1. EXECUTIVE SUMMARY

Since the second of the CMS Comprehensive Reviews in October 2001, the CMS Collaboration has made very significant progress towards the realisation of an experimental set-up ready for LHC operation in April 2007.

It is realistic to expect CMS to install an initial working detector suitable for the LHC pilot run starting in April 2007 and for the physics run starting in August 2007, although the completion of the detector installation can be foreseen beyond this date. The LHCC considers that the CMS schedule to achieve this is challenging. The LHCC noted that additional resources, both in terms of money and manpower, would aid in accelerating the current CMS schedule, and thereby would ensure a timely completion of the initial detector in 2007.

In the event that additional funding is not available to ensure completion of CMS in 2007 as described in the Technical Design Reports, the installation of some components of the Tracker, HCAL, Muon System, and TRIDAS will be deferred in a staging plan which has been prepared. The proposed staging plan for the experiment is aimed at having a small as possible adverse impact on the Higgs and SUSY sensitivity at a luminosity of order $10^{33}$ cm$^{-2}$ s$^{-1}$. In these circumstances, the installation of staged components, in a shutdown after the completion of the low luminosity running, while requiring additional resources, would complete the CMS detector as described in the approved Technical Design Reports for high luminosity running.


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

2. OVERVIEW

The majority of detector sub-systems are now well into the construction phase. Plans for their installation in CMS are being prepared.

The construction of the large solenoid magnet, a time-critical component of the Common Projects of CMS, is progressing satisfactorily.

Progress on problems reported at the previous CMS Comprehensive Review has been clearly demonstrated. The remaining critical items are being addressed by the Collaboration in order to recover as much as possible the incurred delays.
The LHCC considers that the Pixel Vertex Detector is progressing well but expressed its concern at the delays in the front-end drivers, power supplies and the front-end hybrid electronics of the Silicon Strip Tracker.

The Committee noted the impressive progress on the Electromagnetic Calorimeter since the last Comprehensive Review but remains concerned about the very tight schedule for the Electromagnetic Calorimeter electronics and the timely availability of funds for the purchase of the End-cap Electromagnetic Calorimeter crystals.

The LHCC noted the good progress in the Trigger and DAQ Project and awaits submission of the DAQ Technical Design Report by the end of 2002 and a detailed commissioning and integration schedule of the Trigger and DAQ.

The Committee noted the good progress in both the Physics Reconstruction and Selection as well as the Computing and Core Software projects and expressed its satisfaction with the progress.

The LHCC took note of the new CMS Master Schedule V33 and will use it henceforth to monitor the CMS milestones. Although the Committee considers it realistic to expect CMS to install an initial working detector suitable for the first operation of the LHC starting in April 2007 and for the physics run starting in August 2007, it did express its concern on the tight schedule to do so and on the outstanding critical items related to the Electromagnetic Calorimeter electronics, the timely availability of funds for the End-cap Electromagnetic Calorimeter crystals and Silicon Strip Tracker hybrids. Finally, the LHCC considers that the CMS plan to cover any shortage in the available funds to meet the costs-to-completion, amounting to 63 MCHF, is reasonable.

3. TRACKER

Good progress was reported on the Pixel Vertex Detector, with the project converging towards the final design and with no critical items having been identified. Studies in beam of the prototype PSI43 read-out chip in DMILL technology have proven the chip’s functionality and the group is now ready to move to the 0.25 μm technology. A mock-up of the experimental beam pipe and Pixel Vertex Detector insertion method provided very good agreement with the design parameters.

Progress was also reported on the Silicon Strip Tracker (SST). The sensors, mechanics, the module assembly and subsequent module testing procedures are advancing well. The project is guided by a team that is well-organised and structured and which has a reasonable plan. Problems with the Pitch Adapters identified at the previous Comprehensive Review have now been resolved.

The Committee expressed concern on the lower-than-expected batch-to-batch yield of the APV25 read-out chip. Although the yield is now improving, progress will continue to be monitored.

The Committee took note of the delays in the Front-End Drivers (FEDs) and the power supplies. The requirements for the SST in the coming years do not match what can be procured. The LHCC will monitor the effects on the overall SST schedule resulting from these difficulties.

The major critical item is the front-end hybrid electronics, the latest version of which is found not to be flat enough for reliable assembly. The potential consequences of the problem need to be understood. Orders were sent in July 2002 to industry and following reception of satisfactory prototypes, the aim is to order 300 hybrids from three different suppliers. The LHCC considers that the problem with the hybrids is solvable. As it is too early to evaluate the impact of any delays on the overall schedule and costs, the Committee requests a clear statement from the Collaboration at the LHCC meeting in November 2002 of an evaluation of the impact and a programme of measures underway for a solution to the problem.
Although series production of the modules can commence, apart from the front-end hybrids, the Committee considers that the production schedule is challenging and in order to minimize risks, care must be taken to ensure all components are available on time and that the logistics of moving them around the various sites runs smoothly. The LHCC did note that there is a 3-month contingency in the SST schedule before it is needed for installation.

*The LHCC considers that the Pixel Vertex Detector is progressing well but expressed its concern at the delays in the front-end drivers, power supplies and the front-end hybrid electronics of the SST.*

### 4. ELECTROMAGNETIC CALORIMETER (ECAL)

The LHCC noted the good progress on the production of the ECAL Barrel (EB) crystals. The crystal production is not on the critical path. About 25% of the EB crystals will be delivered by the end of 2002. Specification for the ECAL End-cap (EE) crystals has been completed and 100 pre-series crystals will be ordered soon. The bulk of the final production will start in Q4 of 2004 and is contingent on resolving outstanding funding issues. Provision of funds in 2002 to purchase the EE crystals is deemed necessary in order to ensure the timely construction and calibration of the EE. The LHCC considers that CMS is developing a reasonable plan.

The LHCC noted the challenging schedule in implementing the re-designed electronics chain. The primary change to the electronics has been to move the trigger primitive generation from the off-detector electronics on to the detector, implying that the digitized data are read out only upon a Level-1 trigger accept. This will decrease the number of data links and the quantity of off-detector electronics as well as reducing the overall complexity. The Committee is currently reviewing the Addendum to the ECAL TDR.

The Committee took note of the current calibration plan of the ECAL, which consists of beam calibration of about 10 EB Supermodules at the SPS in 2004 and the beam calibration of one EE module in 2006. A 37th Supermodule is now included in the plans and can be tested in 2006 and 2007, as it will not be installed in CMS. *In situ* calibration is also planned and includes an intercalibration via the φ symmetry of the detector and an absolute calibration from the process $Z \rightarrow ee$.

Long-term stability tests of an ECAL Supermodule have validated the design and construction. Following a CMS Engineering Design Review, tenders for the Supermodule mechanical pieces have now been launched.

The LHCC noted the successful beam tests on the M0’ module comprising 100 channels at the SPS in 2002. Data analysis has started and an M0’ analysis workshop is scheduled for November 2002.

The new ECAL schedule is compatible with the CMS Master Schedule V33 and also follows the ECAL electronics schedule. It was noted that there is no float between the ECAL construction and calibration schedule and the ready-for-installation milestone in the Master Schedule. The most critical item is the timely development and implementation of the electronics.

The Committee noted that the current design of the Preshower detector, in which the detector is installed as a single unit, makes the pre-installation of the EE on a dummy a necessity. Given that the EE will be delivered late, a divided Preshower detector would help to facilitate the late installation of the EE, as well as simplifying future maintenance. The LHCC recommends further studies on the Preshower mechanical design.

*The Committee noted the impressive progress since the last Comprehensive Review but remains concerned about the very tight schedule for the ECAL electronics and the timely availability of funds for the purchase of the EE crystals.*
5. **HADRONIC CALORIMETER (HCAL)**

Significant progress was reported on the HCAL. The HCAL project is considered to be within budget and on schedule.

All Megatiles for the Hadronic End-cap (HE) calorimeter are now at CERN and assembly of the first absorber layers has commenced in surface building SX5.

The Hadronic Barrel (HB) and Hadronic Forward (HF) beam tests in 2002 were successful and analysis of the data is underway. Production of the electronics will commence in 2003 for the HB following further beam tests with the LHC-type beam with the 25 ns bunch structure.

Good progress was reported on the HF compared to the status of the previous Comprehensive Review. Moreover, in an effort to recover the short-fall in the HF project, CMS proposed at the previous Comprehensive Review to stage the HCAL calorimeter by incorporating only a single longitudinal read-out of the HB and HE. The funds saved will be directed to completing the HF in 2006. The proposal has since been adopted by CMS.

Following the 2003 test beam period, the HCAL effort will be concentrated at SX5 for slice tests of the HB, HE, Hadronic Outer (HO) and HF calorimeters together with the CMS-type DAQ.

Some concern was, however, expressed for the HB regarding the external leakage problem in the first batch of the Hybrid Pixel Detectors (HPDs) resulting in the need for the supplier to increase the delivery rate and the difficulty in reaching the design noise levels for the Charge Integrating and Encoding (QIE) front-end electronics. The LHCC considers that both concerns are minor and manageable.

*The LHCC has no major concerns regarding the HCAL and considers that the project is on schedule and within budget.*

6. **MUON SPECTROMETER**

Production of the planned first batch of 70 Drift Tube (DT) chambers has started, although it is now expected that only about 60 will be assembled by the end of the year. The Committee requested for the November 2002 LHCC an update to the DT production schedule, including the rate of manufacture in the current turning-on phase and the status of the Torino production site.

Moreover, the LHCC also noted the delays in the production of the MINICRATE electronics units for the DT chambers. However, with the available prototypes and pre-sample of the Read-out and Trigger Boards, the assembly of the first MINICRATE can go ahead by the end of 2002 and two prototype MINICRATES are scheduled to be tested at the SPS beam in May 2003. Given this schedule, the risk remains that the first DT chambers will be installed in the autumn of 2003 in CMS without their MINICRATES. CMS is urged to speed up production of the electronics units for their timely installation in CMS as of 2003.

Progress was reported on the Resistive Plates Chambers (RPCs). The group provided new information in the understanding of the chamber functionality, as detailed in a combined report with the ATLAS RPC group, and a preliminary construction schedule, which the LHCC considers to be tight.

Ageing tests of RPCs at the Gamma Irradiation Facility (GIF) are continuing and the Committee underlines the importance of successfully completing these tests with final chambers and with a closed loop gas system as will be used at the LHC. The requests for ageing tests of several final RPC detectors at the GIF should be given priority in the GIF schedule.
The LHCC noted that CMS is following a strict Quality Assurance / Quality Control plan in the production of the RPCs. Construction of the gaps has started, although currently the rejection rate is higher than expected.

Only preliminary information was presented for the Forward RPCs. CMS is considering staging part of their installation in the experiment.

Good progress was reported for the Cathode Strip Chambers (CSCs) and no concerns were expressed by the Committee.

The LHCC noted the good progress with the CSCs but expressed concern regarding the production rate of the DT chambers and the associated MINICRATE electronics units as well as the tight production schedule for the Barrel RPCs.

7. LVL-1 TRIGGER, HIGHER-LEVEL TRIGGERS AND DAQ

The LHCC noted the good progress on the Trigger and DAQ. The DAQ design has been tested with demonstrators and simulation programmes. The exercise has shown that (a) the system matches the CMS requirements, (b) its modularity and scalability allows it to exploit changes in technology and to adapt to improvements in the delivered machine luminosity, (c) is primarily based on readily-available and maintainable hardware and software standards and (d) it is already feasible with existing technologies to build the system within the cost ceiling. The Technical Design Report will be submitted to the LHCC by the end of 2002.

The single concern lies with the relatively late delivery of the underground service cavern which compresses the time available for the very challenging installation, integration and commissioning of the trigger and DAQ systems in these areas. As part of their Installation Review, CMS has been asked to provide a detailed schedule of the commissioning and integration phases of the Trigger and DAQ.

The LHCC noted the good progress in the Trigger and DAQ Project and awaits submission of the DAQ Technical Design Report by the end of 2002 and a detailed commissioning and integration schedule of the Trigger and DAQ.

8. COMPUTING AND SOFTWARE

Good progress was reported on the Physics Reconstruction and Selection (PRS). Collaboration with both the Trigger/DAQ and Computing and Core Software (CCS) efforts has been positive. This has resulted in a good understanding of the requirements at both low and high luminosities, including the calibration methods and data rates. It was also demonstrated that a single farm that has access to the full event data record and consisting of order $10^3$ number of CPUs can function at LHC start-up at 50 kHz with good physics efficiency. The next step is to finalise the GEANT4 simulation software and to proceed to the analysis of the selected physics channels.

With the DAQ Technical Design Report approaching completion, emphasis of the CCS will be directed to the next round of preparations, which will include addressing the analysis model, performing tests of the LHC Computing Grid (LCG) implementations and building the distributed expertise required for the LHC Computing. Moreover, the data challenge DC04, also referred to as the ‘5% data challenge’ and comprising of a sustained data-taking rate equivalent to 25 Hz at a luminosity of $0.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ for a period of 1 month and corresponding to $5 \times 10^7$ events aims, to validate the deployment of the LCG model. The Computing Technical Design Report will be submitted in the autumn of 2004.

The Committee noted the good progress in both the Physics Reconstruction and Selection and Computing and Core Software projects and expressed its satisfaction with the progress.
9. MANAGEMENT, TECHNICAL COORDINATION, INTEGRATION, SCHEDULES AND COSTS

The LHCC considers that the CMS Management structure is adequate and efficient and considers that the overall CMS plan to bring the detector to completion, including the installation, integration and commissioning, is under control and no major concerns were expressed. Good progress was also reported on the magnet and experimental area.

Moreover, good progress was also reported on the electronics issues. With the exception of the ECAL front-end electronics and the SST hybrid electronics, which are now on the critical path, other detector electronics components are on schedule. Moreover, the Collaboration is continuing to seek common CMS-wide solutions, such as for the low voltage supplies, grounding and shielding. The LHCC noted the convergence of implementing the use of the 400 Hz low voltage power supplies for the whole detector.

The LHCC took note of the new CMS Master Schedule V33. The schedule complies with the start-up of LHC operation in April 2007 and will be henceforth used to monitor the CMS milestones. The Committee considers the schedule to be tight and expressed its concern regarding particularly the critical nature of the ECAL electronics and the timely availability of funds for the End-cap crystals, which risk delaying the installation of the ECAL, and the SST hybrids. In an effort to reduce risks, it requests CMS to ensure in all systems a 3-month contingency between the completion of construction and ready-for-installation milestones.

However, based on V33, the Committee considers that it is realistic to expect CMS to install an initial working detector suitable for the first operation of the LHC starting in April 2007 and for the physics run starting in August 2007, although detector installation can be foreseen beyond this date. The Collaboration will continue looking for ways to save time in projects that are on the critical path, particularly the timely completion of the ECAL and SST.

Detector elements not installed by April 2007 will be part of the upgrade for high luminosities and consist of the following items:

Tracker: the 3rd pixel disk per end-cap.

Muons: the ME4 chamber;

the read-out of the ME 1/1a chambers will be staged (3 channels in one and no muon trigger beyond $|\eta| = 2.1$);

and the End-cap RPC chambers at $1.6 < |\eta| < 2.1$.

HCAL: reduced number of longitudinal samplings.

TRIDAS: LVL-1 output rate reduced to 50 kHz from nominal 100 kHz.

Staging some of the End-cap RPC chambers has been introduced since the previous Comprehensive Review. It will result in an increase of the Level-1 trigger rate for muons in the high pseudorapidity range but without loss of geometrical acceptance.

The installation of staged components, in a shutdown after the completion of the low luminosity running, while requiring additional resources, would complete the CMS detector as described in the approved Technical Design Reports for high luminosity running. The LHCC agrees that for higher luminosity operation and high-mass physics, the full detector redundancy and resolution will be required.

CMS reported a shortfall of 63 MCHF for the completion of the initial detector. The LHCC considers that securing the remaining outstanding 12 MCHF of the total 63 MCHF is important and encourages CMS to continue discussions with the funding agencies before implementing the staging scenario. The Committee considers that the CMS plan to cover the cost-to-completion reasonable.
The first of the CMS Installation Reviews took place on 10-11 September 2002. The Installation Review Committee addressed the projected schedules and milestones, the required resources to carry out the installation as well as identifying any potential risks for the installation. In particular, the Committee was charged with reviewing the following issues: details of the planned activities and work packages, origin of the resources, both in terms of money and manpower, critical path items, assessment of risks, survey, alignment and safety.

The Review Committee congratulated CMS on their excellent presentations and was impressed with the well thought out approach to the installation of the CMS detector at Point 5. The Installation Review Committee concluded that the construction and installation of the CMS experiment has started well. More work is needed on detector services and cabling particularly for the inner detectors and on the final stage DAQ commissioning, but there is every reason to believe that CMS will have a working detector ready for LHC operation in April 2007. The LHCC concurs with the conclusions of the Installation Review Committee. A follow-up Installation Review of CMS is planned for March 2003.

The LHCC took note of the new CMS Master Schedule V33 and will use it henceforth to monitor the CMS milestones. Although the Committee considers it realistic to expect CMS to install an initial working detector suitable for the first operation of the LHC starting in April 2007 and for the physics run starting in August 2007, it did express its concern on the tight schedule to do so and on the outstanding critical items related to the ECAL electronics, the funding profile of the EE crystals and the SST front-end hybrid electronics. Finally, the LHCC considers that the CMS plan to cover the costs-to-completion, amounting to 63 MCHF, is reasonable.