the Measurement of the Branch Ratio of $\psi(2S) \to \omega\eta'$

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Outline

- Motivation
- Data Set
- Data Analysis
- Conclusion and Outlook

Motivation

- Precise Measurement: in PDG, the result is $B(\psi(2S) \to \omega\eta') = 3.2^{+2.5}_{-2.1} \times 10^{-5}$. Bradley made a measurement of this channel and the result is $(0.66 \pm 0.24 \pm 0.15 \pm 0.01) \times 10^{-5}$. By using the $\psi(2S)$ samples in BESIII taken in 2009 and 2012, we could make a more precise measurement of the branch ratio of this channel.
- 12% Rule: the Branch ratio of $J/\psi(\psi(2S)) \to h$ should satisfy a relation:

$$Q_h = \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} \approx 12.7\%. \qquad (1)$$

  In PDG, $B(J/\psi \to \omega\eta') = (1.82 \pm 0.21) \times 10^{-4}$, we can obtain that $Q_{\omega\eta'} = 17.6^{+13.3}_{-11.7}\%$. By making a more precise measurement of the brach ratio of this channel, we can obtain the violation of 12% rule.
- Make a deeper understanding in perturbative QCD.

Data Set

- Working environment: boss.6.6.4.p03.
- Data set:

Table: Data set

	Data	Inclusive MC	Signal MC
2009	1.07×10^8	1.08×10^8	100, 000
2012	3.41×10^8	4.00×10^8	320, 000
Total	4.48×10^8	5.08×10^8	420, 000

Signal MC: $\psi(2S) \to \omega\eta'$, $\omega \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$, $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$.

Data Analysis

- Event Selection
- χ^2 Optimization
- π^0/η Fit
- Further Cuts
- Scattering Plot
- Background Analysis
- Simultaneously Fit for ω/η'
- Systematic Error
- Result

Event Selection

- For charged tracks: $V_{xy} = \sqrt{V_x^2 + V_y^2} < 1.0\mathrm{cm}$, $|V_z| < 10\mathrm{cm}$,
  $|\cos\theta| < 0.93$,
  $\mathrm{nCharge} = 0$.

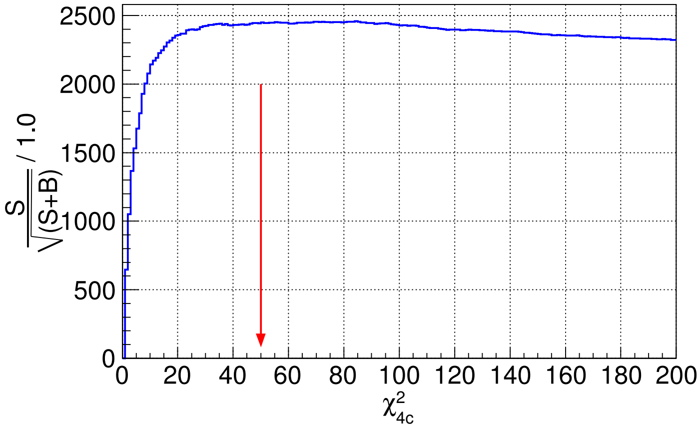
- For photons: $\mathrm{N}_\gamma \geq 4$;
  Barrel EMC: $|\cos\theta| < 0.8$, $E_\gamma \leq 25\mathrm{MeV}$;
  Endcap EMC: $0.86 < |\cos\theta| < 0.92$, $E_\gamma \leq 50\mathrm{MeV}$;
  $0 \leq \mathrm{TDC} \leq 14(\times 50\mathrm{ns})$.

- 4C kinematic fit: $\chi^2_{4c} < 200$.

- π^0/η mass window cut

- ω/η' mass spectrum $m_\omega/m_{\eta'}$

χ^2 Optimization



- S: the events of exclusive MC
- S+B: the events of signal and background of inclusive MC
- We choose $\chi^2_{4c} < 50$ for 2009 and 2012 events.

π^0/η Fit-π^0 Fit

- $\chi^2_{4c} < 50, 0.65 < m_\omega < 0.90(\mathrm{GeV}), 0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$;
- Signal PDF: Crystal Ball function + Gaussian;
- Background PDF: 2nd order Chebyshev Polynomial.

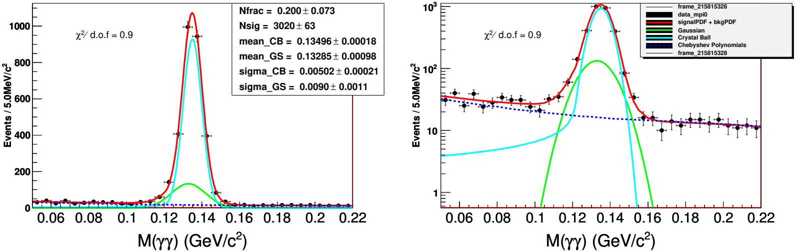


Figure: π^0 fitting

$|m_{\pi^0} - \bar{m}_{\pi^0}| < 3\sigma_{\pi^0}$, $3\sigma_{\pi^0} = 17.4(\mathrm{MeV})$.
We choose $0.117 < m_{\pi^0} < 0.152(\mathrm{GeV})$ for 2009 and 2012 events.

π^0/η Fit-η Fit

- $\chi^2_{4c} < 50, 0.65 < m_\omega < 0.90(\mathrm{GeV}), 0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$;
- Signal PDF: two Crystal Ball functions;
- Background PDF: 2nd order Chebyshev Polynomial.

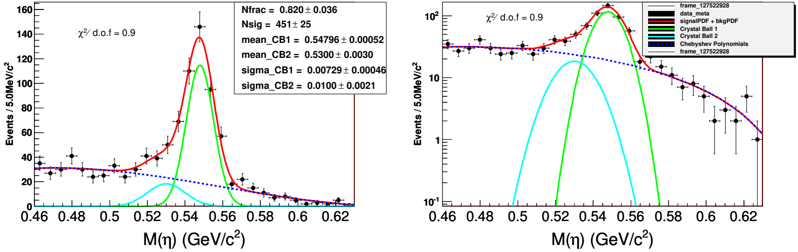


Figure: η fitting

$|m_\eta - \bar{m}_\eta| < 3\sigma_\eta,\ 3\sigma_\eta = 23.3(\mathrm{MeV})$.
We choose $0.521 < m_\eta < 0.568(\mathrm{GeV})$ for 2009 and 2012 events.

Further Cuts

- first cut: $\chi^2_{4c} < 50$;
- second cut: $0.117 < m_{\pi^0} < 0.152(\mathrm{GeV})$;
- third cut: $0.521 < m_{\eta} < 0.568(\mathrm{GeV})$;
- fourth cut($\omega\eta'$ mass window cuts): $0.65 < m_{\omega} < 0.90(\mathrm{GeV})$ and $0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$.

Table: cuts

	signal MC	data	inclusive MC
Total	420000	4.08×10^8	5.06×10^8
After 4c	86057	4991245	5457801
$0 < \chi^2 < 50$	69453	1964449	2086872
$0.117 < m_{\pi^0} < 0.152(\mathrm{GeV})$	64846	979082	1012192
$0.521 < m_{\eta} < 0.567(\mathrm{GeV})$	61977	300283	286399
$\omega\eta'$ cuts	61701	464	620

Scattering Plot

- first cut: $\chi^2_{4c} < 50$;
- second cut: $0.117 < m_{\pi^0} < 0.152(\mathrm{GeV})$;
- third cut: $0.521 < m_{\eta} < 0.568(\mathrm{GeV})$;
- fourth cut: $0.65 < m_{\omega} < 0.90(\mathrm{GeV})$ and $0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$.

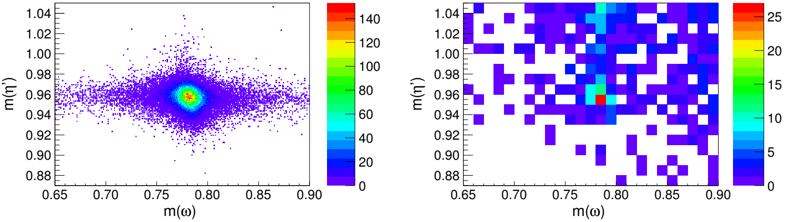


Figure: scattering plot

Background Analysis

After all cuts, by doing the topology, we find out the backgrounds.

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \omega\eta', \omega \to \pi^-\pi^+\pi^0, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	2	321	321
1	$\psi' \to \eta'\pi^+\pi^-\pi^0, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	3	53	374
2	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \omega\eta, \omega \to \pi^-\pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	11	38	412
3	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \pi^-\pi^+\pi^0\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	7	26	438
4	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \omega\omega, \omega \to \pi^-\pi^+\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^-\pi^0\pi^0\pi^+\pi^+\gamma$	6	16	454
5	$\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to \omega\omega, \omega \to \pi^-\pi^+\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^-\pi^0\pi^0\pi^+\pi^+\gamma$	8	13	467
6	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \rho^0\pi^0\eta, \rho^0 \to \pi^+\pi^-, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	35	10	477
7	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \omega\omega, \omega \to \pi^-\pi^+\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^-\pi^0\pi^0\pi^+\pi^+\gamma$	38	9	486
8	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \pi^+\eta\rho^-, \eta \to \gamma\gamma, \rho^- \to \pi^-\pi^0$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	15	8	494
9	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \gamma\pi^+\pi^-\pi^0\pi^0$	$\pi^-\pi^-\pi^0\pi^0\pi^+\pi^+\gamma$	10	8	502
10	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \eta'\pi^+\pi^-, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^+\pi^+\gamma\gamma\gamma$	4	8	510
14	$\psi' \to \omega\eta', \omega \to \pi^-\pi^+\pi^0\gamma_{FSR}, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma$	20	5	536
29	$\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to \omega\eta', \omega \to \pi^-\pi^+\pi^0, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^0\pi^+\pi^+\gamma\gamma\gamma$	46	2	580
50	$\psi' \to \omega\eta', \omega \to \pi^-\pi^+\pi^0, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma e^+e^-$	$e^+\pi^-\pi^-e^-\pi^0\pi^+\pi^+\gamma$	50	1	603
62	$\psi' \to \omega\eta', \omega \to \pi^+\pi^-\gamma, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\pi^-\pi^+\pi^+\gamma\gamma\gamma$	62	1	615

Total number of events is 619. There are three kinds of peaking backgrounds of both ω and η'. The total number is 4.

- $\psi' \to \gamma\eta_c(2S)$, $\eta_c(2S) \to \omega\eta'$, $\omega \to \pi^+\pi^-\pi^0$, $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$;
- $\psi' \to \omega\eta'$, $\omega \to \pi^+\pi^-\pi^0$, $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma e^+e^-$;
- $\psi' \to \omega\eta'$, $\omega \to \pi^+\pi^-\gamma$, $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$.

Simultaneously Fit for ω/η'

- Simultaneously Fit for ω:
  Signal PDF: two Gaussian;
  Background PDF: 3rd order Chebyshev Polynomial;

- Simultaneously Fit for η':
  Signal PDF: Crystal Ball function + Gaussian;
  Background PDF: 2rd order Chebyshev Polynomial;

- Fit model: $sig(\omega) \times sig(\eta') + sig(\omega) \times bkg(\eta') + bkg(\omega) \times sig(\eta') + bkg(\omega) \times bkg(\eta')$.

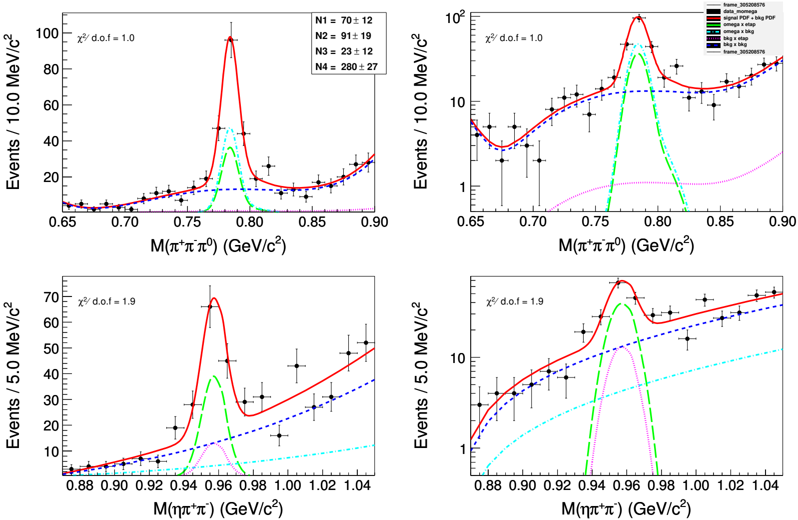


Figure: Simultaneously Fit for ω/η'

Systematic Error

Table: Systematic uncertainty

Uncertainty sources	Systematic uncertainty(%)
Charged track	4.0
Photon selection	4.0
PID	4.0
Fitting range	2.86
Background shape	4.0
$N_{\psi(2S)}$	0.65
Secondary decay	1.89
Others	~ 1.0
Total uncertainty	8.78

The systematic error is:

$$\sigma_B^{syst} = 0.63 \times 10^{-6}. \quad (2)$$

Result

- $N_{\rm sig} = 70 \pm 12$;
- $\epsilon = \frac{61701}{420000} = 14.691\%$;
- $N_{\psi(2S)} = (4.481 \pm 0.029) \times 10^8$;
- $B(\omega \to \pi^+\pi^-\pi^0) = (89.2 \pm 0.7)\% = B_1$;
- $B(\eta' \to \eta\pi^+\pi^-) = (42.6 \pm 0.7)\% = B_2$;
- $B(\pi^0 \to \gamma\gamma) = (98.823 \pm 0.034)\% = B_3$;
- $B(\eta \to \gamma\gamma) = (39.41 \pm 0.20)\% = B_4$.

$$
\begin{aligned}
B(\psi(2S) \to \omega\eta') &= \frac{N_{\rm sig}}{\epsilon \cdot N_{\psi(2S)} \cdot B_1 \cdot B_2 \cdot B_3 \cdot B_4} & (3)\\
&= (7.19 \pm 1.23^{\rm stat.} \pm 0.63^{\rm syst.}) \times 10^{-6} & (4)\\
&= (0.72 \pm 0.12^{\rm stat.} \pm 0.06^{\rm syst.}) \times 10^{-5}. & (5)
\end{aligned}
$$

The branch ratio of $\psi(2S) \to \omega\eta'$ is :

$$B(\psi(2S) \to \omega\eta') = (0.72 \pm 0.12^{\text{stat.}} \pm 0.06^{\text{syst.}}) \times 10^{-5} \quad (6)$$

$$\approx (0.72 \pm 0.13) \times 10^{-5}. \quad (7)$$

Compare with other results:

Table: Comparison of results

	Branch ratio($\times 10^{-5}$)	Significance(σ)
PDG	$3.2^{+2.4}_{-2.0} \pm 0.7$	
Bradley	$0.66 \pm 0.24 \pm 0.15 \pm 0.01$	2.8
	$0.72 \pm 0.12 \pm 0.06$	8.7

With $B(J/\psi \to \omega\eta') = (1.82 \pm 0.21) \times 10^{-4}$, we obtain that:

$$Q_{\omega\eta'} = \frac{B(\psi(2S) \to \omega\eta')}{B(J/\psi \to \omega\eta')} = (3.96 \pm 0.85)\% < 12.7\%. \quad (8)$$

- With the data samples in BESIII taken in 2009 and 2012, we make a precise measurement of the branch ratio of $\psi(2S) \to \omega\eta'$;
- It's the first time that the significance for this channel reaches more than 5σ;
- With the branch ratio of $J/\psi(\psi(2S)) \to \omega\eta'$ in PDG, we obtain that $Q_{\omega\eta'} = 17.6^{+13.9}_{-11.7}\%$. After we make a precise measurement of the branch ratio of $\psi(2S) \to \omega\eta'$, we obtain that $Q_{\omega\eta'} = (3.96 \pm 0.85)\%$, which definitely shows that this channel violate the 12% rule.

Conclusion and Outlook-Outlook

- I havn't finished analysing all the systematic error and this is what I need to do next.

- The peaking background of ω or η' are not solved. I think this needs to be analysised by changing the fitting model for simultaneously fitting and make it systematic error.

- 5c and 6c fit havn't be done. If I finished, this will lead to a systematic error.

- There exists another decay, $\eta' \rightarrow \gamma\pi^+\pi^-$. I need to make a measurement of the branch ratio of this channel also and combine the results of them.


Thank
You

Backup-fitting range

The uncertainty of fitting range is:

$$\frac{|N_{\rm ran} - N_{\rm sig}|_{max}}{N_{\rm sig}} = \frac{2}{70} = 2.86\% \quad (9)$$

No.	$m_\omega(\mathrm{GeV}) \times m_{\eta'}(\mathrm{GeV})$	Fitting result($N_{\rm ran}$)	$\lvert N_{\rm ran} - N_{\rm sig}\rvert$
01	$[0.65, 0.90] \times [0.88, 1.06]$	68 ± 12	2
02	$[0.65, 0.90] \times [0.86, 1.04]$	69 ± 12	1
03	$[0.65, 0.90] \times [0.88, 1.05]$	69 ± 12	1
04	$[0.65, 0.90] \times [0.86, 1.05]$	70 ± 12	0
05	$[0.65, 0.90] \times [0.87, 1.04]$	69 ± 13	1
06	$[0.66, 0.91] \times [0.87, 1.05]$	69 ± 12	1
07	$[0.64, 0.89] \times [0.87, 1.05]$	71 ± 12	1
08	$[0.66, 0.90] \times [0.87, 1.05]$	70 ± 12	0
09	$[0.64, 0.90] \times [0.87, 1.05]$	71 ± 12	1
10	$[0.65, 0.91] \times [0.87, 1.05]$	70 ± 12	0
11	$[0.65, 0.89] \times [0.87, 1.05]$	70 ± 12	0

Backup-backgrounds shape

The uncertainty of background shape is summarised in the table. We use the standard deviation($\sigma_{\rm bkg} = 2.86$) as the error caused by background shapes. So the uncertainty is:

$$\frac{\sigma_{\rm bkg}}{N_{\rm sig}} = \frac{2.86}{70} = 4.0\% \tag{10}$$

Table: Uncertainty of background shapes

No.	$bkg(\omega) \times bkg(\eta')$	Fitting result	$\chi^2_\omega/\mathrm{dof} \times \chi^2_{\eta'}/\mathrm{dof}$
00	$3rd \times 2nd$	70 ± 12	1.0×1.9
01	$2nd \times 2nd$	76 ± 14	1.7×1.8
02	$3rd \times 1st$	70 ± 12	1.0×1.9
03	$1st \times 2nd$	72 ± 12	1.8×1.9
04	$2nd \times 1st$	75 ± 13	1.7×1.9