ABSORPTIVE EFFECTS IN NUCLEON DIFFRACTION DISSOCIATION

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A Deck-type model with absorptive corrections is applied to diffraction dissociation process $Np \to (N\pi)\,p$. The absorption was strengthened by an introduction of a multiplicative factor $\lambda \approx 1.3$, which is associated with inelastic intermediate states. Most of the experimental distribution are satisfactorily described by the model.

1. Introduction

The Fermilab [1] and the CERN-ISR [2] groups have presented interesting new data on the inelastic diffractive process, $Np \to (N\pi)p$. For small values of the mass M, of the diffractively excited system, the Fermilab and the ISR data show a dip in the differential

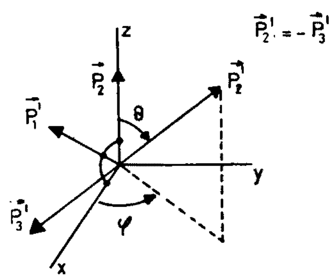

Fig. 1. Definition of the decay angles in the Gottfried–Jackson frame. The variables are indicated in Fig. 2

cross section $d\sigma/dt_1dM$ at $t_1 \simeq -0.2\,(\mathrm{GeV}/c)^2$. This structure has also been studied in a more differential way as a function of the $(N\pi)$ system decay angle in the Gottfried–Jackson frame (Fig. 1) and found to have several interesting features. A similar structure is observed in the elastic pp scattering for $t \approx -1.4\,(\mathrm{GeV}/c)^2$.

It is well known that the absorption effects play an important role in understanding the structure in the $d\sigma/dt$ distributions in elastic scattering and therefore it is interesting to study the role of absorption in the inelastic diffraction. One of the most popular models

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for diffraction dissociation is the double-peripheral model of the Deck type. A natural attempt to explain the observed structure of the t_1-distribution is to introduce the absorption (double-scattering) corrections into that model [3, 4]. So far the analysis of the reactions $\mathrm{Np} \to (\mathrm{N}\pi)\mathrm{p}$ in the framework of the Deck model with absorption has been restricted to study of the most important π-exchange graph and absorptive correction to it. However, a more precise analysis of the $d\sigma/dt_1$ and, in particular, its dependence on the $(\mathrm{N}\pi)$ system decay angle requires taking into account the nucleon exchange and direct production graphs and their absorptive corrections.

In this paper I present a detailed investigation of absorption to a Deck-type model of diffraction dissociation. The Deck amplitudes for three single-scattering and four double-scattering graphs are discussed in Section 2. Detailed comparison with data is presented in Section 3.

2. *The Deck model*

The Good–Walker picture of the diffraction dissociation applied to the production of the three-body final states in the diffraction dissociation process $\mathrm{Np} \to (\mathrm{N}\pi)\mathrm{p}$ leads to the three single-scattering graphs shown in Fig. 2 and to four double-scattering (absorptive corrections) graphs of Fig. 3. In the Good–Walker picture only absorptive corrections to the π- and N-exchange amplitudes are important [3, 5]. Berger and Pirilä [3] have shown that only the final state absorption shown in Fig. 3 is important.

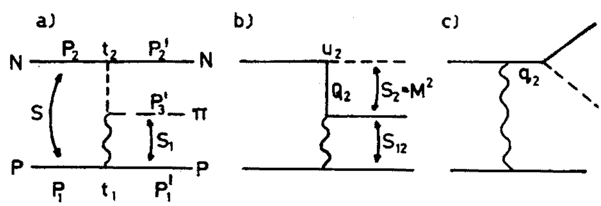

Fig. 2. The three single-scattering graphs: a) pion exchange, b) nucleon exchange and c) direct production

Covariant matrix elements for the three single-scattering graphs are the following (the variables are defined in Fig. 2) [6]:

$$M_\pi = \bar{u}(p_2') \frac{i\sqrt{2}\, g\gamma_5 F_\pi(t_2)}{t_2-\mu^2} M_{\pi\mathrm{p}}(s_1, t_1) u(p_2), \tag{1a}$$

$$M_\mathrm{N} = \bar{u}(p_2') \frac{i\sqrt{2}\, g(Q_2^\mu\gamma_\mu+m)F_\mathrm{N}(u_2)}{u_2-m^2} \gamma_5 M_{\mathrm{Np}}(s_{12}, t_1) u(p_2), \tag{1b}$$

$$M_\mathrm{D} = \bar{u}(p_2') \frac{i\sqrt{2}\, g\gamma_5(q_2^\mu\gamma_\mu+m)F_\mathrm{D}(s_2)}{s_2-m^2} M_{\mathrm{Np}}(s, t_1) u(p_2), \tag{1c}$$

where F_π, F_N and F_D are the form factors incorporating vertex and propagator corrections, $M_{\pi\mathrm{p}}$ and M_{Np} are invariant amplitudes for the elastic process $\pi\mathrm{p} \to \pi\mathrm{p}$ and $\mathrm{Np} \to \mathrm{Np}$, respectively, and g is the $\mathrm{N}\pi$ coupling constant, $g^2/4\pi = 14.5$.

The form factors F_π can be taken from the one-pion-exchange model [7] applied to the low-energy ($s \approx 1.3 \div 3\ \mathrm{GeV}^2$) pion production reactions with nucleons and pions incident on nucleons. We have:

$$F_\pi(t_2) = e^{-b_\pi|t_2-\mu^2|}, \tag{2a}$$

where $b_\pi \approx (2\div 2.5)\ (\mathrm{GeV}/c)^{-2}$, and μ is the pion mass. Because the mass of the produced (Nπ) system is small, the form factor F_π for the high energy diffraction dissociation can be taken as in Eq. (2a). For F_N and F_D I take:

$$F_\mathrm{N}(u_2) = e^{-b_\mathrm{N}|u_2-m^2|}, \tag{2b}$$

$$F_\mathrm{D}(s_2) = e^{-b_\mathrm{D}|s_2-m^2|}, \tag{2c}$$

where b_N and b_D are free parameters.

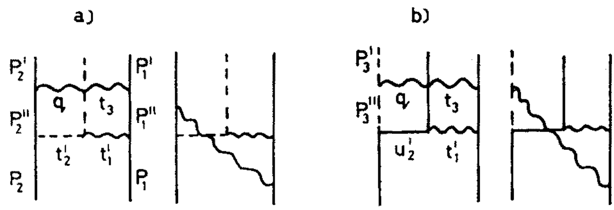

Fig. 3. The absorptive correction graphs to: a) π-exchange, b) N-exchange. All wavy lines denote elastic scattering

Assuming that the off mass-shell corrections are small, the elastic scattering amplitudes can be written as follows:

$$M_{\pi\mathrm{p}}(s_1, t_1) = is_1\sigma_{\pi\mathrm{p}}e^{b_1t_1}, \tag{3a}$$

$$M_{\mathrm{Np}}(s, t) = A(s, t)+B(s, t)\,\frac{\gamma_\mu P_1^\mu+\gamma_\mu P_1^{\mu'}}{2}. \tag{3b}$$

In Eqs. (3) the spin of the target is neglected because in the diffractive limit (large s_1 and small t_1) the scattering angle of the proton in the (πN) rest frame is small. The amplitude M_{Np} can be simplified assuming the t-channel helicity conservation. Then

$$B(s, t) = 0 \tag{4}$$

and

$$A(s, t) = i\,\frac{s}{2m}\,\sigma_{\mathrm{Np}}e^{b_2t}. \tag{5}$$

I consider in detail only this case. Assuming the s-channel helicity conservation one obtains similar final results.

In the absorptive graphs of Fig. 3 we assume the intermediate state particles (N, p) and (π, p) to be on the mass shell. Detailed arguments for the absorbed pion exchange amplitude are presented in Ref. [3]. For the absorbed N-exchange amplitude the arguments and calculation are similar. The absorptive amplitude for the two graphs in Fig. 3a is

$$A^\pi_{\mathrm{abs}} = i\int\frac{d^4q}{(2\pi)^4}\,A_{\mathrm{Np}}(s_{12}, t_3)A_\pi(s, t_1', t_2', s_1', s_2')2\pi\delta(p_1''^2-m^2)2\pi\delta(p_2''^2-m^2), \tag{6}$$

where $A_{Np} = is_{12}\sigma_{Np}e^{b_2 t_3}$ is the elastic Np scattering amplitude and

$$A_\pi = (\tfrac{1}{2}\,\mathrm{Tr}\,(\bar{M}_\pi M_\pi))^{1/2} = \sqrt{2}\,g\,\frac{\sqrt{-t_2'}}{t_2'-\mu^2}\,\sigma_{\pi N}s_1' e^{-b_\pi|t_2'-\mu^2|+b_1 t_1'}$$

is the π-exchange amplitude. Integrating Eq. (6) and consistently dropping correction terms of order $(M/\sqrt{s})$ we obtain

$$M_{abs}^{\pi} = -\frac{M_\pi(t_2-\mu^2)\sigma_{Np}}{8\pi F_\pi(t_2)\sqrt{-t_2}}\exp\left(-\frac{b_1^2 t_1}{b_1+b_2}-(b_1+b_2)\vec{V}^2\right)$$

$$\int_0^\infty dU^2 I_0(2(b_1+b_2)U|\vec{V}|)\frac{\sqrt{-t_2'}}{t_2'-\mu^2}\exp(-U^2(b_1+b_2)-b_\pi|t_2'-\mu^2|). \tag{7}$$

The spin factor of the M_{abs}^{π} has been taken to be the same as in the amplitude M_π. In Eq. (7), the function I_0 is the modified Bessel function, $\vec{V} = \vec{p}_{2T}' + \frac{b_1}{b_1+b_2}\vec{p}_{1T}'$ and $t_2' = -\frac{1}{|x_2|}U^2 - m^2(1-|x_2|)^2/|x_2|$, where $x_2 = p_{2L}'/p_{2CM}$ in the center-of-mass frame.

For the two graphs in Fig. 3b the absorptive amplitude is

$$A_{abs}^{N} = i\int\frac{d^4q}{(2\pi)^4}A_{\pi p}(s_1, t_3)A_N(s, t_1', u_2', s_{12}', t_2')2\pi\delta(p_1''^2-m^2)2\pi\delta(p_3''^2-\mu^2), \tag{8}$$

where $A_{\pi p} = is_1\sigma_{\pi p}e^{b_1 t_3}$ is the elastic πp scattering amplitude and

$$A_N = (\tfrac{1}{2}\,\mathrm{Tr}\,(\bar{M}_N M_N))^{1/2} = \sqrt{2}\,g\,\frac{\sqrt{\mu^2(t_1'-4m^2)-(m^2+\mu^2-u_2'-t_2'+t_1')(u_2'-m^2)}}{u_2'-m^2}$$
$$\times\,\sigma_{Np}s_{12}'e^{-b_N|u_2'-m^2|+b_2 t_1'}$$

is the N-exchange amplitude. After integrating to remove the two delta functions, dropping correction terms of order $(M/\sqrt{s})$, we obtain

$$A_{abs}^{N} = \frac{i}{8\pi^2 s_1}\int d^2\vec{q}_T A_{Np}(s_1, t_3)A_N(s, t_1', u_2', s_{12}', t_2') \tag{9}$$

with $t_3 = -q_T^2$, $t_1' = t_1-(\vec{q}_T^{\,2}+2\vec{q}_T\cdot\vec{p}_{1T}')$, $u_2' = u_2-(\vec{q}_T^{\,2}-2\vec{q}_T\cdot\vec{p}_{3T}')/|x_3|$, $s_{12}'\approx s_{12}$, $t_2' = t_2$, $x_3 = p_{3L}'/p_{2CM}$.

The vectors $\vec{p}_{1T}'$ and $\vec{p}_{3T}'$ are the transverse components of the momenta of final-state particles p and π, respectively; p_{3L}' is the center-of-mass longitudinal component of p_3'. Because x_3 is small, the spin factor in Eq. (9) may be approximately written as

$$\mu^2(t_1'-4m^2)-(m^2+\mu^2-u_2'-t_2'+t_1')(u_2'-m^2)\approx\mu^2(t_1-4m^2)-(m^2+\mu^2-u_2'-t_2+t_1)$$
$$\times(u_2'-m^2) = Y. \tag{10}$$

Inserting Eq. (10) into Eq. (9), we obtain

$$M^{\mathrm{N}}_{\mathrm{abs}} = -\frac{M_{\mathrm{N}}(u_2-m^2)\sigma_{\pi\mathrm{p}}\exp\left(-\dfrac{b_2^2t_1}{b_1+b_2}-(b_1+b_2)\vec{V}^2\right)}{8\pi F_{\mathrm{N}}(u_2)\sqrt{\mu^2(t_1-4m^2)-(m^2+\mu^2-u_2-t_2+t_1)(u_2-m^2)}}$$

$$\times\int_0^\infty dU^2 I_0(2(b_1+b_2)U|\vec{V}|)\,\frac{Y}{u_2'-m^2}\,e^{-b_{\mathrm{N}}|u_2'-m^2|-(b_1+b_2)U^2} \tag{11}$$

with $u_2' = -U^2/|x_3|+m^2(1-|x_3|)+\mu^2(1-1/|x_3|)$, $\quad \vec{V} = \vec{p}\,'_{3T}+\dfrac{b_2}{b_2+b_1}\,\vec{p}\,'_{1T}$.

3. Comparison with data

The model is compared with the data on the neutron dissociation reaction [1] $\mathrm{np}\to(\mathrm{p}\pi^-)\mathrm{p}$ for the incident neutron momenta between 50 GeV/c and 300 GeV/c, with mean value of $\approx$ 200 GeV/c. Our calculation has been performed for the P_{LAB} = 200 GeV/c. The parameters b_1 = 4 GeV^{-2}, b_2 = 5 GeV^{-2}, $\sigma_{\pi\mathrm{N}}$ = 24mb, σ_{Np} = 38mb are taken directly from the elastic and total cross section data. For the formfactor param-

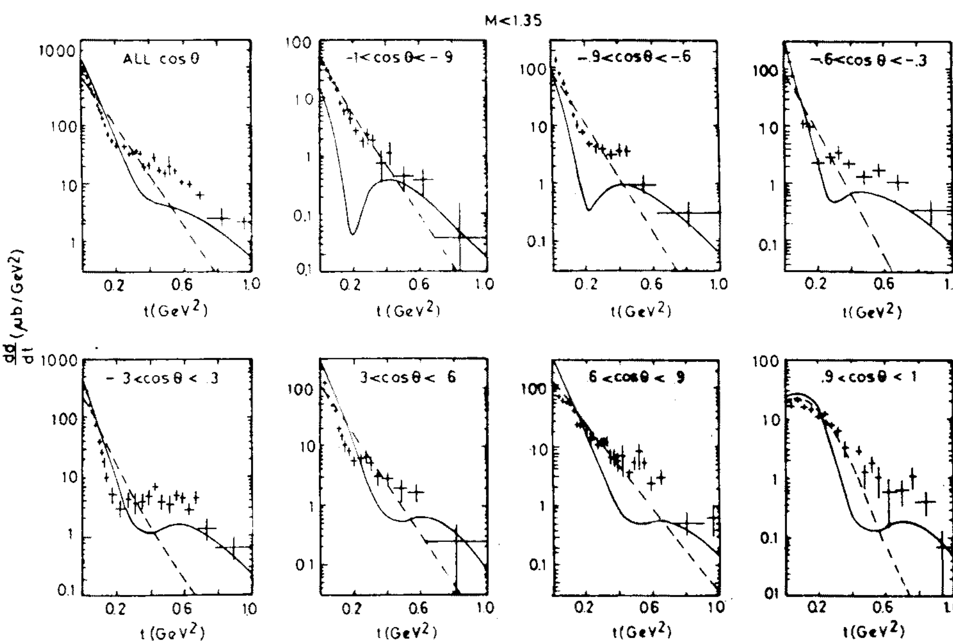

Fig. 4. Distributions in t_1 for M < 1.35 GeV. The solid theoretical curves are computed for $M_{\mathrm{TOT}} = M_\pi + M^\pi_{\mathrm{abs}}$ and b_π = 2GeV^{-2}. Dashed lines show unabsorbed model ($M_{\mathrm{TOT}} = M_\pi+M_{\mathrm{N}}+M_{\mathrm{D}}$) for b_π = 2GeV^{-2}, $b_{\mathrm{N}} = b_{\mathrm{D}}$ = 1GeV^{-2} and are multiplied by 0.33 in order to make the integrated cross section agree with data

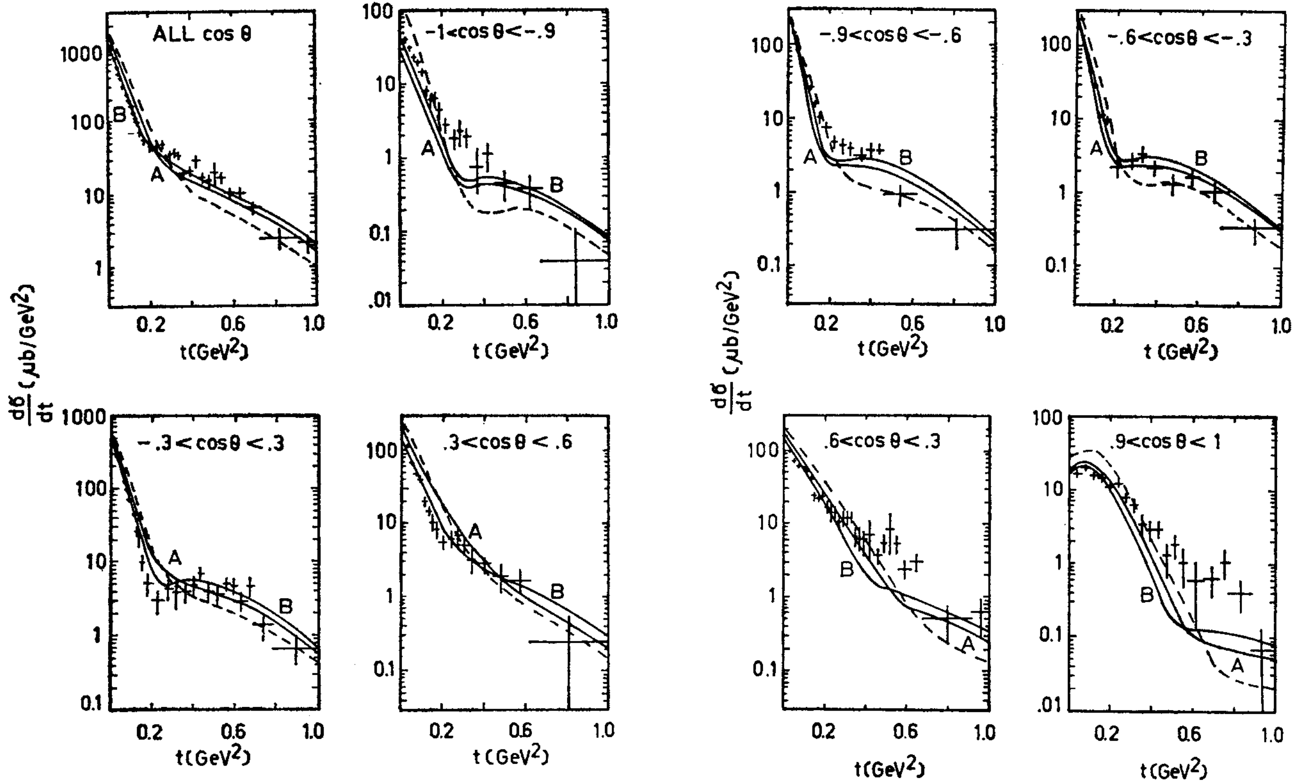

Fig. 5. Distributions in t_1 for $M < 1.35$ GeV. The dashed curves are computed for $\lambda_\pi = \lambda_N = 1$, $b_\pi = 2\ \mathrm{GeV}^{-2}$, $b_N = 1\ \mathrm{GeV}^{-2}$ and $b_D = 1.3\ \mathrm{GeV}^{-2}$. The solid curves are computed for: A) $b_\pi = 2\ \mathrm{GeV}^{-2}$, $b_N = 1\ \mathrm{GeV}^{-2}$, $b_D = 1.5\ \mathrm{GeV}^{-2}$ and $\lambda_\pi = \lambda_N = 1.3$. B) $b_\pi = 2\ \mathrm{GeV}^{-2}$, $b_N = 1 \mathrm{GeV}^{-2}$, $b_D = 1.6\ \mathrm{GeV}^{-2}$, $\lambda_\pi = 1.4$ and $\lambda_N = 1.2$

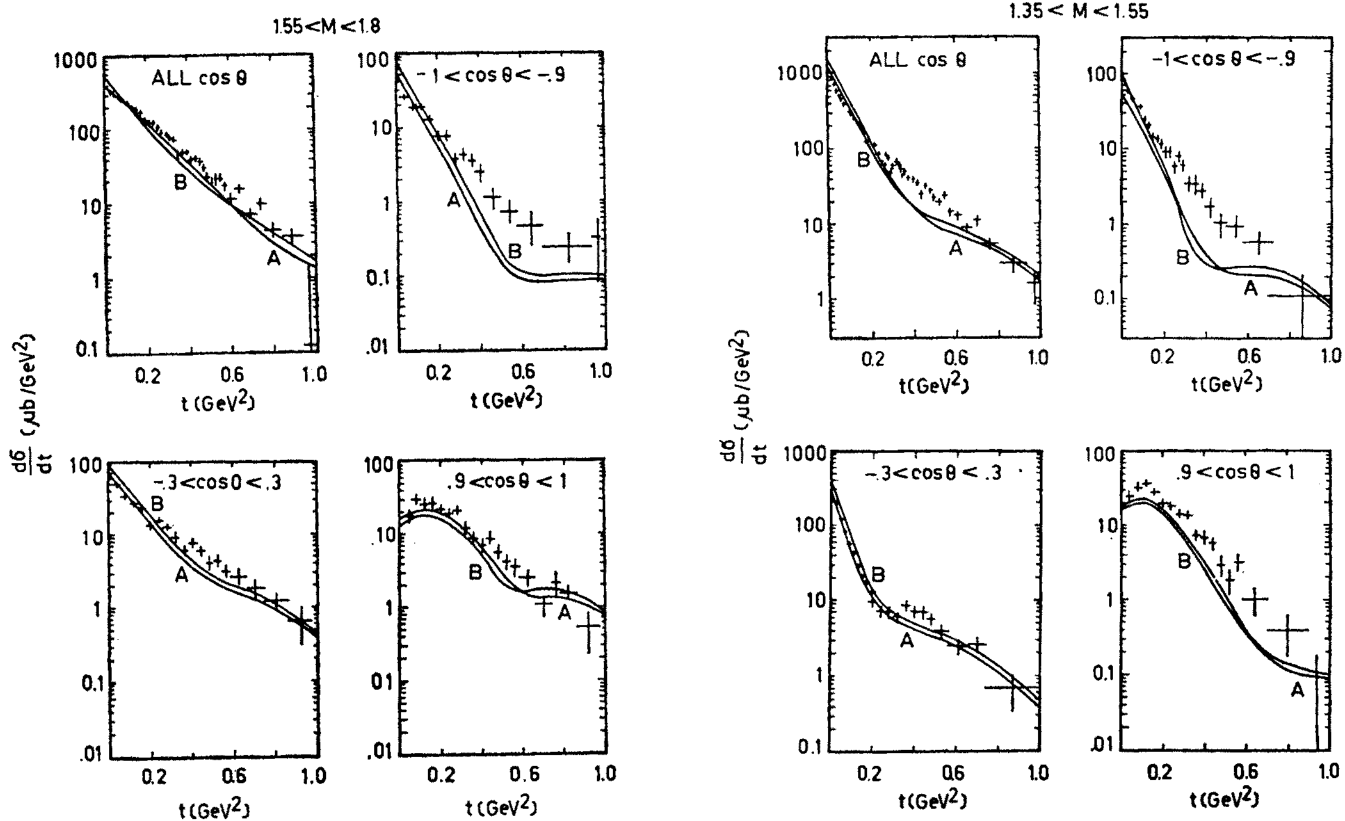

Fig. 6. Distribution in t_1 for $1.35 < M < 1.55$ GeV and $1.55 < M < 1.8$ GeV. The curves are computed as in Fig. 5

eter b_π the value $b_\pi = 2\ \text{GeV}^{-2}$ has been taken (see formula (2a) and related discussion). The parameters b_N and b_D have been adjusted to fit the data. The data are reproduced adequately with $b_N = 1\ \text{GeV}^{-2}$ and $b_D \approx 1.5\ \text{GeV}^{-2}$.

The basic observation about the amplitudes of Section 2 is that in the total cross section only the π-exchange term, $|M_\pi|^2$ is important and the two diagrams: N-exchange diagram and the direct production, tend to cancel, $|M_N+M_D| \approx 0$, $M_\pi \cdot (M_N+M_D) \approx 0$. However, the sum M_N+M_D has an important influence on the decay angular distributions of the (Nπ) system, particularly for $\cos\theta \approx \pm 1$. For $\cos\theta \approx -1$ and $\cos\theta \approx +1$ N-exchange and direct production are important respectively (Fig. 8). The t_1 dependence

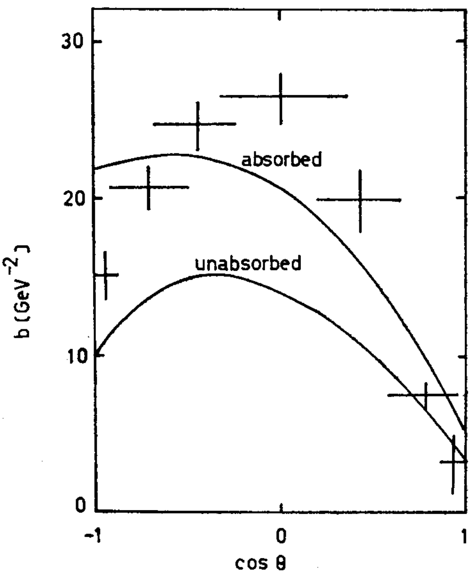

Fig. 7. Logarithmic slope b of the momentum transfer distribution as a function of $\cos\theta$ for unabsorbed and absorbed Deck model

of the π-exchange contribution and the absorptive correction to the π-exchange graph $M_{\text{TOT}} = M_\pi + M^\pi_{\text{abs}}$ is compared with data in Fig. 4. We observe that this simplified version of the model is totally inadequate to reproduce the experimental data.

As the next step we compare the data with calculations which include all the contributions from Fig. 2 and Fig. 3 described with formulae $M_{\text{TOT}} = M_\pi + M_N + M_D + M^\pi_{\text{abs}} + M^N_{\text{abs}}$. Our results are represented by the dashed curves in Fig. 5. The agreement with data, although better than in Fig. 4, is still unsatisfactory.

Several analysis of the two-body reactions have shown that the absorptive effect is stronger than it follows from the elastic intermediate states [8]. The inelastic intermediate states are usually taken into account phenomenologically by the multiplicative factor λ ($\lambda > 1$). In this case the total amplitude for the considered reaction is

$$M_{\text{TOT}} = M_\pi + M_N + M_D + \lambda_\pi M^\pi_{\text{abs}} + \lambda_N M^N_{\text{abs}}. \tag{12}$$

The results of the calculation using (12) and for two sets of values for parameters λ ($\lambda_\pi = \lambda_N = 1.3$ and $\lambda_\pi = 1.4$, $\lambda_N = 1.2$) are shown in Fig. 5 and Fig. 6. The agreement with data becomes quite satisfactory for the case $\lambda_\pi = 1.4$, $\lambda_N = 1.2$ (particularly for small M). The absolute normalizations in Figs. 4–6 are as given by Eqs. (1–12). In Fig. 7 I compare my calculated slopes of the t_1 distribution as a function of $\cos\theta$ for $\lambda_\pi = 1.4$ and $\lambda_N = 1.2$.

We conclude this section with the observation that within the absorbed Deck model there exists the following simple explanation of the dependence on $\cos\theta$ of the structure in the t_1 distribution. For $\cos\theta > 0.3$ the direct production graph, which has not any

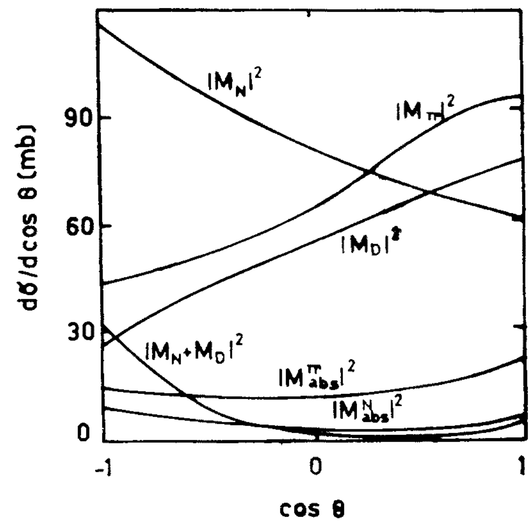

Fig. 8. Distribution in $\cos\theta$, showing the cancellation of M_N and M_D. The model is calculated for $M < 1.35$ GeV, $0.02 < -t_1 < 1$ GeV^2, $b_\pi = 2$ GeV^{-2}, $b_N = 1$ GeV^{-2} and $b_D = 1.3$ GeV^{-2}

absorptive correction, is important (Fig. 8) and the structure in $d\sigma/dt_1$ vanishes. If $\cos\theta < 0.3$ the π- and N-exchange graphs and their absorptive corrections are dominant. In this region of the phase space the structure in $d\sigma/dt_1$ exists for small M. Very clear structure in t_1 distributions at small value $|t_1|$ is observed for small M and $\cos\theta$ ($-0.6 < \cos\theta < 0.3$) where the logarithmic slope b is the greatest.

4. Conclusions

The absorptive Deck model describes satisfactorily the inelastic diffractive process $Np \to (N\pi)p$ in the whole region of the phase space. Two important facts are the following:

a) inclusion of baryon exchange and direct production contributions (as follows from the Good–Walker approach) is crucial for complete agreement with data,

b) theoretical results are very sensitive to strength of the absorptive corrections. The data can be correctly described by a model with "strong" absorption with a phenomenological factor $\lambda > 1$ which accounts for the contribution of the inelastic states to absorptive effects. We find $\lambda \approx 1.3$.

From experience with binary reactions it is known that $\lambda \approx 2$ [8]. However, if the Regge phases and all spin effects are included in the absorbed Deck model the effect of absorption becomes smaller and the necessary inelastic factor stronger.

With normalization $d\sigma/dt_1$ in the total region of phase space it follows, that $b_\pi = 2\,\mathrm{GeV}^{-2}$. This value of b_π is consistent with the one-pion-exchange approximation (Eq. (2a)) and two-dimensional $\cos\theta - \varphi$ distribution in the unabsorbed Deck model [3].

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