CERN/LHCC 2007-007
LHCC-G-126
20 February 2007

LARGE HADRON COLLIDER COMMITTEE

LHCb COMPREHENSIVE REVIEW
January 2007

1. EXECUTIVE SUMMARY

The fifth of the LHCC Comprehensive Reviews of LHCb took place on 29-30 January 2007. The LHCC referees addressed the following areas: Vertex Locator, Silicon Tracker, Outer Tracker, RICH Detectors, Calorimeters, Muon System, Level-0 Trigger and Online Computing, Physics and Computing, Software and the High-Level Trigger, and the issues of Installation, Commissioning and Management.

Since the previous Comprehensive Review in February 2006, the LHCb Collaboration has made very significant progress towards the realisation of an experimental set-up ready to record proton-proton collisions at the LHC. The LHCC expects LHCb to have a working detector installed in time for the beginning of the LHC engineering run in 2007 provided the timely delivery of the sub-detectors and the current smooth advancement of the production and installation schedules is ensured.

Construction of final components is well advanced and installation and commissioning of systems have started in the UX85 underground cavern. The Electromagnetic Calorimeter (ECAL) and the Hadronic Calorimeter (HCAL) have been installed, aligned and cabled in the UX85 experimental cavern and the RICH-2 Ring Image CHerenkov Detector has also been installed in the UX85 cavern. Installation of the infrastructure and technical services in the experimental area is being completed. Issues concerning the interference due to the installation, commissioning and operation of LHC Machine components around the LHCb experimental hall are being successfully handled. The LHCC noted as a concern the delays and resulting tight schedules in the production of the Vertex Locator (VELO), the RICH-1 Detector and the installation of the first station of the Muon System (M1). Measures to mitigate ageing effects of the Outer Tracker are being implemented, although a full understanding of the cause of the resulting gain loss is still lacking.

The principal conclusions and concerns of the LHCC are summarised below. They will allow the Committee to follow up the outstanding issues and to monitor future progress of this project in forthcoming sessions of the LHCC prior to the next LHCb Comprehensive Review one year hence.

2. OVERVIEW

- Very good progress was reported on the VELO. Many technical problems, associated particularly with the silicon modules, RF boxes, and kapton cables, have been resolved. The overall schedule for the detector installation and commissioning is tight but realistic. The major outstanding issue concerns a small leak detected in the RF boxes. The Committee has requested details on the procedures for the precise positioning of the modules with respect to the beam location at the start of the run.

- The TT and IT detectors are well advanced in their construction. The quality of the detectors is excellent. The TT and IT are likely to meet their schedule and be installed and tested in time for the LHC engineering run.
- There has been significant progress in the area of installation and commissioning of the Outer Tracker and related services. The front-end electronics is in production and will be ready in June 2007. In parallel to the detector installation, a remarkable amount of studies has been performed to understand and mitigate the ageing effects observed in the modules from the mass production. Several encouraging results in view of preventing and curing of the symptoms have been obtained, but the source of the problem has not yet been unambiguously identified. Continuation of the ageing investigations and further studies of the impact on the physics performance are still required.
- The Committee took note of the impressive general progress of the RICH detectors, the almost full completion of the RICH-2 assembly, and the success of the pre-commissioning during the September 2006 test beam exercise, during which the integration of several project elements, both in the hardware and software sectors, was performed successfully. The good quality and the regular delivery of the HPDs suggest that the challenging production will be successfully completed. The Committee appreciates the change of supplier and technology for the RICH-1 spherical mirrors following the failure of the beryllium mirror substrate supply. However, parts of the RICH-1 components are not yet available and the RICH-1 schedule to completion remains very tight. The commissioning of the RICH-2 *in situ*, scheduled to start in March 2007, is regarded as the next major milestone of the RICH project.
- Good progress was reported on the Calorimeters with no major concerns having been identified.
- Good progress was reported on the Muon System with no major concerns having been identified, except for the noticeable delay in the installation of the first station.
- Both the Level-0 and Online Systems are on target for the start of the LHC engineering run. While the progress should still be carefully monitored, there are no major concerns identified.
- The physics effort is well on track, and has made impressive progress in assessing the treatment of systematic effects in heavy flavor analyses, and in preparation for the physics topics of the early years of LHC data-taking. The physics studies need to be updated according to the increased realism in the detector geometry and material description. The computing project has progressed well demonstrating simulation and digitization of a large data sample in the Data Challenge DC06. The second part of the Challenge, including large-scale distributed reconstruction, analysis and alignment exercises, is only starting now, which results in a very busy schedule for 2007.
- The software and High Level Trigger infrastructure and algorithms are well advanced. The increased realism of the Data Challenge DC06 simulation has caused a performance deterioration whose impact on physics should be fully investigated. HLT testing on real data during the 2007 LHC engineering run is essential, as well as setting up dedicated data streams to verify the trigger efficiency and bias.
- Much progress was reported on the work in the UX85 experimental cavern. The LHCC considers that although the schedule is tight, it is realistic to expect LHCb to have a working detector installed in time for the beginning of LHC engineering run in 2007 and for the 7 TeV run in 2008.

3. VERTEX LOCATOR

The Vertex Locator (VELO) detector will provide precise measurements of the primary and displaced secondary vertices for beauty and charm identification. This detector is also a vital component for the B-decay trigger. The detector consists of two sets of silicon stations located very close to the beam axis.

Very good progress was reported on the VELO. Production of all silicon modules is underway - 28 delivered out of the 42 needed - albeit with a significant delay with respect to the original schedule. The completion of the module production is expected before the end of March 2007, in time for beam pipe installation scheduled by mid-April 2007. One of the final VELO detector halves, equipped with 10 modules and all auxiliary systems such as the electronics, experimental control system, cooling and alignment software, has been tested successfully during the November 2006 test beam. Successful alignment of the silicon modules shows that they are within tolerance and do not move excessively when moved in to vacuum.

The vacuum vessel is complete and installed with the RF boxes. The completion of the cooling system is foreseen for April 2007. Vacuum tests of the RF boxes *in situ* have been performed and small leaks located at specific corners have been found. The size of the leaks poses no problem for venting and normal operation. However, the leaks might cause saturation of the NEG coating during installation of the modules. More investigations are scheduled for March 2007. The small leaks should have no consequence for the 2007 engineering run. For 2008, a repeat of the bake-out of the beam pipe and RF boxes would be needed.

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4. SILICON TRACKER

The LHCb Silicon Tracker (ST) consists of the single station Trigger Tracker (TT) and three stations of Inner Trackers (IT).

The TT mechanical support structure is installed in the collision hall, and has been mechanically and thermally tested. The cooling system remains to be connected and tested. The mounting of TT supermodules onto this structure has been rehearsed. The IT mechanical support structure has been installed in the hall and is ready to receive the detector and service boxes. The mechanical survey of this structure remains to be done and the installation procedure for the boxes has still to be tested.

The TT detector module production is finished, including spares. The module quality is very good. Sixteen out of 60 supermodules were assembled and the remainder of this relatively simple assembly is to finish by the end of March.

For the IT, 291 out of 336 modules have been finished in a near-to-perfect state. The number of failures in the production process has been relatively large, especially at the beginning of the production. However, these problems have been overcome and module production is to finish by the end of February 2007.

One of the 12 detector boxes has been assembled and is being debugged. The components for the other detector boxes are in hand.

All cables for the TT and IT are available, except for 20m digital optical fiber ribbons, which are in the process of being ordered. Installation and testing of the modules in the hall can be accomplished without these fibers, although this is slightly awkward.

The electronics of the service boxes consist of digitizer boards, control cards and the crates and backplanes. All digitizer boards are fabricated, although they require some rework for adapting the ADC bandwidth by adding a capacitor and replacing some 30% of the VCSEL semiconductor laser diode, where a diode misalignment was detected and traced back to a production batch where a glue had been used that softens when heated during soldering. The delivery time for the new VCSELs is 8 weeks. They will be soldered in by hand, which ensures that even with the bad glue, there is no excessive heating and risk of the failure that was observed earlier. The control cards are produced at CERN and a pre-series is awaited to perform some additional tests. The crates and backplanes have all been assembled, but some need fixing after being damaged in transport. One of the 12 electronics boxes has been fully assembled and is under test.

The high voltage power supplies have all needed crates delivered and 12 out of 22 modules are with LHCb, with the others expected by mid February 2007. Of the low voltage supplies 37% have been delivered and the rest is expected soon.

The online and Detector Control System (DCS) software are advancing well for the IT and the TT versions will follow soon. Continuous improvements are being made to the simulation and reconstruction offline software.

The schedule of the TT and IT is well under control.

The TT and IT detectors are well advanced in their construction. The quality of the detectors is excellent. The TT and IT are likely to meet their schedule and be installed and tested in time for the LHC engineering run.

5. OUTER TRACKER

Significant progress was reported in the area of installation of the Outer Tracker at the LHCb area at Point 8. Seven out of 12 C-frames equipped with detector modules have been installed and the installation is scheduled to finish beginning of March 2007. Installation of services (such as high voltage, low voltage, cabling, cooling, and gas) is proceeding as planned. First results obtained with the alignment system are very encouraging. The production of the front-end electronics is ongoing, with the last production batch being scheduled to be ready in June 2007.

Since the last Comprehensive Review, an impressive amount of dedicated ageing studies have been performed and are closely followed and reviewed by a panel of external experts in a series of workshops. The studies concentrate on obtaining a better understanding of the origin of the ageing, on establishing preventive measures against it and on finding possible cures for aged modules. Although a final explanation is still outstanding, it seems likely that the problem is related to out-gassing of one or several components of the detector modules. Flushing the modules for several months with CO_2 has been shown to significantly reduce the gain loss after irradiation and a procedure has been established to ensure that this is done for all modules. Further improvements are possible when the flushing is done at elevated temperatures of roughly 40-42 ^{o}C. All modules that have not yet been installed have been baked-out. In addition, preparations are on-going to allow *in situ* heating of those modules which are already installed on Side-C. The LHCC notes that this is an important preventive measure and that it should be prepared and done very carefully to exclude any damage to the detectors by, for example, mechanical deformations. Since the estimated time for such an operation is non-negligible it seems prudent to embed it in the overall installation schedule. Encouraging results have also been obtained with straws that have undergone high voltage training for a period between 20 and 60 hours. Despite the fact that the processes occurring at the sense wire are quite different for positive compared to negative high voltage training, it has been demonstrated that it is possible to recover previously aged regions using either polarity. A special detector module allowing a thorough inspection of wires after such a treatment has been built and results are expected soon. Although the results so far look promising, it still has to be confirmed that high voltage training can also be applied in a controlled and safe manner when large areas of the detector have to

be treated simultaneously. Despite the large uncertainties associated to an extrapolation from the present knowledge to real LHCb running conditions, the LHCC recommends to study in more detail the impact of a possible Outer Tracker degradation on the reconstruction and physics performance. At present, it cannot be excluded that the first experience with beam will show that part of the modules have to be rebuilt. Hence, it is important that provisions are made that this remains an option.

There has been significant progress in the area of installation and commissioning of the Outer Tracker and related services. The front-end electronics is in production and will be ready in June 2007. In parallel to the detector installation a remarkable amount of studies has been performed to understand and mitigate the ageing effects observed in the modules from the mass production. Several encouraging results in view of preventing and curing of the symptoms have been obtained, but the source of the problem has not yet been unambiguously identified. Continuation of the ageing investigations and further studies of the impact on the physics performance are still required.

6. RICH DETECTORS

The LHCb Ring Image CHerenkov Detector (RICH) project includes two counters: RICH-1, equipped with two radiators, namely aerogel and gaseous C_4F_{10}, and RICH-2 using gaseous CF_4 as radiator. Both counters make use of arrays of Hybrid Pixel Detectors (HPDs) as photon detectors, all read out with the same electronics chain.

The RICH-2 mechanical components are all available and the detector assembly is almost complete. Its commissioning *in situ* will start in March 2007. All the on-detector electronics are available, including the high voltage and low voltage boards, and the Level-0 boards.

The RICH-1 gas vessel is mounted and sealed to the VELO and to the downstream window.

The mechanical supports of the quartz window and of the HPD arrays are in production (upper set) or in the design phase (lower set). The carbon fibre substrates of the spherical mirrors have been produced by CMA (USA). The substrate shape is satisfactory, exhibiting D0-values of about 1.5 mm and radius deviations with respect to the nominal value of 0.5 %. The coating will be performed in February 2007 by SESO (France). The reflectance obtained from the coating substrate samples is satisfactory, with typical reflectance values of 90%. The aerogel tiles are all available (22 l) and exhibit fully satisfactory clarity. About 30-40% of the components needed for the on-detector electronics have been delivered. The overall schedule to RICH-1 completion is very tight.

The gas systems for the two gas radiators are built and commissioning is starting in February 2007.

The HPD delivery progresses satisfactory with 432 pieces delivered, out of 484 needed (plus 66 spares). The quality control follows the delivery rate without introducing delay and the HPD quality is very good. The present rejection rate is 2.4 % and the average QE at 270 nm is higher than 30%.

A prototype of the off-detector electronics board was tested during the September 2007 test beam and currently a pre-series of 5 units is being assembled. The mass production (another 20 boards) will be submitted at the end of February 2007 and completed by mid April 2007.

The September 2006 test beam, with 25 ns beam structure, represented a successful pre-commissioning of the detectors as several hardware and software final components have operated coherently. This included a large set of HPDs with the final read-out chain, the full online chain including data monitoring, the detector control system and the experiment control system, the full LHCb software environment used to analyse test-beam data, the full LHCb simulation used for data understanding, the alignment

procedure, the experimental setup control via the Conditions Database and the event visualisation via Panoramix.

The response of the RICH detectors has been studied with the new, more detailed Monte Carlo release Data Challenge DC06 and typical figures, averaged over the whole momentum range up to 100 GeV/c, are K detection efficiency of around 88% and pion misidentification around 8%.

A method for detector calibration using kaons from D* decay has been elaborated and tested with simulated data. D* samples are selected on the basis of event kinematics, providing a clean sample of kaons for RICH characterization.

The Committee took note of the impressive general progress of the RICH detectors, the almost full completion of the RICH-2 assembly, and the success of the pre-commissioning during the September 2006 test beam exercise, during which the integration of several project elements, both in the hardware and software sectors, was performed successfully. The good quality and the regular delivery of the HPDs suggest that the challenging production will be successfully completed. The Committee appreciates the change of supplier and technology for the RICH-1 spherical mirrors following the failure of the beryllium mirror substrate supply. However, parts of the RICH-1 components are not yet available and the RICH-1 schedule to completion remains very tight. The commissioning of the RICH-2 in situ, scheduled to start in March 2007, is regarded as the next major milestone of the RICH project.

7. CALORIMETERS

Very good progress was reported since the previous Comprehensive Review on the various calorimeter systems. The Electromagnetic (ECAL) and Hadronic (HCAL) Calorimeters have been fully installed, aligned and cabled. The installation of the preshower system is also complete and cabling activities are well advanced. The production, test and installation of rest of the front-end electronics is also progressing well and should be finished by June 2007. The Collaboration has designed a reasonable plan for commissioning of the detectors that should translate into a fully operating calorimeter system in autumn 2007.

Good progress was reported on the Calorimeters with no major concerns having been identified.

8. MUON SYSTEM

The LHCb Muon System consists of five walls of muon chambers, labelled M1 to M5, with M1 closest to the interaction point. Each wall is covered with Multi-Wire Proportional Chambers (MWPCs) except for the closest region of M1 to the beam line which has triple-Gas Electron Multiplier (GEM) chambers. All the chambers have binary readout and the main motivation is for muon identification and the Level-0 trigger.

Good progress has been made since the last Comprehensive Review. All 1368 MWPCs have been completed and production is continuing to ensure sufficient spares are made; 85% of these chambers have already been shipped to CERN. In addition, all 24 triple-GEM chambers are complete. The installation of services for the M2-M5 walls is in progress, with 3/4 of the electronics and 1/2 of the gas distribution already done. Following the services, the MWPCs can be installed and 1/4 of the M2-M5 chambers are now in place. One issue has been the alignment; the Level-0 trigger constructs tracks using the nominal chamber placement so they must be positioned within 1-2mm (depending on the distance from the beam line). Some chambers were found to have initial positions up to 4mm from nominal and so chamber-by-chamber adjustments have had to be done.

The electronics status, which was a concern at the last Comprehensive Review, is now good. All on-detector electronics production is complete and the remaining off-detector ODE trigger interface board production should be complete within the next month. Commissioning of the DAQ and studies of time alignment of the data have also started.

The schedule for chamber installation is delayed by five months relative to that from the last CR, mainly due to delays in the production and testing of the on-detector electronics, although as stated above, these are now completed. The realignment of chambers also caused a small part of the delay. The M2-M5 chamber installation should now be completed towards the end of July, which is tight but looks feasible.

Installation of services, and hence chambers, of the M1 wall have been delayed due to the detailed services routing design not being completed. This has been caused by a lack of engineering effort. The basic design is now in hand, albeit with some details still to be finalised. Installation of the M1 infrastructure should start in mid-May 2007 and completed well before the closure of the detector. As many M1 chambers will be installed as can be mounted in time for the 2007 LHC engineering run. At least a quadrant should be able to be installed and this will allow important tests of the Level-0 trigger.

Good progress was reported on the Muon System with no major concerns having been identified except for the noticeable delay in the installation of the first station.

9. LEVEL-0 TRIGGER AND ONLINE SYSTEM

The Level-0 trigger comprises the Pile-up system, the Level-0 Calorimeter system, the Level-0 Muon system and the L0 decision unit (L0DU) and consists of a total of 246 boards, including spares, of 13 different kinds. At the time of the review, all boards had passed the Production Readiness Review, 50% of the boards are in production, and 35% of the boards are fabricated. The production of the L0DU is complete. LHCb estimates that the complete Level-0 system will be ready for commissioning in May 2007. The calorimeter slice has been extensively pre-tested in November-December 2006. The schedule includes coarse time alignment done by September 2007 for all Level-0 subsystems. This schedule is well in time for the engineering run of the LHC later in 2007.

The LHCb online system consists of the Timing and Fast Control (TFC), the DAQ and the Experimental Control System (ECS). Most parts of the system have been tested either in stand-alone or at test-beams. The TFC is ready and waiting for the detector components. All DAQ Tell1 boards are expected to be ready in March 2007, while the control software is ready and tested. The provisional network switches are envisioned to be used for the LHC engineering run. The temporary storage system for the engineering run has been ordered. The components of the ECS are ready and integration with the detector components is in progress.

Both the Level-0 and Online Systems are on target for the start of the LHC engineering run. While the progress should still be carefully monitored, there are no major concerns identified.

10. PHYSICS AND COMPUTING

The physics effort has made considerable progress in understanding and controlling the systematics of heavy flavor analysis under LHCb trigger conditions. Concepts of assessing the efficiencies and biases in flavor tagging and lifetime reconstruction, e.g. by

means of control channels in real data are well advanced. Physics studies are well focused on the investigation of early physics with 0.5 – 2 fb^{-1} of integrated luminosity. Very promising are rare B decays, where competitive challenges of the Standard Model might be possible already in the early physics running phase. However, the present studies have been obtained with the detector description used in the Data Challenge DC04, which was too optimistic in terms of material budget and the resulting effects on reconstruction performance. The physics results should therefore be updated with a simulation matching the real geometry. It will also be important to ensure that the detector experts become deeply involved in the physics commissioning process.

The evolution of LHCb computing to provide a reliable distributed production service is characterized by the Data Challenge DC06. In the first part of this Challenge, 140 million signal and 200 million background events have been successfully simulated and digitized during four months in summer 2006. Also, distribution of the Conditions Database and the file catalogue has been exercised, albeit only with a subset of the associated Tier-1 sites. The second part of DC06, including distributed reconstruction, stripping (i.e. skimming) and analysis of a large data sample, as well as a test of the full data chain from the DAQ onwards and an alignment exercise, will only proceed in 2007. This amounts to a very busy programme for this year, resulting in relatively little time to digest lessons from the challenge before the Dress Rehearsal.

The physics effort is well on track, and has made impressive progress in assessing the treatment of systematic effects in heavy flavor analyses, and in preparation for the physics topics of the early years of LHC data-taking. The physics studies need to be updated according to the increased realism in the detector geometry and material description. The computing project has progressed well demonstrating simulation and digitization of a large data sample in the Data Challenge DC06. The second part of the Challenge, including large-scale distributed reconstruction, analysis and alignment exercises, is only starting now, which results in a very busy schedule for 2007.

11. SOFTWARE AND HIGH-LEVEL TRIGGER

The Committee notes that the development of the software infrastructure and algorithms for both the offline reconstruction and analysis and the High Level Trigger (HLT) system is well advanced. A major rebuild of Simulation and Reconstruction software has been concluded in 2006, including a more detailed detector description, new and updated physics event generators, and final data formats. With the increased realism of the simulation, detector occupancies have increased, and reconstruction performance has somewhat deteriorated. In particular, the ghost track rate is relatively high, the momentum resolution is about 0.1% higher in Data Challenge DC06 than in DC04, and the rate of pions misidentified as kaons has increased from 5% to 7.8%. Work is going on to both improve the performance with more refined algorithms and to assess the impact on the physics reach. The Committee notes that the alignment framework is in place and will be fully verified before the start of data taking through an alignment challenge scheduled for April 2007.

The Committee notes that the development of the HLT infrastructure and algorithms is also well advanced. HLT is based on “alleys” chosen on the basis of the Level-0 trigger information. The muon and hadron “alleys” have been successfully tested in DC06, while the electron/photon “alley” and the muon/hadron “alley” are under test. The CPU performance is as about expected for all “alleys”, although some improvements are needed to ensure adequate contingency. Although no HLT is planned for the engineering run in 2007, it is essential that this run is used to test the HLT algorithms and performance. The Committee also considers it important that dedicated data streams are set up to test trigger efficiency and bias.

The software and High Level Trigger infrastructure and algorithms are well advanced. The increased realism of the Data Challenge DC06 simulation has caused a performance deterioration whose impact on physics should be fully investigated. HLT

testing on real data during the 2007 LHC engineering run is essential, as well as setting up dedicated data streams to verify the trigger efficiency and bias.

12. INSTALLATION, COMMISSIONING AND MANAGEMENT

Most of the infrastructure and services have been completed by the end of 2006 and during last year the integration of detectors has advanced steadily. Although the timing is tight, LHCb does not appear to have any significant problems to meet the remaining milestones.

The substantial cabling effort is ongoing and it is essential to maintain a high level of quality control (testing) to guarantee successful operation during the LHC engineering run in November 2007. The beam tests have revealed many issues that have been used extensively to optimize the process of integration and commissioning of the sub-detectors. The thorough schedule of activities described by the LHCb Technical Coordination is appreciated and the LHCC recommends this effort in management to be sustained in 2007. The fact that the online manpower is now reaching a critical level is a matter of concern and the LHCC would like to be informed regularly on the difficulties in this area.

The physics programme of the first years is clear and enthusiastic and it operates as a driving force for the completion of the remaining work of construction and installation. The phases of global commissioning are realistic and fitted to the planned development of the LHC machine with the aim of an efficient start-up in 2008 with 7 TeV beams.

Much progress was reported on the work in the UX85 experimental cavern. The LHCC considers that although the schedule is tight, it is realistic to expect LHCb to have a working detector installed in time for the beginning of LHC engineering run in 2007 and for the 7 TeV run in 2008.