Recent results from LHCb

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On behalf of the LHCb collaboration

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Outline

- Physics program
- LHCb experiment
- Highlights of recent results
  - Mostly from Run I data, some analyses include ongoing Run II data
- Prospects
- Conclusion
LHCb physics scope

• **Main scope**
  – Use heavy flavours (b,c) decays to probe New Physics indirectly
    • Deviations from Standard Model on cleanly-predicted observables
    • Constraints on New Physics parameters even if no detected sign
  – Precise measurements on weak couplings of quarks, “CKM physics”
    • Understand better EW CP violation, as an input to the cosmological puzzle

• **Other topics are considered**
  – Heavy Quarks production at pp collisions
  – Forward EW and QCD physics
  – Search for exotics
  – Heavy ion physics
  – ...
CKM picture: where we start...

Weak interaction couples quarks through elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix.

Weak eigenstates are different from mass eigenstates = CKM matrix is not diagonal and may relate quarks of different generation.

\[ V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \]

Clear hierarchy in the couplings: the further from diagonal, the weaker.

Unitarity imposes relations, among which \( \sum_k V_{ik} V_{jk}^* = 0 \)

Elements forming sides (and angles) of 3 independent “unitarity” triangles, of which only a couple are of interest for heavy-flavour decays.
...and where we stand

Most interesting relation:

\[ V_{ud} V_{ub}^{*} + V_{cd} V_{cb}^{*} + V_{td} V_{tb}^{*} = 0 \]

Sides usually measured in semileptonic decays and oscillation frequency, angles in CP asymmetries

\[ V_{us} V_{ub}^{*} + V_{cs} V_{cb}^{*} + V_{ts} V_{tb}^{*} = 0 \]

CKM picture verified but with higher precision, discrepancies could still arise, e.g. need for precise measurement of \( \gamma \) angle
LHCb detector

**Forward single-arm spectrometer with warm magnet**
(possibility to inverse polarity)

Optimize for b and c hadron studies

**Vertexing**

**Tracking stations**

**Particle ID**

Ring Imaging Cherenkov

Calorimeters and **Muon Chambers**

Inside LHCb acceptance

Acceptance $2 < \eta < 5$

Momentum resolution $\sim 0.5\%$

IP resolution $\sim 20 \mu m$

Time resolution $\sim 45$ fs
10^{11} protons per bunch colliding at 7 (2011) and 8 (2012) TeV

Luminosity at IP8 (LHCb): 2-4 x 10^{32} cm^{-2} s^{-1}

About 1500 charged particles produced at each pp collision

\[ \sigma(b\bar{b}) \sim 75 \, \mu b \text{ at } 7 \text{ TeV}^* \text{ in LHCb acceptance} \]

\sim 40\% \text{ B}^+, 40\% \text{ B}^0, \sim 10\% \text{ Bs}

Remaining b baryons, Bc, etc...

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* J. High Energy Phys. 08 (2013) 117
LHCb data (2015+2016) – ongoing Run II

Bunch colliding at 13 TeV

$\sigma(b\bar{b}) \sim 165 \mu b$ @ 13 TeV* in LHCb acceptance
About 2.3 times the value @ 7-8 TeV

LHCb Integrated Luminosity in pp collisions 2010-2016

* LHCb-PAPER-2016-031
**Angle from $B \rightarrow DK^{(*)}(h,hh)$ decays**

- Use interfering amplitudes in tree-level $B \rightarrow DK^{(*)}(h,hh)$ decays

\[ r_i : \text{amplitude ratios} \]
\[ \delta_i : \text{relative strong phases} \]

\[ A_B r_B e^{i(\delta_B - \gamma)} \]
\[ A_D r_D e^{i\delta_D} \]

\[ \text{In general: } r_D \text{ and } f_D \text{ used as external inputs (e.g. from CLEO-c data)} \]

- Fits use ratios of allowed/suppressed BF + asymmetries
- For multibody D decays, dilution factor due to $\delta_D$ variation across phase space
- Compare to $\gamma$ from loop diagrams: mismatch? BSM particles in the loop?
- Combine LHCb analyses to make averages
\( \gamma \) from \( B \to DK \), different techniques

- \( f_D = \) CP eigenstates, \( D^0 \to K^+K^-, \pi^+\pi^-, Ks\pi^0 \)
- \( f_D = \) flavour states: \( D^0 \to K^+\pi^-, K^-\pi^+ \)
  - Atwood, Dunietz, Soni (ADS) 1997
- \( f_D = \) multibody final states (variation of \( \delta_D \) over phase space)
  - \( Ksh^+h^- \) Giri, Grossman, Soffer, Zupan 2003; Poluektov 2004 (GGSZ-P)
  - \( K^{\pm}\pi^{-/+}\pi^+\pi^- \), multibody ADS
  - \( KsK^{\pm}\pi^{-/+} \), GLS
- Some variants involving neutrals, \( B^0 \) and Bs

**Observables:** charge asymmetries and BF ratios of suppressed/favoured \( D \) decays (applies for self-tagging decays)
\( \gamma \) from trees

Case of \( D^0 \to K^-\pi^+ \) (Cabibbo Allowed), \( D^0 \to K^+\pi^- \) (double Cabibbo Suppressed)

\[
R_h^\pm = \frac{\Gamma \left( B^\pm \to D_{DCS} h^\pm \right)}{\Gamma \left( B^\pm \to D_{CA} h^\pm \right)} = \frac{r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D \pm \gamma)}{1 + (r_B r_D)^2 + 2r_B r_D \cos(\delta_B - \delta_D \pm \gamma)}
\]

For multibody decays, must take into account the interference term between the two amplitudes in the D meson phase space, using a coherence factor \( \kappa_D \)


\[
2r_B r_D \cos(\delta_B + \delta_D \pm \gamma) \to 2r_B r_D \kappa_D \cos(\delta_B + \delta_D \pm \gamma)
\]
\[ \gamma \text{ from } B \to DK \text{ in LHCb} \]

- Many channels under study in LHCb
  - Using either CP, flavour, or multibody final states of D

<table>
<thead>
<tr>
<th>B decay</th>
<th>D decay</th>
<th>Method</th>
<th>Ref.</th>
<th>Status since last combination [28]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^+ \to Dh^+ )</td>
<td>( D \to h^+h^- )</td>
<td>GLW/ADS</td>
<td>[44]</td>
<td>Updated to 3 fb(^{-1} )</td>
</tr>
<tr>
<td>( B^+ \to Dh^+ )</td>
<td>( D \to h^+\pi^-\pi^+\pi^- )</td>
<td>GLW/ADS</td>
<td>[44]</td>
<td>Updated to 3 fb(^{-1} )</td>
</tr>
<tr>
<td>( B^+ \to Dh^+ )</td>
<td>( D \to h^+h^-\pi^0 )</td>
<td>GLW/ADS</td>
<td>[45]</td>
<td>New</td>
</tr>
<tr>
<td>( B^+ \to DK^+ )</td>
<td>( D \to K^0_S h^+h^- )</td>
<td>GGSZ</td>
<td>[46]</td>
<td>As before</td>
</tr>
<tr>
<td>( B^+ \to DK^+ )</td>
<td>( D \to K^0_S K^-\pi^+ )</td>
<td>GLS</td>
<td>[47]</td>
<td>As before</td>
</tr>
<tr>
<td>( B^+ \to Dh^+\pi^-\pi^+ )</td>
<td>( D \to h^+h^- )</td>
<td>GLW/ADS</td>
<td>[48]</td>
<td>New</td>
</tr>
<tr>
<td>( B^0 \to DK^{*0} )</td>
<td>( D \to K^+\pi^- )</td>
<td>ADS</td>
<td>[49]</td>
<td>As before</td>
</tr>
<tr>
<td>( B^0 \to DK^{+\pi^-} )</td>
<td>( D \to h^+h^- )</td>
<td>GLW-Dalitz</td>
<td>[50]</td>
<td>New</td>
</tr>
<tr>
<td>( B^0 \to DK^{*0} )</td>
<td>( D \to K^0_S \pi^+\pi^- )</td>
<td>GGSZ</td>
<td>[51]</td>
<td>New</td>
</tr>
<tr>
<td>( B^0 \to D_S^{+} K^{\pm} )</td>
<td>( D_S^{+} \to h^+h^-\pi^+ )</td>
<td>TD</td>
<td>[52]</td>
<td>As before</td>
</tr>
</tbody>
</table>

arXiv:1611.03076
\[ \gamma \text{ combination of results} \]

**Combination of analyses:**

- \( B^+ \to D K^+ \)
- \( B^0 \to D K^*^0 \)
  - PRD90 (2014) 112002, JHEP 08 (2016) 137
- \( B^0 \to D K \pi \)
  - PRD93 (2016) 112018
- \( B^+ \to D K^+ \pi \pi \)
  - PRD92 (2015) 112005,
- Time dependent \( B_s \to D_s K^+ \)
  - JHEP 11 (2014) 060

\[ \gamma = (72.2_{-7.3}^{+6.8}) \]
Rare (loop) decays

- Weak/Electromagnetic box diagrams $b \rightarrow s(d) \ell^+ \ell^-$
- Observation of $B^0 \rightarrow K^+K^-$
New physics can intervene in the loops/boxes
Can be probed through the analysis of the dynamics of the decays
Or testing, e.g., lepton universality $b \rightarrow s e^+e^-$ / $b \rightarrow s\mu^+\mu^-$
Dynamics for $B^0 \rightarrow K^{*0}\mu^+\mu^-$, $B_s \rightarrow \phi\mu^+\mu^-$

\[
\frac{1}{d\Gamma/dq^2} \frac{d^3\Gamma}{d\cos\theta_l d\cos\theta_K d\Phi} = \frac{9}{32\pi} \left[ \frac{3}{4} (1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right]
+ \frac{1}{4} (1 - F_L) \sin^2 \theta_K \cos 2\theta_l - F_L \cos^2 \theta_K \cos 2\theta_l
+ S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\Phi + S_4 \sin 2\theta_K \sin 2\theta_l \cos \Phi
+ A_5 \sin 2\theta_K \sin \theta_l \cos \Phi + A_6 \sin^2 \theta_K \cos \theta_l
+ S_7 \sin 2\theta_K \sin \theta_l \sin \Phi + A_8 \sin 2\theta_K \sin 2\theta_l \sin \Phi
+ A_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\Phi \right].
\]

$q^2 = \mu^+\mu^-$ invariant mass squared

Formula slightly different between $K^*$ (self-tagging) and $\phi$

$F_L$ : fraction of longitudinal polarization of $K^*/\phi$

$A_6 \sim A_{\text{FB}}$ = forward-backward asymmetry of the dimuon system

$A_5 = S_5$ in the case of $K^*$

They depend on $B \rightarrow K^*/\phi$ form factors and Wilson Coefficients of the OPE
B → X \( \mu^+\mu^- \) results

\[ B^0 \rightarrow K^{*0} \mu^+\mu^- \]

Differential branching fraction is 3.1\( \sigma \) below SM prediction in the lower \( q \) half, no discrepancy for the angular variables with this statistics.

\[ P'_5 = \frac{S_5}{\sqrt{F_L(1 - F_L)}} \]

Form-factor independent

3.7\( \sigma \) combined difference with SM

\[ B_s \rightarrow \phi \mu^+\mu^- \]
Observation of $B^0 \rightarrow K^+ K^-$

$B_s^0 \rightarrow K^+ K^-$ can proceed through a penguin

$B^0 \rightarrow K^+ K^- : \text{annihilation or } W \text{ exchange only}$

$$N(B^0 \rightarrow K^+ K^-) = 201 \pm 33 \pm 14$$

Significance : 5.8$\sigma$ including systematics

$$B(B^0 \rightarrow K^+ K^-) = (7.80 \pm 1.27 \pm 0.81 \pm 0.21) \times 10^{-8}$$
CP violation in baryon decays

CPV seen in B and K decays, never in baryons

Search for direct CPV in $\Lambda_b \to p\pi hh$ decays

Look at triple scalar products

$$C = \vec{p}_p \cdot (\vec{p}_{h^-} \times \vec{p}_{h^+})$$

$$\overline{C} = \vec{p}_\bar{p} \cdot (\vec{p}_{h_1^+} \times \vec{p}_{h_2^-})$$

$$A_T(C) = \frac{N(C > 0) - N(C < 0)}{N(C > 0) + N(C < 0)}$$

$$\overline{A_T(\overline{C})} = \frac{N(\overline{C} > 0) - N(\overline{C} < 0)}{N(\overline{C} > 0) + N(\overline{C} < 0)}$$

Observable measuring CPV:

$$a_{CP}^{T-odd} = \frac{1}{2} \left( A_T - \overline{A_T} \right)$$

arXiv:1609.05216 Submitted to Nature
$\Lambda_b \rightarrow p\pi\pi\pi$ signals and CP violation found for $\Lambda_b \rightarrow p\pi\pi\pi$

First evidence of CP violation in baryon decays

Overall 3.3σ CP violation found for $\Lambda_b \rightarrow p\pi\pi\pi$

No CP violation for $\Lambda_b \rightarrow p\pi KK$
Semileptonics

Theoretically well-understood in the SM
Decays to light leptons well-measured by B factories

a) Not as good for $\tau$ lepton
b) Good way to extract $V_{qb}$ CKM element

a) Any new (charged) intermediate boson/mediator would couples preferentially to $\tau$: LHCb studied $B^0 \rightarrow D^{*+} \tau \nu$ / $B^0 \rightarrow D^{*+} \mu \nu$

b) Use of $b \rightarrow u \mu \nu$ to improve $|V_{ub}|$ (relative uncertainty still $\sim 12\text{-}13\%$) + solve the tension between measurements from exclusive $B \rightarrow \pi \mu \nu$ and inclusive $B \rightarrow \chi_u \mu \nu$:

Use of $\Lambda_b \rightarrow p \mu \nu$ (LHCb-PAPER-2015-013, arXiv:1504.01568)
$B^0 \rightarrow D^{*+} \tau^- \nu_\tau$

Measure:

$$R(D^*) \equiv \frac{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)}$$

= 0.252 in SM (PRD 85094025 (2012)), with very good precision

Using $\tau$ decay:

$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$

Very specific topologies + use of missing mass, muon energy and momentum transfer $q$

Ongoing effort for $\tau$ hadronic final state

R(D*) result

\[ R(D^*) = 0.336 \pm 0.027 \pm 0.030 \]

Follows historical trend, above SM prediction by \( \sim 2.1\sigma \)

**Future results to test lepton universality**: \( R(J/\Psi) \) from \( B_c \), \( R(\Lambda_c) \) from \( \Lambda_b \), \( R(D_s^{(*)}) \) from \( B_s \)

Combined \( R(D) \) and \( R(D^*) \) gives \( 4\sigma \) discrepancy from SM
The flavour ($D^0$ or $\bar{D}^0$) is kinematically determined in the chain $D^{*-} \rightarrow D^0 \pi^+$ / $D^{*-} \rightarrow \bar{D}^0 \pi^-$

$$A_{CP}(D^0 \rightarrow K^- K^+) \equiv \frac{\Gamma(D^0 \rightarrow K^- K^+) - \Gamma(\bar{D}^0 \rightarrow K^- K^+)}{\Gamma(D^0 \rightarrow K^- K^+) + \Gamma(\bar{D}^0 \rightarrow K^- K^+)}$$

In practice, the production asymmetry $A_{CP}(D^0 \rightarrow K^- K^+) = A_{raw}(D^0 \rightarrow K^- K^+) - A_P(D^{*-}) - A_D(\pi^+_s)$ is measured using the raw asymmetries of the decays $D^0 \rightarrow K^+ \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$, and $D^+ \rightarrow \bar{K}^0 \pi^+$, which is known to be small and under control.

Fit to $\delta m \equiv m(h^+ h^- - h^+ \pi^+_s) - m(h^+ h^-)$ for $h = K, \pi$. 

Slow pion detection asymmetry.
Direct CPV measurement in $D^0 \rightarrow K^+K^-$

Combined LHCb value:

$A_{CP}(K^-K^+) = (0.14 \pm 0.15 \text{ (stat)} \pm 0.10 \text{ (syst)})\%$

Most precise single-experiment measurement

**No CP violation in the charm sector!**
Bc physics

- Unique hadron with two heavy quarks $Bc^+ = \bar{b}c$
- Decays through either charm or beauty quark
  - Decays could include lighter $B$ mesons!
- Spectroscopy not very well known
  - About 10 measurements (8 upper limits!)
  - Limitation due to the lack of knowledge of the production $pp(\rightarrow b) \rightarrow Bc$ cross-section: measure products of branching fractions and cross-section ratios
LHCb pioneering work in Bc physics

<table>
<thead>
<tr>
<th>Measured values of physical observables</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{Br(B_c \to J/\psi \pi^+ \pi^- \pi^+)}{Br(B_c \to J/\psi \pi^+)}$ = $2.41 \pm 0.30 \pm 0.33$</td>
<td>0.8 fb$^{-1}$</td>
</tr>
<tr>
<td>$R_{c/u} \equiv \frac{\sigma(B_c) Br(B_c \to J/\psi \pi^+)}{\sigma(B_u) Br(B_u \to J/\psi K^+)}$ = $0.68 \pm 0.02 %$</td>
<td>2 fb$^{-1}$</td>
</tr>
<tr>
<td>$\frac{Br(B_c \to \psi(2S) \pi^+)}{Br(B_c \to J/\psi \pi^+)}$ = $0.250 \pm 0.068 \pm 0.014$</td>
<td>1.0 fb$^{-1}$</td>
</tr>
<tr>
<td>$R_{D_s/\pi} \equiv \frac{Br(B_c \to J/\psi D_s^+)}{Br(B_c \to J/\psi \pi^+)}$ = $2.90 \pm 0.57 \pm 0.24$</td>
<td>3 fb$^{-1}$</td>
</tr>
<tr>
<td>$R_{D_s^<em>/D_s} \equiv \frac{Br(B_c \to J/\psi D_s^{</em>+})}{Br(B_c \to J/\psi D_s^+)}$ = $2.37 \pm 0.56 \pm 0.10$</td>
<td>3 fb$^{-1}$</td>
</tr>
<tr>
<td>$f_{\pm \pm} = \frac{Br_{\pm \pm}(B_c \to J/\psi D_s^{*+})}{Br(B_c \to J/\psi D_s^+)}$ = $(52 \pm 20)%$</td>
<td>3 fb$^{-1}$</td>
</tr>
<tr>
<td>$\frac{Br(B_c \to J/\psi K^+)}{Br(B_c \to J/\psi \pi^+)}$ = $0.079 \pm 0.007 \pm 0.003$</td>
<td>3 fb$^{-1}$</td>
</tr>
<tr>
<td>$\frac{\sigma(B_c)}{\sigma(B_s)} \times Br(B_c \to B_s \pi^+) = 2.37^{+0.37}_{-0.35} \cdot 10^{-3}$</td>
<td>3 fb$^{-1}$</td>
</tr>
<tr>
<td>$\frac{Br(B_c \to J/\psi K^+ K^- \pi^+)}{Br(B_c \to J/\psi \pi^+)} = 0.53 \pm 0.10 \pm 0.05$</td>
<td>3 fb$^{-1}$</td>
</tr>
</tbody>
</table>

And many ongoing results and studies...
Search for Bc annihilation in the KKπ final state – Run I data only

Other processes in the phase space:

Spectrum analysed in bins of Decision Tree classifier
Normalizing channel:

Measured observable:

\[ R_f \equiv \frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to f) \]
Fit Regions definition

5.2 < mKπ, mKK < 5.5 GeV: B inclusive
1.834 < mKπ < 1.894 GeV: D0 band
Excluding these two: non-B and non-D region
Annihilation mKπ < 1.834 GeV
Bs→KK region defined as 5.3 < mKK < 5.4 GeV

χc₀→KK region

n.b: For annihilation and D0, veto B (and χc₀) band(s),
efficiency accounts for this.
Signal in annihilation region

Simultaneous fit to bins of Decision Tree Classifier

\[ \sim 21 \pm 10 \text{ signal events} \]

With a global significance of 2.4\( \sigma \)

Hint of annihilation signal?

Adding Run II data will help to confirm

\[ R_{an, KK\pi} = (8.0^{+4.4}_{-3.8}\text{ (stat) } \pm 0.6\text{ (syst)}) \times 10^{-8} \]

Compare to SM-based conservative range:

\[ \sim [0.1, 1.7] \times 10^{-8} \]
Observation of $B_c \to \chi_{c0}(\to KK)\pi$

$R_{\chi_{c0}\pi} = (9.8^{+3.4}_{-3.0}\text{(stat)} \pm 0.8\text{(syst)}) \times 10^{-6}$

Similar to $(7.0\pm0.3)\times10^{-6}$ for $J/\Psi\pi$

- 21±6 signal events
  - With a global significance of 4σ
  - Strong evidence
Forward physics

hadron PID
muon system
lumi counters
HCAL
ECAL
tracking

ALICE

ATLAS

CMS+TOTEM

LHCb

HeRSChel
HeRSChel

η
Forward physics, resolving $W+b\bar{b}$, $W+cc$, $t\bar{t}$

$LHCb$-PAPER-2016-038
arXiv:1610.08142, submitted to PLB

Analysis done for 4 samples $W^{\pm}(\mu/e \nu) + j1 \ j2$
Main background : $Z(\mu\mu/ee) + \ j1 \ j2$
Results on $W+bb$, $W+cc$, $tt$

<table>
<thead>
<tr>
<th>Signal</th>
<th>$K$</th>
<th>$\mu$ sample yields</th>
<th>$e$ sample yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W^+ + bb$</td>
<td>$1.49^{+0.23}_{-0.22}$</td>
<td>$45.5^{+6.9}_{-6.4}$</td>
<td>$20.5^{+3.1}_{-2.9}$</td>
</tr>
<tr>
<td>$W^- + bb$</td>
<td>$1.67^{+0.33}_{-0.30}$</td>
<td>$28.7^{+5.6}_{-4.9}$</td>
<td>$12.1^{+2.3}_{-2.1}$</td>
</tr>
<tr>
<td>$W^+ + cc$</td>
<td>$1.92^{+0.68}_{-0.58}$</td>
<td>$12.8^{+4.5}_{-3.9}$</td>
<td>$5.7^{+2.0}_{-1.7}$</td>
</tr>
<tr>
<td>$W^- + cc$</td>
<td>$1.58^{+0.87}_{-0.73}$</td>
<td>$5.7^{+3.1}_{-2.6}$</td>
<td>$2.5^{+1.4}_{-1.2}$</td>
</tr>
<tr>
<td>$tt$</td>
<td>$1.17^{+0.35}_{-0.31}$</td>
<td>$8.7^{+2.6}_{-2.3}$  ($\mu^+$)</td>
<td>$3.7^{+1.1}_{-1.0}$ ($e^+$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8.3^{+2.5}_{-2.2}$  ($\mu^-$)</td>
<td>$4.0^{+1.2}_{-1.1}$ ($e^-$)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Expected [pb]</th>
<th>Observed [pb]</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W^+ + bb$</td>
<td>$0.081^{+0.022}_{-0.013}$  $+0.040$</td>
<td>$0.121^{+0.019}_{-0.018}$  $+0.029$</td>
<td>$7.1\sigma$</td>
</tr>
<tr>
<td>$W^- + bb$</td>
<td>$0.056^{+0.014}_{-0.010}$  $+0.018$</td>
<td>$0.093^{+0.018}_{-0.017}$  $+0.023$</td>
<td>$5.6\sigma$</td>
</tr>
<tr>
<td>$W^+ + cc$</td>
<td>$0.123^{+0.034}_{-0.020}$  $+0.060$</td>
<td>$0.24^{+0.08}_{-0.07}$  $+0.08$</td>
<td>$4.7\sigma$</td>
</tr>
<tr>
<td>$W^- + cc$</td>
<td>$0.084^{+0.021}_{-0.015}$  $+0.027$</td>
<td>$0.133^{+0.073}_{-0.062}$  $+0.050$</td>
<td>$2.5\sigma$</td>
</tr>
<tr>
<td>$tt$</td>
<td>$0.045^{+0.008}_{-0.007}$  $+0.012$</td>
<td>$0.05^{+0.02}_{-0.01}$  $+0.02$</td>
<td>$4.9\sigma$</td>
</tr>
</tbody>
</table>

Still compatible with NLO SM-based predictions
Upgrade

- Planned during LS2 (2019-2020)
  - Prepare for acquisition of 50 fb⁻¹
- Detectors:
  - full upgrade of the tracking system
  - new RICH (Particle ID) detectors
  - Calorimeters and muon system: new electronics, more shielding, etc...
- Triggering: full software trigger
  - This removes the limitation of the L0 Hardware trigger (1 MHz)
Summary

- A big variety of results
  - A lot of recent results not shown: e.g., $B_s \rightarrow \phi \gamma$ polarisation ($\text{arXiv:1609.02032}$), $\Sigma \rightarrow p\mu\mu$ (LHCb-CONF-2016-013), etc...
  - Pushing the SM further in the corners and hunt for intervention of NP: e.g., persisting discrepancies in some observables of rare decays
  - Forward physics and Heavy Ion physics programs progressing as well
- Run II data taking is going on efficiently, 2 $\text{fb}^{-1}$ of data already recorded with $\sigma(b\bar{b})(13 \text{ TeV}) > 2 \times \sigma(b\bar{b})(7-8 \text{ TeV})$
  - A lot of news should come with the analysis of the full Run I + 2015 + 2016 sample
- Preparation for upgrade is well advanced and most of the R&D phases are now achieved