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A π-B EXCHANGE DEGENERATE MODEL FOR $V^0\Delta^{++}$ PRODUCTION*

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The forward differential cross section of $\rho\Delta$ production is shown to be reproduced quantitatively by an evasive Reggeized one pion exchange model which smoothly reduces to the Born term at the pion pole. Assuming exact π-B exchange degeneracy leads to predictions for $\omega\Delta$ production which are in agreement with the experimental s and t dependences. Similar agreement is found for $K^*\Delta$ production.

The t-channel one-pion exchange (OPE) appears as the dominant forward production mechanism, at medium energies, in many two-body reactions. There is, however, a considerable controversy as to the detailed features of this process. The proximity of the pion pole to the physical t region suggests the importance of the Born term. Nevertheless, it is clear that the experimental momentum transfer distributions in the relevant reactions force rather severe modifications of the Born amplitude. Such modifications have been suggested (and applied) taking into account off mass shell corrections,[1] absorption,[2] and a variety of Regge-pole and cut models.[3-5]

In this letter we offer evidence that the OPE contribution to the reaction

$$\pi^+ p \rightarrow \rho^0 \Delta^{++} \qquad (1)$$

is consistent with the exchanged pion lying on an evasive (M = 0) Regge-trajectory with a slope near the "universal" value of 1 $(\mathrm{GeV}/c)^{-2}$. This

result is suggested by a recent high statistics experiment[6] at 3.7 GeV/c which provides differential cross sections and spin density matrix elements to a $|t|$ value as large as 1.5 $(\mathrm{GeV/c})^2$. A similar analysis of the reaction

$$\pi^+ p \rightarrow \omega^o \Delta^{++} \tag{2}$$

then provides a stringent test of π-B exchange degeneracy which is well satisfied by the data.[6] Our results are readily extended to the reaction

$$K^+ p \rightarrow K^{*o} \Delta^{++} \tag{3}$$

but <u>cannot</u> properly describe either charged pion photoproduction or np charge exchange scattering.[7] However, our approach when coupled to models such as the one suggested by Jackson and Quigg[5] may provide an overall description which is quite satisfactory.

It has been noted[1,3] that the differential cross section of reaction (1) exhibits shrinkage of the forward peak with increasing primary energy. This behavior suggests a simple Regge-pole parametrization with a steep evasive π-trajectory.[3] However, it has been argued[1] that the shrinkage may originate kinematically from the large widths of the measured ρ and Δ resonances. The availability of the new 3.7 GeV/c data[6] makes it possible to examine the structure of the unnatural parity t-channel exchanges away from the very forward direction. The crucial observation is that the zero seen in $\rho_{00} \frac{d\sigma}{dt}$ at $t' = t - t_{min} = -0.75\ (\mathrm{GeV/c})^2$ enables us to discriminate against models that are quite satisfactory at lower t' values.

We limit our study to $\sigma_0^- = \rho_{00} \frac{d\sigma}{d|t'|}$ to which only unnatural parity $(P = (-1)^{J+1})$ exchanges can contribute. The Born OPE cross section for the process $a + b \rightarrow c + d$ is calculated[8] to be

$$\sigma_0^- = \frac{2\pi}{3sq^2} G^2 \left|\frac{1}{t - m_\pi^2}\right|^2 \frac{a_c^2 b_d^2}{m_\pi^2} [(m_b + m_d)^2 - t] \qquad (4)$$

where

$$q^2 = [s - (m_a - m_b)^2][s - (m_a + m_b)^2]/4s$$
$$a_c^2 = [t - (m_a - m_c)^2][t - (m_a + m_c)^2]/4m_c^2$$
$$b_d^2 = [t - (m_b - m_d)^2][t - (m_b + m_d)^2]/4m_d^2 \quad .$$

The product of the coupling constants $G^2 = (g^2_{\pi\pi\rho}/4\pi)\cdot(g^2_{p\pi\Delta}/4\pi) \approx 0.9$ if widths of 120 MeV are assumed for both the ρ and Δ resonances. We Reggeize this expression by replacing the pion propagator

$$\frac{1}{t - m_\pi^2} \rightarrow \pi\alpha'(0) \frac{1 + e^{-i\pi\alpha}}{2 \sin \pi\alpha} \frac{(1 + 2\alpha)(1 + \frac{2\alpha}{3})\Gamma(\alpha + \frac{1}{2})}{\Gamma(\frac{1}{2})\Gamma(\alpha + 1)} (\frac{s - u}{2s_o})^\alpha \qquad (5)$$

where $\alpha = \alpha'(0)(t - m_\pi^2)$. The model thus consists of an evasive pion with kinematical factors determined by the behavior of the Born amplitude at thresholds and pseudothresholds rather than the factors suggested by the crossing matrix.[9] The reduced residue is smoothly continued from the coupling constants calculated at the pion pole. The only arbitrariness in the functional dependence in Eq. (5) is introduced when we suppress the poles of $\Gamma(\alpha + \frac{1}{2})$. We choose to multiply by the lowest order polynomial in α which has the required zeroes in the measured t region. Alternatively, one may employ a Veneziano-type amplitude where $\Gamma(\alpha + \frac{1}{2})$ is eliminated altogether.[10]

We have performed a fit to the data for reaction (1) at 3.7 GeV/c, minimizing the χ^2 as a function of $\alpha'(0)$, s_o and G^2. The curve shown in Fig. 1a is the best fit result with a χ^2 of 20.1 for 22 degrees of freedom. The best fit parameters are

$$\alpha'(0) = 1.16 \pm 0.03 \ (\mathrm{GeV/c})^{-2}$$
$$2s_0 = 1.08 \pm 0.11 \ \mathrm{GeV}^2$$
$$G^2 = 0.46 \pm 0.05 \quad .$$

The zero observed near $|t'| = 0.75 \ (\mathrm{GeV/c})^2$ is interpreted as a nonsense wrong signature zero in the OPE Regge amplitude corresponding to $\alpha_\pi = -1$. The model is seen to reproduce quantitatively both this zero and the detailed shape of σ_0^- over a large range in t. In particular the apparent change in slope near $|t'| = 0.2 \ (\mathrm{GeV/c})^2$ is well reproduced by our calculation. The fitted G^2 value corresponds to ρ and Δ widths of about 90 MeV each, which may be regarded as satisfactory in view of the simplicity and small number of parameters introduced in this model.

Having fixed the parameters from the fit at 3.7 GeV/c, we compare in Fig. 2 the model predictions with the results of other experiments at different energies.[11-12] We wish to stress that we have not attempted to fit the overall data as different experimental procedures have been applied both to cross-section normalization and to background estimation. In our opinion systematic discrepancies as large as 20% may be present in comparing two different experiments. It may be seen, however, that our calculation provides quantitative agreement with both the s and the t dependence of the data.

We next consider the unnatural parity exchange contribution to reaction (2) for which the nearest t-channel singularity is the B meson with $J^{PG} = 1^{++}$. From the absence of strongly coupled resonances in the s-channel K^+p system, one can argue that reaction (3) proceeds via the exchange of exchange degenerate pairs such as π+B. Assuming then that $\alpha_B = \alpha_\pi = \alpha$ and that the residues are equal (strong exchange degeneracy), one finds that

$$\frac{\sigma_0^-(\rho\Delta)}{\sigma_0^-(\omega\Delta)} = A \cot^2 \frac{\pi\alpha}{2} \tag{6}$$

where $A = 1$ in the limit of exact SU(3) symmetry (assuming that $\Gamma(B \to \varphi\pi) = 0$, as expected for the ideal nonet).

In Fig. 3a we show the data[6] and the best fit curve from an independent fit of $\sigma_0^-(\rho\Delta)/\sigma_0^-(\omega\Delta)$ as a function of t'. The parameters at the minimum value of χ^2 (14 for 19 degrees of freedom) are $A = 0.41\pm0.08$ and $\alpha'(0) = (1.12\pm0.08)$ $(\mathrm{GeV/c})^{-2}$ when a linear trajectory, $\alpha = \alpha'(0)(t - m_\pi^2)$, is assumed. This fitted value of α' agrees well with the value we have obtained using Eq. (4) and the $\rho\Delta$ data alone. The experimental distribution is well reproduced over a wide range of t values, but the significant dip in $\sigma_0^-(\omega\Delta)$ (see Fig. 3b) at $|t'| = 0.17\ (\mathrm{GeV/c})^2$ is <u>unexplained</u> by our model. A possible explanation in terms of a nonsense wrong signature zero of the B amplitude appears to be unattractive both on experimental grounds[6] and the rather good general agreement with π-B exchange degeneracy. The fit of our model to reaction (2) at 3.7 GeV/c is shown in Fig. 3b (see also Fig. 1b). The parameters $\alpha'(0)$ and s_o are fixed to the values found for reaction (1), so that the only parameter varied in the fit is G^2 (the sign of $\mathrm{Exp}(-i\pi\alpha)$ is reversed in Eq. (5) for B exchange). This fit was performed over the range $0.2 \leq |t'| \leq 1.4$ $(\mathrm{GeV/c})^2$ to eliminate complications due to the dip and possible ρ-ω interference.[6] While some systematic deviations are seen at the largest t' values, the overall agreement is good ($\chi^2 = 16.3$ for 15 degrees of freedom), as expected from the agreement shown in Fig. 3a.

From the fit to the $\sigma_0^-(\omega\Delta)$ distribution at 3.7 GeV/c, we find that $G^2 = 0.94\pm0.15$. Combining this result with the previous one for $\rho\Delta$ production we get $A = 0.49\pm0.06$ which suggests possible breaking of either SU(3) or

exchange degeneracy.[13] A further consequence of our analysis is that the $\omega\Delta$ cross section is expected to fall more rapidly with energy than the $\rho\Delta$ cross section. This effect arises kinematically from the decrease of $|t_{min}|$ as s increases, and is evident from the form of Eq. (6). The predicted differential cross section for $\omega\Delta$ at 8 GeV/c is compared to the data[11] in the lower part of Fig. 3b, and is seen to reproduce the experimental energy fall-off.

An independent experimental test of our model may be made utilizing available data on reaction (3). To incorporate possible symmetry breakings we have chosen to use the experimental coupling constants determined by the pionic decay of K^{*o} and Δ^{++}, and take $G^2 = 0.38$. The only changes in Eqs. (4-5) are thus the appropriate different masses and signatures, retaining the values of $\alpha(t)$ and s_o determined in reaction (1). These predictions, shown in Fig. 4, are seen to agree rather well with the data,[14,15] especially so in view of the lack of arbitrariness in the model.

The model proposed for $V^o\Delta^{++}$ production is seen to be in quantitative agreement with experiment. We have considered alternative models to analyze the uniqueness of our conclusions. If the exchanged pion were a fixed pole, or had a trajectory which is almost flat,[7] then a zero at $|t'| \cong 0.75\ (\mathrm{GeV/c})^2$ is not expected. In particular we note that a form factor[1] correction does not produce such a dip. In our opinion the data analysis of Wolf[1] is somewhat misleading as he considers the full differential cross sections which contain contributions from natural parity exchanges which cannot be neglected.[6] Such contributions cannot be reproduced by an OPE amplitude as long as it is modified by a form factor only. Additionally, a flat trajectory does not motivate a possible π-B exchange degeneracy which is strongly indicated by the data. Hence we argue that the shrinkage observed in $\rho\Delta$ production is a consequence

of a π trajectory with a slope $\sim 1\ (\mathrm{GeV/c})^{-2}$, rather than a pure kinematic effect.[1]

Another suggested model[4] with only Regge poles considers contributions from an $M = 1$ pion, its conspirator and a strongly coupled A_1. While this model provides a good fit to data from reaction (1) at small t' values, no structure near $t' \cong -0.75\ (\mathrm{GeV/c})^2$ is suggested. Furthermore the fitted A_1 trajectory is quite different from the π trajectory, so that it may be difficult to construct an exchange degenerate scheme for this model. It is worth noting that we have neglected an A_1 exchange contribution in the present model, indicating that the $\bar{p}A_1\Delta$ coupling may be rather small.

We have also considered the possibility that the zero observed in $\sigma_0^-(\rho\Delta)$ is due to the optical properties of the scattering amplitude.[16] Such a zero would be expected near $t' = -0.6\ (\mathrm{GeV/c})^2$ if the net s-channel helicity flip is one. Present data cannot rule out such a correlation. However, this interpretation leads to some difficulties. One expects that the small pion mass would shift the dip to $|t'|$ values smaller than $0.6\ (\mathrm{GeV/c})^2$, and not larger as seen experimentally. It is possible to circumvent this complication by associating the dip with A_1 exchange rather than with π exchange. However, one would then expect the B contribution to $\omega\Delta$ to show a similar dip which is not observed experimentally.[6] We comment also that the dip observed in $\rho_{11} + \rho_{1-1}$ near $t' = -0.65\ (\mathrm{GeV/c})^2$ for reaction (2) <u>contradicts</u> the simple optical picture.

The present model offers no explanation for the observed forward peaks in the photoproduction of charged pions and np charge exchange. Modification of the OPE Regge amplitude as used in our calculation by appropriate cuts (absorption) does provide a good fit[5] to these problematic reactions. It

is not entirely clear why such cut corrections are not required in the analysis of reactions (1-3), although we note that there is no s-channel structure in K^+p reactions and relatively little in π^+p reactions. A better understanding of the role of Regge cuts is therefore crucial to a complete parametrization of the OPE amplitude.

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FIGURE LEGENDS

Fig. 1. σ_0^- as a function of $|t'|$ at 3.7 GeV/c. (a) $\rho^o\Delta^{++}$; (b) $\omega^o\Delta^{++}$.

Fig. 2. $\sigma_0^-(\rho^o\Delta^{++})$ as a function of $|t'|$ at 3.7, 8.0 and 13.1 GeV/c.

Fig. 3. (a) $\sigma_0^-(\rho^o\Delta^{++})/\sigma_0^-(\omega\Delta)$ as a function of $|t'|$. (b) $\sigma_0^-(\omega^o\Delta^{++})$ as a function of $|t'|$ at 3.7 and 8.0 GeV/c.

Fig. 4. $\sigma_0^-(K^{*o}\Delta^{++})$ as a function of $|t|$ at 2.53, 2.76, 3.20 and 5.0 GeV/c.

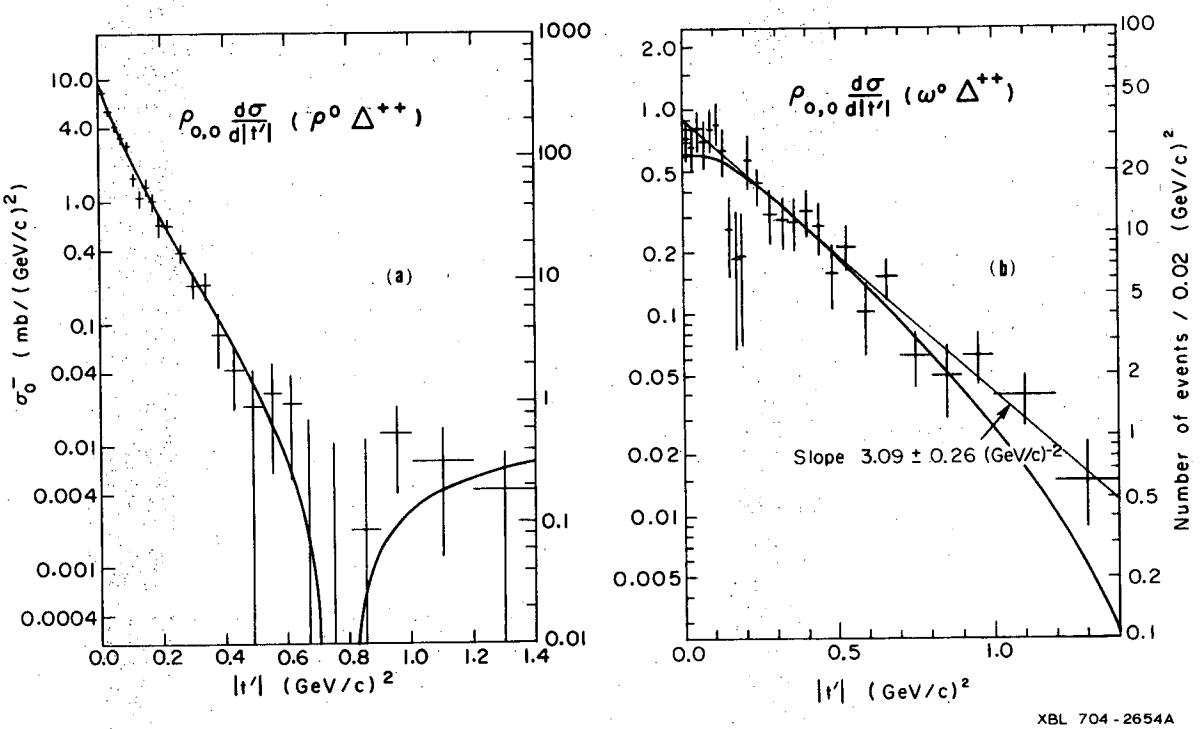
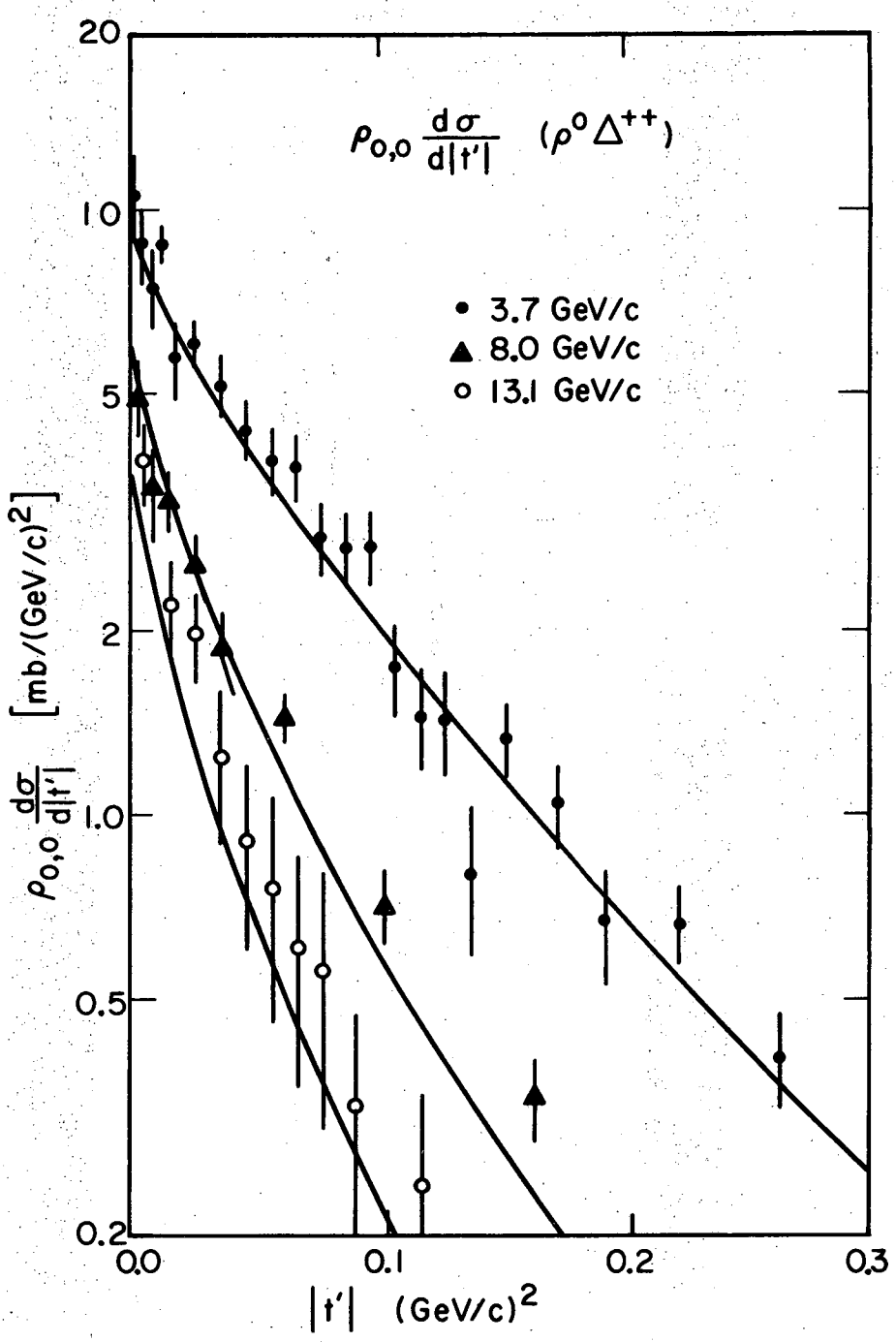

$\rho_{0,0} \frac{d\sigma}{d|t'|}$ ($\rho^0 \Delta^{++}$)
(a)
σ_0^- (mb/ (GeV/c)^2)
|t'| (GeV/c)^2
$\rho_{0,0} \frac{d\sigma}{d|t'|}$ ($\omega^0 \Delta^{++}$)
(b)
Slope 3.09 ± 0.26 (GeV/c)$^{-2}$
Number of events / 0.02 (GeV/c)^2
|t'| (GeV/c)^2
XBL 704-2654A

Fig. 1



XBL 705-2888

Fig. 2

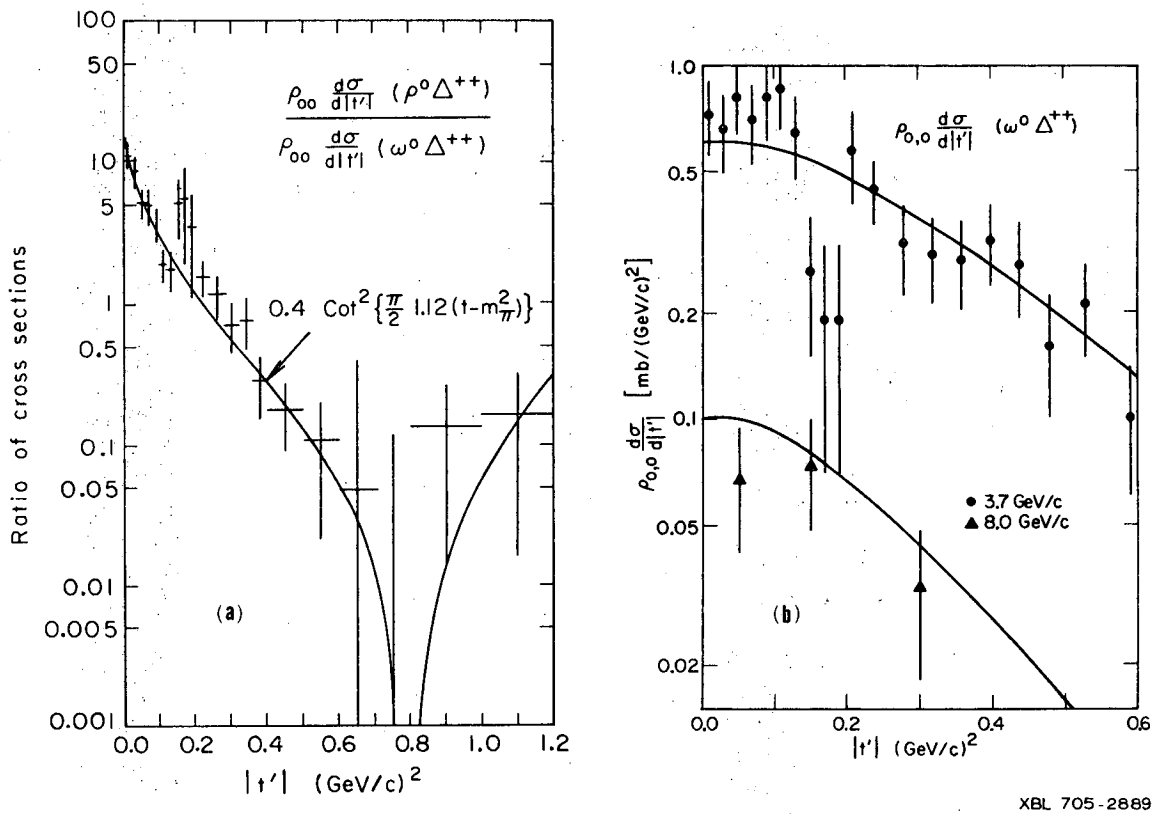

Ratio of cross sections
$\frac{\rho_{00}\frac{d\sigma}{d|t'|}(\rho^0\Delta^{++})}{\rho_{00}\frac{d\sigma}{d|t'|}(\omega^0\Delta^{++})}$
$0.4\ \mathrm{Cot}^2\{\frac{\pi}{2}\ 1.12(t-m_\pi^2)\}$
(a)
$|t'|$ (GeV/c)^2
$\rho_{0,0}\frac{d\sigma}{d|t'|}$ [mb/(GeV/c)^2]
$\rho_{0,0}\frac{d\sigma}{d|t'|}(\omega^0\Delta^{++})$
● 3.7 GeV/c
▲ 8.0 GeV/c
(b)
$|t'|$ (GeV/c)^2
XBL 705-2889

Fig. 3

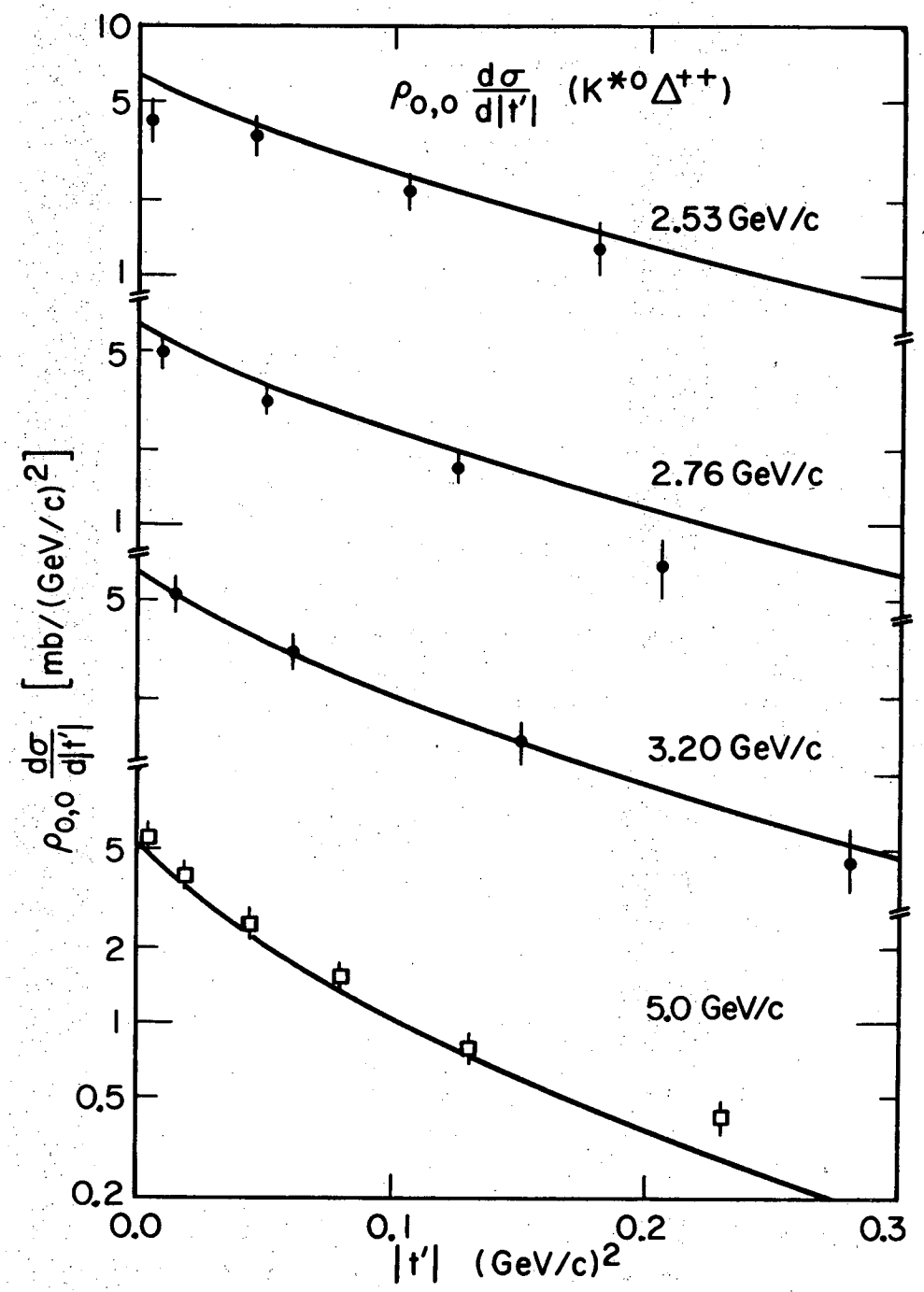


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Fig. 4

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