X(3872) and X states at BESⅢ

Hang Zhou
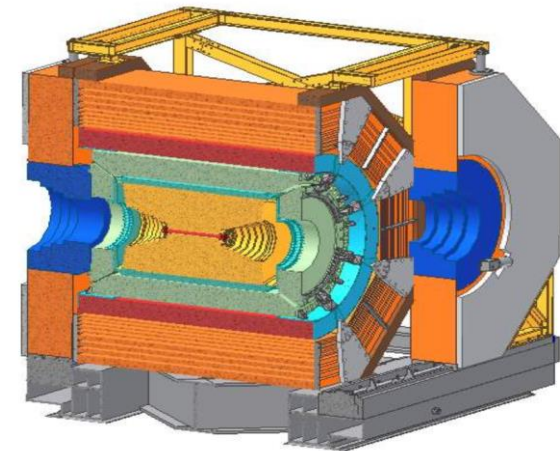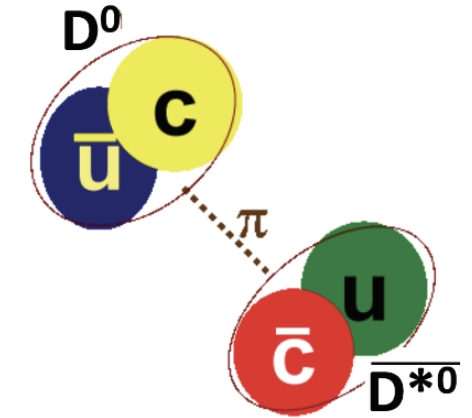
Shandong University

2021.05.15, Qingdao

Outline

- XYZ program at BESIII

- Production of X(3872) at BESIII

- Decay of X(3872) at BESIII

- Other X states at BESIII

- Future of BESIII

- Summary

Profile of X(3872)
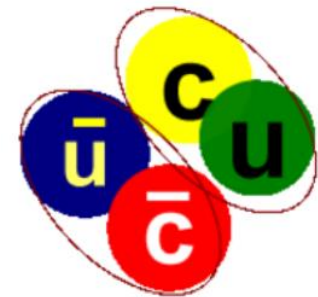
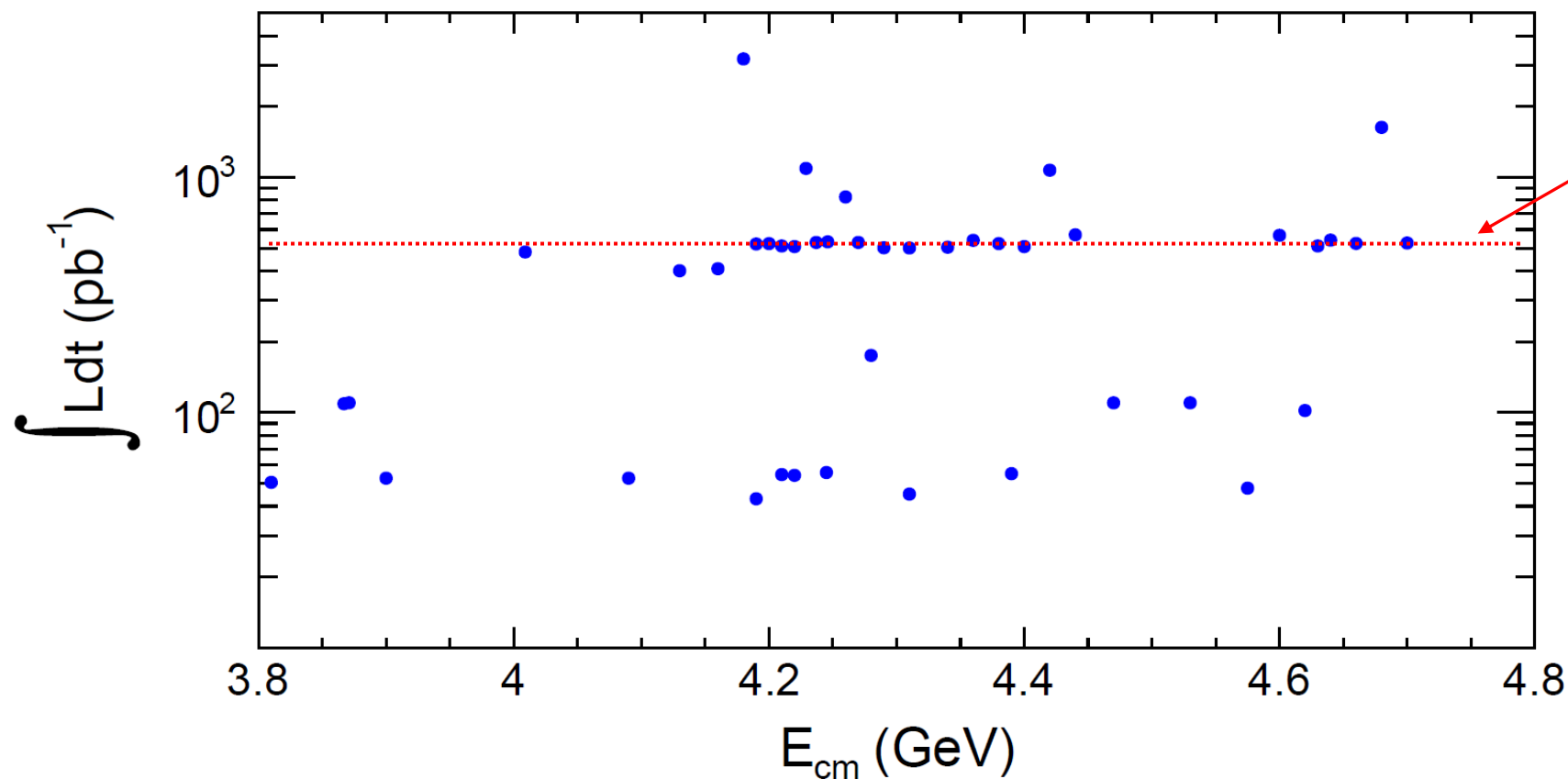|	
Name:	$X(3872)$ or $\chi_{c1}(3872)$
Mass:	3871.69 ± 0.17 MeV (very very close to $D^0 D^{*0}$ threshold)
Width:	$1.39 \pm 0.24 \pm 0.10$ MeV
J^{PC}:	1^{++}
Isospin:	0
Composition:	Yet unclear

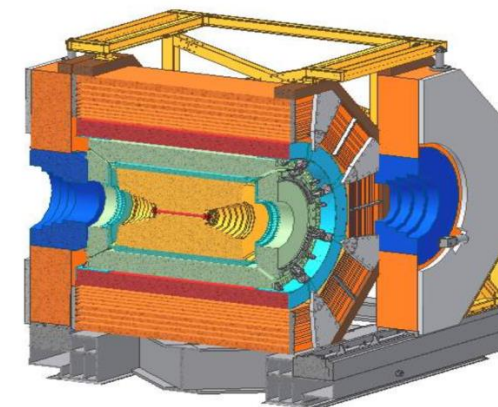

$D^0 - \overline{D^{*0}}$ "molecule"

...?

diquark - diantiquark
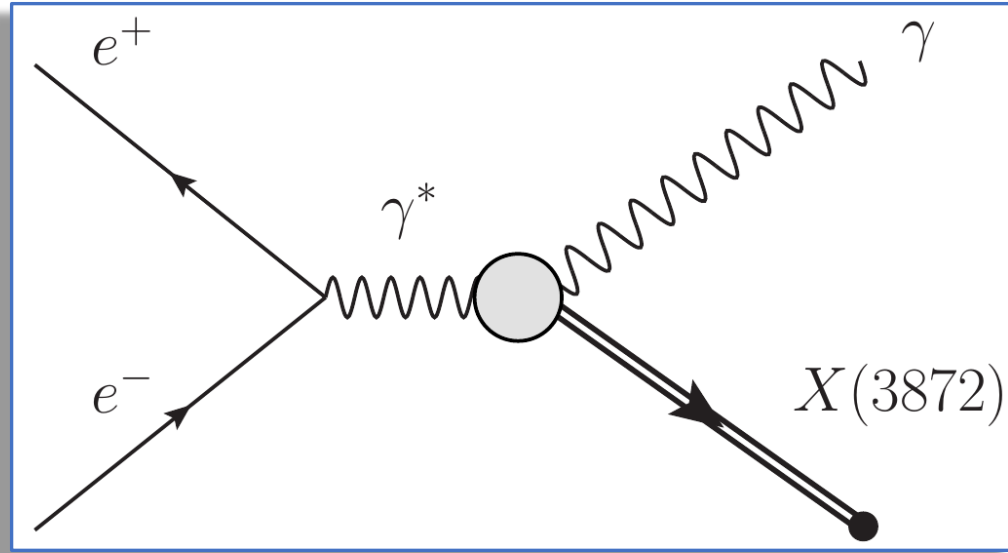
XYZ program at BESIII

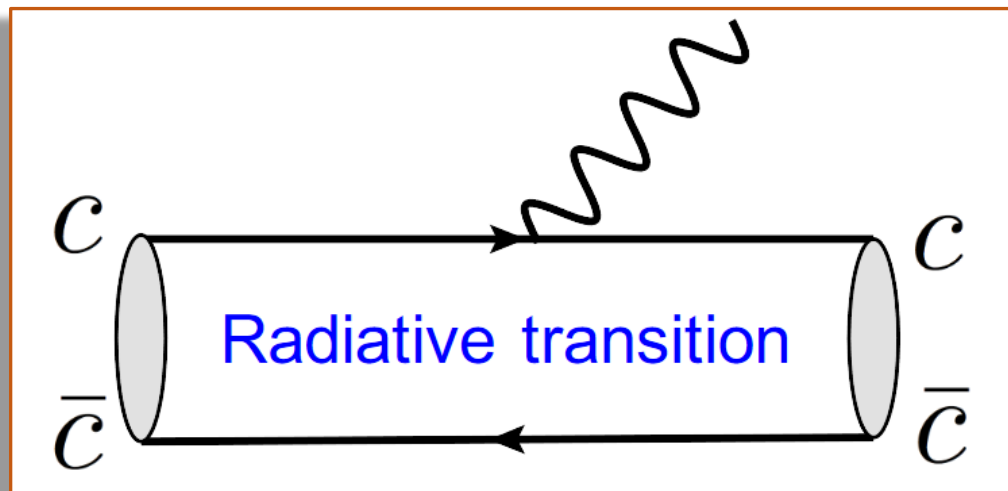
More data in late 2020-2021

- The world largest data samples of e^+e^- collision in **τ-charm** region
- Over **20 fb^{-1}** high luminosity scan data above 4.0 GeV for XYZ study
- Scan data with ~500pb^{-1}/10 MeV, continuedly data taking

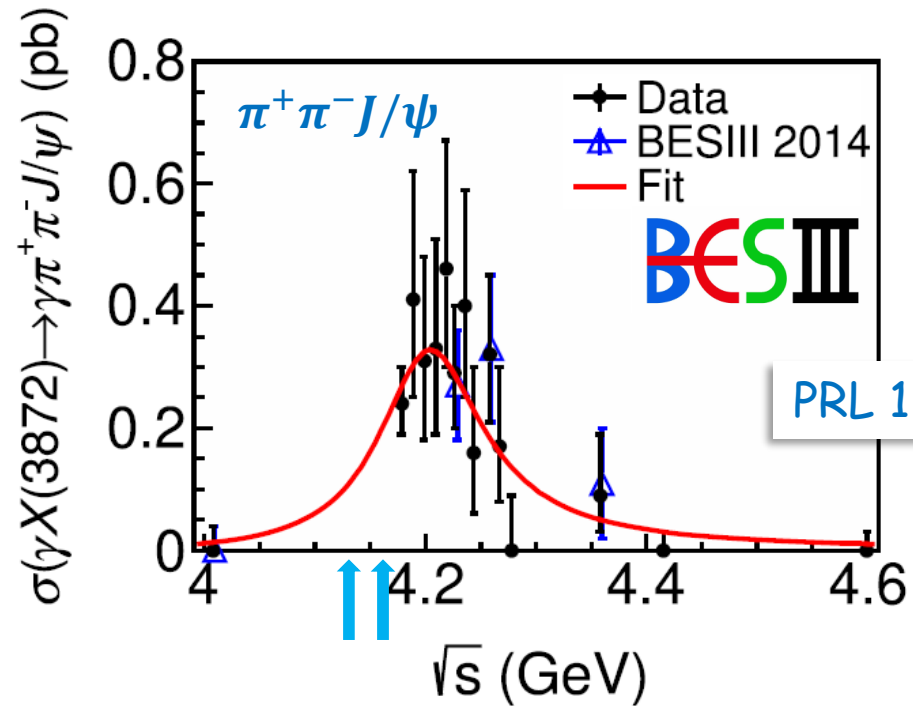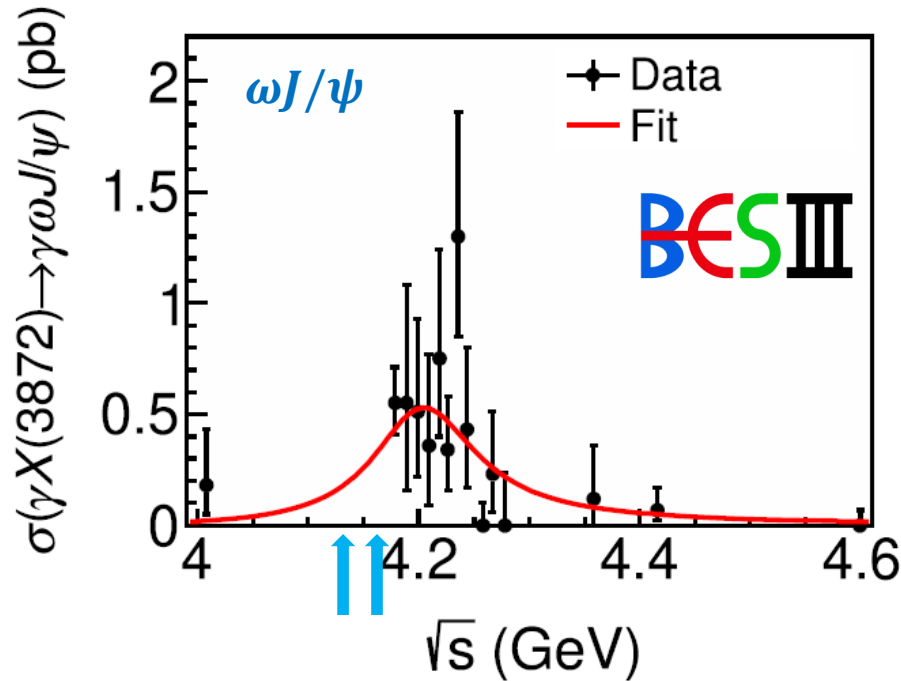# How to produce X(3872) at BESIII

- ➤ Accompany with a photon in e^+e^- collider $[e^+e^- \rightarrow \gamma X(3872)]$

- ➤ Radiative transition process**?**
  $[e^+e^- \rightarrow \psi/Y(1^{--}) \rightarrow \gamma X(3872)(1^{++})]$

Radiative transition

- • Conventional charmonium radiative decay $e.g.\ \psi(2S) \rightarrow \gamma X_{cJ}$

Cross section of $e^+e^- \rightarrow \gamma X(3872)$

PRL 122, 232002

- $e^+e^- \rightarrow \gamma X(3872)$ cross section line-shape by BESIII
- $M = 4200.6^{+7.9}_{-13.3} \pm 3.0$ MeV, $\Gamma = 115^{+38}_{-26} \pm 12$ MeV
- **Unique production mechanism** at BESIII $[Y(4260) \rightarrow \gamma X(3872)]$
- $\dfrac{Br[Y(4260) \rightarrow \gamma X(3872)]}{Br[Y(4260) \rightarrow \pi^+\pi^- J/\psi]} \sim 9\%$ suggest **commonality between Y(4260) and X(3872)**

PLB 725, 127 (2013)/Rev. Mod. Phys. 90, 015003 (2018)

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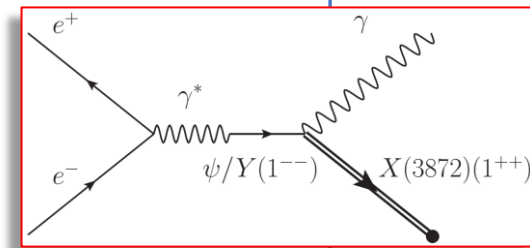
Cross section of $e^+e^- \to \gamma X(3872)$

PRL 122, 232002

- ➢ Production cross section ~ 0.3 pb at 4.2 GeV with $\pi^+\pi^- J/\psi$ channel
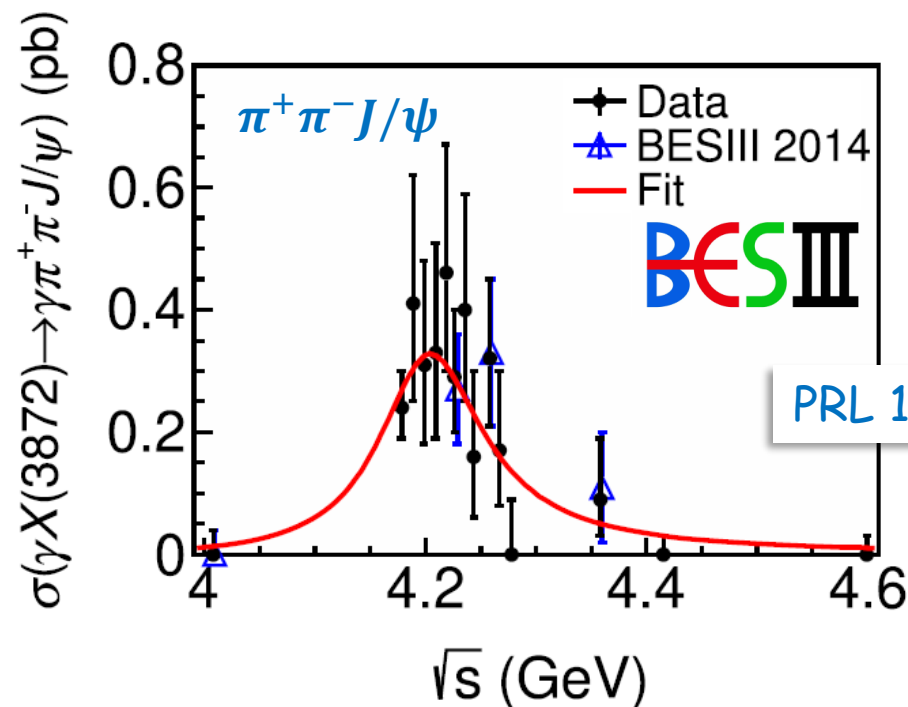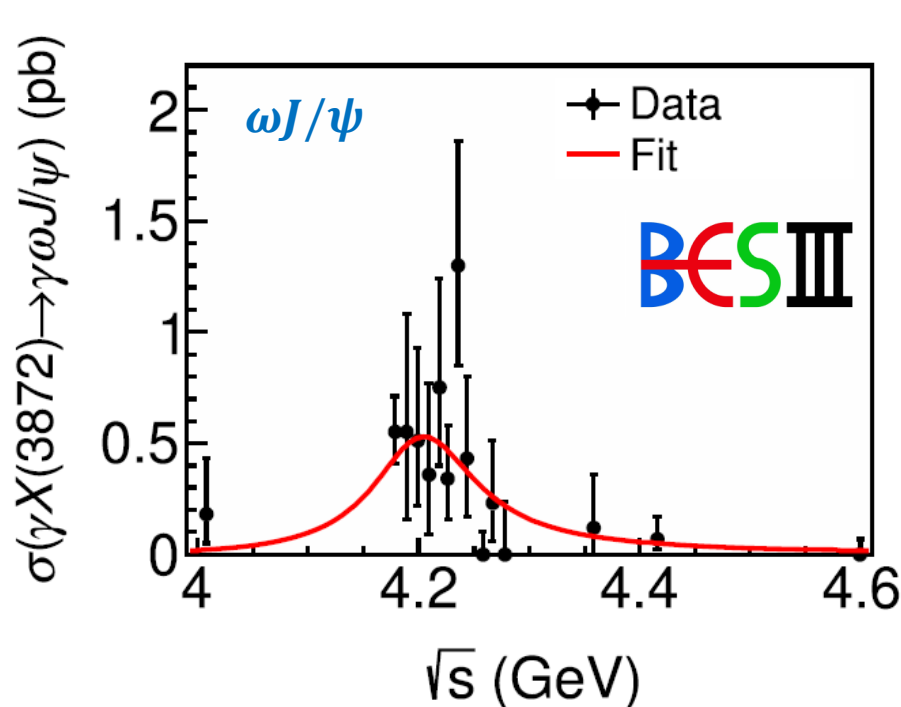- ➢ $Br(X(3872) \to \pi^+\pi^- J/\psi) = (4.1 \pm 1.3)\%$ from BaBar's measurement
  PRL 124, 152001
- ➢ $\sigma[e^+e^- \to \gamma X(3872)] \sim$ **7.3 pb**; Daily luminosity at BESIII $\mathcal{L} = 25$ pb^{-1}
- ➢ BESIII can produce ~ **180 events/day** (**A mini-X(3872) factory**)

Decay of X(3872) at BESIII

$X(3872) \rightarrow \pi^+\pi^- J/\psi$
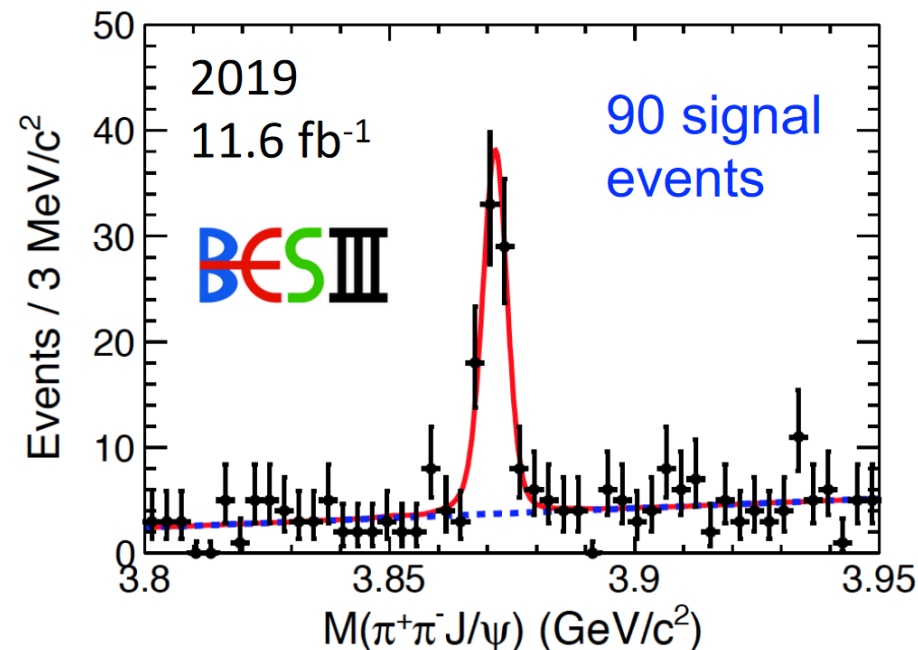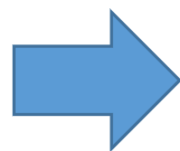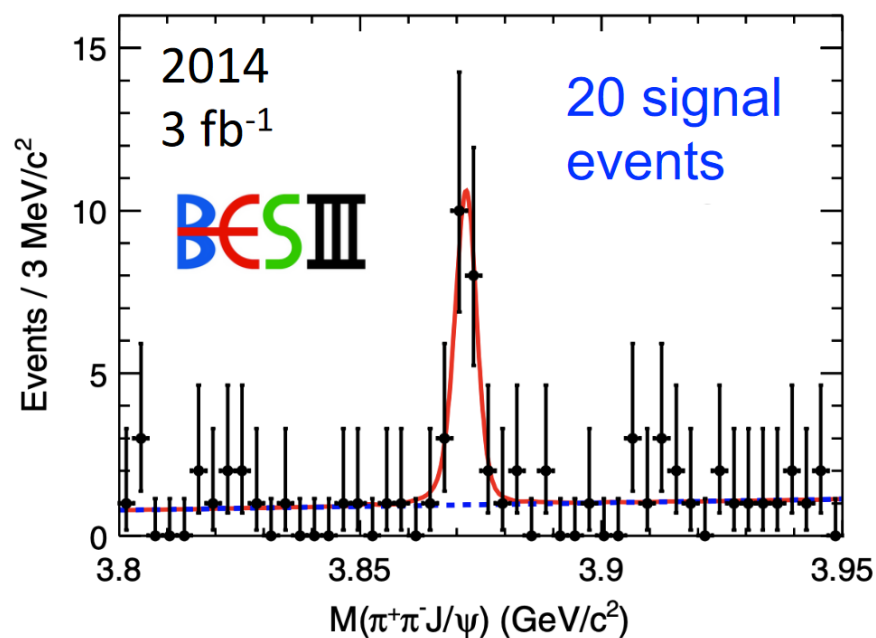
- $X(3872) \rightarrow \pi^+\pi^- J/\psi$ is still the golden channel (clean and productive)
- ISR $\psi(2S)$ events as reference, remaining background $\pi^+\pi^-\pi^+\pi^-$ etc.
- Radiative photon angular distribution $(1 + \alpha \cos^2\theta)$ is on progress…

$X(3872) \rightarrow \omega J/\psi$

PRL 122, 232002 (2019)
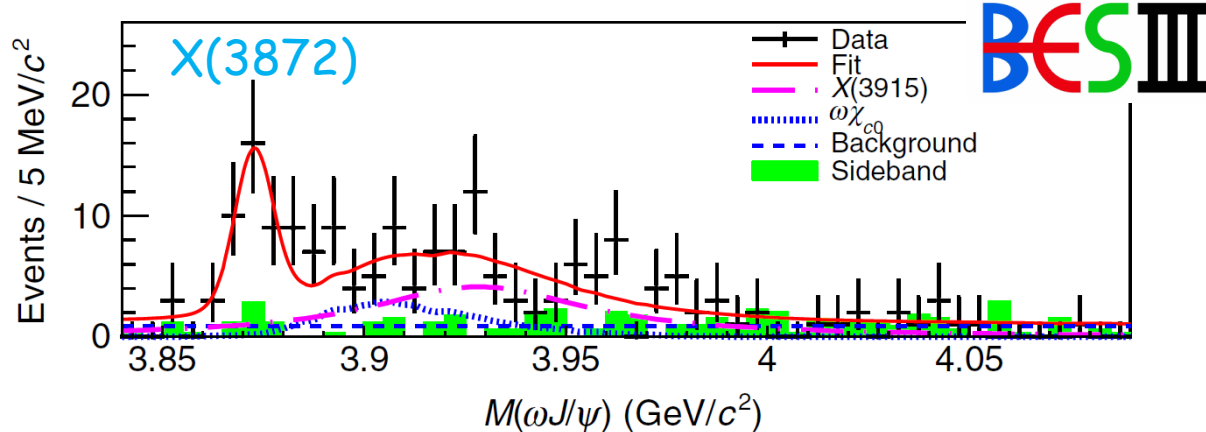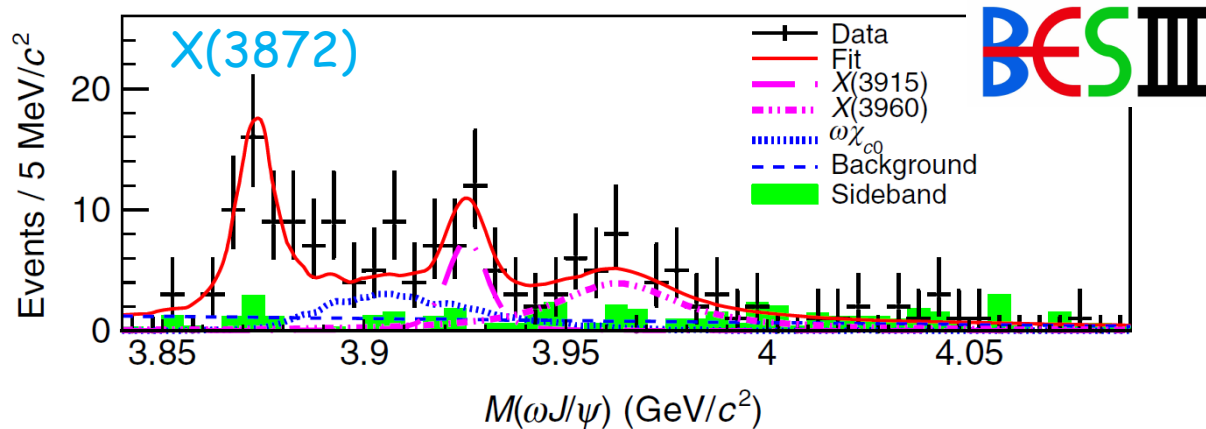
$$\frac{Br[X(3872) \rightarrow \omega J/\psi]}{Br[X(3872) \rightarrow \rho J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2$$

$$R_{X(3872)} = \left| \frac{A(\rho J/\psi)}{A(\omega J/\psi)} \right| \sim 0.2 - 0.3$$

$$R_{\psi(2S)} = \frac{g_{\pi^0 J/\psi}}{g_{\eta J/\psi}} \approx 0.03$$

PRD 85, 011501(R) (2012)

➢ BESIII observed $X(3872) \rightarrow \omega J/\psi$ signal with $> 5\sigma$ for the first time

➢ **Big isospin violation effect (×10 amplitude)**

➢ **X(3872) is very exotic!!**

$X(3872) \to \overline{D^0} D^{*0}$

$D^{*0} \to \gamma D^0$

$D^{*0} \to \pi^0 D^0$

> ➤ BESIII observed $X(3872) \to \overline{D^0} D^{*0}$ signal with **7.4σ significance**

> ➤ No obvious signal observed from $\gamma D^0 \overline{D^0} / \gamma D^+ D^-$

$X(3872) \rightarrow \gamma J/\psi / \gamma \psi(2S)$

best fit (red solid line)
background (blue dashed line)
global ave. (magenta dotted line)
LHCb result (green dash-dot line)
Belle result (gray dashed line)

PRL 124, 242001 (2020)
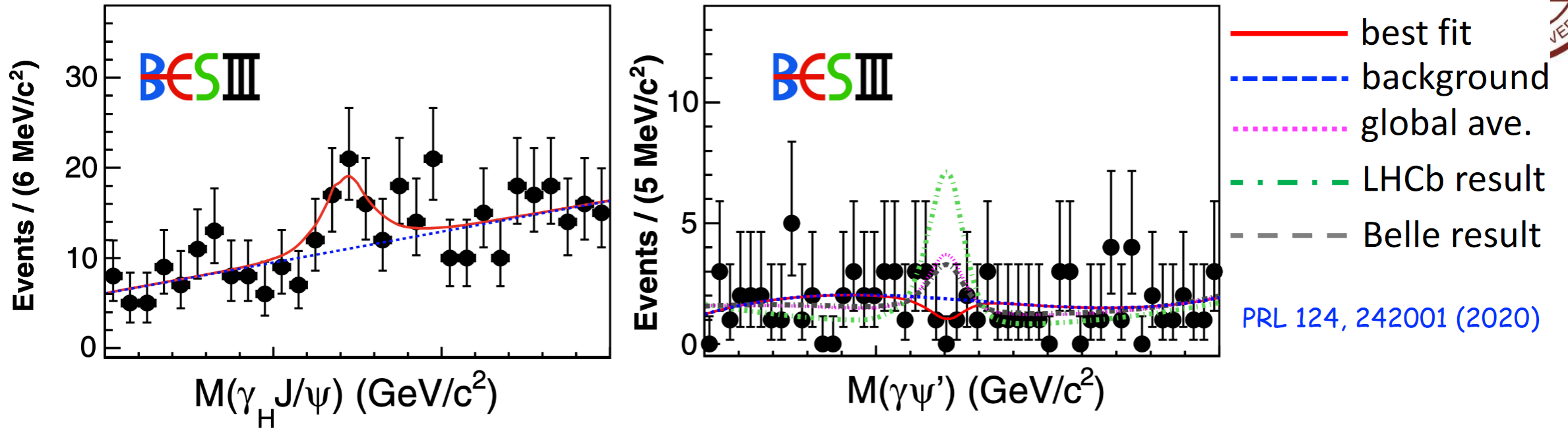
> 3.5σ evidence for $X(3872) \rightarrow \gamma J/\psi$

> No signal for the $X(3872) \rightarrow \gamma \psi(2S)$ (In tension with LHCb result)

PRL 107, 091803 (Belle)
PRL 102, 132001 (BaBar)
NPB 886(665) (LHCb)

| $\dfrac{Br[X(3872) \rightarrow \gamma \psi(2S)]}{Br[X(3872) \rightarrow \gamma J/\psi]}$ | <0.59 @ 90% C.L. (BESIII) | = 3.4 ± 1.4 (BaBar) |
| | <2.1 @ 90% C.L. (Belle) | = 2.46 ± 0.64 ± 0.29 (LHCb) |

Molecule?   Tetraquark?   or something else ...

New decay mode $X(3872) \to \pi^0 \chi_{c1}$
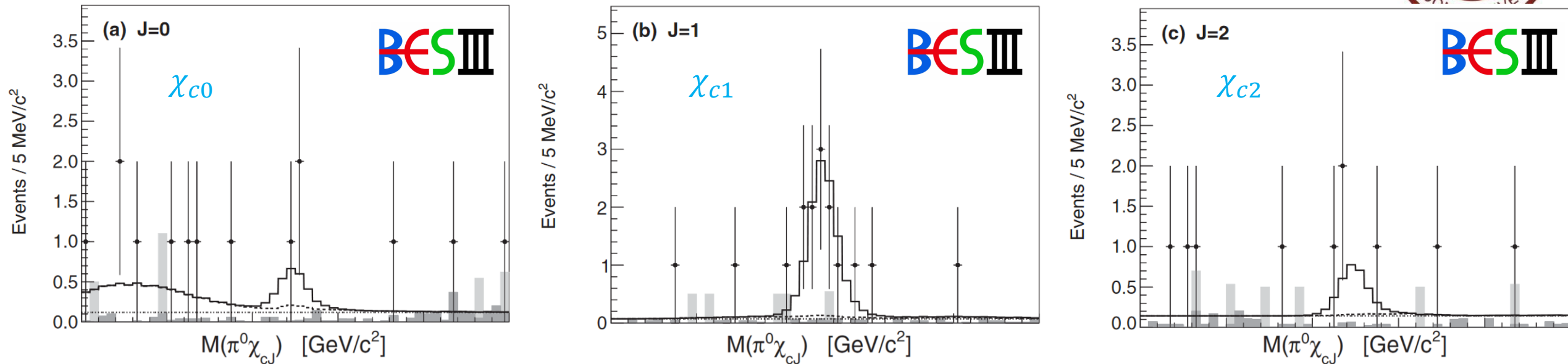
$$Br[X(3872) \to \pi^0 \chi_{c0}]/Br[X(3872) \to \rho J/\psi] \quad <19 \text{ @ } 90\% \text{ C.L.}$$

$$Br[X(3872) \to \pi^0 \chi_{c1}]/Br[X(3872) \to \rho J/\psi] \quad = 0.88^{+0.33}_{-0.27} \pm 0.10$$

$$Br[X(3872) \to \pi^0 \chi_{c2}]/Br[X(3872) \to \rho J/\psi] \quad <1.1 \text{ @ } 90\% \text{ C.L.}$$

> **BESIII observed $X(3872) \to \pi^0 \chi_{c1}$ for the first time with $> 5\sigma$ significance**

> Isospin violation process, comparable decay rate with $\rho J/\psi$ (**disfavor $\chi_{c1}(2P)$ assignment**)

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Branching ratios of $X(3872)$ decay

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]	$\cdots$

BESIII PRL 124, 242001 (2020)

- The relative Brs using $\pi^+\pi^- J/\psi$ as the normalized channel
- $X(3872) \to \overline{D^0}D^{*0}$ is dominant

Decay mode	Branching fraction
$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
$X(3872) \to D^{*0}\bar{D}^0 + $ c.c.	$(52.4^{+25.3}_{-14.3})\%$
$X(3872) \to \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
$X(3872) \to \gamma\psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
$X(3872) \to \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
$B^+ \to X(3872)K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
$X(3872) \to$ unknown	$(31.9^{+18.1}_{-31.5})\%$

Li & Yuan, PRD 100, 094003 (2019)

- Global fit using world data
- Over **30%** decay mode of X(3872) is unknow
- Still have room to search

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What's next for X(3872) at BESIII

Potential topics ongoing:

➤ **Search for $X(3872) \to \pi^+\pi^-\chi_{c1}$**

- Observed $X(3872) \to \pi^0\chi_{c1}$ (isospin violation, P-wave charmonium transition)

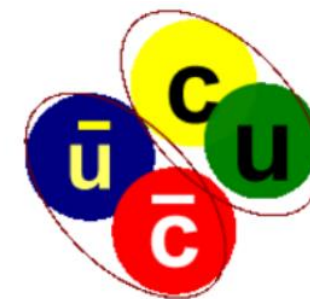- Search for two pions P-wave charmonium transition will give us some clue of X(3872)

➤ **Search for $X(3872) \to$ light hadrons?**

- Over 30% decay modes of X(3872) is still unknow

- $c\bar{c} \to$ light hadrons (annihilation); molecule $\to$ light hadrons (?) ;…

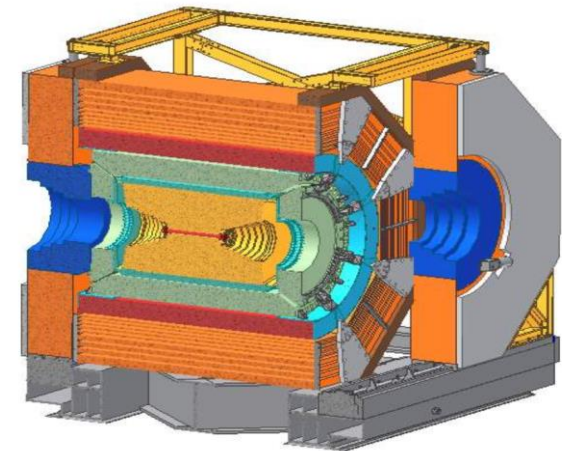- Searching for light hadron final state may tell us more information about X(3872)

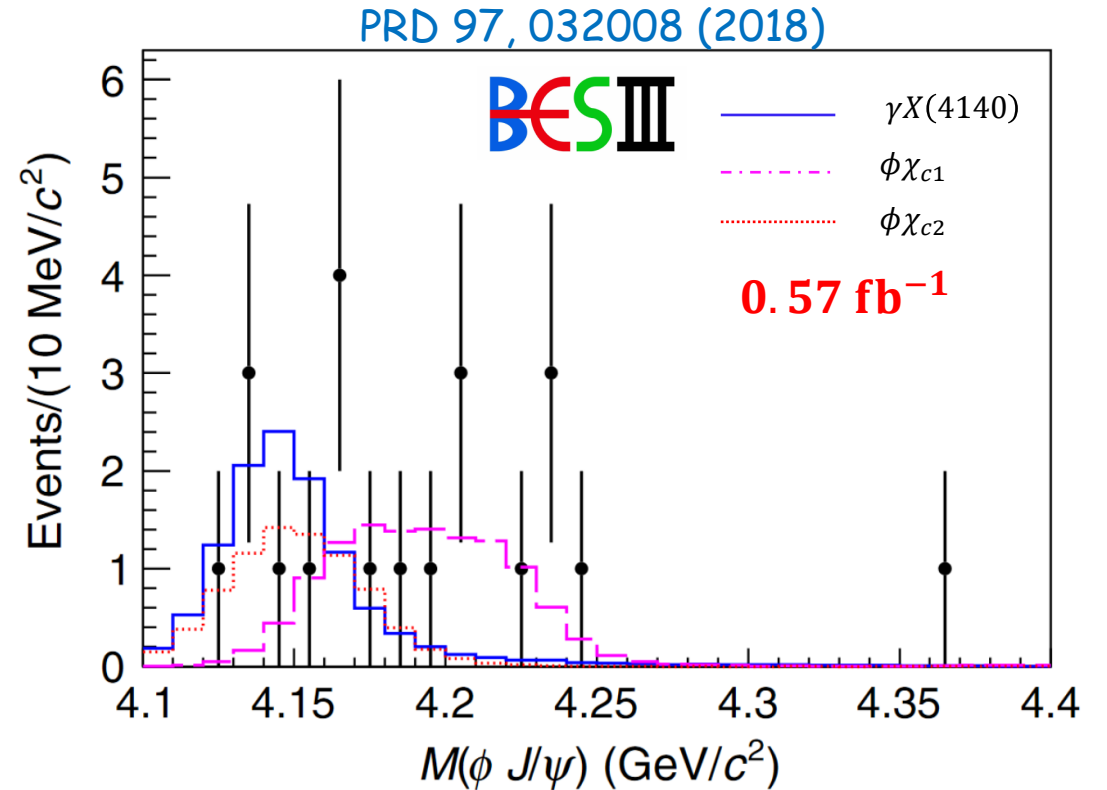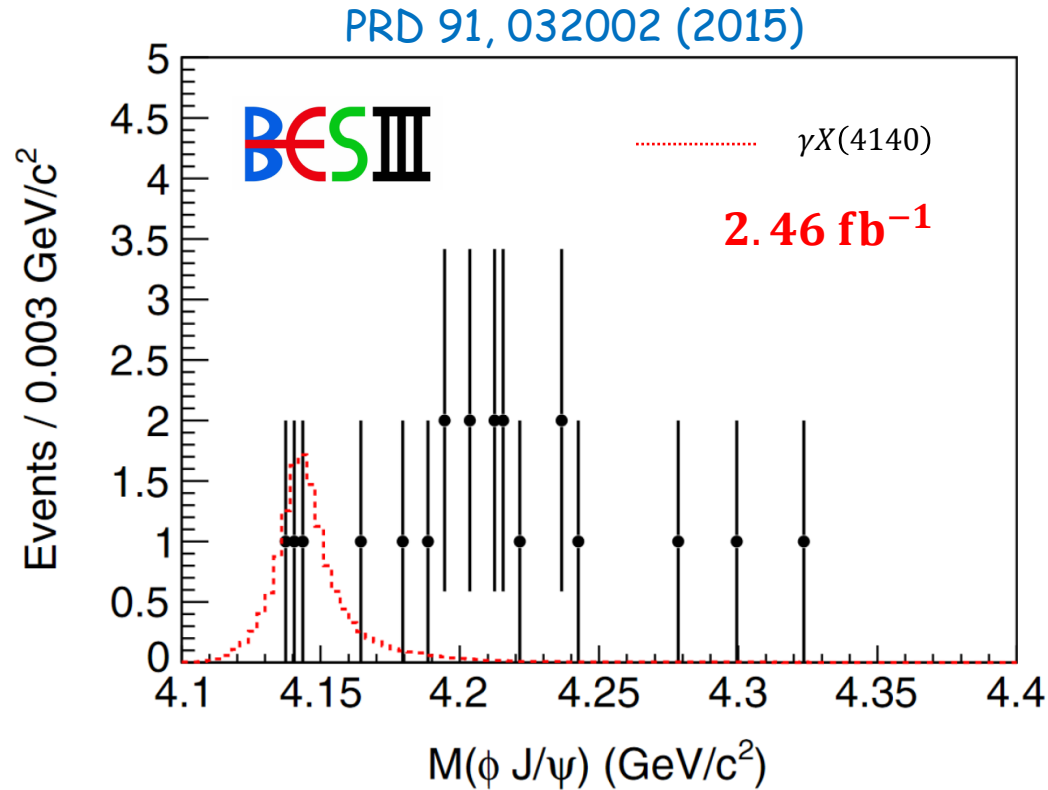$D^0 - \overline{D^{*0}}$ "molecule"

…?
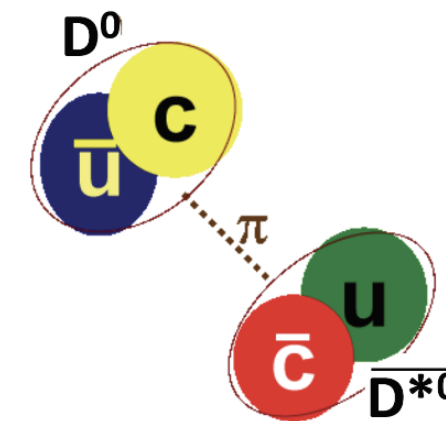
diquark - diantiquark

Other X states at BESIII

X states at BESIII

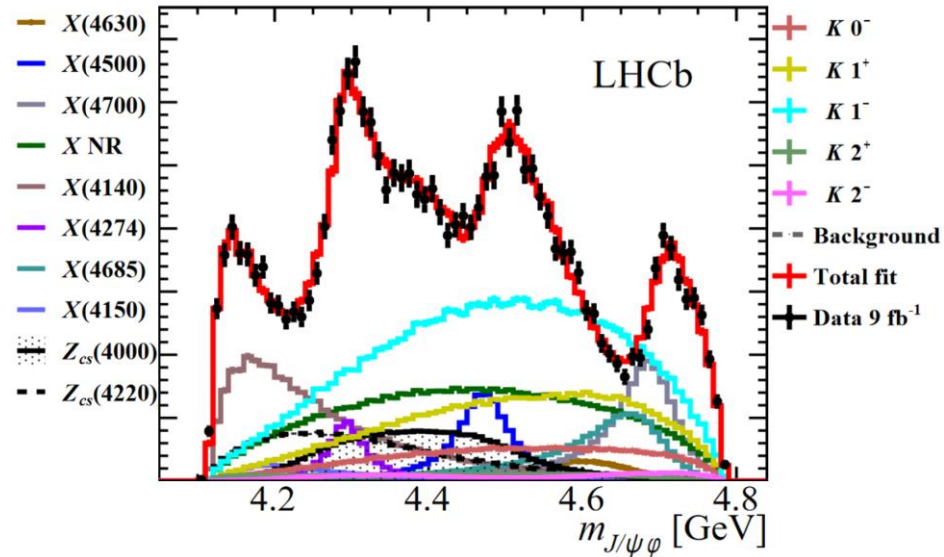Searching for other X states via **radiative transition** at BESIII ($e^+e^- \to \gamma X$)

PRD 91, 032002 (2015)

PRD 97, 032008 (2018)

- No significant X(4140) signal is observed in $\phi J/\psi$ system with about 3 fb^{-1} data at BESIII

X states at BESIII

Contribution	Significance $[\times\sigma]$	M_0 [MeV]	Γ_0 [MeV]	FF [%]
$X(2^-)$				
$X(4150)$	4.8 (8.7)	$4146 \pm 18 \pm 33$	$135 \pm 28^{+59}_{-30}$	$2.0 \pm 0.5^{+0.8}_{-1.0}$
$X(1^-)$				
$X(4630)$	5.5 (5.7)	$4626 \pm 16^{+18}_{-110}$	$174 \pm 27^{+134}_{-73}$	$2.6 \pm 0.5^{+2.9}_{-1.5}$
All $X(0^+)$				$20 \pm 5^{+14}_{-7}$
$X(4500)$	20 (20)	$4474 \pm 3 \pm 3$	$77 \pm 6^{+10}_{-8}$	$5.6 \pm 0.7^{+2.4}_{-0.6}$
$X(4700)$	17 (18)	$4694 \pm 4^{+16}_{-3}$	$87 \pm 8^{+16}_{-6}$	$8.9 \pm 1.2^{+4.9}_{-1.4}$
$NR_{J/\psi\phi}$	4.8 (5.7)			$28 \pm 8^{+19}_{-11}$
All $X(1^+)$				$26 \pm 3^{+8}_{-10}$
$X(4140)$	13 (16)	$4118 \pm 11^{+19}_{-36}$	$162 \pm 21^{+24}_{-49}$	$17 \pm 3^{+19}_{-6}$
$X(4274)$	18 (18)	$4294 \pm 4^{+3}_{-6}$	$53 \pm 5 \pm 5$	$2.8 \pm 0.5^{+0.8}_{-0.4}$
$X(4685)$	15 (15)	$4684 \pm 7^{+13}_{-16}$	$126 \pm 15^{+37}_{-41}$	$7.2 \pm 1.0^{+4.0}_{-2.0}$

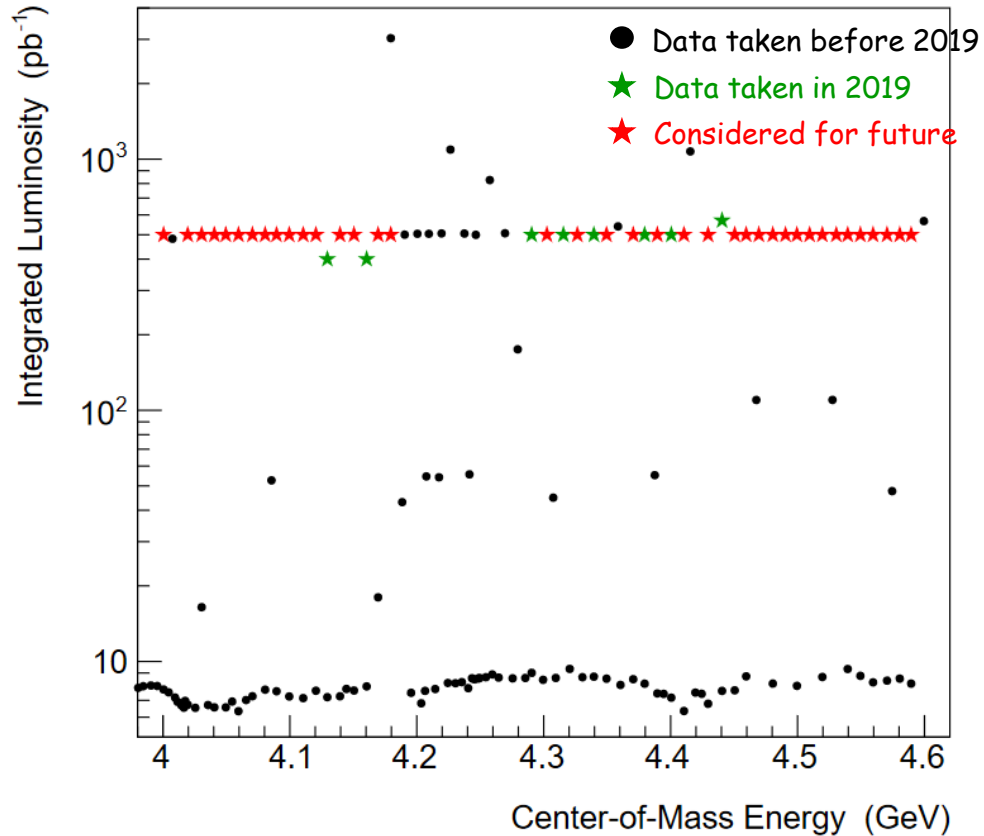- Blooming structures on $\phi J/\psi$ spectrum from LHCb measurement, e.g. X(4140), X(4274), X(4500) etc.

> ➢ BESIII have taken data up to $\sqrt{s} = 5.0$ GeV, more data above 4.6 GeV ($\mathcal{L}\sim4.5$ fb^{-1})
>
> ➢ More data can be used to exam X states at BESIII, e.g. X(4140)…
>
> ➢ More X states can be accessed via radiative transition at BESIII
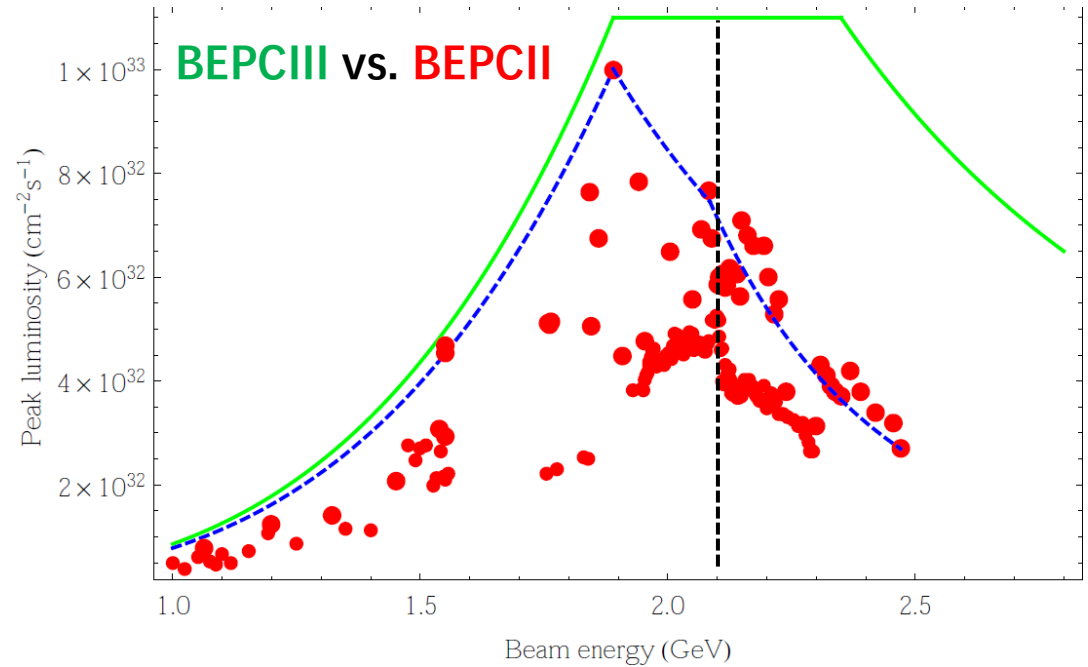
Future of BESIII

Future Physics Programme of BESIII,
Chin. Phys. C 44, 040001 (2020)

BESIII Data Sets

Luminosity performance

- Upgrade to BEPCIII
- $1.5 \times \mathcal{L}_{BEPCII}$ @ 4.2 GeV

More data will be collected, more studies will be carried out!

Summary

- BESIII is one of the competitive experiment on X(3872) study (unique production mechanism, clean environment, mini-X(3872) factory)

- Great progress achieved: solid confirm $X(3872) \rightarrow \omega J/\psi$; observe new decay mode $X(3872) \rightarrow \pi^0 \chi_{c1}$; ...

- BESIII is still keeping eyes on X(3872)

- Data taking is continue, more data for X states study at BESIII

You can expect more from BESIII

Thanks for your listening!

Backup

BESIII experiment

- **Double ring:**
  Symmetric collider

- **CMS energy:**
  2.0-5.0 GeV

- **Design Luminosity:**
  $1 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$