

# Exotic Charmonium-like states at BESIII

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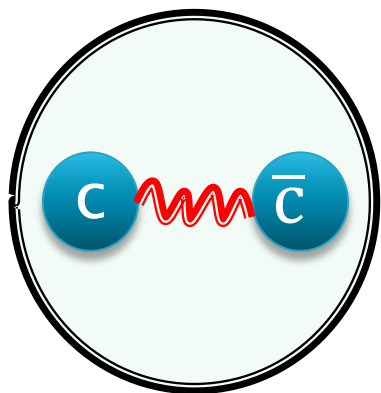
*21–28 March, Moriond QCD 2015*

# Outline

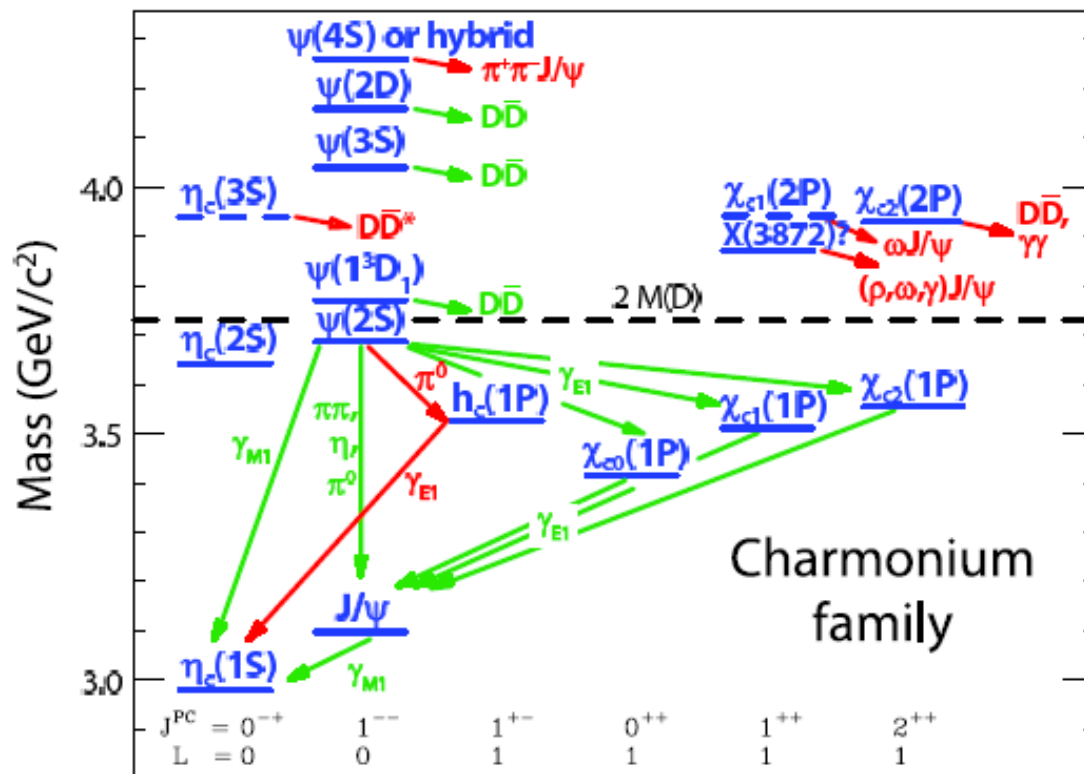
- ▶ Introduction
  - Charmonium & Exotics states
  - BESIII experiment and BEPCII
- ▶ Exotic charmonium-like states at BESIII
  - Z states
  - X & Y states (fast review)
- ▶ Summary & Outlook



# Introduction-Charmonium



Simple image of charmonium



Known charmonium states and candidates, with selected decay modes and transitions. See Yanbiao's talk for details.

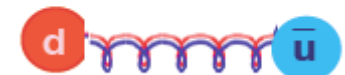
# Introduction–Exotics (types)

- ▶ Exotic candidates because of self–coupling of gluons in QCD
  - Bound gluons (glueball)
  - $q\bar{q}$ –pair with an excited gluon (hybrids)
  - Multi–quark color singlet states
    - $q\bar{q}q\bar{q}$  (tetra–quark and molecular)
    - $q\bar{q}q\bar{q}q$  (penta–quark)
    - $q\bar{q}q\bar{q}q\bar{q}$  (six–quark and baryonium)

Glueball



Hybrid



Pentaquark



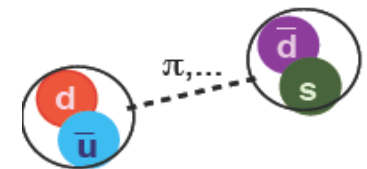
Dibaryon



Tetraquark



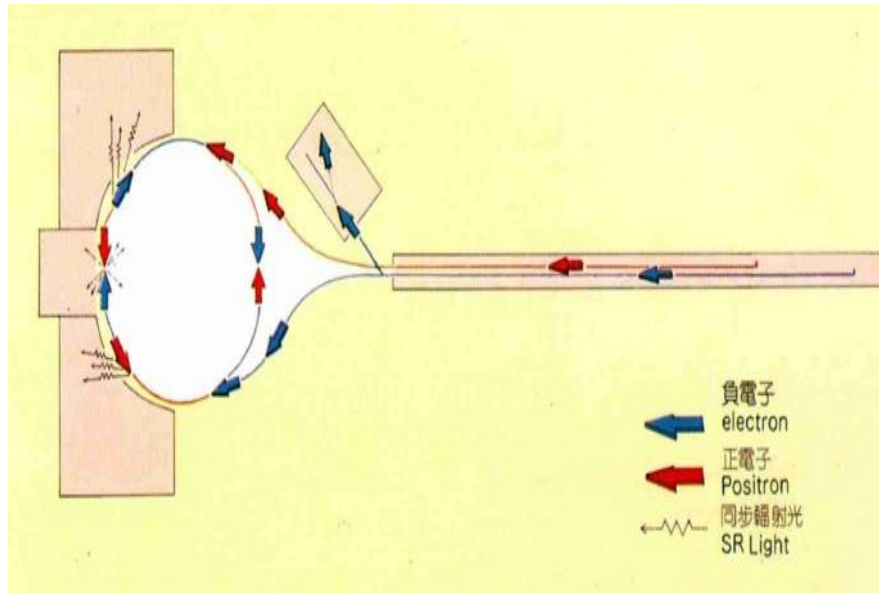
Molecule



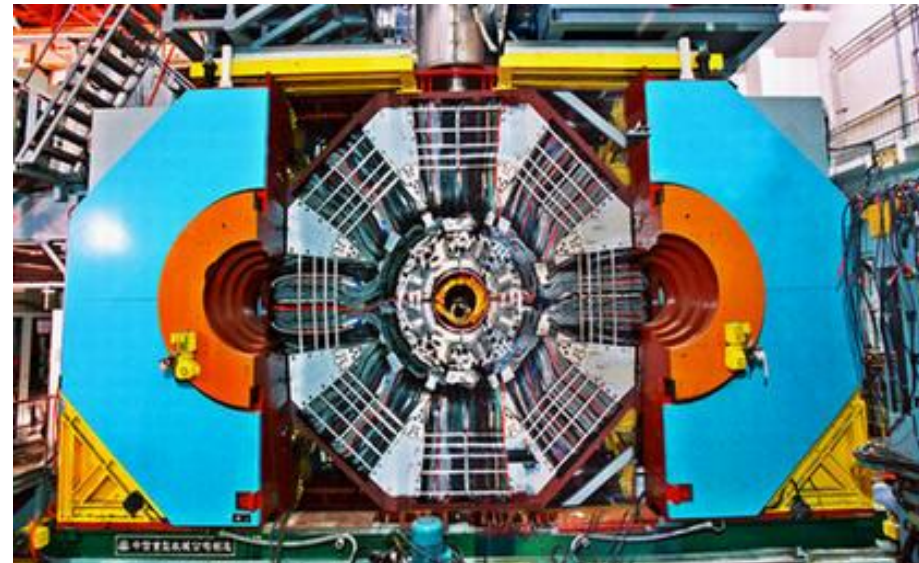
figures from arXiv:1403.1254, S. Olsen

# Introduction–BEPCII & BESIII

BEPCII



BESIII

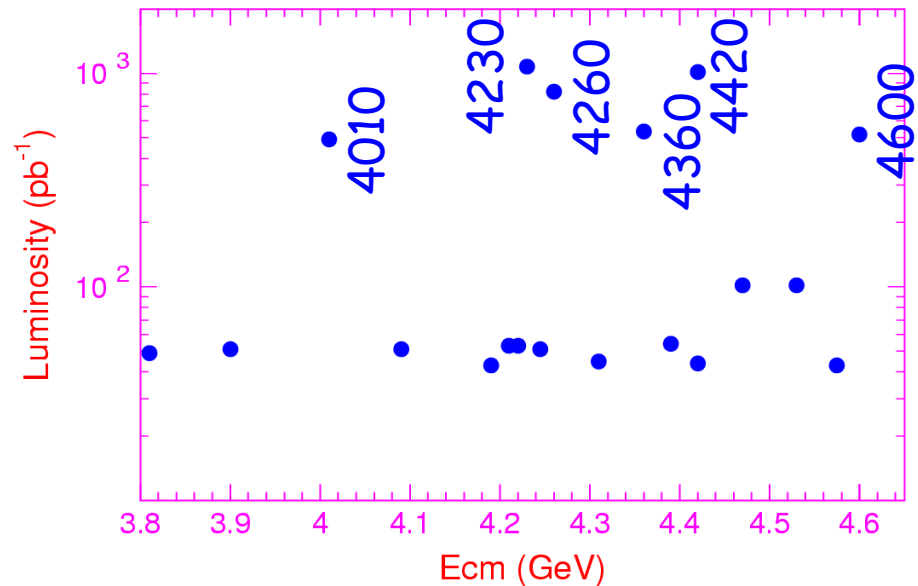


$\sqrt{s} = 2 \sim 4.6$  GeV, rich physics potential .  
Light hadron, charmonium, charm, R & QCD.

# Introduction–BESIII (data samples)

- ~ 0.6 B  $\psi(3686)$  events
  - ~ 1.3 B  $J/\psi$  events
  - ~ 2.9fb<sup>-1</sup>  $\psi(3770)$
  - ~ others including scan and continuum data, etc.
- ~ 24xCLEO-c
  - ~ 21xBESII
  - ~ 11xCLEO-c

5/fb collected above 4 GeV.  
Mainly for **XYZ** states!

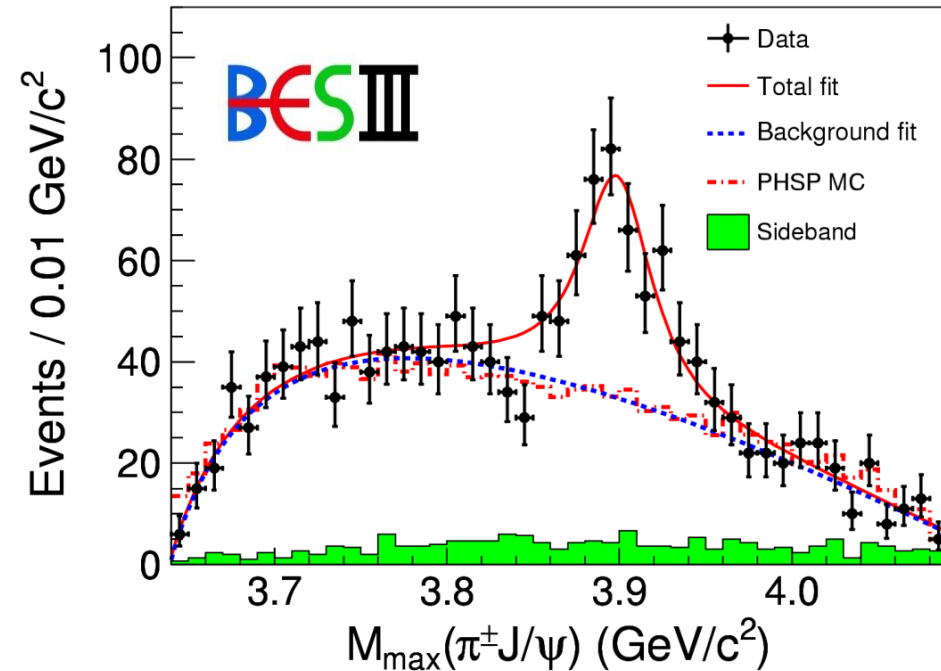




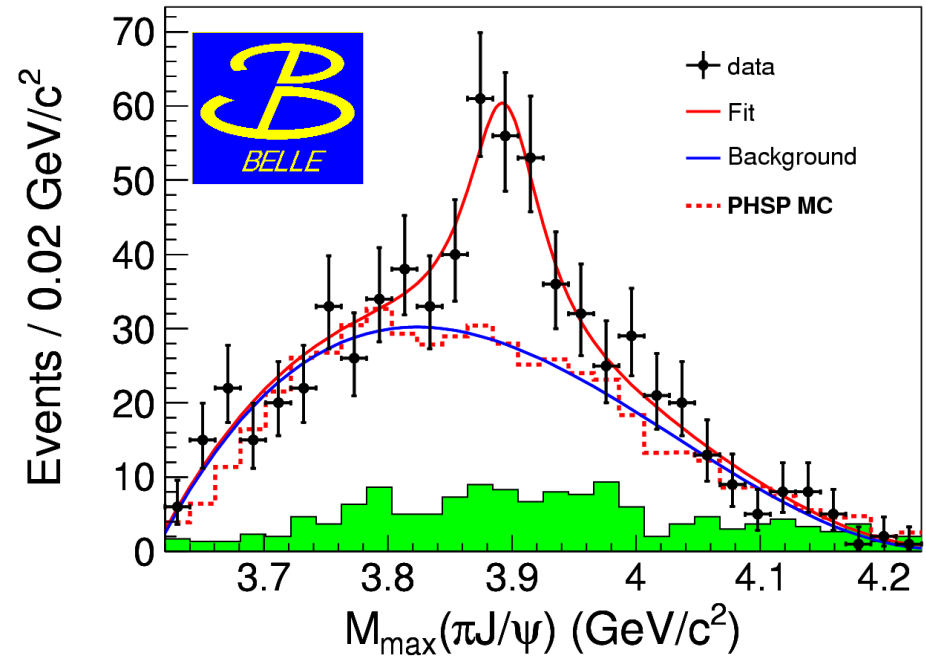
# $Z_c(3900)$ : observed in BESIII and Belle

At 4.26 GeV: PRL 110, 252001

ISR: PRL 110, 252002



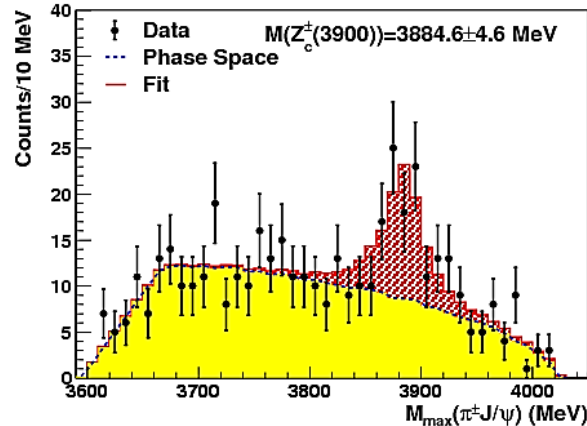
- $M = 3899.0 \pm 3.6 \pm 4.9$  MeV
- $\Gamma = 46 \pm 10 \pm 20$  MeV
- $307 \pm 48$  events
- $> 8\sigma$



- $M = 3894.5 \pm 6.6 \pm 4.5$  MeV
- $\Gamma = 63 \pm 24 \pm 26$  MeV
- $159 \pm 49$  events
- $> 5.2\sigma$

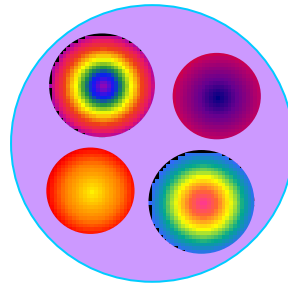
# $Z_c(3900)$ : confirmed by an analysis of CLEOc data

At 4.17 GeV: PLB 727 366–370



- $M = 3885 \pm 5 \pm 1$  MeV
- $\Gamma = 34 \pm 12 \pm 4$  MeV
- $81 \pm 20$  events
- $6.1\sigma$

- Couples to  $c\bar{c}$
- Has electric charge
- At least 4-quarks



- $DD^*$  molecule?
- Tetra-quark?
- Cusp?
- Threshold effect?
- ...

More decay modes? Neutral partner? Excited states?

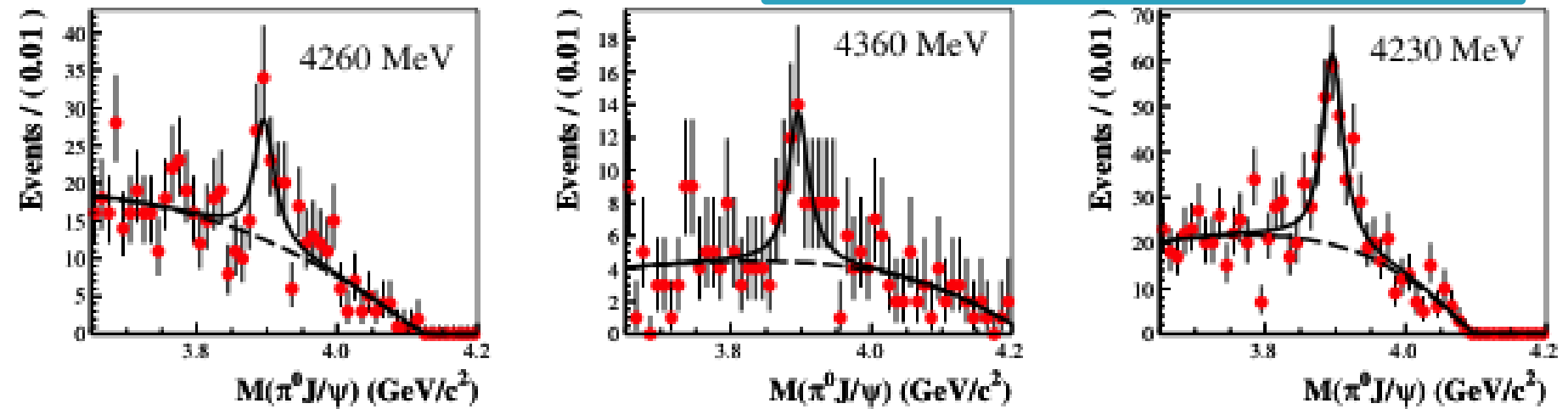
Searched at BESIII



# The neutral partner of $Z_c(3900)$

Fit to  $\pi^0 J/\psi$  spectrum.

BESIII preliminary



A simultaneous fit for three subsamples



Mass =  $3894.8 \pm 2.3$  MeV

Width =  $29.6 \pm 8.2$  MeV

Significance =  $10.4 \sigma$

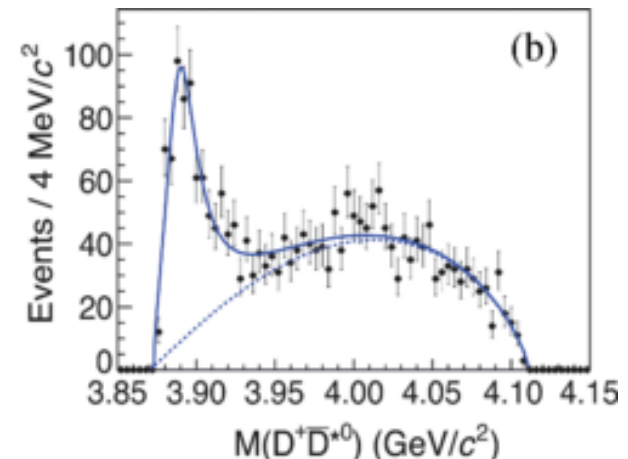
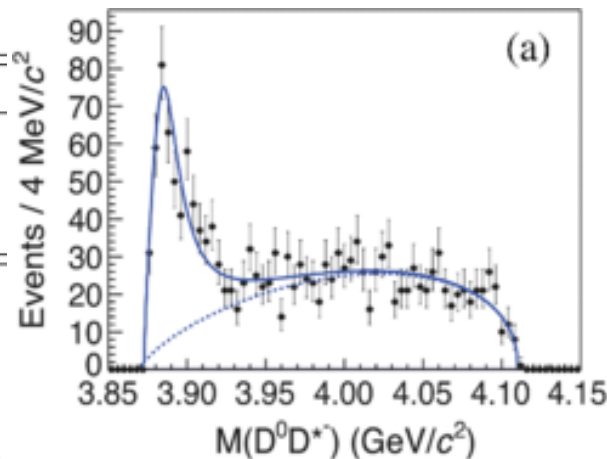
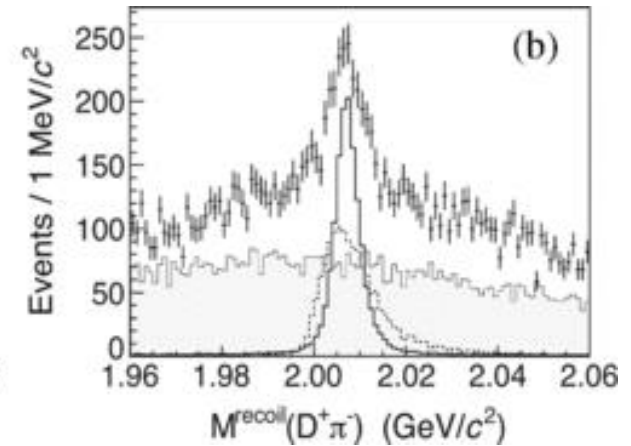
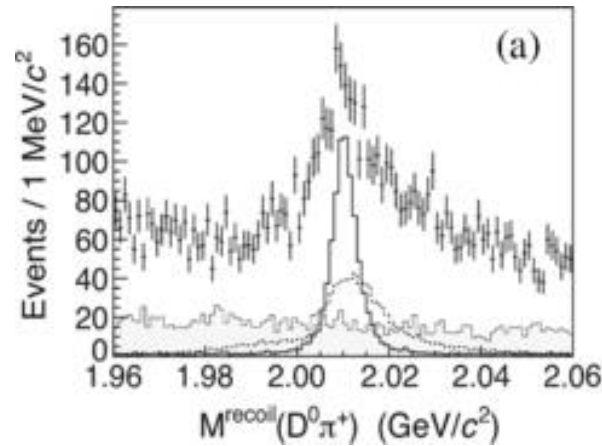
# $Z_c(3885)$

Phys. Rev. Lett. 112, 022001

▶  $e^+e^- \rightarrow \pi^\pm (D\bar{D}^*)^\mp$  at 4.26 GeV

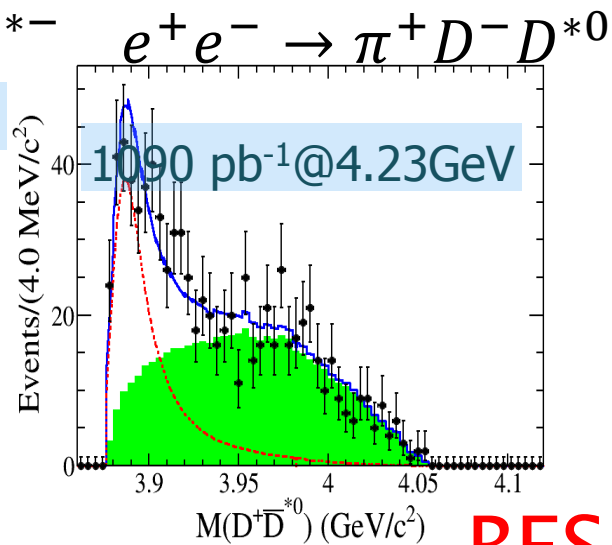
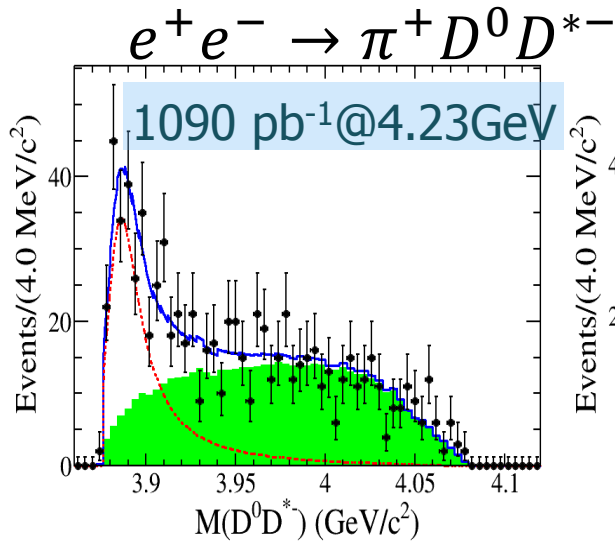
**BESIII**

$\sqrt{s}=4.26\text{GeV}$   
 $525\text{pb}^{-1}$   
 Favor  $J^P = 1^+$



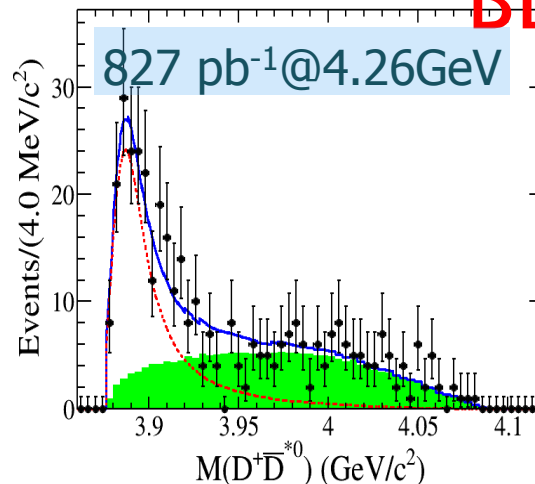
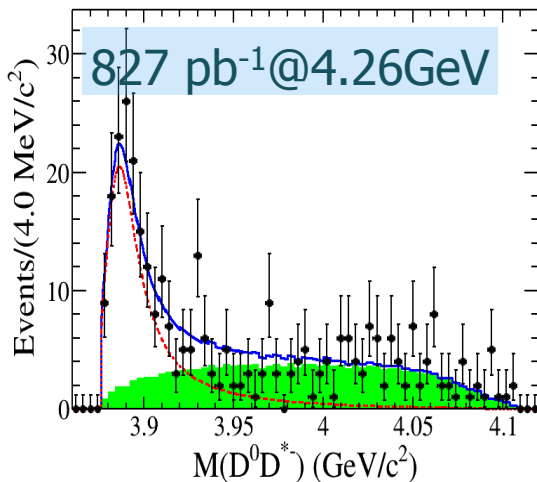
	$Z_c(3885) \rightarrow DD^*$
Mass ( $\text{MeV}/c^2$ )	$3883.9 \pm 1.5 \pm 4.2$
$\Gamma$ (MeV)	$24.8 \pm 3.3 \pm 11.0$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$

# Confirmation of $Z_c(3885)$ by D double-tag



The mass, width, branching fraction are **consistent** with previous results very well.

**BESIII preliminary**



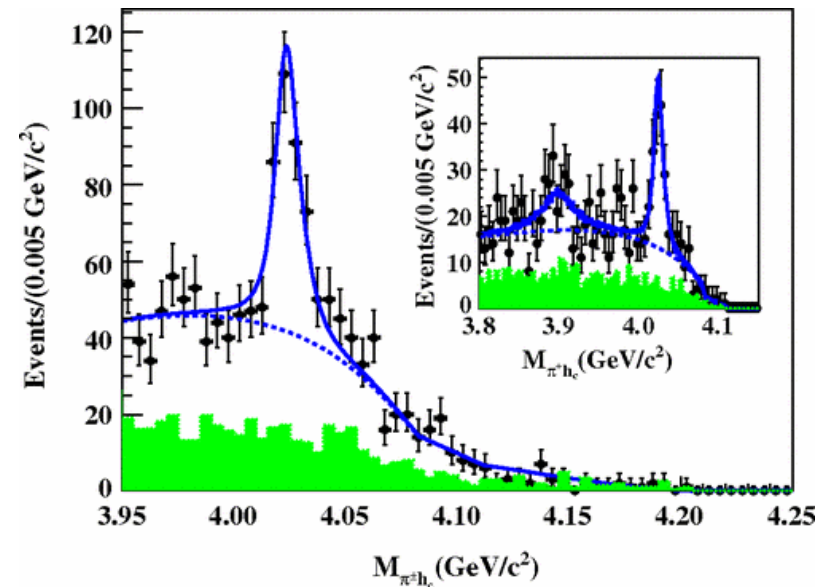
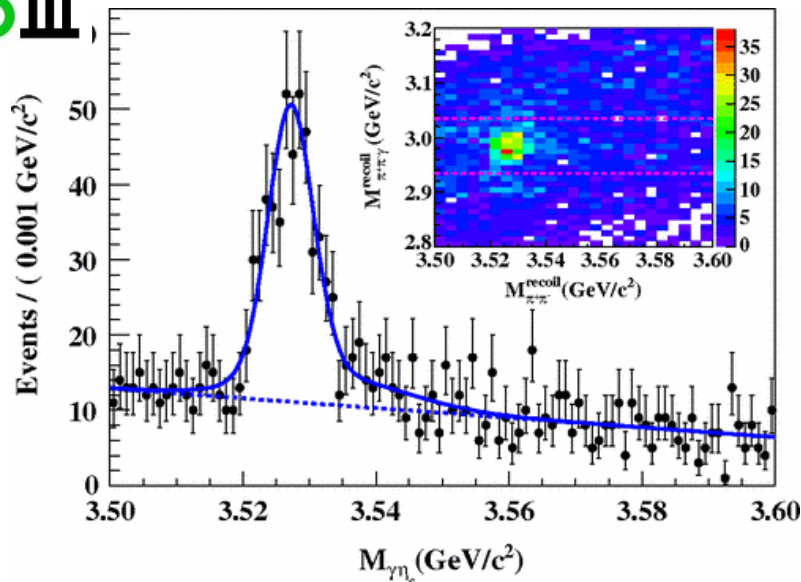
**And angular analysis favors  $J^P = 1^+$**

# $Z_c(4020)$ : charged

Phys. Rev. Lett. 111, 242001

▶  $e^+e^- \rightarrow \pi^+\pi^-h_c$  from 3.90 to 4.42 GeV (13 ·)

BESIII



$$M = (4022.9 \pm 0.8 \pm 2.7) \text{ MeV}/c^2$$

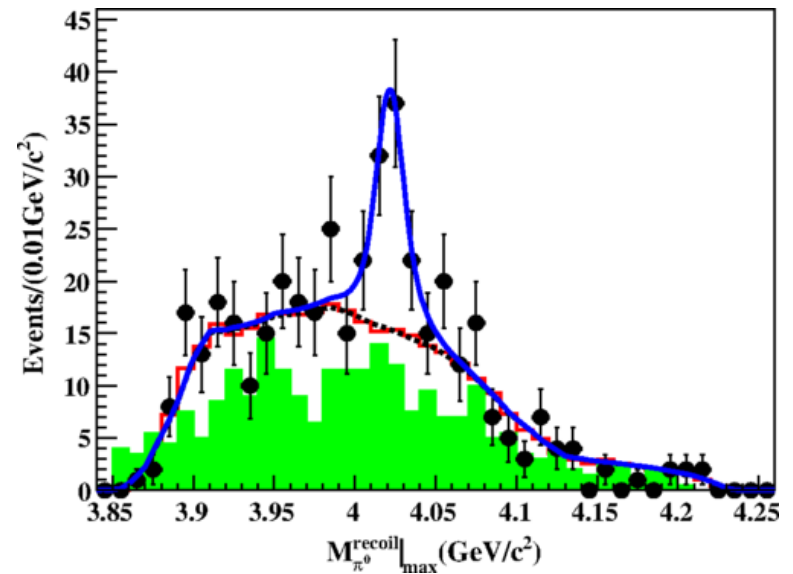
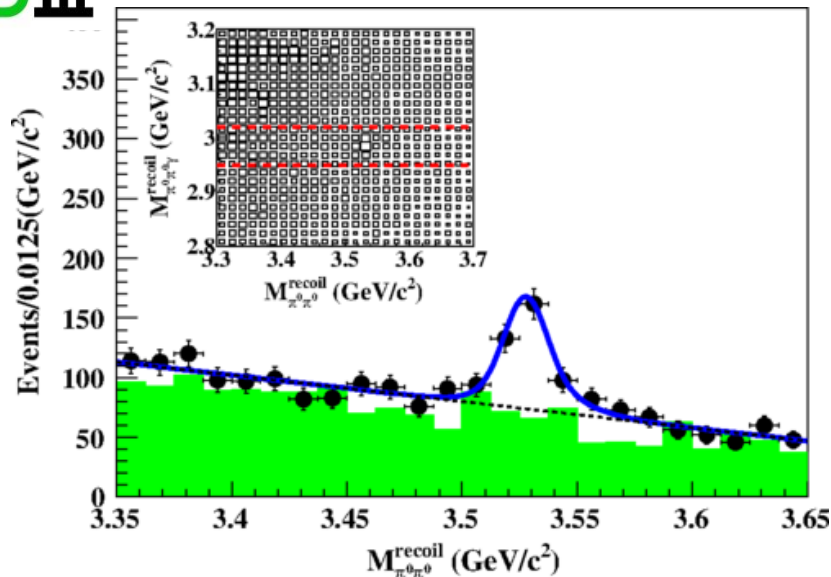
$$\Gamma = (7.9 \pm 2.7 \pm 2.6) \text{ MeV}$$

# $Z_c(4020)$ : neutral

Phys. Rev. Lett. 113, 212002

▶  $e^+e^- \rightarrow \pi^0\pi^0h_c$  @ 4.23, 4.26, 4.36 GeV

BESIII



$M = (4023.9 \pm 2.2 \pm 3.8) \text{ MeV}/c^2$   
Consistent with its charged partner

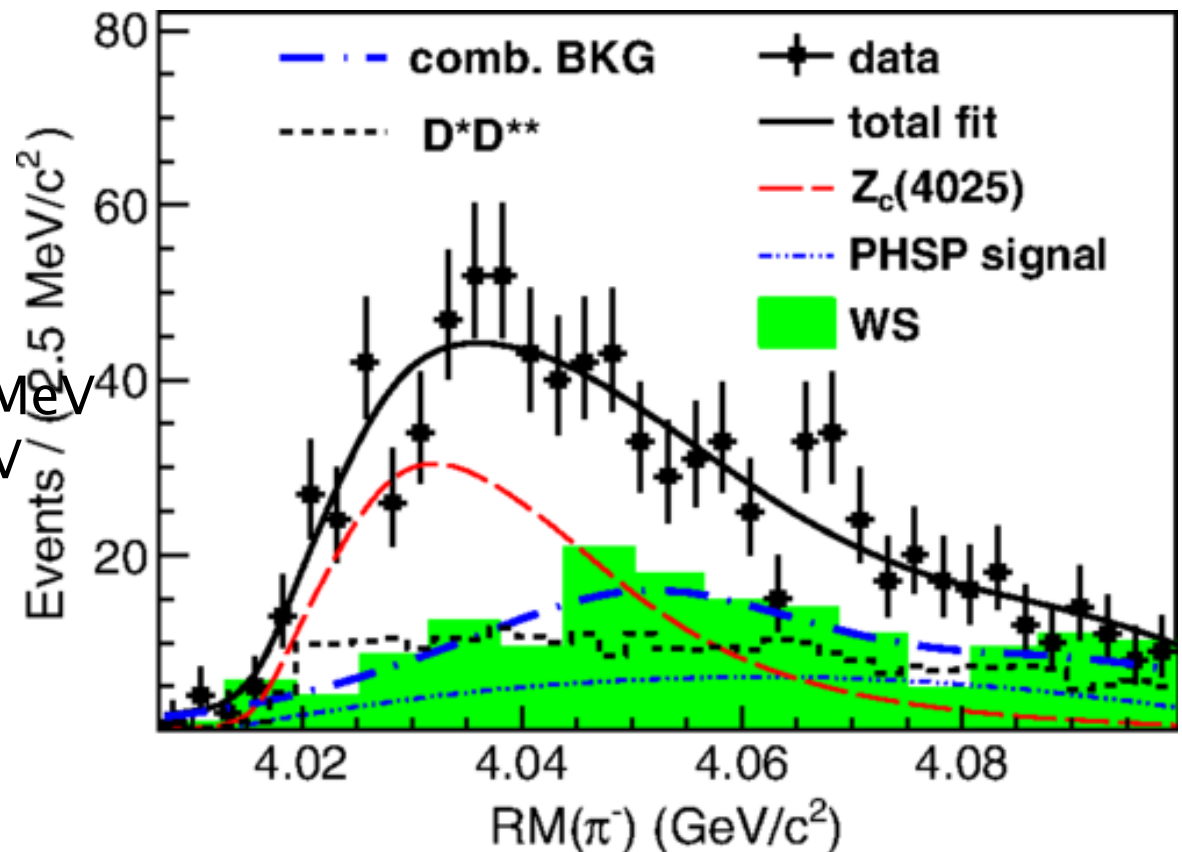
# $Z_c(4025)$

Phys. Rev. Lett. 112, 132001

▶  $e^+e^- \rightarrow \pi^\pm(D^*\bar{D}^*)^\mp$  at 4.26 GeV

BESIII

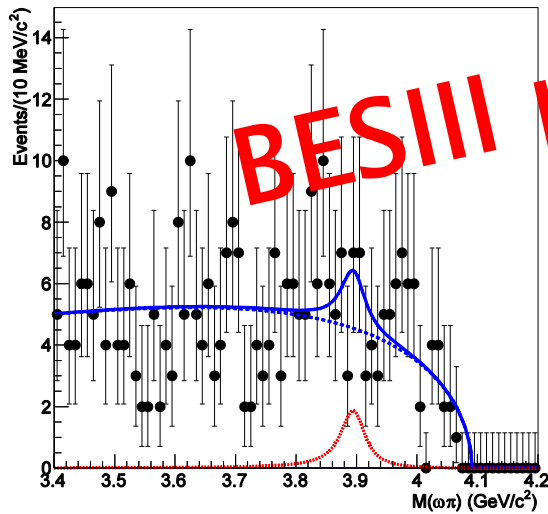
$\sqrt{s} = 4.26 \text{ GeV } 827 \text{ pb}^{-1}$   
 $M = (4026.3 \pm 2.6 \pm 3.7) \text{ MeV}$   
 $\Gamma = (24.8 \pm 5.6 \pm 7.7) \text{ MeV}$



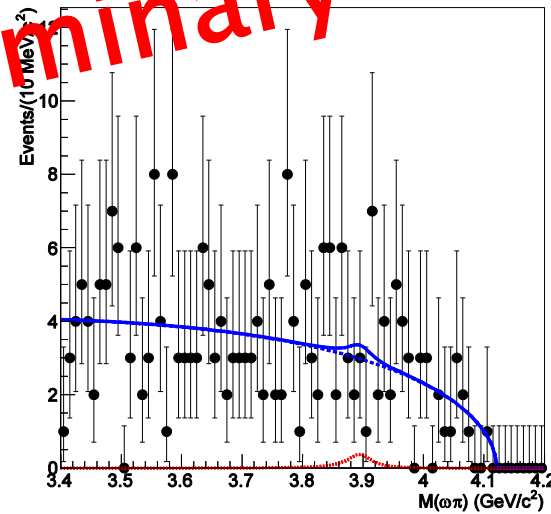


# No significant $Z_c \rightarrow \omega \pi$

$$e^+e^- \rightarrow \omega \pi^+ \pi^- \rightarrow 2(\pi^+ \pi^-) \pi^0$$



1094  $\text{pb}^{-1}$  @4.23 GeV



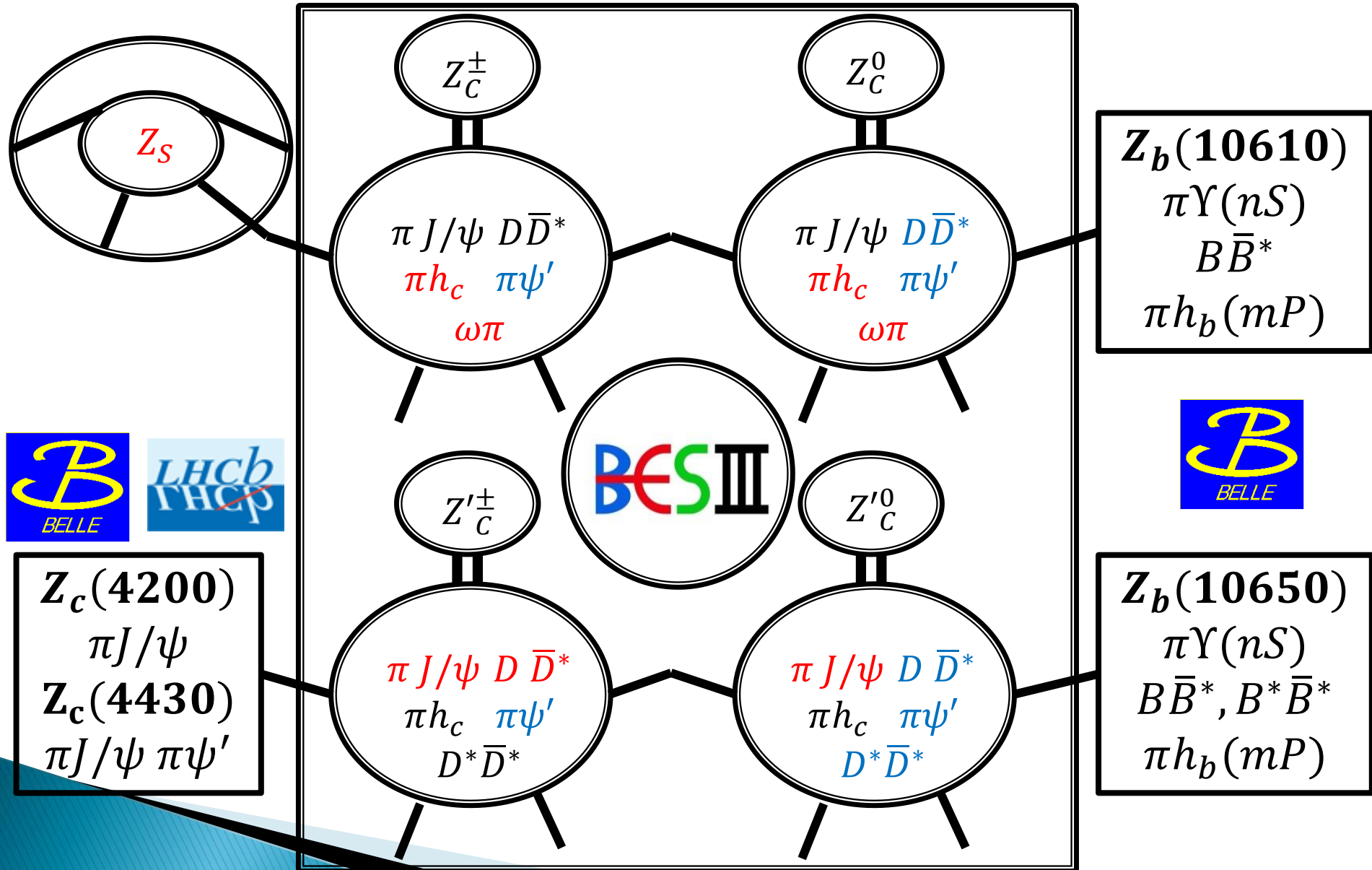
827  $\text{pb}^{-1}$  @4.26 GeV

@4.23 GeV :  $\sigma(e^+e^- \rightarrow Z_c \pi, Z_c \rightarrow \omega \pi) < 0.27 \text{ pb}$

@4.26 GeV:  $\sigma(e^+e^- \rightarrow Z_c \pi, Z_c \rightarrow \omega \pi) < 0.18 \text{ pb}$

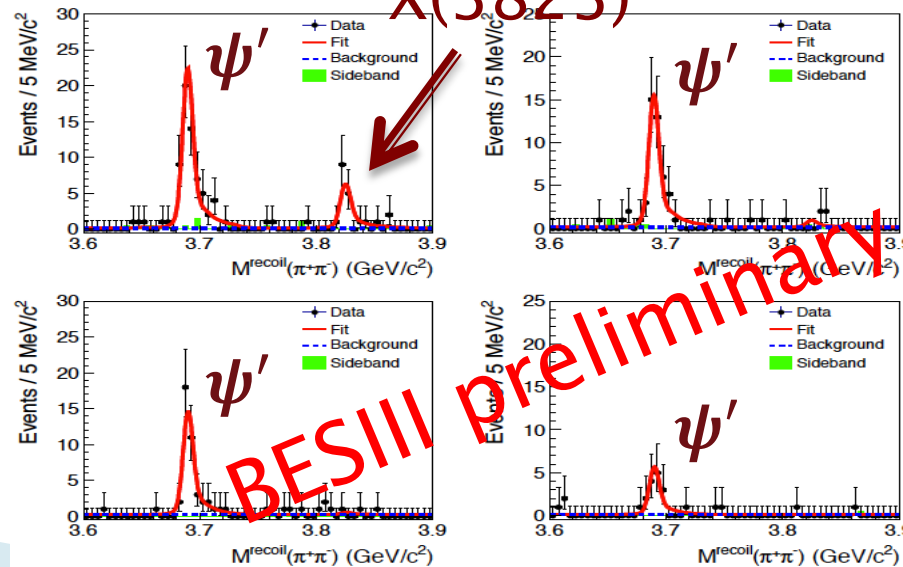
# Z family

Red: not seen    Blue: searching



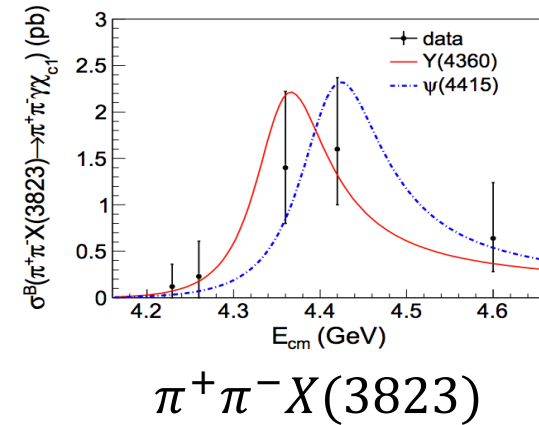
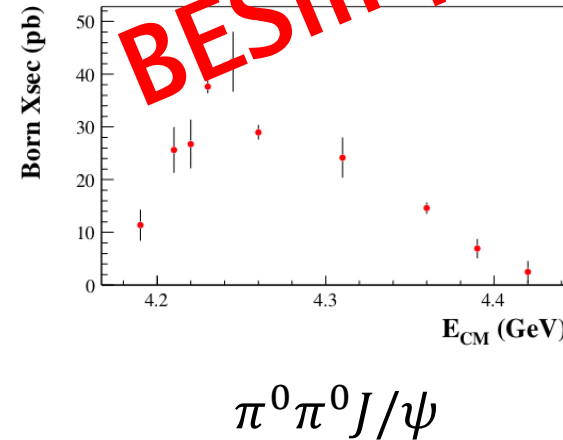
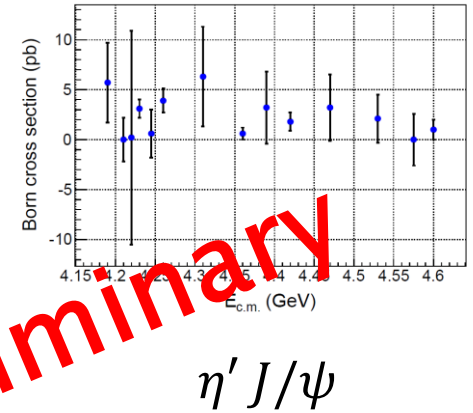
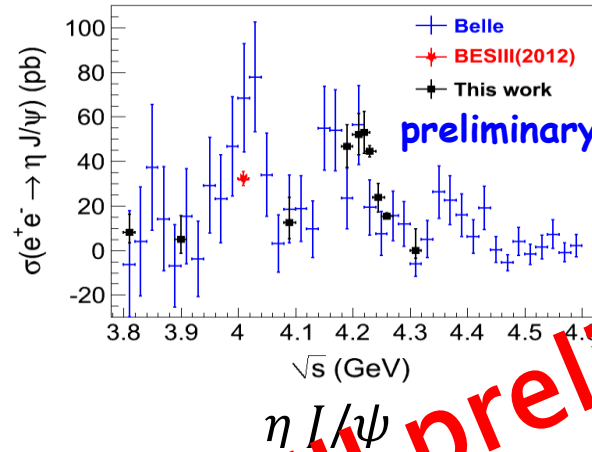
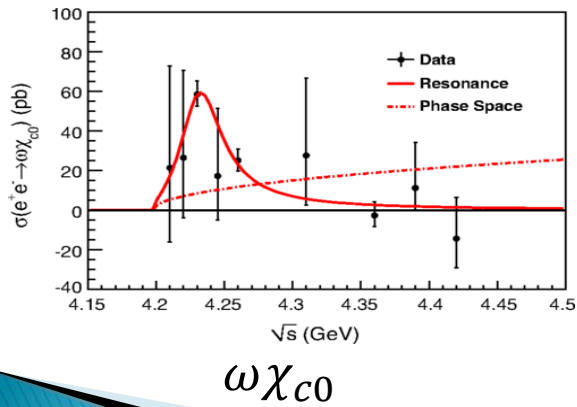
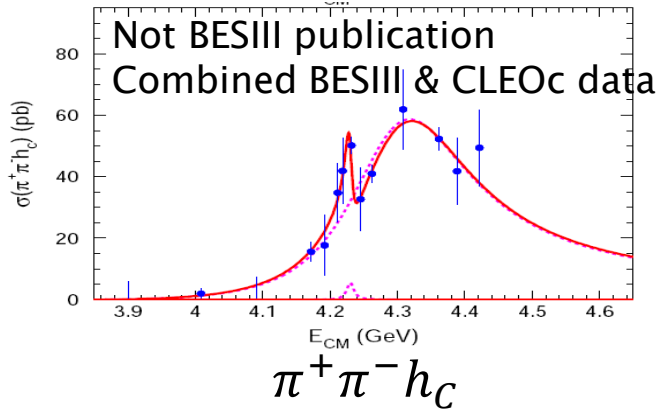
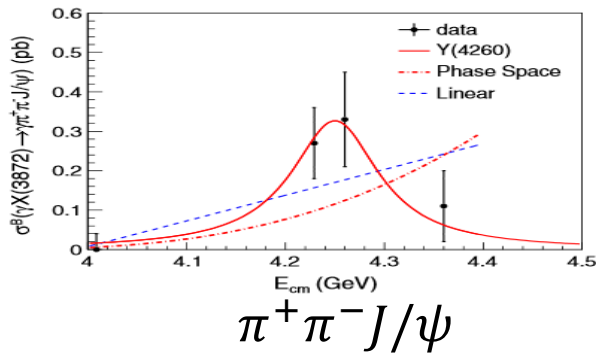
# X at BESIII

- ▶  $e^+e^- \rightarrow \gamma(\pi^+\pi^-J/\psi)$ , new production mode of **X(3872)** observed. Phys. Rev. Lett. 112, 092001
- ▶  $\psi(1^3D_2)$  candidate **X(3823)** is observed via  $e^+e^- \rightarrow \pi^+\pi^-X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$



# Y (1<sup>-</sup>) states at BESIII

## Cross section shapes



Obvious structures, limited statistics.  
Interference must be considered?

# Summary

- ▶ A relatively systematic study on exotic charmonium-like states, XYZ particles, has been performed at BESIII, abundant and interesting results are obtained.
- ▶ However
  - The nature of them is mysterious.
  - The relations between XYZ states are unclear.
  - PWA is needed to clarify  $J^{PC}$ .
  - Some expected states and decay modes are missing.
- ▶ Future
  - More results will come up soon with some analysis are on going.
  - A finer scan from 3.8 to 4.6 GeV at BESIII may be helpful.

# Thanks for your attention!





# Backup

# Introduction–Exotics (nomenclature)

## ▶ Greek Alphabet

- $\alpha$  (helium nucleus)
- $\beta$  (radioactively emitted electron or positron)
- $\psi$  (charmonium)
- $\pi$  (pion meson)
- $\omega$  (light un-flavored meson)  $\Omega$  (baryon)

## ▶ English Letters

- e (electron)
- p (proton or positron)
- H (the Higgs particle)
- W & Z (bosons propagating weak interaction)
- X(3872), Y(4260), Z<sub>c</sub>(3900), *etc.* (unknown nature)

# Other issues and news of $Z$ states

- ▶ Due to their similar masses and width, we assume
  - $Z_c(3900)$  and  $Z_c(3885)$  are a same state  $Z_c$
  - $Z_c(4020)$  and  $Z_c(4025)$  are a same state  $Z'_c$
- ▶ Higher  $Z_c$  excited states?
  - Belle observed  $Z_c(4200)$  and  $Z_c(4430)$  via B decay ( $\pi J/\psi$  &  $\pi \psi'$ ).
  - LHCb observed  $Z_c(4430)$  via B decay ( $\pi \psi'$ )
- ▶  $Z_{cs}$ ?
  - Belle update  $K^+K^-J/\psi$  to Dalitz Plot, no evident structure in  $K^\pm J/\psi$  mass distribution.
- ▶  $Z_b$ ?
  - Belle also observed charged  $Z_b(10610)$ ,  $Z_b(10650)$ .

# Y (1<sup>-</sup>) states at BESIII

- ▶ Structures from  $\pi^+\pi^-h_c$  Phys. Rev. Lett. 111, 242001
- ▶ Cross sections of  $e^+e^- \rightarrow \omega\chi_{c0}$  is measured. No signal of  $\omega\chi_{c1}$  or  $\omega\chi_{c2}$  found. **Disfavor Y(4260) is a  $\omega\chi_{c1}$  molecule.**
- ▶ Cross section of  $e^+e^- \rightarrow \eta J/\psi$  [preliminary]
- ▶ Cross section of  $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$  [preliminary]
- ▶ Cross section of  $e^+e^- \rightarrow J/\psi\eta\pi^0$ , no observation, only upper limit report. [preliminary]
- ▶ Cross section of  $e^+e^- \rightarrow \pi^+\pi^-X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$  [preliminary]
- ▶ Cross section of  $e^+e^- \rightarrow \eta' J/\psi$  [preliminary]
- ▶  $e^+e^- \rightarrow \gamma\phi J/\psi$ , **No significant Y(4140) signal.** [preliminary]
- ▶ Cross section of  $e^+e^- \rightarrow \gamma\chi_{cJ}$ , no observation, only upper limit report. [preliminary]