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During the past twenty years, or so, high intensity electron accelerators and meson factories have allowed us to probe the nuclear dynamics under various extreme conditions.

This workshop offers us with a good opportunity to summarize these studies and forecast their future developments. I will not review all the progresses which have been made ; most of them being discussed by the others speakers during this conference. I will rather concentrate myself on one topic : the study of the interplay of the degrees of freedom of the many nucleon system and the internal degrees of freedom of its constituents. It lies at the boundary of Nuclear Physics and Particle Physics, and its study has really been made possible by the advent of high intensity accelerators of intermediate energy.

Although the issues are still controversy an intense activity is devoted today to its study, and to my opinion its development will be the main axe of the research program of new accelerators which are planed or under construction.

Let me illustrate this statement with the simplest nuclear system : the two nucleon system. Their interaction (Fig. 1) is very well described [1]) at large distances by the pion exchange potential, and at intermediate distances by the exchange of two correlated pions with a total isospin $T = 0$ (which are often parametrized in the OBE potential [2-3]) by the σ meson). Between the exchange of these two pions, one of the nucleons, or both, can be transformed into a Δ. Below the pion production threshold virtual Δ's enter the description of the Nucleon-Nucleon interaction, but above they can be created freely during a collision between two nucleons : the problems of the Nucleon-Nucleon interaction and of the Nucleon-Delta interaction should be solved at the same time in a coupled channel formalism. This is the first place where the internal degrees of freedom of hadrons enter Nuclear Physics.

At small distances the exchange of vector mesons (ρ,ω) plays a role, but it is also here that the quark structure of the nucleon is expected to enter into the game. This is the second place where the internal structure of hadrons plays a role, but the relative importance of these two mechanisms, the double counting problem and the relevance of the description of the nucleus in terms of quarks are still open questions.

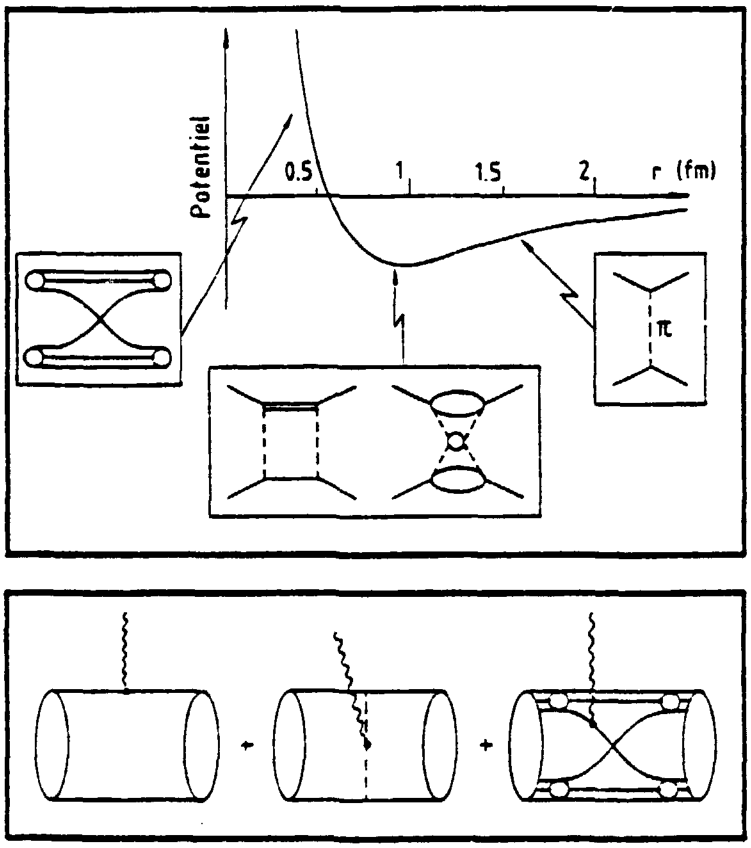


Figure 1. The nucleon-nucleon potential and the dominant driving terms. They must be iterated to obtain the full T-matrix. At long distance the pion exchange mechanism dominates. At intermediate distance a Δ can be created between the exchange of two pions. At short distance heavy mesons can be exchanged, but also the subnuclear degrees of freedom are expected to play a role : the Quark Interchange Mechanism is one possible example. When the electromagnetic probe interacts with the nucleon current in nuclei, gauge invariance requires also its interaction with each charged particle which is exchanged in the driving terms.

Systematic studies of reactions induced by (real or virtual) photons and by pions (or hadrons) provide us with two complementary ways to disentangle these various mechanisms.

The coupling of a photon to a nuclear system is well under control, since it must satisfy the Gauge Invariance Principle and since it is weak enough to be treated as a small perturbation. For instance, the electromagnetic probe has allowed us to disentangle the long range part of the Nucleon-Nucleon interaction, which is mediated by the exchange of a charged pion, and the intermediate range part, which is mediated by the exchange of two correlated pions of which the total charge is vanishing [1-3]).

However the Nucleon-Nucleon interaction at intermediate range, is dominated by mechanisms which involve the creation and the propagation of the Δ as an intermediate state. Its description relies heavily upon our knowledge of the N-Δ interaction. On the one hand, pion induced reactions offer us with a powerfull way to study it. Since the pion is strongly coupled to the Δ, experiments with high statistical accuracy can be performed, but it is absorbed at the nuclear surface, and does not see the entire nuclear volume. On the other hand, a (real or virtual) photon can also exite the Δ, but it interacts weakly and is not absorbed at the nuclear surface. It sees the entire nuclear volume, and can create the Δ in the very center of the nucleus, making possible the study of its interaction in the final state.

At short distances the problem is to disentangle the mechanisms which have to do with the internal structure of the nucleon (quark interchange for instance) and the contribution due to meson exchange, which dominates at large distances but still contributes here. To day, it is difficult to tell what will be the specific role of pion and photon induced reactions, for probing the short range behaviour of nuclear systems. But the sensitivity of a (real or virtual) photon to the local variations of the charge and the magnetization densities should be systematically exploited. Contrary to pions, virtual photons provide us with the possibility of varying independently their energy ω, their sqared mass q^2 and their degree of longitudinal polarization ε.

Most of pion and photon induced reactions, performed until now, can be understood in terms of nucleons, pions and Δ's. However I will show that this agreement is achieved at the price of the adjustement of two parameters (the πNN form factor and the ρ-nucleon coupling constant) which may simulate more subtle short range effects. At the end of my talk, I will discuss briefly the relevance of the analysis of the same reactions in terms of the quark degrees of freedom.

Let me begin with a short description of the method of analysis which I am using. It is fully described in ref.^{5}) in the case of photon induced reactions and its extension to pion induced reaction is straightforward ^{6}).

Starting from effective Lagrangians for the basic πN and γN couplings, the amplitude is expanded into a series of relevant diagrams, as shematically depicted in Fig.2. Besides the Δ creation diagram, the non resonant Born Terms play a significant role in the

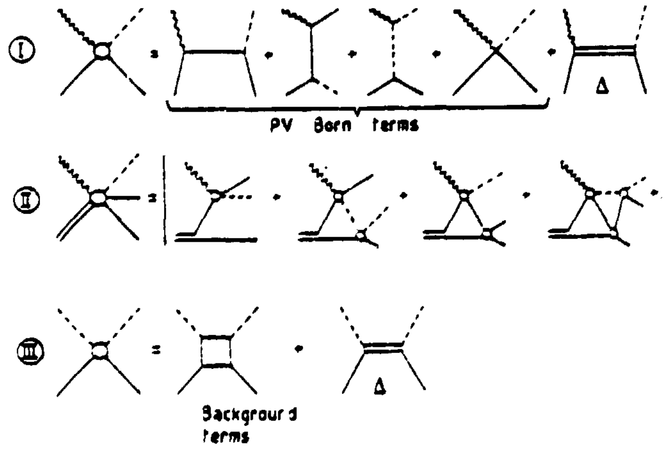


Fig.2 The relevant diagrams in the description of the elementary operators γN → πN (I), πN → πN(III). The multiple scattering series of the pion created at one bound nucleon is schematically depicted in (II).

analysis of the $N(\gamma\pi)N$ reactions. They are computed with the πN pseudo vector (PV) coupling in order to fulfil the constraints due to low energy theorems. I use the non relativistic reduction of these operators, in which all terms up to, and including, order $1/m^2$ are retained. Contrary to pion photo-production, pion- nucleon scattering is dominated by the creation of the Δ in the P_{33} channel. Other partial waves are small, and I parametrize them by the corresponding phase shifts 7).

In a nucleus, the pion, which is photoproduced or which scatters on a bound nucleon, may escape freely or may undergo one or several rescatterings. The details of the calculation of each corresponding diagrams can be found in ref.5). To day I would like only to recall that this diagrammatic approach is very well suited to the analysis of reactions induced in the few body sytems, and has two main advantadges. On the one hand, it allows to deal easily with mechanisms which involve many partial waves. This is particularly convenient when dealing with processes occuring at high energy and/or involving few emitted particles. On the other hand, each diagram can be singled out by looking at its singularity and choosing the kinematics in such a way to enhance it. Indeed this possibility has been fully exploited at Saclay in the study of the $D(\gamma,p\pi^-)p$, $D(\gamma,pp)\pi^-$ or the $^4He(\gamma,p\pi^{\pm})$ reactions 5) and more recently of the $D(\gamma,\pi^{\pm})NN$ reaction 8). The analysis of reactions induced in ^3He is in progress.

Recently I have extended this kind of analysis to pion induced reactions : the $D(\pi^{\pm},p)NN$ reaction 6) performed by a SIN-SACLAY collaboration, and the $D(\pi^{\pm},\pi^{\pm}p)n$ reaction 9) performed at Los Alamos by the Rice University group.

All these studies have allowed us to get a fair understanding of the basic mechanisms which govern the Δ creation and propagation in the few body systems. On the one hand, the multiple scattering expansion is well under control. The few body wave functions are well known. Since the pion propagates on (or very close to) its mass shell the calculation relies upon the well known amplitude of pion photoproduction and scattering on free nucleon. On the other hand, it has been possible to define a part of the $N\Delta$ interaction which does not reduce to the multiple scattering of its constituents (See fig.3). It is mediated by the exchange of virtual mesons, and looks like the NN interaction, to which it is strongly coupled. I will not discuss further these topics since all the details, of the formalism can be found in refs.5 and 10). The most recent developments are given in ref.11).

The pion which scatters or which is photoproduced on a bound nucleon may also be kept inside the nucleus and be reabsorbed by another nucleon. Although the method of calculation of this pion reabsorption diagram is the same as the pion rescattering diagram (see Fig.3), the virtual pion which is reabsorbed is highly off its mass shell, and the free pion photoproduction operator, as well as the pion absorption

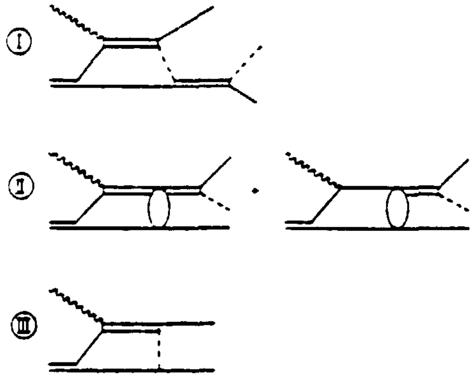


Figure 3. The different pieces of the ΔN interaction. I : The exchange part is mediated by a pion which can propagate on shell. It is very well described by the multiple scattering of the Δ constituents (pion or nucleon). II : The direct part of the NΔ interaction is mediated by the exchange of virtual mesons, and looks like the interaction between two nucleons. III : The NΔ and NN systems are stongly coupled through the NN → NΔ transition amplitude which dominates many break-up channels in reactions induced on the few body systems.

operator, should be corrected. Two ways are usually followed to overcome this difficulty.

On the one hand, since it is far off-shell, the exchanged pion is sensitive to the finite size of the nucleon, and I use at each pion-baryon vertex a monopole form factor

$$F_\pi(q^2) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - q_\pi^2}$$

where q_π^2 is the squared mass of the virtual pion.

On the other hand, other virtual mesons can also be emitted and reabsorbed. Among them the ρ-meson exchange diagram plays an important role (in which case I use a dipole ρ-baryon form factor with a cut-off mass equal to two times the nucleon mass).

I have determined the values of the cut-off mass Λ_ρ and the ratio G_ρ^2/G_π^2 between the square of the rho- and the pion-baryon coupling constants by fitting 12,13) the 90° excitation function of the d(γ,p) reaction cross-section (Fig.4). It turns out that, in this reaction, the ρ-exchange mechanism is negligible below the pion production threshold, and only affects significantly the Δ-N → N-N transition in the resonance region. It is therefore possible to separately determine the cut-off mass $\Lambda_\pi = 1.2$ GeV at low energy and the ratio $G_\rho^2/G_\pi^2 = 1.6$ in the Δ region. They lie in the range of the uncertainties of the currently accepted values 13).

This model also provides us with a good representation of the angular distributions. As an examples, I show in Fig 5 the variation with the photon energy, of the cross section at $\theta_\lambda = 0°$ which has always been a puzzle, but which is fairly well reproduced by the model. Details are given in ref 12. I wish only point out here that the agreement is due to the fact that I compute directly the photodisintegration amplitude from the vector part of the current (I do not use the Siegert

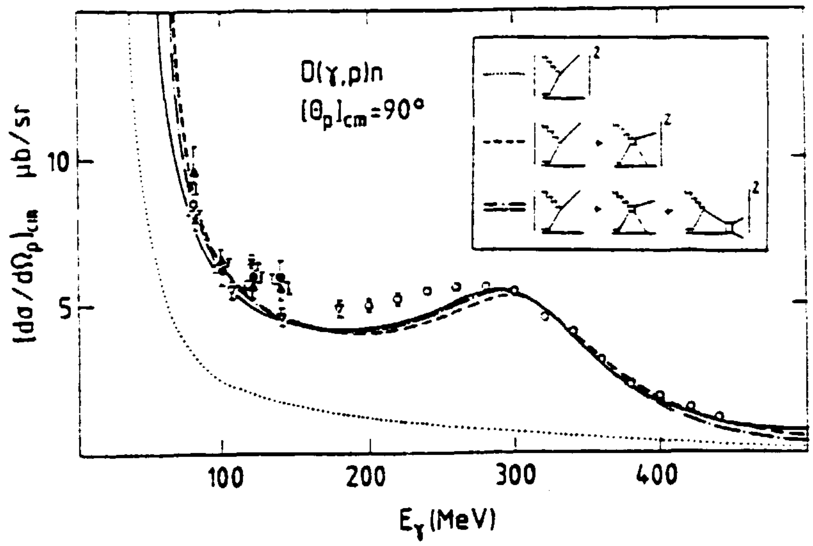


Figure 4. The excitation funtion at θ_p = 90°, of the d(γ,p)n reaction is plotted against the incoming photon energy E_γ. The high energy experimental points have been obtained at Bonn[4]). At low energy the references can be found in refs.[12,13]). The dotted and dashed curves correspond to the plane-wave calculation without and with the exchange current contribution respectively. The dash-dotted and the full curves include also the neutron-proton final state interaction, in the S and S+P states respectively.

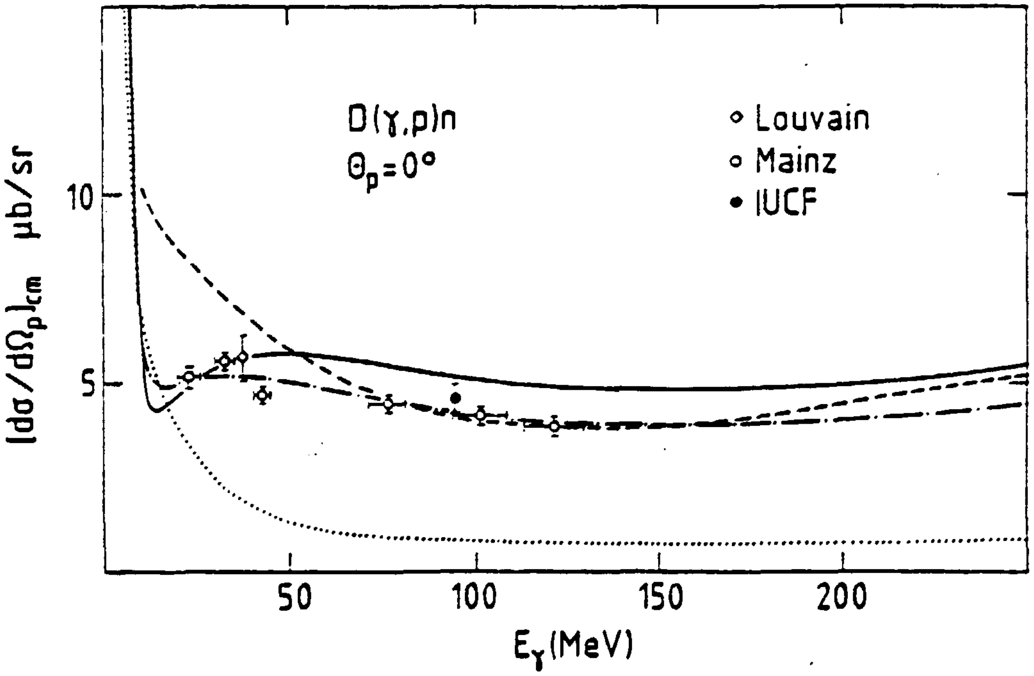


Figure 5- The excitation function at θ_p = 0°, of the d(γ, p)n reaction is plotted against the incoming photon energy. The meaning of the curves is the same as in Fig. 4. The references for the experimental points can be found in ref.[12]).

hypothesis) and to the fact that all terms of order $1/m^2$ are taken into account from the beginning of the calculation.

The extension of this formalism to the photo and the electrodisintegration of the three body systems is straightforward. The only change is the nuclear wave function [15]) and there are no free parameters. The total two-body photodisintegration cross section of ^{3}He is plotted in Fig.6 together with the total photodisintegration cross section of deuteron.

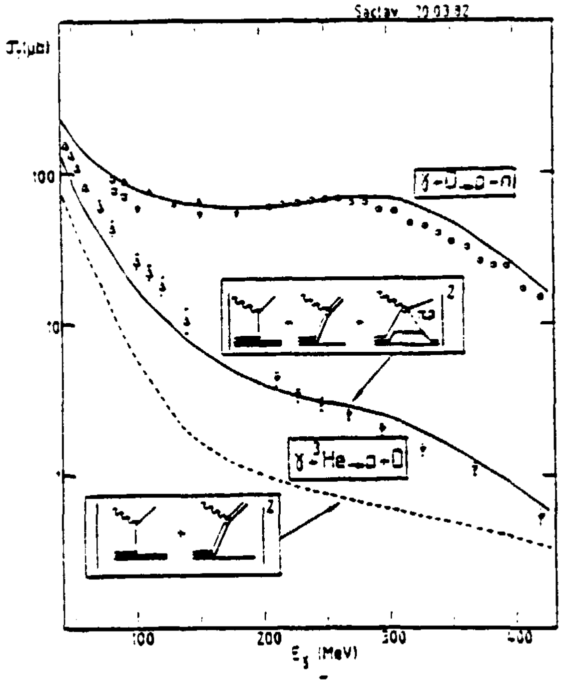


Figure 6 : The integrated cross the two-body photodisintegration of the deuteron and the ^{3}He nucleus are plotted against the energy of the incoming photon. The high energy data points have been recently measured at Bonn[14,16]). The meaning of each curve is explained in the insets.

In both case the contribution of the exchange current is essential to reproduce the data[14,16]). The angular distribution of the proton measured at E_γ = 240 MeV is plotted in Fig.7. The meson exchange contribution is very important and the cross section is very sensitive to the details of the model. For instance the fit to the experimental data [16-18]) is significantly improved when the d-wave parts of the spectator nucleon and the deuteron, which is emitted in the meson exchange diagram, are also taken into account (the d-wave part of the active deuteron is also important[13]), but it is always taken into account in the two-body operator).

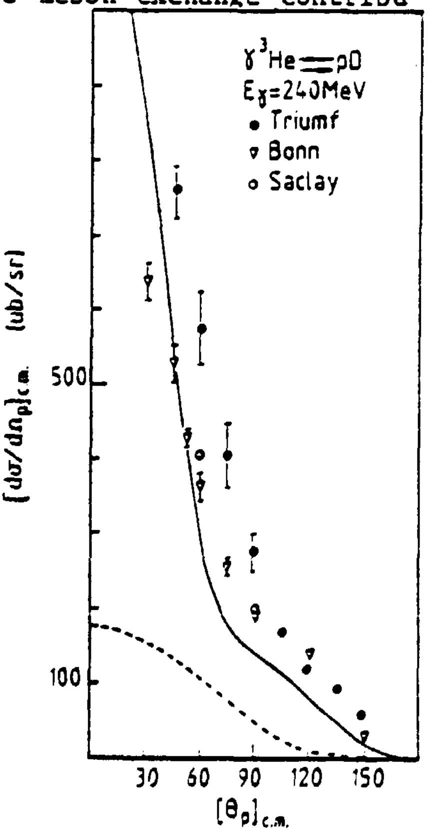


Figure 7 : The angular distribution of the protons emitted in the ^{3}He(γ,p)d reaction when Eγ = 240 MeV. The experiments have been performed at Bonn [16]), Saclay [17]) and TRIUMF [18]). The dashed curve corresponds to the Born approximation. The dash-dotted curve includes the meson exchange contributions, where only the S-wave parts of the final deuton and the three body system are retained. Their D-wave parts are included in the full line curve.

It is only the use of a good, and realistic, three-body wave function and of good elementary operators which allows such a good fit. Had I used a more phenomenological three-body wave function (as a cluster representation which fits the three-body form factors 19) for instance) the disagreement between the theory and the experiment would have been catastrophic.

The proton polarization (Fig 8) in the ^{3}H(γ,p)D reaction is even more sensitive to the details of the model. These final state interactions play a signifiant role and help to bring the theory close to the data. For instance the proton polarization at Eγ = 140 MeV is vanishing in a plane wave treatment. It is worth while to point out that these data have been obtained in the inverse reaction : the radiative capture of polarized protons on deuterium. This is a good example of the complementarity of high intensity proton and electron machines.

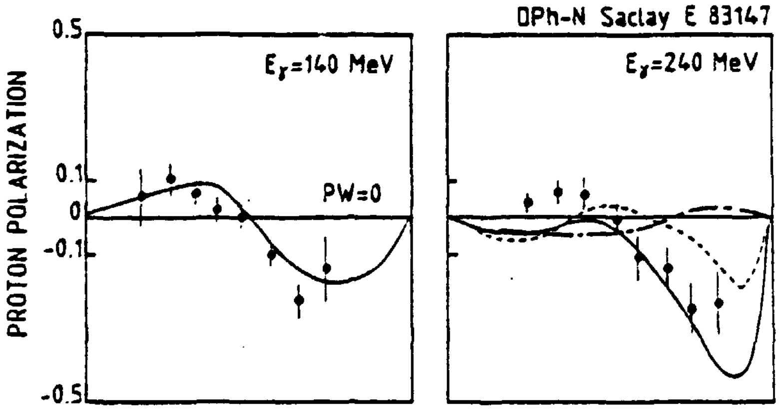
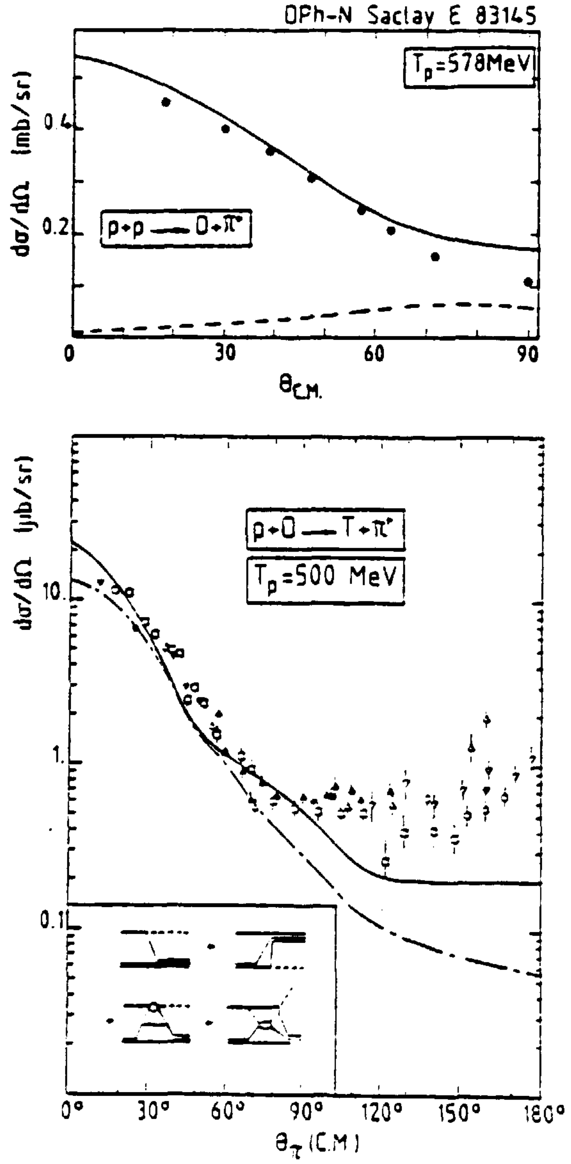


Figure 8 : the proton polarization in the ^{3}He(γ,p)d reaction 18). Only the S wave parts of the three body and the deuton wave function are retained in the dot-dashed curve (plane wave). The D wave parts are included in the broken line curve. The final state rescattering of the proton and the deuton in the S, P and D waves is included in the full line curve.

The same formalism can be applied in a straightforward way to the analysis of the pp → dπ$^+$ reaction 20) and the pd → tπ$^+$ reactions 21). As an example, I show Fig.9 the unpolarized angular distributions of these two reactions at an energy close to the mass of the Δ-resonance. The measurements have been performed at SIN 22), TRIUMF 21) and SATURNE 24).

The Δ creation mechanism dominates the cross section. The cut-off mass Λ_π = 1.2 MeV, in the πNN form factor, is the same as in the analysis of photodisintegration reactions. The ρ-nucleon coupling constant is slightly higher ($G_\rho^2/G_\pi^2 \sim 2.4$), but this is presumably due to the multiple scattering of the pion in the entrance channel. The general trend of the analysing power for polarized proton induced reactions are also well reproduced.



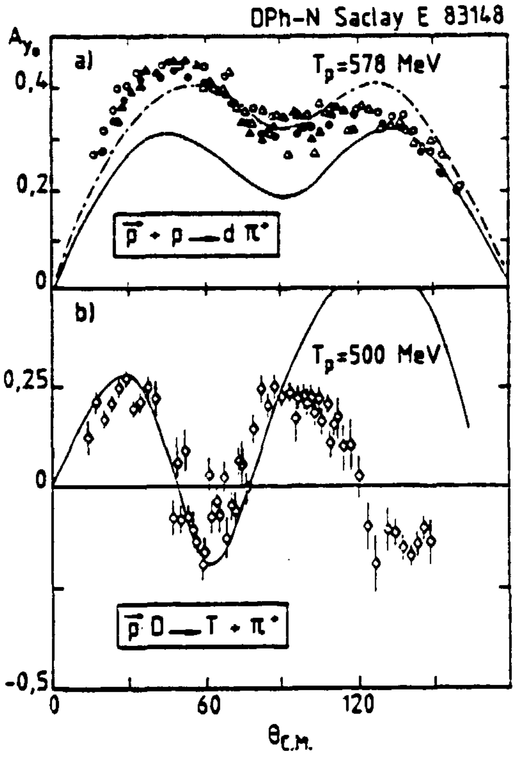


Figure 9 : The unpolarized angular distribution of the reactions pp → $d\pi^+$ (a) and pd → $t\pi^+$ (b). The full line curves represent the full calculation. The broken line curve does not take into account the pion rescattering effects. Only the S-wave parts of the three body system and of the target deuteron are retained when computing the dot-dashed line curve. The data come from refs.[22-24]).

Figure 10 : The analysing power in the reaction pp → $d\pi^+$ (a) and pd → $t\pi^+$ (b). The full line curve represents the full calculation. Only the Δ contribution to the pion rescattering diagram is kept in the dot-dashed line curve. The data an from refs.[22],[23]). Only the Plane Wave results are depicted. The proton-proton scattering or the pd scattering have not yet been included in the initial state.

However, the same discrepancies as in the analysis of the $pd \rightarrow {}^3He\gamma$ reaction remain in the analysis of the $pd \rightarrow t\pi^+$ reactions. While the unpolarized angular distributions are very well reproduced at forward angles, the model underestimates the data at backward angles. While the analysing power of the $pd \rightarrow t\pi^+$ reaction is well reproduced at forward angles, the fit to the data is poor at backward angles.

The source of these discrepancies may be the three-body wave function itself. Although a general consensus in now reached on the stability and the reliability of the numerical solutions of the Fadeev equations, all the existing wave functions underbind the three-body systems. This shortcoming has sizeable consequences even at low momentum transfer 25), and may play a role in the analysis of reactions, such as the $pd \rightarrow t\pi^+$ or $pd \rightarrow {}^3He\gamma$, which involve high momentum components of the wave functions.

Moreover, the cross section of these two body break-up channels is very sensitive to the small components of the three body wave function (See Fig.7). So far I have retained only the dominant S and D waves. The small P-wave components may also play a role, and they must be included before making a definite statement on the source of the disagreement.

These discrepancies may also be the signature of mechanisms which involve the three nucleons of the target. Some examples are given in Fig.11. The photoproduced pion may scatter twice, or two pions may be created on one nucleon and subsequently reabsorbed. The creation of two Δ's may also be considered. Those diagrams are expected to contribute at backward angles, or at high energy, when the diagrams involving two nucleons are suppressed by the nuclear form factors.

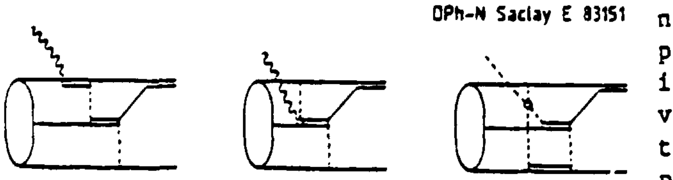


Figure 11 : Possible three nucleon mechanisms in pion or photon induced reactions at intermediate energy. They involve the double scattering of the pion, the creation of two pions at one nucleon and/or the creation of two Δ's.

Athough all these possible explanations must be investigated and open new perspectives for looking for non trivial mechanisms, it is important to begin to firmly establish the basis of our knowledge of the two-body mechanisms.

Since the neutron and one of the protons must recombine into the final deuton, they are strongly suppressed in the two-body break-up channels. On the contrary in the three-body break-up channel, it is possible to select kinematical conditions where these two-body mechanisms are not suppressed. I have discussed the relevant issues in ref.11), and the study of the reaction $^3He(\gamma,p)x$ ref.26) and $^3He(e, e'p)X$, ref.27) are in progress at Saclay. The corresponding pion induced reactions (^{3}He(π, p)X, ^{3}He(π, pp)X or ^{3}He(π, pn)X) are also studied at los Alamos, at SIN and at TRIUMF ref.28). Since J. Morgenstern will discuss the ^{3}He(e, e'p)np reaction, I show in fig. 12 the preliminary results of the study of the ^{3}He(γ, p)X reaction. This is the spectrum of the proton emitted at a fixed angle. While the peak, which appears at the highest momentum, corresponds to the two-body break-up channel, the dominant effect comes from the disintegration of a nucleon pair almost at rest. The top of the corresponding peak corresponds precisely to such a kinematics and its width is due to the Fermi motion of the pair. The curve is the convolution of the model25) and of the monochromatic photon line shape. It is obtained by in flight annihilation of positrons, and the negative tail comes from the subtraction of the bremsstrahlung background (I refer to ref.8) for a detailed discussion of the experimental method). The parameters are the same as in the treatment of the two-body break-up channels, but although the cross section is still sensitive to the correlated two-nucleon wave function, it is only sensitive to the long range part of the spectator nucleon wave function, which is not sensitive to the small component of the three-body wave function but which is basically given by its asymptotic properties.

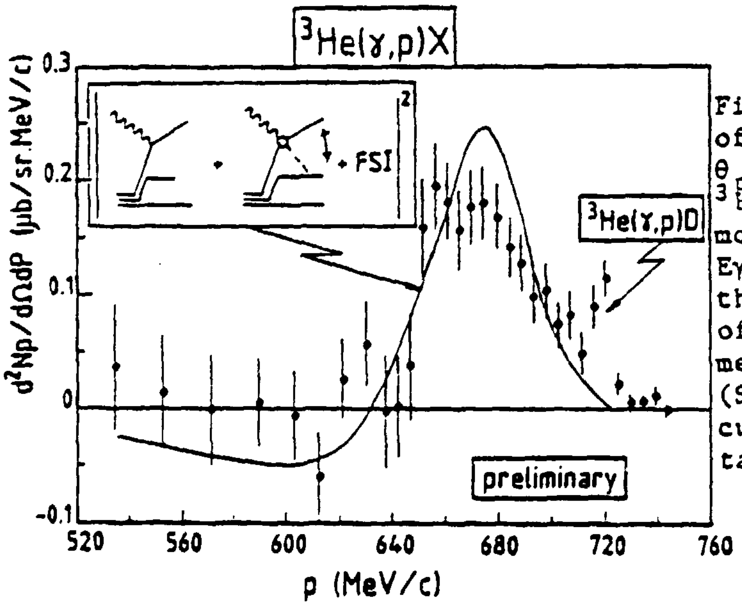


Figure 12 : The spectrum27) of the proton emitted at θ_p = 23° in the reactions ^{3}He(γ, p)X induced by monochromatic photons of Eγ = 310 MeV. The curve is the result of the folding of the model25) and the measured beam line shape. (See ref.8) for the discussion of the experimental method).

Those two-body mechanisms are also very important in the analysis of the electromagnetic form factors of the few body systems. They correspond to the popular meson exchange mechanisms, which are extensively reviewed during this conference 29,30). While gauge invariance constrains the leading terms (order 1/m), low energy theorems and PCAC constrain also the terms of order $1/m^2$ (see for instance ref.5). An elegant way to satisfy these two requirements is to deduce the exchange currents from the pseudo-vector πNN Lagrangian 5,12,13). It is remarkable that such a procedure allows us to reproduce not only the magnetic form factor but also the charge form factors of ^{3}He and T, ref.29).

As in the case of the break-up reactions, this good agrement, at such high momentum transfer, is achieved by introducing two extra parameters, which are not constrained by gauge invariance and PCAC : the cut-off mass of the πNN form factor and the ρ-nucleon coupling constant. I have summarized their values in table 1, and it is remarkable that the analysis of different channels leads to the same set of parameters.

We are naturally lead to ask ourselves the following questions : What is the physical meaning of this πNN form factor ? Is the ρ-exchange concept really relevant.

The ρ-exchange mechanisms has been criticized ^{33}), since it occurs at very short distance (~ .3 fm) and may simulate more subtle mechanisms which involve the quark degree of freedom of the nucleons.

The use of a πNN form factor is a way to go beyond the description of a nucleus in term of point-like structure nucleons, and to take into account their finite size. The cut-off mass of Λ_π = 1.2 GeV, which is needed to reproduce the data, corresponds to a core radius of the nucleon of approximately .5 fm, very close to the "little bag" radius ^{34}). If this were the reality, the problem of quarks in nuclei would reduce to the understanding of the various nucleon form factors. Indeed it is possible ^{35}) to reexpress the pion exchange amplitude in terms of the direct coupling of the pions to the quarks of a bound nucleon (fig.13). This approach is discussed by Giannini^{36}) in this conference and it provides us with a dynamical model for the πNN form factors. At leading order (1/m), the structure and the strength of the meson exchange operators are the same as in the case of the coupling of pion to the nucleon. They differ at the next order ($1/m^2$). However, pseudo-scalar coupling between the pion and the quark has been used, and it has been shown^{37}) that this model leads to a good agreement of pion photo production at threshold only if pseudo-vector coupling is used, and only if the summarion over the complete set of the intermediate three-quark states is performed. It is of course known for a while ^{5}) that πN pseudo vector coupling leads to such a good agreement in models where pions couple to nucleons. Since the meson exchange amplitudes are closely related to the threshold photoproduction amplitudes and since only the pseudo vector coupling is consistent with the PCAC requirements (which fixe terms of order $1/m^2$), the calculation of ref.^{35}) must be done again with the pseudo-vector pion-quark coupling. I bet that the result will be the same as in the conventional meson exchange calculation ^{29}).

But if the nucleon radius is of the order of 1.fm, as in other current models ^{38}), the cut-off mass is only Λ_π ~ 600 MeV, and the pion exchange mechanisms are strongly suppressed : room is left, even at low momentum transfer for more complex mechanisms where the quarks of two distinct nucleons are mixed together $^{33,39-41}$), and which give rise to six-quark clusters in the ground state wave function. Some examples are shown is Fig.13. Of special interest are the diagrams II, in which two

TABLE 1 : The values of the cut-off mass Λ_π of πNN monopole form factor and of the ρ-nucleon coupling constant $G_\rho = g_\rho(1 + K_V)$

Experiment	NN —— NN	Break-up Channels		Electromagnetic form factors	
	Bonn 3)	Photodisintegration 12)	Pion-disintegration 21)	Mathiot 31)	Sauer 29,32)
Λ_π (GeV)	1.3	1.2	1.2	1.25	1.2
G_ρ^2/G_π^2	2.6	1.6	2.4	2.2	2.26
ρNN form factor	monopole Λ_ρ = 1.5 GeV	dipole $\Lambda_\rho = 2\ m_N$	dipole $\Lambda_\rho = 2\ m_N$	monopole Λ_ρ= 1.25 GeV	monopole Λ_ρ= 1.2 GeV

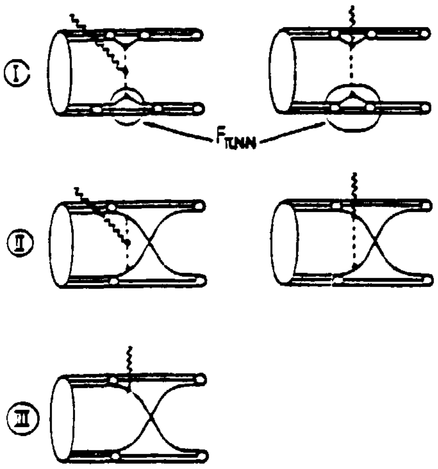


Figure 13 : I : A possible description of the exchange current, in terms of the direct coupling of the pion to the constituent quarks. II : The graphs which must be considered when the final state quark wave function is antisymmetrized. Their importance may be hidden by the phenomenological determination of the πNN form factor. III : The quark interchange mechanism which is expected to be important at very high momentum transfer.

quarks are interchanged at the very time when the pion absorbs the photons. Due to the antisymmetry of the quark in the final state wave function, these mechanisms must be treated on the same footing as the direct mechanisms (Fig.13-I) which have been only considered in refs.35,36). While these effects of the Pauli principle are expected to be small if the nucleon size is small enough, they might be signifiant when their size allows the nucleon to overlap in a nucleus. It is very likely that the complete treatment, of these quark interchange mechanisms, is the way to reconcile the apparent contradiction between the large nucleon size predicted by current nucleon models, and the small size required by the conventional analysis of the electromagnetic properties of the few-body systems.

For sake of completeness, the pure quark interchange diagram (fig.13 III) must be considered 33), but it is expected to contribute at very high momentum transfer and to govern the asymptotic behaviour of the amplitudes.

Finally, the classical meson exchange picture can be complemented, in the framework of the "Hybrid Model", by a direct coupling to a multiquark core. I refer to the Kisslinger's talk [39]) for a detailed discussion of this interesting approach.

Let me now conclude. I hope that I have succeeded to convince yourself that we have now a consistent and successful framework to analyse the reactions induced by photons and pions in the few body systems. Their extensive studies, performed during the last twenty years, have allowed us to understand the basic mechanims which involve the pion and Δ's degrees of freedom in the nucleus. However discrepancies between this standard model and the experiments still remain. Are they due to shortcomings of the model ? Will they be cured by improving it (for instance including relativistic corrections to all orders, or using better nuclear wave functions) ? Or are they the signature of others degrees of freedom ? These are questions which are left open for the future.

Obviously, we have to go beyond the correlations which are due to the exchange of pions or the creation of Δ's. On the one hand, the short range correlations are still badly known and must be studied extensively. On the other hand, we must look for experiments where the effects of pions and Δ's degrees of freedom are strongly suppressed. A promising way is to single out the longitudinal and the transverse response functions in electronuclear reactions. While the transverse response function is dominated by the pion and Δ creation mechanisms, the longitudinal response fonction is not. I have extensively discussed this issue else-where [11,42]) : we badly need a CW electron accelerator in the energy range around 2 GeV.

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