廣西科技大學
Guangxi University of Science and Technology

BESIII

Measurement of the cross section $e^+e^- \to \Sigma^0\bar{\Sigma}^0$ via the initial state radiation technique

Junhua Feng[1,2,3], Guangrui Liao[2], Cong Geng[3], Xiaorong Zhou[4]

[1]Guangxi University of Science and Technology
[2]Guangxi Normal University
[3]Sun Yat-sen University
[4]University of Science and Technology of China

Tau-QCD group meeting,
May 28

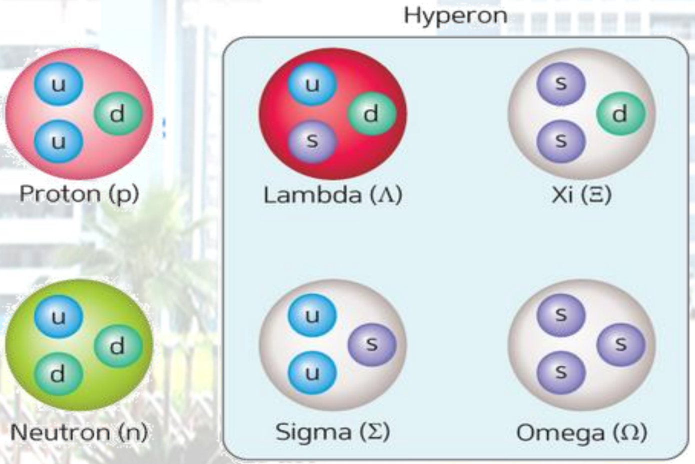
OutLine

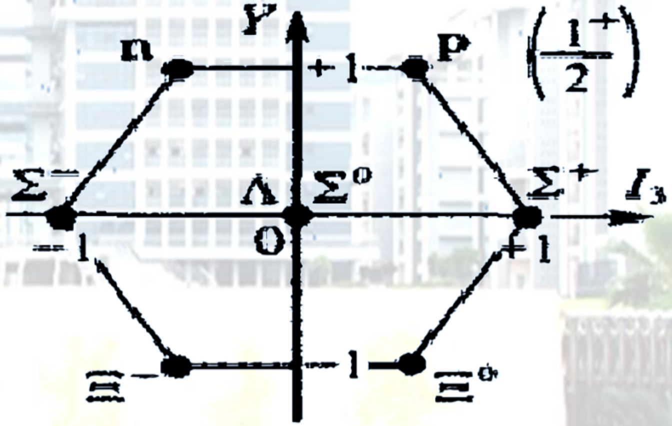
- Motivation
- Boss versions and DATA sets
- Event selection
- Background analysis with the inclusive MC samples
- The $e^+e^- \to \Sigma^0\bar{\Sigma}^0$ cross sections
- The branching fractions of $J/\psi\big(\psi(3686)\big) \to \Sigma^0\bar{\Sigma}^0$
- Summary

Motivation

- The inner structure of baryons can be parameterized using electromagnetic form factors.

- Experiments have reported cross section measurements for all members of the spin-parity $J^P = (1/2)^+$ baryon octet. Different behaviors have been observed near the threshold.
  An unusual behavior near threshold with $e^+e^- \to p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}$
  No obvious threshold effect was observed with $e^+e^- \to \Sigma^\pm\bar{\Sigma}^\mp, \Sigma^0\bar{\Sigma}^0, \Xi^-\bar{\Xi}^+$

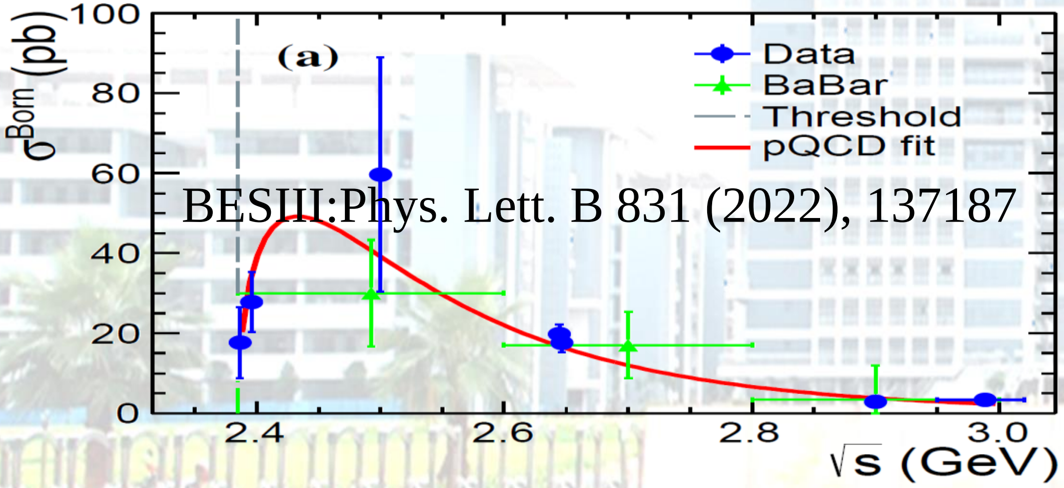




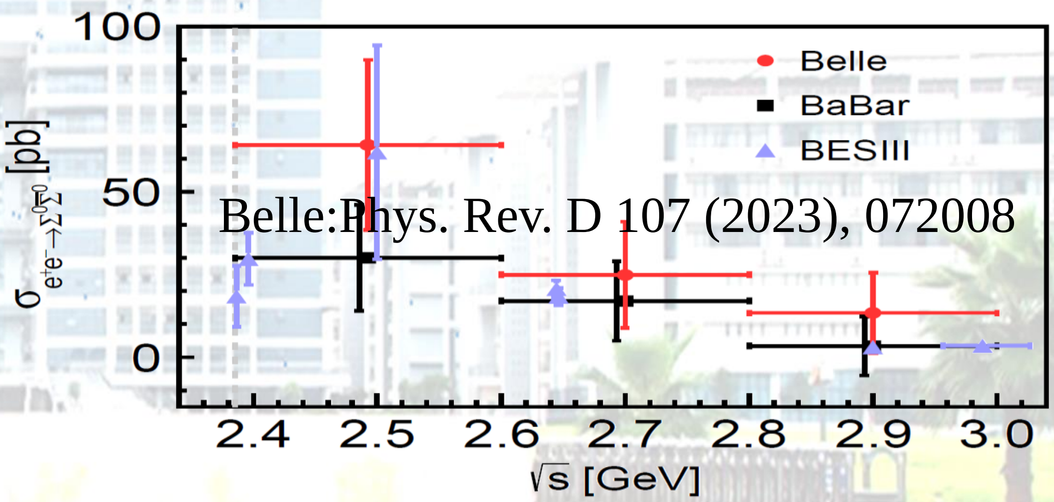
- The unexpected threshold behaviors is discussed as final-state interactions, bound states or near threshold meson resonances, or an attractive Coulomb interaction.

Motivation

- The cross section of the process $e^+e^- \to \Sigma^0\bar{\Sigma}^0$ near its production threshold has been measured by the BESIII using the scan method. A nonzero threshold cross section was observed with a hint of an enhancement at $\sqrt{s} = 2.5$ GeV. However, due to limited statistics, a clear conclusion cannot be drawn.



BESIII:Phys. Lett. B 831 (2022), 137187



Belle:Phys. Rev. D 107 (2023), 072008

- BESIII has collected large luminosity data sets at $\sqrt{s} = 3.773$-4.258 GeV, which can be used to study $e^+e^- \to \gamma^{ISR}\Sigma^0\bar{\Sigma}^0$ via initial state radiation (ISR) technique.

Boss version and DATA sets

➢ The BOSS versions and the Data sets are listed:

$\sqrt{s}$[GeV]	$\mathcal{L}_{\text{int}}$ [pb^{-1}]	run number	Boss Version
3.773 (round02)	2931.8±0.2±13.8	11414-13988, 14395-14604, 20448-23454	7.1.2
3.773 (round15)	4995± - ±19	70522-73929	7.1.2
3.773 (round16)	8157± - ±31	74031-78536	7.1.2
3.773 (round17)	4191± - ±16	78615-81094	7.1.2
4.128	401.5	59163-59573	7.0.5
4.157	408.7	59574-59896	7.0.5
4.178	3189.0±0.2±31.9	43716-45105, 45418-47066	7.0.3
4.189	526.70±2.16±5.3	47543-48170	7.0.3
4.199	526.00±2.05±5.3	48172-48713	7.0.3
4.209	517.10±1.81±5.2	48714-49239	7.0.3
4.219	514.60±1.80±5.2	49270-49787	7.0.3
4.226	44.40±0.03±0.05,1047.34±0.14±10.2	30438-30491,32239-33484	7.0.3
4.236	530.30±2.39±5.3	49788-50254	7.0.3
4.244	538.10±2.69±5.4	50255-50793	7.0.3
4.258	523.74±0.10±5.3,301.93±0.08±3.1	29677-30367,31561-31981	7.0.3

➢ Monte Carlo Simulations

1. The exclusive MC: $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$ with ConExc event generator.
2. The exclusive MC: $e^+e^- \to \gamma^{\text{ISR}}\Lambda\bar{\Sigma}^0 + c.c.$ with ConExc event generator.
3. The exclusive MC: $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ with KKMC event generator.
4. The inclusive MC: $e^+e^- \to q\bar{q}$ (from official inclusive MC).
5. The exclusive MC: $e^+e^- \to \gamma^{\text{ISR}}J/\psi$ and $\gamma^{\text{ISR}}\psi(3686)$ with ConExc event generator.

➢ Data and MC at $\sqrt{s} = 3.773$ GeV used as an example in the following.

Event selection

- The process $e^+e^- \to \gamma^{\rm ISR}\Sigma^0\bar{\Sigma}^0$ is studied with ISR technique. The $\gamma^{\rm ISR}$ is not detected, and the Σ^0 and $\bar{\Sigma}^0$ are reconstructed with the clean process $\Sigma^0 \to \gamma\Lambda \to \gamma p\pi^-$ and $\bar{\Sigma}^0 \to \gamma\bar{\Lambda} \to \gamma\bar{p}\pi^+$, respectively.

Good charged tracks：

1. $|\cos\theta| < 0.93$
2. $|V_{XY}| < 10.0\text{cm}\&|V_Z| < 30.0\text{cm}$
3. $N_{\text{positive track}} \geq 2\&\& \; N_{\text{negative track}} \geq 2$

PID：

1. p:prob(p)>prob(π)&prob(p)>prob(K)
2. $N_{p(\bar{p})} = 1$

Λ and $\bar{\Lambda}$ candidate

1. A Vertex fit with the p and the negative-charged tracks($\bar{p}$ and the positive-charged tracks)
2. $N_\Lambda \geq 1\&\&N_{\bar{\Lambda}} \geq 1$

Good Photon：

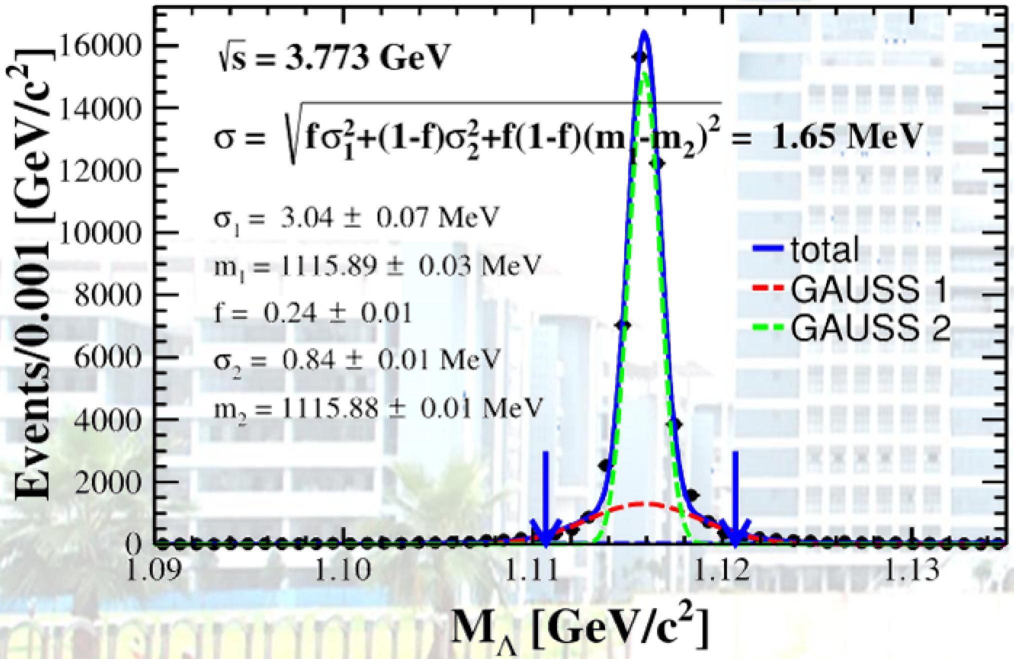
1. $\text{Angle}_{p(\bar{p}),\text{photon}} \geq 10^\circ(20^\circ)$
2. $N_{\text{photon}} \geq 2$

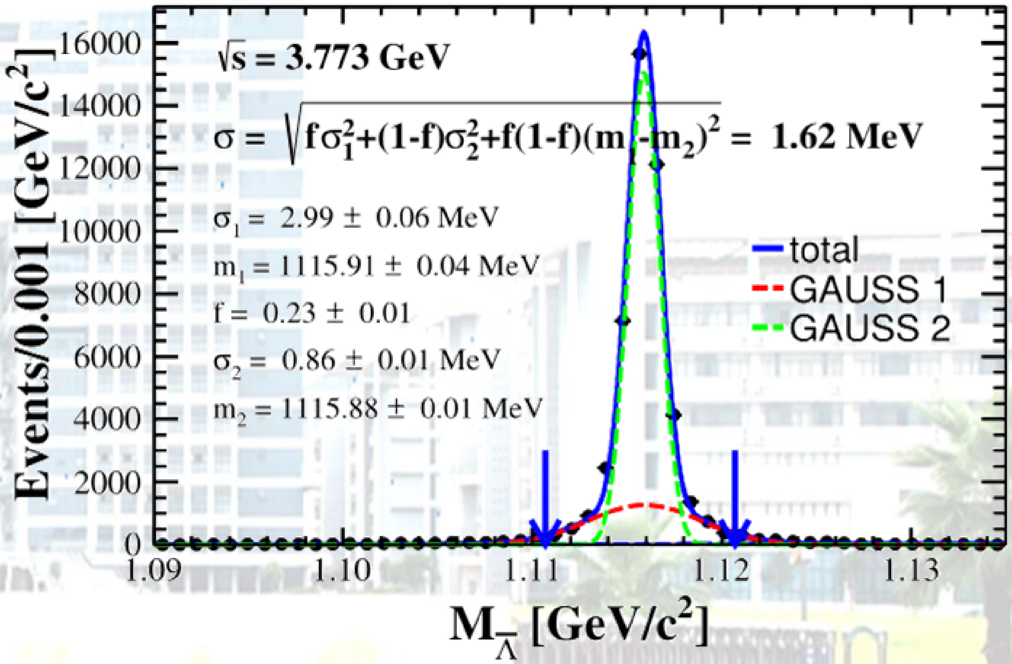
Σ^0 and $\bar{\Sigma}^0$ candidate

1. all the gamma, Λ and $\bar{\Lambda}$
2. Minimum of $\sqrt{\left(M_{\gamma\Lambda} - M_{\Sigma^0}^{\rm PDG}\right)^2 + \left(M_{\gamma\bar{\Lambda}} - M_{\Sigma^0}^{\rm PDG}\right)^2}$

to selection the Σ^0 and $\bar{\Sigma}^0$candidate

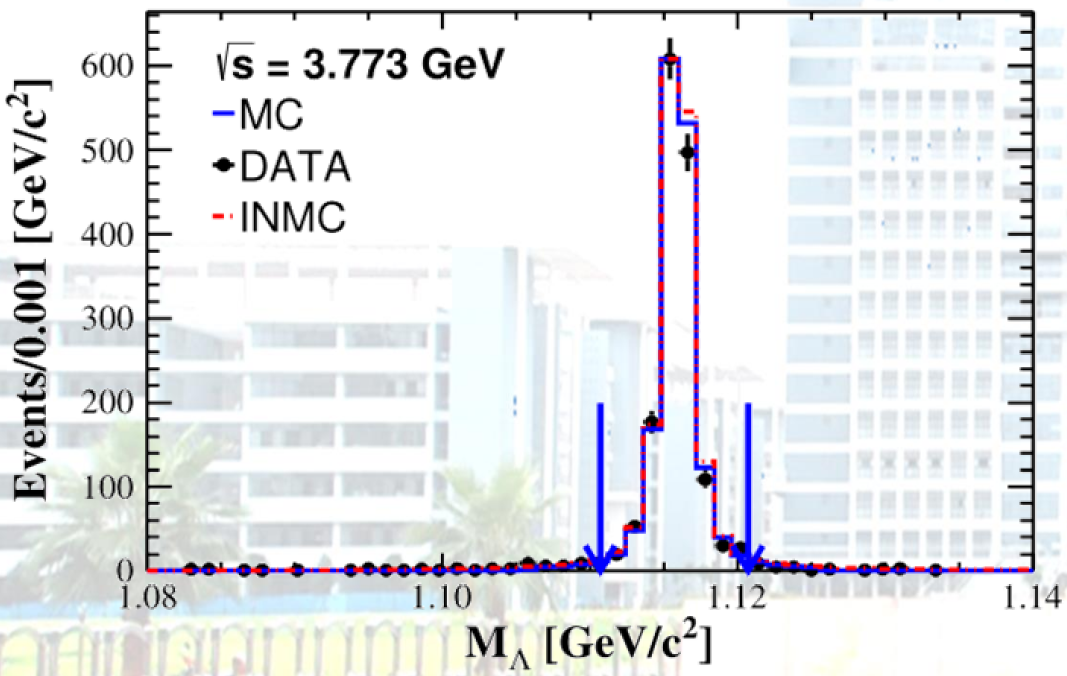
$\mathbf{M_{\Lambda(\bar{\Lambda})}}$ with MC samples

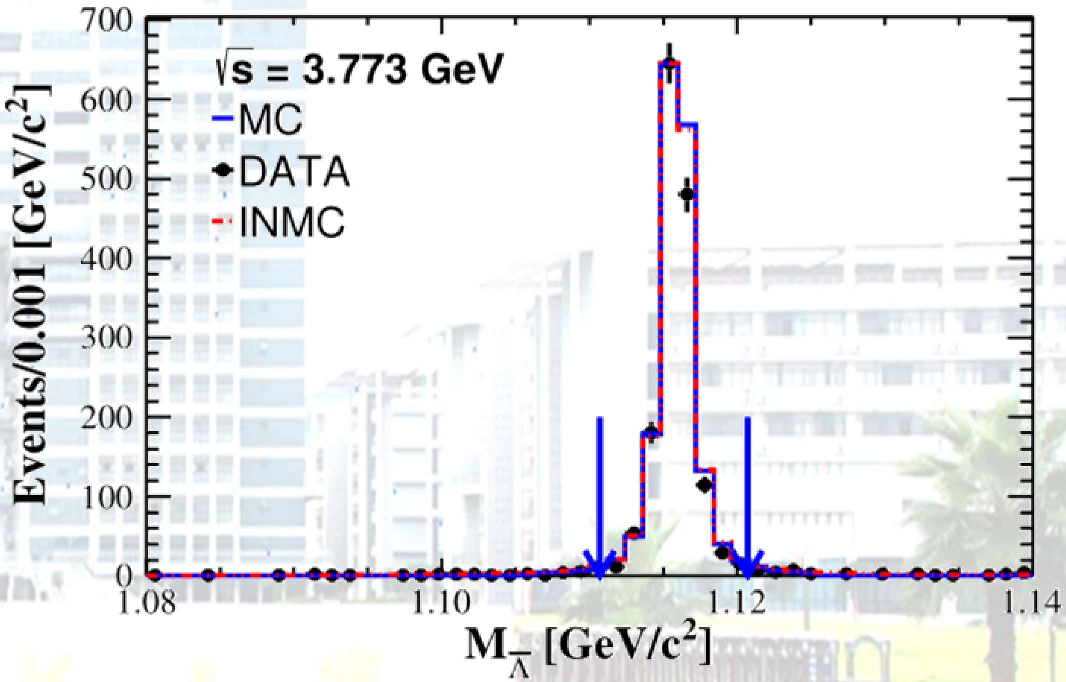




- Fitted to $\mathbf{M_{\Lambda(\bar{\Lambda})}}$ of signal MC samples with double Gaussian function plus linear function, and estimated $\sigma = 1.6$ MeV. Therefore, we required the mass window $\left|\mathbf{M_{\Lambda(\bar{\Lambda})}} - \mathbf{M_{\Lambda}^{PDG}}\right| \leq$ 5.0 MeV.

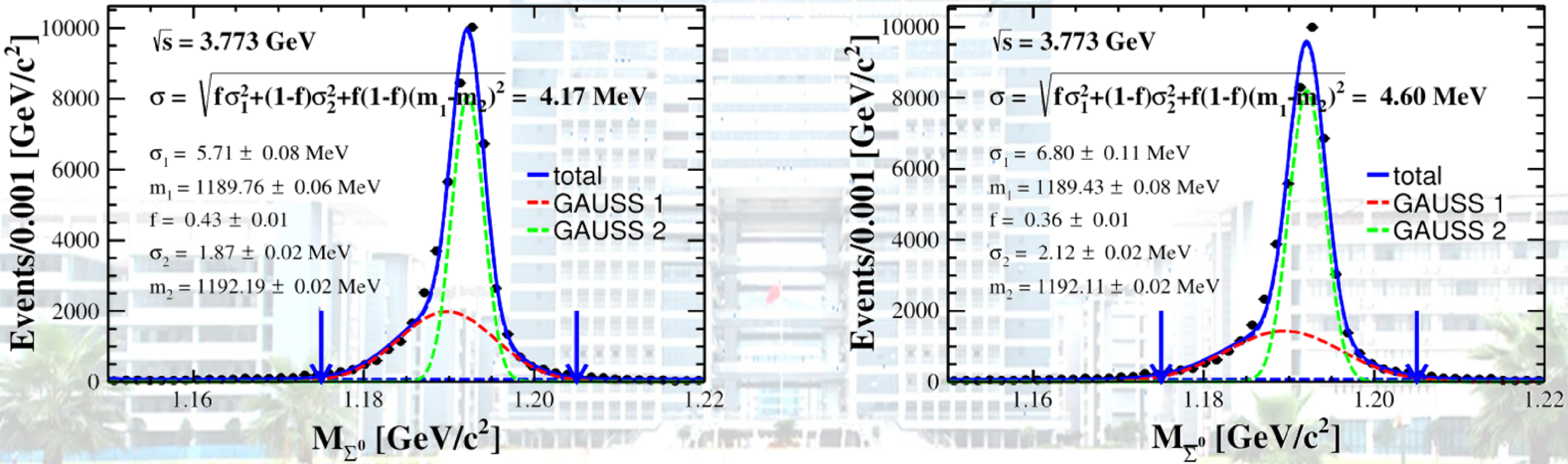
$M_{\Lambda(\bar{\Lambda})}$ distribution





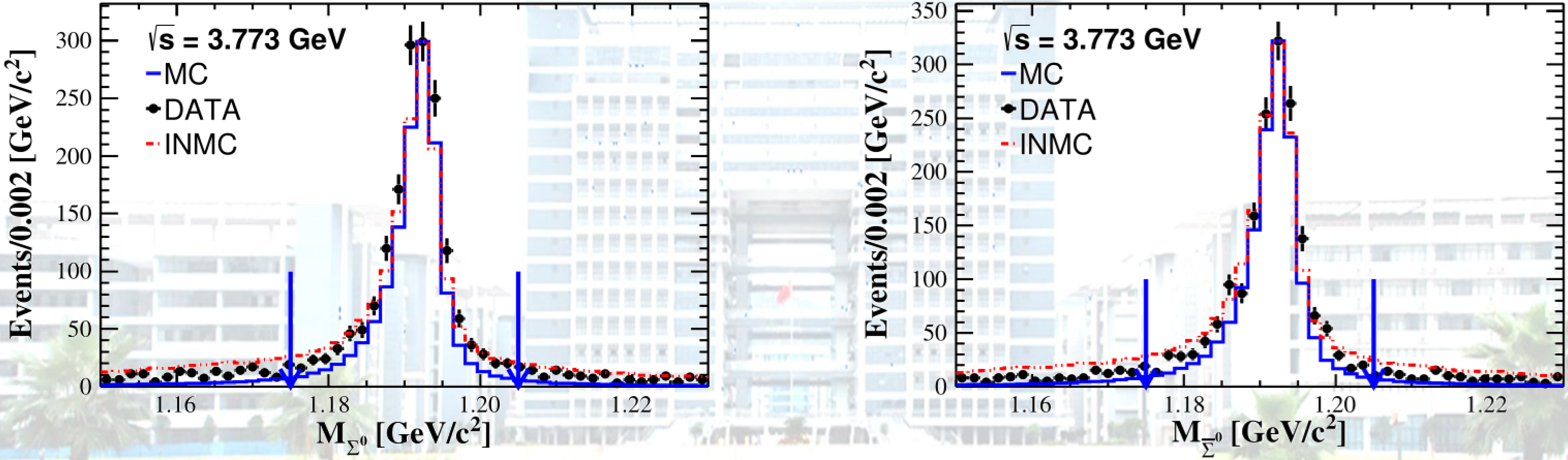
- The distributions of the invariant mass of Λ (left) and $\bar{\Lambda}$ (right) at $\sqrt{s} = 3.773$ GeV. The black dots with error bars is the data, the blue and red dash histograms are the signal MC samples and the inclusive MC samples.

$\mathbf{M}_{\Sigma^0(\bar{\Sigma}^0)}$ with MC samples



- Fitted to $\mathbf{M}_{\Sigma^0(\bar{\Sigma}^0)}$ of signal MC samples with double Gaussian function plus linear function, and estimated $\sigma = 4.5$ MeV. Therefore, we required the mass window $[\mathbf{M}_{\Sigma^0(\bar{\Sigma}^0)} - 4\sigma, \mathbf{M}_{\Sigma^0(\bar{\Sigma}^0)} + 3\sigma]$([1.175,1.205] GeV) is caused by that the photon energy deposited in EMC has a long tail on the low energy side.

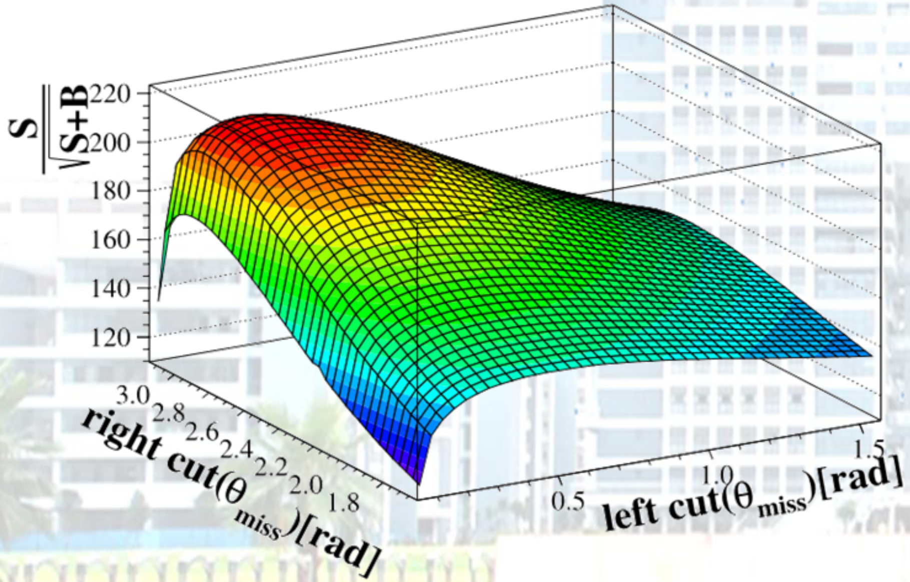
$M_{\Sigma^0(\bar{\Sigma}^0)}$ distribution

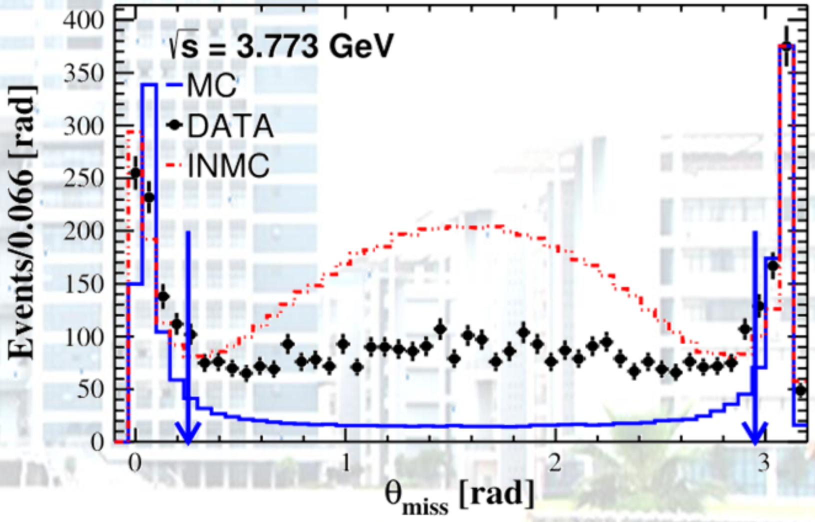


- The distributions of the invariant mass of Σ^0(left) and $\bar{\Sigma}^0$ (right) at $\sqrt{s} = 3.773$ GeV. The black dots with error bars is the data, the blue and red dash histograms are the signal MC samples and the inclusive MC samples.

θ_{miss} distribution

- The ISR photon polar angle θ_{miss} is defined as the angle between the momentum of the recoiling against the $\Sigma^0\bar{\Sigma}^0$ system and the beam direction.

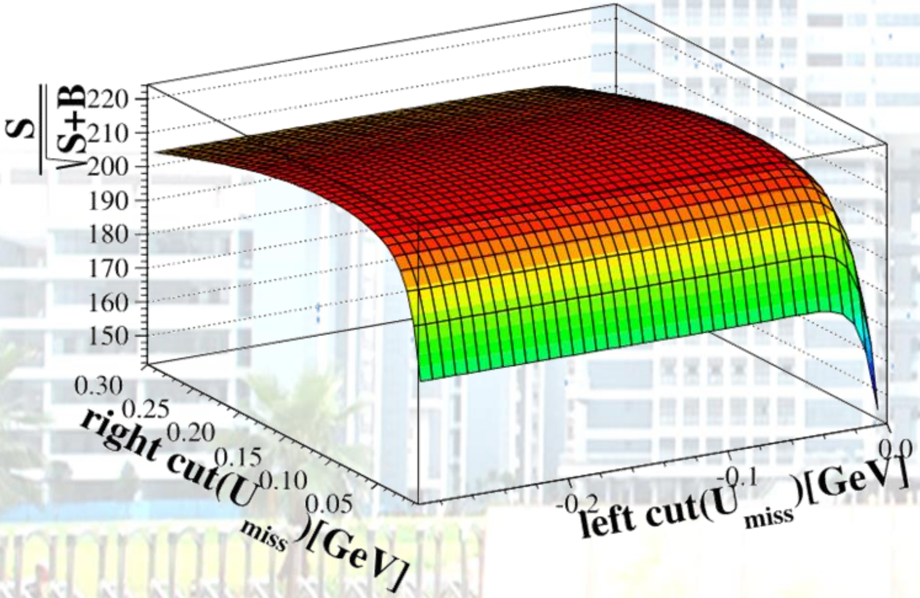


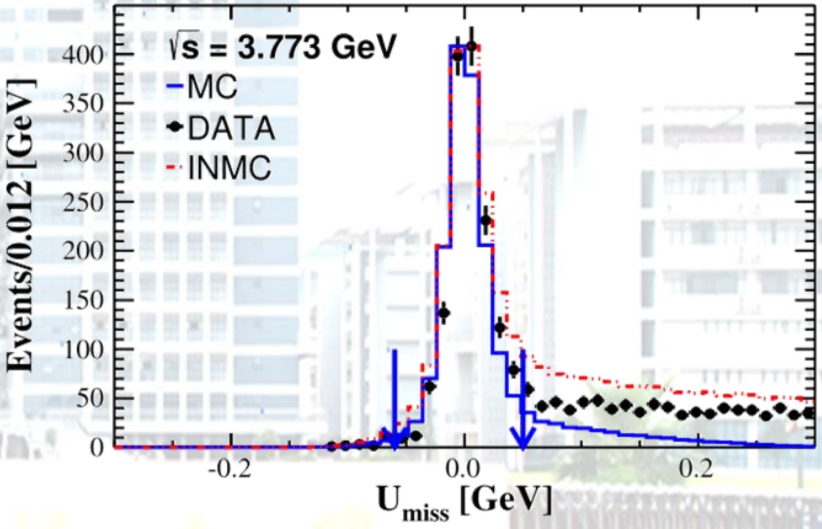


- To suppress the hadronic background, in particular the process $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$, and according to the optimization diagram, the θ_{miss} is required to be in the region $\theta_{\text{miss}} < 0.25$ or $\theta_{\text{miss}} > 2.95$ rad, where the S is the signal events and B is the backgrounds from the inclusive MC samples.

U_{miss} distribution

- The U_{miss} is defined as $U_{\text{miss}} = E^{\text{rec}}_{\Sigma^0\bar{\Sigma}^0} - P^{\text{rec}}_{\Sigma^0\bar{\Sigma}^0}$, where the $E^{\text{rec}}_{\Sigma^0\bar{\Sigma}^0}$ and $P^{\text{rec}}_{\Sigma^0\bar{\Sigma}^0}$ are the energy and momentum of the recoiling against the $\Sigma^0\bar{\Sigma}^0$ system.

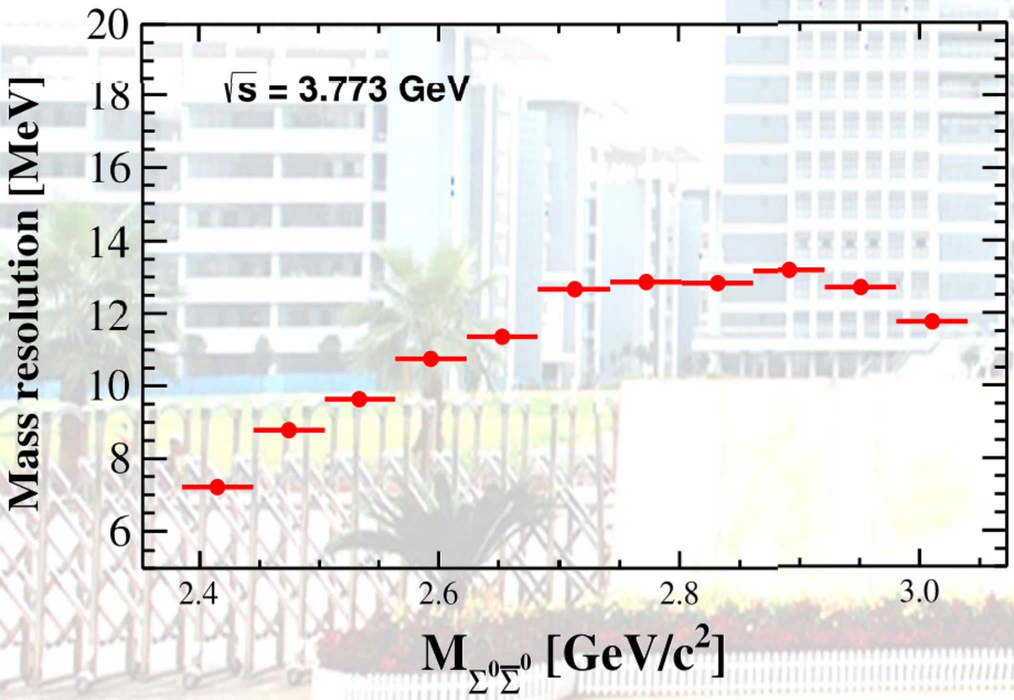


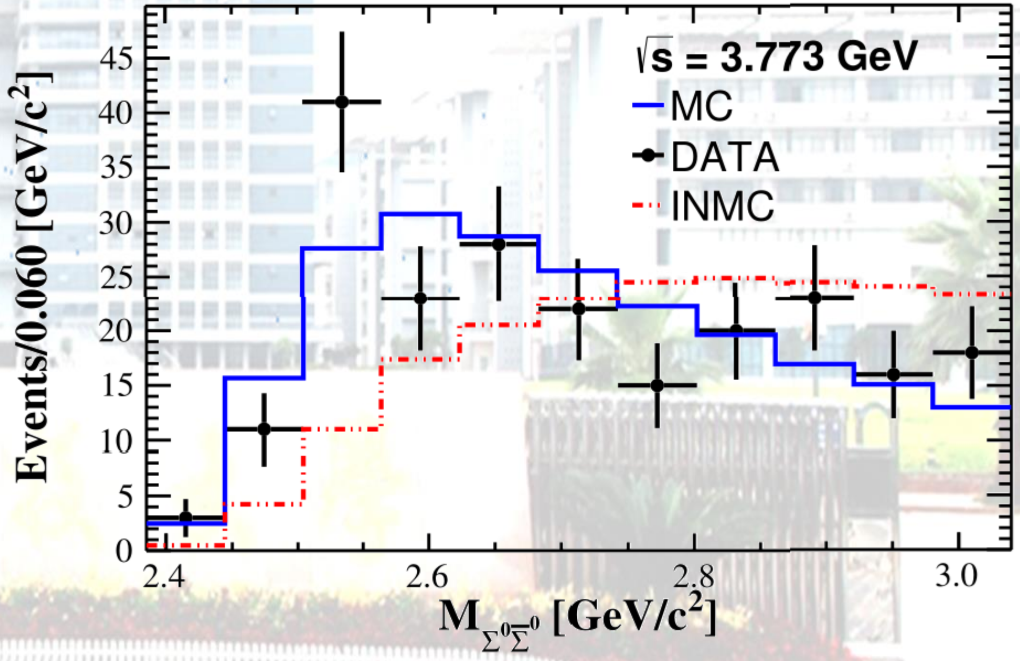


- According to the optimization diagram at $\sqrt{s} = 3.773$ GeV, the U_{miss} is required to be in the region [-0.06,0.05] GeV, where the S is the signal events and B is the backgrounds from the inclusive MC samples.

Mass resolution of $\Sigma^0\bar{\Sigma}^0$

- To reduce the impact of the mass resolution of $\Sigma^0\bar{\Sigma}^0$, when calculating cross section, the mass of $\Sigma^0\bar{\Sigma}^0$ interval size should be greater than 5 times resolution, at least.
- According to the mass resolution of $\Sigma^0\bar{\Sigma}^0$ and the mass distributions of $\Sigma^0\bar{\Sigma}^0$ of data, divide up the mass of $\Sigma^0\bar{\Sigma}^0$ to 9 intervals from threshold to 3.04 GeV.





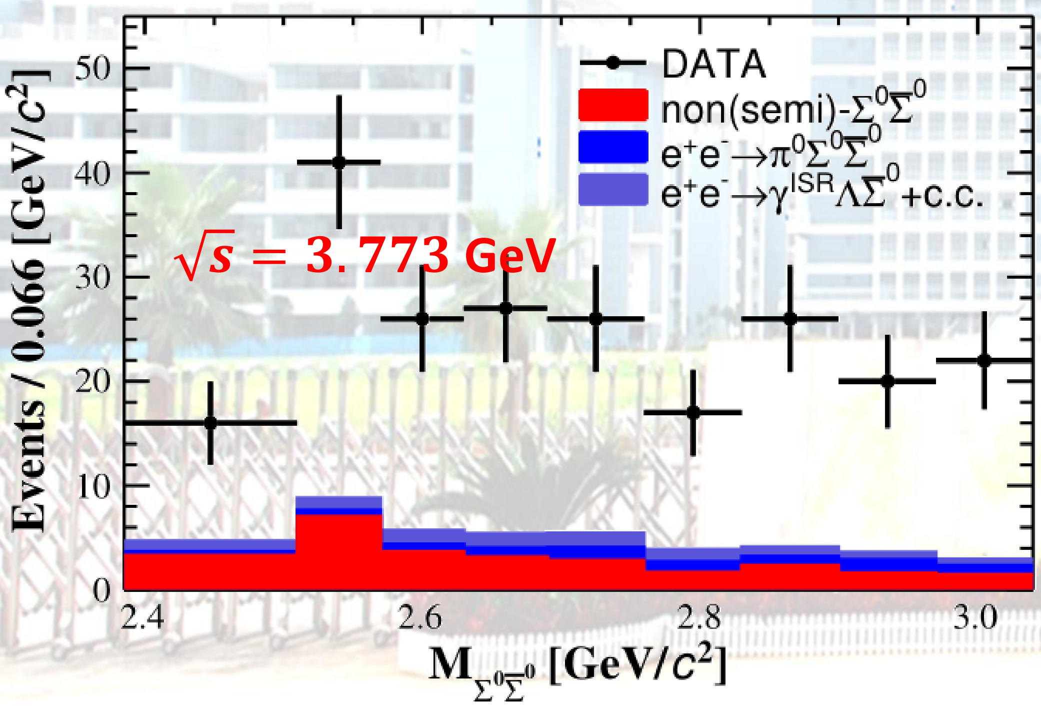
Background analysis

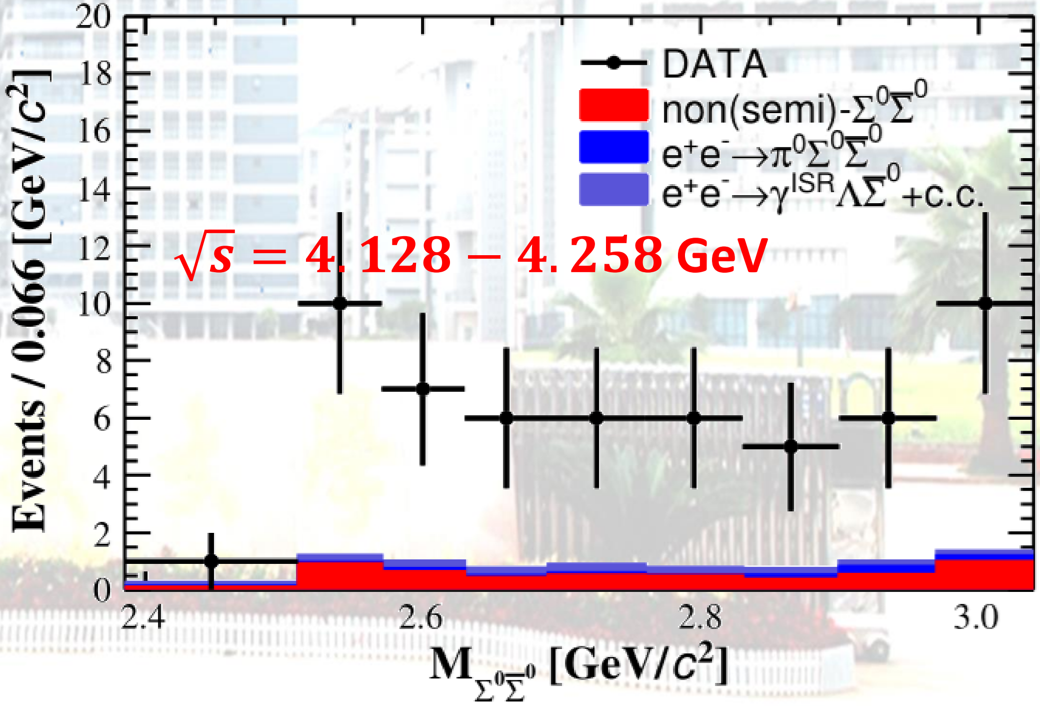
- According to the topology analysis, the possible background channels we need to study are listed as follows. N^{sur} is the number of events survived in the inclusive MC samples and the Ratio represents the ratio of N^{sur} to the total events number. The process $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$ is signal channel.

Channels	N^{sur}	Ratio[%]
$e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$	60502	75.72
$e^+e^- \to \gamma^{\text{ISR}}\Lambda\bar{\Sigma}^0$+c.c.	6047	7.57
$e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$	2356	2.95
Non(semi)-$\Sigma^0\bar{\Sigma}^0$	2356	13.76

Background analysis

➢ After the background analysis, we summarized the background channels. The $e^+e^- \to \gamma^{\mathrm{ISR}}\Lambda\bar{\Sigma}^0 + c.c.$ background events estimated using MC simulation method, the $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ background events estimated with the Data-driven method, the non(semi)-$\Sigma^0\bar{\Sigma}^0$ background events estimated using the inclusive MC samples.





Cross section and $|G_{\mathrm{eff}}|$

- The cross sections at each bin can be expressed as:

$$\sigma_{\Sigma^0\bar{\Sigma}^0}(\sqrt{s}) = \frac{dN_{\mathrm{sig}}/dM_{\Sigma^0\bar{\Sigma}^0}}{\varepsilon * \mathcal{B}^2(\Sigma^0) * \mathcal{B}^2(\Lambda) * d\mathcal{L}_{\mathrm{int}}/dM_{\Sigma^0\bar{\Sigma}^0}}$$

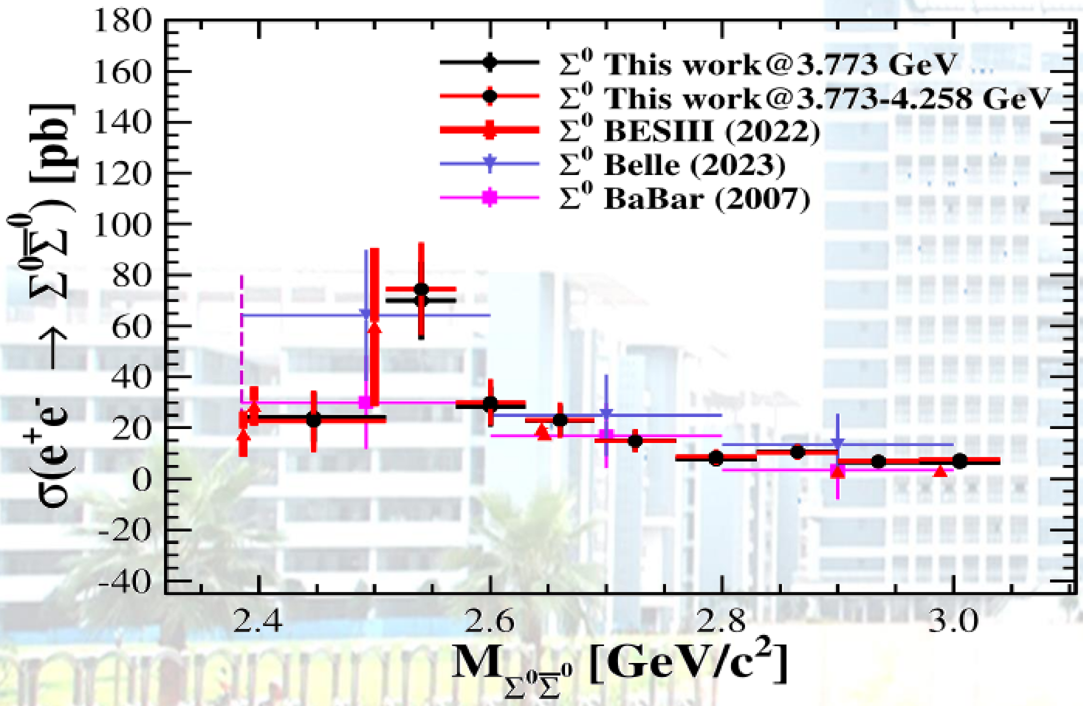
- The cross section for the process $e^+e^- \to \gamma^{\mathrm{ISR}}\Sigma^0\bar{\Sigma}^0$ depends on magnetic $|G_M|$ and electric $|G_E|$ from factors[From Phys. Rev. 124 (1961), 1577] as follows:

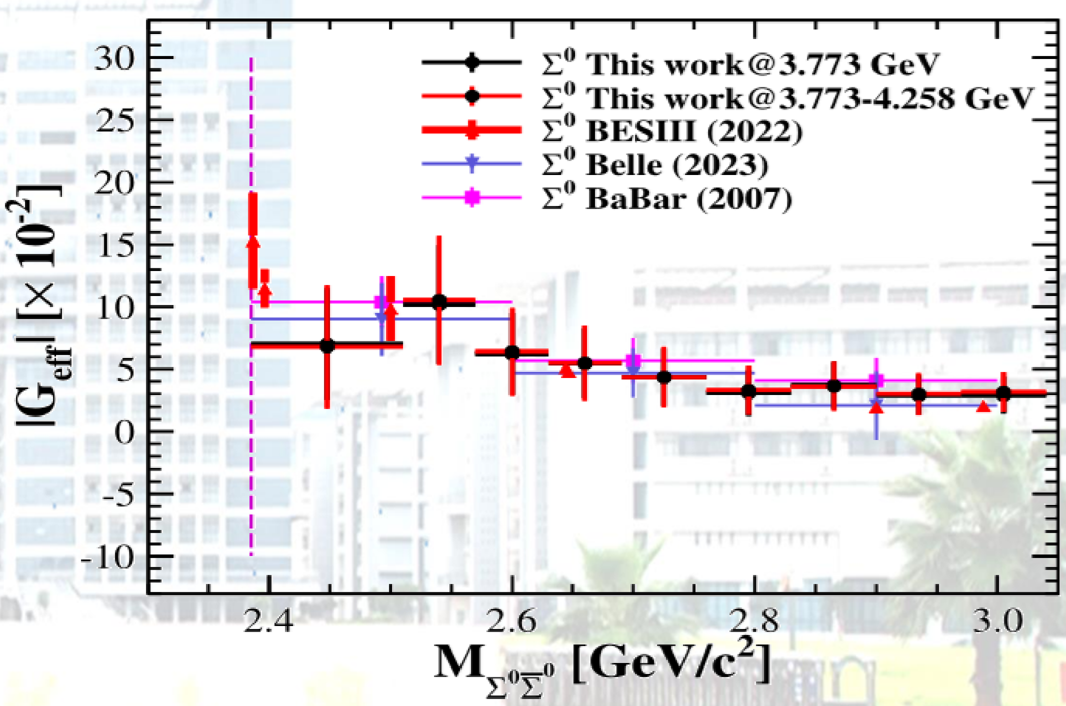
$$\sigma_{\Sigma^0\bar{\Sigma}^0}(\sqrt{s}) = \frac{4\pi\alpha^2\beta}{3\sqrt{s}}\left[\left|G_M(\sqrt{s})\right|^2 + \frac{1}{2\tau}\left|G_E(\sqrt{s})\right|^2\right]$$

- The cross section determines the linear combination of the squared from factors, and we define $\left|G_{\mathrm{eff}}(\sqrt{s})\right|$ to be the effective from factor[From Phys. Rev. D 91 (2015), 112004]:

$$\left|G_{\mathrm{eff}}(\sqrt{s})\right|^2 = \frac{2\tau\left|G_M(\sqrt{s})\right|^2 + \left|G_E(\sqrt{s})\right|^2}{2\tau+1}$$

Cross section and $|G_{\text{eff}}|$





- The $e^+e^- \to \Sigma^0\bar{\Sigma}^0$ cross sections and the distributions of the effective FFs.

Systematic uncertainty

- The uncertainties of the luminosity and the radiative function $W(s,x)$ are estimated to be 0.71% and 1.12% at $\sqrt{s}=3.773$ and 4.128-4.258 GeV. (⇛LF)
- The uncertainty of the intermediate state branching fraction($\Sigma^0(\bar{\Sigma}^0)\to\Lambda\gamma(\bar{\Lambda}\gamma)$ and $\Lambda(\bar{\Lambda})\to p\pi^-(\bar{p}\pi^+)$) is estimated to be 1.6% . (⇛BF)
- The systematic uncertainty due to the photon reconstruction is estimated to be 1.0%.(⇛PR)
- The systematic uncertainty due to the $\Lambda(\bar{\Lambda})$ reconstruction is estimated by studying the decay process $J/\psi\to pK^-\Lambda+\mathrm{c.c.}$, and it is estimated to be 1.94% and 2.09% at $\sqrt{s}=3.773$ and 4.178 GeV. The uncertainties of other energy points between 4.128 and 4.258 GeV is inherited from 4.178 GeV.(⇛ ΛR)
- The uncertainties of the Σ mass window requirement and the U_{miss} requirement are estimated via studying the $\psi(3686)\to\gamma\chi_{C0},\chi_{C0}\to\Sigma^0\bar{\Sigma}^0$decay, and they are estimated to be 0.15% and 2.25%, respectively. (⇛ ΣMW and U_{miss})
- The uncertainty due to the θ_{miss} requirement is estimated via studying $\psi(3686)\to\gamma\chi_{C0}(\to\Sigma^0\bar{\Sigma}^0)$ decay, and it is estimated to be 2.30%. (⇛ θ_{miss})

Systematic uncertainty

- The signal MC samples are generated in phase space (PHSP) model. To consider the uncertainty of the angular distribution, the transverse polarization, and spin correlation between both hyperons Σ^0, we employed the mDIY model. Using $\psi(3686)$ as a commissioning sample, the relative difference of detection efficiency from the PHSP mode and the mDIY model is regarded as the uncertainty of the MC model, and it is estimated to be 1.01%. (⇛⇛MCM)
- The systematic uncertainty of the $e^+e^- \to \gamma^{\mathrm{ISR}}\Lambda\bar{\Sigma}^0 + c.c.$, $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$, and non(semi)-$\Sigma^0\bar{\Sigma}^0$ background events are discussed, and it is estimated to be 6.36% and 5.94% at $\sqrt{s} = 3.773$ and 4.128-4.258 GeV. (⇛⇛ BKG)

Systematic uncertainty

Systematic uncertainty of two data set groups, $\sqrt{s}$ = 3.773 and 4.128-4.258 GeV, are combined as average value weighted by detection efficiencies.

$$\sigma_{\rm tot}^2 = \sum_{i=1}^{2} \omega_i^2 \sigma_i^2 + \sum_{i,j=1;i\neq j}^{2} \rho_{ij}\omega_i\omega_j\sigma_i\sigma_j,$$

$$\omega_i = \frac{\varepsilon_i(dN_{\rm int}/dM_{\Sigma^0\bar{\Sigma}^0})_i}{\sum_{i=1}^{2}\varepsilon_i(dN_{\rm int}/dM_{\Sigma^0\bar{\Sigma}^0})_i},$$

Summary of systematic uncertainty (%) to $e^+e^- \to \gamma^{\rm ISR}\Sigma^0\bar{\Sigma}^0$ cross section measurements in each $M_{\Sigma^0\bar{\Sigma}^0}$, combined all c.m energies.

$M_{\Sigma^0\bar{\Sigma}^0}$[GeV]	LF	BF	PR	ΛR	ΣWM	$U_{\rm miss}$	$\theta_{\rm miss}$	MCM	BKG	Total
[2.385,2.51]										
[2.51,2.57]										
[2.57,2.63]										
[2.63,2.69]										
[2.69,2.76]	0.79	1.60	1.00	1.97	0.15	2.25	2.30	6.31	1.01	7.70
[2.76,2.83]										
[2.83,2.90]										
[2.90,2.97]										
[2.97,3.04]										

Discussion of the cross section

- The perturbative QCD-motivated [PR 550-551 (2015)] energy power (Method 1):

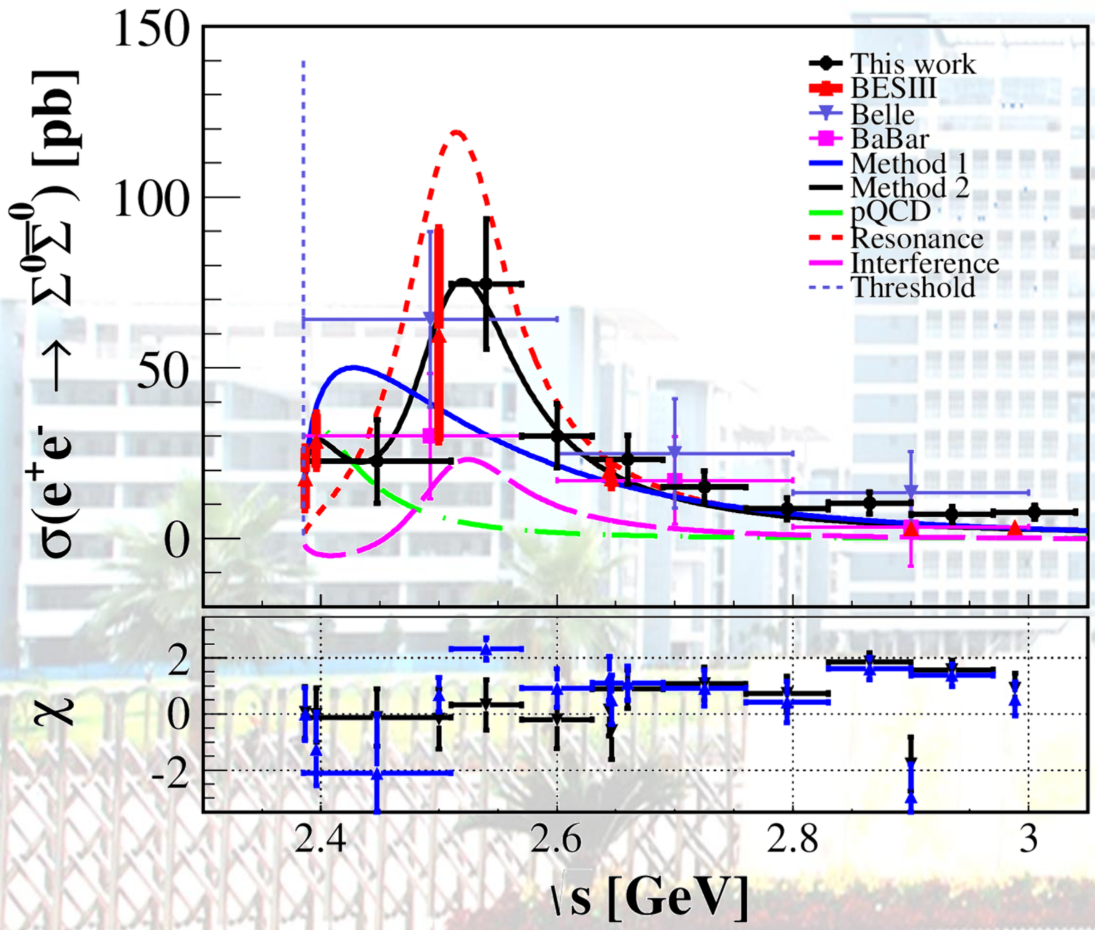
$$\sigma_{B\bar{B}}(s) = \frac{C\beta}{s}\left(1 + \frac{2M_B M_{\bar{B}}}{s}\right)\frac{c_0}{(s - c_1)^4[\pi^2 + \ln^2(s/\Lambda_{\rm QCD}^2)]^2}$$

- The perturbative QCD-motivated energy power function is assumed to model the $e^+e^- \to \gamma^{\rm ISR}\Sigma^0\bar{\Sigma}^0$ line shape product by have considering the contribution of intermediate resonant state, and the function is expressed as (Method 2):

$$\sigma_{B\bar{B}}(s) = \left|\sqrt{\frac{C\beta}{s}\left(1 + \frac{2M_B^2}{s}\right)\frac{c_0}{(s - c_1)^4[\pi^2 + \ln^2(s/\Lambda_{\rm QCD}^2)]^2}} + e^{i\phi}BW(s)\sqrt{\frac{P(s)}{P(M)}}\right|^2$$

Method 1 and 2 : c_0 and c_1 are the normalization and the contribution of resonant states $\Lambda_{\rm QCD} = 0.3$ is the QCD scale.

Discussion of the cross section

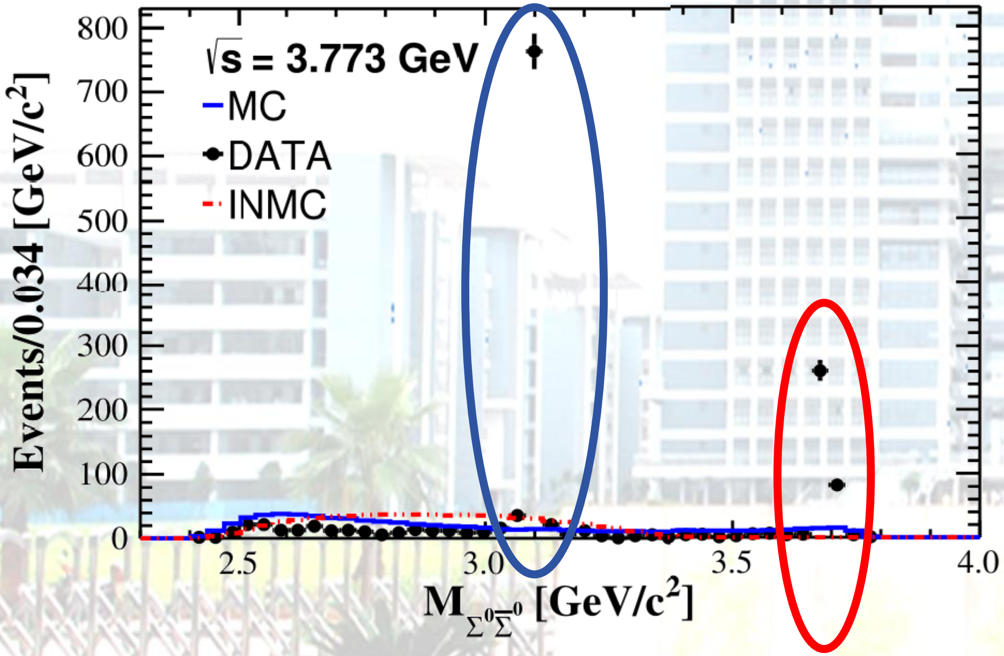


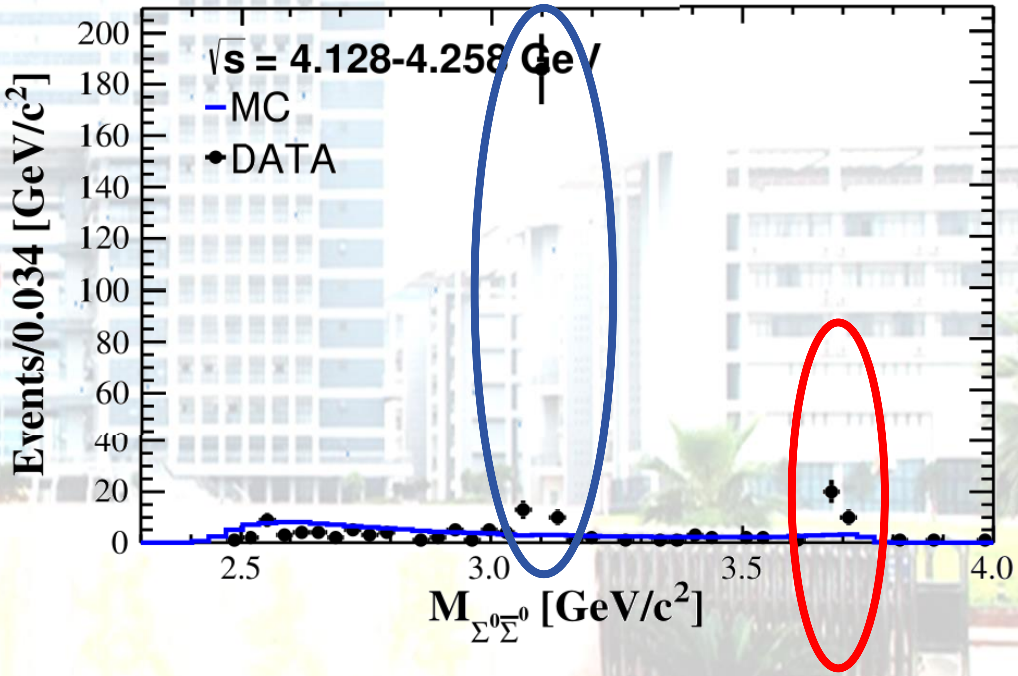
Method	Parameter	$e^+e^- \to \Sigma^0\bar{\Sigma}^0$
1	$c_0 \times 10^3$[pb^{-1}.GeV^{10}]	3.11±0.58
	c_1[GeV]	2.03±0.03
2	c_0[pb^{-1}.GeV^{10}]	23.21±40.81
	c_1[GeV]	2.28±0.18
	$\Gamma^{ee}\mathcal{B}$	2.13±0.76
	M[GeV$/c^2$]	2.51±0.02
	Γ[MeV$/c^2$]	0.11±0.06
	ϕ[rad]	4.61±1.00

According to the fit results with Method 1 and 2, the statistical significance of adding the resonance is 2.6σ.

$M_{\Sigma^0\bar{\Sigma}^0}$ distribution

- It is possible to access the narrow resonances J/ψ (**blue box**) and $\psi(3686)$ (**red box**).



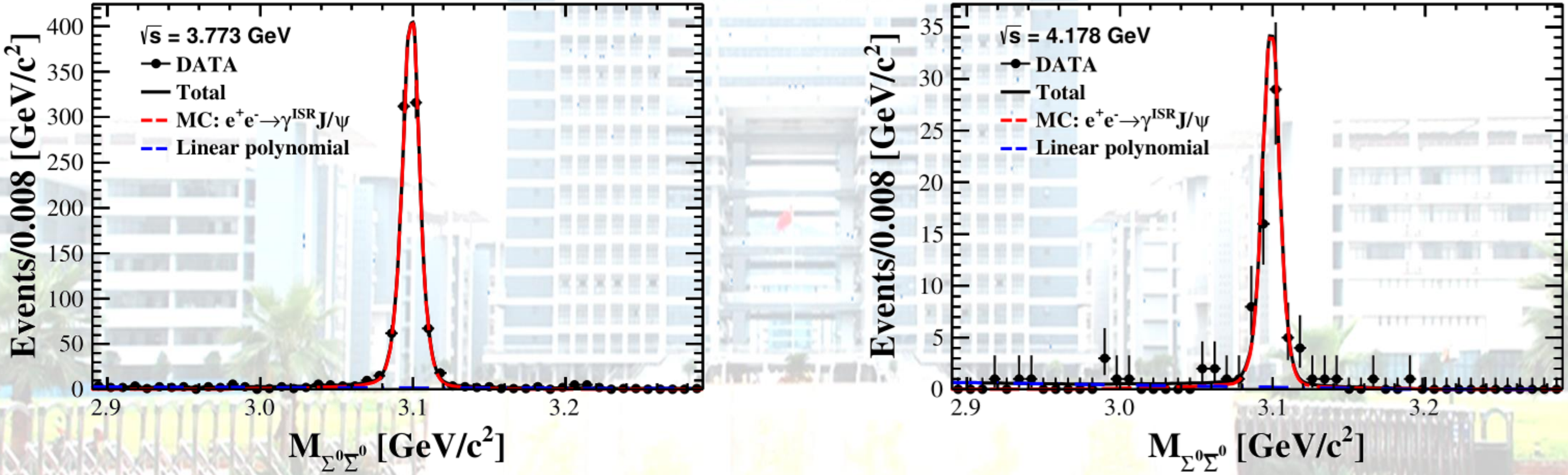


- The distributions of the invariant mass of $\Sigma^0\bar{\Sigma}^0$ at $\sqrt{s}$ = 3.773 and 4.128-4.258 GeV.

Fit to the $M_{\Sigma^0\bar{\Sigma}^0}$ distribution

- The branching ratio obtained by formula:

$$\Gamma(V \to e^+e^-)\mathcal{B}(V \to \Sigma^0\bar{\Sigma}^0) = \frac{N_{\text{sig}}}{\mathcal{L}_{\text{tot}}*\varepsilon_V*\mathcal{B}^2(\Sigma^0)*\mathcal{B}^2(\Lambda)} * \frac{m_V*s}{12\pi^2*\mathrm{W}(s,x_0)} \quad (V = J/\psi)$$

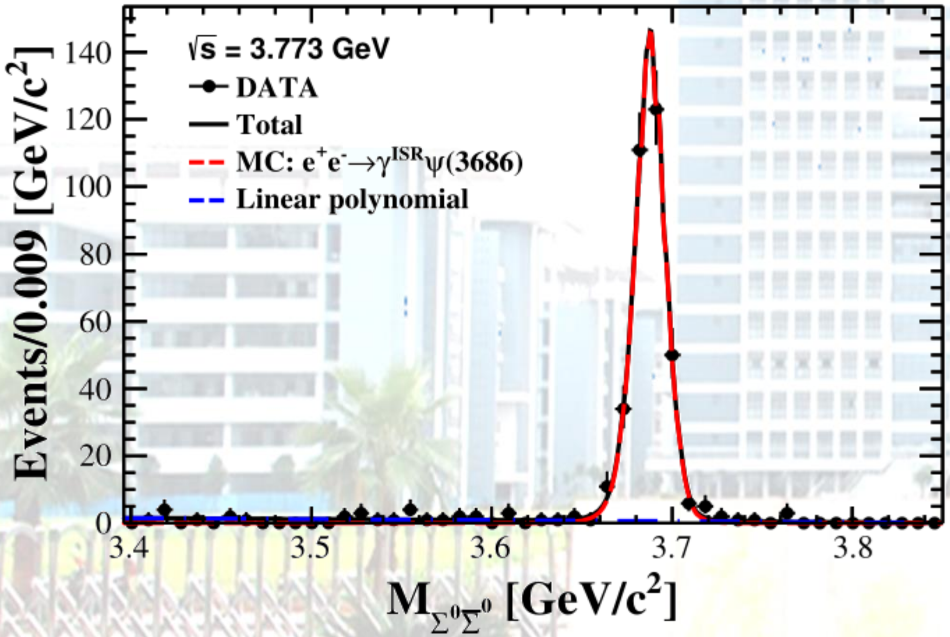


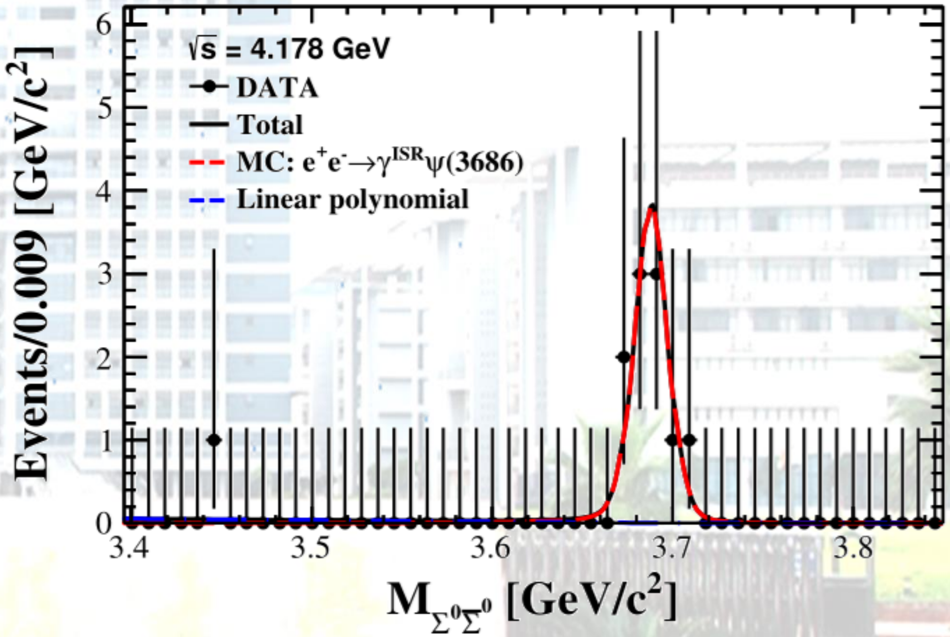
- A simultaneous fit with $\sqrt{s}$ =3.773 and 4.178 GeV: fitted to $M_{\Sigma^0\bar{\Sigma}^0}$ with the correlation MC samples shape plus linear function, and estimated $\mathcal{B}(J/\psi \to \Sigma^0\bar{\Sigma}^0)$. The $\mathcal{B}(J/\psi \to \Sigma^0\bar{\Sigma}^0)$ as a parameter.

Fit to the $M_{\Sigma^0\bar{\Sigma}^0}$ distribution

- The branching ratio obtained by formula:

$$\Gamma(V \to e^+e^-)\mathcal{B}(V \to \Sigma^0\bar{\Sigma}^0) = \frac{N_{sig}}{\mathcal{L}_{tot} * \varepsilon_V * \mathcal{B}^2(\Sigma^0) * \mathcal{B}^2(\Lambda)} * \frac{m_V * s}{12\pi^2 * \mathrm{W}(s, x_0)} \quad (V = \psi(3686))$$





- A simultaneous fit with $\sqrt{s}$ =3.773 and 4.178 GeV: fitted to $M_{\Sigma^0\bar{\Sigma}^0}$ with the correlation MC samples shape plus linear function, and estimated $\mathcal{B}(\psi(3686) \to \Sigma^0\bar{\Sigma}^0)$. The $\mathcal{B}(\psi(3686) \to \Sigma^0\bar{\Sigma}^0)$ also as a parameter.

$\mathcal{B}(J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0)$

- The measured of $\mathcal{B}(J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0)$ are listed as follows:

Process	$\sqrt{s}$[GeV]	W(s,x)	ε_V[%]	$N_{\rm sig}$	This work	Previous results
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	3.773	0.171	9.15	807.56 ± 28.55	10.72 ± 0.37	$11.64 \pm 0.04 \pm 0.23$
	4.178	0.115	9.91	75.45 ± 8.70		
$\psi(3686) \to \Sigma^0\bar{\Sigma}^0$	3.773	1.370	6.12	334.34 ± 18.50	2.34 ± 0.13	$2.44 \pm 0.03 \pm 0.11$
	4.178	0.272	10.08	14.02 ± 3.85		

- They are consistent with the values $\mathcal{B}(J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0)$ measured by BESIII (Phys. Rev. D 95 (2017), 052003), respectively.

- As a check, the sideband method has been used to extract the signal yields and the results of two method are consistent.

Systematic uncertainty(BF)

Some sources of systematic uncertainty on the measurement of the $\mathcal{B}(J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0)$ are the same as the cross section measurement. So, summary of the systematic uncertainty contributions (%) to the measurement of the branching fraction of $J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0$.

Source	Uncertainty of J/ψ	Uncertainty of $\psi(3686)$
LF	0.79	0.79
BF	1.60	1.60
PR	1.00	1.00
ΛR	1.97	1.97
ΣWM	0.15	0.15
$U_{\rm miss}$	2.25	2.25
$\theta_{\rm miss}$	2.30	2.30
MC model	2.47	2.58
Fit region	0.36	0.42
Signal model of the fit	0.09	0.84
Background model of the fit	0.00	0.00
Total	4.97	5.10

Summary

- Based on data samples with the luminosity of 29.34 fb^{-1} at $\sqrt{s} = 3.773$ and 4.128-4.258 GeV, the cross sections for process $e^+e^- \to \gamma^{ISR}\Sigma^0\bar{\Sigma}^0$ and the $\Sigma^0(\bar{\Sigma}^0)$ effective FFs have been measured in 9 $\Sigma^0\bar{\Sigma}^0$ mass intervals from threshold to 3.04 GeV with ISR technique.

  - ✓ The resulting cross sections of $e^+e^- \to \gamma^{ISR}\Sigma^0\bar{\Sigma}^0$ channel and the $\Sigma^0(\bar{\Sigma}^0)$ effective FFs are consistent with previous results from BESIII(Phys. Lett. B 831 (2022), 137187) in different $\Sigma^0\bar{\Sigma}^0$ mass intervals.
  - ✓ In addition, the branching fractions of $J/\psi(\psi(3686)) \to \Sigma^0\bar{\Sigma}^0$ decays are also measured. The results are in good agreements with the latest measurements of BESIII(Phys. Rev. D 95 (2017), 052003).

Thanks!

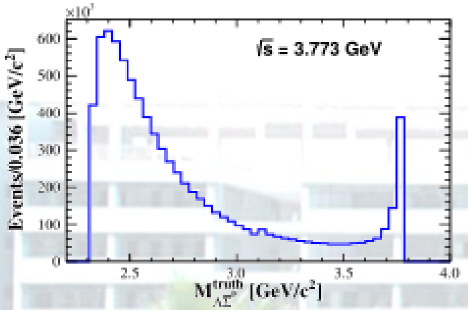
Backup

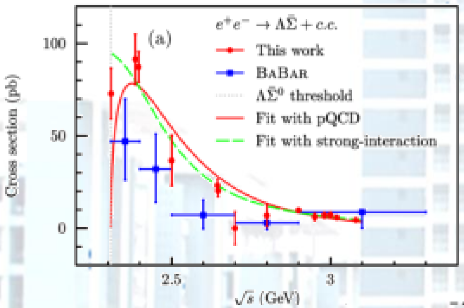
- Monte Carlo Simulations at $\sqrt{s} = 3.773$ GeV

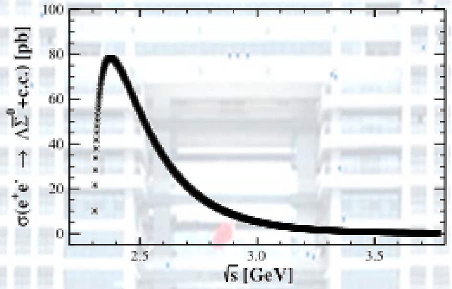
Process	Total number
$e^+e^- \to \gamma^{\mathrm{ISR}}\Sigma^0\bar{\Sigma}^0$	8120000 (round02:round15:round16:round17 = 29:50:82:42)
$e^+e^- \to \gamma^{\mathrm{ISR}}\Lambda\bar{\Sigma}^0$+c.c.	8120000 (round02:round15:round16:round17 = 29:50:82:42)
$e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$	8120000 (round02:round15:round16:round17 = 29:50:82:42)
$e^+e^- \to \gamma^{\mathrm{ISR}}J/\psi$	4060000 (round02:round15:round16:round17 = 29:50:82:42)
$e^+e^- \to \gamma^{\mathrm{ISR}}\psi(3686)$	4060000 (round02:round15:round16:round17 = 29:50:82:42)

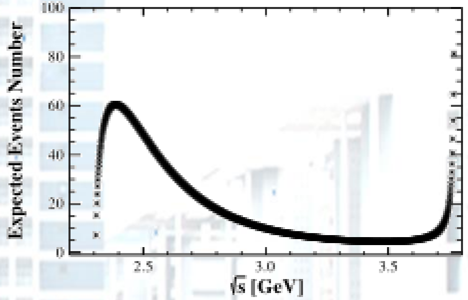
$\Lambda\bar{\Sigma}^0$Background yields

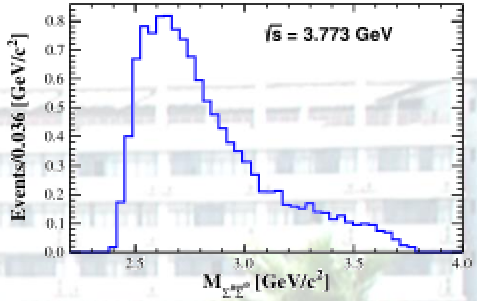
- The dependence of the MC efficiency on $\Lambda\bar{\Sigma}^0$ invariant mass can be obtained by using the $M_{\Lambda\bar{\Sigma}^0}$spectrum from MC truth after being selected by the signal selection criteria to divide that at generator level. And the total number of events of $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$ MC sample is 8120000.







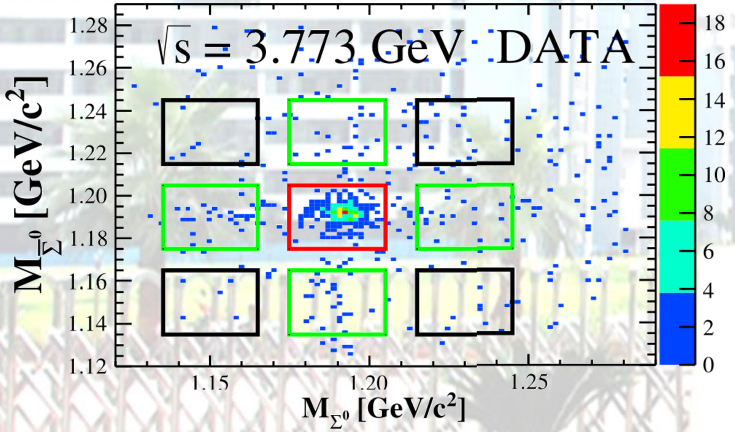


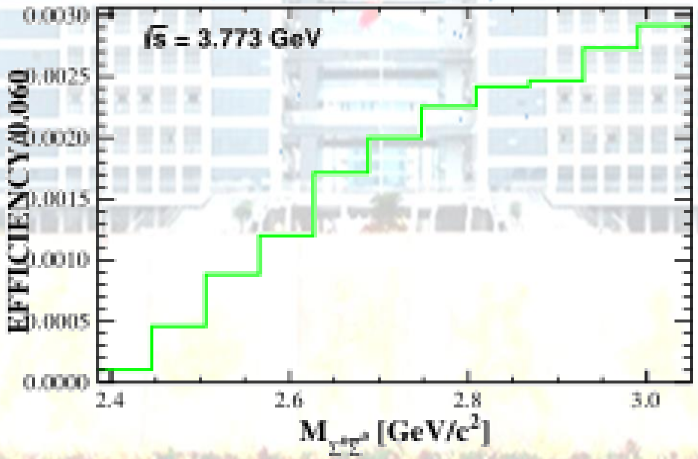


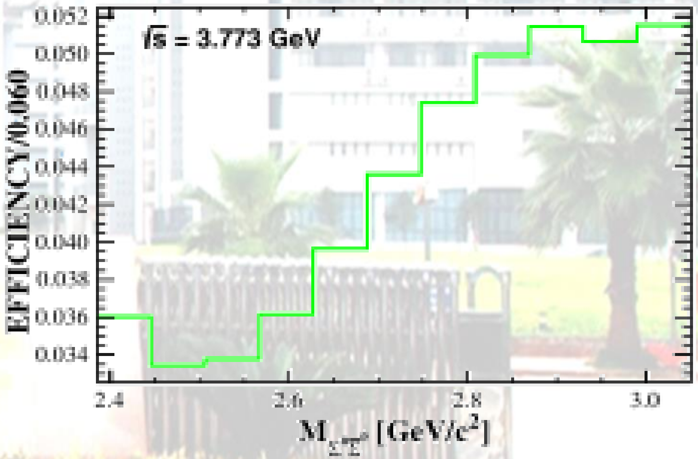
- According to the $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$ lineshape and the distribution of effective luminosity of DATA after ISR process, calculate the expected events number of the $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$ The number of expected events of the $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$ is calculated as 22075.9, so the number of events with decays Σ^0, Λ and $\bar{\Lambda}$ is 9014.1. We can obtained the scaling factor is calculated as 1.11×10^{-3}.
- Finally, we scale the $M_{\Sigma^0\bar{\Sigma}^0}$ spectrum from MC and obtain the $M_{\Sigma^0\bar{\Sigma}^0}$ spectrum, which is the pollution from process $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$. The number of events of this background is estimated as 12.4 ± 3.5.

$\pi^0\Sigma^0\bar{\Sigma}^0$ Background yields

- To ensure a good description of the $e^+e^- \rightarrow \pi^0\Sigma^0\bar{\Sigma}^0$ background in the simulation, we adopted a series of selection conditions. This selection provides a clean $e^+e^- \rightarrow \pi^0\Sigma^0\bar{\Sigma}^0$ event samples.
- The efficiency distributions of the $e^+e^- \rightarrow \pi^0\Sigma^0\bar{\Sigma}^0$ MC samples corresponding to the $e^+e^- \rightarrow \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$(left) and $e^+e^- \rightarrow \pi^0\Sigma^0\bar{\Sigma}^0$(right) selection criteria at $\sqrt{s} = 3.773$ GeV.







$\pi^0\Sigma^0\bar{\Sigma}^0$ Background yields

- To calculate the remaining $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ background contamination in the selected the $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$ signal candidates weighting method is applied:

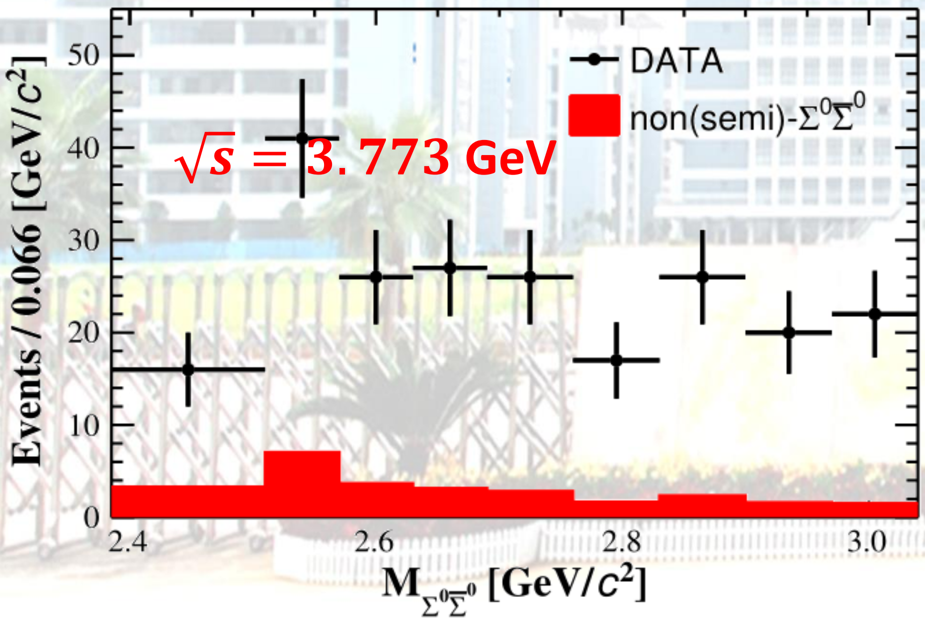
$$N^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0} = \varepsilon^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0} \cdot N^{\text{DATA}}_{\pi^0\Sigma^0\bar{\Sigma}^0} / \varepsilon^{\text{MC}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$$

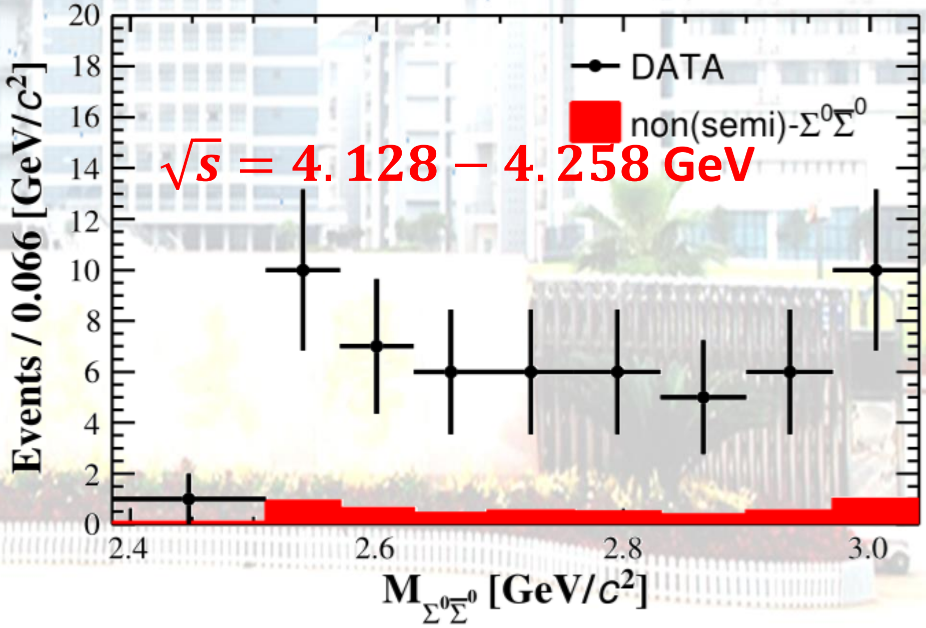
where the $N^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$ is the estimated number of remaining $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ background events with the $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$ events selected, $N^{\text{DATA}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$ is the numbers of the $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ events selected from the DATA, the $\varepsilon^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$ ($\varepsilon^{\text{MC}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$) is obtained by using the $M_{\Sigma^0\bar{\Sigma}^0}$ spectrum of the $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ MC samples after being selected by $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$($e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$) selection criteria to divide that from MC truth.

- Meanwhile, the $M_{\Sigma^0\bar{\Sigma}^0}$ spectrum for process $e^+e^- \to \pi^0\Sigma^0\bar{\Sigma}^0$ from DATA and its background estimated by 2D sideband method are obtained.
- For the determination of the dressed cross section for the process $e^+e^- \to \gamma^{\text{ISR}}\Sigma^0\bar{\Sigma}^0$, the $N^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$ is calculated in each $N^{\text{bkg}}_{\pi^0\Sigma^0\bar{\Sigma}^0}$ intervals.

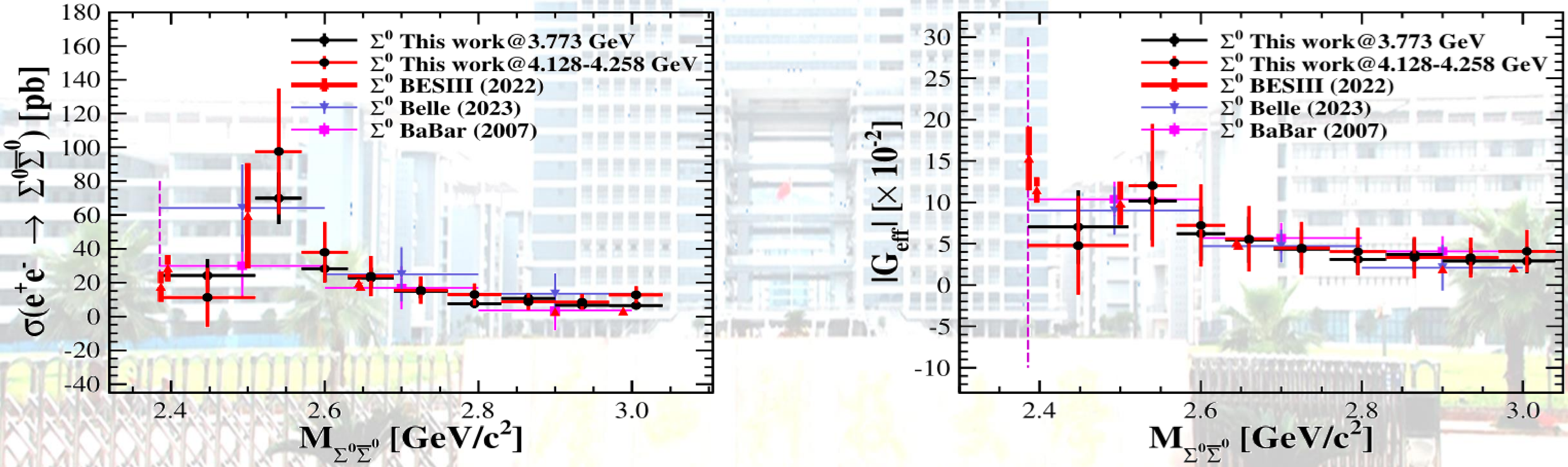
Non(semi)-$\Sigma^0\bar{\Sigma}^0$ Background

- We plan to use the inclusive MC samples to estimate the number of the non-$\Sigma^0\bar{\Sigma}^0$ background or semi-$\Sigma^0\bar{\Sigma}^0$ background events, the number of the background events in signal region is calculated as $N^{\mathrm{INMC}}_{\mathrm{non}-\Sigma}/N^{\mathrm{INMC}}_{\mathrm{Eevnt}} * N^{\mathrm{DATA}}_{\mathrm{Eevnt}}$, where the $N^{\mathrm{INMC}}_{\mathrm{Eevnt}}$ and $N^{\mathrm{DATA}}_{\mathrm{Eevnt}}$ are the number of events remaining after applying all selection criteria, respectively. The $N^{\mathrm{INMC}}_{\mathrm{non}-\Sigma}$ is the number of events that remain after applying all selection criteria and excluding those involving the Σ baryon process.

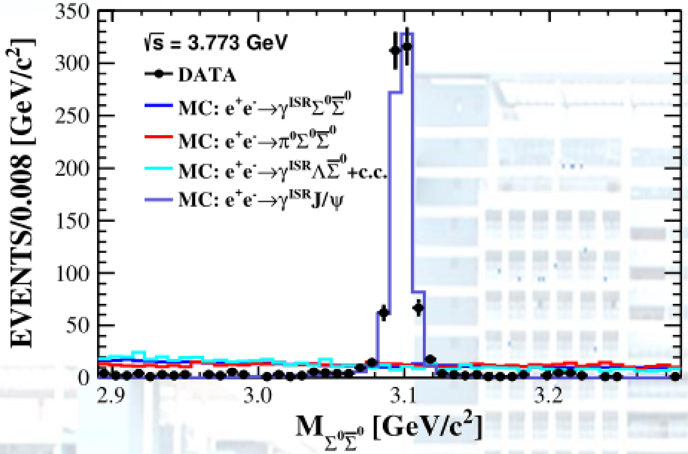


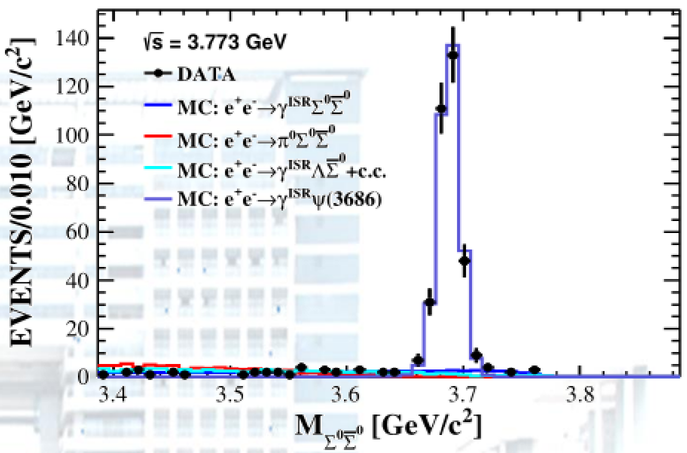


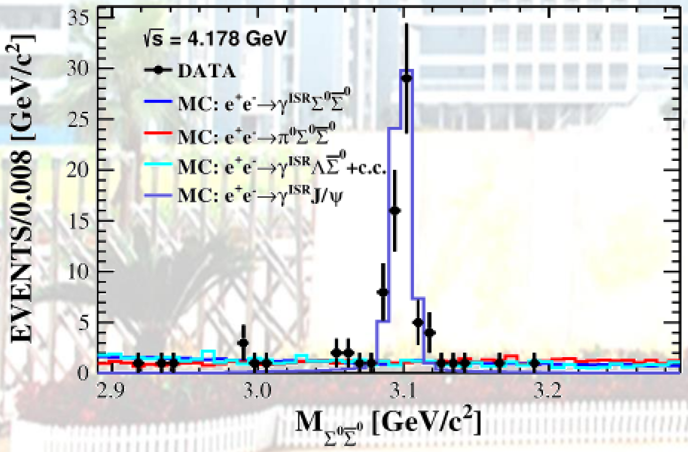
Cross section

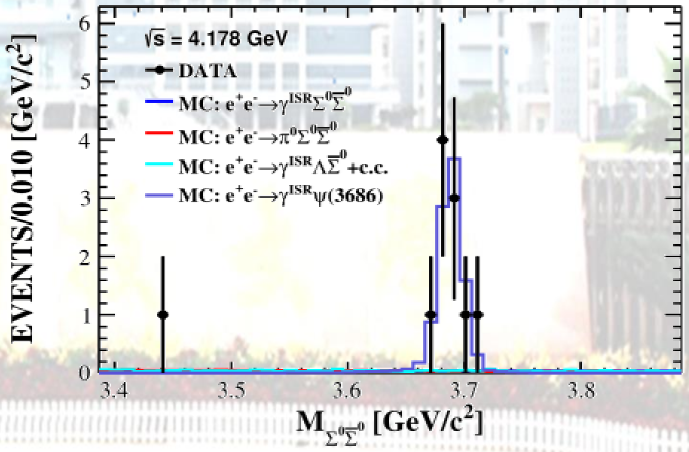


MC-DATA


√s = 3.773 GeV
DATA
MC: e+e-→γISRΣ0Σ̄0
MC: e+e-→π0Σ0Σ̄0
MC: e+e-→γISRΛΣ̄0+c.c.
MC: e+e-→γISRJ/ψ
EVENTS/0.008 [GeV/c2]
MΣ0Σ̄0 [GeV/c2]


√s = 3.773 GeV
DATA
MC: e+e-→γISRΣ0Σ̄0
MC: e+e-→π0Σ0Σ̄0
MC: e+e-→γISRΛΣ̄0+c.c.
MC: e+e-→γISRψ(3686)
EVENTS/0.010 [GeV/c2]
MΣ0Σ̄0 [GeV/c2]


√s = 4.178 GeV
DATA
MC: e+e-→γISRΣ0Σ̄0
MC: e+e-→π0Σ0Σ̄0
MC: e+e-→γISRΛΣ̄0+c.c.
MC: e+e-→γISRJ/ψ
EVENTS/0.008 [GeV/c2]
MΣ0Σ̄0 [GeV/c2]


√s = 4.178 GeV
DATA
MC: e+e-→γISRΣ0Σ̄0
MC: e+e-→π0Σ0Σ̄0
MC: e+e-→γISRΛΣ̄0+c.c.
MC: e+e-→γISRψ(3686)
EVENTS/0.010 [GeV/c2]
MΣ0Σ̄0 [GeV/c2]

Results

$M_{\Sigma^0\bar{\Sigma}^0}$[GeV]	N_{sig}	$\bar{\varepsilon}$[%]	$\mathcal{L}_{eff}(sum)$[pb^{-1}]	$\sigma_{\Sigma^0\bar{\Sigma}^0}$[pb]	$\lvert G_{eff}\rvert(\times10^{-2})$
[2.385,2.51]	12.05±6.43	1.39	93.04	22.62±12.07±1.74	6.78±4.95±0.52
[2.51,2.57]	40.92±9.98	2.69	49.75	74.50±18.17±5.74	10.52±5.19±0.81
[2.57,2.63]	26.24±7.96	3.97	53.54	30.07±9.12±2.32	6.41±3.53±0.49
[2.63,2.69]	26.82±8.05	4.89	57.77	23.09±6.93±1.78	5.49±3.01±0.42
[2.69,2.76]	25.72±7.92	5.67	73.43	15.03±4.63±1.16	4.38±2.43±0.34
[2.76,2.83]	18.37±6.45	6.36	80.85	8.69±3.05±0.67	3.31±1.96±0.25
[2.83,2.90]	26.14±7.76	6.83	89.48	10.42±3.09±0.80	3.63±1.98±0.28
[2.90,2.97]	21.34±6.87	7.43	99.57	7.02±2.26±0.54	3.00±1.70±0.23
[2.97,3.04]	27.77±7.06	7.89	111.53	7.68±1.95±0.59	3.16±1.59±0.24

Process	This work	Previous results
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	$10.72 \pm 0.37 \pm 0.53$	$11.64 \pm 0.04 \pm 0.23$
$\psi(3686) \to \Sigma^0\bar{\Sigma}^0$	$2.34 \pm 0.13 \pm 0.12$	$2.44 \pm 0.03 \pm 0.11$