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

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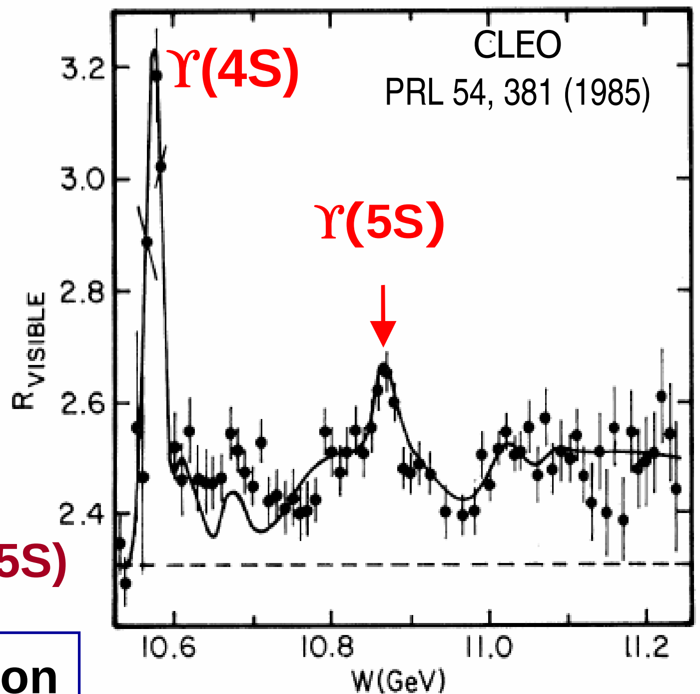
Outline

- Introduction.
- Recent Belle measurements at the Υ(5S).
- Potential B_s studies at the Υ(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 Υ(4S) :
Belle and BaBar



1985: CESR (CLEO,CUSB) ~116 pb^{-1} at Υ(5S)

2003: CESR (CLEO III) ~0.42 fb^{-1} at Υ(5S)

2005: Belle, KEKB ~ 1.86 fb^{-1} at Υ(5S)

2006, June 9-31: Belle, KEKB ~21.7 fb^{-1} at Υ(5S)

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

$e^+ e^- \to$ Υ(5S) $\to B\bar{B}$, $B^*\bar{B}$, $B^*\bar{B}^*$, $B\bar{B}\pi$, $B\bar{B}\pi\pi$, $B_s\bar{B}_s$, $B_s^*\bar{B}_s$, $B_s^*\bar{B}_s^*$

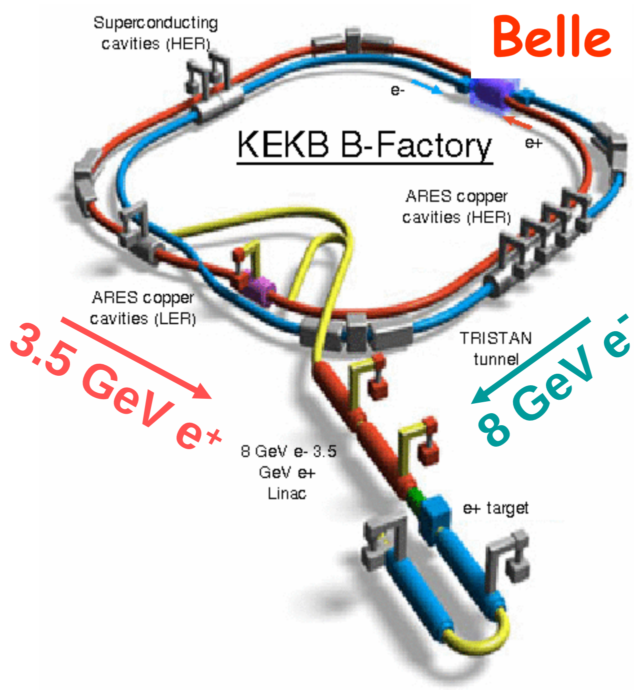
where $B^* \to B\gamma$ and $B_s^* \to B_s\gamma$

M(Υ(5S)) = 10865 ± 8 MeV/c^2 (PDG)

Γ(Υ(5S)) = 110 ± 13 MeV/c^2 (PDG)

B_s rate is ~10-20% => high lumi e^+e^- collider at the Υ(5S) -> B_s factory.

First Y(5S) runs at the KEKB e^+e^- collider



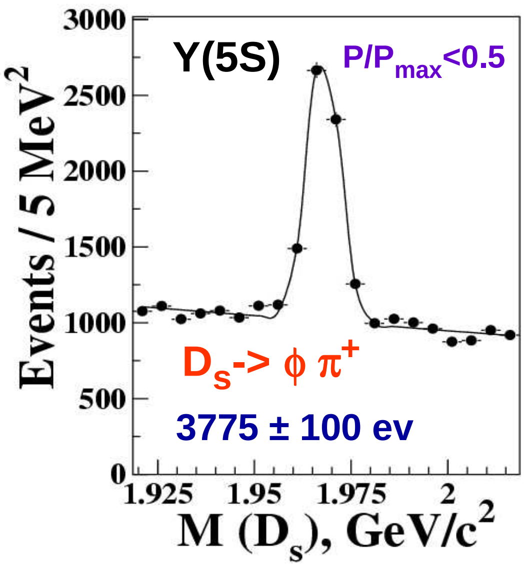
Electron and positron beam energies were increased by 2.7% (same Lorentz boost $\beta\gamma = 0.425$) to move from Y(4S) to Y(5S).

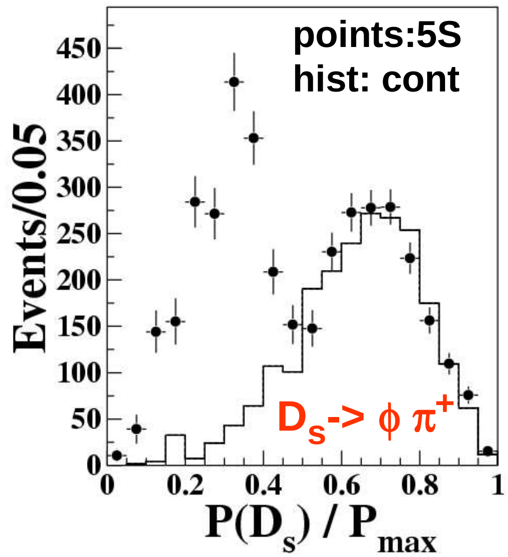
No modifications are required for Belle detector, trigger system or software to move from Y(4S) to Y(5S).

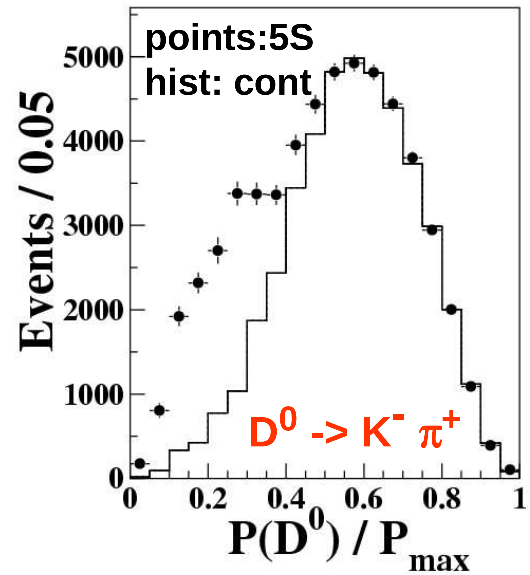
Integrated luminosity of ~1.86 fb^{-1} at 2005 and ~21.6 fb^{-1} at 2006 was taken by Belle detector at Y(5S).
The same luminosity per day can be taken at Y(4S) and Y(5S).

→ Very smooth running

Inclusive analyses : $\Upsilon(5S) \to D_s X$, $\Upsilon(5S) \to D^0 X$







After continuum subtraction and efficiency correction:

Bf ($\Upsilon(5S) \to D_s X$) / 2 = (23.6 ± 1.2 ± 3.6) %

Bf ($\Upsilon(5S) \to D^0 X$) / 2 = (53.8 ± 2.0 ± 3.4) %

L = 1.86 fb^{-1}

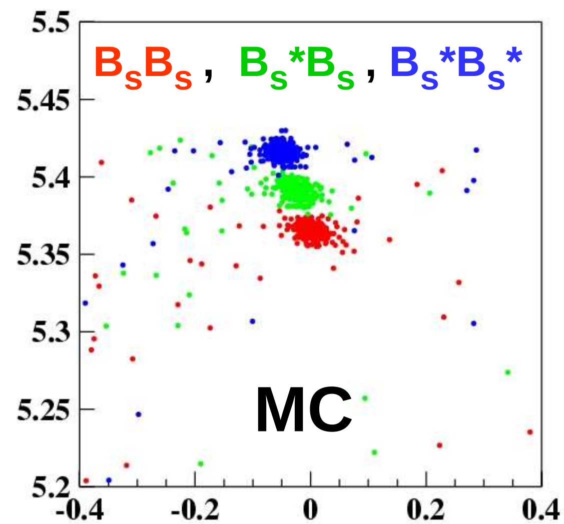
$N_{bb}(5S)$ = 561,000 ± 3,000 ± 29,000 events

=> $f_s = N(B_s^{(*)} B_s^{(*)}) / N(bb)$ = (18.0 ± 1.3 ± 3.2)%

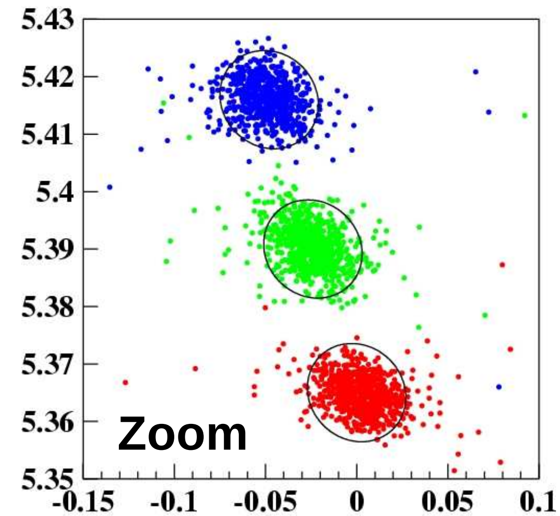
$N(B_s)$ / fb^{-1} = 108,000 ± 21,000 events

in good agreement with CLEO

Signature of fully reconstructed exclusive B_s decays



M_{bc} vs ΔE



M_{bc} vs ΔE

$e^+ e^- \to Y(5S) \to B_sB_s$, $B_s^*B_s$, $B_s^*B_s^*$, where $B_s^* \to B_s\,\gamma$

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

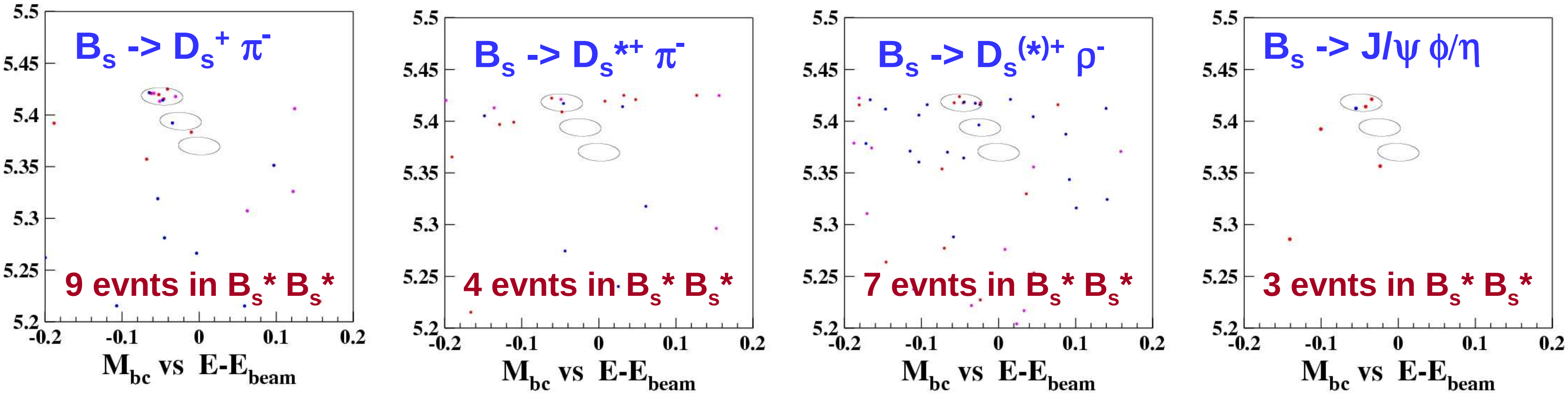
Two variables calculated: $M_{bc} = \sqrt{E^{*2}_{beam} - P^{*2}_{B}}$, $\Delta E = E^*_B - E^*_{beam}$

Figures (MC simulation) are shown for the decay mode $B_s \to D_s^- \pi+$ with $D_s^- \to \phi\, \pi-$.

The signals for B_sB_s, $B_s^*B_s$ and $B_s^*\,B_s^*$ can be well separated.

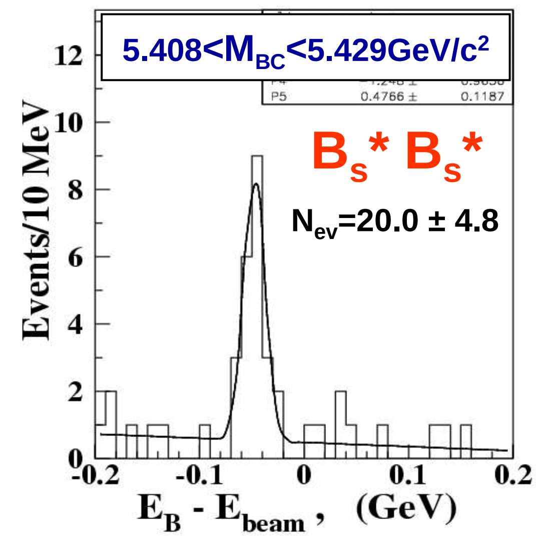
Exclusive $B_s \to D_s^{(*)+} \pi^-/\rho^-$ and $B_s \to J/\psi\ \phi/\eta$ decays

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



$$N(B_s^*B_s^*) / N(B_s^{(*)}B_s^{(*)}) = (94 \pm {}^{6}_{9})\%$$

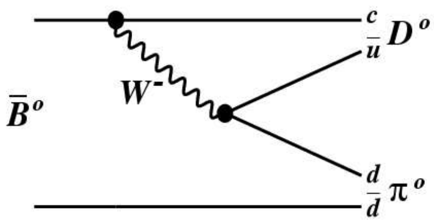
Potential models predict $B_s^*\ B_s^*$ dominance over $B_s^*B_s$ and B_sB_s channels, but not so strong.



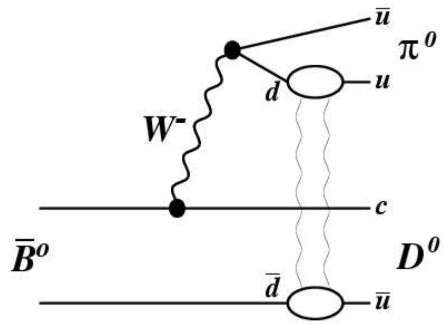
Conclusions:

1. Belle can take ~30 fb^{-1} per month (x2 soon).
2. Number of produced B_s at Y(5S) is ~$10^5/fb^{-1}$.
3. $B_s^*B_s^*$ channel dominates over all $B_s^{(*)}B_s^{(*)}$.
4. Backgrnds in exclusive modes are not large.

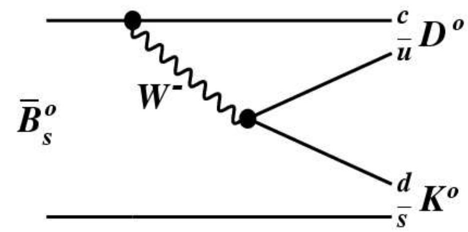
Color-suppressed B_s-> D^0 K^0 decay



Color-suppressed



FSI



Color-suppressed

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

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

If $Bf(B_s\text{->}D^0K^0)$ is ~3x10^{-4}, then ~8 events are expected with 25fb^{-1} at Y(5S).

Semileptonic B_s decays

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

- ***Bf*** $(B_s \to X^+ \ell^- \nu)$
- ***Bf*** $(B_s \to D_s^+ \ell^- \nu)$
- ***Bf*** $(B_s \to D_s^{*+} \ell^- \nu)$

Accuracy is expected to be ~(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* $(B_s \to X^+ \ell^- \nu)$ = *Bf* $(B \to X^+ \ell^- \nu)$

If not, nonstandard contributions should be considered.

How to explain:

$\tau(B^0) > \tau(B_s)$ - 2.9σ difference (in contrast with theory).

$\Delta\Gamma_s/\Gamma_s$ measurement from *Bf* ($B_s \to D_s^{+(*)} D_s^{-(*)}$)

$M_{Bs} = (M_H + M_L)/2$ $\quad\quad$ $\Gamma_s = (\Gamma_H + \Gamma_L)/2$

$\Delta m_s = M_H - M_L$ $\quad\quad$ $\Delta\Gamma = \Gamma_L - \Gamma_H$ >0 in SM

$$i \frac{d}{dt} \begin{pmatrix} B_s \\ \bar{B}_s \end{pmatrix} = (M - i/2\,\Gamma) \begin{pmatrix} B_s \\ \bar{B}_s \end{pmatrix}$$ - Schrődinger equation

Matrices M and Γ 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: $\beta_s = \arg(-V_{ts} V_{tb}^* / V_{cs} / V_{cb}^*) = O(\lambda^2)$ - no *CP*-violation in mixing

BSM : $\phi_s = \arg(- M_{12}/\Gamma_{12})$ $\quad\quad$ $2\theta_s = \phi_s$ $\quad\quad$ $\Delta\Gamma_s = 2\,|\Gamma_{12}|\cos 2\theta_s$

$\Delta\Gamma_s/\Gamma_s$ measurement from *Bf* ($B_s \to D_s^{+(*)} D_s^{-(*)}$)

$\Delta\Gamma_s = 2\,|\,\Gamma_{12}|\cos\phi_s$ $\qquad$ $\Delta\Gamma_s^{SM} = \Delta\Gamma_{CP}^s = 2\,|\,\Gamma_{12}|$

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

$$\Delta\Gamma_{CP}^s = \Sigma\,\Gamma(CP=+) - \Sigma\,\Gamma(CP=-)$$

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

$$\frac{\Delta\Gamma_{CP}^s}{\Gamma_s} \approx \frac{Bf(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - Bf(B_s \to D_s^{(*)+} D_s^{(*)-})/2}$$

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

Assuming corrections are small (~5-7%), *Bf* measurement will provide information about $\Delta\Gamma_{CP}^s$ or $|\Gamma_{12}|$.

$\Delta\Gamma_s/\Gamma_s$ measurement from *Bf* ($B_s \to D_s^{+(*)} D_s^{-(*)}$)

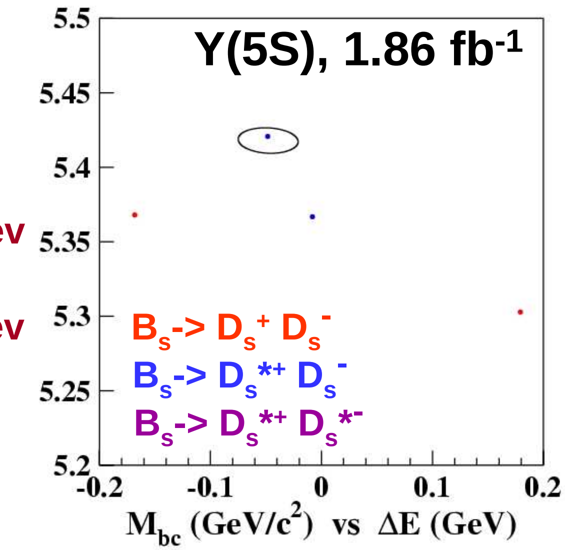
Expected with 25 fb^{-1} at Y(5S):

$Eff(B_s \to D_s^+ D_s^-) \sim 2\times10^{-4}$ N ~ $2.5\times10^6 \times 2\times10^{-4} \times 10^{-2} \sim$ 5 ev

$Eff(B_s \to D_s^{*+} D_s^-) \sim 1\times10^{-4}$ N ~ $2.5\times10^7 \times 10^{-4} \times 2\times10^{-2} \sim$ 5+5 ev

$Eff(B_s \to D_s^{*+} D_s^{*-}) \sim 5\times10^{-5}$ N ~ $2.5\times10^7 \times 5\times10^{-5} \times 3\times10^{-2} \sim$ 4 ev

=>Accuracy of *Bf* ($B_s \to D_s^{(*)+} D_s^{(*)-}$) has to be ~30%.



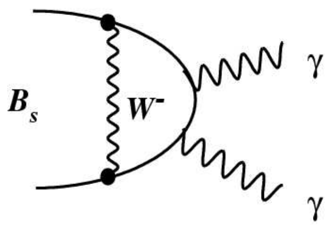
$D_s^+ \to \phi\pi^+$, $K^{*0} K^+$, $K_s K^+$

$$\frac{\Delta\Gamma_{CP}^s}{\Gamma_s} \approx \frac{Bf(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - Bf(B_s \to D_s^{(*)+} D_s^{(*)-}) / 2}$$

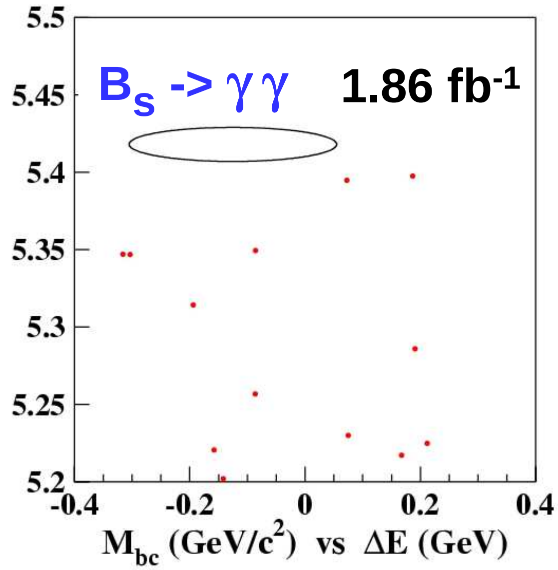
<= should be compared with direct $\Delta\Gamma_s/\Gamma_s$ measurement to test SM.

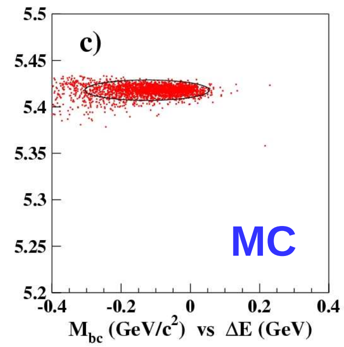
$\Delta\Gamma_s/\Gamma_s$ lifetime difference can be measured directly with high accuracy at Y(5S) and also at Tevatron and LHC experiments.

Exclusive $B_s \to \gamma\gamma$ decay



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





PDG limit : *Bf* $(B_s \to \gamma\gamma) < 1.48 \times 10^{-4}$

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

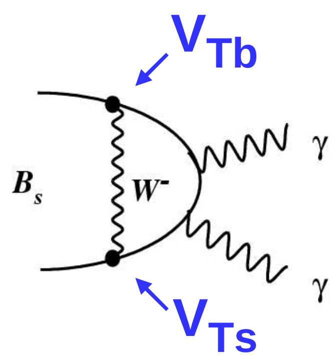
Expected UL with 100 fb^{-1} : *Bf* $(B_s \to \gamma\gamma) < 1. \times 10^{-6}$.

SM : *Bf* $(B_s \to \gamma\gamma) = (0.5\text{-}1.0) \times 10^{-6}$.

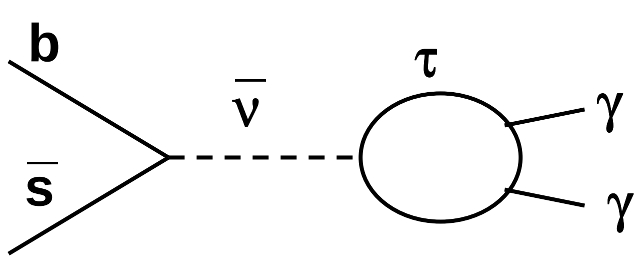
BSM can increase *Bf* up to two orders of magnitude.

Exclusive $B_s \to \gamma\gamma$ decay

Many "conventional" BSM models can be better constrained by $B \to K^* \gamma$ and $B \to s\gamma\gamma$ processes, however not all. In some BSM models $B_s \to \gamma\gamma$ 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. $Bf(B_s \to \gamma\gamma)$ can increase up to one order of magnitude under specific conditions. Decay $B \to \gamma\gamma$ is not affected.



hep-ph/0404152 (Gernintern et al): within R-parity violation SUSY, diagram with sneutrino will increase $Bf(B_s \to \gamma\gamma)$ up to one order of magnitude.

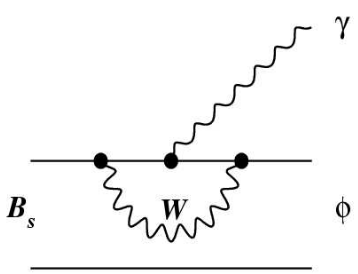
Exclusive $B_s \to K^- \pi^+$ and $B_s \to \phi\,\gamma$ decays

Direct CP-violation => 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%.

$B_s \to \phi\,\gamma$



New Physics can contribute in penguin decay loops.

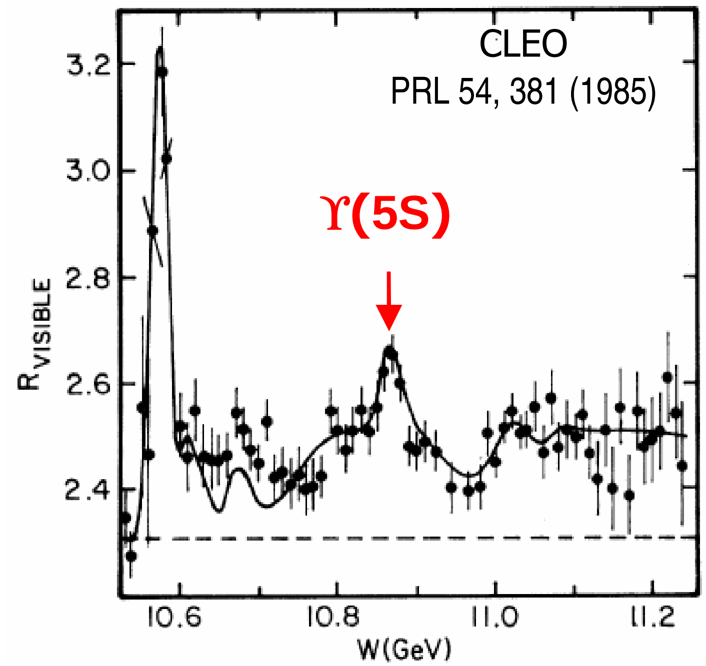
Estimated number of events with 100 fb^{-1} : ~20 ev.

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)

b hadron	fraction(%)
B^+ , B^0	39.8 ± 1.0
B_s	10.4 ± 1.4
b baryons	9.9 ± 1.7



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

$M(\Lambda_b) = (5624 \pm 9)\ \mathrm{MeV/c^2}$

$M(\Lambda_b)\mathrm{x}2 = (11248 \pm 18)\ \mathrm{MeV/c^2}$ => 6.3 % up from Y(4S) CME.

Can Super B factory CM energy range be increased ?

$M(B_c) = (6286 \pm 5)\ \mathrm{MeV/c^2}$

$e^+e^- \rightarrow B_s\overline{B}_s,\ \Lambda_b\overline{\Lambda}_b,\ B_c\overline{B}_c,\ \Xi_b\overline{\Xi}_b$ ... ?

Conclusions

- B_s decays with branching fractions down to 10^{-6} can be studied with statistics of ~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/π 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 ~14 GeV) should be considered for Super B factory. It could provide opportunity to study wide spectrum of b-hadrons, like Λ_b, B_c, Ξ_b.

Background slides

Hadronic event classification

hadronic events at Υ(5S)

Υ(5S) events

b continuum

u,d,s,c continuum

bb events

B_s events

B^0, B^+ events

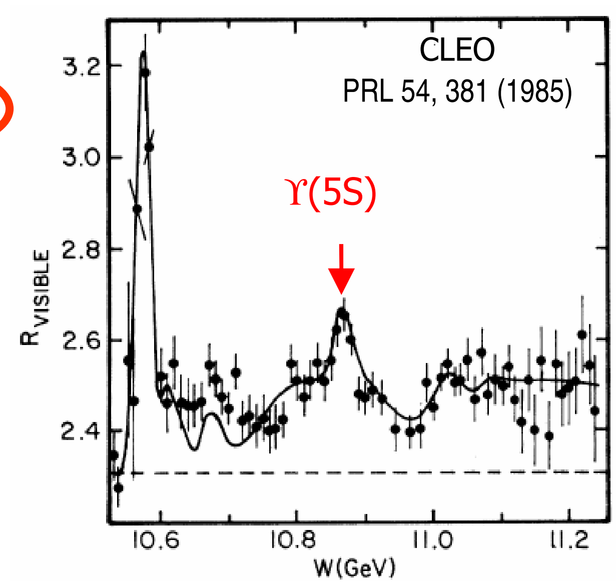
$B_s^* B_s^*$ channel

$B_s^* B_s$

$B_s B_s$

N(*bb* events) = N(hadr, 5S) - N(*udsc*, 5S)

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



Number of $b\bar{b}$ events, number of B_s events

Y(5S) : Lumi = 1.857 ± 0.001 (*stat*) fb^{-1} Cont (below 4S) : 3.670 ± 0.001 (*stat*) fb^{-1}

$N_{bb}(5S)$ = 561,000 ± 3,000 ± 29,000 events => 5% uncertainty (from luminosity ratio)

How to determine $f_s = N(B_s^{(*)} \bar{B}_s^{(*)}) / N(b\bar{b})$?

bb at Y(5S)

$B_s \bar{B}_s$ $B \bar{B}$

$$Bf\,(Y(5S) \to D_s\, X) / 2 = f_s \times Bf\,(B_s \to D_s\, X) + (1 - f_s) \times Bf\,(B \to D_s\, X)$$

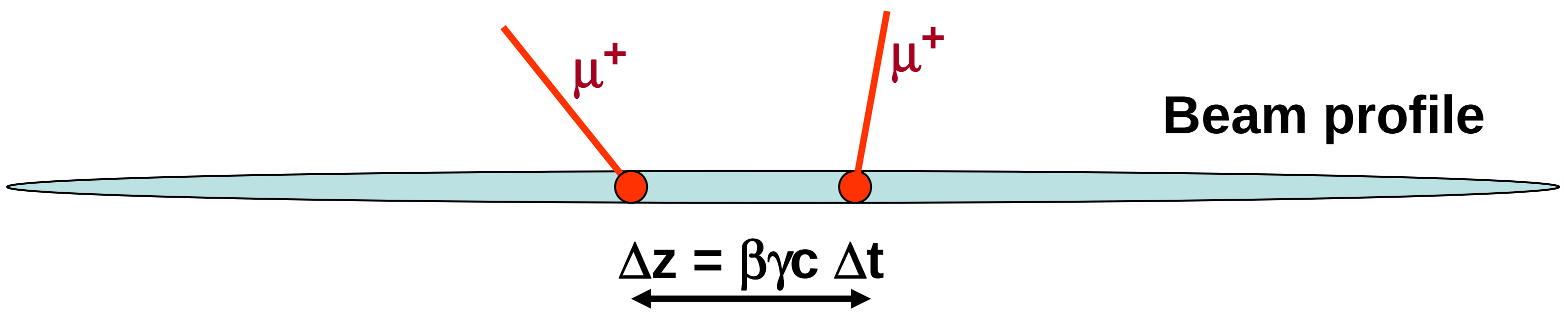
1. *Bf* (B_s -> D_s X) can be predicted theoretically, tree diagrams, large.
2. *Bf* (B -> D_s X) is well measured at the Y(4S).

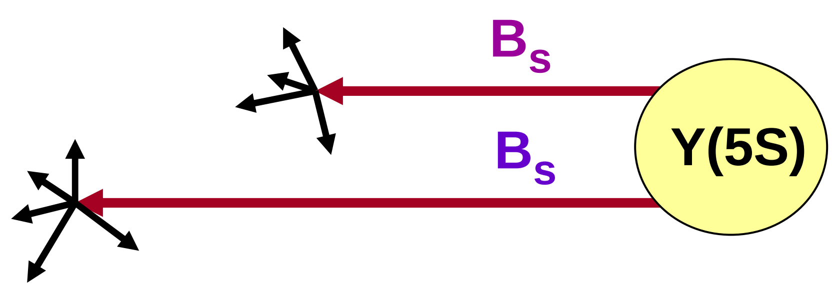
Feasibility of B_s lifetime measurement with same sign leptons

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.

$\Upsilon(5S)$: $B_s(\ell^+)\,B_s(\ell^+)$ / $B_s(\ell^+)\,B_s(\ell^-)$ = 100%

$\Upsilon(5S)$: $B(\ell^+)\,B(\ell^+)$ / $B(\ell^+)\,B(\ell^-)$ ~ 10%





Z_{beam} ~ 3 mm;
Δz ~ 0.1- 0.2 mm.

Comparison with Fermilab B_s studies.

- There are several topics, where Υ(5) running has advantages comparing with CDF and D0:
  1) Model independent branching fraction measurements.
  2) Measurement of decay modes with γ, π^0 and η 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 (*Bf* ($D_s^+ l^- \nu$) using "missing- mass" method).

- There are also disadvantages:
  1) We have to choose between running at Υ(4S) or Υ(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 Υ(5S) is a new tool to study B_s physics. First Belle results are very promising. Collider exists => relatively low price.