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Towards the first kaonic deuterium measurement with the SIDDHARTA-2 experiment

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The SIDDHARTA-2 experiment is presently installed at the interaction point of the DAΦNE electron-positron collider of the National Laboratories of Frascati (LNF-INFN), in Italy, ready to perform the first measurement of the 2p → 1s x-ray transition in kaonic deuterium. This measurement, together with that of the kaonic hydrogen 2p → 1s x-ray transition, performed by the SIDDHARTA experiment in 2009, will allow the determination of antikaon-nucleon isospin-dependent scattering lengths. This paper presents a description of the SIDDHARTA-2 setup, which is getting ready for the kaonic deuterium measurement.

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1. Introduction

The x-ray spectroscopy of light kaonic atoms contributes to the investigation of the strong interaction between kaons and nuclei at low energies [1]. A kaonic atom forms when a K^- meson is stopped in a target and captured in an atomic system through electromagnetic interaction with the nucleus. The captured K^- replaces an electron in a highly excited atomic level, initiating an electromagnetic cascade process that can lead it to the innermost atomic level. On this level, the kaon-nucleus strong interaction produces a shift and broadening of the energy level with respect to the purely electromagnetic calculated values that can be measured through specialized x-ray spectroscopy techniques. In 2009, the SIDDHARTA experiment measured the $2p \rightarrow 1s$ transition in kaonic hydrogen. This measurement allowed to extract the energy shift and width of the 1s kaonic hydrogen atomic level resulting from the strong kaon-proton interaction [2]. With the addition of the kaonic deuterium $2p \rightarrow 1s$ transition measurement, it will be possible to extract the antikaon-nucleon isospin-dependent scattering lengths, that are not directly accessible due to the $\Lambda(1405)$ resonance and its strong coupling to the $\pi\Sigma$ channel located just below the threshold. [1, 3]. The SIDDHARTA-2 experiment, presently installed at the DAΦNE electron-positron collider located at the National Laboratories of Frascati (LNF), Italy, aims to measure the kaonic deuterium $2p \rightarrow 1s$ transition for the first time in 2023/4 [4]. This paper presents the SIDDHARTA-2 apparatus, which is currently installed at the Interaction Region (IR) of the DAΦNE collider, getting ready to start the data taking.

2. The SIDDHARTA-2 apparatus

The full SIDDHARTA-2 experiment was installed on the Interaction Region (IR) of the DAΦNE electron-positron collider, at LNF, in the second half of 2022. The most important elements of the apparatus are:

- The target: a cylindrical cell (125 mm in height and 144 mm in diameter) with 150 μm thick walls made of two layers of Kapton and aluminium support frames. The target gas is filled in the cylindrical cell and kept at a determined pressure and temperature by monitoring the parameters with remote digital sensors.
- The x-ray detectors: 384 Silicon Drift Detectors (SDDs) with 1 cm^2 of active area each and grouped in 48 2×4 SDD units, laterally surround the target for the x-ray detection. A closed-cycle helium refrigerator system keeps the SDDs at 120 K, to provide a resolution of $\sim$ 160 eV at 6 keV [5, 6].
- The kaon trigger: Two plastic scintillators placed one above and one below the DAΦNE Interaction Point (IP). Each scintillator is read by a pair of PTMs on both ends. The Kaon trigger system uses the time-of-flight to select the back-to-back kaons directed to the SIDDHARTA-2 target from the background.
- The VETO systems: The VETO-2 system, consisting of plastic scintillators read by pairs of Silicon Photomultipliers (SiPMs), laterally surrounds the target and the detectors. The target cell, the SDDs and the VETO-2 are placed inside a vacuum chamber, which is kept at

a pressure below 10^{-5} mbar. Outside the vacuum chamber, a VETO-1 system is installed. It consists of 12 plastic scintillators read by pairs of Photo-Multipliers (PMTs) radially displaced around the vacuum chamber. The aim of the VETO systems is to reduce the background generated by the electrons and positrons lost by the beams and from kaons-generated nuclear interactions.

- The luminometer: two plastic scintillators (80 mm × 40 mm × 2 mm each) read by pairs of PMTs to measure the luminosity provided by the collider [7–9].

A schematic drawing of the SIDDHARTA-2 apparatus is shown in Fig. 1. More detailed information on the SIDDHARTA-2 elements can be found in [3, 10]. The SIDDHARTINO experiment, a reduced version of the SIDDHARTA-2 device (with only 64 SDDs installed) used during the phase of optimization of the DAΦNE collider, performed, in 2021, the most accurate measure of the atomic transitions to the 2p level in gaseous K^--^{4}He [11, 12]. This confirmed the expected capabilities of the SIDDHARTA-2 apparatus, as well as its excellent background rejection capacity, and validated the data selection and analysis procedures [13].

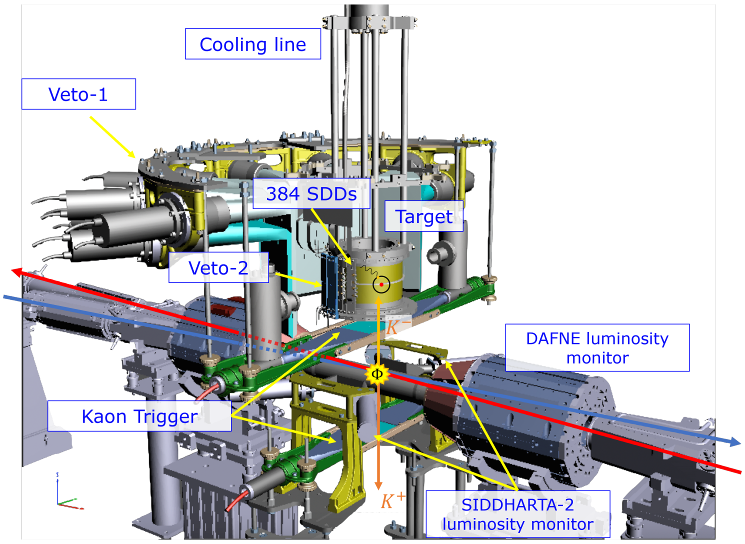

Figure 1: The SIDDHARTA-2 apparatus installed at the DAΦNE Interaction Region at the INFN National Laboratories of Frascati, in schematic view.

3. Conclusions and future perspectives

Currently, the SIDDHRATA-2 experiment is installed at the DAΦNE e^-e^+ collider, and ready to start the first measurement of kaonic deuterium 2p → 1s x-ray transitions. The first data collection is scheduled in spring and summer 2023. Previous measurements conducted by SIDDHARTINO and SIDDHARTA-2 on kaonic ^{4}He have demonstrated the apparatus's high efficiency and the reliability of the data analysis process. The final aim of SIDDHARTA-2 is to perform a similar precision measurement for kaonic deuterium as the kaonic hydrogen one performed by SIDDHARTA. This will result in a better understanding of the strong interactions in the strangeness sector at low energies. The final aim of SIDDHARTA-2 is to perform a similar precision measurement for kaonic deuterium as the one of SIDDHARTA on kaonic hydrogen. This will import in a better understanding of the strong interaction in the strangeness sector and low-energies.

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