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Low-energy kaon-nucleon/nuclei interaction studies at DAΦNE (SIDDHARTA and AMADEUS experiments)

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Summary. — The DAΦNE electron-positron collider at the Laboratori Nazionali di Frascati of INFN has made available a unique-quality low-energy negative-kaons "beam". The SIDDHARTA experiment used this beam to perform unprecedented precision measurements on kaonic atoms, while the AMADEUS experiment plans to perform in the coming years precision measurements on kaon-nuclei interactions at low-energies, in particular to study the kaonic nuclei. The two experiments are briefly presented in this paper.

PACS `36.10.-k` – Exotic atoms and molecules (containing mesons, antiprotons and other unusual particles).
PACS `32.30.Rj` – X-ray spectra.
PACS `25.80.Nv` – Kaon-induced reactions.
PACS `21.85.+d` – Mesic nuclei.

1. – Low-energy kaon-nucleon/nuclei physics at DAΦNE

The recently upgraded DAΦNE [1, 2], electron-positron collider at the Frascati National Laboratory produces the ϕ-resonance, which decays with a probability of about 50% in K^+K^-, providing an excellent quality low energy kaon "beam" (16 MeV of kinetic energy). This beam is intensively used for the study of the low-energy kaon-nucleon/nuclei interaction, a field still largely unexplored. By making use of the negative kaon beam, in 2009 the SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) experiment performed precision measurements of the strong-interaction–induced energy shift and width of the 1s level, via the measurement of the X-ray transitions to this level, for kaonic hydrogen. SIDDHARTA performed as well high-precision measurements for the kaonic helium3 and 4 X-ray transitions to the 2p level. The SIDDHARTA-2, upgrade of SIDDHARTA, presently under preparation, will measure the kaonic deuterium transitions to the 1s level. The final goal is to extract, for the first time, the isospin-dependent antikaon-nucleon scattering lengths, fundamental quantities for the understanding of aspects of chiral symmetry breaking in the strangeness sector.

The AMADEUS (Antikaon Matter at DAΦNE: an Experiment with Unraveling Spectroscopy) experiment will perform the first complete study, in formation and decay processes, of the so-called kaonic nuclear clusters, together with other important low-energy kaon-nuclei measurements. The aim of AMADEUS is to give a definite answer to the debated question of the existence of the K^-pp, K^-ppn and K^-pnn kaonic nuclei and, if such states exist, to measure their properties (binding energies, width and decay channels).

Both experiments are briefly presented in the next sections.

2. – The SIDDHARTA experiment

The SIDDHARTA experiment, used triggered Silicon Drift Detectors (SDD) to measure the X-rays emitted by kaonic atoms formed after stopping kaons in a cryogenic target filled with various type of gases. The trigger was given by a system of two scintillators, placed above and below the beam pipe, measuring the back-to-back emitted charged kaons, so eliminating the high background coming from particles lost from circulating beams. The setup was installed at the electron-positron interaction point at the DAΦNE collider, as shown in fig. 1.

During the 2009 campaign the following series of measurements were performed:

– Kaonic hydrogen X-ray transitions to the 1s level, performing the most precise measurement ever [3].

– Kaonic helium4 transitions to the 2p level, partial results, with a precision at the level of few eV, were already published in ref. [4]: more data are being presently analysed.

– Kaonic helium3 transitions to the 2p level, the first measurement ever. The results were published in ref. [5].

As an example of SIDDHARTA capacity to measure kaonic atoms, we show in fig. 2 the kaonic helium3 spectrum, from which a few eV precison measurement of the peak position [5] was possible.

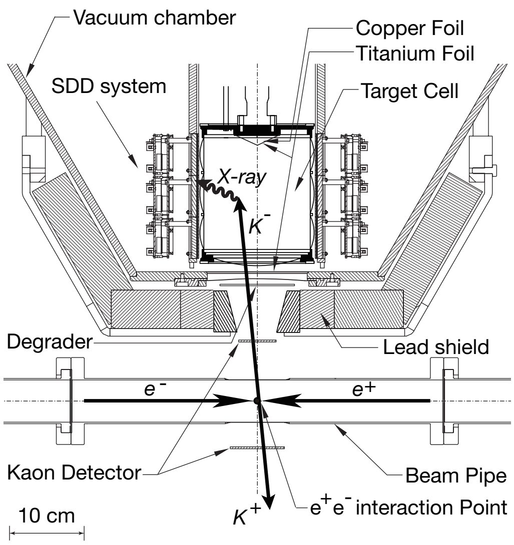

Fig. 1. – An overview of the experimental setup. The whole system was installed at the interaction point of DAΦNE.

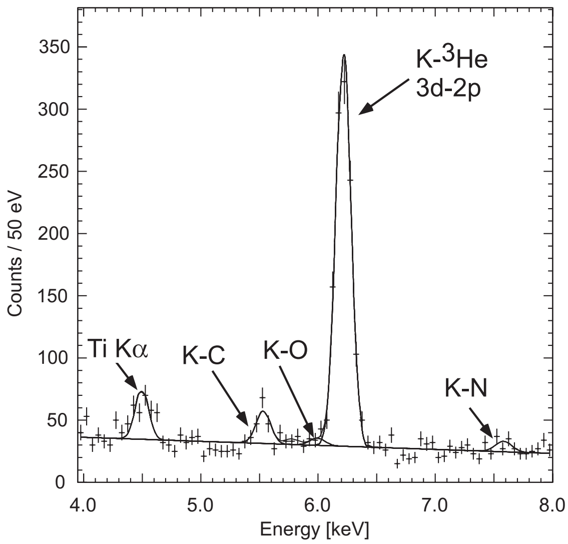

Fig. 2. – Energy spectrum of the kaonic ^{3}He X-rays in coincidence with the K^+K^- events. The kaonic ^{3}He $3d \to 2p$ transition is seen at 6.2 keV. Together with this peak, small other peaks are seen, which are the kaonic atom X-ray lines produced by the kaons stopping in the target window made of Kapton, and the Ti K_α line at 4.5 keV.

Presently, an upgrade of the apparatus, SIDDHARTA-2, is being considered to perform the measurement of kaonic deuterium X-ray transitions to the $1s$ level and of other types of kaonic atoms transitions [6].

3. – The AMADEUS experiment

The scientific case of the so-called "deeply bound kaonic nuclear states" (dubbed as well "kaonic nuclear clusters") represents a hot topic in nuclear physics, both in theoretical and experimental sectors, see [7, 8] and related references.

What emerges is the strong need for a complete experimental study of the scientific case, *i.e.* a clear and clean experiment, measuring deeply bound kaonic nuclear states both in formation and in the decay processes.

The AMADEUS experiment plans to perform the first dedicated, full acceptance, high-resolution measurement of kaonic nuclear clusters in formation and decay processes, at the upgraded-DAΦNE facility, using the K^--stopped processes, implementing the KLOE detector [9] in the central region with a dedicated setup, containing a cryogenic target (filled with deuterium, ^{3}He or ^{4}He gases) and a trigger system.

In the same time "classical kaonic-nuclear physics" processes will be investigated either for the first time or in order to obtain more accurate results than those actually reported in the literature. Cross-sections, branching ratios, rare hyperon decay processes will be investigated, taking advantage of the unique kaon-beam quality delivered by DAΦNE and of the unique characteristics of the KLOE detector.

4. – Conclusions

The DAΦNE collider delivers an excellent-quality low-energy charged-kaons beam. Such a beam was intensively used by the SIDDHARTA Collaboration to perform unique-quality measurements of kaonic atoms (kaonic hydrogen and kaonic helium).

Presently, an enlarged collaboration, SIDDHARTA-2, is upgrading the setup in order to perform kaonic deuterium and other types of kaonic atoms transitions in the near future.

The kaonic-nuclei interaction is going to be investigated by the AMADEUS Collaboration to search for the possible formation and decay of "kaonic nuclear clusters" and of yet unmeasured kaon-nuclei low-energy processes.

The SIDDHARTA-2 and AMADEUS measurements on DAΦNE, together with SIDDHARTA results, are fundamental for the understanding of the non-perturbative QCD in the strangeness sector.

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