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An update of the DIRAC result on the pion-pion $|a_0 - a_2|$ scattering length

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A considerable improvement on the precision of the DIRAC measurement on the pionium lifetime was achieved after the analysis of a dedicated measurement on multiple scattering in the set-up, especially when compared to the published lifetime [1] from a subset of data. A further equally important improvement is obtained by including more data in the analysis. Preliminary values for the new precision show that an accuracy for the lifetime of 10% can be reached with existing data.

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1. Introduction

The DIRAC experiment at CERN aims at measuring the lifetime of the pionium atom ($\pi^+\pi^-$) in its ground state with an accuracy of 10% in order to deduce the $\pi\pi$ scattering length difference $|a_0 - a_2|$ with an accuracy of 5%. A first step towards this goal was the publication of the lifetime deduced from a subset of measured data [1]. The result then was hampered by apparent inconsistencies in the shape of the signal from the break-up of the atoms in the target, due to non-understood multiple scattering in the set-up of the experiment including the target itself. As a consequence we were unable to reliably simulate the shape of the signal in the transverse component Q_T of the $\pi^+\pi^-$ relative momentum Q. The longitudinal component Q_L is far less affected by multiple scattering and was used to deduce the signal strength. In the fitting process the Q-distribution was used as a constraint.

The fact that we used only Q_L distributions for fitting had two important consequences:

- The statistical error was unnecessarily large as the Q_T component was not involved as a second independent measurement.
- Some systematic errors which are especially sensitive on Q_L could be reduced by including Q_T or just fitting Q distributions.

In the following we will shortly sketch the multiple scattering measurement and then discuss improvements.

2. Measurement of the multiple scattering

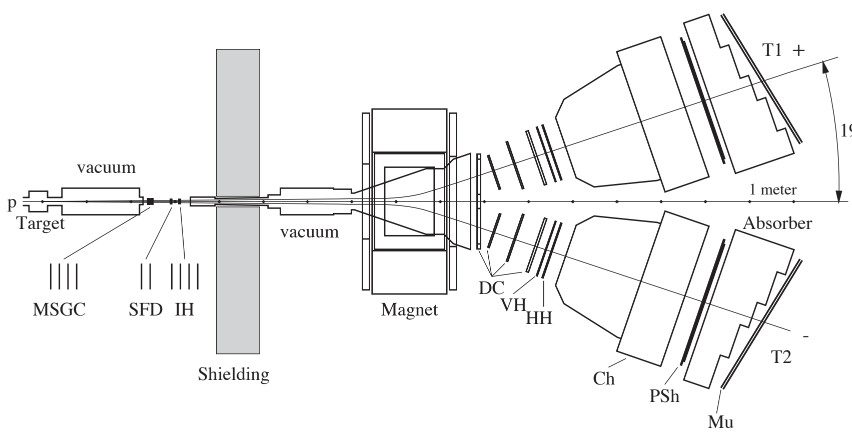

Figure 1: Schematic top view of the DIRAC spectrometer. Upstream of the magnet: target, microstrip gas chambers (MSGC), scintillating fiber detectors (SFD), ionization hodoscopes (IH) and iron shielding. Downstream of the magnet: drift chambers (DC), vertical and horizontal scintillation hodoscopes (VH, HH), gas Cherenkov counters (Ch), preshower detectors (PSh) and, behind the iron absorber, muon detectors (Mu).

The DIRAC double arm spectrometer, shown in Fig.1, is designed to measure $\pi^+\pi^-$ pairs with high resolution ($\sigma_{Q_L} \approx \sigma_{Q_x} \approx \sigma_{Q_y} \approx 0.5 MeV/c$). It contains a number of components which lead to significant multiple scattering. The precise knowledge of this multiple scattering is crucial for simulating the $\pi^+\pi^-$ pairs correctly. Experimentally there existed no check of multiple scattering better than 5% in the momentum range of DIRAC (1.5 to 7 GeV/c). Moreover composite and inhomogeneous materials such as detectors are difficult to describe.

A dedicated measurement was done in 2003 to measure multiple scattering in samples of the relevant materials, using the drift chambers. The samples were placed behind the 3rd DC set, the deflection angle was measured by comparing the track direction obtained from DC1, DC2 and DC3 with the one obtained from DC3 and DC4. The angular resolution of the procedure was measured in control regions adjacent to the samples. A sketch of the set-up is shown in Fig. 2. The set-up allowed to measure multiple scattering (scattering angle times particle momentum) with 1% accuracy

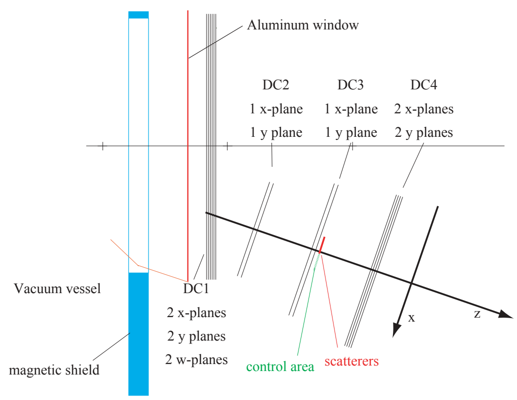

Figure 2: Schematic top view of the set-up used for the measurement of multiple scattering.

The samples were: Ni-foil (98 μm, 99.98% purity), one sample of one plane of micro-strip gas chamber (MSGC), one sample of Scintillation Fiber Detector, SFD-x and one of SFD-w (not used in 2001), one sample of Ionization Hodoscope (IH) and one sample of the aluminum foil (680 μm thick) at the exit of the magnet (see Fig. 2).

The result of this measurement is the following:

- The standard Moliere description of multiple scattering in GEANT-3 for Ni agrees to within 1% with the measurement.
- The effective thicknesses of MSGC, SFD-x and SFD-w had to be enlarged by between 10 and 15%.

These results have partly be confirmed by another study [2], where the multiple scattering in the bulk of detectors upstream (MSGCs, SFDs, IHs) has been measured directly. The agreement between this measurement and the simulation using the adjusted thicknesses of detectors is around $\pm$3%. The need for larger multiple scattering in the simulation was recognized already earlier [3].

3. Improvements

With the thickness corrections implemented into DIRAC-GEANT, the simulation can now be assumed to be accurate to 1% as far as multiple scattering is concerned. In the following we discuss improvements on the break-up probability (P_{br}).

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3.1 Statistical error

With the improved simulation of Q_T, the fitting procedure could now make full use of it and allowed, together with Q_L, to obtain an independent second measurement of the signal, or, by fitting in the $Q_L - Q_T$ plane (2-D fit) to extract the signal strength directly. As a consequence we obtain a reduced statistical error.

The published signal strength was 6530 $\pm$ 294 events [1], the new statistical error is $\pm$ 220 events.The relative statistical accuracy in P_{br} was thus reduced from $\pm$5.1% to $\pm$3.4%.

Further improvements on the statistical error are due to additional statistics from measurements done in 2002 and 2003. Altogether we have $\approx 16000 \pm 420$ events from atom break-up, which leads to a relative statistical error in P_{br} of $\pm$ 2.6%.

3.2 Systematic errors

Major systematic errors were introduced through the uncertainty in multiple scattering, the admixture of K^+K^- and $p\bar{p}$ pairs, the uncertainty of the Coulomb-correlated background due to finite size effects in the correlation, and due to effects in the fit range in Q_L.

3.2.1 Multiple scattering

The published systematic error due to multiple scattering of +1.3% was based on a general uncertainty of multiple scattering of $\pm$5%, and, asymmetrically due to non-understood shape effects (-2.9%). Both errors become obsolete in view of the improved multiple scattering. Conservatively we retain $\pm$1.3%.

3.2.2 Heavy particle-antiparticle admixtures

Indistinguishable admixtures of K^+K^- and $p\bar{p}$ pairs to the $\pi^+\pi^-$ pairs alter the background. Due to their lower speed their Coulomb correlation is more pronounced than for pions and leads to enhancements of the Coulomb-correlated background for low Q. While in transverse direction the enhancement factor is about 3.5 for KK pairs as compared to pions, in longitudinal direction it is about 13.5, due to the different boost, thus almost a factor four larger. The published relative error on P_{br} from the admixture, based on a conservative estimate on the yields [1] is -5.1% [1]. With the additional fitting in Q_T the sensitivity on the admixtures decreases. A fit in Q results in a relative error on P_{br} of -1.3%, hence, as expected, about a factor four lower.

3.2.3 Fit-range

Differences in the Q_L distributions between measurement and simulation, especially for accidental background, have led to a slight dependence of the break-up probability from fit range. Improved laboratory momentum distributions and better acceptance simulation [4], [5] have largely cured this problem, and the new estimated relative error on P_{br} due to this effect is $\pm$0.7%, a factor of two better than the published error.

3.2.4 Finite size effects in Coulomb correlation

The effect of finite size of the source of $\pi^+\pi^-$ pairs on their Coulomb correlation was studied and modifications proposed on the standard Coulomb correlation factor [6]. The correlation was directly measured with the DIRAC spectrometer for $\pi^-\pi^-$ pairs by comparing prompt with accidental distributions. The corresponding experimental correlation function is shown in Fig. 3 together with the modeled one. The apparent disagreement between model and experiment for low

Q leads us to not apply any correction but instead to measure this correlation with better statistics at DIRAC. Thus the errors due to this source remain unchanged with respect to the published error [1], i.e. +0/-3.8%.

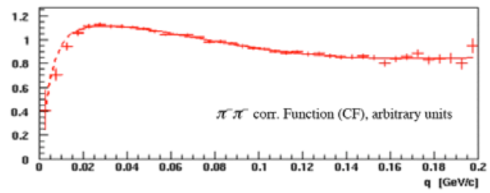

Figure 3: $\pi^-\pi^-$ correlation function as measured with the DIRAC spectrometer and simulation based on the URQMD-hadronization code.

4. Summary

In Table 1 we summarize the results and compare the new and published relative errors on P_{br}. Assuming a break-up probability of 0.45 (still to be determined) the improved errors correspond to a total error in $|a_0 - a_2|$ of +7.4% and -4.2%. Further improvements on results from existing data are expected due to fit procedures and experimental assessment of the finite size correction and a measurement of the heavy particle admixtures.

Table 1: Relative errors on the break-up probability in comparison with those from the published ones [1].

error source	new	published
statistical	± 2.6	± 5.1
systematic multiple scattering	± 1.3	$^{+1.3}_{-2.9}$
systematic heavy particles	$^{+0}_{-1.3}$	$^{+3.0}_{-5.1}$
systematic fit range	± 0.7	± 1.4
systematic finite size	$^{+0}_{-3.8}$	$^{+0}_{-3.8}$
Total	$^{+3.0}_{-5.2}$	$^{+5.5}_{-8.7}$

References

[1] B. Adeva et al. Phys. Lett. B619 (2005) 50

[2] Y. Allkofer, A. Benelli and L. Tauscher DIRAC NOTE 07-09 (Angular resolution and multiple scattering in 'downstream' tracking), 2007

[3] B. Adeva, A. Romero, O. Vazquez Doce, DIRAC NOTE 05-16 (Study of multiple scattering in upstream detectors in DIRAC), 2005

[4] M. Zhabitsky, DIRAC NOTE 07-01 (Parametrization of pi+pi- pairs spectra at the DIRAC kinematic range), 2007

[5] M. Zhabitsky, DIRAC NOTE 06-06 (Parametrization of single particle spectra at the DIRAC kinematic range), 2006

[6] R. Lednicky, DIRAC NOTE 04-06 (Finite-size effects in two-particle production in continues and discrete spectrum), 2004