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THE AMADEUS EXPERIMENT: STUDY OF THE KAONIC NUCLEAR CLUSTERS AT DAΦNE

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Abstract

The AMADEUS experiment will perform the first complete experimental study of the case of the so-called deeply bound kaonic nuclear states. Such a study has deep consequences in a still open sector of the strangeness hadronic/nuclear physics: how the hadron masses and hadron interactions change in the nuclear medium with consequences on the structure of cold dense hadronic matter. AMADEUS will perform exclusive - full acceptance - measurements, all particles in the formation and decay processes of deeply bound nuclear clusters will be detected.

1 The AMADEUS scientific case: Kaonic clusters

The change of the hadron masses and hadron interactions in the nuclear medium and the structure of cold dense hadronic matter are hot topics of hadron physics today. These important, yet unsolved, problems will be the research field of AMADEUS [1].

AMADEUS will search for antikaon-mediated deeply bound nuclear states, which could represent the ideal conditions for investigating the way in which the spontaneous and explicit chiral symmetry breaking pattern of low-energy QCD occur in the nuclear environment.

Such states were predicted by Wycech [2] some time ago; now the availability of experimental facilities for studying these kind of exotic nuclei has triggered a vivid discussion, initiated with the publication of the paper by Akaishi and Yamazaki [3], where a phenomenological strongly attractive $\bar{K}N$ potential is used favouring the existence of nuclear bound states of kaons in nuclei, while contracting the core of the resulting kaonic nucleus, producing a cold and dense nuclear system.

The possible formation of a deeply bound kaonic nuclear state (DBKNS) could provide information concerning the modification of the kaon mass and of the $\bar{K}N$ interaction in the nuclear medium, with many important consequences in hadronic and nuclear physics:

- such compact exotic nuclear systems might get formed with binding energies so large ($\sim$100 MeV) that their widths turn out rather narrow, since the $\Sigma\pi$ decay channel is energetically closed and, additionally, the $\Lambda\pi$ channel is forbidden by isospin selection rule;
- high-density cold nuclear matter might be formed around K^-, which could provide information concerning a modification of the kaon mass and of the $\bar{K}N$ interaction in the nuclear medium;
- empirical information could be obtained on whether kaon condensation can occur in nuclear matter, with implications in astrophysics: neutron stars, strange stars.
- nuclear dynamics under extreme conditions (nuclear compressibility, etc) could be investigated.

2 The framework of AMADEUS

There exist, actually, several different theoretical approaches to the problem, bringing arguments either for, or against the existence of the deeply bound kaonic nuclear states. In between the two extremes of the theoretical debate, there are as well predictions of shallower potentials than those which lead to the kaonic clusters [4]. Currently, the intense theoretical debate undergoing shows even more the importance of the AMADEUS physics case and reinforces the need to perform it in the near future.

From the experimental point of view, several approaches have been followed since first experimental indications of the formation of tribaryonic states K^-ppn and K^-pnn were found at KEK [5] [6], although the last was lately not confirmed [7]. Other facilities allowed to study the problem bringing new data to the field, as it was made by FINUDA at DAΦNE [8], at GSI [9] and at BNL-AGS [10]; data from older, not dedicated, experiments were re-analyzed as well [11] [12]. What emerges, however, is an experimental status of the DBKNS search with few, low statistics and not complete results, which are, rightly, not easy to be attributed to a DBKNS interpretation, since other scenarios cannot be excluded.

From the theoretical and experimental status of these studies arises the need to perform in the future new dedicated experiments, which should attack the DBKNS search both in formation and in the decay processes, as completely as possible. New dedicated experiments are planned at J-PARC, FOPI, GSI, and, of course, AMADEUS at an upgraded DAΦNE.

3 Performing AMADEUS at DAΦNE

The new proposal, AMADEUS at DAΦNE, has the goal to perform, for the first time, a systematic and complete spectroscopic study of deeply bound kaonic nuclei, 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. These high precision measurements will be achieved by implementing the KLOE detector with an inner AMADEUS-dedicated setup, containing a cryogenic target and a trigger system.

The planned upgrade of DAΦNE will reach a luminosity as high as 10^{33} cm^{-2} s^{-1} [13], delivering an integrated luminosity of about 10 fb^{-1} per year, equipped with the dedicated 4π detector KLOE [14] complemented with the AMADEUS apparatus will become the top level scientific center to study

DBKNS using K^- induced processes at rest. In the left part of Fig. 1 the location of AMADEUS setup within KLOE detector is shown.

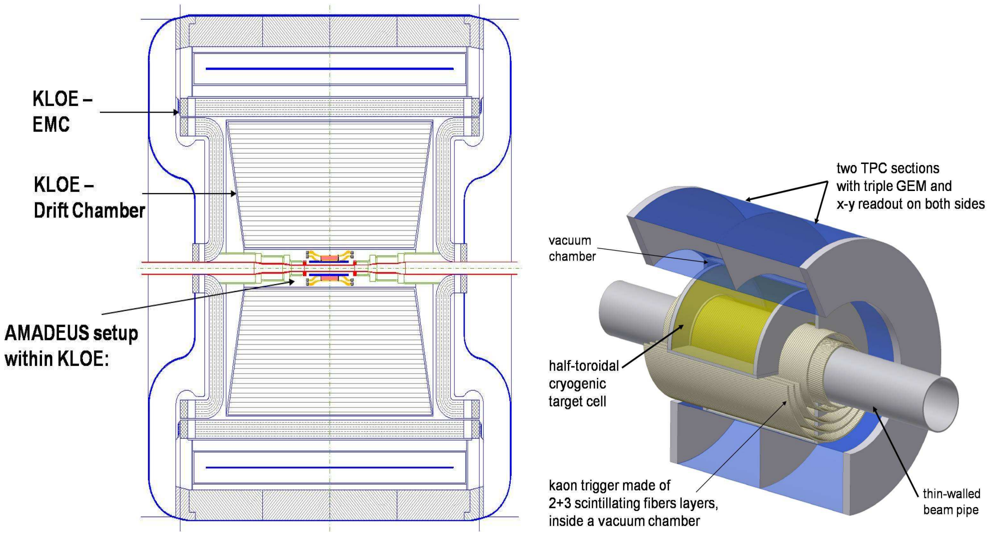

Figure 1: AMADEUS setup implementation position inside KLOE detector (left), and detail of the central region (right).

For the integration of the AMADEUS setup within KLOE a solution which is presently under study is to use a half-toroidal target placed around the beam pipe and surrounding the interaction region. The beam pipe can be a thin-walled aluminum pipe with carbon fiber reinforcement. A degrader which might be an active one, i.e. a scintillator (or scintillating fiber) detector is placed around the pipe just in front of the target. 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.

A Phase-1 of 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 ^3He (stopped K, n) reaction;
- kaonic 3-baryon states $ppnK^-$ and $pnnK^-$, produced via ^4He (stopped

K$^-$, n/p) reactions.

The search for these DBKNS will be performed by the process of K^- stopped in high-density gaseous ^{3}He and ^{4}He targets, measuring their binding energies and their widths. The processes for the case of a ^{4}He target are shown in Fig. 2. The luminosity request of this first phase of AMADEUS is of 4 fb^{-1}.

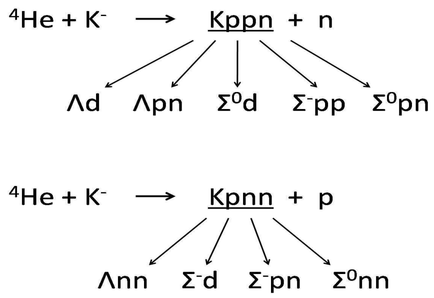

Figure 2: Kaonic tribaryonic clusters formation and decay channels in K^- stopped in ^{4}He processes.

Lately, the KLOE detector capability to reconstruct hyperons with a very good resolution, ideal for DBKNS studies, was proven as one of the first output of the fruitful collaboration between the AMADEUS and the KLOE groups. Preliminary results of the analysis of a sample of the 2005 KLOE data searching for hadronic interactions of the K^- in the ^{4}He gas of the KLOE Drift Chambers [16] has been presented, showing the capabilities in performing nuclear physics measurements with the KLOE detector. An excellent invariant mass resolution, FWHM $\sim$ 1 MeV/c^2, has been found in the reconstruction of the decay of $\Lambda(1116)$ hyperon into proton and negative pion. Also a good performance of KLOE setup detecting neutrons has been recently proved by kloNe group [17].

After this first phase, a second phase of AMADEUS will follow, with an upgraded setup and with a higher luminosity request, where DBKNS complete and systematic spectroscopy will be performed also in heavier targets as Li, B, Be and C. An inner tracker should be eventually installed inside the DC of KLOE (two possible solutions are being considered, either cylindrical GEM detectors or a TPC-GEM combination, see right part of Fig. 1) in order either to reduce the background and/or to perform more refined (better resolution) dedicated measurements. With this second phase the complete scientific program of AMADEUS will be covered:

- 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.

AMADEUS plans as well to perform other more "classical" measurements, by no mean less important. Such measurements are being longly awaited and are extremly important in hadronic physics and in astrophysics.

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