Pion Contribution to K^+-Nucleus Scattering

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The contribution of virtual pions to the total K^+-nucleus cross section in the $P_L = 450$–1000 MeV/c region is found to be about 10%. With this contribution, the data can be explained without the assumption of nucleons "swelling" in the nucleus.

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As a result of its long mean free path, the K^+ meson is a promising probe of the nuclear interior. Contrary to the expectation, there is a persistent discrepancy of about 10% between "conventional" optical model calculations of the K^+-nucleus cross section and the available experimental data. Namely, the experimental cross sections in the $P_L = 450$–1000 MeV/c region are systematically larger than the optical model results [1-3]. The widely accepted explanation of this discrepancy was based on the mechanism of "swelling" or partial deconfinement of nucleons in nuclei [3,4]. A similar mechanism can be used to explain the European Muon Collaboration (EMC) effect in the deep inelastic lepton scattering from nuclei [5]. This led many authors to the conclusion that the K^+-nucleus scattering and the EMC effect reflect the same properties of nucleons in the nucleus.

Here we show that the K^+-nucleus data can be explained without assuming the swelling of nucleons, provided the contribution of virtual nuclear pions is taken into account. As is known [6], some amount of virtual pions in nuclei is necessary to fulfill the energy-momentum sum rule for deep inelastic scattering from nuclei composed of bound nucleons. We show here that the $K^+\pi$ cross section can be larger than the K^+N cross section in the considered energy region. This makes the pionic contribution important to the K^+-nucleus cross section.

At low (resonance) energies the K^+N interaction is relatively weak because of its quark content. The quark structure of the K^+ meson is $|u\bar{s}\rangle$ and does not permit s-channel resonances with the nucleon. But such resonances contribute to the scattering of the K^+ meson from π^- and π^0 mesons, since their structure is represented by $|d\bar{u}\rangle$ and $(1/\sqrt{2})|d\bar{d}-u\bar{u}\rangle$, respectively. Therefore one might expect a large $K^+\pi$ cross section.

Direct experimental results for the $K^+\pi$ cross sections are not available, but these cross sections can be reconstructed from the partial-wave analysis of the K^+p scattering. This analysis gives phenomenological $K\pi$ phase shifts δ_L^{2I}, where I and L are the total isospin and angular momentum of the $K\pi$ system. The experimental results can be fitted with an effective range form for the phase shifts [7]

$$q^{2L+1}\cot\delta_L^{2I} = \frac{1}{a_L^{2I}} + \frac{1}{2} r_L^{2I} q^2 , \tag{1}$$

where q is the c.m. momentum and the phenomenological parameters a_L^{2I} and r_L^{2I} are given by

$$a_S^1 = 2.39\ \mathrm{GeV}^{-1},\quad r_S^1 = -1.76\ \mathrm{GeV}^{-1},$$
$$a_S^3 = -1.00\ \mathrm{GeV}^{-1},\quad r_S^3 = -1.76\ \mathrm{GeV}^{-1}. \tag{2}$$

The contribution of partial waves with $L \neq 0$ is very small and can be neglected in the energy region under consideration. From (1) and (2) we obtain the results for the $I = \frac{1}{2}$ and $I = \frac{3}{2}$ cross sections presented in Fig. 1, where the data for the K^+p cross section are also shown. As we can see from this figure, the $I = \frac{1}{2}$ experimental cross section for $K\pi$ scattering is almost 3 times larger than the K^+p cross section.

The optical model results [2,3] for the ratio

$$R = \sigma(K^{+\,12}\mathrm{C})/6\sigma(K^+d) \tag{3}$$

are shown in Fig. 2 by the lower band. This band repre-

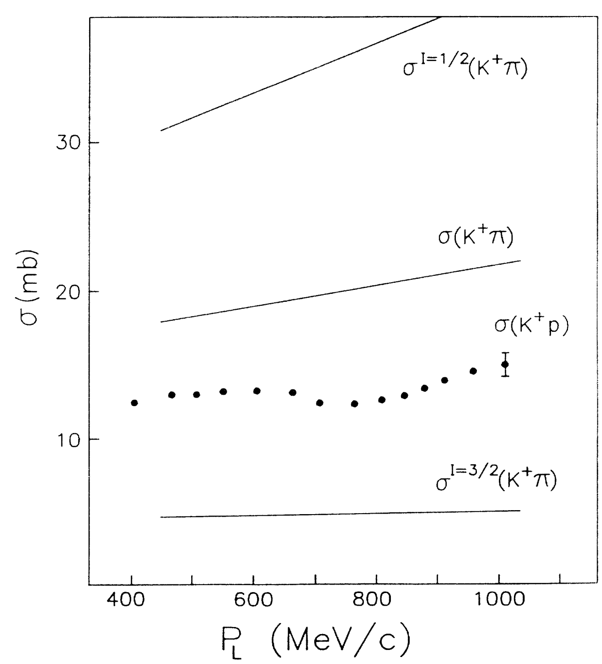

FIG. 1. Phenomenological fit for the $K^+\pi$ cross section. The intermediate line is the average of the two possible isospins, $I = \frac{1}{2}$ and $I = \frac{3}{2}$, of the $K^+\pi$ system. P_L is the laboratory momentum of K^+.

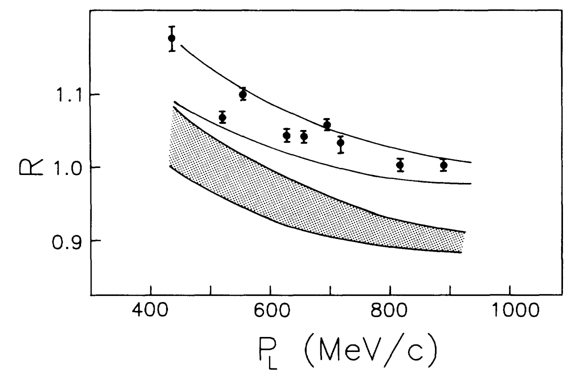

FIG. 2. The total-cross-section ratio for K^+-nucleus scattering. The data for ^{12}C are from Ref. [11]. The lower band shows the optical model results [3]. The upper band is the result of this work.

sents the uncertainty of the "conventional" calculations. Even with many possible sources of uncertainty of the conventional mechanism taken into account, there is still a discrepancy of about 10% between the calculated and experimental results.

We now show that this discrepancy can be eliminated by the contribution of virtual pions. Some amount of virtual mesons is present in a system of bound nucleons interacting by the effective mesonic field. The contribution of these mesons is not included in the elementary projectile-nucleon amplitudes used in the multiple-scattering formalism. The number of pions per one nucleon can be related to the enhancement factor K of the photonuclear sum rule [8]

$$n_\pi = \tfrac{3}{8} K/\langle \omega_\pi^{-1} \rangle m_\pi , \tag{4}$$

where $\langle \omega_\pi^{-1} \rangle$ is an average pion inverse energy. If we take [9] $\langle \omega_\pi \rangle = 400$ MeV, then from (4) we obtain [8] $n_\pi \approx 0.07$ for nuclear matter. Using energy-momentum conservation it was found in Ref. [6] that

$$n_\pi = (\langle \epsilon \rangle - \mu)/\langle \omega_\pi \rangle , \tag{5}$$

where $\langle \epsilon \rangle$ and μ are the average separation energy and the chemical potential. If we use for the nuclear matter $\langle E \rangle = 40$ MeV, $\mu = 8$ MeV, and $\langle \omega_\pi \rangle = 400$ MeV, we obtain the estimate $n_\pi \approx 0.08$, which is very close to the result of Eq. (4). In a recent work, Nakano and Wong [10] obtained the value of $n_\pi = 0.057$. Therefore, for the average number of pions per one nucleon, we use the intermediate value of

$$n_\pi = 0.07 . \tag{6}$$

The energy-momentum distribution of pions and the off-mass-shell continuation of the $K^+\pi$ amplitude are unknown. But as a first approximation, we can neglect them because of the smooth behavior of the $K^+\pi$ cross sections. Instead of (3) we can now write

$$R = R_{\text{opt}} + n_\pi \sigma(K^+\pi)/\sigma(K^+N) , \tag{7}$$

where R_{opt} is the optical model result of Ref. [3] and $\sigma(K^+\pi)$ is the average $K^+\pi$ cross section. For the latter we use the expression

$$\sigma(K^+\pi) = \frac{\sigma^{I=1/2}(K^+\pi) + \sigma^{I=3/2}(K^+\pi)}{2} , \tag{8}$$

since the isospin content of virtual pions is unknown. The last equation is, of course, an approximation that may be improved in later publications.

Numerical results are presented in Fig. 2 by the upper band. As we can see from this figure, the experimental data are now inside the theoretical band.

Let us now briefly discuss the uncertainties and the limitations of this model. First, we do not try to describe the differential cross sections. As pointed out in Ref. [3], there are large additional uncertainties in the experimental and theoretical (optical model) differential cross sections. The clean observable is the ratio of total cross sections. The average separation energy $\langle \varepsilon \rangle$ of ^{12}C is smaller than that of nuclear matter. Therefore n_π for carbon should be correspondingly smaller than the nuclear matter value. On the other hand, some authors claim larger values of n_π [12] and $\langle \varepsilon \rangle$ [13,14]. Therefore we expect that (6) does not significantly overestimate the effect. Equation (7) is certainly an approximate result. Besides usual limitations of the optical model, it is assumed that the multiple scattering from nucleons and the projectile-pion interactions develop independently. It is difficult to assess here the validity of this approximation, but it is likely that the error is smaller than the bare pionic contribution. The large uncertainty comes from Eq. (8), as it follows from Fig. 1. For $\sigma(K^+\pi)$ we simply used a value at the center of the corresponding uncertainty band. This value significantly overestimates the cross section for π^0 mesons, but it is close to the average cross section for the mixture of π^- and π^+ mesons. More detailed analysis of the isospin content of virtual pions as well as of the $K\pi$ phase shifts is needed. Note that results (1) and (2) are based on the elastic unitarity assumption [7] and may underestimate the $K\pi$ cross sections.

We conclude that the discrepancy between the conventional calculations and the data for the K^+-nucleus scattering can be explained by the contribution of virtual pions. These pions are the result of the binding nuclear forces. It was shown [6] that these forces can significantly change the nuclear structure function due to the binding correction. Thus the nuclear effects in the deep inelastic scattering and in the K^+-A scattering indeed may have the same physical origin.

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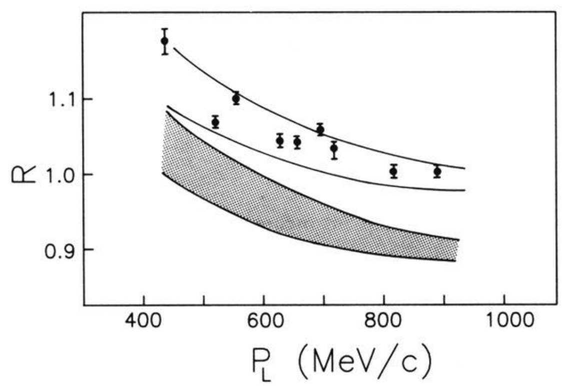

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