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Evidence for πK-atoms with DIRAC

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A B S T R A C T

We present evidence for the first observation of electromagnetically bound $\pi^\pm K^\mp$-pairs (πK-atoms) with the DIRAC experiment at the CERN-PS. The πK-atoms are produced by the 24 GeV/c proton beam in a thin Pt-target and the $\pi^\pm$ and $K^\mp$-mesons from the atom dissociation are analyzed in a two-arm magnetic spectrometer. The observed enhancement at low relative momentum corresponds to the production of 173 ± 54 πK-atoms. The mean life of πK-atoms is related to the s-wave πK-scattering lengths, the measurement of which is the goal of the experiment. From these first data we derive a lower limit for the mean life of 0.8 fs at 90% confidence level.

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πK-scattering
Chiral perturbation

1. Introduction

The study of electromagnetically bound hadronic pairs is an excellent method to probe QCD at very low energy. Opposite charge long-lived hadrons such as pions and kaons can form hydrogen-like atoms bound by the Coulomb interaction. The strong interaction leads to a broadening of the atomic levels and dominates the lifetime of the atom.

Pion–pion interaction at low energy, constrained by the approximate 2-flavour SU(2) (u, d) chiral symmetry, is the simplest and well understood hadron–hadron process [1–3]. The observation of $\pi^+\pi^-$-atoms ($A_{2\pi}$) was reported in Ref. [4] and a measurement of their mean life in Ref. [5].

The low energy interaction between the pion and the heavier (strange) kaon is a tool to study the more general 3-flavour SU(3) (u, d, s) structure of hadronic interaction, which is not accessible in $\pi\pi$-interactions. A detailed study of πK-interaction provides insights into a potential flavour (u, d, s) dependence of the crucial order parameter or quark condensate in Chiral Perturbation Theory (ChPT) [6].

A measurement of the πK-atom ($A_{\pi K}$) lifetime was proposed already in 1969 [7] to determine the difference $|a_{1/2} - a_{3/2}|$ of the s-wave πK-scattering lengths, where the indices 1/2 and 3/2 refer to the isospin of the πK-system. The $\pi^\pm K^\mp$-atom decays predominantly by strong interaction into the neutral meson pair $\pi^0 K^0$ ($\pi^0 \overline{K}^0$). The decay width of the πK-atom in the ground state is given by the relation [7,8]:

$$\Gamma(A_{\pi K}) = \frac{1}{\tau_{1S}} = \frac{8}{9}\alpha^3\mu^2 p^* |a_{1/2} - a_{3/2}|^2 (1+\delta). \tag{1}$$

τ_{1S} is the lifetime of the atom in the ground state, α the fine structure constant, μ the reduced $\pi^\pm K^\mp$ mass, and $p^* = 11.8$ MeV/c the outgoing K^0 or π^0 3-momentum in the πK center-of-mass system. The term $\delta \simeq (4 \pm 2)\%$ [8] accounts for corrections, due to isospin breaking and the quark mass difference $m_u - m_d$. Hence a measurement of $\Gamma(A_{\pi K})$ provides a value for the scattering length $|a_{1/2} - a_{3/2}|$. The mean life of πK-atoms is predicted to be 3.7 ± 0.4 fs [8].

The width $\Gamma(A_{\pi K})$ can also be determined from the s-wave phase shifts obtained from πK-scattering, i.e. from the interaction of kaons with nucleons. The s-wave phase shifts are, however, poorly known due to the absence of data below 600 MeV/c and, correspondingly, the uncertainties in $a_{1/2}$ and $a_{3/2}$ are substantial. The overall interaction is attractive (attractive in the isospin 1/2 and repulsive in the 3/2 state). The Roy–Steiner equations lead, with the available scattering data, to results [9] that are neither consistent with the most precise measurements [10] nor with predictions from ChPT [11].

The method used by DIRAC is to produce pions and kaons with a high energy proton beam impinging on a thin target. Pairs of oppositely charged mesons may interact and form electromagnetically bound systems. Their subsequent ionization in the production target leads to mesons emerging from the target with low relative momentum (thereafter called atomic pairs). The mean life of the πK-atom can then be calculated from the number of observed low-momentum pairs. This method was first proposed in 1985 [12] and was successfully applied to $\pi^+\pi^-$-atoms in Serpukhov on the U-70 synchrotron internal proton beam [4], and with DIRAC-I at the CERN-PS on beam line T8. Data from DIRAC-I lead to a mean life $\tau_{2\pi} = (2.91\pm^{0.49}_{0.62})$ fs for $\pi^+\pi^-$-atoms [5].

Cross sections for $A_{\pi K}$-production have been calculated in Ref. [13]. In this Letter we report on the observation of πK-atoms from the first data with DIRAC-II.

2. Experimental setup

Details on the initial apparatus (DIRAC-I) used to study $\pi^+\pi^-$-atoms can be found in Ref. [14]. A sketch of the modified spectrometer (DIRAC-II) used to collect the πK (and more $\pi\pi$) data is shown in Fig. 1. The 24 GeV/c proton beam **(1)** from the CERN-PS impinges on a 26 μm Pt-target **(2)**. The spill duration is 450 ms with an average intensity of 1.6×10^{11} protons/spill. The proton beam then passes through a vacuum pipe and is absorbed by the beam dump. The secondary particles are collimated through two steel shielding blocks **(3)** and **(7)**, upstream of the microdrift chambers **(4)** and downstream of the ionization hodoscope **(6)**, respectively. They pass through a vacuum chamber **(8)** and are bent by the 1.65 T field of the dipole magnet **(9)**. The two-arm spectrometer is tilted upwards with respect to the proton beam by an angle of 5.7°. Positive particles are deflected into the left arm, negative ones into the right arm.

We now describe in more detail the upgrade which was performed to search for and study πK-atoms [15]. The upstream detectors **(4–6)**, see Fig. 1, were either replaced or upgraded. However, they were not yet fully operational during data taking, and were therefore not used in the analysis presented here. The tracking is performed by drift chambers **(10)** which have a spatial resolution of 85 μm. The vertical hodoscope **(11)** consisting of 20 scintillating slabs with a time resolution below 140 ps is used for timing. The horizontal hodoscope **(12)**, made of 16 horizontal scintillating slabs, is used for triggering by selecting oppositely charged particles with a vertical displacement smaller than 75 mm.

The N_2-Čerenkov detector **(15)** was already used previously to reject electrons and positrons. The refractive index is $n = 1.00029$ and the average number of photoelectrons $N_{pe} = 16$ for particles with velocity $\beta = 1$. The inner part of the original container had to be cut to clear space for the two new Čerenkov detectors needed for kaon identification. Since the momenta of the two mesons originating from the breakup of the πK-atoms are very small in the center-of-mass system, they have similar velocities in the laboratory system, and hence kaons are less deflected than pions. Typical trajectories are shown in Fig. 1.

The heavy gas C_4F_{10}-Čerenkov detectors in both arms **(14)** identify pions but do not respond to kaons nor (anti)protons [16]. Four spherical and four flat mirrors each focus the light towards the phototubes. The alignment of the mirrors was checked with a laser beam [17]. To keep a constant refractive index of $n = 1.0014$, the gas has to be cleaned permanently with a complex recirculating system [18]. The average number of photoelectrons is 28 for particles with $\beta = 1$.

The aerogel Čerenkov detector **(13)** in the left arm identifies kaons and rejects protons [19,20]. Such a detector is required only in the left arm since the contamination from antiprotons in the right arm is small due to their low production rate. The detector consists of three modules. Two modules of 12ℓ each (refractive index $n = 1.015$) cover the relevant momentum range between 4 and 8 GeV/c. The aerogel stacks are 42 cm high and are read out by two 5″-Photonis XP4570 photomutipliers with UV windows. The typical number of photoelectrons is 10 for $\beta = 1$ particles. A third overlapping module with 13ℓ aerogel and $n = 1.008$ cov-