

LARGE HADRON COLLIDER COMMITTEE

LHCb COMPREHENSIVE REVIEW

February 2005

1. EXECUTIVE SUMMARY

The third of the LHCC Comprehensive Reviews of LHCb took place on 31 January – 1 February 2005. The LHCC referees addressed the following areas: Vertex Locator, Inner Tracker and Trigger Tracker, Outer Tracker, RICH Detectors, Calorimeters, Muon System, Trigger & Physics, Online System & Computing, and the topics of Management, Technical Coordination, Integration, Schedules and Costs.

Since the previous Comprehensive Review in January 2004, 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 LHC operation in 2007 provided the timely delivery of the sub-detectors and the smooth advancement of the production schedules is ensured.

Detector technologies to be used have successfully gone through the R&D phase and construction of final components is well underway. The Electromagnetic Calorimeter (ECAL) is ready for installation, while the Hadronic Calorimeter (HCAL) is nearly ready for putting in its final position and will meet its installation milestone. Installation of the infrastructure and technical services in the experimental area are well advanced. Issues concerning interference due to the installation of LHC Machine components in the LHCb experimental hall that could potentially cause delays to the LHCb installation are being addressed. The LHCC noted as a concern the delays and resulting tight schedules in the production of the Vertex Locator (VELO), Trigger Tracker, RICH-1, and Muon System.

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

- The LHCC noted the good progress in the sensors, Hybrid electronics and Pitch Adaptors but expressed concern at difficulties experienced in the ancillary systems particularly the RF box, and bellows. The request for test beam in 2006 for the VELO was noted.
- Good progress was reported on the Inner Tracker and Trigger Tracker. The Committee will continue monitoring the status of sensor delivery and ladder production for the Trigger Tracker as these items are now on the Trigger Tracker critical path.
- Good progress was reported on the Outer Tracker, with its module production, infrastructure and read-out electronics advancing according to schedule. Studies of ageing effects of the Ar/CO₂ gas need to be continued and completed.

- Good progress was reported in all areas for the RICH-1 and RICH-2, including the mechanics, optics, magnetic shielding, and read-out electronics. The major outstanding concerns remain with the tight schedules for both the RICH-1 installation and production of the Hybrid Photo Detectors (HPDs).
- Significant progress was reported on the calorimeters. No major concerns were raised for the LHCb calorimeters. Construction of the calorimeters is either complete or well-advanced and good progress was reported on all ancillary systems.
- Production of MWPC detectors and the associated read-out electronics has started. The Muon Filter is almost complete. The overall schedule is tight but conceivable and a significant amount of work remains for 2005-2006. The LHCC awaits submission of the Addendum to the LHCb Muon System Technical Design Report describing the 3-GEM detector for the M1 Inner Station.
- Good progress was reported on the Level-0, Level-1 and High Level Trigger (HLT). The LHCC concurs with the new LHCb approach of increasing the role of data for calibration and checking of systematics.
- Good progress was reported on the Online System and Computing and no major concerns were noted. LHCb is on schedule to submit the Computing Technical Design Report in June 2005. The LHCC considers that the planned tests for the Online System are essential and encourages the group to continue preparing these tests.
- 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 operation in 2007. Installation of the LHC cryogenics line junction in the UX85 cavern has a very strong impact on the overall LHCb installation schedule. Issues related to over-costs in the RICH and Muon System are being dealt within the Resource Review Board.

3. VERTEX LOCATOR (VELO)

Production of the VELO components is advancing. Fabrication of the final sensors has started, the order for the series Hybrid electronics circuits is about to be placed and the Pitch Adaptors will follow upon the launching of the Hybrid order. Tests on the irradiated pre-production PR-04 module are continuing. The problem of delamination with the Hybrid/Substrate bonding has been solved and studies on the thermal cycling are continuing. Assembly of modules, and in particular the double-sided bonding, has not yet been tested, and the Committee requests a more detailed schedule for the module production. Prototyping and fabrication of the VELO electronics boards are progressing well and analysis of data collected on the whole read-out chain, including the BEETLE chip, in test beam in November 2004 is ongoing. The choice of the final BEETLE chip is scheduled to be made in March 2005. Investigations to understand the source of cross-talk observed in the beam tests are ongoing and the results will be presented to the Committee.

The status of the ancillary systems was reported. The mechanical stand, centre frame and positioning system have been delivered and tested. Two possible solutions – carbon-carbon block and aluminium cast block - are being studied for the interface between the substrate and CO₂ cooling system, with a decision needed soon. The first RF box has been produced but failed the vacuum test. A second RF box is currently being welded. The vacuum vessel will arrive at the end of February 2005, which represents a 4-5 month delay. The full-size welded prototype of the large rectangular bellows failed the ageing tests and a new bellow based on a 'folded' design has been prototyped and tested successfully.

The LHCC took note of the request for test beam in 2006 for the VELO. The aims of the tests consist of alignment studies, testing of the overall software chain and work towards pre-commissioning the detector, including the trigger, for a faster turn-on of the detector for the first LHC run.

The LHCC noted the good progress in the sensors, Hybrid electronics and Pitch Adaptors but expressed concern at difficulties experienced in the ancillary systems particularly the RF box, and bellows. The request for test beam in 2006 for the VELO was noted.

4. INNER TRACKER (IT) AND TRIGGER TRACKER (TT)

Good progress was reported on the Inner Tracker. The final design, which includes a minimal amount of material, is being implemented into the Monte Carlo simulation. Production of ladders is starting and the IT detector installation schedule and the level of the available manpower are considered to be reasonable. The prototype mechanical structures are available. However, despite using the 410- μm thick Silicon sensors, the low signal-to-noise ratio remains a concern.

Design of the Trigger Tracker is being finalized. The production chain for the ladders has been set up and the installation schedule has been developed. The outstanding issue remains with the timely delivery of sensors and possible conflicts with the supply of sensors for the CMS Outer Barrel detector. The ladder production schedule is largely untested. The Committee will continue monitoring the status of sensor delivery and ladder production as these items are now on the Trigger Tracker critical path.

Good progress was reported on the Inner Tracker and Trigger Tracker. The Committee will continue monitoring the status of sensor delivery and ladder production for the Trigger Tracker as these items are now on the Trigger Tracker critical path.

5. OUTER TRACKER

Production of Outer Tracker modules is on schedule with nearly all material being available. Completion of module assembly by the end of 2005 is possible but the schedule has no contingency left and it is unclear whether the manpower effort can be sustained over the required time. Production of the Outer Tracker infrastructure, including the mechanical support structures, is advancing well.

Final components for the read-out electronics – the ASDBLR, OTIS and GOL/AUX - are available and have been tested. Full system tests are scheduled to start in March 2005. Although the start of the series production has been delayed, this is considered not to be critical.

Severe ageing effects with baseline gas mixture Ar/CO₂/CF₄ have been observed during highly-accelerated ageing tests leading to the decision to operate the chambers without CF₄. Long-term ageing tests with Ar/CO₂ and with the complete gas system are continuing, with the option to add CF₄ at a later stage being maintained.

Good progress was reported on the Outer Tracker, with its module production, infrastructure and read-out electronics advancing according to schedule. Studies of ageing effects of the Ar/CO₂ gas need to be continued and completed.

6. RICH DETECTORS

Good progress was reported on the RICH-2 and construction of the detector is according to schedule. Assembly of the superstructure, vessel, windows and beam-tube is complete. The magnetic shielding for the Hybrid Photo Diodes with pixel read-out (HPDs) has been assembled and tested and the design of the HPD mounting mechanics is complete and tested in beam. Most of the spherical glass mirrors have been produced and tested and the mirror support and mirror alignment is also complete and tested. A prototype of the mirror alignment system has been tested.

The design of the RICH-1 is well-advanced for the critical path items. Manufacture of the first beryllium mirror is underway but the LHCC will continue monitoring its production because of failures and delays in the first stages of the production. Manufacture of the main mechanical units will be done during 2005. The Committee considers that the milestone for installation in LHCb by the end of 2005 is tight.

Good progress was reported on the HPDs. Production of wafers and probing for the read-out chips is completed with a better-than-expected yield. The first two batches of read-out chips have been delivered on schedule. Fabrication of the ceramic carriers is complete. All technical problems reported at the last Comprehensive Review and been solved and the signing of the HPD contract is now imminent. However, HPD production has slipped by three months and remains one of the critical issues.

The Committee took note of the continuing studies to integrate the particle identification capabilities of the RICH detectors into the High Level Trigger and of the good progress in the development in the individual system components.

Good progress was reported in all areas for the RICH-1 and RICH-2, including the mechanics, optics, magnetic shielding, read-out electronics. The major outstanding concerns remain with the tight schedules for both the RICH-1 installation and production of the Hybrid Photo Detectors (HPDs).

7. CALORIMETERS

Significant progress was reported on the calorimeters. The Electromagnetic Calorimeter (ECAL) is ready for installation, while the Hadronic Calorimeter (HCAL) is nearly ready for putting in its final position and will meet its installation milestone. Fabrication of PMTs for the ECAL and HCAL is also finished while that for the Cockcroft-Walton bases is well-underway. Production of the Preshower (PS) and Scintillator Pad Detector (SPD) is well-advanced. Measurements on the first delivered Multi-anode PMT (MaPMT) show a significantly deteriorated behaviour of the tube in the magnetic field. This problem has been solved by the addition of magnetic shielding around the tubes. Integration and installation procedures are under control. Good progress was also reported for the read-out electronics and LED monitoring system but the schedule of the former has become tight due to the change in the FPGA of the CROC card which provides the interface to external systems. The unexpected low quality of fibres for the PS and SPD detectors has resulted in the implementation of more stringent Quality Control procedures requiring additional manpower. The overall calorimeter schedule is considered to be reasonable, but attention needs to be paid to potential conflicts with the installation of the LHC machine cryogenic equipment.

Significant progress was reported on the calorimeters. No major concerns were raised for the LHCb calorimeters. Construction of the calorimeters is either complete or well-advanced and good progress was reported on all ancillary systems.

8. MUON SYSTEM

Production of the MWPC chambers has started at all sites except at PNPI-2. The milestone of 10% production has been past in November 2004 but with a seven month delay. The schedule will be re-assessed in March 2005 when all six production centres are up and running. The production rate and yield are as expected and the complete Quality Control and Quality Assurance procedures have been implemented.

Good progress was reported on the read-out electronics. Engineering runs of the chips – CARIOCA, CARIOCA_GEM, DIALOG and SYNC – were submitted in September 2004 and packaged circuits will be received shortly. Fabrication of the front-end boards started in 2004 but modifications to the CARDIAC, IB and ODE boards are needed to finalise the design. The overall electronics schedule is tight but doable provided the engineering runs are successful.

Construction of the Muon Filter is advancing well with filters MF-1 to MF-3 having been assembled. MF4 is delayed owing to difficulties with the installation of the LHC machine cryoline. The MF4 support structure has been assembled.

Preparations for the logistics are underway. Dressing of the MWPC with front-end electronics has been defined and is awaiting the first batch of the units to be checked. The

shipping procedures have also been defined but need to be examined and the testing procedures at CERN need to be analysed.

Integration of the M2-M5 stations is progressing but a significant amount of work remains to be done in the coming two years. Integration of the M2-M5 stations is progressing while that for the M1 station still needs designing. Production of the support structures and chamber mechanical support panels is on the critical path.

The Committee took note of the status of the 3-GEM detector intended for the high-rate region in front of the ECAL. The choice of such detector technology has been adopted in April 2004 and the Addendum to the Muon System Technical Design Report is under preparation and will be submitted to the LHCC.

Production of MWPC detectors and the associated read-out electronics has started. The Muon Filter is almost complete. The overall schedule is tight but conceivable and a significant amount of work remains for 2005-2006. The LHCC awaits submission of the Addendum to the LHCb Muon System Technical Design Report describing the 3-GEM detector for the M1 Inner Station.

9. TRIGGER AND PHYSICS

Good progress was reported on the Level-0, Level-1 and High Level Trigger (HLT). The Testing of the L0 Calorimeter trigger prototype is ongoing and commissioning is scheduled for spring 2006 and the first processor for the L0 Muon trigger will be delivered to CERN in spring 2006. Steady improvements in the L1, HLT trigger and reconstruction algorithms were reported. Improvements to the Monte Carlo event generation were also reported.

The LHCC took note of the new LHCb approach to increase the role of data for calibration and checking of systematics and to minimize the dependence on the Monte Carlo sample. The Committee considers this approach to be reasonable provided that the flexibility to adapt the trigger rate to different requirements is maintained.

Good progress was reported on the Level-0, Level-1 and High Level Trigger (HLT). The LHCC concurs with the new LHCb approach of increasing the role of data for calibration and checking of systematics.

10. ONLINE SYSTEM AND COMPUTING

The LHCb Online System consists of three major sub-systems: the Data Acquisition System (DAQ), the Timing and Fast Controls (TFC) and the Experiment Control System (ECS). Good progress was reported on the DAQ front-end electronics and event building. Most components for the TFC have been procured and the minor problems which have arisen in 2004 are being addressed and solved. Good progress was also reported on the complex and mainly software-oriented ECS.

Steady progress was reported on GAUDI – the LHCb software framework - on the Conditions Database and alignment framework, and on the DIRAC Workload Management Software. Their functionality is continuously being increased and integration with the LHC Computing Grid Project has started. The reconstruction project is also progressing well. Data Challenge 2004, which has the aim of gathering information to be used for preparing the LHCb Computing Technical Design Report, to be submitted in June 2005, is well-underway but Phase II, consisting of the data stripping, has been delayed due to limitations in the current functionality of the Storage Resource Management of the LCG.

The LHCC endorses the plan to run a Real Time Trigger Challenge in 2005 to operate one or more trigger sub-farms under realistic conditions, although it must be recognized that the through-put of the read-out network cannot be fully tested before the final system is in place, and thus remains a risk. The Committee recommends that the performance of the read-out network be simulated including the back-traffic, which has not been considered so far.

Good progress was reported on the Online System and Computing and no major concerns were noted. LHCb is on schedule to submit the Computing Technical Design Report in June 2005. The LHCC considers that the planned tests for the Online System are essential and encourages the group to continue preparing these tests.

11. MANAGEMENT, TECHNICAL COORDINATION, INTEGRATION, SCHEDULES AND COSTS

Much progress was reported in the experimental hall. Assembly of the Dipole Magnet has been completed and the magnet has been commissioned in its final position. Operation of the magnet at its nominal current is according to specification. The field mapping will be done in 2005. Installation of the infrastructure and technical services is advancing well. This includes the on-time installation of the RICH-2 and Outer Tracker common support structure, the Calorimeter rails and all four calorimeter chariots have been placed on rails earlier than planned.

Production of the experimental beam pipe is well-underway and pre-assembly of the complete pipe on the surface is scheduled for October 2005 with installation in the UX85 underground cavern expected in spring 2006.

The Committee took note of the overall LHCb schedule. Installation work is progressing well, but the overall schedule is tight and depends on the timely delivery of the sub-detectors and on the smooth advancement of the production schedules. Installation of the LHC cryogenics line junction in the UX85 cavern has a very strong impact on the overall LHCb installation schedule. All large LHCb structures must be installed prior to October 2005 so that the magnetic field mapping can commence. This in turn requires the completion of the cryogenics line junction to be completed by June 2005. Completion of detector installation is scheduled for November 2006 and closure of the area in April 2007.

The LHCC reviewed the costs of the experiment. All sub-systems except for the RICH and Muon System are within the Memorandum of Understanding cost estimates. The Committee urges the LHCb to resolve the outstanding cost issues soon via the Resource Review Board.

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 operation in 2007. Installation of the LHC cryogenics line junction in the UX85 cavern has a very strong impact on the overall LHCb installation schedule. Issues related to over-costs in the RICH and Muon systems are being dealt with in the Resource Review Board.

E. Tsesmelis