LOW-ENERGY ANTIKAON–NUCLEON/NUCLEI INTERACTION STUDIES BY AMADEUS*

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(Received September 21, 2017)

The AMADEUS experiment deals with the investigation of the low-energy kaon–nuclei hadronic interaction at the DAΦNE collider at LNF-INFN, which is fundamental to solve longstanding questions in the non-perturbative strangeness QCD sector. AMADEUS step 0 consisted in the reanalysis of the 2004/2005 KLOE data, exploiting K^- absorptions in H, ^{4}He, ^{9}Be and ^{12}C, leading to the first invariant mass spectroscopy study with very low-momentum (100 MeV) in-flight K$^-$ captures. With AMADEUS step 1, a dedicated pure carbon target was implemented in the central region of the KLOE detector, providing a high statistic sample of pure at-rest K^- nuclear interaction. The results obtained in the analyses of the hyperon–pion correlated events, searching for the resonant shapes of Y states, will be described.

DOI:10.5506/APhysPolB.48.1875

1. Introduction

The AMADEUS [1] experiment investigates the low-energy K^- hadronic interaction in light nuclei (*e.g.* H, ^{4}He, ^{9}Be and ^{12}C) in order to provide experimental constraints on the non-perturbative QCD in the strangeness sec-

* Presented at the 2$^{\text{nd}}$ Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland, June 3–11, 2017.

tor, by exploiting the low momentum (about 127 MeV/c), almost monochromatic, charged kaons provided by the decay of ϕ mesons at-rest at the DAΦNE factory [2].

In the study of the low-energy QCD with u, d and s quarks, the chiral perturbation theory is not applicable, due to the presence of the broad $\Lambda(1405)$ state just few MeV below the $\bar{K}N$ threshold. The $\Lambda(1405)$ is a $J^P = 1/2^-$ isospin $I = 0$ strange baryon resonance, assigned to the lowest $L = 1$ supermultiplet of the three-quark system, which decays into $(\Sigma\pi)^0$ through the strong interaction. The $\Sigma^0\pi^0$ decay channel, which is free from the $I = 1$ contribution and from the isospin interference term, represents the cleanest signature of the $\Lambda(1405)$ resonance. Despite the fact that the $\Lambda(1405)$ is a four-stars resonance in Particle Data Group (PDG) [3], its nature still remains an open issue. A review of the theoretical works, and references to the experimental literature can be found in [4]. According to the chiral unitary predictions [5], a high-mass pole, coupled to the $\bar{K}N$ production channel and located around 1420 MeV, might contribute to the measured $\Lambda(1405)$ shape. Also interesting is the recent lattice QCD calculation [6]. Since the accessible invariant mass, in K^-p absorption processes, is influenced by the binding energy of the proton in the hosting nucleus, our strategy is to unveil the presence of the high mass pole by exploiting K^- captures in-flight [7, 8]. In this case, the kinetic energy of the kaon sets the energy threshold just below the $\bar{K}N$ threshold. The shape of the $(\Sigma\pi)^0$ spectra is also distorted by the non-resonant production below threshold. A key issue, which is addressed in the analyses described below, is the investigation of the non-resonant hyperon–pion transition amplitude below threshold.

The position of the $\Lambda(1405)$ reflects the strength of the $\bar{K}N$ interaction, thus influencing the possible formation of $\bar{K}$ multi-nucleon bound states. For the di-baryonic kaonic bound state, ppK^- theoretical predictions deliver a wide range of binding energies and widths [9], while the experimental results are contradictory [10–19]. The extraction of ppK^- signal in K^- absorption experiments is strongly affected by the yield and the shape of the competing K^- multi-nucleon absorption processes as clearly evidenced in [20], where the yield of the K^- double-nucleon absorption, when the produced Σ^0p pairs are free from final state interactions [21], was measured for the first time.

2. Data samples

The ongoing AMADEUS analyses refer to two data samples. One is represented by the data collected by the KLOE Collaboration [22] during the 2004/2005 data taking, corresponding to ~ 1.74 fb^{-1}. The KLOE detector [23] is used as an active target, the hadronic interaction of negative kaons with the materials of the apparatus being investigated; in particular K^{-9}Be absorptions in the DAΦNE beryllium thin cylindrical layer and the DAΦNE aluminated beryllium pipe, K^{-12}C and K^-H absorptions in the KLOE Drift Chamber [24] (DC) inner wall (aluminated carbon fiber), K^{-4}He in the DC gas. Extremely rich experimental information is contained in this sample, with K^- hadronic captures both at-rest and in-flight [7].

In order to increase the statistics and as an essential interpretation tool, a high purity carbon target (graphite) was realized in summer 2012 and installed inside the KLOE detector, between the beam pipe and the DC inner wall. The geometry of the target was optimized to maximize the kaon stopping power. The total collected integrated luminosity is ~ 90 pb^{-1}. Up to now, we analysed a sample of 37 pb^{-1} reconstructed data.

Details on the events selection and particle identification for the channels under investigation are given in [1].

3. $Y\pi$ resonant and non-resonant production and the shape of the $\Lambda(1405)$

When extracting the $\Lambda(1405)$ shape from K^- induced reactions in light nuclear targets (see, for example, [25]), the hyperon–pion spectroscopy is influenced by the energy threshold imposed by the last nucleon binding energy. The $m_{\Sigma\pi}$ invariant mass threshold is about 1412 MeV and 1416 MeV, for K^- capture at-rest in ^{4}He and ^{12}C, respectively, thus the K^- absorption at-rest is not sensitive to the $\Lambda(1405)$ high-mass pole. The $\bar{K}N$ sub-threshold region is accessible by exploiting K^-N absorptions in-flight. For a mean kaon momentum of 100 MeV/c, the $m_{\Sigma\pi}$ threshold is shifted upwards by about 10 MeV. Another bias to be considered is represented by the non-resonant $K^-N \rightarrow Y\pi$ transition. The corresponding $m_{Y\pi}$ invariant masses spectra are narrow (of the order of 10 MeV) and peaked below the $\bar{K}N$ threshold. The $\Lambda\pi$ and $\Sigma\pi$ non-resonant transition amplitudes, for K^- capture in light nuclear targets, were never measured. The Λ and π^- kinematic distributions for K^- captures in ^{4}He, both at-rest and in-flight, were calculated in [26]. The momentum probability distribution functions of the emerging hyperon–pion pairs, following K^-n absorptions, are expressed in terms of the K^-n transition amplitudes: the isospin $I = 1$ S-wave non-resonant amplitude ($|f^{\mathrm{nr}}|$) and the resonant $I = 1$ P-wave amplitude, dominated by the $\Sigma^-(1385)$. Since the resonant amplitude is well-known from direct experiments, the measured total momentum distributions can be used to extract the non-resonant $|f^{\mathrm{nr}}|$ amplitude module below the $\bar{K}N$ threshold. The goal of the ongoing analyses is to measure the contributions and the shapes of the non-resonant $\Lambda\pi$ and $\Sigma\pi$ productions. The knowledge of the $(\Sigma\pi)^0$ isospin $I = 0$ non-resonant transition amplitude will allow to disentangle the resonant $\Lambda(1405)$ shape.

Preliminary $\Sigma^+\pi^-$ invariant mass spectra, from K^- captures in the wall of the KLOE DC, neither background subtracted nor acceptance corrected, are shown in Fig. 1. The lower mass peak corresponds to captures in ^{12}C, the two components in-flight (light grey) and at-rest (dark grey) are shown. The high-mass peak centred above 1430 MeV corresponds to K^- absorptions on hydrogen. Such distribution reflects the non-resonant K^-H absorption in-flight, which corresponds to a narrow invariant mass shape peaked below the mass threshold $m_K + m_p + \langle p_K^2 \rangle / 2m_K$. In Fig. 2 (black distribution), the $\Sigma^0\pi^0$ invariant mass spectrum from K^- captures in the KLOE DC wall is shown [27]. The reduced resolution, due to the reconstruction of the three photons clusters, does not allow to disentangle the at-rest from the in-flight capture, moreover the absorbing target (H or ^{12}C) cannot be distinguished in this case. The $m_{\Sigma 0 \pi 0}$ spectrum is compared with the corresponding distribution of K^- captures at-rest in a pure carbon target (Fig. 2, grey/blue distribution), the grey/blue and the black distributions are normalised to unity. In Fig. 2, a vertical 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 vertical line. A spectroscopic study of the kinematic region ranging between the at-rest energy threshold, and the $\bar{K}N$ threshold, opened by the low momentum in-flight capture process, will allow to clarify the nature of the high mass $\Lambda(1405)$ pole.

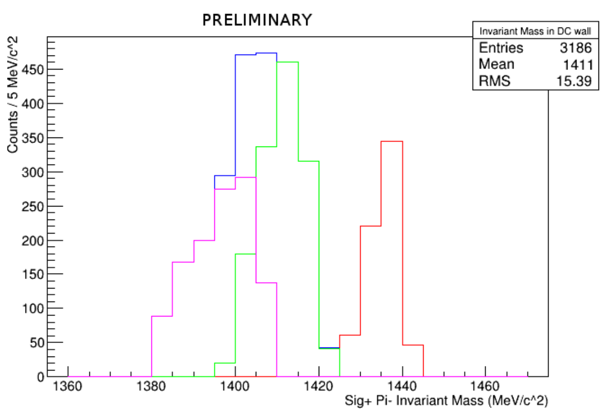

Fig. 1. (Colour on-line) $m_{\Sigma\pi}$ invariant mass distributions. The lower mass peak corresponds to captures in ^{12}C, the two components in-flight (light grey/green) and at-rest (dark grey/magenta) are shown. The high mass peak centered above 1430 MeV corresponds to K^- absorptions on hydrogen.

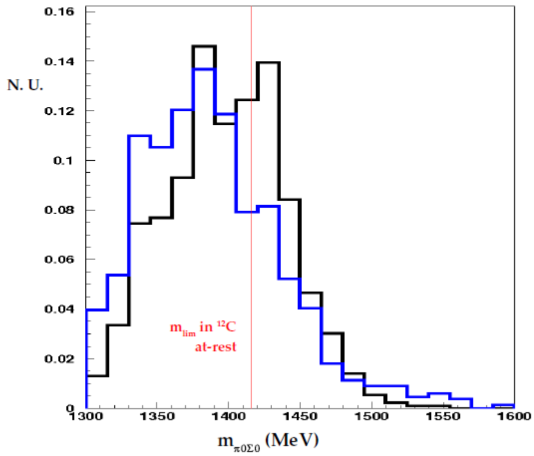

Fig. 2. (Colour on-line) $m_{\Sigma^0\pi^0}$ invariant mass distribution from K^- captures in the KLOE DC wall (black curve) and pure carbon graphite target (grey/blue curve).

4. Conclusions and perspectives

In this work, the investigation of the resonant *versus* non-resonant hyperon–pion production, following K^- absorptions in ^{4}He and ^{12}C is presented. The characterization of the non-resonant $\Sigma^0\pi^0$ production from K^- captures in-flight could enable to evidence and to measure the characteristics of the high-mass pole of the $\Lambda(1405)$.

Presently, a feasibility study [28, 29] is ongoing for the realization of a dedicated AMADEUS experimental setup, in order to deepen and extend the low-energy anti-kaon nuclei interaction studies and obtain fundamental input for the study of QCD with strangeness.

We acknowledge the KLOE Collaboration for their support and for having provided us the data and the tools to perform the analysis presented in this paper. We thank as well the DAΦNE staff for the excellent working conditions and permanent support. 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 Grant-ïn-Aid for Specially Promoted Research (20002003), MEXT, Japan; the Croatian Science Foundation, under project 1680; Minstero 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.

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