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Results and prospects for Y(5S) running at *B*-factories

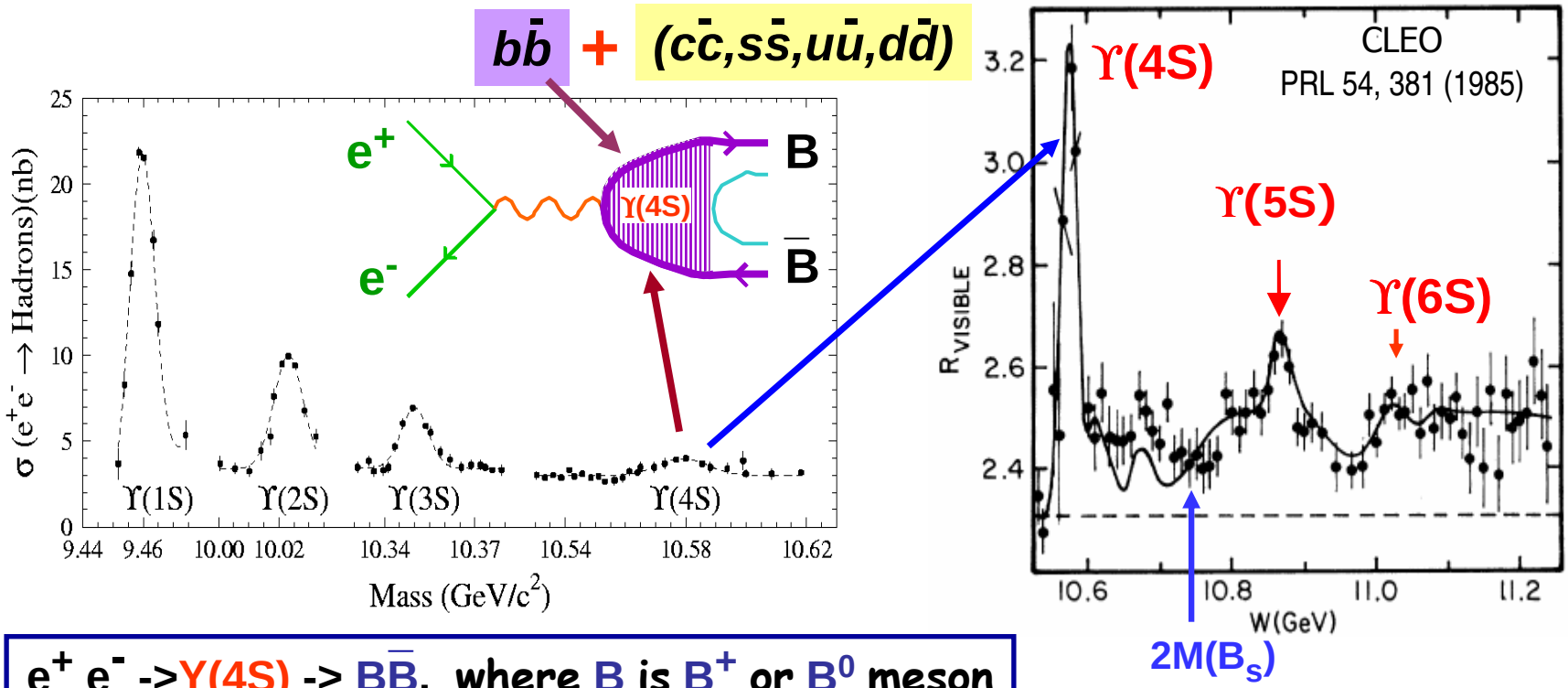
19th Hadron Collider Physics Symposium

May 27-31, 2008, Galena, Illinois.

Outline

- Introduction.
- First Belle results at Y(5S) with 1.86fb^{-1}.
- Recent Belle measurements at Y(5S) with 23.6fb^{-1}.
- Prospects of B_s meson (and other) studies at Y(5S).
- Conclusion.

$e^+ e^-$ hadronic cross section



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

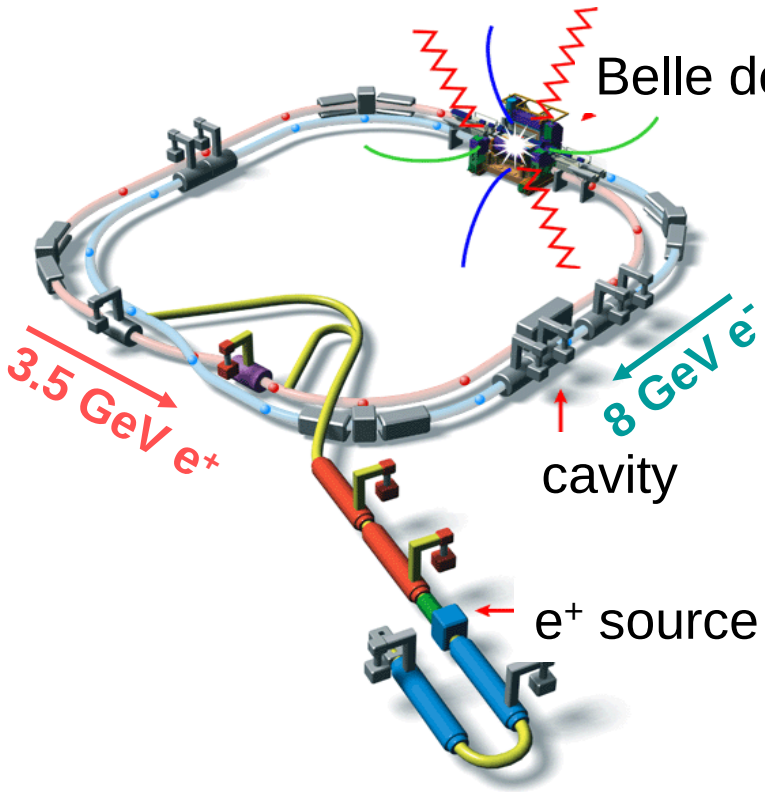
$e^+ e^-$ -> Y(5S) -> $B\bar{B}$, $B^*\bar{B}$, $B^*\bar{B}^*$, $B\bar{B}\pi$, $B\bar{B}\pi\pi$, $B_s\bar{B}_s$, $B_s^*\bar{B}_s$, $B_s^*\bar{B}_s^*$

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

M(Y(5S)) = 10865 ± 8 MeV/c^2 (PDG)

Γ(Y(5S)) = 110 ± 13 MeV/c^2 (PDG)

Belle data taking at Y(5S)



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).

$E(e^+)$: 3.500 GeV -> 3.595 GeV,
$E(e^-)$: 7.996 GeV -> 8.211 GeV.

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

World 5S data:

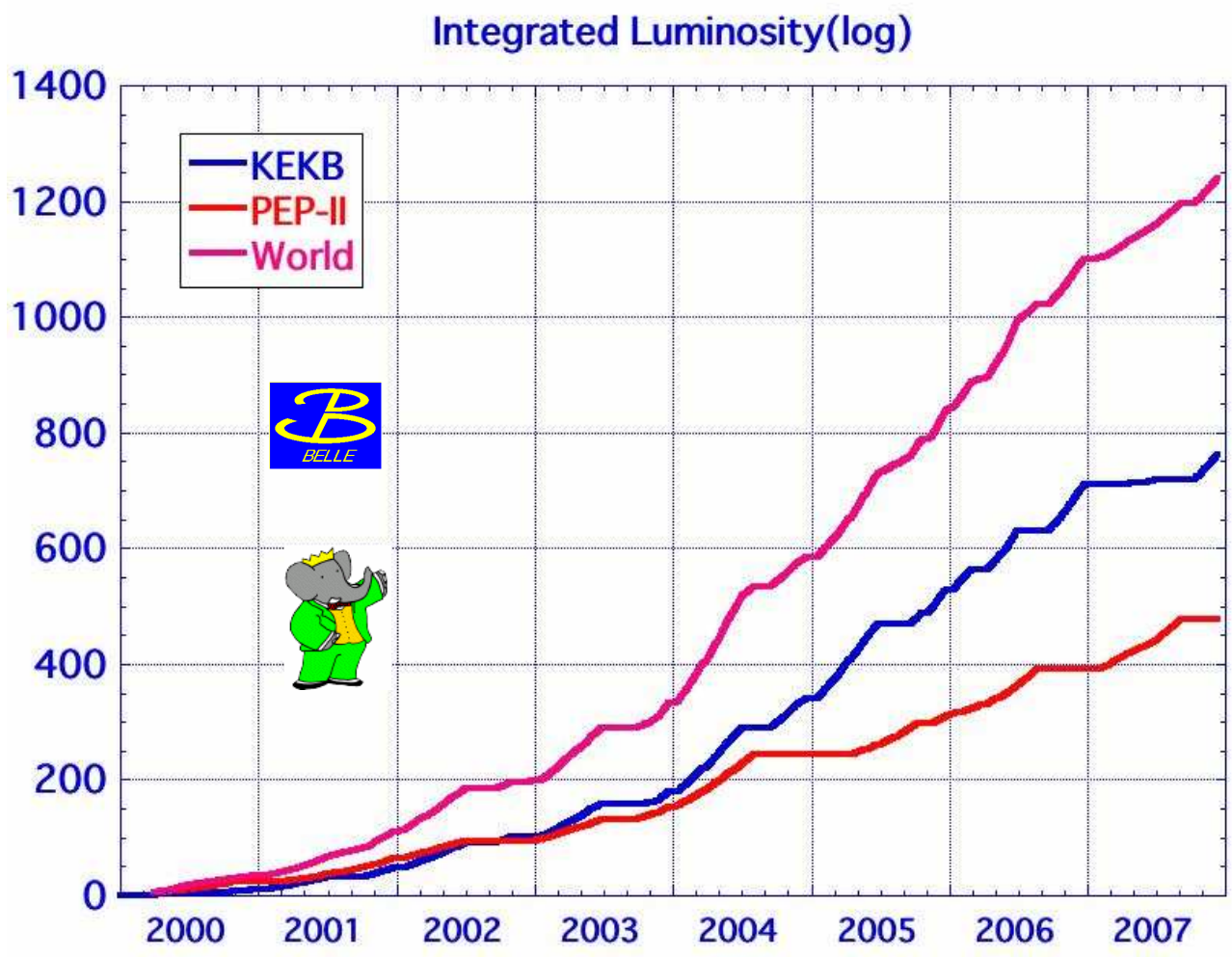
1985: CESR (CLEO,CUSB) ~ 0.1 fb^{-1}
2003: CESR (CLEO III) ~ 0.42 fb^{-1}

2005: KEKB, Belle ~1.86 fb^{-1}

2006: KEKB, Belle ~21.7 fb^{-1}

Belle: very smooth running at 5S, same lumi per day at 4S and 5S

Integrated luminosity



Belle (21 May 08)
All: ~831 fb^{-1} ,
Cont: ~68 fb^{-1} ,
Y(5S): ~24 fb^{-1}

Belle takes ~1fb^{-1}/day

Belle + BaBar > 1 ab^{-1}

Belle upgrade is planned for 2009-2012 to increase lumi ~20 times

Retrospective

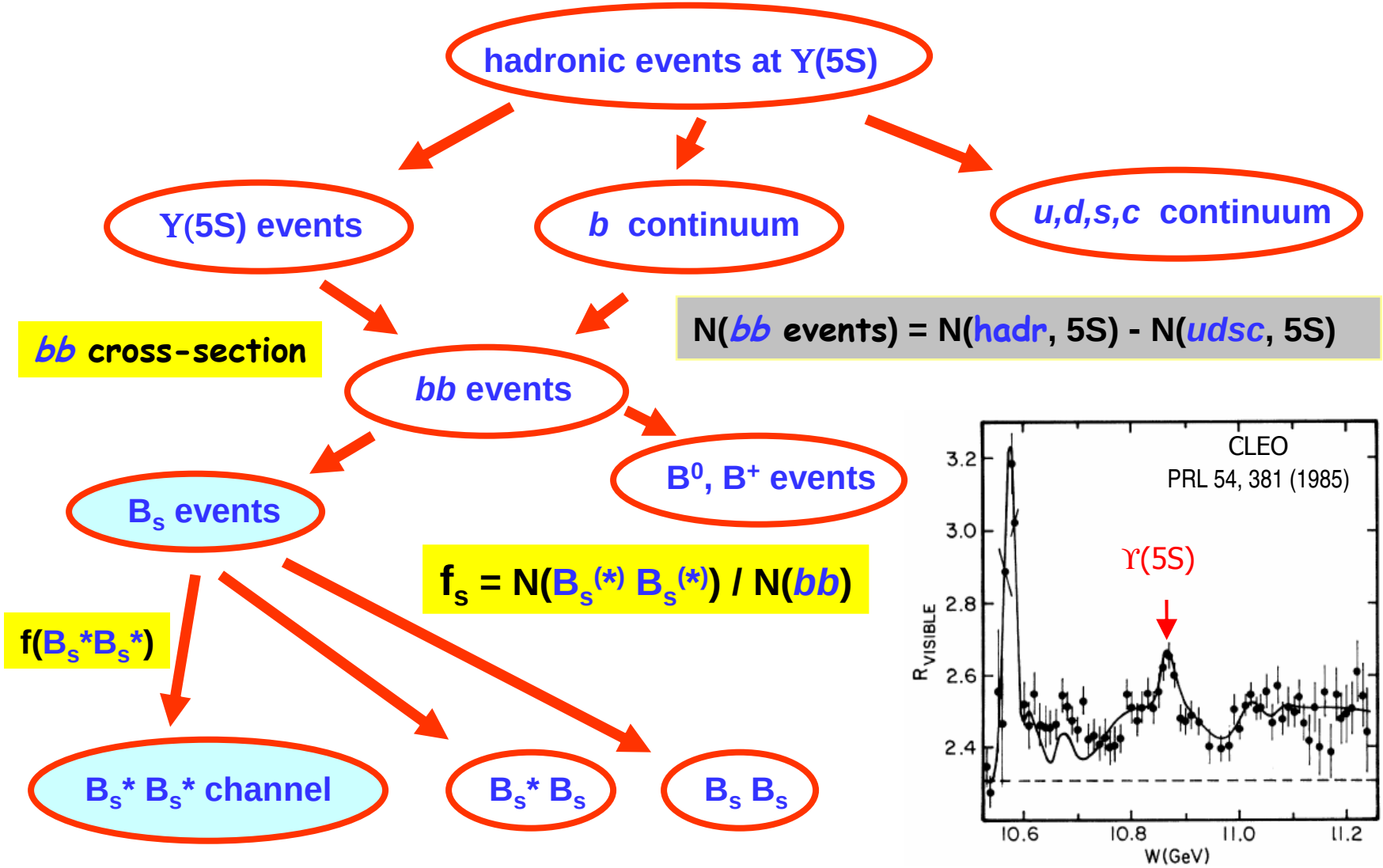
CLEO reported first evidence of B_s production at Y(5S) with 0.42 fb^{-1} in 2005 (the data were taken in summer 2003, but it was announced only in 2004). CLEO also developed approaches to B_s studies at Y(5S).

I found in my mailbox the first mail about Y(5S) to Belle (11 July 2003, NTU Taipei, 122^{0}F/50^{0}C daytime, 104^{0}F at night):

Dear Colleagues,
sorry for very naive question to experts of KEKB and Belle upgrades.
Is there any technical opportunity to move beams to Upsilon(5S) or Upsilon(6S) to study B_s decays?
Best regards, Alexey Drutskoy.

Hi Alexey,
The maximum root(s) of KEKB is about 5% higher than the Y(4s) mass, i.e., it can go to 5s with the same asymmetry, but probably 6s is too far. Since this limitation comes from the max energy of the injector, we can modify it to go to 6s, if physics there is very exciting.
Do you have any idea of physics there?
Regards, Masa Yamauchi.

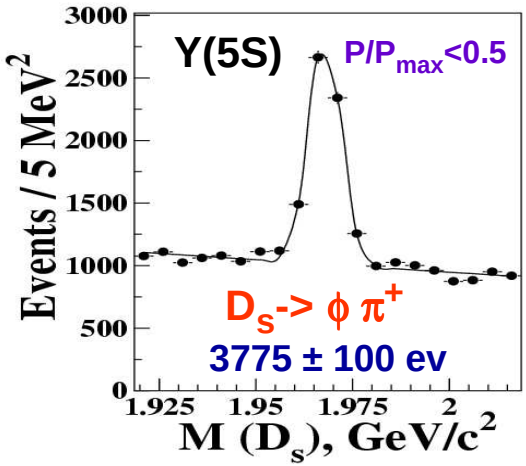
Hadronic event classification at Υ(5S)

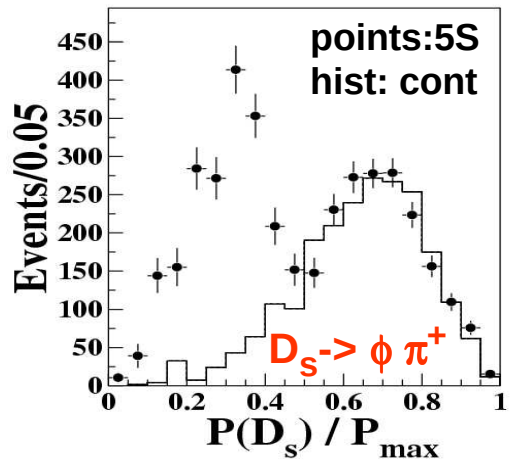


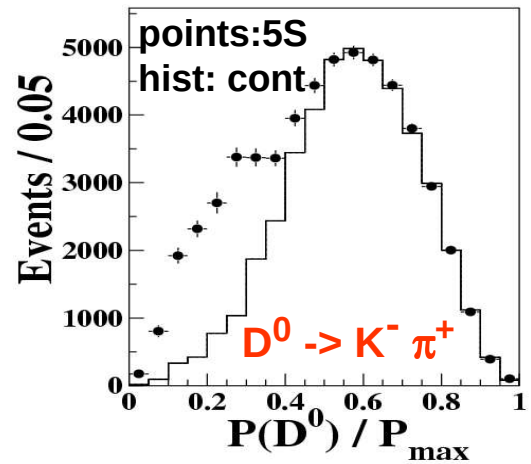
Belle inclusive analysis with $\mathcal{L}$=1.86fb^{-1}

A. Drutskoy et al. (Belle Coll.) PRL 98, 052001 (2007).

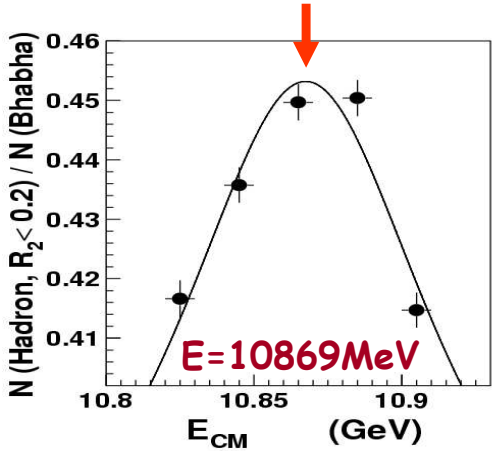
$\mathcal{L}$ = 1.86 fb^{-1}







Energy scan



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

Bf (Y(5S) -> D^0 X) / 2 = (53.8 ± 2.0 ± 3.4) %

Comparing with D$_s$ and D^0 production at Y(4S):

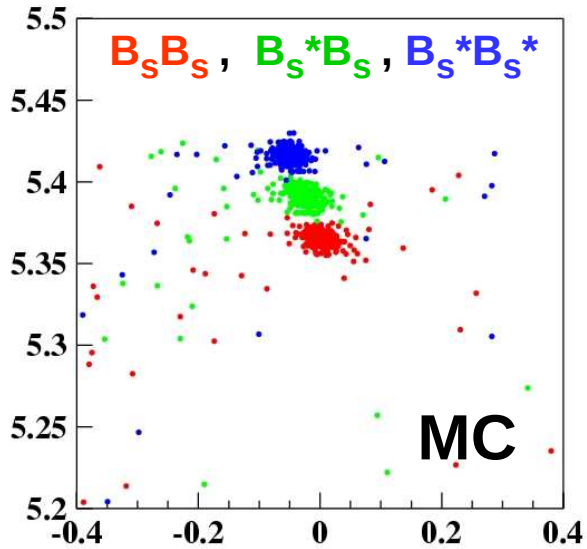
=> f_s = N($B_s^{(*)}$ $B_s^{(*)}$) / N(*bb*) = (18.0 ± 1.3 ± 3.2)%

Continuum subtraction using data below Y(4S):

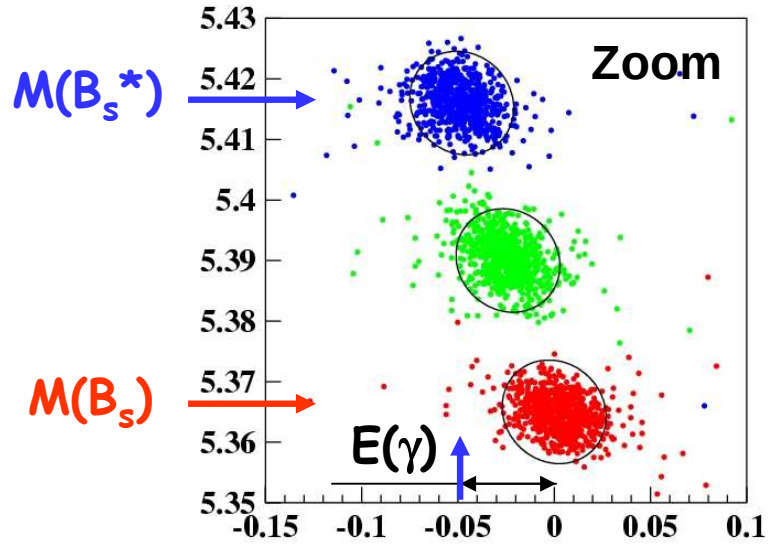
σ(Y(5S)->*bb*) = (0.302 ± 0.015) nb at E=10869MeV

Signature of fully reconstructed exclusive B_s decays

MC simulation: $B_s \to D_s^- \pi^+$ with $D_s^- \to \phi \pi^-$.



M_{bc} vs ΔE



M_{bc} vs ΔE

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

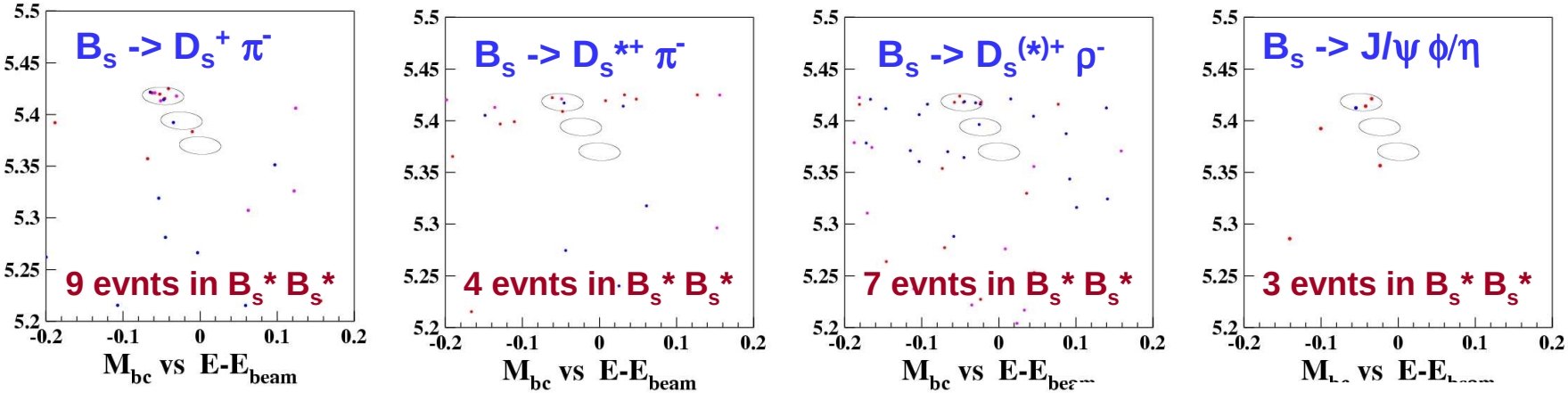
B_s energy (E^*_B) and momentum (P^*_B) are reconstructed, but γ from B_s^* is not rec.

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

Signals in B_sB_s, $B_s^* B_s$ and $B_s^* B_s^*$ channels can be well separated.

Belle exclusive analysis with $\mathcal{L}$=1.86fb^{-1}

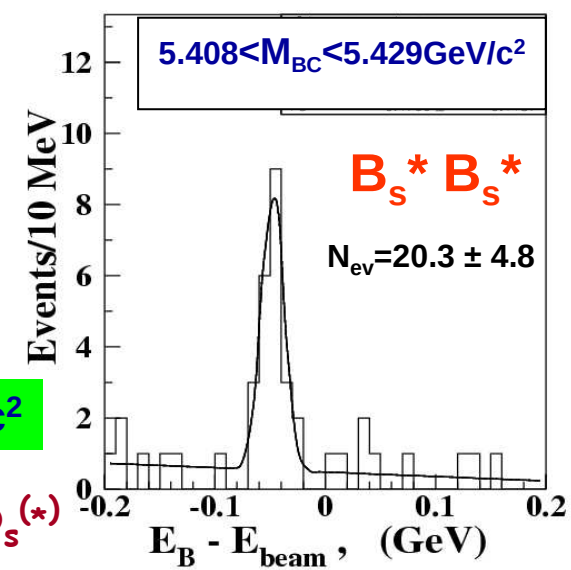
A. Drutskoy et al. (Belle Coll.), PRD 76, 012002 (2007).



Comparing signals within three signal ellipses:

$N(B_s^*B_s^*) / N(B_s^{(*)}B_s^{(*)}) = (93 \pm {}^{7}_{9} \pm 1)\%$

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



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

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

We also set *UL* for B_s decays to $\phi\gamma$, $\gamma\gamma$, K^+K^- and $D_s^{(*)}D_s^{(*)}$

Number of B_s in dataset

Belle $\mathcal{L}$=1.86 fb^{-1} +CLEO 0.42fb^{-1}

hadronic events at Y(5S)

bb continuum included

$\sigma(bb, E=10869) = (0.302 \pm 0.014)$nb

Syst err ~5%, const(4%)

bb events

$f_s = (19.5 \pm {}^{3.0}_{2.3})\%$

B_s events

Syst err ~12-15%, ~4% + A $\mathcal{L}^{-1/2}$

$f(B_s^* B_s^*) = (93 \pm {}^{7}_{9} \pm 1)\%$

B_s^* B_s^* channel

Syst err ~7-10%, ~$\mathcal{L}^{-1/2}$

~10^5 B_s mesons per 1 fb^{-1} at Y(5S)

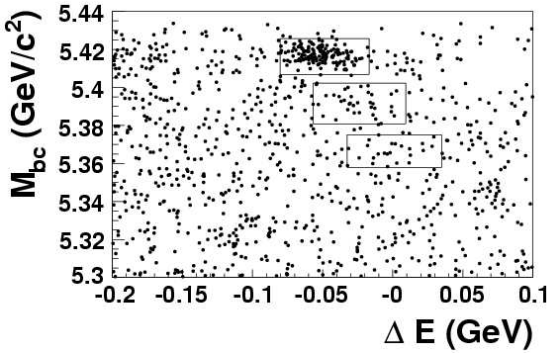
With 23.6fb^{-1} we plan to reduce syst. uncertainties to 4-6% each (8% combined).

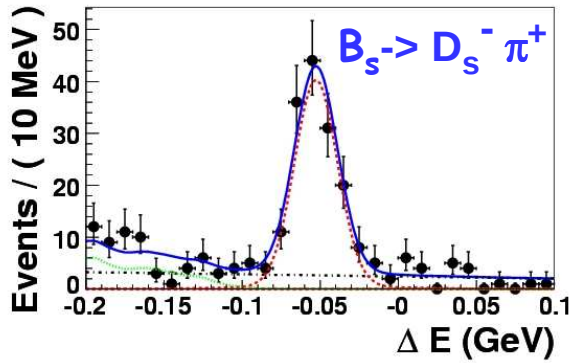
Unreducible syst. uncertainty on $N(B_s)$ in hadron-hardon colliders is ~10%.

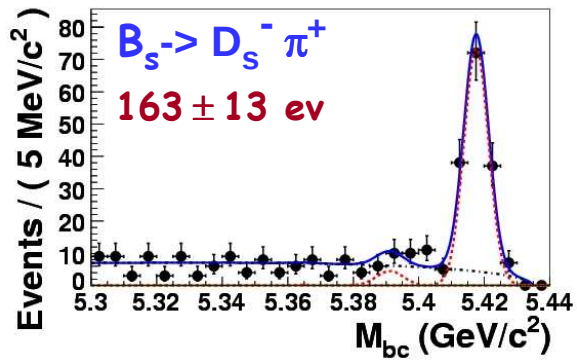
With 100fb^{-1} at Belle: 5% stat & 5% syst err. for $Bf(B_s \to D_s^- \pi^+)$ =>normalization?

Measurement of $B_s \to D_s^+\pi^-$ and $B_s \to D_s^+ K^-$ decays

New Belle measurement with 23.6 fb^{-1}, preliminary







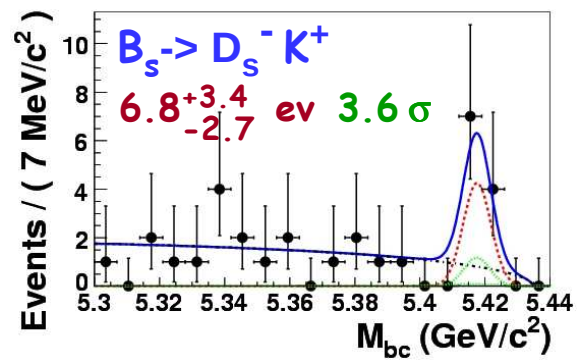
preliminary

$Bf(B_s \to D_s^+\pi^-) = (3.41\ ^{+0.33+0.70}_{-0.31\ -0.67})\ 10^{-3}$

$Bf(B_s \to D_s^+K^-) = (2.2\ ^{+1.1+0.5}_{-0.9-0.4})\ 10^{-4}$

$M(B_s^*) = 5417.6 \pm 0.4 \pm 0.5$ MeV/c^2

$N(B_s^*B_s^*)\ /\ N(B_s^{(*)}B_s^{(*)}) = (89.8 \pm ^{3.8}_{4.0} \pm 0.2)\%$



$R(K/\pi) = (6.5^{+3.3}_{-2.7})\%$

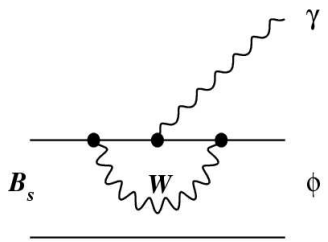
PDG: $M(B_s) = 5366.1 \pm 0.6$ MeV/c^2 → $\Delta(B_s^0) = 51.5 \pm 0.9$ MeV/c^2

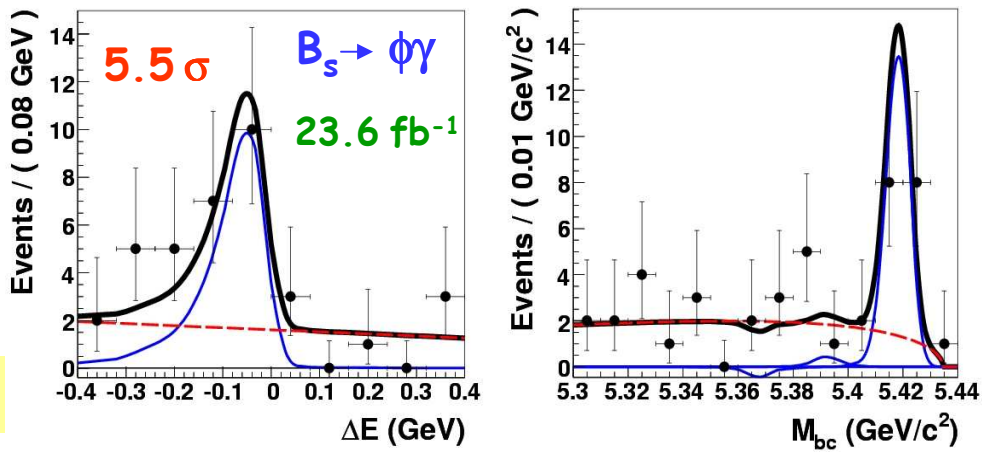
PDG: $Bf(B^0 \to D^+\pi^-) = (2.68 \pm 0.13)\ 10^{-3}$

$\Delta(B^0) = 45.78 \pm 0.35$ MeV/c^2

First observation of $B_s \to \phi\gamma$, search for $B_s \to \gamma\gamma$

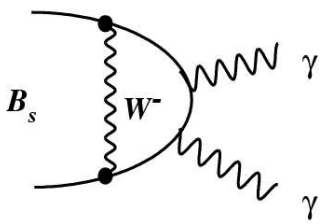
J.Wicht et al (Belle coll.) PRL 100, 121801 (2008)

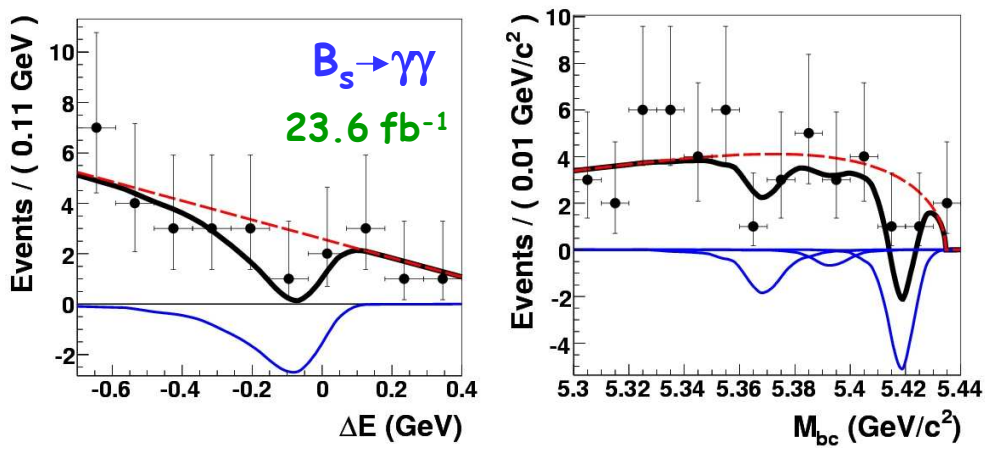




$Bf(B_s \to \phi\gamma) = (5.7^{+1.8+1.2}_{-1.5-1.1})\ 10^{-5}$

PDG: $Bf(B^- \to K^{*0}\gamma) = (4.1 \pm 0.20)\ 10^{-5}$





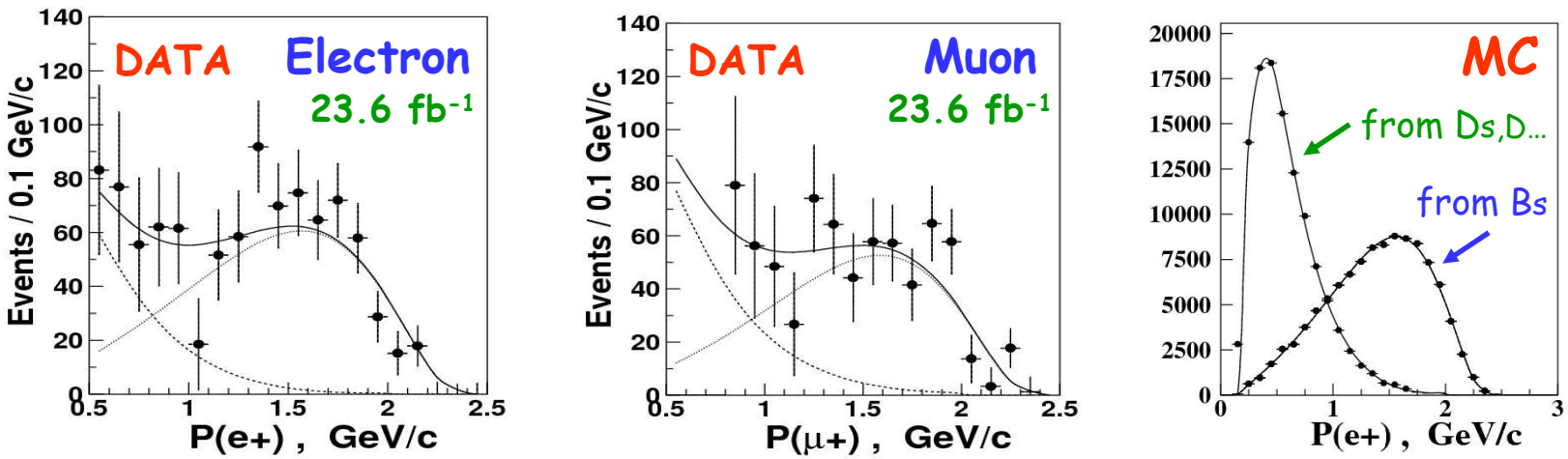
$Bf(B_s \to \gamma\gamma) < 8.7 \times 10^{-6}$ (90%CL)

Our prev. : $Bf(B_s \to \gamma\gamma) < 5.3 \times 10^{-5}$

SM: $Bf \sim (0.5-1.0)\ 10^{-6}$

First measurement of $B_s \to X^+ \ell^- \nu$ decay

Same-sign D_s and lepton sample selected to suppress $B\bar{B}$ and $c\bar{c}$ backgr.



Electron : $Bf(B_s \to X^+ e^- \nu) = (10.9 \pm 1.0 \pm 0.9)\%$

Muon : $Bf(B_s \to X^+ \mu^- \nu) = (9.2 \pm 1.0 \pm 0.8)\%$

preliminary

Combined fit (electron+muon) :

$Bf(B_s \to X^+ l^- \nu) = (10.2 \pm 0.8 \pm 0.9)\%$

arXiv/0710.2548 [hep-ex]

Assuming similar decay widths and $\tau(B_s)/\tau(B^0)=1.00 \pm 0.01$ (theory)

it can be compared to PDG 2007: $Bf(B^0 \to X^+ l^- \nu) = (10.33 \pm 0.28)\%$

Observation of $\Upsilon(5S)\to\Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$

K.-F. Chen et al. (Belle coll), PRL 100, 112001 (2008)

L= 21.7 fb^{-1}

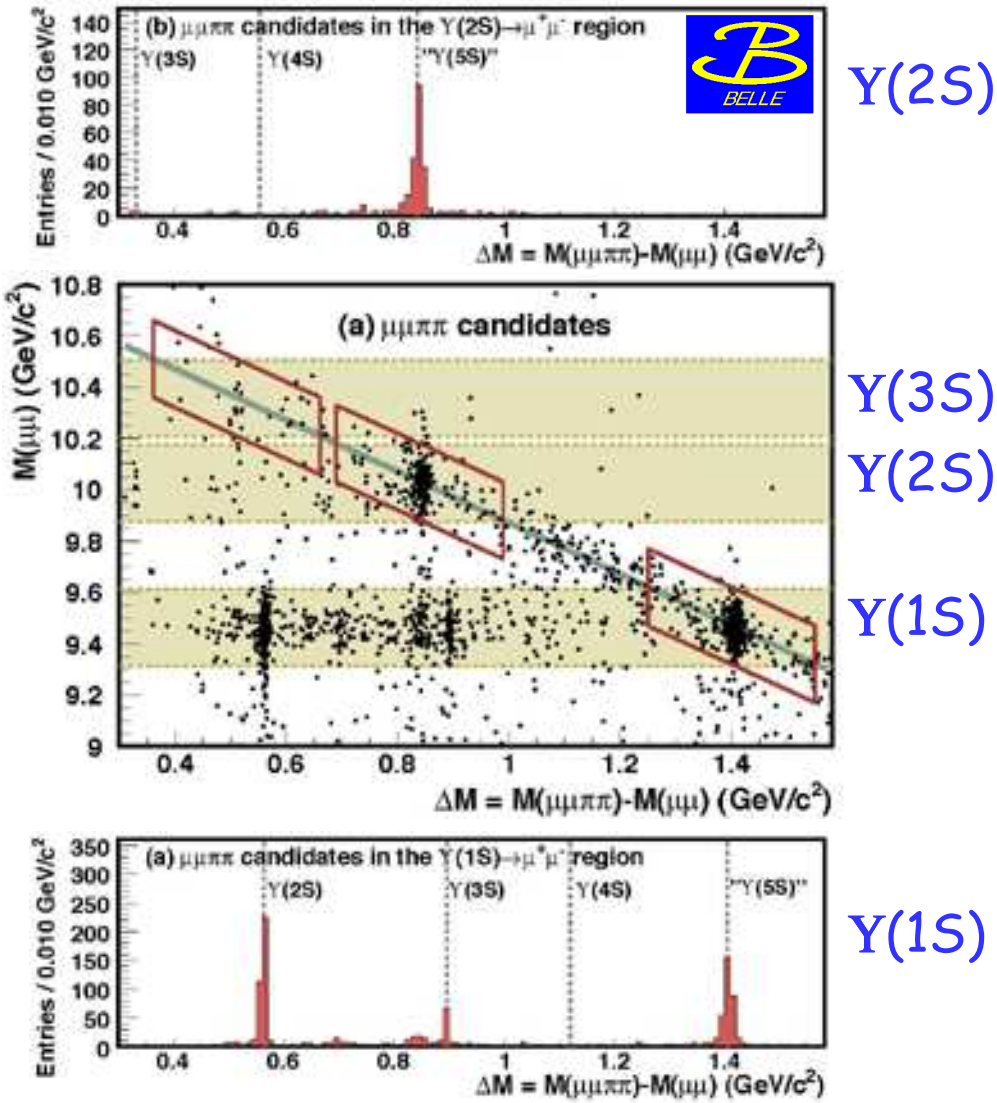
-> look for: $\mu^+\mu^-h^+h^-$

e^+e^- -> $\Upsilon(1S)\,\pi^+\pi^-X$

e^+e^- -> $\Upsilon(2S)\,\pi^+\pi^-X$

Signals are about 1%. Is it similar to recently observed $\Upsilon(4230)$ -> $J/\Psi\,\pi^+\pi^-$ state (hybrid interpret.)?

CME calibration accur. < 1 MeV



Is the Υ(10860) purely Υ(5S)?

4 modes seen : Υ(5S) -> Υ(nS) $h^+ h^-$

Process	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

Expectation: Υ(5S) width comparable to Υ(2S/3S/4S)

Process	$\Gamma_{\rm total}$	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2

Is it not pure Υ(5S)? Energy scan: 12/07 .

New Belle results with 23.6 fb^{-1}

- Measurement of $B_s \to D_s^+\pi^-$ and $B_s \to D_s^+K^-$ decays.

  $Bf(B_s \to D_s^+\pi^-) = (3.41\ ^{+0.33+0.70}_{-0.31-0.67})\ 10^{-3}$

  $Bf(B_s \to D_s^+K^-) = (2.2\ ^{+1.1+0.5}_{-0.9-0.4})\ 10^{-4}$

  preliminary

- First observation of $B_s \to \phi\gamma$ and new upper limit for $B_s \to \gamma\gamma$.

  $Bf(B_s \to \phi\gamma) = (5.7\ ^{+1.8+1.2}_{-1.5-1.1})\ 10^{-5}$

  $Bf(B_s \to \gamma\gamma) < 8.7\times10^{-6}$ **(90% CL)**

- First measurement of $B_s \to X^+\ell^-\nu$ decay.

  $Bf(B_s \to D_s^+\ell^-\nu) = (\ 10.2 \pm 0.8 \pm 0.9\ )\%$

  preliminary

- First measurement of $\Upsilon(5S) \to \Upsilon(nS)\,\pi^+\pi^-$ decays (21.7 fb^{-1}).

  $\Gamma(\Upsilon(5S) \to \Upsilon(1S)\,\pi^+\pi^-) = 0.59 \pm 0.04 \pm 0.09$ MeV

  $\Gamma(\Upsilon(5S) \to \Upsilon(2S)\,\pi^+\pi^-) = 0.85 \pm 0.07 \pm 0.16$ MeV

Other branching fr. expected with 23.6 fb^{-1}

1. $B_s \to D_s^- \rho^+$, $B_s \to D_s^- a_1^+$ decays.
2. $B_s \to J/\psi\ \phi$, $B_s \to J/\psi\ \eta$, $B_s \to J/\psi\ \eta'$ decays.
3. $B_s \to K^+ K^-$ penguin decays.
4. $B_s \to D_s^{+(*)} D_s^{-(*)}$ decays

   Mostly CP eigenstates, important for indirect $\Delta\Gamma_s/\Gamma_s$ measurement.
5. $B_s \to D^0 K^0_S$ color-suppressed decays.
6. $B_s \to D_{sJ}^- \pi^+$ decays.
7. $B_s \to D_s^- \ell^+ \nu$, $B_s \to D_s^{*-} \ell^+ \nu$ ($B_s \to K^- \ell^+ \nu$?) decays.
8. B_s lifetime measurement.
9. With 100 fb^{-1}: $B_s \to K^- \rho^+$, $B_s \to \eta\ \eta^{(\prime)}$, $B_s \to \phi\phi$ decays.
10. Energy scans at high CME: new bb-states, B^* and B_s^* searches.

Comparison with Fermilab B_s studies.

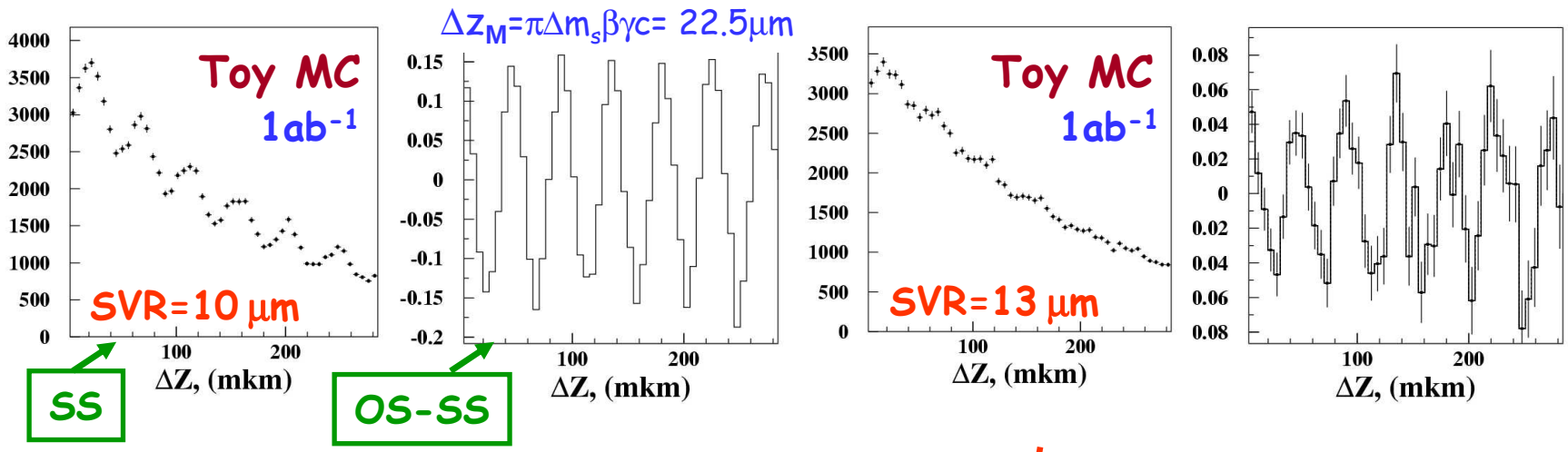
- **There are several advantages in Υ(5S) running, comparing with hadron-hadron colliders (in particular with CDF and D0):**

  1) "Model independent" branching fraction measurements.
  2) Measurement of decay modes with γ, π^0 and η in final state ($D_s^+\rho^-$).
  3) No trigger problems for multiparticle final states (like $D_s^+ D_s^-$).
  4) Inclusive measurements (inclusive photon spectrum, semileptonic *BF*).
  5) Partial reconstruction (*Bf* ($D_s^+ l^- \nu$) using "missing-mass" method).

- **There are also disadvantages:**

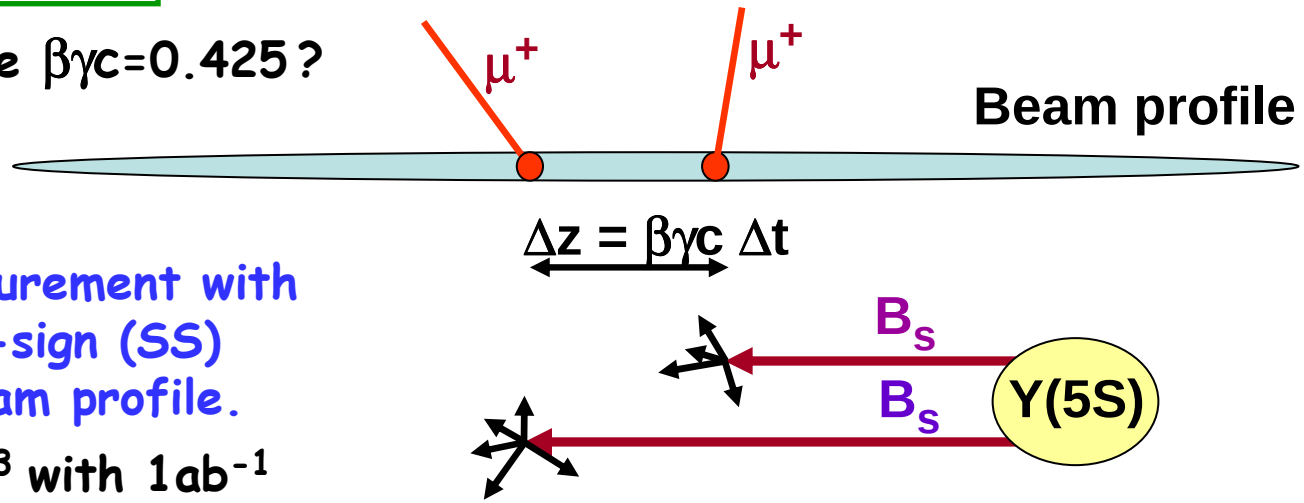
  1) We have to choose between running at Y(4S) or Y(5S).
  2) Number of B_s is smaller than in Fermilab experiments.
  3) Vertex resolution is not good enough to measure B_s mixing (?).

Feasibility of B_s mixing measur. with same-sign leptons



Can we increase $\beta\gamma c$=0.425?

Z_{beam} ~ 3 mm;
Y_{beam} ~ 5 μm.



B_s mixing measurement with two fast same-sign (SS) leptons and beam profile.

$\sigma(A^S_{SL})$~4x10^{-3} with 1ab^{-1}

B_s mixing can be measured with 1ab^{-1} if Single Vertex Resolution SVR<15μm

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

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

(first proposed by Y. Grossman)

BSM effects can decrease lifetime difference $\Delta\Gamma_s$.

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

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

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

This formula is based on assumptions : 1) Contribution of $B_s \to D_s^{+(*)} D_s^{-(*)} n\pi$ is small 2) Decays $B_s \to D_s^{+} D_s^{-*}$ and $B_s \to D_s^{+*} D_s^{-*}$ are dominantly *CP*-even states.

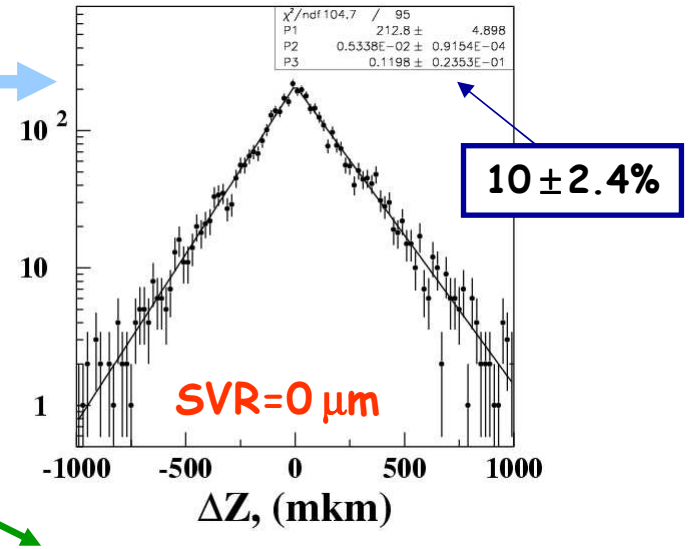
Corrections are expected to be small **(~5-7%)**, $\Delta\Gamma_s^{CP}$ can be measured.

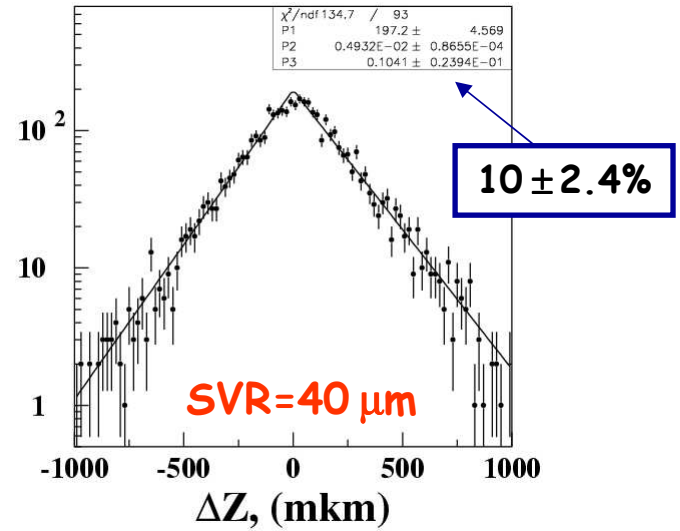
We can test SM comparing $\Delta\Gamma_s^{CP}$ with directly measured $\Delta\Gamma_s$.

Direct $\Delta\Gamma_s$ measurement with $1ab^{-1}$

Toy MC, 4000 events

SVR is not critical





No BSM

$e^+e^- \to \Upsilon(5S) \to B_s^*(CP=+)\,\bar{B}_s^*(CP=-) = B_s(CP=-)\,\gamma\,\bar{B}_s(CP=+)\,\gamma$: *CP* anti-correlated

$$A_1 \exp(-\Gamma_1 t_1) + A_2 \exp(-\Gamma_2 (t_1+\Delta t)) \Rightarrow \begin{cases} A \exp(\Gamma_1 \Delta t), & \text{if } \Delta t<0 \\ A \exp(-\Gamma_2 \Delta t), & \text{if } \Delta t>0 \end{cases}$$

~4000 (eff) CP-fixed events with $1000fb^{-1}$ => 2.4% accuracy in $\Delta\Gamma_s$.

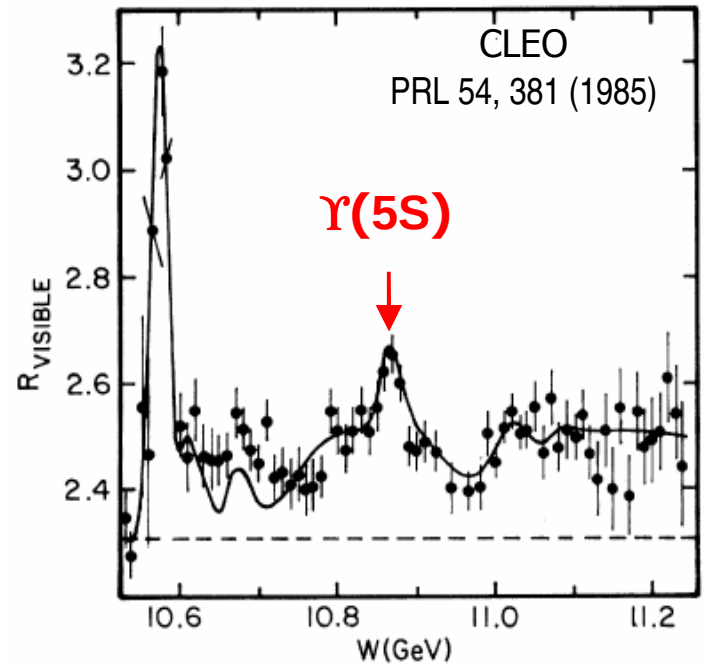
CP-fixed: $D_s^{(*)}D_s^{(*)}$ (1000 ev), $J/\psi\,\eta^{(\prime)}$ (1500), K^+K^-(600), $D^0_{CP}K^0$ (250), $J/\psi\,\phi$ (2200).

4σ measurement of $\Delta\Gamma_s/\Gamma_s$ with $1ab^{-1}$ at Υ(5S)

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- → Y(6S,7S) → $B_s\bar{B}_s$, $\Lambda_b\bar{\Lambda}_b$, $B_c\bar{B}_c$, $\Xi_b\bar{\Xi}_b$ … ?

Conclusions

- **We are discussing possibility to increase Belle dataset at Y(5S) to ~100 fb^{-1} in 2009. Many B_s decays with branching fractions down to 10^{-6} can be measured with statistics of ~100 fb^{-1}.**

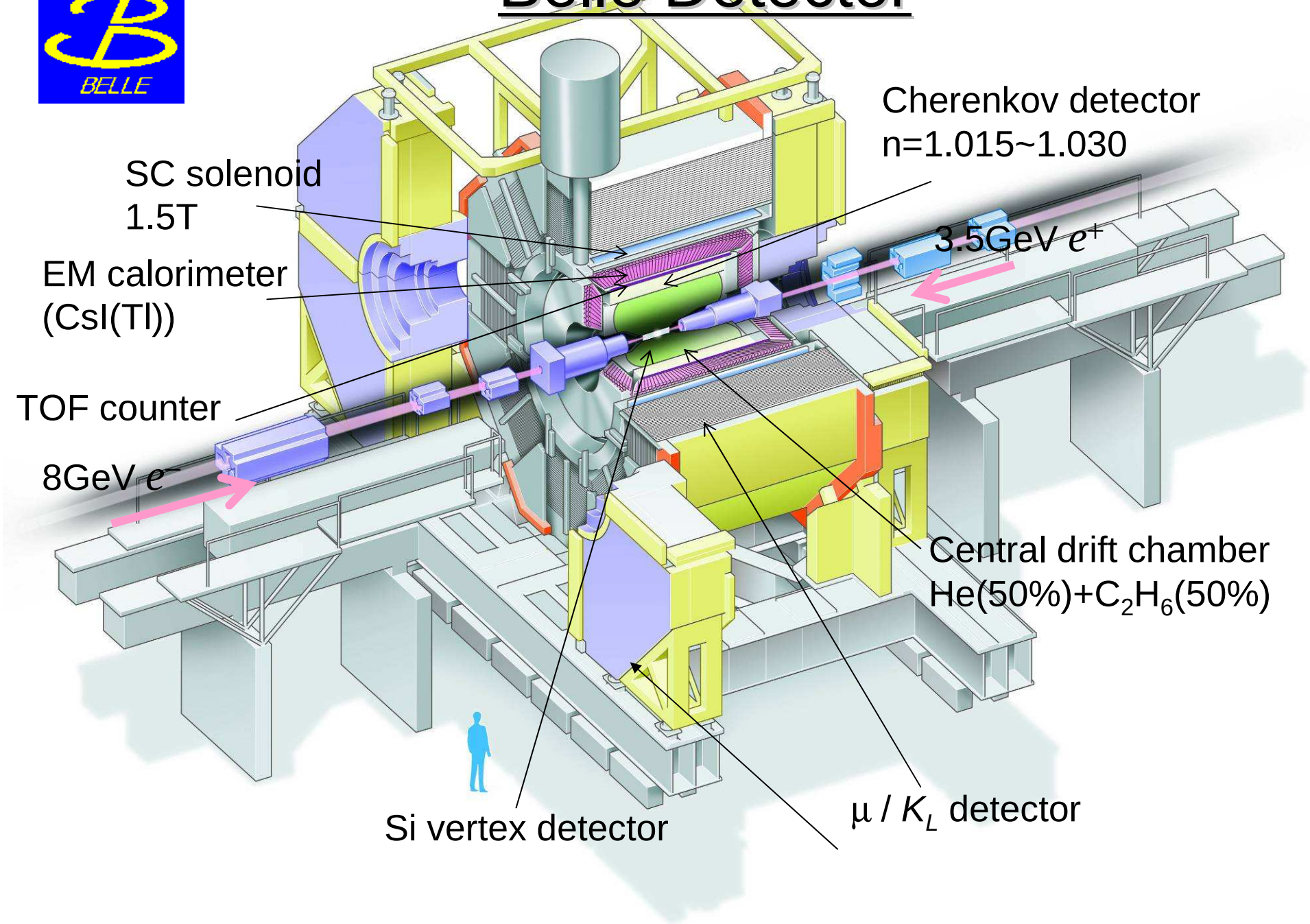
- **Dataset of 1000 fb^{-1} can be taken just after Super Belle upgrade. Important SM tests can be done with statistics of the order of 1 ab^{-1}.**

- **B_s studies at e+ e- colliders running at Y(5S) have some advantages comparing with hadron-hadron colliders. These colliders are in some sense complementary.**

- **It is important to have more flexibility in beam energies at Super *B* factories.**

Background slides

Belle Detector



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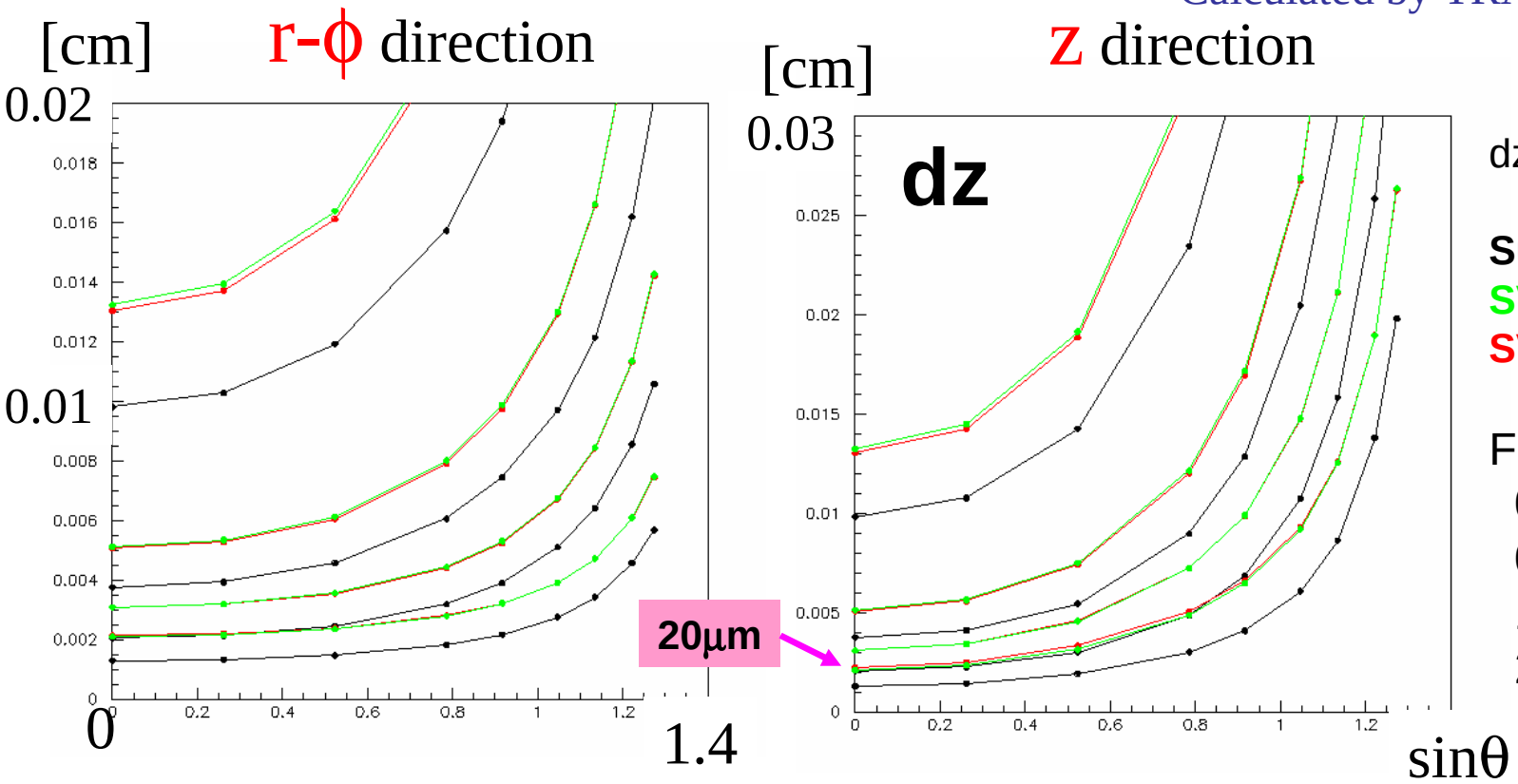
Atami BNM2008
Jan 2008

Impact Parameter resolution

Calculated by TRACKERR



dz resolutoin

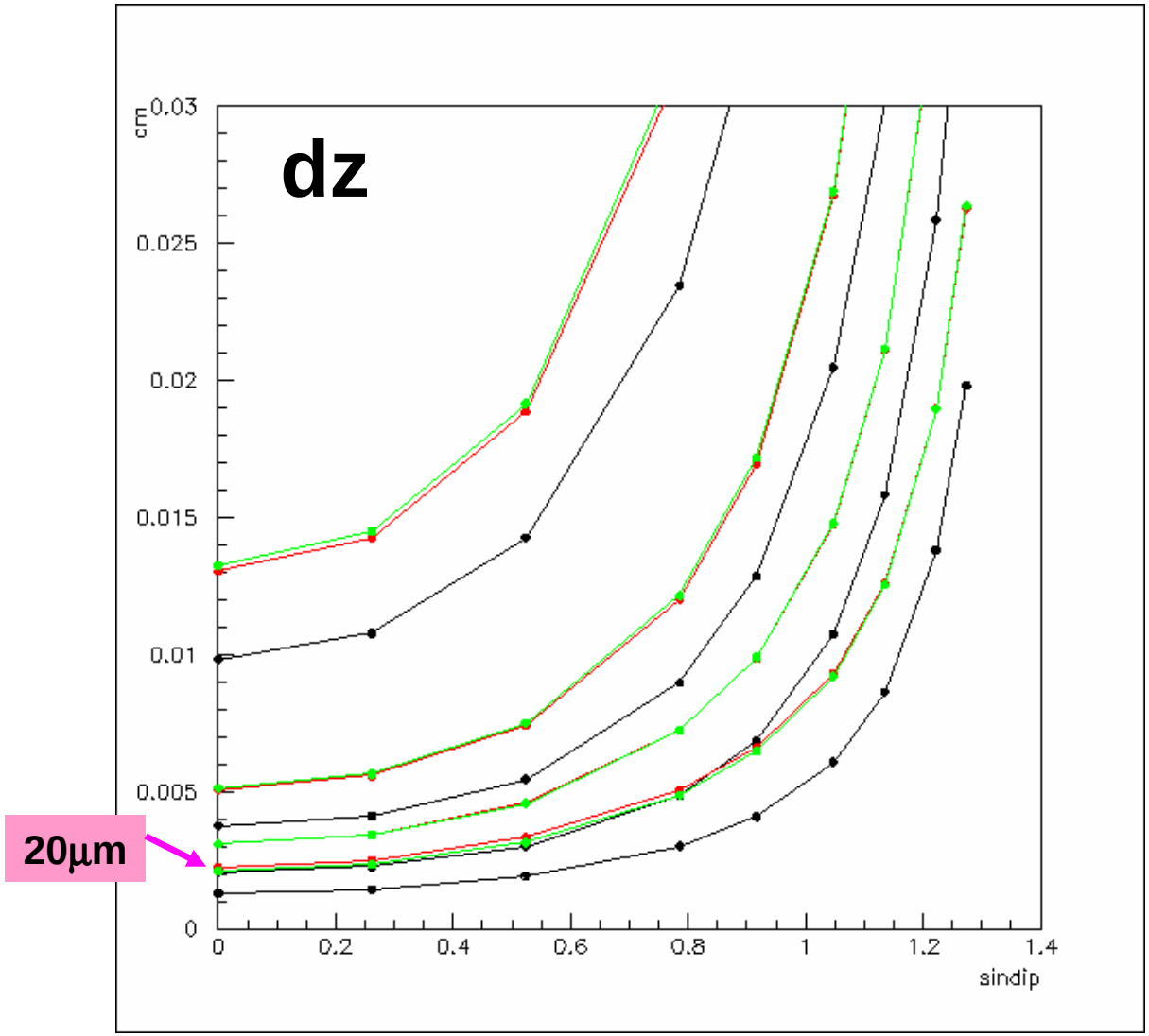
SuperB
SVD3mod
SVD3

For π
0.2GeV
0.5GeV
1.0GeV
2.0GeV

Beampipe radius is important
Competitive performance as the current SVD

Occupancy effects.
Degradation of intrinsic resolution is included.
Efficiency loss is NOT included

dz resolution



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Jan 2008

dz resolutoin

SuperB
SVD3mod
SVD3

For π
0.2GeV
0.5GeV
1.0GeV
2.0GeV

$\Delta\Gamma_s/\Gamma_s$ measurement

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

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

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

- Schrödinger equation

Matrices *M* and *G* 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 : $\phi_s = \arg(-M_{12}/\Gamma_{12})$ $\qquad$ $2\theta_s = \phi_s$ $\qquad$ $\Delta\Gamma_s = 2\,|\Gamma_{12}| \cos 2\theta_s$