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Fractions of $\pi^{\pm}_{\omega}\pi^{\mp}$ and $\pi^{\pm}_{\eta'}\pi^{\mp}$ pairs in pNi collisions at 24 GeV/c and their influence on pionium lifetime measurement

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Abstract

The fractions f_ω and $f_{\eta'}$ of the $\pi^{\pm}_{\omega}\pi^{\mp}$ and $\pi^{\pm}_{\eta'}\pi^{\mp}$ pairs with one pion from the ω and, respectively, η' decays at small values of the relative momentum $Q \leq 4$ MeV/c of pions in the c. m. system of $\pi^+\pi^-$ pair are found to be $f_\omega = 0.150 \pm 0.019$ and $f_{\eta'} = 0.0102 \pm 0.0034$ for pNi interactions at 24 GeV/c. With these values of f_ω and $f_{\eta'}$, the uncertainty in the pionium breakup probability and the corresponding overestimation of the pionium life-time in the DIRAC experiment are $\Delta P_{br}/P_{br} = (3.0 \pm 1.0)\%$ and $\Delta\tau/\tau = (7.8 \pm 2.6)\%$, in comparison with the previous values $\Delta P_{br}/P_{br} = (4.6 \pm 2.4)\%$ and $\Delta\tau/\tau = (12 \pm 6)\%$.

The detection of the pionic atoms formed in interaction of a 24 GeV/c proton beam with a thin Ni target in the DIRAC experiment [1] is based on their breakup, after interacting with target atoms, into $\pi^+\pi^-$ pair with low relative momentum $Q \leq 4$ MeV/c of pions in the atomic pair c. m. system [2]. The creation of atomic pairs is accompanied by a large background which should be accounted for in the measured Q distribution in order to observe the excess due to the atomic signal. The Q distribution of $\pi^+\pi^-$ pairs with pions produced either directly or from decays of the short-lived resonances can be described by point-like Coulomb approximation. However, this approximation must be corrected if the distance between produced pions is larger than ~ 10 fm. Such pion pairs, with the respective path length of about 30 fm in the pair c.m. system, are formed when at least one pion originates from the ω decay. Smaller contribution give also pion pairs with one pion from η' decay. The corresponding finite-size correction, representing one of the main sources of systematic error [3] in the pionium lifetime measurement in the DIRAC experiment, is basically determined by the fractions f_ω and $f_{\eta'}$ of such pion pairs. The f_ω represents the fraction of $\pi^{\pm}_{\omega}\pi^{\mp}$ pairs with one pion from the ω decay and another from other sources (except for pions from η or η' decays or from the decay of the same ω) to the total number of $\pi^+\pi^-$ pairs (except such pairs where only one of the pions comes from η decay). The $f_{\eta'}$ represents the fraction of $\pi^{\pm}_{\eta'}\pi^{\mp}$ pairs with one pion from the η' decay and another from other sources (except for pions from η decay or from the decay of the same η') to the same total number of $\pi^+\pi^-$ pairs as for f_ω.

The values of these fractions f_ω and $f_{\eta'}$ are directly related [4] to the uncertainty in the pionium breakup probability, $\Delta P_{br}/P_{br}$, where $P_{br} = N_A^{br}/N_A$ is the ratio of the number N_A^{br} of breakup atoms to the number N_A of atoms produced in the target, and to the corresponding overestimation of the pionium life-time $\Delta\tau/\tau$. In order to test chiral symmetry breaking of QCD in

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this experiment it is necessary to measure the lifetime of the $\pi^+\pi^-$ atoms in the ground state with the precision of better than 3%.

Up to now, the fractions f_ω and $f_{\eta'}$ have been estimated for pNi collisions at 24 GeV/c [4, 5] and for pp collisions at 24 GeV/c [6].

In [4, 5], the values of $f_\omega = 0.19$ and $f_{\eta'} = 0.01$ for the low-Q $\pi^+\pi^-$ pairs were obtained from the Monte Carlo simulation performed with the UrQMD generator [7]. However, the UrQMD generator was not tuned to the production cross-sections of resonances in pNi collisions at 24 GeV/c, which are not known, and 30% uncertainties in the obtained values of f_ω and $f_{\eta'}$ were arbitrary assumed. The uncertainty in the pionium breakup probability[3] and the corresponding overestimation of the pionium life-time estimated in [4] from these values of f_ω and $f_{\eta'}$ amounted to

$$\Delta P_{br}/P_{br} = (4.6 \pm 2.4)\%, \quad \Delta\tau/\tau = (12 \pm 6)\%. \tag{1}$$

In [6], the values of $f_\omega = 0.165 \pm 0.022$ and $f_{\eta'} = 0.0126 \pm 0.0042$ for the low-Q $\pi^+\pi^-$ pairs were obtained from the Monte Carlo simulation performed with the Fritiof generator [8] tuned to reproduce the production cross-sections of different resonances either directly measured in pp collisions at 24 GeV/c or estimated from other experimental data. With these values of f_ω and $f_{\eta'}$, one obtained

$$\Delta P_{br}/P_{br} = (3.8 \pm 1.0)\%, \quad \Delta\tau/\tau = (9.9 \pm 2.6)\%. \tag{2}$$

However, although the estimates (2) relied on the experimental data and were more precise than in (1), they were obtained for pp, not pNi interactions. Therefore it remains to be shown how these results can be used for determination of the fractions f_ω and $f_{\eta'}$, and consequently $\Delta P_{br}/P_{br}$ and $\Delta\tau/\tau$, for pNi collisions studied in the DIRAC experiment. This is investigated in this note.

Most models for hadron-nucleus collisions are based on the hypothesis of multiple independent collisions of the projectile or its constituents with the nucleons of the target nucleus (see [9], for example). In these models the incident hadron may interact once or several times with the target nucleons depending on the impact parameter of the hadron and on the size of the nucleus. The struck nucleons recoil and either leave the target nucleus or scatter with other target nucleons, yielding second generation nucleons, which can again collide to produce a third generation and so on. For a given nucleus, one can estimate the average number of projectile collisions $\overline{\nu}_A$ from the relation [10]

$$\overline{\nu}_A = A\sigma_{hN}/\sigma_{hA},$$

where σ_{hN} and σ_{hA} are the cross-sections for hadron h interacting with a nucleon N or a nucleus of atomic number A, respectively. The actual number of collisions ν is assumed to be statistically correlated with the number of protons knocked out of the nucleus, either in the interaction of the projectile with the target nucleons or in the collisions of secondary particles coming from the intranuclear cascade. All these protons fall into the class of *grey* tracks, defined by the velocity interval $0.2 \le \beta \le 0.7$ or equivalently a momentum interval of 190 to 920 MeV/c. The relation between the number n_g of grey protons and the average number of collisions for all events with a fixed n_g has been derived in [11, 12].

In general, the available experimental data support the validity of the multiple collision model. Thus in a study of K^+/π^+Al and K^+/π^+Au interactions at 250 GeV/c it has been shown [13] that the average multiplicity of particles is linearly increasing with the average number of collisions, if the sample is subdivided according to different numbers of n_g. The average charged particle multiplicity $\overline{n}$ increases with increase of the rapidity intervals Δy, but this increase is much stronger in the backward (BW) than in the forward (FW) hemispheres, where $\overline{n}$ is only $\approx 12\%$ ($\approx 16\%$) larger in

[3] Notice that the calculation of $\Delta P_{br}/P_{br}$, based on the theory of the final-state interaction, depends on Q_T cut and the analyzed Q-interval. In [4], the effect of Q_T cut was ignored and the region of $Q \le 4$ MeV/c was excluded from the analysis. The last published DIRAC results were obtained in the Q-interval extended down to Q=0 and the cut $Q_T \le 4$ MeV/c was used.

K^+/π^+Al (K^+/π^+Au) collisions than in elementary K^+/π^+p collisions. At fixed rapidity intervals Δy, $\overline{n}$ increases with the number n_g of grey tracks, both in the FW and the BW hemispheres, but this increase is again much stronger BW than FW. Thus by selecting events with small $n_g \leq 1$ one selects *peripheral* collisions on nucleous, while requiring $n_g \geq 3$ one selects interactions with an increasing number of collisions, or more *central* collisions. For $n_g \leq 1$ and in the FW hemisphere, $\overline{n}$ is almost the same for Al and Au and only ≈10% larger than in elementary collisions. The relative fraction of events with $n_g \geq 3$ is relatively small: only ≈ 5.5% for interactions on Al and ≈ 26% on Au [14].

The average resonance production rates in peripheral hadron-nucleus collisions is expected to be almost the same as in elementary collisions. This indeed has been confirmed, although within large errors, by the EHS-NA22 experiment at 250 GeV/c for the ρ^0 production rates in π^+p and peripheral π^+Al and π^+Au collisions [14]:

$$\langle\rho^0\rangle^{\pi^+ p} = 0.46 \pm 0.02, \quad \langle\rho^0\rangle^{\pi^+ Al}_{per.} = 0.45 \pm 0.13, \quad \langle\rho^0\rangle^{\pi^+ Au}_{per.} = 0.43 \pm 0.21.$$

The relative fraction of central pNi collisions is higher than in pAl, but smaller than in pAu collisions, amounting to ≈ 10%. Most of the particles detected in DIRAC are produced in the FW hemisphere in the incident-proton fragmentation processes in the peripheral pNi collisions, where the resonance production rates are expected to be the same as in pp collisions. Therefore the Monte Carlo simulation of pNi collisions has been performed with the Fritiof generator with the parameters tuned to reproduce the resonance production rates in pp collisions, as in [6], and selecting only peripheral pNi collisions with $n_g \leq 1$. Since charged particle multiplicity in the FW hemisphere for peripheral pNi collisions with $n_g \leq 1$ is larger by ≈10% than in elementary pp collisions, one may expect that the fractions f_ω and $f_{\eta'}$ would be slightly smaller than in pp collisions due to a larger number of the $\pi^+\pi^-$ pairs in the denominator of these fractions.

The values of f_ω and $f_{\eta'}$ obtained from the Monte Carlo simulation of pNi collisions with the Fritiof generator are shown as functions of Q in Fig. 1 by black triangles and dots, respectively. As one can see, the shapes of f_ω and $f_{\eta'}$ dependences on Q for pNi collisions are very similar to those found for pp collisions [6], also shown in Fig. 1 by open triangles and dots, respectively.

However the values of f_ω and $f_{\eta'}$ for pNi collisions are systematically smaller by about 10%, as expected, than for pp collisions in all $Q \leq 200$ MeV/c range. At the smallest Q values, they are almost independent of Q and amount to:

$$fw = 0.150 \pm 0.019, \quad f_{\eta'} = 0.0102 \pm 0.0034, \tag{3}$$

with the errors determined by uncertainties in the ω and η' production rates. We also performed simulation for all pNi collisions, not requiring $n_g \leq 1$. The obtained values of f_ω and $f_{\eta'}$ are practically indistinguishable from those shown in Fig. 1.

With the values of f_ω and $f_{\eta'}$ from (3), the uncertainty in the pionium breakup probability and the corresponding overestimation of the pionium lifetime for pNi collisions are

$$\Delta P_{br}/P_{br} = (3.0 \pm 1.0)\%, \quad \Delta\tau/\tau = (7.8 \pm 2.6)\%. \tag{4}$$

The errors of the obtained values $\Delta P_{br}/P_{br}$ and $\Delta\tau/\tau$ in (4) are by a factor of ≈ 2.4 smaller than in the previous estimates (1). This is mainly due to more precise value of the ω production rate, than in [4], which has been determined in [6] from the experimental data, and which is well reproduced by the Fritiof generator with the properly tuned parameters.

References

[1] B. Adeva et al., J. Phys. **G30** (2004) 1929; Phys. Lett. **B619** (2005) 50.

[2] L.L. Nemenov, Sov. J. Nucl. Phys. **41** (1985) 629.

[3] V.V. Yazkov, *Investigation of systematic errors for analysis with DC and ScFi*, DIRAC Note 2008-04 (2008).

[4] R. Lednický, *Finite-size effect on two-particle production in continuous and discrete spectrum*, DIRAC Note 2004-06 (2004), e-Print nucl-th/0501065; R. Lednický, J. Phys. G: Nucl. Part. Phys. **35** (2008) 125109.

[5] J. Smolik, PhD Thesis, Prague, Inst. Phys. (2005) and private communication from R. Lednický.

[6] P.V. Chliapnikov, V.M. Ronjin, *Influence of the ω and η' decays on determining the lifetime of $\pi^+\pi^-$ atoms*, DIRAC Note 2009-03 (2009).

[7] S.A. Bass et al., Prog. Part. Nucl. Phys. **41** (1998) 225.
M. Bleicher et al., J. Phys. **G25** (1999) 1859.

[8] Hong Pi, Comp. Phys. Comm. **71** (1992) 173.

[9] S. Frederiksson et al., Phys. Rep. **144** (1987) 188.

[10] A. Bialas, W. Czyż, Phys. Lett. **51** (1974) 179; W. Busza et al., Phys. Rev. Lett. **34** (1975) 836.

[11] B. Andersson et al., Phys. Lett. **73B** (1978) 343.

[12] M.K. Hegab, J. Hüfner, Nucl. Phys. **A384** (1982) 353.

[13] I.V. Ajinenko et al., EHS-NA22 Collaboration, Z. Phys. **C42** (1989) 377; ibid. **C46** (1990) 569.

[14] I.V. Ajinenko et al., EHS-NA22 Collaboration, Phys. Lett. **B277** (1992) 524.

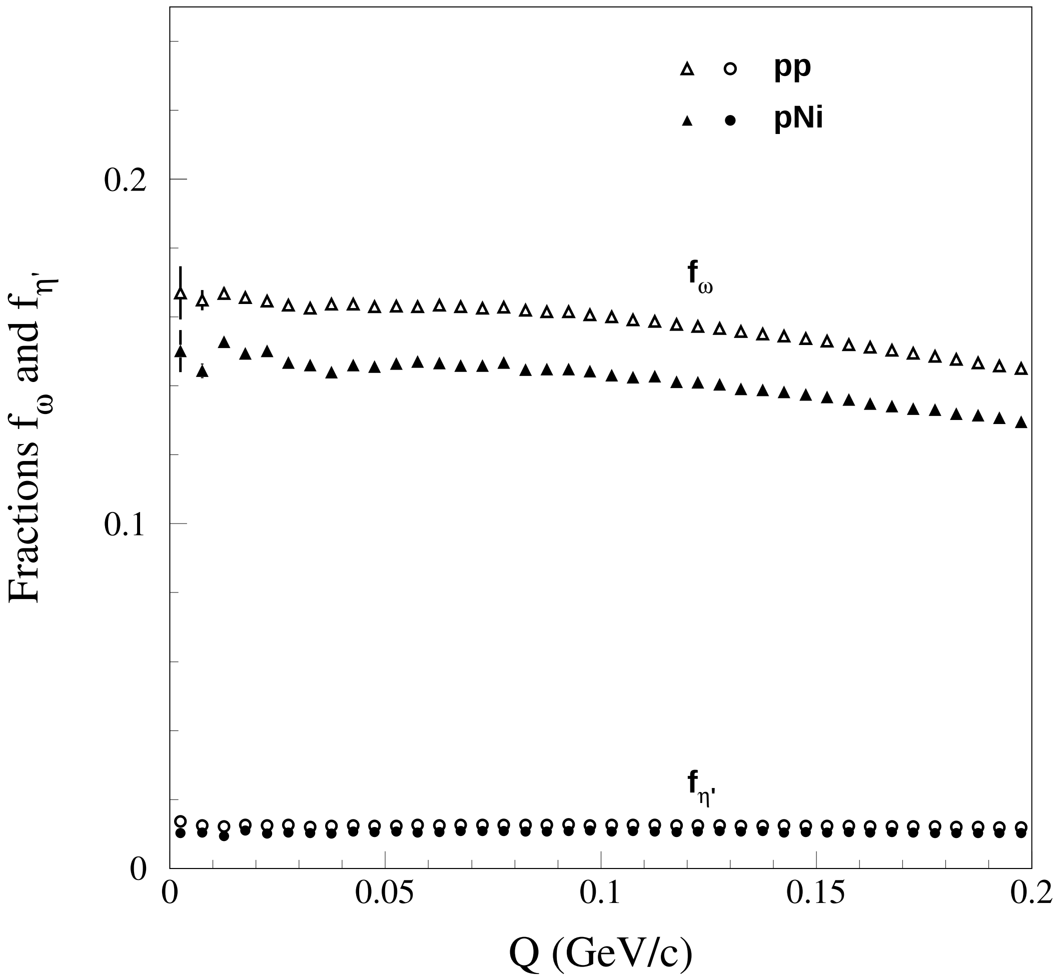

Figure 1: Q dependence of fractions f_ω (triangles) and $f_{\eta'}$ (dots) as found from Monte Carlo simulations with the Fritiof generator for pNi collisions at 24 GeV/c (black triangles and dots) and pp collisions at 24 GeV/c (open triangles and dots).