The $\gamma\omega\pi$ form factor at $Q^2 \simeq 10$ GeV^2

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Abstract

Large discrepancies are observed between the values of the $\omega\pi\gamma$ form factor determined from J/ψ and $\psi(2S)$ decays from that determined from the continuum cross section for $e^+e^- \to \omega\pi^0$.

1 Introduction

While the SU(3)-allowed $\psi(2S) \to \rho\pi$ decay is suppressed, no similar suppression is observed in the isospin-violating VP counterpart process $\psi(2S) \to \omega\pi^0$. Figure 1 shows the $\pi^+\pi^-\pi^0$ mass distribution for $\psi(2S) \to \pi^+\pi^-\pi^0\pi^0$ decays, where there is a small but unmistakeable $\omega(782)$ signal [1]. From this signal, BES determines a branching fraction $\mathcal{B}(\psi(2S) \to \omega\pi^0) = (3.6 \pm 1.7) \times 10^{-5}$, which is $(9 \pm 5)\%$ of the corresponding J/ψ branching fraction, and in reasonable agreement with 14%-rule expectations.

Isospin violations arise from quark-mass differences and electromagnetic (EM) processes. The lowest-order EM diagrams are the single-photon (γ^*) and the γgg processes shown in Figs. 2a and b. If the γ^* process dominates, similar isospin-violating effects should be visible in continuum e^+e^- annihilation.

In the case where the γ^* process dominates, both $\psi \to \omega\pi$ decays (here I use ψ to denote either the J/ψ or $\psi(2S)$ charmonium states) and the continuum $e^+e^- \to \omega\pi$ production can be related to a form factor $f(q^2)$, whose value at $q^2 = 0$ is well determined from the $\omega \to \gamma\pi^0$ decay width. For charmonium decays, the ratio of the electromagnetic factors at $q^2 = m_\psi^2$ and at $q^2 = 0$ is given in ref. [2]

$$\frac{|f(m_\psi^2)|^2}{|f(0)|^2} = \frac{\alpha}{3}\left[\frac{p_\gamma}{p_\omega}\right]^3 \frac{m_\psi}{\Gamma(\omega \to \gamma\pi^0)} \frac{\Gamma(\psi \to \omega\pi^0)}{\Gamma(\psi \to \mu^+\mu^-)} \tag{1}$$

This relation is readily extended to the continuum $e^+e^- \to \omega\pi^0$ process

$$\frac{|f(s)|^2}{|f(0)|^2} = \frac{\alpha}{3}\left[\frac{p_\gamma}{p_\omega}\right]^3 \frac{\sqrt{s}}{\Gamma(\omega \to \gamma\pi^0)} R_{\omega\pi}(s) \tag{2}$$

where $R_{\omega\pi}$ is the ratio of the Born-level cross section for $e^+e^- \to \omega\pi$ to the lowest level QED cross section for $e^+e^- \to \mu^+\mu^-$. These relations are independent of the explicit form of

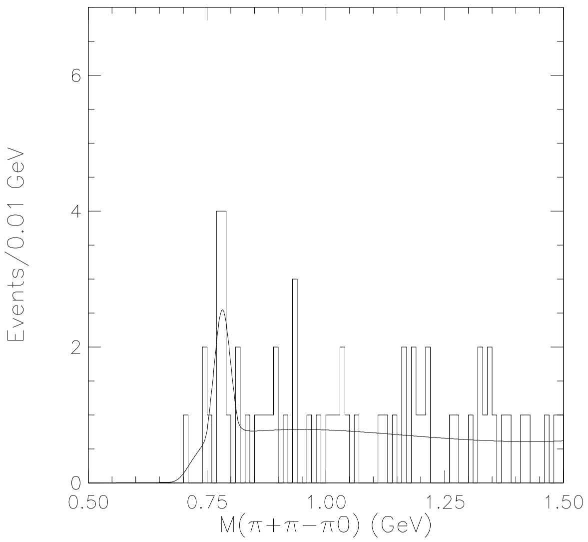

Figure 1: The $\pi^+\pi^-\pi^0$ mass distribution from $\psi(2S) \to \pi^+\pi^-\pi^0\pi^0$ decays. The curve is a fit to a $\omega($ with 13 ± 6 events and a smooth background function.

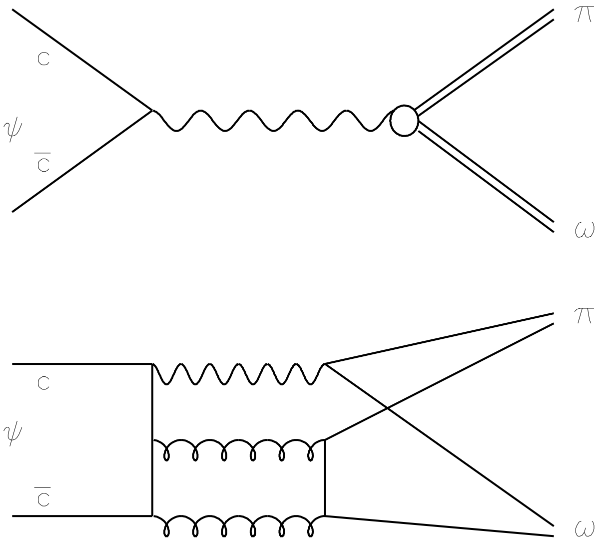

Figure 2: The lowest order diagrams for $\psi \to \omega\pi^0$.

$f(q^2)$. In the vector dominance model (VDM), the form factor is mediated by one or more vector mesons V^*. In this case, the form factor has the functional form

$$f(q^2) \sim \frac{f(0)}{1 - q^2/m^{*2}}, \tag{3}$$

where m^* is some effective mass of the vector mesons involved.

BES accumulated $\sim 22.3\text{pb}^{-1}$ of continuum data at $\sqrt{s} = 4.03$ GeV and 5.1 pb^{-1} around

3.55 GeV. A search for $e^+e^- \to \omega\pi$ in these data samples results in signals of $\sim$ 5 and $\sim$ 3 events at 4.03 and 3.55 GeV, respectively. The distribution of $\pi^+\pi^-\pi^0$ masses recoiling against a π^0 for the 4.03 data is shown in Fig. 3. A clustering of events at the $\omega(782)$ is evident. A similar, although a bit less pronounced clustering is seen in the 3.55 GeV data.

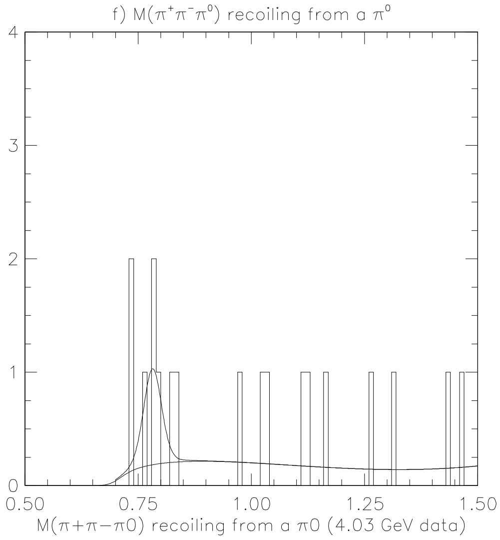

Figure 3: The distribution of $\pi^+\pi^-\pi^0$ masses recoiling from a candidate $e^+e^- \to \pi^+\pi^-2\pi^0$ events at 4.03 GeV.

I determine the R values from the numbers of events via the relation

$$R = \frac{N_{evts}}{\mathcal{L}(1+\delta)\varepsilon\mathcal{B}\sigma_{QED}(e^+e^- \to \mu^+\mu^-)}, \tag{4}$$

where $\mathcal{L} = 22.3$ and 5.1 pb^{-1} are the integrated luminosities at 4.03 and 3.55 GeV, respectively, and $\mathcal{B}$ denotes the product of branching fractions $\mathcal{B}(\omega \to \pi^+\pi^-\pi^0) \times \mathcal{B}^2(\pi^0 \to \gamma\gamma)$, ε is the acceptance and $1+\delta$ is the radiative correction. The factor $\sigma_{QED}(e^+e^- \to \mu^+\mu^-)$ in the denominator is 86.8nb$/s$(GeV^2 (= 5.34 nb at 4.03 GeV and 6.89 nb at 3.55 GeV).

The radiative correction, $1+\delta$, is required because while we are interested in determining the cross section for the Born-level process, the data sample can contain events from higher-order processes, most notably that involving initital state radiation (ISR) as shown in Fig. 4. Here one of the incoming beam particles radiates a photon that carries off a fraction k of its energy and the subsequent e^+e^- annihilation process occurs at a cm energy $\sqrt{s_{eff}}$ that is reduced from its nominal value $\sqrt{s_{nom}}$ by the factor $s_{eff} = (1-k)s_{nom}$. Since some of the events with radiated photons will pass our selection criteria, the radiative correction and acceptance are highly correlated and cannot be determined independently.

According to the formulation of Bonneau and Martin [3], $\sigma_{obs}(s_{nom})$, the observed cross section at s_{nom}, is related to $\tilde{\sigma}_B(s_{eff})$, the Born-level cross section at the reduced energy by

$$\sigma_{obs}(s_{nom}) = \int_0^1 dk \cdot f(k, s_{nom})\ \tilde{\sigma}_B(s_{eff}). \tag{5}$$

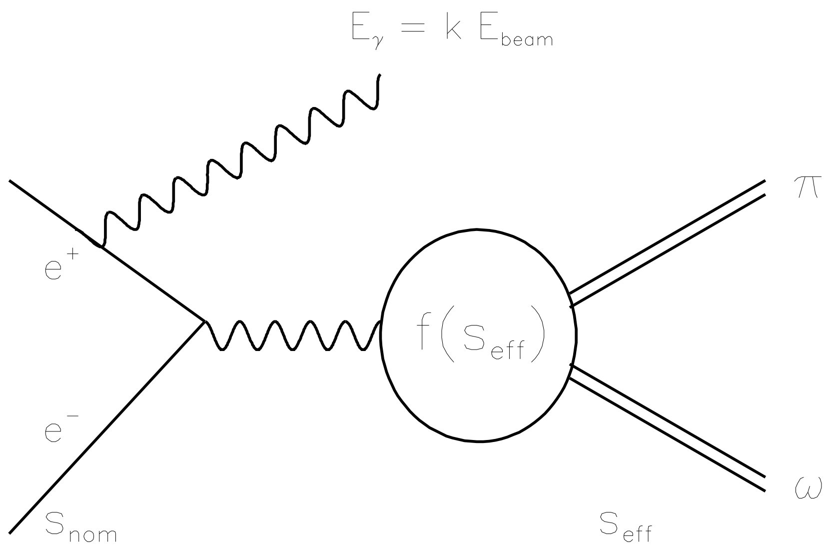

Figure 4: The initial-state-radiation diagram for $\psi \to \omega\pi^0$.

Here $f(k, s_{nom})$ is the sampling function that represents the effective luminosity at s_{nom} and is given by

$$f(k, s_{nom}) = \beta \left[k^{\beta-1}(1+\delta_1) + k/2 \right] - \beta, \tag{6}$$

where

$$\beta = \frac{2\alpha}{\pi}\left[\ln\left(\frac{s_{nom}}{m_e^2}\right) + 1\right] = 0.07876 \tag{7}$$

and

$$\delta = \frac{3\beta}{4} + \frac{\alpha}{\pi}\left[\frac{\pi^2}{3} + \frac{1}{2}\right] = 0.06555 \tag{8}$$

In order to apply this formalism, some model for the energy dependence of $\tilde{\sigma}_B$ must be invoked. I use the parameterization:

$$\tilde{\sigma}_B(s_{eff}) = \tilde{\sigma}_B(s_{nom})\left(\frac{s_{nom}}{s_{eff}}\right)^n, \tag{9}$$

where $n = 3$ corresponds to the high energy behaviour of the VMD model for the $\gamma\omega\pi$ form factor. With this parameterization, the radiative correction is:

$$1 + \delta \equiv \frac{\sigma_{obs}(s_{nom})}{\tilde{\sigma}_B(s_{nom})} = \int_0^1 dk \cdot f(k, s_{nom})\left(\frac{s_{nom}}{s_{eff}}\right)^n \tag{10}$$

I calculate the radiative correction by evaluating the integral in Eq. 10 numerically for values of n ranging from 1 to 4. For each case, I compute the experimental acceptance by generating MC events with ISR included. The results are listed in Table 1. Events that have an ISR photon with substantial energy do not satisfy the selection criteria and models with larger radiative corrections have smaller acceptances. Thus, although in going from $n = 2$ to $n = 3$, the radiative correction increases by a factor of 1.7, the product of the radiative correction and the acceptance changes by less than 30%. For $n \geq 4$ the radiative correction

Table 1: Radiative corrections and acceptance for $e^+e^- \to \omega\pi^0$ at $\sqrt{s} = 4.03$ GeV.

	n=1	n=2	n=3	n=4
	pointlike		VMD	
$1+\delta$	1.10	1.49	2.57	8.24
$\varepsilon_{\omega\pi}$	0.053	0.046	0.035	0.025
$(1+\delta)\varepsilon_{\omega\pi}$	0.058	0.069	0.089	0.21
ε_{K^*K}	0.163	0.14	0.086	0.040
$(1+\delta)\varepsilon_{K^*K}$	0.18	0.19	0.22	0.33

gets very large and the present calculation is probably not applicable. For determining the R values, I use the $n = 3$ result for $(1+\delta)\varepsilon$ and assign the difference between the $n = 2$ and $n = 3$ values as the estimated error. If, in fact, $n \geq 4$ is a better model for $\tilde{\sigma}_B$, the results here can be considered as an upper limit on the R values.

Figure 5 shows the formfactors determined from J/ψ and $\psi(2S)$ decays and those from the continuum production measurements at 3.55 amd 4.03 GeV. It is clear from the figure that the form-factor values determined from the continuum data are significantly smaller than those determined from J/ψ and $\psi(2S)$ decays. Here it is important to recall that the radiative correction proceedure I used probably overestimates the continuum values for the form factors.

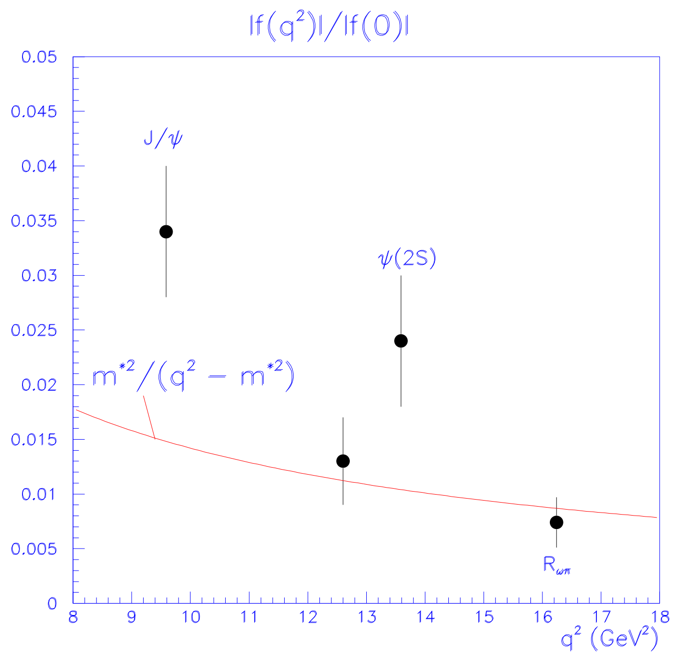

Figure 5: The $\gamma\omega\pi$ formfactor evaluated from the J/ψ and $\psi(2S)$ decay branching ratios and from continuum production at 3.55 and 4.03 GeV.

2 Summary

Continuum BES data provides the opportunity to investigate transition form factors at very small distances. The analysis reported here, although still very preliminary is meant to serve as an existence proof that illustrates BES' capabilities to address this interesting field of investigation.

References

[1] Ye Shuwei discovered this interesting decay mode in the $\psi(2S)$ data.

[2] D. Coffman *et al.* (Mark 3 Collaboration), Phys. Rev. **D38**, 2695 (1988).

[3] G. Bonneau and F. Martin, Nucl. Phys. **B27**, 380 (1971).