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## VECTOR CHARMONIUM AND CHARMONIUMLIKE STATES AT BESIII

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### Outline

- > Introduction
  - Charmonium and charmoniumlike spectrum
  - ➢ BEPCII and BESIII
  - ➢ BESIII data samples
- Recent results at BESIII
- Summary and Outlook

# Charmonium and charmoniumlike spectrum



#### Below open-charm threshold

- ✓ Good agreement between experimental measurements and theoretical predictions
- > Above open-charm threshold
- Many expected states not discovered

## Charmonium and charmoniumlike <u>Y(460)</u> Spectrum



#### >Below open-charm threshold

- ✓ Good agreement between experimental measurements and theoretical predictions
- > Above open-charm threshold
- Many expected states not discovered
- Many unexpected states observed:
  - charmonium final states
  - no conventional charmonium states assignment
  - called charmonium-like or XYZ states
  - "X" states: Neutral, J<sup>PC</sup> ≠ 1<sup>--</sup>, Observed in radiation or hadronic transitions from charmonium(-like) states. Junhao's presentation.
  - "Y" states: Neutral,  $J^{PC} = 1^{--}$ , Observed in  $e^+e^-$  annihilation.
  - "Z" states: Charged, isospin triplet, observed in hadronic transitions from charmonium(-like) states. Ronggang's presentation.

#### The Y states



Searching for new decay modes of known charmonium(-like) states and new charmoniumlike

states are necessary to give a decisive conclusion.

#### **BESIII** data Samples



200/pb around X(3872)

6



Most precise cross section measurement for center-of-mass energy from 3.77 to 4.60 GeV;
 Fit I = |BW<sub>1</sub>+BW<sub>2</sub>\*e<sup>iφ2</sup>+BW<sub>3</sub>\*e<sup>iφ3</sup>|<sup>2</sup> or Fit II =|exp+BW<sub>2</sub>\*e<sup>iφ2</sup>+BW<sub>3</sub>\*e<sup>iφ3</sup>|<sup>2</sup> (other fits ruled out);
 Compare with one Breit-Wigner fit, the significance of the second Breit-Wigner is 7.6σ;

> Y(4260) + Y(4260)	360)? The first of	observation of Y(	$(4360) \to \pi^+ \pi^- J/2$	ψ.

	$R_1$	$R_2$	Y(4260) [PDG2016]	Y(4360) [PDG2016]
M (MeV/ $c^2$ )	$4222.0 \pm 3.1 \pm 1.4$	4320.0±10.4±7.0	4251±9	4346 <u>+</u> 6
$\Gamma_{\rm tot}$ (MeV)	$44.1 \pm 4.3 \pm 2.0$	$101.4^{+25.3}_{-19.7}\pm10.2$	120 <u>±</u> 12	$102 \pm 10$



≻First precise cross section measurement from threshold to 4.6 GeV;

Fit with  $|BW_1+BW_2*e^{i\phi}|^2$ , two resonant structures are evident;

>Compare with one Breit-Wigner fit, the significance of the two Breit-Wigner fit is greater than  $10\sigma$ ;

The parameters of Y(4220) are consistent with those observed in  $\pi^+\pi^- J/\psi$  around 4222 MeV.

	M (MeV/c <sup>2</sup> )	$\Gamma_{tot}$ (MeV)
<i>Y</i> (4220)	$4218.4^{+5.5}_{-4.5}\pm0.9$	$66.0^{+12.3}_{-8.3}\pm0.4$
Y(4390)	$4391.5^{+6.3}_{-6.8}\pm1.0$	$139.5^{+16.2}_{-20.6} \pm 0.6$



➤ Most precise cross section measurement for center-of-mass energy from 4.05 to 4.60 GeV;

- Fit with a coherent sum of three-body phase space term (pink dashed triple-dot line) and two Breit-Wigner functions (green dashed double-dot line and aqua dashed line);
- > The statistical significance of two resonant assumption over one resonant assumption is greater than  $10\sigma$ ;
- $\succ$  M(Y(4220)) = (4228.6±4.1±6.3) MeV/c<sup>2</sup>, Γ(Y(4220)) = (77.0±6.8±6.3) MeV.

 $e^+e^- \rightarrow \pi^0\pi^0\psi(3686)$ 



Y(4360) was observed and subsequently confirmed in e<sup>+</sup>e<sup>-</sup> → (γ<sub>ISR</sub>)π<sup>+</sup>π<sup>-</sup>ψ(3686) by BABAR, Belle, and BESIII, it is interesting to study the Y(4360) in π<sup>0</sup>π<sup>0</sup> transition to ψ(3686) and to examine the isospin symmetry;

- Signal process:  $e^+e^- \rightarrow \pi^0\pi^0\psi(3686), \psi(3686) \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow \ell^+\ell^- (\ell = e \text{ or } \mu);$
- > 16 energy points from  $\sqrt{s} = 4.008$  to 4.600 GeV, the total luminosity is about 5.2 fb<sup>-1</sup>;
- > The result of cross section measurement is consistent with the charged mode from isospin symmetry.





- > Only  $\omega \chi_{c0}$  has significant signal;
- > The cross section is fitted with coherent sum of a Breit-Wigner and a phase space term.

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



 $\Gamma = (28.2.0 \pm 3.9 \pm 1.6) \text{ MeV}$ 

> This observation confirms and improves the previous result;

Further experimental studies with higher statistics are needed to draw a more reliable conclusion on the nature of this structure.

## $e^+e^- \to \phi \chi_{cJ}$





- ► BESIII has measured the cross section of  $e^+e^- \rightarrow \omega \chi_{c0}$  and observed an intermediate resonance around 4226 MeV/c2.
- > Considering that  $\omega$  and  $\phi$  have the same spin, parity, and isospin,  $\omega \chi_{cI}$  and  $\phi \chi_{cI}$  may have a similar production mechanism.
- We study the  $e^+e^- \rightarrow \phi \chi_{c0,1,2}$  at  $\sqrt{s} = 4.60$  GeV (567 pb<sup>-1</sup>), where  $\chi_{c0} \rightarrow \pi^+\pi^-, K^+K^-, K^+K^-\pi^+\pi^-$ , and  $\pi^+\pi^-\pi^+\pi^-$ ,  $\chi_{c1,2} \rightarrow \gamma J/\psi, J/\psi \rightarrow \ell^+\ell^-$  ( $\ell = e \text{ or } \mu$ ), and  $\phi \rightarrow K^+K^-$ .
- ► BESIII has searched for the Y(4140) in the process of  $e^+e^- \rightarrow \gamma \phi J/\psi$ with data samples at c.m. energies  $\sqrt{s} = 4.23$ , 42.6, and 4.36 GeV, but no obvious signal has been observed. We also can repeat this analysis at  $\sqrt{s} = 4.60$  GeV.



▶ No obvious  $e^+e^- \rightarrow \phi \chi_{c0}$  signals are observed, the production  $\sigma(e^+e^- \rightarrow \phi \chi_{c0}) < 5.4$  pb @ 90% C.L.;

- ► The first observation of  $e^+e^- \rightarrow \phi \chi_{c1}$  and  $\phi \chi_{c2}$ ,  $\sigma(e^+e^- \rightarrow \phi \chi_{c1}) = 4.2^{+1.7}_{-1.0}$  pb and  $\sigma(e^+e^- \rightarrow \phi \chi_{c2}) = 6.7^{+3.4}_{-1.7}$  pb;
- No obvious  $e^+e^- \rightarrow \gamma Y(4140)$  signals are observed,  $\sigma(e^+e^- \rightarrow \gamma Y(4140)) \times \mathcal{B}(Y(4140) \rightarrow \phi J/\psi) <$ 1.2 pb @ 90% C.L..





- ► Measure the cross section of  $e^+e^- \rightarrow K\overline{K}J/\psi$  at c.m. energies from 4.189 to 4.600 GeV.
- ➤ The energy dependence of the cross section for  $e^+e^- \rightarrow K^+K^-J/\psi$  is shown to differ from that for  $\pi^+\pi^-J/\psi$  in the region around the Y(4260);
- ➤ The ratio of cross sections for  $e^+e^- \to K^+K^-J/\psi$  and  $e^+e^- \to K_S^0K_S^0J/\psi$  is consistent with expectations from isospin conservation.



► We observe  $e^+e^- \rightarrow \pi^+\pi^-\psi(3770)$  for the first time at 4.42 GeV;

 $\blacktriangleright$  There are hints for peaks at 4.04 and 4.13 GeV/c<sup>2</sup> at 4.42 GeV, while the statistical significance is low.



Three different decay channels  $(D^0\pi^+\pi^-, D^{*+}\pi^-, \text{ and } D^+\pi^+\pi^-)$  are used to search for  $D_1(2420)$ , the neutral mode with  $D_1(2420)^0 \rightarrow D^0\pi^+\pi^-$  is reported with statistical significance of 7.4 $\sigma$  at 4.42 GeV. 17





The Y(4390) or the  $\psi$ (4415) resonance or from any other resonance cannot be distinguished based on the current statistics.

#### Summary & Outlook

Parameters of the Peaks in e<sup>+</sup>e<sup>-</sup> Cross Sections



### Summary & Outlook

- ✓ Recent results on charmonium(-lile) states at BESIII are presented.
- ✓ BESIII is an active and successful experiment for vector charmonium and charmoniumlike spectroscopy.

- Continue to take data and increase the beam energy;
- > Provide more important results in charmonium spectroscopy.

### Thank You! 20

# backup

### Beijing Electron and Positron Collider(BEPCII)

#### beam energy: 1.0 – 2.3 GeV

BESIII

detector



- 1989-2004 (BEPC): L<sub>peak</sub>=1.0x10<sup>31</sup> /cm<sup>2</sup>s
- 2009-now (BEPCII):
  - L<sub>peak</sub>=1.0x10<sup>33</sup>/cm<sup>2</sup>s 21

LINAC



CsI(TI) calorimeter, 2.5% @ 1 GeV

Has been in full operation since 2008!