Physics on Y(5S) at B factories and a super B factory

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Outline

- Introduction.
- Recent Belle measurements at the Y(5S).
- Potential $B_s$ studies at the Y(5S) at Belle and Super Belle.
- What else can be done at Super B factory?
- Conclusion.
Introduction

Asymmetric energy $e^+e^-$ colliders (B Factories) running at Y(4S):
Belle and BaBar

1985: CESR (CLEO,CUSB) $\sim$116 pb$^{-1}$ at Y(5S)
2003: CESR (CLEO III) $\sim$0.42 fb$^{-1}$ at Y(5S)
2005: Belle, KEKB $\sim$ 1.86 fb$^{-1}$ at Y(5S)
2006, June 9-31: Belle, KEKB $\sim$21.7 fb$^{-1}$ at Y(5S)

$e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$, where $B$ is $B^+$ or $B^0$ meson

$e^+e^- \rightarrow Y(5S) \rightarrow B\bar{B}, B^*\bar{B}, B^*\bar{B}^*, BB\pi, BB\pi\pi, B_s\bar{B}_s, B_s^*\bar{B}_s, B_s^*\bar{B}_s^*$

where $B^* \rightarrow B\gamma$ and $B_s^* \rightarrow B_s\gamma$

$M(Y(5S)) = 10865 \pm 8$ MeV/c$^2$ (PDG)

$\Gamma(Y(5S)) = 110 \pm 13$ MeV/c$^2$ (PDG)

$B_s$ rate is $\sim$10-20% $\Rightarrow$ high lumi $e^+e^-$ collider at the $Y(5S) \rightarrow B_s$ factory.
First Y(5S) runs at the KEKB e⁺e⁻ collider

Electron and positron beam energies were increased by 2.7% (same Lorentz boost $\beta\gamma = 0.425$) to move from Y(4S) to Y(5S).

No modifications are required for Belle detector, trigger system or software to move from Y(4S) to Y(5S).

Integrated luminosity of $\sim 1.86 \text{ fb}^{-1}$ at 2005 and $\sim 21.6 \text{ fb}^{-1}$ at 2006 was taken by Belle detector at Y(5S).
The same luminosity per day can be taken at Y(4S) and Y(5S).

→ Very smooth running
Inclusive analyses: $Y(5S) \rightarrow D_s X$, $Y(5S) \rightarrow D^0 X$

After continuum subtraction and efficiency correction:

$B_f (Y(5S) \rightarrow D_s X) / 2 = (23.6 \pm 1.2 \pm 3.6)\%$

$B_f (Y(5S) \rightarrow D^0 X) / 2 = (53.8 \pm 2.0 \pm 3.4)\%$

$=> f_s = \frac{N(B_s^(*) B_s^(*))}{N(bb)} = (18.0 \pm 1.3 \pm 3.2)\%$

$L = 1.86\; fb^{-1}$

$N_{bb}(5S) = 561,000 \pm 3,000 \pm 29,000$ events

$\frac{N(B_s)}{fb^{-1}} = 108,000 \pm 21,000$ events

in good agreement with CLEO
Signature of fully reconstructed exclusive $B_S$ decays

$e^+ e^- \rightarrow Y(5S) \rightarrow B_S B_S$, $B_S^* B_S$, $B_S B_S^*$, where $B_S^* \rightarrow B_S \gamma$

Reconstruction: $B_S$ energy and momentum, photon from $B_S^*$ is not reconstructed.

Two variables calculated: $M_{bc} = \sqrt{E^*_{\text{beam}}^2 - P^*_B^2}$, $\Delta E = E^*_B - E^*_{\text{beam}}$

Figures (MC simulation) are shown for the decay mode $B_S \rightarrow D_s^- \pi^+$ with $D_s^- \rightarrow \phi \pi^-$. The signals for $B_S B_S$, $B_S^* B_S$ and $B_S^* B_S^*$ can be well separated.
Exclusive $B_s \to D_s^{(*)} \pi^-/\rho^-$ and $B_s \to J/\psi \phi/\eta$ decays

**Data at Y(5S), 1.86 fb$^{-1}$**

- $B_s \to D_s^{(*)} \pi^-$
  - 9 evts in $B_s^* B_s^*$
- $B_s \to D_s^{(*)+} \pi^-$
  - 4 evts in $B_s^* B_s^*$
- $B_s \to D_s^{(*)+} \rho^-$
  - 7 evts in $B_s^* B_s^*$
- $B_s \to J/\psi \phi/\eta$
  - 3 evts in $B_s^* B_s^*$

\[
\frac{N(B_s^*B_s^*)}{N(B_s^{(*)}B_s^{(*)})} = (94\pm 6\%)\%
\]

Potential models predict $B_s^* B_s^*$ dominance over $B_s^*B_s$ and $B_s B_s$ channels, but not so strong.

**Conclusions:**
1. Belle can take $\sim 30$ fb$^{-1}$ per month (x2 soon).
2. Number of produced $B_s$ at Y(5S) is $\sim 10^5$/fb$^{-1}$.
3. $B_s^*B_s^*$ channel dominates over all $B_s^{(*)}B_s^{(*)}$.
4. Backgrounds in exclusive modes are not large.
Color-suppressed $B_s \rightarrow D^0 K^0$ decay

$$\frac{Bf(B^0 \rightarrow D^0 \pi^0)}{Bf(B^0 \rightarrow D^+ \pi^-)} = \frac{(2.91 \pm 0.28) \times 10^{-4}}{(3.4 \pm 0.9) \times 10^{-3}} \approx 0.1$$

Which diagram, color-suppressed or FSI, is dominant in $B^0 \rightarrow D^0 \pi^0$ decay? Decay mode $B_s \rightarrow D^0 K^{(*)0}$ has no FSI diagram. If the ratio $Bf(Bs \rightarrow D^0 K^0)/Bf(Bs \rightarrow D_s^+ \pi^-) \sim 0.1$, then color-suppressed diagram dominates. If the ratio is significantly smaller, then FSI diagram dominates.

If $Bf(B_s \rightarrow D^0 K^0)$ is $\sim 3 \times 10^{-4}$, then $\sim 8$ events are expected with $25$ fb$^{-1}$ at $Y(5S)$. 

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Semileptonic $B_s$ decays

At the $Y(5S)$ we can measure precisely semileptonic decays:

\[
Bf (B_s \rightarrow X^+ \ell^- \nu) \\
Bf (B_s \rightarrow D_s^{+} \ell^- \nu) \\
Bf (B_s \rightarrow D_s^{*+} \ell^- \nu)
\]

Accuracy is expected to be \(\sim (5-10)\%\) with 25 fb\(^{-1}\) at $Y(5S)$

Difficult to measure in hadron-hadron colliders.

These $Bf$'s have to be compared with corresponding $B$ meson $Bf$'s. Within SM:

\[
Bf (B_s \rightarrow X^+ \ell^- \nu) = Bf (B \rightarrow X^+ \ell^- \nu)
\]

If not, nonstandard contributions should be considered.

How to explain:

\[\tau(B^0) > \tau(B_s)\] - 2.9\(\sigma\) difference (in contrast with theory).
\[ \frac{\Delta \Gamma_S}{\Gamma_S} \text{ measurement from } Bf \ (B_S \rightarrow D_s^{(*)} D_s^{-(*)}) \]

\[
M_{B_S} = \frac{(M_H + M_L)}{2} \quad \Gamma_S = \frac{(\Gamma_H + \Gamma_L)}{2} \\
\Delta m_S = M_H - M_L \quad \Delta \Gamma = \Gamma_L - \Gamma_H \quad > 0 \text{ in SM}
\]

\[
i \frac{d}{dt} \left( \begin{array}{c} B_S \\ \overline{B}_S \end{array} \right) = \left( M - \frac{i}{2} \Gamma \right) \left( \begin{array}{c} B_S \\ \overline{B}_S \end{array} \right) - \text{Schrödinger equation}
\]

Matrices \( M \) and \( \Gamma \) are t-dependent, Hermitian 2x2 matrices

Assuming CPT: \( M_{11} = M_{22} \quad \Gamma_{11} = \Gamma_{22} \)

\[
| B_{H,L}(t) > = \exp(- ( i M_{H,L} + \Gamma_{H,L}/2)t) | B_{H,L} >
\]

SM: \( \beta_s = \text{arg}(-V_{ts} V_{tb}^* / V_{cs} V_{cb}^*) = O(\lambda^2) \) - no CP-violation in mixing

BSM: \( \phi_s = \text{arg}(- M_{12} / \Gamma_{12}) \quad 2\theta_s = \phi_s \quad \Delta \Gamma_s = 2 | \Gamma_{12} | \cos 2\theta_s \)
\[ \Delta \Gamma_s = 2 \left| \Gamma_{12} \right| \cos \phi_s \quad \Delta \Gamma_s^{SM} = \Delta \Gamma_{CP}^s = 2 \left| \Gamma_{12} \right| \]

Since \( \Delta \Gamma_{CP}^s \) is unaffected by NP, NP effects will decrease \( \Delta \Gamma_s \).

\[ \Delta \Gamma_{CP}^s = \sum \Gamma(\text{CP}=+) - \sum \Gamma(\text{CP}= -) \]

\( B_s \rightarrow D_s^{(*)} + D_s^{(*)} \) decays have \( CP \)- even final states with largest \( BF \)'s of \( \sim (1-3)\% \) each, saturating \( \Delta \Gamma_s / \Gamma_s \).

\[ \frac{\Delta \Gamma_{CP}^s}{\Gamma_s} \approx \frac{\text{Bf}(B_s \rightarrow D_s^{(*)} + D_s^{(*)})}{1 - \text{Bf}(B_s \rightarrow D_s^{(*)} + D_s^{(*)}) / 2} \]

To prove this formula experimentally: a) Contribution of \( B_s \rightarrow D_s^{(*)} D_s^{(*)} n\pi \) is small b) Most of \( B_s \rightarrow D_s^{(*)} D_s^{(*)} \) and \( B_s \rightarrow D_s^{(*)} D_s^{(*)} \) states are \( CP \)- even.

Assuming corrections are small \( \sim (5-7)\% \), \( Bf \) measurement will provide information about \( \Delta \Gamma_{CP}^s \) or \( |\Gamma_{12}| \).
\[ \Delta \Gamma_s / \Gamma_s \text{ measurement from } Bf (B_s \rightarrow D_s^{(*)} D_s^{(*)}) \]

**Expected with 25 fb\(^{-1}\) at Y(5S):**

\[
\begin{align*}
\text{Eff}(B_s \rightarrow D_s^+ D_s^-) & \sim 2 \times 10^{-4} \\
\text{Eff}(B_s \rightarrow D_s^{*+} D_s^-) & \sim 1 \times 10^{-4} \\
\text{Eff}(B_s \rightarrow D_s^{**} D_s^{*+}) & \sim 5 \times 10^{-5}
\end{align*}
\]

\[ N \sim 2.5 \times 10^6 \times 2 \times 10^{-4} \times 10^{-2} \sim 5 \text{ ev} \]

\[ N \sim 2.5 \times 10^7 \times 10^{-4} \times 2 \times 10^{-2} \sim 5 + 5 \text{ ev} \]

\[ N \sim 2.5 \times 10^7 \times 5 \times 10^{-5} \times 3 \times 10^{-2} \sim 4 \text{ ev} \]

\[ B_f (B_s \rightarrow D_s^{*+} D_s^-) \text{ has to be } \sim 30\% . \]

}\[ \Delta \Gamma_{CP}^S \sim \frac{Bf(B_s \rightarrow D_s^{(*)} + D_s^{(*)-})}{1 - Bf(B_s \rightarrow D_s^{(*)} + D_s^{(*)-}) / 2} \]

should be compared with direct \[ \Delta \Gamma_s / \Gamma_s \text{ measurement to test SM.} \]

\[ \Delta \Gamma_s / \Gamma_s \text{ lifetime difference can be measured directly with high accuracy at Y(5S) and also at Tevatron and LHC experiments.} \]
Exclusive $B_S \rightarrow \gamma\gamma$ decay

Natural mode to search for BSM effects, many theoretical papers devoted to this decay.

PDG limit: $Bf(B_S \rightarrow \gamma\gamma) < 1.48 \times 10^{-4}$

90% CL UL with 1.86 fb$^{-1}$: $Bf(B_S \rightarrow \gamma\gamma) < 0.53 \times 10^{-4}$.

Expected UL with 100 fb$^{-1}$: $Bf(B_S \rightarrow \gamma\gamma) < 1. \times 10^{-6}$.

SM: $Bf(B_S \rightarrow \gamma\gamma) = (0.5-1.0) \times 10^{-6}$.

BSM can increase $Bf$ up to two orders of magnitude.
Many “conventional” BSM models can be better constrained by $B \rightarrow K^* \gamma$ and $B \rightarrow s \gamma \gamma$ processes, however not all. In some BSM models $B_s \rightarrow \gamma \gamma$ provides the best limit, in particular in 4-generation model ($V_{Ts}$) and R-parity violating SUSY ($x M(\gamma \gamma)$).

**hep-ph/0302177** (Huang et al): limits on four-generation matrix elements $V_{Tb}$ and $V_{Ts}$ were obtained from $B$ decays. $Bf(B_s \rightarrow \gamma \gamma)$ can increase up to one order of magnitude under specific conditions. Decay $B \rightarrow \gamma \gamma$ is not affected.

**hep-ph/0404152** (Gernintern et al): within R-parity violation SUSY, diagram with sneutrino will increase $Bf(B_s \rightarrow \gamma \gamma)$ up to one order of magnitude.
Exclusive $B_s \to K^- \pi^+$ and $B_s \to \phi \gamma$ decays

Direct CP-violation $\Rightarrow$ non-zero charge asymmetry parameter
$A = (Bf (+) - Bf (-)) / (Bf (+) - Bf (-))$.

Expected number of events with 5 $ab^{-1}$:
$B_s \to K^- \pi^+$: ~300 events.

Large statistics is required to observe direct CP-violation on the level of 10%.

New Physics can contribute in penguin decay loops.

Estimated number of events with 100 $fb^{-1}$: ~20 ev.

Partner of $B \to K^* \gamma$ penguin decay.
Bf’s have to be compared.
What else can be done at Super B Factory?

**PDG (Z→bb, pp at S^{1/2}=1.8TeV)**

<table>
<thead>
<tr>
<th>b hadron</th>
<th>fraction(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B^+ , B^0</td>
<td>39.8 ± 1.0</td>
</tr>
<tr>
<td>B_s</td>
<td>10.4 ± 1.4</td>
</tr>
<tr>
<td>b baryons</td>
<td>9.9 ± 1.7</td>
</tr>
</tbody>
</table>

Rates at e+e- continuum should be similar, baryon production is large.

**M(Λ_b) = (5624 ± 9) MeV/c^2**

**M(Λ_b)×2 = (11248 ± 18) MeV/c^2 ⇒ 6.3 % up from Y(4S) CME.**

**Can Super B factory CM energy range be increased?**

**M(B_c) = (6286 ± 5) MeV/c^2**

\[ e^+e^- \rightarrow B_s \bar{B}_s, \Lambda_b \bar{\Lambda}_b, B_c \bar{B}_c, \Xi_b \bar{\Xi}_b \ldots ? \]
Conclusions

- $B_s$ decays with branching fractions down to $10^{-6}$ can be studied with statistics of $\sim 100$ fb$^{-1}$ at e+e- colliders running at Y(5S).

- $B_s$ studies at e+ e- colliders running at Y(5S) have many advantages comparing with hadron-hadron colliders: high efficiency of photon reconstruction; 100% trigger efficiency; good $K/\pi$ PID, partial reco.

- Many important SM tests can be done with statistics of the order of (100-500) fb$^{-1}$ at Super B factory.

- Possibility to increase CM energy range (up to $\sim 14$ GeV) should be considered for Super B factory. It could provide opportunity to study wide spectrum of $b$-hadrons, like $\Lambda_b$, $B_c$, $\Xi_b$. 
Background slides
Hadronic event classification

hadronic events at $\Upsilon(5S)$

$\Upsilon(5S)$ events

$b$ continuum

$u,d,s,c$ continuum

$bb$ events

$B_0, B^+$ events

$B_s$ events

$B_s^* B_s^*$ channel

$f_s = \frac{N(B_s^* B_s^*)}{N(bb)}$

$N(bb \text{ events}) = N(\text{hadr, 5S}) - N(udsc, 5S)$

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Number of $bb$ events, number of $B_s$ events

$Y(5S)$: Lumi = 1.857 ± 0.001 (stat) fb$^{-1}$

$N_{bb}(5S) = 561,000 ± 3,000 ± 29,000$ events

Cont (below 4S): 3.670 ± 0.001 (stat) fb$^{-1}$

$=> 5\%$ uncertainty (from luminosity ratio)

How to determine $f_s = N(B_s(\ast) B_s(\ast)) / N(bb)$?

$B_f (Y(5S) -> D_s X) / 2 = f_s x B_f (B_s -> D_s X) + (1 - f_s) x B_f (B -> D_s X)$

1. $B_f (B_s -> D_s X)$ can be predicted theoretically, tree diagrams, large.
2. $B_f (B -> D_s X)$ is well measured at the $Y(4S)$. 
Feasibility of $B_S$ lifetime measurement with same sign leptons

Lifetime can be measured using two fast same sign lepton tracks and beam profile. To remove secondary D meson semileptonic decays: $P(\ell)>1.4$ GeV.

$Y(5S): B_S(\ell^+) B_S(\ell^+) / B_S(\ell^+) B_S(\ell^-) = 100\%$

$Y(5S): B(\ell^+) B(\ell^+) / B(\ell^+) B(\ell^-) \sim 10\%$

Beam profile

$\Delta z = \beta \gamma c \Delta t$

$Z_{beam} \sim 3$ mm; $\Delta z \sim 0.1$ - 0.2 mm.
Comparison with Fermilab $B_s$ studies.

- There are several topics, where $Y(5)$ running has advantages comparing with CDF and D0:
  1) **Model independent** branching fraction measurements.
  2) Measurement of decay modes with $\gamma$, $\pi^0$ and $\eta$ in final state ($D_s^+ \rho^-$).
  3) Measurement of **multiparticle** final states (like $D_s^+ D_s^-$).
  4) **Inclusive** branching fraction measurements (semileptonic $B_s$).
  5) Partial reconstruction ($B_f (D_s^+ l^- \nu)$ using “missing- mass” method).

- There are also disadvantages:
  1) We have to choose between running at $Y(4S)$ or $Y(5S)$.
  2) **Number of $B_s$** is smaller than in Fermilab experiments.
  3) Vertex resolution is **not** good enough to measure $B_s$ mixing.

- Running at $Y(5S)$ is a new tool to study $B_s$ physics. First Belle results are very promising. Collider exists $\Rightarrow$ relatively low price.