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PION MOMENTUM SPECTRA IN A NUCLEAR CHARGE EXCHANGE REACTION Mg(t, ^{3}He)

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The charge exchange reaction Mg(t, ^{3}He) was investigated in an experiment using a streamer chamber. The branching ratios of the reaction channels (topologies) were obtained. The experimental momentum spectrum for pions was compared with the calculated one, and only 50% of pions were shown to be emitted by the delta isobars produced on a quasi-free nucleon in the target nucleus. It was also found that the mass of delta incorporated in the nucleus was reduced by 30—50 MeV in comparison with a free delta.

The investigation has been performed at the Laboratory of High Energies, JINR.

Пионные спектры в реакции перезарядки ядер Mg(t, ^{3}He)

С.А.Авраменко и др.

Реакция перезарядки Mg(t,^{3}He) исследована в стримерной камере. Определены соотношения вероятностей каналов реакций (топологий). Экспериментальный импульсный спектр пионов сравнивался с расчетными, что позволило установить, что только 50% пионов могут быть рождены при возбуждении дельта-изобары на квазисвободном нуклоне в ядре мишени. Выяснилось также, что масса связанной в ядре дельта-изобары на 30—50 МэВ меньше массы свободной изобары.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Numerous investigations of the inclusive cross sections in charge exchange reactions (^{3}He, t) at various energies and targets have shown [1,2] a significant role of isobar excitation in the process. It was also observed that the Δ peak in the t energy spectrum was broader and shifted towards a high energy region in the case of nuclear targets as compared with charge exchange on hydrogen. Collective effects like deexcitation of delta via the nonmesonic channel [3,4] $\Delta N \to NN$ or coherent pion production [5,6,7] in the target nucleus, suggested as well as the excitation of the isobar in the projectile nucleus [8], were discussed to explain the observed features.

To find out the predicted channels, the charged particles produced in the charge exchange reactions were registered and measured by large acceptance spectrometers in KEK [9], Dubna [10,11] and Saturne [12] experiments. In this way significant information about the role of collective effects like nonmesonic discharge of the delta isobar $\Delta N \to NN$ was obtained. The coherent pion production observed in the recent experiment [13] has confirmed that the approach is fruitful.

However, for a clear theoretical interpretation of the charge exchange reactions and delta interactions in nuclei, it is necessary to find out all involved processes and to measure the branching ratios of these processes. Our experiment was devoted mainly to this problem because the streamer chamber is really a 4π detector and the corrections due to the efficiency of trigger and chamber sensitivity are quite small. Therefore the reaction channels can be specified according to the number of produced charged particles with a subsequent detailed analysis of the channels. Particularly in this work the pions produced via delta excitation in the target nucleus were searched and the energy of nondelta pions was shown to be rather high. In other words, the analysis was devoted to the investigation of the channel with a single pion where the delta dominance was expected and a large nondelta fraction was rather a surprise.

The experiment was performed using the GIBS spectrometer facility in a 9 GeV/c tritium beam. The details of the experiment were discussed in the previous papers [10,11]. Here we would like to remind of a short list of the event measuring accuracy available in the analysis. The momenta of secondary charged particles were measured for all the events. The typical measuring accuracy of momentum was 2—3% for ^3He nuclei and 1—2% for π^- and protons. The angles were measured with an error equal approximately to a few milliradians.

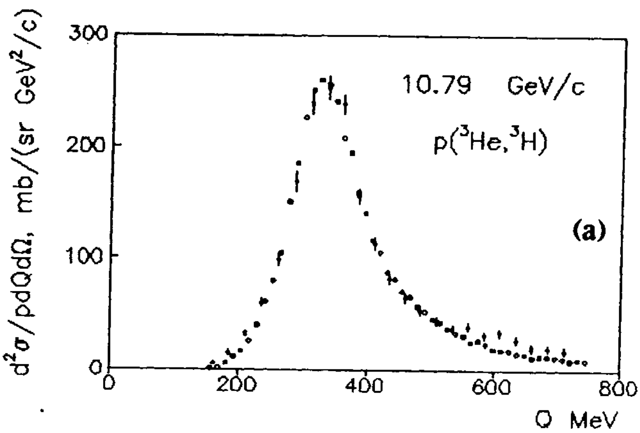
All positive secondary particles were regarded as protons, and negative particles, as π^-. The admixture of electrons (positrons) from γ conversion in the target did not exceed a few per cent of the total number of charged particles produced in the reaction. Nevertheless, almost all these leptons were excluded from the analysis because they were identified by ionization. Naturally, there was no doubt to identify the ^3He track: besides the ionization criterion, the ^3He momentum should be inside the specified band quite different from that expected for possible background tracks of p or d. The ^3He trajectories were extrapolated to the position of the trigger counters to check whether the chamber was triggered by the measured nucleus.

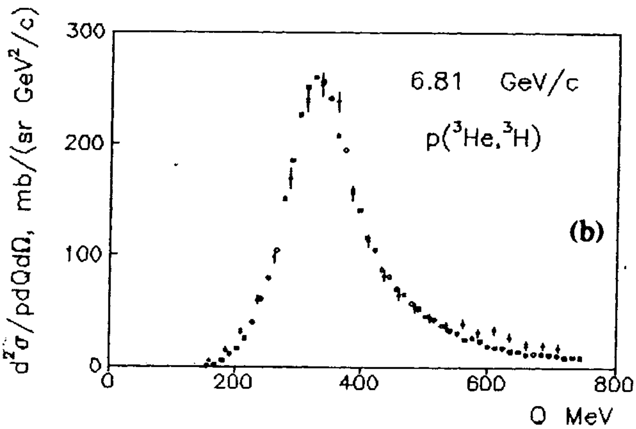
The total number of the identified and analyzed events was 1861. The numbers (N_-) of π^- and (N_+) of protons produced in the interaction were used to specify different channels of the reaction. Quasi-elastic interactions are not the subject of this experiment therefore the data from [3,14] were used to estimate (see also [11]) the fraction of quasi-elastic charge exchanges (0.12±0.01 of the total number of events) and to reduce the number of events in the group ($N_- = 0$, $N_+ = 0$) by 223. The reduced total number, 1638, was used to normalize the topological cross sections presented in the Table. (The cross sections of charge exchange reactions were presented in our previous paper [11].) It should be noted that small corrections like absorption of slow protons in the target were not taken into account in the Table.

One can see in the Table that the channel (1,0) is the most intensive and the only one that can be practically observed in the case of delta production on a quasi-free target nucleon. Now there is a natural idea to calculate the momentum spectrum for pions produced by deexcitation of delta and to compare the calculated distribution with the

Table of the normalized topological cross sections: R — fraction of events with specified topology (N_-, N_+)

N_-	N_+	R
0	0	0.32±0.015
1	0	0.38±0.016
1	1	0.089±0.008
0	1	0.14±0.01
0	2	0.035±0.005
other		0.036





Figs.1a and 1 b. Delta production model test. Points o in (a) and (b) calculated for two beam momentum values; • — experimental data [16]. The calculated spectra normalized at the maximum value. Q — energy, transferred to the target

experimental one. Our calculation is based on the assumption that delta production on the free and quasi-free nucleon should be similar and the same model can be used as in the case of NN interactions.

At first we had to check the model and calculation procedure itself by comparing with the experimental data. To describe delta production in NN interactions, we have used the same formulae and parameters as Jackson [15]:

$$W(\omega) = \frac{\omega_0 \Gamma(\omega)}{0{,}898\pi\,[(\omega^2 - \omega_0^2)^2 + \omega_0^2 \Gamma^2(\omega)\,]};$$

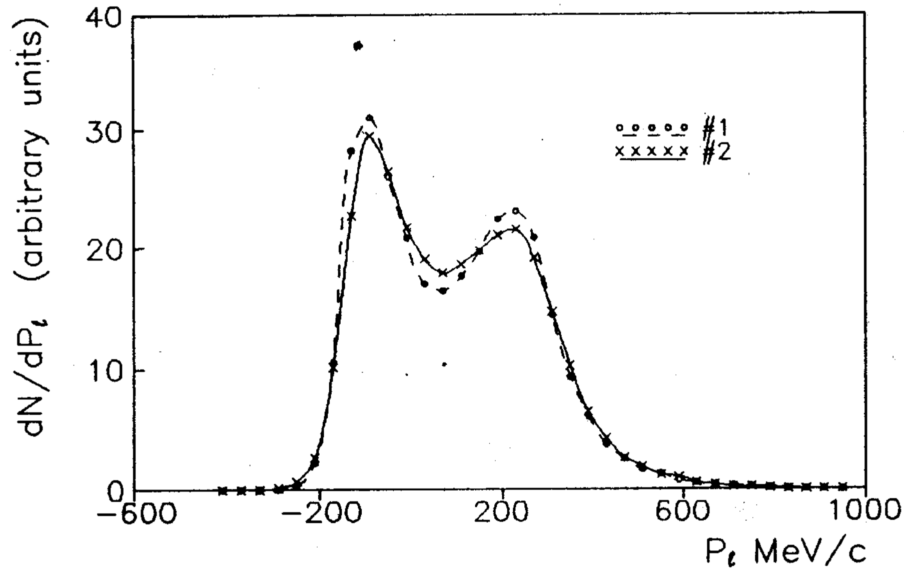


Fig.2. Pion longitudinal momentum calculated for the delta production on: a free nucleon (#1); a quasi-free target nucleon (#2)

$$\Gamma(\omega) = \Gamma_0 \left(\frac{q}{q_0}\right)^3 \frac{\rho(\omega)}{\rho(\omega_0)}; \ \rho(\omega) = [am_\pi^2 + q^2]^{-1};$$

$$a = 2.2; \ \Gamma_0 = 123 \text{ MeV}; \ \omega_0 = 1232 \text{ MeV}.$$

These formulae provide the distribution $W(\omega)$ of delta mass ω and, subsequently, pion momentum q in the Δ frame. Figures 1a and 1b show that the model is good enough to describe the experimental data [16] for the charge exchange reaction on hydrogen target $p(^3\text{He}, t)$ at different projectile energies. It should be also emphasized that in our experiment the beam energy was intermediate (9.15 GeV/c) in comparison with these two reference energies [16]. The same form factor was used here as in [16,17].

The next step in the calculation process was the introduction of nuclear (target) medium effects. One should expect a serious problem how to choose the distribution of Fermi momentum and binding energy for a target nucleon. Figure 2 shows that the pion momentum spectrum is rather insensitive to this choice. Indeed, one can see that two curves are much alike. One of them represents the pion longitudinal momentum distribution calculated in the case of the delta produced on a free nucleon. The second curve is for the delta produced on a quasi-free target nucleon on the

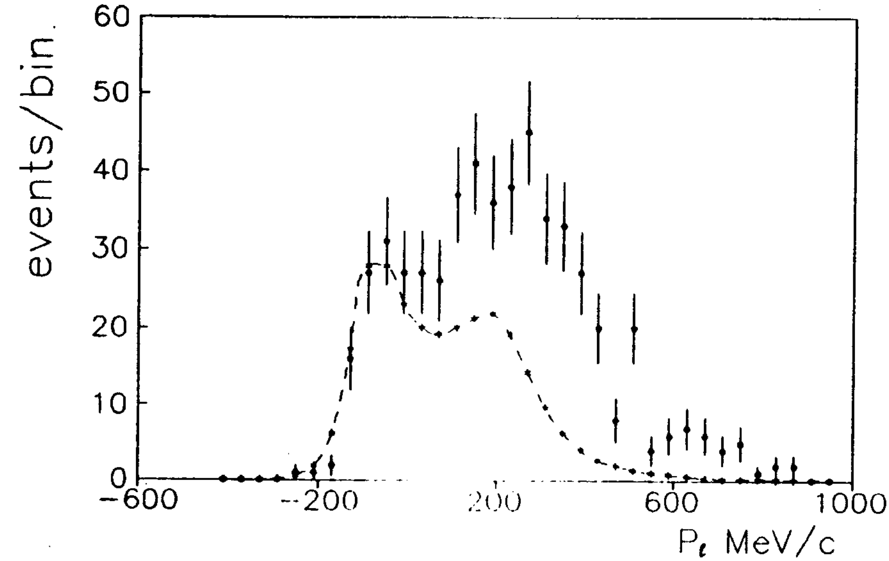


Fig.3. o — pion longitudinal momentum (P_π^l) spectrum (#1 — experiment). x — pion spectrum (#2) calculated for Δ produced on a quasi-free nucleon. The value of Δ mass reduced to 1190 MeV. The calculated spectrum was normalized so that it might not exceed the experimental data in any region of the spectrum

assumption of the Fermi momentum distribution like P^2dP over a 0—200 MeV/c interval (slightly less than in [18]) and a separation energy equal to E_{sep} = 20 MeV (evaluated from [19]). If the two curves are very similar, there cannot be a strong dependence either on the value of E_{sep} or on the Fermi momentum parameters. The additional calculation has proved that the pion momentum spectrum should be independent of the beam momentum distribution. It is worthy of note that such a projectile momentum independence was predicted in [8] for the delta produced in the target contrary to delta production in the projectile. Considering the two peaks in the pion spectrum, it should be noted that they arise from the angular distribution $1 + 3\cos^2\Theta$ which is essential in the OPE model.

All these tests were performed before the comparison of our experimental data and the calculated pion spectrum (see Fig.3). It is clear that only some part of real events can be produced in the process of delta excitation on a quasi-free target nuclon. In addition, it should be stressed that a possible improvement of the calculation procedure (more careful choice of parameters) cannot change this result significantly. Indeed, the calculated spectrum is centered with the value of Δ mass, but the left side is

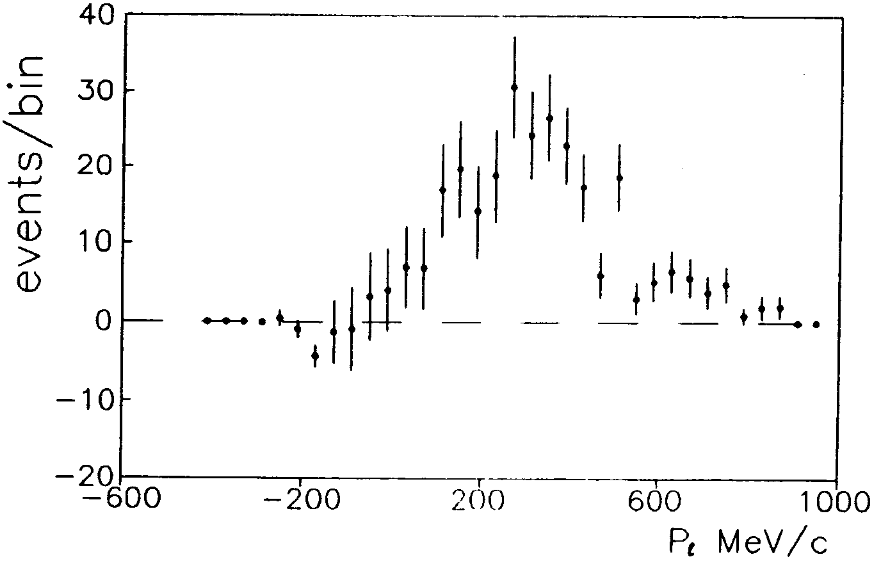


Fig.4. The spectrum of nondelta pions obtained by subtraction of the spectrum (#2) (model) from the spectrum (#1) (experiment); see Fig..3

fixed with the experimental spectrum. Moreover, to improve the left-side fit we had to reduce the delta mass by 40 MeV in comparison with the free delta. But if the delta mass decreases then the width of the pion momentum distribution becomes slightly narrow. (The reduction of the delta mass approximately by the same value of 30 MeV was observed in the Saturne [12] and KEK [9] experiments.)

Finally, we have obtained that 50% of the events are beyond the delta isobar spectrum, see Fig.3. The momentum distribution of these nondelta pions is reproduced in Fig.4. Here the mean value of longitudinal momentum $\langle P_\pi^l \rangle$ = 360 MeV/c is substantially higher than for delta pions, where $\langle P_\pi^l \rangle$ = 90 MeV/c.

The topological cross sections of the charge exchange reaction Mg(t, ^{3}He) were measured in real 4π geometry when minimum corrections for the branching ratios were needed.

The longitudinal momenta of pions were analyzed and it was settled that only 50% of the pions observed in the reaction $t + \mathrm{Mg} \rightarrow {}^3\mathrm{He} + \pi^- + \ldots$ can be described by the momentum spectrum calculated in the frame of the model with the delta produced on a quasi-free target nucleon. The mean momentum for the pions outside the calculated spectrum was much higher than that expected in the case of isobar decay. The production mechanism of these high energy pions should be investigated in future analysis and experiments.

There is evidence that the mass of delta isobar embedded in the Mg nucleus is reduced by the value of 30—50 MeV like a binding energy.

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