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EVIDENCE FOR A CHARGE ASYMMETRY ON THE ω DALITZ PLOT*

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ABSTRACT

The reaction $\pi^+p \to \pi^+p\omega$ has been studied at 3.7 GeV/c using data from the LRL 72-inch hydrogen bubble chamber. An analysis of the $\omega \to \pi^+\pi^-\pi^0$ Dalitz plot for $\sim 4{,}000$ ω events yields no evidence for $\pi^+\pi^-\pi^0$ states with isospin $I \neq 0$ at the level of 10^{-3} in intensity relative to the $I = 0$ intensity. A similar analysis of ~ 500 ω events produced in a kinematical region of known ρ-ω coherence yields no evidence for $\rho^0 \to \pi^+\pi^-\pi^0$ decays with $I \neq 0$ at the 1% level in intensity relative to the $\rho^0 \to \pi^+\pi^-$ mode. A significantly nonzero value of the charge asymmetry $\alpha = (N_+ - N_-)/(N_+ + N_-)$ is observed (0.179 ± 0.051) for ω events produced opposite a $\Delta^{++}(1236)$ in the narrow $t' = |t - t_{min}|$ range $[0.08,\ 0.20\ (\mathrm{GeV}/c)^2]$. We discuss four possible origins for the observed interfering amplitude, whose quantum assignments may be deduced as $I^G = 1^-$, $J^{PC} = 1^{-+}$: (1) C violation in ω decay (which may be ruled out); (2) C violation in $\rho^0 \to \pi^+\pi^-\pi^0$ decay; (3) a miscellaneous coherent background amplitude with these quantum numbers; and (4) a possible exotic resonant state with these quantum numbers.

I. INTRODUCTION

We have performed an analysis of the $\omega \to \pi^+\pi^-\pi^0$ decay Dalitz plot in a search for amplitudes which are small in magnitude (relative to that of the ω), using their possible interference with the ω as a probe. From angular momentum and parity conservation an interference on the ω Dalitz plot is possible only for a spin parity (J^P) state of 1^-. Our Dalitz plot analysis is thus sensitive only to $J^P = 1^-$ amplitudes which overlap the ω in mass (as well as other dynamical variables which characterize the ω state vector). Such amplitudes may be characterized by the isospin, I, of the $\pi^+\pi^-\pi^0$ system, where I could have the values I = 0, 1, 2 or 3. Each value of I gives rise to a distinctive interference pattern on the ω Dalitz plot, which is the basis for our analysis.

Since the $\pi^+\pi^-\pi^0$ decay mode has a G parity $[G = C(-1)^I]$ of -1, strongly decaying states with I odd (1 or 3) must have an even value under charge conjugation C. Hence in particular our search could reveal the presence of a $J^{PC} = 1^{-+}$ state. At present no experiment has established the existence of such a state,[1] which, within the context of the quark model, cannot be formed from a quark-antiquark ($q\bar{q}$) pair.

Our search was motivated by an attempt to find interference effects of the ρ on the ω corresponding to the ω-ρ interference observed[2] in the $\pi^+\pi^-$ mass distribution. We here recall that the observed interference occurred within the restricted kinematical region where the ρ^0 is produced in the quasi-two-body reaction $\pi^+p \to \rho^0\Delta^{++}(1236)$ at 3.7 GeV/c in the momentum transfer region of $t' < 0.14\ (\mathrm{GeV}/c)^2$ ($t' = |t - t_{min}|$ where $|t_{min}|$ is the lowest value of $|t|$ kinematically allowed).

In our present search we have observed evidence for a charge asymmetry on the ω decay Dalitz plot. This asymmetry is observed for

$\omega\Delta^{++}$(1236) events produced at 3.7 GeV/c in the t' interval [0.08, 0.20 $(\mathrm{GeV/c})^2$]. The proximity of this kinematical region to the region of established ω-ρ coherence may be noteworthy; however we can establish no direct link between our observed asymmetry and ρ^0 interference with the ω.

From the Dalitz plot dependence of the asymmetry we deduce that the amplitude interfering with the ω has the quantum assignments $I^G = 1^-$ and $J^{PC} = 1^{-+}$. We discuss four possible origins for the observed interfering amplitude:

(1) C violation in ω decay (which may be ruled out since such a mechanism would presumably affect all ω events, rather than a restricted subsample as observed);

(2) C violation in $\rho^0 \rightarrow \pi^+\pi^-\pi^0$ decay via a $|\Delta I| = 0$ transition;

(3) a miscellaneous background amplitude as postulated by Yuta and Okubo[3] for the specific case of $\eta \rightarrow \pi^+\pi^-\pi^0$ charge asymmetry; and

(4) a possible exotic resonant state $\tilde{\rho}$ with these quantum numbers and mass near 780 MeV.

II. DATA SAMPLE

This study is based on an analysis of 70,000 four-prong events from an exposure of 180,000 pictures in the Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber to a π^+ beam at 3.7 GeV/c. These events were measured on the Flying-Spot Digitizer (FSD); remeasurements of events failing reconstruction were performed either on the FSD or on the on-line COBWEB system using Franckenstein measuring projectors. The reconstruction and fitting were done with the SIOUX program.

The events of interest to this study fit the one-constraint hypothesis

$$\pi^+p \rightarrow \pi^+p\pi^+\pi^-\pi^0 \qquad (1)$$

with a confidence level of 0.01 or better, had no four-constraint fit to the reaction

$$\pi^+p \rightarrow \pi^+p\pi^+\pi^- \qquad (2)$$

with a confidence level better than 0.0001, and had ionization determined by the fit which agreed with the ionization measured either by the FSD or visually. Our final event sample contains 16,617 events of reaction (1) as chosen by these criteria.

III. EXPERIMENTAL RESULTS

A. Outline of the Method

It has been shown[4] that the $\pi^+\pi^-\pi^0$ Dalitz plot can reveal the presence of amplitudes which are coherent with the ω, and which have the quantum assignments $I \neq 0$ and $J^P = 1^-$. Such amplitudes can be detected by means of a generalized asymmetry analysis for $\pi^+\pi^-\pi^0$ events in the ω mass region. This analysis uses the symmetry properties of the $\pi^+\pi^-\pi^0$ amplitude as a function of the Dalitz plot variables (derived from the requirement of Bose statistics for the pions and the symmetry properties of the isospin-dependent part of the $\pi^+\pi^-\pi^0$ wave function) to construct test quantities which are sensitive to the presence of I = 1, 2 and 3 $\pi^+\pi^-\pi^0$ states.

To define these test quantities we use the Dalitz variables (in the $\pi^+\pi^-\pi^0$ rest frame)

$$X = (T_+ - T_-)/Q\sqrt{3}$$

and

$$Y = T_0/Q$$

(where T_n is the kinetic energy of the pion with charge n and Q is the available energy $M_\omega - M_{\pi^+} - M_{\pi^-} - M_{\pi^0}$). In terms of these variables the lowest order decay amplitudes D_I for $\pi^+\pi^-\pi^0$ states with $J^P = 1^-$ and isospin I are[5]

$$\vec{D}_0 = C_0\vec{q}$$
$$\vec{D}_1 = C_1\vec{q}\,X$$
$$\vec{D}_2 = C_2\vec{q}\,(1 - 3Y)$$
and
$$\vec{D}_3 = C_3\vec{q}\,X[(1 - 3Y)^2 - 3X^2]$$

where $\vec{q} = \vec{p}_+ \times \vec{p}_-$, $\vec{p}_n$ is the momentum of the pion with charge n, and the C_I are positive real numbers defined so that

$$\int_{\text{all } X,Y} |\vec{D}_I|^2 dXdY = 1 \quad .$$

With the further definition that $\epsilon_\omega = 2(M_\omega - M)/\Gamma_\omega$, the generalized asymmetries α_I, α_I' are defined in terms of the number of events N^I_{ij} satisfying the conditions

$$\begin{array}{llll} i \equiv + & \text{for} & \vec{D}_0\cdot\vec{D}_I > 0 & \\ i \equiv - & \text{for} & \vec{D}_0\cdot\vec{D}_I < 0 & \\ j \equiv + & \text{for} & \epsilon_\omega > 0 & \text{i.e., } M < M_\omega \\ j \equiv - & \text{for} & \epsilon_\omega < 0 & \text{i.e., } M > M_\omega \end{array}$$

by the relations

$$\alpha_I = [(N^I_{++} + N^I_{+-}) - (N^I_{-+} + N^I_{--})]/N$$
$$\alpha_I' = [(N^I_{++} + N^I_{--}) - (N^I_{+-} + N^I_{-+})]/N$$

where N is the total number of events $N^I_{++} + N^I_{+-} + N^I_{-+} + N^I_{--}$. As noted earlier[4] the utility of the pair $\{\alpha_I, \alpha_I'\}$ lies in their approximate projection properties: α_I measures interference of a $\pi^+\pi^-\pi^0$ state of isospin I and $J^P = 1^-$ with the imaginary part of the ω Breit-Wigner amplitude, and α_I' interference with the real part.

B. Generalized Asymmetry Analysis of the ω

The analysis method outlined in Sec. IIIA (and described in more detail in Ref. 4) is applied in this Section to our π^+p data at 3.7 GeV/c. We consider first our entire sample of ω events; for this data

the asymmetry analysis could give evidence for $\Delta I \neq 0$ $\pi^+\pi^-\pi^0$ decays of the ω.

The $\pi^+\pi^-\pi^0$ mass distributions on which our analysis is based are illustrated in Fig. 1, where we show the ω mass region for $X \leq 0$ and $X > 0$ separately for all events from reaction (1). It may be seen that the background level below the ω is not negligible ($\approx$ 20% in the region $M_\omega \pm 20$ MeV), and, further, is different for the two halves of the Dalitz plot. The ω Dalitz plot for events satisfying the condition

$$\omega \text{ in:} \qquad 764 \leq M(\pi^+\pi^-\pi^0) \leq 804 \text{ MeV} \qquad (3)$$

is shown with its projections in Fig. 2. The curves on the projections are calculated using the lowest order ω Dalitz plot density

$$\lambda = \left| \frac{\vec{q}_+ \times \vec{q}_-}{|\vec{q}_+ \times \vec{q}_-|_{max}} \right|^2 \qquad (4)$$

(defined so that $0 \leq \lambda \leq 1$) normalized to the observed number of events. There is an apparent asymmetry evident from Fig. 2b, with $X > 0$ having a larger population (2420 events) than $X \leq 0$ (2271 events); this effect is mainly due to the difference in the background under the ω for $X \leq 0$ and $X > 0$.

We correct the data for this background using the observations that the background distribution is consistent with being linearly distributed in mass for small intervals about the ω mass ($\pm$ 100 MeV), and that the ω signal is contained within $\pm$ 50 MeV from the central mass value of 784 MeV (see Fig. 1). Then measurements of the background level below and above the ω mass region (at least 50 MeV from 784 MeV) allow an interpolation which measures the background level within the ω mass region.

In Table Ia we present the raw data and the background-corrected values of the asymmetries. It may be seen that all α_I and α_I' are well within two standard deviations of zero, and thus the data offer no significant evidence[6] for ω decay to $\pi^+\pi^-\pi^0$ with $I \neq 0$. A discussion of limits that these results place on the ω decay fractions to $I \neq 0$ $\pi^+\pi^-\pi^0$ states is deferred to Sec. IVA.

We next consider a search for possible $I \neq 0$ $\pi^+\pi^-\pi^0$ decay modes of the ρ^0 via ρ-ω interference. In an earlier Letter[2] destructive interference was demonstrated in our data in the $\pi^+\pi^-$ mass distribution near the mass of the ω for events from reaction (2) subjected to the additional selection criteria

$$\Delta^{++} \text{ in:} \quad 1160 \leq M(p\pi^+) \leq 1280 \text{ MeV} \tag{5}$$

and

$$t' \leq 0.14 \ (\text{GeV/c})^2 \tag{6}$$

(corresponding to an effective t value, t_e, calculated at the central mass values of the ρ and Δ of $|t_e| = 0.22$ (GeV/c)^2). For the kinematic region specified by the relations (5) and (6), therefore, coherence between the $\Delta^{++}\rho^0$ and $\Delta^{++}\omega$ production amplitudes may be considered established at 3.7 GeV/c.

We may then use this kinematic region[7] to search for the rare decay mode

$$\rho^0 \to \pi^+\pi^-\pi^0$$

(where the isospin I of the $\pi^+\pi^-\pi^0$ is 1, 2 or 3) via ρ-ω interference on the ω Dalitz plot. The Dalitz plot for events satisfying the criteria (3), (5) and (6) is shown in Fig. 3a, and the projections in Figs. 3b,c. The curves on the projections (Figs. 3b,c) are the expected distributions (normalized to the observed number of events) using the simplest ω matrix element [see Eq. (4)]. The satisfactory agreement between the expected and observed distributions argues against the presence of large interference terms which survive an integration over the ω mass.

To make this conclusion more quantitative, and to include a possible mass dependent interference, we perform the generalized asymmetry analysis

for the data satisfying conditions (5) and (6). Treating background in the same manner as above for the case of all ω events, we present in Table Ib our results for the region of ρ-ω coherence. We find no significant evidence for a possible $\rho^0 \to \pi^+\pi^-\pi^0$ decay mode with $I \neq 0$; in Sec. IVB we return to this data to determine model dependent estimates of upper limits to the ρ^0 branching fractions which may be inferred from these results.

C. Evidence for a Charge Asymmetry

We here pursue the experimental question whether evidence exists for $I = 1$, $J^{PC} = 1^{-+}$ $\pi^+\pi^-\pi^0$ states which are produced coherently with the ω and which overlap the ω in mass so that interference with the ω is possible. This study was motivated by a search for C violation in $\rho^0 \to \pi^+\pi^-\pi^0$ decay; as shown in Sec. IIIB above we have no evidence for such a violation.

In this Section we analyze the ω Dalitz plot for ω events with different kinematic selection criteria than those imposed in Sec. IIIB. We have found evidence for a large charge asymmetry for $\omega\Delta^{++}$ events in a narrow t' interval centered near 0.15 (GeV/c)^2. The effect is demonstrated in Fig. 4, where we show a comparison of the production angular distribution for $\omega\Delta$ events with $X \leq 0$ and $X > 0$. These distributions are not corrected for background: all events satisfying conditions (3) and (5) are included. It may be seen that these two distributions are consistent with each other for all t' except for systematic departures in the interval

$$0.08 \leq t' \leq 0.20 \ (\text{GeV/c})^2 \ . \tag{7}$$

In this interval the value of $\alpha_1 = 0.18 \pm 0.05$ is significantly nonzero, while all other asymmetry parameters are consistent with zero (see Table Ic).

The large magnitude of α_1 is surprising, so that we digress at this point to mention a few of the many checks performed that attempt to account for a difference between π^+ and π^-. In Fig. 5 we show the $\pi^+\pi^-\pi^0$ mass distributions for events satisfying conditions (5) and (7) for $X \leq 0$ and $X > 0$ separately; we see that the asymmetry is associated with the ω signal, and is not due to an incorrect treatment of a relatively small ($\lesssim 5\%$) incoherent background (coherent background effects are considered in Sec. IVC). For comparison we show in Figs. 6 and 7 the corresponding mass distributions for two adjoining t' intervals, neither of which displays a strong dependence on X. For the interval of smaller t', $[0.00, 0.08\ (\mathrm{GeV}/c)^2]$, the null effect evident from Fig. 6 is consistent with our observations for the region $t' < 0.14\ (\mathrm{GeV}/c)^2$ (see Sec. IIIB). The absence of an appreciable asymmetry effect for the interval of larger t', $[0.20, 1.0\ (\mathrm{GeV}/c)^2]$ (see Fig. 7), indicates that the observed anomaly affects only a restricted t' region.

A further check on the existence of an instrumental bias is a measurement of the charge asymmetry in η decay,

$$\eta \to \pi^+\pi^-\pi^0 \quad .$$

The charge asymmetry in the η mass region (540-560 MeV) is measured to be -0.03 ± 0.05 (based on 400 events, of which 80% are estimated to be η events (see Fig. 1)); the asymmetry in adjoining background mass intervals is also found to be zero within errors. Our result thus agrees well with more precise determinations[8] of the η decay charge asymmetry, $\alpha_\eta = 0.015\pm0.005$.

For the events which satisfy the conditions (3), (5), and (7), that is the $\omega\Delta$ events which show an X dependent effect, studies were made to see if additional evidence for instrumental or dynamical effects exist. These studies[9] were designed to search for distributions other than the ω Dalitz plot dependence on X which would serve to distinguish the π^+ in the ω from the π^-, and thus to ascertain if the ω charge asymmetry is merely the reflection of some other mechanism which is able to distinguish between π^+ and π^-. While these studies are certainly not exhaustive of all possible tests, they represent what we feel are the most plausible physical mechanisms which would be charge dependent.

We note first that the charge asymmetry in our data is maximal when evaluated in the ω rest frame; evaluating the charge asymmetry using kinetic energies computed in the laboratory (α_{lab}) (see Fig. 8a), in the overall π^+p center-of-mass system (α_{cm}) (see Fig. 8b), and in the ω center of mass (α_1), we measure the values

$$\alpha_{lab} = 0.008\pm0.051$$
$$\alpha_{cm} = 0.034\pm0.051$$
$$\alpha_1 = 0.192\pm0.051 \quad .$$

The large value of α_1 (which is consistent with the value 0.179 given in Table Ic) shows that the incoherent background subtraction, not performed in this measurement, is not crucial to establish the effect. The null results for α in the lab and cm suggest that the charge asymmetry may be intrinsic to the ω rest frame.

A further check that the π^+ and π^- in the ω mass band do not retain a memory of the incident π^+ beam is to compare the π^+ and π^- angular distributions with respect to the beam, and with respect to the ω line-of-flight direction, both evaluated in the ω rest frame. No significant difference between π^+ and π^- was found for these distributions. Several models for inducing an ω charge asymmetry would predict results contrary to the above observations. A model which attributes the asymmetry to the measuring procedure (including mismeasurement of the magnetic field, bubble chamber optical distortions, etc.) would lead in general to a value of α_{lab} which is larger than α_1, since the conjectured biases would be in laboratory related variables. A dynamical mechanism leading to a distinction between π^+ and π^- would be, for example, peripheral scattering of the incident π^+, so that the outgoing π^+ retains to a large extent the incident momentum of the incoming π^+. This mechanism would appear to be ruled out by the null result for α_{cm}.

Since the charge states for the π^+ and π^- are different, when the pion interacts with other hadrons different isospin states may be involved. Thus final state correlations, perhaps in the form of resonance formation or Bose symmetry effects, could also distort the ω Dalitz plot. Angular correlation studies of the π^+ and π^- (associated with the ω) with the proton or π^+ (associated with the Δ) revealed no significant charge dependent effect. The two and three body effective mass distributions comparing the π^+ and the π^- of the ω were also consistent. In particular no evidence was found for a contamination of the data by "double ω" events (i.e., no ω signal is discernible when the effective mass of the π^-, π^0 and π^+ associated with the Δ^{++} is plotted), "double Δ^{++}" events, or by significant production of ρ^0 mesons. Our conclusion from all of the above tests is that the only distribution we have found in our ω sample satisfying conditions (3), (5) and (7) which serves to distinguish between the π^+ and π^- in the ω mass band is the ω Dalitz plot distribution in $X = (T_+ - T_-)/Q\sqrt{3}$ (or in variables which are simple functions of X such as the di-pion masses).

Returning to the Dalitz plot analysis, we show in Fig. 9 the ω Dalitz plot and projections for $\omega\Delta^{++}$ (conditions (3) and (5)) events in the t' interval (7). The data is seen to be skewed towards positive X as would be expected if the amplitude interfering with the ω had the form $BX\vec{q}$ (with $B > 0$), indicative of an $I = 1$, $J^{PC} = 1^{-+}$ amplitude. The

dotted curve in Fig. 9b represents the expected distribution if no interference were present (i.e., B = 0). A fit of the data of Fig. 9b to an empirical amplitude

$$\vec{q}\,(1 + BX) \tag{8}$$

gives a χ^2 of 9.7 for 6 degrees of freedom, compared to a χ^2 of 18.7 for a model with $B = 0$. The value of B which minimizes the χ^2 is

$$B = 0.67 \pm 0.22 \quad .$$

The Y distribution calculated using $B = 0$ and $B = 0.67$ are nearly identical; Fig. 9c shows that the calculation using $B = 0.67$ agrees well with the observed Y distribution. Further evidence concerning the Dalitz plot population for these events is given in Fig. 10, where we show the distribution in λ (see Eq. (4)). The curve on this figure is from a calculation which assumes that 5% of the data is from a phase space background (and therefore uniformly distributed in λ) as deduced from the $\pi^+\pi^-\pi^0$ mass distribution (Fig. 5), and the remainder from an $I = 0$, $J^P = 1^-$ state. (We note that a possible interference between an $I = 0$ amplitude and an $I = 1$ amplitude yields a vanishing contribution to the λ distribution, which is sensitive only to the intensities of the two states.) For comparison we show in Fig. 11 the λ distribution for all ω events (Eq. (3)), which also agrees well with the expected $I = 0$, $J^P = 1^-$ distribution plus a phase space background.

The measured Dalitz plot dependence of this interfering amplitude is evidence that the isospin of this $\pi^+\pi^-\pi^0$ state is $I = 1$, so that our result may be viewed as the observation of a $J^{PC} = 1^{-+}$ state. We caution, however, that our analysis offers no evidence that this state is resonant. Also, since only the $J^P = 1^-$ component of the interfering amplitude survives our experimental integration over the decay angular distribution of the normal to the ω decay plane, we have no information that the interfering $\pi^+\pi^-\pi^o$ system is produced in a state of definite spin-parity.

In view of the lack of information implied above, and the small but nonvanishing probability that our observation is a statistical mischance, elaborate speculation about the properties of the interfering amplitude does not appear warranted at this time. We here wish to point out, however, a few further experimental features of the data which may be relevant.

First, we note that the asymmetry is associated with ω events produced opposite a Δ^{++}. This is demonstrated in Fig. 12a, where we show the asymmetry as a function of $p\pi^+$ effective mass for events satisfying conditions (3) and (7). We observe that the asymmetry is large for $1160 \leq M(p\pi^+) \leq 1320$ MeV, in agreement with the observed shape of the $\Delta^{++}(1238)$ (see Fig. 12b).

Second, we present a brief discussion of other phenomena observed for $\omega\Delta$ events with $t' < 0.2\ (\text{GeV}/c)^2$ at 3.7 GeV/c. In Sec. IIIB above we reviewed the observation of ρ-ω interference in our data; the data indicate ρ-ω coherence for t' values up to at least 0.14 $(\text{GeV}/c)^2$, and larger values of t' cannot be ruled out by our data. We return in Sec. IVC to a discussion of ρ-ω interference as a possible mechanism to produce the observed charge asymmetry. Another interesting feature of the $\omega\Delta$ data[10] is a dip in $\rho_{0,0}\, d\sigma/dt'$ (where $\rho_{0,0}$ is the t-channel coordinate system density matrix element for the ω) in the t' interval [0.14, 0.20 $(\text{GeV}/c)^2$]. We can establish no direct relationship between the dip and the Dalitz plot asymmetry due to a lack of adequate statistics. We note, however, that similar reasoning as applied above to the distribution in λ leads one to conclude that the $\rho_{0,0}\, d\sigma/dt'$ dip, if caused by the interference of two amplitudes, necessarily involves both the ω and an additional $I = 0$, $J^{PC} = 1^{--}$ background amplitude. Thus one would have to relate two amplitudes of opposite C if one wished to consider a common mechanism for these two effects.

Finally we comment on the statistical significance of the observed effect. The asymmetry in Table Ic gives a value for α_1 that is 3.5 standard deviations from zero; since our t' interval was chosen to maximize the asymmetry, this probably represents an upper limit to the significance of the effect. We also note that one of the more striking features of Fig. 9b is the large contribution to the asymmetry of the bins bordering on the value $X = 0$ ($\pm$ 0.03); omitting the two central bins from the asymmetry calculation give a value for α_1 of 0.150$\pm$0.057, indicating that this effect at $X = 0$ is not a ful explanation for our asymmetry. This conclusion agrees with the χ^2 fitting for the parameter B (which is three standard deviations from zero), since the models with $B = 0$ and $B = 0.67$ are very similar near $X = 0$, and the bulk of the χ^2 difference must come from large $|X|$.

IV. DISCUSSION AND ANALYSIS OF RESULTS

A. Upper Limits for $\omega \to \pi^+\pi^-\pi^o$ with $I \neq 0$

The null results cited in Sec. IIIB for the Dalitz plot asymmetries for our entire ω sample (see Table Ia) can be used to infer upper limits to the $I \neq 0$ $\omega \to \pi^+\pi^-\pi^o$ decay fractions. However such upper limits are meaningful only if no other $J^P = 1^-$ $\pi^+\pi^-\pi^o$ amplitude is produced coherently with the ω. The presence of such amplitudes could entirely mask the presence of an $I \neq 0$ ω decay mode; in this Section we ignore this complication. Should a different experiment establish the existence of an $I \neq 0$ $\omega \to \pi^+\pi^-\pi^o$ decay fraction inconsistent with our measurement, then the results of this experiment would have to be reinterpreted.

As an explicit example we consider the $I = 1$ $\pi^+\pi^-\pi^0$ decay mode of the ω, and neglect a possible decrease in sensitivity due to finite mass resolution. Then for α_1 and α_1' small (so that their quadratic contributions may be neglected), we may relate the values of $\{\alpha_1, \alpha_1'\}$ to the branching fraction, $\Gamma_{1(\omega)}/\Gamma_\omega$ of $\omega \to \pi^+\pi^-\pi^0$ with $I = 1$ to all ω decays:

$$\Gamma_{1(\omega)}/\Gamma_\omega = \frac{\alpha_1^2 + \alpha_1'^2}{4} \frac{\langle X^2\rangle/\langle 1\rangle}{[\langle|X|\rangle/\langle 1\rangle]^2} \quad .$$

Here we have used the convenient notation

$$\langle Z\rangle = \iint\limits_{\substack{\text{all } X\\ \text{all } Y}} Z\ |\vec{q}|^2\ dXdY \quad ;$$

with our choice of units $\langle X^2\rangle = 0.0133\langle 1\rangle$ and $\langle|X|\rangle = 0.0960\langle 1\rangle$. Including the effects of finite mass resolution, we measure (see Sec. IVB below for details)

$$\Gamma_{1(\omega)}/\Gamma_\omega = (9.7 \pm 7.8) \times 10^{-4} \quad .$$

Present theoretical ideas[11] which attribute the violation of CP invariance in $K_L^0 \to \pi^+\pi^-$ decay to a violation of C invariance in an interaction H_F (characterized by a dimensionless coupling constant $Fm_p^2 \sim 10^{-2}$, where m_p is the mass of the proton) suggest a value of 10^{-4} for $\Gamma_{1(\omega)}/\Gamma_\omega$ if H_F has a $|\Delta I| = 1$ part. Our measured value for $\Gamma_{1(\omega)}/\Gamma_\omega$ is consistent with such an estimate, as well as with the value $\Gamma_{1(\omega)} = 0$. Thus our data cannot test the H_F hypothesis, so that further refinement of our analysis does not appear warranted at present.

The measured asymmetries for $I = 2$ and $I = 3$ yield values of $\Gamma_{2(\omega)}/\Gamma_\omega$ and $\Gamma_{3(\omega)}/\Gamma_\omega$ close in magnitude (and error) to $\Gamma_{1(\omega)}/\Gamma_\omega$. Thus to the order of 10^{-3} in intensity, the $\omega \to \pi^+\pi^-\pi^0$ decay mode is isospin conserving.

B. Upper Limits for $\rho^0 \to \pi^+\pi^-\pi^0$ with $I \neq 0$

Proceeding in formal analogy with the discussion of Sec. IVA above, we use the data in the kinematic region of known ρ-ω coherence to infer upper limits to the $I \neq 0$ $\rho^0 \to \pi^+\pi^-\pi^0$ decay fractions. The warning in the above Section about complications which ensue if other competing coherent amplitudes exist is equally applicable here. In fact, if a large $\rho \to 3\pi$ signal with $I \neq 0$ had been observed by us, then the analysis of Sec. IVA would have been invalidated. The observed null results of Table Ib indicate that the possible existence of $\rho \to 3\pi$ decay modes with $I \neq 0$ does not require a reassessment of the results of Sec. IVA.

To interpret our null results as providing upper limits to the $\rho^0 \to \pi^+\pi^-\pi^0$ decay rates with $I \neq 0$, a model is required for the mass dependence of the $\rho \to 3\pi$ amplitude, and for the degree of coherence of the ρ and ω production amplitudes. We here assume that both the ρ and the ω have simple Breit-Wigner mass distributions

$$b_\lambda(m) = \frac{\sqrt{\Gamma_\lambda/2\pi}}{m_\lambda - m - i\Gamma_\lambda/2} \quad ,$$

with values of the masses and widths taken as

$$m_\omega = 784 \text{ MeV}, \quad \Gamma_\omega = 12 \text{ MeV}$$

and

$$m_\rho = 760 \text{ MeV}, \quad \Gamma_\rho = 120 \text{ MeV}.$$

For the ρ our neglect of phase space and angular momentum barrier considerations will tend to underestimate the fraction of events which are in the neighborhood of the ω mass; thus this mass distribution yields an overestimated branching fraction for $\rho \to 3\pi$ decays. Similarly, we underestimate ξ, the ρ-ω coherence factor, with the measured[12] lower limit of 0.6, which again would lead to an overestimate of the ρ decay fraction.

As an explicit example we consider the $I = 1$ $\pi^+\pi^-\pi^0$ decay mode of the ρ^0. For this special case Eq. (4) of Ref. 4 may be written as

$$\frac{d^3n}{dmdXdY} = |A_\omega|^2 + |A_\rho|^2 + 2\xi \ \mathrm{Re}\{A_\rho A_\omega^*\}$$

where

$$|A_\omega|^2 = N_\omega \frac{\Gamma_\omega/2\pi}{(m_\omega - m)^2 + (\Gamma_\omega/2)^2} \frac{|\vec{q}|^2}{\langle 1\rangle} ,$$

$$|A_\rho|^2 = N_\rho \frac{\Gamma_1}{\Gamma_\rho} \frac{\Gamma_\rho/2\pi}{(m_\rho - m)^2 + (\Gamma_\rho/2)^2} \frac{X^2|\vec{q}|^2}{\langle X^2\rangle}$$

and

$$\mathrm{Re}\{A_\rho A_\omega^*\} = \sqrt{N_\omega N_\rho (\Gamma_\omega/2\pi)(\Gamma_1/2\pi)} \ \mathrm{Re}\left\{\frac{e^{i(\beta_1-\beta)}}{(m_\rho - m - i\frac{\Gamma_\rho}{2})(m_\omega - m + i\frac{\Gamma_\omega}{2})}\right\}$$

$$\times \frac{X|\vec{q}|^2}{[\langle 1\rangle\langle X^2\rangle]^{1/2}} .$$

To facilitate the analysis and show the connection between $\{\alpha_1,\alpha_1'\}$ and $\{\Gamma_1,\beta_1\}$, we present in Fig. 13 the calculated asymmetries as a function of $\beta_1 - \beta$ for the observed experimental conditions[13]: $N_\omega = 570$, $N_\rho = 2500$, $\xi = 0.6$; we fix Γ_1/Γ_ρ at a value of 1% (for small values of α_ω the α_I will scale as $\sqrt{\Gamma_I/\Gamma_\rho}$). The solid curves assume perfect measuring precision ($\sigma = 0$), while the dotted curve uses an ω mass uncertainty of $\sigma = 15$ MeV, chosen as a typical error calculated by SIOUX in the fitted mass of the ω in this kinematical region.[6] (For α_1 the curves for $\sigma = 0$ and $\sigma = 15$ MeV are almost identical; only the $\sigma = 0$ curve is shown for this case.)

Since α_1 and α_1' are both within one standard deviation of zero, we can extract no information from the data on the phase $\beta_1 - \beta$. The measured values of α_1 and α_1' lead to the estimate (calculated using the same parameters and model as for Fig. 13)

$$\Gamma_1/\Gamma_\rho = 0.003\pm0.012$$

(where the error is conservatively estimated by assuming that both α_1 and α_1' are as large as their one standard deviation values). Thus at the 1% level in intensity we have no evidence for the $|\Delta I| = 0$ C-violating decay mode of the $\rho^0 \to \pi^+\pi^-\pi^0$. A similar statement is applicable to the possible decay modes of the ρ^0 to $I = 2$ and $I = 3$ $\pi^+\pi^-\pi^0$ states.

C. Analysis of the Charge Asymmetry

In this Section we remark on a few possible theoretical explanations of our observation of a charge asymmetry on the ω Dalitz plot. Our first comment is that this effect does not appear to be directly related to the existence of a $|\Delta I| = 1$ decay of the ω (see Sec. IVA), since such a decay would yield a charge asymmetry for all ω events (independent of production process), and not for only the restricted subsample of ω's produced opposite a Δ^{++} with $0.08 \le t' \le 0.20$ $(\mathrm{GeV}/c)^2$. Another possible origin for the $J^{PC} = 1^{-+}$ state is a conjectured[11] $|\Delta I| = 0$ C-violating decay of the ρ^0. As discussed in Sec. IVB the ρ and ω production amplitudes are coherent at 3.7 GeV/c for Δ^{++} events with $t' < 0.14$ $(\mathrm{GeV}/c)^2$. In fact this coherence may well extend to larger t', although our data lacks the statistics to prove this assertion. Thus the kinematic region in which the ω Dalitz plot asymmetry is observed overlaps the region of established ρ-ω coherence, and may coincide with it. However it is difficult to reconcile the observed t' dependence of the asymmetry as illustrated in Fig. 4 with the known[10] t' dependence of $\rho^0\Delta^{++}$ and $\omega\Delta^{++}$ production at 3.7 GeV/c. This hypothesis cannot be ruled out in a model-independent fashion by our data alone. A definitive proof that ρ-ω interference is not the causal mechanism of our observed asymmetry would be the observation in a different experiment of coherence between the ρ^0 and ω production amplitudes with no associated ω Dalitz plot asymmetry.

An explanation of the observed charge asymmetry which does not require a violation of C invariance is the mechanism of Yuta and Okubo,[3] which invokes the existence of a coherent $\pi^+\pi^-\pi^0$ background. While such a background would in general consist of a mixture of isospin and angular momentum states, charge asymmetry in ω decay would project out the particular component $I^G = 1^-$, $J^{PC} = 1^{-+}$. From our data we can calculate the maximum expected contribution to the asymmetry following the method of Yuta and Okubo (see the derivation of Eq. (8) of Ref. 3)

$$\alpha_{max} = \left[\frac{2\pi\Gamma_\omega}{\Delta m}\frac{N_B}{N_\omega}\right]^{1/2} 0.834$$

where N_B and N_ω are the number of background and ω events within the mass interval $[M_\omega - \frac{\Delta m}{2}, M_\omega + \frac{\Delta m}{2}]$; the numerical factor 0.834 arises from the non-uniform Dalitz plot population for $J^P = 1^-$. Choosing $\Delta m = 40$ MeV, we measure N_B to be 15, and N_ω to be 336. Evaluating α_{max} for $\Gamma_\omega = 12$ MeV we find that for our data

$$\alpha_{max} = 0.24 \quad .$$

The observed value of α is 0.179±0.051, so that a fraction 0.56±0.32 of the background must be $J^{PC} = 1^{-+}$, $I^G = 1^-$. Thus while our background level is entirely consistent with the amount required by the Yuta-Okubo mechanism, we also note that a relatively large fraction of the background must be in this specific state.

Another possibility which is fully consistent with our data, but which cannot be established, is that the $J^{PC} = 1^{-+}$ state is a resonant state $\tilde{\rho}$ nearly degenerate with the ω. The existence of such a state is forbidden within the context of a $q\bar{q}$ quark model,[14] but is allowed if quark excitation models (e.g., $q\bar{q}q\bar{q}$) were valid. We also note that some models[15] which ascribe the violation of CP conservation in $K_L^0 \rightarrow \pi^+\pi^-$

decay to a violation of C invariance predict the existence of a $J^{PC} = 1^{-+}$ state near the mass that we have observed.

The production mechanism of this exotic state $\tilde{\rho}$ need not be exotic; G-parity selection rules suggest that ρ and B exchange are allowed in the t-channel, just as in the case of ω production. One way to understand the restriction of the asymmetry to the observed small t' interval is to postulate that the exotic state $\tilde{\rho}$ is produced via ρ exchange. Then the production amplitude will vanish in the forward direction (if the ρ has an M1 coupling at the nucleon-Δ^{++} vertex); a steeper t dependence than that of B exchange[16] in $\omega\Delta^{++}$ production is also required to cause the vanishing of the asymmetry at $t' \geqq 0.2\ (\text{GeV}/c)^2$.

V. CONCLUSIONS

We have observed no evidence for ω or ρ^0 decay to $\pi^+\pi^-\pi^0$ final states with $I \geqq 1$. Model dependent upper limits are determined from the data to be much larger than would be expected from currently accepted theories. A sizable charge asymmetry has been observed on the ω decay Dalitz plot, for a restricted sample of ω events. A possible cause of this asymmetry is a $J^{PC} = 1^{-+}$, $I^G = 1^-$ component of the background beneath the ω that is produced coherently, although other interpretations such as the existence of an exotic resonance with these quantum numbers, or as the existence of a $|\Delta I| = 0$ C-violating decay mode of the ρ^0 cannot be ruled out by our data.

VI. ACKNOWLEDGMENTS

We wish to acknowledge helpful discussions with Professors T. D. Lee, S. B. Treiman, S. F. Tuan, and C. Zemach. We thank the Bevatron crew, the LRL 72-inch chamber crew, H. White and the Data Handling Group, and our scanners and measurers for their efforts.

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‡Present address: Department of Physics, Princeton University, Princeton, New Jersey 08540.

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7. Since it is not inconceivable that a sizable asymmetry in a subsample could be washed out by statistical fluctuations within the entire ω sample, the null results obtained for the entire ω sample do not invalidate or obviate such an analysis.
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10. G. S. Abrams, K. W. J. Barnham, W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, and J. MacNaughton, Phys. Rev. Letters 25, 617 (1970).
11. T. D. Lee, Phys. Rev. 139, B1415 (1965).
12. The lower limit for the value of the ρ-ω coherence factor ξ was measured by a reanalysis of our data described in Ref. 2. The method used was an extension of the χ^2 search to include the variable ξ.
13. To determine the quantity N_ω (N_ρ) a hand-drawn background curve was estimated for the $\pi^+\pi^-\pi^o$ ($\pi^+\pi^-$) effective mass distribution for events satisfying Eqs. (5) and (6). The amount of ω (ρ) signal, N_ω (N_ρ), was measured as the number of events above the background curve in the ω (ρ) mass region.
14. For a recent review on exotic mesons, see J. L. Rosner, Review of Exotic Mesons, in Experimental Meson Spectroscopy, ed. by C. Baltay and A. H. Rosenfeld (Columbia University Press, New York, 1970), p. 499.
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Table I. Dalitz plot population of the ω and background mass regions. The values of α_I and α_I' are corrected for incoherent background as described in the text. The errors quoted are statistical only. Events in $\pi^+\pi^-\pi^0$ mass interval (MeV).

I	$\vec{D}_0\cdot\vec{D}_I$	684-734	734-784	784-834	834-884	α_I	α_I'
(a) All ω							
1	≤ 0	371	1580	1780	698	0.026±0.021	-0.028±0.021
	> 0	387	1789	1923	910		
2	≤ 0	339	1610	1746	746	0.035±0.021	0.011±0.021
	> 0	419	1759	1957	862		
3	≤ 0	365	1674	1880	770	-0.028±0.021	-0.019±0.021
	> 0	393	1695	1823	838		
(b) Δ^{++} in, $t' < 0.14$ GeV^2							
1	≤ 0	10	149	154	17	0.045±0.046	0.000±0.046
	> 0	10	163	169	20		
2	≤ 0	5	149	167	19	-0.010±0.046	-0.037±0.046
	> 0	15	163	156	18		
3	≤ 0	10	154	165	20	0.000±0.046	-0.017±0.046
	> 0	10	158	158	17		
(c) Δ^{++} in, $0.08 \leq t' \leq 0.20$ GeV^2							
1	≤ 0	8	103	104	15	0.179±0.051	-0.037±0.051
	> 0	3	147	132	12		
2	≤ 0	5	122	119	10	-0.009±0.051	-0.022±0.051
	> 0	6	128	117	17		
3	≤ 0	8	116	116	12	0.054±0.051	-0.037±0.051
	> 0	3	134	120	15		

FIGURE CAPTIONS

Fig. 1. Distribution of the $\pi^+\pi^-\pi^0$ effective mass near the ω region for all events fitting reaction (1) (16,617 events plotted twice). (a) $X \leq 0$; (b) $X > 0$.

Fig. 2. Decay Dalitz plot for all ω events (4691 entries satisfying Eq. (3)). (a) Two-dimensional plot; (b) X distribution; (c) Y distribution. The curves on the projections are described in the text.

Fig. 3. Decay Dalitz plot for ω events produced opposite a $\Delta^{++}(1236)$ with $t' < 0.14$ (GeV/c)^2 (495 events satisfying Eq. (3), (5) and (6)). (a) Two-dimensional plot; (b) X distribution; (c) Y distribution. The curves on the projections are described in the text.

Fig. 4. Production angular distribution for $\omega\Delta$ events (Eqs. (3) and (5)) for each half of the ω Dalitz plot.

Fig. 5. Distribution of the $\pi^+\pi^-\pi^0$ effective mass near the ω region for Δ^{++} events with satisfying Eqs. (5) and (7). (a) $X \leq 0$; (b) $X > 0$.

Fig. 6. Same distributions as in Fig. 5 but now $t' \leq 0.08$ (GeV/c)^2.

Fig. 7. Same distributions as in Fig. 5 but now $0.20 \leq t' \leq 1.0$ (GeV/c)^2.

Fig. 8. Distribution of the difference in kinetic energy of the π^+ and π^- in the ω mass band for $\omega\Delta$ events in the t' interval $0.08 \leq t' \leq 0.20$ (GeV/c)^2 (380 events). (a) Kinetic energies evaluated in the laboratory system; (b) kinetic energies evaluated in the overall center-of-mass system.

Fig. 9. Decay Dalitz plot for ω events produced opposite a $\Delta^{++}(1236)$ with $0.08 \leq t' < 0.20$ (GeV/c)^2 (380 events). (a) Two-dimensional plot; (b) X distribution; (c) Y distribution. The solid curve represents a best fit to the X distribution with $B = 0.67$; the dotted curve represents the expected distribution if there were no interference ($B = 0$). See text for details.

Fig. 10. Distribution of λ (see Eq. (4)) for $\omega\Delta$ events with $0.08 \leq t' \leq 0.20$ $(GeV/c)^2$ (380 events). The curve is described in the text.

Fig. 11. Distribution of λ for all ω events (4691 entries satisfying Eq. (3)). The curves is described in the text.

Fig. 12. Distributions for ω events with $0.08 \leq t' \leq 0.20$ $(GeV/c)^2$. (a) α_1 as a function of the $p\pi^+$ (recoiling against the ω) effective mass. The values of α_1 are calculated in the same manner as in Table I. (b) Effective mass distribution of the $p\pi^+$ system recoiling against the ω (the ω mass band is defined by Eq. (3)).

Fig. 13. α_1 and α_1' as a function of $\beta_1 - \beta$. See the text for details of the calculations.

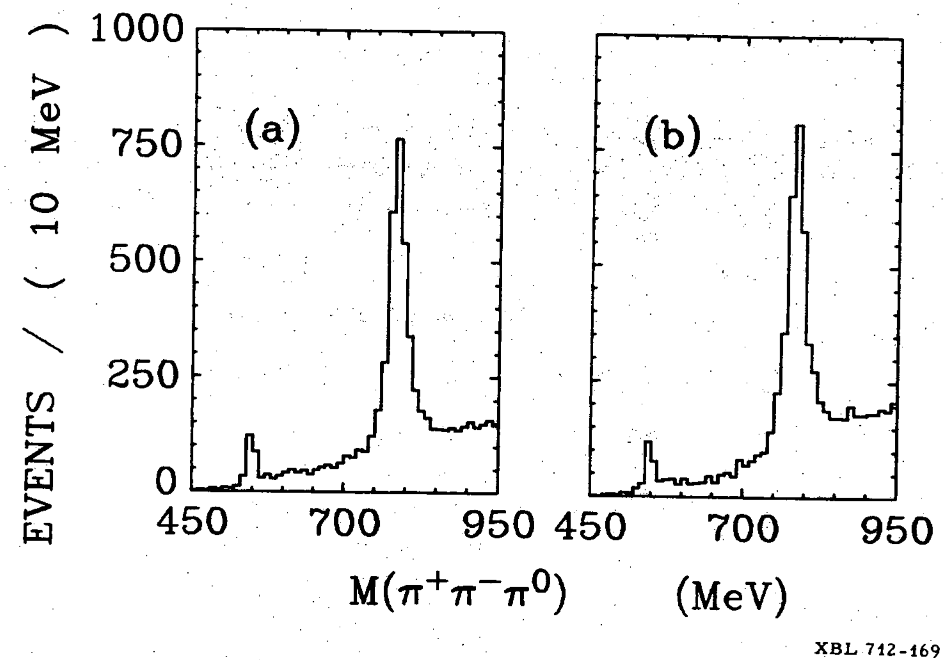
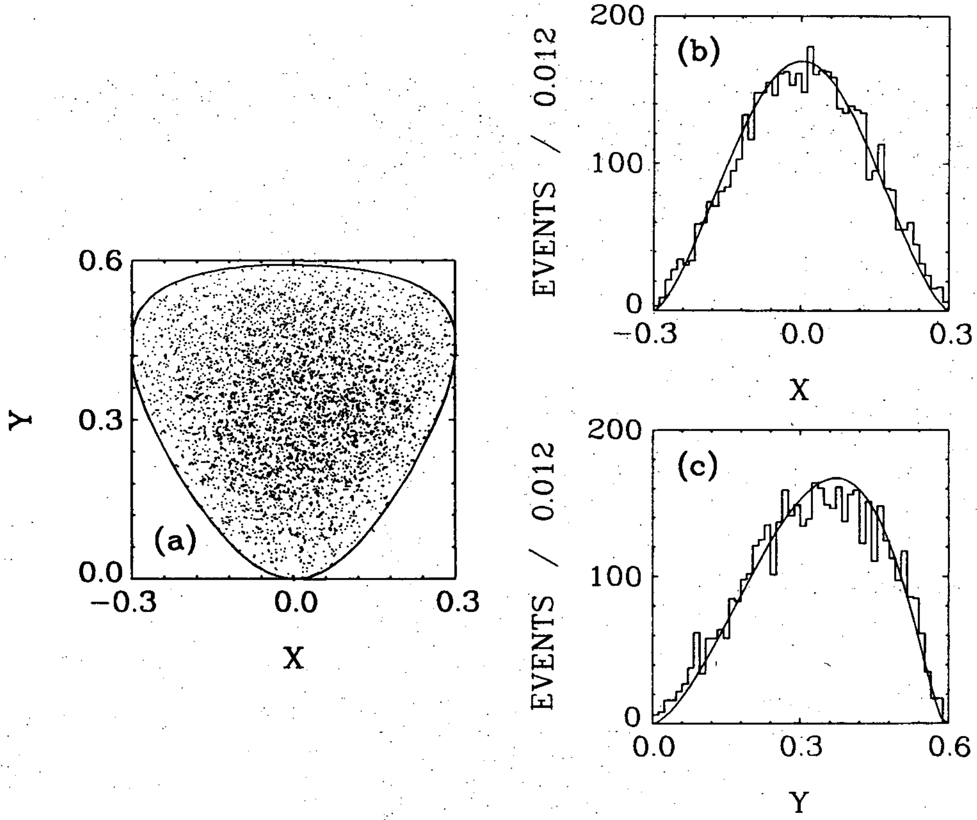


Fig. 1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(b)
(c)
0.6
0.3
0.0
Y
X
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0.0
0.3
EVENTS / 0.012
200
100
0
0.6
XBL 712-201

Fig. 2

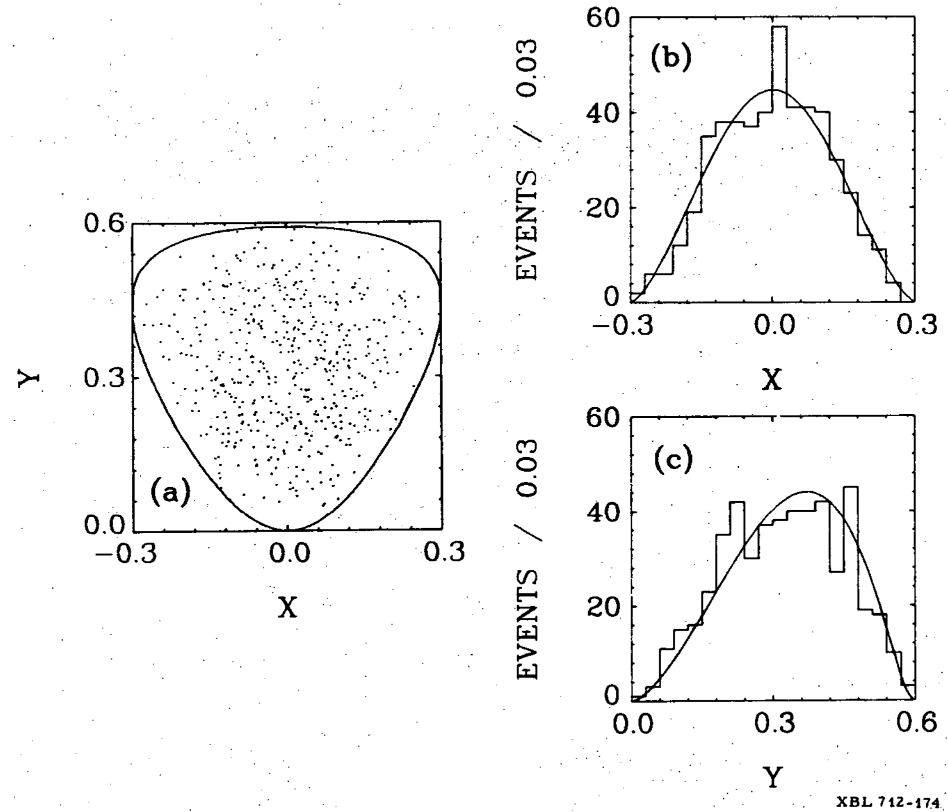
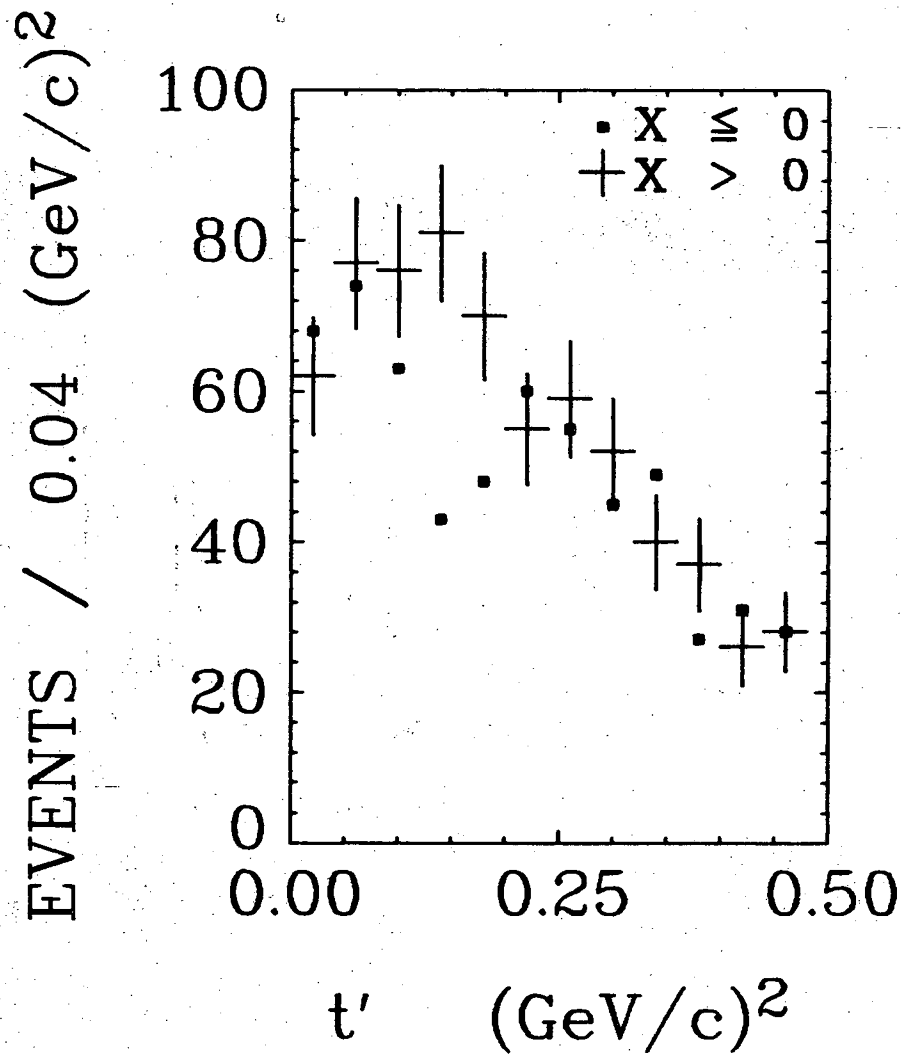
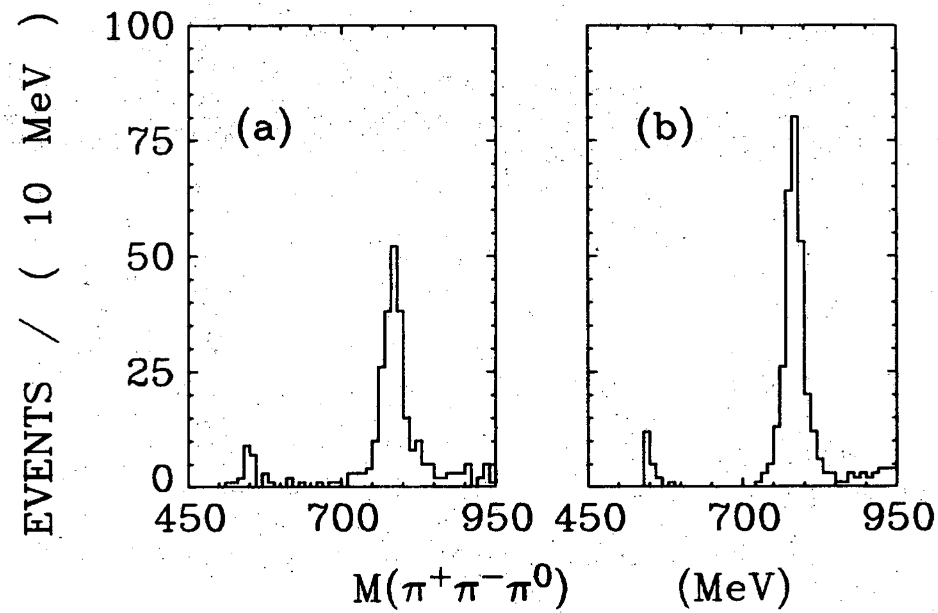

(a)
(b)
(c)
0.6
0.3
0.0
Y
X
−0.3
0.0
0.3
EVENTS / 0.03
60
40
20
0
XBL 712-174

Fig. 3



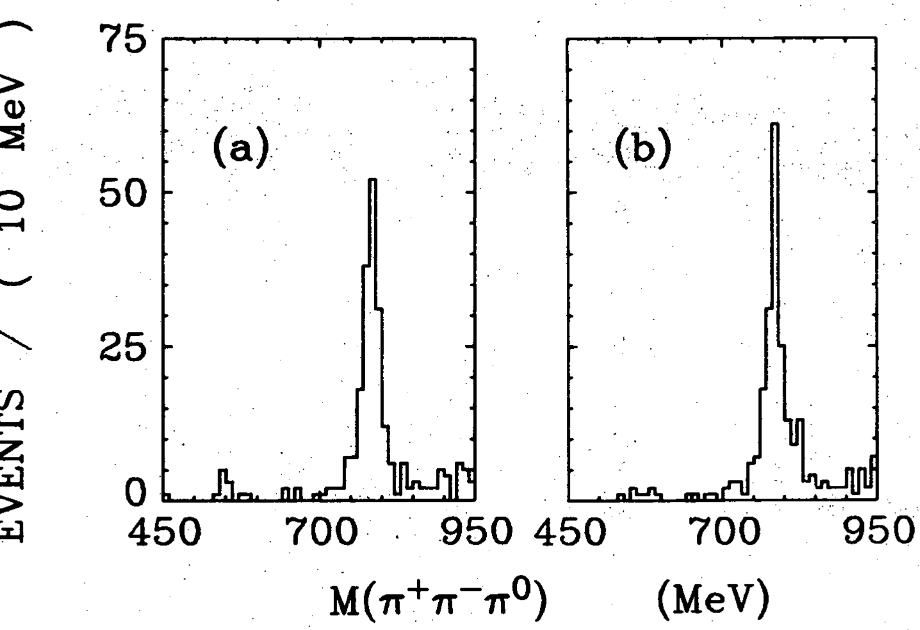
XBL 712-171

Fig. 4



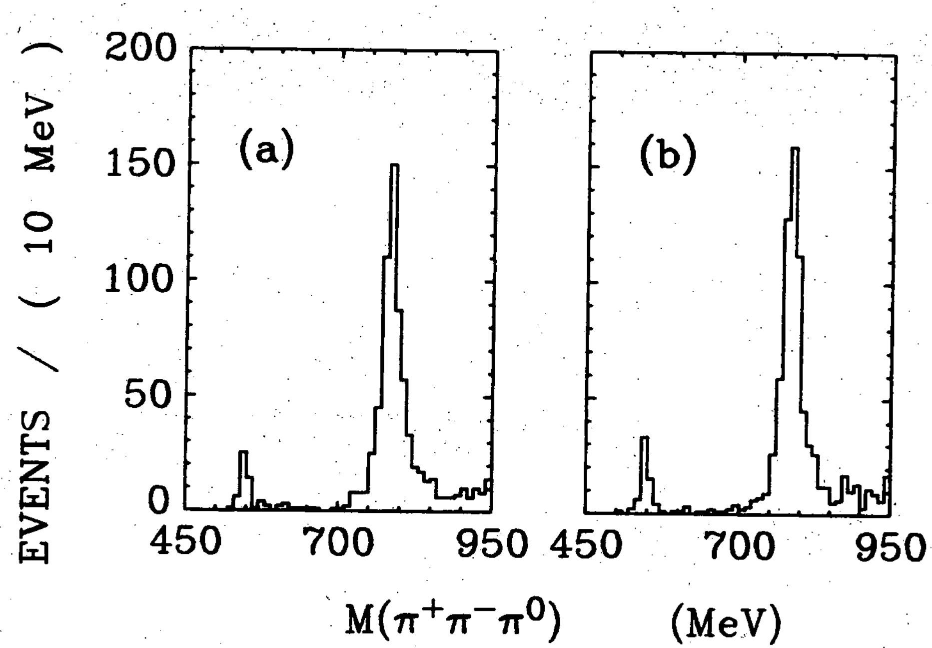
XBL 712-168

Fig. 5



XBL 712-166

Fig. 6



XBL 712-170

Fig. 7

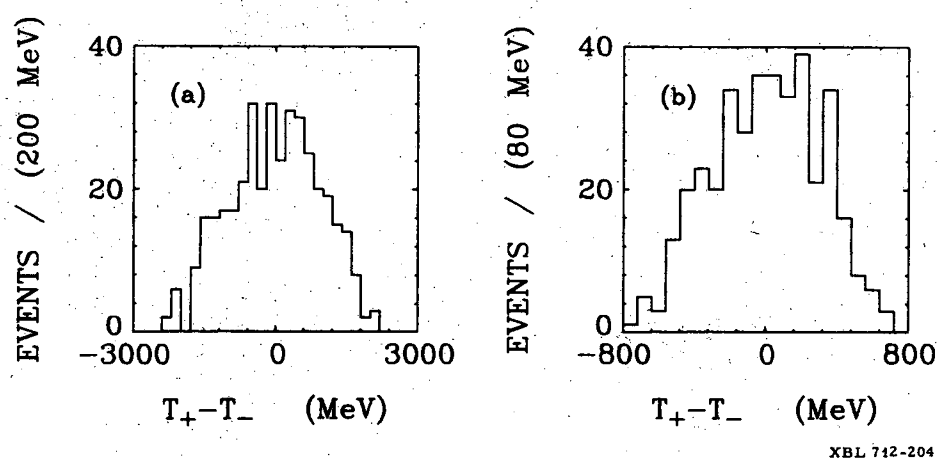

EVENTS / (200 MeV)
(a)
40
20
0
−3000
0
3000
T+−T−   (MeV)
EVENTS / (80 MeV)
(b)
40
20
0
−800
0
800
T+−T−   (MeV)
XBL 712-204

Fig. 8

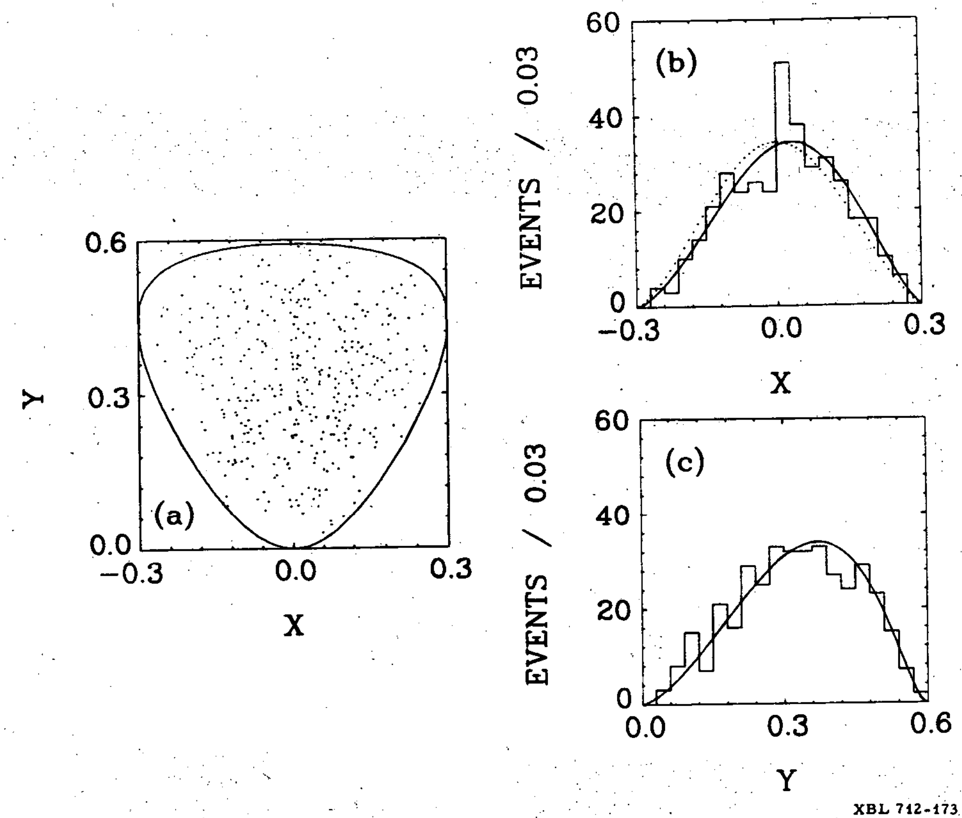
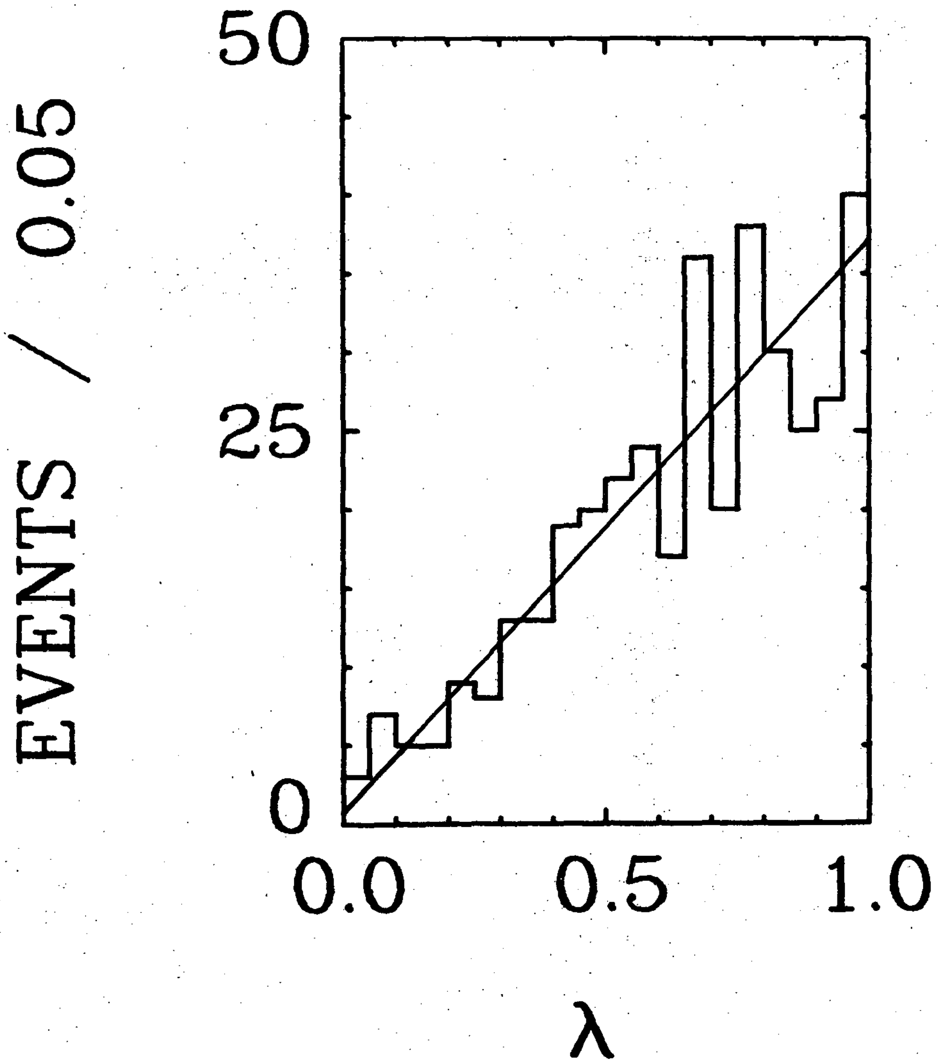
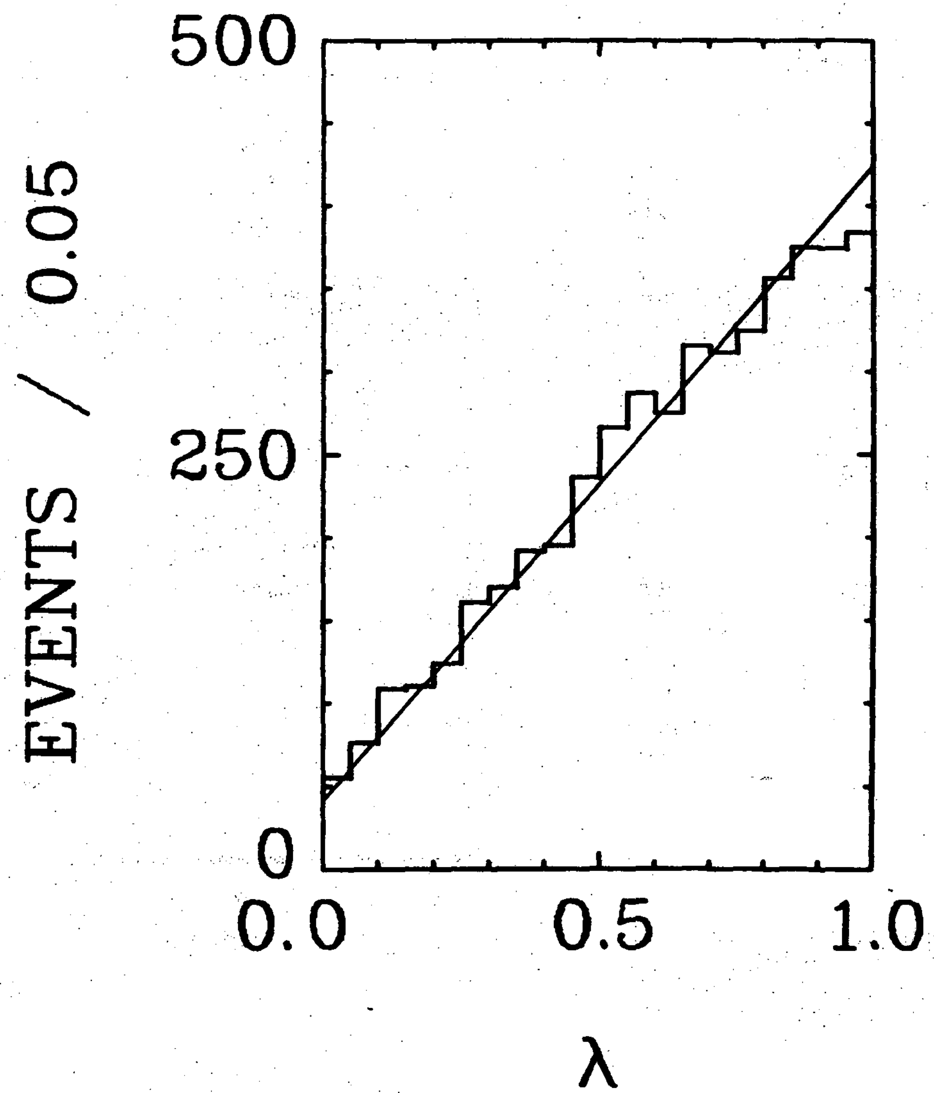

Y
0.6
0.3
0.0
−0.3
0.0
0.3
(a)
X
EVENTS / 0.03
60
40
20
0
(b)
−0.3
0.0
0.3
X
EVENTS / 0.03
60
40
20
0
(c)
0.0
0.3
0.6
Y
XBL 712-173

Fig. 9



XBL 712-196

Fig. 10



XBL 712-195

Fig. 11

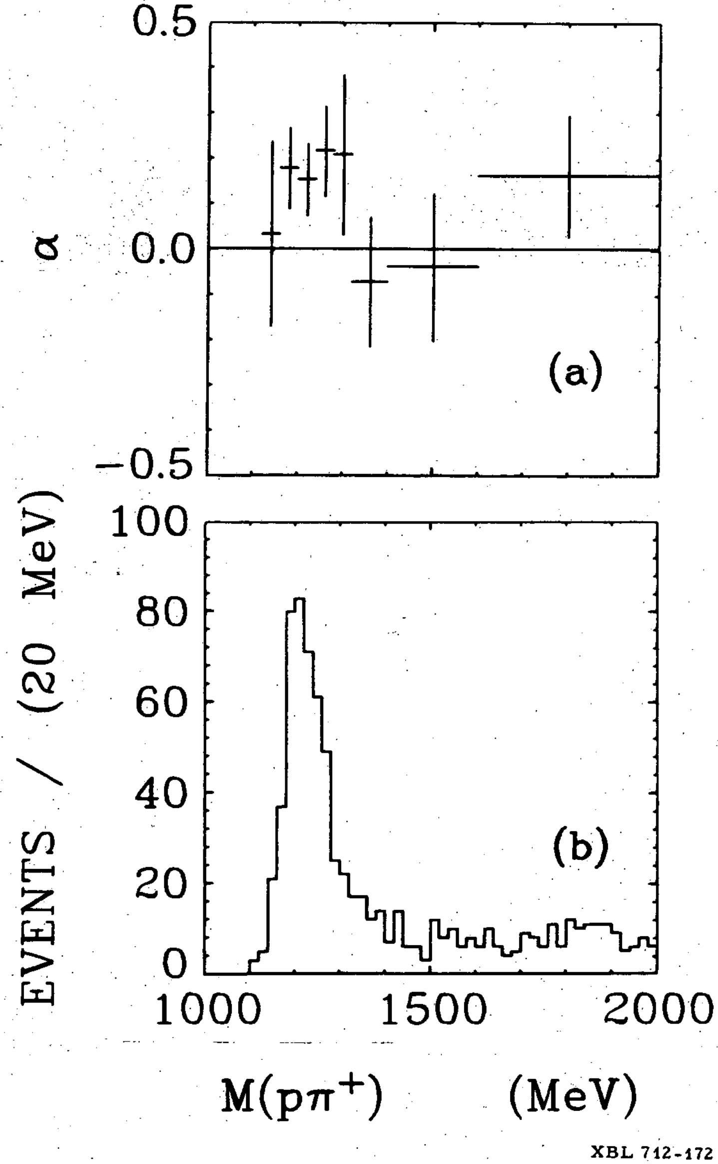

0.5
0.0
−0.5
α
(a)
100
80
60
40
20
0
EVENTS / (20 MeV)
(b)
1000
1500
2000
M(pπ+) (MeV)
XBL 712-172

Fig. 12

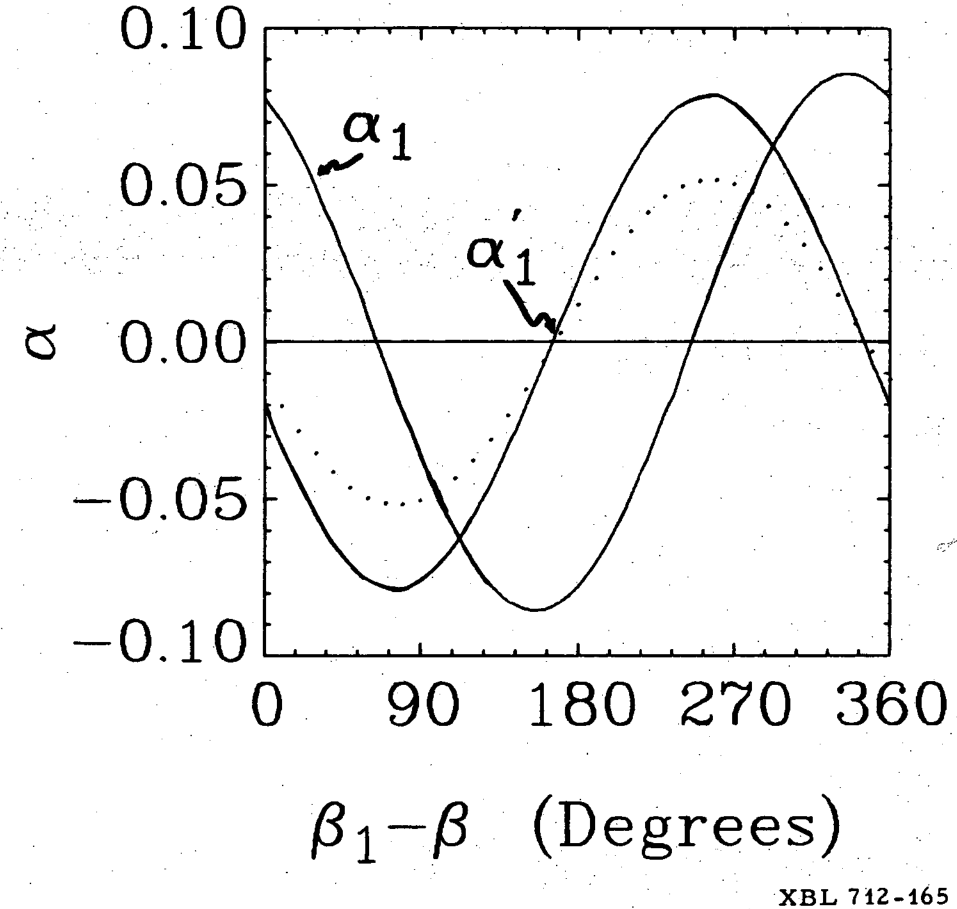

0.10
0.05
0.00
−0.05
−0.10
α
α1
α'1
0
90
180
270
360
β1−β (Degrees)
XBL 712-165

Fig. 13

APPENDIX

Final State Correlation Studies

Among the possible causes of the observed ω Dalitz plot charge asymmetry are effects which may be called dynamic, in the sense that there may exist in our data different forces on the π^+_ω and π^- associated with the ω. Another cause of such an asymmetry could lie in the selection criteria for our event sample, with biases attendant on an injudicious choice of cuts. In this Appendix we consider detailed comparisons of distributions for the π^+_ω and π^-, which in principle could reveal the presence of these two types of effects. Other mechanisms to produce a spurious charge asymmetry, such as a possible measurement bias in the reconstruction of π^+_ω and π^- momenta, are considered in the text.

We explore first the possibility that the incident π^+ beam is responsible for the observed charge asymmetry by virtue of the peripheral nature of high energy interactions, so that the outgoing π^+_ω retains, to some extent, the incident beam direction. Then we would expect to see a peaking in the ω rest frame of the π^+_ω in the direction of the incident π^+ (0° polar angle in the t-channel or "Jackson" frame), and, to the extent that the ω is produced peripherally, in the direction of the outgoing ω (0° in the s-channel or helicity frame). For the $\omega\Delta$ events in the t' region of the observed asymmetry [Eqs. (3), (5), and (7)] no significant difference between the π^+_ω and the π^- angular distributions is observed. In illustration we show in Fig. A1 the ω decay angular distributions in the helicity frame, including both the π^0 and the π^+_Δ (associated with the Δ^{++}) for completeness. Thus within statistics we find no evidence which correlates the beam or ω direction with the presence of an ω charge asymmetry.

Another feature of the data which could serve as a cause of a charge

asymmetry is the presence of two π^+'s in the final state, Eq. (1). A possible confusion of these two identical particles leads to both a dynamical (Bose Symmetry) and a selection bias (choosing the "wrong" ω) contribution to the asymmetry. In Fig. A2 we show that for our data [as above and for the remainder of the Appendix we consider only the 380 events satisfying Eqs. (3), (5), and (7)] the π^+_ω and the π^- have the same angular distribution in the overall center-of-mass system relative to the π^+_Δ. If Bose Symmetry effects were important we should have seen a clustering toward +1 for $\pi^+_\Delta\cdot\pi^+_\omega$ relative to $\pi^+_\Delta\cdot\pi^-$. The fact that this effect is small may be interpreted as implying that the overlap of the wave functions of the two π^+'s is small, in agreement with the notion that the pions propagate separately within the ω and Δ until these resonances decay.

We next consider various effective mass distributions for the final state particles, again comparing the π^+_ω and the π^-. In Fig. A3 we show the ω decay pions in combination with either the π^+_Δ or the proton of the Δ^{++}. The similarity of the $M(\pi^+_\Delta\pi^+_\omega)$ and the $M(\pi^+_\Delta\pi^-)$ distributions is additional evidence that the Bose Symmetry effect is small. We also note that we see no significant evidence for ρ^0 production in the event sample studied.

The consistency of the distributions of $M(p\pi^+_\omega)$ and $M(p\pi^-)$ may be considered as evidence that final state interactions between the proton and the ω decay pions are not important. Another way of interpreting the apparent lack of a strong $\Delta^{++}(1236)$ signal in the $M(p\pi^+_\omega)$ distribution is that for our data "double Δ" events, in which each π^+ in the final state is associated with a Δ^{++}, are not a serious source of contamination.

The three-body effective masses, using again the π^+_Δ or the proton of the Δ^{++}, are shown in Fig. A4. In particular we wish to point out the absence of a strong ω signal in the $M(\pi^+_\Delta \pi^- \pi^o)$ distribution, evidence that "double ω" events are not a serious problem. Thus we find no evidence that our selection criteria have induced the observed asymmetry.

In Fig. A5 we show the effective mass distributions of the Δ^{++} combined with one of the ω decay pions, in a search for final state interactions. One possibility for a difference in the π^+_ω and π^- distributions could be the appearance of strong resonance formation in the $I_z = 1/2$ N^* channel $\Delta\pi^-$, while no enhancement would appear in the $I_z = 3/2$ $\Delta\pi^+_\omega$ channel. Our data does not offer evidence for such an effect.

Finally, we show in Fig. A6 the di-pion mass distributions for the pions within the ω. Here a difference between the π^+_ω and π^- distributions is quite evident, as is expected since these mass combinations are intimately related to the Dalitz variable $X = (T_+ - T_-)/Q\sqrt{3}$.

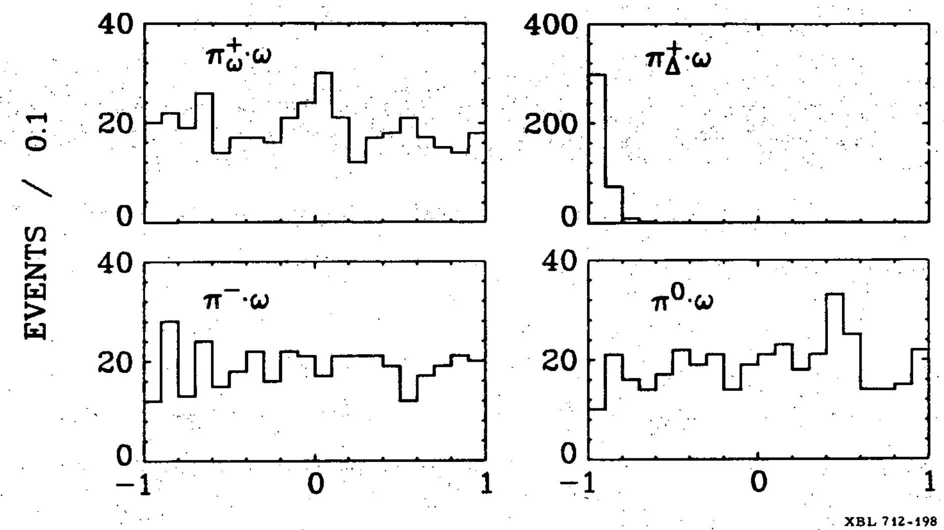
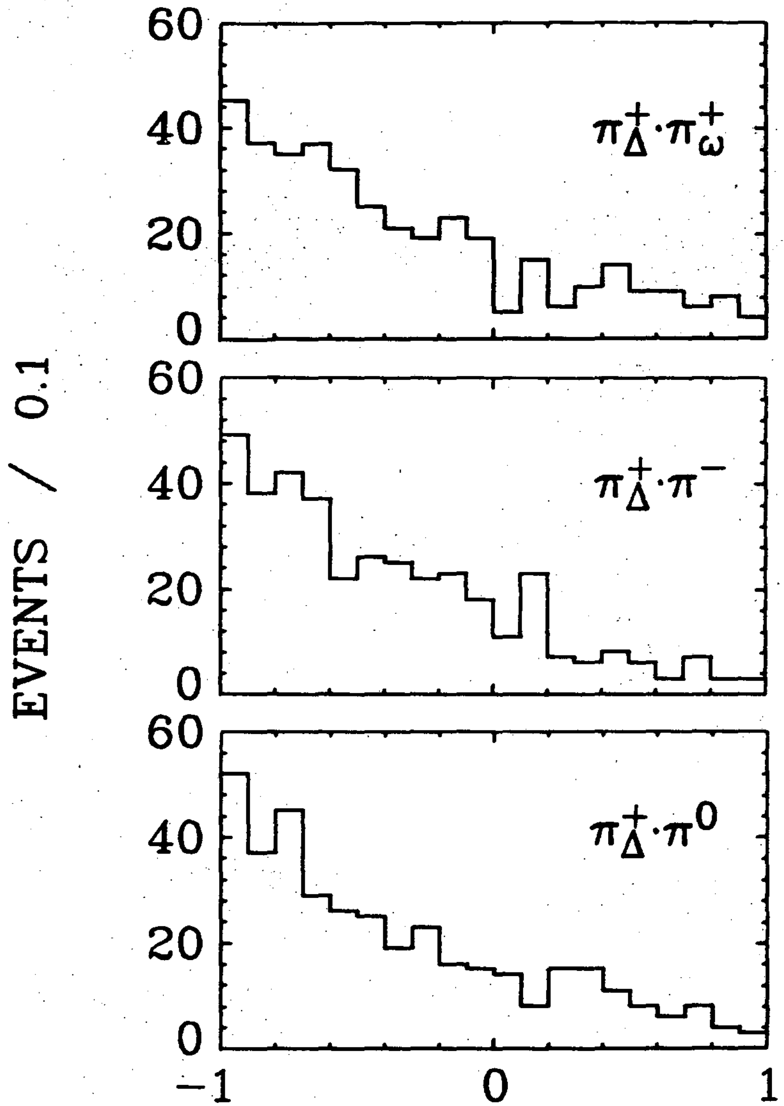
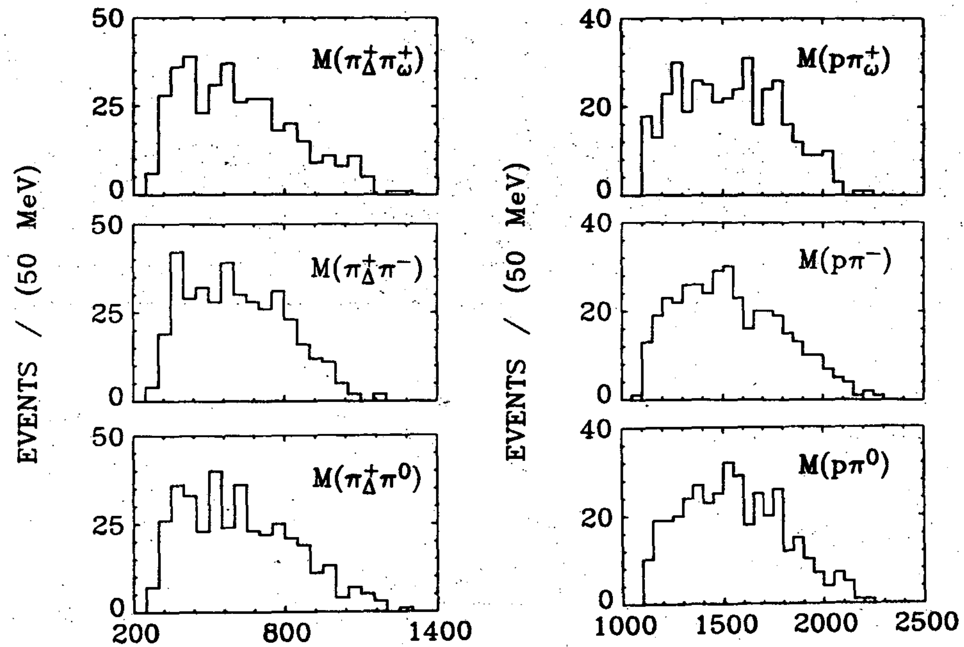


Fig. A1



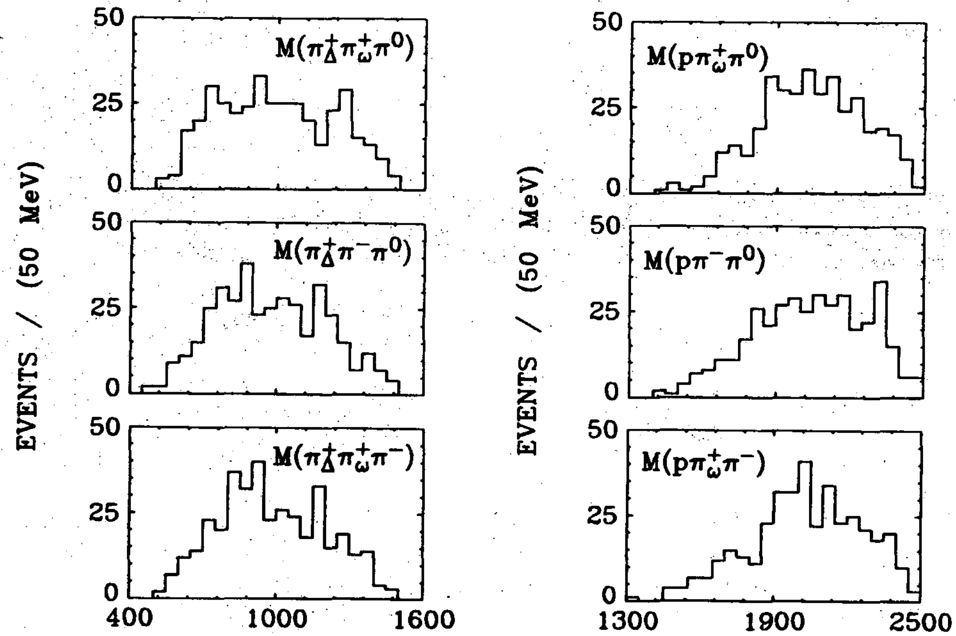
XBL 712-199

Fig. A2



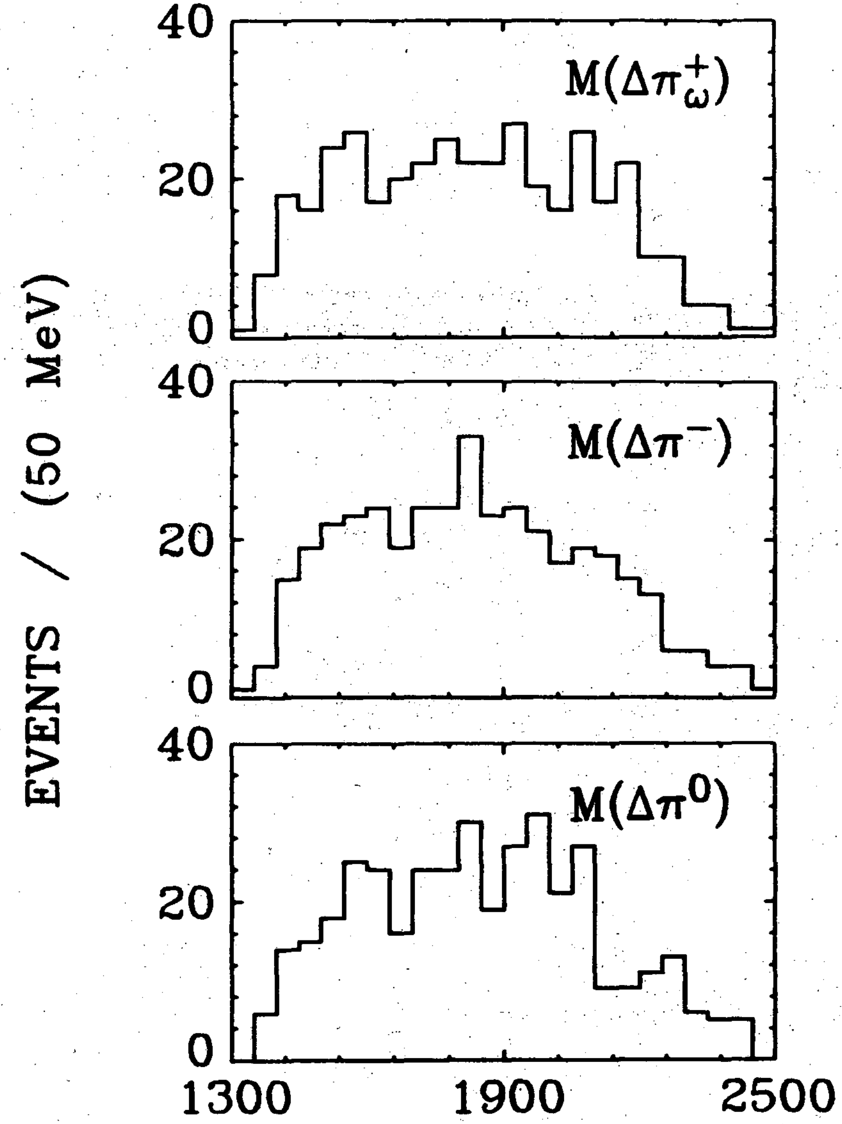
XBL 712-202

Fig. A3



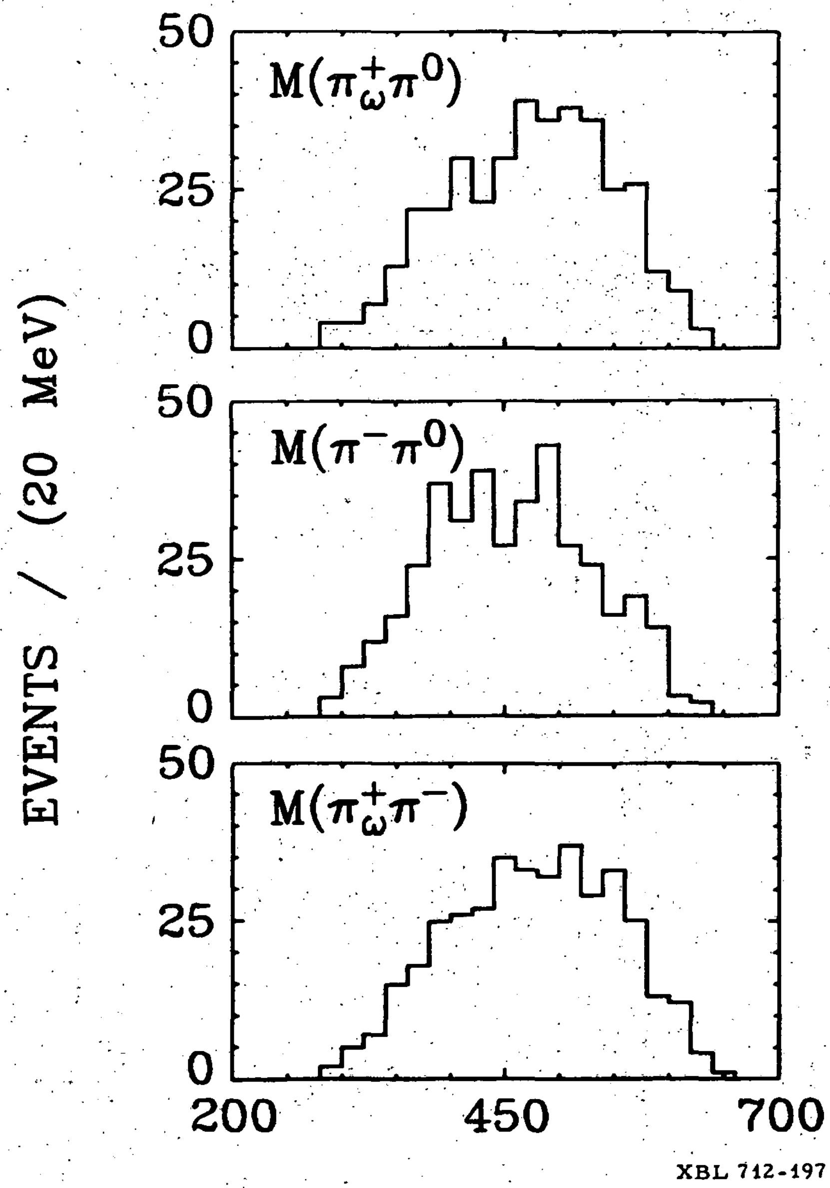
XBL 712-203

Fig. A4



XBL 712-200

Fig. A5



EVENTS / (20 MeV)
50
25
0
$M(\pi^+_\omega\pi^0)$
$M(\pi^-\pi^0)$
$M(\pi^+_\omega\pi^-)$
200
450
700
XBL 712-197

Fig. A6

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