Observation of $B_s \to D_s^{(*)+} D_s^{(*)-}$ and Estimate of $\Delta\Gamma_s$ at Belle

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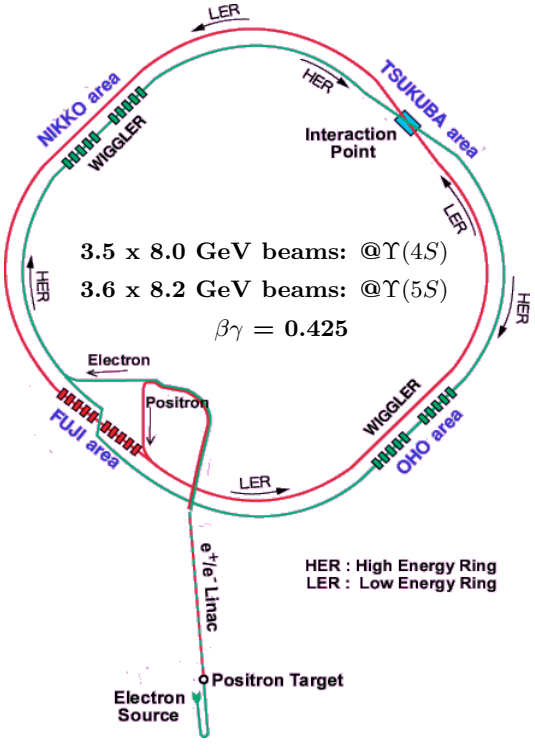
University of Cincinnati

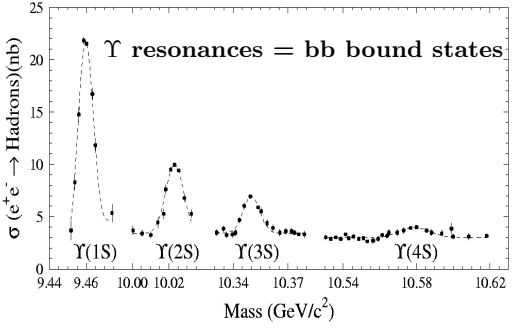
Meeting of the Division of Particles and Fields of the American Physical Society

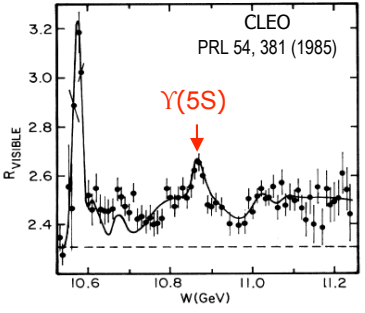
August 9-13, 2011

KEKB Collider and Belle Detector

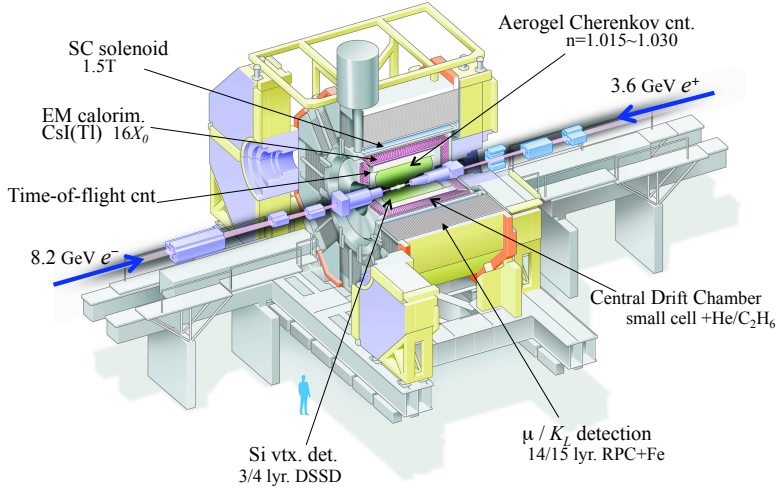
KEKB collider:



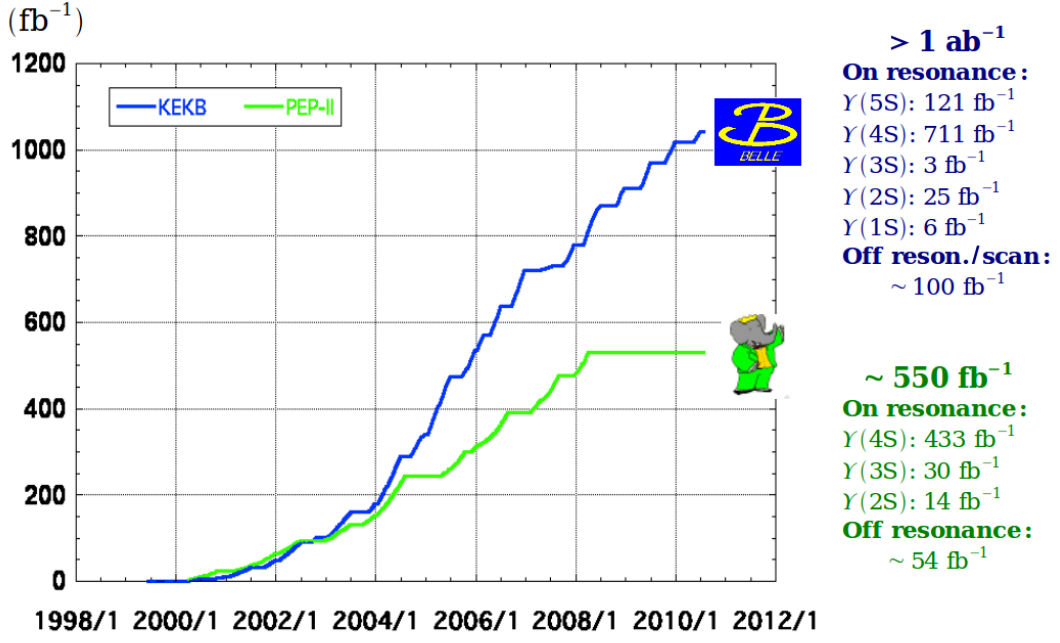




Belle detector:

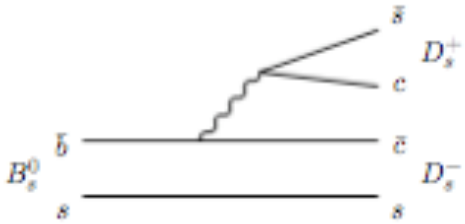


Integrated Luminosity of B Factories



- World luminosity record $L = 2.11 \times 10^{34} cm^{-1} s^{-1}$
- Data taken at $\Upsilon(4S)$, below $\Upsilon(4S)$(continuum), at $\Upsilon(5S)$, and above $\Upsilon(5S)$(scan)
- $\Upsilon(5S)$ is just above $B_s^* B_s^*$ threshold
- $121.4 fb^{-1}$ data, corresponding to 7.11 million $B_s^{(*)} B_s^{(*)}$ pairs, used for this analysis

- CP-even final states
  - $D_s^+ D_s^-$ pure CP-even
  - $D_s^* D_s^{(*)}$ predominantly CP-even



- In the heavy quark limit, while $(m_b - 2m_c) \to 0$ and $N_c \to \infty$
  - $b \to c\bar{c}s$ processes contribute constructively to $\Delta\Gamma_s$
  - $\Gamma[B_s^0(CP+) \to D_s^{(*)-} D_s^{(*)+}]$ saturates $\Delta\Gamma_s^{CP}$
  - assuming negligible CP violation, we can estimate $\Delta\Gamma_s/\Gamma_s$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \frac{2\mathcal{B}(B_s^0 \to D_s^{(*)-} D_s^{(*)+})}{1 - \mathcal{B}(B_s^0 \to D_s^{(*)-} D_s^{(*)+})}$$

Aleksan *et. al.*, PLB 316, 567 (1993) , Dunietz *et. al.* , PRD 63, 114015 (2001)

some theoretical uncertainty

- 3-body $D_s D_s X$ and $D_{sJ} D_s$ final states are not included
- $D_s^{*+} D_s^{*-}$ modes may have a CP-odd component

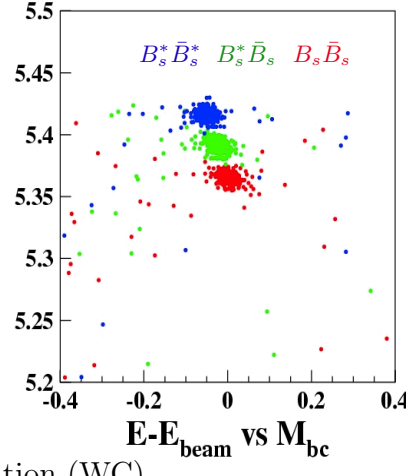
Event Selection

➢ Exclusively reconstructed B_s^0 candidates in $D_s^+ D_s^-$, $D_s^{*\pm} D_s^{\mp}$ and $D_s^{*+} D_s^{*-}$ modes from

- $D_s^+ \to \phi\pi^+, K_S K^+, K^{*0} K^+, \phi\rho^+, K^{*+} K_S, K^{*+} K^{*0}$
  - Charged tracks required to originate from near e^+e^- interaction point
  - Mass cut on intermediate resonances and $D_s^{\pm}$
- $D_s^{*\pm} \to D_s^{\pm}\gamma$ with $|\Delta M_{D_s^* - D_s} - \Delta M^{PDG}| < 12 MeV$

➢ low background:

- small amount of continuum events, 93% rejected based on event topology
- dominant but small background from $\Upsilon(5S) \to B\bar{B}X \to D_s Y$



➢ Observables: the energy difference and the beam energy constrained mass

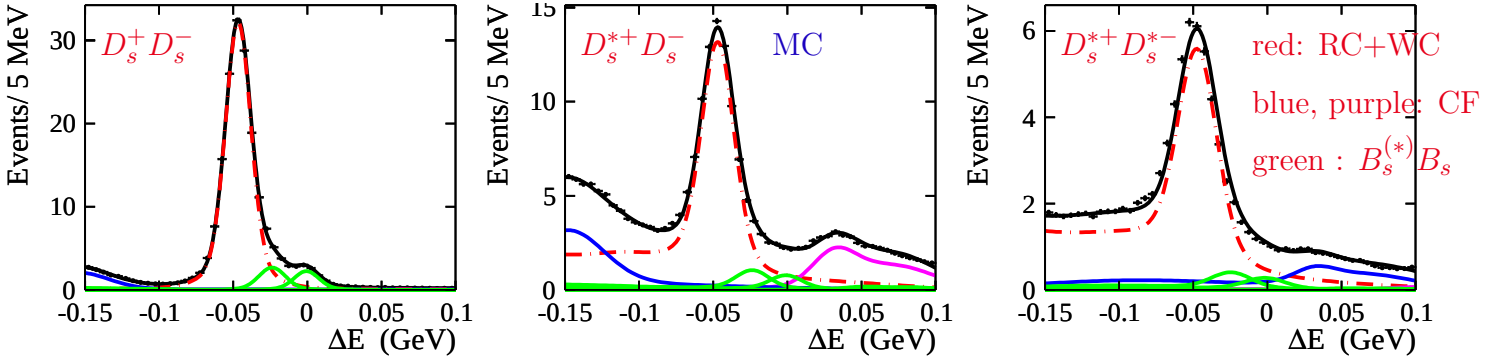
- $\Delta E = E_{B_s^0} - E^*$ within $[-0.15, 0.1] GeV$
- $M_{bc} = \sqrt{E^{*2} - p^2_{B_s^0}}$ within $[5.25, 5.45] GeV/c^2$

➢ cross contamination between modes because of soft photon from D_s^{*+}

- true D_s^{*+} decay is reconstructed with a random photon: wrong combination (WC)
- true D_s^+ decay, not a product of D_s^{*+}, combined with a random photon: cross feed up (CFup)
- true D_s^{*+} candidate lost its photon: cross feed down (CFdown)

Best Candidate Selection

➢ simultaneous fit of three modes to account for large cross-feeds between signal modes



➢ Relative fractions of signal components

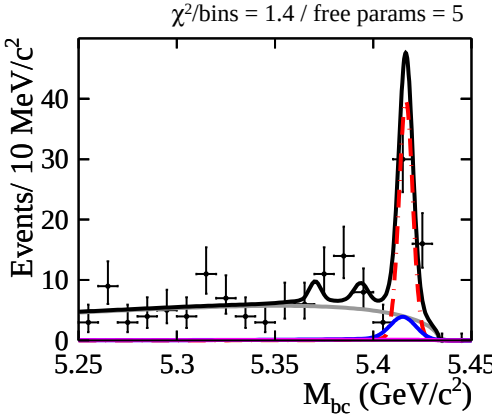
B_s^0 Generated Modes	RC	WC	CF I	CF II
$D_s^+ D_s^-$	76.1	6.0fixed	17.1 ($D_s^{*\pm} D_s^{\mp}$)	0.8 ($D_s^{*+} D_s^{*-}$)
$D_s^{*\pm} D_s^{\mp}$	44.4	38.5fixed	8.2 ($D_s^+ D_s^-$)fixed	8.9 ($D_s^{*+} D_s^{*-}$)
$D_s^{*+} D_s^{*-}$	31.8	37.6fixed	2.0 ($D_s^+ D_s^-$)fixed	28.6 ($D_s^{*\pm} D_s^{\mp}$)fixed

➢ one candidate per event selected with minimum χ^2 (MC: correct 75% of time)

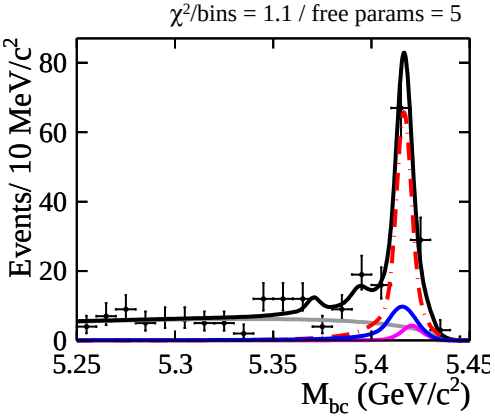
$$\chi^2 = \frac{1}{2+N} \left\{ \begin{array}{l} \sum_{i=1}^{2} \left[(\widetilde{M}_{D_s^i} - M_{D_s})/\sigma_M \right]^2 + \\ \sum_{i=1}^{N} \left[(\widetilde{\Delta M}_{D_s^{*i} - D_s^i} - \Delta M_{D_s^* - D_s})/\sigma_{\Delta M} \right]^2 \end{array} \right\}$$

➢ performed a 2D un-binned maximum likelihood fit to ΔE and M_{bc}

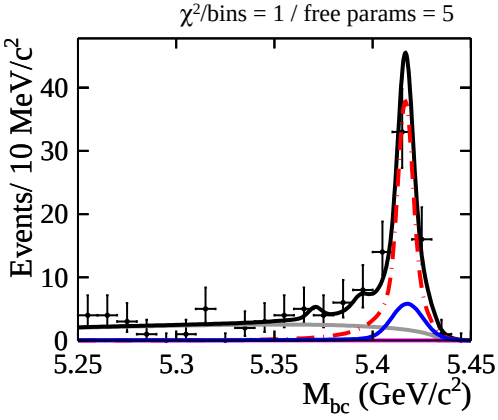
Results with $121.4 fb^{-1}$ PRELIMINARY



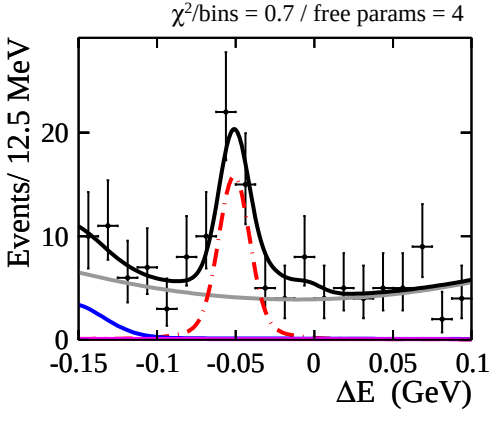
$D_s^+ D_s^- = 33.1^{+6.0}_{-5.4}$

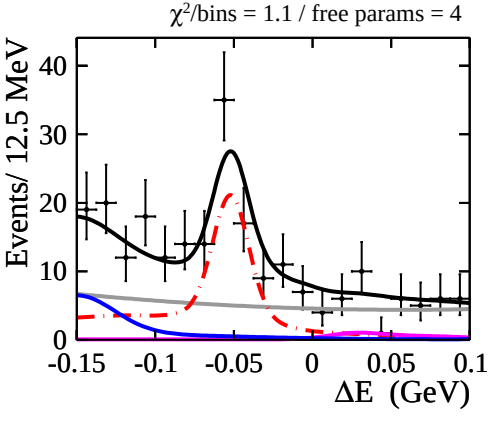


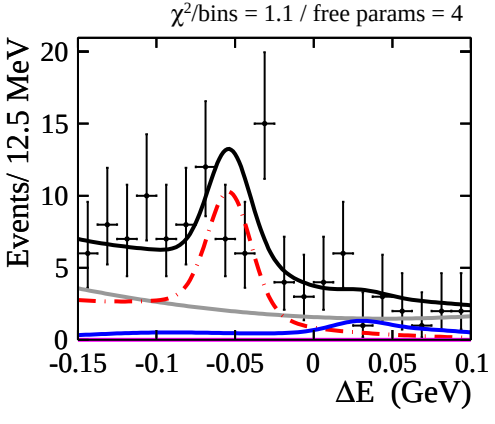
$D_s^{*+} D_s^- = 44.5^{+5.8}_{-5.5}$



$D_s^{*+} D_s^{*-} = 24.4^{+4.1}_{-3.8}$

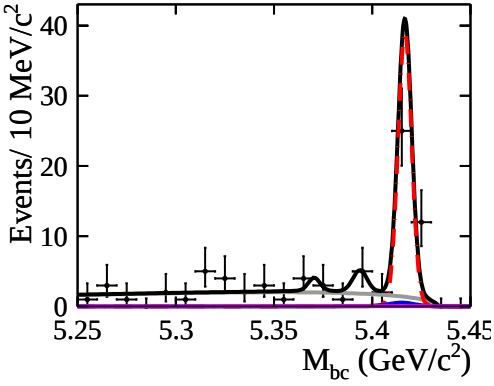




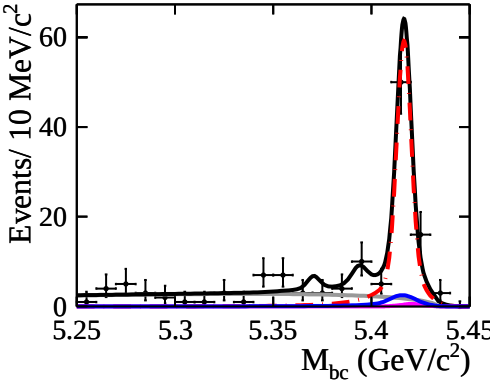


Signal Region Projections PRELIMINARY

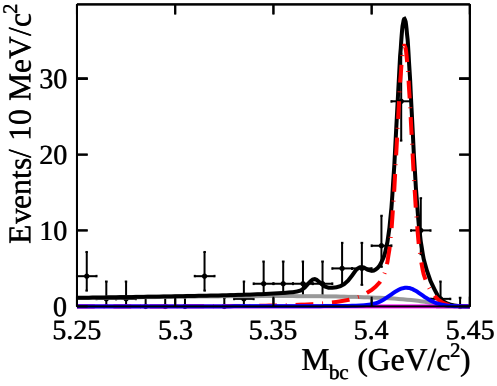
select events in $\Delta E[-0.1, 0.0]$



$D_s^+ D_s^- = 33.1^{+6.0}_{-5.4}$

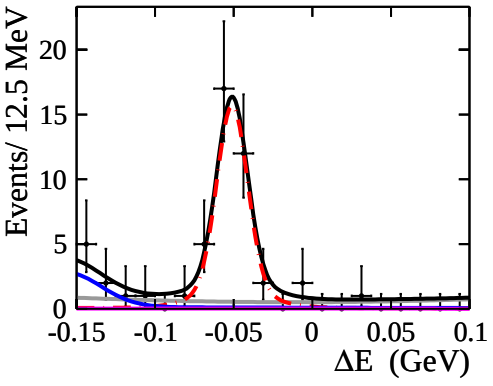


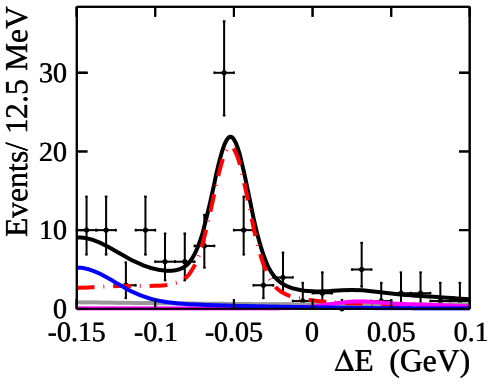
$D_s^{*+} D_s^- = 44.5^{+5.8}_{-5.5}$

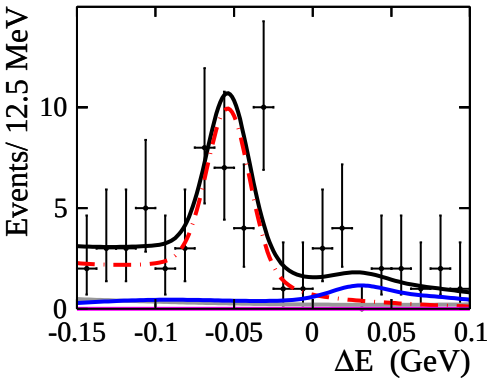


$D_s^{*+} D_s^{*-} = 24.4^{+4.1}_{-3.8}$

select events in $M_{bc}[5.4, 5.43]$







Systematic Errors PRELIMINARY

Source	$D_s^+ D_s^-$		$D_s^* D_s$		$D_s^{*+} D_s^{*-}$		
	$+\sigma$	$-\sigma$	$+\sigma$	$-\sigma$	$+\sigma$	$-\sigma$	
Signal PDF Shape	2.7	2.2	2.2	2.4	5.1	3.8	
Background PDF Shape	1.5	1.2	1.3	1.4	2.9	2.2	
WC + CF fraction	0.7	0.6	4.6	4.5	6.2	6.2	
$\mathcal{R}$ requirement ($q\bar{q}$) suppr.	2.1	2.1	1.7	1.7	1.2	1.2	
Best candidate selection	5.5	0.0	1.5	0.0	1.5	0.0	
$K^{\pm}$ Identification	7.0	7.0	7.0	7.0	7.0	7.0	
K_s Reconstruction	2.0	2.0	2.0	2.0	2.0	2.0	
π^0 Reconstruction	1.1	1.1	1.1	1.1	1.1	1.1	
γ	-	-	3.8	3.8	7.6	7.6	
Tracking	2.2	2.2	2.2	2.2	2.2	2.2	
Polarization	0.1	0.1	0.8	0.7	0.5	1.0	
MC statistics for ε	0.2	0.2	0.4	0.4	0.5	0.5	"External" errors
$D_s^{(*)}$ BF's	8.6	8.6	8.6	8.6	8.7	8.7	
$N_{B_s^{(*)}B_s^{(*)}}$			18.3				
$f_{B_s^* \overline{B}_s^*}$			2.0				
Total	22.7	21.9	22.8	22.7	24.6	24.3	

Results PRELIMINARY

Mode	Y (events)	ε_{MC} ($\times 10^{-4}$)	$\mathcal{B}$ (%)	S
$D_s^+ D_s^-$	$33.1^{+6.0}_{-5.4}$	4.72	$0.58^{+0.11}_{-0.09} \pm 0.13$	11.6
$D_s^{*+} D_s^- + D_s^{*-} D_s^+$	$44.5^{+5.8}_{-5.5}$	2.08	$1.8 \pm 0.2 \pm 0.40$	13.3
$D_s^{*+} D_s^{*-}$	$24.4^{+4.1}_{-3.8}$	1.01	$1.98 \pm 0.3 \pm 0.5$	8.6
Sum	$102.0^{+9.3}_{-8.6}$		$4.3 \pm 0.4 \pm 1.0$	
$\Delta\Gamma_s/\Gamma_s$	$(9.0 \pm 0.9 \pm 2.2)$ %			

$\Delta\Gamma_s/\Gamma_s = 2\mathcal{B}/(1-\mathcal{B})$

Statistical significance

$S = \sqrt{-2ln(\mathcal{L}_0/\mathcal{L}_{max})}$

$\Delta\Gamma_s/\Gamma_s$ compare to :

our measurement with 23.6 fb^{-1} : $(14.7^{+3.6+4.2}_{-3.0-4.1})\%$
(PRL 105, 201802 (2010))

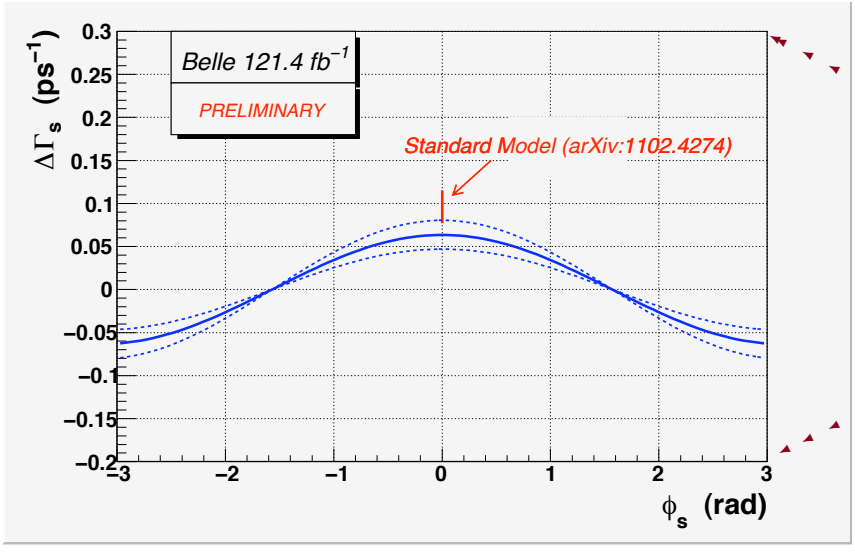
PDG average: $(9.2^{+5.1}_{-5.4})\%$

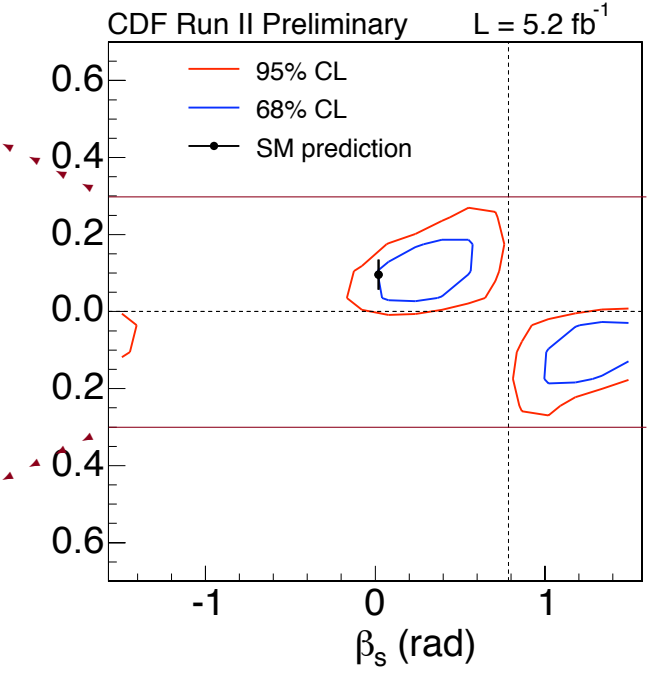
$\Delta\Gamma_s$ with CPV

$$4\,\mathcal{B}(B_s \to D_s D_s) = \left(\frac{\Delta\Gamma}{\cos\varphi}\right)\left[\frac{1+\cos\varphi}{1+\Delta\Gamma/2} + \frac{1-\cos\varphi}{1-\Delta\Gamma/2}\right]$$

$$\text{where } \varphi = \text{Arg}\left(\frac{M_{12}}{\Gamma_{12}}\right)$$

Dunietz, Fleischer, Nierste, PRD 63, 114015 (2001)





Conclusion

- Exclusive measurements with $121.4 fb^{-1}$ data

  PRELIMINARY RESULTS

  - $\mathcal{B}(B_s \to D_s^+ D_s^-) = (0.6 \pm 0.1 \pm 0.1)\%$
  - $\mathcal{B}(B_s \to D_s^{*\pm} D_s^{*\mp}) = (1.8 \pm 0.2 \pm 0.40)\%$
  - $\mathcal{B}(B_s \to D_s^{*+} D_s^{*-}) = (1.98 \pm 0.3 \pm 0.5)\%$ (First observation)

- Statistically more precise measurement of $\Delta\Gamma_s/\Gamma_s$, assuming negligible CPV

  - $\Delta\Gamma_s/\Gamma_s = (9.0 \pm 0.9 \pm 2.2)\%$
  - Some small theoretical uncertainties exist, e.g.
    size of 3-body partial widths is unknown,
    CP-odd component of Ds*Ds* is unknown.