Kaonic Hydrogen - Status of the DEAR Experiment

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on behalf of the DEAR Collaboration
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The objective of the DEAR experiment is a precision measurement of the strong interaction shifts and widths of the K-series lines in kaonic hydrogen and the first observation of the same quantities in kaonic deuterium. These results will allow a precise determination of the isospin dependent kaon-nucleon scattering lengths and will help to determine the kaon-nucleon sigma terms. With the present performance of the DAFNE collider a kaonic hydrogen measurement with a precision better than the best existing experiment seems feasible now. In a preparing experiment kaonic nitrogen X rays were measured.

§1. The DEAR scientific program

The DEAR (DAFNE Exotic Atom Research) experiment[1)] is based on the determination of the energy of X-rays emitted in the transitions to the ground states of kaonic atoms.

A kaonic atom is formed when a negative kaon enters a target, looses its kinetic energy through ionization and excitation of the atoms and molecules of the medium and eventually is 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 kaon reaches a low-n state with small angular momentum, strong interaction with the nucleus causes its absorption. This strong interaction is the reason for a shift in the energies of the low-lying levels from the purely electromagnetic values and the finite lifetime of the state corresponds to an increase in the observed level width.

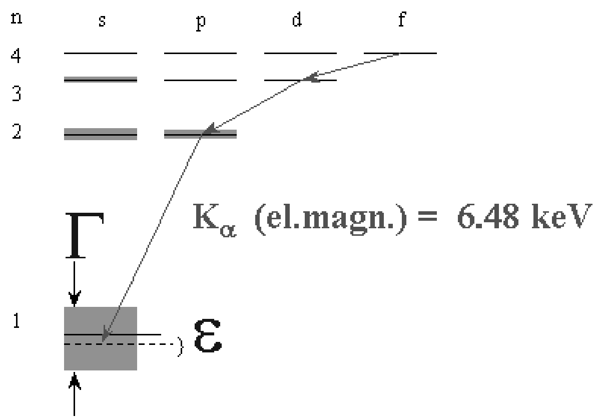

Fig. 1. Schematic view of the energy levels of kaonic hydrogen showing shift and width

The shift ϵ and the width Γ of the 1s state of kaonic hydrogen are related to the real and imaginary parts of the complex S-wave scattering length

$$\epsilon + i\,\Gamma\,/\,2 = 2\,\alpha^3\,\mu^2\,a_{Kp} = (412\text{ eV fm}^{-1})\,a_{Kp}$$

where α is the fine structure constant and μ is the reduced mass of the K^-p system. This expression is known as the Deser Trueman formula.[2)–4)] A similar relation applies for the case of kaonic deuterium and the corresponding scattering length a_{Kd}

$$\epsilon + i\,\Gamma\,/\,2 = 2\,\alpha^3\,\mu^2\,a_{Kd} = (601\text{ eV fm}^{-1})\,a_{Kd}$$

(here μ is the reduced mass of the K^-d system).
a_{Kp}, and a_{Kd} are related to the isospin dependent scattering lengths a_0 and a_1

$$a_{Kp} = (a_0 + a_1)\,/\,2$$

$$a_{Kd} \propto a^{(0)} + C$$

where

$$a^{(0)} = (a_{Kp} + a_{Kn})\,/\,2 = (\,a_0 + 3\,a_1\,)\,/\,4$$

represents the lowest order impulse approximation (kaon scattering on "free" nucleons). The second term C contains all higher order corrections (which turn out to be bigger than first order ones) and requires the full machinery of three-body calculations.

An accurate determination of the isospin scattering lengths will place strong constraints on low-energy KN dynamics, which in turn constrains the SU(3) description of chiral symmetry breaking. In particular the determination of these scattering lengths is one of the primary uncertainties in the phenomenological procedure used to calculate the kaon-nucleon sigma terms.[5)]

§2. The Frascati Phi factory

DAΦNE (Double Annular Phi Factory for Nice Experiments) is an electron positron collider with collision energy tuned to the Phi resonance at 1.02 GeV c.m. $e^+ e^-$ annihilation. The Phi production cross section is ≈ 3000 nanobarn (corrected for radiative losses)

The design goals are a peak luminosity of $\geq 10^{32}$ cm^{-2} s^{-1} (running at 120 bunches per ring, 5A beam current) and a beam livetime of 2h.

In April 2002 @DEAR a peak luminosity of $4 \cdot 10^{31}$ cm^{-2} s^{-1} (running at 40 bunches per ring, beam currents ≤ 0.8A) and a beam livetime ≤ 1h was achieved. The luminosity per day was ≈ 1000 nb^{-1}

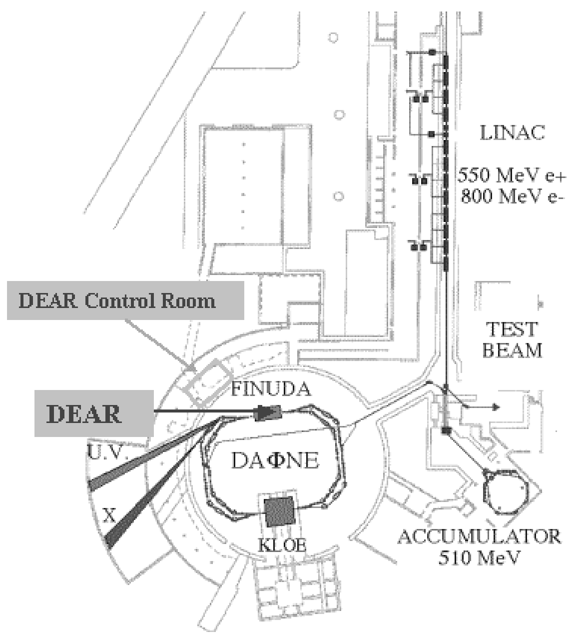

Fig. 2. Layout of DAFNE

The crucial point is the low-energy X ray background (mainly from electron gamma showers resulting from lost e^+ or e^- due to either Touschek scattering ($e^+ e^+$ or $e^- e^-$) or residual gas interaction.

§3. The experimental setup

We use a light weight cryogenic gas target with a diameter of 12cm operated with hydrogen at a temperature of T=25K and a pressure of P=2bar which results in a density of 2.1g/l, (0.03 of liquid hydrogen density). For the nitrogen runs (T=120K, P=1.5bar) the density was 4.36g/l (0.0054 of liquid nitrogen density). The walls and the entrance window of the target are 75 micron kapton. The entrance window is situated 13.1cm above the phi production region. As X ray detectors we use 16 CCDs, with total sensitive area of 116 cm^2 the depletion depth is 40 micron. Each

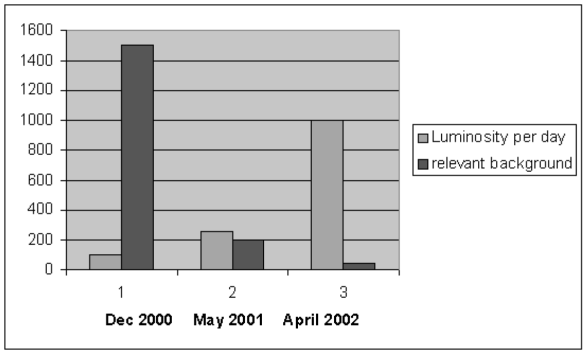

Fig. 3. DAFNE achievments: Integrated luminosity and background per luminosity (number of X rays @6keV seen by our detectors, arbitrary units)

chip has 1 millon pixels, so the readout with the necessary excellent energy resolution (140eV FWHM @ 4.5keV) is slow and prohibits tagging.

The kaon production is monitored by 2 plastic scintillators, one on each side of the pipe (lateral) which detect K^+ K^- coincidences.[11)]

Fig. 4. DEAR apparatus installed at DAFNE interaction point 2

§4. Kaonic nitrogen

In preparation for the kaonic hydrogen run of November/December 2002 we measured kaonic nitrogen X rays. These data demonstrate the functioning of the experimental apparatus including the kaon degrader which is needed to slow down the kaons from 16MeV (phi decay at rest) to about 4MeV kinetic energy to stop them in the gas target. For the hydrogen run these data are important as background measurement. To date a part of the kaonic nitrogen data is analyzed, see figure 5 and 6. Zirconium was placed inside the target to provide a calibration line, calicium is contained in the reinforcement of the target cell, aluminum fluorescence X rays come from the vacuum vessel, some strontium and also gold and silver is contained in the CCD coupling and electronics. Special care was take to avoid iron in the experimental apparatus, since the kaonic hydrogen K-alpha X ray line should not be distorted.

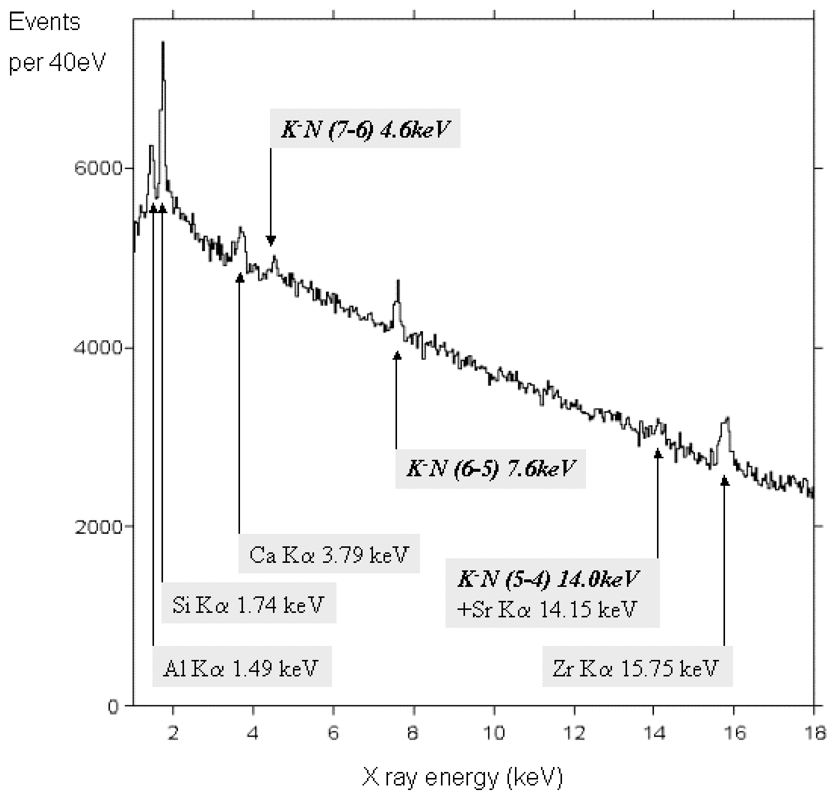

Fig. 5. Kaonic nitrogen X ray spectrum

§5. Kaonic hydrogen 2002 and future

For the data taking of November/December 2002 we expect about 3000 measured kaonic hydrogen K-alpha events, given a yield of the transition of 2%. This would allow a determination of the shift and width with a precision comparable or better than the best existing experiment, the KpX experiment[6)–8)] at KEK. To achieve the final goal, a measurement at the percent level, a new type of soft X ray detectors has to be applied.

Recently developed technology, the 'silicon drift diode' (SDD) detectors[9),10)] are very promising. SDDs have extremely small anode capacitance and so allow to gain higher energy resolution at shorter shaping times compared to conventional photodiodes and Si(Li) detectors. A project to apply this technology to exotic atoms spectroscopy is currently being prepared. The goal is to combine timing capability (tagging with the incoming kaon) with excellent energy resolution, radiation hardness, large active area and low sensitivity to minimal ionizing particles. A possible

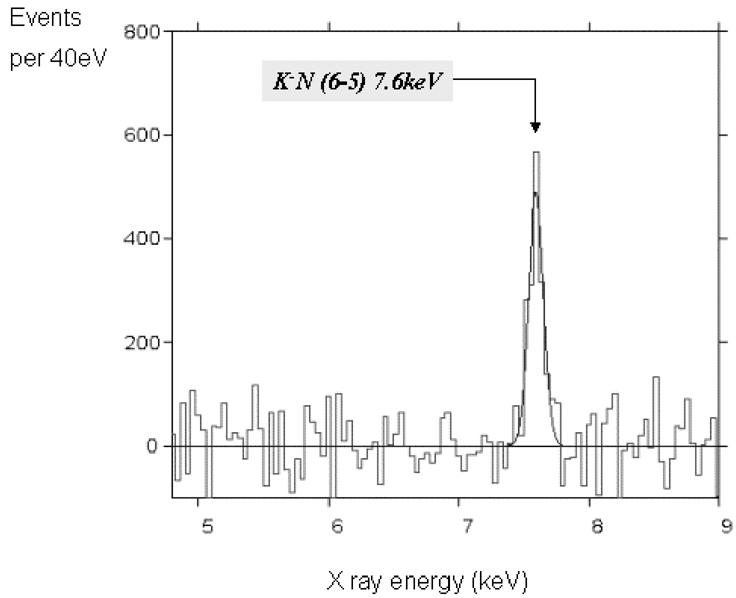

Fig. 6. Kaonic nitrogen X ray spectrum, background subtracted, fit of the 7.6keV line

next exotic atoms data taking however can only start after 2003, since at the beginning of 2003 the FINUDA experiment will be installed at DAFNE.

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