Measurement of $\pi^+\pi^-$ atom lifetime at DIRAC

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The DIRAC experiment aims to measure the lifetime of $\pi^+\pi^-$ atoms in the ground state with 10% precision, using the 24 GeV/c proton beam of the CERN Proton Synchrotron. As the value of the above lifetime of order 10^{-15}s is dictated by a strong interaction at low energy, the precise measurement of this quantity enables to determine a combination of S-wave pion scattering lengths to 5%. Pion scattering lengths have been calculated in the framework of chiral perturbation theory with high precision. Thus the accurate measurement of these values would submit the understanding of chiral symmetry breaking of QCD to a crucial test. The results on the $\pi^+\pi^-$ atom detection and the preliminary estimation of their lifetime are presented.

1. Introduction

Pionium ($A_{2\pi}$) is the hydrogen-like atom consisting of π^+ and π^- mesons. Its lifetime is dominated by the charge-exchange process $\pi^+\pi^- \to \pi^0\pi^0$ and decay width is proportional to the square of the difference between the isoscalar and isotensor S-wave $\pi\pi$-scattering lengths $a_0 - a_2$. The predicted value for the $A_{2\pi}$ lifetime in the ground state, according to the Chiral Perturbation Theory at leading and next-to-leading order in isospin breaking, is of the order of $3 \cdot 10^{-15}$ s [1–3].

The goal of the DIRAC Experiment [4] is to measure the $A_{2\pi}$ lifetime with 10% accuracy in order to determine $|a_0 - a_2|$ with 5% precision in a model independent way [5]. The determination of the S-wave $\pi\pi$-scattering lengths will yield the size of the two-flavour quark condensate [6].

2. Experimental method

The production cross section of $A_{2\pi}$ in the high-energy inclusive processes have been obtained by L.Nemenov [5]. Relativistic $A_{2\pi}$ produced in hadron-nucleus interaction moves in the target material before their decay. The electro-magnetic interactions with the atoms of the medium might, however, lead to the pionium excitation or breakup (ionization). From the knowledge of the atomic interaction cross sections, for a given target material and thickness, one can calculate the breakup probability P_{br} for arbitrary values of the atom momentum and lifetime [7].

"Atomic pairs" produced from the $A_{2\pi}$ breakup have very small relative momentum in their c.m. system $Q < 3$ MeV/c that allows to observe they over the background of pions pairs produced in the free state. Moreover the number of the produced $A_{2\pi}$ can be obtained through the number of free pions pairs. Thus comparing the ratio of detected "atomic pairs" to the number of produced $A_{2\pi}$ with the calculated dependence of P_{br} on τ, one can determine the atom lifetime.

3. The DIRAC apparatus

The DIRAC setup is located at CERN, at the ZT8 beam area of the PS East Hall. It became operational at the end of 1998 and has been collecting data since the summer of 1999, using the 24 GeV/c proton beam extracted from the PS accelerator.

DIRAC is a fixed-target experiment and its apparatus is designed to detect charged pion pairs with high resolution over the pair relative momentum (see Fig.1). It consists of a straight detector section between the target station and the analyzing magnet (2.3 Tm bending power), and of a double arm spectrometer downstream the magnet.

A multi-level trigger system has been designed to select "atomic pairs" from the overwhelming background of uncorrelated $\pi^+\pi^-$ pairs. The Cherenkov, preshower and muon detectors ensure rejection of e^+e^- and $\mu^+\mu^-$ pairs at trigger level. Pairs of $p\pi^-$ are identified by offline analysis of time-of-flight measurements.

4. Experimental results

The number of ionized $A_{2\pi}$ is measured directly from the excess of $\pi^+\pi^-$ pairs with very low relative momentum ($Q < 3$ MeV/c) compared to the expected number of "free" pairs simulated using pairs of accidental coincidences. The Q-distribution of $\pi^+\pi^-$ pairs obtained with the platinum, titanium and nickel targets in 1999–2002 are presented on the Fig.2. The first preliminary result on the lifetime of $\pi^+\pi^-$ atom obtained with the Ni 2000 data are given on the Fig.3.

The DIRAC experiment is collecting statistics to achieve the final goal of measuring the lifetime of pionium with 10% accuracy. A preliminary analysis of data collected two last years with three targets shows the excess of $\pi^+\pi^-$ pairs coming from the breakup of $A_{2\pi}$. By now the total number of the observed "atomic pairs" amounts 5500. A preliminary result in the $A_{2\pi}$ lifetime measurement averaged for Ni and Ti targets is $3.6^{+0.9}_{-0.7} \times 10^{-15}$ s (statistical error only amounts 22%). The accurate determination of systematic errors requires a background measurement. The 10% accuracy on the atom lifetime value will require running beyond 2002.

REFERENCES

1. A. Gall et al., Phys.Lett.B 462 (1999) 335.
2. J. Gasser et al., Phys.Lett.B 471 (1999) 244-250.
3. G. Colangelo et al., Phys.Lett.B 488 (2000) 261-268.
   G. Colangelo et al., Nucl.Phys.B 603 (2001) 125-179.
4. B. Adeva et al., Proposal to the SPSLC, CERN/SPSLC 95-1, SPSLC/P 284, (1994).
5. L.L. Nemenov, Sov.J.Nucl.Phys. 41 (1985) 629.
6. N.H. Fuchs et al., Phys.Lett.B 269 (1991) 183; Phys. Rev. D 47 (1993) 3814.
7. L.G.Afanasyev and A.V.Tarasov: Yad.Fiz. 59 (1996) 2212; Phys.Atom.Nucl. 59 (1996) 2130.

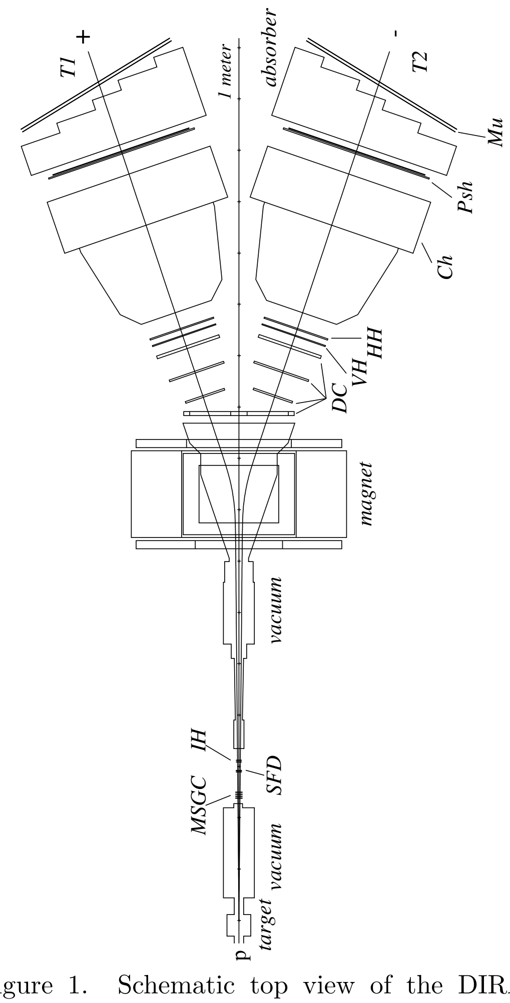


Figure 1. Schematic top view of the DIRAC spectrometer. Moving from the target station toward the magnet there are: four MicroStrip Gas Chambers (*MSGC*), two Scintillating Fiber Detectors (*SFD*) and two Ionization Hodoscopes (*IH*). Downstream the dipole magnet, on each arm of the spectrometer, are located: four modules of Drift Chambers (*DC*), the Vertical and Horizontal Scintillation Hodoscopes (*VH, HH*), the Cherenkov counter (*Ch*), the Preshower detector (*PSh*) and, behind the iron absorber, the Muon detector (*Mu*).

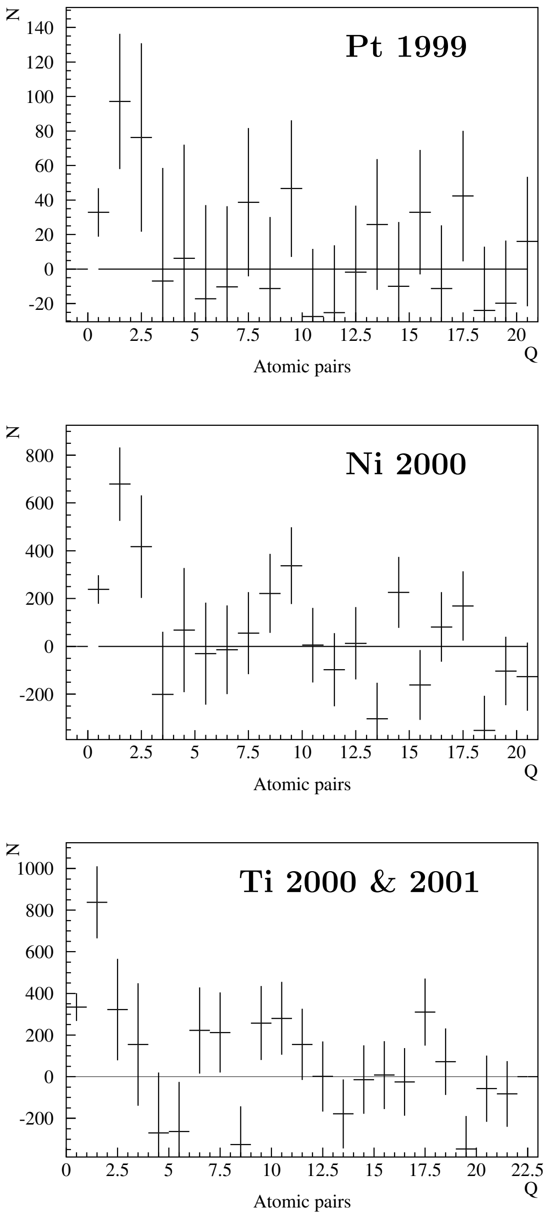
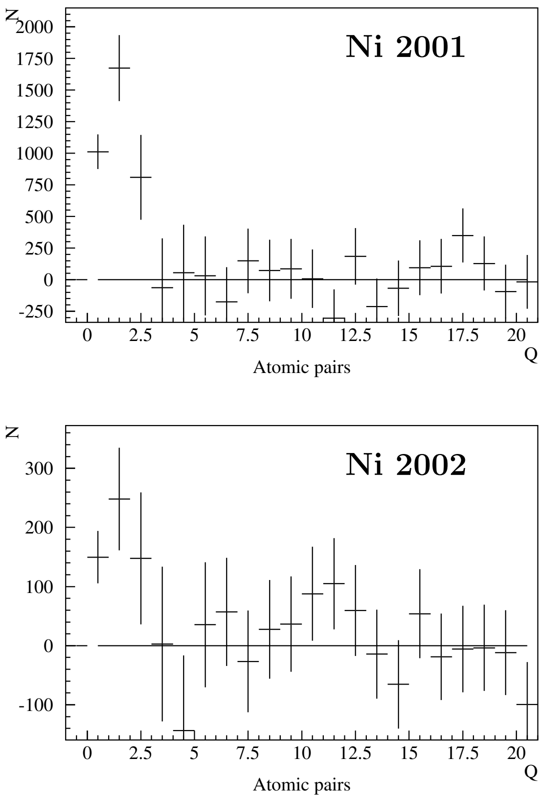


Figure 2. Distributions of the $\pi^+\pi^-$ pair excess over relative momentum for data collected with the platinum, titanium and nickel targets in 1999–2002. The “atomic pairs” are observed as the peaks at low Q.



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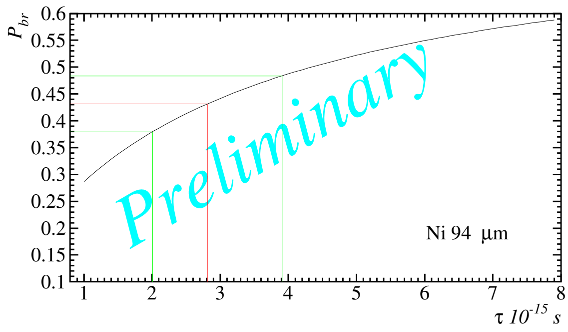

Figure 3. The calculated probability of pionium breakup as a function of its lifetime for the Ni target of 94 μm thick (curve). The measured probability of the pionium breakup obtained form Ni 2000 data is shown with its statistical errors as the horizontal lines. The crossing gives the lifetime value of $\tau = (2.8^{+1.1}_{-0.8}) \cdot 10^{-15}$ s