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Authors
Grether, D.F.
Gidal, G.

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D. F. Grether and G. Gidal

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

THE REACTION $\pi^+ p \to \eta^0 \Delta^{++}$: A TEST OF A_2 REGGE POLE EXCHANGE*

D. F. Grether and G. Gidal

Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

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ABSTRACT

New results are presented on the reaction $\pi^+ p \to \eta^0 \Delta^{++}$ between 1.2 and 2.67 GeV/c. The data above 2 GeV/c, when combined with some existing data, give evidence for a dip in the t distribution near t = - 1.5 GeV/c. This dip, and other features of the data, are adequately described by an A_2 Regge pole model. The effective A_2 trajectory is calculated and found to disagree with that obtained from the reaction $\pi^- p \to \eta^0 n$.

We have performed a measurement of the total and differential cross sections and the Δ^{++} decay angular distributions for the reaction

$$\pi^+ p \to \eta^0 \Delta^{++} \tag{1}$$

at incident momenta between 1.3 and 3.0 GeV/c. At the higher energies this reaction is expected to proceed by the exchange of only the A_2 trajectory in the t channel, and hence provides a check of the properties of A_2 exchange deduced from the reaction

$$\pi^- p \to \eta^0 n. \tag{2}$$

In addition, these new data, when combined with some existing data, allow us to explore a higher |t| region than previously possible in either reaction (1) or (2). We observe a dip near $t = -1.5\ \mathrm{GeV}/c^2$ that, in terms of standard nonsense wrong-signature zero (NWSZ) Regge models, would correspond to the A_2 trajectory passing through $-1\ \mathrm{GeV}/c^2$.

The new measurements are based on several Bevatron exposures of the Lawrence Radiation Laboratory 25-inch hydrogen bubble chamber to π^+ of momenta 1.28, 1.39, 1.55, 1.62, 1.75, 1.85, 2.3, and 2.67 GeV/c. We include in the analysis published data between 3 and 4 GeV/c[1] (henceforth referred to as 3.5 GeV/c) and data at 3.7 GeV/c.[2] In total, some 95 000 four-prong events were measured on the Flying-Spot Digitizer (FSD) and on the on-line Francken-steins (COBWEB) and constrained to the (1c) hypothesis

$$\pi^+ p \to \pi^+ p\, \pi^+ \pi^- \pi^0 \ . \qquad (3)$$

Extensive use was made of the automatic ionization measurements available from the FSD in order to discriminate between conflicting hypotheses. In Fig. 1 we show the $\pi^+\pi^-\pi^0$ and the $\pi^+ p$ mass distributions from hypothesis (3) at 2.67 GeV/c to illustrate the relatively small potential backgrounds.

In Fig. 2 we show the momentum dependence of the cross section for our data and the 3.5-GeV/c data together with the measurements reported at 3.7,[2] 5,[3] 8,[4] and 13 GeV/c.[5] The total cross sections for our data and the 3.5-GeV/c data were estimated on the basis of background curves hand drawn under the η^0 and Δ^{++} peaks. The errors on the cross sections reflect both the statistical uncertainty and the accuracy with which we believe we can estimate the back-grounds.[6] The cross section has been corrected for the unseen η^0 decay modes. We note that the data exhibit the characteristic peak above threshold and then a power law behavior above approximately 2 GeV/c. A fit of the data shown above 2 GeV/c gives a $p^{-1.5}$ behavior. We limit further remarks in this paper to incident momenta above 2 GeV/c.

Selection of $\eta^0\Delta^{++}$ events for further consideration was as follows. The events from the 25-inch bubble chamber were [in addition to the 1c fit to reaction (3)] fitted to the 2c hypothesis

$$\pi^+ p \rightarrow \pi^+ p\, \eta^0 \qquad \eta^0 \rightarrow \pi^+\pi^-\pi^0 . \tag{4}$$

An event was selected as an η event if

$$\chi^2(2c) - \chi^2(1c) \leq 3.$$

For "double η" events the combination with the smaller χ^2 (2c) was chosen. The events at 3.5 and 3.7 GeV/c were not constrained to the 2c hypothesis, and the selection of η events was $0.54 \leq M(\pi^+\pi^-\pi^0) \leq 0.56$ GeV. The events were further selected as Δ^{++} events if $1.15 \leq M(p\pi^+) \leq 1.30$ GeV. The shaded area in Fig. 1b shows the events selected by the 2c fit at 2.67 GeV/c.

In order to examine the production and decay distributions for reaction (1) with the highest statistics available, we combine the events at 2.3, 2.67, 3.5, and 3.7 GeV/c. Examination of these distributions at the individual momenta shows that there is little variation with momentum. In Fig. 3a we show the t distribution together with the prediction of the NWSZ Regge pole model of Krammer and Maor[7] for 3 GeV/c (the mean momentum of the data) normalized to the number of events in the forward peak. The model incorporates both the ρ and A_2 trajectories in a simultaneous fit[8] to the reactions $\pi^+p \rightarrow \pi^0\ \Delta^{++}$, $\pi^+p \rightarrow \eta^0\ \Delta^{++}$, and $K^+p \rightarrow K^0\ \Delta^{++}$. The prominent features of the t distribution are

(i) a dip at low values of $|t|$; this lack of events in the forward direction appears at all our energies, and is clearly evident in the t' distribution (insert in Fig. 3a) which removes the kinematic effect of the finite width of the Δ^{++}. In terms of the model of Krammer and Maor, which fits the dip quite well, the dip is indicative of the predominantly spin-flip character of the reaction amplitude;

(ii) the absence of any dip structure near $t = -0.5\ GeV/c^2$; this had been observed in previous data[1,4] and in reaction (2).[9] Assuming a normal A_2 trajectory, this absence of a dip is consistent only with the Gell-Mann Ghost-Killing mechanism in NWSZ models;[7]

(iii) a dip in the vicinity of $t = -1.5\ GeV/c^2$ that has not been previously observed in either reaction (1) or (2). Krammer and Maor's model predicts such a dip (see Fig. 3a) corresponding to a zero in the signature factor when the A_2 trajectory crosses -1. The interpretation of the dip in the experimental distribution as resulting from A_2 exchange depends crucially upon whether the secondary maximum (roughly $1.7 \leq |t| \leq 3.5\ GeV/c^2$) (a) consists of real $\eta\Delta^{++}$ events rather than background, and (b) itself results from A_2 exchange rather than some other process. We comment on these two questions below.

To analyze the effect of non-$\eta\Delta^{++}$ events we have calculated a correction factor based on hand-drawn background curves under the η and Δ^{++} peaks, comparison with the region on either side of the η, and an estimate of the η and Δ^{++} tails. The corrected t distribution is shown in Fig. 3b and is thus our estimate of the distribution of true $\eta\Delta^{++}$ events. The secondary maximum is somewhat reduced but still present, and the dip is, if anything, more prominent.

With regard to the exchange mechanism, we have studied, albeit with poor statistics, the backward differential cross section at each energy to see if baryon exchange could account for the secondary maximum. These distributions are flat between $u = -0.2\ GeV/c^2$ and $u = 0.5\ GeV/c$, in contrast with the backward peaks characteristic of baryon exchange.[10]

The Δ-decay density matrix elements in the t-channel helicity (Jackson) frame are shown in Figs. 3c-e together with the predictions by Krammer and Maor. Also shown are the M1 dominance-model[11] predictions of

$$\rho_{33} = 0.373, \ \mathrm{Re}\rho_{3-1} = 0.216, \text{ and } \mathrm{Re}\rho_{31} = 0.$$

Both predictions agree with the general trend of the data. We observe in particular that the density matrix elements in the secondary maximum have about the same value as the average behavior at small $|t|$, suggesting that this high $|t|$ region has the same production mechanism (i. e., A_2 exchange) as the low $|t|$ region.

In Fig. 3d we plot a particular combination of the density matrix elements,

$$RT = \rho_{33}\rho_{11} - (\mathrm{Re}\rho_{31})^2 - (\mathrm{Re}\rho_{3-1})^2 , \tag{5}$$

that tests for the exchange of a single trajectory.[12] This test requires that Eq. (5) be zero if the contributing amplitudes are relatively real. A violation of this condition implies the exchange of more than one trajectory, but satisfaction gives no information. The data are consistent with zero for all values of t.

We conclude that our data are consistent with a NWSZ model of A_2 exchange, including the observation of the dip expected when the A_2 trajectory crosses -1. Recently "strong-cut" Regge models[13] have been proposed as alternatives to NWSZ models. To date, calculations of strong-cut models are not available for reaction (1) and in general have not been applied to as low values of lab momentum or as high values of $|t|$ as discussed here. However, Bander and Gotsman[14] have argued that the apparent M1 dominance seen in the density matrix elements and the absence of a dip at t = - 0.5 GeV/c (observed in previous data as well as in ours) rules out a large class of strong-cut models. Thus it is of interest to see if future calculations of strong-cut models can explain these features of reaction (1) and, in addition, the dip near t = - 1.5 GeV/c.

Finally, we calculate the effective A_2 trajectory. Following Mathews,[15] a linear fit is made to

$$\frac{d\sigma}{dt} = \frac{G(t)}{P_{inc}^2} \left(\frac{s-u}{2}\right)^{2\alpha(t)} .$$

As a necessary condition for the use of this equation, all the contributing helicity amplitudes must have the same $(s-u)^\alpha$ dependence; hence, the ρ_{ij} for reaction (1) at a given t should be independent of s. Such an independence is indeed observed, within statistics, in the data above 2 GeV/c.

In Fig. 4 we then show the $\alpha_{eff}(t)$ derived from a least-squares fit of Eq. (4), using our data and available data above 3 GeV/c.[1-4] A linear fit to these points gives

$$\alpha(t) = (0.87 \pm 0.03) + (1.75 \pm 0.13)\, t.$$

For comparison we also show in Fig. 4 $\alpha_{eff}(t) = (0.34 \pm 0.03) + (0.35 \pm 0.08)t$ derived in a similar linear fit[15] to the reaction $\pi^- p \to \eta^0 n$. The fit of Krammer and Maor used $\alpha = 0.4 + 0.9\,t$ for the A_2 trajectory. Exchange degeneracy requires a universal (ρ, A_2) trajectory, and for comparison we show the commonly accepted ρ trajectory, $\alpha = 0.57 + 0.91\,t$. This trajectory is in only fair agreement with the data.

Clearly the reactions $\pi^- p \to \eta^0 n$ and $\pi^+ p \to \eta^0 \Delta^{++}$ give different effective A_2 trajectories. This disagreement may indicate the presence of additional exchanged trajectories. A similar comparison[16] between the reactions $\pi^- p \to \pi^0 n$ and $\pi^+ p \to \pi^0 \Delta^{++}$ gave nearly identical effective ρ trajectories.

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8. In general, data of laboratory momentum > 3 GeV/c and $|t| < 1.0$ GeV/c^2 were used in the fit. For $\eta^0\Delta^{++}$ only $d\sigma/dt$ at 3.5 GeV/c and 8 GeV/c were used, hence we treat the model as yielding predictions for lab momentum < 3 GeV/c, regions of $|t| > 1.0$ GeV/c^2, and especially for the density matrix elements.

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FIGURE LEGENDS

Fig. 1. Invariant mass distributions for the reaction $\pi^+ p \rightarrow \pi^+ p\, \pi^+ \pi^- \pi^0$ at 2.67 GeV/c.

(a) $p\pi^+$ combinations recoiling off an η^0.

(b) $\pi^+\pi^-\pi^0$ combinations recoiling off a Δ^{++}. The shaded area indicates the events selected as η^0's by the 2c fit.

Fig. 2. Total cross section vs laboratory momentum for the reaction $\pi^+ p \rightarrow \eta^0 \Delta^{++}$. The solid curve is $P_{lab}^{-1.5}$, from a fit to the data above 2 GeV/c. The cross-section values for $P_{lab} < 1.7$ GeV/c are upper limits.

Fig. 3. Combined data for the reaction $\pi^+ p \rightarrow \eta^0 \Delta^{++}$ at momenta 2.3, 2.67, 3.5, and 3.7 GeV/c.

(a) t distribution with no background correction. The solid curve is the prediction according to the model of Krammer and Maor (see Ref. 7) calculated at 3 GeV/c and normalized to the number of events in the forward peak. The insert is the t' distribution for small |t'|

(b) t distribution with background correction.

(c-e) Density matrix elements in the t-channel helicity (Jackson) frame as a function of t. The solid curves are the predictions by Krammer and Maor, the dashed curves the predictions by the M1 dominance model.

(d) The combination of density matrix elements,

$$RT = \rho_{33}\rho_{11} - (\mathrm{Re}\rho_{31})^2 - (\mathrm{Re}\rho_{3-1})^2,$$ as a function of t.

Fig. 4. α_{eff}, the effective trajectory, for the reaction $\pi^+ p \rightarrow \eta^0 \Delta^{++}$ as a function of t. The solid curve is a fit to the data points of $(0.87 \pm 0.03) + (1.75 \pm 0.13)t$. The dashed curve is the effective trajectory for $\pi^- p \rightarrow \eta^0 n$ of $(0.34 \pm 0.03) + (0.35 \pm 0.08)t$ (see Ref. 15). The dot-dashed curve is a nominal ρ trajectory of $0.57 + 0.91t$.

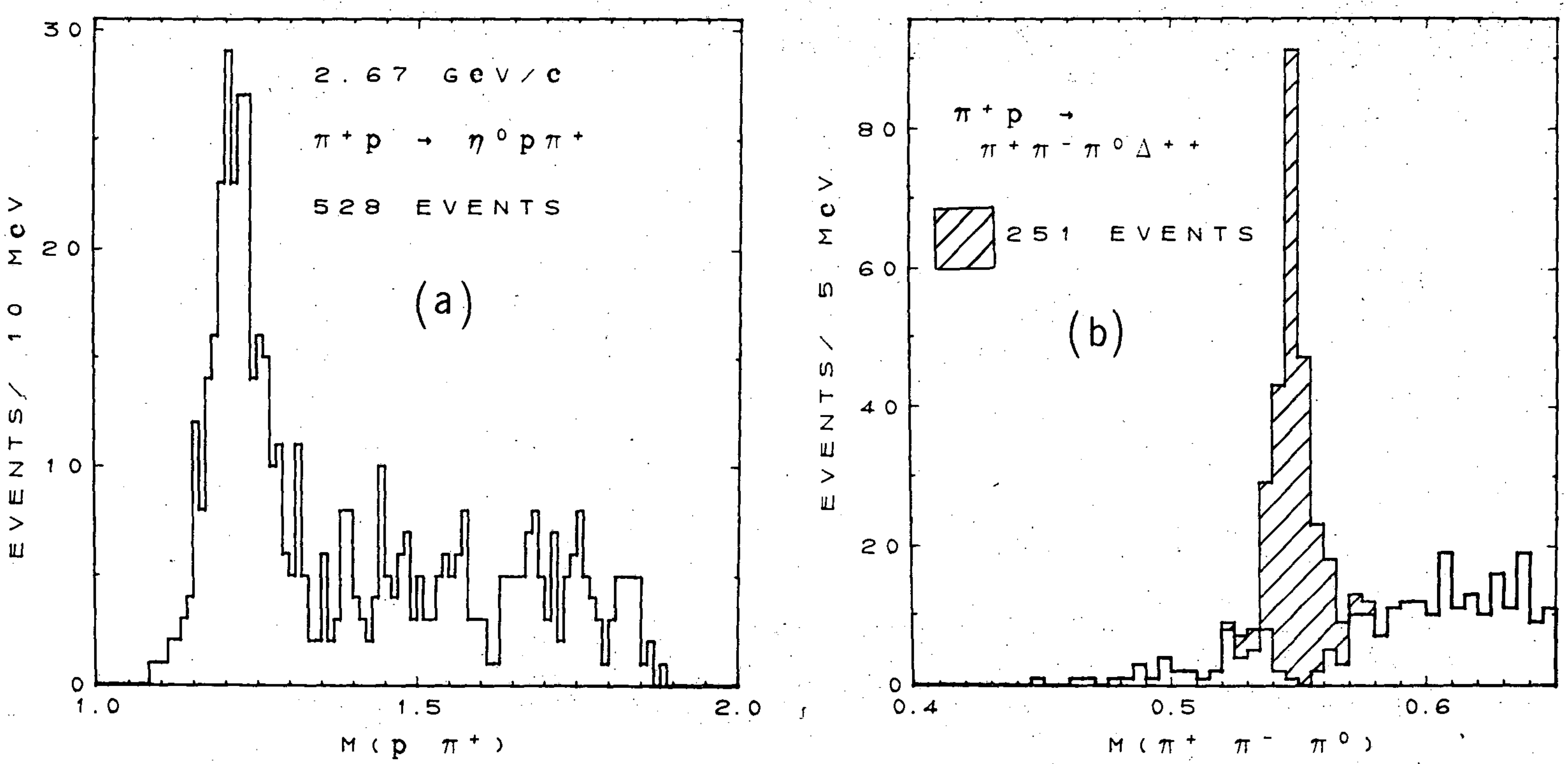

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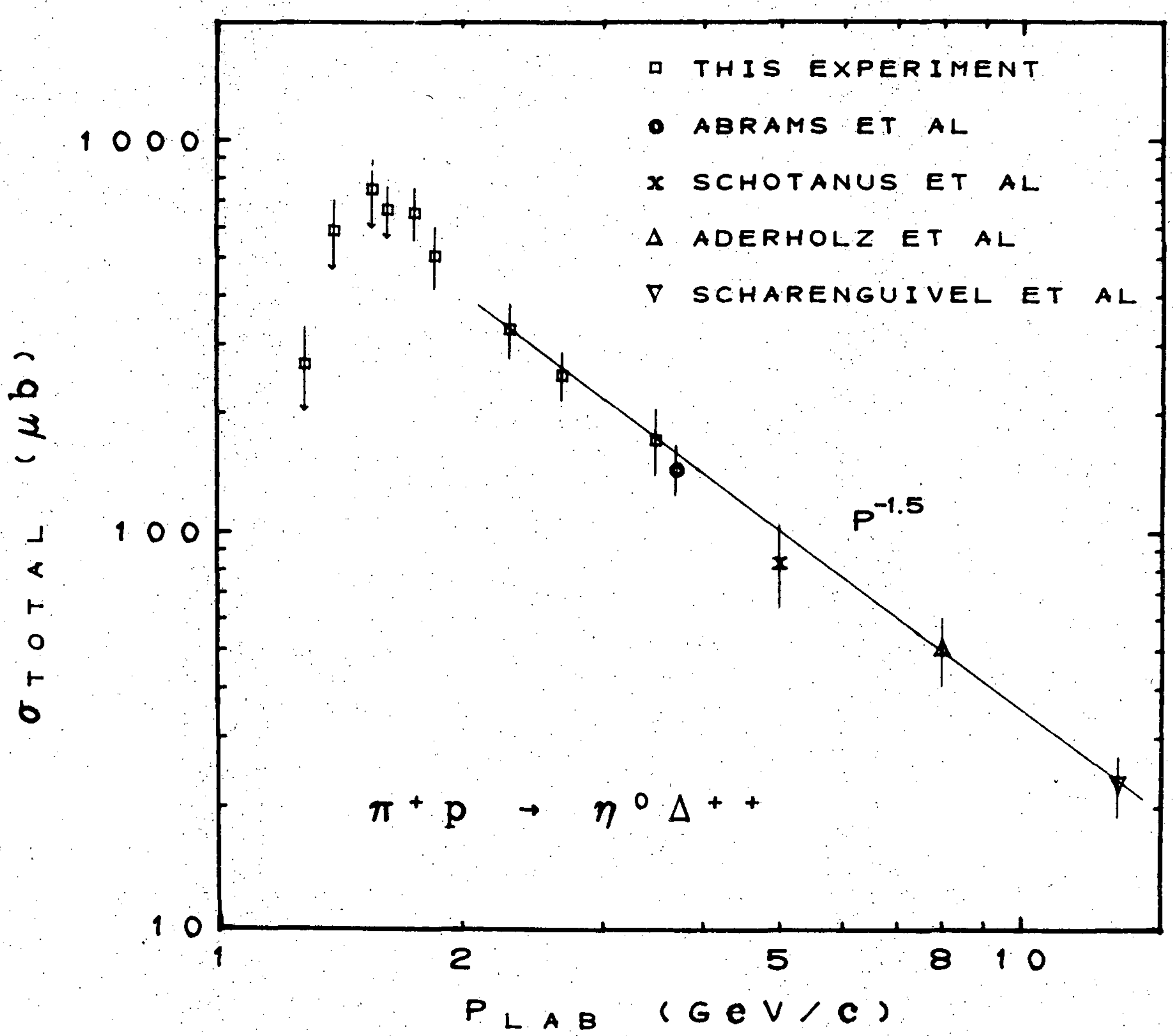
Fig. 1



XBL 7012-7412

Fig. 2

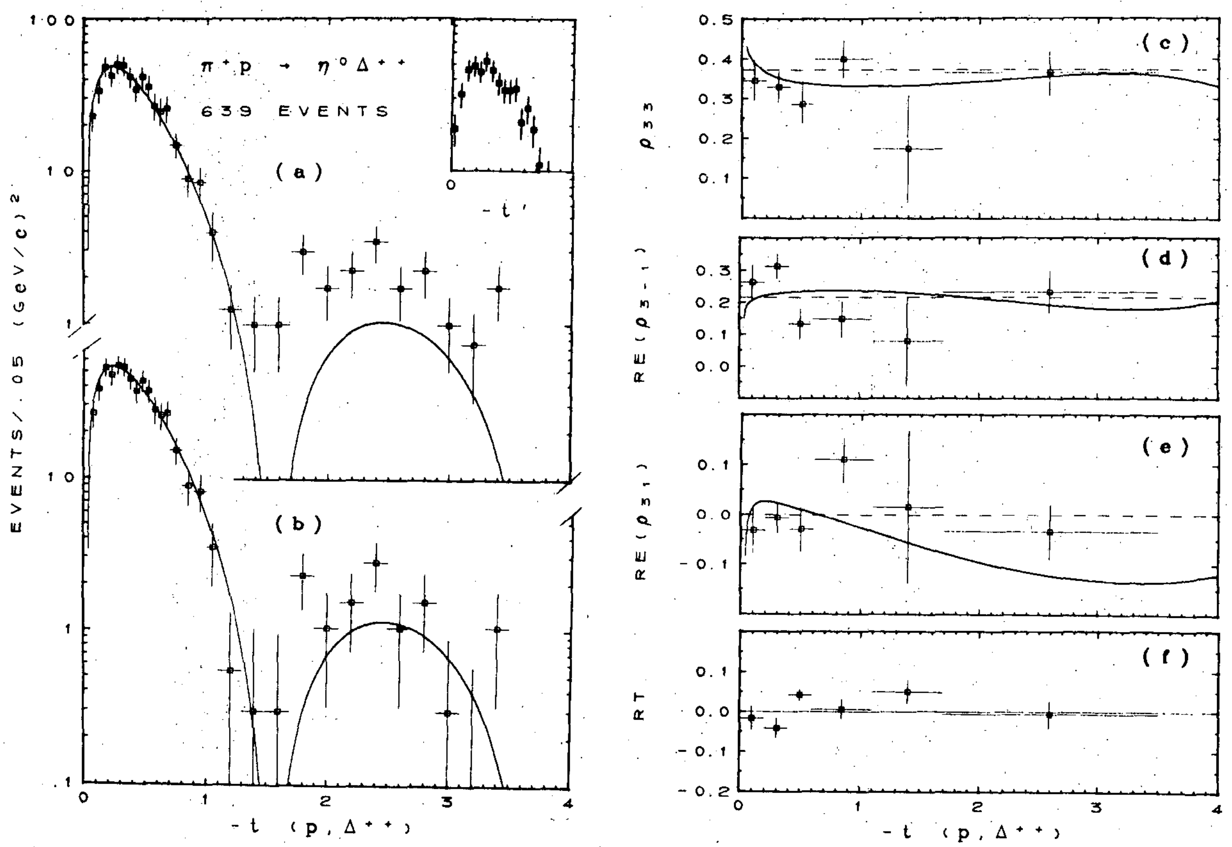


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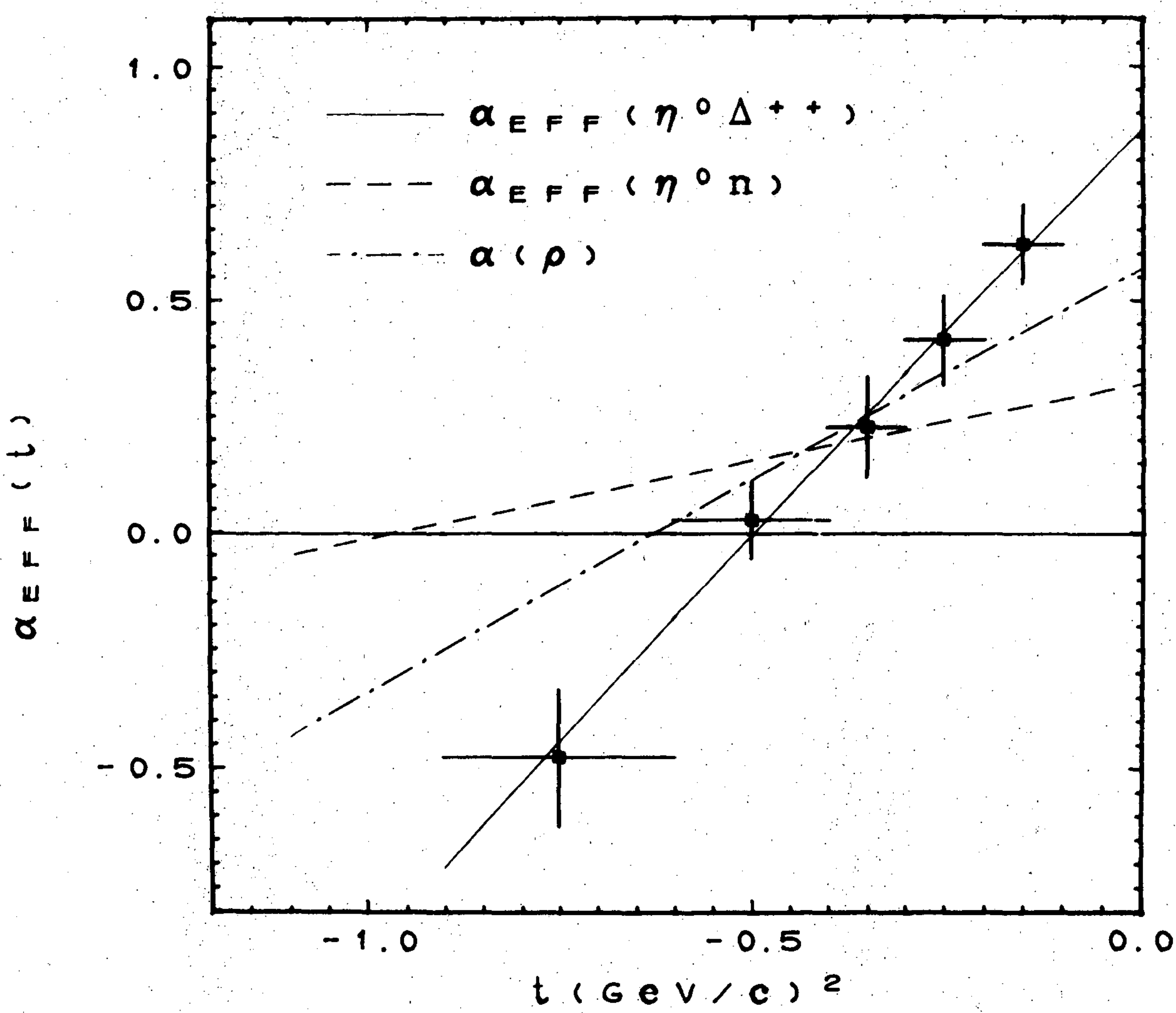
Fig. 3



XBL 7012-7413

Fig. 4