Study of $\psi(2S) \to \gamma\eta'$ and $\psi(2S) \to \omega\pi^0$, $\omega\eta$

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Contents

Introduction

- Content of η, η': controversial !
  containing c-quark or gluon ?
- Measuring B($\psi(2S) \to \gamma\eta'$) can tests some models
- B($\psi(2S) \to \omega\pi^0$) related with B($\psi(2S) \to \pi^+\pi^-$)
  both EM processes, at J/ψ we have

$$\frac{\mathcal{B}(\mathcal{J}/\psi \to \omega\pi')}{\mathcal{B}(\mathcal{J}/\psi \to \pi^+\pi^-)} \approx 3$$

$$\frac{F_{\omega\pi^0}(m^2_{J/\psi})}{F_{\pi^+\pi^-}(m^2_{J/\psi})} \approx \frac{1}{3} \quad \text{(EM form-factor)}$$

- Relevant to the anomaly in $\psi(2S)$ decays
  Strongly suppressed $\rho\pi, K^*K$ are VP modes
  How about $\omega\eta$ (VP mode either)
  $\gamma\eta'$ (radiative VP)
  $\omega\pi^0$ (purely EM VP)

Preselection

- $Nchrg = 2,\ 2 \leq Nneu \leq 10,\ \sum Q_i = 0$
- Vertex: $R_{xy} = \sqrt{x^2 + y^2} < 10mm,\ |z| < 15cm, \qquad |z_1 - z_2| < 6cm$
- $Mfit = 2,\ p_{xy} > 80MeV,\ |\cos\theta| < 0.8$
- $IJK > 0$ in skip_bad_run

B($\psi(2S) \to \gamma\eta'$) via $\eta' \to \gamma\rho^o$
— Selection

- $N_{good-\gamma} = 2.or.3,\ Enunk < 0.2GeV$ (Total energy of other γ's)
  for good-γ, requires

$$Hits \geq 3;\ \ Lays \geq 2;$$
$$\Delta\theta < 40^o;\ \ \theta_{vsc} > 10^o;\ \ \theta_{vsn} > 110^o$$

- $\chi^2_{4C} < 15$ at the hypothesis of $\pi^+\pi^-2\gamma$
- $\theta_{acol} > 50^o,\ Emis = Ecm - E_{\pi^+} - E_{\pi^-} > 1.6GeV$
- $XSE_1 + XSE_2 < -2$
- $0.40GeV/c^2 < m_{\pi^+\pi^-} < 0.90GeV/c^2$

— Events & Acceptance

- $N_{sgn} = 30.8 \pm 6.3$, with BW-fit
- $\varepsilon_{acc} = 24.2\%$, with MC study (including ang. distr.)

— Background & Systematic errors

- BKG with a MC sample, 10 times of data yields:
  $N_{bkg} = 1.40 \pm 0.50$
- Systematic error is 0.35×10^{-4}

— Result

$$\boxed{\mathrm{B}(\psi(2S) \to \gamma\eta') = (1.17 \pm 0.25 \pm 0.35) \times 10^{-4}}$$

Ratio comparing with B($J/\psi \to \gamma\eta'$) is

$Q_{\gamma\eta'} = 0.027 \pm 0.010$

Suppressed !

$B(\psi(2S) \to \gamma\eta')$ via $\eta' \to \pi^+\pi^-\eta(\to 2\gamma)$

— Selection

- $N_{good-\gamma} = 3.or.4,\ Enunk < 0.2GeV$
  for good-γ, requires

$$Hits \geq 3;\quad Lays \geq 2;$$
$$\Delta\theta < 40^o;\quad \theta_{vsc} > 5^o;\quad \theta_{vsn} > 30^o$$

- $\chi^2_{4C} < 15$ at the hypothesis of $\pi^+\pi^-3\gamma$
- $\theta_{acol} > 110^o,\ Emis > 2.5GeV,\ m_{\pi^+\pi^-} < 0.42GeV/c^2$
- $XSE_1 + XSE_2 < -2$
- $|m_{2\gamma_1} - 0.5475| < 0.05GeV/c^2$

— Events & Acceptance

$\Delta_{2\gamma} = m_{2\gamma} - 0.5475$

In the mass window of $|m_{\pi^+\pi^-2\gamma} - 0.958| < 0.05$

$\Delta_{2\gamma}$	(-0.15,-0.05)	(-0.05,+0.05)	(+0.05,+0.15)
evts	3	10	2

$N_{sgn} = (10 \pm \sqrt{10}) - \left(\frac{5}{2} \pm \frac{\sqrt{5}}{2}\right) = 7.5 \pm 3.4$

$\varepsilon_{acc} = 14.4\%$, including ang. distr.

— Background & Systematic errors

- BKG with a MC sample, 10 times of data yields:

$$N_{bkg} = 0.35 \pm 0.30$$

- Systematic error is 2.6×10^{-5}

— Result

$$\boxed{B(\psi(2S) \to \gamma\eta') = (7.8 \pm 3.7 \pm 2.6) \times 10^{-5}}$$

$B(\psi(2S) \to \omega\pi^0)$ via $\omega \to \pi^+\pi^-\pi^0$

— Selection

- $110^o < \theta_{acol} < 175^o,\ Emis > 1.9GeV,\ m_{\pi^+\pi^-} < 0.60$
- $N_{good-\gamma} \leq N_{required} + 1,\ Enunk < 0.2GeV$
  for good-γ, requires

$$Hits \geq 3;\quad Lays \geq 2;$$
$$\Delta\theta < 40^o;\quad \theta_{vsc} > 10^o;\quad \theta_{vsn} > 6^o$$

4C-fit for $\pi^+\pi^-4\gamma$ and $\pi^+\pi^-3\gamma$ respectively

A. $\underline{\pi^+\pi^-4\gamma}$:

- $\chi^2_{\pi^+\pi^-4\gamma} < \chi^2_{\pi^+\pi^-3\gamma}$, $\chi^2_{\pi^+\pi^-4\gamma} < 15$
- $|m_{\gamma_1\gamma_2} - 0.13498| < 0.05$, $|m_{\gamma_3\gamma_4} - 0.13498| < 0.05$

B. $\underline{\pi^+\pi^-3\gamma}$:

- $\chi^2_{\pi^+\pi^-3\gamma} < \chi^2_{\pi^+\pi^-4\gamma}$(if exists), $\chi^2_{\pi^+\pi^-3\gamma} < 15$
- $|m_{\gamma_3\gamma_4} - 0.13498| < 0.05$

Where, $\theta_{vsc} < 90^o$ for γ_1, γ_2, and $\theta_{vsc} > 90^o$ for γ_3, γ_4

— Events & Acceptance

- $N_{sgn} = 12.1 \pm 4.7$, with BW-fit
- $\varepsilon_{acc} = 8.74\%$, with MC study (considering ang. distr.)

— Background & Systematic errors

- BKG with a MC sample, 10 times of data yields:

  $N_{bkg} = 1.35 \pm 0.66$
- Systematic error is 1.1×10^{-5}

— Result

$$\boxed{\mathrm{B}(\psi(2S) \to \omega\pi^0) = (3.8 \pm 1.7 \pm 1.1) \times 10^{-5}}$$

Ratio comparing with $\mathrm{B}(J/\psi \to \omega\pi^0)$ is

$$Q_{\omega\pi^0} = 0.090 \pm 0.050$$

$\mathrm{B}(\psi(2S) \to \omega\eta)$ via $\omega \to \pi^+\pi^-\pi^0$ and $\eta' \to 2\gamma$

— Selection

Same with $\psi(2S) \to \omega\pi^0$ except

$$|m_{\gamma_3\gamma_4} - 0.5475| < 0.05$$

— Events & Acceptance

No obvious signal found

Define $\Delta_\eta = m_{\gamma_3\gamma_4} - 0.5475$

1. $m_\omega \in (0.62, 0.84)$

Δ_η	(-0.15,-0.05)	(-0.05,+0.05)	(+0.05,+0.15)
Nevt	7	<u>12</u>	8

2. $\Delta_\eta \in (-0.05, +0.05)$

m_ω	(0.40,0.62)	(0.62,0.84)	(0.84,1.06)
Nevt	8	<u>12</u>	7

So $N_{sgn} = (12 \pm \sqrt{12}) - (\frac{30}{4} \pm \frac{\sqrt{30}}{4}) = 4.5 \pm 3.7$

and $\varepsilon_{acc} = 10.34\%$

— Systematic errors & Result

Since no obvious signal, set an upper limit instead

$$\frac{\int_0^{N_{up}} gauss(4.5, 3.7)dx}{\int_\infty^{N_{up}} gauss(4.5, 3.7)dx} = 0.9$$

$$\Longrightarrow N_{up} = 9.43, \mathcal{B}(\psi(\in\mathcal{S}) \to \omega\eta) < \imath\infty \times \infty\prime^{-\nabla}\ (\exists\prime\%\,\mathcal{CL})$$

into count the systematic errors, the upper limit reads

$$\boxed{\mathrm{B}(\psi(2S) \to \omega\eta) < 8.2 \times 10^{-5}\ (90\%\,CL)}$$

Ratio comparing with $\mathrm{B}(J/\psi \to \omega\eta)$ is

$Q_{\omega\eta} < 0.059\ (90\%\,CL)$

Conclusions

- $\psi(2S) \to \gamma\eta'$, a radiative VP mode, is suppressed too. Two independent processes, $\eta' \to \gamma\rho^o$ and $\eta' \to \pi^+\pi^-\eta$ yield consistent results.
- $\psi(2S) \to \omega\eta$, a hadronic VP mode like $\rho\pi, K^*K$, is suppressed.
- Impressingly, the purely EM VP decay, $\psi(2S) \to \omega\pi^0$ is not yet suppressed if taking into account the effects of QED continuum and the dependency of EM form-factor on Ecm.