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$\bar{p}^4$He REACTION CROSS SECTION AT 610 MeV/*c*

Dubna–Frascati–Padova–Pavia–Torino Collaboration

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Antiproton helium reaction cross section has been measured at 179.6 MeV with a self shunted streamer chamber in a magnetic field. Charged prong multiplicity, branching ratios and ^{3}He production probability are given. Comparison with $\bar{p}^2$H data is performed.

In this paper we report the results obtained at the LEAR facility of CERN in the study of the inelastic interaction of 607.7 MeV/*c* antiprotons on ^{4}He. The experimental apparatus, consisting of a self shunted streamer chamber filled with helium at 972 mbar and 25°C and placed in a magnetic field of 0.8 T has been described in detail in ref. [1]. Considering the energy degradation in the thin walls and scintillators of the beam channel ($\Delta E \cong 0.33$ MeV) the $\bar{p}$ energy was 179.6 MeV. The sensitive volume of the chamber was $(90 \times 70 \times 18)$ cm^3 and the beam rms radius was 1 cm. The scanning efficiency for the detection of the vertices of $\bar{p}^4$He events was 99.5% in the 70 cm central part of the chamber. To avoid the lack of efficiency in detecting the total number of prongs of each event in the zones near the windows of the chamber, only the central 55 cm long part of the chamber has been considered useful for the prong multiplicity measurements. In this fiducial volume 1097 reaction events have been produced by about 3.6×10^6 $\bar{p}$. The main $\bar{p}^4$He reactions are listed in table 1, where for the sake of brevity, heavy particles with one positive electric charge, i.e. tritons, deuterons and protons, are indicated by X; N is the number of neutrons ($0 \leqslant N \leqslant 3$) and M is the number of neutral pions ($M \geqslant 0$). The reactions are ordered following the total number of charged prongs. Table 1 has been written neglecting initial state and final state interactions and kaon production. If initial ($\bar{p}p \to \bar{n}n$) and final ($\pi^-p \leftrightharpoons \pi^0n$, $\pi^+n \leftrightharpoons \pi^0p$) charge exchange processes were taken into account, further reaction channels should be considered which could lead for instance to events without heavy charged prongs or with more than two heavy positive prongs. However from available $\bar{p}^2$H data [2,3] it follows that charge exchange processes affect only about 5%, while K production represents only about 4%, of all the annihilation processes and table 1 may be considered as a good reference for the observed events.

The total charge of the system being odd (+1), it is evident that only the events with an even number of prongs are those with production of ^{3}He.

The charged prong multiplicity and the total and partial reaction cross section values are reported in

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Table 1
List of the possible $\bar{p}^4$He reactions neglecting initial and final state interactions. X = t, d, p; $0 \leqslant N \leqslant 3$ and $M \geqslant 0$.

Number of charged prongs	$\bar{p}^4$He reaction products	Reaction type	Number of charged pions
1	$X + \bar{n} + Nn$	charge exchange	0
1	$X + Nn + M\pi^0$	$\bar{p}$p annihilation	0
2	$\bar{p} + {}^4He$	elastic scattering	0
2	$\bar{p} + {}^3He + n$	inelastic scattering	0
2	${}^3He + \pi^- + M\pi^0$	$\bar{p}$n annihilation	1
3	$\bar{p} + 2X + Nn$	inelastic scattering	0
3	$2X + \pi^- + Nn + M\pi^0$	$\bar{p}$n annihilation	1
3	$X + 2\pi^\pm + Nn + M\pi^0$	$\bar{p}$p annihilation	2
4	${}^3He + 3\pi^\pm + M\pi^0$	$\bar{p}$n annihilation	3
5	$2X + 3\pi^\pm + Nn + M\pi^0$	$\bar{p}$n annihilation	3
5	$X + 4\pi^\pm + Nn + M\pi^0$	$\bar{p}$p annihilation	4
6	${}^3He + 5\pi^\pm + Nn + M\pi^0$	$\bar{p}$n annihilation	5
7	$2X + 5\pi^\pm + Nn + M\pi^0$	$\bar{p}$n annihilation	5
7	$X + 6\pi^\pm + Nn + M\pi^0$	$\bar{p}$p annihilation	6
8	${}^3He + 7\pi^\pm + Nn + M\pi^0$	$\bar{p}$n annihilation	7

table 2, where the errors are only statistical. The percentage error on the total reaction cross section is 3%. We have estimated a further systematic error of 2.5% due to scanning efficiency, target transparency and beam dose counting. The behaviour of the charged prong multiplicity is also shown in fig. 1 and it is evident that the frequency of even prong events is much smaller than that of odd prong events.

While the $\bar{p}^4$He interaction for $\bar{p}$ at rest has been studied [4,5] both experimentally and theoretically, neither data nor predictions are available for $\bar{p}$ in flight. Thus we discuss briefly our results in the light of the present knowledge of the interaction of $\bar{p}$ with protons and a few-nucleon system. Bubble chamber experiments have shown that, at our energy, the $\bar{p}$p and $\bar{p}^2$H annihilation cross sections are 98 mb and

Table 2
Multiplicity and cross sections for the inelastic events in the $\bar{p}^4$He interactions.

Number of charged prongs	Number of events	Reaction cross section (mb)	Number of charged pions	Cross section (mb)	
				^{4}He	^{2}H (ref. [2])
1	77	16.4 ± 1.9	0	16.4 ± 1.9	11.6 ± 0.7
2	46	9.8 ± 1.4	0, 1, 2	82.7 ± 4.2	42.4 ± 1.5 [a]
3	343	72.9 ± 3.9			
4	94	20.0 ± 2.1	3, 4	110.6 ± 4.8	86.8 ± 2.4
5	426	90.6 ± 4.4			
6	26	5.5 ± 1.1	5, 6	23.2 ± 2.2	21.4 ± 1.2
7	83	17.7 ± 2.0			
8	2	0.4 ± 0.3	7	0.4 ± 0.3	–
Total	1097	233.3 ± 7.0	–	233.3 ± 7.0	271.8 ± 4.2 [b] 162.8 ± 3.1 [c]
^{3}He production		35.7 ± 2.8			

[a] Annihilation only. [b] Total cross section. [c] Annihilation + charge exchange.

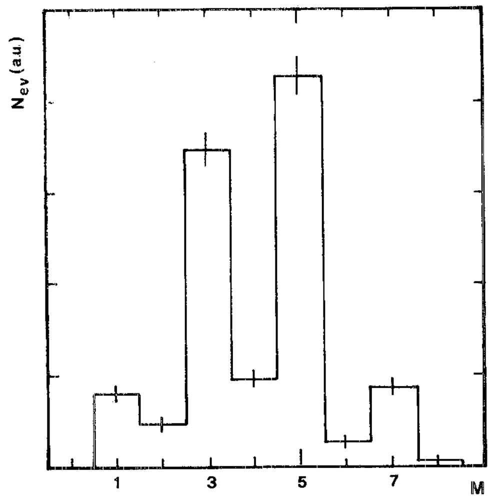

Fig. 1. Distribution of the charged prong multiplicity *M* of the inelastic $\bar{p}^4$He events.

162 mb respectively [6,2]. The $\bar{p}^2$H data have been analyzed in the framework of Glauber's theory in the eikonal approximation, considering on mass shell nucleons and multiple nuclear scatterings up to the second order [7,8]. This theory, having the total cross section $\sigma_{\bar{p}n}$ for the $\bar{p}$ interaction on the free neutron as a free parameter, describes the data well and explains the cross section defect in ^{2}H in terms of shadow effects between the two nucleons. The ratio $\sigma_{\bar{p}n}/\sigma_{\bar{p}p}$ is near to one; in particular, at our energy, its value is ~1.01 [8]. Glauber's theory has been applied also to the study of the $\bar{p}^3$He and $\bar{p}^3$H interactions [9] and it predicts, for the $\bar{p}^3$He interaction at 600 MeV/*c*, a reaction cross section $\sigma_R \sim 270$ mb. On the basis of these considerations the value $\sigma_R = 233$ mb we have found for ^{4}He appears to be too low, but its smallness is comprehensible considering that in this strongly bound nucleus shadow effects are likely to be important. Indeed, these effects are less important for ^{2}H and not adequately taken into account in the simplest formulation of Glauber's theory. Clearly, experimental data on $\bar{p}^3$He interaction and theoretical studies on the $\bar{p}^4$He are necessary in order to clarify this situation. As a last point, we want to comment briefly on our measurement of the branching ratios in light of the annihilation data available for the ^{2}H. In the present analysis we have not distinguished protons from positive pions, thus we cannot directly compare the charged pion multiplicity in deuterium with that in helium. Nevertheless $\bar{p}^4$He reactions with a different number of charged prongs can be grouped, so that their whole yield can be compared directly with that of the same group of $\bar{p}^2$H events, the matching between corresponding groups is given by the same mixture of charged pion multiplicity. As we stated before this procedure is correct within the limits in which charge exchange effects and kaon production are negligible. The groups of events so obtained are indicated in the fourth column of table 2. As shown in table 1, the one charged prong events are annihilations with zero charged pions or charge exchange; four and five charged prong events are annihilations with production of 3 or 4 charged pions and six and seven charged prong events are annihilations with 5 or 6 charged pions. The group of two and three charged prong events contain inelastic scattering and annihilation into 1 or 2 charged pions together; thus their yield cannot be compared with a corresponding channel for the deuterium.

Table 3
Branching ratios for $\bar{p}^4$He and $\bar{p}^2$H reaction products.

Number of charged pions	Number of events	Branching ratios	
		^{4}He	^{2}H (ref [2])
0	77	10.9 ± 1.2	9.3 ± 0.6
3,4	520	73.6 ± 3.2	72.0 ± 2.7
5,6	109	15.4 ± 1.5	17.7 ± 1.1
Total	706		

Table 3 shows that the branching ratios for the events with 0, (3,4) and (5,6) charged pions in ^{4}He are equal, within the errors, to the corresponding ones in ^{2}H. This could indicate that the pion multiplicities from the annihilations on the strongly bound nucleons in ^{4}He are similar to those in ^{2}H and that charge exchange effects in the initial and final state of the reaction are not relevant.

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