Chapter 150
Kaonic Deuterium Precision Measurement at DAΦNE: The SIDDHARTA-2 Experiment

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Abstract Light kaonic atoms spectroscopy offers the unique opportunity to perform experiments equivalent to scattering at vanishing relative energies. This allows the determination of the antikaon-nucleus interaction at threshold, without the need of extrapolation to zero energy, as in the case of scattering experiments. In this framework, the SIDDHARTA-2 collaboration aims to perform the first measurement of kaonic deuterium transition to the fundamental level, which is mandatory to extract the isospin dependent antikaon—nucleon scattering lengths. The experiment will be carried out at the DAΦNE collider of LNF-INFN in 2019–2020.

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150.1 The Scientific Case

When a negatively charged kaon enters a target, it is slowed down and loses its kinetic energy through the interaction with the medium.

The kaon is then captured by an atom replacing an electron and forms a kaonic atom in a highly excited state. The kaonic atom cascades down to the low n-states where the strong interaction between the antikaon and the nucleus adds up to the electromagnetic one. The observables of interest are the shift (ϵ) and the width (Γ) of the atomic levels caused by the strong interaction. The SIDDHARTA collaboration measured, in 2009, the shift and the width of the kaonic hydrogen 1 s level [1], while SIDDHARTA-2, a major upgrade of SIDDHARTA, aims to perform the first measurement of the kaonic deuterium transition to the 1 s level. From the X-rays emitted by kaonic hydrogen and kaonic deuterium, is possible to extract the K^-p (and K^-d) scattering lengths using the Deser–Treumann type formulae with isospin-breaking corrections [2, 3]:

$$\epsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K^-p}[1 - 2\alpha\mu(ln\alpha - 1)a_{K^-p} + \ldots] \tag{150.1}$$

where:
μ: the reduced mass of the K^-p (K^-d) system;
α: the fine-structure constant.
These two quantities allow to determine the antikaon-nucleon isoscalar a_0 and isovector a_1 scattering lengths, trough the equations:

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1] \quad ; \quad a_{K^-n} = a_1 \tag{150.2}$$

$$a_{K^-d} = \frac{4[m_N + m_K]}{[2m_N + m_K]}Q + C \tag{150.3}$$

$$Q = \frac{1}{2}[a_{K^-n} + a_{K^-p}] = \frac{1}{4}[a_0 + 3a_1] \tag{150.4}$$

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Q: K^- scattering from each (free) nucleon of deuterium;

C: includes the K^-d three-body interaction, which can be studied by solving Faddeev-type equations.

The antikaon-nucleon scattering lengths are fundamental quantities to understand the QCD in the non-perturbative regime in the strangeness sector, with implications from particle and nuclear physics to astrophysics.

150.2 The SIDDHARTA-2 Experimental Setup

DAΦNE [4, 5] (Double Annular Φ Factory for Nice Experiments), a world-class electron-positron collider at LNF-INFN, Italy, is a unique low-energy kaon source via the decay of ϕ-mesons, produced with a momentum of 127 MeVc^{-1} and a spread δp/p below 0.1%. Due to the extremely low yield ($\simeq$0.1%) of the K^-d transition to 1 s level, an improved setup with respect to SIDDHARTA [6], has been developed, in order to perform the kaonic deuterium measurement with a precision similar to the kaonic hydrogen one. The new apparatus (Fig. 150.1a) increases drastically the signal-to-background ratio, by gaining in solid angle, taking advantage of the new SDDs geometry, and reducing the background thanks to the faster SDDs response and to the additional veto systems [7].

A cryogenic target cell, made by Kapton walls and reinforced with aluminium supports, operates below 30 K at a pressure of 0.4 MPa (3% LHD), optimizing the kaon stopping efficiency. A dedicated cooling system consisting in 4 CryoTigers reduces the temperature of the detectors down to 120 K, improving both the energy resolution (140 eV at 6 KeV) and the timing response (below 400 ns). Each element of the setup has been optimized using GEANT4 simulations and already tested during the SIDDHARTA run. Figure 150.1b shows the K^-d simulated spectrum, for an expected $\epsilon_{1s} = -800$ eV and $\Gamma_{1s} = 750$ eV and assuming an yield of 0.1% for the K_α transition, for an acquired luminosity of 800 pb^{-1}. The fit indicates that both ϵ_{1s} and Γ_{1s} are evaluated with a precision comparable with the kaonic hydrogen one measured by SIDDHARTA.

150.3 Conclusions

Light kaonic atoms spectroscopy allows to obtain fundamental informations for understanding the non-perturbative QCD with strangeness. The SIDDHARTA-2 experiment will perform the first measurement of the kaonic deuterium transitions, which allow to extract the isospin dependent antikaon-nucleon scattering lengths. Presently the SIDDHARTA-2 setup is under tests and debug, with the aim to be installed at DAΦNE and take data in 2019–2020.

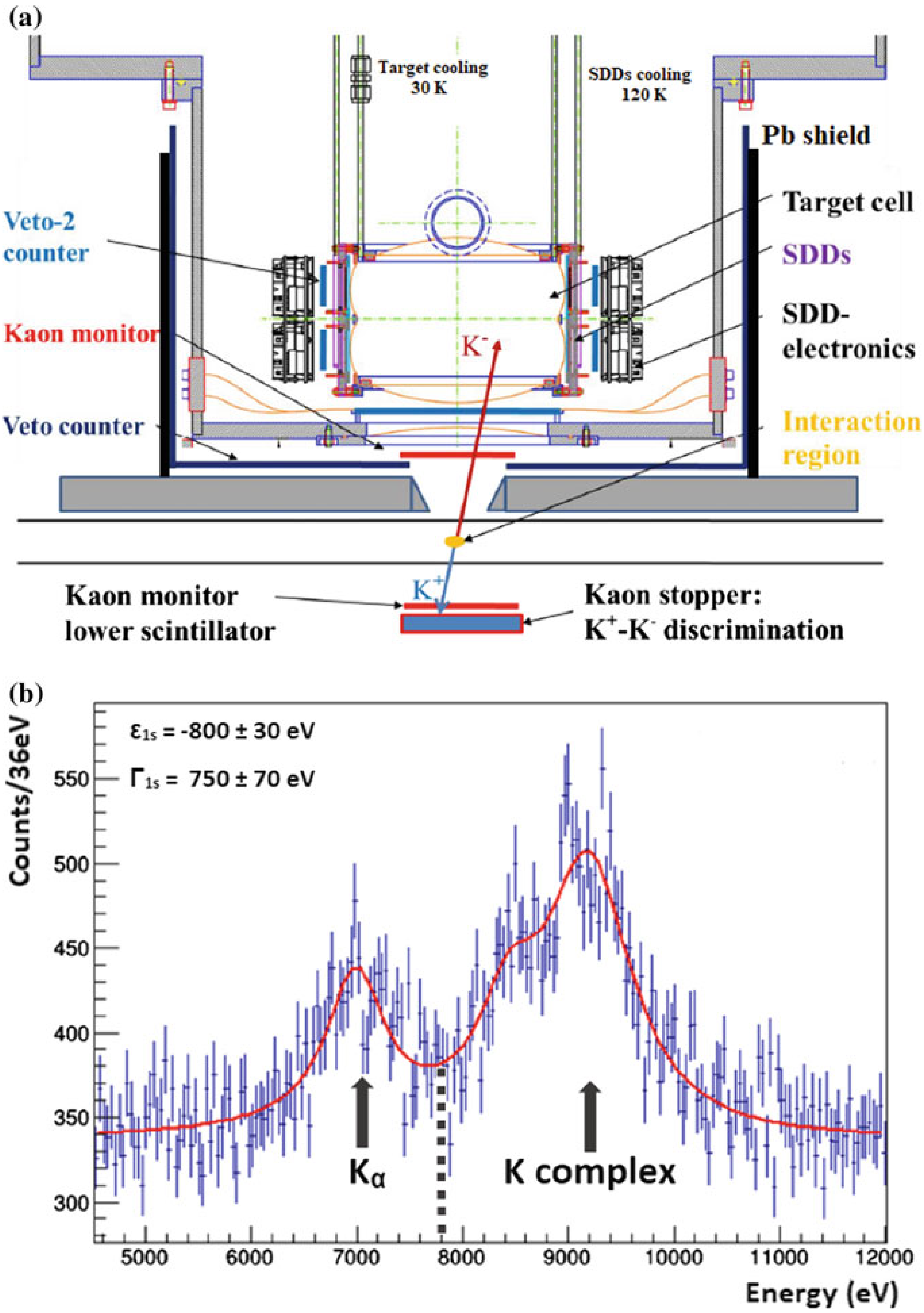

Fig. 150.1 **a** Cross section layout of SIDDHARTA-2 setup (adapted from [8]); **b** Simulated $K^{-}d$ Monte Carlo spectrum corresponding to an integrated luminosity of 800 pb^{-1}, assuming $\epsilon_{1s} = -800$ eV and $\Gamma_{1s} = 750$ eV, and an yield of 0.1%. Dot line at 7834 eV corresponds to the pure QED K_{α} value (adapted from [8])

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