Branching Fractions for $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$ and $\bar{p}p \rightarrow \omega\omega$

Rod McCrady
Carnegie Mellon University

CB Note 319 Vesion 1.0 November 21, 1997

Abstract

We have measured $BR(\bar{p}p \rightarrow \omega\omega)$ by looking at the peak in the momentum spectra of the decay products of the ω's. The method does not rely on normalization to $\pi^\circ\pi^\circ$. The value obtained is $BR(\bar{p}p \rightarrow \omega\omega) = 3.15 \pm 0.25\%$, which is consistent with the value previously published by Crystal Barrel, $3.32 \pm 0.34\%$. For $BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega)$, we obtain $15.7 \pm 1.0\%$, a surprisingly large value.

The branching fractions $BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega)$ and $BR(\bar{p}p \rightarrow \omega\omega)$ are determined from the number of such events in the minimum bias data sample. In this way, one does not rely on trigger simulation in the determination of the detection efficiency from Monte Carlo data, as one would when using triggered data.

The efficiencies for event detection are determined by passing a known number of Monte Carlo events through the same analysis procedure as the experimental data. The fraction of events which are detected is defined as the detection efficiency for the given analysis method. The Monte Carlo data sample used in the efficiency calculations consists of two sets which were combined after detector simulation and kinematic fitting were done. The first set had 18955 events resulting from the analysis of 149936 events of the type $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$, $\omega \rightarrow \pi^\circ\gamma$. The second set was 6010 events from 49873 events of the type $\bar{p}p \rightarrow \omega_1\omega_2$, $\omega_1 \rightarrow \pi^+\pi^-\pi^\circ$, $\omega_2 \rightarrow \pi^\circ\gamma$. The generated events allowed the π°'s to decay to $\gamma\gamma$ with a branching fraction of 98.802%, so the number of generated events should be multiplied by $(0.98802)^2$ to get the number of generated events in the desired final state: 146365 ± 59 for $\pi^+\pi^-\pi^\circ\omega$, and 48685 ± 34 for $\omega\omega$. These data sets were combined to mimic the experimental data, which had about 25% $\omega\omega$ events.

The masses of the ω's in the Monte Carlo are Breit-Wigner distributed between 0 and $2m_\omega$; they were not restricted to $m_\omega \pm 3\Gamma$ as in older versions of CBGEANT.

1 $BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega)$

The number of $\pi^+\pi^-\pi^\circ\omega$ events in the data sample is

$$N_{\pi^+\pi^-\pi^\circ\omega} = N_{mb} \cdot f_{ann} \cdot BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega) \cdot BR(\omega \rightarrow \pi^\circ\gamma) \cdot (BR(\pi^\circ \rightarrow \gamma\gamma))^2 \cdot \epsilon_{\pi^+\pi^-\pi^\circ\omega},$$

so

$$BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega) = \frac{N_{\pi^+\pi^-\pi^\circ\omega}}{N_{mb} \cdot f_{ann} \cdot BR(\omega \rightarrow \pi^\circ\gamma) \cdot (BR(\pi^\circ \rightarrow \gamma\gamma))^2 \cdot \epsilon_{\pi^+\pi^-\pi^\circ\omega}}.$$

$N_{mb} = 1693709$ is the number of minimum bias triggers which resulted in events being recorded. Some of these events, however, occur with the antiproton still in flight. Studies [3] indicate that $f_{ann} = 96\%$ of the minimum bias triggers result in $\bar{p}p$ annihilation at rest. For $BR(\omega \to \pi^\circ\gamma)$ and $BR(\pi^\circ \to \gamma\gamma)$, the PDG [1] values of $8.5 \pm 0.5\%$ and $98.798 \pm 0.032\%$ are used.

The number of events of the type $\bar{p}p \to \pi^+\pi^-\pi^\circ\omega$ is determined by examining the $\pi^\circ\gamma$ mass spectrum of events which satisfy a kinematic fit to the hypothesis $\bar{p}p \to \pi^+\pi^-\pi^\circ\pi^\circ\gamma$. The cut on the confidence level of this fit is varied to check for its effect on the result. This cut should ensure that the events to be analyzed are from the flat region of the confidence level (CL) distributions in order to eliminate background events, which possibly have different effects in the Monte Carlo data than in the experimental data, and thus effect the calculated efficiency. Figures 1 A and B show the CL distributions of the events under analysis. A cut of $CL > 0.20$ satisfies the stated reqirement. Because the measurement resolution is expected to be of similar magnitude to the natural width of the distribution, the peaks in the experimental and Monte Carlo data are fitted with a Voigtian function. The Voigtian is a Breit-Wigner function (the natural shape) convoluted with a Gaussian (representing the resolution). In the fit, Γ, the natural width of the ω, is fixed to $8.43 MeV/c^2$, the PDG value [1]. The Gaussian width, σ is fit; the values obtained are $11.82 \pm 0.56 MeV/c^2$ for experimental data and $11.14 \pm 0.14 MeV/c^2$ for Monte Carlo data.

Table 1 shows the results of the branching ratio calculation with various CL cuts. The result does not depend strongly on the cut. With a cut of $CL > 0.20$, the result is $15.7 \pm 1.0\%$.

CL cut	$N_{MC\ \pi^+\pi^-\pi^\circ\omega}$	$\epsilon_{\pi^+\pi^-\pi^\circ\omega}$	$N_{\pi^+\pi^-\pi^\circ\omega}$	$BR(\bar{p}p \to \pi^+\pi^-\pi^\circ\omega)$
1%	22983	.11783± .00078	2366	.1488 ± .0093
5%	20902	.10716± .00074	2229	.1542 ± .0097
10%	19084	.09784± .00071	2098	.1589 ± .0100
15%	17659	.09054± .00068	1872	.1533 ± .0098
20%	16347	.08381± .00066	1779	.1573 ± .0100
25%	15173	.07779± .00063	1666	.1588 ± .0102
30%	14101	.07229± .00061	1545	.1584 ± .0102
35%	13064	.06698± .00059	1465	.1621 ± .0105

Table 1: Results of analysis of the $\pi^\circ\gamma$ mass spectra. The numbers of detected Monte Carlo and experimental data events, detection efficiencies, and resulting branching fractions are shown as a function of CL cut.

2 $BR(\bar{p}p \to \omega\omega)$ from the $\omega\omega$ Momentum Spectrum

The $BR(\bar{p}p \to \omega\omega)$ can be determined by examining the momentum spectra of the decay products of the ω's. For $\bar{p}p$ annihilation at rest, the ω's will each have a momentum of $518.5 MeV/c$, if both ω's have masses of $781.96 MeV/c^2$. Measurement of the contents of such a signal allows one to count the number of $\bar{p}p \to \omega\omega$ events.

In order to investigate the effects of the Breit-Wigner shape of the ω mass spectra on the momentum spectrum, a simple computer program was used to generate ω's with masses independently distributed according to a Breit-Wigner function with width $\Gamma = 8.43 MeV/c^2$.

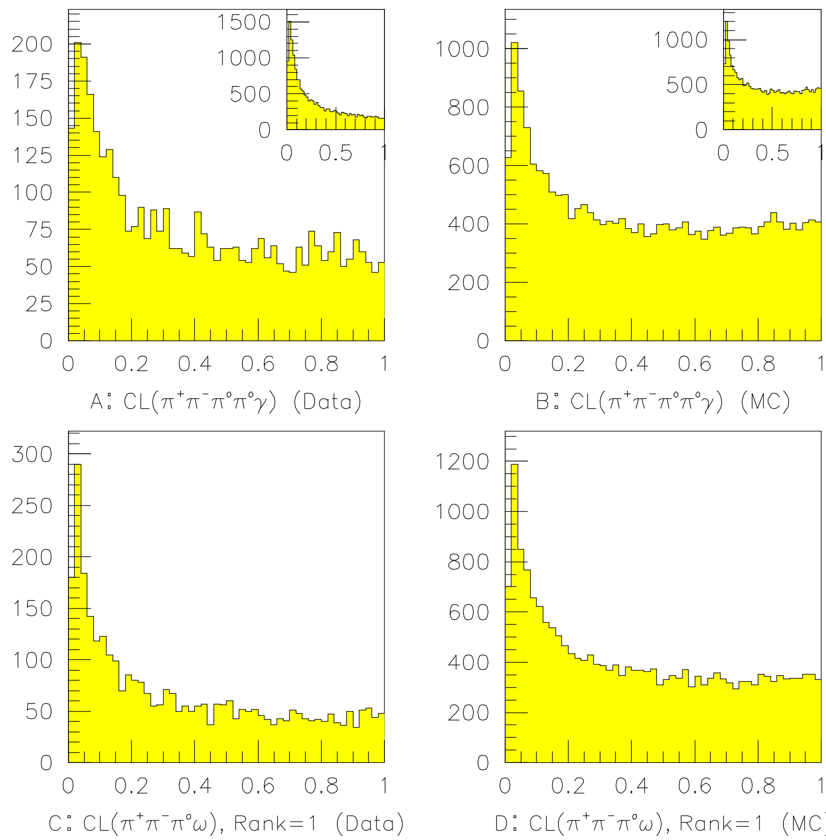

Figure 1: A,B: The Confidence Level (CL) distributions for fits to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\pi^\circ\gamma$, for Experimental and Monte Carlo data respectively. The mass of one $\pi^\circ\gamma$ combination is required to lie within $50 MeV/c^2$ of the ω mass. The CL distributions without this cut on the $\pi^\circ\gamma$ mass are shown inset. C,D: The CL distributions for fits to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$, requiring the rank of the fit to be 1, for Experimental and Monte Carlo data respectively.

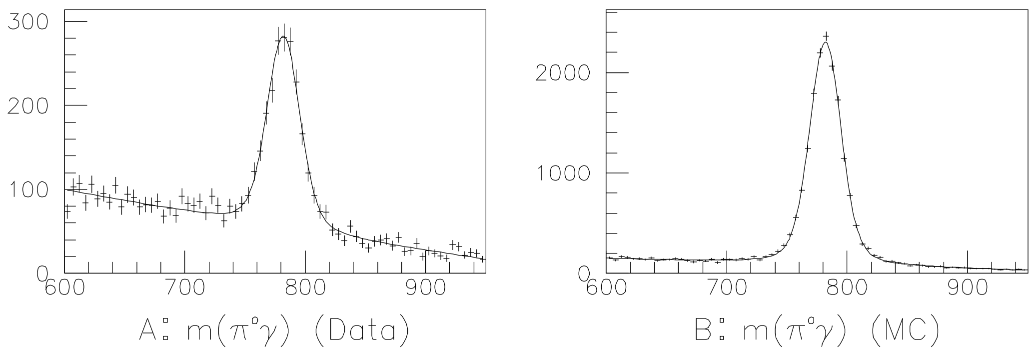

Figure 2: A: The $\pi^\circ\gamma$ mass distribution (2 entries per event) in the region of the ω mass, for experimental data, with a 20% CL cut. B: The same histogram for the Monte Carlo data.

The momentum, $q_{\omega\omega}$, that each pair would have (from $\bar{p}p$ annihilation) is then calculated. This program simulates kinematics only; no detector response nor resolution effects are included. The $q_{\omega\omega}$ spectrum is also described well by a Breit-Wigner function (see Figure 3 A.) The experimental and Monte Carlo data are therefore fit with a Voigtian function.

Table 2 lists momenta for other 2-body channels which are likely to appear in the $\pi^+\pi^-\pi^\circ\pi^\circ\gamma$ data sample; the $\omega\omega$ peak should be well separated from the others. Note that only $\omega\omega$ events will contribute to the peak in the momentum spectrum. In contrast, the mass spectra of the decay products will show peaks at the ω mass regardless of whether the other final state particles constituted an ω. This leads to the expectation that this $q_{\omega\omega}$ spectrum method will produce a more pure signal, and will allow easy integration of the signal without requiring a background subtraction.

Channel	Momentum
$\bar{p}p \rightarrow \omega\omega$	518.5 MeV/c
$\bar{p}p \rightarrow \omega\eta$	656.4 MeV/c
$\bar{p}p \rightarrow \omega\eta'$	350.5 MeV/c

Table 2: Momenta for $\bar{p}p$ annihilations into two mesons.

Because the natural shape of the peak in the momentum spectrum is a Breit-Wigner function whose width is similar to the experimental resolution, the peaks are fit with Voigtian functions.

There are some practical limitations of this measurement scheme, however. If the mass spectrum of one of the ω's is restricted, the shape of the momentum spectrum changes (see Figure 3 B.) Making CL cuts changes the mass distributions, but not in a simple way, so determining the correct value for the natural width of the momentum distribution is difficult. Leaving Γ_q as a free parameter in the fits results in large fluctuations in its fitted value. Figure 4 shows the distribution of $\omega \rightarrow \pi^\circ\gamma$ masses, for a CL cut of 25%. The distributions span a range of about $50MeV/c^2$, so in the Voigtian fits to the peaks, Γ_q is fixed to $10.0MeV/c$.

The data used in this analysis were kinematically fit to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\pi^\circ\gamma$ with CL>1%, and also had been successfully fit to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$ (but the kinematic variables were

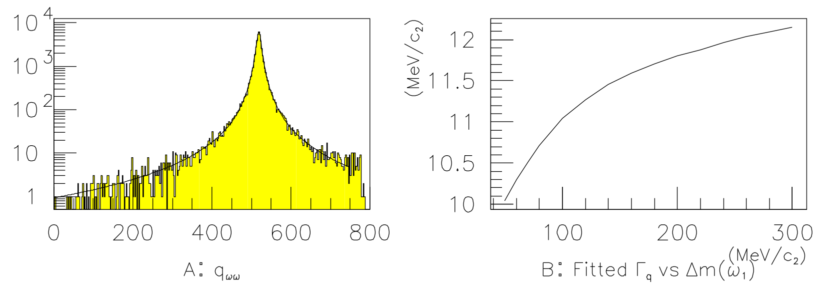

Figure 3: A: Simulation of the distribution of momenta, $q_{\omega\omega}$, of ω's from $\bar{p}p \rightarrow \omega\omega$, where the ω masses have a nonrelativistic Breit-Wigner distribution. The simulation is of kinematics only; no detector response nor resolution effects are included. The fit to the $q_{\omega\omega}$ distribution with a nonrelativistic Breit-Wigner function yields a width $\Gamma_q = 12.6 MeV/c^2$. B: The fitted width, Γ_q, of the $q_{\omega\omega}$ distribution, where the mass of one of the ω's is required to lie within a mass window $\Delta(m_1)$ centered at the central mass of the ω, as a function of the width of the mass window.

not adjusted to reflect the latter fit.) The momentum spectra contain the momenta of the $\pi^+\pi^-\pi^\circ_1$ system, where π°_1 is the π° which was not the $\omega \rightarrow \pi^\circ\gamma$ decay product. Figure 5 shows the $q_{\omega\omega}$ spectra. The Voigtian fits, with fixed $\Gamma_q = 10 MeV/c$, yield Gaussian widths of $6.36 \pm .77 MeV/c$ and $5.65 \pm .26 MeV/c$ for the experimental and Monte Carlo data.

The formula used in the calculation is:

$$BR(\bar{p}p \rightarrow \omega\omega) = \frac{N_{\omega\omega}}{N_{mb} \cdot f_{ann} \cdot BR(\omega\omega \rightarrow \pi^+\pi^-\pi^\circ\pi^\circ\gamma) \cdot (BR(\pi^\circ \rightarrow \gamma\gamma))^2 \cdot \epsilon_{\omega\omega}}.$$

Here $BR(\omega\omega \rightarrow \pi^+\pi^-\pi^\circ\pi^\circ\gamma) = 2 \times BR(\omega \rightarrow \pi^\circ\gamma) \times BR(\omega \rightarrow \pi^+\pi^-\pi^\circ) = 15.0 \pm 0.9\%$. The factor of two accounts for the two combinations of of ω decays which lead to the desired final state ($\omega_1 \rightarrow \pi^+\pi^-\pi^\circ, \omega_2 \rightarrow \pi^\circ\gamma,\ and\ \omega_2 \rightarrow \pi^+\pi^-\pi^\circ, \omega_1 \rightarrow \pi^\circ\gamma$.) The values for the individual branching fractions of the ω are taken from the PDG [1]: for $\omega \rightarrow \pi^\circ\gamma$, $8.5 \pm 0.5\%$; for $\omega \rightarrow \pi^+\pi^-\pi^\circ$, $88.8 \pm 0.7\%$.

Table 3 shows the results of this method. The CL cut for event selection was varied to demonstrate that its value does not significantly affect the result. A CL cut of 25% selects events from the flat region of the CL distribution (see Figures 1 C and D.) The value of Γ_q was fixed to $10.0 MeV/c^2$, corresponding to a narrow range of masses for the ω decaying to $\pi^\circ\gamma$ (see Figures 4 and 3 B.) With these values, the result for the branching fraction $BR(\bar{p}p \rightarrow \omega\omega)$ is $3.15 \pm 0.25\%$.

3 Comparison with Previous CB Measurements

The $BR(\bar{p}p \rightarrow \omega\omega)$ has previously been measured and published as $3.32 \pm 0.34\%$ [2]. The method for this previous measurement differed from that presented here in three significant ways:

1. Mass peaks, as opposed to momentum peaks, were fitted.

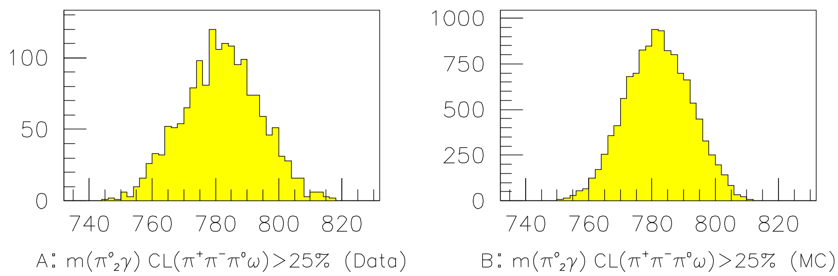

Figure 4: A: The distribution of $\pi_2^\circ\gamma$ masses for events where the fit to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$, $\omega \rightarrow \pi_2^\circ\gamma$ had $CL \geq 25\%$ and a rank of 1, for experimental data. B: The same histogram for Monte Carlo data.

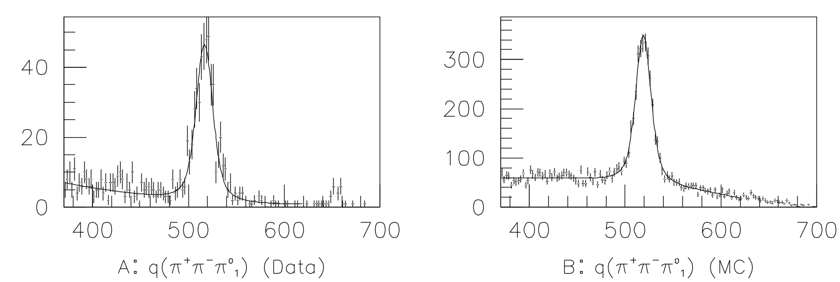

Figure 5: A: The distribution of momenta, $q_{\pi\pi\pi}$, of the $\pi^+\pi^-\pi_1^\circ$ system, for events satisfying the fit to $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ\omega$, $\omega \rightarrow \pi_2^\circ\gamma$ with $CL \geq 25\%$ and a rank of 1, for experimental data. The small peak near $650 MeV/c$ is due to $\bar{p}p \rightarrow \omega\eta$. B: The same histogram for Monte Carlo data.

CL cut	$N_{MC\ \omega\omega}$	$\epsilon_{\omega\omega}$	$N_{\omega\omega}$	$BR(\bar{p}p \to \omega\omega)$
5%	4366	$.08968 \pm .00136$	720	$.0335 \pm .0024$
10%	3930	$.08072 \pm .00129$	650	$.0336 \pm .0024$
15%	3582	$.07358 \pm .00123$	586	$.0332 \pm .0025$
20%	3316	$.06811 \pm .00118$	520	$.0318 \pm .0024$
25%	3069	$.06304 \pm .00114$	476	$.0315 \pm .0024$
30%	2818	$.05788 \pm .00109$	454	$.0327 \pm .0026$
35%	2558	$.05254 \pm .00104$	394	$.0313 \pm .0025$
40%	2391	$.04911 \pm .00100$	354	$.0301 \pm .0025$
45%	2168	$.04453 \pm .00096$	327	$.0306 \pm .0026$
50%	1969	$.04044 \pm .00091$	302	$.0312 \pm .0027$

Table 3: Results of analysis of the ω decay products' momentum spectra: the numbers of detected events, detection efficiencies, and resulting branching fractions are shown as a function of the CL cut.

2. The peaks were fitted with Gaussian, instead of Voigtian, functions.

3. The version of CBGEANT used to generate the Monte Carlo events for the efficiency calculation generated ω's whose masses were within 3Γ of the central mass of the ω.

Both ω's were seen in the $\pi^\circ\gamma$ decay mode. The reason for fitting mass peaks instead of the momentum peaks was that the background under the momentum peak was poorly defined. In the analysis presented here, the data which had been kinematically fit to $\bar{p}p \to \pi^+\pi^-\pi^\circ\pi^\circ\gamma$ also had a poorly defined background, probably because of a large contribution from events which were not of the desired type. Requiring a successful kinematic fit to $\bar{p}p \to \pi^+\pi^-\pi^\circ\omega$ was the crucial step in cleaning up the spectrum. The data for the previous measurement had been fit to $\bar{p}p \to \pi^\circ\pi^\circ\gamma\gamma$, and probably had a large level of contamination.

Measuring the contents of the $\omega \to \pi^\circ\gamma$ invariant mass peak will include events where the other set of final state particles were not from ω decays. This would overestimate the number of $\bar{p}p \to \omega\omega$ events, causing the measured value of $BR(\bar{p}p \to \omega\omega)$ to be too large.

Use of a Gaussian function underestimates the number of events in the peak, because the tails fall of rapidly and thus do not include events in the much larger tails of the Breit-Wigner distribution. This would cause the measured value of $BR(\bar{p}p \to \omega\omega)$ to be too small.

The truncated mass distribution of the CBGEANT ω's make those ω's more easily identifiable than in the real data, since they lie close to the central mass (particularly since the distribution is fitted with a Gaussian function.) This would make the efficiency for detection seem higher, and therefore make the measured branching fraction smaller than its true value.

These effects appear to offset each other in such a way as to not significantly effect the final result for $BR(\bar{p}p \to \omega\omega)$.

References

[1] R.M. Barnett *et al*, Phys. Rev. **D54** (1996).

[2] C.Amsler *et al*, Z. Phys. C **58** 175 (1993).

[3] M.Burchell, CB Note 185, (1992), Unpublished.