Recent results on XY from BESIII

Ke LI (like@ihep.ac.cn)
Shandong University
Institute of High Energy Physics
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)

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 $X(3823)\ (\psi(1^{3}D_{2}))$


Triplet $(1^{3}D_{1,2,3})$

$1^{3}D_{2} \rightarrow \text{DD forbidden, narrow}$

Potential model: $1^{3}D_{2} \rightarrow \gamma \chi_{c1}, \chi_{c2}$ with large width.
Use $p^{+}p^{-}$ transition to produce $1^{3}D_{2}$ with $J^{PC}=2^{--}$ D-wave ($L=2$) transition is expected.
\[ e^+ e^- \rightarrow \pi^+ \pi^- X, X \rightarrow \gamma \chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi \]

Ke Li (SDU&IHEP)

arXiv:1503.08203
Simultaneous fit of $\gamma\chi_{c1}$ (left) and $\gamma\chi_{c2}$ (right) events.

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

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

D-wave is expected.
Limited statistics
limited informations
Born cross section $\sigma[e^+e^- \to \pi^+\pi^- X(3823)] \cdot B(X(3823) \to \gamma \chi_{c1})$

\[
\frac{\sigma[e^+e^- \to \pi^+\pi^- X(3823)] \cdot B(X(3823) \to \gamma \chi_{c1})}{\sigma[e^+e^- \to \pi^+\pi^- \psi'] \cdot B(\psi' \to \gamma \chi_{c1})}
\]

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

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

\[
\frac{B(X(3823) \to \gamma \chi_{c2})}{B(X(3823) \to \gamma \chi_{c1})} < 0.42 \text{ at 90\% C.L.}
\]

$\approx 0.24$ (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 σ) $B^+ \rightarrow \phi J/\psi K^+$
6.0 $fb^{-1}$ at $\sqrt{s} = 1.96$ TeV

CMS $B^+ \rightarrow \phi J/\psi K^+$
5.2 $fb^{-1}$ at $\sqrt{s} = 7$ TeV

D0 (3.1σ) $B^+ \rightarrow \phi J/\psi K^+$
10.4 $fb^{-1}$ at $\sqrt{s} = 1.96$ TeV

or not?

V.S.

Belle $\gamma\gamma \rightarrow \phi J/\psi$
825 $fb^{-1}$ $e^+e^-$ collider

LHCb $B^+ \rightarrow \phi J/\psi K^+$
0.37 $fb^{-1}$ at $\sqrt{s} = 7$ TeV
(2.4σ) disagreement with CDF

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

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), $\phi \rightarrow K_SK_L$ ($K_L$ is missing) and $\phi \rightarrow \pi^+\pi^-\pi^0$
\[ \phi \rightarrow K^+ K^- \quad \phi \rightarrow K_S^0 K_L^0 \quad \phi \rightarrow \pi^+ \pi^- \pi^0 \]

\[ \sqrt{s} = 4.23 \text{ GeV} \]

\[ \sqrt{s} = 4.26 \text{ GeV} \]

\[ \sqrt{s} = 4.36 \text{ GeV} \]
Combine six modes (three $\phi$ modes × two $J/\psi$ modes)

$\sqrt{s} = 4.23$ GeV

$\sigma^B \cdot B < 0.35$ pb

$\sqrt{s} = 4.26$ GeV

$\sigma^B \cdot B < 0.28$ pb

$\sqrt{s} = 4.36$ GeV

$\sigma^B \cdot B < 0.33$ pb

Sum of all data sets

Three events seems like $Y(4140)$.

No background from MC studies
No significant $Y(4140)$ signal.

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

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (GeV/$c^2$)</th>
<th>Luminosity (pb$^{-1}$)</th>
<th>$(1 + \delta)$</th>
<th>$n^{\text{prod}}$</th>
<th>$\sigma^B \cdot B$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.23</td>
<td>1094</td>
<td>0.840</td>
<td>&lt;339</td>
<td>&lt;0.35</td>
</tr>
<tr>
<td>4.26</td>
<td>827</td>
<td>0.847</td>
<td>&lt;207</td>
<td>&lt;0.28</td>
</tr>
<tr>
<td>4.36</td>
<td>545</td>
<td>0.944</td>
<td>&lt;179</td>
<td>&lt;0.33</td>
</tr>
</tbody>
</table>

Systematic uncertainty is considered.

Compared with $X(3872)$ production. *PRL 112, 092001*

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

$$= 0.33 \pm 0.12\text{(stat)} \pm 0.02\text{(syst)} \text{ pb at } \sqrt{s} = 4.26 \text{ GeV}.$$

Take $B(X(3872) \rightarrow \pi^+\pi^- J/\psi) = 5\%$. *arXiv: 0910.3138*

And $B(Y(4140) \rightarrow \phi J/\psi) = 30\%$, 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.

4.23 GeV

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

Phase-space modified Breit-Wigner

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

with significance $> 9\sigma$

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

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

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

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

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

A structure?

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 $9\sigma$

Preliminary results
Results  (BESIII Preliminary)

| $\sqrt{s}$ (GeV) | $N^{\text{obs}}$ | $L_{\text{int}}$ (pb$^{-1}$) | $1+\delta$ | $\sum_{i} B_{i}$ | $|1+\Pi|^{2}$ | $\sigma^{B}$ (pb) |
|-----------------|-----------------|-----------------|-------------|-----------------|----------------|----------------|
| 4.190           | 2.8 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 6.7    | 1047.3           | 0.925       | 0.0107          | 1.056          | 3.1 $\pm$ 0.6 $\pm$ 0.3          |
| 4.245           | 0.3 $\pm$ 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 $\pm$ 6.1    | 825.7            | 0.939       | 0.0089          | 1.054          | 3.9 $\pm$ 0.8 $\pm$ 0.4          |
| 4.310           | 2.0 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\pm$ 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 $\eta'/\psi$ 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 $\gamma J/\psi$

<table>
<thead>
<tr>
<th>$\sqrt{s}$/GeV</th>
<th>$N_{\text{obs}}$</th>
<th>significance ($\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_0$</td>
<td>7.0±6.6</td>
<td>1.6</td>
</tr>
<tr>
<td>$x_1$</td>
<td>4.4±2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>$x_2$</td>
<td>1.8±1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>4.230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_0$</td>
<td>0.2±2.3</td>
<td>0.0</td>
</tr>
<tr>
<td>$x_1$</td>
<td>6.7±4.3</td>
<td>1.9</td>
</tr>
<tr>
<td>$x_2$</td>
<td>13.3±5.2</td>
<td>2.9</td>
</tr>
<tr>
<td>4.260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_0$</td>
<td>0.1±1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>$x_1$</td>
<td>3.0±3.0</td>
<td>1.1</td>
</tr>
<tr>
<td>$x_2$</td>
<td>7.5±3.9</td>
<td>2.3</td>
</tr>
<tr>
<td>4.360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_0$</td>
<td>0.1±0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>$x_1$</td>
<td>5.2±4.9</td>
<td>2.4</td>
</tr>
<tr>
<td>$x_2$</td>
<td>4.4±4.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Ke Li (SDU&IHEP)

3rd XYZ Workshop
Combine all the data sets.

Evidence for
\( e^+e^- \rightarrow \gamma Xc_1 \) \( (3.0\sigma) \)
\( e^+e^- \rightarrow \gamma Xc_2 \) \( (3.4\sigma) \)

\[ \begin{array}{|c|c|c|}
\hline
\sqrt{s} \text{ (GeV)} & \sigma^{\text{UP}} \text{ (pb)} & \sigma^{\text{B}} \text{ (pb)} \\
\hline
Xc_0 & 188 & 65.1\pm 61.3\pm 7.2 \\
Xc_1 & 5.2 & 2.3\pm 1.4\pm 0.2 \\
Xc_2 & 18 & 4.8\pm 4.5\pm 0.5 \\
\hline
4.009 & & \\
\hline
Xc_0 & 27 & 0.7\pm 8.0\pm 0.1 \\
Xc_1 & 1.7 & 0.7\pm 0.5\pm 0.1 \\
Xc_2 & 5.0 & 2.7\pm 1.1\pm 0.3 \\
\hline
4.230 & & \\
\hline
Xc_0 & 26 & 0.5\pm 8.9\pm 0.1 \\
Xc_1 & 1.2 & 0.4\pm 0.4\pm 0.1 \\
Xc_2 & 4.2 & 2.0\pm 1.1\pm 0.2 \\
\hline
4.260 & & \\
\hline
Xc_0 & 24 & 0.7\pm 5.0\pm 0.1 \\
Xc_1 & 3.0 & 1.4\pm 1.3\pm 0.1 \\
Xc_2 & 5.0 & 2.2\pm 2.3\pm 0.2 \\
\hline
4.360 & & \\
\hline
\end{array} \]
How to explain?
Narrow Y state?

$M(Y) = (4230 \pm 8) \text{ MeV}/c^2$
$\Gamma_t = (38 \pm 12) \text{ MeV}$

Consist with each other
Hope it is not a joke!

$M(Y) = (4216 \pm 18) \text{ MeV}/c^2$
$\Gamma(Y) = (39 \pm 32) \text{ MeV}$

Ke Li (SDU&IHEP)
3rd XYZ workshop
Summary

• The $X(3823) (\psi(1^3D_2))$ is observed with significance $6.2\sigma$ via $e^+e^- \rightarrow \pi^+\pi^-\gamma\chi_{c1}$

• The $Y(4140)$ is searched via $e^+e^- \rightarrow \gamma\phi\chi/\psi$, 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 $e^+e^- \rightarrow \eta\phi/\psi$ is measured from 3.81 to 4.60 GeV. Interesting structures. Maybe same with $\omega\chi_{c0}$.

• Cross section of $e^+e^- \rightarrow \eta'\phi/\psi$ is measured, possible same structure with that in $\eta\phi/\psi$

• 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 $\omega\chi_{c0}, \eta\phi/\psi$. Try other channels.

Thanks for your attention.