Search for a wrong-flavour contribution to $B_s \rightarrow D_s\pi$ at LHCb

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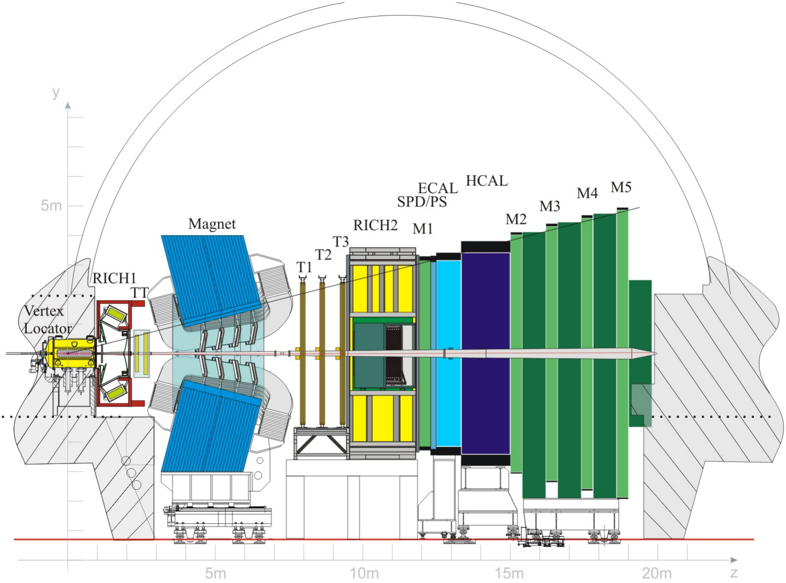
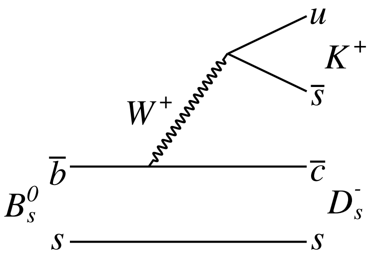
The LHCb detector



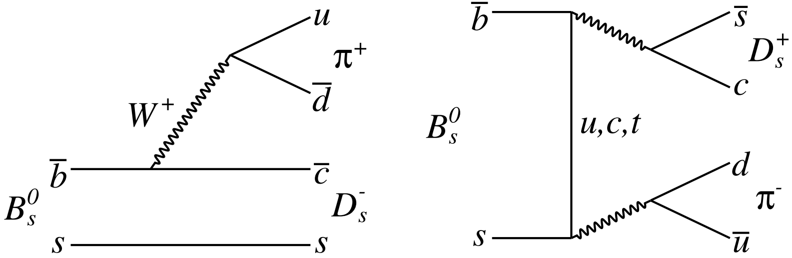
Background

- It's assumed that in the Standard Model, $B_s \to D_s\pi$ is flavour-specific
    - so $B_s \to D_s^- \pi^+$ 'all' the time
    - and $B_s \to D_s^+ \pi^-$ none of the time
    - conversely for the $\bar{B}_s$
- Many results indirectly rely on this assumption
- This has never been explicitly checked by any experiment
- There are very small higher-order SM contributions as well as possible BSM contributions
    - for example, an exotic quark with charge $-\frac{4}{3}$
- The aim of the analysis was to measure any contribution from the wrong-flavour decay
- Run as a side project to measurement of $B_s^0 \to D_s K$

Wrong-flavour decay in $B_s^0 \rightarrow D_s K$



Wrong-flavour decay



Decay description

- Two initial states (B_s^0, $\overline{B}_s^0$), two final states ($D_s^-\pi^+$, $D_s^+\pi^-$)
- Initial state is unknown due to mixing
  - need flavour tagging
- Need a full description of propagation and decay of B_s^0 mesons to fit against data

Decay description

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

$$\Gamma(\overline{B}_s^0(t)\to f) = \frac{1}{2}\mathcal{N}_f|A_f|^2(1-a)(1+|\lambda_f|^2)e^{-\Gamma_s t}$$
$$\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + D_f \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos\left(\Delta m_s t\right) + S_f\sin\left(\Delta m_s t\right)\right],$$

Time fit

$$\Gamma(\overline{B}^0_s(t)\to \overline{f}) = \frac{1}{2}\mathcal{N}_f|\bar{A}_{\bar{f}}|^2(1+|\bar{\lambda}_{\bar{f}}|^2)e^{-\Gamma t}$$
$$\left[\cosh\left(\frac{\Delta\Gamma t}{2}\right) + D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma t}{2}\right)\right.$$
$$\left. + C_{\bar{f}}\cos(\Delta m t) - S_{\bar{f}}\sin(\Delta m t)\right],$$

$$\Gamma(B^0_s(t)\to \overline{f}) = \frac{1}{2}\mathcal{N}_f|\bar{A}_{\bar{f}}|^2\frac{1}{1-a}(1+|\bar{\lambda}_{\bar{f}}|^2)e^{-\Gamma t}$$
$$\left[\cosh\left(\frac{\Delta\Gamma t}{2}\right) + D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma t}{2}\right)\right.$$
$$\left. - C_{\bar{f}}\cos(\Delta m t) + S_{\bar{f}}\sin(\Delta m t)\right].$$

Parameterisation

- The wrong flavour-contribution is parameterised with D_f, $D_{\bar{f}}$, S_f and $S_{\bar{f}}$.
- Standard Model prediction is that they will be zero – flavour-specific
- The are higly correlated, so reparameterise to:

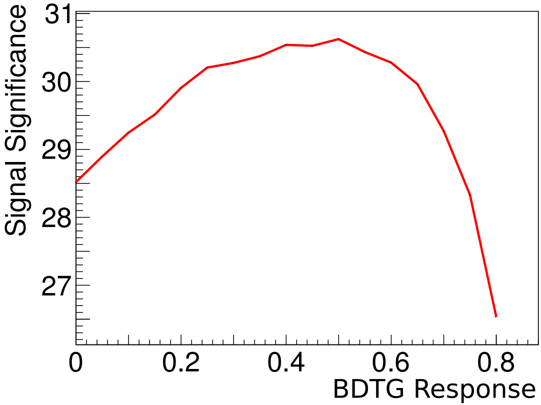
$$\overline{S} = \frac{S_f + S_{\bar{f}}}{2} \qquad \Delta S = \frac{S_f - S_{\bar{f}}}{2}$$
$$\overline{D} = \frac{D_f + D_{\bar{f}}}{2} \qquad \Delta D = \frac{D_f - D_{\bar{f}}}{2}$$

- Which should also all be zero
- These are our parameters of interest

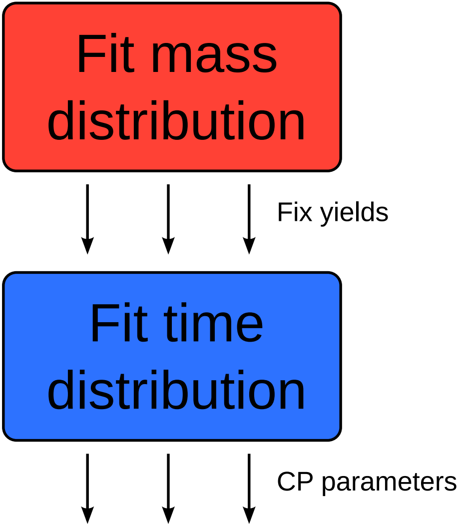
Event selection

- The event selection was originally tuned for $B_s^0 \to D_s K$
  - It doesn't know about the K so is safe to use
- Uses a BDT trained on background-subtracted data
- Optimised to maximise

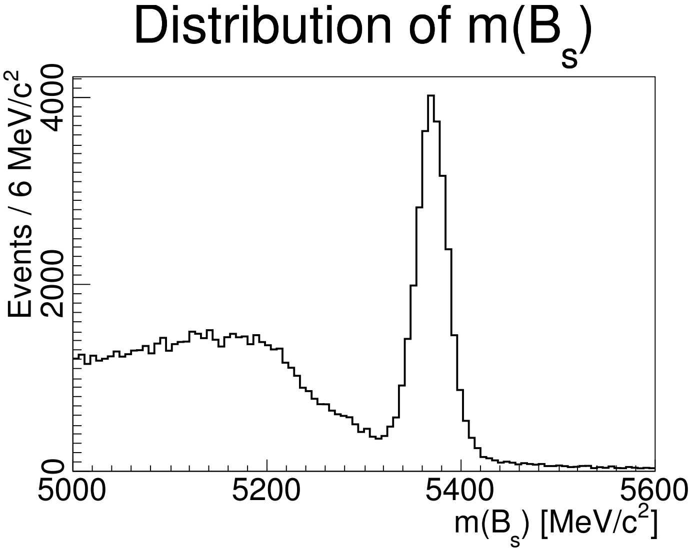
$$S = \frac{N_{sig}}{\sqrt{N_{sig} + N_B}}$$



Analysis plan



Mass fit


Distribution of m(B_s)
Events / 6 MeV/c^2
0
2000
4000
5000
5200
5400
5600
m(B_s) [MeV/c^2]

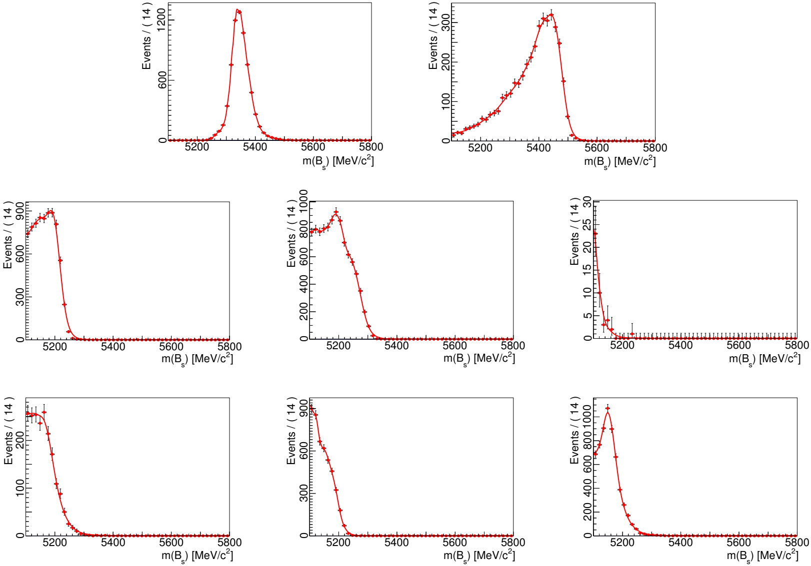
Backgrounds

- Fully reconstructed
  - $B^0 \to D\pi$, $B^0 \to D_s\pi$, $\Lambda_b \to \Lambda_c\pi$
- Low-mass B_s^0
  - $B_s^0 \to D_s\rho$, $B_s^0 \to D_s^*\pi$, $B_s^0 \to D_s^*\rho$
- Low-mass B^0
  - $B^0 \to D\rho$, $B^0 \to D_s^*\pi$, $B^0 \to D^*\pi$
- Combinatorial

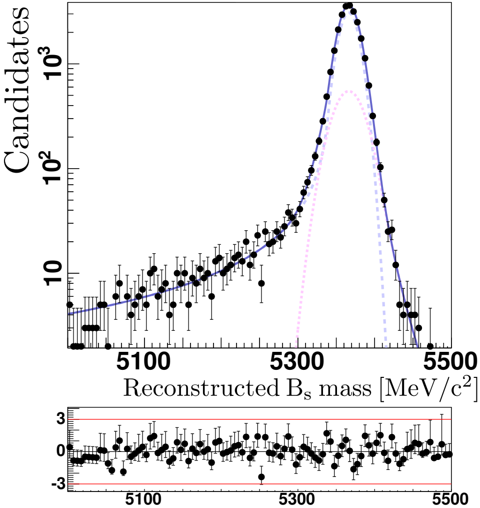
Mass fit

- Most backgrounds are modelled on simulated data
- Combinatorial is an exponential fitted to sidebands in data
- Signal is a double Crystal Ball function
- Yields of some backgrounds are fixed based on relative expected yields
- The $B^0 \to D\pi$ yield is fixed based on a fit to a set of real $B^0 \to D\pi$ events

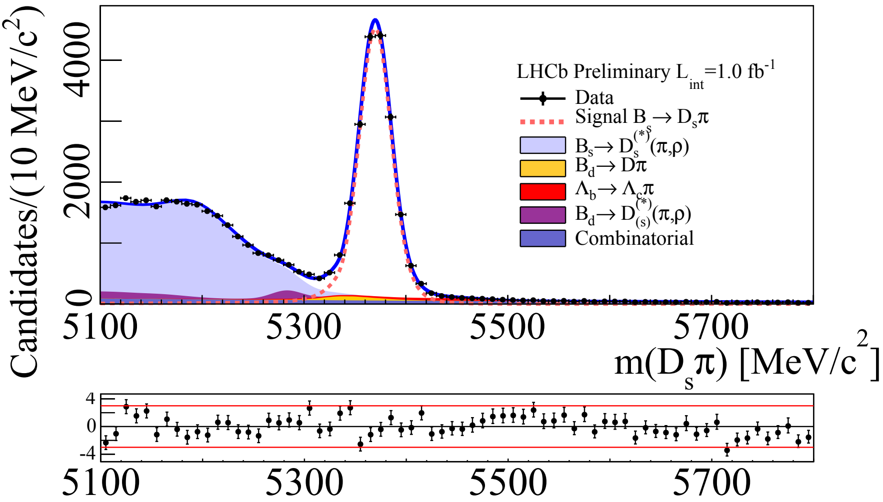
Background templates



Signal template

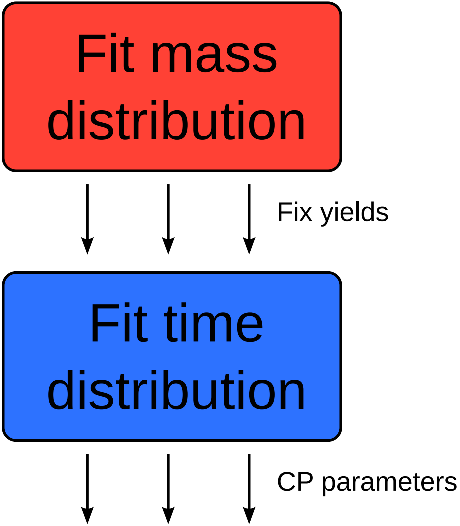


Mass fit



27,965 $\pm$ 187 $B_s^0 \to D_s\pi$ events

Analysis plan



Time fit backgrounds

Oscillating with wrong-flavour	Flavour specific	Non-oscillating
$B^0 \to D\pi$	$B^0 \to D_s\pi$	$\Lambda_b \to \Lambda_c\pi$
$B^0 \to D\rho$	$B^0 \to D_s^*\pi$	Combinatorial
$B^0 \to D^*\pi$	$B_s^0 \to D_s\rho$	
	$B_s^0 \to D_s^*\pi$	
	$B_s^0 \to D_s^*\rho$	

Time fit fixed parameters

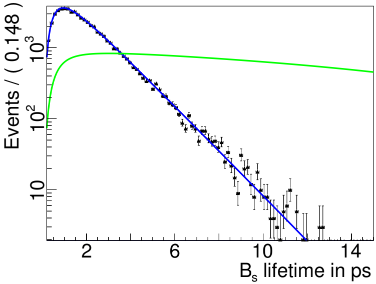
Parameter	Value
Γ_d	$0.656\,\mathrm{ps}^{-1}$
$\Delta\Gamma_d$	$0\,\mathrm{ps}^{-1}$
Δm_d	$0.507\,\mathrm{ps}^{-1}$
Γ_s	$0.658\,\mathrm{ps}^{-1}$
$\Delta\Gamma_s$	$-0.116\,\mathrm{ps}^{-1}$
Γ_{Λ_b}	$0.719\,\mathrm{ps}^{-1}$
Γ_{comb}	$0.800\,\mathrm{ps}^{-1}$

- $\overline{S}$, $\overline{D}$, ΔS, ΔD are floated, as are the tagging efficiencies and Δm_s

Time fit

- Decay-time acceptance and decay-time resolution are modelled on simulated data

$$\begin{cases} 0 & \text{when } (at)^n - b < 0 \text{ or } t < 0.2 \text{ ps}, \\ \left(1 - \frac{1}{1+(at)^n - b}\right) \times (1 - \beta t) & \text{otherwise}, \end{cases}$$



Parameter	Value
a	1.42 ± 0.204 ps^{-1}
b	0.0230 ± 0.0364
n	1.81 ± 0.066
β	0.0363 ± 0.0118 ps^{-1}

Sources of systematic uncertainty

Decay-time resolution This is fitted on simulated data and its width is varied by 20%

Decay time acceptance This is fitted on simulated data and each parameter is varied within its measured uncertainty

Background yields These are varied within their measured uncertainties from the mass fit

Background parametrisation The time fit is performed as an sFit which does not model the backgrounds

Physics parameters Various fixed physics parameters (Γ_s, $\Delta\Gamma_s$ etc.) from PDG or LHCb are varied within their published uncertainties

Flavour tagging calibration Measured on $B^+ \to J/\psi K^+$ data and varied within measured uncertainties

Asymmetries Production, detection and flavour tagging asymmetries are varied consistent with what is observed in data

Sources of systematic uncertainty

	Parameter			
Source	$\overline{S}$	$\overline{D}$	ΔS	ΔD
Decay-time resolution	0.022	0.020	0.001	0.000
Flavour tagging calibration	0.004	0.008	0.001	0.000
Background yields	0.007	0.010	0.002	0.003
Background parametrisation	0.005	0.008	0.002	0.001
Physics parameters	0.003	0.117	0.002	0.002
Asymmetries	0.006	0.009	0.001	0.169
Decay time acceptance	0.003	0.528	0.002	0.002
Total systematic uncertainty	0.025	0.541	0.004	0.169

Results

$$
\begin{aligned}
\overline{S} &= 0.197 \pm 0.150 \pm 0.025 \\
\overline{D} &= -0.888 \pm 0.098 \pm 0.541 \\
\Delta S &= 0.066 \pm 0.083 \pm 0.004 \\
\Delta D &= -0.062 \pm 0.050 \pm 0.169
\end{aligned}
$$

- All the parameters are within 2σ of zero and ΔS and ΔD are less than 1σ
- At this level of uncertainty, no evidence of non-flavour-specific decays of $B_s^0 \to D_s\pi$

Results

- ΔD is related to the difference in the effective lifetimes of $D_s^- \pi^+$ and $D_s^+ \pi^-$
- The above result effectively states that $|\Delta D| < 0.1$
    - it is possible to put a constraint on the difference in effective lifetimes between these two final states
- The effective lifetime is given by $\tau_{\mathrm{eff}} = \tau_{B_s^0} \left(1 + D_f \times \frac{\Delta\Gamma_s}{2\Gamma_s}\right)$, and using the measured value of ΔD we find

$$\left| \frac{\Delta \tau_{\mathrm{eff}}}{\tau_{B_s^0}} \right| \lesssim 0.02.$$

- This shows that the $D_s^- \pi^+$ and the $D_s^+ \pi^-$ have the same lifetime to better than 2%
- In the case that the $B_s^0 \to D_s \pi$ decay is assumed to be flavour-specific, this provides a test of CPT invariance which predicts that particles and anti-particles have equal lifetimes

Thank you