ABSORPTIVE EFFECTS IN PERIPHERAL PRODUCTION PROCESSES : THE REACTION $\pi^+ p \rightarrow \omega N^{*++}$

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ABSTRACT

We report on the calculations we have done on the reaction $\pi^+ p \rightarrow \omega N^{*++}$, followed by the decays $\omega \rightarrow \pi^+ \pi^0 \pi^-$ and $N^{*++} \rightarrow \pi^+ p$, using the model of Gottfried and Jackson in which the one meson exchange model, in this case ρ exchange, is modified to take into account absorption in the initial and final state due to competition from other open channels. It is shown that the suppression of the low partial waves introduced by this model changes the predicted decay distributions significantly to be in rough agreement with the experimental data.

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1. INTRODUCTION

In the theoretical analysis of production processes in elementary particle collisions at a few GeV/c incident laboratory momentum, the following experimental features have been of great importance :

(a) a large part of the many body final states seems to go via production of one or several resonances or dynamically unstable particles, e.g., the nucleon isobar $N^*(1238)$, the two-pion resonance $\rho(750)$ and the three-pion resonance $\omega(780)$. In particular the three, four and five particle final states are often the result of a quasi-two-body production process, followed by the decay of the unstable particles ;

(b) the quasi-two-body production processes occur preferably to small momentum transfer ("peripheral processes") ;

(c) the distribution in the decay of the unstable particles.

The property (a) means a considerable simplification from the theoretical point of view. The many body production process can be split into a production process, giving a low number of stable and/or unstable particles, followed by the decay of the unstable particles, and these two processes can be treated essentially separately. In this paper we will be concerned only with the case of quasi-two-body production processes, and especially with the process

$$\pi^+ p \rightarrow \omega N^{*++}, \quad N^{*++} \rightarrow \pi^+ p, \quad \omega \rightarrow \pi^+ \pi^0 \pi^- \qquad (1)$$

Experimentally, 10-30% of the five body final state $\pi^+\pi^0\pi^-\pi^+ p$ in $\pi^+ p$ collisions at 2.35-4 GeV/c laboratory momentum occur through reaction (1) [1)-4)].

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The property (b) suggests a theoretical interpretation in terms of a one meson exchange (OME) model (often called "peripheral model") [5], in which the production process is described by a Feynman diagram of the type shown in Fig. 1. The dominance of the small momentum transfer in the production process is thought to come from the propagator denominator of the exchanged particle. However, for particles with spin, there occurs in the numerator of the production cross-section an increasing function of the momentum transfer, which in most cases completely masks the decrease given by the denominator. This results in a cross-section, which is not damped at high momentum transfer, a feature which becomes worse for increasing spin of the particles involved.

Until recently the way out of this defect has been to invoke form factors [5]; because of the structure of the strongly interacting particles, the production amplitudes should be multipled by functions decreasing with increasing momentum transfer, thus giving the desired damping at large production angles. Due to the lack of a reliable theory for calculating such form factors, the usual procedure has in general been to choose a suitable parametrization of the form factors and to determine the parameters by comparison with the experimentally measured cross-sections, hoping that the parameters will be energy independent. The rapid variation of the form factors necessary to obtain agreement with the data casts some doubt on this approach [5),6)].

The reason for believing in the peripheral model despite this drawback comes from property (c) : for a given spin parity of the exchanged particle, one obtains characteristic decay properties of the unstable particles, assuming its spin is known. Conversely, from the experimental decay distribution, assuming a OME production mechanism, one may be able to derive certain spin-parity properties of the exchanged particle [7),8)].

2. DESCRIPTION OF THE ABSORPTION MODEL

Recently several authors [6),9)-12)] have suggested another modification of the unadorned peripheral model which could give the collimation to small production angles. The essential observation in this approach is that the special production process one looks at has to compete with all other open channels in the collisions of the incident particles. As the more complex reactions - one argues - occur mainly at low angular momentum, this competition should affect the specific production process mostly in its low partial waves. This effect is not taken into account at all in the unadorned peripheral model, which in fact often gives low partial waves exceeding the unitarity limit [9)].

There have been slightly different ways suggested to remedy this defect, the common feature of all being a suppression of the low partial waves. We describe here the model by Sopkovich [10)], further elaborated by Gottfried and Jackson [9)], and by Chiu and Durand [6),12)]. In this model the suppression of the low partial waves is derived using a high energy form of the distorted wave Born approximation (DWBA) for potential scattering, extended to take into account the spin of the particles involved. The theory is formulated in terms of the Jacob and Wick generalization of the usual partial-wave expansion to the T matrix elements in the helicity representation [13)], which reads

$$\langle\lambda_3\lambda_4|T(\cos\Theta)|\lambda_1\lambda_2\rangle = \sum_{j=j_{min}}^{\infty}(j+\tfrac{1}{2})\langle\lambda_3\lambda_4|T(j)|\lambda_1\lambda_2\rangle\, d^{j}_{\lambda_1-\lambda_2,\lambda_3-\lambda_4}(\Theta) \qquad (2)$$

In this expression λ_i, i = 1-4, is the helicity of the i:th particle of Fig. 1, Θ is the production angle $j_{min} = \max\{|\lambda_1-\lambda_2|, |\lambda_3-\lambda_4|\}$, and $d^j_{\lambda,\mu}(\Theta)$ is the usual matrix element of the rotation operator. In Eq. (2), we have suppressed the dependence of the T matrix on the energy. It is convenient to convert the sum in Eq. (2) to an integral [8),9)]:

$$\langle \lambda_3 \lambda_4 | T(\cos\theta) | \lambda_1 \lambda_2 \rangle \approx \int_{J_{min}}^{\infty} x\, dx \langle \lambda_3 \lambda_4 | T(x) | \lambda_1 \lambda_2 \rangle J_n(x\, 2 \sin \tfrac{\theta}{2}) \tag{3}$$

Here $J_n(y)$ is the Bessel function of order $n = |\lambda_1 - \lambda_2 - \lambda_3 + \lambda_4|$.

The DWBA approach suggests the following expression for the partial wave helicity amplitudes

$$\langle \lambda_3 \lambda_4 | T(x) | \lambda_1 \lambda_2 \rangle = $$
$$= \exp[i\, \delta_f(x)] \langle \lambda_3 \lambda_4 | B(x) | \lambda_1 \lambda_2 \rangle \exp[i\, \delta_i(x)] \tag{4}$$

In this equation $\langle \lambda_3 \lambda_4 | B(x) | \lambda_1 \lambda_2 \rangle$ are the partial wave helicity amplitudes as calculated from the OME model and $\delta_i(x)$ [$\delta_f(x)$] is the phase shift for the elastic scattering in the initial (final) state. Because $\exp[i\,\delta(x)]$ is small for small x values (cf. below), the formulae (3) and (4) actually give the desired suppression of the low partial waves.

For the actual determination of the phase shifts we assume, as has usually been done in this context [6),9)], that the elastic scattering is purely diffractive and helicity non-changing, given by the scattering on a partially absorbing disc of radius R and absorptivity A. This is usually a good enough approximation [14)]. One then derives

$$\frac{d\sigma_{el}}{dt} = \frac{\sigma_{tot}^2}{16\pi} \exp\left[\frac{R^2}{4} t\right] \tag{5}$$

$$\exp[2 i\, \delta(x)] \approx 1 - 2A \exp[-\gamma x^2] \tag{6}$$

$$A = \frac{\sigma_{tot}}{8 \pi R^2} \qquad (7)$$

$$\gamma = \frac{8}{R^2 q^2} \qquad (8)$$

Here q stands for the momentum of either particle in the centre of mass system (CMS), σ_{tot} and σ_{el} is the total, respectively the elastic cross-section, and $-t$ as usual the invariant momentum transfer squared. For consistency of this model we require $2A \leq 1$.

The parameters R_i and A_i for the elastic scattering in the initial state can be determined directly from experiment. In actual cases it then turns out that $2A_i$ takes values roughly between 0.7 and 1.0. The elastic scattering in the final state, involving unstable particles, is of course not known. We assume, however, that it can be parametrized in the same manner as that in the initial state [8),16)]. From comparison of the differential cross-section as calculated from Eqs. (3)-(8) with the experimentally measured ones, rough agreement is in general obtained from the following values of the final state elastic scattering parameters : $2A_f \gtrsim 1$ and $R_f \approx 1.5 R_i$ [8),16)].

The theoretical foundation of the main formula, Eq. (4), is certainly not very good. One of the assumptions used in its derivation is that the production cross-section under study is but a small fraction of the total cross-section. In most cases this is well fulfilled. But to arrive at Eq. (4) it seems necessary also to assume that the range of the interaction responsible for the transition to the special final state under study is much smaller than the remaining interaction, an assumption which is certainly not fulfilled. Also the use of potential theory is dubious [17)]. All these points have been noted by the above-mentioned authors [6),9)]. However, the formula has such an appealing structure and its experimental predictions are in such unexpectedly good agreement with the data [18)] (at least at not too high an energy), that we believe it to be at least a good approximation. One severe criticism against it is maybe its somewhat cavalier treatment of the spin dependence of the elastic scattering, which is supposed to be entirely given by its helicity non-changing part. When the particles involved have high spin, which is often the case in the final state (N^* has spin 3/2, ω has spin 1 for example), this might not be a good approximation.

3. APPLICATION OF THE MODEL TO THE REACTION $\pi^+ p \to \omega N^{*++}$

We now turn to the specific process (1). The experiments performed at a few GeV/c laboratory momentum [1)-4),20),21)] show predominant production to small momentum transfer. We interpret this as an indication for a OME production mechanism. As only non-strange particles can be exchanged, the a priori candidates are the well-established ones π, η, ρ, ω and φ. Of these, however, due to G parity conservation, only ρ survives. Neglecting a possible contribution from exchange of mesons of higher mass, the process (1) is then in the OME model described by the Feynman diagram of Fig. 2.

The most general coupling of ρ to π and ω is given by [5)]

$$\frac{f}{m_1} \rho_\mu \varepsilon_{\mu\nu\lambda\sigma} \partial_\nu \pi \partial_\lambda \omega_\sigma \tag{9}$$

while for the coupling of ρ to p and N^* we assume the magnetic coupling as suggested by Sakurai and Stodolsky [22)]. To the extent that one may neglect couplings involving two derivatives, this form follows by requiring ρ to be coupled to a conserved current and is given by [5)]

$$i\, G\, \rho_\mu \; \overline{N_\nu^*} \left[\delta_{\mu\nu} - \frac{1}{m_3 + m_4} \gamma_\mu \partial_\nu \right] \gamma_5\, p \tag{10}$$

In Eqs. (9) and (10), $\varepsilon_{\mu\nu\lambda\sigma}$ is the totally antisymmetric fourth-rank tensor whose non-vanishing elements are 1 and m_i the mass of the i:th particle in the enumeration of Fig. 2 ; the fields of the particles are denoted by the same symbol as the particle itself. Further f and G are dimensionless coupling constants, the order of magnitude of which can be estimated. From the virtual decay of ω into ρ and π [23)], one has the estimate $f^2/4\pi \approx 0.4$ for a width $\Gamma(\omega \to \pi^+\pi^0\pi^-) \approx 9$ MeV. For G the ρ photon analogy gives [24)] $G^2/4\pi \approx 20$-40 for the $p\rho^+N^{*++}$ vertex.

It is then a matter of algebra to write down the 12 independent Born helicity amplitudes. Using the labelling of the particles as in Fig. 2 and denoting by $E_i(v_i)$ the energy (velocity) of the i:th particle in the total CMS and by $q(q')$ the CMS momentum of either particle in the initial (final) state, we put

$$\langle\lambda_3\lambda_4|B(\cos\Theta)|\lambda_2\rangle =$$

$$= \frac{f}{m_1}\cdot\frac{G}{m_2+m_4}\cdot\frac{1}{m_5^2-t}\cdot q^2\cdot m_3^{1-|\lambda_3|}\cdot E_3^{|\lambda_3|}\cdot \quad (11)$$

$$\cdot\left(\cos\frac{\Theta}{2}\right)^{|\lambda_2-\lambda_3+\lambda_4|}\left(\sin\frac{\Theta}{2}\right)^{|\lambda_2+\lambda_3-\lambda_4|}\langle\lambda_3\lambda_4|\mathcal{B}(\cos\Theta)|\lambda_2\rangle$$

We also introduce the following auxiliary notation

$$\xi_\pm = \sqrt{(E_2+m_2)}\sqrt{(E_4+m_4)}\left[\frac{q}{E_2+m_2} \pm \frac{q'}{E_4+m_4}\right] \quad (12)$$

$$\eta_\pm = \sqrt{(E_2+m_2)}\sqrt{E_4+m_4)}\left[1 \pm \frac{q}{E_2+m_2}\,\frac{q'}{E_4+m_4}\right] \quad (13)$$

$$\alpha = v_3/v_1 \quad (14)$$

$$\beta = v_4/v_2 \quad (15)$$

We then obtain for the quantities $\langle\lambda_3\lambda_4|\mathcal{B}|\lambda_2\rangle$ defined in Eq. (11)

$$\langle 1, \tfrac{3}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle =$$
$$= \mp (\cos\Theta - \alpha)\left[\eta_{\pm}(1 \mp \cos\Theta) - \frac{m_2 + m_4}{q}\xi_{\mp}\right] + \frac{1}{2}(\eta_{\pm} \pm v_3 \xi_{\pm})\sin^2\Theta \tag{16a}$$

$$\langle 0, \tfrac{3}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle = \pm\sqrt{2}\left[\eta_{\pm}(1 \mp \cos\Theta) - \frac{m_2 + m_4}{q}\xi_{\mp}\right] \tag{16b}$$

$$\langle -1, \tfrac{3}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle = 2(\eta_{\pm} \pm v_3 \xi_{\pm}) \tag{16c}$$

$$\langle 1, \tfrac{1}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle = -\frac{1}{\sqrt{3}}\Big\{ \frac{m_2 + m_4}{q}\Big[\xi_{\pm}(\cos\Theta - \alpha) \pm$$
$$\pm \frac{E_4}{m_4}(1 + v_3 v_4)\xi_{\mp}(1 \pm \cos\Theta)\Big] \pm \frac{E_4}{m_4}(\cos\Theta - \beta) \cdot$$
$$\cdot \left[2\eta_{\pm}(\cos\Theta - \alpha) \mp (\eta_{\pm} \pm v_3\xi_{\pm})(1 \pm \cos\Theta)\right] \mp$$
$$\mp \frac{1}{2}(\eta_{\mp} \mp v_3 \xi_{\mp})\sin^2\Theta \Big\} \tag{16d}$$

$$\langle 0, \tfrac{1}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle =$$
$$= \frac{1}{\sqrt{6}}(1 \mp \cos\Theta)\left[\frac{m_2 + m_4}{q}\xi_{\pm} + \eta_{\mp}(1 \pm \cos\Theta) \pm \frac{2E_4}{m_4}\eta_{\pm}(\cos\Theta - \beta)\right] \tag{16e}$$

$$\langle -1, \tfrac{1}{2} | \mathcal{B} | \pm \tfrac{1}{2} \rangle = \frac{2}{\sqrt{3}} \Big[\mp \frac{m_2+m_4}{2} \; \frac{E_4}{m_4} (1 + v_3 v_4) \xi_{\mp} + \tag{16f}$$

$$+ \eta_{\mp} (\cos\theta - \alpha) + \frac{E_4}{m_4} (\eta_{\pm} \pm v_3 \xi_{\pm}) (\cos\theta - \beta) \pm$$

$$\pm (\eta_{\mp} \mp v_3 \xi_{\mp}) (1 \mp \cos\theta) \Big]$$

The remaining 12 amplitudes can be obtained using the symmetry relation following from parity conservation

$$\langle -\lambda_3 \; -\lambda_4 | B(\cos\theta) | -\lambda_2 \rangle = (-1)^{\lambda_2 + \lambda_3 - \lambda_4} \langle \lambda_3 \; \lambda_4 | B(\cos\theta) | \lambda_2 \rangle \tag{17}$$

When introducing these expressions into Eq. (4), we also make a small angle approximation by putting $\cos\theta$ (and $\cos\theta/2$) equal to one, however using the exact expression at those places where the difference between $\cos\theta$ and a number of order of magnitude one occurs. We also replace x in $\exp[-\gamma x^2]$ of Eq. (6) by $(x-\frac{1}{2})$ in an attempt to relate the absorption to the orbital rather than to the total angular momentum [8].

In applying formula (4) we remark that experimentally the cross-section for reaction (1) is a very small fraction of the total cross-section for $\pi^+ p$ collision (typically around 0.4 mb compared to the total of around 30 mb), so we expect the process (1) to be well described by the theory outlined above. For the parameters R_i and A_i of the elastic scattering in the initial state we use values taken directly from experiment, while for the corresponding parameters of the final state we find that the following choice gives a reasonable fit to the data

$$2 A_f = 1 \tag{18}$$

$$R_f^2 = 3 R_i^2 \tag{19}$$

For the coupling constants we use the following value

$$\frac{f^2}{4\pi} \cdot \frac{G^2}{4\pi} = 16 \qquad (20)$$

These values are used at all energies. We have not attempted to make some sort of best fit of these parameters to the experimental results. Let us only remark that we can also obtain roughly the same fit for a somewhat lower value of R_f and simultaneously a somewhat lower value of the product of the coupling constants.

We have thus specified all parameters and may now use the model to calculate experimentally measurable quantities. These are the differential production cross-section $d\sigma/dt$ (or $d\sigma/d\Omega$) and the spin space density matrix elements ρ_{ik} [7),8)] for ω and N^* in their respective rest frame and with the axis of quantization along the momentum of the incident pion, respectively proton. These elements determine, in these respective frames,

for the decay $\omega \rightarrow \pi^+\pi^0\pi^-$ the distribution of the normal to the decay plane of the three pions,

for the decay $N^{*++} \rightarrow \pi^+ p$ the distribution of the momentum of either of the decay particles.

4. COMPARISON WITH EXPERIMENT

To our knowledge the most detailed experimental analysis of reaction (1) has been carried out at 4 GeV/c incident momentum [4] and we discuss the reaction at this energy first. Figure 3 shows the cross-section as function of the momentum transfer. The solid line is the curve calculated from the described model and with the values (18)-(20) for the parameters not directly determined from experiment. The agreement between the experimental distribution and the theoretical one can be said to be fair, even if the detailed slope is not well reproduced by the theoretical curve ; the experimental cross-section is even more peaked. However, there are reasons [8] to believe that a form factor should be included in the OME diagram coming from an anomalous threshold at the lower vertex of Fig. 2. To give an indication what kind of form factor one needs, we have in Fig. 3 also plotted (dotted line) the result obtained by multiplying the amplitudes (3) by $\exp(t/a)$, $a = 2\ (\mathrm{GeV}/c)^2$ [25]. This is a fairly slowly varying form factor and it does not meet with the criticism of the form factor needed to bring the unadorned peripheral model into agreement with the data. To this end one would need $a \approx 0.3$.

We next turn to the decay parameters ρ_{ik}, the experimental values [26] of which are plotted in Figs. 4 and 5, together with the theoretical results obtained in our model (solid lines) and in the unadorned peripheral model (dotted lines). As has already been pointed out [2),4], the experimental results differ significantly from the prediction of the unadorned peripheral model with ρ exchange. This has led to the statement that the process cannot be described by exchange of only a ρ meson, but that one has to invoke also exchange of mesons of unnatural spin parity (spin s, parity $(-1)^{s+1}$), presumably 1^+ (the B meson). However, as can be seen from the solid lines of Figs. 4 and 5, the ρ exchange model, modified to take into account absorption, is in reasonable agreement with the data, especially if one takes into account both experimental and theoretical uncertainties.

At first instance this rather large change obtained by suppressing the low partial waves is astonishing. To our knowledge, in all other cases studied so far within this model, the decay parameters have but undergone minor changes [27]. However, for exchange of mesons with spin $\neq 0$, there is really no reason to believe that the suppression of the low partial waves could not give rise to large changes. In fact, it is not difficult to see that in the very much simplified model of scattering of scalar particles by means of vector-meson exchange, the suppression of the low partial waves in the direct channel (the s channel of Fig. 1) affects mostly the very lowest partial waves in the crossed channel too, and indeed gives dominance of the s wave in this channel. We have not studied this effect analytically in a more realistic case but believe it to be responsible for the large change due to absorption found numerically in the case under study.

We thus conclude that it is not unreasonable that the suppression of the low partial waves under certain circumstances could give a large change of the spin-parity pattern in the crossed channel, thus influencing the predicted decay distributions of the unstable particles. The fact that the results of our detailed numerical calculations within the absorption model fit so well with the experimental data is, according to our opinion, to be considered as an independent confirmation of the model.

There have been data published on reaction (1) also at other energies. We give in Fig. 6 the comparison of our results for the cross-section with the experimental data at 2.35, 2.62 and 2.90 GeV/c incident momentum [20]. Again the order of magnitude of the cross-section comes out well. Because of poor statistics it makes no sense to compare the slope. At 3.65 GeV/c the data [3] and the theoretical results are not very much different from those at 4 GeV/c. At 2.77 GeV/c [2] the lower limit for ρ_{00} averaged over the whole interval of momentum transfer is 0.55 ± 0.06. The average theoretical value for ρ_{00} is approximately 0.7.

Finally, we want to mention that at 8 GeV/c incident momentum the cross-section calculated using the values (18)-(20) is greater than the experimental results [21] by a factor of about 10. This is a reminiscence of the violent increase with energy of the cross-section in the unmodified peripheral model, a feature which thus cannot be completely overcome in our model, at least not in its present form. Maybe a more realistic treatment of the elastic scattering in the final state could give better agreement.

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25) In a completely correct treatment the form factor should be incorporated into the Born amplitudes (11) before the partial wave expansion is made. However, this will not make much difference because a slowly varying form factor of this kind has the same effect as suppressing the low partial waves which, in this model, are anyhow very much suppressed.

26) Result of the Aachen-Berlin-Birmingham-Bonn-Hamburg-London-Munich collaboration, as communicated privately by N. Schmitz. We want to thank Dr. Schmitz for permission to use these data.

27) Cf., however, the results for the decay parameters of N^{*++} in the reaction $K^+p \rightarrow K^0N^{*++}$ in Ref. [18].

FIGURE CAPTIONS

Figure 1. Feynman diagram for a OME process.

Figure 2. Feynman diagram for ρ meson exchange in the process $\pi^+ p \to \omega N^{*++}$.

Figure 3. The differential production cross-section for the process $\pi^+ p \to \omega N^{*++}$ at 4 GeV/c. The experimental values are from Ref. [4] (events with $-t > 1.05$ $(GeV/c)^2$ are not shown). The curve (a) is calculated using the model as described in the text, the curve (b) is obtained by also including a form factor $\exp t/a$, $a = 2$ $(GeV/c)^2$.

Figure 4. The decay parameters for ω in the process $\pi^+ p \to \omega N^{*++}$ at 4 GeV/c. The experimental values are from Ref. [26]. The solid lines are calculated using the model as described in the text, the dotted lines are the result in the unadorned ρ meson-exchange model.

Figure 5. The decay parameters for N^{*++} in the process $\pi^+ p \to \omega N^{*++}$ at 4 GeV/c. Same experiment and notation as in Fig. 4.

Figure 6. The differential production cross-section for the reaction $\pi^+ p \to \omega N^{*++}$ calculated in the model described in the text compared to the experimental data of Ref. [20] (events with $\cos\theta < 0.45$ are not shown).

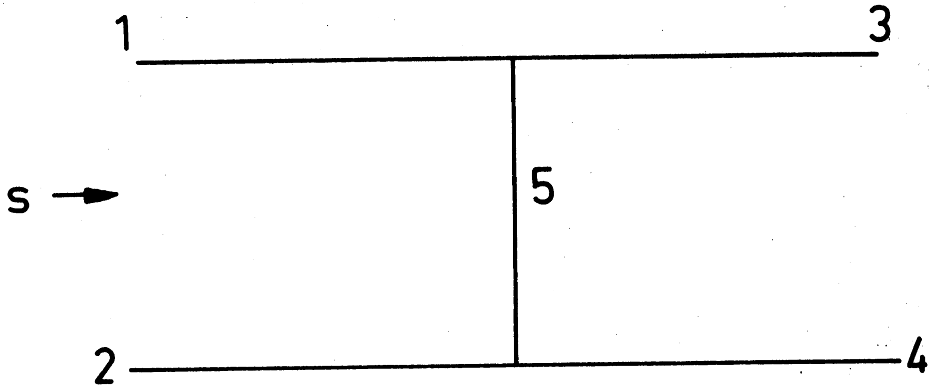


FIG. 1

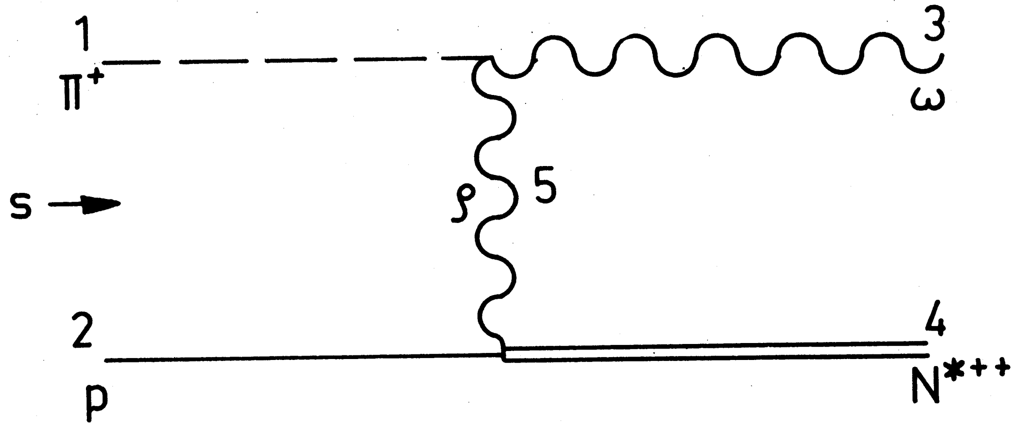
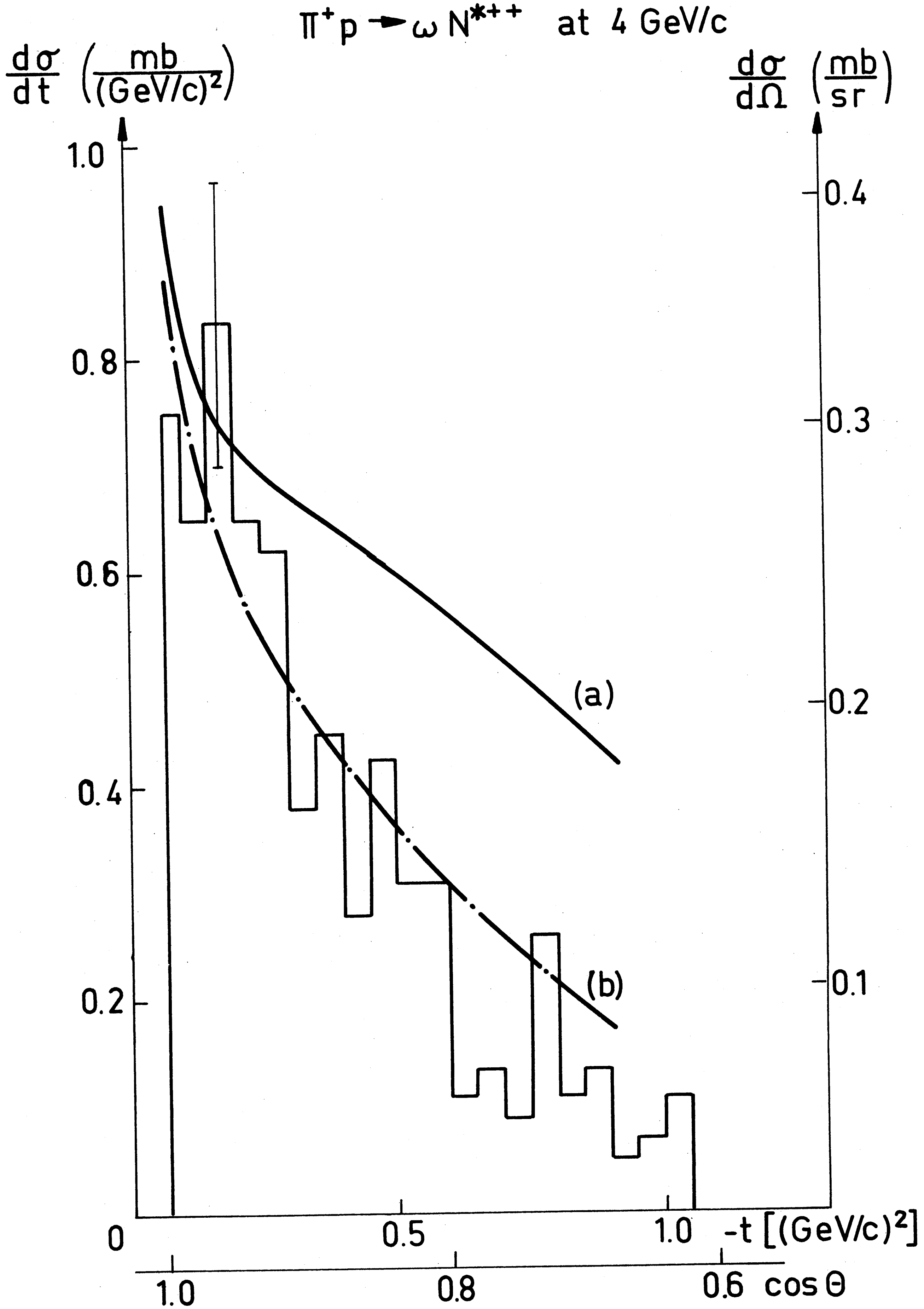


FIG. 2



π⁺p → ω N*⁺⁺ at 4 GeV/c
dσ/dt (mb/(GeV/c)²)
dσ/dΩ (mb/sr)
1.0
0.8
0.6
0.4
0.2
0
0.4
0.3
0.2
0.1
(a)
(b)
0.5
1.0
-t [(GeV/c)²]
1.0
0.8
0.6
cos Θ

FIG. 3

$\pi^+ p \rightarrow \omega N^{*++}$ at 4 GeV/c

Decay parameters for ω

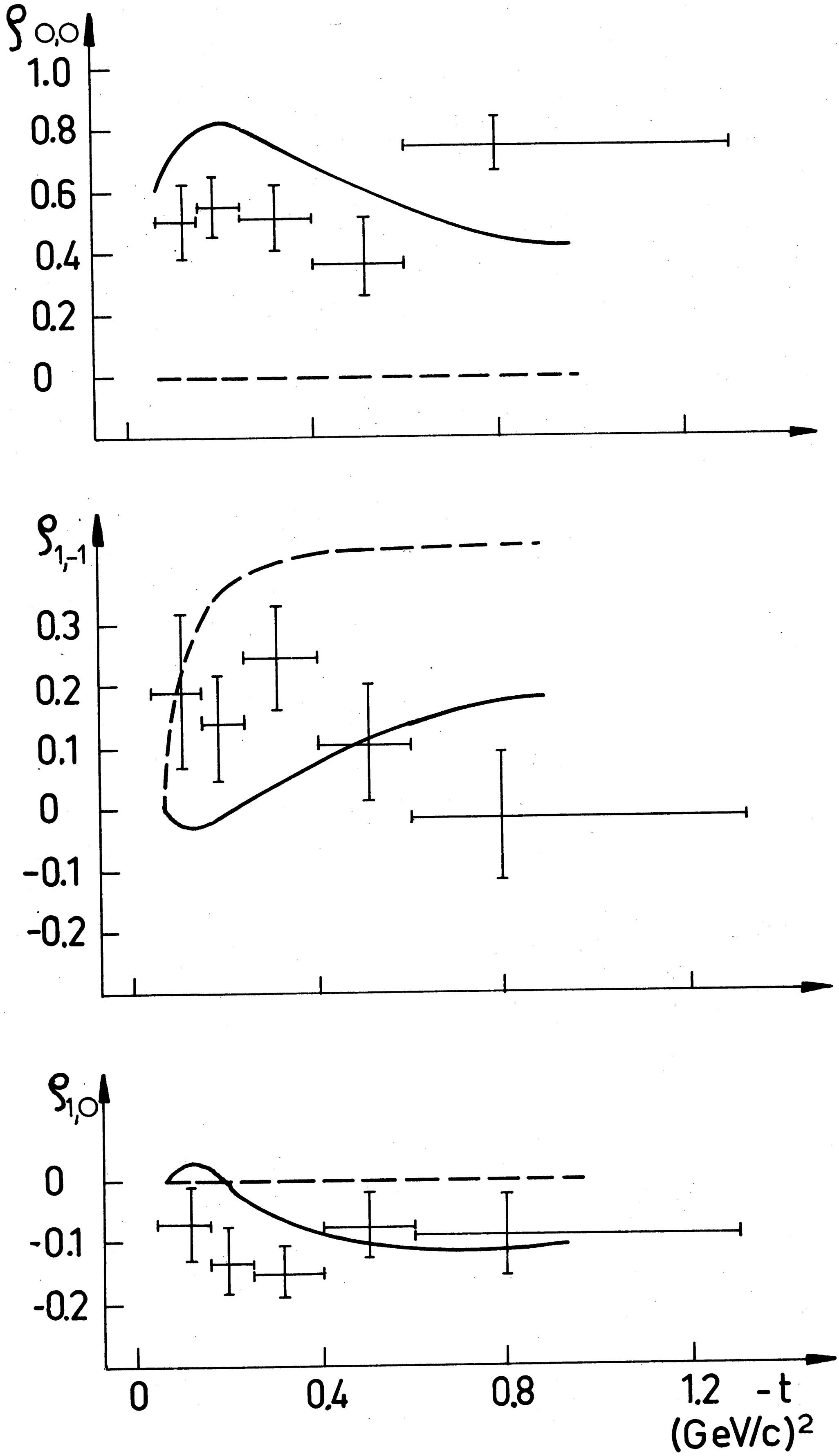
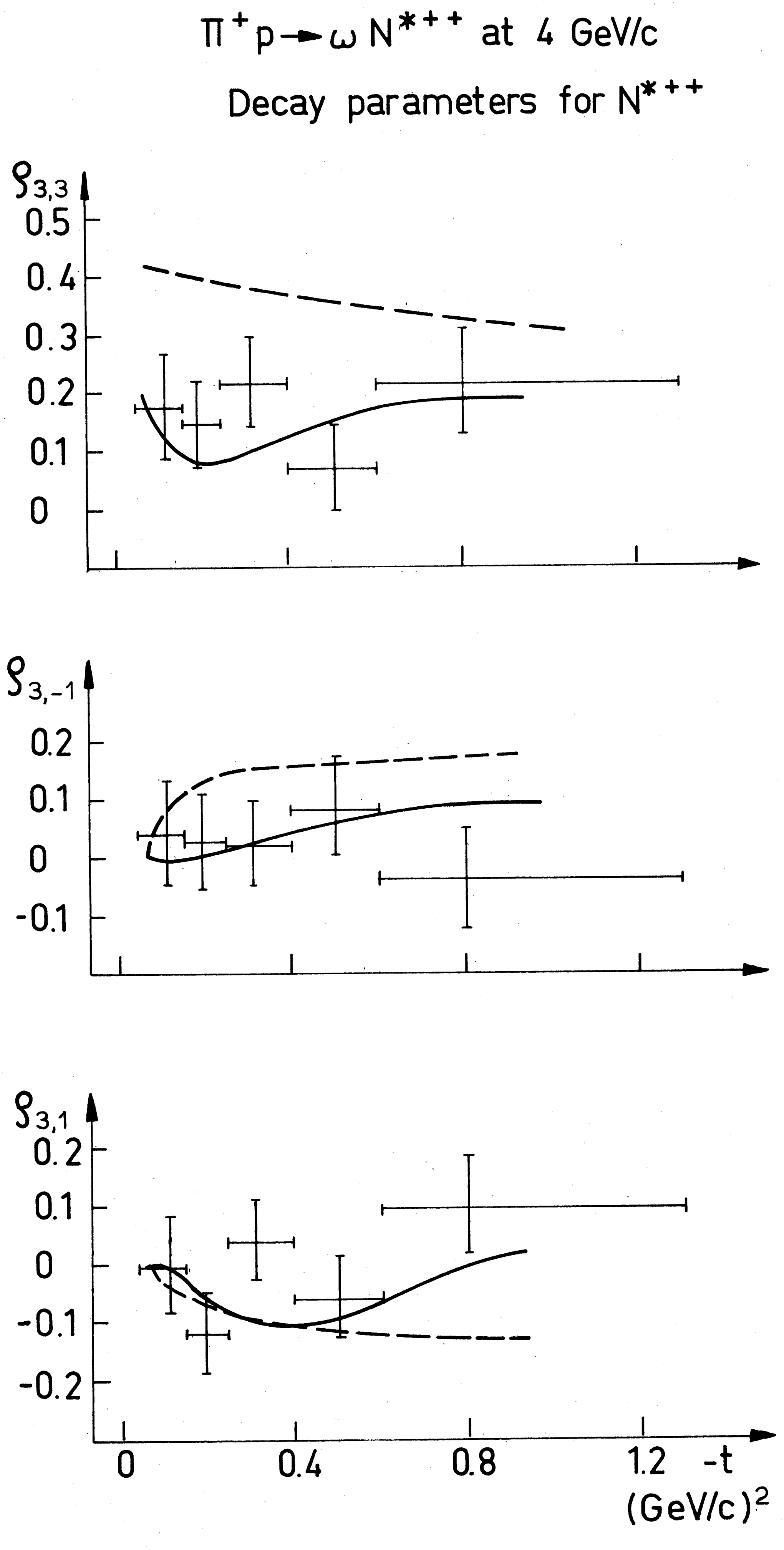


FIG. 4



Π⁺p → ω N*⁺⁺ at 4 GeV/c
Decay parameters for N*⁺⁺
ρ3,3
0.5
0.4
0.3
0.2
0.1
0
ρ3,-1
0.2
0.1
0
-0.1
ρ3,1
0.2
0.1
0
-0.1
-0.2
0
0.4
0.8
1.2
-t
(GeV/c)²

FIG. 5

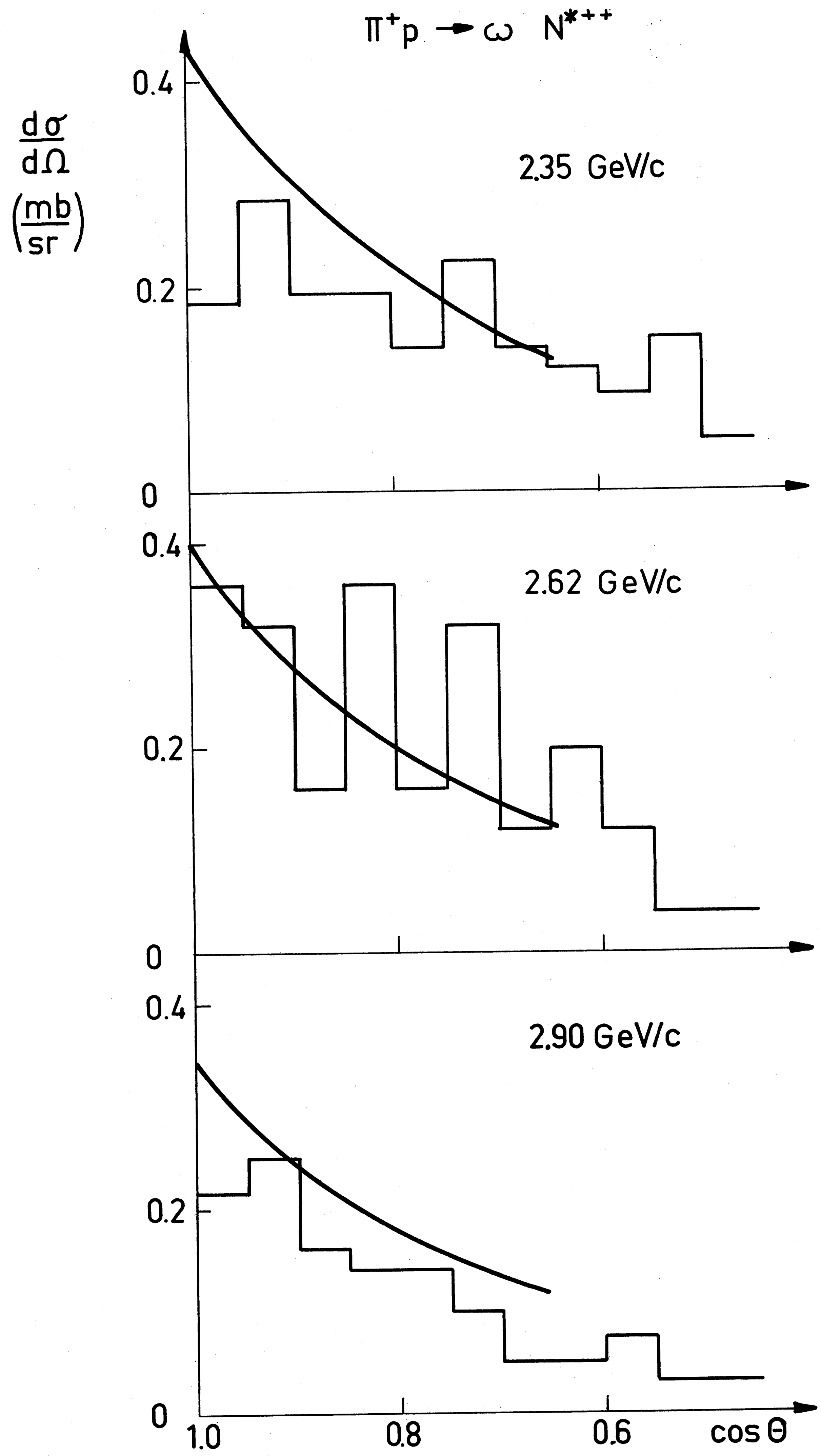


FIG. 6