Search for h_c hadronic decays and $\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega$

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Outline

- **Part I**
  - Search for h_c hadronic decays
- **Part II**
  - Search for $\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega$

Part I:

Search for h_c hadronic decays

Outline

- Motivation
- Data Sample and MC Simulation
- Analysis
  - ✓ $h_c \to 3(\pi^+\pi^-)\pi^0$
  - ✓ $h_c \to 2(\pi^+\pi^-)\pi^0\eta$
  - ✓ $h_c \to 2(\pi^+\pi^-)\eta$
  - ✓ $h_c \to p\bar{p}\pi^0$
  - ✓ $h_c \to p\bar{p}$
- Summary

Motivation

*BAM-00512: Search for hc to pp-bar+X hadronic decays, by Lin Zhu et al.

- Study of charmonium states is crucial for reaching a deeper understanding of the low-energy regime of QCD.
- There have been few measurements of the decays of the spin-singlet charmonium state $h_c(^1P_1)$, since its discovery in 2005.

Mode	BR($h_c \to X$)	Reference
$\gamma\eta_c$	~50%	PRD 72. 032001, et al
$\gamma\eta$	$(4.7\pm2.1)\cdot10^{-4}$	PRL 116. 251802 (2016)
$\gamma\eta'$	$(1.5\pm0.4)\cdot10^{-3}$	
$\pi^+\pi^-\pi^0$	$(1.6\pm0.4\pm0.2)\cdot10^{-3}$	PRD 99. 072008 (2019)
$2(\pi^+\pi^-)\pi^0$	$(7.44\pm0.94\pm1.52)\cdot10^{-3}$	
$3(\pi^+\pi^-)\pi^0$	$(4.7\pm2.2\pm1.1)\cdot10^{-3}$	
$p p\pi^+\pi^-$	$(2.9\pm0.3\pm0.3)\cdot10^{-3}$	
$p\bar{p}$	$<1.5\cdot10^{-4}$	PRD 88. 112001 (2013)
$K^+K^-\pi^+\pi^-\pi^0$	$(3.33\pm0.6\pm0.6)\cdot10^{-3}$	PRD 102. 112007 (2020)
$K_S^0K^\pm\pi^\mp\pi^+\pi^-$	$(2.8\pm0.9\pm0.6)\cdot10^{-3}$	
$\pi^+\pi^-\pi^0\eta$	$(7.2\pm1.8\pm1.4)\cdot10^{-3}$	
$K^+K^-\eta$	$<5.8\cdot10^{-4}$	
$p\bar{p}\pi^+\pi^-\pi^0$	$(3.84\pm0.83)\cdot10^{-3}$	BAM-00512*
$p\bar{p}\eta$	$(6.41\pm1.74)\cdot10^{-4}$	
$p\bar{p}\pi^0$	$<6.59\cdot10^{-4}$	
…	…	

Red: Sig. >5σ (8 channels ~52.8%) Bule: 3σ < Sig. < 5σ (3 channels ~ 1.05%)

Data samples

Data set	Number of events	BOSS version
09+12 $\psi(3686)$ data	4.48×10^8	6.6.4.p03
2021 $\psi(3686)$ data[1,2]	2.28×10^9 (half)	706
09+12 $\psi(3686)$ inclusive MC	5.06×10^8	6.6.4.p03
PHSP MC	1×10^5 for each channel	6.6.4.p03

[1] */besfs4/offline/data/706-1/psip/round14/opendst*
[2] *https://indico.ihep.ac.cn/event/13971/session/15/contribution/102/material/slides/0.pdf*

◎ Mode I:

$$\mathrm{h_c} \to 3(\pi^+\pi^-)\pi^0$$

Initial Event Selection

Charged tracks

- $|R_{xy}| < 1\ cm, |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $\boldsymbol{N = 6, N_m = N_p = 3}$

Particle identification

- Prob(pi)> Prob(p), Prob(pi)> Prob(K)
- $\boldsymbol{N_{\pi^+} = N_{\pi^-} = 3}$

Vertex Fit for $3(\pi^+\pi^-)$

A 6C kinematic fit with

$\psi(3686) \rightarrow 3(\pi^+\pi^-)\gamma\gamma\gamma\gamma.$

- Additional 4C kinematic fit for $3\gamma3(\pi^+\pi^-)$, $4\gamma3(\pi^+\pi^-)$ and $5\gamma3(\pi^+\pi^-)$ final states.

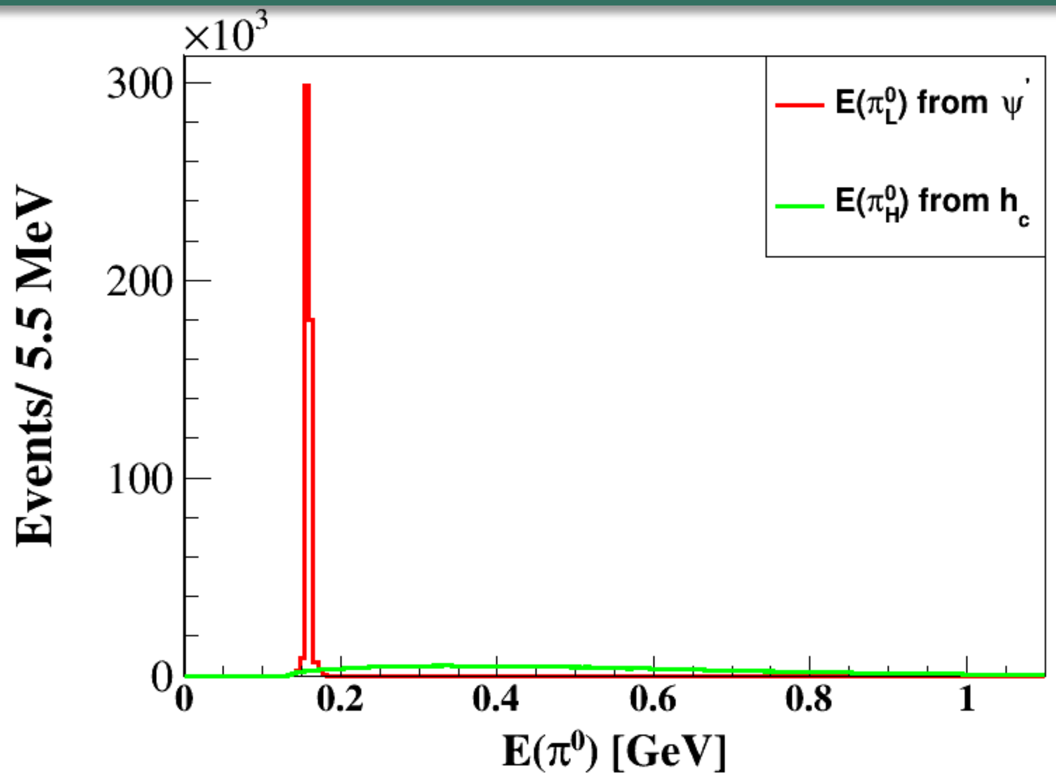
Good photon

- $0 \leq TDC \leq 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \geq 4}$

1C for π^0:

- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

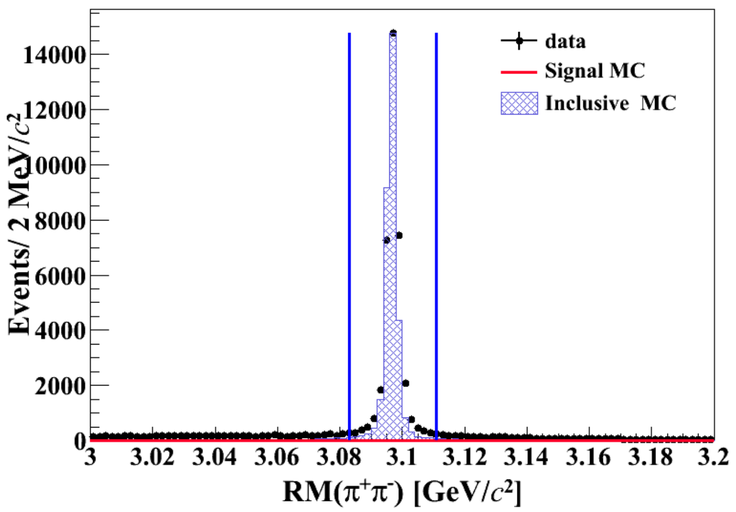
Energy distribution of two π^0

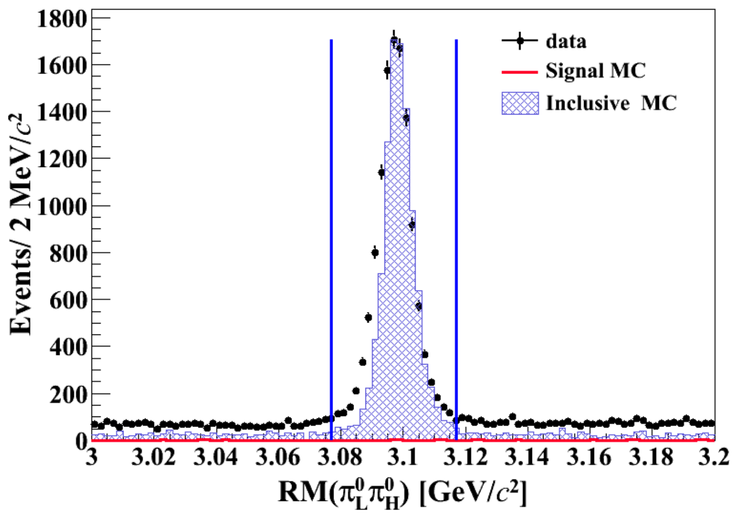


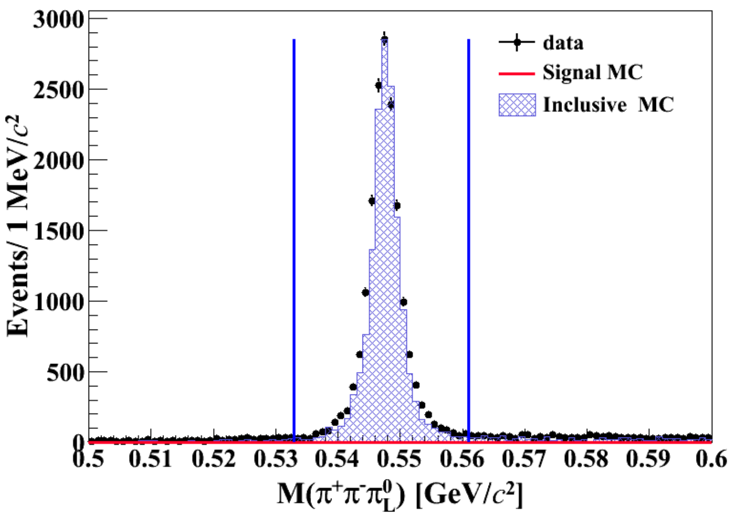
- ◆ $\psi(3686) \to \pi^0{}_L h_c$
- ◆ $h_c \to p\bar{p}\pi^0{}_H$

- The energy of bachelor π^0 from $\psi(3686)$ is lower than that from $\mathbf{h_c}$.
- The lower one is tagged as $\pi^0{}_L$, and the higher one is tagged as $\pi^0{}_H$.

Veto on $\psi(3686) \to \pi\pi J/\psi$ or $\eta \to \pi^+\pi^-\pi^0_L$

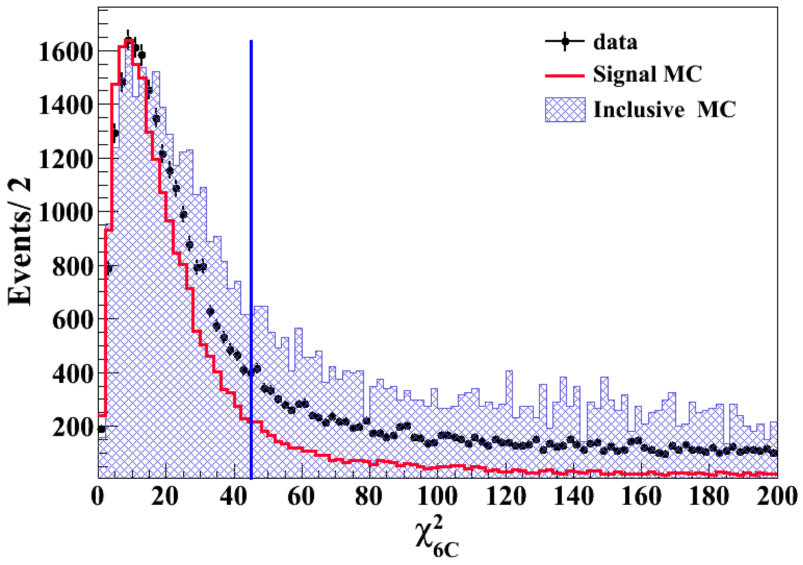


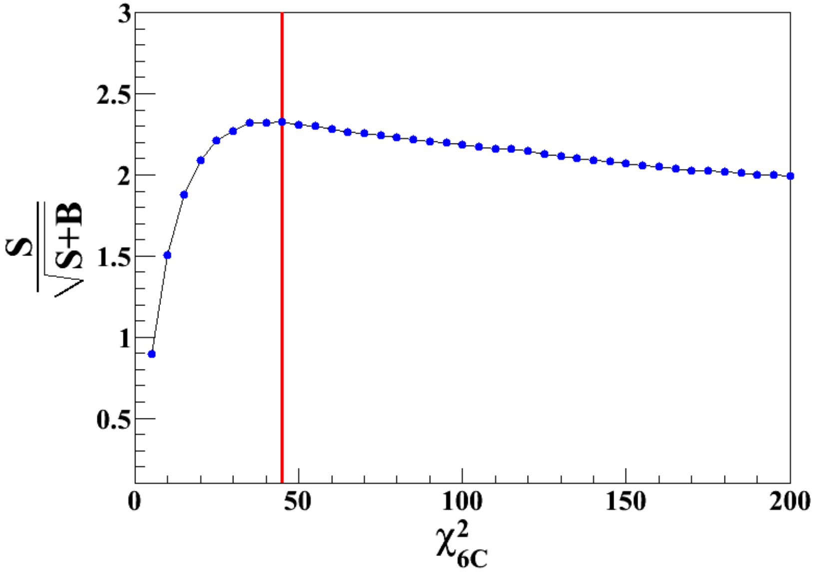




- $|RM(\pi^+\pi^-) - m(J/\psi)| > 14 MeV/c^2$
- $|RM(\pi^0_L\pi^0_H) - m(J/\psi)| > 20 MeV/c^2$
- $|M(\pi^+\pi^-\pi^0_L) - m(\eta)| > 12 MeV/c^2$

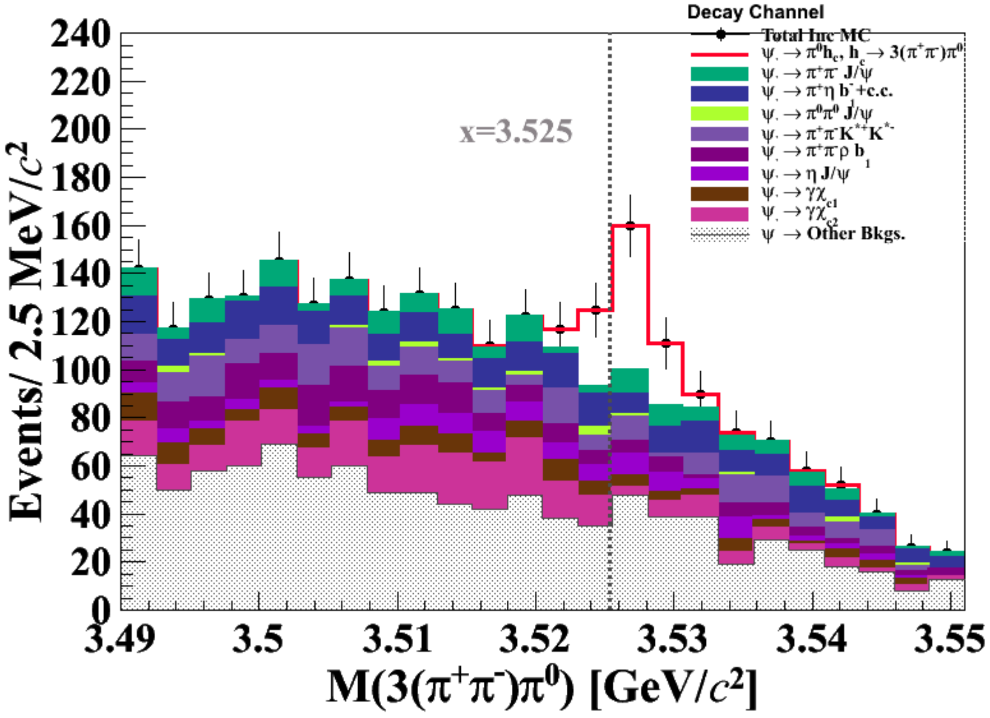
6C kinematic fit



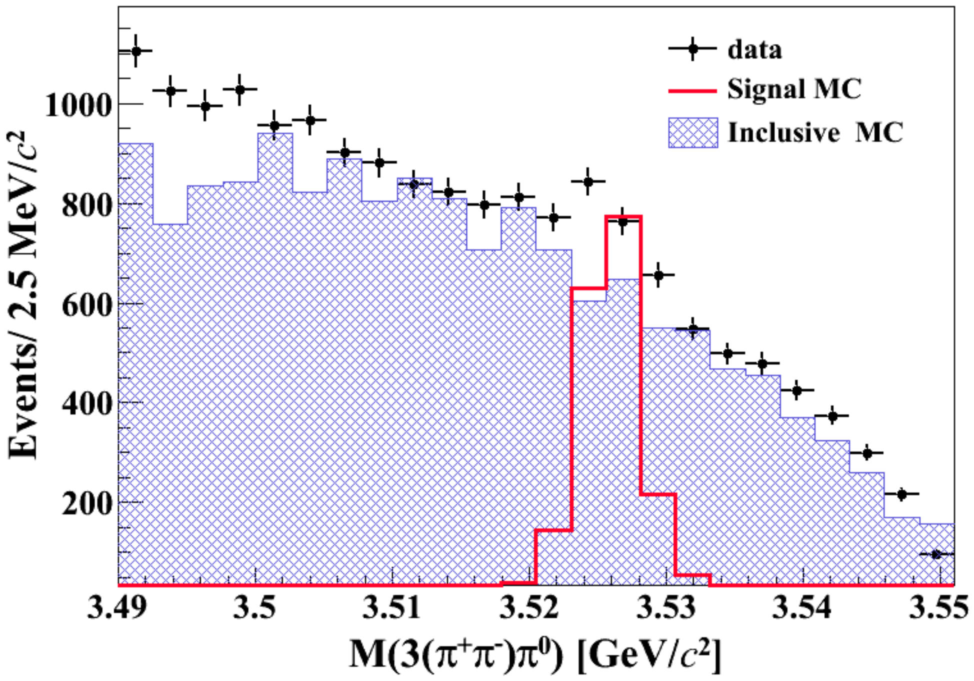


- $\chi^2_{6C} < 45$
- Additional requirement
  - ✓ $\chi^2_{4C}(\,\mathbf{4\gamma 3(\pi^+\pi^-)}\,) < \chi^2_{4C}(\,\mathbf{3\gamma 3(\pi^+\pi^-)}\,)$
  - ✓ $\chi^2_{4C}(\,\mathbf{4\gamma 3(\pi^+\pi^-)}\,) < \chi^2_{4C}(\,\mathbf{5\gamma 3(\pi^+\pi^-)}\,)$

$M(3(\pi^+\pi^-)\pi^0)$



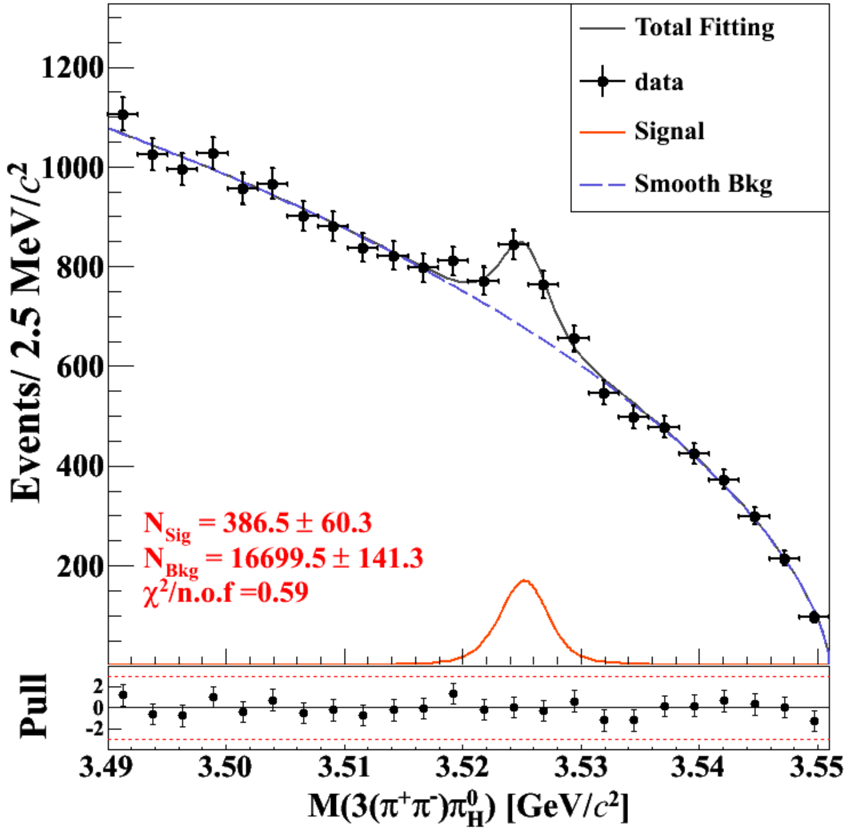
Decay Channel
Total Inc MC
ψ' → π⁰h_c, h_c → 3(π⁺π⁻)π⁰
ψ' → π⁺π⁻ J/ψ
ψ' → π⁺η b₁⁻ +c.c.
ψ' → π⁰π⁰ J/ψ
ψ' → π⁺π⁻K*⁺K*⁻
ψ' → π⁺π⁻ρ b₁
ψ' → η J/ψ
ψ' → γχ_c1
ψ' → γχ_c2
ψ → Other Bkgs.
x=3.525
Events/ 2.5 MeV/c²
M(3(π⁺π⁻)π⁰) [GeV/c²]



data
Signal MC
Inclusive MC
Events/ 2.5 MeV/c²
M(3(π⁺π⁻)π⁰) [GeV/c²]

h_c Signal fit

- Significance= 6.6 σ



Fitting function is described as:

$$\mathrm{P.D.F.} = \mathrm{N_{sig}} \cdot (\mathrm{MCShape} \otimes \mathrm{Gaussian}(m, \sigma)) + \mathrm{N_{bkg}} \cdot \mathrm{Argus}(r, s, p)$$

$$B(h_c \to 3(\pi^+\pi^-)\pi^0) = \frac{N^{obs}}{N_{tot} \cdot B(\psi(3686) \to \pi^0 h_c) \cdot B(\pi^0 \to \gamma\gamma)^2 \cdot \varepsilon}$$

- ✓ $Br(\psi(3686) \to \pi^0 h_c) = (8.6 \pm 1.3) \times 10^{-4}$
- ✓ $Br(\pi^0 \to \gamma\gamma) = (98.823 \pm 0.034)\%$

Mode	N^{obs}	$\varepsilon(\%)$	$B(\times 10^{-3})$
$h_c \to 3(\pi^+\pi^-)\pi^0$	386.5±60.3	3.92	~

◎ Mode II:

$$\mathbf{h_c \to 2(\pi^+\pi^-)\pi^0\eta}$$

Initial Event Selection

Charged tracks

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

Particle identification

- Prob(pi)> Prob(p), Prob(pi)> Prob(K)
- $\boldsymbol{N_{\pi^+} = N_{\pi^-} = 2}$

Vertex Fit for $2(\pi^+\pi^-)$

A 7C kinematic fit with $\psi(3686) \to 2(\pi^+\pi^-)\gamma\gamma\gamma\gamma\gamma\gamma.$

- $\chi^2_{7C}\left(\boldsymbol{3\pi^0 2(\pi^+\pi^-)}\right)$
- Additional 4C kinematic fit for $5\gamma 2(\pi^+\pi^-)$, $6\gamma 2(\pi^+\pi^-)$ and $7\gamma 2(\pi^+\pi^-)$ final states.

Good photon

- $0 \le TDC \le 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \ge 6}$

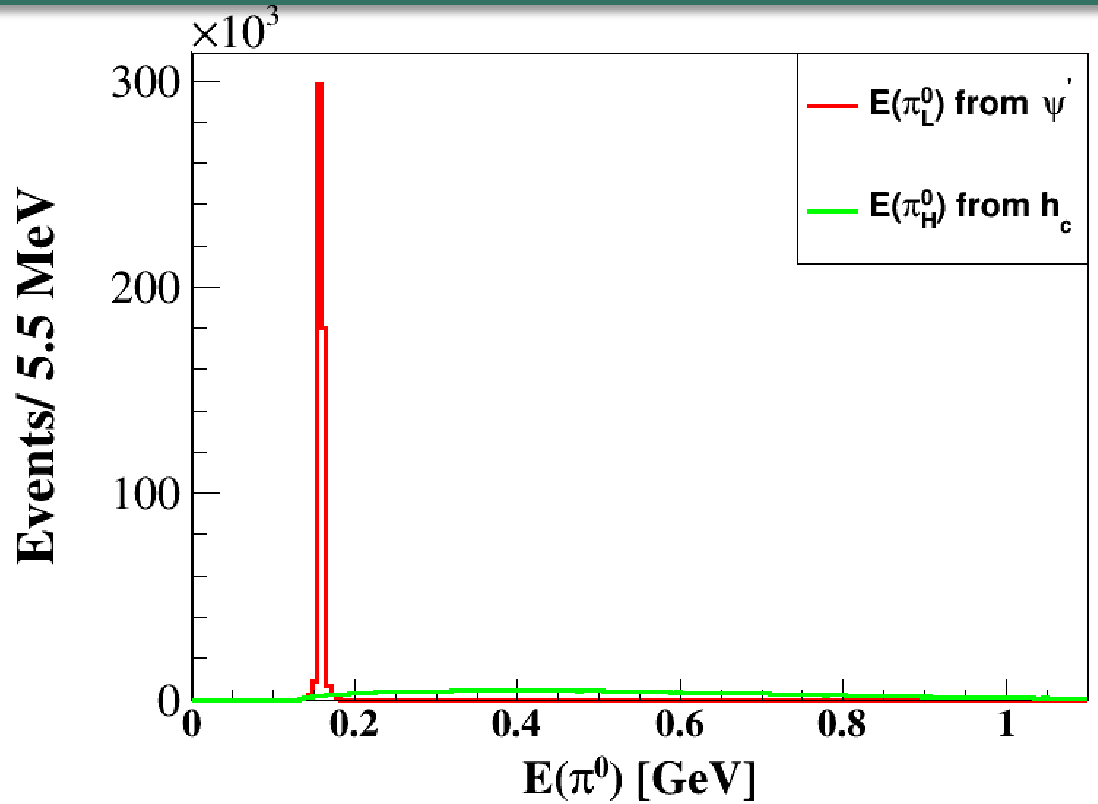
1C for π^0 :

- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

1C for η:

- …

Energy distribution of two π^0

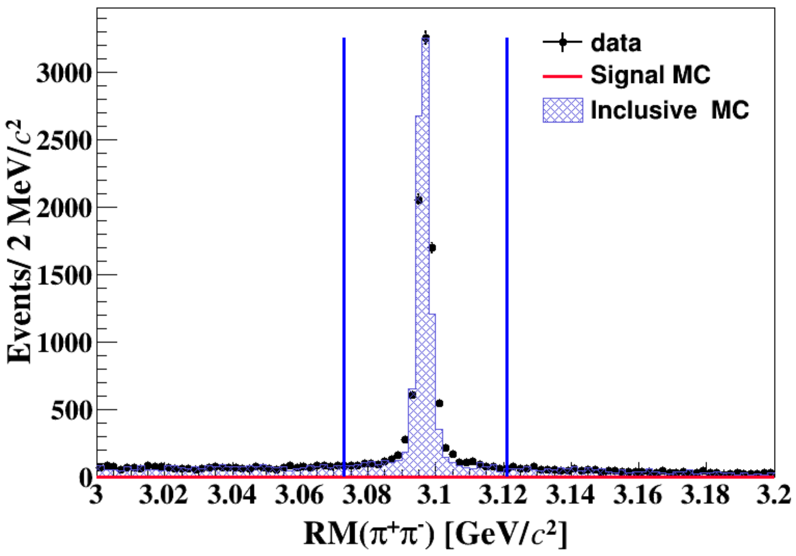


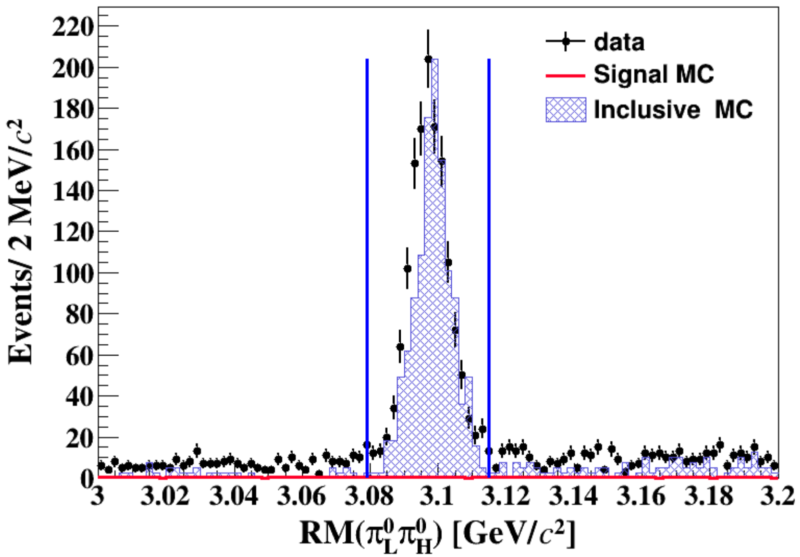
◆ $\psi(3686) \to \pi^0{}_L h_c$

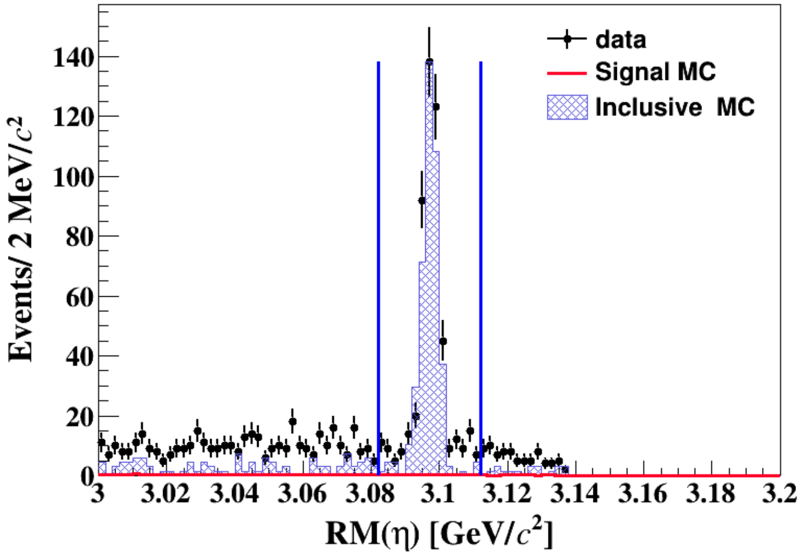
◆ $h_c \to p\bar{p}\pi^0{}_H$

- The energy of bachelor π^0 from $\psi(3686)$ is lower than that from $\mathbf{h_c}$.
- The lower one is tagged as $\pi^0{}_L$, and the higher one is tagged as $\pi^0{}_H$.

Veto on $\psi(3686) \to \pi\pi\, J/\psi$ or $\to \eta\, J/\psi$

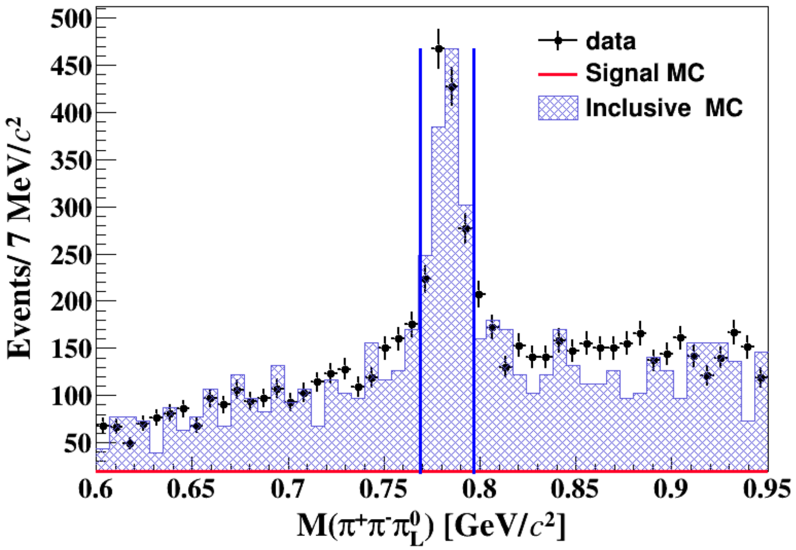


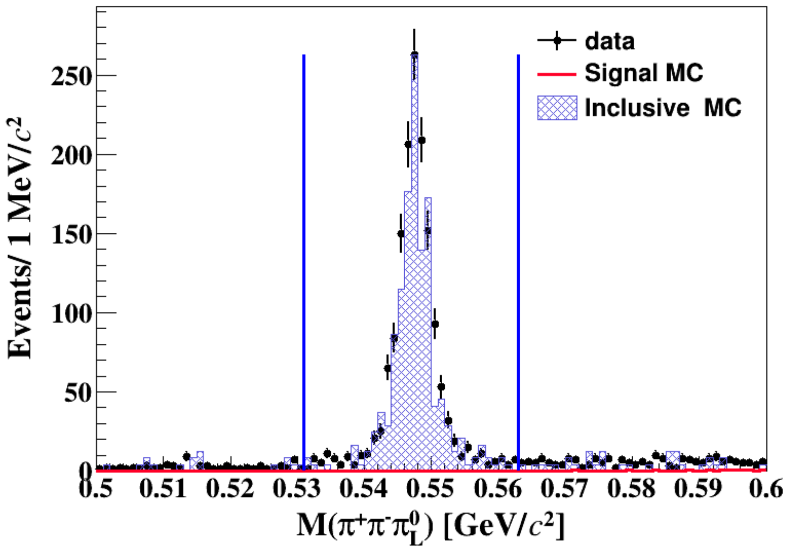


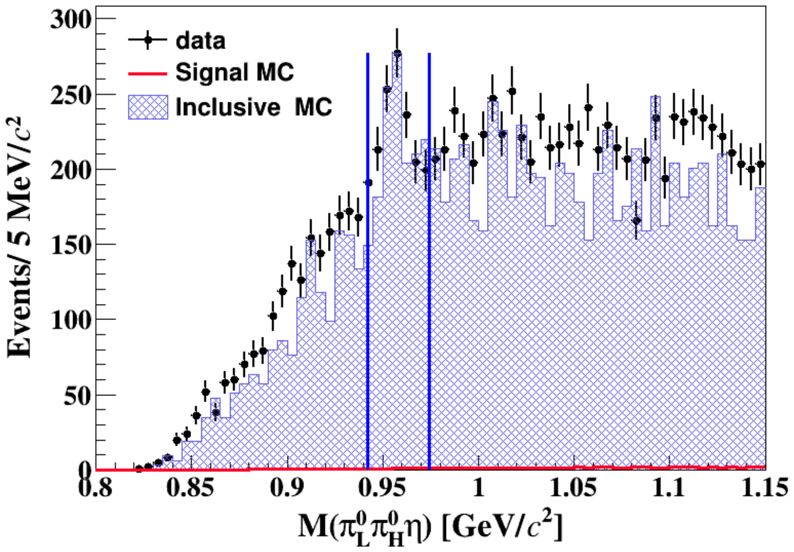


- $|RM(\pi^+\pi^-) - m(J/\psi)| > 22MeV/c^2$
- $|RM(\pi^0_L\pi^0_H) - m(J/\psi)| > 20MeV/c^2$
- $|RM(\eta) - m(J/\psi)| > 15MeV/c^2$

Veto on $\eta/\omega \to \pi^+\pi^-\pi^0_L$ or $\eta' \to \pi^0_L\pi^0_H\eta$

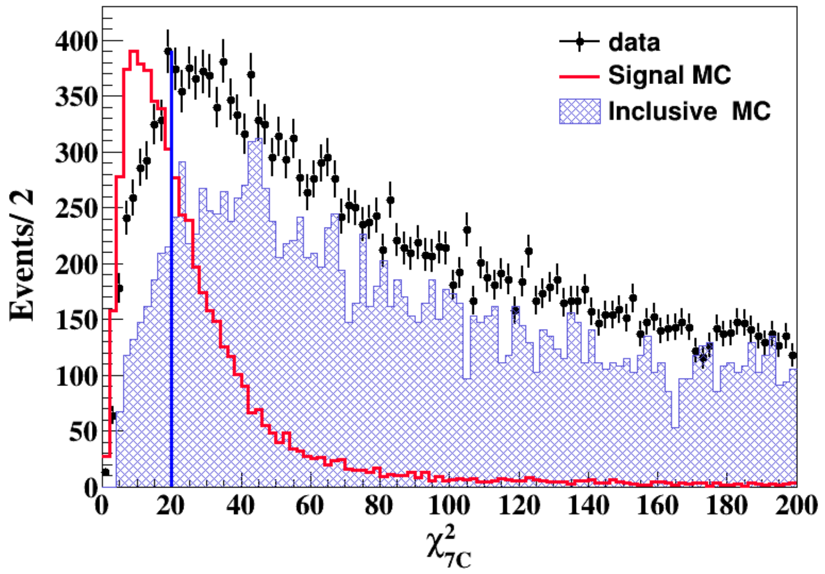


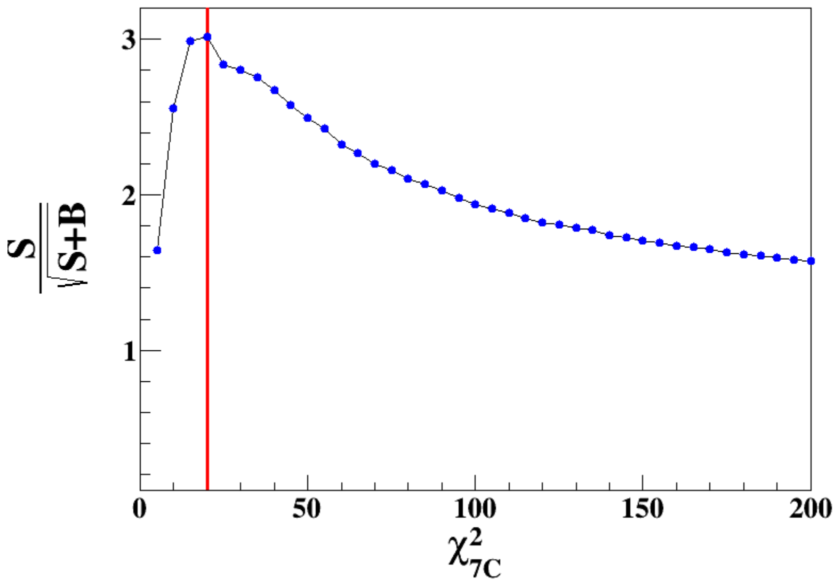


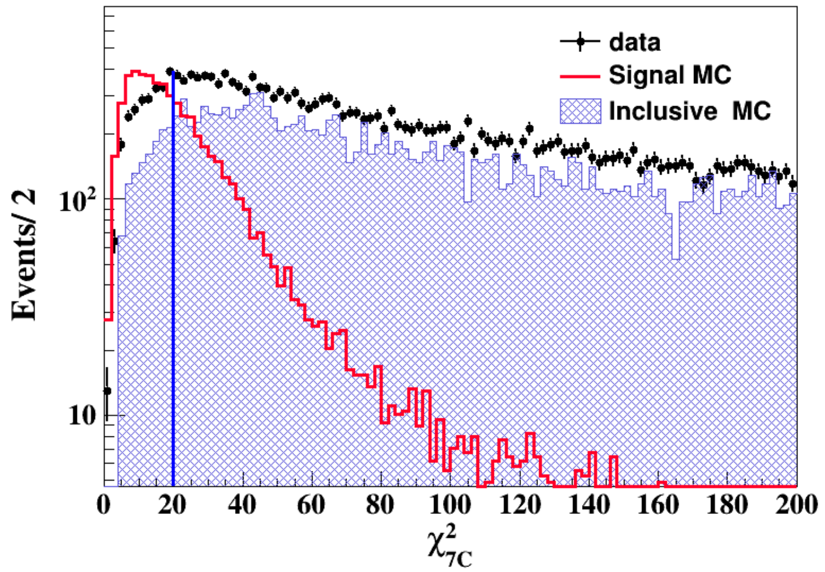


- $|M(\pi^+\pi^-\pi^0_L) - m(\omega)| > 0.014\mathrm{MeV}/c^2$
- $|M(\pi^+\pi^-\pi^0_L) - m(\eta)| > 0.014\mathrm{MeV}/c^2$
- $|M(\pi^0_L\pi^0_H\eta) - m(\eta')| > 0.016\mathrm{MeV}/c^2$

7C kinematic fit

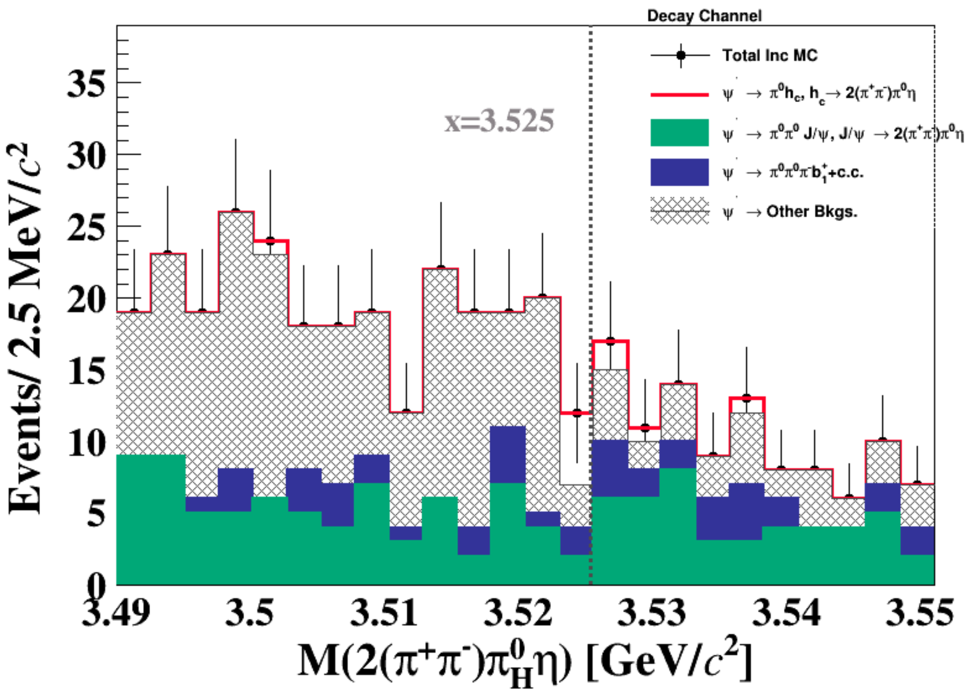


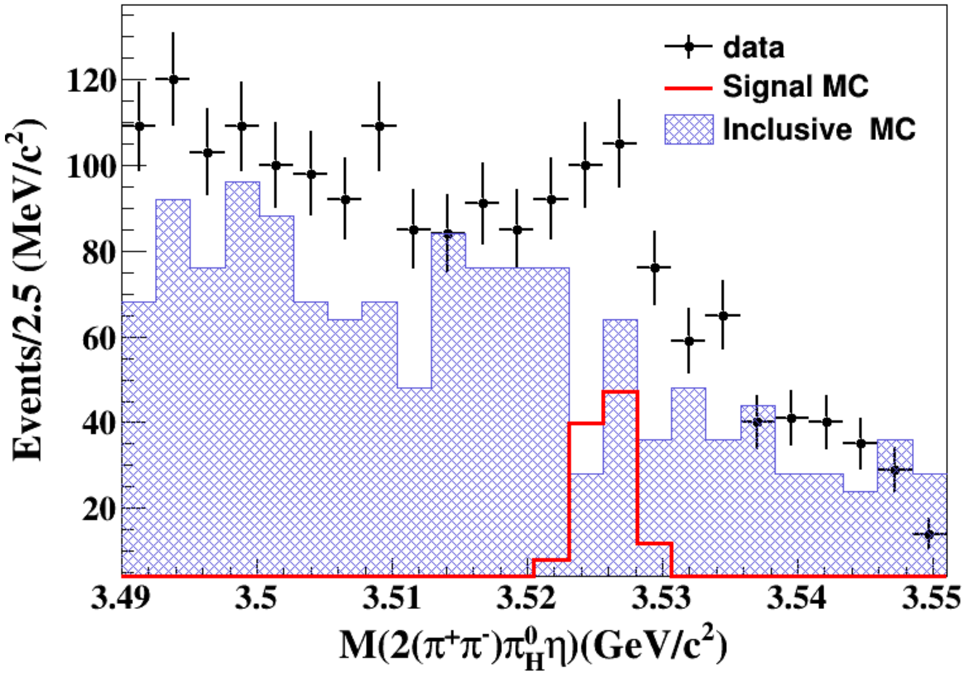




- $\chi^2_{7C} < 20$
- Additional requirement
  - ✓ $\chi^2_{7C}\left(\mathbf{2\pi^0\eta 2(\pi^+\pi^-)}\right) < \chi^2_{7C}\left(\mathbf{3\pi^0 2(\pi^+\pi^-)}\right)$
  - ✓ $\chi^2_{4C}(\mathbf{6\gamma 2(\pi^+\pi^-)}) < \chi^2_{4C}(\mathbf{5\gamma 2(\pi^+\pi^-)})$
  - ✓ $\chi^2_{4C}(\mathbf{6\gamma 2(\pi^+\pi^-)}) < \chi^2_{4C}(\mathbf{7\gamma 2(\pi^+\pi^-)})$

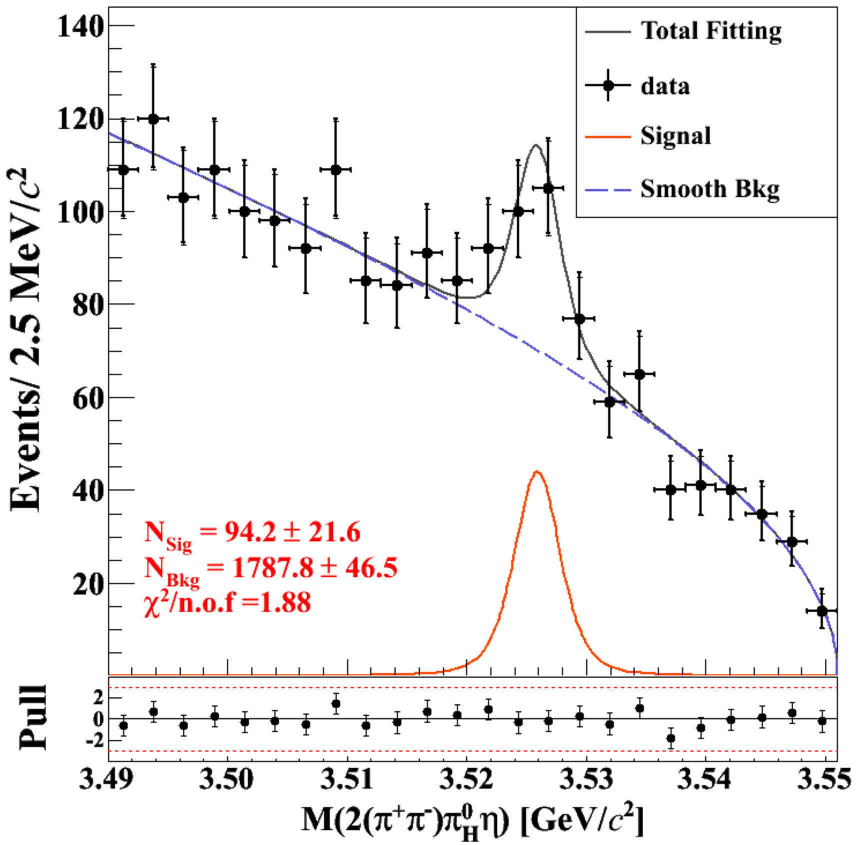
$M(2(\pi^+\pi^-)\pi^0\eta)$





h_c Signal fit

- Significance= 4.8 * σ



□ Fitting function is described as:

$$\mathrm{P.D.F.} = \mathrm{N_{sig}} \cdot \left(\mathrm{MCShape} \otimes \mathrm{Gaussian}(\mathrm{m}, \boldsymbol{\sigma})\right) + \mathrm{N_{bkg}} \cdot \mathrm{Argus}(\mathrm{r}, \mathrm{s}, \mathrm{p})$$

$$\boldsymbol{B}(\boldsymbol{h_c} \to 2(\pi^+\pi^-)\pi^0\boldsymbol{\eta}) = \frac{\boldsymbol{N^{obs}}}{\boldsymbol{N_{tot}} \cdot \boldsymbol{B}(\boldsymbol{\psi}(3686) \to \boldsymbol{\pi^0 h_c}) \cdot \boldsymbol{B}(\boldsymbol{\pi^0} \to \boldsymbol{\gamma\gamma})^2 \cdot \boldsymbol{B}(\boldsymbol{\eta} \to \boldsymbol{\gamma\gamma}) \cdot \boldsymbol{\varepsilon}}$$

- ✓ $Br(\psi(3686) \to \pi^0 h_c) = (8.6 \pm 1.3) \times 10^{-4}$
- ✓ $Br(\pi^0 \to \gamma\gamma) = (98.823 \pm 0.034)\%$
- ✓ $Br(\eta \to \gamma\gamma) = (39.41 \pm 0.20)\%$

Mode	N^{obs}	$\varepsilon(\%)$	$B(\times 10^{-3})$
$h_c \to 2(\pi^+\pi^-)\pi^0\boldsymbol{\eta}$	94.2±21.6	2.06	~

◎ Mode III:

$$\mathbf{h_c \rightarrow 2(\pi^+\pi^-)\eta}$$

Initial Event Selection

Charged tracks

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

Particle identification

- Prob(pi)> Prob(p), Prob(pi)> Prob(K)
- $\boldsymbol{N_{\pi^+} = N_{\pi^-} = 2}$

Vertex Fit for $2(\pi^+\pi^-)$

A 6C kinematic fit with

$\psi(3686) \to 2(\pi^+\pi^-)\gamma\gamma\gamma\gamma.$

- Additional 4C kinematic fit for $3\gamma 2(\pi^+\pi^-)$, $4\gamma 2(\pi^+\pi^-)$ and $5\gamma 2(\pi^+\pi^-)$ final states.

Good photon

- $0 \leq TDC \leq 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \geq 4}$

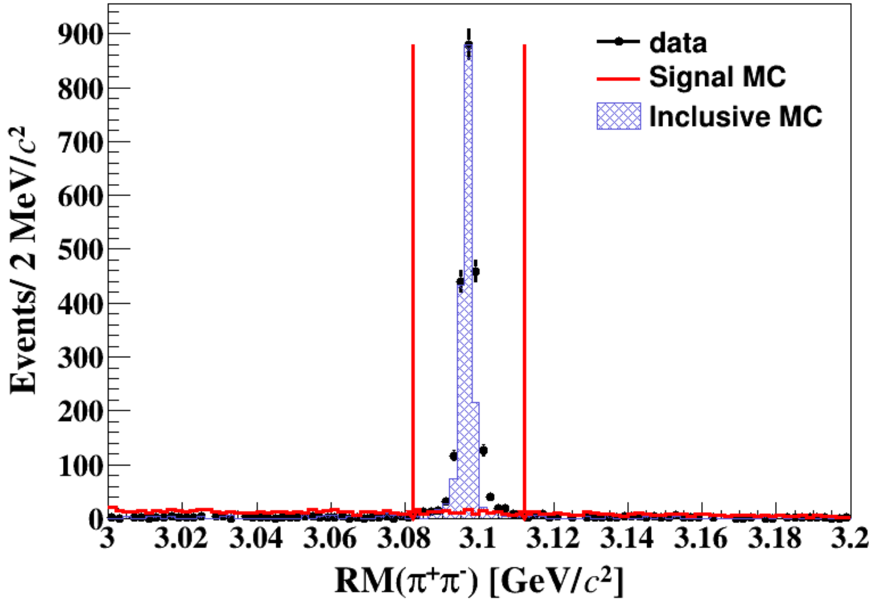
1C for π^0 :

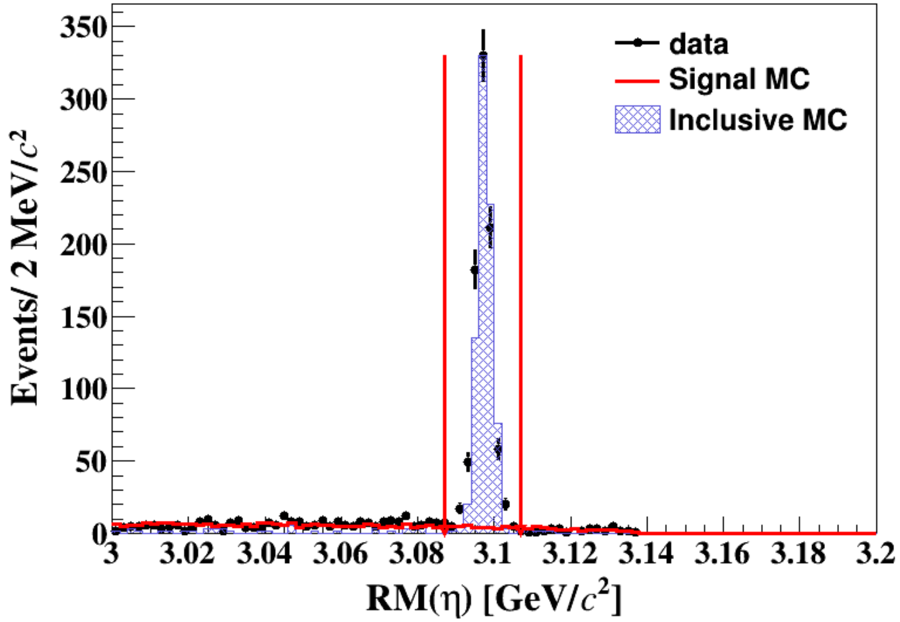
- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

1C for η:

- …

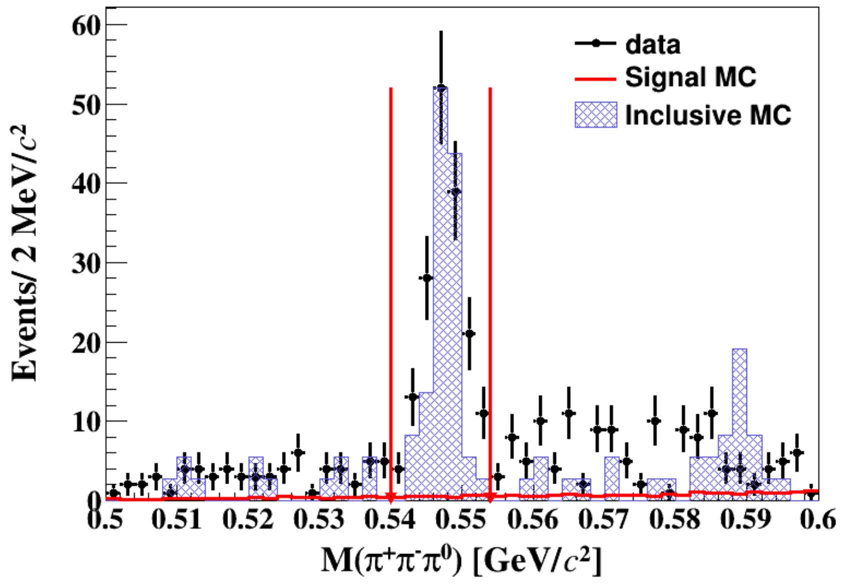
Veto on $\psi(3686) \to \pi\pi J/\psi$ or $\to \eta J/\psi$

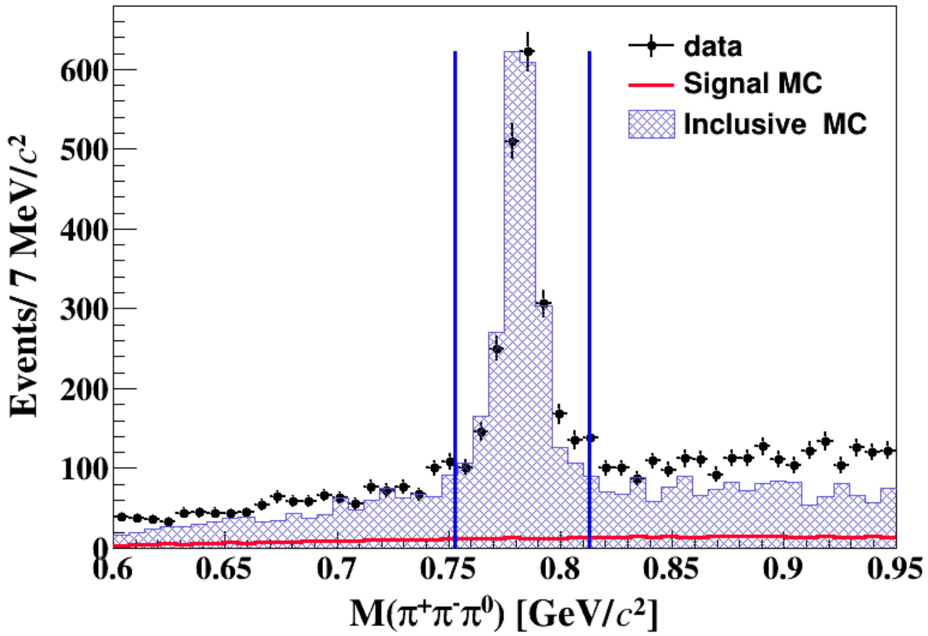




- $|RM(\pi^+\pi^-) - m(J/\psi)| > 15\ MeV/c^2$
- $|RM(\eta) - m(J/\psi)| > 10\ MeV/c^2$

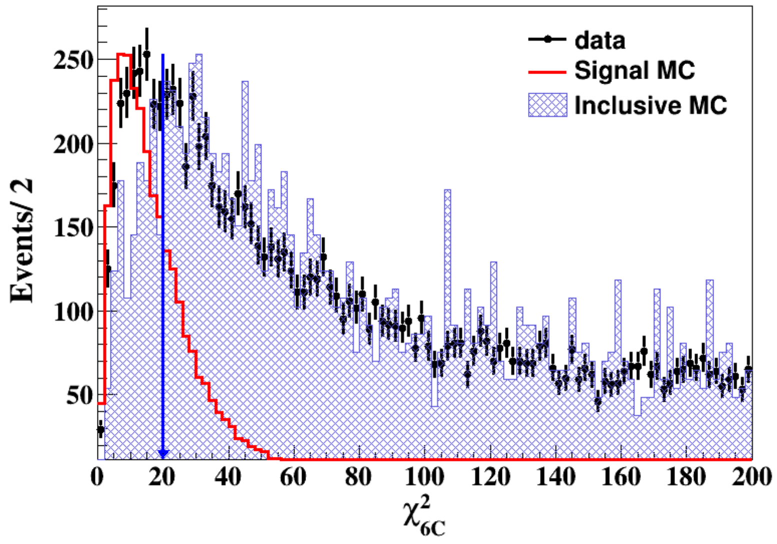
Veto on $\eta/\omega \to \pi^+\pi^-\pi^0_L$

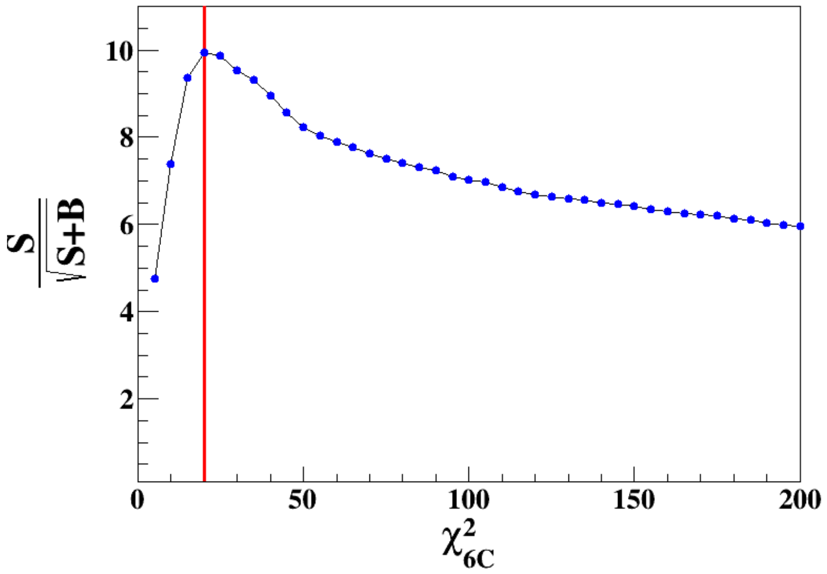


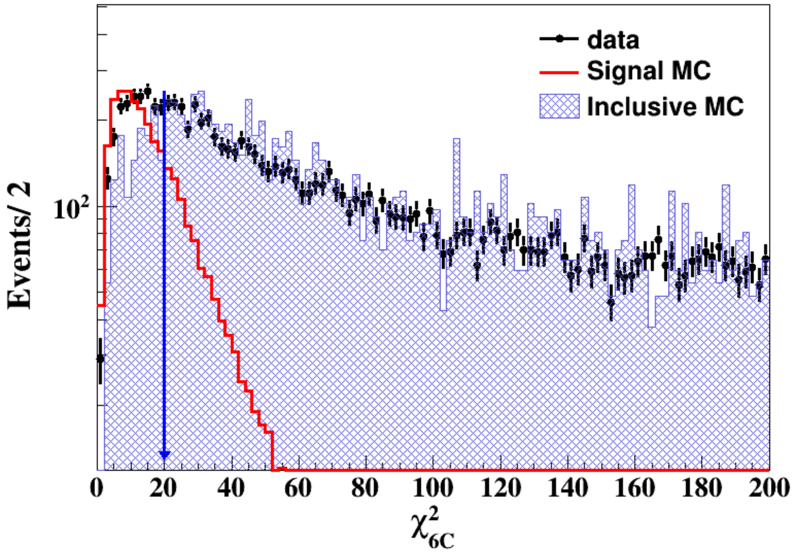


- $\left|M(\pi^+\pi^-\pi^0_L) - m(\omega)\right| > 0.03\ \mathrm{MeV}/c^2$
- $\left|M(\pi^+\pi^-\pi^0_L) - m(\eta)\right| > 0.007\ \mathrm{MeV}/c^2$

6C kinematic fit

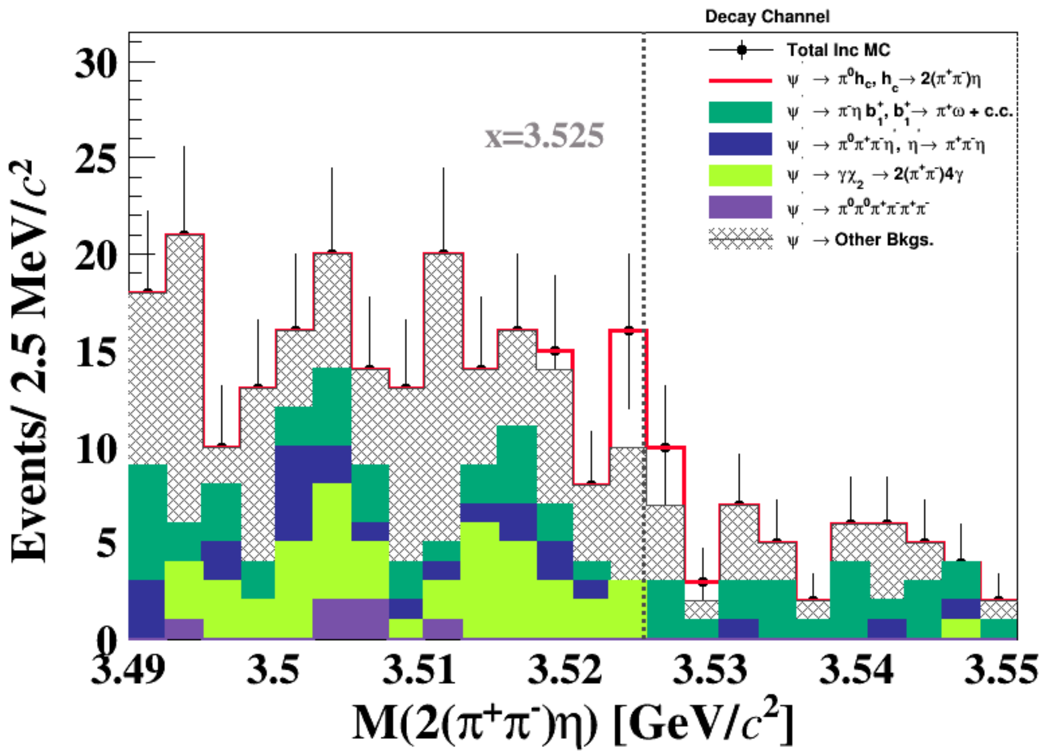


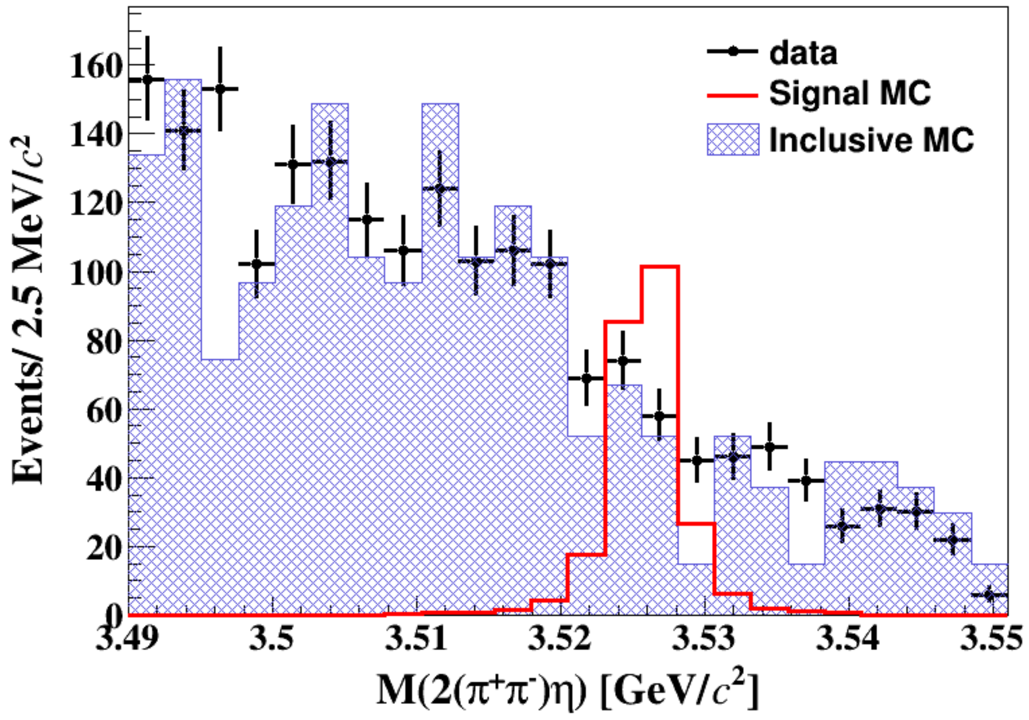




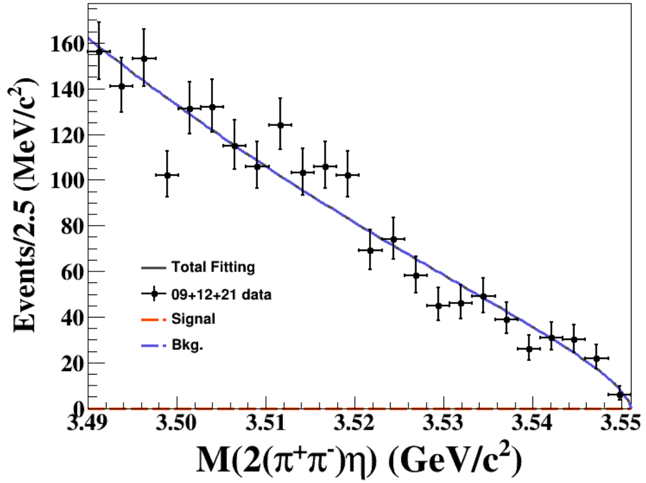
- $\chi^2_{6C} < 20$
- Additional requirement
  - ✓ $\chi^2_{4C}(\mathbf{4\gamma 2(\pi^+\pi^-)}) < \chi^2_{4C}(\mathbf{3\gamma 2(\pi^+\pi^-)})$
  - ✓ $\chi^2_{4C}(\mathbf{4\gamma 2(\pi^+\pi^-)}) < \chi^2_{4C}(\mathbf{5\gamma 2(\pi^+\pi^-)})$

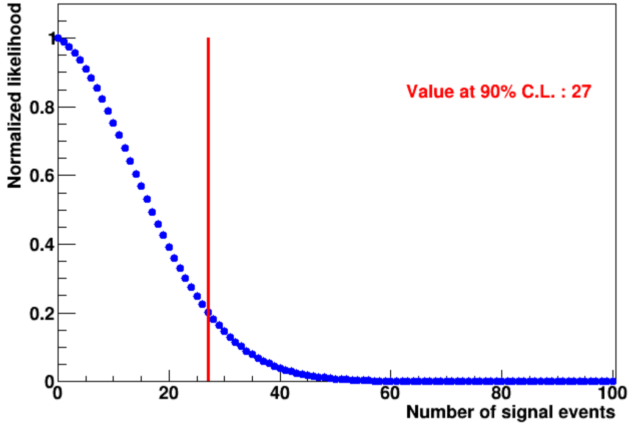
$M(2(\pi^+\pi^-)\eta)$


Decay Channel
Total Inc MC
ψ → π0hc, hc→ 2(π+π-)η
ψ → π-η b1+, b1+→ π+ω + c.c.
ψ → π0π+π-η, η→ π+π-η
ψ → γχ2 → 2(π+π-)4γ
ψ → π0π0π+π-π+π-
ψ → Other Bkgs.
x=3.525
Events/ 2.5 MeV/c2
M(2(π+π-)η) [GeV/c2]
0
5
10
15
20
25
30
3.49
3.5
3.51
3.52
3.53
3.54
3.55


data
Signal MC
Inclusive MC
Events/ 2.5 MeV/c2
M(2(π+π-)η) [GeV/c2]
0
20
40
60
80
100
120
140
160
3.49
3.5
3.51
3.52
3.53
3.54
3.55

h_c Signal fit：Upper limit of number of signal/branching fraction





□ Fitting function is described as:

$$\mathrm{P.D.F.} = \mathrm{N_{sig}} \cdot \left(\mathrm{MCShape} \otimes \mathrm{Gaussian}(\mathrm{m}, \boldsymbol{\sigma})\right) + \mathrm{N_{bkg}} \cdot \mathrm{Argus}(\mathrm{r}, \mathrm{s}, \mathrm{p})$$

□ Upper limit of number of signal

we determine the upper limit $h_c \rightarrow p\bar{p}\pi^0$ with Bayesian method.

And, N_{sig} = 27 at 90% C.L..

□ Upper limit of number of branching fraction

$$B(h_c \rightarrow 2(\pi^+\pi^-)\eta) < \frac{N^{obs}}{N_{tot} \cdot B(\psi(3686) \rightarrow \pi^0 h_c) \cdot B(\pi^0 \rightarrow \gamma\gamma) \cdot B(\eta \rightarrow \gamma\gamma) \cdot \varepsilon}$$

Mode	N^{sig}	$\varepsilon(\%)$	$B(\times 10^{-4})$
$h_c \rightarrow 2(\pi^+\pi^-)\eta$	27	5.25	~

◎ Mode IV:

$$h_c \to p\bar{p}\pi^0$$

Initial Event Selection

Charged tracks

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

Particle identification

- Prob(p)> Prob(pi), Prob(p)> Prob(K)
- n(p)=n($\bar{p}$)=1

Vertex Fit for $\bar{p}p$

A 6C kinematic fit with

$\psi(3686) \to 4\gamma\ \bar{p}p$.

- Additional 4C kinematic fit for $3\gamma\ \bar{p}p$, $4\gamma\ \bar{p}p$ and $5\gamma\ \bar{p}p$ final states.

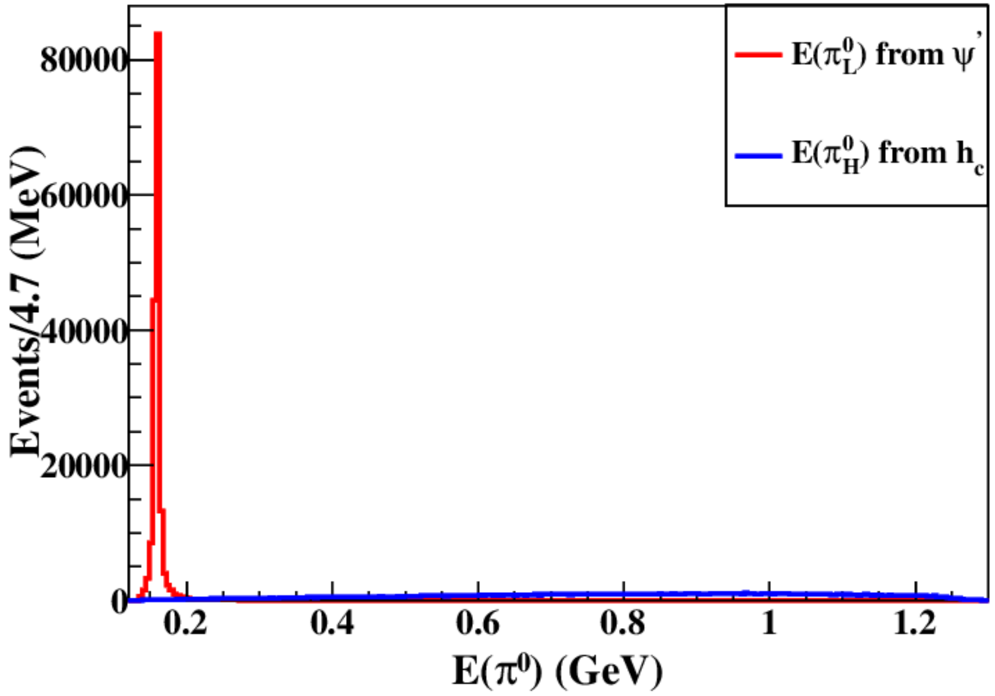
1C for π^0 :

- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

Good photon

- $0 \leq TDC \leq 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \geq 4}$

Energy distribution of two π^0



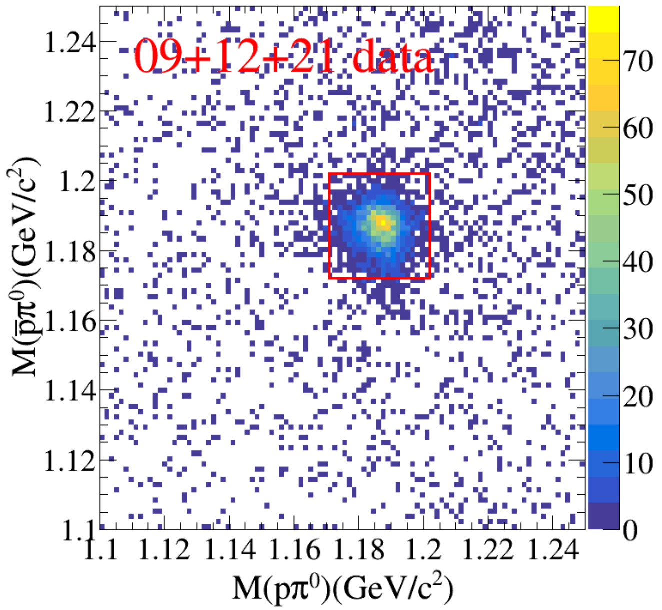
◆ $\psi\,(3686) \rightarrow \pi^0{}_L h_c$

◆ $h_c \rightarrow p\bar{p}\pi^0{}_H$

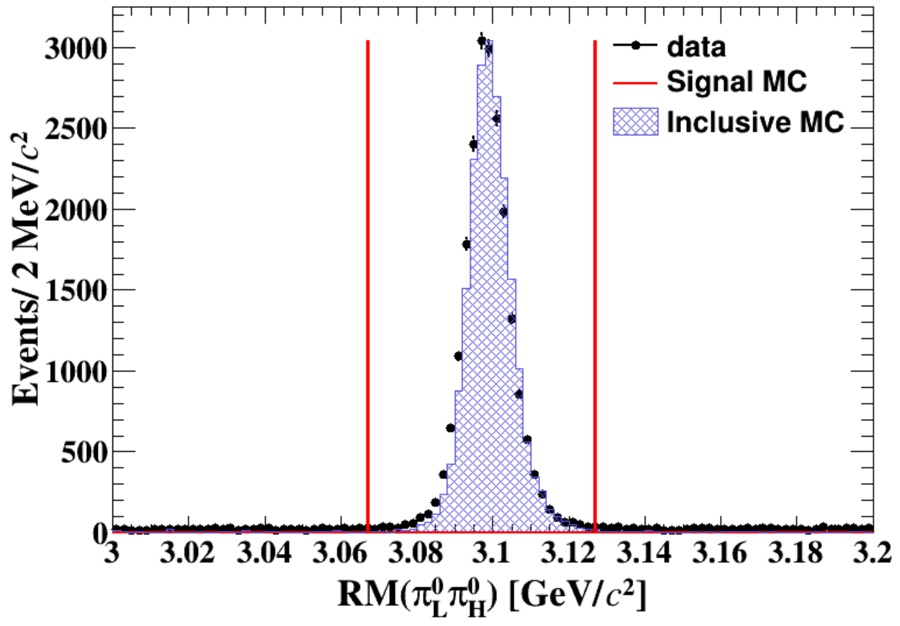
- The energy of bachelor π^0 from $\psi(3686)$ is lower than that from h_c.
- The lower one is tagged as $\pi^0{}_L$, and the higher one is tagged as $\pi^0{}_H$.

Veto $\psi(3686) \to \Sigma^+\bar{\Sigma}^-$ && Veto $\psi(3686) \to \pi^0_L\pi^0_H J/\psi$

- A) ! ($(1.172 < M_{p\pi^0} < 1.202)$&&$(1.171 < M_{\bar{p}\pi^0} < 1.202)$)



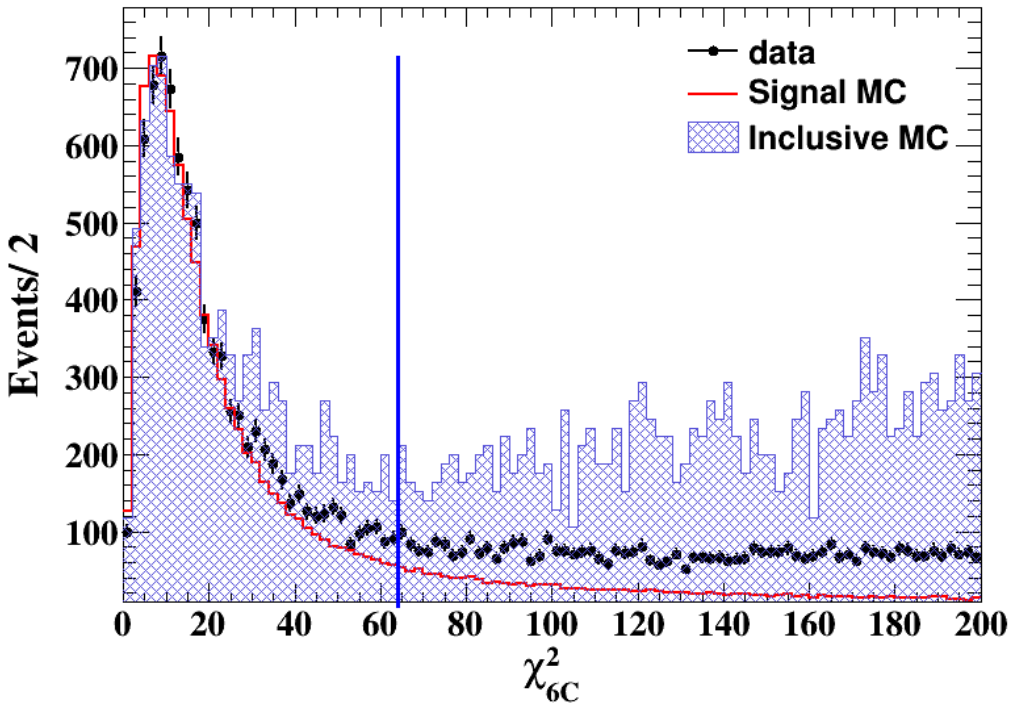
- B) | RM($\pi^0_L\pi^0_H$)- m(J/ψ)| > 30 MeV/c²

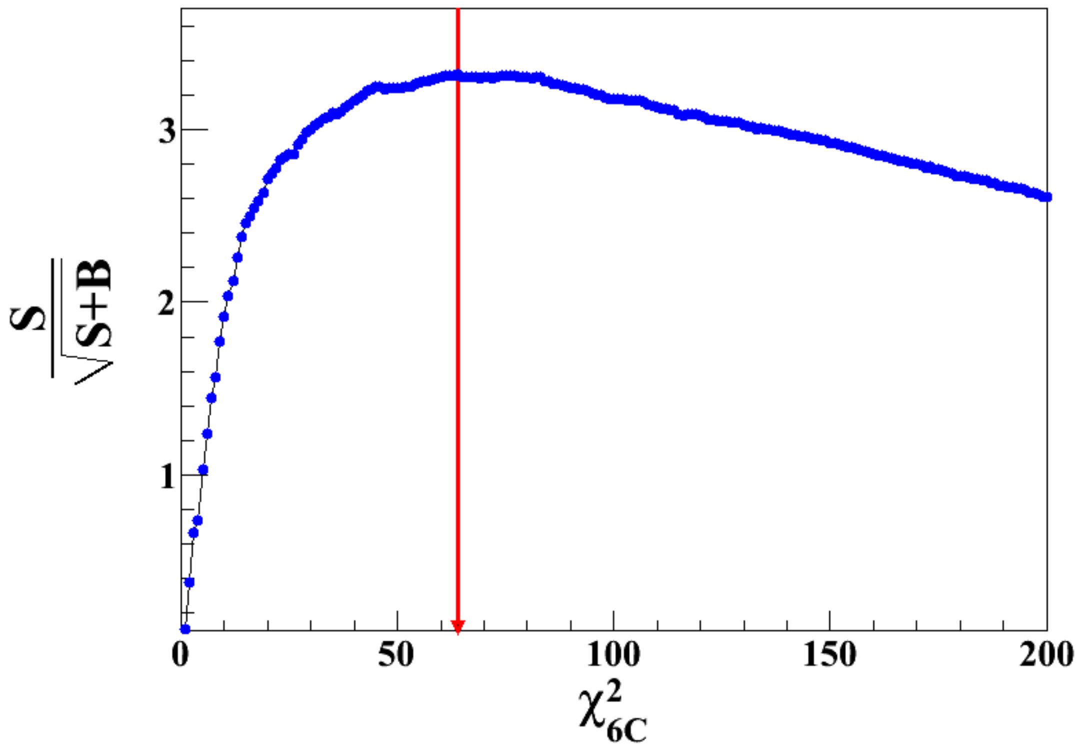


- In the two combinations of $p\pi^0/\bar{p}\pi^0$, which are $p\pi^0_L/\bar{p}\pi^0_H$ and $p\pi^0_H/\bar{p}\pi^0_L$ combinations, we select the one by minimizing

$$\Delta = \sqrt{(M_{p\pi^0} - M_{\Sigma^+})^2 + (M_{\bar{p}\pi^0} - M_{\bar{\Sigma}^-})^2}$$

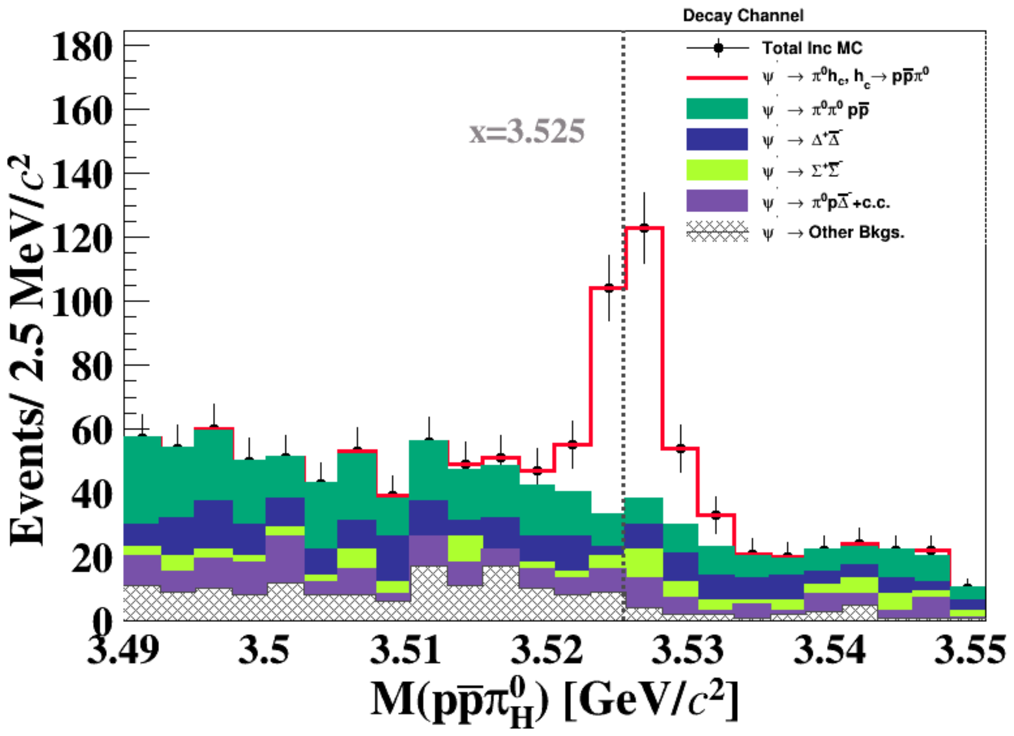
6C kinematic fit

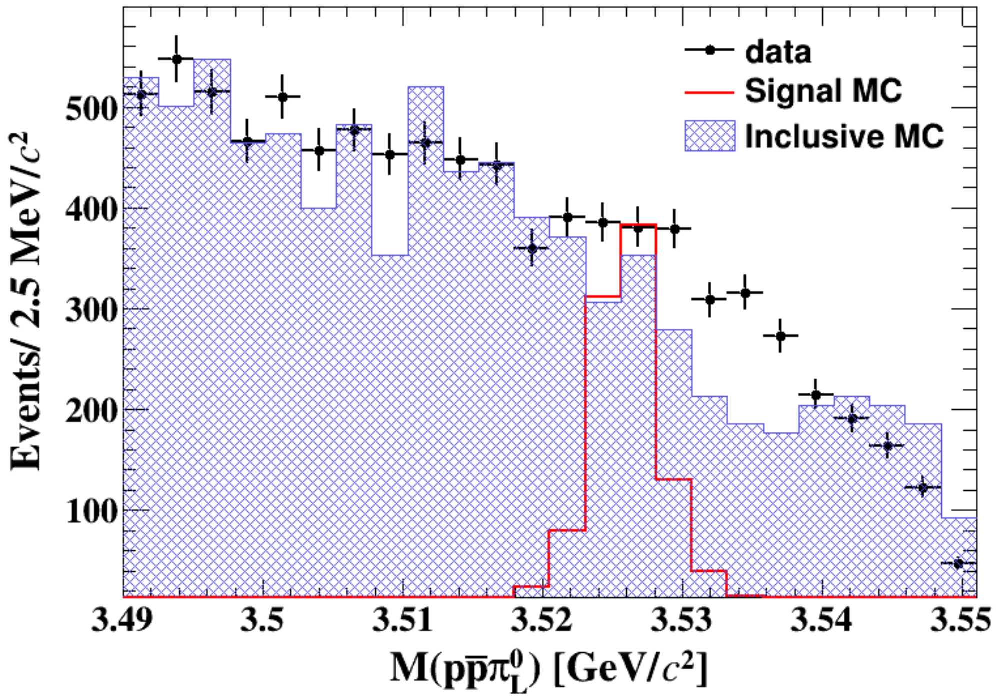




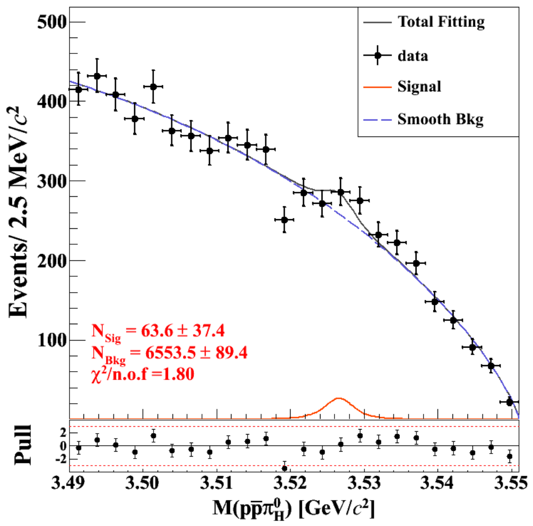
- $\chi^2_{6C} < 64$
- Additional requirement
  - $\chi^2_{4C}(4\gamma p\bar{p}) < \chi^2_{4C}(3\gamma p\bar{p})$
  - $\chi^2_{4C}(4\gamma p\bar{p}) < \chi^2_{4C}(5\gamma p\bar{p})$

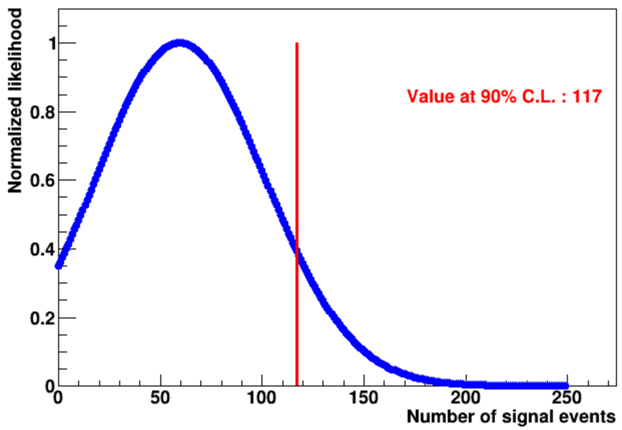
$M(p\bar{p}\pi^0)$


Decay Channel
Total Inc MC
ψ → π⁰h_c, h_c → pp̄π⁰
ψ → π⁰π⁰ pp̄
ψ → Δ⁺Δ̄⁻
ψ → Σ⁺Σ̄⁻
ψ → π⁰pΔ̄⁻+c.c.
ψ → Other Bkgs.
x=3.525
Events/ 2.5 MeV/c²
M(pp̄π⁰_H) [GeV/c²]


data
Signal MC
Inclusive MC
Events/ 2.5 MeV/c²
M(pp̄π⁰_L) [GeV/c²]

h_c Signal fit：Upper limit of number of signal/branching fraction





□ Fitting function is described as:

$$\mathbf{P.D.F.} = \mathbf{N_{sig}} \cdot \left(\mathbf{MCShape} \otimes \mathbf{Gaussian}(\mathbf{m}, \boldsymbol{\sigma})\right) + \mathbf{N_{bkg}} \cdot \mathbf{Argus}(\mathbf{r}, \mathbf{s}, \mathbf{p})$$

□ Upper limit of number of signal

we determine the upper limit $h_c \to p\bar{p}\pi^0$ with Bayesian method.

And, N_{sig} = **117 at 90% C.L.**.

□ Upper limit of number of branching fraction

$$B(h_c \to p\bar{p}\pi^0) < \frac{N^{obs}}{N_{tot} \cdot B(\psi(3686) \to \pi^0 h_c) \cdot B(\pi^0 \to \gamma\gamma) \cdot B(\pi^0 \to \gamma\gamma) \cdot \varepsilon}$$

Mode	N^{sig}	$\varepsilon(\%)$	$B(\times 10^{-4})$
$h_c \to p\bar{p}\pi^0$	117	23.00	~

◎ Mode V:

$$\mathbf{h_c \rightarrow p\bar{p}}$$

Initial Event Selection

Charged tracks

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

Particle identification

- Prob(p)> Prob(pi), Prob(p)> Prob(K)
- n(p)=n($\bar{p}$)=1

Vertex Fit for $\bar{p}p$

Good photon

- $0 \leq TDC \leq 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\boldsymbol{N_\gamma \geq 2}$

1C for π^0 :

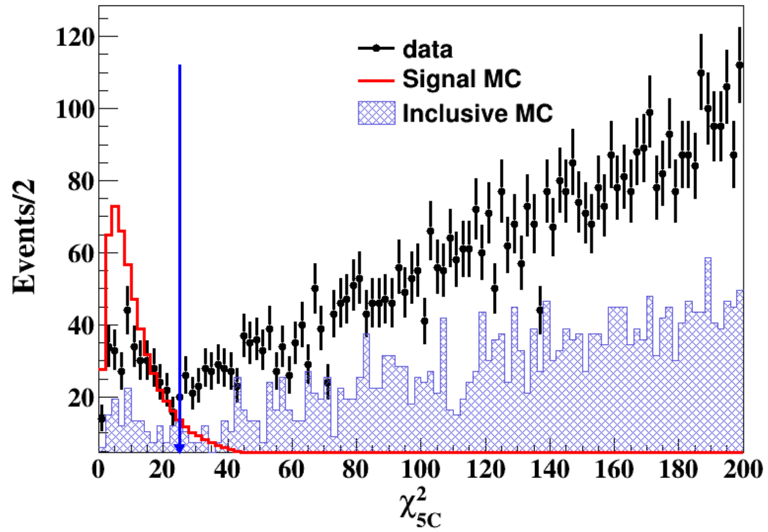
- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

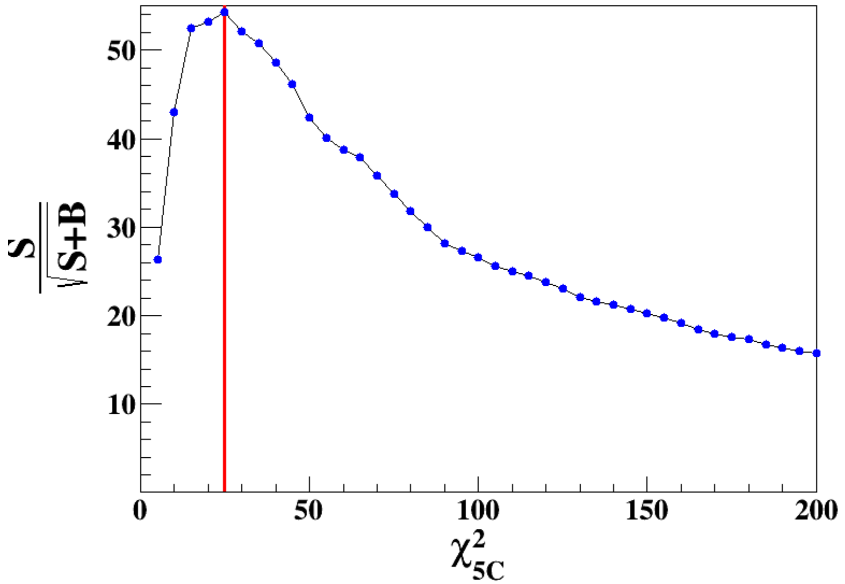
A 5C kinematic fit with

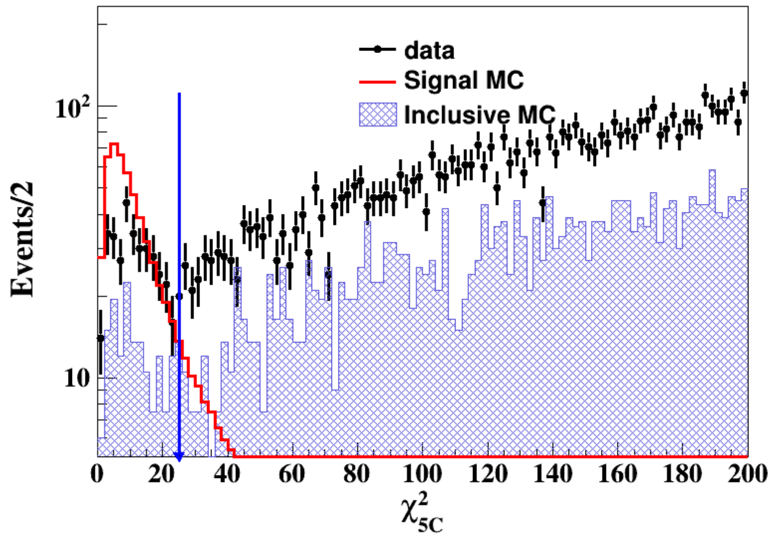
$\psi(3686) \rightarrow 2\gamma\ \bar{p}p$.

- Additional 4C kinematic fit for $1\gamma\ \bar{p}p$, $2\gamma\ \bar{p}p$ and $3\gamma\ \bar{p}p$ final states.

5C kinematic fit

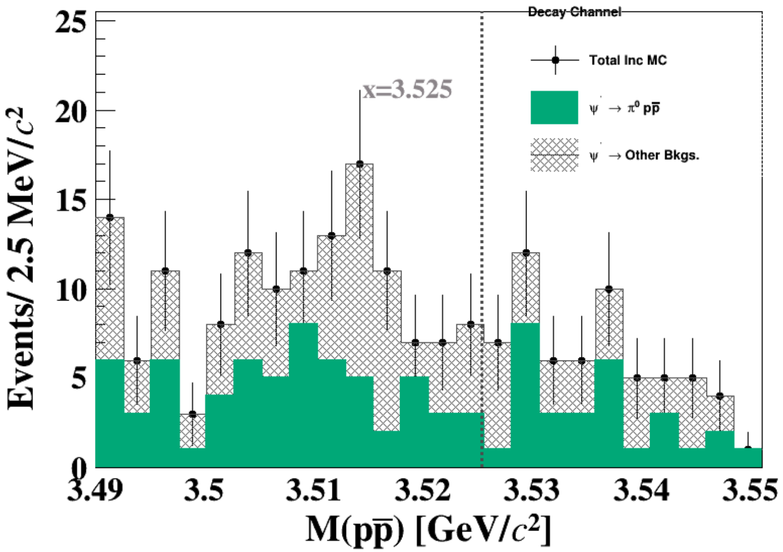






- $\chi^2_{5C} < 25$
- Additional requirement
  – $\chi^2_{4C}(2\gamma p\bar{p}) < \chi^2_{4C}(1\gamma p\bar{p})$
  – $\chi^2_{4C}(2\gamma p\bar{p}) < \chi^2_{4C}(3\gamma p\bar{p})$

M(p$\bar{p}$)



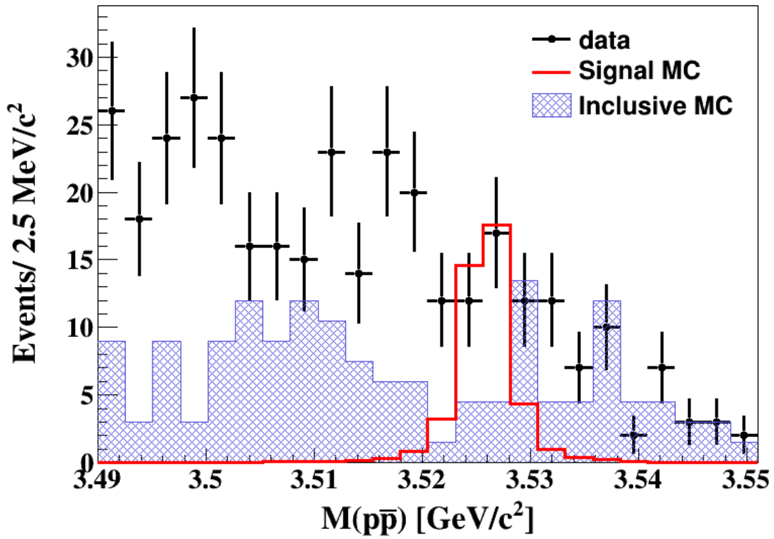
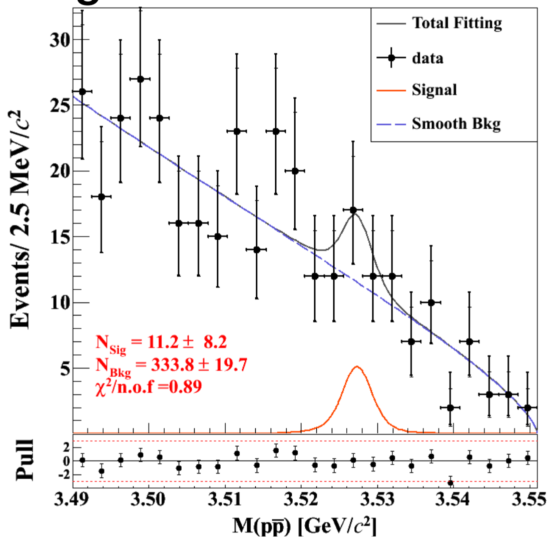


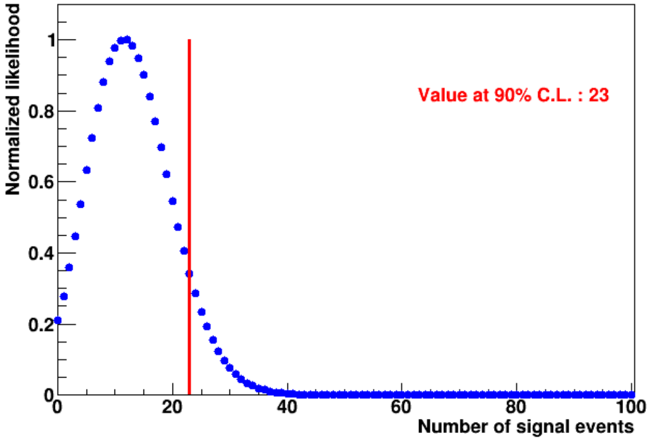
Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \pi^0 p\bar{p}$	$\pi^0 p\bar{p}$	0	112	112
2	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to e^+e^-$	$e^+e^-\pi^0\pi^0\pi^0$	4	49	161
3	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to e^+e^-\gamma^f$	$e^+e^-\pi^0\pi^0\pi^0\gamma^f$	1	15	176
4	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-$	$e^+e^-\pi^0\pi^0$	8	13	189
5	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-\pi^0\pi^0\pi^0$	9	11	200
6	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}$	$p\bar{p}\gamma$	5	8	208
7	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-\gamma^f$	$e^+e^-\pi^0\pi^0\gamma^f$	3	7	215
8	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \mu^+\mu^-\gamma^f$	$\mu^+\mu^-\pi^0\pi^0\gamma^f$	2	4	219
9	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \mu^+\mu^-\gamma^f$	$\mu^+\mu^-\pi^0\pi^0\pi^0\gamma^f$	7	4	223
10	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to p\bar{p}$	$p\bar{p}\gamma$	10	4	227
11	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-\pi^0\pi^0$	13	3	230
12	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-\gamma^f\gamma^f$	$e^+e^-\pi^0\pi^0\gamma^f\gamma^f$	20	3	233
13	$\psi' \to p\bar{p}\gamma^f$	$p\bar{p}\gamma^f$	6	2	235
14	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to e^+e^-\gamma^f\gamma^f$	$e^+e^-\pi^0\pi^0\pi^0\gamma^f\gamma^f$	11	2	237
15	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0 p\bar{p}\gamma$	14	1	238
16	$\psi' \to \bar{p}\Delta^+, \Delta^+ \to \pi^0 p$	$\pi^0 p\bar{p}$	15	1	239
17	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^+\pi^-, J/\psi \to e^+e^-\gamma^f$	$e^+e^-\pi^0\pi^+\pi^-\gamma^f$	16	1	240
18	$\psi' \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0 p\bar{p}$	17	1	241
19	$\psi' \to \Lambda\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to e^+\nu_e\bar{p}$	$e^+\nu_e\pi^- p\bar{p}$	18	1	242
20	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}\gamma^f$	$p\bar{p}\gamma\gamma^f$	19	1	243
21	$\psi' \to p\bar{p}\gamma^F$	$p\bar{p}\gamma^F$	12	1	244

h_c Signal fit：Upper limit of number of signal/branching fraction

Significance= 1.4 $*\sigma$





□ Fitting function is described as:

$$\mathrm{P.D.F.} = \mathrm{N_{sig}} \cdot \left(\mathrm{MCShape} \otimes \mathrm{Gaussian}(m, \sigma)\right) + \mathrm{N_{bkg}} \cdot \mathrm{Argus}(r, s, p)$$

□ Upper limit of number of signal

we determine the upper limit $h_c \to p\bar{p}\pi^0$ with Bayesian method.

And, N_{sig} = 23 at 90% C.L..

□ Upper limit of number of branching fraction

$$B(h_c \to p\bar{p}) < \frac{N^{obs}}{N_{tot} \cdot B(\psi(3686) \to \pi^0 h_c) \cdot B(\pi^0 \to \gamma\gamma) \cdot \varepsilon}$$

Mode	N^{sig}	$\varepsilon(\%)$	$B(\times 10^{-5})$
$h_c \to p\bar{p}$	23	17.38	~

Summary & Next to do

Mode	N_{h_c}	$\varepsilon(\%)$	$Br(h_c \to X)$(this work)	Significance(σ)	$Br(h_c \to X)$ [1,2](pre.result)
$h_c \to 3(\pi^+\pi^-)\pi^0$	386.5±60.3	3.92	$\sim\mathbf{10^{-3}}$	**6.6**	$<\mathbf{9\times 10^{-3}}$
$h_c \to 2(\pi^+\pi^-)\pi^0\eta$	94.2±21.6	2.06	$\sim\mathbf{10^{-3}}$	**4.8**	- -
$h_c \to 2(\pi^+\pi^-)\eta$	<27	5.25	$\sim\mathbf{10^{-4}}$	- -	- -
$h_c \to p\bar{p}\pi^0$	<117	23.00	$\sim\mathbf{10^{-4}}$	- -	<6.59$\times\mathbf{10^{-4}}$
$h_c \to p\bar{p}$	<23	17.38	$\sim\mathbf{10^{-5}}$	- -	<1.5$\times\mathbf{10^{-4}}$

- Using 448M + 2280M ψ(3686) data sample collected at BESIII in 2009, 2012 and 2021
- ✓ **Evidence** the signals of $\boldsymbol{h_c \to 3(\pi^+\pi^-)\pi^0}$ is observed for the **first time ;** and observed strong evidence of $\boldsymbol{h_c \to 2(\pi^+\pi^-)\pi^0\eta}$ **.**
- ✓ No obvious signal for $h_c \to 2(\pi^+\pi^-)\eta, h_c \to p\bar{p}\pi^0$, $h_c \to p\bar{p}$ is observed and the corresponding upper limits of the branching fractions is given at 90% C.L. .

- Next to do
- ☐ Optimize the selection criteria
- ☐ To study the intermediate state process of each mode
- ☐ Systematics
- ☐ Search for more $\mathbf{h_c}$ hadronic decay patterns

[1]*P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01.*
[2]*BAM-00512: Search for hc to pp-bar+X hadronic decays, by Lin Zhu et al.*

Part II:

Search for $\psi(3686) \to \Sigma^{+}\bar{\Sigma}^{-}\omega$

Outline

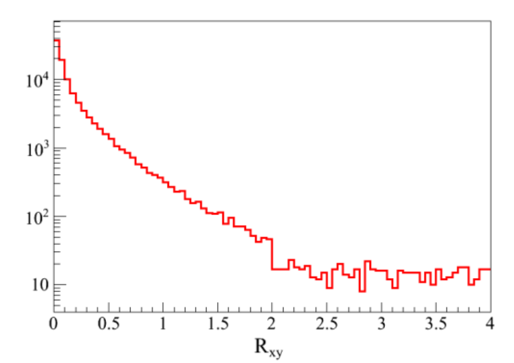
- Motivation
- Data Sample and MC Simulation
- Initial Event Selection
- Further Event Selection
- Scatter & Dalitz plot
- Fit result
- Summary

Motivation

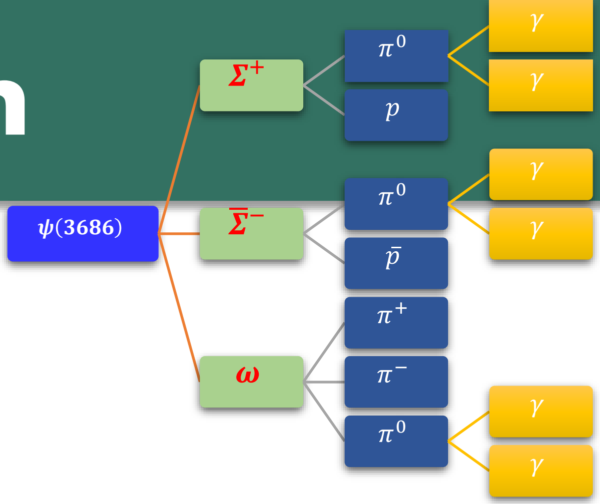
- Many studies of flavor SU(2) and SU(3) allowed and forbidden baryonic decay in J/ψ and $\psi(3686)$ have been done. For example, $J/\psi \to \Xi^{+}\bar{\Xi}^{-} + c.c.$, $\Sigma^{*+}\bar{\Sigma}^{*-} + c.c.$, are SU(2) and SU(3) allowed decay modes, whereas $J/\psi \to \Sigma^{0}\bar{\Lambda}$, $\Xi^{*0}\bar{\Xi}^{*0}$ SU(2) and SU(3) forbidden decay modes. **Among these decay channels, the branching ratios of allowed decay modes are much higher than those of forbidden modes**.
- However, the isospin-conserved decay of $\psi(3686) \to \Lambda\bar{\Lambda}\omega$ has been observed (BAM-00366) with a preliminary branching fraction of $(3.42 \pm 0.34 \pm 0.31) \times 10^{-5}$, **but no any report about the decay mode $\boldsymbol{\psi(3686) \to \Sigma^{+}\bar{\Sigma}^{-}\omega}$**. We can try to search for this decay and search for the potential Σ^{*} state or threshold enhancement in baryon pair mass spectrum.

Dataset

- BOSS version: 664p03
- Data sample: 448M ψ(3686) taken in 2009 and 2012
- Inclusive MC: 506M ψ(3686) Inclusive MC of which for 106M for 2009 and 400M for 2012
- Signal MC: 2009 : 2012=1 : 4 total 0.5 M for $\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega, \Sigma^+ \to p\pi^0, \bar{\Sigma}^- \to \bar{p}\pi^0, \omega \to \pi^+\pi^-\pi^0$



Initial Event Selection



Charged tracks

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

Particle identification

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

A 7C kinematic fit with

$\psi(3686) \to p\bar{p}\pi^+\pi^-\gamma\gamma\gamma\gamma\gamma\gamma.$

- Additional 4C kinematic fit for $5\gamma\bar{p}p\pi^+\pi^-$, $6\gamma\ \bar{p}p\pi^+\pi^-$ and $7\gamma\bar{p}p\pi^+\pi^-$ final states.

Good photon

- $0 \leq TDC \leq 14$
- Barrel : $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $N_\gamma \geq 6$

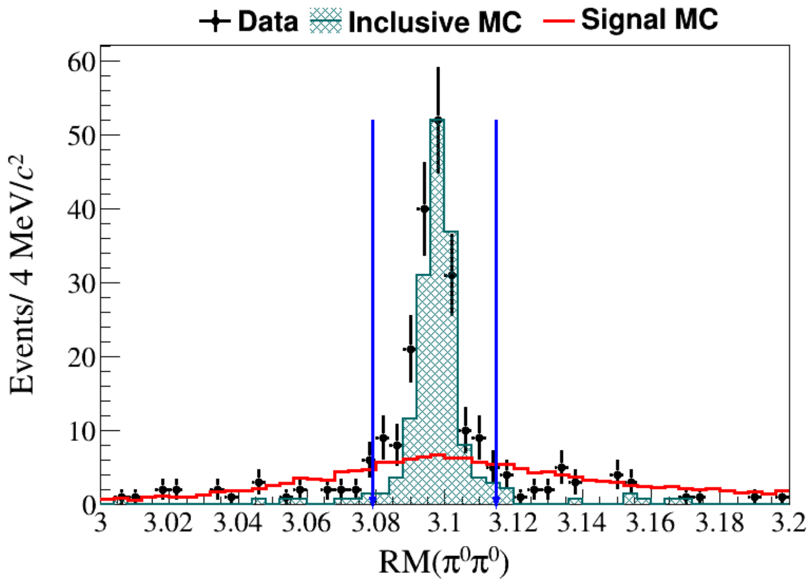
1C for π^0:

- A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

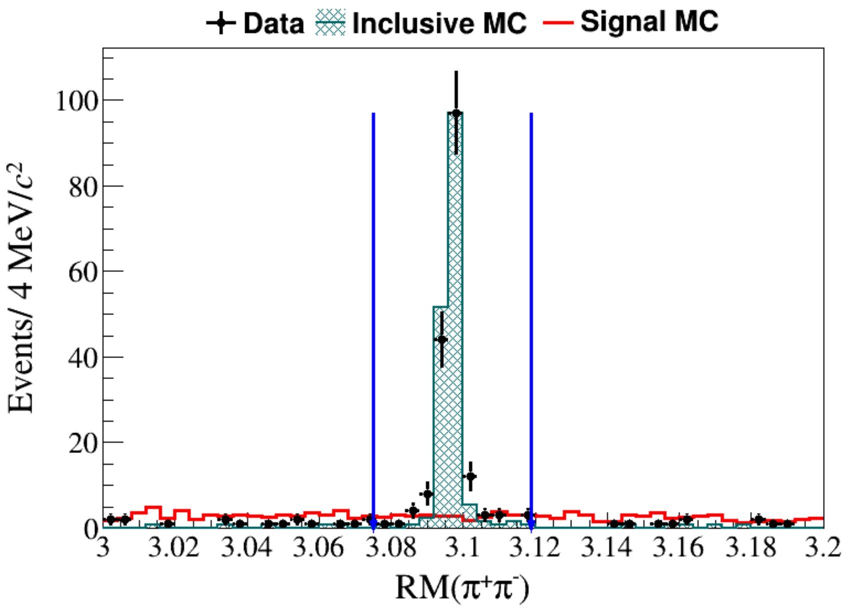
- $\Delta_{min} = \sqrt{(M_{\pi^+\pi^-\pi^0} - m_\omega)^2 + \left(M_{p\pi^0} - m_{\Sigma^+}\right)^2 + \left(M_{\bar{p}\pi^0} - m_{\bar{\Sigma}^-}\right)^2} \Rightarrow \Sigma^+_{\min}, \bar{\Sigma}^-_{\min}, \omega_{\min}$

Further Event Selection II: Veto on $\psi(3686) \to \pi\pi J/\psi$

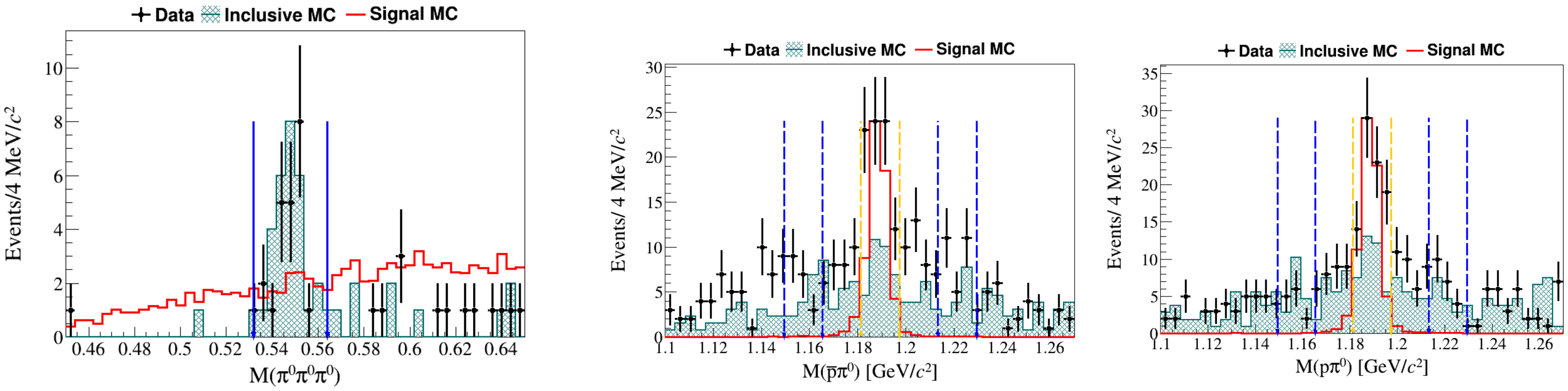
- $|RM(\pi^0\pi^0) - m(J/\psi)| > 20\ MeV/c^2$



- $|RM(\pi^+\pi^-) - m(J/\psi)| > 20 MeV/c^2$

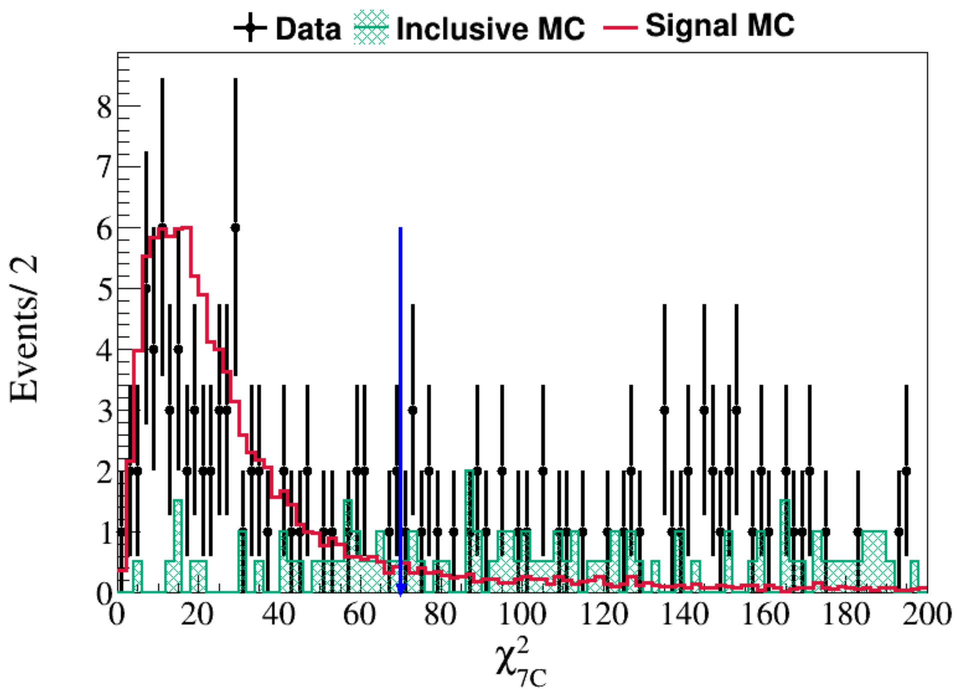


Further Event Selection III: Veto on $\eta \to \pi^0\pi^0\pi^0$ && $M(p\pi^0_\Sigma)$



- $|M(\pi^+\pi^-\pi^0) - m(\eta)| > 16\mathrm{MeV}/c^2$
- $|M(p\pi^0_\Sigma) - m(\Sigma^+)| < 8MeV/c^2$

Further Event Selection IV: 7C kinematic fit



- $\chi^2_{7C} < 60$
- Additional requirement
  - $\chi^2_{4C}(6\gamma pp\pi^+\pi^-) < \chi^2_{4C}(5\gamma pp\pi^+\pi^-)$
  - $\chi^2_{4C}(6\gamma pp\pi^+\pi^-) < \chi^2_{4C}(7\gamma pp\pi^+\pi^-)$

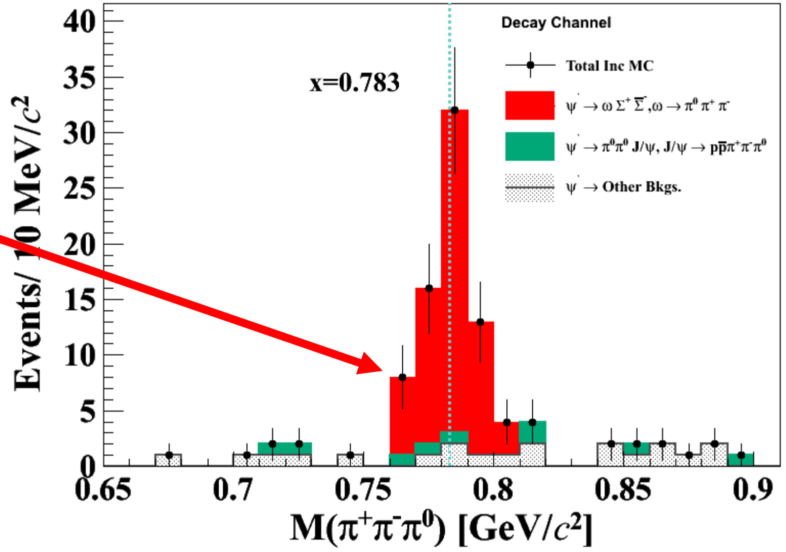
Background Study && $M(\pi^+\pi^-\pi^0)$

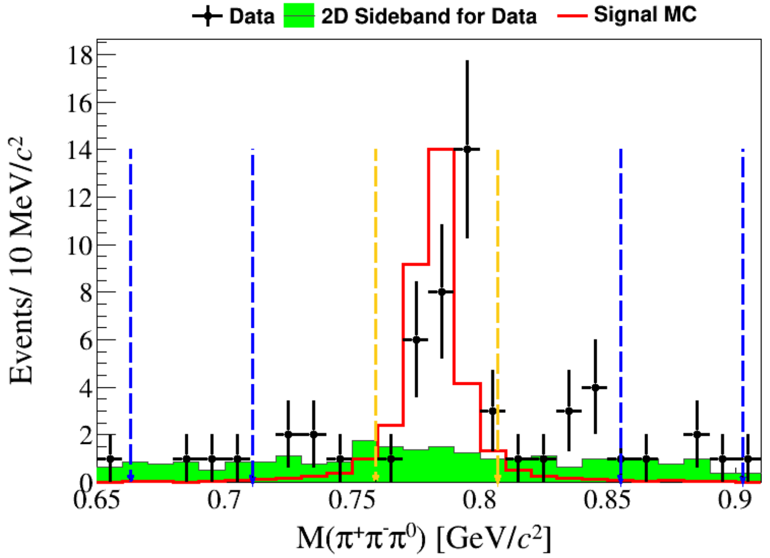
After all the selections, the rest of inclusive MC sample is listed:

Table 1: Decay trees and their respective final states.

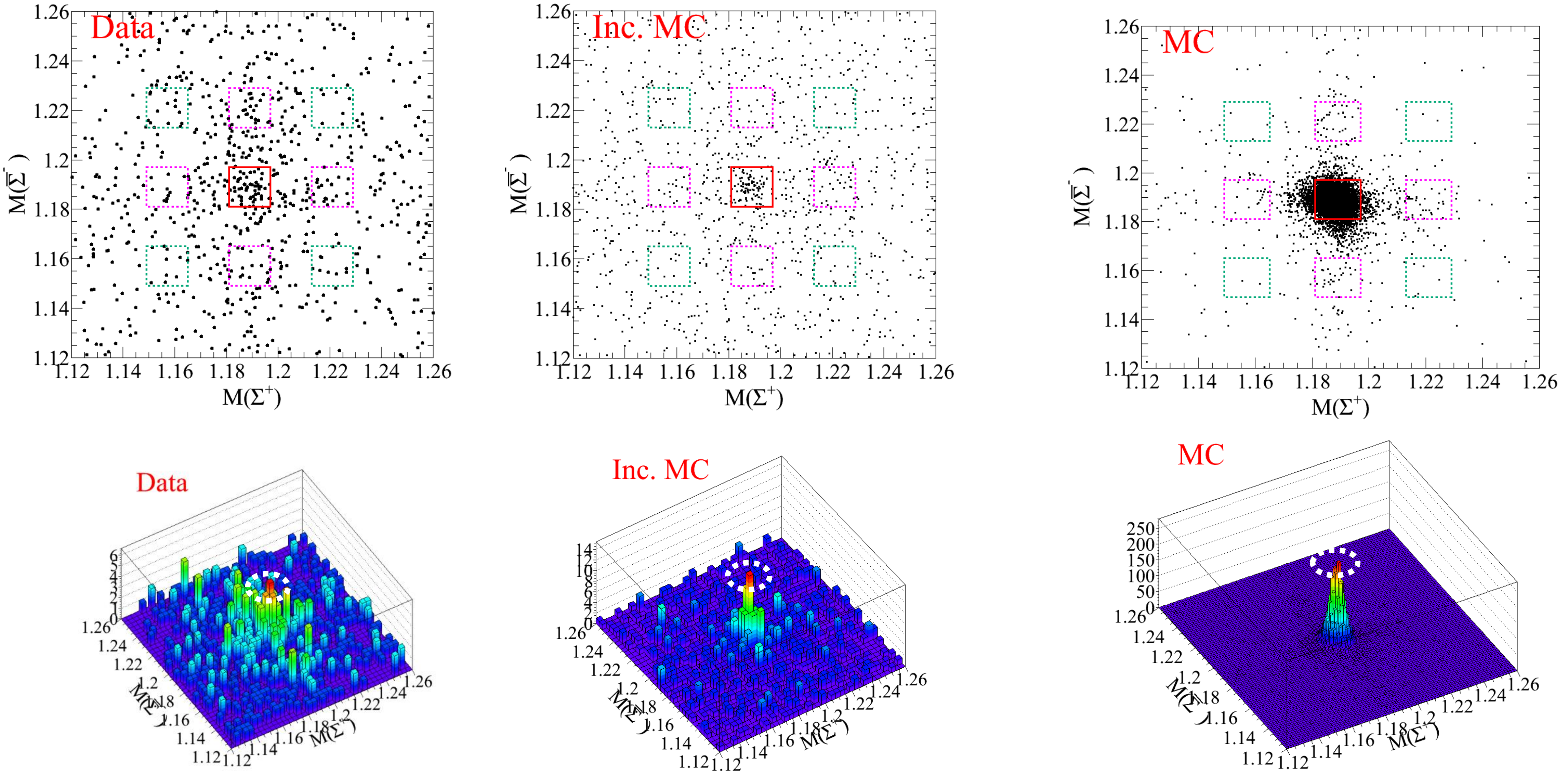
rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \omega\Sigma^+\bar{\Sigma}^-, \omega \to \pi^0\pi^+\pi^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	0	65	65
2	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^0\pi^+\pi^- p\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	1	5	70
3	$\psi' \to K^{*-}\Delta^{++}\bar{\Sigma}^-, K^{*-} \to \pi^-\bar{K}^0, \Delta^{++} \to \pi^+ p, \bar{\Sigma}^- \to \pi^0\bar{p}, \bar{K}^0 \to K^0_S,$ $K^0_S \to \pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	10	2	72
4	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \pi^+\pi^-\Delta^+\bar{\Delta}^+, \Delta^+ \to \pi^0 p, \bar{\Delta}^+ \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma$	3	1	73
5	$\psi' \to \omega\Sigma^+\bar{\Sigma}^-, \omega \to \pi^0\pi^+\pi^-\gamma^f, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma^f$	4	1	74
6	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^-\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	5	1	75
7	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \bar{\Sigma}^-\Sigma^{*+}, \bar{\Sigma}^- \to \pi^0\bar{p}, \Sigma^{*+} \to \pi^+\Lambda, \Lambda \to \pi^- p$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	6	1	76
8	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+\Delta^0\bar{p}\gamma^F, \Delta^0 \to \pi^- p$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma^F$	7	1	77
9	$\psi' \to K^{*+}\bar{\Delta}^+\Sigma^0, K^{*+} \to \pi^+ K^0, \bar{\Delta}^+ \to \pi^0\bar{p}, \Sigma^0 \to \Lambda\gamma, K^0 \to K^0_S,$ $\Lambda \to \pi^- p, K^0_S \to \pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma$	8	1	78
10	$\psi' \to \pi^0 h_c, h_c \to \rho^0\Sigma^+\bar{\Sigma}^-, \rho^0 \to \pi^+\pi^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	9	1	79
11	$\psi' \to \pi^-\rho^+\Sigma^+\bar{\Sigma}^-, \rho^+ \to \pi^0\pi^+, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	2	1	80
12	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to p\bar{p}b_1^0, b_1^0 \to \pi^0\omega, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma$	11	1	81
13	$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \bar{\Sigma}^-\Sigma^{*+}, \bar{\Sigma}^- \to \pi^0\bar{p}, \Sigma^{*+} \to \pi^0\Sigma^+, \Sigma^+ \to \pi^0 p$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	12	1	82
14	$\psi' \to \pi^0 h_c, h_c \to p\bar{p}b_1^0, b_1^0 \to \pi^0\omega, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	13	1	83
15	$\psi' \to \pi^0\Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	14	1	84
16	$\psi' \to p\bar{\Delta}^+ b_1^0, \bar{\Delta}^+ \to \pi^0\bar{p}, b_1^0 \to \pi^0\omega, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	15	1	85
17	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \rho^-\bar{\Sigma}^0\Sigma^+, \rho^- \to \pi^0\pi^-, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Sigma^+ \to \pi^0 p,$ $\bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma\gamma$	16	1	86
18	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to p\bar{p}b_1^0, b_1^0 \to \pi^0\omega, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma$	17	1	87
19	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \pi^0\Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^-\bar{p}$	$\pi^0\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	18	1	88
20	$\psi' \to \rho^-\bar{\Sigma}^{*0}\Sigma^+, \rho^- \to \pi^0\pi^-, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \Sigma^+ \to \pi^0 p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	19	1	89
21	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \omega p\bar{p}, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	20	1	90
22	$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \pi^0\Sigma^+\bar{\Sigma}^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	21	1	91
23	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \rho^+\Sigma^0\bar{\Sigma}^-, \rho^+ \to \pi^0\pi^+, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^- \to \pi^0\bar{p},$ $\Lambda \to \pi^- p$	$\pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma\gamma$	22	1	92
24	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \pi^+\pi^- p\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	23	1	93
25	$\psi' \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \Delta^{++}\bar{\Delta}^{++}, \Delta^{++} \to \pi^+ p, \bar{\Delta}^{++} \to \pi^-\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^- p\bar{p}$	24	1	94

Signal Channel

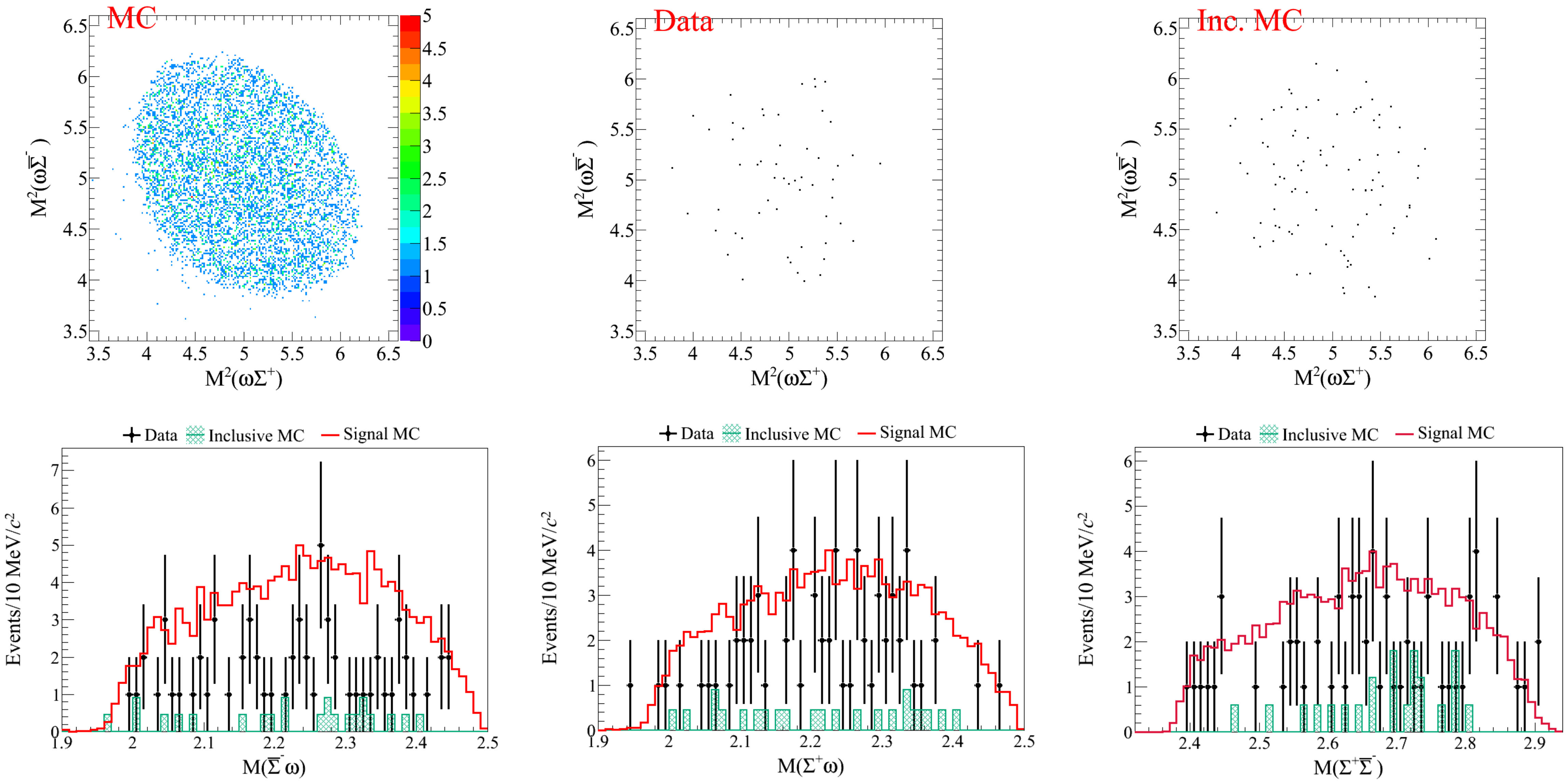




Scatter Plot of $M(\bar{\Sigma}^-)$ v.s. $M(\Sigma^+)$

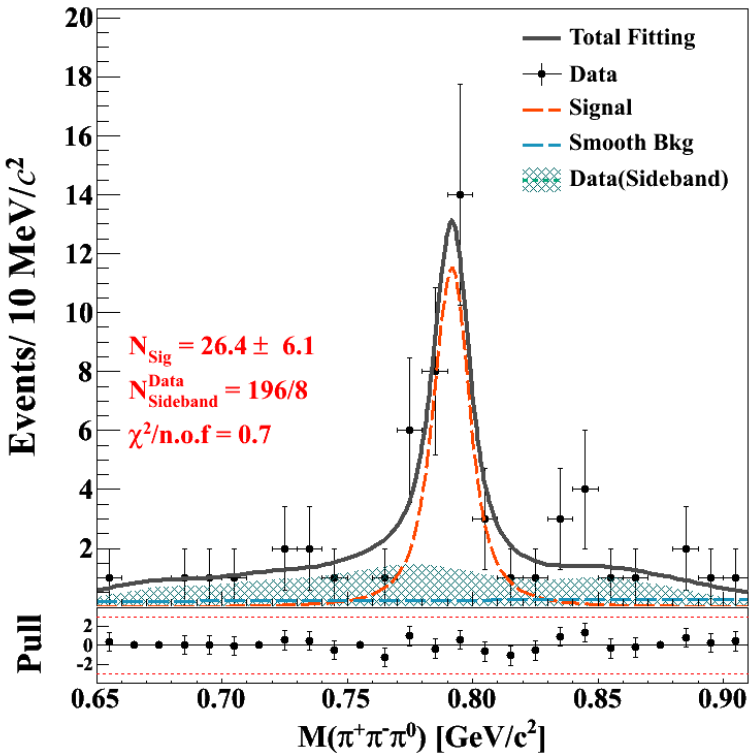


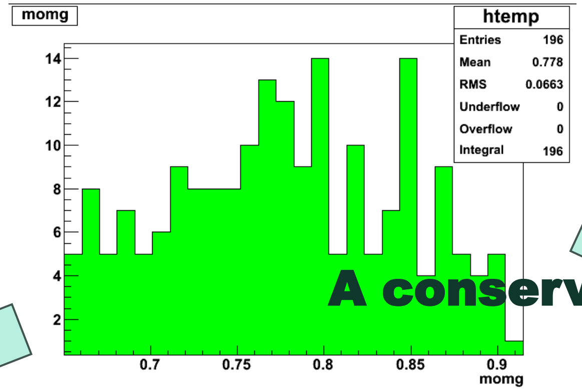
Dalitz Plot of $M(\omega\bar{\Sigma}^-)^2$ v.s. $M(\omega\Sigma^+)^2$

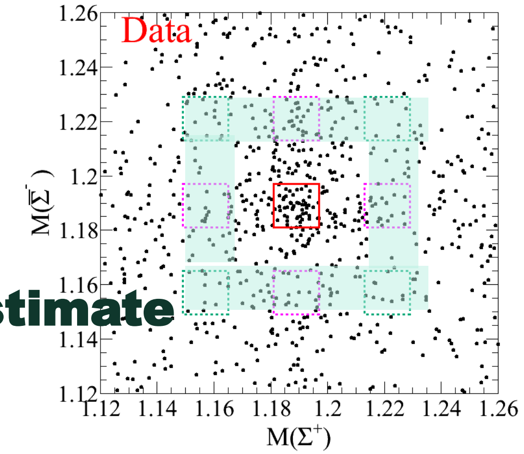


Fit to data & preliminary result

- **Significance: 6.5 *σ**







A conservative estimate

- **Fitting function is described as:**

$$N_{sig} \cdot \left(MCshape \otimes Gaussian(m, \sigma)\right) + N_{bkg} \cdot Chebychev + N_{SD}^{Bkg} \cdot SDshape$$

- $B\ (\Sigma \to p\pi^0)$=51.57%
- $B(\omega \to \pi^+\pi^-\pi^0)$=89.3%
- $B\ (\pi^0 \to \gamma\gamma)$=98.82%

$$B(\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega) = \frac{N^{obs}}{N_{\psi(3686)} \cdot B^2(\Sigma \to p\pi^0) \cdot B(\omega \to \pi^+\pi^-\pi^0) \cdot B^3(\pi^0 \to \gamma\gamma)}$$

Mode	N^{obs}	$\varepsilon(\%)$	$B(\times 10^{-5})$
$h_c \to p\bar{p}\pi^0$	26.4±6.1	1.41	1.82±0.42

Summary & Next to do

Using 448M ψ(3686) data sample collected at BESIII in 2009 and 2012

- The signals of $\boldsymbol{\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega}$ is observed for the **first time ;** and the preliminary BR is found to be comparable with $\boldsymbol{\psi(3686) \to \Lambda\bar{\Lambda}\omega}$:

$Br(\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega)$	$Br(\psi(3686) \to \Lambda\bar{\Lambda}\omega)^1$
$(1.82\pm0.42)\times \mathbf{10^{-5}}$	$\left(3.42 \pm 0.34(stat) \pm 0.31(syst.)\right) \times \mathbf{10^{-5}}$

- No obvious structure found in the $\omega\Sigma$ system.
- No abnormal structure found in the $\Sigma^+\bar{\Sigma}^-$ system.

Next to do

- Systematic uncertainty.
- **Run** the latest[2] ~2.5 billion ψ(3686) data.

[1] BAM-00336, Honghong Zhang et al., Study of Psi' to omega Labamda Lambdabar
[2] with BOSS 7.0.6: run66258-run69292, /besfs4/offline/data/706-1/psip/round14/opendst

Thank You! ☺

Optimization with FOM approach

- A figure-of-merit (FOM) approach is performed to optimize the selection criteria.

$$\mathbf{FOM} = \frac{\mathbf{S}}{\sqrt{\mathbf{S}+\mathbf{B}}}$$

S : expected yield of signal in data, estimated from the equation

$$\mathbf{S} = \mathbf{N}_{\boldsymbol{\psi}(3686)}^{\mathbf{09+12data}} \cdot \prod_{i} \mathscr{B}_i \cdot \boldsymbol{\varepsilon}^{\mathbf{MC}}$$

(has been re-normalized with our **pre-measured branching fraction**.)

B : normalized background events from the inclusive MC sample to data according to the ratio of the $\psi(3686)$ events. (has been normalized to the data size.)

Further Event Selection I: Optimization with FOM approach

◆ A figure-of-merit (FOM) approach is performed to optimize the selection criteria.

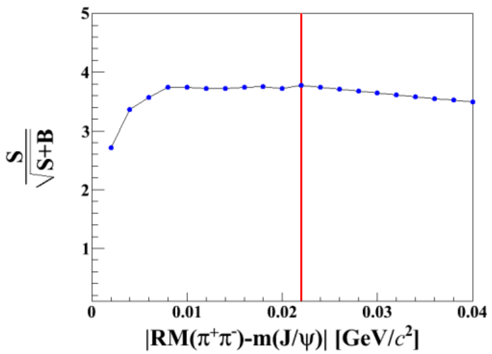
$$\mathbf{FOM} = \frac{\mathbf{S}}{\sqrt{\mathbf{S}+\mathbf{B}}}$$

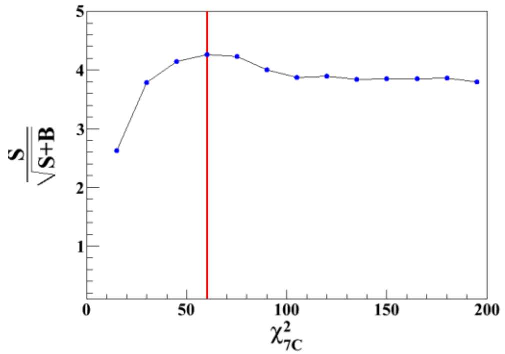
S : expected yield of signal in data, estimated from the equation

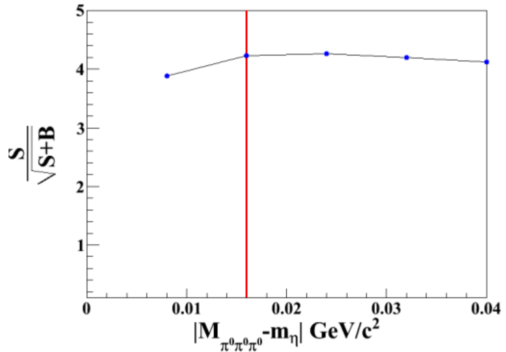
$$\mathbf{S} = \mathbf{N}_{\boldsymbol{\psi}(3686)}^{\mathbf{09+12data}} \cdot \prod_i \mathscr{B}_i \cdot \boldsymbol{\varepsilon}^{\mathbf{MC}}$$

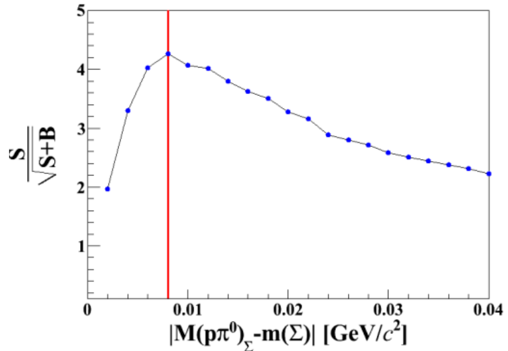
(has been re-normalized with our **pre-measured branching fraction**.)

B : normalized background events from the inclusive MC sample to data according to the ratio of the $\psi(3686)$ events. (has been normalized to the data size.)

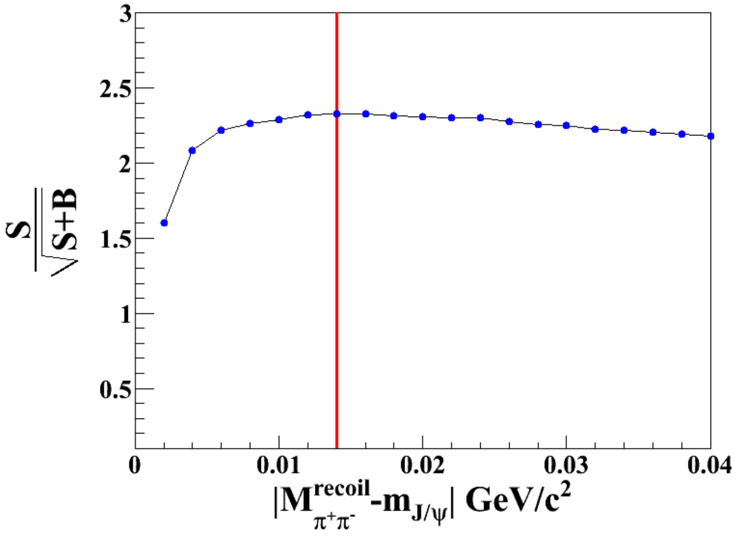




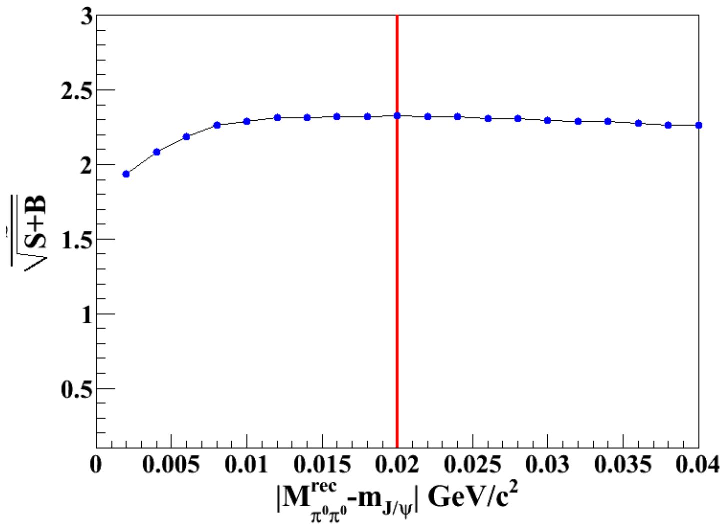




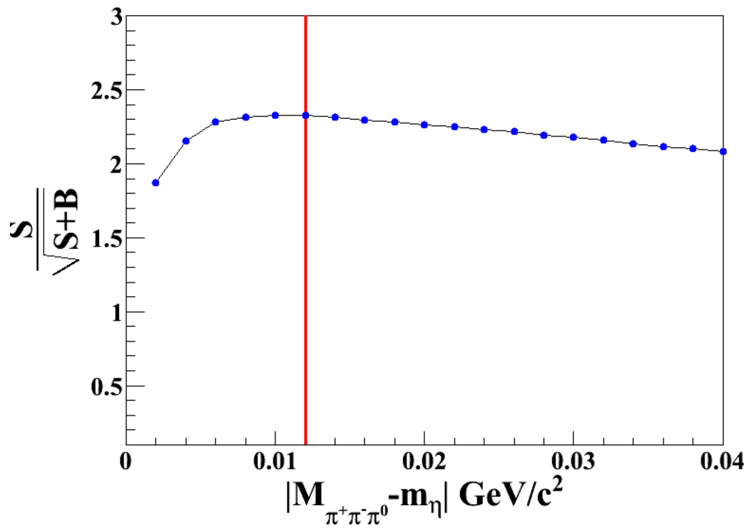
Mode I



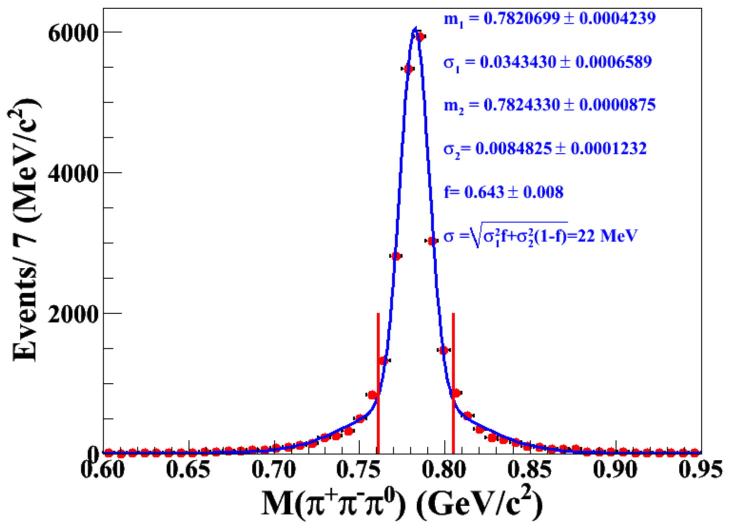
3
2.5
2
1.5
1
0.5
0
0.01
0.02
0.03
0.04
$\frac{S}{\sqrt{S+B}}$
$|M^{recoil}_{\pi^+\pi^-}-m_{J/\psi}|$ GeV/c^2



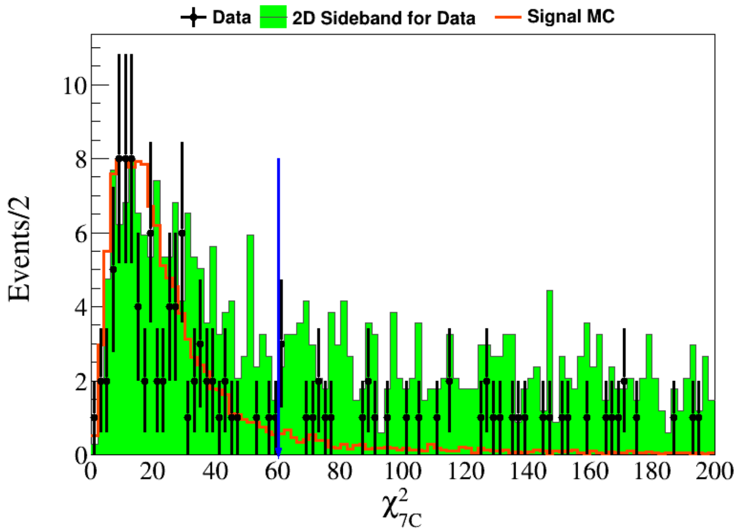
3
2.5
2
1.5
1
0.5
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
$\sqrt{S+B}$
$|M^{rec}_{\pi^0\pi^0}-m_{J/\psi}|$ GeV/c^2



3
2.5
2
1.5
1
0.5
0
0.01
0.02
0.03
0.04
$\frac{S}{\sqrt{S+B}}$
$|M_{\pi^+\pi^-\pi^0}-m_{\eta}|$ GeV/c^2



m1 = 0.7820699 ± 0.0004239
σ1 = 0.0343430 ± 0.0006589
m2 = 0.7824330 ± 0.0000875
σ2= 0.0084825 ± 0.0001232
f= 0.643 ± 0.008
σ = √(σ1²f+σ2²(1-f))=22 MeV
Events/ 7 (MeV/c²)
M(π⁺π⁻π⁰) (GeV/c²)



Data
2D Sideband for Data
Signal MC
Events/2
χ²7C