$\Delta\Gamma_s/\Gamma_s$ from $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ at $\Upsilon(5S)$

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Outline

$\Upsilon(5S)$ at KEKB

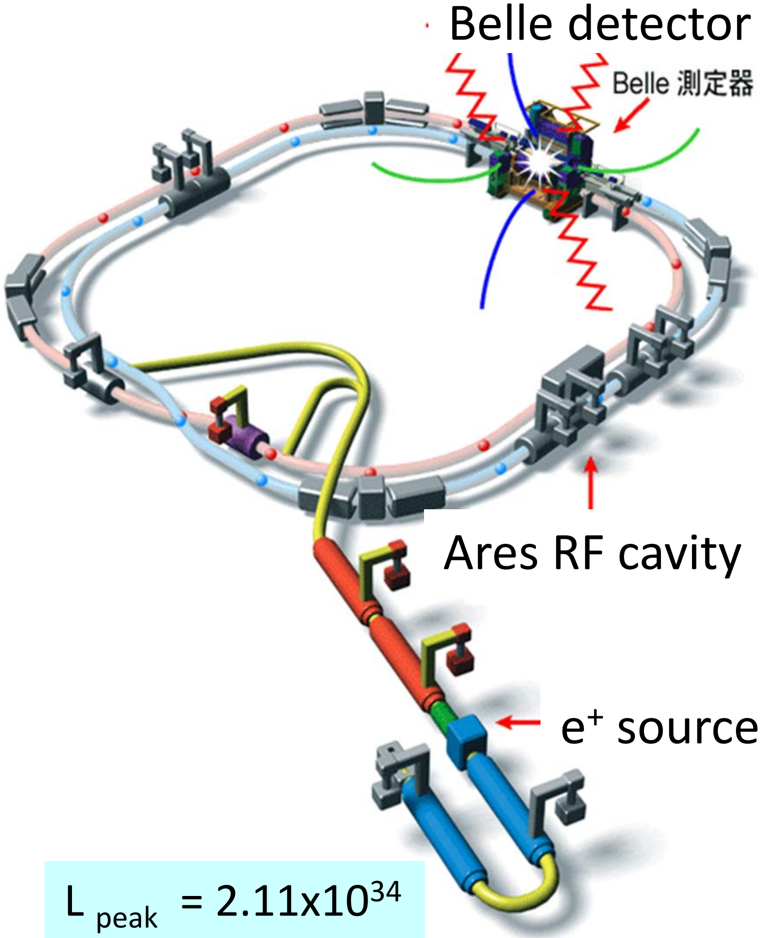
B_s Oscillation Parameters

Analysis: $B_s \to D_s^{(*)+} D_s^{(*)-}$

Result

The Belle Experiment at KEKB

Multipurpose large-solid-angle magnetic spectrometer



$L_{peak} = 2.11 \times 10^{34}$

Primary aim - CP violation at $\Upsilon(4S)$

Operated at : $\Upsilon(4S)$, $\Upsilon(5S)$, $\Upsilon(3S)$, $\Upsilon(2S)$, $\Upsilon(1S)$, Yb scan and others

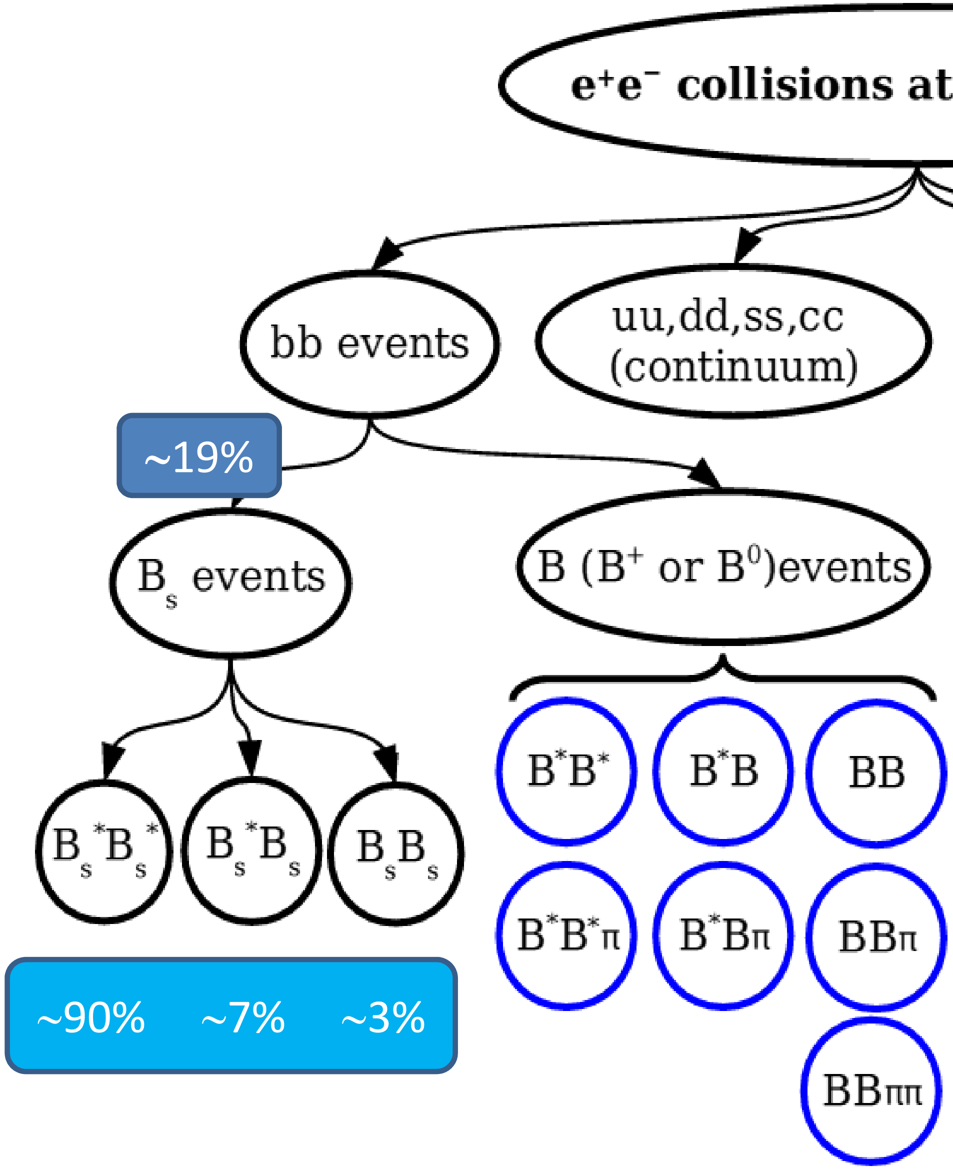
Beam($e^- e^+$) energies changed, Crossing angle & boost maintained

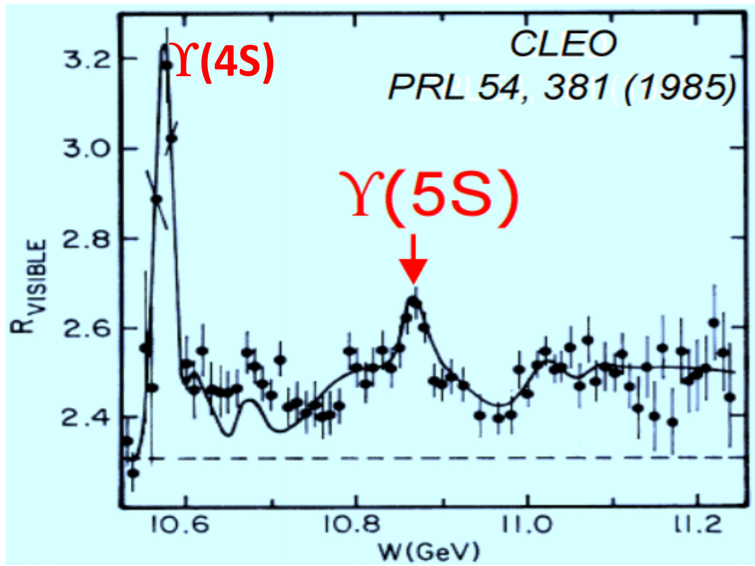
$\Upsilon(4S)$:	~710 fb^{-1}
$\Upsilon(5S)$:	~129 fb^{-1}
$\Upsilon(3S)$:	2.9 fb^{-1}
$\Upsilon(2S)$:	24 fb^{-1}
$\Upsilon(1S)$:	5.7 fb^{-1}
Y_b scan:	8.1 fb^{-1}
Off-peak:	~90 fb^{-1}

Total Luminosity 1000 fb^{-1}

World record, era of ab^{-1}

Event Classification at Υ(5S)





$B_{(s)}$ excited states decay to $B_{(s)}$ γ

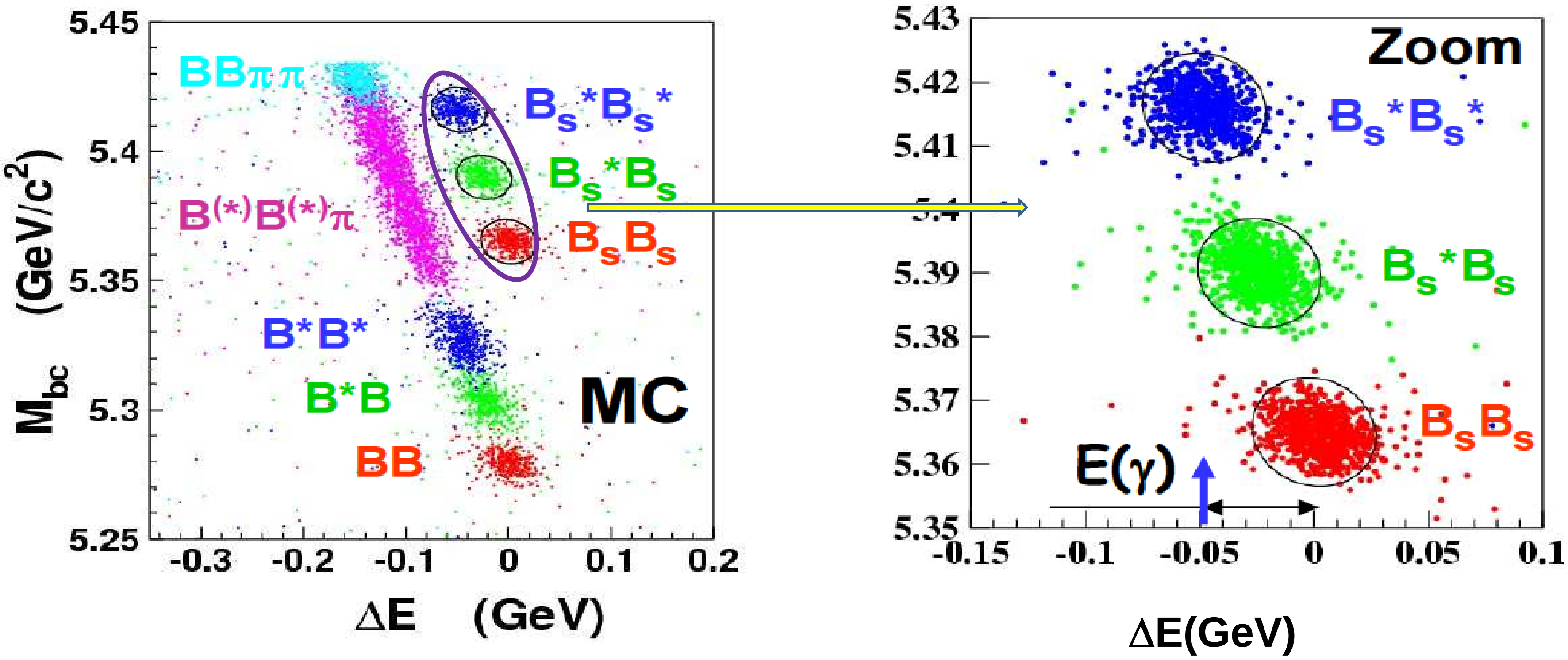
Almost entire source of B_s at $\Upsilon(5S)$ is B_s^*

$B_s^* \to B_s\gamma$ $\Delta M = M_{B_s^*} - M_{B_s} \approx 50 MeV/c^2$

Important variables

$$\Delta E = E_B - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$$



Belle $\Upsilon(5S)$ Data Sample

2005 : 1.86 fb^{-1}
2006: 21.7 fb^{-1}
2007: 7.9 fb^{-1}
2008: 28.2 fb^{-1}
2009: 76.9 fb^{-1}

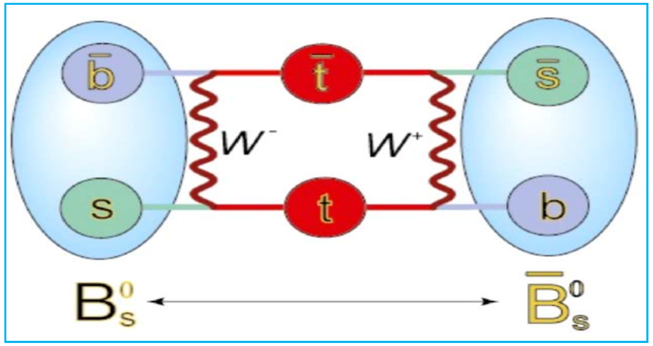
Total (On peak): 121 fb^{-1}

Rest of the world at $\Upsilon(5S)$ $\sim$ 1 fb^{-1}

Data Analyzed: 23.6 fb^{-1}

2.75×10^6 B_s decays

$B_s - \bar{B}_s$ Oscillation/Mixing



Evolution of B_s flavor eigenstates governed by Schrödinger equation

$$i\frac{d}{dt}\begin{pmatrix} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{pmatrix} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2} \end{pmatrix} \begin{pmatrix} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{pmatrix}$$

Mass eigenstates
Heavy & Light

$$|B_H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$$

$$|B_L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$$

With $|p|^2 + |q|^2 = 1$

Phase $\phi_s^{SM} = arg(-\frac{M_{12}}{\Gamma_{12}}) \approx 0.04\ rad$

mass and width difference are observables

$$\Delta m_s = M_H - M_L \simeq 2\,|M_{12}|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \simeq 2\,|\Gamma_{12}|\cos\phi_s$$

For CP conserved, q=p and

$$|B_H\rangle = \left|B_s^{CP-odd}\right\rangle$$

$$|B_L\rangle = \left|B_s^{CP-even}\right\rangle$$

$$\Delta\Gamma_s^{CP} = \Gamma_s(B_s^{CP-even}) - \Gamma_s(B_s^{CP-odd})$$

Effect of non-zero phase leads to:

$$\Delta\Gamma_s = \Delta\Gamma_s^{CP} \cos\phi_s$$

New physics may alter the situation:

$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

New phase could be large

Δm_s measured with good precision

CDF & D0 at Tevatron

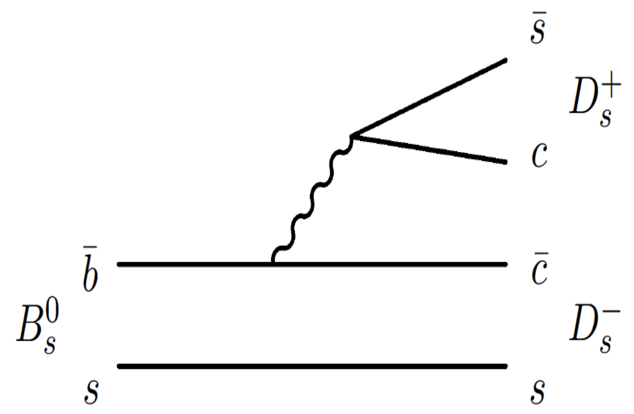
$17.77 \pm 0.12 ps^{-1}$

$\Delta\Gamma_s$ a long way to go

Large in SM

ALEPH, D0, CDF

$B_s \to D_s^{(*)+} D_s^{(*)-}$ offers unique possibility
-no time dependent measurement,
- just counting



CKM favoured $B_s \to D_s^{(*)+} D_s^{(*)-}$ is Dominantly CP-even, CP-odd part can be ignored (or corrected)
– *under heavy quark limit for* m_c

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \frac{2\mathcal{B}(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - \mathcal{B}(B_s \to D_s^{(*)+} D_s^{(*)-})}$$

Aleksan, Yaouanc, Oliver, Pene, Raynal, Phy Lett B316, 567 (1993)
Duniets, Fleischer, Nierste, Phys ReV D63, 114015 (2001)

B_s Candidate Reconstruction

$$D_s^+ \to \left\{ \begin{array}{l} \phi\pi^+ \\ K_s^0 K^+ \\ \bar{K}^{*0} K^+ \\ \phi\rho^+ \\ K^{*+} \bar{K}_s^0 \\ K^{*+} \bar{K}^{*0} \end{array} \right\}$$

$$\left\{ \begin{array}{lcl} \phi & \to & K^+ K^- \\ K_s^0 & \to & \pi^+\pi^- \\ \bar{K}^{*0} & \to & K^-\pi^+ \\ \rho^+ & \to & \pi^+\pi^0 \\ K^{*+} & \to & K_s^0\pi^+ \end{array} \right\}$$

Good K/π identification and vertex constraint,
helicity cut to improve D_s signal whenever possible

$$D_s^{*\pm} \to D_s^{\pm}\gamma$$

$\Delta M = M(D_s, \gamma) - M(D_s)$

~144 MeV/c^2

$B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ using energy difference and beam-energy-constrained mass

$$\Delta E = E_B - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$$

$B_s \to D_s^{(*)+} D_s^{(*)-}$ Candidate Selection

$5.2 < M_{bc} < 5.45$ GeV/c^2

$-0.15 < \Delta E < 0.1$ GeV

Multiple candidates possible

Only one candidate within three modes per event

Best candidate: Minimum χ^2 based on M(Ds) and ΔM

$$\Delta M = M_{D_s\gamma} - M_{D_s}$$

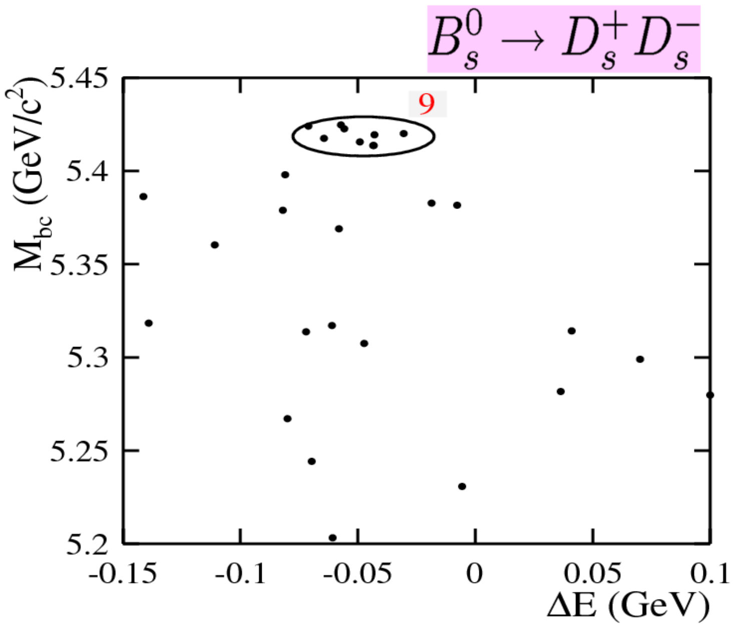
$$\chi^2 = \frac{1}{M+N}\left\{\sum_{i=1}^{M}[(\tilde{M}_{D_s} - M_{D_s})/\sigma_M]^2 + \sum_{i=1}^{N}[(\Delta\tilde{M}_{D_s} - \Delta M_{D_s})/\sigma_{\Delta M}]^2\right\}$$

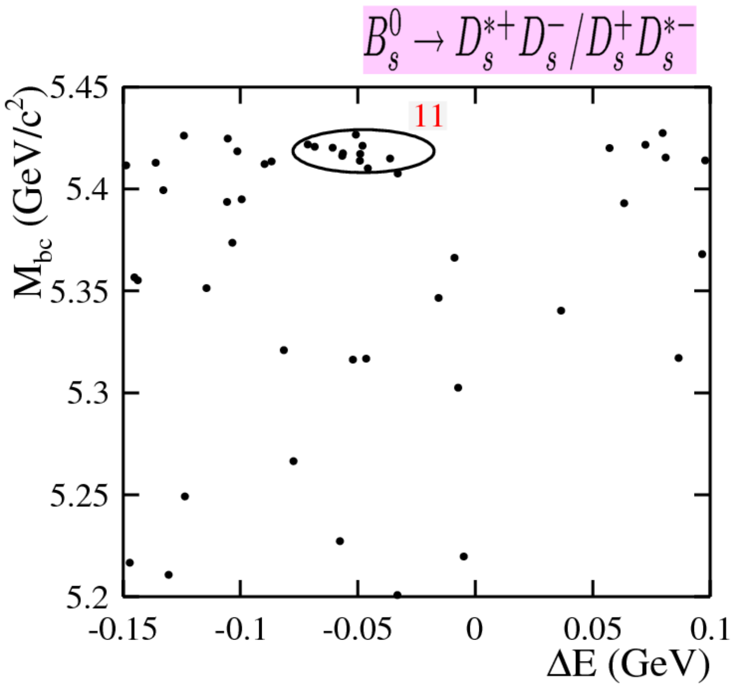
Reconstructed ($\tilde{M}_{D_s}$)

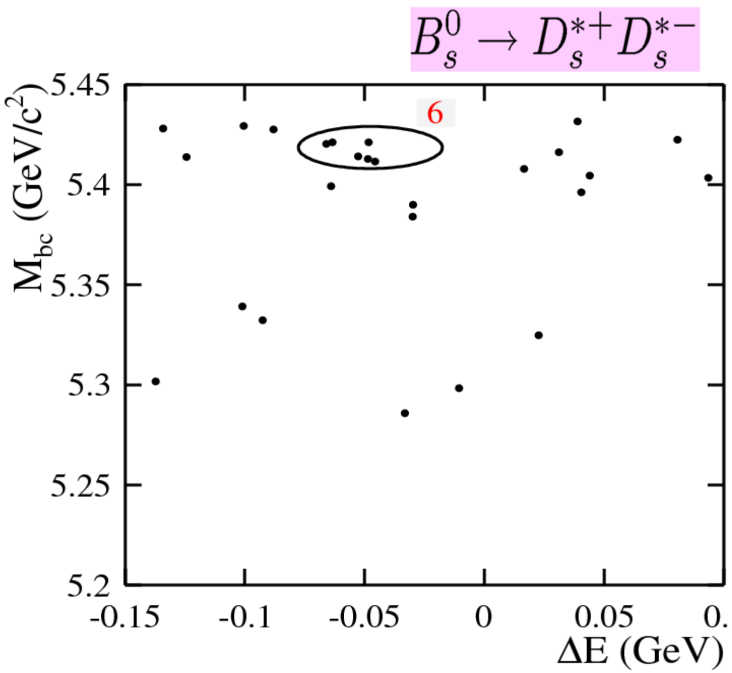
PDG (M_{D_s})

Candidate events in $\Delta E - M_{bc}$ Plane

Data 23.6 fb^{-1}







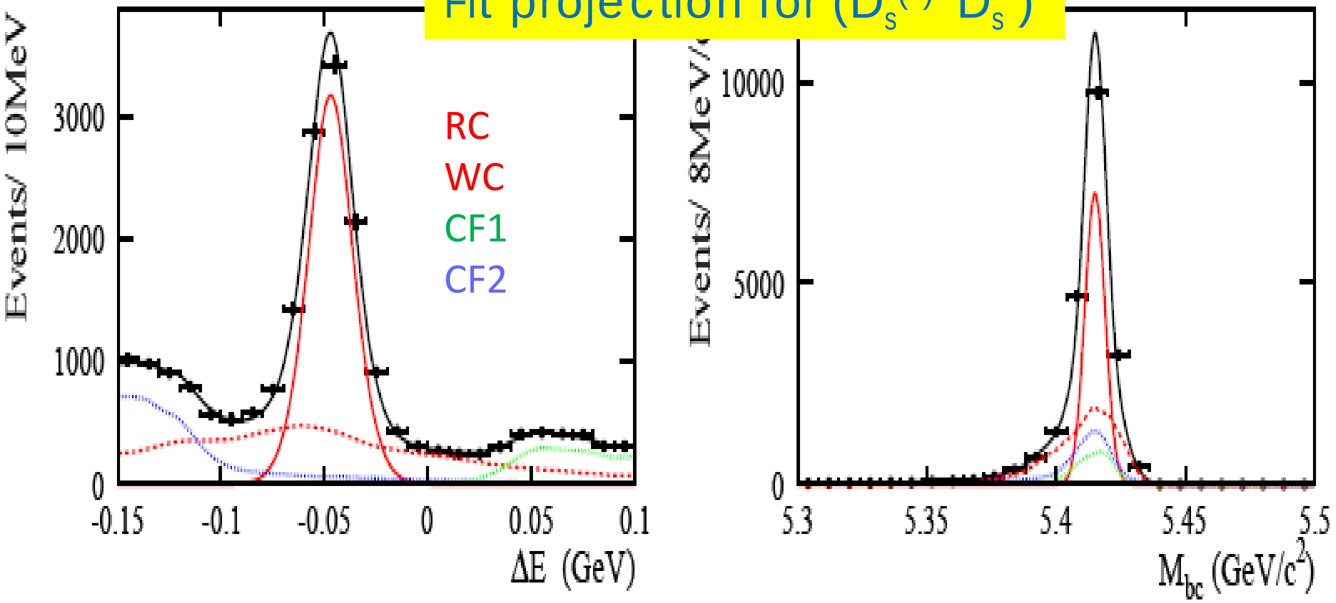
Signal extraction

Two-dimensional un-binned ML fit in (ΔE, M_{bc}) simultaneous over 3 modes

Understand the fit first

Signal MC for $B_s \to D_s^{(*)+} D_s^{(*)-}$ fitted in all three modes

Fit projection for ($D_s^{(*)}$ D_s)



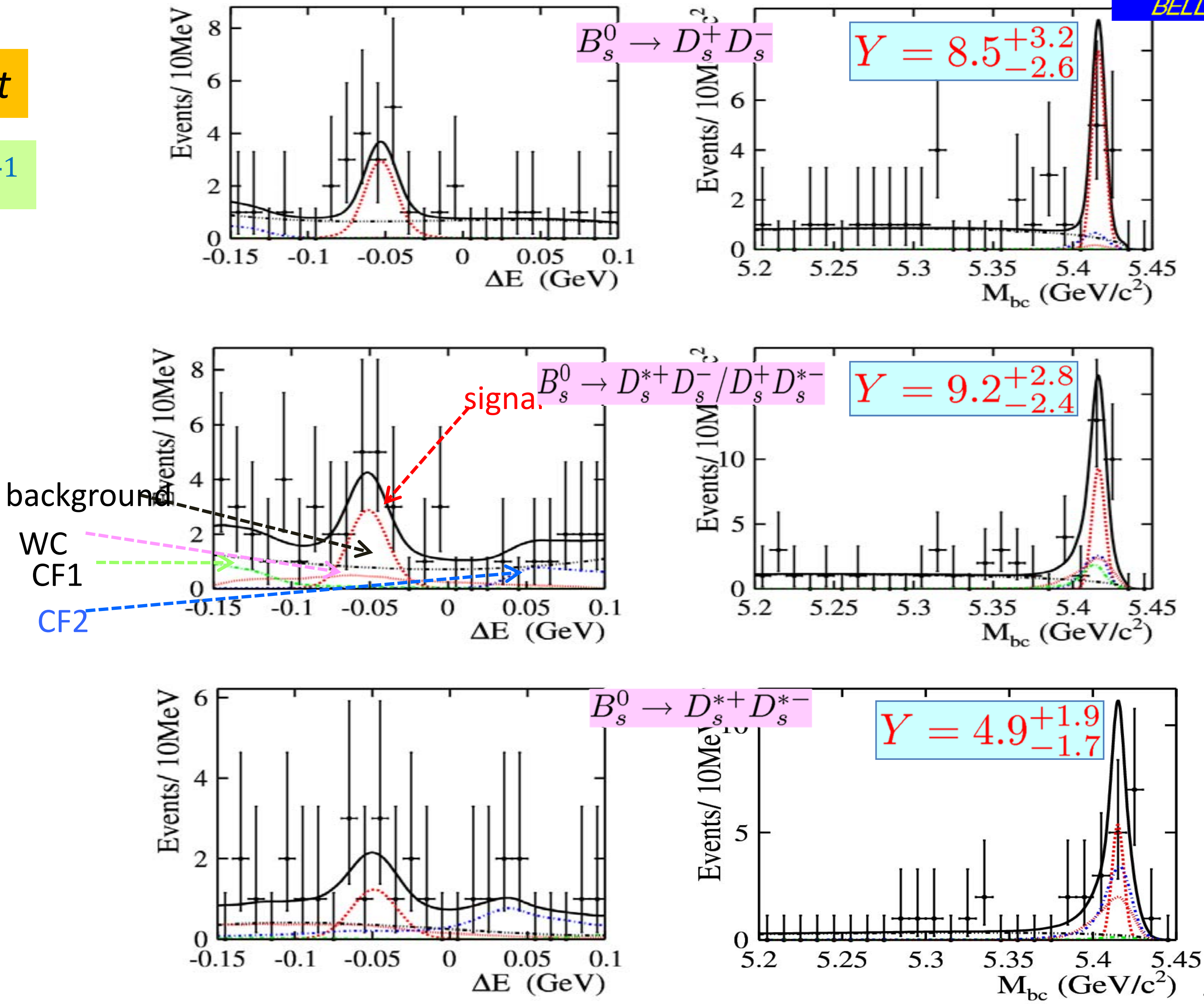
Signal PDF modeled using MC. Corrected for resolution using control sample from Data : $B_s \to D_s^{(*)+} \pi^-$ and $B^- \to D_s^{(*)-} D^0$

Generic background by Chebyshev in ΔE and ARGUS in M_{bc}

Simultaneous 2-D fit in (ΔE , M_{bc}) over 3 modes

Fit Result

(23.6 fb^{-1}



Fitted number of events and $B_s \to D_s^{(*)+} D_s^{(*)-}$ decay branching fractions, after efficiency corrections

(23.6 fb^{-1}

Mode	Yield (events)	$\mathcal{B}\%$	S(σ)
$D_s^+ D_s^-$	$8.5^{+3.2}_{-2.6}$	$1.0^{+0.4+0.3}_{-0.3-0.2}$	6.2
$D_s^{*+} D_s^- / D_s^{*-} D_s^+$	$9.2^{+2.8}_{-2.4}$	$2.8^{+0.8}_{-0.7} \pm 0.7$	6.6
$D_s^{*+} D_s^{*-}$	$4.9^{+1.9}_{-1.7}$	$3.1^{+1.2}_{-1.0} \pm 0.8$	3.2
Sum	$22.6^{+4.7}_{-3.9}$	$6.9^{+1.5}_{-1.3} \pm 1.9$	

First Observation (6.6)

First Evidence (3.2)

Systematic errors dominated by
$D_s^{(*)}$ decay BF, $\Upsilon(5S)$ decay BF and K-PID

Our Result

BELLE

$$\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = (6.9^{+1.5}_{-1.3} \pm 1.9)\%$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \frac{2\mathcal{B}}{(1-\mathcal{B})} = (0.147^{+0.036+0.044}_{-0.030-0.042} \pm 0.004)\%$$

Theory

$$PDG: \quad 0.092^{+0.051}_{-0.054}$$

SM $\Delta\Gamma_s/\Gamma_s$ = **0.127 ± 0.024**

Using ΔM_s from experiment ;
Lenz, Nierste , hep-ph/0612167

Summary

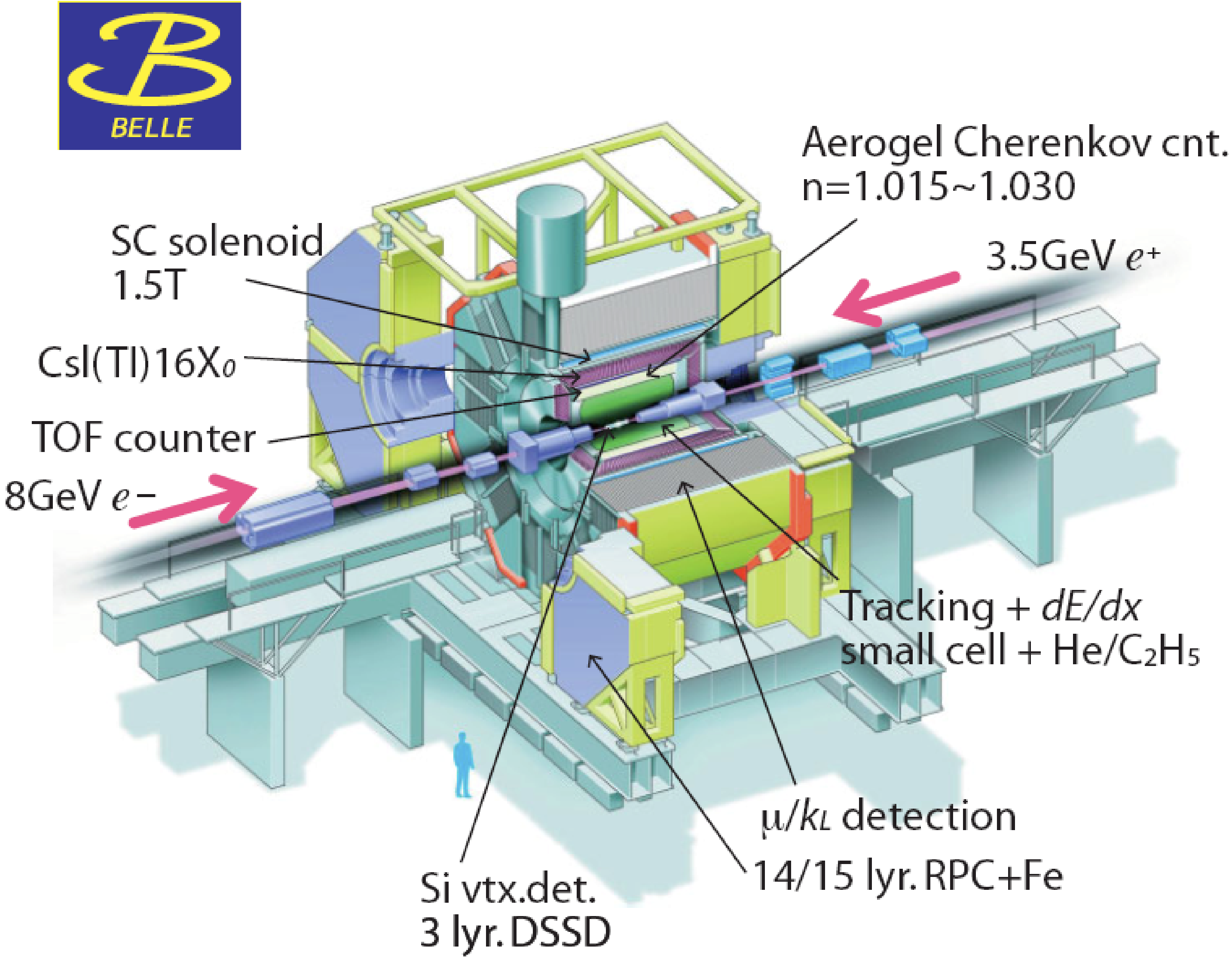
We have analyzed 23.6fb^{-1} data at $\Upsilon(5S)$

We have measured
$B_s \to D_s^{(*)+} D_s^{(*)-}$ Decay Branching Ratios

Using this measurement we determine
B_s oscillation parameter $\Delta\Gamma_s/\Gamma_s$

With ~100 fb^{-1} data at $\Upsilon(5S)$ yet to be analyzed,
significantly better measurements expected soon

Backup



BELLE
Aerogel Cherenkov cnt.
n=1.015~1.030
SC solenoid
1.5T
3.5GeV e^+
CsI(Tl)16X_0
TOF counter
8GeV $e-$
Tracking + dE/dx
small cell + He/C_2H_5
μ/k_L detection
14/15 lyr. RPC+Fe
Si vtx.det.
3 lyr. DSSD

Systematic Errors

Source	$D_s^+ D_s^-$		$D_s^* D_s$		$D_s^{*+} D_s^{*-}$	
	$+\sigma$	$-\sigma$	$+\sigma$	$-\sigma$	$+\sigma$	$-\sigma$
DATA/MC calibration	0.3	0.3	0.0	0.1	0.2	0.1
CR PDF	0.7	0.7	0.2	0.3	0.5	0.4
Background PDF	1.1	1.3	1.9	2.0	3.0	3.0
WC+CF PDF	0.3	0.3	1.5	1.5	4.4	4.4
WC/CF fraction	0.2	0.2	5.0	5.0	8.7	8.7
Continuum suppression	1.8	1.8	1.8	1.8	1.8	1.8
Best candidate selection	6.9	0.0	2.2	0.0	2.2	0.0
$K^{\pm}$ identification	9.5	9.5	10.0	10.0	10.3	10.3
K_s	1.0	1.0	1.0	1.0	1.0	1.0
π^0	1.1	1.1	1.1	1.1	1.0	1.0
γ	-	-	3.8	3.8	7.6	7.6
Tracking	6.2	6.2	6.2	6.2	6.2	6.2
Polarization	0.2	0.0	0.8	0.5	0.7	0.3
Acceptance (ε)	1.1	1.1	0.9	0.8	1.0	1.0
$D_s^{(*)}$ BF's	12.4	12.4	12.4	12.4	12.5	12.5
Luminosity	± 1.3					
$\sigma_{\Upsilon(5S)}$	± 4.6					
$f_{B_s^{(*)}\overline{B}_s^{(*)}}$	± 15					
$N_{B_s^*\overline{B}_s^*}/N_{B_s^{(*)}\overline{B}_s^{(*)}}$	$^{+4.2}_{-4.4}$					
Total	24.6	23.7	24.8	24.8	27.2	27.2

Signal region and the cross-feeds

MC in different modes