Proc. 8th Int. Conf. Quarks and Nuclear Physics (QNP2018)
JPS Conf. Proc. **26**, 023011 (2019)
https://doi.org/10.7566/JPSCP.26.023011

Low-energy K⁻ Hadronic Interactions with Light Nuclei by AMADEUS

Magdalena Skurzok[1,2], Massimiliano Bazzi[2], Gabriele Belotti[3], Mario Alexandru Bragadireanu[4], Damir Bosnar[5], Michael Cargnelli[7], Catalina Curceanu[2], Luca de Paolis[2,8], Raffaele Del Grande[2,8], Laura Fabbietti[9,10], Carlo Fiorini[3,6], Francesco Ghio[11,12], Carlo Guaraldo[2], Ryugo Hayano[13], Mihai Iliescu[2], Masahiko Iwasaki[14], Paolo Levi Sandri[2], Johann Marton[7], Marco Miliucci[2,8], Pawel Moskal[1], Shinji Okada[14], Dorel Pietreanu[4], Kristian Piscicchia[2,15], Angels Ramos[16], Alessandro Scordo[2], Hexi Shi[2], Michał Silarski[1], Diana Laura Sirghi[2,4], Florin Sirghi[2,4], Antonio Spallone[2], Oton Vazquez Doce[9,10], Eberhard Widmann[7], Sławomir Wycech[17] and Johann Zmeskal[7]

[1]*Institute of Physics, Jagiellonian University, Kracow, Poland*
[2]*INFN, Laboratori Nazionali di Frascati, Frascati, Rome, Italy*
[3]*Politecnico di Milano, Dip. di Elettronica, Informazione e Bioingegneria, Milano, Italy*
[4]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Magurele, Romania*
[5]*Department of Physics, Faculty of Science, University of Zagreb, HR-10000 Zagreb, Croatia*
[6]*INFN Sezione di Milano, Milano, Italy*
[7]*Stefan-Meyer-Institut für subatomare Physik, Vienna, Austria*
[8]*Universit degli Studi di Roma Tor Vergata, Rome, Italy*
[9]*Excellence Cluster "Origin and Structure of the Universe", Garching, Germany*
[10]*Physik Department E12, Technische Universität München, Garching, Germany*
[11]*INFN Sezione di Roma I, Rome, Italy*
[12]*Istituto Superiore di Sanit, Rome, Italy*
[13]*The University of Tokyo, Tokyo, Japan*
[14]*RIKEN, The Institute of Physics and Chemical Research, Saitama, Japan*
[15]*Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi, Rome, Italy*
[16]*Departament de Fisica Quantica i Astrofisica and Institut de Ciencies del Cosmos, Universitat de Barcelona, Marti i Franques 1, Barcelona, Spain*
[16]*National Centre for Nuclear Research, Warsaw, Poland*

E-mail: magdalena.skurzok@lnf.infn.it

(Received February 1, 2019)

The AMADEUS collaboration aims to provide new experimental constraints to the K⁻N strong interaction in the regime of non-perturbative QCD, exploiting low-energy K⁻ hadronic interactions with light nuclei (e.g. H, ^{4}He, ^{9}Be and ^{12}C). The low-momentum kaons ($p_K \sim 127$ MeV/c) produced at the DAΦNE collider are ideal to explore both stopped and in-flight K⁻ nuclear captures. The KLOE detector is used as an active target, allowing to achieve excellent acceptance and resolutions for the data. In this work the results obtained from the study of $\Lambda\pi^-$ and Λp correlated production in the final state are presented.

KEYWORDS: strangeness, antikaon interactions in nuclear matter

1. Introduction

The theoretical investigation of the low-energy K⁻N interaction predicts, in the energy region below the K⁻N threshold, a sufficiently attractive interaction to form a bound state in the isospin I=0 channel [1, 2]. In [3–7] the I=0 Λ(1405) is interpreted as a pure $\bar{\text{K}}$N bound state, this leads to the prediction of deeply bound kaonic nuclear states. According to Chiral models [8–12] the Λ(1405) emerges as a superposition of two states, as a consequence of the K^-N interaction is much less attractive, which implies the prediction of only slightly bound kaonic nuclear states.

The experimental investigation of the K^-pp bound state properties in K^- induced reactions is strongly biased by the competing K^- - multi-nucleon absorption processes leading to the same final states (see e. g. [13, 14]). In Ref. [15, 16] 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 Σ^0p final states exploiting low-energy K^- captures on a ^{12}C target. In particular, in Ref. [15] the corresponding low-energy cross sections are measured, these represent a crucial ingredient for the determination of the in-medium K^- optical potential [17, 18]. In Section 2 a brief summary of the analysis [15] is given.

The experimental investigation of the Λ(1405) properties is also challenging. The resonance line-shape is found to depend on both the production mechanism and the observed decay channel. Moreover in K^- induced reactions the non-resonant contribution to the final state $\Sigma\pi$ production has to be also taken into account. In Section 3 a brief summary of the results obtained in [19] is given, which could give important information on the underlying $\bar{K}N$ interaction models.

The described analyses refer to a sample of 1.74 fb^{-1} integrated luminosity collected by the KLOE collaboration [20] during the 2004/2005 data campaign. Low-energy K^-s are produced at the DAΦNE collider [21], from the Φ-meson decay nearly at-rest, with a momentum of about 127 MeV/c. The K^- captures, at-rest and in-flight, on the materials of the KLOE detector, used as an active target, are investigated.

In summer 2012 a high purity carbon target (graphite) was realized and installed inside the KLOE detector, between the beam pipe and the DC inner wall.

2. K^- multi-nucleon absorption cross sections and branching ratios in Λp and Σ^0p final states

The possible existence of the K^-pp bound state can be investigated in low-energy K^- induced reactions by reconstructing the decays to $\Lambda(\Sigma^0)$p.

Recently, $\Lambda(\Sigma^0)$p decay modes were investigated by the AMADEUS collaboration in K^{-12}C absorption [15]. These studies allowed to perform the first comprehensive measurements of two, three and four nucleon absorption branching ratios (BRs) and cross sections for low-momentum kaons in Λp and Σ^0p channels. The BR of the Σ^0p direct production in K^- 2NA quasi free interaction is found to be greater than the corresponding Λp production, contrary to what is expected by comparing the pure phase spaces. This gives important indications on the underlying three-body interaction. The Λp spectra are entirely interpreted in terms of K^- multi-nucleon absorption processes, an eventual contribution due to the intermediate formation of a K^-pp bound state completely overlaps with the K^- 2NA in this channel, hence the corresponding yield is not extracted.

3. Resonant and non-resonant $Y\pi$ transition amplitudes below the $\bar{K}N$ threshold

In the investigation of the Λ(1405) properties, produced through the K^-p mechanism in light nuclear targets, two biases have to be taken into account. The first bias is the energy threshold imposed by the absorbing nucleon binding energy (for K^- capture at rest on ^{4}He the $\Sigma\pi$ invariant mass threshold is about 1412 MeV, while for ^{12}C it is about 1416 MeV). In order to access the $\bar{K}N$ sub-threshold region corresponding to the Λ(1405) high-mass predicted pole (about 1420 MeV), K^-N absorption in-flight has to be exploited. For a mean kaon momentum of 100 MeV/c, the $\Sigma\pi$ invariant mass threshold is shifted upwards by about 10 MeV.

Among the three $(\Sigma\pi)^0$ charge combinations $\Sigma^0\pi^0$ represents the best signature for the Λ(1405) resonance, since it is free from the isospin I=0 background. In Fig. 1 the $\Sigma^0\pi^0$ invariant mass spectrum from K$^-$ captures in ^{12}C nuclei for two data samples is shown [22]. The black distribution corresponds to the 2004/2005 data campaign, which include both K$^-$ captures at-rest and in flight. The blue distribution is obtained from 2012 data which include K$^-$ captures at-rest. The blue and the black distributions are normalized to unity. A red line indicates the energy threshold corresponding to K$^-$ absorption in ^{12}C at-rest. A rich sample of in-flight K$^-$^{12}C captures can be easily identified above the red line. The $\Lambda(1405)$ shape can be now extracted after subtracting the $\Sigma^0\pi^0$ non-resonant contribution.

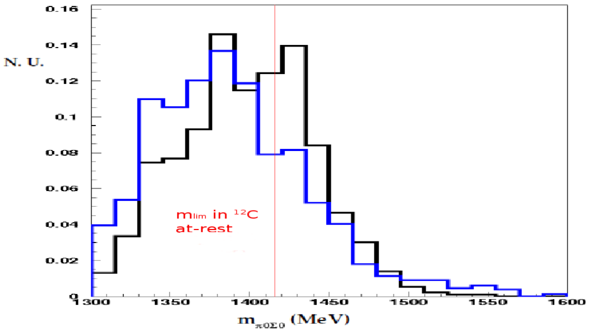

Fig. 1. The $m_{\Sigma^0\pi^0}$ invariant mass distribution from K$^-$ captures in the KLOE DC wall (black curve) and pure carbon graphite target (blue curve).

The second bias is related to the non-resonant K$^-N \to \Sigma\pi$ contribution that has to be subtracted in order to extract the $\Lambda(1405)$ shape. The K$^-$n $\to \Lambda\pi^-$ non-resonant transition amplitude modulus below the $\bar{\text{K}}$N threshold was obtained for the first time in [19] exploiting K$^-$ absorptions on ^{4}He target nuclei.

In this work the measured $\Lambda\pi^-$ invariant mass, momentum and angular distributions were simultaneously fitted by means of dedicated Monte Carlo simulations based on the phenomenological K$^-$-nucleus absorption model described in Ref. [23] (the fit is shown in Fig. 2). All the resonant and non-resonant contributing reactions were taken into account together with the background process due to ΣN $\to \Lambda$N$'$ conversion reactions, and the contamination of K$^-$^{12}C. The non-resonant transition amplitude modulus is found to be $|A_{K^-n\to\Lambda\pi^-}| = (0.334 \pm 0.018 \text{ stat} ^{+0.034}_{-0.058} \text{ syst})$ fm at (33±6) MeV below the $\bar{\text{K}}$N threshold. This result can serve as a reference for the corresponding chiral predictions (See. Ref. [18, 24–28]). Moreover it can be used to get information on the isospin I=0 non-resonant counterpoint contributing to the $\Sigma^0\pi^0$ invariant mass shape shown in Fig. 1.

4. Acknowledgments

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 650962/0001 VI/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), Strange Matter project; Polish National Science Center through grant No. UMO-2016/21/D/ST2/01155.

References

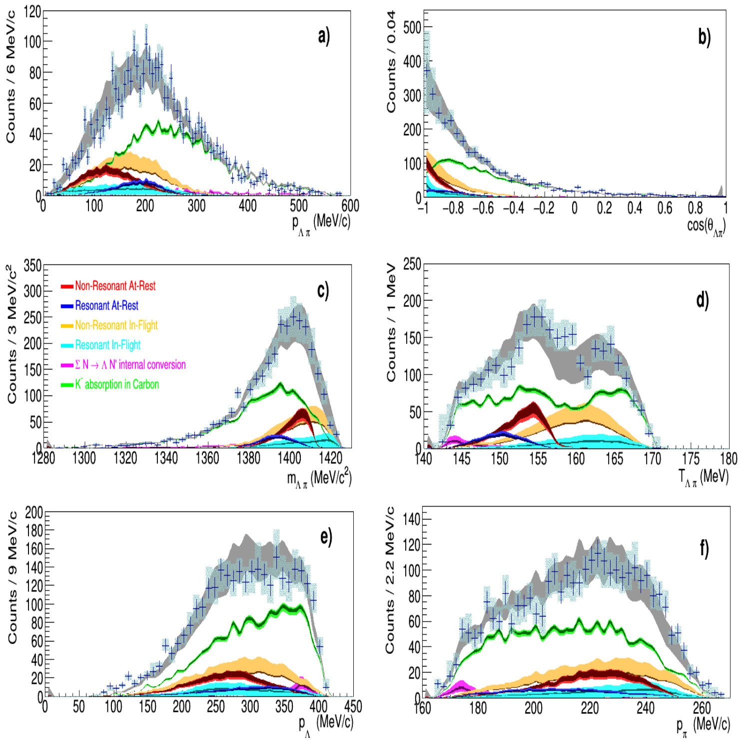

Fig. 2. Panels a-f: $p_{\Lambda\pi}$ ($\Lambda\pi$ momentum), $\cos(\theta_{\Lambda\pi})$ (cosine of angle between Λ and π), $m_{\Lambda\pi}$ ($\Lambda\pi$ invariant mass), $T_{\Lambda\pi}$, p_Λ (Λ momentum) and p_π (π momentum) distributions [19]. The experimental data and the corresponding statistical errors are represented by the black crosses, the systematic errors are light blue boxes. The different contributions included in the fit are shown by the colored histograms: non-resonant at-rest (red), resonant at-rest (blue), non-resonant in-flight (brown), resonant in-flight (cyan), $\Sigma N \to \Lambda N'$ internal conversion (magenta), K^- absorptions in Carbon (green). The light and dark bands correspond to systematic and statistical errors, respectively. The gray band shows the total fit with the corresponding statistical error.

[1] S. Wycech, Nucl. Phys. A **450**, 399c (1986).
[2] Y. Akaishi, T. Yamazaki, Phys. Lett. B **535**, 70 (2002).
[3] Y. Akaishi, T. Yamazaki, Phys. Rev. C **65**, 044005 (2002).
[4] Y. Ikeda and T. Sato, Phys. Rev. C **76**, 035203 (2007).
[5] S. Wycech, A. M. Green, Phys. Rev. C **79**, 014001 (2009).
[6] J. Revai and N. V. Shevchenko, Phys. Rev. C **90**, 034004 (2014).
[7] S. Maeda, Y. Akaishi, T. Yamazaki, Proc. Jpn. Acad. B **89**, 418 (2013).
[8] A. Dote, T. Hyodo, W. Weise, Phys. Rev. C **79**, 014003 (2009).
[9] N. Barnea, A. Gal, E. Z. Liverts, Phys. Lett. B **712**, 132 (2012).
[10] Y. Ikeda, H. Kamano and T. Sato, Prog. Theor. Phys. **124**, 533 (2010).
[11] P. Bicudo, Phys. Rev. D **76**, 031502 (2007).
[12] M. Bayar and E. Oset, Nucl. Phys. A **914**, 349 (2013).
[13] T. Suzuki, et al., Mod. Phys. Lett. A **23**, 2520 (2008).
[14] Y. Sada, et al. PTEP **2016** (5) 051D01 (2016).
[15] R. Del Grande, et al., arXiv:1809.07212 (2018).
[16] O. Vazques Doce, et al., Phys. Lett. B **758**, 134 (2016).
[17] E. Friedman and A. Gal, Nucl. Phys. A **959**, 66 (2017).
[18] J. Hrtankova and J. Mares, Phys. Rev. C **96**, 015205 (2017).
[19] K. Piscicchia et al., Phys. Lett. B **782**, 339 (2018).
[20] F. Bossi et al., Riv. Nuovo Cim. **31**, 531 (2008).

[21] A. Gallo et al., Conf. Proc. **C060626**, 604 (2006).
[22] K. Piscicchia, PhD thesis (2013), http://www.infn.it/thesis/thesis_dettaglio.php?tid=7097.
[23] K. Piscicchia, S. Wycech and C. Curceanu, Nycl. Phys. A **954**, 75 (2016).
[24] A. Cieplý, et al., Nucl. Phys. A **954**, 17 (2016).
[25] A. Cieplý and J. Smejkal, Nucl. Phys. A **881**, 115 (2012).
[26] Y. Ikeda, T. Hyodo and W. Weise, Nucl. Phys. A **881**, 98 (2012).
[27] Z. H. Guo and J. A. Oller, Phys. Rev. C **87**, 035202 (2013).
[28] M. Mai and U. G. Meissner, Eur. Phys. J. A **51**, 30 (2015).