PROCEEDINGS OF SCIENCE

Kaonic X-ray experiments at DAFNE using SIDDHARTA

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The $\overline{K}N$ system at rest makes a sensitive testing ground for chiral SU(3) symmetry in QCD, especially for the explicit symmetry breaking induced by the relatively large mass of the strange quark.
At the DAΦNE electron-positron collider of Laboratori Nazionali di Frascati we study kaonic atoms, taking advantage of the low-energy kaons from Φ-mesons decaying nearly at rest. The low-energy antikaon-nucleon interaction in kaonic hydrogen and kaonic deuterium can be investigated under favorable conditions.
The DEAR (DAΦNE Exotic Atom Research) experiment at LNF delivered the most precise data on kaonic hydrogen up to now. DEAR and its follow-up experiment SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) are using X-ray spectroscopy of kaonic atoms to measure the strong interaction induced shift and width of the ground state. SIDDHARTA will be the first experiment on kaonic deuterium ever, and kaonic hydrogen will be remeasured with greatly improved precision.
From the shift and width in K^-p and K^-d the isospin-dependent antikaon-nucleon scattering lengths can be determined, quantities essential as constraints for low-energy QCD.

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1. Kaonic atoms in low energy QCD

Low energy phenomena in strong interaction can not (yet?) be described in terms of quarks and gluons. Instead, effective field theories are used that contain the appropriate degrees of freedom to describe physical phenomena occurring at a chosen length scale, but ignore the substructure and the degrees of freedom at shorter distances (corresponding to higher energies). Chiral perturbation theory was extremely successful in describing systems like pionic atoms, unfortunately it is not applicable for the kaonic systems. This is due to presence of resonances like the Λ(1405), only slightly below the reaction threshold.

There are however non-perturbative coupled-channel techniques based on the driving terms of the chiral effective Lagrangian which proved to be useful. They generate the Λ(1405) dynamically as a $\overline{K}N$ quasibound state and as a resonance in the $\pi\Sigma$ channel. A general feature of the theory in this field is that it relies heavily on input from experimental data. The data comes from kaon scattering experiments, atomic x ray measurements and the energy and width of known resonances. The existing data on low energy KN and $\overline{K}N$ scattering are rare, poor in statistics and conflicting, furthermore the extrapolation to zero energy introduces model dependencies.

The kaonic atom experiments deliver input for theory and are also tools to test the ability of theoretical models to accommodate the set of experimental values. The vividness of the field was stimulated by recent and ongoing experimental work. For some of the newer theoretical works see: [3] [4] [6] [9] [5]

To extract the isospin dependant $\overline{K}N$ scattering lengths, in addition to kaonic hydrogen a measurement of kaonic deuterium is necessary, which is the central goal of our experiment.

Furthermore the understanding of the $\overline{K}N$ interaction at threshold is important for the search for kaon nuclear clusters as predicted by the model of Akaishi and Yamazaki [8]. The existence of these kaonic clusters is still controversial, various new experiments are currently being planned throughout the world, at LNF the AMADEUS experiment [12].

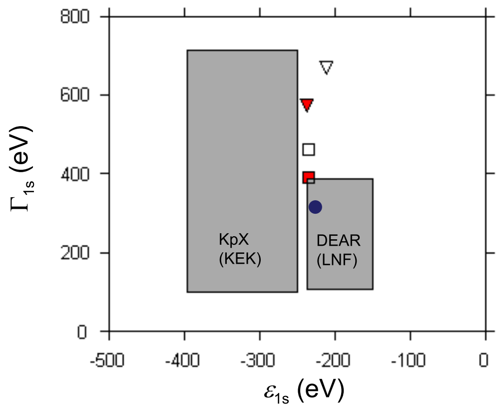

Figure 1: Shift and width of K$^-$p: experimental results [1] [2] are given by the gray boxes. The open triangle denotes the value in [3] if the authors apply the Deser formula [7] on scattering lengths derived from a fit using scattering data, branching ratios, the $\pi\Sigma$ mass spectrum and the kaonic atom data from DEAR; the filled triangle gives the value when they include isospin breaking corrections [4]. Their fit restricted to the DEAR data results in the open and filled square respectively. The dot gives the result from [9]

2. Experimental program

A kaonic atom is formed when a negative kaon enters a medium, looses its kinetic energy through ionization and excitation of the atoms and molecules and eventually is captured, replacing the electron, in an excited orbit (n $\simeq$ 25). Via different cascade processes (Auger transitions, 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. The 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.

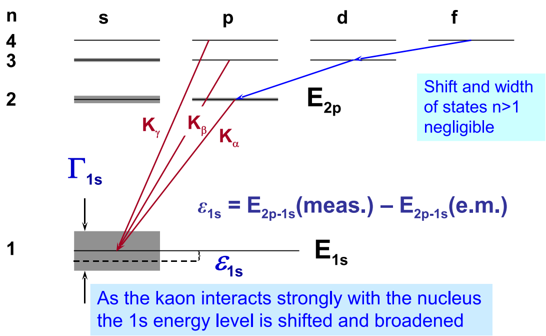

Figure 2: Schematic view of the energy levels of kaonic hydrogen showing the shift and width due to strong interaction

In a previous experiment at LNF (DEAR) we obtained the most precise results for kaonic hydrogen existing up to now. [2]. See fig.1 for a compilation of experimental and theoretical results, fig.2 to illustrate the shift and width of transitions in kaonic atoms. The precision obtained in DEAR was clearly limited by the poor signal to background ratio, so for improved experiments, especially for kaonic deuterium where the signal is expected to be 10 times smaller as compared to kaonic hydrogen, an other experimental technique had to be developed: soft-x-ray detectors with good energy and timing resolution, high counting rate capability and enough robustness to be operated in the radiation environment of an accelerator. This is the SIDDHARTA project (Silicon Drift Detectors for Hadronic Atom Research by Timing Application)

The SDD chips developed by the company PNsensor and the MPI for extraterrestrial physics within the project have a nearly square structure with an active area of 1 cm^2 and a thickness of 450 μm. Three of these structures are integrated on one chip, 2 chips make up a SDD detector module. We will use 216 cm^2 of SDDs and 2 x 3 trigger scintillators to tag on the charged kaons.

Since the soft X-ray background at DAΦNE originates almost entirely from electromagnetic showers from lost beam particles as was seen in DEAR, by demanding a coincidence of the X-ray with the nearly back-to-back emitted charged kaons (See fig. 3) we will get much cleaner spectra. Practically only charged kaon correlated background will remain.

Silicon Drift Detectors (SDDs) are based on the principle of sideward depletion introduced by Gatti and Rehak [11]. In an advanced SDD design optimized for X-ray spectroscopy there is no field-free region, the whole volume is sensitive to the absorption of ionizing radiation. Each

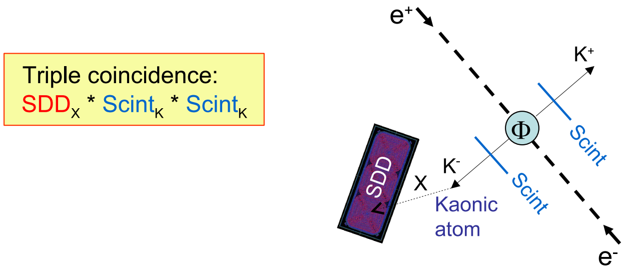

Figure 3: Scheme of the triggered detection system for kaonic X-rays.

electron generated in this volume has to fall down to the point of lowest potential energy, which is the anode in the center of the front side. The small value of the anode capacitance (which is almost independent of the detector area) results in a large amplitude and a short rise time of the output signal. Compared to conventional photodiodes the SDDs can be operated at higher counting rates and yield a much better energy resolution.

The kaonic atom experimental program using these SDDs will be starting at LNFrascati in 2007 with test measurements.

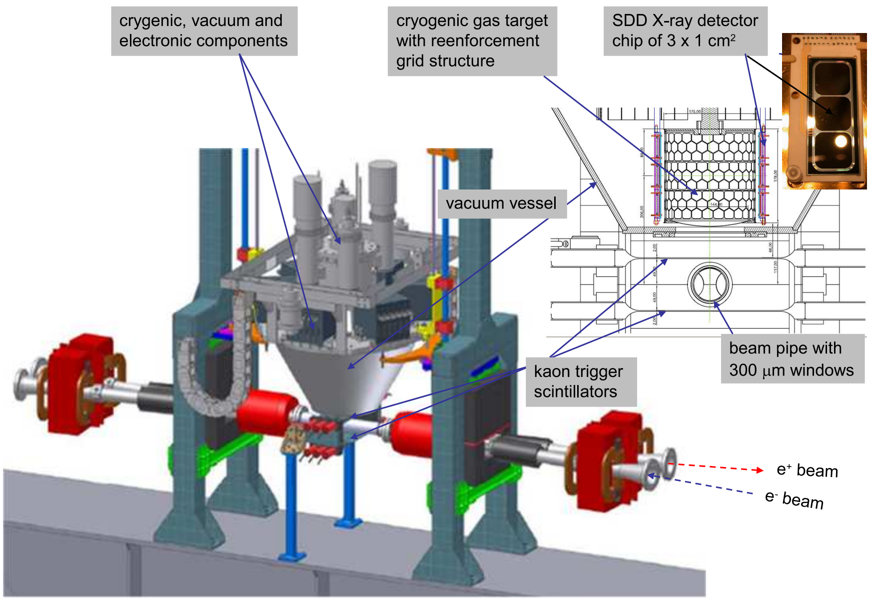

Figure 4: The planned SIDDHARTA setup, 3d view, drawing, photo of SDD

We will use a cryogenic gas target with about 0.03 of liquid hydrogen density. An overview of the setup is shown in fig.4. A simulation of the expected signal and background and the obtainable precision for extracting the shift and width of kaonic deuterium are shown in fig.5 for an integrated luminosity of 600 pb^{-1}. This first-time-ever result and a renewed measurement of kaonic hydrogen with greatly improved precision will allow to feed the low energy QCD descriptions with precise data and allow a stringent test of the understanding of chiral symmetry breaking.

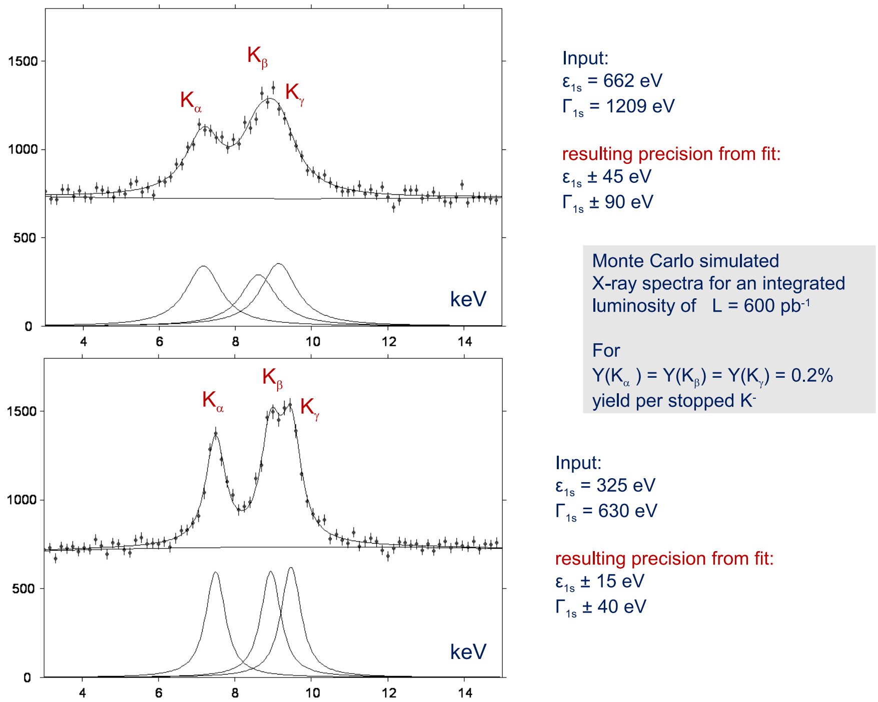

Figure 5: Monte Carlo simulation of the kaonic deuterium experiment, assuming background intensities as measured in DEAR. Note the good background suppression resulting in a signal/background ratio of about 1:1. Input for shift and width: from [5] upper graph, from [10] lower graph.

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