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Status of the LHCb Experiment

Report to April 2007 RRB
by the LHCb Collaboration

1. Introduction

Installation of all sub-systems for the LHCb spectrometer in the cavern is progressing fast. In addition to the spectrometer magnet, RICH-2 and the calorimeter system, the entire beam pipe is fully in place now. Installation of chambers for the muon system is completed for the C-side of M2 to M5 and work on the A-side has started. Cable installation for the Preshower and Scintillator Pad detectors is progressing as planned. RICH-2 is fully equipped with the HPD's and system commissioning will start soon. Installation of the Outer Tracker is close to completion and the Inner Tracker frames have been installed. The detector box for the Trigger Tracker is now in place and waiting for the sensor module installation. The gas enclosure box for RICH-1 is installed and sealed to the VELO vacuum vessel and the beam pipe. The VELO vacuum tank is ready to receive the detector box as soon as the beam pipe is commissioned. Installation of the online system in the electronics barracks in the pit and in the control room at the surface is ongoing. In summary, the progress of the LHCb experiment is still compatible with taking data during the 2007 engineering run at 900 GeV. Having these data early is highly desirable for the alignment and calibration of the detector in order to ensure efficient physics analysis as soon as the physics data at 14 TeV become available.

2. Detector Subsystems

2.1 Beam Pipe

The last beryllium cone, UX85/3 was delivered in October 2006. Leaks had been observed during the preliminary vacuum tests in Russia and cured with a varnish coating over the whole external surface. Acceptance tests at CERN by the AT/VAC group following the bake-out of the chamber at 250° C observed leaks. After locally applying varnish, the final vacuum tests verified the chamber to be leak tight for bake-out temperatures up to 180° C, sufficient to activate the NEGs in the first few cycles. After the NEG coating, it was installed in the experiment. The AT/VAC group expressed a serious concern on the mid to long-term stability of the varnish due to the temperature cycles and irradiation. This is aggravated by the fact that about 2/3 of this section is inside of the RICH-2 and not easily accessible. A study to develop a strategy for acquiring a replacement section has started. The beam pipe support with much reduced material compared to the original design has been produced and installed. The mechanical stability has been verified in situ applying forces equivalent to that of the chamber under vacuum. Installation of the complete beam pipe, including the last stainless steel section, has been completed and the entire beam pipe was aligned in March 2007. Plexiglas and aluminium protections have been put in place around the beryllium sections while the installation of the experiment continues. Vacuum tests of the whole 23 meter long experimental chamber are in progress: The mechanical behaviour of the whole assembly has been verified to be as expected from the design. The aluminium spare section of UX85/3 has been built at CERN by TS/MME, due to the inability of the contracted company to deliver the chambers: The aluminium spares of the

other two sections are also under fabrication at CERN by TS/MME.

Changes: Fixed bake-out equipment inside RICH2 has been replaced with a removable one to ease access to UX85/3.

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

Plans: Bake out the whole vacuum chamber in May 2007 and complete commissioning. Finish fabrication of the aluminium spare sections at CERN and perform their acceptance tests and NEG coating.

2.2 Magnet

The magnet was fully commissioned already in 2005.

Changes: None.
Concerns: None.

Plans: Test the combined operation with the compensator magnets (LHC machine).

2.3 Vertex Locator (VELO)

In early November 2006, the right-half detector base with 10 mounted sensor modules was commissioned in the H8 test beam together with the final HV and LV power supplies and the final readout electronic chain. The alignment constants were derived from the data and the stability of the modules in a realistic operation environment was established. The final (42nd) module was delivered to CERN in February 2007. The burn-in process kept pace with the delivery and the last module was mounted on the base in March 2007. Two of the four Pile-Up modules have been successfully mounted and one complete half of the VELO has been surveyed with a 3D measuring machine. Electronics board production is finished and 30% of them have been tested. Installation of the long distance signal cables, as well as the control and power cables is due for completion by mid April 2007. The RF boxes were transported to CERN, NEG coated, and installed in the VELO vessel in December 2006. They have undergone leak test and bake out. During the test, leaks were discovered in the RF boxes, which had not been present before. There is no immediate consequence for the LHC operation in coming few years, and evacuation and venting procedures compatible with the LHC running for this period have been established. However, the LHC vacuum group has expressed a serious concern about the quality of the machine vacuum when the beam current would reach the design value. For this reason, production of replacement RF boxes is now under study. The vacuum vessel and the evacuation and venting procedures have been commissioned.

Changes: CAEN LV delivery has been delayed to the end May.

Concerns: Leak developed in RF boxes. Funding profile for ECS component of VELO.

Plans: Install remaining pile-up modules, survey second VELO half, and dress halves ready for installation starting June 2007. Install and connect LV and HV systems. Finish construction and install the CO_2 cooling system. Commission VELO interlock system.

2.4 Outer Tracker

All straw-tube modules have been installed in the aluminium C-frame supports. During the installation, the modules as well as the services to the C-frames (gas, cooling, HV, LV, fast and slow control, data fibres etc.) have been re-tested and the resulting quality assurance data have been stored. The detector has been aligned and surveyed, and the RASNIK alignment monitoring system has been installed and tested. Most of the cabling from the counting house to the detector through patch panels has been completed and tested. The LV and HV power supplies have been installed and connected to the detector C-frames. They

are currently commissioned together with the development of the control software. About 50% of the Front-End Electronics (FEE) has been produced and one detector station has been equipped with the FEE. The commissioning of this station has started using the Commissioning Rack (CRACK), prepared by the Online group, with the data acquisition and the FEE and TELL-1 control software. Noise studies have been carried out and the timing stability has been checked with test-pulses. For the observed gain loss under irradiation discovered for the production modules, it was found that long-term flushing and heating of the straw-tube modules were effective to reduce the effect. Preparation to apply them in situ is ongoing. For recovery, positive and negative HV training procedures were established. However, they do not prevent the reappearance of the gain loss. The consequences from the gain loss on the actual operation of the LHCb experiment are still under study.

Changes: None.

Concerns: Delay in the production of the Front-End Electronics and in the construction of the infrastructure needed for the maintenance and service for the upper part of the detector. Loss of gain under irradiation.

Plans: Complete the production and installation of the FE electronics. Make the second (final) alignment and survey of the detector. Prepare for in situ heat treatment.

2.5 Silicon Tracker

The production and quality assurance programme of detector modules for TT is now completed, including 15% spare modules. The quality of the modules is very good and the fraction of bad readout strips is below one per-mil. The production of IT modules is still ongoing, about 290 out of the foreseen 384 modules, including 15% spares, have been completed and fully tested. The TT support frames and detector box have been installed and surveyed. After the C_6F_{14} cooling system is connected and the beam pipe baked out, the first modules will be installed. The IT support frames have been cabled up and installed, and an initial survey has been performed. The second IT detector box is currently being equipped with modules. A test stand that will permit to check a fully equipped detector box in the laboratory is being set up. Each box will be tested in the laboratory before being installed in LHCb. All the Service Box crates have been assembled and tested. The full batch of 712 digitizer boards has been delivered, and testing of the boards is ongoing. One problem has been identified that requires a minor modification on all the boards. In addition, about 50% of the boards have one or more faulty VCSEL diodes, which need to be replaced. The repair work is scheduled to start very soon and is expected to finish by May. Pre-series Service-Box control cards have been tested successfully and the series production of 60 boards has been launched. Additional manpower for ST-specific slow-control software has been found.

Changes: None.

Concerns: Very tight schedule for IT module production, testing and box assembly. Delays in readout electronics. Outstanding contribution from Spain.

Plans: Complete the production and quality assurance of IT modules. Assemble, test and install IT detector boxes, followed by commissioning. Install TT detector modules and start commissioning. Complete and commission readout electronics. Continue work on the development of detector-specific software.

2.6 RICH

The gas enclosure of the RICH-1 detector has been installed, and all external seals (including the beam pipe seal) have been leak-tested. The four spherical carbon-fibre mirrors have

been manufactured by CMA in US, and coated for reflectivity by SESO in France. All parameters, including the focus quality, the radii of curvature and reflectivities, exceed expectations. The alignment of the spherical and flat-mirror system is now proceeding prior to installation. The manufacture of the RICH-1 photon detector housing is currently underway. The full Aerogel production of 16 tiles has been completed and a trial installation of the Aerogel box and the mirror mechanics will soon take place. The RICH-2 detector has long been installed and the optical system has remained stable. The experimental and detector control systems (ECS and DCS) are ready, and full commissioning of RICH-2 through the 100m data links and off-detector readout will soon start. The photon detector cohort of 484 HPDs is now ready to be installed, with 500 HPDs delivered to the test centres. Additional 50 spare tubes are currently being produced. The quality of the tubes is excellent; the average quantum efficiency is above the contract specification and the tube rejection rate is only 3%. All HPDs, with their ancillary electronics, have been mounted into RICH-2, and also the upper half of the RICH-1 HPD columns have been fully populated. The on-detector electronics production has now been completed, and the off-detector Level-1 electronics boards are well into production. A system test of three production HPD columns at the CERN H8 test beam with 25ns bunch structure was successful, and a Cherenkov-ring reconstruction and alignment challenge, using the final RICH software, is well advanced. RICH calibration procedures, both in hardware and using physics data, are in advanced preparation.

Changes: None.

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

Plans: Begin commissioning of the full RICH-2 detector with the final experimental and detector control systems, HV, LV and Level-1 systems in May 2007. Complete the electronics production (Level-1) by June. Finish HPD production and testing (including spares) by June 2007. Finish populating RICH-1 columns with HPDs and electronics by June 2007. Start commissioning the completed RICH-1 detector by July 2007.

2.7 Calorimeter

One half of the ECAL and HCAL detectors have been fully tested up to the Front-End (FE) electronics using the LED monitoring systems, and all of the FE modules have been delivered and installed. The full readout chain including all calorimeter sub-detectors up to the DAQ (TELL-1 boards) and including the Level-0 calorimeter trigger is being validated on a dedicated test bench. The commissioning of the Preshower (PS) and Scintillator Pad Detector (SPD) sub-detectors using the LED monitoring system is progressing well. The cabling from the PS and SPD Very-Front-End (VFE) cards to the FE crates started with some delay but is now proceeding according to schedule. All of the PS/SPD VFE electronics cards have been produced, tested and are currently being installed on the detector periphery. The series production of the FE cards for the PS has started with considerable delay and 16 pre-series cards are now available. The testing and installation of the cards from the series production will take place in parallel with the detector commissioning activities, and is expected to finish by June 2007. The implementation of the monitoring and HV systems as well as of the various detector controls, and related software is well advanced. Global calorimeter commissioning with the full readout chain and trigger logic, involving a slice of all calorimeter sub-detectors is scheduled to start around mid April 2007.

Changes: None.

Concerns: Still very tight schedule for the production and testing of the PS/SPD FE cards.

Plans: Start the global calorimeter commissioning in mid April 2007.

2.8 Muon

The production of Muon Chambers (both MWPC and 3-GEM) was completed at the end of 2006. The construction of 10% spare chambers will be launched within the coming six months. The chamber dressing with Faraday cages has been completed for the M2-M5 chambers and the Front-end Electronics (FE) installation is well advanced. The delivery of CARDIAC FE-boards is now progressing well. Because of delays due to the burn-in procedure, the FE installation has to proceed in parallel with the chamber installation. The Off-Detector Electronics boards are in production and under test. A test of the complete readout chain was successfully performed in the special 40 MHz test beam in the end of 2006. The HV system has been ordered and delivery is in progress. Installation of the muon system in the pit started in November. A total of 650 chambers have been installed: 100% of the C-side is completed and installation of the A-side started. Chamber testing and alignment are ongoing in parallel with the installation. Installation of gas and cables on the A-side restarted after the insertion of the beam pipe and is to 50% complete. The racks with the off-detector electronics are being cabled. Work on the ECS and on software for the system commissioning, time alignment, run control is progressing well. Design of M1 infrastructure is in progress and panels have been ordered.

Changes: More parallel work during the installation phase.

Concerns: Manpower for chamber installation and commissioning. Delays in M1 integration and installation.

Plans: Complete installation and commissioning of the M2-M5 system, including the electronics and HV system. Complete infrastructure and services. Install M1 chambers partially and commission them. Order material for spare chambers and launch production.

2.9 Trigger

Last PRRs have been successfully completed for the Level-0 pile-up boards and for the Level-0 Calorimeters SPD control board. Two pile-up modules have been mounted on the VELO detector base and the remaining two are in production. Production of the Level-0 trigger boards is running smoothly: 58% are ready and tested, and 35% are in production. The commissioning of the Level-0 Decision Unit and the Level-0 Muon trigger started in February 2007 and of the Level-0 Calorimeters triggers in April 2007. A version of the High Level Trigger (HLT) algorithm that can be used to benchmark CPUs for the event filter farm has been produced and is in use with simulated data. Modification of the selection strategy to profit more from the 1 MHz readout scheme is progressing. In the new scheme, Tracking Stations, Muon Stations and ECAL/HCAL information is available at an earlier stage than that with the old 40 kHz readout scheme. With this information, transverse momentum can be determined with a good precision for a few charged tracks selected in the earlier stage of the HLT. A combination of the impact parameter and transverse momentum for those tracks provides a sufficient reduction factor for the next stage. The HLT flow allows the commissioning and monitoring in an optimal manner. A new strategy to divide the bandwidth among the different components of the Level-0 trigger that takes into account the performance of the HLT has been defined.

Changes: None.

Concerns: Tight time schedule for production of the Level-0 electronics.

Plans: Produce and test all Level-0 trigger boards and install them in the experiment. Start tuning HLT once off-line selections for benchmark channels is matured. Prepare a version

of HLT for engineering run, emphasizing the monitoring aspects rather than its performance.

2.10 Online

Installation of the online system is progressing. The control system hardware (Control PCs, Interfaces for CAN and SPECs bus as well as Ethernet equipment, etc) is being installed in the barracks. The Control Network is operational and being used to test the online system hardware installed. The Timing and Fast Control system is installed and cabled. Commissioning Racks are extensively used for local activities by the subsystems. Out of 310 required TELL-1 modules, 270 have been produced and tested. They are now being installed cabled and tested progressively. Installation should be finished by the end of April 2007. Enough modules for the initial detector commissioning are available and installed. Building and integration of subdetector DCS and ECS components progress. Monitoring and Histogram project are on track and making good progress. Data Acquisition system infrastructure (Networking, racks, etc.) is ready and one sub-farm is installed. The network and the sub-farm are used to test the connectivity of the installed TELL-1 boards. Testing of file-writing and of the link to tape storage at the computer centre (Tier-0) is in progress.

Changes: None.

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

Plans: Continue installing equipment and get ready for detector commissioning.

2.11 Computing

The physics quality reconstruction software was released prior to Christmas 2006 and is currently being used in production. Progress is still being made to improve the tracking software performance and speed, and to adapt tracking for the 2007 engineering run conditions at $\sqrt{s}$ = 900 GeV. Further improvements to tune the particle identification, for charged and neutral particles are still being made. The software framework for the Tracking Station alignment is available and work progresses towards a global tracking alignment challenge. The distributed database aspect of the original alignment challenge has been completed successfully. The testing and development of the computing model continues. A decision has been reached on how best to stream the data from the experiment directly, as well as output from the stripping stage of the data processing. Full DAQ-T0-T1 data chain stress tests are envisaged for summer 2007. The necessary tools are in place and have been exercised. The ongoing LHCb Data Challenge continues to be plagued with data access problems. We are working closely with the sites, the LCG project and middleware developers to resolve the problems. On the other hand, Monte Carlo production is running smoothly. Many useful lessons with regard to operational issues have been learnt during the data challenge.

Changes: Global detector alignment aspect of the alignment challenge to be completed by June.

Concerns: Stability of the LCG infrastructure and development of middleware issues associated with data access.

Plans: Continue evaluation of computing model. Production for physics analysis.

3. Experimental Area

The last main infrastructure issue is the completion of the radiation shielding wall dividing the UX85 cavern into two areas. All the components are available at P8. The erection of the upper part started in March 07 and its completion is foreseen for the end of May 07. Installation of the front part and mobile plug are in preparation. Its completion is scheduled

for August 07. Gas piping work on the gantry started in November 06, but the advancement is very slow. Corrective action is being taken. Other detector services such as cooling systems are progressing as scheduled. Almost all the long distance cables have been installed and installation of the short distance cables is progressing well.

Changes: None

Concerns: Cool-down programme of the cryo-lines of the 8-1 for June 2007 (no major conflicts with the LHCb co-activities expected). Many parallel activities in the experimental area, mainly in the VELO-TT and RICH1 area. Presence of the beryllium beam pipe in the experiment during the sub-system installation work.

Plans: Complete the radiation shielding wall and gas piping.

4. Cost and Funding

At the time of the last RRB meeting on 24th of October 2006, the LHCb under-funding was 1.302 MCH with pending requests to the funding agencies in ES (20 kCHF), IT (200 kCHF), US-NSF (450 kCHF) and UK (400 kCHF). Since then, Spain and UK have confirmed their extra contributions by the requested amount. The request by the University of Syracuse to the NSF for a funding period of 2007 to 2009 has not been accepted for this year due to missing resources. However, the NSF agreed to grant 30 kCHF for 2007 for CPUs at IP8 via Syracuse. In the mean time, France has decided to provide 300 kCHF as their extra contribution to the completion of the experiment, in addition to 500 kCHF they had already agreed to provide in addition to their original MoU contribution. Further, Brazil has granted 55 kCHF as their contribution to the CPU farm. This is the first Brazilian contribution to the LHCb detector. Both the Brazilian and UK contributions have already been transferred to CERN. In conclusion, the current under-funding is reduced to 497 kCHF. Taking into consideration the cost of the CPUs of 3.420 MCHF, there is no immediate problem with this level of under-funding. However for mid and long-term, not only the CPU farm has to be completely equipped in order to fully exploit the physics programme at physics optimised luminosities, but we also have to consider the purchase of a replacement beryllium section of the beam pipe, UX85/3, as explained in Section 2.1. Although the production cost for this is not yet known, it is believed that a substantial amount of additional funding will be required for its purchase.