Branching Fraction of $\psi(2S) \to \omega\eta'(\eta' \to \eta\pi^+\pi^-)$

TAN Yinghua, ZHANG Zhenyu, ZHOU Xiang

School of Physics and Technology, Wuhan University

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Outline

- Motivation
- Data Set
- Data Analysis
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Motivation

- Precise Measurement:

	$B(\psi(2S) \to \omega\eta')(\times 10^{-5})$
PDG	$3.2^{+2.4}_{-2.0} \pm 0.7$
Bradley	$0.66 \pm 0.24 \pm 0.15 \pm 0.01$

- 12% Rule:

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

	$B(J/\psi \to \omega\eta')(\times 10^{-4})$	$Q_{\omega\eta'}(\%)$
PDG	1.82 ± 0.21	$17.6^{+13.3}_{-11.7}$
Bradley	$1.47 \pm 0.06 \pm 0.13 \pm 0.03$	4.49 ± 1.96

- Make a deeper understanding in perturbative QCD.

Data Set

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

$\psi(2S) \to \omega\eta'$	HELAMP 1.0 0.0 0.0 0.0 $-$1.0 0.0
$\omega \to \pi^+\pi^-\pi^0$	OMEGA_DALITZ
$\pi^0 \to \gamma\gamma$	PHSP
$\eta' \to \pi^+\pi^-\eta$	PHSP
$\eta \to \gamma\gamma$	PHSP

Data Analysis

- Event Selection
- χ^2_{4c} Optimization
- Further Cuts
- Scattering Plot
- Background Analysis
- Simultaneously Fit for ω/η'
- Result

Event Selection

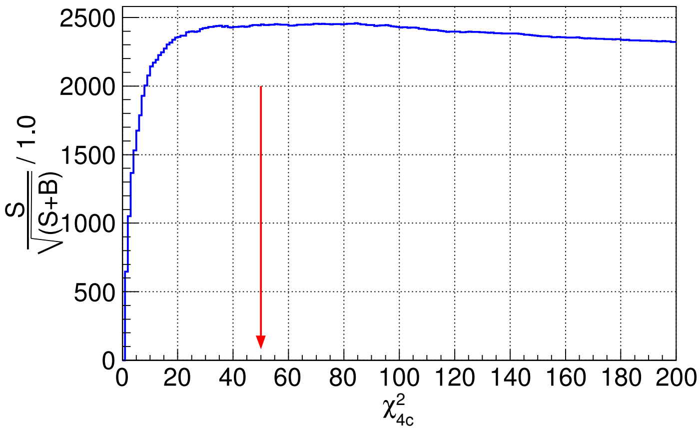
- For charged tracks: $V_{xy}=\sqrt{V_x^2+V_y^2}<1.0\mathrm{cm}$, $|V_z|<10\mathrm{cm}$, $|\cos\theta|<0.93$, $\mathrm{n_{Charge}}=0$.
- For photons: $\mathrm{N}_\gamma \geq 4$;
  Barrel EMC: $|\cos\theta|<0.8$, $E_\gamma \leq 25\mathrm{MeV}$;
  Endcap EMC: $0.86<|\cos\theta|<0.92$, $E_\gamma \leq 50\mathrm{MeV}$;
  $0 \leq \mathrm{TDC} \leq 14(\times 50\mathrm{ns})$.
- 4C kinematic fit: $\chi^2_{4c}<200$.
- π^0/η mass window constraints.
- ω/η' mass spectrum $m_\omega/m_{\eta'}$.

Event Selection

- Photons selections.
  Define $\gamma_1, \gamma_2, \gamma_3, \gamma_4$,
  define $m_{ij} = \gamma_i + \gamma_j (i \neq j)$,
  define $\delta_n = (m_{ij} - m_{\pi^0})^2 + (m_{kl} - m_\eta)^2$,
  choose the minimal δ to reconstruct π^0/η.

- Pions selection.
  Define $\pi_1^+, \pi_2^+, \pi_1^-, \pi_2^-$,
  define $m_{\omega ij} = m_{\pi_i^+} + m_{\pi_j^-} + m_{\pi^0}$, $m_{\eta' kl} = m_{\pi_k^+} + m_{{}_l^-} + m_\eta$
  define $\delta_n = (m_{\omega ij} - m_\omega)^2 + (m_{\eta' kl} - m_{\eta'})^2$,
  choose the minimal δ to reconstruct ω/η'.

χ^2_{4c} Optimization



- S: the events of signal 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 function;
- Background PDF: 2nd order Chebyshev Polynomial.

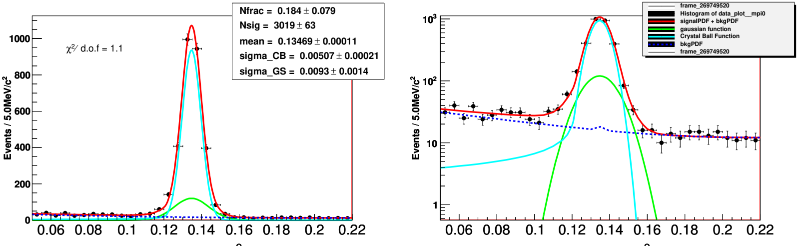


Figure: π^0 fitting

$|m_{\pi^0} - \bar{m}_{\pi^0}| < 3\sigma_{\pi^0}$, $3\sigma_{\pi^0} = 17.4(\mathrm{MeV})$.
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.

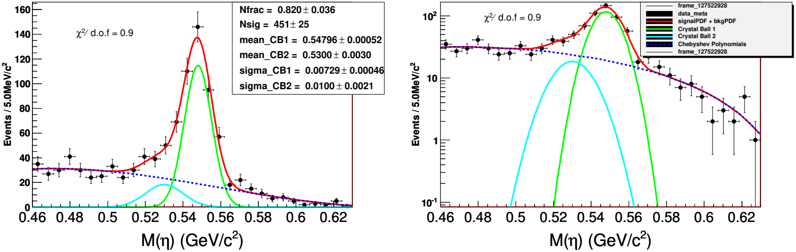


Figure: η fitting

$|m_\eta - \bar{m}_\eta| < 3\sigma_\eta$, $3\sigma_\eta = 23.3(\mathrm{MeV})$.
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	rate(%)	data	inclusive MC
Total	420000	100	4.48×10^8	5.06×10^8
After 4c	86057	20.5	4991245	5457801
$0 < \chi^2 < 50$	69453	16.5	1964449	2086872
π^0 cut	64846	15.4	979082	1012192
η cut	61977	14.8	300283	286399
$\omega\eta'$ cuts	61701	14.7	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 $0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$.

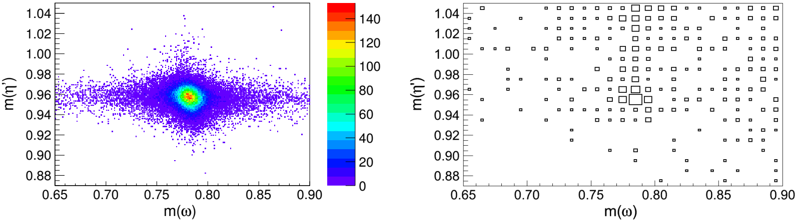


Figure: Scattering plot

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 signal is 326, and the number of peaking backgrounds of both ω and η' is 4, resulting the uncertainty of di-peaking backgrounds is $4/326 = 6.90\%$.

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

Simultaneously Fit for ω/η'

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

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

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

Simultaneously Fit for ω/η'

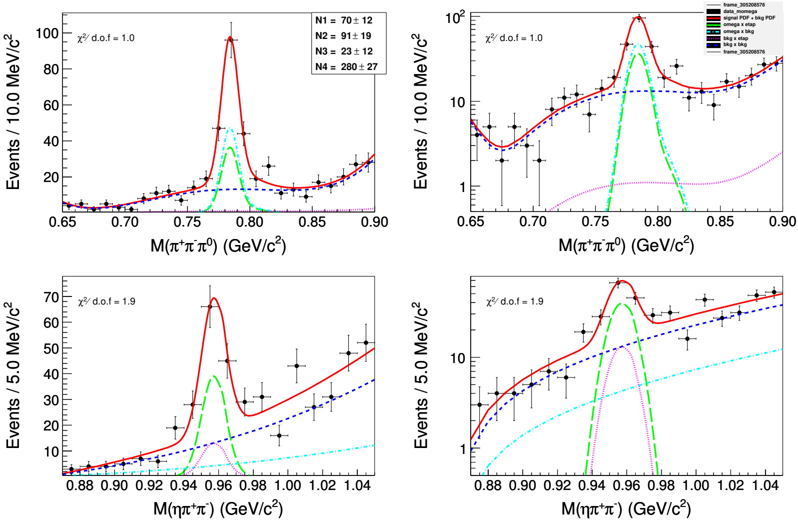


Figure: Simultaneously Fit for ω/η'

Result

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

$$B(\psi(2S) \to \omega\eta') = \frac{N_{\text{sig}}}{\epsilon \cdot N_{\psi(2S)} \cdot B_1 \cdot B_2 \cdot B_3 \cdot B_4} \quad (2)$$

$$= (7.19 \pm 1.23^{\text{stat.}}) \times 10^{-6} \quad (3)$$

Systematic Error

Table: Systematic uncertainty

Uncertainty sources	Systematic uncertainty(%)
Charged track	4.00
Photon selection	4.00
Fitting range	2.86
Background shape	8.57
$N_{\psi(2S)}$	0.65
Secondary decay	1.89
Di-peaking background	6.90
Number of constraints	23.23
Total uncertainty	26.55

The systematic error is:

$$\sigma_B^{\text{syst.}} = 1.91 \times 10^{-6}. \quad (4)$$

Conclusion and Outlook-the Result

The branching fraction of $\psi(2S) \to \omega\eta'(\eta' \to \eta\pi^+\pi^-)$ is :

$$B(\psi(2S) \to \omega\eta') = (7.19 \pm 1.23^{\text{stat.}} \pm 1.91^{\text{syst.}}) \times 10^{-6} \quad (5)$$

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
This result	$0.719 \pm 0.123 \pm 0.191$	8.7

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

$$Q_{\omega\eta'} = \frac{B(\psi(2S) \to \omega\eta')}{B(J/\psi \to \omega\eta')} = (3.95 \pm 1.33)\% < 12.7\%. \quad (6)$$

- The measurement of the branching fraction of $\psi(2S) \to \omega\eta'(\eta' \to \eta\pi^+\pi^-)$ is almost finished.
  $B(\psi(2S) \to \omega\eta') = (7.19 \pm 1.23^{\text{stat.}} \pm 1.91^{\text{syst.}}) \times 10^{-6}$,
  $Q_{\omega\eta'} = (3.95 \pm 1.33)\%$;

- Comparisons of the results before:

	$B(\psi(2S) \to \omega\eta')(\times 10^{-5})$	$Q_{\omega\eta'}(\%)$
PDG	$3.2^{+2.4}_{-2.0} \pm 0.7$	$17.6^{+13.3}_{-11.7}$
Bradley	$0.66 \pm 0.24 \pm 0.15 \pm 0.01$	4.49 ± 1.96
This result	$0.719 \pm 0.123 \pm 0.191$	3.95 ± 1.33

Conclusion and Outlook-Outlook

- There exists another decay model for $\psi(2S) \to \omega\eta'$, which is $\eta' \to \gamma\pi^+\pi^-$. The branching fraction of this model will be measured in the next step and the results of them will be combined;

- The branching Fraction of $J/\psi \to \omega\eta'$ will also be measured by using the samples taken in 2009 and 2012;

- Some other branching fractions of VP channels will be measured in the future.


Thank
You

Backup-Fitting range

The uncertainty of fitting range is:

$$\frac{|N_{\mathrm{ran}} - N_{\mathrm{sig}}|_{max}}{N_{\mathrm{sig}}} = \frac{2}{70} = 2.86\% \tag{7}$$

No.	$m_{\omega}(\mathrm{GeV}) \times m_{\eta'}(\mathrm{GeV})$	Fitting result(N_{ran})	$\lvert N_{\mathrm{ran}} - N_{\mathrm{sig}}\rvert$
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 the background shape is:

$$\frac{|N_{\rm bkg} - N_{\rm sig}|_{\rm max}}{N_{\rm sig}} = \frac{6}{70} = 8.57\% \tag{8}$$

Table: Uncertainty of background shapes

No.	$bkg(\omega) \times bkg(\eta')$	Fitting result($N_{\rm bkg}$)	$\|N_{\rm bkg} - N_{\rm sig}\|$
00	$3rd \times 2nd$	70 ± 12	0
01	$2nd \times 2nd$	76 ± 14	6
02	$3rd \times 1st$	70 ± 12	0
03	$1st \times 2nd$	72 ± 12	2
04	$2nd \times 1st$	75 ± 13	5

Backup-Number of constraints

- First cut: $\chi^2_{6c} < 50$;
- Second cuts(ω/η' mass window cuts): $0.65 < m_\omega < 0.90(\mathrm{GeV})$ and $0.87 < m_{\eta'} < 1.05(\mathrm{GeV})$.

Table: cuts

	signal MC	rate	data	inclusive MC
Total	420000	100%	4.48×10^8	5.06×10^8
After 6c	76729	18.3%	885595	877064
$\chi^2_{6c} < 50$	61282	14.6%	298611	286543
ω/η' cuts	45030	10.7%	1087	1510

Backup-Number of constraints

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

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

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

Backup-Number of constraints

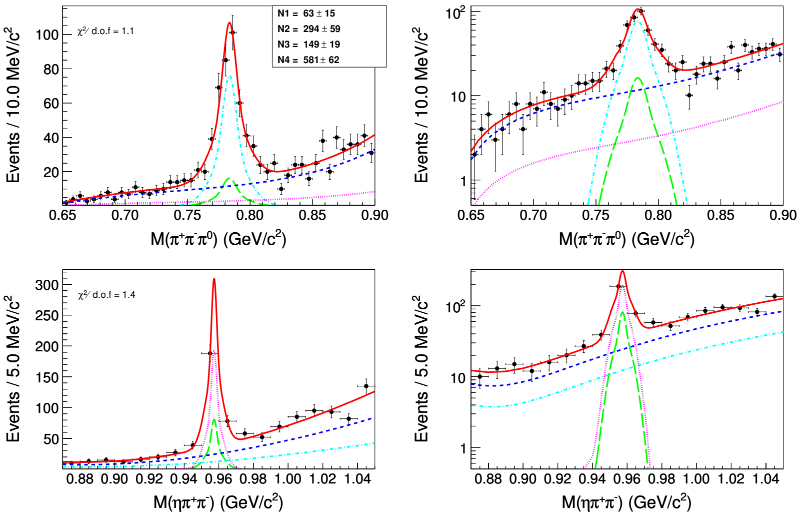


Figure: Simultaneously Fit for ω/η'

Backup-Number of constraints

- $N_{\mathrm{sig}} = 63 \pm 15$;
- $\epsilon = \frac{45030}{420000} = 10.721\%$;
- $N_{\psi(2S)} = (4.481 \pm 0.029) \times 10^8$;
- $B(\omega \to \pi^+\pi^-\pi^0) = (89.2 \pm 0.7)\% = B_1$;
- $B(\eta' \to \eta\pi^+\pi^-) = (42.6 \pm 0.7)\% = B_2$;
- $B(\pi^0 \to \gamma\gamma) = (98.823 \pm 0.034)\% = B_3$;
- $B(\eta \to \gamma\gamma) = (39.41 \pm 0.20)\% = B_4$.

$$B(\psi(2S) \to \omega\eta') = \frac{N_{\mathrm{sig}}}{\epsilon \cdot N_{\psi(2S)} \cdot B_1 \cdot B_2 \cdot B_3 \cdot B_4} \quad (9)$$

$$= (8.86 \pm 2.11^{\mathrm{stat.}}) \times 10^{-6} \quad (10)$$

The uncertainty caused by the number of constraints is:

$$\frac{|B_{6c} - B_{4c}|}{B_{4c}} = 23.23\% \quad (11)$$