Study of $\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega$

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Outline

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- Data Set and MC Samples
- Event Selection
- Background Study
- Branching Fraction Measurement
- Intermediate State
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Motivation

1. Search for potential excited baryons

Evidence of a resonance Λ^* has been found in ψ(3686)→ $\Lambda\bar{\Lambda}\omega$ [1]with a significance of 3.0σ.

Searching for potential excited baryons in similar process ψ(3686)→ $\Sigma^0\bar{\Sigma}^0\omega$ is of interest.

2. Search for possible $B\bar{B}$ threshold enhancements

An enhancement near the $\Lambda\bar{\Lambda}$ mass threshold has been observed referring to ψ(3686) → $\Lambda\bar{\Lambda}\phi$[2].

We attempt to find threshold enhancement in $\Sigma^0\bar{\Sigma}^0$. ψ(3686)→ $\Sigma^0\bar{\Sigma}^0\omega$ may be a feasible channel to search for it.

3. Measure the branching fraction

The decay ψ(3686)→ $\Sigma^0\bar{\Sigma}^0\omega$ has not been observed at BESIII yet, and we plan to measure this branching fraction.

[1] M. Ablikim *et al*. [BESIII Collaboration], Phys.Rev.D , **106**, 112011 (2022).
[2] M. Ablikim *et al*. [BESIII Collaboration], Phys. Rev. D, **104**, 052006 (2021).

Data Set and MC Samples

Data Set	Number ($\times 10^6$)	Total ($\times 10^6$)
2009 $\psi(3686)$ data	107.7 ± 0.6	2712.4 ± 14.3 [3]
2012 $\psi(3686)$ data	345.4 ± 2.6	
2021 $\psi(3686)$ data	2259.3 ± 11.1	

MC Samples	Number ($\times 10^6$)	Total ($\times 10^6$)
Inclusive MC (2009+2012+2021)	About 2.81	About 2.81
Signal MC PHSP + OMEGA_DALITZ **($\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega$, $\Sigma^0 \to \gamma\Lambda$, $\bar{\Sigma}^0 \to \gamma\bar{\Lambda}$, $\omega \to \pi^0\pi^+\pi^-$)**	0.1 (2009)	3.0
	0.4 (2012)	
	2.5 (2021)	
Background MC JPIPI+PHSP **($\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \pi^0\Sigma^0\bar{\Sigma}^0$, $\Sigma^0 \to \gamma\Lambda$, $\bar{\Sigma}^0 \to \gamma\bar{\Lambda}$, $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$)**	5.0	5.0

BOSS Version: 7.0.9

[3] Cheng Liu *et al*, Determination of the number of ψ(3686) events taken in 2021. arXiv:2403.06766v2 [hep-ex] 12 Mar 2024.

Event Selection

$$\psi(3686) \longrightarrow \Sigma^0\bar{\Sigma}^0\omega \longrightarrow \gamma\Lambda\,\gamma\bar{\Lambda}\,\omega \longrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p}\,\gamma\gamma$$

1. Charged Tracks

- $|cos\theta| \leq 0.93$
- $N_p \geq 3$ && $N_n \geq 3$

2. Good Photons

- $0 \leq TDC \leq 14$
- Endcap: $E \geq 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- Barrel: $E \geq 0.025$ GeV, $|cos\theta| < 0.8$
- $\theta_{c\gamma} \geq 10°$
- $4 \leq N_\gamma(\text{good}) \leq 15$

3. Rec. Λ and $\bar{\Lambda}$

- PID to select p and $\bar{p}$
  $Prob\ (p) > Prob\ (\pi^+)$ && $Prob\ (p) > Prob\ (K^+)$
  $Prob\ (\bar{p}) > Prob\ (\pi^-)$ && $Prob\ (\bar{p}) > Prob\ (K^-)$
- p with Trk^- and $\bar{p}$ with Trk^+.
  vertex fit and secondary vertex fit.
- For more than one combination, choose
  $$\Delta_{min} = \left(M_{p\pi^-} - m(\Lambda)\right)^2 + \left(M_{\bar{p}\pi^+} - m(\bar{\Lambda})\right)^2$$

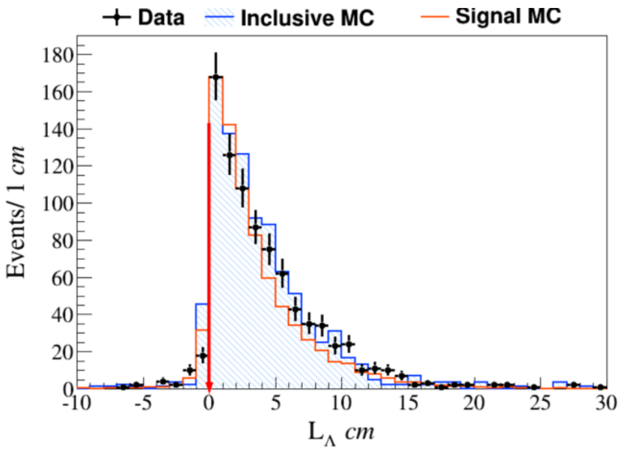
4. $\pi^+\pi^-$ from ω

- Vertex fit on the rest unused positive and negative tracks .

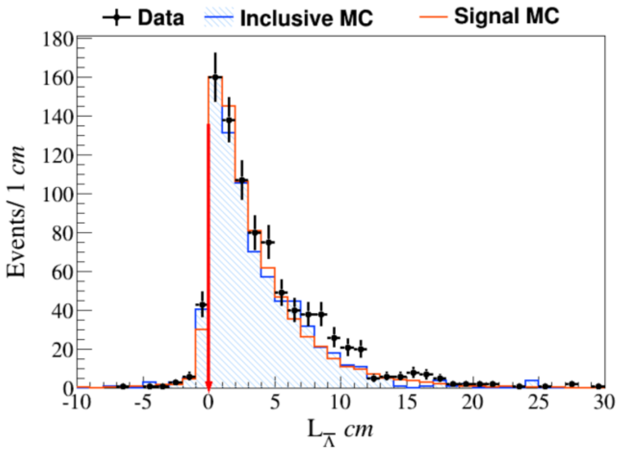
5. Kinematic Fit

- 5C kinematic fit (4C+1C: $M_{\gamma\gamma}{\to}M_{\pi^0}$) is performed over all possible $\pi^0 2(\pi^+\pi^-)p\bar{p}\gamma\gamma$ combinations. The combination with the least χ^2_{5c} is selected as for further analysis.
- 4C kinematic fit, calculate the values of $\chi^2_{4c}(4\gamma)$, $\chi^2_{4c}(3\gamma)$, $\chi^2_{4c}(5\gamma)$.

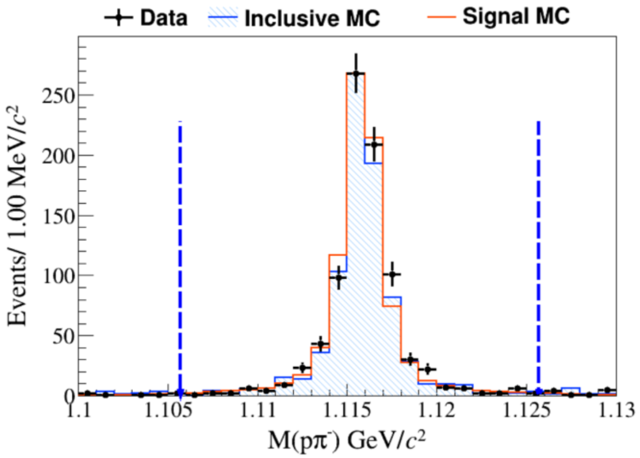
Further Selection

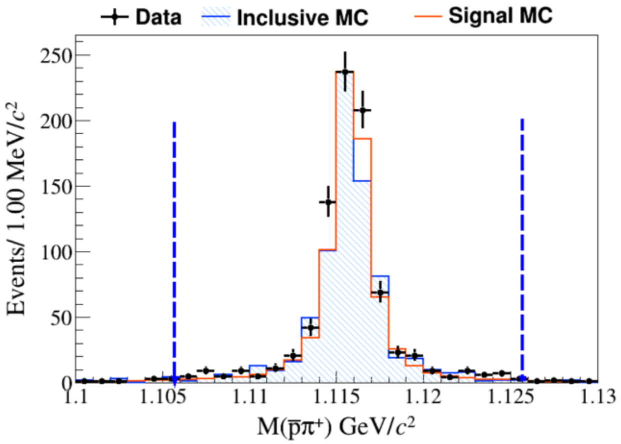


Decay length of Λ, $L_\Lambda > 0$



Decay length of $\bar{\Lambda}$, $L_{\bar{\Lambda}} > 0$

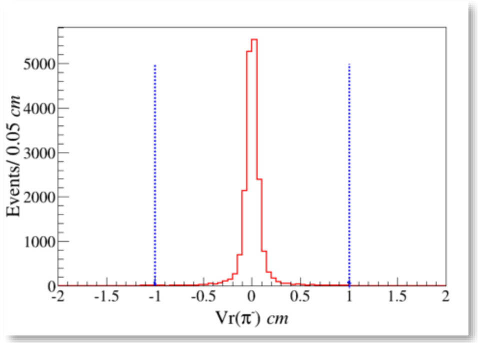


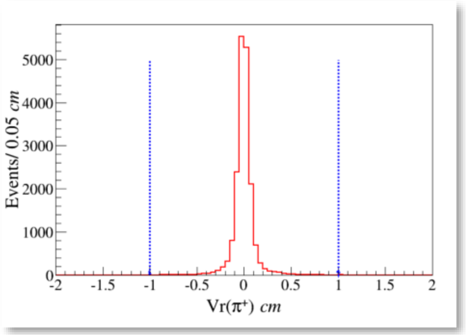


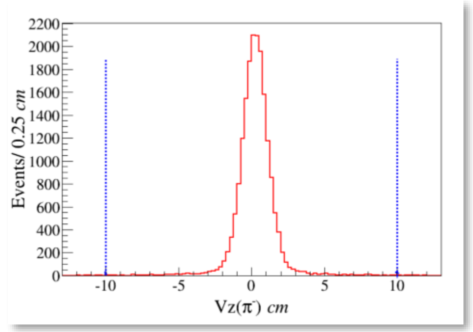
| M(pπ^-) – m(Λ) | < 0.01 (GeV/c^2)

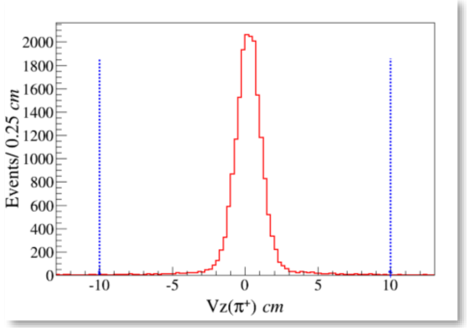
| M($\bar{p}\pi^+$) – m($\bar{\Lambda}$) | < 0.01 (GeV/c^2)

Vertex requirements on $\pi^+\pi^-$ from ω





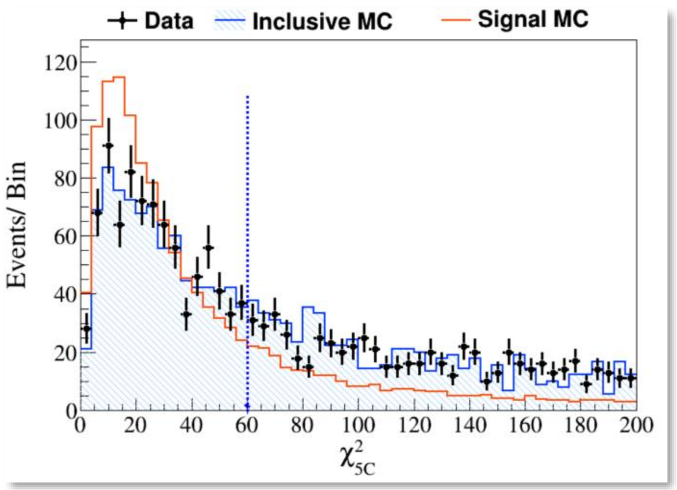




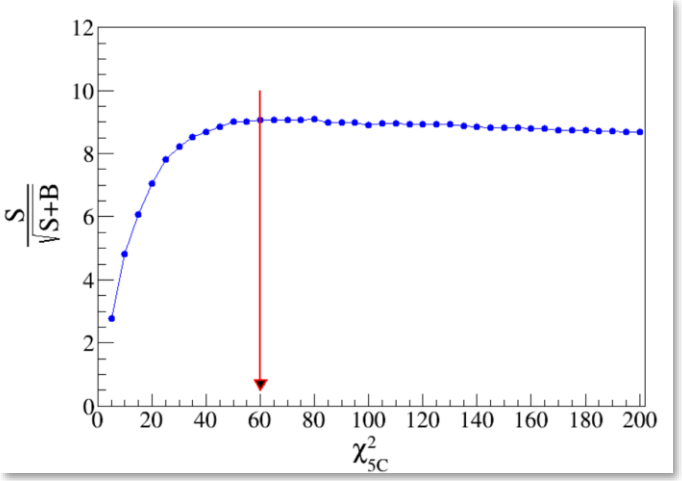
$V_r(\pi^+) < 1$ cm
$V_r(\pi^-) < 1$ cm
$|V_z(\pi^+)| < 10$ cm
$|V_z(\pi^-)| < 10$ cm

Veto Background (I)

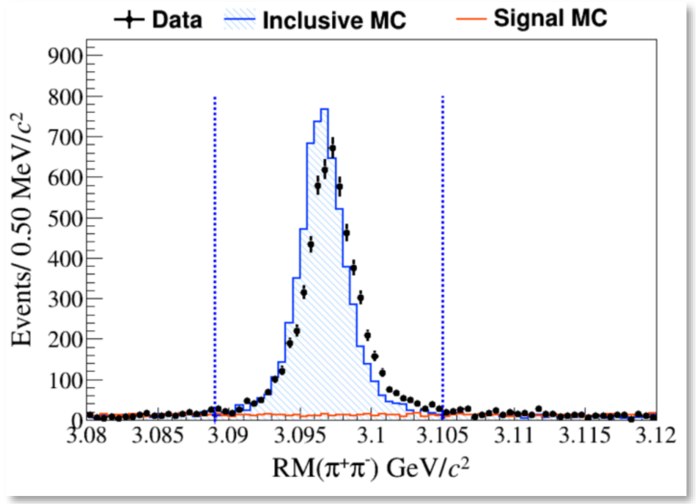
χ^2_{5C} distributions and FOM optimization

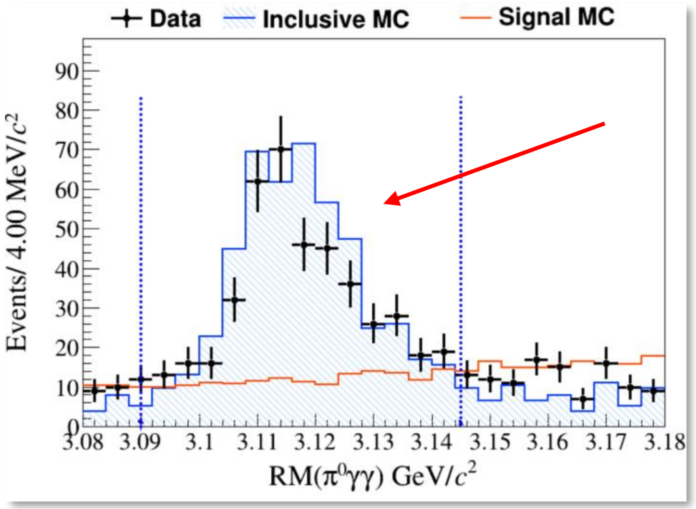


$\chi^2_{5C} < 60$



Suppress $\pi^+\pi^-$ $(\pi^0\pi^0)$ J/ψ background





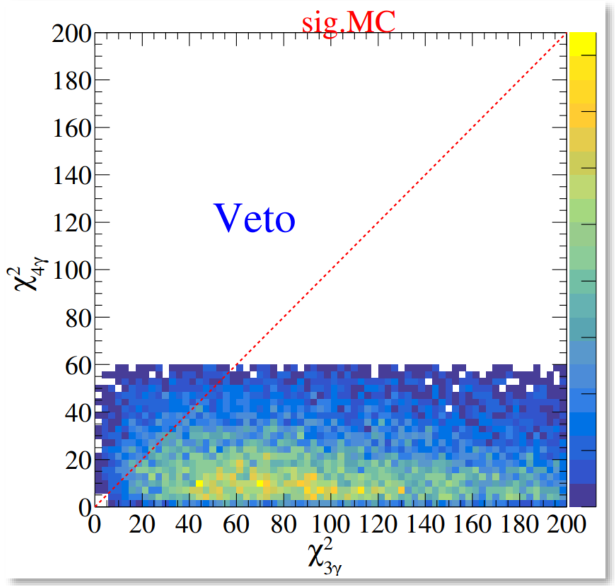
Due to the energy leakage of photons

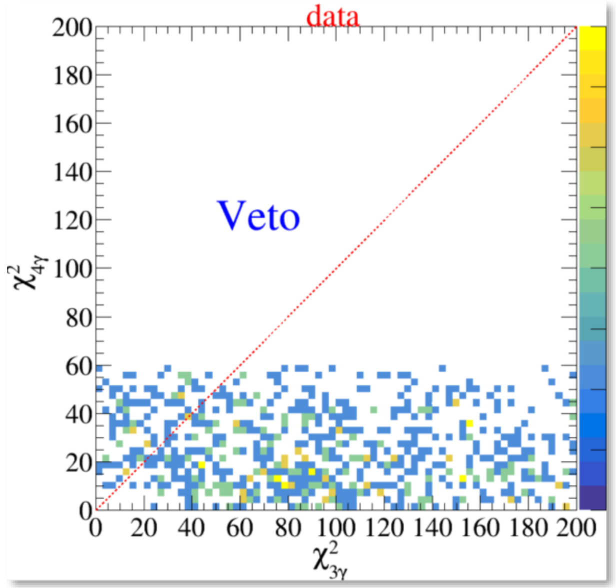
Veto $|M^{rec}(\pi^-\pi^+) - m(J/\psi)| < 0.008$ GeV/c^2

Veto $3.09 < M^{rec}(4\gamma) < 3.145$ GeV/c^2

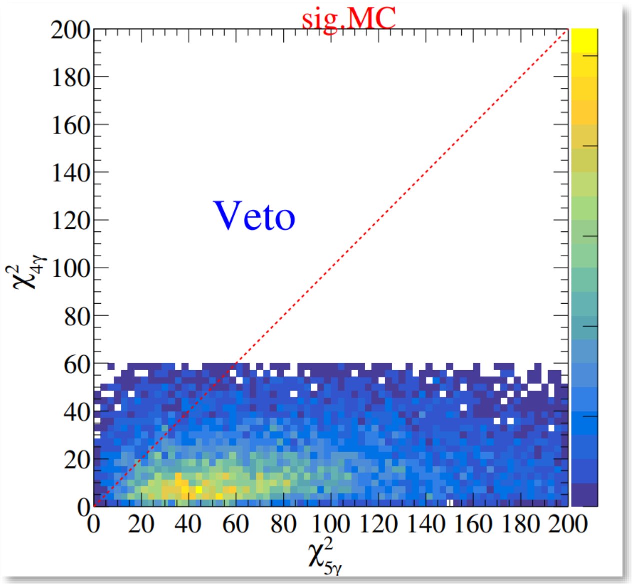
Veto Background (II)

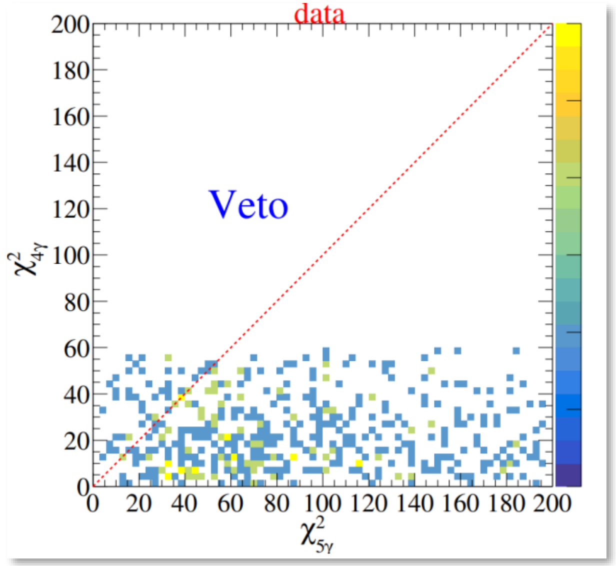
Suppress the backgrounds with one more or one less photon in their final states.





Veto $\chi^2_{4c}(4\gamma) > \chi^2_{4c}(3\gamma)$ events

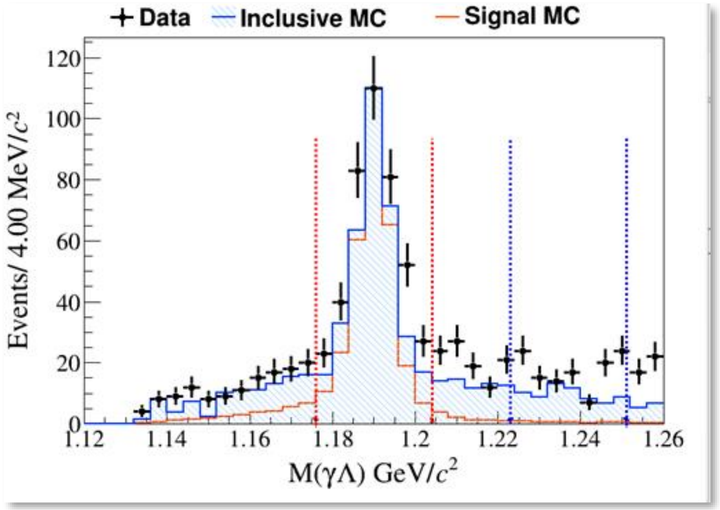


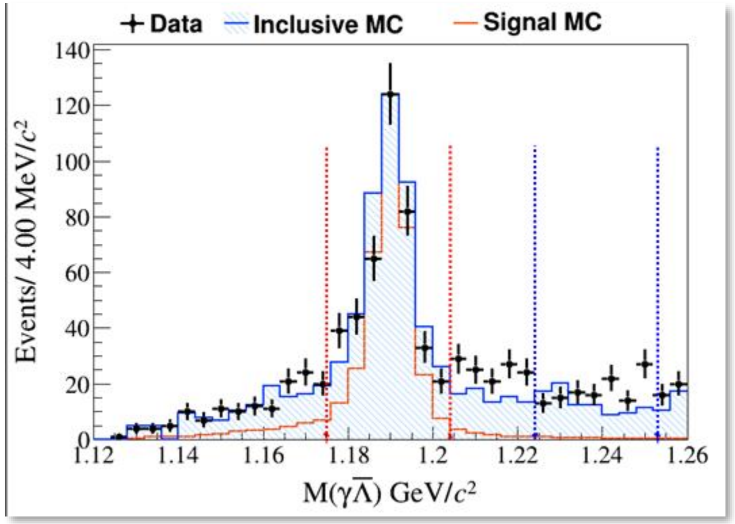


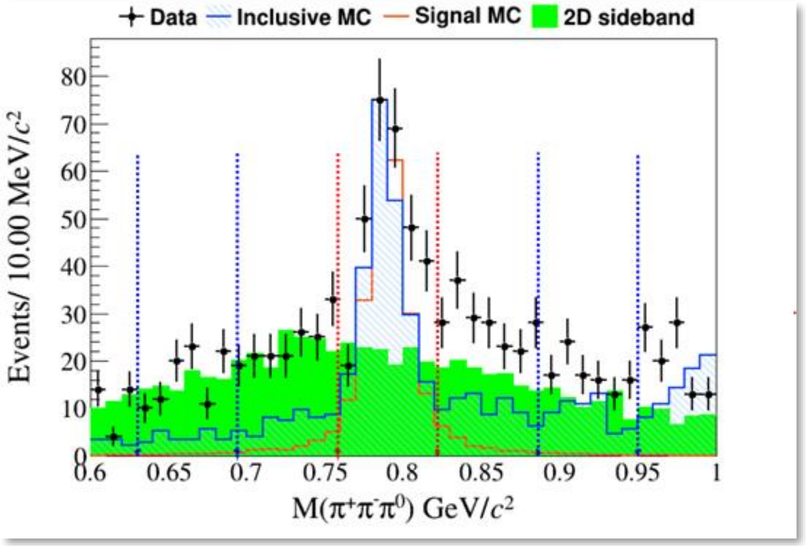
Veto $\chi^2_{4c}(4\gamma) > \chi^2_{4c}(5\gamma)$ events

Mass windows

Invariant mass distributions of Σ^0, $\bar{\Sigma}^0$ and ω.







signal region: [1.176,1.204] (GeV/c^2)
SD region:[1.223,1.251] (GeV/c^2)

signal region: [1.175,1.204] (GeV/c^2)
SD region: [1.224,1.253] (GeV/c^2)

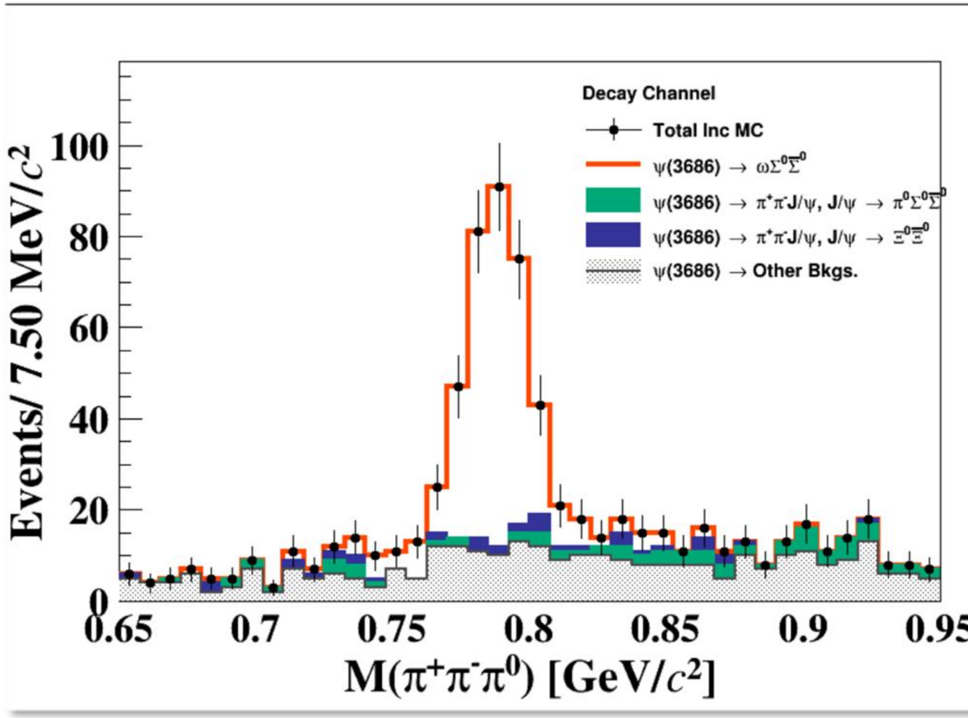
signal region: [0.758,0.822] (GeV/c^2)
SD region1: [0.630,0.694] (GeV/c^2)
SD region2: [0.886,0.950] (GeV/c^2)

The left sideband of Σ^0 and $\bar{\Sigma}^0$ are not used, since they are close to the threshold.

Background Analysis

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \omega\Sigma^0\bar{\Sigma}^0, \omega \to \pi^0\pi^+\pi^-, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	5	329	329
2	$\psi' \to \pi^+\pi^-J/\psi, J/\psi \to \pi^0\Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	4	72	401
3	$\psi' \to \pi^+\pi^-J/\psi, J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	13	38	439
4	$\psi' \to \pi^+\Xi^{*-}\bar{\Xi}^0, \Xi^{*-} \to \pi^-\Xi^0, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Xi^0 \to \pi^0\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	3	17	456
5	$\psi' \to \pi^-\bar{\Xi}^{*+}\Xi^0, \bar{\Xi}^{*+} \to \pi^+\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	25	17	473
6	$\psi' \to \pi^0\pi^0J/\psi, J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	0	15	488
7	$\psi' \to \pi^+\pi^-J/\psi, J/\psi \to \Sigma^{*0}\bar{\Sigma}^{*0}, \Sigma^{*0} \to \pi^0\Lambda, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	1	11	499
8	$\psi' \to \pi^0\pi^+\pi^-\Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	36	8	507
9	$\psi' \to \pi^-\bar{\Xi}^{*+}\Xi^0, \bar{\Xi}^{*+} \to \pi^0\bar{\Xi}^+, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	49	7	514
10	$\psi' \to \pi^-\bar{\Xi}^+\Xi^{*0}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*0} \to \pi^0\Xi^0, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^0 \to \pi^0\Lambda, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	21	6	520
11	$\psi' \to \bar{K}^*\Lambda\bar{\Xi}^0, \bar{K}^* \to \pi^+K^-, \Lambda \to \pi^-p, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-K^-p\bar{p}$	18	6	526

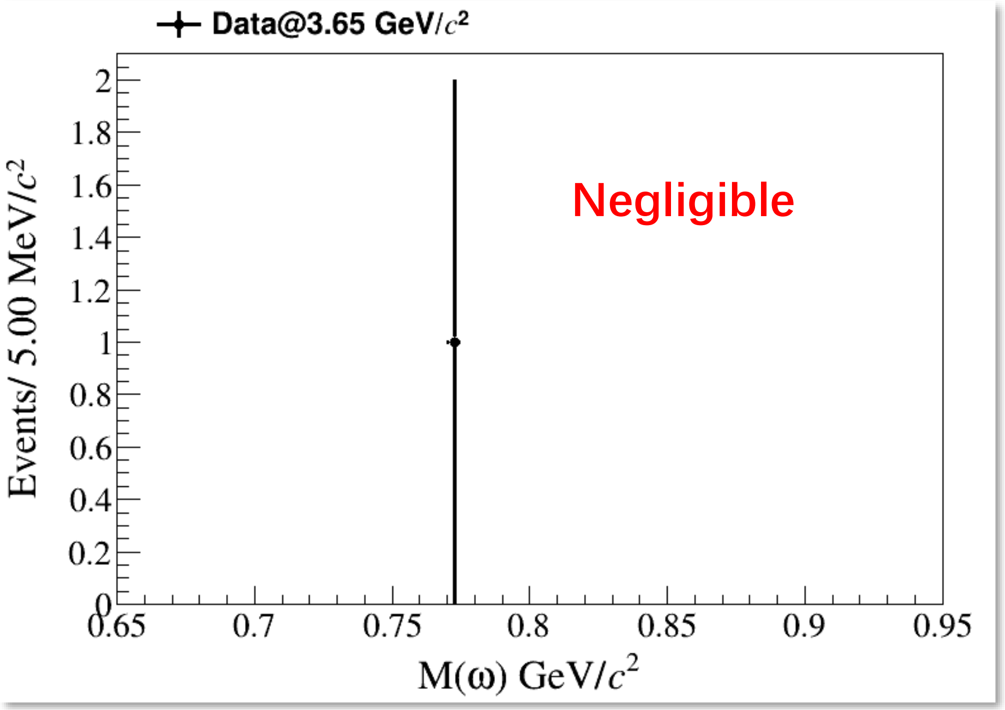
(rest entries: 214)



Based on topology analysis, there is no potential peaking contribution on M_ω spectrum.

QED Background

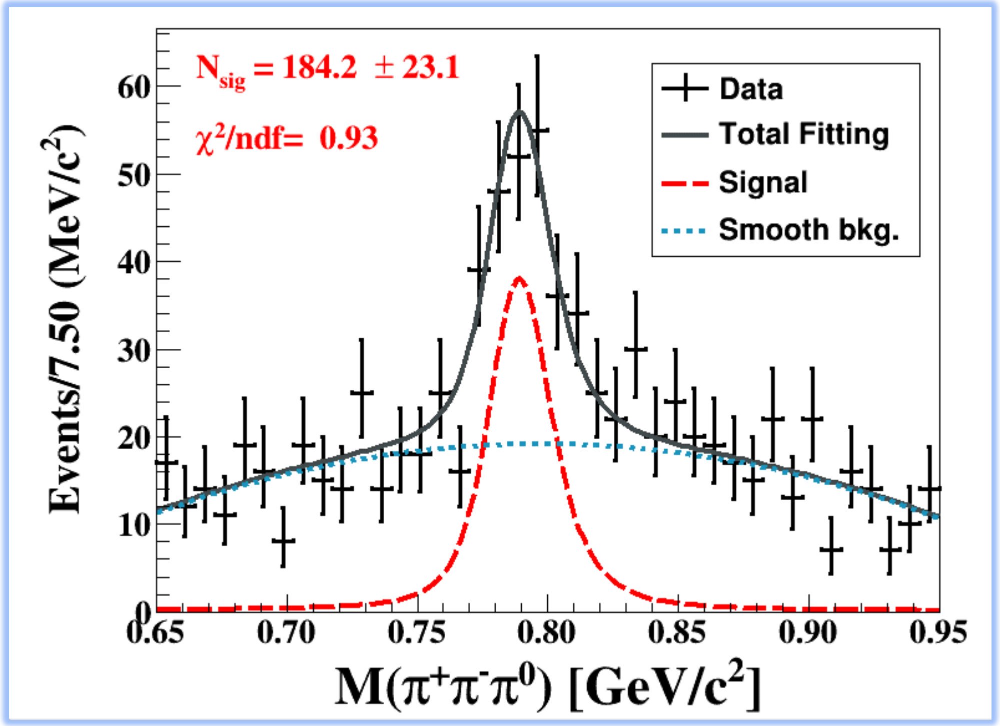
The same event selection is performed on the data sample collected in 2021 at $\sqrt{s}$ = 3.65 GeV. The corresponding luminosity is 401 pb^{-1}.



Branching Fraction Measurement

An unbinned extended likelihood fit is performed on $\pi^+\pi^-\pi^0$ invariant mass spectrum.

Signal: MC-simulated shape (KeysPdf)
Background: 2nd Chebyshev polynomial.



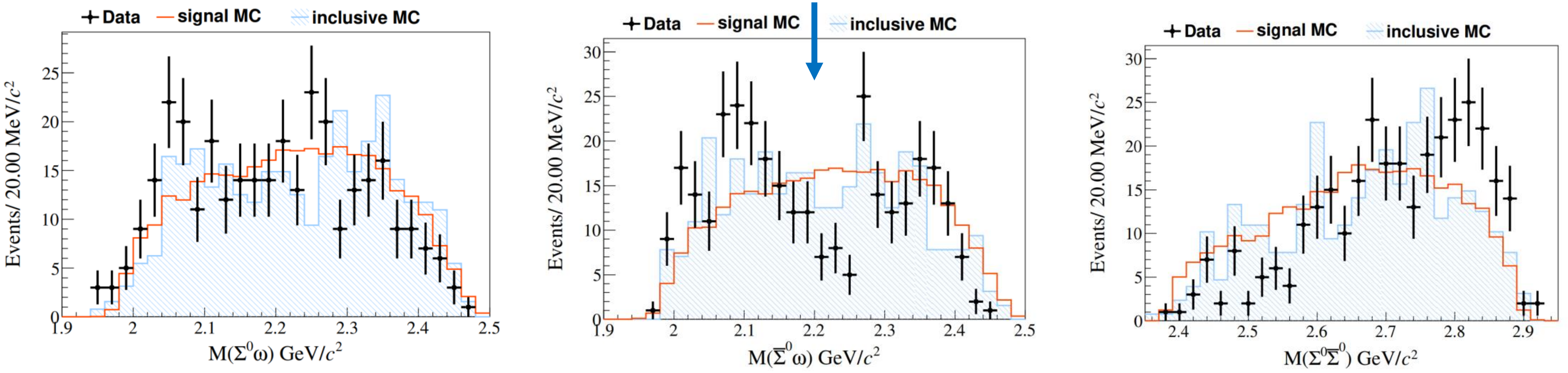
Signal Yields	Efficiency $\varepsilon_{eff}(\%)$	Significance	BR($\times 10^{-5}$)
184.2 ± 23.1	0.62	9.3σ	1.27 ± 0.16 (stat.)

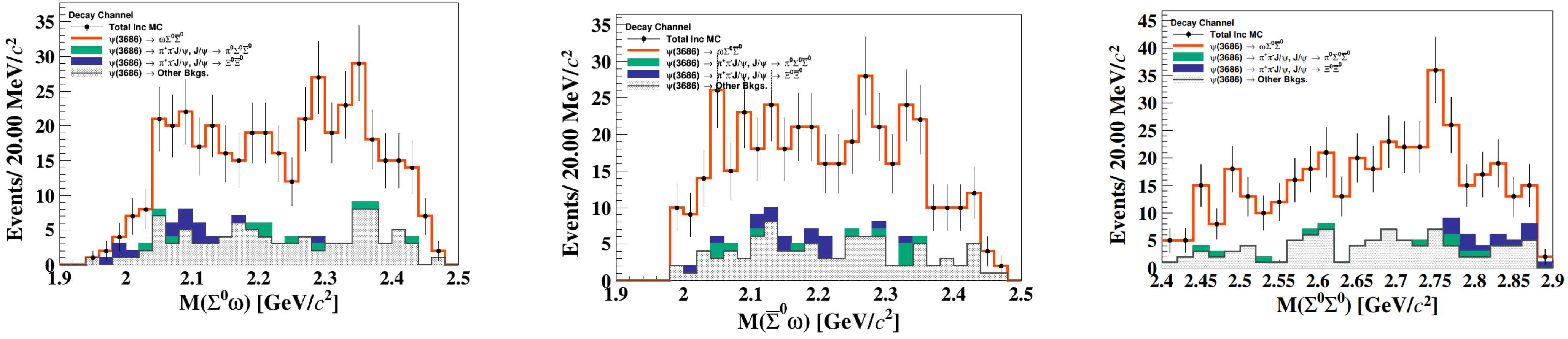
$$Br(\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega)$$
$$= N_{\omega}^{obs}/(N_{data}^{total} * Br(\Sigma^0 \to \gamma\Lambda) * Br(\bar{\Sigma}^0 \to \gamma\bar{\Lambda}) * Br(\omega \to \pi^0\pi^+\pi^-) * \boldsymbol{\varepsilon}_{eff})$$
$$\approx (1.27 \pm 0.16) \times 10^{-5}$$

Intermediate State (I)

Require M_{Σ^0}, $M_{\bar{\Sigma}^0}$ and M_ω are all in their respective mass regions.

Discrepancy between the data and signal MC.

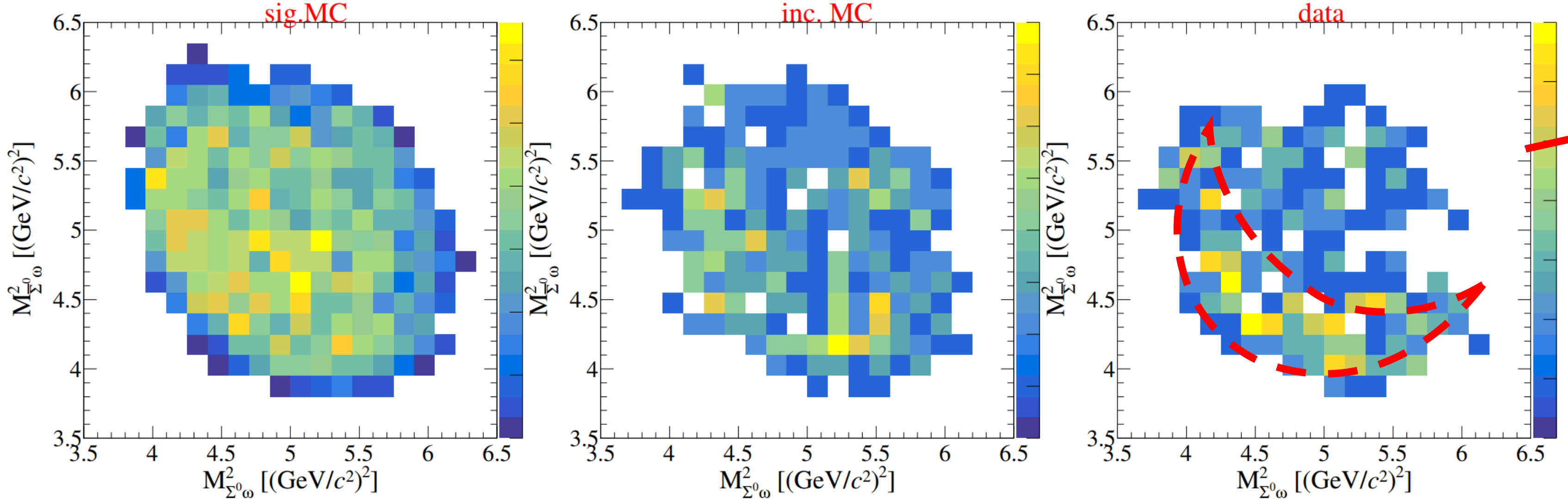




Visualization of backgrounds in the inclusive MC.

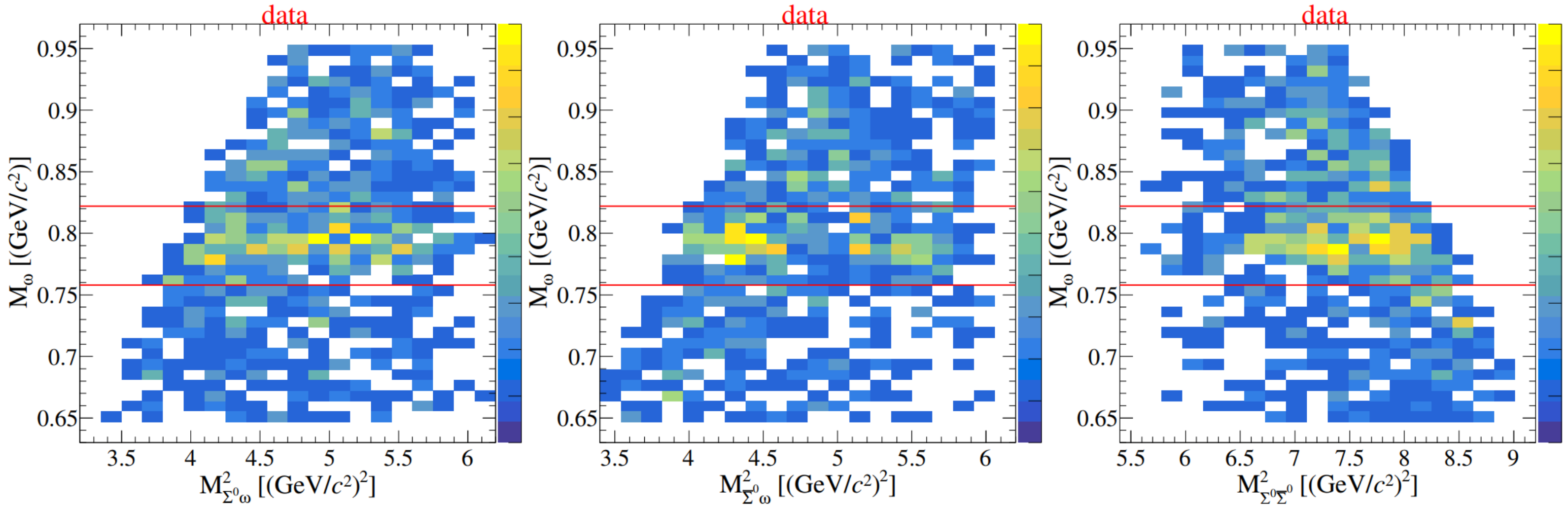
Intermediate State (II)

Dalitz plots of $M^2\left(\Sigma^0\omega\right)$ vs $M^2\left(\bar{\Sigma}^0\omega\right)$



Characteristic distribution, evidence of intermediate states?

$M(\omega)$ vs $M^2\left(\bar{\Sigma}^0\omega\right)$, $M^2\left(\Sigma^0\omega\right)$ and $M^2\left(\Sigma^0\bar{\Sigma}^0\right)$



- **The Characteristic distribution is only in ω signal region.**
- **The distributions slope along $M(\omega)$.**

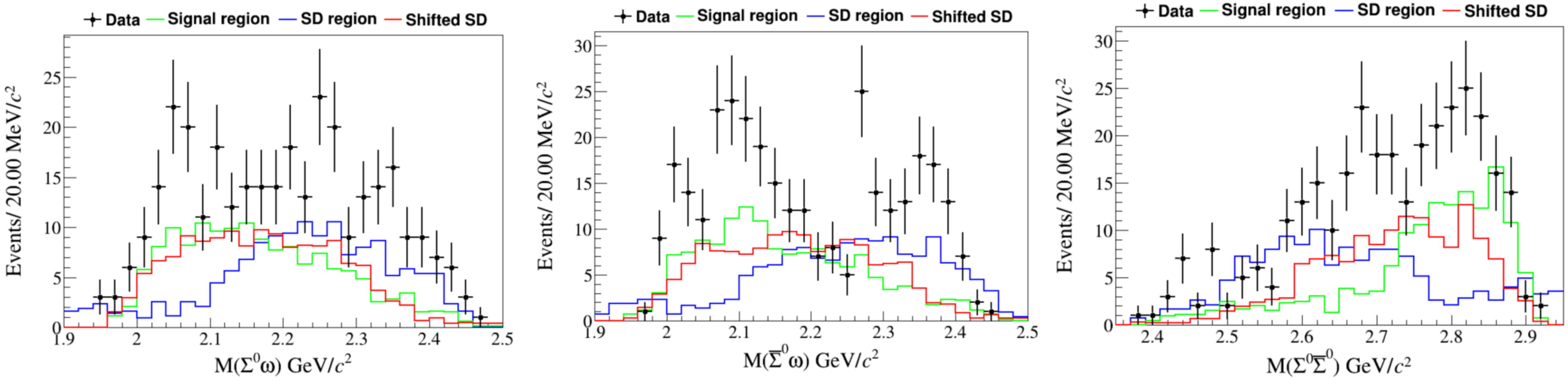
Intermediate State (III)

A shift is performed on ω sideband, by forcing $M_{\pi^+\pi^-\pi^0}$ back into ω signal region.
Maintain the momentum, and randomly assign its mass within the signal region using an uniform distribution.

$$E^{\text{shift}}_{\pi^+\pi^-\pi^0} = \sqrt{M^{\text{shift}}_{\pi^+\pi^-\pi^0} + p^2_{\pi^+\pi^-\pi^0}}$$

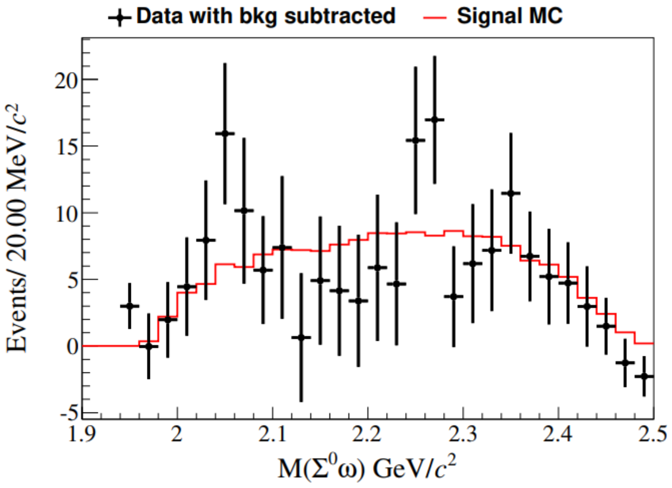
Exclusive MC of the dominant background channel is generated to examine effects of the shift.

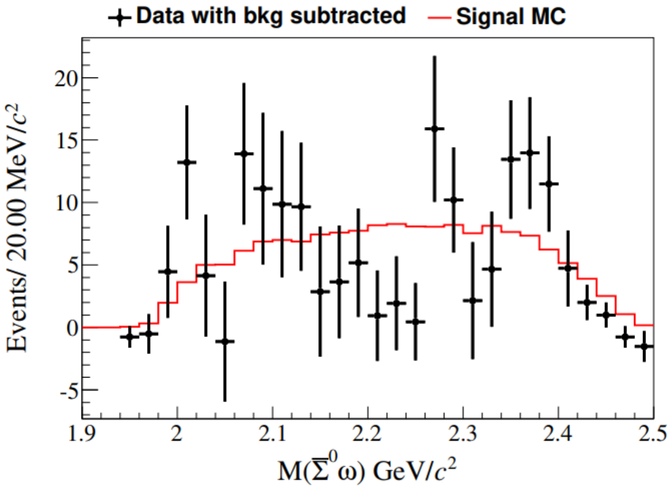
$$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \pi^0\Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^- p$$
$$\bar{\Lambda} \to \pi^+\bar{p}$$

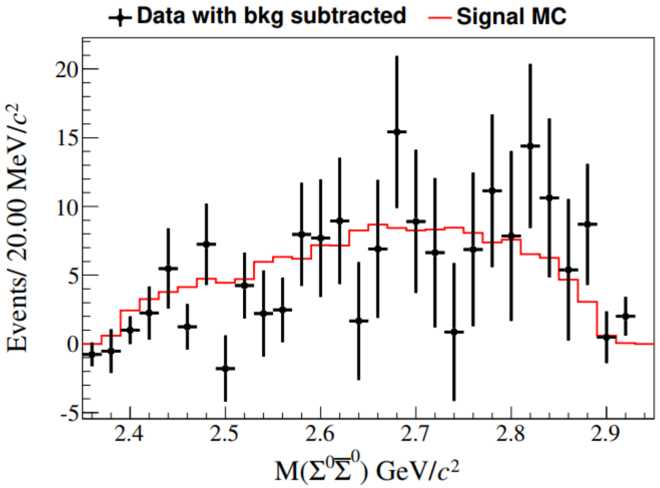


Intermediate State (IV)

Subtract the background from data with shifted ω sideband.



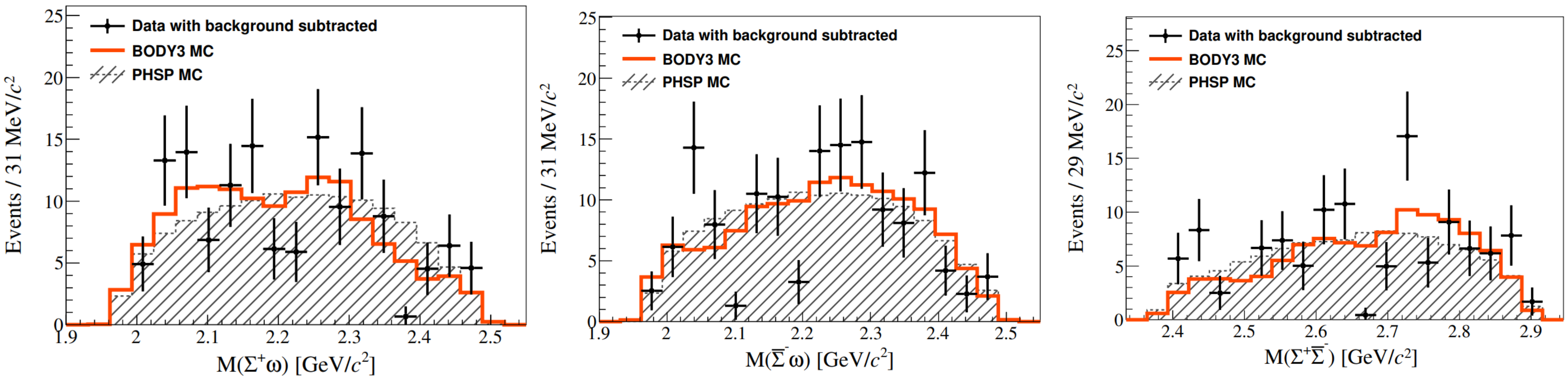


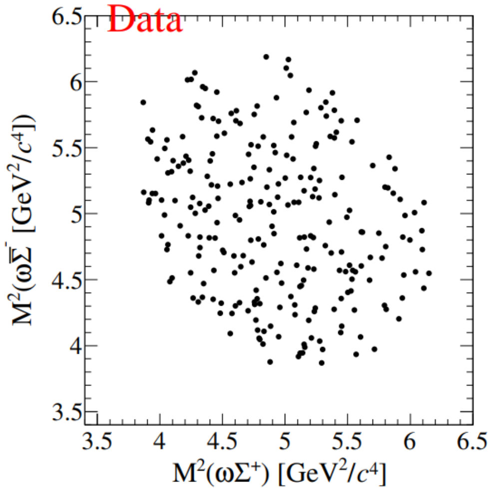


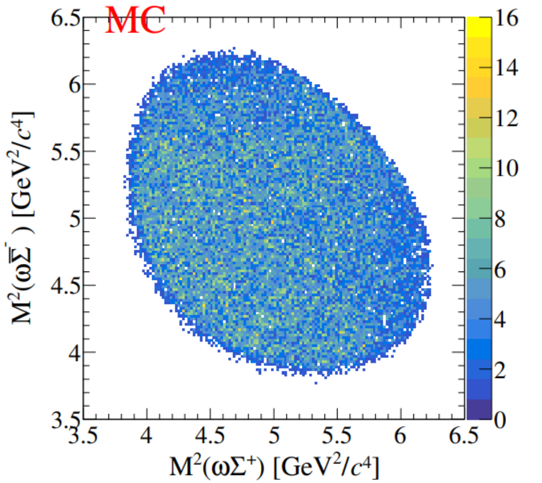
Clear peaks of intermediate states.

Intermediate State (V)

We looked into previous work, the isospin partner process $\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega$. [4]





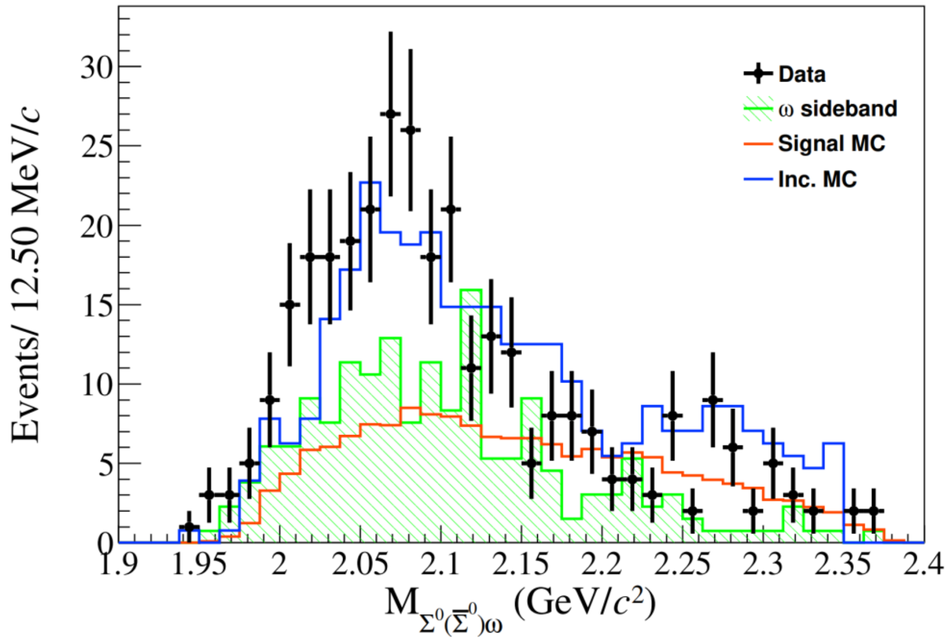


It's difficult to distinguish indications or clues available, due to the limited statistics.

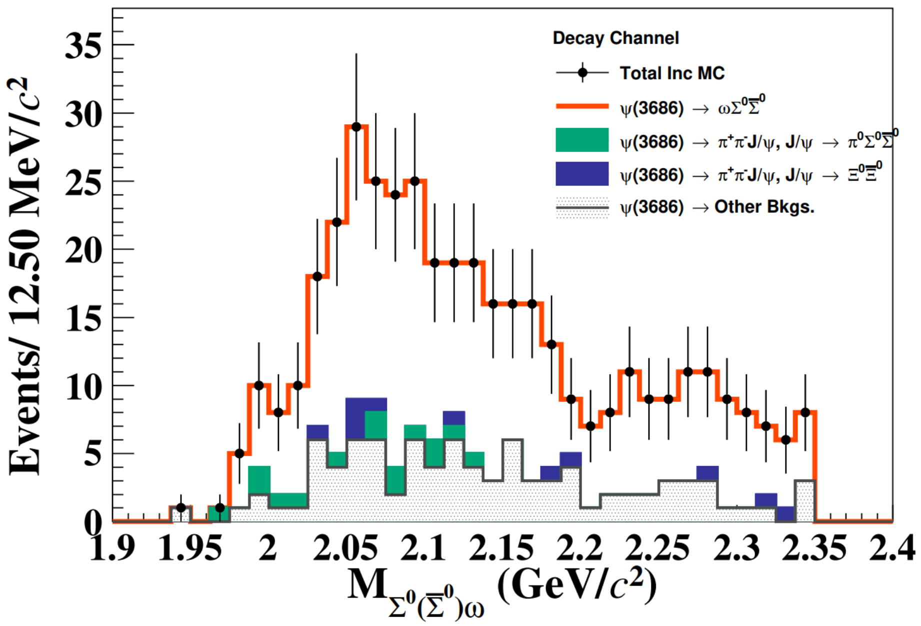
[4] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D, **108**, 092011 (2023).

Intermediate State (VI)

We compare the values between $M_{\Sigma^0\omega}$ and $M_{\bar{\Sigma}^0\omega}$, then only retain the one with lower mass.



Distributions after the operation.



Background distributions in inclusive MC sample.

Intermediate State (VII)

Function to fit

Signal: **Relativistic Breit-Wigner (RBW)**

(Relativistic Voigt is not analytic)

$$|BW(m)|^2 = \frac{k}{(m-m_0)^2+m_0^2\Gamma^2},$$

where

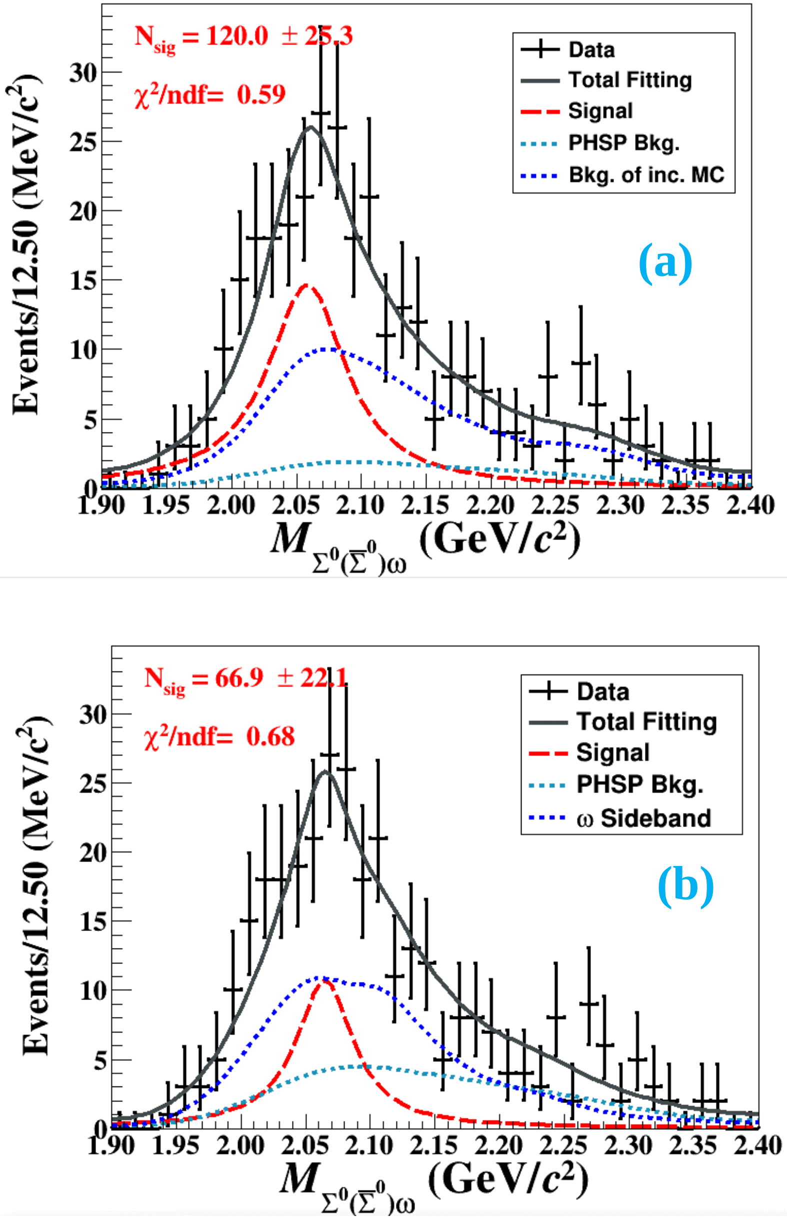
$$k = \frac{2\sqrt{2}m_0\Gamma\sqrt{m_0^2(m_0^2+\Gamma^2)}}{\pi\left(\sqrt{m_0^2+\sqrt{m_0^2(m_0^2+\Gamma^2)}}\right)}$$

Background: (a) Signal deducted inclusive MC + PHSP MC of $\psi(3686)\to \Sigma^0\bar{\Sigma}^0\omega$.

Or

(b) Shifted ω sideband + PHSP MC of $\psi(3686)\to \Sigma^0\bar{\Sigma}^0\omega$.

Background Function	Significance	Mass (MeV/c^2)	Width (MeV)
(a)	5.4σ	2058.2 ± 8.8	73.7 ± 14.5
(b)	3.7σ	2065.8 ± 12.2	54.2 ± 21.6



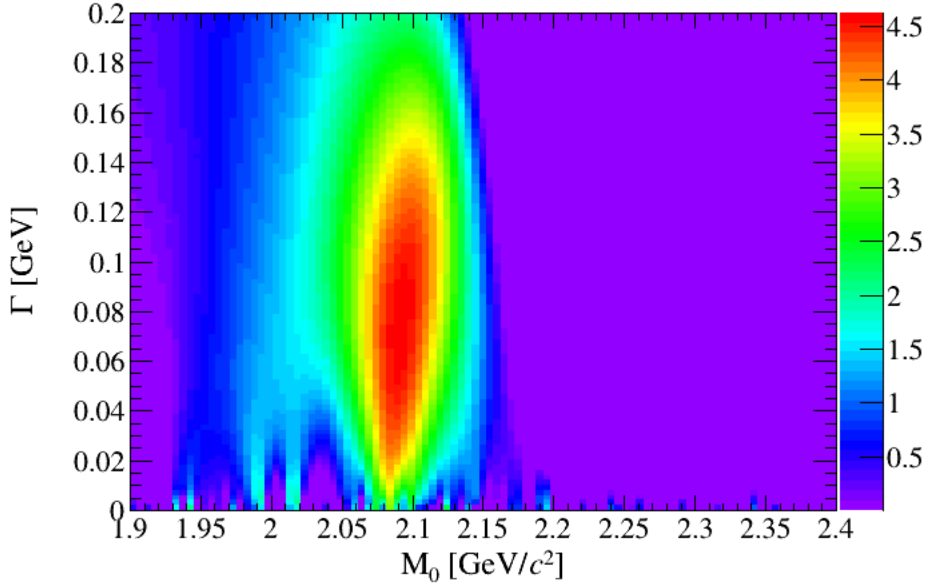
Intermediate State (VIII)

- **The uncertainty of sideband normalization is estimated by varying the fixed number of events one standard deviation. The uncertainty of sideband range is estimated by expanding the range by 10 MeV/c^2. After considering the uncertainties, the significance reduced to 3.5σ.**

- **The look-elsewhere effect (LEE) is estimated[5]. The entire fitting parameter space is divided into 10,000 pixels, then we calculate the significance of background-only MC at each fixed pixel.**

We can count the Euler characteristics on the significance map to estimate the LEE.

After considering the LEE, the significance is only 2.4σ.



The significance map

[5] Ofer Vitells, Eilam Gross, Estimating the significance of a signal in a multi-dimensional search. Astropart.Phys. 35 (2011), 230-234

Systematic Uncertainties of Branching Fraction

Source	Uncertainty (%)
Tracking ($\pi^+\pi^-$ from ω)	2 (1 per pion) [6].
Photon detection	2 (0.5 per photon) [7]
π^0 reconstruction	1[8]
Quoted (ω) branching fraction	0.78[9]
Quoted (π^0) branching fraction	0.03[9]
Quoted $\Lambda(\bar{\Lambda})$ branching fraction	0.78[9]
Total number of $\psi(3686)$	0.53[3]
Σ^0mass window	2.72
$\bar{\Sigma}^0$mass window	negligible
Veto J/ψ (Recoil $\pi^+\pi^-$)	negligible
Veto J/ψ (Recoil $\gamma\gamma\pi^0$)	3.77
Fit range	negligible

- **Directly cited from previous works.**

- **Mass windows and fit range**

  Shrink and expand the mass windows, then perform Barlow test on the branching fraction. $\varsigma = \frac{|V_{\text{nominal}} - V_{\text{test}}|}{\sqrt{|\sigma^2_{V\ \text{nominal}} - \sigma^2_{V\ \text{test}}|}}$

  For $\varsigma < 2$, the differences in branching fractions are due to statistical fluctuation. For $\varsigma > 2$, take the largest differences in branching fractions as the uncertainty.

Systematic Uncertainties of Branching Fraction

Source	Uncertainty (%)
Signal shape	1.30
Background function	0.80
Kinematic fit	1.13
MC sample size	0.73
Λ reconstruction, mass window and PID	3.56
$\bar{\Lambda}$ reconstruction, mass window and PID	1.77
Data-MC discrepancy	5.34
Total	8.18

- **Signal shape**
  Replace signal function with a double Gaussian function.
- **Background function**
  Use $\Sigma^0\bar{\Sigma}^0$ sideband instead of the Chebyshev polynomial.
- **Kinematic fit**
  Compare efficiency change with and without helix parameter corrections[10]
- **MC sample size**
  $\sqrt{(1-\varepsilon)/N\cdot\varepsilon}$, where N is the size of signal MC samples.
- **Λ $\bar{\Lambda}$ Reconstruction**
  The control sample of $J/\psi \to pK^-\bar{\Lambda}$ + c.c[11] is used to correct the efficiency. The correction factor is defined as $f^i = \frac{\varepsilon_{data}}{\varepsilon_{MC}}$, and the corrected efficiency is calculated by
  $$\varepsilon_{\text{corrected}} = \frac{\Sigma_i N^i_{\text{select}} \times f^i}{\Sigma_i N^i_{\text{generate}}}$$
  The total uncertainties of f^i are taken the uncertainty of Λ $\bar{\Lambda}$ reconstruction.
- **Data-MC discrepancy**
  Correct the polar angle distributions of final particles in the signal MC to the data, bin by bin. Take the efficiency difference after correction as the uncertainty.

Summary

- Using $(2712.4 \pm 14.3) \times 10^6$ $\psi(3686)$ data events, the decay $\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega$ is observed with a statistical significance of 9.3σ. The branching fraction is measured as
$$Br\left(\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega\right) = (1.27 \pm 0.16 \pm 0.11) \times 10^{-5}.$$
Compared with the previous work[4], $Br(\psi(3686) \to \Sigma^+\bar{\Sigma}^-\omega) = (1.90 \pm 0.18 \pm 0.20) \times 10^{-5}$, the isospin conservation is upheld according to the measurements. (1:1 is expected)

- An intermediate state is found with the significance of 2.5σ. Its mass and width are measured to be $(2065.8 \pm 12.2 \pm 7.6)$ MeV/c^2 and $(54.2 \pm 21.6 \pm 19.8)$ MeV, respectively. However, because of the limited statistics, it is difficult to determine the properties of the intermediate state.

THANK YOU 😊

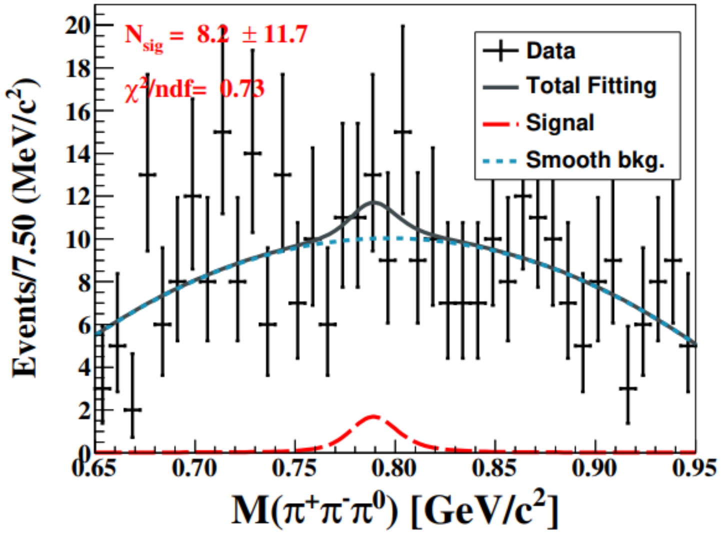
Reference

[1] M. Ablikim *et al*. [BESIII Collaboration], Phys.Rev.D , **106**, 112011 (2022).
[2] M. Ablikim *et al*. [BESIII Collaboration], Phys. Rev. D, **104**, 052006 (2021).
[3] Cheng Liu *et al*, Determination of the number of ψ(3686) events taken in 2021. arXiv:2403.06766v2 [hep-ex] 12 Mar 2024.
[4] M. Ablikim *et al*. [BESIII Collaboration], Phys. Rev. D, **108**, 092011 (2023).
[5] Ofer Vitells, Eilam Gross, Estimating the significance of a signal in a multi-dimensional search. Astropart.Phys. 35 (2011), 230-234
[6] M. Ablikim et al. [BESIII Collaboration], Study of χ_{cJ} radiative decays into a vector meson, Phys. Rev. D 83, 112005(2011).
[7] Vindhyawasini Prasad. Study of photon detection efficiency in $e^+e^- \to \gamma\mu^+\mu^-$ process, BESIII DocDB-doc-765-v5.
[8] Martin Ripka et al, π^0 reconstruction efficiency, [Online] BESIII Analysis Memo.
[9] P. L. Workman et al. [Particle Data Group], Prog. Theor. Exp. Phys. 2022, 083C01 (2022).
[10] Data Quality Group [Online] DataQuality Page - Charmonium Working Group (ihep.ac.cn)
[11]Yipu Liao et al, Study of $J/\psi \to \bar{\Lambda}\pi^{\pm}\Sigma^{\mp}$, arXiv:2306.10319 [hep-ex].

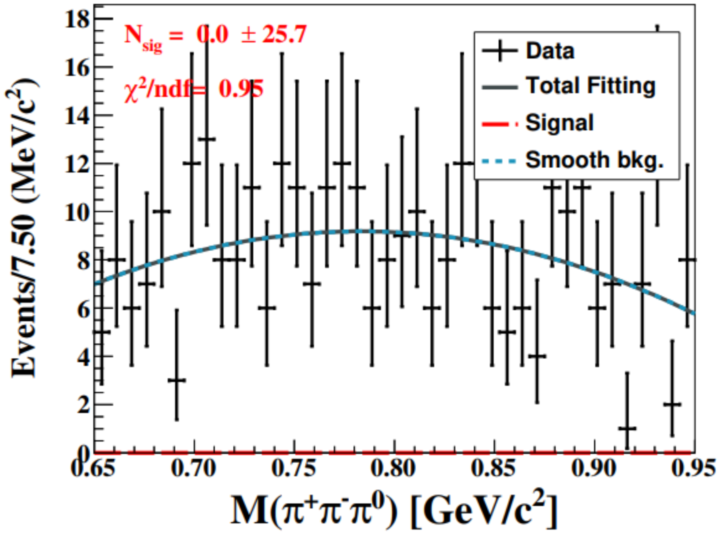
Backup

Fit to Sideband

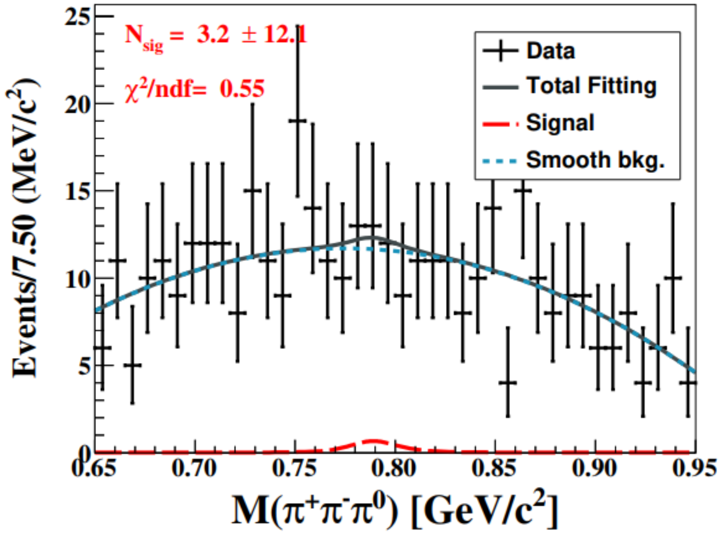
We performed the same fit to Σ^0 sideband, $\bar{\Sigma}^0$ sideband and 2-D sideband.



Σ^0 sideband



$\bar{\Sigma}^0$ sideband



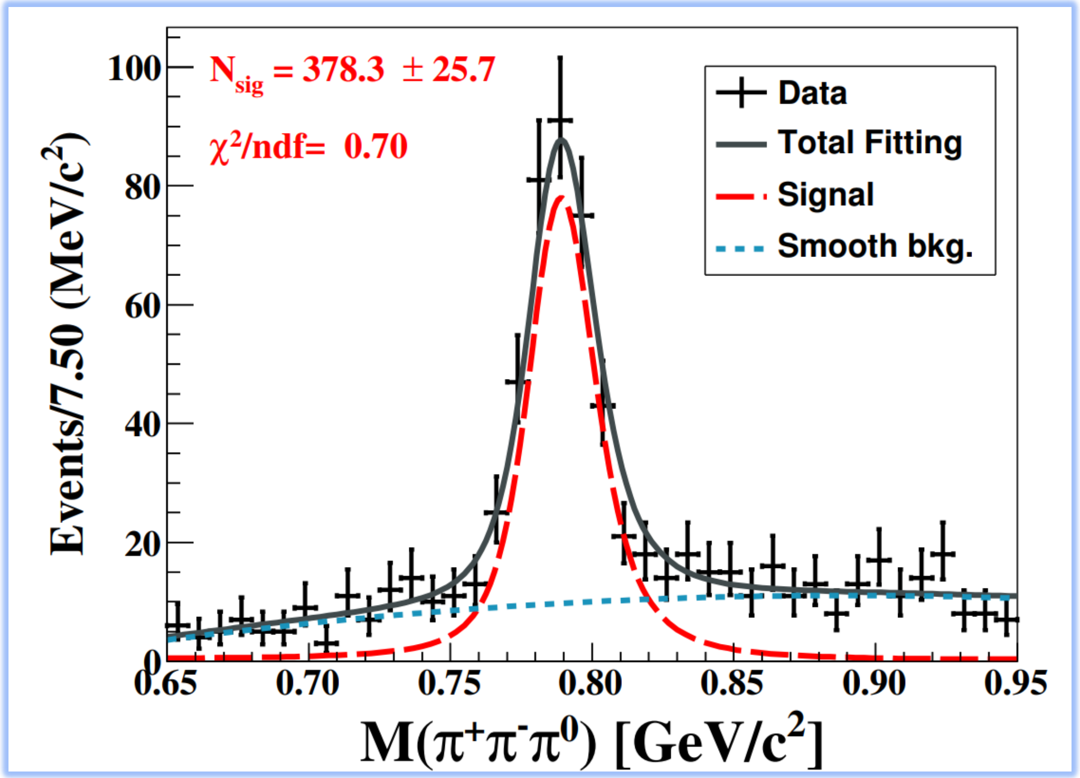
$\Sigma^0\bar{\Sigma}^0$ 2D sideband

Peaking contribution from sidebands is negligible.

IO Check

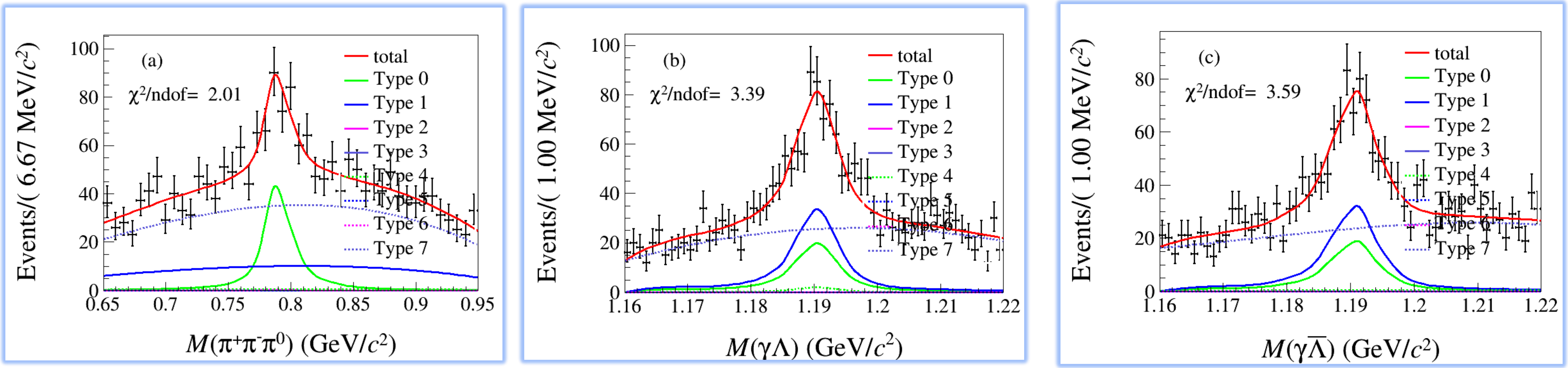
We perform the same fit to the selected inclusive MC sample.
The output result of ω yield accords with the input within 1σ.

Input ω events	362
Output ω events	378.3 ± 25.7



Simultaneous Fit

The result of simultaneous fit accords with 1D fit



Signal Yields	Detection ε_{eff}(%)	Significance	BR($\times 10^{-5}$)
230.1 ± 29.0	**0.76**	**-**	**1.25 ± 0.16 (stat.)**

$$Br(\psi(3686) \to \Sigma^0\bar{\Sigma}^0\omega)$$
$$= N_{\omega}^{obs}/(N_{data}^{total} * Br_{\Sigma^0} * Br_{\bar{\Sigma}^0} * Br_{\omega} * \boldsymbol{\varepsilon_{eff}})$$
$$\approx(\mathbf{1.25 \pm 0.16}) \times 10^{-5}$$

PDF model	Event Type
Type0 (signal)	$\omega\Sigma^0\bar{\Sigma}^0$
Type1	non-ω Σ^0 $\bar{\Sigma}^0$
Type2	ω Σ^0 $non-\bar{\Sigma}^0$
Type3	ω $non-\Sigma^0$ $\bar{\Sigma}^0$
Type4	non-ω Σ^0 $non-\bar{\Sigma}^0$
Type5	non-ω $non-\Sigma^0$ $\bar{\Sigma}^0$
Type6	ω $non-\Sigma^0$ $non-\bar{\Sigma}^0$
Type7	non-ω $non-\Sigma^0$ $non-\bar{\Sigma}^0$

Introduction to Look-Elsewhere Effect[13]

8.2 The LEE with two parameters (m, Γ) undefined under the null hypothesis.

In cases where there are two parameters undefined under the null hypothesis, such as mass (m) and width (Γ) the Look Elsewhere Effect is broader. Ref [14] solved the case for a multi-dimensional search.

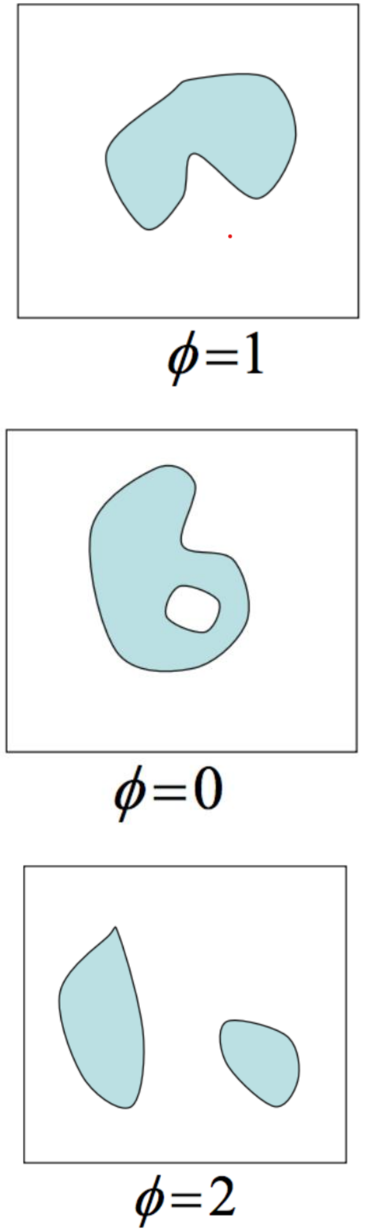
Suppose we would like to estimate the global significance of some observed excess. When allowing both the mass and the width float, we observe that the highest significance of $Z\sigma$ occurs for some specific mass and width. This observation corresponds to a local background fluctuation with a p-value of p_{local}. However, any fluctuation at any mass and width in the 2D search plane of m and Γ would have drawn our attention. The increased probability to observe a fluctuation of $Z\sigma$ or more anywhere in the mass-width plane $A = (m, \Gamma)$ (LEE) is given by the global p-value, p_{global}. The local p-value is based on scanning the $q_0(m, \Gamma)$ test statistic, $q_0(m, \Gamma)$ given by

$$q_0(m, \Gamma) = -2 \log \frac{L(0, m, \Gamma, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{m}, \hat{\Gamma}, \hat{\theta})}. \tag{55}$$

The distribution of the maximum local significance $u = Z^2 = \max_{m,\Gamma} q_0(m, \Gamma)$ was studied in [14]. The global p-value is given by

$$p_{global} \approx E[\phi(A_u)] = p_{local} + e^{-u/2}(N_1 + \sqrt{u} N_2) \tag{56}$$

where N_1 and N_2 are coefficients that are estimated by calculating the average Euler characteristic of the plane A. To solve for N_1 and N_2, it is convenient to set two reference levels u_0 and u_1, find the Euler characteristics for each level, and solve the consequent system of two linear equations. In a 2D manifold with closed islands, some with holes, each disconnected full island takes the value $+1$. Each hole contributes -1. In that sense a full round shape has the Euler characteristic of $+1$. If you dig a hole in it, its Euler characteristics becomes $+1 - 1 = 0$ (Figure 12).



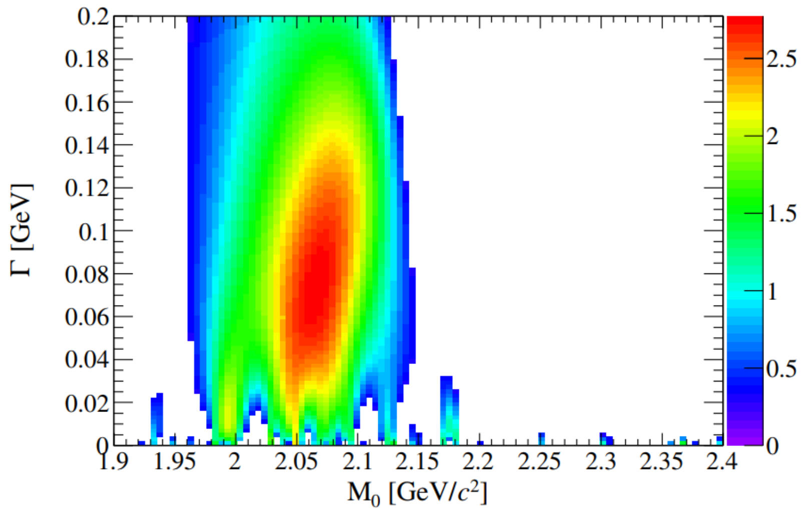
[13] Proceedings of the 2017 European School of High-Energy Physics, Evora, Portugal, 6–19 September 2017, edited by M. Mulders and G. Zanderighi, CERN Yellow Reports: School Proceedings, Vol. 3/2018, CERN-2018-006-SP (CERN, Geneva, 2018)

Estimate The Look-Elsewhere Effect

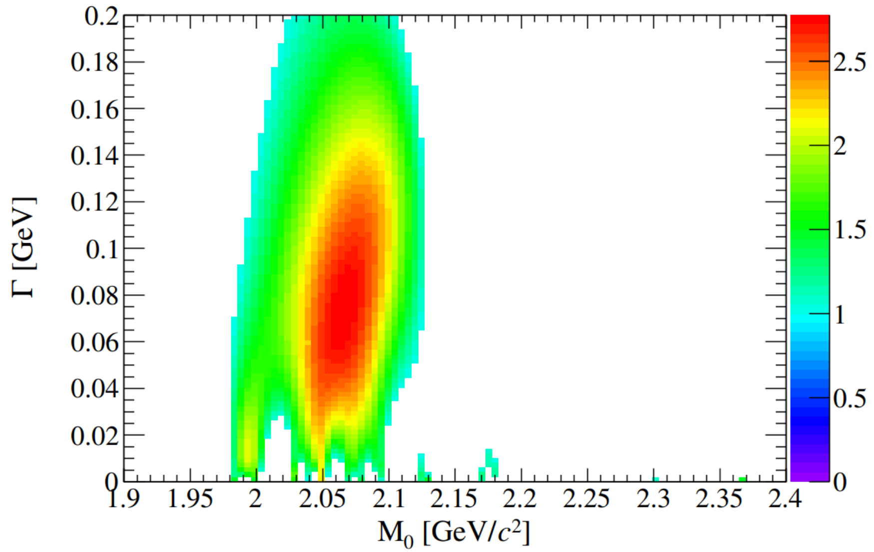
In this analysis, we generated a set of 10 background-only MC samples, each has 3000 events. We choose the reference level of μ as 0.1 and 1, respectively. Solving the equation, this gives $N_1 \approx 10$, $N_2 \approx 1$.

Use the formula $p_{\text{global}} \approx E[\phi(A_u)] = p_{\text{local}} + e^{-u/2}(N_1 + \sqrt{u}N_2)$,

for u =13.6, it gives p_{global} =0.01509 (double side probability) , Z=2.4σ

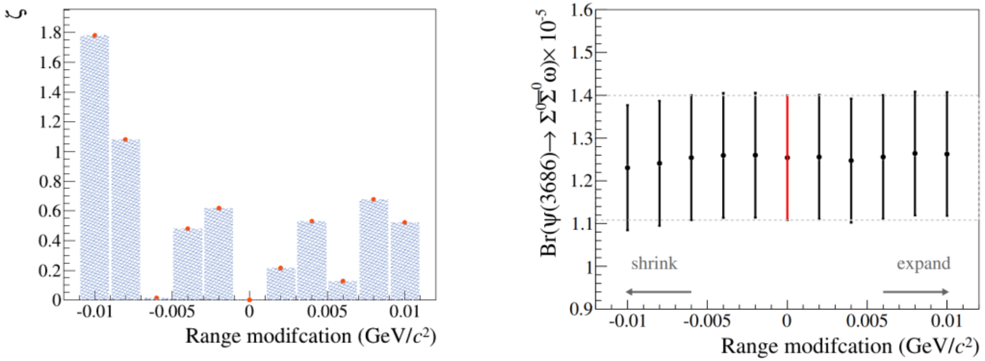


μ>0.1

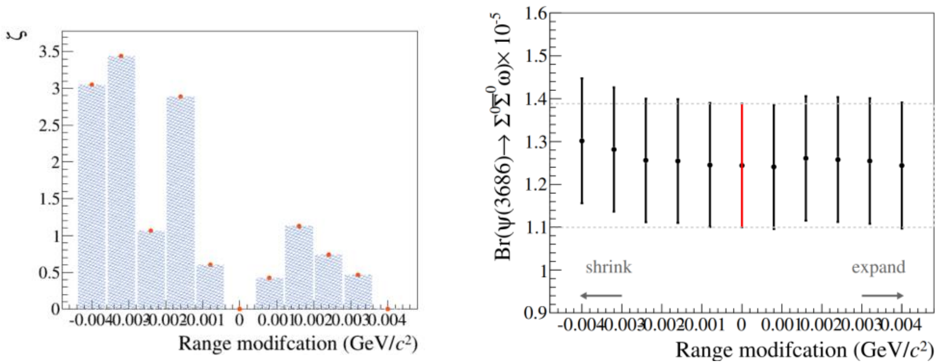


μ>1

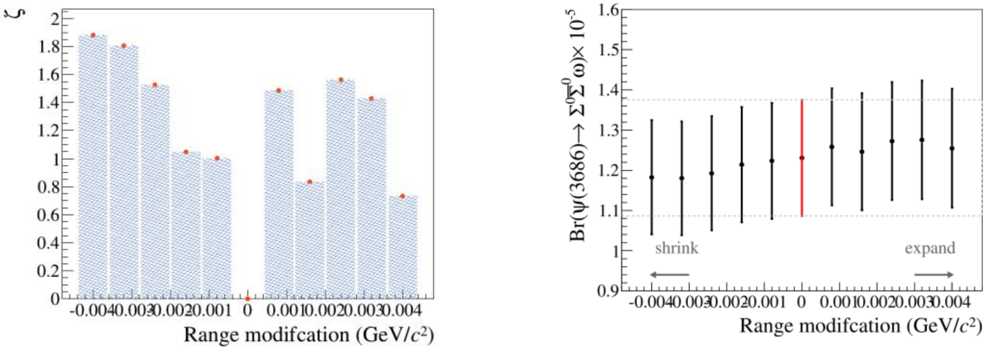
Barlow Test of Mass Windows



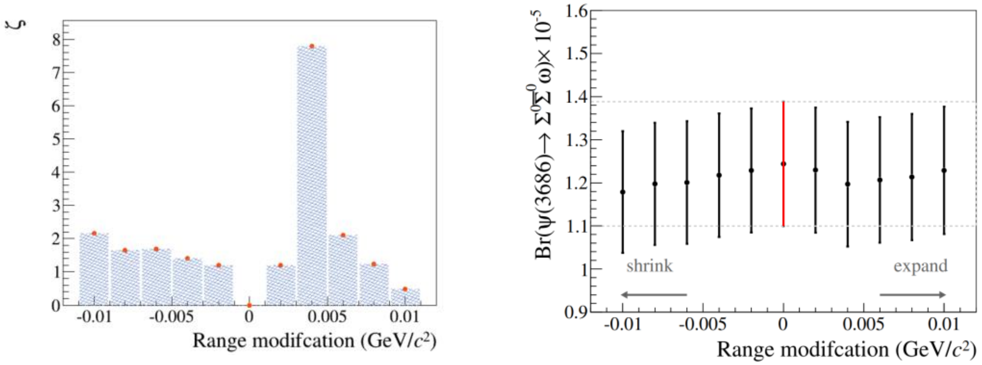
Fitting range



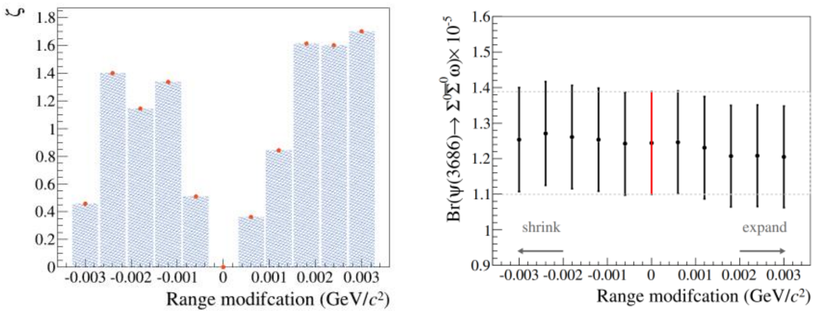
Σ^0 mass window



$\bar{\Sigma}^0$ mass window



Veto J/ψ, recoil $\gamma\gamma\pi^0$mass window



Veto J/ψ, recoil $\pi^+\pi^-$mass window

Decay Cards

```
Decay psi(2S)
1.0000 Sigma0 anti-Sigma0 omega                          PHSP;
Enddecay

Decay Sigma0
1.0000    gamma  Lambda0                         PHSP;
Enddecay

Decay  anti-Sigma0
1.0000   gamma anti-Lambda0                          PHSP;
Enddecay

Decay omega
1.000   pi-   pi+  pi0                           OMEGA_DALITZ;
Enddecay

End
```

Decay Card of signal MC

```
Decay psi(2S)
1.000    J/psi  pi+ pi-                JPIPI;
Enddecay

Decay J/psi
1.000     pi0 Sigma0 anti-Sigma0      PHSP;
Enddecay

Decay Sigma0
1.0000    gamma  Lambda0                      PHSP;
Enddecay

Decay anti-Sigma0
1.0000    gamma  anti-Lambda0                  PHSP;
Enddecay

Decay Lambda0
1.000    p+ pi-              PHSP;
Enddecay

Decay anti-Lambda0
1.000    anti-p- pi+             PHSP;
Enddecay

Decay pi0
1.000    gamma gamma                   PHSP;
Enddecay

End
```

Decay Card of $\pi^0\Sigma^0\overline{\Sigma}^0$ exclusive MC