High-momentum tail on spectrum of spectator protons in the reaction $\bar{p}d \to p_s K\bar{K}$...

V. M. Kolybasov and Yu. N. Sokol'skikh
Physics Institute, Academy of Sciences of the USSR

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The problem of the high-momentum tail on the spectrum of spectator protons from the reaction $\bar{p}d$–$p_s K\bar{K}$... can be solved through a careful analysis of the rescattering of the final pions in various possible channels.

One puzzle in the physics of the interaction of antiprotons with nuclei is the high-momentum tail on the distribution of spectator protons in $\bar{p}d$ annihilation accompanied by the formation of a pair $K\bar{K}$: $\bar{p}d$–$p_s K\bar{K}$... (Ref. 1). Unsuccessful attempts[2] to find a simple explanation of this tail have left room for suggestions that it is related to some unusual mechanisms for the process: a two-nucleon mechanism for the absorption of antiprotons[3] or a process accompanied by the formation of glueballs.[4]

In a previous study, we were able to successfully describe the high-momentum part of the spectrum of spectator protons in the reaction $\bar{p}d$–$p_s 5\pi$ by means of a mechanism involving a rescattering of pions in the final state.[5] In addition, it was shown that a rescattering of pions at large spectator momenta leads in a natural way to a shift and a broadening of the peak corresponding to the resonance $\zeta(1480)$, in agreement with experimental observations.[6] It would thus seem extremely unnatural if the pion rescattering processes, which determine the picture in the $\bar{p}d$–$p_s 5\pi$ channel, were not also important in the $\bar{p}d$–$p_s K\bar{K}$... channels.

We have accordingly undertaken a careful study of the role played by pion rescattering in the process $\bar{p}d$–$p_s K\bar{K}$.... We used the method of Ref. 5; i.e., we analyzed diagrams like that in Fig. 1. Our study differed from Refs. 2, where a similar but unsuccessful attempt was made, in the following ways.

1. The experimental distribution with respect to the momentum of the spectator proton, p_s, in Ref. 1 was actually constructed for all events in which the number of charged particles in the final state was equal to or greater than four. Consequently, we did not restrict the analysis to the $\bar{p}d$–$p_s K\bar{K}\pi^+\pi^-$ channel, as was done in Ref. 2. We instead considered all channels which contribute significantly to the annihilation cross section:

$$\bar{p}d - p_s K_1^0 K^{\mp} \pi^- \pi^{\pm} \pi^0 \tag{1}$$

$$p_s K_1^0 K_1^{\mp} \pi^- \pi^{\pm} \tag{2}$$

$$p_s K_1^0 K^0 \pi^- \pi^- \pi^+ \tag{3}$$

$$p_s K_1^0 K^{\pm} \pi^- \pi^{\mp} \pi^0 \pi^0. \tag{4}$$

2. The pole diagrams in Fig. 1(a) contribute protons with momenta up to 150

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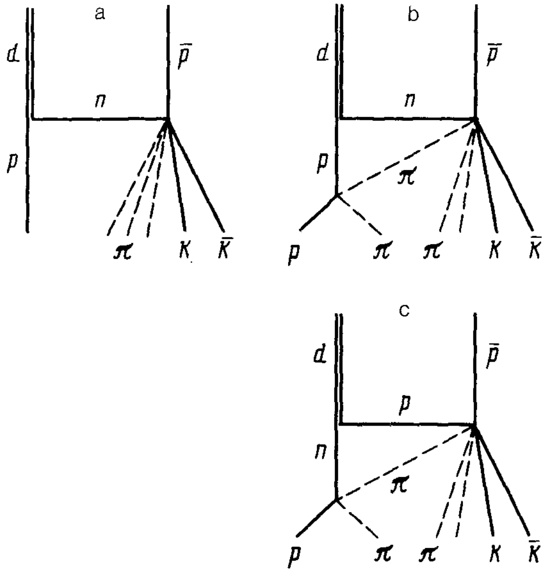

FIG. 1. Feynman diagrams for the process $\bar{p}d$–$p_s K\bar{K}$... .

MeV/c for the most part. At higher momenta, a rescattering of pions, i.e., diagrams of the type in Fig. 1(b), is predominant. An important point is that several charged and neutral pions may be rescattered in each of the channels listed above, and the corresponding diagrams would add together in a coherent way. Even in the channel $\bar{p}d$–$p_s K\bar{K}\pi^+\pi^-$, the incorporation of a rescattering of the π^- meson would increase the amplitude by a factor of 4/3 from that in the case studied in Ref. 2, where the scattering of only the π^+ meson was taken into account. At high spectator momenta the cross section increases by a factor of 16/9, i.e., nearly doubles. (Here we have taken into account the fact that in terms of energy the pions fall in the isobar region.) This factor is not enough to completely correct the situation in Ref. 2, but there are more pions in the other channels, (1), (3), and (4), and the enhancement factor is correspondingly larger.

3. We considered the possibility that there would first be an annihilation of the $\bar{p}$ with a proton and then a charge exchange of a π meson with a spectator neutron [the diagram in Fig. 1(c)]. There is no pole diagram in this case, and the entire contribution goes into the region of large momenta of the residual proton. Since the diagrams in Figs. 1(b) and 1(c) in several channels add together coherently, we need to know the relative phase shift of the corresponding $\bar{p}n$ and $\bar{p}p$ amplitudes. For rough estimates, we set this phase shift equal to zero.

Incorporating these three factors raises the high-momentum part of the spectrum of spectator protons by a factor of about four in comparison with that in Refs. 2. The calculation technique, which involves complex integrations over a multiparticle phase volume, will be presented in a more detailed paper. Here we simply note that we used a Breit-Wigner amplitude with the correct angular dependence for the πN scatterings. The antiproton annihilation vertices were assumed to be constant, in agreement with the inclusive spectra of the π and K mesons. We used the Bonn-potential wave func-

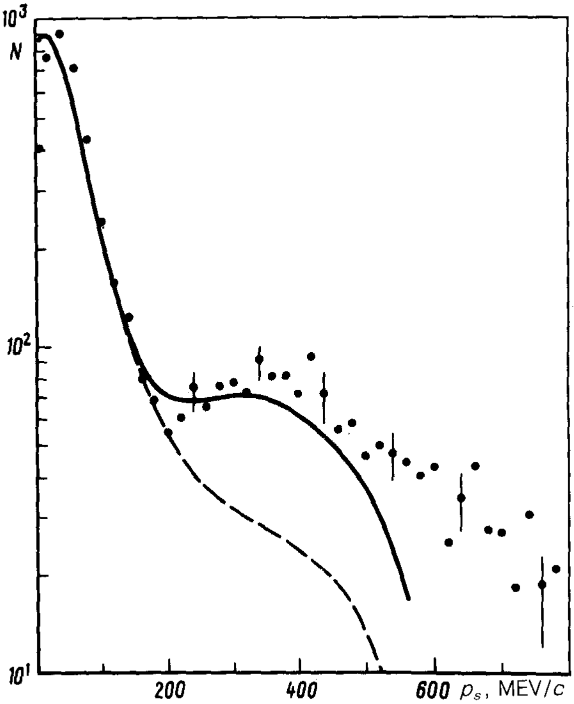

FIG. 2. Inclusive momentum distribution of protons from the reaction $\bar{p}d\text{–}p_sK\bar{K}\ldots$. Dashed line—From Refs. 2; solid line—calculated by the method described in the present letter.

tion for the deuteron. We ignored rescatterings of the K mesons because of their small cross sections.

Figure 2 shows the results of our calculation (the solid curve) along with experimental data.[1] The dashed curve is the calculation of Refs. 2, which took into account only the rescattering of a single π^+ meson, in the $\bar{p}d\text{–}p_sK\bar{K}\pi^+\pi^-$ channel (our calculation for this case yields a value 20% lower than that of Ref. 2 at $p_s = 350$ MeV/c; in the absence of other factors, this result would lead to an even greater discrepancy with experiment). We see that the theoretical and experimental results agree well up to 500 MeV/c. On the one hand, this agreement is evidence for the validity of the model which was selected, which explains the presence of a significant number of protons with large momenta on the basis of very simple physical factors. On the other hand, we see that the problem of the high-momentum tail has been basically solved without introducing any exotic mechanisms. At $p_s > 500$ MeV/c, sequential rescatterings of two pions or more complex possibilities are apparently important.

We conclude by pointing out three circumstances. First, aside from the renormalization at the peak at the left in Fig. 2, our calculations have no adjustable parameters. Second, the question of the relative phase shift of the diagrams with $\bar{p}n$ and $\bar{p}p$ annihilation requires further study. Third, because of technical complications our calculations ignored the fact that a moving antiproton undergoes annihilation. There are reasons to believe that incorporating this fact would lead to a further improvement in the agreement at large spectator momenta.

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