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The search for the G-parity violating decay of the ω, $\omega \rightarrow \pi^+\pi^-$ which may then interfere with ρ^o decay is nearly as old as these particles themselves.[1-5] The conditions required to observe such an effect are: (i) a reaction yielding copious ω and ρ^o production, (ii) production of ω and ρ^o in the same helicity states for a given interval in four-momentum transfer squared t, (iii) the large ω-ρ^o sample must originate from an incident momentum region small enough to preserve the ω-ρ^o relative production phase, (iv) mass resolution demonstrably high enough to show such interference effects.

We have observed a phenomenon which we interpret as the $\omega\rho$ interference effect--occurring as destructive interference--in the reactions:

$$\pi^+ p \rightarrow \pi^+\pi^-\pi^+ p \qquad \text{(12,672 events)} \qquad (1)$$

which is accompanied by the reaction

$$\pi^+ p \rightarrow \pi^+\pi^-\pi^o\pi^+ p \qquad \text{(15,066 events)} . \qquad (2)$$

The data is taken from a recent exposure consisting of 180,000 pictures from the LRL 72-inch bubble chamber in a separated π^+ beam at the Bevatron, spanning momenta between 3.7 and 4.0 GeV/c. We have concentrated on the channels

$$\pi^+ p \rightarrow \pi^+\pi^-\Delta^{++} \qquad \text{(6634 events)} \qquad (1a)$$

and $\pi^+ p \rightarrow \pi^+\pi^-\pi^0\Delta^{++}$ (9114 events) (2a)

for which we estimate ρ^0 production as 2900 events and ω^0 production as 1900 events. The phenomenon we observe consists of a four-standard deviation "valley" in the $M(\pi^+\pi^-)$ distribution centered at the ω^0 mass (the 780-790 MeV bin). Furthermore we observe a significant change in both the decay angular distribution and the asymmetry of the ρ when passing through $m_{\pi\pi} = m_\omega$. All of these above phenomena collectively appear as dips in the moments $N\langle Y_2^0\rangle$ as well as $N\langle Y_1^0\rangle$ extending over the same general mass regions.

As a preliminary to establish what width dips we could reasonably expect to see, we have calculated the non-Gaussian resolution function from the distribution of known errors in $m_{\pi\pi}$ for the events used in the analysis. The resulting function is shown in Fig. 1, and is of FWHM 10±0.5 MeV. In Fig. 1 we also display an idealized interference dip of FWHM 13 MeV, and compare it to an idealized Breit-Wigner for no interference.* When resolution is folded into the idealized dip, a significant but not complete filling occurs. Thus observable dips in the mass plot, if not statistical fluctuations, must reflect even greater true effects. Since the model in Fig. 1 is matched to the number of events in our sample, and because the 5.2 S.D. effect changes only to 4.9 S.D., our conclusion here is that such a dip should be observable with our statistical accuracy. Note that there is no experimental significance to the 5.2 S.D. quoted in this idealized example; the point is that the <u>change</u> in statistical significance, when resolution is considered, is small.

We now discuss the qualitative behavior of the data which suggests a ρ-ω interference. Figure 2 shows the effect as originally noticed, with no t-cuts. The dip in the $m_{\pi\pi}$ mass plot occurs very near the ω mass. In some other

*I.e., the ρ-Breit-Wigner is assumed to be perfectly known. Since in our real data this is not the case, the statistical significance of the effect will be reduced.

experiments, the search for incoherent $\omega \to 2\pi$ has dictated that $|t|$ be large, as is evident from Figs. 3 and 4 which show the very different t distributions for $\pi^+ p \to \rho\Delta^{++}$ and $\pi^+ p \to \omega\Delta^{++}$. As may be noted the t distribution for ρ productions falls off much more rapidly than that for ω production. We expect maximal <u>coherent</u> interference to occur where the term

$$\frac{(\rho\ \text{amplitude})(\omega\ \text{amplitude})}{(\rho\ \text{intensity}) + (\omega\ \text{intensity})}$$

is maximal, i.e., at lowest $|t|$. Moreover, we stress that here we must look for a coherent effect and must thus guarantee that the ρ and ω overlap in the same helicity state (for any cut on t). Figures 5 and 6 show the spin density matrix elements for ρ and ω, as determined from fits to our two final states. It is clear that only in the region for $|t| < 0.2\ (\text{GeV/c})^2$ does the above term have a relatively large value <u>and</u> appreciable overlap in the same helicity state occurs (see ρ_{00}). Figure 7 shows the resulting mass plot for $|t| > 0.2\ (\text{GeV/c})^2$. No statistically significant effect is present. When the data comes from $|t| < 0.2$, the apparent interference is greatly enhanced, as is shown in Fig. 8. (The similarity of the cos θ distributions for ρ and ω for $|t| < 0.2$ illustrates the overlap in the helicity state $|j,m\rangle = |1,0\rangle$, and is presented in Fig. 9. For the ρ, θ is the angle between the incident π^+ and the outgoing π^+ in $\pi^+\pi^-$ center-of-mass system. For the ω, θ is the angle between the incident π^+ and the normal to the ω decay plane in the ω center of mass.)

Another qualitative argument against the possibility of a statistical fluctuation of 4 standard deviations at the ω mass is given by examination of the decay angular distribution vs cos θ of the $\pi^+\pi^-$ system as we pass through m_ω. Figure 10b* shows a set of these angular distributions for 10-MeV

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* Fig. 10a shows the mass plot when a production angle cut approximately equivalent to $|t| < .2$ is made, plus the application of a Δ^{++} purification technique. The cos θ plots in Fig. 10b correspond to this latter mass plot.

intervals in the $\pi^+\pi^-$ mass. The change in the character of the angular distribution at m_ω shows that something anomalous is indeed occurring. The flat distribution observed may be primarily residual S-wave background after some cancellation of ρ and ω amplitudes has occurred.

Finally, let us consider the behavior of the moments N, $N\langle Y_2^0\rangle$ and $N\langle Y_1^0\rangle$. In Figs. 11 and 12 we show $N\langle Y_2^0\rangle$ and $N\langle Y_1^0\rangle$ in 20-MeV intervals. To the extent that factorization at the nucleon vertex is valid we can express these as

$$N = C_1(|A_p|^2 + |A_s|^2)$$

$$N\langle Y_2^0\rangle = C_2|A_p|^2$$

and

$$N\langle Y_1^0\rangle = C_3 \, \mathrm{Re}(A_p^* A_s)$$

where C_1, C_2, and C_3 are normalizing constants. We would expect an interference in the p-wave to be more prominent in $N\langle Y_2^0\rangle$ than in N, and perhaps of wider extent in $N\langle Y_1^0\rangle$ than in $N\langle Y_2^0\rangle$.* This result seems to be born out by the data.

As a very preliminary quantitative result (which should be interpreted as defining the order of the effect seen) we obtain an estimate of the $\frac{\omega \to 2\pi}{\omega \to 3\pi}$ branching ratio. To minimize the problems of incomplete knowledge of the S-wave background, we fit to the central portion of the mass plot alone. The model incorporates the coherent sum of two Breit-Wigner amplitudes (for ρ and ω) with arbitrary relative phase β, plus an incoherent flat background:

$$\frac{d\sigma}{dm} = \int_{t_{min}}^{t_{max}} \frac{d^2\sigma}{dt\,dm}\,dt = \int_{t_{min}}^{t_{max}} \left\{ C + C'\left| B_\rho e^{a_\rho t/2} + \alpha_\omega e^{i\beta} B_\omega e^{a_\omega t/2} \right|^2 \right\} dt \, .$$

Here B_λ indicates a P-wave Breit-Wigner of the form

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* This result is expected if the S-wave background has a non-negligible real part.

$$B_\lambda = \frac{m_\lambda^{3/2}\Gamma_\lambda^{1/2}}{(m^2 - m_\lambda^2) - im_\lambda\Gamma_\lambda} , \qquad \Gamma_\lambda = \Gamma_{\lambda o}\frac{m_\lambda}{m}\left(\frac{m^2 - 4m_\pi^2}{m_\lambda^2 - 4m_\pi^2}\right)^{3/2}$$

where m_λ and $\Gamma_{\lambda o}$ are the mass and width parameters.

A typical least-squares fit is shown in Fig. 13, where $|t| < 0.2$. Note that the smooth curve is the unfolded theoretical model. The solid histogram is the data, and the points are predicted numbers of events/bin (and error in the prediction) including resolution effects. In this fit, four parameters were taken as known from the literature or from our t-distributions:

$$m_\omega = 783.3 \text{ MeV}$$
$$\Gamma_\omega = 12.2 \text{ MeV}$$
$$a_\rho \approx 15 \ (\text{GeV}/c)^{-2}$$
$$a_\omega \approx 3 \ (\text{GeV}/c)^{-2} .$$

Two parameters not well established for this reaction are m_ρ and Γ_ρ. They are also not well determined from the fitting to the central region of the mass plot. Thus we looked at the sensitivity of the values of β, α_ω and C/C' to various discrete values of m_ρ and Γ_ρ. We tried

$$130 \leq \Gamma_\rho \leq 190 \quad \text{in 10-MeV steps,}$$
$$760 \leq m_\rho \leq 790 \quad \text{in 10-MeV steps.}$$

The result is that while β is quite insensitive to everything, α_ω and C/C' depend critically on Γ_ρ. From the variation of χ^2, we get

$$m_\rho = 780 \pm 10 \text{ MeV}$$
$$\beta = 188^\circ \pm 13^\circ \quad \text{(completely destructive interference)} .$$

From the enitre mass plot we estimate the best value of Γ_ρ to be 170±10. The above parameters then are constrained between the following limits

$$0.043\pm0.017 \leq \alpha_\omega \leq 0.060\pm0.022$$

$$8\% \leq \text{background} \leq 22\% \quad .$$

Thus we adopt as a rough value of α_ω:

$$\alpha_\omega \approx 0.051\pm0.030 \quad .$$

This result propagates (with suitable corrections for helicity amplitudes, t-cuts, and ρ/ω ratio) into an approximate branching ratio

$$\frac{\omega \rightarrow 2\pi}{\omega \rightarrow 3\pi} \approx 2.7^{+3.0}_{-2.0}\% \quad .$$

It should be noted that this includes only the coherent interference between ρ and ω. We consider the effect, at its present level, as only qualitative and defer questions of significance of this result until simultaneous fits of mass plots and moments of spherical harmonics are completed.

FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission.

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5. S. M. Flatté, Phys. Rev. 155, 1517 (1967) and S. M. Flatté, Study of $\omega \rightarrow \pi^+\pi^-$ in $K^-p \rightarrow \Lambda\omega$ From 1.2 to 2.7 GeV/c, UCRL-18687, submitted to Physical Review.
6. P. E. Schlein, Phys. Rev. Letters 19, 1052 (1967).

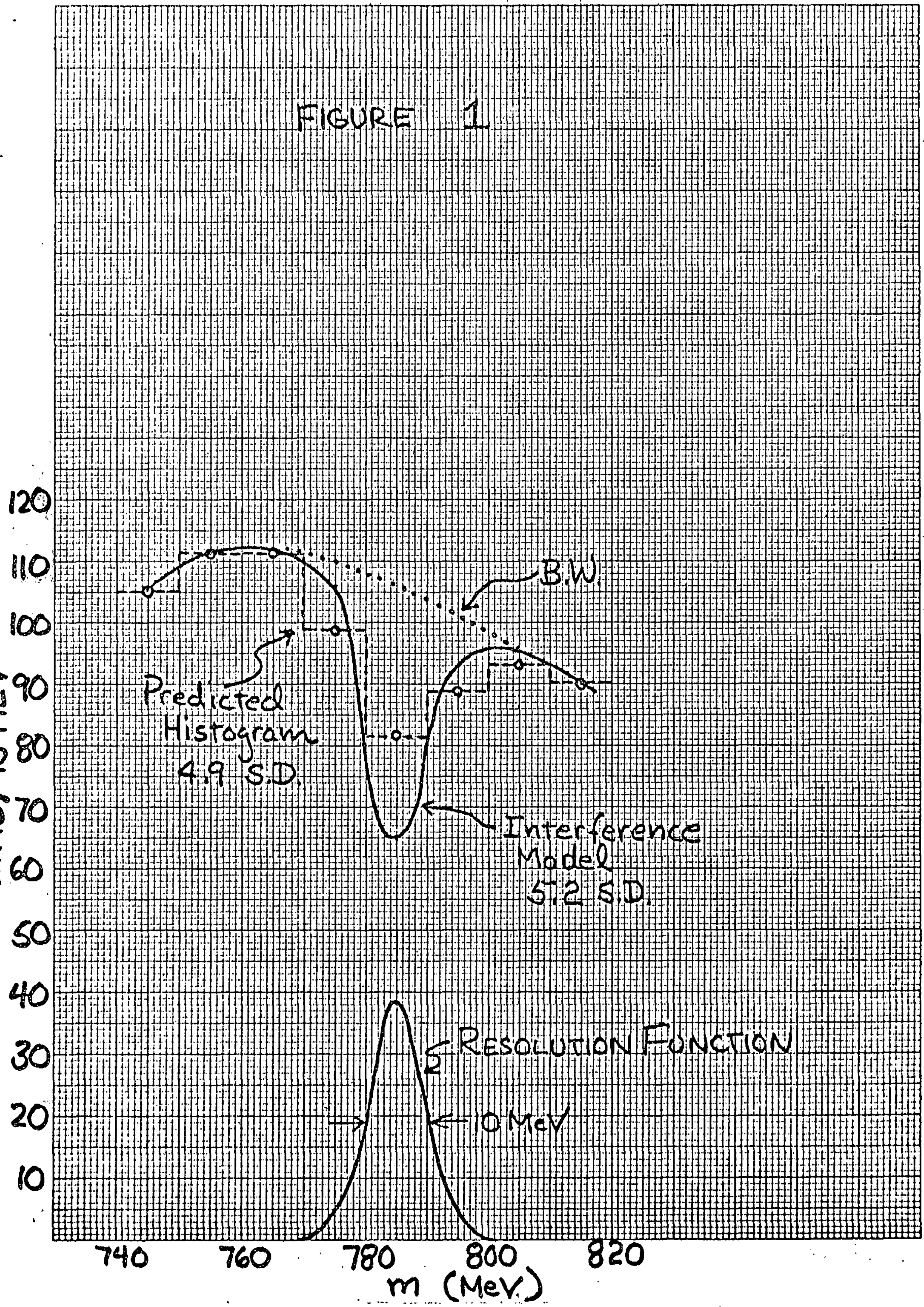


FIGURE 1
B.W.
Predicted
Histogram
4.9 S.D.
Interference
Model
5.2 S.D.
RESOLUTION FUNCTION
10 MeV
EVENTS/10 MEV
120
110
100
90
80
70
60
50
40
30
20
10
740
760
780
800
820
m (MeV)

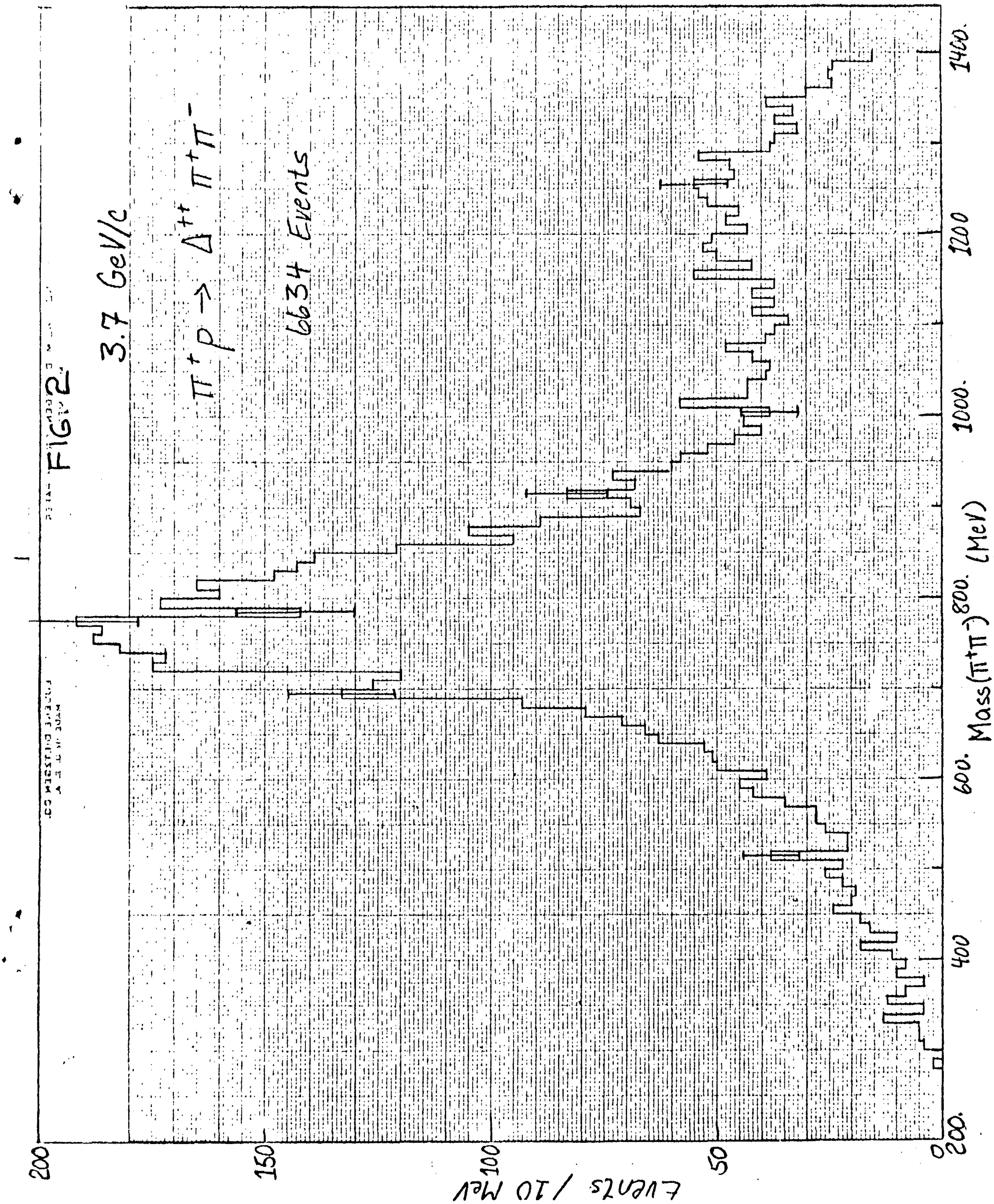


FIG 2
3.7 GeV/c
π⁺p → Δ⁺⁺ π⁺π⁻
6634 Events
Events / 10 MeV
0
50
100
150
200
Mass(π⁺π⁻) (MeV)
200.
400
600.
800.
1000.
1200
1400.

FIG. 3

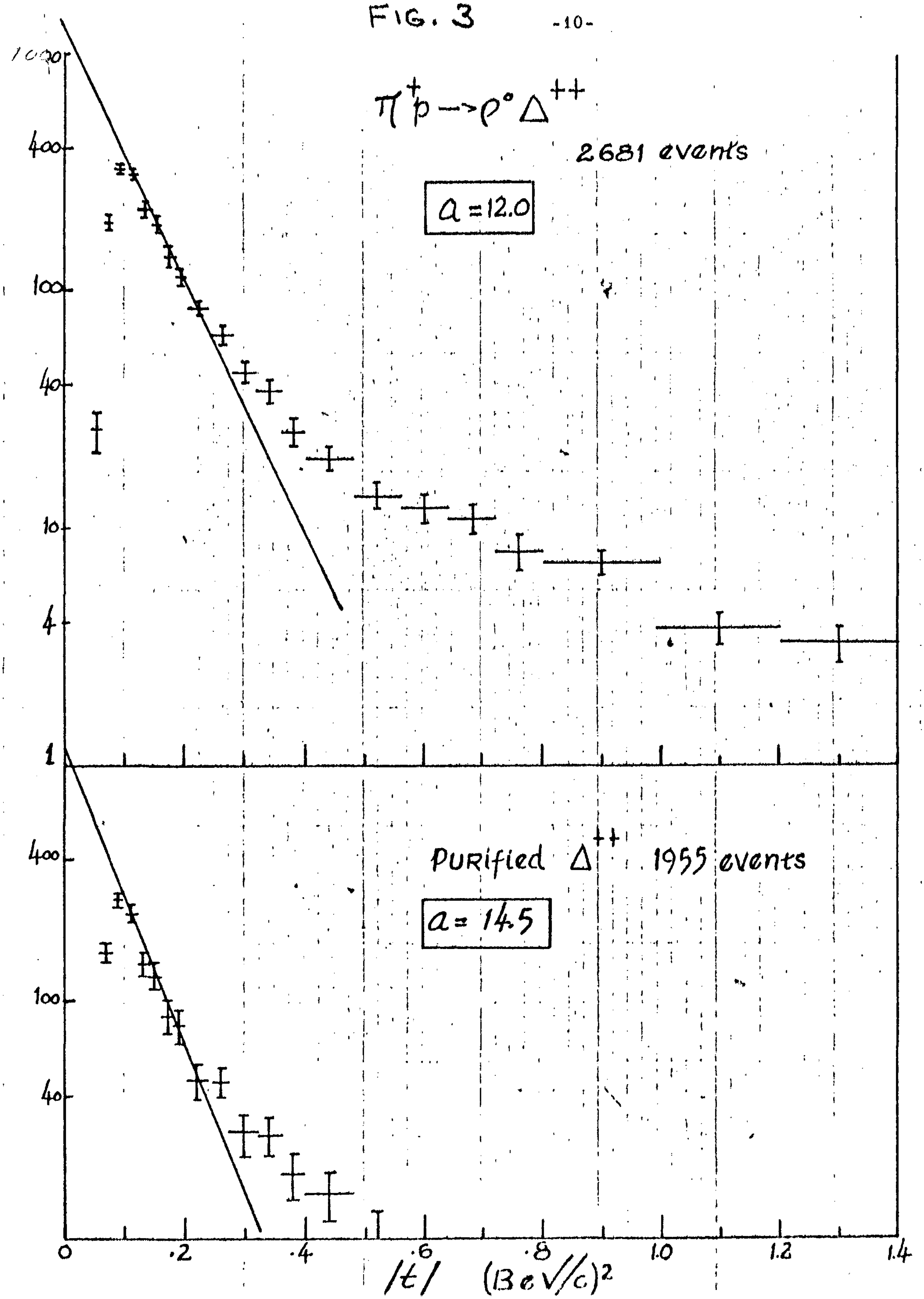
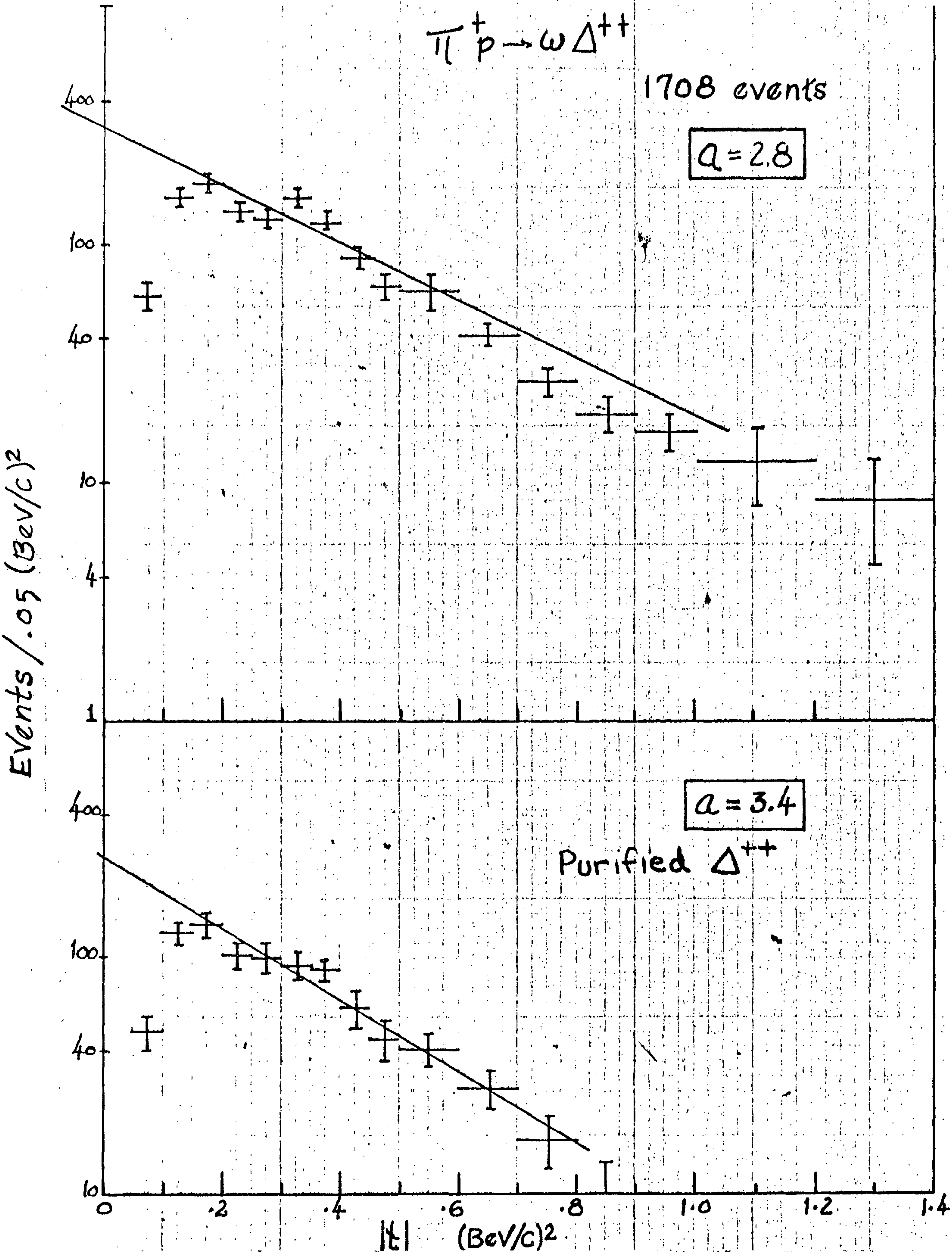
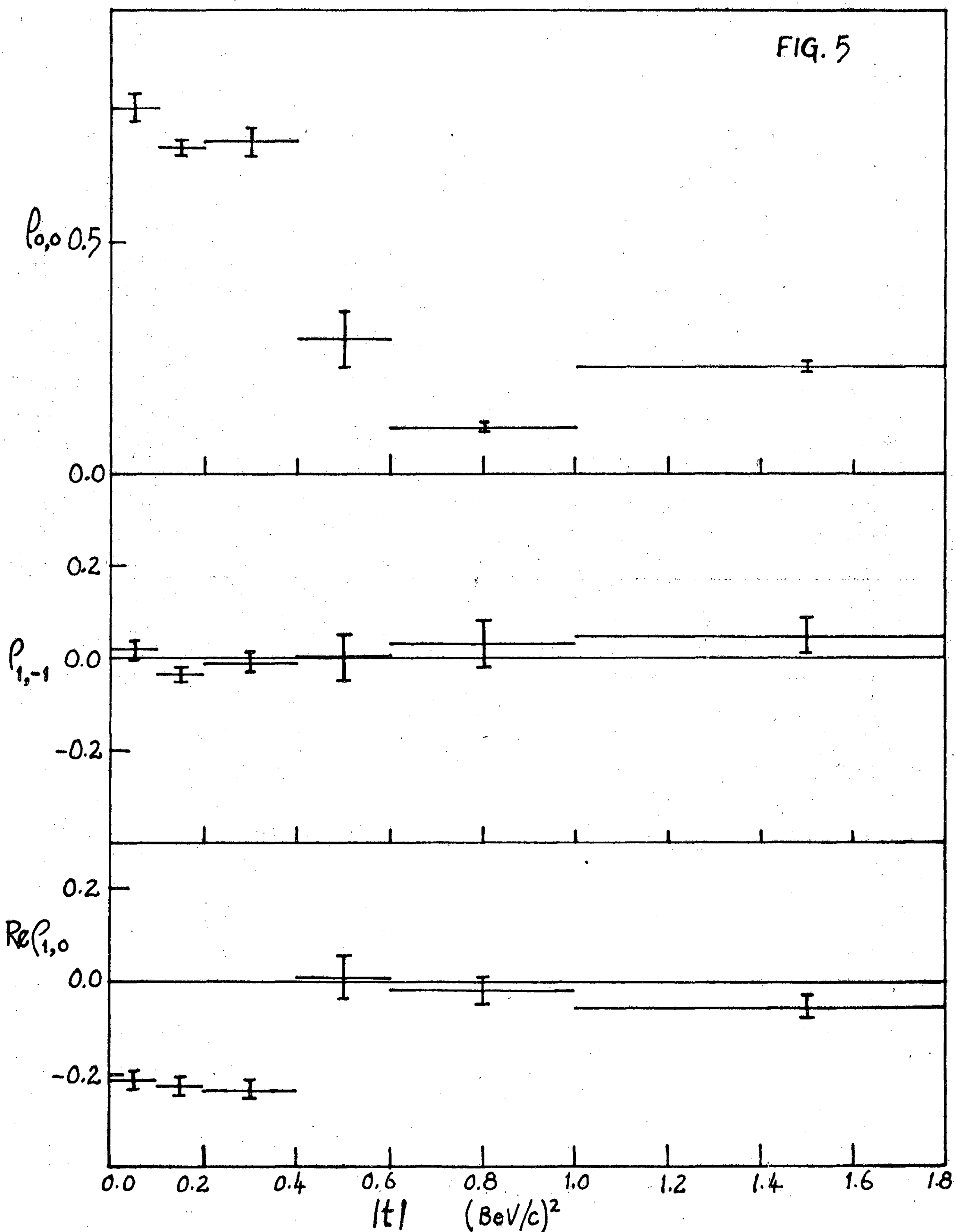

1000
400
100
40
10
4
1
$\pi^+ p \to \rho^\circ \Delta^{++}$
2681 events
a = 12.0
400
100
40
Purified Δ^{++} 1955 events
a = 14.5
0
.2
.4
.6
.8
1.0
1.2
1.4
/t/ (BeV/c)²

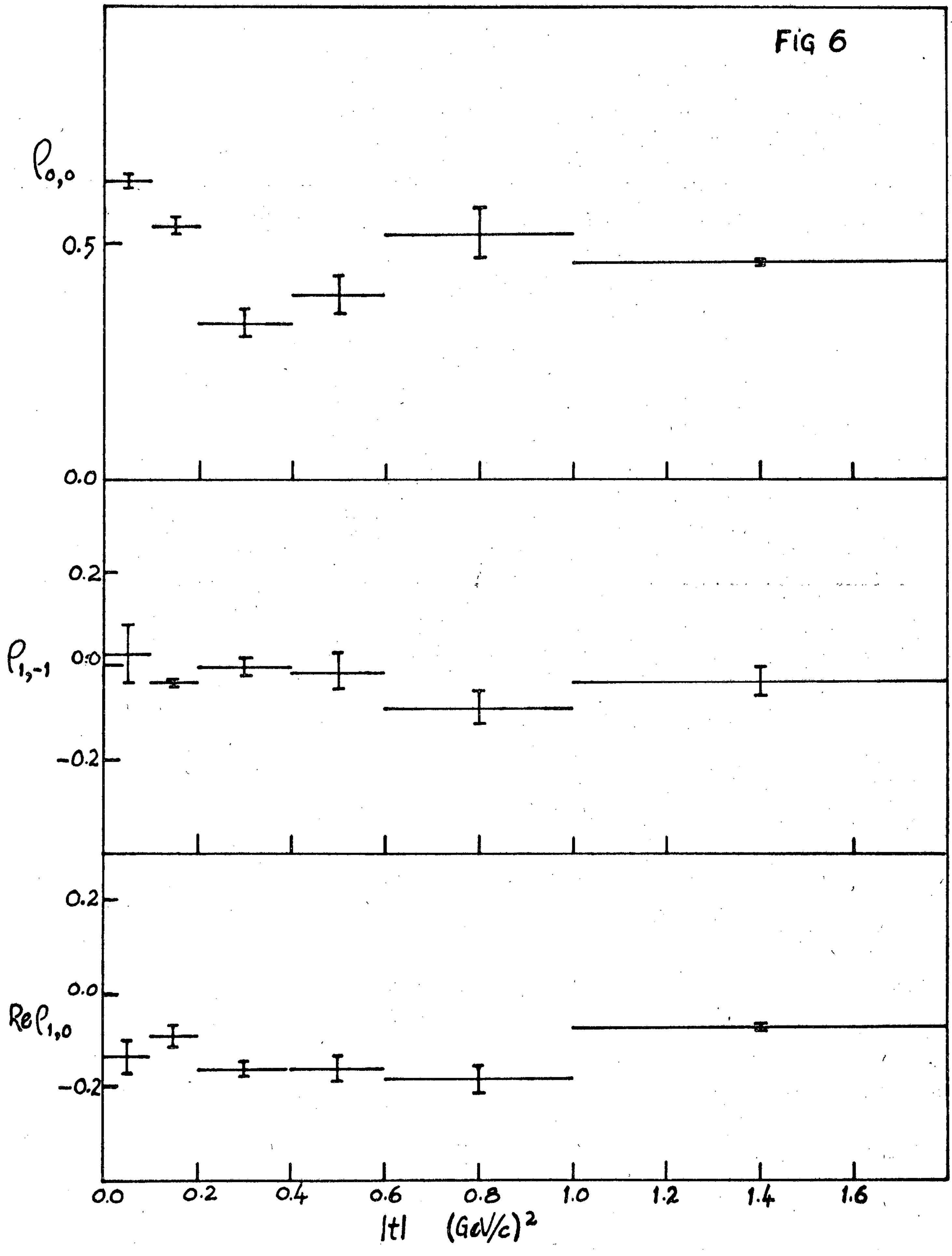
FIG. 4


$\pi^+ p \to \omega \Delta^{++}$
1708 events
a = 2.8
a = 3.4
Purified Δ^{++}
Events / .05 $(BeV/c)^2$
|t| $(BeV/c)^2$
400
100
40
10
4
1
0
·2
·4
·6
·8
1·0
1·2
1·4

$\pi^+ p \rightarrow \rho^0 \Delta^{++}$ 2681 EVENTS (doubles counted once)



$\pi^+ p \to \omega \Delta^{++}$ 1613 EVENTS (doubles counted once)



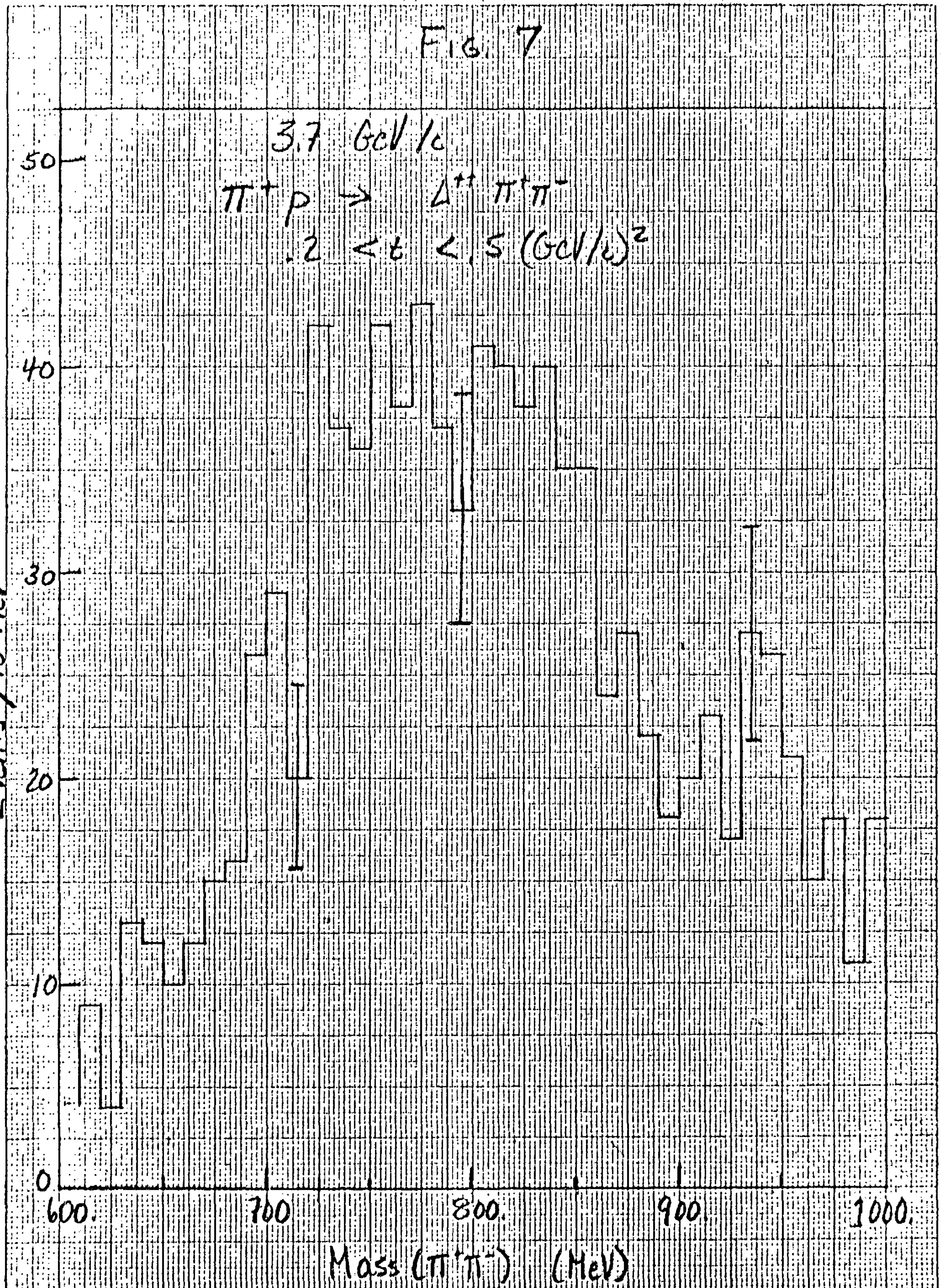


FIG. 7
3.7 GeV/c
$\pi^+ p \rightarrow \Delta^{++} \pi^+ \pi^-$
$.2 < t < .5\ (GeV/c)^2$
Events / 10 MeV
0
10
20
30
40
50
600.
700
800.
900.
1000.
Mass ($\pi^+\pi^-$) (MeV)

FIG. 8

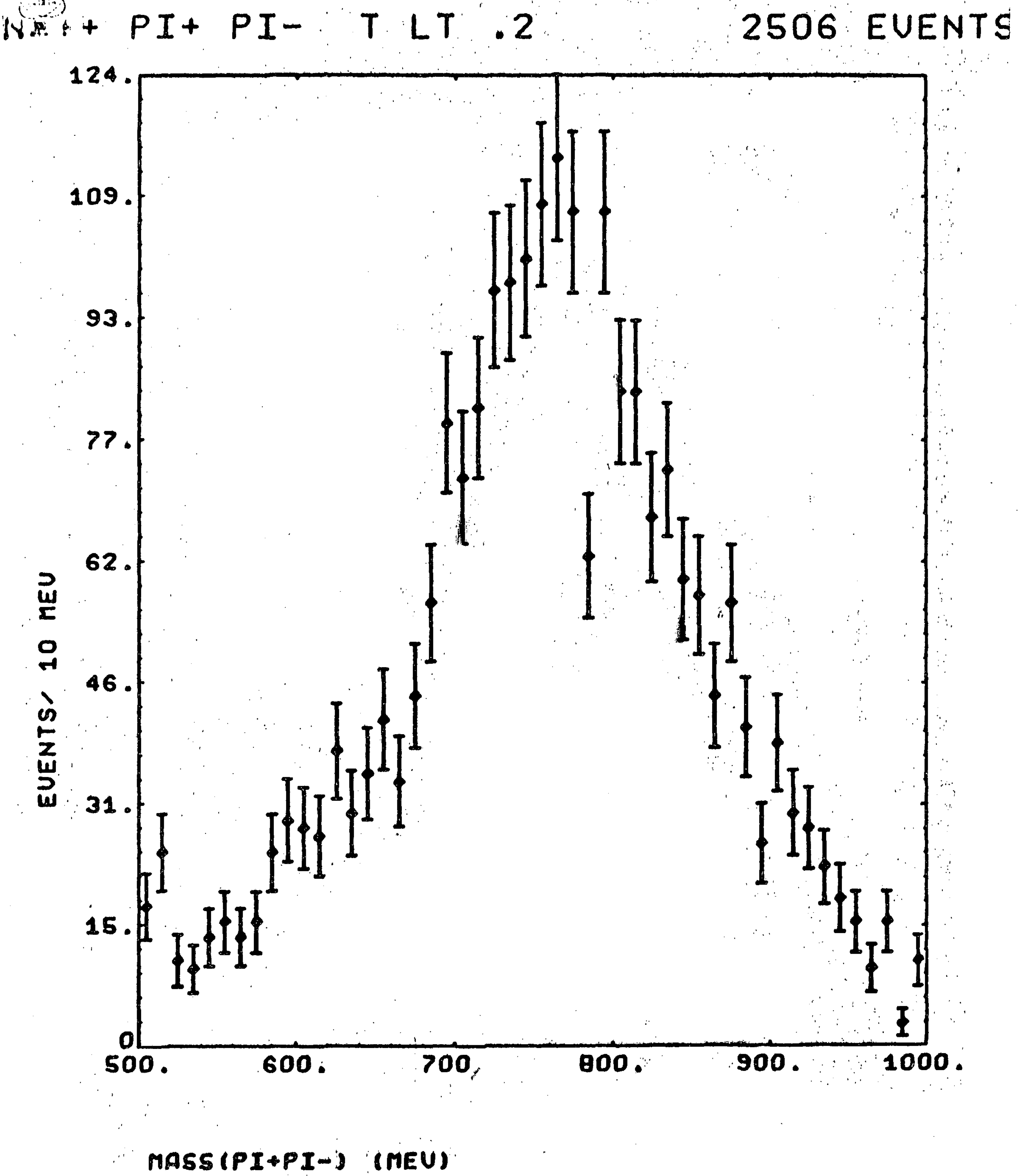
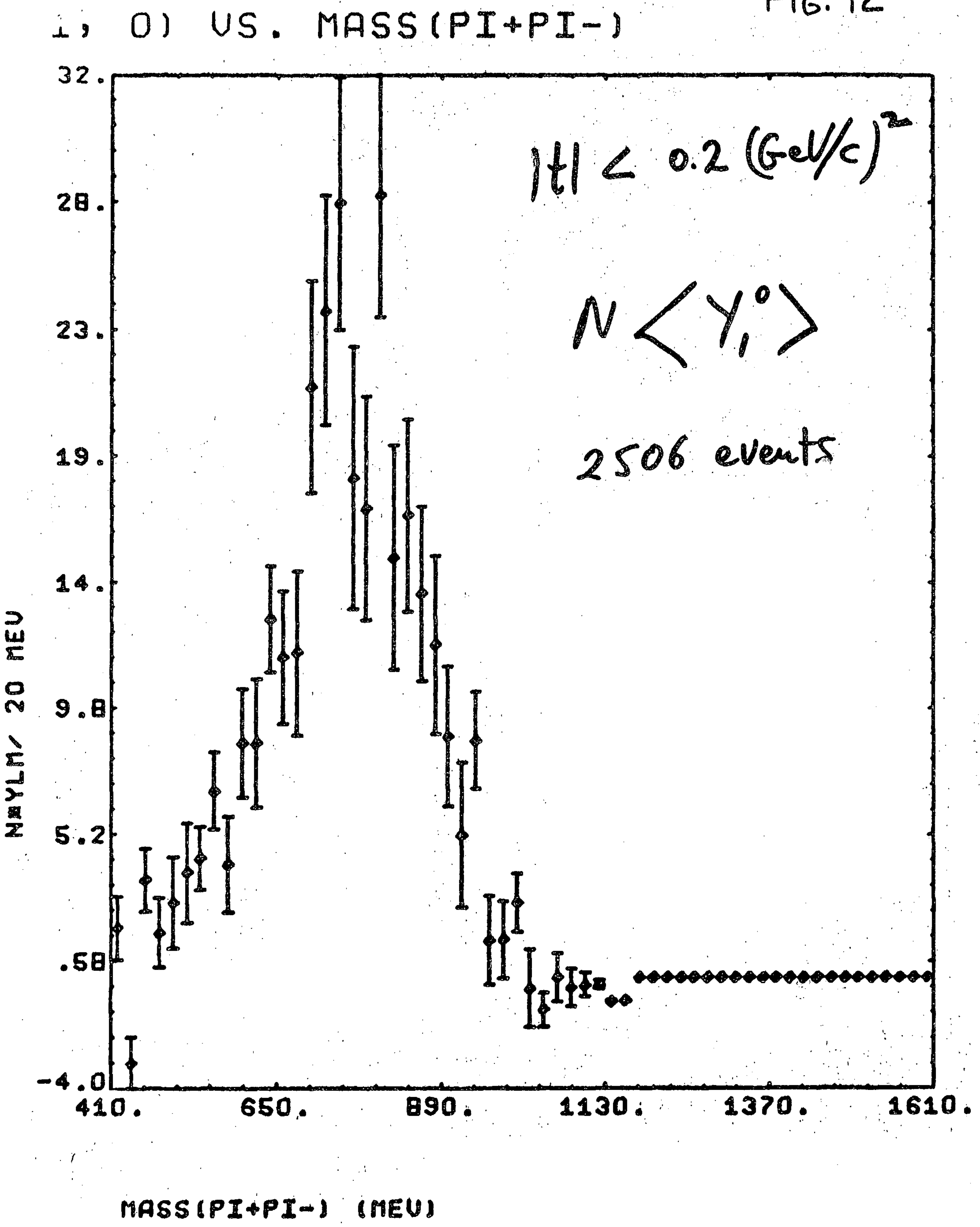

PI+ PI- T LT .2
2506 EVENTS
EVENTS/ 10 MEV
124.
109.
93.
77.
62.
46.
31.
15.
0
500.
600.
700.
800.
900.
1000.
MASS(PI+PI-) (MEV)

FIG. 12


1, 0) VS. MASS(PI+PI-)
|t| < 0.2 (GeV/c)^2
N ⟨Y_1^0⟩
2506 events
N*YLM/ 20 MEV
32.
28.
23.
19.
14.
9.8
5.2
.58
-4.0
410.
650.
890.
1130.
1370.
1610.
MASS(PI+PI-) (MEV)

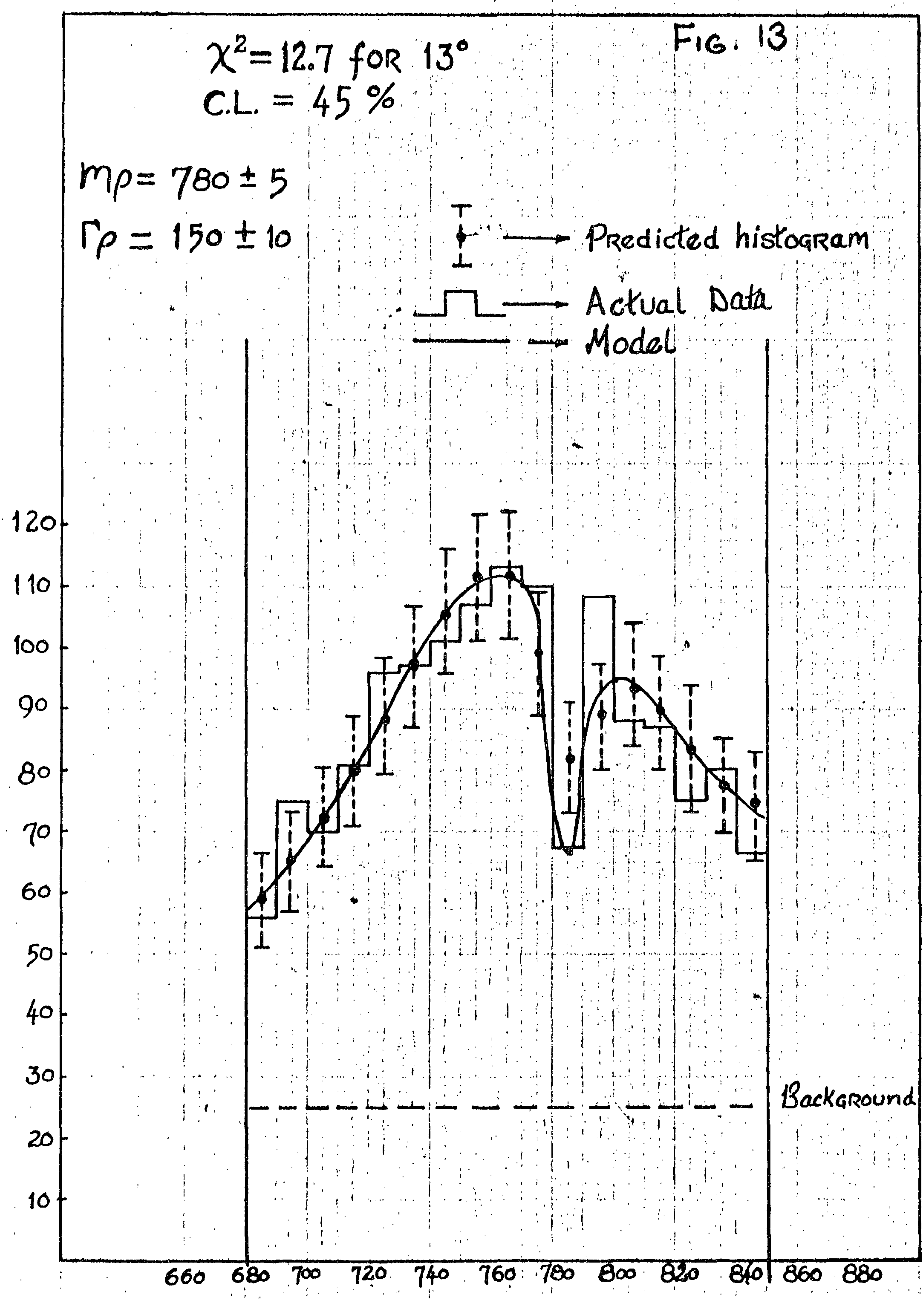


FIG. 13
$\chi^2 = 12.7$ FOR 13°
C.L. = 45 %
$m_\rho = 780 \pm 5$
$\Gamma_\rho = 150 \pm 10$
Predicted histogram
Actual Data
Model
Background
120
110
100
90
80
70
60
50
40
30
20
10
660
680
700
720
740
760
780
800
820
840
860
880

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