Contribution to the XVth International
Conference on High-Energy Physics,
Kiev, U. S. S. R., August 26-
September 4, 1970

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A COMPARISON OF $\Delta\eta$ AND $\Delta\eta'$ PRODUCTION AT 3.7 GeV/c*

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August 14, 1970

ABSTRACT

The channels $p\pi^+\eta$ and $p\pi^+\eta'$ are studied at 3.7 GeV/c. The $\Delta^{++}\eta$ and $\Delta^{++}\eta'$ data are compared to a Reggeized A_2 exchange model, and are found to be adequately described. The branching ratio $R = \Gamma(A_2 \to \eta'\pi)/\Gamma(A_2 \to \eta\pi)$ is measured directly from the $\eta'\pi$ and $\eta\pi$ mass distributions, as well as from the ratio of the coupling constants for $\Delta^{++}\eta'$ and $\Delta^{++}\eta$ production. Both estimates are consistent with a value of $R = 0.04 \pm 0.04$.

I. INTRODUCTION

We present preliminary results of a study of production mechanisms of $\Delta^{++}(1236)$--meson resonance channels, and of a search for resonances in many-body final states. The data sample consists of events with four charged prongs in the final state from π^+p interactions at 3.7 GeV/c.

In Section II we present the details of the data handling. In Section III we discuss in tandem the channels $p\pi^+\eta$ and $p\pi^+\eta'$. Both reactions are found to be dominated by Δ^{++} production, though we observe the decay of the A_2 into $\eta\pi$. The $\Delta^{++}\eta$ channel is found to confirm an earlier study[1] that the Δ is polarized as expected for a magnetic dipole (M1) transition at the nucleon vertex, and agreement is found with a Reggeized A_2-exchange model.[2] The $\Delta^{++}\eta'$ channel is amenable to a similar analysis, and is shown to be adequately described by the same model as the $\Delta^{++}\eta$ channel.

II. EXPERIMENTAL DETAILS

The Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber was exposed to an electrostatically separated π^+ beam at momenta near 3.7 GeV/c. Using both kinematic fitting and ionization information, we find[3,4] in the four-prong final state topology

$$\pi^+p \rightarrow p\pi^+\pi^+\pi^- \qquad (16\ 300 \text{ events}) \qquad (1)$$

$$\pi^+p \rightarrow p\pi^+\pi^+\pi^-\pi^0 \qquad (16\ 400 \text{ events}) \qquad (2)$$

$$\pi^+p \rightarrow p\pi^+\pi^+\pi^- \text{ MM} \qquad (7400 \text{ events}) \qquad (3)$$

Reaction (1) is a four-constraint (4C) kinematic fit, while reaction (2) is a one-constraint (1C) fit and reaction (3) is a zero-constraint (0C) calculation. The events considered under reaction (3) are those with two or more missing neutrals for which there is a proton identifiable by ionization.

The total cross sections for reactions (1) and (2) are 3.52±0.10 and 3.62±0.10 mb as given previously.[4]

III. $p\pi^+\eta$ AND $p\pi^+\eta'$

In Fig. 1 we show the mass distribution of the $\pi^+\pi^-\pi^o$ system from reaction (2) (two combinations per event). ω production dominates the reaction but an η signal is also clearly visible, with a width corresponding to our resolution of about 15 MeV FWHM. For purposes of analysis we define an η mass region:

$$\eta: \quad 538\text{-}558 \text{ MeV} \quad . \tag{4}$$

Using this cut, we show the $\eta p\pi^+$ Dalitz plot in Fig. 2a, and the three possible mass projections in Fig. 2b,c,d. The dominant feature of the Dalitz plot is the strong $\Delta^{++}(1236)$ signal accounting for $\sim 45\%$ of the $\eta p\pi^+$ events. The simultaneous formation of Δ^{++} and η is also demonstrated in the shaded portion of Fig. 1, where the mass of the $\pi^+\pi^-\pi^o$ system recoiling against a $p\pi^+$ mass interval at the Δ^{++}, namely,

$$\Delta^{++}: \quad 1160\text{-}1280 \text{ MeV} \tag{5}$$

is plotted.

In Fig. 1 we observe that the Δ^{++} cut leaves very little background under the η signal and therefore we estimate the $\Delta^{++}\eta$ cross section from Fig. 2b. Correcting for the tails of the η, we estimate the ratio of double resonance events to all events in reaction (2) to be

$$\frac{\pi^+ p \to \Delta^{++}\eta, \quad \Delta^{++} \to \pi^+\pi^-\pi^o}{\pi^+ p \to \pi^+ p \pi^+\pi^-\pi^o} = 0.0094 \pm 0.0012 \quad .$$

We then find the cross section for $\Delta^{++}\eta$ production to be[5] 147 ± 21 μb.

Turning to the reaction $\pi^+ p \to \pi^+ p \eta'$ we show the missing mass (MM) distribution for reaction (3) in Fig. 3. An η signal with a width of ~ 50 MeV is seen on a large background; we estimate 220 ± 60 $p\pi^+\pi^+\pi^-\eta$ events in reaction (3).

This corresponds[6] to a cross section for $\pi^+p \rightarrow p\pi^+\pi^+\pi^-\eta$ of 62±17 μb. In Fig. 4 we show a scatter plot of the ($\pi^+\pi^-$MM) effective mass plotted against MM for a narrow Δ^{++} cut. A small narrow concentration of events is seen for low ($\pi^+\pi^-$MM) masses at values of MM near the η. We identify this signal as the η', where η' decays to ππη. There are approximately 50 events in this cluster and, from a similar plot for Δ^{++} removed (not shown), we find that the η' events are predominantly associated with Δ^{++} formation, in agreement with the results of Trilling et al.[7] based on a much smaller sample. In order to determine the cross section for $\eta'\Delta^{++}$ production, we use a feature discussed by Rittenberg[8]: The phase space for $3\pi^o$'s from the $\pi^o\pi^o\eta_{charged}$ decay of the η' peaks in the η mass region and has a width roughly corresponding with that of our missing mass η. Therefore the η' decays in reaction (3) include both $\pi^+\pi^-\eta_{neutral}$ and about[8] 75% of $\pi^o\pi^o\eta_{charged}$. We include this correction in our determination of the cross section.

For the analysis of the $\Delta^{++}\eta'$ reaction we have taken those events of reaction (3) with a missing mass in the η region (510-590 MeV/c^2) and refitted them as a one-constraint hypothesis

$$\pi^+p \rightarrow p\pi^+\pi^+\pi^-\eta \qquad (\eta \rightarrow \text{neutrals}) \qquad (6)$$

with a missing η in order to improve the resolution. Although this gives only a 25% pure $\pi^+p\pi^+\pi^-$"η" sample, we find that this technique does not appear to lose any $\Delta^{++}\eta'$ events in reaction (3) and considerably improves our mass resolution. In Fig. 5 we show the $\pi^+\pi^-\eta$ mass distribution for all events fitting reaction (6). The η' signal can be seen at 960 (MeV/c)^2 and the background is reduced almost to zero by the addition of a Δ^{++} selection, as in (5). We define our η' signal as those events with a $\pi^+\pi^-\eta$ mass in the interval

η': 940-980 MeV (109 events) (7)

The $\eta' p\pi^+$ Dalitz plot is shown in Fig. 6 together with the three mass projections. Like the $\eta p\pi^+$ reaction, $\eta' p\pi^+$ is dominated by Δ^{++} production, and we show the $\eta\pi^+$ and $p\eta'$ mass projections with this signal removed. No significant evidence for other enhancements in the $\eta' p\pi^+$ final state is found. From Fig. 6c, we can set rough limits on the number of decays $A_2^+ \rightarrow \eta'\pi^+$, namely 3±3. This figure can be compared with our estimate of the number of $A_2^+ \rightarrow \eta\pi^+$ decays from Fig. 2c, namely 50±12. Correcting for the η,η' branching ratios[5] we estimate the ratio $(A_2 \rightarrow \eta'\pi)/(A_2 \rightarrow \eta\pi)$ to be 0.04±0.04, much lower than previously measured values.[10] The $\Delta^{++}\eta'$ cross section is determined from Fig. 6b, the $p\pi^+$ mass distribution for events in (6), where we estimate 53±11 $\Delta^{++}\eta'$ events. We correct for the unseen decay modes of the η' as discussed above, and find a cross section for $\Delta^{++}\eta'$ production of 30±6 μb.

The $\Delta^{++}\eta$ and $\Delta^{++}\eta'$ differential cross sections are shown in Fig. 7. (The kinematic variable plotted is $t' = |t - t_{min}|$, where $|t_{min}|$ is the smallest value of $|t|$ kinematically allowed.) A marked similarity may be seen in the shape of the angular distributions from the two channels. A further resemblance between the two channels is evident in Fig. 8, where the Δ^{++} density matrix elements are shown. For both reactions the Δ has a polarization that is consistent with that expected for a magnetic dipole (M1) transitions: $\rho_{33} = 3/8$, Re $\rho_{3,-1} = \sqrt{3}/8$, and Re $\rho_{3,1} = 0$. This feature has been noted previously for the $\Delta\eta$ channel.[1]

The curves shown in Figs. 7 and 8 are calculated using the Reggeized A_2 exchange model of Krammer and Maor.[2] While for the $\Delta\eta$ reaction we have used the coupling constants given by these authors, the $\Delta\eta'$ channel represents an extension of their model, for which we have calculated a $\pi A_2\eta'$ coupling constant which gives a best fit to the data. In the curves presented we have used Krammer

and Maor's solution.[2] The ratio of coupling constants obtained is:

$$\frac{g^2_{\pi A_2 \eta'}}{g^2_{\pi A_2 \eta}} = 0.38 \pm 0.07 \quad .$$

The agreement of the differential cross sections and the Δ density matrix elements with the model predictions is quite good.

We can relate the ratio of coupling constants to an expected ratio of decay widths using a simple d-wave angular momentum barrier:

$$\frac{\Gamma_{A_2 \to \eta' \pi}}{\Gamma_{A_2 \to \eta \pi}} = \frac{g^2_{\pi A_2 \eta'}}{g^2_{\pi A_2 \eta}} \left(\frac{P_{\pi \eta'}}{P_{\pi \eta}} \right)^5 \approx 0.01$$

This result is also smaller than the branching ratio of Ascoli et al.[10], but is compatible with our own previously quoted limit of 0.04±0.04.

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*Supported by the U.S. Atomic Energy Commission.

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1. D. Brown, G. Gidal, R. W. Birge, S. Fung, W. Jackson and R. T. Poe, Phys. Rev. D1, 3053 (1970); D. F. Grether, G. Borreani, and G. Gidal, "The Reaction $\pi^+ p \rightarrow \eta^o \Delta^{++}$ Between 1.3 and 4.0 GeV/c," submitted to the XVth International Conference on High-Energy Physics, Kiev, U.S.S.R., 1970.
2. M. Krammer and U. Maor, Nuclear Physics B13, 651 (1969).
3. More detailed information may be found in G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, Phys. Rev. Letters 23, 1351 (1969) and Ref. 4.
4. G. S. Abrams, K. W. J. Barnham, W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, and J. MacNaughton, "Observation of Regge Pole Effects in $\rho^o\Delta^{++}$ and $\omega^o\Delta^{++}$ Production at 3.7 GeV/c," UCRL-19743 (submitted to Phys. Rev. Letters).
5. We use an η branching fraction into $\pi^+\pi^-\pi^o$ of 0.230±0.011, Particle Property Tables, Rev. Mod. Phys. 42, 87 (1970). The $\pi^+\pi^-\gamma$ decay mode is not included by the η selection of Eq. (4), even though kinematically all events with a missing γ fit the π^o hypothesis. Study shows that all such misassigned events have a $\pi^+\pi^-\pi^o$ mass greater than $\sim 570\,(\mathrm{MeV/c})^2$.
6. The branching fraction of η to all neutrals is taken as 0.715 from the Particle Property Tables (Ref. 5).
7. G. H. Trilling et al., Phys. Letters 19, 427 (1965).
8. A. Rittenberg, Ph.D. Thesis, UCRL-18863, 1969 (unpublished).
9. The branching fraction of η' to $\pi\pi\eta$ is taken as 0.66±0.04 from Particle Property Tables (Ref. 5).
10. G. Ascoli et al., Phys. Rev. Letters 20, 1321 (1968).

FIGURE CAPTIONS

Fig. 1. Distribution of the $\pi^+\pi^-\pi^o$ mass for all events from reaction (2) (16,433 events plotted twice); the shaded events correspond to opposing $p\pi^+$ masses in the Δ^{++} region 1160-1280 $(MeV/c)^2$.

Fig. 2. Distributions from the channel $p\pi^+\eta$, where $\eta \rightarrow \pi^+\pi^-\pi^o$ (337 events). (a) $p\pi^+\eta$ Dalitz plot. (b) $p\pi^+$ mass distribution. (c) $\eta\pi^+$ mass distribution. (d) $p\eta$ mass distribution.

Fig. 3. Distribution of the Missing Mass (MM) for all events from reaction (3) (7400 events).

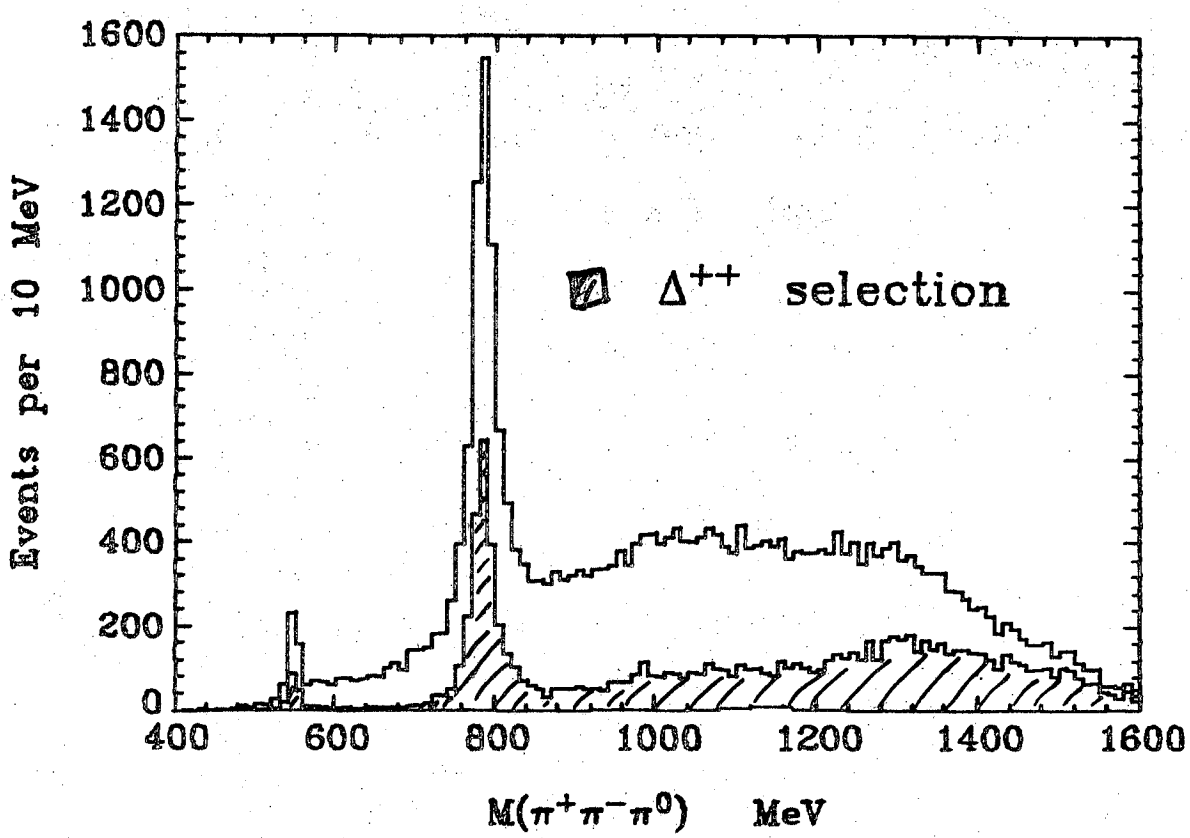
Fig. 4. Scatter plot of the ($\pi^+\pi^-$ MM) mass vs MM for events from reaction (3) with an opposing Δ^{++}, Eq. (5) (5944 events).

Fig. 5. $\pi^+\pi^-\eta$ mass distribution for events from reaction (6) (2454 events); the shaded events oppose a $p\pi^+$ mass in the Δ^{++} region, Eq. (5).

Fig. 6. Distributions from the channel $p\pi^+\eta'$, where the η' is selected by Eq. (7). (a) $p\pi^+\eta'$ Dalitz plot. (b) $p\pi^+$ mass distribution. (c) $\eta'\pi^+$ mass distribution ($p\pi^+$ not in Δ^{++} band, Eq. (5)). (d) $p\eta'$ mass distribution ($p\pi^+$ not in Δ^{++} band). The smooth curves are phase space predictions normalized to the number of events (44) with Δ^{++} out.

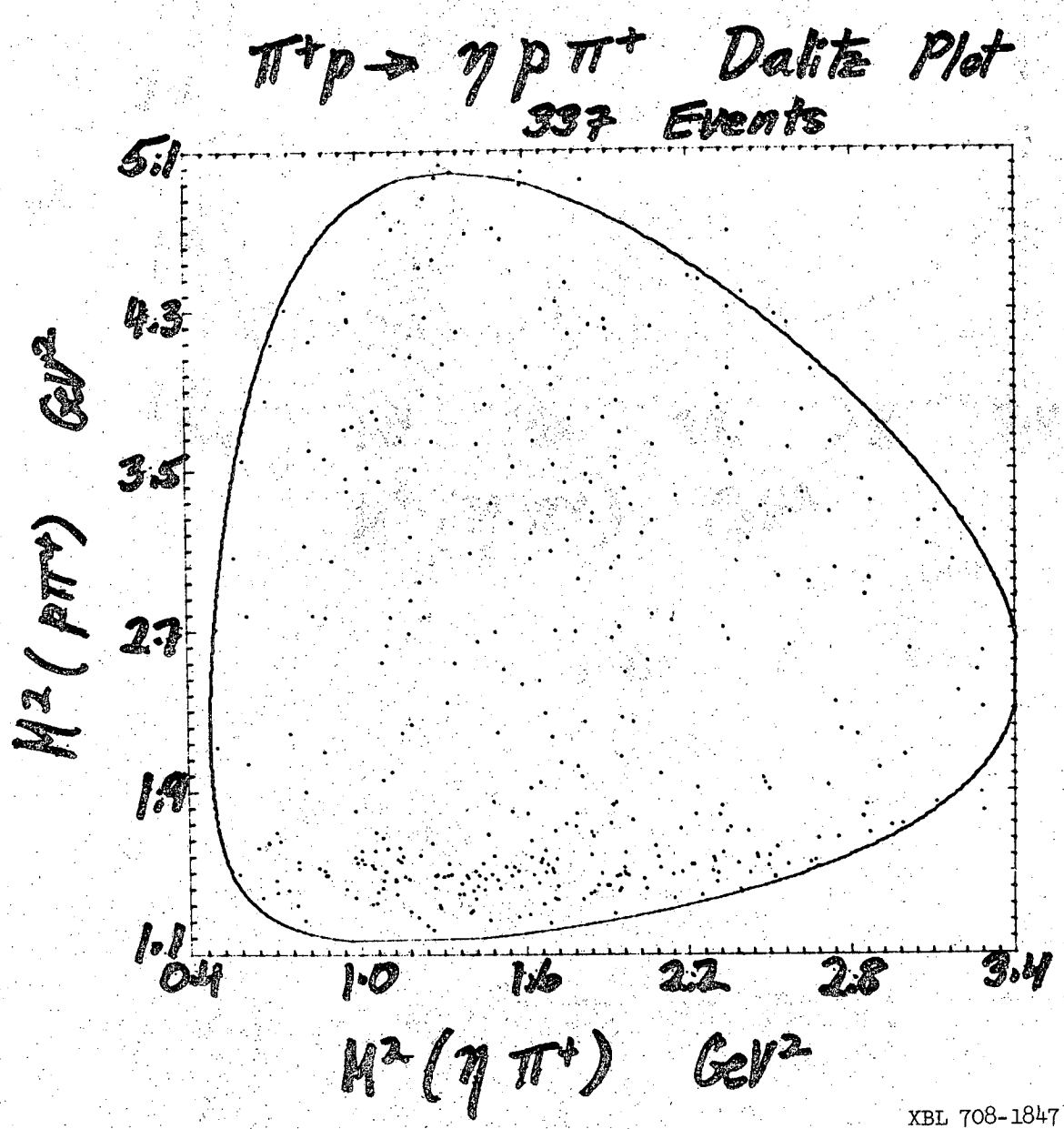
Fig. 7. Differential cross sections for $\Delta^{++}\eta$ and $\Delta^{++}\eta'$ production. The curves are described in the text.

Fig. 8. Density matrix elements of the Δ^{++} in the t-channel coordinate system for $\Delta\eta$ and $\Delta\eta'$ events.



XBL 708-1845

Fig. 1



XBL 708-1847

Fig. 2a

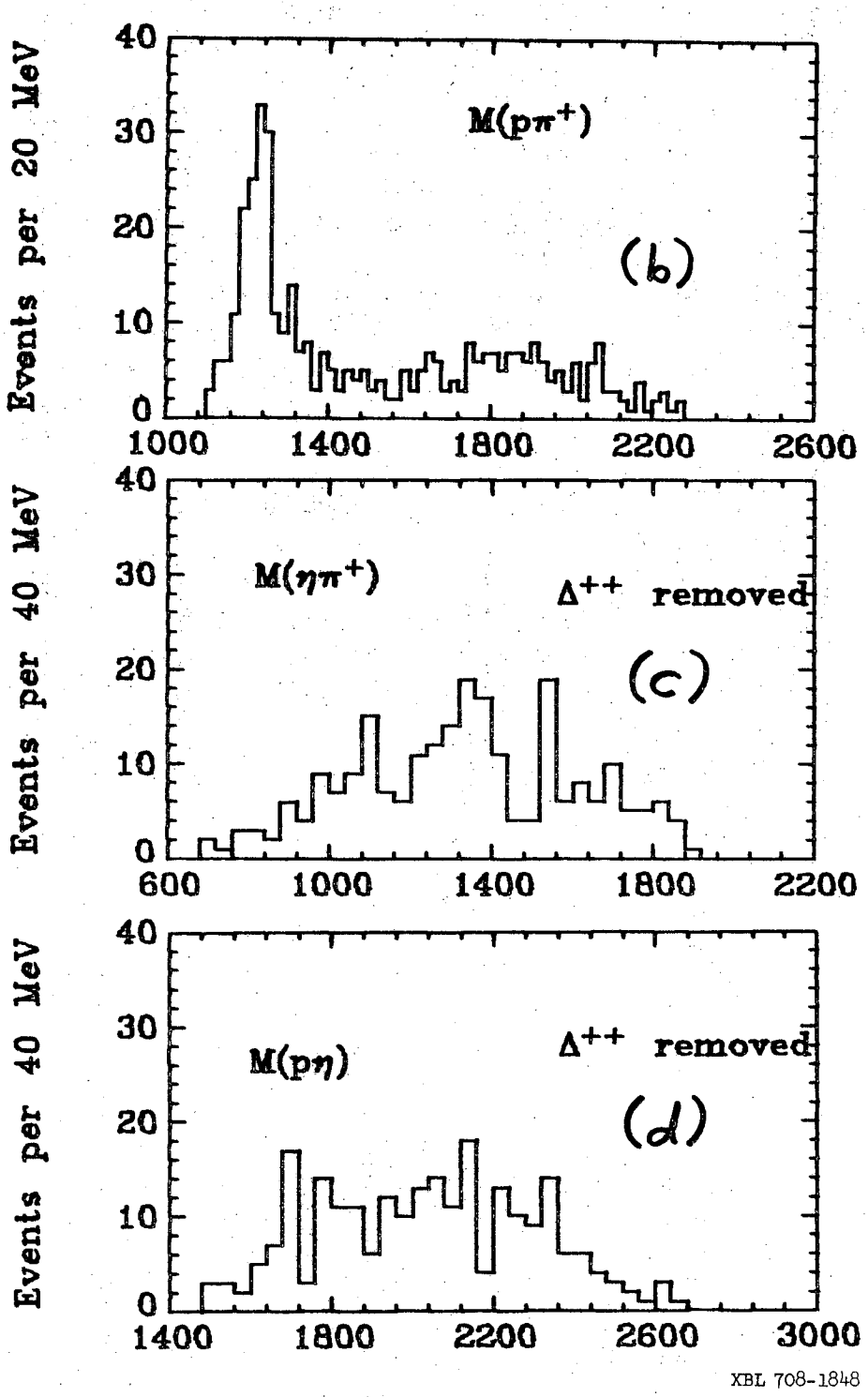

Events per 20 MeV
M(pπ+)
(b)
1000
1400
1800
2200
2600
Events per 40 MeV
M(ηπ+)
Δ++ removed
(c)
600
1000
1400
1800
2200
Events per 40 MeV
M(pη)
Δ++ removed
(d)
1400
1800
2200
2600
3000
XBL 708-1848

Fig. 2b, c, d

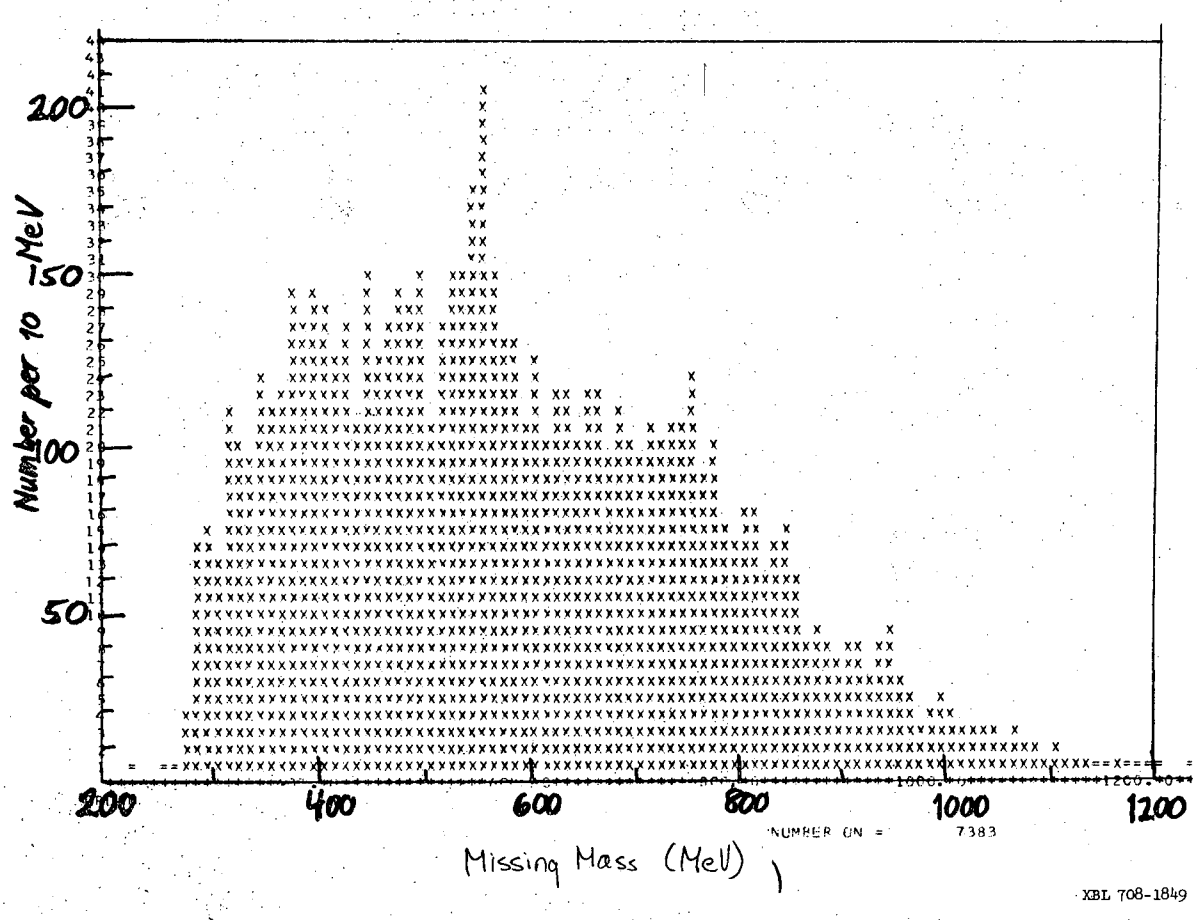
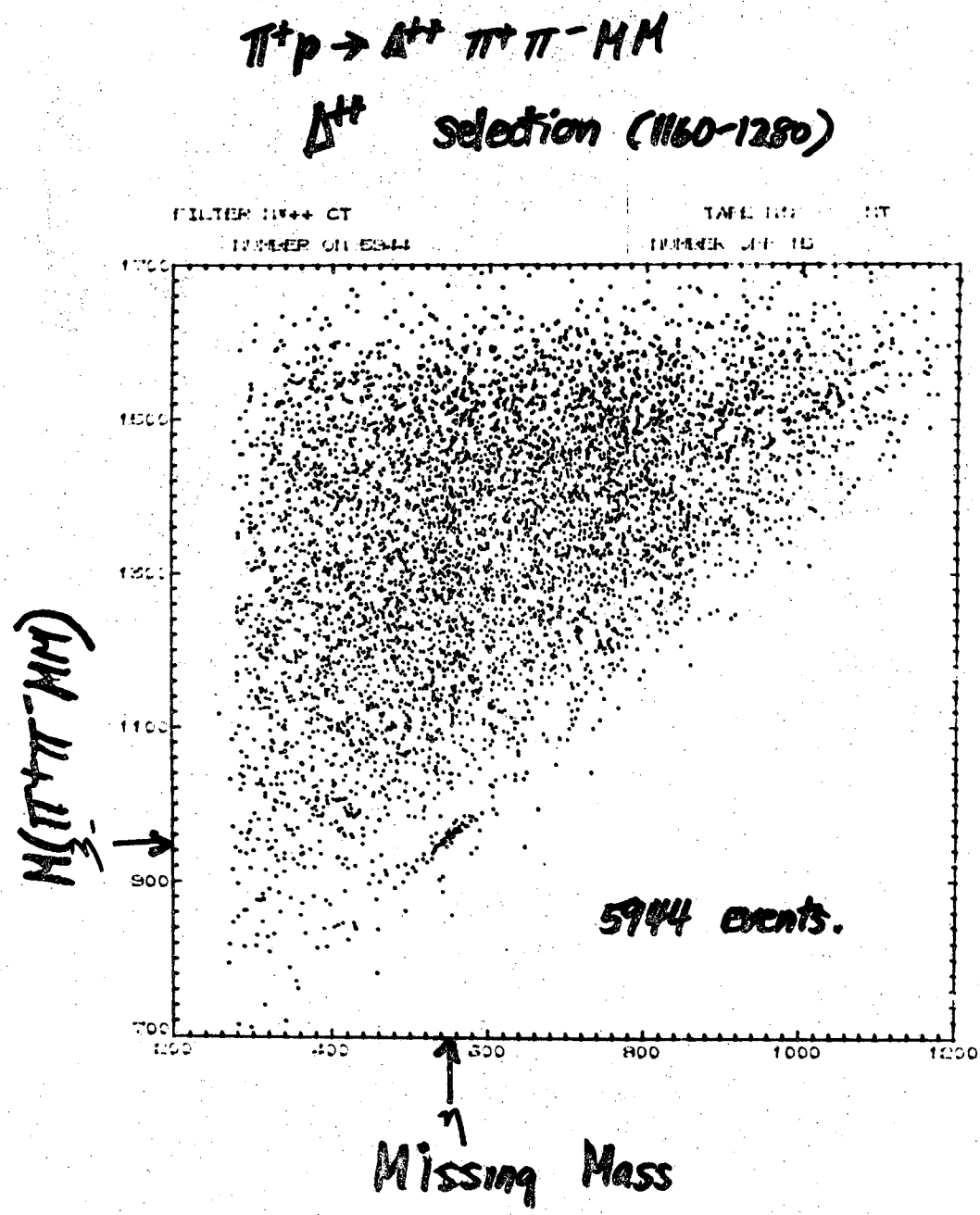
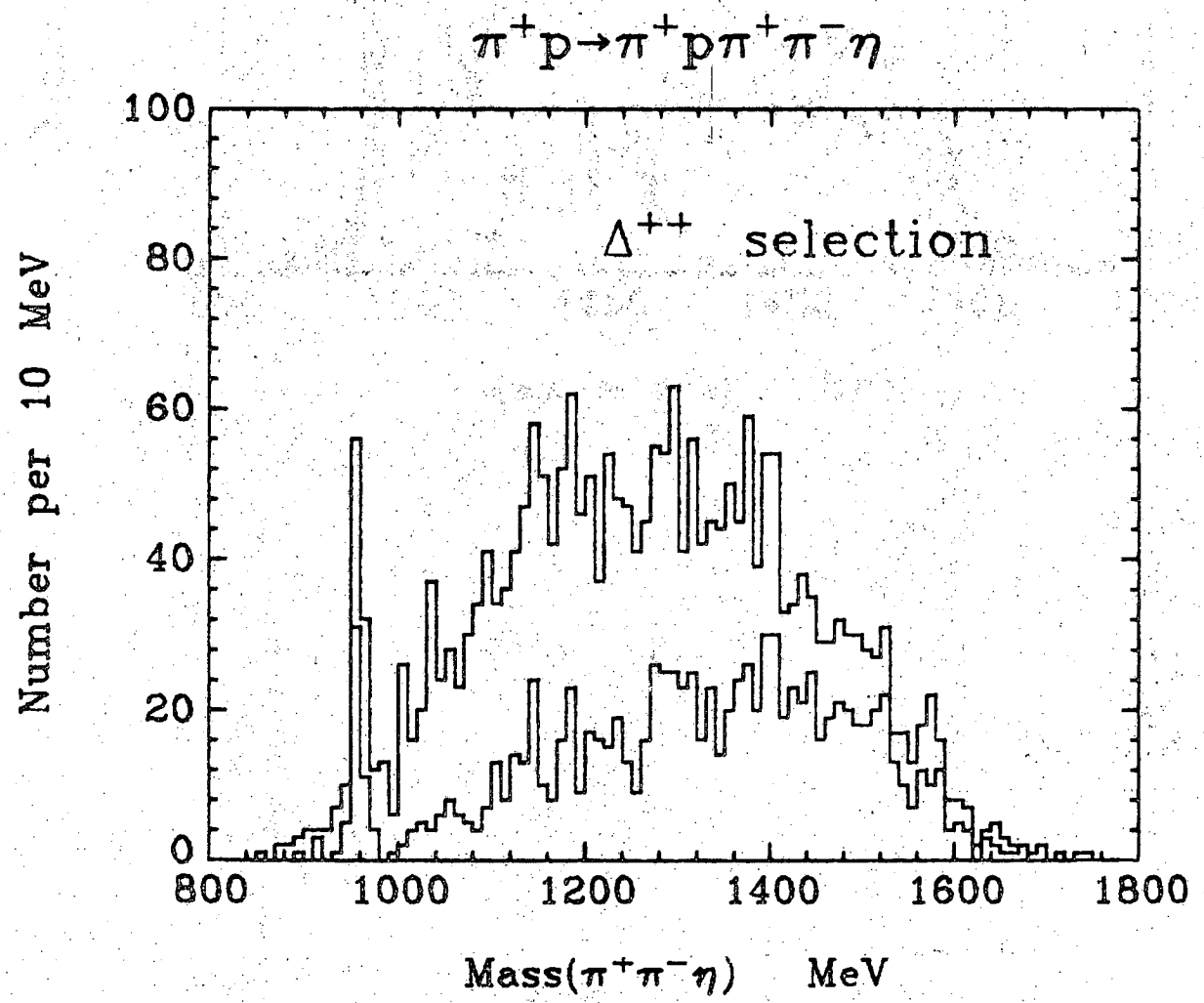

Number per 10 MeV
200
150
100
50
200
400
600
800
1000
1200
NUMBER ON = 7383
Missing Mass (MeV)
XBL 708-1849

Fig. 3



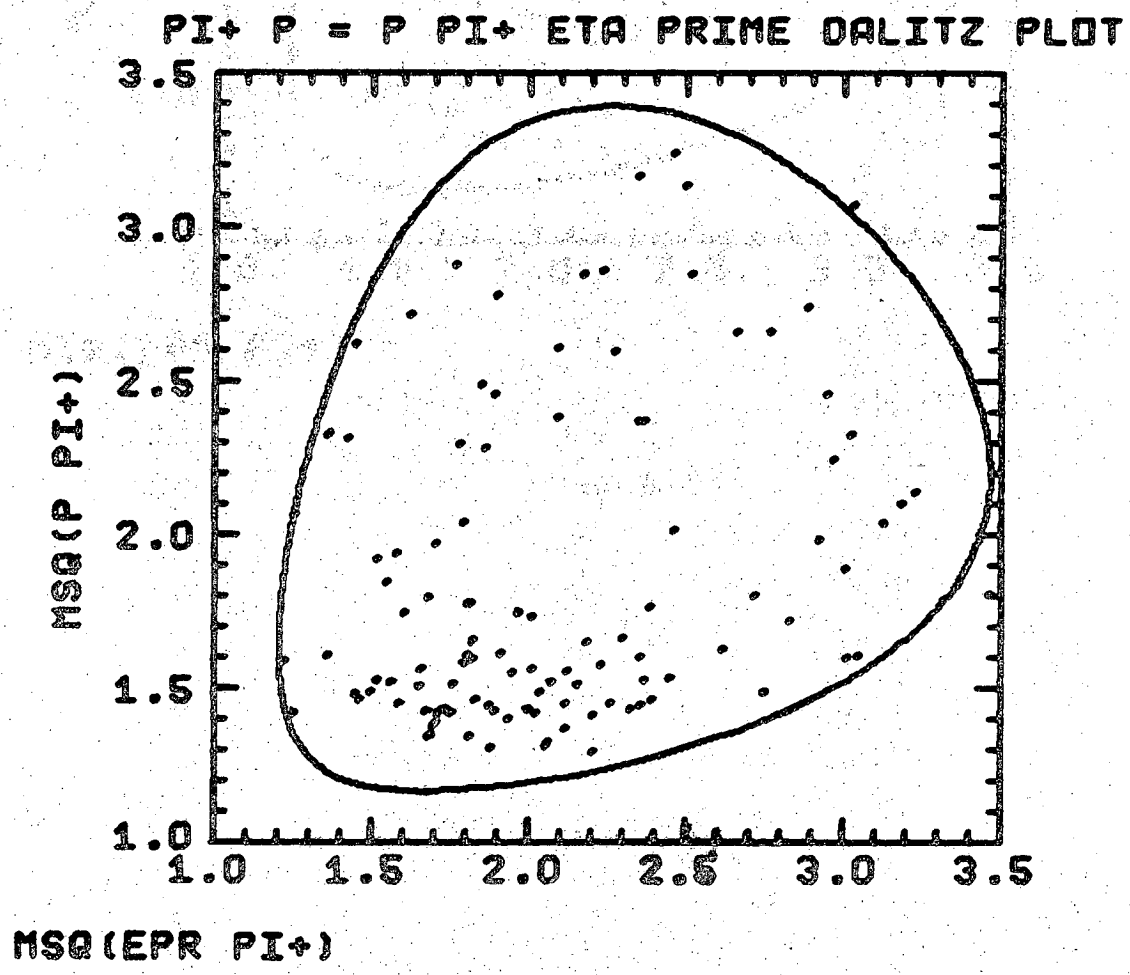
XBL 708-1850

Fig. 4



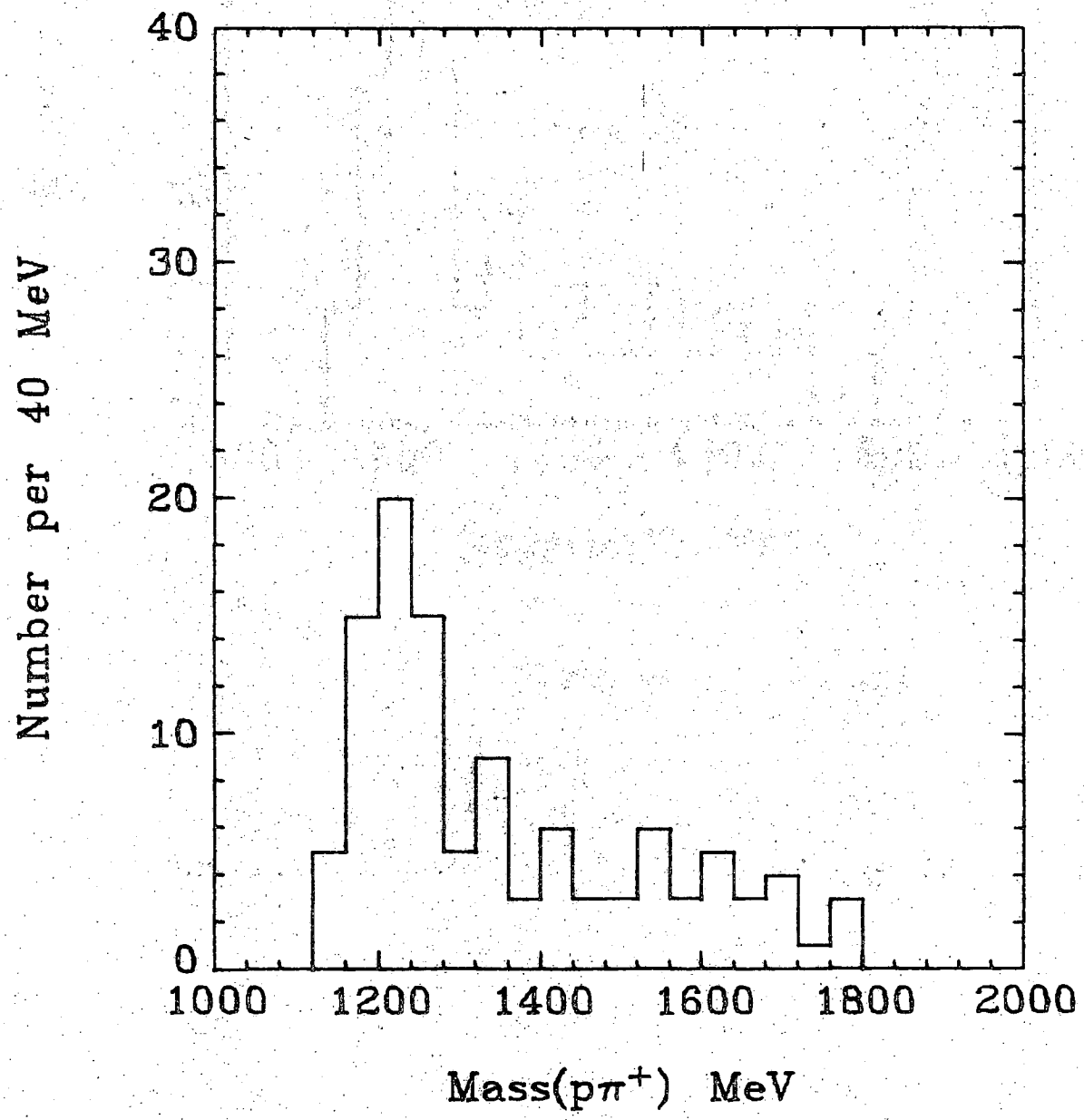
XBL 708-1851

Fig. 5



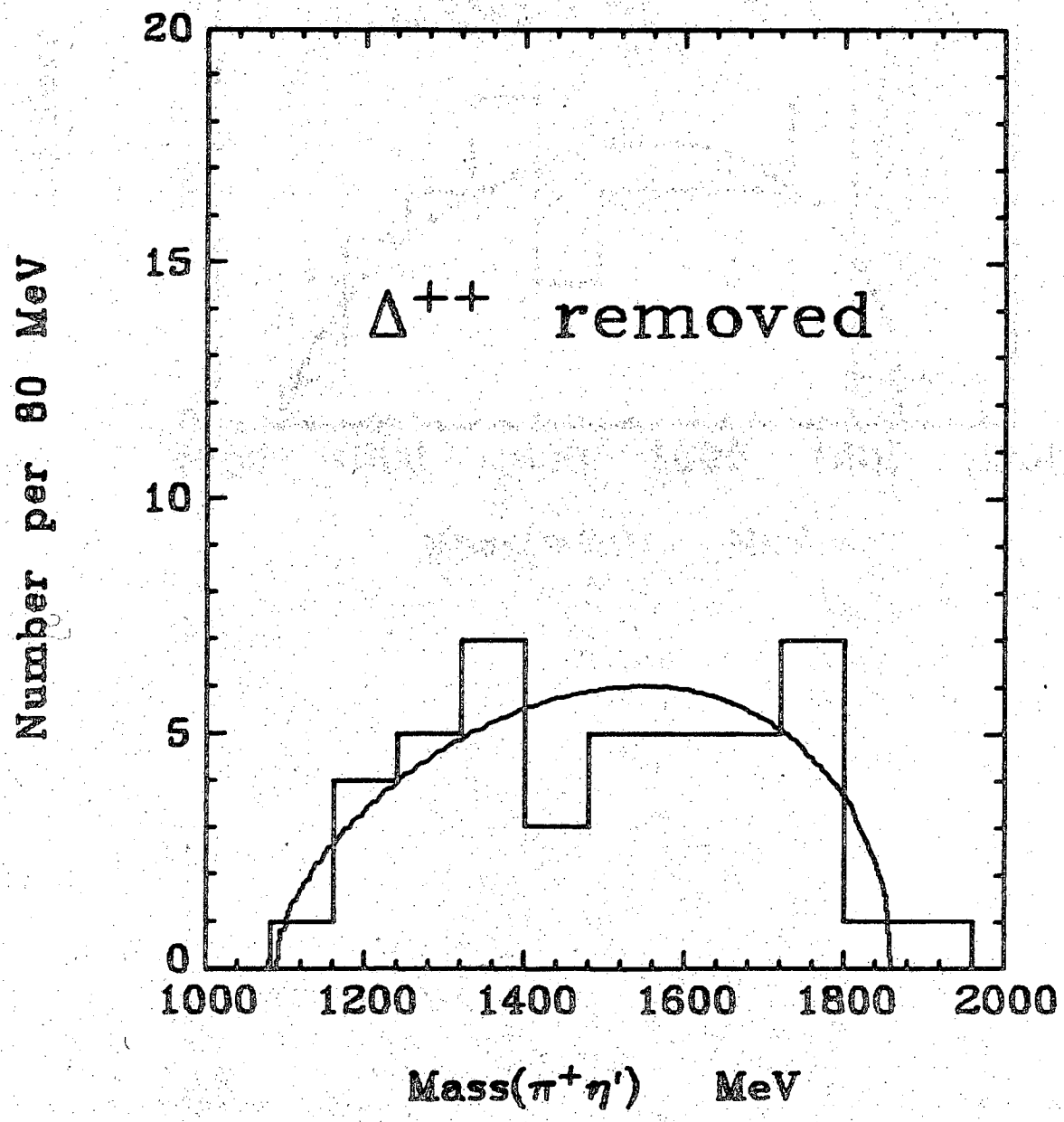
XBL 708-1852

Fig. 6a



XBL 708-1853

Fig. 6b



XBL 708-1854

Fig. 6c

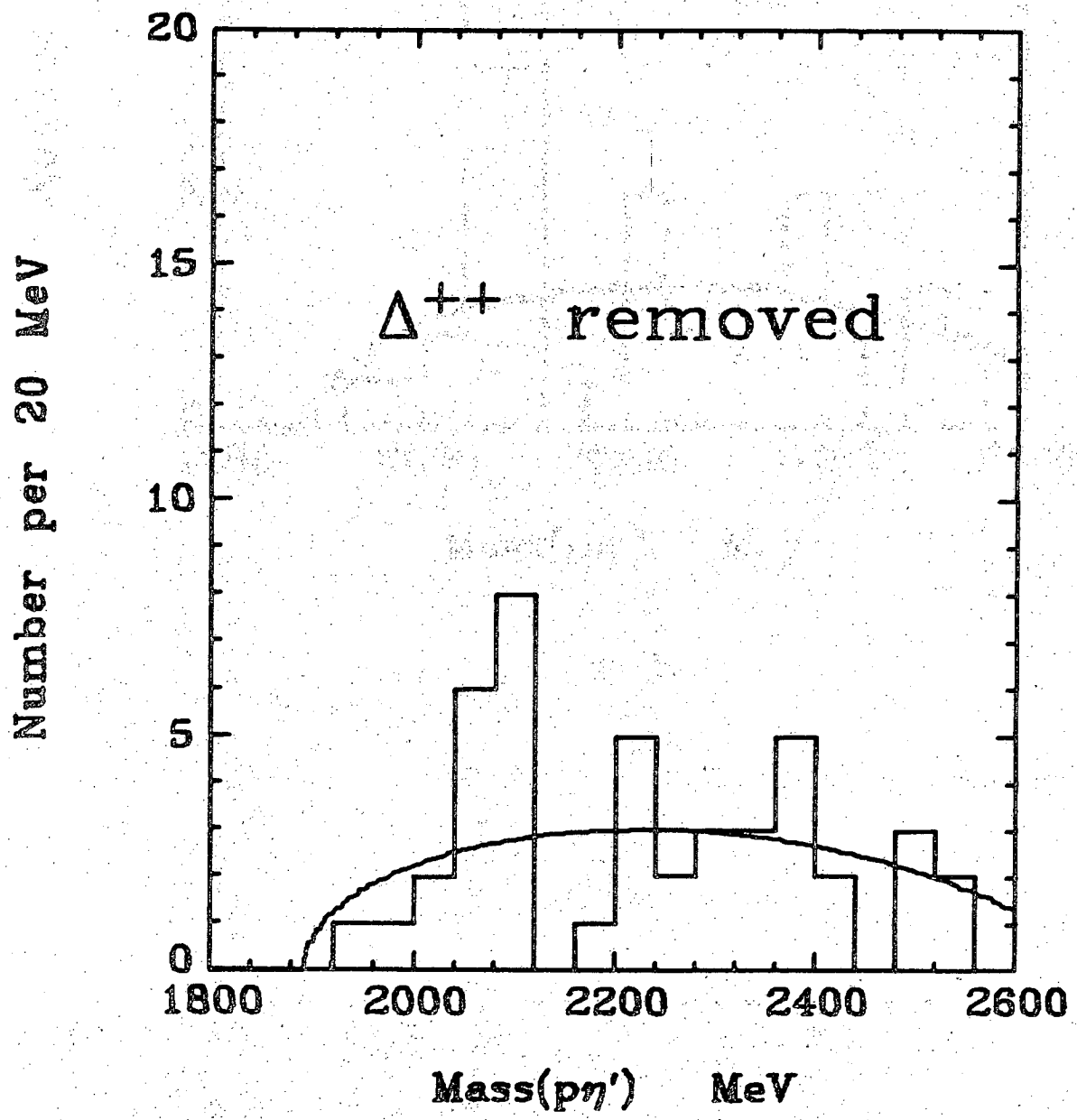


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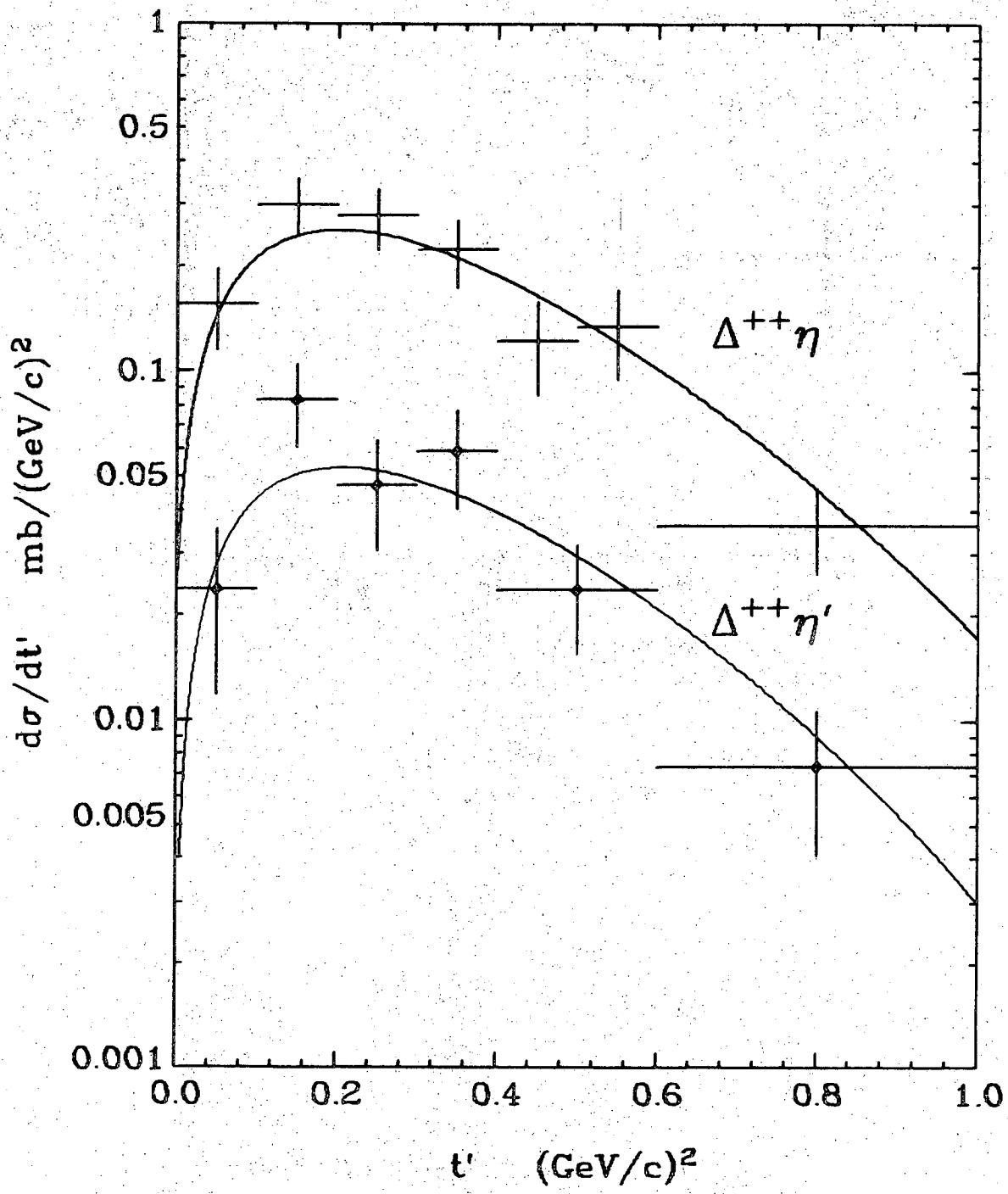
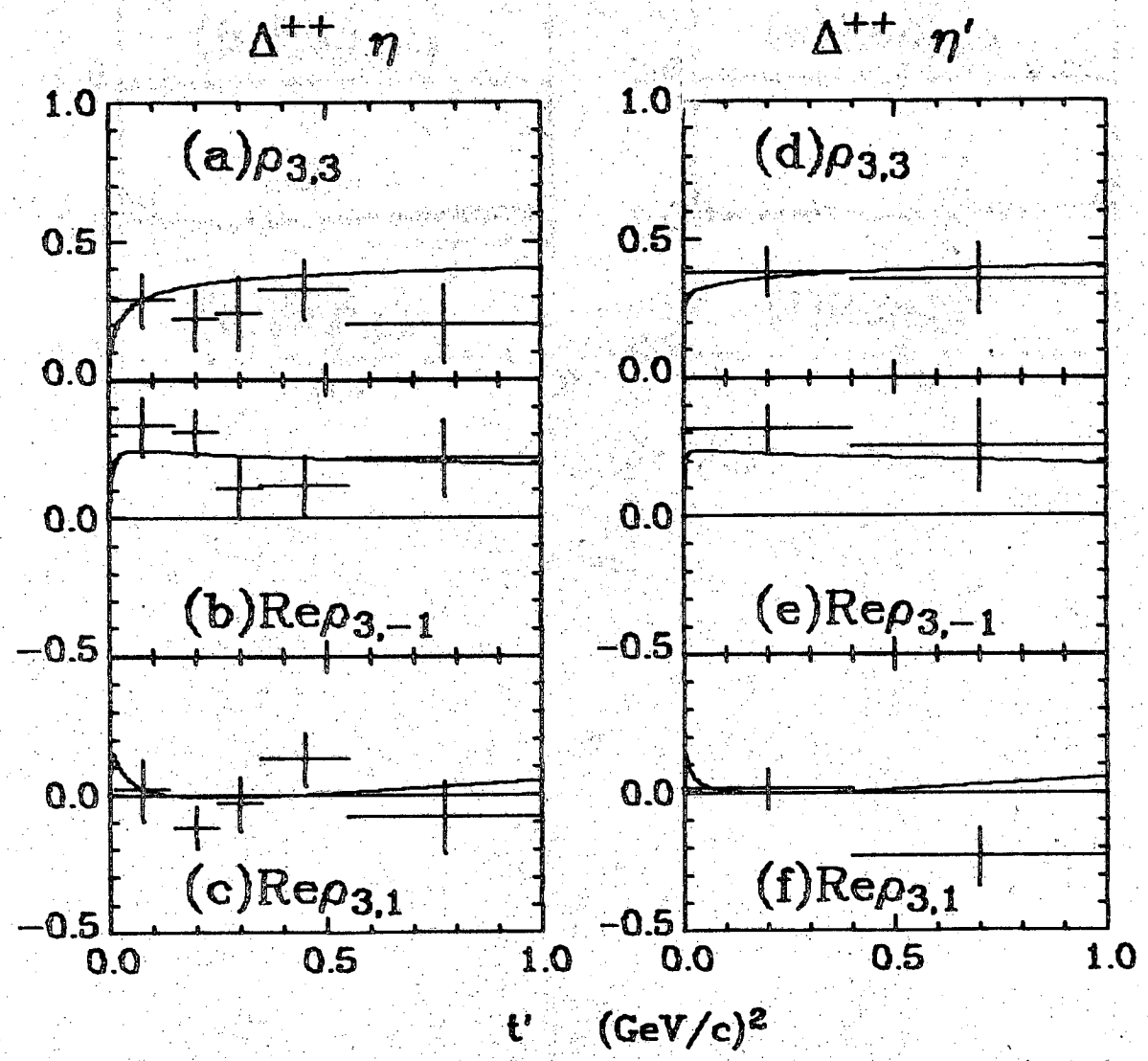
Fig. 6d



XBL 708-1856

Fig. 7



XBL 708-1857

Fig. 8

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