SEMI COHERENT INTERACTIONS WITH DEUTERON

G. Alberi
and
F. Baldracchini

Istituto di Fisica Teorica dell'Università, Miramare, Trieste

Istituto Nazionale di Fisica Nucleare, Sezione di Trieste

(Talk given by G. Alberi in the Topical Meeting on Multiparticle Production on Nuclei, Trieste, June 1976).

Ten years ago Stodolsky[1] discussed the possibility of selecting different t-exchange mechanisms in high-energy hadron-nucleus reaction using different excited states of the nuclear system. The selection rules are resumed in table I, together with the corresponding transition operator for the nucleus. With isovector and spin flip transitions or both, one can also study the propagation in nuclear matter of true resonances, like A_2 for incident π-mesons and Δ_{33} for incident protons, and therefore learn about the interaction of these resonances with the nucleon. Unfortunately the experiments proved to be quite difficult[2] and only the transition $0^+ \to 2^+$ in ^{12}C was successfully studied[2], but it did not provide new information on the elementary interaction.

For the deuteron it seems impossible to have such transitions, because we don't have excited states. However, one expects for the deuteron break-up aD → cNN a strong final state interaction for small invariant masses of the two nucleon system. This produces an enhancement in the spectrum of the invariant mass

$$m_{12} = \sqrt{S_{12}} = \sqrt{(p_1 + p_2)^2} \tag{1}$$

which corresponds to definite quantum numbers and therefore all the selection rules of Table I can be applied: if we accept only the events of the peak, we can consider this as a semicoherent reaction. Although this enhancement was seen at low energy for incident electrons[3] or protons[4], it was never seen for high energy experiments, because of low energy resolution: the peak has a width of a few MeV($\Gamma \sim \frac{a^{-2}}{m}$ where a is the scattering length).

As recently reported[5] a peak of the same type was observed for $m_{12} \sim m + m_\Delta$ in the charge exchange reaction pD→npp at 1.66 GeV/c. We suggest here that this peak is due to an intermediate Δ-N state in

S-wave (See Table II) and therefore for angular momentum, parity conservation in the $\Delta N \rightarrow NN$ transition and Pauli principle in the two proton final state, it has to be a 2^+ state.

Before starting the discussion of this hypothesis, one has to recall that this enhancement was seen for the momenta of the spectator > 250 MeV/c and therefore it seems to be the main cause of the high momentum tail in the spectator distribution. The hypothesis of the ΔN virtual state was actually borne out from the channel dependence of the tail[6,7], even before the discovery of the peak in m_{12} . The high momentum tail has been thoroughly discussed in the literature in the framework of multiple scattering theory by Wallace[8] and Golovin et al.[9], in connection with the experiment D(p,2p)n by Perdrisat et al.[10], but the gap between experiment and theory is still present, even in the sophisticated treatment including spin[9]. The reason why the double scattering is not important on the high momentum tail, was found in Ref. 11; the most likely configuration of the two nucleons resulting from a double scattering at small t occurs when they recoil transversely to the beam and this corresponds to a small region of the phase space in the break-up. In the case of elastic scattering the two nucleons must recoil transversely because they have to form the deuteron in the final state and this explains why the effect is much larger in this case[12].

In order to check our hypothesis, we consider the multiple scattering contribution as negligible background, which is justified by the above discussion. So the enhancement in m_{12} can be described in term of a model, inspired by the second Feynman diagram of Table II. For the transition amplitude $N\Delta \rightarrow NN$ we use the multichannel K-matrix formalism[13]: channel (1) is NN, L=2, S=0 and channel (2) is ΔN, for L=0 and S=2. Its expression is

$$T_{12} = \frac{-q_1^2 M_{12}}{M_{11}M_{22}-M_{12}M_{21}-i(M_{22}q_1^5 + M_{11}q_2) - q_1^5 q_2} \qquad (2)$$

where q_i are the C.M. momenta and $M_{ij} = 1/A_{ij} + \frac{1}{2}B_{ij}q_i^2\delta_{ij}$ in the effective range approximation. While for the channel (2) this approximation is justified, being $q_2 \sim 0$, for the channel (1), it is meant, only, as 2° order polinomial approximation for the $q_1^5 \cot\delta$, in the region of interest. For the deuteron vertex we use the connection to the non-relativistic Hulthen-wave function(14). To the π vertices, and propagator, we substitute the experimental value of the differential-cross section for the real process $pN \to n\Delta$: this drastic simplification is possible, if we consider the vertex $\pi N\Delta$ as slowly varying function of internal variables as compared with the deuteron wave function.

The diagram can be computed analitically in the non relativistic limit for the Δ-propagator and the result for the cross section is

$$\frac{d\sigma}{d\sqrt{S_{12}}} = \frac{\left[272 \frac{mb}{(GeV/c)^2}\right]}{\lambda(S_o,m^2,M^2)} \frac{2}{3} \frac{M}{m^2\Delta^2} \frac{H^2}{2\pi} \left| \log A_\alpha - \log A_\beta \right|^2 \left|T_{12}\right|^2 S_{12} \times$$

$$\times \frac{(S_1-4m^2)S_1}{b} \left(e^{-b|t+|} - e^{-b\times .15}\right) q_1 \times \frac{5}{6} \qquad (3)$$

where

$$A_\chi = \frac{\sqrt{\epsilon_\chi^2 + \frac{i\Gamma m_\Delta}{2}} + i\chi - \Delta/2}{\sqrt{\epsilon_\chi^2 + \frac{i\Gamma m_\Delta}{2}} + i\chi + \Delta/2}, \quad \epsilon_\chi^2 = q_1^2 \frac{m_\Delta}{m} + \left(1 - \frac{m_\Delta}{m}\right)\left(m_\Delta m - \frac{\Delta^2}{4} - \frac{\chi^2}{2}\right)$$

$$S_o = (m+M)^2 + 2MT_{lab}, \quad S_1 = 4m^2 + 2m\, T_{lab}, \quad |t+| = (S_{12}-M^2)^2/(16k^2)$$

$$T_{lab} = \sqrt{k^2+m^2} - m, \quad \frac{d\sigma}{dt}(pp \to \Delta^{++} n)\Big|_{exp} = 272\, e^{bt} \frac{mb}{(GeV/c)^2}$$

M is the deuteron mass and $b = 11.8\ (\mathrm{GeV/c})^{-2}$; k is the momentum of the proton in the rest system of the deuteron. The Hulthen wave function is $\Psi(q) = \frac{H}{\pi\sqrt{2}} \left(\frac{1}{\alpha^2+q^2} - \frac{1}{\beta^2+q^2}\right)$.

The results shown in Fig. 1, are in good agreement with the experiment, in form and in absolute value. The parameter used are $A_{22} = 5$ F and $B_2 = 1.5$ F and $\sqrt[3]{A_{12}} = .4$ F.

This approach can be very useful, for a rough theoretical evaluation of the effect, in other cases: however, a more systematic study of the spin dependence of the $\pi N\Delta$ vertex is needed to study the angular distibution of the two final protons. To be consistent with the previous treatment, we check that π-exchange with a form-factor e^{bt} explains the experimental values of $\frac{d\sigma}{dt}$ $(pp \to \Delta^{++}n)$[15] (*).

The vertex $\pi N\Delta$, as from Jackson and Pilkuhn[16], is

$$V_{s_z',S_z} = \overline{U}_\mu(S_z)P_\mu\, u(s_z')\frac{G^*}{m_\pi} \tag{4}$$

where U and u are Rarita-Schwinger and Dirac spinors and P_μ is the nucleon momentum.

In the same spirit of the previous calculation we take the vertex function outside the loop integral and we calculate it for zero internal momentum of the deuteron: as from the kinematics of Fig. 2, the Δ_{33} resonance is recoiling along the trimomentum transfer $\vec{\Delta}$. Choosing as z-axis the direction of $\vec{\Delta}$, all the matrix elements vanish except $V_{\pm 1/2, \pm 1/2}$, so that the angular distribution in the C.M. of the two proton system is

(*) The check is done at 2.8 GeV/c and the result is scaled down at 1.65 GeV/c, using the $q^{-2}\ S^{-1}$ dependence of the cross-section.

$$\frac{d\sigma}{d\cos\vartheta^*} \propto \sum_{M'} |Y_{2M'}(\cos\vartheta^*)|^2 \; *$$

$$* \sum_{M} \Big| \sum_{s_z' S_z} V_{s_z' S_z} \langle 1M|1/2\; s_z'\; 1/2\; s_z\rangle\langle 3/2\; S_z\; 1/2\; s_z|\; 2M'\rangle \Big|^2 =$$

$$= |V_{1/2\;1/2}|^2 (3/2\,|Y_2^1|^2 + |Y_2^0|^2) = \tag{5}$$

$$= |V_{1/2\;1/2}|^2 \frac{5}{16\pi} (1 + 3\cos^2\vartheta^*).$$

The comparison of this prediction with the experimental results in Fig. 3, shows that our hypothesis survives the crucial test of the angular distribution. We recall that a consequence of our hypothesis is that the final state of the two protons is a pure 2^+ state.

It is worth recalling briefly that a similar situation occurs for the reaction $K^- D \to \pi^- \Lambda p$, when only high momentum spectators and forward angles for π^- are considered. As from Fig. 4, there is a sharp peak in the Λp mass distribution, at the ΣN treshold: as in the previous case it can be described by a virtual ΣN state(17). However, in this case the spin of Σ is 1/2, like the Λ, and we expect therefore an $\ell = 0$ state, for the Λp system. This is confirmed by recent data by Hepp(18), shown in Fig. 5. There we can see that the forward-backward asymmetry is becoming very small in correspondence of the peak.

REFERENCES.

(1) L. Stodolsky, Phys. Rev. 144, 1145 (1966).

(2) W. Mehlop et al. in Proceedings of High-Energy Collisions involving nuclei, ed. G. Bellini, L. Bertocchi and P.G. Rancoita, Trieste, September 1974. L.J. Köester Ibidem.

(3) M.R. Yearian and E.B. Hughes, Phys. Lett. 10, 235 (1964).

(4) I. Slaus, in Few Particle Problems, Proceedings of the Int. Conf. in Los Angeles, 1972.

(5) B.S. Aladashvili et al., Warsaw preprint, 1976.

(6) B.S. Aladashvili et al., Nucl. Phys. B86, 461 (1975).

(7) G. Alberi, V. Hepp, L.P. Rosa and Z.D. Thomè, CERN Ref. Th. 2113, to be published in Nucl. Phys. B.

(8) J.M. Wallace, Phys. Rev. 5C, 609 (1972).

(9) B.M. Golovin, G.I. Lykasov, A.M. Rozanova and V.A. Tarasov, Sov. Journ. of Nucl. Phys. 16, 602 (1973).

(10) C.F. Perdrisat et al., Phys. Rev. 187, 1201 (1969).

(11) G. Alberi, Z.D. Thomè and L.P. Rosa, Phys. Rev. Lett. 34, 503 (1975).

(12) D. Julius, Fortschritte für Physik 22, 311 (1974).

(13) M.H. Ross and G.L. Shaw, Phys. Rev. 126, 806 (1962).

(14) G. Alberi, E. Castelli, P. Poropat and M. Sessa INFN/AE 72/3
G. Alberi, INFN/AE 73/1.

(15) NN and ND Interactions, UCRL-20000 NN, 1970.

(16) J.D. Jackson and H. Pilkuhn, Nuovo Cimento 33, 906 (1964).

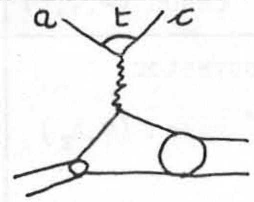
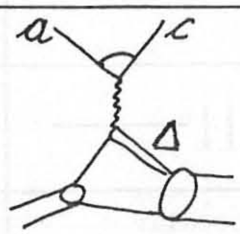
(17) E. Satoh, Y. Iwamura and Y. Takahashi, Phys. Rev. Lett. 35, 1128 (1975).

(18) CERN -Heidelberg- Munich Collaboration. Private Communication by V. Hepp.

TABLE I

Nuclear Operator	Exchange	Nuclear Transition $(J^p, T) \rightarrow (J^{p'}, T')$
1	Isoscalar $0^+, 1^-, 2^+$ meson (ω, φ, f)	$(0^+, 0) \rightarrow (0^+, 0)$ $\rightarrow (2^+, 0)$
τ	Isovector $0^+, 1^-, 2^+$ meson (φ, A_2)	$(0^+, T) \rightarrow (0^+, T)$ $\rightarrow (2^+, T)$ $T_z \rightarrow T_z \pm 1$ analogue states
$r\tau$	——— || ———	$(0^+, 0) \rightarrow (1^-, 1)$ giant resonances
σ	Isoscalar $0^-, 1^+$ meson (η, η') mag. coupling of 1^- meson (ω)	$(0^+, 0) \rightarrow (1^+, 0)$
$\sigma\tau$	Isovector $0^-, 1^+$ meson (π) mag. coupling of (φ)	$(0^+, 0) \rightarrow (1^+, 1)$ $(1^+, 0) \rightarrow (0^+, 1)$ $\rightarrow (2^+, 1)$
	Isospinor $0^-, 1^+$ meson (K, K^*)	$(1^+, 0) \rightarrow (1^+, 1/2)$

TABLE II

m_{12}	$(J^P_,\ T)$	Dynamics	Kinematical Region
$\sim 2m$	$(0^+_,\ 1)$		Low t Low Spectator Momentum
$\sim m+m_\Delta$	$(2^+_,\ 1)$		Low t High Spectator Momentum

Isovector and spin flip transitions in deuteron break-up

Figure Captions.

Fig. 1. Mass distribution of the two protons in the charge exchange reaction $pD \rightarrow n(pp)$ at 1.65 GeV/c incident proton momentum. The experimental data are from Ref. 7.

Fig. 2. Kinematics, spin notation of the final state interaction diagram.

Fig. 3. Angular distribution of the two protons in their center of mass. The experimental data are from Ref. 7.

Fig. 4. Mass distribution of the Λp system in the reaction $K^- D \rightarrow \pi^- (\Lambda p)$ at 700-850 MeV/c. The figure is taken from Ref. 17.

Fig. 5. Forward-Backward asymmetry for the angular distribution in the C.M. of the (Λp) system as function of the invariant mass. The data are from Ref. 18.

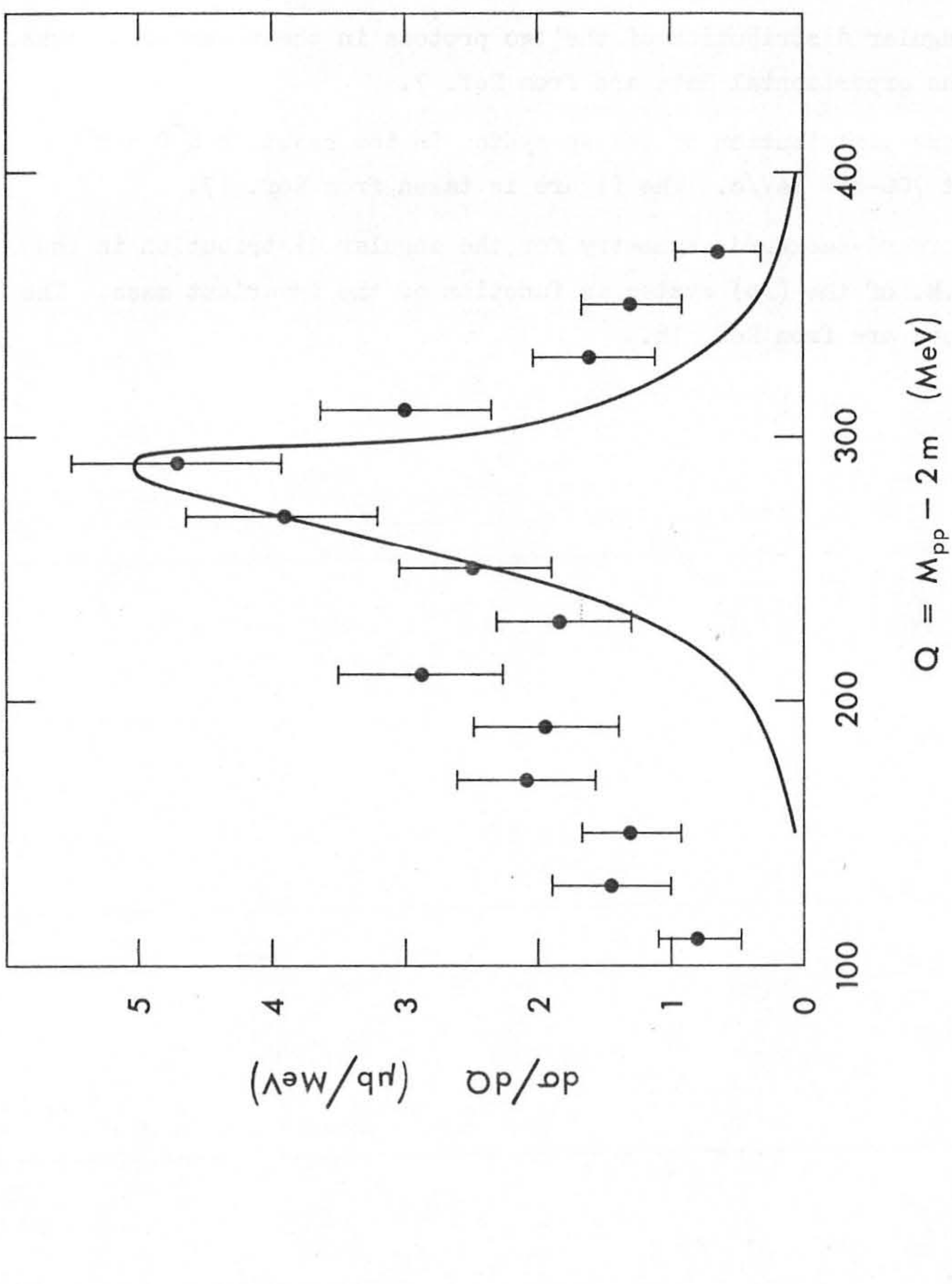
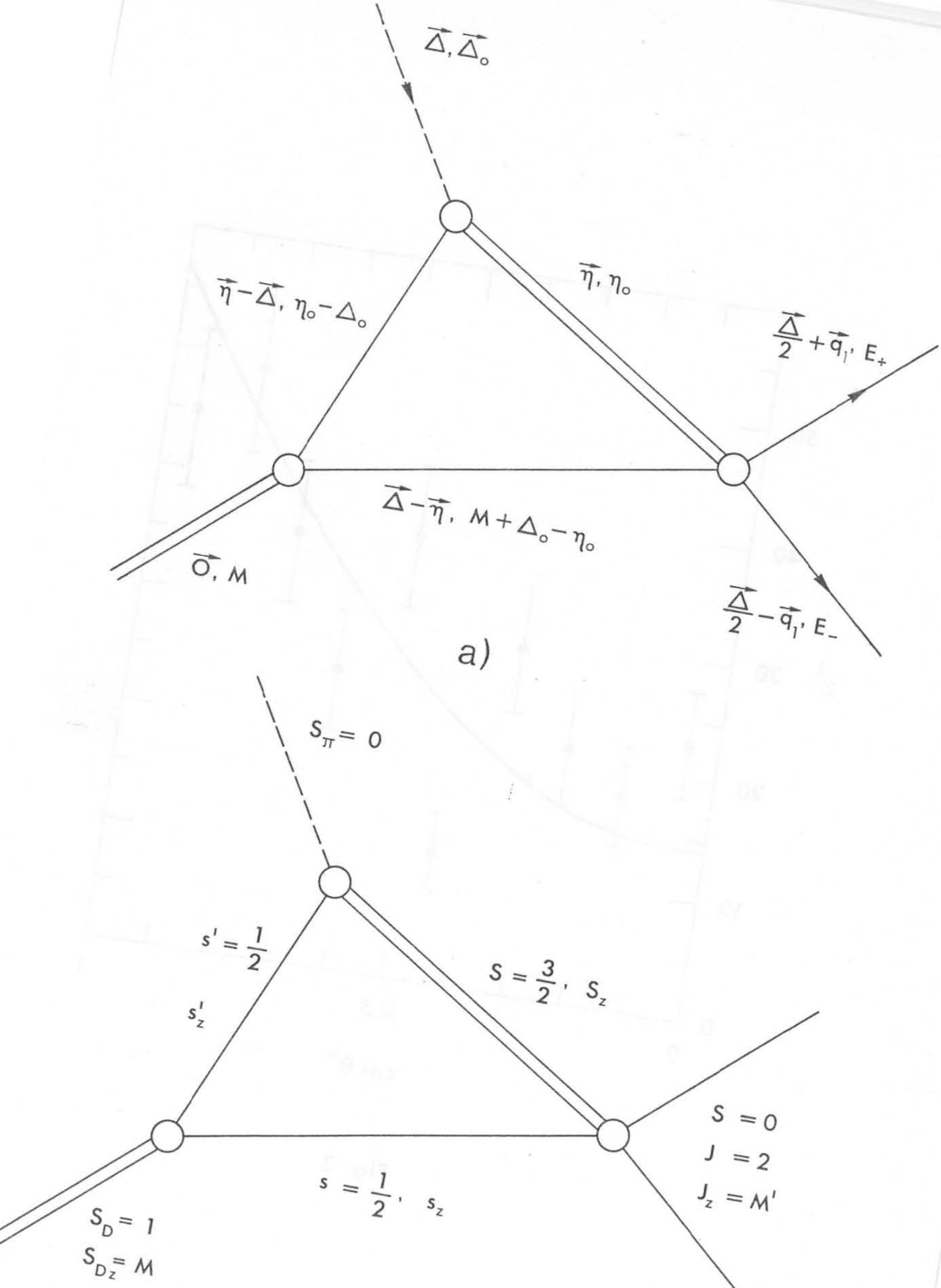


Fig. 1



$\vec{\Delta}, \vec{\Delta}_o$
$\vec{\eta} - \vec{\Delta}, \eta_o - \Delta_o$
$\vec{\eta}, \eta_o$
$\frac{\vec{\Delta}}{2} + \vec{q}_1, E_+$
$\vec{\Delta} - \vec{\eta}, M + \Delta_o - \eta_o$
$\vec{O}, M$
$\frac{\vec{\Delta}}{2} - \vec{q}_1, E_-$
a)
$S_\pi = 0$
$s' = \frac{1}{2}$
s'_z
$S = \frac{3}{2}, S_z$
$S = 0$
$J = 2$
$J_z = M'$
$s = \frac{1}{2}, s_z$
$S_D = 1$
$S_{Dz} = M$
b)

447

Fig. 2

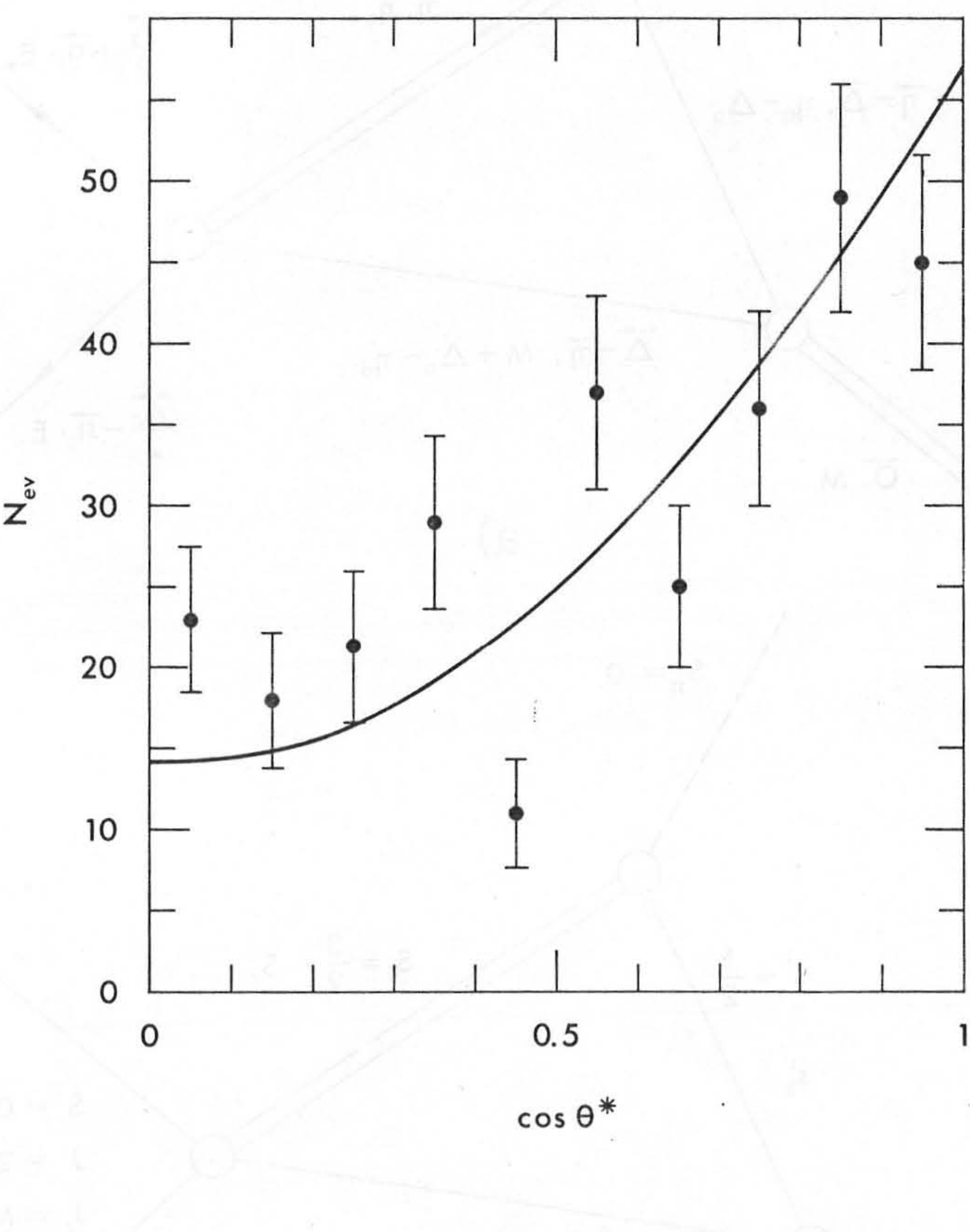


Fig. 3

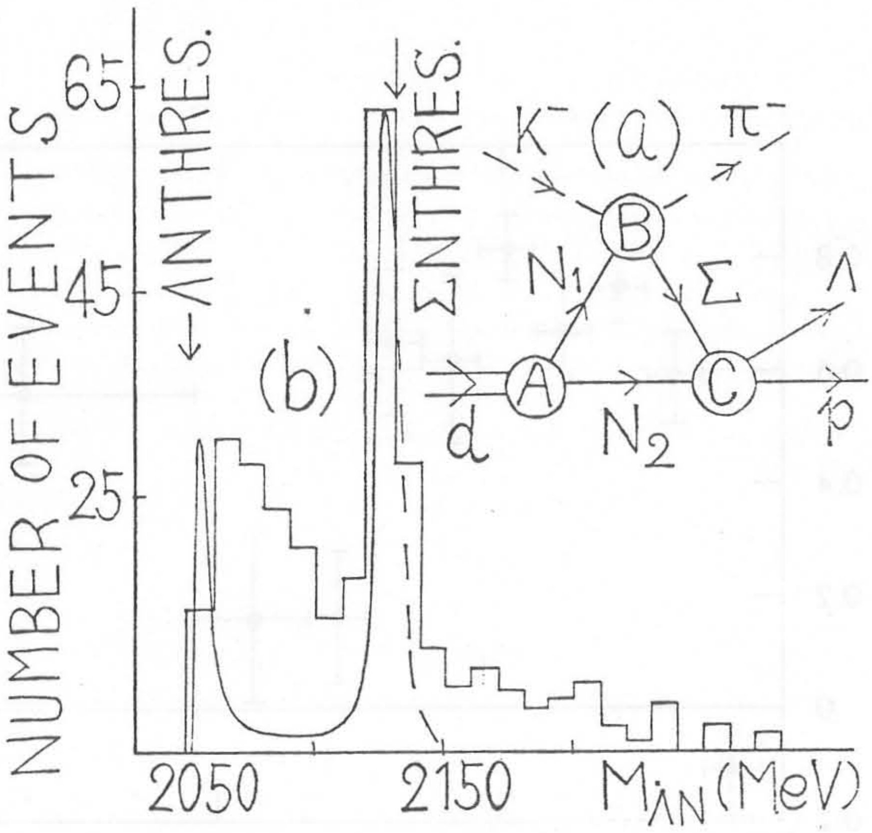

NUMBER OF EVENTS
65
45
25
← ΛN THRES.
ΣN THRES.
(b)
(a)
K^-
π^-
B
N_1
Σ
Λ
A
C
d
N_2
p
2050
2150
$M_{\Lambda N}$ (MeV)

Fig. 4

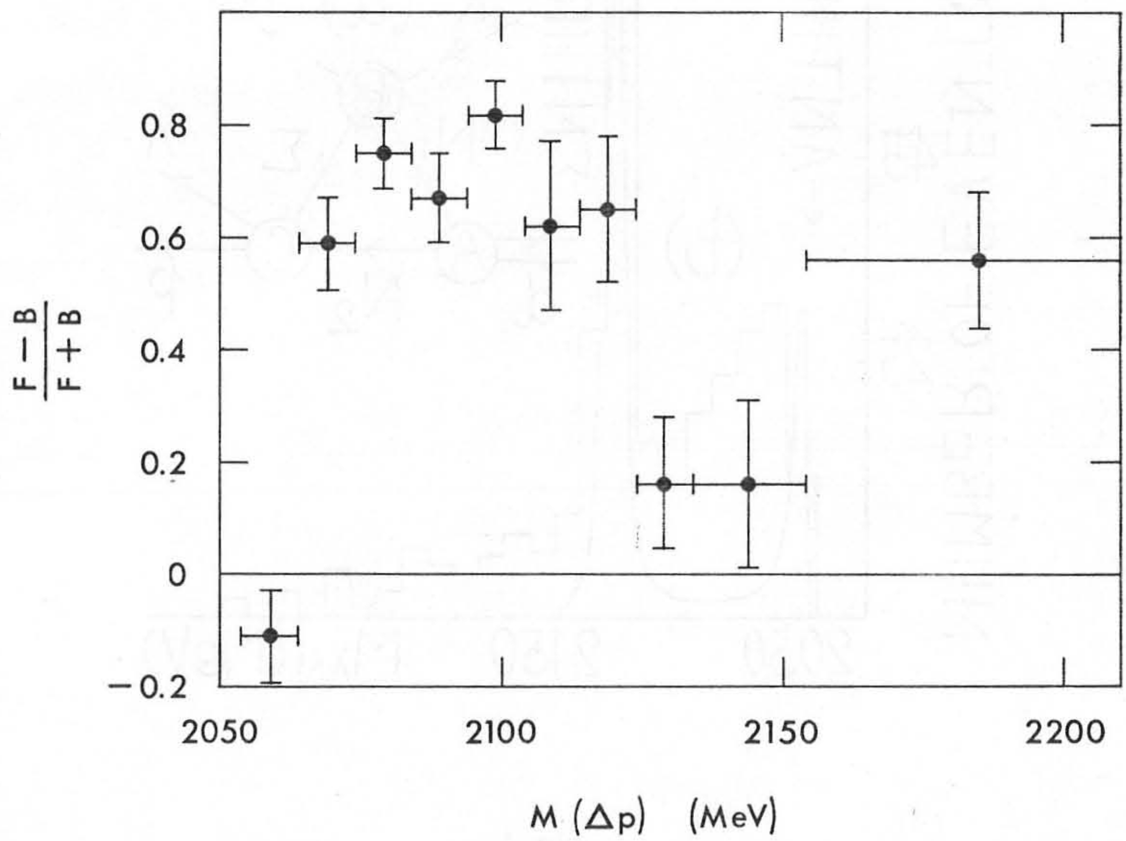


Fig. 5