Physics Potential at the $\Upsilon(5S)$

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Motivation

New Physics in Bs - $\bar{B}_s$ mixing

sizeable CP-violating phase in Bs - $\bar{B}_s$ mixing is unambiguous signal of NP

CP angle $\gamma$

modes in common to Bs and $\bar{B}_s$ as for instance $D_s(*)K(*)$ are sensitive to weak phase $\gamma$ and a sizeable width difference $\gamma = \Delta \Gamma / 2 \Gamma$ leads to new CP violation phenomena

test of duality

detailed and comprehensive study of Bs decays as crucial quantitative probe of duality; for $C_p = 1$ (Vcb, Vub, Vtd, ...) and intellectual curiosity/honesty (I. Bigi)
What is unique about $\Upsilon(5S)$?

Coherent $B_s - \bar{B}_s$ pair production

with anti-symmetric ($C = -1$) and symmetric wave function ($C = +1$)

$C = -1$ for $(B_s, \bar{B}_s)$ and $(B_s^*, \bar{B}_s^*)$, like $\Upsilon(4S)$

$C = +1$ for $(B_s, \bar{B}_s^*)$ and $(B_s^*, \bar{B}_s)$, new

e+e- environment, good photon detection

upgrade of existing facility

beam-energy constraint

average over $\Delta m_s$ oscillation
### Symmetric vs. Anti-symmetric wavefunction

**Two realizations of the EPR paradoxon**

<table>
<thead>
<tr>
<th>$C=-1$</th>
<th>$C=+1$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flavor of both $B$s remain completely anti-correlated until one $B$ decays.</strong></td>
<td><strong>Tagging flavor of one $B$ does NOT guarantee the other $B$s to be in the opposite flavor state at the same instant.</strong></td>
</tr>
<tr>
<td>If, at any times, decays occur to $CP$ eigenstates of equal $CP$ parity, then there is $CP$ violation.</td>
<td>If, at any times, decays occur to $CP$ eigenstates of opposite $CP$ parity, then there is $CP$ violation.</td>
</tr>
<tr>
<td>In principle, given a non-zero $y=\Delta \Gamma/2\Gamma$, the $\Delta t = t_1-t_2$ time distribution can be anti-symmetric.</td>
<td>Even with a non-zero $y=\Delta \Gamma/2\Gamma$ the $\Delta t = t_1-t_2$ time distribution is always symmetric.</td>
</tr>
</tbody>
</table>
Methods for NP and $\gamma$

1) Lifetime Measurements in different $B_s$ final states (the BaBar Method)

2) Time-integrated rate measurements of coherent $B_s \overline{B_s}$ decays to $(D_s K) (D_s K)$ (the Xing Method)

3) Rate measurements of CP tagged $B_s$ decays to $D_s K$ (the Falk-Petrov Method)
Time distribution of untagged Bs

\[ \Delta = \Gamma \Delta t, \lambda = q \overline{A} r / p A r, y = \Delta \Gamma / 2 \Gamma \]

For C = -1:

\[ P(t, \Delta)^- \propto \exp(-|\Delta|) \left\{ (1 + |\lambda|^2) \cosh(y \Delta) - 2 \Re(\lambda) \sinh(y \Delta) \right\} \]

For C = +1:

\[ P(t, \Delta)^+ \propto \exp(-|\Delta|) \left\{ (1 + |\lambda|^2 - y (2 \Re(\lambda))) \cosh(y |\Delta|) \\
(1 - y |\lambda|^2 - 2 \Re(\lambda)) \sinh(y |\Delta|) \right\} \]

Flavor states: \( \lambda = 0 \)  
only second order terms in \( y \)

CP eigenstates: \( |\lambda| = 1 \)  
first order terms in \( y \),  
prefactor scales with  
\( \Re(\lambda) = \cos(\text{CP phase}) \)

States with interfering amplitudes: \( |\lambda| \neq 1 \)
In search for NP

1) Measure $y$ in semileptonic decays and CP eigenstates with zero SM prediction of phase

SM: $y_{sl} = y_{CP}$  \quad CP = J/ΨΦ, Ds+Ds-, J/Ψη
NP: $y_{CP} = y_{sl} \cos(\Phi)$  \quad $\Phi$ = phase of NP

2) Value of $y$ itself depends on NP (Dunietz, Fleischer, Nierste)

$y = y_{SM} \cos(\Phi)$

$y_{SM}$ from theoretical estimate or

$y_{SM} = BR(Ds^{(*)} + Ds^{(*)-})$ in Shifman-Voloshin limit
Resolution on $y$

$10^7 B_s^(*) \bar{B}_s^(*)$

$1\sigma$ error of a measurement with central value $y=0.1$

$R^{+-} = \frac{f(C=-1)}{f(C=-1) + f(C=+1)}$

50,000 reconstructed $D_s^+ \rightarrow \psi' \nu \nu$ events

3000 reconstructed $J/\psi \Phi, D_s^+ D_s^-$ events
## Experimental situation

**Lifetime difference**

\[ y = \frac{\Delta \Gamma}{2 \Gamma} \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Year</th>
<th># events</th>
<th>Statistical Sensitivity for y</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3</td>
<td>1998</td>
<td>15,000</td>
<td>~0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(inclusive B, 10% Bs)</td>
<td></td>
</tr>
<tr>
<td>DELPHI</td>
<td>1999</td>
<td>1,300</td>
<td>~0.15</td>
</tr>
<tr>
<td>CDF</td>
<td>1999</td>
<td>2,000</td>
<td>~0.15</td>
</tr>
<tr>
<td>BaBar</td>
<td>2005?</td>
<td>50,000</td>
<td>~0.01</td>
</tr>
</tbody>
</table>

**Using B_s Flavor specific states**

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<th>Experiment</th>
<th>Year</th>
<th># events</th>
<th>Statistical Sensitivity for y</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>1998</td>
<td>58</td>
<td>~0.2</td>
</tr>
<tr>
<td>ALEPH</td>
<td>2000</td>
<td>16</td>
<td>~0.25</td>
</tr>
<tr>
<td>BaBar</td>
<td>2005?</td>
<td>3,000</td>
<td>~0.02</td>
</tr>
</tbody>
</table>

**Using B_s CP eigenstates**

Theoretical estimate:

\[ y = 0.075 \pm 0.035 \]

(Beneke, Buchalla, Dunietz, Greub, Lenz, Nierste and KEK-Hiroshima Group)
LEP B-Lifetime Working Group

Flavor specific
$\tau_{fs} = 1.471 \pm 0.059 \text{ps}$

$y = 1 - \tau_{CP}/\tau_{fs} = 0.10 \pm 0.16$

CP eigenstate
$\tau_{CP} = 1.32 \pm 0.19 \text{ps}$
$\gamma$ dependent modes

$D_s^+ K^-, D_s^{*+} K^-, D_s^+ K^{*-}, D_s^{*+} K^{*-}$

Figure 1: Tree-level diagram $b \to c u \bar{d}$ in $B_s^0 \to D_s^{(*)+} K^{(*)+}$.

$|\lambda| = \frac{|V_{ub} V_{cs}|}{|V_{cb} V_{us}|}$

Figure 2: Tree-level diagram $b \to c u \bar{s}$ in $B_s^0 \to D_s^{(*)+} K^{(*)-}$. 
Sensitivity to $\gamma$

$\gamma = -0.5, |\lambda| = 0.5$
Resolution on $\gamma$

$10^7 B_s(*) \bar{B}_s(*)$

1σ error of a measurement with central value $\gamma = 90°$.

Besides parameter varied other parameters are fixed to $y=0.1$, $R_{+-}=0.5$, $|\lambda|=0.3$.

Assumes partial reconstruction of $D_s^{*+} K^-$. 

1000 reconstructed $D_s K$ events
Resolution on $\gamma$

$10^8 \text{Bs}(*) \bar{\text{Bs}}(*)$

1σ error of a measurement with central value $\gamma = 90^\circ$.

Besides, parameter varied other parameters are fixed to $y=0.1$, $R_{+-}=0.5$, $|\lambda|=0.3$. 

10,000 reconstructed $D_s K$ events
**Xing Method**

Time-integrated rates for joint ($B_s, \bar{B}_s$) decay into ($f, \bar{f}$), ($\bar{f}, f$) and ($f, \bar{f}$) with

$$f = D_s + K^-, D_s^* + K^-, D_s + K^{*-}, D_s^* + K^{*-}$$

Two independent ratios ($f, \bar{f})/(f, \bar{f})$ and ($f, \bar{f})/(f, f)$ for $C=\pm 1$

Requires hadronic phase $\delta \neq 0$

Minimum statistics $10^{11} B_s(*)B_s(*)$
Falk-Petrov Method

Minimum statistics $10^{11} B_s(*)\bar{B}_s(*)$

$A_{CP} = A(B_s, CP \rightarrow D_s + K^-)$

$\sqrt{2}A_{CP}$

A$_2$ = $A(B_s \rightarrow D_s + K^-)$

A$_1$ = $A(B_s \rightarrow D_s + K^-)$

A$_1$, A$_2$ flavor-tagged $B_s$ Amplitudes, measured by Fermilab, corrected for $x_s$ oscillation

ACP CP-tagged $B_s$ Amplitudes, measured by e+e- factory at $\Upsilon(5S)$

In SM: only time-integrated rate measurements

NP: triangle becomes time-dependent.
Accelerator Upgrades

BaBar options:

1) same machine at $E_{cm}=10.87\text{GeV}$
   drop in luminosity by 30%, similar boost

2) Luminosity optimized machine
   requires new RF station and new IP magnet design

3) Luminosity optimized machine with maximum boost
   not necessary! Measurement of $x_s$ is for Fermilab only.
   Techniques at $\Upsilon(5S)$ must work without flavor-tagging.

Luminosity projections:
up to 2005 $500\text{fb}^{-1}$ at $\Upsilon(4S)$, by then $150\text{fb}^{-1}/\text{year}$
$\rightarrow 100\text{fb}^{-1}/\text{year}$ at $\Upsilon(5S)$ is "conservative" estimate
$100\text{fb}^{-1} \equiv 10^7 \text{ Bs}(\L^+) \text{ Bs}(\L)$
Comparison to Fermilab

Run II will start in March 2001, 2 fb$^{-1}$ in first 2 years
4000 reconstructed J/$\Psi\Phi$ events,
error on $y$ of 0.02

up to 2006: 10-20 fb$^{-1}$

1 year of Run II yield $\equiv$ 1 year of BaBar $\Upsilon(5S)$ yield,
BUT BaBar would come 3-4 years later.

Nevertheless the $\Upsilon(5S)$ has the unique feature of
correlated $B_s\bar{B}_s$ pair production and better photon
detection as for instance needed in J/$\Psi\eta$.
Complementary $B_s$ physics program to Fermilab.
CESR run at the $\Upsilon(5S)$

1988 CESR three months run at $\Upsilon(5S)$ with 140 pb$^{-1}$

Main question addressed is $\text{BR}(\Upsilon(5S) \to Bs(*)\overline{Bs}(*))$

CLEO measurements were consistent that 1/3 of resonance cross section was due to Bs production. However, statistical significance was limited.

CUSB-II with high resolution BGO calorimeter found clear evidence for Bs* mesons. Excess of 47 MeV photons at $\Upsilon(5S)$, but not at $\Upsilon(4S)$. By width of peak one can tell whether from $B^*$ or Bs* (Doppler-broadening). 20%-55% Bs* mesons.
Summary

A sizeable $\Delta \Gamma$ introduces new CP violating effects.

Possibility to detect New Physics by testing the CP phase in channels like $B_s \to J/\psi \phi$ with a negligible Standard Model phase.

$B_s \to D^* s K$ samples are a promising source to measure the CP angle $\gamma$. Different methods exploit either the time distribution of untagged $B_s \to D^* s K$ events or rate measurements of fully reconstructed $\Upsilon(5S)$ events where one $B_s$ decays into $D^* s K$ and the other into a CP eigenstate or $D^* s K$.

Methods have been proposed that make explicit use of the correlated $B_s \bar{B}_s$ production at the $\Upsilon(5S)$. Further work is needed to make these techniques experimentally feasible.