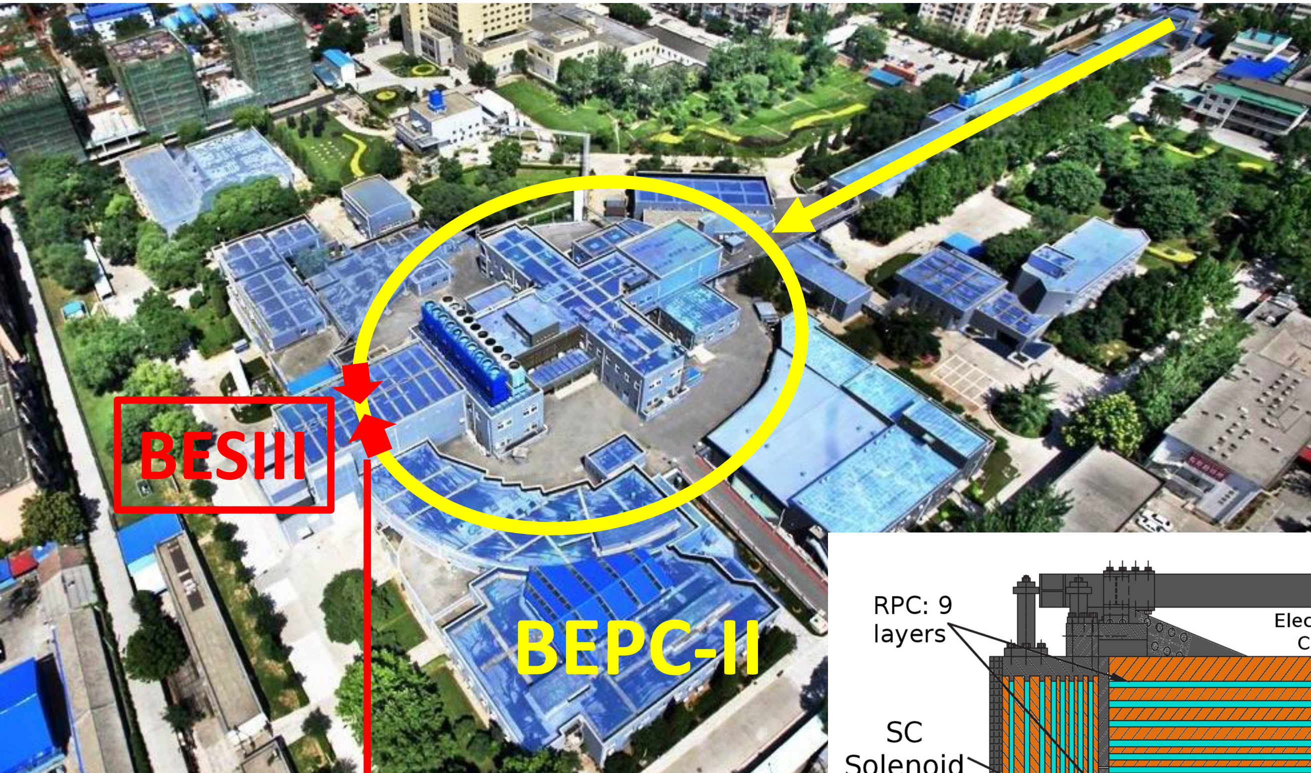
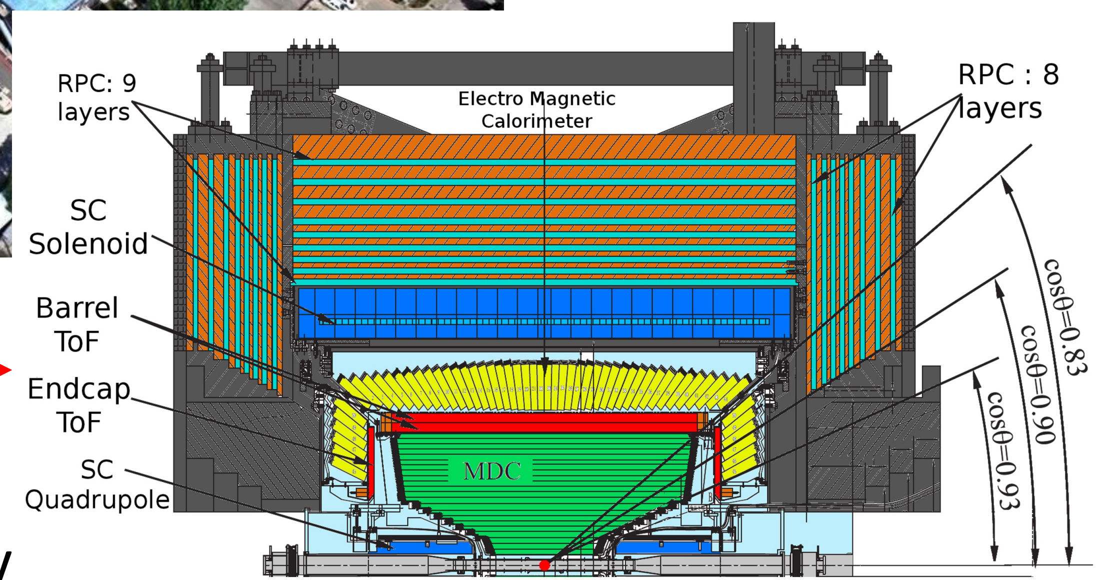
The cross section measurements of electron positron annihilation into hidden charm

Yong Xie
(on behalf of the BESIII collaboration)

PhiPsi2022, Shanghai

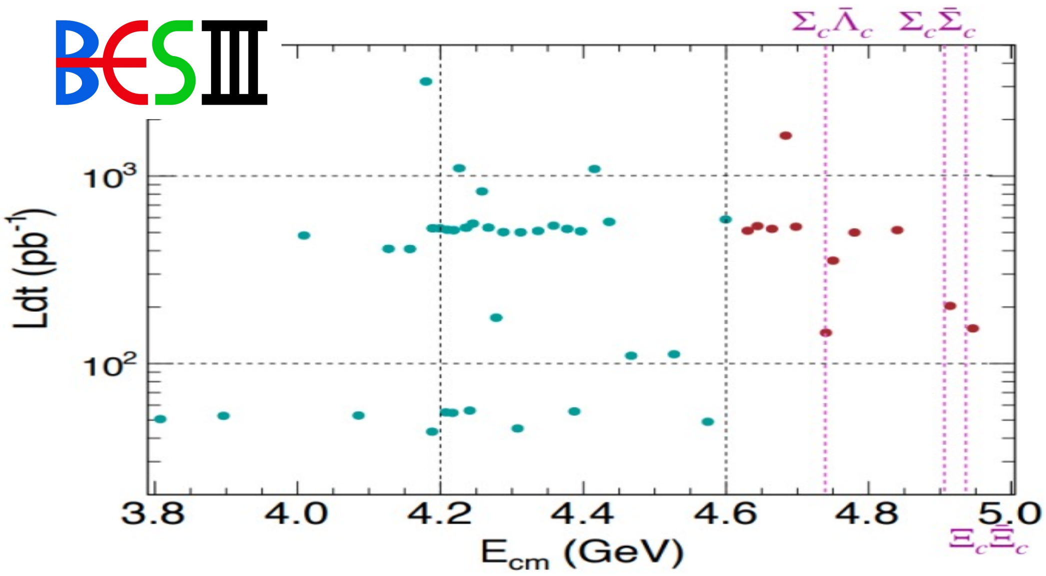
The BEPCII and BESIII

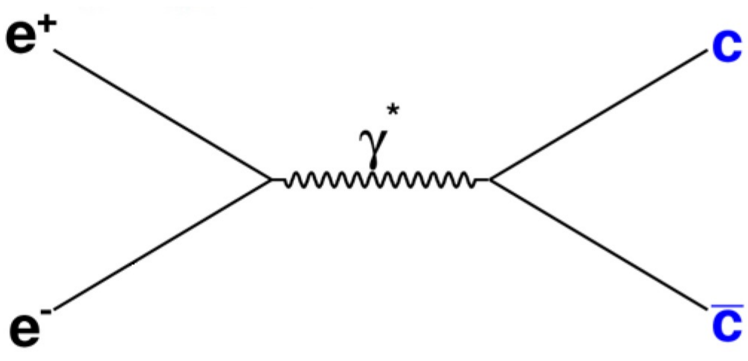




- Beam energy: 1.0 – 2.47 GeV
- Luminosity: $1 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 3.773 GeV

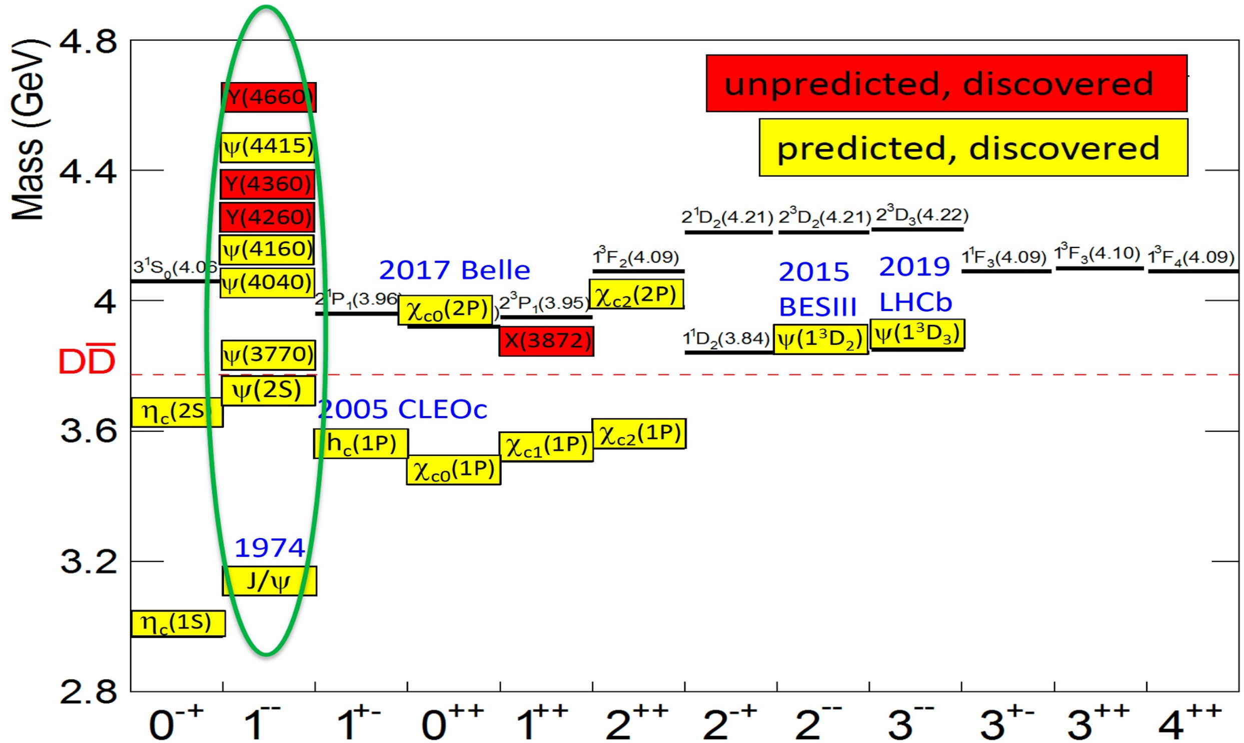
BESIII data sample





- This talk will focus on the $23\ \mathrm{fb}^{-1}$ scan data sample at 3.8 – 5 GeV for the study of the vector charmonium(like)-states, which can be directly produced by e^+e^- annihilation.

The Y-states



✓ Conventional charmonium states above threshold ($\psi(3770)$…)

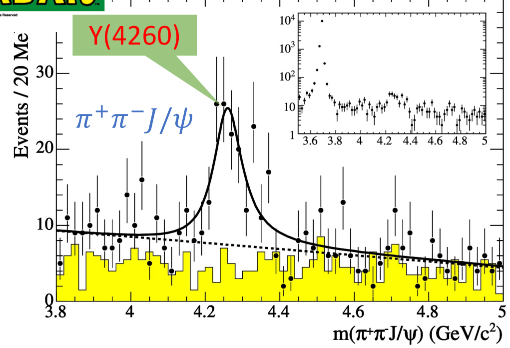
- Agree with the expectation of the quark potential model: mainly decay into open-charm mesons ($\mathrm{D}^{(*)}\overline{\mathrm{D}}^{(*)}$)

✓ Charmonium-like Y-states (Y(4260)…)

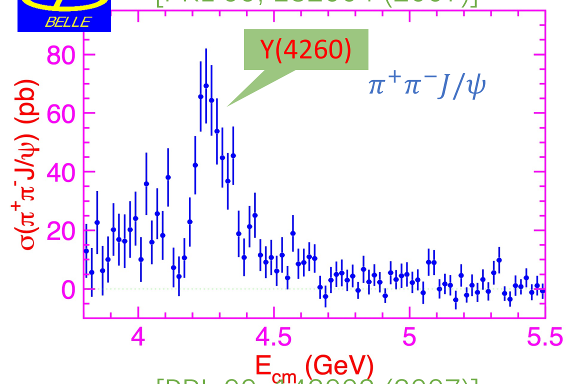
- disagree with the simple ccbar scenario: widely decay into hidden-charm mesons (ccbar: like J/ψ, $\psi(2S)$…)

The Y-states

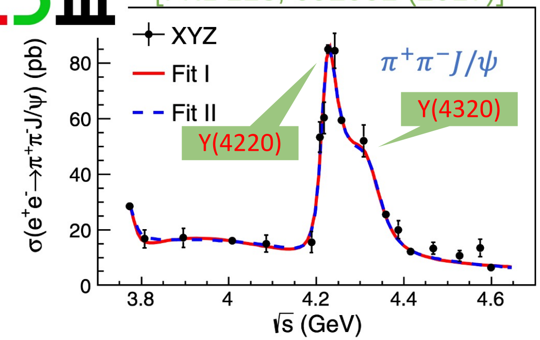
[PRL 95, 142001 (2005)]



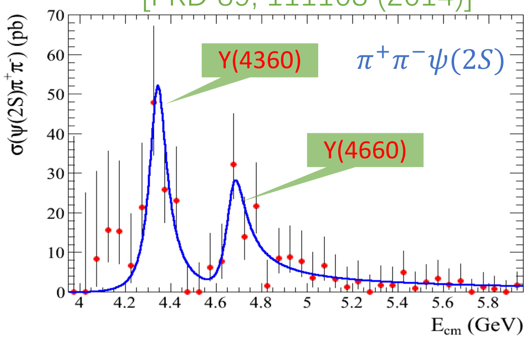
[PRL 99, 182004 (2007)]



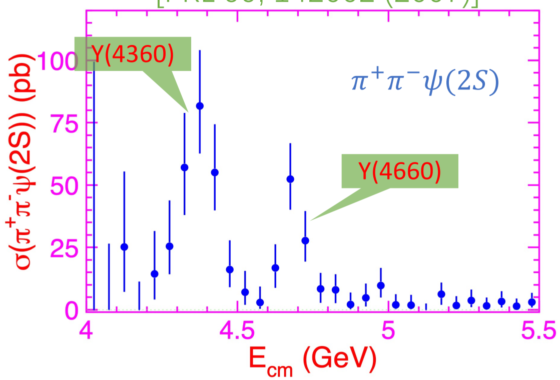
[PRL 118, 092001 (2017)]



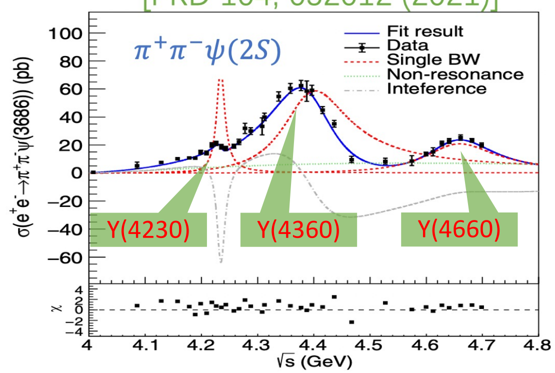
[PRD 89, 111103 (2014)]



[PRL 99, 142002 (2007)]



[PRD 104, 052012 (2021)]



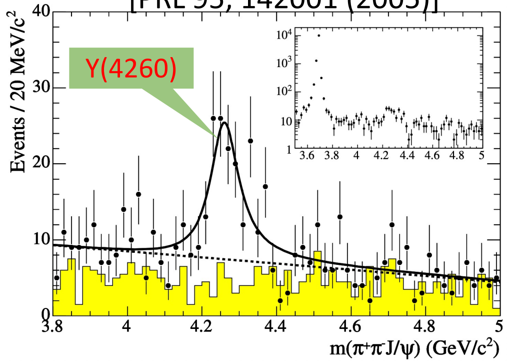
- ✓ Many resonance structures in hidden-charm processes, identified as vector Y-states
- ✓ Since they disagree with quark model, then what are these Y-states?
  - Hadronic molecules?
  - Baryonia?
  - Tetraquark states? ...

More studies are still needed!

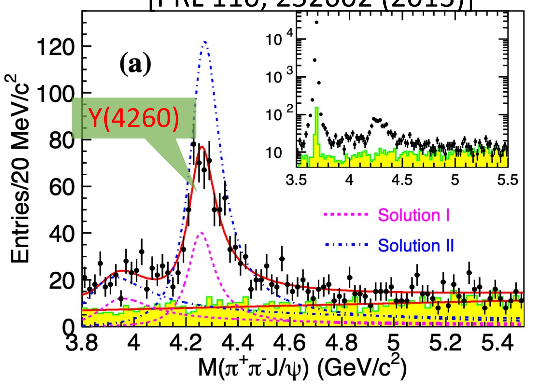
Recent BESIII measurements on $e^+e^- \rightarrow \text{hidden charm}$

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

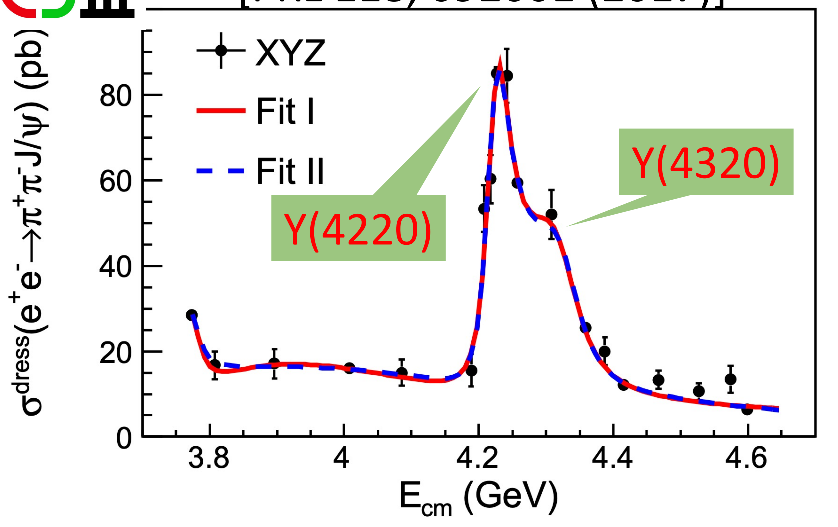
[PRL 95, 142001 (2005)]



[PRL 110, 252002 (2013)]



[PRL 118, 092001 (2017)]

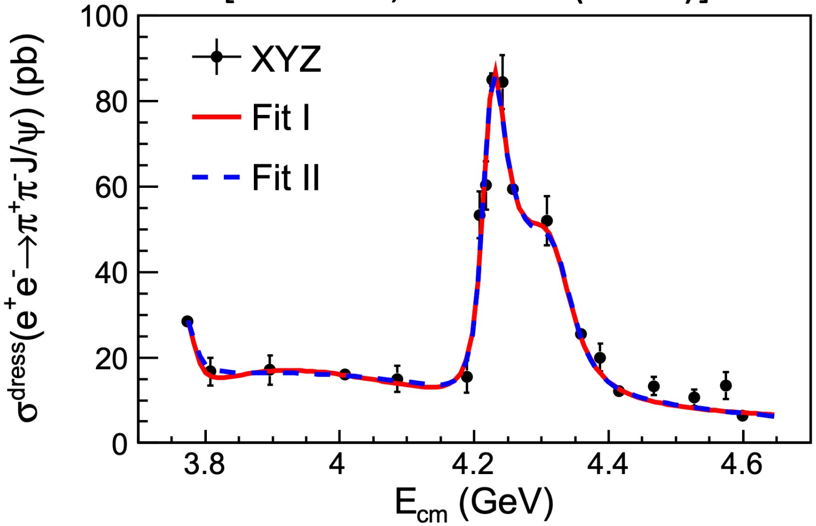


✓ The Y(4260) was firstly seen by BaBar, comfirmed by Belle

✓ Later split into two states Y(4220) and Y(4320) by BESIII

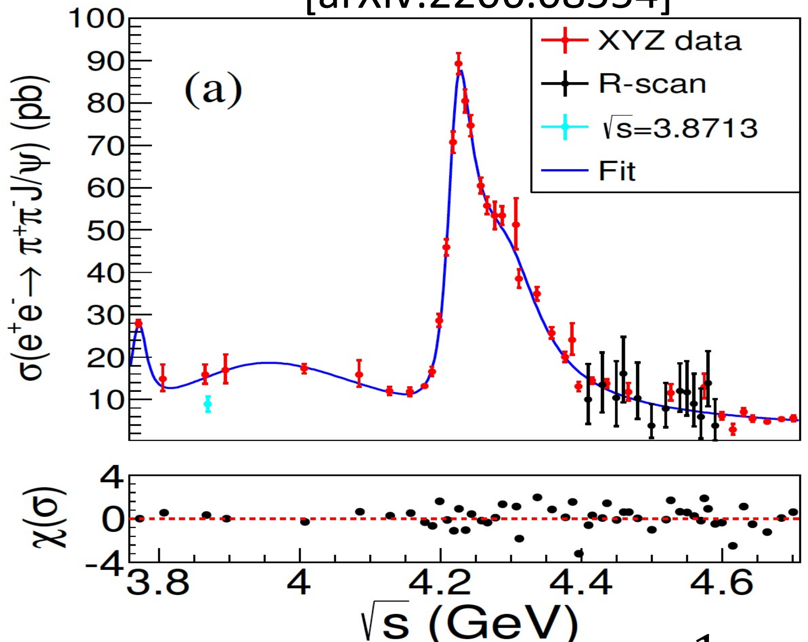
$e^+e^- \to \pi^+\pi^- J/\psi$

[PRL 118, 092001 (2017)]



Previous ($\mathcal{L}_{\text{int}} = 9\ \text{fb}^{-1}$)

[arXiv:2206.08554]



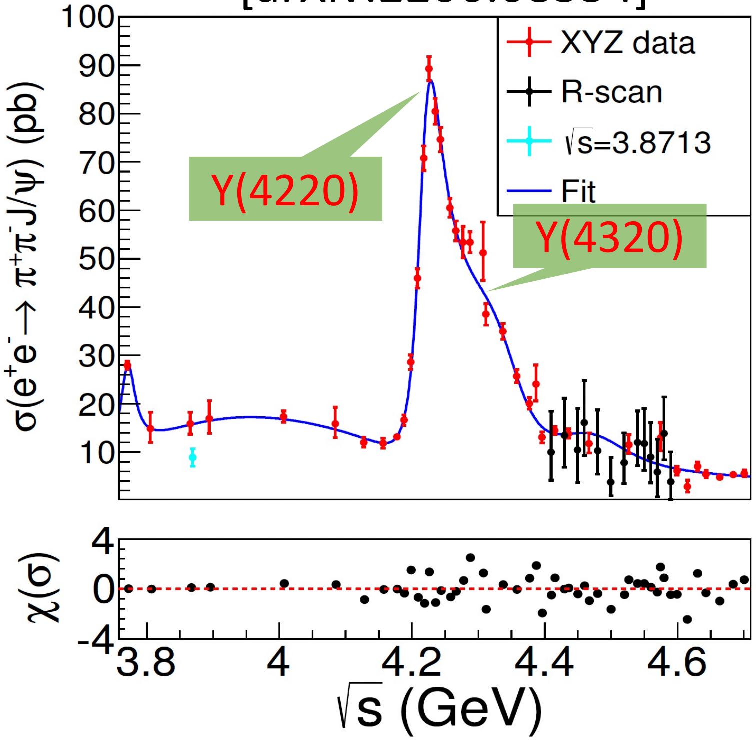
Now ($\mathcal{L}_{\text{int}} = 23\ \text{fb}^{-1}$)

- Much higher statistics
- Better MC simulation
- Enhanced tracking efficiency

➢ Improved precisions!

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

[arXiv:2206.08554]



✓ Fit model (sum of resonances):

$$\sigma_{\text{fit}}(\sqrt{s}) = |R_{\psi(3770)}(\sqrt{s})|^2 + \left|\sum_{i=0}^{n} R_i(\sqrt{s}) e^{j\phi_i}\right|^2$$

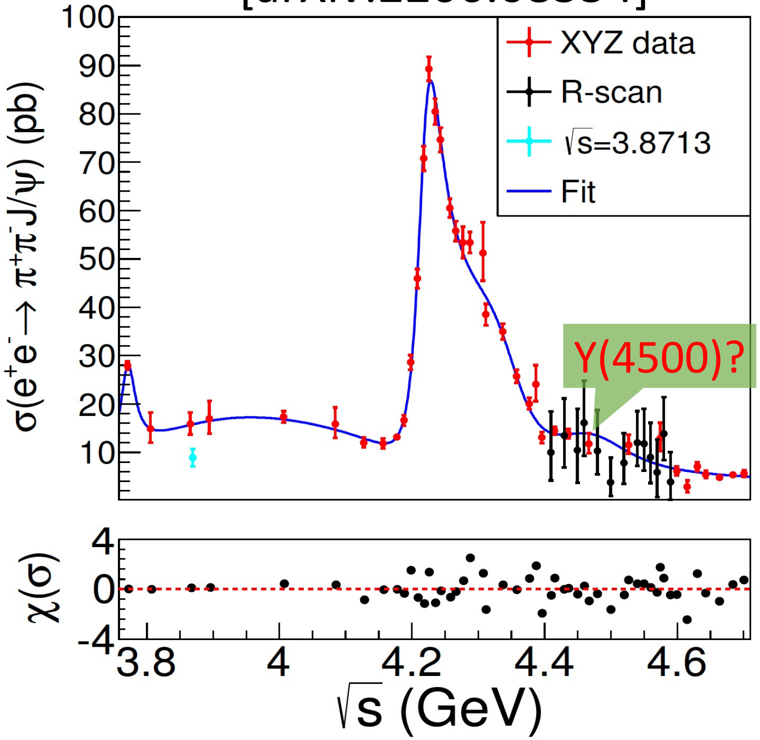
✓ Structure around 4 GeV better fit by a BW (than exp)

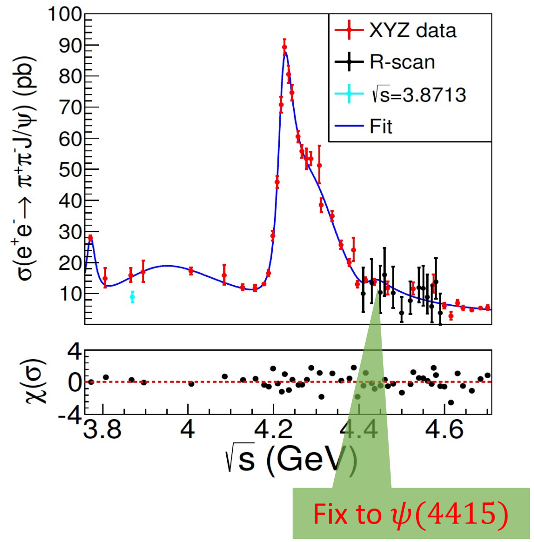
✓ The $Y(4220)$ and $Y(4320)$ are observed with $> 10\sigma$!

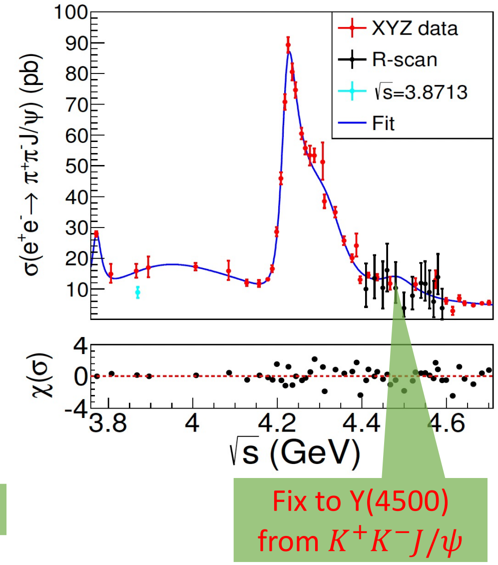
$M[Y(4220)] = 4221.4 \pm 1.5 \pm 2.0\ \text{MeV}/c^2$
$\Gamma[Y(4220)] = 41.8 \pm 2.9 \pm 2.7\ \text{MeV}$
$M[Y(4320)] = 4298 \pm 12 \pm 26\ \text{MeV}/c^2$
$\Gamma[Y(4320)] = 127 \pm 17 \pm 10\ \text{MeV}$

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

[arXiv:2206.08554]







✓ Enhancement near 4.5 GeV with a 3σ evidence!

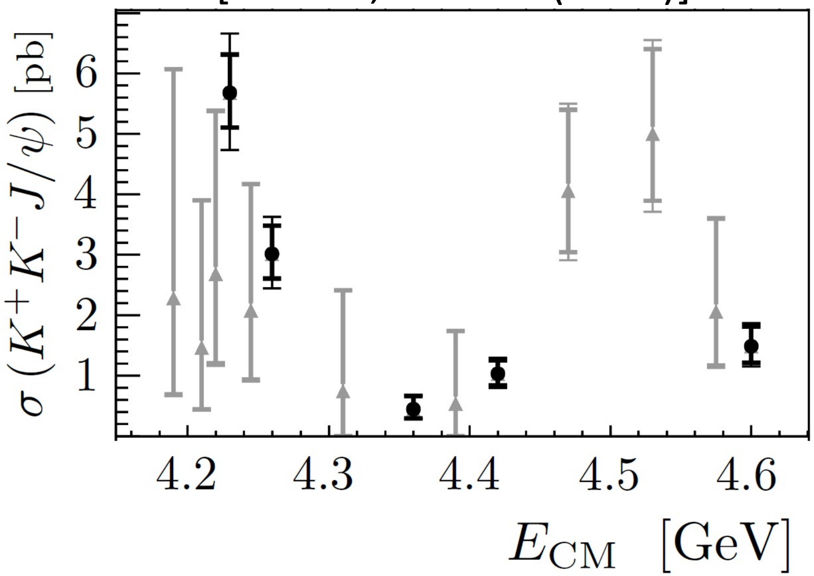
$M(R) = 4471.1 \pm 36.2 \mathrm{MeV}/c^2$
$\Gamma(R) = 159.7 \pm 97.0 \mathrm{~MeV}$

The new Y(4500)?

✓ Also tried to fix it to $\psi(4415)$, or Y(4500) from K^+K^-J/ψ [arXiv:2204.07800]

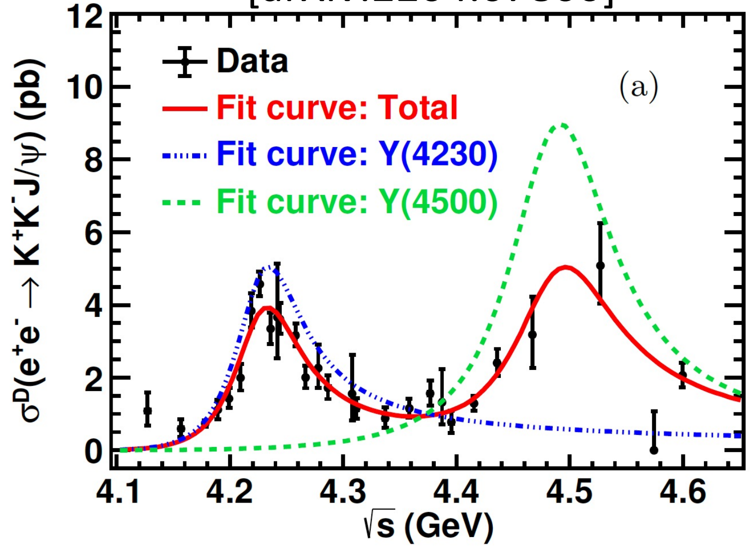
$e^+e^- \to K^+K^-J/\psi$

[PRD 97, 071101 (2018)]



Previous ($\mathcal{L}_{\text{int}} = 4.7\ \text{fb}^{-1}$)

[arXiv:2204.07800]



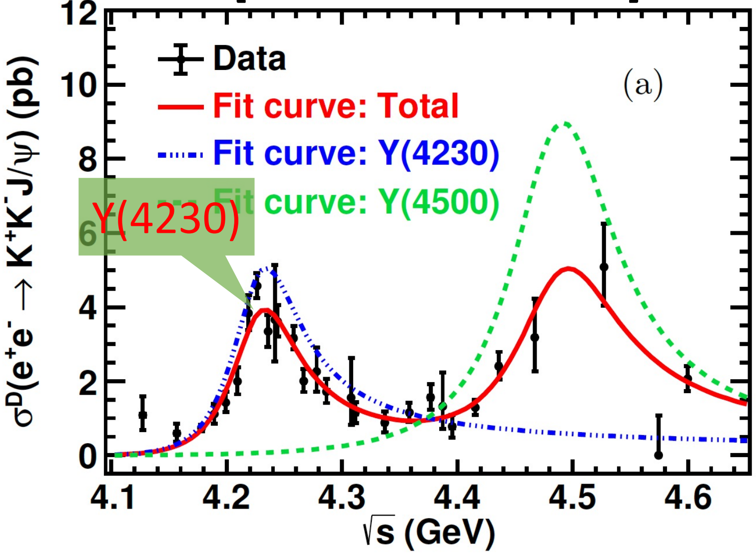
Now ($\mathcal{L}_{\text{int}} = 15.6\ \text{fb}^{-1}$)

- Much higher statistics
- Partial-reconstruction method

➢ Improved precisions!

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

[arXiv:2204.07800]



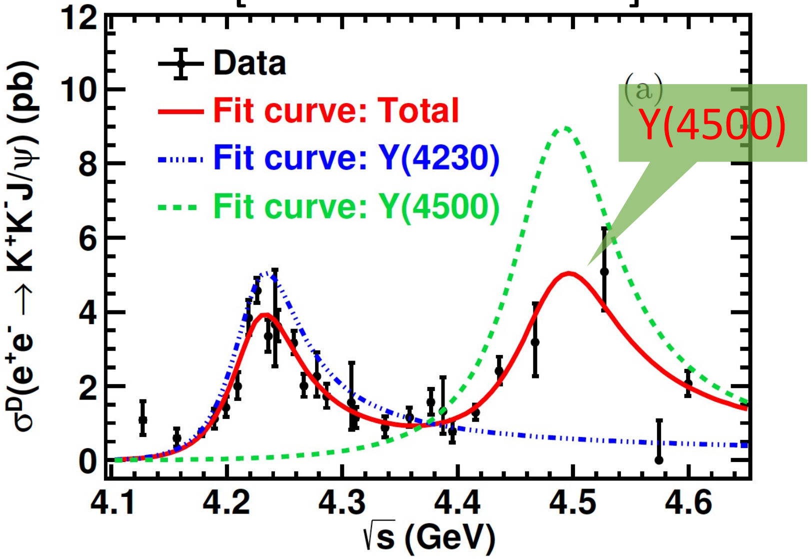
✓ First observation of $Y(4230) \to K^+K^-J/\psi$!

$$0.02 < \frac{\mathcal{B}(Y(4230) \to K^+K^-J/\psi)}{\mathcal{B}(Y(4230) \to \pi^+\pi^-J/\psi)} < 0.26$$

	Parameters	Solution I	Solution II
$Y(4230)$	M(MeV)	$4225.3 \pm 2.3 \pm 21.5$	
	Γ_{tot}(MeV)	$72.9 \pm 6.1 \pm 30.8$	
	$\Gamma_{ee}\mathcal{B}$(eV)	$0.42 \pm 0.04 \pm 0.15$	$0.29 \pm 0.02 \pm 0.10$
$Y(4500)$	M(MeV)	$4484.7 \pm 13.3 \pm 24.1$	
	Γ_{tot}(MeV)	$111.1 \pm 30.1 \pm 15.2$	
	$\Gamma_{ee}\mathcal{B}$(eV)	$1.35 \pm 0.14 \pm 0.06$	$0.41 \pm 0.08 \pm 0.13$
phase angle	φ(rad)	$1.72 \pm 0.09 \pm 0.52$	$5.49 \pm 0.35 \pm 0.58$

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

[arXiv:2204.07800]



✓ First observation of $Y(4500)$ with $> 8\sigma$!
Also an evidence in $e^+e^- \to \pi^+\pi^-J/\psi$

✓ Consistent with some theoretical predictions:

- 5S-4D mixing scheme [PRD 99,114003 (2019)]
- heavy-antiheavy hadronic molecules model [ProgrPhys 41,65(2021)]
- Lattice QCD result for a $(cs\bar{c}\bar{s})$ state [PRD 73,094510 (2006)]

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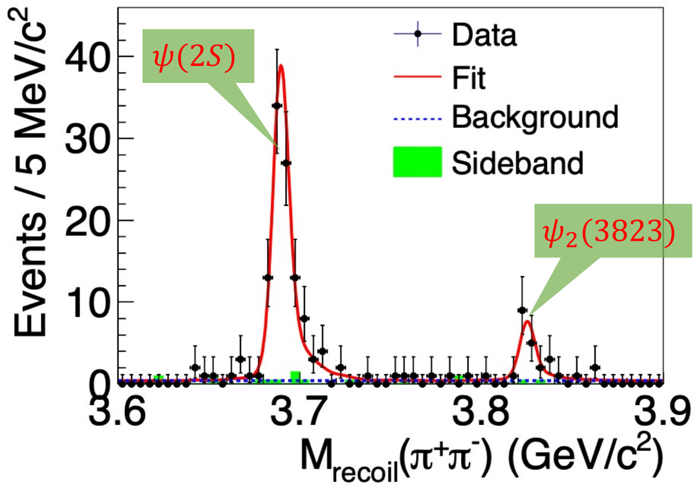
$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

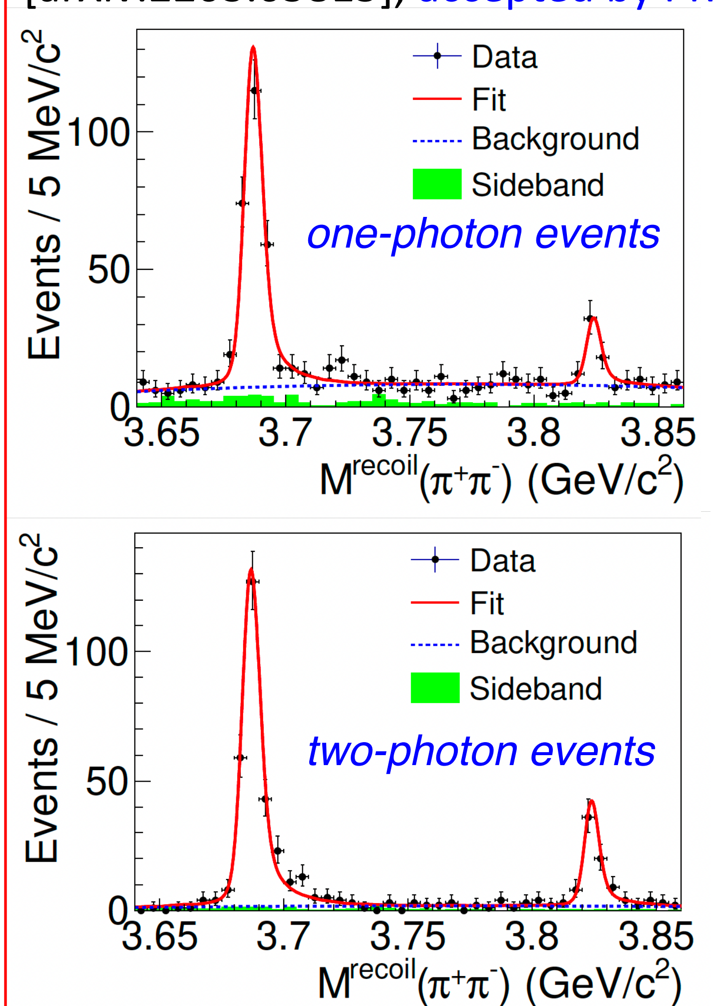
Previous

[PRL 115, 011803 (2015)]



Now

[arXiv:2203.05815], accepted by PRL



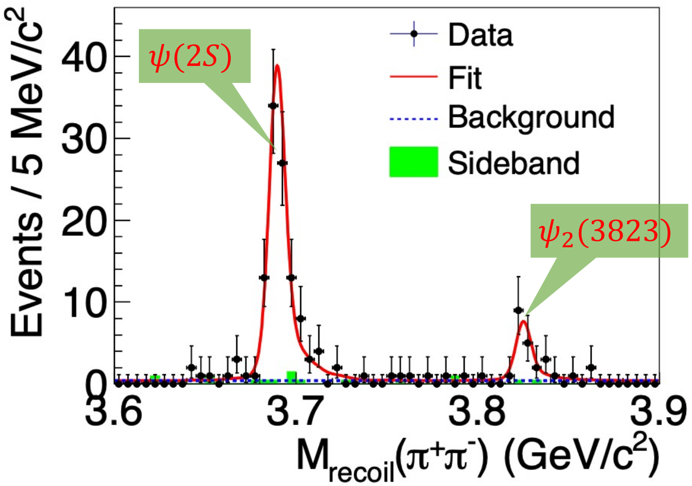
- Higher statistics ($4.7\ \text{fb}^{-1} \to 11.3\ \text{fb}^{-1}$)
- Partial-reconstruction by missing a photon (~2 times efficiency of the full-reconstruction)
- Low background level

➢ Improved precisions!

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

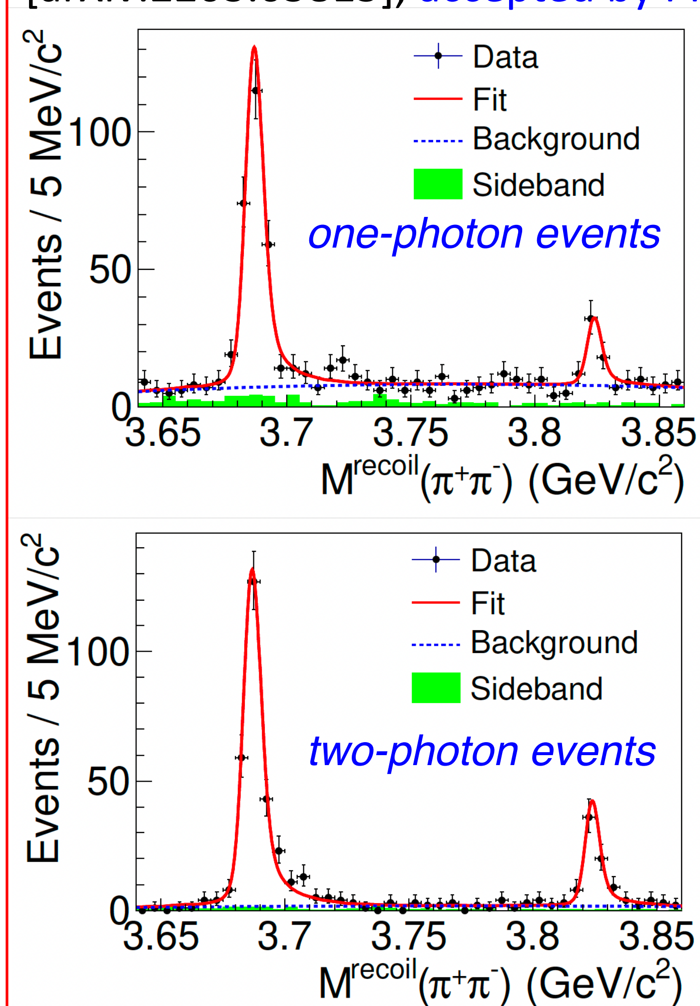
Previous

[PRL 115, 011803 (2015)]



Now

[arXiv:2203.05815], accepted by PRL

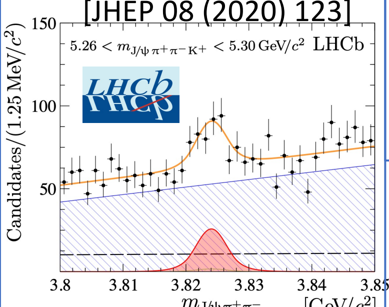


✓ Mass and width of $\psi_2(3823)$:

$$M[\psi_2(3823)] = 3823.12 \pm 0.43 \pm 0.13\ \text{MeV}/c^2$$
$$\Gamma[\psi_2(3823)] < 2.9\ \text{MeV at 90\% C.L.}$$

Most precise to date!

[JHEP 08 (2020) 123]



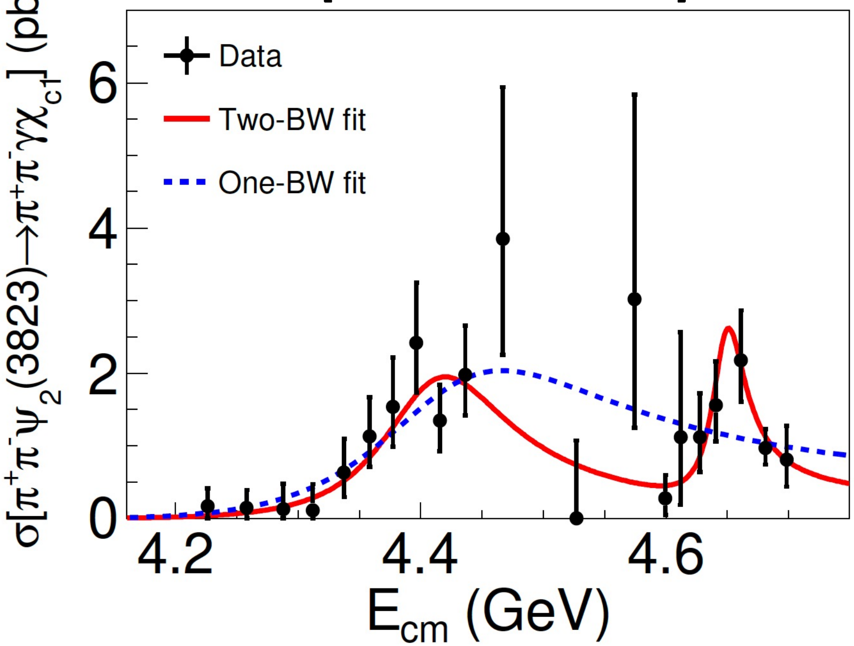
Better than LHCb:

$M[\psi_2(3823)] - M[\psi(2S)]$
$= 137.98 \pm 0.53 \pm 0.14\ \text{MeV}/c^2$

$\Gamma[\psi_2(3823)] < 5.2$ MeV at 90% C.L.

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

[arXiv:2203.05815]



Cross section measurement

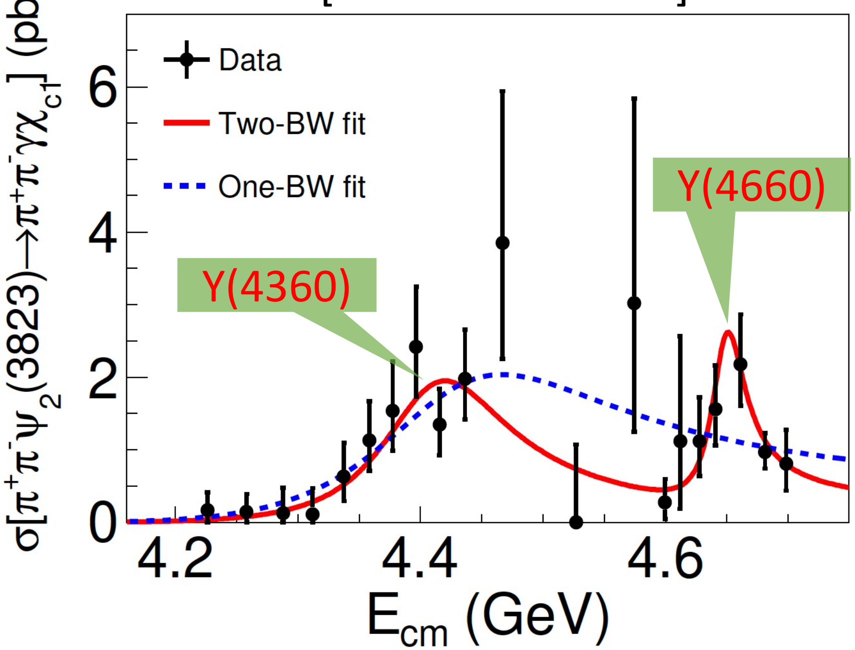
✓ Observation of resonance structures with $> 5\sigma$ over continuum

- Both for the two-BW and the One-BW hypotheses

✓ First observation of Y-states → D-wave charmonium!

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

[arXiv:2203.05815]



Parameters in two-BW hypothesis:

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

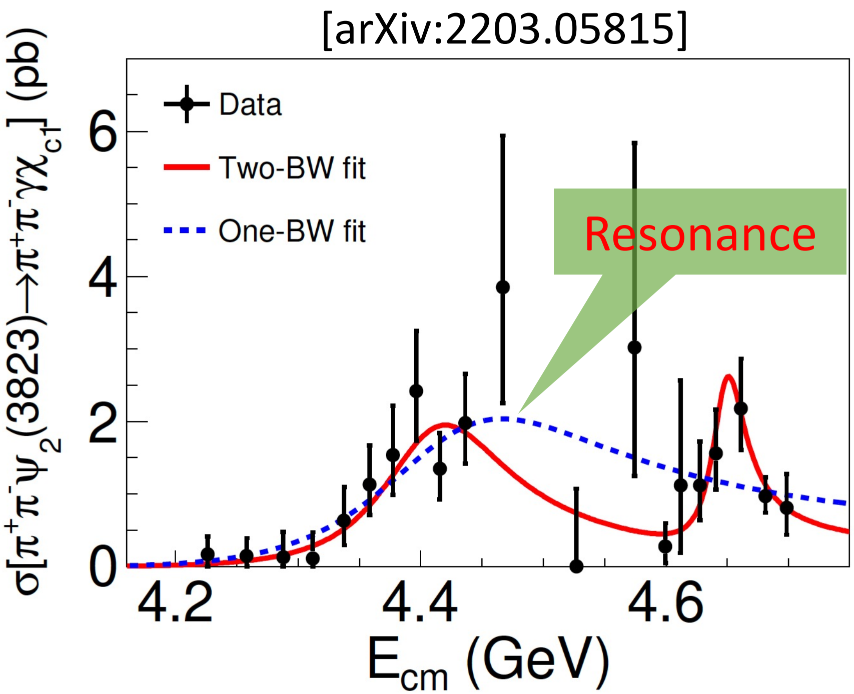
✓ Two-BW hypothesis:

- Consistent with $Y(4360)$ and $Y(4660)$

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

- 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))

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

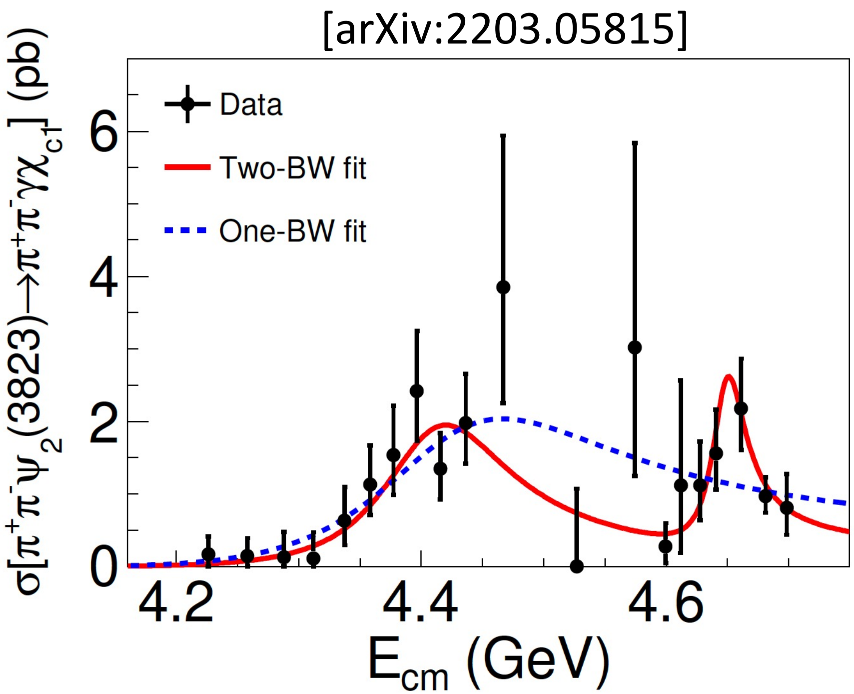


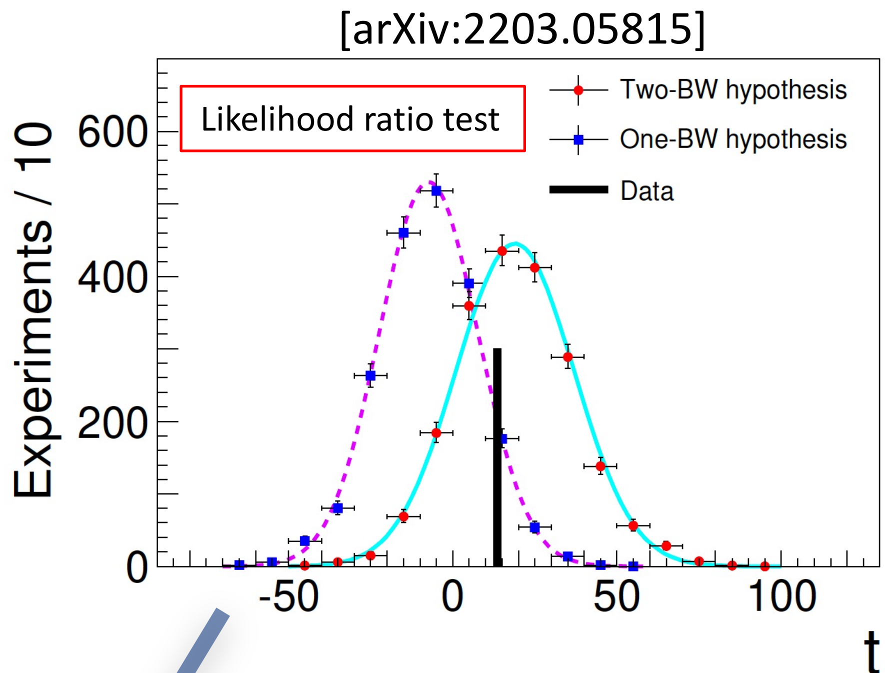
Parameters in one-BW hypothesis:

$M(R) = 4417.5 \pm 26.2 \pm 3.5\text{MeV}/c^2$
$\Gamma(R) = 245 \pm\ 48 \pm\ 13\ \text{MeV}$

✓ One-BW hypothesis:
- Large width, not observed before!

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

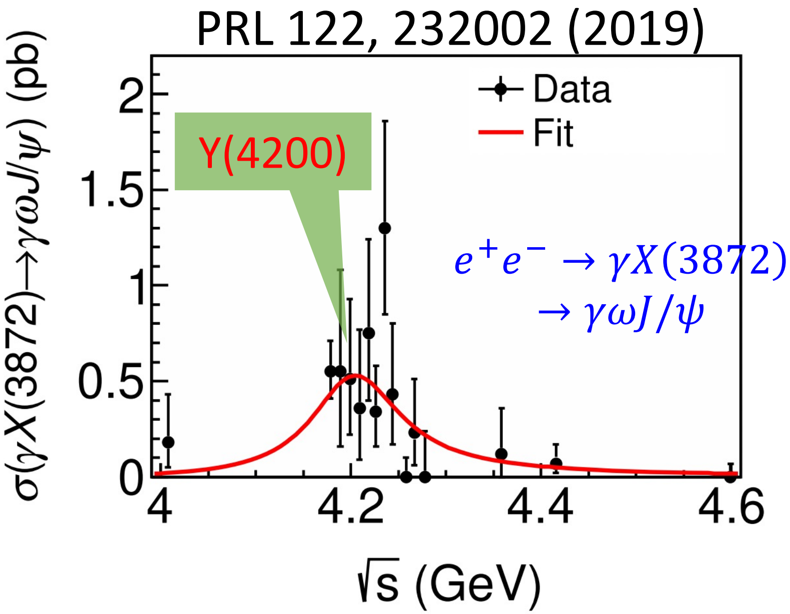


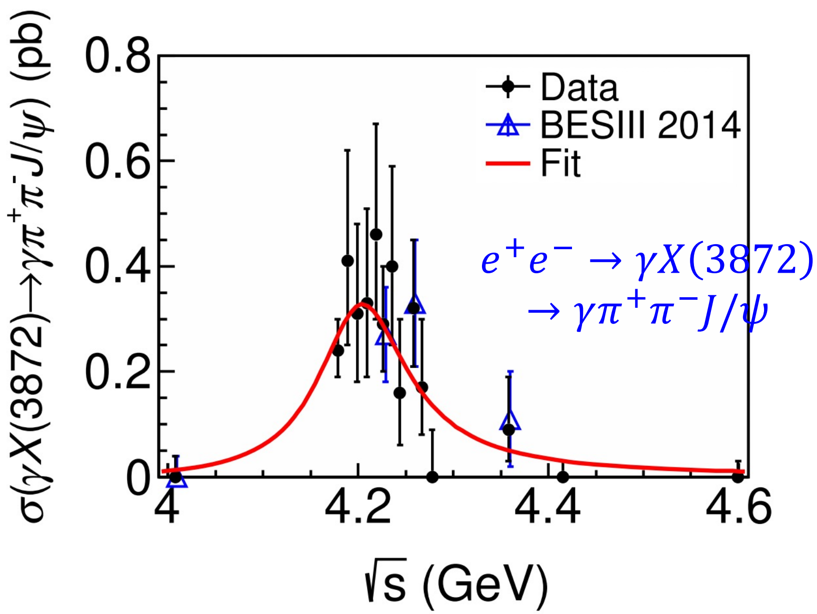


✓ $t = -2\ln\frac{\mathcal{L}_{1BW}}{\mathcal{L}_{2BW}}$ to discriminate between hypotheses:

- Data favor the two-BW hypothesis: $t = 13.6$
- Data disfavor the one-BW hypothesis by 1.7σ

Search for $X(3872) \to \pi^0\chi_{c0}, \pi\pi\chi_{c0}$

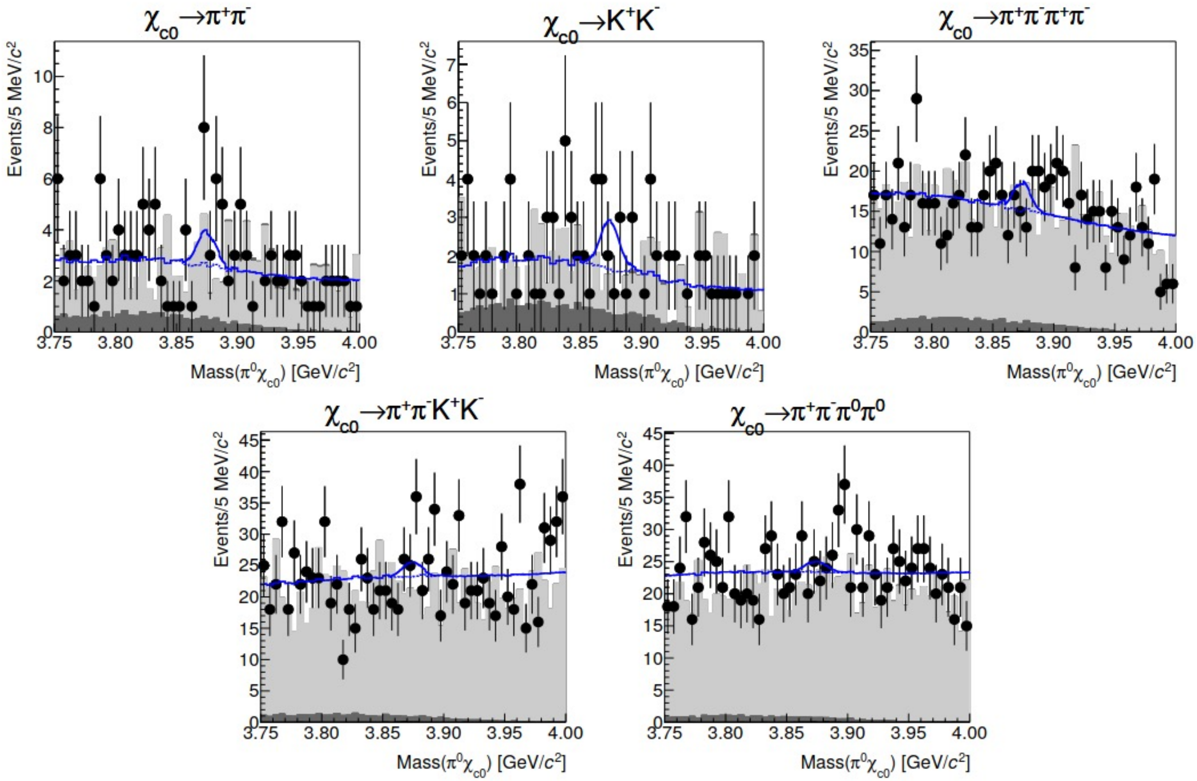




✓ The $X(3872)$ can be effectively produced in $e^+e^- \to \gamma X(3872)$ near 4.2 GeV.

Search for $X(3872) \to \pi^0\chi_{c0}, \pi\pi\chi_{c0}$

[PRD 105, 072009 (2022)]



No significant signal ($< 3\sigma$)
The upper limits are given

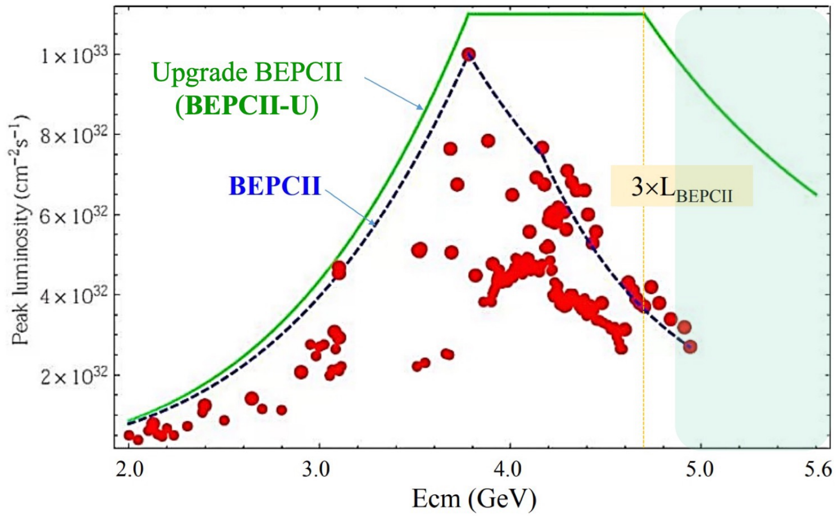
Ratio	90% C.L Upper Limit
$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^-J/\psi)}$	3.6
$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^0\chi_{c1})}$	4.5
$\frac{\mathcal{B}(X(3872)\to\pi^+\pi^-\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^-J/\psi)}$	0.56
$\frac{\mathcal{B}(X(3872)\to\pi^0\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^-J/\psi)}$	1.7

Summary

- ✓ The BESIII did a lot of efforts for studying the Y-states through the ($e^+e^- \to$ hidden charm) processes.

- ✓ Higher precisions (cross section, resonance parameters)
- ✓ New observations [the new $Y(4500)$ state; the new decay Y-states → D-wave charmonium]

- ✓ Even better measurements can be achieved with the upcoming upgrades on the BEPCII and BESIII.



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Thank you!