Time-dependent CP violation measurements from beauty to open charm decays

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on behalf of LHCb collaboration

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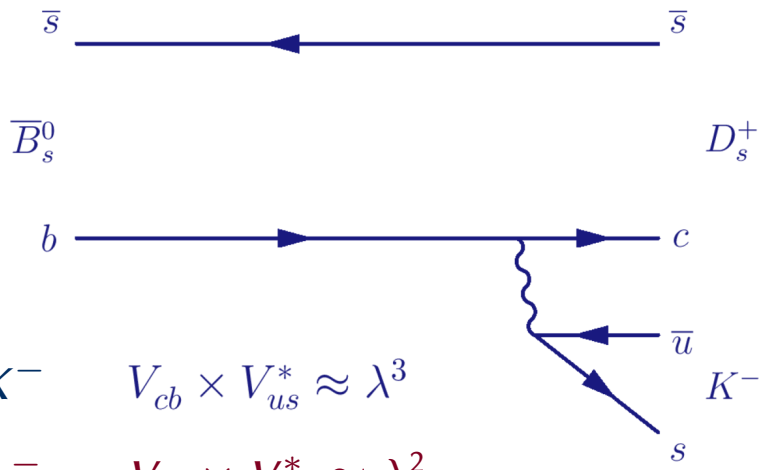
Nikhef

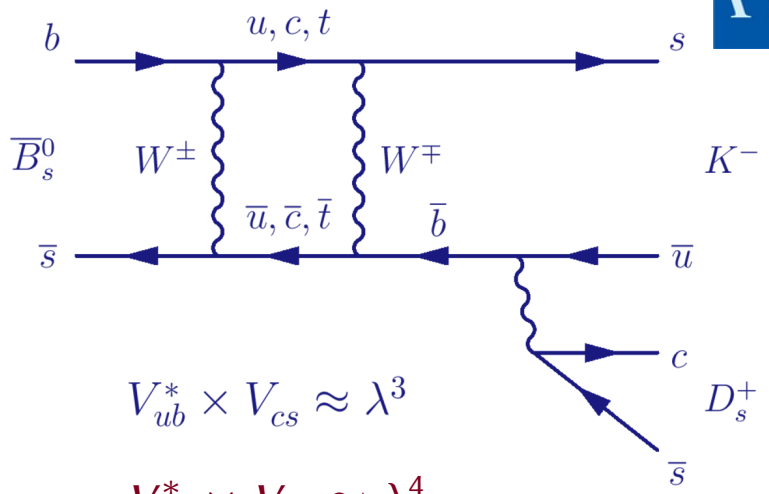
LHCb

B TO OPEN CHARM DECAYS

- Wide variety of measurements possible using decay time dependent analyses
  - ϕ_s from $B_s \to D_s^+ D_s^-$ [PRL 113, 211801]
  - Penguin pollution constraint on $\sin(2\beta)$ from $B \to D^+ D^-$ [PRL 117, 261801]
  - $B_s - \bar{B}_s$ mixing frequency from $B_s \to D_s^- \pi^+$ [NJP 15 (2013) 053021]
  - γ from $B_s \to D_s^- K^+$ and $B \to D^- \pi^+$ [JHEP 06 (2018) 084, JHEP 03 (2018) 059]
    - No CP violation in decay, unlike time-independent measurements
    - Interference of decays with and without mixing
    - Need to resolve oscillations
- Presenting results using 3fb^{-1} of run 1 data

Decay time dependent analyses





for $\bar{B}^0_s \to D^+_s K^-$ $\quad V_{cb} \times V^*_{us} \approx \lambda^3$ $\quad V^*_{ub} \times V_{cs} \approx \lambda^3$

for $\bar{B}^0 \to D^+ \pi^-$ $\quad V_{cb} \times V^*_{ud} \approx \lambda^2$ $\quad V^*_{ub} \times V_{cd} \approx \lambda^4$

Sensitive to $\gamma - 2\beta_s$ ($\bar{B}^0_s \to D^+_s K^-$) or $\gamma + 2\beta$ ($\bar{B}^0 \to D^+ \pi^-$)

- Small yields (6k in run I)
- $D^+_s \to K^+K^-\pi^+, K^-\pi^+\pi^-, \pi^+\pi^-\pi^+$
- More difficult backgrounds
- $\Delta M_s = (17.75 \pm 0.02) ps^{-1}$
- $\Delta\Gamma_s = (0.088 \pm 0.006) ps^{-1}$
- Large interference effects

- Large yields (480k in run I)
- $D^+ \to K^-\pi^+\pi^+$
- Clean signal
- $\Delta M_d = (0.507 \pm 0.002) ps^{-1}$
- Negligible $\Delta\Gamma_d$
- Small interference effects

Decay time formalism

$$\frac{\mathrm{d}\Gamma_{B_s^0\to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos\left(\Delta m_s t\right) - S_f\sin\left(\Delta m_s t\right)\right],$$

$$\frac{\mathrm{d}\Gamma_{\bar{B}_s^0\to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos\left(\Delta m_s t\right) + S_f\sin\left(\Delta m_s t\right)\right],$$

$$C_f = \frac{1-r_{D_sK}^2}{1+r_{D_sK}^2},$$

Assuming no CPV in mixing or decay:
$r_{D_sK} \sim 0.4$

$$A_f^{\Delta\Gamma} = \frac{-2r_{D_sK}\cos(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}^2}, \quad A_{\overline{f}}^{\Delta\Gamma} = \frac{-2r_{D_sK}\cos(\delta+(\gamma-2\beta_s))}{1+r_{D_sK}^2},$$

$$S_f = \frac{2r_{D_sK}\sin(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}^2}, \quad S_{\overline{f}} = \frac{-2r_{D_sK}\sin(\delta+(\gamma-2\beta_s))}{1+r_{D_sK}^2}.$$

Decay time formalism

$$\frac{d\Gamma_{B^0_s \to f}(t)}{dt} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right.$$
$$\left. + C_f \cos\left(\Delta m_d t\right) - S_f \sin\left(\Delta m_d t\right)\right],$$

$$\frac{d\Gamma_{\overline{B}^0_s \to f}(t)}{dt} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right.$$
$$\left. - C_f \cos\left(\Delta m_d t\right) + S_f \sin\left(\Delta m_d t\right)\right],$$

$$r_{D\pi} = \tan\theta_c \frac{f_{D^+}}{f_{D_s}}\sqrt{\frac{\mathcal{B}(B^0 \to D_s^+\pi^-)}{\mathcal{B}(B^0 \to D^-\pi^+)}} = 0.0182 \pm 0.0012 \pm 0.0036(SU(3))$$

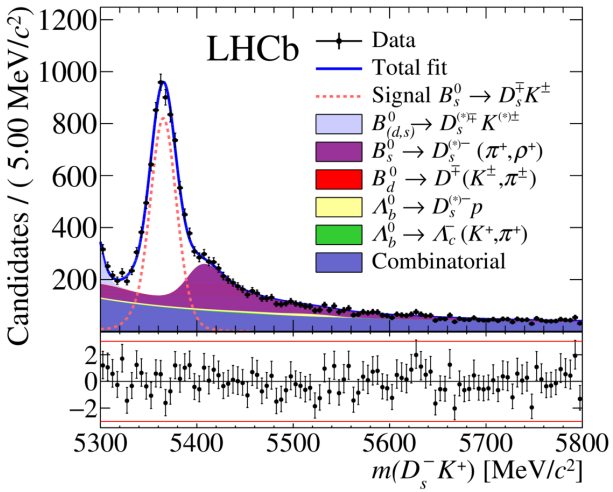
[JHEP 06 (2018) 084]

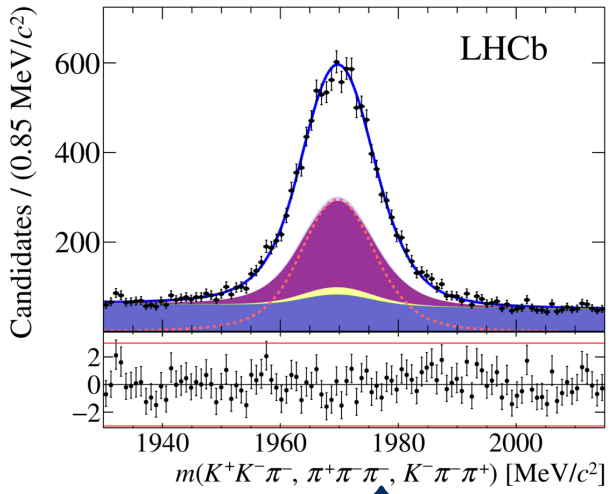
$$C_f = \frac{1-r_{D\pi}^2}{1+r_{D\pi}^2} = -C_{\bar{f}}, \quad \Rightarrow \text{no sensitivity } C_f = 1$$

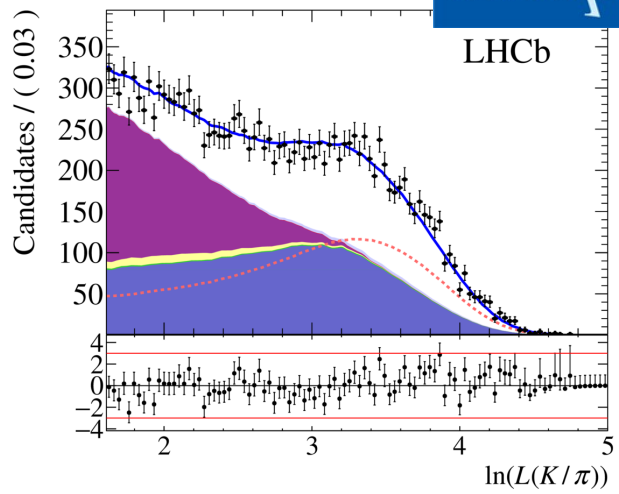
$$S_f = -\frac{2r_{D\pi}\sin\left[\delta-(2\beta+\gamma)\right]}{1+r_{D\pi}^2},$$

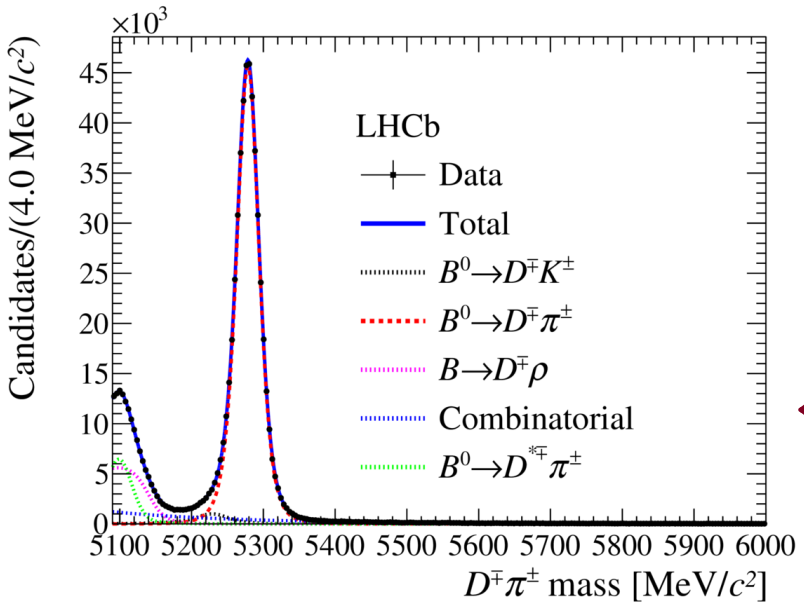
$$S_{\bar{f}} = \frac{2r_{D\pi}\sin\left[\delta+(2\beta+\gamma)\right]}{1+r_{D\pi}^2},$$

Signal mass fits









$B^0 \to D_s^- K^+$ Signal yield of 5955 ± 90

[JHEP 03 (2018) 059]

$B^0 \to D^- \pi^+$ Signal yield of $(479 \pm 0.7) \times 10^3$

[JHEP 06 (2018) 084]

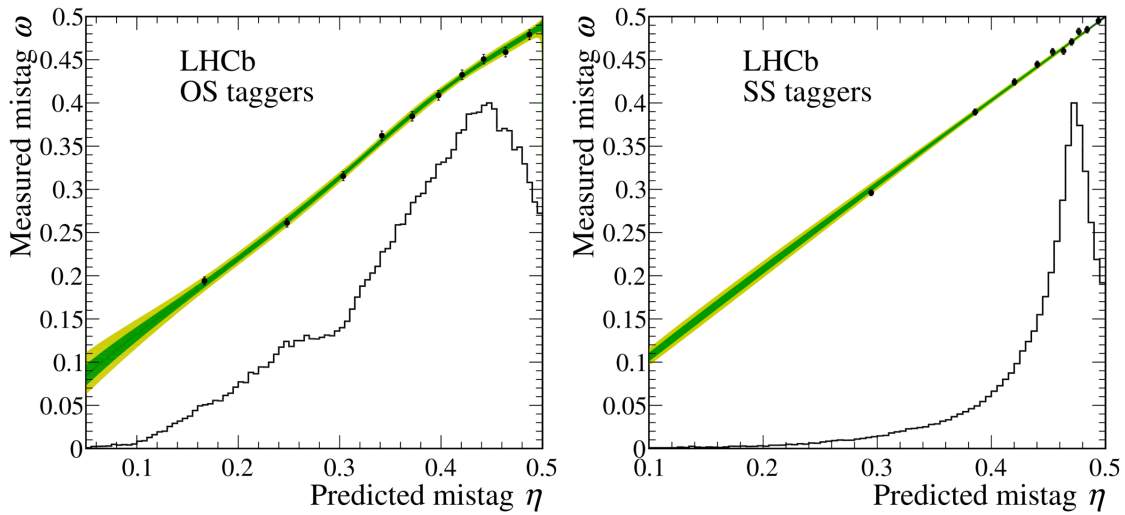
Flavor tagging [JHEP 06 (2018) 084, JHEP 03 (2018) 059]

$B_s^0 \to D_s^- \pi^+$	ε_{tag} [%]	ε_{eff} [%]
OS only	12.94 ± 0.11	1.41 ± 0.11
SS only	39.70 ± 0.16	1.29 ± 0.13
Both OS and SS	24.21 ± 0.14	3.10 ± 0.18
Total	76.85 ± 0.24	5.80 ± 0.25

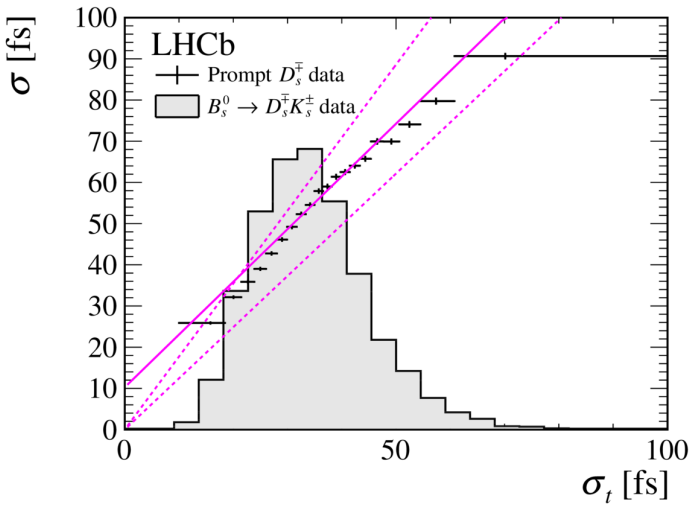
- Calibration using $B_s^0 \to D_s^- \pi^+$
- $\epsilon_{eff} = \epsilon_{tag}(1 - 2 < \omega >)^2$

- $B^0 \to D^- \pi^+$: self tagging calibration ($C_f = 1$)
- Tagging efficiency of $\sim 85\%$

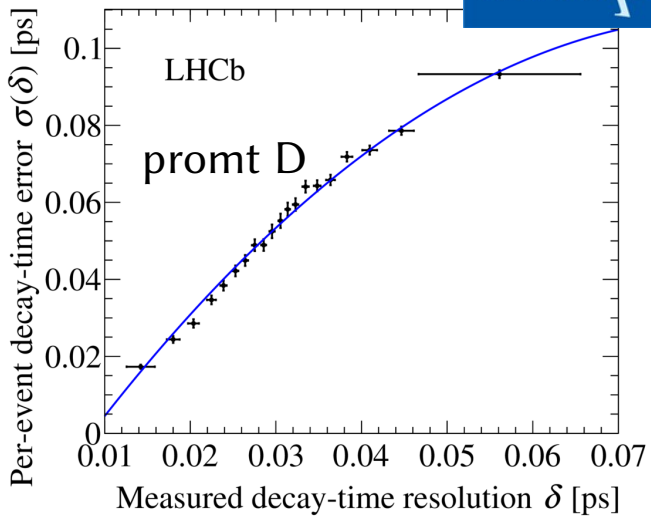
  79% SS, 37% OS, 31% both
- $\epsilon_{eff} = (5.59 \pm 0.01)\%$

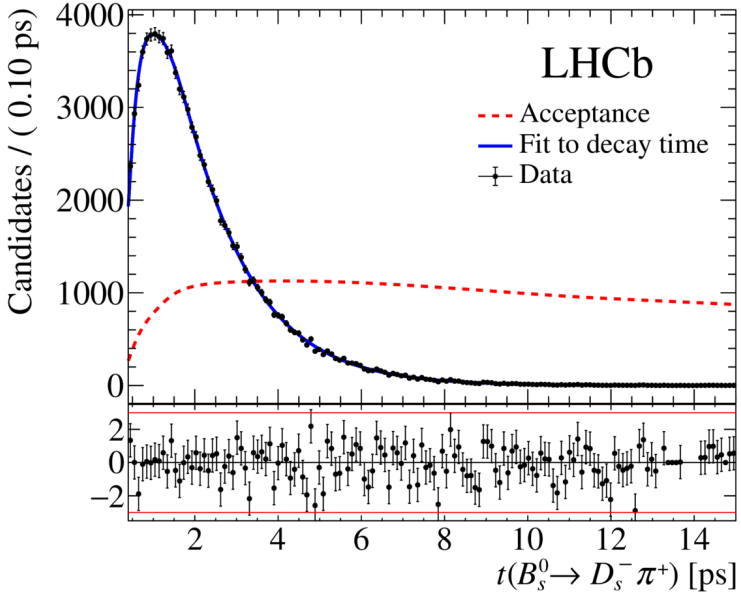


Decay time acceptance and resolution [JHEP 06 (2018) 084, JHE



- per event decay time error
- calibrated using prompt $D_{(s)}$ decays



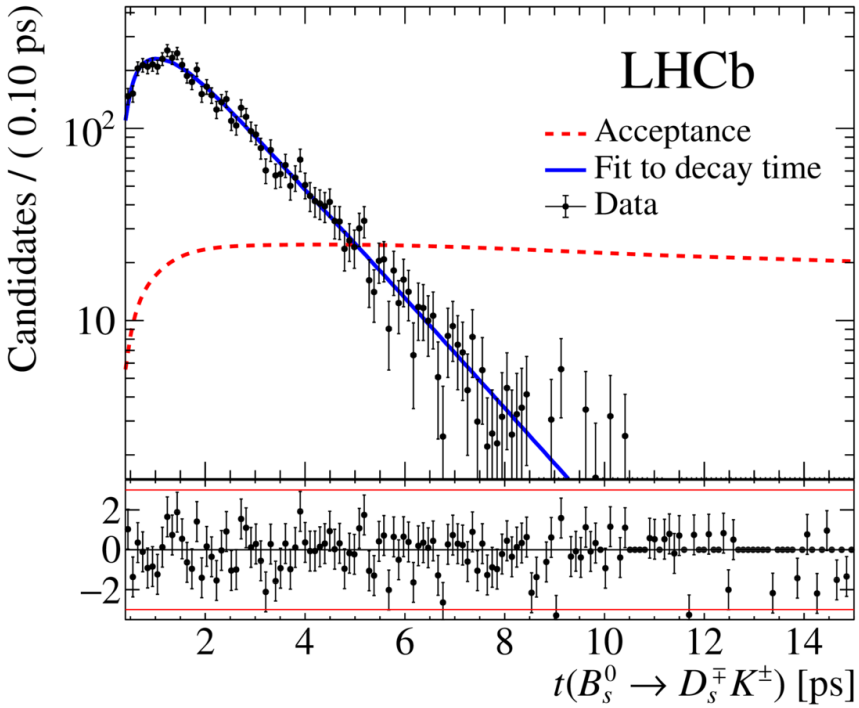


- Use known $B_{(s)} \to D_{(s)}^- \pi^+$ lifetime
- For $B_s \to D_s^- K^+$ correct for $D_s\pi/D_sK$ differences with simulation

Fit results and systematics [JHEP 06 (2018) 084, JHEP 03 (2018) 059]

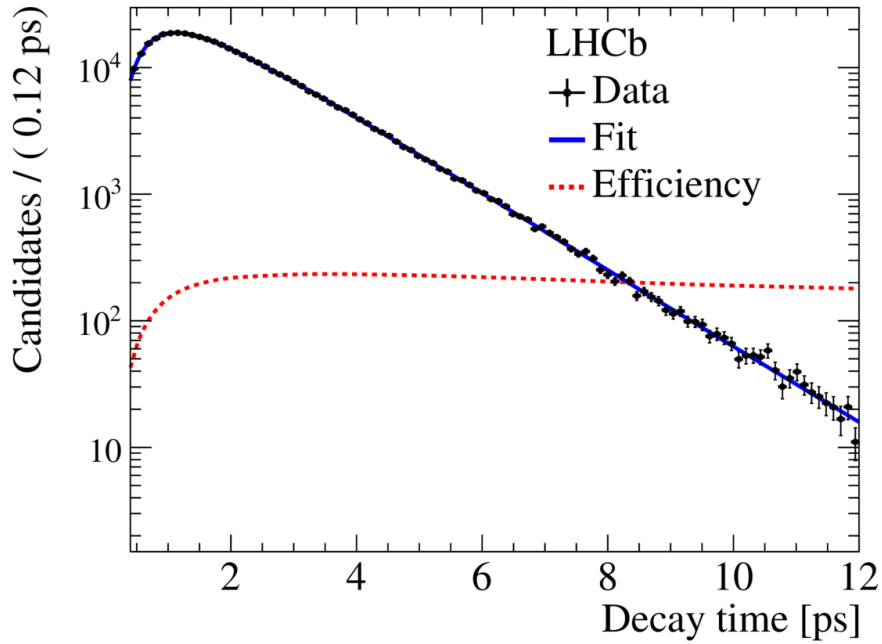
$B_s \to D_s^- K^+$

Parameter	Value
C_f	$0.730 \pm 0.142 \pm 0.045$
$A_f^{\Delta\Gamma}$	$0.387 \pm 0.277 \pm 0.153$
$A_{\overline{f}}^{\Delta\Gamma}$	$0.308 \pm 0.275 \pm 0.152$
S_f	$-0.519 \pm 0.202 \pm 0.070$
$S_{\overline{f}}$	$-0.489 \pm 0.196 \pm 0.068$



$B^0 \to D^- \pi^+$

$$S_f = 0.058 \pm 0.020\,(\text{stat}) \pm 0.011\,(\text{syst}),$$
$$S_{\bar{f}} = 0.038 \pm 0.020\,(\text{stat}) \pm 0.007\,(\text{syst}),$$



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Source	C_f	$A_f^{\Delta\Gamma}$	$A_{\overline{f}}^{\Delta\Gamma}$	S_f	$S_{\overline{f}}$
Detection asymmetry	0.02	0.28	0.29	0.02	0.02
Δm_s	0.11	0.02	0.02	0.20	0.20
Tagging and scale factor	0.18	0.02	0.02	0.16	0.18
Tagging asymmetry	0.02	0.00	0.00	0.02	0.02
Correlation among observables	0.20	0.38	0.38	0.20	0.18
Closure test	0.13	0.19	0.19	0.12	0.12
Acceptance, simulation ratio	0.01	0.10	0.10	0.01	0.01
Acceptance data fit, Γ_s , $\Delta\Gamma_s$	0.01	0.18	0.17	0.00	0.00
Total	0.32	0.55	0.55	0.35	0.35

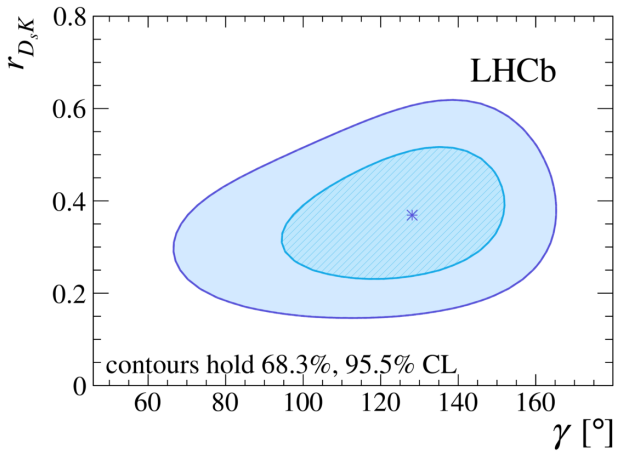
$B^0 \to D^- \pi^+$

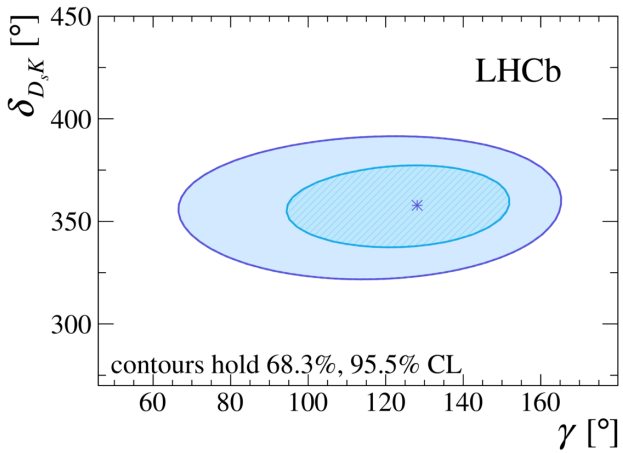
$$S_f = 0.058 \pm 0.020\,(\text{stat}) \pm 0.011\,(\text{syst}),$$
$$S_{\bar{f}} = 0.038 \pm 0.020\,(\text{stat}) \pm 0.007\,(\text{syst}),$$

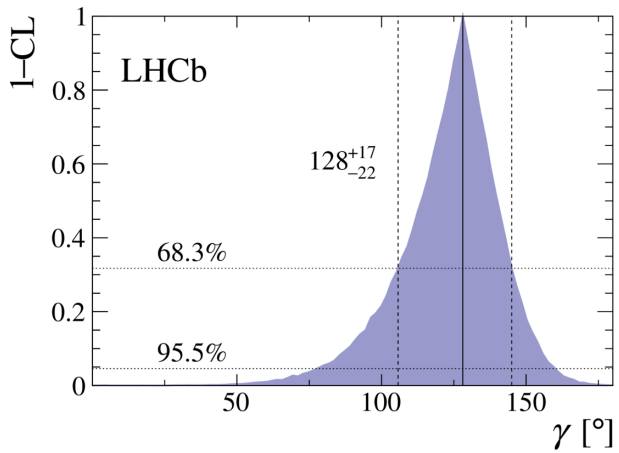
Source	S_f	$S_{\bar{f}}$
uncertainty of Δm	0.0073	0.0061
fit biases	0.0068	0.0018
background subtraction	0.0042	0.0023
PID efficiencies	0.0008	0.0008
flavour-tagging models	0.0011	0.0015
flavour-tagging efficiency asymmetries	0.0012	0.0015
$\epsilon(t)$ model	0.0007	0.0007
assumption on $\Delta\Gamma$	0.0007	0.0007
decay-time resolution	0.0012	0.0008
assumption on C	0.0006	0.0006
total	0.0111	0.0073
statistical uncertainty	0.0198	0.0199

Constraints on γ

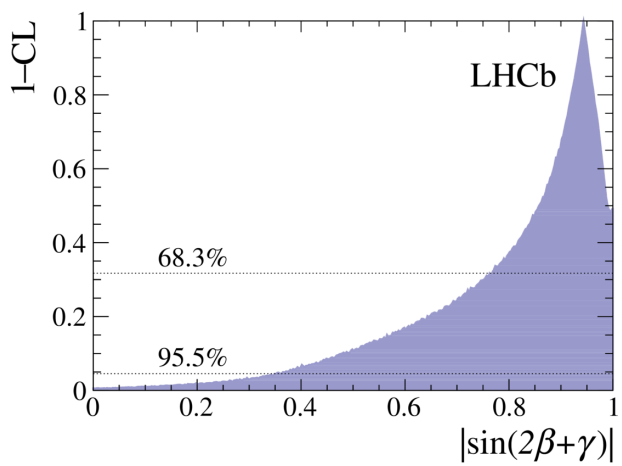
$B_s \to D_s^- K^+$ [JHEP 03 (2018) 059]

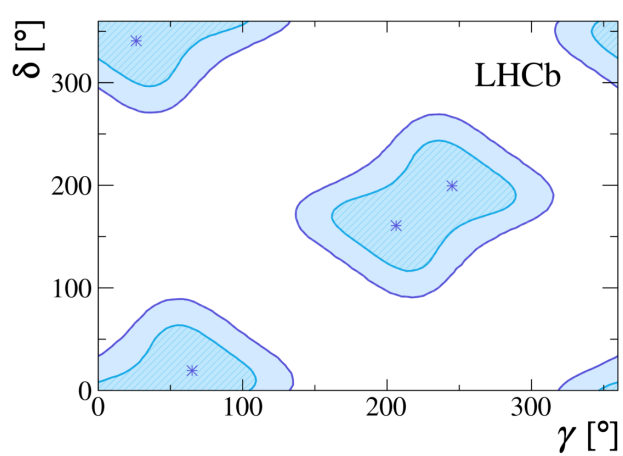


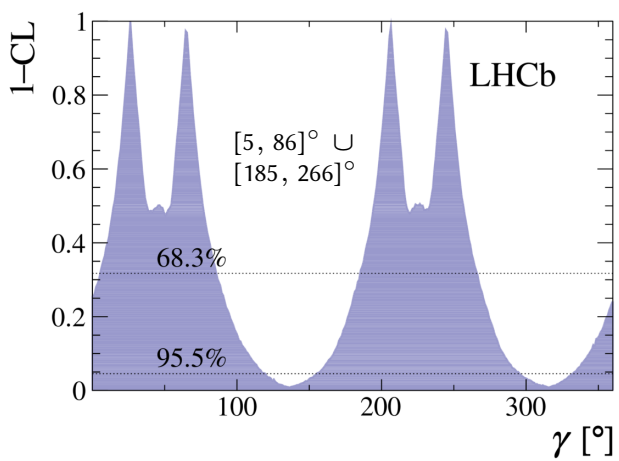




$B \to D^- \pi^+$ [JHEP 06 (2018) 084]

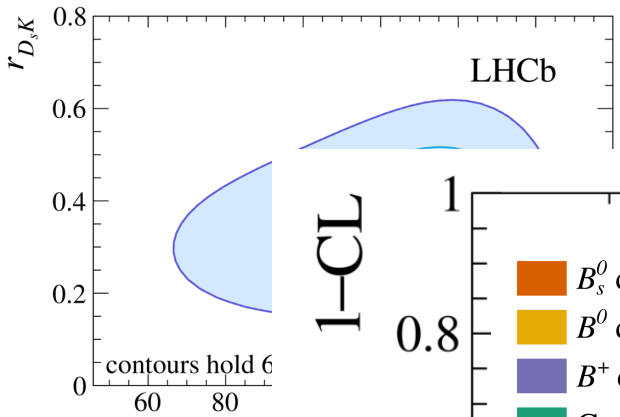


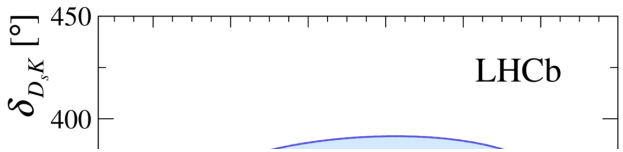


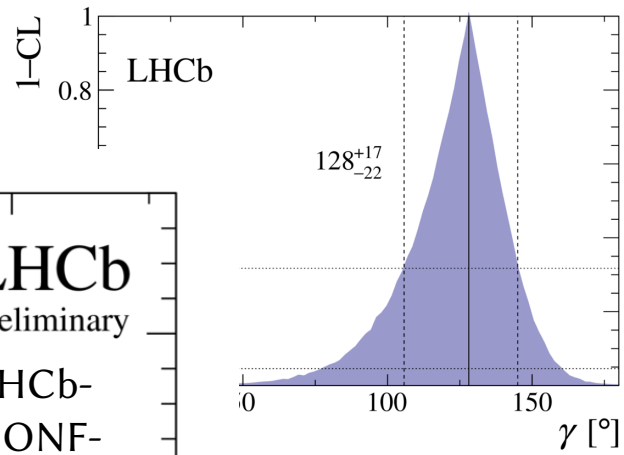


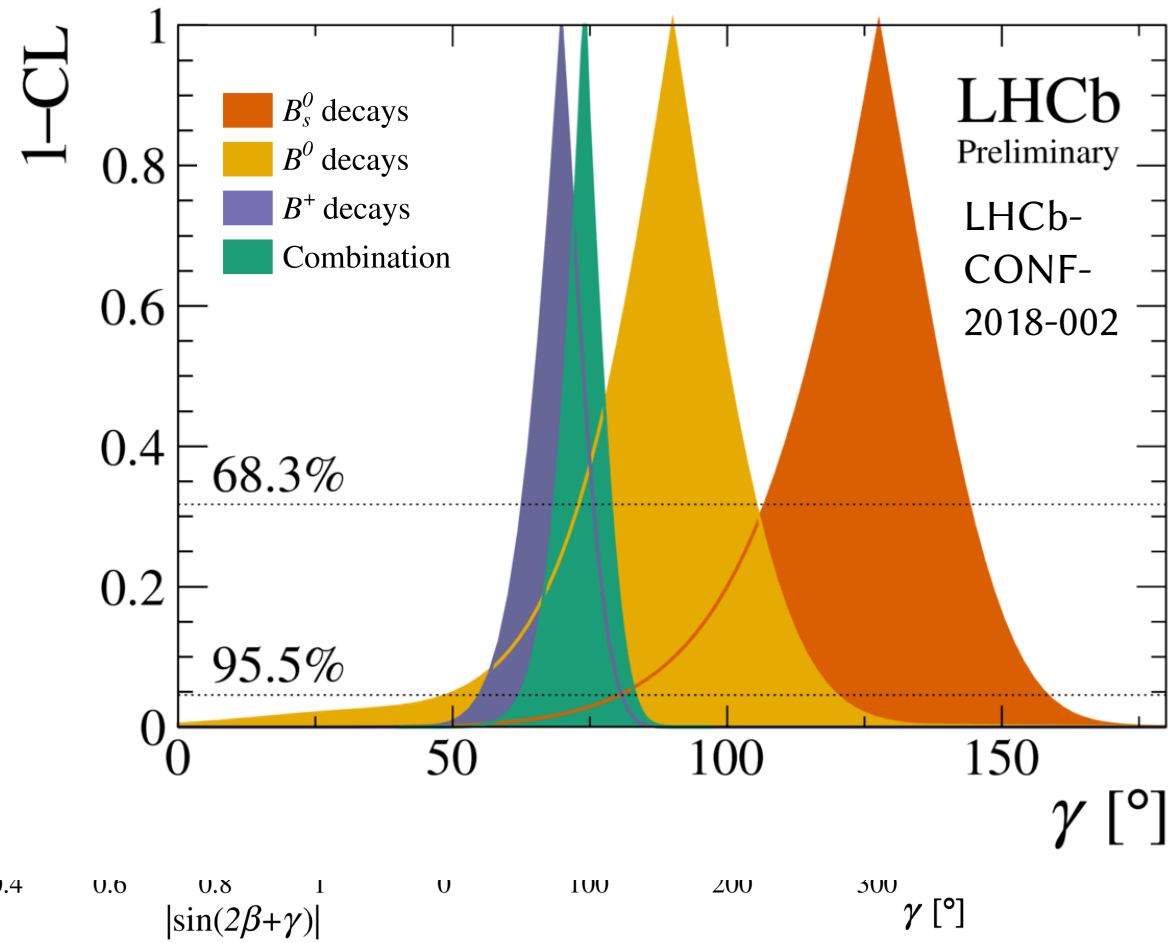
Constraints on γ

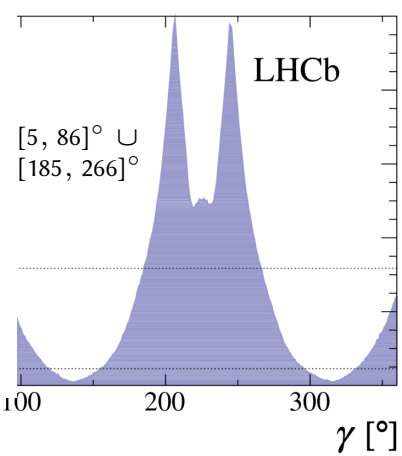
$B_s \to D_s^- K^+$ [JHEP 03 (2018) 059]











Prospects [LHCb-PUB-2018-009]

- Results shown with run 1 data (3fb^{-1})
- Analyses with run 2 data (6fb^{-1}) ongoing
- With LHCb upgrade 2, we can reach 1° sensitivity for γ with $B_s \to D_s^- K^+$

		$B_s^0 \to D_s^\mp K^\pm$			$B^0 \to D^\mp \pi^\pm$			
Parameters	Run 1	$23\,\text{fb}^{-1}$	$50\,\text{fb}^{-1}$	$300\,\text{fb}^{-1}$	$23\,\text{fb}^{-1}$	$50\,\text{fb}^{-1}$	$300\,\text{fb}^{-1}$	
S_f, $S_{\bar{f}}$	0.20	0.043	0.027	0.011	0.02	0.0041	0.0026	0.0010
$A_f^{\Delta\Gamma}$, $A_{\bar{f}}^{\Delta\Gamma}$	0.28	0.065	0.039	0.016	–	–	–	
C_f	0.14	0.030	0.017	0.007	–	–	–	

- More decay modes such as $B_s \to D_s K\pi\pi$

  ... also with exited charm states D_s^* and D^*
- Belle 2 will start contributing soon

  .. not with B_s decays

BACKUP