Recent results from Belle

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INT workshop, Seattle

Nov. 2-13, 2015
The Belle experiment

World record:
\[ L = 2.1 \times 10^{34}/\text{cm}^2/\text{sec} \]

ARES(LER)

8 x 3.5 GeV
22 mrad crossing

1999-2010
1014/fb

The KEKB Collider

Mt. Tsukuba

Belle

~ 1 km in diameter
Integrated luminosity of B factories

<table>
<thead>
<tr>
<th>Ecm (GeV)</th>
<th>Npoints</th>
<th>Lum per point (fb⁻¹)</th>
<th>Physics analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.865</td>
<td>1</td>
<td>121.4</td>
<td>Yππ, h_bππ, B(<em>)B(</em>)π</td>
</tr>
<tr>
<td>10.63-11.02</td>
<td>6+16</td>
<td>~1</td>
<td>R_b, Yππ, h_bππ</td>
</tr>
<tr>
<td>10.75-11.05</td>
<td>61</td>
<td>~0.05</td>
<td>R_b</td>
</tr>
<tr>
<td>10.52</td>
<td>1</td>
<td>1.03</td>
<td>Continuum bkg. est.</td>
</tr>
</tbody>
</table>

> 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 resonance/scan:
~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
Y(4S): 433 fb⁻¹
Y(3S): 30 fb⁻¹
Y(2S): 14 fb⁻¹
Off resonance:
~ 54 fb⁻¹
e^+e^- annihilation of vector bottomonia

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

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

\[ \Upsilon(nS), \ Upsilon_b \ldots \]
ISR production of vector charmonia

\[ J/\psi, \psi', \psi'', \psi_3770, \psi_{4040}, \psi_{4160}, \psi_{4418} \]

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

\[ M^2(\pi^+J/\psi) \text{(GeV/c}^2)^2 \]

\[ M^2(\pi^+J/\psi) \text{(GeV/c}^2)^2 \]

\[ \gamma_{\text{ISR}} \]

\[ \gamma \]

\[ e^+ \rightarrow \gamma^* \]

\[ e \rightarrow \gamma_{\text{ISR}} \]

\[ e \rightarrow \gamma \]

\[ e \rightarrow \gamma_{\text{ISR}} \]

\[ e \rightarrow \gamma \]

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\[ e \rightarrow \gamma \]

\[ e \rightarrow \gamma_{\text{ISR}} \]

\[ e \rightarrow \gamma \]
Outline

• $R_b$ measurement
  \[ R_b = \frac{\sigma(e^+e^- \rightarrow b\bar{b})}{\sigma^0(e^+e^- \rightarrow \mu^+\mu^-)} \]

• $e^+e^- \rightarrow \pi^+\pi^-\gamma(nS)$, $\pi^+\pi^-h_b(nP)$, $B^(*)B^(*)\pi$
  – $\gamma(5S)$, $\gamma(6S)$, $Z_b$

• $e^+e^- \rightarrow \pi^+\pi^-\psi(nS)$, $K^+K^-J/\psi$
  – $Y(4260)$, $Y(4360)$, $Y(4660)$, $Z_c$ & $Z_{cs}$

• Summary
$e^+e^- \rightarrow \bar{b}b$ inclusive & exclusive

- Understand better the vector states above open bottom
- Study charged bottomoniumlike states
Previous results on $Z_b$ states

$Z_b$ is observed in five different modes:

- $Z_{b}(10610)$
- $Z_{b}(10650)$

**Average for $Z_b^\pm$:**

\[
\langle M_1 \rangle = 10607.2 \pm 2.0 \text{ MeV} \\
\langle \Gamma_1 \rangle = 18.4 \pm 2.4 \text{ MeV} \\
\langle M_2 \rangle = 10652.2 \pm 1.5 \text{ MeV} \\
\langle \Gamma_2 \rangle = 11.5 \pm 2.2 \text{ MeV}
\]

**$Z_b^0$ Results:**

\[
\langle M_1 \rangle = 10609 \pm 7 \pm 6 \text{ MeV}
\]

Consistent with $Z_b^\pm$

\[
M_1 - M_{B} - M_{B^*} = 2.4 \pm 2.1 \text{ MeV} \\
M_2 - M_{B^{*}} - M_{B^{**}} = 1.8 \pm 1.8 \text{ MeV}
\]
Procedure:

1. Count hadronic events
2. Subtract scaled cont. (udsc)
3. Subtract ISR $\gamma(1S,2S,3S)$
4. Do efficiency correction
5. Divided by lum & $\sigma^0(\mu\mu)$

- No ISR corr.; no VP corr.
- Fit with constant width BW in small energy range.
- Need better model to fit

Agree with BaBar: PRL102, 012001 (2009) with improved precision
Ecm=10.54-11.20 GeV, 5 MeV step for >300 points, 3.9 fb$^{-1}$ in total

Belle: arXiv:1501.01137
\[ F = |A_{nr}|^2 + |A_r + A_{5S}e^{i\phi_{5S}} f_{5S} + A_{6S}e^{i\phi_{6S}} f_{6S}|^2 \]

\( \gamma(5S): \)
Mass = (10881.9 ± 1.0 ± 1.2) MeV
Width = (49.8 ± 1.9 ± 2.1 ± 2.8) MeV

\( \gamma(6S): \)
Mass = (11002.9 ± 1.1 ± 0.8 ± 0.9) MeV
Width = (38.5 ± 1.6 ± 1.5 ± 1.3 ± 2.1 ± 2.4) MeV

\[ \Delta \phi = -1.86 \pm 0.24_{0.10} \pm 0.10 \text{ rad} \]

- Results agree with previous measurements
- Suffers from model uncertainties (signal, background parametrization, interference, thresholds, coupled channel effect)

Belle: arXiv:1501.01137
$E_{cm} = 10.54 - 11.20\, \text{GeV}, \, 5\, \text{MeV} \text{ step for } >300\, \text{points}, \, 3.9\, \text{fb}^{-1}\, \text{in total}$
$E_{cm} = 10.54 - 11.20$ GeV, 5 MeV step for >300 points, 3.9 fb$^{-1}$ in total

\[
\mathcal{F} = |A_{nr}|^2 + |A_T + A_{5S} e^{i\phi_{5S}} f_{5S} + A_{6S} e^{i\phi_{6S}} f_{6S}|^2
\]

- No ISR corr.; no VP corr.
e^+ e^- \rightarrow \pi^+ \pi^- \gamma(nS)

- tag \gamma(nS) \rightarrow \mu^+ \mu^- and select \pi^+ \pi^-,

\gamma(5S):
Mass = (10891.9 \pm 3.2 \pm 0.6) \pm 1.5 MeV
Width = (53.7 \pm 7.1) \pm 5.6 \pm 0.9 MeV

\gamma(6S):
Mass = (10987.5 \pm 6.4 \pm 2.5) \pm 2.2 \pm 2.1 MeV
Width = (61 \pm 9) \pm 19 \pm 20 MeV

\Delta \phi = -1.0 \pm 0.4 \pm 1.0 \pm 0.1 \text{ rad}

- Results agree with previous measurements
- Also agree with fit with Rb reasonably well
- Still room for improvement

Belle: arXiv:1501.01137
$Z_b$ in $\gamma(5S) \rightarrow \pi^+\pi^-\gamma(nS)$

- 121 fb$^{-1}$ data, tag $\gamma(nS) \rightarrow \mu^+\mu^-$ and select $\pi^+\pi^-$

<table>
<thead>
<tr>
<th>Final state</th>
<th>$\gamma(1S)\pi^+\pi^-$</th>
<th>$\gamma(2S)\pi^+\pi^-$</th>
<th>$\gamma(3S)\pi^+\pi^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal yield</td>
<td>2090 ± 115</td>
<td>2476 ± 97</td>
<td>628 ± 41</td>
</tr>
<tr>
<td>Efficiency, %</td>
<td>45.9</td>
<td>39.0</td>
<td>24.4</td>
</tr>
<tr>
<td>$B_{\gamma(nS)\rightarrow\mu^+\mu^-}$, % [14]</td>
<td>2.48 ± 0.05</td>
<td>1.93 ± 0.17</td>
<td>2.18 ± 0.21</td>
</tr>
<tr>
<td>$\sigma_{e^+e^-\rightarrow\gamma(nS)\pi^+\pi^-}$, pb</td>
<td>1.51 ± 0.08 ± 0.09</td>
<td>2.71 ± 0.11 ± 0.30</td>
<td>0.97 ± 0.06 ± 0.11</td>
</tr>
<tr>
<td>$\sigma_{\gamma(1S)\pi^+\pi^-}$, pb</td>
<td>2.27 ± 0.12 ± 0.14</td>
<td>4.07 ± 0.16 ± 0.45</td>
<td>1.46 ± 0.09 ± 0.16</td>
</tr>
<tr>
<td>$\sigma_{\gamma(2S)\pi^+\pi^-}$, pb [1]</td>
<td>1.61 ± 0.10 ± 0.12</td>
<td>2.35 ± 0.19 ± 0.32</td>
<td>1.44$^{+0.55}_{-0.45}$ ± 0.19</td>
</tr>
</tbody>
</table>

Z̄_b in γ(5S)→π⁺π⁻γ(nS)

- Full partial wave analysis of γ(5S)→π⁺π⁻μ⁺μ⁻
- Mass, width, fraction, and JP=1+ of Z̄_b states determined

π⁺π⁻γ(1S)  π⁺π⁻γ(2S)  π⁺π⁻γ(3S)
# Z\(_b\) in \(\Upsilon(5S) \rightarrow \pi^+\pi^-\Upsilon(nS)\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(\Upsilon(1S)\pi^+\pi^-)</th>
<th>(\Upsilon(2S)\pi^+\pi^-)</th>
<th>(\Upsilon(3S)\pi^+\pi^-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_{Z_b^\pm(10610)\pi^\pm}, %)</td>
<td>4.8 ± 1.2(^{+1.5}_{-0.3})</td>
<td>18.1 ± 3.1(^{+4.2}_{-0.3})</td>
<td>30.0 ± 6.3(^{+5.4}_{-7.1})</td>
</tr>
<tr>
<td>(Z_b(10610)) mass, MeV/c(^2)</td>
<td>10608.5 ± 3.4(^{+3.7}_{-1.4})</td>
<td>10608.1 ± 1.2(^{+1.5}_{-0.2})</td>
<td>10607.4 ± 1.5(^{+0.8}_{-0.2})</td>
</tr>
<tr>
<td>(Z_b(10610)) width, MeV/c(^2)</td>
<td>18.5 ± 5.3(^{+6.1}_{-2.3})</td>
<td>20.8 ± 2.5(^{+0.3}_{-2.1})</td>
<td>18.7 ± 3.4(^{+2.5}_{-1.3})</td>
</tr>
<tr>
<td>(f_{Z_b^\pm(10650)\pi^\pm}, %)</td>
<td>0.87 ± 0.32(^{+0.16}_{-0.12})</td>
<td>4.05 ± 1.2(^{+0.9}_{-0.15})</td>
<td>13.3 ± 3.6(^{+2.6}_{-1.4})</td>
</tr>
<tr>
<td>(Z_b(10650)) mass, MeV/c(^2)</td>
<td>10656.7 ± 5.0(^{+1.1}_{-3.1})</td>
<td>10650.7 ± 1.5(^{+0.5}_{-0.2})</td>
<td>10651.2 ± 1.0(^{+0.4}_{-0.3})</td>
</tr>
<tr>
<td>(Z_b(10650)) width, MeV/c(^2)</td>
<td>12.1(^{+11.3}<em>{-4.8})(^{+2.7}</em>{-0.6})</td>
<td>14.2 ± 3.7(^{+0.9}_{-0.4})</td>
<td>9.3 ± 2.2(^{+0.3}_{-0.5})</td>
</tr>
<tr>
<td>(\phi_Z), degrees</td>
<td>67 ± 36(^{+24}_{-52})</td>
<td>−10 ± 13(^{+34}_{-12})</td>
<td>−5 ± 22(^{+13}_{-33})</td>
</tr>
<tr>
<td>(c_{Z_b(10650)}/c_{Z_b(10610)})</td>
<td>0.40 ± 0.12(^{+0.05}_{-0.11})</td>
<td>0.53 ± 0.07(^{+0.32}_{-0.11})</td>
<td>0.69 ± 0.09(^{+0.18}_{-0.07})</td>
</tr>
<tr>
<td>(f_{\Upsilon(nS)f_2(1270)}, %)</td>
<td>14.6 ± 1.5(^{+6.3}_{-0.7})</td>
<td>4.09 ± 1.0(^{+0.33}_{-1.0})</td>
<td>−</td>
</tr>
<tr>
<td>(f_{\Upsilon(nS)(\pi^+\pi^-)_S}, %)</td>
<td>86.5 ± 3.2(^{+3.3}_{-4.9})</td>
<td>101.0 ± 4.2(^{+6.5}_{-3.5})</td>
<td>44.0 ± 6.2(^{+1.8}_{-4.3})</td>
</tr>
<tr>
<td>(f_{\Upsilon(nS)f_0(980)}, %)</td>
<td>6.9 ± 1.6(^{+0.8}_{-2.8})</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

\[\sigma_{Z_b^\pm(10610)\pi^\pm} \times B_{\Upsilon(1S)\pi^\pm} = 109 \pm 27^{+35}_{-10} \text{ fb}\]
\[\sigma_{Z_b^\pm(10610)\pi^\pm} \times B_{\Upsilon(2S)\pi^\pm} = 737 \pm 126^{+188}_{-85} \text{ fb}\]
\[\sigma_{Z_b^\pm(10610)\pi^\pm} \times B_{\Upsilon(3S)\pi^\pm} = 438 \pm 92^{+92}_{-114} \text{ fb}\]

\[\sigma_{Z_b^\pm(10650)\pi^\pm} \times B_{\Upsilon(1S)\pi^\pm} = 20 \pm 7^{+4}_{-3} \text{ fb}\]
\[\sigma_{Z_b^\pm(10650)\pi^\pm} \times B_{\Upsilon(2S)\pi^\pm} = 165 \pm 49^{+43}_{-20} \text{ fb}\]
\[\sigma_{Z_b^\pm(10650)\pi^\pm} \times B_{\Upsilon(3S)\pi^\pm} = 194 \pm 53^{+43}_{-25} \text{ fb}\]

◆ Relative BR of \(Z_b\) decays

$e^+e^- \rightarrow \pi^+\pi^-h_b(nP)$

- Reconstruct $\pi^+\pi^-$, require $\pi^+/\pi^-$ recoil mass in $Z_b$ region: $10.59 < M_{\text{miss}}(\pi) < 10.67$ GeV/c$^2$
- check the $\pi^+\pi^-$ recoil mass for $h_b(nP)$

Belle: arXiv:1508.06562
$e^+e^- \rightarrow \pi^+\pi^- h_b(nP)$

$\Upsilon(5S)$:
Mass = (10884.7 $\pm 3.2^{+2.9}_{-2.2}$ $^{+8.6}_{-6.0}$) MeV
Width = (44.2 $\pm 11.9^{+7.8}_{-2.2}$ $^{+2.2}_{-15.8}$) MeV

$\Upsilon(6S)$:
Mass = (10998.6 $\pm 6.1^{+16.1}_{-1.1}$) MeV
Width = (29 $\pm 20^{+12}_{-7}$) MeV

$\Delta\phi = 0.64 \pm 0.37^{+0.11}_{-0.0} \pm 0.13^{+0.0}_{-0.0}$ rad

- Resonant parameters agree with from $e^+e^- \rightarrow \pi^+\pi^- \Upsilon(nS)$
- $e^+e^- \rightarrow \pi^+\pi^- h_b(nP)$ at the same level as $e^+e^- \rightarrow \pi^+\pi^- \Upsilon(nS)$
- 1st obs. of $\Upsilon(6S) \rightarrow \pi^+\pi^- h_b(nP)$

Belle: arXiv:1508.06562
\( Z_b \) in \( \gamma(6S) \rightarrow \pi^+ \pi^- h_b(nP) \)

- Events mainly from \( Z_b \) intermediate states
  - not clear if only one \( Z_b \) or both.
- Belle II will tell us.

Belle: arXiv:1508.06562
$Z_b$ in $\gamma(5S) \rightarrow [B^*(*)B^*(*)]^+\pi^- + c.c.$

- $B B \pi = \bar{B}^0 B^+ \pi^- + c.c.$
- $B B^* \pi = \bar{B}^* B^+ \pi^- + c.c.$ / $\bar{B}^0 B^{*+} \pi^- + c.c.$
- $B^* B^* \pi = \bar{B}^* B^* + \pi^- + c.c.$
- One $B$ is reconstructed
- Select a bachelor $\pi^\pm$
- Check $B\pi$ recoil mass

Belle preliminary

18 $B$ decay modes combined

12263 $\pm$ 168 $B$ signals

B sidebands
\( Z_b \) in \( \gamma(5S) \to [B^*(B^*)]^+ \pi^- + c.c. \)

Combine the B with a charged pion
calculate recoil mass of \( B\pi \)

Cross sections are not available yet!

\[ N(B\pi) = 13 \pm 25 \quad N(BB^*\pi) = 357 \pm 30 \quad N(B^*B^*\pi) = 161 \pm 21 \]
\[ Z_b \text{ in } \gamma(5S) \rightarrow [B^{(*)}B^{(*)}]^{+}\pi^{-} + \text{c.c.} \]

Check recoil mass of bachelor $\pi^{\pm}$

Assuming $Z_b$ decays are saturated by observed channels, $B^{(*)}B^{*}$ channels dominate the $Z_b$ decays
### BRs of $Z_b$ decays

<table>
<thead>
<tr>
<th>Channel</th>
<th>Fraction, %</th>
<th>$Z_b(10610)$</th>
<th>$Z_b(10650)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Upsilon(1S)\pi^+$</td>
<td>0.60 ± 0.17 ± 0.07</td>
<td>0.17 ± 0.06 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>$\Upsilon(2S)\pi^+$</td>
<td>4.05 ± 0.81 ± 0.58</td>
<td>1.38 ± 0.45 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>$\Upsilon(3S)\pi^+$</td>
<td>2.40 ± 0.58 ± 0.36</td>
<td>1.62 ± 0.50 ± 0.24</td>
<td></td>
</tr>
<tr>
<td>$h_b(1P)\pi^+$</td>
<td>4.26 ± 1.28 ± 1.10</td>
<td>9.23 ± 2.88 ± 2.28</td>
<td></td>
</tr>
<tr>
<td>$h_b(2P)\pi^+$</td>
<td>6.08 ± 2.15 ± 1.63</td>
<td>17.0 ± 3.74 ± 4.1</td>
<td></td>
</tr>
<tr>
<td>$B^+\bar{B}^0 + \bar{B}^0 B^{*+}$</td>
<td>82.6 ± 2.9 ± 2.3</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>$B^{*+}\bar{B}^{*0}$</td>
<td>—</td>
<td>70.6 ± 4.9 ± 4.4</td>
<td></td>
</tr>
</tbody>
</table>
The Y states

PRL99, 142002
670/fb

PRL99, 182004
548/fb

PRL95, 142001
273/fb

PRL98, 212001
298/fb

PRL101, 172001
695/fb

Update with full Belle data

Y(4008)
Y(4260)
Y(4360)
Y(4660)
Y(4630)
Still observed two resonances, Y(4008) and Y(4260), agrees with Belle’s previous results.

1. Fit with two coherent resonances $|BW_1 + BW_2 \times \exp(i\phi)|^2$+bkg.
2. Mass of Y(4008) is lower than before
3. Fit quality: $\chi^2/\text{ndf}=101/84$, confidence level is 9.3%
$e^+e^- \rightarrow \pi^+\pi^-J/\psi$ from ISR

PRL110, 252002 (2013)

- $M^2(\pi\pi)$ vs. $M^2(\pi J/\psi)$ for $4.15 < M(\pi\pi J/\psi) < 4.45$ GeV
- (inset) Background events in $J/\psi$-mass sidebands
- Structures both in $\pi\pi$ and $\pi J/\psi$ systems
- 689 events in $J/\psi$ signal region, purity~80%
Z(3900)$^+$ observed in two experiments!

- $M = 3894.5 \pm 6.6 \pm 4.5$ MeV
- $\Gamma = 63 \pm 24 \pm 26$ MeV
- 159 $\pm$ 49 events
  - $>5.2 \sigma$

- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV
- $\Gamma = 46 \pm 10 \pm 20$ MeV
- 307 $\pm$ 48 events
  - $>8 \sigma$
\( e^+e^- \rightarrow \pi^+\pi^-\psi(2S) \) via ISR

\[ \psi'(\rightarrow J/\psi \pi\pi \text{ or } \mu\mu) + \pi\pi \]
no extra tracks
detection of \( \gamma_{\text{ISR}} \) is not required

- Clear signal of missed massless particle \( (M_{\text{rec}}^2(\psi'\pi\pi) \approx 0) \)
- Polar angle distribution agrees well with ISR expectation
- Combinatorial background estimated by \( \psi' \) sidebands
- Bkgs from real \( (\psi'\pi\pi)_{\text{non ISR}} \) or \( \psi'\mathcal{X}_{\text{non }\pi\pi} \) are negligibly small

Two significant clusters:
\( Y(4360)+Y(4660) \);
a few events at \( Y(4260) \)

Fit with Two BWs


\[ \psi' \rightarrow J/\psi \, \pi \pi \]

\[ \psi' \rightarrow \mu \mu \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Solution I</th>
<th>Solution II</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{Y(4360)} )</td>
<td>4347 ± 6 ± 3</td>
<td>4652 ± 10 ± 11</td>
</tr>
<tr>
<td>( \Gamma_{Y(4360)} )</td>
<td>103 ± 9 ± 5</td>
<td>68 ± 11 ± 5</td>
</tr>
<tr>
<td>( \mathcal{B}[Y(4360) \rightarrow \pi^+ \pi^- \psi(2S)] \cdot \Gamma_{Y(4360)}^{\pi^+ \pi^-} )</td>
<td>9.2 ± 0.6 ± 0.6</td>
<td>10.9 ± 0.6 ± 0.7</td>
</tr>
<tr>
<td>( M_{Y(4660)} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Gamma_{Y(4660)} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \mathcal{B}[Y(4660) \rightarrow \pi^+ \pi^- \psi(2S)] \cdot \Gamma_{Y(4660)}^{\pi^+ \pi^-} )</td>
<td>2.0 ± 0.3 ± 0.2</td>
<td>8.1 ± 1.1 ± 1.0</td>
</tr>
<tr>
<td>( \phi )</td>
<td>32 ± 18 ± 20</td>
<td>272 ± 8 ± 7</td>
</tr>
</tbody>
</table>
Fit with Three BWs

\[ \psi' \rightarrow J/\psi \pi\pi + \mu\mu \]

Fit with Three BWs

\[ \psi' \rightarrow J/\psi \pi\pi + \mu\mu \]


<table>
<thead>
<tr>
<th>Parameters</th>
<th>Solution III</th>
<th>Solution IV</th>
<th>Solution V</th>
<th>Solution VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{Y(4260)} )</td>
<td></td>
<td></td>
<td>4259 (fixed)</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_{Y(4260)} )</td>
<td></td>
<td></td>
<td>134 (fixed)</td>
<td></td>
</tr>
<tr>
<td>( \mathcal{B}[Y(4260) \rightarrow \pi^+\pi^- \psi(2S)] \cdot \Gamma_{Y(4260)}^{e+e^-} )</td>
<td>1.5 ± 0.6 ± 0.4</td>
<td>1.7 ± 0.7 ± 0.5</td>
<td>10.4 ± 1.3 ± 0.8</td>
<td>8.9 ± 1.2 ± 0.8</td>
</tr>
<tr>
<td>( M_{Y(4360)} )</td>
<td></td>
<td></td>
<td>4365 ± 7 ± 4</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_{Y(4360)} )</td>
<td></td>
<td></td>
<td>74 ± 14 ± 4</td>
<td></td>
</tr>
<tr>
<td>( \mathcal{B}[Y(4360) \rightarrow \pi^+\pi^- \psi(2S)] \cdot \Gamma_{Y(4260)}^{e+e^-} )</td>
<td>4.1 ± 1.0 ± 0.6</td>
<td>4.9 ± 1.3 ± 0.6</td>
<td>21.1 ± 3.5 ± 1.4</td>
<td>17.7 ± 2.6 ± 1.5</td>
</tr>
<tr>
<td>( M_{Y(4660)} )</td>
<td></td>
<td></td>
<td>4660 ± 9 ± 12</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_{Y(4660)} )</td>
<td></td>
<td></td>
<td>74 ± 12 ± 4</td>
<td></td>
</tr>
<tr>
<td>( \mathcal{B}[Y(4660) \rightarrow \pi^+\pi^- \psi(2S)] \cdot \Gamma_{Y(4260)}^{e+e^-} )</td>
<td>2.2 ± 0.4 ± 0.2</td>
<td>8.4 ± 0.9 ± 0.9</td>
<td>9.3 ± 1.2 ± 1.0</td>
<td>2.4 ± 0.5 ± 0.3</td>
</tr>
<tr>
<td>( \phi_1 )</td>
<td>304 ± 24 ± 21</td>
<td>294 ± 25 ± 23</td>
<td>130 ± 4 ± 2</td>
<td>141 ± 5 ± 4</td>
</tr>
<tr>
<td>( \phi_2 )</td>
<td>26 ± 19 ± 10</td>
<td>238 ± 14 ± 21</td>
<td>329 ± 8 ± 5</td>
<td>117 ± 23 ± 25</td>
</tr>
</tbody>
</table>

Significance of \( Y(4260) \) is 2.4\( \sigma \)  
Affect the parameters of \( Y(4360) \) and \( Y(4660) \) significantly!
Z_c states from Y(4360) decays?

ψ' → J/ψ ππ

ψ' → μμ

An unbinned maximum-likelihood fit is performed on the distribution of $M_{\text{max}}(\pi^{\pm}\psi(2S))$, the maximum of $M(\pi^+\psi(2S))$ and $M(\pi^-\psi(2S))$, simultaneously with both modes.

- $M(Z_c) = 4054 \pm 3 \pm 1$ MeV/c$^2$
- $\Gamma = 45 \pm 11 \pm 6$ MeV
- **Significance: $>3.5\sigma$**


PRD91, 112007
No significant $Z_c$ in Y(4660) decays!

$\psi' \rightarrow J/\psi \pi\pi$

$\psi' \rightarrow \mu\mu$

Event selections are almost the same as in Phys. Rev. D 77, 011105(R) (2008)

Shaded hist.: $J/\psi$ mass sidebands

- +one resonance.
- Fit with $\psi(4415)$

$\chi^2/\text{ndf}=30/11$
- $M=4747\pm117\text{MeV}$
- $\Gamma=671\pm86\text{MeV}$

$4\text{-}6\text{ GeV}: 213\text{ events}$
- $35\text{ bkg}, 178\pm16\text{ signals}$

$$\sigma_i = \frac{n_{i}^{\text{obs}} - f \times n_{i}^{\text{bkg}}}{\mathcal{L}_i \cdot \epsilon_i \cdot \mathcal{B}(J/\psi \rightarrow l^+l^-)}$$
Search for $Z_{cs} \rightarrow KJ/\psi$ states

No evident structure in $K^\pm J/\psi$ mass distribution under current statistics
Summary

- With the world’s largest data samples in bottomonium energy region Belle achieved a lot
  - Improved knowledge on $\Upsilon(5S)$ and $\Upsilon(6S)$
  - New results on the $Z_b$ states
- With ISR events, Belle studied charmoniumlike states
  - Improved measurement of $Y(4360)$ & $Y(4660)$
  - Evidence for $Z_c(4050)\rightarrow \pi\psi'$ but no $Z_{cs}$ yet
- Still lots of analyses on going, results soon
- Belle II is coming ......

Thanks a lot!
The end
Charmonium region at Belle II

ISR produces events at all CM energies BESIII can reach

At 4.26 GeV for $\pi^+\pi^- J/\psi$

$\varepsilon_{\text{BESIII}} = 46\%$

$\varepsilon_{\text{Belle}} = 10\%$
Is $c cg$ already there?

Very rich structure!
$M(\pi^+\pi^-)\text{ distributions}$

$\psi' \rightarrow J/\psi \, \pi\pi$

$\psi' \rightarrow \mu\mu$

$Y(4360)$

$\sigma + f_0(980)$

$Y(4660)$

PRD91, 112007
$Z_b \text{ in } \Upsilon(5S) \rightarrow \pi^+ \pi^- \Upsilon(nS)$

$M_{\Upsilon \pi\pi} = A_{Z_1\pi} + A_{Z_2\pi} + A_{\Upsilon\sigma} + A_{\Upsilon f_0} + A_{\Upsilon f_2} + A_{NR}$

$A_{NR}^{NR}(s_{23}) = c_1^{NR}e^{i\delta_1^{NR}} + c_2^{NR}e^{i\delta_2^{NR}} s_{23}$