XYZ spectroscopy at BESIII

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(on the behalf of BESIII collaboration)

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2015 European Nuclear Physics Conference
Aug.31-Sep.4, University of Groningen/KVI-CART
Outline

- Introduction
  - Hadrons and XYZ states

- XYZ spectroscopy at BESIII
  - BESIII data samples for XYZ study
  - The XYZ states

  ✓ $\text{X}(3872), \text{X}(3823)$
  ✓ Abundant structures above 4GeV
  ✓ $\text{Z}_c(3900)/\text{Z}_c(3885), \text{Z}_c(4020)/\text{Z}_c(4025)$

- Summary
Constitution of hadrons in QCD

• Quark Model

   Mesons
   Color-anticolor pairs

   Baryons
   Red-blue-green triplets

• Exotic states predicted by QCD

   Tetraquark
   Tightly bound diquark&anti-diquark

   Molecule
   Loosely bound meson&anti-meson

   Pentaquark
   S=+1

   Six-quark state
   Tightly bound 6 quarks

   Hybrid
   More than 2 quarks and gluon
BESIII and BESIII

First physics run starts from 2009!

Double ring:
Symmetric collider
CMS energy:
2.0~4.6 GeV
Design Luminosity @\(\psi(3770)\)
\(1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}\)
(70% achieved, \(\sim 20\text{pb}^{-1}/\text{day}\))
• Below open charm threshold
  
  Good agreement between discovery and theoretical prediction.

• Above open charm threshold
  
  Many expected states are not observed
  Many unexpected states are observed: XYZ states
Data samples for XYZ states at BESIII

- Luminosity $\sim 5$ fb$^{-1}$
- Large data samples around $\Psi(4040)$, $Y(4260)$, $Y(4360)$, $\Psi(4415)$ and $Y(4660)$
\( X(3823)/X(3872) \)

- \( X(3823) \) in \( e^+e^- \rightarrow \pi^+\pi^- \gamma X_{c1} \)  PRL 115,011803 (2015)

- \( X(3872) \) in \( Y(4260) \rightarrow \gamma \pi^+\pi^- J/\Psi \)  PRL 112,092001 (2014)
\[ e^+ e^- \rightarrow \pi^+ \pi^- X(3823) \rightarrow \pi^+ \pi^- \gamma \chi_{c1} \]

- Potential channel: \( 1^3D_2 \rightarrow \gamma \chi_{c1}, \gamma \chi_{c2} \) with large width.
- \( M=3821.7 \pm 1.3 \pm 0.7 \text{MeV}, \Gamma < 16 \text{MeV}. \)
- Good candidate of \( \Psi(1^3D_2) \).
- Both \( \Upsilon(4360) \) and \( \Psi(4415) \) line shape give reasonable description.
M = 3871.9 ± 0.7 ± 0.2 MeV, Γ < 2.4 MeV.

A new Y(4260) decay mode and new X(3872) production mode: Y(4260) → γX(3872)

If we take B(X(3872) → π⁺π⁻ J/Ψ) ~ 5%, (>2.6% in PDG)

\[
\frac{\sigma(e^+e^-\rightarrow\gamma X(3872))}{\sigma(e^+e^-\rightarrow\pi^+\pi^- J/\Psi)} \sim 11.2\% \text{ large transition ratio!}
\]
Abundant structures above 4GeV

• Cross section of $e^+e^-\rightarrow\pi^+\pi^-J/\Psi(h_c)$  PRL 110, 252001(2013)

• Cross section of $e^+e^-\rightarrow\omega\chi_{c0}$  PRL 114, 092003(2015)

• Cross section of $e^+e^-\rightarrow\eta J/\Psi$  PRD 91,112005(2015)

• Cross section of $e^+e^-\rightarrow\eta' J/\Psi$  Preliminary
$e^+e^- \rightarrow \pi\pi J/\Psi$ and $e^+e^- \rightarrow \pi\pi h_c$

- $\sigma(\pi^0\pi^0 J/\Psi)$ arXiv:1506.06018
- $\sigma(\pi^+\pi^- h_c)$ PRL 111,242001 (2013)
- $\sigma(\pi^0\pi^0 h_c)$ PRL 113,212002 (2014)

- $\sigma(\pi^+\pi^- h_c) \sim \sigma(\pi^+\pi^- J/\Psi)$ different line shape
- A possible structure near 4.23GeV for $\sigma(\pi^+\pi^- h_c)$
- No large iso-spin violation in $\sigma(\pi\pi h_c)$ and $\sigma(\pi\pi J/\Psi)$
Observation of $e^+e^-\rightarrow\omega\chi_{c0}$

- $\Psi(4S)$? EPJC 74:3208 (2014)
- Threshold effect?
- .......

- Cross section peak near 4.23GeV
- Fit with BW
  Mass=4230$\pm$8$\pm$6MeV
  Width=39$\pm$12$\pm$2MeV
Observation of $e^+e^- \rightarrow \eta J/\Psi$ and $e^+e^- \rightarrow \eta' J/\Psi$

- Agree with previous results with improved precision
- Structure near 4.2GeV: $\Psi (4160) \rightarrow \eta J/\Psi$

- First observation at 4.23GeV and 4.26GeV, couldn’t tell the line-shape due to the statistics.
- $\sigma(\eta' J/\Psi)$ is much lower than $\sigma(\eta J/\Psi)$ which is in contradiction to the NRQCD calculation. PRD 89, 074006 (2014)
$Z_c$ states at BESIII

• $Z_c(3900)^\pm$ in $e^+e^- \rightarrow \pi^+ \pi^- J/\Psi$  PRL 110,252001 (2013)

• $Z_c(3900)^0$ in $e^+e^- \rightarrow \pi^0 \pi^0 J/\Psi$  arXiv:1506.06018, accepted by PRL

• $Z_c(3885)^\pm$ in $e^+e^- \rightarrow \pi^+ (D D^*)^-$ PRL 112, 022001 (2014)

• $Z_c(3885)^0$ in $e^+e^- \rightarrow \pi^0 (D D^*)^0$ Preliminary

• $Z_c(4020)^\pm$ in $e^+e^- \rightarrow \pi^+ \pi^- h_c$  PRL 111.242001 (2013)

• $Z_c(4020)^0$ in $e^+e^- \rightarrow \pi^0 \pi^0 h_c$  PRL 113,212002 (2014)

• $Z_c(4025)^\pm$ in $e^+e^- \rightarrow \pi^+ (D^* D^*)^-$ PRL 112,132001 (2013)

• $Z_c(4025)^0$ in $e^+e^- \rightarrow \pi^0 (D^* D^*)^0$  arXiv:1507.02404
$e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi \pi J/\Psi$

- $Z_c(3900)^\pm$, observed by BESIII, confirmed by Bell and CLEO-c data.
- $Z_c(3900)^0$, evidence with $3.7\sigma$ at CLEO-c, observed by BESIII.

<table>
<thead>
<tr>
<th>$Z_c(3900)$</th>
<th>Mass(MeV)</th>
<th>Width(MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_c(3900)^\pm$</td>
<td>3899.0$\pm$3.6$\pm$4.9</td>
<td>46$\pm$10$\pm$20</td>
</tr>
<tr>
<td>$Z_c(3900)^0$</td>
<td>3894.8$\pm$2.3$\pm$2.7</td>
<td>29.6$\pm$8.2$\pm$8.2</td>
</tr>
</tbody>
</table>

Iso-spin triplet is established!
$e^+ e^- \rightarrow \pi Z_c(3885) \rightarrow \pi (D \bar{D}^*)$

**Preliminary**

- $Z_c(3885)^\pm$, observed by BESIII.
- Have a mass and width close to $Z_c(3900)$.

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<tr>
<td>$Z_c(3885)^\pm$</td>
<td>$3883.9 \pm 1.5 \pm 4.2$</td>
<td>$24.8 \pm 3.3 \pm 1.0$</td>
</tr>
<tr>
<td>$Z_c(3885)^0$</td>
<td>$3885.7 \pm 4.3 \pm 8.4$</td>
<td>$35 \pm 11 \pm 15$</td>
</tr>
</tbody>
</table>

Iso-spin triplet is established!
$e^+e^- \rightarrow \pi \ Z_c(4020) \rightarrow \pi \ \pi \ h_c$

- $Z_c(4020)$, observed by BESIII.
- A hint for $Z_c(3900)^{\pm} \rightarrow \pi^\pm \ h_c$
- $Z_c(4020)$, near the $D^* \bar{D}^*$ threshold.

Iso-spin triplet is established!

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<th>$Z_c(4020)$</th>
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<th>Width(MeV)</th>
</tr>
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<tbody>
<tr>
<td>$Z_c(4020)^{\pm/}$</td>
<td>4022.9$\pm$0.8$\pm$2.7</td>
<td>7.9$\pm$2.7$\pm$2.6</td>
</tr>
<tr>
<td>$Z_c(4020)^0$</td>
<td>4023.8$\pm$2.2$\pm$3.8</td>
<td>Fixed(=7.9)</td>
</tr>
</tbody>
</table>

PRL 111,242001 (2013)

PRL 113,212002 (2014)
$e^+e^- \rightarrow \pi \, Z_c(4025) \rightarrow \pi \, (D^*\overline{D}^*)$

- $Z_c(4020)$, observed by BESIII.
- The $Z_c(4020)$ and $Z_c(4025)$ are consistent within 1.5σ.
- If they are the same state:
  \[
  \frac{\Gamma(Z_c(4025) \rightarrow D^*\overline{D}^*)}{\Gamma(Z_c(4020) \rightarrow \pi h_c)} = 12 \pm 5
  \]

Iso-spin triplet is established!

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<th>$Z_c(4025)$</th>
<th>Mass(MeV)</th>
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</tr>
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<tbody>
<tr>
<td>$Z_c(4025)^+$</td>
<td>4026.3±2.6±3.7</td>
<td>24.8±5.6±7.7</td>
</tr>
<tr>
<td>$Z_c(4025)^0$</td>
<td>4025.5 $^{+2.0}_{-1.7}$±3.1</td>
<td>23.0±6.0±1.0</td>
</tr>
</tbody>
</table>
Summary of $Z_c$ states at BESIII

$e^+e^- \rightarrow \pi^+ \pi^- J/\Psi$

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

$e^+e^- \rightarrow \pi^+ \pi^- h_c$

$e^+e^- \rightarrow \pi^0 \pi^0 h_c$

$e^+e^- \rightarrow \pi^+ (D\bar{D}^*^-)$

$e^+e^- \rightarrow \pi^0 (D\bar{D}^*)^0$

$e^+e^- \rightarrow \pi^+ (D\bar{D}^*)^0$

$Z_c(3900)^\pm$?

$Z_c(3900)^0$?

$Z_c(4020)^\pm$?

$Z_c(4020)^0$?
Summary

• Lots of progress in charmonium-like studies at BESIII recently.

• Observation of $e^+e^- \to \gamma X(3872) \& \pi^+\pi^- X(3823)$.

• Observation of $Z_c$ states.

• Measurements of many hidden charm final states.

• $X, Y, Z$ particles are correlated.

• BESIII will continue to study the XYZ states.

Thank you!