



ICHEP2018 SE_UL

XXXIX INTERNATIONAL CONFERENCE
ON *high Energy* PHYSICS

JULY 4 - 11, 2018
COEX, SEOUL

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中国科学院高能物理研究所
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BESIII

STUDIES OF XYZ AT BESIII

Bin Wang (on the behalf of BESIII collaboration)

Institute of High energy Physics, CAS

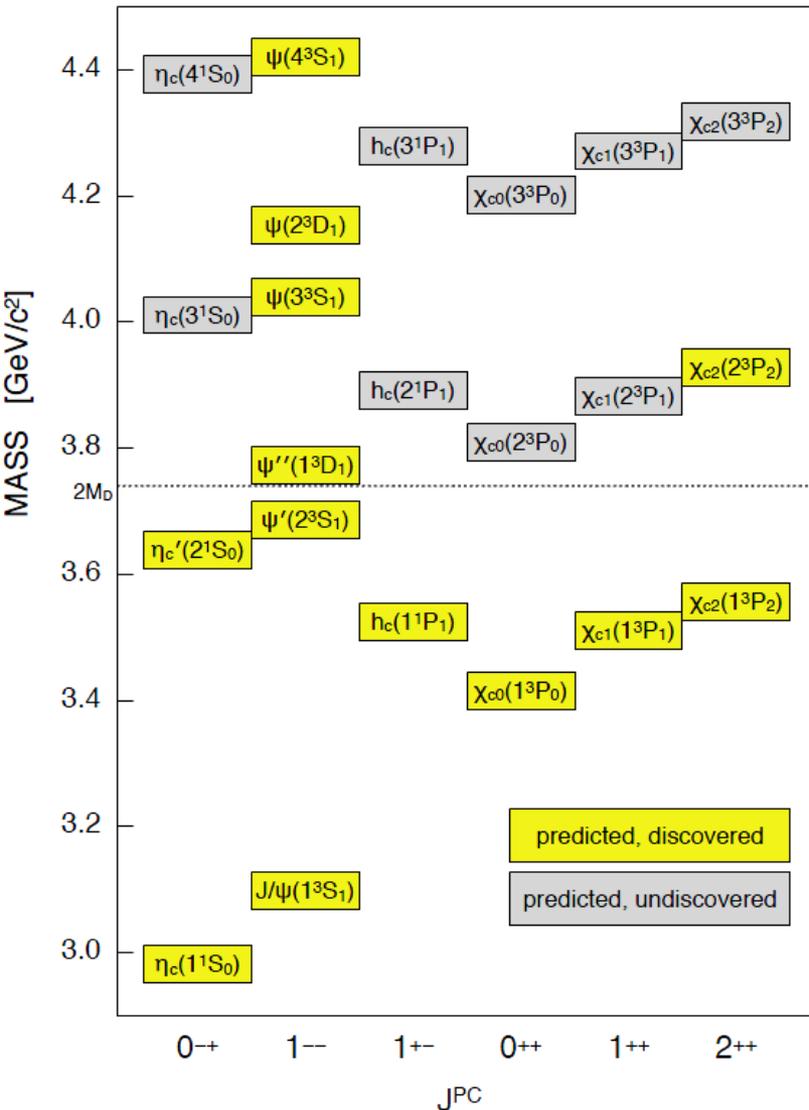
wangbin@ihep.ac.cn



Outline

- Introduction
 - Charmonium and XYZ spectrum
 - BEPCII and BESIII
 - BESIII data samples
- Studies of XYZ states
- Summary and Outlook

Charmonium and XYZ spectrum



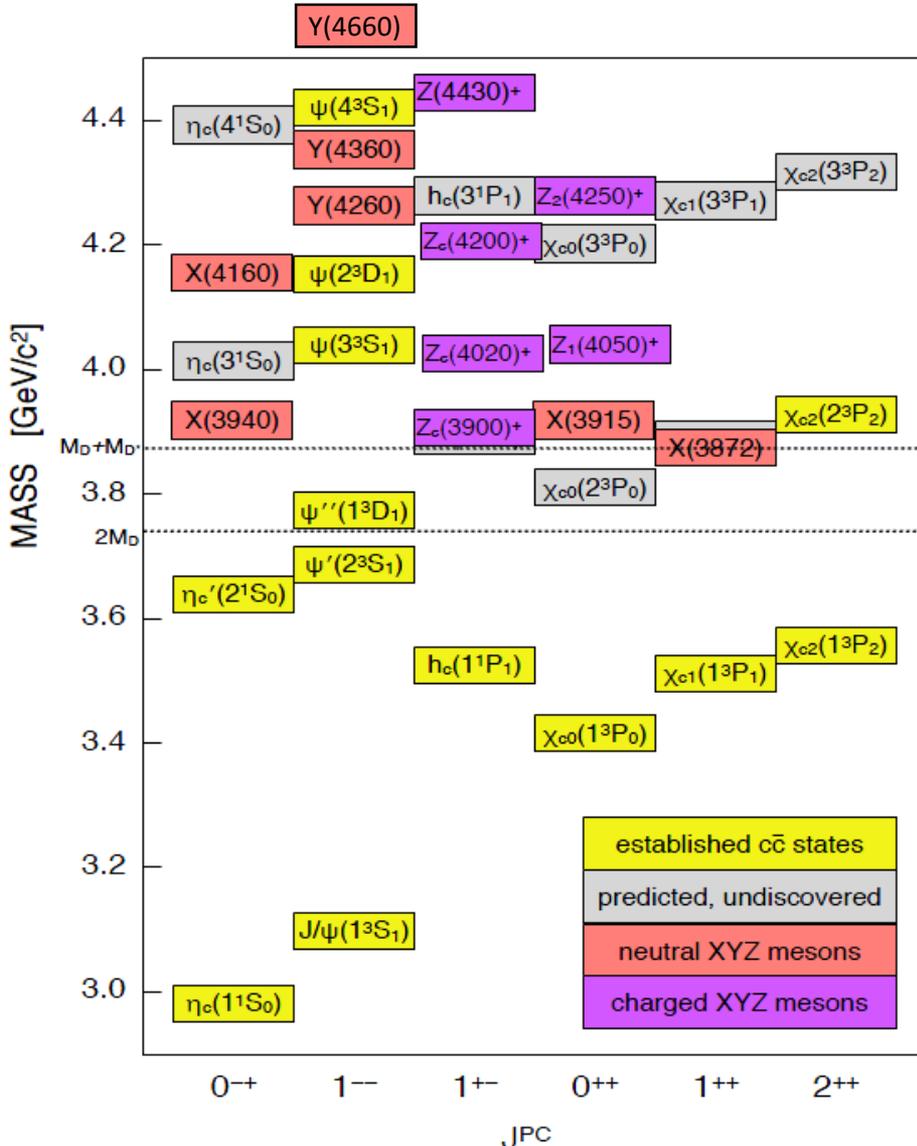
➤ Below open-charm threshold

✓ Good agreement between experimental measurements and theoretical predictions

➤ Above open-charm threshold

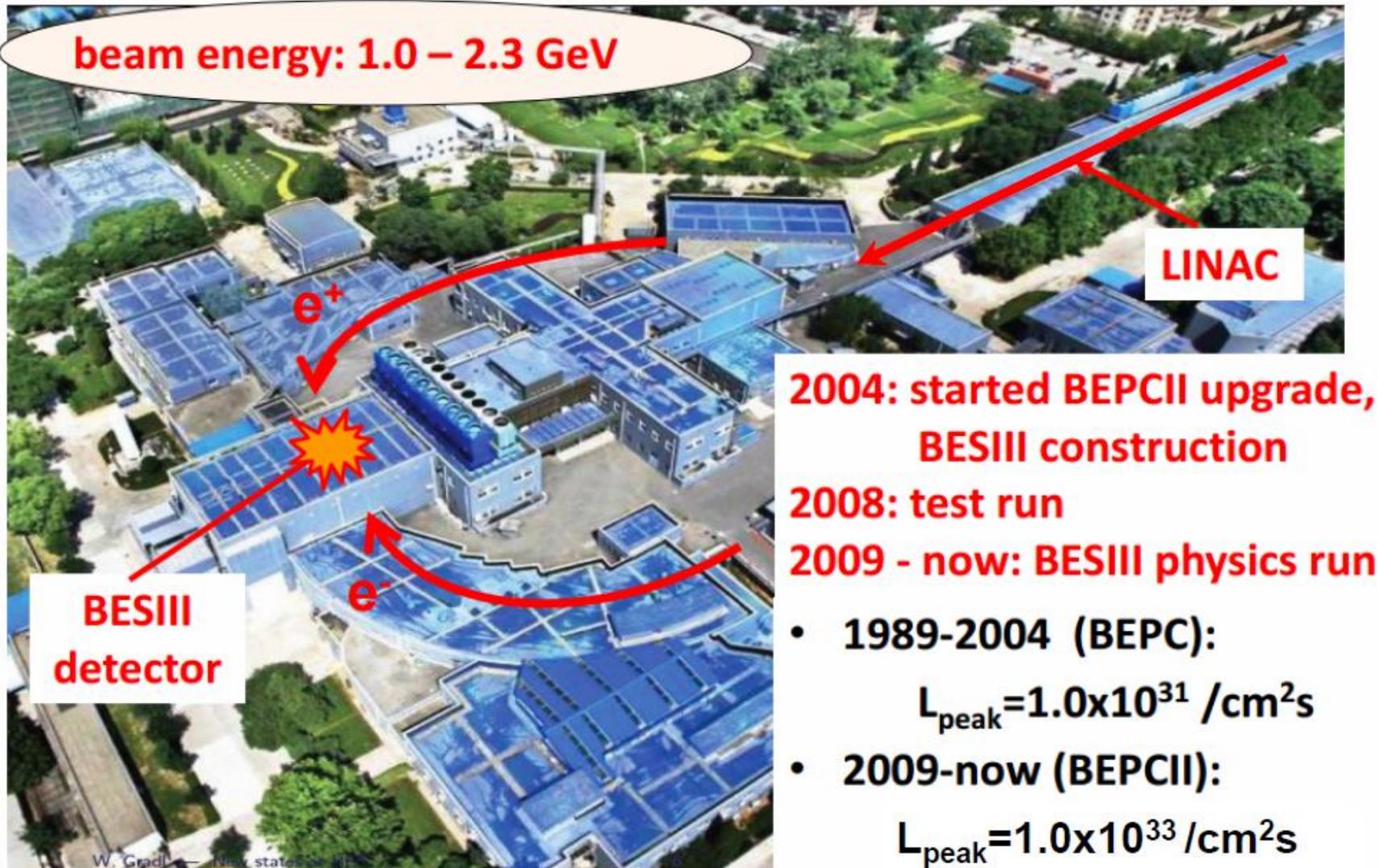
- Many expected states not discovered

Charmonium and XYZ spectrum

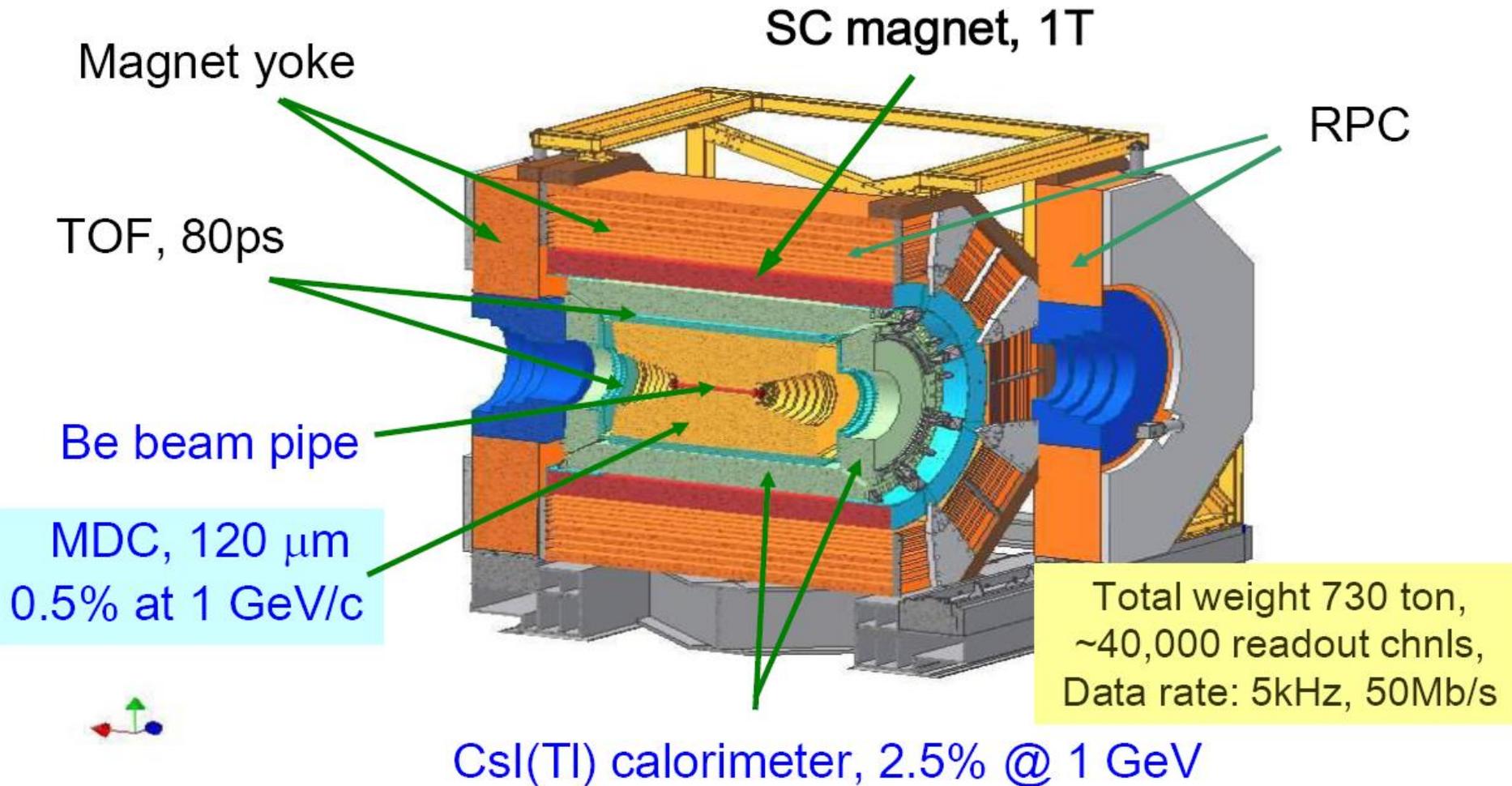


- Below open-charm threshold
- ✓ Good agreement between experimental measurements and theoretical predictions
- Above open-charm threshold
 - Many expected states not discovered
 - Many unexpected states observed:
 - charmonium final states
 - no conventional charmonium states assignment
 - called **charmonium-like or XYZ states**
- **To do list**
 - ☐ New decay modes of known charmonium(-like) states
 - ☐ New charmonium(-like) states

Beijing Electron and Positron Collider(BEPCII)



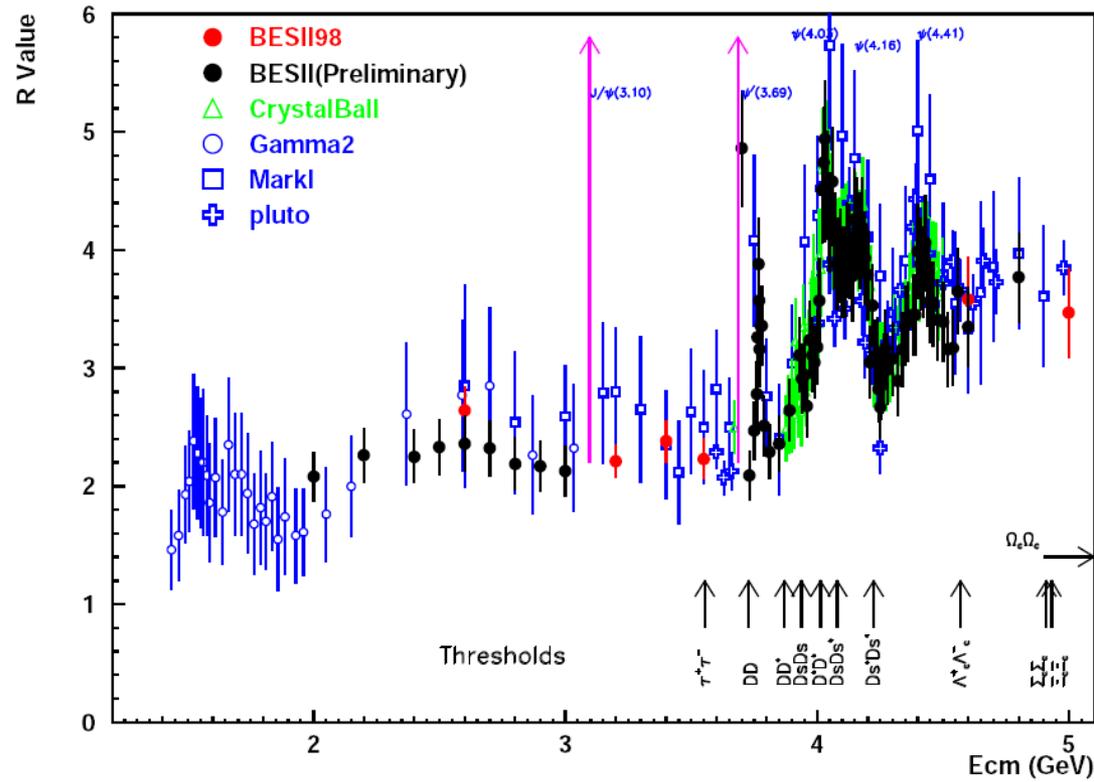
The BESIII detector



Has been in full operation since 2008!

BESIII data Samples

- 2009: 106M $\psi(2S)$
225M J/ψ
- 2010: 975 pb^{-1} at $\psi(3770)$
- 2011: 2.9 fb^{-1} at $\psi(3770)$ (total)
482 pb^{-1} at 4.01 GeV
- 2012: 0.45B $\psi(2S)$ (total) → 2018
1.3B J/ψ (total) → 5.0B J/ψ
- 2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
~50 pb^{-1} at 3.81, 3.90, 4.09, 4.19, 4.21
4.22, 4.245, 4.31, 4.39, 4.42 GeV
- 2014: 1029 pb^{-1} at 4.42 GeV
110 pb^{-1} at 4.47 GeV
110 pb^{-1} at 4.53 GeV
48 pb^{-1} at 4.575 GeV
567 pb^{-1} at 4.6 GeV
0.8 fb^{-1} R-scan from 3.85 to 4.59 GeV (104 points)
- 2015: R-scan from 2-3 GeV + 2.175 GeV data
- 2016: ~3 fb^{-1} at 4.18 GeV (for D_s)
- 2017: 500/pb each for 7 energy points between 4.19~4.28 GeV
400/pb around chic_c1
200/pb around X(3872)



~ 130 points for R scan (~1.3 fb^{-1})

~ 8 fb^{-1} above 4.0 GeV in total

Studies of XYZ states

➤ The Z_c states

Phys. Rev. Lett 119, 072001 (2017)

----- Determination of J^P of $Z_c(3900)$

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

Phys. Rev. D 97, 071101(R) (2018)

➤ $e^+e^- \rightarrow K\bar{K}J/\psi$

Phys. Rev. D 97, 052001 (2018)

➤ $e^+e^- \rightarrow \pi^+D^0D^{*-}$

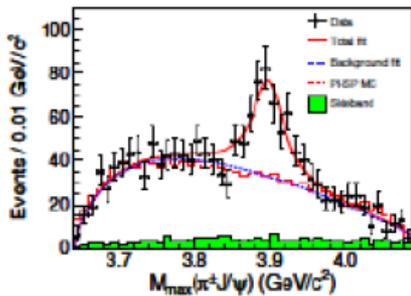
Preliminary result

➤ $e^+e^- \rightarrow \phi\chi_{c1,2}$

Phys. Rev. D 97, 032008 (2018)

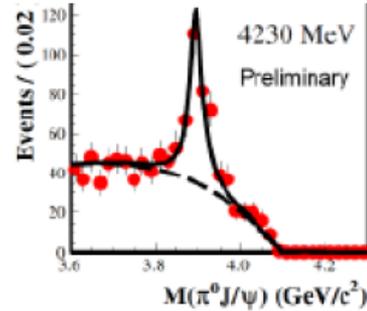
The Z_c states

PRL 110, 252001 (2013)



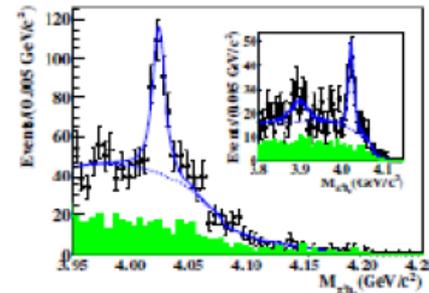
$$e^+e^- \rightarrow \pi^- \pi^+ J/\psi$$

PRL 115, 112003 (2015)



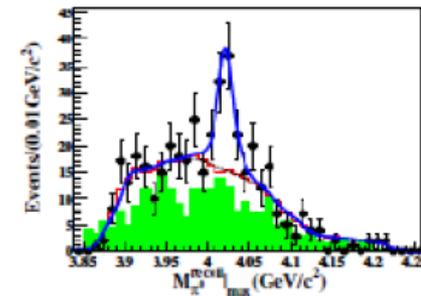
$$e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$$

PRL 111, 242001(2013)



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

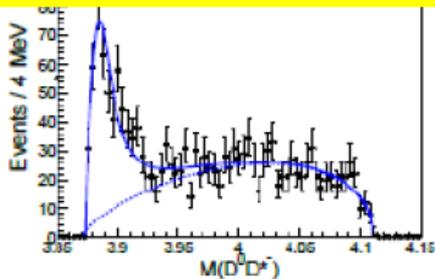
PRL113,212002 (2014)



$$e^+e^- \rightarrow \pi^0 \pi^0 h_c$$

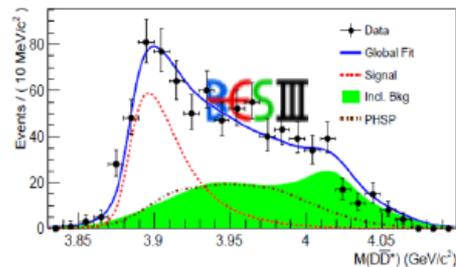
ST: PRL 112, 022001(2014)

DT: PRD92, 092006 (2015)



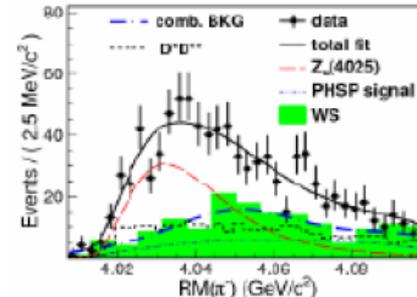
$$e^+e^- \rightarrow \pi^- (D \bar{D}^*)^+$$

PRL 115, 222002 (2015)



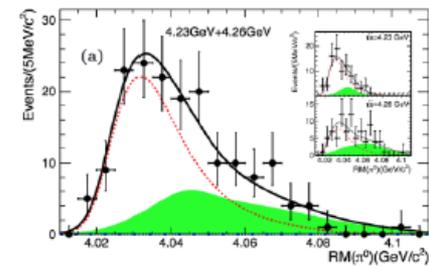
$$e^+e^- \rightarrow \pi^0 (D^* \bar{D})^0$$

PRL 112, 132001 (2014)



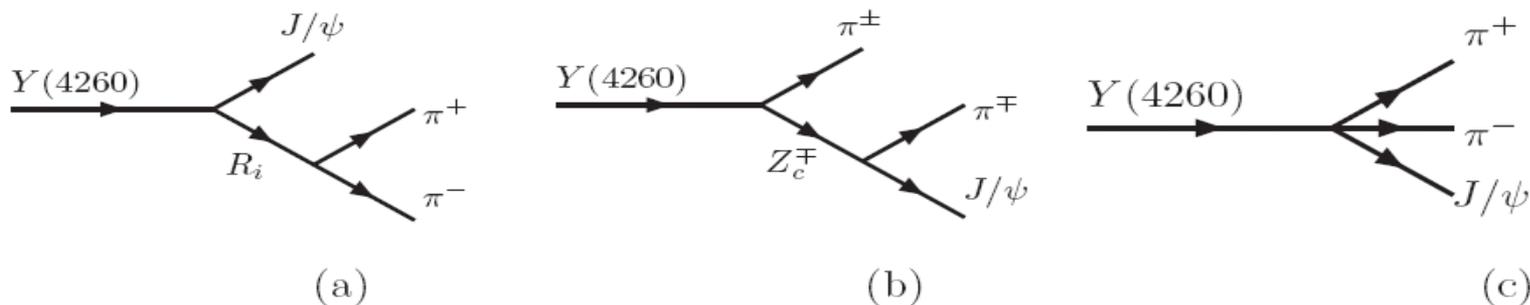
$$e^+e^- \rightarrow \pi^- (D^* \bar{D}^*)^+$$

PRL115, 182002 (2015)

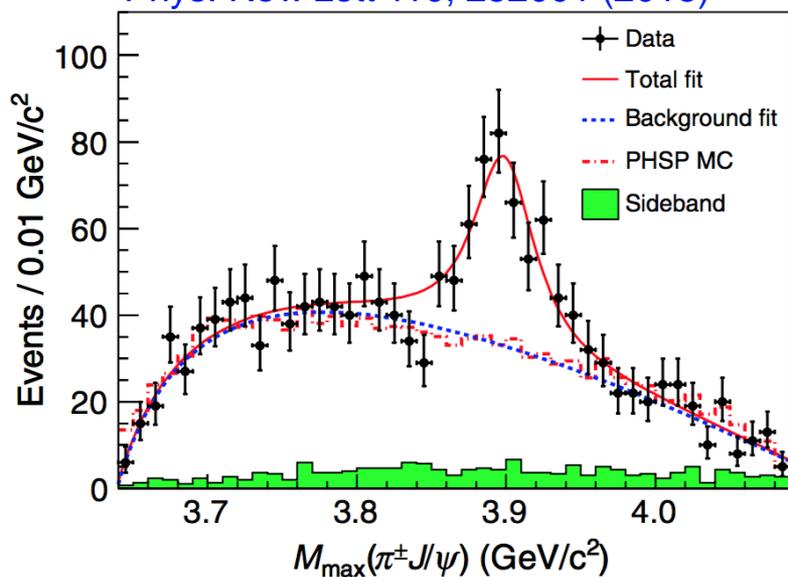


$$e^+e^- \rightarrow \pi^0 (D^* \bar{D}^*)^0$$

Determination of J^P of $Z_c(3900)$



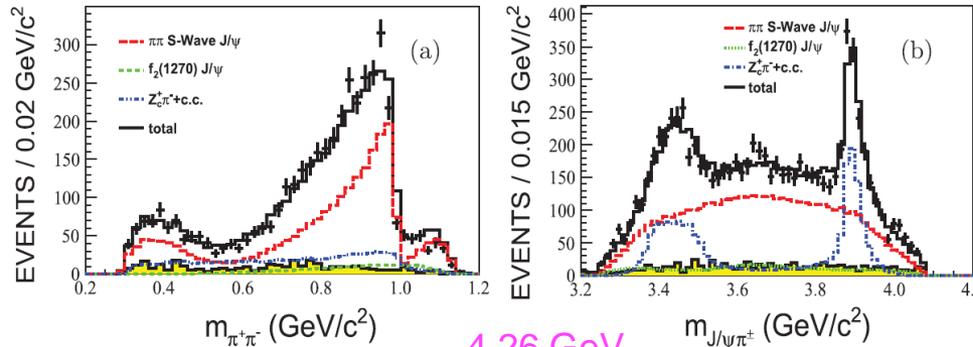
Phys. Rev. Lett 110, 252001 (2013)



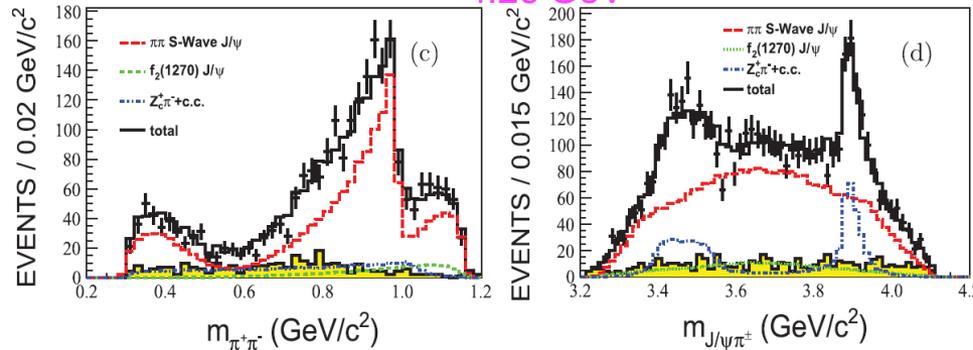
- Six contributions are considered in the amplitude:
 - $\sigma(500)$, $f_0(980)$, $f_2(1270)$, and $f_0(1370)$ in the $\pi^+\pi^-$ mass spectrum;
 - $Z_c(3900)^\pm$ in the $\pi^\pm J/\psi$ mass spectrum;
 - The nonresonant process: $e^+e^- \rightarrow \pi^+\pi^- J/\psi$.
- Five J^P assumptions: 0^- , 1^- , 1^+ , 2^- , and 2^+ .

Determination of J^P of $Z_c(3900)$

4.23 GeV



4.26 GeV



- Simultaneous fit to data samples at 4.23 GeV and 4.26 GeV. $Z_c(3900)^+$ and $Z_c(3900)^-$ states are assumed as isospin partner, share the same mass and coupling constants;
- $Z_c(3900)^\pm$ is parameterized with Flatte-like formula:

$$BW(s) = \frac{1}{s - M^2 + i(g'_1 \rho_{\pi J/\psi}(s) + g'_2 \rho_{D^* D}(s))}$$

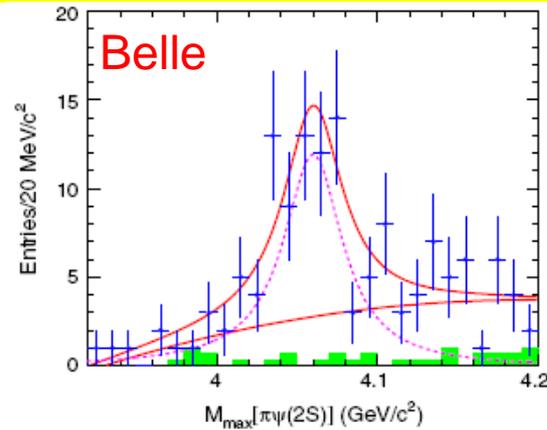
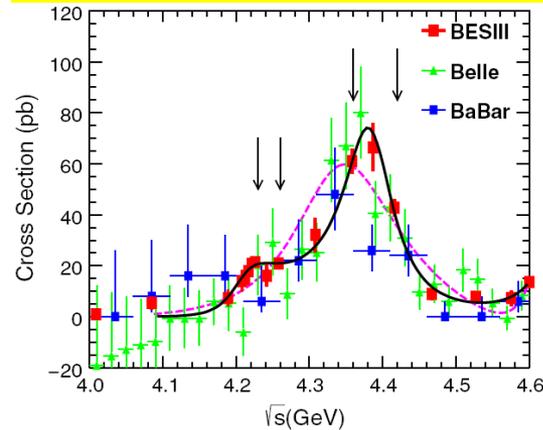
Hypothesis	$\Delta(-2 \ln L)$	$\Delta(\text{ndf})$	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

Z_c	Mass	g'_1 (GeV ²)	g'_2/g'_1
1^+	$3901.5 \pm 2.7 \pm 38.0$	$0.075 \pm 0.006 \pm 0.025$	$27.1 \pm 2.0 \pm 1.9$

- J^P of Z_c favor to be 1^+ with statistical significance larger than 7σ over other quantum numbers;
- g'_2/g'_1 is consistent with previous result 27.1 ± 13.1 , estimated based on the measured decay width ratio of $Z_c(3885)^\pm \rightarrow (D\bar{D}^*)^\pm$ and $Z_c(3900)^\pm \rightarrow \pi^\pm J/\psi$.

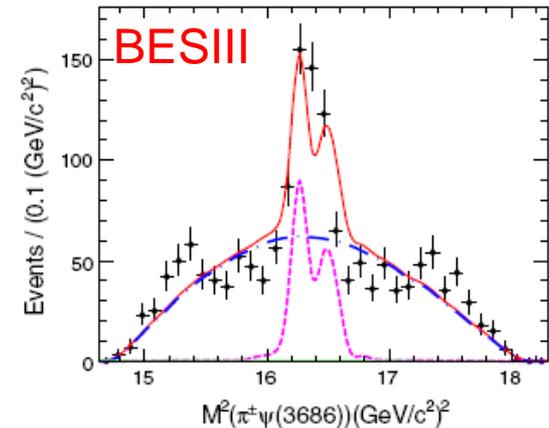
$$e^+e^- \rightarrow \pi^0\pi^0\psi(3686)$$

Belle: Phys. Rev. D 91, 112007 (2015) & BESIII: Phys. Rev. D 96, 032004 (2017)



$$\text{Mass} = (4054 \pm 3 \pm 1) \text{ MeV}/c^2$$

$$\text{Width} = (45 \pm 11 \pm 6) \text{ MeV}$$

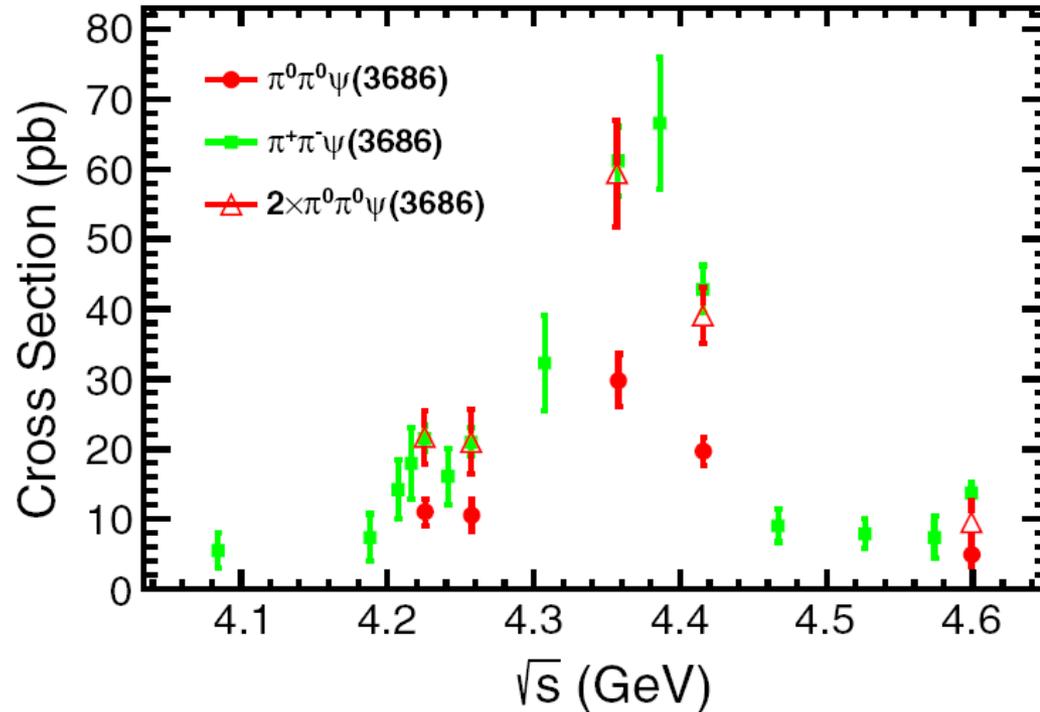


$$\text{Mass} = (4032.1 \pm 2.4) \text{ MeV}/c^2$$

$$\text{Width} = (26.1 \pm 5.3) \text{ MeV}$$

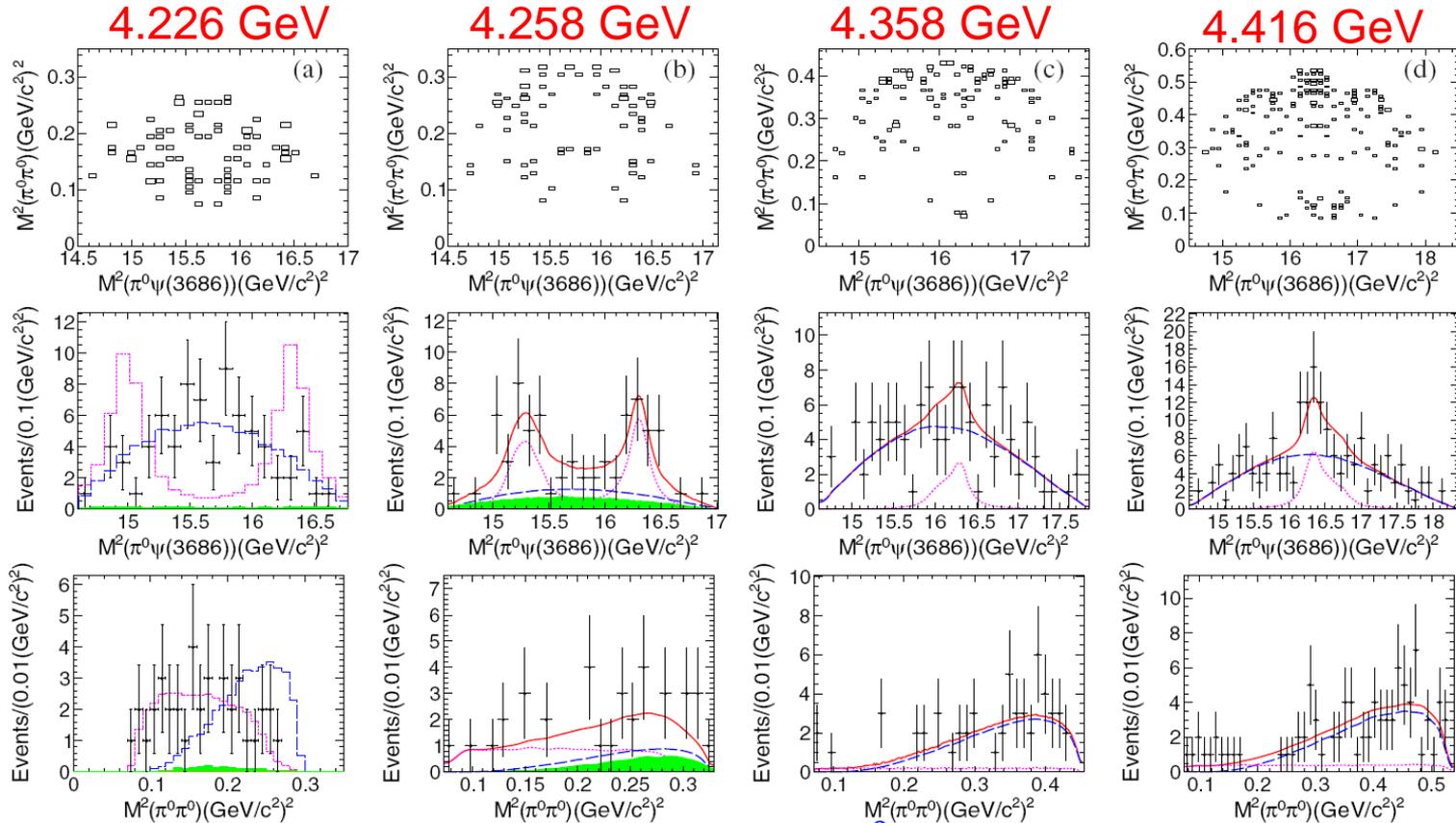
- $Y(4360)$ was observed and subsequently confirmed in $e^+e^- \rightarrow (\gamma_{ISR})\pi^+\pi^-\psi(3686)$ by BABAR, Belle, and BESIII, it is interesting to study the $Y(4360)$ in $\pi^0\pi^0$ transition to $\psi(3686)$ and to examine the isospin symmetry;
- A charmoniumlike structure observed in $\pi^\pm\psi(3686)$ invariant mass by BESIII and Belle measurements. We can search for its neutral isospin partner in $e^+e^- \rightarrow \pi^0\pi^0\psi(3686)$.
- The width of the intermediate state in BESIII measurement varies in a wide range for different kinematic region within the data set, more data and theoretical input are necessary.

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

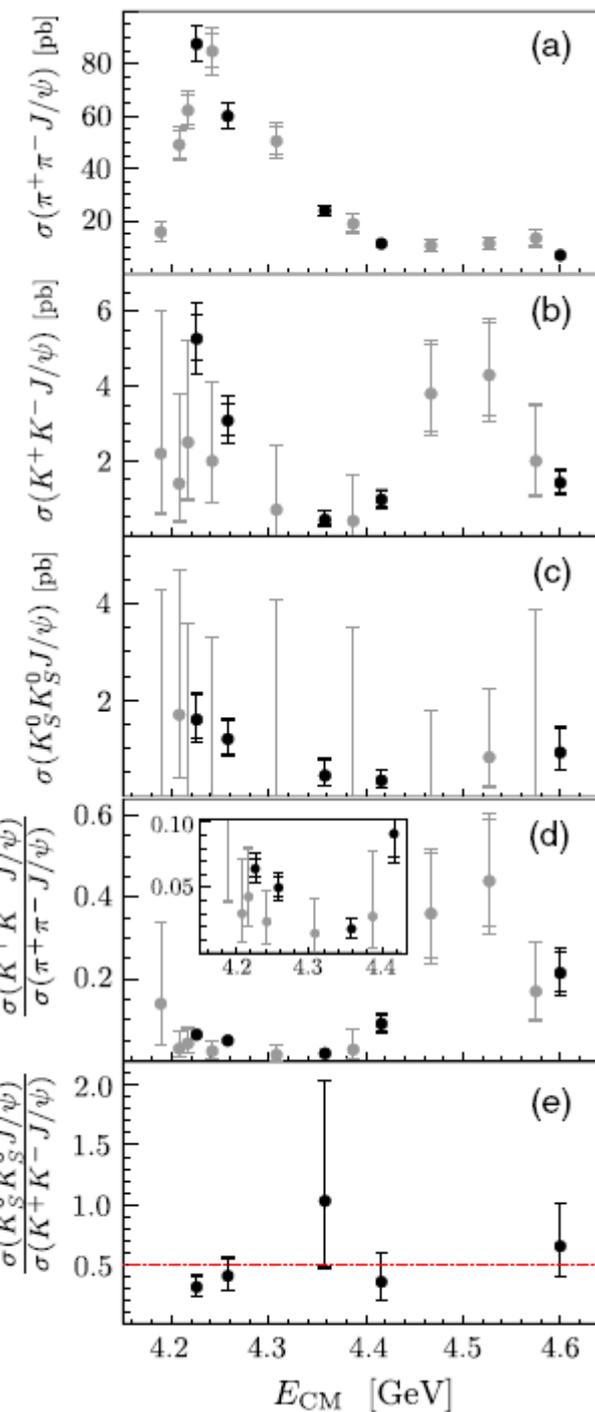


- Decay channel: $e^+e^- \rightarrow \pi^0\pi^0\psi(3686)$, $\psi(3686) \rightarrow \pi^+\pi^-J/\psi$, $J/\psi \rightarrow \ell^+\ell^-$ ($\ell = e$ or μ);
- 16 energy points from $\sqrt{s} = 4.008$ to 4.600 GeV, the total luminosity is about 5.2 fb^{-1} ;
- The result of cross section measurement is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

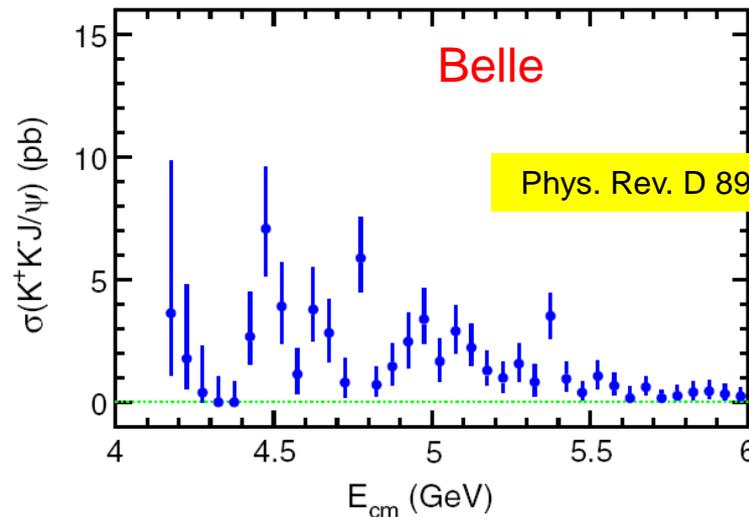
$$e^+e^- \rightarrow \pi^0\pi^0\psi(3686)$$



- A neutral charmoniumlike structure is observed in $\pi^0\psi(3686)$ invariant mass;
- A simple fit with S-wave Breit-Wigner function is performed, and yield a mass with mass $(4038.7 \pm 6.5) \text{ MeV}/c^2$, which confirms the structure in the charged mode;
- No obvious $Z_c(3900)^0$ state is observed in the fit.

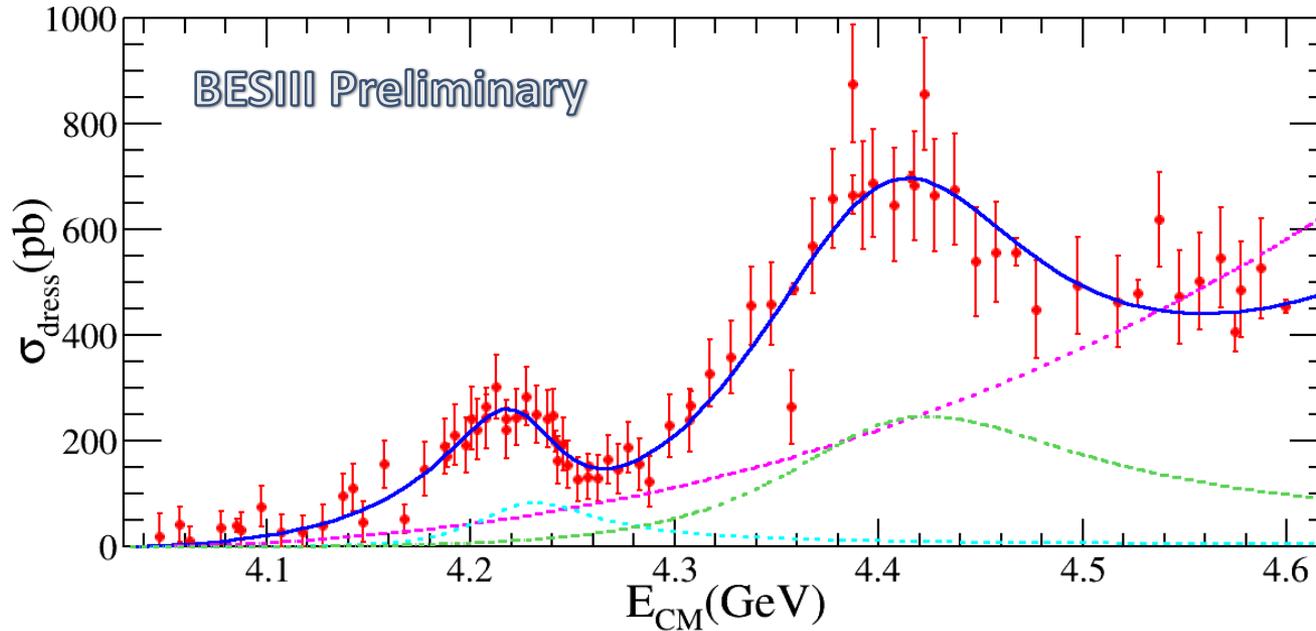


$$e^+ e^- \rightarrow K \bar{K} J/\psi$$



- Measure the cross section of $e^+ e^- \rightarrow K \bar{K} J/\psi$ 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 $e^+ e^- \rightarrow K^+ K^- J/\psi$ and $e^+ e^- \rightarrow K_S^0 K_S^0 J/\psi$ is consistent with expectations from isospin conservation.

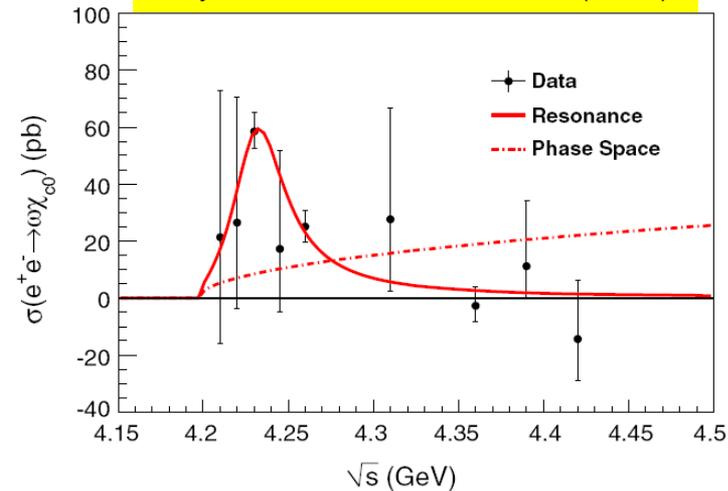
$$e^+e^- \rightarrow \pi^+ D^0 D^{*-}$$



- 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 10σ ;
- $M(Y(4220)) = (4224.8 \pm 5.6 \pm 4.0) \text{ MeV}/c^2$, $\Gamma(Y(4220)) = (72.3 \pm 9.1 \pm 0.9) \text{ MeV}$.
- $M(Y(4390)) = (4400.1 \pm 9.3 \pm 2.1) \text{ MeV}/c^2$, $\Gamma(Y(4390)) = (181.7 \pm 16.9 \pm 7.4) \text{ MeV}$.

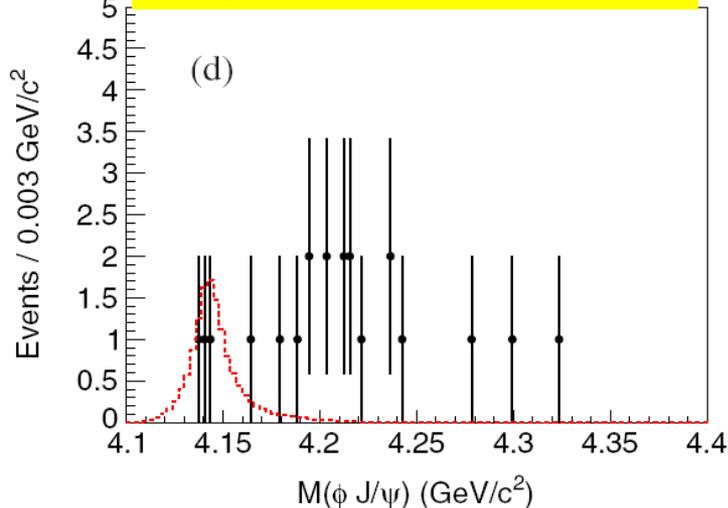
$$e^+e^- \rightarrow \phi\chi_{c1,2}$$

Phys. Rev. Lett. 114, 092002 (2015)



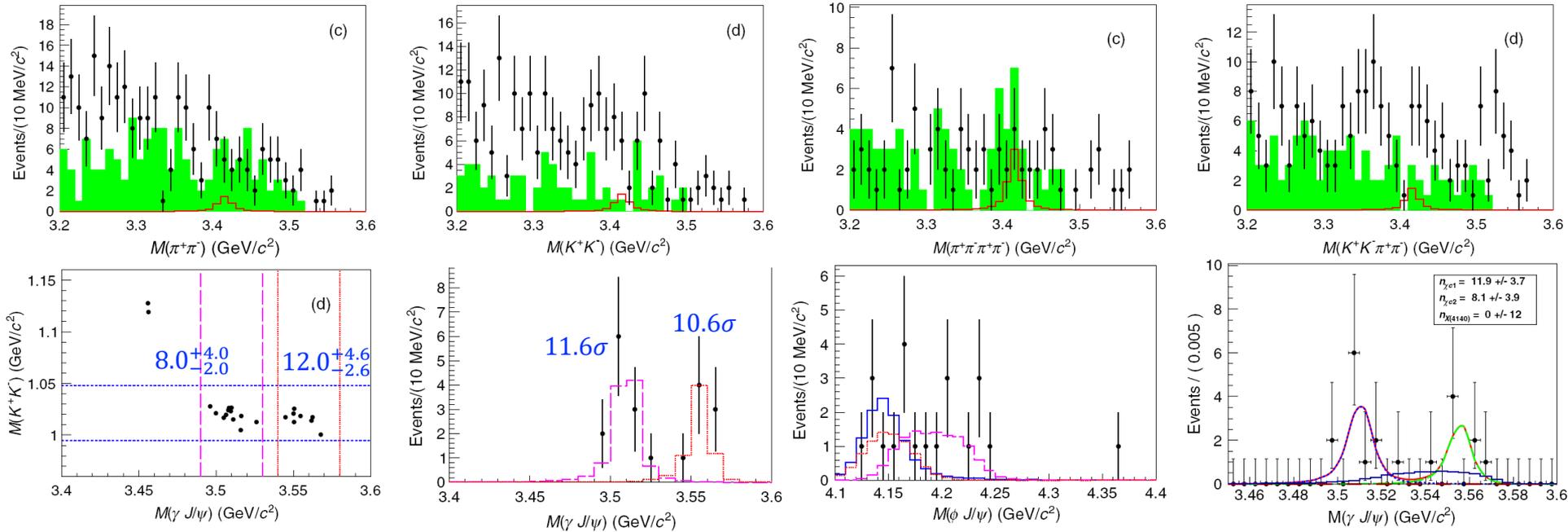
- BESIII has measured the cross section of $e^+e^- \rightarrow \omega\chi_{c0}$ and observed an intermediate resonance around 4226 MeV/c².
- Considering that ω and ϕ have the same spin, parity, and isospin, $\omega\chi_{cJ}$ and $\phi\chi_{cJ}$ may have a similar production mechanism.
- We study the $e^+e^- \rightarrow \phi\chi_{c0,1,2}$ at $\sqrt{s} = 4.60$ GeV (567 pb⁻¹), where $\chi_{c0} \rightarrow \pi^+\pi^-, K^+K^-, K^+K^-\pi^+\pi^-,$ and $\pi^+\pi^-\pi^+\pi^-$, $\chi_{c1,2} \rightarrow \gamma J/\psi, J/\psi \rightarrow \ell^+\ell^-$ ($\ell = e$ or μ), and $\phi \rightarrow K^+K^-$.

Phys. Rev. D 91, 032002 (2015)



- 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 $\sqrt{s} = 4.23, 4.26,$ and 4.36 GeV, but no obvious signal has been observed. We also can repeat this analysis at $\sqrt{s} = 4.60$ GeV.

$$e^+ e^- \rightarrow \phi \chi_{c1,2}$$



- 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..

Summary & Outlook

- Recent results of XYZ states at BESIII are presented. BESIII is an active and successful experiment for charmonium(-like) spectroscopy study.
 - A new Z_c structure in $\pi\psi(3686)$?
 - The J^P of $Z_c(3900)$ is determined to be 1^+ .
-
- Continue to take data and increase the beam energy;
 - Provide cutting-edge results in charmonium spectroscopy.

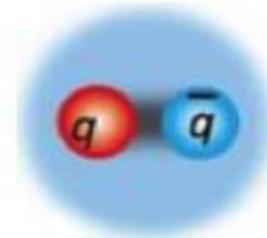
Thank You!

Backup

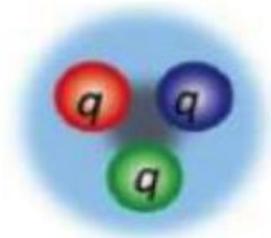
Hadrons: naive and exotic

- Naive quark model:
 - 2 quarks: meson ($q\bar{q}$)
 - 3 quarks: baryon (qqq)
- QCD predicts the exotic states:
 - Multiquark states: $N_{\text{quarks}} \geq 4$
 - Molecule: bound state of hadrons
 - Hybrid: $N_{\text{quarks}} \geq 2 + \text{gluon}$
 - Glueball: $N_{\text{quarks}} = 0$ (gg, ggg, \dots)

meson



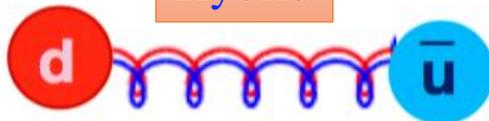
baryon



Multiquark



Hybrid



Glueball



Molecule

