

# XYZ physics at BESIII experiment

Zhiqing Liu

Johannes Gutenberg University Mainz

[liuz@uni-mainz.de](mailto:liuz@uni-mainz.de)

On behalf of BESIII Collaboration

The logo for the BESIII experiment, with the letters "B", "E", "S", and "III" in blue, red, green, and black respectively.

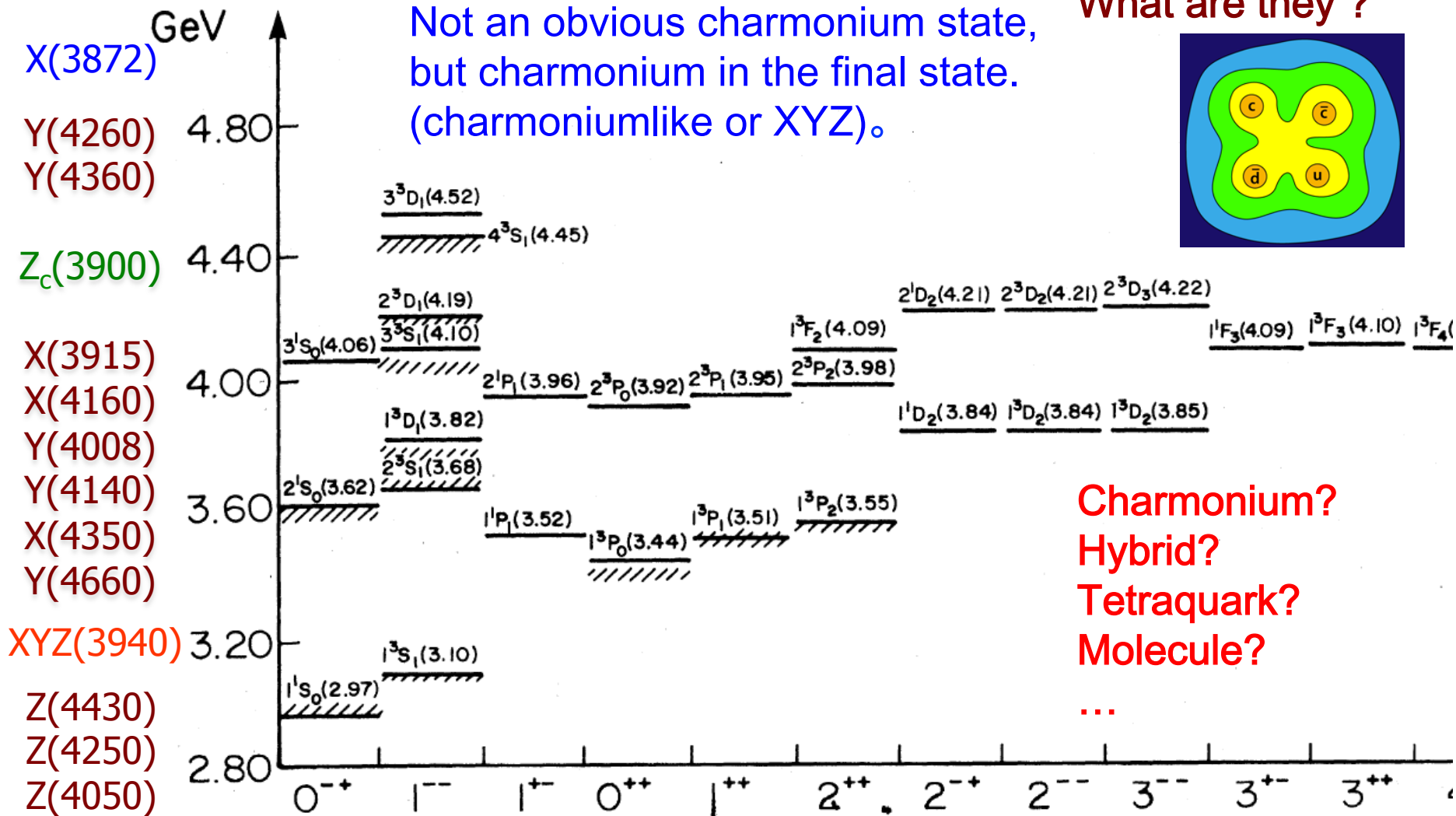
BESIII

*26th Rencontres de Blois, 20th May, 2014*

# Outline

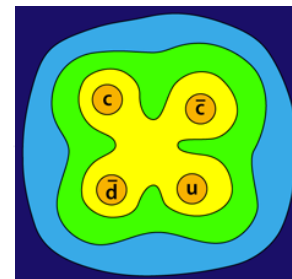
- Introduction
- Observation of  $Z_c(3900)$
- Observation of  $Z_c(4025)$  &  $Z_c(4020)$
- Observation of  $Y(4260) \rightarrow \gamma X(3872)$  &  $\omega\chi_{c0}$
- Summary and outlook

# Charmonium and XYZ states



Not an obvious charmonium state, but charmonium in the final state. (charmoniumlike or XYZ).

What are they ?



Charmonium?  
Hybrid?  
Tetraquark?  
Molecule?

...

# Beijing Electron Positron Collider (BEPC II)

First physics run starts  
from 2009 !

Linear

BESIII  
 $e^-$   
 $e^-$

Double ring:

Symmetric collider

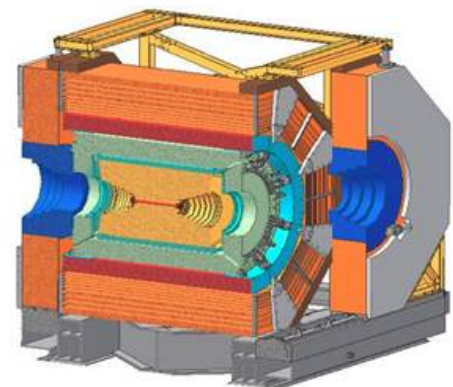
CMS energy:

2.0 - 4.6 GeV

Design Luminosity @  $\psi(3770)$ :

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

(70% achieved,  $\sim 20 \text{ pb}^{-1} / \text{day}$ )



# What do we do at BESIII?

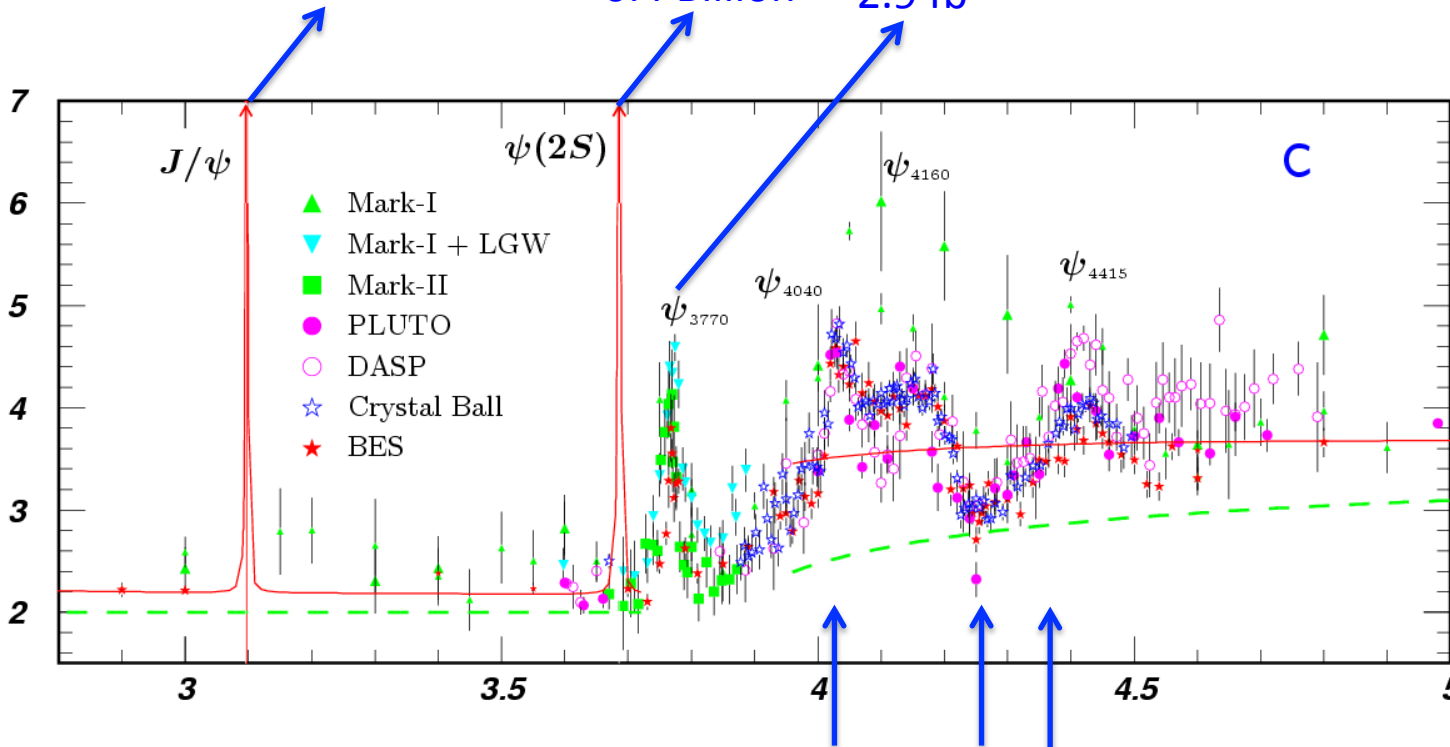
See J. F. Hu's talk

Light hadrons + charmonium decay + D meson

1.3 Billion

0.4 Billion

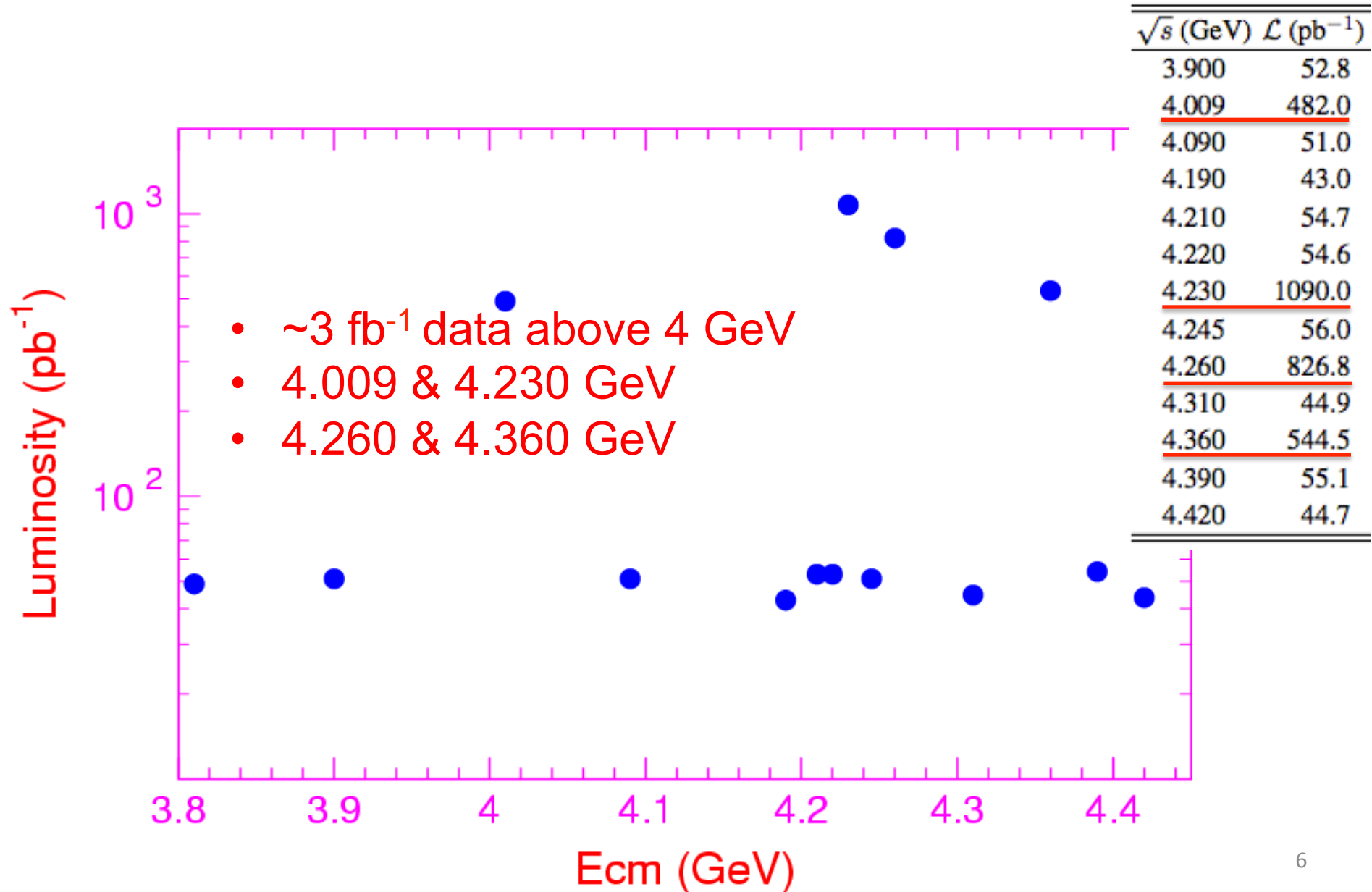
2.9 fb<sup>-1</sup>



$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb <sup>-1</sup> )
3.900	52.8
4.009	482.0
4.090	51.0
4.190	43.0
4.210	54.7
4.220	54.6
4.230	1090.0
4.245	56.0
4.260	826.8
4.310	44.9
4.360	544.5
4.390	55.1
4.420	44.7

- High potential in studying XYZ particles above threshold !
- Huge data near 4.26 GeV, 4.36 GeV...

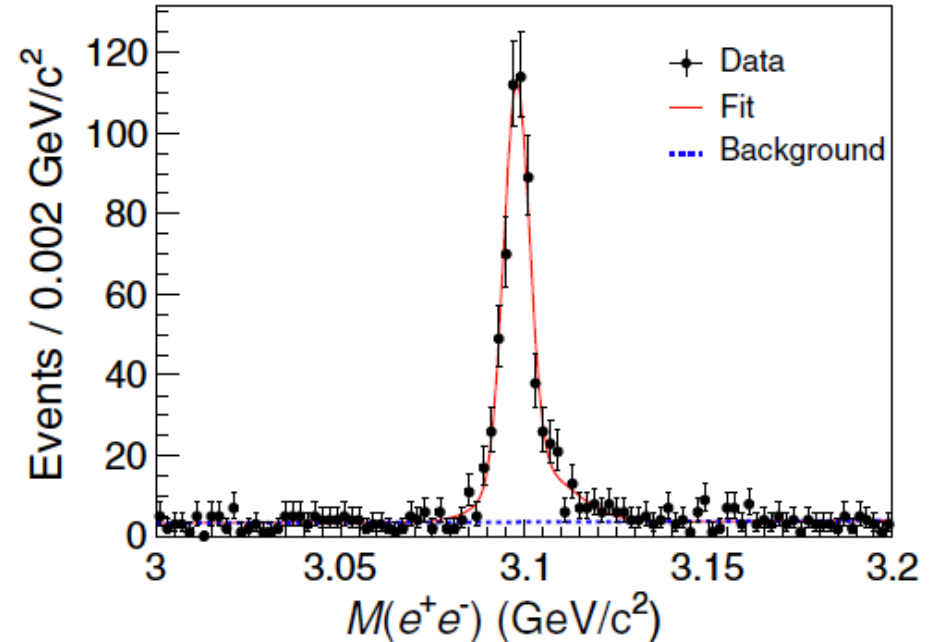
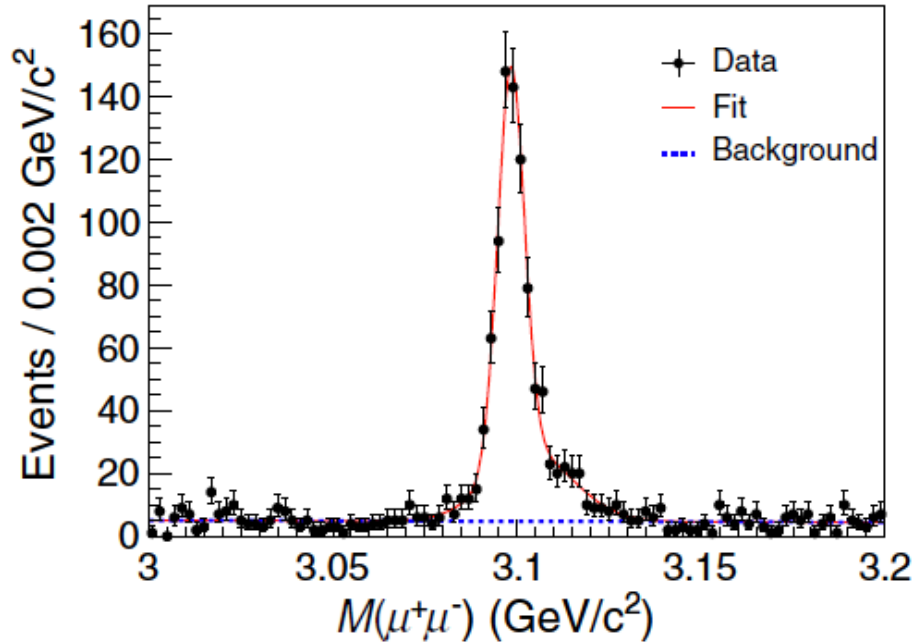
# New XYZ data at BESIII



# I. Discovery of $Z_c(3900)$

# $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ at BESIII

PRL 110,252001 (2013).

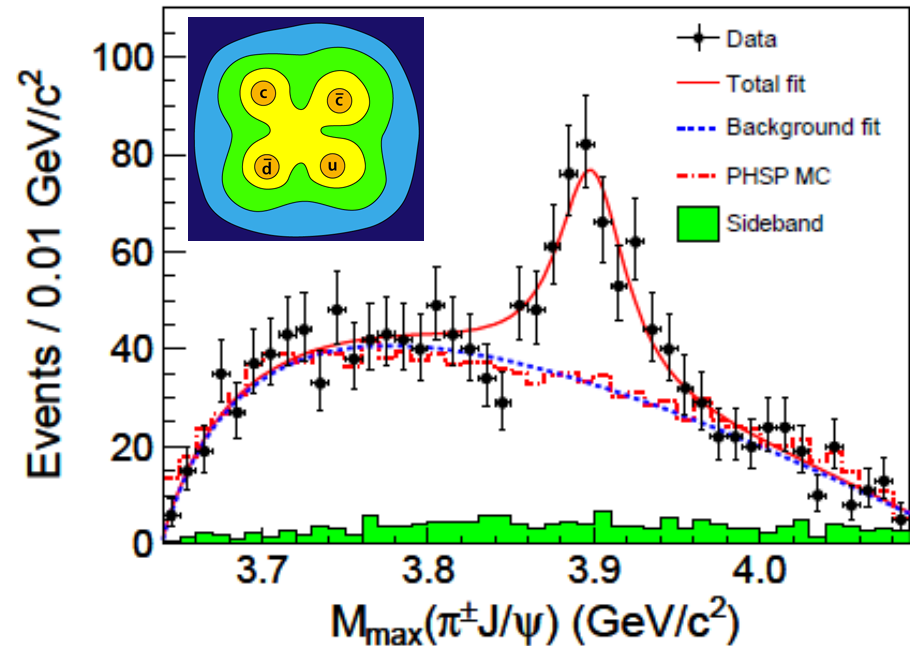
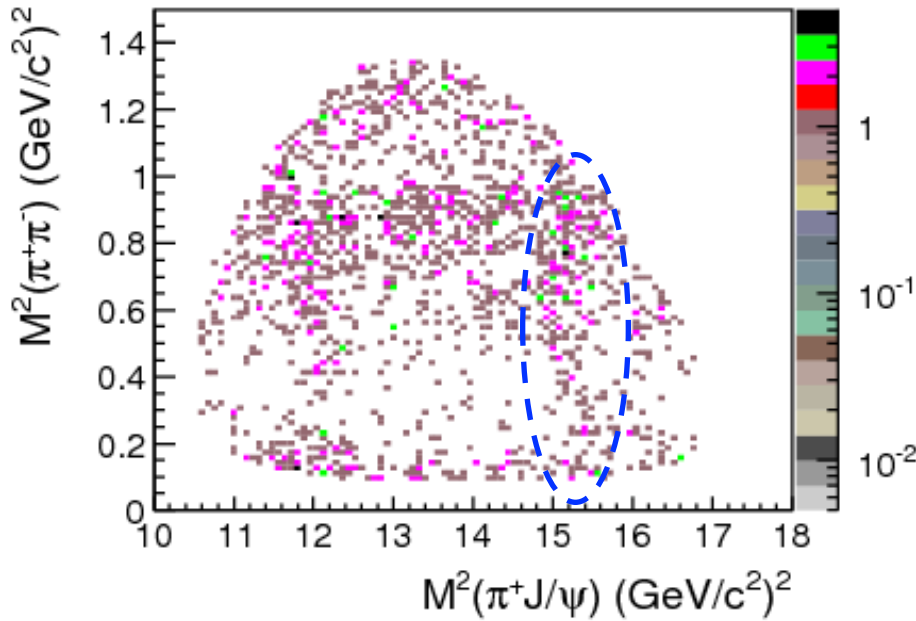


1.  $\text{Lum}=525 \text{ pb}^{-1}$  @ 4.26 GeV at BESIII
2.  $N(\mu^+\mu^-)=882\pm 33$ ;  $N(e^+e^-)=595\pm 28$ .
3. Born cross section:  $\sigma^{\text{B}}=(62.9\pm 1.9\pm 3.7) \text{ pb}$  @ BESIII.
4. Good agreement with Belle and BaBar.
5. Analysis is valid and unbiased.



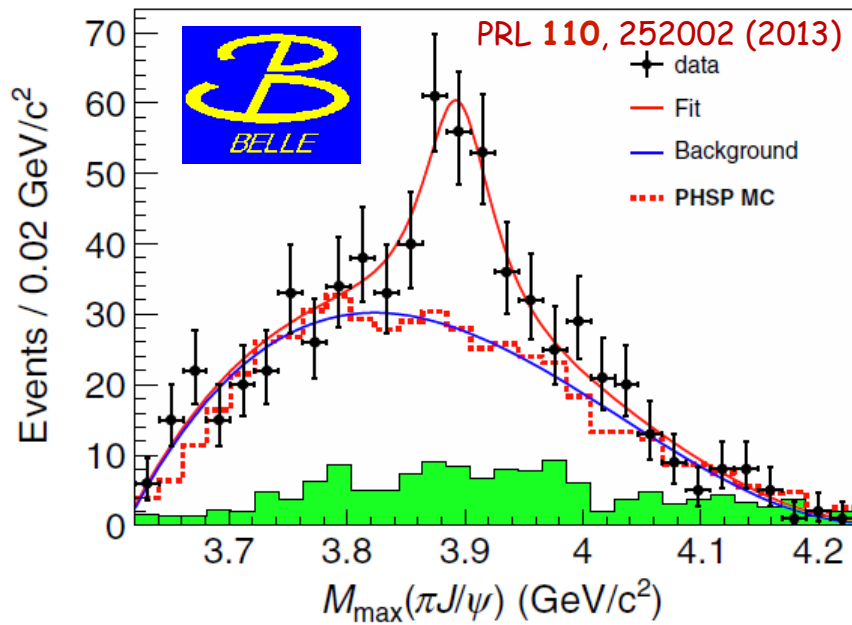
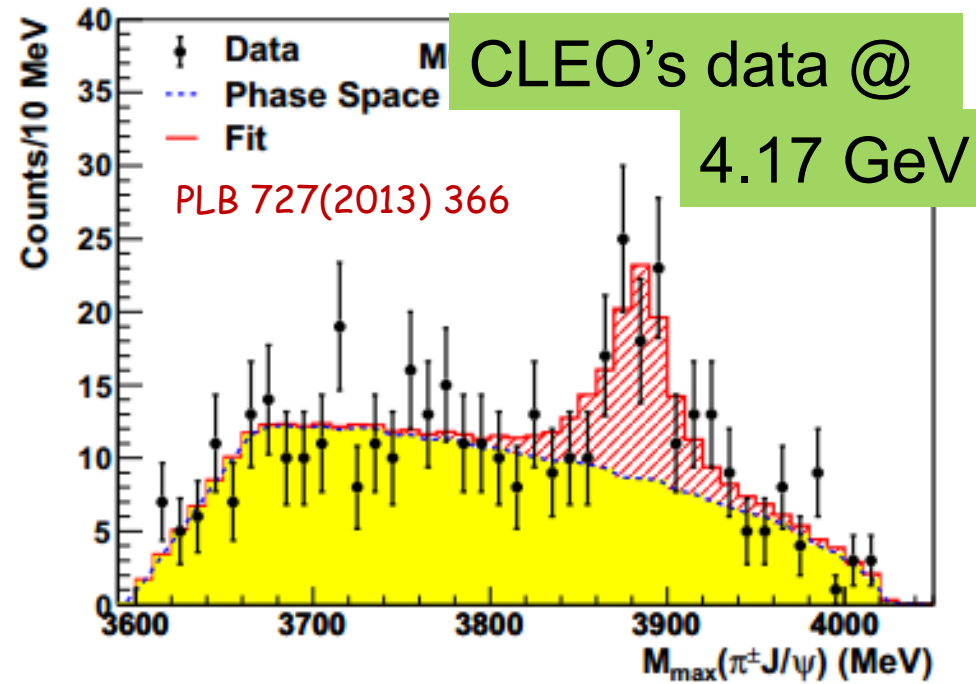
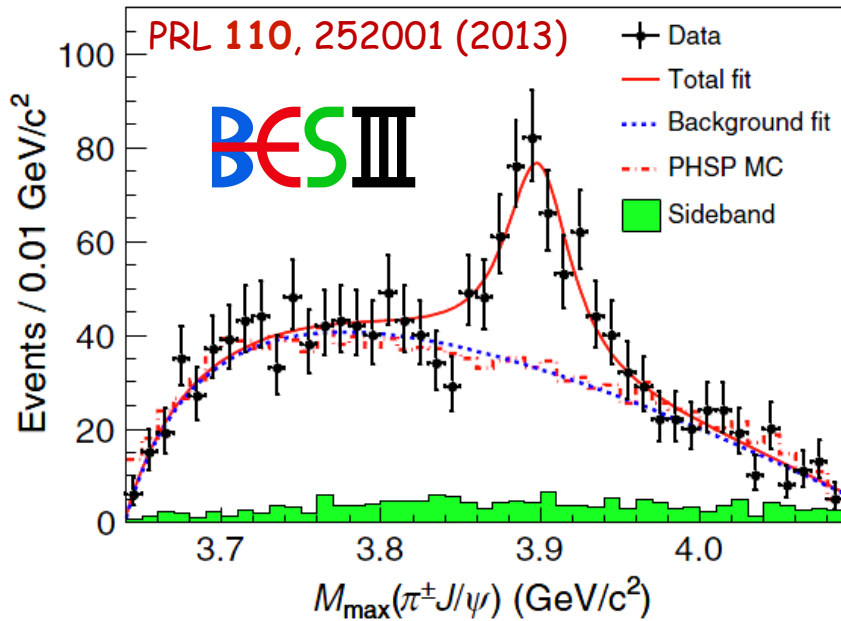
# Charged state — — $Z_c(3900)$

- Requiring  $J/\psi$  mass window:  $[3.08, 3.12]$  GeV, we have 1595 signal events, with purity  $\sim 90\%$ .



- New charged resonance, exotic 4 quark hadron?!
- Fit  $M_{\max}(\pi^\pm J/\psi)$  mass distribution; avoid cross counting
- S-Wave Breit Wigner; phase space factor; efficiency corrected.
- $M=(3899.0\pm 3.6\pm 4.9)\text{MeV}$ ;  $\Gamma=(46\pm 10\pm 20)\text{MeV}$ .
- Statistical significance:  $>8\sigma$ , discovery!

# Good News



1. CLEO's data:  $M=3886\pm 6\pm 4$  MeV,  $\Gamma=33\pm 6\pm 7$  MeV.
2. Belle:  $M=(3894.5\pm 6.6\pm 4.5)$  MeV;  $\Gamma=(63\pm 24\pm 26)$  MeV.
3. BESIII:  $M=(3899.0\pm 3.6\pm 4.9)$  MeV;  $\Gamma=(46\pm 10\pm 20)$  MeV
4.  $Z_c(3900)=Z(3900)^\pm$ .

# Exotic hadron

- Solid evidences from several experiments for the observation of  $Z_c(3900)$  at the same time !
- Wide discussions about its nature.

## Notes from the Editors: Highlights of the Year

Published December 30, 2013 | *Physics* 6, 139 (2013) | DOI: 10.1103/Physics.6.139

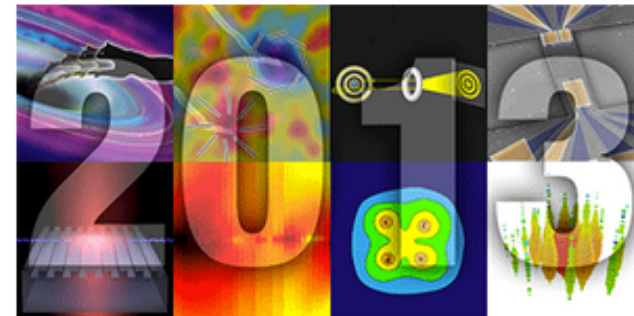
***Physics* looks back at the standout stories of 2013.**

As 2013 draws to a close, we look back on the research covered in *Physics* that really made waves in and beyond the physics community. In thinking about which stories to highlight, we considered a combination of factors: popularity on the website, a clear element of surprise or discovery, or signs that the work could lead to better technology. On behalf of the *Physics* staff, we wish everyone an excellent New Year.

– Matteo Rini and Jessica Thomas

### Four-Quark Matter

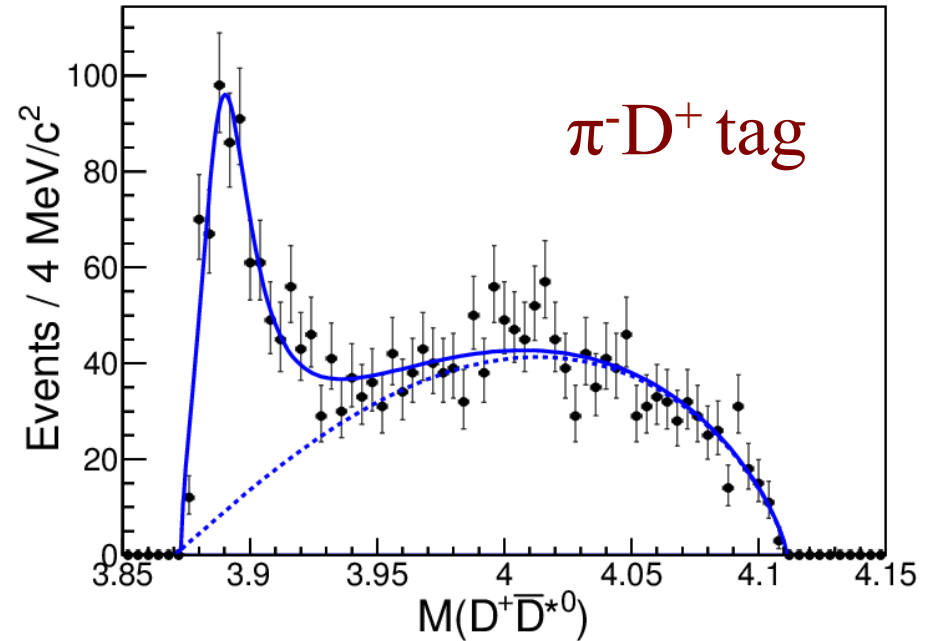
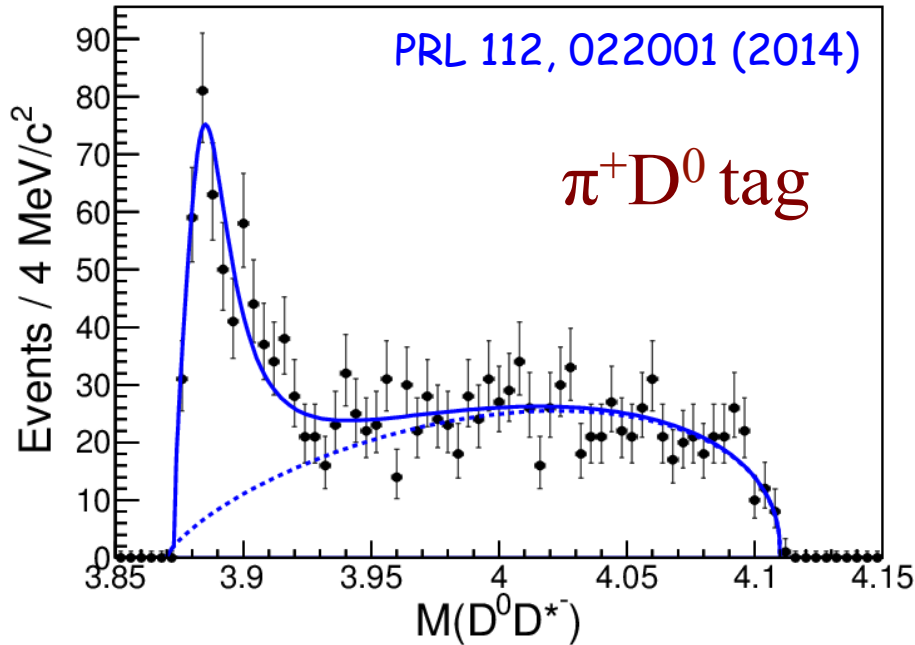
Quarks come in twos and threes—or so nearly every experiment has told us. This summer, the BESIII Collaboration in China and the Belle Collaboration in Japan reported they had sorted through the debris of high-energy electron-positron collisions and seen a mysterious particle that appeared to contain four quarks. Though other explanations for the nature of the particle, dubbed  $Z_c(3900)$ , are possible, the “tetraquark” interpretation may be gaining traction: BESIII has since seen a series of other particles that appear to contain four quarks.



Images from popular *Physics* stories in 2013.

$$\text{II. } e^+e^- \rightarrow \pi^+(DD^*)^- + \text{c.c.}$$

$$e^+e^- \rightarrow \pi^+(DD^*)^-$$



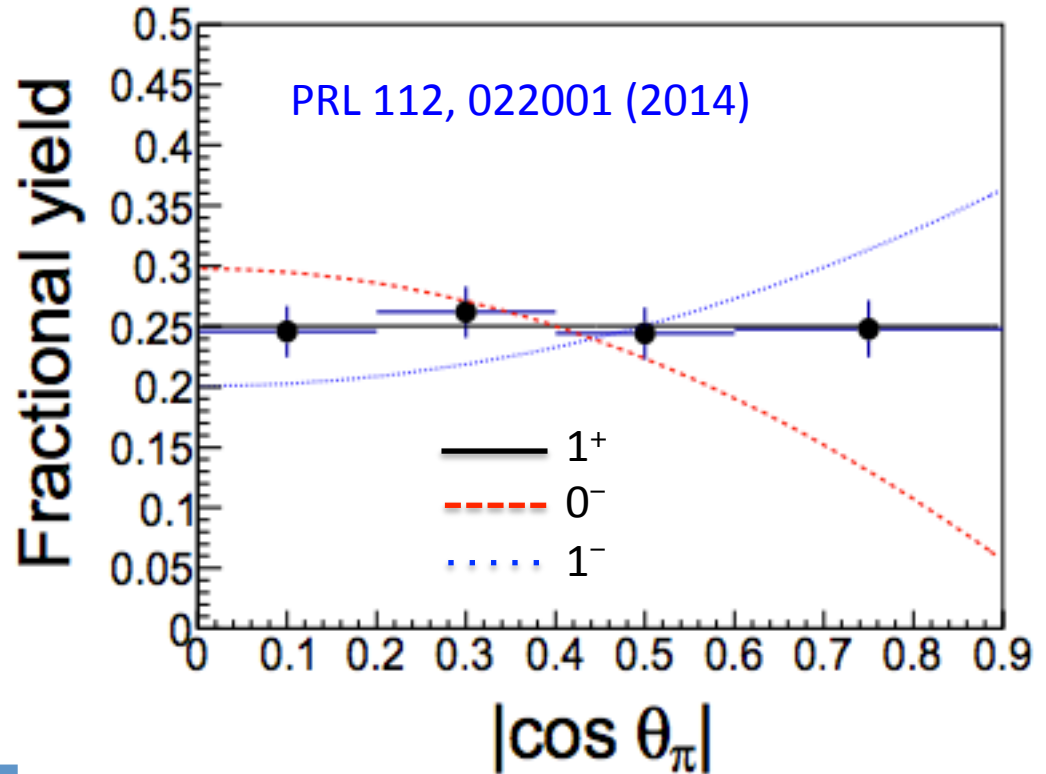
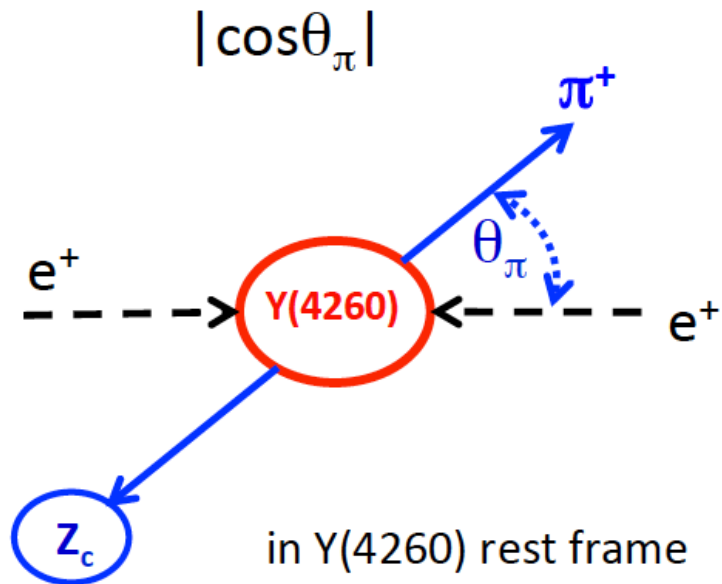
- Lum=525 pb-1 data @ 4.26 GeV, Peak near threshold.
- Angular distribution ( $\pi D$ ) disfavor  $DD_1$  component.
- Fit with mass dependent BW, report pole position.
- Polynomial background.

$$Z_c(3885) = Z_c(3900)$$

Production rate are much higher than  $\pi^\pm J/\psi$  !

	$Z_c(3885) \rightarrow DD^*$
Mass ( $\text{MeV}/c^2$ )	$3883.9 \pm 1.5 \pm 4.2$
$\Gamma$ (MeV)	$24.8 \pm 3.3 \pm 11.0$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$

# Spin-Parity of $Z_c(3885)$



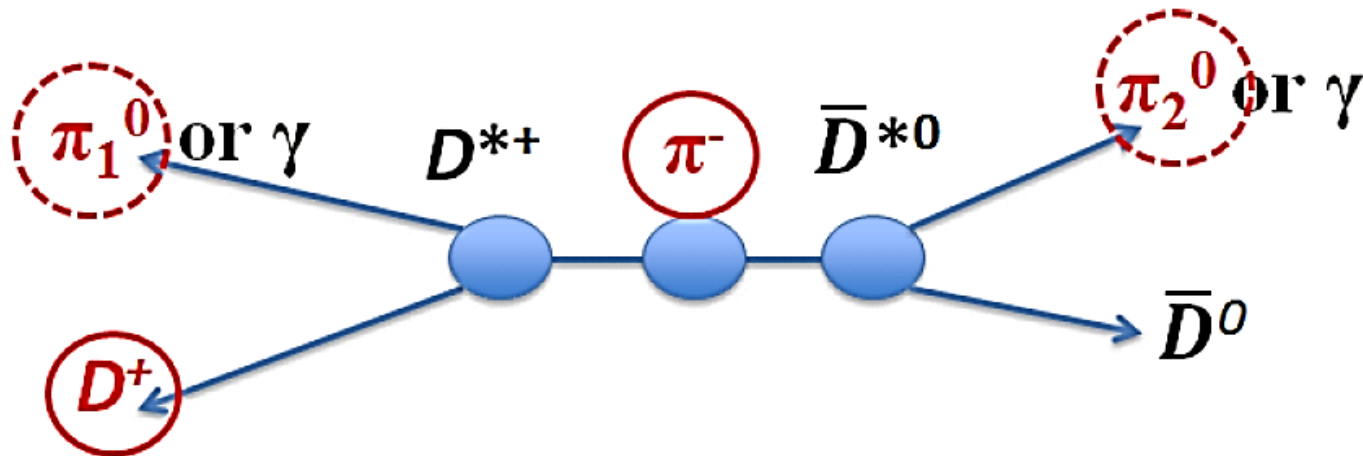
$J^P$	L	$dN/d \cos\theta_\pi $
$1^+$	S-wave	flat
$0^-$	P-wave	$\sin^2\theta_\pi$
$1^-$	P-wave	$1+\cos^2\theta_\pi$

Favor  $J^P=1^+$

$$\text{III. } e^+e^- \rightarrow \pi^\pm Z_c(4025)/Z_c(4020)$$

# $e^+e^- \rightarrow \pi^- (D^* \underline{D}^*)^+ + \text{c.c.}$ at BESIII

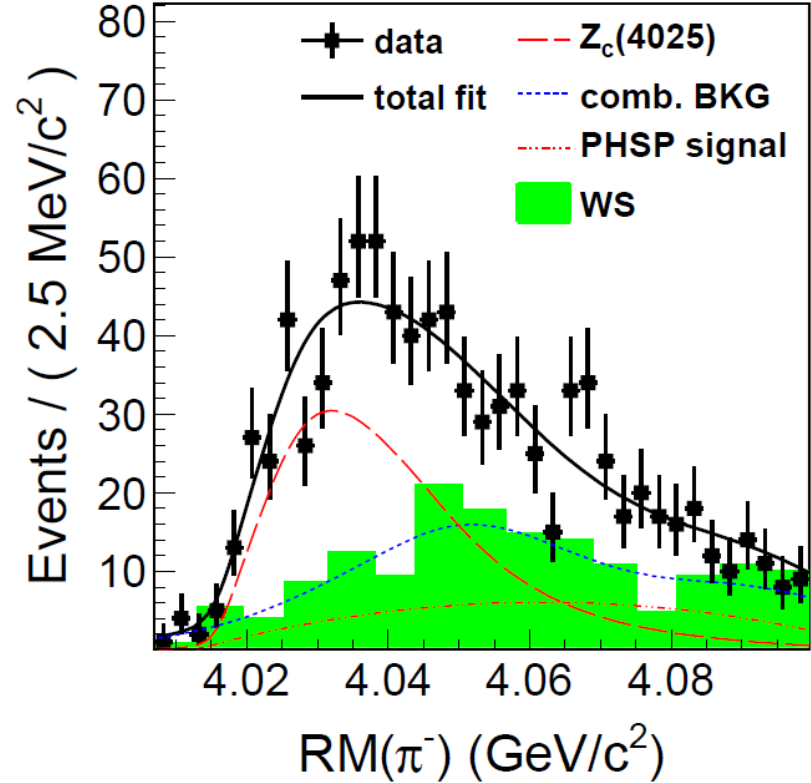
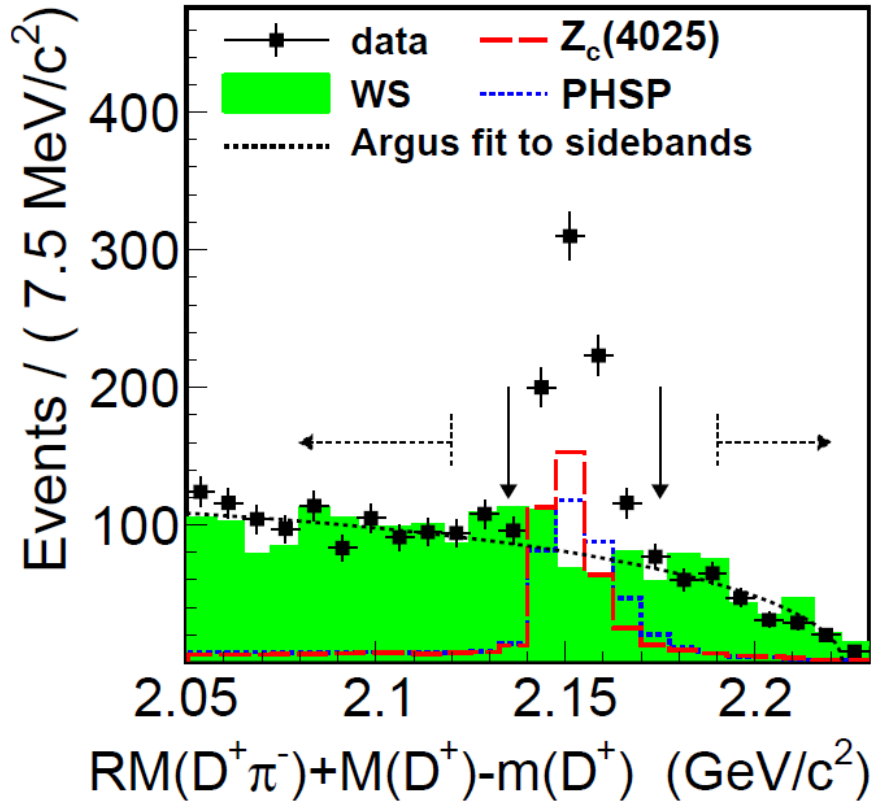
- 827 pb<sup>-1</sup> data at  $E_{\text{cm}} = 4.26$  GeV
- Tag a  $D^+$  and a bachelor  $\pi^-$ , reconstruct one  $\pi^0$  to suppress the background.



Topology of the decays of the signal process. Thick line circled  $D^+$  and  $\pi^-$  are detected in the final states and at least one of the dashed line circled  $\pi_1^0$  or  $\pi_2^0$  is tagged.



# $e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* \bar{D}^*)^+ + c.c.$



Fit to  $\pi^\pm$  recoil mass (RM) yields  $401 \pm 47$   $Z_c(4025)$  events.

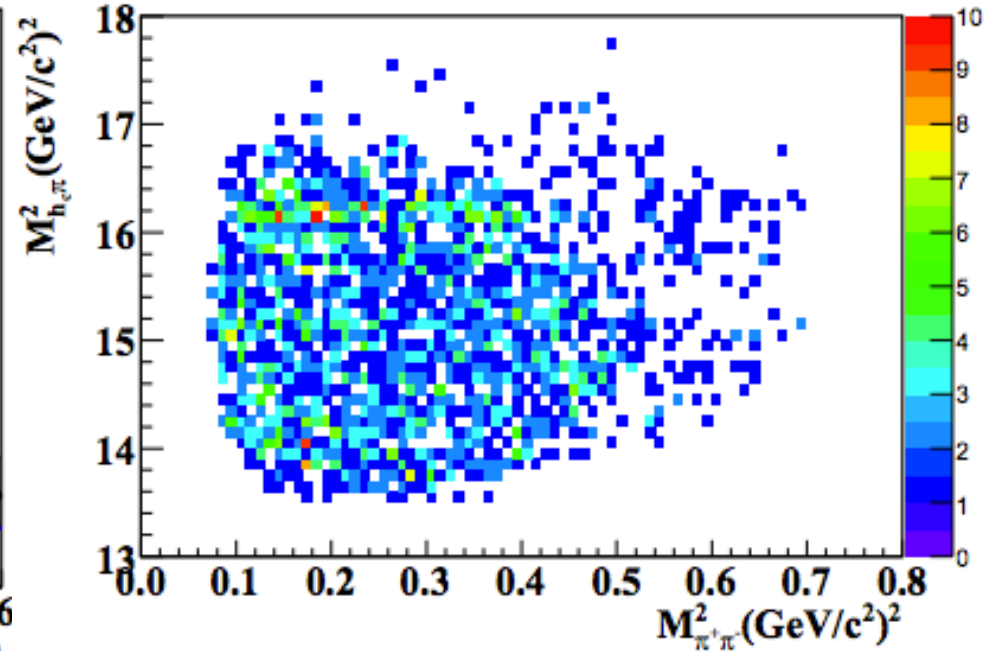
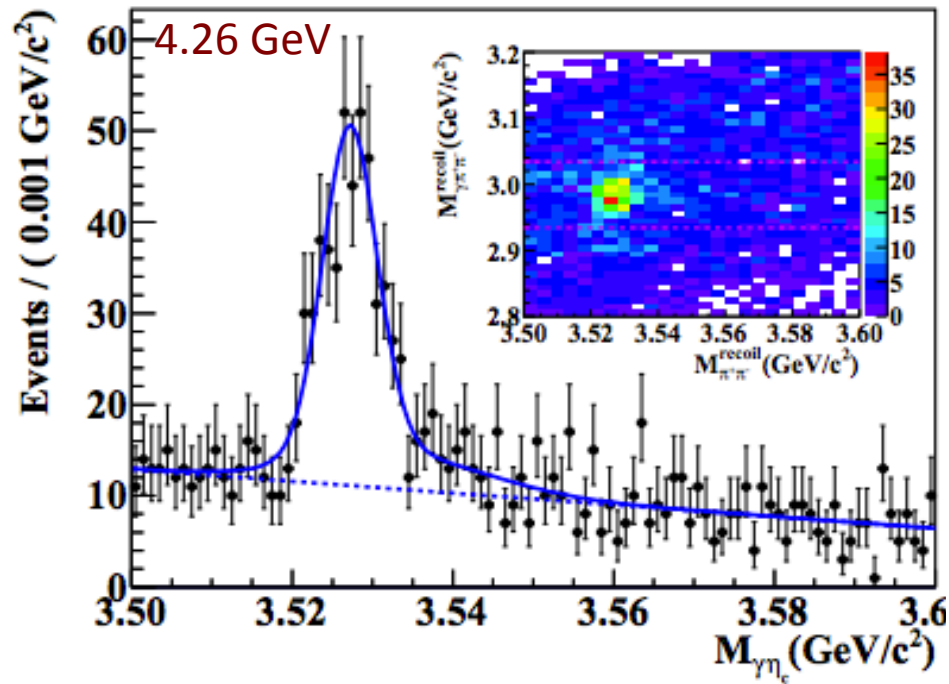
$M[Z_c(4025)] = (4026.3 \pm 2.6 \pm 3.7)$  MeV;  $\Gamma[Z_c(4025)] = (24.8 \pm 5.6 \pm 7.7)$  MeV

$$\sigma(e^+e^- \rightarrow \pi^\pm (\overline{D^* D^*})^\mp) = (137 \pm 9 \pm 15) \text{ pb}$$

Significance  $> 10\sigma$

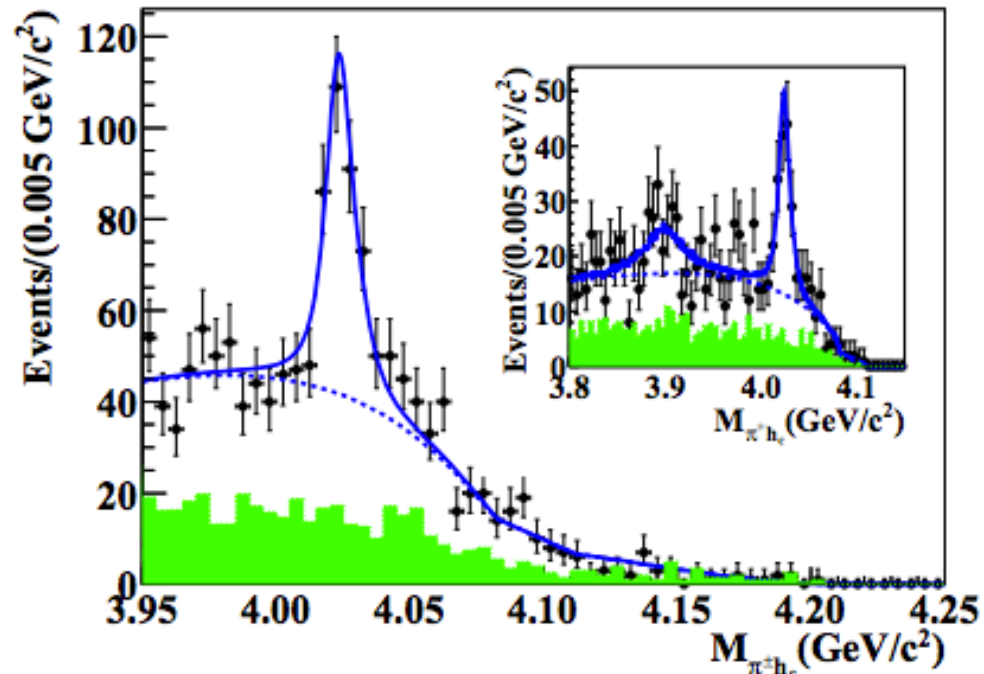
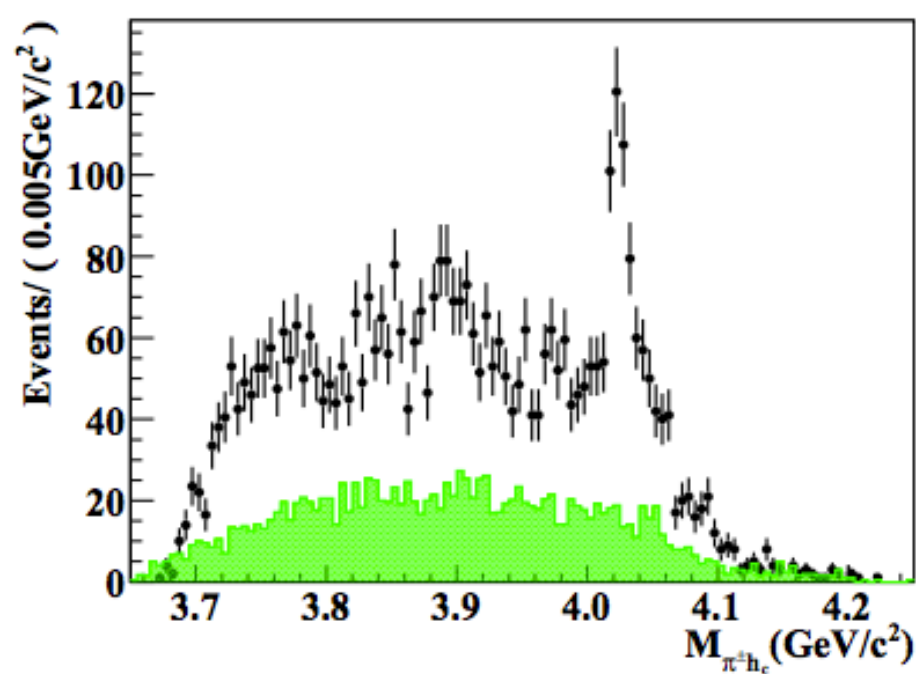
$$R = \frac{\sigma(e^+e^- \rightarrow \pi^\pm Z_c^\mp(4025) \rightarrow \pi^\pm (\overline{D^* D^*})^\mp)}{\sigma(e^+e^- \rightarrow \pi^\pm (\overline{D^* D^*})^\mp)} = (65 \pm 9 \pm 6)\% \quad \text{PRL112,132001 (2014)}$$

$$e^+e^- \rightarrow \pi^+\pi^-h_c$$



1. Good  $e^+e^- \rightarrow \pi^+\pi^-h_c$  signal, with  $h_c \rightarrow \gamma\eta_c$  &  $\eta_c \rightarrow 16$  exclusive channels.
2.  $h_c$  signal region: [3.518, 3.538] GeV, sideband: [3.49, 3.51] & [3.56, 3.58] .
3. Events accumulate around  $M(\pi^\pm h_c) \sim 16 \text{ GeV}^2$

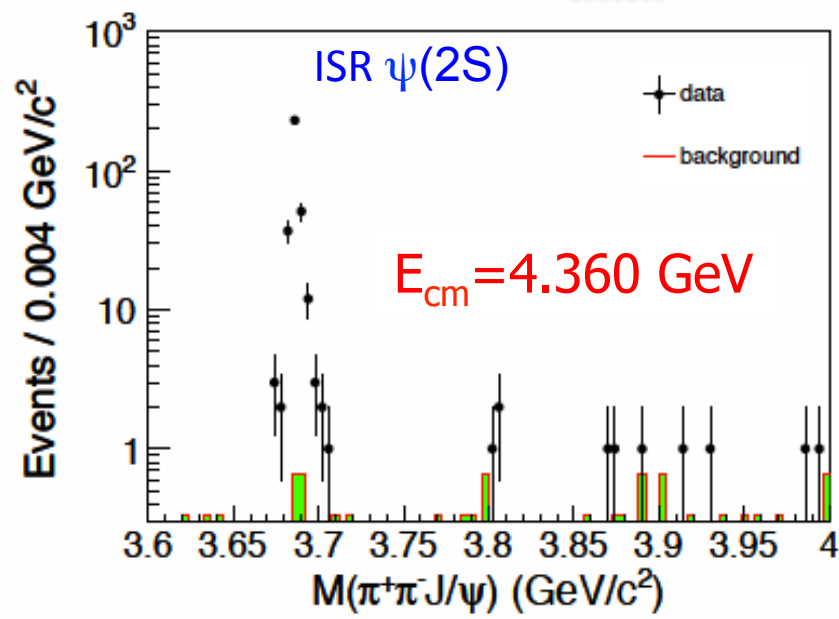
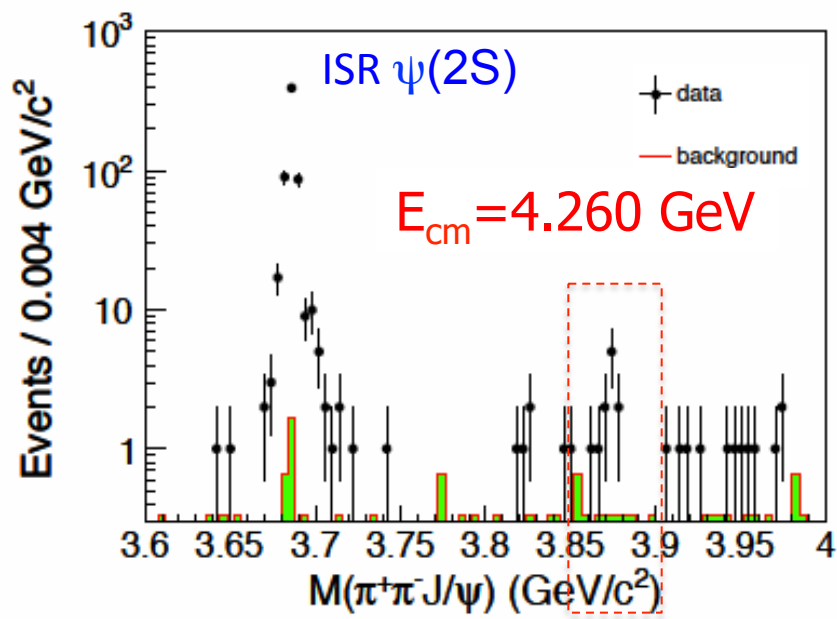
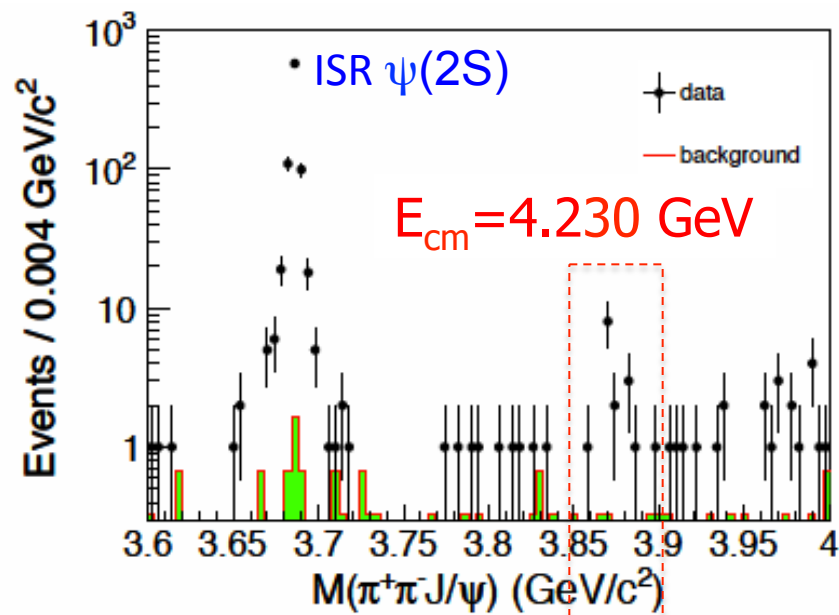
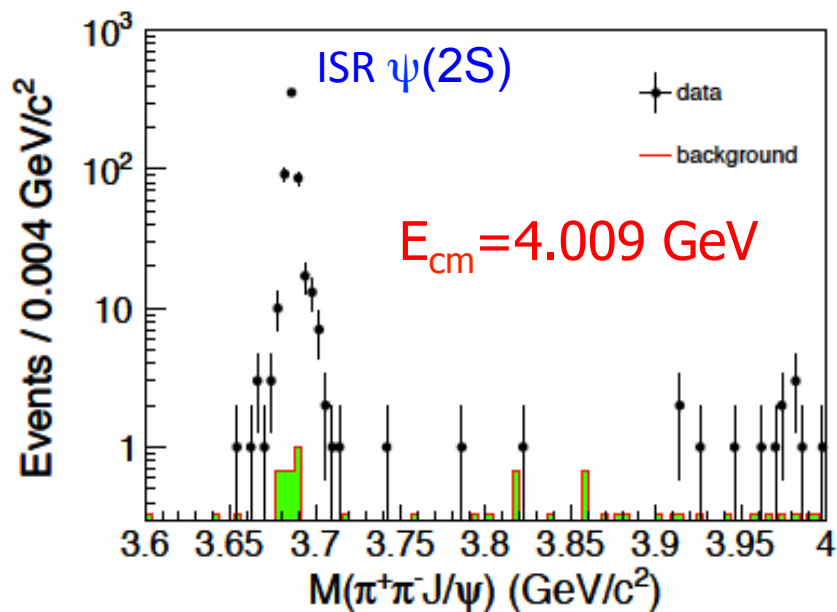
# $e^+e^- \rightarrow \pi^+ Z_c(4020)$



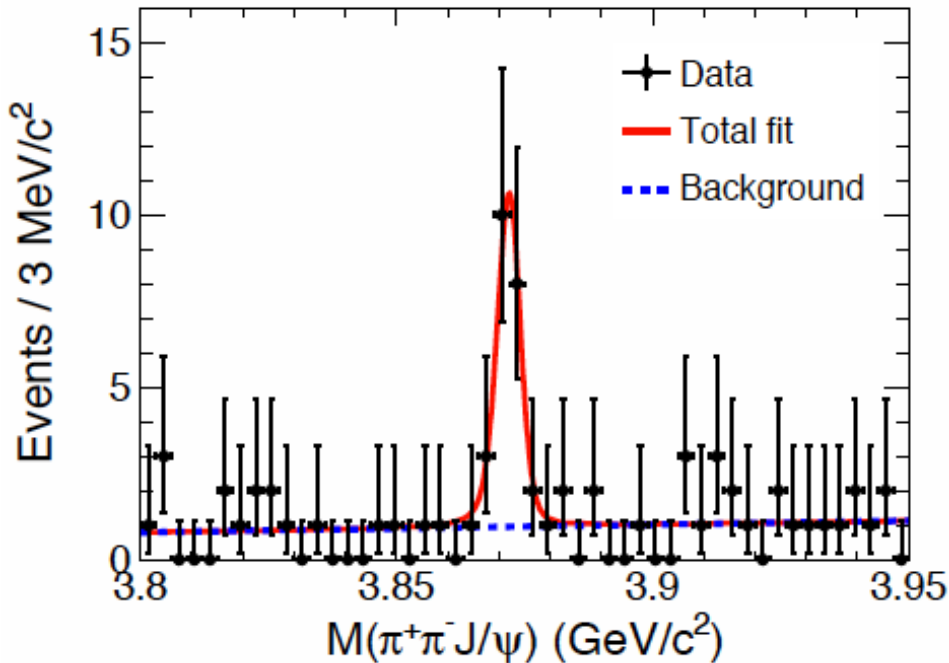
1. 1D projection of  $M(\pi^\pm h_c)$  invariant mass distribution.
2. Signal: BW function convolving Gaussian+bkg; efficiency has been applied; phase space included.
3.  $M[Z_c(4020)] = (4022.9 \pm 0.8 \pm 2.7) \text{ MeV}$ ;  $\Gamma[Z_c(4020)] = (7.9 \pm 2.7 \pm 2.6) \text{ MeV}$ .
4. Significance:  $>8.9\sigma$

IV.  $Y(4260) \rightarrow \gamma X(3872) / \omega \chi_{c0}$

# $e^+e^- \rightarrow \gamma(\pi^+\pi^-J/\psi)$ at BESIII



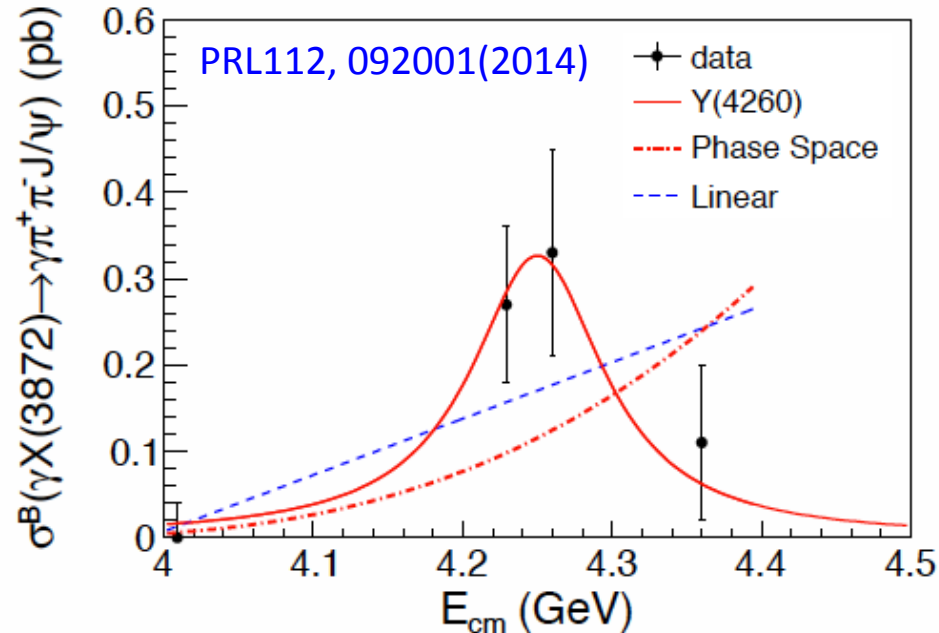
# $Y(4260) \rightarrow \gamma X(3872)$



$$M = (3871.9 \pm 0.7 \pm 0.2) \text{ MeV}$$

$$\Gamma < 2.4 \text{ MeV}$$

Significance:  $6.3 \sigma$



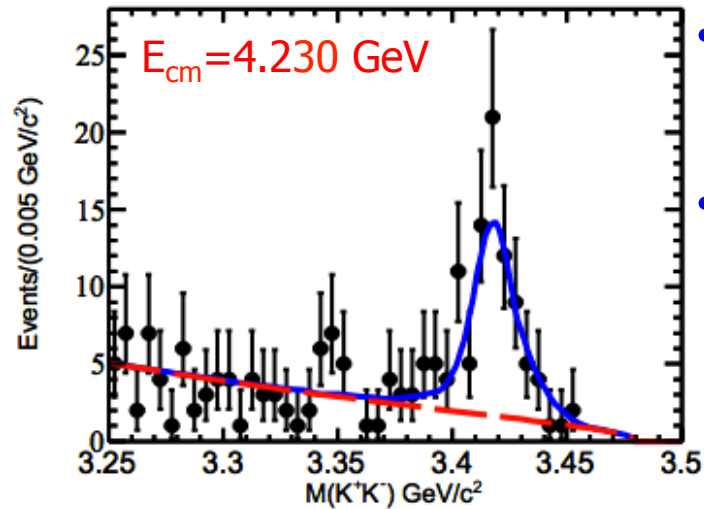
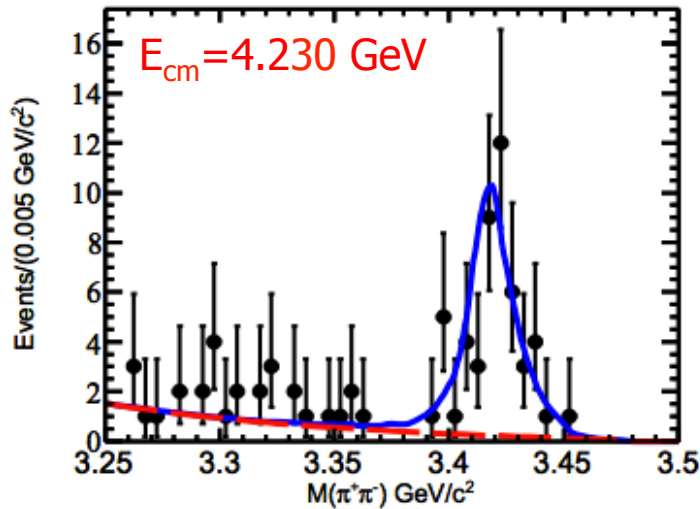
Fit with:

1.  $Y(4260): \chi^2/\text{ndf} = 0.49/3$
2.  $E1 \text{ PHSP}: \chi^2/\text{ndf} = 8.7/3$
3.  $\text{Linear}: \chi^2/\text{ndf} = 5.5/2$

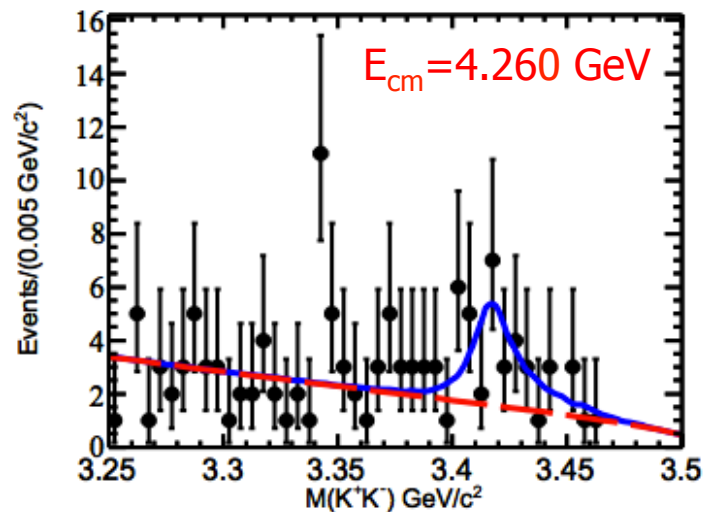
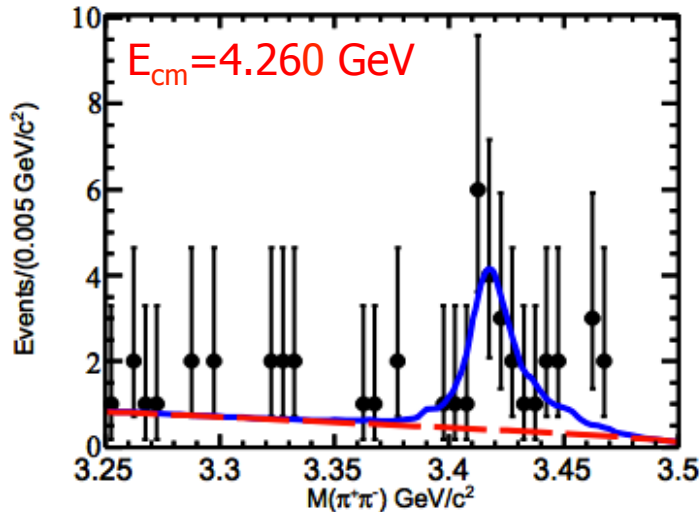
$$\frac{\mathcal{B}[Y(4260) \rightarrow \gamma X(3872)]}{\mathcal{B}(Y(4260) \rightarrow \pi^+ \pi^- J/\psi)} = 0.1$$

# $e^+e^- \rightarrow \omega \chi_{c0}$ at $E_{cm} = 4.23$ & $4.26$ GeV

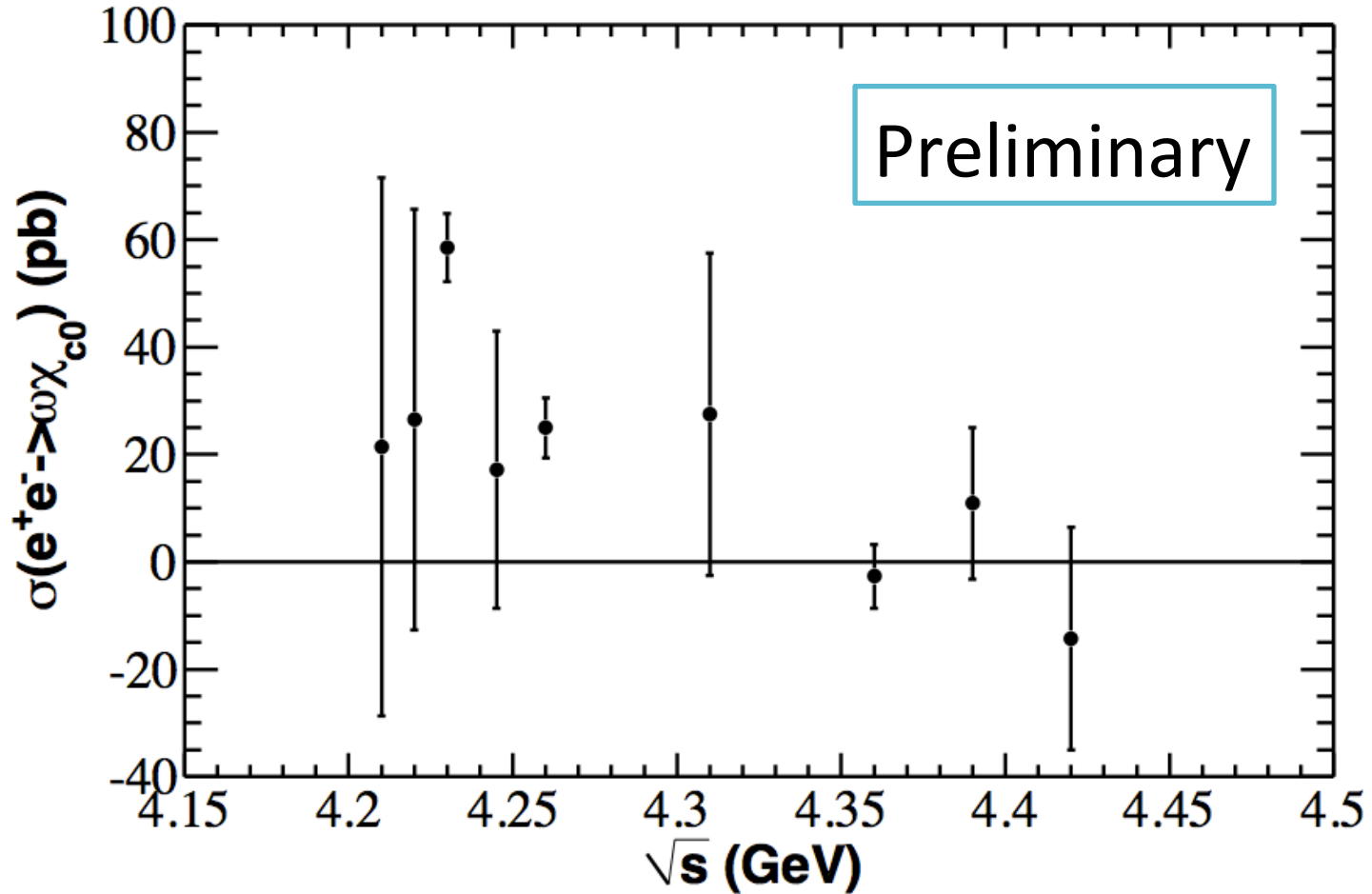
Preliminary



- $\omega \rightarrow \pi^+\pi^-\pi^0$ ,  
 $\chi_{c0} \rightarrow \pi^+\pi^-/K^+K^-$
- $\omega$  are required to be in signal region.



# $e^+e^- \rightarrow \omega\chi_{c0}$ at BESIII



The cross section peaks near 4.23 GeV.



# Summary

- BESIII observed a charged Charmonium-like state  $Z_c(3900)$ .
- Possible partner particle  $Z_c(4025)/Z_c(4020)$  also found
- Observed  $Y(4260) \rightarrow \gamma X(3872)$  decay &  $e^+e^- \rightarrow \omega \chi_{c0}$  for the first time.
- Understand them with more data & effort.

# Outlook: what's next @ BESIII

1. PWA of  $Y(4260) \rightarrow \pi^+\pi^-J/\psi$ , more precise mass and width measurement of  $Z_c(3900)$ +Spin-parity determination.
2. Neutral partners, such as  $Z^0$  and  $Z^{0'}$
3. Line shape study of  $\pi^+\pi^-J/\psi$ , also  $\pi Z_c(3900)$ .
4. Try to distinguish different multi-quark models: tetraquark, hadron molecule...
5. Search for new decay modes, production rate...
6. Other puzzling XYZ states...

Thank you (谢谢) !