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Exotic atoms by the DIRAC experiment

Collaboration

DIRAC

Abstract content

DIRAC is an experiment which aims to study double-exotic atoms formed by π- and K-mesons to check the QCD predictions. DIRAC is a fixed target experiment which uses the proton beam, extracted from the CERN Proton Synchrotron at 24 GeV/c. Exotic hydrogen-like atoms are generated in relativistic proton-nuclei collisions and later identified through characteristic ("atomic") pairs of mesons with low relative momenta. Atomic pairs originate from the ionization of exotic atoms in collisions with ordinary atoms in thin dense foils. The ionization process is competitive to annihilation of exotic atoms due to strong interaction. Thus the study of exotic atoms reveals parameters of the strong interaction of pions and kaons at low energy. There is an accurate relation between $\pi^+\pi^-$ atom lifetime and a difference of S-wave pion-pion scattering lengths with isospin 0 (a_0) and 2 (a_2). A similar relation connects the lifetime of πK atom to pion-kaon scattering lengths with isospin 1/2 and 3/2. The values of above mentioned scattering lengths are predicted with high precision by low energy QCD theories, i.e. chiral perturbation theory (χPT) and lattice gauge theory (LQCD). Lifetimes of $\pi^+\pi^-$ and πK atoms, predicted by theory, are of the order 10^{-15} s.
In 2017 DIRAC reported the measurement of the πK atom lifetime in the ground state based on statistics of about 350 ionized πK atoms. This lifetime measurement leads to the deduced value of the S-wave isospin-odd πK scattering length $|a_0^-| = \frac{1}{3}|a_{1/2} - a_{3/2}| = (0.072^{+0.031}_{-0.020})M_\pi^{-1}$. Earlier the collaboration measured the $\pi^+\pi^-$ atom (pionium) lifetime with 9% precision.
The DIRAC collaboration collected data towards observation of long-lived (metastable) states of pionium. The observation of long-lived states opens the possibility to measure the energy difference between ns and np states and to determine the value of the combination $(2a_0 + a_2)$ of S-wave $\pi\pi$ scattering lengths. The experiment uses a two-foil method: after production in the beryllium foil, the atoms propagate through a permanent magnetic field to reach the ionization foil, made of platinum. The distance of about 10 cm between foils is large enough for ns-states to vanish due to annihilation. The lifetime of states with $l > 0$ is defined by radiative de-excitation into ns-states, followed by annihilation: typical lifetimes are of the order 10^{-11} s, depending on the atomic state. Only $\pi^+\pi^-$ atoms in states with non-zero angular momentum can get into the ionization foil. We report the observation of long-lived (metastable) states of $\pi^+\pi^-$ atoms and the measurement of their lifetime.

Presenter(s) : ZHABITSKY, Mikhail (Joint Institute for Nuclear Research, Dubna)

Primary author(s) : ZHABITSKY, Mikhail (Joint Institute for Nuclear Research, Dubna)

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