Presented to the "Topical
Meeting on High Energy
Collisions Involving Nuclei"
Trieste, September 1974

COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF-74/71(P)
12 Dicembre 1974

J. Banaigs, J. Berger, M. Cottereau, F.L. Fabbri, L. Goldzahl, C. Le Brun, P. Picozza and L. Vu Hai: MESON PRODUCTION BELOW 1 GeV FROM D-D INTERACTION.

Servizio Documentazione
dei Laboratori Nazionali di Frascati del CNEN
Casella Postale 70 - Frascati (Roma)

Laboratori Nazionali di Frascati del CNEN
Servizio Documentazione

LNF-74/71(P)
12 Dicembre 1974

J. Banaigs(x), J. Berger(x), M. Cottereau(o), F.L. Fabbri, L. Goldzahl(x), C. Le Brun(o), P. Picozza and L. Vu Hai(x): MESON PRODUCTION BELOW 1 GeV FROM D-D INTERACTION. -

Invited talk, presented by P. Picozza, to the "Topical Meeting on High Energy Collisions Involving Nuclei" Trieste, September 1974 (to appear in the Proceedings).

1. - INTRODUCTION. -

A study of the reaction

$$d + d \rightarrow He^4 + mm^o$$

has been performed at the Saclay Synchrotron "Saturne" with incident deuterons of momentum between 1.9 and 3.8 GeV/c.

The interest of the reaction is in the purity of zero isospin of the mm^o system. The aim of this experiment was to test the charge symmetry for one π^o missing mass, to bring in evidence the ABC effect, and finally to study isoscalar meson production.

The extracted deuteron beam was focused on a liquid deuterium target (6 cm length). The α particles were analyzed by a double focusing magnetic spectrometer. Scintillator counters were placed in the intermediate image and others in the final image. The particles were identified by the time of flight between the two sets of counters (14 meters distant) and by the energy loss in the plastic scintillators. For each incident deuteron momentum the experimental points have been measured at constant laboratory angles, varying the momentum of the recoil α particle.

2. - CHARGE SYMMETRY TEST. -

The process $d + d \rightarrow He^4 + \pi^o$ has been studied with 1.89 GeV/c incident deuterons and at a center of mass angle of 79 deg. to test the charge symmetry. This reaction is forbidden by the isotopic spin conservation law, since the isospin of deuteron and He^4 is zero and that of π^o is one. A small violation of electromagnetic origin in charge symmetry is expected in this reaction, since it can go through virtual η--production and π - η mixing.

The result of our measurement is consistent with no π^o production, and we can set an upper limit of the differential cross section for this production $d\sigma/d\Omega^{x} \leq 1.9 \times 10^{-35}$ cm^2/sr. This limit is 5 times lower than the previous(1) for this reaction, but obtained at different energy.

In order to compare our measurement with the former ones, we used a theoretical prediction(2) obtained in the frame of the impulse approximation and neglecting the isospin conservation law. From the comparison of the calculated value with our experimental limit, it turns out that isospin is conserved within at least 99.73%.

3. - ABC EFFECT. -

The ABC effect was first observed from Abashian, Booth and Crowe(3), as an enhancement in the missing mass spectrum of $p + d \rightarrow He^3 + mm^o$, just above the 2π threshold. For a long time it was regarded as an evidence for an $I = 0$ $\pi\pi$ resonance at 310 MeV. This idea is now refused, since such state has never been seen in ordinary hadronic processes, like π^-p and k^-p with two pions in the final state, or in photoproduction. More recent experiments show the ABC as a huge, sharp spike at around 310 MeV in the missing mass spectrum of the reaction $n + p \rightarrow d + mm^o$(4, 5), $d + p \rightarrow He^3 + mm^o$ (5, 6), and with the present experiment also in $d + d$ $He^4 + mm^o$ (7). Only this last reaction selects a 2π state of zero isospin. The ABC, therefore, appears only in the processes where the final state is a bound state of nucleons, and it is in a $I = 0$ isospin state. The ABC is not evident in $p + p \rightarrow d + (mm)^+$ (4) and in $p + d \rightarrow H^3 + (mm)^+$ (3, 6) where the mm are in $I = 1$ state.

However, for this last process, Saclay data(6) show a small deviation of the phase space, that could be interpreted as a contribution of the ABC effect.

In Fig. 1 is shown a spectrum obtained with 2.29 GeV/c incident deuterons and at $\theta_{lab} = 0.3$ deg. The abscissa is the He^4 recoil momentum; also a missing mass scale is shown. The ABC effect shows up very clearly centered at a missing mass of 326 ± 11 MeV.

Fig. 2 shows an other momentum distribution of the He^4. This spectrum has been obtained at 2.5 GeV/c and at $\theta_{lab} = 7.4$ deg, and we can see the ABC effect associate with the He^4 emitted backward and forward in the center mass system.

We note a large structure located in the region of the largest observable mass (forward-backward transition). Actually, this structure appears in all the spectra were ABC effect occurs, also in the dp and np interactions. The phase space of the final state with 2π or 3π cannot account for such a structure.

For incident deuteron momenta between 1.9 and 3.8 GeV/c the central mass of ABC effect varies with the kinematical condition between 300-350 MeV.

Fig. 3 shows the angular distribution of ABC effect for an incident deuteron momentum of 2.5 GeV/c. It is strongly forward peaked, and what is natural in a symmetric reaction, also backward peaked. It is interesting to note that also in the case of the not symmetric reaction $p + d \longrightarrow He^3 + ABC$ the angular distribution is strongly forward and backward peaked.

In Fig. 4 the behaviour of the differential cross section is shown at $\theta^{x}_{He4} = 180^{o}$ for the ABC production versus the total c.m. energy. This cross section varies very rapidly with the energy and presents a maximum at $W^{x} = 4.23$ GeV. These two last results show that the ABC effect requires particular conditions for energy and angle in order to be observed.

4. - MESON PRODUCTION. -

In the spectrum obtained at 3.32 GeV/c incident deuterons and at $\theta_{lab} = 0.3$ deg. in the backward emisphere (v. Fig.5) the maximum mass observable is about 850 MeV. The ABC effect is also evident and a bump about 800 MeV, in the region of ω^{o}, is seen. The differential cross section for the ω^{o} in this kinematical condition can be evaluated about 1.0 ± 0.3 nb/sr. There is no evidence for a η^{o} production.

We want particularly notice that in the spectrum obtained at 3.82 GeV/c incident deuterons and at $\theta_{lab} = 0.3$ deg. (v. Fig. 6), where the ABC effect complitely vanishes, there is no production of missing mass lower than 550 MeV. There is a little ω^{o} signal, but no other meson is observed.

We have made many runs at different angles and deuteron momenta, in order to look for other mesons with masses up to 1 GeV. Within the limits of our experimental resolution no other bump has been seen.

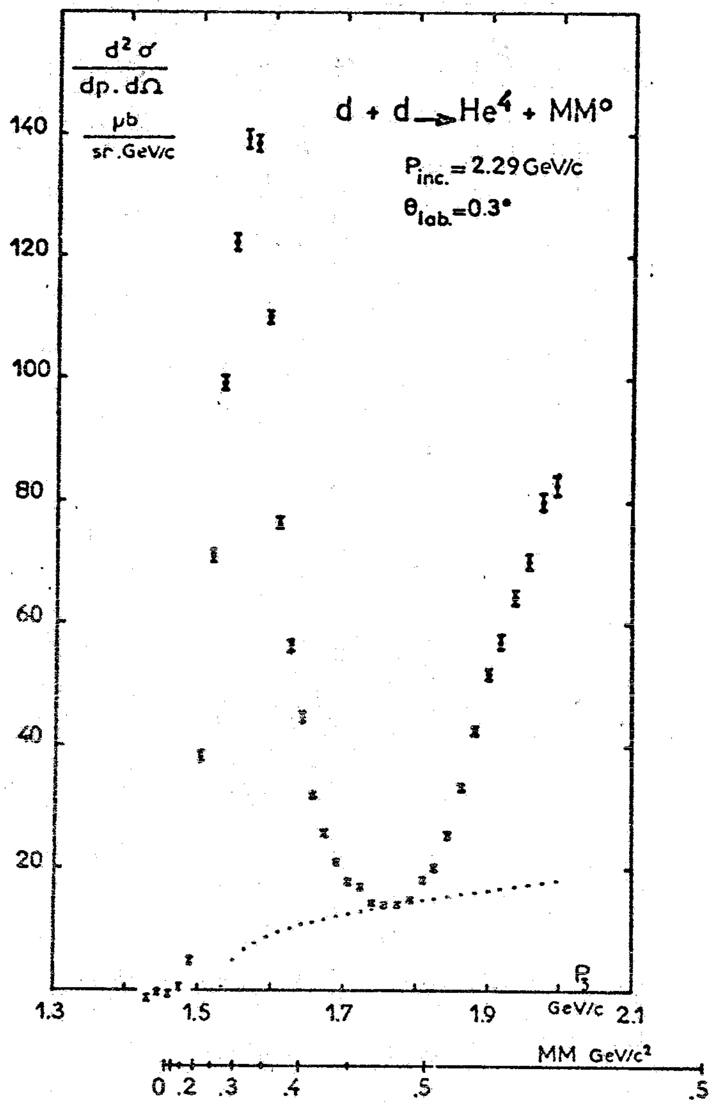

FIG. 1 - Laboratory momentum spectrum for recoil He^4 at $P_{inc} = 2.29$ GeV/c, $\theta_{lab} = 0.3$ deg. The dotted line shows the Lorentz invariant phase space for two pion production.

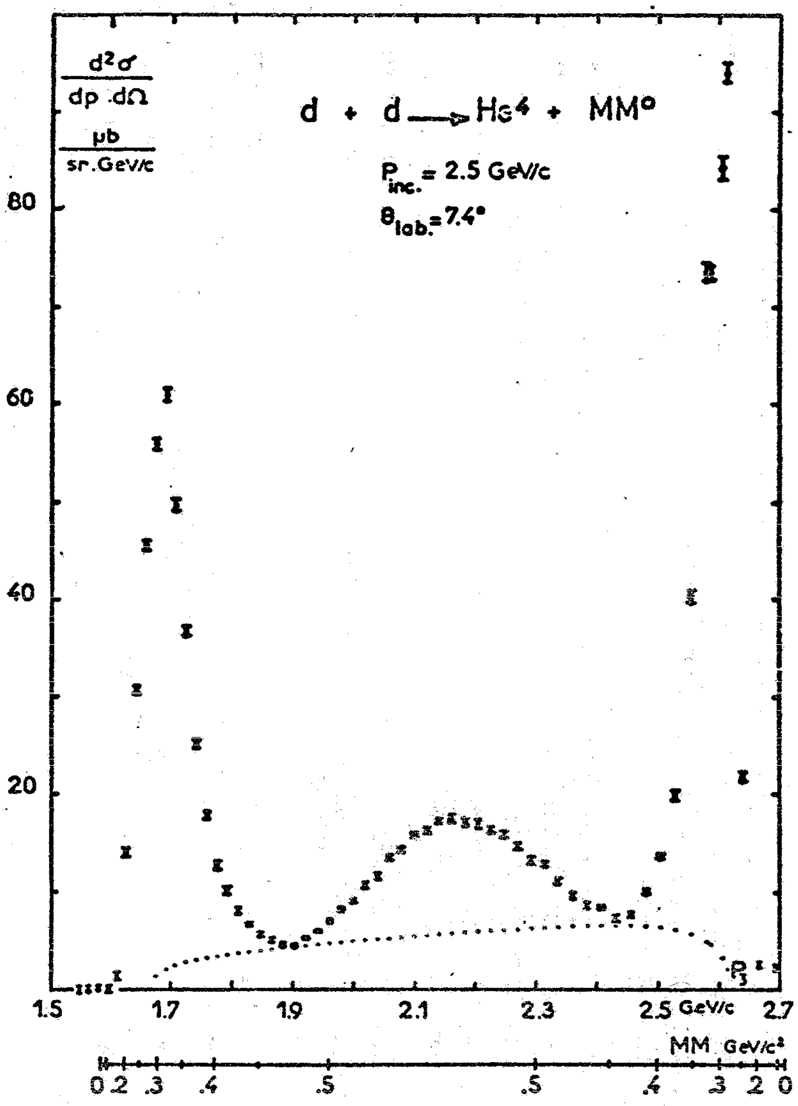

FIG. 2- Laboratory momentum spectrum for recoil He^4 at $P_{inc} = 2.5$ GeV/c, $\theta_{lab} = 7.4$ deg. The dotted line shows the Lorentz invariant phase space for two pion production.

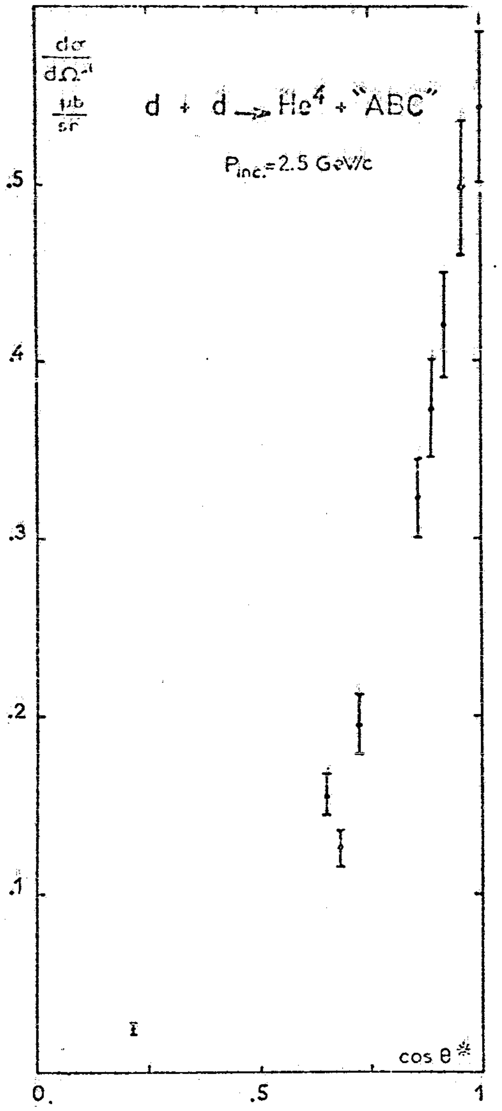

FIG. 3- Center of mass system angular distribution at $P_{inc} = 2.5$ GeV/c.

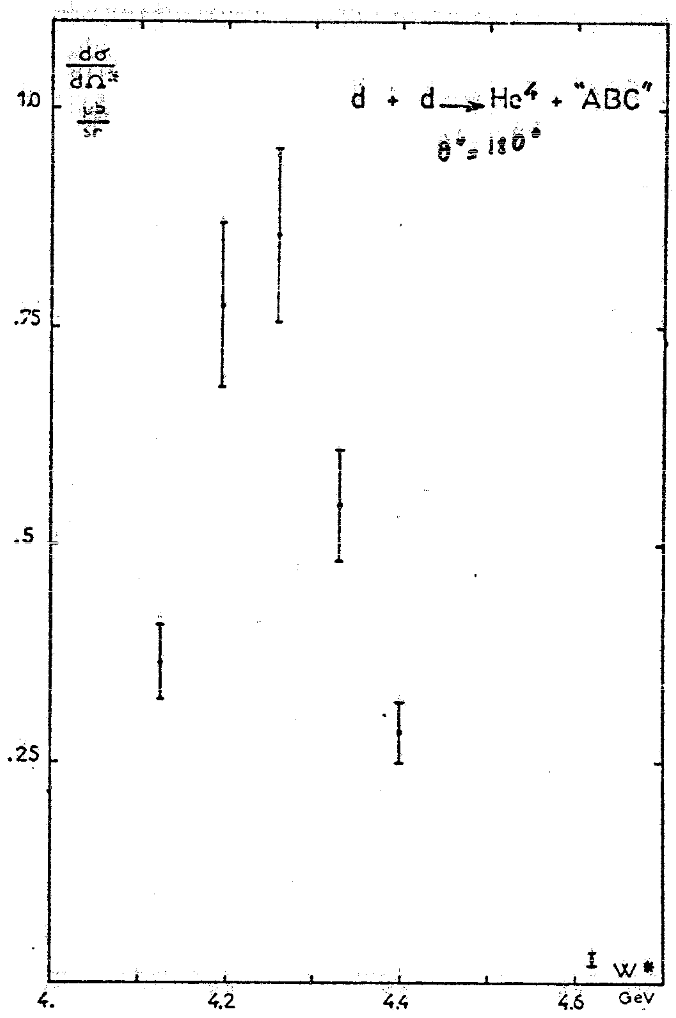

FIG. 4--Differential cross section $d\sigma/d\Omega^{x}$ at $\theta^{x}_{He4} = 180^{o}$ versus the total c.m. energy W^{x}.

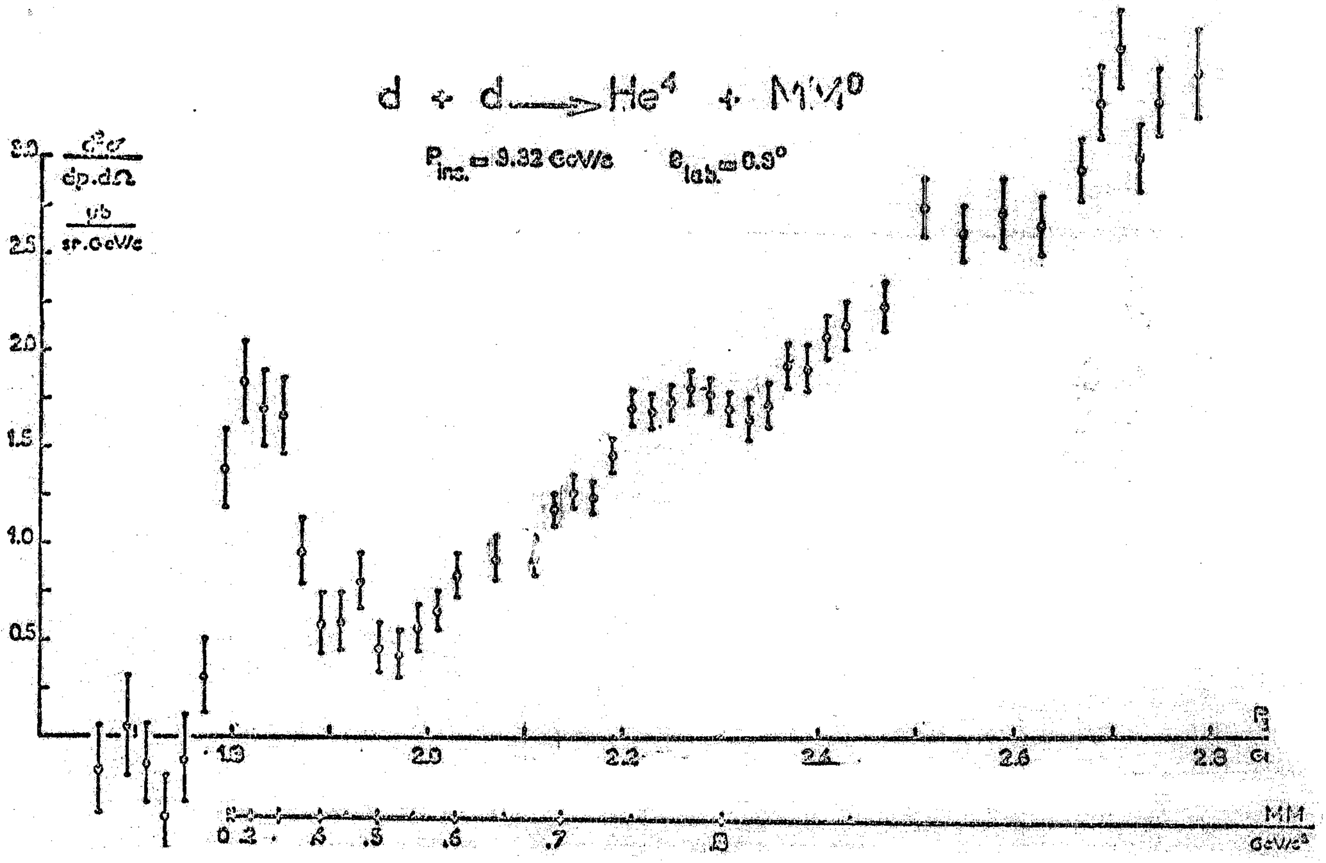

FIG. 5 - Laboratory momentum spectrum for recoil He^4 at $P_{inc} = 3.32$ GeV/c, $\theta_{lab} = 0.3$ deg.

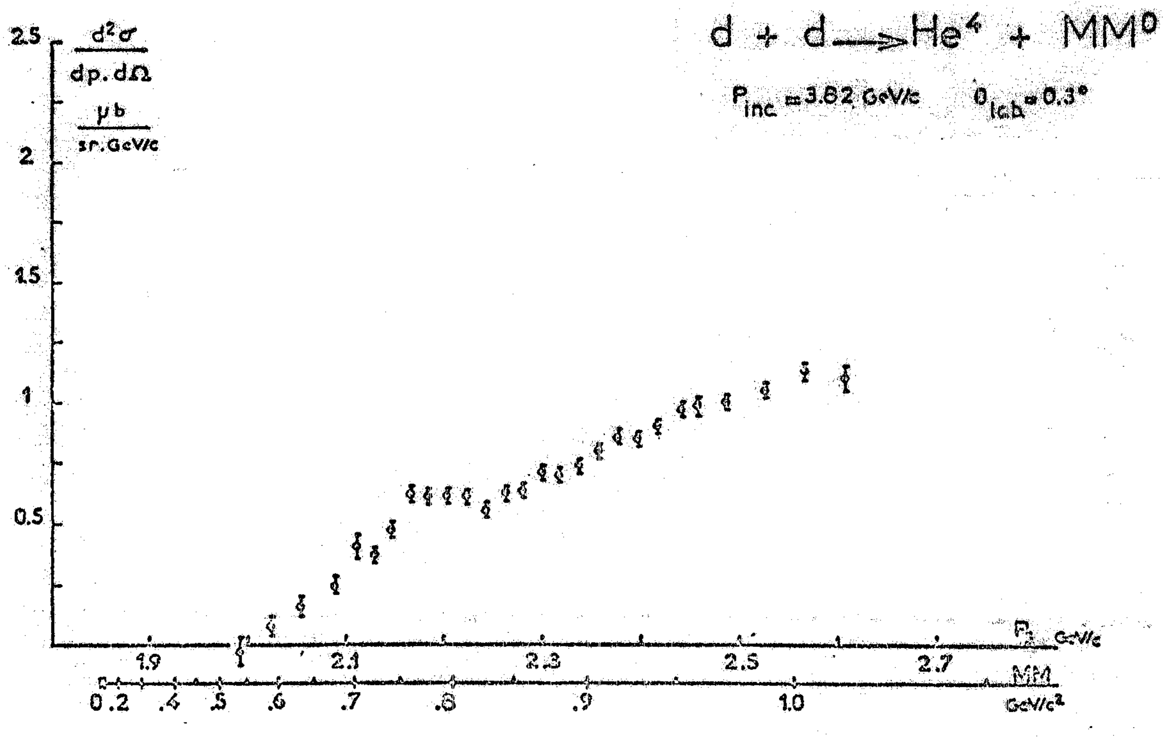

FIG. 6 - Laboratory momentum spectrum for recoil He^4 at $P_{inc} = 3.82$ GeV/c, $\theta_{lab} = 0.3$ deg.

5. - ABC MODELS. -

Since ABC is the more relevant effect observed in the study of the reaction, we discuss some recent models proposed to explain this enhancement. The ABC effect was first explained in terms of an atractive interaction between the two pions in the S wave and in zero isospin state; but this leads to a $\pi\pi$ scattering length in the range of 1 to 3 m_{π}^{-1} (3, 4). These values are much larger than those obtained in other processes involving a $\pi\pi$ interaction. More recent theoretical explanations are based on the following models.

The phenomenological approach of Brody(8) is based on the $p+d \rightarrow He^3 + mm^o$ reaction (v. Fig. 7a). The ABC is explained using the information about the momentum transfer dependence of the He^3 form factor, which is obtained by the experimental results of meson production in the same reaction, and in terms of a single particle-exchange model. The ABC effect, therefore, should be due to the difficulty to form a He^3 nucleus when the relative momentum of the constituent nucleons is high. In this model also a relatively small $\pi\pi$ scattering length is used.

A model proposed from Anjos, Levy and Santoro(9) for the $d+p \rightarrow He^3 + mm^o$ reaction is shown in Fig. 7b. Two pions are produced in a two step reaction $N_1 + p \rightarrow d_i + \pi_1$ followed by $d_i + N_2 \rightarrow He^3 + \pi_2$, where N_1 and N_2 are the nucleons of the initial deuteron, and d_i an intermediate deuteron, which is considered as a real particle. The calculated spectra at each energy show backward and forward peaks and a wide bump at the highest missing mass. These results are due to the peaked angular distribution of the intermediate processes. When both reactions take place in the forward direction one gets the forward ABC; when they take place in the backward direction one gets the backward ABC, and when one takes place in the forward direction and the other in the backward direction one gets the middle bump. The energy dependence of the ABC effect is deduced from those of the intermediate reactions.

The diagram shown in Fig. 7c was proposed by Risser and Shuster(10) and originally applied to explain the feature of the reaction $N+N \rightarrow d+\pi\pi$, but it may also be extended to pd and dd interactions. In this model the process proceeds predominantly through the intermediate production of two Δ resonances by one pion exchange. The two-decay-nucleons are then constrained to form a deuteron in the final state. The low-mass enhancement ABC effect corresponds to the parallel decay of the two Δ's; the high-mass enhancement corresponds to the antiparallel decay. Particular kinematical conditions are to the origin of the enhancements.

What is the validity of these models?

The Brody fit reproduces some data on $p+d \rightarrow He^3 + ABC$, but it is unable to describe the Saclay data $d+p \rightarrow He^3 + ABC$. Moreover, it does not provide at all for the middle bump experimentally observed.

As to the Anjos et al. model, the calculation of the authors leads to a satisfactory agreement with the $d+p \rightarrow He^3 + mm^o$ data; Barry in a critical review(11) of the ABC models, however, remarks that this model does not provide even a qualitative description of the data now available. A generalization to other nuclei is not yet evident.

The Risser-Shuster model is in agreement with the $n+p \longrightarrow d+mm^o$ data; up to now the authors have not applied this model to other nuclei, but the calculation made by Barry is unable to account for the large ABC effect seen in $d+d \rightarrow He^4+mm^o$; also a fit of $d+p \rightarrow He^3+ABC$ data is not good.

In conclusion a convincing explanation of the ABC effect is still an open question. A careful comparison of the behaviour of the ABC in the different reactions in which it has been observed, can give a more insight in this field.

As a peculiar example the $d+d \rightarrow He^4+ABC$ and the $d+p \rightarrow He^3+ABC$ cross section versus the total center mass energy minus the final nucleus mass are compared in Fig. 8. The energy interval in which ABC appears is wider for the dd than for the pd reaction. In addition the differential cross section for the dd is larger than for pd. The experimental study of $n+p \rightarrow d+ABC$ is not yet complete but the set of data now available(4) shows that the cross section of this reaction is much higher than that of $d+p \rightarrow He^3+ABC$ and $d+d \rightarrow He^4+ABC$. There is not, therefore, for this effect a regular behaviour of the cross section with the involved nuclei.

We think that the study of the phenomena like to ABC can be useful to understand Δ excitation in the nuclei, and to verify if nuclear collisions can be also accounted in terms of the interaction of their constituent nucleons, or, on the contrary, if it is more convenient to treat the nuclei in the aim of the bootstrap theory.

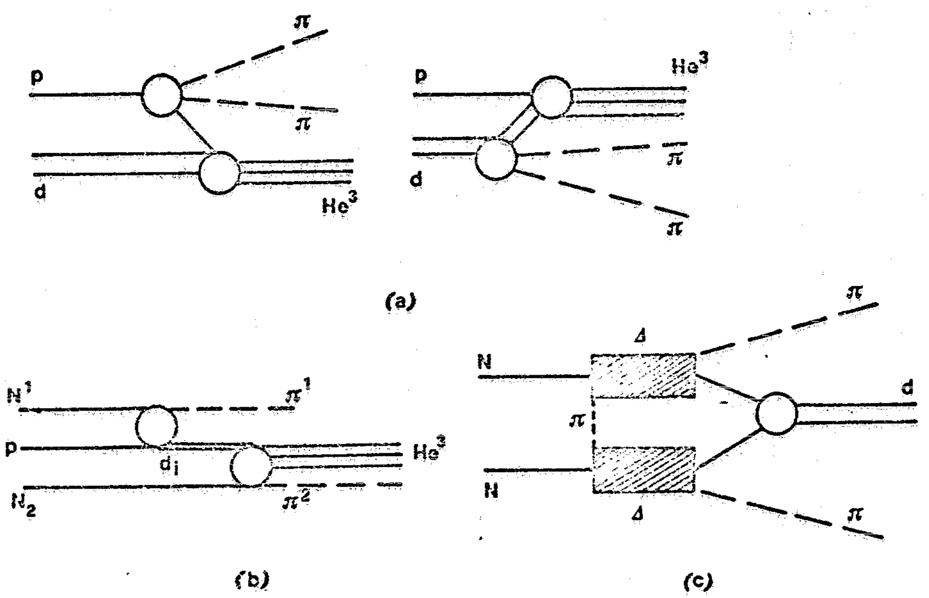

FIG. 7 - a) Single particle exchange model of Brody; b) Dynamical model of Anjos et al., c) One pion exchange model of Risser and Shuster.

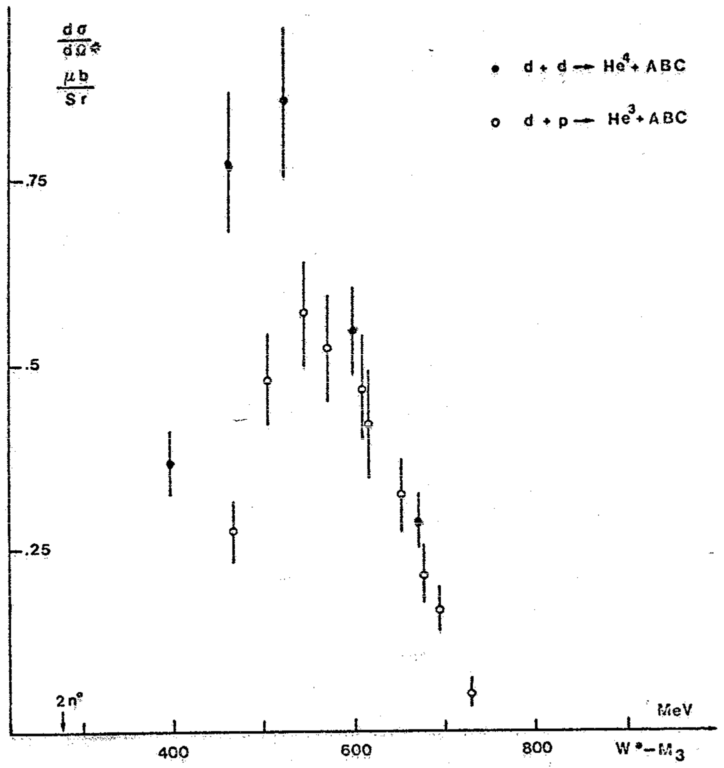

FIG. 8 - Differential cross sections $d\sigma/d\Omega^{*}$ at $\theta_3^{*} = 180^{\circ}$, versus the total c. m. energy W^{*} minus the final nucleus mass, for the reaction $d+p \rightarrow He^3 + ABC$ (o) and $d+d \rightarrow He^4 + ABC$ (●).

REFERENCES.-

(1) - J.A. Poirier and M. Pripstein, Phys. Rev. 130, 1171 (1963).

(2) - K.R. Greider, Phys. Rev. 122, 1919 (1961).

(3) - A. Abashian, N.E. Booth, K.M. Crowe, R. Hill and E. Rogers, Phys. Rev. 132, 2296 (1963); N.E. Booth, Phys. Rev. 132, 2305 (1963); N.E. Booth, A. Abashian and K.M. Crowe, Phys. Rev. 132, 2309 (1963); N.E. Booth and A. Abashian, Phys. Rev. 132, 2314 (1963).

(4) - R.J. Homer, Q.H. Khan, W.K. Mc Farlane, J.S.C. McKee, A.W. O'Dell, L. Riddiford, P.G. Williams and D. Griffiths, Phys. Letters 9, 72 (1964); J.H. Hall, T.A. Murrary and L. Riddiford, Nucl. Phys. B12, 573 (1969); G. Bizard, F. Bonthonneau, J.L. Laville, C. Le Brun, F. Lefebvres, J.C. Malherbe, R. Regimbart, J. Berger, J. Duflo, L. Goldzahl, F. Plouin and L. Vu Hai, Communication to the Conf. at Uppsala (1973), pag. 114.

(5) - J. Banaigs, J. Berger, J. Duflo, L. Goldzahl, M. Cottereau and F. Lefebvres, Nucl. Phys. B 28, 509 (1971).

(6) - J. Banaigs, J. Berger, L. Goldzahl, T. Risser, L. Vu Hai, M. Cottereau and C. Le Brun, Nucl. Phys. B 67, 1 (1973).

(7) - J. Banaigs, J. Berger, L. Goldzahl, T. Risser, L. Vu Hai, M. Cottereau, C. Le Brun, F.L. Fabbri and P. Picozza, Phys. Letters 43B, 535 (1973); Communication to the Conf. at Uppsala (1973), p. 117.

(8) - H. Brody, Phys. Rev. Letters 28, 1217 (1972).

(9) - J.C. Anjos, D. Levy and A. Santoro, Nucl. Phys. B 67, 37 (1973).

(10) - T. Risser and M.D. Shuster, Phys. Letters 43B, 68 (1973); I. Bar Nir, T. Risser and M.D. Shuster, Preprint TAUP-418-74 (1974).

(11) - G.W. Barry, Preprint Purdue University (1974).