

BESIII

Recent results on XY from BESIII



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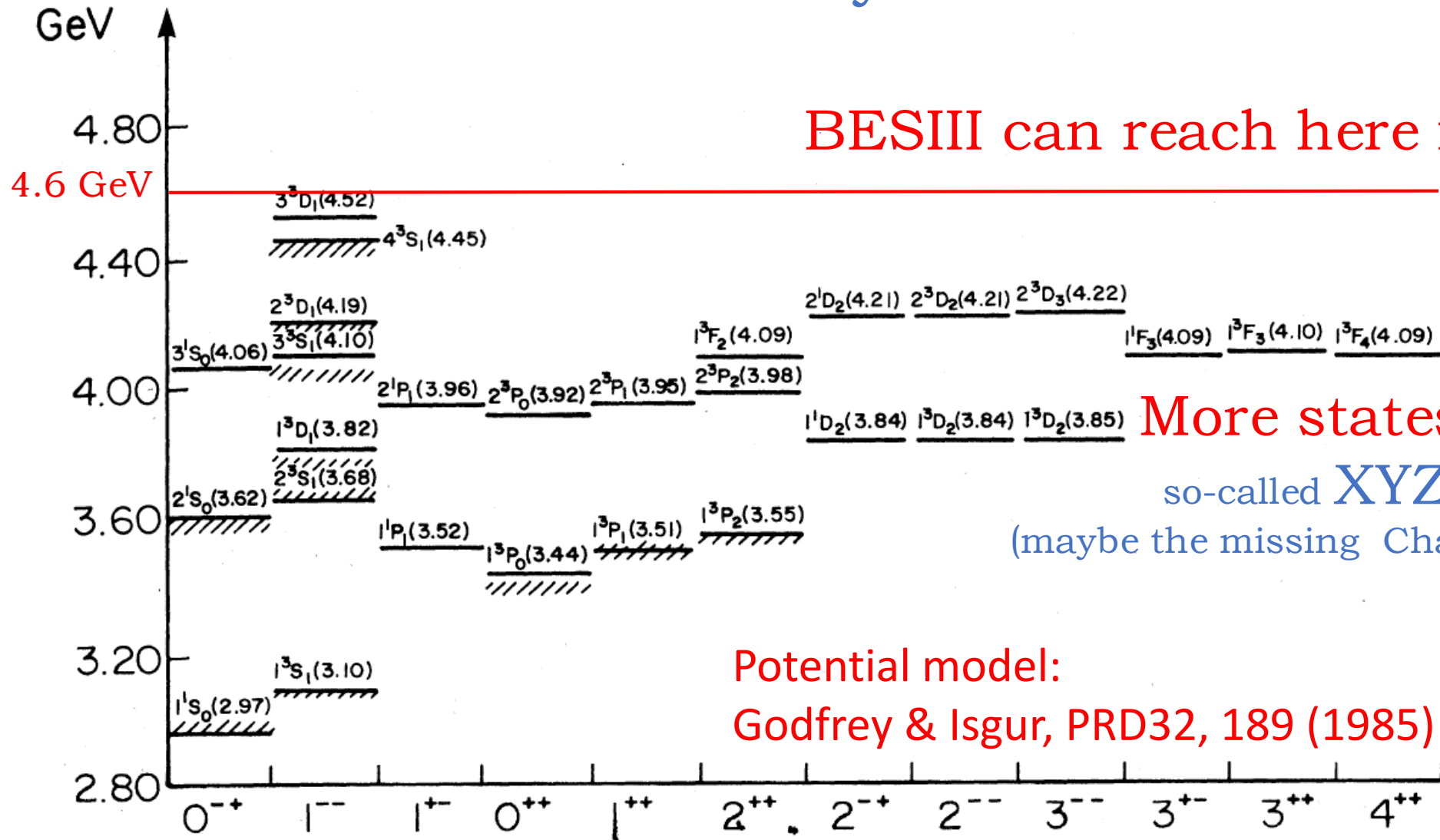
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Outline:

- What we can study at BESIII
- Recent results on XY
 - Observation of $X(3823) (\psi(1^3D_2))$ ([arXiv:1503.08203](#))
 - Search for $Y(4140)$ via $e^+e^- \rightarrow \gamma\phi J/\psi$ ([PRD 91,032002](#))
 - Study of $\omega\chi_{c0}$ ([PRL 114,092003](#))
 - Cross section of $e^+e^- \rightarrow \eta J/\psi$ ([arXiv: 1503.06644](#))
 - Cross section of $e^+e^- \rightarrow \eta' J/\psi$ ([preliminary](#))
 - Search for $e^+e^- \rightarrow \gamma\chi_{cJ}$ ([CPC, 39\(4\) \(2015\) 041001](#))
- Summary

What we can study at BESIII



BESIII can reach here for now

More states?

so-called XYZ

(maybe the missing Charmonium)

Potential model:

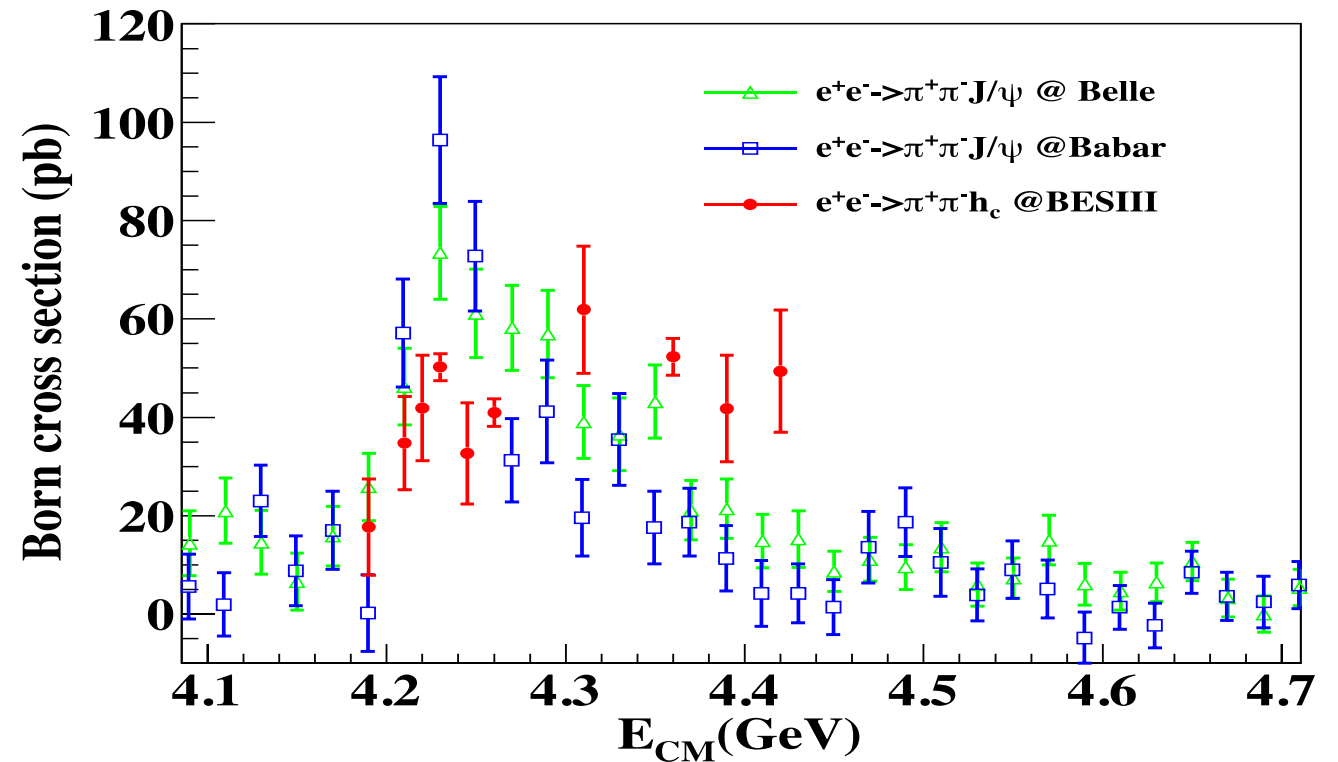
Godfrey & Isgur, PRD32, 189 (1985)

Property of $Y(4260)$ and other Y states

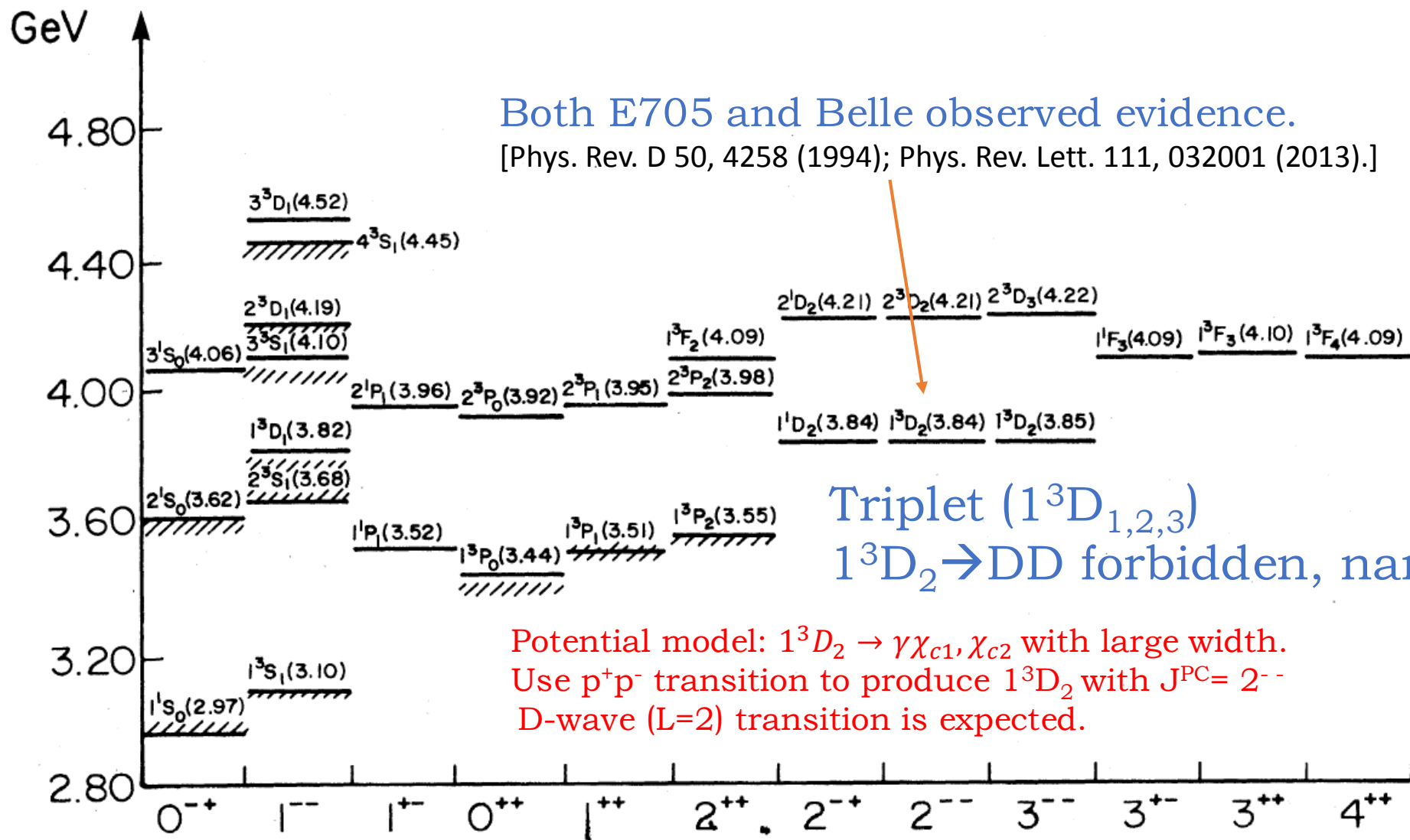
Try to search and study the Y decays exclusively at BESIII

- Cross section of $e^+e^- \rightarrow \pi\pi J/\psi$ (h_c)
- Observation of $e^+e^- \rightarrow \gamma X(3872)$ indicates $Y(4260) \rightarrow \gamma X(3872)$
- Study of $\omega\chi_{c0}$
- Cross section of $e^+e^- \rightarrow \eta J/\psi$
- Cross section of $e^+e^- \rightarrow \eta' J/\psi$
- Search for $e^+e^- \rightarrow \gamma\chi_{cJ}$

Others are on-going



Observation of X(3823) ($\psi(1^3D_2)$)

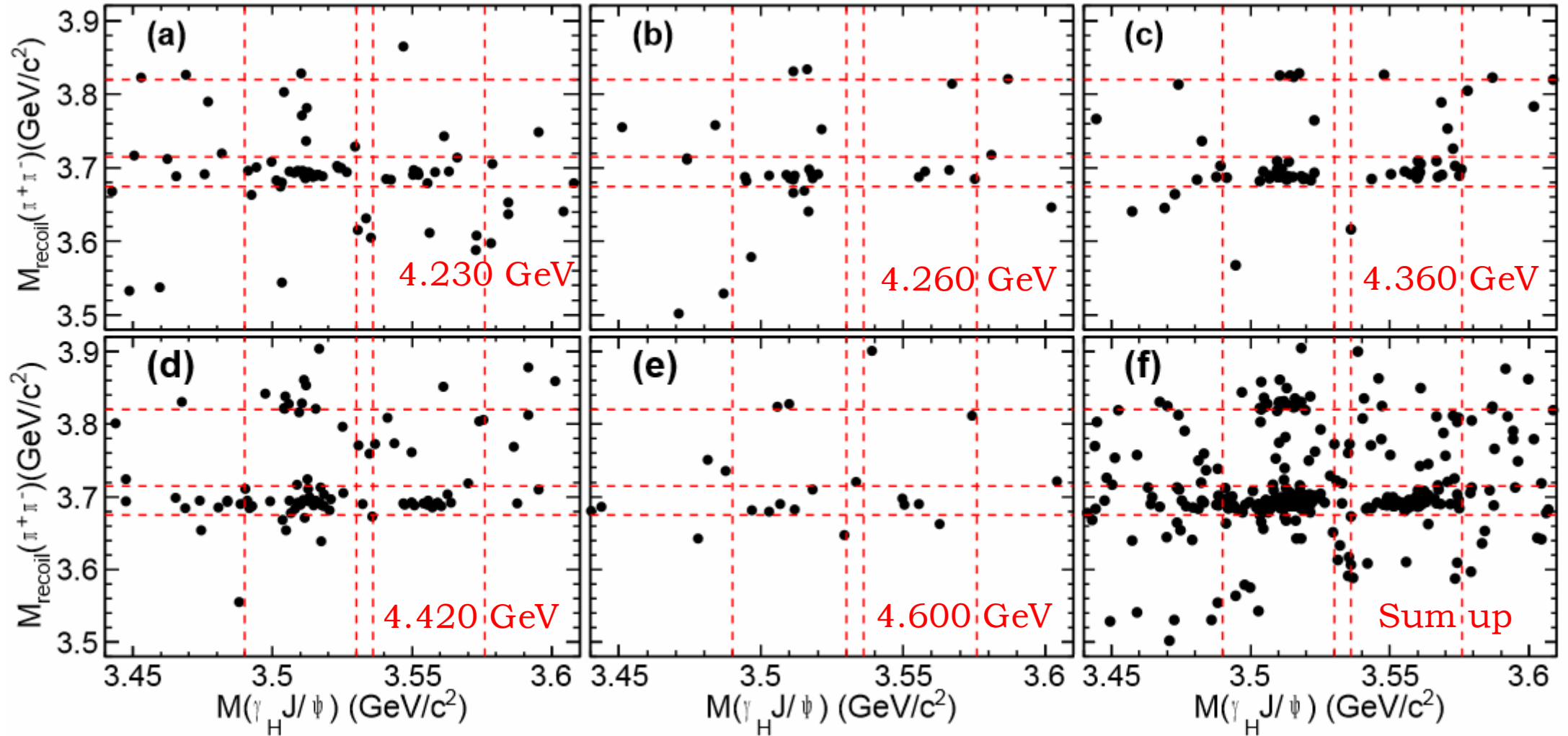


Both E705 and Belle observed evidence.
 [Phys. Rev. D 50, 4258 (1994); Phys. Rev. Lett. 111, 032001 (2013).]

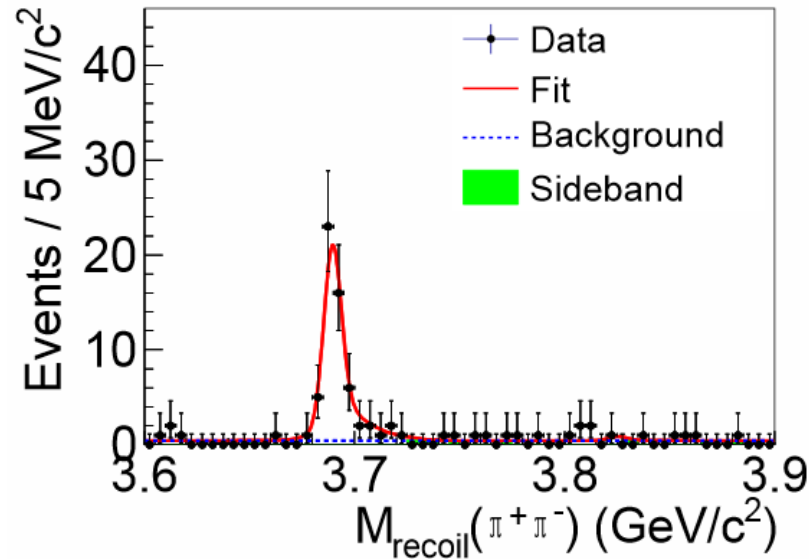
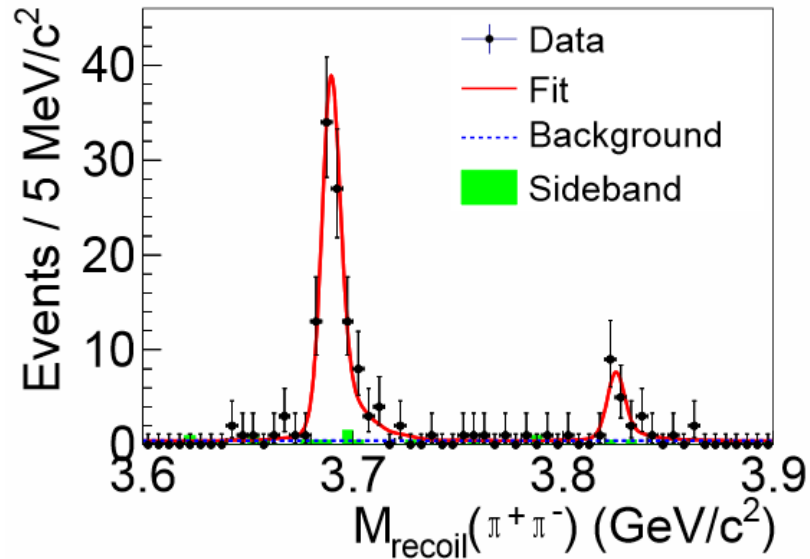
Triplet ($1^3D_{1,2,3}$)
 $1^3D_2 \rightarrow DD$ forbidden, narrow

Potential model: $1^3D_2 \rightarrow \gamma \chi_{c1}, \chi_{c2}$ with large width.
 Use p^+p^- transition to produce 1^3D_2 with $J^{PC} = 2^{--}$
 D-wave ($L=2$) transition is expected.

$$e^+e^- \rightarrow \pi^+\pi^-X, X \rightarrow \gamma\chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi$$



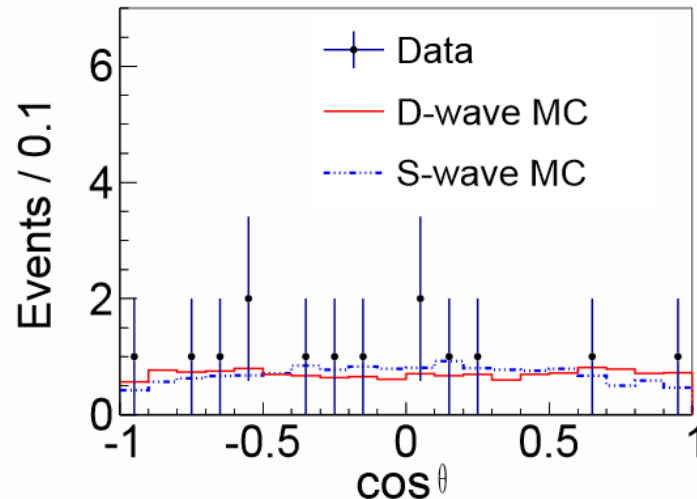
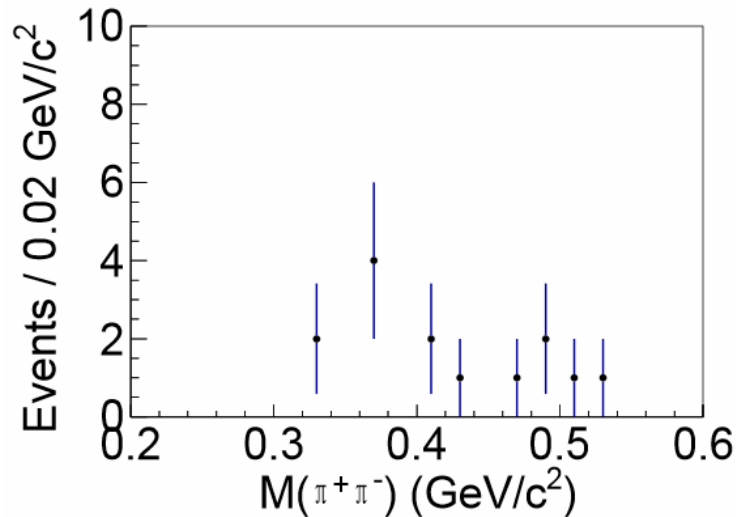
arXiv:1503.08203



Simultaneous fit of $\gamma\chi_{c1}$ (left) and $\gamma\chi_{c2}$ (right) events

$$M(X(3823)) = (3821.7 \pm 1.3(stat) \pm 0.7(syst)) \text{ MeV}/c^2$$

$$\Gamma(X(3823)) < 16 \text{ MeV at 90\% C. L. consist with Belle}$$



D-wave is expected.
Limited statistics
limited informations

Born cross section $\sigma[e^+e^- \rightarrow \pi^+\pi^-X(3823)] \cdot \mathcal{B}(X(3823) \rightarrow \gamma\chi_{c1})$

$$\frac{\sigma[e^+e^- \rightarrow \pi^+\pi^-X(3823)] \cdot \mathcal{B}(X(3823) \rightarrow \gamma\chi_{c1})}{\sigma[e^+e^- \rightarrow \pi^+\pi^-\psi'] \cdot \mathcal{B}(\psi' \rightarrow \gamma\chi_{c1})} \text{ (pb)}$$

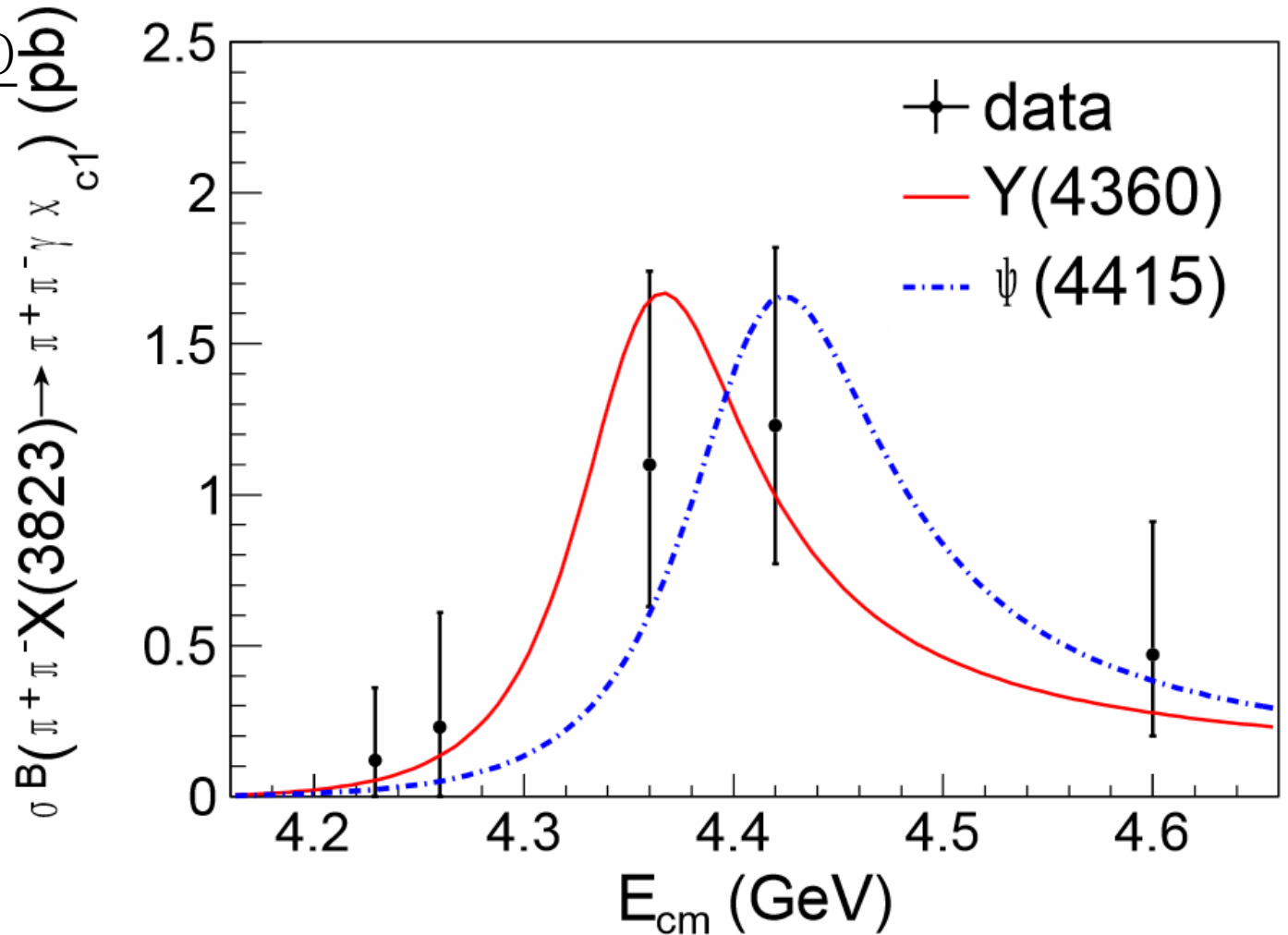
$$= 0.20^{+0.13}_{-0.10} \text{ (4.36 GeV)}$$

$$= 0.39^{+0.21}_{-0.17} \text{ (4.42 GeV)}$$

$$\frac{\mathcal{B}(X(3823) \rightarrow \gamma\chi_{c2})}{\mathcal{B}(X(3823) \rightarrow \gamma\chi_{c1})}$$

$$< 0.42 \text{ at 90\% C.L.}$$

$$\approx 0.24 \text{ (PRD 55,4001)}$$



Search for $Y(4140)$ via $e^+e^- \rightarrow \gamma\phi J/\psi$

Exist

CDF (3.8σ) $B^+ \rightarrow \phi J/\psi K^+$

CDFII ($>5\sigma$) $B^+ \rightarrow \phi J/\psi K^+$

6.0 fb^{-1} at $\sqrt{s} = 1.96\text{ TeV}$

CMS $B^+ \rightarrow \phi J/\psi K^+$

5.2 fb^{-1} at $\sqrt{s} = 7\text{ TeV}$

D0 (3.1σ) $B^+ \rightarrow \phi J/\psi K^+$

10.4 fb^{-1} at $\sqrt{s} = 1.96\text{ TeV}$

V.S.

or not?

Belle $\gamma\gamma \rightarrow \phi J/\psi$

825 fb^{-1} e^+e^- collider

Belle $B^+ \rightarrow \phi J/\psi K^+$ $772 \times 10^6 \bar{B}B$

LHCb $B^+ \rightarrow \phi J/\psi K^+$

0.37 fb^{-1} at $\sqrt{s} = 7\text{ TeV}$

(2.4σ) disagreement with CDF

BABAR $B^+ \rightarrow \phi J/\psi K^+$ $469 \times 10^6 \bar{B}B$

A good candidate for $D_s^* \bar{D}_s^*$ molecular.

Positive C-parity,

radiative transition of 1^{--} charmonium (-like) states at BESIII?

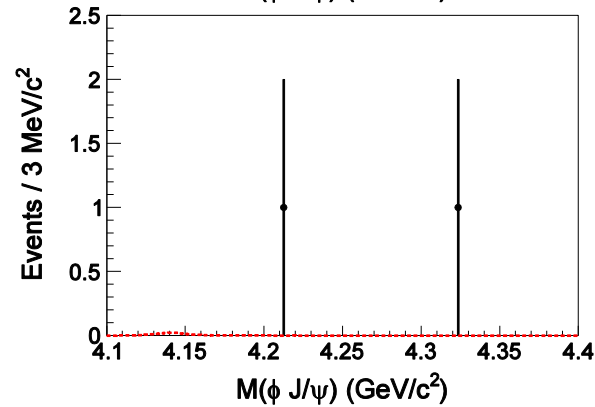
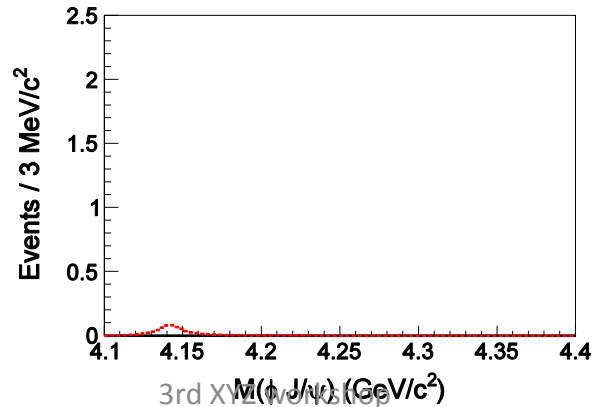
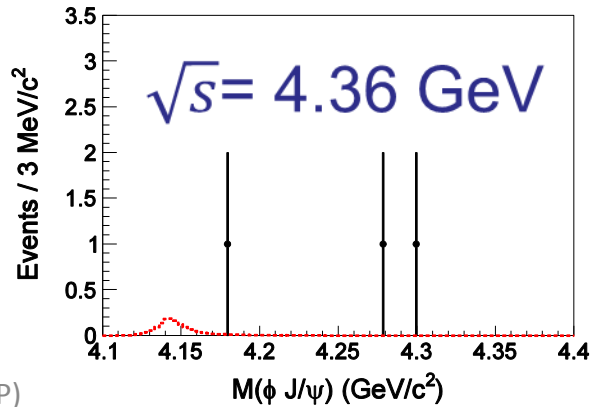
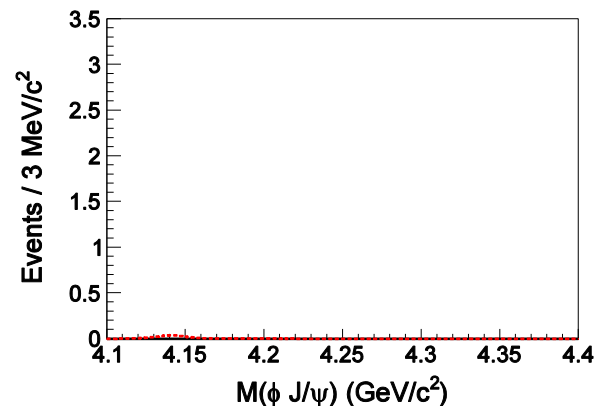
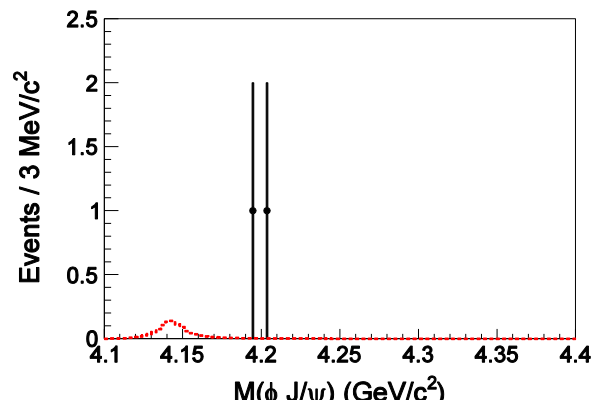
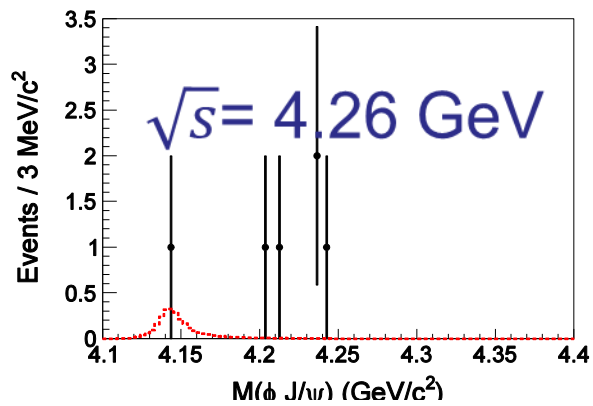
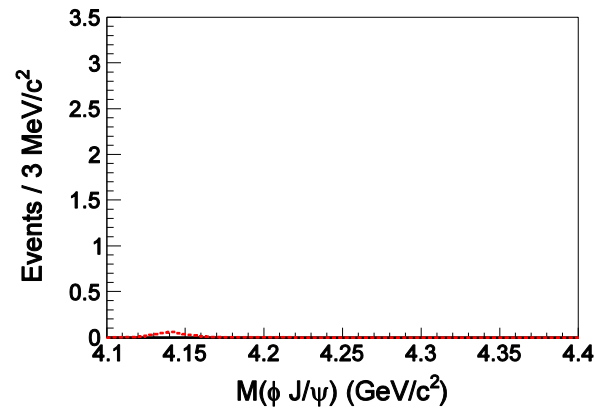
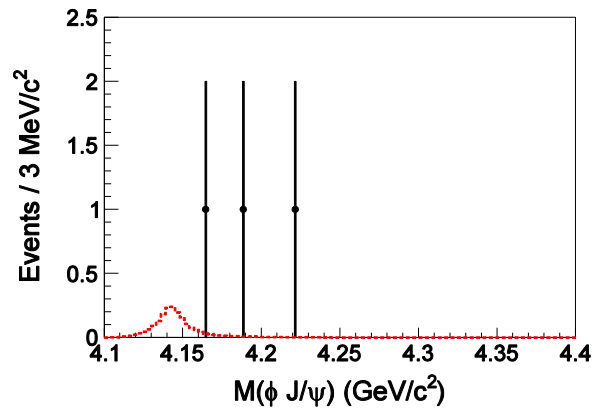
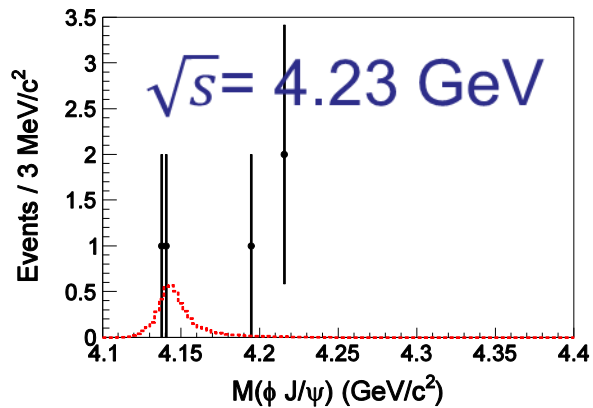
$e^+e^- \rightarrow \gamma\phi J/\psi, J/\psi \rightarrow e^+e^-/\mu^+\mu^-$

with $\phi \rightarrow K^+K^-$ (one Kaon can be missing), $\phi \rightarrow K_S K_L$ (K_L is missing) and $\phi \rightarrow \pi^+\pi^-\pi^0$

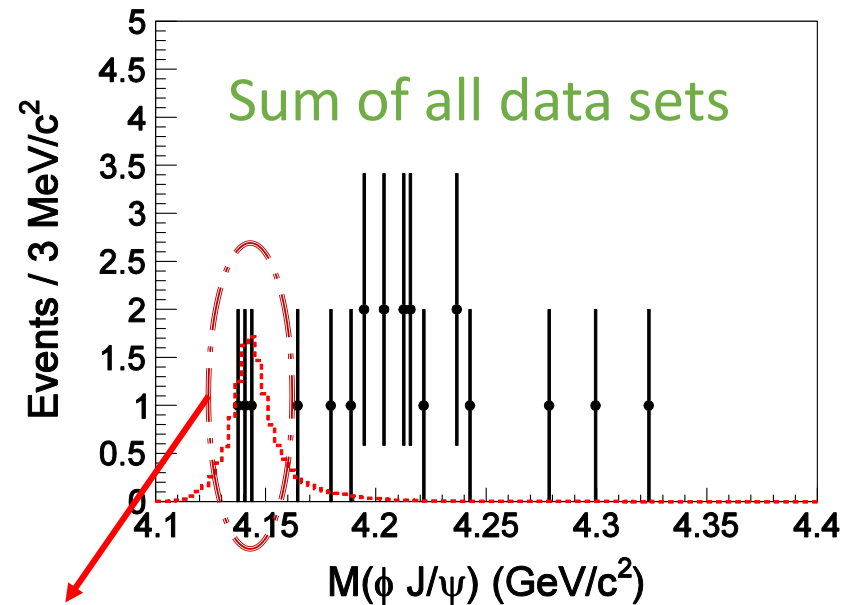
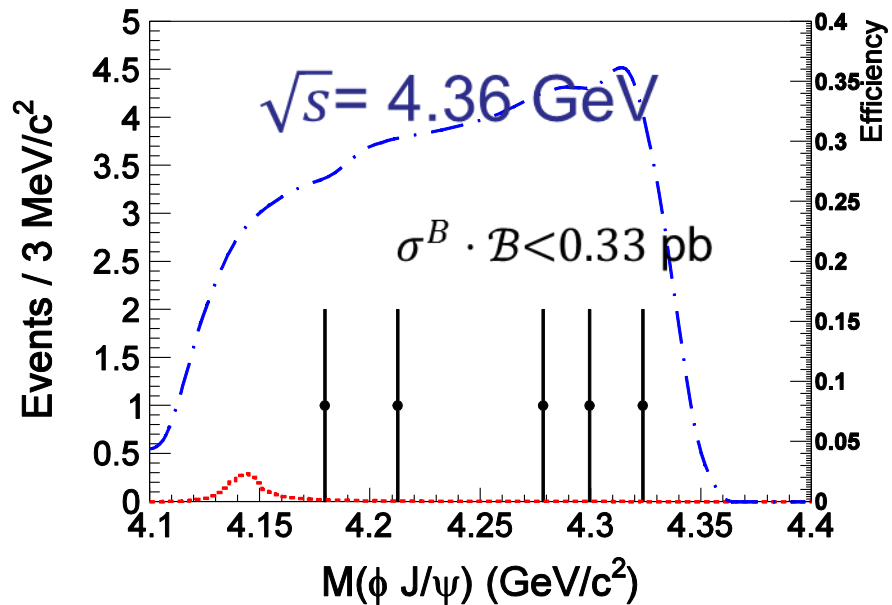
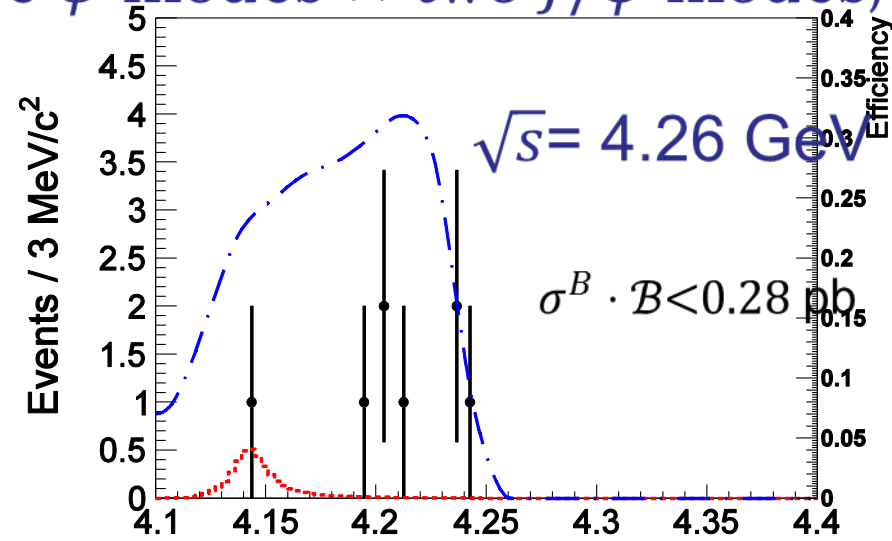
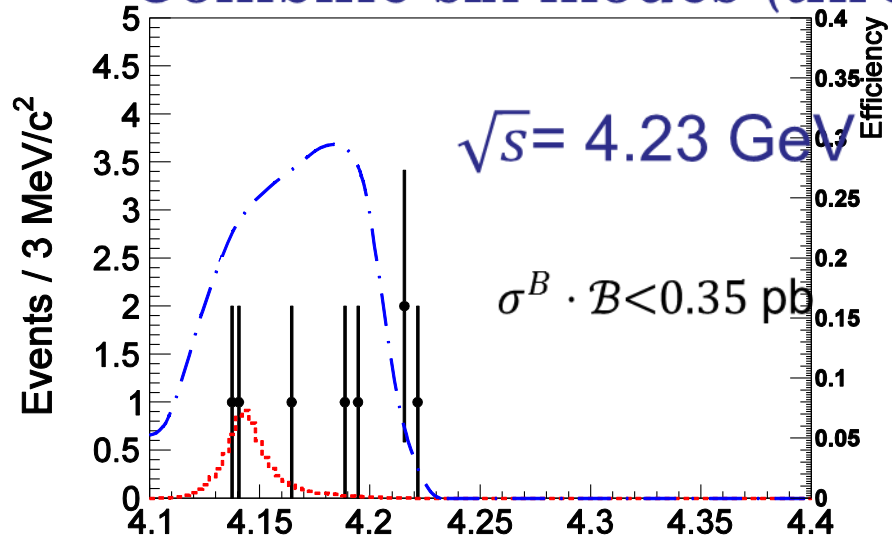
$$\phi \rightarrow K^+ K^-$$

$$\phi \rightarrow K_S^0 K_L^0$$

$$\phi \rightarrow \pi^+ \pi^- \pi^0$$



Combine six modes (three ϕ modes \times two J/ψ modes)



Three events seems like $Y(4140)$.
 No background from MC studies

No significant $Y(4140)$ signal.

Upper limit at the 90% C.L. for $\sigma^B \cdot \mathcal{B} = \sigma^B(e^+e^- \rightarrow \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \rightarrow \phi J/\psi)$

\sqrt{s} (GeV/ c^2)	Luminosity (pb $^{-1}$)	$(1 + \delta)$	n^{prod}	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	<339	<0.35
4.26	827	0.847	<207	<0.28
4.36	545	0.944	<179	<0.33

Systematic uncertainty is considered.

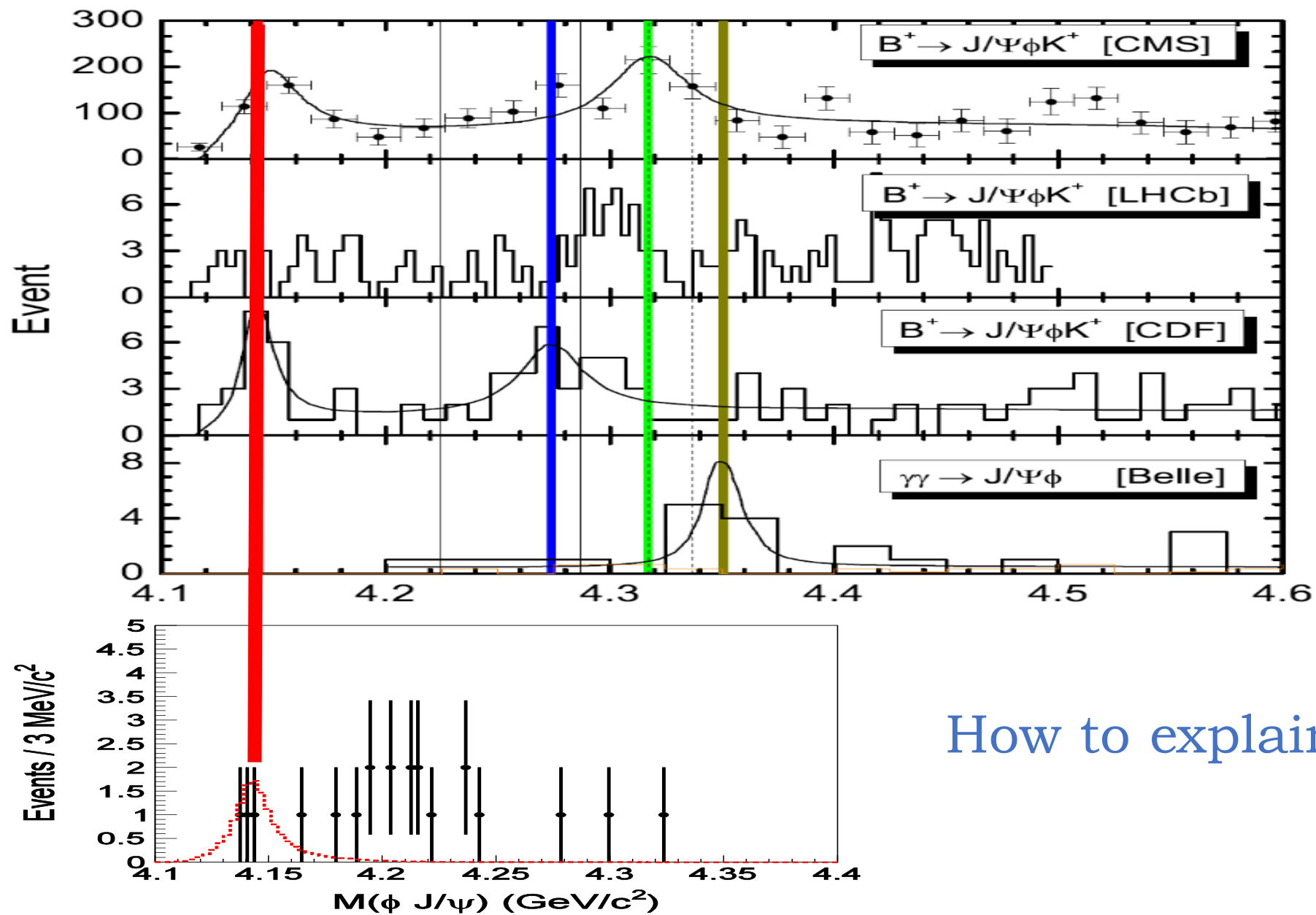
Compared with $X(3872)$ production. [PRL 112, 092001](#)

$$\begin{aligned} & \sigma^B(e^+e^- \rightarrow \gamma X(3872)) \cdot \mathcal{B}(X(3872) \rightarrow \pi^+\pi^-J/\psi) \\ &= 0.27 \pm 0.09(\text{stat}) \pm 0.02(\text{syst}) \text{ pb at } \sqrt{s} = 4.23 \text{ GeV,} \\ &= 0.33 \pm 0.12(\text{stat}) \pm 0.02(\text{syst}) \text{ pb at } \sqrt{s} = 4.26 \text{ GeV.} \end{aligned}$$

Take $\mathcal{B}(X(3872) \rightarrow \pi^+\pi^-J/\psi) = 5\%$. [arXiv: 0910.3138](#)

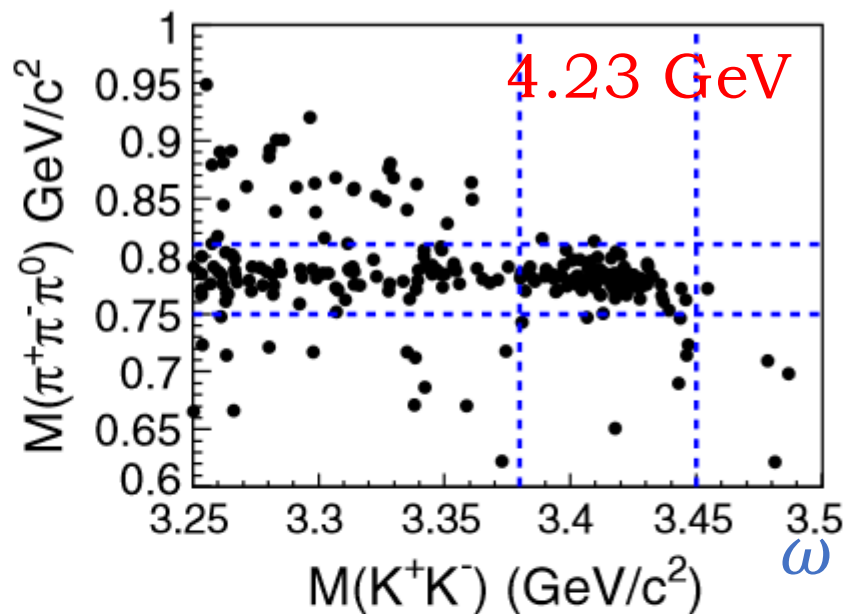
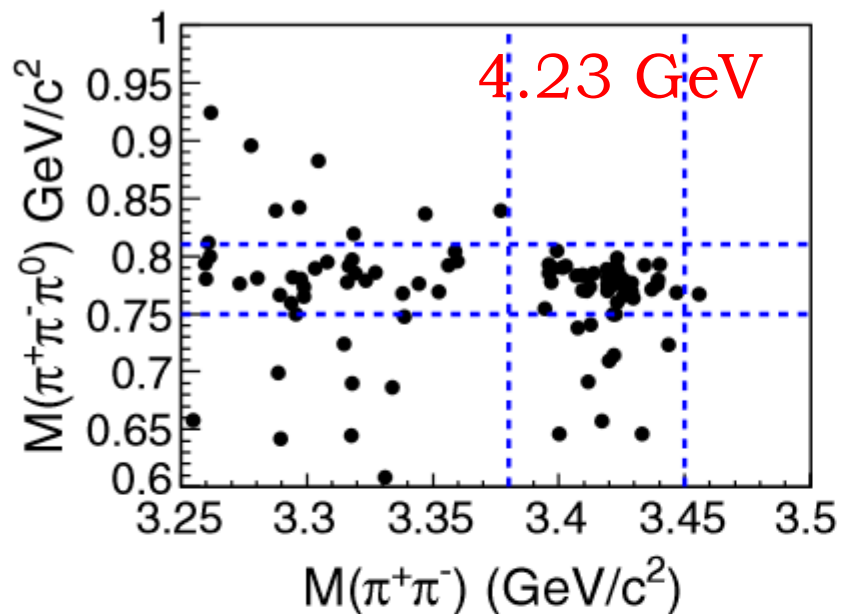
And $\mathcal{B}(Y(4140) \rightarrow \phi J/\psi) = 30\%$, molecular calculation, [PRD 80, 054019](#).

$$\frac{\sigma^B(e^+e^- \rightarrow \gamma Y(4140))}{\sigma(e^+e^- \rightarrow \gamma X(3872))} \lesssim 0.1 \text{ at } \sqrt{s} = 4.23 \text{ and } 4.26 \text{ GeV.}$$

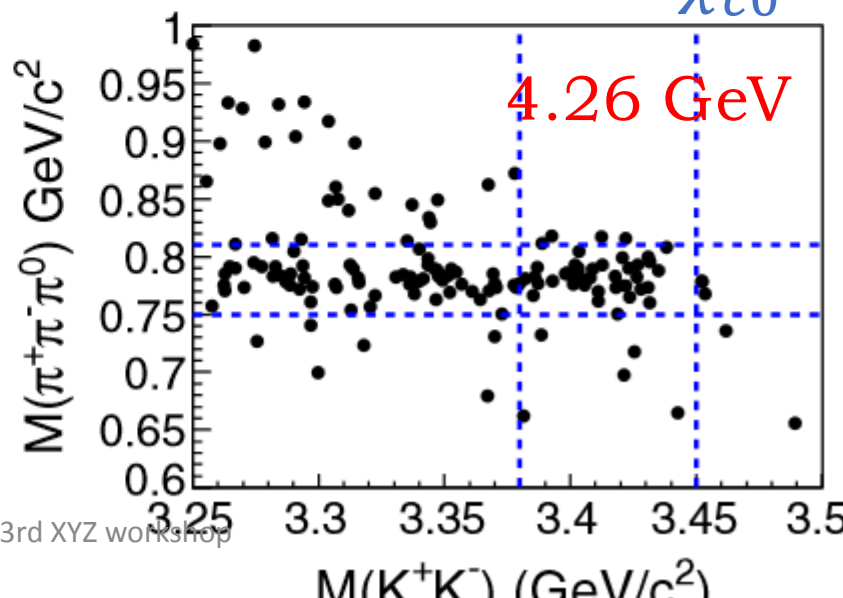
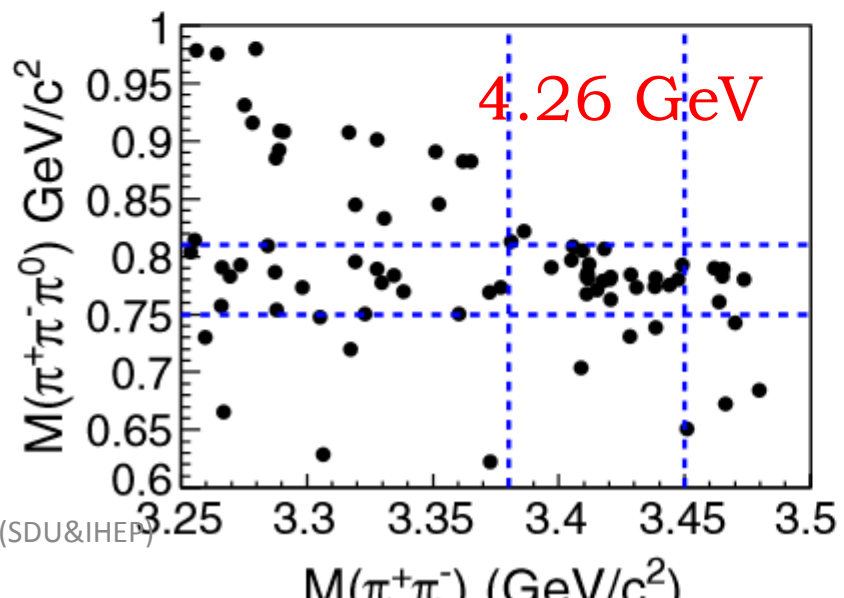


How to explain?

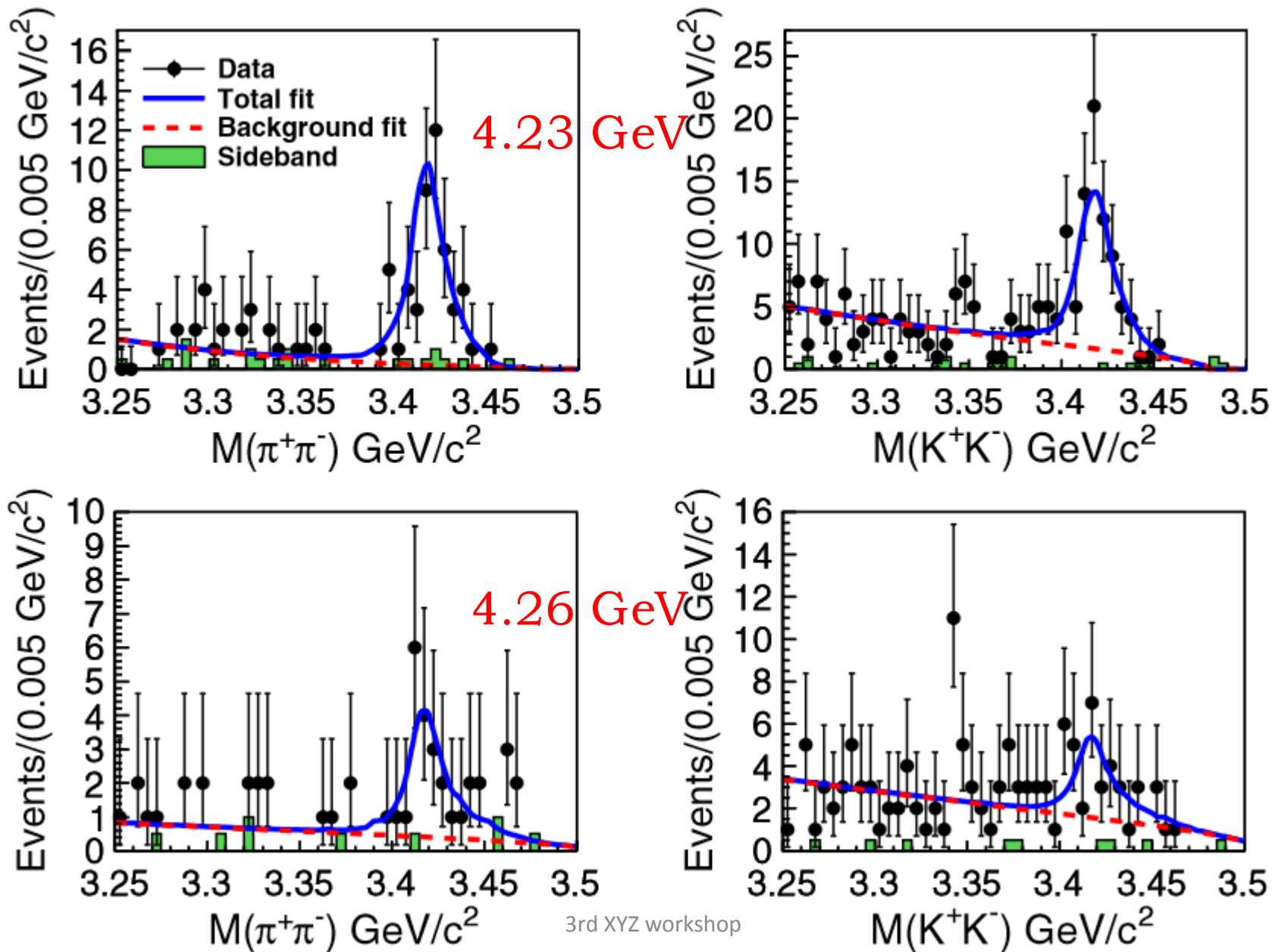
Study of $\omega\chi_{c0}$ from 4.21 to 4.42 GeV



$\omega \rightarrow \pi^+\pi^-\pi^0$
 $\chi_{c0} \rightarrow K^+K^-/\pi^+\pi^-$



Unbin likelihood fit is performed on $\pi^+\pi^-/K^+K^-$ simultaneously



Fit to $\sigma(e^+e^- \rightarrow \omega\chi_{c0})$

Phase-space modified Breit-Wigner

$$\text{BW}(\sqrt{s}) = \frac{\Gamma_{ee}\mathcal{B}(\omega\chi_{c0})\Gamma_t}{(s - M^2)^2 + (M\Gamma_t)^2} \times \frac{\Phi(\sqrt{s})}{\Phi(M)}$$

with significance $> 9\sigma$

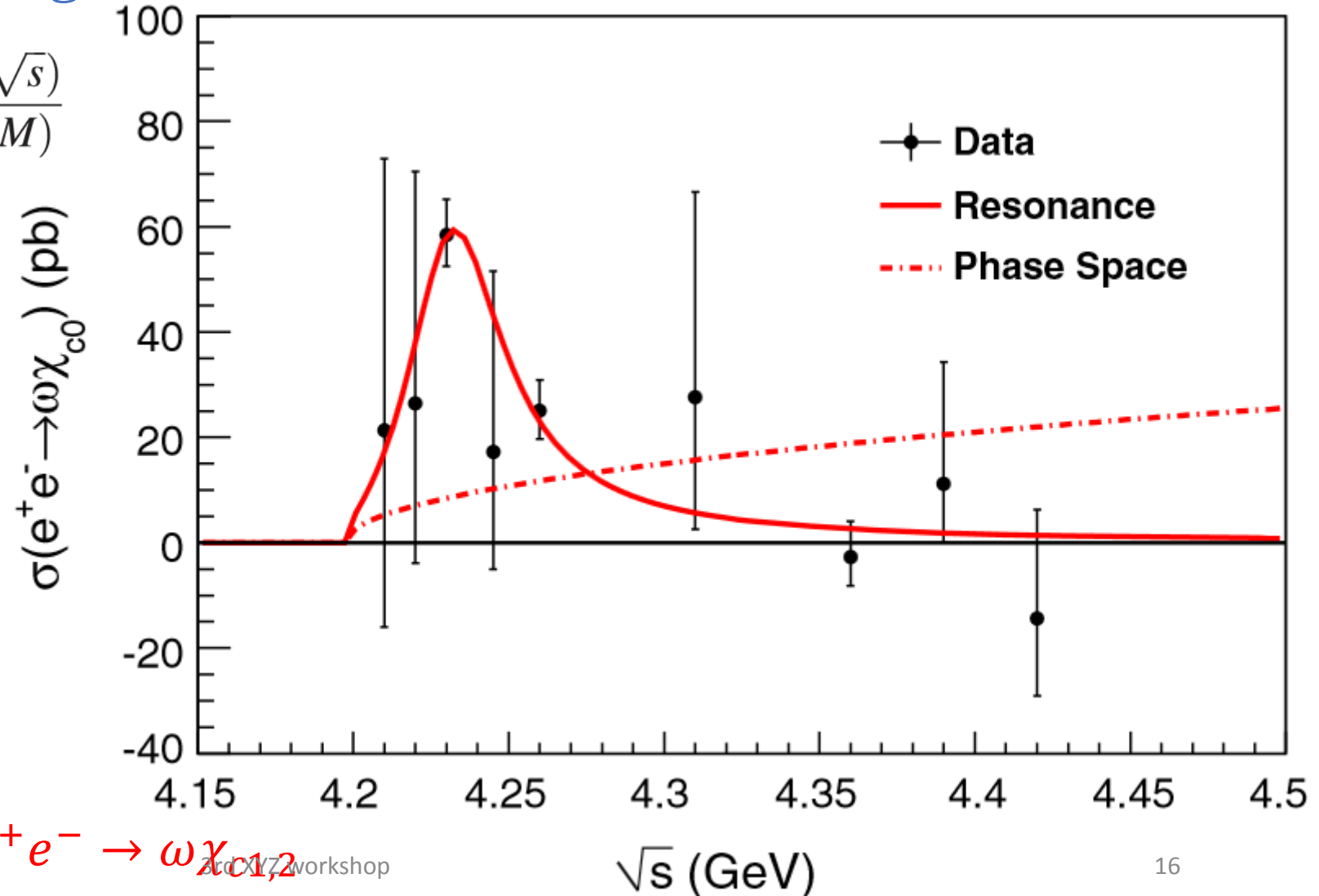
$$\Gamma_{ee}\mathcal{B}(\omega\chi_{c0}) = (2.7 \pm 0.5) \text{ eV}$$

$$M(Y) = (4230 \pm 8) \text{ MeV}/c^2$$

$$\Gamma_t = (38 \pm 12) \text{ MeV}$$

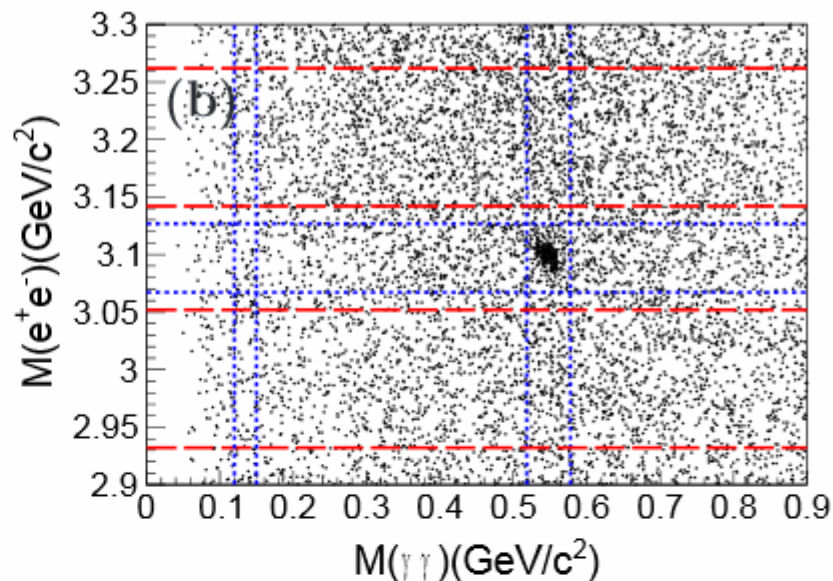
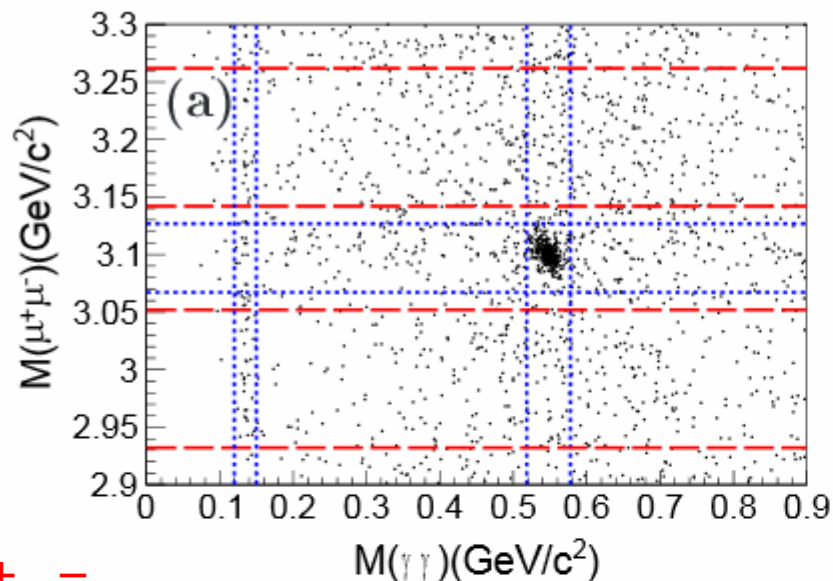
Not consist with $Y(4260)$
from $\pi\pi J/\psi$

No significant signals for $e^+e^- \rightarrow \omega\chi_{c1,2}$



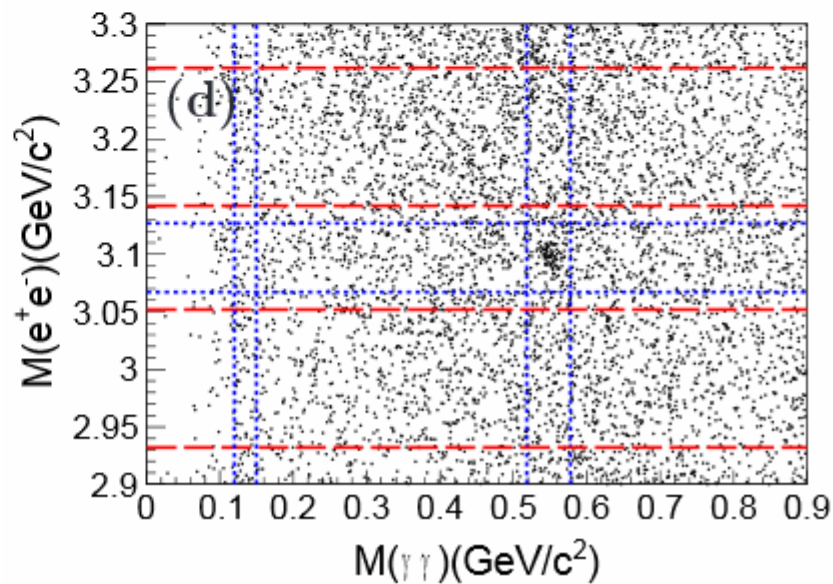
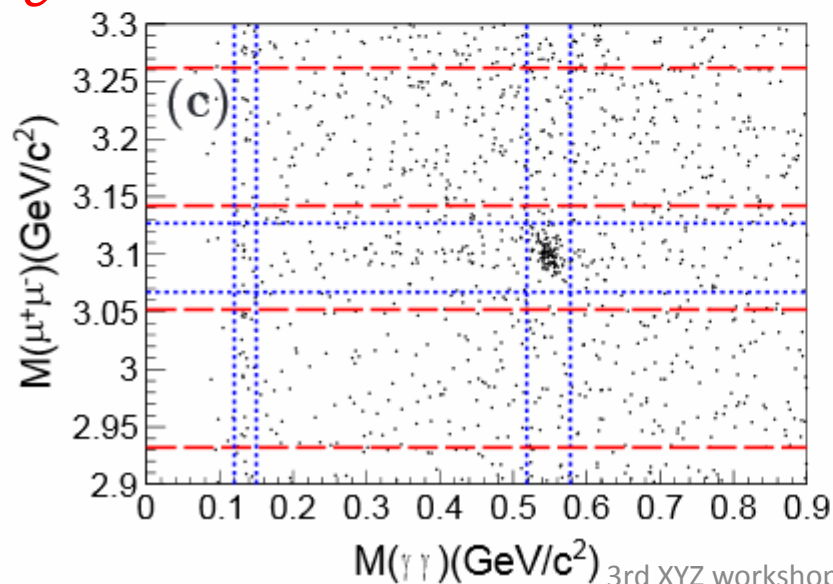
Cross section of $e^+e^- \rightarrow \eta J/\psi$

4.23 GeV



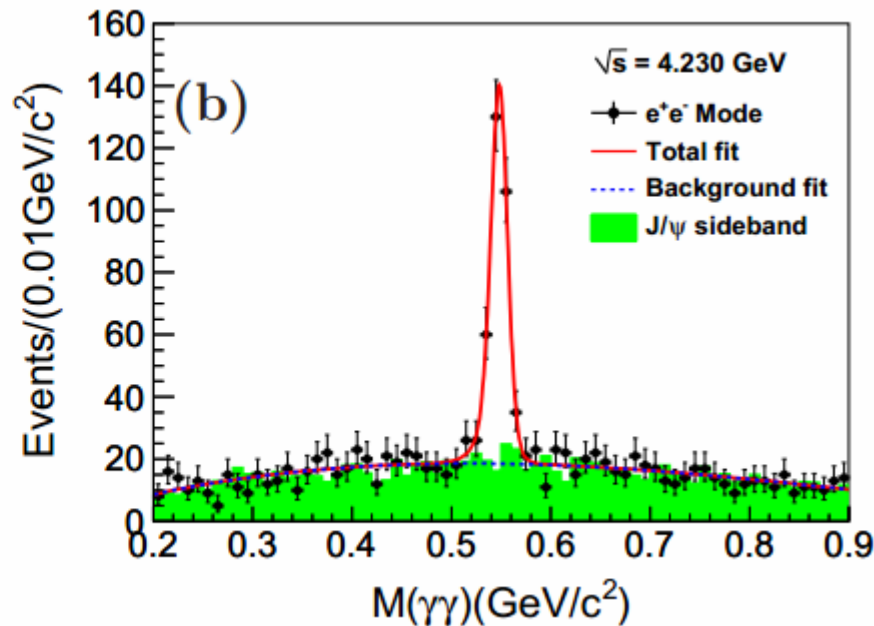
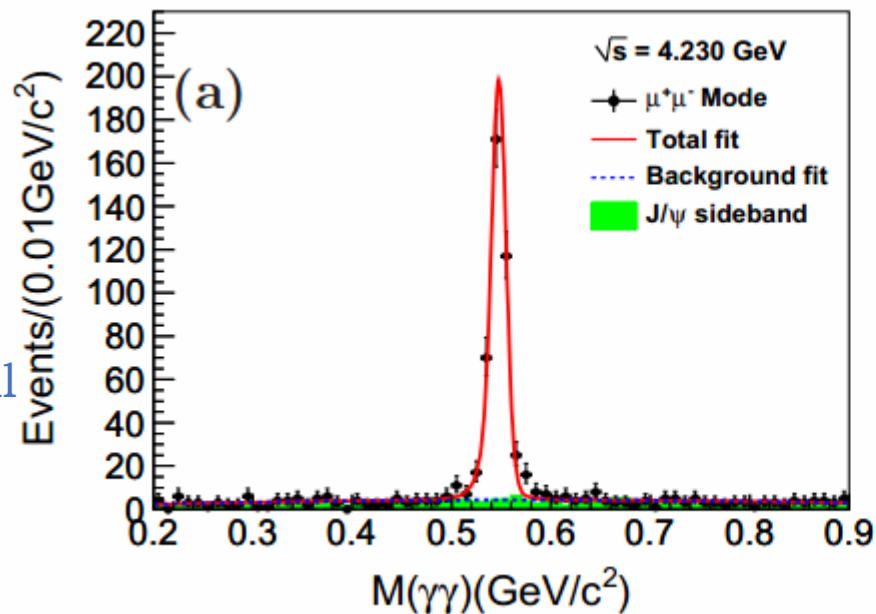
$\eta \rightarrow \gamma\gamma$
 $J/\psi \rightarrow \mu^+\mu^-/e^+e^-$

4.26 GeV



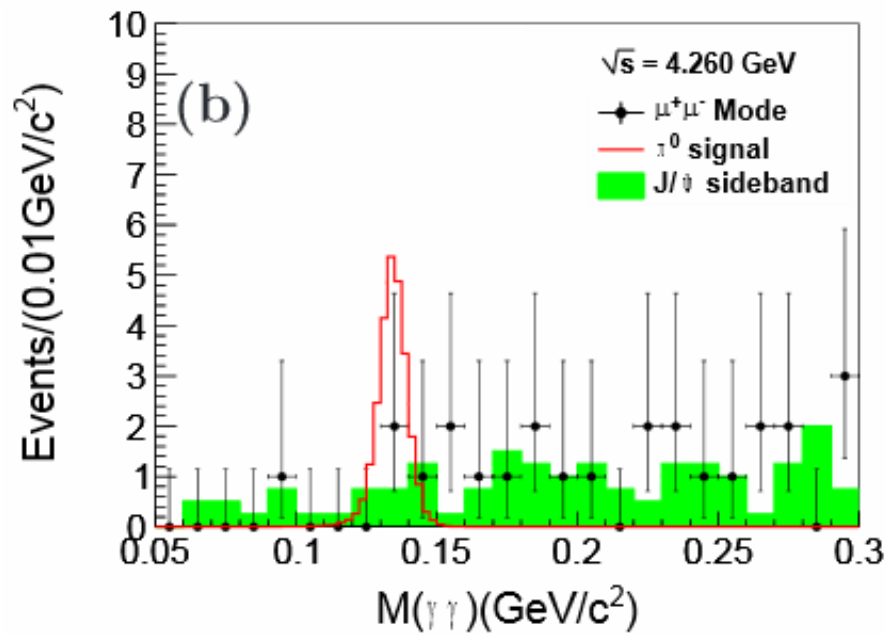
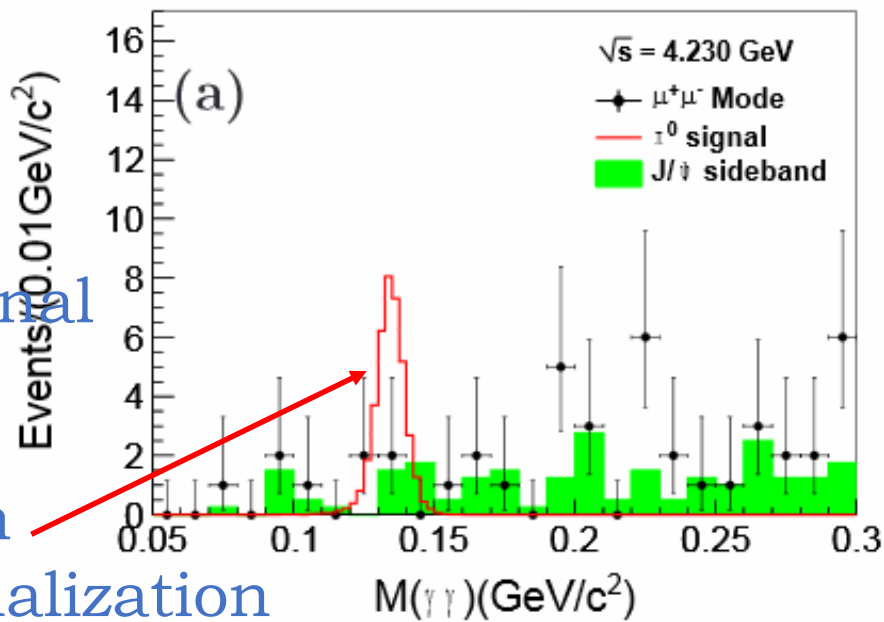
$$e^+e^- \rightarrow \eta J/\psi$$

Clear signal,
Sideband works well



$$e^+e^- \rightarrow \pi^0 J/\psi$$

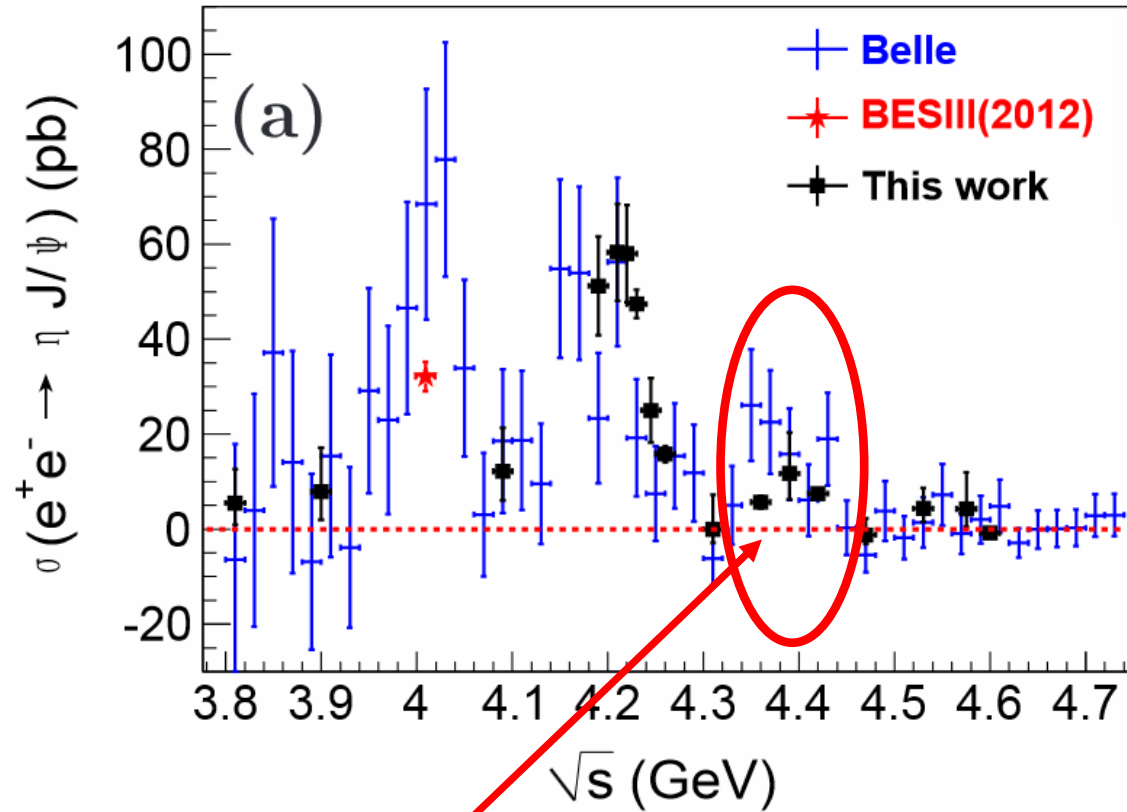
No obvious signal



MC shape with
arbitrary normalization

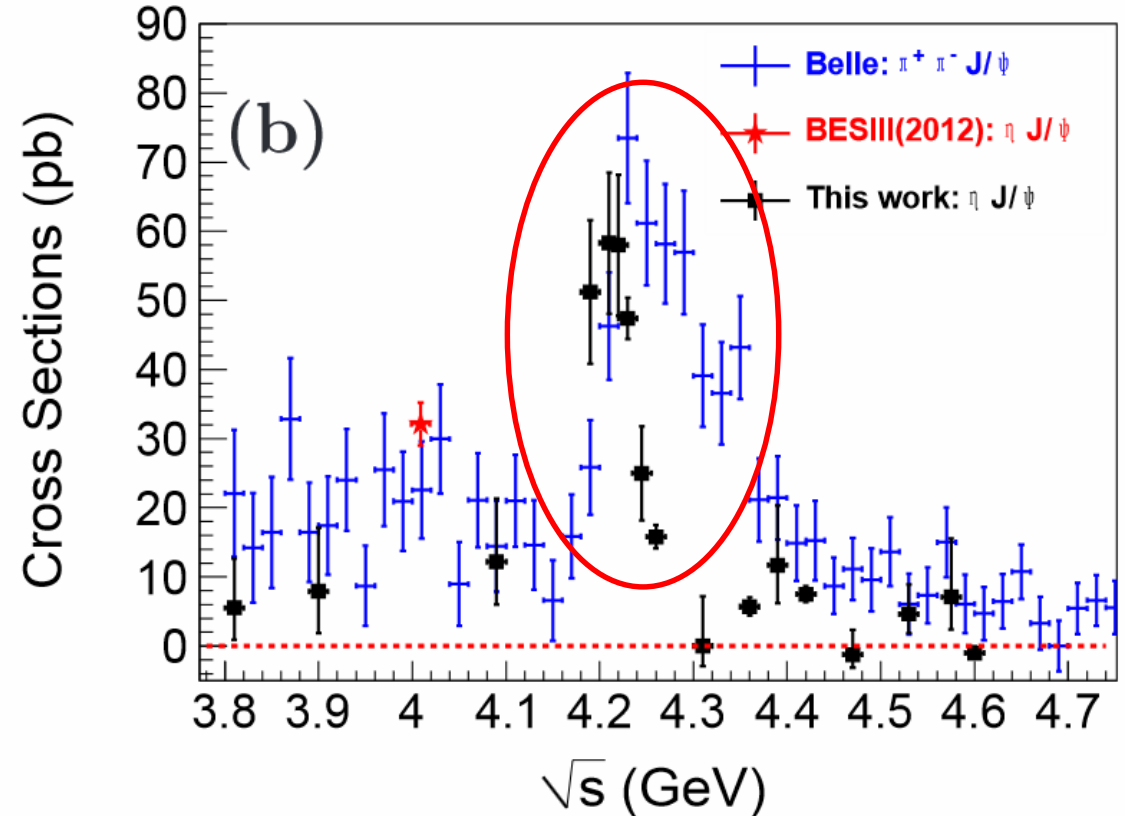
Born cross section of $e^+e^- \rightarrow \eta J/\psi$

Compare with previous measurements



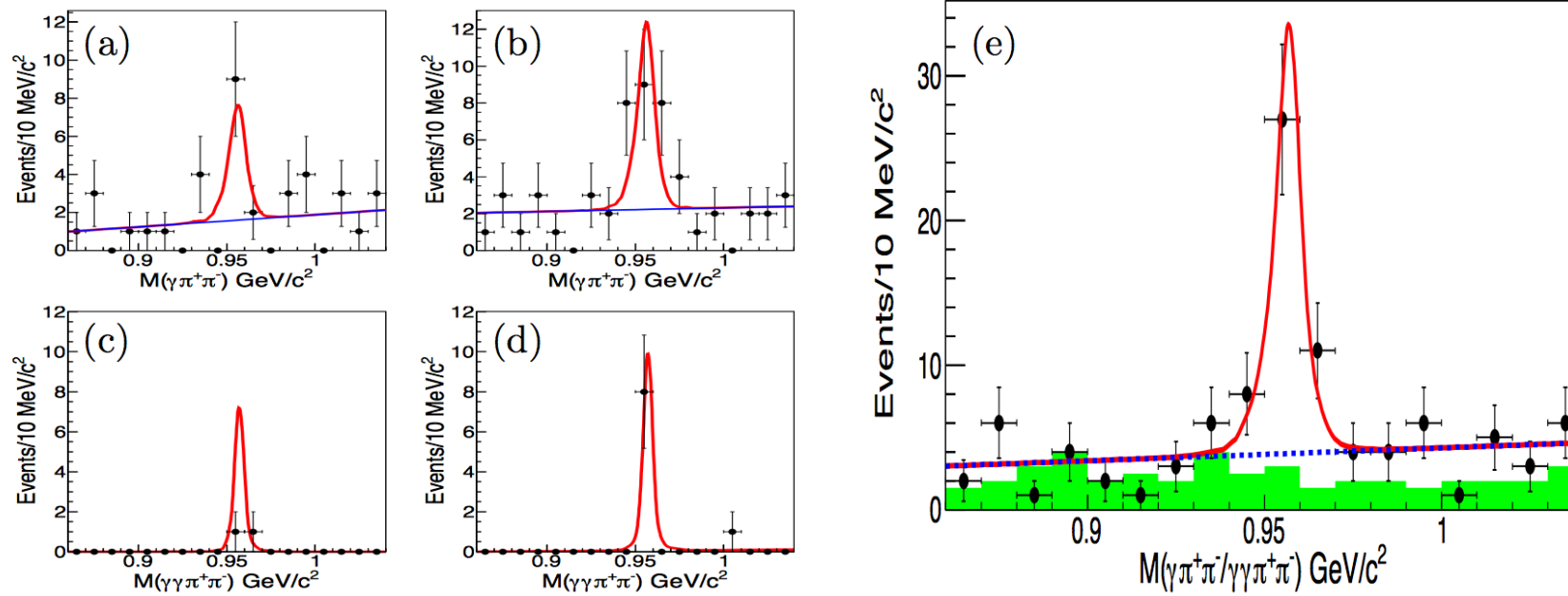
A structure?

Compare with $e^+e^- \rightarrow \pi^+\pi^- J/\psi$



Narrower than $Y(4260)$,
but similar with $\omega\chi_{c0}$

Cross section of $e^+e^- \rightarrow \eta'J/\psi$



Simultaneous fit to combine $\eta' \rightarrow \gamma\pi^+\pi^-/\eta\pi^+\pi^-$, $J/\psi \rightarrow \mu^+\mu^-/e^+e^-$
at 4.23 GeV

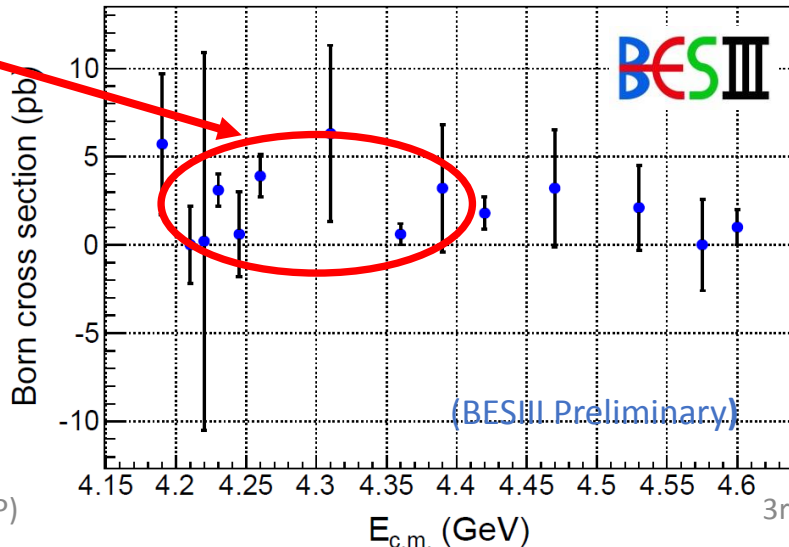
significance 9σ

Preliminary results

Results (BESIII Preliminary)

\sqrt{s} (GeV)	N^{obs}	L_{int} (pb $^{-1}$)	$1+\delta$	$\sum \epsilon_i \mathcal{B}_i$	$ 1 + \Pi ^2$	σ^{B} (pb)
4.190	2.8 ± 1.7 (< 6.4)	43.1	0.879	0.0123	1.056	$5.7 \pm 3.5 \pm 0.5$ (< 13.0)
4.210	0.0 ± 1.3 (< 4.2)	54.6	0.905	0.0118	1.057	$0.0 \pm 2.1 \pm 0.1$ (< 6.8)
4.220	0.1 ± 6.3 (< 4.5)	54.1	0.917	0.0113	1.057	$0.2 \pm 10.6 \pm 0.1$ (< 7.6)
4.230	33.7 ± 6.7	1047.3	0.925	0.0107	1.056	$3.1 \pm 0.6 \pm 0.3$
4.245	0.3 ± 1.1 (< 4.1)	55.6	0.933	0.0098	1.056	$0.6 \pm 2.3 \pm 0.1$ (< 7.6)
4.260	28.2 ± 6.1	825.7	0.939	0.0089	1.054	$3.9 \pm 0.8 \pm 0.4$
4.310	2.0 ± 1.4 (< 5.3)	44.9	0.950	0.0071	1.052	$6.3 \pm 4.4 \pm 0.6$ (< 16.6)
4.360	2.1 ± 1.8 (< 6.3)	539.8	0.954	0.0063	1.051	$0.6 \pm 0.5 \pm 0.1$ (< 1.8)
4.390	1.0 ± 1.0 (< 4.0)	55.2	0.957	0.0057	1.051	$3.2 \pm 3.2 \pm 0.4$ (< 12.8)
4.420	9.8 ± 4.0 (< 14.7)	1023.3	0.959	0.0054	1.053	$1.8 \pm 0.7 \pm 0.2$ (< 2.7)
4.470	1.8 ± 1.6 (< 5.5)	110.7	0.963	0.0050	1.055	$3.2 \pm 2.8 \pm 0.5$ (< 9.8)
4.530	1.0 ± 1.0 (< 4.0)	110.5	0.967	0.0042	1.055	$2.1 \pm 2.1 \pm 0.3$ (< 8.4)
4.575	0.0 ± 0.5 (< 5.3)	47.7	0.970	0.0041	1.055	$0.0 \pm 2.5 \pm 0.1$ (< 26.5)
4.600	2.9 ± 2.7 (< 5.8)	567.7	1.000	0.0051	1.055	$1.0 \pm 0.9 \pm 0.1$ (< 1.9)

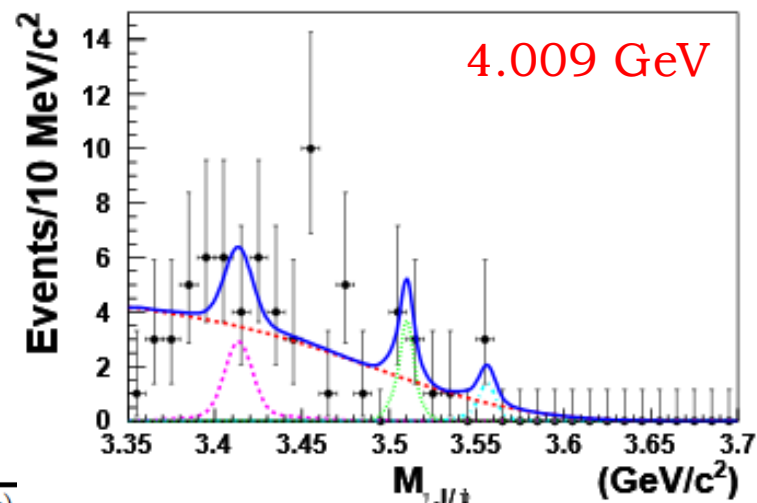
Y(4260) or similar with $\omega\chi_{c0}$



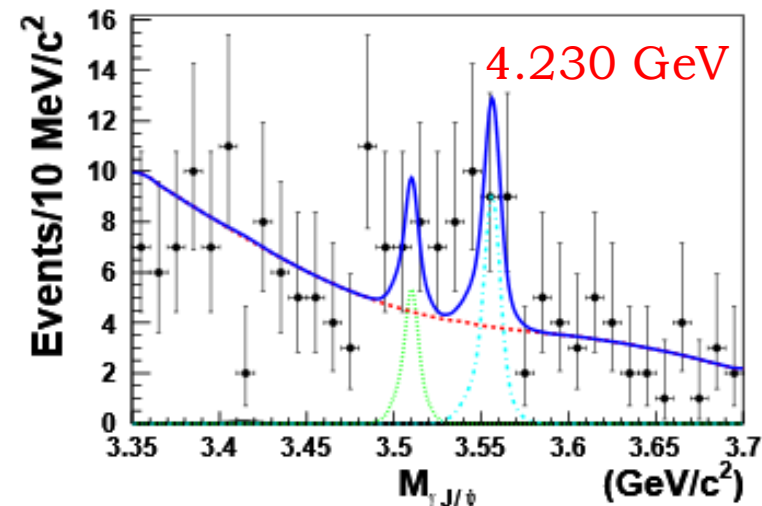
Significant $\eta' J/\psi$ signals were observed at 4.230 and 4.260 GeV, and the upper limits of cross section at 90% C.L. were set for the other 12 c.m. energy points. Comparing with the cross section of $e^+e^- \rightarrow \eta J/\psi$, the cross section is much lower in the case of $e^+e^- \rightarrow \eta' J/\psi$ and that is lower than the theoretical calculation in the framework of NRQCD, too.

Search for $e^+e^- \rightarrow \gamma\chi_{cJ}$ from 4.009 to 4.360 GeV

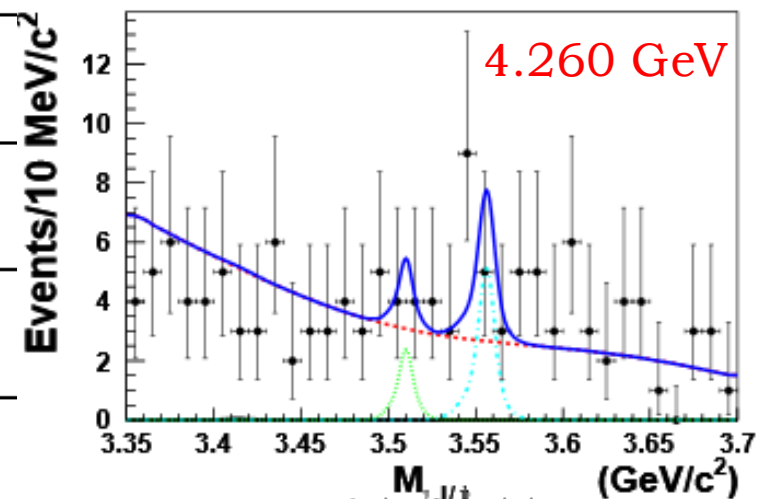
Invariant mass of $\gamma J/\psi$



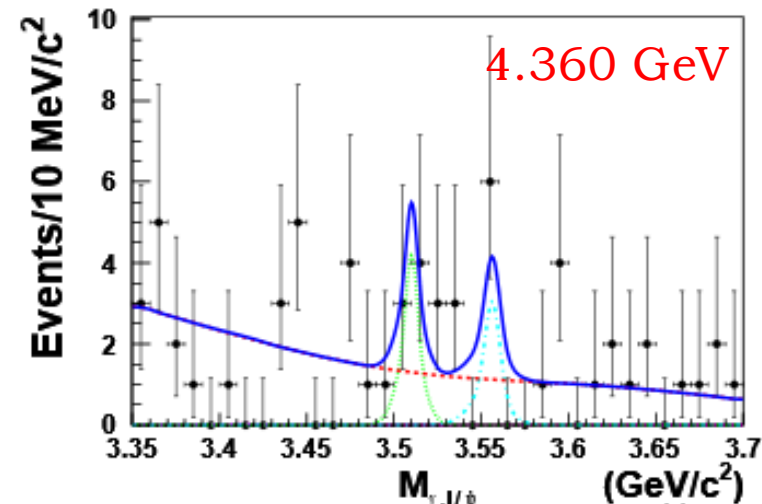
(a)



(b)



3rd XYZ workshop



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\sqrt{s}/GeV		N^{obs}	significance (σ)
4.009	χ_{c0}	7.0 ± 6.6	1.6
	χ_{c1}	4.4 ± 2.6	2.2
	χ_{c2}	1.8 ± 1.7	1.5
4.230	χ_{c0}	0.2 ± 2.3	0.0
	χ_{c1}	6.7 ± 4.3	1.9
	χ_{c2}	13.3 ± 5.2	2.9
4.260	χ_{c0}	0.1 ± 1.9	0.0
	χ_{c1}	3.0 ± 3.0	1.1
	χ_{c2}	7.5 ± 3.9	2.3
4.360	χ_{c0}	0.1 ± 0.7	0.0
	χ_{c1}	5.2 ± 4.9	2.4
	χ_{c2}	4.4 ± 4.5	2.0

Combine all the data sets.

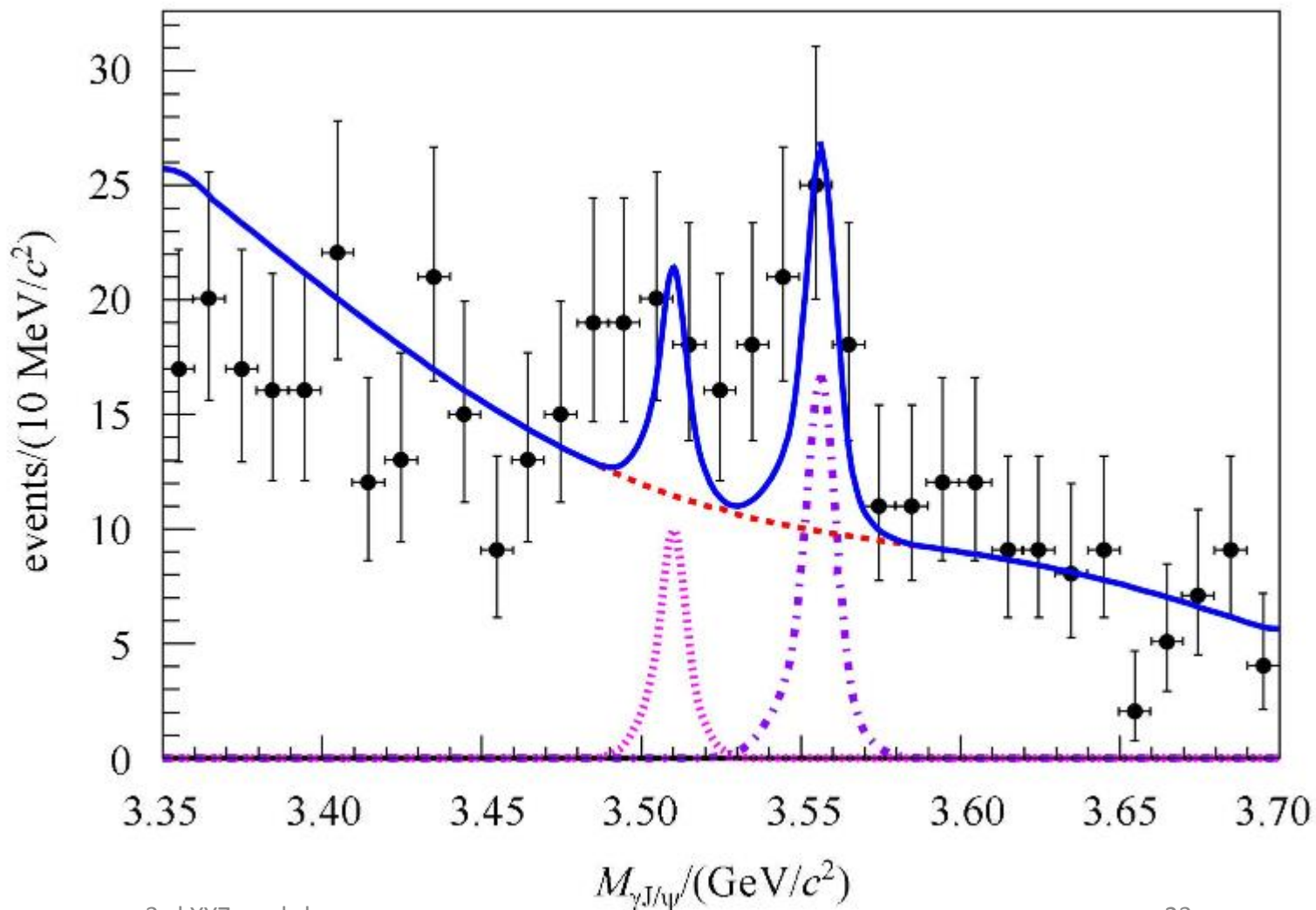
Evidence for

$$e^+e^- \rightarrow \gamma\chi_{c1} \quad (3.0\sigma)$$

$$e^+e^- \rightarrow \gamma\chi_{c2} \quad (3.4\sigma)$$

\sqrt{s} (GeV)		σ^{UP} (pb)	σ^B (pb)
4.009	χ_{c0}	188	$65.1 \pm 61.3 \pm 7.2$
	χ_{c1}	5.2	$2.3 \pm 1.4 \pm 0.2$
	χ_{c2}	18	$4.8 \pm 4.5 \pm 0.5$
4.230	χ_{c0}	27	$0.7 \pm 8.0 \pm 0.1$
	χ_{c1}	1.7	$0.7 \pm 0.5 \pm 0.1$
	χ_{c2}	5.0	$2.7 \pm 1.1 \pm 0.3$
4.260	χ_{c0}	26	$0.5 \pm 8.9 \pm 0.1$
	χ_{c1}	1.2	$0.4 \pm 0.4 \pm 0.1$
	χ_{c2}	4.2	$2.0 \pm 1.1 \pm 0.2$
4.360	χ_{c0}	24	$0.7 \pm 5.0 \pm 0.1$
	χ_{c1}	3.0	$1.4 \pm 1.3 \pm 0.1$
	χ_{c2}	5.0	$2.2 \pm 2.3 \pm 0.2$

Ke LI (SDU) & IHEP



3rd XYZ workshop

How to explain?

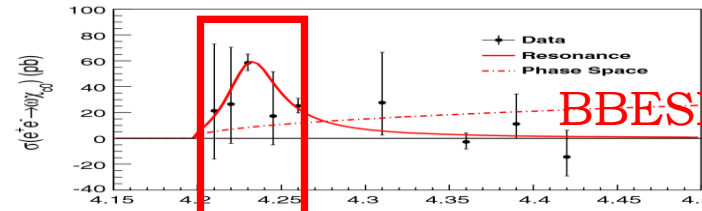
Narrow Y state?

$$M(Y) = (4230 \pm 8) \text{ MeV}/c^2$$

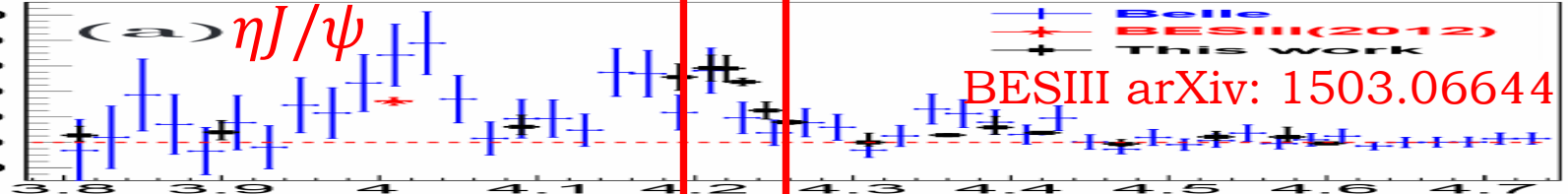
$$\Gamma_t = (38 \pm 12) \text{ MeV}$$

$\omega\chi_{c0}$

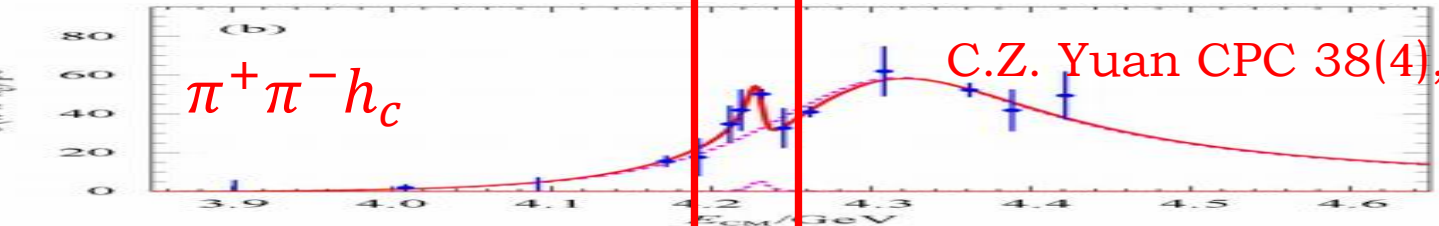
$\omega\chi_{c0}$



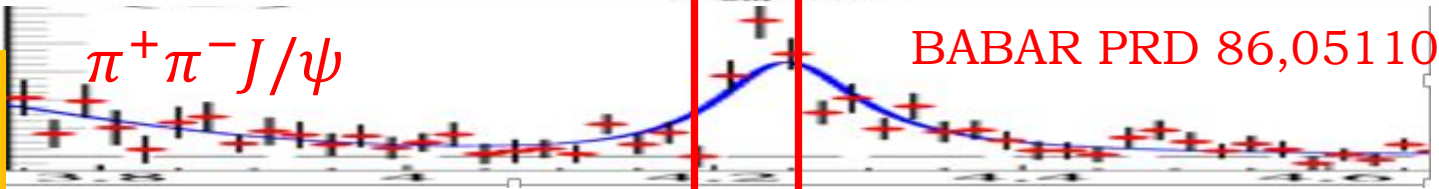
BESIII PRL 114,092003



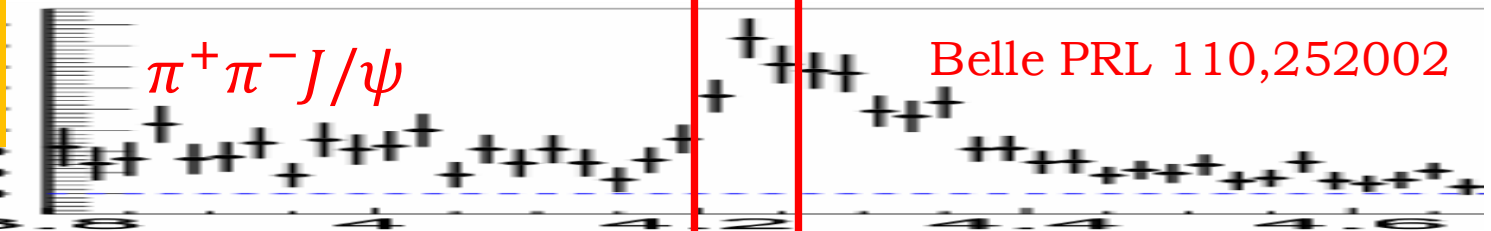
BESIII arXiv: 1503.06644



C.Z. Yuan CPC 38(4),043001

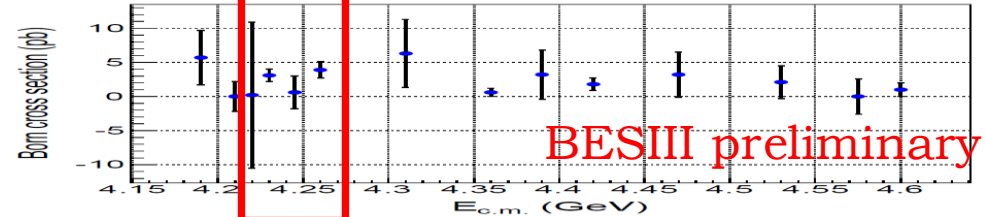


BABAR PRD 86,051102



Belle PRL 110,252002

$\eta' J/\psi$



BESIII preliminary

$$M(Y) = (4216 \pm 18) \text{ MeV}/c^2$$

$$\Gamma(Y) = (39 \pm 32) \text{ MeV}$$

$\pi^+\pi^-h_c$

Consist with each other

Hope it is not a joke!

Summary

- The X(3823) ($\psi(1^3D_2)$) is observed with significance 6.2σ via $e^+e^- \rightarrow \pi^+\pi^-\gamma\chi_{c1}$
- The Y(4140) is searched via $e^+e^- \rightarrow \gamma\phi J/\psi$, no obvious signal (three events)
- Study of $e^+e^- \rightarrow \omega\chi_{cJ}$ indicates a state with
 $M(Y) = (4230 \pm 8) \text{ MeV}/c^2$ $\Gamma_t = (38 \pm 12) \text{ MeV}$
- Cross section of $e^+e^- \rightarrow \eta J/\psi$ is measured from 3.81 to 4.60 GeV.
Interesting structures. **Maybe same with $\omega\chi_{c0}$.**
- Cross section of $e^+e^- \rightarrow \eta' J/\psi$ is measured,
possible same structure with that in $\eta J/\psi$
- Process of $e^+e^- \rightarrow \gamma\chi_{cJ}$ is searched, evidence for $\gamma\chi_{c1}/\chi_{c2}$
- The narrow state Y(4216) in $\pi^+\pi^-h_c$ consist with $\omega\chi_{c0}$, $\eta J/\psi$.
Try other channels.

Thanks for your attention.