Overview

1. Operations so far in 2018
2. Physics results
3. Upgrade progress
Operations so far in 2018

- Excellent start to data-taking this year
- Recorded nearly 0.5 fb$^{-1}$ so far
- Data-taking efficiency at 90%
- Very similar running plan as in 2017
  - Try to record equal luminosity with both magnet polarities
- Hope for 2.5 fb$^{-1}$ delivered this year
- Successful commissioning during the intensity ramp
- Collected a large NoBias sample intended for charm physics programme
Real-time alignment and calibration

- Run real-time alignment and calibration of the detector
- Data buffered out of first software trigger stage
- Second software trigger runs asynchronously
- Permits Turbo real-time analysis strategy
Run real-time alignment and calibration of the detector
Data buffered out of first software trigger stage
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Permits Turbo real-time analysis strategy
Offline operations

- Offline resource usage dominated by Monte Carlo
  - Continuing to push ‘lossless’ fast simulation: e.g. ReDecay
- Utilised the trigger farm during winter shut-down
- Prompt offline reconstruction now in full swing
LHCb physics papers

- 428 papers in total
  - 12 published in 2018 so far
  - 19 papers currently with the Editorial Board
  - About 35 papers under review
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CP violation in $B^0 \rightarrow D^{\mp} \pi^{\pm}$ decays

- Interference between oscillation and decay brings sensitivity to CKM angles $\beta$ and $\gamma$

$$\Gamma_{B^0 \rightarrow f}(t) \propto e^{-\Gamma t}[1 + C_f \cos(\Delta mt) - S_f \sin(\Delta mt)]$$

$$S_f = \pm \frac{2r_{D\pi} \sin[\delta \mp (2\beta + \gamma)]}{1 + r_{D\pi}^2}$$

- Split by companion hadron PID to maximise statistical sensitivity
• Intereference between oscillation and decay brings sensitivity to CKM angles $\beta$ and $\gamma$

\[
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\]

\[
S_f = \mp \frac{2 r_{D\pi} \sin[\delta \mp (2\beta + \gamma)]}{1 + r_{D\pi}^2}
\]

• Measure $B^0 - \bar{B}^0$ asymmetry for each $D^\mp \pi^\pm$ final state

\[
S_f = 0.058 \pm 0.020 \pm 0.011 \quad S_{\bar{f}} = 0.038 \pm 0.020 \pm 0.007
\]

\[
\gamma \in [5, 86] \cup [185, 266] \degree \ @ 68\% \ CL
\]
CKM angle $\gamma$ with $B^\pm \rightarrow DK^\pm$, $D \rightarrow K^0_S h^- h^+$ decays

- Same $B^\pm \rightarrow (D \rightarrow K^0_S h^- h^+)K^\pm$ final state accessible with $D^0$ and $\bar{D}^0$
  - Sensitive to $\gamma$ through interference of $b \rightarrow \bar{c}u\bar{s}$ and $b \rightarrow \bar{u}c\bar{s}$ transitions (GGSZ)
    \[
x_\pm \equiv r_B \cos(\delta_B \pm \gamma) \quad y_\pm \equiv r_B \sin(\delta_B \pm \gamma)
    \]
- Model-independent approach
  - Measuring yields between opposite strong phase bins in $K^0_S h^- h^+$ Dalitz plot
- Use 2 fb$^{-1}$ of data collected in 2015–2016
- Reconstruct $K^0_S \pi^- \pi^+$ and $K^0_S K^- K^+$, with $K^0_S \rightarrow \pi^- \pi^+$ decays
- Experimental effects controlled with $B \rightarrow D \mu X$ and $B \rightarrow D \pi$ samples
CKM angle $\gamma$ with $B^{\pm} \rightarrow DK^{\pm}$, $D \rightarrow K^0_S h^- h^+$ decays

- Measure around 4000 $K^0_S \pi^- \pi^+$ and 500 $K^0_S K^- K^+$ signal candidates

- Most precise single measurement of $\gamma$ to date

$$\gamma = (80^{+10}_{-9})^\circ$$
Updated LHCb average of $\gamma$

- Combine LHCb measurements sensitive to $\gamma$
  - 14 time-integrated, 2 time-dependent
  - Seven new or updated inputs since last combination

![Diagram showing confidence level for $\gamma$]

- Measured to $\sim 20^\circ$ precision in 2010\(^1\); huge progress with LHCb data

\(^{1}\text{PoS (ICHEP 2010) 269}\)
CP violation in $B^0_{(s)} \rightarrow h^+ h^-$ decays

- Analysis of $\pi^+ \pi^-$ and $K^+ K^-$ motivated similarly to $B^0 \rightarrow D^{\pm} \pi^{\mp}$
  - Sensitive to direct CPV in decay, $C_f$, in addition
- Measure time-integrated asymmetries $A^{B}_{CP}$ with $K^+ \pi^-$ and $K^- \pi^+$ final states
  - Detector-induced asymmetries controlled using charm control samples

\[
C_{\pi^+ \pi^-} = -0.34 \pm 0.06 \pm 0.01 \\
S_{\pi^+ \pi^-} = -0.63 \pm 0.05 \pm 0.01 \\
C_{K^+ K^-} = 0.20 \pm 0.06 \pm 0.02 \\
S_{K^+ K^-} = 0.18 \pm 0.06 \pm 0.02 \\
A^{\Delta \Gamma}_{K^+ K^-} = -0.79 \pm 0.07 \pm 0.10 \\
A^{B^0}_{CP} = -0.084 \pm 0.004 \pm 0.003 \\
A^{B^0_s}_{CP} = 0.213 \pm 0.015 \pm 0.007
\]

- Measure 4.0 $\sigma$ deviation of $(C_{K^+ K^-}, S_{K^+ K^-}, A^{\Delta \Gamma}_{K^+ K^-})$ from $(0, 0, -1)$ no-CPV expectation; strongest evidence to date
Asymmetries in $D^0 \to h^+ h^- \mu^+ \mu^-$ decays

- Rare charm decays very sensitive to BSM contributions
  - Unique laboratory to probe FCNCs in the up-type quark sector
- Decays $D^0 \to h^+ h^- \mu^+ \mu^-$ allows for rich variation of CPV across 5D phase space
  - Branching fractions around $10^{-8}$, first observed at LHCb

- All measured asymmetries consistent with zero, flat in $m(\mu^+ \mu^-)$
Evidence for the decay $B_s^0 \rightarrow \bar{K}^*0 \mu^+ \mu^-$

- Intriguing deviations from SM seen in $b \rightarrow s \ell \ell$ decays, e.g. $\bar{B}^0 \rightarrow \bar{K}^*0 \mu^+ \mu^-$
- Can investigate similar dynamics in $b \rightarrow d$ transitions
- Decay $B_s^0 \rightarrow \bar{K}^*0 \mu^+ \mu^-$ highly suppressed in the SM, $\sim 10^{-8}$, so sensitive to NP, but not yet observed
- Search with 4.6 fb$^{-1}$ of data outside $J/\psi$ and $\psi(2S)$ regions
Evidence for the decay $B^0_s \rightarrow \bar{K}^{*0} \mu^+ \mu^-$

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- Search with $4.6 \text{fb}^{-1}$ of data outside $J/\psi$ and $\psi(2S)$ regions

- Excess with $3.4 \sigma$ significance, detailed studies possible with the LHCb upgrade

$$\mathcal{B}(B^0_s \rightarrow \bar{K}^{*0} \mu^+ \mu^-) = [2.9 \pm 1.0 \text{ (stat)} \pm 0.2 \text{ (syst)} \pm 0.3 \text{(norm)}] \times 10^{-8}$$
Observation of a new $\Xi_b^-$ resonance

- LHCb an excellent laboratory for heavy quark spectroscopy
- Some ground state and many excited charm and beauty states still to discover
- Search for excited $\Xi_b^-$ states decaying to $\Lambda_b^0 K^-$ or $\Xi_b^0 \pi^-$

• Observe new state: $\Xi_b(6227)^-$
Observation of a new $\Xi_b^-$ resonance

LHCb-PAPER-2018-013

- Measure relative production rates with $\Lambda_b^0 \to \Lambda_c^+ \mu^- X$ and $\Xi_b^0 \to \Xi_c^+ \mu^- X$ samples
- Measure mass and width with $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ samples

$$m_{\Xi_b(6227)^-} = 6226.9 \pm 2.0 \pm 0.3 \pm 0.2 \text{ MeV}/c^2$$

$$\Gamma_{\Xi_b(6227)^-} = 18.1 \pm 5.4 \pm 1.8 \text{ MeV}/c^2$$
• LHCb discovered the $\Xi_{cc}^{++}$ (ccu) in $\Lambda_c^+ K^- \pi^+ \pi^+$ spectrum in 2017\(^2\)
• Consistent with a weakly decaying object, but lifetime left for later study
• Revisit 1.6 fb\(^{-1}\) data sample, using $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$ control mode

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\[
\tau(\Xi_{cc}^+) = (256^{+24}_{-22} \pm 14) \text{ fs}
\]

Search for a dimuon resonance in the $\Upsilon$ mass region

- New elementary scalar objects predicted by several SM extensions
- LHCb’s excellent mass resolution allows for searches at very low masses
- Fit $\mu^+\mu^-$ spectrum, scanning a signal model in steps
- Background model validated against Drell-Yan simulation and same-sign dimuon data
- Exclude $m(\phi)$ hypotheses where fitted yield has $\geq 20\%$ correlation with $\Upsilon(nS)$ yields

![Graph showing dimuon spectrum with $m(\mu^+\mu^-)$ in GeV on the x-axis and candidates in $18.6$ MeV on the y-axis.](graph1.png)

![Graph showing cross-section $\sigma(gg \to \phi) \times B(\phi \to \mu\mu)$ in pb on the y-axis and $m(\phi)$ in GeV on the x-axis.](graph2.png)

$\sqrt{s} = 8$ TeV
Search for tetraquarks in the $\Upsilon(\mu^+\mu^-)$ spectrum

- Many of heavy flavour exotic states now known, but none with $> 2$ heavy quarks
- Search for $b\bar{b}b\bar{b}$ decaying to $\Upsilon(nS)\mu^+\mu^-$ in $\sqrt{s} = 7, 8, \text{ and } 13 \text{ TeV}$ datasets
  - Predictions $\in 18.5-19 \text{ GeV}/c^2$
  - Search $\in 17.5-20 \text{ GeV}/c^2$

- No significant signal observed
- Limits on $\sigma \times B$ set as a function of $m(X_{b\bar{b}b\bar{b}})$
- Largest deviation, $2.5 \sigma$, seen at $19.35 \text{ GeV}/c^2$
  - Above the $\eta_b\eta_b$ and $\Upsilon(1S)\Upsilon(1S)$ thresholds
Central exclusive production of charmonium at 13 TeV

- CEP of charmonia at LHCb can constrain gluon PDF down to $x \approx 2 \times 10^{-6}$
  - Probes coupling of a di-gluon pomeron and a photon, leaving incoming protons intact
- Can now use HERSChEL subdetector to veto objects at very high rapidities$^3$
  - Reduce backgrounds from proton disassociation by half

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$^3$JINST 13 (2018) no.04, P04017 (LHCb-DP-2016-003)
• Reconstruct muon pairs
• Veto busy events with HERSCHEL information
• Measure $J/\psi$ and $\psi(2S)$ cross-sections

\[
\begin{align*}
\sigma(pp \rightarrow pJ/\psi p) &= 99 \pm 16 \pm 10 \pm 16 \text{ pb} \\
\sigma(pp \rightarrow p\psi(2S)p) &= 10.2 \pm 1.0 \pm 0.3 \pm 0.4 \text{ pb}
\end{align*}
\]
LHCb can act as a fixed-target experiment with SMOG gas injection system
Charm production measurements constrain proton charm quark PDF at high \( x \)
No significant sign of intrinsic charm
Rich programme ahead; can reach \( \sqrt{s_{NN}} = 69 \text{ GeV} \)
Upgrade

- Comprehensive LHCb Upgrade to be ready for Run 3
  - Instantaneous luminosity increase by factor five
  - Full-detector read-out at 40 MHz
Lots of progress

- **VELO** prototype modules being assembled and characterised, sensor wafers delivered and being tested
- **UT** sensor production well underway, some delays from readout chip, construction of bare staves in full swing, flex cables tested, slice tests of the full readout chain ongoing
- Upgrade **RICH** detector module installed at the pit and taking data
- **SciFi** mat production now complete, studies perform to determine fibre ageing
- **CALO/MUON** boards in production or tendering
- Now ordered all PCIe40 **DAQ** boards
- **Installation** workshop held for LS2
Trigger and computing

• Ongoing monumental effort to have full software trigger at 40 MHz
• “Upgrade Software and Computing” TDR now released (LHCb-TDR-017)
• Working on computing model with a document due 2018 Q3 (LHCb-TDR-018)
Summary

- The detector and online are performing beautifully in 2018
- Continue to make many world’s-first and -best measurement
- Upgrade preparation for 2021 now a main focus for the collaboration