$I = 0, \, C = -1$ mesons from 1940 to 2410 MeV

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Abstract

New Crystal Barrel data are reported for $\bar{p}p \to \omega \eta$ and $\bar{p}p \to \omega \pi^0 \pi^0$ with $\omega$ decaying to $\pi^+ \pi^- \pi^0$. The $\omega \eta$ data confirm angular distributions obtained earlier from data where $\omega \to \pi^0 \gamma$. The new $\omega \eta$ data provide accurate measurements of vector and tensor polarisations of the $\omega$ and lead to considerable improvements in masses and widths of $s$-channel resonances.

A new $J^P C = 3^+ - I = 0$ resonance is observed with mass $M = 2025 \pm 20$ MeV and width $\Gamma = 145 \pm 30$ MeV. Polarisation is close to zero everywhere and tensor polarisations are large, as is the case also for $\bar{p}p \to \omega \pi^0$.

Earlier publications have reported studies of $\bar{p}p \to \omega \eta$ [1] and $\bar{p}p \to \omega \pi^0 \pi^0$ [2] for beam momenta 600 to 1940 MeV/c. That work concerned all-neutral final states where $\omega$ decays to $\pi^0 \gamma$. Those data suffer from the disadvantage that much of the information concerning $\omega$ polarisation is lost, because it is transferred to the unmeasured polarisation of the decay photon. In order to recover that information, we present here new data where $\omega \to \pi^+ \pi^- \pi^0$. In these data, the polarisation of the $\omega$ is determined fully by the normal $\vec{n}$ to the decay plane of the $\omega$, as explained in an accompanying paper on $\omega \pi^0$ and $\omega \eta \pi^0$ final states [3]. Data for $\bar{p}p \to \omega \eta$ have also been reported by Peters [4].

Analyses of channels with quantum numbers $C = +1, I = 0$ and 1 [5-7] have led to a spectrum of $s$-channel resonances consistent with almost all of the expected $q \bar{q}$ states in the mass range 1900-2400 MeV. The data presented here lead to major improvements in the identification of resonances with $I = 0, C = -1$. All the expected states are observed except for two $J^{PC} = 1^{--}$ states. In that sector there is a problem separating $^3S_1$ and $^3D_1$ partial waves.

The present work follows closely the procedures described in the accompanying paper on $I = 1, C = -1$, where data for final states $\omega \pi^0, \omega \eta \pi^0$ and $\pi^- \pi^+$ are discussed. Most experimental details are common to that work, so we refer to it for description of the experimental set-up and many technical details.

The essential experimental problem is to minimise background from $\eta \pi^+ \pi^- \pi^0$ in the $\omega \eta$ data and from $\pi^+ \pi^- \pi^0 \pi^0 \pi^0$ in the $\omega \pi^0 \pi^0$ data. An initial selection requires that both charged particles are produced with centre of mass angle $\theta$, $|\cos \theta| \leq 0.65$, in order to avoid edge-effects in the drift chamber. Here $\theta$ is the lab angle of the $\omega$ with respect to the beam. At least 11 digitisations are required in this chamber, with at least one hit in the first three layers and at least one in the last three. In the preliminary selection, a 4C kinematic fit is required with confidence level $> 5\%$ for $\eta \pi^+ \pi^- \pi^0$ or $\pi^+ \pi^- \pi^0 \pi^0 \pi^0$.

After this initial selection, clear signals are observed for $\omega \to \pi^+ \pi^- \pi^0$ in both sets of data, as shown in Figs. 1(a) and (b); all $\pi^0$ combinations are included in the latter figure. The

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background under the $\omega$ is fitted to a quadratic function of mass and the $\omega$ is fitted to a Gaussian. Events are selected for further processing in the mass range 760–804 MeV; the few events where more than one $\pi^+\pi^-\pi^0$ combination lies in this interval are rejected. Surviving events are then subjected to a kinematic fit to final states $\omega\eta$ or $\omega\pi^0\pi^0$, setting the $\omega$ mass to 781.95 MeV.

Table 1: Numbers of selected events (including background)

| Beam momentum (MeV/c) | $\omega\eta$ | $\omega\pi^0\pi^0$ |
|-----------------------|-------------|------------------|
| 600                   | 1139        | 5446             |
| 900                   | 4768        | 25071            |
| 1200                  | 2106        | 11510            |
| 1525                  | 612         | 4893             |
| 1642                  | 1209        | 11031            |
| 1940                  | 469         | 5241             |

The final selection of $\omega\eta$ and $\omega\pi^0\pi^0$ requires a confidence level ($CL$) > 10% and greater than that of any background channel. As a minor refinement to check that the $\omega$ is well reconstructed, it is required that $CL(\omega\eta) > 0.8 \times CL(\pi^+\pi^-\pi^0\eta)$ and $> 0.5 \times CL(\pi^+\pi^-4\gamma)$. Corresponding cuts are applied in the selection of $\omega\pi^0\pi^0$ events. The efficiency with which events pass the final kinematic fit is determined as a function of $\pi^+\pi^-\pi^0$ mass, and this is used to evaluate the resulting background under the $\omega$. For $\omega\pi^0\pi^0$ it increases steadily with beam momentum over the range 13 to 16%; for $\omega\pi^0\pi^0$ it is 28–35%. Here we also allow for the contribution to background from ‘wrong’ combinations of the spectator $\pi^0$ with $\pi^+\pi^-$. Numbers of selected events are shown in Table 1.

As explained in the accompanying paper [3], the background may be estimated in a second way. Decays of the $\omega$ are enhanced near the edge of its Dalitz plot because of the momentum dependence of the matrix element for $\omega$ decay. Figs. 1(c) and (d) show plots of the number of events against the square of this matrix element. One sees straight lines with intercepts which provide another estimate of the background; it agrees with the first within errors. This background is included into the partial wave analysis described below, using Monte Carlo events which pass the data selection; they are generated according to $\pi^+\pi^-\pi^0\eta$ or $\pi^+\pi^-\pi^0\pi^0\pi^0$ phase space.

We now compare angular distributions for present $\omega\eta$ data with those from all-neutral data where $\omega \rightarrow \pi^0\gamma$. Figs. 1(e)-(j) show error corridors through the latter data. Points with errors are superposed from present data. (Both sets of data are corrected for acceptance). The absolute efficiency for tracking charged particles has a significant uncertainty; it is sensitive to precise cuts on the number of layers and the $\chi^2$ for the fit to a helix. Therefore, the absolute scale for present charged data is normalised to that for all-neutral data.

Particles are thrown forwards in the lab system by the Lorentz boost due to beam momentum. In consequence, $\omega$ are detected efficiently only in the backward hemisphere in the centre of mass. This is adequate, since conservation of C-parity demands that the production angular distribution is symmetric forwards and backwards with respect to the beam. Figs. 1(e)–(j) show
Figure 1: $M(\pi^+\pi^-\pi^0)$ from the preliminary data selection for (a) $\omega\eta$ data, (b) $\omega\pi^0\pi^0$ at 900 MeV/c; the number of events v. the matrix element squared for $\omega$ decay to (c) $\omega\eta$, (d) $\omega\pi^0\pi^0$; (e)-(j): curves show the error corridor for $\omega\eta$ differential cross sections where $\omega$ decays to $\pi^0\gamma$; corrections have been applied for angular acceptance; points with errors show new results for $\omega$ decays to $\pi^+\pi^-\pi^0$; the vertical dashed lines show the cut-off in $\cos \theta_\omega$ which has been used.
that the shapes of angular distributions agree well for the backward hemisphere between the two sets of data. This agreement, seen particularly clearly at 900 MeV/c where statistics are highest, is a valuable cross-check on experimental techniques. In the forward hemisphere, we reject events where the acceptance for the $\omega$ drops rapidly. This requires a cut $\cos\theta_\omega < 0.7$ at 600 and 900 MeV/c, $\cos\theta_\omega < 0.2$ at higher momenta. These cuts reject only $\sim 10\%$ of selected events.

Vector and tensor polarisations of the $\omega$ are determined following the procedures described in the accompanying paper [3]. We discuss first results for the two-body final state $\omega\eta$. Fig. 2 shows values of vector polarisation $P_y$ and also $Re T_{21}$ at four momenta; Fig. 3 shows values of $Re T_{22}$ and $T_{20}$. Tensor polarisations are large. Experimental values of $Im T_{21}$ and $Im T_{22}$ are consistent with zero, as predicted theoretically.

We turn now to the partial wave analysis. This follows precisely the lines described for $I = 1$, $C = -1$ [1–3]. In outline, partial wave amplitudes are described as a sum

$$ f = \sum_i g_i \exp(i\phi_i) B_L(q) B_{L}(p) \frac{1}{M_i^2 - s - iM_i\Gamma_i} $$

(1)

over $s$-channel resonances of constant width; fitted parameters are masses and widths, coupling constants $g_i$ and phases $\phi_i$. Blatt-Weisskopf centrifugal barrier factors $B_\ell$ and $B_L$ are included for production with orbital angular momentum $\ell$ in the $\bar{p}p$ channel and decay with orbital angular momentum $L$; $p$ and $q$ are centre of mass momenta in $\bar{p}p$ and meson channels respectively. We adopt a radius of 0.83 fm for the centrifugal barrier radius in all partial waves up to angular momentum 3, as determined in Ref. [5]; this radius is increased to 1.1 fm for higher partial waves.

The spectroscopic notation is described in detail in the accompanying paper [3]. All triplet partial waves may couple in either the $\bar{p}p$ entrance channel or in the decay to orbital angular momentum $L = J \pm 1$. A resonance is expected to have the same phase $\phi$ in these coupled channels, through rescattering between the two channels. For present data there is an accurate
determination of the relative phase only for the two $2^{--}$ states; it is $-5.3 \pm 17.6^\circ$ for the lower one and $1.7 \pm 17.6^\circ$ for the second. These are both consistent with zero, as expected. The same result was found also in Refs. 3 and 5, with somewhat better errors. Coupling constants for coupled channels are therefore fitted to a real ratio $r = g_{L=J+1}/g_{L=J-1}$.

Table 2 shows parameters of fitted resonances. The information from the polarisation of the $\omega$ leads to major improvements in the $\omega\eta$ channel compared with the earlier work of Ref. [1]. For this channel, all resonances are now well determined in mass and width, except for the $3^{--}$ state at 2285 MeV. Columns 5 and 7 of Table 2 show changes in log likelihood when each resonance is omitted from the fit and remaining resonances are re-optimised. For convenience, columns 6 and 8 show corresponding values from the earlier analyses. One sees immediately a considerable increase in the significance of most resonances.

Analysis of the $\omega\pi^0\pi^0$ channel gives less precise results for several reasons. One is that the $\omega$ polarisation information is distributed over 3-body phase space, though it is all used in the maximum likelihood fit. The decay channels which are significant are $\omega f_2(1270)$, $\omega\sigma$ and $b_1(1235)\pi$, see Ref. [2]; there is also a contribution from $f_0(1500)\omega$ at the highest two momenta. The $b_1\pi$ channel is weak. The $\omega\sigma$ channel is strong for several partial waves, particularly $J^{PC} = 1^{--}$; here $\sigma$ stands for the $\pi\pi$ S-wave amplitude, as parametrised by Bugg, Sarantsev and Zou [8]. There is a problem concerning the treatment of the $\omega\sigma$ amplitude. In $\pi\pi$ elastic scattering, there is an Adler zero close to threshold, as a consequence of the nearly massless pion. In coupling to heavy channels, $\bar{p}p$ and $\omega$, it is not clear whether the Adler zero should be present in the amplitude or not. Some examples are known where the Adler zero is definitely absent, e.g. $J/\Psi \to \omega\sigma$ [9]. We have explored both possibilities for every partial wave, choosing the better alternative for every resonance. This leads to considerable but unavoidable flexibility in the fit.

A related problem is that there are large interferences between $\omega\sigma$ and $\omega f_2$. The precise phases of these amplitudes affect masses of fitted $s$-channel resonances; masses can shift with fitted phases in such a way as to keep changes in log likelihood small. It leads to rather large errors in resonance parameters for those partial waves where $\omega\sigma$ contributions are big. A final consideration is that background is fairly high for $\omega\pi^0\pi^0$ data. Although the 3-body data demand large contributions to many partial waves, requiring the presence of resonances, they
Table 2: Resonance parameters from a combined fit to $\omega \eta$ and $\omega \pi^0 \pi^0$, using both $\omega \to \pi^0 \gamma$ and $\omega \to \pi^+ \pi^- \pi^0$ decays. Values in parentheses are fixed. Values of $r$ are ratios of coupling constants $g_{J+1}/g_{J-1}$. Columns 5 and 7 show changes in $S = \log$ likelihood when each resonance is omitted from this fit and others are re-optimised; columns 6 and 8 show a comparison with previous work.

| $J^P$ | Mass $M$ (MeV) | Width $\Gamma$ (MeV) | $r$ | Previous $\Delta S(\omega \eta)$ | $\Delta S(\omega \eta)$ | Previous $\Delta S(\omega \pi\pi)$ | $\Delta S(\omega \pi\pi)$ |
|-------|----------------|----------------------|-----|-------------------------------|--------------------------|----------------------------------|---------------------------|
| 1++   | 1965 ± 45      | 345 ± 75             | -0.20 ± 0.17 | 1808                         | 209                      | 700                               | 143                       |
| 1+-   | 2215 ± 40      | 325 ± 55             | 4.45 ± 1.16 | 272                          | 76                       | 1020                              | 360                       |
| 3++   | 2025 ± 20      | 145 ± 30             | 0.60 ± 0.49 | 341                          | -                        | 234                               | -                         |
| 3+-   | 2275 ± 25      | 190 ± 45             | -0.74 ± 0.60 | 253                          | 17                       | 140                               | 240                       |
| 1--   | 1960 ± 25      | 195 ± 60             | 2.4 ± 0.45  | 1258                         | 281                      | 393                               | 1515                      |
| 1--   | 2205 ± 30      | 350 ± 90             | -3.0 ± 1.8  | 180                          | 53                       | 1410                              | 1021                      |
| 2--   | 1975 ± 20      | 175 ± 25             | 0.60 ± 0.10 | 948                          | 34                       | 1203                              | 478                       |
| 2--   | 2195 ± 30      | 225 ± 40             | 0.28 ± 0.59 | 160                          | 94                       | 356                               | 590                       |
| 3--   | 1945 ± 20      | 115 ± 22             | 0.0 ± 1.0   | 752                          | 230                      | 5793                              | 595                       |
| 3--   | 2285 ± 60      | 230 ± 40             | 1.4 ± 1.0   | 98                           | 46                       | 1156                              | 510                       |
| 3--   | 2255 ± 15      | 175 ± 30             | ~ 50        | 145                          | 187                      | 1436                              | 695                       |
| 4--   | 2250 ± 30      | 150 ± 50             | (0)         | 70                           | -                        | -                                 | 35                        |
| 5--   | ~ 2250         | 320 ± 95             | (0)         | 677                          | -                        | 244                               | -                         |

lead to rather imprecise determinations of resonance parameters in many cases.

We now discuss individual partial waves, beginning with singlet states. Their intensities in the $\omega \eta$ data as a function of mass are shown in Fig. 4. Intensities of the strong contributions to $\omega \pi \pi$ data are shown in Fig. 5. There are some changes compared with Figs. 5 and 6 of Ref. 2. In several cases, these changes arise directly from better determinations of $r$ parameters, by switching of amplitudes between different $L$ values in the final state for a given $J^P$.

The spectroscopic notation of Fig. 5 is illustrated by that for panel (b) as an example. There, $^3D_2 \equiv 2s^1 \ell J$ denotes the initial $\bar{p}p$ state, where $\ell = 2$ combines with spin $s = 1$ to make $J = 2$; $P = (-1)^\ell$ and $C = (-1)^{\ell + s}$. The $J = 2$ states may decay with $L = 0$, 2 or 4. In almost all cases, only the lowest $L$ is significant for $\omega \pi^0 \pi^0$ data, because of the centrifugal barrier. In Fig. 5(h), $^5S_2 \equiv 2s^2 \ell J$ denotes the final state $\omega f_2$ with $s' = 2$, $L = 0$, $J = 2$. It is usually necessary to include all available $s'$ values for the lowest $L$. Examples are Figs. 5(h) and (i), where $s' = 1$ and 2 respectively, combining with $L = 1$ to make $J = 1$; Clebsch-Gordon coefficients tend to favour larger values of $s'$.

For $J^{PC} = 3^{+ -}$, the present data reveal a new resonance which escaped detection in the earlier analyses. It lies at $2025 \pm 20$ MeV with $\Gamma = 145 \pm 30$ MeV. A $q\bar{q}$ state is expected close to this mass as the singlet partner to $^3F_2$, $^3F_3$ and $^3F_4$ states observed clearly in Ref. 5. Spin-spin splitting is believed to come from a $\delta$ function at zero radius [10]. In the absence of such splitting in $F$-waves, the singlet state is expected to lie at the centroid of the triplet states weighted by their multiplicities, namely at $2024 \pm 5$ MeV; this agrees with the present result.

A second $3^{+ -}$ state is observed at $2275 \pm 25$ MeV. This compares with the prediction of
Figure 4: Intensities of partial waves fitted to $\omega\eta$ data; $L$ are orbital angular momenta in the decay, and $3S1$, for example, denotes $\bar{p}p\,3S_1$.

$2292 \pm 9$ MeV from triplet states. Both of these $3^{+-}$ states are determined very largely by the $\omega\eta$ data. Although they make sizeable contributions to $\omega\pi^0\pi^0$ data, errors are large there for masses and widths.

For $J^{PC} = 1^{+-}$, two states are observed at 1965 and 2215 MeV. The accuracy of the mass determination of the lower state comes mostly from $\omega\eta$, although there is a large contribution in $\omega\pi^0\pi^0$ too. The error is sizeable, because this resonance is at the bottom of the available mass range. The upper state is required by the strong $^5P_1(\omega f_2)$ contribution of Fig. 5(i). Both masses are slightly lower than those from Refs. [1] and [2], as a consequence of the new $\omega$ polarisation information. The $q\bar{q}$ centrifugal barrier is weaker for $1^+$ states than for $3^+$, so it is to be expected that $1^+$ will resonate somewhat lower than $3^+$, as is observed. The lower $1^{+-}$ state now appears in $\omega\eta$ almost purely with $L = 0$ decays; that is a large change from the earlier result of Ref. [1]. The new polarisation data for the $\omega$ have provided a major improvement in the determination of parameters $r = g_{L=J+1}/g_{L=J-1}$, which describe the ratio of coupling constants $g$ for $L = J \pm 1$.

We turn now to triplet partial waves, beginning with the $1^{--}$ sector, which is the most difficult. For $J^{PC} = 1^{--}$, there are large contributions in $\omega\pi^0\pi^0$ and these data are mostly responsible for fixing the upper resonance at 2205 MeV. The $\omega\eta$ data do however produce the best determination of the lowest $1^{--}$ resonance at 1960 MeV; it is weaker in $\omega\pi^0\pi^0$, though clearly visible in the $b_1(1235)\pi$ channel, Fig. 5(a). It couples strongly to $^3D_1$, where its mass is best determined; it is probably the radial excitation of $\omega(1650)$.

Four $1^{--}$ states are expected in this mass range: two $^3S_1$ and two $^3D_1$. Unfortunately, $^3S_1$ and $^3D_1$ are not well separated for remaining $1^{--}$ states in the absence of data from a polarised target. From a comparison with $I = 1$, $C = -1$ [3] where data are available from a polarised
Figure 5: Intensities of the large partial waves fitted to $\omega \pi^0 \pi^0$ data. The spectroscopic notation is discussed in the text.
target for the final state $\pi^-\pi^+$, higher resonances are expected around 2110–2150 and 2230 MeV and at a higher mass 2350–2400 MeV. It is possible that the state we report at 2205 MeV is a blurred combination of two states in the mass range 2110–2230 MeV. It has a large $\omega\sigma$ contribution, shown in Figs. 5(m) and (n), and this contribution is somewhat flexible, as discussed above. This resonance does have quite a large $^3D_1$ amplitude, and is consistent with the $^3D_1$ state expected around 2230 MeV. We have attempted to put two $1^-\pi$ resonances into the mass range 2100–2230 MeV, but they collapse to a single state.

In earlier work of Refs. [1] and [2], there was evidence for a further $1^-\pi$ state at 2300 ± 45 MeV. Although an improvement in log likelihood of ~ 300 is possible by including this state, there is no well defined optimum for its mass and width. Therefore it is omitted from the final fit. Omitting it has little effect on other partial waves.

For $J^P = 2^-$, two resonances are definitely required for two reasons. Firstly, the phase variation visible in the Argand diagram of Fig. 7 below for $^3D_2$ $L = 1$ is larger than can be provided by a single resonance. Secondly, the structure observed in Fig. 5(b) requires two resonances. The lower one is well determined by both $\omega\eta$ data ($M = 1981 \pm 23$ MeV) and $\omega\pi\pi$ data (1973 ± 24 MeV). The upper one is determined better by $\omega\eta$ data. By comparison with $I = 1, C = -1$ of Ref. 3, it is expected around 2235 MeV. In present data it appears somewhat lower, at 2195 ± 30 MeV, though within the combined errors.

For $J^{PC} = 3^-$, three states are definitely required. The lowest contributes a huge $f_{2\omega\omega}$ signal in $\pi^0\pi^0\omega$ data, see Fig. 5(d); it is also quite large in $\omega\eta$. This state is expected to lie close to the very well defined $I = 1$ state $\rho_3(1982)$. That resonance is defined by extensive $\bar{p}p \rightarrow \pi^-\pi^+$ data at 100 MeV/c steps of momentum down to 360 MeV/c (a mass of 1910 MeV) [11]; its mass is 1982 ± 14 MeV and the width 188 ± 24 MeV. In present data, the $I = 0$ state optimises at 1944 ± 16 MeV in $\omega\pi^0\pi^0$ and at 1951 ± 21 MeV in $\omega\eta$. Table 2 quotes an average value 1945 ± 20 MeV; the error allows for the small discrepancy between channels. It is remarkably narrow in both data sets: $\Gamma = 115 \pm 22$ MeV. This narrow width is required to fit a very rapid variation in differential cross sections between beam momenta of 600 and 900 MeV/c. However, we warn that this state lies right at the bottom of the available mass range, so there could be some systematic error in determining its mass and width.

A $^3G_3$ state is required strongly by both $\omega\eta$ and $\omega\pi^0\pi^0$ data. It optimises at $M = 2255 \pm 15$ MeV with $\Gamma = 175 \pm 30$ MeV. It is conspicuous because of its different helicity components from $^3D_3$, hence different tensor polarisations. A $^3D_3$ state is also required at a similar mass. However, this is the least well determined of all the resonances. It makes a fairly small contribution to $\omega\eta$ data. For $\omega\pi^0\pi^0$, a strong contribution is required. However, the mass drifts up to 2310 MeV with only a small improvement in log likelihood; in the earlier analysis of Ref. 2, it optimised instead at 2180 ± 40 MeV. These instabilities in mass are correlated with flexibility in fitting the $\omega\sigma$ component in $\omega\pi\pi$. For the present solution, our final best estimate for the mass (mostly from $\omega\eta$ data) is 2285 ± 60 MeV. For both $\omega\eta$ and $\omega\pi^0\pi^0$, this $^3D_3$ state is obscured by the very large low mass contributions from $\omega_3(1945)$.

A small but well determined $^3G_4$ peak is now required in $\omega\eta$; a $^3G_5$ state is required strongly by both $\omega\eta$ and $\omega\pi^0\pi^0$ data. For all G-states, the intensity peaks strongly at ~ 2300 MeV, see Figs. 4 and 5. However, there is a very strong centrifugal barrier in the $\bar{p}p$ channel. In consequence, we find anomalously low resonance masses for all three G-states, compared with neighbouring F-states, which cluster from 2260 to 2305 MeV. We use standard Blatt-Weisskopf centrifugal barrier factors, which are derived assuming a square well potential. This may not be
a good approximation for very high partial waves such as $G$-states.

Fig. 6 shows a plot of observed resonances versus $M^2$, where $M$ is mass. They conform closely to straight-line trajectories resembling Regge trajectories, to which they are related. They are compared in the figure with a slope of 1.143 GeV$^2$. That slope is determined from very precise results for $I = 0 \, C = +1$ [5]; for those quantum numbers, data are available from seven channels including valuable $\pi^-\pi^+$ data from a polarised target. Within the errors of present determinations, there is good agreement with this slope.

Fig. 7 shows Argand diagrams for all partial waves. A remarkable feature of the vector polarisations of Fig. 2 for $\omega\eta$ is that they are everywhere small. The same feature has been observed for $\omega\pi^0$. Vector polarisation depends on the imaginary parts of interferences between partial waves. The small observed polarisation requires coherence amongst all partial waves. It is discussed in detail in the accompanying paper.

In summary, the new data provide a considerable improvement in parameters of several resonances. This arises from more accurate polarisation information for the $\omega$, leading to better phase determinations. A new but expected $3^{++}$ resonance is observed at $2025 \pm 20$ MeV with $\Gamma = 145 \pm 30$ MeV.

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Figure 7: Argand diagrams for fitted $\omega\eta$ partial waves. Crosses show beam momenta 600, 900, 1050, 1200, 1350, 1525, 1642, 1800 and 1940 MeV/c; all move anti-clockwise with increasing beam momentum.
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