THE DEAR EXPERIMENT AT DAΦNE

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This paper gives an overwiew of the DEAR (DAΦNE Exotic Atom Research) experiment, which is fully ready to collect data at the new DAΦNE ϕ-factory at the Laboratori Nazionali di Frascati dell'INFN. The objective of the DEAR experiment is to perform 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. The aim is to obtain a precise determination of the isospin-dependent kaon-nucleon scattering lengths which will represent a breakthrough in $\bar{K}N$ low-energy phenomenology and will allow us to determine the kaon-nucleon sigma terms. The sigma terms give a direct measurement of chiral symmetry breaking and are connected to the strangeness content of the proton. First results on background measurements with the DEAR NTP setup installed on DAΦNE are reported.

1 Introduction

DEAR (DAΦNE Exotic Atom Research) [1]– one of the first experiments which will collect data at the new ϕ-factory DAΦNE [2] of the Laboratori Nazionali di Frascati dell'INFN, will observe X rays from kaonic hydrogen and kaonic deuterium, using the "K^- beam" from the decay of ϕs produced by DAΦNE, a cryogenic pressurized gaseous target and Charge-Coupled Devices (CCDs) as X ray detectors.

DEAR aims at a *precision* measurement of the strong interaction shifts and widths of the K-series lines in kaonic hydrogen and kaonic deuterium. K^-d will be measured for the first time. In this way, a precise determination of the isospin dependent $\bar{K}N$ scattering lengths will be obtained. At a machine luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ the number of events which DEAR can collect in *one week* will surpass by an order of magnitude the current world data set.

2 The DEAR scientific program

A kaonic atom is formed when a negative kaon entering a target loses its kinetic energy and is captured in an excited orbit, replacing the electron. Three processes then compete in the deexcitation of the newly formed kaonic atom: dissociation of the surrounding molecules, external Auger transitions and radiative transitions.

When a kaon reaches low-n states with small angular momentum, it is absorbed through a strong interaction with the nucleus. This strong interaction causes a shift in the energies of the low-lying levels from their purely electromagnetic values, whilst the decreased lifetime of the state results in an increase of the observed level width. 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 parts of the complex S-wave scattering length:

$$\epsilon + \frac{i}{2}\Gamma = 2\alpha^3 \mu_{K^-p}^2 a_{K^-p} = (412\ eV\ fm^{-1}) \cdot a_{K^-p} \tag{1}$$

where α is the fine structure constant and μ_{K^-p} the reduced mass of the K^-p system. This expression is known as the Deser-Trueman formula [3]. A similar relation applies for the case of kaonic deuterium and the corresponding scattering length a_{K^-d}:

$$\epsilon + \frac{i}{2}\Gamma = 2\alpha^3 \mu_{K^-d}^2 a_{K^-d} = (601\ eV\ fm^{-1}) \cdot a_{K^-d} \tag{2}$$

where μ_{K^-d} is the reduced mass of the K^-d system.

These observable scattering lengths (a_{K^-p} and a_{K^-d}) are related to the isospin dependent scattering lengths (a_0 and a_1):

$$a_{K^-p} = \frac{1}{2}(a_0 + a_1) \tag{3}$$

$$a_{K^-d} = 2(\frac{m_N + m_K}{m_N + m_K/2})a^{(0)} + C \tag{4}$$

where

$$a^{(0)} = \frac{1}{2}(a_{K^-p} + a_{K^-n}) = \frac{1}{4}(a_0 + 3a_1) \tag{5}$$

represents the lowest order impulse approximation and C contains higher order contributions, including three-body effects.

DEAR should reach a one order of magnitude improvement in the precision of the K^-p scattering length with respect to the most accurate data presently available from KEK [4]. This will represent a breakthrough in the low-energy $\bar{K}N$ phenomenology and make possible the discrimination of different theoretical approaches and methods of analysis. Moreover, 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. Crucial information about the nature of chiral symmetry breaking, and to what extent chiral symmetry is broken, is provided by the calculation of the meson-nucleon sigma terms [5]. The meson-nucleon sigma term is defined as the expectation value of a double commutator of the chiral symmetry breaking part of the strong-interaction Hamiltonian, H_{SB}:

$$\sigma_N^{ba} = i < p|[Q_b^5, [Q_a^5, H_{SB}]]|p > \tag{6}$$

Here $|p>$ means a proton state of momentum p and Q_a^5 and Q_b^5 represent the axial-vector charges.

The low energy theorem relates the sigma terms to the meson-nucleon scattering amplitude [5]. A phenomenological procedure starting from the experimental scattering amplitudes can then be used to determine the sigma terms and, therefore, to measure chiral symmetry breaking [6]. According to an evaluation based on the uncertainities in the phenomenological procedure [7], the sigma terms can be extracted at a level of 20%, by combining the DEAR precision measurement at threshold with the bulk of the most recent analyses of low energy $K^{\pm}N$ scattering data.

The sigma terms are important also as inputs for the determination of the strangeness content of the proton. The strangeness fraction is dependent on both kaon-nucleon and pion-nucleon sigma terms, but is more sensitive to the first one [8].

3 DEAR Experimental setup

The scientific program of DEAR will be performed in two steps: with an NTP (Normal Temperature and Pressure) target filled with nitrogen, and with a cryogenic target with hydrogen (deuterium).

The NTP target, presented in Fig. 1, consists of a pure nitrogen volume at room temperature equipped with four CCD-05. The purpose is to measure background, compare it with Monte Carlo calculations and tune the degrader thickness by optimizing the signal coming from $7 \rightarrow 6$ ($\sim$ 4.6 keV) and $6 \rightarrow 5$ ($\sim$ 7.6 keV) kaonic nitrogen transitions. The yield of these transitions being higher (by a factor of ten) than those of kaonic hydrogen permits faster feedback. Kaonic nitrogen x-ray transitions will be measured by DEAR *for the first time*.

For the measurement of kaonic hydrogen (deuterium), a pressurized cryogenic target was built, to achieve a balance between high kaon stopping power in the target cell and the loss of x-ray yield due to Stark mixing. The target will operate at a temperature of 25 K and a pressure of 3 bar. 16 CCD-22's will be used as x-ray detectors. Under these conditions, the expected yield of the K_α X rays per stopped kaon lies between (1-3)%, according to recent cascade calculations [9] and the KEK results [4].

Further details regarding the NTP setup can be found in Ref. [10], while a description of the DEAR cryogenic setup can be found in Ref. [1].

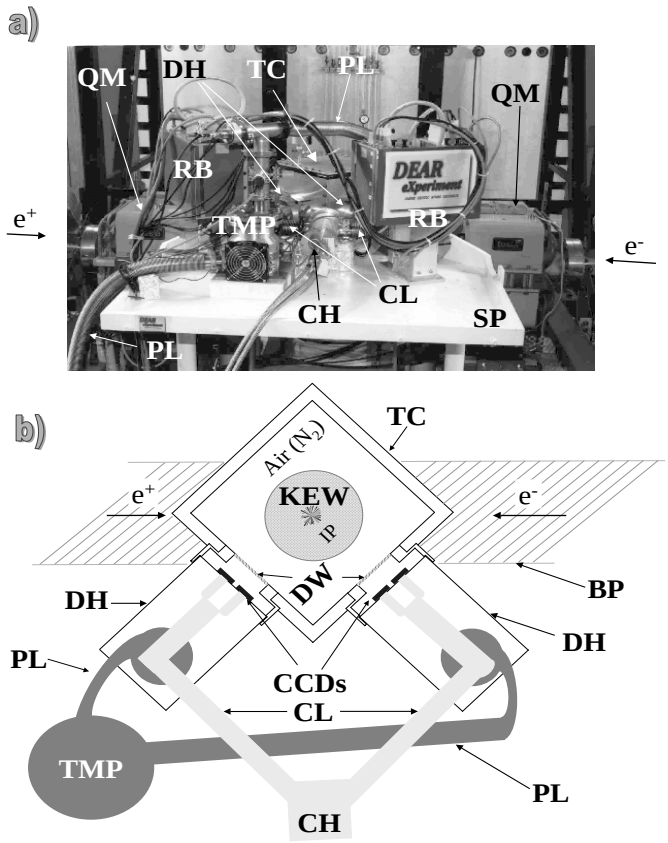

Figure 1. a) The NTP setup installed in the DAΦNE hall; b) Schematic drawing of the NTP setup. The displayed components are: RB = readout box; TMP = turbomolecular pump; CH = cooling head; Cl - cooling line; PL = pumping line; TC = target chamber; DH = detector housing; QM - quadrupole magnet; BP = beam pipe; KEW = kaon entrance window; DW = detector window; IP = interaction point; SP = setup platform.

4 First background measurement at DAΦNE with the NTP setup

The NTP setup was installed at DAΦNE in February 1999.

At the date of the Symposium (9-10 December, 1999), *no e^+e^- collisions have yet been produced in the DEAR interaction region*, because the machine luminosity is being optimized in the other interaction region, where the KLOE solenoid is installed.

The backgrounds relevant for the DEAR experiment are low energy ($\leq$ 20 keV) X rays and ionizing particles. A low-energy X ray hit in a CCD gives a "single-pixel" event - a pixel with charge content above a selected noise threshold, surrounded by eight neghbour pixels displaying charge contents below threshold. Hits of more than one pixel are called "clusters", and are mainly caused by charged particles.

Using the fully shielded DEAR NTP setup the following types of beams have been monitored in the period from March to July 1999: a) only positron beams; b) only electron beams; c) electron and positron beams at the same time. Background data, in terms of *clusters*, were then compared with DEAR Monte Carlo simulation.

Fig. 2 shows, as an example, the number of clusters per half-CCD per minute observed with electron beams circulating in DAΦNE. The time dependence is given with respect to the injection time of the beam into the accelerator ring. The time between two adjacent points represents the exposure time of 10 minutes. The time behaviour of the number of clusters follows the time behaviour of the injected electrons (shown in the upper part of the figure). The simulations agree very well with the measurements.

Under the working conditions of the measurements (no collisions) and at the present status of the accelerator, the most important background comes from Touschek scattering [11] with a contribution from beam-gas interactions [12].

All measurements can be well reproduced by the DEAR Monte Carlo simulation using the standard beam parameters for the DEAR interaction region. The quantitative agreement between simulation and measurements is very convincing.

In addition, the *shielding factor* could be measured and compared with the Monte Carlo value; the experimental value of 3.6 ± 0.2 is perfectly compatible with the calculated value of 3.8 ± 0.4. More details can be found in Ref. [10].

Since the goal of DEAR is to detect kaonic hydrogen X rays, the study of x-ray background is very important, since the final statistical accuracy attainable with DEAR will critically depend on the level of this background. The observed energy spectra do not show any sign of unwanted structure. This confirms the purity of the materials used.

Tests of the possibility of using fluorescence lines for on-line energy calibration from titanium and zirconium foils, placed in the target cell and excited by the background particles, were also successfully performed.

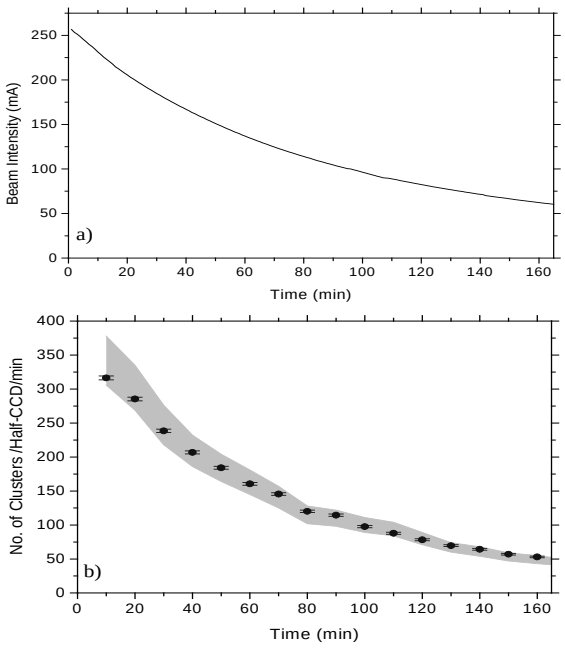

Figure 2. a) Electron beam intensity (mA) for the period 6:21 - 9:01 a.m. June 27, 1999 with only electrons circulating in the DAΦNE main ring; b) Observed number of clusters per half - CCD per minute (filled circles) during the corresponding beam period. The shaded area shows the results of the DEAR Monte Carlo simulation.

5 Summary

The DEAR experiment will improve the precision in the measurement of the K^-p scattering length by a factor of ten and make the first measurement of the scattering length for kaonic deuterium. A percent-level measurement of the isospin dependent $\bar{K}N$ scattering length will represent a breakthrough in the low-energy $\bar{K}N$ phenomenology, implying the possibility of discriminating between many existent theoretical approaches and methods of analysis. It will

be possible to determine the kaon-nucleon sigma terms, which give directly the degree of chiral symmetry breaking and allow to obtain an indication of the strangeness content of the proton.

At the time of writing, the first stage of the DEAR scientific program is in progress. The NTP nitrogen target is installed at DAΦNE. Background measurements have been performed and the first kaons are eagerly awaited.

The cryogenic hydrogen target is being tested in the laboratory and is ready for installation at the beginning of 2000.

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