# Search for $B_c \rightarrow DD$ decays and measurement of $A_{CP}(B^+ \rightarrow D^+_{(s)}\overline{D}^0)$

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**on behalf of the LHCb collaboration**

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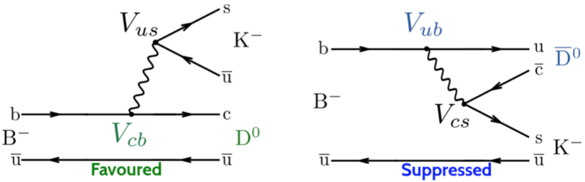
1. Search for $B_c^+$ decays to two charm mesons

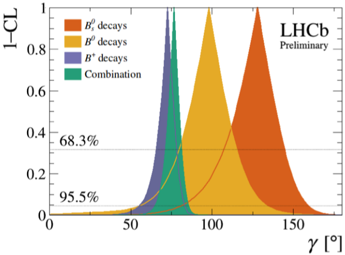
2. Measurement of the CP asymmetry in $B^+ \to D_{(s)}^+ \overline{D}^0$ decays

# CKM angle $\gamma$

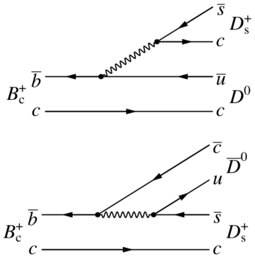
- $\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$ is the least well known angle of the Unitarity triangle
- The only CP violating parameter that can be measured through tree decays
  - Important Standard Model **benchmark**
  - Compare tree and loop level determinations to test for **new physics** - currently consistent but with large uncertainties
- Theoretically pristine $|\delta_\gamma \leq \mathcal{O}(10^{-7})|$ [JHEP 01 (2014) 051]
- Access through the interference of $b \to c$ and $b \to u$ decays to the same final state
- World average of $(73.5^{+4.2}_{-5.1})^\circ$ [HFLAV] dominated by the combination of LHCb measurements $(76.8^{+5.1}_{-5.7})^\circ$ made with $B^+$, $B^0$ and $B^0_s$ [LHCb-CONF-2017-004]



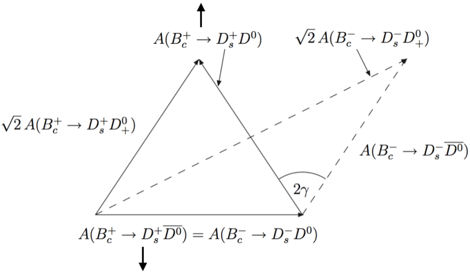

interference $\sim$ 10%



- **CP violation not yet observed in $\mathbf{B_c^+}$ mesons**
- $B_c^+ \to D_{(s)}^{(*)+} D^{(*)}$ decays, where $D$ is an admixture of $D^0$ or $\overline{D}^0$, have been proposed to measure $\gamma$ [Phys. Rev. D 62, 057503, Phys. Rev. D 65, 034016]
- Advantage over traditional $B \to DK$ since the sides of the amplitude triangles are of comparable length, interference $\sim 100\%$
- Disadvantage is small $B_c^+$ production cross section, lifetime, branching fractions, final state




$V_{ub}$, not colour suppressed




$V_{cb}$, colour suppressed

# Analysis strategy



$$\frac{f_c}{f_u}\times\mathcal{B}(B_c^+ \to D_{(s)}^+ D) = \mathcal{B}(B^+ \to D_{(s)}^+ \overline{D}^0)\times\frac{N(B_c^+)}{N(B^+)}\times\frac{\varepsilon(B^+)}{\varepsilon(B_c^+)}$$

- From 2011/12 data
- From MC

$D_s^+ \to K^+K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$
$D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+$

- Combining an LHCb measurement with theory predictions, predict $f_c/f_u$ in the range $0.24\% - 1.2\%$ [PRL 114, 132001 (2015), PRD 68, 094020 (2003), PRD 89, 034008 (2014)]
- $\mathcal{B}(B_c^+)$ theory predictions

| Channel | Prediction for the branching fraction $[10^{-6}]$ | | | |
|---|---|---|---|---|
| $B_c^+ \to D_s^+ \overline{D}^0$ | $2.3 \pm 0.5$ | 4.8 | 1.7 | 2.1 |
| $B_c^+ \to D_s^+ D^0$ | $3.0 \pm 0.5$ | 6.6 | 2.5 | 7.4 |
| $B_c^+ \to D^+ \overline{D}^0$ | $32 \pm 7$ | 53 | 32 | 33 |
| $B_c^+ \to D^+ D^0$ | $0.10 \pm 0.02$ | 0.32 | 0.11 | 0.32 |

[Phys. Rev. D 86, 074019, arXiv:hep-ph/0211021, Phys.Lett.B555:189-196,2003, Phys. Rev. D 73, 054024]

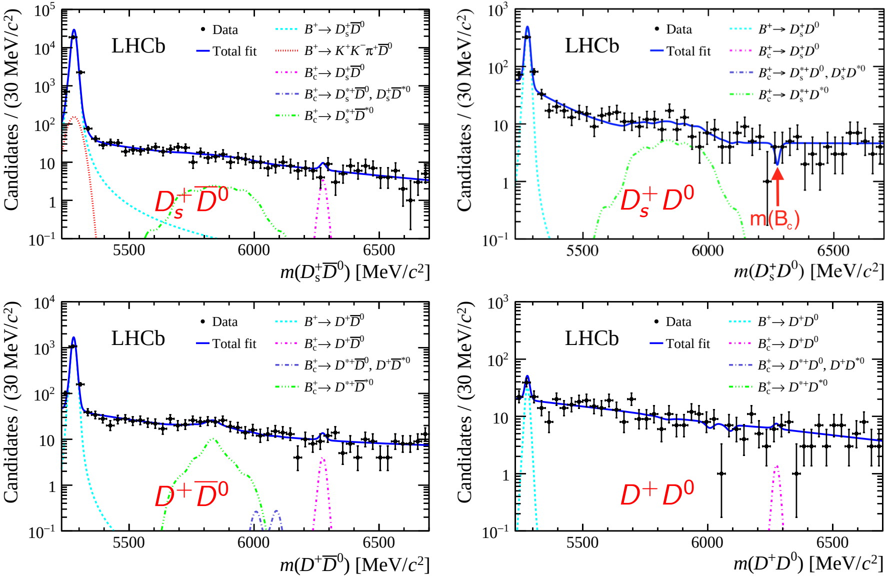
# Fit model



- An MVA is used to reject combinatorial background: 85% signal efficiency, 99% background rejection
- The fit model is comprised of six components
  - $B^+ \to D^+_{(s)} D$ model
  - $B^+_c \to D^+_{(s)} D$ model
  - $B^+_c \to D^{*+}_{(s)} D, D^+_{(s)} D^*$ model
  - $B^+_c \to D^{*+}_{(s)} D^*$ model
  - For $B^+ \to D^+_s \overline{D}^0$ modes, the single charm background $B^+ \to K^+ K^- \pi^+ \overline{D}^0$
  - Combinatorial background, described by an exponential plus a constant
- An unbinned extended maximum likelihood is performed simultaneously to both $D^0$ decay modes with only the total $B^+_c$ yield floating
- Systematics are included in the fit as Gaussian constraints

# Mass fits: $D^0 \to K^-\pi^+$

Nucl. Phys. B 930 (2018) 563



- Measured branching fractions [upper limit set at 90%(95%) C.L.]:

$$\frac{f_c}{f_u} \times \frac{\mathcal{B}(B_c^+ \to D_{(s)}^+ D)}{\mathcal{B}(B^+ \to D_{(s)}^+ D)} = \frac{N(B_c^+)}{N(B^+)} \times \frac{\varepsilon(B^+)}{\varepsilon(B_c^+)}$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^0)}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (\ \ 3.0 \pm 3.7) \times 10^{-4}\ [< 0.9\,(1.1) \times 10^{-3}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^+ D^0)}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (-3.8 \pm 2.6) \times 10^{-4}\ [< 3.7\,(4.7) \times 10^{-4}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^+ \overline{D}^0)}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (\ \ 8.0 \pm 7.5) \times 10^{-3}\ [< 1.9\,(2.2) \times 10^{-2}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^+ D^0)}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (\ \ 2.9 \pm 5.3) \times 10^{-3}\ [< 1.2\,(1.4) \times 10^{-2}].$$

# Branching fractions: $B_c^+ \to D^* D$

- Measured branching fractions [upper limit set at 90%(95%) C.L.]:

$$\frac{f_c}{f_u} \times \frac{\left(\mathcal{B}(B_c^+ \to D_{(s)}^{+*} D)\mathcal{B}(D_{(s)}^{+*}) + \mathcal{B}(B_c^+ \to D_{(s)}^+ D^*)\right)}{\mathcal{B}(B^+ \to D_{(s)}^+ D)} = \frac{N(B_c^+)}{N(B^+)} \times \frac{\varepsilon(B^+)}{\varepsilon(B_c^+)}$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^{*+}\overline{D}^0) + \mathcal{B}(B_c^+ \to D_s^+\overline{D}^{*0})}{\mathcal{B}(B^+ \to D_s^+\overline{D}^0)} = (-0.1 \pm 1.5) \times 10^{-3}\ [< 2.8\,(3.4) \times 10^{-3}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^{*+}D^0) + \mathcal{B}(B_c^+ \to D_s^+ D^{*0})}{\mathcal{B}(B^+ \to D_s^+\overline{D}^0)} = (-0.3 \pm 1.9) \times 10^{-3}\ [< 3.0\,(3.6) \times 10^{-3}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to (D^{*+} \to D^+\pi^0,\gamma)\overline{D}^0) + \mathcal{B}(B_c^+ \to D^+\overline{D}^{*0})}{\mathcal{B}(B^+ \to D^+\overline{D}^0)} = (\ \ 0.2 \pm 3.2) \times 10^{-2}\ [< 5.5\,(6.6) \times 10^{-2}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to (D^{*+} \to D^+\pi^0,\gamma)D^0) + \mathcal{B}(B_c^+ \to D^+ D^{*0})}{\mathcal{B}(B^+ \to D^+\overline{D}^0)} = (-1.5 \pm 1.7) \times 10^{-2}\ [< 2.2\,(2.8) \times 10^{-2}].$$

# Branching fractions: $B_c^+ \to D^* D^*$ Nucl. Phys. B 930 (2018) 563

- Measured branching fractions [upper limit set at 90%(95%) C.L.]:

$$\frac{f_c}{f_u} \times \frac{\mathcal{B}(B_c^+ \to D_{(s)}^{+*} D^*)}{\mathcal{B}(B^+ \to D_{(s)}^+ D)} = \frac{1}{\mathcal{B}(D_{(s)}^{+*})} \times \frac{N(B_c^+)}{N(B^+)} \times \frac{\varepsilon(B^+)}{\varepsilon(B_c^+)}$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^{*+} \overline{D}^{*0})}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (\ \ 3.2 \pm 4.3) \times 10^{-3}\ [< 1.1\,(1.3) \times 10^{-2}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^{*+} D^{*0})}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (\ \ 7.0 \pm 9.2) \times 10^{-3}\ [< 2.0\,(2.4) \times 10^{-2}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^{*+} \overline{D}^{*0})}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (\ \ 3.4 \pm 2.3) \times 10^{-1}\ [< 6.5\,(7.3) \times 10^{-1}],$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^{*+} D^{*0})}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (-4.1 \pm 9.1) \times 10^{-2}\ [< 1.3\,(1.6) \times 10^{-1}].$$

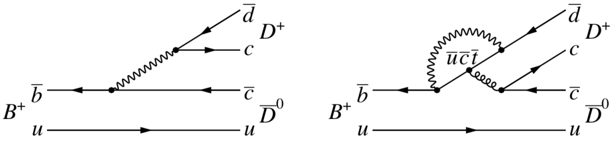
1. Search for $B_c^+$ decays to two charm mesons

2. Measurement of the CP asymmetry in $B^+ \to D_{(s)}^+ \overline{D}^0$ decays

- Measure the CP asymmetry of the $B^+$ normalisation modes

$$A_{CP} = \frac{\Gamma(B^- \to D^-_{(s)} D^0) - \Gamma(B^+ \to D^+_{(s)} \overline{D}^0)}{\Gamma(B^- \to D^-_{(s)} D^0) + \Gamma(B^+ \to D^+_{(s)} \overline{D}^0)}$$

- A CP asymmetry requires two diagrams to contribute to the decay of a similar size and with differing weak (CKM elements) and strong phases (final state interactions)
- $B^+ \to D^+_{(s)} \overline{D}^0$ has both tree and penguin contributions
- SM predicts $A_{CP}(B^+ \to D^+ \overline{D}^0) = \mathcal{O}(1)\%$ [PRD 81, 034006 (2010)]
- PDG value is $A_{CP}(B^+ \to D^+ \overline{D}^0) = (3 \pm 7)\%$
- **$A_{CP}$ can be enhanced by new physics contributions**



# How to measure $A_{CP}$



- The raw asymmetry can be measured directly from the fitted yields

$$A_{raw} = \frac{N(D^-_{(s)} D^0) - N(D^+_{(s)} \overline{D}^0)}{N(D^-_{(s)} D^0) + N(D^+_{(s)} \overline{D}^0)}$$

- Corrections to $A_{raw}$ need to be made to account for the B production asymmetry and detection asymmetries

$$A_{CP} = A_{raw} - A_P - A_D$$

- Where $A_P$ and $A_D$ are defined as

$$A_P = \frac{\sigma(B^-) - \sigma(B^+)}{\sigma(B^-) + \sigma(B^+)}$$

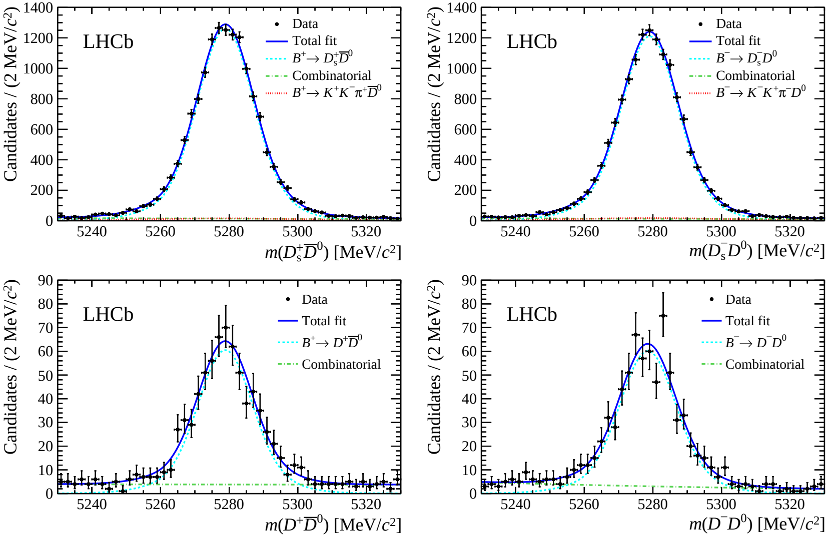
$$A_D = \frac{\varepsilon(B^- \rightarrow D^-_{(s)} D^0) - \varepsilon(B^+ \rightarrow D^+_{(s)} \overline{D}^0)}{\varepsilon(B^- \rightarrow D^-_{(s)} D^0) + \varepsilon(B^+ \rightarrow D^+_{(s)} \overline{D}^0)}$$

- **Need an excellent understanding of the detector and its potential to introduce asymmetries**

# Mass fits: $D^0 \to K^-\pi^+$

J. High Energ. Phys. 05 (2018) 160

- $A_{raw}$ is $(-1.8 \pm 0.5)\%$ for $B^+ \to D_s^+\overline{D}^0$ and $(2.0 \pm 2.7)\%$ for $B^+ \to D^+\overline{D}^0$



# $A_{CP}$ measurement

J. High Energ. Phys. 05 (2018) 160

- Detector asymmetries from trigger, tracking, PID and $K\pi$ detection evaluated
- $A_P + A_D$ is $(-1.4 \pm 0.5)\%$ for $B^+ \to D_s^+ \overline{D}^0$ and $(-0.3 \pm 0.4)\%$ for $B^+ \to D^+ \overline{D}^0$
- Putting everything together

$$A_{CP}(B^+ \to D_s^+ \overline{D}^0) = (-0.4 \pm 0.5 \pm 0.5)\%$$

$$A_{CP}(B^+ \to D^+ \overline{D}^0) = (2.3 \pm 2.7 \pm 0.4)\%$$

- Results consistent with zero so **no evidence of CP violation**
- **First measurement** of $A_{CP}(B^+ \to D_s^+ \overline{D}^0)$ and **most precise measurement** of $A_{CP}(B^+ \to D^+ \overline{D}^0)$ to date ($2.5\times$ better precision than PDG value)
- **Run I + II follow up paper expected next year**

# Conclusion and prospects

- The CP asymmetry in $B^+ \to D^+_{(s)}\overline{D}^0$ decays was measured and a search was performed for $B_c^+ \to DD$ decays
- The $B_c^+$ channel with the largest theory prediction is
$$\mathcal{B}(B_c^+ \to D^+\overline{D}^0) = 5.3 \times 10^{-5}$$
- Combining the 90%(95%) limit with the most optimistic value for $f_c/f_u = 1.2\%$
$$\mathcal{B}(B_c^+ \to D^+\overline{D}^0) < 6.0(7.0) \times 10^{-4}$$
- Limits are consistent with the theoretical expectations
- LHCb collected 6 $\text{fb}^{-1}$ during run II, and is set to collect 50 $\text{fb}^{-1}$ over less than 10 years during upgrade phase and 300 $\text{fb}^{-1}$ by the end of the second upgrade
    - Likely to observe $B_c^+ \to D^+\overline{D}^0$, however, measurement of $\gamma$ with these modes probably still out of reach
    - Expect statistical uncertainties in $A_{CP}$ measurements to halve with a run II update

# Backup

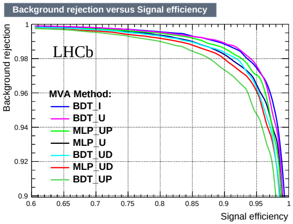
# MVA

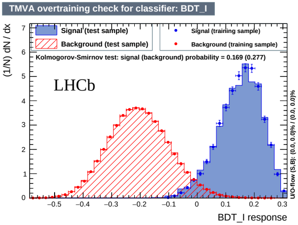
- $B_c^+ \to D_{(s)}^+ \overline{D}^0$ MC was used as the signal sample
- Background training sample ($\sim 10^5$ events):
  - Data from $B^+$ upper mass sideband ($5350 < m(D_{(s)}^+ D) < 6200\,\text{MeV}$)
  - Combined background from $\overline{D}^0$ and $D^0$ and wide charm mass windows

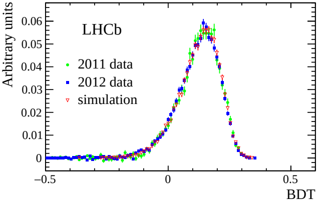
| Rank | Variable | Variable Importance ($\times 10^{-2}$) |
|---|---|---|
| 1 | $m(D_s^+)$ | 6.391 |
| 2 | $m_{23}^2(\pi^+ K^-)$ | 6.115 |
| 3 | $m_{13}^2(K^+ K^-)$ | 5.925 |
| 4 | $\log(p_T(z1))$ | 5.832 |
| 5 | $\log(\text{DLL}_{K\pi}(p1) + 5)$ | 5.692 |
| 6 | $\log(\tau(D_s^+)/\Delta\tau)$ | 5.435 |
| 7 | $\log(\tau(B_c^+)/\Delta\tau)$ | 5.403 |
| 8 | $\log(\tau(D^0)/\Delta\tau)$ | 5.310 |
| 9 | $\log(p_T(p3))$ | 5.258 |
| 10 | $\log(p_T(p1))$ | 5.157 |
| 11 | $\log(\text{DLL}_{K\pi}(p3) + 5)$ | 5.040 |
| 12 | $m(D^0)$ | 4.903 |
| 13 | $\log(\text{DLL}_{K\pi}(z1) + 5)$ | 4.762 |
| 14 | $\log(p_T(z2))$ | 4.754 |
| 15 | $IP\chi^2(B_c^+)$ | 4.388 |
| 16 | $\log(p_T(p2))$ | 4.071 |
| 17 | $\log(\text{vertex } \chi^2(\text{D}_\text{s}^+))$ | 3.666 |
| 18 | $\log(10 - \text{DLL}_{K\pi}(p2))$ | 3.213 |
| 19 | $\log(\text{vertex } \chi^2(\text{D}^0))$ | 3.047 |
| 20 | $\log(\text{vertex } \chi^2(\text{B}_\text{c}^+))$ | 2.895 |
| 21 | $\log(10 - \text{DLL}_{K\pi}(z2))$ | 2.743 |

# MVA response

- Tried out BDT and MLP (default neural network of TMVA) with various transformations
- Used k-folding technique
  - Train 5 MVAs, each time witholding a different 20% for testing
  - Evaluate the response using the MVA that withheld the event from training
- Best performance from BDT with identity transformation
- Good separation of signal and background
- Agreement between sWeighted $B^+$ data and MC



# Simultaneous fit

- An unbinned extended maximum likelihood is performed simultaneously to both $D^0$ decay modes
- Only the total $B_c^+$ yield is floating

$$N_{B_c^+}^{K\pi} = \frac{N_{B^+}^{K\pi}\varepsilon_{B_c^+}^{K\pi}/\varepsilon_{B^+}^{K\pi}}{N_{B^+}^{K\pi}\varepsilon_{B_c^+}^{K\pi}/\varepsilon_{B^+}^{K\pi} + N_{B^+}^{K\pi\pi\pi}\varepsilon_{B_c^+}^{K\pi\pi\pi}/\varepsilon_{B^+}^{K\pi\pi\pi}} N_{B_c^+}^{\mathrm{tot}}$$

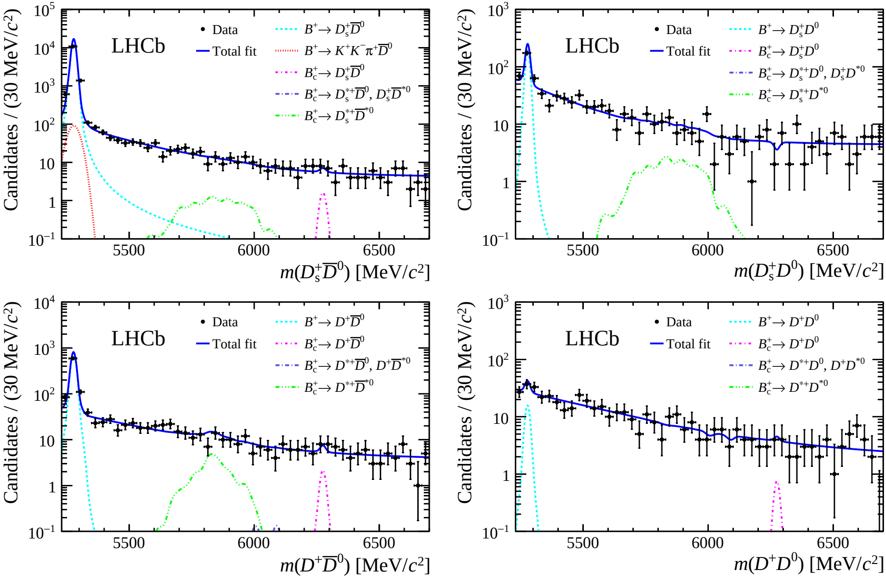
$$N_{B_c^+}^{K\pi\pi\pi} = \frac{N_{B^+}^{K\pi\pi\pi}\varepsilon_{B_c^+}^{K\pi\pi\pi}/\varepsilon_{B^+}^{K\pi\pi\pi}}{N_{B^+}^{K\pi}\varepsilon_{B_c^+}^{K\pi}/\varepsilon_{B^+}^{K\pi} + N_{B^+}^{K\pi\pi\pi}\varepsilon_{B_c^+}^{K\pi\pi\pi}/\varepsilon_{B^+}^{K\pi\pi\pi}} N_{B_c^+}^{\mathrm{tot}}$$

- The efficiencies are measured using MC

Table 2: Ratio $\varepsilon_{B_c^+}/\varepsilon_{B^+}$ of total efficiencies of $B_c^+$ decays relative to the corresponding fully reconstructed $B^+$ decays. The quoted uncertainties are statistical only.

| | Reconstructed state | | | |
|---|---|---|---|---|
| | $D_s^+ \overset{(-)}{D}{}^0$ with $D^0 \to$ | | $D^+ \overset{(-)}{D}{}^0$ with $D^0 \to$ | |
| Decay channel | $K^-\pi^+$ | $K^-\pi^+\pi^-\pi^+$ | $K^-\pi^+$ | $K^-\pi^+\pi^-\pi^+$ |
| $B_c^+ \to D_{(s)}^+ \overset{(-)}{D}{}^0$ | $0.420 \pm 0.005$ | $0.373 \pm 0.009$ | $0.441 \pm 0.007$ | $0.398 \pm 0.010$ |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^0, D_{(s)}^+ \overset{(-)}{D}{}^{*0}$ | $0.372 \pm 0.006$ | $0.317 \pm 0.010$ | $0.381 \pm 0.008$ | $0.337 \pm 0.011$ |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^{*0}$ | $0.339 \pm 0.006$ | $0.278 \pm 0.009$ | $0.342 \pm 0.007$ | $0.297 \pm 0.010$ |

# Mass fits: $D^0 \to K^-\pi^+\pi^-\pi^+$



# Systematics on the yields

Table 4: Systematic uncertainties on the $B_c^+$ yields, for the combined fit to both the $D^0 \to K^-\pi^+$ and the $D^0 \to K^-\pi^+\pi^-\pi^+$ decay channels. The total systematic uncertainty is calculated as the quadratic sum of the individual components.

| Source | Reconstructed state $D_s^+\overline{D}^0$ | $D_s^+D^0$ | $D^+\overline{D}^0$ | $D^+D^0$ |
|---|---|---|---|---|
| $B_c^+ \to D_{(s)}^+ \overset{(-)}{D}{}^0$ | | | | |
| Signal shape | 0.25 | 0.28 | 0.31 | 0.13 |
| Signal model | 0.40 | 0.34 | 0.61 | 0.44 |
| $B_c^+$ mass | 0.64 | 0.62 | 0.79 | 0.51 |
| Background model | 1.12 | 1.75 | 1.88 | 0.56 |
| Fit bias | 0.70 | 1.28 | 0.27 | 0.19 |
| Total | 1.54 | 2.30 | 2.17 | 0.91 |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^0, D_{(s)}^+ \overset{(-)}{D}{}^{*0}$ | | | | |
| Signal composition | 7.6 | 5.5 | 7.1 | 5.7 |
| Background model | 11.9 | 17.5 | 16.4 | 4.5 |
| Fit bias | 5.5 | 9.4 | 3.9 | 1.3 |
| Total | 15.2 | 20.6 | 18.3 | 7.4 |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^{*0}$ | | | | |
| Polarisation | 23 | 14 | 9 | 5 |
| Background model | 43 | 98 | 37 | 9 |
| Fit bias | 10 | 7 | 8 | 1 |
| Total | 49 | 99 | 39 | 10 |

# Systematics on the normalisation

Table 5: Systematic uncertainties, in %, on the normalisation of the $B_c^+$ branching fraction determination. The total systematic uncertainty is calculated as the quadratic sum of the individual components.

| | | Reconstructed state | | | |
|---|---|---|---|---|---|
| | | $D_s^+ \overset{(-)}{D}{}^0$, with $D^0 \to$ | | $D^+ \overset{(-)}{D}{}^0$, with $D^0 \to$ | |
| Channel | Source | $K^-\pi^+$ | $K^-\pi^+\pi^-\pi^+$ | $K^-\pi^+$ | $K^-\pi^+\pi^-\pi^+$ |
| Common | $B^+$ stat. | 0.7 | 0.9 | 3.1 | 4.3 |
| | $B^+$ signal shape | 0.0 | 0.0 | 0.0 | 0.3 |
| | $B^+$ signal model | 0.1 | 0.2 | 0.1 | 0.3 |
| | Background model | 0.0 | 0.6 | 1.6 | 1.3 |
| | $B^+ \to \overline{D}{}^0 K^+ K^- \pi^+$ | 1.4 | 1.4 | — | — |
| | $B_c^+$ lifetime | 1.5 | 1.5 | 1.5 | 1.5 |
| | PID | 2.4 | 0.9 | 1.2 | 3.2 |
| | $D^0$ model | — | 1.1 | — | 0.7 |
| $B_c^+ \to D_{(s)}^+ \overset{(-)}{D}{}^0$ | Simulation stat. | 1.2 | 2.4 | 1.6 | 2.5 |
| | Total | 3.5 | 3.6 | 4.3 | 6.3 |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^0, D_{(s)}^+ \overset{(-)}{D}{}^{*0}$ | Simulation stat. | 1.7 | 3.3 | 2.0 | 3.3 |
| | Signal composition | 1.0 | 0.8 | 0.7 | 2.6 |
| | Total | 3.8 | 4.3 | 4.5 | 7.1 |
| $B_c^+ \to D_{(s)}^{*+} \overset{(-)}{D}{}^{*0}$ | Simulation stat. | 1.7 | 3.4 | 2.0 | 3.3 |
| | Polarisation | 1.5 | 0.4 | 1.4 | 1.3 |
| | $\mathcal{B}\,(D^{*+} \to D^+\pi^0, \gamma)$ | — | — | 1.5 | 1.5 |
| | Total | 3.9 | 4.4 | 4.9 | 6.9 |