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IPNO-DRE 88-35

THREE-BODY MECHANISMS IN HADRON COLLISIONS
The A = 3 system

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Hadronic Physics in the 1990's with multi-GeV Electrons - SEILLAC (France)
June 27-July 1, 1988.

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R. *Frascaria*

In the energy domain of the elementary excitations of a nucleon, proton induced reactions on light nuclei can excite real isobars inside the nucleus. The region of the Δ(1232) has received considerable attention during the seventies. For instance the $pd \to t\pi^+$ has been extensively studied in the energy range from threshold production to 800 MeV (Ref. 1). These experiments were mainly performed at forward pion angles with the goal to understand how the reaction proceeds : the result of this study is that two body reaction prevails, and that these (p,π) reactions could be interpreted in terms of $pp \to d\pi$ "*elementary*" interaction with intermediate Δ excitations in the 400–800 MeV energy range.

A few years ago we start an experimental program at the National Lab. (LNS) Saturne, to study the excitation functions of the proton deuteron system in interaction in a higher energy range looking in different outgoing channels :

1)	$pd \to dp$	$0.6 < T_p < 2.9$ GeV	(Réf. 2)
2)	$pd \to t\pi^+$ and $\tau\pi^\circ$	$0.6 < T_p < 1.5$ GeV	(Réf. 3)
3)	$pd \to \tau\eta$	$0.92 < T_p < 2.6$ GeV	(Réf. 3 et 4)

where t and τ are respectively the ^3H and ^3He nuclei.

The aim of this work was on two folds :

- To see how the other isobars play a role in these reactions and if a possible change of internal isobar properties like mass and width could be observed.
- To reveal some possible formation of resonant isobar-nuclear states. In this sense the choice of kinematical conditions emphasizing the multibaryon mechanism is of great importance : this is the case for backward elastic scattering or very backward meson production where the two nucleons of the deuterium have to share the high transferred momentum. So the three reactions were systematically studied at or very near of $\theta_p = \theta_\pi = \theta_\eta = 180°$.

The main experimental results are shown on Fig. 1 for pd → dp (θ_p = 180°) and on Fig. 2 for pd → Tπ° and pd → Tη ($\theta_\pi = \theta_\eta$ = 180°).

The elastic excitation function shows an exponential decrease as a function of energy from the large structure around 0.6 GeV which was previously observed (Ref. 5) to 2.1 GeV where we observed for the first time a large plateau starting at 2.4 GeV. A calculation (Ref. 2) in terms of a one nucleon exchange *plus* a one pion exchange (ONE-OPE) was able to give the general trend of the cross sections (see Fig. 1) as a function of energy. In fact this result is the consequence of the similarity of the behaviour of the pd → dπ (θ_π = 180°) cross sections.

The ONE-OPE exchange graph could be calculated in a more elementary point of view. This is shown on Fig. 3a) where this graph is analyzed in terms of the elementary πN → πN interaction. This mecanism connects the three nucleons all together through the meson exchange. This is a three body mechanism. The empty dot means a πN → πN interaction expressed in terms of elastic πN amplitudes and contains the different isobar excitations. Unfortunately this elementary analysis has never been performed.

For the meson reactions, the excitation functions at $\theta_\pi = \theta_\eta$ = 180° display large structures, at T_p = 1.2 GeV for the π production, at T_p = 1.35 and T_p = 1.9 GeV for the η production. No calculations, involving, one nucleon exchange (one body mechanism), or pion exchange mechanism (two body mechanism) were able to explain the enhancements in the experimental excitation functions. For instance on Fig. 4 is displayed a calculation by Berthet (Ref. 3) in a model of Locher and Weber (Ref. 6). The large bump is completely missed by a factor of 30 ! This calculation is based on the OPE mechanism (with an exchange term) as shown on Fig. 3b. It is essentially a two body mechanism, the meson connecting only 2 of the 3 baryons in the reaction as shown by graph 2 on Fig. 3b.

In the same way that in the elastic pd scattering where a 3-body mechanism is needed to share the high momentum transfer between the 3 nucleons, we can think here in a two nucleon plus one pion exchange mechanism (TNE-OPE) which is depicted on Fig. 3c (graph 1).

A simple model due to Barry (Ref. 7) giving the pion production in terms of the πd → πd(θ_π = 180°) was able to reproduce the main trend of the excitation function (Ref. 3) as shown on Fig. 5). Nevertheless the bump was not well accounted for.

Very recently J.M. Laget and J.F. Lecolley (Ref. 8) were able to develop a complete calculation including one, two and three-body mechanisms exchange terms and antisymmetrized terms for the last two. The result of this calculation is shown on Fig. 6 where the full line curve represents the result of the full calculation including the 3-body mechanism (graph. 2, Fig. 3c) this term being not included in the dashed and the dot-dashed line curves. The full calculation reproduces the oscillatory pattern of the cross-section. This is due partly to the interference between the two and three body amplitudes and partly to the energy behaviour of the pion nucleon elastic scattering $I = \frac{1}{2}$ amplitude, which is dominated by the N^* resonances in the range of the second maximum. This result emphasizes the important role played by the three-body mechanism.

One can find a more direct evidence for three body mechanisms by studying the $pd \rightarrow \tau\eta$ ($\theta_\eta = 180°$) excitation function. Due to the higher mass of the η, the momentum transfer is larger in this channel than in the $pd \rightarrow \tau\pi^\circ$ reaction, the one -and two- body mechanisms are therefore suppressed. The $\tau\eta$ output channel being in a pure $I = \frac{1}{2}$ isospin state, the intermediate $N^*(I = \frac{1}{2})$ excitations are prevailing.

In a straightforward extension of their $pd \rightarrow \tau\pi^\circ$ calculation, Laget and Lecolley have calculated the coherent η production by pd capture (Ref. 9). The new ingredient in the calculation is the $\eta N \rightarrow \pi N$ amplitude. They use the latest partial wave analyses of the elementary $\pi^- p \rightarrow \eta N$ reaction (Ref. 10). Each partial wave is parametrized in terms of one or two resonances. The $S_{11}(1520)$ resonance is located just above the threshold and dominates. There is a destructive interference between the tail of the $P_{11}(1470)$ and the $P_{11}(1690)$ resonances, which is shown on Fig. 7 where one can see the good agreement between this analysis and the experimental total cross sections. The calculated $\theta_\eta = 180°$ $pd \rightarrow \tau\eta$ excitation function is shown on Fig. 7 in comparison with the experimental data (Ref. 3 et 4) as a function of the proton kinetic energies. A fair accounting of the data is obtained, both in shape and magnitude, except in the $T_p = 1$ GeV region where the deep minimum is not reproduced. The origine of this discrepancy can be found in the elementary $\pi N \rightarrow \eta N$ amplitude, which is less constrained at low energy than at high energy.

This 3-body mechanism lead to a constant value for the deuteron analysing power T_{20} in rather close agreement with the experimental values and this observation is a further evidence for its important role played in η-meson production.

The pd → τη reaction appears to be the most powerful way to single out the three body mechanism. In the next future a more systematical study would be particularly interesting to refine this picture. Backward angular distributions of spin observables could be useful.

To carry on this work on the proton deuteron system in interaction, the study of the pd → $^{3}_{\Lambda}HK^{+}$ reaction is of great interest.

The Λ cannot exchange a π or a ρ with one nucleon : this enhances the relative contributions of three body forces in hypernucleus production. This reaction should proceed via three body mechanisms such as the one shown on Fig. 8. The S''_{11} (1650) should rose above (S''_{11} → ΛK (10 %). This reaction has never been observed. A new program has been accepted (Ref. 11) at the Saturne National Lab. to take a sight at this reaction.

To summarize, looking backward to the original goal of these studies, the π and η meson productions at large angles show up large structures which are due to the mesonic degrees of freedom in the interaction of the proton with the deuteron, exciting N^{*} isobars in intermediate states. They act as a powerful filter to create a few of them and to study their propagation in nuclei. This propagation does not seem to change the free properties of these isobars. The meson double scattering mechanism provides a reasonable way to understand the coherent meson production in pd capture. It is difficult to say now if this coherent process corresponds to eigen states of the A = 3 system. In counter part the sharing of the momentum transfer between the 3 nucleons makes hopeless the observation of high momentum components in coherent proton captures.

To conclude, and in a perspective of hadron physics with a multi GeV electron accelerator, I would like to stress the role that can be plaid by the electromagnetic probe in that field. The experimental data (Ref. 13) of the reaction $^{3}He(\gamma,p)d$ for θ_p = 90° are shown on Fig. 9 in comparison with a complete calculation by J.M. Laget (Ref. 12) where one-body, two body and meson double scattering are included (full line curve). The contribution of the three body mechanism is the dash-dotted line and its importance is the difference between the full line curve and the dashed-line curve which only includes the one and two-body mechanisms. Contrary to the pd → $t\pi^{+}$ or pd →tη, the γ^{3} He → pd reaction presents the advantage to be opened below the pion production threshold : here both mesons are off shell and this meson double scattering is a prototype of three-body exchange current. The question is : could these three nucleon exchange currents tell us something about a given part of three body forces ? Owning to gauge invariance photon induced reactions should allow such a perspective. In particular as proposed and calculated by J.M. Laget (Ref. 12) the ^{3}He(γ,pn) reaction or the transverse part of ^{3}He(e,e',2p) emphasizes three body mechanisms if studied in kinematical conditions where both mesons travel off shell : in this case the virtual meson rescattering can be viewed as a genuine three body meson exchange which is linked via gauge invariance to the corresponding three body forces. This needs, of course, a large amount of work but very promising.

I would like to acknowledge J.M. Laget for fruitful discussions in the course of preparing this paper.

REFERENCES

1) See for instance P.L. Walden, High energy Phys. Conf., Versailles July 1981, and references therein

2) P. Berthet, R. Frascaria, M.P. Combes, Ch. F. Perdrisat, B. Tatischeff, J. Banaigs, J. Berger, A. Codino, J. Duflo, L. Goldzahl, F. Plouin, F. Fabbri, G. Picozza, L. Satta and M. Boivin J. Phys. G : Nucl. Phys. 8(1982)L111-L116

3) P. Berthet, R. Frascaria, J-P Didelez, Ch. F. Perdrisat, G. Pignault, J. Banaigs, J. Berger, L. Goldzahl, F. Plouin, F. Fabbri, P. Picozza, L. Satta, M. Boivin and J. Yonnet Nucl. Phys. A443(1985)589-600

4) R. Frascaria, P. Berthet, J. Banaigs, J. Berger, M. Boivin, J-P Didelez, J. Duflo, F. Fabbri, L. Goldzahl, Ch. F. Perdrisat, G. Picozza, G. Pignault, L. Satta and J. Yonnet Int. Conf. on Nucl. Phys., C 69 Vol., Florence August 1983

5) B.E. Bonner, C.L. Hollas, C.L. Newson, P.J. Riley and G. Glass, Phys. Rev. Lett. 39(1977)1253

6) M.P. Locher and H.J. Weber, Nucl. Phys. B76(1974)400

7) G.W. Barry, Phys. Rev. D7(1973)44

8) J.M. Laget and J.F. Lecolley, Phys. Lett. 194(1987)177

9) J.M. Laget and J.F. Lecolley, Preprint DPHN/Saclay n° 2510(1988)

10)R.D. Baker et al., Nucl. Phys. B156(1979)93

11)R. Frascaria and Siebert et al., exp. n° 182 CE LNS, April 1988

12)J.M. Laget, Few Body Systems, XIe European Conf. FONTEVRAUD (Aug. 87) page 126

13)N.M. O. Fallon et al., Phys. Rev. C5(1972)1926, P.E. Argan et al., Nucl. Phys. A237(1975)447, W.J. Briscoe et al., Phys. Rev. C32(1985)1956.

FIGURE CAPTION

Fig. 1 : The pd → dp(for θ_p = 180°) excitation function. The full line curve corresponds to the ONE-OPE calculation as described in the text.

Fig. 2 : The pd → $\tau\pi^{\circ}$ and pd → $\tau\eta$(for $\theta_\pi = \theta_\eta$ = 180°) excitation functions. The curves are guide eyes.

Fig. 3 : Different two-body or three-body mechanism graphs which are explained in the text.

Fig. 4 : The pd → $\tau\pi^{\circ}$(for θ_π = 0°) excitation function in comparison with the ONE-OPE calculation(full line curve) (see text).

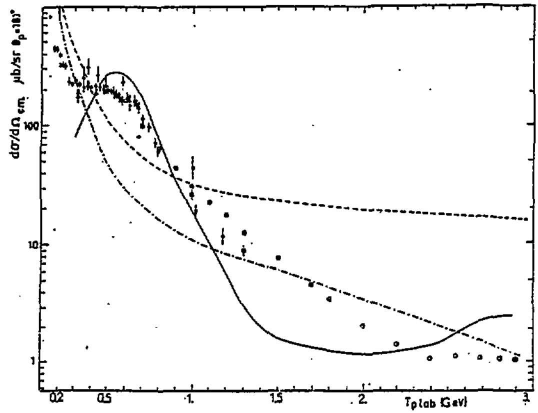
Fig. 5 : The pd → $\tau\pi^{\circ}$(for θ_π = 0°) excitation function in comparison with the calculation in the Barry model. (The full line curve has been normalized at low energy).

Fig. 6 : The pd → $\tau\pi^{\circ}$(for θ_π = 0°) excitation function in comparison with the Laget and Lecolley calculation. Full line curve : full calculation including the 3-body mechanism (3-BM) ; this 3-BM is not included in the dashed and the dot-dashed line curves.

Fig. 7 : The pd → $\tau\eta$(for θ_η = 180°) excitation function in comparison with the full calculation of Laget and Lecolley. In the lower part of the figure, the $\pi N \to N\eta$ total cross sections are plotted where the S_{11} and P_{11} wave contributions are also shown.

Fig. 8 : Skeleton graph corresponding to the pd → ${}^{3}_{\Lambda}HK^{+}$ reaction for forward angles (2-BM) and backward angles (3-BM)

Fig. 9 : The ${}^{3}He(\gamma,p)d$ excitation function in comparison with the Laget and Lecolley model. The full line curve corresponds to the complete calculation with the 3-body mechanism (3-BM) ; the dashed line corresponds to the same calculation where the 3-BM has been suppressed.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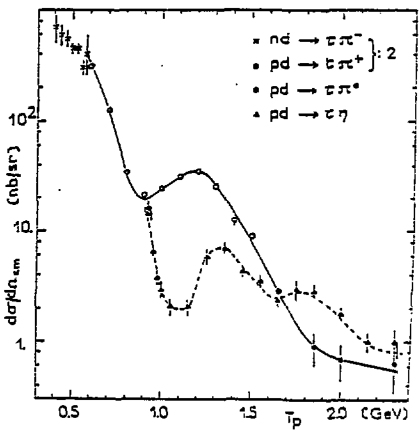
10
1
0.2
0.5
1.
1.5
2.
Tp lab (GeV)
3.

Fig. 1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pd → tπ⁺
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Tp
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(GeV)

Fig. 2

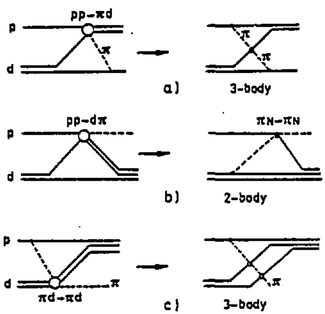

Fig. 3

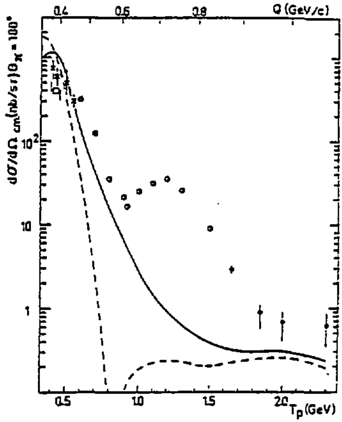

Fig. 4

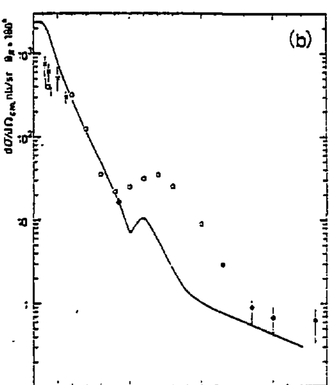

Fig. 5

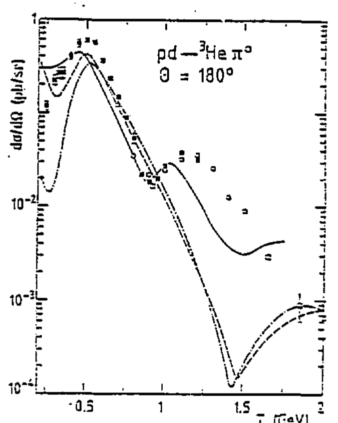

Fig. 6

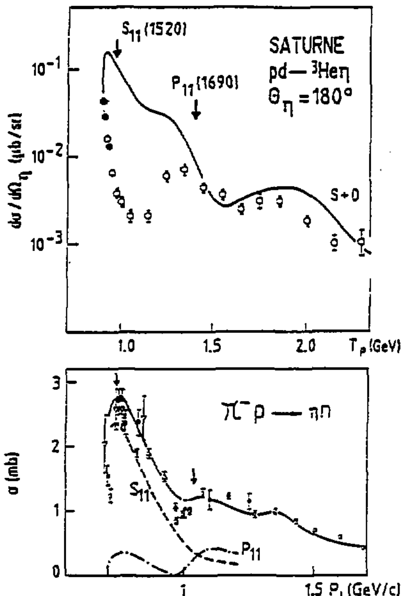

Fig. 7

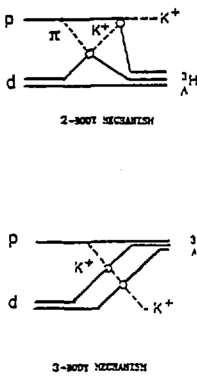

Fig. 8

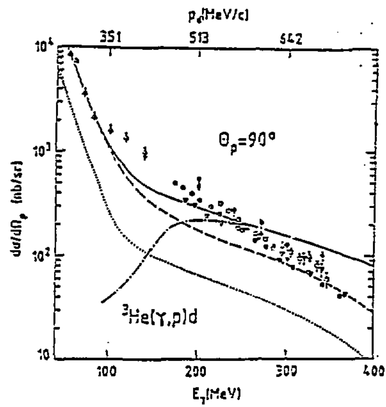

Fig. 9