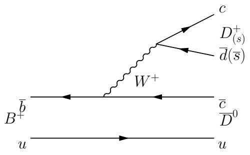
Beauty to doubly open charm decays at LHCb

Fionn Bishop

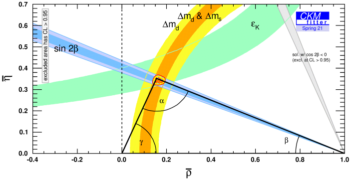
University of Cambridge

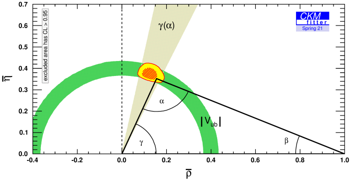


Birmingham Particle Physics Seminar
02/03/22

Introduction

- New Physics may be at energies inaccessible directly by the LHC
  - → Look for indirect effects on flavour physics observables
    - CKM parameters
    - Lepton universality

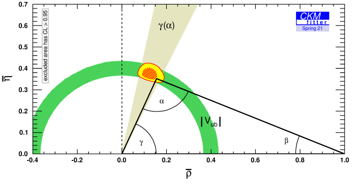


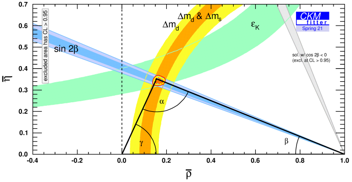


[http://ckmfitter.in2p3.fr]

CKM Unitarity

- CKM triangle determined with quantities accessible in tree- and loop-level decays
  - SM $\rightarrow$ equal
  - NP could break this equality
- Beauty to open charm decays provide access to these parameters
  - γ, β





[http://ckmfitter.in2p3.fr]

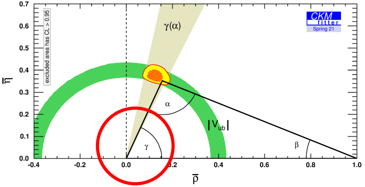
CKM phase γ

- CKM phase γ determines amount of hadronic CP violation in SM
- Accessible in interference between $b \to c$ and $b \to u$ transitions
  - Measurement dominated by $B^+ \to DK^+$
- One of least well-measured CKM parameters:
  - $\gamma = (65.4^{+3.8}_{-4.2})^\circ$ [JHEP 12 (2021) 141]

$$\mathcal{A}^{CP} = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B} \to \overline{f})}$$

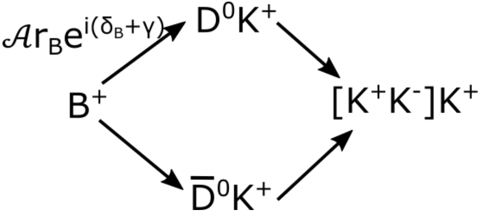
$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

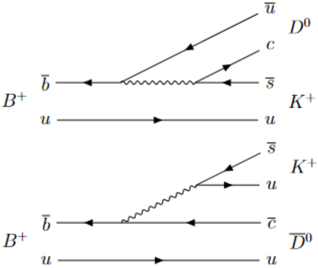
$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\gamma} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\gamma} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\gamma} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\gamma} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\gamma} & c_{23}c_{13} \end{pmatrix}$$



[http://ckmfitter.in2p3.fr]

- $\mathcal{B}(B^\pm \to D^0_+ K^\pm)$, $\mathcal{B}(B^+ \to D^0 K^+)$, $\mathcal{B}(B^+ \to \overline{D}^0 K^+)$
  - CP-even eigenstate D^0_+ identified as $\pi^+\pi^-$ or K^+K^-
- $\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D}^0 K^+)} \sim 0.1$ limits sensitivity





CKM phase γ: GLW method

- $\mathcal{B}(B^\pm \to D^0_+ K^\pm)$, $\mathcal{B}(B^+ \to D^0 K^+)$, $\mathcal{B}(B^+ \to \overline{D}^0 K^+)$
  - CP-even eigenstate D^0_+ identified as $\pi^+\pi^-$ or K^+K^-
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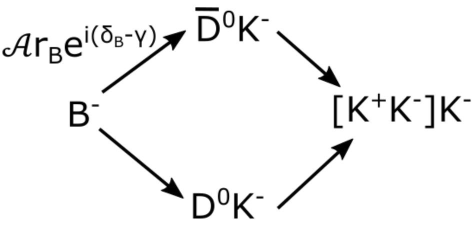
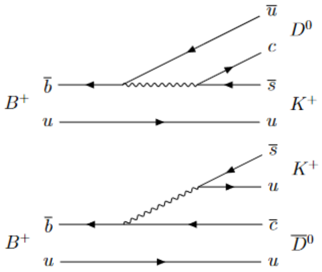
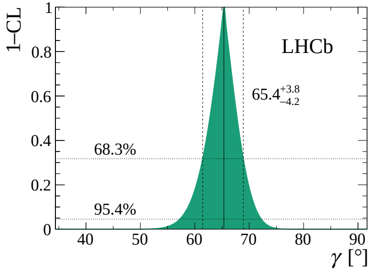




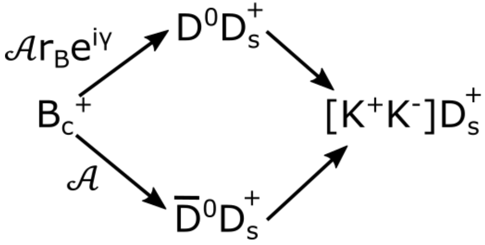
- ADS
  - $D^0 \to K^+\pi^-$ maximises interference
  - Dependence on charm hadronic parameters
    - LHCb, CLEO, BESIII
- GGSZ
  - $D \to K^0_S h^+ h^-$
  - Distribution in $m(K^0_S h^+)$ vs $m(K^0_S h^-)$
  - Limited interference and/or external inputs

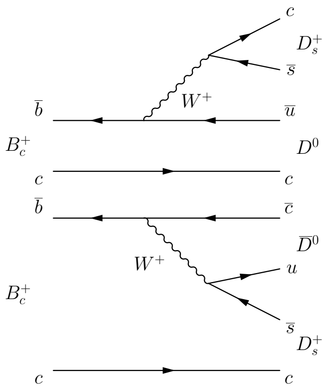
- Time-dependent
  - $\Gamma(t)(B^0_s \to D^\pm_s K^\mp)$



[JHEP 12 (2021) 141]

- $\frac{A(B_c^+ \to D^0 D_s^+)}{A(B_c^+ \to \overline{D}^0 D_s^+)} \sim 1$ + no strong phase difference expected [PRD 65 034016]
  - $\to$ Very strong interference with GLW final states!
  - $\to$ Excellent sensitivity to γ for a given yield
- Could also do GGSZ extraction





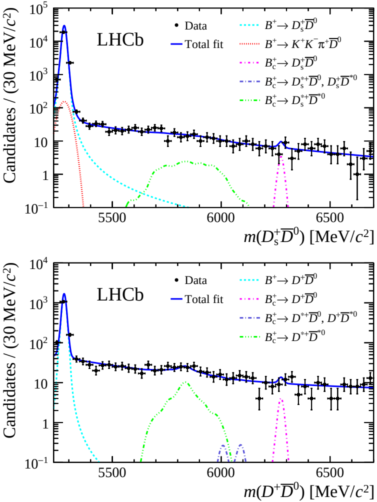
$B_c^+ \to DD$

- Large range in predicted branching fractions
  - $\to$ Measurement useful for constraining understanding of B_c^+
- Hadronic B branching fractions could be affected by New Physics [EPJC 80 951, PRD 102 071701, JHEP 10 (2021) 235]
  - e.g. left-handed W'

$B_c^+ \to$	$\mathcal{B}/10^{-6}$ [PRD86 074019]	$\mathcal{B}/10^{-6}$ [PRD86 094028]
$D_s^+ \overline{D}^0$	2.3	0.3
$D_s^+ D^0$	3.0	0.2
$D^+ \overline{D}^0$	32	1.3
$D^+ D^0$	0.10	0.008

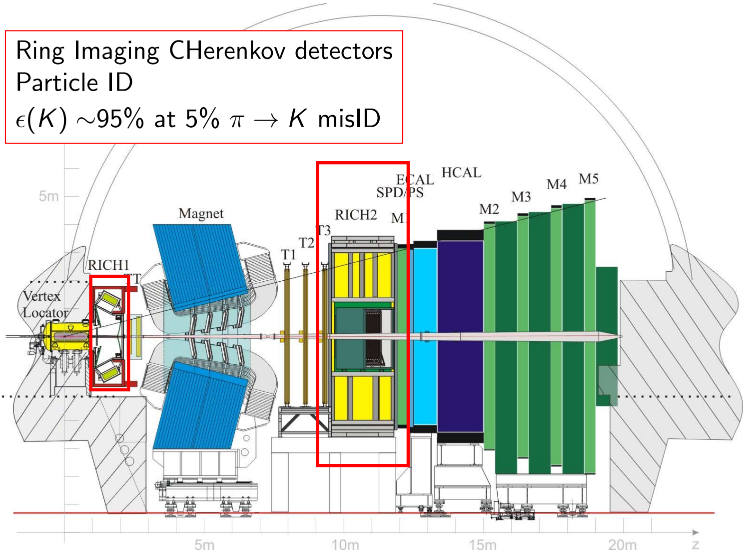
$B_c^+ \to DD$

- Experimentally challenging:
  - Small branching fractions
  - Small production cross section: $\frac{f_c}{f_u} \sim 0.8\%$
  - Short lifetime
  - High-multiplicity final state
- No evidence found in Run 1 dataset [NPB 930 (2018) 563]

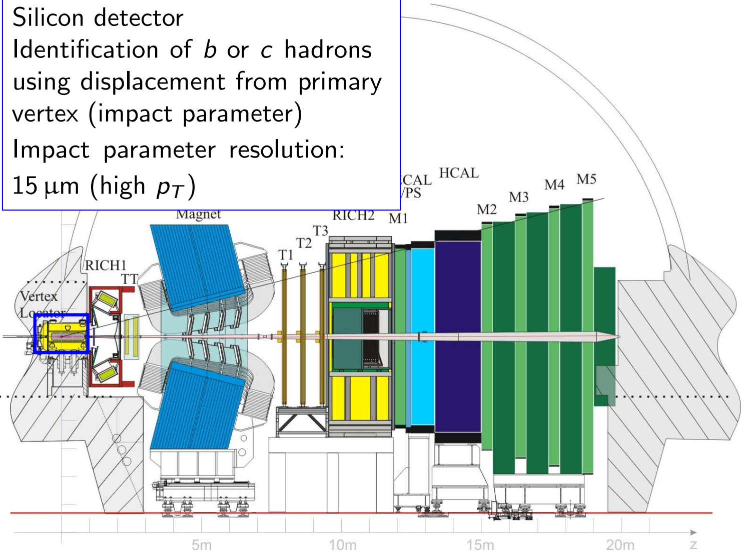


- Optimised for beauty and charm
- Single-arm forward spectrometer: $2 < \eta < 5$

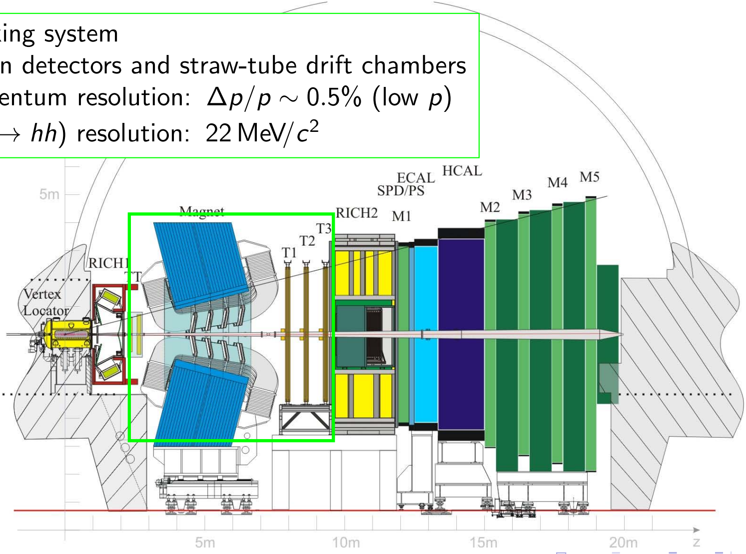
Ring Imaging CHerenkov detectors
Particle ID
$\epsilon(K) \sim 95\%$ at 5% $\pi \rightarrow K$ misID



VErtex LOcator
Silicon detector
Identification of b or c hadrons using displacement from primary vertex (impact parameter)
Impact parameter resolution: $15\,\mu m$ (high p_T)

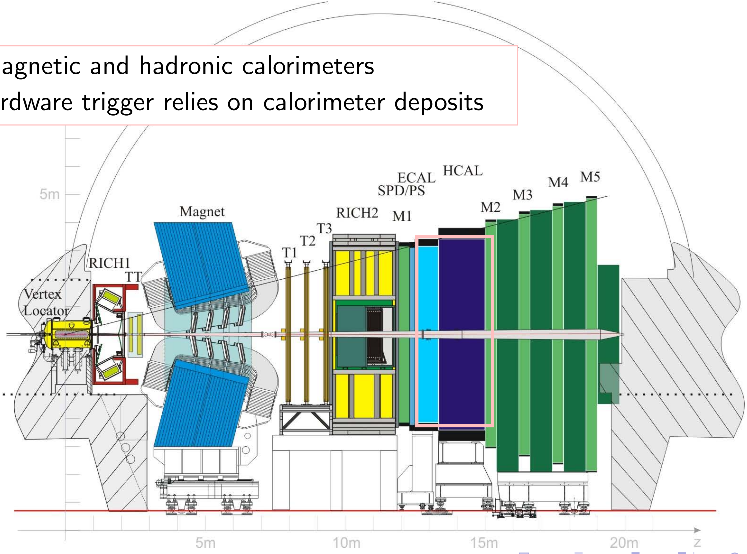


Tracking system
Silicon detectors and straw-tube drift chambers
Momentum resolution: $\Delta p/p \sim 0.5\%$ (low p)
$m(B \to hh)$ resolution: $22\,\mathrm{MeV}/c^2$



Electromagnetic and hadronic calorimeters

Initial hardware trigger relies on calorimeter deposits

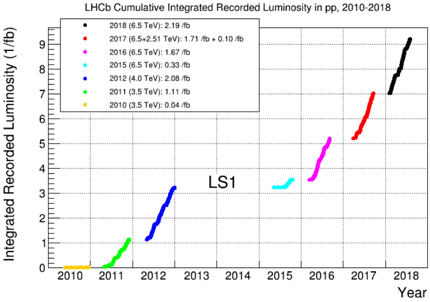


The LHCb dataset

- 2011: $1\,\text{fb}^{-1}$ @ $\sqrt{s} = 7\,\text{TeV}$ } Run 1
- 2012: $2\,\text{fb}^{-1}$ @ $\sqrt{s} = 8\,\text{TeV}$ } Run 1
- 2015-18: $6\,\text{fb}^{-1}$ @ $\sqrt{s} = 13\,\text{TeV}$ } Run 2

$$\frac{\sigma(pp \to B, 13\,\text{TeV})}{\sigma(pp \to B, 8\,\text{TeV})} \sim 2$$

$\to$ Run 2 dataset 4x larger



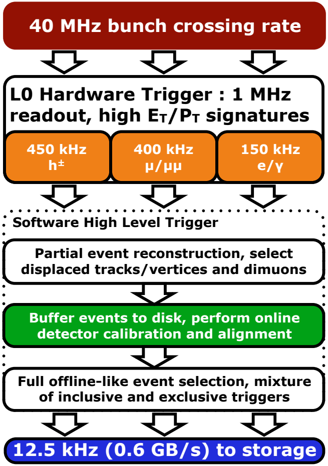
Search for $B_c^+ \to DD$ decays

- Search for 16 $B_c^+ \to D_{(s)}^{(*)+} \overset{(-)}{D}{}^{(*)0}$ decays
  - 6 $B_c^+ \to D_{(s)}^{(*)+} \overset{(-)}{D}{}^{0}$ channels
  - Both fully and partially reconstructed (miss one or more neutral particles from D^*) decays
  - $D^0 \to K\pi(\pi\pi)$, $D^+ \to K\pi\pi$, $D_s^+ \to KK\pi$
  - $D^{*+} \to D^0\pi^+$
- Use $9\,\text{fb}^{-1}$ collected from 2011-2018 (Run 1+2)
- Measure or set limit on $\mathcal{B}$ relative to $B^+ \to D\bar{D}^0$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to DD)}{\mathcal{B}(B^+ \to D\bar{D}^0)} = \frac{N_{B_c^+ \to DD}}{N_{B^+ \to D\bar{D}^0}}\frac{\varepsilon_{B^+ \to D\bar{D}^0}}{\varepsilon_{B_c^+ \to DD}}$$

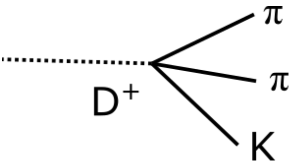
- L0 Hardware Trigger
  - High E_T deposit in CALO
- HLT1
  - High quality track displaced from PV
- HLT2
  - Topological triggers: Candidates consistent with multibody B decay
  - Geometric and kinematic variables

LHCb 2015 Trigger Diagram



D candidates:

- Combine good-quality, high p_T tracks
- Incompatible with originating from PV
- PID requirements



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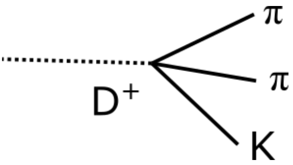
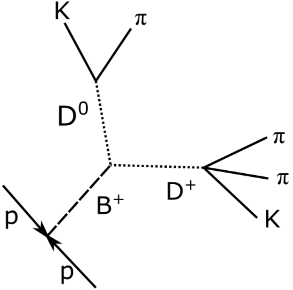


B candidates:

- Combine two D candidates
- Good vertex quality

Single-charm and charmless backgrounds:

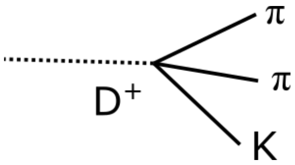
- D mass windows
- Minimum D lifetimes



Data selection

D candidates:

- Combine good-quality, high p_T tracks
- Incompatible with originating from PV
- PID requirements



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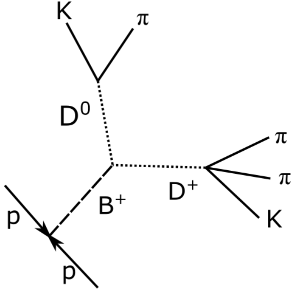
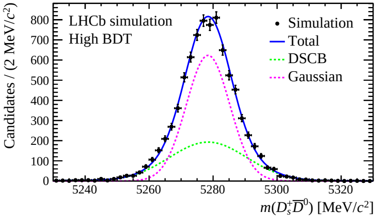


Vetoes:

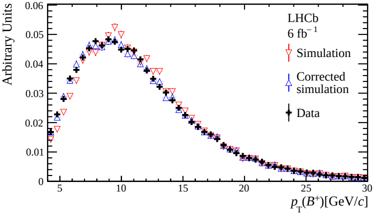
- $B^0_{(s)} \to D\pi^+(\pi^-\pi^+)$ decays
- D^+/D_s^+ cross-feed

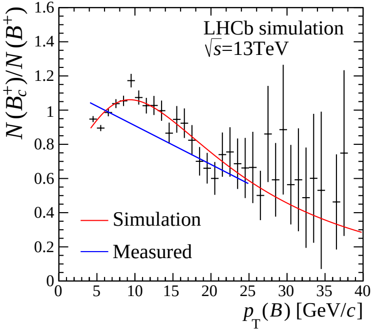
- Simulation for:
  - Acceptance+selection efficiencies
  - MVA training
  - Model mass distributions



- Corrections:
  - PID corrections: Calibration samples
  - Momentum scale+resolution
  - B kinematics

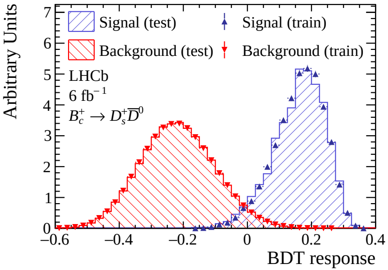
- B^+:
  - Correct to match $(p_T(B^+), y(B^+))$ in background-subtracted data
  - Gradient Boosted Reweighter
- B_c^+:
  - Linear dependence of $\frac{f_c}{f_u}$ on $(p_T(B), y(B))$ has been measured
  - Correct so that $N(B_c^+)/N(B^+)$ matches



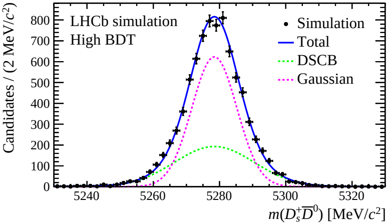


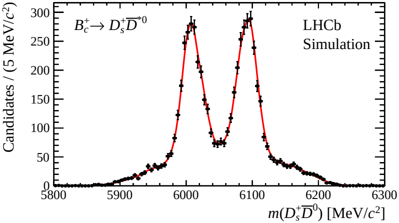
- Boosted Decision Tree (BDT) further reduces combinatorial background
  - Signal: Simulated signal
  - Background: Sideband data in extended D mass window
  - Kinematic and PID variables

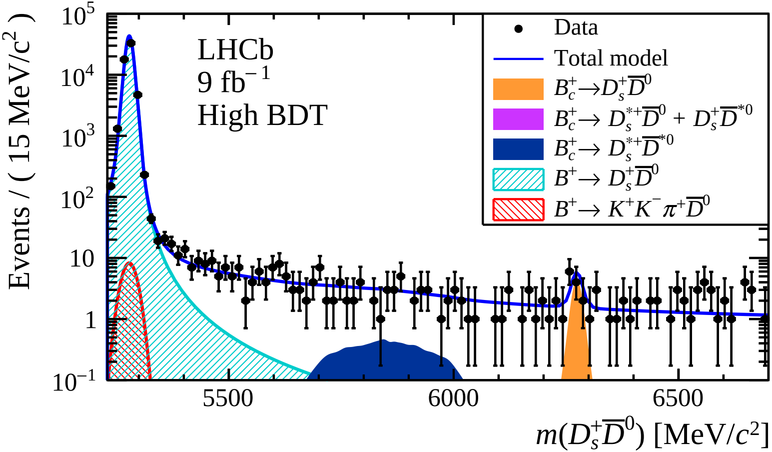
- Discard lowest purity data
- Split remainder into low/medium/high samples
  - Splitting enhances signal sensitivity
  - Include low-purity data to constrain background shape



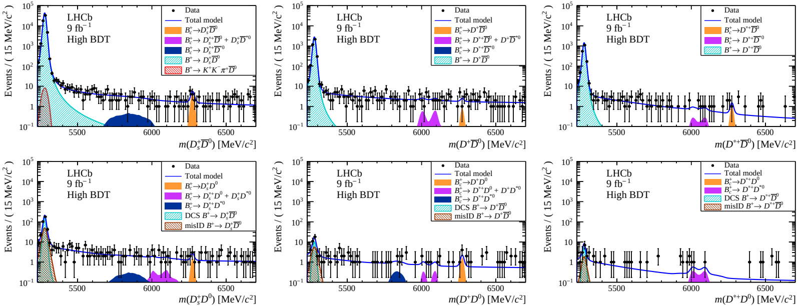
- Fully reconstructed signal + normalisation
  - Shape parameters from fit to simulation
  - + freedom for width, mass
- Partially reconstructed signal
  - Missing π^0 or γ
  - Kernel Density Estimate of simulation
- Small $B^+ \to KK\pi\overline{D}^0$ yield constrained from D_s^+ sideband data
- Combinatorial






LHCb
9 fb^{-1}
High BDT
Data
Total model
$B_c^+ \to D_s^+ \overline{D}^0$
$B_c^+ \to D_s^{*+} \overline{D}^0 + D_s^+ \overline{D}^{*0}$
$B_c^+ \to D_s^{*+} \overline{D}^{*0}$
$B^+ \to D_s^+ \overline{D}^0$
$B^+ \to K^+ K^- \pi^+ \overline{D}^0$
Events / (15 MeV/c^2)
$m(D_s^+ \overline{D}^0)$ [MeV/c^2]
5500
6000
6500
10^{-1}
1
10
10^2
10^3
10^4
10^5

$\mathcal{B}(B_c^+ \to DD)$ - Model



$\mathcal{B}(B_c^+ \to DD)$ - Model

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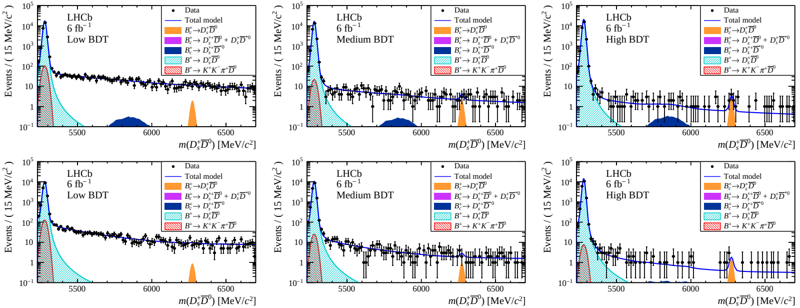


- Simultaneous fit to BDT samples and D^0 final states
- Sharing signal strength and nuisance parameters

- Measure relative to abundant $B^+ \to D\bar{D}^0$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to DD)}{\mathcal{B}(B^+ \to D\bar{D}^0)} = \frac{N_{B_c^+ \to DD}}{N_{B^+ \to D\bar{D}^0}}\frac{\varepsilon_{B^+ \to D\bar{D}^0}}{\varepsilon_{B_c^+ \to DD}}$$

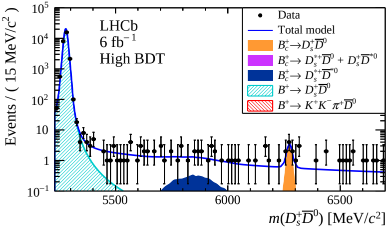
- Efficiency (ε) ratio from simulation
- Systematics either as fractional uncertainties or freedom in model parameters
  - Dominant systematics: Signal and background shapes, B_c^+ kinematic correction

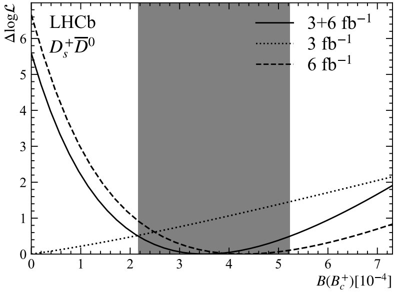
- 3.4σ evidence for $B_c^+ \to D_s^+ \overline{D}^0$
- External inputs for $\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)$ and $\frac{f_c}{f_u}$

$$\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^0) =$$

$$(3.5^{+1.5+0.3}_{-1.2-0.2} \pm 1.0) \times 10^{-4}$$
$$(\text{stat}, \text{sys}, \text{ext})$$

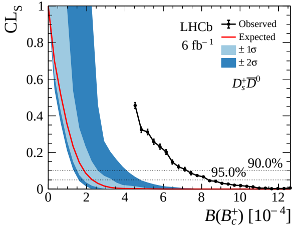
- Two orders of magnitude larger than SM prediction

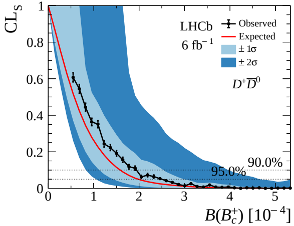




- Upper limits on $\mathcal{B}$ at 90(95)% CL
- Use frequentist CLs method implemented in GammaCombo

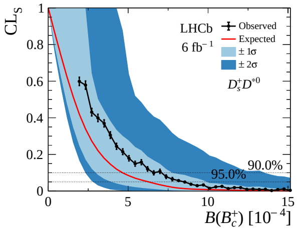
$$\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^0) < 7.2\,(8.4) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D_s^+ D^0) < 3.0\,(3.7) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^+ \overline{D}^0) < 1.9\,(2.5) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^+ D^0) < 1.4\,(1.8) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^{*+} \overline{D}^0) < 3.8\,(4.8) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^{*+} D^0) < 2.0\,(2.4) \times 10^{-4}$$

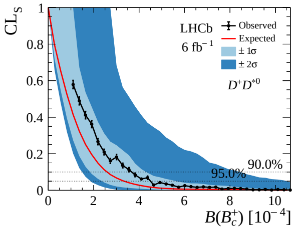




plus ten upper limits on $B_c^+ \to D^{(*)}D^{(*)}$ using partially reconstructed decays

$$\mathcal{B}(B_c^+ \to D_s^{*+}\overline{D}^0) < 5.3(5.7) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D_s^{*+}D^0) < 0.9\,(1.0) \times 10^{-3}$$
$$\mathcal{B}(B_c^+ \to D_s^+\overline{D}^{*0}) < 5.3\,(5.7) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D_s^+D^{*0}) < 6.6\,(8.4) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^+\overline{D}^{*0}) < 6.5\,(8.2) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D^+D^{*0}) < 3.7\,(4.6) \times 10^{-4}$$
$$\mathcal{B}(B_c^+ \to D_s^{*+}\overline{D}^{*0}) < 1.3\,(1.5) \times 10^{-3}$$
$$\mathcal{B}(B_c^+ \to D_s^{*+}D^{*0}) < 1.3\,(1.6) \times 10^{-3}$$
$$\mathcal{B}(B_c^+ \to D^{*+}\overline{D}^{*0}) < 1.0\,(1.3) \times 10^{-3}$$
$$\mathcal{B}(B_c^+ \to D^{*+}D^{*0}) < 7.7\,(8.9) \times 10^{-4}$$





CP violation in $B^{-/0} \to DD$ decays

$$\mathcal{A}^{CP} = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B} \to \overline{f})}$$

Neutral meson oscillations:

$$\Gamma(t; B^0 \to D^+ D^-) \propto (1 + q_b[\mathcal{S} \sin(\Delta m t) - \mathcal{C} \cos(\Delta m t)])$$

$q_b = \pm 1$: b charge at production
Δm: Mass difference between eigenstates

CP violation in mixing and decay:

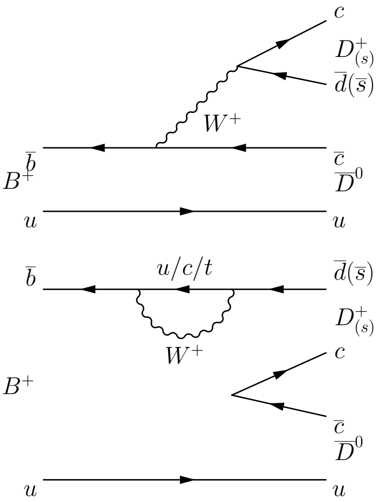
$$\Gamma(t; B^0 \to D^{*\pm} D^{\mp}) \propto (1 \pm \mathcal{A}^{CP})(1 + q_b[\mathcal{S}^{\pm} \sin(\Delta m t) - \mathcal{C}^{\pm} \cos(\Delta m t)])$$

CP violation in $B \to DD$ decays

- Interference between:
  - $b \to c$ in tree
  - $b \to u$ in penguin

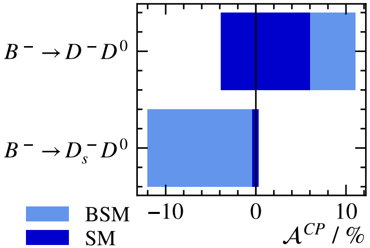
$\to$ Small $\mathcal{A}^{CP}$

- $\mathcal{A}^{CP}(B^- \to D^- D^0) \sim 1\%$
- $\mathcal{A}^{CP}(B^- \to D_s^- D^0) \sim 0.1\%$



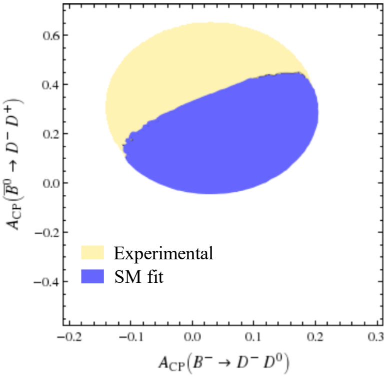
Motivation

- BSM models can enhance ACP
  - e.g. 4th generation quarks [IJTP 55 5290]
  - SUSY [PRD 79 055004]



Motivation

- Isospin symmetry predicts relations between CP observables
  - $\mathcal{A}^{CP}(B^- \to D_s^- D^0) \approx \mathcal{A}^{CP}(\overline{B}^0 \to D_s^- D^+)$
  - $\mathcal{A}^{CP}(B^- \to D^- D^0) \approx C(B^0 \to D^- D^+)$
- Deviations could indicate NP



[PRD 91 034027 (2015)]

Current status

Quantity	World average	Measurements
$\mathcal{A}^{CP}(B^- \to D_s^- D^0)$	$-0.4 \pm 0.7\%$	[LHCb I]
$\mathcal{A}^{CP}(B^- \to D^- D^0)$	$1.6 \pm 2.5\%$	[LHCb I, Belle I, BaBar]
$\mathcal{A}^{CP}(B^- \to D^{*-} D^0)$	$-6 \pm 13\%$	[BaBar]
$\mathcal{A}^{CP}(B^- \to D^- D^{*0})$	$13 \pm 18\%$	[BaBar]
$\mathcal{A}^{CP}(B^- \to D^{*-} D^{*0})$	$-15 \pm 11\%$	[BaBar]
$\mathcal{A}^{CP}(B^0 \to D^{*+} D^-)$	$1.3 \pm 1.4\%$	
$C(B^0 \to D^{*+} D^-)$	-0.02 ± 0.08	
$S(B^0 \to D^{*+} D^-)$	-0.83 ± 0.09	[LHCb II, Belle I, BaBar]
$C(B^0 \to D^{*-} D^+)$	-0.03 ± 0.09	
$S(B^0 \to D^{*-} D^+)$	-0.80 ± 0.09	
$C(B^0 \to D^{*+} D^{*-})$	0.01 ± 0.09	[Belle I, BaBar]
$S(B^0 \to D^{*+} D^{*-})$	-0.59 ± 0.14	
$C(B^0 \to D^+ D^-)$	-0.22 ± 0.24	[LHCb I, Belle I, BaBar]
$S(B^0 \to D^+ D^-)$	$-0.76^{+0.15}_{-0.13}$	

Current status

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$$\mathcal{A}^{CP} = \mathcal{A}_{raw} - \mathcal{A}_P - \mathcal{A}_D$$

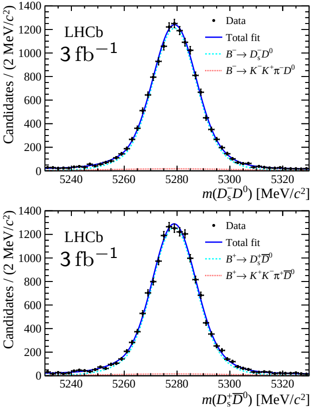
- Raw asymmetry: Fit to selected data

$$\mathcal{A}_{raw} = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)}$$

- Correct for production and detection asymmetries: Calibration samples

$$\mathcal{A}_P = \frac{\sigma(B^-) - \sigma(B^+)}{\sigma(B^-) + \sigma(B^+)}$$

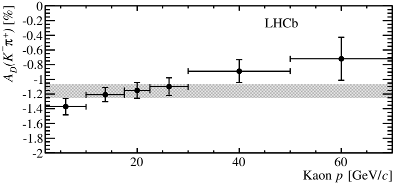
$$\mathcal{A}_D = \frac{\varepsilon(B^-) - \varepsilon(B^+)}{\varepsilon(B^-) + \varepsilon(B^+)}$$



[JHEP 05 (2018) 160]

$K\pi$ detection asymmetry

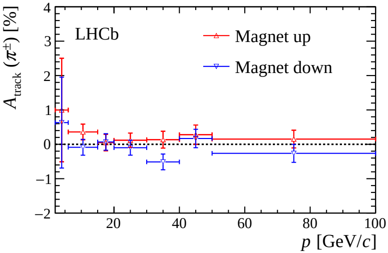
- Largest detection asymmetry: $\sim 1\%$
- Charge asymmetry of kaon-detector interactions
- Function of kinematics
  - Most strongly of momentum
  - Also η due to amount of material passed through
- Difference in raw asymmetry between $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to K^0_S\pi^+$ samples



[LHCb-PAPER-2014-013]

Other detection asymmetries

- Smaller detection asymmetries:
  - Pion tracking
  - PID response
  - L0 trigger efficiency



[LHCb-PAPER-2016-013]

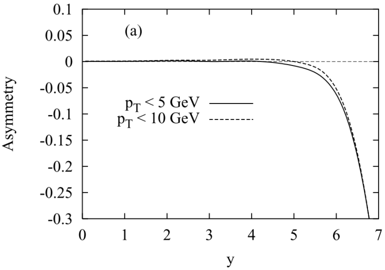
Production asymmetries

- *pp* collisions favour production of $B^+ = \bar{b}u$ over B^-

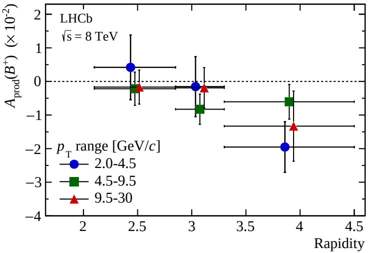
$\rightarrow$ Production asymmetry

  - Larger at higher η, lower p_T

- Measured in decays with known $\mathcal{A}^{CP}$
  - $B^+ \rightarrow \overline{D}^0 \pi^+$
  - $B^+ \rightarrow J/\psi K^+$



[arXiv:hep-ph/0003056]



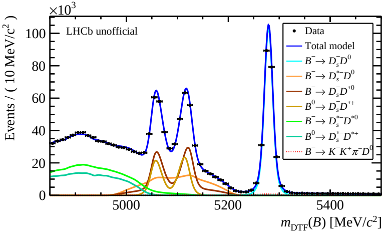
[LHCb-PAPER-2016-054]

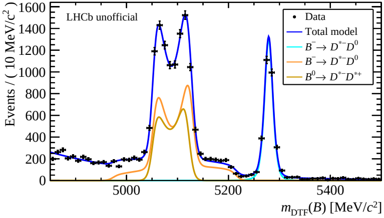
$$\mathcal{A}^{CP}(B^- \to D_s^- D^0) = (-0.4 \pm 0.5(stat) \pm 0.5(sys))\%$$
$$\mathcal{A}^{CP}(B^- \to D^- D^0) = (2.3 \pm 2.7(stat) \pm 0.4(sys))\%$$

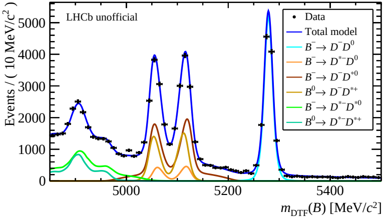
- Dominant systematics:
  - Production asymmetry
  - $K\pi$ detection asymmetry
- First measurement of $\mathcal{A}^{CP}(B^- \to D_s^- D^0)$
- $3\times$ improvement on $\mathcal{A}^{CP}(B^- \to D^- D^0)$

$\mathcal{A}^{CP}(B^- \to DD)$

- Update with Run 2 data
- Add $D^{*-}D^0$ channel
- Measure decays with one missing particle
  - $\to$ 7 decays total







$\mathcal{A}^{CP}(B^-)$ prospects (unofficial)

Table 1: Statistical and systematic uncertainties on $\mathcal{A}^{CP}$. Statistical uncertainty is entirely from $\mathcal{A}_{raw}$. The systematic uncertainty is dominated by uncertainty on the production asymmetry.

Decay	Run1+2	PDG
$B^- \to D_s^- D^0$	$(X \pm 0.2 \pm 0.3)\%$	$(-0.4 \pm 0.7)\%$
$B^- \to D_s^{*-} D^0$	$(X \pm 1.1 \pm 0.3)\%$	-
$B^- \to D_s^- D^{*0}$	$(X \pm 1.7 \pm 0.3)\%$	-
$B^- \to D^- D^0$	$(X \pm 1.0 \pm 0.3)\%$	$(1.6 \pm 2.5)\%$
$B^- \to D^{*-} D^0$	$(X \pm 1.6 \pm 0.3)\%$	$(-6 \pm 13)\%$
$B^- \to D^- D^{*0}$	$(X \pm 3.3 \pm 0.3)\%$	$(13 \pm 18)\%$
$B^- \to D^{*-} D^{*0}$	$(X \pm 2.7 \pm 0.3)\%$	$(-15 \pm 11)\%$

- Dominant systematics:
  - Contribution of $\mathcal{A}^{CP}(B^+ \to J/\psi K^+)$ to $\mathcal{A}_P$
  - Calibration sample size for $K^-\pi^+$ detection asymmetry
  - Combinatorial model (partially reconstructed)

Current status

Quantity	World average	Measurements
$\mathcal{A}^{CP}(B^- \to D_s^- D^0)$	$-0.4 \pm 0.7\%$	[LHCb I]
$\mathcal{A}^{CP}(B^- \to D^- D^0)$	$1.6 \pm 2.5\%$	[LHCb I, Belle I, BaBar]
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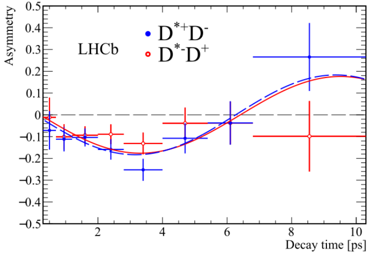
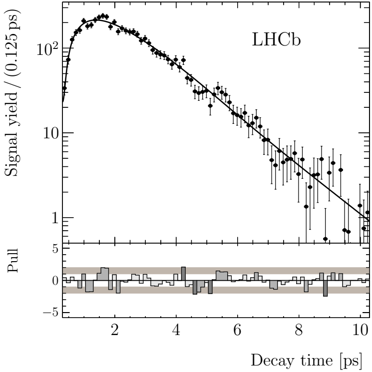
$S(B^0 \to D^+ D^-)$	$-0.76^{+0.15}_{-0.13}$	

$\mathcal{A}^{CP}(B^0 \to DD)$

- 'Flavour tag' candidates as B^0 or $\overline{B}^0$ based on rest of event
- Fit to background-subtracted decay time distribution

→ B^0- $\overline{B}^0$ asymmetry as a function of decay time





[JHEP 03 (2020) 147]

$\mathcal{A}^{CP}(B^0 \to DD)$

- (almost) CP eigenstate → Minimal/no detector asymmetry

$$\mathcal{S}_{D^*D} = -0.861 \pm 0.077 \pm 0.019$$

$$\Delta\mathcal{S}_{D^*D} = 0.019 \pm 0.075 \pm 0.012$$

$$\mathcal{C}_{D^*D} = -0.059 \pm 0.092 \pm 0.020$$

$$\Delta\mathcal{C}_{D^*D} = -0.031 \pm 0.092 \pm 0.016$$

$$\mathcal{A}_{D^*D} = 0.008 \pm 0.014 \pm 0.006$$

$$(\mathcal{S}_{D^{*\pm}D^{\mp}} = \mathcal{S}_{D^*D} \pm \Delta\mathcal{S}_{D^*D})$$

Run 1+2 data [JHEP 03 (2020) 147]

$$\mathcal{S}_{D^+D^-} = -0.54^{+0.17}_{-0.16} \pm 0.05$$

$$\mathcal{C}_{D^+D^-} = 0.26^{+0.18}_{-0.17} \pm 0.02$$

Run 1 data [PRL 117 261801]

- Dominant systematics:
  - Background subtraction
  - Flavour tagging

Current status

Quantity	World average	Measurements
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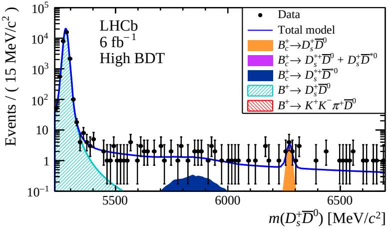
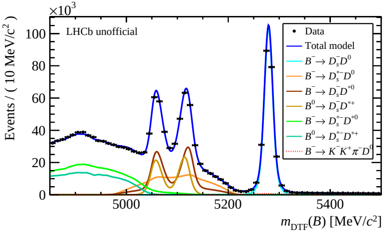
Summary

- Beauty to doubly open charm decays provide access to SM and BSM physics
- $B_c^+ \to DD$
  - Improved understanding of rare B_c^+ meson
  - Sensitivity to CKM phase γ
  - Search for 16 $B_c^+ \to DD$ decays [JHEP 12 (2021) 117]
  - 3.4σ evidence for $B_c^+ \to D_s^+ \overline{D}^0$



Summary

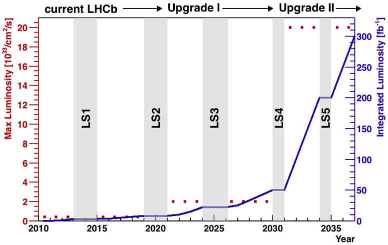
- CP violation in $B \to DD$
  - Sensitivity to BSM physics if uncertainties reduced
  - LHCb measurements on $\mathcal{A}^{CP}(B^- / B^0)$ presented
  + Prospects for B^- asymmetries with Run 2 data



Summary

- Run 3: $5\times$ higher instantaneous luminosity
  - $\rightarrow$ At least $25\,\text{fb}^{-1}$
- Removal of hardware trigger
- Real-time analysis and calibration in software triggers

$\rightarrow$ $\sim 3\times$ increase in trigger efficiency in Run 3

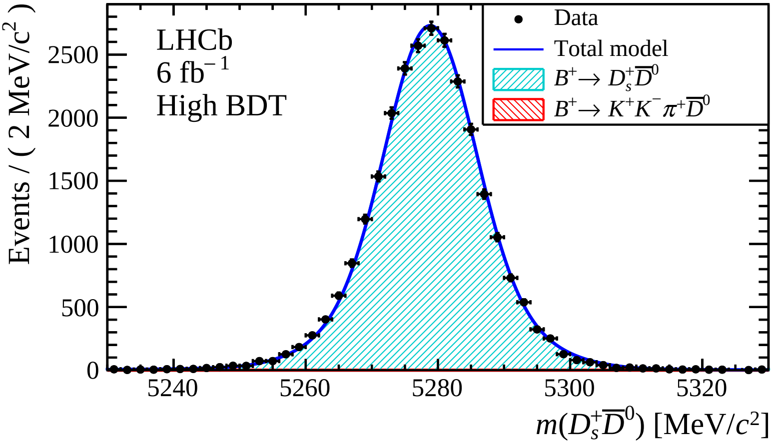


$\rightarrow$ $\sim 9\times$ more data!

- Confirm or refute evidence for $B_c^+ \rightarrow D_s^+ \overline{D}^0$ with under one year of data
- $3\times$ reduction in uncertainties on $\mathcal{A}^{CP}$

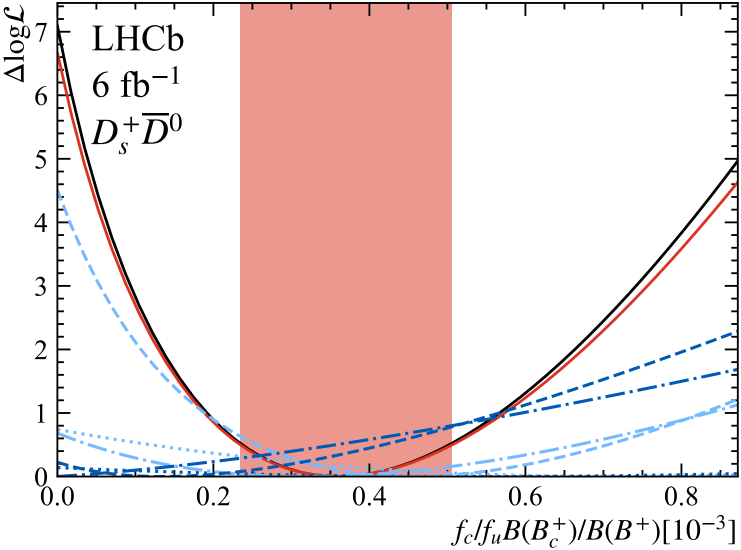
Backup

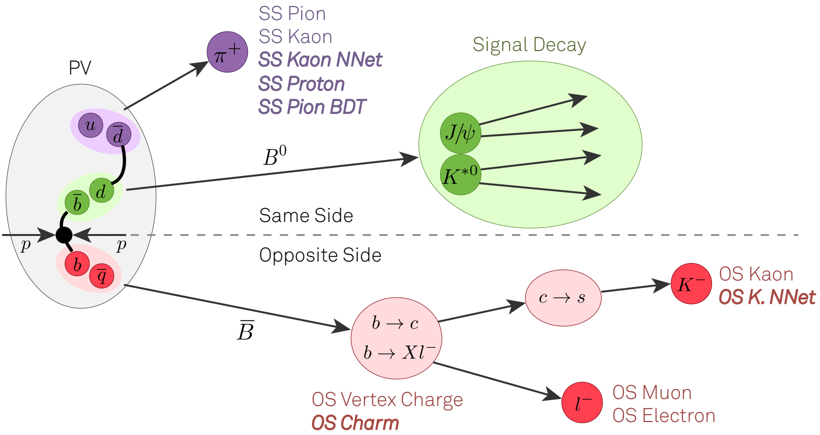
Fit to $B^+ \to DD$ in data



$B_c^+ \to DD$ systematics

Final state	$D_s^+ D^0$		$D^+ D^0$		$D^{*+} D^0$	
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
B_c^+ signal shape	9.4	3.8	4.8	5.3	2.8	3.9
B_c^+ production spectrum	3.7	2.4	3.9	2.4	4.2	2.9
B^+ production spectrum	0.5	0.9	0.6	1.0	0.6	1.1
Hit resolution parameterisation	–	1.5	–	1.2	–	2.2
R simulation sample size	1.2	1.0	1.4	1.1	1.5	1.5
$R'_{(+,0)}$ simulation sample size	1.4	0.9	2.1	1.2	1.1	1.1
R'' simulation sample size	1.5	0.8	1.7	0.9	–	–
B_c^+ lifetime	1.3	1.4	1.3	1.3	2.1	2.6
PID efficiencies	1.6	1.2	2.8	0.8	2.2	1.4
Multiple $B_{(c)}^+$ candidates	0.4	0.4	0.6	0.5	1.4	1.2
Data-simulation differences	0.1	0.1	0.1	0.1	0.1	0.2
$B^+ \to \overline{D}^0 K^+ K^- \pi^+$	0.7	0.5	–	–	–	–
$\mathcal{B}(D^{*+} \to D^+ X^0)$	–	–	1.5	1.5	–	–
R total	10.4	5.3	7.2	6.6	6.3	6.5
$R'_{(+,0)}$ total	4.6	3.7	5.7	3.8	5.5	5.0
R'' total	4.6	3.7	5.5	3.7	–	–

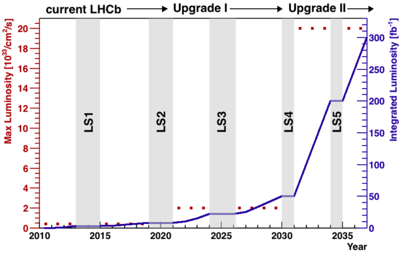

LHCb
6 fb^{-1}
$D_s^+\overline{D}^0$
$\Delta\log\mathcal{L}$
0
1
2
3
4
5
6
7
0.0
0.2
0.4
0.6
0.8
$f_c/f_u B(B_c^+)/B(B^+)[10^{-3}]$



SS Pion
SS Kaon
SS Kaon NNet
SS Proton
SS Pion BDT
π^+
PV
u
$\bar{d}$
d
$\bar{b}$
B^0
Signal Decay
J/ψ
K^{*0}
Same Side
p
p
Opposite Side
b
$\bar{q}$
$\bar{B}$
$b \to c$
$b \to Xl^-$
$c \to s$
K^-
OS Kaon
OS K. NNet
OS Vertex Charge
OS Charm
l^-
OS Muon
OS Electron

Prospects for Run 3

- $5\times$ higher instantaneous luminosity
  - $\rightarrow$ At least $25\,\mathrm{fb}^{-1}$ in Run 3
- Major upgrades
  - PID and tracking detectors
  - Electronics
  - Data acquisition system



Prospects for Run 3

- Removal of hardware trigger
- Real-time analysis and calibration in software triggers

$\rightarrow \sim 3\times$ increase in trigger efficiency in Run 3