Strangeness in the Universe? Advances and perspectives in the low-energy kaon-nucleon/nuclei interaction studies at the DAΦNE collider

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The DAΦNE electron-positron collider at the Laboratori Nazionali di Frascati of INFN, Italy, has made available a unique quality low-energy negatively charged "kaons beam", which is used to study the kaon-nucleon/nuclei interactions at low energies, by the SIDDHARTA and AMADEUS collaborations. SIDDHARTA has already performed unprecedented precision measurements of kaonic atoms, and is being presently upgraded, as SIDDHARTA-2, to approach new frontiers. The AMADEUS experiment plans to perform in the coming years precision kaon-nuclei interactions at low-energies measurements, to study the possible formation of kaonic nuclei and of the $\Lambda(1405)$ and many other processes involving strangeness. These studies have implications going from particle and nuclear physics to astrophysics, helping to understand the role of strangeness in the Universe.

1 Low energy kaon-nucleon/nuclei studies at DAΦNE

The recently upgraded DAΦNE [1, 2] electron-positron collider at the Frascati National Laboratory of INFN produces the ϕ-resonance, which decays with a probability of about 50% in $K^+ K^-$, providing an excellent quality low-energy kaon "beam". This beam is intensively used for the study of the low-energy kaon-nucleon/nuclei interactions, a field still lacking experimental data. By making use of this beam, in 2009 the SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) experiment performed a precision measurement of the strong interaction induced energy shift and width of the 1s level, via the measurement of the X-ray transitions of kaonic hydrogen, and high precision measurements of the kaonic helium3 and 4 X-ray transitions to the 2p level. The first exploratory measurement of kaonic deuterium was performed too. SIDDHARTA-2, a major 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 to understand the chiral symmetry breaking mechanism. The AMADEUS (Antikaon Matter at DAΦNE: an Experiment with Unraveling Spectroscopy) experiment will perform the first complete study of the low-energy kaon-nuclei interactions by using a series of cryogenic gaseous targets, as d, ^{3}He, ^{4}He , 4He, and solid targets.

Among the aims of AMADEUS there are: the measurement of the $\Lambda(1405)$ decaying to Σ π in all possible charge combinations, and to give a definite answer to the debated question of the existence of the kaonic nuclei. If such states exist we will measure their properties (binding energies, width and decay channels). Presently, as a first step towards AMADEUS realization, we are analyzing the 2004-2005 KLOE data.

2 The SIDDHARTA and SIDDHARTA-2 experiments

In the SIDDHARTA experiment the monochromatic low-energy charged kaons produced at the DAΦNE collider are degraded in energy and stopped in a cryogenic gaseous target, where kaonic atoms are efficiently produced. An important element of the apparatus is the charged kaon trigger, which is based on the coincidence of the signals from two plastic scintillation counters mounted top and bottom of the e^+ e^- interaction point. The trigger system takes advantage of the back-to-back topology of the produced low-energy kaons: $\Phi\to K^+ K^-$ and its use drastically increases the signal-to-background ratio, because most of the background is generated by non interacting e^+ and e^- beam particles, uncorrelated in time with the collisions.

The kaons which are stopped inside the target produce highly excited kaonic atoms which deexcite to the fundamental level, emitting X rays. These X rays were detected by 144 Silicon Drift X-ray Detectors (SDDs) mounted around the target. A detailed description of the experimental setup is given in Ref. [3]. The setup was installed above the electron-positron interaction point at the DAΦNE collider in 2009. The following measurements were performed:

- kaonic hydrogen X-ray transitions to the 1s level, the most precise measurement ever [3];
- kaonic helium4 transitions to the 2p level, the first measurement using a gaseous target [3, 4];
- kaonic helium3 transitions to the 2p level, the first measurement ever [5, 6];
- kaonic deuterium X-ray transitions to the 1s level - as an exploratory measurement [7].

The 1s-state strong-interaction shift ϵ and width Γ of kaonic hydrogen were determined to be: $\epsilon = -283 \pm 36(\text{stat}) \pm 6(\text{syst})$ eV and $\Gamma = 541 \pm 89(\text{stat}) \pm 22(\text{syst})$ eV.

These are the most precise results ever compared to the previous measurements [8, 9]. The values of ϵ and Γ are consistent with the theoretical predictions [10]. The SIDDHARTA results allow the most precise evaluation of the K^{-}p scattering length, which yields strong constraints on the theoretical description of the low-energy antikaon-nucleon interactions [11, 12, 13]. For a more complete study of the isospin dependent antikaon-nucleon interaction, the measurement of the shift and width of kaonic-deuterium 1s state is mandatory. Presently, a major upgrade of the apparatus, SIDDHARTA-2, is undergoing. The upgrade is going to improve the signal/background ratio by a factor about 20 in order to perform the measurement of kaonic deuterium X-ray transitions to the 1s level and of other types of kaonic atoms transitions [14]

3 The AMADEUS experiment

The low-energy (p $\leq$ 100 MeV/c) kaon-nuclei interaction studies represent the main aim of the AMADEUS experiment [15, 16]. These type of measurements require detecting all charged and neutral particles coming from the K^{-} interactions with various targets with an almost 4π acceptance. The AMADEUS collaboration plans to implement the existent KLOE detector [17, 18] in the free internal region between the beam pipe and the Drift Chamber inner wall (having a diameter of 50 cm) with a dedicated setup. The dedicated setup includes: the target, which can be either solid or a gaseous cryogenic one, a tracker system (TPC-GEM) and a trigger (scintillating fibers read by SiPM detectors). The negatively charged kaons may stop inside the target or interact at low energies, initiating a series of processes. Among these, a key-role is played by the generation of $\Lambda(1405)$ which can decay into Σ^0 π^0, Σ^+ π^- or $\Sigma^-\pi^+$ We plan to study all these three channels in the same data sample. We plan as well to verify the possible existence of “kaonic nuclear cluster” by studying the Λp and Λd channels. Many other kaon-nuclei processes will be investigated, either for the first time, or in order to obtain more accurate results than those actually reported in literature. In the summer of 2012 a half cylinder carbon target was built and installed inside the Drift Chamber of KLOE as a first step towards the AMADEUS realization. The target thickness was optimized to have a maximum of stopped kaons (about 24% of generated) without degrading too much the energy of resulting charged particles inside the target material. The experiment run from October to the end of 2012. The analysis of these data is ongoing; it will provide new insights in the low-energy interactions of charged kaons in the nuclear matter.

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). SIDDHARTA-2 will perform the kaonic deuterium and other types of kaonic atoms transitions measurements in the near future. The kaonic-nuclei interactions at low-energies are being investigated by the AMADEUS collaboration to search for the possible formation and decay of “kaonic nuclear cluster” and of yet un-measured kaon-nuclei low-energy processes. SIDDHARTA, SIDDHARTA(-2) and AMADEUS are and will continue to provide unique quality results, which will help to understand the role of strangeness in the Universe.

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