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Status of the LHCb Experiment

Report to October 2007 RRB
by the LHCb Collaboration

1. Introduction

Installation of the large sub-detectors has been completed, i.e. the Outer Tracker, RICH-2, Calorimeter and Muon System (except the first station). The beam pipe is now fully commissioned and ready to be used. RICH-2 is fully equipped with photon detectors and readout electronics and ready to be used for the global commissioning. Commissioning of the Calorimeter and Muon System is advancing, as well as that of the corresponding Level-0 trigger electronics. The cause of the Outer Tracker gain loss with irradiation has been identified and preventative measures are being taken. For the remaining sub-detectors, infrastructures and auxiliary systems are fully in place for the VELO, Trigger Tracker and Inner Tracker, and will soon be followed by the installation of the detectors themselves. RICH-1 has its gas enclosure box closed with the mirrors inside and is waiting for the photon detectors to be installed. The online system is being installed and tested, and is already used by the subsystems for their commissioning. The LHCb DAQ system is flexible so that the initial DAQ capacity that is sufficient for the expected LHC operation in 2008 will be quickly upgraded in 2009 to match the increasing event rate. This allows us to purchase CPUs in a cost effective manner. Continuous improvements are being made for the physics software and particular efforts are made in the development of High Level Trigger algorithms to minimize systematic effects. Although we still suffer from the storage access problem and some instability of the sites, the Grid is fully integrated for simulation, reconstruction and analysis. Efforts are being made to consolidate some of the core software. Although the overall schedule remains tight, we are confident to be ready for the LHC beam collisions in 2008.

2. Detector Subsystems

2.1 Beam Pipe

Commissioning of the whole 23-meter long beam pipe passing through the detector was completed in early June by the CERN Vacuum Group, after its installation and alignment in March. The installation of the neon gas injection system, which is crucial in preserving the properties of the non-evaporable getter coating (NEG), was completed in May. Test of the neon gas injection system was done and the interface with the pressure control system of the Vertex Locator (VELO) vacuum tank validated. After the installation of the removable bake-out equipment, the beam pipe was pumped down, reaching a pressure of the order of 10^{-7} mbar. During the bake-out and NEG activation phase, the VELO vacuum tank was heated to 150°C and the NEG coated parts reached 220°C. The temperature of the third Be section, UX85/3, was limited to 180°C due to the concerns on the long-term reliability of its varnish. Once the bake-out was complete, a pressure of 10^{-11} mbar was achieved. Finally the beam pipe was filled with ultra-pure neon to atmospheric pressure. Plexiglas and aluminium protections have been put back in place to allow necessary activities around the beam pipe for the different detectors. The aluminium spare sections of UX85/1 and UX85/2 are under fabrication at CERN by TS/MME group (UX85/3 Al spare was already produced as reported in April 2007).

Changes: None.

Concerns: Mid to long-term reliability of the UX85/3 varnish coating. Procurement of a replacement section.

Plans: Finish fabrication of the aluminium spare sections at CERN and perform their acceptance tests and NEG coating. Complete final survey of the beam pipe position after the LHCb magnet tests and shortly prior to the start of the LHC. Initiate design and development of new beam pipe supports with further reduced material. Improve reliability of aluminium bellows for additional spares. Investigate a replacement for the third section of the Be beam pipe.

2.2 Magnet

The LHCb dipole has been tested and operated in 2005 already together with a complete field mapping. Since then, several sub detectors, detector supports and access structures have been installed and a new test together with the measurement of the impact on this equipment was scheduled between 1st and 15th October 2007. At the same time the Magnet Control and Safety System with all control sensors and the communication with the LHCb Detector Safety System (DSS) will be commissioned. As the power converter electronics has been upgraded, the re-commissioning of this equipment has been planned as well. Finally, the communication with the CERN Control Centre and the remote control of the LHCb dipole from the CERN Control Centre together with the compensator magnets will be tested.

Changes: None.
Concerns: None.

Plans: No further activity planned after the October test.

2.3 Vertex Locator (VELO)

The assembly on the base of all VELO sensor modules (42 normal modules with *r*- and ϕ-sensors and 4 Pile-up modules with only *r*-sensors) has been completed. Both detector halves have been surveyed. The C-side half has a slight twist resulting in a maximum sensor displacement of approximately 150 microns, which will be compensated during the detector half mounting into the VELO vacuum tank. All (88) repeater boards have been fully tested. The CO_2 cooling plant for the sensor modules has been transported to CERN and installed in the pit. The CO_2 transfer line has been fully installed and using a dummy load the system has been successfully commissioned. A stability of 0.3 degrees has been achieved when switching from zero to full load. All analogue signal cables were installed, connecters mounted and tested. The hardware of the high voltage (HV) system including cables has been fully installed. Electronics for the interlock system has been designed and built and is currently under test. All the readout and control electronics have been installed in the pit. A small leak has developed in RF boxes, which is considered by the CERN Vacuum Group to be incompatible with high luminosity running from 2009/2010 onwards. Evacuation and venting procedures compatible with LHC running before that time have been established, and a replacement program for the boxes is underway, starting with R&D to establish the possibility of machining the foils from solid blocks rather than pressing in a mold.

Changes: Recall of several CAEN low voltage (LV) modules has led to a delay in the commissioning of the LV system.

Concerns: Small leak developed in RF boxes, although not critical for the coming few years.

Plans: Complete the remaining cabling (LV, temperature sensors, and Pile-up modules). Integrate the cooling system in the global ECS and perform long-term test. Commission

DAQ and control chain with full chain test. Install the two detector halves in the vacuum tank after the magnet test, along with a survey of the detector supports. Commission interlock system. Start production of the spare VELO modules.

2.4 Outer Tracker

The detector installation has been completed, including the cables from the counting house to the detector through patch-panels. All the gas connections have been completed and the whole detector is continuously flushed with CO_2. The cooling system for the electronics has been commissioned. The HV and LV power supplies have been connected to the detector and to the on-board electronics and tested. The delay in the production of the front-end (FE) electronics has been contained and this is now in its final stage. Three of the four OT TELL1 crates for the readout are ready. The full control and readout chain of a subset of the OT has been tested with test-pulse and is continuously used for the detector commissioning. A dedicated cosmic trigger for the OT is being assembled. Ageing studies have been on-going for the understanding, prevention and cure of the observed gain loss under irradiation at a particular rate. This has been traced to the out-gassing of the two-components glue used to seal the module gas envelopes. Besides flushing, thermal treatment (at about 40°C) has been found to be effective in preventing the ageing effect and preparations to warm up all modules in situ are on-going. HV training procedures have been established for recovery from the gain loss.

Changes: Overall delay in the commissioning of the complete OT caused by the final alignment and survey of the OT C-Frames and the FE electronics installation.

Concerns: Uncertainty in the long-term behaviour of the gain loss.

Plans: Complete survey and alignment, and electronics installation and commissioning. Perform in situ heat treatment.

2.5 Silicon Tracker

All Inner Tracker (IT) modules, including 15% spares, have been assembled. Quality assurance measurements have been completed for 90% of the modules and the quality of the tested modules is very good. The assembly of the five out of 12 IT detector boxes has been completed. Three boxes have been surveyed and have undergone a full HV test. The IT support frames are fully equipped with the infrastructure and ready to receive the detector boxes. Trigger Tracker (TT) detector boxes are in position, equipped with the cabling and cooling pipe connections and prepared to receive sensor modules, which are ready to be installed. Service Boxes electronics have been assembled and have passed burn-in tests. The installation of Service Boxes and detectors was delayed by a problem discovered during burn-in tests of the Service-Box Control Cards. The source of the problem was traced to an LVDS driver chip on the Control Card, solved by replacing the chip with a different type. Significant progress has been made in the ECS software for IT and work to adapt it for TT has started. HV and LV power supplies have been installed and their commissioning is close to completion. First tests of the C_6F_{14} cooling system have been successful.

Changes: None.

Concerns: Manpower for ECS software is still tight. Delayed funding profile for Germany (MPI) and Spain.

Plans: Complete the quality assurance of IT modules and the assembly and testing of IT detector boxes. Complete the testing of Service Boxes and install them. Install IT detector boxes and TT detector modules. Complete ECS software. Start in-situ commissioning of the detectors in IP8 and get the system ready for global commissioning.

2.6 RICH

RICH-1 is in an advanced state of construction. The gas enclosure is complete, and the mirrors have been installed and recently aligned in situ. The fabrication of the top photon detector (HPD) housing and rail system is complete and fabrication of the bottom housing is underway. Test installations in the gas enclosure of the upper HPD box and the aerogel have been successful. The aerogel fabrication has ended and the tiles have been stored and individually sealed. The design of the lower HPD rails and mounting system is nearly ready and manufacture will soon start. The design of the RICH-1 top and bottom photon funnels is still awaiting the final design of the magnetic monitoring system. The RICH-1 column-dressing of HPD photon detectors and electronics is finished. The RICH-2 detector was installed in the pit nearly two years ago and has been fully equipped with the photon detector and related electronics. The application of HV to the HPDs has been successfully achieved. The RICH-2 detector is now ready for global commissioning with the LHCb online system. The full complement of HPDs (484+66 spares) has been delivered, fully tested, and their performance exceeds specifications with a production yield of 97% achieved. After applying HV on RICH-2, nine out of 288 photon detectors (~3%) were found to have become faulty and will need to be replaced. We are closely monitoring the HPD performance during the RICH commissioning process, with emphasis on identifying any possible tube degradation. The full production of off-detector Level-1 electronics boards has been completed. A system test of three production HPD columns at the CERN H8 test beam with 25ns bunch structure was successfully achieved, and the alignment challenge with Cherenkov rings spanning up to five HPDs has been a vital test-bed for the final system. Substantial improvements have been made to the RICH reconstruction software, as part of the ongoing 'Data Challenge 06' software studies. RICH calibration procedures, both in hardware and using physics data, are in advanced preparation.

Changes: None.

Concerns: The tight schedules for the final design and production of the RICH-1 photon-funnel region and the magnetic monitoring system.

Plans: Finish installation and commissioning of the RICH-1 detector, operating with full HV to 20kV, by the end of February 2008. Full RICH system ready for global commissioning by March 2008.

2.7 Calorimeter

The Calorimeter detector installation is complete and commissioning is progressing well. The complete readout chain has been tested for the first time in the experimental cavern using a slice of the HCAL detector. In this global test the LED monitoring system was used to flash the photomultipliers of the HCAL inner region, generating a L0 trigger, reading out the corresponding event and storing the data for offline analysis. As a next step it now is foreseen to add gradually slices of all other Calorimeter sub-detectors, with the ECAL being already well prepared to participate in this global test. A lot of progress has been made in the commissioning of the PS and SPD detectors. Both detectors are fully cabled and all Very Front End electronics boards are now installed on the detector periphery and tested. The Preshower Front End electronics cards have all been produced, tested and installed. One half of the PS and SPD detectors has been commissioned using the LED system. The commissioning of the Calorimeter monitoring and HV systems is well advanced, including the implementation of the ECS. It is foreseen to have the full readout chain and trigger logic operational for one half of all Calorimeter sub-detectors by the end of this year.

Changes: None.

Concerns: None.

Plans: Make one half of Calorimeter system fully operational by end 2007, and the full system by February 2008.

2.8 Muon

All of the Multi-Wire Proportional Chambers (MWPCs) for M2 to M5 have been installed, except for 20 which were found to be defective (out of a total 1084 installed). They have been fully tested with cosmic rays before installation and checked successfully for gas leaks and electronics noise after installation. All the MWPCs and 3-GEMs for M1 have been produced and more than 50% have been dressed with Faraday cages and electronics. M1 chambers have been successfully conditioned under irradiation at GIF. Additional spares (10%) for the FE cards have been produced. The off-detector electronics cabling is completed for M2-M5. The debugging of the readout chain down to the electronics installed in the muon tower has been completed to 90% on the C-side and is in progress on the A-side. The installation of the HV system is in progress. The position alignment of the chambers is well advanced. The cable chains have been installed and connected. Work on the ECS and on software for system commissioning, time alignment and run control is progressing well. The design of M1 infrastructure has been finalized, including the cable layout. The M1 support panels have been installed.

Changes: None.

Concerns: Lack of manpower for chamber commissioning, alignment and M1 installation. Delays in M1 installation and commissioning. More work in parallel with Calorimeter.

Plans: Produce spare chambers and install missing chambers on M2-M5. Complete position alignment. Install the air-cooling system for the central region. Complete commissioning of M2-M5 at subsystem level and to be ready for the global commissioning. Install M1 infrastructure, services and chambers, and perform at least partial commissioning.

2.9 Trigger

Production of all the Level-0 trigger electronics boards was completed in August 2007. All Pile-up modules were mounted on the VELO detector bases. Half of the Level-0 Calorimeters and half of the Level-0 Muon Trigger have been installed. Testing the cabling between FE electronics and Level-0 trigger boards has been the main commissioning activity. For the High Level Trigger (HLT), the new 1 MHz trigger strategy has been implemented for muons and hadrons, while the electron line is under development and will be implemented within the next month. The triggers have been shown to give high efficiencies for a few off-line selected benchmark channels. The work on partial reconstruction of so-called seeded tracks in the tracking stations behind the magnet (T-stations) is progressing well, showing that this can be performed within the allotted CPU time budget. The HLT flow has been optimized to facilitate its commissioning and monitoring. Code has been developed to allow on-line monitoring and off-line analysis of the trigger decisions. A fast method to allow the trigger to follow the luminosity decay during a fill has been agreed upon, and the details on how to implement this are being worked out.

Changes: None.

Concerns: None.

Plans: Complete the commissioning of the Level-0 Trigger. Adapt the HLT to use the latest improvements to the tracking software. Start using the on-line farm to run the code and test the commissioning and monitoring tools.

2.10 Online

Installation of the online system is mostly completed. Still to do are some Controls PCs for the muon HV system and, of course, the HLT farm that will be installed gradually. For the first slice of the farm (~200 boxes) a market survey has been launched and a tender will follow in November with an aim to have them in hand by June 2008. A second slice (~800 boxes) will be tendered in Q1 2008 ready for installation early in 2009. The actual purchasing procedure will be adjusted according to the delivered LHC luminosity, to optimize the resources invested in the farm. The integration of the subsystems into the ECS is progressing and global commissioning will start in October 2007. The current capacity of the Readout Network is approx. 20%, sufficient for the start-up of the LHC. The strategy for the upgrade will be finalized when the plan for LHC operation becomes better known. The Timing and Fast Control system is complete and being commissioned together with the individual sub-detectors. The Beam Intensity and Phase Monitor modules were successfully tested in the recent 25 ns operation at the SPS. The final prototype will be produced before end of 2007. The Histogramming and Monitoring project is well advanced. A first release of the histogram presenter will be published by end of November, in time for intense use in the commissioning of the detector.

Changes: None.

Concerns Very thin manpower coverage for installation and setting-up.

Plans: Start global commissioning.

2.11 Computing

The charged particle identification algorithms have been significantly improved over the summer. Also the track reconstruction has achieved a lower ghost rate and better momentum resolution than before. The physics analysis groups will profit from these achievements through a re-reconstruction of the simulated data planned to start in November this year. A new software framework that accommodates both on-line and off-line track pattern recognition was developed. The major algorithms have already been converted to use the new framework with similar or better performance. Work to convert the survey measurements into alignment constants to be used by the reconstruction program is in progress. While VELO alignment is well advanced, more work is needed for the T-station alignment. We expect to complete this by January 2008. Event simulation and reconstruction of specific signals has continued at a moderate pace. Several issues were discovered when starting data re-processing on the Grid, as simulated raw data files had to be recalled from tape mass storage. The DIRAC framework was modified in order to optimize files pre-staging prior to job submission. The progress of the re-processing was slowed down by the migration of many sites to a new operating system SL4 that introduced many instabilities. All these problems have been overcome now. The re-engineering of DIRAC (DIRAC3) is well underway and is expected to be in production for the end of the year. Recent developments of similar frameworks by the other LHC experiments confirm the choice of the DIRAC strategy (using pilot agents for job submission) to be sound. LHCb was very active in testing the first releases of Storage Resource Manager (SRM) v2.2. Several issues have been identified and fed back to developers. Tests will resume in October, and LHCb expects SRM v2.2 to be available for the full chain test in spring 2008. Data transfers from DAQ to Tier-0 are being performed. Distribution to Tier-1s with reconstruction will follow before the end of the year. LHCb is fully committed to participating in the combined challenge with all the other experiments to be held in May (with transfers at the nominal rate). Analysis on the Grid is increasing steadily despite hiccups due to site instabilities. The Ganga project (common with ATLAS) is progressing very well and being widely accepted.

Changes: DIRAC3 to be available in production for the end of 2007 rather than September.

Concerns: SRM v2.2 functionality and deployment; handling of multi-platform support for middleware (ensuring consistency with application software).

Plans: Alignment challenge in spring 2008. Prepare for a full demonstration of the computing model in spring 2008 using DIRAC3 and Ganga.

3. Experimental Area

The installation of the upper part of the radiation-shielding wall was started in March 2007 as foreseen and completed in May 2007 as expected. However, the erection of the front part was started just in July with a delay of 4-5 weeks. The delay was due to an additional concrete layer on the floor (not foreseen) needed in order to adjust the level of the ground before starting the assembly of the concrete blocks (~300 blocks). Seven layers of blocks over sixteen layers were installed by the end of September 2007. The mobile radiation plug (24 tonnes) is under construction at the surface. The final assembly and the installation on site (UX85) are foreseen by November. The global completion of the radiation shield is rescheduled for December 2007. After replacing the contractor in June, the gas piping works on the gantry both sides A & C, plus piping for the muon system and RICH-2 were achieved by the end of September 2007. Piping for RICH-1 remains to be performed, and is scheduled for the end of October after the magnet test. Installation of other detector services such as cooling systems are almost complete and the commissioning is progressing as scheduled.

Changes: The global completion of the radiation shield initially scheduled for August 2007 shifted to December 2007.

Concerns: None.

Plans: Complete installing of the radiation shielding wall and commissioning of all the services.

4. Cost and Funding

4.1 Overall Funding Situation

The detector cost remains unchanged as 75.341 MCHF. With the MoU signed contributions, and additional contributions from Brazil, CERN, France, Germany Italy, Netherlands, Spain, UK, and the US National Science Foundation, the missing funding for the CPU farm was 497 kCHF at the time of the April 2007 RRB, provided all the commitments are honoured. Recently, the US National Science Foundation has communicated to us that they have developed a plan to supplement funding to the Syracuse University Group for its contributions to the CPU farm. The supplement is expected to be in the form of two installments, the first for 200 kUSD by about November 2007 and a second installment also of 200 kUSD a year later, with the latter payment, as usual, subject to the availability of funds at that time. With their contribution, the CPU farm is now fully financed. A summary of the funding is given in Table 1.

4.2 VELO Replacement Modules

While all the other sub-detector components were designed to sustain their performance up to an integrated luminosity of 20 fb^{-1}, the VELO silicon sensors are expected to be replaced after an integrated luminosity of 6 fb^{-1}, as they will suffer from severe radiation damage by being very close to the beam. This was already indicated in the Technical Design Report, and means that the 42 sensor modules must be duplicated, which is far more than the usual number of spares (typically between 10 and 15%). Therefore, the Collaboration Board agreed that it was reasonable to share a part of this cost among the collaboration. The total material cost for the production of the extra 42 modules is calculated to be 1.0 MCHF, based on the experience of producing the first 42 modules. An additional 300 kCHF is needed in order to produce modules in an accelerated manner so that the production can be completed by early 2010. This brings a further advantage that a sufficient number of sensor modules would be available in case of a drastic accident such as a beam loss close to the VELO region at an early stage of the LHC operation. Within the VELO project, 500 kCHF would be covered by UK-Liverpool (300 kCHF approved and 200 kCHF requested as their M&O Category B contribution) and CH-EPFL requested 300 kCHF as their additional contribution to the project. We would like to have approval from the RRB that the remaining 500 kCHF would be split among all of the funding agencies, over a period of five years, with the same sharing as for the Category A M&O cost. The actual amount per year would thus be very small. The infrastructure and manpower cost at Liverpool where the module production will take place, estimated to be 2.3 MCHF, will be covered by UK. We would like to note that the high radiation dose expected in the region of VELO might impose a severe restriction on the module replacement work, defined by the Radio Protection CERN Regulations, which could make it difficult to finish the work during the annual shut down period. Possible loss of data taking could then be avoided by pre-installing all the sensor modules on replacement detector bases. We may indeed consider producing two detector bases, which would cost around 900 kCHF for two, at the time of the operation. However, it is not yet clear whether such a precaution is indeed necessary and we need to gain more information on activation in the coming years before concluding on the need for spare bases.

4.3 Replacement Beam Pipe Section

As reported in previous RRB meetings, the third beryllium section of the beam pipe was delivered with an inferior quality. The repair made by the CERN Vacuum Group was successful and it will be used for the initial period of the LHC operation. However, the CERN Vacuum Group expressed a strong concern for the long-term reliability of the section as it will be subject to high irradiation doses when the LHCb runs with the nominal luminosity, and requested that a replacement should be produced. In order to provide the third section within the specifications, the production method must be changed. If this could be done by the Russian manufacturer who produced the original Be beam pipe, we believe that this cost could be covered by extra funding that has now been granted by CERN. However, if it can only be done by another manufacturer, the cost may go up substantially. The CERN Vacuum Group, who will be responsible for the procurement, is in the process of converging to a viable solution by the end of this year. Due to the long production time, the purchase procedure must start during 2008.

5. Collaboration Issues

The LHCb collaboration has welcomed University College Dublin (Ireland) as a full member of the collaboration. The group is led by Ronan McNulty (who worked on DELPHI and CDF) with an additional faculty member, three post-docs and students. Since November 2003, the group has participated in the experiment as a Technical Associate institute, mainly in the area of online, making several crucial contributions related to the network switch. After completing several technical projects, they requested to become a full member of the collaboration in order to participate in physics analysis. They have secured their funding for M&O and skilled software manpower to contribute to the area of core computing, in particular the bookkeeping service for data, where effort was urgently needed. Although they cannot promise any contribution to the capital investment at this moment, it was felt that their commitment towards the core software would be sufficient to admit them to the collaboration, with a strong hope that this would help the development of particle

physics activity in Ireland. The Collaboration Board has encouraged them to keep seeking further opportunities to increase their funding.
Andrey Golutvin from ITEP Moscow has been elected as the new spokesperson of the experiment and will start from the 1st of May 2008 for a period of three years.

Table 1: Funding of the LHCb experiment

	Number of institutes	Signed MoU contribution [MCHF]	Extra detector contribution [MCHF]	Extra CPU contribution [MCHF]	Total contribution [MCHF]
Brazil	2	0.000	0.000	0.055	0.055
China	1	0.100	0.000	0.000	0.100
France	5	7.500	0.000	0.800	8.300
Germany	3	-	-	-	-
BMBF	-	3.757	0.381	0.300	4.438
MPI-HD	-	2.200	0.000	0.000	2.200
Italy	9	10.000	0.847	0.000	10.847
Netherlands	2	6.300	0.381	0.000	6.681
Poland	3	0.500	0.000	0.000	0.500
Romania	1	0.300	0.000	0.000	0.300
Russia	5	2.500	0.000	0.000	2.500
Spain	2	2.000	0.000	0.020	2.020
Switzerland	2	7.900	0.000	0.000	7.900
UK	8	10.300	0.044	0.400	10.744
Ukraine	2	0.200	0.000	0.000	0.200
US	1	0.000	0.000	1.040	1.040
CERN	1	16.700	0.799	0.000	17.499
Total	47	70.257	2.452	2.615	75.324