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Quasifree production of Σ's in the reaction $^{12}C(K^-,\pi^+)$

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The quasifree production of hyperons by K^- on C and Li has been calculated. A purely kinematical model has been used to correlate experimental $N(K^-,\pi^+)Y$ cross sections with the reaction amplitude of the kaon with a bound nucleon. In all cases one observes experimental points at lower missing mass values than the computed quasifree production cutoff. This is interpreted that a bound hypernucleus state exists.

The experimental pion spectra from nuclei bombarded by kaons lead to the observation and interpretation of bound hypernuclear states.[1-3] However, the quasifree production of a hyperon on a bound nucleon may interfere with the observation of the bound-state peak. The incoming kaon interacts with a nucleon in the target nucleus whereupon a free hyperon and a pion evanesce leaving a nucleus behind with A-1 nucleons. These quasifree reactions produce a peak corresponding to a two-particle reaction but they are displaced because of the binding of the struck nucleon and they are widened because of the Fermi momentum of that nucleon. This wide distribution might mask hypernuclear states and therefore, its location should be well established. The quasifree reactions have been discussed by Dalitz and Gal[4] and by Chrien, Hungerford, and Kishimoto.[5] The former authors ignored nuclear structure. Chrien *et al.*[5] used structure functions for the bound proton and the experimentally determined KN-$Y\pi$ amplitudes to calculate the proton-kaon interaction. The kaon-proton interaction is off shell and the authors do not state at which energy the reaction amplitudes are used. This calculation produces peaks that are close to the peaks that are attributed to the formation of a hypernucleus in its ground state.

In this paper, we propose to use a model described in Ref. 6. It makes use of an initial-state interaction to take account of the binding and the Fermi momentum after which the energy is determined for the reaction vertex. Figure 1 diagrammatically shows this interpretation of the quasifree reaction. All the momenta given in the diagram are four momenta. The bubble presents the initial interaction in which the four momentum p_1-p_0 is transmitted to the target nucleus and this energy-momentum transfer makes possible the dissociation of the target into a particle with momentum q and the remainder of the target with momentum p_5. Both particles are on the mass shell. The assumption that seems to hold for classical particles implies that all off-shell interactions sum up to this simple procedure. The initial-state interaction makes possible the conservation of energy and momentum at any instant during the reaction,

$$p_1+p_2=p_0+q+p_5=p_3+p_4+p_5 \ . \tag{1}$$

The fragments with momentum q and with p_5 emanate from a recoiling moving target in whose rest system the three-vectors satisfy,

$$\mathbf{q}'+\mathbf{p}_5'=0 \ . \tag{2}$$

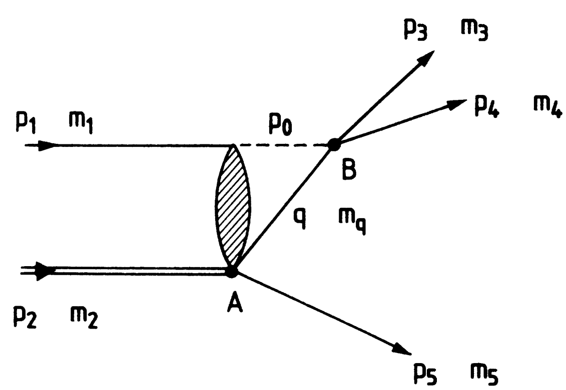

FIG. 1. Quasifree interaction diagram. The bubble represents the transfer of energy momentum to the target nucleus that is dissociated into the fragments m_q and m_5. The verteci A as well as B are on the mass shell. p_1 represents the four momentum of the incoming kaon, q is the four vector of the Fermi momentum of the transferred proton. m_3, m_4 and m_5 are the masses of the pion, hyperon, and recoil, respectively.

These equations make possible the computation of p_0,

$$(p_1+p_2-p_0)^2=(q+p_5)^2=(q'+p_5')^2 . \quad (3)$$

The recoil velocity of the target is,[7]

$$\boldsymbol{\beta}=(\mathbf{p}_1-\mathbf{p}_0)/(E_1+m_2-E_0) . \quad (4)$$

The Fermi momentum q' and p_5', which are in the recoiling target system, are Lorenz transformed by the velocity $\boldsymbol{\beta}$ into the laboratory system.

The total energy at the vertex B is

$$s=(p_0+q)^2 . \quad (5)$$

The momentum transfer is

$$t=(p_0-p_3)^2 . \quad (6)$$

The energy s depends on p_0 as well as on the Fermi momentum q. When the Fermi momentum increases, p_0

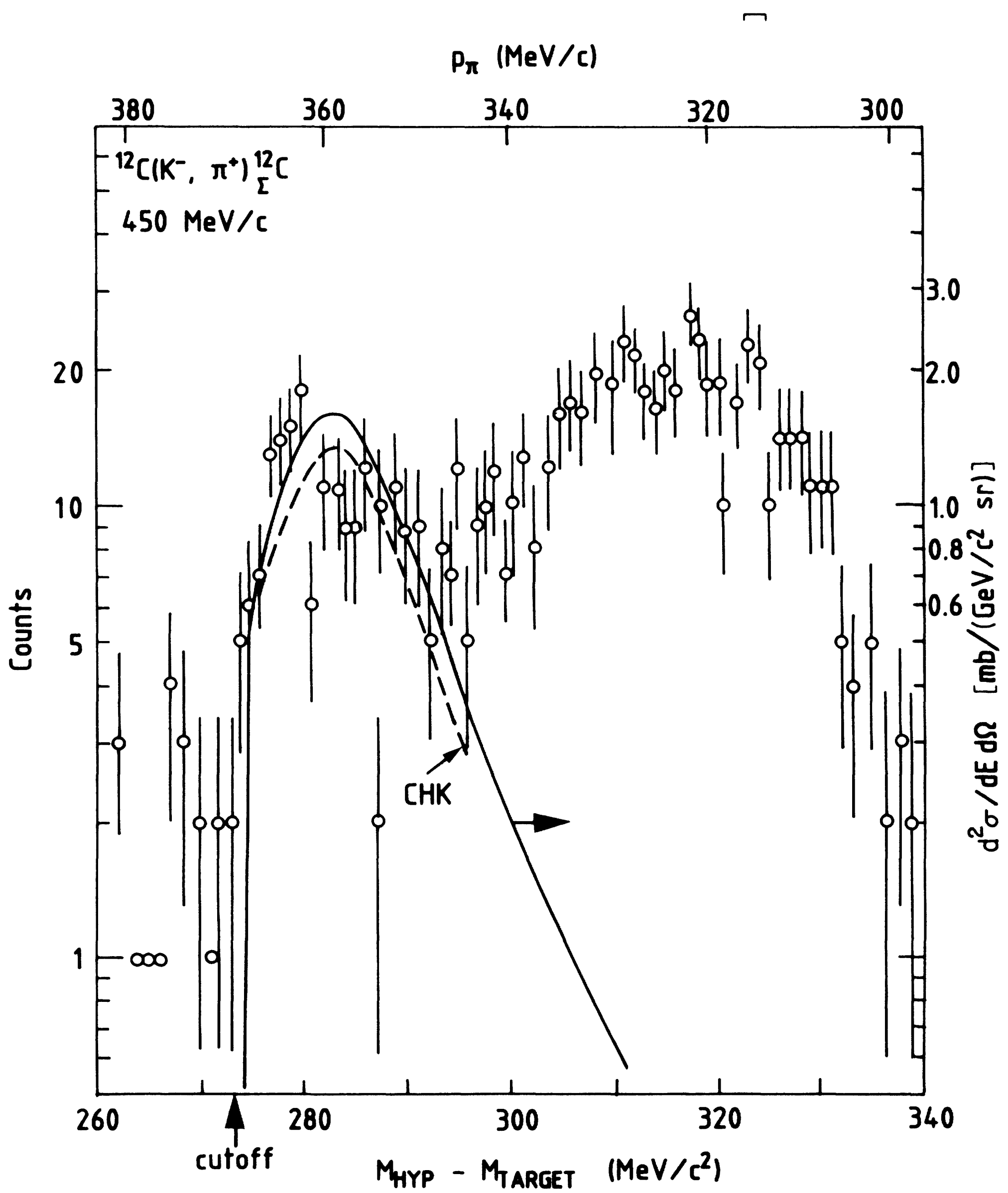

FIG. 2. The pion spectrum at 0° from the reaction $^{12}C(K^-,\pi^+)$ at 450 MeV/c incident momentum. The abscisse presents the mass difference between the hypernucleus and the target. It is equal to the difference between the total energy of the kaon and the pion. The left-hand ordinate is in arbitrary units. The right-hand ordinate presents the value of the computed cross sections. The calculated quasifree reaction is normalized at its maximum. The dashed curve is from Ref. 5. The cutoff value is the minimum possible mass difference for the quasifree reaction.

will decrease because of the condition for energy conservation. The total energy of the vertex B will not appreciably change for increasing momentum transfer for a particular reaction. As a consequence, if a resonance at the vertex B exists one cannot scan through the resonance by changing the momentum transfer without a change of the incident momentum. Or, one may not observe a resonance because this model will not show resonances at the position where the simple impulse approximation would. The use of the distorted-wave impulse approximation will not change this prediction because it only modifies the magnitudes of the reactions, it does not shift the spectra.

The cross section is calculated in the usual way, flux factor times the three-body phase-space times the structure function of the transferred particle with momentum q in the target nucleus times the matrix element square for the vertex B. The cross sections for the $Kp \rightarrow Y\pi$ system are taken from Ref. 8, from which the invariant matrix elements are calculated. The structure function for the proton in ^{12}C, which has to be transformed from the recoiling system to the laboratory system, is obtained from Ref. 9. A similar function is used for Li. The constants are determined by the nuclear radius and the binding energy. The cross section for the three-body final state is integrated over the unobserved particles. The reaction is assumed to be coplanar.

Figure 2 shows the experimental data for 450 MeV/c kaons on carbon as a function of the difference between the mass of the hypernucleus and the mass of the target that is equal to the total-energy difference of the kaon and the pion. The computed curve is adjusted at its maximum to the experimental data. However, the calcula-

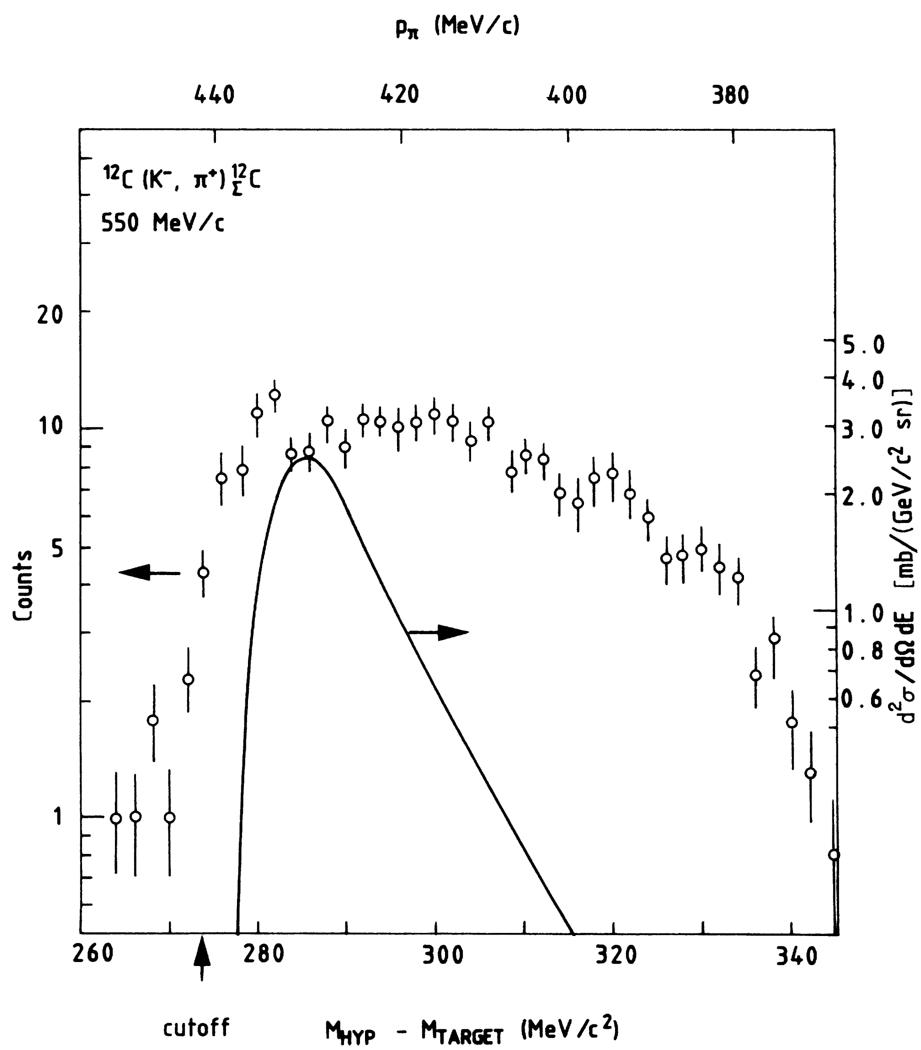

FIG. 3. The pion spectrum at 0° from the reaction $^{12}C(K^-,\pi^+)$ at 550 MeV/c. As in Fig. 2 the computed curve is adjusted at its maximum to the experimental points which is at 285 MeV/c^2.

tion is absolute except for some possible statistical factors (spin has not been considered). The cross-section values are presented on the right-hand scale. In Ref. 10 Walcher presented experimental values for the cross section that are a factor of 10 larger than the computed values. The dashed curve shows the results of the relative calculation of Chrien, Hungerford, and Kishimoto.[5] The arrow presents the kinematical limit for the quasifree process. The experimental points at mass values lower than the cutoff are interpreted as showing the formation of the bound hypernucleus state. The remaining cross section for this state is much smaller than formerly assumed.

Figure 3 shows the same results for 550 MeV/c incident kaons. The left-hand ordinate corresponds to the experimental data and the right-hand side to the calculated cross section. The fit is made at 285 MeV/c^2. These results show clearly that the points left of the theoretical curve, at lower mass values correspond to the hyperon bound state. As in Fig. 2, the fit to the experimental results is made at the maximum of the computed curve which is at 285 MeV/c^2.

Figure 4 presents the results for 713 MeV/c kaons on ^{6}Li. In this case, the experimental and calculated cross sections are in agreement. It is surprising that the experimental cross sections for carbon at 450 MeV/c and for Li at 713 MeV/c are very similar, whereas the computed values vary by a factor of about 20. The dashed curve presents again the calculated result of Ref. 5.

The present calculation produces mass distributions that are narrower than those from the impulse approximation, which is due to the constancy of s for the reaction vertex B as already discussed. The shift to mass values larger than those observed supports strongly the existence of bound states.

Below threshold the sigma could be produced in a virtual state that interacts with a nucleon to produce a lambda and a nucleon except for a possible cusp at the threshold[11] of sigma production. Below the threshold one might expect a continuous background between the lambda peak and the peak attributed to the bound sigma. This background is seen in Fig. 4 of Ref. 12. The present calculation cannot estimate the contribution of these triangular diagrams. These effects and a possible partial experimental overlap of the bound and quasifree production makes the evaluation of the value for the cross section of the bound state uncertain.

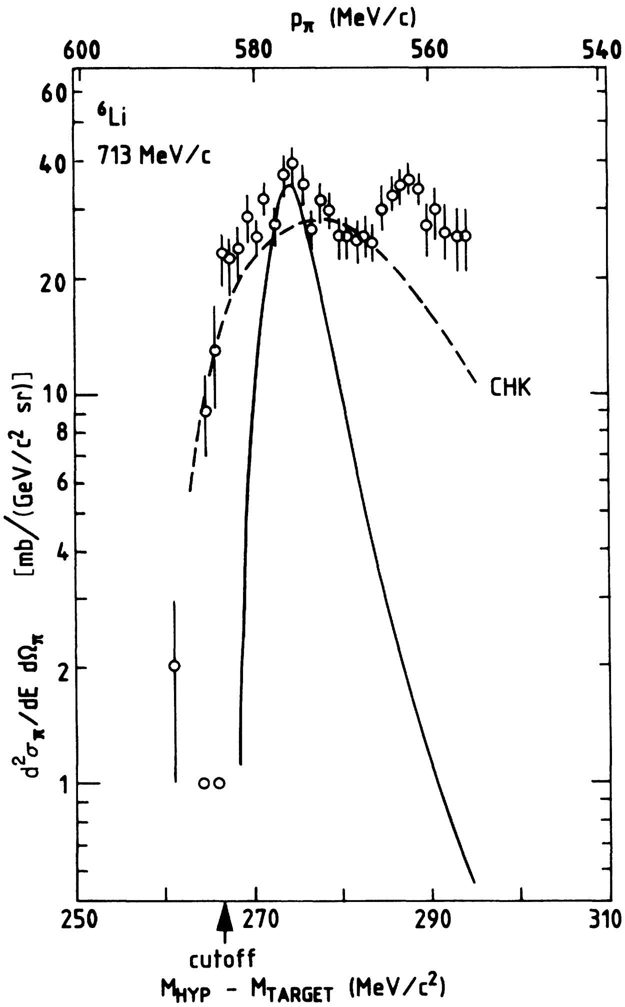

FIG. 4. The pion spectrum of the reaction ^{6}Li(K^-,π^+) at 713 MeV/c. The experimental data and the calculated result are absolute.

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