Two and three nucleon $K^-$ absorption in nuclei

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Abstract

We analyze the peaks in the $(Λp)$ and $(Λd)$ invariant mass distributions, observed in recent FINUDA experiments and claimed to be signals of deeply bound kaonic states, and find them to be naturally explained in terms of $K^-$ absorption by two or three nucleons leaving the rest of the target nucleus as a spectator. For reactions on heavy nuclei, the subsequent interactions of the particles produced in the primary absorption process with the residual nucleus play an important role. Thus at present there is no experimental evidence of deeply bound $K^-$ states in nuclei.

Key words: $K^-$ absorption in nuclei, many body absorption, final state interaction
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1. $K^-$-nucleons bound states at FINUDA

The possibility of having deeply bound $K^-$ states in nuclei is receiving much attention both theoretically (see for example Ref. [1] for an overview) and experimentally. Here we discuss recent FINUDA data that have been sometimes used to imply the existence of deeply bound $K^-$ states.

A peak observed by the FINUDA collaboration [2] in the invariant mass distribution of $Λp$, following $K^-$ absorption in a mixture of light nuclei, was interpreted as evidence for a $K^-pp$ bound state, with 115 MeV binding and 67 MeV width. However, it was soon shown in [3] that the peak seen is naturally explained in terms of $K^-$ absorption on a pair of nucleons leading to a $Λp$ pair, followed by final state interactions (FSI), i.e. by the rescattering of $p$ or $Λ$ on the remnant nucleus, and that the back-to-back correlation of the $Λp$ pairs is preserved to large extent. Fig. 1 shows the $Λp$ invariant mass distribution for $K^-$ absorption in a mixture of light nuclei following the proportion [2]: 51% $^{12}$C, 35% $^6$Li and 14% $^7$Li, including kaon boost machine corrections [4]. However, we stress...
that in this mixture the contribution of reactions with $^{12}$C is absolutely dominant, about 99%. This is mostly due to the two orders of magnitude higher overlap of the nuclear density with the corresponding $K^-$ wavefunction $\int d\vec{r} |\Psi_{K^-}(\vec{r})|^2 \rho_A(\vec{r})$ in $^{12}$C than in Li. Nevertheless, in order to verify in detail our model of $K^-$ two nucleon absorption dynamics, our choice of $\Psi_{K^-}(\vec{r})$, and our simulation of FSI, experimental spectra for separate nuclei are necessary, while at the moment the $(\Lambda p)$ invariant mass distribution is only available for the mixture of the three lightest targets [2].

More recently, a new experiment of the FINUDA collaboration [5] found a peak on the invariant mass of $\Lambda d$ following the absorption of a $K^-$ on $^6$Li, which was interpreted as a signature for a bound $KNNN$ state with 58 MeV binding and 37 MeV width. Note that this result is in disagreement with the previous FINUDA statement [2], since the bound state of the $K^-$ with three nucleons should have a larger binding energy than with two nucleons.

A similar experiment was performed at KEK [6] on $^4$He target, looking at the $\Lambda d$ invariant mass following $K^-$ absorption. It is claimed, however, that the observed peak could be a signature of three body absorption.

In Ref. [7] we performed detailed calculations of $K^-$ absorption by three nucleons in $^6$Li and showed that all features observed in [5] could be well interpreted in the picture of three body kaon absorption, as suggested in [6], with the rest of the nucleons acting as spectators - see Fig. 2. It is also important to note that $^{12}$C was also used as a target in the same FINUDA experiment, and the corresponding $\Lambda d$ invariant mass spectrum does not show a clear peak [5]. This was attributed in [5] to FSI of the particles produced in the primary absorption process with the residual nucleus, in complete agreement with the mechanisms discussed in Ref. [3].
Fig. 2. The $\Lambda d$ invariant mass distribution (left plot) and $\Lambda d$ angular distribution (right plot) for $K^-$ absorption in $^6\text{Li}$. Histogram and error bars are from the experimental paper [5], while the dot-dashed curve is the result of our calculation [7].

2. Conclusions

We have shown that the peaks observed by FINUDA in the $(\Lambda p)$ [2] and $(\Lambda d)$ [5] invariant mass distributions, following the absorption of stopped $K^-$ in different nuclei, are naturally explained in terms of:
- $K^-$ absorption by two [3] or three [7] nucleons correspondingly, leaving the rest of the target nucleus as spectator;
- for the reactions on heavy nuclei, the subsequent interactions of the particles produced in the primary absorption process ($\Lambda, p, d$, etc.) with the residual nucleus have to be taken into account.

Thus, at present, there is no experimental evidence of deeply bound $K^-$ states in nuclei.

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