Title

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THE REACTION $\pi^+ p \to \eta^0 \Delta^{++}$ BETWEEN 1.3 AND 4.0 GeV/c; A MEASUREMENT OF THE EFFECTIVE A_2 TRAJECTORY

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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THE REACTION $\pi^+ p \rightarrow \eta^o \Delta^{++}$ BETWEEN 1.3 AND 4.0 GeV/c; A MEASUREMENT OF THE EFFECTIVE A_2 TRAJECTORY*

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August 1970

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[*] Work done under the auspices of the U. S. Atomic Energy Commission.

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

$$\pi^+ p \to \eta^0 \Delta^{++} \qquad (1)$$

at incident momenta between 1.3 and 4.0 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 a comparison with the reaction $\pi^- p \to \eta^0 n$ provides a consistency check of the model. The lower energy results can be used to search for a strong $\eta^0 \Delta^{++}$ branching ratio of the several I = 3/2 resonances postulated for this energy region and this will be the subject of a future communication.

The new measurements are based on several Bevatron exposures of the 72-inch hydrogen bubble chamber to π^+ of incident momenta 1.35, 1.45, 1.67, and of the 25-inch hydrogen bubble chamber to π^+ of 1.28, 1.39, 1.55, 1.75, 1.85, 2.3, and 2.67 GeV/c. The measurements between 3 and 4 GeV/c have already been published.[1] In total, 95 000 four-prong events were measured on the flying spot digitizer (FSD) and the on-line Franckensteins (COBWEB) and constrained to the (1c) hypothesis

$$\pi^+ p \to \pi^+ p\, \pi^+ \pi^- \pi^0 \qquad (2)$$

In Fig. 1 we show the $\pi^+\pi^-\pi^0$ and the $\pi^+ p$ mass distributions from hypothesis (2) at 2.67 GeV/c to illustrate our resolution and potential backgrounds.

In Table I we present the cross section for $\pi^+p \to \eta^0\Delta^{++}$ and the numbers of events used at the several momenta. The cross section has been corrected for the unseen η^0 decay modes. The momentum dependence of the cross section is also shown in Fig. 2, together with the measurement reported at 8 GeV/c.[2] The total cross sections 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 backgrounds. We note that the data exhibits 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.

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 (2)) fitted to the 2c hypothesis

$$\begin{aligned}\pi^+p \to \pi^+p\ &\eta^0 \\ &\lfloor\!\to \pi^+\pi^-\pi^0\end{aligned} \qquad (3)$$

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 $\chi^2(2c)$ was chosen.

For this preliminary report the events from the 72-inch chamber had not been fitted to the 2c hypothesis. We selected the η events by a mass cut, $.54 \text{ GeV} \leq M(\pi^+\pi^-\pi^0) \leq .56$. For the double η events (10% at 1.35 GeV/c; negligible at 3-4 GeV/c) we chose one combination randomly. For all data, the Δ^{++} mass cut was 1.15 GeV $\leq M(p\pi^+) \leq$ 1.30.

In Figs. 3a and 3b we show the differential cross sections $d\sigma/dt$. We have combined nearby momenta[3] in order to increase statistics. Krammer and Maor[4] have done a simultaneous fit to the reactions $\pi^+p \to \pi^0\Delta^{++}$, $\pi^+p \to \eta^0\Delta^{++}$, and $K^+p \to K^0\Delta^{++}$ with a $\rho + A_2$ Regge pole model. The fit included our 3-4 GeV/c data for the first two reactions and generally relied on data above 3 GeV/c. The solid curve on Fig. 3a is then the prediction of the Krammer and Maor model using the parameters determined in their fit to the higher energy data. The agreement becomes somewhat poorer at the lower momenta, but perhaps could be improved with a new three-reaction fit incorporating our new data. The prediction of the model for the integrated cross section is also shown in Fig. 2.

To examine the differential cross section in more detail, we have combined the results from all momenta above 2 GeV/c. The result is shown in Fig. 4 together with a prediction of Krammer and Maor at the average momentum 3 GeV/c, normalized to the forward peak. The arrow shows the maximum t value attainable at 2.3 GeV/c for a Δ^{++} mass of 1.3 GeV.

The prominant features of these differential cross sections are (i) the absence of any dip structure near $t = -0.5$; this had already been observed in previous data and in the corresponding reaction $\pi^+p \to \eta^0 n$; (ii) a clear dip at low values of t; this lack of events in the forward direction appears at all our energies and is most easily seen in the combined $d\sigma/dt'$ distribution shown in the insert; and (iii) Evidence for a dip in the vicinity of $t = -1.4$ GeV/c^2. A dip in this region is expected for an even signature A_2 trajectory and the theoretical curve shown exhibits such behavior. This is the first experiment to show this even signature zero for $\alpha = -1$.

Another test of the model is provided by the spin density matrix elements for the Δ^{++} decay. These are shown in Fig. 4 in the Jackson frame as a function of t, together with the predictions of Krammer and Maor. The two are consistent down to the lowest energy. [The predictions of the M1 dominance model are $\rho_{33} = .373$, $\rho_{3-1} = .216$, and $\rho_{31} = 0$].

As a measure of the effective A_2 trajectory, Mathews[5] has discussed a linear fit of the available data with

$$\frac{d\sigma}{dt} = \frac{G(t)}{P_{1ab}^2}\left(\frac{s-u}{2}\right)^{2\alpha(t)} \qquad (4)$$

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 the reaction (1) at a given t should be independent of s. In Fig. 5 we show the integrated ρ_{ij} for the momenta considered. Their behavior and that of the total cross section indicate that we can use the differential cross section down to 2.3 GeV/c to determine $\alpha(t)$. In Fig. 6 we show the $\alpha(t_i)$ derived from a least squares fit to Eq. (4) using (a) available data above[6] 2 GeV/c; (b) data in (a) plus our data between 1.6 and 2 GeV/c; and (c) only our data between 1.6 and 3.7 GeV/c. Linear fits to these points give

$$\text{(a)}\quad \alpha(t) = (0.87 \pm 0.03) + (1.75 \pm 0.13)t$$

$$\text{(b)}\quad \alpha(t) = (.75 \pm .05) + (1.55 \pm 0.11)t$$

$$\text{(c)}\quad \alpha(t) = (0.75 \pm .03) + (1.66 \pm 0.10)t$$

For comparison we also show in Fig. 6 $\alpha(t)$ for the reaction $\pi^- p \to \pi^0 n$ yielding $\alpha_{\text{eff.}}(t) = (.34 \pm .03) + (.35 \pm .08)t$ in a similar linear fit.[5,7] Exchange degeneracy requires a universal (ρ, A_2)

trajectory and for comparison we show the commonly accepted ρ trajectory, $\alpha = 0.57 + 0.91t$. This trajectory is in fair agreement with the data.

Clearly the reactions $\pi^- p \rightarrow \eta^o n$ and $\pi^+ p \rightarrow \eta^o \Delta^{++}$ give different effective A_2 trajectories. A similar comparison[11] between the reactions $\pi^- p \rightarrow \pi^o n$ and $\pi^+ p \rightarrow \pi^o \Delta^{++}$ gave identical effective ρ trajectories.

ACKNOWLEDGEMENTS

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   D. Brown et al., Phys. Rev. D1, 3053 (1970).
2. M. Aderholz et al., Nuclear Physics B8, 45 (1968).
3. The 3-4 GeV/c data has been combined with unpublished data of Goldhaber et al. at 3.7 GeV/c.
4. M. Krammer and U. Maor, Nuclear Physics B13, 651 (1969); see also G. H. Renninger and K. U. L. Sarma, Phys. Rev. 178, 2201 (1967). Krammer & Maor's model uses a zero-width Δ^{++}. In order to apply the model at low energies, where the effect of the finite width of the Δ^{++} is not negligible, we integrated the model over a Breit-Wigner. To retain the cross-section predictions of the model at high energy, it was then necessary to scale the parameters X1 - X4 by a factor of 1.34.
5. R. D. Mathews, Nuclear Phys. B11, 339 (1969).
6. In addition to this experiment, we use data at 8 GeV/c from Ref. 2 and at 5 GeV/c (Bonn-Durham-Nijmegen-Paris-Strasbourg-Turin collaboration, private communication).
7. It should be noted that these $\alpha(t)$ points deduced from the energy dependence of $\pi^- p \to \eta^0 n$ show considerable nonlinearity and that the resulting slope is shallower than other meson trajectories. More detailed fits[8,9] for the amplitudes have yielded trajectories as diverse as $\alpha = 0.40 + 0.90t$ and $\alpha = .40 + .65t$. The intercept $\alpha_{\Lambda_2}(0)$ deduced[10] from total cross section data is 0.34 ± .03, in agreement with all the aforementioned analyses.

8. M. Krammer and U. Maor, Nuovo Cimento 52A, 308 (1967); P. Manheim and U. Maor, private communication.

9. R. J. N. Phillips and W. Rarita, Phys. Rev. Letters 15, 807 (1965).

10. V. Barger et al., Nuclear Physics B5, 411 (1968).

11. G. Gidal et al., Phys. Rev. Letters 23, 994 (1969).

TABLE I.

$\pi^+ p \rightarrow n^o \Delta^{++}$

P_{LAB}(GeV/c)	Number of Events	Cross Section (μb)
1.28	84	.28 ± .06
1.39	175	.63 ± .10
1.55	184	.71 ± .12
1.62	270	.78 ± .11
1.75	188	.66 ± .10
1.85	119	.56 ± .10
2.30	156	.33 ± .05
2.67	251	.25 ± .04
3.5	90	.17 ± .03

FIGURE CAPTIONS

Fig. 1. Mass distributions for $\pi^+\pi^-\pi^0$ recoiling from a Δ^{++} and for π^+p recoiling from an η^0, at 2.67 GeV/c.

Fig. 2. Total cross section for $\pi^+p \to \eta^0\Delta^{++}$ as a function of incident pion momentum. The solid curve is the prediction of Krammer and Maor (Ref. 4).

Fig. 3. Differential cross sections, $d\sigma/dt$ for $\pi^+p \to \eta^0\Delta^{++}$ for eight groups of incident pion momenta. The solid curves are the predictions of Krammer and Maor (Ref. 4).

Fig. 4. The combined differential cross sections, $d\sigma/dt$, adding the data at 2.3, 2.67, 3-4, and 3.7 GeV/c. The arrow shows the maximum t value available at 2.3 GeV/c for a Δ^{++} mass of 1.3 Gev. The insert shows $d\sigma/dt'$ near the forward direction.

Fig. 5. Spin density matrix elements for Δ^{++} decay in the Jackson frame for eight groups of incident pion momenta. The solid curves are the predictions of Krammer and Maor (Ref. 4).

Fig. 6. Integrated spin density matrix elements as a function of incident pion momentum. The solid curve is the prediction of Krammer and Maor while the dashed curve is that of the M1 dominance model.

Fig. 7. The effective trajectory, $\alpha(t)$ as determined from several combinations of the data as discussed in the text.

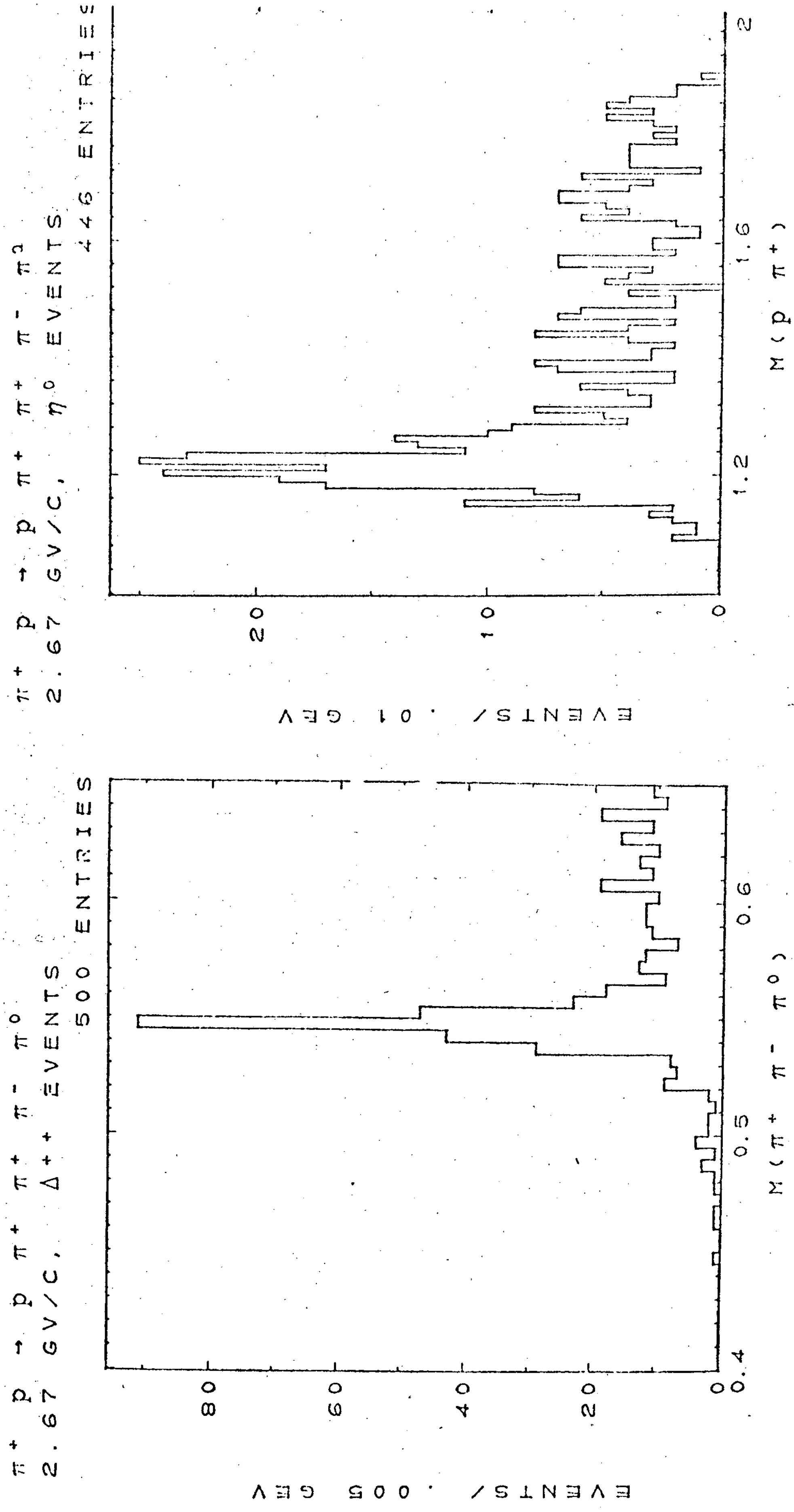
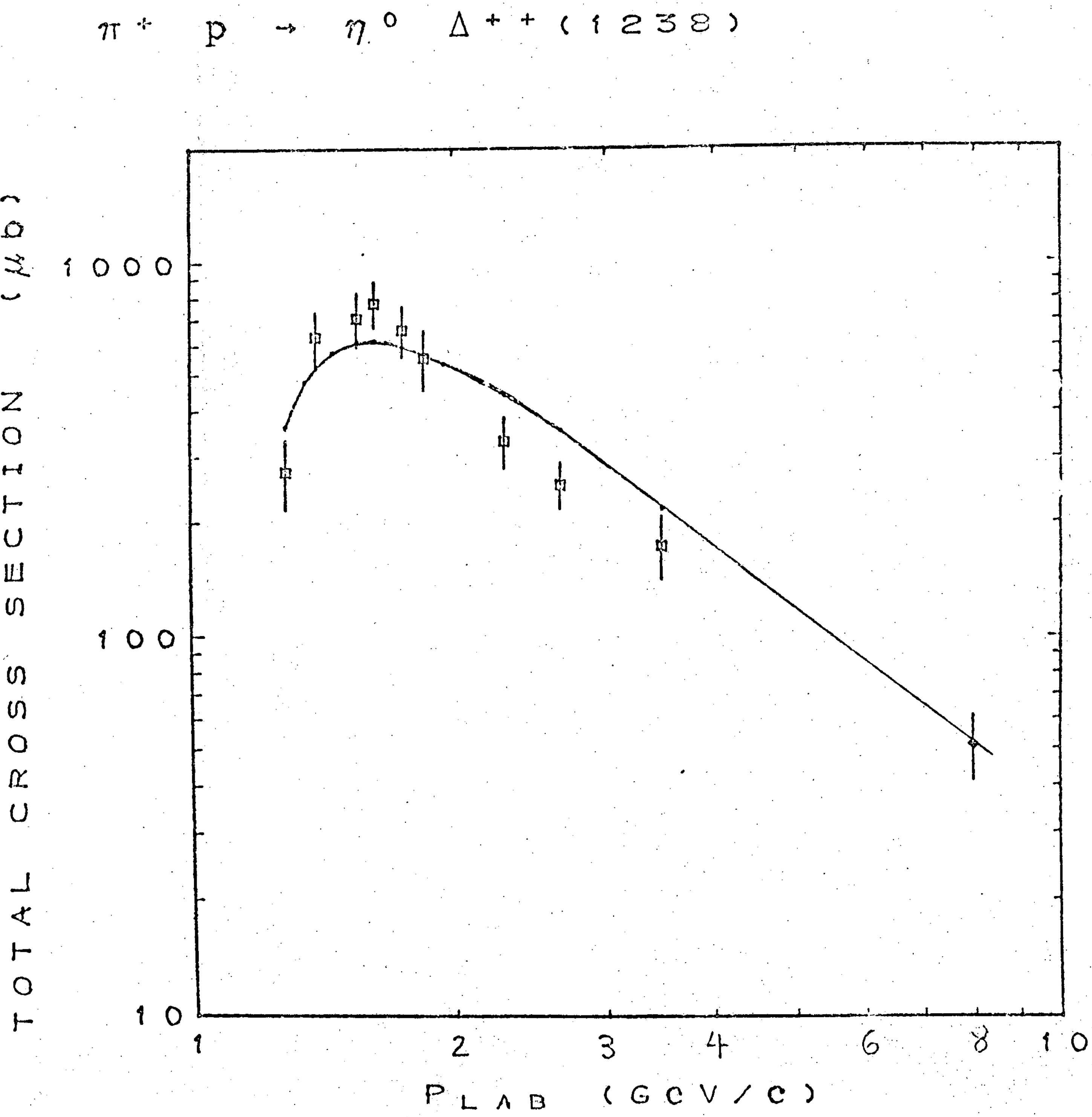

$\pi^+ p \to p \pi^+ \pi^+ \pi^- \pi^0$
2.67 GV/C, η^0 EVENTS
446 ENTRIES
EVENTS/ .01 GEV
0
10
20
1.2
1.6
2
$M(p\pi^+)$
$\pi^+ p \to p \pi^+ \pi^+ \pi^- \pi^0$
2.67 GV/C, Δ^{++} EVENTS
500 ENTRIES
EVENTS/ .005 GEV
0
20
40
60
80
0.4
0.5
0.6
$M(\pi^+ \pi^- \pi^0)$

Fig. 1



$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
TOTAL CROSS SECTION (μb)
1000
100
10
1
2
3
4
6
8
10
PLAB (GeV/c)

Fig. 2

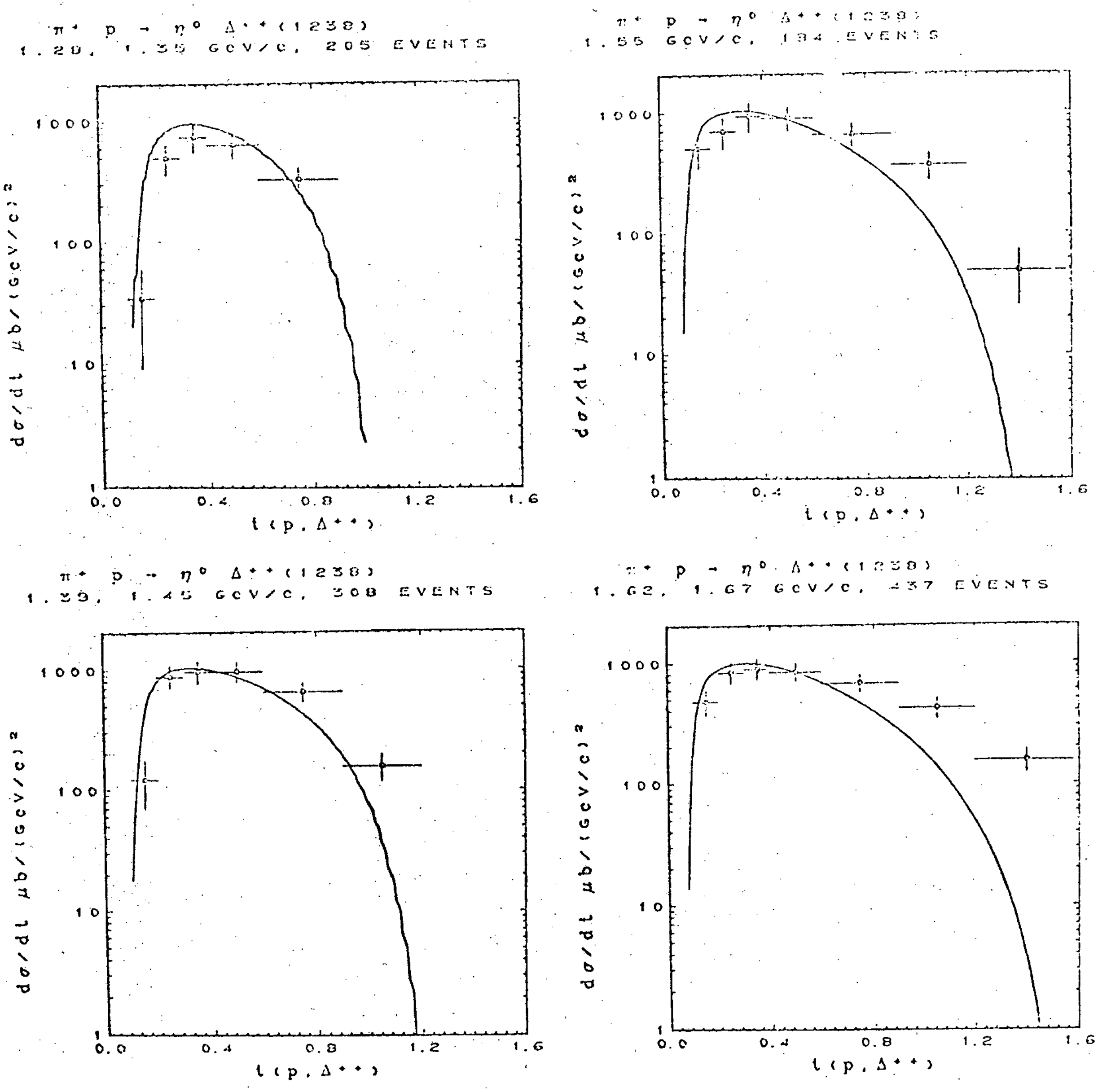
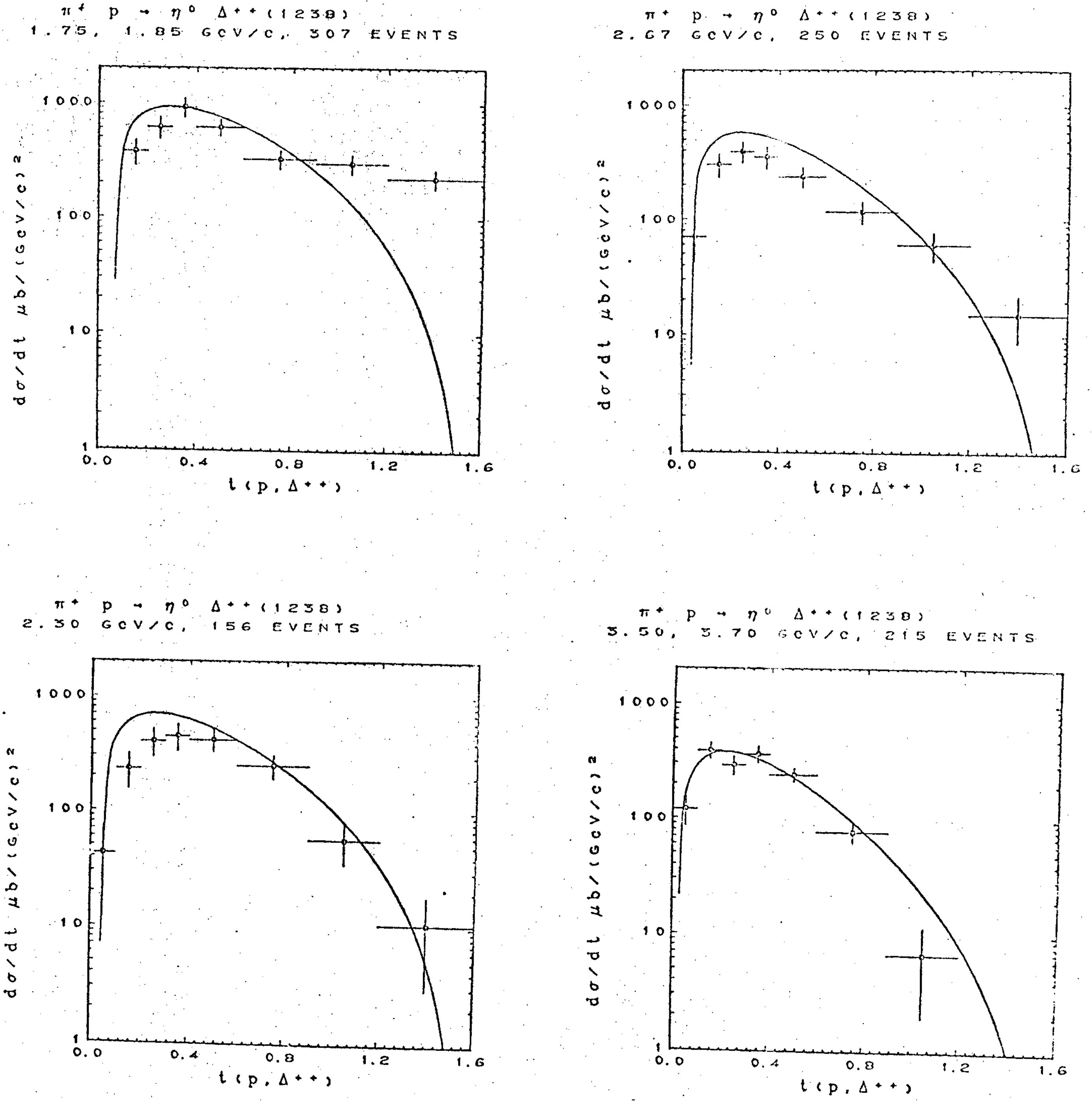

π+ p → η0 Δ++(1238)
1.29, 1.35 GeV/c, 205 EVENTS
π+ p → η0 Δ++(1238)
1.55 GeV/c, 184 EVENTS
π+ p → η0 Δ++(1238)
1.39, 1.45 GeV/c, 308 EVENTS
π+ p → η0 Δ++(1238)
1.62, 1.67 GeV/c, 437 EVENTS
dσ/dt μb/(GeV/c)²
1000
100
10
1
0.0
0.4
0.8
1.2
1.6
t(p, Δ++)

Fig. 3a



$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
1.75, 1.85 GeV/c, 307 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
2.67 GeV/c, 250 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
2.30 GeV/c, 156 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
3.50, 3.70 GeV/c, 215 EVENTS

Fig. 3b

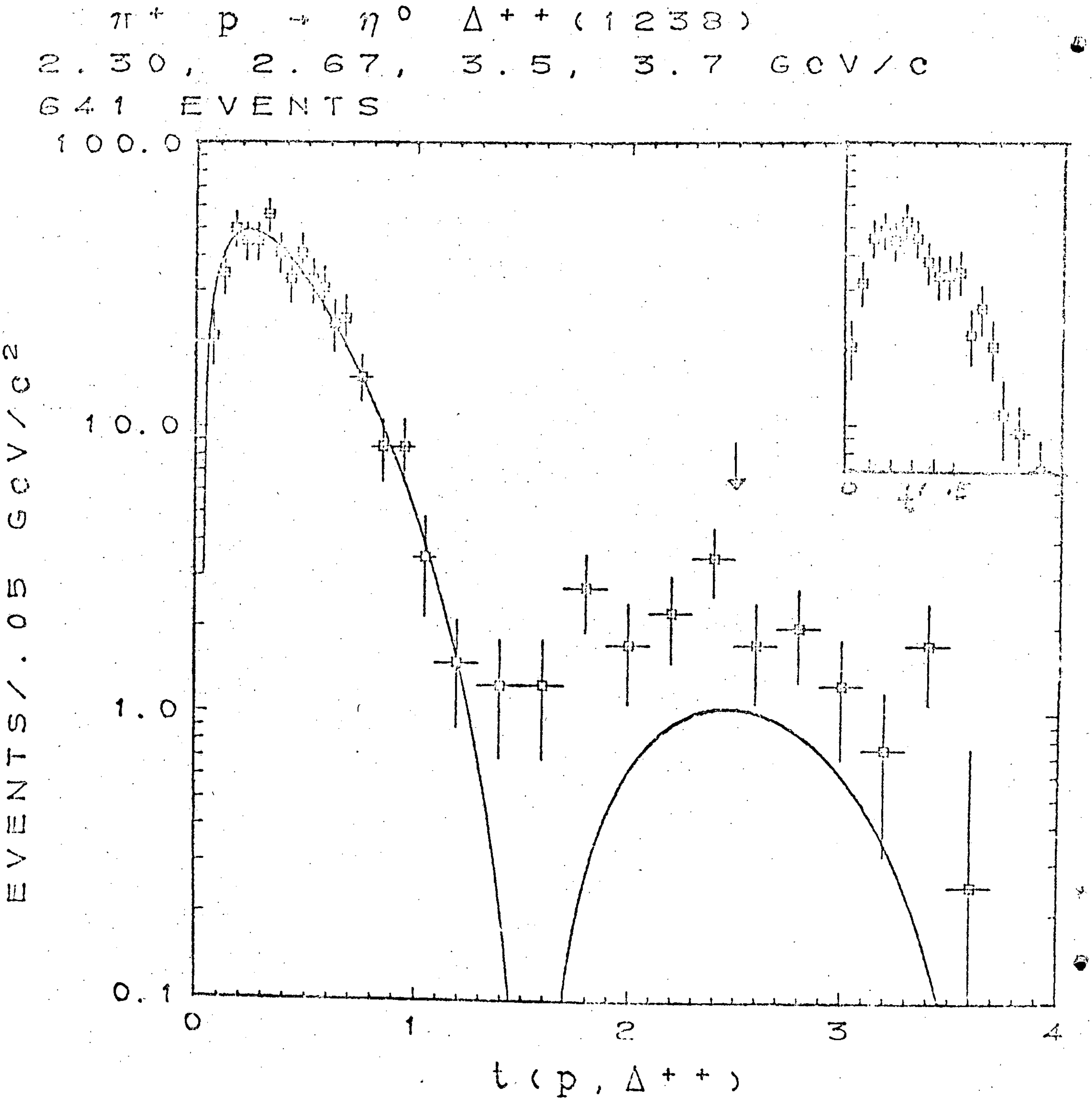

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
2.30, 2.67, 3.5, 3.7 GeV/c
641 EVENTS
100.0
10.0
1.0
0.1
EVENTS/.05 GeV/c^2
0
1
2
3
4
t(p, Δ^{++})
0
.5

Fig. 4

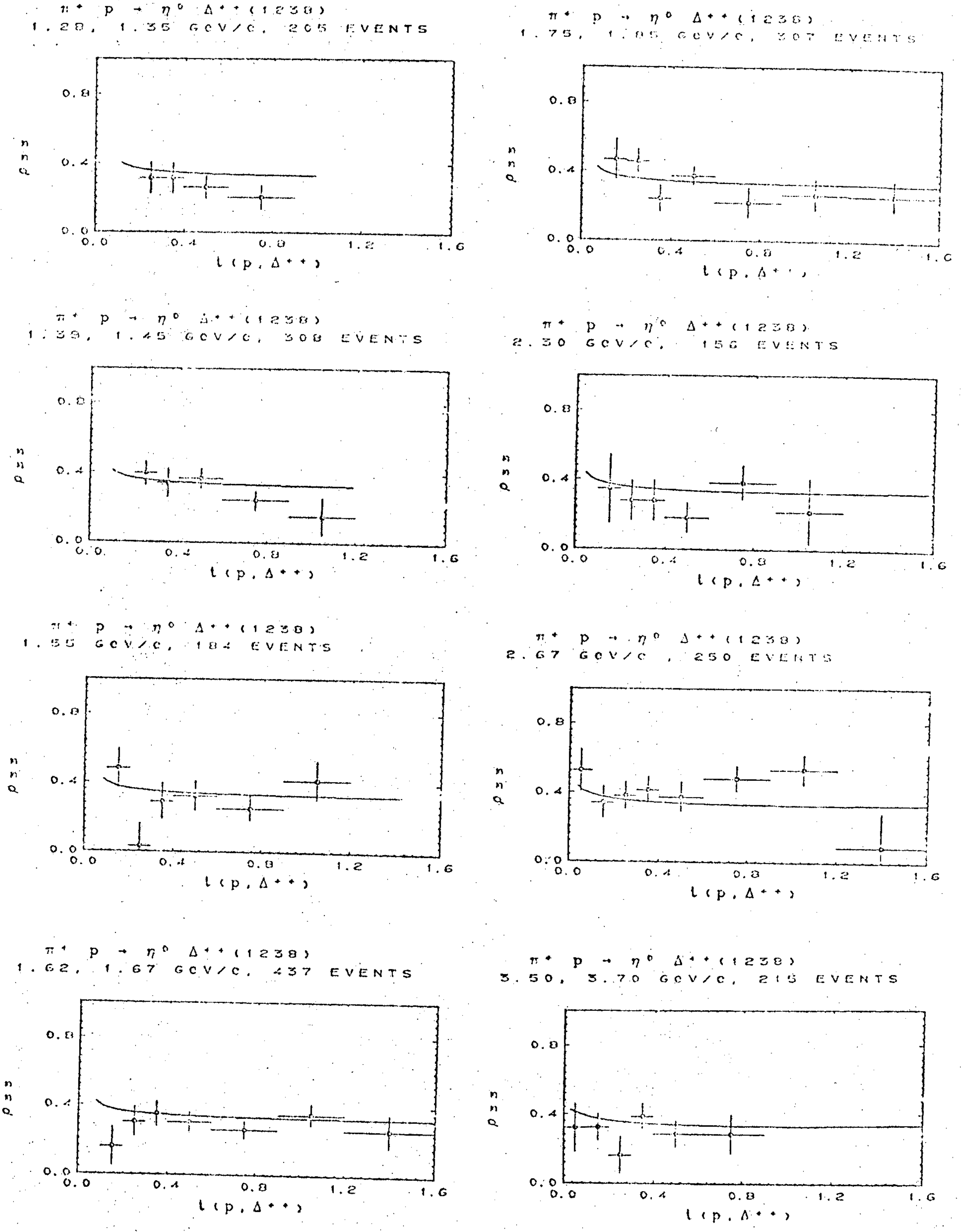

π⁺ p → η⁰ Δ⁺⁺(1238)
1.28, 1.35 GeV/c, 205 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
1.75, 1.85 GeV/c, 307 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
1.39, 1.45 GeV/c, 308 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
2.30 GeV/c, 156 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
1.55 GeV/c, 184 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
2.67 GeV/c, 250 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
1.62, 1.67 GeV/c, 437 EVENTS
π⁺ p → η⁰ Δ⁺⁺(1238)
3.50, 3.70 GeV/c, 215 EVENTS
ρ33
0.0
0.4
0.8
0.0
0.4
0.8
1.2
1.6
t(p, Δ⁺⁺)

Fig. 5a

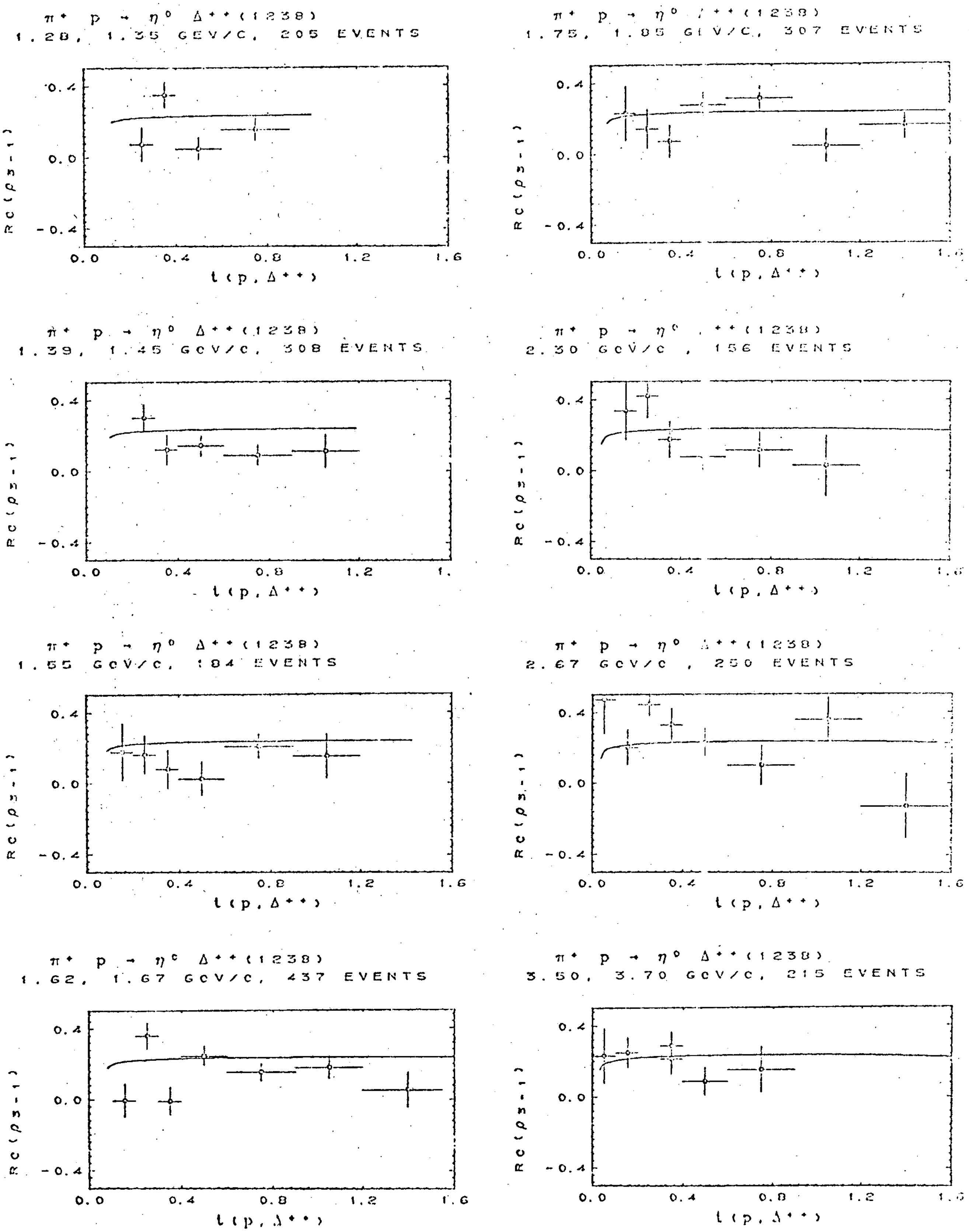
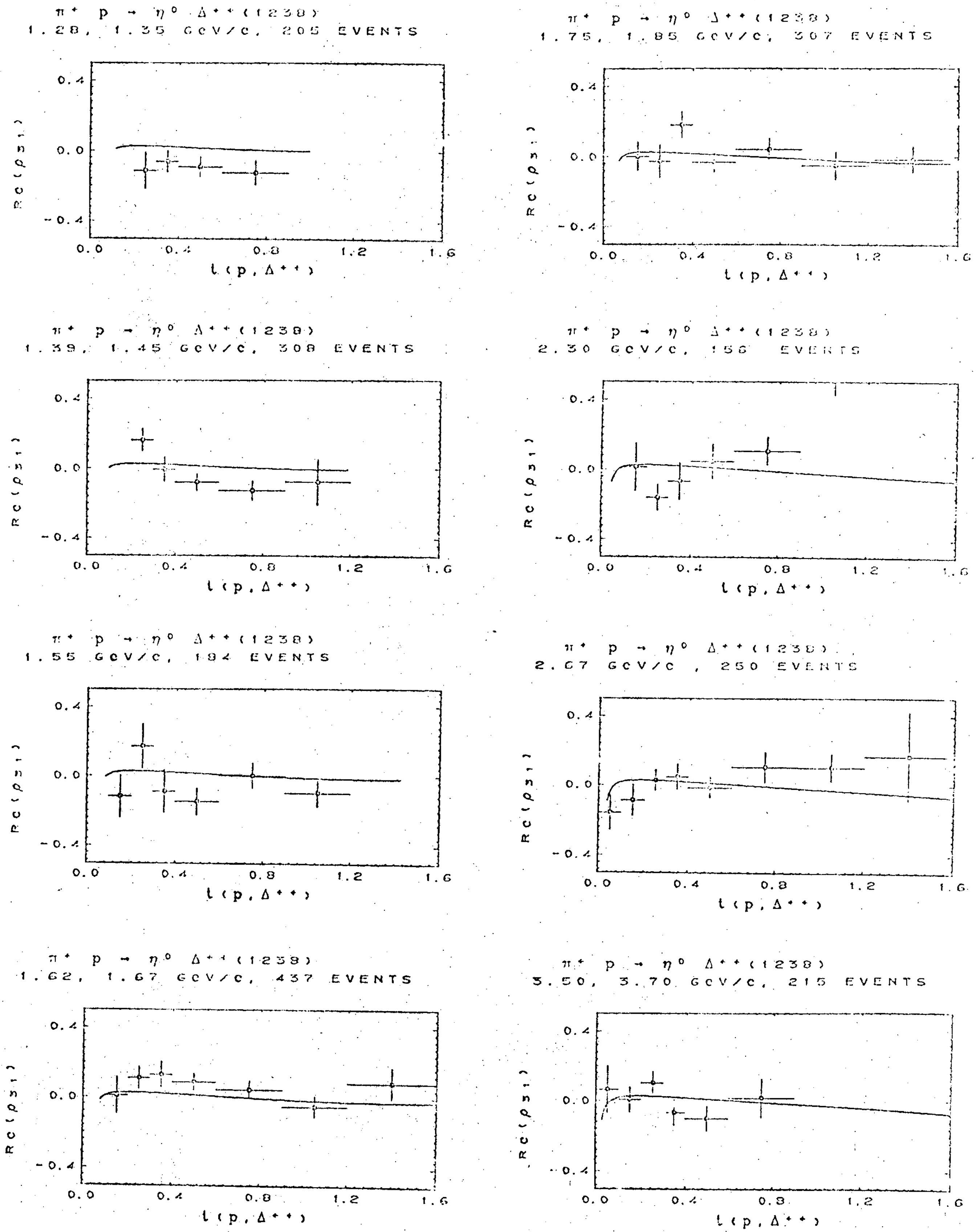

π+ p → η0 Δ++(1238)
1.28, 1.35 GeV/c, 205 EVENTS
π+ p → η0 Δ++(1238)
1.75, 1.85 GeV/c, 307 EVENTS
π+ p → η0 Δ++(1238)
1.39, 1.45 GeV/c, 308 EVENTS
π+ p → η0 Δ++(1238)
2.30 GeV/c, 156 EVENTS
π+ p → η0 Δ++(1238)
1.55 GeV/c, 184 EVENTS
π+ p → η0 Δ++(1238)
2.67 GeV/c, 250 EVENTS
π+ p → η0 Δ++(1238)
1.62, 1.67 GeV/c, 437 EVENTS
π+ p → η0 Δ++(1238)
3.50, 3.70 GeV/c, 215 EVENTS
Re(ρ3-1)
0.4
0.0
-0.4
0.0
0.4
0.8
1.2
1.6
t(p, Δ++)

Fig. 5b



$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 1.28, 1.35 GeV/c, 205 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 1.75, 1.85 GeV/c, 307 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 1.39, 1.45 GeV/c, 308 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 2.30 GeV/c, 156 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 1.55 GeV/c, 184 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 2.67 GeV/c, 250 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 1.62, 1.67 GeV/c, 437 EVENTS

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$ 3.50, 3.70 GeV/c, 215 EVENTS

Fig. 5c

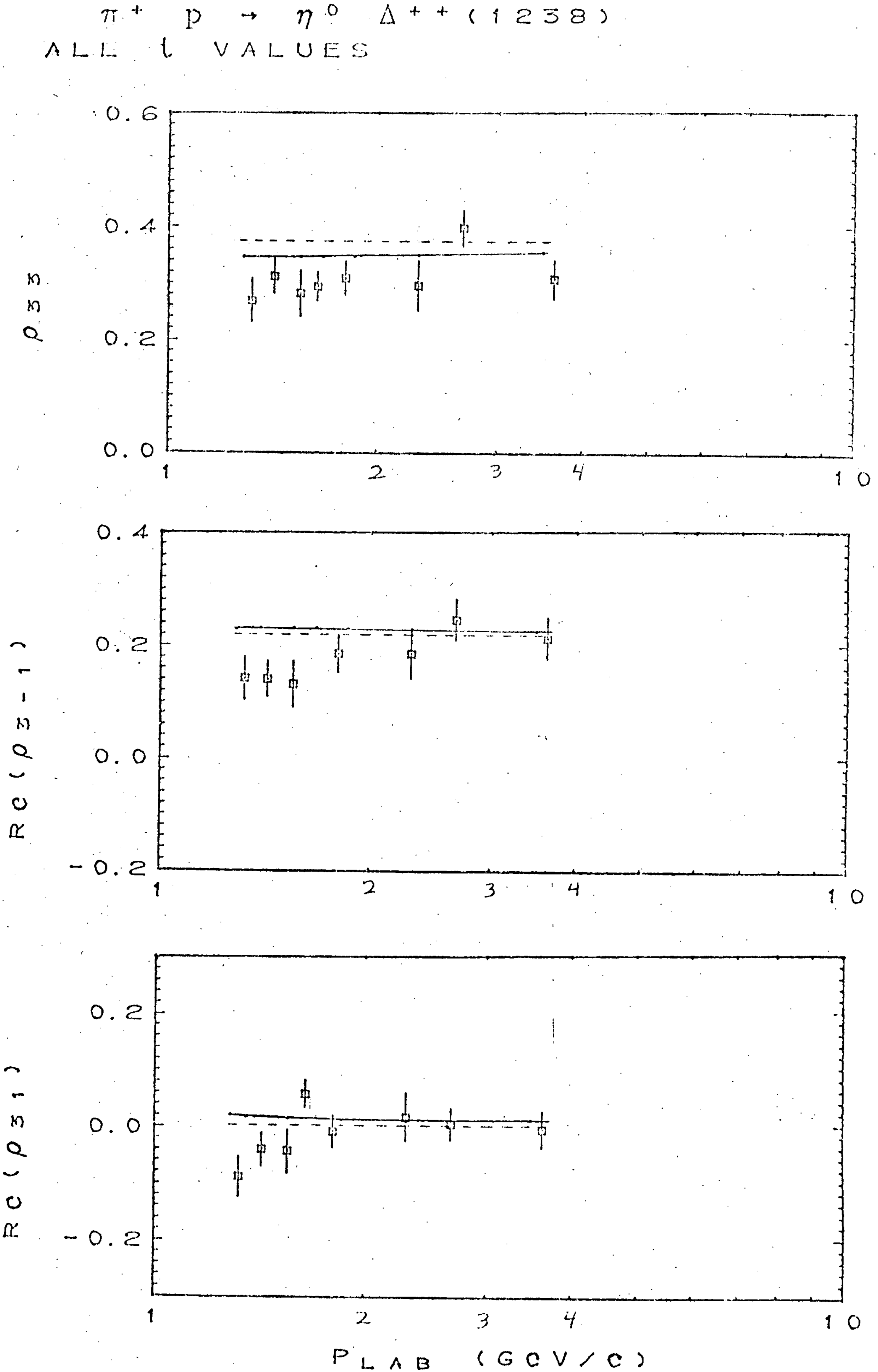
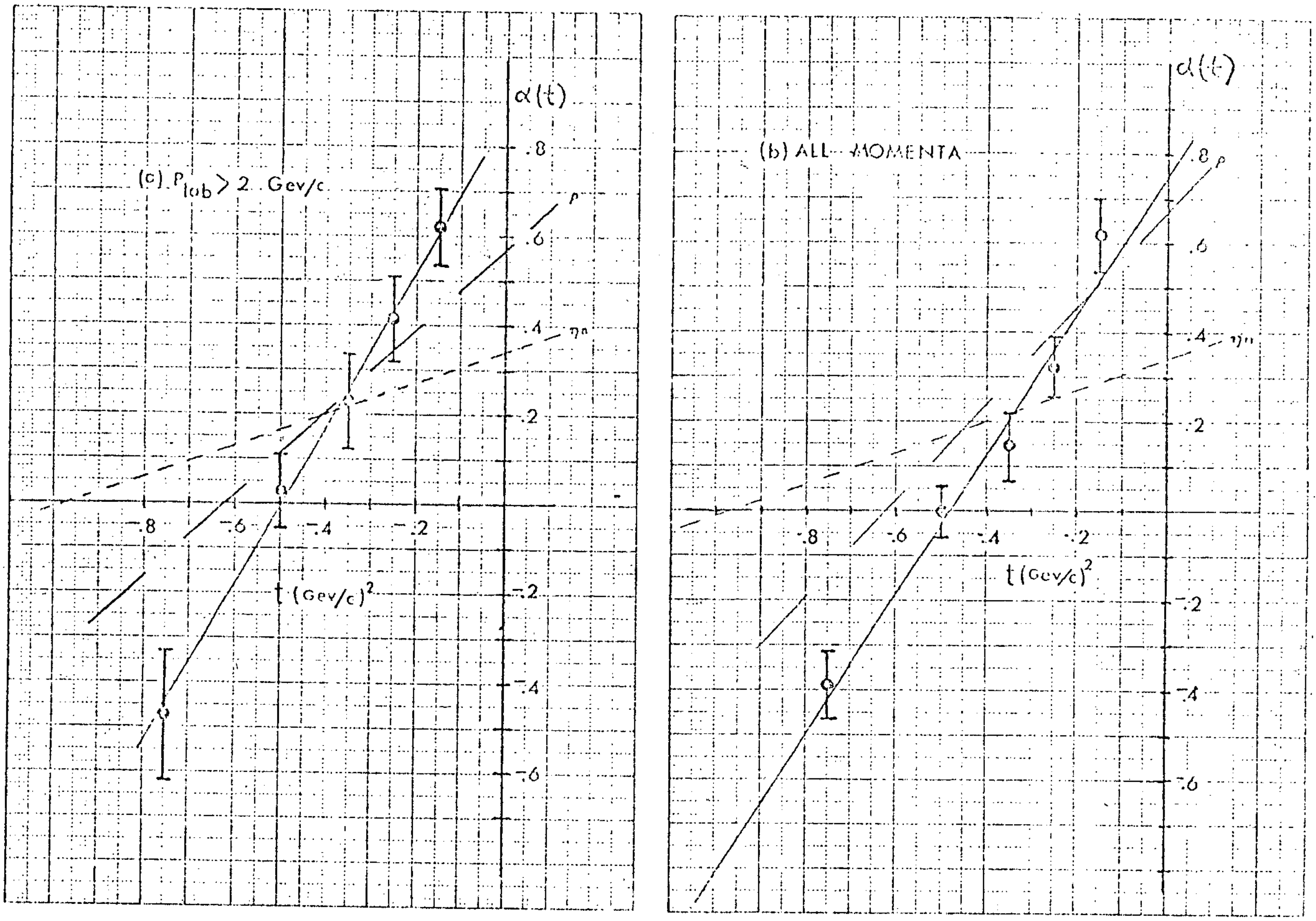
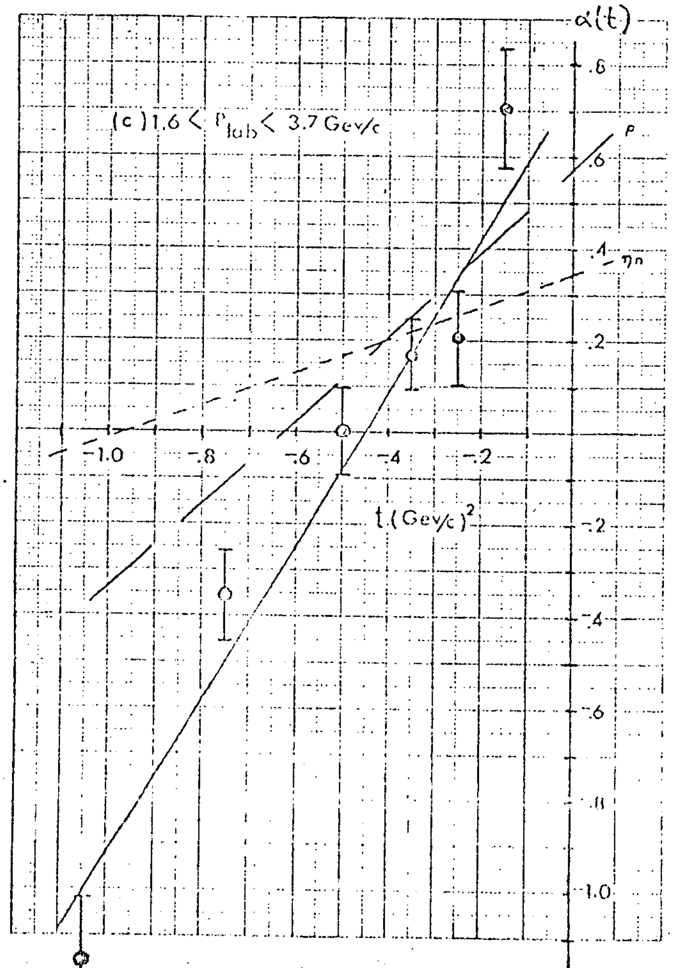

$\pi^+ p \to \eta^0 \Delta^{++}(1238)$
ALL t VALUES
ρ_{33}
0.6
0.4
0.2
0.0
1
2
3
4
10
Re(ρ_{3-1})
0.4
0.2
0.0
-0.2
1
2
3
4
10
Re(ρ_{31})
0.2
0.0
-0.2
1
2
3
4
10
P_{LAB} (GeV/c)

Fig. 6





(a) $\alpha = .87 \pm .03$
$+ (1.75 \pm .13)t$

(b) $\alpha = .75 \pm .05$
$+ (1.55 \pm .11)t$

(c) $\alpha = .75 \pm .03$
$+ (1.66 \pm .10)t$

Fig. 7

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