Ongoing analysis about the hidden-bottom hadronic transition of $\Upsilon(6S)$

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KEKB/Belle: world highest luminosity $e^+e^-$ collider

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

8 x 3.5 GeV  
22 mrad crossing  
1999-2010  
1014/fb  
The KEKB Collider
Belle Detector
Integrated Luminosity of B factories

Belle recorded more than 1 ab$^{-1}$!

- KEKB
- PEP-II

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$^{-1}$
- $Y(2S)$: 14 fb$^{-1}$

Off resonance:
- $\sim 54$ fb$^{-1}$
Integrated Luminosity of B factories

Belle recorded more than 1 ab\(^{-1}\)!

<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>(\gamma\pi\pi, h_b\pi\pi, B^{(<em>)}B^{(</em>)}\pi)</td>
</tr>
<tr>
<td>10.63-11.02</td>
<td>6+16</td>
<td>(\sim1)</td>
<td>(R_b, \gamma\pi\pi, h_b\pi\pi)</td>
</tr>
<tr>
<td>10.75-11.05</td>
<td>61</td>
<td>(\sim0.05)</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>

\(~550\) fb\(^{-1}\)

On resonance:
- \(Y(4S): 433\) fb\(^{-1}\)
- \(Y(3S): 30\) fb\(^{-1}\)
- \(Y(2S): 14\) fb\(^{-1}\)

Off resonance:
- \(\sim 54\) fb\(^{-1}\)
Motivation

\( \textit{X}(3872) \), the first observed exotic state, candidate of tetraquark.
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$Z_c \rightarrow \pi^+ J/\psi$

PRL, 110.252001/PRL, 110.252002
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\(Z_c \to \pi^+ J/\psi\)

Top of highlights of Year 2013!

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Motivation

\(X(3872)\), the first observed exotic state, candidate of tetraquark.

More candidates: \(X(4140), Y(4260)\) ...
How to understand their nature? Partners in bottomonium?
Motivation

- The heavy quarkonium systems are successfully described while Belle experiment observed the hadronic transitions from $\Upsilon(5S)$ state have anomalously high rate.

- May imply evidence for four-quark admixtures in $\Upsilon(5S)$ and $\Upsilon(6S)$ wave function.
Experiments

- $\omega \chi_{b1/b2}$ are observed in $\Upsilon(5S)$ data.

- $e^+ e^- \rightarrow \omega \chi_{c1,2}$ are also found in BESIII, which might come from $\psi(4415)$ and $\psi(4660)$, it is easily to come to us that $\omega \chi_{b1/b2}$ might be found in $\Upsilon(6S)$.

- BESIII experiment found $e^+ e^- \rightarrow \phi \chi_{c1,2}$ in $\psi(4660)$ region (preliminary result). Correspondingly, it is interesting to search for $\phi \chi_{bJ}$ in $\Upsilon(6S)$ data.
Currently an article discussed the hidden-bottom hadronic transition (arXiv: 1701.00894) and predicted the branching ratio of $\Upsilon(6S) \to \phi \chi_{bJ}$ and $\omega \chi_{bJ}$.

<table>
<thead>
<tr>
<th>Decay Chain</th>
<th>$\Upsilon(6S) \to \phi \chi_{b0}$</th>
<th>$\Upsilon(6S) \to \phi \chi_{b1}$</th>
<th>$\Upsilon(6S) \to \phi \chi_{b2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Br(\times 10^{-6})$</td>
<td>0.62~4.62</td>
<td>0.50~3.43</td>
<td>2.22~15.18</td>
</tr>
<tr>
<td>$Br(\times 10^{-3})$</td>
<td>0.15~2.81</td>
<td>0.63~11.68</td>
<td>1.08~22.02</td>
</tr>
</tbody>
</table>

Based on $\sim 10$ fb$^{-1} \Upsilon(6S)$ dataset, we suppose not to find any signal of $\phi \chi_{bJ}$ according to the predicted branching fraction, but worth trying.
\( \phi \chi_{bJ} \) mode

Inclusively, two kinds of decay chain:

\[ \mathcal{B}(\Upsilon(6S) \to \phi \chi_{b1}) = (2.7 \pm 1.0^{+1.4}_{-0.8}) \times 10^{-3}; \]
\[ \mathcal{B}(\Upsilon(6S) \to \phi \chi_{b2}) = (3.1 \pm 1.4^{+1.6}_{-0.9}) \times 10^{-3}. \]

\[ M = 10968.7 \pm 3.1 \text{ MeV}/c^2; \]
\[ \Gamma = 32.0 \pm 12.0 \text{ MeV}; \]

\( \chi_{b1} \) 3.7 \( \sigma \), \( \chi_{b2} \) 3.5 \( \sigma \)

preliminary result

THREE orders of magnitude larger!
ωχ_{bJ} mode

Significance: χ_{b1} 5.1σ, χ_{b2} 4.7σ

Different distribution of π⁺π⁻π⁰ corresponding to χ_{b1} and χ_{b2}.

- \mathcal{B}(\Upsilon(6S) \rightarrow 3\pi\chi_{b1}) = (9.5 \pm 4.4^{+5.0}_{-2.7}) \times 10^{-3}
- \mathcal{B}(\Upsilon(6S) \rightarrow \omega\chi_{b2}) = (2.7 \pm 2.2^{+1.4}_{-0.8}) \times 10^{-3}

Consistent with prediction.

Suppose to be larger branching fractions!
Summary

• The measured branching fractions $\Upsilon(6S) \to \phi \chi_{bJ}$ do not fit the theory well. Huge improvement should be done for the theory.

• It is interesting that the $\pi\pi\pi \chi_{bJ}$ behavior differently in $\chi_{b1}$ and $\chi_{b2}$.
Summary

• Belle II detector has been installed. A HUGE WAVE OF DATA IS APPROCHING!!!
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Thanks for your attention!
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