Status of the LHCb experiment

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1 Introduction

The LHCb experiment collected around 38 pb^{-1} of integrated luminosity during the 2010 LHC run at a centre of mass energy of 7 TeV. A majority of the data were taken at an instantaneous luminosity close to the LHCb design value, although the pile-up rate was much higher than nominal. Thanks to the outstanding performance of the LHCb detector and its operation the overall data taking efficiency exceeded 90%. The LHCb experiment is already prodiving high quality measurements in the forward direction which complement well the physics results from the General Purpose Detectors, ATLAS and CMS. The detector is optimised for flavour physics, and the results obtained with first data, which already match the Tevatron and B-factories in certain benchmark analyses, indicate that there is excellent New Physics discovery potential in the coming run.

2 Detector Subsystems

All LHCb subsystems performed very well over the full year of running in 2010. The average channel efficiency was above 99%. The long technical stop over the Christmas break was used very effectively for repair, maintenance and consolidation work. Almost all subsystems have been accessed in order to prepare the LHCb detector for running at the highest level of performance over the next two years. All service systems have been well maintained and safety systems have undergone the yearly test. The detector was ready for operation well in time for the re-start of the 2011 LHC run.

2.1 Beam Pipe

Manufacturing of the replacement for the biggest Beryllium cone of the beam pipe (UX85-3) is in progress at the contractor site. All sections are ready for final assembly. Manufacturing drawings of a lighter version of the support (fixed points) located in the magnet are being finalized; they consist of smaller collars made out of Beryllium and plastic based interface rings. The placement of the contract is expected in the coming months. Carbon-composite cables are being investigated as a replacement for the metallic cables and rods currently in use; the qualification of their mechanical properties in a radioactive environment is being pursued. Spares for the aluminium bellows are planned to be manufactured at CERN. A replacement of the Stainless Steel bellow will also be prepared.

2.2 Vertex Locator (VELO)

All components of the VELO performed well throughout the 2010 physics run, and a good start has been made for 2011. VELO operations have been streamlined for the 2011 run, with operational support now being provided by two piquets, rather than 24 hour shifts at the experiment as was the case in 2010. Responsibility for the motion control of the VELO now lies with the central LHCb shifter. This system has been subject to a review and a presentation at the LHC machine protection group. A comprehensive alarm system has been put in place during the 2010-2011 technical stop, together with a number of other additional safety features. As reported at the last RRB, the insulation on the pipes of the CO_2 cooling system was defective, leading to ice formation at the joints of the insulation pieces. The insulation of the full system was replaced during the long Technical Stop (TS) over the Christmas break. The mechanics of the first half of the replacement VELO system has been delivered to CERN and surveyed. The first batch of modules is expected to be delivered in early April. The assembly laboratory is being prepared for the mounting of the modules on the mechanics.

2.3 Silicon Tracker (ST)

The operation of the Inner Tracker (IT) and Tracker Turicensis (TT) has been very stable during the 2010 Physics Run. The operation of the detectors is in the hands of the central shift crew, with support from an on-call piquet. Detailed monitoring of the detector status and performance ensures safe and efficient data taking. During the TS a lot of work was invested in fixing the non-working channels in both detectors and in making the whole system more robust and reliable. Currently more than 99.8% of the channels in the TT and 98.6% of channels in the IT are fully operational. In the recent past some sectors of the TT detector have shown high currents when beams are present and colliding. The origin of these currents is not yet understood. Although this behaviour does not affect the performance of the detector, a clear understanding of the problem is required, since the effect increases with luminosity.

2.4 Outer Tracker (OT)

The detector and readout electronics operate reliably and the fraction of dead channels was well below 1% throughout 2010 operation. Five out of the 432 VC SEL transmitters on the on-detector serializer boards died. They were successfully replaced and all Front-End (FE) Electronics spares have been repaired. Extensive burn-in tests have been performed during the TS. Calibration parameters have been determined, transferred to the appropriate databases, and found to be stable during detector operation. In 2010 the detector was operated with 1.5% of molecular oxygen added to the nominal Ar/CO_2 gas mixture in order to reduce the effect of aging; further irradiation in situ during the TS confirmed the beneficial effects of this addition. A large analysis effort has been made to produce tools for a timely determination of the onset of aging effects. These studies have been complemented by threshold and HV scans. These procedures have been demonstrated to be sensitive to gain variations of the order of 10%. Curing existing gain losses through a HV training procedure has also been demonstrated in situ and a remotely-controlled procedure has been tested during the TS.

2.5 RICH systems

Both RICH1 and RICH2 detectors took data until the end of 2010 in a stable and efficient way. During the TS in total 32 (19 in RICH1 and 13 in RICH2) degraded HPDs were replaced. In addition, High Voltage power supplies were exchanged that were slightly noisy towards the end of 2010 data taking. In order to distribute data more evenly over the readout system, eight UKL1 boards in RICH2 and one in RICH1 were added. During 2010 scintillation light caused significant increase in the data size, although Particle Identification (PID) performance was not degraded. This problem will be tackled by adding a small fraction of CO_2 (around 5%) to the CF_4 in RICH2 as a quencher. At the start-up in March 2011 a technical run was taken with CO_2 in RICH1 to demonstate that the aerogel recovers its expected performance when isolated from C_4F_{10}. Although the data are still being analyzed, the results seem to be very promising. The design of the gas tight box that will contain the aerogel is being finalized. At present the RICH system is running extremely smoothly and efficiently.

2.6 Calorimeters (SPD, PS, ECAL and HCAL)

The first data taken in 2011 were used for the inter-cell time alignment. A precision better than 1 ns for the ECAL and HCAL and 1.5 ns for the PS and SPD has been achieved. The gain stability of ECAL is being permanently monitored using the LED system to a 1% level during data taking. Using online data, the monitoring has improved towards an automatic alarm processing. The system surveys pedestal, noise, and gain stability for the PMT. Energy flow and π^0 quality reconstruction will also be used to monitor the calibration. During the TS, a few faulty or noisy PMTs and FE electronics boards were changed in order to achieve 100% functioning of the calorimeter channels. Some ECAL channels have also been equipped with new integrator electronics boards which allow the PMT currents to be measured in parallel to the standard DAQ chain.

2.7 Muon System

The analysis of the 2010 LHCb run data has confirmed that the muon system is performing very well indeed. During the TS five MWPCs and one GEM chamber have been replaced. Moreover actions were taken to fix a few HV problems and to recondition about 300 chambers that suffered from HV trips during the previous run. The HV has been lowered by 50 V in most regions with cathode readout in order to minimise detector ageing effects. After the TS only about 0.11% of the readout channels remained dead. The muon control system has been improved resulting in a better monitoring of the hardware configuration. Several procedures have been implemented to make the recovery of tripping HV channels easier and more efficient.

2.8 Online System

The last tranche of Event Fliter Farm (EFF) nodes has now been purchased, and the system is now installed, commissioned and in its final configuration. The EFF now consists of 550 dual quad-core computers and 800 dual hexa-core processors of the latest generation, on which more than 20000 copies of the HLT software can be run. In addition to this work, and in order to cope with the running conditions far above design specifications, the readout network has required consolidation. Therefore, a second router chassis with additional line-cards has been installed so that the significantly higher event size can be handled. The work was completed during the TS and was performed without major interruption of services.

2.9 Concerns and plans of the detector subsystems

Concerns:

- Following the electron beam welding of the first two sections of the *Beryllium* beam pipe UX85-3, small cracks have been observed in a small area close to the weld.
- Breaking VCSELs: although at a low frequency, this has to be followed closely.
- High currents in some TT modules when beams are present and colliding.
- Some HCAL PMTs have a dark current which seems to increase with time. This has to be monitored and kept under control.

- Uncertainty in the long term behaviour of the gain loss in the Outer Tracker system remains the main concern.

Plans:

- Complete the VELO spare during the first half of 2011.
- Order new VCSELs of a different production type and test these under radiation. Once proven to survive, LHCb will consider replacing some of the installed VCSELs.
- Continue further investigation of the TT high current problem in situ and on a test module in Zuerich.
- Periodic threshold/HV scans with the OT system in order to measure 2D gain maps and monitor aging effects.
- Design and construction of the aerogel box

3 Overview of the LHCb operations

3.1 Operations at the Pit

In 2010 the LHCb detector was efficiently operated by only two people on duty in the control room. This model will continue during 2011. The shift team is complemented by the weekly experts-on-call for each sub-system in order to solve the most urgent matters. A 'run chief', appointed for each week, oversees the global strategy for operation and data taking. The data taking is operated and monitored through the use of a highly reliable and automated centralised Experiment Control System developed in PVSS.

A complete framework for beam, background and luminosity monitoring at LHCb has been developed in order to maximise the ratio of useful luminosity over background. This framework has also helped the LHC operators to commission the LHC machine extensively, providing real-time information on beam losses and quality of injection of the anti-clockwise beam.

At the beginning of the 2011 run a full programme of calibrations and scans with the LHC beams to re-commission the LHCb sub-detectors was performed using the first few fills with 3 bunches. During one early fill the spectrometer magnet was switched off in order to collect data needed for global spatial alignment. The LHCb detector is now fully operational and in good shape. The VELO closure procedure has become a part of the standard shifter training and is already handled smoothly by central shifters. Nevertheless, as an insurance the VELO piquet will be in attendance during VELO closing for the first few weeks of the run.

The High Level Trigger (HLT) software framework has been completely revised over the TS in order to improve the code structure, the reliability and the speed. The HLT farm was upgraded with the additional 100 multi-PC boxes (400 nodes) and is now fully operational at the pit with the Physics trigger successfully working. In view of the size of the farm, a major effort was invested during the TS in making the configuration and control of the farm both faster and more dynamic in order to improve further the data taking efficiency. These improvements have been successfully commissioned.

'Luminosity leveling' will be vital to LHCb during 2011 so that the experiment can collect maximum integrated luminosity in the optimum conditions. A clear procedure and protocol has been defined together with the LHC. A luminosity leveling driver has been developed in LHCb and work is in progress on the LHC side to finalize the extension of the IP optimization tool to handle the luminosity leveling.

The LHCb central shifter situation at the experiment is acceptable. All shifters from last year are required to attend a refresher course before resuming shift duties this year. Three refresher sessions and two trainings for new shifters have been held up to now.

Concerns: LHCb will again be operating in a new domain of luminosity. The stability of the detector has to be followed very closely with rapid analysis and feedback.

The shifter situation requires attention during the year so that the availability of trained manpower remains at the right level.

Plans: Further optimisation of the tools to handle the luminosity leveling.

3.2 Trigger

At the end of the 2010 data taking period the LHC delivered a peak luminosity close to our nominal luminosity of $2\times10^{32}\,\text{cm}^{-2}\text{s}^{-2}$. As this was achieved with only 344 pairs of colliding bunches (instead of the design 2622) the average number of pp interactions per crossing was significantly higher (up to 2.5) than our design value (0.4). This has had significant consequences on the trigger and the computing.

The LHCb trigger is fully functional and was able to cope with these conditions although only 60% of the Event Filter Farm (EFF) was available. The Level-0 (L0) trigger was run with increasing thresholds as the luminosity increased. Because of the bandwidth limitation of RICH UKL1 boards and high average event sizes, increased thresholds were used, combined with global event cuts on SPD and VELO multiplicities to reject too busy events which contribute significantly to the average CPU time spent per event. Consequently the L0 bandwidth of 1 MHz was not saturated in 2010, reaching a peak of 400 kHz. The 1 MHz readout will be commissioned in 2011 as the number of bunches in the machine increases and the additional CPU available in the EFF will allow the global event cuts to be relaxed.

During the TS the nominal EFF has been installed and is now used during data taking. An additional batch of CPUs is being installed providing another 15% of CPU power.

The high level trigger (HLT) is fully commissioned and uses the data of all subdetectors. Several new developments necessary to accommodate the unanticipated running conditions were commissioned during September–October of the 2010 run. Further developments using boosted decision trees which allow for higher efficiencies on hadronic beauty and charm decays have been included in 2011. Once a luminosity of 3×10^{32} cm^{-2}s^{-2} has been reached, the experiment will be collecting very clean samples of roughly 1 kHz each of b decays to leptons, b decays to hadrons and charm. A small rate of unbiased and beam-gas events are also collected for calibration purposes. The total output rate is 3 kHz, exceeding the design value of 2 kHz. This increase is necessitated by the wider physics programme that the experiment is now committed to pursuing, in particular in the area of charm decays.

This large rate poses stringent constraints on the stripping, which aims at reducing the total size of the data by a factor 10 before distribution on several Tier1 sites for analysis. This is achieved by combining around 400 physics preselections organised in 10 streams covering the whole of the LHCb physics programme. The retention rate for stripping is still a factor of 2 above the canonical 10% but we are working to reduce this in the longer term. Because some large rate channels like $D \to hhh$ and $J/\psi \to \mu\mu$ cannot be accommodated in this reduced rate, a micro-DST was commissioned in 2010 and will be used for many analyses.

Concerns: High trigger output rate of 3 kHz needed to accommodate our physics programme.

Plans: Commissioning of 1 MHz readout. Use of micro-DST in many analyses.

3.3 Data processing

In 2010 LHCb collected 155 TB of raw data at $\sqrt{s} = 7$ TeV with high efficiency [1]. In accordance with the computing model, the RAW data were distributed to the Tier-1s where both reconstruction and stripping was carried out. After the introduction of global event cuts in July 2010, in order to reject very busy events, the reconstruction went smoothly and was able to cope with the significantly large-than-design average event sizes that were recorded. Due to the fast evolution of the machine luminosity and the learning period with real data we performed several reconstruction and stripping cycles, more than foreseen in the steady state.

Between April 2010 and April 2011 the CPU share on Tier1 sites was about 50% for user jobs, 25% simulation and 25% reconstruction and stripping. On Tier2 sites more than 90% of the CPU was used for simulation. The CPU usage efficiency was 85% on Tier1s and 90% on Tier2.

The computing model has been updated [2] to accommodate the changed running conditions. The average event sizes for raw, DST and simulated DST are increased by 60% and the trigger output rate by 50%.

These increases have critical consequences on CPU and storage requirements.

There will be a shortfall of CPU power available for the winter 2012 reprocessing of the 2011 data. We will need 30% extra peak power during the full reprocessing period in order to finalise it within 2 months.

For disk storage we will reduce the number of DST replicas from 6 to 4. But still we will fall 1.9 PB short of the 2011 pledges, and 5 PB for disk in 2012.

Concerns: The amount of computing resources for both CPU and disk space are critically low for 2011 and 2012. We will attempt to mitigate this by delaying processing and reducing copies. In 2012 we require additional resources, in particular disk space.

Plans: We will implement an aggressive policy for removal of old data sets in order to be able to collect and process the 2011 data.

4 Validation of the detector performance using data

The key features of LHCb performance are excellent vertex and impact parameter resolution, high track reconstruction and particle identification efficiency and a flexible trigger which effectively selects particles produced in the decays of heavy flavours.

Compared to the other LHC experiments, in the months prior to first collisions LHCb could only benefit to a very limited extent from using cosmic rays due to the forward geometry of the spectrometer. Therefore much attention was paid during the 2010 run to validating the detector performance with collision data. Modest discrepancies compared with Monte Carlo expectations have been observed in a few places. These imperfections are being addressed with the highest priority and a continuous improvement in the understanding of detector performance is ongoing.

Excellent vertexing capabilities and proper time resolution are provided by the Vertex Locator (VELO), the detectors of which approach to within 8 mm of the beam line during collisions. The sensors of the VELO have been aligned to an accuracy of a few μm using tracks. The individual hit resolution of the sensors is a strong function of the sensor pitch and projected angle (the angle perpendicular to the strip direction). A single hit resolution of 4 μm has been achieved at optimal projected track angle for the smallest pitch size.

The large impact parameter (IP) of the track with respect to the interaction vertex is a distinctive feature to identify heavy flavour particle decays. The currently achieved impact parameter resolution of 14 μm in the highest P_T bin agrees very well with the Monte Carlo expectation. Slightly different slopes observed in data and Monte Carlo resolution, as a function of $1/P_T$, probably indicate a still imperfect description of the multiple scattering in the Monte Carlo. Closely related to the IP resolution is the vertex resolution which is a quantity crucial for the proper time reconstruction and for separating vertices from multiple interactions. Vertex resolutions have been measured by randomly splitting all reconstructed tracks into two subsets and by reconstructing vertices from each of the subsets. For a typical vertex producing 25 tracks the resolution has been found to be 15 μm in X and Y, and 75 μm in Z. Further improvement in alignment is expected with further advances in understanding of weakly constrained degrees of freedom.

Good progress has been achieved on the alignment of the tracking detectors, the TT and the three stations of the main tracker (T1, T2, T3), using data with reconstructed tracks from $J/\psi \to \mu^+\mu^-$ and $D^0 \to K^-\pi^+$ decays. Cluster resolutions of 55 μm have been obtained for the silicon microstrip detectors in both the TT and Inner Tracker (IT) which occupies the inner parts of the T1, T2 and T3 stations. The measured values are consistent with the binary resolution of the detectors; that does not pose any limitation on the momentum resolution for charm and beauty particles limited by multiple scattering. For the outer parts of the T1, T2 and T3 stations, which are made of 5 mm diameter Kapton/Al straw tubes, a spatial resolution of 250 μm has been measured with data. Some improvement is expected after better alignment of the spectrometer.

A continuous progress in the spectrometer alignment and calibration of momentum resolution is reflected in improved agreement between data and Monte Carlo for the invariant mass resolution measured for selected benchmark decays. The most recent alignment has significantly improved the invariant mass resolutions for D and B mesons, and for the J/ψ and Υ resonances. The evolution in understanding the J/ψ mass resolution is demonstrated in Figure 1. In the track

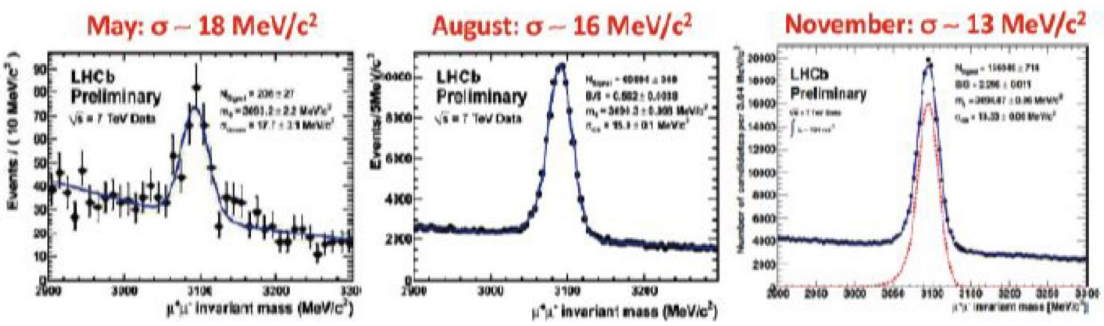

Figure 1: The $\mu^+\mu^-$ invariant mass distribution in the J/ψ region.

reconstruction algorithm the hits in the VELO, TT, IT and OT detectors are combined to form particle trajectories from the VELO to the calorimeter system. Several methods have been implemented to assess the tracking efficiency on data. In particular $K^0_S \to \pi^+\pi^-$ candidates have been reconstructed from one existing long track, leaving hits in all tracking sub-detectors for one of the daughters, and the VELO track pointing to the calorimeter cluster for the second daughter. The efficiency of long tracks is defined by the integral of the K^0_S peak for cases where the VELO track is used in a long track which points to the calorimeter cluster normalised by the integral of the peak without the long track association. The efficiency has been found to be 95% for all long tracks with P_T above 100 MeV/c which is in agreement with Monte Carlo expectation in the full physics range of

LHCb within $\sim 4\%$. A similar method has been applied to evaluate the efficiency of the track reconstruction in VELO.

The track reconstruction efficiency can be also evaluated using the ratio of the branching ratios for well measured decay channels, which result in final states with different number of particles, such as $D^0 \to K\pi$ and $D^0 \to K\pi\pi\pi$. The ratio of the corresponding rates is proportional to the track reconstruction efficiency squared: $\epsilon(track) \propto \sqrt{\frac{N(K\pi\pi\pi)}{N(K\pi)} \times \frac{BR(K\pi)}{BR(K\pi\pi\pi)}}$. Using this method the ratio of the efficiencies obtained with data and Monte Carlo has been found to be 1.03 ± 0.03.

Excellent identification of leptons and hadrons is fundamental for the LHCb physics programme. Pion, kaon and proton identification is based on using the information from two RICH detectors which contain three different radiators, silica aerogel and C_4F_{10} gas in RICH1, and CF_4 gas in RICH2. Combining the two radiators RICH1 provides a separation between kaons and pions for momenta up to 50 GeV/c. Particles with higher momenta up to 100 GeV/c are identified using RICH2. The performance of pion and proton identification has been studied using the daughter particles of reconstructed K_S mesons and Λ baryons. For the kaons, the reconstructed $\phi \to K^+K^-$ decays have been used. Identifying only a single track using RICH information, and leaving the other unbiased, yields a sufficiently pure sample that can be used to measure the kaon identification efficiency. We now also use kaons from $D^0 \to K\pi$ decay channel in D^* decays.

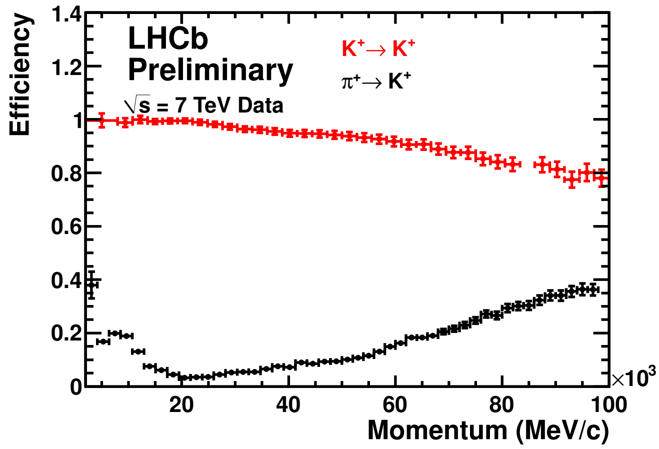

Figure 2: The RICH π/K separation performance as a function of momentum.

The K/π separation performance achieved currently is shown in Figure 2. The best performance is achieved in the momentum range from 5 to 70 GeV/c where most hadrons from b decays are produced.

Electron and photon identification is mainly based on the balance of the energy deposited in the calorimeter system and the track momentum, and the matching between the corrected barycenter position of the calorimeter cluster and the extrapolated track impact point. The electromagnetic calorimeter has been calibrated to $\sim$2% accuracy resulting in a π^0 invariant mass resolution of $\sim$7 MeV/c^2. Using the electrons produced in photon conversions the electron identification efficiency has been found to be $\geq$90% with a misidentification rate of $\sim$3-5% for the electrons with momentum above 10 GeV/c.

Muons are identified by extrapolating well reconstructed tracks with $P \geq$3 GeV/c into the muon stations and matching the tracks with the hits within the corresponding fields of interest. Using a sample of reconstructed $J/\psi \rightarrow \mu^+\mu^-$ decays the muon identification efficiency has been measured to be (97.3$\pm$1.2)% which is in good agreement with Monte Carlo expectations. The efficiency is a flat function of momentum above 10 GeV/c. Corresponding μ/π and μ/K misidentification rates are dominated by the π, K decays in flight and found to be below 1% for $P\ > 20$ GeV/c.

5 Physics achievements

LHCb has exploited the data collected in 2010 to perform many high quality measurements. These have included production studies, which being made in the forward region are unique at the LHC, and the first analyses of heavy flavour decays. Although the 2010 dataset is two orders of magnitude lower than that the experiment will collect in the coming couple of years, it is already sufficient to obtain sensitivities very similar to those of the B-factories and Tevatron, and to make several new observations. All these studies have benefitted from the fact that the resolution and performance of the detector is close to Monte Carlo expectation in all key aspects.

The study of bound $c\bar{c}$ and $b\bar{b}$ states, and related resonances, decaying into di-muons is a natural early physics topic for LHCb. The production mechansim for onia systems at hadron colliders is not well understood, and measurements from the LHC can provide invaluable new input. Due to its forward acceptance and dedicated heavy flavour trigger LHCb has the highest sample of J/ψ events at the LHC. LHCb has published results on inclusive J/ψ production [3], made the first observation of double J/ψ production at the LHC [4] and released preliminary results on upsilon production (see Fig. 3) [5]. The $J/\psi \rightarrow \mu^+\mu^-$ signature has also been used to isolate a sample of $B_c^+ \rightarrow J/\psi\pi^+$ decays [6]. Studies are ongoing on $\psi(2S)$, the χ_c system, and the $X(3872)$, all of which have been observed in the 2010 dataset.

Semileptonic decays have been used to make the first analysis of b-hadron production at the LHC [7]. The measured cross-section at $\sqrt{s}$ = 7 TeV of $(284 \pm 20 \pm 49)$ μb is very close to the value used in previous LHCb Monte Carlo studies, thereby validating one of the assumptions in estimating the experiment's B-physics sensitivity. This result has since been confirmed from the measurement of $b \rightarrow J/\psi X$ production [3]. LHCb has also performed the first measurements of open charm production [8], showing that events containing $c\bar{c}$ are around twenty times more abundant than those with $b\bar{b}$. This enormous production rate will be harnessed by the experiment in searches for CP-violation and very rare decays

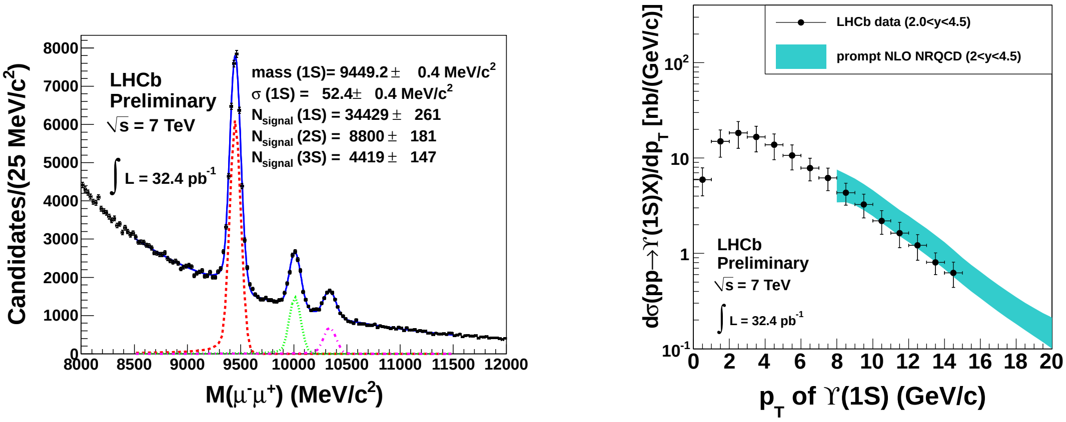

Figure 3: LHCb preliminary upsilon results. Left: invariant mass spectrum of selected $\Upsilon \to \mu^+\mu^-$ candidates. Right: differential $\Upsilon(1S)$ production cross-section compared with the NLO NRQCD predictions [5].

in charm hadrons. The experiment already has a sample of $D^0 \to K\pi, KK, \pi\pi$ events similar in size to that of the B-factories.

Searching for the very rare decay mode $B_s^0 \to \mu^+\mu^-$ is of paramount importance in flavour physics, as its value is predicted with a good precision in the Standard Model ($(0.32 \pm 0.02) \times 10^{-8}$ [9]), but large enhancements are possible in many variants of Supersymmetry and alternative models. This analysis therefore represents one of the most promising ways to look for New Physics at the LHC. LHCb has recently completed and submitted for publication a search for this mode based on the $\sim 40\,\mathrm{pb}^{-1}$ of data collected in 2010 [10]. No signal is seen, and an upper limit is placed on the branching ratio of 5.6×10^{-8} at the 95% confidence level. This number is very similar to that achieved by the Tevatron experiments [11], but is based on around two orders of magnitude less data. With the data foreseen in 2011-12 it will be possible to improve the sensitivity of the search to around the Standard Model value of the branching ratio.

LHCb will be the first experiment to perform precise studies of CP-violation in the $B_s^0 - \bar{B}_s^0$ system. Already with the little data accumulated in 2010 it has been possible to discover new decay channels which will be important topics for future study. These include new states in semi-leptonic B_s^0 decays [12], the gluonic-Penguin dominated mode $B_s^0 \to K^*\bar{K}^*$ [13] and the $b \to c\bar{c}s$ CP-eigenstate decay $B_s^0 \to J/\psi f_0(980)$ [14]. The importance of the latter channel is that it can be used to measure the B_s mixing phase, ϕ_s, which parameterises mixing induced $B_s^0 - \bar{B}_s^0$ CP-violation, alongside the 'golden' mode $B_s^0 \to J/\psi\phi$. The study of this latter phenomenon is extremely important, as any significant enhancement in the CP-violating phase above the small value predicted in the Standard Model will be a clear sign of New Physics.

The $B_s^0 \to J/\psi\phi$ analysis is an exceedingly non-trivial study, being a time

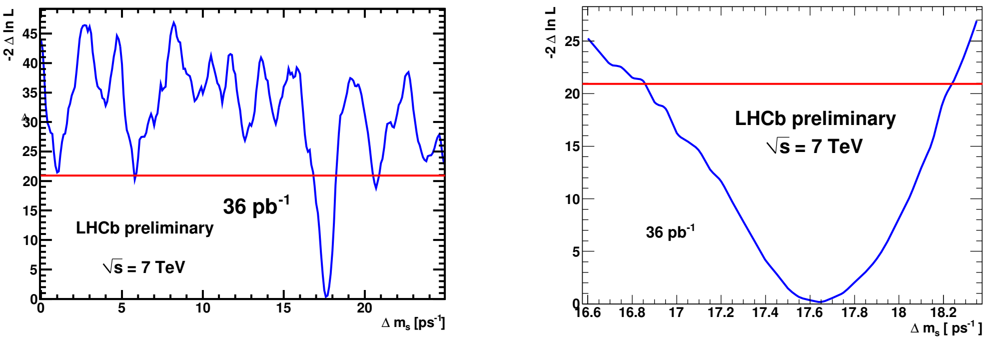

Figure 4: LHCb preliminary likelihood profile scans for Δm_s, showing a wide (left) and narrow (right) range for this parameter. Only statistical uncertainties are considered in the figure [18].

dependent angular measurement. As demonstrated in contributions to the 2011 Winter conferences LHCb has already established the components of the analysis, validating its proper time reconstruction with measurements of $b-$hadron lifetimes [15], making first studies of the untagged angular distributions in $B_s^0 \rightarrow J/\psi\phi$ and the control channel $B^0 \rightarrow J/\psi K^{*0}$ [16] and developing the flavour tagging strategy [17]. Critical in the measurement is the ability to resolve the very fast $B_s^0 - \bar{B}_s^0$ oscillations, and this has been demonstrated by a measurement of the parameter Δm_s, as shown in Fig. 4. A value is obtained of $\Delta m_s = 17.63 \pm 0.11\,(\text{stat.}) \pm 0.04\,(\text{syst.})\,\text{ps}^{-1}$ [18]. This result is consistent with, and more precise than, previous measurements performed at the Tevatron with much larger data sets.

Very recently all these analysis elements have been brought together in a preliminary flavour tagged ϕ_s study [19]. The sample size is not yet sufficient to extract a value for ϕ_s itself, but contours may be drawn in the plane of ϕ_s against $\Delta\Gamma_s$ (where $\Delta\Gamma_s$ is the width difference between the B_s^0 mass eigenstates). This is shown in Fig. 5. With the integrated luminosity expected in 2011 LHCb will be able to measure ϕ_s with significantly higher precision than has been possible at other experiments.

An important responsibility of LHCb is to provide a precise determination of the unitarity triangle angle γ, both in tree level decays such as $B^\pm \rightarrow DK^\pm$ and in loop-dominated modes, such as $B^0 \rightarrow \pi^+\pi^-$. Although the data sample accumulated in 2010 is too small to allow γ to be measured, the foundations for this programme have already been laid with a series of studies which illustrate the potential of LHCb in hadronic final states, and the power of the particle identification capabilities provided by the RICH system. Studies of two-body B decays [20] have yielded evidence of CP-violation in the channel $B^0 \rightarrow K\pi$ (Fig. 6), with a value consistent with that measured at the B-factories. Studies of b-hadron decays into final states containing charmed hadrons have yielded the

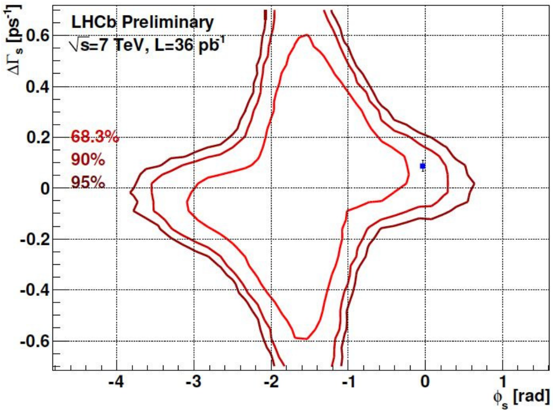

Figure 5: Contours indicating allowed region for ϕ_s against $\Delta\Gamma_s$ from preliminary LHCb analysis. Only statistical uncertainties are considered but these are dominant with the present dataset. The point with small error bar close to $\phi_s = 0$ is the Standard Model prediction.

first observation of the decay $B_s^0 \to D^0 K^{*0}$ [21], a preliminary determination of the production ratio of B_s^0 to B^0 mesons [22], and world best measurements of the branching ratio of decays such as $B_s^0 \to D_s^+ \pi^- \pi^+ \pi^-$ [23]. The high yields and good purity observed in all these modes bode very well for the future of the LHCb γ measurement programme.

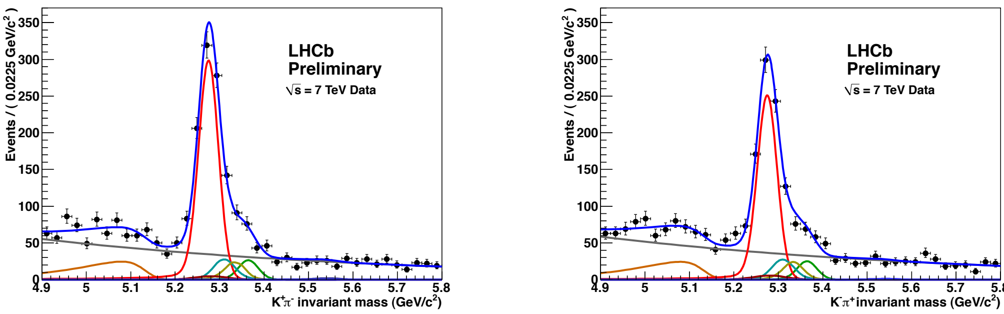

Figure 6: $B^0 \to K\pi$ events selected in the 2010 LHCb data. Left $K^+\pi^-$ and right $K^-\pi^+$ selection. The fitted signal component is the dominant red curve. The difference in yields between $K^+\pi^-$ and $K^-\pi^+$ is driven by the direct CP-violation in the decay. The other curves show the contribution of background components. [20].

The unique forward geometry and low-p_T acceptance of LHCb also allows for unique and important measurements to be performed in physics areas beyond heavy-flavour. First preliminary results of W and Z production have been released, including a determination of the W charge asymmetry as a function of lepton-pseudorapidity [24]. Studies in soft-QCD have included measurements of inclusive

ϕ production [25]. Results will soon be released on central exclusive production of di-muon final states.

6 Upgrade plans

Results obtained from data collected in 2010 show that the LHCb detector is robust and functioning well. While LHCb will be able to measure a host of interesting channels in heavy flavour decays in the upcoming few years, a limit of about 1 fb^{-1} of data per year cannot be overcome with the current detector, resulting in an integrated luminosity of the order of 5 fb^{-1} by the second long shutdown of the LHC. To overcome this limitation and to exploit fully the flavour-physics potential of the LHC, the Collaboration is planning to upgrade the detector and has therefore submitted to the LHCC at the beginning of March 2011 a Letter Of Intent (LOI) for the LHCb Upgrade [26].

The main focus of the upgrade is to run at a luminosity of about $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and to increase the read-out of the experiment to 40 MHz, so that the increase in luminosity can be exploited with an improved trigger. With the upgraded detector a much more flexible software-based triggering strategy will allow a large increase not only in data rate, as the detector would collect 5 fb^{-1} per year, but also the ability to increase trigger efficiencies especially in decays to hadronic final states. In addition, it will be possible to change triggers to explore different physics as LHC discoveries point us to the most interesting channels. Our physics scope extends beyond that of flavour. Possibilities for interesting discoveries exist over a whole variety of phenomena including searches for Majorana neutrinos, exotic Higgs decays and precision electroweak measurements. The upgraded detector will be able to collect about 50 fb^{-1} of data integrated over around ten years of operation. Table 1 summarises the expected sensitivities for some key flavour physics observables of the upgraded LHCb experiment as compared to the precisions that will be reached with the current detector.

Implementing the 40 MHz read-out for the upgrade will require replacing all the front-end electronics to satisfy the requirements of reading data from every bunch-crossing in the upgraded LHCb. The existing architecture includes a Level-0 pipeline buffer and derandomiser, limiting the readout speed and hence the trigger rate to 1 MHz. Any increase beyond 1 MHz requires their removal and a re-design of the electronics. High-speed optical links will be installed to accommodate the increase in data volume from the detector. Data compression schemes will be implemented on the detectors to minimise the number of these links. Though the aim is to eliminate the hardware-based part of the trigger, a throttling mechanism known as the Low Level Trigger (LLT) will be designed to control the data flow into the data acquisition.

Apart from upgrading the front-end electronics of all sub-detectors to 40 MHz, coping with luminosities of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ does not require substantial rebuilds of the Muon System, Outer Tracker and Calorimeters. For the RICH detectors, the

Table 1: Sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that expected after LHCb has accumulated 5 fb^{-1} and that which will be achieved with 50 fb^{-1} by the upgraded experiment, all assuming $\sqrt{s} = 14$ TeV. (Note that at the upgraded experiment the yield/fb^{-1} in hadronic B and D decays will be higher on account of the software trigger.)

Type	Observable	Current precision	LHCb (5 fb^{-1})	Upgrade (50 fb^{-1})	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	-	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	-	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.17	0.15	0.03	0.02
B_s mixing	$2\beta_s$ $(B_s \to J/\psi\phi)$	0.35	0.019	0.006	~ 0.003
Right-handed currents	$S(B_s \to \phi\gamma)$	-	0.07	0.02	< 0.01
	$\mathcal{A}^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	-	0.14	0.03	0.02
E/W penguin	$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$	-	0.14	0.04	0.05
	$s_0\, A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	-	4%	1%	7%
Higgs penguin	$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	30%	8%	$< 10\%$
	$\frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)}$	-	-	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	γ $(B \to D^{(*)}K^{(*)})$	$\sim 20^\circ$	$\sim 4^\circ$	0.9°	negligible
	γ $(B_s \to D_s K)$	-	$\sim 7^\circ$	1.5°	negligible
	β $(B^0 \to J/\psi\, K^0)$	1°	0.5°	0.2°	negligible
Charm CPV	A_Γ	2.5×10^{-3}	2×10^{-4}	4×10^{-5}	-
	$A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

vessels will be reused, but since the front-end electronics is encapsulated within the current photon detectors (HPDs) they will need to be replaced. The VELO sensors will also have to be replaced, due to the increased radiation dose expected in the upgrade. The possibility of equipping it with pixel sensors is under study. Replacement of the silicon tracking stations is also required, since the front-end electronics is attached to the sensors. In addition, owing to the higher occupancies in the upgrade environment, the RICH aerogel radiator and the first muon station (M1) will be removed. The removal of the preshower (PS), and scintillating pad detector (SPD) is also being considered. A new component of the particle identification system based on time-of-flight (TORCH) is proposed to augment the low-momentum particle identification capabilities.

It is proposed to install the upgrade during the second long shutdown of the LHC. This upgrade would not be tied to any luminosity increase of the LHC, as by that time it is expected that $L > 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$ will already be available. The open geometry of the LHCb detector will allow portions of the upgraded detector to be installed in any reasonably long time-window. A staging strategy has been developed that will allow individual elements to be installed when received and when installation time is available. This will be achieved by reading out all the detectors at the current 1 MHz readout rate, even if they have 40 MHz capabilities, until the upgrade installation is complete.

7 Financial issues

The status of the accounts is healthy and there is no cash flow problem foreseen. For 2010 M&0 Cat.A budget, the expenditures have generally respected our forecast and for 2011 we do not expect surprises. As 2010 was the first full operations year, we note a small decrease in detector related expenditures, as opposed to Core Computing, as expected.

In view of the long shutdown in 2013/2014 and of the foreseeable significant interventions on subdetectors and on general safety and infrastructure, we have requested and obtained permission to maintain the Common Fund accounts active until the year 2013.

Both the VELO replacement construction and financing mechanism are working well. No institute has indicated that it has additional requests for funds to be presented to the RRB.

The 3rd part of the LHCb EFF was acquired and installed during the winter stop, using CORE and non-CORE funds.

The financial status of the collaboration is currently satisfactory. In the near future, however, and pending the approval of the upgrade framework, bids will be submitted to funding agencies to secure the resources necessary for significantly increased R&D activities. The future health of the experiment requires that these requests are favourably received.

8 Collaboration matters

- Pierluigi Campana (INFN, Frascati) will start his three years Spokesperson mandate on June 1, 2011.

- Roger Forty (CERN) has been appointed as Deputy Spokesperson. His term starts on June 1, 2011.

- Burkhard Schmidt (CERN) has been appointed as Deputy Spokesperson. His term starts on June 1, 2011.

- Andreas Schopper (CERN) has been appointed as the Upgrade Coordinator. His term starts on June 1, 2011.

- Carmelo D'Ambrosio (CERN) has been appointed as the RICH Project Leader for two years. His term starts on July 1, 2011.

- The group from the University of Birmingham, led by Nigel Watson and Cristina Lazzeroni, was accepted as a new member of the LHCb Collaboration in March 2011. The group will be initially composed of about 5-6 authors and expected to contribute to computing tasks related in particular to production operations. They also contribute to the development of the RICH photodetectors for the LHCb Upgrade.

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