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THE DEAR EXPERIMENT ON DAΦNE*

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on behalf of the DEAR Collaboration

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The DEAR project is one of the first experiments at the new DAΦNE ϕ-factory at the Laboratori Nazionali di Frascati dell'INFN. The objective of DEAR is a precise determination of the isospin-dependent kaon–nucleon scattering lengths, through a 1% measurement of the K_α line shift in kaonic hydrogen and the first observation of the line shift in kaonic deuterium.

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1. DEAR scientific program

The DEAR (**D**AΦNE **E**xotic **A**tom **R**esearch) experiment is based on the determination of the energy of X-rays emitted in the ground state cascade transitions of kaonic atoms [1].

A kaonic atom is formed when a negative kaon enters a target, loses 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 purely electromagnetic values, and the finite lifetime of the state corresponds to an increase in the observed level width. This view is sketched in figure 1.

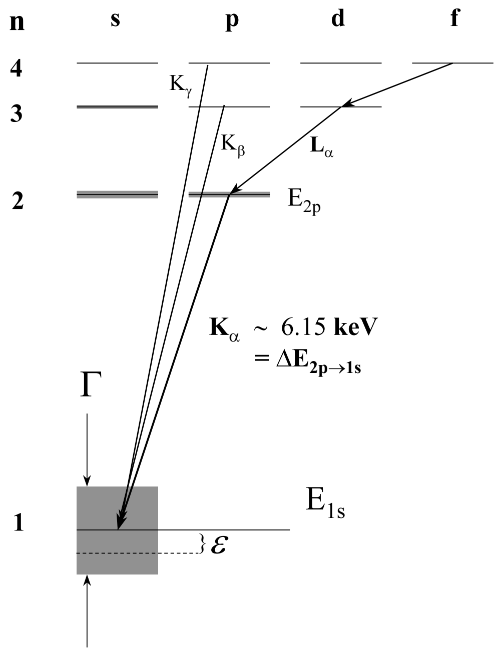

Fig. 1. Schematic view of the level scheme of kaonic hydrogen indicating the K_α, K_β and K_γ transitions, and the level shifts and widths, which are only relevant for states $n \leq 2$.

For the DEAR experiment the kaonic hydrogen K_α transition is of main experimental interest as it can be 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}

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

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

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

These simple relations are known to hold quite accurately for these atoms [3], their correction being smaller than 1%.

The observable scattering lengths are related to the isospin scattering lengths a_0 and a_1 in the following way

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

$$a_{K^-d} = \frac{1}{2}\left(\frac{m_N + m_K}{m_N + m_K/2}\right)(a_0 + 3a_1) + \ C\ . \tag{4}$$

In the case of deuterium, the first term represents the lowest-order impulse approximation in which the kaon scatters from each "free" nucleon. The second term, C, contains all higher-order contributions, including three-body effects. In fact this second term turns out to be even larger than the first term. Thus the extraction of the two isospin scattering lengths requires a sophisticated analysis.

An accurate determination of the K^-N isospin scattering lengths will place strong constraints on low energy K^-N dynamics, which in turn constrains the SU(3) description of chiral symmetry breaking [4]. Crucial information about the nature of chiral symmetry breaking, and to what extent chiral symmetry must be broken, is provided by the calculation of the meson–nucleon sigma terms.

A meson–nucleon sigma term is defined [5] as the nucleon expectation value of the equal-time (sigma) double commutator of the chiral symmetry breaking part of the strong-interaction Hamiltonian. The sigma term is therefore a quantity which directly gives the degree of chiral symmetry breaking. Consequently, its relation to the scattering amplitude represents (taking all the kinematical variables for this process going to zero) the corresponding low-energy theorem in the soft meson limit [5].

A phenomenological procedure, which implies dispersion relations and suitable extrapolations, allows one to extract the sigma term from measured cross sections [5]. However, only estimates of the KN sigma terms (there are two, in correspondence with the two isospin states of the KN system) exist so far, due to poor $K^{\pm}N$ scattering data at low energies and to uncertainties in the phenomenological procedure.

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, but is more sensitive to the kaon–nucleon sigma terms [6].

2. The experimental status

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

The NTP target consists of a pure nitrogen volume at room temperature at 1 bar pressure. This setup, which is presently installed in the DEAR interaction region on DAΦNE, was used to study the background situation there. CCDs (Charge-Coupled Devices) [7, 8] are used for the detection of X-rays in the energy range between 1 keV and 20 keV and are able to separate these events from charged-particle hits. In a first stage the systematic background investigations included three different beam situations without collisions, where the effects of particle losses from the beams are well known (mainly Touschek effect and beam-gas interaction): only electrons or only positrons circulating, and both beams simultaneously circulating but vertically separated in the DEAR interaction point (IP) [9–11]. These measurements are well suitable to test Monte Carlo predictions for the DEAR setup [12, 13]. All these measurements showed good agreement with the results of the DEAR Monte Carlo simulations [9] for different beam intensities and lifetimes.

In December 1999 the first collisions were achieved in the DEAR IP and the charged kaons from ϕ-decay were unambiguously observed with the DEAR kaon monitor. This kaon monitor consists of two scintillation counters placed on opposite sides of the beam pipe at the DEAR IP [14]. ϕ-particles decaying into K^+K^- pairs are expected to give a coincident signal in both scintillators. With this detector the first kaons ever were observed in the DEAR interaction region [14]. Figure 2 shows the obtained time spectrum. The start of the TDC was given by the coincidence signal of the kaon monitor, the stop by the bunch crossing signal. The time sequence was inverted to reduce the dead-time of the detector, which would be caused by the much higher rate of bunch crossings than coincidence counts. Two peaks can be clearly separated, the background peak (*e.g.* Bhabha-scattered beam particles) and the peak of the charged kaons. The kaons take about 1.3 ns longer to reach the detector due to their large mass. Without collisions in the DEAR IP, of course, the kaon peak vanishes and only the background peak is present.

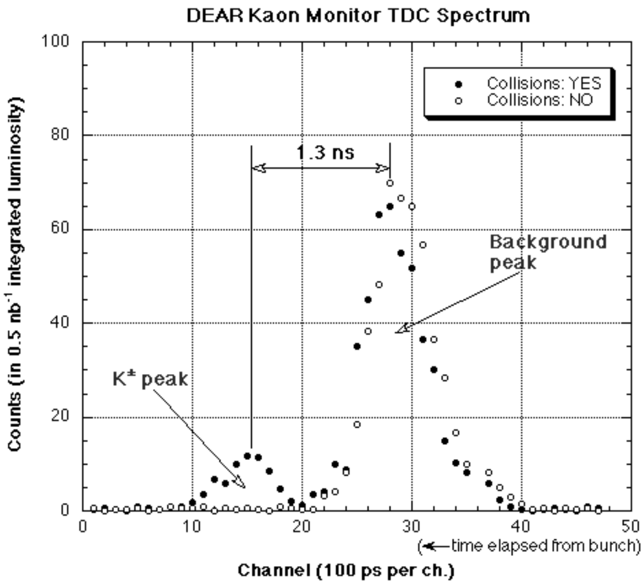

Fig. 2. TDC spectrum of the DEAR kaon monitor showing the first kaons ever observed in the DEAR IP. Filled circles correspond to data taken with colliding beams. The background peak and the kaon peak are separated by 1.3 ns due to the longer time-of-flight of the kaons. Without collisions (open circles) the kaon peak vanishes.

Figure 3 shows the X-ray energy spectrum measured with the CCD detectors in the 2 days of collisions. An overall integrated luminosity of approximately 60 nb^{-1} was collected during this period [15]. The fluorescence X-ray peaks of aluminum (detector and target housing), silicon (CCD chips) and zirconium (kaon entrance window), introduced in order to provide a calibration line at the high-energy side of the spectrum, are visible. The dotted lines indicate the expected positions of the kaonic nitrogen X-rays [16]. No corresponding peaks could yet be identified. Following the Monte Carlo simulation only $\sim$6 counts were expected for the 6-5 transition at the given beam conditions and integrated luminosity, for the other transitions the expected count rate was equal or less [12, 13].

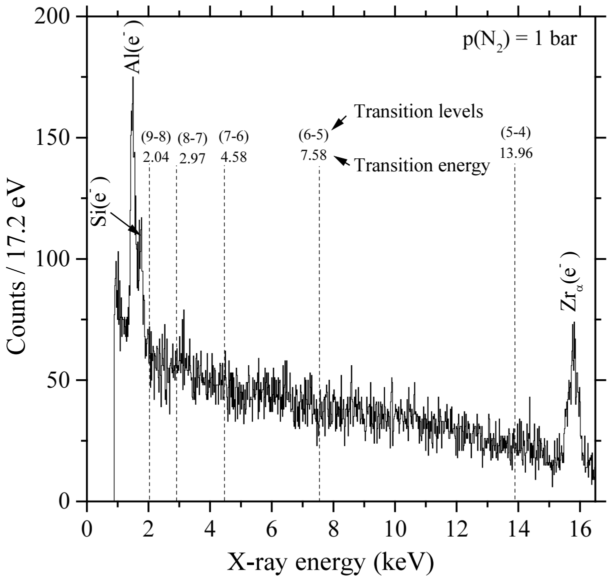

Fig. 3. X-ray energy spectrum obtained with the CCD detectors, colliding beams and a target filled with nitrogen. The fluorescence X-ray lines of the setup materials are visible. The dotted lines indicate the expected positions of the given kaonic nitrogen transitions and their energies. No kaonic nitrogen peak is observable. The peak at the low-energy side of the spectrum is already part of the noise peak of the CCD-detector.

No disturbing X-ray peaks are visible around 6 keV. This shows the purity of the used target and detector materials, especially the purity of the used aluminum, because in common aluminum alloys impurities of iron and manganese are present which would create disturbing fluorescence peaks at 5.9 keV and 6.4 keV.

The background in the DEAR interaction region was investigated also for the case of colliding beams by analyses of the number of clusters counted in the CCD detectors. After normalizing the recorded background to beam currents and lifetimes [9] no significant difference was found for colliding and non-colliding beams; for the latter the beam bunches were circulating on a central orbit, but separated in time.

No difference in the background rates was found if the beam current was split into 23 or 40 bunches [15].

The ratio between X-rays in the region of interest around 6 keV and clusters was found to be constant at $\sim 8\times 10^{-4}$ for all investigated beam conditions. This reflects the fact that background X-rays originate from the same source as cluster events [9, 15, 17]. Counting clusters therefore allows a precise background measurement within a short time and with high statistics.

Additionally to the shielding of the detectors and the target cell two lead walls were placed on both sides of the interaction region, outside the quadrupole magnets. Their shielding factor was measured to be 2.4 [15,17] in agreement with the Monte Carlo simulation. Any shielding which reduces the background is of paramount importance for the measurement of the kaonic X-ray lines.

The agreement between simulation and measurement confirms our understanding of the experimental setup in the environment of the DEAR interaction region and strengthens our confidence that the DEAR configuration can indeed reach the planned challenging level of precision.

3. Summary

The first collisions were achieved in the DEAR IP and the first kaons were unambiguously observed by the DEAR kaon monitor. Extensive systematic background studies were performed for non-colliding beams where the particle losses from the beams are well understood. The background situation in the DEAR interaction region is reproduced well by the DEAR Monte Carlo simulation. It was successfully demonstrated that in the case of collisions X-rays can be extracted out of the large background without problems by the CCD detectors.

The DEAR experiment combines newly available techniques to initiate a renaissance in the investigation of the badly understood low-energy kaon–nucleon interaction. It should stimulate theorists to perform the many needed, but still undone calculations. DEAR is regarded to have the potential for a breakthrough in the low-energy kaon–nucleon phenomenology and should give a precision test for theories of chiral symmetry breaking.

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