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Measurement of $Br(J/\Psi \rightarrow \omega\eta)$

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Outline

- ① **Motivation**
- ② **Measurement of Br(Ψ(2S)→ωη)**
- ③ **Measurement of Br(J/Ψ→ωη)**
- ④ **Systematic error analysis**
- ⑤ **Summary and Outlook**

Motivation

- **According to PDG, there is a puzzle that most of the branching ratios for J/Ψ→VP and Ψ(2S)→VP do not satisfy the "12% rule".**

  "12% rule": $Q_h = \frac{B(\Psi(2S) \to hardons)}{B(J/\Psi \to hardons)} \approx 12.7\%$

- **When we work out the accurate measurement of decay branch ratio, it can help us to have a better understanding of "12% rule" and "ρπ puzzle". What's more, it can play an important role in improving the development of quantum chromodynamics(QCD) in the non-perturbative energy field.**

- **On March 17, 2018, we report the result of Br(Ψ(2S)→ωη) : (1.94±0.35±0.39)×10^-6 . In order to examine "12% rule", the result of Br(J/Ψ→ωη) is also needed.**

- **In PDG, the result of J/Ψ→ωη is (1.74±0.20)×10^-3 . With BESIII, we can improve the result, so the precision can be enhanced and the uncertainty can be decreased.**

Measurement of $Br(\Psi(2S)\rightarrow\omega\eta)$

Reported last time at BESIII Physics and Software Workshop on March 17, 2018.

- **Event Selection**
- **Simultaneously fit**
- **The result of branch ratio**

Event Selection

For charged tracks:

$$V_{xy} = \sqrt{V_x^2 + V_y^2} < 1.0cm, |V_z| < 10cm \qquad |\cos\theta| < 0.93$$

nCharge = 0 nCharged Tracks = 2

For photons:

$$N\gamma \geqslant 4$$

$$|\cos\theta| < 0.8, E\gamma \geq 25MeV(barrelEMC)$$

$$0.86 < |\cos\theta| < 0.92, E\gamma \geq 50MeV(endcapEMC)$$

$$0 \leq TDC \leq 14(\times 50ns)$$

4c kinematic fit

π^0 mass constrain

ω mass spectrum m(3pi)

η mass spectrum m(eta)

Cut and Fit range:

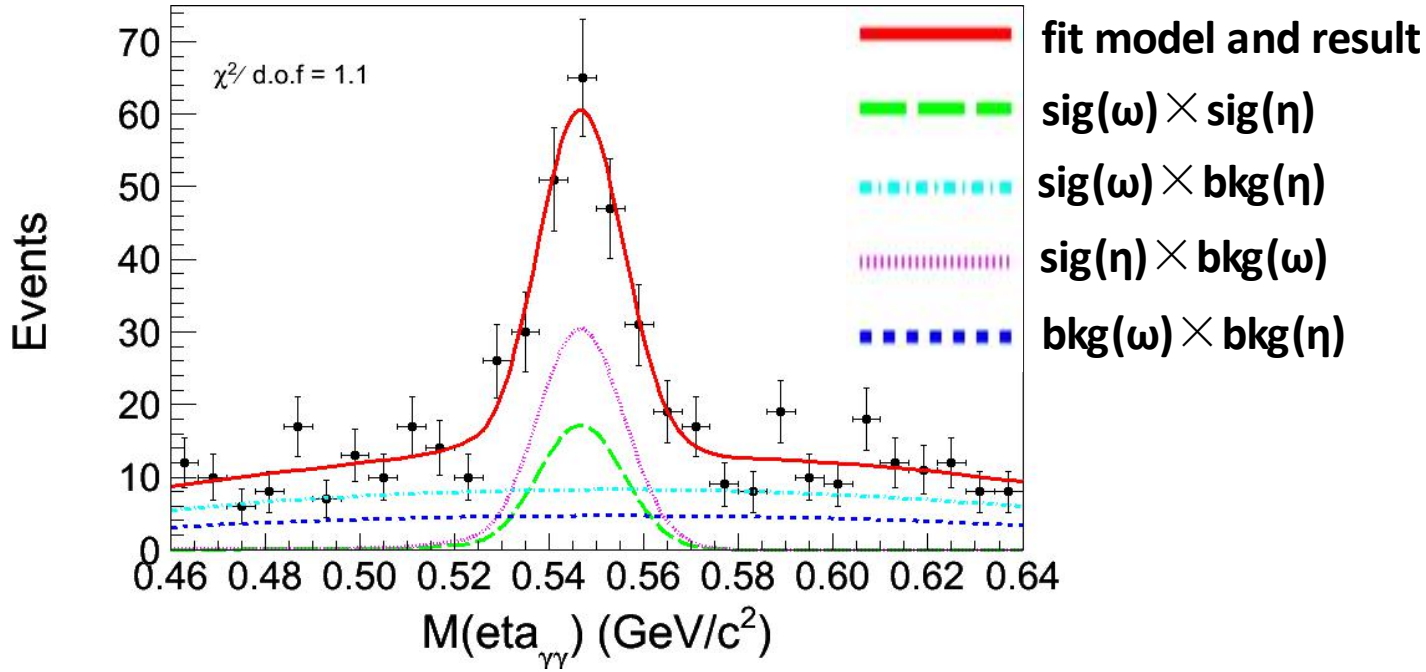
first cut : χ^2<25

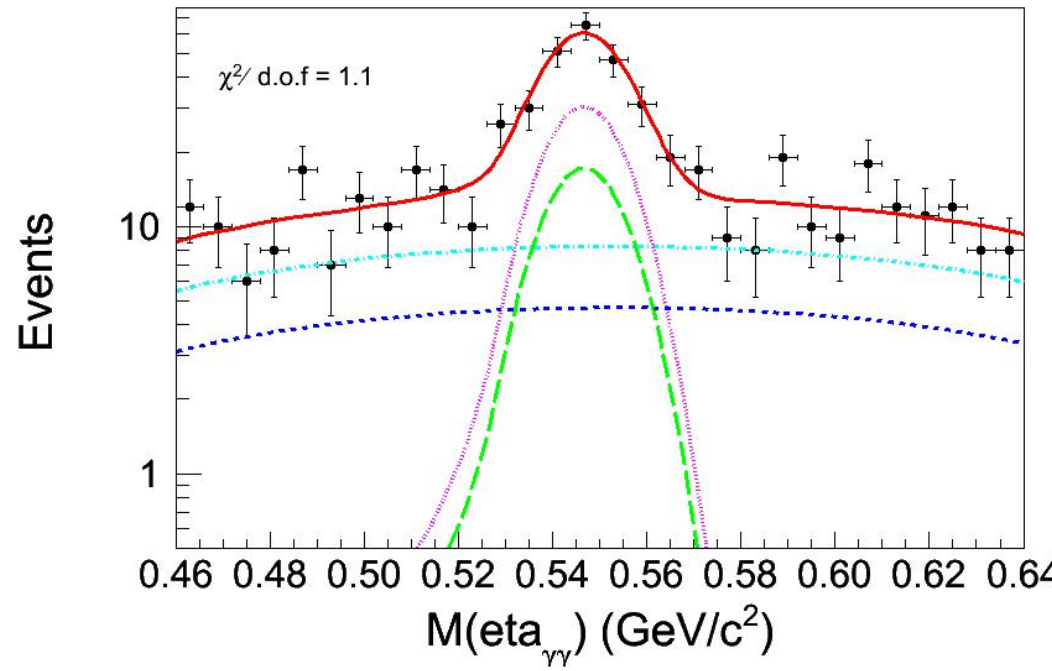
second cut (ω η mass window cuts) :
0.46<m(eta)<0.64 and 0.65<m(3pi)<0.9 (GeV)

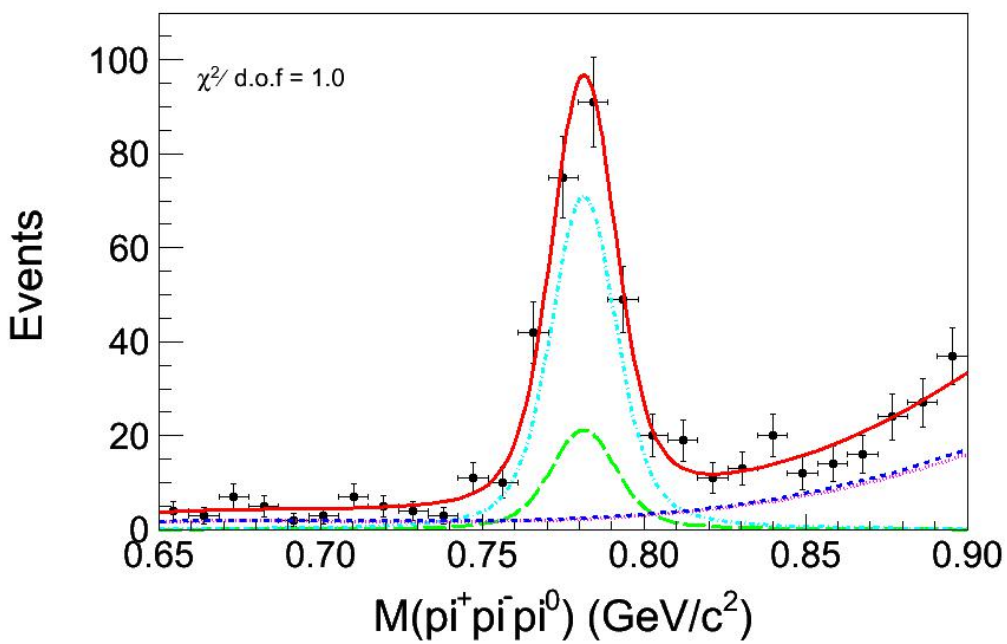
Simultaneously fit

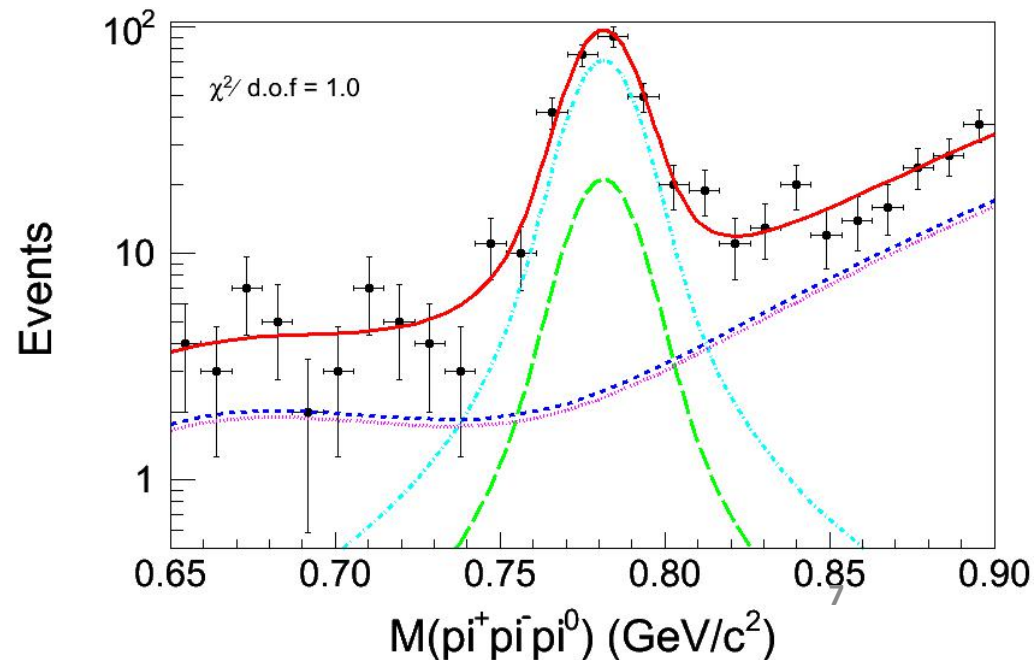
- **omega:**
- **signal PDF : Breit–Wigner $\otimes$ Gaussian**
- **background PDF : 2nd order Chebyshev polynomial**
- **eta:**
- **signal PDF : one Crystal Ball function**
- **background PDF : 1st order Chebyshev polynomial**

- **fit model : sig(ω) $\times$ sig(η) + sig(ω) $\times$ bkg(η) + sig(η) $\times$ bkg(ω) + bkg(ω) $\times$ bkg(η)**


fit model and result
sig(ω)×sig(η)
sig(ω)×bkg(η)
sig(η)×bkg(ω)
bkg(ω)×bkg(η)
χ²/ d.o.f = 1.1
Events
M(eta_γγ) (GeV/c²)


χ²/ d.o.f = 1.1
Events
M(eta_γγ) (GeV/c²)


χ²/ d.o.f = 1.0
Events
M(pi⁺pi⁻pi⁰) (GeV/c²)


χ²/ d.o.f = 1.0
Events
M(pi⁺pi⁻pi⁰) (GeV/c²)

The result of branch ratio：

- Nsig： 67±12
- ε： 22.2%
- $N_{\psi(2S)}$： 4.48×10^{8}
- $B(\omega\to\pi^{+}\pi^{-}\pi^{0})$： 0.892
- $B(\eta\to2\gamma)$： 0.394
- $B(\pi^{0}\to2\gamma)$： 0.988

Systematic uncertainty analysis

Ψ(2S)→ωη	5c fit (%)
fit model	18.7
Photon efficiency	4
Track efficiency	2
Branch ratio of Decay channel	0.9
Kinematic constraints	5.5
PID	<0.1
Resonant background	1.4
Number of Ψ(2S) events	0.6
Summary	20.1

$$Br(\psi(2S)\to\omega\eta)=\frac{n_{sig}}{\varepsilon\times B(\omega\to\pi^{+}\pi^{-}\pi^{0})\times B(\eta\to\gamma\gamma)\times B(\pi^{0}\to\gamma\gamma)\times N_{\psi'}}$$
$$=(1.94\pm0.35\pm0.39)\times10^{-6}$$

Measurement of Br(J/Ψ→ωη)

- **Data set**
- **Event Selection**
- **Background analysis and background cuts**
- **final cuts**
- **simultaneously fit**
- **result**

Data Set

- **Working Environment: Boss 6.6.4**

- **J/Ψ Data: data09 + data12**
  (total: 1.31 billion)

- **J/Ψ Inclusive MC: inMC09 + inMC12**

- **Exclusive MC : $J/\Psi \rightarrow \omega\eta$**
  $\omega \rightarrow \pi^+\pi^0\pi^-$
  $\eta \rightarrow \gamma\gamma$
  $\pi^0 \rightarrow \gamma\gamma$

2012 Exclusive MC events: 470,000
2009 Exclusive MC events: 100,000

Event Selection

For charged tracks:

$$V_{xy} = \sqrt{V_x^{\ 2} + V_y^{\ 2}} < 1.0cm, |V_z| < 10cm \qquad |\cos\theta| < 0.93$$

nCharge = 0 nCharged Tracks = 2

For photons:

$$N\gamma \geqslant 4$$

$$|\cos\theta| < 0.8, E\gamma \geq 25MeV\,(barrelEMC)$$

$$0.86 < |\cos\theta| < 0.92, E\gamma \geq 50MeV\,(endcapEMC)$$

$$0 \leq TDC \leq 14(\times 50ns)$$

4c kinematic fit

π^0 mass constrain

ω mass spectrum m(3pi)

η mass spectrum m(eta)

chi2 optimization (same as Ψ(2S)→ωη):

chi2 < 25

Background analysis

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

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \to \omega\eta, \omega \to \pi^-\pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	0	133570	133570
1	$J/\psi \to \gamma\eta', \eta' \to \omega\gamma, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^0\pi^+\gamma\gamma$	5	2038	135608
2	$J/\psi \to a_2^0\rho^0, a_2^0 \to \eta\pi^0, \rho^0 \to \pi^+\pi^-, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	9	1227	136835
3	$J/\psi \to \gamma\pi^+\pi^-\pi^0\pi^0$	$\pi^-\pi^0\pi^0\pi^+\gamma$	6	963	137798
4	$J/\psi \to \rho^-\eta\pi^+, \rho^- \to \pi^-\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	3	792	138590
5	$J/\psi \to \rho^+\pi^-\eta, \rho^+ \to \pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	10	766	139356
6	$J/\psi \to \omega\eta, \omega \to \pi^-\pi^+\pi^0\gamma_{FSR}, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	8	658	140014
7	$J/\psi \to a_2^-\rho^+, a_2^- \to \eta\pi^-, \rho^+ \to \pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	30	490	140504
8	$J/\psi \to a_2^+\rho^-, a_2^+ \to \eta\pi^+, \rho^- \to \pi^-\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	2	480	140984
9	$J/\psi \to \eta\rho^0\pi^0, \eta \to \gamma\gamma, \rho^0 \to \pi^+\pi^-$	$\pi^-\pi^0\pi^+\gamma\gamma$	4	399	141383
10	$J/\psi \to \omega\pi^0\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^0\pi^0\pi^0\pi^+$	11	390	141773

Total number of events is 144913

Total number of background is 11343

Two main background:

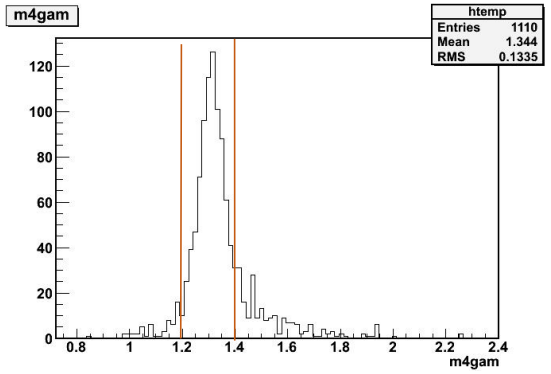
$J/\Psi \to \gamma\eta'$, $\eta' \to \omega\gamma$, $\omega \to \pi^+\pi^0\pi^-$

$J/\Psi \to a_2^0\rho^0$, $a_2^0 \to \eta\pi^0$, $\rho^0 \to \pi^+\pi^-$, $\eta \to \gamma\gamma$

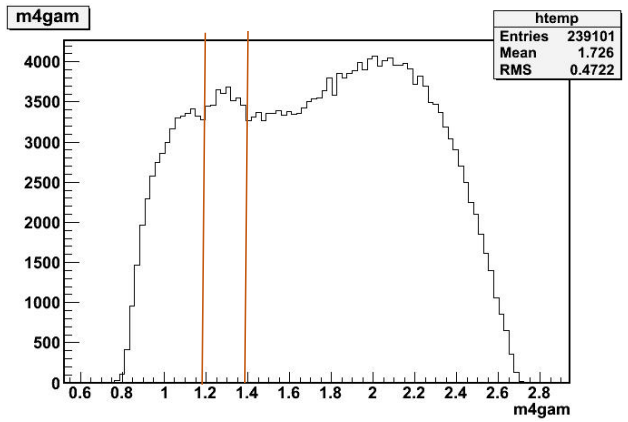
Background cut

$J/\Psi \rightarrow a_2^0 \rho^0$

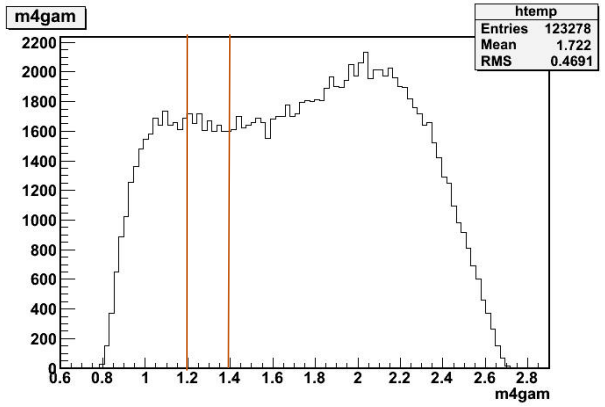
m4gam< 1.2 ||
m4gam > 1.4



1. Exclusive MC for $J/\Psi \rightarrow a_2^0 \rho^0$



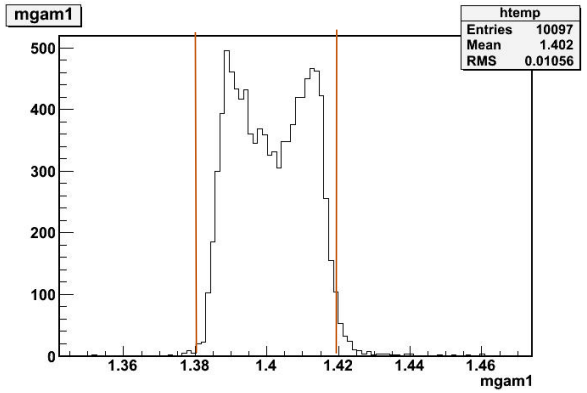
2. data



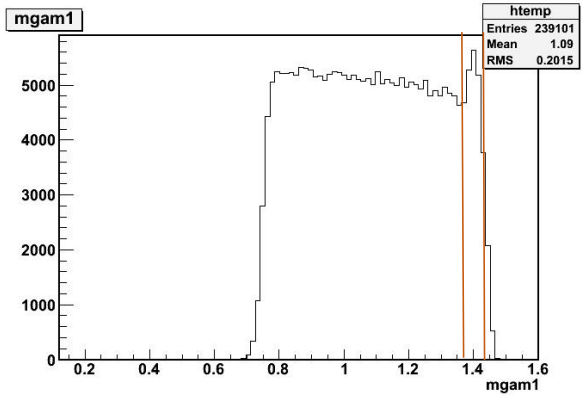
3. Exclusive MC for $J/\Psi \rightarrow \omega\eta$

$J/\Psi \rightarrow \gamma\eta'$

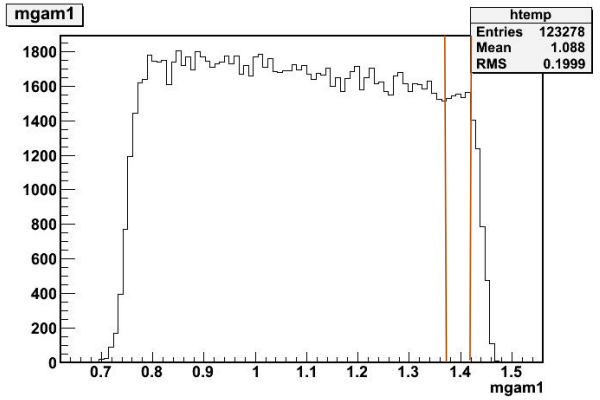
mgam1< 1.38 ||
mgam1 > 1.42



1. Exclusive MC for $J/\Psi \rightarrow \gamma\eta'$



2. data



3. Exclusive MC for $J/\Psi \rightarrow \omega\eta$

Background analysis

- **After the background cuts, by doing the topology, we analyze the backgrounds again.**

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \to \omega\eta, \omega \to \pi^-\pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	0	118085	118085
1	$J/\psi \to \gamma\eta', \eta' \to \omega\gamma, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^0\pi^+\gamma\gamma$	5	1815	119900
2	$J/\psi \to \gamma\pi^+\pi^-\pi^0\pi^0$	$\pi^-\pi^0\pi^0\pi^+\gamma$	6	890	120790
3	$J/\psi \to \rho^-\eta\pi^+, \rho^- \to \pi^-\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	3	710	121500
4	$J/\psi \to \rho^+\pi^-\eta, \rho^+ \to \pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	8	678	122178
5	$J/\psi \to \omega\eta, \omega \to \pi^-\pi^+\pi^0\gamma_{FSR}, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	9	601	122779
6	$J/\psi \to a_2^-\rho^+, a_2^- \to \eta\pi^-, \rho^+ \to \pi^+\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	29	465	123244
7	$J/\psi \to a_2^+\rho^-, a_2^+ \to \eta\pi^+, \rho^- \to \pi^-\pi^0, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	2	433	123677
8	$J/\psi \to \omega\pi^0\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^0\pi^0\pi^0\pi^+$	10	370	124047
9	$J/\psi \to \eta\rho^0\pi^0, \eta \to \gamma\gamma, \rho^0 \to \pi^+\pi^-$	$\pi^-\pi^0\pi^+\gamma\gamma$	4	367	124414
10	$J/\psi \to a_2^0\rho^0, a_2^0 \to \eta\pi^0, \rho^0 \to \pi^+\pi^-, \eta \to \gamma\gamma$	$\pi^-\pi^0\pi^+\gamma\gamma$	15	308	124722

The total number of events: 127546

No.	decay chain	nEvt
1	$J/\Psi \to \omega\eta$, $\omega \to \pi^0\gamma$, $\eta \to \gamma\gamma$	62
2	$J/\Psi \to \omega\eta$, $\omega \to \pi^0 e^+e^-$, $\eta \to \gamma\gamma$	60
3	$J/\Psi \to \omega\eta$, $\omega \to \pi^0\mu^+\mu^-$, $\eta \to \gamma\gamma$	20
4	$J/\Psi \to \omega\eta$, $\omega \to \pi^+\pi^-\gamma$, $\eta \to \gamma\gamma$	2
5	$J/\Psi \to \omega\eta\pi^0$, $\omega \to \pi^+\pi^-\pi^0$, $\eta \to \gamma\gamma$	1
6	$J/\Psi \to \omega\eta$, $\omega \to \eta\gamma$, $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$	1

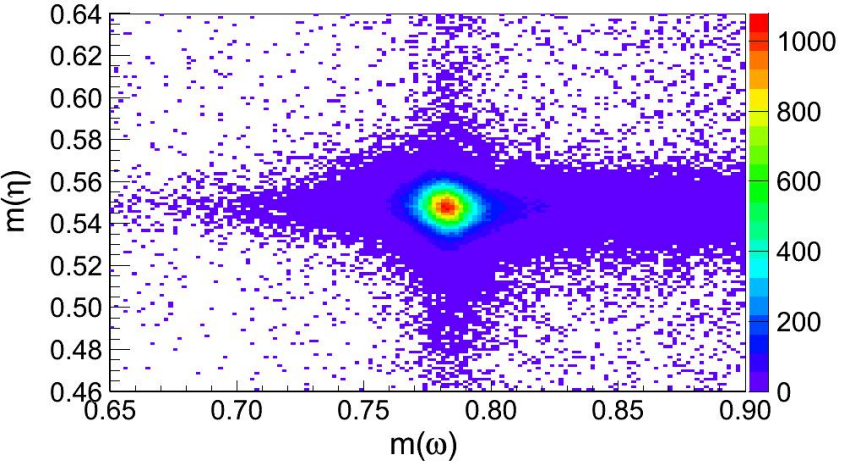
The total number of both omega and eta peaking background : 146

final cuts

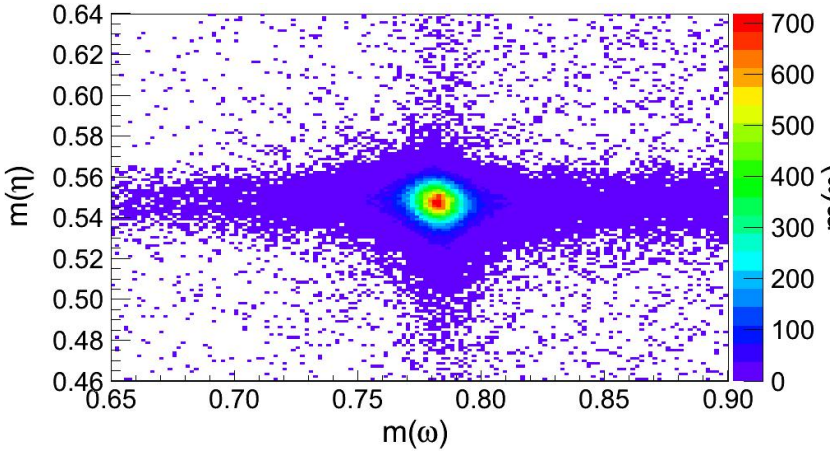
- Data : data09 + data12
- Cut and Fit range:
  - first cut : $\chi^2<25$
  - second cut (pi^0 mass constrain)
  - third cut (ω η mass window cuts) : 0.46<m(eta)<0.64 and 0.65<m(3pi)<0.9 (GeV)
  - fourth cut (background cuts) : mgam1< 1.38 || mgam1 > 1.42 and m4gam< 1.2 || m4gam > 1.4

	data	the percentage of the data events left	exclusive MC	the percentage of the exclusive MC events left	inclusive MC	the percentage of the inclusive MC events left
The total events			570000	100		
after event selection	9556022	100	170617	29.9	8507795	100
after 0<chi2<25	2904880	30.4	123898	21.8	2552452	30
after 0.46<meta<0.64	1804099	18.9	123796	21.7	1875803	22
after 0.65<m3pi<0.9	239101	2.5	123278	21.6	144913	1.7
after mgam1< 1.38 || mgam1 > 1.42	224324	2.35	116680	20.5	135113	1.6
after m4gam< 1.2 || m4gam > 1.4	196868	2.06	103196	18.1	118869	1.4

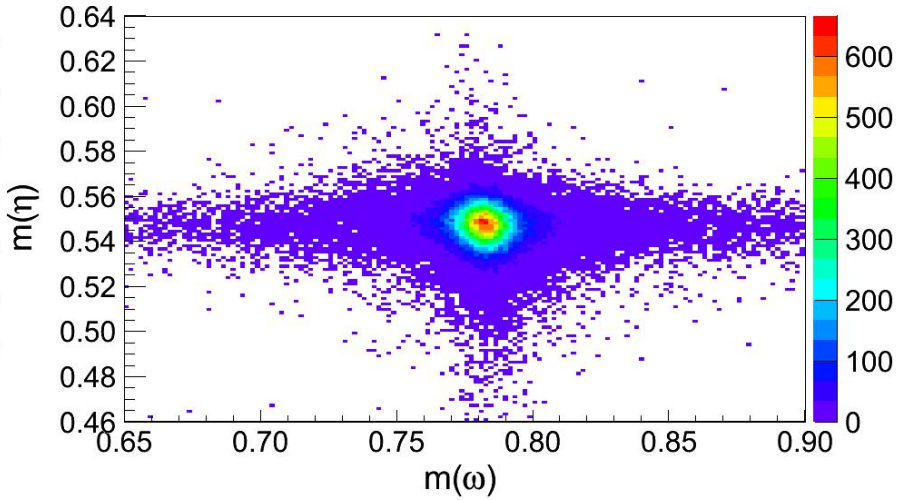
Scatter Diagram : M(eta) vs M(omega)



data



inclusive MC

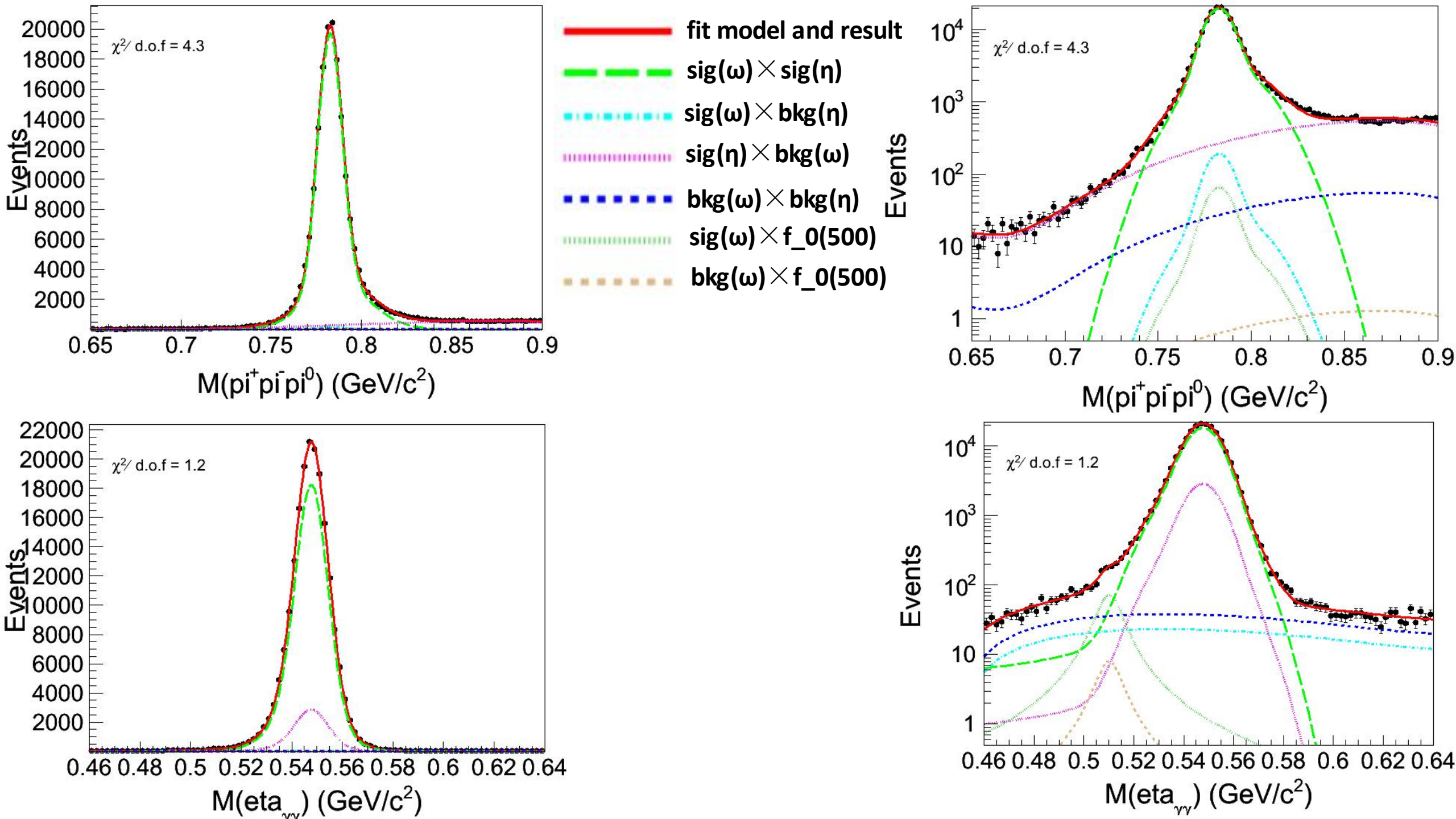


exclusive MC

Simultaneously fit

- **omega:**
- **signal PDF : one Gauss + one Crystal Ball functions**
- **background PDF : 3rd order Chebyshev polynomial**
- **eta:**
- **signal PDF : one Gauss + one Crystal Ball functions**
- **background PDF : 2nd order Chebyshev polynomial**
- **f_0(500) background PDF : Breit–Wigner ⊗ Gaussian**

- **fit model : sig(ω)×sig(η) + sig(ω)×bkg(η) + sig(η)×bkg(ω) + bkg(ω)×bkg(η) + sig(ω)×f_0(500) + bkg(ω)×f_0(500)**


fit model and result
sig(ω)×sig(η)
sig(ω)×bkg(η)
sig(η)×bkg(ω)
bkg(ω)×bkg(η)
sig(ω)×f_0(500)
bkg(ω)×f_0(500)
χ²/ d.o.f = 4.3
Events
M(pi⁺pi⁻pi⁰) (GeV/c²)
χ²/ d.o.f = 1.2
M(eta_γγ) (GeV/c²)

The result of branch ratio:

- **Nsig： 165814±420**
- **ε： 18.1%**
- **$N_{J/\psi}$： 1.31×10^{9}**
- **$B(\omega\to\pi^{+}\pi^{-}\pi^{0})$： 0.892**
- **$B(\eta\to2\gamma)$： 0.394**
- **$B(\pi^{0}\to2\gamma)$： 0.988**

$$Br(J/\psi\to\omega\eta)=\frac{n_{sig}}{\varepsilon\times B(\omega\to\pi^{+}\pi^{-}\pi^{0})\times B(\eta\to\gamma\gamma)\times B(\pi^{0}\to\gamma\gamma)\times N_{J/\psi}}$$
$$=(2.05\pm0.01)\times10^{-3}$$

Systematic uncertainty analysis

J/Ψ→ωη	5c fit (%)
fit model	~4.0
Photon efficiency	4
Track efficiency	2
Branch ratio of Decay mode	0.9
Kinematic fit constraints	5.5
PID	<0.1
Resonant background	0.1
Number of J/Ψ events	0.6
Summary	~8.2

Systematic uncertainty analysis

- **1. systematic error of fit model include:**
  - **a) change chi2<25 to chi2<30 and chi2<35**
  - **b) change η fitting range from [0.46, 0.64] to [0.458, 0.642] and [0.462, 0.638]**
  - **c) change ω fitting range from [0.65, 0.9] to [0.648, 0.902] and [0.652, 0.898]**
  - **d) change background model : not finished**

chi2	BR result	eta fit range	BR result	omega fit range	BR result
chi2<25	**2.03**×10^-3	**[0.46 , 0.64]**	**2.03**×10^-3	**[0.65 , 0.90]**	**2.03**×10^-3
chi2<30	**2.04**×10^-3 (0.5%)	**[0.458 , 0.642]**	**2.03**×10^-3 **(0.1%)**	**[0.648 , 0.902]**	**2.02**×10^-3 **(0.3%)**
chi2<35	**2.05** ×10^-3 (1%)	**[0.462 , 0.638]**	**2.03**×10^-3 **(0.1%)**	**[0.652 , 0.898]**	**2.03**×10^-3 **(0.5%)**
uncertainty	**1%**	**uncertainty**	**0.1%**	**uncertainty**	**0.5%**

Conservatively estimate the uncertainty for fit model : 4%

summary and outlook

- **Combined with systematic uncertainty analysis, the result of branch ratio of J/Ψ→ωη is (2.05±0.01±0.17)×10^{-3}, which fits the result from PDG: (1.74±0.20)×10^{-3}.**

- **Together with the result of Br(Ψ(2S)→ωη) : (1.94±0.35±0.39)×10^{-6}, the Q_h value can be calculated:**

$$Q_h = \frac{Br(\Psi(2S) \to \omega\eta)}{Br(J/\Psi \to \omega\eta)} = \frac{(1.94 \pm 0.35 \pm 0.39) \times 10^{-6}}{(2.05 \pm 0.01 \pm 0.17) \times 10^{-3}} = 0.095^{+0.036}_{-0.032}\%$$

- **From this result, we can get the conclusion that the decay of J/Ψ(Ψ(2S))→ωη violates the "12% rule" seriously.**

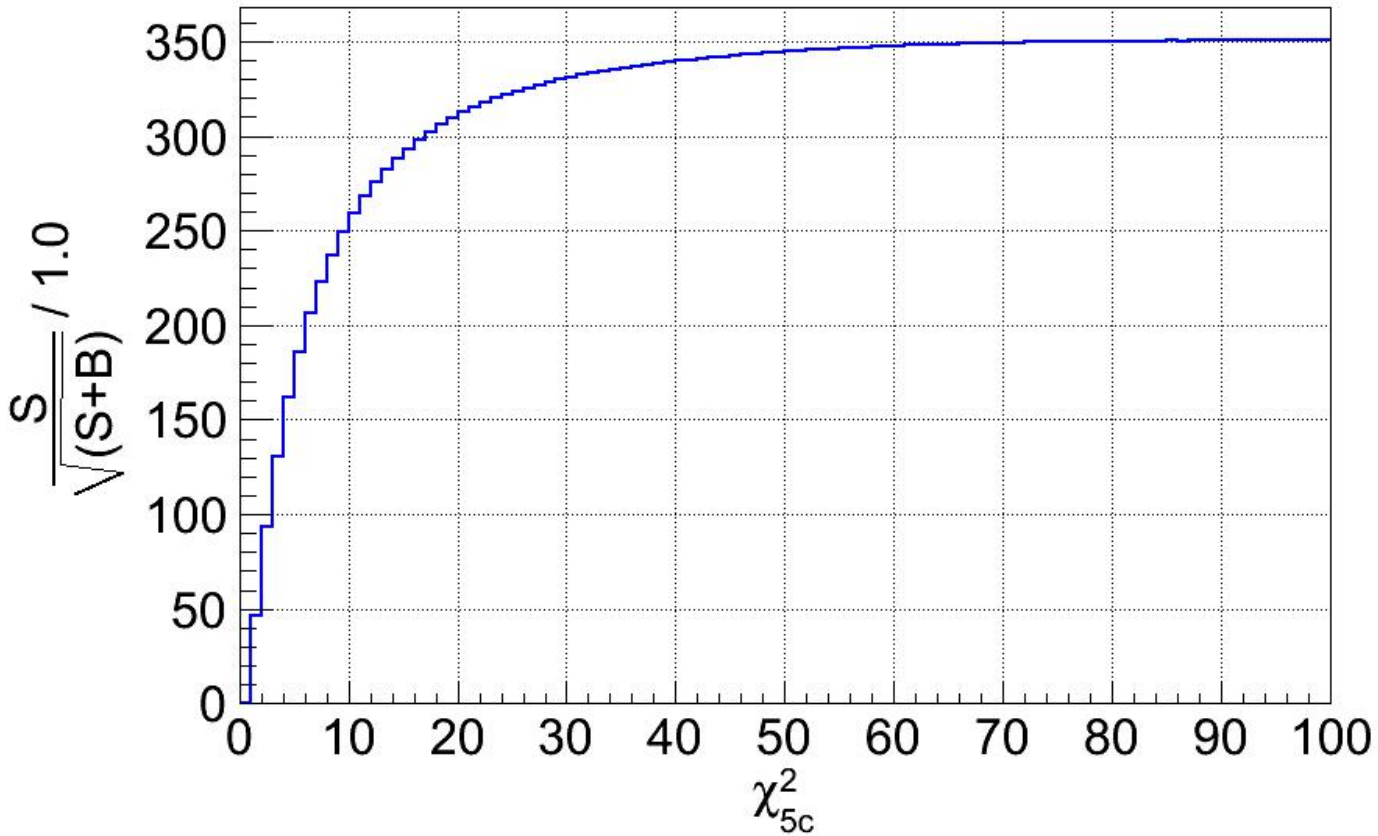
- **Outlook : Improve the systematic uncertainty analysis.**

  Improve simultaneously fit result (do not use background cuts).

Thank you

Back up

chi2 cut for events in 2009 and 2012 data



(5c fit)

we choose chi2<25 for 2009 and 2012 data events

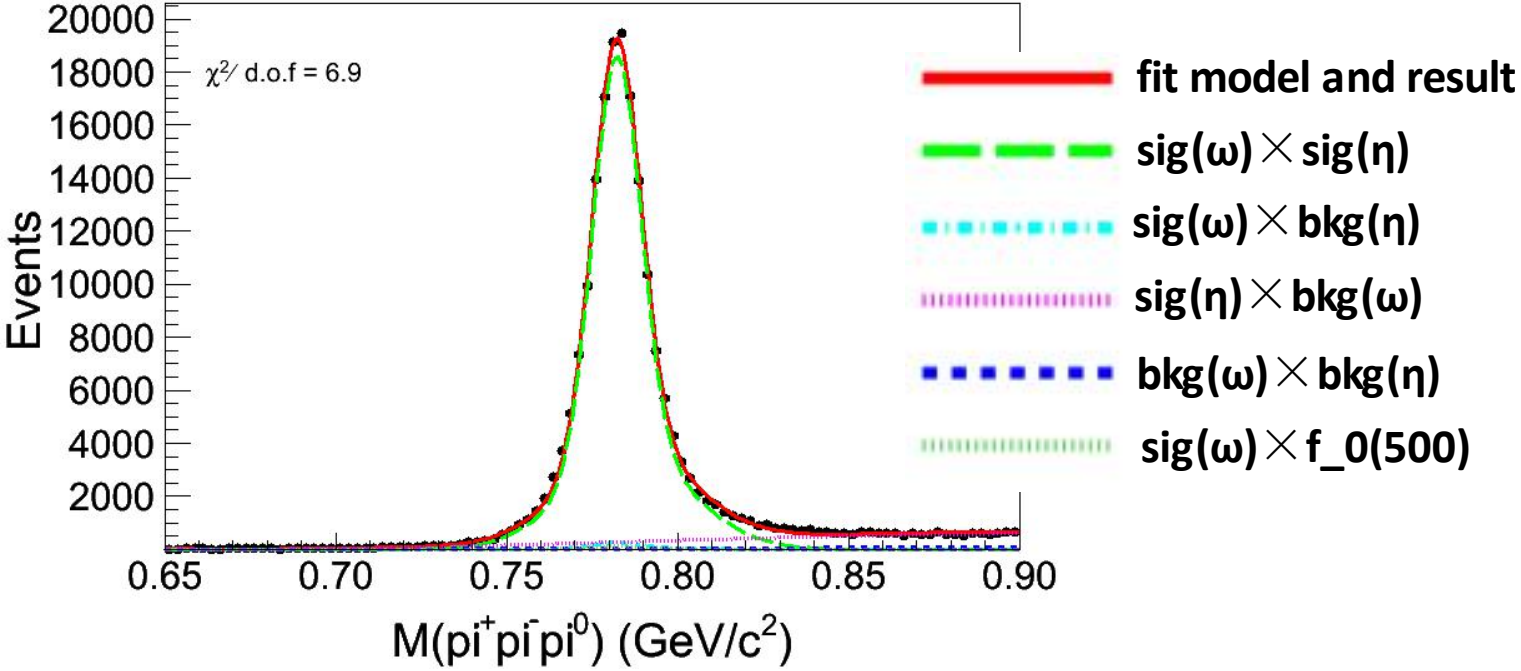
S : the events of exclusive MC

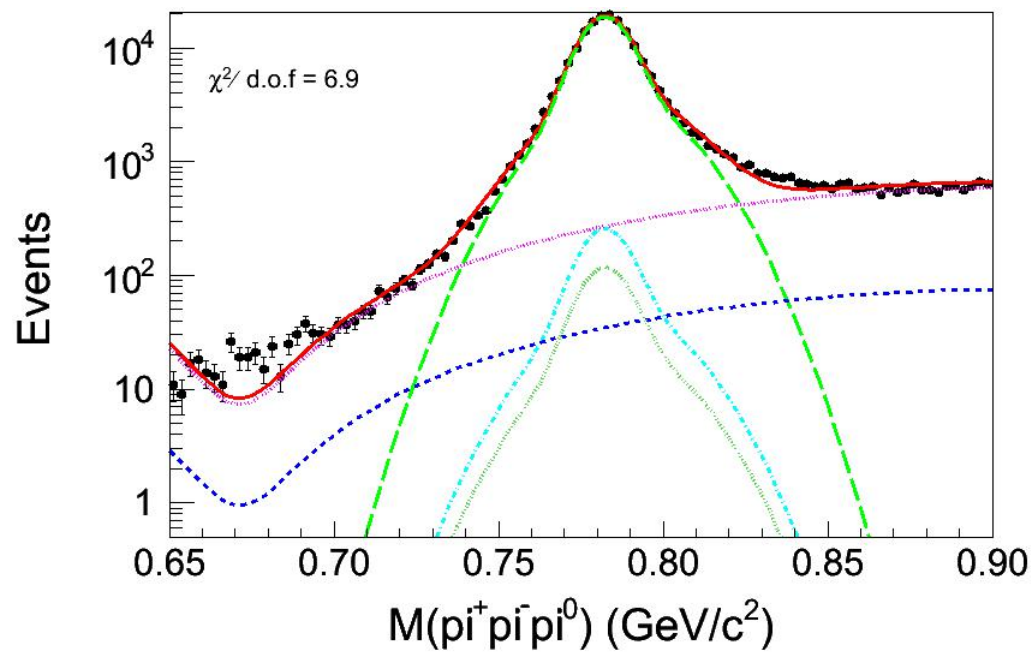
S+B : the total events of signal and background of inclusive MC

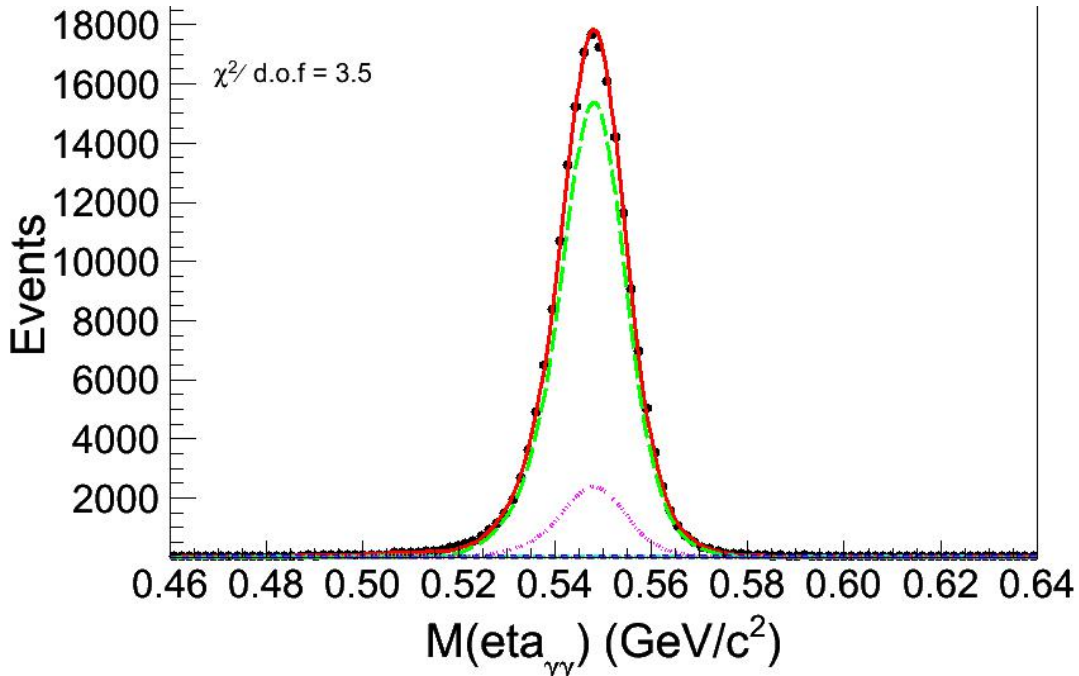
Simultaneously fit (for 4c fit)

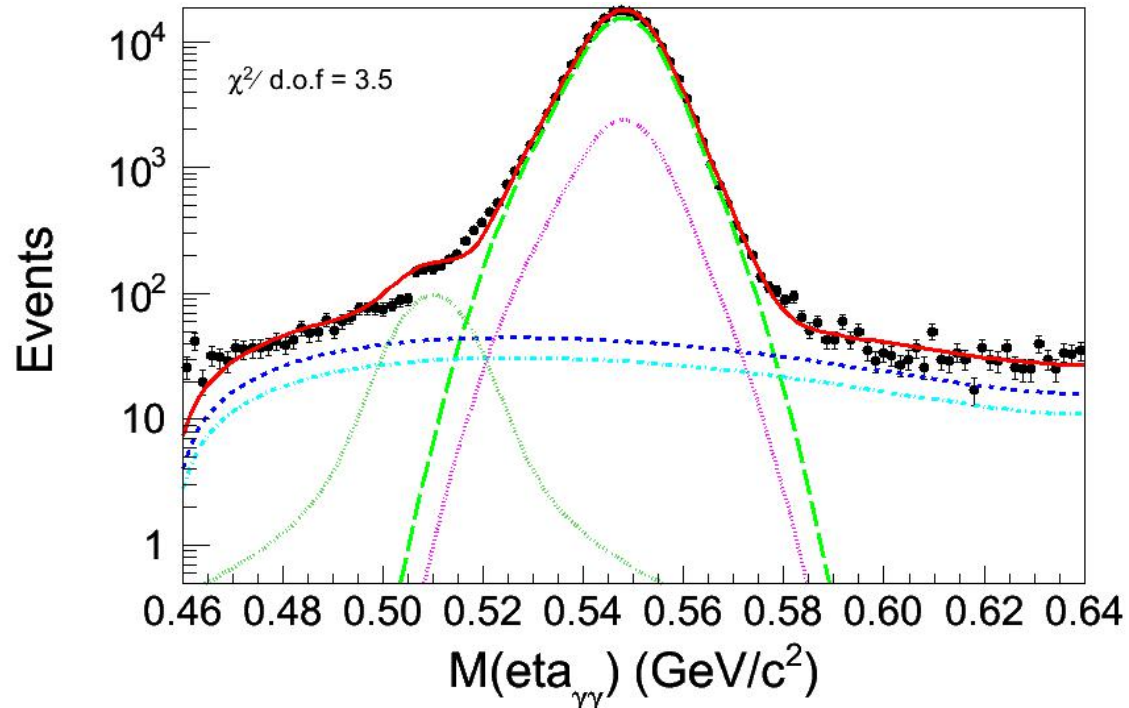
- **omega:**
- **signal PDF : one Gauss + one Crystal Ball functions**
- **background PDF : 2nd order Chebyshev polynomial**
- **eta:**
- **signal PDF : one Gauss + one Crystal Ball functions**
- **background PDF : 2nd order Chebyshev polynomial**
- **f_0(500) background PDF : Breit–Wigner ⊗ Gaussian**

- **fit model2 : sig(ω)×sig(η) + sig(ω)×bkg(η) + sig(η)×bkg(ω) + bkg(ω)×bkg(η) + sig(ω)×f_0(500) + bkg(ω)×f_0(500)**


χ²/ d.o.f = 6.9
Events
M(pi⁺pi⁻pi⁰) (GeV/c²)
fit model and result
sig(ω)×sig(η)
sig(ω)×bkg(η)
sig(η)×bkg(ω)
bkg(ω)×bkg(η)
sig(ω)×f_0(500)


χ²/ d.o.f = 6.9
Events
M(pi⁺pi⁻pi⁰) (GeV/c²)


χ²/ d.o.f = 3.5
Events
M(eta_γγ) (GeV/c²)


χ²/ d.o.f = 3.5
Events
M(eta_γγ) (GeV/c²)

The result of branch ratio：(4c fit)

- **Nsig：170201±425**
- **ε：18.7%**
- **$N_{\psi(2S)}$：1.31×10^9**
- **B(ω→$\pi^+\pi^-\pi^0$)：0.892**
- **B(η→2γ)：0.394**
- **B(π^0→2γ)：0.988**

$$Br(\psi(2S)\to\omega\eta)=\frac{n_{sig}}{\varepsilon\times B(\omega\to\pi^+\pi^-\pi^0)\times B(\eta\to\gamma\gamma)\times B(\pi^0\to\gamma\gamma)\times N_{\psi'}}$$
$$=(2.00\pm0.01)\times10^{-3}$$