Comparison of $B_s^0 \to D_s^- \mu^+ \nu_\mu$ and $B^0 \to D^- \mu^+ \nu_\mu$ to test SU(3) symmetry

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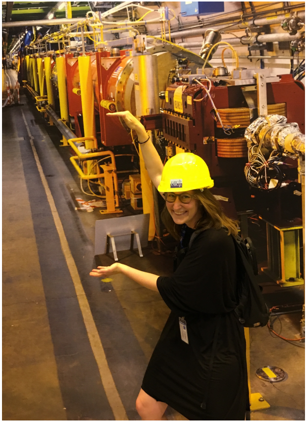
About me

- From Denmark
- Studying at Niels Bohr Institute in Copenhagen
- Finishing my master thesis in atroparticle physics



Outline

Introduction

Analysis strategy

Results:

- $B^0 \to D^- \mu^+ \nu_\mu$
- $B_s^0 \to D_s^- \mu^+ \nu_\mu$
- Comparison of $B^0 \to D^- \mu^+ \nu_\mu$ and $B_s^0 \to D_s^- \mu^+ \nu_\mu$

Conclusion and outlook

Studying semileptonic $B^0_{(s)} \to D^-_{(s)}\mu^+\nu_\mu$ decays

⋆ Purpose: test SU(3) symmetry by comparing the form factors (FFs) for $B^0_s \to D^-_s$ and $B^0 \to D^-$.

Form Factors

- FF accounts for the hadronic part of the decay (non-perturbative QCD)

SU(3) symmetry in B_s and B^0 decays

- Same FF is expected → only difference is the spectator quark (s/d)

FF useful input for other studies (f_s/f_d from hadronic decays).

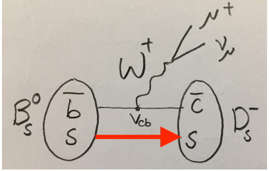


Fig 1. $B^0_s \to D^-_s\mu^+\nu_\mu$

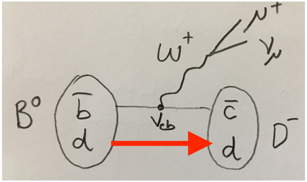


Fig 2. $B^0 \to D^-\mu^+\nu_\mu$

Measuring FF in semileptonic decays

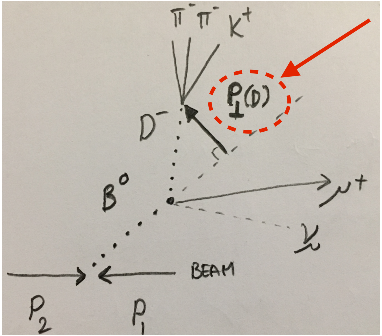
⋆ The FF is a function of the transfer momentum of the W-boson q^2 and is parametrised as an expansion of the parameter ρ^2 [[1]].

Challenge:

- Cannot reconstruct q^2 due to missing ν_μ

Alternate approach: variable $P_\perp(D)$

- Correlated with q^2
- Fully reconstructed, good resolution



$P_\perp(D)$ in B meson decay

1

[1]M. Neubert, Heavy-quark symmetry, Physics Reports 245 (1994)

$P_\perp(D)$ dependence on FF

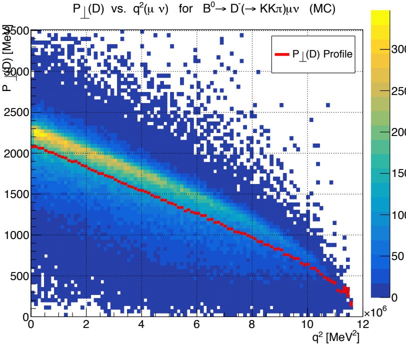


Fig 1. Correlation between $P_\perp(D)$ and q^2 from MC

MC generated with different FF changes q^2 and $P_\perp(D)$ distributions $\rightarrow$

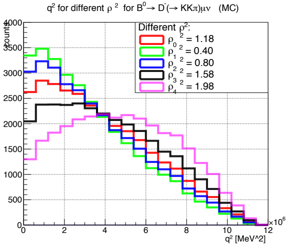


Fig 2. q^2 for different ρ^2

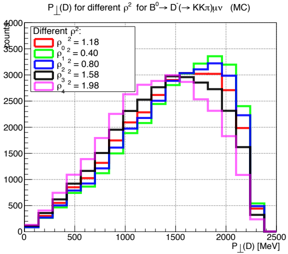


Fig 3. $P_\perp(D)$ for different ρ^2

Analysis goal and strategy

Goal:

⋆ Determine the $P_\perp(D)$ distribution for $B_s^0 \to D_s^- \mu^+ \nu_\mu$ and $B^0 \to D^- \mu^+ \nu_\mu$ to compare them for a SU(3) test

Strategy:

- Split data sample in bins of the variable $P_\perp(D)$
- Perform a fit to the corrected B mass in each bin to obtain signal yields and thereby the distributions:
  - $P_\perp(D)(B_s^0 \to D_s^- \mu^+ \nu_\mu)$
  - $P_\perp(D)(B^0 \to D^- \mu^+ \nu_\mu)$.
- Finally compute the ratio: $P_\perp(D)(B_s^0 \to D_s^- \mu^+ \nu_\mu)/P_\perp(D)(B^0 \to D^- \mu^+ \nu_\mu)$

Corrected B mass fit to the data

LHCb data Run 1, selection inherited from B_s^0 and D_s lifetime measurement [2].

Corrected B mass variable:

$$m_{corr} = p_{\perp,D\mu} + \sqrt{m_{D\mu}^2 + p_{\perp,D\mu}^2} \quad (1)$$

- Compensates for part of the missing momentum
- Makes the B mass distribution more narrow

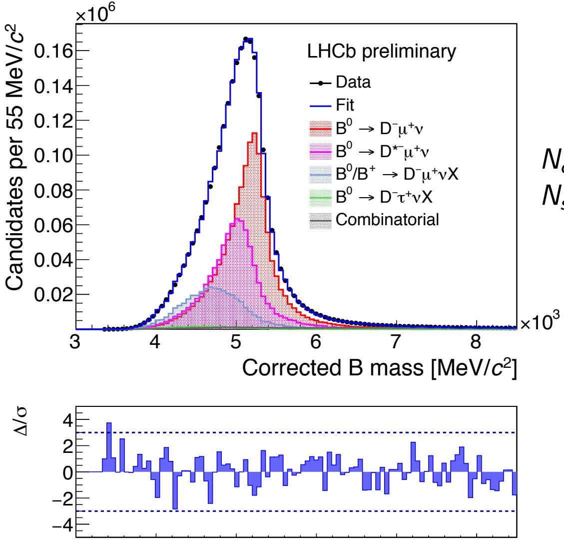
Binned least-squares fit:

- ⋆ **Purpose: discriminate signal from backgrounds and determine the signal composition**
- ⋆ Mass shapes for signal and backgrounds are obtained from both MC and control sample of data [2]

[2] LHCb-ANA-2016-068, March 7, 2017

$$B^0 \rightarrow D^- \mu^+ \nu_\mu$$

Corrected mass fit for $B^0 \to D^- \mu^+ \nu_\mu$



- $\star$ $\chi^2/ndf = 109.6/88$
- $\star$ prob $= 0.059$

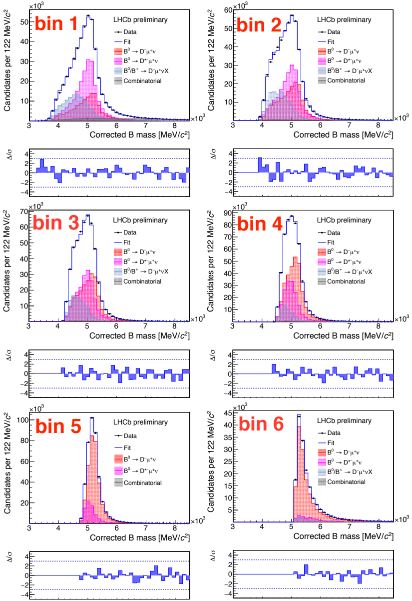
$N_{candidates} \sim 2.6M$

$N_{signal} = (1.284 \pm 0.014)$ M

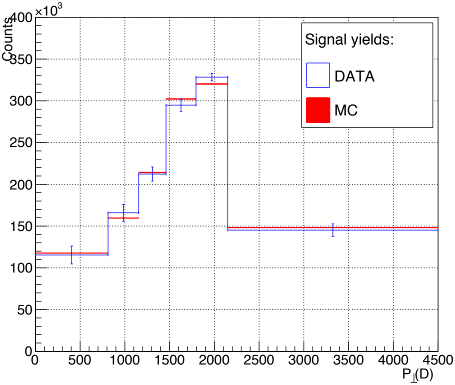
Determine $P_\perp(D)(B^0 \to D^- \mu^+ \nu_\mu)$

Data sample is split into 6 bins of $P_\perp(D)$:

1) 0-812 MeV
2) 812-1155 MeV
3) 1155-1460 MeV
4) 1460-1795 MeV
5) 1795-2150 MeV
6) 2150-4500 MeV



Preliminary $P_\perp(D)$ distribution for $B^0 \to D^-\mu^+\nu_\mu$



Remarks:

Good agreement between Data and MC (FF from known world average values [3]) validates the method

- $\chi^2 = 4.90/5$
- prob $= 0.43$

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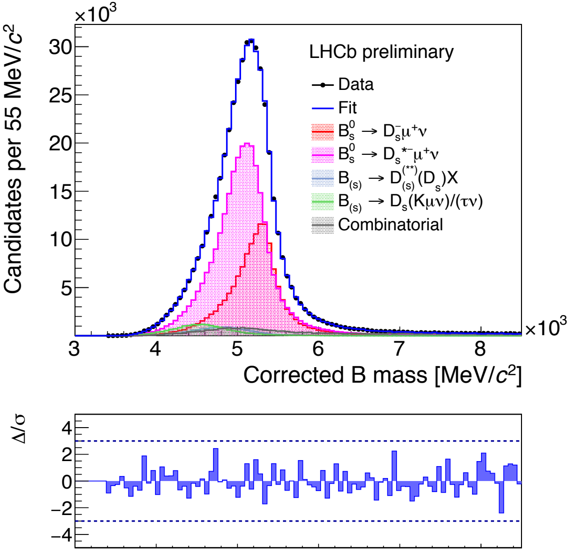
[3] Y. Amhis et al.,"Averages of b-hadron, c-hadron, and tau-lepton properties as of summer 2016"

$$B_s^0 \to D_s^- \mu^+ \nu_\mu$$

Corrected mass fit for $B_s^0 \to D_s^- \mu^+ \nu_\mu$

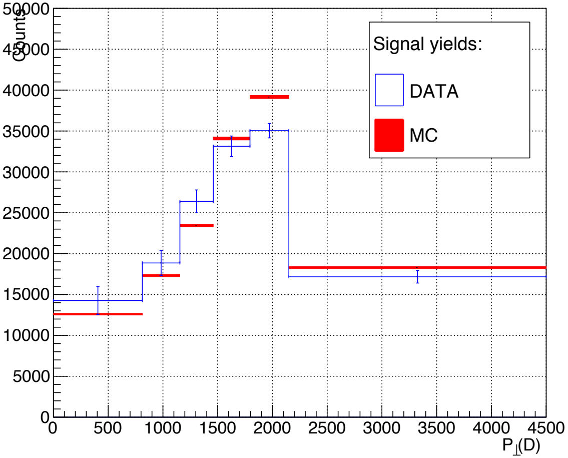


- $\chi^2/ndf = 84.01/89$
- prob = 0.63

$N_{candidates} \sim 470K$

$N_{signal} = (137 \pm 2.4)$ K

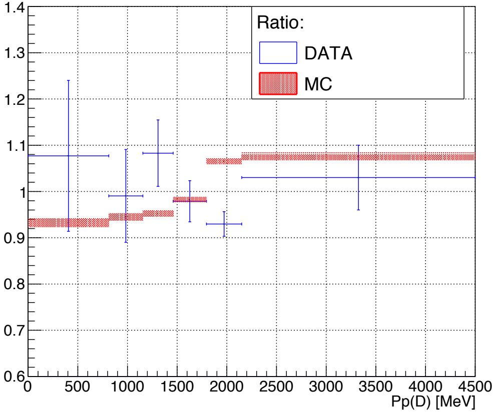
Preliminary $P_\perp(D)$ distribution for $B_s^0 \to D_s^- \mu^+ \nu_\mu$



Remarks

- MC is generated under assumption of perfect SU(3)
- Observe a tension in two bins (3 and 5)
- Need to include systematic uncertainties (eg. fitting assumptions)

Preliminary comparison of $P_\perp(D)(B_s^0 \to D_s^- \mu^+ \nu_\mu)$ and $P_\perp(D)(B^0 \to D^- \mu^+ \nu_\mu)$



Remarks:

More work needed for meaningful comparison.

Yet, first step into the test of SU(3) symmetry between $B_s^0 \to D_s^-$ and $B^0 \to D^-$ decays.

Next step:

Assess the sensitivity of the ratio of $P_\perp(D)$ distributions to the FF parameter ρ^2

Conclusion and outlook

Conclusion:

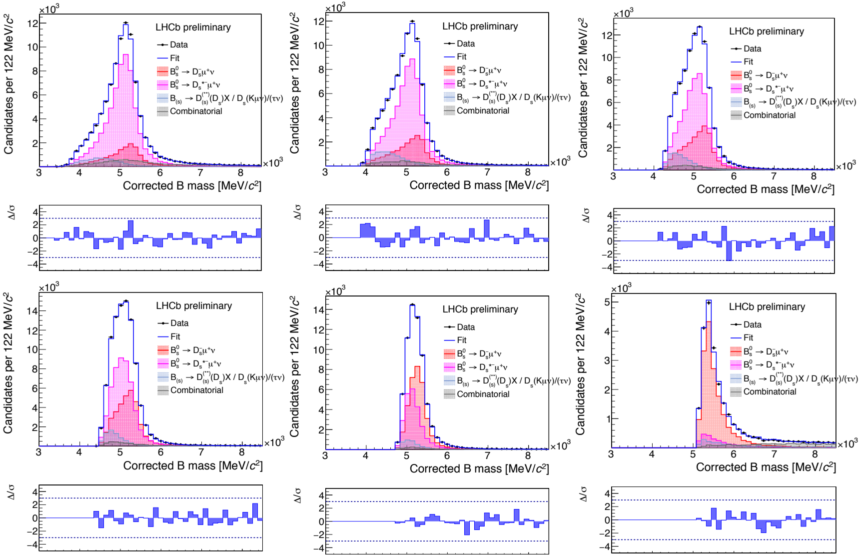
- ⋆ We made the first attempt to compare $B_s^0 \to D_s^- \mu^+ \nu_\mu$ and $B^0 \to D^- \mu^+ \nu_\mu$ decays.
- ⋆ We have proven that we can extract the $P_\perp(D)$ distribution of $B \to D\mu\nu$ decays and validates the method on the known B^0 sample.
- ⋆ Still to finalise the work on the B_s^0 case to make the test, but the method looks already promising.
- ⋆ Next steps: try to extract the FF parameter from the fit of the ratio of $P_\perp(D)$ distributions and to add run 2 data

Thank you for your attention!

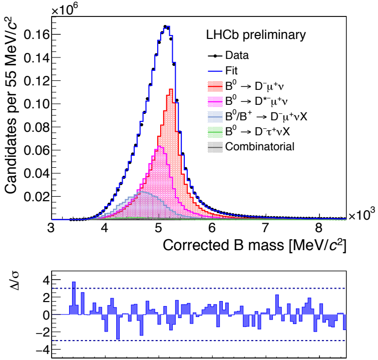
Back-up slides

Mass fit in each bin for $B_s^0 \to D_s \mu \nu$

Mass fit in each bin



Fit Result for integrated sample of $B^0 \to D\mu\nu_\mu$



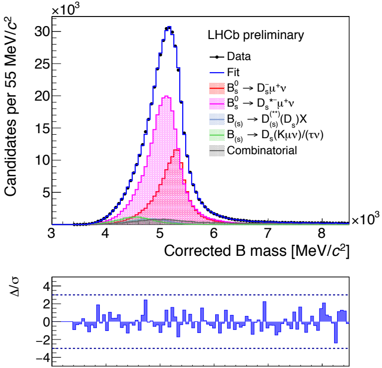
- $\chi^2/ndf = 109.6/88$
- prob $= 0.059$

$$f_{B^0 \to D^- \mu^+ \nu)} = (49.18 \pm 0.54)\%$$
$$f_{(B^0 \to D^{*-} \mu^+ \nu)} = (31.24 \pm 0.93)\%$$
$$f_{(B^0/B^+ \to D^- \mu^+ \nu X)} = (15.96 \pm 1.22)\%$$
$$f_{(B^0 \to D^{*-} \tau^+ \nu X)} = (1.26 \pm 0.77)\%$$
$$f_{(combinatorial)} = (2.37 \pm 0.07)\%$$

[3] LHCb-ANA-2016-068, March 7, 2017

Corrected mass fit for $B_s^0 \to D_s \mu\nu$

Mass fit result:



- $\chi^2/ndf = 84.01/89$
- prob $= 0.63$

$$f_{(B_s \to D_s^- \mu^+ \nu)} = (29.2 \pm 0.518)\%$$

$$f_{(B_s \to D_s^{*-} \mu^+ \nu)} = (57.9 \pm 0.886)\%$$

$$f_{(B_{(s)} \to D_{(s)}^{**-} (D_s) X)} = (3.14 \pm 0.717)\%$$

$$f_{(B_{(s)} \to D_{(s)} (K\mu\nu)/\tau\nu)} = (3.97 \pm 0.288)\%$$

$$f_{(combinatorial)} = (5.80 \pm 0.135)\%$$

[8] LHCb-ANA-2016-068, March 7, 2017

Stripping

Quantity	$K^+K^-\pi^-$ requirement (`b2DsPhiPiMuXB2DMuNuX`)	$K^+\pi^-\pi^-$ requirement (`b2DpMuXB2DMuNuX`)
ProbNNghost(μ, π, K)	< 0.5	< 0.5
Minimum IP$\chi^2(\mu, \pi, K)$	> 4.0	> 9.0
$p_T(\mu)$	> 600 MeV/c	> 800 MeV/c
$p(\mu)$	–	> 3.0 GeV/c
PIDmu(μ)	> 0.0	> 0.0
Track χ^2/ndf	-	< 4.0
$p_T(K)$, $p_T(\pi)$	> 150 MeV/c	> 300 MeV/c
$p(K)$, $p(\pi)$	> 1.5 GeV/c	> 2.0 GeV/c
PIDK(K)	> 0.0	> 4.0
PIDK(π)	< 20.0	< 10.0
D daughters' $\sum p_T$	–	> 1.8 GeV/c
D vertex χ^2/ndf	< 8.0	< 6.0
D χ^2/ndf separation from PV	> 20	> 100
D DIRA	> 0.99	> 0.99
$m(D^-_{(s)})$	$\in [1789.620, 2048.490]$ MeV/c^2	$\in [1789.620, 1949.620]$ MeV/c^2
$m(K^+K^-)$	$\in [979.455, 1059.455]$ MeV/c^2	–
B vertex χ^2/ndf	< 20.0	< 6.0
B DIRA	> 0.99	> 0.999
$m(D_{(s)}\mu)$	$\in [0.0, 1000.0]$ GeV/c^2	$\in [2.5, 6.0]$ GeV/c^2
$v_z(D) - v_z(B)$	> -0.3 mm	> 0.0 mm

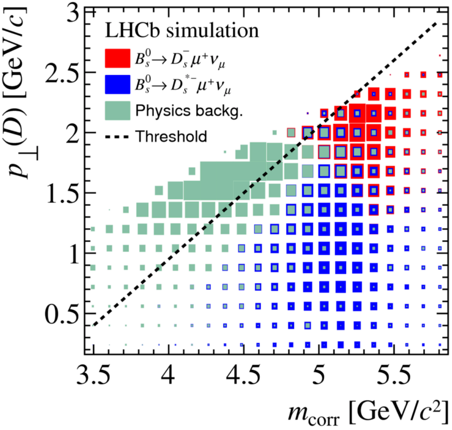
Table 1: Summary of stripping selections for (left) $K^+K^-\pi^-$ and (right) $K^+\pi^-\pi^-$ samples.

Offline selection

Quantity	$K^+K^-\pi^-$ requirement	$K^+\pi^-\pi^-$ requirement
ProbNNk(K)	> 0.2	> 0.2
ProbNNpi(π)	> 0.2	> 0.5
ProbNNmu(μ)	> 0.2	> 0.2
$p(K)$	$> 2\,\mathrm{GeV}/c$	$> 3\,\mathrm{GeV}/c$
$p(\pi)$	$> 2\,\mathrm{GeV}/c$	$> 5\,\mathrm{GeV}$
$p_T(K),\ p_T(\pi)$	$> 300\,\mathrm{MeV}/c$	$> 500\,\mathrm{MeV}/c$
$D^-_{(s)}$ vertex χ^2/ndf	< 6.0	< 6.0
$m(K^+K^-)$	$\in [1.008, 1.032]\ \mathrm{GeV}/c^2$	–
$p_\perp(D)[\,\mathrm{MeV}/c]$	$> 1500 + 1.1 \times (m_{\mathrm{cor}}[\,\mathrm{MeV}/c^2] - 4500)$	
t_D	$> 0.1\,\mathrm{ps}$	
m_{corr}	$[3000, 8500]\ \mathrm{MeV}/c^2$	
$m(D^-_{(s)})$	$\in [1.85, 1.89]\ \mathrm{GeV}/c^2$ for B^0 $\in [1.94, 2.00]\ \mathrm{GeV}/c^2$ for B^0_s	$\in [1.85, 1.89]\ \mathrm{GeV}/c^2$
$m(D^-_{(s)}\mu^+)$	$> 3.1\ \mathrm{GeV}/c^2$ $\notin [5.200, 5.400]\ \mathrm{GeV}/c^2$ (for B^0) $\notin [5.280, 5.480]\ \mathrm{GeV}/c^2$ (for B^0_s)	$> 3.1\ \mathrm{GeV}/c^2$ $\notin [5.200, 5.400]\ \mathrm{GeV}/c^2$
$m(\mu^+\mu^-)$	$\notin [3.040, 3.160]\ \mathrm{GeV}/c^2$ $\notin [3.635, 3.735]\ \mathrm{GeV}/c^2$	$\notin [3.040, 3.160]\ \mathrm{GeV}/c^2$ $\notin [3.635, 3.735]\ \mathrm{GeV}/c^2$
$m(Kp\pi)$	$\notin [2.260, 2.310]\ \mathrm{GeV}/c^2$	$\notin [2.260, 2.310]\ \mathrm{GeV}/c^2$

Table 2: Summary of offline selection criteria for the (left) $K^+K^-\pi^-$ and (right) $K^+\pi^-\pi^-$ samples. See text for motivations for the various mass vetoes.

Selection in 2dim plane of $P_{\perp}(D)$ vs. m_{corr}



Distribution of the classes of simulated events in the two-dimensional plane. The region accepted in our selection is below the dashed line.[4]

[3] https://cds.cern.ch/record/2263774/files/Supplementary-LHCb-PAPER-2017-004.pdf

Data Samples

- Collected by LHCb in Run1 at $\sqrt{s} = 7 - 8$ TeV and L=3 fb^{-1}.
- Samples and selection inherited from B_s^0 and D_s lifetime measurement. [5]
- Same sign data (SS) are $D^{\pm}\mu^{\pm}$ combinations used to model combinatorial background.

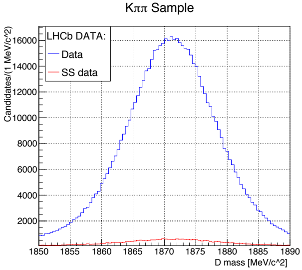


Fig 6. N∼ 2.6 M

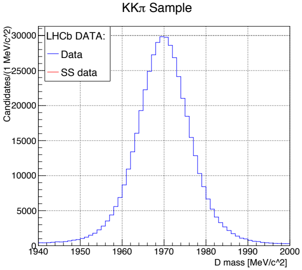


Fig 7. N∼ 470 K

[2] LHCb-ANA-2016-068, March 7, 2017

Data samples for OS and SS

After selection:

- Opposite sign candidates (OS):
  $N_{OS}(B^0 \to K\pi\pi) = 2{,}611{,}001$
  $N_{OS}(B_s^0 \to KK\pi) = 467{,}951$
- Same sign candidates (SS):
  $N_{SS}(B^0 \to K\pi\pi) = 28{,}767$
  $N_{SS}(B_s^0 \to KK\pi) = 14{,}228$

Simulated signal and background contribution for B0 and Bs

Sample	Event type	Candidates after selection	Efficiency $[10^{-4}]$
$B_s^0 \to D_s^-(\to K^+K^-\pi^-)\mu^+\nu X$	13774002	566419	7.05
$B^0 \to D^-(\to K^+K^-\pi^-)\mu^+\nu X$	11874022	290353	3.95
$B^0 \to D^-(\to K^+\pi^-\pi^-)\mu^+\nu X$	11874042	149131	8.49
$B_s^0 \to D_s^{(*)-}D_s^{(*)+}$	13873201	3037	1.98
$\Lambda_b^0 \to \Lambda_c^+ D_s^{(*)-}(\pi^0)$	15894301	3330	1.06
$B^+ \to D^{(*)0}D_s^{(*)+}$	12875601	2071	1.35
$B^0 \to D^{(*)-}D_s^{(*)+}$	11876001	1780	1.16
$B^- \to D_0^{*0}(2400)(\to D_s^{(*)+}K^+)\mu^-\nu$	12775001	6447	2.23
$\overline{B}^0 \to D_0^{*-}(2400)(\to D_s^{(*)+}K_S^0)\mu^-\nu$	11774001	6236	2.09
$B_s^0 \to D^0 D_s K$	13796000	4636	1.61
$B^+ \to D^-(\to K^+K^-\pi^-)\pi^+\mu^+\nu X$	12875011	44734	2.25
$B^+ \to D^-(\to K^+\pi^-\pi^-)\pi^+\mu^+\nu X$	12875031	18226	4.12

Table 3: Samples of simulated data used in the analysis. Signal components are on the top, expected physics backgrounds for the B_s^0 sample are in the middle, and expected B^+ backgrounds to the B^0 samples are at the bottom.

Simulated signal mixture for B0 and Bs

Process	$\mathcal{B}$ [%]	Decay model
$B_s^0 \to D_s^- \mu^+ \nu$	2.1000	HQET2 1.17 1.074
$B_s^0 \to D_s^{*-}(\to D_s^- X)\mu^+\nu$	5.1000	HQET2 1.16 1.370 0.845 0.921
$B_s^0 \to D_{s0}^{*-}(\to D_s^{(*)-} X)\mu^+\nu$	0.7000	ISGW2
$B_s^0 \to D_{s1}^{-}(\to D_s^{(*)-} X)\mu^+\nu$	0.4000	ISGW2
$B_s^0 \to D_{s1}^{\prime -}(\to D_s^{(*)-} X)\mu^+\nu$	0.4000	ISGW2
$B_s^0 \to D_s^- \tau^+(\to \mu^+\nu\nu)\nu$	0.138	ISGW2
$B_s^0 \to D_s^{*-}(\to D_s^{(*)-} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.2770	ISGW2
$B_s^0 \to D_{s0}^{*-}(\to D_s^{(*)-} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0310	ISGW2
$B_s^0 \to D_{s1}^{\prime -}(\to D_s^{(*)-} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0310	ISGW2
$B^0 \to D^- \mu^+ \nu$	2.1700	HQET2 1.18 1.074
$B^0 \to D^{*-}(\to D^- X)\mu^+\nu$	1.6218	HQET 1.20 1.426 0.818 0.908
$B^0 \to D_1^-(\to D_{(0)}^* X)\mu^+\nu$	0.1848	ISGW2
$B^0 \to D_2^{*-}(\to D_{(0)}^{(*)} X)\mu^+\nu$	0.1652	ISGW2
$B^0 \to D_0^{*-}(\to D^{(*)-} X)\mu^+\nu$	0.1436	ISGW2
$B^0 \to D^- \pi^+\pi^- \mu^+\nu$	0.1197	PHSP
$B^0 \to D^{*-}(\to D^- X)\pi^+\pi^-\mu^+\nu$	0.0902	PHSP
$B^0 \to D_1^{\prime -}(\to D^{(*)-} X)\mu^+\nu$	0.0616	ISGW2
$B^0 \to D^- \pi^0\pi^0 \mu^+\nu$	0.0294	PHSP
$B^0 \to D^{*-}(\to D^- X)\pi^0\pi^0\mu^+\nu$	0.0237	PHSP
$B^0 \to D^- \pi^0 \mu^+\nu$	0.0198	GOITY_ROBERTS
$B^0 \to D^{*-}(\to D^- X)\pi^0\mu^+\nu$	0.0149	GOITY_ROBERTS
$B^0 \to D^- \tau^+(\to \mu^+\nu\nu)\nu$	0.1910	ISGW2
$B^0 \to D^{*-}(\to D^- X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0841	ISGW2
$B^0 \to D_2^{*-}(\to D_{(0)}^{(*)} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0110	ISGW2
$B^0 \to D_1^-(\to D_{(0)}^* X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0087	ISGW2
$B^0 \to D_0^{*-}(\to D^{(*)-} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0069	ISGW2
$B^0 \to D_1^{\prime -}(\to D^{(*)-} X)\tau^+(\to \mu^+\nu\nu)\nu$	0.0053	ISGW2

Table 4: Processes contributing to the simulated samples of inclusive (top) $B_s^0 \to D_s^- \mu^- \nu X$ and (bottom) $B^0 \to D^- \mu^+ \nu X$ decays. Branching fractions and decay models used in generation are also reported.

Simulated signal and background in categories

Category	Decay	$\mathcal{B}$ $[10^{-4}]$	$\epsilon_{\mathrm{bkg}}/\epsilon_{\mathrm{sig}}$	$f_{q/\Lambda}/f_d$	$f_{\mathrm{bkg}}/f_{KK\pi}$ [%]
B^+ $(K^+K^-\pi^-)$	$B^+ \to D^-\mu^+X$	97 ± 16	0.569 ± 0.006	1	6.02 ± 1.12
B^+ $(K^+\pi^-\pi^-)$	$B^+ \to D^-\mu^+X$	97 ± 16	0.485 ± 0.005	1	5.12 ± 0.95
$B \to DD$	$B^0 \to D^-D^+_{(s)}X$	4.60 ± 0.67	0.174 ± 0.004	1	0.09 ± 0.02
	$B^0 \to D^-D^+X$	0.14 ± 0.01	0.174 ± 0.004	1	< 0.01
	$B^0_s \to D^-D^+$	0.15 ± 0.04	0.281 ± 0.006	0.26 ± 0.02	< 0.01
	$B^- \to D^-D^0$	0.10 ± 0.01	0.197 ± 0.005	1	< 0.01
Λ^0_b	$\Lambda^0_b \to \Lambda^+_c D^-X$	0.09 ± 0.04	0.156 ± 0.003	0.60 ± 0.08	< 0.01
	$\Lambda^0_b \to D^-n\mu^+\nu$	–	–	–	–

Table 7: Background contributions for the $B^0 \to D^-(\to K^+K^-\pi^-)\mu^+\nu X$ and $B^0 \to D^-(\to K^+\pi^-\pi^-)\mu^+\nu X$ samples.

Category	Decay	$\mathcal{B}$ $[10^{-4}]$	$\epsilon_{\mathrm{bkg}}/\epsilon_{\mathrm{sig}}$	$f_{q/\Lambda}/f_s$	$f_{\mathrm{bkg}}/f_{\mathrm{sig}}$ [%]
$B \to DD$	$B^0 \to D^{(*)-}D_s^{(*)+}$	12.74 ± 1.60	0.174 ± 0.004	3.86 ± 0.22	1.08 ± 0.36
	$B^+ \to D^{(*)0}D_s^{(*)+}$	11.36 ± 1.29	0.197 ± 0.005	3.86 ± 0.22	1.09 ± 0.36
	$B^0_s \to D_s^{(*)-}D_s^{(*)+}$	12.17 ± 3.93	0.281 ± 0.006	1	0.43 ± 0.19
$B \to DK\mu\nu$	$B^- \to D_s^{(*)+}K^-\mu^-X$	6.10 ± 1.00	0.319 ± 0.005	3.86 ± 0.22	0.95 ± 0.33
	$B^0 \to D_s^{(*)-}K^0_S\mu^+X$	6.10 ± 1.00	0.299 ± 0.005	3.86 ± 0.22	0.89 ± 0.31
$B \to DDK$	$B^0_s \to D^0D_s^-K^+$	0.24 ± 0.09	0.236 ± 0.004	1	0.01 ± 0.01
	$B^0_s \to D^-D_s^+K^0$	0.17 ± 0.06	0.236 ± 0.004	1	0.01 ± 0.01
Λ^0_b	$\Lambda^0_b \to \Lambda^+_c D_s^{(*)+}(\pi^0)$	4.31 ± 1.69	0.156 ± 0.003	2.34 ± 0.31	0.20 ± 0.10
	$\Lambda^0_b \to D_s^+\Lambda^0\mu^-\nu$	–	–	–	–

Table 6: Background contributions for the $B^0_s \to D^-_s(\to K^+K^-\pi^-)\mu^+\nu X$ sample grouped into four main categories. The signal branching fraction, $\mathcal{B}(B^0_s \to D^-_s\ell^+\nu X) = (7.9\pm2.4)\%$, is the dominant source of uncertainty for the estimated relative fractions.

Motivation for measuring SU(3) in $B_0 \to D^-$ and $B_s^0 \to D_s^-$

- Uncertainties on fs/fd using semileptonic and hadronic decays:[6]

Table 3: Uncorrelated uncertainties of the two LHCb measurements of f_s/f_d [3,5]. The particle identification uncertainty present in both measurements is considered fully uncorrelated since the semileptonic measurement was performed analyzing an integrated luminosity of 3 pb^{-1} acquired in 2010, while the hadronic measurement was performed analyzing an integrated luminosity of 1 fb^{-1} acquired in 2011.

Source	Semileptonic (%)	Hadronic(%)
Statistical	3.0	1.7
SU(3) breaking and form factors	-	8.8
Bin dependent uncertainty	1.0	-
Semileptonic decay model	3.0	-
Backgrounds	2.0	-
Tracking efficiency	2.0	-
$\mathcal{B}(\overline{B}_s^0 \to D^0 K^+ X \mu \bar{\nu}_\mu)$	$^{+4.1}_{-1.1}$	-
$\mathcal{B}((B^-/\overline{B}^0) \to D_s^+ K X \mu \bar{\nu}_\mu)$	2.0	-
Detector acceptance and reconstruction	-	0.7
Hardware trigger efficiency	-	2.0
Offline selection	-	1.1
Boosted decision tree cut	-	1.0
Particle identification	1.5	1.5
Combinatorial background	-	1.0
Signal shape (tails)	-	0.6
Signal shape (core)	-	1.0
Total	$^{+7.1}_{-5.9}$	± 9.6

- ⋆ Result using hadronic decays: fs/fd $= 0.259 \pm 0.015$.

[4] https://cds.cern.ch/record/1559262/files/LHCb-CONF-2013-011.pdf?version=1