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Low energy kaon nuclei interaction studies at DAΦNE

O. Vazquez Doce[1,a], J. Zmeskal[2], M. Bazzi[1], M. Bragadireanu[3], P. Buhler[2], M. Cargnelli[2], C. Curceanu[1], F. Ghio[4], C. Guaraldo[1], M. Iliescu[1], T. Ishiwatari[2], P. Kienle[25], P. Levi Sandri[1], J. Marton[2], P. Mullner[2], K. Suzuki[2], S. Okada[1], D. Pietreanu[1], M. Poli Lener[1], A. Rizzo[1], A. Romero Vidal[1], A. Scordo[1], D. Sirghi[13], A. d'Ufizzi[1], E. Widmann[2], and B. Wunschek[2]

[1] LNF-INFN, Frascati (Roma), Italy
[2] Stefan-Meyer-Institut, OAW, Vienna, Austria
[3] IFIN-HH, Bucarest, Romania
[4] Istituto Superiore di Sanita, Roma, Italy
[5] TUM, Munich, Germany

Abstract. A preliminar study of these kind of hadronic interactions is being done by the AMADEUS collaboration by analyzing the existent KLOE data.

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 kaonic 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.

Deeply bound kaonic nuclear states were predicted by Wycech [2], and in the recent years an intense debate is going on following the publication by Yamazaky and Akaishi [3] predicting that these clusters could be formed by interactions of K^- in light nuclei. These states are supposed to be formed by a nucleus with a K^- attached inside, favoured by the strongly attractive $\bar{K}p$ potential. It has been initially argued that kaonic nuclear clusters may be formed with large binding energies of order 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 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. It arises the need to perform in the future new dedicated experiments, which should attack the kaonic clusters search both in the formation and in the decay processes, as completely as possible. New dedicated experiments are planned at J-PARC and GSI, and AMADEUS at DAΦNE plans to detect all particles in the formation and the decay processes of such exotic systems, if they exist, taking advantage of the high luminosity reached by the recently upgraded DAΦNE accelerator.

2 The AMADEUS experiment

In order to confirm or deny the existence of such exotic objects, as described above, the AMADEUS collaboration will study the K^- hadronic interactions in light nuclei with a systematic and complete spectroscopy 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 has reached 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

[a] e-mail: oton.vazquezdoce@lnf.infn.it

of the KLOE setup detecting neutrons has been recently checked by kloNe group [14].

The KLOE detector is composed basically by a 4π drift chamber surrounded by an electromanetic calorimeter and has been succesfully taking data at DAΦNE since 1999. The combination of the dedicated AMADEUS setup with the excellent performance of the KLOE apparatus will offer the top level scientific center to study kaonic clusters using K^- induced processes at rest, and other processes of low-energy K^- nuclear interactions.

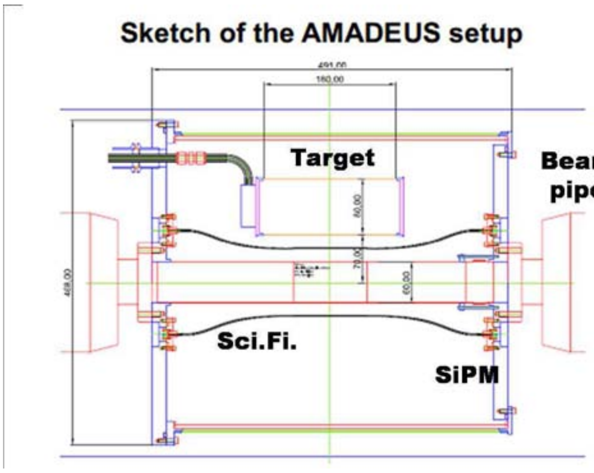

Fig. 1. Sketch of the AMADEUS setup with lateral view. Aluminun and carbon fiber beam pipe, target and scintilliating fibers read by silicon photomultipliers are included.

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 state ppK$^-$, produced via ^{3}He (stopped K, n) reaction;
- kaonic 3-baryon states ppnK$^-$ and pnnK$^-$, produced via ^{4}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.

If such deeply bound kaonic nuclear clusters exist, the we will complete the physics program perfomring a systematic spectroscopy study, including:

- determination of binding energies, decay widths and quantum numbers of all states, including excited ones,
- measurement of the spin-orbit interaction,
- determination of partial widths of kaonic nuclear states by observation of all decay channels,
- Dalitz analysis of the 3-body decays of the kaonic nuclei will reflect the momentum wave functions and the angular momentum transfer, so one can study the size of kaonic nuclei and assign spin and parity to the decaying state,
- obtain, as a by-product, information concerning the multi-nucleon absorption mode.

The luminosity request for this phase of AMADEUS is of 3 - 4 fb^{-1}. A second phase of the experiment with and upgraded setup and higher luminosity request will be performed with heavier targets Li, B, Be and C.

Three main components of the experimental setup are presently under study, including the high gaseous density target, a trigger system made of scintilliating fibers, and a tracking device placed internally of the KLOE drift chamber. A detailed view of the AMADEUS setup inside the inner region of the KLOE drift chamber, with some of the elements mentioned above 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 was installed recently 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 scintilliating 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, taking advantage of the fact that the Φ mesons are produced practically at rest (with a transversal boost of around 10 - 20 MeV) in DAΦNE. A prototype was already built, with fiber read by silicon photomultiplier and successfully tested in DAΦNE. Further studies and optimization are undergoing.

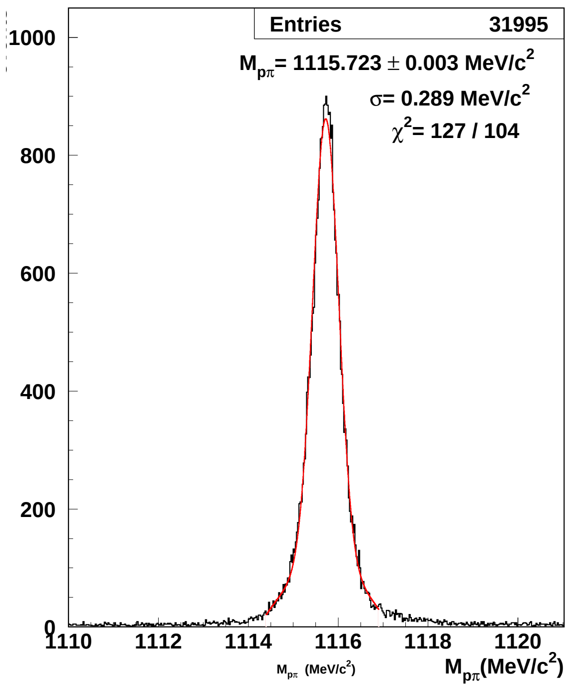

Fig. 2. Λ invariant mass reconstruction.

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, the possible hadronic interactions of K^- in the KLOE setup materials in the collected data from previous KLOE runs [18] were investigated.

The KLOE drift chamber contains mainly helium, and a Monte Carlo study shows that 0.1% of the K^- flying through the chamber should be stopped in the gas, giving an unique scenario to study the 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 $\Lambda(1116)$ 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 the figure 2, where the signal shape in the proton-pion 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, being under evaluation. The measurement shows an excellent mass resolution FWHM $\sim$ 700 KeV/c^2, found in the reconstruction of the decay of Λ into proton and negative pion.

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

Also neutral vertices are seached for, as the expected resulting from the formation of a lambda(1405) decaying to neutral particles, $\Sigma^0\pi^0$. In this case the excellent performance of the electromagnetic calorimeter and its resolution for the detection of photons is crucial, and has been proved by the identification of pairs $\Sigma^0\pi^0$ detected along the K^- path.

In conclusion, a selection of thousands of $\Lambda(1115)$ baryons has been made from $\sim 1.1 \mathrm{fb}^{-1}$ of KLOE data, allowing to investigate diferent 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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