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EVIDENCE FOR REGGE SHRINKAGE IN π EXCHANGE

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A B S T R A C T

We review the possible ways of determining the Regge behaviour of π exchange from the data and conclude that the most reliable way is to study $\rho^H_{oo} d\sigma/dt$ for $\pi^- p \to \rho^o n$. Using such data we find evidence for a pion trajectory of conventional Regge slope. We also isolate the pion trajectory using data for $\gamma p \to \omega p$.

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The Regge behaviour of unnatural parity exchange (π, B, K...) is hard to confirm as their contributions are frequently hidden by those from the higher lying natural parity exchange trajectories (A_2, ρ, K^*...). The π exchange pole near the physical region is evident by the sharp peak (or dip) in the forward cross-section but to test whether it lies on a Regge trajectory we need data which isolate π exchange at larger t. For this reason it is essential to use polarization data which separate unnatural from natural parity exchange.

Processes in which π exchange can contribute are listed in the Table according to the behaviour of the π exchange amplitude in the forward direction, t' = 0. The available data offer two ways of isolating unnatural parity exchange. First by using $\rho_{00} d\sigma/dt$ and $(\rho_{11} - \rho_{1-1}) d\sigma/dt$ for π and K initiated vector meson production and secondly by the use of polarized photon beams for the photoproduction processes. An important advantage in considering the energy dependence of the natural and unnatural parity exchange contributions separately is that the relative separation of the resulting effective trajectories, $\alpha_{eff}(t)$, is not affected by normalization uncertainties. Before we study such data we discuss the problems of observing the π trajectory from cross-section data alone.

The cross-sections of the reactions in the first column of the Table show a sharp forward spike with height and width indicating π exchange. Here the π contributes equally to the double flip (n = 2) and evasive non-flip (n = 0) s channel helicity amplitudes. Thus the π contribution itself vanishes in the forward direction, however, it can produce the spike by destructive interference with a non-vanishing background in the n = 0 amplitude. Such a mechanism arises naturally in an absorption model approach [1)-3)]. Further insight is obtained by comparison of processes related by line reversal : ($np \to pn$, $\bar{p}p \to \bar{n}n$), ($K^+n \to K^{*0}p$, $K^-p \to \bar{K}^{*0}n$) with K^* produced with unit s channel helicity, ($\gamma n \to \pi^- p$, $\gamma p \to \pi^+ n$). In each case the two reactions have approximately equal cross-sections [*)] at t = 0 with the second reaction having a flatter slope than the first. This is explained [4)-6)] by the interference of ρ exchange with absorbed π (and to a lesser extent A_2) exchange. Finally there is evidence [7)-10),5)] that natural parity exchange dominates for $-t \gtrsim 0.3$ GeV^2. From the complicated composition of the helicity amplitudes it is clear that the energy dependence of these cross-sections will not reveal the nature of π exchange. The effective trajectories [11),12)]

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*) Further data are needed for $K^+n \to K^{*0}p$ and $\bar{p}p \to \bar{n}n$ to establish the forward equality.

for $-t < 1\ \mathrm{GeV}^2$ oscillate near $\alpha_{eff}(t) = 0$ with structure suggestive of π Regge exchange for small t and natural parity $(A_2, \rho \ldots)$ exchange at larger t.

A similar conclusion applies for the processes $pp \rightarrow n\Delta^{++}$ [13] and $pp \rightarrow \Delta^0 \Delta^{++}$ [14]. Here the cross-section is composed of even more amplitudes and unfortunately the density matrix elements of the Δ decay do not provide a separation of natural and unnatural parity exchange.

On the other hand, $\rho_{oo} d\sigma/dt$ for the π and K initiated vector meson production reactions shown in the Table are particularly favourable for isolating π exchange. It is well known that natural parity exchange cannot produce a helicity zero natural parity meson (such as ρ or K^*) from a π or K beam. This is exactly true if the vector meson is produced with t channel helicity zero and true to order 1/s for s channel helicity zero. In the presence of absorption (conserving s channel helicities) this statement remains true to order 1/s for s channel helicity zero vector mesons but is no longer valid at all in the t channel. We therefore only consider s channel amplitudes and density matrices.

For the above reactions $\rho_{oo} d\sigma/dt$ is the dominant part of the cross-section for $-t \lesssim 0.2\ \mathrm{GeV}^2$, as anticipated from π exchange. π exchange contributes to the s channel helicity flip amplitude for $\pi^- p \rightarrow \rho^o n$ (non-flip for $\pi^+ p \rightarrow \rho^o \Delta^{++}$) and the resulting forward dip (peak) is observed in $\rho_{oo} d\sigma/dt$. For larger t $\rho_{oo} d\sigma/dt$ rapidly becomes a small fraction of the cross-section and consequently it requires high statistics experiments to reveal the π trajectory in this region. These have recently become available for $\pi^- p \rightarrow \rho^o n$. A study of $\rho_{oo} d\sigma/dt$ for this process has the advantage over that for $\pi^+ p \rightarrow \rho^o \Delta^{++}$ in that the corrections to π pole exchange are expected to be less in helicity flip than non-flip amplitudes.

Here we determine the energy dependence of the amplitudes for $\pi^- p \rightarrow \rho^o n$ from the $\pi^- p \rightarrow \pi^- \pi^+ n$ data at 17.2 GeV/c [15], 15 GeV/c [16], 6.95 GeV/c [17],*) and 2.77 GeV/c [18]. At each energy we perform an amplitude analysis using the observed s channel moments ($\rho_{oo} - \rho_{11}$, ρ_{1-1}, Re ρ_{10}, Re ρ_{1s}, Re ρ_{os}) as described in Ref. 10). This method allows for the possibility of absorbed π and A_2 exchange in s and p wave $\pi^+\pi^-$

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*) These data included some from the $\pi^+ n \rightarrow \pi^+ \pi^- p$ channel.

production in a model independent way. The only assumption *) is that the amplitudes with the quantum numbers of A_1 exchange are negligible. From the resulting p wave $\pi^+\pi^-$ production amplitudes we calculate the components of the $\pi^- p \rightarrow \rho^0 n$ cross-section shown in Fig. 1, and these in turn are used to determine effective Regge trajectories, $\alpha_{eff}(t)$. At lower energies the complications from interfering final states (πN^*) are increased, as well as the possibility of s channel resonance effects, and so the 2.77 GeV/c data are omitted in the trajectory determinations shown in Fig. 2. However, if these data are included, it is encouraging to see that there is no essential change from the values shown in Fig. 2, apart from an over-all reduction in the errors. A steeper and more linear trajectory is obtained for $\rho_{oo} d\sigma/dt$ for $-t > 0.3$ (shown by the dotted values in Fig. 2).

To overcome the problems of normalization of different experiments using different mass cuts, we extrapolated, for each energy in turn, the $\rho_{oo} d\sigma/dt$ values to the π pole ($t = \mu^2 = 0.02$ GeV^2), by fitting to the form $a(-t')\exp[b(t-\mu^2)]/(t-\mu^2)^2$ for $-t < 0.2$ GeV^2. Thus α_{eff} for the extrapolated $\rho_{oo} d\sigma/dt$ is constrained to go through zero at $t = \mu^2$. This single requirement normalizes the other α_{eff} values.

In Fig. 2, we compare the results with linear trajectories of slope 0.9 GeV^{-2} for π and A_2 exchange. The results are very encouraging from a Regge view point :

(i) the π trajectory resulting from $\rho_{oo} d\sigma/dt$ is consistent **) with Regge behaviour ***) ; the only amplitude which is expected to contribute is due to π exchange, with little (absorptive) correction since it is a flip amplitude ;

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*) Experimental support for the assumption of negligible unnatural parity exchange contributions to s channel nucleon non-flip amplitudes has recently been obtained from the observed equality of the recoil and target polarizations in $\gamma p \rightarrow \pi^0 p$ in the region of 4 GeV/c. A compilation of these polarizations is shown in Ref. 19).

**) The high value of α_{eff} at $-t = 0.45$ GeV^2 arises from the relatively low $\rho_{oo} d\sigma/dt$ in the 6.95 GeV/c data.

***) It is interesting to note that the observed $\pi^+ p \rightarrow \rho^0 \Delta^{++}$ and $\pi^+ p \rightarrow \omega \Delta^{++}$ $\rho_{oo}^{GJ} d\sigma/dt$ ratio at 3.7 GeV/c has been explained [20] in terms of an approximately exchange degenerate π-B trajectory of conventional slope.

(ii) the α_{eff} values for $(\rho_{11} \pm \rho_{1-1})d\sigma/dt$ show the predicted natural, unnatural parity separation, and moreover, reasonable absolute values ; here the π and A_2 pole contributions to the evasive $n = 0$ amplitude would have large corrections in an absorption approach.

By inspection of the behaviour of the cross-section components, it is easy to interpret the α_{eff} values found for the cross-section. We see that $\rho_{oo}d\sigma/dt$ dominates at small t and $(\rho_{11} + \rho_{1-1})d\sigma/dt$ at larger t, and this is reflected in $\alpha_{eff}(d\sigma/dt)$.

Finally we briefly consider photoprocesses as a means of isolating unnatural parity exchange. The polarized photon asymmetry observed [7),8)] in $\gamma p \rightarrow \pi^+ n$ indicates approximate equality of natural and unnatural parity exchange in the extreme forward direction, and that the natural parity contribution rapidly increases until it dominates the cross-section for $-t \gtrsim 0.05$ GeV^2. We have already remarked on the complications of using such data to determine the π trajectory. However, in principle, the electroproduction process $e^- p \rightarrow e^- \pi^+ n$ could be used, since the cross-section for longitudinally polarized photon exchange is observed [21)] to dominate away from $q^2 = 0$ (cf., the behaviour of $\rho_{oo}d\sigma/dt$ for $\pi^- p \rightarrow \rho^o n$).

Also for $\gamma p \rightarrow \omega p$ natural (P, f, A_2) and unnatural parity (π) exchange can be separated by using a polarized photon beam and observing the ω decay moments. Such data exist [22)] at 2.8, 4.7 and 9.3 GeV/c and indicate an unnatural parity contribution of 60% at the lowest energy decreasing to about 10% at the highest energy. The resulting α_{eff} values, which are shown in Fig. 3, are in good agreement with expectations. Moreover the data indicate that here the unnatural parity exchange contributes dominantly to an s channel single flip amplitude and so improved statistics could give further information on the π trajectory.

We conclude that the present evidence indicates that π exchange is associated with a Regge trajectory of conventional slope, and moreover, that the most reliable determination will come from a study of $\rho_{oo}d\sigma/dt$ extracted from the high statistics experiments which are in progress for $\pi^- p \rightarrow \pi^- \pi^+ n$.

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t'	$\sqrt{-t'}$	Constant
$np \rightarrow pn$	$pp \rightarrow n\Delta^{++}$	$pp \rightarrow \Delta^{o}\Delta^{++}$
$\pi^{-}p \rightarrow \rho^{o}n$ $K^{-}p \rightarrow \bar{K}^{*o}n$ with $\lambda_{v} = 1$	$\pi^{-}p \rightarrow \rho^{o}n$ $K^{-}p \rightarrow \bar{K}^{*o}n$ with $\lambda_{v} = 0$	$\pi^{+}p \rightarrow \rho^{o}\Delta^{++}$ $K^{+}p \rightarrow K^{*o}\Delta^{++}$ with $\lambda_{v} = 0$
$\gamma p \rightarrow \pi^{+}n$	$\gamma p \rightarrow \pi^{-}\Delta^{++}$ $\gamma p \rightarrow \omega p$	$\gamma p \rightarrow \omega\Delta^{+}$

<u>TABLE</u> Processes listed according to the behaviour of the (dominant) π exchange amplitude in the forward direction $t' \equiv t - t_{min} = 0$. The cross-sections for producing vector mesons (ρ, K^{*}) of s channel helicity $\lambda_{v} = 0$ and 1 are $\rho_{oo}d\sigma/dt$ and $2\rho_{11}d\sigma/dt$ respectively. Corresponding entries can be made for processes with ρ, K^{*} replaced by f, K^{**}, and also for processes related by line reversal, e.g., $\bar{p}p \rightarrow \bar{n}n$, $\gamma n \rightarrow \pi^{-}p$.

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FIGURE CAPTIONS

Figure 1 The components of the $\pi^- p \to \rho^0 n$ cross-section reconstructed from the amplitude analyses of the s channel moments of the $\pi^- p \to \pi^- \pi^+ n$ data [15)-18)]. At each energy the extrapolated $\rho_{00} d\sigma/dt$ data are normalized to the π exchange pole (one cross-section unit = 0.482 mb.GeV^{-2} integrating over the ρ Breit-Wigner resonance between 700 and 830 MeV).

Figure 2 The effective Regge trajectories calculated from the $\pi^- p \to \rho^0 n$ cross-sections of Fig. 1 using $\ell n(p_L^2 d\sigma/dt) = 2\,\alpha_{eff}\,\ell n\, s$ + constant. The solid (dotted) error bars indicate that the 2.77 GeV/c data are omitted (included).

Figure 3 The effective Regge trajectories calculated from the data for $\gamma p \to \omega p$ obtained using the SLAC laser beam [22)]. The lines indicate Pomeron and pion trajectories of slope 0.2 and 0.9 GeV^{-2}, respectively.

COMPOSITION OF THE $\pi^- p \to \rho^0 n$ CROSS SECTION AT DIFFERENT ENERGIES

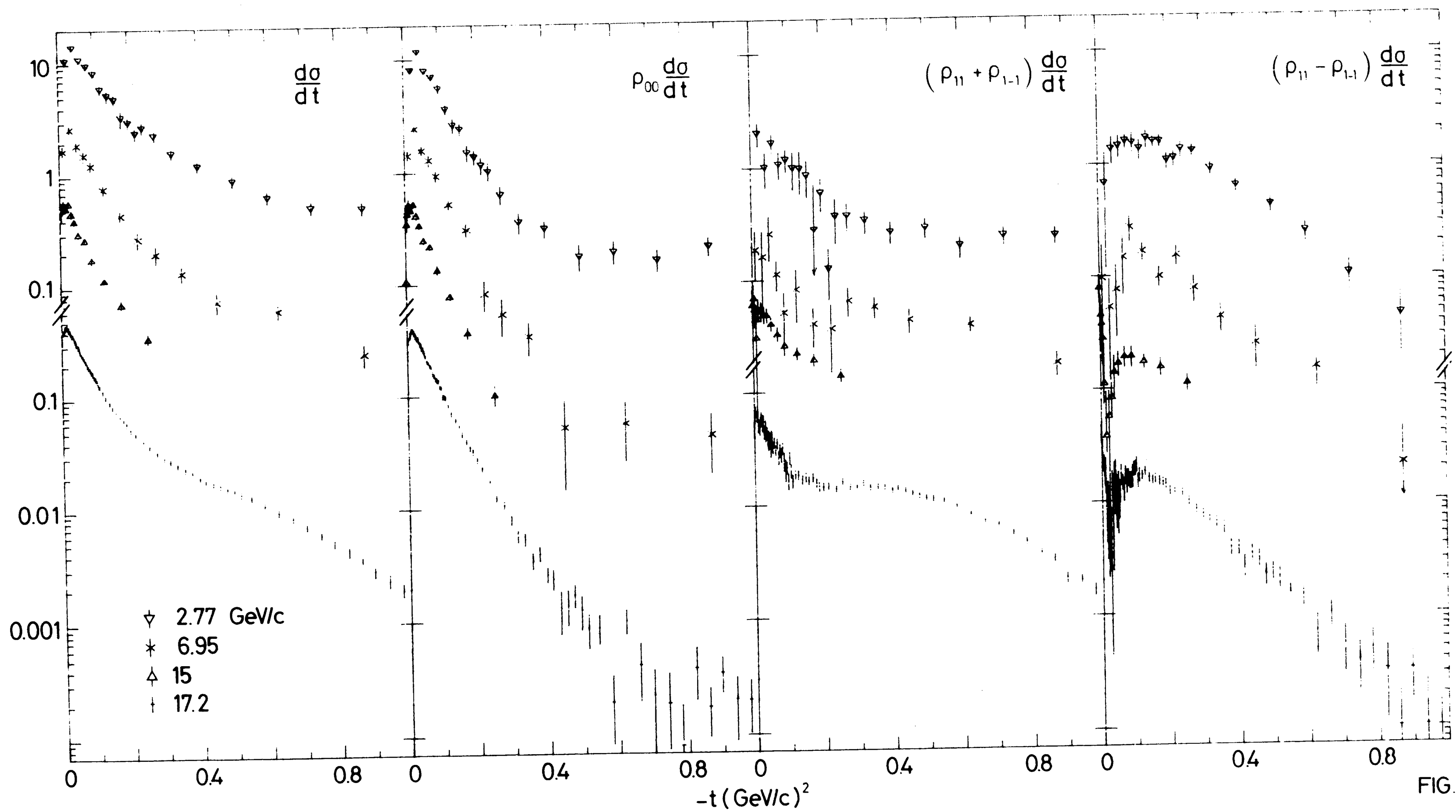
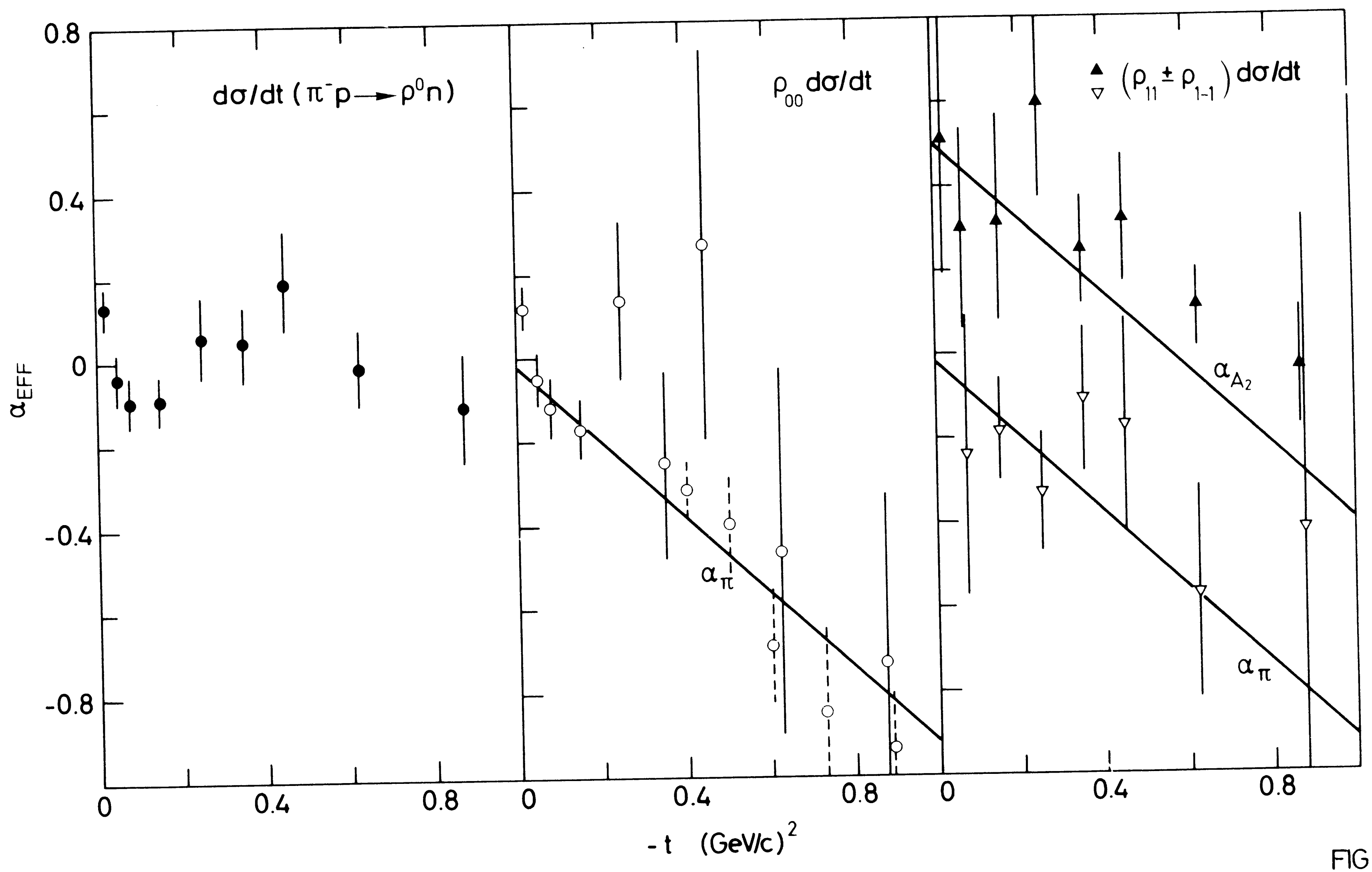
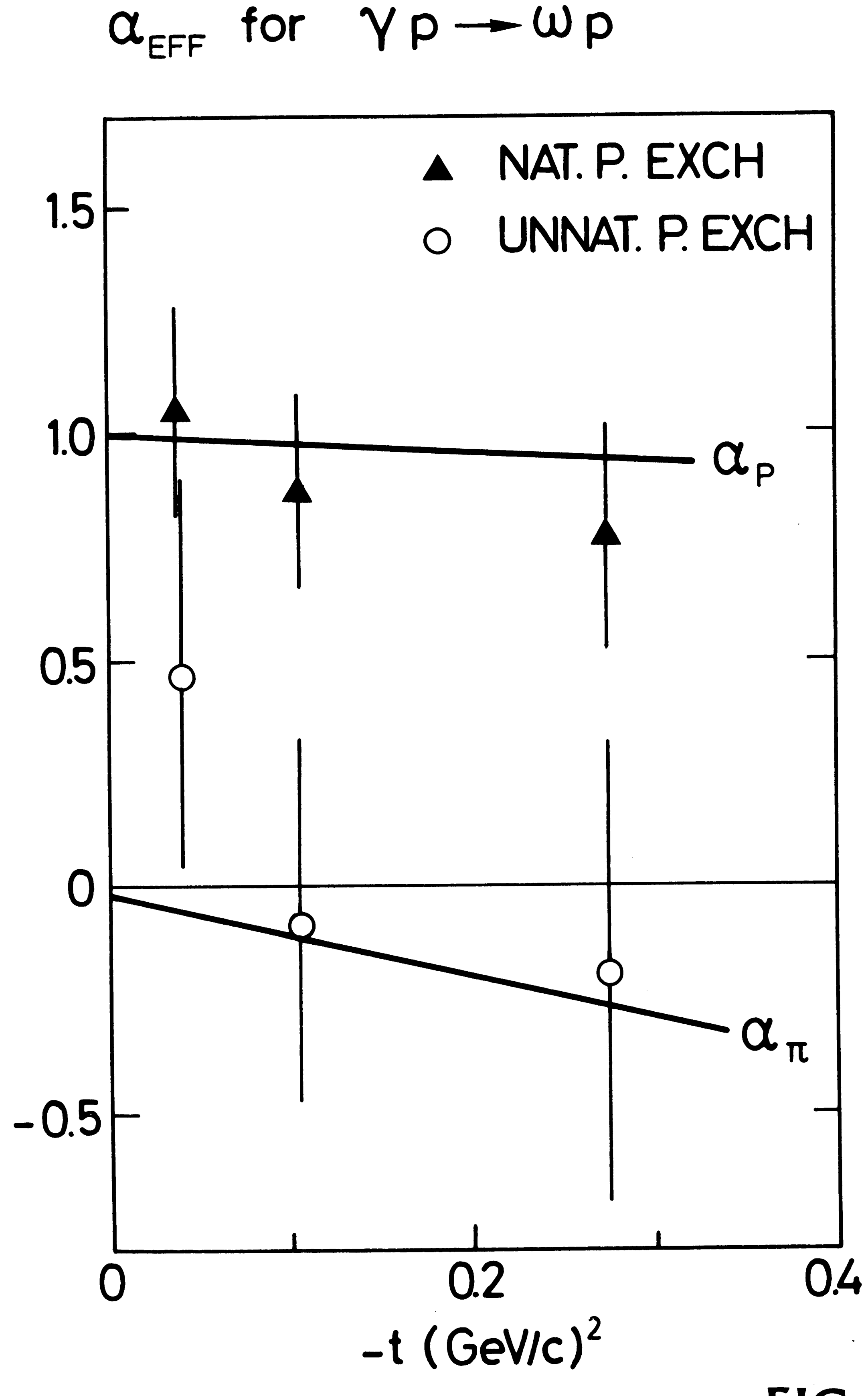


FIG.1



$d\sigma/dt\ (\pi^- p \rightarrow \rho^0 n)$
$\rho_{00}\ d\sigma/dt$
▲ ▽ $(\rho_{11} \pm \rho_{1-1})\ d\sigma/dt$
α_{EFF}
α_π
α_{A_2}
0.8
0.4
0
-0.4
-0.8
-t (GeV/c)^2

FIG. 2



α_EFF for γp → ωp
NAT. P. EXCH
UNNAT. P. EXCH
1.5
1.0
0.5
0
-0.5
α_P
α_π
0
0.2
0.4
-t (GeV/c)²

FIG.3