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HADRONIC INTERACTIONS OF K^- IN LIGHT NUCLEI: THE AMADEUS EXPERIMENT AND KLOE DATA ANALYSIS*

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The AMADEUS experiment will perform for the first time full-acceptance studies of hadronic interactions of K^- in light nuclei, with a complete experimental program for the case of the deeply bound kaonic nuclear states. The possible formation of a kaonic cluster could provide information concerning the modification of the kaon mass and of the $\bar{K}N$ interaction in the nuclear medium A preliminary study of this kind of hadronic interaction is being done by the AMADEUS Collaboration by analyzing the KLOE data.

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1. Kaonic nuclear clusters

The study of the kaonic nuclear clusters has deep consequences in an open sector of the strangeness hadronic/nuclear physics: how the hadron masses and hadron interactions change in the nuclear medium.

AMADEUS will search [1] for antikaon-mediated deeply bound nuclear states, which could bring important information for investigating the way in which the spontaneous and explicit chiral symmetry breaking pattern of low-energy QCD occur in the nuclear environment.

The deeply bound kaonic nuclear states, or kaonic clusters, were predicted by Wycech [2], and in the recent years an intense debate is going on following the publication by Yamazaky and Akaishi [3] of the prediction that these clusters could be formed by interactions of K^- in light nuclei. These states are formed by a nucleus with a K^- attached inside, favoured by the strongly attractive $\bar{K}p$ potential. It has been initially argued that

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kaonic nuclear clusters may be formed with large binding energies of the order of 100 MeV and narrow widths since the $\Sigma\pi$ decay channel is energetically closed and, additionally, the $\Lambda\pi$ channel is forbidden by isospin selection rule.

Several experimental approaches were pursued [4–8], and previous data from non-dedicated experiments are being reanalyzed [9]. However, the possible experimental indications of the formation of dibaryonic K^-pp and trybarionic K^-ppn states have received alternative explanations in the framework of known processes. Recent more advanced calculations of the $K-pp$ system [10,11] suggest relatively moderate binding and large widths for such states.

What emerges at present is an experimental status of the case with few, low statistics and incomplete results, which are, rightly, not easy to be attributed to a kaonic clusters interpretation, since other scenarios cannot be excluded.

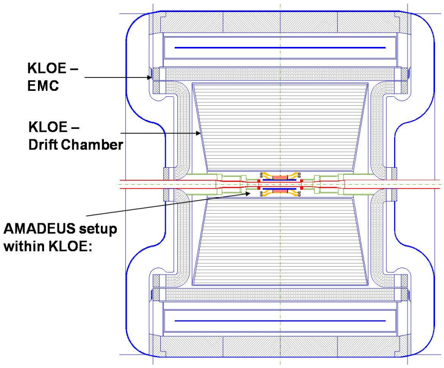
2. The AMADEUS experiment

The AMADEUS Collaboration has the goal to study the K^- hadronic interactions in light nuclei in order to confirm or deny the existence of this kind of deeply bound states, with a systematic and complete spectroscopic study both in formation and in the decay processes. Moreover, AMADEUS aims to perform other types of measurements as: elastic and inelastic kaon interactions on various nuclei, obtaining important information for a better understanding of the undergoing processes.

The DAΦNE accelerator at the Frascati National Laboratories, is a $e^+ e^-$ collider tuned to be a Φ meson factory, where kaons coming from the decay of the Φ are copiously produced. After its recent upgrade [12], it is expected to reach a luminosity as high as 5×10^{32} cm^{-2} s^{-1}.

The experimental setup will consist of the implementation of an AMADEUS dedicated setup in the KLOE spectrometer [13], taking advantage of the 50 cm radius gap present around the interaction point. The KLOE detector capability to reconstruct hyperons with a very good resolution, ideal for kaonic clusters studies, was proven recently, as explained in the next section. Also a good performance of the KLOE setup detecting neutrons has been recently checked by KLONE (KLOE Neutron Efficiency) group [14].

The KLOE detector is composed basically by a 4π drift chamber surrounded by an electromagnetic calorimeter and has been successfully taking data at DAΦNE since 1999. The combination of the dedicated AMADEUS setup with the nice performance of the KLOE apparatus will offer the top level scientific center to study kaonic clusters using K^- induced processes at rest. In the left part of Fig. 1 the location of the AMADEUS setup within the KLOE detector is shown.



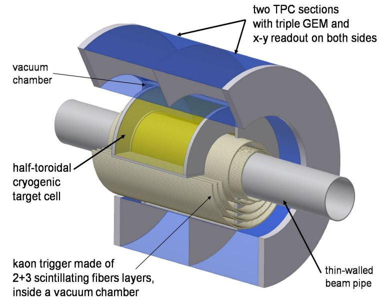


Fig. 1. AMADEUS setup implementation position inside the KLOE detector (left), and detail of the central region (right).

For the integration of the AMADEUS setup within KLOE a Phase-1 of the AMADEUS experiment was already proposed [15] together with a luminosity request and a physics program. The AMADEUS first phase program foresees the investigation of the most basic antikaon-mediated clusters, namely kaonic dibaryon and 3-baryon states $pp\,K^-$, $ppn\,K^-$ and $pnn\,K^-$, produced via ^{3}He (stopped K, n/p) reactions. The search for these bound states will be performed by the process of K^- stopped in high-density cryogenic gaseous ^{3}He and ^{4}He targets, measuring their binding energies and their widths. After this first step, a second phase of AMADEUS will follow, with an upgraded setup and with a higher luminosity request, a complete and systematic spectroscopy will be performed also in heavier targets as Li, B, Be and C. With this second phase the complete scientific program of AMADEUS will be covered, with the determination of binding energies, decay widths and quantum numbers of all states, including excited ones, measurement of the spin–orbit interaction, and obtaining as a by-product information concerning the multi-nucleon absorption mode.

Three main components of an experimental setup are presently under study, including the high gaseous density target, a trigger system made of scintillating fibers, and a tracking device placed internally of the KLOE drift chamber. A design of those components can be seen in Fig. 1.

A toroidal or half-toroidal gaseous target will be used to stop the charged kaons coming from the Φ decay. This target, in a first phase of the experiment, will contain light nuclei, starting with ^{4}He and ^{3}He. A similar target is installed currently in DAΦNE, for the SIDDHARTA [16] experiment, and our group will take advantage of the experience gained in working with it.

One or two layers of scintillating fibers surrounding the beam pipe will be used to trigger the passage of kaons to give the start signal of the acquisition of the experiment. This detector is essential, delivering an optimal trigger condition by making use of the back-to-back topology of the kaons generated from the Φ-decay, profiting of the fact that Φ mesons are produced practically at rest (with a transversal boost of around 10 MeV) in DAΦNE. The development tests of the trigger system uses SiPM (silicon photo-multipliers) to read the scintillating fibers (hundreds of channels are projected).

A tracking device could be eventually installed around the target, prior to the Drift chamber of KLOE. This would serve as vertex detector for the products coming from the interaction of the K^- in the nuclei of the target, in order either to reduce the background and/or to perform more refined (better resolution) dedicated measurements. Two possible solutions are being considered, either cylindrical GEM detectors or a TPC-GEM combination The AMADEUS Collaboration is working characterizing several prototypes of TPG for this task.

3. KLOE data analysis in search for K^- ^{4}He interactions

As a preliminary search for signals of kaonic nuclear clusters inside the KLOE setup, and as first output of the fruitful collaboration between the AMADEUS and KLOE groups, people from the AMADEUS Collaboration are investigating the possible hadronic interactions developed by K^- along the KLOE setup in the collected data from previous KLOE runs [18].

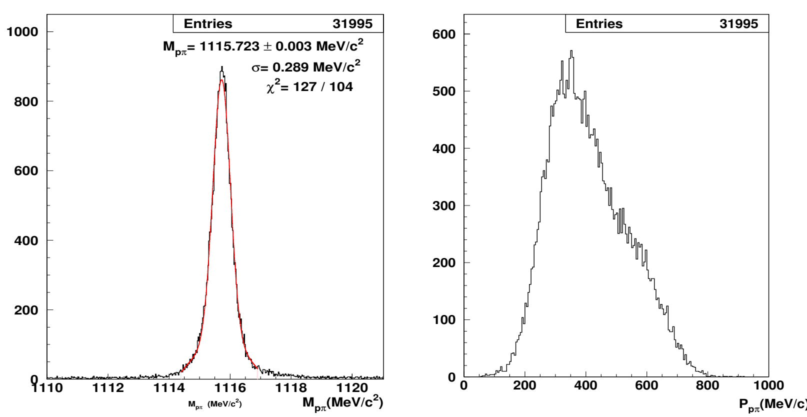


Fig. 2. Λ invariant mass reconstruction (left) and momentum spectra for the selected vertices made by proton and negative pion (right).

The KLOE drift chamber is composed mainly by helium, and a Monte Carlo study shows how 0.1% of the K^- flying through the chamber should be stopped in the gas, giving an unique scenario to study the developed hadronic interactions in such an "active target". Preliminary results of the analysis of a sample of the 2005 KLOE data (corresponding to an integrated luminosity of $\sim 1.1\ \mathrm{fb}^{-1}$) has shown the capabilities in performing nuclear physics measurements with the KLOE detector [17].

The strategy is focused on the identification of possible specific decay products of the kaonic nuclear clusters: specifically into channels containing the $\Lambda(1115)$ hyperon, present in most of the expected decay channels of the bound states. An excellent result has been already achieved with a precise determination of the lambda mass, as can be seen in Fig. 2, where the signal shape in the invariant mass spectrum for the selected events is shown. The statistical error is below 3 KeV, with the systematics depending on the momentum calibration of the KLOE setup, and this being evaluated. The measurement presents an excellent mass resolution, FWHM $\sim 700\,\mathrm{KeV}/c^2$, found in the reconstruction of the decay of Λ into proton and negative pion.

Vertices produced by this lambda particles with protons or deuterons are searched along the K^- (tracked or extrapolated) decay path, as direct signals of the formations of these clusters, or absorptions of K^- by the nucleons of the gas nuclei.

Also neutral vertices are searched for, as the expected resulting from the formation of a lambda(1405) decaying to neutral particles, $\Sigma^0\pi^0$. In this case the good behaviour of the electromagnetic calorimeter and its resolution for the detection of photons is crucial, and has been demonstrated by the identification of pairs $\Sigma^0\pi^0$ detected along the K^- path, as can be seen in Fig. 3.

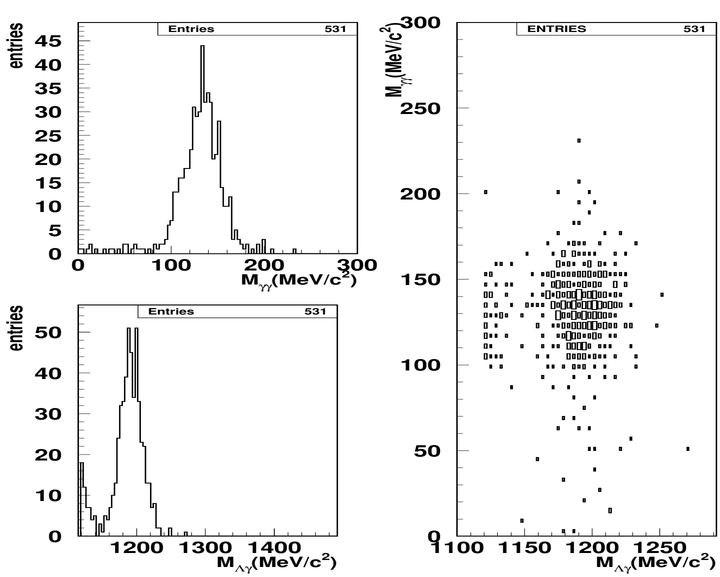


Fig. 3. Invariant mass for detected Σ^0 and π^0 neutral vertices (left). The correlation between them (right) shows a clear background-free region.

In conclusion, a selection of thousands of $\Lambda(1115)$ baryons has been made from $\sim 1.1\ fb^{-1}$ of KLOE data, allowing to investigate different kind of reaction products from the interaction of K^- in the drift chamber. The number and the quality of the signal opens the door for studies of many hadronic physics hot topic items, proving KLOE to be a powerful instrument for performing very interesting physics not only in the sectors where already it is well known worldwide, delivering top results, but in the strange nuclear and hadronic physics sectors too.

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