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$\bar{p}D$ and $\bar{p}\,{}^4$He annihilation cross sections at very low energy

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Abstract

The $\bar{p}D$ and $\bar{p}^4$He total annihilation cross sections have been measured with the Obelix apparatus at LEAR at, respectively, three and two values of the $\bar{p}$ incident momentum between 70 MeV/c and 36 MeV/c. The values of the $\bar{p}D$ annihilation cross section, at such low energies, are in agreement with a surprising result obtained in a recent low statistics measurement of the antiprotonic deuterium K_α X-rays [M. Augsburger et al., Phys. Lett. B 461 (1999) 417] (see following article), concerning the unexpected narrow width of the antiprotonic deuterium 1s level.

1. Introduction

An experimental procedure for the measurement of $\bar{p}p$ annihilation cross section at very low energy was developed by the Obelix experiment [1] at LEAR. The procedure was based on the ability in using gaseous targets at different pressures (from 10^{-4} bar to 3 bar absolute pressure) [2] and in recording both the coordinates of the vertex and the time of the annihilation [3]. Using this technique, the $\bar{p}p$ annihilation cross section was measured at several values of the $\bar{p}$ incident momentum between 175 MeV/c and 38 MeV/c [4–6].

The last measurements of the $\bar{p}p$ total annihilation cross section, at four values of the $\bar{p}$ incident momentum between 70 MeV/c and 38 MeV/c, were performed during the 1996 data taking period [6]. In the same period, measurements of the $\bar{p}D$ and $\bar{p}^4$He total annihilation cross sections at very low energy were performed too. The $\bar{p}D$ annihilation cross section was measured at three values of the $\bar{p}$ incident momentum, around 70 MeV/c, 46 MeV/c and 36 MeV/c and the $\bar{p}^4$He annihilation cross section at two values, around 70 MeV/c and 47 MeV/c. The experimental layout and the procedure adopted for the data taking were the same as those ones adopted in the previous measurements of the $\bar{p}p$ annihilation cross section. They are described in detail in [4,6] and will not be illustrated here again.

The measurements of $\bar{p}D$ and $\bar{p}^4$He annihilation cross sections, presented in this work, are the first measurements of $\bar{p}$-Nucleus cross sections at these very low energies, apart from a previous low statistic measurement of $\bar{p}^4$He annihilation cross section, between 40 MeV/c and 50 MeV/c, performed at LEAR with a streamer chamber [7]. These measurements allow new information on the low energy parameters of the $\bar{p}$-Nucleus interaction to be obtained.

2. Results and discussion

In Table 1 the measured values of the $\bar{p}D$ and $\bar{p}^4$He total annihilation cross sections, multiplied by the square of the velocity β^2, and the corresponding $\bar{p}$ incident momenta are reported. Due to the additional dependence on $1/\beta$, introduced in the $\bar{p}$-Nucleus annihilation cross section, at low energy, by the Coulomb interaction [8], this representation is the most effective for plotting and comparing $\bar{p}$-Nucleus annihilation cross sections in this energy range.

The uncertainties on the $\bar{p}$ incident momenta account both for the thickness of the fiducial volume

Table 1
Measured values of the $\bar{p}D$ and $\bar{p}^4$He total annihilation cross sections, multiplied by the square of the incoming beam velocity, and the relative $\bar{p}$ incident momenta. In addition to the statistical and systematic errors, an overall normalization error of 2.5% has to be considered

Gaseous target	$\bar{p}$ incident momentum (MeV/c)	$\beta^2\sigma_{ann}^T$ (mbarn)
D_2	69.6 ± 1.5	3.45 ± 0.08(stat) ± 0.15(sys)
	45.7 ± 3.5	2.12 ± 0.06(stat) ± 0.33(sys)
	36.3 ± 5.1	1.96 ± 0.08(stat) ± 0.55(sys)
^{4}He	70.4 ± 1.3	4.63 ± 0.10(stat) ± 0.19(sys)
	47.0 ± 3.3	2.45 ± 0.10(stat) ± 0.35(sys)

and for the spread of the beam momentum distribution due to the momentum degradation of the beam. The systematic errors on the $\beta^2\sigma^T_{\rm ann}$ values are obtained as the quadratic addition of the possible systematic uncertainties on the counting of the annihilation events, on the evaluation of the beam crossing the target and on the determination of the $\bar{p}$ incident momentum. This last uncertainty produces the dominant effect. In addition to these systematic errors, an overall normalization error of 2.5% has to be considered. It arises from the quadratic addition of the uncertainties on different corrections, like Monte Carlo corrections for apparatus efficiencies, that may affect all the values of the cross section to the same extent.

Details about recognition of in flight events, corrections for efficiencies, background subtraction and systematic error evaluation can be found in [6]. Here it is only worth emphasizing that the measurements of the $\bar{p}p$ and $\bar{p}D$ annihilation cross sections, at the corresponding $\bar{p}$ incident momenta, were performed in exactly the same experimental conditions as regards degradation of the beam, target gas pressure, timing and geometry. In fact, the $\bar{p}$ stopping power is equivalent in hydrogen and deuterium (apart from a small contribution from the nuclear stopping power, effective only at very low energies [9,10]). Therefore, the values of the $\bar{p}p$ and $\bar{p}D$ annihilation cross sections, at the same $\bar{p}$ incident momenta, share the same systematics, apart from a negligible difference in the acceptance of the apparatus for $\bar{p}p$ and $\bar{p}D$ events, which was evaluated by an accurate Monte Carlo simulation.

In Fig. 1 the values of the $\bar{p}D$ and $\bar{p}\,^4$He total annihilation cross section, from Table 1 and from [7], multiplied by the square of the incoming beam velocity, are plotted as a function of the $\bar{p}$ incident momentum. The data are compared with the calculations of [11,12], performed in the framework of a scattering length approximation [8,13]. Such an analysis was made previously in [14], using the $\bar{p}p$ annihilation cross section data measured by Obelix [4,5]. In that analysis it was demonstrated that the imaginary parts of the S-wave scattering length and P-wave scattering volume, obtained from the $\bar{p}p$ annihilation cross section data, are in good agreement with those extracted from protonium data.

In [11,12] the calculations for the $\bar{p}D$ annihilation cross section were performed in terms of the S-wave scattering length and P-wave scattering volume. The value of the P-wave scattering volume was extracted, by means of the Deser-Trueman formula [15,16], from the recent atomic data [17] on the shift and the broadening of the antiprotonic deuterium 2p level.

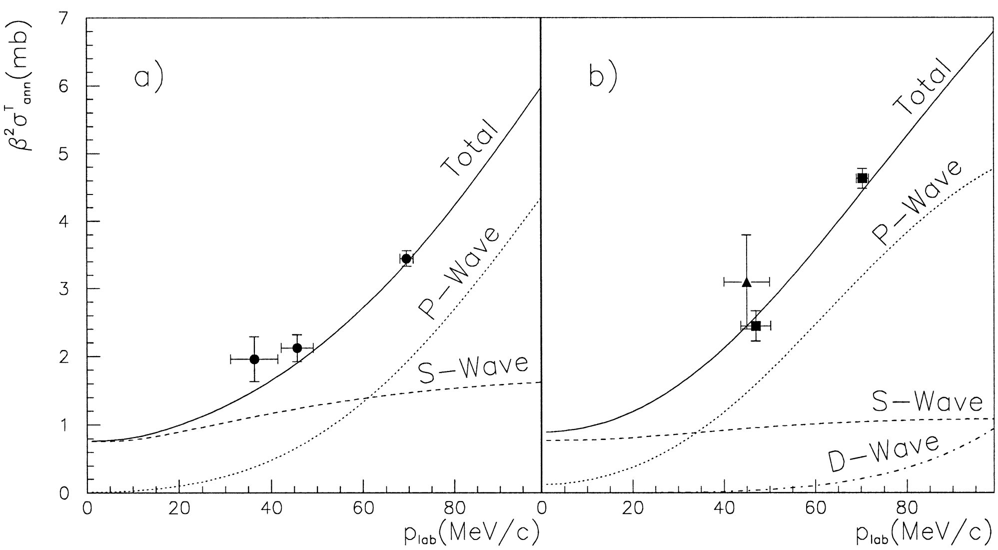

Fig. 1. Values of $\bar{p}D$ (a) and $\bar{p}\,^4$He (b) total annihilation cross sections, multiplied by the square of the incoming beam velocity, as a function of the $\bar{p}$ incident momentum. (●) and (■) are from Table 1; (▲) from [7], The data are compared with the calculations of [11,12].

The value of the S-wave scattering length was deduced from the calculations of Wycech et al. [18], who obtained -2.17 keV for the antiprotonic deuterium 1s shift and 1.24 keV for the 1s width.

In Fig. 1a the general behaviour of the $\bar{p}D$ annihilation cross section appears quite well reproduced by these calculations. This agreement is in line with the result obtained with a recent low statistics measurement of the antiprotonic deuterium K_α X-rays [19] (following paper). In this measurement, the values obtained for the antiprotonic deuterium 1s shift and 1s width are, respectively, -1050 ± 250 eV (repulsive) and 1100 ± 750 eV. This latter result appears somewhat unexpected, since the 1s width measured for antiprotonic deuterium has the same size as the spin-averaged 1s width of the antiprotonic hydrogen.

In the case of $\bar{p}\,^4$He annihilation, the analysis in [11,12] was performed in terms of S-wave, P-wave and D-wave scattering parameters. P-wave and D-wave scattering parameters were extracted from atomic data [20]. Concerning S-wave parameters, no experimental information is available; the scattering length was taken close to the one adopted for the $\bar{p}D$ system. In Fig. 1b the results of the calculations are compared with the $\bar{p}\,^4$He annihilation cross section data from Table 1 and [7]. Again, the general behaviour of the annihilation cross section seems to be reproduced quite well.

3. Summary

Measurements of the $\bar{p}D$ and $\bar{p}\,^4$He total annihilation cross sections at $\bar{p}$ incident momenta lower than 70 MeV/c have been performed by the Obelix experiment at LEAR. Simple theoretical calculations in the scattering length approximation [11,12] reproduce quite well the experimental data.

The value of the P-wave scattering volume used for the analysis of the $\bar{p}D$ data was obtained from recent antiprotonic deuterium data [17], whereas the value used for the S-wave scattering length is close to a recent low statistics measurement of the antiprotonic deuterium 1s width obtained in [19]. The good agreement of these calculations with the present $\bar{p}D$ annihilation cross section data is in line with the surprising result obtained in [19] for the 1s width of antiprotonic deuterium, which results unexpectedly similar to the spin-averaged protonium 1s width.

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