Contribution to the Lund International
Conference on Elementary Particles,
June 25-July 1, 1969, Lund, Sweden

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FURTHER STUDY OF THE H(990) EFFECT*

G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall,
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There have been two recent critiques of the H-meson. Fung et al.[1] pointed out that a cut on the 2 pion mass in the ρ region leads to a purely kinematical enhancement in the 3 pion mass at $\sim$ 990 MeV in the reaction $\pi^+ p \rightarrow \Delta^{++}\pi^+\pi^-\pi^o$. Barbaro-Galtieri and Soding,[2] in a very thorough review of the problem, pointed out furthermore that a considerable part of the residual H enhancement could be explained by the η' decay mode $\eta'(958) \rightarrow \pi^+\pi^-\gamma$ where in the fitting procedure for these events the γ is misinterpreted as a π^o.

While we concur with both of the above two observations we find that in a sample of 17,082 $\pi^+ p \rightarrow \pi^+\pi^-\pi^o\pi^+ p$ events, without ρ selection--a procedure which Fung et al. correctly objected to--and after allowing for the $\eta' \rightarrow \pi\pi\gamma$ decay mode there is a small but distinct residual effect; let us call it h(1000). Furthermore, the h(1000) effect shows up clearly primarily <u>outside</u> of the Δ^{++} band.

We have studied this problem in an exposure of 180,000 pictures of the 72-inch hydrogen bubble chamber at the Bevatron to a 3.7-GeV/c π^+ beam (hereafter called "new" experiment). This was combined, whenever feasible, with earlier data[3,4] (hereafter called "old" experiment).

To interpret our observed effect, we need a quantitative comparison between η' production and the H effect. We first proceed with our data on η' production:

1. The Reaction $\pi^+ p \to p\pi^+\pi^+\pi^- \eta_{neutral}$

We have treated the events of the type $\pi^+ p \to p\pi^+\pi^+\pi^- + MM$ (MM = missing mass) which did not give a one constraint π^o fit by attempting a 1C fit with η_n^o. While this procedure will of course include some events in which the neutral MM is not really an η_n it does pick up essentially all η_n events. In particular the $\eta' \to \pi^+\pi^-\eta_n$ decay is very clearly separated (see Fig. 1). We find in agreement with the earlier observation of Trilling et al.[4] that η' production goes exclusively via $\pi^+ p \to \Delta^{++}\eta'$ [32 events (new) + 7 events (old)] (see Fig. 2). To ascertain that the above procedure does not loose any η_n events (or pick up spurious ones leading to η') we have examined the MM distribution (for a 30% subsample). Figure 3 shows $M(\pi^+\pi^- MM)$ vs MM for events in the Δ^{++} band. The η' events are a clearly distinguished cluster and agree in number with the above estimate.

Finally, there is one well-known subtle point in our procedure. Namely, to what extent we are also observing the decay mode:

$$\eta' \to \pi^o\pi^o\eta_{ch}, \quad \eta_{ch} \to \pi^+\pi^-\pi^o ,$$

since $m(\pi^o\pi^o\pi^o)$ happens to be close to the η mass in this decay. From the known branching ratios of the η, 28.9% η_{ch} and 71.1% η_n, we find that the 39 η' events here observed represent 47.4% to 57% of the $\eta' \to \pi\pi\eta$ decay mode depending on whether our procedure includes none or all of the $\eta' \to \pi^o\pi^o\eta_{ch}$ mode. Let us adopt the most conservative point of view; namely, that the 39 events correspond to 47.4% and estimate an error corresponding both to the statistical and systematic uncertainty of ± 10 events.

2. The Reaction $\pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^o$

If we consider the entire $\pi^+\pi^-\pi^o$ distribution, $2 \times 17{,}082$ combinations, the η and ω stand out clearly and some structure at 1000 MeV is discernible (see Fig. 4). The η (~ 330 events), the ω (~ 4500 events), and Δ^{++} (~ 7000 events) account for a large fraction of the total number of events. In these numbers the events corresponding to double resonance formation (e.g., $\omega\Delta^{++}$) are given twice. Thus to get a clearer picture of the various channels it is important to separate them as much as possible.

a. The Channel $\pi^+ p \rightarrow \Delta^{++}\pi^+\pi^-\pi^o$

As will be discussed elsewhere we have "purified" the Δ^{++} sample by background subtraction. Figure 5 shows a $\pi^+\pi^-\pi^o$ mass plot in 10-MeV intervals. We note a narrow peak (Γ = 20 MeV) at 980 MeV, possibly on a somewhat broader base. If we look at $M(\pi^+\pi^-\gamma)$ instead, we note a corresponding narrow peak at 965 MeV (see Fig. 6). We find that for the "new" experiment 82% of the events have a corresponding $\pi^+ p \rightarrow p\pi^+\pi^+\pi^-\gamma$ fit in which the γ replaces the π^o but all other track assignments remain the same. From our data we cannot distinguish between these two interpretations. We can use our observed $\eta' \rightarrow \pi\pi\eta_n$ rate to predict the number of $\eta' \rightarrow \pi\pi\gamma$ events. The Particle Data Group[5] give $R = \frac{\eta' \rightarrow \pi\pi\gamma}{\eta' \rightarrow \pi\pi\eta} = \frac{22}{71} = 0.31 \pm 0.04$, while Barbaro-Galtieri and Soding[2] quote Rittenberg's value of $R = \frac{35}{65} = 0.54 \pm 0.06$. The larger value of R combined with our 39 $\eta' \rightarrow \pi^+\pi^+\eta_n$ events predicts $39 \times \frac{54\%}{47.4\%} = 44.5 \pm 12.5$ $\eta' \rightarrow \pi\pi\gamma$ events. These events are shaded in Figs. 5 and 6. The peaks we observe are somewhat larger, but could be accounted for without stretching the errors appreciably. What is much more indicative of a residual effect is the peak we observe <u>outside</u> of the Δ^{++}.

b. The Channel $\pi^+ p \rightarrow \pi^+ p \pi^+ \pi^- \pi^o$

In order to reduce background we have made various cuts in which the following events are removed.

(i) The events with an ω meson $M(\pi^+\pi^-\pi^o) = 760\text{-}820$ MeV.

(ii) The $\pi^+\pi^-\pi^o$ mass combinations corresponding to the reflection of an η meson $M(\pi^+\pi^-\pi^o) = 540\text{-}560$ MeV.

(iii) The $\pi^+\pi^-\pi^o$ mass combinations corresponding to the reflection of a Δ^{++} $M(p\pi^+) = 1130\text{-}1300$ MeV.

(iv) The Δ^{++} band itself.

In Fig. 7 we show the $\pi^+\pi^-\pi^o$ mass spectrum with cuts (i) and (ii); Fig. 8 with cuts (i) to (iii); and Fig. 9 with cuts (i) to (iv). The number of events which can be ascribed to the h(1000) signal are shown in each case. We find thus that there appears to be a residual effect $M_h \cong 1000$ MeV, $\Gamma_h \cong 50$ MeV which may have contributed in some degree to the old H(990) observations, particularly in the $\pi^+ d \rightarrow \pi^+\pi^-\pi^o pp$ reaction. This effect appears to be produced primarily in the channel

$$\pi^+ p \rightarrow p\pi^+ h(1000) \quad .$$

As the h(1000) occurs on a very large background we are at present unable to determine J^P, decay modes, or whether it occurs as the decay of another object, e.g.,

$$X^+ \rightarrow \pi^+ + h^o(1000) \quad .$$

Furthermore, it is noteworthy that in our data we observe only about 20 cases of $\varphi \rightarrow K^+K^-$ (also produced outside the Δ^{++} band).[6] This implies about 10 $\varphi \rightarrow \pi\rho$ decays are expected. Thus the h(1000) effect cannot be due to the $\pi\rho$ decay of the φ meson in this case. This also raises the interesting

question whether the $\varphi \rightarrow \pi\rho$ observations in the literature[5] could actually be attributed in part to h(1000).

In conclusion then, while the H(990) may be dead, the h(1000) appears to have arisen like a phoenix from the ashes.

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

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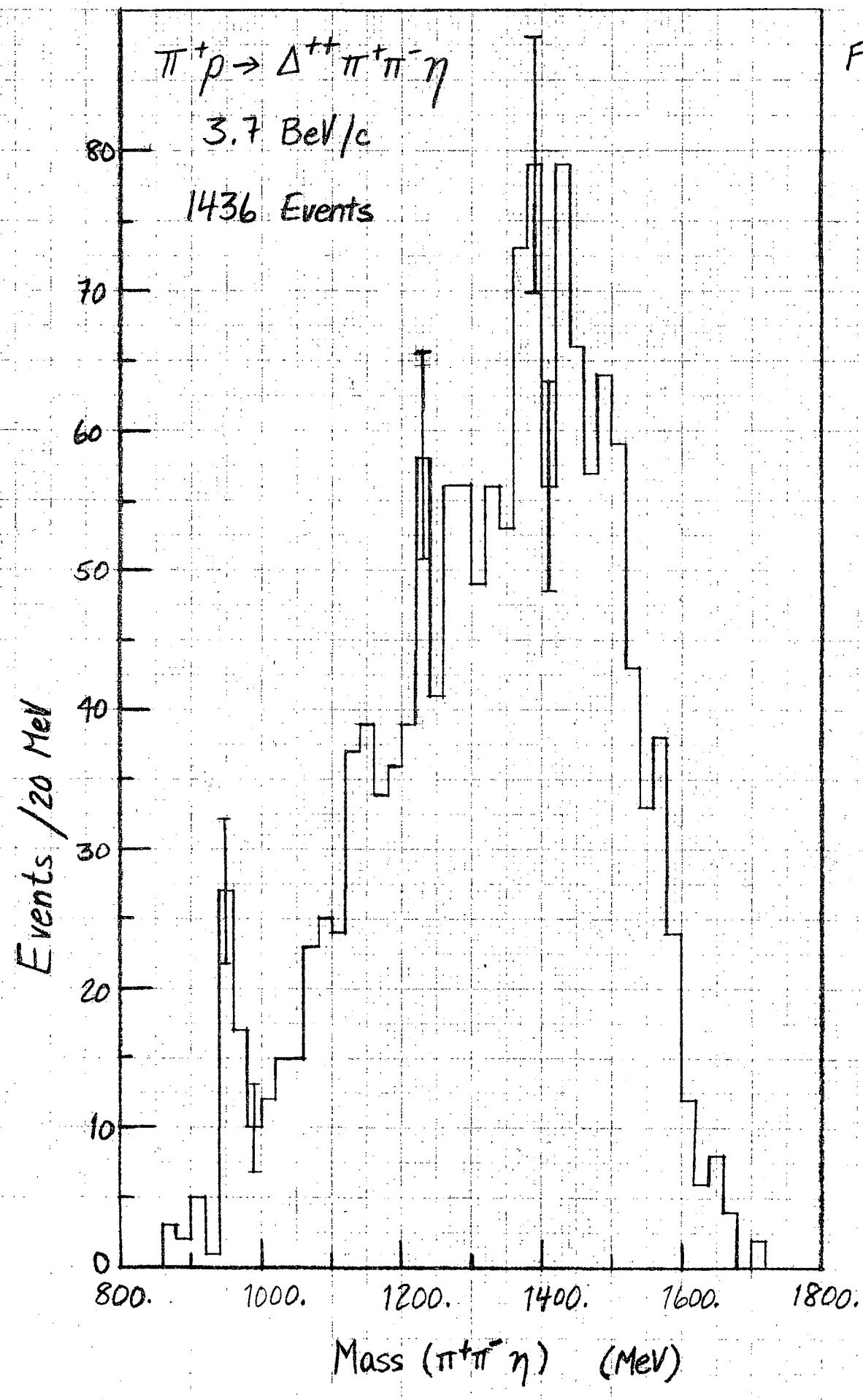

$\pi^+ p \rightarrow \Delta^{++} \pi^+ \pi^- \eta$
3.7 BeV/c
1436 Events
Events /20 MeV
0
10
20
30
40
50
60
70
80
800.
1000.
1200.
1400.
1600.
1800.
Mass ($\pi^+\pi^-\eta$) (MeV)

Fig. 1

Fig. 2

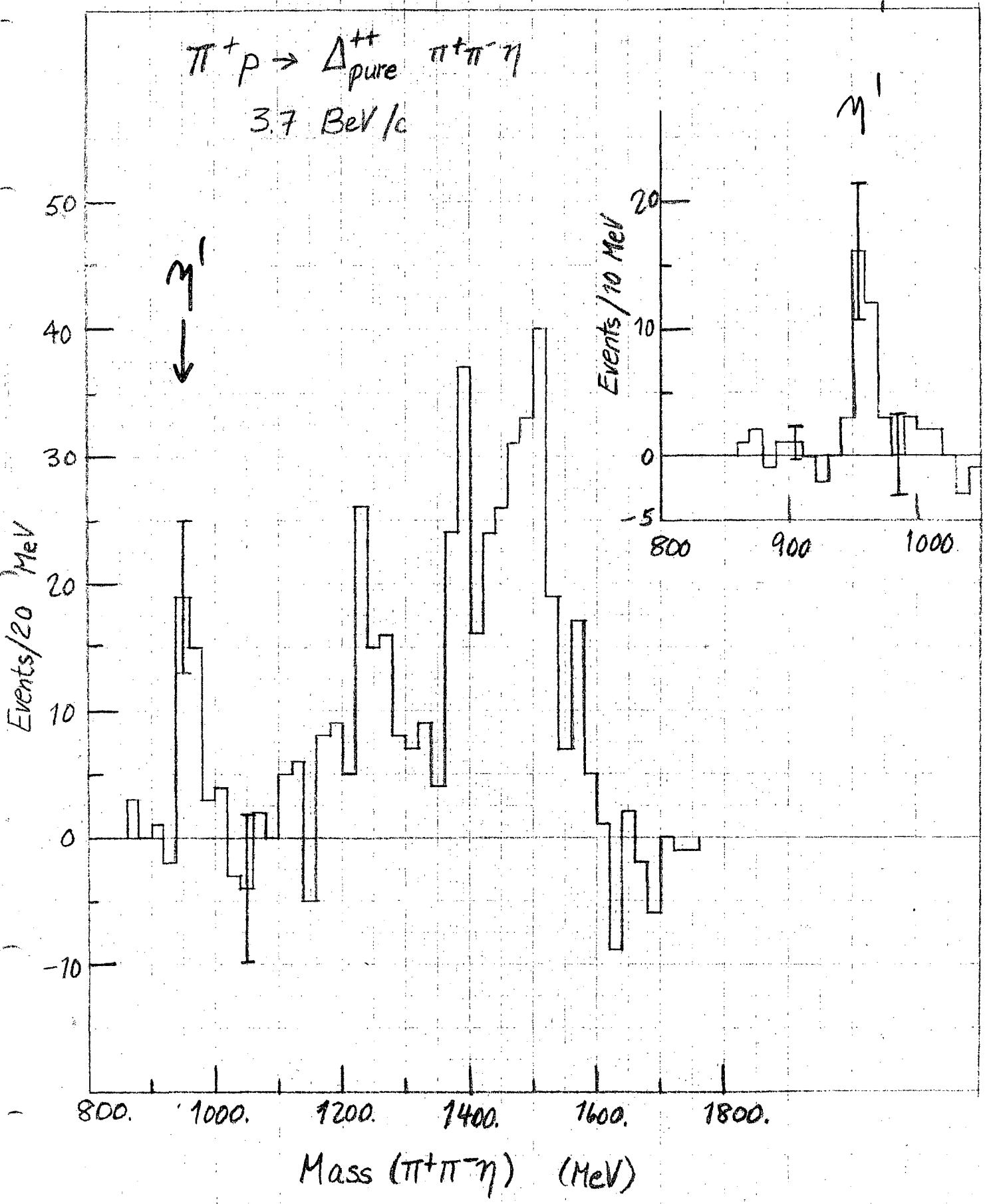

$\pi^+ p \to \Delta^{++}_{pure}\ \pi^+\pi^-\eta$
3.7 BeV/c
η'
η'
Events/20 MeV
Events/10 MeV
50
40
30
20
10
0
-10
20
10
0
-5
800
900
1000
800.
1000.
1200.
1400.
1600.
1800.
Mass ($\pi^+\pi^-\eta$) (MeV)

Fig. 3

3.7 BeV/c $\pi^+ p \rightarrow \Delta^{++} \pi^+ \pi^- MM$

1756 Events

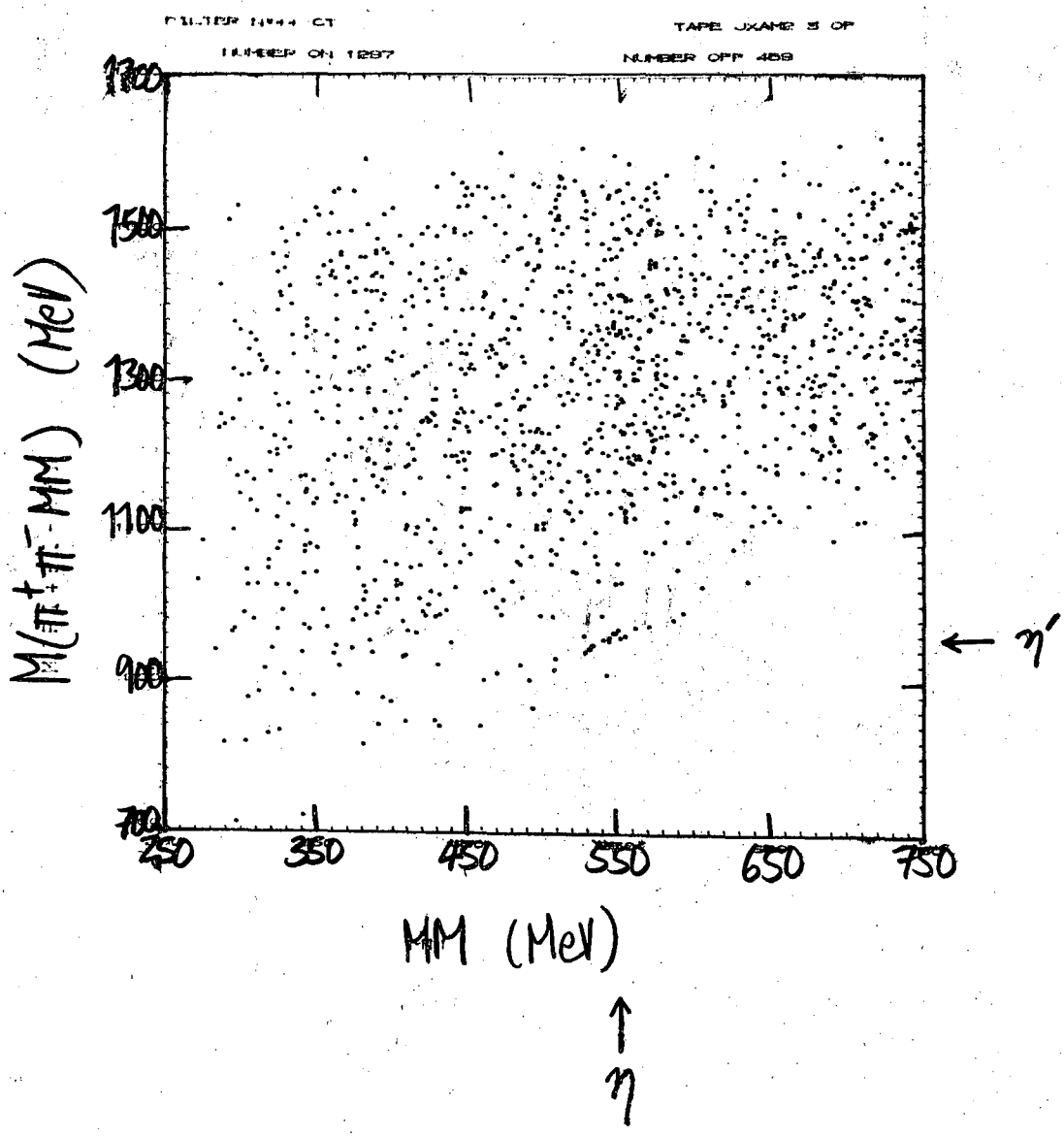


Fig. 4

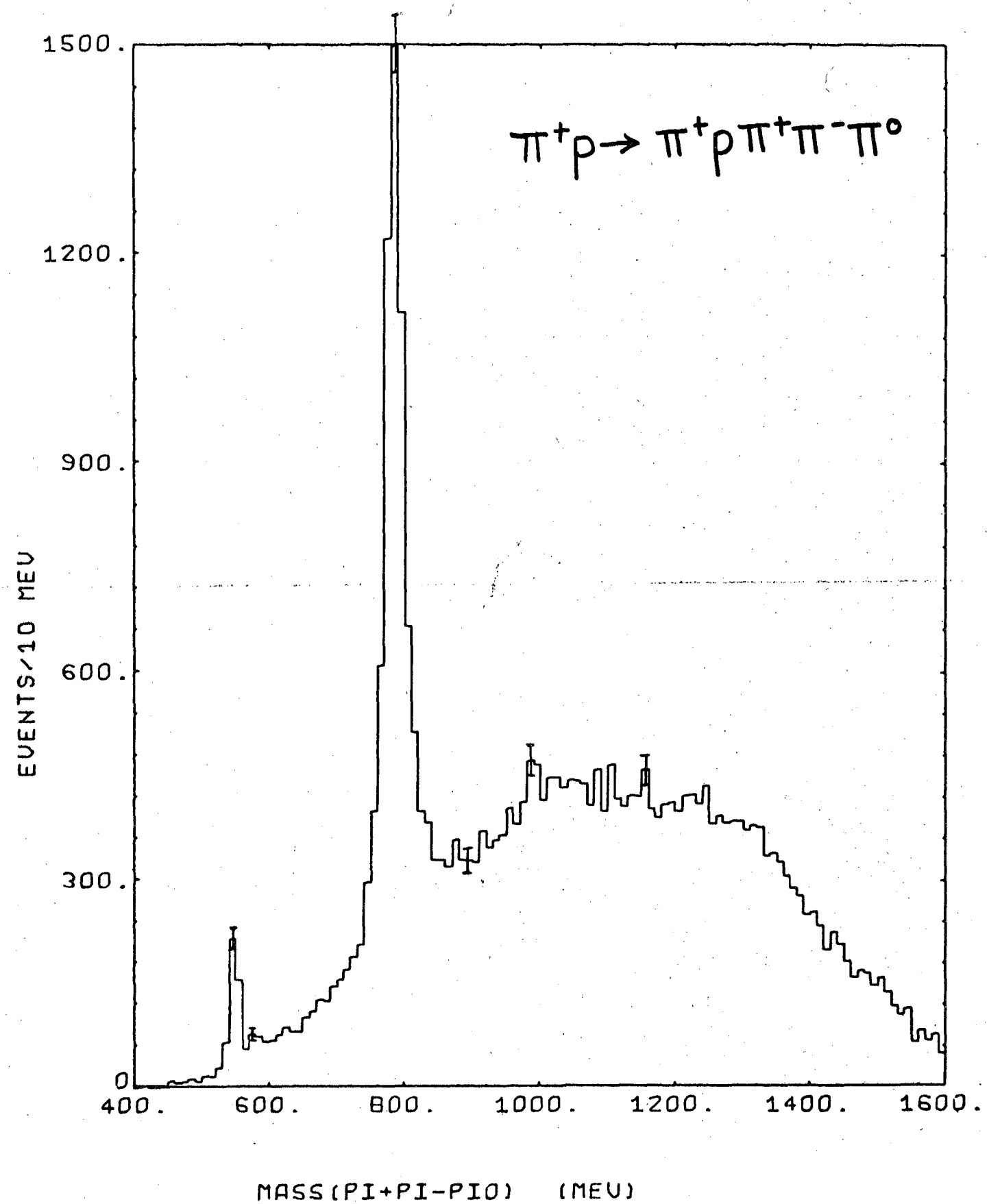
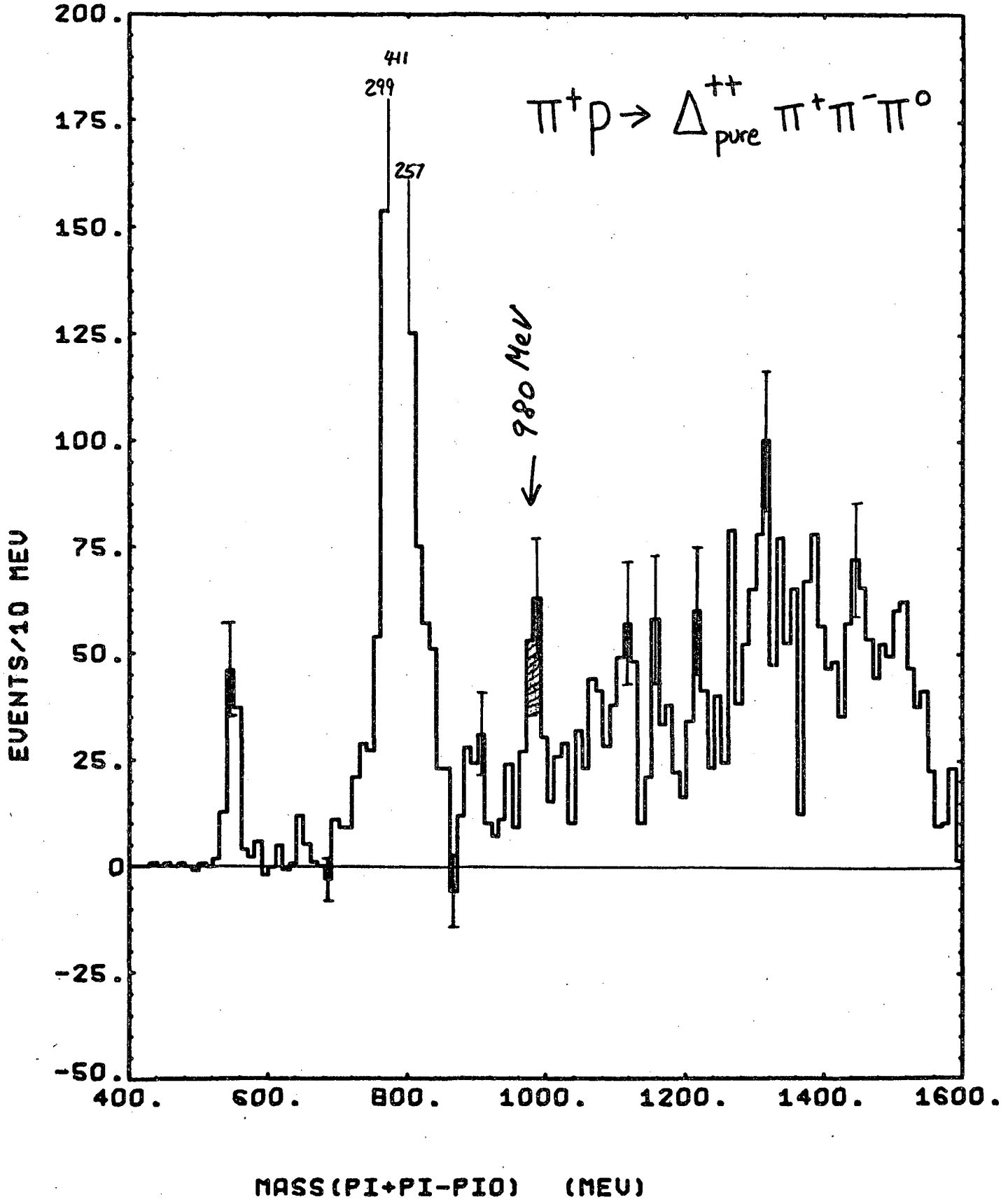

3.7 BEV/C
2 X 17082 EVENTS
$\pi^+ p \rightarrow \pi^+ p \pi^+ \pi^- \pi^0$
1500.
1200.
900.
600.
300.
0
EVENTS/10 MEV
400.
600.
800.
1000.
1200.
1400.
1600.
MASS(PI+PI-PIO) (MEV)

Fig. 5

3.7 BEV/C

4890 EVENTS



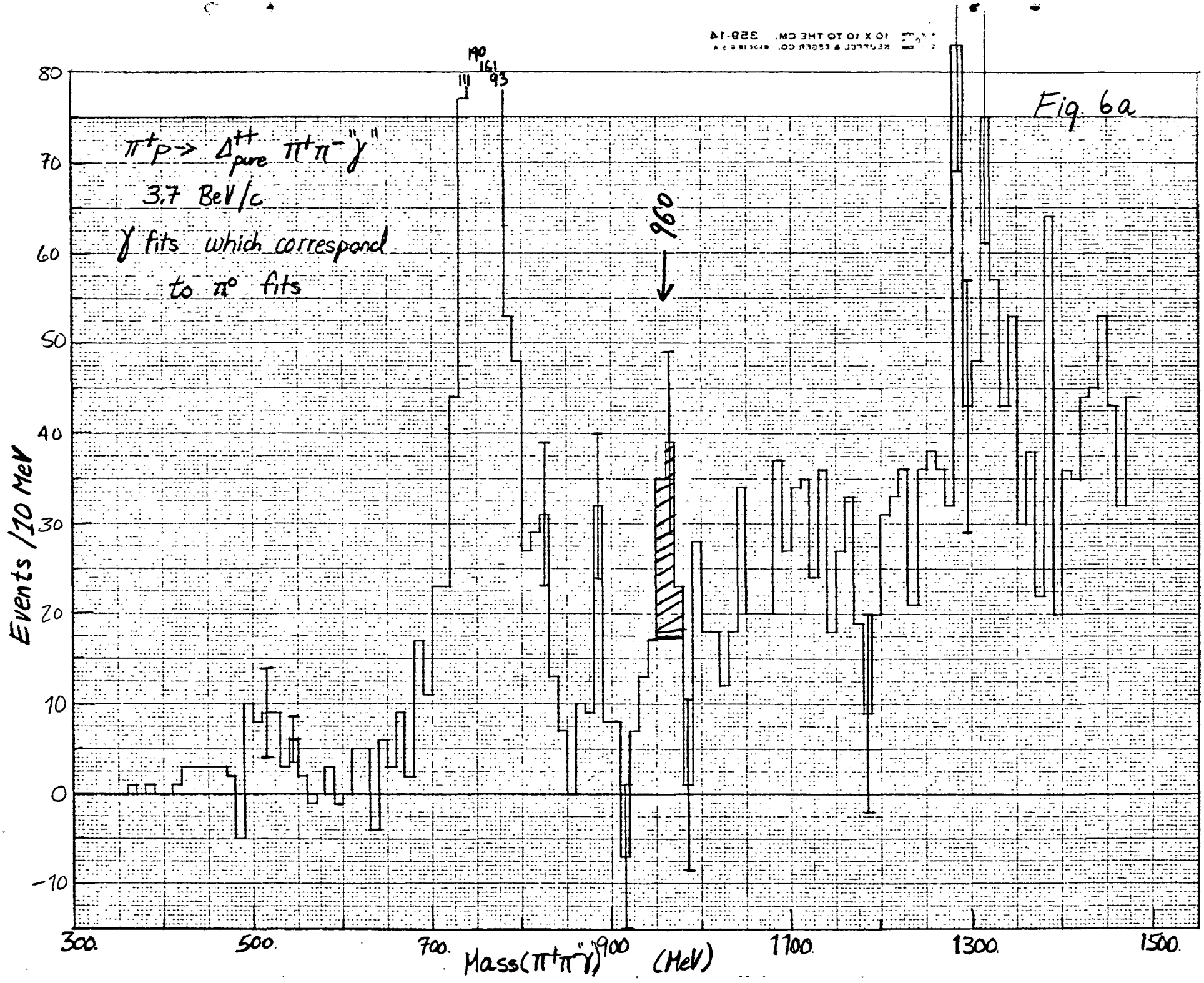


Fig. 6a
$\pi^+ p \to \Delta^{++}_{pure}\ \pi^+\pi^-\ "\gamma"$
3.7 BeV/c
γ fits which correspond to π^0 fits
960
111
190
161
93
Events /10 MeV
80
70
60
50
40
30
20
10
0
-10
300.
500.
700.
900
1100.
1300.
1500.
Mass($\pi^+\pi^-\gamma$) (MeV)

Fig. 6b

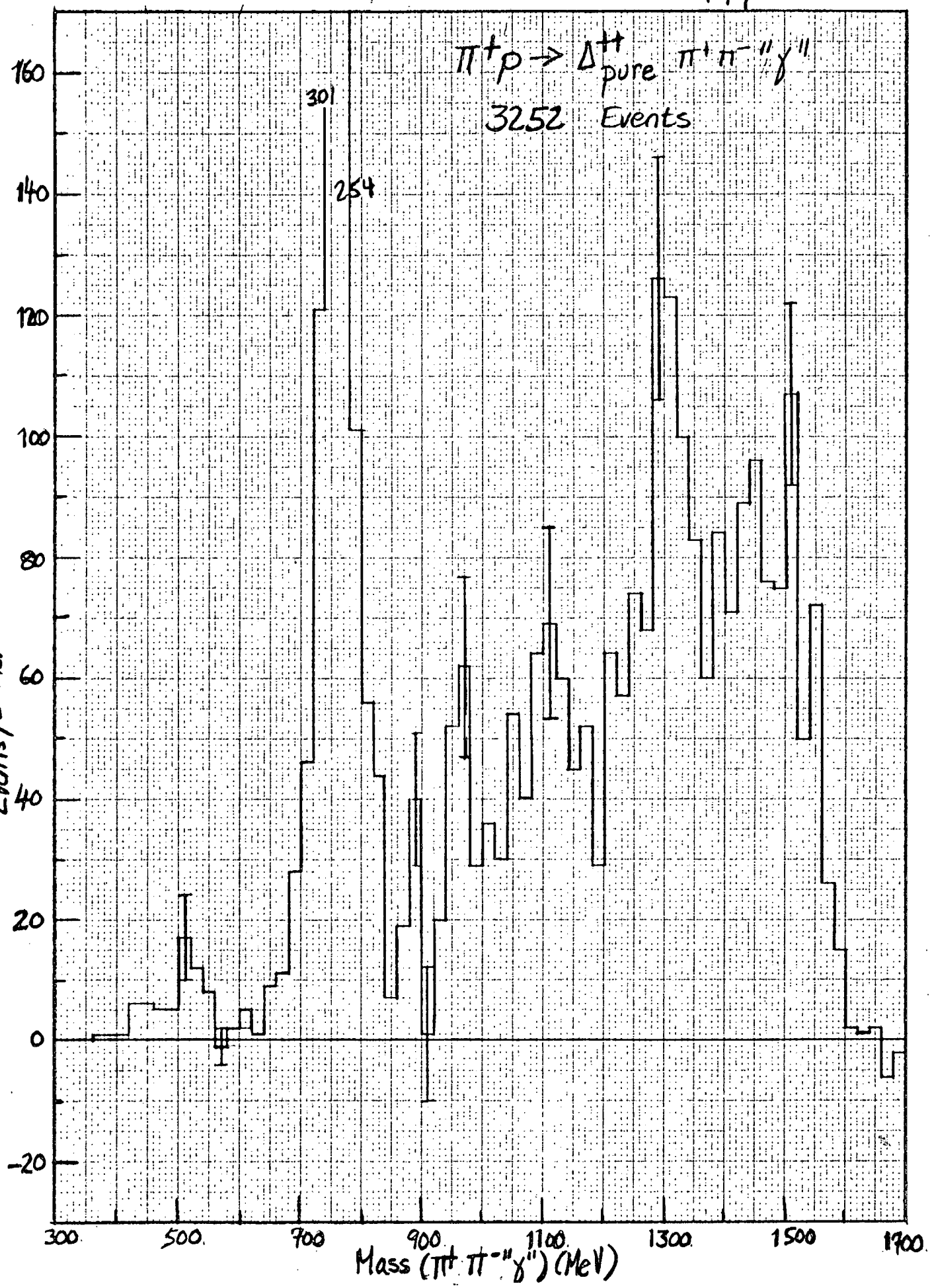

$\pi^+ p \to \Delta^{++}_{pure}\ \pi^+\pi^-\text{"}\gamma\text{"}$
3252 Events
301
254
Events /20 MeV
Mass ($\pi^+\pi^-$"γ") (MeV)
160
140
120
100
80
60
40
20
0
-20
300
500
700
900
1100
1300
1500
1700

Fig. 7

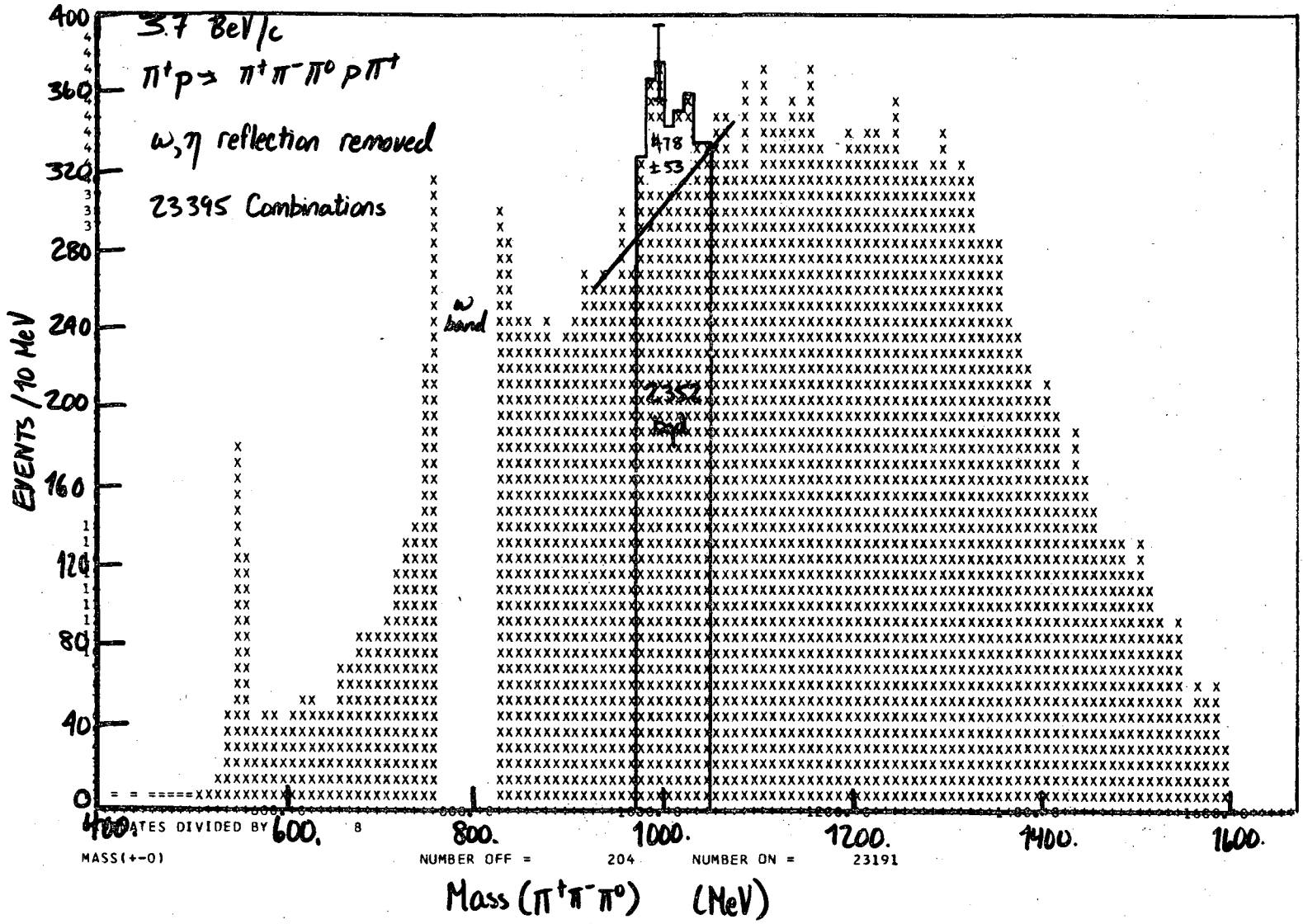

3.7 BeV/c
π⁺p → π⁺π⁻π⁰pπ⁺
ω, η reflection removed
23395 Combinations
ω band
478 ±53
2352
EVENTS / 10 MeV
400
360
320
280
240
200
160
120
80
40
0
400.
600.
800.
1000.
1200.
1400.
1600.
MASS(+-0)
NUMBER OFF = 204
NUMBER ON = 23191
Mass (π⁺π⁻π⁰) (MeV)

Fig. 8

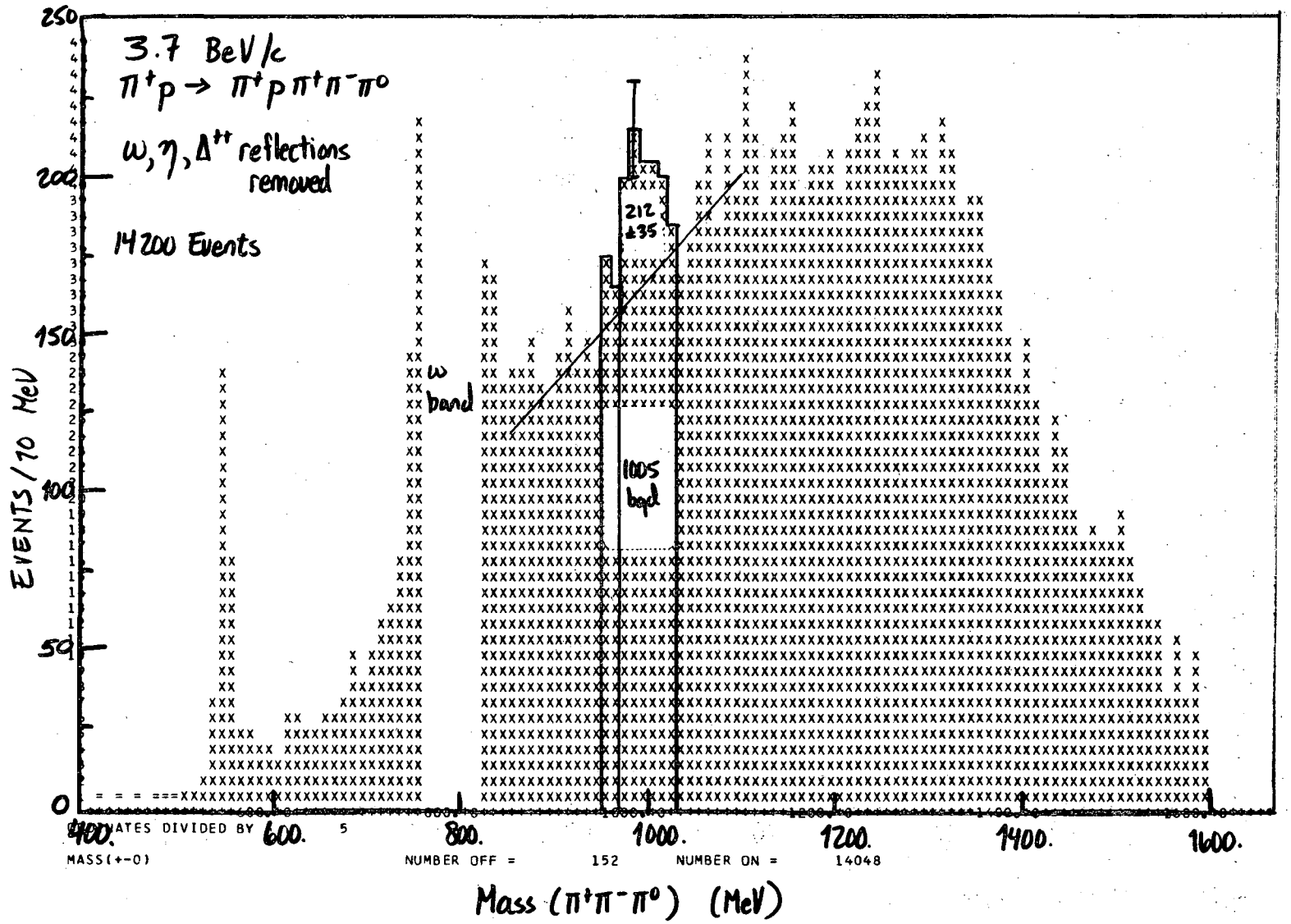
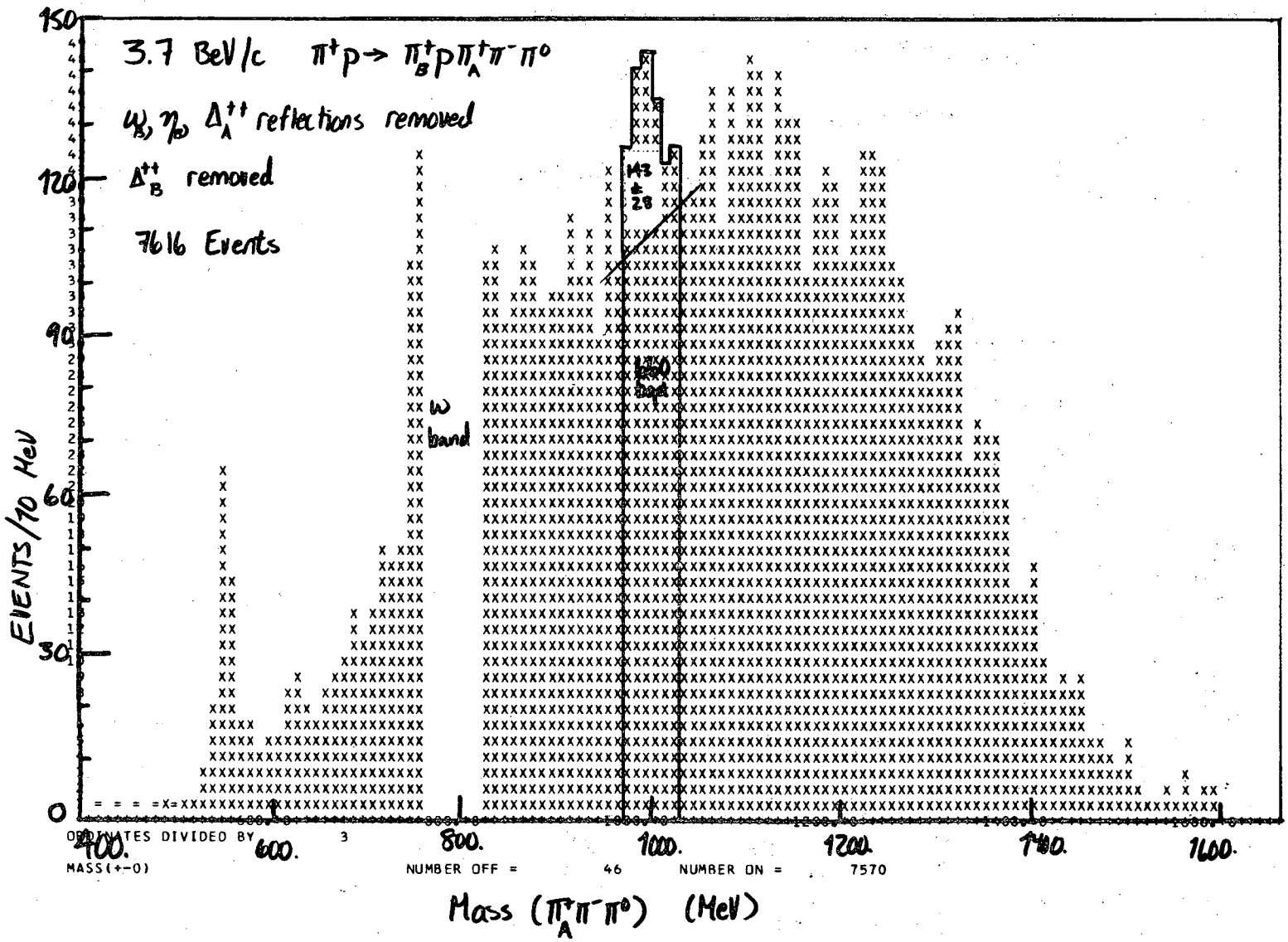

3.7 BeV/c
$\pi^+ p \to \pi^+ p \pi^+ \pi^- \pi^0$
$\omega, \eta, \Delta^{++}$ reflections removed
14200 Events
212 ±35
ω band
1005 band
EVENTS/10 MeV
250
200
150
100
50
0
400.
600.
800.
1000.
1200.
1400.
1600.
MASS(+-0)
NUMBER OFF = 152
NUMBER ON = 14048
Mass ($\pi^+\pi^-\pi^0$) (MeV)

Fig. 9


3.7 BeV/c $\pi^+ p \to \pi_B^+ p \pi_A^+ \pi^- \pi^0$
$\omega_B, \eta_B, \Delta_A^{++}$ reflections removed
Δ_B^{++} removed
7616 Events
143 ± 28
ω band
EVENTS/10 MeV
150
120
90
60
30
0
400.
600.
800.
1000.
1200.
1400.
1600.
ORDINATES DIVIDED BY 3
MASS(+-0)
NUMBER OFF = 46
NUMBER ON = 7570
Mass ($\pi_A^+ \pi^- \pi^0$) (MeV)

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