Experimental Results on $Z_c(3900)$ (BESIII & Belle)

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Outline

1. Discovery of $Z_c(3900)$ at BESIII.
2. Discovery of $Z(3900)^{\pm}$ at Belle.
3. Comparison between different experiments.
5. More Zc states from BESIII
BESIII’s data

1. BEPCII is a symmetric Collider.
2. BESIII take data at e+e- c.m energy from 2 to 4.6 GeV.
3. Design luminosity $1*10^{33}/\text{cm}^2/\text{s}$, reach 70%.

BESIII can study XYZ particle above 4 GeV with world’s largest scan data sets.
1. Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb\(^{-1}\) data @ 4.26 GeV.
2. Peak position of \(\gamma(4260) \rightarrow \pi^+\pi^- J/\psi\) cross section.
3. \(N(\mu^+\mu^-)=882 \pm 33; N(e^+e^-)=595 \pm 28;\) purity \(\sim90\%\).
1. Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb$^{-1}$ data @ 4.26 GeV.
2. Peak position of $\gamma(4260)\rightarrow\pi^+\pi^-J/\psi$ cross section.
3. $N(\mu^+\mu^-)=882 \pm 33$; $N(e^+e^-)=595 \pm 28$; purity $\sim 90\%$.
4. Born cross section: $\sigma^B=(62.9 \pm 1.9 \pm 3.7)$ pb at BESIII.
5. Good agreement with Belle and BaBar.
$Z_c(3900)$ from BESIII

1. Structure in $M(\pi^\pm J/\psi)$ mass distribution.
2. Phase space reflection of $Z_c(3900)$. 

PRL 110, 252001 (2013).
$Z_c(3900)$ from BESIII

PRL 110, 252001 (2013).
1. 1D fit to extract resonant parameters.
2. Divided Dalitz plot by diagonal line; Fit $M_{\text{max}}(\pi^{\pm}J/\psi)$ mass distribution.
3. S-Wave Breit Wigner; $p^*q$ phase space factor; efficiency applied.
4. $M=(3899.0 \pm 3.6 \pm 4.9)$ MeV; $\Gamma=(46 \pm 10 \pm 20)$ MeV.
5. Statistical significance: $>8\sigma$, discovery!
$Z_c(3900)$ from Belle

Integrated luminosity of B factories

> 1 ab$^{-1}$
On resonance:
Y(5S): 121 fb$^{-1}$
Y(4S): 711 fb$^{-1}$
Y(3S): 3 fb$^{-1}$
Y(2S): 25 fb$^{-1}$
Y(1S): 6 fb$^{-1}$
Off reson./scan:
$\sim$ 100 fb$^{-1}$

$\sim$ 550 fb$^{-1}$
On resonance:
Y(4S): 433 fb$^{-1}$
Y(3S): 30 fb$^{-1}$

ISR technique

$J^{PC} = 1-$
$\psi', \psi'', Y...$
Z(3900)± from Belle

1. Belle collected data at/near Y(nS) (n=1,...,5) resonance.
2. Almost full Belle data sample used: Lum=967 fb⁻¹ data.
3. Using ISR photon non-tagged method, Y(4260) was observed significantly.
4. 4.15<M(π⁺π⁻J/ψ)<4.45 GeV to select Y(4260) resonance.
5. Dalitz plot also shows structures.
$Z(3900)^\pm$ from Belle

PRL 110, 252002 (2013)
Z(3900)± from Belle

1. Belle use the same fit strategy to $M_{\text{max}}(\pi^\pm J/\psi)$ distribution.
2. S-Wave BW, $p^*q$ phase space factor, efficiency applied.
3. Belle observed 689 events, with 139 background.
4. $M=(3894.5\pm6.6\pm4.5)$ MeV; $\Gamma=(63\pm24\pm26)$ MeV.
5. Significance: $5.2\sigma$. 
1. $Z_c(3900) = Z(3900) \pm$.
2. CLEO’s data at 4.17 GeV by K. Seth. (586pb$^{-1}$)
3. $M = 3886 \pm 4 \pm 2$ MeV, $\Gamma = 37 \pm 4 \pm 8$ MeV.
4. Significance $> 5\sigma$
1. The $\pi^+\pi^-$ amplitude is similar in $Y(4260) \rightarrow \pi^+\pi^- J/\psi$ decay.
2. Help understand the $Y(4260)$ and $Z_c(3900)$?
The nature of $Z_c(3900)$?

1. Tetraquarks
   • arXiv:1110.1333, 1303.6857
   • arXiv:1304.0345, 1304.1301...

2. Hadronic molecules
   • arXiv:1303.6608, 1304.2882, 1304.1850...

3. Four quark state (1 or 2)
   • arXiv:1304.0380...

4. Meson loop
   • arXiv:1303.6355
   • arXiv:1304.4458...

5. ISPE model
   • arXiv:1303.6842...

6. ...
Future Working Plan

1. Precise mass and width measurement; and Spin-Parity determination with more data (4 × @4.26 GeV) at BESIII (PWA ongoing).

2. Give a line-shape measurement of both Y(4260) and \( \pi^{\pm}Z_c(3900) \) with BESIII scan data.

3. More decay modes \([\pi\psi’, \rho\eta_c, \text{open charm,}…]\)

4. Spin-parity of Zc and Zc’

5. Production mechanisms, production rates

6. Test various theoretical models

7. Neutral partners of Zc and Zc’

8. Excited Zc, Zc’ states? \( Z_{cs} \rightarrow KJ/\psi \) states?

9. Other XYZ states?
e\(^+\)e\(^-\) \rightarrow \pi^+\pi^-h_c(1P) at BESIII

- $h_c \rightarrow \gamma \eta_c$, $\eta_c \rightarrow$ hadrons [16 exclusive decay modes]
  - $p \bar{p}$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p \bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-+c.c.$, $K_S^0K^+\pi^-\pi^-+c.c.$, $K^+K^-\pi^0$
  - $p \bar{p}\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$

Ecm=4.26 GeV

Ecm=4.36 GeV
Observation of $Z_c(4020)$

- Obvious structure around 4.2 GeV
- Simultaneously fit to 4.230/4.260/4.360 data (2.4 fb$^{-1}$)
- $M = 4022.9 \pm 0.8 \pm 2.7$ MeV;
- $\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV

$\sigma = 8.7 \pm 1.9 \pm 2.8 \pm 1.4$ pb @ 4.230
7.4$\pm 1.7 \pm 2.1 \pm 1.2$ pb @ 4.260
10.3$\pm 2.3 \pm 3.1 \pm 1.6$ pb @ 4.360

Significance: $8.9\sigma$ ($Z_c(4020)$)
No significant $Z_c(3900)$ ($2.1\sigma$)
$e^+e^- \rightarrow \pi^\pm (D \bar{D}^*)^\mp \rightarrow Z_c(3885)$ with $525/\text{pb}$ @4.26 GeV

Partial reconstruct: reconstruct “bachelor” $\pi$
reconstruct $D^0 \rightarrow K \pi$ and $D^+ \rightarrow K \pi$
looking at the recoiling mass of $\pi$

BESIII: arXiv:1310.1163
Submitted to PRL

Fit with mass-dependent BW with phase space factor and efficiency correction.

The pole mass and width are reported for $Z_c(3885)$.

<table>
<thead>
<tr>
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<th>$Z_c(3885) \rightarrow D \bar{D}^*$</th>
<th>$Z_c(3900) \rightarrow \pi J/\psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (MeV/c²)</td>
<td>$3883.9 \pm 1.5 \pm 4.2$</td>
<td>$3899 \pm 3.6 \pm 4.9$</td>
</tr>
<tr>
<td>$\Gamma$ (MeV)</td>
<td>$24.8 \pm 3.3 \pm 11.0$</td>
<td>$46 \pm 10 \pm 20$</td>
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<tr>
<td>$\sigma \times B$ (pb)</td>
<td>$83.5 \pm 6.6 \pm 22.0$</td>
<td>$13.5 \pm 2.1 \pm 4.8$</td>
</tr>
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Assuming the $Z_c(3885)$ is due to $Z_c(3900)$:

$$\frac{\Gamma(Z_c(3885) \rightarrow D \bar{D}^*)}{\Gamma(Z_c(3900) \rightarrow \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

Strange behavior of $Y(4260) - Z_c(3900)$! Large non-DD coupling!
\[ e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* D^*)^+ + \text{c.c.} \]

Strategy: reconstruct \( D^+ \) from \( D^{*+} \);
reconstruct "bachelor" \( \pi \) at least on \( \pi^0 \) from \( D^* \) decays
looking at the recoil side of \( \pi \)

827 pb\(^{-1} \) data at 4.260 GeV

arXiv: 1308.2760
Submitted to PRL

Fit to \( \pi^\pm \) recoil mass yields \( 401 \pm 47 \) \( Z_c(4025) \) events
\[ M = 4026.3 \pm 2.6 \pm 3.7 \text{ MeV} ; \Gamma = 24.8 \pm 5.6 \pm 7.7 \text{ MeV} \]

\[ R = \frac{\sigma(e^+e^- \rightarrow Z_c^\pm(4025)\pi^\mp \rightarrow (D^* \bar{D}^*)^\pm \pi^\mp)}{\sigma(e^+e^- \rightarrow (D^* \bar{D}^*)^\pm \pi^\mp)} = (65 \pm 9 \pm 6)\% \]
Summary

• The charged charmoniumlike state $Z_c(3900)$ has been observed by BESIII + Belle + (CLEO’s data?).

• Coupling to charmonium state and charged.

• Can not be an conventional Charmonium!

• Probably a four quark state (tetraquark or hadron molecule?).

• Further work is need experimentally to identify the nature.

Thanks!