

RECENT EXPERIMENTAL RESULTS ON
THE LOW-ENERGY K^- INTERACTION WITH
NUCLEONS BY AMADEUS*

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(Received October 7, 2019)

Recent results obtained by the AMADEUS Collaboration on the experimental investigation of the K^- low-energy interaction with light nuclei

* Presented at the 3rd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland, June 23–28, 2019.

are summarised. The step 0 of AMADEUS consists in the analysis of the data collected at the DAΦNE collider with the KLOE detector during the 2004/2005 data taking campaign. The low momentum K^- particles ($p_K \sim 127$ MeV/ c) are absorbed in the light nuclei contained in the detector setup (H, ^4He , ^9Be and ^{12}C) and hyperon-pion/hyperon-nucleons, emitted in the final state, are reconstructed. From the study of $\Lambda\pi^-$ and Λp correlated production, important information on the $\bar{K}N$ strong interaction in the non-perturbative QCD regime are extracted.

DOI:10.5506/APhysPolB.51.121

1. Introduction

The AMADEUS Collaboration aims at providing experimental information on the low-energy strong interaction between K^- and nucleons with implications ranging from the domain of nuclear physics to astrophysics [1].

The investigation of the antikaon-nucleon ($\bar{K}N$) interaction is fundamental for the comprehension of the nature of the $\Lambda(1405)$ (isospin $I = 0$), which means experimentally measured mass is about 27 MeV below the $\bar{K}N$ threshold [2] and has a dynamical origin. In phenomenological potential models [3–7], the resonance is interpreted as a pure $\bar{K}N$ bound state, in chiral models [8–12], the resonance appears as a superposition of two states coupled respectively to the $\Sigma\pi$ and $\bar{K}N$ channels. The relative position of the two states is determined by the strength of the $\bar{K}N$ interaction potential. The experimental investigation of the $\Lambda(1405)$ properties is also challenging because the resonance line-shape is found to depend on both the production mechanism and the observed decay channel. Moreover, if the $\Lambda(1405)$ is produced in K^- -induced reactions, the non-resonant $\Sigma\pi$ production contribution has to be considered. In Ref. [13], the non-resonant hyperon-pion ($Y\pi$) production in the $I = 1$ channel, where the resonant counterpart due to the $\Sigma(1385)$ formation is well-known, is investigated. In Section 2, the results obtained in Ref. [13] are summarised.

The strength of the $\bar{K}N$ sub-threshold interaction also influences the formation of bound states of antikaons with more than one nucleon. The experimental search of such exotic bound states in K^- -induced reactions cannot disregard a comprehensive characterisation of the K^- multi-nucleon absorption processes due to the overlap with the K^- bound state formation over a broad range of the phase space [14, 15]. The K^- multi-nucleon absorption cross sections at low-energy are also crucial for the interpretation of the data in heavy-ion collisions [16]. The role of the K^- absorption on more than one nucleon has been recently demonstrated to be fundamental in the determination of the K^- -nucleus optical potential [17, 18]. A phenomenological K^- multi-nucleon absorption term, constrained by global absorption

bubble chamber data, was added to the K^- single-nucleon potential, in order to achieve good fits to K^- atoms data along the periodic table [17, 18]. In Ref. [19], a complete study of the K^- interactions with two, three and four nucleons ($2NA$, $3NA$ and $4NA$) processes has been performed. The details of the data analysis will be given in Section 3.

The step 0 of AMADEUS consists in the re-analysis of the data collected by the KLOE Collaboration [20] during the 2004/2005 data taking campaign and corresponding to 1.74 fb^{-1} integrated luminosity. The low-momentum K^- ($p_K \sim 127 \text{ MeV}/c$), produced at the DAΦNE collider [21] from the ϕ -meson decay nearly at-rest, are captured on the nuclei in the materials of the beam pipe setup and of the KLOE detector (H, ^4He , ^9Be and ^{12}C) used as active target. The analysed data sample allows to investigate both at-rest ($p_K \sim 0 \text{ MeV}/c$) and in-flight K^- nuclear captures. $Y\pi$ and YN /nuclei pairs produced in the final state of the K^- absorptions are reconstructed.

2. Modulus of the $K^-n \rightarrow \Lambda\pi^-$ amplitude below threshold

The experimental investigation of the $\Lambda(1405)$ properties, produced in stopped K^- reactions with light nuclei, is disturbed by two main biases:

- the $\Sigma\pi$ ($I = 0$) invariant mass line-shape is biased by the energy threshold, shifted from 1432 MeV to lower energies (1412 MeV in ^4He and 1416 MeV in ^{12}C) due to the separation energy of the absorbing proton. In in-flight K^- reactions, the energy threshold is shifted upward due to the kinetic energy of the kaon?
- the shape of the non-resonant $K^-p \rightarrow (\Sigma\pi)^0$ reactions has to be taken into account.

In Ref. [13], the non-resonant $K^-n \rightarrow \Lambda\pi^-$ process is investigated, considering K^-n single-nucleon absorptions on ^4He . Since the $\Sigma^-(1385)$ ($I = 1$) resonance is well-known, the corresponding non-resonant transition amplitude ($|T_{K^-n \rightarrow \Lambda\pi^-}|$) can be extracted and used to test the theoretical predictions below threshold.

In this work, the experimentally extracted $\Lambda\pi^-$ invariant mass, momentum, and angular distributions were simultaneously fitted by using dedicated MC simulations. All the contributing reactions were taken into account: non-resonant processes, resonant processes and the primary production of Σ followed by the $\Sigma N \rightarrow \Lambda N'$ conversion process. The simulations of non-resonant/resonant processes were based on the results of [22]. The analysis allowed the extraction of the non-resonant transition amplitude modulus $|T_{K^-n \rightarrow \Lambda\pi^-}|$ at $\sqrt{s} = (33 \pm 6) \text{ MeV}$ below the $\bar{K}N$ threshold, which is found to be

$$|T_{K^-n \rightarrow \Lambda\pi^-}| = \left(0.334 \pm 0.018 \text{ (stat.)}_{-0.058}^{+0.034} \text{ (syst.)} \right) \text{ fm}. \quad (1)$$

The result of this analysis (with combined statistical and systematic errors) is shown in Fig. 1 and compared with the theoretical predictions (see Refs.: Ramos–Magas–Feijoo [23], Ikeda–Hyodo–Weise [24], Cieplý–Smejkal [25], Guo–Oller 1 and 2 [26], Mai–Meissner 2 and 4 [27]). This measurement can be used to test and constrain the S-wave $K^-n \rightarrow \Lambda\pi^-$ transition amplitude calculations.

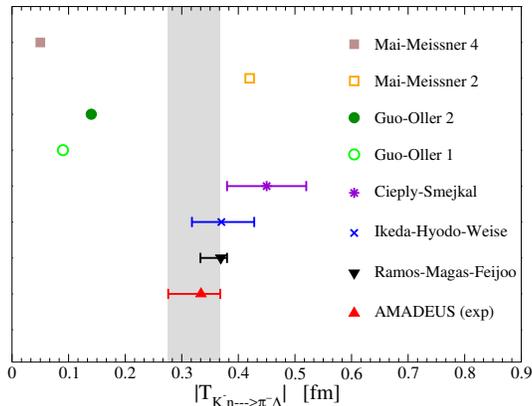


Fig. 1. Modulus of the non-resonant amplitude for the $K^-n \rightarrow \Lambda\pi^-$ process at 33 MeV below the $\bar{K}N$ threshold obtained by AMADEUS, compared with theoretical predictions: Ramos–Magas–Feijoo [23], Ikeda–Hyodo–Weise [24], Cieplý–Smejkal [25], Guo–Oller 1 and 2 [26], Mai–Meissner 2 and 4 [27]. The plot was adapted from Ref. [28].

3. K^- multi-nucleon absorption branching ratios and cross sections

The absorption of the K^- on two, three or more nucleons is investigated by the AMADEUS Collaboration in Refs. [15, 19], by reconstructing Λp and $\Sigma^0 p$ pairs emitted in K^- hadronic interactions with ^{12}C nuclei.

In Ref. [19], Branching Ratios (BRs) and cross sections of the K^- $2NA$, $3NA$ and $4NA$ were obtained by means of a simultaneous fit of the Λp invariant mass, Λp angular correlation, Λ and proton momenta using the simulated distributions for both direct Λ production and Σ^0 production followed by $\Sigma^0 \rightarrow \Lambda\gamma$ decay. The K^- nuclear capture was calculated for both at-rest and in-flight interactions, based on the K^- absorption model described in Refs. [22, 29]. In the first case, the absorption from atomic $2p$ state is assumed. Fragmentations of the residual nucleus following the hadronic interaction were also considered. For the $2NA$, the important contributions of both final-state interactions (FSI) of the Λ and the proton were taken

into account, as well as the conversion of primary produced sigma particles ($\Sigma N \rightarrow \Lambda N'$); this allows to disentangle the quasi-free (QF) production. The global BR for the K^- multi-nucleon absorption in ^{12}C (with $\Lambda(\Sigma^0)p$ final states) is found to be compatible with bubble chamber results. The measured BRs and low-energy cross sections of the distinct $2NA$, $3NA$ and $4NA$, reported in Table I, will be useful for the improvement of microscopical models of the K^-NN absorption and for a future generalisation to K^- absorption reaction calculations involving even more than two nucleons.

TABLE I

Branching ratios (for the K^- absorbed at-rest) and cross sections (for the K^- absorbed in-flight) of the K^- multi-nucleon absorption processes. The K^- momentum is evaluated in the centre-of-mass reference frame of the absorbing nucleons, thus it differs for the $2NA$ and $3NA$ processes. The statistical and systematic errors are also given.

| Process | Branching ratio [%] | σ [mb] | @ p_K [MeV/c] |
|------------------------------|---|---|-----------------|
| $2NA$ -QF Λp | $0.25 \pm 0.02(\text{stat.})^{+0.01}_{-0.02}(\text{syst.})$ | $2.8 \pm 0.3(\text{stat.})^{+0.1}_{-0.2}(\text{syst.})$ | @ 128 ± 29 |
| $2NA$ -FSI Λp | $6.2 \pm 1.4(\text{stat.})^{+0.5}_{-0.6}(\text{syst.})$ | $69 \pm 15(\text{stat.}) \pm 6(\text{syst.})$ | @ 128 ± 29 |
| $2NA$ -QF $\Sigma^0 p$ | $0.35 \pm 0.09(\text{stat.})^{+0.13}_{-0.06}(\text{syst.})$ | $3.9 \pm 1.0(\text{stat.})^{+1.4}_{-0.7}(\text{syst.})$ | @ 128 ± 29 |
| $2NA$ -FSI $\Sigma^0 p$ | $7.2 \pm 2.2(\text{stat.})^{+4.2}_{-5.4}(\text{syst.})$ | $80 \pm 25(\text{stat.})^{+46}_{-60}(\text{syst.})$ | @ 128 ± 29 |
| $2NA$ -CONV Σ/Λ | $2.1 \pm 1.2(\text{stat.})^{+0.9}_{-0.5}(\text{syst.})$ | — | — |
| $3NA$ Λpn | $1.4 \pm 0.2(\text{stat.})^{+0.1}_{-0.2}(\text{syst.})$ | $15 \pm 2(\text{stat.}) \pm 2(\text{syst.})$ | @ 117 ± 23 |
| $3NA$ $\Sigma^0 pn$ | $3.7 \pm 0.4(\text{stat.})^{+0.2}_{-0.4}(\text{syst.})$ | $41 \pm 4(\text{stat.})^{+2}_{-5}(\text{syst.})$ | @ 117 ± 23 |
| $4NA$ Λpnn | $0.13 \pm 0.09(\text{stat.})^{+0.08}_{-0.07}(\text{syst.})$ | — | — |
| Global $\Lambda(\Sigma^0)p$ | $21 \pm 3(\text{stat.})^{+5}_{-6}(\text{syst.})$ | — | — |

The Λp direct production in $2NA$ -QF is phase space favoured with respect to the corresponding $\Sigma^0 p$ final state, the ratio between the final-state phase spaces for the two processes is $\mathcal{R}' \simeq 1.22$. From the BRs in Table I, we measure

$$\mathcal{R} = \frac{\text{BR}(K^- pp \rightarrow \Lambda p)}{\text{BR}(K^- pp \rightarrow \Sigma^0 p)} = 0.7 \pm 0.2(\text{stat.})^{+0.2}_{-0.3}(\text{syst.}). \quad (2)$$

The dominance of the $\Sigma^0 p$ channel is then evidence of the important dynamical effects involved in the measured processes; hence the ratio in Eq. (2) gives important information on the $\bar{K}N$ dynamics below the threshold [30].

The possible contribution of a K^-pp bound state, decaying into a Λp pair, was also investigated. The $2NA$ -QF is found to completely overlap with the K^-pp , except for small, unphysical, values of the bound state width of the order of $15 \text{ MeV}/c^2$ or less. A further selection of back-to-back Λp production was performed by selecting $\cos\theta_{\Lambda p} < -0.8$ in order to make a direct comparison with the corresponding FINUDA measurement. The invariant-mass distribution is compatible with the shape presented in Ref. [31]. The obtained spectra are completely described in terms of K^- multi-nucleon absorption processes, with no need of a K^-pp component in the fit, and the extracted BRs are in agreement with those obtained from the fit of the full data sample.

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]; the Austrian Federal Ministry of Science and Research BMBWK 650962/0001VI/2/2009; the Croatian Science Foundation, under project 8570; Ministero degli Affari Esteri e della Cooperazione Internazionale, Direzione Generale per la Promozione del Sistema Paese (MAECI), Strange Matter project; the National Science Centre, Poland (NCN) through grant No. UMO-2016/21/D/ST2/01155; EU STRONG-2020 (grant agreement 824093).

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