Observation of $\chi_{cJ} \to p\bar{p}\pi^+\pi^-\pi^0$, $p\bar{p}\omega$ and Evidence of $\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$

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outline

- Motivation
- Data sample
- Event selection
- Analysis
  - $\chi_{cJ}/\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$
  - Investigate the intermediate process
- Summary & next to do

Motivation

- $R_1 = \frac{\Gamma^h_{h_c}}{\Gamma^h_{\eta_c(1S)}} = 0.010 \pm 0.001$ and 0.083 ± 0.018 based on pQCD and NRQCD calculation[1] .
- $R_2 = \frac{B(\eta_c(2S) \to h)}{B(\eta_c(1S) \to h)} = \frac{B(\eta_c(2S) \to \gamma\gamma)}{B(\eta_c(1S) \to \gamma\gamma)} \approx 0.52 \sim 1.56$ [2] .
- $h_c \to p\bar{p}\pi^+\pi^-\pi^0$ is observed with strong significance of 4.9σ based on ~448M $\psi(3686)$ data sample at BESIII [3] .
- Search for $\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$ is important to test the calculation above.
- Large blank room of χ_{cJ} decays need to be filled up [4] .
- ~2.7B $\psi(3686)$ data sample at BESIII give us an excellent chance to investigate this topic via $\psi(3686) \to \gamma p\bar{p}\pi^+\pi^-\pi^0$ decay

[1] Phys. Rep.. 41, 1(1978); [2]Phys. Rev. Lett. 50, 569 (1983); [3] Journal of High Energy Physics. 05, 108 (2022)
[4] PDG2022, Prog. Theor. Exp. Phys. 2022, 083C01. (2022).

Data sample

Data set	Number of events	Boss version
09+12 $\psi(3686)$ data 2021 $\psi(3686)$ data	4.48×10^8 22.60×10^8 } ~2.7 Billion	709
09+12 $\psi(3686)$ inclusive MC 2021 $\psi(3686)$ inclusive MC	5.06×10^8 $\sim 23\times 10^8$	
PHSP MC	3 million (09+12+21)	

Event selection

Good charged track selection

- $|R_{xy}| < 1\ cm,\ |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $\boldsymbol{N = 4, N_m = N_p = 2,\ \ \Sigma Q = 0}$

Particle identification

- Prob(pi)> Prob(p), Prob(pi)> Prob(K),Prob(pi)>0.001
- Prob(p)> Prob(pi), Prob(p)> Prob(K),Prob(p)> 0.001
- $\boldsymbol{N_{\pi^+} = N_{\pi^-} = N_p = N_{\bar{p}} = 1}$

Vertex Fit for $p\bar{p}\pi^+\pi^-$

Good photon selection

- $0 \leq TDC \leq 14$
- Barrel: $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E >$ **0.025 GeV**, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \geq 3}$

1C for π^0 list

- $0.08\mathrm{GeV/c^2} < M(\pi^0) < 0.2\mathrm{GeV/c^2}$
- $\chi^2_{1C}(\pi^0) < 200$
- $N_{\pi^0} \geq 1$

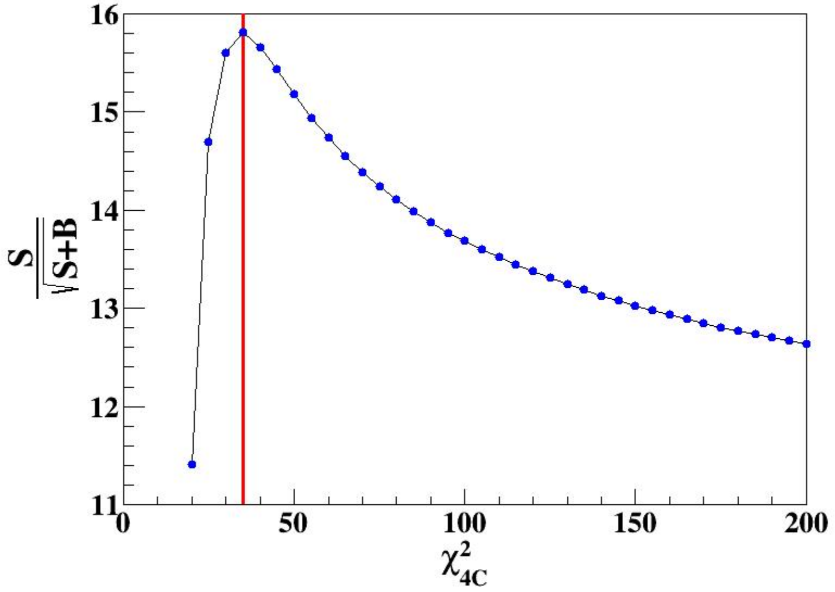
4C-kinematic fit

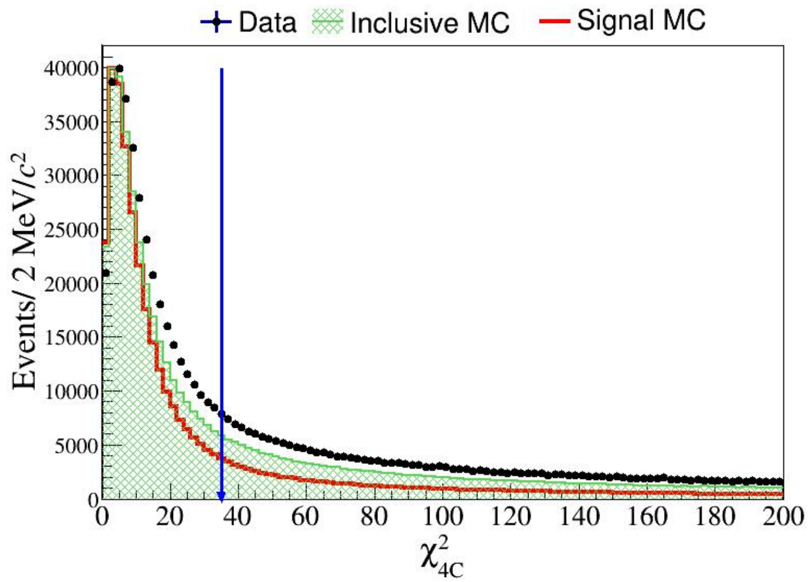
- choose the photons with least χ^2_{4C}.
- Additional 4C kinematic fit for $2\gamma p\bar{p}\pi^+\pi^-$, $3\gamma p\bar{p}\pi^+\pi^-$ and $4\gamma p\bar{p}\pi^+\pi^-$ final states.

3C-kinematic fit

- To separate the signal from background $\psi(3686) \rightarrow p\bar{p}\pi^+\pi^-\gamma\gamma(\pi^0)$

Further Event selection
4C kinematic fit

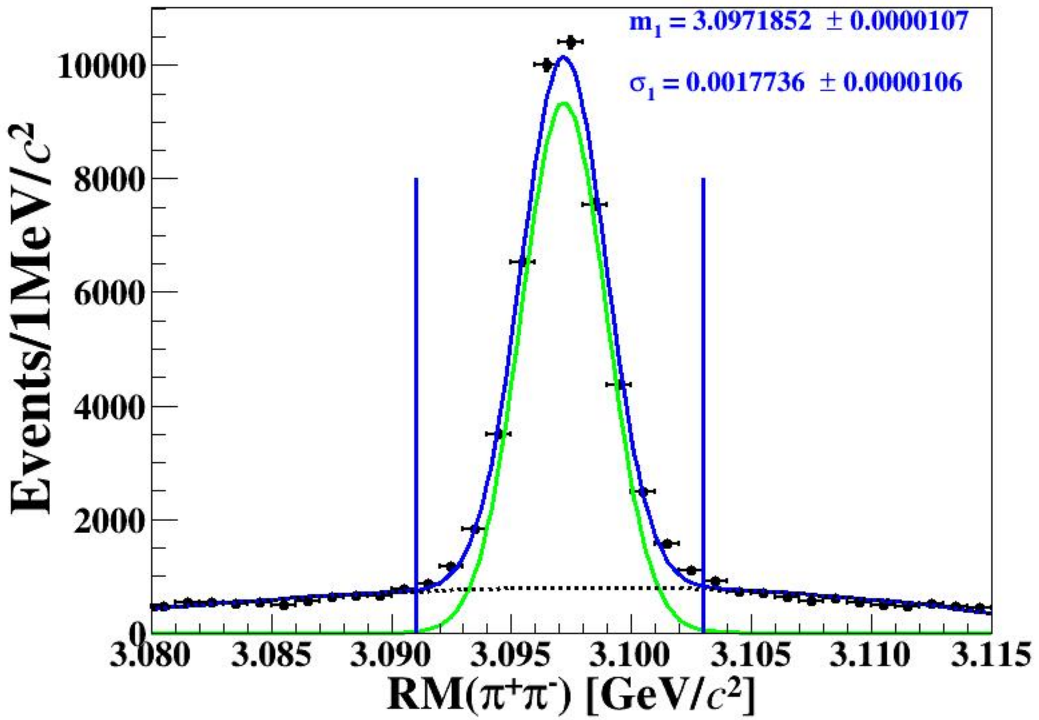


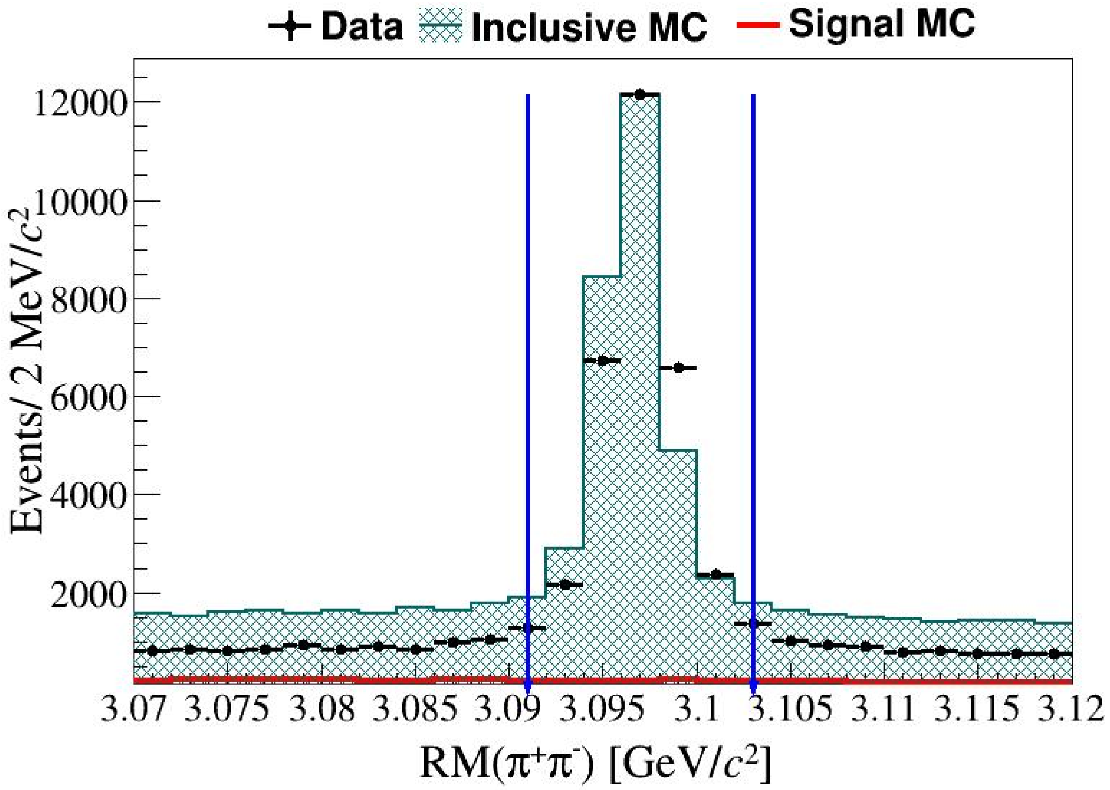


- $\chi^2_{4C} < 35$
- Additional requirement：
  - ✓ $\chi^2_{4C}(p\bar{p}\,\gamma\gamma(\pi^0)\gamma) < \chi^2_{4C}(p\bar{p}\,\gamma\gamma(\pi^0))$
  - ✓ $\chi^2_{4C}(p\bar{p}\,\gamma\gamma(\pi^0)\gamma) < \chi^2_{4C}(p\bar{p}\,\gamma\gamma(\pi^0)2\gamma)$
  - ✓ $\chi^2_{4C}(3\gamma p\bar{p}) < \chi^2_{4C}(2\gamma p\bar{p})$
  - ✓ $\chi^2_{4C}(3\gamma p\bar{p}) < \chi^2_{4C}(4\gamma p\bar{p})$

Background study

Veto on $\psi(3686) \to \pi^+\pi^-\ J/\psi$

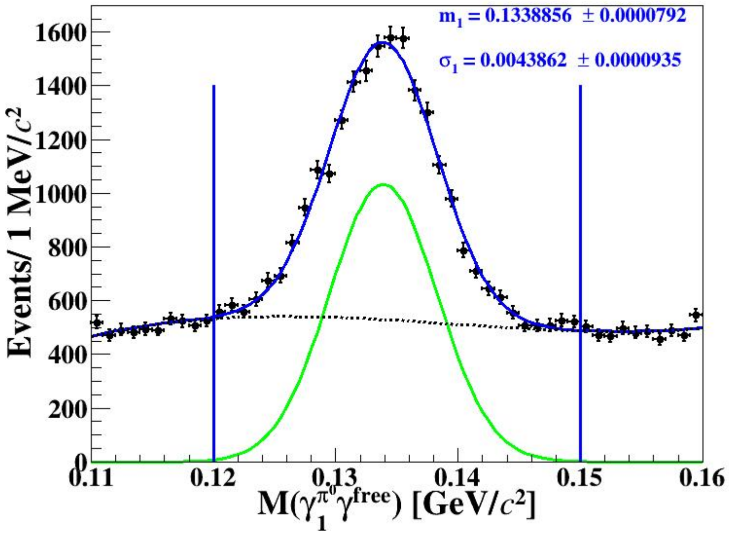


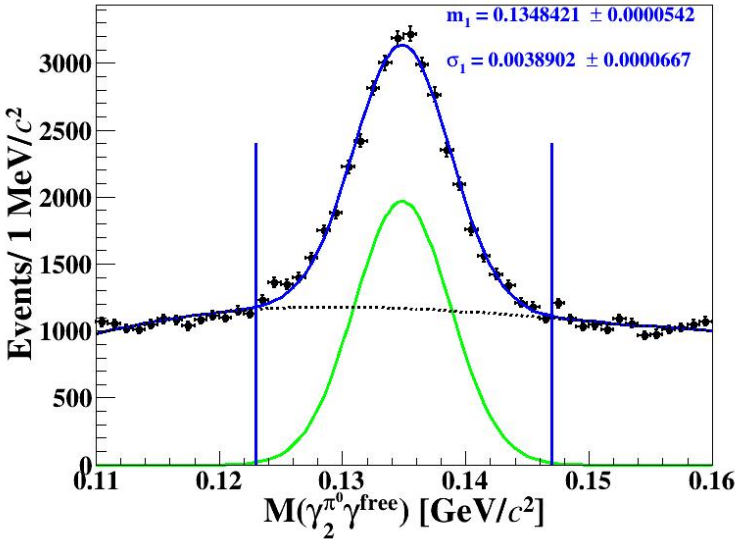


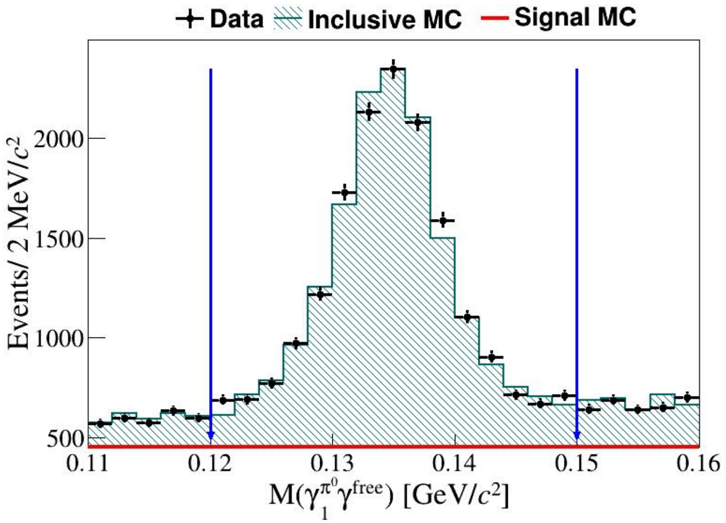
- $|RM(\pi^+\pi^-) - m(J/\psi)| > 6\ MeV/c^2$

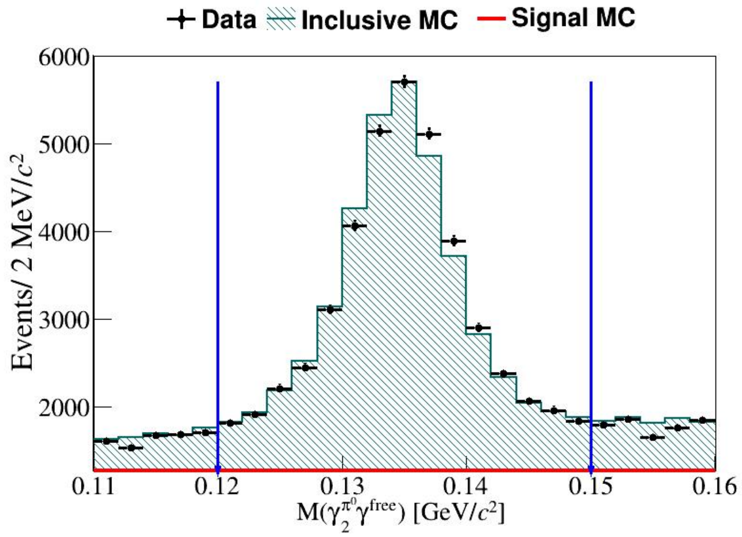
Background study

Veto on $\pi^0 \to \gamma^{\pi^0}\gamma^{free}$(Wrong Combination)





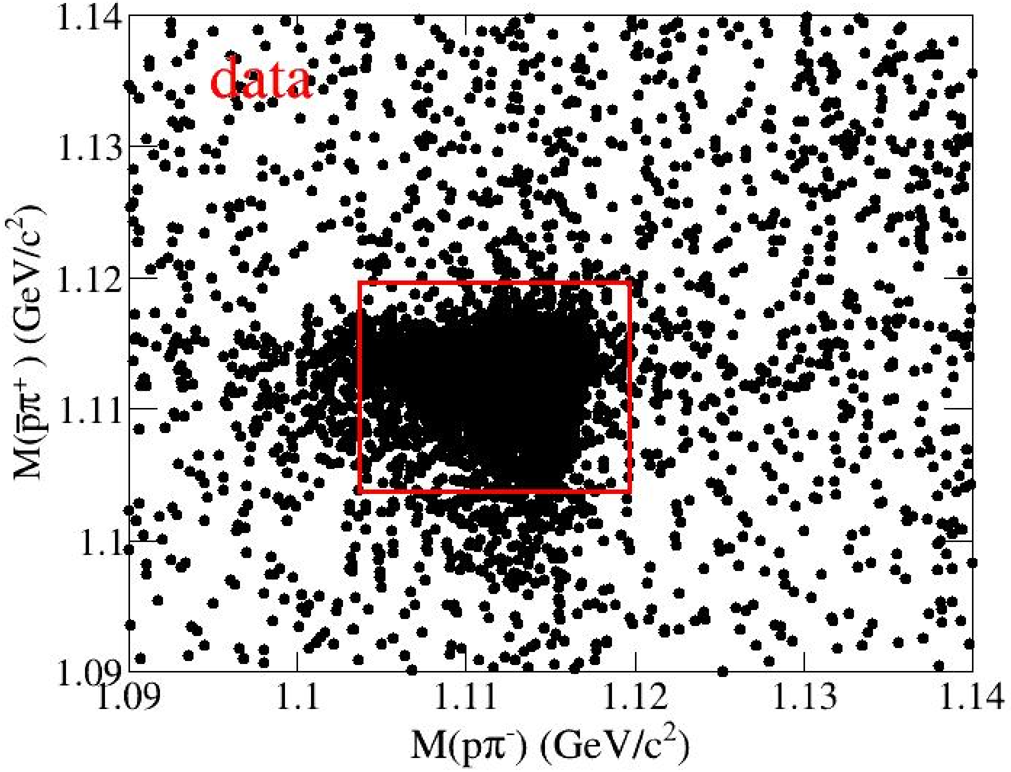




- $\left|M\left(\gamma_1^{\pi^0}\gamma^{free}\right) - m(\pi^0)\right| > 15\ \mathrm{MeV}/c^2$
- $\left|M\left(\gamma_2^{\pi^0}\gamma^{free}\right) - m(\pi^0)\right| > 12\ \mathrm{MeV}/c^2$

Background study

Veto on $\Lambda(\bar{\Lambda})$

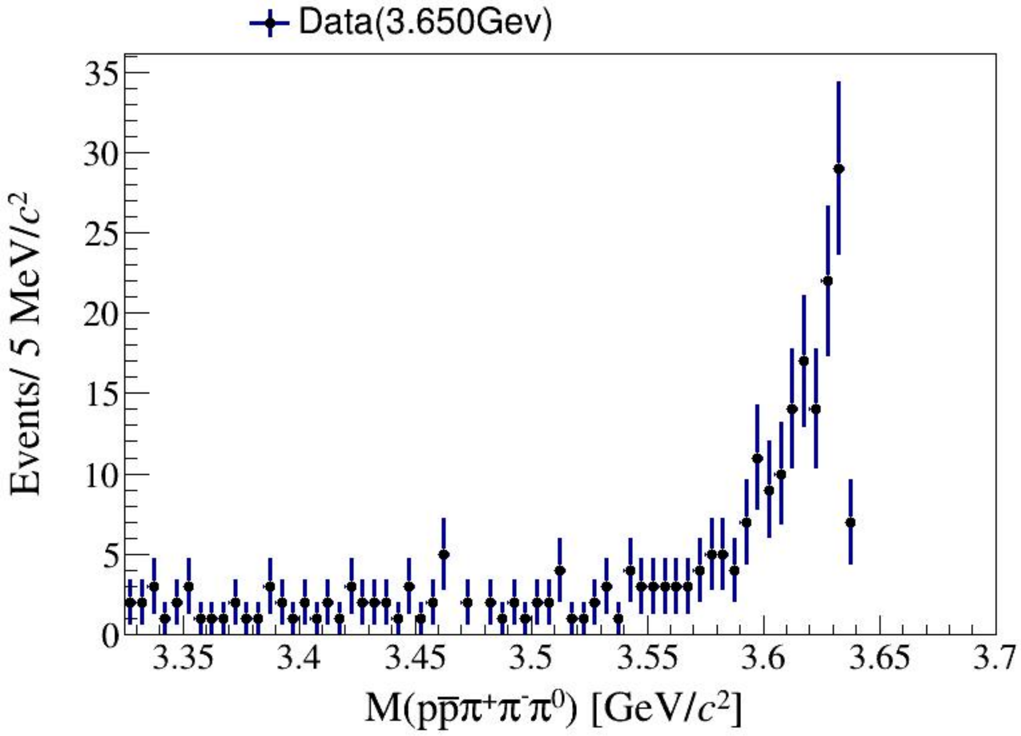


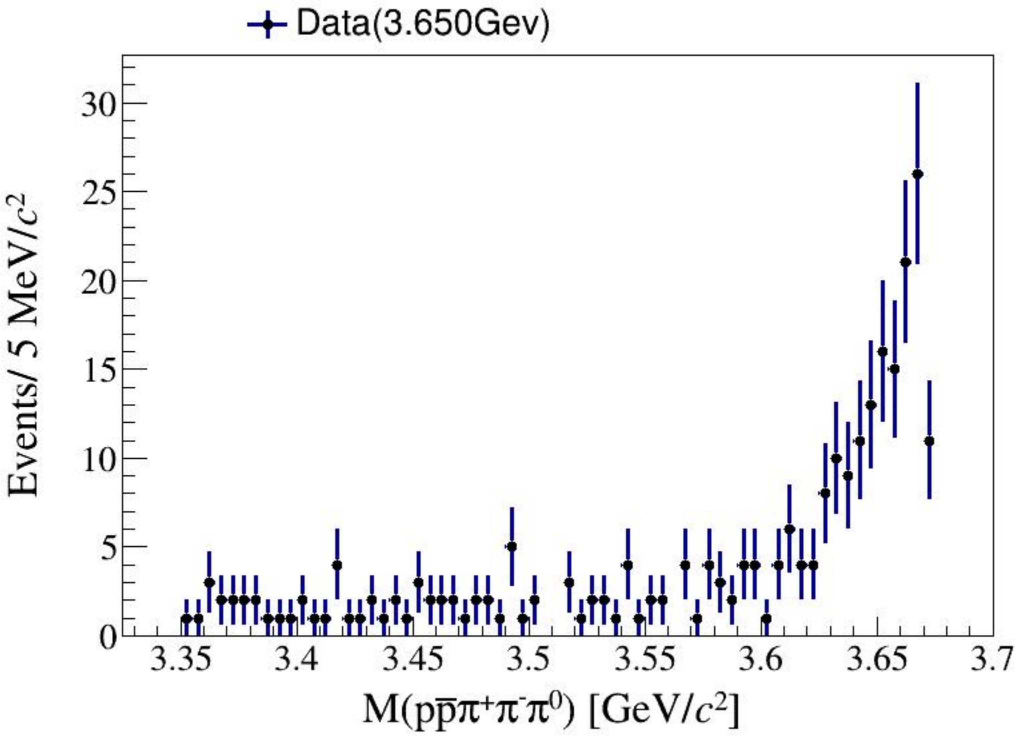
$M(p\pi^-)$ vs $M(\bar{p}\pi^+) \in (1.104, 1.120)\,GeV/c^2$

Background study

Background from continuum data

@3.650GeV(09+12+21): 434.95pb^{-1} (online)





$$f_{continuum} = \frac{\mathcal{L}_{3.686}}{\mathcal{L}_{3.650}} \times \frac{\sigma_{3.686}}{\sigma_{3.650}} = \frac{3878.55/pb}{434.95/pb} \times \frac{3.650^2}{3.686^2}$$

$$N_{continuum} = N_{3.650} \times f_{continuum} \approx 2133.43$$

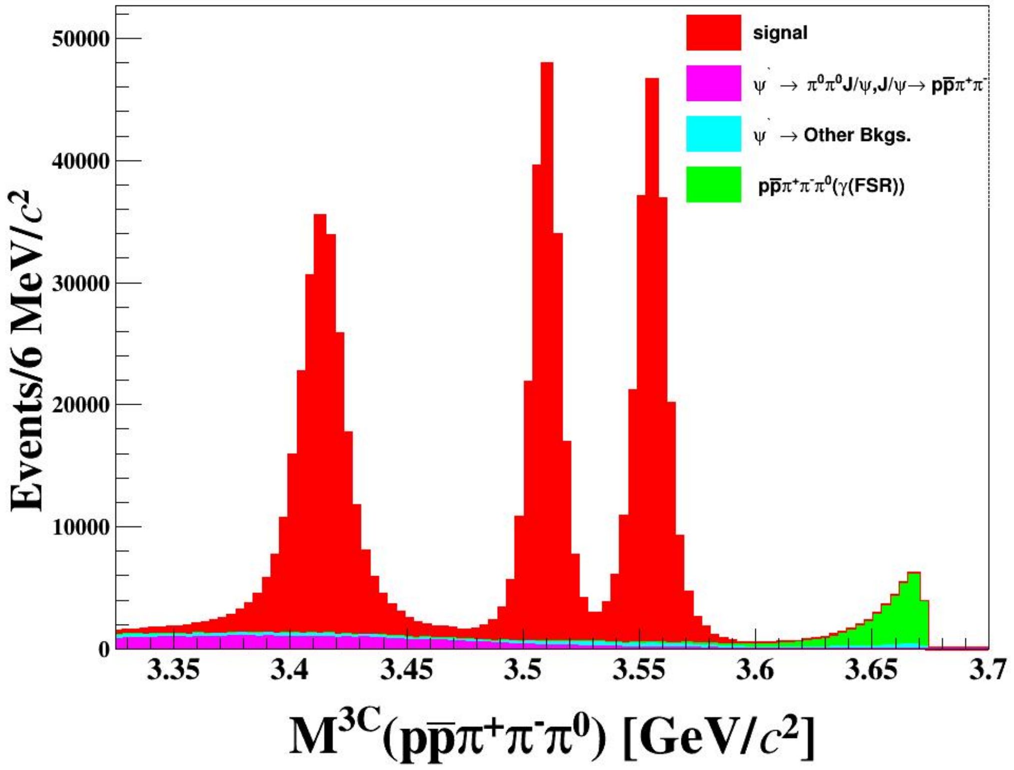
$$m_{shift} = a(m - m_0) + m_0$$

$$m_0 : M_{p\bar{p}\pi^+\pi^-\pi^0}$$

$$a = \frac{(3.686 - m_0)}{(3.650 - m_0)}$$

Topology analysis

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	1	62525	62525
2	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	9	43291	105816
3	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	2	42935	148751
4	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^+\rho^-, \rho^- \to \pi^0\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	5	23554	172305
5	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	0	23446	195751
6	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^-\bar{\Delta}^+\Delta^{++}, \bar{\Delta}^+ \to \pi^0\bar{p}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	4	23165	218916
7	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^+\Delta^+\bar{\Delta}^{++}, \Delta^+ \to \pi^0 p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	32	22877	241793
8	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^+\rho^-, \rho^- \to \pi^0\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	19	22583	264376
9	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	15	22563	286939
10	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	12	22117	309056
11	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	56	21095	330151
12	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	33	20728	350879
13	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^+\rho^-, \rho^- \to \pi^0\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	7	20653	371532
14	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+\pi^- p\bar{p}$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}$	6	19603	391135
15	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to p\bar{p}h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	11	19522	410657
16	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \pi^-\bar{\Delta}^+\Delta^{++}, \bar{\Delta}^+ \to \pi^0\bar{p}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	3	15248	425905
17	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \pi^+\Delta^+\bar{\Delta}^{++}, \Delta^+ \to \pi^0 p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	17	14970	440875
18	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \pi^+\Delta^+\bar{\Delta}^{++}, \Delta^+ \to \pi^0 p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	20	14138	455013
19	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \pi^-\bar{\Delta}^+\Delta^{++}, \bar{\Delta}^+ \to \pi^0\bar{p}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	39	14015	469028
20	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \omega p\bar{p}, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	25	11879	480907
21	$\psi' \to \pi^0\pi^+\pi^- p\bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}$	26	11503	492410
22	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \omega p\bar{p}, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	21	11399	503809
23	$\psi' \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}$	30	9398	513207
24	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+ p\bar{\Delta}^{++}, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}$	42	8982	522189
25	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^-\bar{\Delta}^0\Delta^+, \bar{\Delta}^0 \to \pi^+\bar{p}, \Delta^+ \to \pi^0 p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	55	6384	528573
26	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^+\Delta^0\bar{\Delta}^+, \Delta^0 \to \pi^- p, \bar{\Delta}^+ \to \pi^0\bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	35	6333	534906
27	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \rho^-\bar{p}\Delta^{++}, \rho^- \to \pi^0\pi^-, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	18	5917	540823
28	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \rho^+ p\bar{\Delta}^{++}, \rho^+ \to \pi^0\pi^+, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	34	5831	546654
29	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \pi^0\pi^-\bar{p}\Delta^{++}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	22	5510	552164
30	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^-\bar{p}\Delta^{++}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}$	76	5360	557524
31	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \pi^0\pi^+ p\bar{\Delta}^{++}, \bar{\Delta}^{++} \to \pi^- \bar{p}$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	44	5184	562708
32	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \omega p\bar{p}, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	87	4878	567586
33	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^0\pi^-\bar{p}\Delta^{++}, \Delta^{++} \to \pi^+ p$	$\pi^0\pi^+\pi^- p\bar{p}\gamma$	61	4767	572353



signal $\psi' \to \pi^0\pi^0 J/\psi$ $\psi' \to p\bar{p}\pi^+\pi^-\pi^0(\gamma_{FSR})$

FSR correction

Background of $\psi(2S) \rightarrow p\bar{p}\pi^+\pi^-\pi^0(\gamma_{FSR})$:

FSR correction: we used the control sample $\psi(3686) \rightarrow \gamma\chi_{c0}, \chi_{c0} \rightarrow p\bar{p}\pi^+\pi^-(\gamma_{FSR})$ to estimate the difference of FSR factor between MC and data.

Good charged track selection

- $|R_{xy}| < 1\ cm,\ |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $N = 4, N_m = N_p = 2,\ \Sigma Q = 0$

Particle identification

- Prob(pi)> Prob(p), Prob(pi)> Prob(K),Prob(pi)>0.001
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- $N_{\pi^+} = N_{\pi^-} = N_p = N_{\bar{p}} = 1$

Vertex Fit for $p\bar{p}\pi^+\pi^-$

Good photon selection

- $0 \leq TDC \leq 14$
- Barrel: $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap： $E > \mathbf{0.025\ GeV}$, $0.86 < |cos\theta| < 0.92$
- $N_\gamma \geq 2$

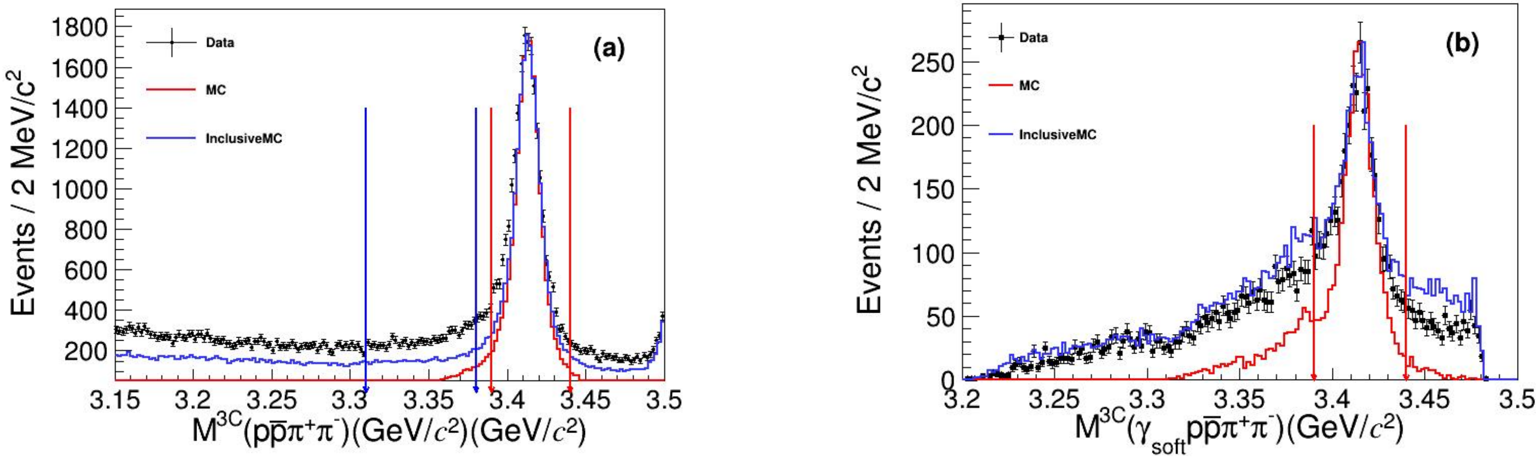
4C-kinematic fit

- choose the photons with least χ^2_{4C}.

3C-kinematic fit

FSR correction

The FSR correction factor is defined as: $f = \frac{R_{FSR}^{data}}{R_{FSR}^{MC}}$ $R_{FSR} = \frac{N_{FSR}}{N_{nonFSR}}$

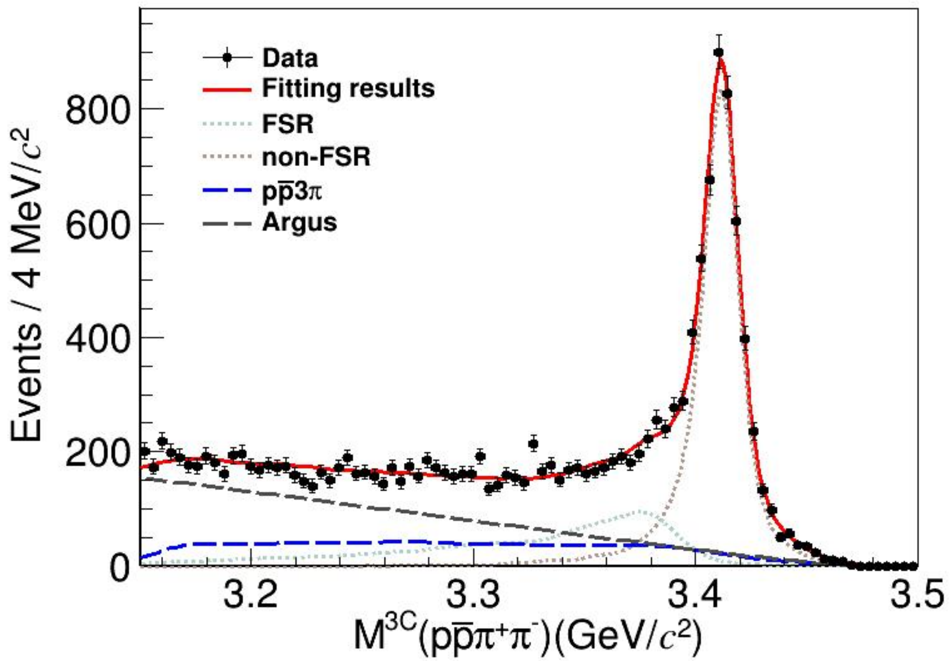


no FSR region : $\mathrm{M}^{3\mathrm{C}}(\mathrm{p}\bar{\mathrm{p}}\pi^+\pi^-)$: 3.39~3.44GeV/c^2

FSR tail region : $\mathrm{M}^{3\mathrm{C}}(\mathrm{p}\bar{\mathrm{p}}\pi^+\pi^-)$: 3.30~3.38GeV/c^2 && $\mathrm{M}^{3\mathrm{C}}((\mathrm{p}\bar{\mathrm{p}}\pi^+\pi^-)\gamma_{\mathrm{soft}})$: $3.39\sim3.44\mathrm{GeV}/c^2$

FSR correction

We get the FSR ration of data sample by fitting.



- $R^{data}_{FSR} = \frac{N^{FSR}_{data}}{N^{nonFSR}_{data}}$ =0.429±0.029
- $R^{MC}_{FSR} = \frac{N^{FSR}_{MC}}{N^{nonFSR}_{MC}} = 0.253$
- $f = \frac{R^{data}_{FSR}}{R^{MC}_{FSR}} = 1.69 \pm 0.12$

We also listed the results for four similar studied channels. One finds that they are consistent with each other.

	Lina	Yaqian	GuangRui	Suxian
Decay channel	$\eta_c(2S) \to K^+K^-\eta$	$\eta_c(2S) \to VV$	$\eta_c(2S) \to \pi^+\pi^-\eta$	$\eta_c(2S) \to 3(\pi^+\pi^-)$
f	1.61±0.09	1.70±0.10	1.62±0.07	1.62±0.13

Fit method for $M(p\bar{p}\pi^+\pi^-\pi^0)$

- $\eta_c(2S)$Fit line shape : $(\mathrm{BW}(\mathrm{m};\mathrm{M},\Gamma)\times E_\gamma^3\times f_d(E_\gamma)\otimes\mathrm{DG}(m_1,\sigma_1,m_2,\sigma_2,\mathrm{f})\times\boldsymbol{\epsilon}(\mathbf{m}))\otimes\mathrm{G}(\delta m_3,\delta\sigma_3)$

m: $M^{3C}_{p\bar{p}\pi^+\pi^-\pi^0}$

$\mathrm{BW}(\mathrm{m};\mathrm{M},\Gamma)$:Breit-Wigner function $\frac{1}{2\pi}\cdot\frac{\Gamma}{(m-m_0)+\Gamma^2/4}$

E_γ: transition photon energy in rest frame $\frac{M^2_{\psi(2S)}-m^2}{2M_{\psi(2S)}}$

$\epsilon(\mathrm{m})$: argus function (fix)

$\mathrm{DG}(m_1,\sigma_1,m_2,\sigma_2,\mathrm{f})$: Double Gaussian function, detector resolution (fixed)

$\mathrm{G}(\delta m_3,\delta\sigma_3)$: Gaussian function, difference between data and MC

- χ_{cJ} line shape: MC shape ⊗ Gaussian function

- Background components : ① $\boldsymbol{\psi(2S)\to p\bar{p}\pi^+\pi^-\pi^0(\gamma_{FSR})}$: Exclusive MC shape

  ② other background : Argus function

$\eta_c(2S)$ Efficiency curve: $\epsilon(\mathrm{m})$

```
LSFLAT eta_c(2S)
ChangeMassMin eta_c(2S) 3.30
ChangeMassMax eta_c(2S) 3.75
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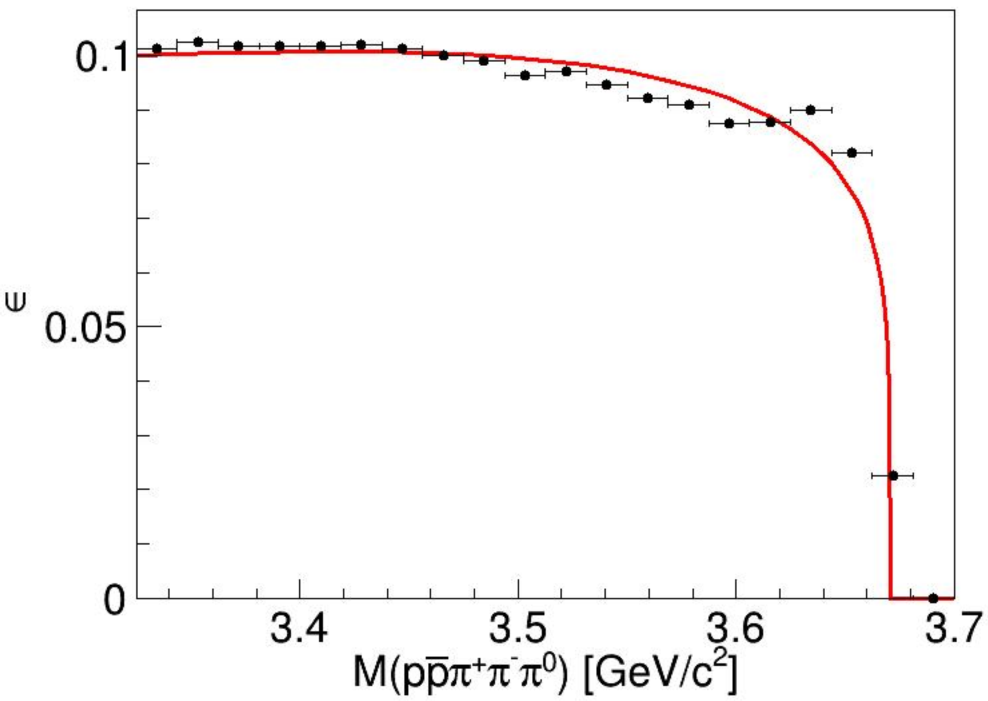
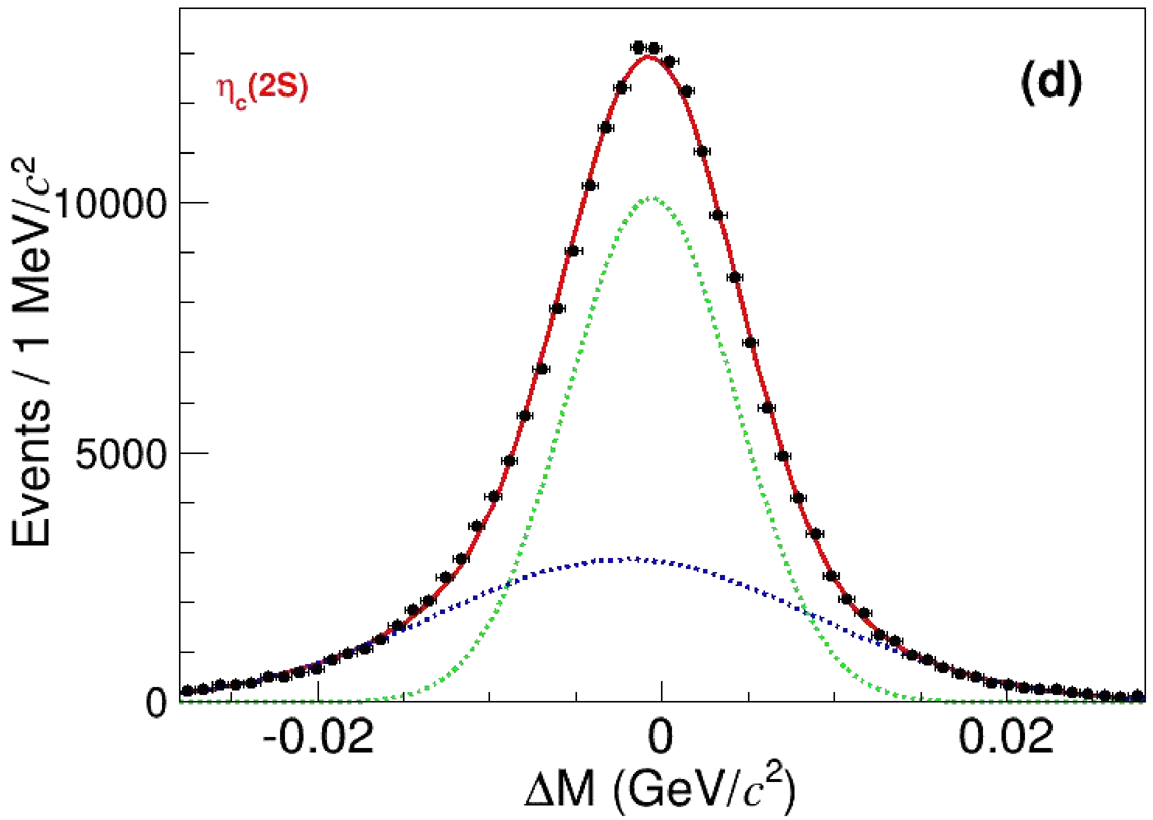
argus function:

$m(1-(m/3.67)^2)^{0.169} \times e^{-0.6787(1-(m/3.67)^2)}$



$\eta_c(2S)$ Mass resolution from signal MC

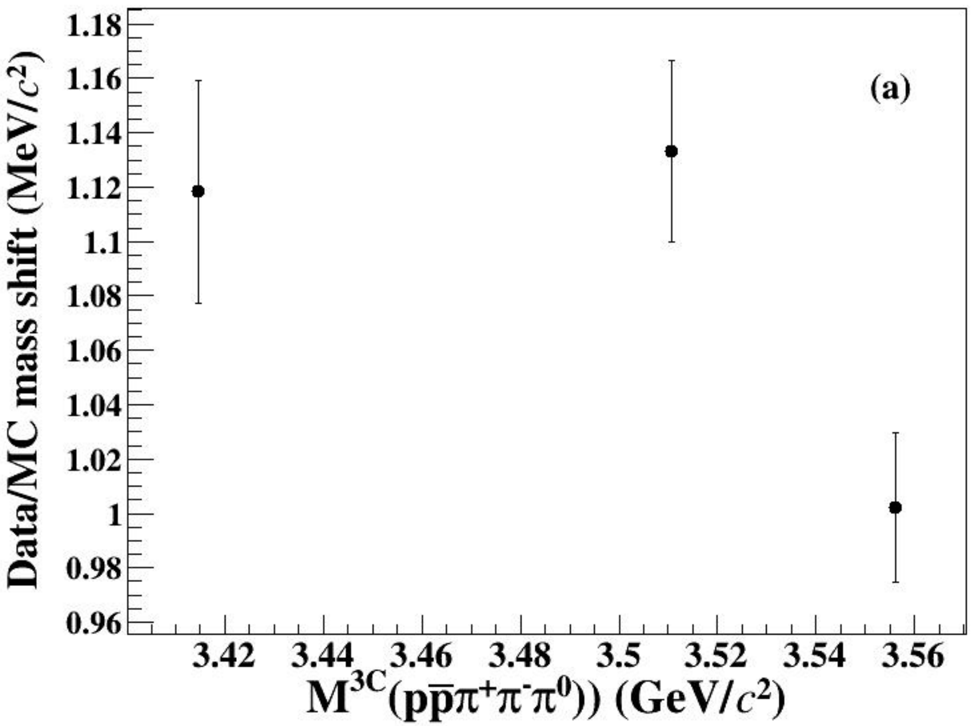


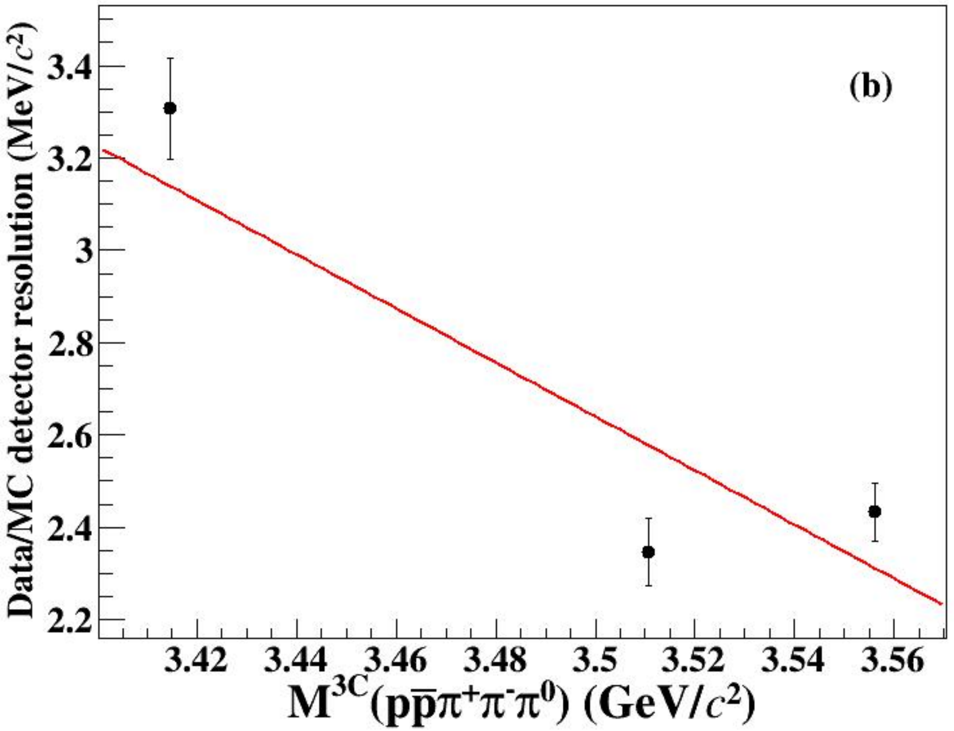
To obtain **Double Gauss(m,σ)** parameters, we fitted the mass difference ($\Delta M = M^{3C}_{p\bar{p}\pi^+\pi^-\pi^0} - M^{truth}_{p\bar{p}\pi^+\pi^-\pi^0}$) distribution from signal MC sample .

$\eta_c(2S)$ Detector resolution difference between data and MC

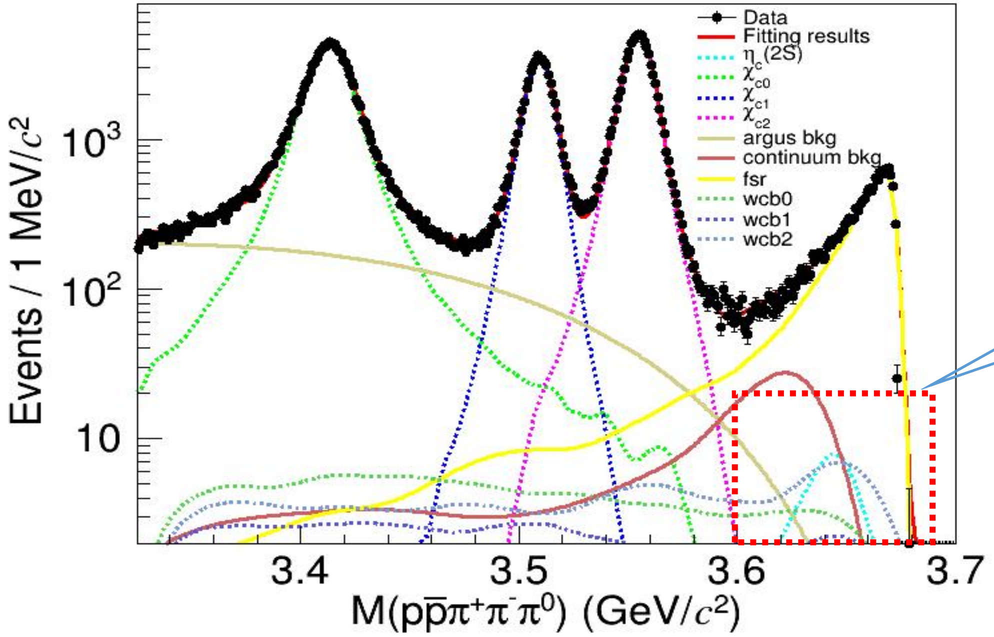
Gauss (m,σ)

	m	σ
χ_{c0}	1.118±0.041 Mev/c^2	3.307±0.109 Mev
χ_{c1}	2.345±0.033 Mev/c^2	2.347±0.072 Mev
χ_{c2}	1.000±0.027 Mev/c^2	2.433±0.064 Mev





Preliminary result

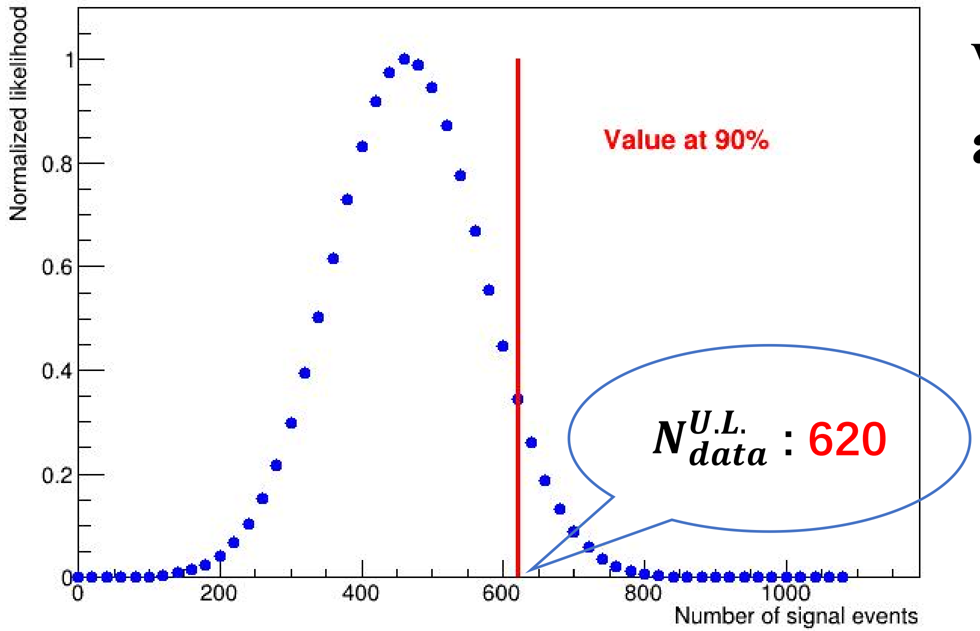


Statistical Significance: 3.16σ

$$B(\chi_{cJ}/\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0) = \frac{N^{obs}_{\chi_{cJ}/\eta_c(2S)}}{N^{tot}_{\psi(2S)} \cdot B(\psi(2S) \to \gamma\chi_{cJ}/\eta_c(2S)) \cdot B(\pi^0 \to \gamma\gamma) \cdot \epsilon}$$

channel	N^{obs}	$\epsilon(\%)$	Branching fraction
$\chi_{c0} \to p\bar{p}\pi^+\pi^-\pi^0$	(1.180±0.004) $\times 10^5$	9.23	(4.880±0.017) $\times 10^{-3}$
$\chi_{c1} \to p\bar{p}\pi^+\pi^-\pi^0$	(5.346±0.026) $\times 10^4$	9.70	(2.112±0.011) $\times 10^{-3}$
$\chi_{c2} \to p\bar{p}\pi^+\pi^-\pi^0$	(8.447±0.032) $\times 10^4$	8.79	(3.772±0.014) $\times 10^{-3}$
$\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$	(4.65±1.42)$\times 10^2$	7.05	(3.521±1.081) $\times 10^{-3}$

Preliminary result



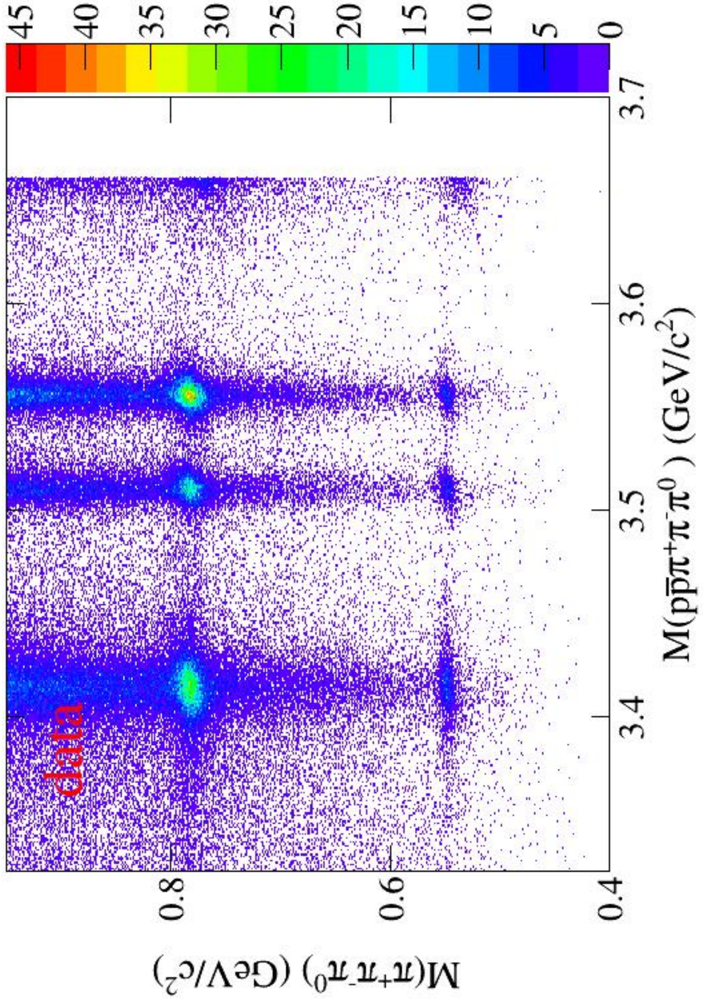
We calculate the upper limits of the branching fractions are :

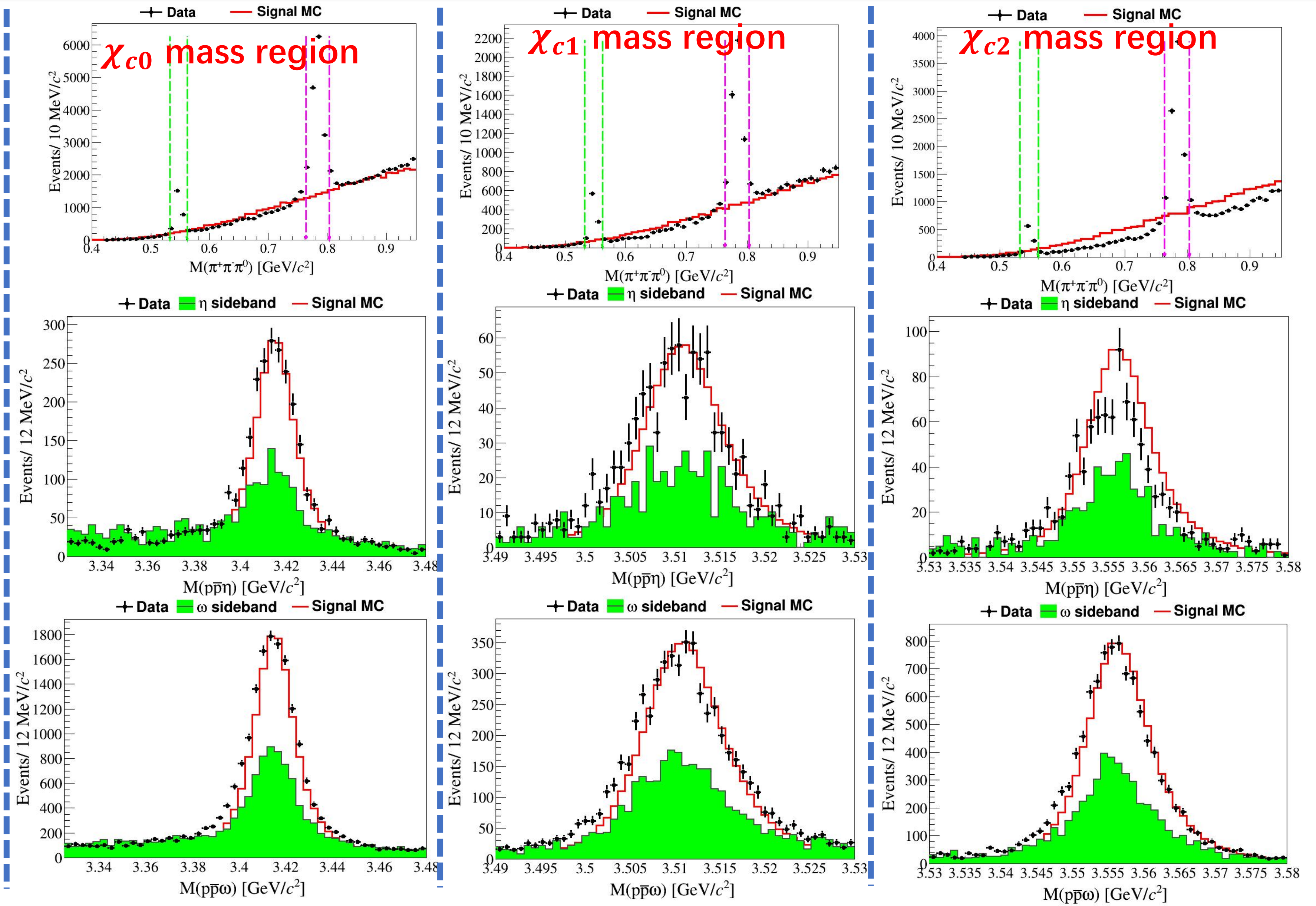
$$B(\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0)$$

$$< \frac{N_{data}^{U.L.}}{N_{\psi(2S)}^{tot} \cdot B(\psi(2S) \to \gamma\eta_c(2S)) \cdot B(\pi^0 \to \gamma\gamma) \cdot \epsilon^{MC}}$$

Channel	Branching fraction	PDG
$\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$	$< 4.69\times 10^{-3}$	-

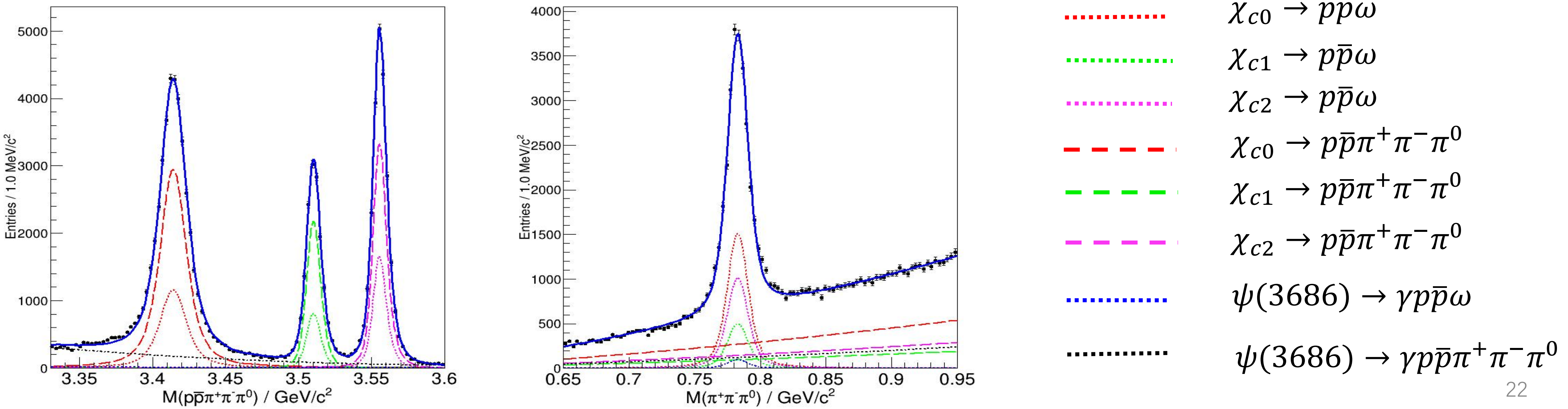
Investigate the intermediate process





Pre. 2D fit to Investigate the intermediate process

Event type	$\mathrm{M}(p\bar{p}\pi^+\pi^-\pi^0)$	$\mathrm{M}(\pi^+\pi^-\pi^0)$
$\chi_{cJ} \to p\bar{p}\omega$	$\chi_{cJ}(\to p\bar{p}\omega)$ MC shape $\otimes \mathrm{G}(\Delta m, \Delta\sigma)$	$BW \otimes \mathrm{G}(m, \sigma)$
$\chi_{cJ} \to p\bar{p}\pi^+\pi^-\pi^0$	$\chi_{cJ}(\to p\bar{p}\pi^+\pi^-\pi^0)$ MC shape $\otimes \mathrm{G}(\Delta m, \Delta\sigma)$	Polynomial function
$\psi(3686) \to \gamma p\bar{p}\omega$	Polynomial function	$BW \otimes \mathrm{G}(m, \sigma)$
$\psi(3686) \to \gamma p\bar{p}\pi^+\pi^-\pi^0$	Polynomial function	Polynomial function



Preliminary result

$$B(\chi_{cJ} \to p\bar{p}\omega) = \frac{N^{obs}_{\chi_{cJ}}}{N^{tot}_{\psi(2S)} \cdot B(\psi(2S) \to \gamma\chi_{cJ}) \cdot B(\omega \to \pi^+\pi^-\pi^0) \cdot B(\pi^0 \to \gamma\gamma) \cdot \epsilon}$$

	N^{sig}	$\varepsilon(\%)$	Br
$\chi_{c0} \to p\bar{p}\omega$	$(1.194 \pm 0.016) \times 10^4$	9.47	$(5.396 \pm 0.073) \times 10^{-4}$
$\chi_{c1} \to p\bar{p}\omega$	$(3.948 \pm 0.085) \times 10^3$	9.74	$(1.741 \pm 0.038) \times 10^{-4}$
$\chi_{c2} \to p\bar{p}\omega$	$(8.010 \pm 0.115) \times 10^3$	8.63	$(4.084 \pm 0.059) \times 10^{-4}$

Summary & next to do

- Summary:

Using about 2.7 billion $\psi(3686)$ events at BESIII，

✓ The evidence of $\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$ is observed with 3.16σ for the first time， and its BR. is measured to be $(3.521 \pm 1.081) \times 10^{-3}$and the upper limit of the BR. of $\eta_c(2S) \to p\bar{p}\pi^+\pi^-\pi^0$: $< 4.69 \times 10^{-3}$.

✓ $\chi_{cJ} \to p\bar{p}\pi^+\pi^-\pi^0$ is observed for the first time， the BR. are determined to be $(4.880 \pm 0.017) \times 10^{-3}$, $(2.112 \pm 0.011) \times 10^{-3}$ and $(3.772 \pm 0.014) \times 10^{-3}$ for J =0, 1 and 2, respectively.

✓ The intermediate process $\chi_{cJ} \to p\bar{p}\omega$ is also observed for the first time， their BR. are determined to be $(5.396 \pm 0.073) \times 10^{-4}$, $(1.741 \pm 0.038) \times 10^{-4}$， $(4.084 \pm 0.059) \times 10^{-4}$ for J =0, 1 and 2, respectively.

- Next to do:
  - Perform the analysis of systematic uncertainty

$Observation\ of\ \eta_c(2S) \to 3(\pi^+\pi^-)\ and\ Measurements\ of\ \chi_{cJ}(1P) \to 3(\pi^+\pi^-)\ in\ \psi(3686)\ radiative\ transitions$

Abstract

The hadronic decay $\eta_c(2S) \to 3(\pi^+\pi^-)$ is observed with a statistical significance of 9.3 standard deviations using $(448.1 \pm 2.9) \times 10^6$ $\psi(3686)$ events collected by the BESIII detector at the BEPCII collider. The measured mass and width of $\eta_c(2S)$ are $(3643.4 \pm 2.3\,(\mathrm{stat}) \pm 4.4\,(\mathrm{syst}))\ \mathrm{MeV}/c^2$ and $(19.8 \pm 3.9\,(\mathrm{stat}) \pm 3.1\,(\mathrm{syst}))$ MeV, respectively, which are consistent with the world average values within two standard deviations. The product branching fraction $\mathcal{B}[\psi(3686) \to \gamma\eta_c(2S)] \times \mathcal{B}[\eta_c(2S) \to 3(\pi^+\pi^-)]$ is measured to be $(9.2 \pm 1.0(\mathrm{stat}) \pm 1.2(\mathrm{syst})) \times 10^{-6}$. Using $\mathcal{B}[\psi(3686) \to \gamma\eta_c(2S)] = (7.0^{+3.4}_{-2.5}) \times 10^{-4}$, we obtain $\mathcal{B}[\eta_c(2S) \to 3(\pi^+\pi^-)] = (1.31 \pm 0.15\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})\,(^{+0.64}_{-0.47})\,(\mathrm{extr})) \times 10^{-2}$, where the third uncertainty is from $\mathcal{B}[\psi(3686) \to \gamma\eta_c(2S)]$. We also measure the $\chi_{cJ} \to 3(\pi^+\pi^-)$ $(J = 0,\ 1,\ 2)$ decays via $\psi' \to \gamma\chi_{cJ}$ transitions. The branching fractions are $\mathcal{B}[\chi_{c0} \to 3(\pi^+\pi^-)] = (2.080 \pm 0.006(\mathrm{stat}) \pm 0.068(\mathrm{syst})) \times 10^{-2}$, $\mathcal{B}[\chi_{c1} \to 3(\pi^+\pi^-)] = (1.092 \pm 0.004(\mathrm{stat}) \pm 0.035(\mathrm{syst})) \times 10^{-2}$, and $\mathcal{B}[\chi_{c2} \to 3(\pi^+\pi^-)] = (1.565 \pm 0.005\,(\mathrm{stat}) \pm 0.048\,(\mathrm{syst})) \times 10^{-2}$.

DOI : https://doi.org/10.1103/PhysRevD.106.032014

$Search\ for\ \eta_c(2S) \rightarrow \omega\omega/\omega\phi\ in\ \psi(3686) \rightarrow \gamma\eta_c(2S)\ decay\ and\ Measurements\ of\ \chi_{cJ}(1P) \rightarrow \omega\omega/\omega\phi\ in\ \psi(3686) \rightarrow \gamma\chi_{cJ}(1P)\ decay$

Abstract

Using a sample of 2708.1×10^6 $\psi(3686)$ events collected with the BESIII detector at the BEPCII collider in 2009, 2012 and 2021, we search for $\eta_c(2S) \rightarrow \omega\omega$ and $\omega\phi$ via $\psi(3686) \rightarrow \gamma\eta_c(2S)$. The ω is reconstructed with $\pi^+\pi^-\pi^0$ and ϕ with K^+K^- final states. No obvious signal events are observed. The upper limits of the branching fractions at 90% confidence level are determined to be $Br(\psi(2S) \rightarrow \gamma\eta_c(2S), \eta_c(2S) \rightarrow \omega\omega) < 6.13 \times 10^{-7}$ and $Br(\psi(2S) \rightarrow \gamma\eta_c(2S), \eta_c(2S) \rightarrow \omega\phi) < 1.08 \times 10^{-7}$, respectively. We also update the branching fractions of $\chi_{cJ}(1P) \rightarrow \omega\omega$ decays and $\chi_{cJ}(1P) \rightarrow \omega\phi$ decays via $\psi(2S) \rightarrow \gamma\chi_{cJ}$ transition. The branching fractions are determined to be $Br(\chi_{c0} \rightarrow \omega\omega) = (9.42 \pm 0.09 \pm 0.38) \times 10^{-4}$, $Br(\chi_{c1} \rightarrow \omega\omega) = (5.93 \pm 0.07 \pm 0.27) \times 10^{-4}$, $Br(\chi_{c2} \rightarrow \omega\omega) = (8.02 \pm 0.08 \pm 0.35) \times 10^{-4}$, $Br(\chi_{c0} \rightarrow \omega\phi) = (1.19 \pm 0.03 \pm 0.06) \times 10^{-4}$, $Br(\chi_{c1} \rightarrow \omega\phi) = (2.04 \pm 0.14 \pm 0.15) \times 10^{-5}$, and $Br(\chi_{c2} \rightarrow \omega\phi) = (8.48 \pm 0.96 \pm 0.61) \times 10^{-6}$, where the first uncertainty is statistical and second is systematic.

link:https://docbes3.ihep.ac.cn/DocDB/0011/001195/010/omegaomega_and_omegaphi_memo8.pdf

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9.1 Lineshape of $\eta_c(2S)$

Before fitting to the mass spectrum, the lineshape of signal is defined firstly. For the $\eta_c(2S)$ signal, the lineshape is given below

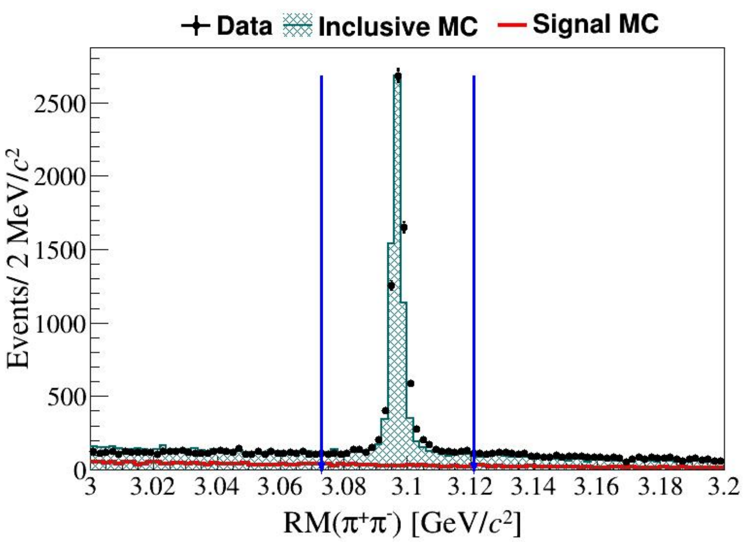
$$(BW(m; M, \Gamma) \times E_\gamma^3 \times f_d(E_\gamma) \otimes DG(m_1, \sigma_1, m_2, \sigma_2, f) \times \epsilon(m)) \otimes G(\delta m_3, \delta\sigma_3), \tag{13}$$

where m is the 3C kinematic fitted mass of $\omega\omega$ or $\omega\phi$, $BW(m; M, \Gamma)$ is the Breit-Wigner function for $\eta_c(2S)$ or χ_{cJ}, the form of the $BW(m)$ is $\frac{1}{2\pi} \cdot \frac{\Gamma}{(m-m_0)^2+\Gamma^2/4}$ with M and Γ representing the mass and width of the resonance. $E_\gamma = \frac{M^2_{\psi(2S)}-m^2}{2M_{\psi(2S)}}$ is the energy of the transition photon in the rest frame of $\psi(2S)$ ($M_{\psi(2S)}$ is the nominal mass of $\psi(2S)$). $f_d(E_\gamma)$ is the function to damp the diverging tail raised by E_γ^3, the possible form of the damping function is used by KEDR for a similar process, which is $\frac{E_0^2}{E_\gamma E_0+(E_\gamma-e_0)^2}$, where $E_0 = \frac{M^2_{\psi(2S)}-M^2_{\eta_c(2S)}}{2M_{\psi(2S)}}$ is the peaking energy of the transition photon. $DG(m_1, \sigma_1, m_2, \sigma_2, f)$ is a double Gaussian function used to describe the mass resolution, the parameters are estimated by using signal MC samples. $\epsilon(m)$ is the MC efficiency as a function of m. $G(\delta m_3, \delta\sigma_3)$ is a single Gaussian function, which describes the difference of mass and resolution between data and MC sample.

Thanks

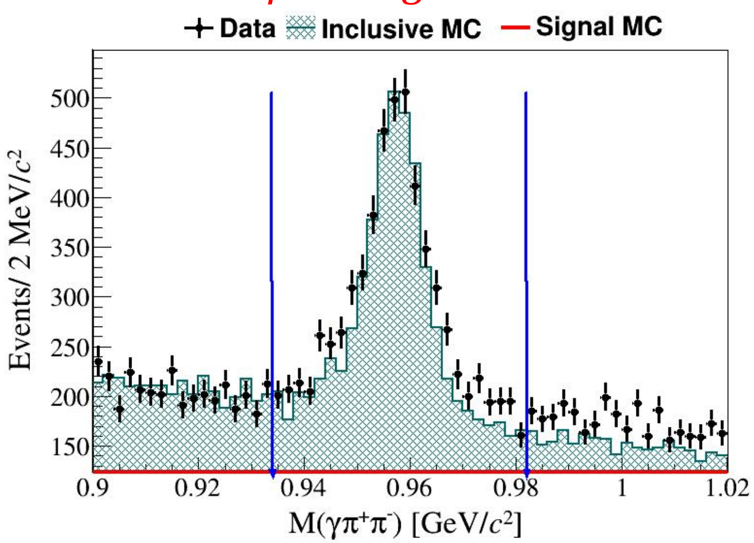
Back up

$\pi^+\pi^- J/\psi$ background



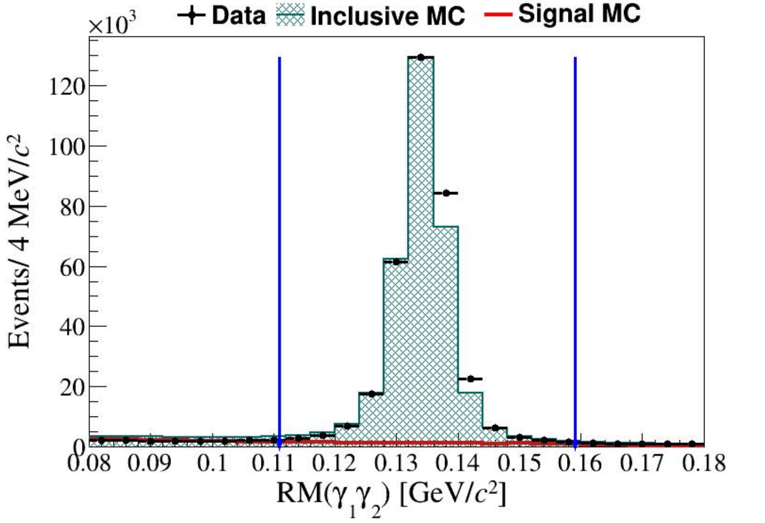
- $|RM(\pi^+\pi^-) - m(J/\psi)| > 24\ MeV/c^2$

η' background



- $|M(\gamma\pi^+\pi^-) - m(\eta')| > 24\ MeV/c^2$

π^0 background



- $|M(\gamma_1\gamma_2) - m(\pi^0)| > 24\ MeV/c^2$