# Observation of a two-step Glauber process in a double charge exchange of $\pi^+$ mesons by nuclei

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A two-step Glauber process in a double charge exchange of charged particles was observed for the first time. The cross section of the process for $\pi^+$ mesons with a momentum of 2.9 GeV/$c$ produced as a result of double charge exchange in a mixture of carbon and xenon nuclei ($\langle A \rangle = 25$) is equal to $26 \pm 16$ $\mu$b, consistent with the theoretical prediction.

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In their theoretical paper Gevorkyan et al.[1] investigated the double charge exchange of charge $\pi$ mesons with energies $\gtrsim 2$GeV, within the framework of the Glauber theory; this exchange proceeds via a two-step process

$$\pi^{\mp} + 2p\,(2n) \to X^{0}pn \to \pi^{\pm}\,2n(2p), \tag{1}$$

where $X^0 = \pi^0, \eta, \rho^0, \omega, f, A_1^0$, etc. This mechanism gives rise to a small angle emission of energetic $\pi$ mesons with momenta that differ little from the initial momentum. In this investigation we predict the cross section for double charge exchange of intermediate and heavy nuclei, which is governed by this mechanism. These predictions thus far have not been verified experimentally.

We have investigated the double charge exchange of $\pi^+$ mesons with a momentum of 2.9 GeV/c by using the photographs of the 120-liter propanexenon bubble chamber[2] which was placed in an 18-kG magnetic field. The xenon content in the mixture is 52% by weight. We have scanned 116 000 stereo photographs. The scanning program provided for the search of events that had in the final state one $\pi^-$ meson and any number of protons that have been stopped in the bubble chamber

$$\pi^+ + A \to \pi^- + kp + A', \tag{2}$$

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where $k = 0, 1, 2, \ldots$ . The scanning efficiency was 90 $\pm$ 3%. We have identified 153 cases of the reaction (2), of which 137 cases were measured. We measured the momenta $p_{\pi^-}$ and the emission angels $\theta_{\pi^-}$ of $\pi^-$ mesons (with an accuracy of $\pm$ 13% and $\pm 1^0$) and the momenta and the emission angles of protons (with an accuracy of $\pm$ 10 MeV/c and $\pm 2^0$). The momenta of protons that were stopped in the bubble chamber were in the range of 120 to 700 MeV/c.

The two-step process (1) for $\pi^+$ mesons has the form

$$\begin{aligned} &\pi^+ + n_A \to X^o + p \\ &X^o + n'_A \to \pi^- + p, \end{aligned} \tag{3}$$

where $n_A$ is the neutron in the nucleus. The dominating intermediate states $X^0$ must be the $\rho^0$ meson, $\omega$ meson and $f$ meason.[1] As is evident from the production cross sections of these particles at our initial momentum, their contribution amounts to 82, 11, and 7%, respectively. Figure 1 shows the obtained $p_{\pi^-}$ — momentum distributions of all the measured cases of the reaction (2), which were divided into five groups according to the number of protons with energies $\geqslant$20 MeV. This boundary was selected on the basis of an experimental kinetic-energy distribution of protons from the reaction (2), in which there was a large abundance of cases with an energy $<$20 MeV, which corresponds to the evaporative process. As the calculation based on the Monte Carlo method showed, the protons have an average energy of about 70 MeV in the reactions (3).

The same calculation showed that 80% of the cases of the process (3) had $\pi^-$ mesons with $p_{\pi^-} \geqslant 2400$ MeV/c and $\theta_{\pi^-} \leqslant 14^0$, if the errors of our measurements are taken into account. Seven such cases, represented by dark columns in Fig. 1, have been identified. All these events have the value of transferred 4-momentum squared $<0.25$ $(\mathrm{GeV/c})^2$, i.e., the condition of small momentum transfer is satisfied for them.[1] The events with $\theta_{\pi^-} \leqslant 14^0$ are represented by cross-hatched columns in Fig. 1.

As follows from Fig. 1, six of the seven events, which satisfy the selection rules for the two-step process (3), are in the histogram 1c, i.e., they pertain to the events with two final-state protons (with energies $\geqslant$20 MeV), which is a necessary condition for the process (3). One event is in the histogram 1d. We can assume that it is attributable to the reaction

$$\pi^+ + n_A \to \pi^- + \pi^+ + p, \tag{4}$$

in which an energetic $\pi^-$ meson is produced, and a $\pi^+$ meson is absorbed by a quasi deuteron of a nucleus

$$\pi^+ + (pn) \to p + p\,. \tag{5}$$

This assumption is based on the experimental evidence that the reaction (4) at our momentum has the largest cross section among the single-nucleon reactions and that the reaction (5) is dominant in the absorption of $\pi^+$ mesons in a nucleus.[3]

The $\pi^+$ mesons produced in the reaction (4) can also be absorbed by a pair of neutrons

$$\pi^+ + (nn) \to p + n, \tag{6}$$

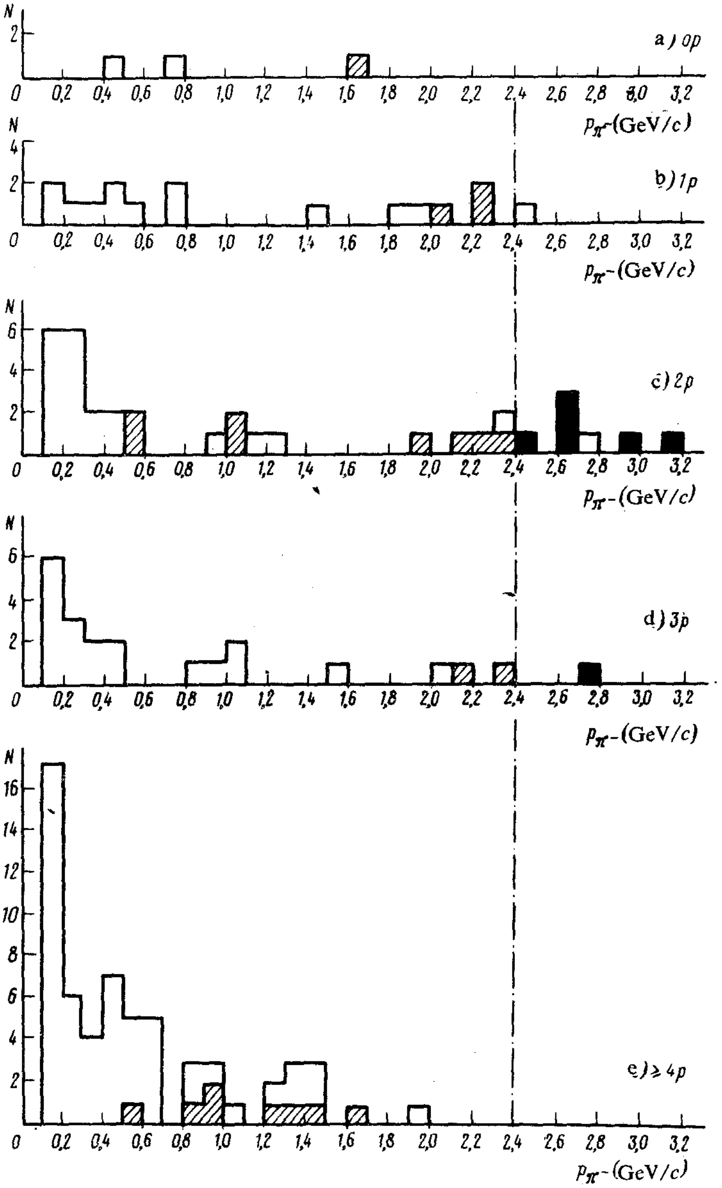

Fig. 1. Momentum distributions of $\pi^-$ mesons in the reaction (2) for different number of protons with energies ≥20 MeV. See the text for notations.

so that the processes (4) and (6), in which two protons are produced, can be the background source of the sought-for two-step process (3). As shown in the experiment,[3] the reaction (6) is at least a factor of two less probable than the reaction (5) and if we hypothesize that one dark event in Fig. 1d has the processes (4) and (5) as its origin, then the estimate, which takes into account the results of Ref. 3, as applied to nuclei of our mixture, shows that the background of the processes (4) and (6) amounts to 0.7 event of the selected events with two protons.

Another background source is the reaction $\pi^+ + A \to \pi^- + kp + m\pi^0 + A'$, in which the $\gamma$-ray quanta from the decay of $\pi^0$ mesons have not been recorded in the bubble chamber. A calculation showed that such a background amounts to 0.2 event.

One more background source for the process (3) can be the reaction

$$\pi^+ + n_A \to \pi^- + \Delta^{++} \tag{7}$$

with a subsequent absorption of the isobar[4,5] and production of two final-state protons

$$\Delta^{++} + n_A \to p + p . \tag{8}$$

However, one of the protons in such a process has a momentum $\geqslant 550$ MeV/c, while our bubble chamber has recorded protons with momenta $< 700$ MeV/c. Thus, the events of the processes (7) and (8) generally are incompatible with our scanning program. A more complex isobar-absorption mechanism than (8) involves the emission of a larger number of protons than that in the process (3).

Figure 2 shows the momentum distribution of protons for six events represented by dark columns in Figl 1c. We can see that it does not correspond with the assumption that the processes (7) and (8) exist. The curve represents the distribution calculated

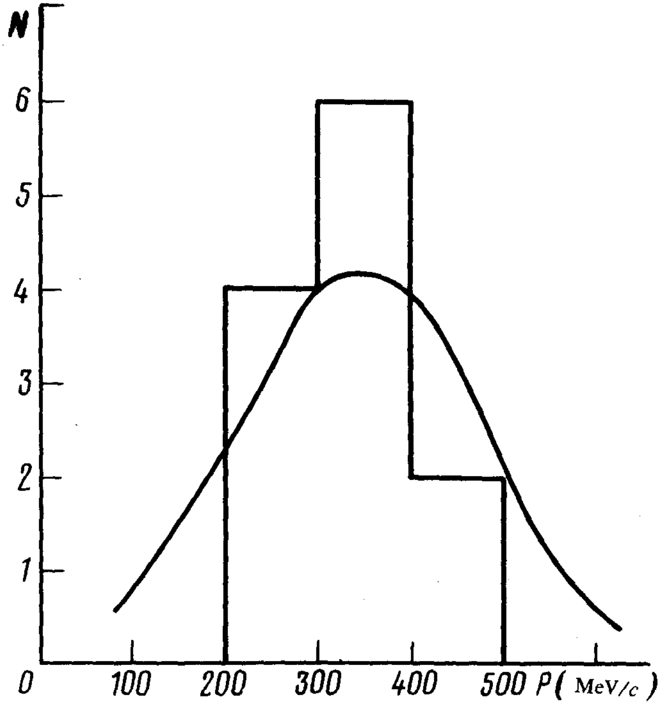

Fig. 2. Momentum distribution of protons for the events represented by the dark columns in Fig. 1c. The curve represents the predicted distribution for the process (3).

according to the Monte Carlo method for the process (3).

Thus, as follows from the preceding discussion, at least five of the six candidates selected can be reliably identified with the two-step Glauber process of double charge exchange of $\pi^+$ mesons by a nucleus.

To calculate the cross section of the process (3), we introduced corrections to the scanning efficiency, to the immeasurability of events, to the fraction of events with $p_\pi - < 2400$ MeV/c and $\theta_\pi - > 14^0$ and to the number of events in which at least one proton did not stop in the bubble chamber. The last correction, calculated by using the Monte-Carlo method, amounted to 28%. The cross section of the process (3), which is related to the average nucleus of the C and Xe mixture ($\langle A \rangle = 25$), is equal to 26 ± 16 $\mu$b, if all the corrections are taken into account. The error includes the possible background from the processes (4) and (6).

According to Gevorkyan et al.,[1] the predicted cross section of the Glauber double-charge-exchange process (3) at a momentum of 2.9 GeV/c is equal to 9 $\mu$b for a carbon nucleus and to 97 $\mu$b for a xenon nucleus. Hence, the cross section for the average nucleus of our mixture is equal to 19 $\mu$b, in good agreement with the value obtained by us.

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