$X(3872)$ at BESIII

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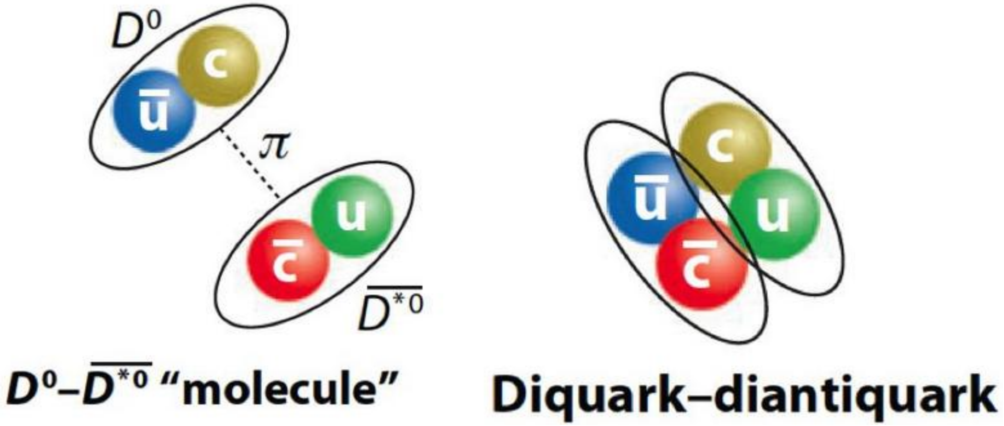
on behalf of BESIII Collaboration

What have we known about $X(3872)$

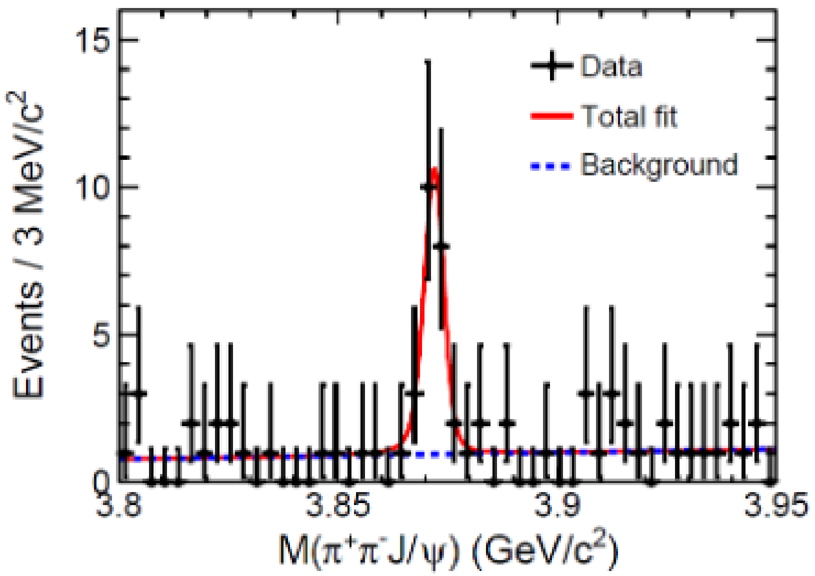
- Mass
  - $3871.68 \pm 0.17 \text{ MeV}/c^2$
  - $B_E = 0.01 \pm 0.20 \text{ MeV}/c^2$
- Width
  - $< 1.2 \text{ MeV}$
- $J^{PC} = 1^{++}$
- Production
  - In $pp/p\bar{p}$ collision
  - In B decays
  - In Y decays
- Decay
  - $\pi^+\pi^- J/\psi$ and $\omega J/\psi$
  - $\gamma J/\psi$ and $\gamma\psi(3686)$
  - $D^0\bar{D}^{*0} + c.c.$

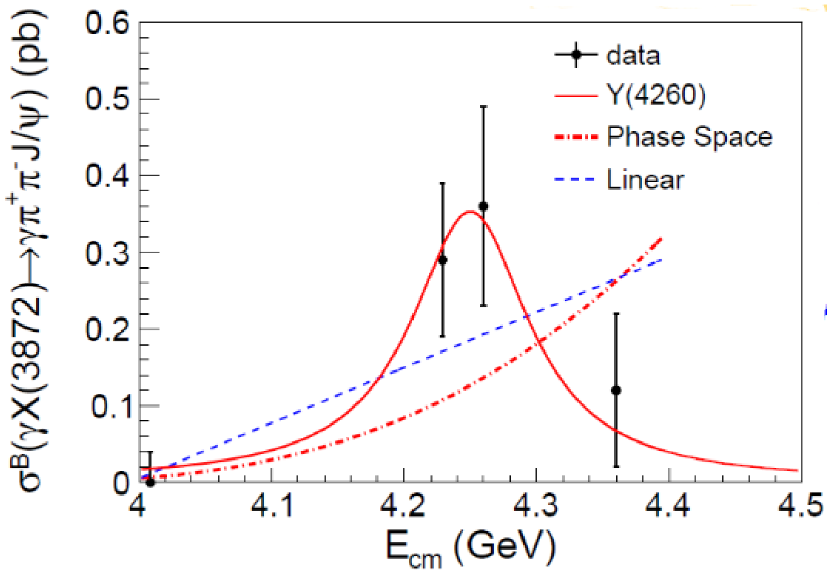
- What is it?
  - **Loosely $D^0\bar{D}^{0*}$ bound state?**
  - **Mixture of $\chi_{c1}{}'$ and $D^0\bar{D}^{0*}$?**
  - **Cusp?**
  - **Tetraquarks?**



What BESIII have contributed

[PRL 112,092001(2014)]





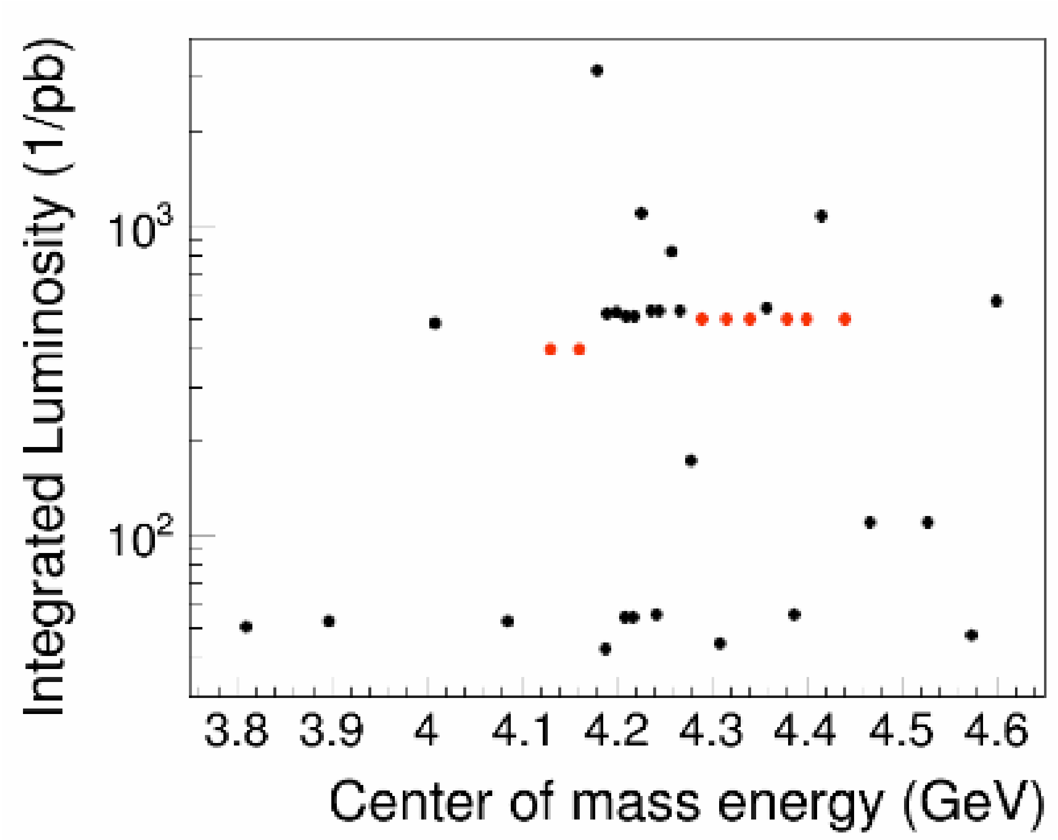
A new $X(3872)$ production mode

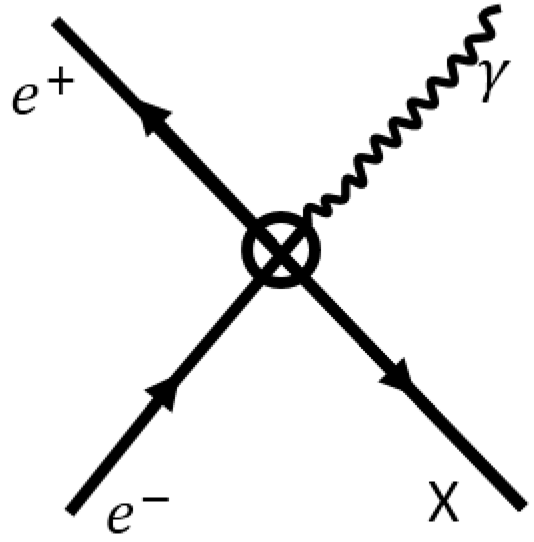
If we take $\mathcal{B}(X(3872) \to \pi\pi J/\psi)$~5% (>3.2% in PDG)

$$\frac{\sigma\left(e^+e^-\to\gamma X(3872)\right)}{\sigma(e^+e^-\to\pi\pi J/\psi)} \sim 10\% \text{ around } Y(4260)$$

Large production rate, low background level

What BESIII now have



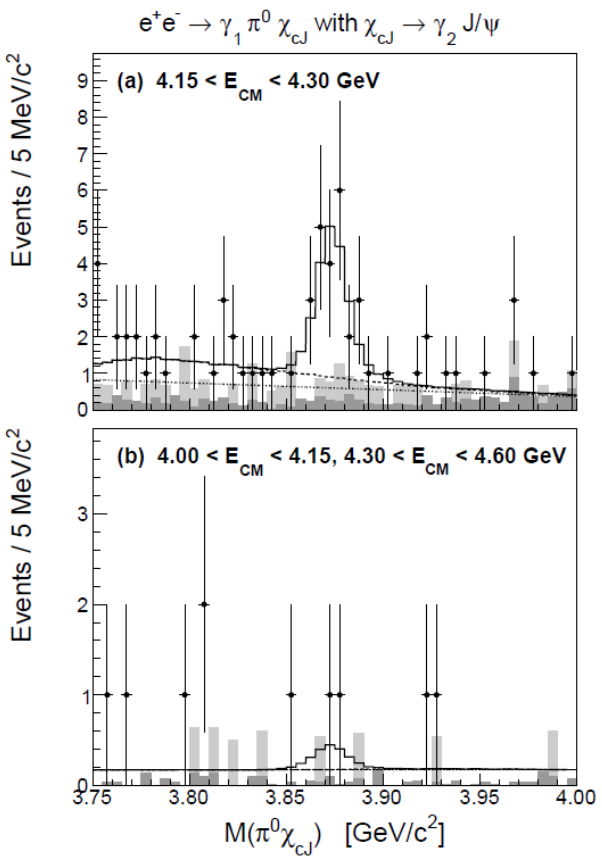


- ➢Massive data sample around the $Y(4230)$ peak, with the total integrated luminosity larger than $9.0\ \mathrm{fb}^{-1}$
- ➢More data are being taken this year.
- ➢Background is much lower than in other productions.

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

- In conventional $c\bar{c}$ hypothesis, $\Gamma\big(X(3872) \to \pi^0\chi_{c1}(1P)\big) \sim 0.06\ \mathrm{keV}$
- In tetraquark/molecular state hypothesis, the decay width could be sizeable.

  [PRD **77**, 014013(2008)], [PRD 92, 034019(2015)]



- $\chi_{cJ}(1P)$ mass window: $[3.35,\ 3.60]\ \mathrm{GeV/c^2}$.
- Very clear signal of $X(3872)$, $N_{X(3872)} = 16.9^{+5.2}_{-4.9}$
- Statistical significance is 4.8σ
- No $X(3872)$ events outside of $Y(4260)$ zone

arXiv:1901.03992

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

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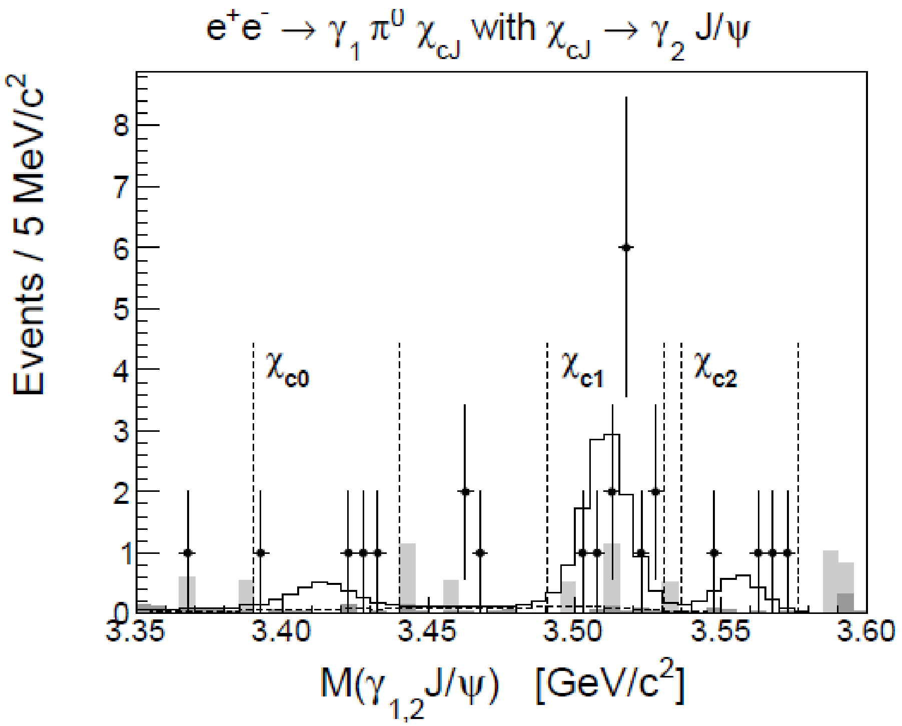
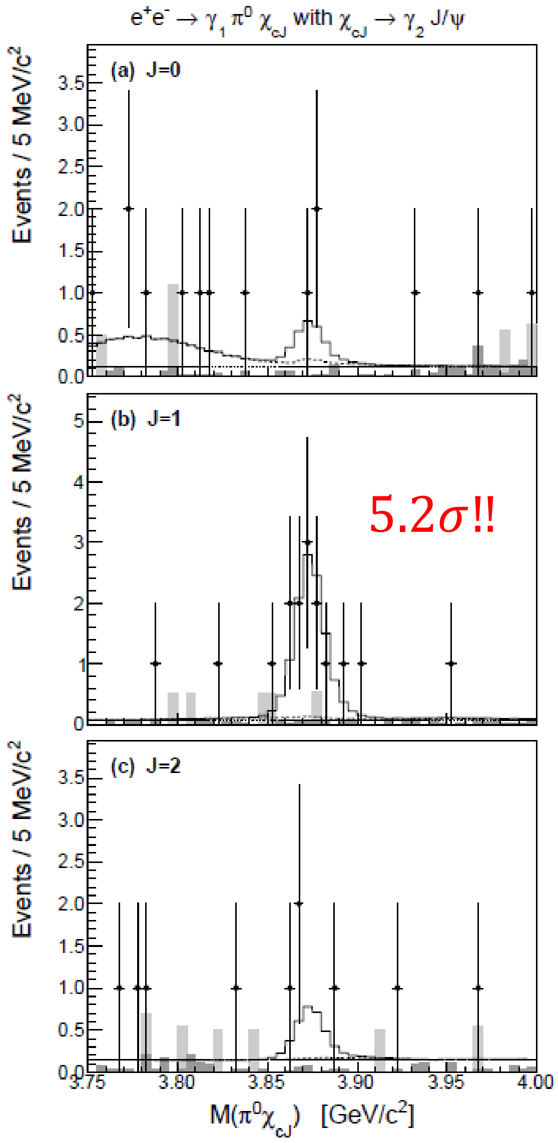




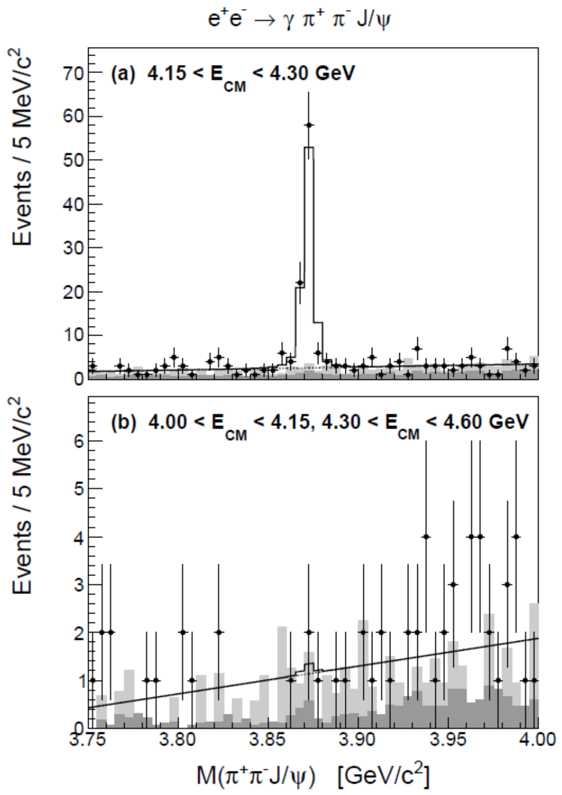
5.2σ!!

- After $X(3872)$ mass window cut applied, very clear cluster of $\chi_{c1}(1P)$ events
- $|M(\gamma_2 J/\psi) - M_0(\chi_{cJ})| < 25(20)\ MeV/c^2$ for $J = 0(1,2)$
- Sum J = 0,1,2, $N_{X(3872)} = 15.1^{+4.8}_{-3.8}$

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

	$\pi^+\pi^- J/\psi$	$\pi^0\chi_{c0}$	$\pi^0\chi_{c1}$	$\pi^0\chi_{c2}$
Event yield	$84.1^{+10.1}_{-9.4}$	$1.9^{+1.9}_{-1.3}$	$10.8^{+3.8}_{-3.1}$	$2.5^{+2.3}_{-1.7}$
Significance (σ)	16.1	1.6	5.2	1.6
Ratio to $\pi^+\pi^- J/\psi$	…	$6.6^{+6.5}_{-4.5} \pm 1.1\ (19)$	$0.88^{+0.33}_{-0.27} \pm 0.10$	$0.40^{+0.37}_{-0.27} \pm 0.04(1.1)$

*Numbers in the parentheses are upper limits at 90% C.L.



- Using $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) > 3.2\%$ and $< 6.4\%$, it is found that
$$\mathcal{B}\big(X(3872) \to \pi^0\chi_{c1}(1P)\big) \sim 3 - 6\%$$

- Using $\Gamma_{X(3872)} \sim 1.2$ MeV, we get the predicted
$$\mathcal{B}\big(X(3872) \to \pi^0\chi_{c1}(1P)\big) \sim 0.5\%$$

- Conclusion: disfavor the $c\bar{c}$ interpretation of the $X(3872)$.

arXiv:1901.03992

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

arXiv:1903.04695

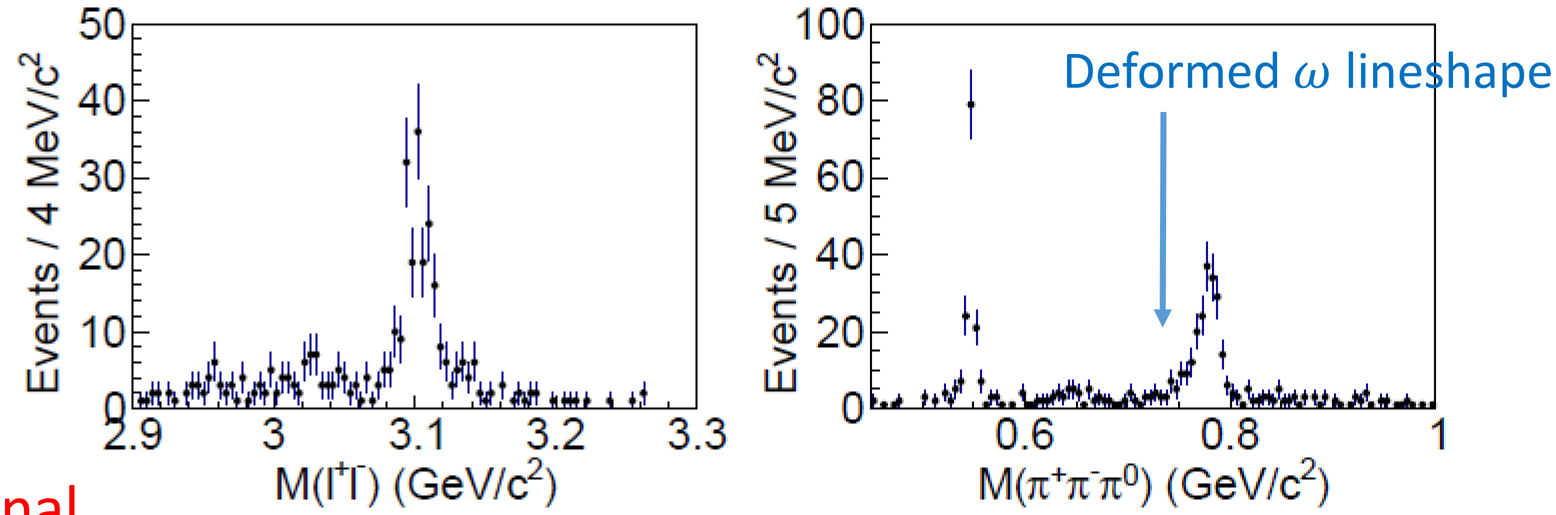
- Belle and *BABAR* reported 4σ evidence for this decay, and give

$$\frac{\mathcal{B}(X(3872) \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

- BESIII is expected to find $\sim 70\ X(3872) \to \omega J/\psi$ events with the data accumulated around $Y(4230)$.

Full reconstruction

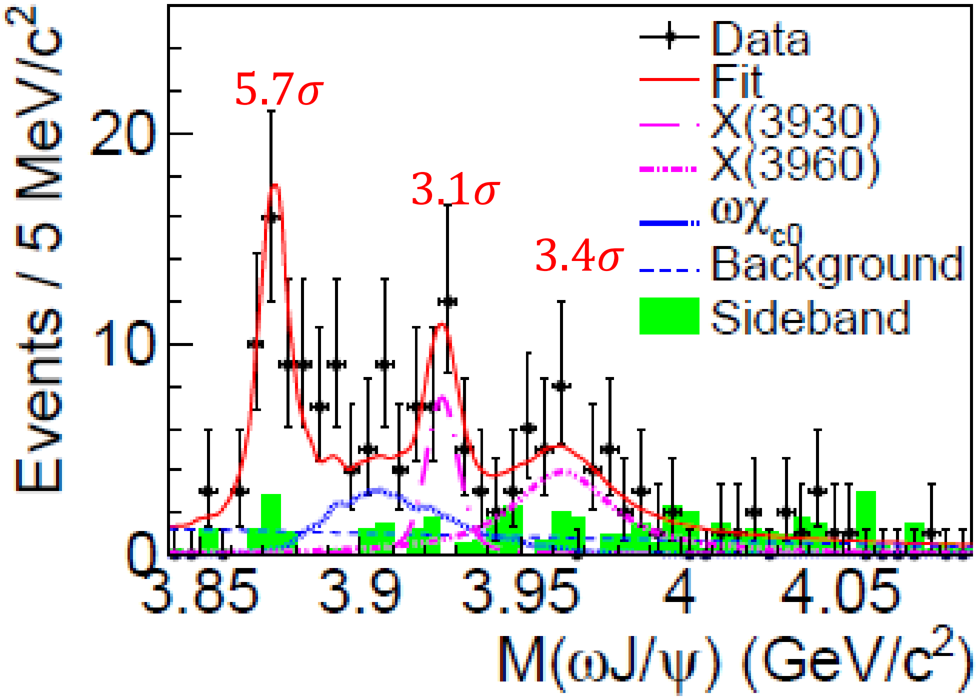
Use $J/\psi \to e^+e^-/\mu^+\mu^-$

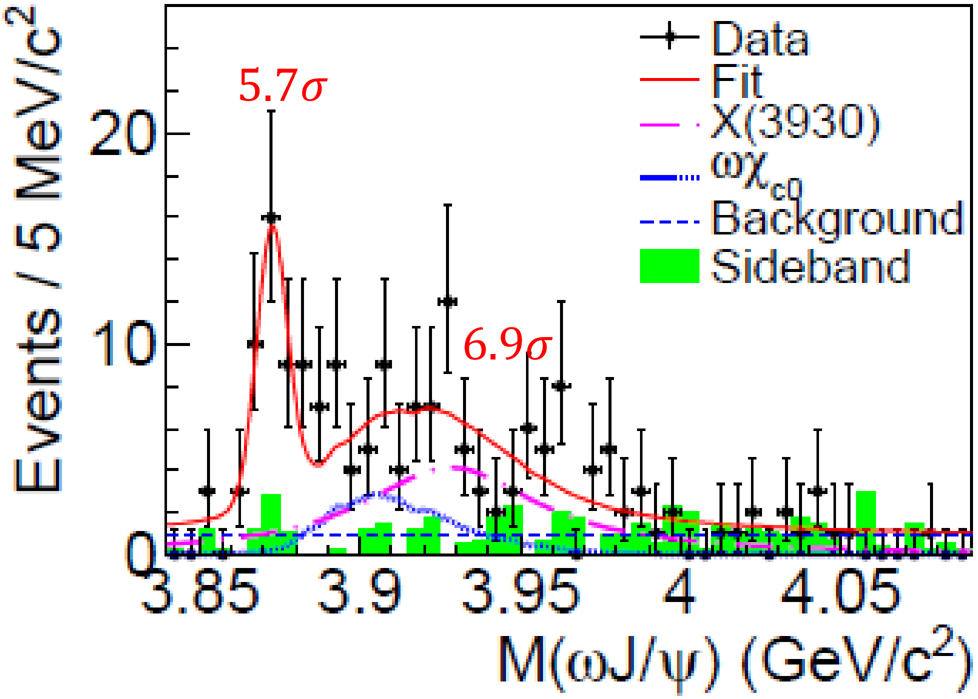


Significant $e^+e^- \to \gamma\omega J/\psi$ signal,
compared with $e^+e^- \to \gamma_{ISR}\psi(2S)$ $[\psi(2S) \to \eta J/\psi]$

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

arXiv:1903.04695





At least one additional BW-formed resonance expect $X(3872)$

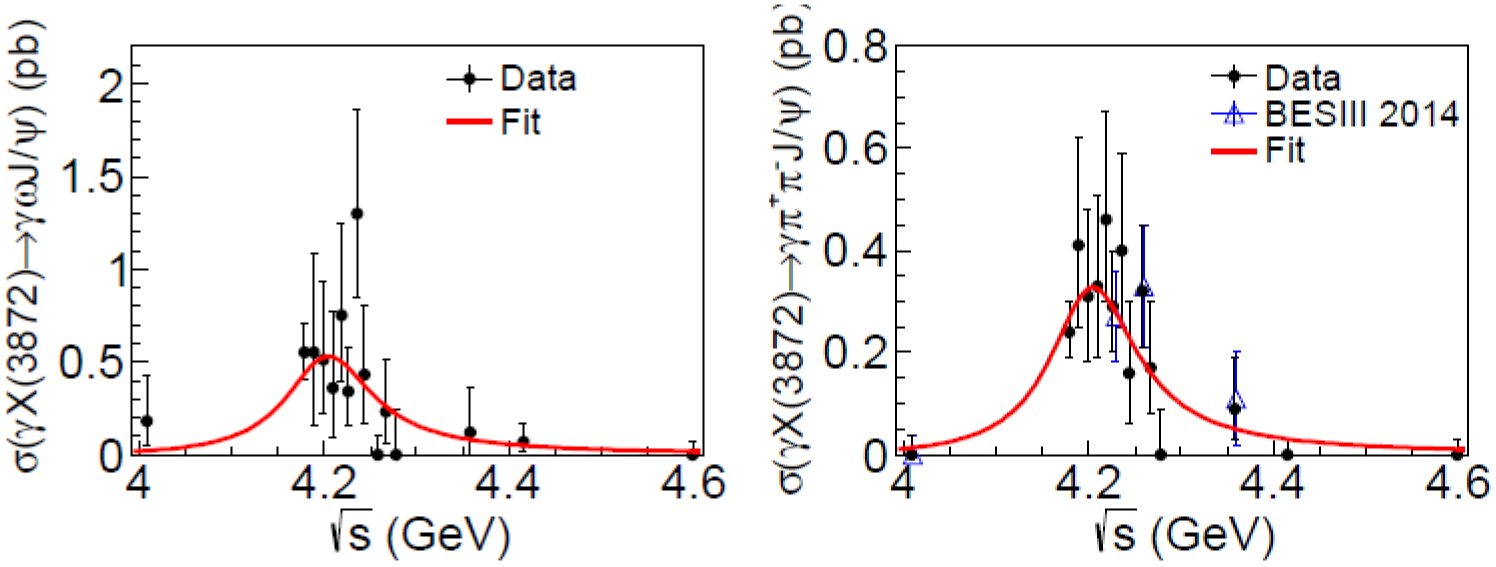
- $X(3915)$ along with $X(3960)$.
- or $X(3930)$

Hard to distinguish the two hypotheses since only 2.5σ difference between them.

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

arXiv:1903.04695

	$X(3872)$	$X(3915)$	$X(3960)$	$X(3930)$
Mass (in MeV/c^2)	$3873.3 \pm 1.1 \pm 1.0$	$3926.4 \pm 2.2 \pm 1.2$	$3963.7 \pm 5.5 \pm 1.3$	$3932.6 \pm 8.7 \pm 4.7$
Width (in MeV)	1.2	$3.8 \pm 7.5 \pm 2.6$	$33.3 \pm 34.2 \pm 8.3$	$59.7 \pm 15.5 \pm 3.7$



$$M = 4200.6^{+7.9}_{-13.3} \pm 3.0\ \mathrm{MeV}/c^2$$
$$\Gamma = 115^{+38}_{-26} \pm 12\ \mathrm{MeV}$$

- By fitting the cross sections of $e^+e^- \to \gamma X(3872)$ with $X(3872) \to \omega J/\psi$ and $X(3872) \to \pi^+\pi^- J/\psi$, we give

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

0.8 ± 0.3 from *BABAR*

More measurements

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

Combined the BaBar, Belle, and LHCb

$$\frac{\mathcal{B}[X(3872)\to\gamma\psi(2S)]}{\mathcal{B}[X(3872)\to\gamma J/\psi]} = 2.31 \pm 0.57 \quad \begin{cases} 3.4 \pm 1.4, BABAR \\ < 2.1\ (90\% C.L.), \text{Belle} \\ 2.46 \pm 0.64 \pm 0.29, \text{LHCb} \end{cases}$$

3.6σ and 3.5σ

5.5σ and 0.4σ

$>$ 8σ and 4.4σ

Also

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

$\sim$30 $X(3872) \to \gamma J/\psi$ and $\sim$20 $X(3872) \to \gamma\psi(2S)$ events expected on BESIII

A good test for the existing measurements!

Datasets and decay chain

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

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

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

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

$J/\psi \to \mu\mu/ee$

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

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

$\psi(3686) \to \mu\mu$

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

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

$\sqrt{s}$ 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 $X(3872) \to \gamma J/\psi, \gamma\psi(3686)$

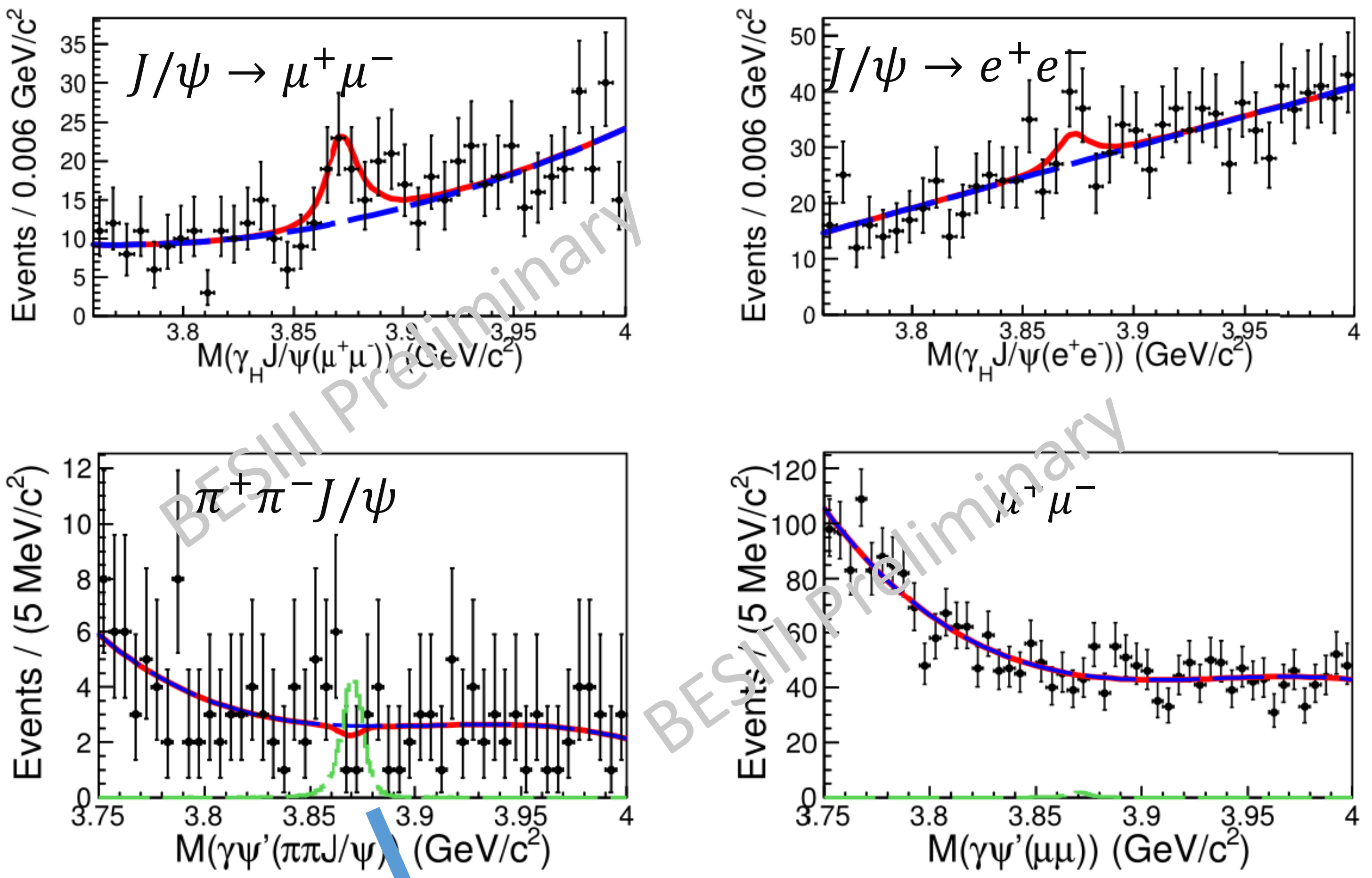
Requirement:

$cos\theta_\gamma \in [-0.7,\ 0.7]$ in $J/\psi \to e^+e^-$

$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03)\ \mathrm{GeV/c^2}$

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

Simultaneous fit; significance $> 3.5\sigma$



Requirement:

$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03)\ \mathrm{GeV/c^2}$

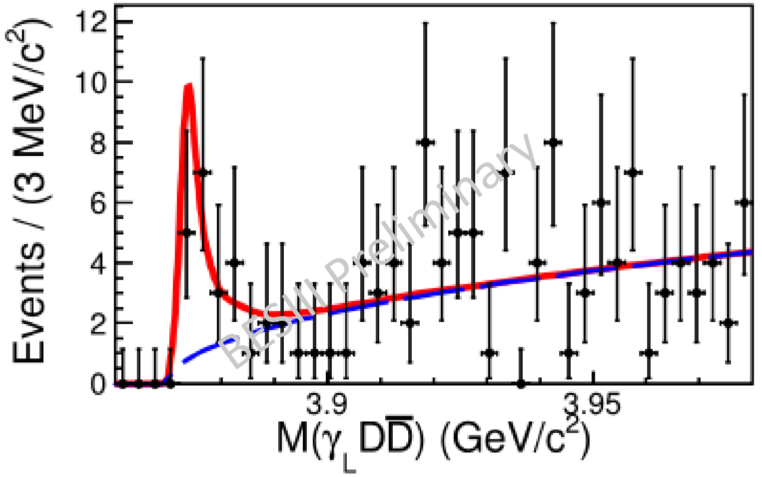
$|M(\pi^+\pi^-)_{recoil} - m_{\psi(3686)}| > 0.01\ \mathrm{GeV/c^2}$

Simultaneous fit; no evident signal

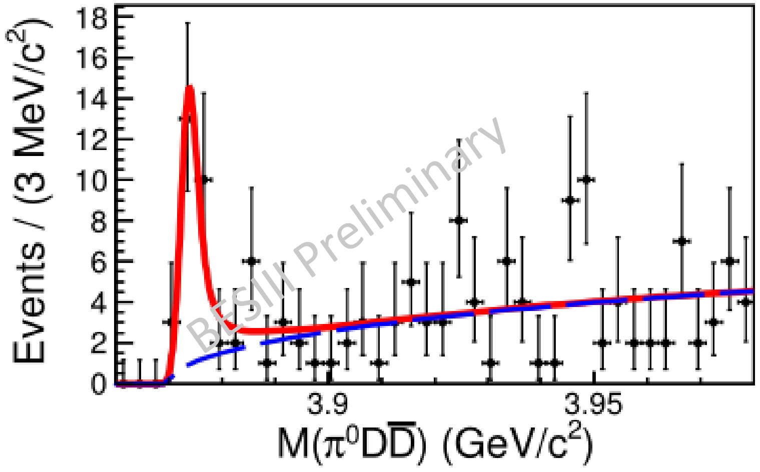
$$\frac{B[X(3872)\to\gamma\psi(3686)]}{B[X(3872)\to\gamma J/\psi]} < 0.59 \text{ at 90\% C.L.}$$

Expectation strength

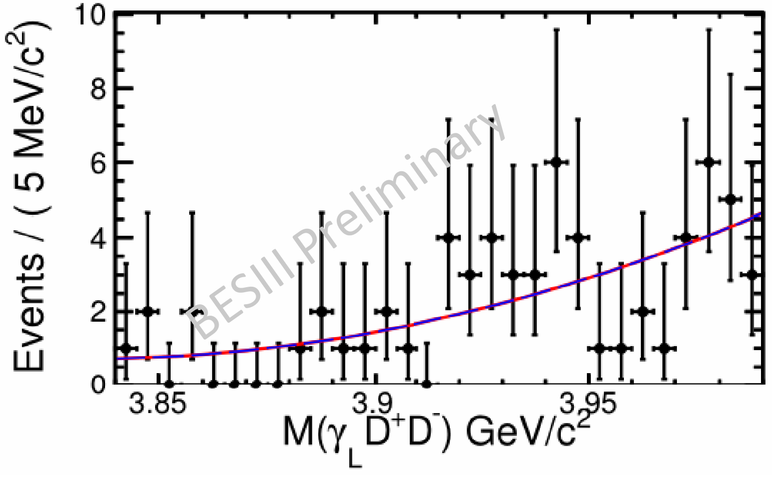
Study of $X(3872) \to D^0\bar{D}^{*0}$ and γD^+D^-



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



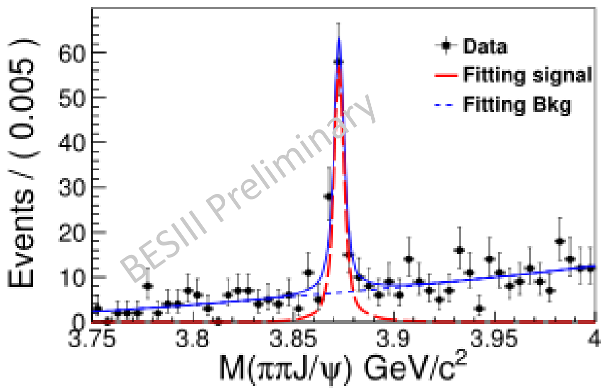
$N_{DD^*} = (32.5 \pm 5.5)$



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

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

No evident signal for γD^+D^-



mode	$D^{*0}\bar{D}^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-	$\omega J/\psi$	$\pi^0\chi_{c1}$
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99	$1.7^{+0.4}_{-0.3} \pm 0.2$ [27]	$0.88^{+0.33}_{-0.27} \pm 0.10$ [37]

BESIII Preliminary

arXiv:1903.04695

arXiv:1901.03992

Using the same way in Ref.[PRL **112**, 092001(2014)] to reconstruct $X(3872) \to \pi^+\pi^- J/\psi$ as the reference channel.

Summary and outlook

- Great progress achieved recently:
  - New decay mode of $X(3872)$ is observed, $X(3872) \to \pi^0 \chi_{c1}$
  - First firm observation of $X(3872) \to \omega J/\psi$
  - More decays are searched and measured
- BESIII provide essential test for the existing measurements
- BESIII is taking more data

Back up

Background suppression

- π^0/η suppression
  - In decays with two photons in final states
  - $|M(\gamma_L\gamma_H) - m_{\pi^0}| > 0.02\ \mathrm{GeV/c^2}$, $|M(\gamma_L\gamma_H) - m_\eta| > 0.03\ \mathrm{GeV/c^2}$
- $X(3872) \to \gamma J/\psi$
  - $cos\theta_\gamma \in [-0.7,\ 0.7]$ in $J/\psi \to e^+e^-$
  - $|M(\gamma_L J/\psi) - m_{\chi_{c1,2}}| > 0.02\ \mathrm{GeV/c^2}$
- $X(3872) \to \gamma\psi(3686)$
  - $|M(\pi^+\pi^-)_{recoil} - m_{\psi(3686)}| > 0.01\ \mathrm{GeV/c^2}$

Calculating the upper limits of the relative ratios

- In calculating the relative ratios, the statistical uncertainty of both denominator and numerator must be considered.
  - For example, in calculating the $\frac{B[X(3872)\to\gamma J/\psi]}{B[X(3872)\to\gamma\psi(3686)]}$, we sampling the likelihood distribution for $\gamma J/\psi$ and $\gamma\psi(3686)$ mode randomly.
  - After thousands of sampling, the likelihood distribution of the ratio could be obtained, in which the statistical uncertainties from both channels are considered.
  - Then a Gaussian presented the systematic uncertainty is smeared on the distribution.
  - Thus the new distribution would be the distribution of the ratio considering the statistical and systematic uncertainties.