The DEAR experiment on DAΦNE

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Abstract. DEAR is one of the first experiments 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.

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. This will allow to determine the kaon-nucleon sigma terms which give a direct measurement of chiral symmetry breaking and are connected to the strangeness content of the proton.

The status of the experiment is reported, together with the results of the first measurements on DAΦNE Accelerator.

THE DEAR SCIENTIFIC PROGRAM

A kaonic atom is formed when a negative kaon enters a target, loses its kinetic energy through ionization and excitation processes of the atoms and molecules of the medium and eventually is captured, replacing the electron, in an excited orbit. 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:

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

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}:

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

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 [5,6].

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 [7].

DEAR EXPERIMENTAL SETUP

The scientific program of DEAR will be developed in two stages: with an NTP (Normal Temperature and Pressure) target and with a cryogenic target (hydrogen and deuterium).

The NTP target consists of a pure nitrogen volume at room temperature, equipped with 2 CCD detectors each containing two CCD-05 chips. Its purpose is to observe background, compare to Monte Carlo calculations and to tune the degrader thickness by optimizing the signal for the kaonic nitrogen $7 \rightarrow 6$ transition at ~ 4.5 keV. The yield of the signal being higher than that of kaonic hydrogen, faster feedback is possible.

A description of the DEAR NTP setup can be found in [8].

For the measurement of kaonic hydrogen, a pressurized cryogenic gaseous target was constructed which permits a balance between high kaon stopping density in the target cell and decreasing x-ray yield due to Stark mixing.

The initial target conditions will be a hydrogen pressure of 3 bar and a temperature of 25 K, which results in a target density of 3.6×10^{-3} g/cm^3. After the kaon has been slowed down in the target, it is captured by a hydrogen atom and the cascade begins. Some K-series X rays exit the target and interact with the CCD detector. The CCD chips are cooled to a temperature of 160 K to limit dark current noise. The CCDs are then read out by a set of custom electronics and digitized data are transmitted via a fiber-optic link to the two data acquisition computers in the DEAR control room. Compressed data are stored on magnetic-optical disks for further analysis; online diagnostic and analysis programs also exist for the real-time monitoring of the data.

Further details and a description of the DEAR cryogenic setup can be found in [9].

RESULTS OF THE MEASUREMENTS AT DAΦNE WITH THE NTP SETUP

The NTP setup was installed at DAΦNE in February 1999.

An extensive series of measurements with only electrons or positrons circulating and with beams colliding in the KLOE IP and vertically split in the DEAR IP was performed [10].

A first period of data taking with collisions in the DEAR Interaction Point (IP) was performed in December 1999 [11]. Beams colliding in the DEAR IP could only be investigated for a short period (60 hours) during this run. A second period of runs with beams colliding in the DEAR IP was assigned from August 24 to September 11, 2000 [12]. The beam period was devoted to two main goals, namely understanding and reducing the background in the DEAR region and increasing the luminosity, after the major changes performed on the machine during the shutdown in Spring 2000.

DEAR explored the effect on background reduction obtained by:

- using the horizontal scrapers on electrons and on positrons in the DEAR region;
- using the vertical scrapers on electrons and on positrons in the DEAR region;
- using the horizontal scrapers on electrons and positrons in the KLOE region, the effect of which is shown in Figure 1;
- the change of the crossing angle in the DEAR IP, the effect of which is shown in Figure 2;
- the change of the vertical direction of trajectories in the DEAR IP, the effect of which is shown in Figure 3.

The overall reduction of the background by inserting the scrapers was about a factor of 3, while a 10% reduction could be obtained by changing the horizontal crossing angle.

The X-ray spectrum which was collected in stable conditions by DEAR during this period is shown in Figure 4. It corresponds to a total integrated luminosity

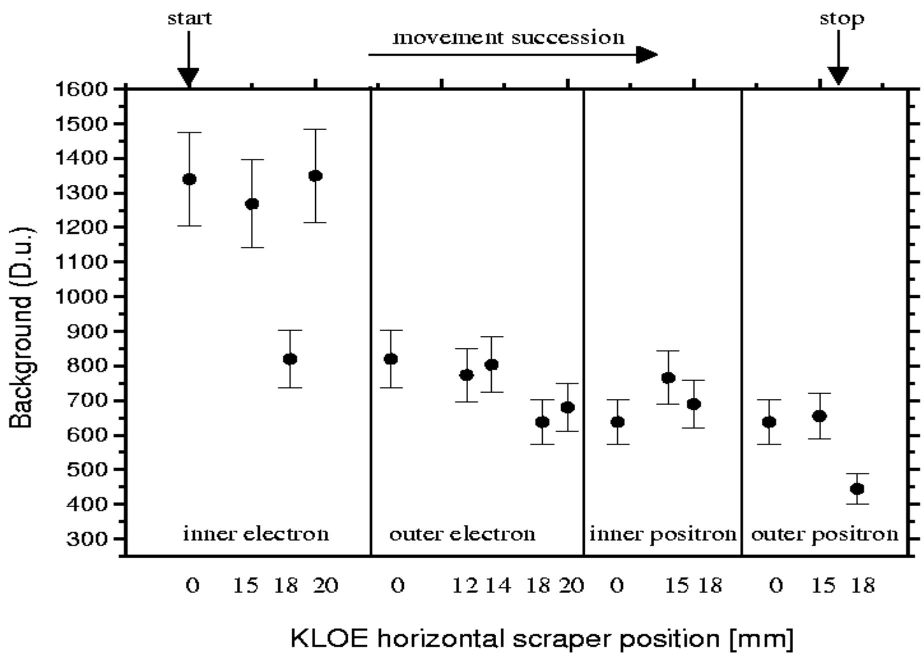

FIGURE 1. Dependence of the background in DEAR on the position of the scrapers on the KLOE side. First the inner electron scraper was inserted, followed by the outer one, then the inner positron scraper, followed again by the outer one. The successive improvement of the background is evident. Note: DEAR units (D.u.) = Number of clusters per CCD per Beamloss (mA) - see Ref. [10].

of 172.1 nb^{-1}. The positions of the 4.58 and 7.58 keV kaonic nitrogen lines are indicated. The expected count rate in the peaks for the collected luminosity is by far too low to be observed with the actual background.

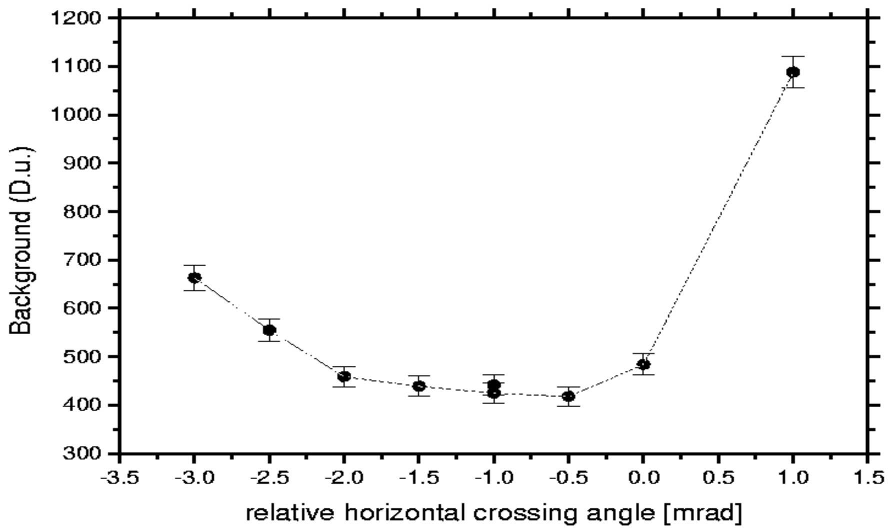

FIGURE 2. Dependence of the background in DEAR on the relative horizontal crossing angle of the beams in the DEAR IP. For the scan, the electron crossing angle was changed. The angle is given in mrad with respect to the DAΦNE reference setting (here indicated with 0).

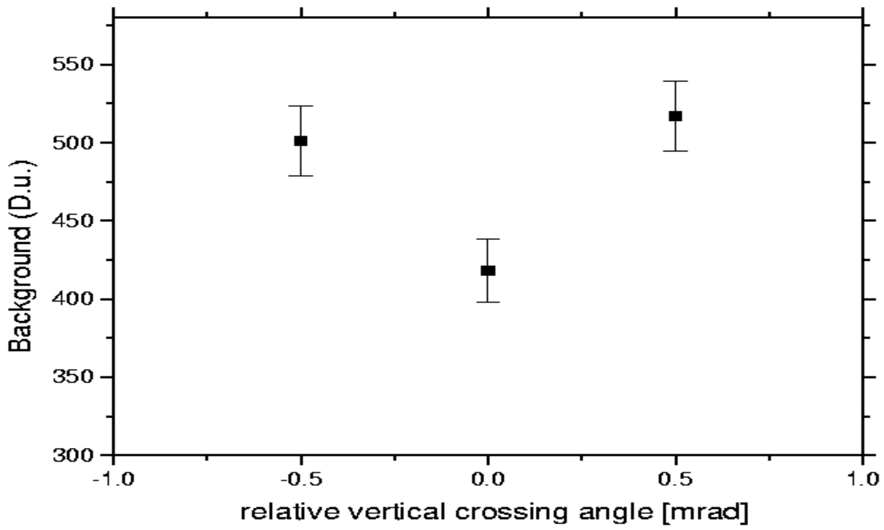

FIGURE 3. Dependence of the background in DEAR on the relative vertical crossing angle of the beams in the DEAR IP. For the scan, the electron crossing angle was changed. The angle is given in mrad with respect to the DAΦNE reference setting (here indicated with 0).

In conclusion, the period of measurements with collisions in the DEAR IP from August 31 to September 11, 2000, has given the following main results:

- the background observed with beams colliding in the DEAR IP (split in KLOE) turned out about 2.6 times higher with respect to the one observed in the collision period of December 1999, before the shutdown;
- the average peak luminosity was increased by about a factor of 4.2 with respect to December 1999, reaching a maximum of 5×10^{30} cm^{-2}s-1;
- the overall improvement of the accelerator performance (signal/background) was therefore about 1.6;

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

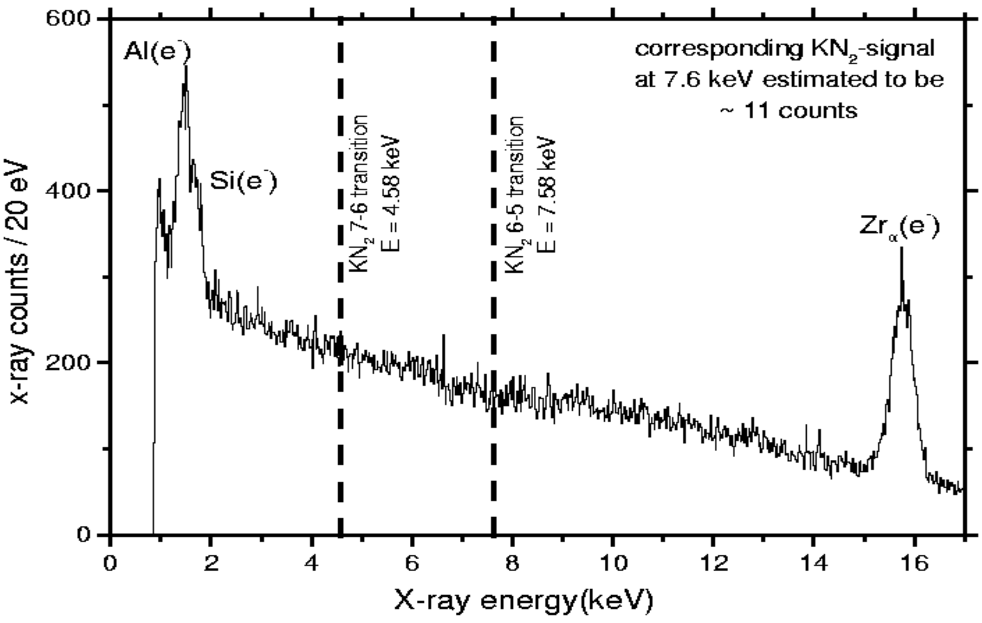

FIGURE 4. Energy spectrum of X rays observed in the period of beams colliding in the DEAR interaction region. The calculated positions of two kaonic nitrogen transitions are indicated. Electronic X-ray lines from aluminium, silicon and zirconium are clearly visible.

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 and took data with collisions in the DEAR IP. The DEAR NTP setup equipped with the CCD X-ray detector worked very well, however the present background level is too high for the present luminosity to allow an unambigous detection of a kaonic nitrogen signal. Further improvements in the background reduction (using dedicated shielding) and in increasing the signal (higher machine luminosity) might then allow determination of the kaonic nitrogen lines.

Then the main scientific programme will start with the installation and measurements performed with the hydrogen cryogenic target. The cryogenic hydrogen target is being tested in the laboratory and is ready for installation in 2001.

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