Radiative Transitions above 4 GeV at BESIII

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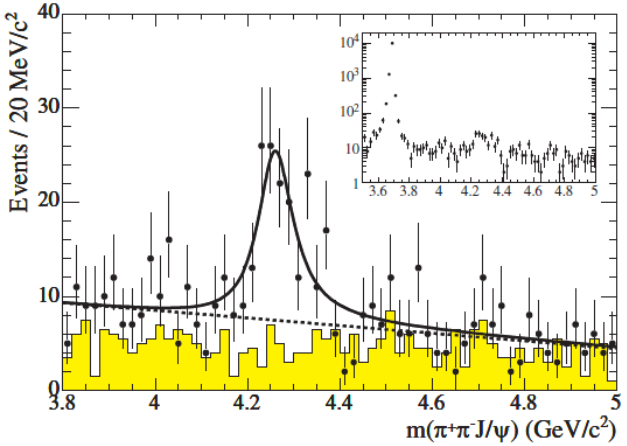
Radiative transitions and $Y(4260)$

- Many unconventional charmonium-like (so-called XYZ) states were discovered, e.g. $X(3872)$, $Y(4260)$, $Y(4360)$..., while the nature of the states remains unclear.

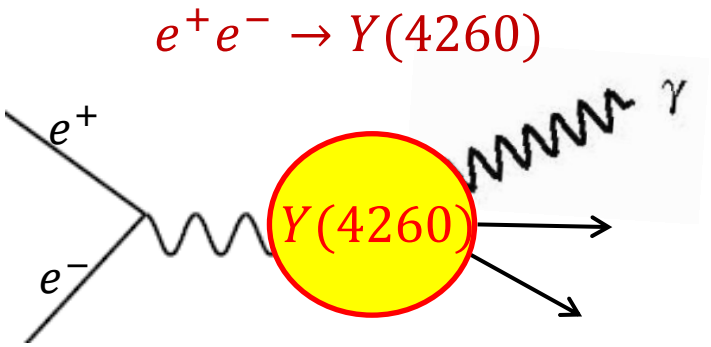
- $Y(4260)$ was observed in ISR process $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$ by BaBar, which has $J^{PC} = 1^{--}$ and can be directly produced in e^+e^- collisions;
- The $Y(4260)$ is heavier than DD threshold, but mostly decays to $\pi^+\pi^- J/\psi$;



- There's no place for $Y(4260)$ in the conventional charmonium family;
- The newly observed Z_c particles seem to couple with $Y(4260)$.

Radiative transitions and $Y(4260)$

- To better understand the nature of $Y(4260)$, it's important to investigate the radiative transitions between the $Y(4260)$ and the lower mass charmonium(-like) states (e.g. $X(3872)$, χ_{cJ}).



- Search for new C-even charmonium(-like) states (e.g. $Y(4140)$, $Y(3915)$) via radiative transitions.
- The e^+e^- collider BEPCII can reach 4.6 GeV for now, so we can produce $Y(4260)$ directly.

Radiative transitions

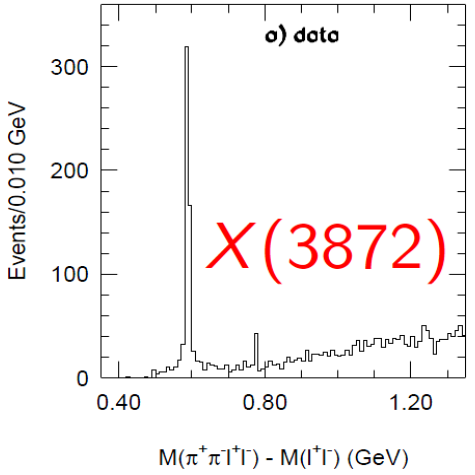
1. Observation of $e^+e^- \to \gamma X(3872)$ (RPL 112,092001)
2. Search for $e^+e^- \to \gamma Y(4140)$ (PRD 91,032002)
3. Search for $e^+e^- \to \gamma \chi_{cJ}$ (CPC, 39(4) (2015) 041001)

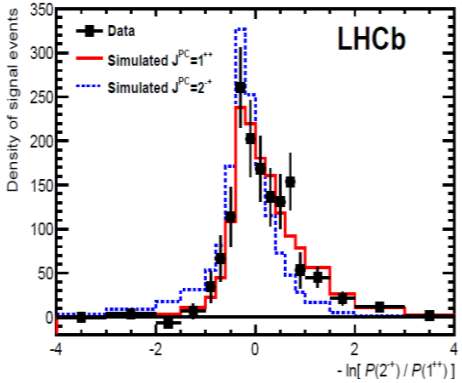
*The results in the talk are based on **4** energy points*

0.5 fb^{-1}	$\psi(4040)$ at **4.009** GeV
1.9 fb^{-1}	$Y(4260)$ at **4.23** and **4.26** GeV
0.5 fb^{-1}	$Y(4360)$ at **4.36** GeV

The feature of $X(3872)$

- **Discovered** by Belle in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ in 2003, and confirmed by many other experiments;
- very **narrow** (<1.2 MeV);
- BaBar and Belle observed $X(3872) \to \gamma J/\psi$, ensuring $X(3872)$ **C-even** state;
- Spin parity $\boldsymbol{J^P = 1^+}$ (CDF and LHCb) ;
- **Very close** to $D\overline{D}^*$ threshold, a good candidate for a hadronic molecule or a tetraquark state;
- Only observed in B meson decays and hadron collisions; radiative transition at BESIII?

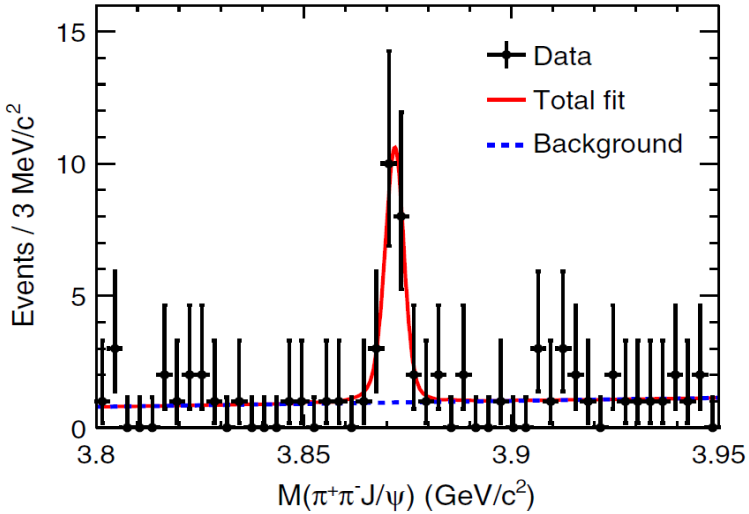


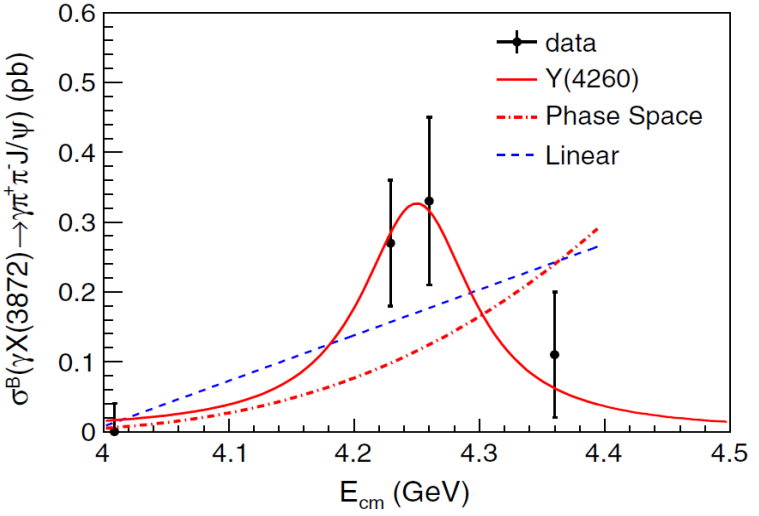


Observation of $e^+e^- \to \gamma X(3872)$ via $X(3872) \to \pi^+\pi^- J/\psi$

- **Observe** $e^+e^- \to \gamma X(3872)$ for the first time with a significance 6.3σ.
- **Measured mass** is $M\big(X(3872)\big) = (3871.9 \pm 0.7 \pm 0.2)\ \mathrm{MeV}/c^2$, agrees with previous measurements well.
- **Measured** $\sigma^B[e^+e^- \to \gamma X(3872)] \times \mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]$ at 4.009, 4.23, 4.26, 4.36 GeV.
- These results suggest that $X(3872)$ may come from $Y(4260)$ decay. Assuming $\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]$=5%,

$$\frac{\mathcal{B}(Y(4260) \to \gamma X(3872))}{\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)} \approx 0.1$$





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

Exist

CDF first reported evidence for $Y(4140)$ in $B^+ \to \phi J/\psi K^+$; CDFII claimed observation (>5σ)

CMS and D0 studied $B^+ \to \phi J/\psi K^+$; with resonance parameters consistent with CDF

or not?

Belle did not confirm $Y(4140)$ in the $B^+ \to \phi J/\psi K^+$ and $\gamma\gamma \to \phi J/\psi$

LHCb did not find $Y(4140)$ in $B^+ \to \phi J/\psi K^+$

BABAR found no evidence for $Y(4140)$ by study $B^+ \to \phi J/\psi K^+$

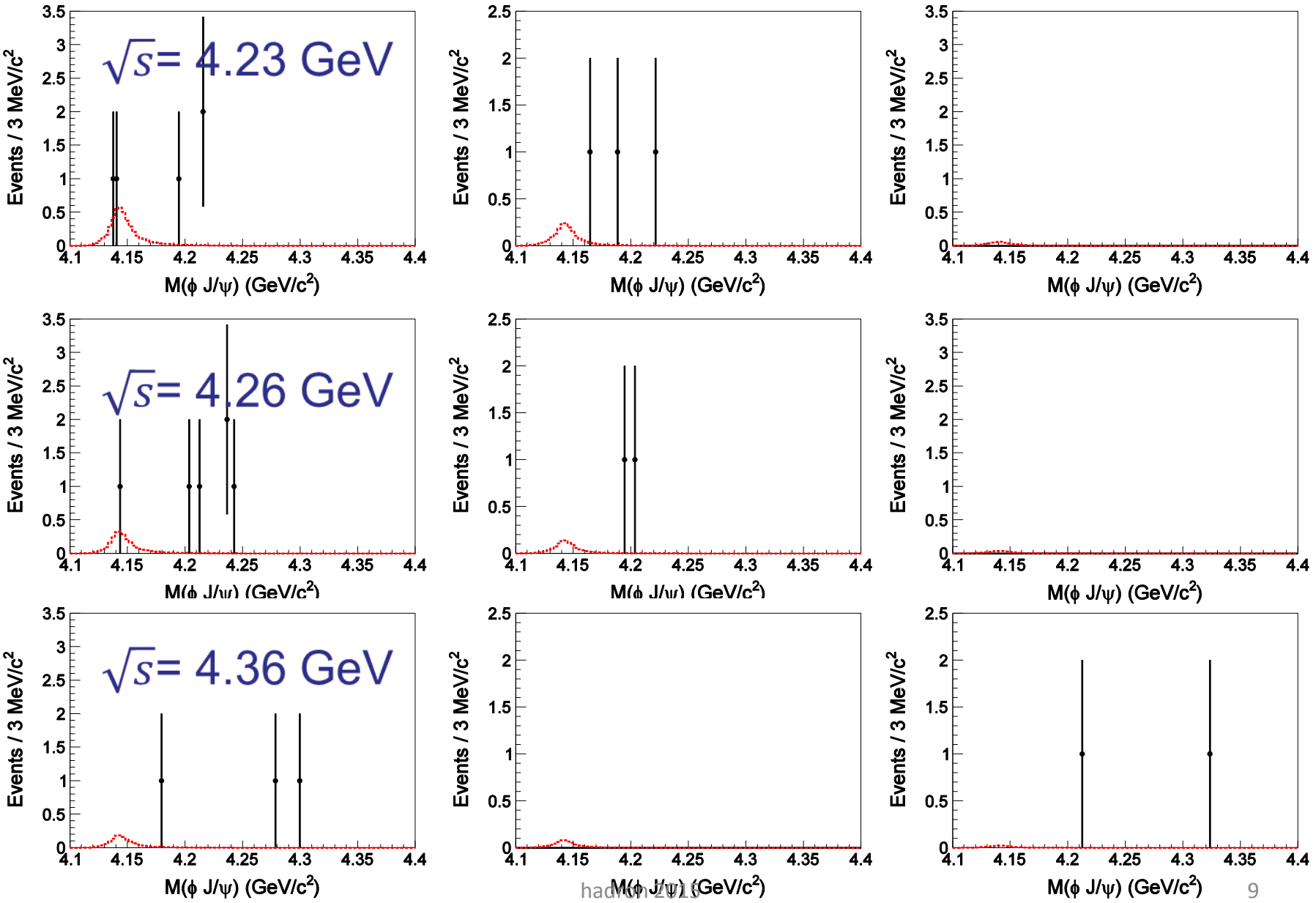
Search for $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$

- The mass and width of $Y(4140)$ given by CDFII are 4143.4 $\pm$ 3.1 MeV/c^2 and 15.3 $\pm$10.7 MeV;
- $Y(4140)$ is not a conventional charmonium state, but a good candidate for $D_s^*\overline{D_s^*}$ molecular state;
- Both ϕ and J/ψ have $\boldsymbol{J^{PC} = 1^{--}}$, the $Y(4140)$ has positive C-parity and can be searched for through radiative transition of $Y(4260)$.

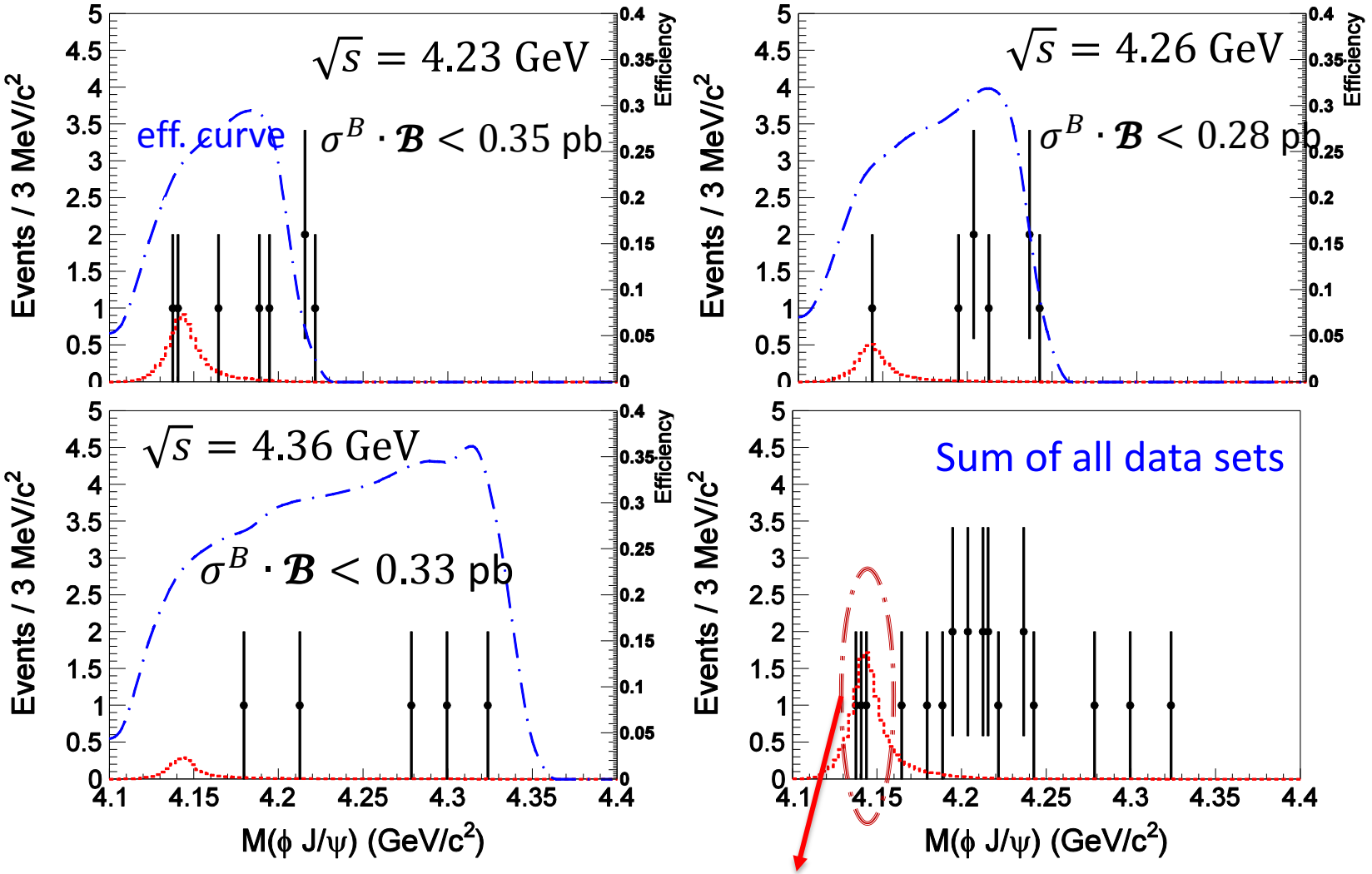
➢ $e^+e^- \to \gamma\phi J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$

- 1. $\phi \to K^+K^-$ (one Kaon is missing),
- 2. $\phi \to K_SK_L$ (K_L is missing),
- 3. $\phi \to \pi^+\pi^-\pi^0$

$\phi \to K^+K^-$ $\phi \to K_S^0 K_L^0$ $\phi \to \pi^+\pi^-\pi^0$



Combine 6 modes (3 ϕ modes × 2 J/ψ modes)



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

No significant $Y(4140)$ signal found

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

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

Systematic uncertainty included

- Compared with the X(3872) production (same magnitude)
  $\sigma^B(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$
  = 0.27$\pm$0.09(stat) $\pm$0.02(syst) pb at $\sqrt{s}$= 4.23 GeV,
  = 0.33$\pm$0.12(stat) $\pm$0.02(syst) pb at $\sqrt{s}$ = 4.26 GeV.

- Take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ = 5%. arXiv: 0910.3138
  And $\mathcal{B}(Y(4140) \to \phi J/\psi)$ = 30%, molecular calculation. PRD 80, 054019.

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

Search for $e^+e^- \to \gamma\chi_{cJ}$ at $\sqrt{s}$ > 4 GeV

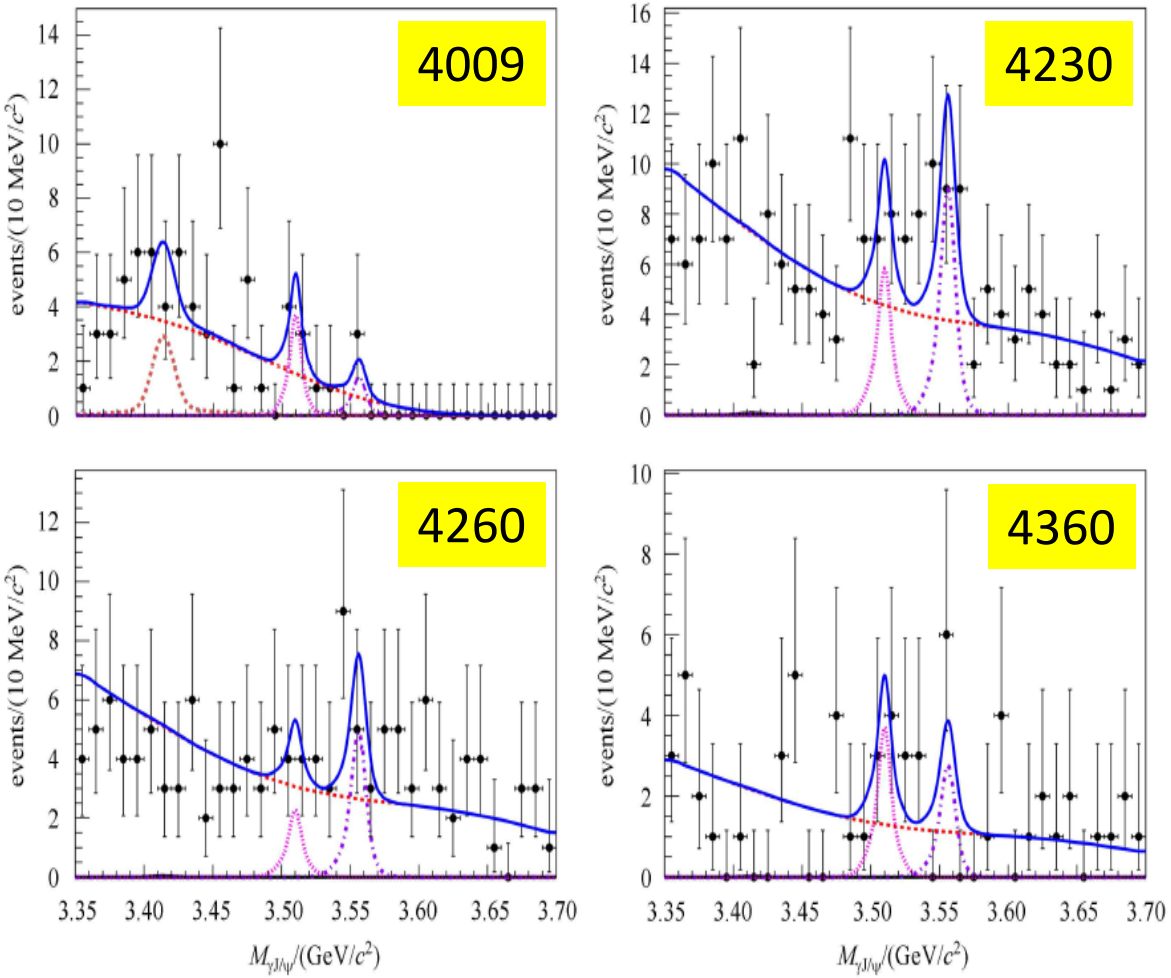
- The cross sections of $e^+e^- \to \gamma\chi_{cJ}$ have been evaluated theoretically with the framework of NRQCD;
- In experiment, CLEO investigated the process but failed to observe a signal;
- BESIII has collected large data sample for deeply investigate the processes, which may provide more information on the properties of $Y(4260)$.

- The process is reconstructed by

$$e^+e^- \to \gamma\chi_{cJ}$$
$$\hookrightarrow \gamma J/\psi$$
$$\hookrightarrow \mu^+\mu^-$$

Search for $e^+e^- \to \gamma\chi_{cJ}$ at $\sqrt{s}$ > 4 GeV

Unbinned likelihood fit to $M(\gamma J/\psi)$



Signal: a double-Gaussian determined from MC at 4.260 GeV;

Background: radiative dimuon MC shape;

Data: limited statistics

Search for $e^+e^- \to \gamma\chi_{cJ}$ at $\sqrt{s}$ > 4 GeV

The results on $e^+e^- \to \gamma\chi_{cJ}$ born cross section measurement

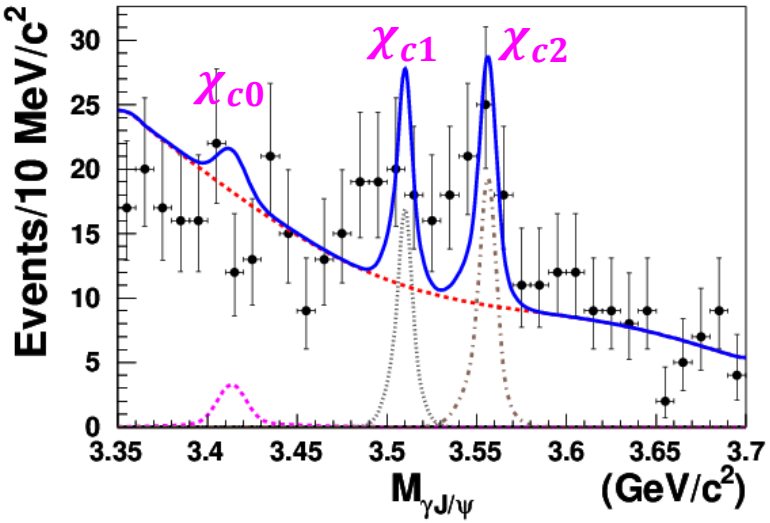
$\sqrt{s}$/GeV		N^{obs}	significance (σ)	N^{UP}	σ^{UP}/pb	σ^{B}/pb
4.009	χ_{c0}	7.0±6.6	1.6	18	179	65.0±61.3±4.2
	χ_{c1}	4.4±2.6	2.2	9	5.3	2.4±1.4±0.2
	χ_{c2}	1.8±1.7	1.5	6	18	4.7±4.4±0.6
4.230	χ_{c0}	0.2±2.3	0.0	7	26	0.7±8.0±0.1
	χ_{c1}	6.7±4.3	1.9	14	1.7	0.7±0.5±0.1
	χ_{c2}	13.3±5.2	2.9	22	5.0	2.7±1.1±0.3
4.260	χ_{c0}	0.1±1.9	0.0	5	25	0.5±8.8±0.1
	χ_{c1}	3.0±3.0	1.1	7	1.1	0.4±0.4±0.1
	χ_{c2}	7.5±3.9	2.3	14	4.2	2.0±1.1±0.2
4.360	χ_{c0}	0.1±0.7	0.0	3	23	0.7±5.0±0.1
	χ_{c1}	5.2±4.9	2.4	10	2.9	1.4±1.3±0.1
	χ_{c2}	4.4±4.5	2.0	9	5.0	2.3±2.3±0.2

arXiv:1310.8597

- Significance σ is small due to limited statistics;
- The upper limits on σ^B are compatible with the theoretical prediction;
- The first uncertainty of σ^B is statistical, and the second systematic.

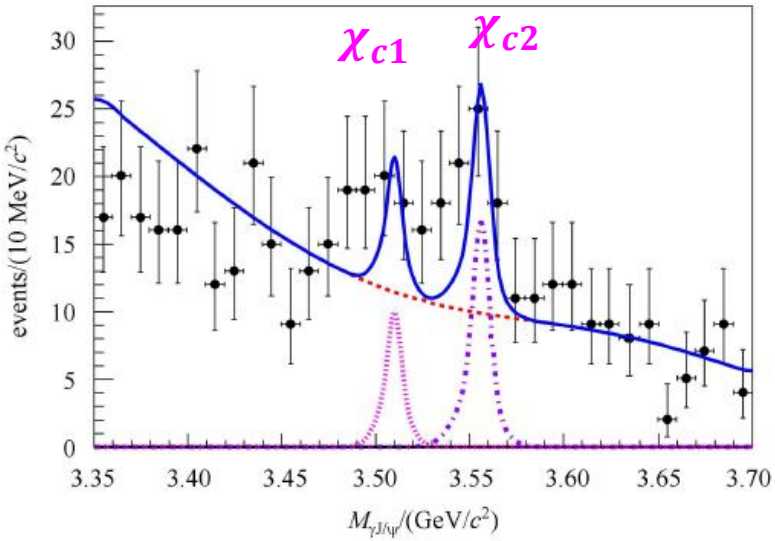
Evidence for $e^+e^- \to \gamma\chi_{c1}/\chi_{c2}$

Fit to *the sum of* $M(\gamma J/\psi)$ distribution of the 4 energy points



The statistical significances for χ_{c0}, χ_{c1}, χ_{c2} are **1.2σ, 3.0σ, 3.4σ** respectively.

A simultaneous fit to $M(\gamma J/\psi)$ at 4 energy points with assuming the production $\sigma(e^+e^- \to \gamma\chi_{cJ})$ at different $\sqrt{s}$ follows the lineshape of $Y(4260)$



The statistical significances for χ_{c0}, χ_{c1}, χ_{c2} are **0, 2.4σ, 4.0σ** respectively.

Summary

- Transition $e^+e^- \to \gamma X(3872)$ at $\sqrt{s}$ > 4 GeV is observed with significance 6.3σ, perhaps via $Y(4260) \to \gamma X(3872)$.
- The $Y(4140)$ is searched via $e^+e^- \to \gamma\phi J/\psi$, no evidence is found (three events).
- The evidence for $e^+e^- \to \gamma\chi_{c1}/\chi_{c2}$ at $\sqrt{s}$ > 4 GeV is found.
- We are still analyzing the data; more interesting results are expected.

Thank you!