Prospects for Hadron Physics at Belle II

Roberto Mussa – INFN Torino

Bormio 29/1/2014
Outline

Bottomonium and Charmonium spectra
Charmed+Beauty Mesons+Baryons
Charged Bottomonia

High Energy Scans at ~11 GeV
ISR scans on Charmonium region
Double Charmonium
Hyperons and Dibaryons in Upsilon decays

Belle-II @ superKEKB: collaboration, machine, detector
Decays on Resonance Peak

**Y(nS) Peak Running**
- **2002-3**: CLEO-III 1,2,3S
- **2006**: Belle 3,5S
- **2007**: Belle 5S
- **2008**: Babar 2,3S
  - Belle 1,2,5S
- **2009**: Belle 2,5S

**Y(2,3S) Peak Bonus:**
- Tagged 1S from
- \( Y(2,3S) \rightarrow \pi^+\pi^- Y(1S) \)

**PI+PI-Tagged Decays**

**Y(4S) Peak Running**
- \( e^+e^- \rightarrow Y(nS) \gamma_{\text{ISR}} \)
- \( \sigma(1S@10580) = 19 \text{ pb} \)
- \( \sigma(2S@10580) = 17 \text{ pb} \)
- \( \sigma(3S@10580) = 29 \text{ pb} \)
- (*) untagged \( \gamma_{\text{ISR}} \)

**With 50 ab^{-1} at 4S**: 0.95, 0.85, 1.45 G at 1, 2, 3S
5 amazing years for bottomonium spectroscopy:

- $\Upsilon_b / \Upsilon(5S)$: observation of large dipion transitions to $\Upsilon(1,2,3S)$ from 20 MeV above $5S$ peak
- Discovery of $\eta_b (2008)$
- Discovery of the triple cascade $\Upsilon_b \rightarrow Z_b \rightarrow h_b \rightarrow \eta_b$
  * 4 parabottomonia
  * 2 charged bottomonia
- Discovery (ATLAS) of $\chi_b (3P)$

Bottomonium 2008-12
Inclusive search: \( e^+ e^- \rightarrow Y(5S) \rightarrow \pi^+ \pi^- + \ldots \)

Simultaneous discovery of \( h_b(1,2P) \)

New pathway to \( Y(1D) \) states

Residuals of the dipion recoil mass spectrum
\( h_b(1,2P) \) from \( \Upsilon(5S) \)

<table>
<thead>
<tr>
<th>( \Upsilon(1S) )</th>
<th>Yield, ( 10^3 )</th>
<th>Mass, MeV/c^2</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_b(1P) )</td>
<td>50.4 ± 7.8^{+4.5}_{-9.1}</td>
<td>9898.3 ± 1.1^{+1.0}_{-1.1}</td>
<td>6.2 ( \sigma )</td>
</tr>
<tr>
<td>3S ( \rightarrow ) 1S</td>
<td>56 ± 19</td>
<td>9973.01</td>
<td>2.9 ( \sigma )</td>
</tr>
<tr>
<td>( \Upsilon(2S) )</td>
<td>143.5 ± 8.7 ± 6.8</td>
<td>10022.3 ± 0.4 ± 1.0</td>
<td>16.6 ( \sigma )</td>
</tr>
<tr>
<td>( \Upsilon(1D) )</td>
<td>22.0 ± 7.8</td>
<td>10166.2 ± 2.6</td>
<td>2.4 ( \sigma )</td>
</tr>
<tr>
<td>( h_b(2P) )</td>
<td>84.4 ± 6.8^{+23.}_{-10}</td>
<td>10259.8 ± 0.6^{+1.4}_{-1.0}</td>
<td>12.4 ( \sigma )</td>
</tr>
<tr>
<td>2S ( \rightarrow ) 1S</td>
<td>151.7 ± 9.7^{+9.0}_{-20}</td>
<td>10304.6 ± 0.6 ± 1.0</td>
<td>15.7 ( \sigma )</td>
</tr>
<tr>
<td>( \Upsilon(3S) )</td>
<td>45.6 ± 5.2 ± 5.1</td>
<td>10356.7 ± 0.9 ± 1.1</td>
<td>8.5 ( \sigma )</td>
</tr>
</tbody>
</table>

Significance after correcting for systematics effects: \( h_b(1P) \) 5.5\( \sigma \) \( h_b(2P) \) 11.2\( \sigma \)

Masses very close to the COG of \( \chi \) states, as expected from one gluon exchange.

\[ \Delta M_{HF}(1P) = 1.6^{+1.5}_{-1.0} \text{ MeV/c}^2 \]
\[ \Delta M_{HF}(2P) = 0.5^{+1.6}_{-1.2} \text{ MeV/c}^2 \]

Ratio of spin flip vs noflip dipion transitions totally unexpected from theory....
The two charged bottomonium states are observed in single pion recoil in 5 processes:

- inclusive $Y(5S)$ decays to $h_b(1,2P)$
- Dalitz plot of exclusive $Y(5S)$ dipion transitions to $Y(1,2,3S)$

![Graphs showing charged bottomonium states $Z_b's$ and their decay modes](image)
Belle discovered two charged bottomonium-like resonances:

**Z(10610)**
- $M=10607.2\pm2.0$ MeV
- $\Gamma=18.4\pm2.4$ MeV
- $M_B + M_{B^*} = 10604.5\pm0.6$ MeV

**Z(10650)**
- $M=10652.2\pm1.5$ MeV
- $\Gamma=11.5\pm2.2$ MeV
- $M_{B^*} + M_{B^{**}} = 10650.2 \pm 1.0$ MeV

Analysis of angular distributions suggests $J^P=1^+$ for both these states. Observation of $Z_b$ decays to $BB^*$ and $B^*B^*$ is consistent with molecular nature of the charged bottomonia. (Voloshin, Bondar, et al)

ArXiV:1207.4345:
Evidence of neutral partner of lower $Z_b$ in $Y\pi^0$ with 4.9 sigma significance
$Z_b \to \bar{B}B^* + \bar{B}B^*$, $B^*\bar{B}^*$

\[
\text{BF} \left[ Y(5S) \to B^*\bar{B}^* \pi \right] \quad \text{preliminary}
\]

Belle 121.4 fb$^{-1}$

significance

- $\bar{B}B$
- $(4.25 \pm 0.44 \pm 0.69) \%$ 9.3$\sigma$
- $(2.12 \pm 0.29 \pm 0.36) \%$ 5.7$\sigma$

Channel | Fraction, %
--- | ---
$Y(1S)\pi^+$ | $Z_b(10610)$ $0.32 \pm 0.09$ $Z_b(10650)$ $0.24 \pm 0.07$
$Y(2S)\pi^+$ | $4.38 \pm 1.21$ $2.40 \pm 0.63$
$Y(3S)\pi^+$ | $2.15 \pm 0.56$ $1.64 \pm 0.40$
$h_b(1P)\pi^+$ | $2.81 \pm 1.10$ $7.43 \pm 2.70$
$h_b(2P)\pi^+$ | $4.34 \pm 2.07$ $14.8 \pm 6.22$
$B^+\bar{B}^0 + \bar{B}^0 B^*$ | 86.0 $\pm$ 3.6 $-$
$B^{**} + \bar{B}^{*0}$ | $-$ 73.4 $\pm$ 7.0

ArXiV:1209.6450

52nd Bormio Meeting, 29/1/2014 R.Mussa, Hadron Physics at Belle II
Belle-II: future prospects

Neutral partners of Zb states proposed by Bondar et al.
Open questions: $B \rightarrow K Z^+_c$

Belle observed 3 charged peaks in $B$ decays to charmonium + $K$
$cc=\Psi' > Zc(4430)$
$cc=\chi_{c1} > Zc(4050,4250)$

Never confirmed by Babar

LHCb will have the final word?
Open questions: $X(3872) \rightarrow \gamma (J/\psi, \psi')$

**Babar** [PRL 102 (2009), 132001]:
evidence of radiative decay to both $J/\psi$ and $\psi'$:

$$\frac{\text{BR}(X3872 \rightarrow \gamma \psi')}{\text{BR}(X3872 \rightarrow \gamma J/\psi)} = 3.4 \pm 1.4$$

- disfavors the molecular model,
- favors $J^{PC}=1^{++}$
- disfavors $J^{PC}=2^{-+}$

**Belle** [PRL 102 (2009), 132001]:
confirms radiative decay to $J/\psi$ but not to $\psi'$

Statistically limited: challenge for Belle-II
Maybe possible at BES-III (poster by S.Braun) or LHCb
Rediscovery of $\eta_b$

Babar 2008:

$\chi_b(2P) \rightarrow \gamma Y(1S)$

$\gamma_{\text{ISR}} Y(1S)$

$Y(3S) \rightarrow \eta_b(1S)$

$\chi_b(1P) \rightarrow \gamma Y(1S)$

$\gamma_{\text{ISR}} Y(1S)$

$Y(2S) \rightarrow \eta_b(1S)$

Sideband subtracted spectrum of $\pi\pi\gamma$ recoil at the $h_b$ peaks.


PRL 101,071801(2008)
PRL 103,161801(2009)
Discovery of $\eta_b(2S)$

$L_{dt} = 121.4 \text{ fb}^{-1}(5S) + 12 \text{ fb}^{-1} \text{ (scan)}$

PRL 109 (2012) 232002

$h_b(2P) \rightarrow \gamma \eta_b(2S)$

Sideband subtracted spectrum of $\pi\pi\gamma$ recoil at the $h_b(2P)$ peak.
Parabottomonia vs theory

$\eta_b(2S)$ vs $\eta_b(1S)$

Some tension with the most accurate NRQCD prediction, but very close to lattice QCD (Meinel) predictions.

Spin averaged 1P-1S splitting seems not to depend on scale

52nd Bormio Meeting, 29/1/2014
Parabottomonia vs theory

$\eta_b(2S)$ vs $\eta_b(1S)$

10 MeV discrepancy w/ earlier Babar and CLEO results: Skewed lineshape as in charmonium?

Spin averaged 1P-1S splitting seems not to depend on scale: only 1% difference with charmonium: similarly, the tensor-vector splitting remains constant also in D,Ds.

<table>
<thead>
<tr>
<th>$c\bar{u}$</th>
<th>$c\bar{d}$</th>
<th>$c\bar{s}$</th>
<th>$c\bar{c}$</th>
<th>$b\bar{b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M(2$^+$)-M(1$^-$), in MeV/c$^2$</td>
<td>452 ± 2</td>
<td>449±4</td>
<td>461±2</td>
<td>458.3±0.1</td>
</tr>
</tbody>
</table>
Charmed and Beauty hadron spectra

From Oka's talk at Hadron 2013
Charmed and Beauty hadron spectra
Search for $\eta_b(1S) \rightarrow \gamma \gamma$
via exclusive channel: $\pi^+\pi^-\gamma(\gamma\gamma)$ !!

NRQCD NNLL prediction:
Penin et al., NP B699(2004),183

$\Gamma(\eta_b(1S) \rightarrow \gamma \gamma) = 0.66\pm0.09$ keV

With $\Gamma(\eta_b) = 10$ MeV,

$\text{BR}(\eta_b(1S) \rightarrow \gamma \gamma) = 0.66\times10^{-4}$

~25 events with 1 ab$^{-1}$ at Y(5S)
Search for $\eta_b(1S)\rightarrow \gamma\gamma$
via exclusive channel: $\pi^+\pi^-\gamma(\gamma\gamma)$ !!

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With $\Gamma(\eta_b) = 10$ MeV,

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~25 events with 1 ab$^{-1}$ at $Y(5S)$

Search for S=0 D-wave state via $h_b(2P)$
Search for $\eta_b(1S) \rightarrow \gamma\gamma$
via exclusive channel: $\pi^+\pi^-\gamma(\gamma\gamma)$ !!

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~25 events with 1 ab$^{-1}$ at Y(5S)

Search for S=0 D-wave state via $h_b(2P)$

$Y(1^1D_2)$

$\eta_b(2S)$

$\eta_b(2S)$

$\eta_b(3S)$
Scans of the $b\bar{b}$ threshold region

BaBar scans: - 132 points, 25/pb, 10.54, 11.2 GeV
Belle scans: - 61 points, 50/pb, 10.75-11.05 GeV
- 16 points, 1/fb, 10.63-11.02 GeV

Future prospects at Belle-II: Full reconstruction of all $B(*)B(*)$+pion components

No evidence of Ali peak at 10.91
Scans of the $c\bar{c}$ threshold region: ISR

DD
D*D
D*D
DD$\pi$
DD*$\pi$

$\Lambda_c \bar{\Lambda}_c$
Full decomposition of \( R: \) Babar/Belle vs CLEO-c
Full decomposition of R:Babar/Belle vs CLEO-c

\[ \sigma(\text{nb}) \]

- \( D_s^+D_s^- \)
- \( D_s^0D_s^- \)
- \( D_s^0D_s^+ \)

\[ m(D^*_sD_s^0) \ (\text{GeV/c}^2) \]

- \( D_s^+D_s^- \)
- \( D_s^0D_s^+ \)

\[ m(D^*D^0) \ (\text{GeV/c}^2) \]

- \( D_s^0D_s^+ \)
- \( D_s^0D_s^- \)

\[ M(D^*_sD^-), \ (\text{GeV/c}^2) \]

- \( D_s^+D_s^- \)
- \( D_s^0D_s^- \)

\[ E_{\text{CM}} \ (\text{GeV}) \]
All limits above th.predictions

**BR(Y(1S) → f )*10^6**

<table>
<thead>
<tr>
<th>Y(1S) → γχ_{c0}</th>
<th>90%CL UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y(1S) → γχ_{c1}</td>
<td>23</td>
</tr>
<tr>
<td>Y(1S) → γχ_{c2}</td>
<td>7.6</td>
</tr>
<tr>
<td>Y(1S) → γη_{c}</td>
<td>57</td>
</tr>
</tbody>
</table>

PRD82(2010),051504R

**NRQCD predictions**

[K. T. Chao et al., hep-ph/0701009]

<table>
<thead>
<tr>
<th>QCD</th>
<th>QCD+QED</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>3.2</td>
</tr>
<tr>
<td>4.5</td>
<td>9.8</td>
</tr>
<tr>
<td>5.1</td>
<td>5.6</td>
</tr>
<tr>
<td>2.9</td>
<td>4.9</td>
</tr>
</tbody>
</table>

**QCD**

**QED**
Former observations by ARGUS and CLEO

- Inclusive production of \((\text{anti})\text{deuteron in } Y(1,2S)\) decays :
  \[
  \mathcal{B}^\text{dir}(Y(1S) \rightarrow \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.
  \]
  \[
  \mathcal{B}(Y(2S) \rightarrow \bar{d} + X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}.
  \]

- Enhanced \((3x)\) production of low momentum hyperons in hadronic events from bottomonium decays w/ respect to continuum.

BELLE has exploited the \(Y(1,2S)\) record samples to search for the long sought
H-dibaryon : \((\text{Jaffe, PRL38 (1977),195 })\)
A tightly bound \text{tri-diquark}, or a loosely bound \text{S}=2 hypernucleus?

R.Mussa, Hadron Physics at Belle II
Many studies ongoing from $Y(1,2S)$ decays, and from continuum:
- pentaquark searches,
- exclusive BR($\Lambda\Lambda + n$ pions)
- inclusive production of hyperons
- $\Lambda\Lambda$ and $\Xi^- p$ (+cc) correlations
- antideuteron spectra (and more)
Search for $\Lambda\Lambda$ threshold enhancements

BELLE analysed ~50 exclusive channels with hyperon-antihyperon pairs + up to 6 light hadrons and with (0,1) neutral pion.

Both Y(1,2S) data and continuum were analysed.

$Y(1S) \rightarrow \Lambda\Lambda^\pm \pi^\mp K^+ K^-$

![Near threshold enh.](image)

<table>
<thead>
<tr>
<th>Final state $X$</th>
<th>$Y(1S) \rightarrow X$</th>
<th>$Y(2S) \rightarrow X$</th>
<th>$e^+e^- \rightarrow q\bar{q} \rightarrow X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^-$</td>
<td>2.16</td>
<td></td>
<td>1.83</td>
</tr>
<tr>
<td>$\Lambda\Lambda + K^+K^-$</td>
<td>2.94</td>
<td></td>
<td>4.60</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-)$</td>
<td>2.96</td>
<td>3.07</td>
<td>4.23</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- K^+K^-$</td>
<td>4.61</td>
<td></td>
<td>6.08</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- p\bar{p}$</td>
<td>2.06</td>
<td></td>
<td>0.57</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 3(\pi^+\pi^-)$</td>
<td>0.31</td>
<td>2.97</td>
<td>3.76</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-) K^+K^-$</td>
<td>0.36</td>
<td></td>
<td>3.75</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-) p\bar{p}$</td>
<td>&lt;0.1</td>
<td></td>
<td>0.83</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- 2(K^+K^-)$</td>
<td>0.50</td>
<td>0.29</td>
<td>4.27</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- \pi^0$</td>
<td>1.95</td>
<td></td>
<td>2.36</td>
</tr>
<tr>
<td>$\Lambda\Lambda + K^+K^- \pi^0$</td>
<td></td>
<td></td>
<td>1.51</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-) \pi^0$</td>
<td>&lt;0.1</td>
<td>0.36</td>
<td>2.33</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- K^+K^- \pi^0$</td>
<td>&lt;0.1</td>
<td></td>
<td>2.10</td>
</tr>
<tr>
<td>$\Lambda\Lambda + \pi^+\pi^- p\bar{p} \pi^0$</td>
<td>&lt;0.1</td>
<td></td>
<td>1.28</td>
</tr>
<tr>
<td>$\Lambda\Lambda + 3(\pi^+\pi^-) \pi^0$</td>
<td>1.38</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-) K^+K^- \pi^0$</td>
<td>1.28</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\Lambda + 2(\pi^+\pi^-) p\bar{p} \pi^0$</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Search for H dibaryon

Recently studied by E522, STAR, ALICE

Theory: recent lattice calculations
HALQCD, NPLQCD Coll.: ~8 MeV binding

Belle has searched for H dibaryon in the following channels:
- $\Lambda\pi p + \Lambda\Lambda(+cc)$ [PRL 110, 222002 (2013)]
- $\Xi p$ (+cc) [preliminary]

52nd Bormio Meeting, 29/1/2014
The double charmonium process was discovered by Belle by studying the momentum spectrum of J/ψ. By plotting the mass of particles recoiling against the J/ψ, Belle observed the peaks of charmonium C=0 states and discovered X(3940). This reaction challenges our understanding of perturbative QCD. Leading order prediction was O(0.1) the observed value. NLO calculations 'almost' solved the discrepancy.

<table>
<thead>
<tr>
<th>J/ψ (c ¯c)_res</th>
<th>σ × B &gt; 2 [fb]</th>
<th>η_c (1S)</th>
<th>χ_c0</th>
<th>η_c (2S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>σ × B &gt; 2 [fb]</td>
<td>25.6 ± 2.8 ± 3.4</td>
<td>6.4 ± 1.7 ± 1.0</td>
<td>16.5 ± 3.0 ± 2.4</td>
</tr>
<tr>
<td>BABAR</td>
<td>σ × B &gt; 2 [fb]</td>
<td>17.6 ± 2.8 ± 1.5</td>
<td>10.3 ± 2.5 ± 1.4</td>
<td>16.4 ± 3.7 ± 2.4</td>
</tr>
<tr>
<td>NRQCD: Braaten&amp;Lee¹</td>
<td>σ [fb]</td>
<td>3.78 ± 1.26</td>
<td>2.40 ± 1.02</td>
<td>1.57 ± 0.52</td>
</tr>
<tr>
<td>...with relativistic corr²</td>
<td>7.4 ± 10.9</td>
<td>7.6 ± 11.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liu,He,&amp;Chao²</td>
<td>5.5</td>
<td>6.9</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Zhang,Gao,&amp;Chao³</td>
<td>14.1</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

\[ \mathcal{L} \sim 357 \text{fb}^{-1} \]
Double $\bar{c}c : J/\psi + D$ recoil method

Full reconstruction of one additional D meson and plot of the mass recoiling against the $J/\psi + D$ system allowed to confirm $X(3940)$ and find one more state at 4156 MeV.

Future prospects at Belle-II: Full reconstruction of $\chi_c$ or $\eta_c$ will allow to exploit the recoil technique and scan the charmonium(-like) $C=-1$ states.
Belle-II Collaboration

23 countries,
94 institutions,
560 collaborators
KEKB upgrade

- **SuperKEKB**
  - **New beam pipe & bellows**
  - **Replace short dipoles with longer ones (LER)**
  - **Redesign the lattices of HER & LER to squeeze the emittance**
  - **Low emittance positrons to inject**
  - **Damping ring**
  - **Low emittance gun**
  - **TiN-coated beam pipe with antechambers**
  - **Positron source**
  - **New positron target / capture section**
  - **Add / modify RF systems for higher beam current**

- **Diagrams**
  - **KEKB upgrade**
  - **Belle II**
  - **Colliding bunches**
  - **New superconducting / permanent final focusing quads near the IP**
  - **KEKB upgrade**

- **Equation**
  - \[ L = \frac{\gamma}{2e\rho} \left( 1 + \frac{\sigma_y^2}{\sigma_x^2} \right) \left( \beta_y \frac{R_L}{R_y} \right) \]
  - **Target:** \[ L = 8 \times 10^{35} / \text{cm}^2 / \text{s} \]
New beam pipe
Belle-II: Detector

- K_\mu and muon detector:
  - Resistive Plate Counter (barrel outer layers)
  - Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

- EM Calorimeter:
  - CsI(Tl), waveform sampling (barrel)
  - Pure CsI + waveform sampling (end-caps)

- Particle Identification
  - Time-of-Propagation counter (barrel)
  - Prox. focusing Aerogel RICH (fwd)

- Vertex Detector
  - 2 layers DEPFET + 4 layers DSSD

- Central Drift Chamber
  - He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

- Electron (7 GeV)
- Positron (4 GeV)

Beryllium beam pipe
2 cm diameter

Detector
Belle-II: Vertex detectors

- PXD + SVD Belle II
- SVD Belle
- sBelle Design Group, KEK Report 2008-7

Impact parameter resolution $z_0$
Belle-II: Barrel PID

- Quartz radiator, mirror and wedge
- MCP-PMT
- Waveform digitizer
- Support structure

Challenging time resolution (100 ps)

<table>
<thead>
<tr>
<th></th>
<th>(\pi\pi) eff.</th>
<th>fake</th>
<th>(\rho\gamma) eff.</th>
<th>fake</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP</td>
<td>98.1%</td>
<td>2.9</td>
<td>99.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Belle</td>
<td>88.5</td>
<td>11.6</td>
<td>87.5</td>
<td>10.0</td>
</tr>
</tbody>
</table>

⇒ substantial improvement over Belle. This will help for, e.g., separating \(D_s^+ \rightarrow K^- K^+ \pi^+\) from \(D^+ \rightarrow K^- \pi^+ \pi^+\), removing \(D^0 \rightarrow K^- \pi^0\) from \(D^0 \rightarrow K^- K^+\), etc.
Belle-II: Forward PID

Aerogel radiator

n~1.05

Hamamatsu HAPD

Test Beam setup

Aerogel

Hamamatsu HAPD

Q.E. ~33% (recent good ones)

Cherenkov angle distribution

Single photon angle resolution $\sigma_\theta = 13.5\text{mrad}$

# of photoelectrons $N_{pe} = 15.3$

$6.6\sigma \pi/K$ at 4GeV/c!
Belle-II: Luminosity

Goal of Belle II/SuperKEKB

- Same size data as Belle
- Commissioning starts in early 2015.
- Shutdown for upgrade

Peak luminosity ($\text{cm}^{-2}\text{s}^{-1}$)

Integrated luminosity ($\text{ab}^{-1}$)

Calendar Year


9 months/year
20 days/month

Belle-II: Luminosity
SuperKEKB: Schedule

SuperKEKB construction

Detector upgrade to Belle II

Belle roll out

Dismantling KEKB

Fabrication and tests of ring components

Install and set up

Electricity and cooling facility

MR & DR buildings

DR tunnel

Linac upgrade / operation for PF&PF-AR

SuperKEKB operation

Accelerator tuning

BEAST

Physics run

Upgraded Linac operation for SuperKEKB, PF, PF-AR

Calendar

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<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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<tr>
<td>Japan FY</td>
<td>2010</td>
<td>2011</td>
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Nov. 2013 - Jan. 2015
In the last decade, B-factories have found most of the still missing pieces in bottomonium and charmonium spectra. S and P wave spectra below thresholds are almost complete: only the 2\textsuperscript{nd} radial excitations (singlet 3S and 3P, doublet 3S) are missing.

Many new questions arose from unexpected states across and above thresholds: Belle, Babar and BES-III are discovering a plethora of new states, the so called XYZ mesons, which require a spectroscopy with new degrees of freedom (tetraquarks, molecules, hybrids).

Precise tests of NRQCD will require $O(10^9)$ samples of $Y(1,2,3S)$ decays or larger.

Charged bottomonia (Zb states) have provided unique pathways to discover the missing spin singlet states. Their understanding is tightly coupled to the study of the charmonium-like counterparts (Zc states) observed by Belle and BES-III. Running at or above $Y(5S)$ is compulsory for making further progress on this topic.

Bottomonia provides also a unique environment for the study of hyperon-nucleon interactions, as their annihilations produce slow hyperons in large quantities, and are the only mesons which can produce nuclei (from deuteron to He-4). Possible studies include further searches for the long sought H-dibaryon.

Belle-II is designed to run at 40 times higher luminosity, to accumulate 50 ab\textsuperscript{-1} of data by 2022, and will start physics running in 2016.