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# CORRECTIONS TO THE QUASI-FREE PROCESS

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Abstract: At intermediate energy the photon-nucleus interaction is dominated by the quasi-free process: the photon interacts with one nucleon moving in a mean potential. The other nucleons are spectator in the sense that their overall effect is to create a mean optical potential in which the outgoing particles move (Distorted Wave Impulse Approximation).

The limits of the validity of this process will be discussed on the basis of the results of the analysis of the two following kinds of reactions:

1. The $A(\gamma,\pi)B$ reactions induced by a monochromatic photon beam. Here the spectrum of pions emitted at a given angle is measured.

2. The $A(\gamma,p\pi)B$ reactions induced by a bremsstrahlung beam. Here the proton and the pion are detected in coincidence.

The dominance of this mechanism decreases quickly when the momentum of the spectator system increases, and strong deviations appear. They are understood in terms of the onset of two nucleon mechanisms. Two of them are of dominating importance: the $\Delta$-N interaction and the meson exchange corrections to the $\gamma N \rightarrow N\pi$ vertex. We shall put the emphasis on their consequences on the yield of pion photoproduction reactions induced on few body systems.

At intermediate energy the photon nucleus interaction is dominated by the quasi-free process. The photon interacts with one nucleon moving in a mean potential. The other nucleons are spectator, in that sense that their overall effects are to create a mean optical potential in which the outgoing particles move (Distorted Wave Impulse Approximation (DWIA).

In the $\Delta(1236)$ region, this mechanism accounts for almost all of the total photoabsorption cross section on light nuclei. When the Fermi motion and the Pauli exclusion principle are taken into account, the measured total cross section for absorption of a photon on the Deuterium[1] or the Li and Be isotopes[2] are well reproduced[1,3].

This mechanism is rather simple and we are interested in going beyond this one nucleon background, from which nothing new can be learned on the elementary amplitude and the low momentum part of the nucleon wave function.

The deviations from the quasi-free process appear when the momentum transfer becomes high and it must be realized that they represent only a few percent of the total photoabsorption cross section. However, their study is very important, because they can be understood as the onset of the two nucleon mechanisms. I shall devote the remainder of my talk to their analysis. The first reason is that the $\Delta(1236)$ plays a capital role in the description of the elementary amplitude of the reaction $\gamma N \to \pi N$, and the electromagnetic probe is the cleanest way to create it from a nucleon, allowing us to study unambiguously its interactions with the other nucleons inside nuclei. Most of the observed deviations from the quasi-free process can be explained in terms of the final state $\Delta N$ interaction[4-7]. The second reason is that the $\Delta(1236)$ also plays an important role in the analysis of the $\gamma N \to N\pi\pi$ reactions above $E\gamma$=400 MeV. The double pion photoproduction reactions can be described, with great degree of accuracy, as the quasi two-body reactions $\gamma N \to \pi\Delta$[8,9]. Above $E\gamma$=400 MeV the influence of this double pion photoproduction channel on the single pion photoproduction reactions on nuclei has been recently observed[7,10]. One of the pion emitted at a nucleon as reabsorbed by another nucleon in the nucleus. This meson exchange current correction to the elementary $\gamma N \to N\pi$ amplitude accounts for the remaining deviations from the quasi-free process.

Let us now develop these ideas in more detail and choose as an example the simplest nucleus, the deuterium. This is the best laboratory to study the $\Delta$-N interaction and to compare this simplified description of the three-body $\pi NN$ system to the exact result of a more general theory, in which the practical calculation can be performed with a degree of accuracy which is difficult (cr impossible) to reach when heavier nuclei are considered. In Fig. 1, the different steps of the history of a pion, created by a photon at a nucleon in the deuterium, are depicted. It can escape freely from the target without suffering any interaction. This is the pion photoproduction reaction on quasi-free nucleon (diagram II). The two outgoing nucleons can interact after the elementary reaction. This is a correction coming from final-state interaction (diagram III). The pion can suffer one or several scattering before escaping the nucleus (diagrams IV and V). Those mechanisms allow us to study the $\Delta$-N interaction which can be split into an exchange part (diagram VI) and a direct term (diagram VII). The first term in the development of the exchange part corresponds precisely to the exchange of a real pion, and the study of the pion-nucleon rescattering graphs leads to an understanding of this part of the $\Delta$-N interaction. The last possibility for the pion is to be reabsorbed by another nucleon and never escape (diagram VIII). This internal pion is now very far from its mass shell and cannot be distinguished from the virtual pions which mediate the nucleon-nucleon interaction; these diagrams correspond to the so-called meson-exchange current effects.

The Born terms play an important role in all these diagrams and are of dominating importance near the single pion photoproduction threshold. The physical problems are the same in this kinematical region and can be handled with the same methods as those we shall describe here (cf. Ref. 5,11). If the Born amplitude is extrapolated in the unphysical region (below one pion threshold) the corresponding operators are those which permit us to treat the meson exchange current effects on the cross-section of the reactions induced by a low energy photon beam ($E_\gamma \lesssim 140$ MeV). Therefore, strong similarities appear in the description of all these mechanisms in quite different energy range. The topology of the relevant diagrams and their methods of calculation are nearly the same. The only change concerns the operators which appear at the various vertices and the emphasis can be put on the different aspects of the interaction by adequately choosing the kinematics. In the following we shall always take into account these Born terms, but we shall put the emphasis on the study of the $\Delta$-nucleus interaction.

Let us now briefly describe this method of calculation. Clearly we start with the pion-nucleon multiple scattering expansion. Since strong interactions occur in the final state, this method would be impracticable if a small set of relevant diagrams could not be selected. The best way to single out a diagram is to look for its singularities and to choose the kinematics of the reactions in such a way that they come close to the physical region. The contribution of the corresponding diagram exhibits a rapid variation above a slowly varying background. This method presents two advantages. For an experimentalist it is easy to select the relevant kinematical variables to be measured in an experiment, and for a theoretician it is possible to compute the amplitude of the dominant mechanism and to check the model in detail.

Let us illustrate this method on the simplest mechanism which occurs when an intermediate energy photon interacts with the deuteron. The pion photoproduction on quasi-free nucleon (diagrams II in Fig. 1), which accounts for almost all the total photo-nuclear cross section[1-3]. The cross section

$$\frac{d\sigma}{d\Omega_\pi d\,\underset{\sim}{p}_r} = (1 + \beta_r \cos\,\theta_r)\ \rho\ (p_r)\ \frac{d\sigma}{d\Omega_\pi}\ (Q,\omega) \qquad (1)$$

is nothing but the relation between the counting rate of the $D(\gamma,p\pi^-)p$ reaction, the cross section $\frac{d\sigma}{d\Omega}$ $(\omega)$ of the elementary $\gamma n \rightarrow p\pi$ reaction (which depends only on the pion angle $\omega$ and the total energy Q available in the center of mass frame of the $\pi N$ pair), the number $\rho(\underset{\sim}{p}_r)\ d\underset{\sim}{p}_r$ of target nuc' 'ns per unit volume in the momentum space and the photon flux $(1+\beta_r\cos\theta_r)$ seen by the target nucleon moving with the velocity $-\ \underset{\sim}{\beta}_r$ and momentum $-\ \underset{\sim}{p}_r$. This is known as the spectator nucleon model and has been extensively used in the past to deduce the cross section of the $\gamma n \rightarrow p\pi^-$ reaction cross section from the $\gamma D \rightarrow pp\pi^-$ yield. It exhibits also the two kinds of singularities which appear in the diagrams in Fig. 1. The singularities of the vertex, and the singularities of the matrix element itself. For instance when the amplitude of the elementary reaction $\gamma N \rightarrow N\pi$ is expanded (diagram I in Fig. 1) the $\Delta(1236)$ pole in the s-channel leads to a strong variation of the cross section when the energy at the corresponding vertex comes close to the mass of the $\Delta(1236)$ resonance. The other singularity is associated with the intermediate nucleon propagator and is contained in the deuteron wave function. For low values of the spectator nucleon momentum the momentum distribution reduces to the nucleon pole

$$\rho(p_r) \underset{p_r \rightarrow 0}{\sim} \left[\frac{1}{p_r^2+\alpha^2}\right]^2 \qquad (2)$$

The singularity $p_r^2 = -\alpha^2$ is very near the physical region and makes dominent the quasi-free process when the spectator nucleon momentum approaches zero. This behaviour is clearly apparent in Fig. 2 where the momentum distribution of the nucleons emitted in the $\gamma D \rightarrow pp\pi^-$ reaction, studied in an bubble chamber experiment[12], is shown. When the spectator nucleon momentum is low the model in which only one nucleon is active accounts well for the data. Its contribution decreases quickly when the momentum increases and becomes small enough to be overwhelmed by the mechanism involving two nucleons. The excess of events observed for high values of the recoiling nucleon momentum is entirely due to the pion-nucleon rescattering mechanism[4], which will be discussed in more detail later. However, the statistical accuracy of these data does not allow us to extract differential cross sections and the momentum distribution was obtained by selecting the events with a given value of the momentum $p_r$ and integrating over all the remaining independent kinematical variables.

Another example is provided by the spectrum of the pion emitted at a given forward angle, when a monochromatic beam is used. Such an experiment has been recently carried on at Saclay with the new monochromatic photon beam ($N_\gamma \sim 5.10^7$ particles/s in $\Delta E_\gamma \sim 3$ MeV at $E_\gamma = 300$ MeV). The preliminary data[13] confirm and reproduce the theoretical predictions[5] depicted in Fig. 3 where the $\pi^+$ and $\pi^-$ spectrum are drawn. The enhancement near the maximum pion momentum is due to the strong NN interaction in the $^1S_0$ state. (Note the different effects of the pp and the nn interaction coming from the Coulomb force). Their relative velocity is vanishing here. When the pion momentum decreases the momentum of one of the emitted nucleon goes through zero and the broad bump is entirely due to the quasi-free mechanism. When the pion momentum decreases again, the importance of the quasi-free process decreases and small deviations might appear in the part of the pion spectrum, where the emitted nucleon momenta begin to be high. However, this pion spectrum is still an integrated quantity and the deviations from the quasi-free process are still overwhelmed by the dominant one nucleon mechanism.

To go beyond and to learn something more, experiments must be performed in which the statistical accuracy is good enough when all independent kinematical variables are measured. The complete knowledge of the kinematics implies the detection of at least two particles in coincidence, and the measurement of small cross section. Hence high duty-cycle and high intensity accelerators are needed. The performances of the 600 MeV electron Saclay Linac have made possible the achievement of the experiments which are now described.

We have seen that the quasi-free mechanism is dominant when the spectator nucleon momentum is low. In that region the nucleon momentum distribution in a nucleus is well known. The different deuterium wave-functions differ by about ±5% below $p_r \sim 150$ MeV/c. Therefore, this quasi-free region allows us to determine the cross-section of the elementary reaction $\gamma n \to p\pi^-$ with the help of eq. 1. In Fig. 4 the value of this cross section, deduced from the yield of the $\gamma D \to pp\pi^-$ reaction[6] or the $^4He(\gamma, p\pi^-)$ reaction[14] analyzed in the frame work of DWIA[15], are compared. The agreement between the two sets of values is excellent and they are well reproduced by the theoretical model[16].

To study in detail the mechanisms involving more than one nucleon, which appear when the momentum of the emitted nucleons increases, it is convenient to perform an experiment in which the one nucleon contribution is kept constant and minimized. By inspection of eq. 1, it is easy to be convinced that the absolute value $P_R$ of the recoiling system, the energy Q and the angle $\omega$ must be kept constant. The remaining independent kinematical variable is the angle $\Theta_r$ made by the recoiling system and the incoming photon direction (or equivalently the energy of the photon). Hence, we have measured[6,7] the angular distribution of a proton emitted with a constant momentum $p_r$ = 400 MeV/c in the reaction $\gamma D \to pp\pi^-$, when Q = 1200 MeV and $\omega = 90°$. It is depicted in Fig. 5 and exhibits a strong anisotropy which contrasts strongly with the spectator nucleon model predictions. A strong peak clearly appears near $\Theta_r \sim 45°$. This violent structure is almost entirely due to the pion-nucleon single scattering mechanism (diagram IV in Fig. 2) and is the signature of the corresponding singularity. The matrix element exhibits a moving logarithmic singularity (associated with the on-shell propagation of the internal pion), which comes close to the physical region when the angle $\Theta_r$ approaches 45° (see Ref. 5 for a detailed discussion of this phenomenon). This result is very important, the exchange part of the Δ-N interaction is very simple. The dominance of the one-pion exchange term and the smallness of the pion multiple scattering are strongly supported by this result. However, the measured cross section decreases less rapidly, when $\Theta_r$ increases, than the pion-nucleon rescattering contribution. This difference is well accounted for by the following mechanism. Two pions are emitted at one nucleon and one of them is reabsorbed by the other nucleon. The cross section of the reaction

$\gamma N \to N\pi\pi$ increases very quickly between 400 MeV and 600 MeV[8,9] and this is precisely in this energy range that the influence of this elementary reaction on the yield of the $\gamma D \to pp\pi^-$ reaction is the strongest. This mechanism can also be viewed as a meson exchange correction to the amplitude of the $\gamma N \to N\pi$. The internal pion is far from its mass shell ($-16\, m_\pi^2 \leq q^2 \leq -9\, m_\pi^2$) and cannot be distinguished from the virtual pions surrounding the nucleons in the deuterium. It is impossible to know whether this pion is photoproduced at one nucleon and then reabsorbed by the other, or is emitted at one nucleon and reaches the other when it absorbs the photon; the two descriptions are equivalent. A detailed description of this phenomenon can be found in ref. 10.

In the experiment described above the relative kinetic energy $T_{\Delta N}$ between the emitted $\Delta(1236)$ and the other nucleon is high and the $\Delta$-N interactions is mainly mediated by the peripheral one pion exchange term (diagram VI in Fig. 1). Partial waves with high angular momentum are involved and the centrifugal barrier prevents the two particles from coming close together. Furthermore, the real nature of the exchanged pion makes the one pion exchange contribution very important in describing the long ranged part of the $\Delta$-N interaction. The question now is to learn something more about the $\Delta N$ interaction at low energy, where the low angular momenta are involved and where the centrifugal barrier does not exist ($L_{\Delta N}=0$) or is so small that the two particles can interact at short distances. In these circumstances the $\Delta(1236)$ and the nucleon can interact strongly and clearly a single diagram cannot reproduce reality: a multiple scattering series must be summed, an example of which is drawn in diagram VII of Fig. 1 (See also ref. 5). This is a very difficult task and the problem can be simplified, as in the N-N scattering case, in the following way. The partial waves with high momenta ($L_{\Delta N} \geq 1$) are parametrized by the one pion exchange term (diagram VI in Fig. 1) which has been shown to account fairly well for the experimental data when the relative kinematic energy $T_{\Delta N}$ of the $\Delta N$ pair is high (See Fig. 5). The s-wave is parametrized in terms of an effective range expansion near the $\Delta$-N threshold. This kind of analysis permits us to reproduce the angular distribution[6] of the proton emitted in the $\gamma D \to pp\pi^-$ reaction with a constant momentum ($p_r$=150 MeV/c) when the mass of $\pi N$ pair is Q=1220 MeV. The quasi-free contribution is still dominant but significant deviations (about 20%) appear clearly in Fig. 6. The one loop diagrams (III and IV in Fig. 1) cannot reproduce the entire angular distribution. The rise near the forward angles is due to the nucleon-nucleon scattering diagram III (their relative kinetic energy decreases when $\theta_r$ decreases)and the enhancement near $\theta_r=120°$ is due to the pion nucleon scattering diagram IV (e.g. the peripheral one pion exchange $\Delta N$ interaction). The remaining descrepancy is accounted for by parametrizing the s-wave $\Delta N$ amplitude by its effective range expansion and adjusting the values of the scattering length a and the effective range r to reproduce the experimental data. When $L_{\Delta N}=0$ (s-wave) two states are possible: $J^\pi=1^+$ ($^3S_1$wave) or $J^\pi=2^+$ ($^5S_2$ wave). The data can be fitted equally well either by the $J^\pi=1^+$ state alone with a=-1.fm and r=3fm, or the $J=2^+$ state also with a=-.5fm and r=3fm (note that the sign convention is the same as in the N-N scattering case: $q \cot g\, \delta \sim -1/a$). It is worthwhile noting the relative kinetic energy scale. The s-wave interaction reproduces the data near $T_{\Delta N}=0$ and the peripheral one pion exchange $\Delta N$ interaction reproduces the data for high values of $T_{\Delta N}$.

The relative importance of these two waves cannot be decided on the basis of this experiment alone. However, they can be distinguished by measuring the high energy part of the spectrum of the pions emitted at backward angle when a monochromatic photon beam is used. It is clearly apparent in Fig. 7 that the $J^\pi=2^+$ state ($^5S_2$ wave) contribution is strongly suppressed when compared to the $J^\pi=1^+$ state ($^3S_1$ wave) contribution (the same parameters as in Fig. 6 are used). This suppression is easily understood if we realize that, after its interaction with one nucleon, the $\Delta(1236)$ decays by emitting another nucleon and that all the nucleon-nucleon states are not allowed. In the high energy part of the pion spectrum, the relative kinetic energy of these two outgoing nucleons is small and they must emerge in the $^1S_0$ state. When the pion wave is coupled to this state it is possible to obtain the $J=1^+$ state $\left[{}^1S_0(NN),\ \ell_\pi=1\right]$, but not the $J^\pi=2^+$ state (the lowest momentum required are $\left[{}^3P_2(NN),\ \ell_\pi=0\right]$ or $\left[{}^3P_2(NN),\ \ell_\pi=2\right]$or $\left[{}^1D_2(NN),\ \ell_\pi=1\right]$), due to momentum and parity conservation.

This high energy part of the pion spectrum was recently studied at Saclay[13]. To improve the statistical accuracy of the data, it was integrated over 20 MeV/c below the maximum pion momentum, and the excitation function of this quantity was measured. The data seems to favor the $J=2^+$ state near the $\Delta N$ threshold, where a cusp effect is clearly apparent. However, these data are still preliminary. This experiment is very difficult because the cross section is rather small and because the monochromatic photon flux is not high enough. More experimental work is needed to improve the accuracy before a definite conclusion can be drawn.

Let us now describe an application of these ideas to photopion reactions involved on an heavier nucleus. In Fig. 8 we have plotted the excess of events found when the measured yield of the $^4$He $(\gamma,p\pi^-)$ reaction[14] is compared to the prediction of a DWIA Model[15]. For low values of the momentum of the recoiling system, this model provides us with a good description of the experimental data (see also Fig. 4). The deviations appear only for high values of the momentum transfer ($p_r \tilde{}$ 200 MeV/c). They can be understood in the framework of a model in which two nucleons are active, as shown by the diagrams in the inset of Fig. 8. The meson exchange current corrections to the single pion photoproduction amplitude account well for the high energy part of the spectrum, whereas the s-wave Δ-N interaction accounts for its low energy part. Here also the data seem to prefer the $J=2^+$ $(^5S_2)$ state, but the situation is more complicated than in the case of deuterium. In $^4$He it is also possible to reach the T=2 ΔN states. However, their contribution is small since the T=1 ΔN state seems to account for almost all the data.

In conclusion, the recently measured deviations from the quasi-free process can be understood in terms of three simple mechanisms:

- The peripheral ΔN interaction mediated by the real pion exchange diagram.
- The central ΔN interaction which can be parameterized at low energy by an effective range expansion. The $J=2^+$ state ($^5S_2$ wave), with $a=-.5$fm and $r=3$fm, seems to be preferred.
- The meson exchange corrections to the $\gamma N\to N\pi$ amplitude, which are connected to the $\gamma N\to N\pi\pi$ reaction and are of rising importance above $E_\gamma \tilde{}$400 MeV.

These three mechanisms provide us with an elegant way of analyzing the deviations measured in different kinematical conditions, but it must be realized that they represent the minimal framework for describing a small set of experiments. For instance, the description of the $^5S_2(\Delta N)$ wave near the ΔN threshold by a real scattering length is a very strong limitation of the model. Since this state can be coupled to the $^1D_2(NN)$ wave and since the ΔN states must also be coupled to the πNN non-resonant states a complex scattering length should have been used, or the fit should have been made in the framework of a multichannel effective range expansion. However, the scarceness of the data prevents, for the moment, such sophistication. Clearly more experimental results are needed to check these ideas in more detail and under other kinematical conditions.

On the theoretical side it is necessary to understand why such a simple scheme works. Clearly we have parametrized the three-body $\pi NN$ systems by the quasi-two-body $\Delta N$ system. The compatibility of the present bulk of experimental data with such a parametrization is encouraging, but it is necessary to understand it at a more fundamental level by solving the corresponding relativistic three-body problem, or by taking into account explicitly the constraints of the three-body unitarity.

The $\Delta$-N system is as fundamental as the nucleon-nucleon system. It is also the starting point of most of the studies of the behavior of the $\Delta(1236)$, or more generally of the pion inside the nucleus. Its importance justifies more efforts in its understanding. Moreover, the study of photo-pion reactions on few body targets are a good test case where the approximation needed by the complex nature of heavy nuclei must be checked.

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## FIGURE CAPTIONS

Fig. 1. The different steps of the history of a pion in the deuterium.
I: The pion photoproduction amplitude on a free nucleon is expanded in terms of the Born terms and the s-channel Δ formation amplitude.
II: Pion photoproduction on quasi-free nucleon.
III: Final state nucleon-nucleon interaction.
IV: Pion-nucleon single rescattering.
V: Pion-nucleon multiple scattering.
VI: Exchange part of the Δ-N interaction.
VII: Direct part of the Δ-N interaction.
VIII: Pion reabsorption mechanism. In all those diagrams the symbol B at the $\gamma N \to N\pi$ vertex represents the Born terms of diagram I.

Fig. 2. The momentum distribution of a nucleon emitted in the $\gamma D \to pp\pi^-$ reaction. The experimental points are taken from Ref. 12. The dashed line curve is obtained when only one active nucleon is considered (spectator nucleon model). The full line curve is obtained when pion-nucleon single scattering and nucleon-nucleon rescattering are included (reprinted from Ref. 4.).

Fig. 3. The spectra of the pion, emitted in the $\gamma D \to nn\pi^+$ and the $\gamma D \to pp\pi^-$ reactions at $(\theta_\pi)_{Lab}=46.5°$, when $E\gamma=299$ MeV. The broken line curves include only the quasi-free contribution, whereas the full line curves include also the final state N-N interaction.

Fig. 4. Comparison of the $\gamma n \to p\pi^-$ reaction cross section extracted (in the framework of the pion photoproduction on a quasi-free nucleon model) from the yield of the $D(\gamma, p\pi^-)$ reaction (full circles) or the $^4He\ (\gamma, p\pi^-)$ reaction (open squares). The curve is the prediction of Ref. 16.

Fig. 5. The angular distribution of a nucleon emitted in the $D(\gamma, pp)\pi^-$ reaction with a constant momentum $p_r=400$ MeV/c when Q=1200 M[illegible] $\omega=90°$. The ratio between the experimental yield [6] and the yield which should have been obtained if only one nucleon were active (diagrams II, in Fig. 1) is plotted. The full line curve is obtained when pion-nucleon single rescattering mechanisms are considered (diagrams IV in Fig. 1) whereas the dashed line curve takes also into account the meson exchange corrections to the single pion photo-production amplitude.

Fig. 6. The angular distribution of a nucleon emitted in the $D(\gamma,p\pi^-)$ reaction, with a constant momentum $p_r$=150 MeV/c when Q=1220 MeV and $\omega$=90°. The relative deviations from the quasi-free process contribution are plotted. The full line curve includes the contribution of the one loop diagrams III and IV in Fig. 1. The dashed (dash-dotted) line curve is obtained when the Δ-N interaction in the $J=1^+(J=2^+)$ state is taken into account. The relative kinetic energy between the Δ and the nucleon is plotted on abscissa. Note the cusp at the Δ-N threshold.

Fig. 7. a) The spectrum of the pion emitted in the $\gamma D \to nn\pi^+$ reaction, at $(\theta_\pi)_{Lab.}$=126.6° when Eγ=316 MeV. The dotted line curve includes only the quasi-free contribution, whereas the full line curve includes also the final state nn interaction. The dash-dotted (resp. broken) line curve includes also the ΔN interaction in the $J=2^+$ (resp $J=1^+$) state.
b) The excitation function of the high energy part of the pion spectrum integrated over 20 MeV/c. The experimental points are very preliminary, and show the tendency of the experimental data.

Fig. 8. The excess of events found in the analysis of $^4He(\gamma,p\pi^-)$ reaction, when the experimental yield is compared to the predictions of a DWIA model. The full line curve takes into account the meson exchange correction as indicated in the inset. The dot-dashed (resp. broken) line curve takes also into account the effects of the ΔN rescattering in the $J=2^+$ (resp. $J=1^+$) state. The parameters are the same as in Figs. 5 and 6.

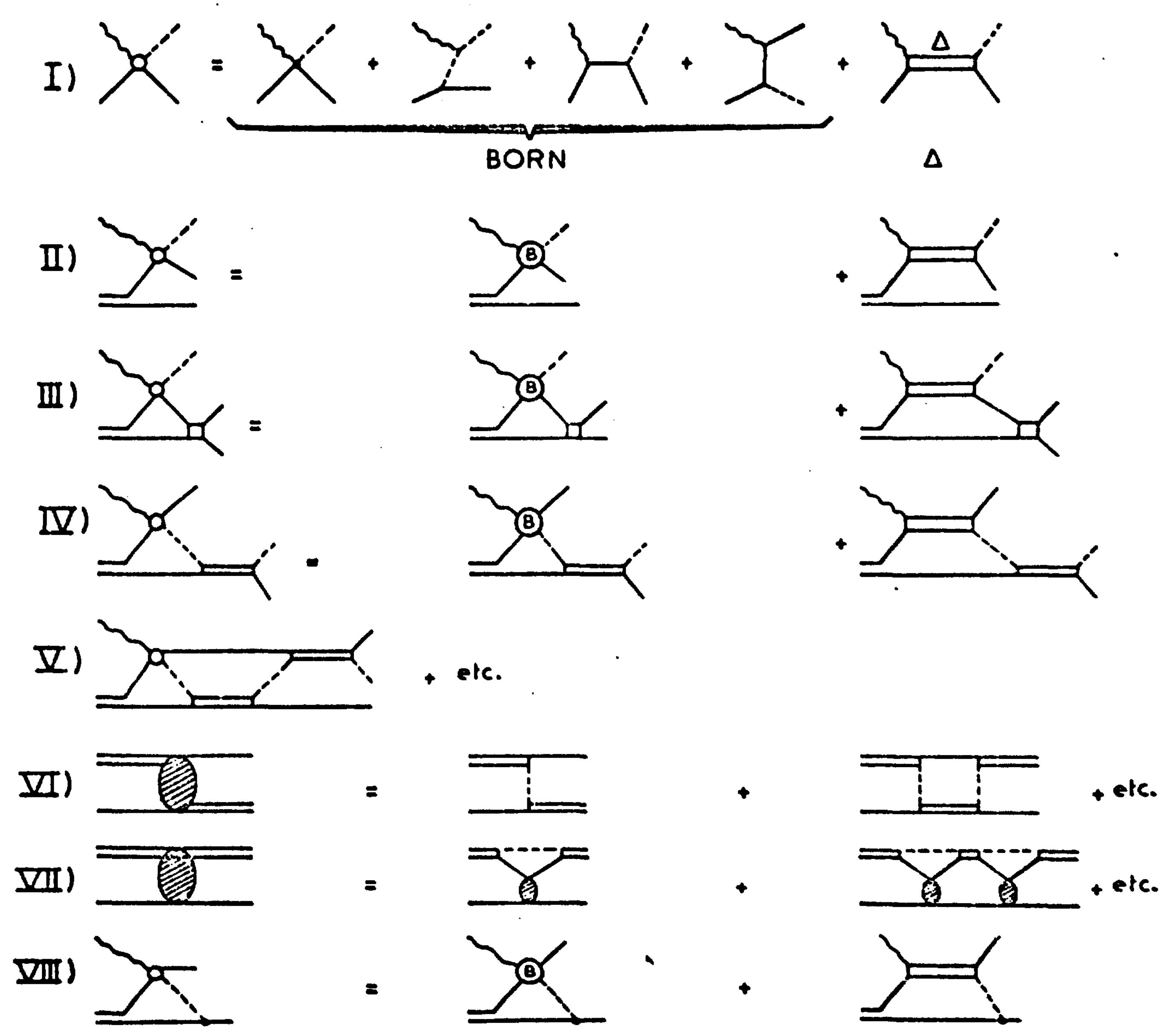



Fig. 1

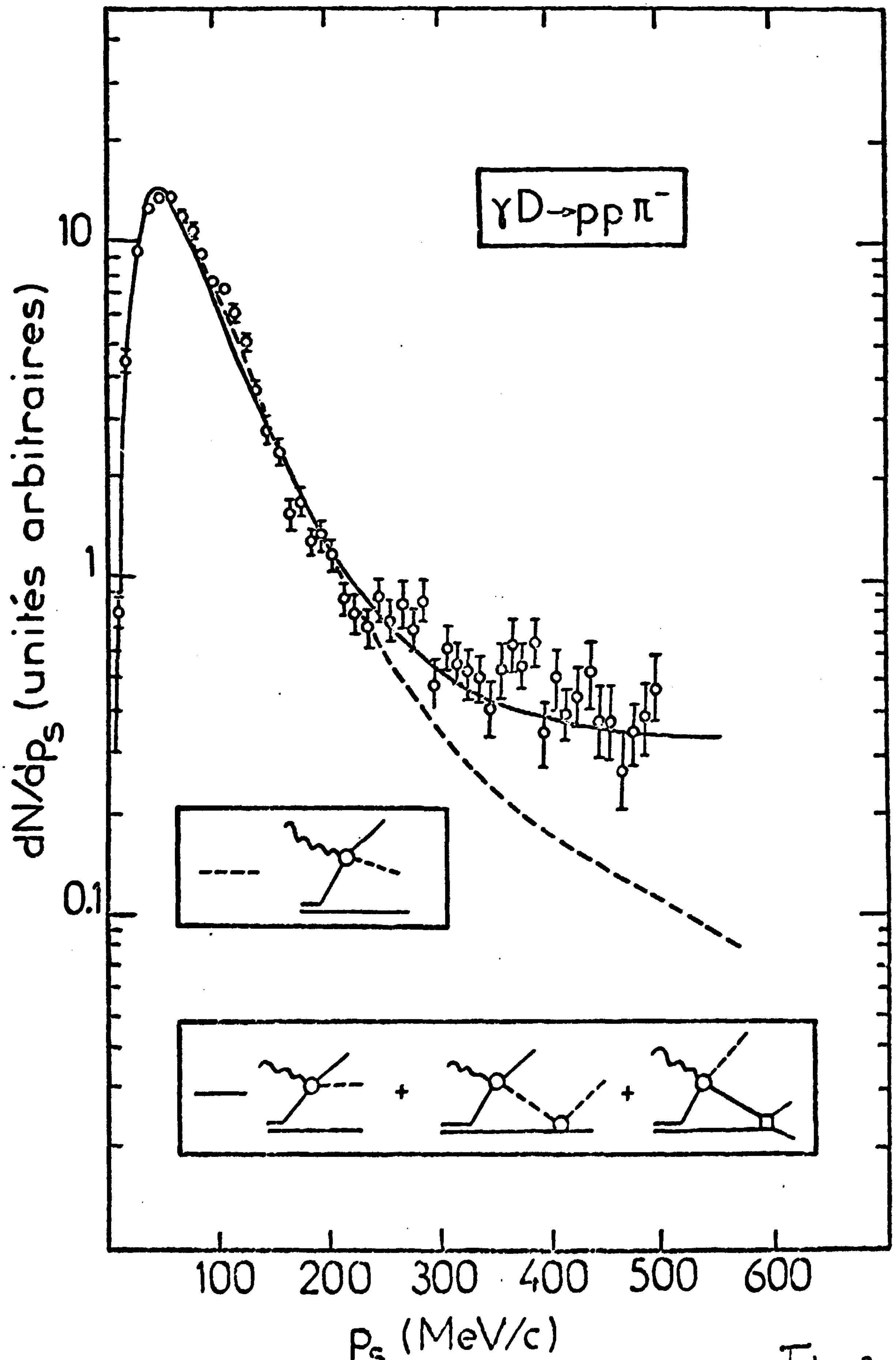

γD→ppπ⁻
10
1
0.1
dN/dp_s (unités arbitraires)
100
200
300
400
500
600
P_s (MeV/c)
+
+

Fig. 2

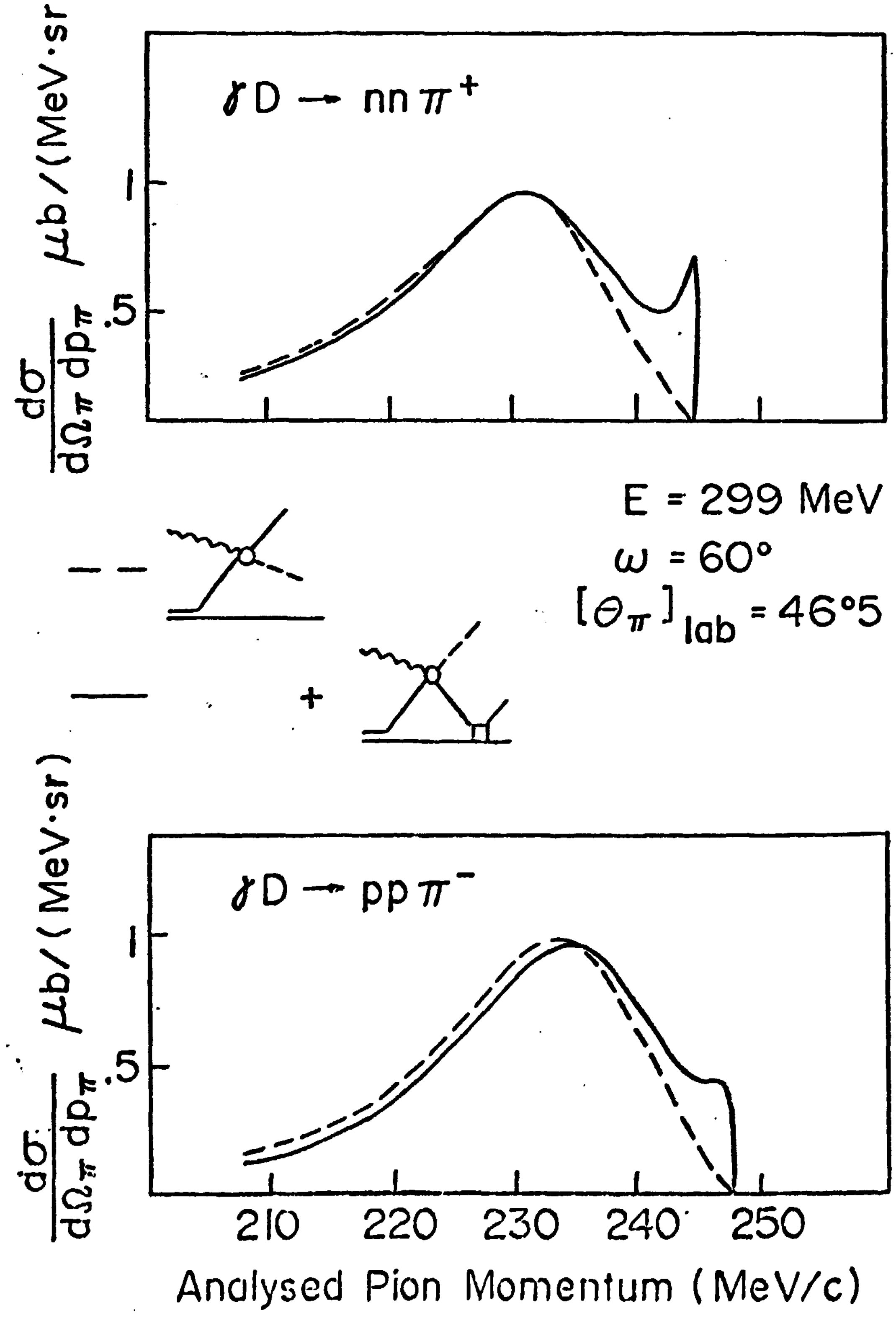

γD → nnπ⁺
γD → ppπ⁻
E = 299 MeV
ω = 60°
[θπ]lab = 46°5
dσ/dΩπ dpπ μb/(MeV·sr)
1
.5
210
220
230
240
250
+
Analysed Pion Momentum (MeV/c)

Fig. 3

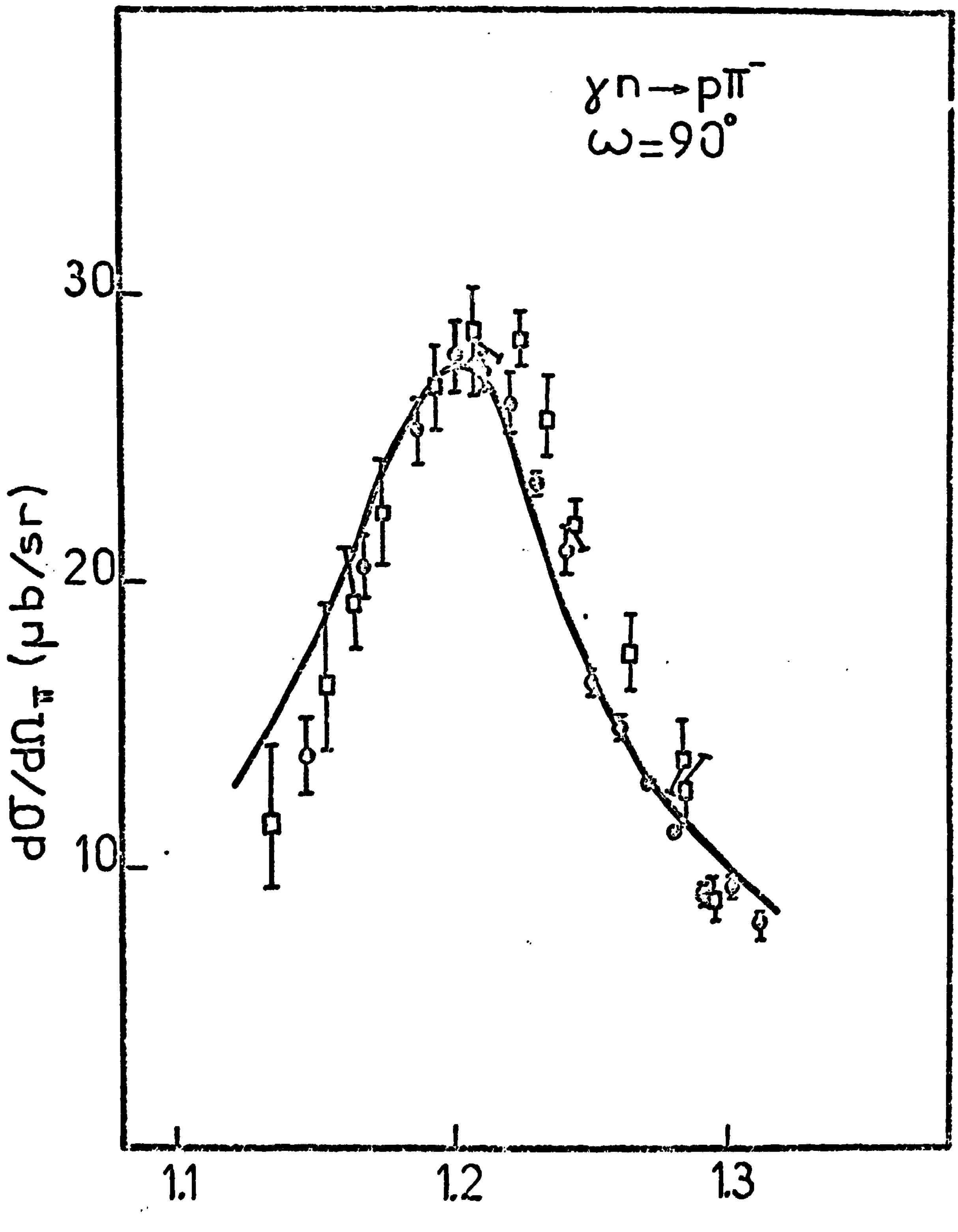
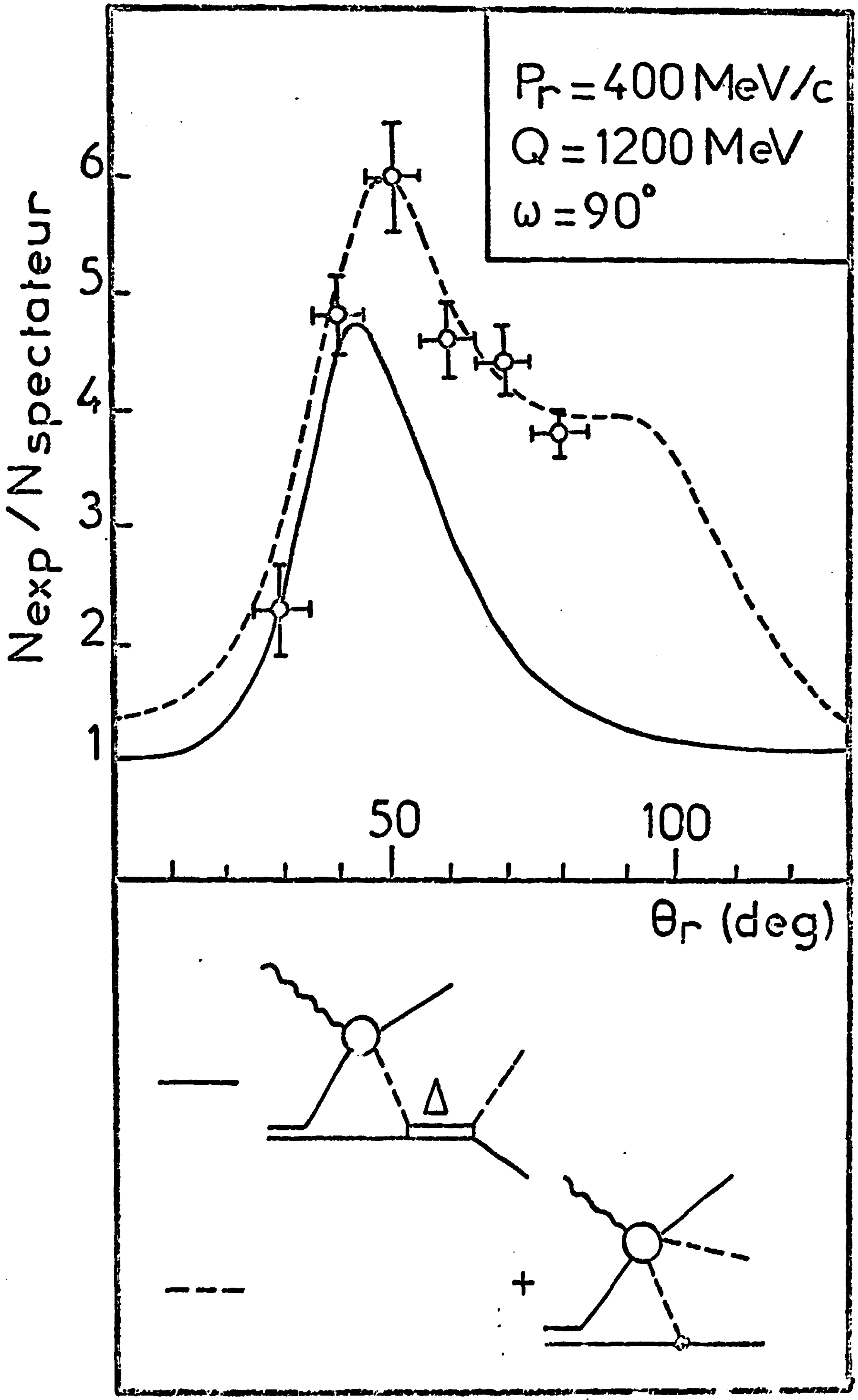
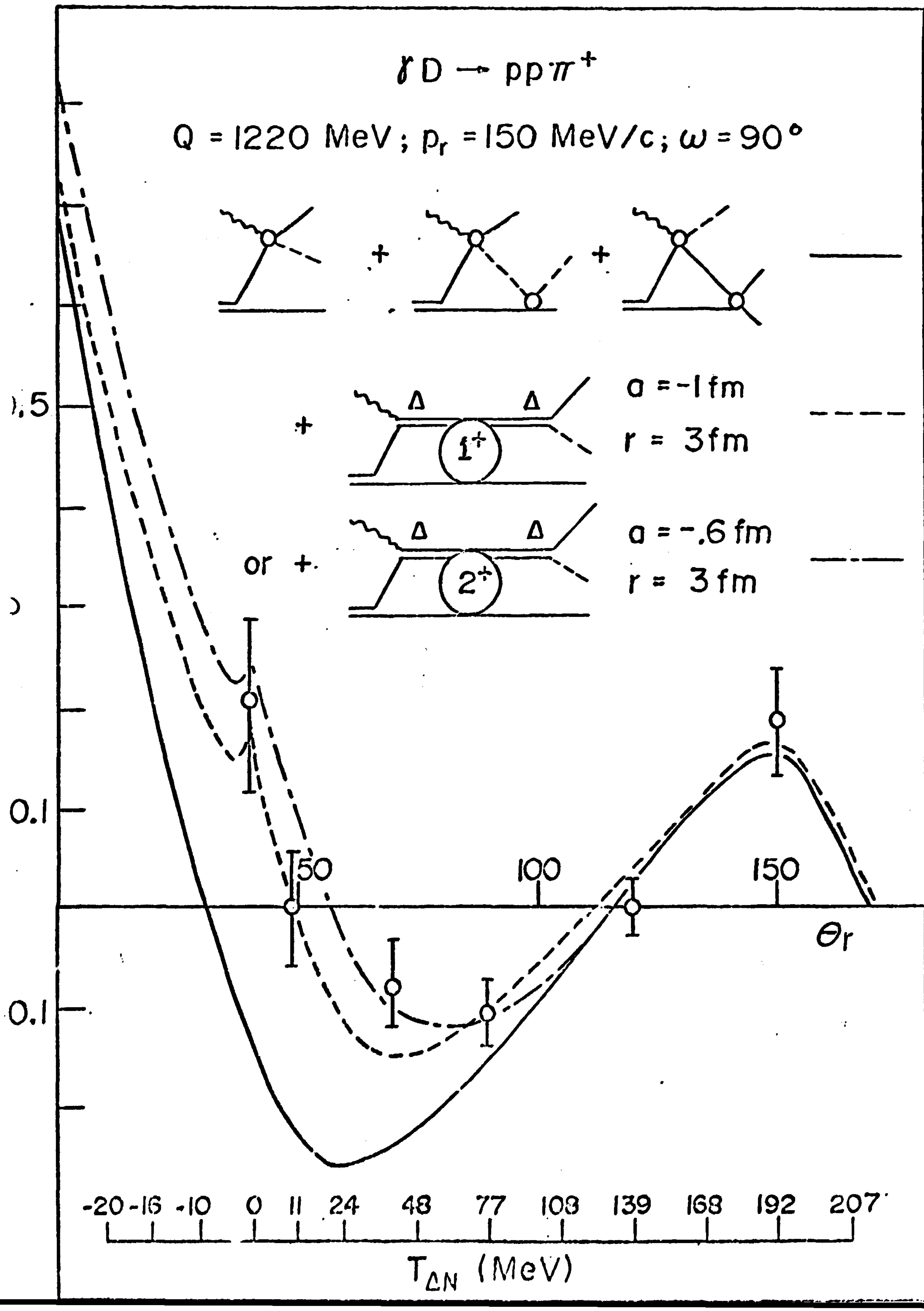



Fig. 4



$P_r = 400$ MeV/c
$Q = 1200$ MeV
$\omega = 90°$
$N_{exp} / N_{spectateur}$
1
2
3
4
5
6
50
100
$\theta_r$ (deg)
Δ
+



γD → ppπ⁺
Q = 1220 MeV ; p_r = 150 MeV/c ; ω = 90°
a = -1 fm
r = 3fm
a = -.6 fm
r = 3 fm
or +
Δ
1⁺
2⁺
).5
0.1
0.1
50
100
150
θr
-20 -16 -10 0 11 24 48 77 108 139 168 192 207
T_ΔN (MeV)

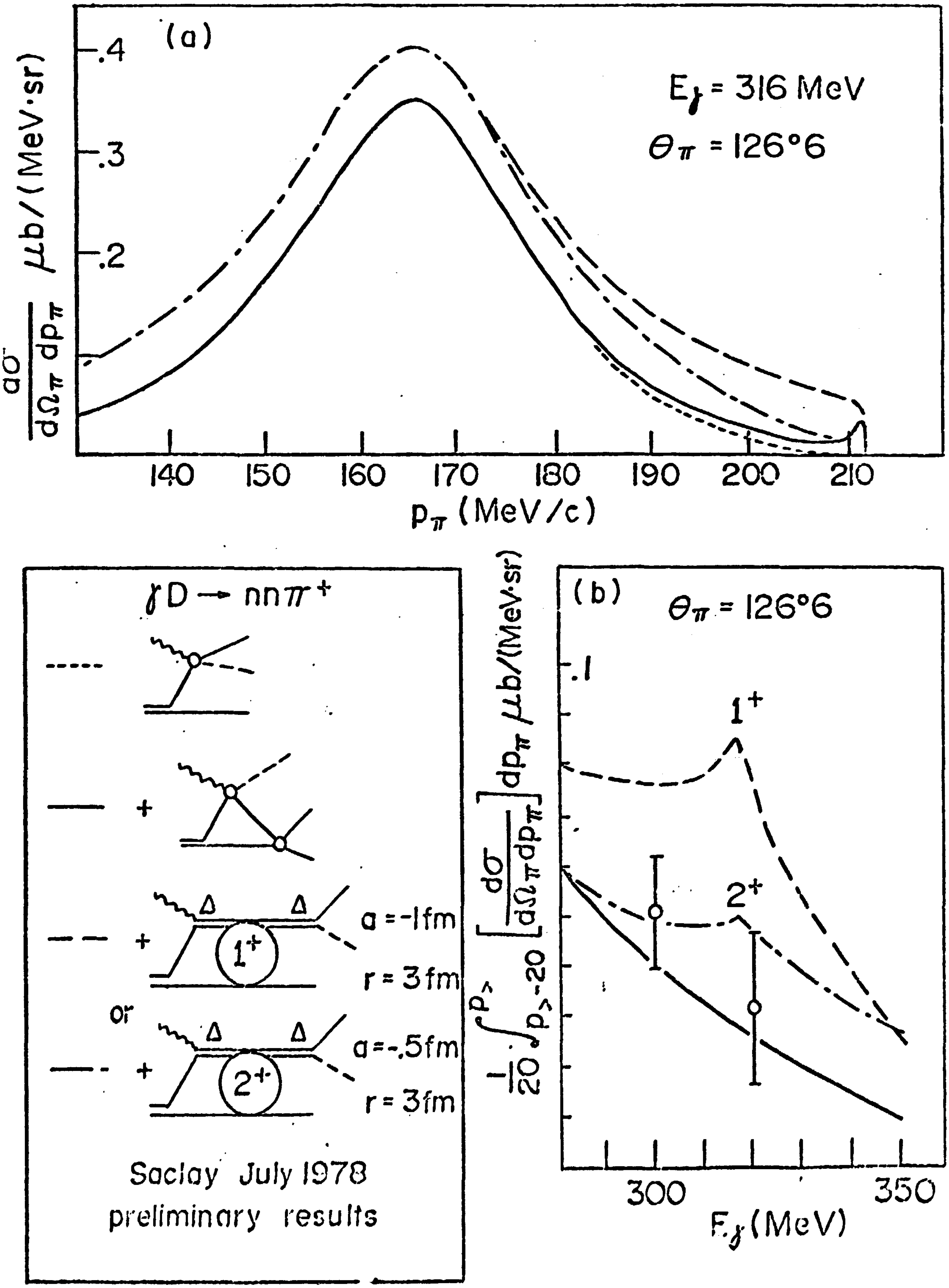
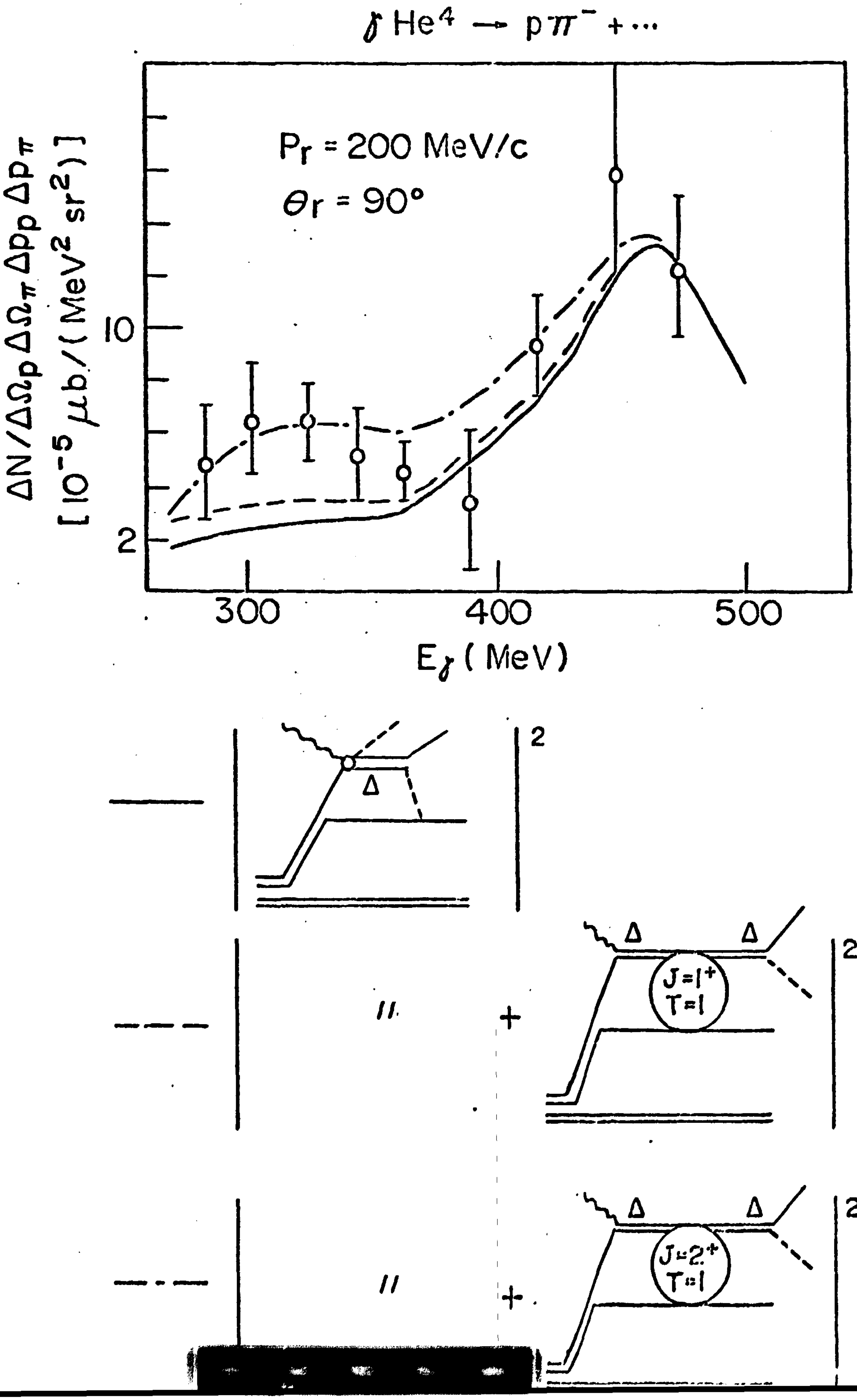

(a)
$E_\gamma$ = 316 MeV
$\theta_\pi$ = 126°6
.4
.3
.2
$\frac{d\sigma}{d\Omega_\pi dp_\pi}$ $\mu$b/(MeV·sr)
140
150
160
170
180
190
200
210
$p_\pi$ (MeV/c)
$\gamma D \to nn\pi^+$
+
+
+
Δ
Δ
a = -1fm
$1^+$
r = 3fm
or
Δ
Δ
a = -.5fm
$2^+$
r = 3fm
Saclay July 1978
preliminary results
(b)
$\theta_\pi$ = 126°6
.1
$1^+$
$2^+$
$\frac{1}{20}\int_{p_>-20}^{p_>}\left[\frac{d\sigma}{d\Omega_\pi dp_\pi}\right]dp_\pi$ $\mu$b/(MeV·sr)
300
350
$E_\gamma$(MeV)

Fig. 7



γ He4 → p π- + ···
Pr = 200 MeV/c
θr = 90°
ΔN/ΔΩp ΔΩπ Δpp Δpπ
[10-5 μb/(MeV2 sr2)]
10
2
300
400
500
Eγ (MeV)
Δ
2
Δ
Δ
J=1+
T=1
=
+
J=2+
T=1