Time-dependent measurement from beauty to open charm at LHCb

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on behalf of the LHCb collaboration

28 July 2020 to 6 August 2020 virtual

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Time - dependent beauty to open charm analyses @ LHCb

- Determine CP coefficients related to weak phases β, γ, β_s
- Require tagging the initial $B^0_{(s)}$ flavour
- Require a time-dependent analysis to observe the meson oscillations
- Fit the decay-time-dependent decay rates
- Also requires knowledge of external parameters e.g. Γ, ΔΓ, Δm

check also: Beauty to open charm final states at LHCb by Wojciech Krupa

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CP violation in $B^0 \to D^{*\pm} D^{\mp}$ decays

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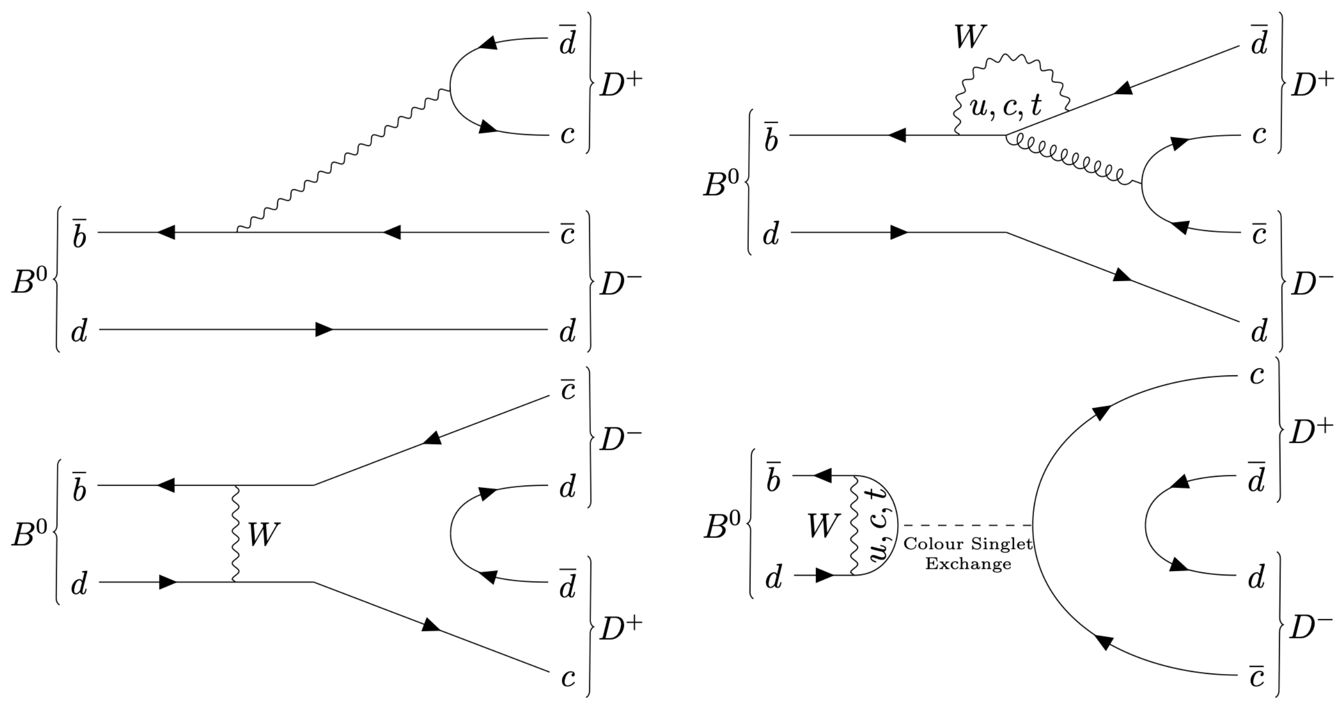
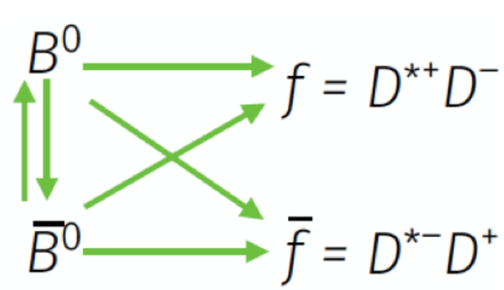
- First measurement of CPV in $B^0 \to D^{*\pm} D^{\mp}$ in LHCb
- $b \to c\bar{c}\bar{d}$ transition with tree, penguin and exchange diagrams, expect mixing-induced CPV and possible direct CPV contributions
- 

- Not a CP eigenstate: four decay-rates for B^0 and $\bar{B}^0$ events to f and $\bar{f}$ final states, eg



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The formalism

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external input

CP coefficient

- The TD decay rate

$$\frac{\mathrm{d}\Gamma_{\bar{B}^0,f}(t)}{\mathrm{d}t} = \mathrm{e}^{-t/\tau}(1+\mathcal{A}_{D^*D})\left[1+(S_{D^*D}+\Delta S_{D^*D})\sin(\Delta m t)-(C_{D^*D}+\Delta C_{D^*D})\cos(\Delta m t)\right]$$

- where the CP coefficients are (HFLAV convention)

$$S_{D^*D} = \frac{1}{2}(S_f + S_{\bar{f}}),$$
$$\Delta S_{D^*D} = \frac{1}{2}(S_f - S_{\bar{f}}),$$
$$C_{D^*D} = \frac{1}{2}(C_f + C_{\bar{f}}),$$
$$\Delta C_{D^*D} = \frac{1}{2}(C_f - C_{\bar{f}}),$$
$$\mathcal{A}_{D^*D} = \mathcal{A}_{f\bar{f}}.$$

$$S_f = \frac{2\mathcal{I}m\lambda_f}{1+|\lambda_f|^2}, \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}, \qquad \lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f},$$

$$\mathcal{A}_{f\bar{f}} = \frac{\left(|A_f|^2+|\bar{A}_f|^2\right)-\left(|A_{\bar{f}}|^2+|\bar{A}_{\bar{f}}|^2\right)}{\left(|A_f|^2+|\bar{A}_f|^2\right)+\left(|A_{\bar{f}}|^2+|\bar{A}_{\bar{f}}|^2\right)},$$

$S_{D^*D} = -\sin(2\beta)$ if

we neglect penguin contributions to the D*D amplitudes

strong phase between $B^0 \to D^{*+}D^-$ and $B^0 \to D^{*-}D^+$ is 0, and the amplitudes are the same

The analysis

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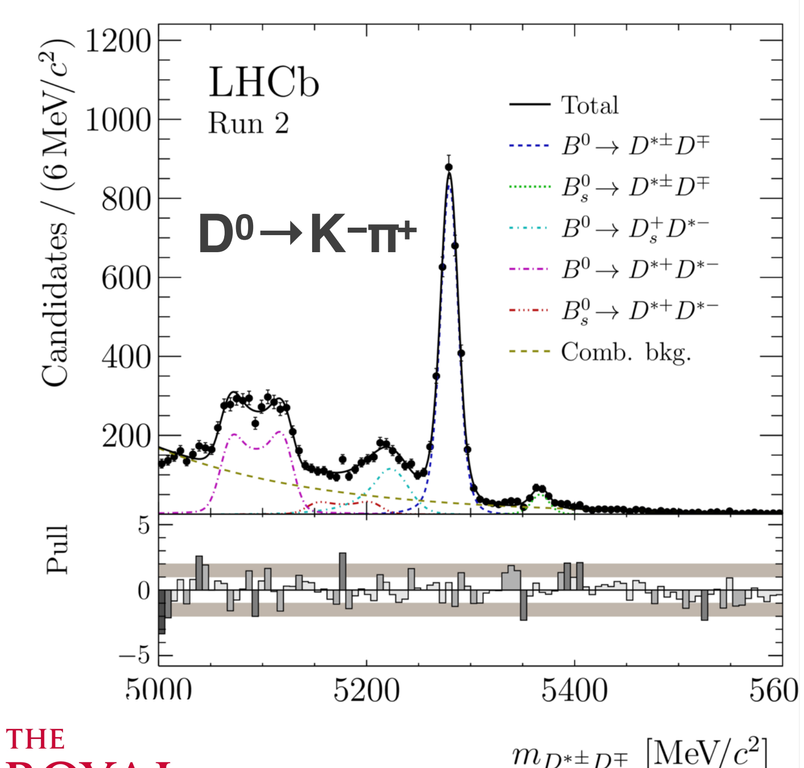
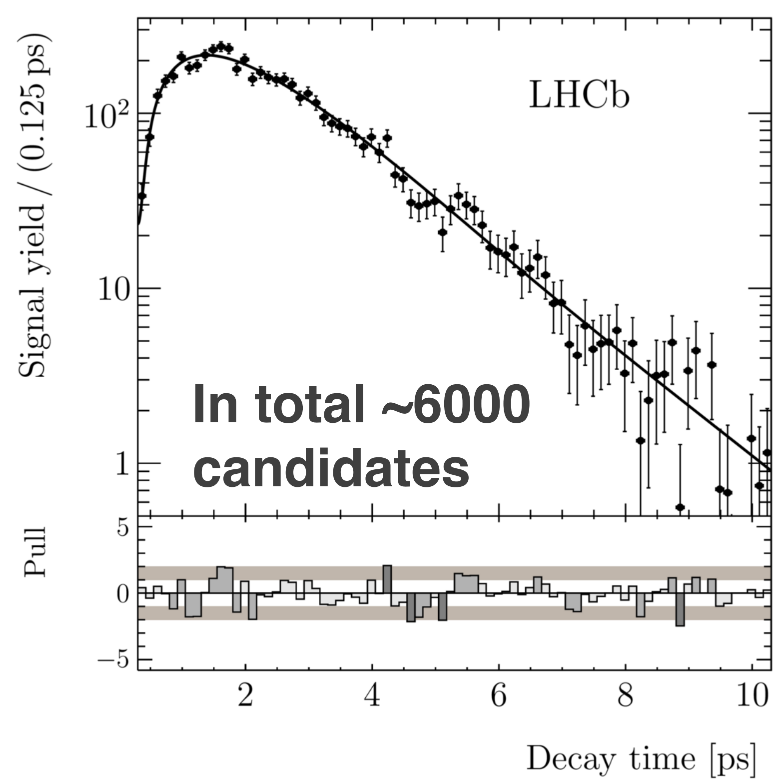
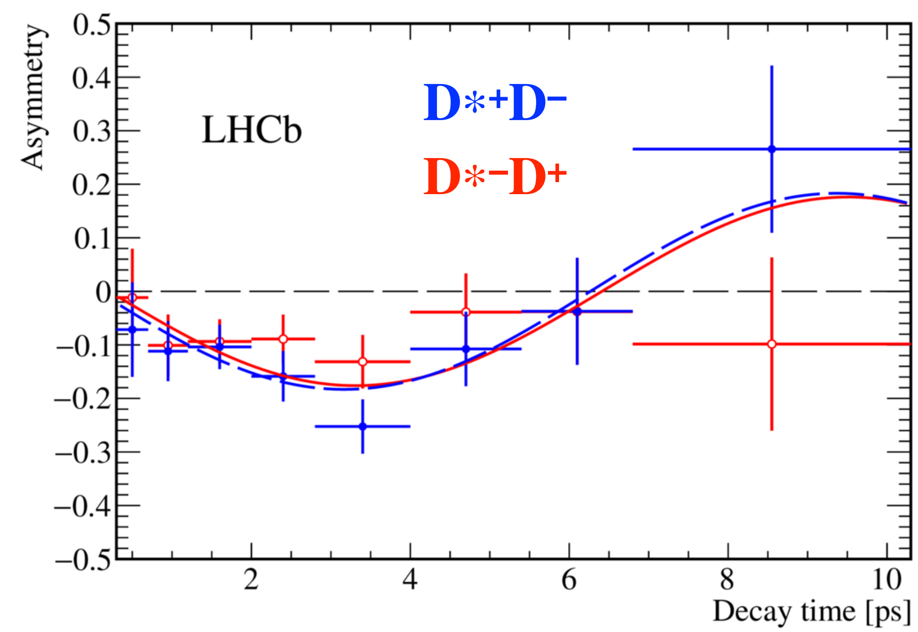
- Use the full data sample 2011-2018, ~9 fb^{-1}
- Decay reconstructed as $B^0 \to D^{*+}(D^0\pi^+)D^-$ with $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^-\pi^+$, $D^- \to K^-\pi^+\pi^-$
  - Split into four data samples: ($K3\pi$, $K\pi$) x (Run1, Run2)
- A decay-time fit is performed simultaneously on the four data samples to measure the CP coefficients







Results

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- The most precise single measurement of CP violation in this decay channel to date

$$
\begin{aligned}
S_{D^*D} &= -0.861 \pm 0.077\,(\text{stat}) \pm 0.019\,(\text{syst})\\
\Delta S_{D^*D} &= 0.019 \pm 0.075\,(\text{stat}) \pm 0.012\,(\text{syst})\\
C_{D^*D} &= -0.059 \pm 0.092\,(\text{stat}) \pm 0.020\,(\text{syst})\\
\Delta C_{D^*D} &= -0.031 \pm 0.092\,(\text{stat}) \pm 0.016\,(\text{syst})\\
\mathcal{A}_{D^*D} &= 0.008 \pm 0.014\,(\text{stat}) \pm 0.006\,(\text{syst})
\end{aligned}
$$

NEW!

- The hypothesis of CP conservation is excluded at more than 10 standard deviations, obtained using Wilk's theorem
- C_{D^*D} and A_{D^*D} are compatible with zero, indicating no CPV in decay
- Fixing them to 0, $\sin(2\beta) = S_{D^*D} = -0.839 \pm 0.070$, 1.9σ away from WA
- Compatible with previous measurements of Babar and Belle

Phys. Rev. D79 (2009) 032002, Phys. Rev. D85 (2012) 091106

CP violation in $B^0 \to D^{\mp}\pi^{\pm}$ decays

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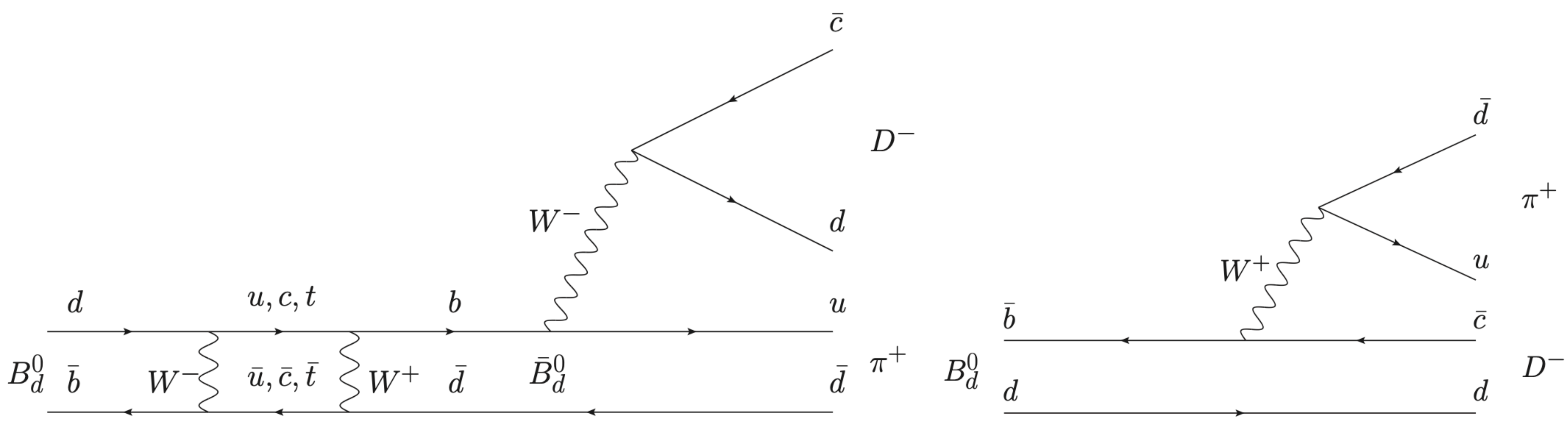
- B^0 and $\bar{B}^0$ can both decay to same final state $D^{\mp}\pi^{\pm}$ via $b \to cW$ or $b \to uW$ (analogous to $B^0_s \to D_s^{\mp}K^{\pm}$)

- Interference obtained between mixing and decay for neutral B^0



$V_{ub}^{*} \times V_{cd} \approx \lambda^4$ $V_{cb} \times V_{ud}^{*} \approx \lambda^2$

- Weak phase difference is $(\gamma + 2\beta)$ for B^0

The formalism

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- The TD decay rates

$$\Gamma_{B^0\to f}(t) \propto e^{-\Gamma t}\left[1 + C_f \cos(\Delta m\, t) - S_f \sin(\Delta m\, t)\right]$$
$$\Gamma_{B^0\to \bar{f}}(t) \propto e^{-\Gamma t}\left[1 + C_{\bar{f}} \cos(\Delta m\, t) - S_{\bar{f}} \sin(\Delta m\, t)\right]$$

external input

CP coefficient

- where

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

- Need $r_{D\pi}$ as an input: constrained from BaBar Phys. Rev. D78 (2008) 032005 and Belle Phys. Rev. D82 (2010) 051103
- 2β: constrained from HFLAV

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The results

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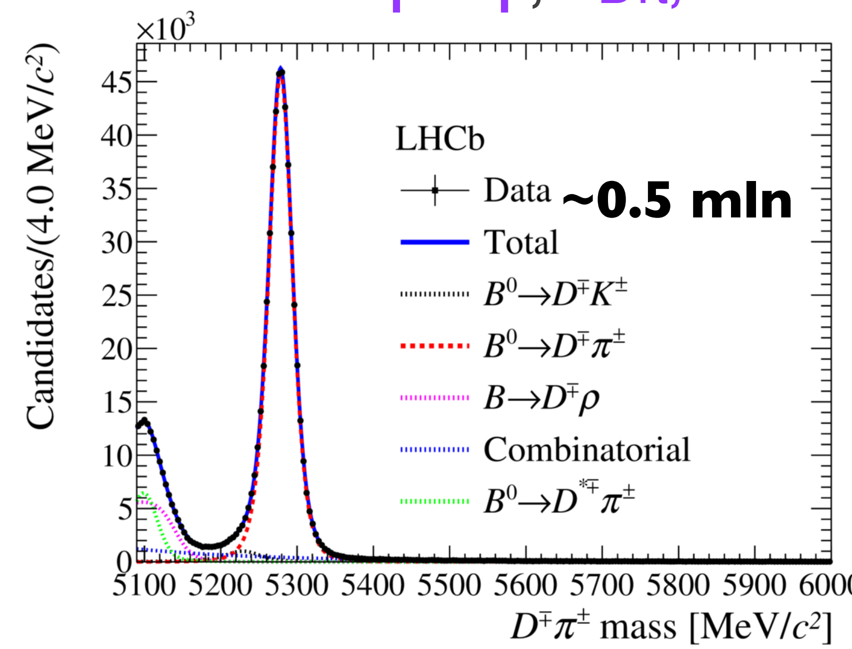
- The values of S_f and $S_{\bar{f}}$ determined from a multidimensional maximum- likelihood fit are interpreted in terms of $2\beta+\gamma$, $r_{D\pi}$, and the strong phase δ

Run 1 ($3fb^{-1}$)

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

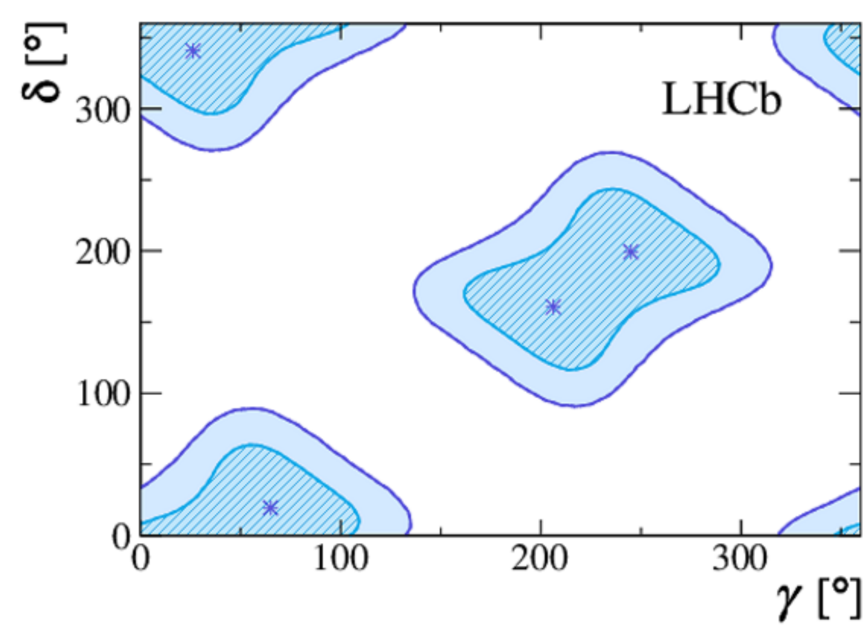


- Using $r_{D\pi}$ as an input: calculated with PDG values

$$r_{D\pi} = 0.0182 \pm 0.0012 \pm 0.0036$$

- The confidence intervals (68% CL) are

$$|\sin(2\beta+\gamma)| \in [0.77, 1.0]\,,$$
$$\gamma \in [5, 86]^\circ \cup [185, 266]^\circ\,,$$
$$\delta \in [-41, 41]^\circ \cup [140, 220]^\circ\,,$$



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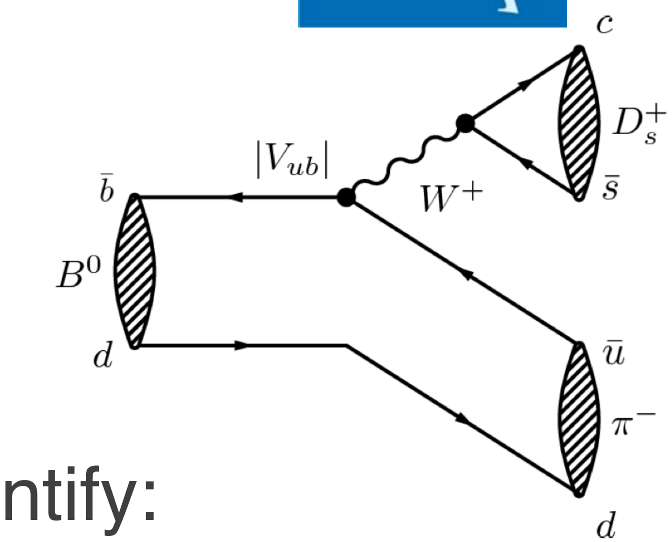
The $B^0 \to D_s^+ \pi^-$ decays

LHCb



- Clean hadronic tree decay

$$\mathcal{B}(B^0 \to D_s^+ \pi^-) \propto |V_{ub}|^2 |V_{cs}|^2 |F(B^0 \to \pi^-)|^2 f_{D_s^+}^2 |a_{\rm NF}|^2$$

- The branching fraction of $B_d \to D_s \pi$ can be used to quantify:
  - The magnitude of the CKM matrix element $|V_{ub}|$
  - Non-factorisable strong interaction effects in $b \to u$ decays
  - $r_{D\pi}$ essential for the TD $B_d \to D\pi$ analysis, using the branching fraction of $B_d \to D_s \pi$

$$r_{D\pi} = \tan\theta_c \frac{f_{D^+}}{f_{D_s^+}} \sqrt{\frac{\mathcal{B}(B^0 \to D_s^+ \pi^-)}{\mathcal{B}(B^0 \to D^- \pi^+)}}$$

  - Using 5/fb: preliminary LHCb-PAPER-2020-021

$$\mathcal{B}(B^0 \to D_s^+ \pi^-) = (19.4 \pm 1.8\,(\text{stat}) \pm 1.4\,(\text{syst}) \pm 1.2\,(\mathcal{B})) \times 10^{-6}$$

NEW!

$$r_{D\pi} = 0.0163 \pm 0.0011 \pm 0.0033$$

Best precision, in agreement with the WA

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Measurement of the CKM angle γ with $B_s \to D_s^{\mp} K^{\pm}$ decays

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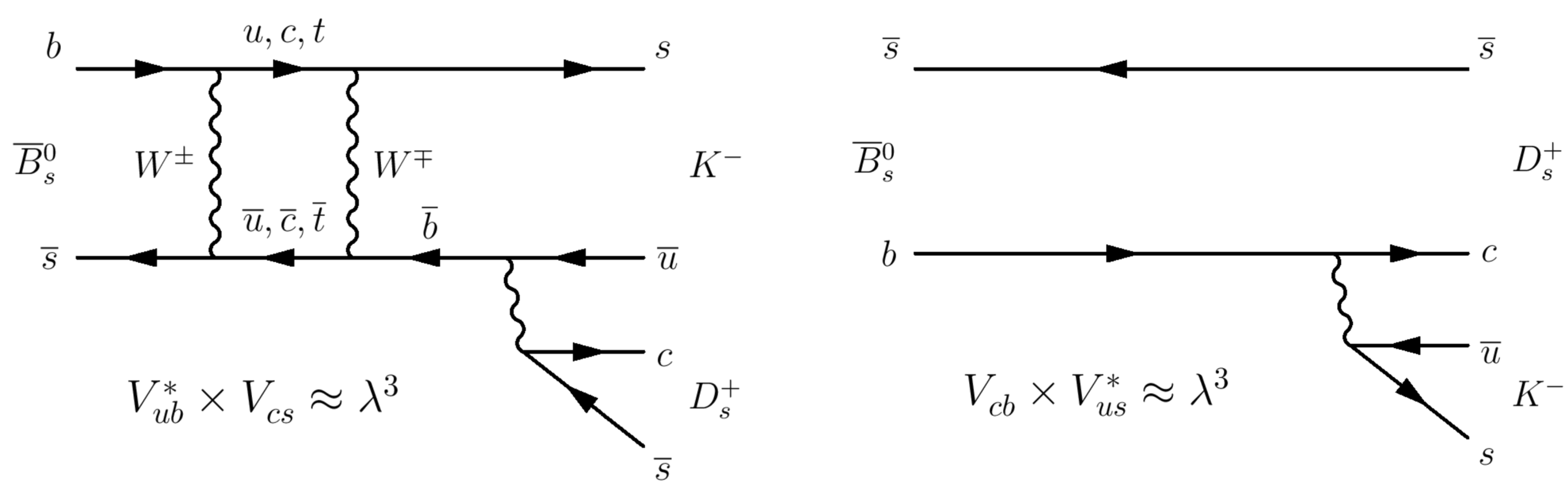
- B^0_s and $\bar{B}^0_s$ can both decay to same final state $D_s^{\mp}K^{\pm}$
  - one via $b \to cW$, the other via $b \to uW$
- Interference achieved by neutral B^0_s mixing (requires knowledge of $-2\beta_s \equiv \phi_s$)



- Weak phase difference is $(\gamma - 2\beta_s)$ analogous to $(\gamma - 2\beta)$ for B^0

For the recent $2\beta_s$ measurements, check out the talk of Peilian Li, Beauty to charmonium decays at LHCb

The formalism

external input

CP coefficient

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- The TD decay rate

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

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

- where

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

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

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

The results

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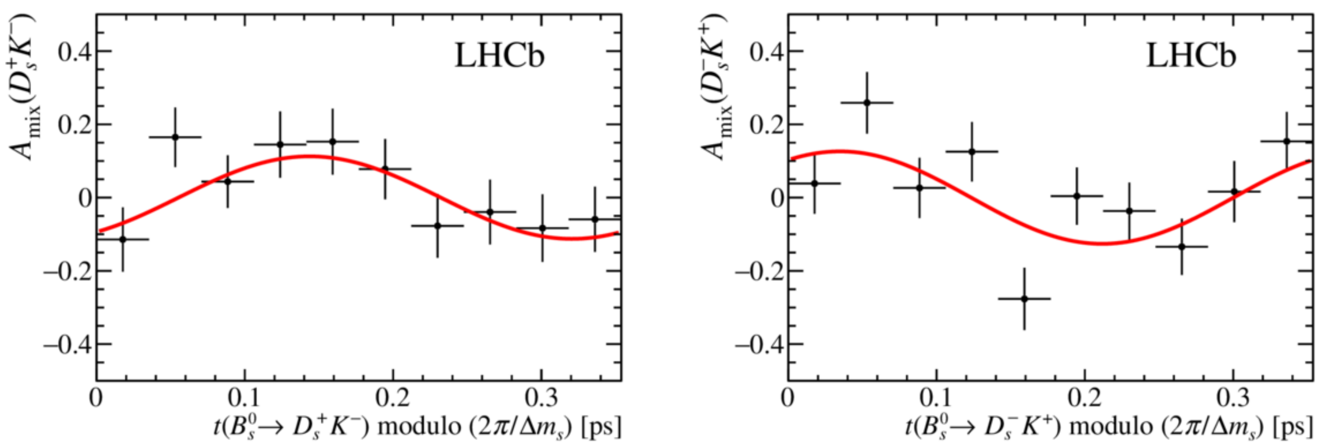
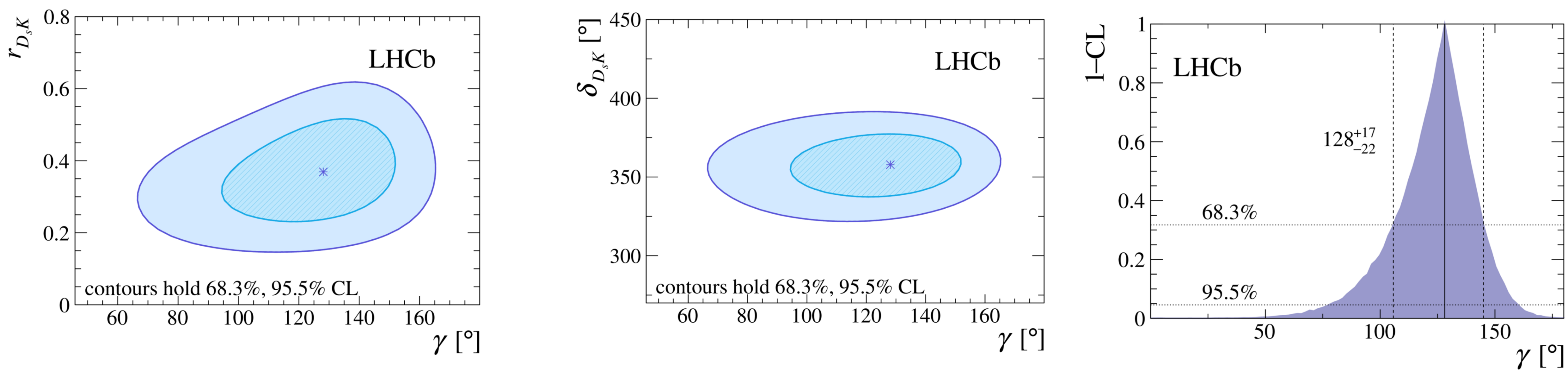
- Fit for decay-time-dependent asymmetry

Run 1 ($3 fb^{-1}$)



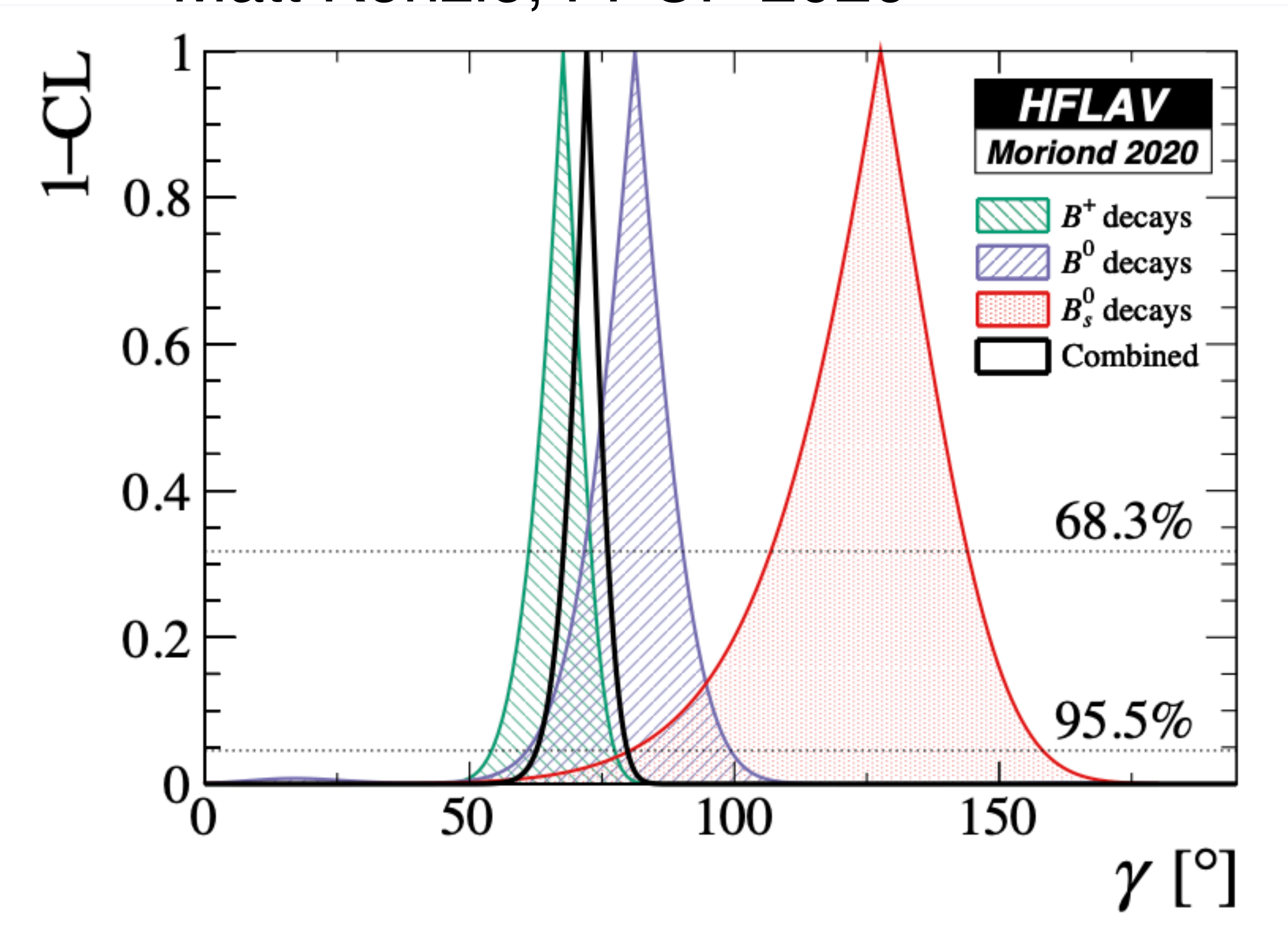
C_f	$0.730 \pm 0.142 \pm 0.045$
$A_f^{\Delta\Gamma}$	$0.387 \pm 0.277 \pm 0.153$
$A_{\bar{f}}^{\Delta\Gamma}$	$0.308 \pm 0.275 \pm 0.152$
S_f	$-0.519 \pm 0.202 \pm 0.070$
$S_{\bar{f}}$	$-0.489 \pm 0.196 \pm 0.068$

- The results are interpreted in terms of r_{DsK}, δ, γ



The constrains on γ

Matt Kenzie, FPCP 2020



$$\gamma = \left(72.1^{+4.1}_{-4.5}\right)^{\circ}$$

Indirect constraints are
$$\gamma = \left(65.7^{+1.0}_{-2.7}\right)^{\circ}(\sim 2\sigma)$$

Comparison between B^0_s and B^+ initial state $\sim 2\sigma$

For the status update, check out Time-integrated measurements of the CKM angle gamma at LHCb by Sneha Made

Summary and prospects

- Today: Time-dependent measurements using:
  - $B^0 \to D^{*\pm}D^{\mp}$ decays (CKM angle 2β)
  - $B_s \to D_s^{\mp}K^{\pm}$ decays (CKM angle γ): with LHCb upgrade 2, we can reach 1°
  - $B^0 \to D^{\mp}\pi^{\pm}$ decays (CKM angle γ)
- The $B^0 \to D_s^{\pm}\pi^{\mp}$ decays: essential input to study the CP asymmetries in $B^0 \to D^{\mp}\pi^{\pm}$

future projections arXiv:1812.07638

		$B_s^0 \to D_s^{\mp}K^{\pm}$			$B^0 \to D^{\mp}\pi^{\pm}$			
Parameters	Run 1	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 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	–	–	–	

- Working towards finishing the Run2 analyses and adding new decay channels such as $B_s \to D_s^{\mp}K^{\pm}\pi^{\mp}\pi^{\pm}$, excited D and D* modes, etc.

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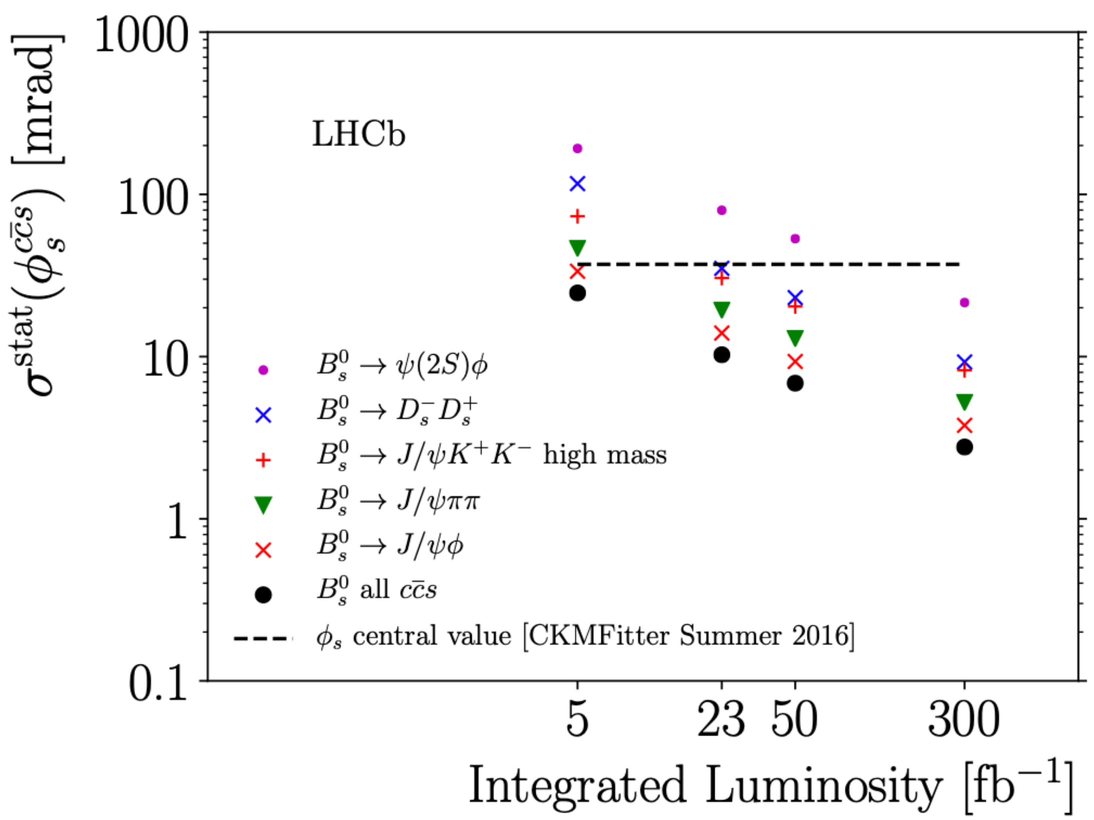
BACKUP

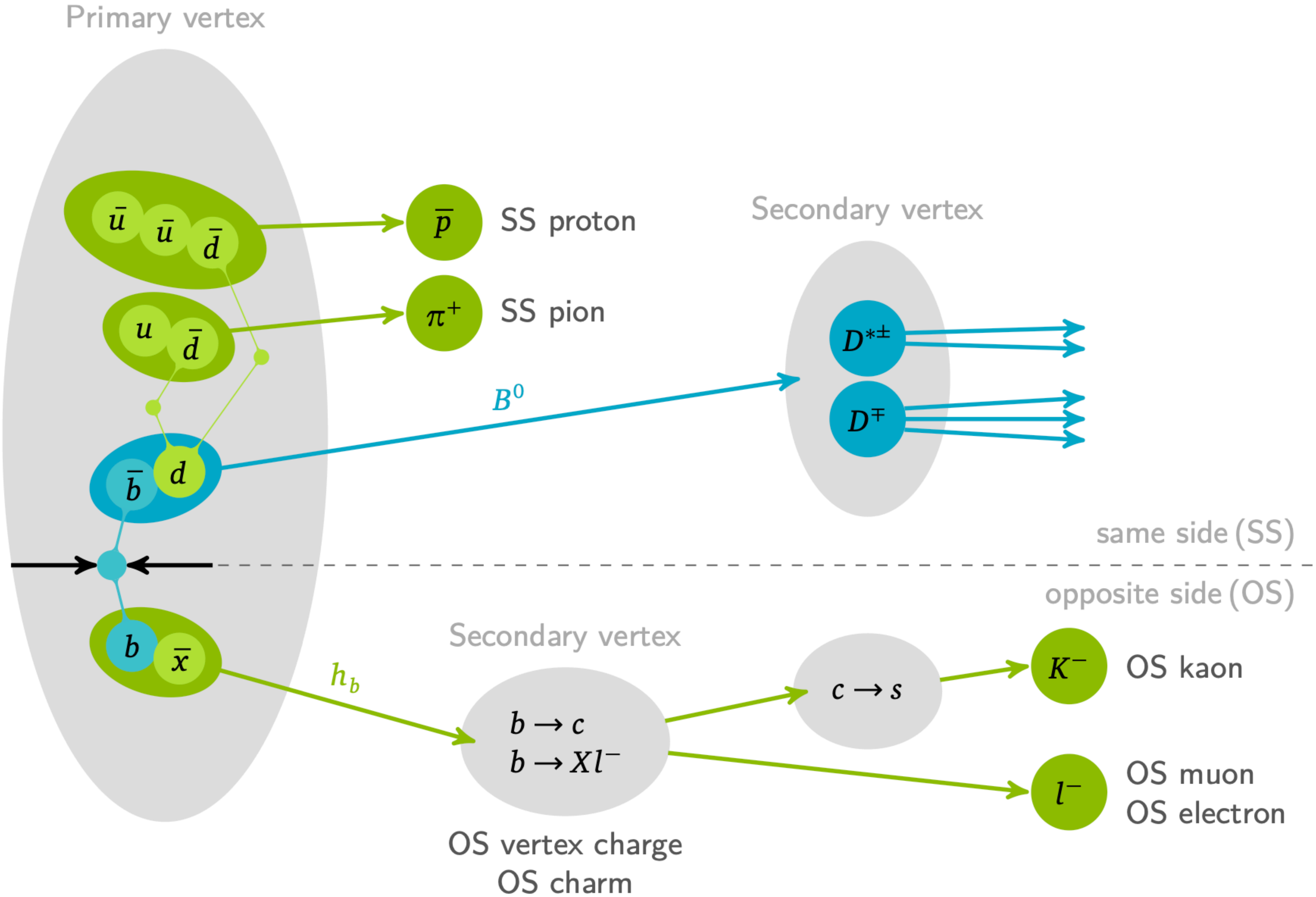
Previous TD B2OC analyses

- check out also:
  - ϕ_s from $B_s \rightarrow D_s^+ D_s^-$ [PRL 113, 211801]
  - Penguin pollution constraint on sin(2β) from $B \rightarrow D^+ D^-$ [PRL 117, 261801]
  - $B_s - \bar{B}_s$ mixing frequency from $B_s \rightarrow D_s \pi$ [NJP 15 (2013) 053021]

Prospects for $-2\beta_s \equiv \phi_s$ *arXiv:1812.07638*



Taggers at LHCb



More formalism ($B^0 \to D^{*\pm} D^{\mp}$ decays)

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$$\frac{d\Gamma_{\bar{B}^0,f}(t)}{dt} = e^{-t/\tau}(1 + A_{D^*D})\Big[1 + (S_{D^*D} + \Delta S_{D^*D})\sin(\Delta m t) - (C_{D^*D} + \Delta C_{D^*D})\cos(\Delta m t)\Big]$$

$$\frac{d\Gamma_{B^0,f}(t)}{dt} = e^{-t/\tau}(1 + A_{D^*D})\Big[1 - (S_{D^*D} + \Delta S_{D^*D})\sin(\Delta m t) + (C_{D^*D} + \Delta C_{D^*D})\cos(\Delta m t)\Big]$$

$$\frac{d\Gamma_{\bar{B}^0,\bar{f}}(t)}{dt} = e^{-t/\tau}(1 - A_{D^*D})\Big[1 + (\Delta S_{D^*D} - S_{D^*D})\sin(\Delta m t) - (\Delta C_{D^*D} - C_{D^*D})\cos(\Delta m t)\Big]$$

$$\frac{d\Gamma_{B^0,\bar{f}}(t)}{dt} = e^{-t/\tau}(1 - A_{D^*D})\Big[1 - (\Delta S_{D^*D} - S_{D^*D})\sin(\Delta m t) + (\Delta C_{D^*D} - C_{D^*D})\cos(\Delta m t)\Big]$$

$$\frac{d\Gamma(t)}{dt} = \frac{e^{-t/\tau_d}}{8\tau_d}(1 + r\mathcal{A}_{D^*D})\times \Big[1 - d(S_{D^*D} + r\Delta S_{D^*D})\sin(\Delta m t) + d(C_{D^*D} + r\Delta C_{D^*D})\cos(\Delta m t)\Big]$$

$$\frac{S_{D^{*\pm}D^{\mp}}}{\sqrt{1 - C^2_{D^{*\pm}D^{\mp}}}} = -\sin(\phi_{\text{mix}} + \phi_{\text{dec}} \pm \delta_{D^*D}).$$

$$S_f = \frac{-2\,|A_f||\bar{A}_f|\sin(\phi_{\text{mix}} + \phi_{\text{dec}} - \delta_f)}{|A_f|^2 + |\bar{A}_f|^2},$$

$$S_{\bar{f}} = \frac{-2\,|A_{\bar{f}}||\bar{A}_{\bar{f}}|\sin(\phi_{\text{mix}} + \phi_{\text{dec}} + \delta_f)}{|A_{\bar{f}}|^2 + |\bar{A}_{\bar{f}}|^2},$$

$$C_f = \frac{|A_f|^2 - |\bar{A}_f|^2}{|A_f|^2 + |\bar{A}_f|^2},$$

$$C_{\bar{f}} = \frac{|A_{\bar{f}}|^2 - |\bar{A}_{\bar{f}}|^2}{|A_{\bar{f}}|^2 + |\bar{A}_{\bar{f}}|^2},$$

Systematic uncertainties ($B^0 \to D^{*\pm} D^{\mp}$ decays)

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Source	$\Delta C_{D^* D}$	$C_{D^* D}$	$\Delta S_{D^* D}$	$S_{D^* D}$
Fit bias	0.002	0.002	0.002	0.002
Mass model	0.006	0.014	0.003	0.011
$\Delta m_d, \tau_d, \Delta\Gamma_d$	0.001	0.003	0.001	0.001
Decay-time resolution	<0.001	<0.001	<0.001	<0.001
Decay-time acceptance	<0.001	<0.001	<0.001	<0.001
Flavour tagging	0.015	0.014	0.012	0.015
Total syst. uncertainty	0.016	0.020	0.012	0.019

Source	$\mathcal{A}_{\text{raw}}^{K\pi\pi\pi,\text{Run1}}$	$\mathcal{A}_{\text{raw}}^{K\pi\pi\pi,\text{Run2}}$	$\mathcal{A}_{\text{raw}}^{K\pi,\text{Run1}}$	$\mathcal{A}_{\text{raw}}^{K\pi,\text{Run2}}$
Fit bias	0.0013	0.0007	0.0008	0.0004
Mass model	0.0025	0.0024	0.0021	0.0016
$\Delta m_d, \tau_d, \Delta\Gamma_d$	0.0003	0.0002	0.0002	0.0001
Decay-time resolution	0.0002	0.0001	0.0001	0.0001
Decay-time acceptance	0.0003	0.0001	0.0002	0.0001
Flavour tagging	0.0001	0.0001	0.0001	0.0001
Total syst. uncertainty	0.0028	0.0025	0.0023	0.0016

More formalism ($B_s \to D_s K$ decays)

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$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} = -C_{\bar{f}} = -\frac{1-|\lambda_{\bar{f}}|^2}{1+|\lambda_{\bar{f}}|^2},$$

$$S_f = \frac{2\mathcal{I}m(\lambda_f)}{1+|\lambda_f|^2}, \quad A_f^{\Delta\Gamma} = \frac{-2\mathcal{R}e(\lambda_f)}{1+|\lambda_f|^2},$$

$$S_{\bar{f}} = \frac{2\mathcal{I}m(\lambda_{\bar{f}})}{1+|\lambda_{\bar{f}}|^2}, \quad A_{\bar{f}}^{\Delta\Gamma} = \frac{-2\mathcal{R}e(\lambda_{\bar{f}})}{1+|\lambda_{\bar{f}}|^2}.$$

Data fits to $B_s \to D_s h$ decays

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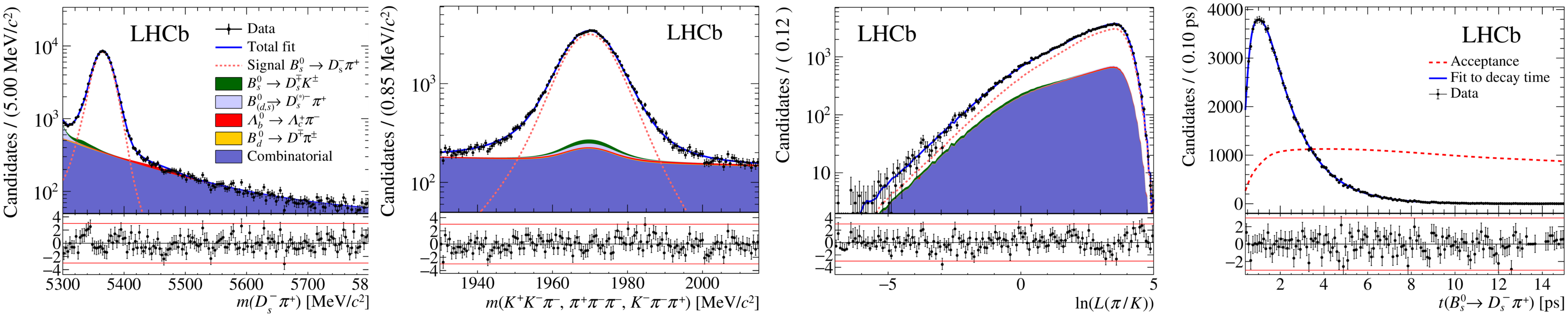
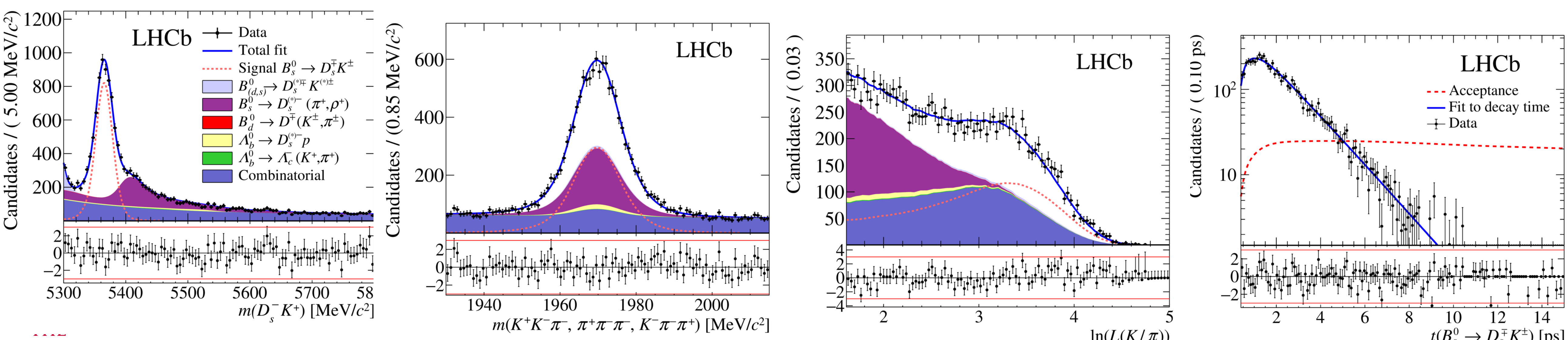
- $Bs \to Ds\pi$



- $Bs \to DsK$



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Systematic uncertainties

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$B_s \to D_s K$ decays

Source	C_f	$A_f^{\Delta\Gamma}$	$A_{\bar{f}}^{\Delta\Gamma}$	S_f	$S_{\bar{f}}$
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

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Flavour tagging performance

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$B_s \to D_s \pi$ decays

$B_s^0 \to D_s^- \pi^+$	$\varepsilon_{\rm tag}$ [%]	$\varepsilon_{\rm eff}$ [%]
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

Tagging ($B^0 \to D^{\mp}\pi^{\pm}$ decays)

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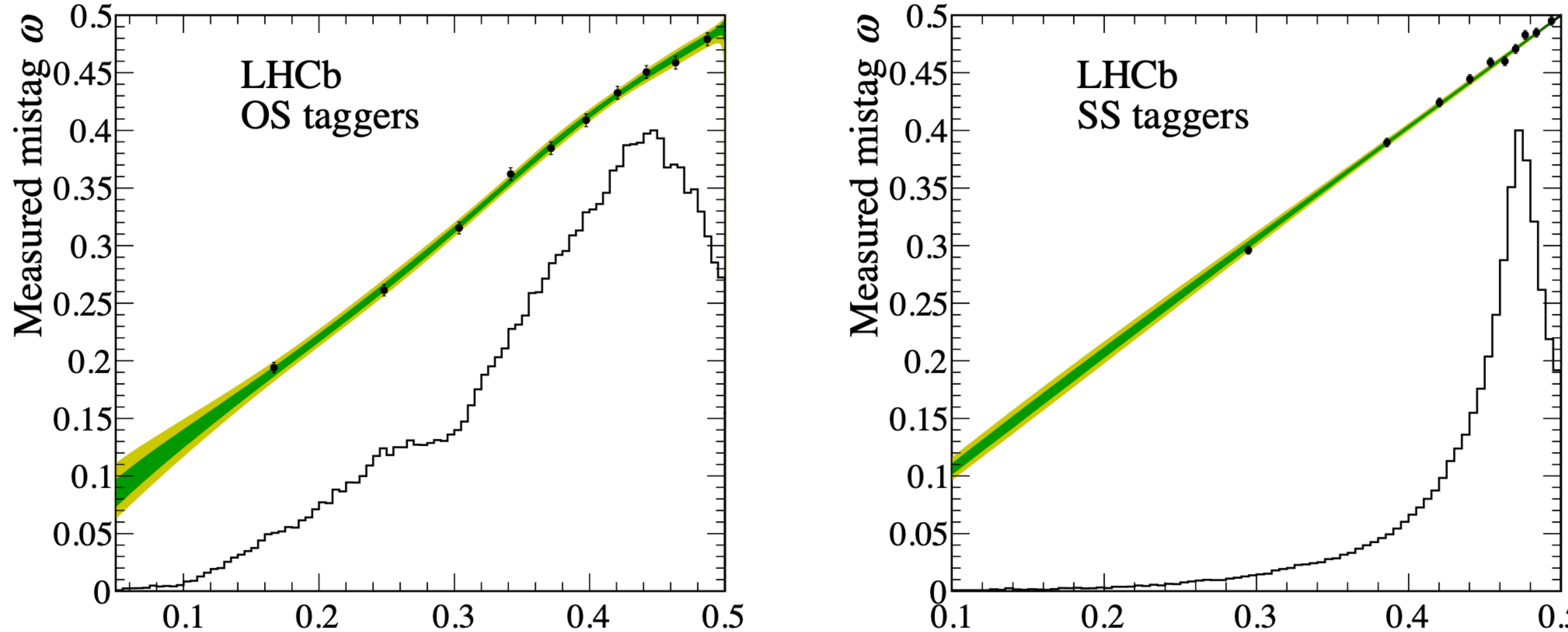


$$S_f \to (\Delta^- - \Delta^+) S_f \,, \qquad C_f \to (\Delta^- - \Delta^+) C_f$$

$$A_\mathrm{P} = \frac{\sigma(\overline{B}^0) - \sigma(B^0)}{\sigma(\overline{B}^0) + \sigma(B^0)} \,, \qquad A_\mathrm{D} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})} \,,$$

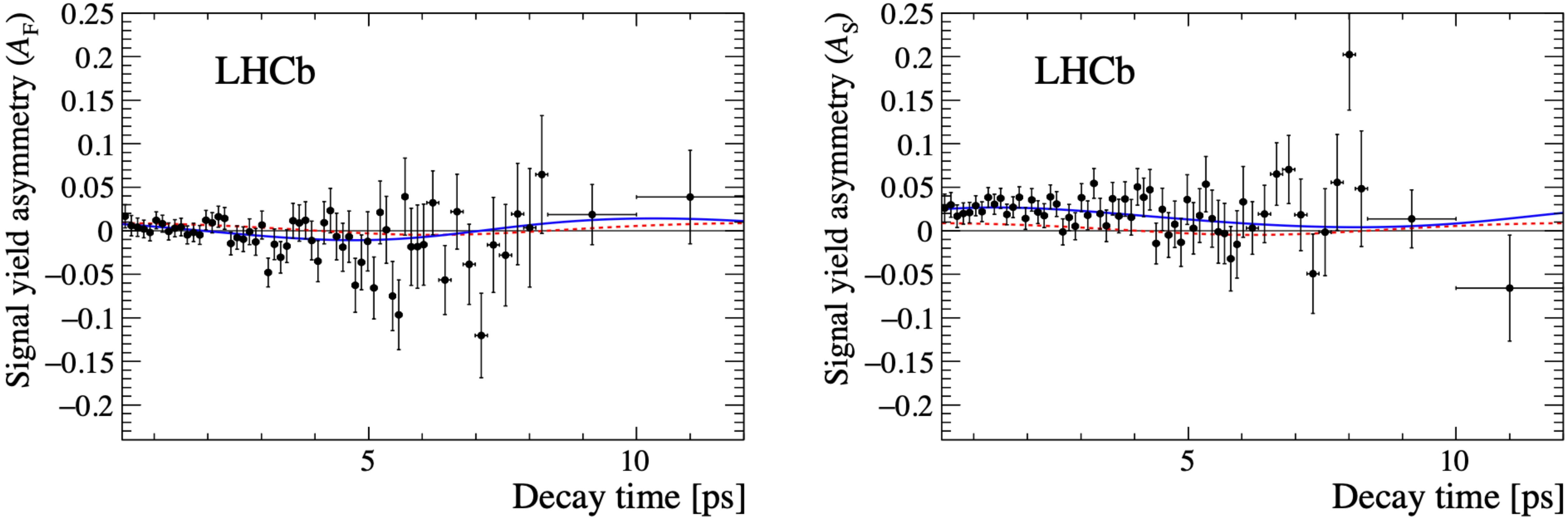
$$(\Delta^- - \Delta^+) S_f \to (\Delta^- - A_\mathrm{P}\Delta^+)(1 + A_\mathrm{D}) S_f \,, \qquad (\Delta^- - \Delta^+) C_f \to (\Delta^- - A_\mathrm{P}\Delta^+)(1 + A_\mathrm{D}) C_f \,,$$

$$\Delta^{\pm} = \frac{1}{2}\varepsilon_\mathrm{OS}\Big[1 - \varepsilon_\mathrm{SS} + d_\mathrm{OS}\Big(1 - \varepsilon_\mathrm{SS} - 2\omega(\eta_\mathrm{OS})(1 + \varepsilon_\mathrm{SS})\Big)\Big] \pm \frac{1}{2}\varepsilon_\mathrm{OS}\Big[1 - \varepsilon_\mathrm{SS} + d_\mathrm{OS}\Big(1 - \varepsilon_\mathrm{SS} - 2\overline{\omega}(\eta_\mathrm{OS})(1 + \varepsilon_\mathrm{SS})\Big)\Big]$$

$$\Delta^{\pm} = \frac{1}{4}\varepsilon_\mathrm{OS}\varepsilon_\mathrm{SS}\Big[1 + \sum_{j=\mathrm{OS,SS}} d_j\Big(1 - 2\omega(\eta_j)\Big) + d_\mathrm{OS}d_\mathrm{SS}\Big(1 - 2\omega(\eta_j) + 2\omega(\eta_\mathrm{OS})\omega(\eta_\mathrm{SS})\Big)\Big] \pm \frac{1}{4}\varepsilon_\mathrm{OS}\varepsilon_\mathrm{SS}\Big[1 + \sum_{j=\mathrm{OS,SS}} d_j\Big(1 - 2\overline{\omega}(\eta_j)\Big) + d_\mathrm{OS}d_\mathrm{SS}\Big(1 - 2\overline{\omega}(\eta_j) + 2\overline{\omega}(\eta_\mathrm{OS})\overline{\omega}(\eta_\mathrm{SS})\Big)\Big]$$

$$\varepsilon_\mathrm{tag}\langle\mathcal{D}^2\rangle = (5.59 \pm 0.01)\%$$

Decay-time-dependent signal-yield asymmetries ($B^0 \to D^{\mp}\pi^{\pm}$ decays)



favoured modes $$A_{\mathrm{F}} = \frac{\Gamma_{B^0\to f}(t) - \Gamma_{\bar{B}^0\to \bar{f}}(t)}{\Gamma_{B^0\to f}(t) + \Gamma_{\bar{B}^0\to \bar{f}}(t)}$$

suppressed modes $$A_{\mathrm{S}} = \frac{\Gamma_{\bar{B}^0\to f}(t) - \Gamma_{B^0\to \bar{f}}(t)}{\Gamma_{\bar{B}^0\to f}(t) + \Gamma_{B^0\to \bar{f}}(t)}.$$

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Systematic uncertainties

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($B^0 \to D^{\mp}\pi^{\pm}$ decays)

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

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Further results ($B^0 \to D_s^+\pi^-$ decays)

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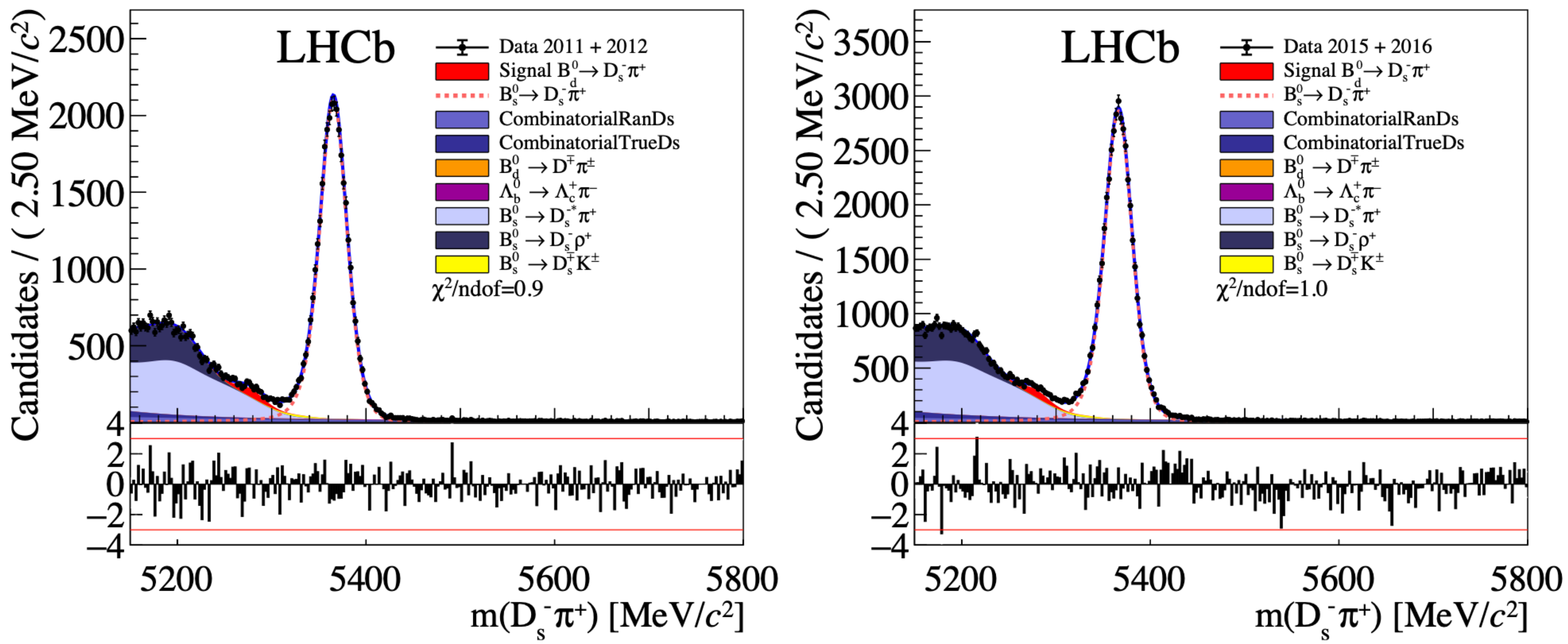

(a) Run 1 (b) Run 2

	Run 1	Run 2
$\epsilon_{B^0\to D_s^+\pi^-}$ (%)	0.1412 ± 0.0010	0.1922 ± 0.0012
$\epsilon_{B^0\to D^-\pi^+}$ (%)	0.3485 ± 0.0016	0.4536 ± 0.0016
$N_{B^0\to D^-\pi^+}$	$497\,052 \pm 1287$	$629\,423 \pm 1639$
$\mathcal{B}(B^0 \to D^-\pi^+)$	$(2.52 \pm 0.13) \times 10^{-3}$	
$\mathcal{B}(D^- \to K^+\pi^-\pi^-)$	$(9.38 \pm 0.16) \times 10^{-2}$	
$\mathcal{B}(D_s^- \to K^-K^+\pi^-)$	$(5.39 \pm 0.15) \times 10^{-2}$	

preliminary!

$$|V_{ub}||a_{\mathrm{NF}}| = (3.14 \pm 0.32) \times 10^{-3}$$

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Systematic uncertainties
($B^0 \to D_s^+ \pi^-$ decays)

LHCb

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Source	$\mathcal{B}(B^0 \to D_s^+ \pi^-)$
Fit model	
Signal shape parametrisation	5.1%
$B^0 \to D_s^+ \pi^-$ signal width	1.5%
$B^0 \to D_s^+ \pi^-$ mean	0.2%
Partially reconstructed backgrounds	4.2%
MisID backgrounds	0.6%
Efficiencies	
Hardware trigger efficiency	0.3%
BDT efficiency	1.1%
PID efficiency	1.1%
Total	7.0%

preliminary!

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