Chapter 24
Kaonic Atoms Measurement at DAΦNE: SIDDHARTA and SIDDHARTA-2

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Abstract Light kaonic atoms studies provide the unique opportunity to perform experiments equivalent to scattering at threshold, being their atomic binding energies in the keV range. High precision atomic X-rays spectroscopy ensures that the energy shift and broadening of the lowest-lying states of the kaonic atoms, induced by the strong interaction between the kaon and nucleus, can be detected. Kaonic hydrogen and kaonic deuterium are the lightest atomic systems and their study deliver

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the isospin-dependent kaon-nucleon scattering lengths. The SIDDHARTA collaboration was able to perform the most precise kaonic hydrogen measurement to date, together with an exploratory measurement of kaonic deuterium. The measurement of the kaonic deuterium will be realized in the near future by a major upgrade of SIDDHARTA: SIDDHARTA-2. In this paper an overview of the main results obtained by SIDDHARTA together with the future plans are presented.

24.1 The SIDDHARTA Experiment

The DAΦNE (Double Annular Φ Factory for Nice Experiments) accelerator is an electron-positron collider [1, 2] at the National Laboratory Frascati (LNF) in Italy. It is a unique low-energy kaons source via the decay of ϕ-mesons produced almost at rest, with a probability of about 48.9% in K^+K^-. The charged kaons are produced with a momentum of 127 MeV/c, and a momentum spread Δp/p < 0.1%.

The SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) experiment measured various kaonic exotic atoms using the kaons delivered by DAΦNE.

The kaonic atoms are produced efficiently by stopping the low-energy monochromatic charged kaons inside a cryogenic gaseous target. The kaons are captured by target atoms forming kaonic atoms in highly excited orbits. The system decays by emitting radiation, which is measured.

The charged kaon trigger is a crucial feature of the experiment and it is based on the coincidence of two plastic scintillation counters mounted top and bottom of the interaction point of e^+e^-. This trigger system takes advantage of the back-to-back topology of the produced low-energy kaons: $\Phi \rightarrow K^+K^-$ and its use drastically increases the signal-to-background ratio, because most of the background is generated by e^+ and e^- particles lost from the beams, in asynchronous timing with collisions. Another fundamental element of the apparatus is the gas-target system, because the yields of kaonic-atoms X-rays decrease at sensitively higher densities due to collisions and Stark mixing.

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The most precise kaonic hydrogen measurement existing in literature was realized by the use of new triggerable X-ray detectors, the Silicon Drift Detectors, characterized by excellent energy and timing resolutions, essential for the background suppression. A detailed description of the experimental setup is given in [3].

With SIDDHARTA the following measurements were performed:

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

The $1s$—level shift ε_{1s} and width Γ_{1s} of kaonic hydrogen measured by SIDDHARTA are:

$$\varepsilon_{1s} = -283 \pm 36\,(stat) \pm 6\,(syst)\;\; eV \tag{24.1}$$

$$\Gamma_{1s} = 541 \pm 89\,(stat) \pm 22\,(syst)\;\; eV. \tag{24.2}$$

The precise determination of the K-series X-rays for kaonic hydrogen atoms provides new constraints on theories, having reached a quality which demands refined low-energy $\overline{K}N$ interaction calculations [8, 9].

24.2 SIDDHARTA-2 Experiment

SIDDHARTA-2 is a new experiment, which will be installed on DAΦNE collider in spring 2019 and will take advantage of the experience gained in the preceding SIDDHARTA experiment [3–6]. The goal of the new apparatus is to increase drastically the signal-to-background ratio, by gaining in solid angle, taking advantage of new SDDs with improved timing resolution, and by implementing additional veto systems. Figure 24.1 shows the schematic of the SIDDHARTA-2 apparatus.

A detailed Monte Carlo simulation was performed within GEANT4 framework to optimise the critical parameters of the setup, like target size, gas density, detector configuration and shielding geometry. The Monte Carlo simulation took into account all the improvements with the following assumptions: the values of shift and width of the 1s ground state of kaonic deuterium are −800 eV and 750 eV, respectively; yields ratios $K_\alpha : K_\beta : K_{total}$ are those of kaonic hydrogen, with an assumed K_α yield of 10^{-3}. Figure 24.2 shows the expected spectrum for an integrated luminosity of 800 pb^{-1} delivered by DAΦNE in similar machine background conditions as in the SIDDHARTA runs. The shift and width for kaonic deuterium 1s level can be determined with precisions of about 30 eV and 80 eV, respectively. These values are of the same order as the SIDDHARTA results for kaonic hydrogen.

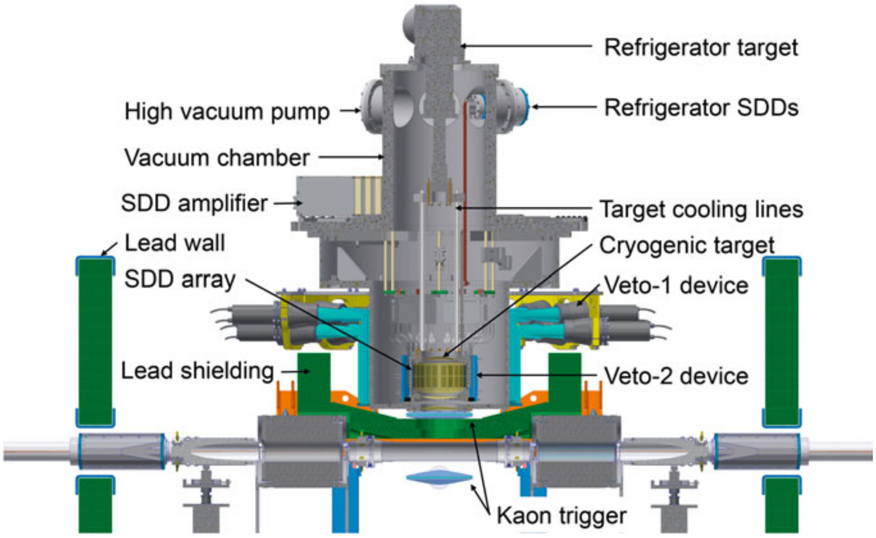

Fig. 24.1 The SIDDHARTA-2 setup with the cryogenic target cell surrounded by the SDDs and the Veto-2 system within the vacuum chamber, while the Veto-1 device is surrounding the vacuum chamber on the outside

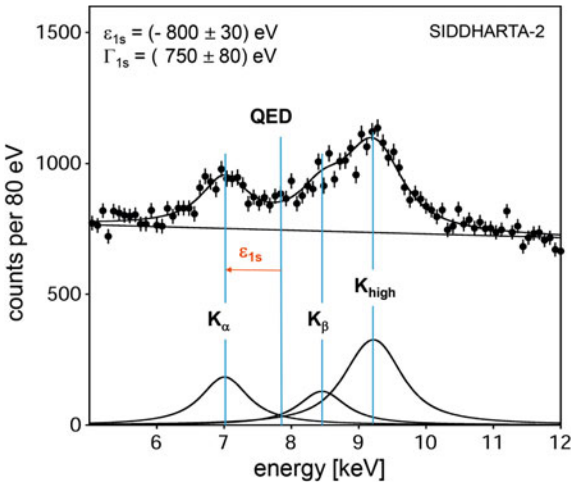

Fig. 24.2 The simulated SIDDHARTA-2 kaonic deuterium spectrum, assuming a shift $\varepsilon_{1s} = -800\,\text{eV}$ and width $\Gamma_{1s} = 750$ eV of the 1s state, and a K_α yield of 10^{-3}. The spectrum was simulated for an integrated luminosity of $800\,\text{pb}^{-1}$

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