \Lambda p[A-pp]_{g.s.}$;
b) $K^-_{stop}pp[A-pp] \to \Sigma^0 p[A-pp]_{g.s.}$, $\Sigma^0 \to \Lambda\gamma$;
c) $K^-_{stop}pp[A-pp] \to \Sigma^+ n[A-pp]_{g.s.}$, $\Sigma^+ n \to \Lambda p$,
$K^-_{stop}n[A-n] \to \Sigma^0\pi^-[A-n]_{g.s.}$, $\Sigma^0 p \to \Lambda p$,
$K^-_{stop}p[A-p] \to \Sigma^+\pi^-[A-p]_{g.s.}$, $\Sigma^+ n \to \Lambda p$;
d) $K^-_{stop}pp[A-pp] \to \Sigma^0 p[A-pp]_{g.s.}$, $\Sigma^0 n \to \Lambda n$,
$K^-_{stop}pn[A-np] \to \Sigma^- p[A-pn]_{g.s.}$, $\Sigma^- p \to \Lambda n$,
$K^-_{stop}ppn[A-ppn] \to \Lambda pn[A-ppn]_{g.s.}$;
e) $K^-_{stop}pN[A-pN] \to \Lambda N[A-pN]_{g.s.}$, $N[A-pN] \to Np[A-ppN]$,
$K^-_{stop}pp[A-pp] \to \Lambda p[A-pp]_{g.s.}$, $\Lambda[A-pp] \to \Lambda n[A-ppn]$.

All the ten reactions were simulated in impulse approximation, where the interacting nucleons are assumed to move with Fermi motion inside a nucleus and the Λ and p are then injected in the full simulation of the FINUDA apparatus. The simulated reactions were analyzed with the same cuts of the data and finally corrected for the apparatus acceptance. The reaction a) describes the direct process of Λp production, where both Λ and p are expected to leave the nucleus undisturbed. Therefore, their invariant mass distribution is expected to mark the upper edge of Λp invariant mass. In b) an intermediate Σ^0 is excited which promptly decays to $\Sigma^0 \to \Lambda\gamma$ by emitting a 74 MeV γ. For the group c) reactions, the Λp pairs are the product of a secondary reaction, the $\Sigma N \to \Lambda N$ conversion. For the reactions of group d), the final Lambdas and protons belong to different reaction steps, their invariant mass is therefore expected to be broad. For the group e) reactions, the particles in the final state are required to interact with the residual nucleus before being detected. In this case, Final State Interactions are accounted for by following the method described in Ref. [2]. In addition to the $A(K^-_{stop}, \Lambda p)A'_{g.s.}$ reaction where the A' appears in its ground state, A' can be left in an excited state. The residual nucleons can also be emitted as separate particles or as clusters of nucleons. Simulations have to be performed to study the effects of final state configurations different from $A'_{g.s.}$.

In order to take into account all the reactions and the behavior of all the observables, the 10 reactions were requested to fit at the same time 5 data distributions, i.e., the Λp missing mass, the Λp invariant mass, the Λ and p momentum and the distribution of the Λp opening angle cosine. All the reaction rates were left free to vary in the fit and the minimization was performed by a maximum likelihood method as explained in Ref. [6]. The procedure estimated the fractions of different reactions through a fit to the Λp data, and took account of statistical uncertainties in both data and Monte Carlo. The absorption processes of a negative kaon by few-nucleon systems have been studied since long time, but the experimental results are available on few nuclei and, whenever available, they are characterized by low statistics [7]. On the other

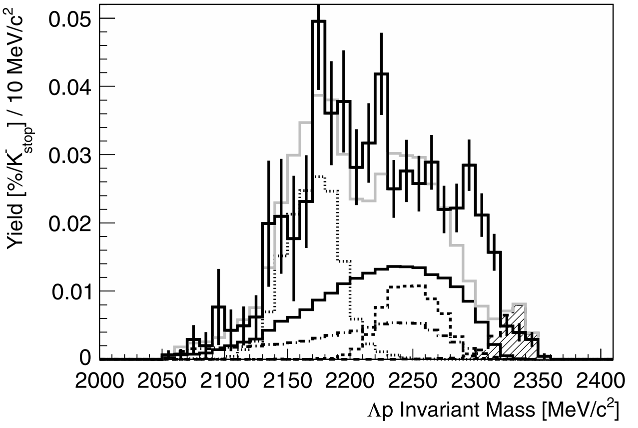

Fig. 1. Invariant mass distributions of Λp pairs from K^- absorption on ^{9}Be. Black histogram with error bars: data; gray histogram: global fit result; other histograms: simulations, see text for the details.

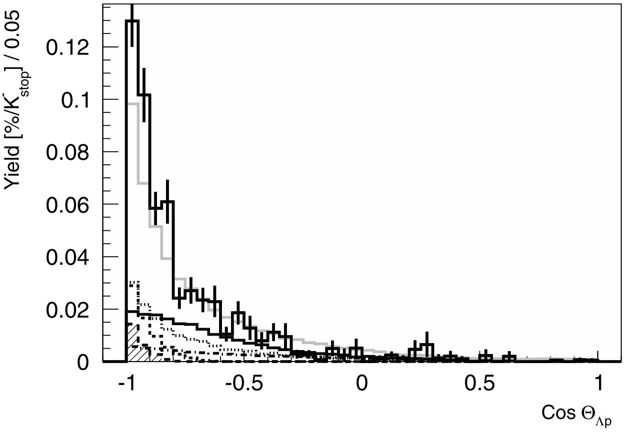

Fig. 2. Cos$\Theta_{\Lambda p}$ distribution from K^- absorption on ^{9}Be. Black histogram with error bars: data; gray histogram: global fit result; other histograms: simulations, see text for the details.

hand, the theoretical predictions of the reactions absorption rates are inferred from old data [8], preventing the fit procedure from being reliably constrained.

This paper reports the preliminary results obtained on ^{9}Be data.

Fig. 1 shows the results of the Λp invariant mass fitting: the black histogram corresponds to the data and the gray histogram shows the outcome of the global fit. The result of simulations matches the data well except at around $M_{\Lambda p} = 2300\ \text{MeV}/c^2$, where the data clearly display a bump. The reaction a) cannot explain it since the outcome of simulations (hatched) is rightly peaked at $2330\ \text{MeV}/c^2$, that is at the edge of the Λp invariant mass data. Reaction b) (dashed) is located fairly below $2300\ \text{MeV}/c^2$. Groups d) (three dots-dashed) and e) (dot-dashed) reactions are flat and cannot reproduce any bump shape. Finally, the reactions of group c) (dotted) lie in the low-energy region of Λp invariant mass close to the end of the apparatus acceptance.

The excess strength at Λp invariant mass $\sim 2300\ \text{MeV}/c^2$ is also clearly observable on the $\cos\Theta_{\Lambda p}$ distribution (Fig. 2); in fact, at around $\cos\Theta_{\Lambda p} = -1.0$ there is a part of spectrum which cannot be reproduced by any of the considered reactions. In addition, reactions of groups c), d) and e) can only describe the long tail of the angular distribution.

The comparison between data and simulations clearly indicates that this analysis leaves out (at least) one reaction channel.

3. Discussion

The model of Ref. [2], based on an initial $K^-_{stop} pN$ absorption being followed by a Λ or N FSI, predicts a broad Λp invariant mass and angular distribution (dot-dashed curves in Figs. 1 and 2). Such a model is unable to describe the excess strength at Λp invariant mass $\sim 2300\ \mathrm{MeV}/c^2$ and $\cos\Theta_{\Lambda p} \sim -1.0$. Moreover, the simulation of $K^-_{stop} ppn[A - ppn]$ three nucleon absorption (group d)) and the Σ conversion reactions show a similar behavior thus being unable to reproduce the excess strength.

The present analysis confirms that the Λp data coming from K^-_{stop} absorption by ^{9}Be cannot be explained only by the set of the considered quasi-free reactions. Further analyses are underway to extract the features of the observed excess strength around $2300\ \mathrm{MeV}/c^2$ by means of detailed simulations to be injected into the global fit procedure and to verify the findings for the other nuclei investigated by FINUDA.

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