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G. Kramer and K. Schilling
Physikalisches Staatsinstitut
II. Institut für Experimentalphysik, Hamburg

L. Stodolsky
Deutsches Elektronen-Synchrotron DESY, Hamburg

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Physikalisches Staatsinstitut
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L. Stodolsky*
Deutsches Elektronen-Synchrotron DESY, Hamburg

* Work supported by the Volkswagenwerk-Foundation.
Present address: Laboratoire de Physique Théorique et Hautes Energies
Orsay, France.

Abstract

The contribution of the intermediate vector meson state in photoproduction is equal in strength to the direct Born terms and when combined with the Born term, can give an effect simulating strong absorption for the photon.

Calculations of absorption effects in photo-production reactions have included absorption only for the outgoing particles since the incoming photon, obviously, is not strongly interacting.[1] On the other hand, the qualitative and even quantitative success of the "ρ-dominance" or "ρ-photon analogy" assumption[2] in which the photon in a matrix element is replaced by strongly interacting vector mesons seems to suggest that $\gamma + N \rightarrow \pi + N$, for example, should resemble $\rho + N \rightarrow \pi + N$ (transverse ρ's only) in which both final and initial state absorption effects are present. On the experimental side, we can only say that if simple model calculations, such as π exchange for high energy photo-pion production, are to drop off with angle as strongly as the data indicate, more absorption is necessary than can be obtained with <u>reasonable</u> absorption for just the outgoing particle[3].

In this note we would like to point out that there is a simple effect present in photo-production which cannot be neglected and which, in fact, can give results identical to absorption for the photon. It arises from taking into account the effect of the intermediate state "vector meson + proton" in producing the final state. This may seem at variance with the absorption model assumption of neglecting intermediate states except insofar as they lead to an average optical potential in the elastic channels. But is should be realized that this assumption may be violated if a particular intermediate state can couple initial and final states strongly and if the resulting amplitude adds in smoothly with the direct amplitude to give a coherent effect in all partial amplitudes. Then it becomes necessary to consider a generalized absorption model in which more than the ingoing and outgoing channels are treated explicitly. These conditions can be fulfilled for the vector meson channel in photo-production since the vector mesons are produced by a strong diffraction like mechanism. On the other hand we will assume that intermediate states such as (πN^*), $(K\Lambda)$ etc. need not be treated explicitly. The situation then is like that in the explanation[4] of how there may be strong absorption - like effects for high energy photons in complex nuclei: an effective linear combination of photon plus vector meson is the "incoming" particle.

For definiteness let us consider as an example $\gamma+p\rightarrow\pi^{+}+n$ with a specific Born approximation graph to which we apply our "absorption" effects. We take for simplicity π exchange in this reaction although its relation to experiment is obscure. Then only the ρp and not ωp and ϕp contribute as intermediate states and our problem is represented by the sum of the two graphs in Fig. 1. (Absorption for the outgoing pion line is understood).

We present our argument in the frame work of distorted wave Born approximation as it has been used for the formulation of absorption effects in strong interactions[5]. Then the T matrix element for $\gamma + p \rightarrow \pi^+ + n$ can be written as

$$T = < \psi_\pi^{(-)} \mid V_{\pi\gamma} + V_{\pi\rho} \mid \psi_\gamma^{(+)} > \qquad (1)$$

where $V_{\pi\gamma}$ is the "direct potential" creating a π from a γ and $V_{\pi\rho}$ creating a π from a ρ. In our example these are the π exchange graphs, but the reader will recognize that what we do is actually totally general and the V's can represent the complete $\gamma,\rho \rightarrow \pi$ potential. We are using the particle index (with the nucleon suppressed) to indicate the corresponding component in channel space.

Now let us show how it can come about that when the complete wave function of the photon, with the ρ component included, is written down that Equ. (1) gives effectively strong absorption in the initial state. We have for the photon wave function to first order in e:

$$\psi_\gamma^{(+)} = \chi_\gamma - G_\rho^{(+)} \, T_{\rho\gamma} \, \chi_\gamma \qquad (2)$$

with the incoming plane wave χ and $G_\rho^{(+)}$ being the Green's function for the scattered ρ wave. Of course, here and in the following, if not stated otherwise, only transverse ρ's are being considered. Obviously, π exchange graphs with transverse ρ or γ incident are at the same, large, total energy just related by a constant

$$V_{\pi\gamma} = g \, V_{\pi\rho} \quad , \quad g = e/f_{\rho\pi\pi} \qquad (3)$$

With this relation and the wave function Equ. (2) we can write the T matrix element (1) in the following form:

$$T = g < \psi_\pi^{(-)} \mid V_{\pi\rho} \left(1 - G_\rho^{(+)} \frac{1}{g} T_{\rho\gamma} \right) \chi_\gamma > . \qquad (4)$$

If experimental numbers for photo-ρ-production[6] and for g are put together $\frac{1}{g} T_{\rho\gamma}$ has the size, the energy dependence and angular dependence of a strong interaction elastic scattering amplitude[6,7]. Furthermore if we assume that it is mainly positive imaginary[8], it is found that the thus defined elastic scattering amplitude also meets the requirements that the total cross section implied by the optical theorem and the opacity of the elastic scattering are reasonable[7]. (This is not completely trivial and given the experimental data, sets some limits on the range of g). Therefore taking $\frac{1}{g} T_{\rho\gamma}$ as an elastic scattering matrix element, even off the energy-shell (as would follow from using optical model type production wave functions) the wave function in the ket of the right hand side of (4) is essentially a wave function for a strongly absorbed vector particle. In the ρ-dominance or dissociation model, of course, $\frac{1}{g} T_{\rho\gamma}$ is just the ρ-proton elastic scattering amplitude and the wave function is just the ρ-p wave function[7]. In any case we introduce either as actual ρ-p scattering quantities or as phenomenological constructs

$$\psi_{\rho}^{(+)} = (1 - G_{\rho}^{(+)} T_{\rho\rho}) \chi_{\rho} \tag{5}$$

where we define

$$T_{\rho\rho} = \frac{1}{g} T_{\gamma\rho} . \tag{6}$$

Then the T matrix element (1) becomes

$$< \psi_{\pi}^{(-)} \mid V_{\pi\gamma} + V_{\pi\rho} \mid \psi_{\gamma}^{(+)} > = g < \psi_{\pi}^{(-)} \mid V_{\pi\rho} \mid \psi_{\rho}^{(+)} > \tag{7}$$

with the effective ρ scattering wave function defined by Equ. (5). This just shows that the transition amplitude for $\gamma + p \to \pi^{+} + n$ has strong absorption on both sides. Furthermore if $\psi_{\rho}^{(+)}$ is in fact the actual ρ-p wave function then we do have the situation mentioned in the first paragraph that $\gamma + p \to \pi^{+} + n$ is proportional to $\rho^{o} + p \to \pi^{+} + n$ (transverse ρ's only).

Let us now develop a more detailed treatment which can handle the finite ρ mass, the production of longitudinal ρ's in the intermediate state and variations in the coupling constants closely paralleling that in the usual absorption model[5]. This is of theoretical as well as practical interest since it gives us an "approximate ρ-γ analogy" in which we can study the effect of finite ρ mass and variation of other parameters.

Just as in the conventional absorption model, we can take the intermediate "energy-shell" contribution to get a Ross-Shaw[9] type modification. In a given partial wave and given initial and final helicity states this corresponds for the outgoing π in Equ. (1) to

$(\psi_\pi^{(-)})_j \to \frac{1}{2}\,(1 + e^{2i\delta_\pi^j})(\chi_\pi)_j$, where δ_π is the (imaginary) phase shift for πN scattering in the given state. For the right half of the matrix element (1) we have, keeping the delta function part from $G_\rho^{(+)}$ in Equ.(2):

$$(V_{\pi\gamma} + V_{\pi\rho})\psi_\gamma^{(+)} = (V_{\pi\gamma} + V_{\pi\rho}\; i\pi\;\delta(H_o - E_\gamma)\;T_{\rho\gamma})\chi_\gamma \qquad (8)$$

Writing for the partial wave helicity amplitude of total angular momentum j:

$$< \chi_\pi\; |V_{\pi\gamma}|\; \chi_\gamma >_j = eV^j(0)$$

$$< \chi_\pi\; |V_{\pi\rho}|\; \chi_\rho >_j = f_{\rho\pi\pi} V^j(m_\rho) \qquad (9a)$$

As discussed above we assume $T_{\rho\gamma}$ can be written as constant times strong interaction elastic scattering amplitude which we call for obvious reasons $T_{\rho\rho}$. Should further data show this assumption to be invalid then, of course, some other parametrization would have to be used. Then

$$T^j_{\rho\gamma} = g' T^j_{\rho\rho} = g' \frac{1}{2i}\,(e^{2i\delta^j_\rho} - 1) \qquad (9b)$$

and we have for T_j, the partial wave amplitude of T in Equ. (1):

$$T_j = \frac{1}{2}\,(1 + e^{2i\delta^j_\pi})\; e\left[V^j(0) + \frac{f_{\rho\pi\pi}}{e}\, g' V^j(m_\rho)\,\frac{1}{2}\,(e^{2i\delta^j_\rho} - 1)\right] \qquad (10)$$

Clearly when $f_{\rho\pi\pi} g' = e$ and m_ρ has no effect in V^j then (10) becomes

$$T_j = \frac{1}{2}\,(1 + e^{2i\delta^j_\pi})\; eV^j(0)\;\frac{1}{2}(1 + e^{2i\delta^j_\rho}) \qquad (11)$$

giving a Ross-Shaw type initial and final state absorption.

We can also arrive at a Gottfried-Jackson[10] type prescription by assuming that optical model wave functions for the π and also for the photo-produced ρ in the Eikonal approximation are actually correct even "inside" the nucleon, corresponding at a given impact parameter to:

$$\psi_\pi^{(-)*}(x) = \chi_\pi^*(x)\, e^{-\int_z^\infty dz' \frac{1}{2\lambda_\pi}}$$

$$\psi_\gamma^{(+)}(x) = \chi_\gamma(x) + g'\chi_\rho(x) \left(e^{-\int_{-\infty}^{z} dz' \frac{1}{2\gamma_\rho}} - 1\right) \qquad (12)$$

where the λ's are "mean-free-path" parameters characterizing the absorption. Upon inserting in Equ.(1), we can, if the λ's are the same, write the term involving the product of the exponentials as proportional to $e^{2i\delta(b)}$, where $\delta(b)$ is the π-N scattering phase shift for a definite impact parameter b. With the terms involving indefinite integrals we run into the usual problem in this formulation of the absorption model for different initial and final state absorption, which we resolve by the usual (though not very well justified) assumption that the ranges of $V_{\pi\gamma}$ and $V_{\pi\rho}$ are small compared to the ranges of the absorptive "potentials" allowing us to put $z = o$ in the exponentials and so to replace it by $e^{i\delta(b)}$ [1,5]. This gives us a Gottfried-Jackson absorption version for Equ.(1) (using angular momentum j instead of impact parameter b):

$$T_j = e^{i\delta_\pi^j}\, e\left[V^j(0) + \frac{f_{\rho\pi\pi}}{e} g'\, V^j(m_\rho)\, (e^{i\delta_\rho^j} - 1)\right] \qquad (13)$$

Note the terms with the indefinite integrals drop out in the limit

$$\frac{f_{\rho\pi\pi}g'}{e} V^j(m_\rho) = V^j(0) \quad \text{and} \quad \lambda_\pi = \lambda_\rho \quad .$$

We consider formula (13) as the final result of our derivation which we use for studying the behaviour of the modified π exchange in various cases. Now for the purpose of numerical evaluation we fix the parameters of the $T_{\rho\rho}$ amplitude found in Equ. (9b) to be the same as in elastic π-p scattering. This is justified by the fact that the slope in t for photo-ρ-production ($\frac{d\sigma}{dt} \sim e^{At}$) is approximately the same as for π elastic scattering, $A = 8\ GeV^{-2}$ [6,11]. Furthermore if $T_{\rho\rho}$ is taken to be the actual elastic ρp scattering amplitude, then we also can use the fact that ρp and the πp total cross sections are about equal[12].

The parameter g' is then estimated from experiment as follows:

$T_{\gamma\rho} = g' \, T_{\rho\rho} = g' \, T_{\pi\pi}$ gives at 4 GeV

$\sigma(\gamma \to \rho) = g'^2 \, \sigma\,(\pi \to \pi)$, or 16 μb = $g'^2 \cdot$ 5.6 mb[6,11] yielding

$g'^2 = \frac{e^2}{4\pi} \frac{1}{2.55}$. Thus if $f_{\rho\pi\pi}{}^2/4\pi = 2.55$ (corresponding to a

ρ width of 130 MeV) $f_{\rho\pi\pi} g'$ does in fact equal e.

Then the ρ and π absorptions are the same, characterized by a j dependence $1 - e^{2i\delta^j} = C\, e^{-\alpha(j - 1/2)^2}$ with $\alpha = \frac{1}{2Aq^2}$, and C a constant to be fixed later.

With these numbers, we have computed, using Equ. (13), the $\frac{d\sigma}{dt}$ curves for our modified pion exchange in $\gamma + p \to \pi^+ + n$. In Fig. 2 we compare them with those calculated on the usual assumption of absorption for the outgoing π only. We obtain, naturally, a steeper slope with Equ. (13). With C put at 0.90, we have a slope of $3(\mathrm{GeV})^{-2}$ for $-t > 0.1\ (\mathrm{GeV})^2$, roughly in agreement with experiment.[13] The rather large value for C (C = 0.75 would be more realistic) seems to be necessary because the unmodified Born graph simply tends to rise for small (-t) and then flatten out. The small angle structure of a dip and then a peak at $\Theta = 0^o$ is a result of absorption modification, not our particular formulation, and increases with the amount of absorption. This feature is not present in the preliminary data of SLAC and Desy[13] and indicates, as is known, that more than simple π exchange is needed.

For $E_\gamma > 3$ GeV we find that there is essentially no difference (less than 10%), with $f_{\rho\pi\pi} g' = e$, between (13) which includes the effect of the finite ρ mass and a calculation in which the mass of the transverse ρ's in the intermediate state is neglected and the photon is simply treated as if it was a strongly interacting ρ like Equ. (7). There are differences but in the nucleon helicity non-flip amplitudes which are small. To include the possible effects of longitudinal ρ's which are found to be present in the photo-ρ-production, we use the apparently successful [6] spin independence hypothesis, defined in Ref.14, namely that the spin projection on a fixed axis in the center of mass frame in $\gamma \to \rho$ is preserved. This leads to longitudinal ρ's for essentially non-zero production angle but a high energy the amplitudes for $\rho \to \pi$ outside the forward region become so small that this also has no appreciable effect. We might expect some influence from the kinematic and spin effects at lower energy. For this purpose, we exhibit in Fig.3 $\frac{d\sigma}{dt}$ at E_γ = 2 GeV under different assumptions like neglect of ρ mass and spin dependence. Even at 2 GeV the differences are not dramatic. The cross section $\frac{d\sigma}{dt}$ based on Equ.(7) shows a larger forward peak than $\frac{d\sigma}{dt}$ obtained from Equ.(13) (see Fig.2).

Deviations from $f_{\rho\pi\pi}g' = e$ corresponding to $f_{\rho\pi\pi}$ varying the ρ width between 90 and 160 MeV produces some quantitative but not qualitative variations, of course, such as sign reversal, will do away with the strong absorption effects.

In summary, we wish to emphasize the following points:

1) In all photo-production calculations, the intermediate vector meson contribution is empirically as strong as the "direct" photon interaction and cannot be ignored.
2) At high energy, kinematic and spin effects seem to become small so that with the choice of the relative phase for the coupling constants of ρ^0 and γ as suggested from the "ρ-photon analogy" and with coupling constants inferred from experiment, we can expect a result simulating strong absorption for the photon of the same amount as the absorption in the final state.

In this way we provide a justification for such procedures as taking the angular distribution for $\gamma + p \to \pi^+ + n$ from $\pi^+ + n \to \rho^0 + p$ (transverse ρ's only), without necessarily relying on specific models of the electromagnetic current.

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Figure Captions:

Fig.1: Direct photon and intermediate vector meson contributions to pion exchange.

Fig.2: The $\frac{d\sigma}{dt}$ curves for pion exchange in $\gamma + p \to \pi^+ + n$ for E_γ = 2,5,8 and 16 GeV (lab. system). Upper curves include final state absorption for the pion and the absorption caused by the intermediate $\rho^o p$ state. Lower curves are simple pion exchange with final state absorption only. Absorption parameters are: $A = 8\ GeV^{-2}$, $C = 0.9$.

Fig.3: The $\frac{d\sigma}{dt}$ curves for pion exchange in $\gamma + p \to \pi^+ + n$ for $E_\gamma = 2$ GeV (lab.syst.) showing the effect of finite ρ^o mass and production of longitudinal ρ's. Dashed curve has longitudinal ρ's included and effect of finite ρ mass via Equ.(13). Solid curve is with ρ mass and longitudinal components neglected.

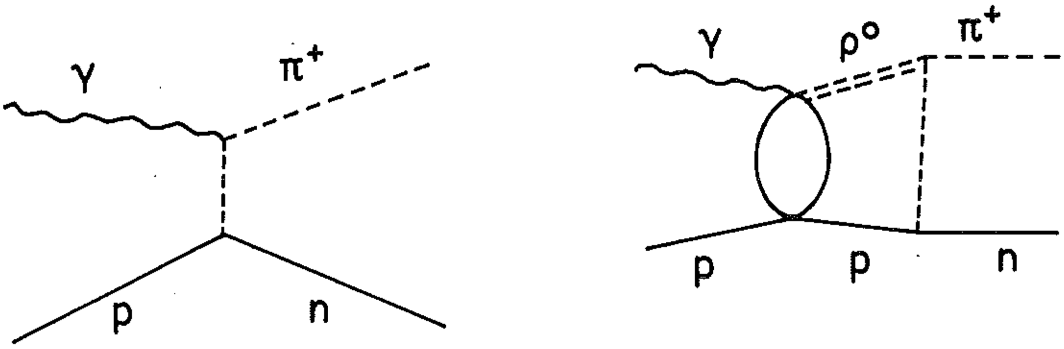
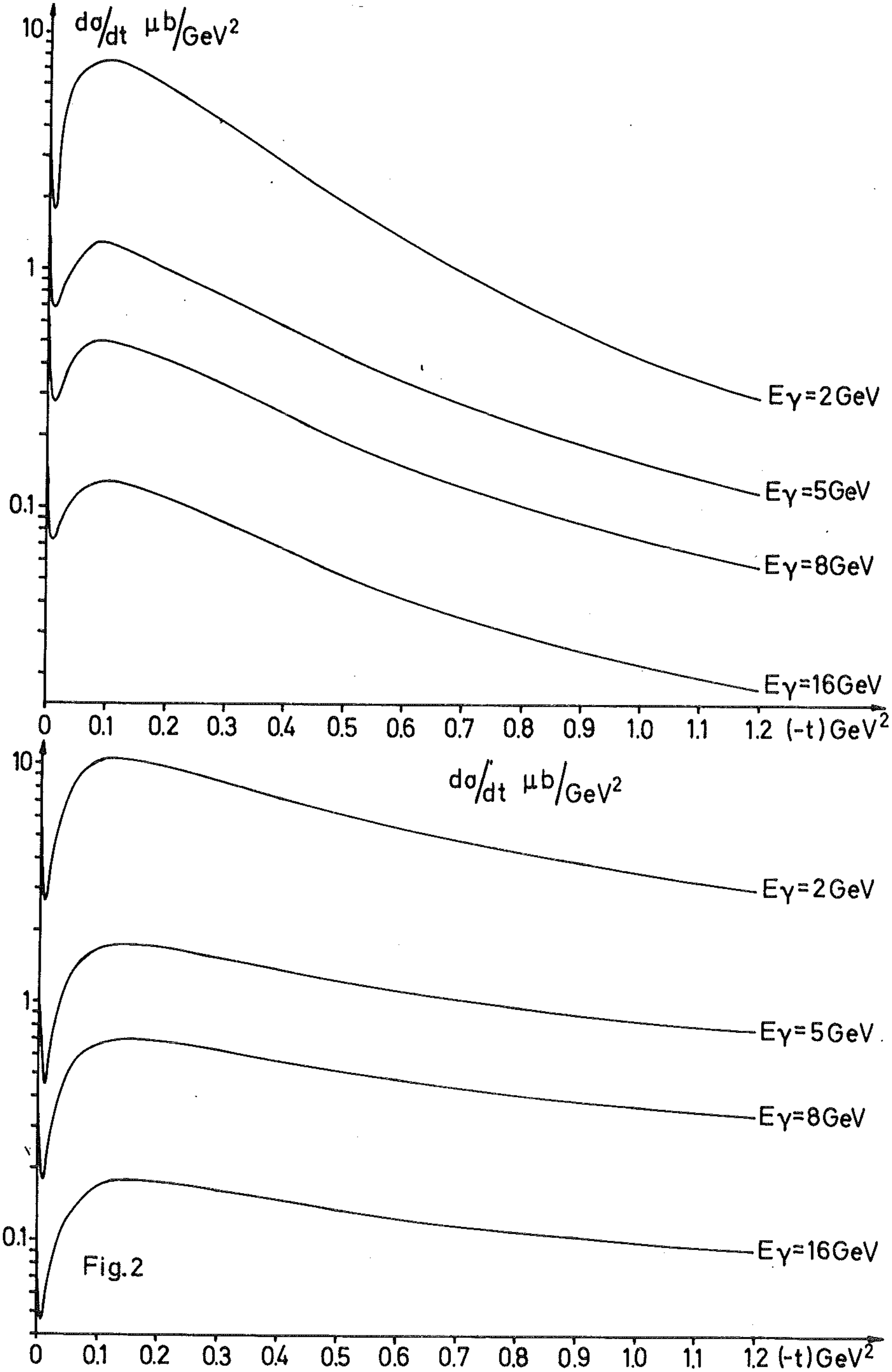


Fig.1


dσ/dt μb/GeV²
10
1
0.1
Eγ=2GeV
Eγ=5GeV
Eγ=8GeV
Eγ=16GeV
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2 (-t) GeV²
dσ/dt μb/GeV²
10
1
0.1
Eγ=2GeV
Eγ=5GeV
Eγ=8GeV
Eγ=16GeV
0
0.1
0.2
0.3
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1.2 (-t) GeV²
Fig. 2

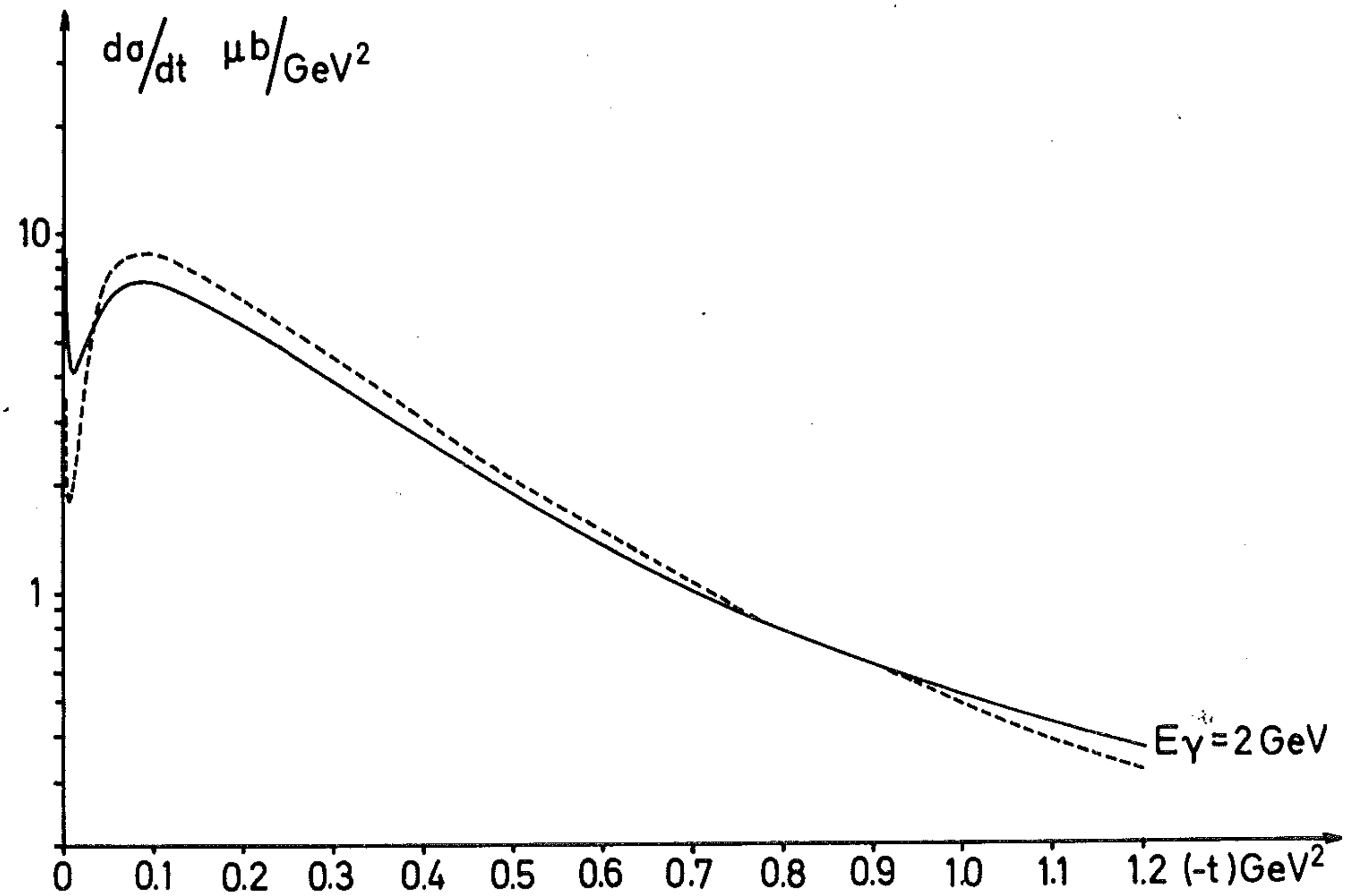

Fig. 3