Kaonic nitrogen and hydrogen from DEAR

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On behalf on the DEAR Collaboration

1. DEAR scientific program

DEAR (DAΦNE Exotic Atom Research) is one of the first experiments at the DAΦNE φ-factory at the Laboratori Nazionali di Frascati dell'INFN [1]. The objective of DEAR is a precise determination of the isospin dependent antikaon-nucleon scattering lengths, through a percent measurement of the K_α line shift and width in kaonic hydrogen, and a similar, being the first one in the same time, measurement of kaonic deuterium.

DEAR measures the X-ray transitions occurring in the cascade processes of kaonic atoms; a kaonic atom is formed when a negative kaon (coming from the φ-decay, produced at DAΦNE) enters a target, loses its kinetic energy through the ionizations and excitations of the atoms and molecules of the medium, and is eventually captured, replacing the electron, in an excited orbit. Via different cascade processes (Auger effect, Coulomb deexcitation, scattering) the kaonic atom deexcites to lower states. When a low-*n* state with small angular momentum is reached, the **strong interaction** with the nucleus comes into play. This strong interaction is the reason for a **shift** in energy of the lowest-lying level from the purely electromagnetic value and the finite lifetime of the state – corresponding to an increase in the observed level **width**.

For kaonic hydrogen and deuterium the K-series transitions are of main experimental interest since they are the only ones affected by the strong interaction. The K_α lines as clearly separated from the higher K transitions. The shift ε and the width Γ of the 1s state of kaonic hydrogen are related in a fairly model-independent way to the real and imaginary part of the complex s-wave scattering length, a_{K^-p} **:**

$$e + i\,G/2 = 412\; a_{K^-p}\; eV\; fm^{-1}$$

This expression in known as the Deser-Trueman formula [2]. A similar relation applies to the case of kaonic deuterium and to its corresponding scattering length, a_{K^-d}:

$$e + i\,G/2 = 614\; a_{K^-d}\; eV\; fm^{-1}$$

The measured scattering lengths are then related to the isospin-dependent scattering lengths, a_0 and a_1:

$$a_{K^-p} = (a_0 + a_1)/2$$

$$a_{K^-n} = a_1$$

The extraction of a_{K^-n} from a_{K^-d} requires a more complicated analysis than the impulse approximation (K^- scattering from each – free – nucleon): higher order contributions associated with the K^-d three-body interaction have to be taken into account. This means to solve the three-body Faddeev equations by the use of potentials, taking into account the coupling among the multichanneled interactions. An accurate determination of the K^-N isospin dependent scattering lengths will place strong constraints on the low-energy K^-N dynamics, which in turn constrains the SU(3) description of chiral symmetry breaking [3]. Crucial information about the nature of chiral symmetry breaking, and to what extent the chiral symmetry must be broken, is provided by the calculation of the meson-nucleon sigma terms.

A meson-nucleon sigma term is defined [4] as the nucleon expectation value of the equal-time double commutator of the chiral symmetry breaking part of the strong-interaction Hamiltonian. The sigma term is then a quantity which directly gives the degree of chiral symmetry breaking. Consequently, its relation to the scattering amplitude represents the corresponding low-energy theorem in the soft meson limit [4].

A phenomenological procedure, which implies dispersion relations and suitable extrapolations allows to extract the sigma term from the measured amplitudes. Presently only estimates for the KN sigma terms exist; a measurement of the K^-N scattering lengths at few percent level should allow the determination of these quantities, with a precision better than 20%.

The sigma terms are also important inputs for the determination of the strangeness content of the proton. The strangeness fraction depends on both kaon-nucleon and pion-nucleon sigma terms, being more sensitive to the first ones [5].

2. The DEAR setup at DAFNE

A schematic drawing of the DEAR setup, installed at the DAFNE collider, is shown in Figure 1. A pressurized cryogenic target is used (23 K and 1.82 bar, for kaonic hydrogen measurement), in order to optimize the number of kaons stopped in the target, and, in the same time, not to have a reduction of the signal due to the Stark effect. The X-ray detector system consists of 16 CCDs. The main elements of the setup are indicated in the Figure 1.

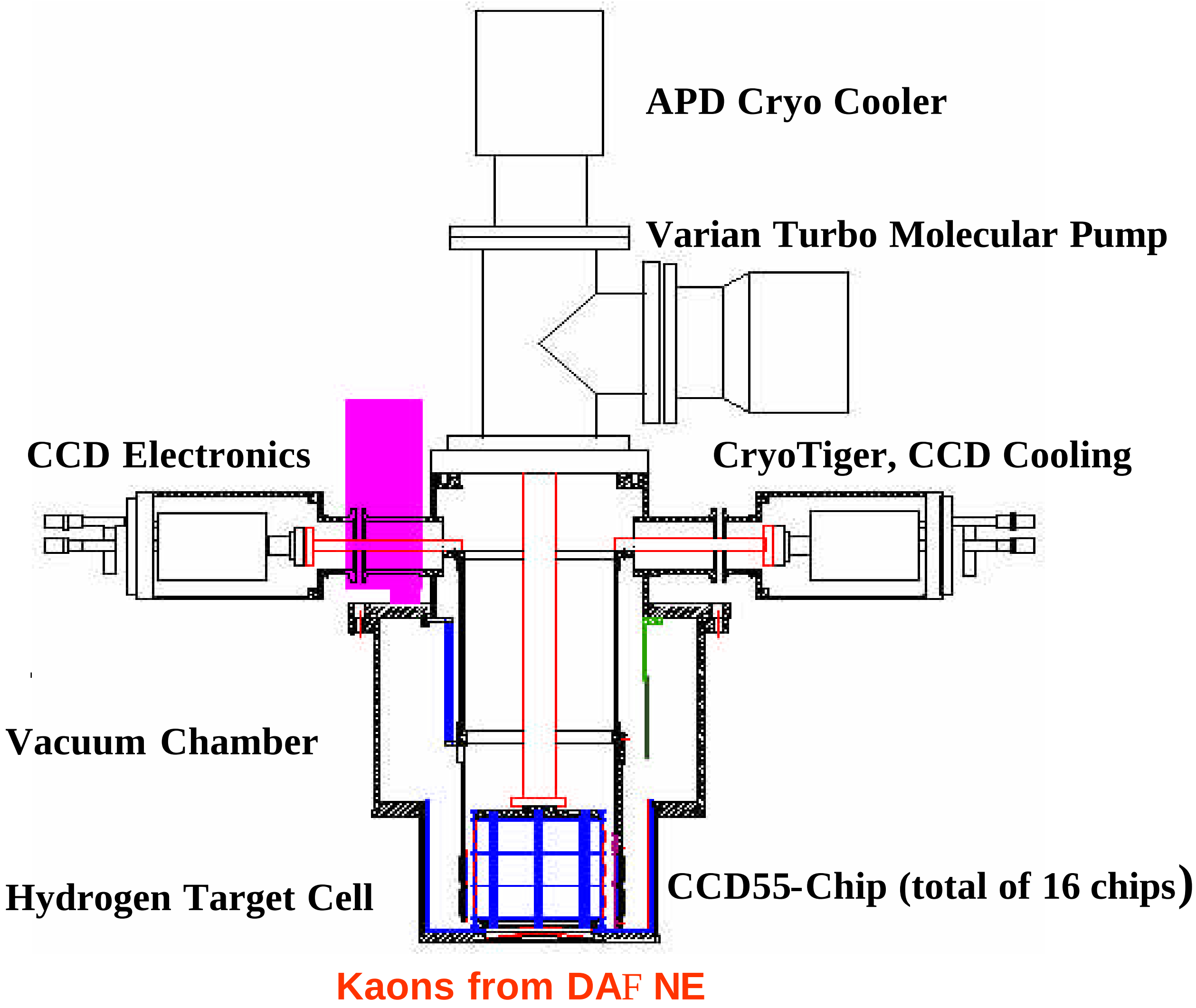

Figure 1: The DEAR experimental setup

The setup was installed in one of the two interaction regions of DAΦNE, and had periods of data taking starting from December 1999, when first collisions were achieved.

The first periods of data taking were dedicated to background understanding and reduction, by the use of appropriate shielding and machine optics solutions. This period was followed by a measurement of the first exotic atom at DAFNE, namely the kaonic nitrogen, in May 2001. The 7->6 transition at 4.6 keV and the 6->5 transition at 7.6 keV were clearly identified among other X-ray electronic excitations of the elements present in the setup material elements (iron, copper, zinc). As a consequence, a new target, built completely in kapton, with a fiber glass reinforcement, was used for the next run periods in 2002.

In October 2002 the kaonic nitrogen was remeasured; the X-ray spectrum was very clean (no electronic X-ray transitions were present in the region of interest: 6 – 8 keV) and kaonic nitrogen lines clearly visible. The first measurement of kaonic hydrogen followed (November – December 2002).

The preliminary results of these measurements are reported below.

3. Kaonic nitrogen preliminary results

The measurement of kaonic nitrogen had the following objectives:

- to prove the feasibility of the DEAR method to produce and detect exotic atoms using the K^- beam from ϕ-decay in DAΦNE. The choice of nitrogen is dictated by the high yields of the transitions, so allowing a fast feedback;
- to optimize the kaon stopping point distribution, by learning how to finalize the degrader, in the view of the delicate kaonic hydrogen measurement.

These objectives were achieved; the first kaonic nitrogen spectrum was measured in May 2001, the results being published in [6]. In October 2002 the kaonic nitrogen spectrum was re-measured, with the new target built completely in kapton (see Section 2) and the degrader was optimized such as to have the signal uniformly distributed on all the 16 CCDs. The preliminary results, as a background subtracted spectrum, are shown in Fig. 2.

The spectrum shown in Fig. 2 corresponds to a statistics of about 10.5 pb^{-1} of integrated luminosity; the 2 kaonic nitrogen lines are clearly visible: there are about 5200 events at the 7.6 keV transition and about 2200 events at the 4.6 keV transition. The calcium peak is coming from the fiber glass reinforcement of the target; titanium and zirconium lines are coming from calibration foils placed inside the target in the view of the calibration of the energy scale to be performed during the kaonic hydrogen measurement.

The data analysis is in progess, with the goal of determining the yields of the transitions, being this the first measurement of these quantities.

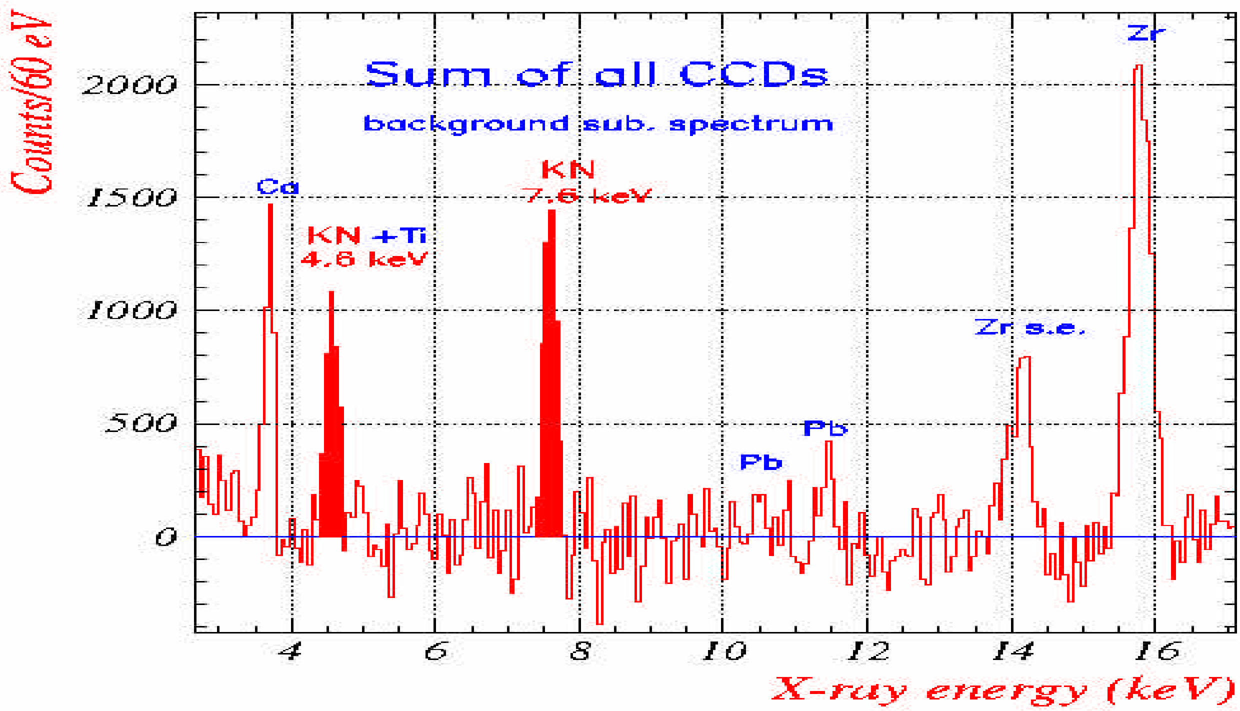

Figure2: Preliminary kaonic nitrogen background subtracted spectrum (October 2002)

4. Kaonic hydrogen preliminary results

The kaonic hydrogen data acquisition lasted from 31 October 2002 until 16 December 2002, for a total integrated luminosity of about 58 pb^{-1}. This measurement was followed, until 23 December 2002, by a pure background measurement, necessary for the background subtraction.

The preliminary results, for a partial statistics analyzed at present (about 20 pb^{-1}), are giving good indication for the presence of the K_α line and the rest of the K-complex lines (both at about 3σ evidence).

Data analysis is in progress .

5. Future plans

For the future, in order to achieve the percent level precision measurement for the kaonic hydrogen and deuterium transitions, an upgrade of the DEAR setup is foreseen. One of the problems to cope with during the kaonic hydrogen measurement was still the presence of a high background. The CCD devices used to detect X rays are non-triggerable devices, due to the fact that the data read-out is slow (seconds). In order to further reduce the background, the use of the timing information is a must; consequently DEAR is planning to use, instead of the non-triggerable CCDs, new devices (Silicon Drift Detector) in which fast triggering is feasible. The trigger is given by the entrance of a charged kaon in the target volume. The event can be identified and measured with high accuracy (150 ps) and low contamination (1%) by uing a three-scintillator telescope, synchronized with the bunch frequency. The method was already tested and worked well, in the present phase of the DEAR experiment, in the kaon and luminosity monitor. The excellent timing performance (1μs) to be used in the trigger, together with the excellent energy resolution (140 eV at iron position) of the SDD will allow a dramatic decrease of the background (S/B ratio about 1/1 for kaonic hydrogen and 1/3 – 1/10 for kaonic deuterium) and to perform the planned precision measurements. Moreover, other exotic atoms (kaonic helium and other light atoms, as well as eventual sigmonium atoms) and a high-precision measurement of the charged kaon mass will eventually become feasible.

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