The DEAR Experiment at DAΦNE

presented by C. Petrascu on behalf of the DEAR Collaboration:

W.H. Breunlich, M. Cargnelli, B. Gartner, R. King, J. Marton, J. Zmeskal
Institute for Medium Energy Physics, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria

G. Beer, A.C. Sanderson
Univ. of Victoria, Dept. of Physics and Astronomy, P.O. Box 3055 Victoria, BC V8W 3P6, Canada

S. Bianco, A.M. Bragadireanu*, F.L. Fabbri, C. Guaraldo, M. Iliescu*, B. Lauss†
V. Lucherini, C. Petrascu*
INFN - Laboratori Nazionali di Frascati C.P. 13, Via E. Fermi 40, I-00044 Frascati, Italy

M. Bregant, E. Milotti, E. Zavattini
Univ. degli Studi di Trieste, Dip. di Fisica and INFN Sezione di Trieste, Via A. Valerio 2, I-34127, Trieste, Italy

T. Ishiwatari, M. Iwasaki, D. Tomono, T. Yoneyama
Tokyo Institute of Technology, 2-12-1 Ookayama Meguro, Tokyo 152, Japan

R.S. Hayano
Univ. of Tokyo, Dept. of Physics, 7-3-1 Hongo, Bunkyo, Tokyo 113, Japan

S.N. Nakamura
Inst. of Physical and Chemical Research (RIKEN), 2-1 Hirosawa, Wako, Saitama 351-01, Japan

T. Koike
KEK, High Energy Accelerator Research Organization, Tanashi Campus 3-2-1 Midori, Tanashi, Tokyo 188, Japan

T. Ponta
Inst. of Physics and Nuclear Engineering "Horia Hulubei", Dept. of High Energy Physics, P.O. Box MG-6 R-76900 Magurele, Bucharest, Romania

M. Augsburger, D. Chatellard, P. Knowles, F. Mulhauser, L.A. Schaller, L. Schellenberg, H. Schneuwly
Univ. de Fribourg, Inst. de Physique, Bd. de Perolles, CH-1700 Fribourg, Switzerland

J.-P. Egger
Univ. de Neuchatel, Inst. de Physique, 1 rue A.-L. Breguet, CH-2000 Neuchatel, Switzerland

T.M. Ito, R. Seki**
W.K. Kellogg Radiation Laboratory California Institute of Technology, Pasadena, CA 91125, USA
** *Department of Physics and Astrophysics, California State University, Northridge, CA 91330, USA*

---

*on leave of absence from Inst. of Physics and Nuclear Engineering "Horia Hulubei", Dept. of High Energy Physics, P.O. Box MG-6 R-76900 Magurele, Bucharest, Romania

†on leave of absence from Institute for Medium Energy Physics, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria

Abstract

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 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, with the aim of obtaining a precise determination of the isospin-dependent kaon-nucleon scattering lengths. The final goal is 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 first background results, which are compared with a Monte Carlo calculation.

INTRODUCTION

The low energy kaon-nucleon interaction is still an experimentally largely unexplored field. More than 15 years ago, R.H. Dalitz made the following statement[1]: "The most important experiment to be carried out in low energy K-meson physics today is the definitive determination of the energy level shift in the K^-p and K^-d atoms, because of their direct connection with the physics of the $\bar{K}N$ interaction and their complete independence from all other kinds of measurements which bear on this interaction", statement that can be repeated today.

DEAR (DAΦNE Exotic Atom Research)– one of the first experiments which will collect data at the new ϕ-factory DAΦNE 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[2].

The number of events which DEAR can collect in *one week* with kaonic hydrogen at $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity will surpass by an order of magnitude the current world data set.

DEAR SCIENTIFIC PROGRAM

A kaonic atom is formed when a negative kaon entering a target loses its kinetic energy and 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 is causing a shift in the energies of the low-lying levels from their purely electromagnetic values, whilst the finite 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 better 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 then related to the isospin dependent scattering lengths (a_0 and a_1). 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[4]. The meson-nucleon sigma term is defined[4] as the expectation value of a double commutator of the chiral symmetry breaking part of the strong-interaction Hamiltonian, H_{SB}:

$$\sigma_N^{ba} = i < p|[Q_b^5, [Q_a^5, H_{SB}]]|p > \tag{3}$$

with the proton state $|p >$ of momentum p, Q_a^5 and Q_b^5 representing the axial-vector charges.

The low energy theorem relates the sigma terms to the meson-nucleon scattering amplitude[4]. A phenomenological procedure starting from the experimental scattering amplitudes is then used to determine the sigma terms and, therefore, to measure chiral symmetry breaking[5]. According to an evaluation based on the uncertainities in the phenomenological procedure[6], the sigma terms can be extracted at a level of 20%, by combining the DEAR precision measurement at threshold with the bulk of 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[7].

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].

In order to achieve a balance between high kaon stopping density in the target cell and decreasing x-ray yield due to Stark mixing, a pressurized cryogenic gaseous target has been realized for the measurement of kaonic hydrogen.

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[2].

STATUS OF THE EXPERIMENT

At the date of this paper (October, 1999), no e^+e^- collisions were produced in the DEAR interaction region, and, consequently, no ϕ-production occured. Under these conditions only background studies could be performed. The background relevant for the DEAR experiment - low energy (≤ 20 keV) X rays and ionizing particles - was investigated.

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

A DEAR Monte Carlo simulation was performed in the framework of the CERN simulation package GEANT 3, using an improved version of the 3.21 code to simulate the physical processes involved in the DAΦNE interaction region and in the DEAR setup. In

particular, the behaviour of photons, electrons and positrons must be accurate below 10 keV, the standard cut-off of the GEANT package[2].

The observed energy spectra do not show any signal of unwanted structure. This proves the cleanness of the used construction materials. The number of x-ray events (single-pixel hits) and of clusters (multi-pixel events), the latter corresponding to particles hitting the active area of the CCD detector, were observed. At the present status of the accelerator the most important background comes from Touschek scattering[9] with a contribution from beam-gas interaction[10].

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. Hence one can conclude that, with respect to the expected background and, therefore, to the control of the statistical error, the configuration chosen for the measurement of the strong interaction shifts and widths in kaonic hydrogen and kaonic deuterium will reach the planned challenging level of accuracy.

Once the machine will deliver kaons in the DEAR interaction region with an acceptable luminosity and under good vacuum conditions, kaonic nitrogen lines with the NTP target will be measured. Then the cryogenic target equipped with sixteen CCD-22 chips will be installed. The goal with this setup is a 1% measurement of the shift and a few percent measurement of the width of the K_α line in kaonic hydrogen, followed by the first observation of the shift and width in kaonic deuterium.

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 of kaonic deuterium. In this way the the $\bar{K}N$ isospin dependent scattering lengths will be determined at a percent level precision, revitalizing the field of low-energy kaon-nucleon interaction. These observations will then allow the determination of the kaon-nucleon sigma terms, which will reveal the degree of chiral symmetry breaking and give an indication of the strangeness content of the proton.

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

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

REFERENCES

1. R.H. Dalitz *et al.*, Proceedings of the *Conference on Hypernuclear and Kaon Physics*, ed. by B. Povh, Max–Plank Institute Report MPI H–1982–V20, p.201 (1982).
2. S. Bianco *et al.*, "The DEAR case", LNF-98/039 (1998), to be published in Rivista del Nuovo Cimento.
3. S. Deser *et al.*, Phys. Rev. **96**, 774 (1954);
   T.L. Trueman, Nucl. Phys. **26**, 57 (1961);
   A. Deloff, Phys. Rev. **C13**, 730 (1976).
4. E. Reya, Rev. Mod. Phys **46**, 545 (1974);
   H. Pagels, Phys. Rep. **16**, 219 (1975).
5. E. Reya, Phys. Rev. **D7**, 3472 (1973).
6. B. Di Claudio *et al.*, Lett. Nuovo Cimento **26**, 555 (1979);
   A.D. Martin and G. Violini, Nuovo Cimento **30**, 105 (1981).
7. R.L.Jaffe and C.L. Korpa, Comments Nucl. Part. Phys. **17**, 163 (1987).
8. C. Petrascu, "Monte Carlo calculation for the new NTP DEAT setup", DEAR Technical Note IR-12 (February 3, 1999).
9. S. Guiducci, in *Proceedings of the 5the EPAC'96 Conference* Eds. S. Myres *et al.*, Institute of Physics Publishing, Bristol and Philadelphia, p.1365 (1996);
10. S. Guiducci and M.A. Iliescu, LNF-97/002 (IR) (1997).