Results from Υ(5S) running at Belle

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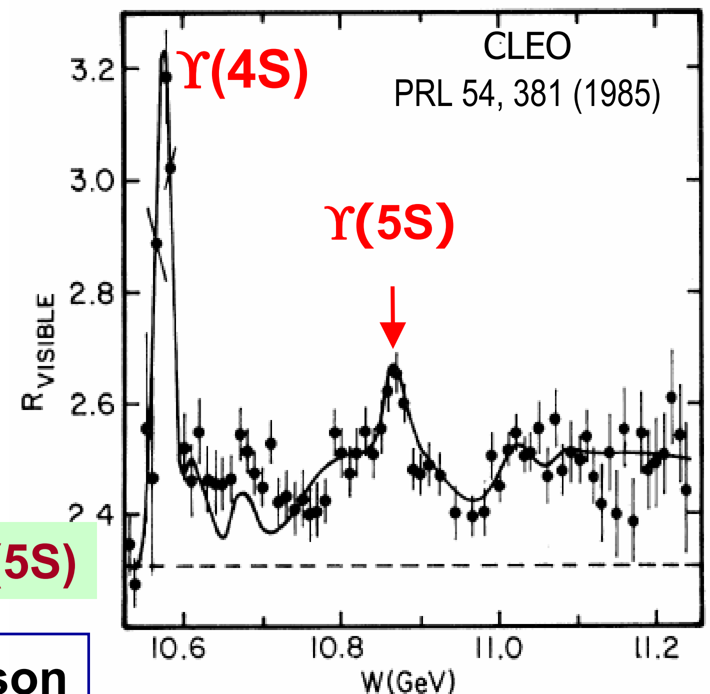
Outline

- Introduction.
- Inclusive production of J/Ψ, D^0 and D_s at the $\Upsilon(5S)$.
- Exclusive decays $B_s \to J/\Psi\ \phi\ (/\eta)$ and $B_s \to D_s^{+(*)}\ \pi^-\ (/\rho^-)$.
- Search for rare B_s decays.
- Future B_s physics at Super Belle.
- Conclusion.

First Υ(5S) results from Belle are reported in:
Inclusive decays: ***hep- ex/0608015, submitted in PRL,***
Exclusive decays: ***hep- ex/0610003, conf. paper.***

Introduction

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



1985: CESR (CLEO,CUSB) ~0.1 fb^{-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)

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

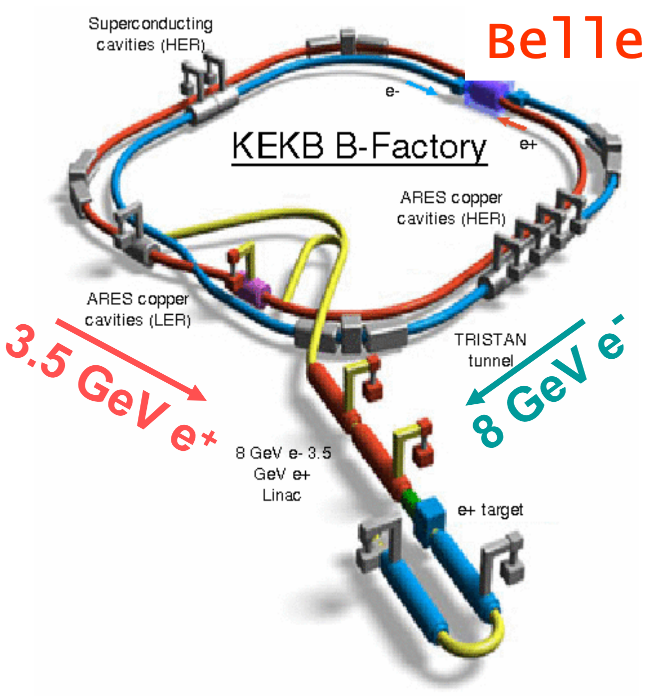
$e^+ e^-$ -> Υ(5S) -> $B\bar{B}$, $B^*\bar{B}$, $B^*\bar{B}^*$, $B\bar{B}\pi$, $B\bar{B}\pi\pi$, $B_s\bar{B}_s$, $B_s^*\bar{B}_s$, $B_s^*\bar{B}_s^*$

where B^* -> B γ and B_s^* -> B_s γ

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.

Y(5S) Engineering Run 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).

3 days of engineering run at Y(5S) : June 21 – June 23 , 2005.

Energy scan (30pb^{-1} at 5 points) : Y(5S) peak position E_{CM} = 10869 MeV was chosen.

Integrated luminosity of ~1.86 fb^{-1} was taken by Belle detector !!!

→ **Very smooth running**

Hadronic event classification

hadronic events at $\Upsilon(5S)$

$\Upsilon(5S)$ events

b continuum

u,d,s,c continuum

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

bb events

B_s events

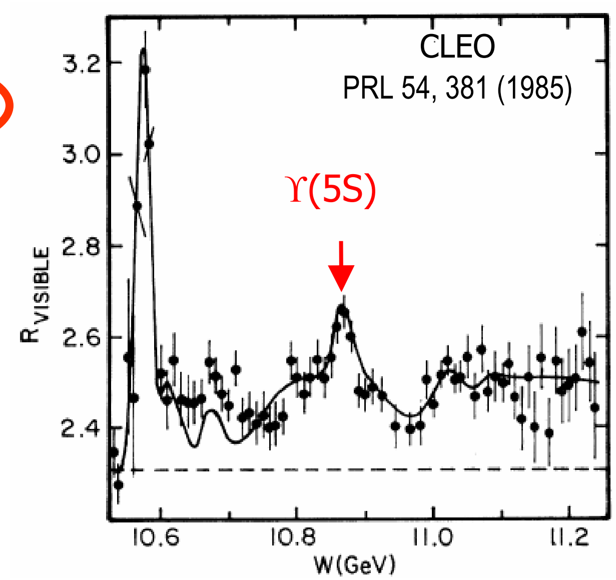
B^0, B^+ events

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

$B_s^* B_s^*$ channel

$B_s^* B_s$

$B_s B_s$



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

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).

This method was developed by CLEO.

Inclusive analysis : Y(5S) -> D_s X , D_s -> $\phi\ \pi$

Estimate : hep- ex/0508047 CLEO

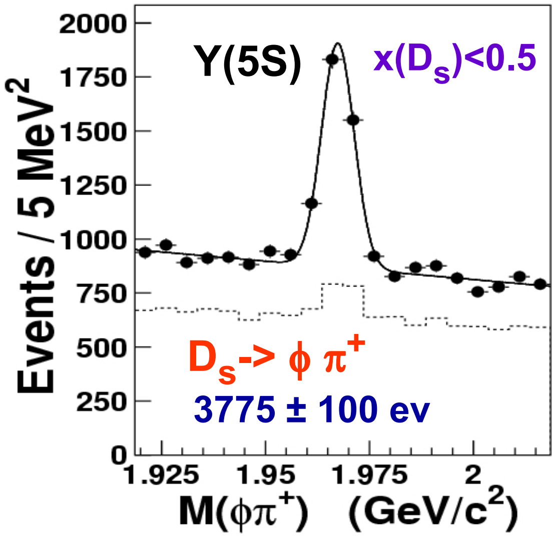
Bf (B_s -> D_s X) = (92 ± 11) %

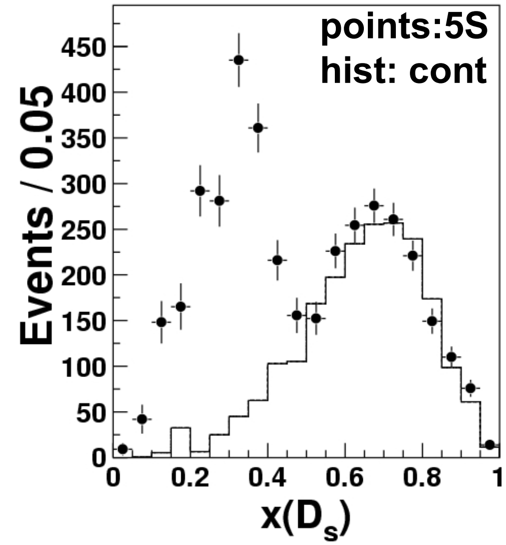
PDG 2006:

Bf (B -> D_s X) = (8.7 ± 1.2)%

Bf(D_s-> $\phi\ \pi^+$) = (4.4 ± 0.6)%

$x(D_s) = P(D_s) / P_{max}(D_s)$



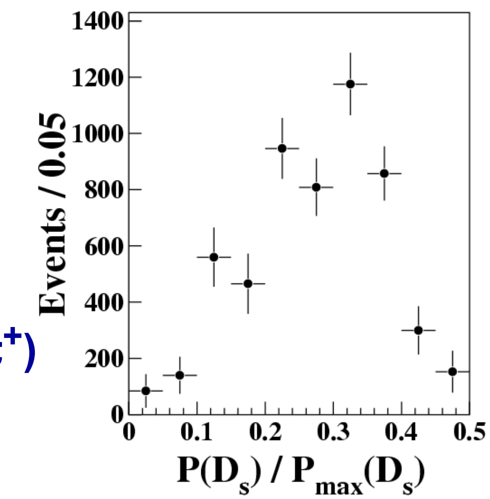


After continuum subtraction and efficiency correction:

Bf (Y(5S) -> D_s X) / 2 = (23.6 ± 1.2 ± 3.6) %

=> f_s = (17.9 ± 1.4 ± 4.1)%   Syst. err. dominates by Bf(D_s->$\phi\pi^+$)

CLEO (update) $f_s = (16.8 \pm 2.6\,^{+6.7}_{-3.4})$% from D_s analysis



Inclusive analysis : $\Upsilon(5S) \to D^0 X$, $D^0 \to K^- \pi^+$

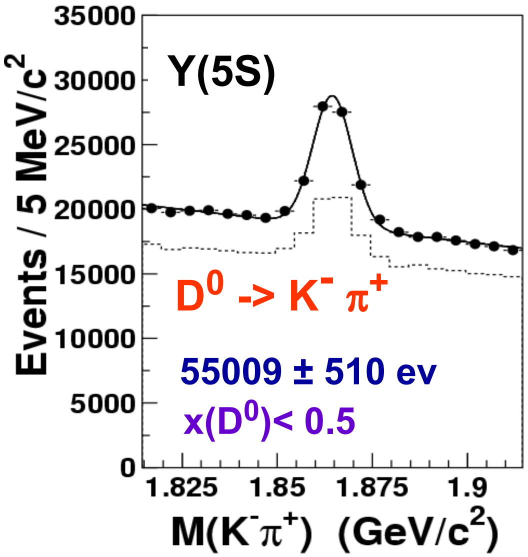
Estimate : hep- ex/0508047 CLEO

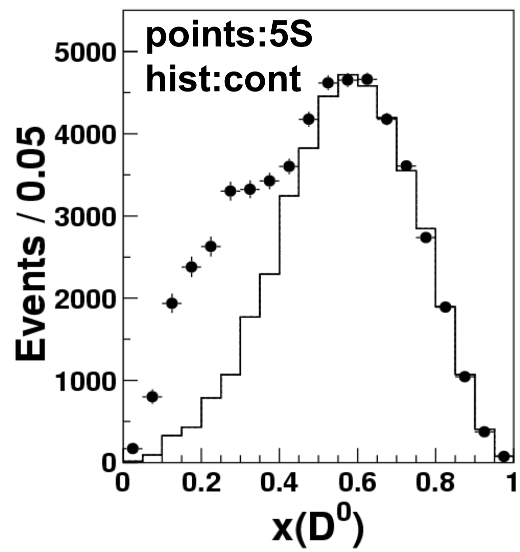
$Bf(B_s \to D^0 X) = (8 \pm 7)$ %

PDG 2006:

$Bf(B \to D^0 X) = (64.0 \pm 3.0)$ %

$Bf(D^0 \to K^- \pi^+) = (3.80 \pm 0.07)$ %





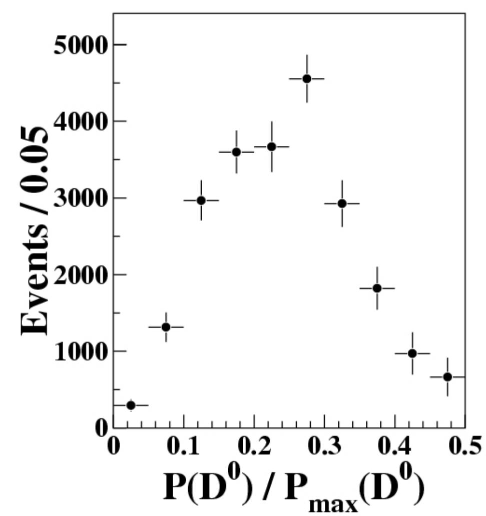
After continuum subtraction and efficiency correction:

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

=> $f_s = (18.1 \pm 3.6 \pm 7.5)$% Syst. error dominated by N(*bb*).

Combining with D_s result: $f_s = (18.0 \pm 1.3 \pm 3.2)$%

CLEO (combined D_s, ϕ and B analyses) : $f_s = (21 ^{+6}_{-3})$%



Inclusive analysis : Y(5S)-> J/Ψ X , J/Ψ -> $\mu^+\mu^-$

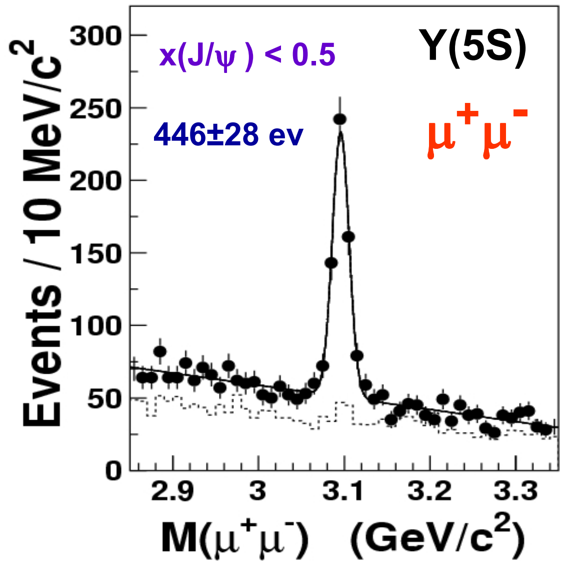
Theory :

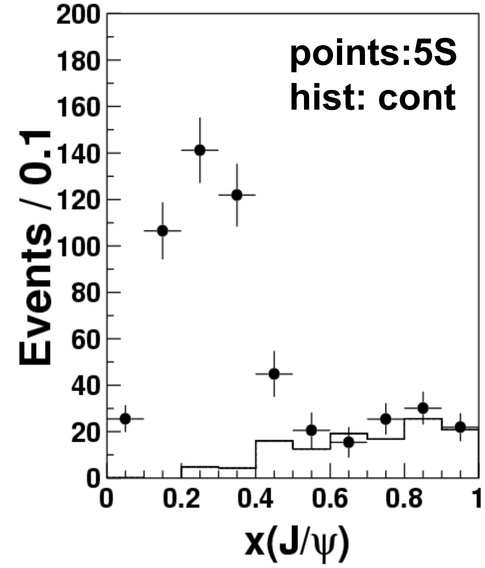
$$\frac{Bf(B_s \to J/\Psi\ X)}{Bf(B \to J/\Psi\ X)} = 1.00 \pm 0.10$$

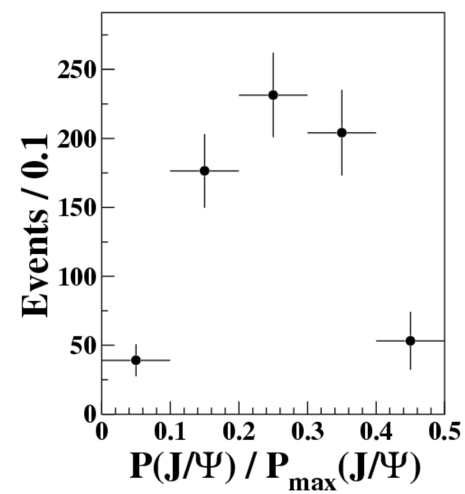
PDG:

Bf (B -> J/Ψ X) = (1.094 ± 0.032) %

Bf (J/Ψ -> $\mu^+ \mu^-$) = (5.88 ± 0.10) %





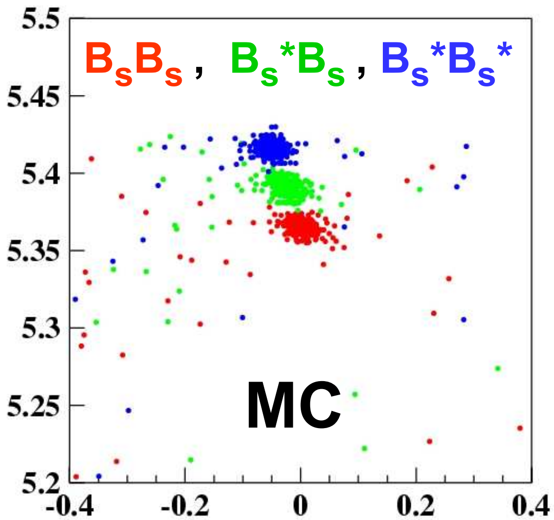


After continuum subtraction and efficiency correction:

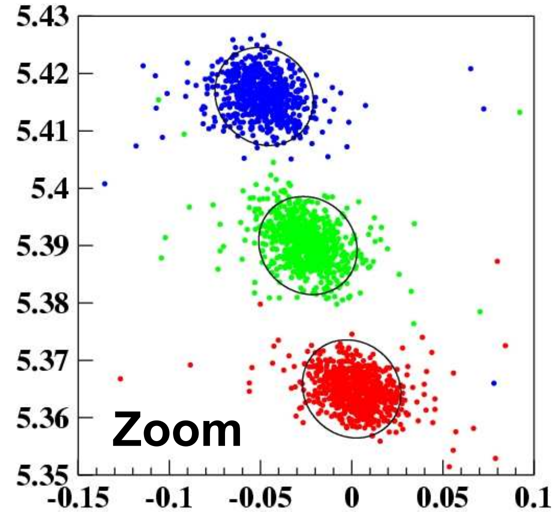
Bf (Y(5S) -> J/Ψ X) / 2 = (1.030 ± 0.080 ± 0.067) %

Good agreement with expectations => *bb* number is correct

Signature of fully reconstructed exclusive B_s decays



M_{bc} vs ΔE



M_{bc} vs ΔE

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

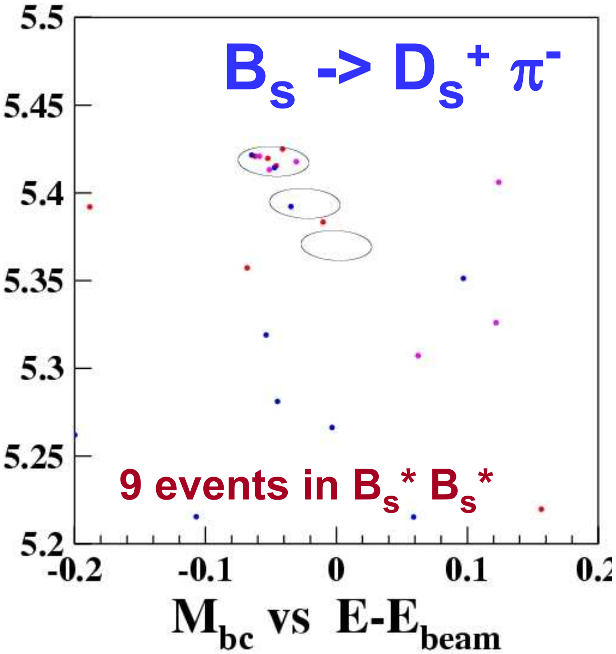
Reconstruction: B_s energy and momentum, photon from $B_s{}^*$ is not reconstructed.

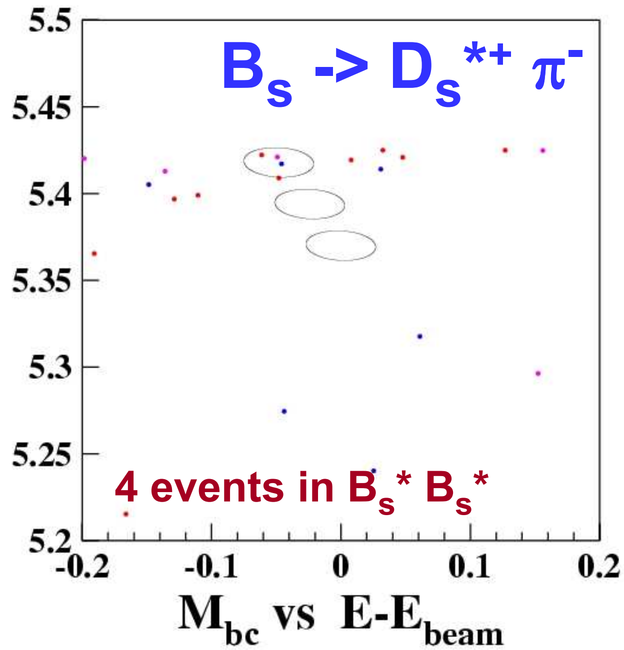
Two variables calculated: $M_{bc} = \sqrt{E^{*2}_{beam} - P^{*2}_{B}}$, $\Delta E = E^*_B - E^*_{beam}$

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

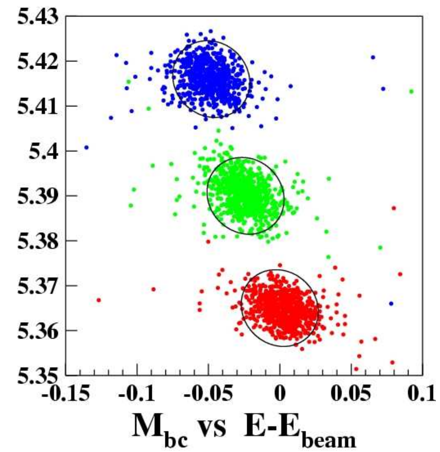
The signals for B_sB_s, $B_s{}^*B_s$ and $B_s{}^*\ B_s{}^*$ can be separated well.

Exclusive $B_s \to D_s^{(*)+} \pi^-$ decays

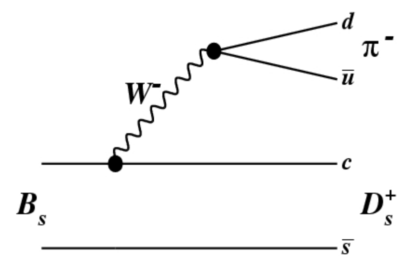




B_sB_s , $B_s^*B_s$, $B_s^*B_s^*$



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



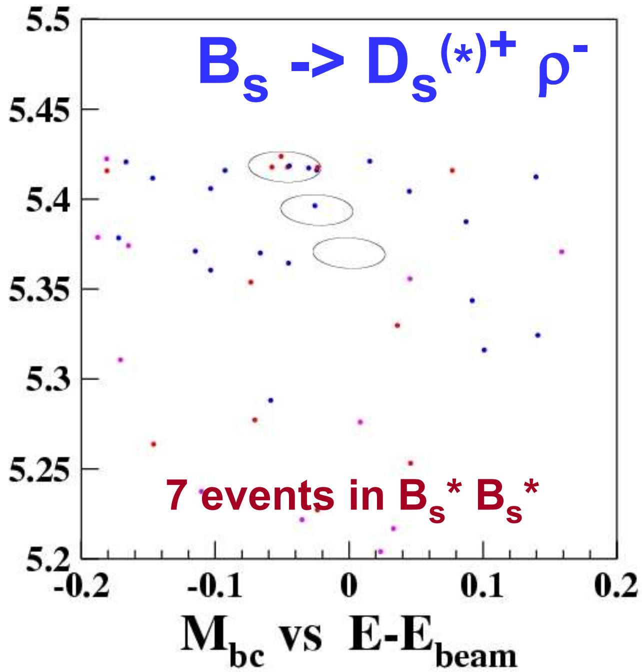
Clear signal at $B_s^* B_s^*$ channel ; no signals in $B_s^* B_s$ and B_sB_s.

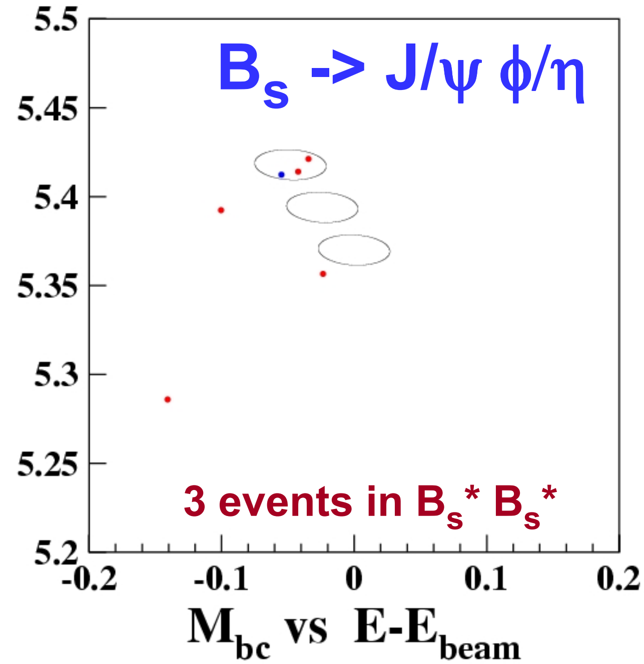
Taking # of B_s's from the inclusive analysis:

$Bf(B_s \to D_s^+ \pi^-) = (0.68 \pm 0.22 \pm 0.16)\%$

CDF, recalculated using PDG 2006: $Bf(B_s \to D_s^+ \pi^-) = (0.38 \pm 0.05 \pm 0.14)\%$

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





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

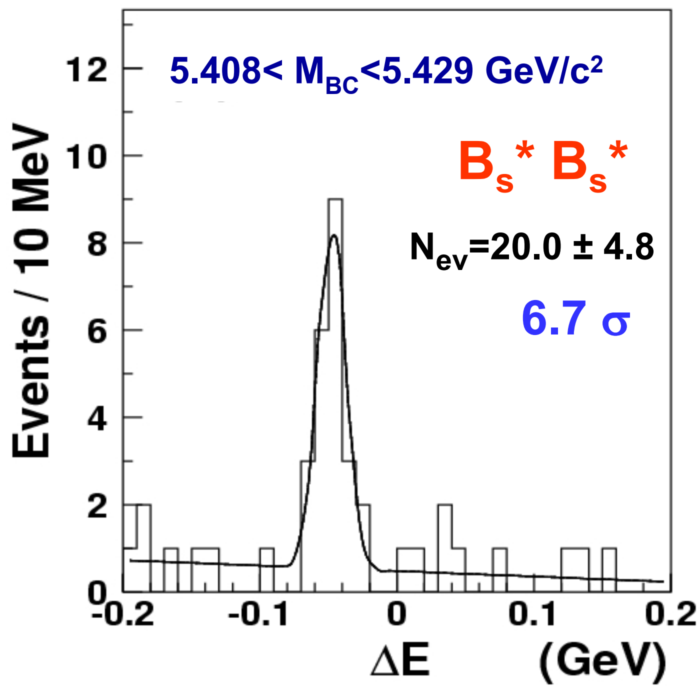
$B_s \to J/\psi\,\phi$, $B_s \to J/\psi\,\eta(\gamma\gamma)$

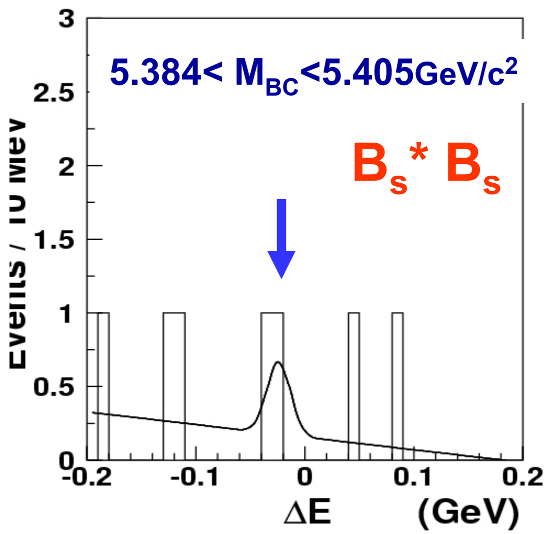
Clear signal at $B_s^* B_s^*$ channel ; signals in $B_s^* B_s$ and $B_s B_s$ channels are not seen.

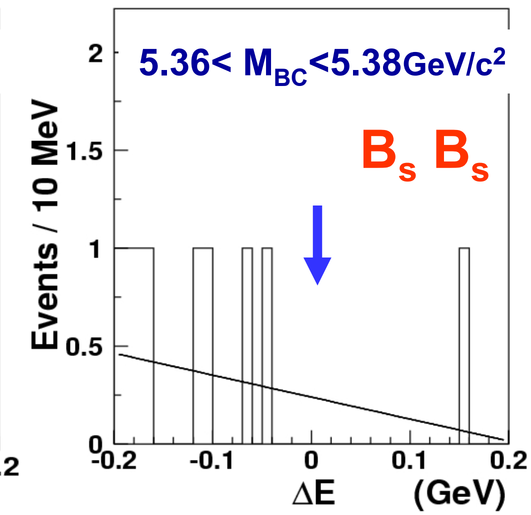
$B_s^* B_s^*$ dominance was also observed by CLEO.

We can combine all shown channels to obtain quantitative $B_s^{(*)}$ parameters.

ΔE distributions, sum of all B_s decay modes







N_{ev}= 1.3 ± 2.0 ev. => small signal

Decay $\Upsilon(5S) \to B_s^* B_s^*$, with $B_s^* \to B_s \gamma$.

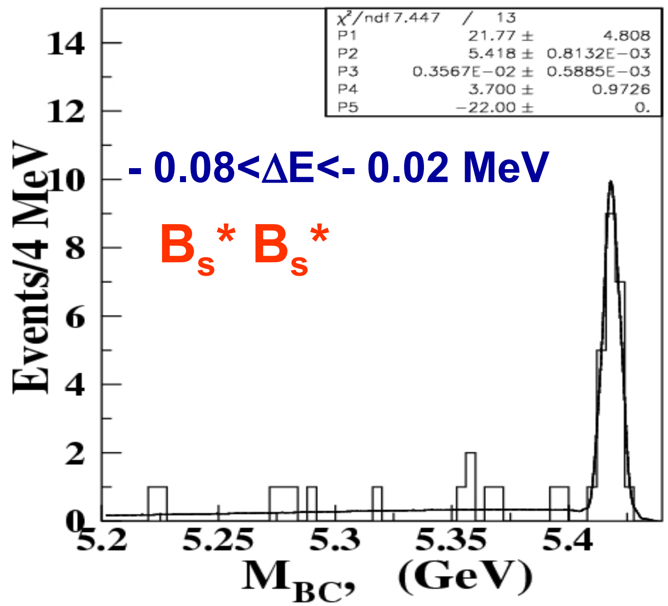
$\Delta E^{peak} = E_{cm}(accel.)/2 - E_{cm}(real)/2 - E(\gamma)$

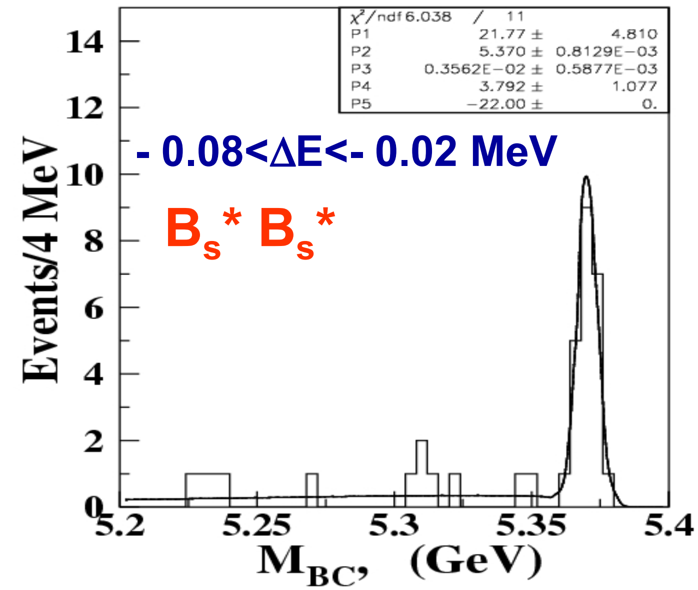
$\Delta E^{peak} = -47.8 \pm 2.6$ MeV

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

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

M_{BC} distribution, sum of all B_s decay modes





$$M_{bc} = \sqrt{E^{*2}_{B} - P^{*2}_{B}} = M(B_s^*)$$

$$M_{bc} = \sqrt{(E^*_B + \Delta E^{peak})^2 - P^{*2}_{B}} = M(B_s)$$

$M(B_s^*) = 5418 \pm 1 \pm 3$ (acc. err) MeV/c^2

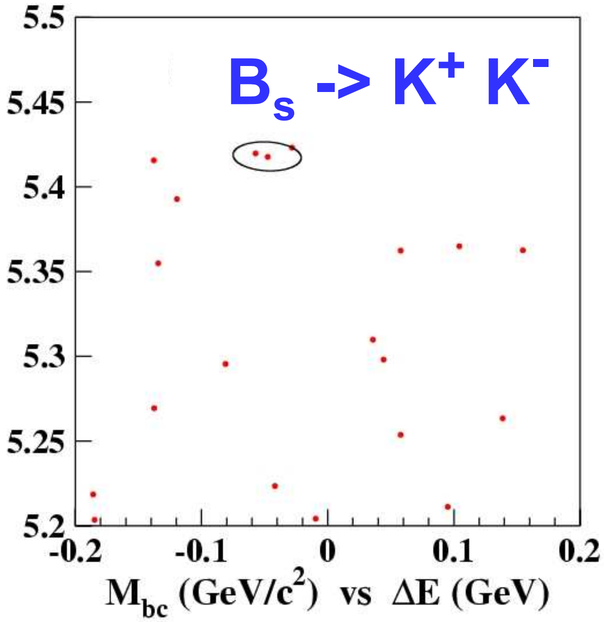
$M(B_s) = 5370 \pm 1 \pm 3\ MeV/c^2$

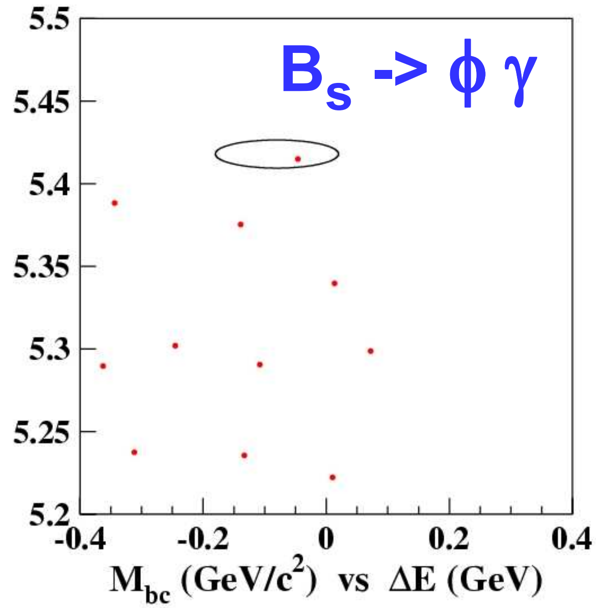
PDG: $M(B_s) = 5369.6 \pm 2.4\ MeV/c^2$

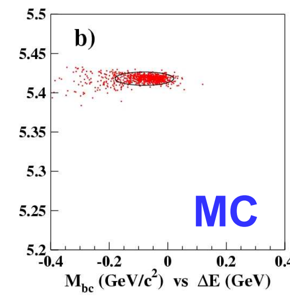
CDF: $M(B_s) = 5366.0 \pm 0.8\ MeV/c^2$

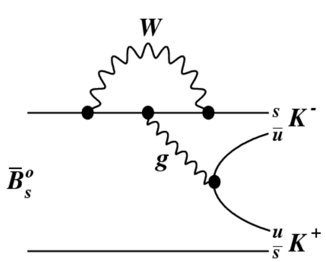
Stat. and syst. accuracy better than 1 MeV/c^2 is expected with 23 fb^{-1} .

Exclusive B_s -> $K^+ K^-$ and B_s -> $\phi\gamma$ decays



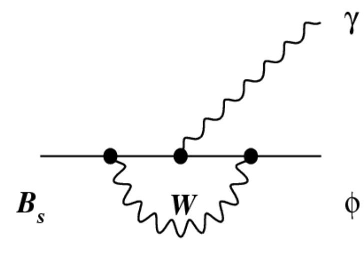






Tight cuts are used to suppress bkgr.

Signal: 2 events
Bgr. ~ 0.14 ev.
Est. sign.~ 0.7 ev.



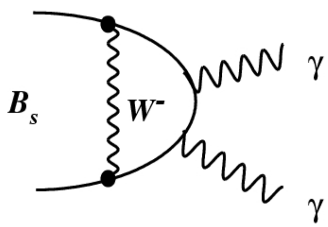
Signal: 1 event
Bgr. ~ 0.15 ev.
Est. sign.~ 0.4 ev.

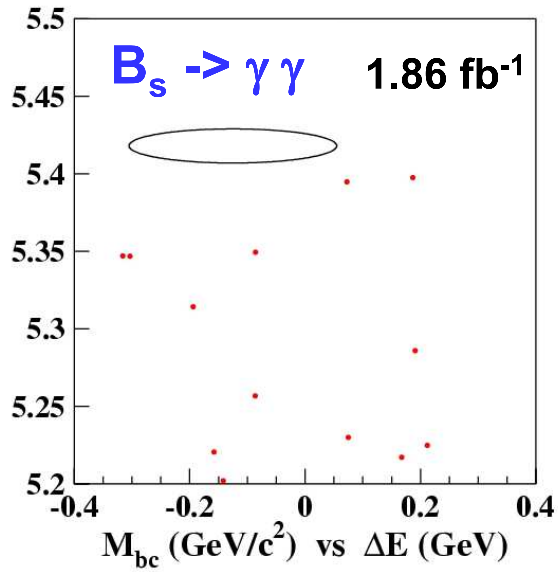
Partner of B -> K+ π- penguin decay

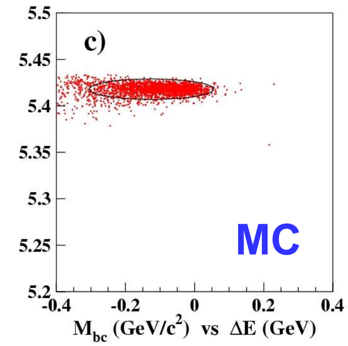
Partner of B -> K* γ penguin decay

=> Small signals are expected with 23 fb^{-1}.

Exclusive $B_s \to \gamma\gamma$ decay







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

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

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

Expected UL with 23 fb^{-1} : *Bf* ($B_s \to \gamma\gamma$) < $4. \times 10^{-6}$.

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

BSM can increase *Bf* up to one-two orders of magnitude (*hep-ph/0302177* – four-generation model ; *hep-ph/0404152* – R parity violation SUSY).

Exclusive $B_s \to D_s^{(*)+} D_s^{(*)-}$ decays

$Bf(B_s \to D_s^+ D_s^-) < 6.7\%$ at 90% *CL*

$Bf(B_s \to D_s^{*+} D_s^-) < 12.1\%$ at 90% *CL*

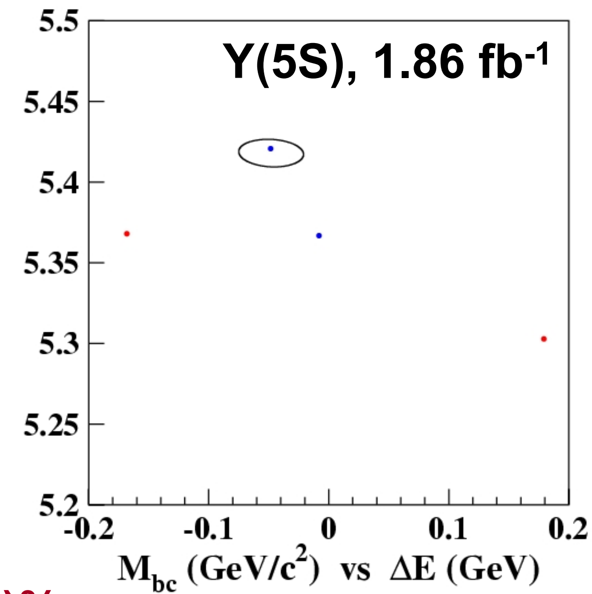
$Bf(B_s \to D_s^{*+} D_s^{*-}) < 25.7\%$ at 90% *CL*

$B_s \to D_s^+ D_s^-$

$B_s \to D_s^{*+} D_s^-$

$B_s \to D_s^+ D_s^{*-}$

$B_s \to D_s^{*+} D_s^{*-}$



Expected (1.86 fb^{-1}): ~ 0.5 events in each mode

Expected with 23 fb^{-1}: $Bf(B_s \to D_s^{(*)+} D_s^{(*)-}) = (7 \pm 2)\%$

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

$B_s \to D_s^{(*)+} D_s^{(*)-}$ decays are *CP*- even states with large *BF's*, leading to large $\Delta\Gamma_s/\Gamma_s$:

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

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

(*I. Dunietz et al , PRD63,114015 (2001)*)

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 23 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.

$$A_{SL} = \frac{N(b\bar{b} \to \ell^+ \ell^+ X) - N(b\bar{b} \to \ell^- \ell^- X)}{N(b\bar{b} \to \ell^+ \ell^+ X) + N(b\bar{b} \to \ell^- \ell^- X)}$$

=> lepton charge asymmetry

$$A^s_{SL} = (\Delta\Gamma_s / \Delta m_s) \tan(\phi_s)$$

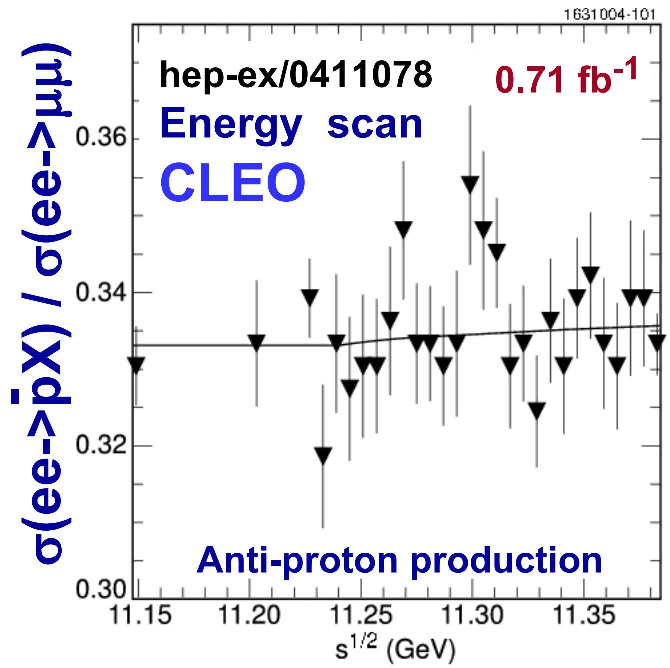
BSM can increase A_{sl} (*Z.Xing, hep-ph/9705358*)

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 ± 9) MeV/c^2

$M(\Lambda_b)$x2 = (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- → $B_s\overline{B}_s$, $\Lambda_b\overline{\Lambda}_b$, $B_c\overline{B}_c$, $\Xi_b\overline{\Xi}_b$ ... ?

Conclusions

- Inclusive production branching fractions of J/Ψ, D^0 and D_s mesons are measured at Y(5S). Ratio of B_s meson production over all *bb*-events is determined: $f_s = (18.0 \pm 1.3 \pm 3.2)\%$ (in good agreement with CLEO).

- Significant exclusive B_s signals are observed in $Y(5S) \to B_s^* B_s^*$ channel. Combining all studied decay modes, mass of B_s^* meson was measured: $M(B_s^*) = 5418 \pm 1 \pm 3$(acc.calib) MeV/$c^2$, and mass of B_s was measured: $M(B_s) = 5370 \pm 1 \pm 3$ MeV/c^2. Obtained B_s mass is in agreement with recent CDF measurement $M(B_s) = 5366.0 \pm 0.8$ MeV/c^2.

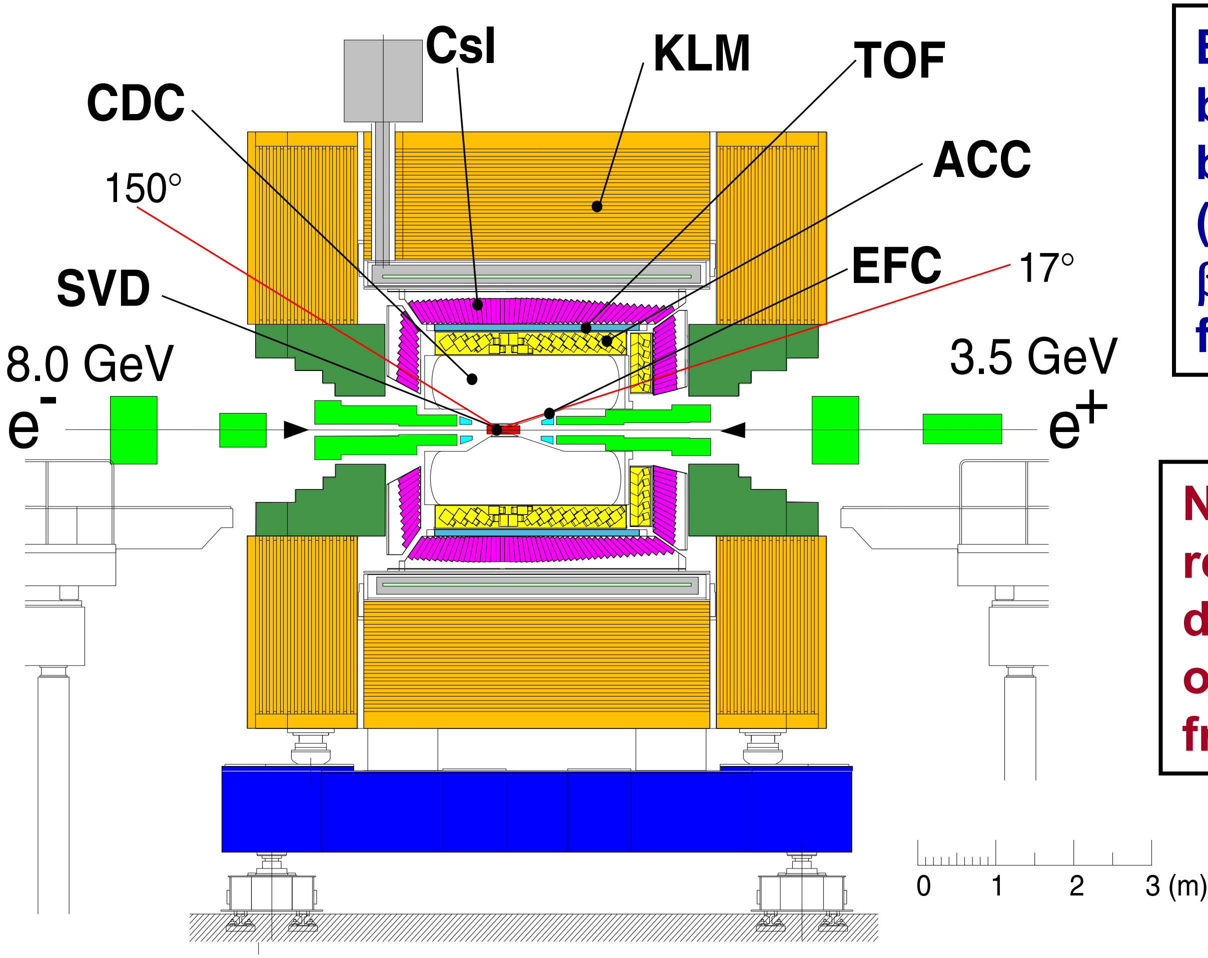
- Rare B_s decays are searched for at Y(5S) for the first time.

- B_s studies at e+ e- colliders running at Y(5S) have many advantages comparing with hadron-hadron colliders: high efficiency of photon reconstruction; no problems with trigger efficiency; good K/π PID. Engineering runs demonstrated, that background level is not large for studied decays.

- Many significant B_s signals are expected with 23 fb^{-1}. Important SU(3) tests can be performed. Rare B_s decays should be observed.

Background slides

Belle Detector



Electron and positron beam energies have to be 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).

Inclusive analyses : selections

Particle ID:

π/K : standard ID(K/π)

$J/\Psi \to \mu^+ \mu^-$:

Standard Muon ID

$D^0 \to K^+ \pi^-$: no cuts

$D_s \to \phi\pi$:

$| M(\phi) - M(K+K-) | < 12$ MeV/c^2 ~3σ

$|\cos(\theta_{heli})\ (D_s)| > 0.25$ for $\phi\pi+$

No continuum suppression cuts.

Exclusive analyses: selections

Particle ID:

K/π: standard ID(K/π) ; standard lepton ID

Masses:

$\pi^0 \to \gamma\gamma$ 3σ

$K_S \to \pi^+ \pi^-$ 3σ

$K^{*0} \to K^+ \pi^-$

$\eta \to \gamma\gamma$ 2.5σ

$\rho^+ \to \pi^+ \pi^0$, $P(\gamma) > 150$ MeV/c

$\phi \to K^+K^-$ 3σ

$-30 < M(\mu^+\mu^-) - M(J/\psi) < 30$ MeV/c^2 3σ

$-100 < M(e^+e^-) - M(J/\psi) < 30$ MeV/c^2

$D_s^+ \to \phi\pi^+$, $K^{*0} K^+$, $K_s K^+$ 3σ

$D_s^{*+} \to D_s^+ \gamma$: $M(D_s\gamma) - M(D^*_s)$, 2σ , $P(\gamma) > 50$ MeV/c

Continuum suppression:

Angle between B_s thrusts: $|\cos\theta| < 0.8$ for $D_s^{(*)+} \pi^-$; $|\cos\theta| < 0.9$ for J/Ψ ; $|\cos\theta| < 0.7$ for $D_s^{(*)+} \rho^-$; $|\cos\theta| < 0.6$ for $K^{*0} K^+$ modes ; *Fox2*<0.3 for $D_s^{(*)+} \pi^- / \rho^-$; *Fox2*<0.4 for J/ψ modes