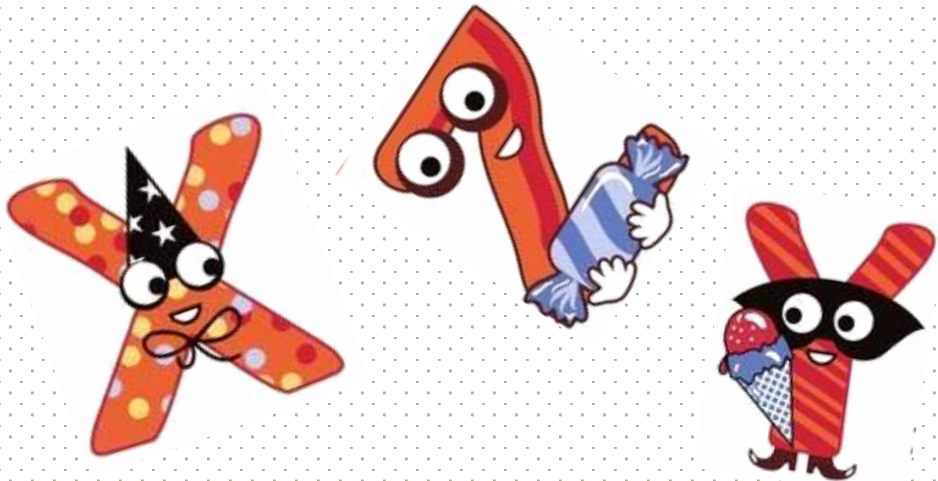# Recent results on spectroscopy of XYZ states from BESIII

Sun Zhentian

Institute of High Energy Physics, CAS

On Behalf of BESIII Collaboration

Sep. 23, 2020, Beauty2020

Institute of High Energy Physics Chinese Academy of Sciences

Beijing Electron and Positron Collider(BEPCII)

LINAC

BESIII

e⁺

e⁻

Storage ring

Beam energy: 1~2.3GeV
Ecms= 2~4.6 GeV
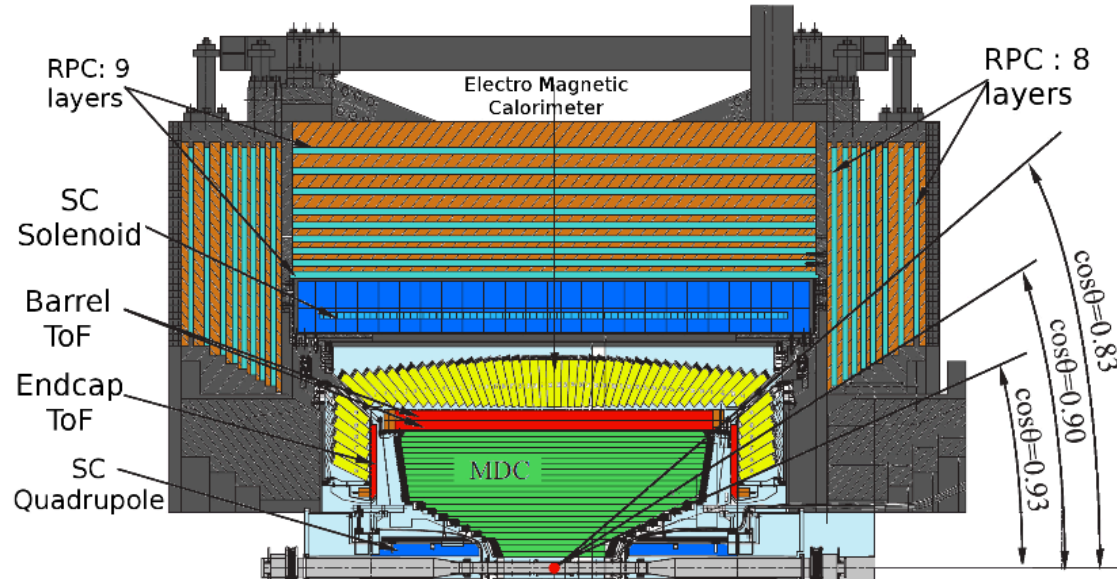
Upgrade in 2019

Beam energy: 1~2.45GeV
**Ecms= 2~4.9 GeV**

Chin. Phys. C 44, 040001 (2020)

Beijing Spectrometer (BESIII)

- **Inner to Outside：**
- ✓ **Main Drift chamber(MDC), momentum resolution: 0.5%@1GeV@1T**
- ✓ **Time of flight System(TOF), time resolution: 68ps@barrier, 110ps@endcap**
- ✓ **Electromagnetic Calorimeter(EMC), energy resolution:2.5%,**
  position resolution:6mm@1GeV
- ✓ **Solenoid super-conducting magnet(SSM), 1 Tesla**
- ✓ **Muon chamber(MUC), spatial resolution: 2cm**
- **Acceptance: 93% of 4π**
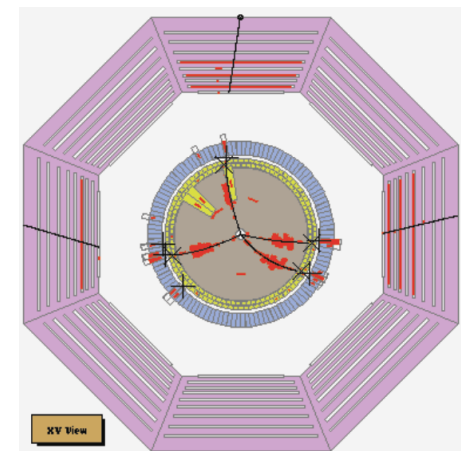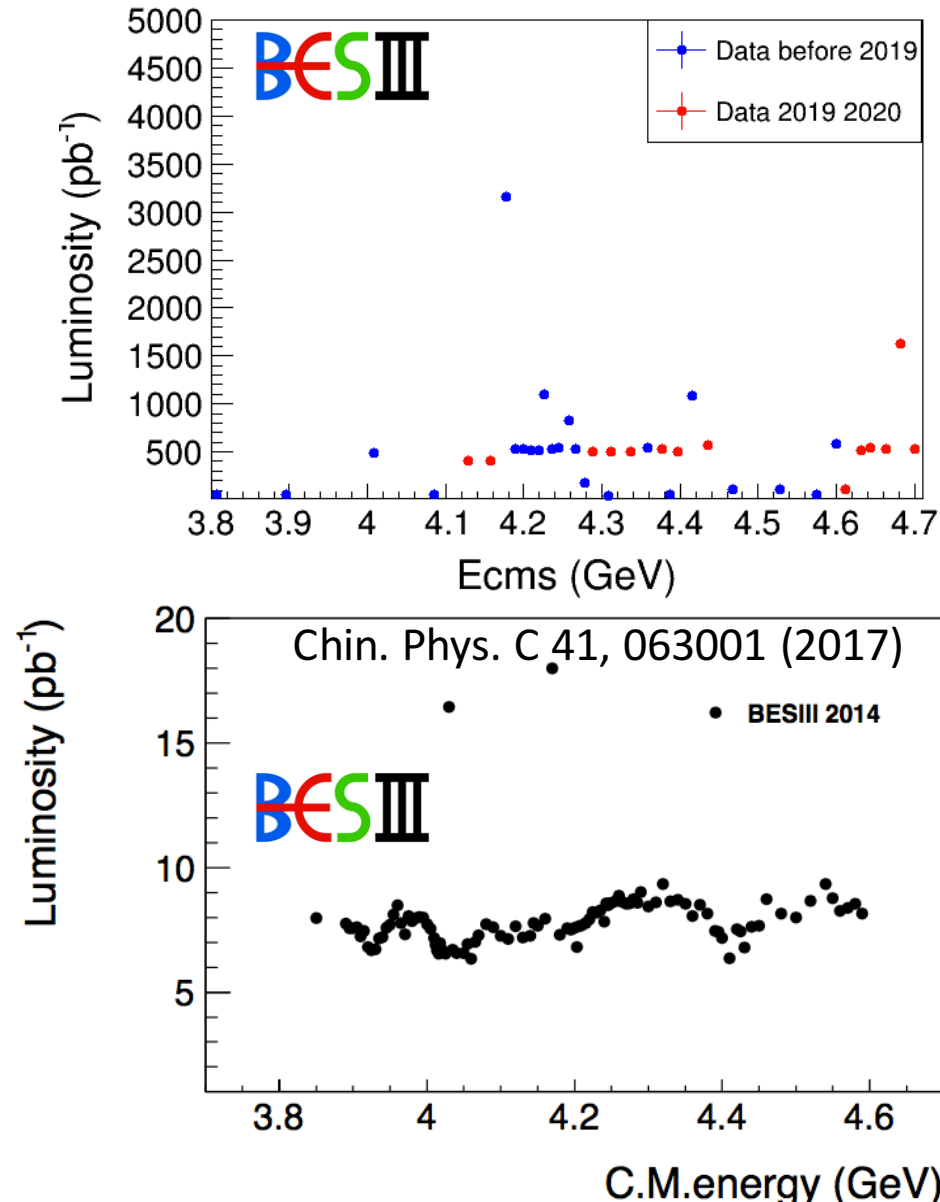
XYZ data

☐ ~20 fb^{-1} e$^+$e$^-$ collision data event in open charm region from 3.8-4.7GeV.

☐ Massive events on several special energy points: Such as 4.26GeV, and 4.36GeV

R-scan data in open charm region

☐ Energy points with luminosity < 20 pb^{-1}

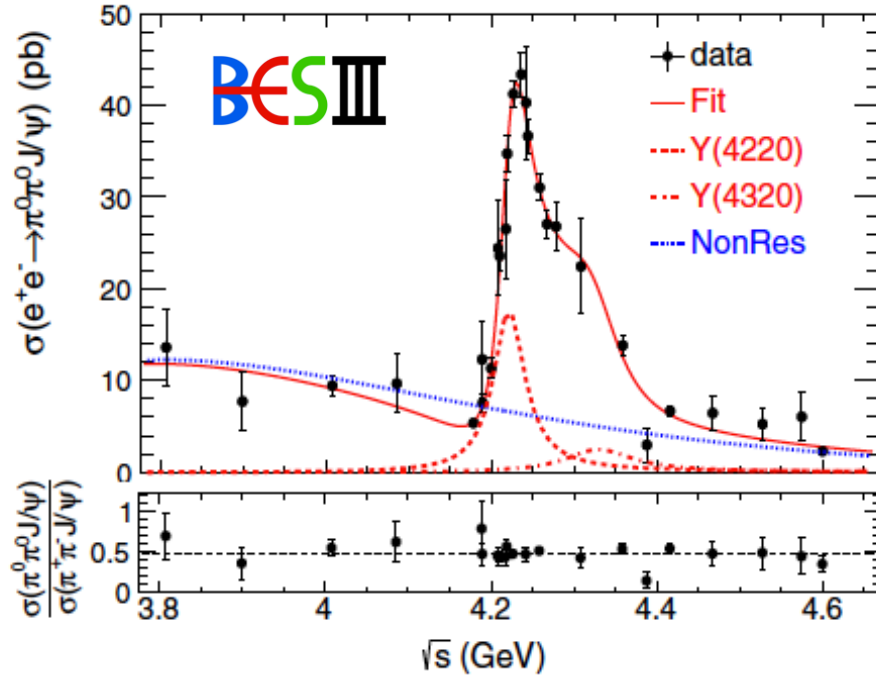☐ Initially taken for R study, can also help the XYZ study

Y state: Charmoniumlike Vector states

Cross section of e⁺e⁻ →π⁰π⁰J/ψ

PRD 102, 012009 (2020)

□ The measured cross section compared with e⁺e⁻ →π⁺π⁻J/ψ satisfy the isospin symmetry.

□ In the fitting, the parameter of Y(4320) are fixed to charged mode. Significance(Y(4320))=4.3σ

□ And the measured parameter of Y(4220) also agree with that in e⁺e⁻ →π⁺π⁻J/ψ.

Y(4220):M = (4220.4$\pm$2.4$\pm$2.3) MeV,   Γ = (46.2$\pm$4.7$\pm$2.1) MeV

$$\sigma_{\text{fit}}(\sqrt{s}) = |\sqrt{\sigma_{NY}(\sqrt{s})} + f_1(s)e^{i\phi_1} + f_2(s)e^{i\phi_2}|^2,$$

$$\sigma_{NY}(\sqrt{s}) = \Phi(\sqrt{s})e^{-P_0(\sqrt{s}-M_{\text{thd}})+p_1}$$

$$f_i(s) = \frac{M_i}{\sqrt{s}} \frac{\sqrt{12\pi\Gamma_{ee}^i \Gamma_{\text{tot}}^i \mathcal{B}_{\pi^0\pi^0 J/\psi}^i}}{s - M_i^2 + iM_i\Gamma_{\text{tot}}^i} \times \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M_i)}},$$
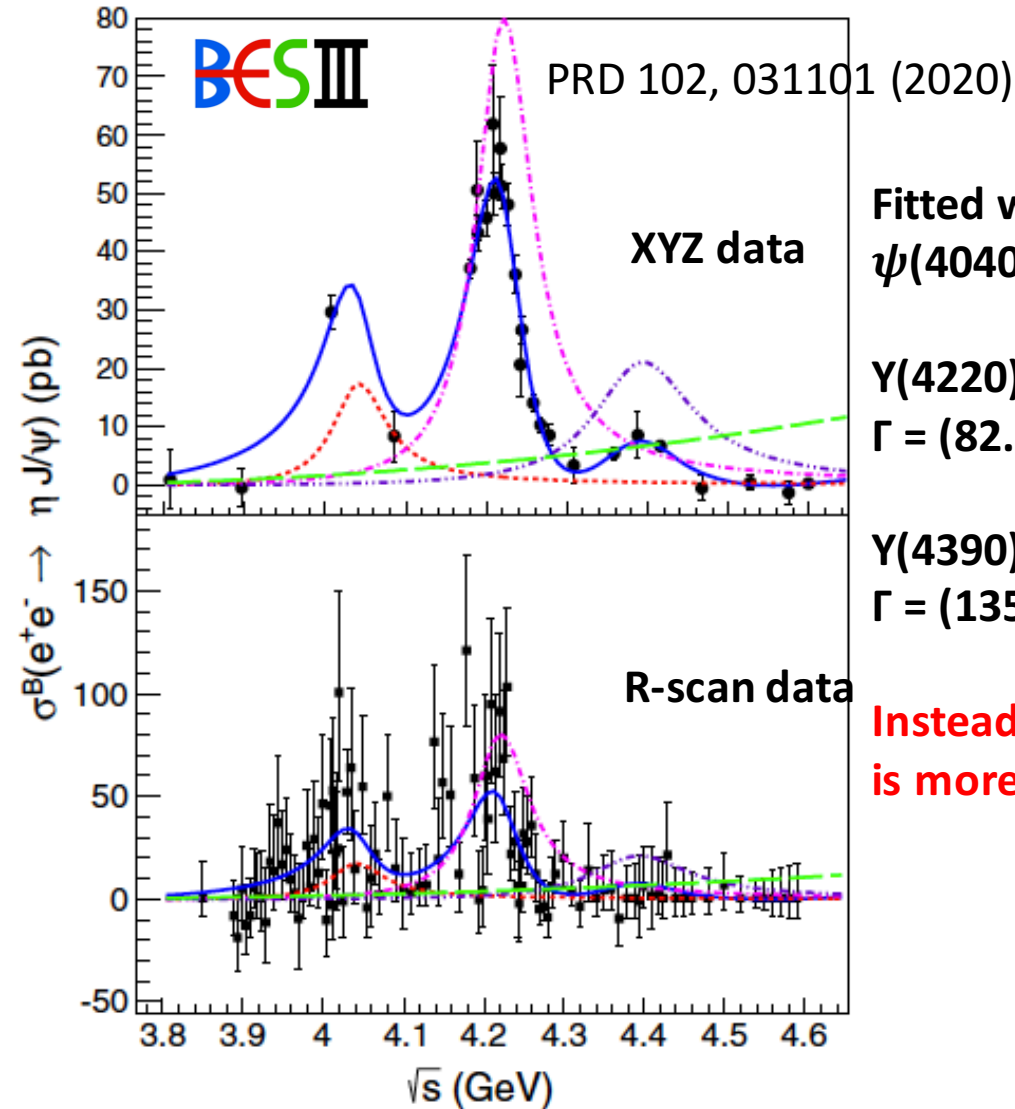
e⁺e⁻ →π⁺π⁻J/ψ PRL 118, 092001 (2017)

6
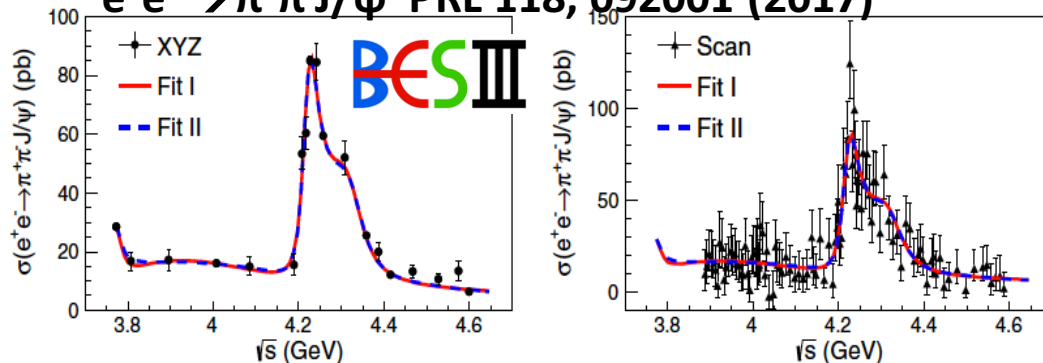
$\sigma(e^+ e^- \to \eta J/\psi)$

Previous works
Belle PRD D87,051101(R) (2013)
BESIII PRD91,112005 (2015)

BESⅢ   PRD 102, 031101 (2020)

XYZ data

R-scan data
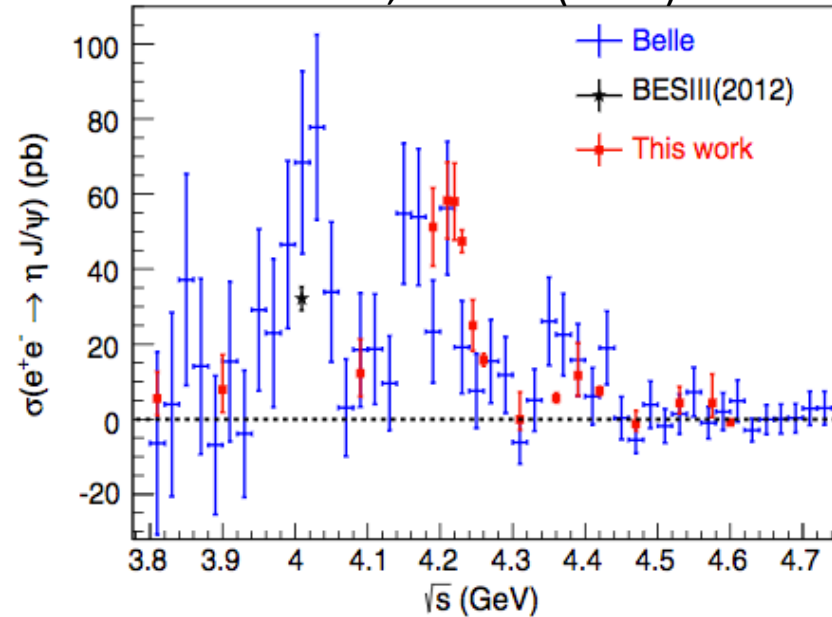
Fitted with continuum+ 3 states:
$\psi(4040)$ fixed to PDG value

Y(4220): M = (4218.6±3.8±2.5) MeV,
Γ = (82.0±5.7±0.4) MeV

Y(4390): M = (4382.0±13.3±1.7) MeV,
Γ = (135.8±60.8±22.5) MeV

Instead of $\psi(4160)$ the second peak
is more likely to be Y(4220).

Comparison of Y(4220) parameters in different channels
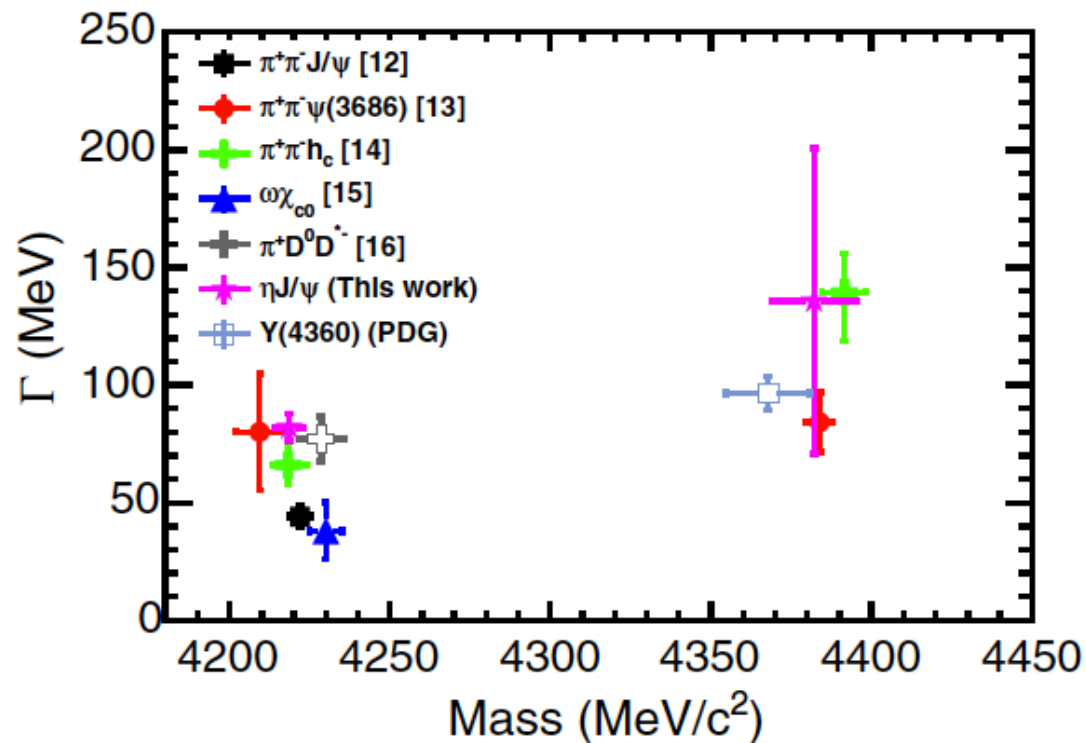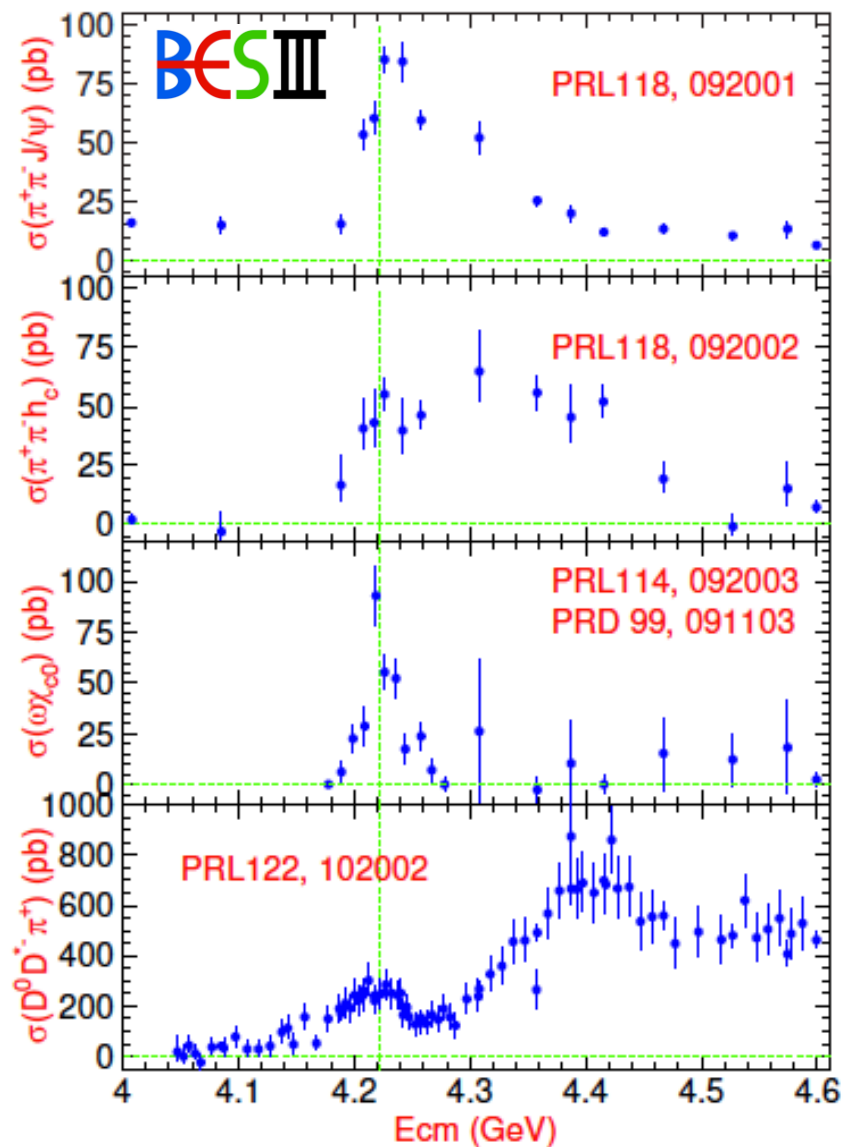
The mass of Y(4220) in $e^+e^- \rightarrow \eta J/\psi$ is compatible with other channels.

Cross section of $e^+e^- \to D^+D_1(2420)^- +$c.c., with $D_1(2420)^+ \to \pi^+\pi^-D^+$

$\sigma(e^+e^- \to D^+D_1(2420)^-)$

$\sigma(e^+e^- \to \pi^+\pi^-\psi(3770))$
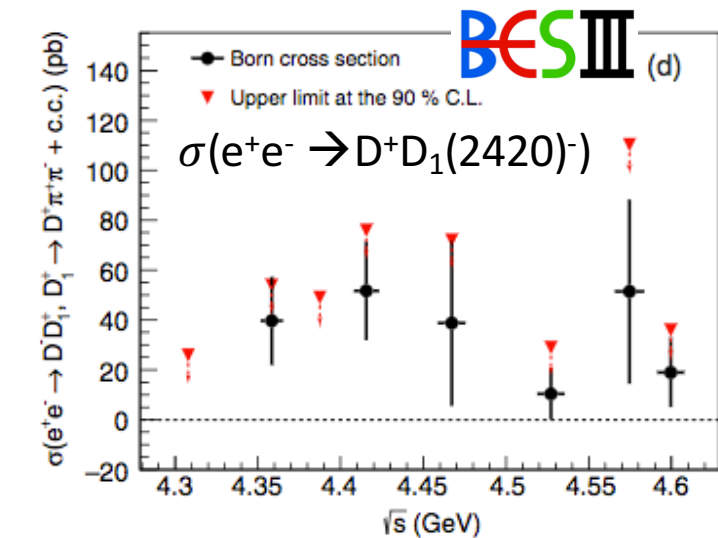
$\sigma(e^+e^- \to D^+D_1(2420)^-)$

$\sigma(e^+e^- \to \pi^+\pi^-\psi(3770))$

PRD 100, 032005 (2019)
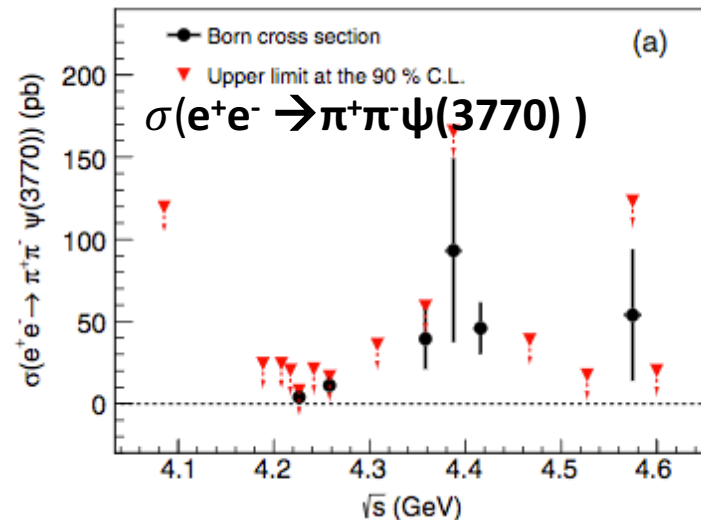**Full reconstruction method**
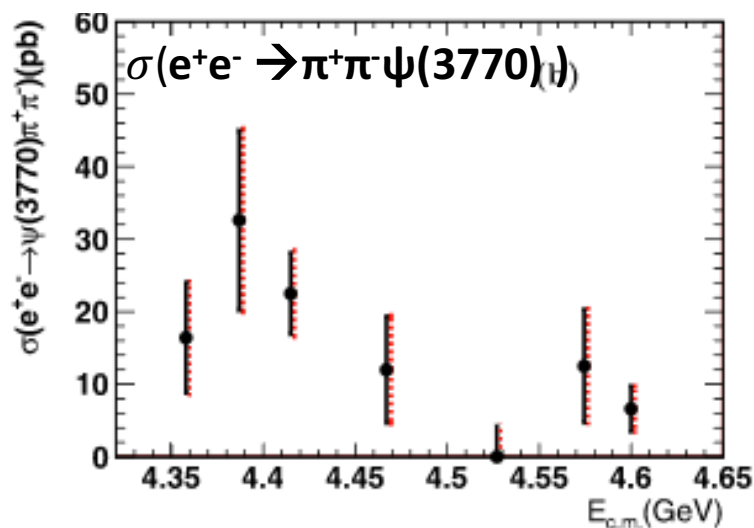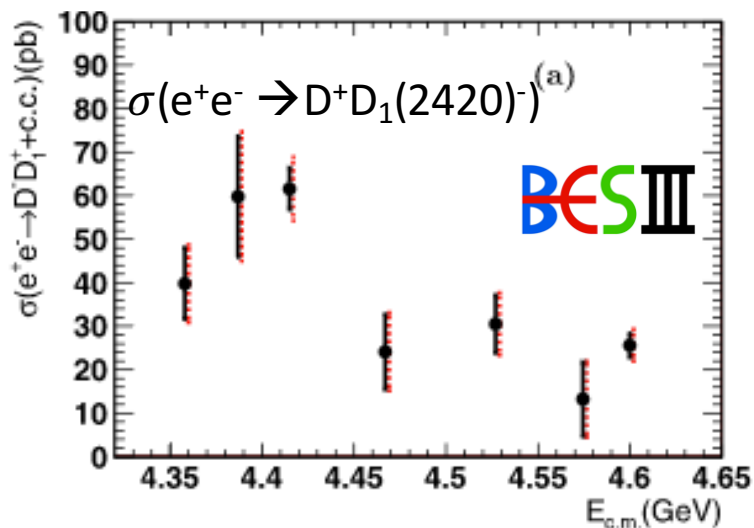
PLB 804 (2020) 135395
Partial reconstruction method.
Only reconstruct $\pi^+\pi^-D^+$

$\sigma(e^+e^- \to D^+D_1(2420)^-)$ **is measured.**
This can provide information to the
Molecular model explanation of Y states

$\sigma(e^+e^- \to \pi^+\pi^-\psi(3770))$ **is also measured.**
D1(2420): M = (2427.2$\pm$1.0$\pm$1.2) MeV,
Γ = (23.2$\pm$2.3$\pm$2.3) MeV

Z_c state: Isospin non-zero Charmoniumlike states with heavy quark pair $c\bar{c}$ inside

PWA of $e^+e^- \to \pi^0\pi^0 J/\psi$

PRD 102, 012009 (2020)

☐ **Simultaneous fit of 4 energy points near Y(4230).**

☐ **J^p of Zc^0 favor to be 1^+, confirm the result in charged mode**

☐ **$M(Zc^0) = (3893.0 \pm 2.3 \pm 19.9)$ MeV, $\Gamma(Zc^0) = (44.2 \pm 5.4 \pm 9.1)$ MeV**

$e^+e^- \to \pi^+\pi^- J/\psi$ PRL 119, 072001 (2017)

√s=4.23GeV

√s=4.26GeV

11

$\sigma(e^+e^- \to \pi^0 Z_c^0 \to \pi^0\pi^0 J/\psi)$
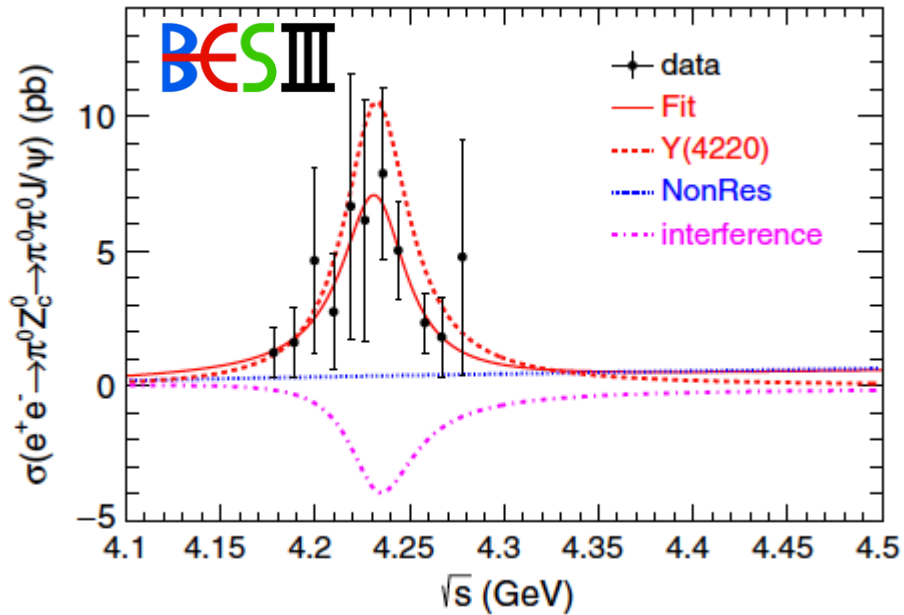
PRD 102, 012009 (2020)

- **The Zc fraction is extracted with PWA**
- **A hint of connection between Y(4220) and Zc(3900)**

Parameters	Solution I	Solution II
$p_0(c^2/\text{MeV})$	0.0 ± 11.3	
p_1	$(1.8 \pm 1.9) \times 10^{-2}$	
$M(R)$ (MeV/c^2)	4231.9 ± 5.3	
$\Gamma_{\text{tot}}(R))$ (MeV)	41.2 ± 16.0	
$\Gamma_{ee}\mathcal{B}_{R \to \pi^0 Z_c(3900)^0}$ (eV)	0.53 ± 0.15	0.22 ± 0.25
$\phi(R)$	$(-103.9 \pm 33.9)°$	$(112.7 \pm 43.0)°$

Evidence of $e^+e^- \to \pi Z_c^{(\prime)}, Z_c^{(\prime)} \to \rho^{\pm}\eta_c$

PRD 100, 111102(R) (2019)
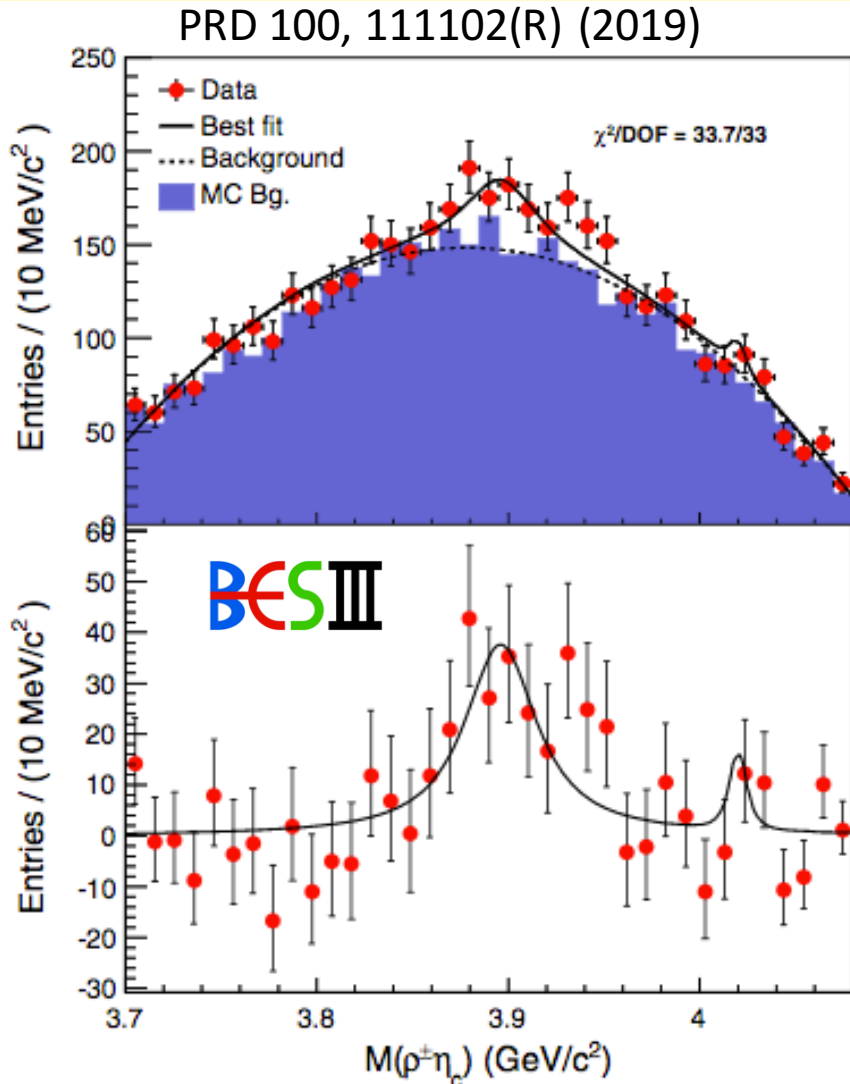
- ❑Nine η_c channels are used to reconstruct η_c.
- ❑After the η_c and ρ mass window, a hint of $Z_c(3900)$ peak can be seen on the recoiled mass of the bachelor π.
- ❑The blue histogram is η_c sideband. Z_c parameter are fixed to latest measurement.

- ❑Strong evidence of Zc(3900) →$\rho\eta_c$ is observed at √s=4.23GeV, with statistical significance 4.3σ(3.9σ including systematic uncertainty)
- ❑No significant Zc'(4020)→$\rho\eta_c$ observed. (statistical significance 1.0σ)

$$R_{Zc}=Br(Z_c \rightarrow \rho\eta_c)/Br(Z_c \rightarrow \pi J/\psi)$$

TABLE III. Comparison of the measured $R_{Z_c(3900)}$ and $R_{Z_c(4020)}$ with the theoretical predictions.

| Ratio	Measurement	Tetraquark	Molecule
$R_{Z_c(3900)}$	2.3 ± 0.8 [29]	230^{+330}_{-140} [12]	$0.046^{+0.025}_{-0.017}$ [12]
		$0.27^{+0.40}_{-0.17}$ [12]	1.78 ± 0.41 [17]
		0.66 [13]	6.84×10^{-3} [18]
		0.56 ± 0.24 [14]	0.12 [19]
		0.95 ± 0.40 [15]	
		1.08 ± 0.88 [16]	
		1.28 ± 0.37 [17]	
		1.86 ± 0.41 [17]	
$R_{Z_c(4020)}$	< 1.2 [4]	$6.6^{+56.8}_{-5.8}$ [12]	$0.010^{+0.006}_{-0.004}$ [12]

BESIII result   Theoretical prediction

A.Esposito et.al., PLB 746(2015), 194-201

This measurement

Molecular Zc

Tetraquak Type-1

14
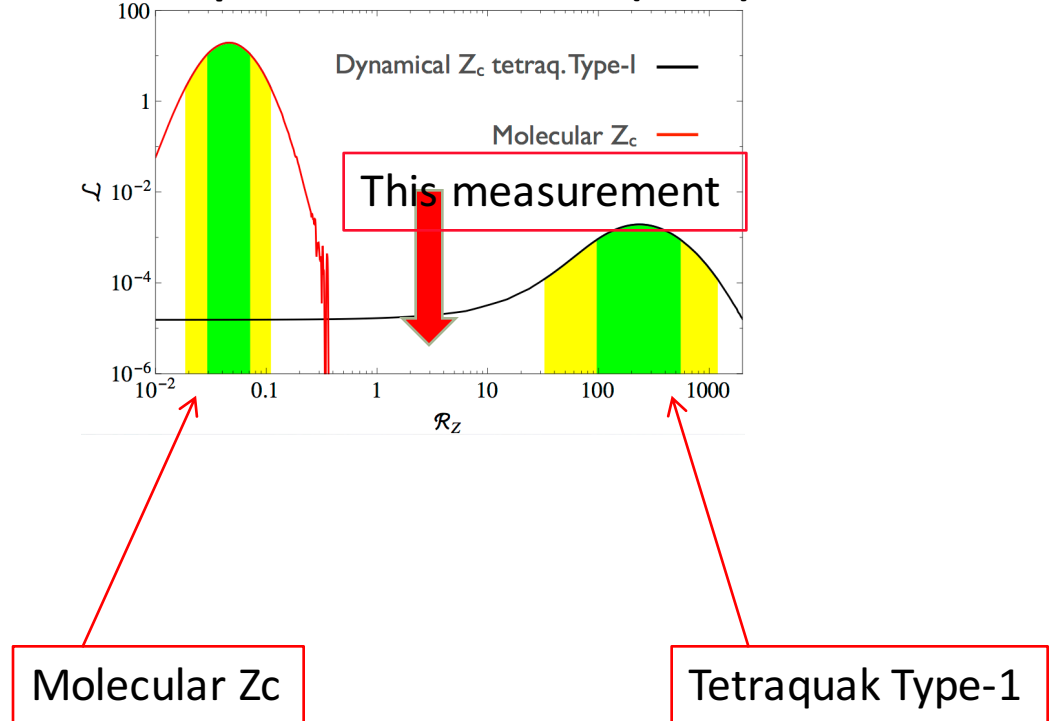
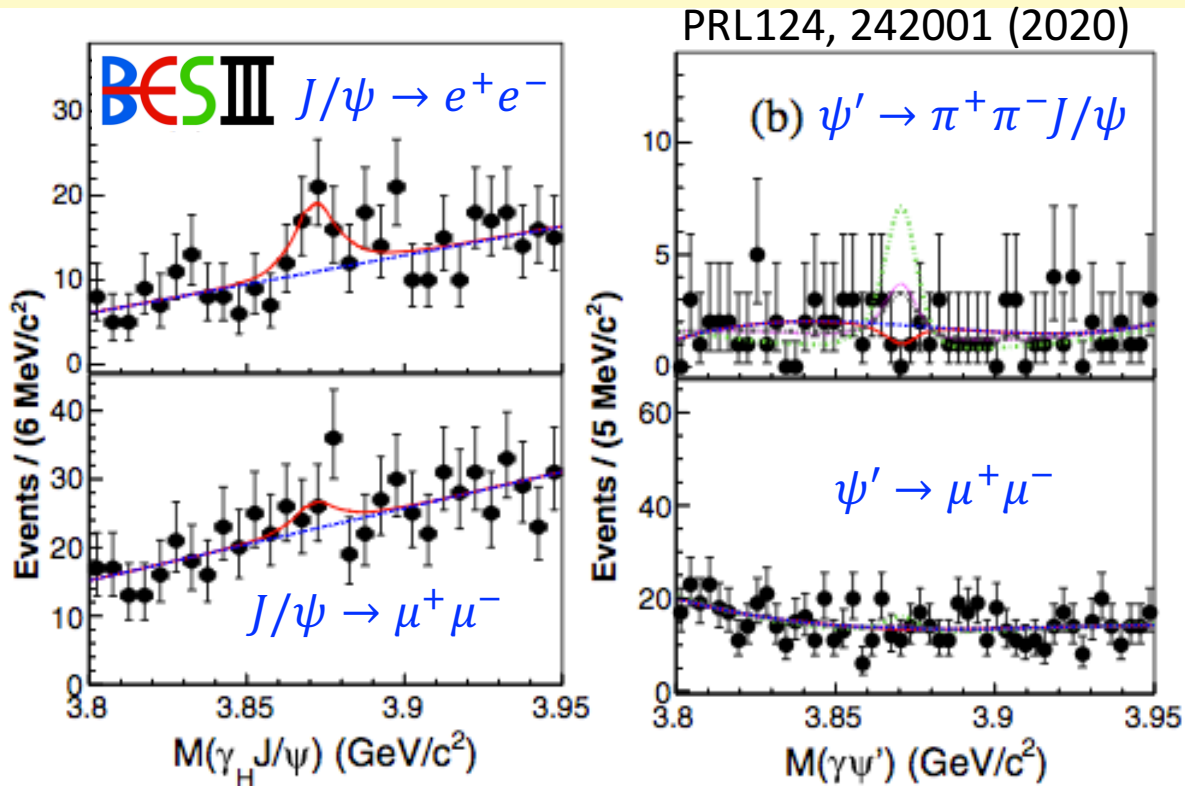# X state: other states not well understood
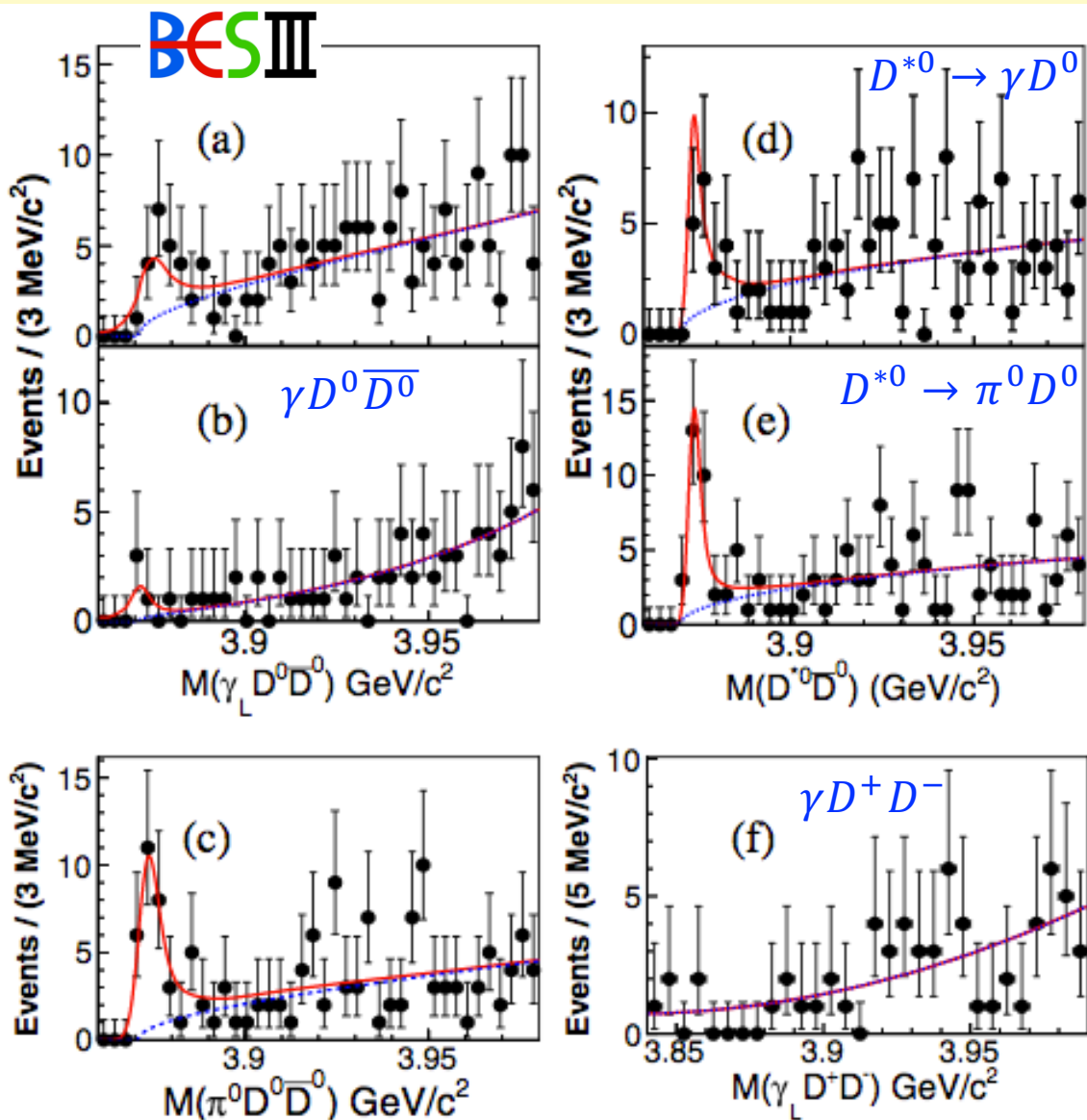
PRL124, 242001 (2020)

TABLE I. Relative branching ratios and UL on branching ratios compared with $X(3872) \to \pi^+ \pi^- J/\psi$ [18,27], where systematic uncertainties have been taken into account.

Mode	Ratio	UL
$\gamma J/\psi$	0.79 ± 0.28	$\cdots$
$\gamma \psi'$	-0.03 ± 0.22	< 0.42
$\gamma D^0 \bar{D}^0$	0.54 ± 0.48	< 1.58
$\pi^0 D^0 \bar{D}^0$	-0.13 ± 0.47	< 1.16
$D^{*0} \bar{D}^0 +$ c.c.	11.77 ± 3.09	$\cdots$
$\gamma D^+ D^-$	$0.00^{+0.48}_{-0.00}$	< 0.99
$\omega J/\psi$	$1.6^{+0.4}_{-0.3} \pm 0.2$ [18]	$\cdots$
$\pi^0 \chi_{c1}$	$0.88^{+0.33}_{-0.27} \pm 0.10$ [27]	$\cdots$

X(3872) described with Flatte in ref.
PLB 680, 453 (2009)

$$D(E) = E - E_f + \frac{i}{2}\left(g_1 k_1 + g_2 k_2 + \Gamma(E) + \Gamma_c\right)$$

16

Evidence of X(3872)→$\gamma J/\psi$

$J/\psi \to e^+ e^-$

$J/\psi \to \mu^+ \mu^-$

(b) $\psi' \to \pi^+ \pi^- J/\psi$

$\psi' \to \mu^+ \mu^-$

M($\gamma_H J/\psi$) (GeV/c^2)

M($\gamma \psi'$) (GeV/c^2)

- Evidence of X(3872)→γJ/ψ with significance 3.5 σ

- Uplimit of
  $$R_\psi = \frac{B[X(3872) \to \gamma \psi']}{B[X(3872) \to \gamma J\psi]} < 0.59 \text{ (CL. 90\%)}$$
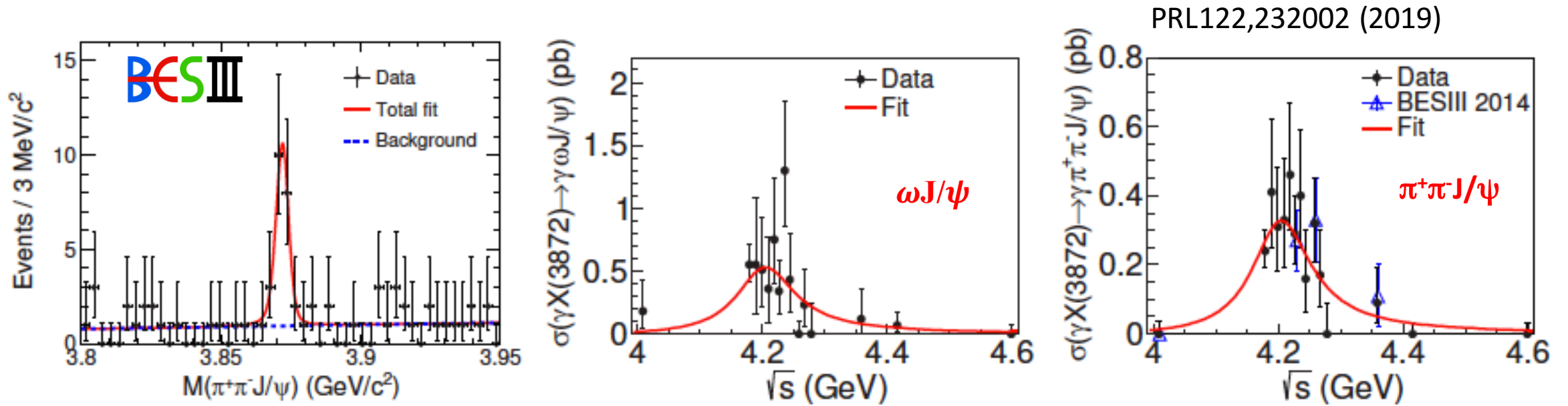
- Previous measurement of R_ψ
  BaBar: 3.4±1.4
  LHCb: 2.46±0.64±0.29
  Belle: <2.1 (CL. 90%)

- BESIII's result have tension with BarBar and LHCb's result.

- This ration R_ψ can provide information for distinguishing different theoretical models of X(3872)

17

e⁺e⁻→γX(3872)→γωJ/ψ, γ π⁺π⁻J/ψ

PRL122,232002 (2019)

□ **Cross section measurement of e⁺e⁻→γX(3872) for (mid) *ωJ/ψ* and (right) π⁺π⁻J/ψ channel**

□ **Simultaneous fit to the cross section with a single Breit-Wigner resonance**

$$M[Y(4200)] = 4200.6^{+7.9}_{-13.3} \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma[Y(4200)] = 115^{+38}_{-26} \pm 12 \text{ MeV}$$

$$\mathcal{R} = \frac{\mathcal{B}[X(3872)\to\omega J/\psi]}{\mathcal{B}[X(3872)\to\pi^+\pi^- J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2$$

A possible of connection between Y and X(3872)

Summary

- Y(4220) with mass around 4.22 GeV are observed in many decay modes. $\sigma\ (e^+e^- \to \pi^0\pi^0 J/\psi)$ and $\sigma(e^+e^- \to \eta J/\psi)$ are new released.

- $\sigma(e^+e^- \to D^+D_1(2420)^-)$ and $\sigma(e^+e^- \to \pi^+\pi^-\psi(3770))$ are measured

- PWA of $e^+e^- \to \pi^0\pi^0 J/\psi$ are performed, confirm the J^p of $Z_c(3900)^0$ to be 1^+, connection between Y(4220) and Zc(3900) is observed.

- Evidence of $Z_c(3900) \to \rho^\pm \eta_c$ is observed.

- Evidence of X(3872)$\to \gamma J/\psi$ is observed and the ratio
  $R_\psi = \dfrac{B[X(3872) \to \gamma\psi']}{B[X(3872) \to \gamma J\psi]} < 0.59$ have tension with LHCb and BaBar's result.

- Cross section of $e^+e^- \to \gamma X(3872) \to \gamma\omega J/\psi$ and $e^+e^- \to \gamma X(3872) \to \gamma\ \pi^+\pi^- J/\psi$

 are measured and possible connection between Y structure and X(3872) is observed.

- **More results are coming.**