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V. D'Amico, G. Fazio, S. Jannelli, F. Mezzanares and R. Potenza:

$^7Li + d \rightarrow 2\alpha + n$ REACTION: II) EXPERIMENTAL RESULTS AT $E_d = 1.0$ MeV.

519

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ABSTRACT -

The ^{7}Li + d $\rightarrow$ 2α + n reaction was studied at E_d = 1.0 MeV, detecting the bidimensional spectra of the α-particles at various angles.

The internal energy spectra of the two identical α-n systems formed in the final state and the angular correlations of the α-particles in the systems of the relative coordinates were extracted.

The results agree with the hypothesis that the α-n systems are polarized.

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1. - INTRODUCTION -

A method of analysis of the bidimensional spectra of a reaction $P + T \rightarrow A_1 + A_2 + A_3$ was given in a preceeding paper(1). That method allowed to transform the bidimensional spectra in the laboratory system (LS) to the systems of the relative coordinates (RCS) of the three final particles, allowing also a first treatment of the identity of the particles.

That method was developed to analyse the experimental results of the $^7Li + d \rightarrow 2\alpha + n$ reaction, which, at low deuteron energy, seems to proceed via a sequential decay involving ^5He formation or at least strong interactions in the α-n systems present in the final state.

We have used that method to analyze the characteristics of the α-n systems, that is the energy spectra and the angular correlations.

2. - EXPERIMENTAL RESULTS -

2.1. - Bidimensional spectra in the laboratory system.

A natural Li target, 0,5 mg/cm^2 thick, evaporated on a polyvinilformal backing of 0.1 μm, was bombarded with deuterons accelerated by the 2.7 MV Van de Graaff machine of the Catania laboratories.

The energy of the deuterons was $E_d = 1.0$ MeV.

The produced particles were detected by two movable surface barrier detectors supplied by ORTEC.

One of these remained in fixed position and acted also as a beam monitor(1).

The intensity of the beam was measured by a charge integrator using a Faraday cup, deep enough to avoid the excape of the secondary electrons.

The target thickness was measured by the method of the thin quartz cristal, as reported in ref. (2).

As reported in ref. (1), the pulses of the two movable detectors were sent to a fast-slow coincidence system ensuring a time resolution $\tau \leq 30$ ns.

The coincident pulses were sent to a Laben 4096 channels analyzer, which gave the bidimensional spectra of the two α's produced in the reaction $^7Li + d \rightarrow 2\alpha + n$.

One of the detector (detector 1) was fixed at $\theta_1 = 88.4^o$ and $\phi_1 = 0^o$, while the second one (detector 2) was allowed to rotate between $\theta_1 = 30^o$ and $\theta_2 = 110^o$ at $\phi_2 = 180^o$. Measurements were made in steps $\Delta\theta_2 = 2^o$. The errors on the absolute values of the cross sections were about 15%.

The bidimensional spectra were constitued, as known(1, 3), by distributions of pulses contained in strips of the kinematic plane E_1 E_2 around the kinematic curves(1) of the reaction. As explained in ref. (1), the pulses in any strip were projected on the corresponding kinematic curve by a method which took into account the spread of the pulses due to the finite resolving power in energy and angle.

The bidimensional spectra are then reduced to the curves of $d^3\sigma / ds d\Omega_1 d\Omega_2$, which is proportional to the density of pulses per unit length of the kinematic curve.

Fig. 1 reports $d^3\sigma / ds d\Omega_1 d\Omega_2$ vs. s for some measured spectra.

Fig. 2 gives the angular correlation in the laboratory system for the two α-particles, which agrees with previous results(3).

2.2. - Experimental results in the system of the relative coordinates. -

After transforming to the RCS by use of the proper jacobians(1), it is possible to obtain:

a) The energy spectra for given relative angles Ω_{i-jk} and Ω_{rel}(1) where $i \neq j \neq k$ and i, j and k = 1, 2, 3 are particle labels and the label 3 indicates the residual nucleus (in the present case the neutron). Fig. 3 gives these energy spectra for $\theta_{rel} = 0^o$, 90^o and 180^o and $\phi_{rel} = 0^o$ and 180^o, irrespective of the values of θ_{i-jk}. The angular interval of θ_{rel} is $\Delta\theta_{rel} = 20^o$.

Since the energies in the RCS are connected by the relation $E_{i-jk}+E_{j-k}=E_d+Q-P^2/2M$ where P is the total momentum of the system, we have preferred to report in the figures the energy E_{j-k} which for k = 3 is the internal energy of the α-n systems. The spectra contain mixed together the pulses due to the two identical α_1-n and α_2-n systems.

As it can be seen the spectra show a pronounced peak at $E_{j-3} = 0.95 \pm 0.1$ MeV, which corresponds to that observed in the $n + {}^4He$ scattering(4), as expected in presence of the sequential decay ${}^7Li + d \rightarrow \alpha + {}^5He \longrightarrow \alpha + \alpha + n$(3, 5).

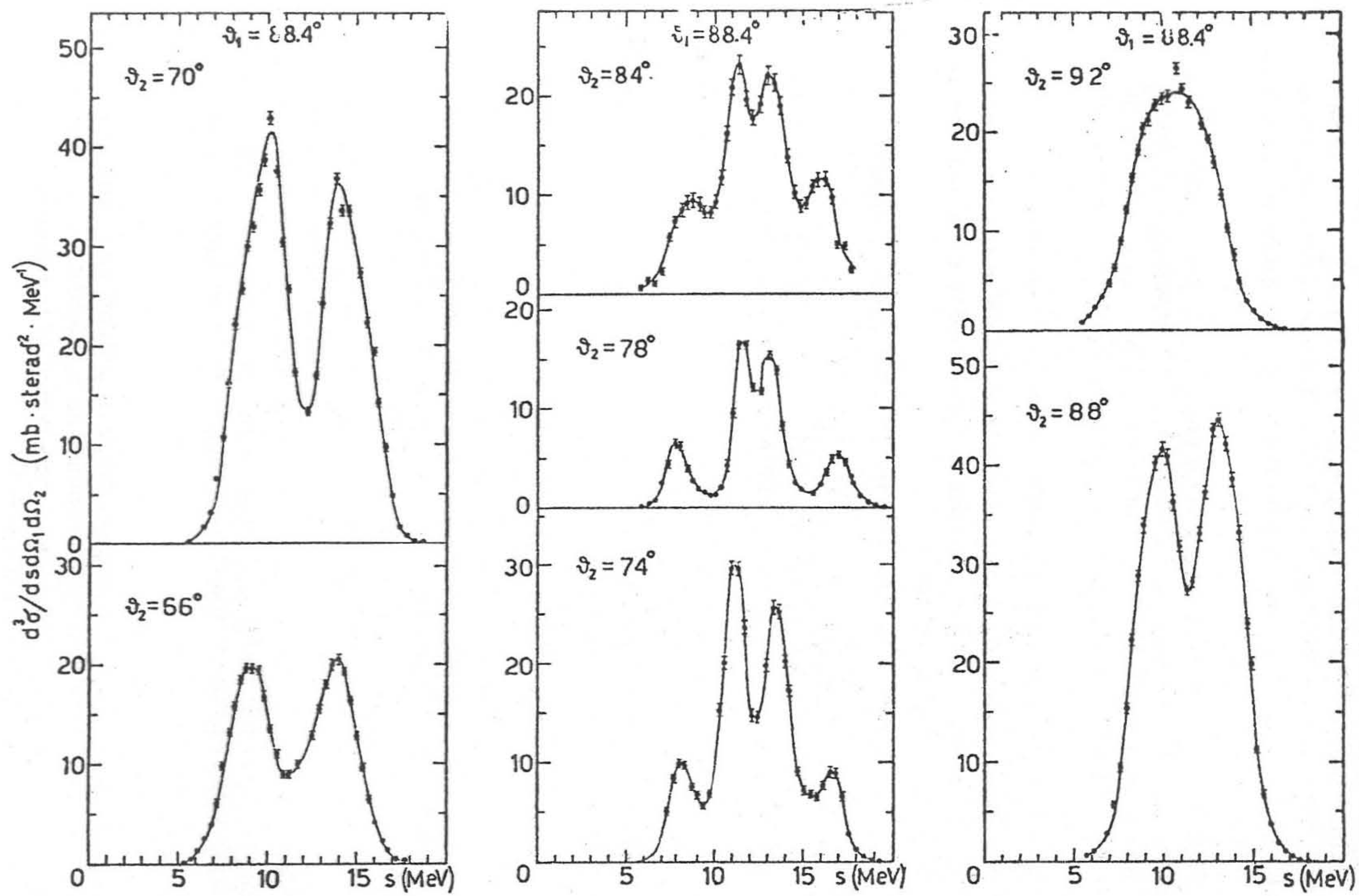

FIG. 1 - Distribution of counts along the kinematic curves in the LS for E_d = 1.0 MeV, θ_1 = 88.4°, $\phi_2 - \phi_1$ = 180° and various values of θ_2.

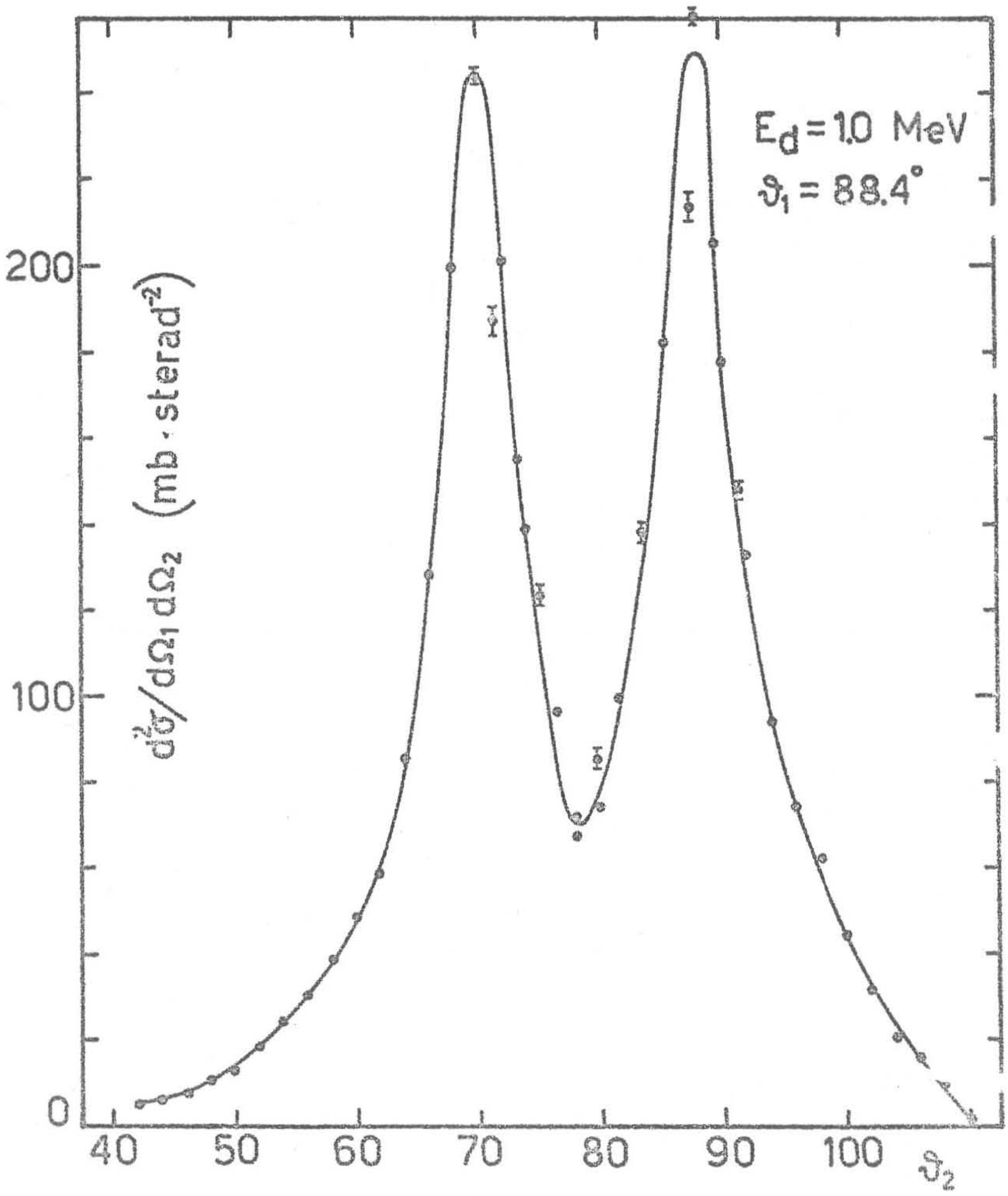

FIG. 2 - Integrated angular correlation of the two α-particles in the LS for E_d = 1.0 MeV, θ_1 = 88.4°, $\phi_2 - \phi_1$ = 180°.

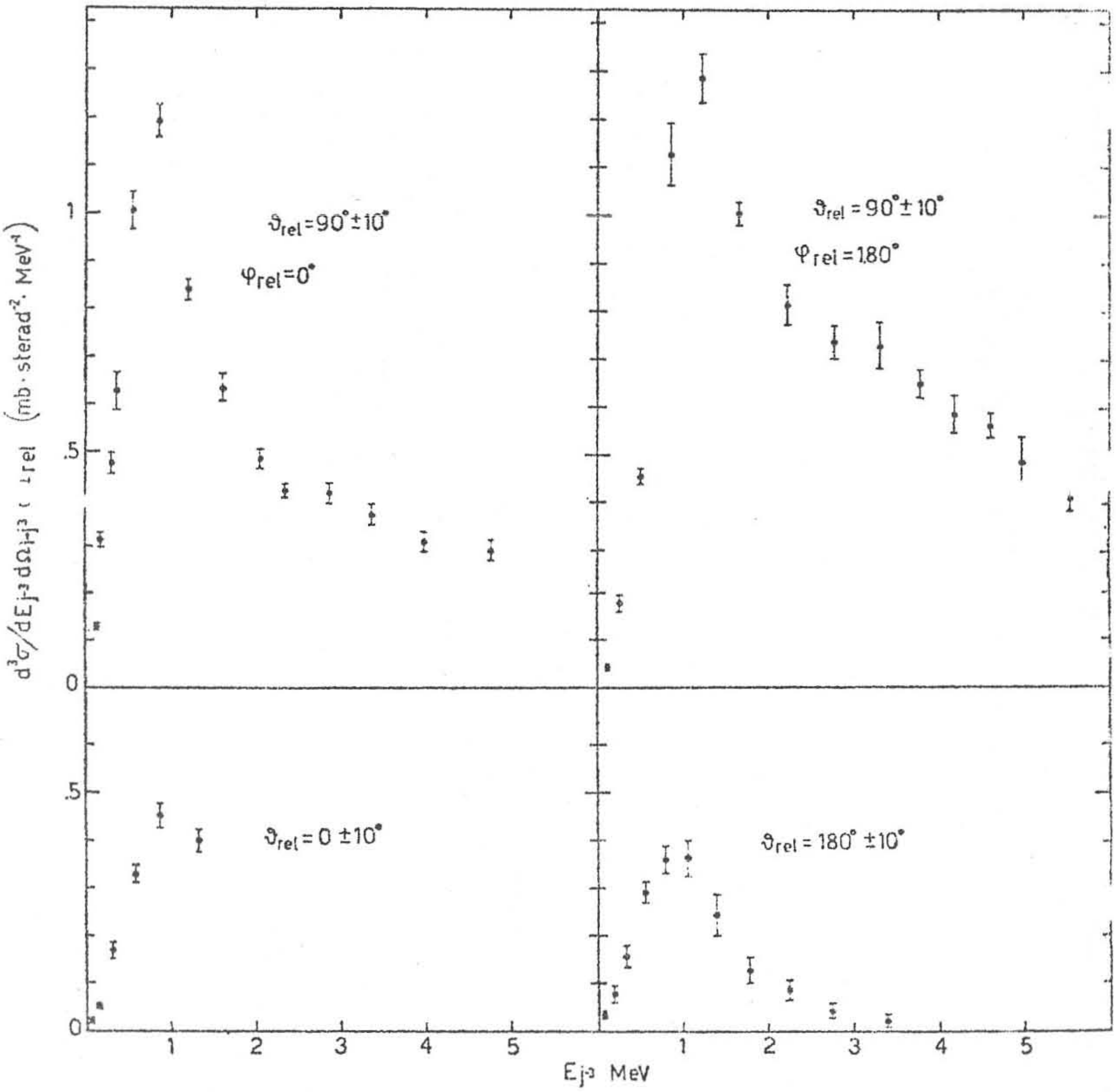

FIG. 3 - Internal energy spectra of the α -n systems seen at various angles θ_{rel} of the emitted α -particles with respect to the direction of the motion of the α -n centre of mass.

It is to be noted that the energy spectra show high energy tails strongly dependent from the polar and azymuthal relative angles. This would suggest that the sequential decay involves at least two states of the α-n system.

The absence of the high energy tail of the spectrum at low values of θ_{rel} is caused by our treatment of the identity of the particles[1]. It implies in fact a net cut of the kinematic curve in two parts, with a different treatment of the pulses contained in them to take into account the identity of the two α-particles. This causes the disappearance of certain regions in the space spanned by the RCS, without however affecting appreciably the pulses attributed to the other regions.

b) The angular correlations in the RCS for given internal energies. Fig. 4 gives these angular correlations for energies $0.2 \leq E_{j-3} \leq 0.4$ MeV; $0.4 \leq E_{j-3} \leq 0.6$ MeV; $0.6 \leq E_{j-3} \leq 1.2$ MeV; $1.4 \leq E_{j-3} \leq 3.8$ MeV.

The angular correlation around the peak energy shows clear maxima around $\theta_{rel} = 90^o$.

In this energy region the angular correlation is well given (see Fig. 6) by $W(\theta) \propto 1+3\ \mathrm{sen}^2\theta$, in agreement with previous results[3].

The most interesting characteristic of the other angular correlations is the clear asymmetric behaviour with respect to ϕ_{rel} and the fact that the asymmetry is energy dependent.

2.3 - Asymmetries in the angular correlations.

We report in Fig. 5 the quantity

$$\frac{\sigma(\theta_{rel}, 0) - \sigma(\theta_{rel}, \pi)}{\sigma(\theta_{rel}, 0) + \sigma(\theta_{rel}, \pi)} = A(\theta_{rel})$$

for the same energy intervals to which Fig. 4 refers.

It can be noted that $A(\theta_{rel})$ is dependent regularly on the energy, taking the smallest values around $E_{j-3} = 1$ MeV, that is around the peak in the energy spectrum.

We note that the asymmetry $A(\theta)$ cannot be explained for by the identity of the α-particles, since the effects of the latter are limited to the pulses recorded on the same kinematic curve, while thepoints at different values of ϕ_{rel} belong to different kinematic curves, with the exception of an interval $\Delta\theta_{rel} \approx 20^o$ around $\theta_{rel} = 0^o$ and $\theta_{rel} = 180^o$.

The asymmetry cannot even be explained for by contributions from direct break-up or ^{8}Be formation, which, if any in the angular in-

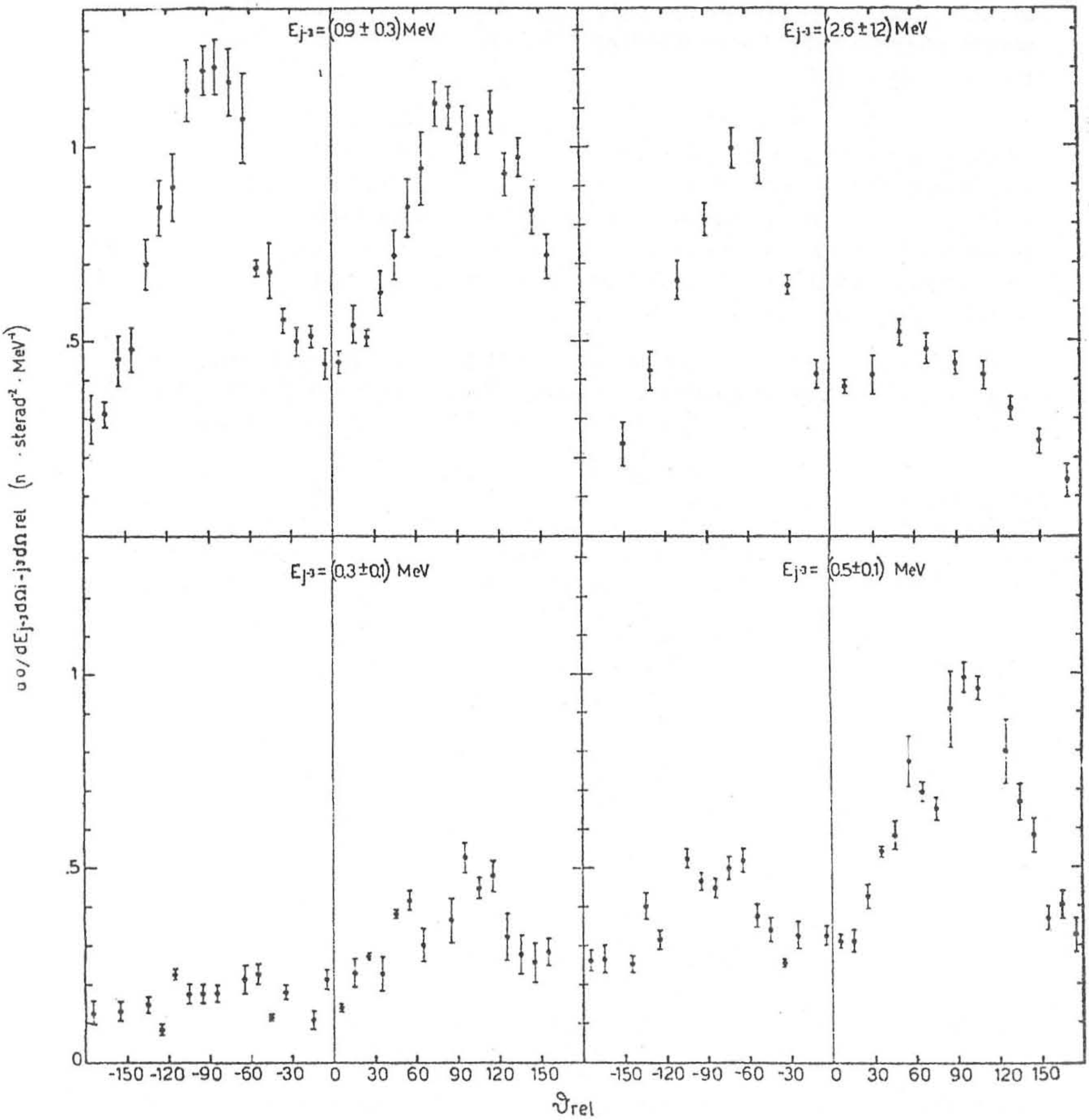

FIG. 4 - Angular correlations of the α-particles in the RCS for various internal energy intervals. Since θ_{rel} can be interpreted as the angle of the α-particle in the centre of mass of the α-n system when the motion of this latter is described in the system of the centre of mass of the three particles, the shown angular correlations can be interpreted as the angular distribution of the α-particles produced in the decay of the correlated α-n system.

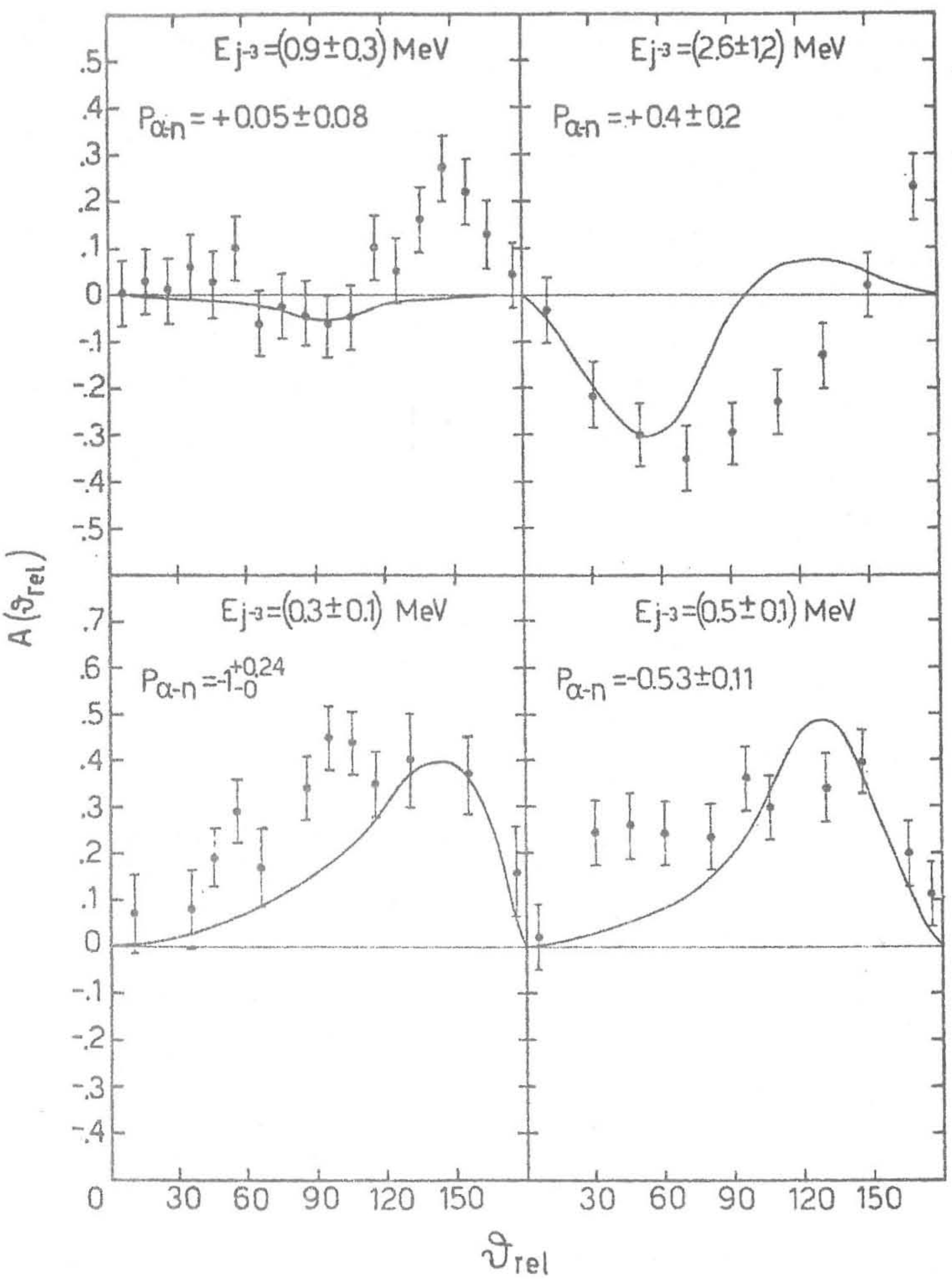

FIG. 5 - Asymmetry in the angular correlations for various internal energies of the α -n systems. The curves are computed under the hypothesis of an elastic scattering of polarized neutrons on ^{4}He. The values of $P_{\alpha\text{-}n}$ give the polarization of the decaying α-n systems.

terval we are concerned with, are both spread out quite uniformly along the kinematic curves and would give symmetrical contributions to the angular correlations, because of the symmetry of the jacobians with respect to ϕ_{rel}.

So it seems natural to attribute the asymmetries to formation of polarized α-n systems in the $^7Li + d \rightarrow \alpha + {}^5He$ reaction. In this hypothesis the analysing characteristics of the n + ^4He scattering would give account of the found asymmetries.

2.4. - Polarization of the α-n system.

Assuming that we are concerned with vectorial polarization of the α-n system, similar to that produced by incidence of polarized neutrons on ^4He, it is possible to write:

$$\sigma(\theta_{rel}, \phi_{rel}) = \sigma(\theta_{rel})\,(1 + A(\theta_{rel}) \cos \phi_{rel}).$$

The quantity $\sigma(\theta_{rel}) = \dfrac{\sigma(\theta_{rel}, 0) + \sigma(\theta_{rel}, \pi)}{2}$ is reported in Fig. 6. For internal energies below and around the peak, it can be given by $\sigma(\theta) \propto (1 + k \,\mathrm{sen}^2\, \theta)$, with energy dependent values of k, given in Fig. 6. At greater values of the internal energy the correlation appears asymmetric also with respect to $\theta_{rel} = 90^o$.

In the hypothesis of sequential decay, calling $P_{\alpha-n}$ the polarization of the α-n system formed as a strongly interacting complex with weak coupling to the other α-particle produced in the reaction, it is possible to write:

$$A(\theta) = P_{\alpha-n} \cdot (-P_n(\pi - \theta)), \tag{1}$$

where $P_n(\theta)$ is the analysing power of a sort of scattering between the neutron and the α-particle belonging to the α-n system. All the quantities appearing in eq. (1) can be energy dependent. The minus sign and the change to $\pi - \theta$ is due to the fact that we detect the α-particle and not the neutron. Of course $P_n(\theta)$ would reduce to the polarization of the neutron in the elastic scattering n + ^4He[6] if the phase shifts involved in the actual α-n interaction were the same as in the real scattering[7, 8].

There are arguments[5] to say that it is perhaps necessary to correct the phase shifts at least from the rigid sphere contribution. In this case one would expect no contribution from the $s_{1/2}$ phase shift, since it is entirely a rigid sphere phase shift in the n + ^4He elastic scattering. However, the absence of the l=0 contribution to the polari-

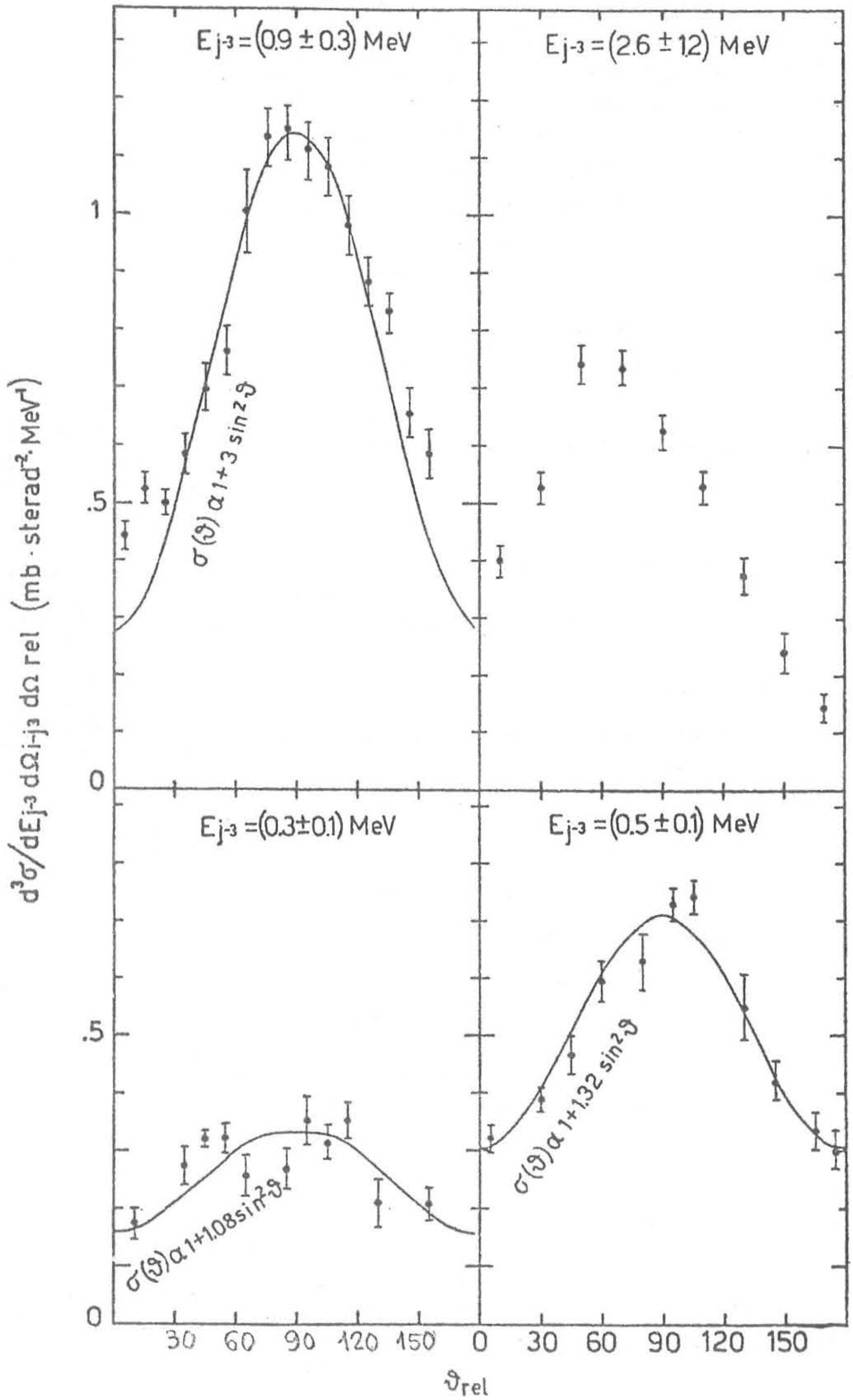

FIG. 6 - Angular correlations for the unpolarized α-n systems.

zation would cause[6] $P_n(\theta) = 0$ at $\theta = 90^o$, and this does not seem the case, at least outside the main peak region, as Fig. 5 shows.

So, in spite of the crudeness of the procedure, one can attempt to compute the asymmetry $A(\theta)$ making use of the neutron polarization in the n + ^{4}He elastic scattering. The curves so obtained are reported in Fig. 5 together with the deduced values of $P_{\alpha-n}$. The fit cannot be considered poor. The results of this fit are that $P_{\alpha-n}$ is energy dependent, and changes sign going through the energy peak.

3. - CONCLUSIONS -

The present results allow to conclude that:

a) The ^{7}Li + d $\rightarrow$ 2α + n reaction at E_d = 1.0 MeV proceeds via sequential decay that involves the formation of strongly interacting α-n systems.

b) These intermediate α-n systems are polarized and the asymmetry in the angular distribution of the emitted particles can be described roughly as that produced in the elastic scattering of polarized neutrons from ^{4}He[6] provided the polarization of them is different at the various energies.

c) The treatment of the data on the kinematic curve by means of two exchanged jacobians[1] seems to exaust all the effects of the identity of the two α-particles.

d) There is no clear evidence for contributions from the direct break-up or the ^{8}Be formation in the level around E_x = 11.4 MeV, which alone can be seen at the explored energies and angles.

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REFERENCES -

(1) - V. D'Amico, S. Jannelli, F. Mezzanares and R. Potenza, Nuovo Cimento, to be published.

(2) - N. Arena, G. Calvi, S. Cavallaro, R. Potenza, M. Sandoli, and R. De Leo, Nuovo Cimento, to be published.

(3) - C. Milone and R. Potenza, Nuclear Phys. 84, 25 (1966).
(4) - S. Bashkin, F.P. Mooring and B. Petree, Phys. Rev. 82, 378 (1951).
(5) - G.C. Phyllips, T.A. Griffy and I.C. Biedenharn, Nuclear Phys. 21, 327 (1960).
(6) - W. Haeberli, Fast Neutron Physics, part. II - ed. J.B. Marion and J.L. Fowler (Interscience 1963), pg. 1379-1427.
(7) - J.D. Seagrave, Phys. Rev. 92, 1222 (1953).
(8) - E. Clementel and C. Villi, Nuovo Cimento 2, 1121 (1955).