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COHERENT MESON PRODUCTION

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Abstract

In this talk we briefly review the basic features of the $(^3He,t)$ reaction on p and d targets, the (α,α') reaction on the proton and coherent pion production. The (α,α') reaction serves as a link between the mechanism of delta excitation in the projectile and coherent pion production. The interesting properties of this latter phenomenon are discussed. Finally a few words are said about coherent η production as an intrument to determine the ηNN coupling.

1 The $(^3He,t)$ reaction on p, d and nuclear targets.

The original motivation behind much work done later was the observation of the shift of the delta peak in nuclei in the $(^3He,t)$ reaction compared to the reaction on proton targets [1, 2], see fig. 1. This shift has been much discussed and usually a collective Δh excitation in the nucleus is involved as the reason for the shift, or at least part of it [3, 4]

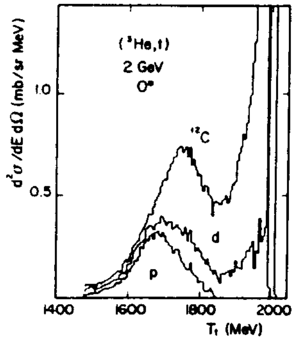

Fig. 1: $(^3He,t)$ excitation on proton, deuteron and ^{12}C targets.

Here I just want to recall the attention on two basic features of fig. 1:

i) the strength in the deuteron excitation function is also considerably shifted. Obviously one can not invoke collective effects in the deuteron to explain this shift.

ii) the quasielastic peak for ^{12}C at large t energies in fig. 1 extrapolates below the Δ peak and some of this strength is actually tied to quasielastic channels and not Δ production.

The shift in the deuteron was naturally explained in terms of Δ excitation in the projectile [5]. While the approaches of [3, 4] consider only Δ excitation in the target (DET), in ref. [5] the authors considered also Δ excitation in the projectile (*DEP*), see fig. 2

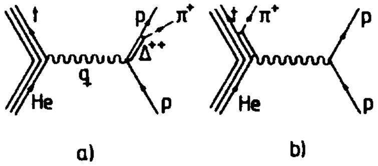

fig. 2: a) Δ excitation in the target (*DET*). b) Δ excitation in the projectile *DEP*.

In [5] it was found that while the *DEP* mechanism was small in the $(^3He,t)$ reaction on the proton target, this was not the case in a neutron target because the strength of the *DEP* mechanism is increased by a factor 3 and the one of the *DET* mechanism is decreased by a factor 3 with respect to the reaction on the proton. This occurs simply because of the isospin dependence of the amplitude. On the other hand the *DEP* mechanism concentrates its strength at larger t energies, as can be easily seen by making a boost in the *DET* mechanism. As a consequence the $(^3He,t)$ reaction on the n target has its strength shifted towards largest t energy and the sum of the p and n strengths reproduces well the experimental values as it is shown in ref. [6]. In this latter work the $(^3He,^3He)$ reaction is studied theoretically and it was found there that the *DEP* mechanism is largely dominant. Such experiments are not yet done and we think they would be very useful to help us gain control on the basic dynamics of this reaction.

The second point is that there are many quasielastic channels, not tied to Δ excitation or pion production, reflected in the large peak in fig. 2 at t energies close to $2000\,MeV$. A thorough description of all the channels that contribute to this peak is done in ref. [7]. It is not our point to discuss it here but we recall that a substantial part of the strength below the apparent Δ peak in the ^{12}C excitation function is due to these channels and has nothing to do with modifications of the Δ properties in the medium.

2 The (α,α') reaction in the Δ excitation region.

Now we come back to the question of Δ excitation in the projectile. The experimental evidence for the relevance of this channel was given recently in the (α,α') experiment [8]. This is an interesting reaction where the *DET* mechanism is forbidden and only the *DEP* mechanism is allowed, see fig. 3

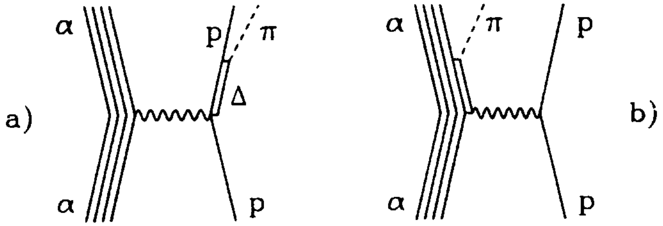

fig. 3: Δ excitation in the $p(\alpha,\alpha')$ reaction.
a) *DET* mechanism, forbidden by isospin,
b) *DEP* mechanism, allowed by isospin.

The experiment of [8] was searching for the Roper excitation but simultaneously found a very large background of Δ excitation in the projectile as is shown in fig. 4. The solid line in the figure is the theoretical result of ref. [9].

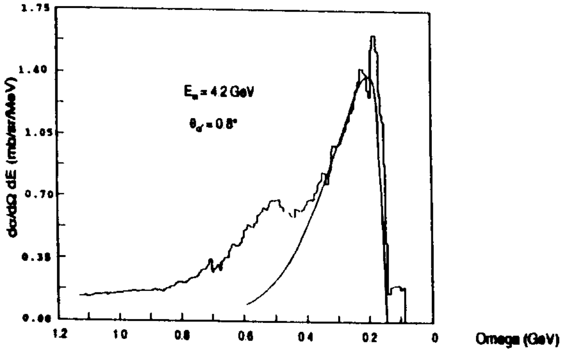

fig. 4: Excitation function for the (α,α') reaction on a proton target. Theory from [9].

The shape of the energy distribution is well reproduced in fig. 4 by the theoretical results of [9] based on the mechanism of Δ excitation in the projectile. The strength is also well reproduced as one can see in fig. 5 for the energy integrated cross section as a function of the α' scattering angle.

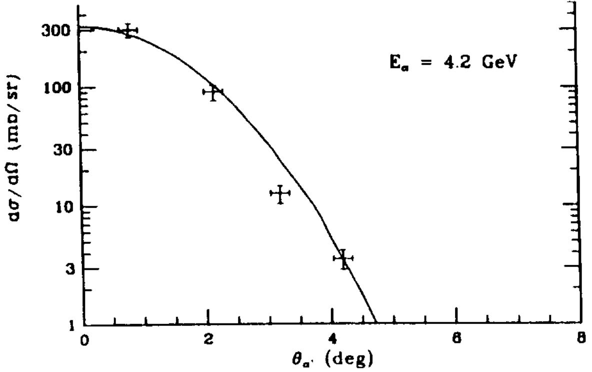

fig. 5: Angular distribution of the energy integrated cross section in the $p(\alpha, \alpha')$ reaction. Theory from [9].

The elementary $NN \to N\Delta$ cross sections are also well reproduced with the model which we use [9] which contains one pion and ρ exchange modulated by the indirect effect of short range correlations.

3 The alternative point of view in the (α, α') reaction: coherent pion production.

The calculations of [9] for the (α, α') reaction account for distortion of the N wave functions crossing the α particle as well as distortion of the produced pion and renormalization of the Δ properties in the medium.

Now we would like to take in alternative point of view on the (α, α') reaction which is easily visualized if the α particle, (^4He nucleus) is assumed to be at rest and a proton is shot against it. We would then have

$$p +^4 He \longrightarrow p +^4 He + \pi^0$$

$$\longrightarrow n +^4 He + \pi^+ \qquad (1)$$

In both cases we have a reaction of the type (p, p) or (p, n), with pion production, leaving the nucleus in its ground state. This is what we call coherent pion production in nuclei, in this case coherent pion production on ^4He. Only, in this experiment the pion is not seen and its variables are integrated in the measured cross section.

The fact, however, that we reproduce this experiment with our theoretical tools gives us confidence to use them to make predictions for coherent pion production in different nuclei.

4 Coherent pion production in nuclei.

Coherent pion production of the type of eqs. (1) or different nuclei has been the subject of recent theoretical investigations [10, 11, 12]. Although there are still some differences in the input and the results in the different approaches, many of the features of the reaction are common. Particularly the peak of the energy distribution of the coherent production cross section is shifted considerably towards lower excitation energy, more or less peaking at the same position as the shifted peak of the inclusive cross section. In ref. [12] it was shown that this channel in addition to the other incoherent channels of ref. [9] was partly responsible for the shift of the Δ peak observed in the $(^3He, t)$ inclusive cross section of ^{12}C in fig. 1. It was also proved that the reaction does not proceed like ordinary Bremsstrahlung, where the interaction of the proton with the nucleus allows a real pion to be produced, see fig. 6a. It rather proceeds as depicted in fig. 6b where the interaction of the pion with the nucleus is the responsible agent for the reaction

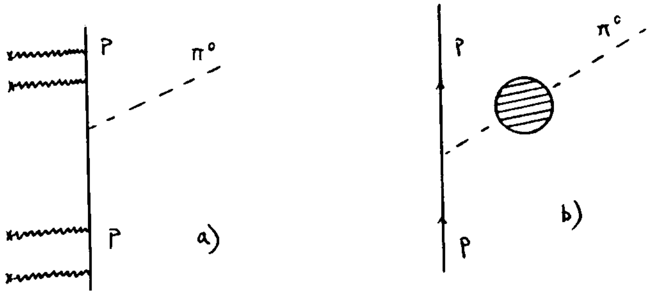

Fig. 6: Different mechanisms for coherent pion production. a) Bremsstrahlung like (forbidden for kinematical reasons for forward angles of the proton. b) Production through the interaction of the pion with the nuclear medium.

The fact that the mechanism of fig. 6b is responsible for the reaction allows us to qualify the reaction as virtual pion production followed by the elastic scattering of the virtual pion with the nucleus till it becomes real and can be observed. The study of these reactions will help us enlarge our knowledge of pion nuclear physics by extending the information of the pion nuclear interaction to the realm of virtual pions.

In what follows we present some results obtained recently for coherent pion production on different nuclei. In fig. 7 we show the results for the (p,n) reaction creating coherently a π^+ on ^{12}C, ^{40}Ca and ^{208}Pb as a function of the energy for proton beams of $T_p = 800 MeV$.

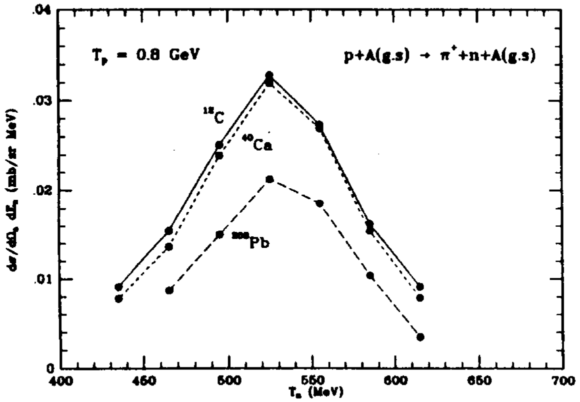

fig. 7: Cross sections for coherent π^+ production with the (p,n) reaction on ^{12}C,^{40}Ca,^{208}Pb as a function of the pion energy.

We can see that the strength in the different nuclei is similar, with ^{12}C with a little bigger cross section than ^{40}Ca or ^{208}Pb.

The differential cross sections are interesting. They are rather forward peaked in the direction of the (p,n) momentum transfer, particularly in heavy nuclei, like ^{208}Pb, see fig. 8.

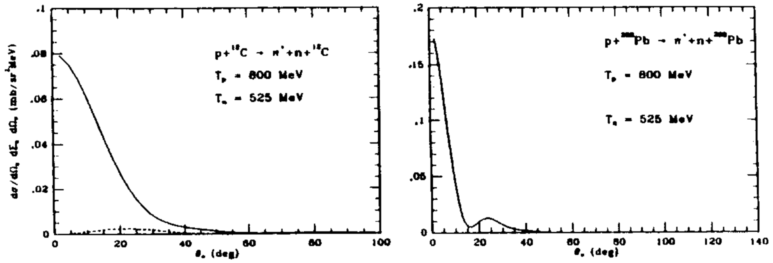

fig. 8: differential cross sections for coherent pion production in ^{12}C and ^{208}Pb.

In fig. 9 we also show how the cross sections change with the energy of the beam. The cross sections increase as the beam energy increases.

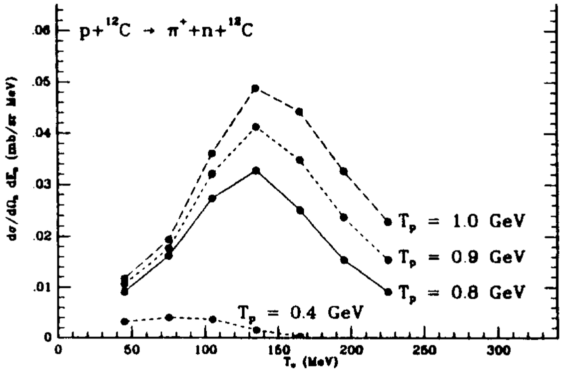

fig. 9: Cross sections for coherent p production in the (p,n) reaction on ^{12}C for different incident beam energies.

Experiments on this reaction are coming, with preliminary results on coherent π^+ production on the $(^3He,t)$ reaction on ^{12}C [13], which shows qualitative similarities with the results of [12] regarding the position of the peak and the angular distribution.

Some useful information on coherent pion production in the (p,n) reaction is given by the experiment of [14]. There a "π^+ alone" was detected meaning that no other charged particles were produced simultaneously. Hence this channel includes coherent π^+ production and incoherent $pn \to nn\pi^+$ processes. In fig. 10 we show our calculated results for the coherent part of this cross section, adapted to the experimental cuts. We observe that about 1/3 of the cross section corresponds to coherent pion production and that the position of the peak of the cross section corresponds to the experimental one.

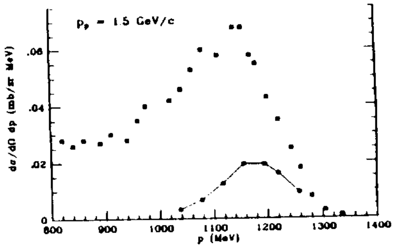

fig. 10: Experimental cross section for "π^+ alone in (p,n) on ^{12}C, including coherent π^+ production and $pn \to nn\pi^+$. The curve shows our calculated coherent cross section.

In ref. [15] there are also recent theoretical calculations of the (p,n) coherent production on ^{12}C. Although the features are qualitatively similar to those found here, the peak in [15] is displaced to smaller pion energies than in our case and the strength of the cross section is about less than a factor of two bigger. The coherent pion cross section of ref. [11] for the $(^3He,t)$ reaction is also about a factor of two bigger than in [12] or [16]. These observations make us conclude that experiments on the reaction are really needed to help us understand better the dynamics of the process.

Coherent pion production offers the possibility of changing the energy of the beam, or the angle and energy of the outgoing nucleon in order to create arbitrary off shell initial conditions of the pions and extend our knowledge of the pion nucleus interaction to arbitrarily off shell pions, a completely new realm of physics, complementary to our information on real pion and which should put extra constraints on theoretical models of the pion nucleus interaction.

One can also see that the cross section is roughly proportional to

$$(V_l^2 cos^2\theta + V_t^2 sin^2\theta)F(\vec{q}-\vec{q}\,')^2 \qquad (2)$$

with V_l, V_t the longitudinal and tranverse parts of the $NN \rightarrow N\Delta$ interaction and $F(\vec{q}-\vec{q}\,')^2$ the nuclear form factor ($\vec{q}$ momentum of the initial virtual pion and $\vec{q}\,'$ momentum of the final real pion). The presence of the form factor makes the cross section very forward peaked and hence this stresses the contribution of the longitudinal part of the $NN \rightarrow \Delta N$ interaction. Hence coherent pion production is a good source of information on this part of the elementary amplitude.

One should also stress the fact that one can now produce a π^0 coherently with the (p,p') reaction. This would allow us to study π^0 elastic scattering on nuclei (starting from off shell pions) and this would be the first study of π^0 elastic scattering on nuclei.

On the other hand the fact that the pions are produced in a very narrow cone and its energy is well known by detecting the energy of the emerging nucleon (small recoil nuclear energy) should stimulate thoughts to see if one can use this reaction to produce monochromatic and unidirectional pion beams like in the tagging of photons.

5 Coherent eta production.

We will be deliberaty brief here since a contribution is published in these proceeding elaborating on this issue [17]. The topic was raised in a recent paper [18] in which is was shown that the study of coherent η production in nuclei is a useful tool to determine the elementary ηNN coupling, since the cross section around the peak of the $N^*(1535)$ excitation is proportional to $g^2_{\eta NN}$, with all the other elements in the cross section well under control. In ref [17] the authors report additional information concerning the dependence of the cross section on the angle of the outgoing nucleon of the (p,p') reaction, which should be of use to experimental facilities planning to do this experiment, which is feasible particularly in facilities like CELSIUS or COSY.

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