Chapter 63
Recent AMADEUS Studies of Low-Energy K^-—Nucleus/Nuclei Interactions

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Abstract We briefly report the recent results obtained by the AMADEUS collaboration on experimental studies of the K^- low-energy interactions with light nuclei and outline the future perspectives.

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D. Elia et al. (eds.), *The XVIII International Conference on Strangeness in Quark Matter (SQM 2019)*, Springer Proceedings in Physics 250,
https://doi.org/10.1007/978-3-030-53448-6_63

63.1 Introduction

The low-energy QCD describing the strong interaction remains still poorly known in the strangeness sector due to the lack of fundamental experimental results. One of the key-issues is the investigation of the low-energy interaction between K^- mesons and nucleons/nuclei reflected by the $\Lambda(1405)$ resonance properties and possible kaonic bound state formation in the isospin I = 0 channel [1, 2]. Recently, two different theoretical approaches considered this issue. The phenomenological potential models [3–7] consider the I = 0 $\Lambda(1405)$ as a pure $\bar{K}N$ bound state and thus predicting the existence of deeply bound kaonic nuclear states. The chiral models [8–12] predict the $\Lambda(1405)$ as a superposition of two states, which results in a much less attractive K^-N and leads to the prediction of only slightly bound kaonic nuclear states. Therefore, to clarify this issue, experimental data are needed.

The AMADEUS collaboration performed measurements which set new experimental constraints to the K^-N strong interaction in the non-perturbative QCD exploiting the low-energy K^- hadronic interactions with light nuclei (e.g. H, ^{4}He, ^{9}Be and ^{12}C) [13]. The excellent quality low-momentum kaon beam ($p_K \sim 127$ MeV/c) delivered by the DAΦNE electron-positron collider [14] and the KLOE detector [15] as an active target were used to explore both stopped and in-flight K^- nuclear captures.

A complete characterization of the K^- two-, three- and four-nucleon absorptions (2NA, 3NA and 4NA) was performed for the first time in the Λp and $\Sigma^0 p$ final states studying the low-energy K^- captures on a solid ^{12}C target [16, 17]. Moreover, the possible contribution of a K^-pp bound state to the measured Λp spectrum was investigated. A summary of the analysis [16] is shown in Sect. 2.

The experimental investigation of the non-resonant hyperon-pion production in I = 1 channel ($K^-n \rightarrow \Lambda\pi^-$) [18] was carried out to provide important informations on the $\Lambda(1405)$ resonance structure. Sec. 3 presents a summary of the obtained results.

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The described analyses have been performed for the data sample of 1.74 fb^{-1}, collected by the KLOE collaboration [15] during the 2004/2005 data taking period.

63.2 Characterisation of the K$^-$ Multi-nucleon Absorptions in Λp and Σ^0p Final States; Search for the K$^-$pp Bound State

The AMADEUS collaboration performed studies of $\Lambda(\Sigma^0)$p channels in K$^-$ absorption on ^{12}C [16] which allowed to extract for the first time two, three and four nucleon absorption branching ratios (BRs) and cross sections for low-momentum kaons in the investigated channels. The Λp direct production in 2NA-QF is expected to be phase space favoured with respect to the corresponding Σ^0p final state and the ratio between the final state phase spaces for the two processes is $\mathcal{R}' \simeq 1.22$. From the BRs we measure:

$$\mathcal{R} = \frac{\mathrm{BR}(\mathrm{K}^-\mathrm{pp} \to \Lambda\mathrm{p})}{\mathrm{BR}(\mathrm{K}^-\mathrm{pp} \to \Sigma^0\mathrm{p})} = 0.7 \pm 0.2(\mathrm{stat.})^{+0.2}_{-0.3}(\mathrm{syst.}). \qquad (63.1)$$

The dominance of the Σ^0p channel is then evidence of the important dynamical effects involved in the measured processes.

The reconstruction of $\Lambda(\Sigma^0)$p channels allows also for the search of a signal corresponding to eventual intermediate formation of a K$^-$pp nuclear cluster. The performed analysis shows that the K$^-$ multi-nucleon absorption processes are sufficient to describe the Λp spectrum (right panel of Fig. 63.1). The contribution of

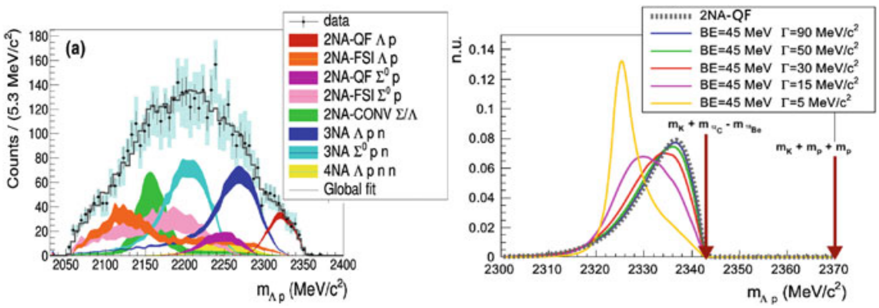

Fig. 63.1 (left) Λp invariant mass distribution for the K$^-$ absorption on ^{12}C listed in the legend. Black points represent the data, black error bars correspond to the statistical errors, cyan error bars correspond to the systematic errors. The gray line distributions represent the global fitting functions. (right) Calculated Λp invariant mass distributions for the process K^{-12}C $\to$ K$^-$pp + ^{10}Be $\to$ Λp + ^{10}Be, for a bound state with BE = 45 MeV and = 5, 15, 30, 50 and 90 MeV/c^2 (yellow, magenta, red, green and blue curves respectively). The gray curve is the shape of the 2NA-QF. The areas of the distributions are normalised to unity. These figures are adapted from [16]

the possible K^-pp bound state completely overlaps with 2NA-QF, except for small values of the bound state width (less than 15 MeV/c^2), as it is shown in the left panel of Fig. 63.1.

63.3 Investigation of Non-resonant $A_{K^-n\to\Lambda\pi^-}$ Transition Amplitude Below the $\bar{K}N$ Threshold

In order to investigate the $\Lambda(1405)$ resonance properties, produced through the K^- induced reaction in light nuclear targets, it is essential to take into account two biases. One bias is related to the invariant mass threshold due to the absorbing nucleon binding energy (for K^- capture at rest on ^4He and on ^{12}C the $\Sigma\pi$ invariant mass threshold is about 1412 MeV, and 1416 MeV, respectively). The $\bar{K}N$ sub-threshold region associated to the $\Lambda(1405)$ high-mass predicted pole (about 1420 MeV), can be explored by measurement of K^-N absorption in-flight. The in-flight contribution (for kaons with mean momentum of 100 MeV/c) shifts by about 10 MeV the $\Sigma\pi$ invariant mass threshold.

The second bias is the contribution of non-resonant $K^-N \to Y\pi$ reaction. The non-resonant transition amplitude modulus $|A_{K^-n\to\Lambda\pi^-}|$ was extracted for the first time in the $K^-n \to \Lambda\pi^-$ process, considering K^-n single nucleon absorptions in ^4He [18]. For this purpose experimentally extracted $\Lambda\pi^-$ invariant mass, momentum and angular distributions were simultaneously fitted using dedicated MC simulations that include non-resonant processes, resonant processes and the primary production of a Σ followed by the $\Sigma N \to \Lambda N'$ conversion process. The simulations of non-resonant/resonant processes were performed based on the results of phenomenological calculations presented in [19]. The data analysis gave $|A_{K^-n\to\Lambda\pi^-}|(33\pm6)$ MeV = 0.334 ± 0.018 (stat.) $^{+0.034}_{-0.058}$ (syst.) fm. This measurement allows to test and constrain recent calculations for S-wave $K^-n \to \Lambda\pi^-$ transition amplitude.

63.4 Conclusion

The interactions of low-momentum kaons K^- with nucleons/nuclei in light nuclear targets are investigated by AMADEUS with the aim to provide new experimental constraints to the K^-N strong interaction in the non-perturbative regime of the QCD in the strangeness sector. BRs and cross sections for the two-, three- and four-nucleon absorptions in the Λp and $\Sigma^0 p$ final states were determined by the studies of low-energy K^- interactions in a solid carbon target. The experimental investigation of the non-resonant $K^-N \to Y\pi$ production was performed for the first time for K^-n single nucleon absorption in ^4He. This result is substantial for the determination of the I = 1 background biasing the $\Lambda(1405)$ spectrum.

Acknowledgment We acknowledge the KLOE/KLOE-2 Collaboration for their support and for having provided us the data and the tools to perform the analysis presented in this paper. We acknowledge the CENTRO FERMI - Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi", for the project PAMQ. Part of this work was supported by the Austrian Science Fund (FWF): [P24756-N20]; Austrian Federal Ministry of Science and Research BMBWK 650962/0001VI/2/2009; the Croatian Science Foundation, under project 8570; Minstero degli Affari Esteri e della Cooperazione Internazionale, Direzione Generale per la Promozione del Sistema Paese (MAECI), StrangeMatter project; Polish National Science Center through grant No. UMO-2016/21/D/ST2/01155; EU STRONG-2020 (grant agreement 824093).

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