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.
BESIII’s data

1. BEPCII is a symmetric Collider.
2. Covering CM energy from 2 to 4.6 GeV.
3. Design luminosity $1 \times 10^{33}$/cm$^2$/s, reach 70%.
4. Large J/$\psi$, $\psi(2S)$, $\psi(3770)$... and above 4 GeV...

BESIII can study XYZ particle above 4 GeV with world’s largest scan data sets.
1. Very simple and straightforward analysis.
2. The produced vector charmonium(like) state almost in rest frame.
3. $Y(4260) \rightarrow \pi^+\pi^- J/\psi$, four charged track detected ($\pi^+\pi^- e^+e^-$ & $\pi^+\pi^- \mu^+\mu^-$).
Z_c(3900) from BESIII

1. Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb⁻¹ data @ 4.26 GeV.
2. Peak position of γ(4260)→π⁺π⁻J/ψ cross section.
3. N(μ⁺μ⁻)=882±33; N(e⁺e⁻)=595±28; purity ~90%.

PRL 110,252001 (2013).
1. Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb\(^{-1}\) data @ 4.26 GeV.
2. Peak position of \(\gamma(4260) \to \pi^+\pi^- J/\psi\) cross section.
3. \(N(\mu^+\mu^-) = 882 \pm 33; N(e^+e^-) = 595 \pm 28\); purity \(~90\%\).
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

2. Structure in M(π⁺J/ψ) mass distribution.
3. Phase space reflection effect of Z_c(3900).
$Z_c(3900)$ from BESIII

PRL 110, 252001 (2013).

1. Structure in $M(\pi^+J/\psi)$ mass distribution.

2. Phase space reflection of $Z_c(3900)$.
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. $M=(3899.0 \pm 3.6 \pm 4.9) \text{MeV}$; $\Gamma=(46 \pm 10 \pm 20) \text{MeV}$.
5. Statistical significance: $>8\sigma$, discovery!
Z(3900) from Belle

Integrated luminosity of B factories

(\text{fb}^{-1})

1200
1100
1000
900
800
700
600
550
450
400
300
200
100
0

2004/1 2002/1 2000/1 2001/1 1998/1

All data sets (at different energy points) can be used for ISR analysis.

\begin{align*}
\text{KEKB} & \quad \text{PEP-II} \\
> 1 \text{ ab}^{-1} & \\
\text{On resonance:} & \\
\Upsilon(5S): 121 \text{ fb}^{-1} & \\
\Upsilon(4S): 711 \text{ fb}^{-1} & \\
\Upsilon(3S): 3 \text{ fb}^{-1} & \\
\Upsilon(2S): 25 \text{ fb}^{-1} & \\
\Upsilon(1S): 6 \text{ fb}^{-1} & \\
\text{Off reso./scan:} & \\
\sim 100 \text{ fb}^{-1} & \\
\sim 550 \text{ fb}^{-1} & \\
\text{On resonance:} & \\
\Upsilon(4S): 433 \text{ fb}^{-1} & \\
\Upsilon(3S): 30 \text{ fb}^{-1} & \\
\end{align*}

ISR technique

\[J^{PC} = 1^{-} \]

\[\psi', \psi'', \Upsilon, \ldots\]
\( \pi^+ \pi^- J/\psi \) process via ISR

1. ISR photon non-tagged.
2. Clear signal of missing massless particle.
3. Polar angle distribution agree with ISR expectation.
4. \( \psi(2S) \) signal was used to calibrate both cross section and mass.

<table>
<thead>
<tr>
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<th>( e^+e^- )</th>
<th>( \mu^+\mu^- )</th>
<th>QED</th>
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<tbody>
<tr>
<td>( \sigma(\Upsilon(4S)) )</td>
<td>((14.12 \pm 0.18 \pm 0.85) \text{ pb})</td>
<td>((15.09 \pm 0.11 \pm 0.79) \text{ pb})</td>
<td>((14.25 \pm 0.26) \text{ pb})</td>
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<tr>
<td>( \sigma(\Upsilon(5S)) )</td>
<td>((13.79 \pm 0.44 \pm 0.83) \text{ pb})</td>
<td>((13.33 \pm 0.25 \pm 0.70) \text{ pb})</td>
<td>((13.42 \pm 0.25) \text{ pb})</td>
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<tr>
<td>( \sigma(\Upsilon(2S)) )</td>
<td>((16.75 \pm 0.85 \pm 1.01) \text{ pb})</td>
<td>((16.63 \pm 0.54 \pm 0.87) \text{ pb})</td>
<td>((16.03 \pm 0.29) \text{ pb})</td>
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1. Full Belle data sample used: Lum=967 fb$^{-1}$.
2. Study the $\pi^+\pi^-J/\psi$ using ISR photon non-tagged method.
3. $\gamma(4260)$ was observed significantly, agree with BaBar.
4. $4.15<M(\pi^+\pi^-J/\psi)<4.45$ GeV to select $\gamma(4260)$ events.
5. Dalitz plot shows structures in $M(\pi^\pm J/\psi)$ mass distribution.
$Z(3900)^{\pm}$ from Belle

![Graphs and histograms showing the $Z(3900)^{\pm}$ from Belle experiments.](Image)
1. Belle observed 689 events, with 139 background in $Y(4260)$ region.
2. Belle use the 1D fit strategy to $M_{\text{max}}(\pi^{\pm}J/\psi)$ distribution.
3. S-Wave BW, $p^*q$ phase space factor, efficiency applied.
4. $M=(3894.5 \pm 6.6 \pm 4.5) \text{ MeV}; \Gamma=(63 \pm 24 \pm 26) \text{ MeV}.$
5. Significance: $5.2 \sigma$. Observation!
1. **CLEO**’s data: $M = 3885 \pm 5$ MeV, $\Gamma = 34 \pm 13$ MeV.

2. **Belle**: $M = (3894.5 \pm 6.6 \pm 4.5)$ MeV; $\Gamma = (63 \pm 24 \pm 26)$ MeV.

3. **BESIII**: $M = (3899.0 \pm 3.6 \pm 4.9)$ MeV; $\Gamma = (46 \pm 10 \pm 20)$ MeV.

4. $Z_c(3900) = Z(3900)^\pm$. 

*CLEO’s data @ arXiv: 1304.3036*
The nature of $Z_c(3900)$?

1. Tetraquarks
   • L. Maiani, A. Ali et al.

2. Hadronic molecules
   • U.-G. Meissner, F. K. Guo et al.

3. Four quark state (1 or 2)
   • M. B. Voloshin

4. Meson loop
   • Q. Zhao et al.

5. ISPE model
   • X. Liu et al.

6. …
Future Working Plan

1. Precise mass and width measurement; and Spin-Parity determination with more data (4 $\times$ @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. Search for more decay channels of $Z_c(3900)$, such as DD* ...

4. Search for partner particle of $Z_c(3900)$, the $Z_c(4020) \rightarrow \pi^{\pm}h_c$? Or the $Z_c(4025) \rightarrow D^*D^*$ $\pm$?

5. ...


Summary

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

• Can not be an conventional Charmonium!

• A four quark state (tetraquark? hadron molecule? Or sth else?).

• Further work is needed experimentally to identify its nature.

Thanks!
backup
M(π⁺π⁻) amplitude in Y(4260) → π⁺π⁻J/ψ

1. The π⁺π⁻ amplitude is similar in Y(4260) → π⁺π⁻J/ψ decay.
2. Help understand the Y(4260) and Zc(3900)?