Status of the LHCb experiment

CERN-RRB-2015-040

29 April 2015

1 Introduction

The last two years of Long Shutdown (LS1) have been occupied with intense activity to prepare the sub-detectors and infrastructure for Run 2. This work has been successfully completed on schedule and LHCb is now ready for first collisions at 13 TeV. Indeed first data with tracks were already collected during the LHC injection test at the end of 2014, and again in March 2015, where the protons of beam-2 were dumped on an absorber at the end of the injection line (so-called 'TED shots'), allowing LHCb to detect the secondary particles produced. A summary of the LS1 activities and the status of the sub-detectors is presented in Sect. 2.

Significant improvements to the running strategy are being finalised. Most important of these is the move to a 'split HLT', where the second stage of the High Level Trigger is deferred and only run after a 'physics quality' alignment and calibration has been performed on the data. This approach will allow for more discriminating selections to be applied, and ensure that the recorded data are more closely aligned with the requirements of the offline analysis. The preparations for Run 2 operations are summarised in Sect. 3.

Throughout 2014 the LHCb collaboration has continued to analyse at an undiminished rate the data collected in Run 1. Over 250 papers have been submitted to journals. Many recent results have attracted attention, such as the angular analysis of the $B^0 \to K^* \mu^+ \mu^-$ decay with the full Run 1 data set, the first measurement of the CKM matrix element V_{ub} with $\Lambda_b^0 \to p \mu \nu$ decays, and the determination of the mixing phase in B^0 and B_s^0 decays. These results are discussed in Sect. 4.

Finally, significant efforts have been invested into preparations for the LHCb Upgrade, scheduled to be installed in Long Shutdown 2. This work is described in a separate document [1].

2 Detector sub-systems

The maintenance and consolidation work on all sub-systems and services is complete, the experimental cavern is closed and all sub-detectors are ready for Run 2.

The beam pipe has been successfully re-installed, with a new third section and much lighter support structures for sections two and three. The closing of the sub-detectors and a final survey of most of the sub-systems followed. Just before the sector test in early March, the beam pipe was brought under vacuum. First data with tracks were successfully collected during the TED shots in November 2014 and March 2015, and have been exploited for calibration and alignment studies. After upgrading the magnet safety system, the LHCb dipole was ramped-up successfully for test purposes. This was followed by a test of the RICH1 magnetic distortion calibration system. A position monitoring system for the Inner Tracker has been installed and operated successfully.

2.1 Beam pipe

The beam pipe re-installation was completed by mid-November 2014, and is shown in Fig. 1. A final verification of the vacuum tightness of the whole beam pipe was carried out after the re-installed parts were baked-out and reconnected to the UX85/1 section that was left in place during LS1. The beam pipe was put under vacuum at the end of November after all sub-detectors had been closed. At the end of January it was filled with neon at atmospheric pressure to allow for final maintenance-related interventions in certain areas of the detector. It has been under vacuum since mid-February.

The tension of the new beryllium/carbon-fibre support system located in the magnet is monitored and read-out via the PVSS control framework. The data are regularly checked by the CERN TE-VSC group. Variations of the tension during pump-down and neon injection were observed, in agreement with expectation. Variations on the tension were also observed during the switching on and off of the dipole current.

2.2 Vertex Locator (VELO)

Extensive maintenance activities and many hardware upgrades were successfully performed during LS1. The low voltage was refurbished and a new model of

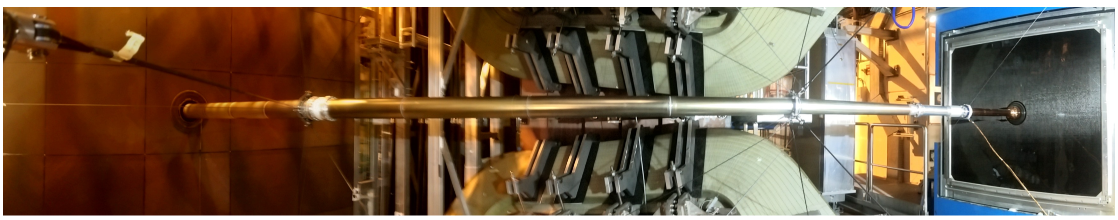

Figure 1: Photograph of the reinstalled beam pipe in the region between RICH 1 (right) and RICH 2 (left), passing through the dipole. The new support structure is visible.

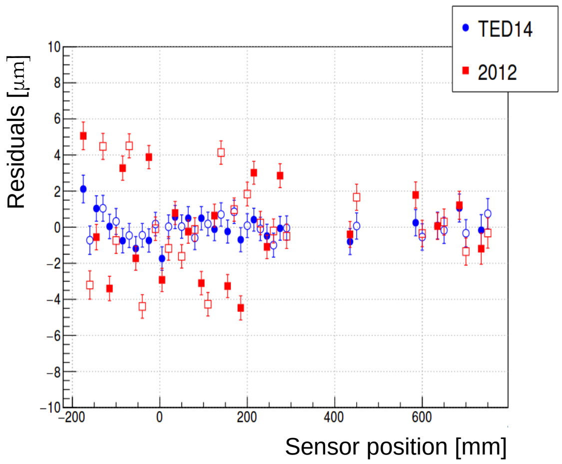

Figure 2: Alignment residuals in the VELO determined with a Run 1 file from 2012 (red squares) and with TED data from 2014 (blue circles), plotted against sensor position b along the beam direction. Observe the improvement with the more recent data.

bulk power supplies was installed to improve reliability and reduce the risk of high currents at the connectors. The improved low voltage system is now fully operational. A stock of fully tested spare TELL1 DAQ boards has been built up. The last scheduled maintenance to the chillers of the cooling system is scheduled for early April. The VELO-specific WinCC control software has been re-written, mostly to simplify and improve the recovery procedure after unexpected losses of power. The new SPECS control interface has been successfully commissioned. A new system to send text messages from the VELO WinCC alert system to the expert on-call has been deployed. A new offline monitoring framework that allows for automated data quality control has been released and is currently under test. A new procedure to address the non-uniform radiation damage in the VELO sensors by applying different bias voltages to each sensor has been developed and will be tested once new data from charge-collection efficiency scans are available. During the TED runs in November 2014 and March 2015 the entire VELO system was successfully exercised and several thousand tracks were recorded. This data sample has been analysed to obtain a promising preliminary internal alignment of the VELO sensors, as seen in Fig. 2.

2.3 Silicon Tracker (ST)

The Silicon Tracker, consisting of the TT and IT systems, was successfully operated periodically in LS1, during so-called 'commissioning weeks', and was also powered for short calibration tests. At all other times, the detector was left in a safe state with no power on the front-ends and no high voltage applied to the sensors. The sensors were cooled throughout the full shutdown period. The fraction of working channels is currently 99.64% and 99.26% for the TT and the IT, respectively. Several interventions were made to improve the operation of the detector for Run 2. The cooling system was upgraded and has been running without problems since March 2014. Scheduled maintenance work was performed on the low and high voltage systems. The control system code has been completely redesigned to improve the maintainability and to optimise the time needed to configure the complete system. The new code was tested thoroughly during the operation periods. Finally, a new SPECS control interface was installed and tested successfully in March.

A new alignment system, based on the Brandeis CCD Angle Monitor (BCAM) apparatus developed for the ATLAS muon detectors, has been installed to provide real-time monitoring of the movement of the IT stations. Two BCAMs are needed for each station and passive reflective targets are installed on each half station. The system was calibrated during the closure of the detectors and first measurements were made during the LHCb magnet test in March. Relative movements in the z-direction of up to 1 cm were seen, where the accuracy of the measurement is better than 1 mm. These movements are compatible with expectations. The positioning and the alignment of the IT stations were improved after the installation of the new beam-pipe. The relative position of the two halves was measured and small modifications were made to the stoppers that define the closed positions of the stations.

The detectors were closed in November and data were collected during the TED shots that month. The secondary particles produced were used to make an initial alignment of the detectors. In 2015, the first collision data will be used to check the time alignment of the detector with respect to the beam and a run will be dedicated to making a charge-collection efficiency scan. The depletion voltage of the sensors can be determined using the data from this scan and then compared to the expectation from simulation to check the effects of radiation damage. The leakage current of the sensors has also been measured and agrees well with the predictions.

2.4 Outer Tracker (OT)

During the last six months of LS1 several hardware interventions were performed on the Outer Tracker. In January 2015 a fraction of the OT modules was scanned with a ^{90}Sr source to provide a reference measurement for the forthcoming run. Data collected from source radiation were also taken to verify that the response of the OT had not degraded during LS1.

Throughout the commissioning activities of 2015 the HV supply has been operating stably. In February a water leak in the cooling circuit of the front-end electronics was discovered, which was easily reachable and fixed. The mass flow controllers were replaced in March in order to improve the stability of the gas mixture during Run 2. The finite accuracy of these controllers means that the gas mixture has changed slightly compared to before. Gain measurements will be used to adjust the composition until the detector has the same response as in Run 1.

In addition, considerable effort was devoted to performing the time-alignment (also known as 't_0-calibration') within the online software framework. This improved time-alignment will lead to a corresponding improvement in the tracking performance within the trigger.

2.5 RICH system

The consolidation of the RICH system during LS1 was completed successfully and both RICH detectors are now ready for data taking. A total of 82 new HPDs were installed and all HPDs in RICH1 with a high probability to fail before 2018 were replaced. Some RICH1 HPDs that are still in good working order but may require replacement before 2018 were moved to RICH2, where future interventions are much easier. The HPD readout electronics were tuned for running at high L0 trigger rate, which should improve the number of detected photons per track by a few percent. The hardware required for the SPECS protocol, which is needed to configure the HPD readout electronics, has been upgraded. The software servers for the new hardware had to be ported from Windows to Linux and this was completed successfully. New UKL1 boards, which will increase the available bandwidth of RICH data to the HLT farm, will be produced. A prototype board has been made and tested and the production of more boards will start soon. The system used to calibrate the corrections (MDCS) for the presence of the magnetic field was refurbished in view of new calibration runs in 2015.

On the software front, automatic calibration procedures for the RICH refractive index and HPD alignment have been developed and these will be used within the split-HLT framework. The procedure for the extraction of the corrections for the magnetic field distortions has been modified, resulting in a noticeable improvement of the Cherenkov resolution in RICH 1. New MDCS scans were taken when the LHCb magnet was tested, ready for the start of data taking.

2.6 Calorimeters (SPD, PS, ECAL and HCAL)

All maintenance activities scheduled for the shutdown are complete. Several of the interventions were major in scope, for example the replacement of 30 km of plastic monitoring fibres in the ECAL by more radiation-hard quartz fibres, as shown in Fig. 3. After the closure of the full calorimeter system in November, one side of the ECAL had to be briefly reopened in January to fix a dead Cockcroft-Walton PMT-base. During this intervention the opportunity was also taken to modify the magnetic shielding for 66 new PMTs in the HCAL. This modification was performed in order to reproduce the configuration in the ECAL, whose PMTs exhibited better stability and lower dark current during Run 1.

Figure 3: Replacement of the monitoring fibres in the ECAL.

The focus of attention is now the detector calibration. Scans with Cs source have been performed to calibrate the HCAL. A new automated calibration procedure is under preparation, which follows the detector ageing fill by fill. Some steps of this procedure were already validated during the LHCb commissioning weeks by re-running old data on the Full Experiment System Test (FEST), as well as using new data collected with the TED shots. The full implementation will be ready before the LHC start-up.

In summary, the calorimeters are ready to take data with all channels fully functional, as demonstrated during cosmic data-taking and the TED runs.

2.7 Muon system

The final maintenance interventions on the muon system were completed at the beginning of 2015 and the detector was closed in February, then surveyed and adjusted to its nominal position in March. Over the last few months the system has been fully recommissioned. For example, the noise level of the front-end channels has been measured in order to define the operating thresholds to be used in Run 2, and test-pulse runs have been executed to check the consistency between data acquired by the muon system and the L0-muon trigger.

Regular data taking of cosmic events is now underway. These data will allow the verification and a preliminary adjustment of the muon-system timing. The muon group is also defining the goals of the special data taking runs that will be performed in the coming months, using beam-gas interactions enhanced by the LHCb gas injection system (SMOG), as well as events from first beam-beam collisions. The events collected during these runs will be exploited for spatial and precise timing alignment.

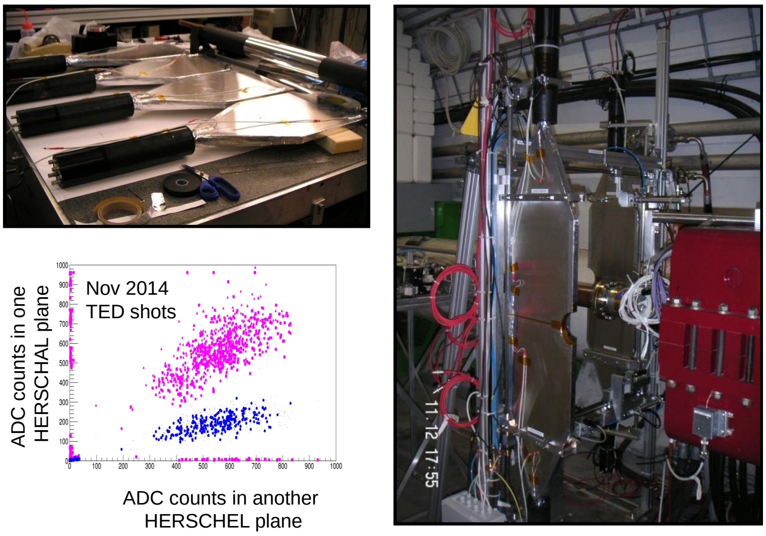

Figure 4: HERSCHEL florward-shower counters. Top left: light-guides and PMT assemblies in lab. Right: one station, in open 'garage position' in tunnel. Bottom left: beam data from November TED shots, showing correlated behaviour between three planes.

2.8 Forward shower counters

During the latter part of 2014 several planes of plastic scintillator, read-out by high-current compliant PMTs were installed in five locations in the tunnel, either side of LHCb. This very modest system, named HERSCHEL, will enhance LHCb's capabilities in diffractive physics, by enabling the experiment to detect events with large rapidity gaps in which one or both interacting protons dissociates and gives rise to light in the shower counters. HERSCHEL successfully took data during the TED shots in November 2014. See Fig. 4 for some representative photographs and plots.

2.9 Online system

The new SPECS hardware is being installed, and is now present for almost all sub-systems. The upgrade of the farm is progressing well. The servers, totalling 200 boxes, have arrived and 1600 additional disks have been mounted in the trays. The servers are being installed in the barracks and will be cabled up over the next few weeks.

The commissioning of the online system is progressing well. The operational details of the split HLT and of the online alignment and calibrations will be finalised over the coming two months.

3 Operations

Operational activities are currently focused on preparing the 'split HLT', the online data quality procedures and the subsequent offline data processing for first physics collisions in 2015. In this new trigger approach the data passing HLT1, the first stage of the software trigger, will be temporarily saved to disc. The alignment and calibration of these data will be assessed, and if necessary new constants determined. Then HLT2, the second stage of the software trigger, will be deployed.

3.1 Trigger

Since the last RRB, the trigger configuration that will be used in 2015 has become better defined. In particular, a preliminary L0 bandwidth division has been agreed with the physics working groups, which will be reoptimised once the first 13 TeV data become available. An L0 bandwidth division to be used in the so-called 'early measurement' period for cross-section measurements has also been agreed and implemented, and the saturation thresholds of the calorimeter and muon readouts have been raised from 5 to 6 GeV, in case the p_{T} spectrum at 13 TeV centre-of-mass energy is significantly harder than simulation suggests.

On the HLT side, it has been demonstrated that the full offline charged track and RICH reconstructions can be executed in HLT2, and all trigger lines are being rewritten in order to take advantage of this new functionality. The major inclusive triggers for charm and b-physics have already been fully reoptimised, gaining upwards of 20% in efficiency depending on the charm signal mode being considered, with significant gains for b-physics modes as well. For some hard-to-trigger modes involving kaons, the use of particle identification allows the overall trigger efficiency to be more than doubled for the same output rate in simulation, although the real gains will of course only be clear once real collision data arrive. Lifetime-unbiased triggers for certain key hadronic charm and b-physics modes have also been shown to be viable and implemented, and the inclusive lepton triggers have also been reoptimised.

Development of the new HLT 'turbo stream' is also well advanced. This stream contains selected events from HLT2 lines where the subsequent offline reconstruction is unnecessary and rapid analysis based on only the HLT2 reconstructed candidate decays is foreseen. This line will be first tested by the cross-section analyses planned with data taken during the first 25 ns LHC runs.

3.2 Detector calibration

The calibration and alignment of the detector between HLT1 and HLT2 has been implemented and commissioned offline, and will face its first online test during the beam-gas data-taking with the SMOG gas injection system at the end of April. This data-taking will also be used to commission the full HLT data-flow, leaving

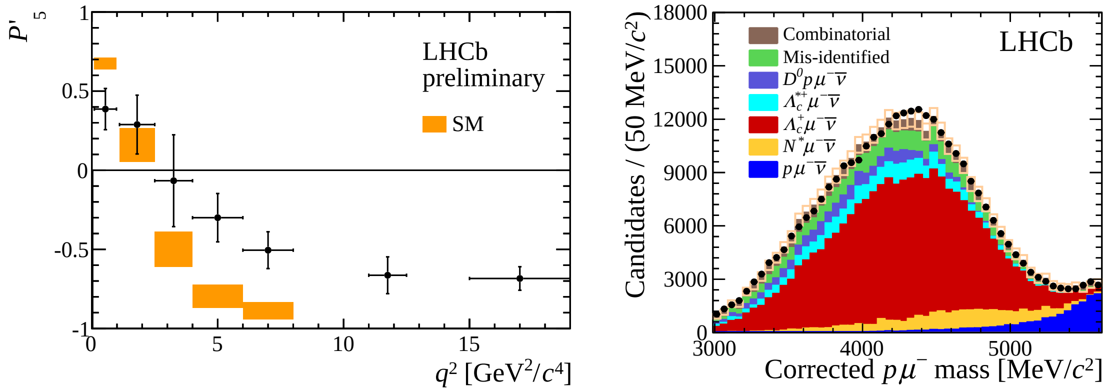

Figure 5: (left) P_5' asymmetry versus q^2 in $B^0 \to K^*\mu^+\mu^-$. Figure from Ref. [5]. (right) Corrected $p\mu$ mass used to observed the decay $\Lambda_b^0 \to p\mu^-\overline{\nu}$. Figure from Ref. [7].

a month to debug any problems before the collision data-taking starts at the end of May.

Work is also well underway to commission the detailed monitoring of the automatic calibrations and alignment procedures, essential in order to maintain high quality data.

3.3 Computing

The computing usage in 2014 [2, 3] and the resources estimates for 2016 and beyond [4] are discussed in detail in separate documents.

4 Physics results

During the period between October 2014 and April 2015 LHCb has produced many high-profile publications and preliminary results. At the time of writing LHCb has submitted 251 papers to journals.

The most recent highlight is the 3 fb^{-1} update of the angular analysis of the electroweak penguin decay $B^0 \to K^*\mu^+\mu^-$, presented at the Moriond EW conference in March [5]. The flavour-physics community was anxiously awaiting the new result, and speculating whether it would confirm the deviation from the Standard Model (SM) expectation seen with 2011 data in an angular distribution named P_5' [6]. This observable is in principle robust against form-factor uncertainties and therefore a good place to look for the effects of New Physics. The new measurement shown in Fig. 5 (left) confirms the deviation seen in the region $4 < q^2 < 8$ GeV/c^2, where q^2 is the dimuon mass squared. The deviation is at the level of 3.7σ when computed with respect to predictions using the latest form-factor calculations. This exciting result is being digested by theorists, who must decide whether the

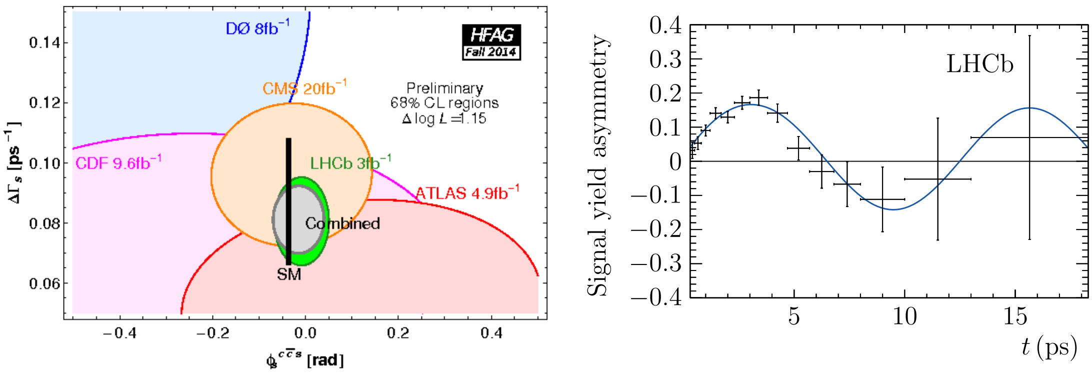

Figure 6: (left) Constraints on the mixing angle $\phi_s^{c\bar{c}s}$ and the decay width difference in the B_s^0 system from various experiments. Figure courtesy of HFAG [11]. (right) Measured B^0 oscillation in $B^0 \to J/\psi K_S^0$. Figure from Ref. [12].

SM predictions are as reliable as originally thought and, if so, then assess whether the deviation can be interpreted as a hint of New Physics.

Other recent measurements with rare b-hadron decays include angular analyses of $B^0 \to K^* e^+ e^-$ at $q^2 < 1$ GeV$/c^2$ [8] and $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$ at high q^2 [9], as well as the first observation of $B_{(s,d)}^0 \to \pi^+\pi^-\mu^+\mu^-$ [10].

Another very important highlight first shown at Moriond EW is the measurement of the CKM matrix element V_{ub} using $\Lambda_b^0 \to p\mu\nu$ decays [7], the first observation of which is shown in Fig. 5 (right). There has been a long standing discrepancy between values of V_{ub} obtained from exclusive b-meson decays, such as $B \to \pi\ell\nu$, and analyses of inclusive $b \to u\ell\nu$ decays. LHCb has for the first time performed a V_{ub} measurement at a hadron collider, a feat that many had never thought possible, using the exclusive baryon decay mentioned above. The measured value is $|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$, where the uncertainties are experimental, due to lattice QCD calculations, and V_{cb}, respectively. This precise measurement is compatible with other exclusive determinations performed by the b-factories with meson decays and is 3.5σ discrepant with the average of the inclusive measurements.

Final Run 1 analyses of the benchmark measurements of the mixing phase in B^0 and B_s^0 decays have been reported. Using $B_s^0 \to J/\psi K^+ K^-$ decays [13] the value of the B_s^0 mixing phase $\phi_s = -0.058 \pm 0.049 \pm 0.006$ is determined, which is consistent with the SM prediction and much more precise than measurements from any other experiment (Fig. 6, left). The B^0 mixing phase is measured with the decay $B^0 \to J/\psi K_S^0$ [12] (Fig. 6, right). The value $S = 0.731 \pm 0.035 \pm 0.020$, which equals $\sin 2\beta$ in the SM, has similar precision than that obtained by Babar and Belle using the same decay channel. Including Run 2 data, LHCb is expected to dominate the world average for this measurement. As the precision in these measurements approaches one degree, the control of potential sub-leading effects from penguin diagrams is required. This can be done with Cabibbo-suppressed decays, such as $B_s^0 \to J/\psi K_S^0$, where these penguin topologies are relatively enhanced. LHCb has

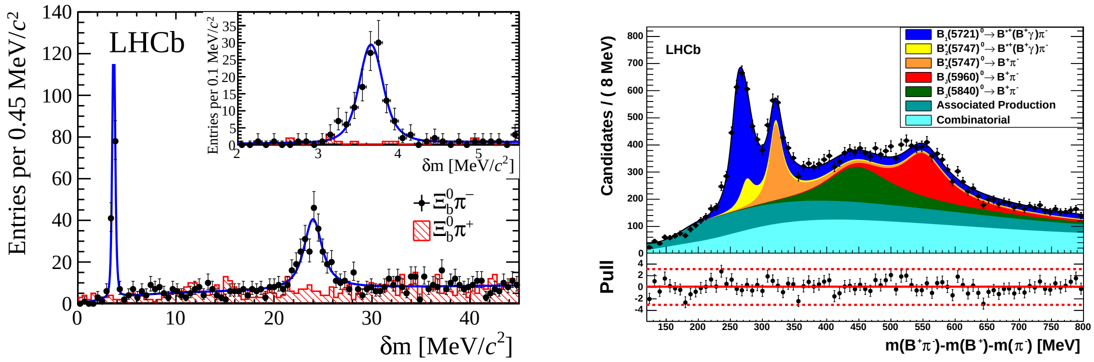

Figure 7: (left) $\Xi_b^0\pi^-$ mass distribution showing the $\Xi_b^{'-}$ and Ξ_b^{*-} peaks. The inset is a zoom to the $\Xi_b^{'-}$ peak. Figure from Ref. [17]. (right) $B^0\pi^+$ and $B^+\pi^-$ mass distribution with the fitted components shown. Figure from Ref. [18].

for the first time measured CP asymmetry observables in this decay [14], paving the way for future precision measurements in this area. All of the above results have profitted from significant improvements in the LHCb flavour tagging performance.

Similar studies can be performed with charmless b-hadron decays. LHCb has recently reported the first observation of the decay $B^0 \to \rho^0\rho^0$ [15], and performed an angular analysis that has allowed the longitudinal polarisation of the ρ^0 meson to be determined. This study confirm the Babar result with a better precision and thus resolves a longstanding Babar-Belle discrepancy for this decay. The same procedure is also applied to the channel $B_s^0 \to K^*\overline{K}^*$ [16].

LHCb has discovered four new particles in the field of b-hadron spectroscopy. Two new baryons denoted $\Xi_b^{'-}$ and Ξ_b^{*-} have been observed with overwhelming significance in the $\Xi_b^0\pi^-$ spectrum (Fig. 7, left) [17]. These observations were the subject to a CERN press release and attracted much public interest. Similarly, in the $B^0\pi^+$ and $B^+\pi^-$ spectrum, the known states $B_1(5721)$ and $B_2^*(5747)$ are confirmed and knowledge of their mass and width is significantly improved [18]. Two other structures are found, denoted $B_J(5840)$ and $B_J(5960)$, which are consistent with the yet unobserved radially excited $B(2S)$ and $B^*(2S)$ mesons (Fig. 7, right).

Amplitude analyses in B meson decays provide an ideal laboratory for charm and charmonium spectroscopy, profitting from a clean and well-defined initial state. The decay $B^+ \to J/\psi\,\rho^0\pi^+$ has been used to determine unambiguously the quantum numbers of the $X(3872)$ exotic meson to be $J^{PC} = 1^{++}$ [19]. In the decay $B^- \to D^+K^-\pi^-$, the $D_J(2760)^0$ resonance is determined to have spin 1 [20].

The forward acceptance of the LHCb experiment also allows for electroweak and QCD measurements complementary to those of the central rapidity experiments. Recent publications have included the measurement of the $Z \to e^+e^-$ cross-section at 8 TeV [21] and the total inelastic cross-section at 7 TeV [22]. Finally, LHCb's ability to reconstruct displaced vertices has been used to set limits on the production of long lived particles decaying to jet pairs [23].

The preparations for 13 TeV data analysis are progressing. Several analysis groups are preparing for first cross-section measurements at this new energy. In some cases the 'turbo stream' will be used, meaning the analysis will be performed on signal candidates selected at the HLT level, without the need for further offline processing. This will serve as a first test for Run 3, where such analyses will be an integral part of the computing model.

5 Financial issues

The status of the accounts is healthy and no cash-flow problems are foreseen. The expenditure on the 2014 M&O cat. A budget has followed forecasts. Due to the long shutdown in 2013-14 and the planned significant interventions on the sub-detectors, together with the work required for general safety and infrastructure, LHCb has recorded a slight overspend on the M&O cat. A budget in 2014, as was also the case in 2013. However, the funds that were buffered in previous years, with these expenditures in mind, mean that all requirements can be satisfied within a constant budget.

6 Collaboration matters

At the LHCb Collaboration Board meeting of December 2014 the Yandex School of Data Analysis was accepted as an associate member of the collaboration, sponsored by ITEP.

References

[1] LHCb collaboration, *Status of the LHCb upgrade*, CERN-RRB-2015-041.

[2] C. Bozzi, *LHCb Computing Resource usage in 2014 (I)*, Tech. Rep. LHCb-PUB-2014-042. CERN-LHCb-PUB-2014-042, CERN, Geneva, Aug, 2014.

[3] C. Bozzi, *LHCb Computing Resource usage in 2014 (II)*, Tech. Rep. LHCb-PUB-2015-004. CERN-LHCb-PUB-2015-004, CERN, Geneva, Jan, 2015.

[4] C. Bozzi, *LHCb Computing Resources: 2016 request and 2017 outlook*, Tech. Rep. LHCb-PUB-2015-003. CERN-LHCb-PUB-2015-003, CERN, Geneva, Jan, 2015.

[5] LHCb collaboration, *Angular analysis of the $B_d^0 \to K^{*0}\mu^+\mu^-$ decay*, Mar, 2015. LHCb-CONF-2015-002.

[6] LHCb collaboration, R. Aaij *et al.*, *Measurement of form-factor-independent observables in the decay $B^0 \to K^{*0}\mu^+\mu^-$*, Phys. Rev. Lett. **111** (2013) 191801, arXiv:1308.1707.

[7] LHCb collaboration, R. Aaij *et al.*, *First determination of $|V_{ub}|$ using the exclusive decay $\Lambda_b^0 \to p\mu^-\overline{\nu}$*, LHCb-PAPER-2015-013, in preparation.

[8] LHCb collaboration, R. Aaij *et al.*, *Angular analysis of the $B^0 \to K^{*0}e^+e^-$ decay in the low-q^2 region*, arXiv:1501.0303, to appear in JHEP.

[9] LHCb collaboration, R. Aaij *et al.*, *Differential branching fraction and angular anaysis of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decays*, arXiv:1503.0713, submitted to JHEP.

[10] LHCb collaboration, R. Aaij *et al.*, *Study of the rare B_s^0 and B^0 decays into the $\pi^+\pi^-\mu^+\mu^-$ final state*, Phys. Lett. **B743** (2015) 46, arXiv:1412.6433.

[11] Heavy Flavor Averaging Group, Y. Amhis *et al.*, *Averages of b-hadron, c-hadron, and τ-lepton properties as of summer 2014*, arXiv:1412.7515, updated results and plots available at http://www.slac.stanford.edu/xorg/hfag/.

[12] LHCb collaboration, R. Aaij *et al.*, *Measurement of CP violation in $B^0 \to J/\psi K_S^0$ decays*, arXiv:1503.0708, submitted to Phys. Rev. Lett.

[13] LHCb collaboration, R. Aaij *et al.*, *Precision measurement of CP violation in $B_s^0 \to J/\psi K^+K^-$ decays*, Phys. Rev. Lett. **114** (2015) 041801, arXiv:1411.3104.

[14] LHCb collaboration, R. Aaij *et al.*, *Measurement of the time-dependent CP asymmetries in $B_s^0 \to J/\psi K_S^0$*, arXiv:1503.0705, submitted to JHEP.

[15] LHCb collaboration, R. Aaij *et al.*, *Observation of the $B^0 \to \rho^0\rho^0$ decay from an amplitude analysis of $B^0 \to (\pi^+\pi^-)(\pi^+\pi^-)$ decays*, arXiv:1503.0777, submitted to PLB.

[16] LHCb collaboration, R. Aaij *et al.*, *Measurement of CP asymmetries and polarisation fractions in $B_s^0 \to K^{*0}\overline{K}^{*0}$ decays*, arXiv:1503.0536, submitted to JHEP.

[17] LHCb collaboration, R. Aaij *et al.*, *Observation of two new Ξ_b^- baryon resonances*, Phys. Rev. Lett. **114** (2015) 062004, arXiv:1411.4849.

[18] LHCb collaboration, R. Aaij *et al.*, *Precise measurements of the properties of the $B_1(5721)^{0,+}$ and $B_2^*(5747)^{0,+}$ states and observation of structure at higher invariant mass in the $B^+\pi^-$ and $B^0\pi^+$ spectra*, arXiv:1502.0263, to appear in JHEP.

[19] LHCb collaboration, R. Aaij *et al.*, *Probing orbital angular momentum in decays of the $X(3872)$ state to $\rho J/\psi$ and redetermination of its quantum numbers*, LHCb-PAPER-2015-015, in preparation.

[20] LHCb collaboration, R. Aaij *et al.*, *First observation and amplitude analysis of the $B^- \to D^+K^-\pi^-$ decay*, arXiv:1503.0299, submitted to PRD.

[21] LHCb collaboration, R. Aaij *et al.*, *Measurement of $Z \to e^+e^-$ production at $\sqrt{s} = 8$ TeV*, arXiv:1503.0096, submitted to JHEP.

[22] LHCb collaboration, R. Aaij *et al.*, *Measurement of the inelastic pp cross-section at a centre-of-mass energy of $\sqrt{s} = 7$ TeV*, JHEP **02** (2014) 029, arXiv:1412.2500.

[23] LHCb collaboration, R. Aaij *et al.*, *Search for long-lived particles decaying to jet pairs*, arXiv:1412.3021, to appear in Eur. Phys. J. C.