Overview of Heavy Flavour results from the LHCb experiment

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on behalf of the LHCb collaboration

University of Glasgow

January 8th, 2020
LHCb physics

- huge $b$ and $c$ production cross-sections at LHC
  - relatively light: both $b$ and $\bar{b}$ in tight cone around either beam
- LHCb has largest samples of $b$ and $c$ decays
  - can probe SM and NP using precision measurements
    - (over-)constrain SM parameters (CKM matrix!)
    - new sources of CP violation
    - rare decays
  - gain better understanding of (effective models of) QCD
originally designed to study CPV and rare $b$ and $c$ decays, nowadays GPD in forward region

- tracking efficiency $> 96\%$ (multibody final states!)
- excellent vertexing: decay time resolution $\sim 45$ fs
- very good momentum resolution: $dp/p \sim 0.5 - 1.0\%$
- software trigger (HLT) input rate: $1$ MHz
**LHCb experiment**

**LHCb physics**

- **LHCb has largest samples of b and c decays**
- **steady stream of publications**
  - Nov 15th, 2019: **500th publication**
  - now: **507 papers (submitted)**
- here are the publications since July 2019:
  - Search for CP violation and observation of P violation in $\Lambda_\mathrm{b}^0 \to p\pi^-\pi^+\pi^-$ decays, PAPER-2019-028, [arXiv:1912.10741], PRL, 23 Dec 2019
  - Test of lepton universality with $\Lambda_\mathrm{b}^0 \to p\Lambda K^-$ decays, PAPER-2019-040, [arXiv:1912.08139], JHEP, 04 Dec 2019
  - Measurement of the $\Xi_{cc}^0$ mass, PAPER-2019-037, [arXiv:1911.08594], JHEP, 19 Nov 2019
  - Observation of the semileptonic decay $B^+ \to p\pi^-\ell^+\nu_\ell$, PAPER-2019-034, [arXiv:1911.08187], JHEP, 19 Nov 2019
  - Determination of quantum numbers for several excited charmed mesons observed in $B^- \to D^{\ast+}\pi^-\pi^-$ decays, PAPER-2019-027, [arXiv:1911.05957], PRD, 14 Nov 2019
  - Search for $A^0 \to \mu^+\mu^-$ decays, PAPER-2019-031, [arXiv:1910.06926], PRL, 15 Oct 2019
  - Search for the doubly charmed baryon $\Xi_{cc}^+$, PAPER-2019-029, [arXiv:1907.00954], 01 Jul 2019
  - Amplitude analysis of the $B^+ \to \pi^+\pi^+\pi^-$ decay, PAPER-2019-017, [arXiv:1909.05212], PRD, 11 Sep 2019

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**Overview Heavy Flavour LHCb**

M. Schiller (Glasgow)

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list on last page is clearly far too much to cover
will therefore pick or point to a few highlights:

- first, there are excellent talks by other LHCb collaborators:
  - Wednesday: Carla Marin Benito: Test of Lepton Universality with $\Lambda_b \to pK\ell\ell$ decays LHCb-PAPER-2019-040, [arXiv:1912.08139]
  - Thursday: Cesar Luiz Da Silva: Physics opportunities with a future soft particle tracker in LHCb
  - Thursday: Jozef Tomasz Borsuk: $b \to s\ell\ell$ transitions at LHCb
  - Thursday: Milosz Zdybal: Particle Correlations at LHCb
  - Thursday: Mateusz Jacek Goncerz: Exotic searches at LHCb
  - Thursday: Simone Meloni: Test of lepton flavour universality in $b \to c\ell\nu$ decays at the LHCb experiment

- will cover some of the excellent work that was done in various areas
  - can only cover so much in half an hour — my apologies...

- Precision measurement of the $\Xi^{+\pm}_c$ mass, PAPER-2019-037, [arXiv:1911.08594], JHEP, 19 Nov 2019
- Measurement of $|V_{cb}|$ with $B^0 \to D_s^{(*)}\mu^+\nu_\mu$ decays, preliminary, to appear shortly
(some) highlights
\[ m_{\Xi^{++}_{cc}} = (3621.34 \pm 0.74) \text{ MeV/}c^2 \] (stat. only — it's a production measurement)

measure production cross-section of \( \Xi^{++}_{cc} \) in \( \Lambda^+_c K^- \pi^+ \pi^+ \)

- in kinematic region \( 4 < p_T < 15 \text{ GeV/}c^2 \) and \( 2.0 < y < 4.5 \)
- relative to the \( \Lambda^+_c \) production cross-section:

\[
\frac{\sigma(\Xi^{++}_{cc})}{\sigma(\Lambda^+_c)} = (2.22 \pm 0.27 \pm 0.29) \times 10^{-4}
\]
2016-2018 data, 5.6 fb$^{-1}$, published not one month apart

- precision measurement of mass of $\Xi_{cc}^{++}$ in $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$: $m_{\Xi_{cc}^{++}} = (3621.55 \pm 0.23 \text{ (stat)} \pm 0.30 \text{ (syst)})$ MeV/c$^2$

- world’s most precise measurement of $\Xi_{cc}^{++}$ mass
data samples: 7 and 13 TeV data

measurement of production fraction ratio \[ \frac{f_c}{f_u+f_d} \] in \( B_c^- \rightarrow J/\psi \mu^- \nu_\mu \)

\[
\frac{f_c}{f_u+f_d} = \begin{cases} 
    (3.63 \pm 0.08 \pm 0.12 \pm 0.86) \cdot 10^{-3} & \text{for 7 TeV} \\
    (3.78 \pm 0.04 \pm 0.15 \pm 0.89) \cdot 10^{-3} & \text{for 13 TeV}
\end{cases}
\]

first uncertainty statistical, second from \( \mathcal{B}(B_c^- \rightarrow J/\psi \mu^- \nu_\mu) \), last from fractions of \( B_s^0 \) and \( \Lambda^0_b \)

continue to test QCD (predictions) with measurements like this
First observation of excited $\Omega^0_b$ states
First observation of excited $\Omega_{b}^{0}$ states

- **LHCb**
  - **Data**
  - **Full fit**
  - **$\Xi_{c}^{+} \rightarrow pK^{-}\pi^{+}$**
  - **Background**

- **Candidates / 1 MeV**
  - 2440, 2460, 2480, 2500
  - 2000, 4000, 6000, 8000

- **LHCb**
  - **Data**
  - **Full fit**
  - **$\Xi_{b}^{0} \rightarrow \Xi_{c}^{+}\pi^{-}$**
  - **Background**

- **Candidates / 5 MeV**
  - 5700, 5750, 5800, 5850, 5900
  - 1000, 2000

**reconstruct $\Xi_{c}^{+} \rightarrow pK^{-}\pi^{+}$** (arrows indicate cuts)
- data samples: 1 fb$^{-1}$ at $\sqrt{s} = 7$ TeV, 2 fb$^{-1}$ at 8 TeV and 6 fb$^{-1}$ at 13 TeV
- from displaced tracks with clear PID assignment forming good vertex
- veto main BG from mid-ID’ed $D_{s}^{+} \rightarrow K^{+}(K/\pi)^{-}\pi^{+}$, $D^{*+} \rightarrow (D^{0} \rightarrow K^{-}\pi^{+})\pi^{+}$, and $\phi \rightarrow K^{+}K^{-} + \text{random track}$

**reconstruct $\Xi_{b}^{0} \rightarrow \Xi_{c}^{+}\pi^{-}$** (arrows indicate cuts)
- use BDT to further suppress combinatorial BGs by factor 2.5 (90% efficiency)
- 19.2 ± 0.2 k very clean $\Xi_{b}^{0}$ candidates
First observation of excited $\Omega^0_{b\ell}$ states

**selection and fit**

- take $\Xi^0_{b\ell}$ and add prompt charged $K$
  - $\Xi^0_{b\ell}K$ vertex kinematically constraint to primary vertex
  - study $\delta M = M(\Xi^0_{b\ell}K) - M(\Xi^0_{b\ell})$ distribution
- right sign candidates ($\Xi^0_{b\ell}K^-$) and wrong sign ones ($\Xi^0_{b\ell}K^+$)
  - wrong sign candidates crucial to control background shape
- optimize PID requirements on $K^-$ using FOM $\epsilon_{MC}/(\sqrt{B} + 5/2)$ from WS for $520 < \delta M/\text{MeV} < 570$ (expected BG yield scaled to a 10 MeV window for narrow peaks)
- double-gaussian resolution function $\sigma_M$; in relevant $\delta M$ range, $\sigma_M = 0.7 - 0.8$ MeV
- fit peaks: Breit-Wigner with Blass-Weisskopf barrier factor, convolved with resolution function

![Graphs showing data and fit results](arXiv:2001.00851)
results, systematics

<table>
<thead>
<tr>
<th>Peak of $\delta M$ [MeV]</th>
<th>width [MeV]</th>
<th>signal yield</th>
<th>local significance</th>
<th>global significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$523.74 \pm 0.31$</td>
<td>0.00$^{+0.65}_{-0.00}$</td>
<td>14.6$^{+6.2}_{-5.1}$</td>
<td>3.6</td>
<td>2.1</td>
</tr>
<tr>
<td>$538.40 \pm 0.28$</td>
<td>0.00$^{+0.42}_{-0.00}$</td>
<td>17.5$^{+6.4}_{-5.4}$</td>
<td>3.7</td>
<td>2.6</td>
</tr>
<tr>
<td>$547.81 \pm 0.26$</td>
<td>0.47$^{+0.64}_{-0.47}$</td>
<td>47.2$^{+11.0}_{-9.9}$</td>
<td>7.2</td>
<td>6.7</td>
</tr>
<tr>
<td>$557.98 \pm 0.35$</td>
<td>1.4$^{+1.0}_{-0.8}$</td>
<td>56.8$^{+13.9}_{-12.5}$</td>
<td>7.0</td>
<td>6.2</td>
</tr>
</tbody>
</table>

- local significance from $S_{data} = \sqrt{2 \log(\mathcal{L}_{max}/\mathcal{L}_0)}$ where $\mathcal{L}_0$ is LH with signal yield fixed to 0
- global significance (incl. “look-elsewhere” effect) from distribution of $S_{pe}$ in pseudo-experiments (with yields fixed to 0)
- (non-negligible) sources of systematic uncertainty on $\delta M$:

<table>
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<tr>
<th></th>
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<tbody>
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<tr>
<td>total</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

mass uncertainties are: stat., syst., syst. from $m_{\Xi^0_b}$
widths at 90(95) % CL, and central value for heaviest peak

two new excited $\Omega^{-}_b$ states observed, and hints of two more
\[ |V_{cb}| \quad \text{from} \quad B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu \]
determine $|V_{cb}|$ from $b \rightarrow c$ transition

- inclusively, i.e. $b$-hadron $\rightarrow c$-hadron + charged lepton

  + no hard-to-calculate bound QCD states
  - difficult to ensure truly selection inclusive

- inclusive average: $|V_{cb}| = (42.19 \pm 0.78) \times 10^{-3}$ (HFLAV 2018)

- exclusively, e.g. $B^0 \rightarrow D^- \mu^+ \nu_{\mu}$

  + much easier to do experimentally
  - need **form-factors** (FF) to interpret result: quarks in strongly bound system

  - exclusive average: $|V_{cb}| = (39.25 \pm 0.56) \times 10^{-3}$

- slight tension between averages!

  - CLN FF parametrisation used in excl. measurements cause of tension?
  - new measurements: try also e.g. BGL FF param. (more general, but truncation of series in BGL somewhat arbitrary), and compare

  - will show preliminary exclusive determination on next few pages...
\[ |V_{cb}| \text{ from semileptonic } b \rightarrow c: \text{ (some) theory} \]

**vector case:**

\[
\frac{d^4 \Gamma(B \rightarrow D^* \mu \nu)}{dw \, d \cos \theta_\mu \, d \cos \theta_D \, d\chi} = \frac{3m_B^3 m_{D^*}^2 G_F^2}{16(4\pi)^4} \eta_{EW}^2 |V_{cb}|^2 |\mathcal{A}(w, \theta_\mu, \theta_D, \chi)|^2
\]

- with recoil variable \( w = v_B \cdot v_{D^*} = (m_B^2 + m_{D^*}^2 - q^2)/(2m_B m_{D^*}) \)
- express amplitude in terms of \( w \) and helicity angles:
  \[ |\mathcal{A}(w, \theta_\mu, \theta_D, \chi)|^2 = \sum_{i=1}^{6} \mathcal{H}_i(w) k_i(\theta_\mu, \theta_D, \chi) \]
- terms \( \mathcal{H}_i(w) \) depend on \( w, B \) and \( D^* \) masses, and **form factors** \( (FF) h_{A1}(w), R_1(w), R_2(w) \)

**pseudoscalar case similar:** (form factor here \( \mathcal{G}(w) \))

\[
\frac{d\Gamma(B \rightarrow D \mu \nu)}{dw} = \frac{G_F^2 m_D^3}{48\pi^3} (m_B + m_D)^2 \eta_{EW}^2 |V_{cb}|^2 (w^2 - 1)^{3/2} |\mathcal{G}(w)|^2
\]
data sample, selection

- analysis based on 7 and 8 TeV data (3 fb$^{-1}$)
- use $B_s^0 \rightarrow D_{s}^{(*)-} \mu^+ \nu_\mu$ decays
  - trigger on high $p_T$ $\mu$ associated with 1-3 charged displaced tracks
  - offline, select $\mu^+$ plus three tracks consistent with $D_{(s)}^- \rightarrow K^+ K^- \pi^-$
    - $m_{K^+K^-} \in [1008, 1032]$ MeV/$c^2$ to suppress BG under $D_{(s)}^-$ peaks, and keep signal and reference channel kinematics similar
    - $m_{K^+K^-\pi^-}$ mass in $D^-$ or $D_s^-$ range
  - produce clean $D_{(s)}^-$ peaks by optimising selection using track/vertex quality, vertex displacement, $p_T$ and PID criteria
  - measure yields relative to reference decays ($B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu$)
- only partial reconstruction: $D_{(s)}^- (\rightarrow \phi (K^+ K^-) \pi^-) \mu^+$
  - cross-contamination between $D^- \mu^+$ and $D_s^- \mu^+$ samples below 0.1% (based on simulation)
  - combinatorial BG from same-sign $D_{(s)}^- \mu^-$ candidates
  - veto misreconstructed/mis-IDed $B_s^0 \rightarrow \psi^{(')} (\rightarrow \mu^+ \mu^-) \phi (\rightarrow K^+ K^-)$, $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) \mu^- \bar{\nu}_\mu X$ and $B_{(s)}^0 \rightarrow D_{(s)}^\pi^+$
 partial reconstruction

- final state not fully reconstructed ($\gamma/\pi^0$ from $D_s^{*-}$ and also $\nu_\mu$)
- separate signal/remaining BGs in
  - $p_\perp(D_s^-\mu^+)$ (transverse to the $B_s^0$ flight direction)
  - $m_{corr} = \sqrt{m^2(D_s^-\mu^+) + p^2_\perp(D_s^-\mu^+) + p_\perp(D_s^-\mu^+)}$
- white dashed line: cut for analysis (dashed-dotted for systematics)
cannot fully reconstruct recoil variable \( w \) (for form factors!)

- but \( p_{\perp}(D_{s}^{-}) \) is a good proxy (white line: average)
- \( p_{\perp}(D_{s}^{-}) \) also has some small correlation with helicity angles \( \cos \theta_{D} \) and \( \cos \theta_{\mu} \)
signal and reference yields from fit to 2D distribution of $p_\perp, m_{corr}$

- use $B_s^0$ modes are signal
  - easier LQCD calculation due to heavier $s$ quark
  - FF theory calculations available for whole $q^2$ spectrum
  - less contamination due to less contamination from partially reconstructed decays)

- 2D templates from simulation (signal, reference decays and physics bkg) and same-sign data (combinatorial bkg)
  - floating FF parameters used to rebuild the 2D templates for signal and reference decays at each fit iteration

- $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu\mu$ yields expressed as a function of $|V_{cb}|$ by integrating over the respective differential decay rates (equations in 2 slides)
  - FF described by either the CLN or BGL parametrization, with some parameters constrained to their LQCD determinations

- all other yields left free to float in the fit
\(|V_{cb}| \) from \(B_0^+ \rightarrow D_s^{(*)} - \mu^+ \nu_\mu\)

**analysis strategy**

**analysis strategy illustration**

![Graphs showing LHCb Simulation preliminary results](image)

- recalculate 2D templates in \(p_{\perp}, m_{\text{corr}}\) for each FF parameter change
first, fit reference channel, keeping total signal yields floating $N_{ref}$

for signal fit: express signal yields $N_{sig}$ in terms of $N_{ref}$:

- $N_{sig} = N_{ref} \tau \int \frac{d\Gamma(B^0_s \to D_s^{(*)-} \mu^+\nu_\mu)}{d\zeta} d\zeta$ where
  - $\zeta = \begin{cases} w & \text{for } B^0_s \to D_s^- \mu^+\nu_\mu \\ (w, \cos \theta_\mu, \cos \theta_D, \chi) & \text{for } B^0_s \to D_s^{*-} \mu^+\nu_\mu \end{cases}$
  - $N^{(*)} = \frac{N_{ref}^{(*)} \xi^{(*)}}{\mathcal{B}(B^0 \to D^{(*)-} \mu^+\nu_\mu)}$, with $\xi^{(*)}$ efficiency ratio signal/reference mode
  - $K = \frac{f_s}{f_d} \frac{\mathcal{B}(D_s^- \to K^+K^-\pi^-)}{\mathcal{B}(D^- \to K\pi\pi)}$ and $K^* = \frac{f_s}{f_d} \frac{\mathcal{B}(D^{*-} \to D^-\chi)}{\mathcal{B}(D^- \to K\pi\pi)}$
  - take a $f_s/f_d$ measurement from an independent data sample
results

- external inputs (experimental/theory, preliminary):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_s/f_d \times b(D_s^+ \to K^-K^+\pi^-) \times \tau [ps]$</td>
<td>0.01913 ± 0.00076</td>
</tr>
<tr>
<td>$\mathcal{B}(D^- \to K^-K^+\pi^-)$</td>
<td>0.00993 ± 0.00024</td>
</tr>
<tr>
<td>$\mathcal{B}(D^*^- \to D^-\pi^-)$</td>
<td>0.323 ± 0.006</td>
</tr>
<tr>
<td>$\mathcal{B}(B^0 \to D^-\mu^+\nu\mu)$</td>
<td>0.0231 ± 0.0010</td>
</tr>
<tr>
<td>$\mathcal{B}(B^0 \to D^{*-}\mu^+\nu\mu)$</td>
<td>0.0505 ± 0.0014</td>
</tr>
</tbody>
</table>

- preliminary result:

CLN form factor fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{cb}</td>
</tr>
<tr>
<td>$\mathcal{G}(0)$</td>
<td>1.102 ± 0.034(stat) ± 0.004(ext)</td>
</tr>
<tr>
<td>$\rho(D^-_s)$</td>
<td>1.268 ± 0.047(stat) ± 0.001(ext)</td>
</tr>
<tr>
<td>$\rho^2(D^{*-}_s)$</td>
<td>1.23 ± 0.17(stat) ± 0.01(ext)</td>
</tr>
<tr>
<td>$R_1(1)$</td>
<td>1.34 ± 0.25(stat) ± 0.02(ext)</td>
</tr>
<tr>
<td>$R_2(1)$</td>
<td>0.83 ± 0.16(stat) ± 0.01(ext)</td>
</tr>
</tbody>
</table>

BGL form factor fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$</td>
<td>V_{cb}</td>
</tr>
<tr>
<td>$\mathcal{G}(0)$</td>
<td>1.097 ± 0.034 (stat) ± 0.008 (ext)</td>
</tr>
<tr>
<td>$d_1$</td>
<td>$-0.0172 ± 0.0074$ (stat) ± 0.0007 (ext)</td>
</tr>
<tr>
<td>$d_2$</td>
<td>$-0.256 ± 0.047$ (stat) ± 0.002 (ext)</td>
</tr>
<tr>
<td>$b_1$</td>
<td>$-0.060 ± 0.068$ (stat) ± 0.013 (ext)</td>
</tr>
<tr>
<td>$a_0$</td>
<td>$0.0374 ± 0.0086$ (stat) ± 0.0008 (ext)</td>
</tr>
<tr>
<td>$a_1$</td>
<td>$0.28 ± 0.26$ (stat) ± 0.08 (ext)</td>
</tr>
<tr>
<td>$c_1$</td>
<td>$0.0031 ± 0.0022$ (stat) ± 0.0006 (ext)</td>
</tr>
</tbody>
</table>

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January 8th, 2020 25 / 28

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#### largest systematic uncertainties on $|V_{cb}|$ from $f_s/f_d$ and $D_s^-(s) \rightarrow K^+K^-\pi^-$ model

<table>
<thead>
<tr>
<th>Source</th>
<th>CLN parametrization</th>
<th>Uncertainty</th>
<th>BGL parametrization</th>
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<tbody>
<tr>
<td>$f_s/f_d \times \mathcal{B}(D_s^- \rightarrow K^+K^-\pi^-) \times \tau$</td>
<td>$</td>
<td>V_{cb}</td>
<td>$</td>
</tr>
<tr>
<td>$\mathcal{B}(D^- \rightarrow K^+\pi^-)$</td>
<td>0.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\mathcal{B}(D_s^- \rightarrow D^-X)$</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>$\mathcal{B}(B_0^0 \rightarrow D^-\mu^+\nu_\mu)$</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>$\mathcal{B}(B_0^0 \rightarrow D_s^-\mu^+\nu_\mu)$</td>
<td>0.4</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>$m(B_0^0)$, $m(D_s^{-*})$</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>$\eta_{EW}$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>$h_{A_1}(1)$</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Background</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Fit bias</td>
<td>1.2</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Corrections to simulation</td>
<td>0.8</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Form-factor parametrization</td>
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<td>3.1</td>
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<td>Background</td>
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<tr>
<td>Fit bias</td>
<td>0.0</td>
<td>0.1</td>
<td>0.5</td>
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<tr>
<td>Corrections to simulation</td>
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<tr>
<td>Background</td>
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<td>3.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Statistical (stat)</td>
<td>0.6</td>
<td>4.7</td>
<td>3.4</td>
</tr>
</tbody>
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novel approach for exclusive determination of $|V_{cb}|$:
- exploit ratio $B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu / B_d^0 \to D^{(*)-} \mu^+ \nu_\mu$ to cancel systematics
- template-based fit in $m_{\text{corr}} - p_\perp(D_{(s)}^{-})$ plane
  - helps to suppress BGs
- express form-factor dependence in terms of observed quantities

$|V_{cb}|$ (CLN) = $(41.4 \pm 0.6 \text{ (stat)} \pm 0.9 \text{ (syst)} \pm 1.2 \text{ (ext)}) \times 10^{-3}$

$|V_{cb}|$ (BGL) = $(42.3 \pm 0.8 \text{ (stat)} \pm 0.9 \text{ (syst)} \pm 1.2 \text{ (ext)}) \times 10^{-3}$


- tension with inclusive average reduced
- consistent results from both FF parametrisations!
- stay tuned: paper will come out soon
conclusion
LHCb continues to provide precision results in wide-ranging topics

- precision CKM physics
- spectroscopy
- ...

Stay tuned:

- run 2 data set is being more fully exploited by analyses
- we’re also busy building and commissioning the LHCb Upgrade
  - full detector read out at 40 MHz with higher pile-up
  - full software trigger running at full rate, important especially for hadronic channels
- hope for an order of magnitude more in statistics