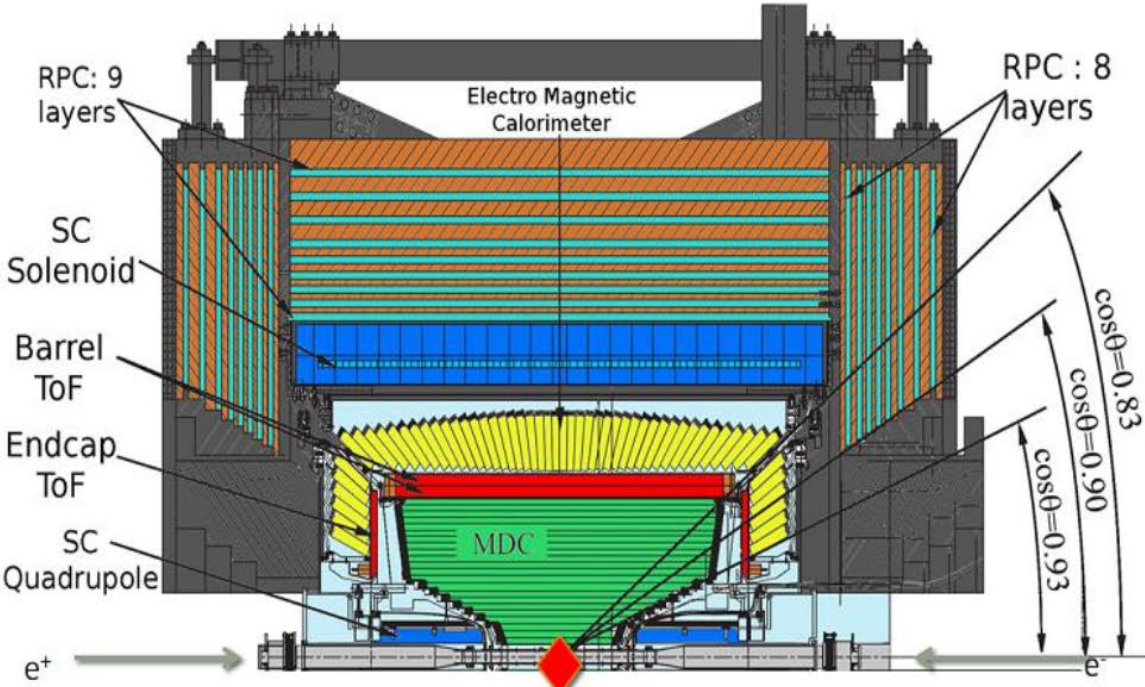# Measurements of cross sections e^+e^- annihilation into final states including hidden charm resonances

Qixin Li
(on behalf of the BESIII collaboration)

Qingdao 2024.08.14

BEPCII and BESIII

RPC: 9 layers

RPC: 8 layers

Electro Magnetic Calorimeter

SC Solenoid

Barrel ToF

Endcap ToF

SC Quadrupole

$\cos\theta=0.83$

$\cos\theta=0.90$

$\cos\theta=0.93$

MDC

e^+

e^-

τ-c region $\sqrt{s} = 2 - 5$ GeV

XYZ data 22fb^{-1}

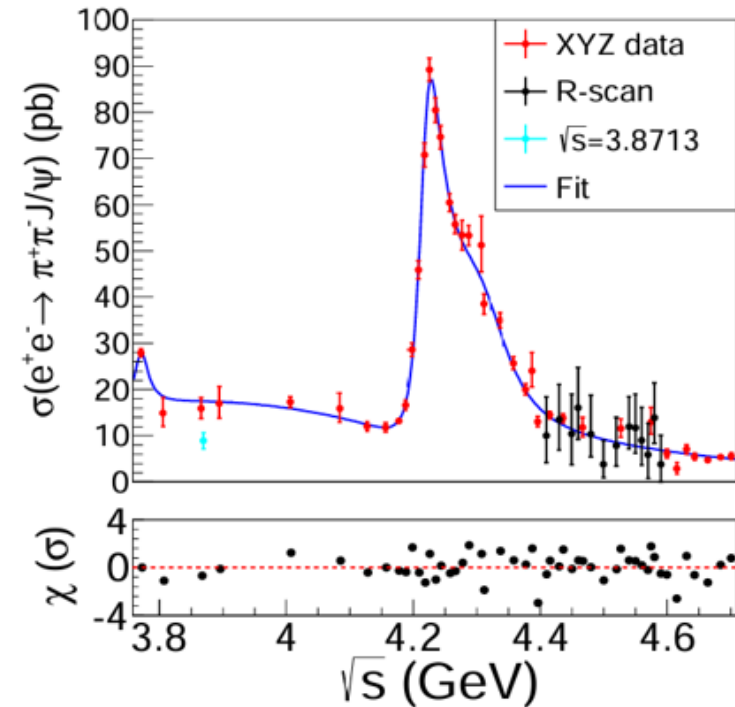$\int L dt$ (pb^{-1})

$\sqrt{s}$ (GeV)
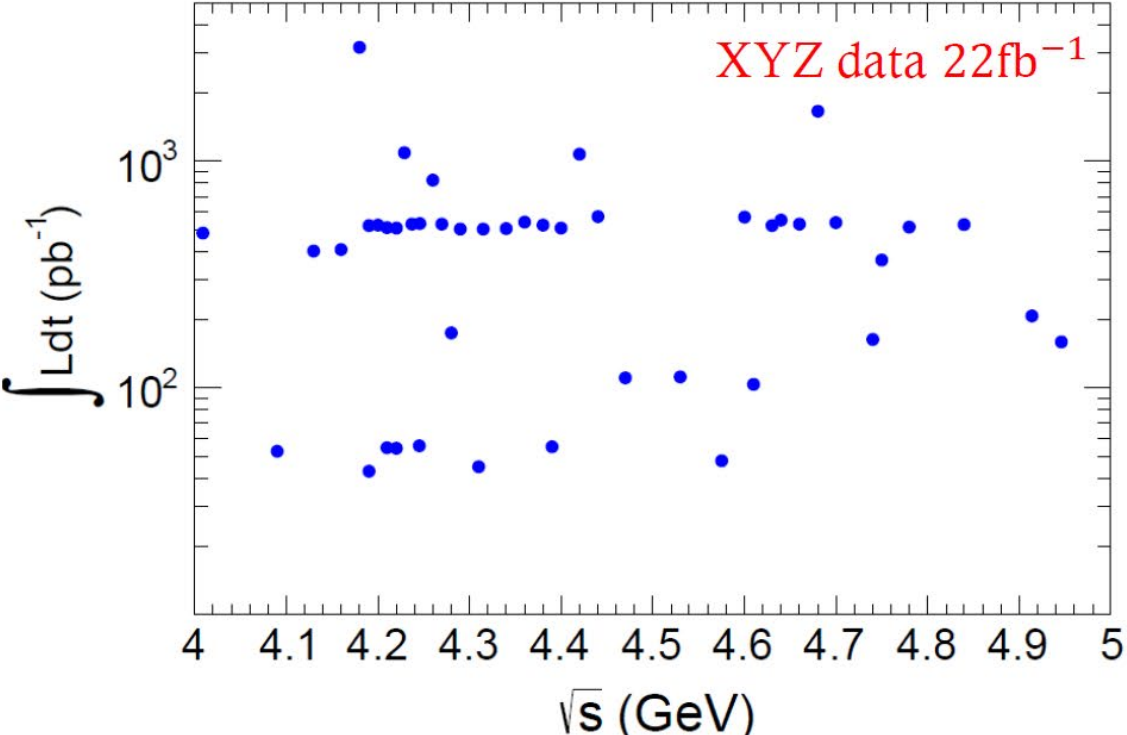
Introduction

- In the past decade many charmonium-like states were observed experimentally.

- Y states showing strong coupling to hidden-charm final states

- Precise measurements of production cross sections and resonance parameters needed

  - to clarify nature of these states

  - to distinguish among different theoretical models
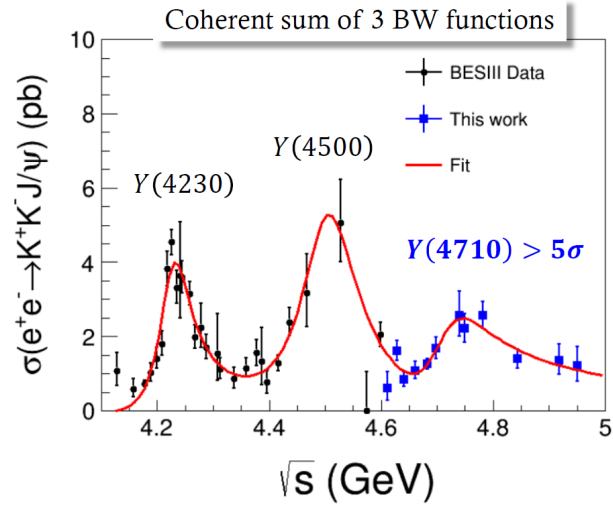
Study of $e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$
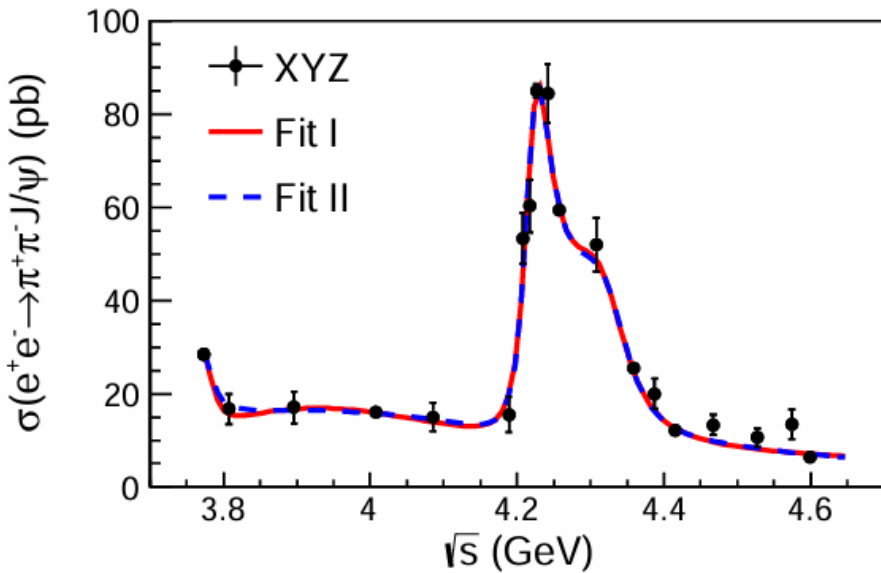
➤ Improves upon the precision of results

➤ Y(4220): Mass=(4222.0±3.1±1.4) MeV, Width=(44.1±4.3±2.0) MeV (10σ)

➤ Y(4320): Mass=(4298.0±12±26) MeV, Width=(127±17±10) MeV (10σ)

➤ A small enhancement around 4.5 GeV with a significance about 3σ ψ(4415)?

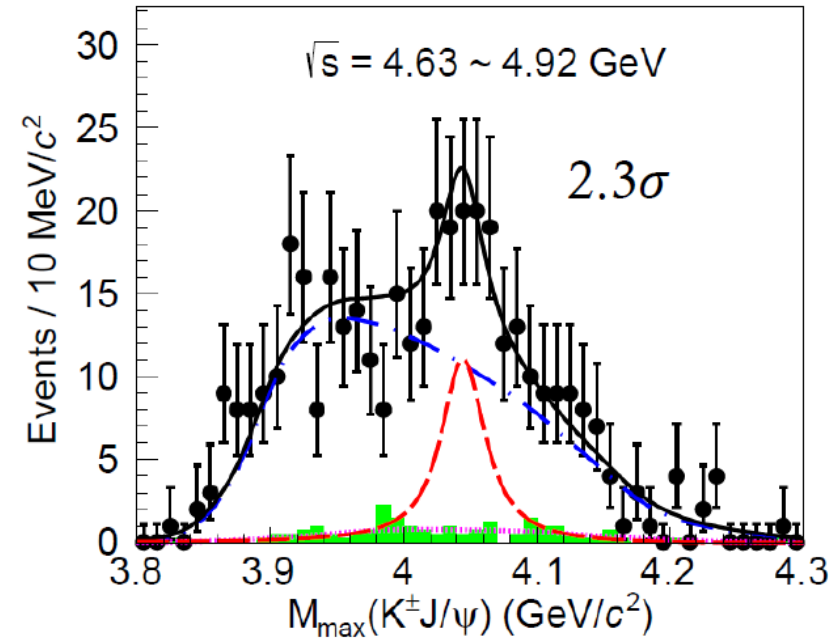# Study of $e^+ e^- \rightarrow K^+ K^- J/\psi$

PRL 131, 211902 (2023)

Coherent sum of 3 BW functions

$Y(4500)$

$Y(4230)$

$Y(4710) > 5\sigma$

4.61-4.95 GeV

5.85 fb^{-1}

$\sqrt{s} = 4.63 \sim 4.92$ GeV

2.3σ

CPC, 46, 111002 (2022) BESIII

	BESIII	This work
$M_{Y(4230)}$ (MeV/c^2)	4225.3 ± 2.3	4225.2 ± 2.2
$\Gamma_{Y(4230)}$ (MeV)	72.9 ± 6.1	70.7 ± 6.1
$M_{Y(4500)}$ (MeV/c^2)	4484.7 ± 13.3	4498.9 ± 12.7
$\Gamma_{Y(4500)}$ (MeV)	111.1 ± 30.1	123.7 ± 24.9
$M_{Y(4710)}$ (MeV/c^2)		4708.3 ± 14.8
$\Gamma_{Y(4710)}$ (MeV)		125.7 ± 31.3
$\Gamma_{ee}\mathcal{B}_{Y(4710)\rightarrow K^+K^-J/\psi}$ (eV)		$0.16\text{-}1.61$

➢ New vector charmonium-like state (over 5σ)   5S or mixing ?

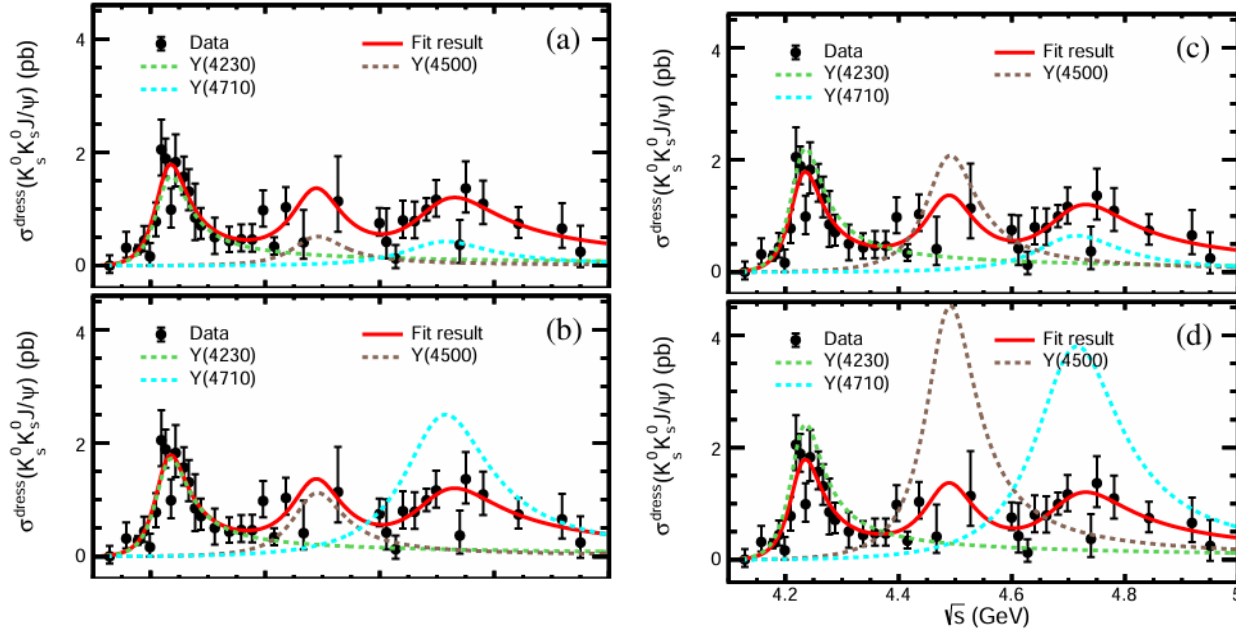➢ No significant structure is observed in the KJ/ψ system

$$\frac{\mathcal{B}[Z_{cs}(3985) \rightarrow KJ/\psi]}{\mathcal{B}[Z_{cs}(3985) \rightarrow DD_s^* + D_sD^*]} < 0.03 \quad @\ 90\%\ \text{CL}$$

Study of $e^+ e^- \rightarrow K_s K_s J/\psi$

PRD 107, 092005 (2023)

4.13-4.95 GeV

21.2 fb^{-1}

Parameter	Solution I	Solution II	Solution III	Solution IV
M_{4230} (MeV/c^2)			$4226.9 \pm 6.6 \pm 22.0$	
Γ_{4230} (MeV)			$71.7 \pm 16.2 \pm 32.8$	
$(\Gamma_{ee}\mathcal{B})_{4230}$ (eV)	$0.13 \pm 0.02 \pm 0.05$	$0.14 \pm 0.03 \pm 0.06$	$0.18 \pm 0.05 \pm 0.07$	$0.20 \pm 0.04 \pm 0.07$
M_{4500} (MeV/c^2) (fixed)			$4484.7 \pm 13.3 \pm 24.1$ [Ref. [31]]	
Γ_{4500} (MeV) (fixed)			$111.1 \pm 30.1 \pm 15.2$ [Ref. [31]]	
$(\Gamma_{ee}\mathcal{B})_{4500}$ (eV)	$0.08 \pm 0.09 \pm 0.04$	$0.17 \pm 0.14 \pm 0.05$	$0.31 \pm 0.26 \pm 0.11$	$0.68 \pm 0.24 \pm 0.18$
ϕ_{4500} (rad)	$1.02 \pm 0.57 \pm 0.56$	$1.74 \pm 1.11 \pm 0.46$	$4.26 \pm 0.76 \pm 0.91$	$4.98 \pm 0.31 \pm 0.74$
M_{4710} (MeV/c^2)			$4704.0 \pm 52.3 \pm 69.5$	
Γ_{4710} (MeV)			$183.2 \pm 114.0 \pm 96.1$	
$(\Gamma_{ee}\mathcal{B})_{4710}$ (eV)	$0.12 \pm 0.09 \pm 0.11$	$0.68 \pm 0.26 \pm 0.21$	$0.18 \pm 0.20 \pm 0.10$	$1.04 \pm 0.60 \pm 0.35$
ϕ_{4710} (rad)	$0.92 \pm 0.99 \pm 0.84$	$5.37 \pm 0.46 \pm 0.95$	$5.38 \pm 1.02 \pm 0.80$	$3.55 \pm 0.27 \pm 1.03$

$$\frac{\sigma^{Born}(K_s K_s J/\psi)}{\sigma^{Born}(K^+ K^- J/\psi)} = 0.426^{+0.038}_{-0.031} \pm 0.018$$

➢ Clear structure around 4.220 GeV can be seen

➢ No clear structure around 4.500 GeV is found (maybe it's due to lower statistics)

➢ Enhanced structure Y(4710) with a statistical significance 4.2σ
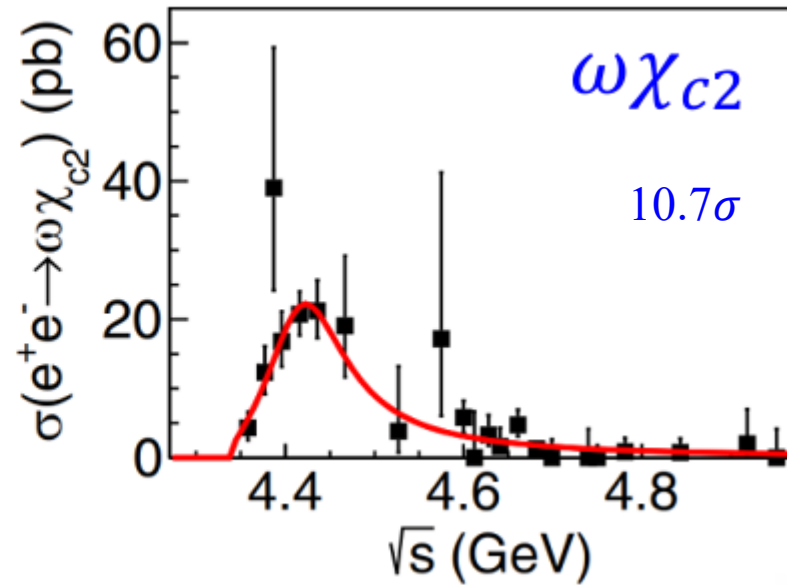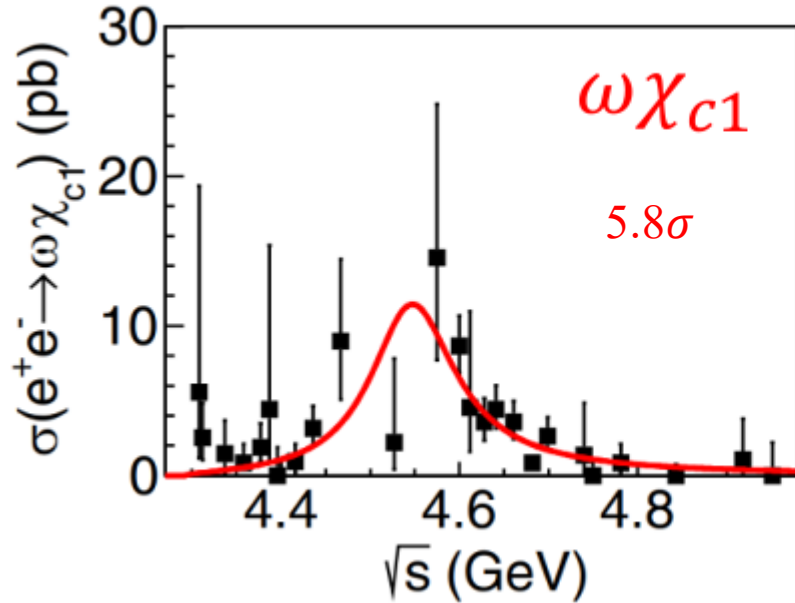
Study of $e^+ e^- \longrightarrow \omega \chi_{c1,2}$

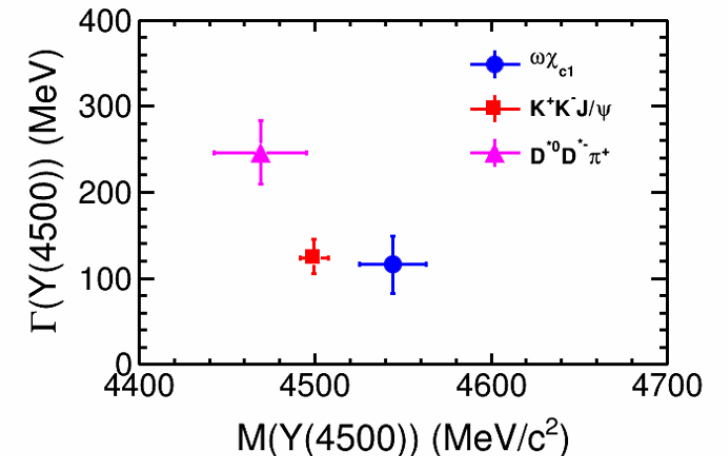$\sqrt{s} = 4.308 \sim 4.951$ GeV, 11 fb^{-1}, > 20 energy points

Y(4500)?

Two structures are observed

$M_1 = (4544.2 \pm 18.7 \pm 1.7)$ MeV/c^2
$\Gamma_1 = (116.1 \pm 33.5 \pm 1.7)$ MeV

A new particle?

$M_2 = (4413.6 \pm 9.0 \pm 0.8)$ MeV/c^2
$\Gamma_2 = (110.5 \pm 15.0 \pm 2.9)$ MeV
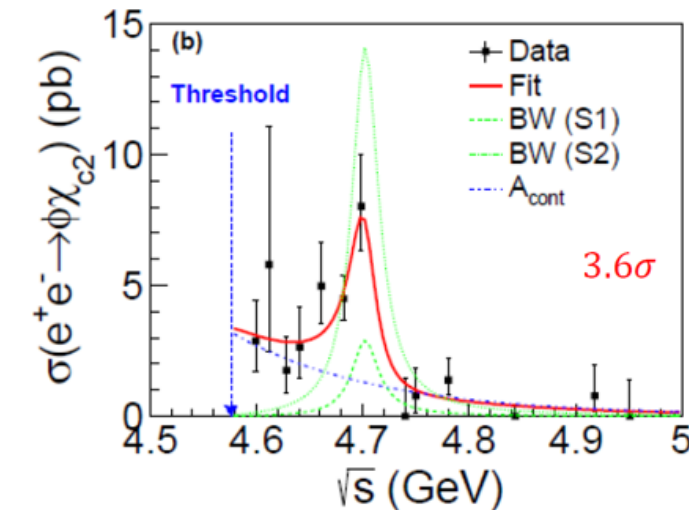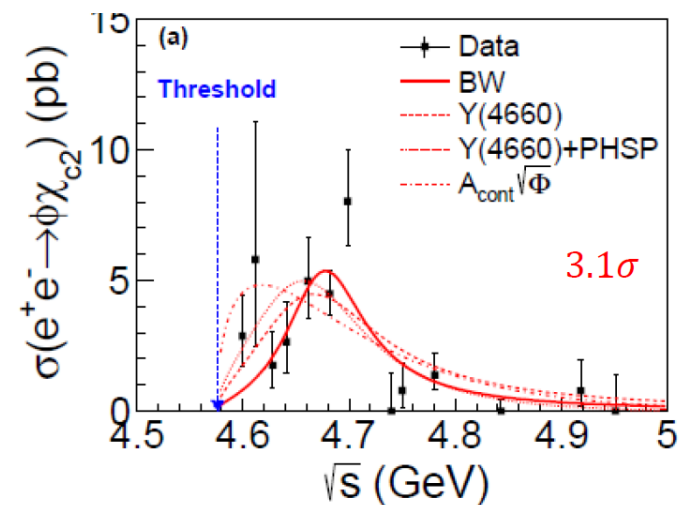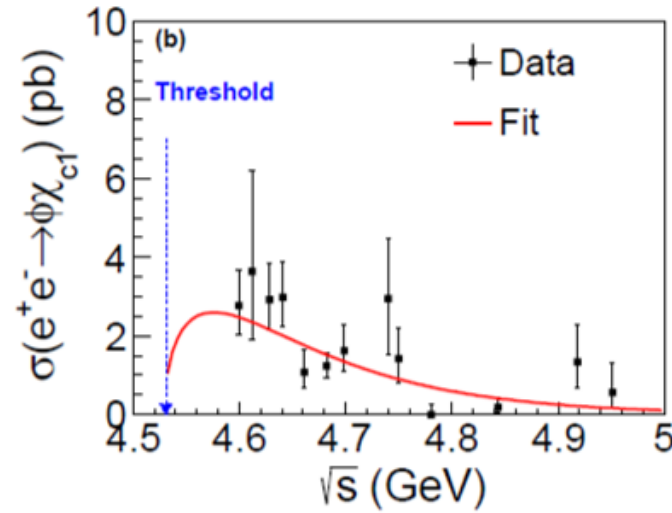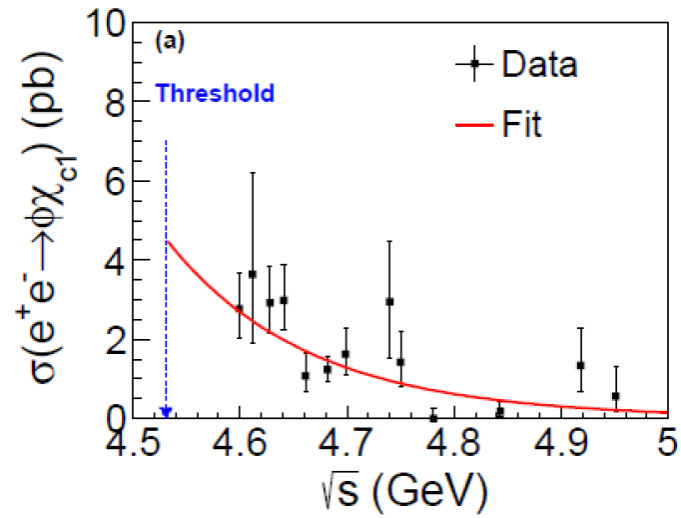
Consistent with $\psi(4415)$

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

4.60~4.95 GeV

$6.4 fb^{-1}$

$$\sigma^{\text{U.L.}} \mathcal{B} = \frac{N_{\gamma X}^{\text{N.L.}}}{\mathcal{L}_{\text{int}}(1+\delta)\frac{1}{|1-\Pi|^2}\mathcal{B}_{J/\psi}}$$
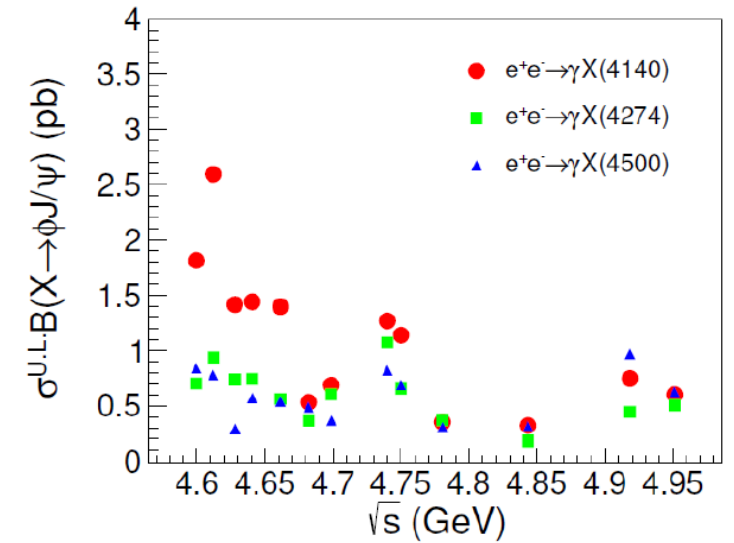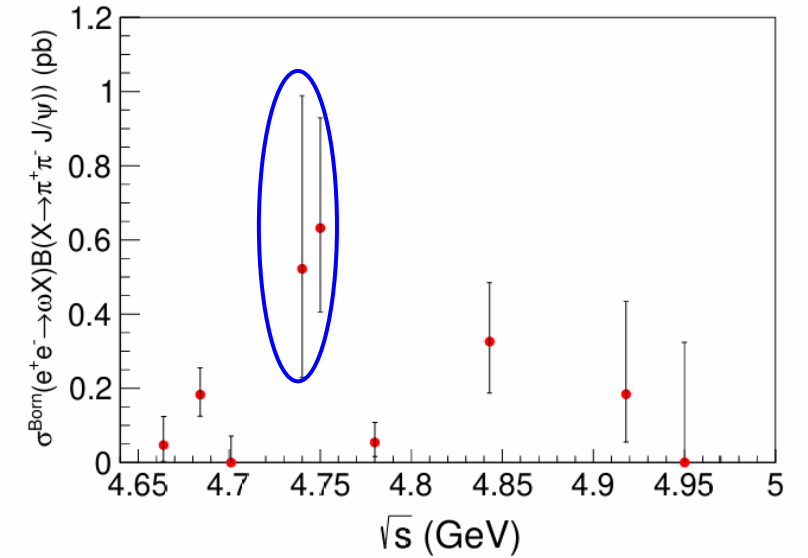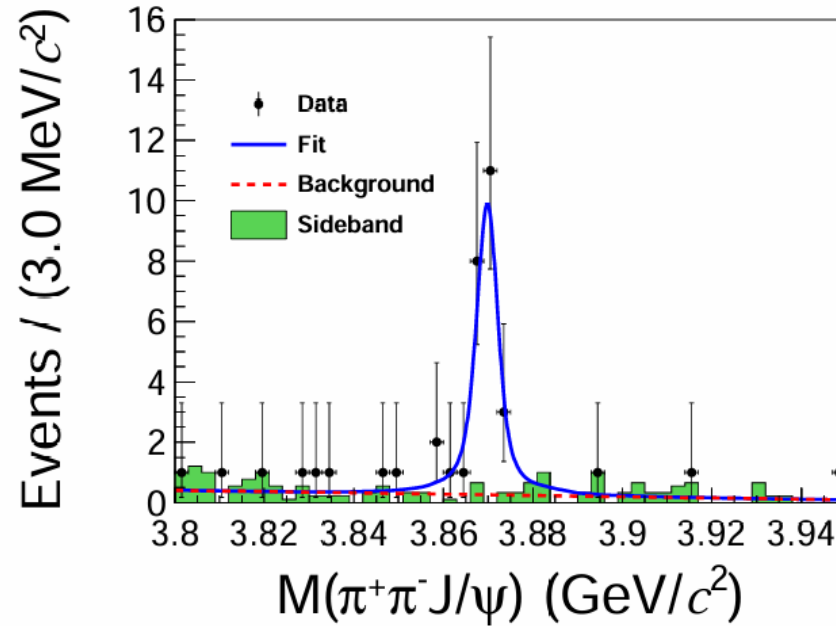

- $\phi \chi_{c1,2}$ signal is observed (over 10σ)
- $Y(4660) \rightarrow \phi \chi_{c2}$ (evidence)
- No obvious structure in the $\phi J/\psi$ system

Study of $e^+e^- \rightarrow \omega X(3872)$

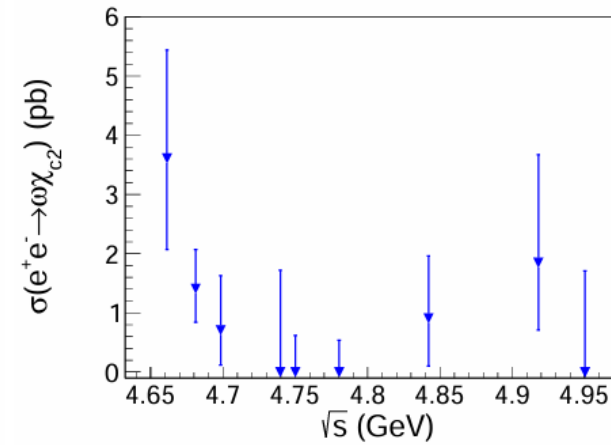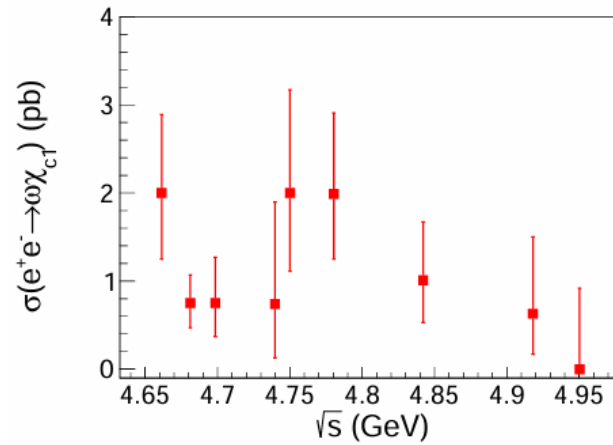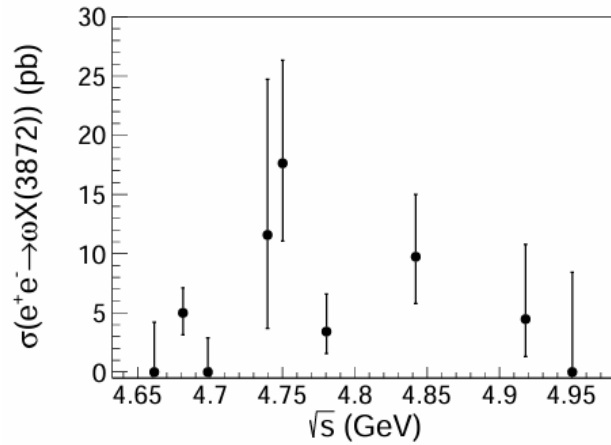PRL130, 151904 (2023)

4.66~4.95 GeV

$4.7 fb^{-1}$

➤ New X(3872) production process (7.8σ)

➤ May be from decays of some non-trivial structures

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\mathrm{int}}$(pb^{-1})	N_{sig}	$\epsilon(1+\delta)$ (%)	σ^{B}(pb)	$\sigma_{\mathrm{up}}^{\mathrm{B}}$(pb)	Significance
4.661	529.63	$0.33^{+1.36}_{-0.33}$	28.3	$0.5^{+2.1}_{-0.5} \pm 0.1 \pm 0.2$	5.6	-
4.682	1669.31	$8.00^{+3.34}_{-2.68}$	24.6	$4.6^{+1.9}_{-1.5} \pm 0.4 \pm 1.5$	11.5	3.4σ
4.699	536.45	$0.00^{+0.95}_{-0.00}$	27.0	$0.0^{+1.6}_{-0.0} \pm 0.0 \pm 0.0$	3.3	-
4.740	164.27	$1.67^{+1.77}_{-1.10}$	21.8	$10.9^{+11.6}_{-7.2} \pm 1.0 \pm 3.5$	40.6	1.0σ
4.750	367.21	$5.00^{+2.58}_{-1.92}$	22.4	$14.2^{+7.4}_{-5.5} \pm 1.4 \pm 4.5$	38.2	3.1σ
4.781	512.78	$1.00^{+1.36}_{-0.70}$	31.6	$1.5^{+2.0}_{-1.0} \pm 0.2 \pm 0.5$	6.5	0.7σ
4.843	527.29	$4.67^{+2.58}_{-1.92}$	26.7	$7.8^{+4.3}_{-3.2} \pm 0.7 \pm 2.5$	21.1	2.6σ
4.918	208.11	$1.00^{+1.36}_{-0.70}$	22.6	$5.0^{+6.8}_{-3.5} \pm 0.4 \pm 1.6$	21.7	0.7σ
4.951	160.37	$0.00^{+0.95}_{-0.00}$	20.4	$0.0^{+6.8}_{-0.0} \pm 0.0 \pm 0.0$	14.7	-

X(3872) production > 4.6 GeV

$$R_{\gamma J/\psi/\pi^+\pi^- J/\psi} \equiv \frac{\mathcal{B}(X(3872) \to \gamma J/\psi)}{\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)}$$

Experiment	$R_{\gamma J/\psi/\pi\pi J/\psi}$
$e^+e^- \to \gamma X(3872)$ BESIII	0.79 ± 0.28
$B^\pm \to K^\pm X(3872)$ Belle	0.21 ± 0.06
$e^+e^- \to \omega X(3872)$ This work	$0.38 \pm 0.20 \ (< 0.83)$
Average	0.25 ± 0.06

➤ $\sigma_{\omega X(3872)} / \sigma_{\omega \chi_{c1}} = 5.2 \pm 1.0 \pm 1.9$

➤ $\sigma_{\omega X(3872)} / \sigma_{\omega \chi_{c2}} = 5.5 \pm 1.1 \pm 2.4$

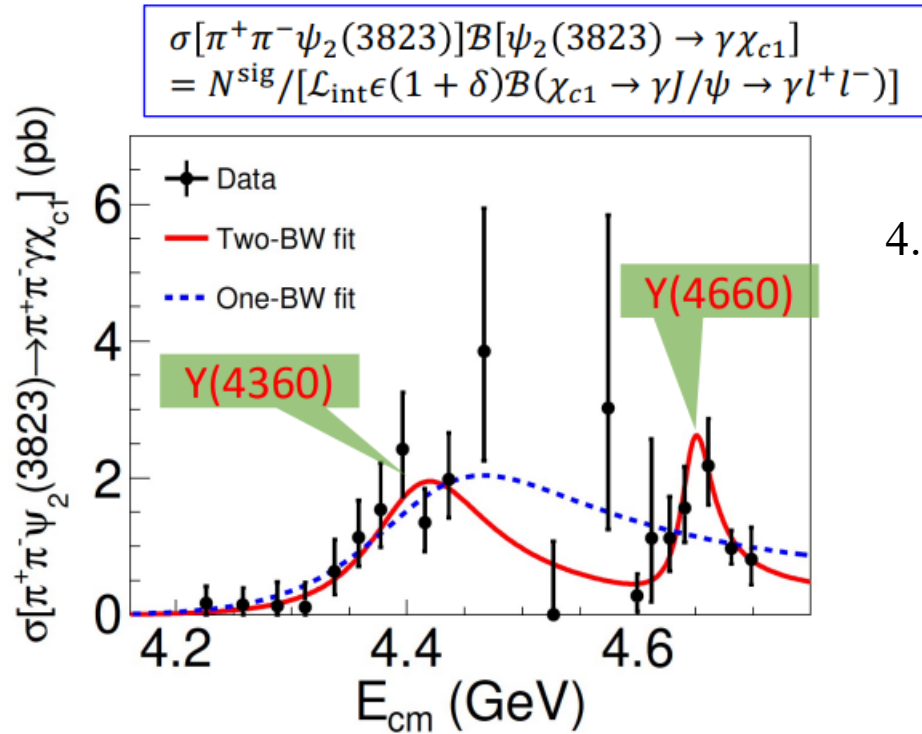➤ $\sigma_{\phi X(3872)} / \sigma_{\phi \chi_{c1}} < 9$ @ 90% CL

➤ Help constrain the possible $\chi_{c1}(2P)$ component in the $X(3872)$ wave function.

$$\sigma_{\gamma X(3872)} / \sigma_{\omega X(3872)} < 0.23 \text{ @ 90\% CL}$$

Observation of $e^+ e^- \rightarrow \pi^+\pi^- \psi_2(3823)$

$$\sigma[\pi^+\pi^-\psi_2(3823)]\mathcal{B}[\psi_2(3823) \rightarrow \gamma\chi_{c1}]$$
$$= N^{\text{sig}}/[\mathcal{L}_{\text{int}}\epsilon(1+\delta)\mathcal{B}(\chi_{c1} \rightarrow \gamma J/\psi \rightarrow \gamma l^+l^-)]$$

4.23~4.70 GeV

11.3 fb^{-1}

Parameters	Solution I	Solution II
$M[R_1]$	$4406.9 \pm 17.2 \pm 4.5$	
$\Gamma_{\text{tot}}[R_1]$	$128.1 \pm 37.2 \pm 2.3$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_1}\mathcal{B}_2$	$0.36 \pm 0.10 \pm 0.03$	$0.30 \pm 0.09 \pm 0.03$
$M[R_2]$	$4647.9 \pm 8.6 \pm 0.8$	
$\Gamma_{\text{tot}}[R_2]$	$33.1 \pm 18.6 \pm 4.1$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_2}\mathcal{B}_2$	$0.24 \pm 0.07 \pm 0.02$	$0.06 \pm 0.03 \pm 0.01$
ϕ	$267.1 \pm 16.2 \pm 3.2$	$-324.8 \pm 43.0 \pm 5.7$

✓ Resonance structures $> 5\sigma$
- Both for the two-BW and the One-BW hypotheses
- First observation of Y-state $\rightarrow D$-wave charmonium!

$\pi\pi\psi_2(3823)$ is the second decay channel of $Y(4660)$ [the first one is $\pi\pi\psi(2S)$]
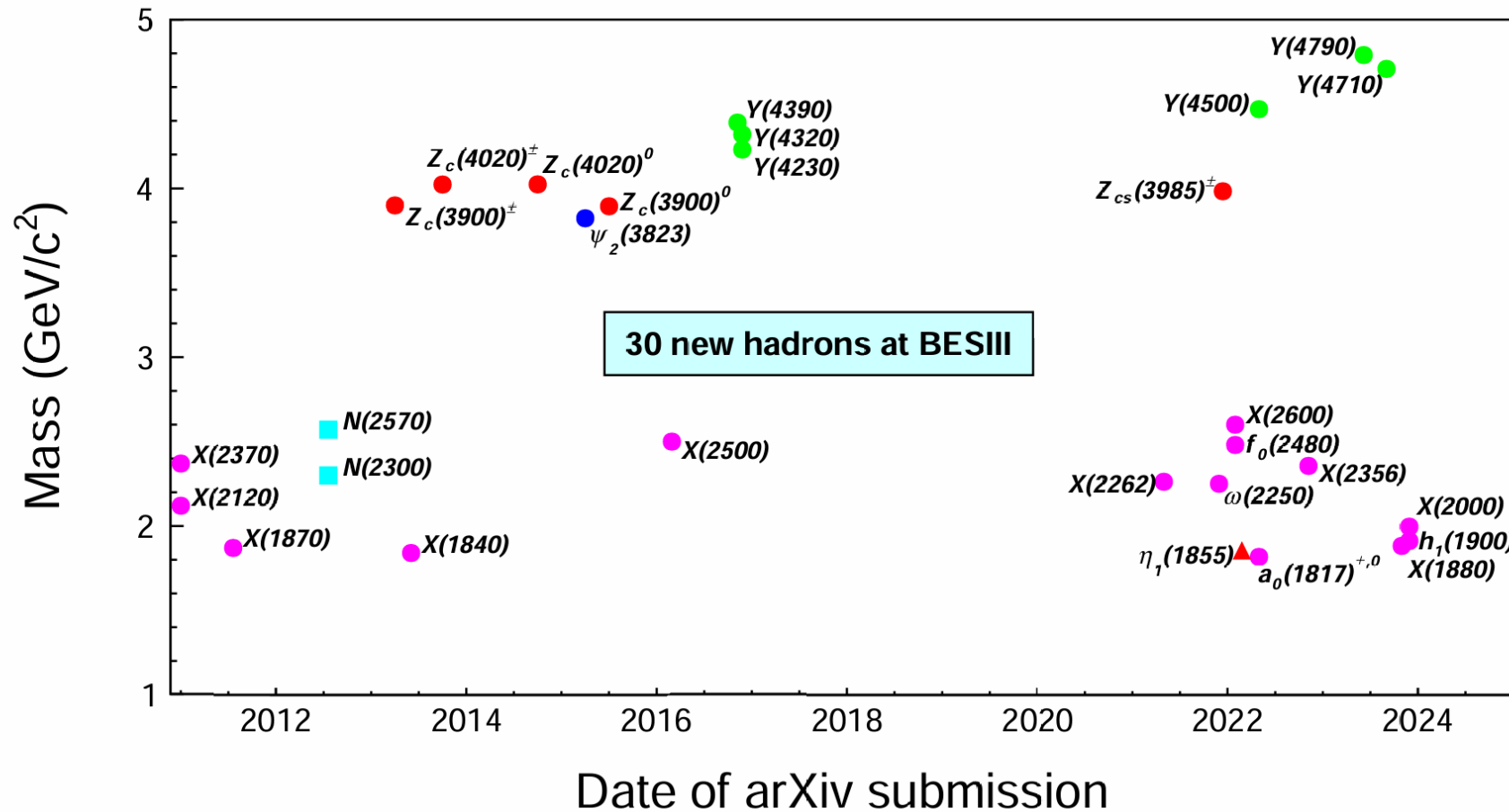
- Inconsistent with many interpretations of Y(4660):
  - $f_0(980)\psi(2S)$ hadron molecule (PLB 665, 26 (2018))
  - $\Sigma_c^0\bar{\Sigma}_c^0$ baryonium (J. Phys. G 35, 075008 (2008))
  - excitation of Y(4260) (PRD 89, 114010 (2014))

$$\frac{\Gamma[\psi(4660)\rightarrow\pi^+\pi^-\psi_2(3823)]}{\Gamma[\psi(4660)\rightarrow\pi^+\pi^-\psi(2S)]} \sim 20\%$$
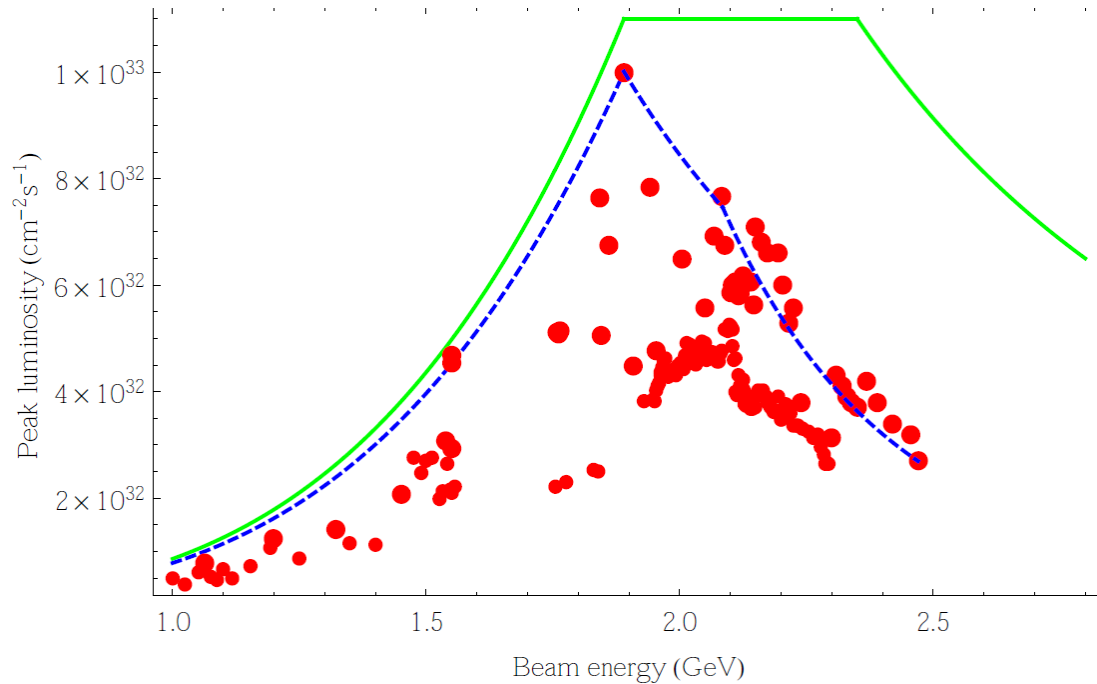
11

New hadrons discovered at BESIII

12 charmonium(-like) state

BEPCII-U

From Y. Zhang@Lanzhou

BEPCII-U vs BEPCII

- Luminosity * 3 @ 2.35 GeV

- Highest Beam Energy: 2.47 GeV -> 2.8 GeV

- Commissioning of BEPCII-U on 2025.01.01

Summary

- We reported cross-section measurement results including hidden charm final states at BESIII

- BESIII have a excellent performance about the charmonium-like states studies

- Upcoming upgrades on BEPCII and BESIII

  - Much large peak luminosity

  - Higher precision for measurements

Thank you