Experimental evidence for $\pi K$-atoms

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Abstract (nr. 710)

We present evidence for the first observation of electromagnetically bound pion-kaon pairs (piK- atoms) with the DIRAC-II experiment at the CERN-PS. The mean life of piK- atoms is related to the s-wave piK-scattering lengths, a measurement of which is relevant to low energy QCD, in particular chiral perturbation theories including the s-quarks. The atoms are produced by a 24 GeV/c proton beam in a thin Pt-target and the dissociated pions and kaons analyzed in a two-arm magnetic spectrometer. The observed enhancement at low relative momentum corresponds to the production of 173 +- 54 piK-atoms. From these first data we derive a lower limit for the mean life of 0.8 fs at the 90% confidence level.
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\[
\delta = (4.0 \pm 2.2) \%
\]

\[
\Gamma = \frac{1}{\tau} = 8p^* \mu^2 \alpha^3 \left[ \frac{1}{3} (a_3 - a_1) \right]^2 (1 + \delta)
\]

with \( \delta = (4.0 \pm 2.2)\% \) from isospin breaking

\[a_1, a_3: \text{S-wave scattering lengths}
\]

Isospin \((K\pi) = 1/2, 3/2\)

Coulomb force:
- \( E\,(1s) = 2.9 \text{ keV} \) non relativistic
- \( r_B\,(1s) = 250 \text{ fm} \)

Strong force:
- \( \Delta E \approx 10 \text{ eV} \) stronger binding
- \( \pi^+K^+ \) decays to \( \pi^0K^0 \):
  prediction: \( \tau \approx 3.7 \text{ fs} \)

\(73'000 \text{ revolutions}\)

\((\pi^+K^- \) decays to \( \pi^0\bar{K}^0\))

K\(\pi\)-atoms not seen before, therefore theoretical prediction for \( \tau \) from scattering lengths:

\[
\text{reduced mass}
\]

\[
\Gamma = \frac{1}{\tau} = 8p^* \mu^2 \alpha^3 \left[ \frac{1}{3} (a_3 - a_1) \right]^2 (1 + \delta)
\]

\[a_1, a_3: \text{S-wave scattering lengths}
\]

Isospin \((K\pi) = 1/2, 3/2\)
$a_1 - a_3 = 0.269 \pm 0.015$

all data on $K\pi \rightarrow K\pi$ (KN scattering)

$\pi\pi \rightarrow KK$, unitarity, etc…

$\tau = 3.7 \pm 0.4$ fs

realistic: $1 < \tau < 5$ fs !!

Motivation for a measurement of $\tau$: better $|a_1 - a_3|$ data (10%):

$10\%$ means $20\%$ on $\tau$

ChPT extended to s-quark

Pionium: $\pi^+\pi^-$ atoms: [u,d-quarks] very good agreement between ChPT and lifetime measurements from the DIRAC-experiment at CERN. B. Adeva et al., PLB 619 (2005) 50
We measure the nr. of surviving atoms by ionizing them in a thin target.

24 GeV/c p on 28 µm Pt

Particle identification by Cherenkov radiation:

- $\pi K p$ (absent)
- $K p$ (absent)
- $K$ (absent)
- $e$ (absent)

- $N_2$ (1 bar, veto)
- Heavy gas ($C_4F_{10}$, veto)
- Aerogel (Uni Zürich)
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Challenge: large detector (40 cm long) with low light yield (+UV absorption)

Design (novel development) of aerogel counters

Kaon spectrum

K+ signal wanted but not p signal... 
N(p) >> N(K)

Photoelectrons for 10 cm thickness: 
(Measurement with cosmic muons)

n= 1.008

n= 1.015

2 indices at high momenta (small angles)
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**Trick 1:**
Light yield

- PM
- Increasing thickness in center
- Position [cm]

**Trick 2:**
Wavelength shifter: TPB dissolved in chloroform on Tetratex
n=1.008

Beam data:

- Number of photoelectrons in n=1.015 (from K- spectrum with reversed polarity)
- 94% efficiency for K
- 93% rejection for p

Number of photoelectrons in n=1.015
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14 liters \( n=1.008 \) from Novosibirsk
(238 tiles, 3 €/cm\(^3\)) \((\rho = 0.039 \text{ g/cm}^3)\)

24 liters \( n=1.015 \) from Panasonic
(248 tiles, 1.6 $/cm^3)

\( n = 1.015 \)

40 cm
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- Look for an excess of pairs with very low relative momentum $Q_L$
- A large number of atomic pairs means a long mean life of the atom
1) choose $p\pi$ events with $p$ misidentified as $K^+$ (using accidentals)

2) choose $\pi^+\pi^-$ events with $\pi^+$ misidentified as $K^+$

Accidental (time uncorrelated) pairs can be used to describe the smooth background in $Q_L$

3) Enhancement due to Coulomb $p\pi$ pairs would be shifted out of $Q_L \sim 0$ region
• The non-Coulomb pairs are well described from accidentals (c1)
• The Coulomb pairs must be simulated (c2)

173 ± 54 pairs, 3.2σ

Significant?

147 ± 36 pairs consistent!
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Breakup probability and mean life $\tau$

$$P_{br} = \frac{\text{number of atomic pairs}}{\text{number of produced atoms}} (\text{calculated from the number of Coulomb pairs})$$

$$P_{br} = 64 \pm 25\%$$

$\tau > 0.8 \text{ fs} @ 90\% \text{ C.L.}$

$$|\Delta a| = |a_1 - a_3| < 0.58 \text{ m}_{\pi^{-1}}$$

- πK-atoms have been observed
- more data with 98 μm Ni-target (lower $P_{br}$, but rising)
- goal: 20% error on $\tau = 10\%$ error on $|\Delta a|$
We have presented the first evidence for the production of $K\pi$ atoms

$173 \pm 54$ $K\pi$ atoms
Significance increased by the observation of Coulomb pairs

A lower limit on the mean life is established with CL 90%: $\tau > 0.8$ fs

The goal of the DIRAC-II experiment is to measure the mean life with a precision of 20%
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Participants

80 Physicists from 18 Institutes

- CERN Geneva, Switzerland
- Czech Technical University Prague, Czech Republic
- Institute of Physics ASCR Prague, Czech Republic
- Nuclear Physics Institute ASCR Rez, Czech Republic
- INFN-Laboratori Nazionali di Frascati Frascati, Italy
- Trieste University and INFN-Trieste Trieste, Italy
- University of Messina Messina, Italy
- KEK Tsukuba, Japan
- Kyoto Sangyou University Kyoto, Japan
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