DRAFT
CERN/LHCC 2003-006
LHCC-G-025
18 February 2003

LARGE HADRON COLLIDER COMMITTEE

LHCb COMPREHENSIVE REVIEW
January 2003

1. EXECUTIVE SUMMARY

The first of the LHCC Comprehensive Reviews of LHCb took place on 27-28 January 2003. The LHCC referees addressed the following areas: Vertex Locator and Inner Tracker, Outer Tracker, RICH Detectors, Calorimeters, Muon System, Tracking Performance, Trigger, Computing and Software, Physics Performance and the topics of Management, Technical Coordination, Integration, Schedules and Costs.

Since the approval of the Technical Proposal in 1998, 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 and the LHCC expects LHCb to have a working detector installed in time for the beginning of LHC operation in April 2007.

In particular, all detector technologies to be used, except for the RICH photodetector, the TT station, the inner part of the M1 muon chamber and the full-length Outer Tracker, have successfully gone through the R&D phase and construction of the final components has either started or is imminent.

The re-optimisation of the LHCb detector has led to a more elegant experiment and with the same physics performance as specified in the Technical Proposal. The LHCC awaits submission of the LHCb Re-optimisation Technical Design Report and related Trigger Technical Design Report in September 2003.

The LHCC noted as a major concern the delay in the choice of photodetector for the RICH. The Committee encourages focused studies of the Hybrid Photo-Diode (HPD) and Multi-Anode Photomultiplier (MAPMT) options with the aim of the final decision to be taken in September 2003.

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

- Good progress was reported on the Vertex Locator (VELO). The LHCC considers that the interface of the VELO secondary vacuum to that of the LHC machine is the most critical issue but is being handled satisfactorily. The LHCC recommended general approval of the Inner Tracker Technical Design Report. Although the Committee has no major concerns, it noted that the signal-to-noise ratio of the long ladders is marginal and that also the physics performance will be re-visited in view of the LHCb detector re-optimisation.

- The LHCC noted that the Outer Tracker has been reduced to three stations in the re-optimised LHCb set-up. Preparation for production of the chambers and the read-out electronics is progressing well. Certain further studies related to the evaluation of the full-length chambers and the detector's ageing characteristics remain outstanding.
- The RICH detectors are progressing well. Re-engineering of the RICH-1 detector is approaching completion. The major concern remains the delay in the choice of photodetector. The Committee encourages focused studies of the Hybrid Photo-Diode (HPD) and Multi-Anode Photomultiplier (MAPMT) options with the aim of the final decision to be taken in September 2003.
- No major concerns were raised for the LHCb calorimeters. Construction of the ECAL and HCAL calorimeters is progressing well and the start of the SPD and PS construction is imminent. Although the electronics schedule is tighter, the main components are close to their final design and have already undergone extensive prototyping.
- The LHCC recommended general approval of the Addendum to the Muon System Technical Design Report. The Muon System is moving into its production phase, albeit with a tight production schedule. The choice between Triple GEM and MWPCs for the inner regions of the first muon station M1 will be made in the summer 2003.
- The LHCC noted the impressive progress made in studying the tracking performance of the re-optimised LHCb detector. The tracking resolutions (vertex, proper time and mass resolutions), together with the overall physics potential are similar to those described in the Technical Proposal, but with the results having been obtained with a more realistic Monte Carlo.
- The particle identification performance of the RICH, Muon System and Calorimeters, with the exception of an increase in the pion misidentification as kaons, which must be optimized further, is comparable to that quoted in the respective Technical Design Reports and satisfy the requirements of LHCb.
- The trigger system is considered vital to the success of the LHCb experiment. Although the first studies of the trigger are encouraging, further detailed work is in progress leading up to the submission of the Trigger Technical Design Report in September 2003.
- Good progress was reported on the LHCb Online System. In addition, the Committee noted the carefully designed software framework and the provision of common components and tools, developed in part with EP Division and the LCG, for the offline software. Migration of the software to C++, as well as event Monte Carlo production and the Data Challenges, are well-underway.
- Although the physics performance study is still preliminary, event yields indicate that the physics aims given in the Technical Proposal will be met with the re-optimised LHCb detector. Further work is needed to complete the physics assessment and should include a detailed evaluation of systematic uncertainties.
- The LHCC considers that although a significant amount of work lies in front of the experiment, it is realistic to expect LHCb to have a working detector installed in time for the beginning of LHC operation in April 2007. The LHCC also noted that the LHC Machine schedule has implications to the LHCb detector installation and the issue will be followed up in the March 2003 LHCC Installation Review.

3. VERTEX LOCATOR (VELO) AND INNER TRACKER

Good progress was reported on the VELO. After detailed evaluation, the BEETLE front-end chip has been selected over the alternative SCTA_VELO. The BEETLE is based on 0.25 μm technology, is radiation-hard and production is of high yield. 16-chip hybrids have been constructed and tested successfully. Design of the sensors is pending and a review will be held in February 2003 to finalise the strip lay-out and outer dimensions

while taking into account the re-optimised LHCb detector. The most critical items lie with the interface of the VELO secondary vacuum to that of the LHC machine. However, following the successful production of a full-size prototype and a second review with the LHC machine groups, go-ahead for the start of production of the secondary vacuum system has been given. The LHCC has requested a progress report in May 2003 covering particularly the status of the strip lay-out design together with a detailed schedule and plan for the construction and installation.

The Committee finds the detector technology proposed for the Inner Tracker adequate to achieve the physics goals stated in the Technical Proposal and recommended general approval of the Inner Tracker Technical Design Report. Although the Committee had no major concerns, it noted that the signal-to-noise ratio of the long ladders is marginal and also that the physics performance will be re-visited in view of the LHCb detector re-optimisation. In addition, the LHCC noted that further R&D is needed for the Trigger Station (TT). The design of the TT should be finalised in time for the submission of the LHCb Detector Re-optimisation Technical Design Report in September 2003.

Good progress was reported on the Vertex Locator (VELO). The LHCC considers that the interface of the VELO secondary vacuum to that of the LHC machine is the most critical issue but is being handled satisfactorily. The LHCC recommended general approval of the Inner Tracker Technical Design Report. Although the Committee has no major concerns, it noted that the signal-to-noise ratio of the long ladders is marginal and that also the physics performance will be re-visited in view of the LHCb detector re-optimisation.

4. OUTER TRACKER

The re-optimisation of the LHCb detector has led to the reduction of the number of tracking stations from 9 to 4, of which three constitute the Outer Tracker. The performance of the detector was studied at the time of the Technical Design Report in 2001 and is found to be adequate to meet the physics goals of the experiment. The preferred gas mixture is $Ar/CF_4/CO_2$ (75%/15%/10%). Although no traces of silicon were found in the system, concern remains on the possibility of etching by the CF_4 gas. A possible change of gas to the back-up solution Ar/CO_2 (80%/20%) will not change the detector design and the Outer Tracker group will continue studying both options. Preparation for production of the chambers is progressing well. However, the LHCC noted that a full-length prototype has not yet been produced, that work to ensure flatness of the straw tubes is ongoing, and that tests with high-intensity heavily-ionising particles have not yet been performed to validate the ageing characteristics of the detector. Good progress was reported on the ASDBLR and OTIS read-out electronics.

The LHCC noted that the Outer Tracker has been reduced to three stations in the re-optimised LHCb set-up. Preparation for production of the chambers and the read-out electronics is progressing well. Certain further studies related to the evaluation of the full-length chambers and the detector's ageing characteristics remain outstanding.

5. RICH DETECTORS

The basic design of the RICH-2 detector has remained unchanged since submission of the Technical Design Report in 2000 and an Engineering Design Review was completed successfully in March 2002.

However, major design changes have been proposed for the RICH-1 detector. The modifications consist of reducing the amount of material within the acceptance of the tracking stations, incorporating carbon-fibre or beryllium mirrors, including magnetic shielding for the photodetectors since a magnetic field is required by the Level-1 trigger in the region of the RICH-1 detector and including a two-mirror lay-out as for RICH-2.

The revised design is nearly complete and will be described in the LHCb Detector Re-optimisation Technical Design Report.

The most critical item concerning the RICH detectors is the timely development and choice for the photodetector. Although progress was reported on both the Hybrid Pixel Detector (HPD) and Multi-Anode PMT (MAPMT) options, further work needs to be carried-out before a final decision is made in September 2003. In particular, a solution to the problem of bump-bonding the read-out chip to the silicon is needed as a matter of urgency for the former option, while verification of the read-out electronics and evaluation of the extra costs are needed for the MAPMT. The LHCC noted that the December milestone for the HPD was not met, and the Committee strongly encourages the Collaboration to carefully review their plans and report back to the next LHCC session.

The RICH detectors are progressing well. Re-engineering of the RICH-1 detector is approaching completion. The major concern remains the delay in the choice of photodetector. The Committee encourages focused studies of the Hybrid Photo-Diode (HPD) and Multi-Anode Photomultiplier (MAPMT) options with the aim of the final decision to be taken in September 2003.

6. CALORIMETERS

Significant progress was reported on the calorimeters. The production of both the Shashlik Electromagnetic Calorimeter (ECAL) and the Hadronic Tile Calorimeter (HCAL) is well-underway. Design of the cell, module and Multi-Anode PMT (MAPMT) coupling has been completed for the Pad Detector (SPD) and for the Preshower (PS). Two module box prototypes have been built and tested successfully in beam and series production of the SPD and PS modules is scheduled to commence in March 2003. The schedule for the front-end electronics is tighter, but the major components are close to their final design and their performance matches the specifications as shown by the extensive prototyping.

No major concerns were raised for the LHCb calorimeters. Construction of the ECAL and HCAL calorimeters is progressing well and the start of the SPD and PS construction is imminent. Although the electronics schedule is tighter, the main components are close to their final design and have already undergone extensive prototyping.

7. MUON SYSTEM

The Collaboration proposed replacing the Resistive Plate Chambers (RPCs) with MWPC detectors. The reason for the change is the ageing of the RPCs as demonstrated by extensive tests at the Gamma Irradiation Facility (GIF) at CERN. The conclusions of the tests are that whereas RPCs can be built to meet the specifications of the Technical Design Report, their performance would degrade rapidly due to ageing effects, making them unable to operate at the rates expected in the required regions.

The decision to replace RPCs with MWPCs has doubled the total surface area of the latter which is now required and the organisation and responsibilities must be worked out in detail.

Station M1 has undergone design changes since the submission of the Technical Design Report in 2001. The station now has 2 wire gaps instead of 4, the structural panels are made from NOMEX honeycomb rather than polyurethane foam, the average thickness has been reduced from 33% to 15% X_0 and the two gaps are read out independently. The choice between Triple GEM chambers and modified MWPCs for the inner regions (R1 and R2) of Station M1 will be made in June 2003 following further R&D especially on ageing effects due to high particle rates of above 100 kHz/cm^2.

The LHCC finds the MWPC detector technology proposed for the muon chambers adequate to achieve the physics goals stated in the Technical Proposal and recommended

general approval of the Addendum to the Muon System Technical Design Report. Start of production is therefore imminent but the LHCC noted that the construction schedule is tight.

Good progress was reported on the read-out electronics components consisting of the main elements CARIOCA, DIALOG, and SYNC.

The LHCC recommended general approval of the Addendum to the Muon System Technical Design Report. The Muon System is moving into its production phase, albeit with a tight production schedule. The choice between Triple GEM and MWPCs for the inner regions of the first muon station M1 will be made in the summer 2003.

8. TRACKING WITH RE-OPTIMISED LHCb DETECTOR

Impressive progress was reported on the studies of the tracking performance of the re-optimised LHCb detector. Compared to the Technical Proposal, a more realistic and robust simulation of the trigger, detector description, pattern recognition and track reconstruction has been developed and used in these studies. The results show that in terms of tracking efficiency, rejection of background, reconstruction of the primary vertex, proper time and mass resolutions, the tracking performance of the LHCb re-optimised detector is similar to that quoted in the Technical Proposal and Technical Design Reports. In addition, a series of tests have been carried-out providing a measure of the robustness. Due to the present limited statistics in the background Monte Carlos, further work is needed to complete the study of the backgrounds, and the LHCC will review the status of these studies again in May 2003.

The LHCC noted the impressive progress in studying the tracking performance of the re-optimised LHCb detector. The tracking resolutions (vertex, proper time and mass resolutions), together with the overall physics potential are similar to those described in the Technical Proposal, but with the results having been obtained with a more realistic Monte Carlo.

9. PARTICLE IDENTIFICATION

Good progress was noted for the overall particle identification studies in the LHCb re-optimised detector configuration. The particle identification is based on the RICH detectors for hadrons, the Muon System for muons and the calorimeters for electrons (and neutrals). The particle identification performance of the detectors, with the exception of an increase in the pion misidentification as kaons, which must be optimised further, is comparable to that quoted in the respective Technical Design Reports and satisfy the requirements of LHCb. The current results have been found using a much-improved pattern recognition for the tracking. The revised lay-out of the tracking detectors is well-matched to the requirements of the particle identification.

The particle identification performance of the RICH, Muon System and Calorimeters, with the exception of an increase in the pion misidentification as kaons, which must be optimised further, is comparable to that quoted in the respective Technical Design Reports and satisfy the requirements of LHCb.

10. TRIGGER

The LHCC considers that a sound trigger system is needed for the success of the LHCb experiment. The design of the Level-0 hardware and architecture is robust and has reached a mature stage of development. The trigger algorithms provide a sensible trigger menu. The first studies for the software-based Level-1 trigger provide encouraging results. Adding the P_T information from the VELO and the TT tracking station to that of the displaced vertex improves the Level-1 capability and the overall algorithm execution

times and performance are good. The software Higher-Level Trigger, which is a considerable task, needs further detailing and its capability to be proven.

Although the first studies on the trigger are encouraging, the Committee concluded that it is too early to judge the ultimate overall performance of the trigger system since a considerable amount of simulation and algorithm development still needs to be done leading up to the submission of the Trigger Technical Design Report in September 2003.

The trigger system is considered vital to the success of the LHCb experiment. Although the first studies of the trigger are encouraging, further detailed work is in progress leading up to the submission of the Trigger Technical Design Report in September 2003.

11. COMPUTING AND SOFTWARE

The LHCb Online System consists of three major sub-systems – the Data Acquisition (DAQ), the Timing and Fast Controls (TFC) and the Experiment Control System (ECS) – and its architecture is that presented in the Technical Design Report. The output rates to storage are considered to be manageable and the event sizes are expected to decrease with the re-optimised LHCb detector. The design of the system is sound and a plan exists for its implementation.

An offline software framework, GAUDI, based on C++, has been developed for use in event processing applications and for which a common set of components and tools has been provided. Migration of the LHCb software to GAUDI is nearly complete. Large sets of data (up to 5 million events) have been produced successfully at several regional centers and a series of Data Challenges are planned for the future deployment and validation of the computing infrastructure and software. The LHCC also took note of the Collaboration's common software developments with EP Division and the LHC Computing Grid Project (LCG).

Good progress was reported on the LHCb Online System. In addition, the Committee noted the carefully designed software framework and the provision of common components and tools, developed in part with EP Division and the LCG, for the offline software. Migration of the software to C++, as well as event Monte Carlo production and the Data Challenges, are well-underway.

12. PHYSICS PERFORMANCE

Preliminary studies with the re-optimised LHCb detector indicate that the physics goals stated in the Technical Proposal will be reached with the new configuration. The LHCC encourages further assessment of the physics reach of the experiment as the new and more realistic simulation framework is in place. In particular, further evaluation of systematic uncertainties arising from the inelastic cross-section, and the event model describing average multiplicities and multiplicity distributions is required. Moreover, evaluation of the π^0 identification should be continued.

Although the physics performance study is still preliminary, event yields indicate that the physics aims given in the Technical Proposal will be met with the re-optimised LHCb detector. Further work is needed to complete the physics assessment and should include a detailed evaluation of systematic uncertainties.

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

The LHCC considers that the organisation of the LHCb collaboration and the management structure is adequate and efficient. It was noted that although a very competent technical coordination team has been put in place, it is found to be small in numbers, thus necessitating part-time work in certain areas. Coordination of the electronics is proceeding well. The collaboration consists of 564 physicists, engineers

and Ph.D. students from 45 institutes from 13 countries. As agreed in the Memorandum of Understanding, the cost ceiling of the experiment is set at 75 MCHF.

The LHCC took note of the LHCb schedules and milestones. The schedule is consistent with the start of global commissioning of the detector in October 2006 so that the experiment is ready for beam in April 2007. Many important milestones must be met in 2003. The LHC considers that although a significant amount of work lies ahead, it is realistic to expect LHCb to have a working detector installed in time for the beginning of LHC operation in April 2007.

Assembly of the dipole magnet at Point 8 is commencing. It is planned to be completed in September 2003 and will be followed by a field-mapping by April 2004.

Good progress was reported on the experimental area and interface to the LHC Machine. A new design of the experimental beampipe was made in September 2002 and a plan has been agreed with the LHC vacuum group. Installation of infrastructure and services at Point 8 is proceeding well. The major installation constraints are given by the LHC Machine transport and installation activities via the PX84 shaft and across the UX85 (LHCb) experimental area. The crucial period will be in 2003-2004 due to extensive LHC Machine activities and any significant delays of the LHC Machine installation at Point 8 may result in severe consequences on the installation of the experiment. Furthermore, another constraint comes from the LHC Machine injection tests, currently planned for April 2006. The LHCC noted the good collaboration between LHCb and the LHC Machine, which will facilitate resolution of outstanding conflicts at Point 8.

Installation of the LHCb experiment will be reviewed at the LHCC Installation Review of March 2003. The review will concentrate on the installation of LHCb in the underground experimental cavern, including the projected schedules and milestones and the required resources to successfully carry-out the installation.

The LHCC considers that although a significant amount of work lies in front of the experiment, it is realistic to expect LHCb to have a working detector installed in time for the beginning of LHC operation in April 2007. The LHCC also noted that the LHC Machine schedule has implications to the LHCb detector installation and the issue will be followed up in the March 2003 LHCC Installation Review.