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EXCHANGE MECHANISMS FOR $\pi^- p \to \rho^0 n$ AND $\rho - \omega$ INTERFERENCE

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A B S T R A C T

A simple prescription, incorporating π and A_2 exchange contributions, is proposed for the 17.2 GeV/c $\pi^- p \to \rho^0 n$ production amplitudes. Further evidence for this interpretation comes from the observed $\rho - \omega$ interference effects and from the energy dependence of ρ^0 production data.

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The reaction $\pi^- p \to \rho^o n$ is well-known historically as a process in which π exchange can be studied. However, it has also been noted that simple one-pion exchange does not provide a complete description of the production mechanisms [1),2)]. Here we investigate the non π exchange contributions and present a simple phenomenological model which describes the helicity structure and t dependence of the 17.2 GeV/c ρ^o production data [3)]. Examination of the energy dependence and of ρ-ω interference effects provides support for our description.

The ρ production *) amplitude combinations P_o, P_+ and P_- can be extracted [4),5)] from $\pi^- p \to \pi^- \pi^+ n$ cross-section and density matrix data. P_o describes helicity zero dipion production and P_+ (P_-) describe helicity 1 production by natural (unnatural) parity exchange to leading order in energy. Neglect of A_1 quantum number exchange ensures [5)] that P_o and P_- are single amplitudes and their relative phase, φ, can also be determined. P_+ is an incoherent sum of amplitudes with and without helicity flip at the nucleon vertex (of which the former is expected to dominate).

The P wave amplitudes **) obtained from the high statistics 17.2 GeV/c data [3)] are shown in Fig. 1 for the t channel (Gottfried-Jackson) frame. For our present purposes, the s channel decomposition could equally well be used, but the t channel allows a somewhat clearer separation of the modifications to π exchange.

Elementary one-pion exchange only couples to P_o in the t channel frame. The non-zero values of $P_\pm$, which moreover do not vanish in the forward direction, thus imply an additional contribution which is not (evasive) pole exchange. Such a cut effect is expected [7),2)] to be most important in the s channel net helicity non-flip amplitude H^1_{+-}. The cut, C, then contributes equally to P_+ and P_- in the s channel, and on crossing to the t channel contributes to P_+, P_-, P_o in the ratio $1 : \cos\chi : \sin\chi$, where χ is the s-t crossing angle ($\sin\chi > 0$).

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*) That is the P wave $\pi^-\pi^+$ production amplitudes in the ρ mass region.

**) We consider only the solution with P_o and P_- essentially phase coherent which was shown [6)] to be the physical solution for $-t < 0.2$ GeV^2.

The inclusion of C allows an adequate description of P_-, but the observed ratio of $|P_+|$ to $|P_-|$ as a function of t necessitates the introduction of a natural parity exchange contribution (A_2 exchange) which interferes destructively with C in P_+. This leads us to the parametrization

$$\begin{aligned} P_0 &= \pi + C \sin\chi \\ P_- &= C \cos\chi \\ P_+ &= A_2 + C \end{aligned} \qquad (1)$$

where the t dependence is parametrized as

$$\begin{aligned} \pi &= g_\pi \frac{\sqrt{-t}}{\mu^2 - t}\, e^{b_\pi t}\, e^{-i\pi\alpha_\pi/2} \\ C &= g_c\, e^{b_c t}\, e^{-i\pi\alpha_c/2} \\ A_2 &= -t\, g_A\, e^{b_A t}\, e^{-i\pi\alpha_A/2} \end{aligned} \qquad (2)$$

with $\alpha_i = \alpha_0^i + \alpha_i' t$ determining the phase of the i^{th} contribution.

The phase difference between π and C is controlled by the relative phase, φ, of P_0 and P_-, which is consistent with $\varphi = 180^\circ$ for all -t less than 0.5 GeV^2. P_0 and P_- determine the π and C contributions, and then, given the phase difference *) $\alpha_A - \alpha_c$, $|P_+|$ determines the A_2 exchange contribution. We take $\alpha_c = \alpha_\pi$ and, at $t = 0$, $\alpha_A - \alpha_c = 0.5$. Allowing a linear dependence on t of the A_2-C phase difference, we obtain the overall fit **) in the t region -0.005 to -0.5 GeV^2 shown in Fig. 1.

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*) The data impose bounds on this phase difference. At $-t \sim 0.05$ $|\alpha_A - \alpha_c| \lesssim 0.6$, decreasing to $|\alpha_A - \alpha_c| \lesssim 0.2$ at $-t \sim 0.5$ GeV^2.

**) As $|P_+|^2$ has a quadratic dependence on A_2, a second solution exists. This is found to be unphysical, having an A_2 contribution whose phase, relative to C, varies extremely rapidly with t, and whose magnitude shows an anomalously rapid t dependence.

The simple parametrization of Eqs. (1) and (2) is an excellent description of the 17.2 GeV/c data out to $-t = 0.5$ GeV^2. The description of P_+ is also reasonable in the region beyond -0.5 GeV^2, where this amplitude dominates. Two possible contributions which have been neglected could easily be incorporated without changing the essential features. <u>First</u>, from processes such as $KN \to KN$, $\pi N \to \eta N$, and from the non-zero polarization in $\gamma p \to \pi^+ n$, there is some evidence for a small A_2 helicity non-flip coupling at the nucleon vertex. Such a coupling will be important for polarization predictions in $\pi N \to \rho N$, but enters the unpolarized observables only as a small correction to the t dependence of A_2 and a small reduction of coherence between C and A_2 in P_+. <u>Secondly,</u> a Reggeized π exchange can have a $\lambda_t = \pm 1$ coupling (vanishing at $t = \mu^2$ of course) to P_-. This coupling is present in dual Born models [8] and is such as to fill in the crossing matrix zero ($\cos \chi = 0$ at $-t \sim 0.6$ GeV^2) in P_- in the t channel frame (or equivalently in P_0 in the s channel frame). Figure 1 indeed indicates the need for such a contribution to P_- at large t.

Having established a parametrization for the phases and t dependence of the π, C and A_2 contributions for $-t < 0.5$ GeV^2, we look at the energy dependence that would arise from the phase-energy relationship. Figure 2 shows the effective trajectories, $\alpha_{eff}(t)$, for P_0, P_+ and P_- (in the s channel) obtained *) by analyzing $\pi^- p \to \pi^- \pi^+ n$ data, Refs. 3),10)-13), in the energy range 4 to 17 GeV/c. In the model of Eq. (1), the s channel P_0 is pure π exchange and $\alpha_\pi = 0.5(t - \mu^2)$ is a reasonable compromise trajectory. Qualitatively, the structure of α_{eff} for P_+ can be easily understood with our description. C is the dominant contribution at small t ($\alpha_c \approx \alpha_\pi$) and A_2 dominates at $t \sim -0.5$, while there is a cancellation at intermediate t values ($t \sim -0.25$) which leads to an α_{eff} above the A_2 trajectory. However, although the t behaviour is correct, the phase-energy prediction is approximately 0.2 lower than α_{eff} obtained from the data.

At 17.2 GeV/c, ρ-ω interference effects have been shown [14] to be largest in P_+ in the interval $0.1 < -t < 0.4$ GeV^2 and we shall concentrate on this amplitude. Figure 3 shows a breakdown of P_+ into its C and A_2 components, as determined above, for three relevant t intervals.

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*) The method used is described in Ref. 9), except that here we use the s channel observable $(\rho_{00} + \rho_{ss}/3) d\sigma/dt$ in the place of $|P_0|^2$. This is an update of that calculation to include recent data.

The phase of P_+ relative to P_- can thus be obtained. For $\pi^- p \to \omega n$, ρ quantum number exchange contributes to P_+. Since B quantum number exchange in $\pi N \to \omega N$ is smaller than π exchange in $\pi N \to \rho N$, the B cut should be small compared to ρ exchange *). Unfortunately, there are no data on $|P_+|$ for $\pi N \to \omega N$ at or near 17 GeV/c. Thus, the modulus, as well as the phase, must be estimated before a ρ-ω interference pattern can be predicted. The simplest model is to take exchange degenerate ρ and A_2 contributions: $\rho = iA_2 \tan \frac{1}{2}\pi \alpha_A(t)$. This then ensures, via SU_3, a real $KN \to K^*N$ amplitude in agreement with duality for an exotic direct channel process. Constructing P_+ for ω production in this way then yields the ρ - ω modulating factors shown in Fig. 3. Conversely, the relative moduli and phases of the ρ and ω production amplitudes P_+ derived from fitting the experimental data at 17.2 GeV/c [14], yield the P_+ amplitudes for ω production that are shown by crosses in Fig. 3. These estimates are in reasonable accord with the ρ-A_2 exchange degeneracy prescription. In particular the change of phase of P_+ with t, required by the observed ρ-ω effects, is well reproduced by the admixture of C and A_2 contributions to P_+ for $\pi^- p \to \rho^0 n$.

Further confirmation comes from the observed ratio [15] of $|P_+|$ in $K^- p \to \bar{K}^{*0} n$ and $K^+ n \to K^{*0} p$. P_+ for $K^+ n \to K^{*0} p$ ($C + A_2 + \rho$ exchange) is suppressed since the resultant of $A_2 + \rho$, which is predominantly real, cancels with the real C contribution. On the other hand, for $K^- p \to \bar{K}^{*0} n$ ($C + A_2 - \rho$ exchange), the resultant of $A_2 - \rho$ is approximately imaginary and adds incoherently to C.

The exchange degeneracy of ρ and A_2 leads to a zero of the ρ contribution at $\alpha_\rho = 0$ which is not observed in P_+ obtained from the available $\pi^+ n \to \omega p$ data at 6-7 GeV/c [16),17)]. Thus, some modification at larger t or at lower energy to P_+ in ω production will be necessary. Insight into this effect should come from a study of the ρ - ω effects in the 4-6 GeV/c Argonne [13] $\pi^- p \to \pi^- \pi^+ n$ (and $\pi^+ n \to \pi^- \pi^+ p$) data. In Fig. 3, we predict the ρ - ω modulating factor for P_+ at 4 GeV/c, using the 17 GeV/c amplitude components, ρ-A_2 exchange degeneracy and the phase-energy relation. The observed effect in P_+, for $0.08 < -t < 0.2$, in the preliminary data [13] at 4 GeV/c indicates a somewhat larger relative ρ-ω production phase $(240 \pm 20^\circ)$ than that predicted by the model $(\approx 210^\circ)$.

*) This is consistent with the small ρ - ω interference effects observed in P_- [cf., Ref. 14)].

In summary, we have presented a simple picture of the dominant contributions to natural parity vector meson production, in terms of which the main features of the t and s dependence of $\pi^- p \to \rho^0 n$ data and the $\rho - \omega$ interference patterns are readily understood.

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FIGURE CAPTIONS

Figure 1 : The ρ production amplitudes in the t channel frame at 17.2 GeV/c. The points are the results of an amplitude analysis of the CERN-Munich $\pi^- p \to \pi^- \pi^+ n$ data for $700 < M_{\pi\pi} < 850$ MeV. The curves are the results of the fit to the amplitudes in the interval $0.005 < -t < 0.5$ GeV^2 that is described in the text. The values of the parameters are $g_c/g_\pi = -1.21$, corresponding to a cut strength of 0.93 of that in the William's model [7], $g_A/g_\pi = 8.2$, $b_\pi = 0.6$ GeV^{-2}, $b_c = 0.8$ GeV^{-2}, $b_A = 2.5$ GeV^{-2} and $\alpha'_A - \alpha'_c = 0.43$ GeV^{-2} ($\chi^2 = 0.7$ per degree of freedom).

Figure 2 : The effective trajectories, calculated using s channel amplitude components obtained by analysing $\pi^- p \to \pi^- \pi^+ n$ data in the energy range 4-17 GeV/c.

Figure 3 : The (complex) C and A_2 contributions to P_+ for ρ production at 17.2 GeV/c are shown for three t bins, with C chosen to be real and negative. The dashed line indicates the ρ exchange contribution to $\pi^- p \to \omega n$ obtained assuming ρ-A_2 exchange degeneracy. The P_+ amplitudes for $\pi^- p \to \rho^o n$ $(C + A_2)$ and $\pi^- p \to \omega n$ (ρ) then yield the ρ - ω modulating factors shown at 17 GeV/c which can then be compared with the observed effects in Ref. 14) [a 7 MeV resolution is folded in as described in Ref. 14)]. Conversely the crosses are the predictions for P_+^ω obtained from the values of $|P_+^\omega / P_+^\rho|$ and ϕ tabulated in Ref. 14). The 4 GeV/c predictions for the modulating factor (with a 3 MeV mass resolution folded in) come from scaling C relative to A_2 and ρ by an energy dependence $\alpha_A - \alpha_C = 0.5 + 0.4t$. The ρ-ω modulating factors are calculated using $\Gamma(\omega \to \pi^+ \pi^-)/\Gamma(\omega \to \text{all}) = 0.0175$ and $\Gamma_\omega = 10$ MeV.

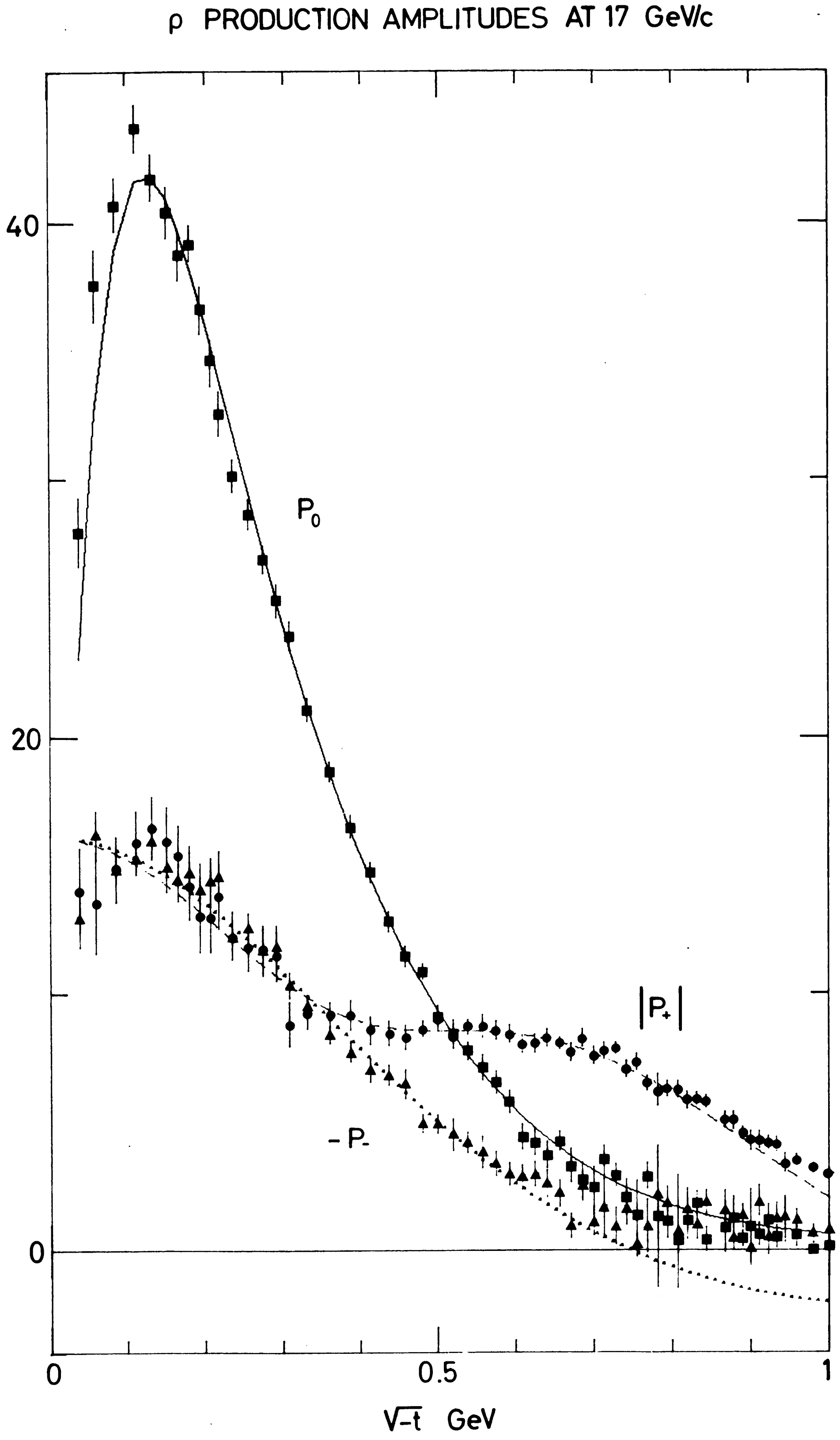

Fig 1

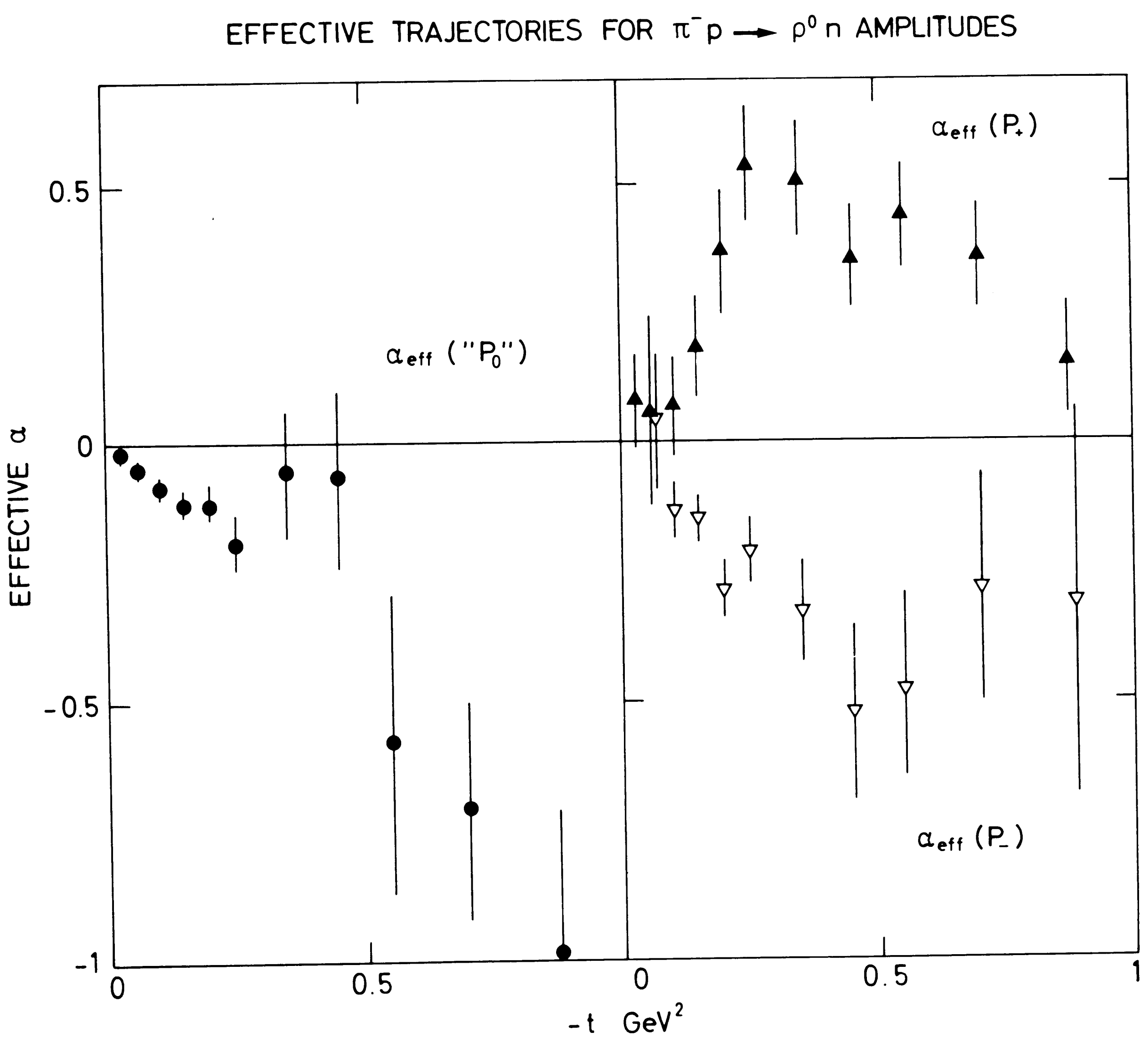
EFFECTIVE TRAJECTORIES FOR $\pi^- p \longrightarrow \rho^0 n$ AMPLITUDES
EFFECTIVE α
0.5
0
-0.5
-1
α_{eff} ("P_0")
α_{eff} (P_+)
α_{eff} (P_-)
0
0.5
0
0.5
1
-t GeV^2

Fig 2

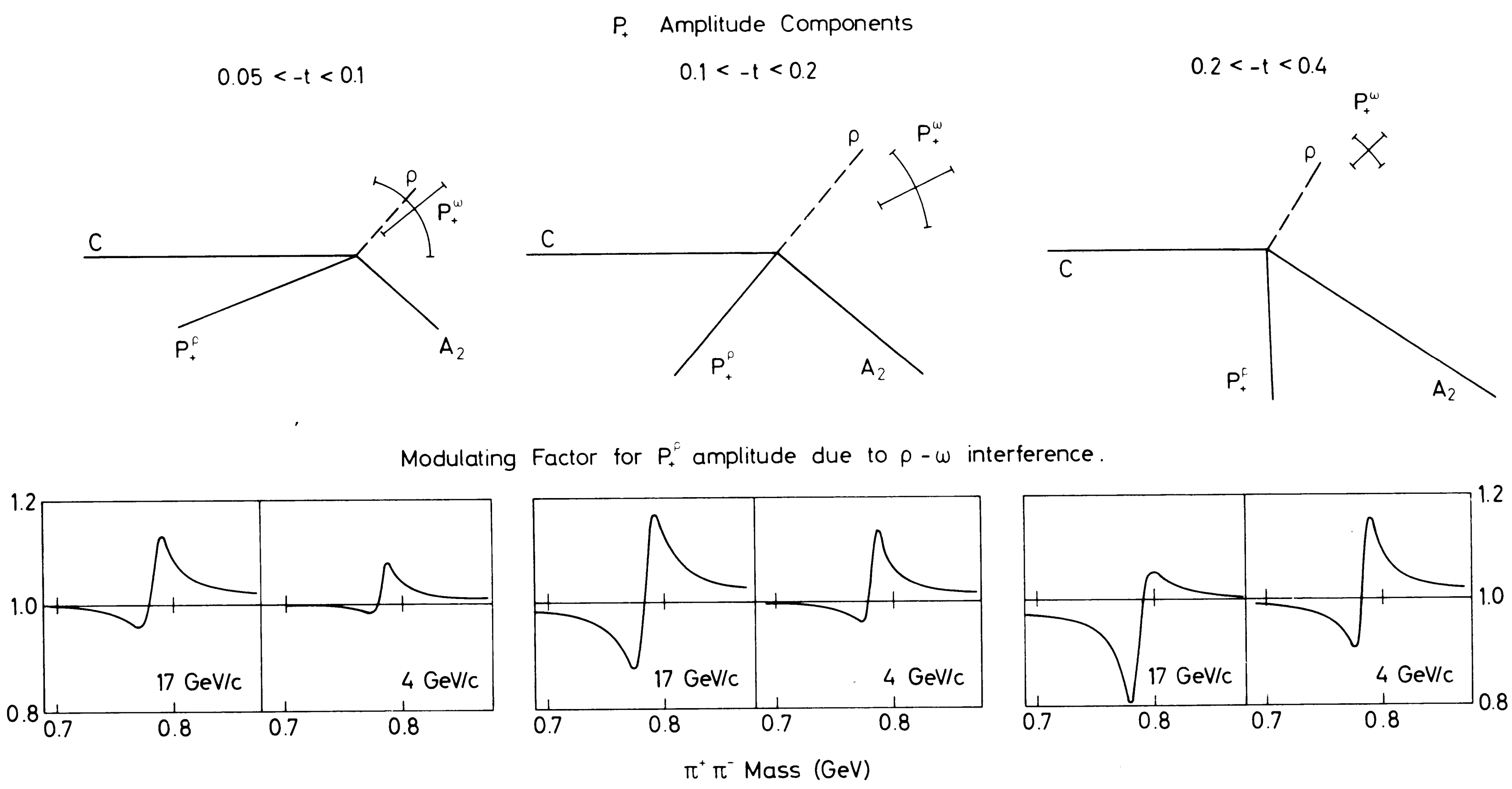
P+ Amplitude Components
0.05 < -t < 0.1
0.1 < -t < 0.2
0.2 < -t < 0.4
C
ρ
P+ω
P+ρ
A2
Modulating Factor for P+ρ amplitude due to ρ - ω interference.
1.2
1.0
0.8
0.7
0.8
17 GeV/c
4 GeV/c
π+ π- Mass (GeV)

Fig 3