

**BESIII**



# Study of Charmonium(-like) Spectroscopy and Decay at BESIII

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on behalf of the BESIII Collaboration



**ISMD2022**

51st International Symposium on  
Multiparticle Dynamics (ISMD2022)

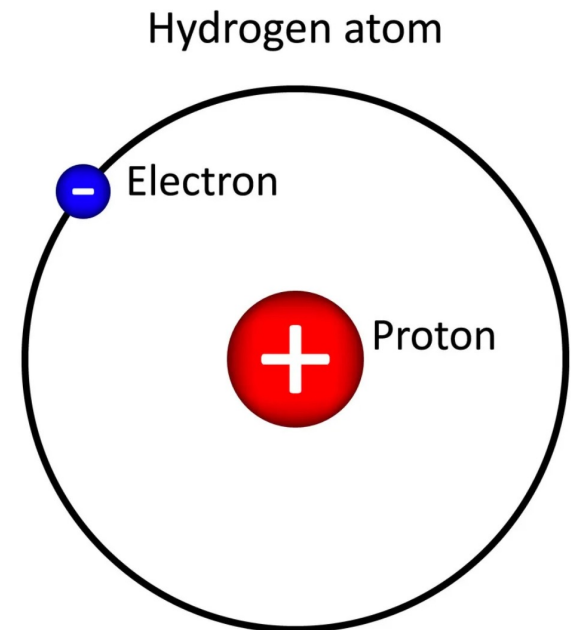
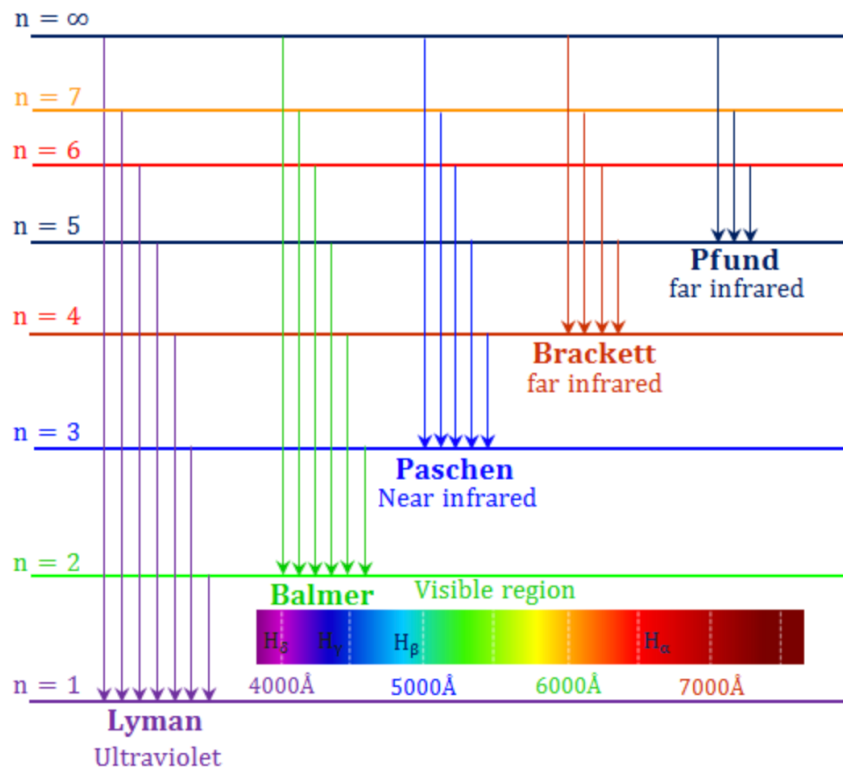
# Outline

- **Introduction**
- **Charmonium(-like) spectroscopy**
- **Charmonium decay**
- **Summary and outlook**

Only part of the publications from BESIII experiments are mentioned, and for more information please refer to <http://english.ihep.cas.cn/bes/re/pu/pjp/>

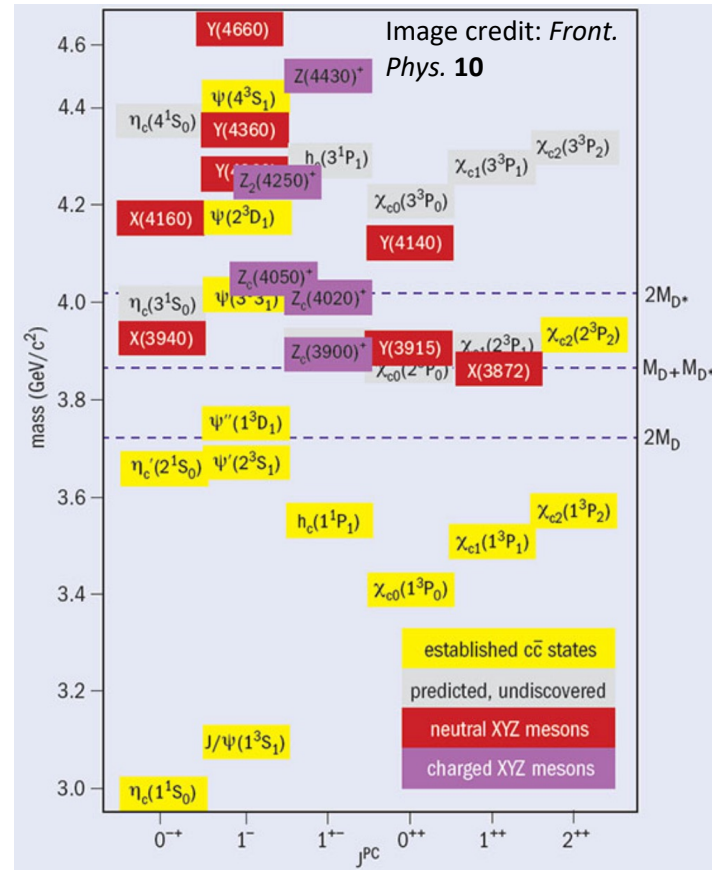
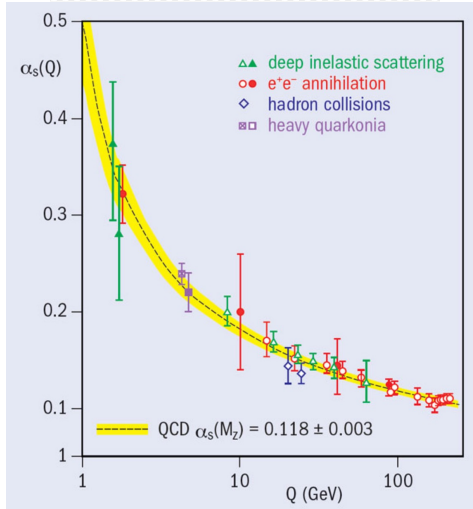
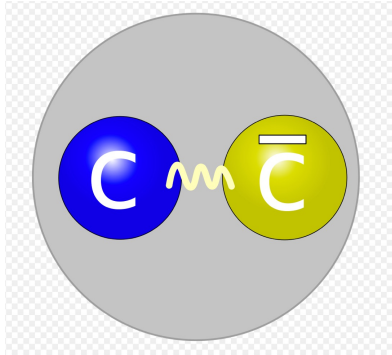
# Why to Study the Charmonium States?

Spectrum and transitions reveal the physics behind, such as hydrogen atom and QED



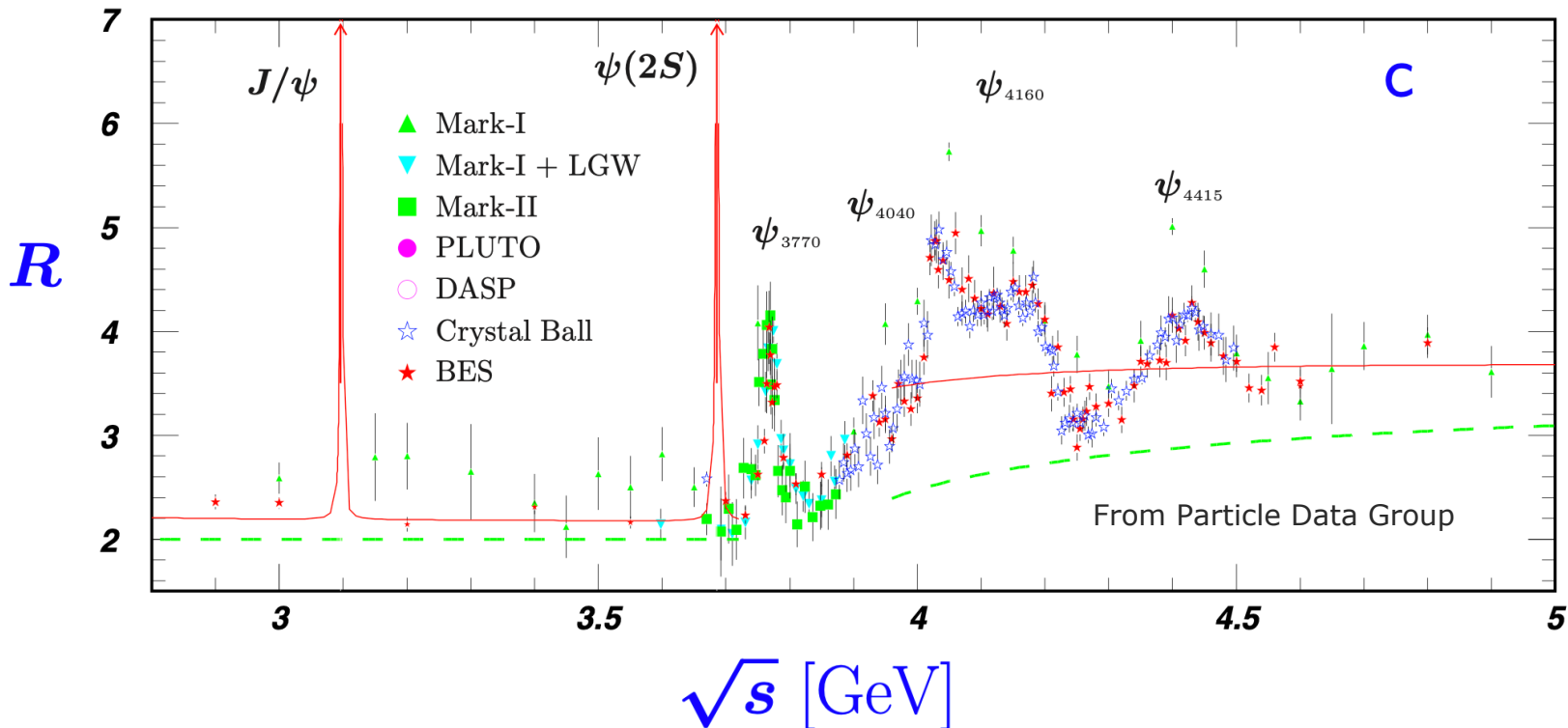
# Why to Study the Charmonium States

There is no doubt that we could understand QCD better by studying Charmonium states



# How to Study Charmonium States at BESIII?

- ❖ The accelerator collected the world largest electron-positron collision data with  $\sqrt{s}$  between 3-5 GeV
- ❖ The detector measure the decay final states with high precision



# Beijing Electron Positron Collider (BEPCII)



Beam energy:  
1-2.5 GeV

Design luminosity:  
 $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

Optimum energy:  
1.89 GeV

Energy spread:  
 $5.16 \times 10^{-4}$

Bunch length: 1.5  
cm

Total current: 0.91  
A

Linac: ~200 m

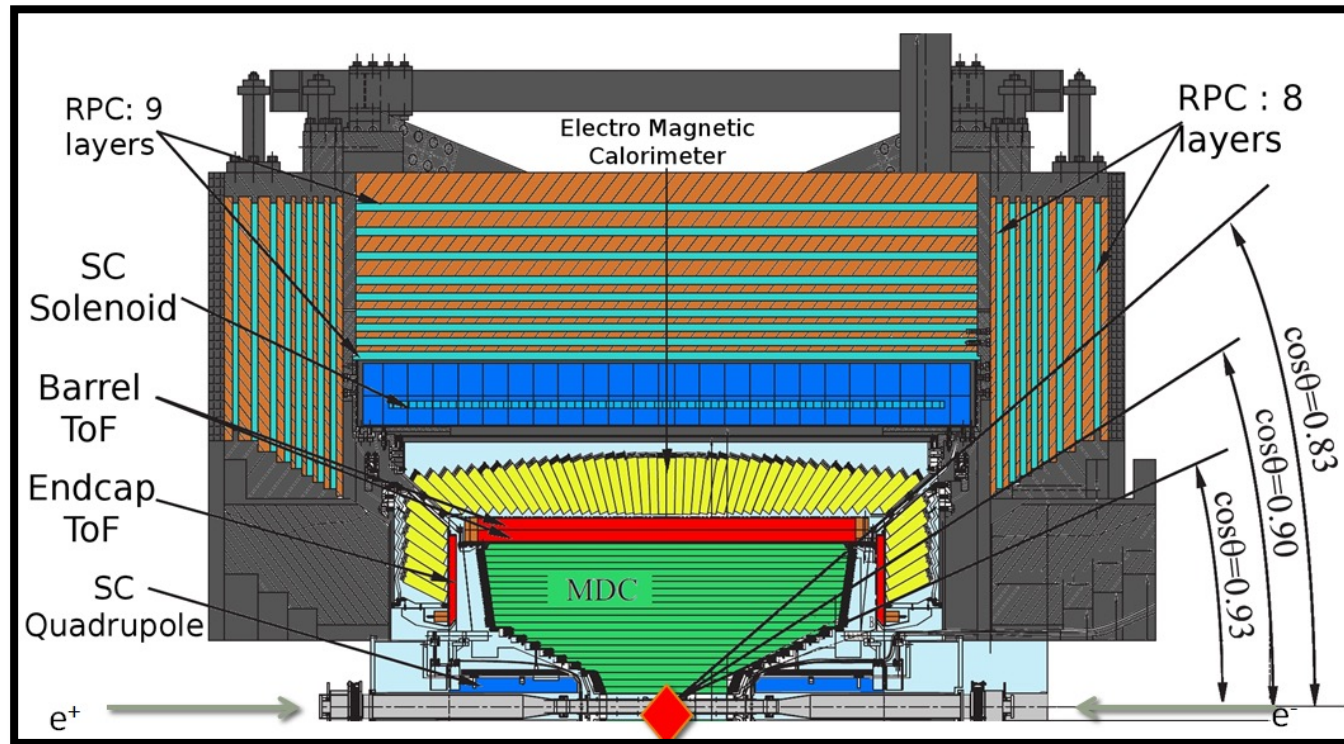
Circular: ~240 m

**2004: started BEPCII/BESIII  
construction**

**2008: test run**

**2009 - now: BESIII physics run**

# BESIII Detector



Charged-particle momentum resolution@1GeV: 0.5%

Photon energy resolution@1 GeV: 2.5% (5%) for barrel (endcap); position resolution 6mm

$dE/dx$  resolution: 6% for electrons from Bhabha process

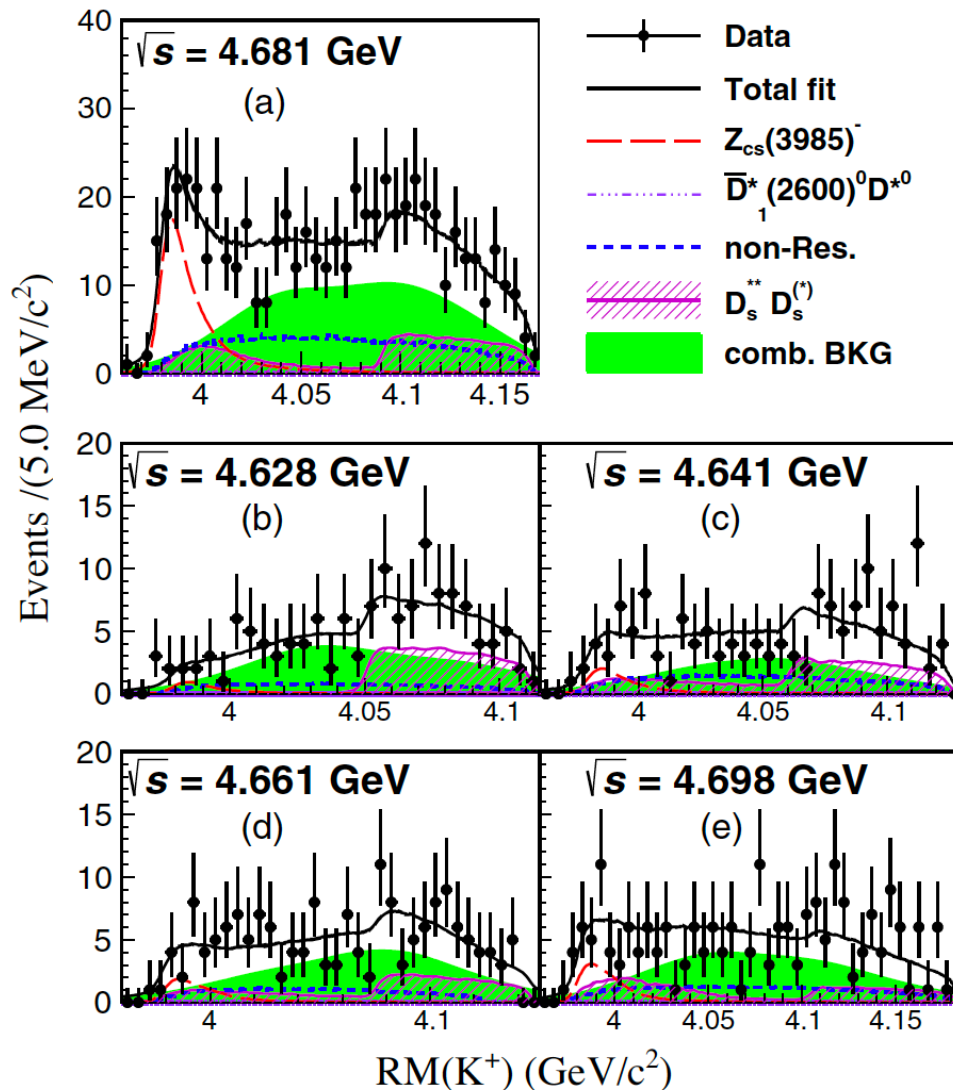
Time resolution of TOF: 68 ps (60 ps) for barrel (endcap)

SC magnetic: 1 T

Trigger and DAQ: 4 kHz, with event size 12 Kbytes

*Collaboration >500 Members from 72 institutions in 15 countries!*

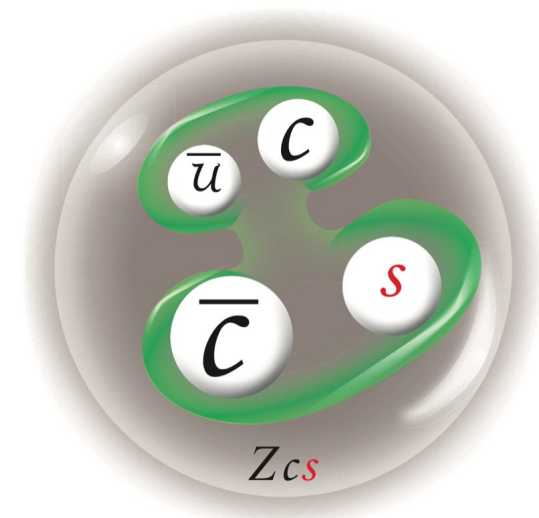
# Observation of a Near-Threshold Structure in the $K^+$ Recoil-Mass Spectra in $e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$



## 5.3 $\sigma$

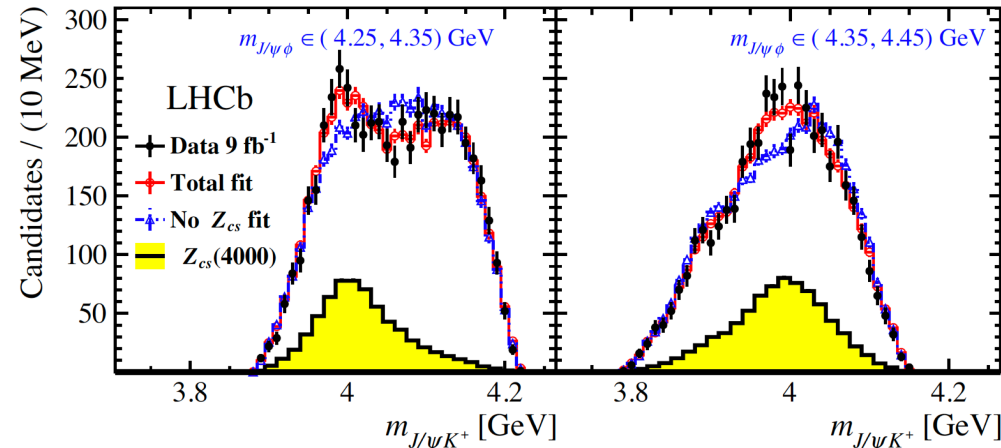
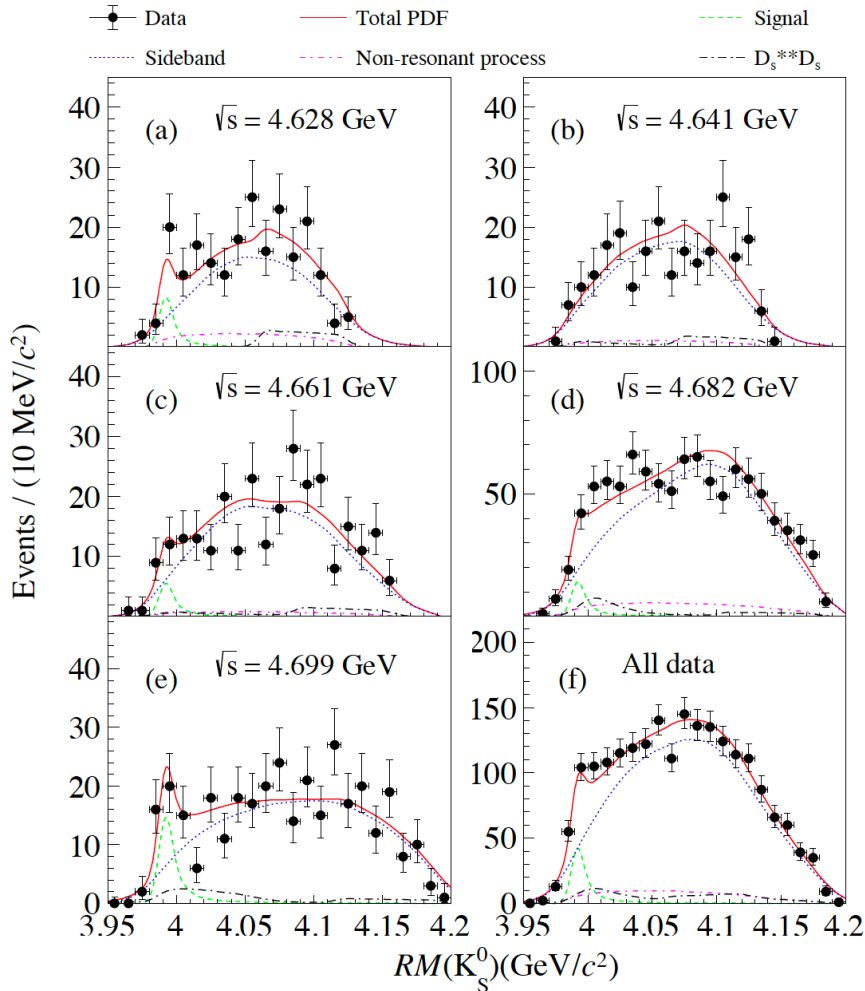
$$m_{\text{pole}}[Z_{cs}(3985)^-] = (3982.5_{-2.6}^{+1.8} \pm 2.1) \text{ MeV}/c^2,$$

$$\Gamma_{\text{pole}}[Z_{cs}(3985)^-] = (12.8_{-4.4}^{+5.3} \pm 3.0) \text{ MeV}.$$



More than 130 citations

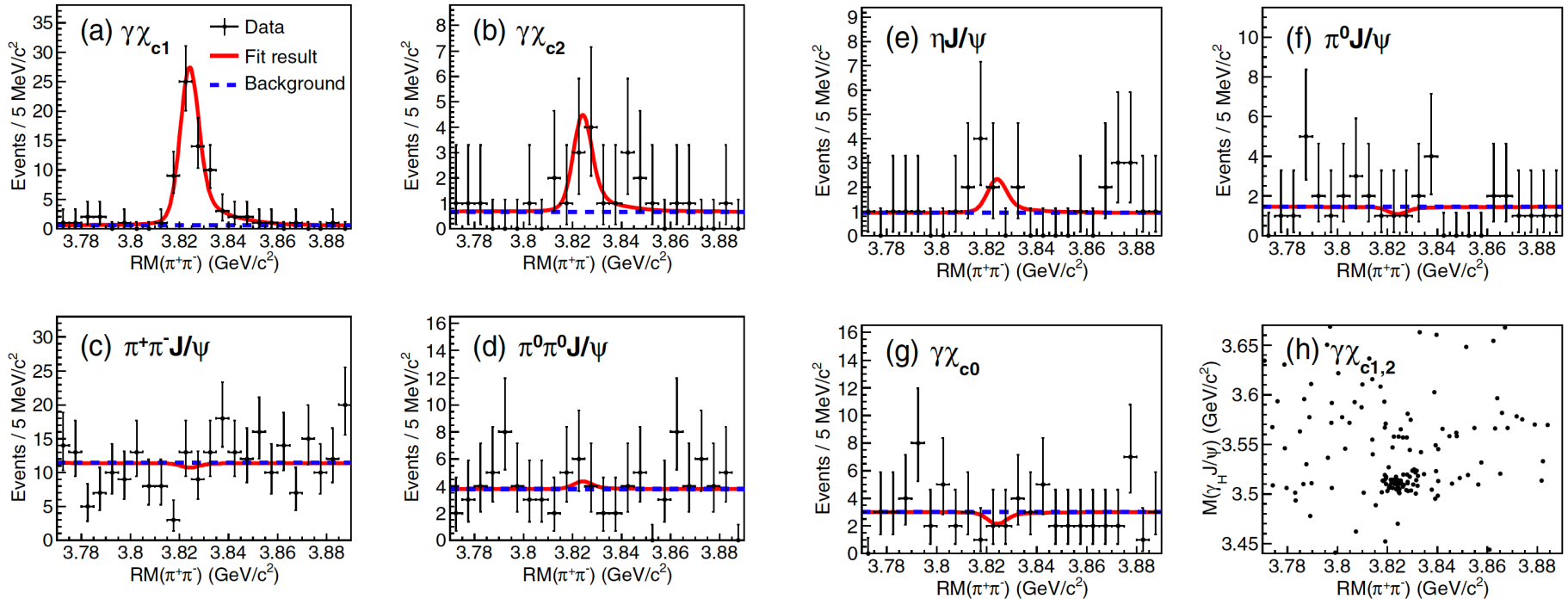




Strong evidence of the isospin partner is observed at BESIII

LHCb observed the similar states, named  $Z_{cs}(4000)$ , while the width is very different from the one at BESIII

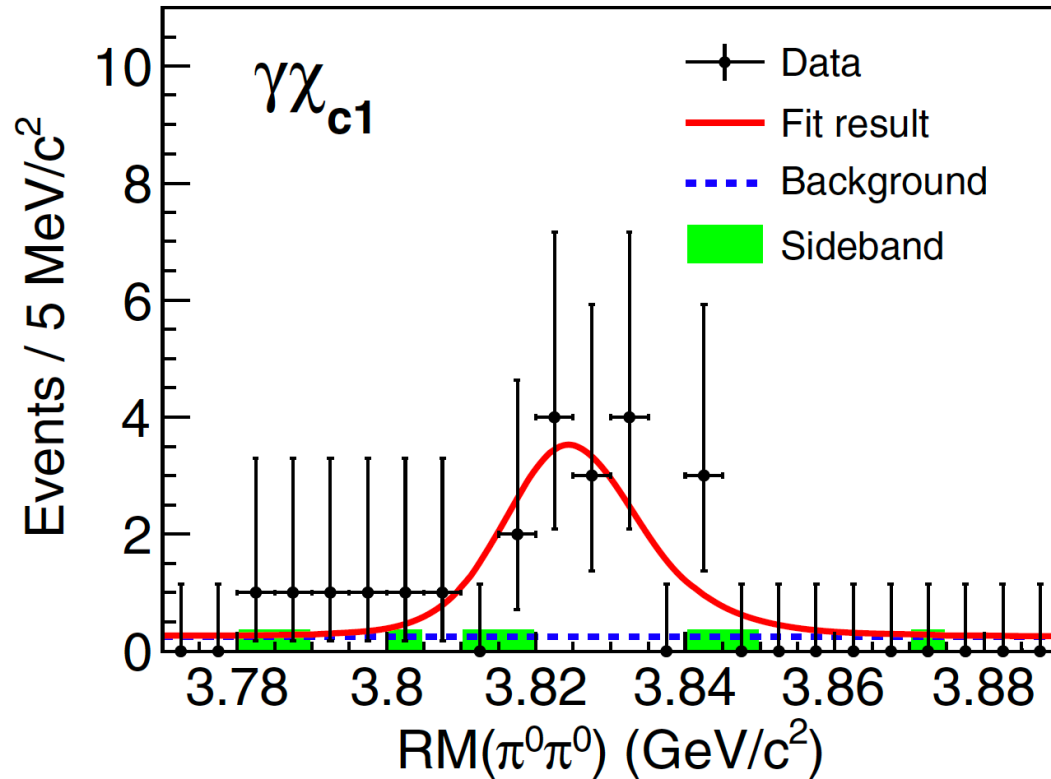
# Search for New Decay Modes of the $\psi_2(3823)$ and the Process $e^+e^- \rightarrow \pi^0\pi^0\psi_2(3823)$



$\psi_2(3823) \rightarrow \gamma\chi_{c2}$ :  $3.2\sigma$ ;  $\psi_2(3823) \rightarrow \gamma\chi_{c1}$ :  $11.8\sigma$ ; the ratio between them is 0.28, consistent with predictions

No significant signal in other decay modes

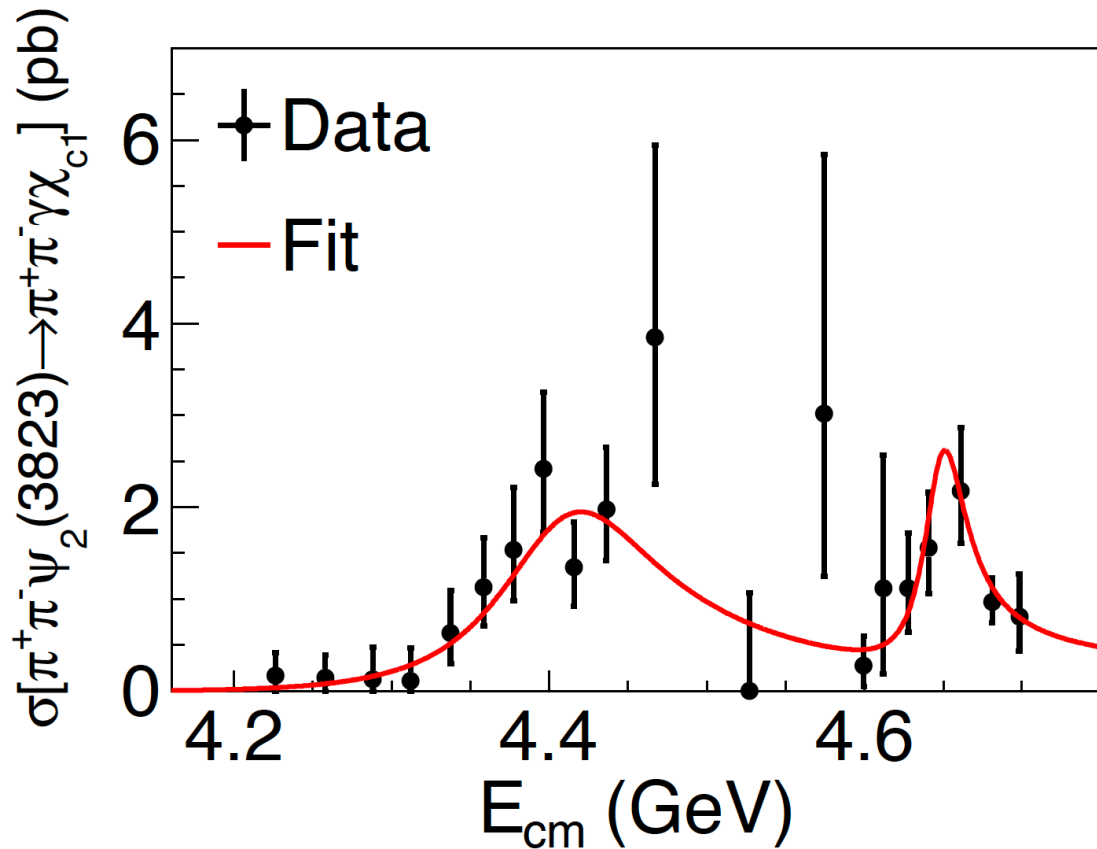
# Search for New Decay Modes of the $\psi_2(3823)$ and the Process $e^+e^- \rightarrow \pi^0\pi^0\psi_2(3823)$



$e^+e^- \rightarrow \pi^0\pi^0\psi_2(3823)$   $4.3\sigma$ ;

Consistent with isospin symmetry prediction.

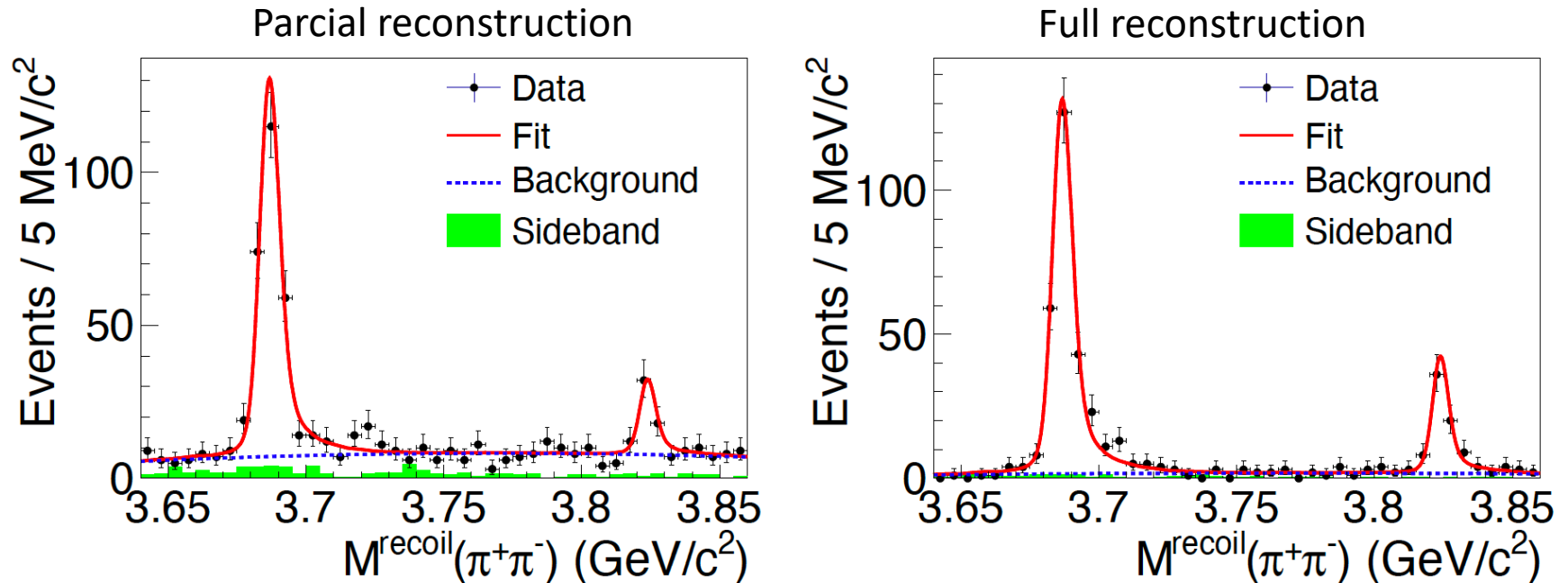
# Observation of Resonance Structures in $e^+e^- \rightarrow \pi^+\pi^-$ $\psi_2(3823)$ and Mass Measurement of $\psi_2(3823)$



For the first time, two resonance structures are observed, and they are consistent with  $Y(4360)$  and  $Y(4660)$ ;

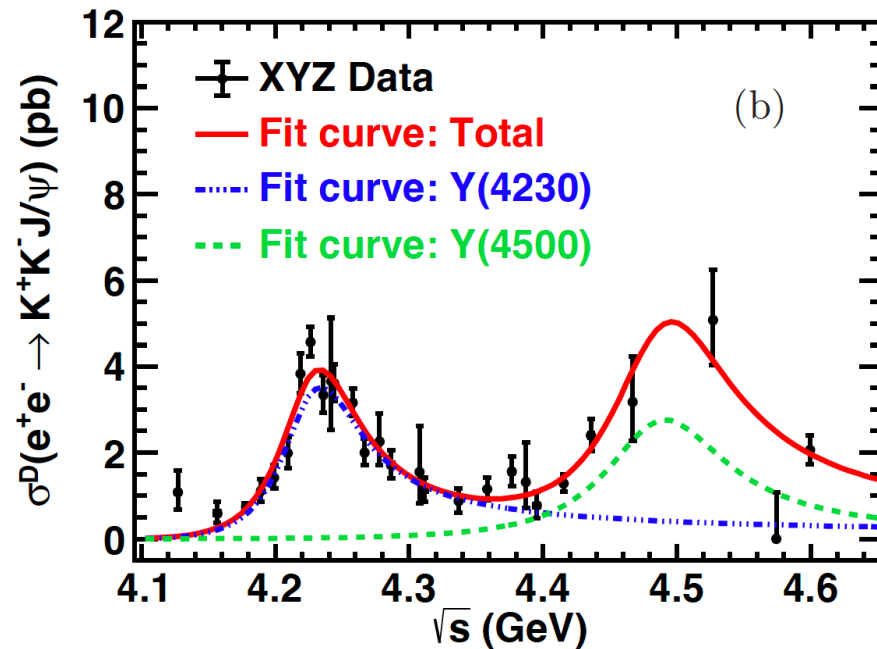
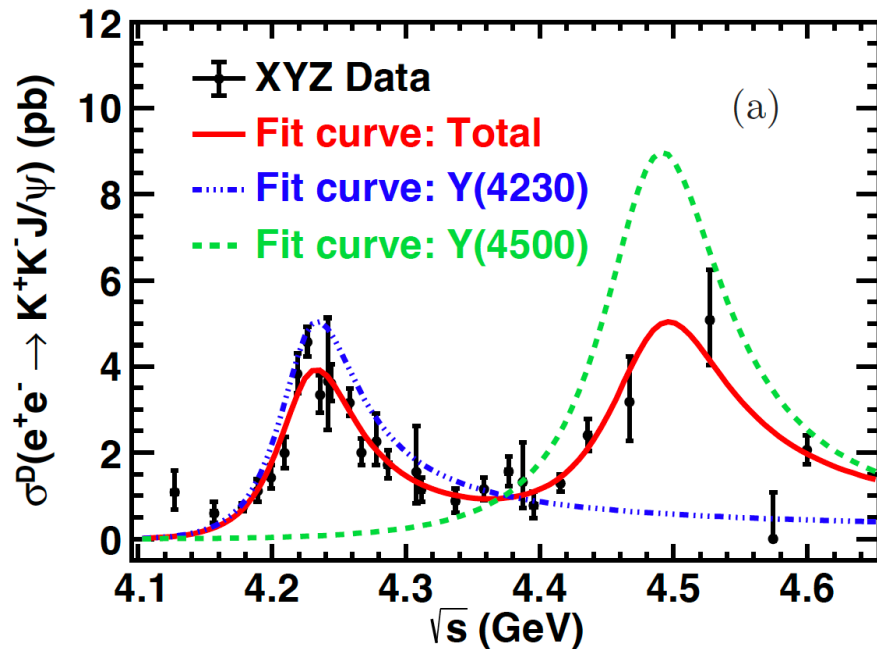
This indicates that the coupling between  $Y$  states and D-wave charmonium is popular.

# Observation of Resonance Structures in $e^+e^- \rightarrow \pi^+\pi^-$ $\psi_2(3823)$ and Mass Measurement of $\psi_2(3823)$



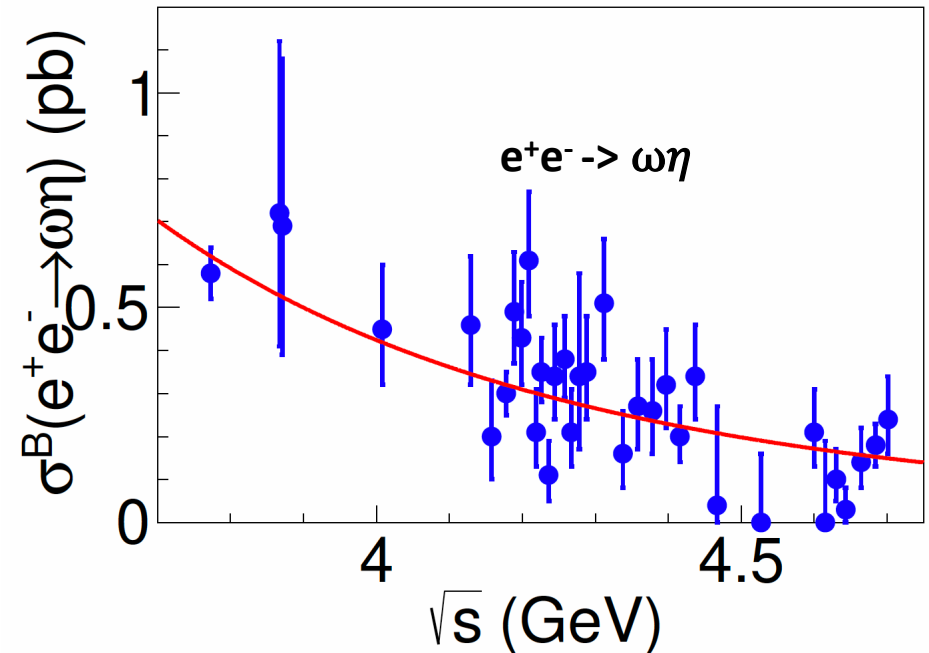
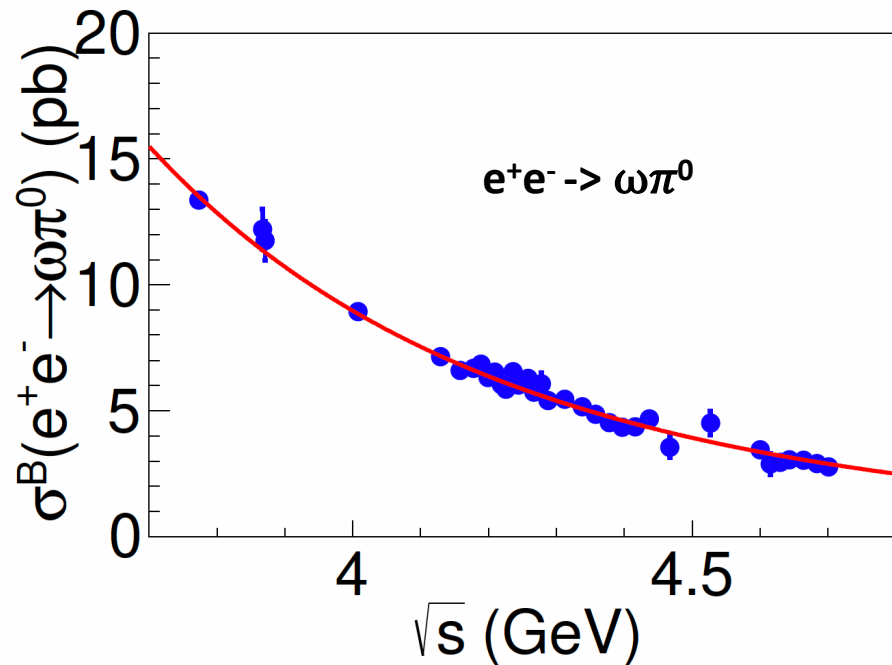
The mass of  $\psi_2(3823)$  is measured by taking  $\psi(3686)$  as reference to be  $3823.12 \pm 0.43 \pm 0.13$  MeV, and the result is the most precise; the upper limit of its width is set to be 2.9 MeV, which is the most stringent constraint. <sup>13</sup>

# Observation of the Y(4230) and a New Structure in $e^+e^- \rightarrow K^+K^-J/\psi$



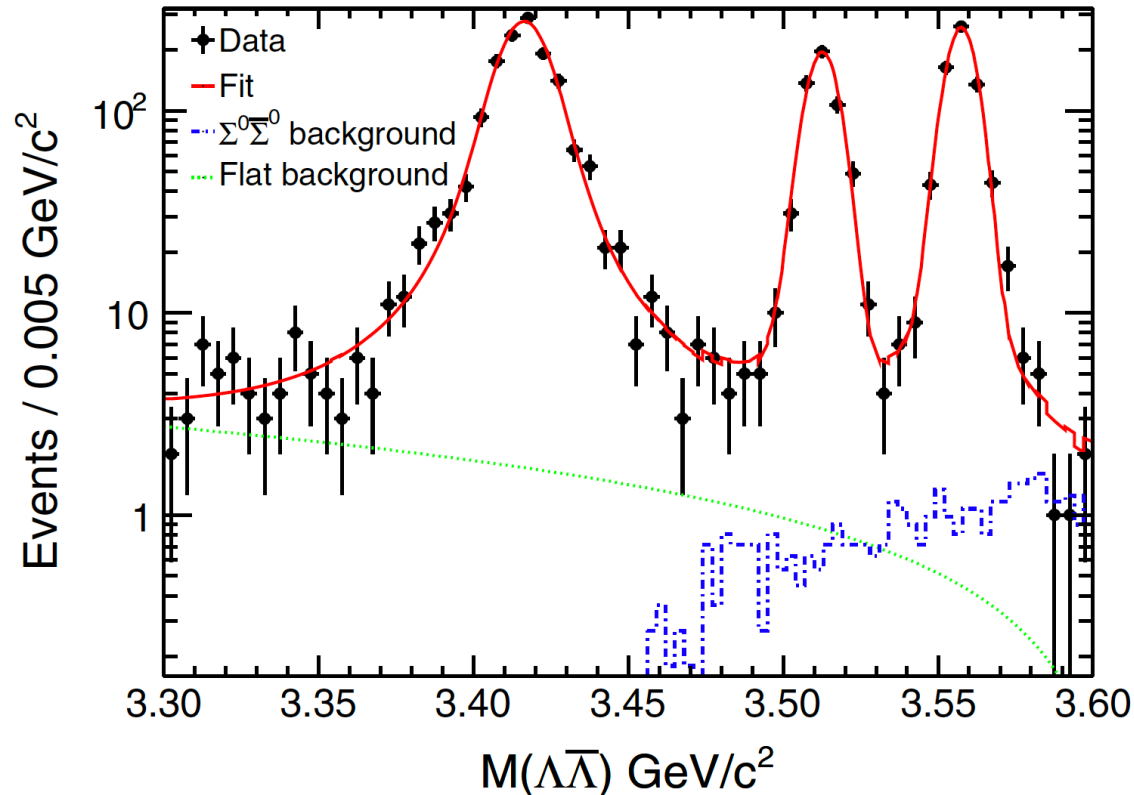
For the first time Y(4230) is observed in  $K^+K^-J/\psi$  mode; one second structure named Y(4500) is observed for first time, which is waiting for the theoretical interpretation for its nature.

# Cross Section Measurement of the Process $e^+e^- \rightarrow \omega\pi^0$ and $e^+e^- \rightarrow \omega\eta$ at Center of Mass Energies between 3.773 and 4.701 GeV



No significant  $Y$  state is observed

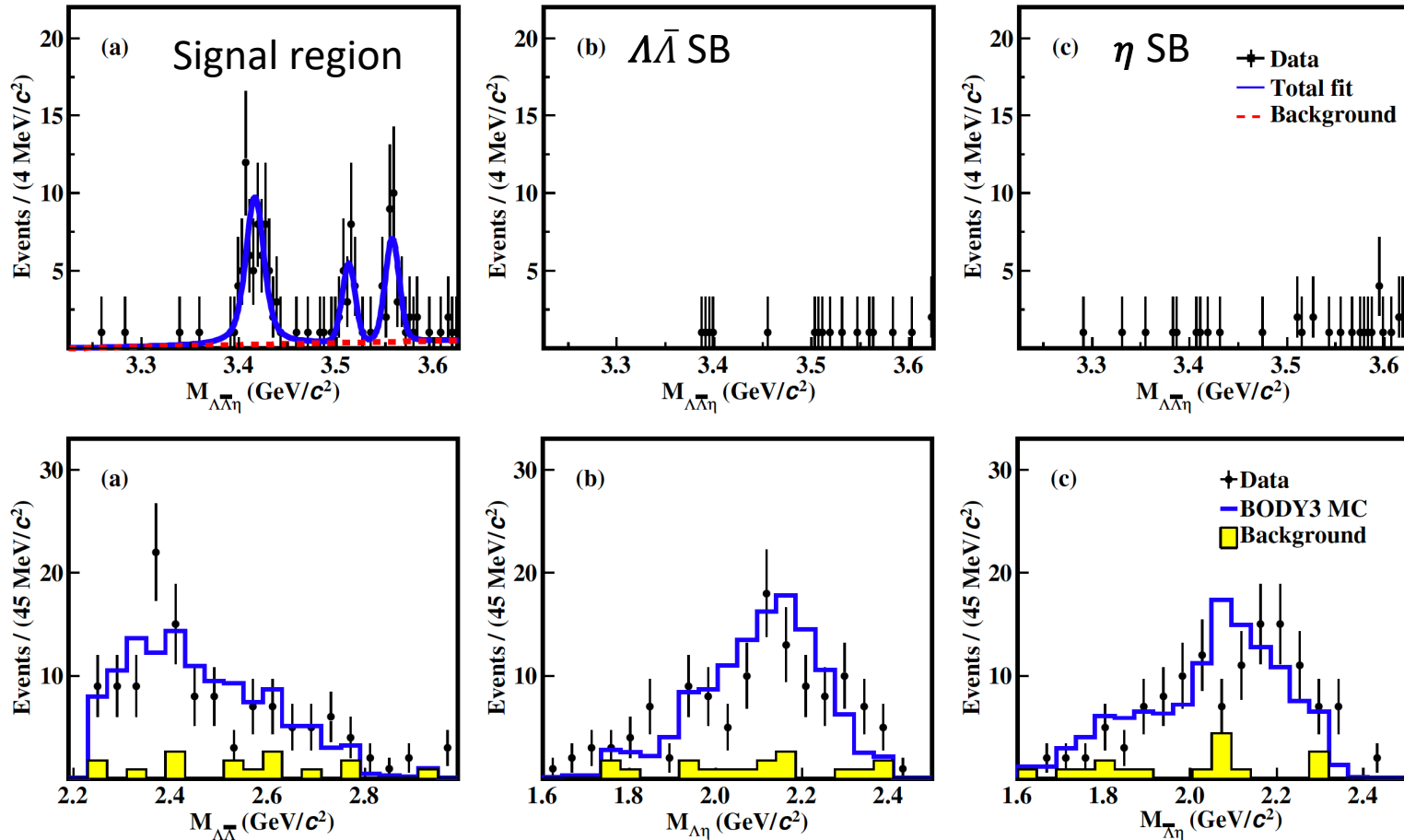
# Measurement of Branching Fractions of $\psi(3686) \rightarrow \bar{\Sigma}^0 \Lambda + \text{c.c.}$ and $\chi_{cJ} \rightarrow \Lambda \bar{\Lambda}$



Our result for is consistent with world average value with improved precision, but not consistent with current theoretical predictions.

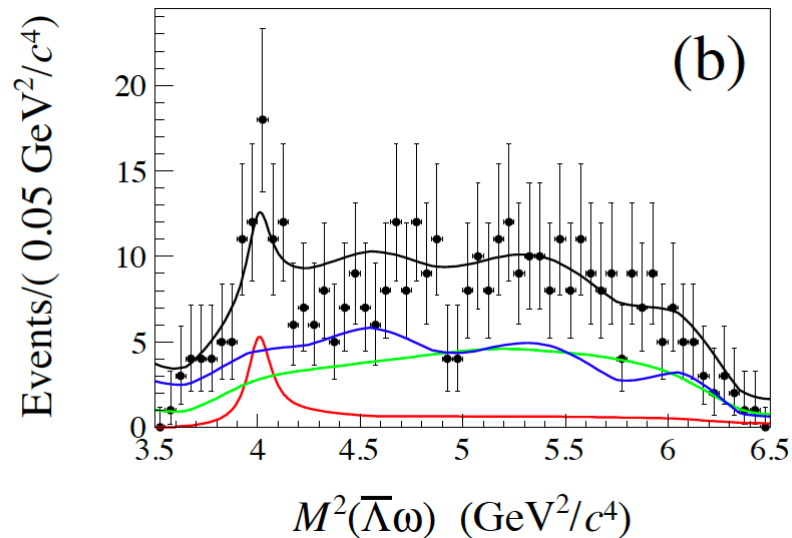
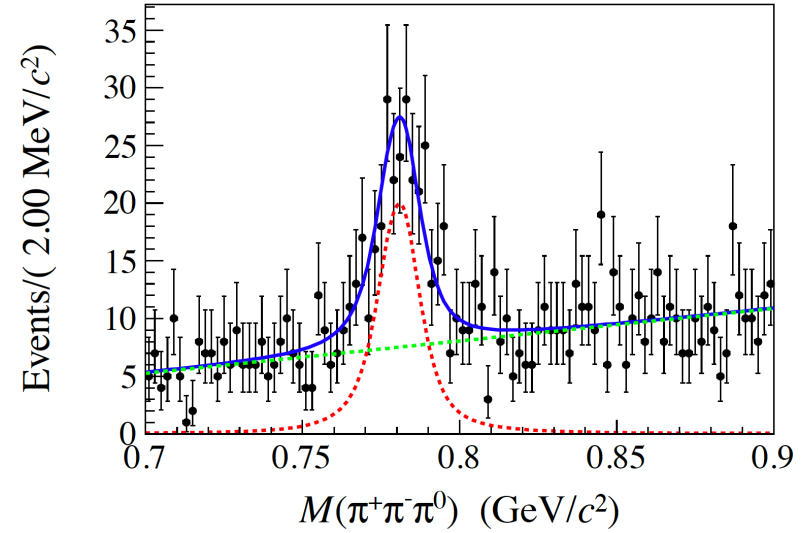
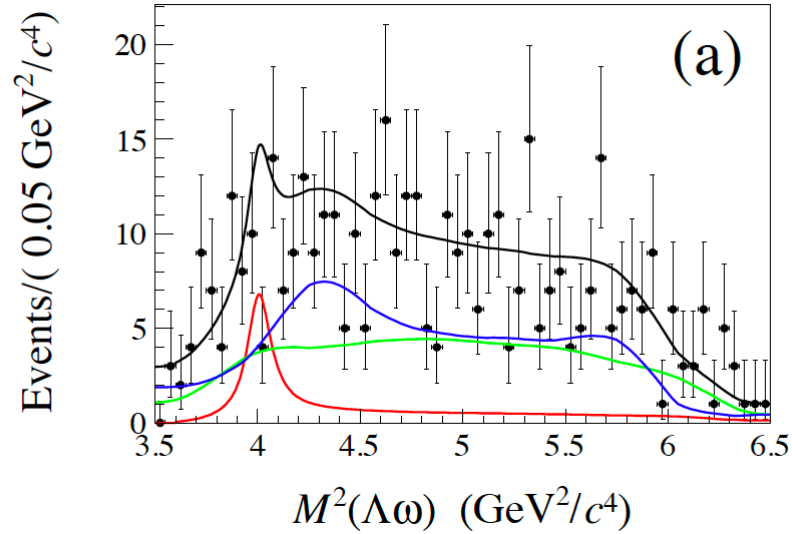


# Observation of $\chi_{cJ} \rightarrow \Lambda \bar{\Lambda} \eta$



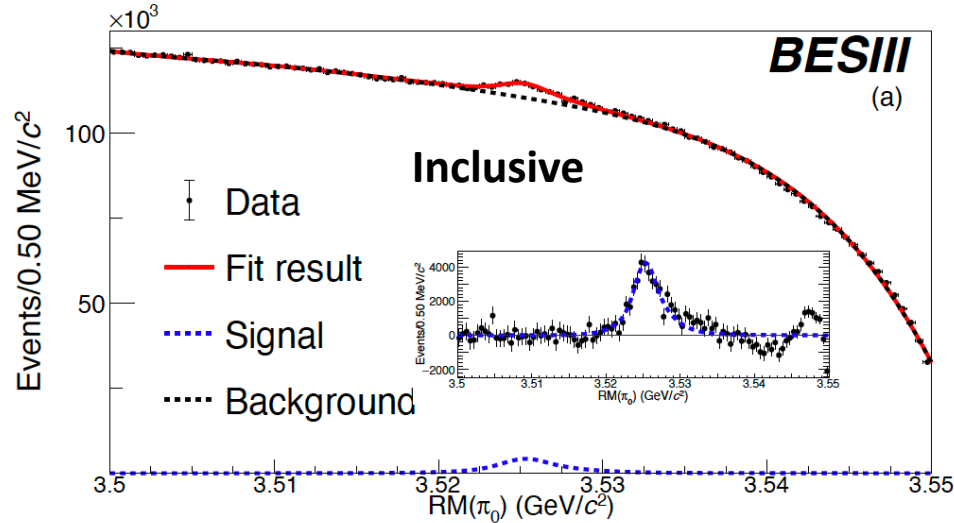
First observation of these processes, and no obvious enhancement is observed in any of the two combinations of the three body decays.

# Study of $\psi(3686) \rightarrow \Lambda \bar{\Lambda} \omega$

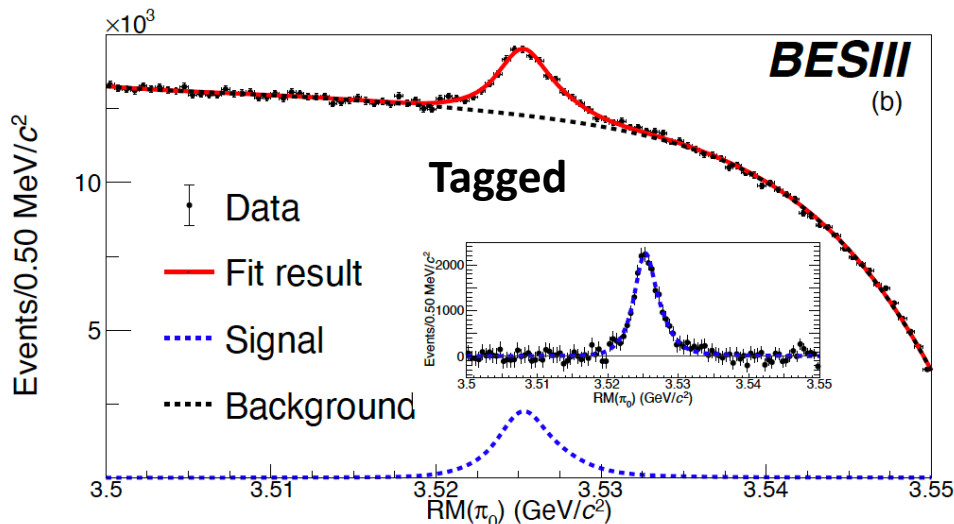


First observation of this process;  
A hint of excited  $\Lambda$  state with mass  
around 2 GeV is observed with  
significance of  $3\sigma$ .

# Study of the $h_c(1P_1)$ Meson via $\psi(2S) \rightarrow \pi^0 h_c$ Decays at BESIII

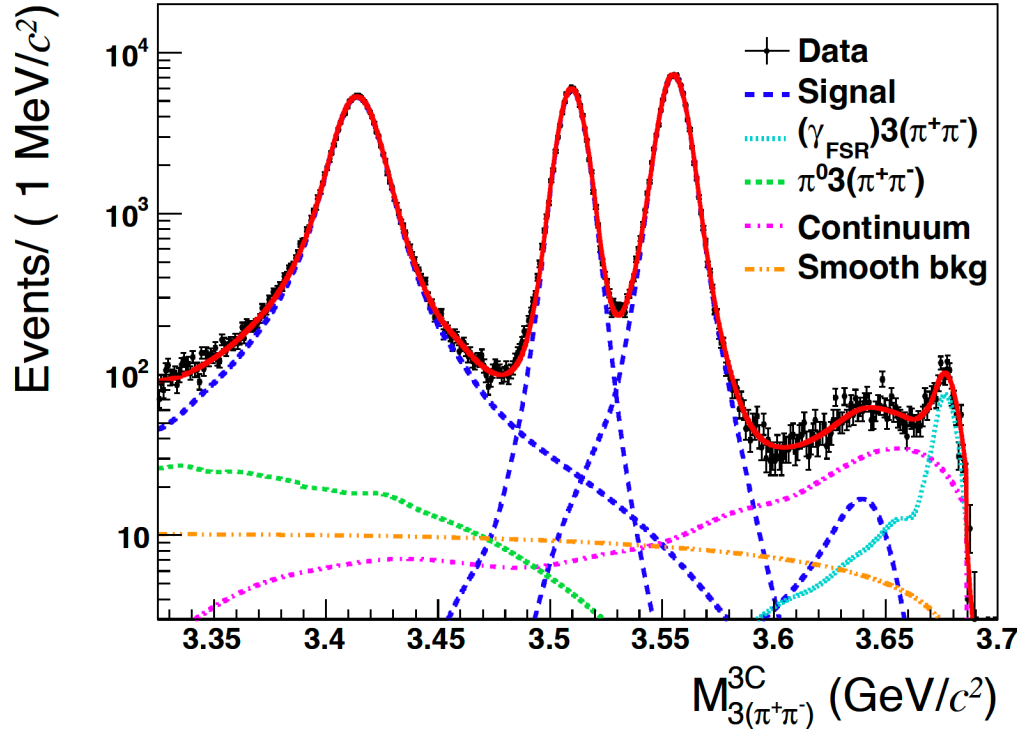


- inclusive:  $\psi(2S) \rightarrow \pi^0 h_c$  with  $h_c \rightarrow$  anything,
- tagged:  $\psi(2S) \rightarrow \pi^0 h_c$  with  $h_c \rightarrow \gamma \eta_c$ .



Variable	Value	PDG Value [5]
$M(h_c)$ (MeV/c <sup>2</sup> )	$3525.32 \pm 0.06 \pm 0.15$	$3525.38 \pm 0.11$
$\Gamma(h_c)$ (MeV)	$0.78^{+0.27}_{-0.24} \pm 0.12$	$0.7 \pm 0.4$
$N_{\text{Tag}}(h_c)$	$23118^{+1500}_{-1398}$	—
$\mathcal{B}_{\text{Inc}} \times \mathcal{B}_{\text{Tag}} (10^{-4})$	$4.17^{+0.27}_{-0.25} \pm 0.19$	$4.58 \pm 0.64$ (BESIII [11]) $4.16 \pm 0.48$ (CLEO [23])
$N_{\text{Inc}}(h_c)$	$46187 \pm 2123$	—
$\mathcal{B}_{\text{Inc}} (10^{-4})$	$7.23 \pm 0.33 \pm 0.38$	$8.60 \pm 1.30$
$\mathcal{B}_{\text{Tag}} (\%)$	$57.66^{+3.62}_{-3.50} \pm 0.58$	$50 \pm 9$

# Observation of $\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$ and Measurements of $\chi_{cJ}$ in $\psi(3686)$ Radiative Transitions



$\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$  is observed with significance of  $9.3\sigma$ ; its mass and width are measured to be consistent with world average;

$$\frac{\mathcal{B}[\eta_c(2S) \rightarrow 3(\pi^+\pi^-)]}{\mathcal{B}[\eta_c(1S) \rightarrow 3(\pi^+\pi^-)]} = 0.77 \pm 0.59$$

Channel	$N_{\text{data}}^{\text{sig}}$	$\epsilon^{\text{corr}}$ (%)	$\mathcal{B}_{\text{measured}} (\times 10^{-2})$	$\mathcal{B}_{\text{PDG}} (\times 10^{-2})$
$\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$	$568.8 \pm 63.3$	$13.84 \pm 0.01$	$1.31 \pm 0.15 \pm 0.13_{-0.47}^{+0.64}$	-
$\chi_{c0} \rightarrow 3(\pi^+\pi^-)$	$145300 \pm 396$	$15.92 \pm 0.01$	$2.080 \pm 0.006 \pm 0.068$	$1.20 \pm 0.18$
$\chi_{c1} \rightarrow 3(\pi^+\pi^-)$	$84317 \pm 299$	$17.67 \pm 0.01$	$1.092 \pm 0.004 \pm 0.035$	$0.54 \pm 0.14$
$\chi_{c2} \rightarrow 3(\pi^+\pi^-)$	$112510 \pm 347$	$16.85 \pm 0.01$	$1.565 \pm 0.005 \pm 0.048$	$0.84 \pm 0.18$

# Summary

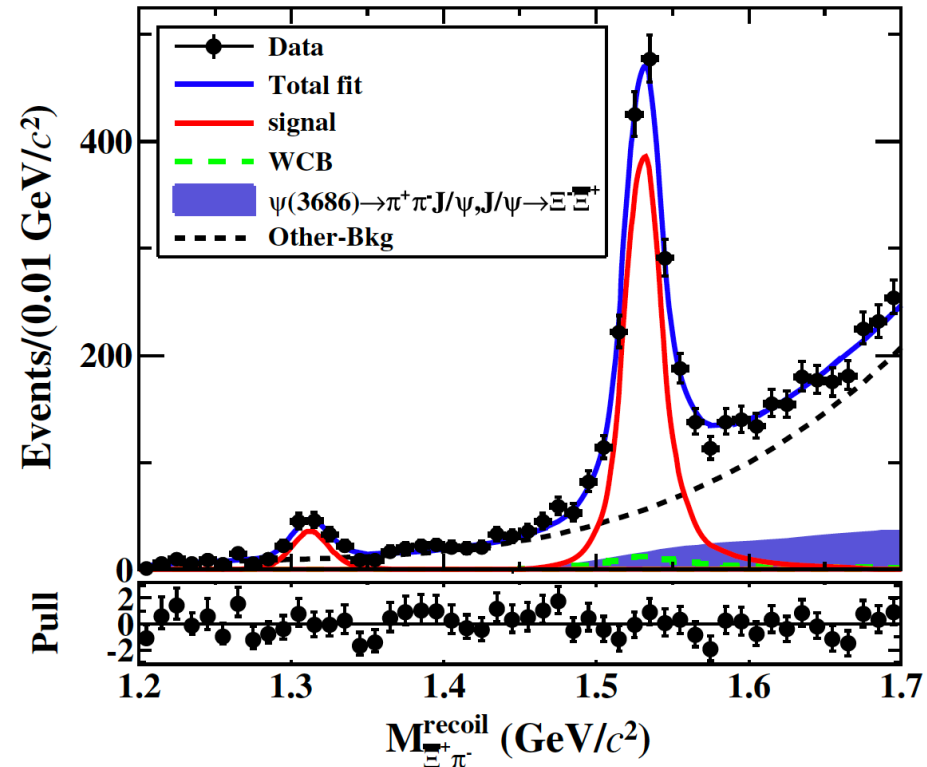
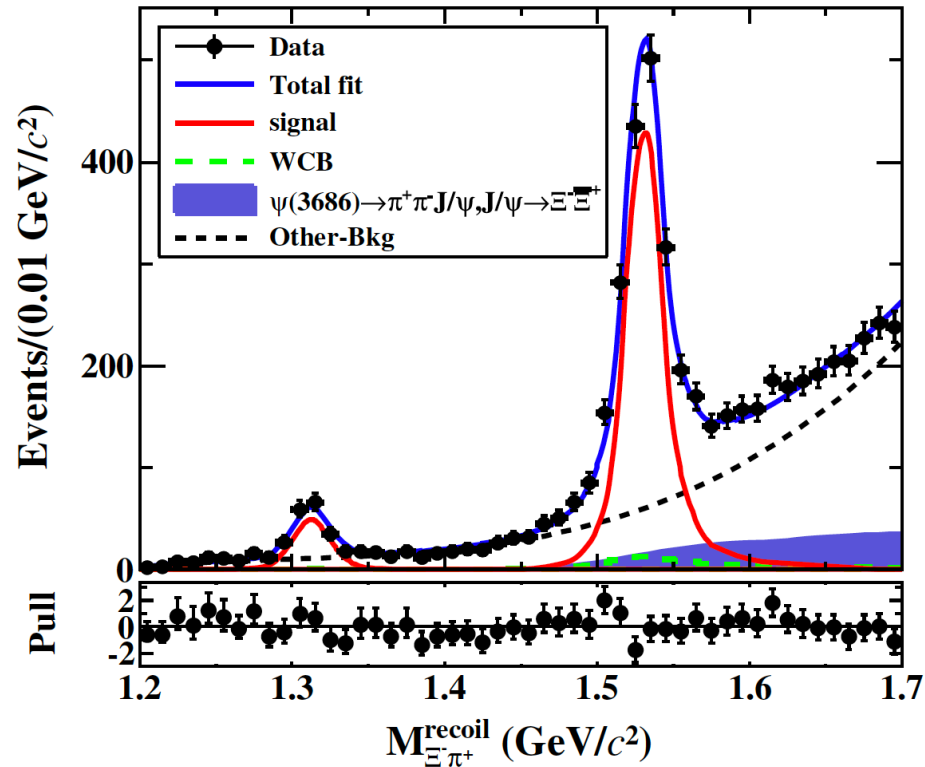


- Based on world largest electron-positron annihilation data in the charm region, the charmonium(like) states could be studied in high precision
- With these results, we hope to understand the QCD better, especially in the low energy region
- More data will be collected

**THANK YOU!**

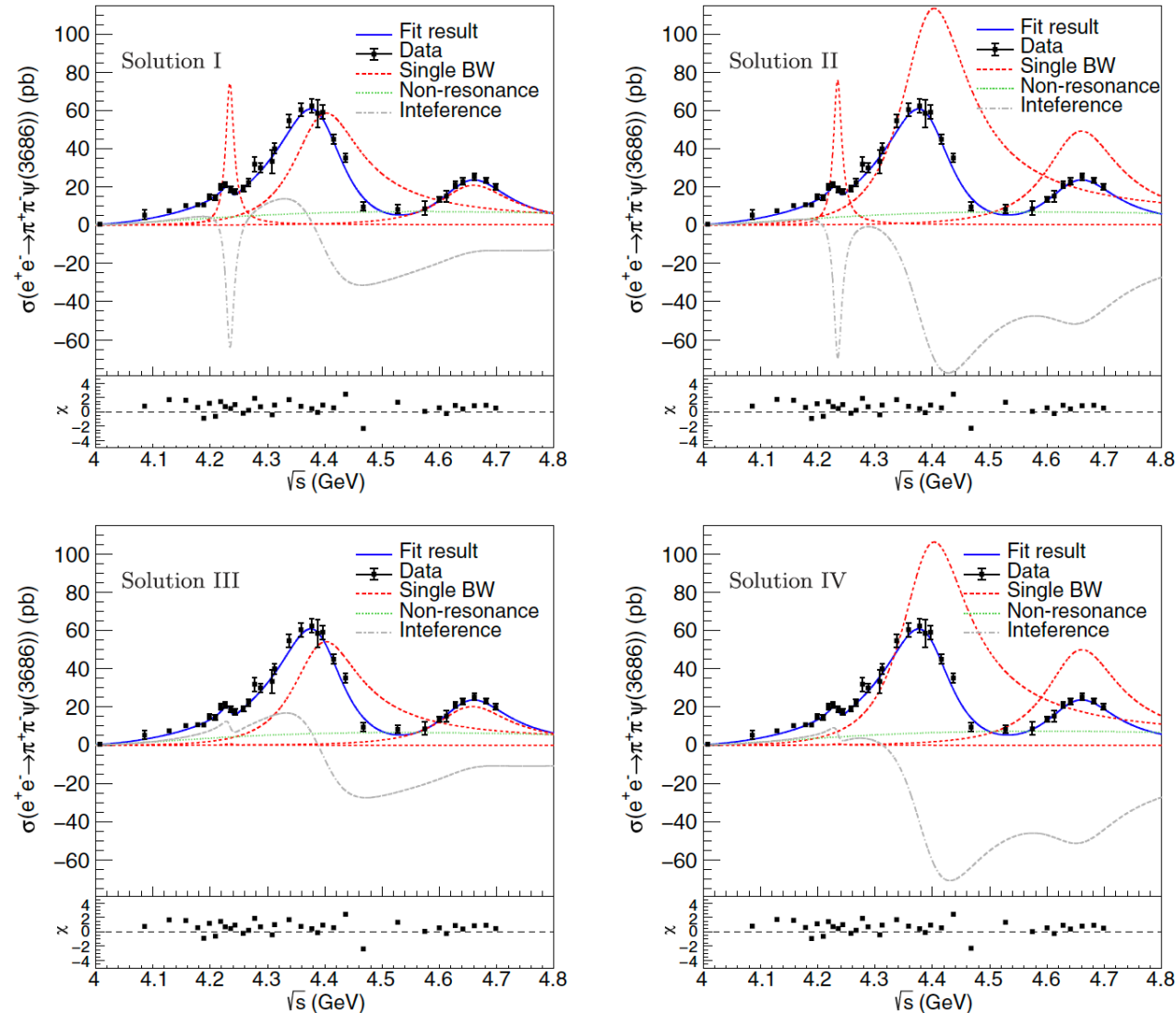
# Extra slides

# Observation of $\psi(3686) \rightarrow \Xi^0(1530) \bar{\Xi}^0(1530)^0$ and $\Xi^0(1530) \bar{\Xi}^0$



First observations, and the results could be used to test SU(3) flavor symmetry, isospin symmetry, and “12%” rule.

# Cross Section Measurement of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ from $\sqrt{s}=4.0076$ GeV to 4.6984 GeV

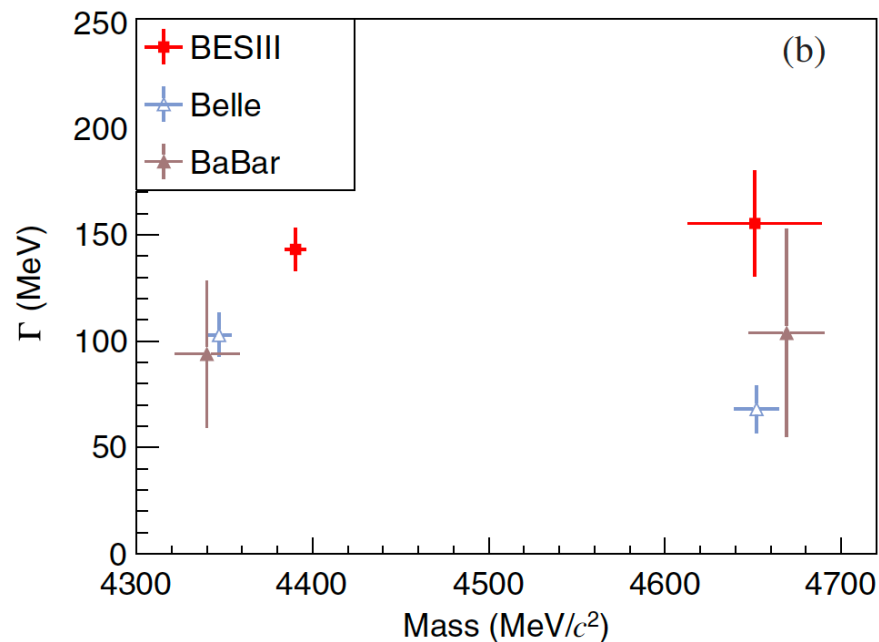
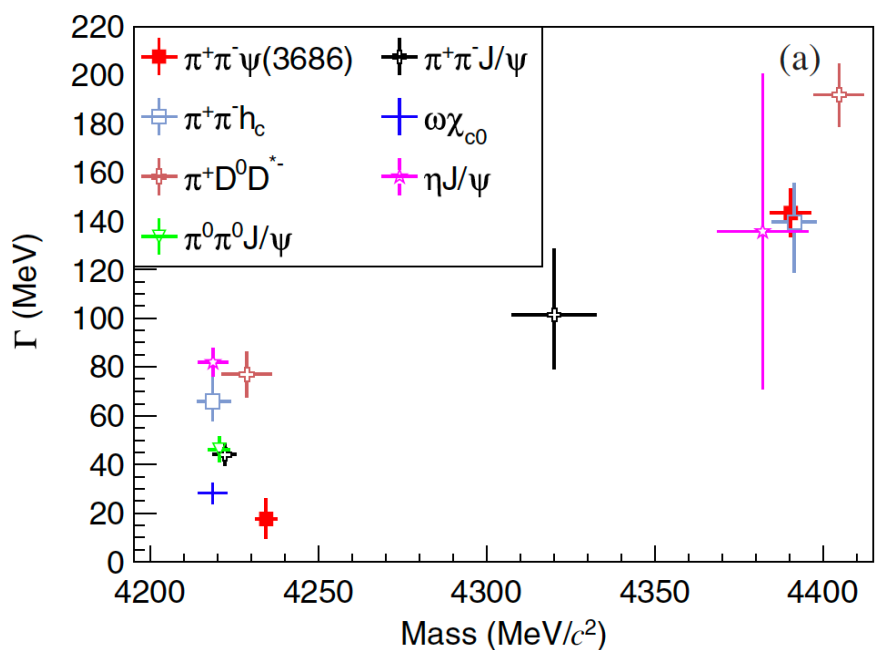


Y(4220), Y(4390) and Y(4660) are confirmed in this process;

Three BW functions + continuous component fits the data well, and four solutions are with same fit quality.



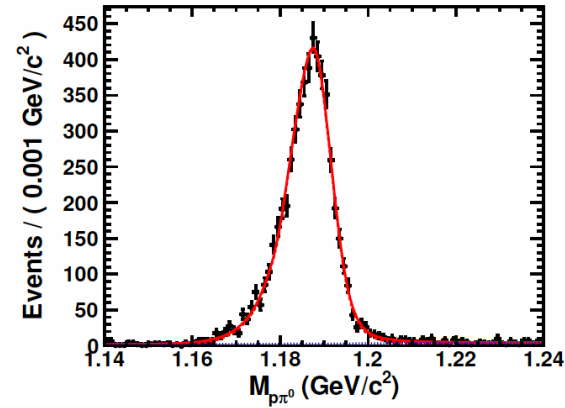
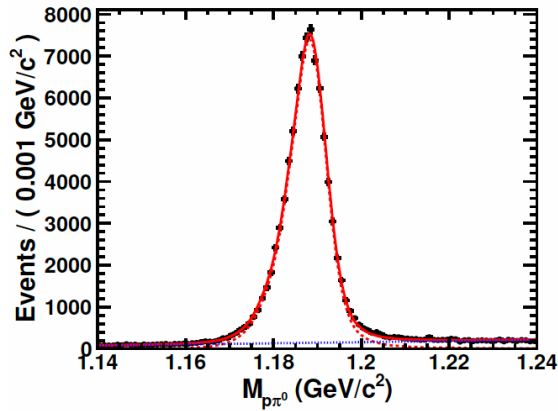
# Cross Section Measurement of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ from $\sqrt{s}=4.0076$ GeV to 4.6984 GeV



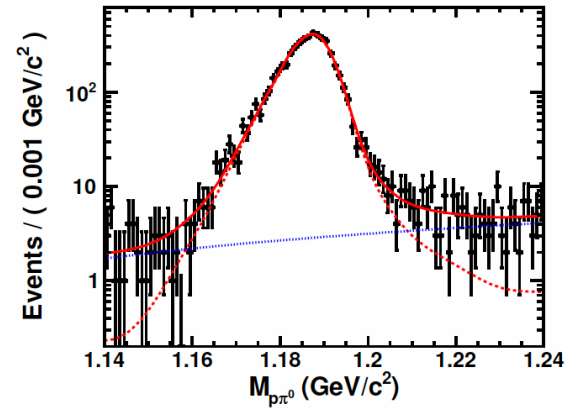
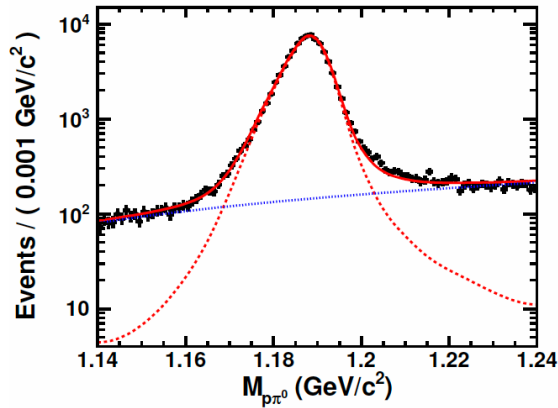
Comparations among different publications, and more study is needed

# Measurement of Branching Fractions of $\psi(3686)$ and $J/\psi$ to $\Sigma^+$ and $\Sigma^-$

$J/\psi$

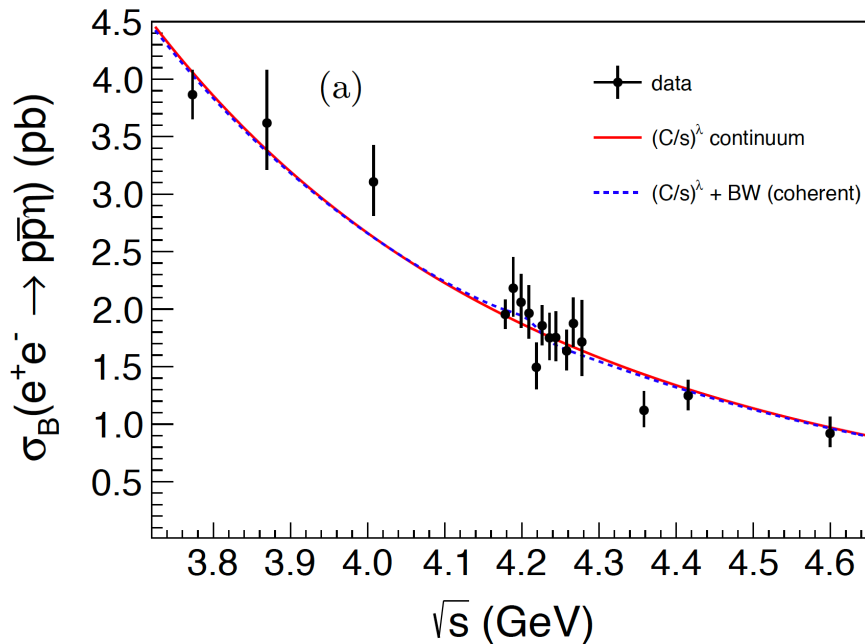


$\psi(3686)$

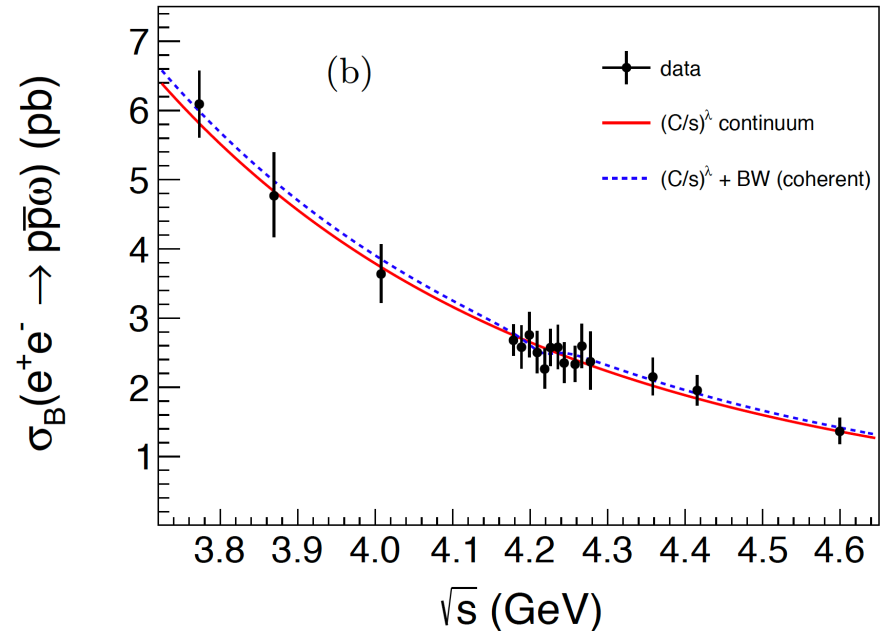


Violate the "12%" rule.

# Cross section measurement of $e^+e^- \rightarrow \eta(p\bar{p})$ and $e^+e^- \rightarrow \omega(p\bar{p})$ at center of mass energies between 3.773 and 4.6 GeV



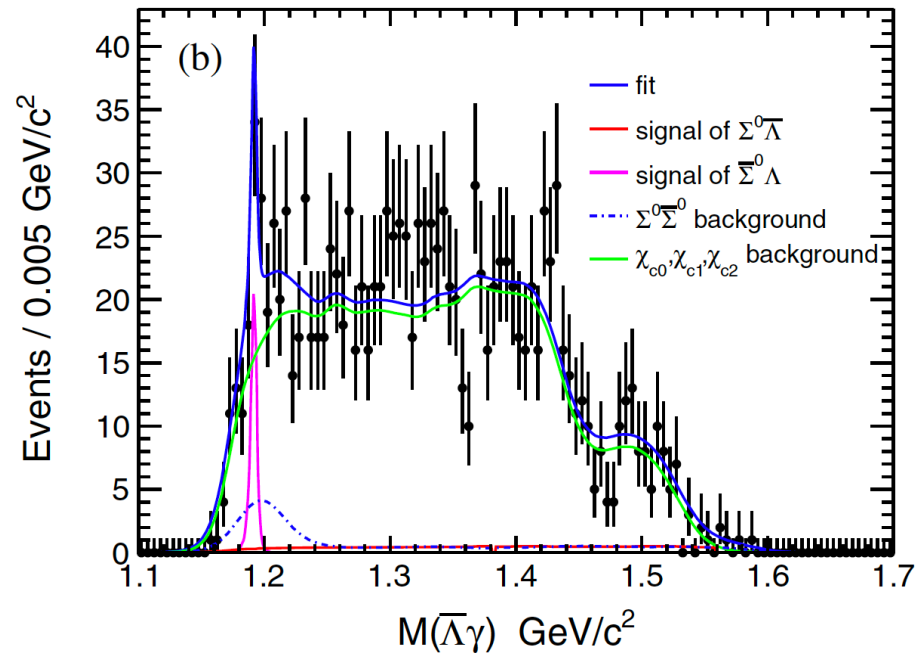
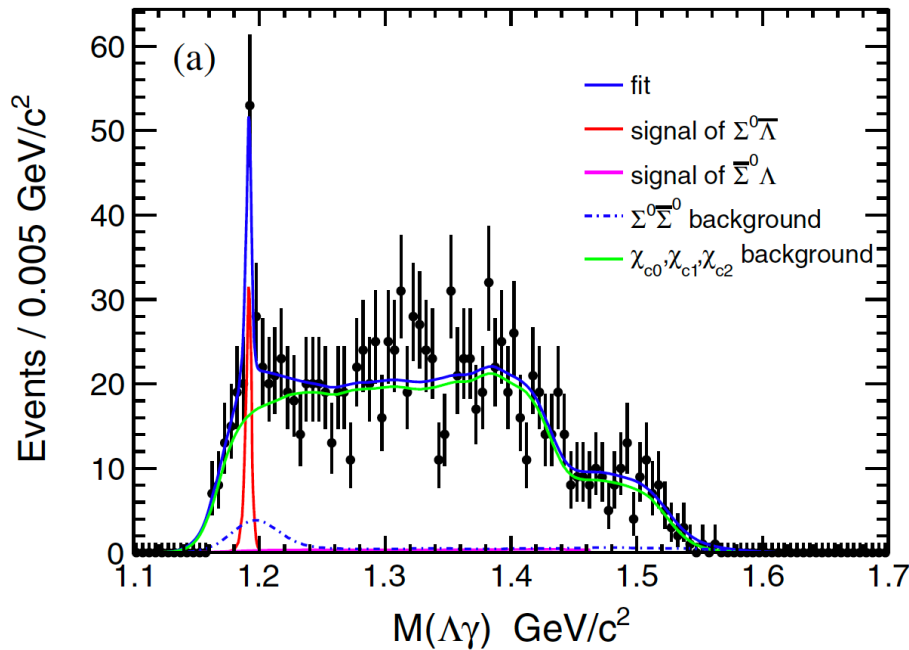
$e^+e^- \rightarrow \eta(p\bar{p})$



$e^+e^- \rightarrow \omega(p\bar{p})$

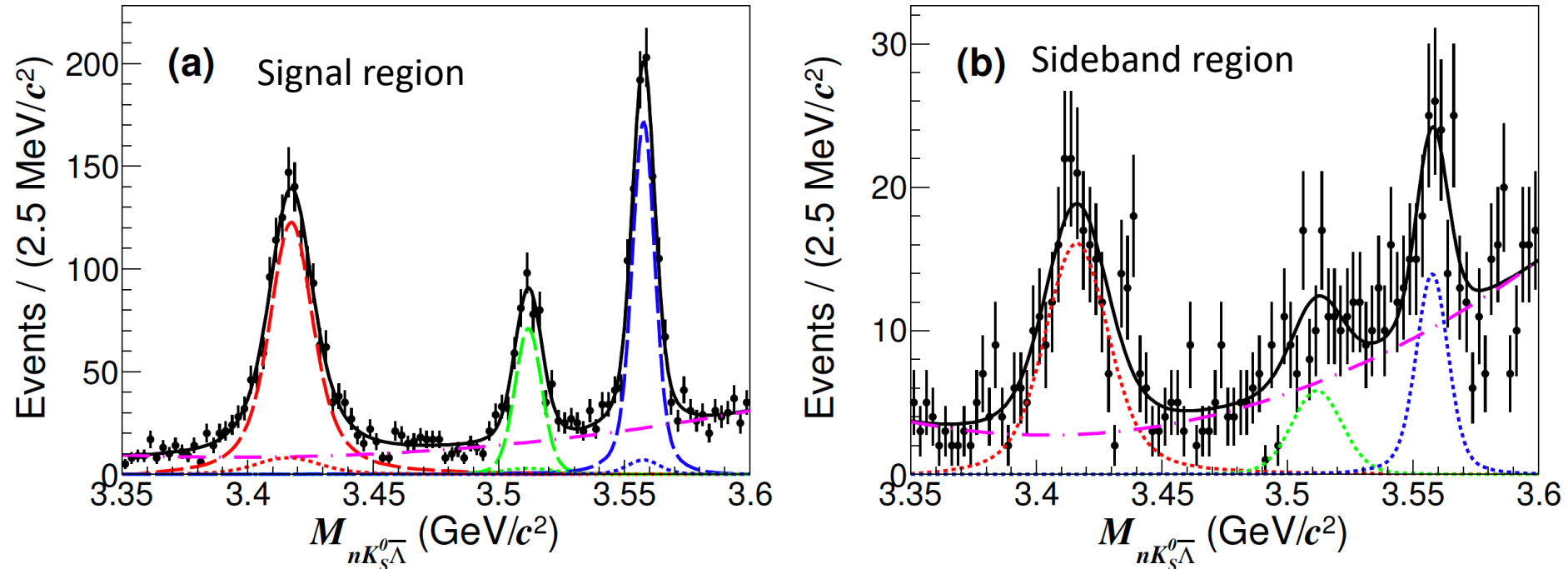
No significant  $Y$  state is observed

# Measurement of Branching Fractions of $\psi(3686) \rightarrow \bar{\Sigma}^0 \Lambda + \text{c.c.}$ and $\chi_{cJ} \rightarrow \Lambda \bar{\Lambda}$



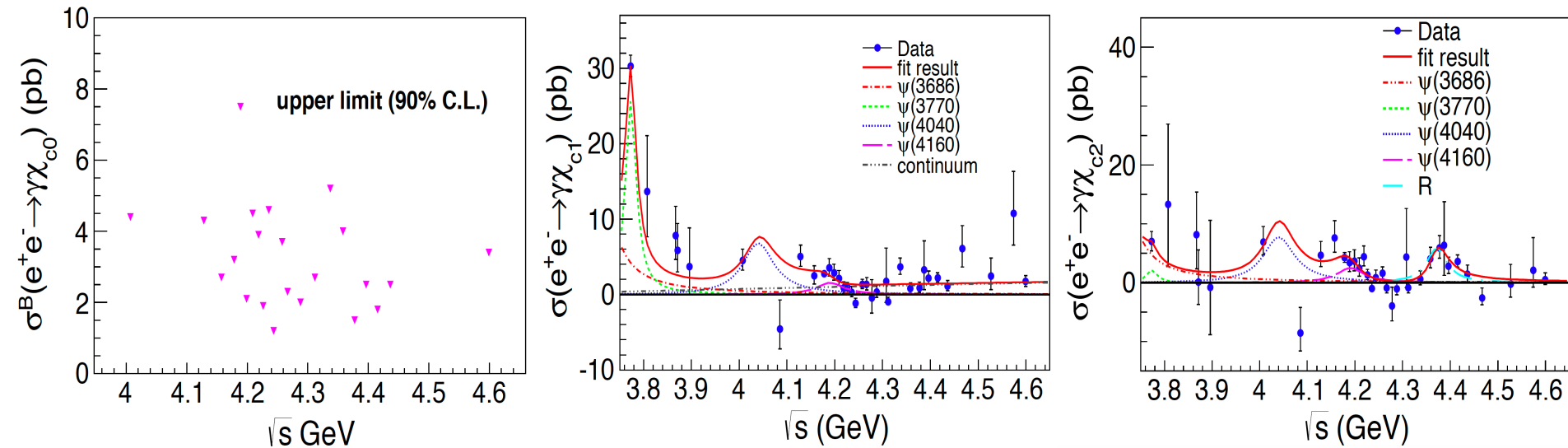
The branching fraction of this isospin breaking decay,  $\psi(3686) \rightarrow \bar{\Sigma}^0 \Lambda + \text{c.c.}$ , is measured to be  $(1.60 \pm 0.31 \pm 0.58) \times 10^{-6}$ , which is significantly smaller than the result from CLEO-c, which is  $(12.3 \pm 2.4) \times 10^{-6}$

# Observation of the decay $\chi_{cJ} \rightarrow nK_S^0\bar{\Lambda} + \text{c.c.}$



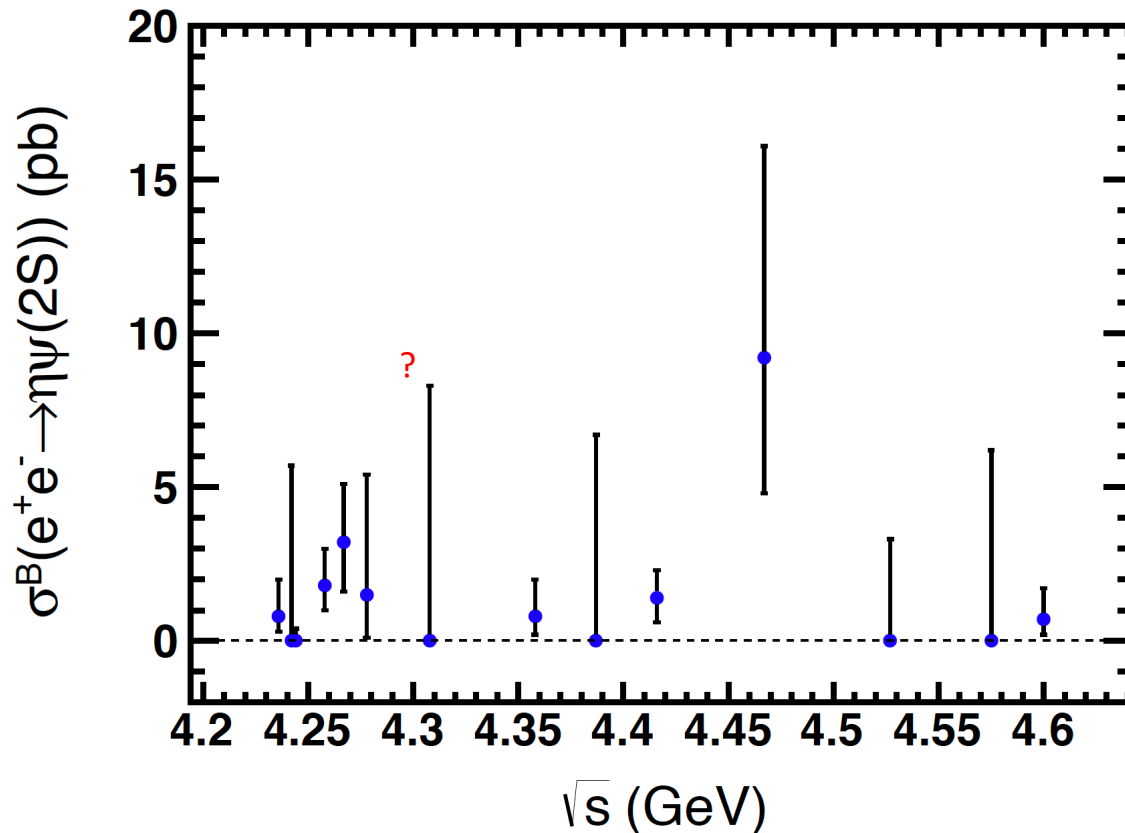
These processes are observed for the first time, and the branching fraction results are consistent with the isospin symmetry models with comparing with the charged modes.

# Measurement of $e^+e^- \rightarrow \gamma\chi_{cJ}$ cross sections at center of mass energies between 3.77 and 4.60 GeV



$e^+e^- \rightarrow \gamma\chi_{c(1,2)}$  are observed for the first time (@4.178 GeV, 7.6 and 6.0  $\sigma$ ); One new resonance is needed to describe  $e^+e^- \rightarrow \gamma\chi_{c2}$  cross section (6.0  $\sigma$ ), with mass and width consistent with Y(4360); Larger  $B(\psi(4160) \rightarrow \gamma\chi_{c2})$  is observed than potential model prediction.

# Observation of $e^+e^- \rightarrow \eta \psi(2S)$ at center of mass energies from 4.236 to 4.600 GeV



First observation of this production process ( $5\sigma$ )

Due to low statistics, it is hard to get the information about Y state from this cross section lineshape