8 Study of Coulomb-bound πK pairs

C. Amsler, A. Benelli, and J. Rochet

in collaboration with:
CERN, Czech Technical University, Institute of Physics and Nuclear Physics Institute ASCR (Czech Republic), Laboratori Nazionali di Frascati, Messina University, Trieste University, KEK, Kyoto Sangyo University, Tokyo Metropolitan University, IFIN-HH (Bucharest), JINR (Dubna), Skobeltsin Institute for Nuclear Physics (Moscow), IHEP (Protvino), Santiago de Compostela University, Bern University.

(DIRAC Collaboration)

In 2007 we have observed for the first time electromagnetically bound $\pi^{\mp}K^{\pm}$-pairs ($\pi^{\mp}K^{\pm}$-atoms) [1, 2]. The π^+K^--atom is unstable and decays through the strong force into $\pi^0\bar{K}^0$ (while π^-K^+-atoms decay into π^0K^0). The mean life τ, which we intend to measure, is related to the S-wave πK-scattering lengths a_1 and a_3 in the isospin 1/2 and 3/2 states, respectively. The πK-scattering length is of interest to test chiral perturbation theories extended to the s-quark. From the 2007 data sample we reported the observation of 173 ± 54 πK-pairs [1, 2]. This result led to a lower limit for the mean life of πK-atoms of 0.8 fs in the 1s-state, which could be translated into an upper limit of the difference in scattering lengths $|a_1 - a_3| < 0.58\ m_\pi^{-1}$.

The DIRAC experiment was initially designed to study $\pi^+\pi^-$-atoms. Final results for $\pi^+\pi^-$ have been published recently [3]. From a sample of 21'227 $\pi^+\pi^-$ atomic pairs the difference in the isospin 0 and 2 scattering lengths could be measured with a 4% accuracy, $|a_0 - a_2| = 0.2533 \pm 0.0109\ m_\pi^{-1}$. The corresponding mean life is 3.15 ± 0.28 fs. An overview of the DIRAC experiment can be found in ref. [4].

A sketch of the DIRAC spectrometer to collect πK (and also more $\pi\pi$) data is shown in Fig. 8.1. Details can be found in previous annual reports and also in ref. [5]. The 24 GeV/c proton beam from the CERN-PS passes through a thin (100 μm) Ni-target. The secondary particles traverse a scintillation fiber detector (SFD) and a ionization hodoscope (IH) with which the opening angle between pairs of secondaries can be measured. The pions and kaons are analyzed in a double-arm magnetic spectrometer measuring the momentum vectors of two oppositely charged hadrons. Positive particles are deflected into the left arm, negative ones into the right arm. The spectrometer is slightly tilted upwards with respect to the proton beam. Electrons and positrons are vetoed by the N_2-Čerenkov detectors and muons by their signals in scintillation counters behind steel absorbers. Kaons are separated from pions and protons by heavy gas (C_4F_{10}) Čerenkov counters (which fire on pions) and by aerogel Čerenkov counters (which fire on both pions and kaons, but not not on the more numerous protons). Our group has developed and built the 37ℓ aerogel Čerenkov counter [6] and the gas system for the C_4F_{10} counters [7]. The signal from πK-atoms is observed for πK-pairs with a very small relative momentum (typically $|Q_L| <$ 3 MeV/c is the c.m.s system).

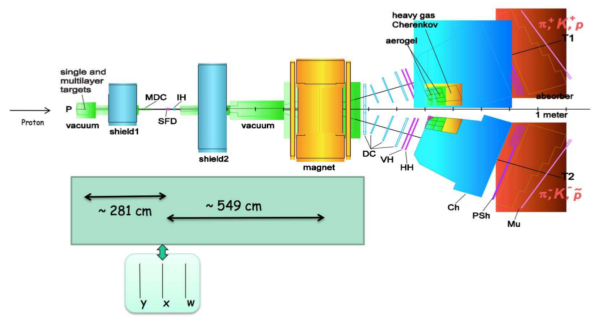

Fig. 8.1 – *Sketch of the upgraded DIRAC-II spectrometer, showing the locations of the Čerenkov counters to identify electrons, pions and kaons. MDC: microdrift chambers, SFD: scintillator fiber detector, IH: ionization hodoscope, DC: drift chambers, VH, HH: vertical and horizontal scintillation hodoscopes, CH: N_2-Čerenkov counter, PSh: preshower, Mu: muon counters.*

In 2007 we used only the detectors downstream of the magnet, but the scintillation fiber detector (SFD) was available for the 2008 – 2010 run to determine the interaction point in the production target with much better precision. The SFD (Fig. 8.2) consists of 3 planes of 205 μm scintillating fibers. Two planes (x- and y-planes) are made of 8 layers each with 480 fibers while the third (w-plane) contains 3 layers of 320 fibers. The fibers are read out in columns of 8, respectively 3 fibers by 30 × 16 Hamamatsu H6568 photomultipliers. The area covered by each plane is about 10 × 10 cm^2 and contributes only 1% radiation length. The timing resolution is 460 ps. Tracks are measured with good resolution (σ = 60 μm) and high efficiency (98%). This leads to a substantial improvement in the resolution on the transverse momentum Q_T (from 3 MeV/c to 1 MeV/c) and also reduces the background.

During 2010 we tuned the Monte Carlo simulation of the SFD and compared with data. A substantial improvement has been achieved (for more details see ref. [8]). Noise, cross-talk between fibers, efficiency and background tracks have been inserted into the simulation. The simulated data were then submitted to the same analysis code as the experimental data. To study the performance of the SFD we used in turn two planes (e.g. y and w). The reconstructed tracks were then extrapolated to the third plane (e.g. x, see Fig. 8.3) and the measured hits compared with the predicted ones.

The excellent agreement between data and Monte Carlo is illustrated in Fig. 8.4 showing both the probability to find a hit within ± 1 mm from the extrapolated trajectories and the probability to find both hits in the third plane if two tracks are found in the first two planes. The loss in the center is due to a hardware suppression algorithm of fiber cross-talks. The ionization hodoscope can be used to reduce background and select true double hits. From these plots one obtains track resolutions for the 2008-9-10 data of σ = 220 μm for single tracks and 550 μm for double tracks.

Thus the SFD performed as expected from simulations and we could proceed with the analysis of the data using the three planes. We obtain a Q_x

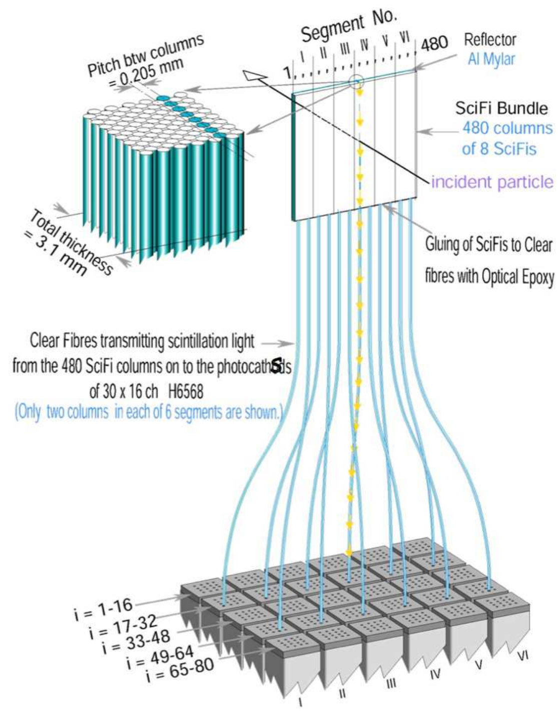

Fig. 8.2 – *Sketch of the SFD (x- and y-planes).*

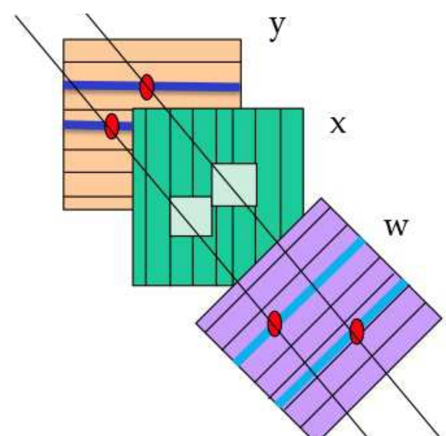

Fig. 8.3 – *Measurement of the SFD performance with 2 out of 3 planes.*

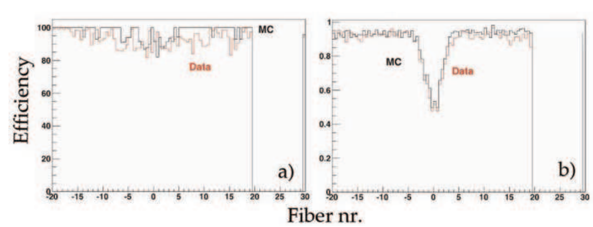

Fig. 8.4 – *a) Probability to find one hit in the x-plane around the extrapolated track; b) probability to find both hits for two tracks.*

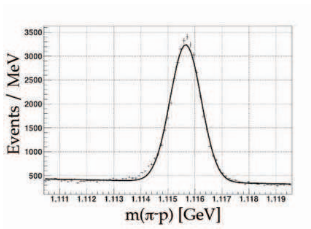

FIG. 8.5 – *$\pi^- p$ mass distribution showing the Λ signal.*

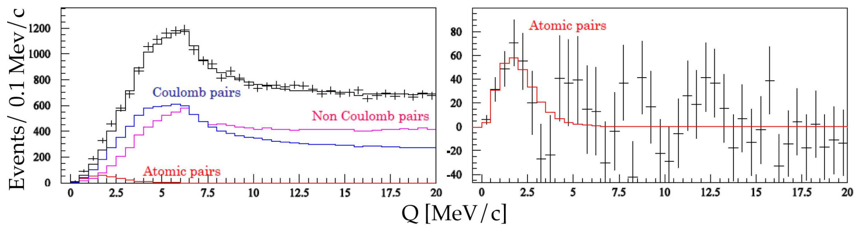

FIG. 8.6 – *$\pi^- K^+ + \pi^+ K^-$ events as a function of relative momentum Q. The enhancement at low Q in the right plot is due to πK atomic pairs.*

and Q_y resolution better than 0.5 MeV/c and reconstruct the momentum transfer Q between the kaon and the pion with a resolution of 1 MeV/c. As a calibration tool and momentum resolution measurement we reconstruct Λ decays into $\pi^- p$. The mass distribution shown in Fig. 8.5 confirms the correct energy scale, the value for the Λ mass 1115.7 $\pm$ 0.5 MeV being fully compatible with the PDG value (1115.683 $\pm$ 0.006 MeV).

Clean πK events are selected by the SFD and IH detectors to resolve the ambiguity of single and double tracks in the upstream part of the apparatus (Fig. 8.1). Particle identification is performed using the heavy gas and aerogel Čerenkov detectors. The precise time difference between the two tracks from the atomic candidates pairs is achieved using the VH. Events with muons or electrons are eliminated using the nitrogen Črenkov and muon detectors. We finally select events with relative transverse and longitudinal momenta between the two mesons of $Q_T < 4$ MeV/c and $|Q_l| < 20$ MeV/c, repectively. Figure 8.6 (left) shows the preliminary distribution of $\pi^- K^+ + \pi^+ K^-$ events as a function of relative momentum Q (points with error bars).

The fit results are shown in red (atomic pairs), blue (Coulomb pairs), magenta (non-Coulomb pairs). The sum of Coulomb and non Coulomb pairs is displayed in black. The contribution from atomic pairs is shown in red in Fig. 8.6 (right). We find 277 $\pm$ 52 atomic pairs to be compared with 173 $\pm$ 54 from the 2007 run. However, in 2007 our goal was the first observation of πK-atoms and hence a target was chosen (Pt) for which the production cross section was high. The breakup probability for πK-atoms as a function of mean life (53% for 3.7 fs) is flattening off above ~ 4 fs. Therefore we could only give a lower limit for the mean life of πK-atoms. In 2008-9-10 we used a Ni-target which produces fewer atoms but for which the dependence between breakup probability and mean life is described by a steeper function, thus allowing a more accurate measurement of the mean life.

The final analysis of the 2008 – 2010 data is in progress. Due to a slow degradation of the light ($n = 1.008$) aerogel with time (probably due to humidity), we could only use the $n = 1.015$ aerogel and had therefore to restrict the maximum kaon momentum to 5.5 GeV/c, thus unfortunately reducing statistics. Also, a recalibration of the preshower detector (Psh) is required to suppress background from electron-positron pairs which is significant in the new data. Data taking for the DIRAC experiment will be completed in autumn 2012.

[1] B. Adeva *et al.* (DIRAC Coll.), Phys. Lett. **B 674** (2009) 11.

[2] Y. Allkofer, PhD Thesis, University of Zurich (2008).

[3] B. Adeva *et al.* (DIRAC Coll.), Phys. Lett. **B 704** (2011) 24.

[4] J. Schacher, CERN courier, March 2012, p. 24.

[5] B. Adeva *et al.* (DIRAC Coll.), Nucl. Instrum. Methods in Phys. Res. **A 515** (2003) 467.

[6] Y. Allkofer *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 582** (2007) 497; Y. Allkofer *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 595** (2008) 84. C. Amsler, Proc. of Science PoS EPS-HEP (2009) 078.

[7] S. Horikawa *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 595** (2008) 212.

[8] A. Benelli, dirac.web.cern.ch/DIRAC/talk/talk1101.pdf .