Long-Distance Contribution to $\Delta\Gamma_s$ in the $B_s - \bar{B}_s$ System

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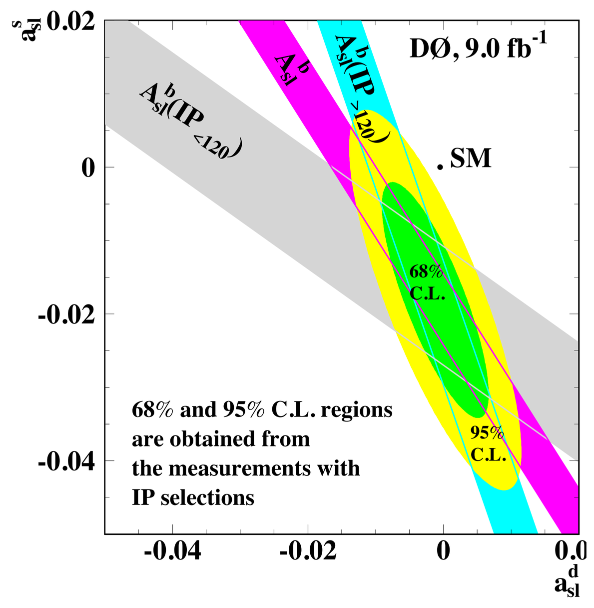
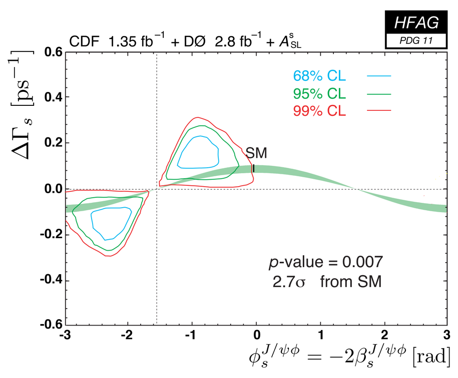
a_{sl} and $\Gamma_{12,s}$

- Motivated by D0 dimuon asymmetry:





OPE:

$\Delta\Gamma_s^{SM} = (0.087 \pm 0.021)\text{ps}^{-1}$

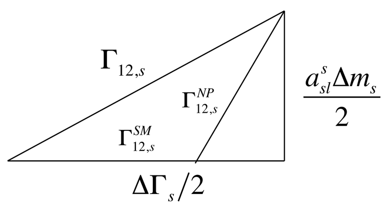
$\Delta\Gamma_s^{SM}/\Gamma_s^{SM} = (13.3 \pm 3.2)\%$

$\Delta m_s^{SM} = (17.3 \pm 2.6)\text{ps}^{-1}$

$\varphi_s^{SM} = (0.22 \pm 0.06)^\circ$

- a_{sl} is related to and bounded by $\Gamma_{12,s}$

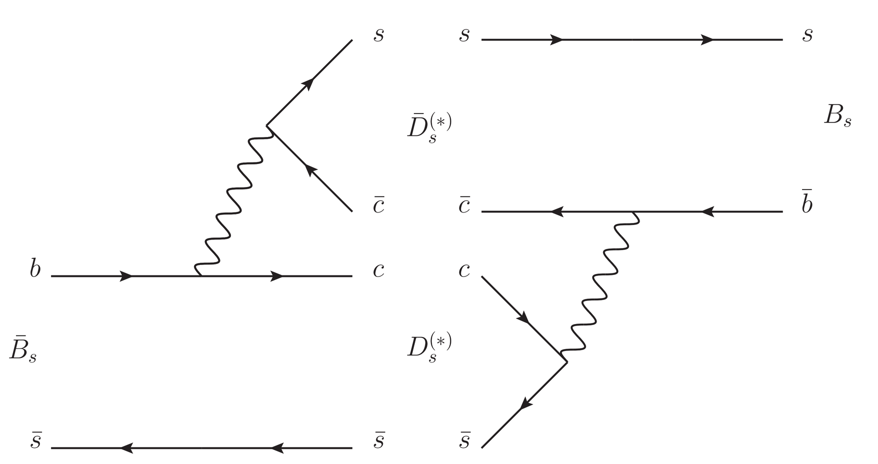
$$a^s_{sl} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s = \frac{2|\Gamma_{12,s}|}{\Delta m_s}\sin\phi_s$$



$\Gamma_{12,s}$ needs to be enhanced at least ×3

Two-body contribution to $\Delta\Gamma_s$

$$\Gamma_{12,s} = \sum_f \Gamma_{12f} = \frac{1}{2m_{B_s}}\sum_f \langle B_s|H_W|f\rangle\langle f|H_W|\bar{B}_s\rangle$$



- $|\Delta\Gamma_s/\Gamma_s(f)| \le 2\sqrt{Br(\bar{B}_s \to f)Br(B_s \to f)}$
- $D_s^{(*)}\bar{D}_s^{(*)}$ results agree with early work
- P-wave D_s^{**} contribution is negligible (due to mismatch and cancelation)
- $D_{sJ}(2700)$ contribution is non-negligible (broad width ⇒ consider in 3-body case)

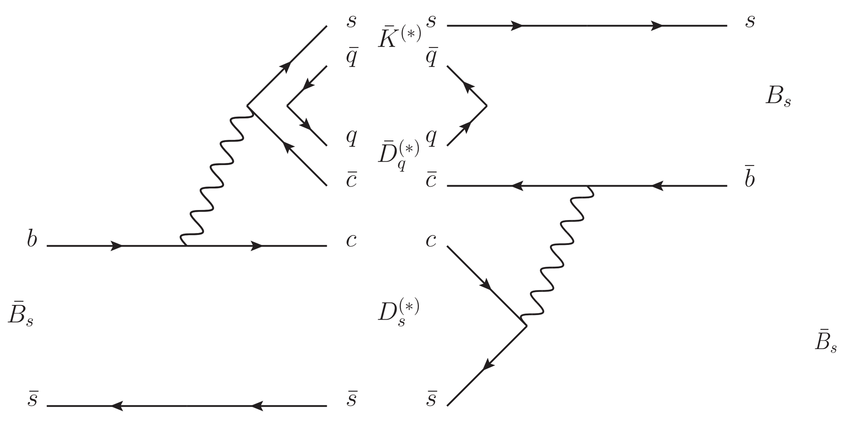
An update

Mode(f)	$\mathcal{B}(\bar{B}_{s,(u)} \to f)$ (%) data	$\mathcal{B}(\bar{B}_s \to f)$ (%) this work	$\Delta\Gamma_f/\Gamma_s$ (%) this work
$D_s\bar{D}_s$	1.04 ± 0.35 (1.00 ± 0.17)	$1.4 \pm 0.3 \pm 0.3$	$2.7 \pm 0.6 \pm 0.6$
$D_s^*\bar{D}_s + D_s\bar{D}_s^*$	2.75 ± 1.08 (1.58 ± 0.33)	$1.8 \pm 0.4 \pm 0.4$	$3.6 \pm 0.8 \pm 0.8$
$D_s^*\bar{D}_s^*$	3.08 ± 1.49 (1.71 ± 0.24)	$2.3 \pm 0.5 \pm 0.5$	$3.8 \pm 0.8 \pm 0.8$
$D_s^{(*)}\bar{D}_s^{(*)}$	4.9 ± 1.4 6.9 ± 2.3 4.0 ± 1.5 (4.29 ± 0.74)	$5.5 \pm 1.2 \pm 1.1$	$\boxed{10.2 \pm 2.2 \pm 2.1}$
$D_s^{(*)}\bar{D}_s^{**}$, $D_s^{**}\bar{D}_s^{(*)}$, $D_s^{**}\bar{D}_s^{**}$	N/A	$2.6 \pm 0.7 \pm 0.5$	$\boxed{0.2 \pm 0.3 \pm 0.04}$

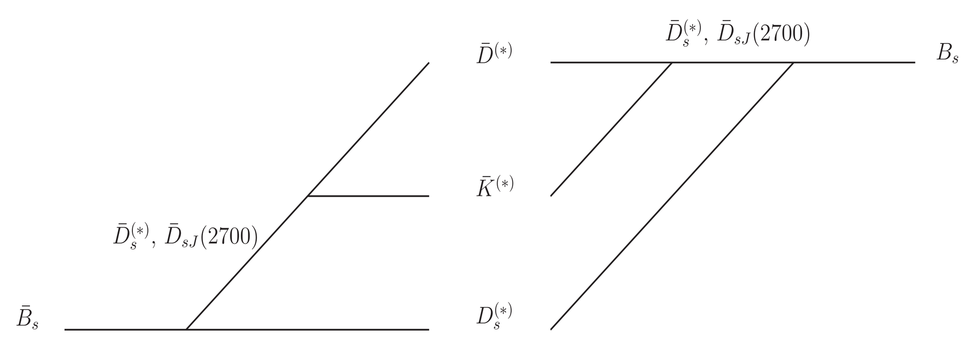
Mode(f)	$\mathcal{B}(\bar{B}_s \to f)$ (%)	$\mathcal{B}(B_s \to f)$ (%)	$\Delta\Gamma_f/\Gamma_s$ (%)
$D_s\bar{D}_{sJ}(2700)$	$0.44 \pm 0.18 \pm 0.09$	$0.02 \pm 0.01 \pm 0.01$	$0.21 \pm 0.08 \pm 0.04$
$D_s^*\bar{D}_{sJ}(2700)$	$2.0 \pm 0.8 \pm 0.4$	$0.08 \pm 0.03 \pm 0.02$	$0.73 \pm 0.27 \pm 0.15$
$D_s^{(*)}\bar{D}_{sJ}(2700)$	$2.5 \pm 1.0 \pm 0.5$	$0.11 \pm 0.03 \pm 0.02$	$1.9 \pm 0.7 \pm 0.4$ [a]
$D_s^{**}\bar{D}_{sJ}(2700)$	$0.14 \pm 0.08 \pm 0.03$	$0.02 \pm 0.07 \pm 0.01$	$0.08 \pm 0.03 \pm 0.02$ [a]

[a] The contribution from CP conjugate modes $\bar{f}$ is included.

Three-Body Contribution to $\Delta\Gamma_s$



Current-produced | Transition



Current-produced Dominated by D_{sJ} | Transition Dominated by $D_s^{(*)}$

- Need to reproduce existing data of $B_{u,d}$ decays first:
  - Scenario I: Use pole model with $D_s^{(*)}$ and D_{sJ} poles
  - Scenario II: Include NR effect in current-produced $\bar{D}\bar{K}$
- Experimental results can be reasonably reproduced:

Comparing to experimental rates of SU(3) related current-produced modes

Measurement	BaBar Data(%)	Belle Data(%)	Our Results (%) Scenario I (I') Pole model with D_{sJ} (without D_{sJ})	Scenario II Pole model+NR	Remarks
Category 1: $\bar{D}\bar{K}$ in current with $\bar{B} \to D$ transition					
$\mathcal{B}(\bar{B}_u \to D_u\bar{D}_{sJ}(2700)^-) \times \mathcal{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0K^-)$	N/A	$0.113^{+0.026}_{-0.040}$	$0.12 \pm 0.08 \pm 0.03$ (0)	$0.12 \pm 0.08 \pm 0.03$	Input for Scenario I.
$\mathcal{B}(\bar{B}_u \to D_u\bar{D}^0K^-)$	0.131 ± 0.014	0.222 ± 0.033	~ 0.23 (~ 0.07)	~ 0.11	Color-suppressed diagram neglected.
$\mathcal{B}(\bar{B}_d \to D_d\bar{D}^0K^-)$	0.107 ± 0.011	N/A	$0.22 \pm 0.14 \pm 0.05$ $(0.06 \pm 0.03 \pm 0.01)$	$0.10^{+0.23}_{-0.02} \pm 0.02$	Input for Scenario II.
$\mathcal{B}(\bar{B}_d \to D_d\bar{D}_{sJ}(2700)^-) \times \mathcal{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0K^-)$	N/A	N/A	$0.11 \pm 0.07 \pm 0.02$ (0)	$0.11 \pm 0.07 \pm 0.02$	
Category 2: $\bar{D}\bar{K}$ in current with $\bar{B} \to D^*$ transition					
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}^0K^-)$	0.247 ± 0.021	N/A	$0.67 \pm 0.45 \pm 0.14$ $(0.07 \pm 0.03 \pm 0.01)$	$0.32^{+0.75}_{-0.13} \pm 0.07$	Input for Scenario II.
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}_{sJ}(2700)^-) \times \mathcal{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0K^-)$	N/A	N/A	$0.50 \pm 0.33 \pm 0.11$ (0)	$0.50 \pm 0.33 \pm 0.11$	
Category 3: $\bar{D}^*\bar{K}$ in current with $\bar{B} \to D$ transition					
$\mathcal{B}(\bar{B}_d \to D_d\bar{D}^{*0}K^-)$	0.346 ± 0.041	N/A	$0.35 \pm 0.21 \pm 0.07$ $(0.20 \pm 0.10 \pm 0.04)$	$0.35 \pm 0.21 \pm 0.07$	
$\mathcal{B}(\bar{B}_d \to D_d\bar{D}_{sJ}(2700)^-) \times \mathcal{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^{*0}K^-)$	N/A	N/A	$0.11 \pm 0.07 \pm 0.02$ (0)	$0.11 \pm 0.07 \pm 0.02$	
Category 4: $\bar{D}^*\bar{K}$ in current with $\bar{B} \to D^*$ transition					
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}^{*0}K^-)$	1.060 ± 0.092	N/A	$0.94 \pm 0.62 \pm 0.20$ $(0.15 \pm 0.08 \pm 0.03)$	$0.94 \pm 0.62 \pm 0.20$	
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}_{sJ}(2700)^-) \times \mathcal{B}(\bar{D}_{sJ}(2700)^- \to D^{*0}K^-)$	N/A	N/A	$0.52 \pm 0.33 \pm 0.11$ (0)	$0.52 \pm 0.33 \pm 0.11$	
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}^{*+}\bar{K}^0)$	0.826 ± 0.080	N/A	~ 0.91 (~ 0.15)	~ 0.91	Color-suppressed diagram neglected.
$\mathcal{B}(\bar{B}_d \to D_d^*\bar{D}^{*+}K^0_S)$	0.44 ± 0.08	0.34 ± 0.08	~ 0.46 (~ 0.07)	~ 0.46	Color-suppressed diagram neglected.

Three Body Contribution to $\Delta\Gamma_s$

Scenario I (I'): Pole Contribution Only

Modes with $\bar{K}$				Modes with $\bar{K}^*$			
Mode(f)	$\mathcal{B}_{\mathcal{J}}(\bar{B}_s \to f)$(%)	$\mathcal{B}_{\mathcal{T}}(B_s \to f)$(%)	$\Delta\Gamma_f/\Gamma_s$(%)	Mode(f)	$\mathcal{B}_{\mathcal{J}}(\bar{B}_s \to f)$(%)	$\mathcal{B}_{\mathcal{T}}(B_s \to f)$(%)	$\Delta\Gamma_f/\Gamma_s$(%)
$D_s\bar{D}^0K^-$	$0.19 \pm 0.12 \pm 0.04$ $(0.06 \pm 0.03 \pm 0.01)$	$0.04 \pm 0.02 \pm 0.01$ $(0.03 \pm 0.02 \pm 0.01)$	$0.17 \pm 0.10 \pm 0.03$ $(0.09 \pm 0.04 \pm 0.02)$	$D_s\bar{D}^0K^{*-}$	$(0.07 \pm 0.03 \pm 0.01)$	$(0.03 \pm 0.01 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_sD^-\bar{K}^0$	$0.19 \pm 0.12 \pm 0.04$ $(0.05 \pm 0.03 \pm 0.01)$	$0.04 \pm 0.02 \pm 0.01$ $(0.03 \pm 0.02 \pm 0.01)$	$0.16 \pm 0.09 \pm 0.03$ $(0.08 \pm 0.04 \pm 0.02)$	$D_sD^-\bar{K}^{*0}$	$(0.06 \pm 0.03 \pm 0.01)$	$(0.03 \pm 0.01 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_s^*\bar{D}^0K^-$	$0.64 \pm 0.43 \pm 0.13$ $(0.07 \pm 0.03 \pm 0.01)$	$0.09 \pm 0.05 \pm 0.02$ $(0.06 \pm 0.03 \pm 0.01)$	$0.38 \pm 0.23 \pm 0.08$ $(0.12 \pm 0.05 \pm 0.03)$	$D_s^*\bar{D}^0K^{*-}$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.07 \pm 0.03 \pm 0.01)$
$D_s^*D^-\bar{K}^0$	$0.62 \pm 0.42 \pm 0.13$ $(0.07 \pm 0.03 \pm 0.01)$	$0.09 \pm 0.05 \pm 0.02$ $(0.06 \pm 0.03 \pm 0.01)$	$0.37 \pm 0.22 \pm 0.08$ $(0.11 \pm 0.05 \pm 0.02)$	$D_s^*D^-\bar{K}^{*0}$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.07 \pm 0.03 \pm 0.02)$
$D_s\bar{D}^{*0}K^-$	$0.30 \pm 0.18 \pm 0.06$ $(0.17 \pm 0.08 \pm 0.04)$	$0.09 \pm 0.05 \pm 0.02$ $(0.08 \pm 0.04 \pm 0.02)$	$0.31 \pm 0.21 \pm 0.06$ $(0.23 \pm 0.11 \pm 0.05)$	$D_s\bar{D}^{*0}K^{*-}$	$(0.18 \pm 0.08 \pm 0.04)$	$(0.08 \pm 0.04 \pm 0.02)$	$(0.24 \pm 0.12 \pm 0.05)$
$D_sD^{*-}\bar{K}^0$	$0.29 \pm 0.18 \pm 0.06$ $(0.17 \pm 0.08 \pm 0.04)$	$0.09 \pm 0.04 \pm 0.02$ $(0.08 \pm 0.04 \pm 0.02)$	$0.30 \pm 0.20 \pm 0.06$ $(0.22 \pm 0.11 \pm 0.05)$	$D_sD^{*-}\bar{K}^{*0}$	$(0.17 \pm 0.08 \pm 0.04)$	$(0.08 \pm 0.04 \pm 0.02)$	$(0.24 \pm 0.11 \pm 0.05)$
$D_s^*\bar{D}^{*0}K^-$	$0.89 \pm 0.59 \pm 0.18$ $(0.14 \pm 0.07 \pm 0.03)$	$0.17 \pm 0.09 \pm 0.03$ $(0.11 \pm 0.05 \pm 0.02)$	$0.65 \pm 0.39 \pm 0.14$ $(0.23 \pm 0.11 \pm 0.05)$	$D_s^*\bar{D}^{*0}K^{*-}$	$(0.05 \pm 0.02 \pm 0.01)$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_s^*D^{*-}\bar{K}^0$	$0.86 \pm 0.57 \pm 0.18$ $(0.14 \pm 0.06 \pm 0.03)$	$0.16 \pm 0.09 \pm 0.03$ $(0.10 \pm 0.05 \pm 0.02)$	$0.64 \pm 0.38 \pm 0.13$ $(0.22 \pm 0.10 \pm 0.05)$	$D_s^*D^{*-}\bar{K}^{*0}$	$(0.05 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
Total			$5.9 \pm 3.6 \pm 1.2$[a] $(2.6 \pm 1.2 \pm 0.5)$[a]	Total			$(1.9 \pm 0.9 \pm 0.4)$[a]

[a] The contribution from CP conjugate modes $\bar{f}$ is included.

Scenario II: Pole contribution + NR in $\bar{D}\bar{K}$ time-like form factors

Modes with $\bar{K}$				Modes with $\bar{K}^*$			
Mode(f)	$\mathcal{B}_{\mathcal{J}}(\bar{B}_s \to f)$(%)	$\mathcal{B}_{\mathcal{T}}(B_s \to f)$(%)	$\Delta\Gamma_f/\Gamma_s$(%)	Mode(f)	$\mathcal{B}_{\mathcal{J}}(\bar{B}_s \to f)$(%)	$\mathcal{B}_{\mathcal{T}}(B_s \to f)$(%)	$\Delta\Gamma_f/\Gamma_s$(%)
$D_s\bar{D}^0K^-$	$0.09^{+0.22}_{-0.02} \pm 0.02$	$0.04 \pm 0.02 \pm 0.01$	$0.08 \pm 0.15 \pm 0.01$	$D_s\bar{D}^0K^{*-}$	$(0.07 \pm 0.03 \pm 0.01)$	$(0.03 \pm 0.01 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_sD^-\bar{K}^0$	$0.09^{+0.22}_{-0.02} \pm 0.02$	$0.04 \pm 0.02 \pm 0.01$	$0.07 \pm 0.13 \pm 0.01$	$D_sD^-\bar{K}^{*0}$	$(0.06 \pm 0.03 \pm 0.01)$	$(0.03 \pm 0.01 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_s^*\bar{D}^0K^-$	$0.31^{+0.74}_{-0.13} \pm 0.13$	$0.09 \pm 0.05 \pm 0.02$	$0.11 \pm 0.38 \pm 0.02$	$D_s^*\bar{D}^0K^{*-}$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.07 \pm 0.03 \pm 0.01)$
$D_s^*D^-\bar{K}^0$	$0.29^{+0.71}_{-0.13} \pm 0.13$	$0.09 \pm 0.05 \pm 0.02$	$0.11 \pm 0.38 \pm 0.02$	$D_s^*D^-\bar{K}^{*0}$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.07 \pm 0.03 \pm 0.02)$
$D_s\bar{D}^{*0}K^-$	$0.30 \pm 0.18 \pm 0.06$	$0.09 \pm 0.05 \pm 0.02$	$0.31 \pm 0.21 \pm 0.06$	$D_s\bar{D}^{*0}K^{*-}$	$(0.18 \pm 0.08 \pm 0.04)$	$(0.08 \pm 0.04 \pm 0.02)$	$(0.24 \pm 0.12 \pm 0.05)$
$D_sD^{*-}\bar{K}^0$	$0.29 \pm 0.18 \pm 0.06$	$0.09 \pm 0.04 \pm 0.02$	$0.30 \pm 0.20 \pm 0.06$	$D_sD^{*-}\bar{K}^{*0}$	$(0.17 \pm 0.08 \pm 0.04)$	$(0.08 \pm 0.04 \pm 0.02)$	$(0.24 \pm 0.11 \pm 0.05)$
$D_s^*\bar{D}^{*0}K^-$	$0.89 \pm 0.59 \pm 0.18$	$0.17 \pm 0.09 \pm 0.03$	$0.65 \pm 0.39 \pm 0.14$	$D_s^*\bar{D}^{*0}K^{*-}$	$(0.05 \pm 0.02 \pm 0.01)$	$(0.04 \pm 0.02 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
$D_s^*D^{*-}\bar{K}^0$	$0.86 \pm 0.57 \pm 0.18$	$0.16 \pm 0.09 \pm 0.03$	$0.64 \pm 0.38 \pm 0.13$	$D_s^*D^{*-}\bar{K}^{*0}$	$(0.05 \pm 0.02 \pm 0.01)$	$(0.03 \pm 0.02 \pm 0.01)$	$(0.08 \pm 0.04 \pm 0.02)$
Total			$4.5 \pm 4.4 \pm 0.9$[a]	Total			$(1.9 \pm 0.9 \pm 0.4)$[a]

Conclusion

- Final results:

Scenario I (Pole model)	Scenario II (Pole model + NR)
$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*,**)}\bar{D}_s^{(*,**)}) = (10.4 \pm 2.5 \pm 2.2)\%$	$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*,**)}\bar{D}_s^{(*,**)}) = (10.4 \pm 2.5 \pm 2.2)\%$
$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*)}\bar{D}_s^{(*)}\bar{K}) = (5.9 \pm 3.6 \pm 1.2)\%$	$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*)}\bar{D}_s^{(*)}\bar{K}) = (4.5 \pm 4.4 \pm 0.9)\%$
$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*)}\bar{D}_s^{(*)}\bar{K}^*) = (1.9 \pm 0.9 \pm 0.4)\%$	$\Delta\Gamma_s/\Gamma_s\,(D_s^{(*)}\bar{D}_s^{(*)}\bar{K}^*) = (1.9 \pm 0.9 \pm 0.4)\%$
$\Delta\Gamma_s/\Gamma_s\,(\text{Total}) = (18.2 \pm 7.0 \pm 3.8)\%$	$\Delta\Gamma_s/\Gamma_s\,(\text{Total}) = (16.7 \pm 7.8 \pm 3.5)\%$

- Our results agree with the SD ones.
- Enhancement in $\Delta\Gamma_s$ if confirmed must have NP origin.
- Three-body contribution cannot be neglected.
- Predictions on 3-body decay rates can be checked.