



Recent BESIII results of X(3872)

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On behalf of BESIII collaboration

2019-8-17, Hadron 2019, Guilin



Outline

- Introduction of X(3872), BEPCII and BESIII
- Recent **three** BESIII results

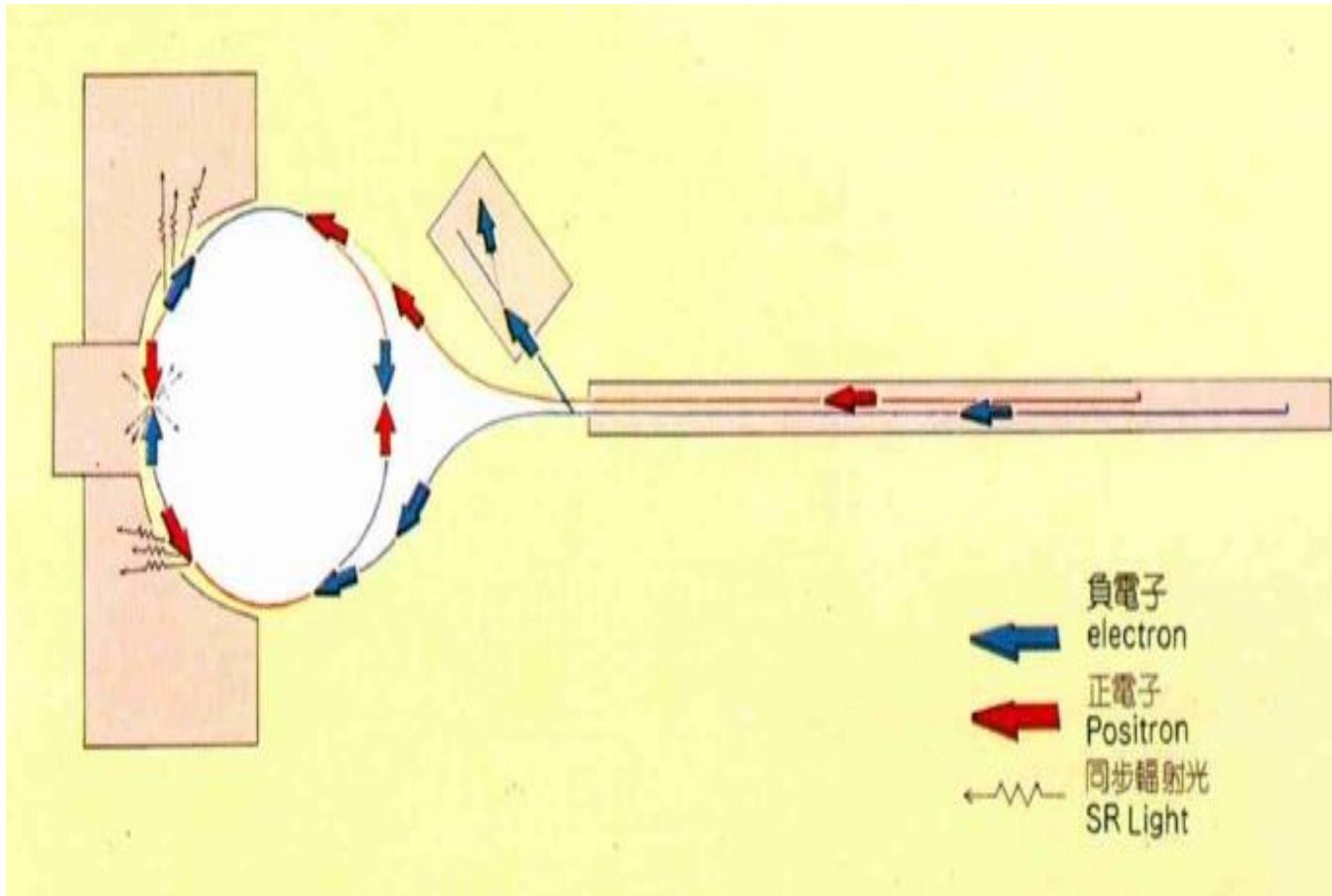
- First observed in $B \rightarrow K(\pi^+\pi^-J/\psi)$ [Belle]
 - Mass: close to $D^{*0}D^0$ threshold
 - 3871.68 ± 0.17 MeV, $B_E = 0.01 \pm 0.20$ MeV
 - Width: very narrow
 - < 1.2 MeV
- $J^{PC}=1^{++}$ [CDF and LHCb]
- No iso-spin partner has been found yet
- Production
 - pp, p \bar{p} collision, B decays, γ^*N , $\pi^\pm\text{Li}$
 - $e^+e^- \rightarrow \gamma X(3872)$
- Decay BR:
 - open charm ~ 50%
 - charmonium ~0(%)

Overview of $X(3872)$

- Nature
- (multi-quark candidate)
- D^0D^{*0} molecule
 - Hybrid: mass too low
 - Charmonium state: $\chi_{c1}(2P)$
 - Tetra-quark: no charged partner be found
 - Cusp effect
 - Etc.
 - Mixture of above ...

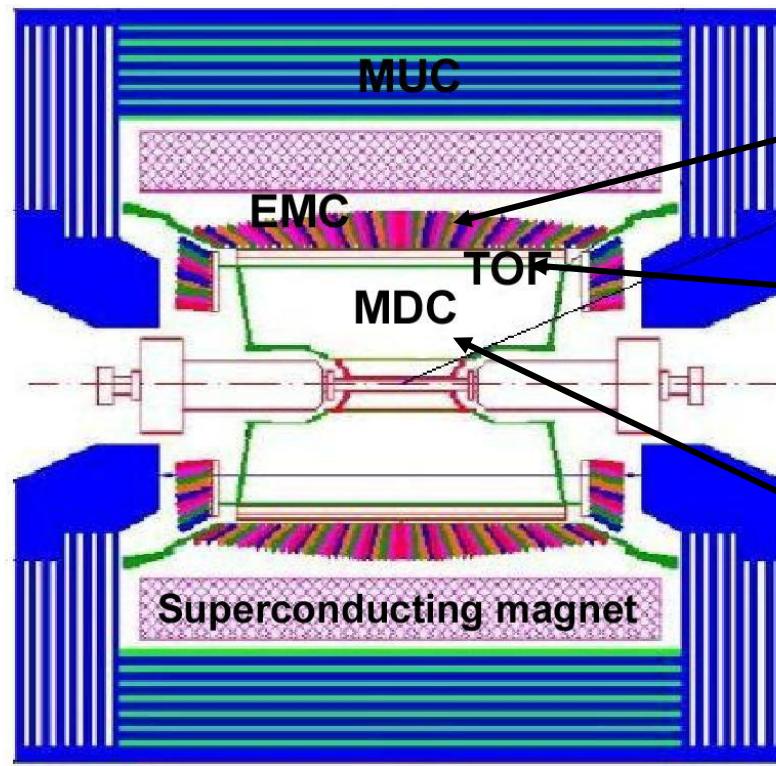
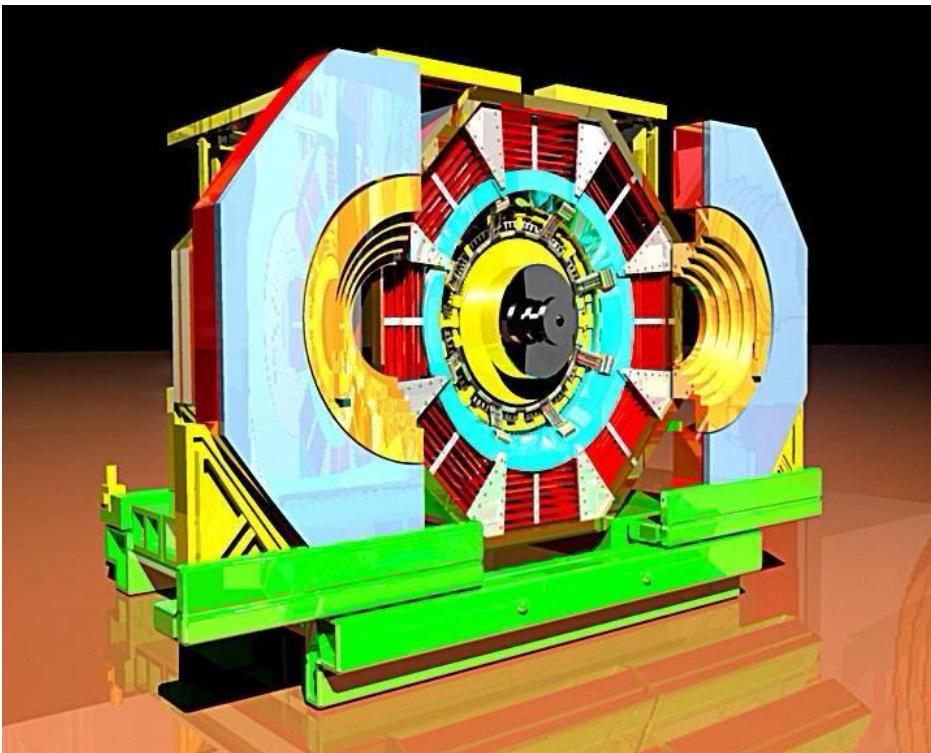
BEPCII: Beijing Electron - Positron Collider II

北京 电子 - 正电子 对撞机 II



CMS energy: $2.0 \sim 4.6 \text{ GeV}$; Luminosity: $1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$

BESIII: BEijing Spectrometer III 北京 谱仪 III



2.5% @ Barrel
5.0% @ Endcaps
with 1 GeV

80 ps @ Barrel
110 (60) ps @ Endcaps

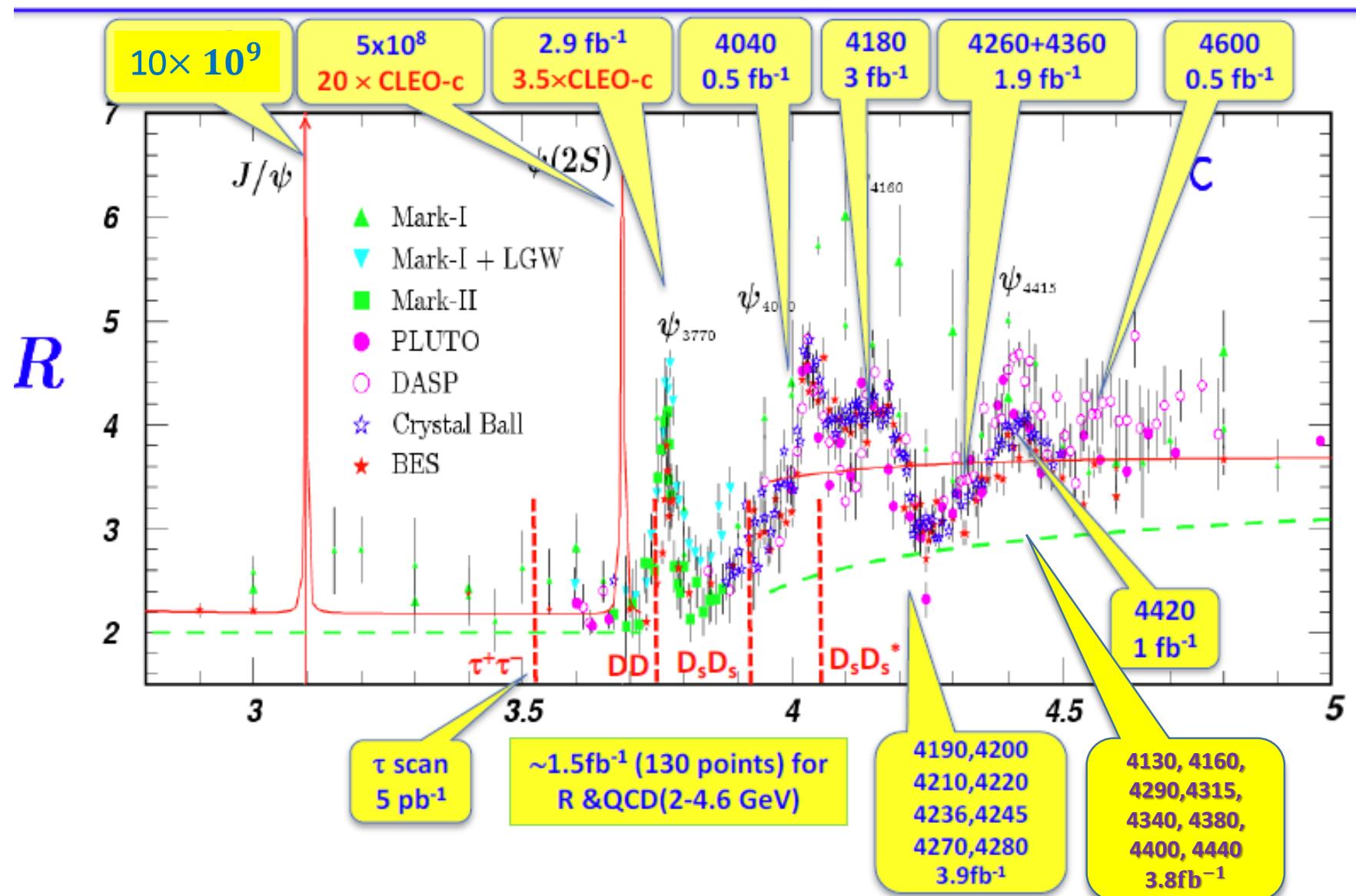
1T magnetic field
0.5% with 1 GeV/c

A general purpose detector with a 93% solid angle coverage

BESIII data: the largest e^+e^- collision samples in τ -charm region

Physics:

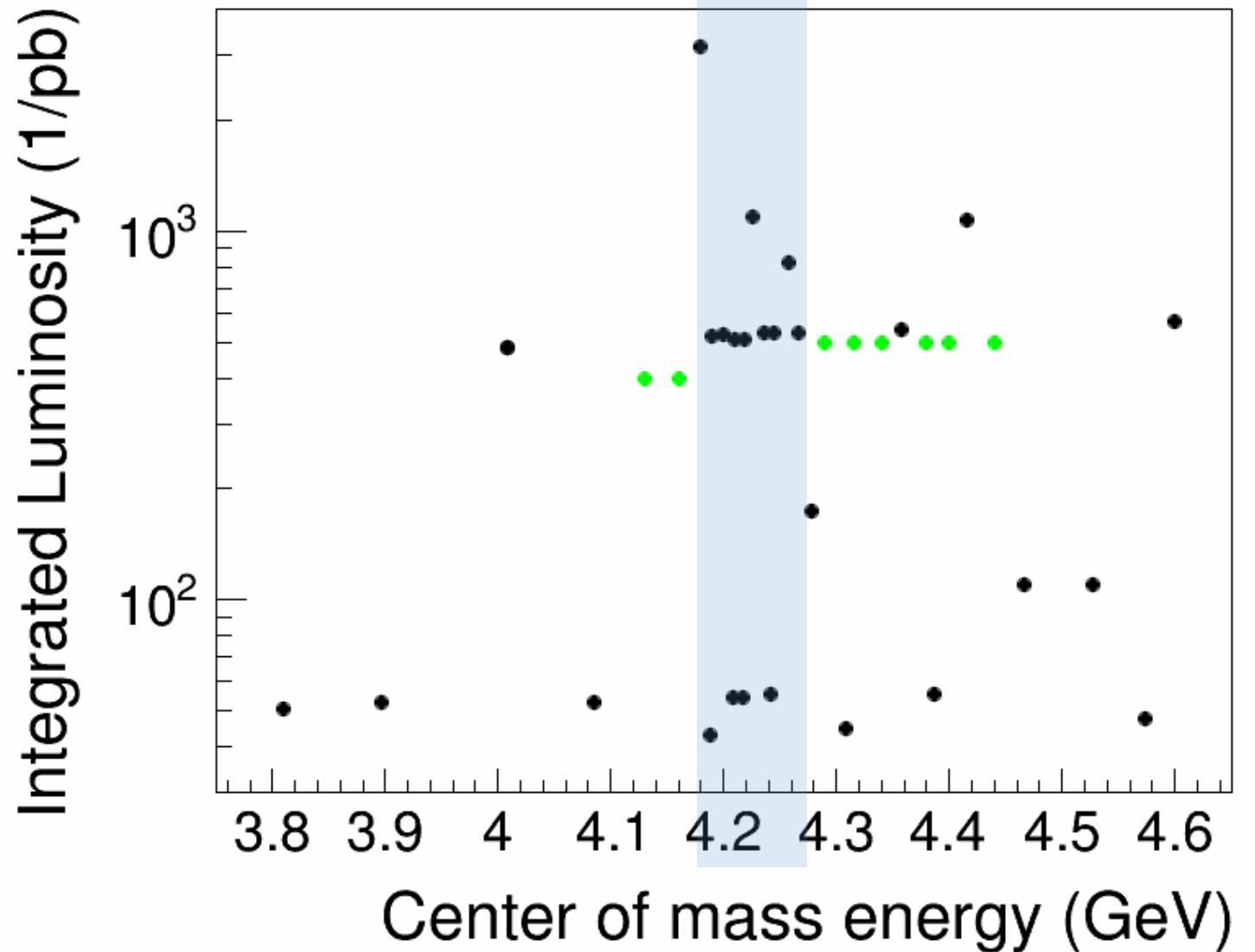
- light hadron
- charmonium
- charm
- R-value & QCD
- new physics



XYZ data sets

Total: about 17 fb^{-1}

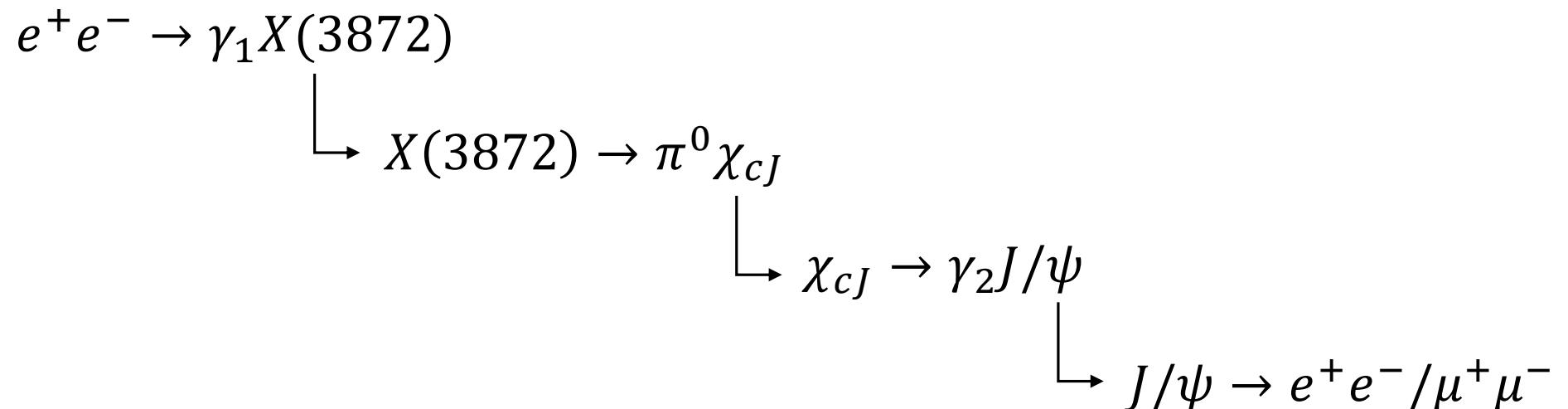
$e^+e^- \rightarrow Y(?) \rightarrow \gamma X(3872)$

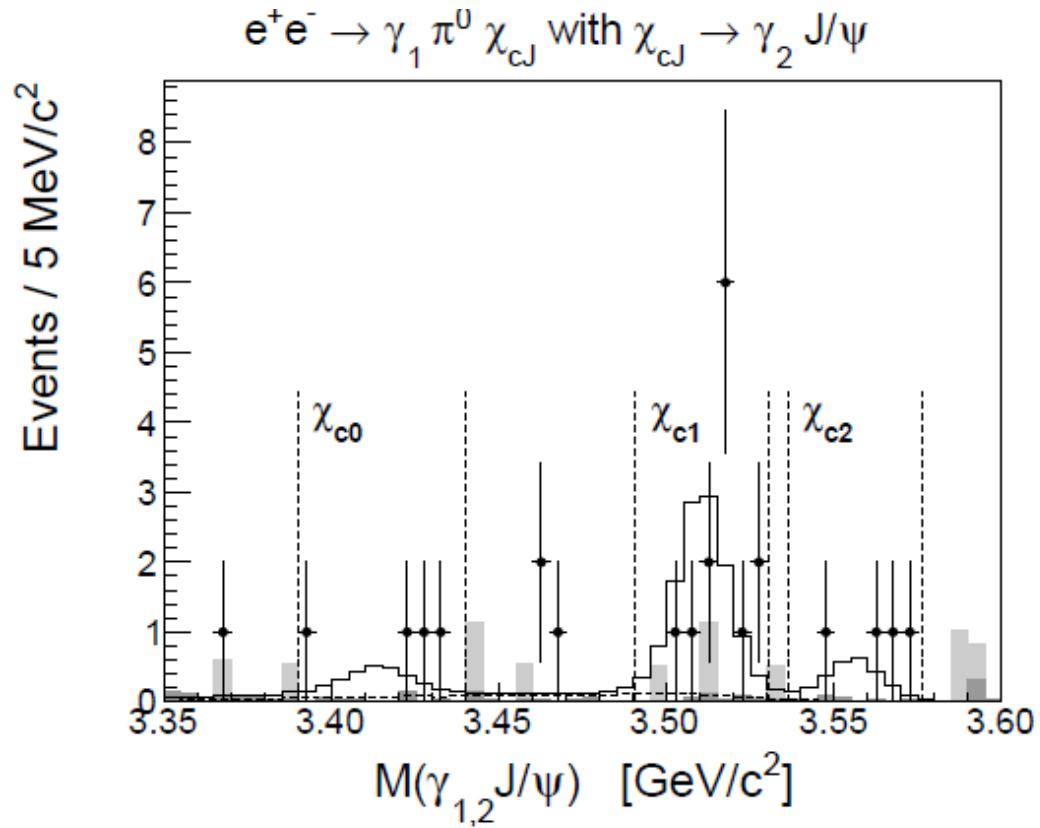


Observation of $X(3872) \rightarrow \pi^0 \chi_{c1}(1P)$

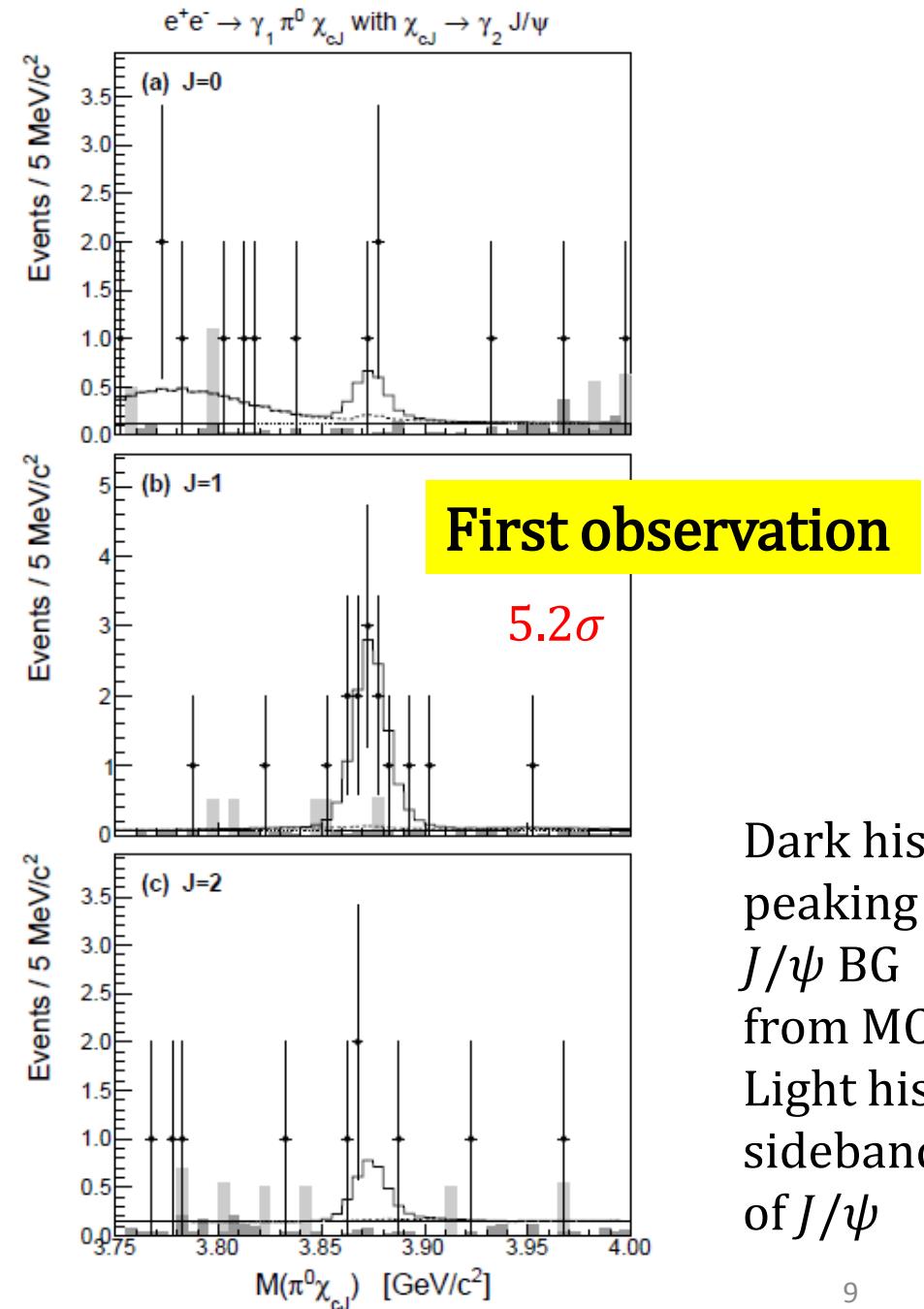
- In conventional $c\bar{c}$ hypothesis, $\Gamma(X(3872) \rightarrow \pi^0 \chi_{c1}(1P)) \sim 0.06$ keV
- In tetra-quark/molecular state hypothesis, the decay width could be sizeable.
[PRD 77, 014013(2008)], [PRD 92, 034019(2015)]

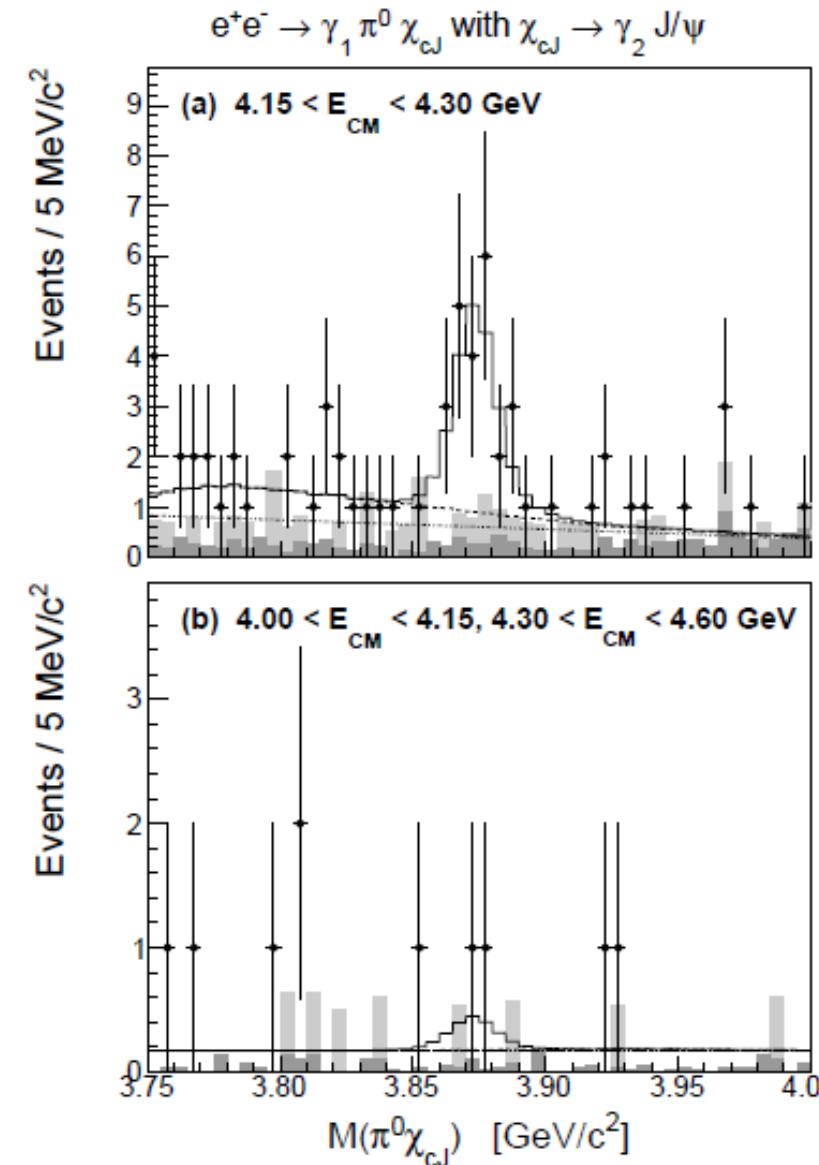
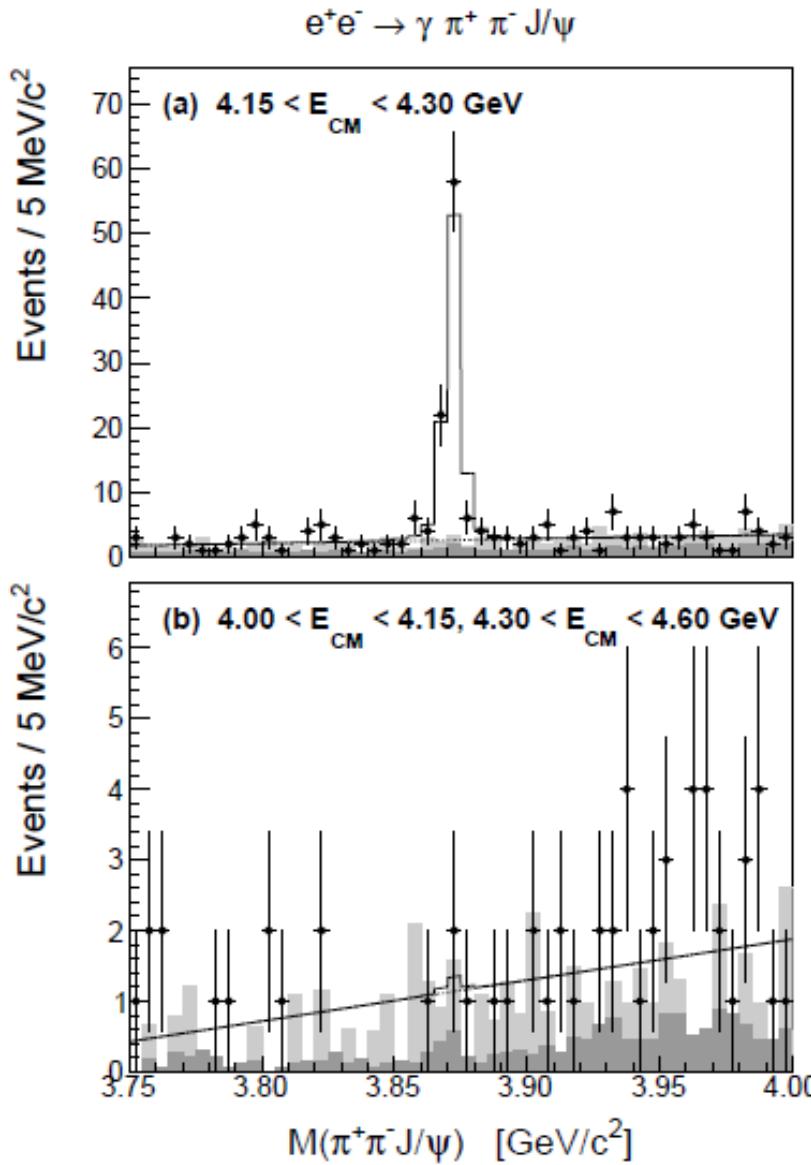
9.0 fb^{-1} e^+e^- collision data with center-of-mass energy between 4.15 and 4.30 GeV





After select $X(3872)$ signal region, clear $\chi_{c1}(1P)$ signal is observed; and vice versa.





Dark hist: peaking
 J/ψ BG from MC
Light hist: sideband
of J/ψ

Hint: X(3872) is related to Y(4220)

	$\pi^+\pi^- J/\psi$	$\pi^0\chi_{c0}$	$\pi^0\chi_{c1}$	$\pi^0\chi_{c2}$
Event yield	$84.1^{+10.1}_{-9.4}$	$1.9^{+1.9}_{-1.3}$	$10.8^{+3.8}_{-3.1}$	$2.5^{+2.3}_{-1.7}$
Signal significance (σ)	16.1	1.6	5.2	1.6
Efficiency (no ISR) (%)	32.3	8.8	14.1	12.8
Efficiency ratio (with ISR)	...	0.272	0.435	0.392
$\mathcal{B}(\chi_{cJ} \rightarrow \gamma J/\psi) \times \mathcal{B}(\pi^0 \rightarrow \gamma\gamma)$ (%)	...	1.3	33.5	19.0
Total systematic error (%)	...	17.0	11.9	9.4
$\mathcal{B}(X \rightarrow \pi^0\chi_{cJ})/\mathcal{B}(X \rightarrow \pi^+\pi^- J/\psi)$...	$6.6^{+6.5}_{-4.5} \pm 1.1$ (19)	$0.88^{+0.33}_{-0.27} \pm 0.10$	$0.40^{+0.37}_{-0.27} \pm 0.04$ (1.1)

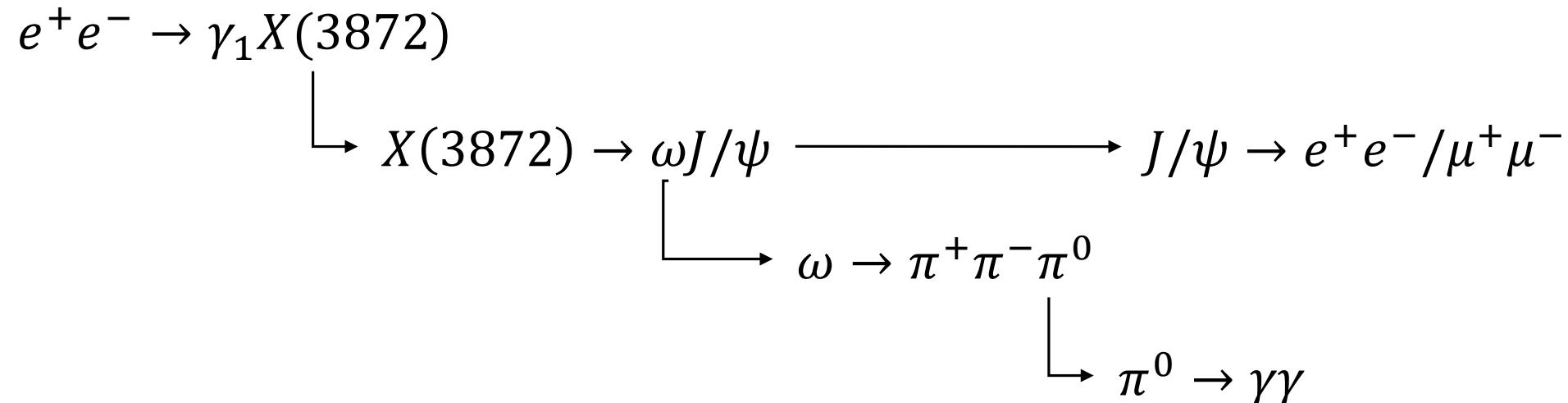
- Using $\mathcal{B}(X(3872) \rightarrow \pi^+\pi^- J/\psi) > 3.2\%$ and $< 6.4\%$, it is found that $\mathcal{B}(X(3872) \rightarrow \pi^0\chi_{c1}(1P)) \sim 3 - 6\%$
- Using $\Gamma_{X(3872)} \sim 1.2$ MeV, conventional $c\bar{c}$ hypothesis predicts $\mathcal{B}(X(3872) \rightarrow$

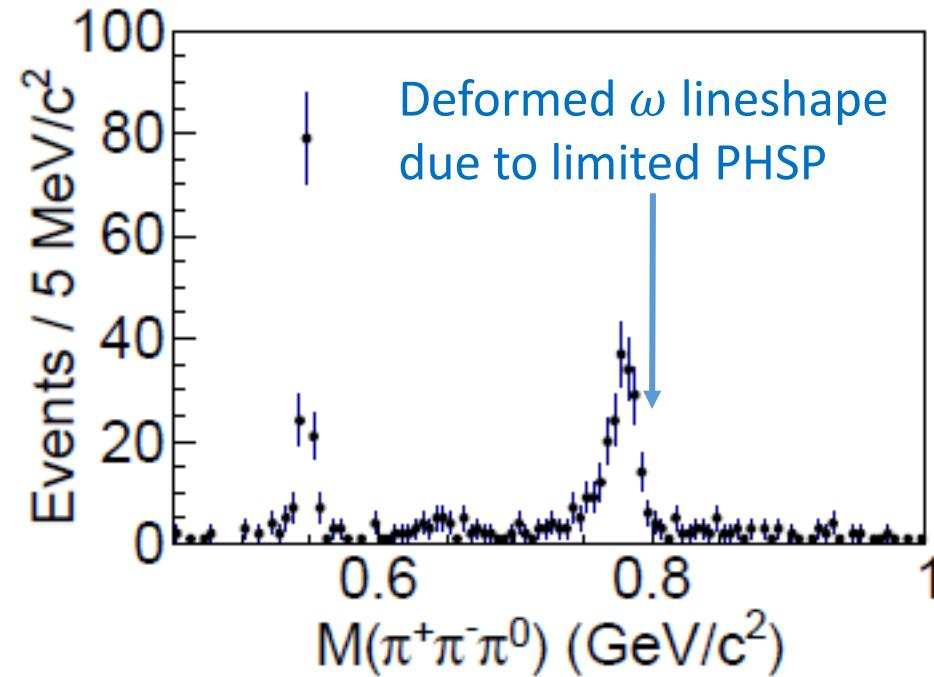
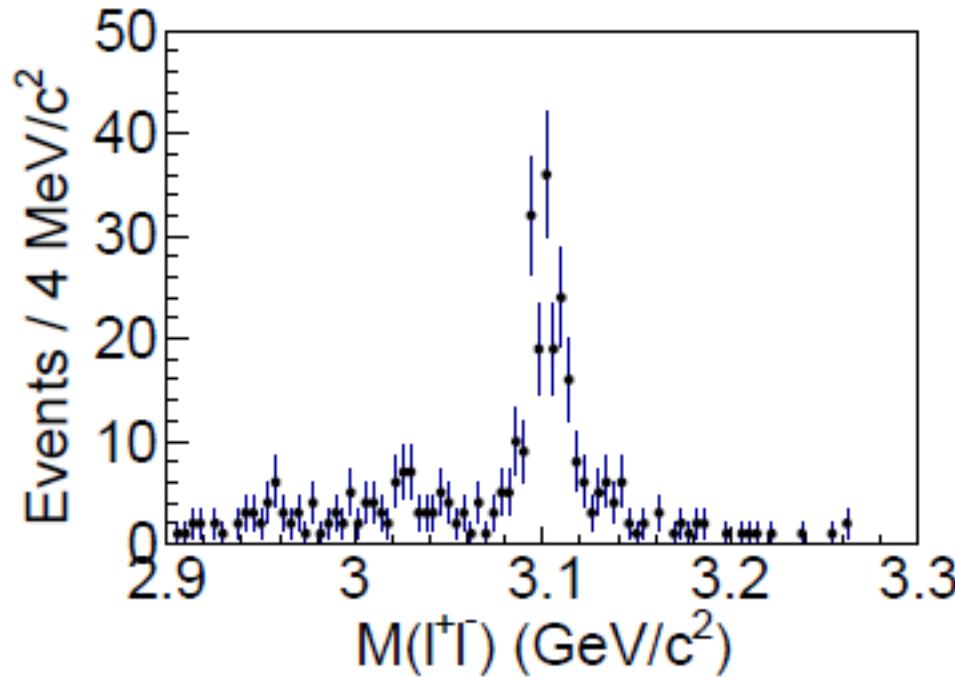
Observation of $X(3872) \rightarrow \omega J/\psi$

[Phys. Rev. Lett. 122, 232002 \(2019\)](#)

- Belle and *BABAR* reported 4σ evidence for this decay, and give
iso-spin conserved $\frac{\mathcal{B}(X(3872) \rightarrow \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X(3872) \rightarrow \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$
iso-spin violated

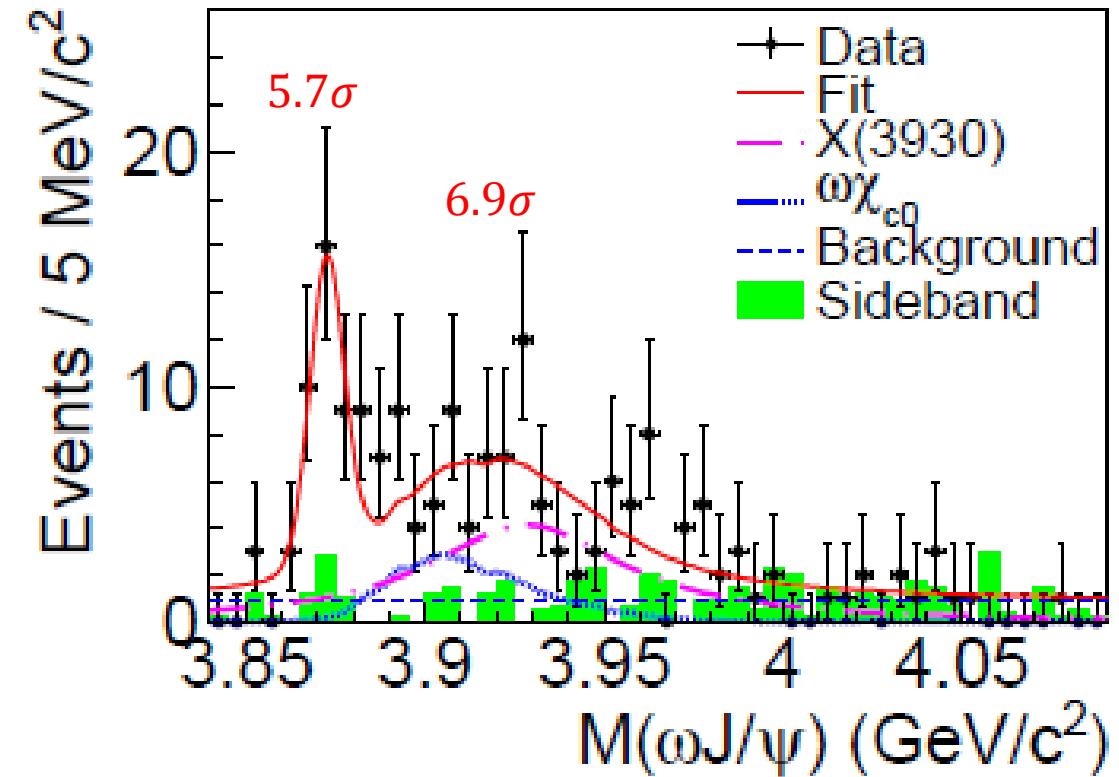
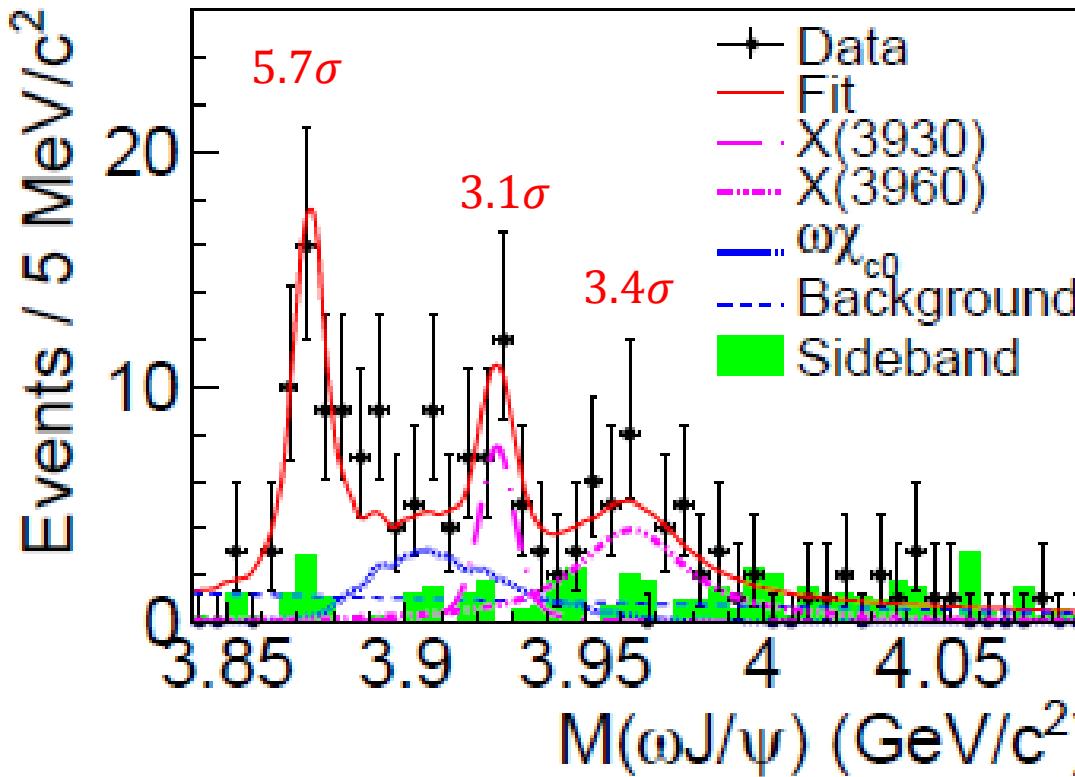
- BESIII is expected to find ~ 70 $X(3872) \rightarrow \omega J/\psi$ events with the data accumulated around 4.2 GeV.



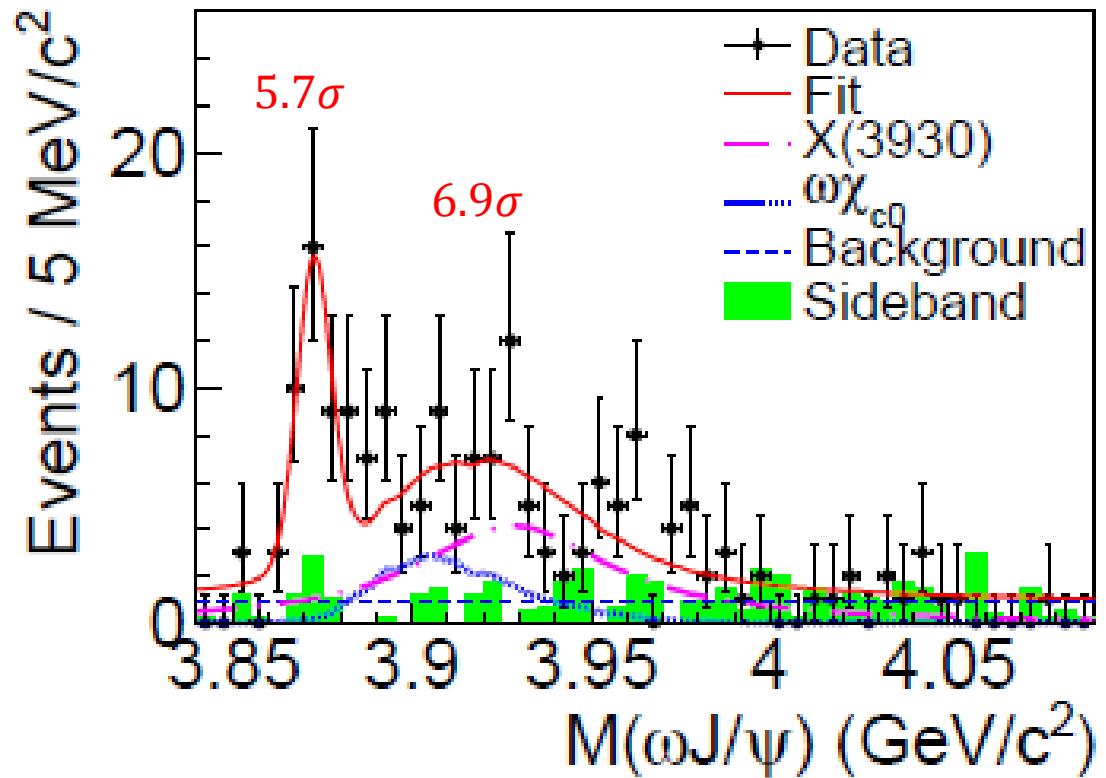
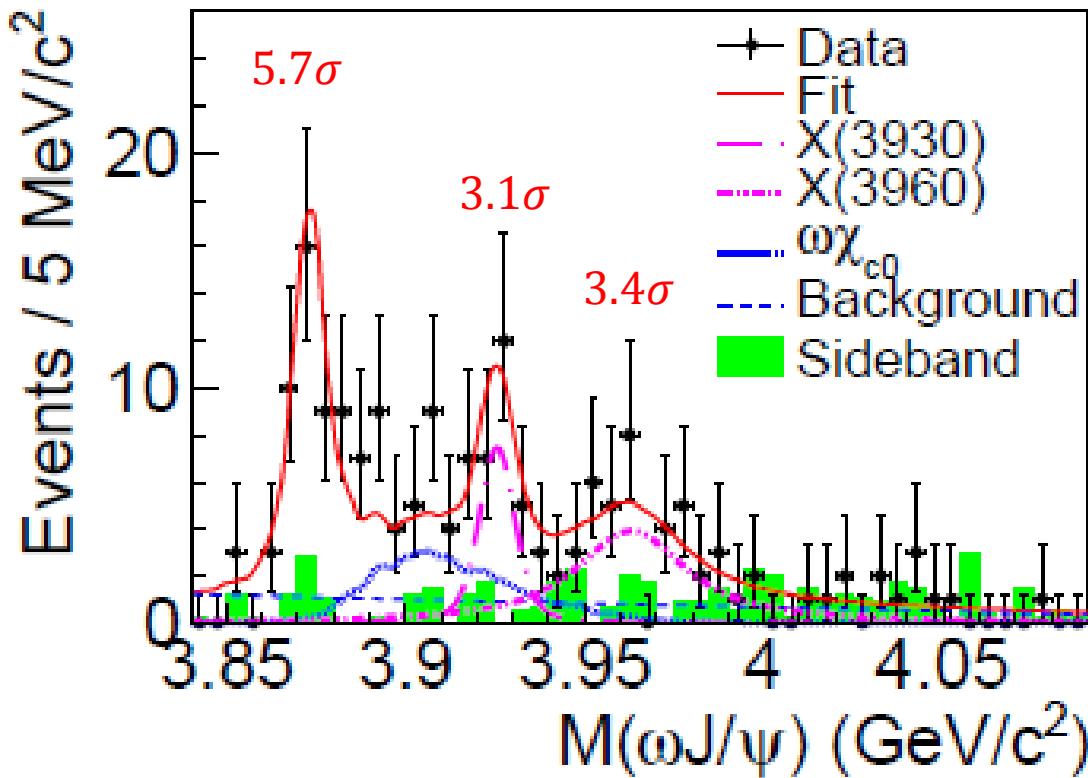


Full reconstruction

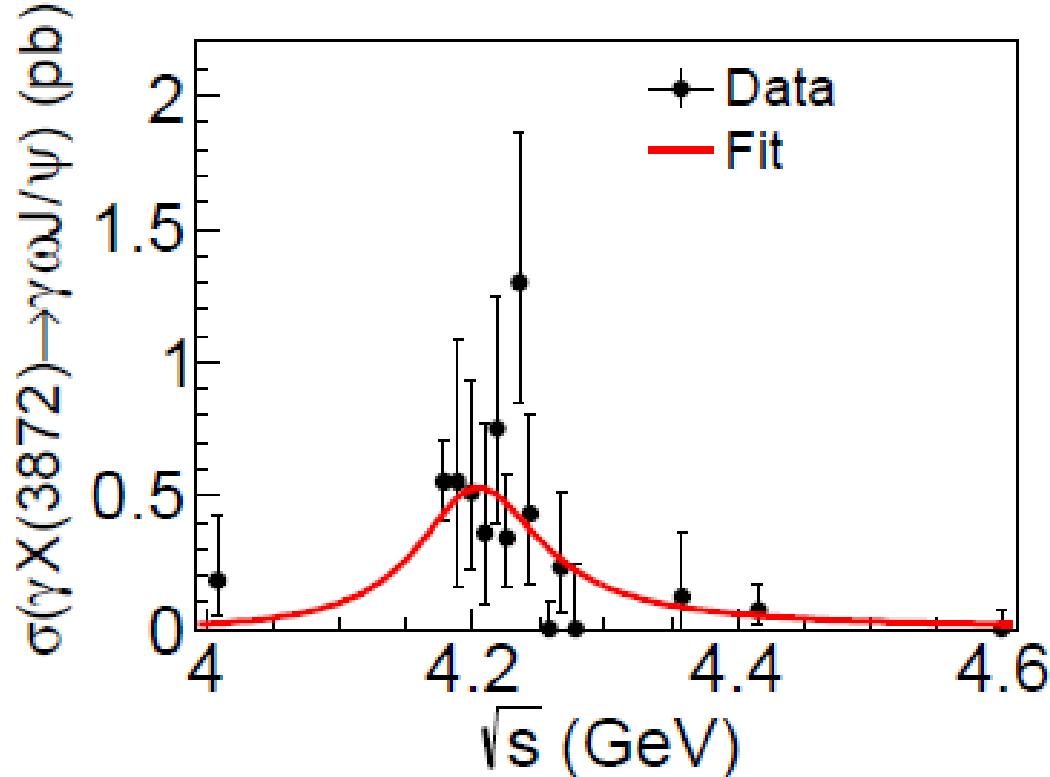
Significant $e^+e^- \rightarrow \gamma\omega J/\psi$ signal, compared with $e^+e^- \rightarrow \gamma_{ISR}\psi(2S)$ [$\psi(2S) \rightarrow \eta J/\psi$]



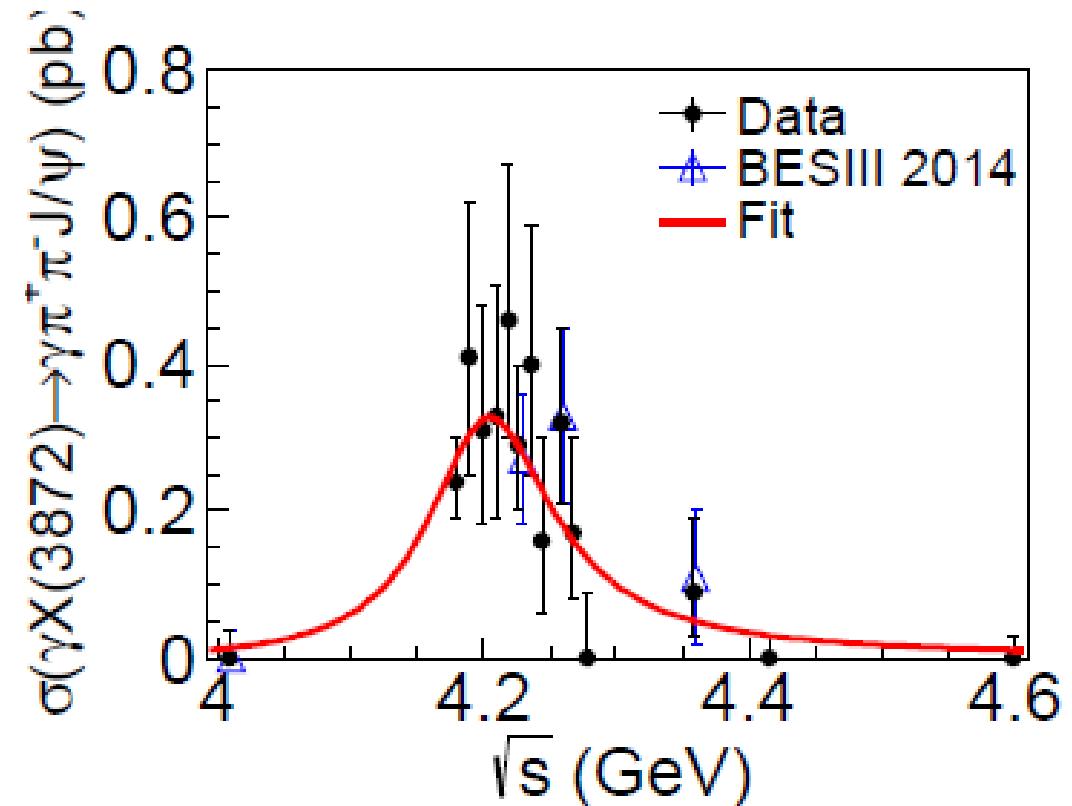
At least one additional BW-formed resonance except $X(3872)$.
 Hard to distinguish the two hypotheses (only 2.5 σ difference):
 additional **one** V.S. **two** resonances.



	Mass	Width
$X(3872)$	3873.3 ± 1.1 (3872.8 ± 1.2)	1.2 (1.2)
$X(3915)$	3926.4 ± 2.2 (3932.6 ± 8.7)	3.8 ± 7.5 (59.7 ± 15.5)
$X(3960)$	3963.7 ± 5.5	33.3 ± 34.2



Simultaneous fit



$$M = 4200.6^{+7.9}_{-13.3} \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma = 115^{+38}_{-26} \pm 12 \text{ MeV}$$

$$\mathcal{R} \equiv \frac{\mathcal{B}[X(3872) \rightarrow \omega J/\psi]}{\mathcal{B}[X(3872) \rightarrow \pi^+ \pi^- J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2, \text{ agree with the previous measurements.}$$

Input for the hadronic molecule interpretation for the X(3872) resonance

$$X(3872) \rightarrow D^0 \bar{D}^{*0} + c.c., \gamma J/\psi, \gamma \psi(2S), \gamma D^+ D^-$$

Combined the BaBar, Belle, and LHCb

$$\frac{\mathcal{B}[X(3872) \rightarrow \gamma \psi(2S)]}{\mathcal{B}[X(3872) \rightarrow \gamma J/\psi]} = 2.31 \pm 0.57$$

$3.4 \pm 1.4, BABAR$	3.6σ and 3.5σ
< 2.1 (90% C.L.), Belle	5.5σ and 0.4σ
$2.46 \pm 0.64 \pm 0.29$, LHCb	$> 8\sigma$ and 4.4σ

Also

$$\frac{\mathcal{B}[X(3872) \rightarrow \gamma J/\psi]}{\mathcal{B}[X(3872) \rightarrow \pi^+ \pi^- J/\psi]} = 0.24 \pm 0.05$$

Significances for $\gamma J/\psi$ and $\gamma \psi(3686)$

$\sim 30 X(3872) \rightarrow \gamma J/\psi$

events expected on BESIII

$\sim 20 X(3872) \rightarrow \gamma \psi(2S)$

A good test for the existing measurements!

Datasets and decay chain

$X(3872) \rightarrow D^0 \bar{D}^{*0} + c.c.$

$D^{*0} \rightarrow \gamma D^0, \pi^0 D^0$

$D^0 \rightarrow K\pi, K\pi\pi, K\pi\pi\pi$

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

$J/\psi \rightarrow \mu\mu/ee$

$X(3872) \rightarrow \gamma\psi(3686)$

$\psi(3686) \rightarrow \pi^+ \pi^- J/\psi$

$\psi(3686) \rightarrow \mu\mu$

$X(3872) \rightarrow \gamma D^+ D^-$

$D^\pm \rightarrow K\pi\pi, K\pi\pi\pi$

\sqrt{s} GeV	Luminosity (pb $^{-1}$)
4.1783	3189.0
4.1888	521.9
4.1989	523.7
4.2092	511.2
4.2187	508.2
4.2263	1092
4.2357	528.9
4.2438	532.7
4.2580	826
4.2668	529.3
4.2777	174.5

Study of $X(3872) \rightarrow \gamma J/\psi, \gamma\psi(3686)$

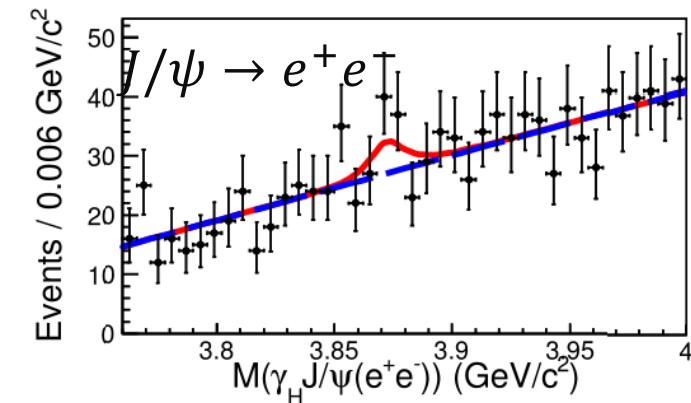
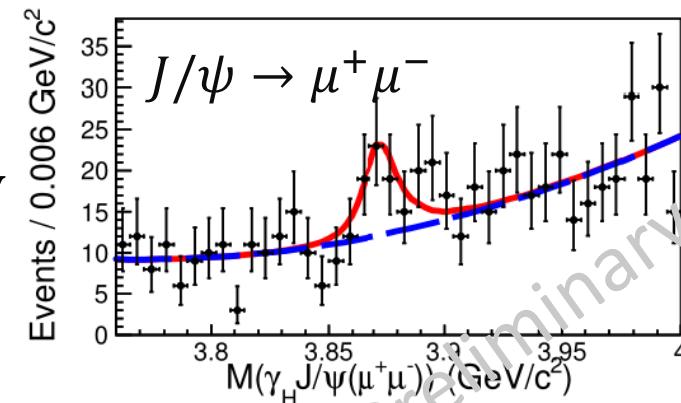
Requirement:

$$\cos\theta_\gamma \in [-0.7, 0.7] \text{ in } J/\psi \rightarrow e^+e^-$$

$$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03) \text{ GeV}$$

$$|M(\gamma_L J/\psi) - m_{\chi_{c1,2}}| > 0.02 \text{ GeV}$$

Simultaneous fit; significance $> 3.5\sigma$



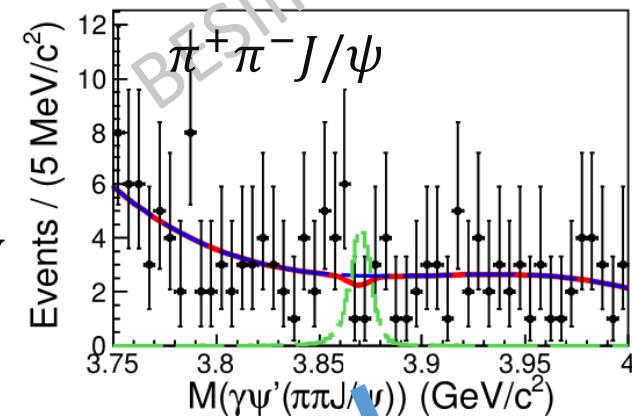
Requirement:

$$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03) \text{ GeV}$$

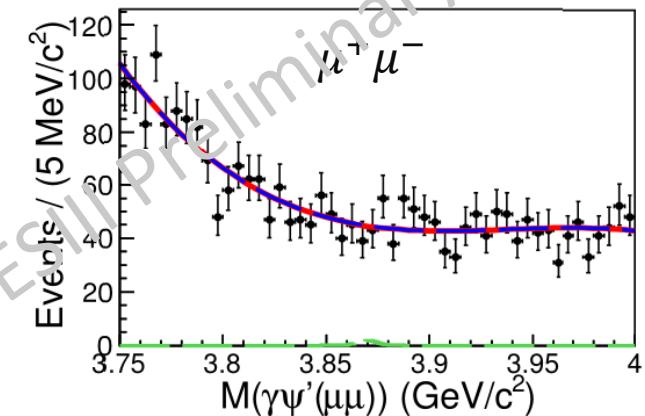
$$|M(\pi^+\pi^-)_{recoil} - m_{\psi(3686)}| > 0.01 \text{ GeV}$$

Simultaneous fit; no evident signal

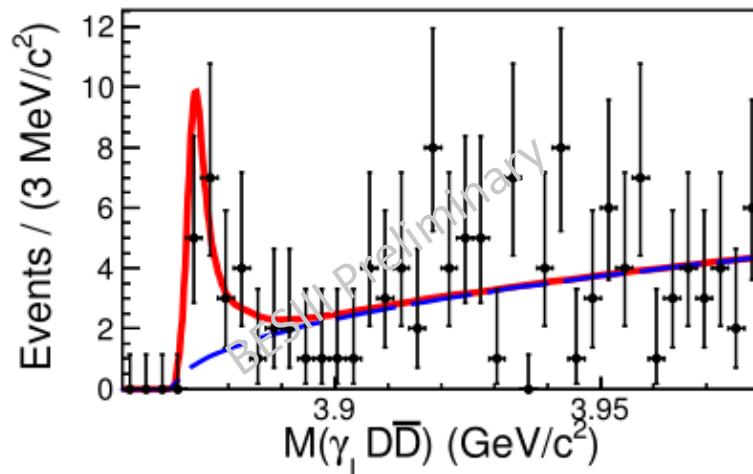
$$\frac{B[X(3872) \rightarrow \gamma\psi(3686)]}{B[X(3872) \rightarrow \gamma J/\psi]} < 0.59 \text{ at 90\% C.L.}$$



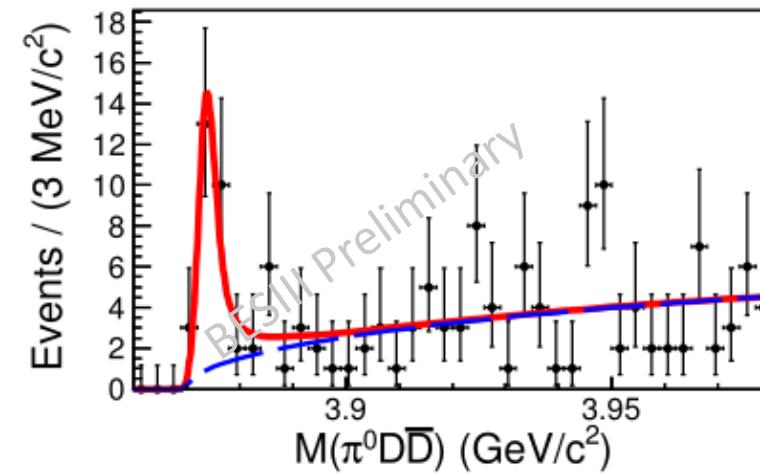
Expectation strength



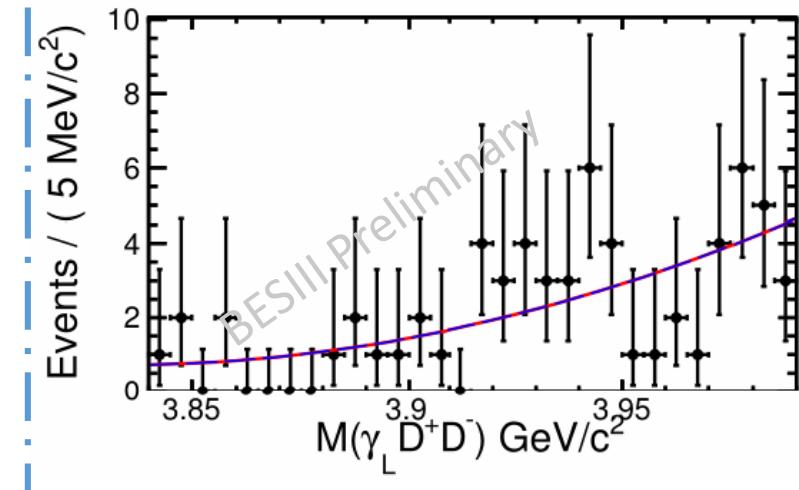
Study of $X(3872) \rightarrow D^0\bar{D}^{*0}$ and γD^+D^-



$$N_{D\bar{D}^*} = (25.5 \pm 4.4)$$



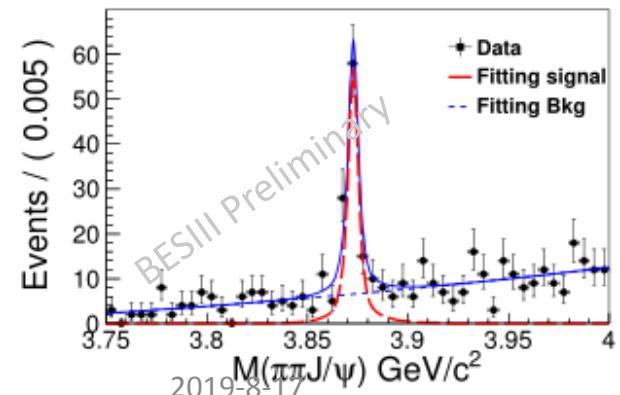
$$N_{D\bar{D}^*} = (32.5 \pm 5.5)$$



$$N_{\gamma D^+D^-} = 0.0^{+0.5}_{-0.0}$$

- Simultaneous fit on $D^{*0} \rightarrow \gamma D^0$ and $\pi^0 D^0$
- Significance $> 7.4\sigma$

No evident signal for γD^+D^-



mode	$D^{*0}D^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99

Using $X(3872) \rightarrow \pi^+\pi^-J/\psi$ as the reference channel.

Summary and outlook

- Great progress achieved at BESIII recently:
 - New decay mode of $X(3872)$ is observed, $X(3872) \rightarrow \pi^0 \chi_{c1}$
 - First firm observation of $X(3872) \rightarrow \omega J/\psi$
 - More decays, $D^0 \bar{D}^{*0} + c.c.$, $\gamma J/\psi$, $\gamma \psi(2S)$, $\gamma D^+ D^-$, are searched and measured

Summary and outlook

Parameter index	Decay mode	Branching fraction
1	$X(3872) \rightarrow \pi^+ \pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \rightarrow D^{*0} \bar{D}^0 + c.c.$	$(52.4^{+25.3}_{-14.3})\%$
3	$X(3872) \rightarrow \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
4	$X(3872) \rightarrow \gamma \psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
5	$X(3872) \rightarrow \pi^0 \chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
6	$X(3872) \rightarrow \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
7	$B^+ \rightarrow X(3872) K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \rightarrow X(3872) K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
$X(3872) \rightarrow \text{unknown}$		$(31.9^{+18.1}_{-31.5})\%$

Inputs of global fit
C.H. Li, C.Z. Yuan
arXiv:1907.09149

The peak cross
section of
 $e^+ e^- \rightarrow \gamma X(3872)$
at 4.226 GeV is
 $5.5^{+2.8}_{-3.6}$ pb

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 - More decays, $D^0 \bar{D}^{*0} + c.c.$, $\gamma J/\psi$, $\gamma \psi(2S)$, $\gamma D^+ D^-$, are searched and measured
- Hint of relation between $X(3872)$ and $Y(42xx)$ states.
- Evidence of $X(3915)$ or $X(3960)$ in $\omega J/\psi$ channel.
- BESIII have more $3.8 fb^{-1}$ $e^+ e^-$ collision data between 4.13 and 4.44 GeV this year, new results are on the way.



Thanks!