19 December 2018

LHCC deliberation on Phase I upgrades

Summary of LHCC reports on the Phase I upgrade TDRs as documented in the minutes of the LHCC session from December 2013 to May 2017

LHCC deliberation on Phase I upgrades

1. Report on the LHCC review of the ALICE Phase-I Readout and Trigger System TDR
2. Report on the LHCC review of the ALICE Phase-I Time Projection chamber TDR
3. Report on the LHCC review of the ALICE Phase-I Inner Tracking System TDR
4. Report on the LHCC review of the ALICE Muon Forward Tracker TDR
5. Report on the LHCC review of the ALICE Offline-Online Computing System (O2) TDR
8. Report on the LHCC review of the ATLAS Phase-I LAr Calorimeter TDR
10. Report on the LHCC review of the ATLAS Forward Proton (AFP) TDR
11. Report on the LHCC review of the CMS Phase-I Hadron Calorimeter TDR
12. Report on the LHCC review of the CMS Pixel Detector Upgrade TDR
13. Report on the LHCC review of the CMS Phase-I Level 1 Trigger TDR
15. Report on the LHCC review of the LHCb Phase-I Particle Identification TDR
17. Report on the LHCC review of the LHCb Phase-I Trigger and Online TDR

References:

1. Report on the LHCC review of the ALICE Phase-I Readout and Trigger System TDR


LHCC 116, 4-5 December 2013

The LHCC received two Technical Design Reports (TDRs) from ALICE, one for the new Inner Tracker System (ITS) (CERN-LHCC-2013-024) and one for the upgrade of the Read-out and Trigger System (CERN-LHCC-2013-019).

LHCC 118, 4-5 June 2014

The Trigger & Readout Upgrade TDR is now with the UCG and the TPC Upgrade TDR, submitted during the last LHCC meeting in March 2014, is under review by the LHCC.
Two of the five expected ALICE TDRs are by now endorsed by LHCC and UCG: the new Inner Tracking System (ITS) and the upgrade of the Readout and Trigger System.

The ALICE Readout and Trigger system was reviewed in depth at this LHCC session. The architecture has been streamlined, with all upgraded detectors using now the Common Readout Unit (CRU) and having continuous readout capability. The CRU specification is driven by the TPC, with a common PC140 FPGA-based solution being developed together with LHCb. A design review has taken place and prototype development is underway. The SAMPA MPW1 ASIC for continuous readout has been produced and tested. The prototype chip containing the analog part (charge sensitive amplifier and shaper) showed substantial ringing on the shape of large pulses. This defect can now also be reproduced in simulations and the analog part of the layout is being revised for the next prototype cycle. The MPW2 (with all channels) is being prepared for submission in July 2015. The Fast Interaction Trigger has undergone successful prototyping tests. Three different solutions are under study to facilitate continuous readout at 200 kHz. Other aspects of the system are proceeding on schedule. The LHCC congratulates the collaboration on the recent progress.

The Phase-I upgrade programme includes multiple developments in the readout system as well as a new trigger. All upgraded detectors will have continuous readout capability.

2. Report on the LHCC review of the ALICE Phase-I Time Projection chamber TDR


The ALICE experiment presented an update of the status of the upgrade of the Time Projection Chamber (TPC). The main goal of the TPC upgrade is to allow for a continuous readout with 50 kHz. This rate cannot be achieved with the current gated Multi-Wire Proportional Chamber (MWPC) readout, which is limited to 3 kHz. The technology of choice for the upgrade is a multilayer Gas Electron Multiplier (GEM) readout. The ALICE requirements for TPC operation with continuous readout are an ion back flow (IBF) into the drift space less than 1% and an energy resolution of 12% for a $^{55}$Fe signal. A quadruple GEM stack with a Ne-CO$_2$-N$_2$ gas mixture with a mixture of foils with various pitches met these requirements for various operating conditions. Extensive Monte Carlo simulations were performed under the conditions of an IBF of 1% and a gain of 2000. These studies showed that the TPC standalone momentum resolution with GEMs is slightly worse than for MWPCs, but that the global track resolution including the Inner Tracking System (ITS) is the same. The dE/dx resolution is the same of the upgraded configuration compared to the current detector. The simulations also show that the TPC retains its performance under pile-up conditions. The space charge distortions with continuous readout, however, are significant. Assuming again an IBF of 1% and a gain of 2000 with the Ne-CO$_2$-N$_2$ gas mixture, a Pb-Pb collider run at 50 kHz will result in the accumulation of ions from 8000 events in the drift volume and distortions at small r and z reach 20 cm for r and 8 cm for z. To obtain the specified tracking resolutions, corrections at the per-mille level are required and the space charge fluctuations need to be taken into account. Using a fluctuating space-charge map in the Monte
Carlo, based on real data, to simulate track distortions, it was determined that the space charge map could be considered static over a timescale of 5 ms, that is, every 5 ms the map needs to be updated. It is of critical importance for the experiment to have a very robust and high performing online track finding algorithm. Because of the continuous readout of the TPC, the TPC raw data has to be reduced by roughly a factor of 20 to be manageable. This is achieved through an online track reconstruction scheme where hits not assigned to tracks get discarded. As a result, the online reconstruction will have to be exceedingly high performing and requires inclusion of space-charge distortion corrections at the 5 ms level. A three-stage online calibration algorithm has been developed and tested. The procedure starts out with a reference map from Monte Carlo, which incorporates the readout geometry and known gain and IBF non-uniformities. An average correction map is then determined from high-statistics, high \( p_T \) track samples, updated several times per fill. This accounts for slow variations of luminosity and ambient conditions. At the third level, this average map is scaled by the average of the actual TPC running conditions, updated every 5 ms. This calibration and correction algorithm was tested in Monte Carlo and a momentum resolution is obtained which is within a factor of two from the environment with no distortions.

Offline the track reconstruction undergoes a last level of correction, when a high precision space charge map in conjunction with external tracking information from the ITS is used. Tremendous progress on the technical design of the TPC is being made. Given the high physics value of the detector, the Committee remains concerned about the viability of the preferred technology solution. More details regarding a review are in the ALICE section of this report.

LHCC 119, 24-25 September 2014

The LHCC has been impressed by the progress in optimising the performance and robustness of the Time Projection Chamber (TPC) read-out with respect to ion feedback and energy resolution. These developments confirm earlier impressions that the TPC is the viable solution for the tracking and particle identification needs for the envisaged heavy-ion measurements at high read-out speed. The LHCC continues to follow this effort closely and anticipates that a viable solution for the read-out will be specified in time for the construction of the chamber to proceed as planned.

The TPC upgrade was further reviewed by the LHCC at this session, particularly with regard to the read-out design. Detailed studies have continued with small proto-types based on Gas Electron Multiplier (GEM) detectors or a mixture of GEMs and Micromegas, with varying pitches and hole sizes. In this controlled environment, configurations have been identified which deliver the required 12% \( dE/dx \) resolution whilst keeping ion back flow (IBF) below 1%, with some contingency. Discharge probabilities in the 4-GEM case have been evaluated and found to be acceptably small due to the relatively modest gain. A large IROC proto-type for a 4-GEM solution is built and now being commissioned. A large 2-GEM + Micromegas IROC prototype is in production. It is planned to test both of these prototypes in test beams in autumn 2014.

Simulated studies of TPC track parameter resolutions show around a 30% degradation in \( p_T \) resolution at the nominal IBF factor-of-20 relative to no IBF. This loss can almost fully be recovered by using information from the ITS, with a simulated track linking efficiency in excess of 95%. A separate statement from the LHCC has been published, reaffirming its belief that a TPC solution is viable and noting the progress towards a read-out solution.

For the Time Projection Chamber (TPC) read-out, the new backplane prototypes have been successfully tested and are ready for production. The main concern at present is over the RCU2 upgraded read-out control board, where there are still significant issues with the Microsemi SmartFusion2 FPGA chip. These problems, which were revealed in test-beams in June 2014, include a failure of FPGA reprogramming after irradiation fluencies of a few kRad, single event latch-ups in the slow control, DDL2 interface timing, and remote programming of the FPGAs. The manufacturer (Microsemi) is engaging with the ALICE Collaboration at an encouraging level and further support from them will be vital in solving these problems.
The Addendum to the Time Projection Chamber (TPC) Technical Design Report is expected to be submitted to the LHCC by the end of January 2015. The TPC TDR submitted in April 2014 is still under review and ALICE continues to conduct a substantial R&D program.

The LHCC received the Addendum to the Time Projection Chamber (TPC) Technical Design Report. Following the review of the TPC Technical Design Report in February 2014, an extensive R&D programme was launched by ALICE. The LHCC is impressed by the progress in the R&D campaign since then. The 4-GEM baseline (comprised of stacks of four Gas Electron Multiplier layers) has been extensively characterized, together with other alternative solutions. It has been shown to exceed the requirements of 1% ion back flow and 12% energy resolution, although with only a small contingency according to the prototype studies. The R&D studies have also indicated that the original specifications for the TPC can be relaxed. Given the crucial role in the ALICE physics programme of a TPC capable of operating up to 50kHz, the limited margin remains a concern. The LHCC encourages ALICE to move forward with the current baseline design and to submit the documentation for the UCG cost review, whilst in parallel continuing a vigorous R&D campaign to explore chamber configurations that could provide additional operating margin. The LHCC expects to present its recommendation at its meeting in June 2015.

The Time Projection Chamber (TPC) is crucial to the success of the ALICE upgrade. The TPC’s unique features are its tracking capabilities down to $p \sim 200$ MeV/c and its particle identification performance over a broad range of momenta as highlighted in the ALICE Upgrade Letter of Intent. Key physics elements, such as low-mass di-lepton studies, measurements of heavy-flavour suppression and quarkonia production, rely predominantly on the TPC’s performance.

On 2 February 2015 the LHCC received the Addendum to the TPC Technical Design Report, which summarized the results of the extensive R&D programme conducted in the year following the first TPC Technical Design Report review in February 2014. Impressive progress has been made in this R&D campaign, including a detailed characterization of the 4-GEM solution, both geometrically and with respect to voltage distributions, using small prototypes. A successful test beam campaign with the Gas Electron Multiplier (GEM) detectors 4-GEM and 2-GEM+MicroMegas IROC prototypes in December 2014 provided further important results. Other technologies, such as a 2GEM+MicroMegas solution have been explored but not with the same rigour. Substantially more R&D would be necessary for this and other technologies in order to explore their potential for a more comfortable solution.

It is unlikely that substantial improvements over the baseline design can be achieved through further R&D in the short term. Given the pressing need to make progress towards the start of production in autumn 2015, ALICE decided for the 4-GEM solution as the baseline technology choice. This implies some technical risk insofar as the original ion backflow (IBF) and dE/dx resolution specifications are met with only a small contingency according to the prototype studies. In the addendum, ALICE has shown through simulations that failing to meet the original specifications by a relatively small margin (IBF increasing from 1% to 2% and energy resolution from 12% to 14%), does not have a severe effect on the physics programme. Despite these findings the LHCC remains concerned about the construction and operational constraints that such small margins imply, especially given the crucial role of the TPC for the ALICE physics programme and the requirement of operating up to 50kHz.
The success of the ALICE upgrade relies on simultaneous high performance of the TPC and the ITS. Neither the ITS nor the TPC standalone tracking are able to cope with the performance requirements outlined in the ALICE Upgrade Letter of Intent. Only the combined use of both is capable of delivering the design performance. Distortions in the TPC have considerable implications for the calibration. The onus will be on the Osystem and its flexibility in reacting to different running conditions.

The LHCC encourages ALICE to move forward with the current baseline design and to submit the documentation for the UCG cost review, whilst in parallel continuing a vigorous R&D programme to continue to optimize the chamber configuration and operational parameters (such as gas mixture and GEM foil hole pitches) and to explore alternative chamber designs. The LHCC expects to present its recommendation at its meeting in June 2015.

**LHCC 122, 3-4 June 2015**

The ALICE experiment is ready for Run II. The ALICE detector recorded first collisions at 13TeV proton-proton centre-of-mass energy. The production of the new RCU2 read-out electronics for the Time Projection Chamber (TPC) has been completed. The boards have been installed in one TPC sector, with the rest of them to be installed during Technical Stop 1 (TS1). The TPC has been commissioned and is ready for Run II data taking.

The upgrade of the Time Projection Chamber (TPC) consists of the replacement of the present Multi-Wire Proportional Chamber (MWPC)-based readout chambers by a new design, consisting of quadruple Gas Electron Multiplier (GEM) planes allowing continuous operation without active ion gating, as well as new pipelined read-out electronics. Prototypes of the new readout chambers were tested extensively during the past year and meet the experiment's requirements for ion backflow blocking and energy resolution, although with only modest contingency. The TPC is crucial to the success of all ALICE upgrades. The original TDR (CERN-LHCC-2013-020, 3 March, 2014) has been updated with an Addendum (CERN-LHCC-2015-002, 2 February, 2015). Based on the review of the Addendum for the TPC upgrade and following the endorsement of the UCG, the LHCC recommended for approval the ALICE Time Projection Chamber Technical Design Report. The UCG identified some remaining issues that will need close monitoring. Construction, assembly and testing of the TPC will require a substantial amount of expertise and proficient project management. Critical items are the timely delivery of the common front-end read-out chip, SAMPA, for the TPC and Muon Chamber (MCH) upgrades and the development and testing of multi-channel cascaded high-voltage power supplies for the GEM stacks. The funding profile has a large peak in 2018, exposing the project to schedule risk, should the Front End Cards (FECs) be delayed.

**LHCC 123, 23-24 September 2015**

The Engineering Design Review for the read-out chambers of the TPC (excluding electronics) is scheduled for 4 November 2015. There have been suggestions to add some features to the SAMPA chip (e.g. compression). The LHCC referees strongly advise ALICE to focus on the current design and speed up the production of the second prototype. In the schedule presented to the in-depth review in June 2015, the SAMPA MPW2 submission was foreseen for July 2015. The submission is now expected by the end of the year.

The upgrade of the TPC consists of the replacement of the present Multi-Wire Proportional Chamber (MWPC)-based readout chambers by a new design, consisting of quadruple Gas Electron Multiplier (GEM) planes allowing continuous operation without active ion gating, as well as new pipelined readout electronics. Prototypes of the new readout chambers were tested extensively during the past year and meet the experiment's requirements for ion backflow blocking and energy resolution, although with only modest contingency. The TPC is crucial to the success of all ALICE upgrades.
The Collaboration held an Engineering Design Review in November 2015 with positive feedback from the reviewers.

**LHCC 124, 2-3 December 2015**

For the upgrade of the readout chambers of the Time Projection Chamber (TPC), technical solutions matching the physics requirements have been developed. ALICE decided on a 4-GEM (Gas Electron Multiplier) stack. The ALICE experiment gave an update on the status of the Inner Tracker System (ITS) and the Time Projection Chamber (TPC) upgrade.

The upgrade of the TPC consists of the replacement of the present Multi-Wire Proportional Chamber (MWPC)-based readout chambers by a new design, consisting of quadruple Gas Electron Multiplier (GEM) planes allowing continuous operation without active ion gating, as well as new pipelined readout electronics. Prototypes of the new readout chambers were tested extensively during the past year and meet the experiment's requirements for ion backflow blocking and energy resolution, although with only modest contingency. The TPC is crucial to the success of all ALICE upgrades.

**LHCC 125, 2-3 March 2016**

TPC Upgrade: Readout Chamber Test Procedures Following a request from the LHCC, ALICE provided a detailed plan for the testing of the new TPC read-out chambers. This included procedures for the pre-production chambers, which will be close to the final version, as well as for the production versions. ALICE foresees comprehensive commissioning tests on pre-production ROCs. These tests will be undertaken at the various assembly sites (Yale for IROC, HPD and GSI for OROC) in newly developed low-volume and thin entrance windows vessels to allow for fast flushing and full irradiation with X-rays respectively: measurement of gain, its uniformity and stability long term and discharge stability are foreseen.

In particular, the full irradiation (full load of 10 nA/cm²) with an X-ray source will provide performance and stability tests of the system under full load. These tests should also validate the HV design of the ROC.

A test campaign at SPS in fall 2016 with RD51 has been scheduled. Within this test beam one pre-production ROC equipped with prototype electronics will be tested and the noise behaviour of the complete front-end system will be verified.

The LHCC acknowledges the need for thorough testing procedures of all aspects of the readout chambers before and during production and encourages ALICE to follow this comprehensive plan closely.

3. **Report on the LHCC review of the ALICE Phase-I Inner Tracking System TDR**


**LHCC 117, 5-6 March 2014**

The UCG reviewed the ALICE Inner Tracking System upgrade (ITS; CERN-LHCC-2013-024). The ALICE ITS upgrade is motivated by the need to provide low-mass high-precision tracking at small radii to measure secondary vertices of heavy-flavour decays down to zero \( p_T \) at interaction rates of up to 50 kHz in Pb-Pb collisions. The UCG findings are: a) the ALICE ITS upgrade is a
challenging project with an aggressive time schedule; b) the manpower profile is adequate; c) ALICE should establish a good quality control programme to ensure uniformity in manufacturing of modules and staves at the different production sites; d) the yield for sensor production should be scrutinized, as a higher-than-assumed yield could translate into considerable cost savings if promptly recognized and addressed. The UCG recommends to the LHCC approval of the ALICE ITS upgrade cost estimate.

ALICE has presented three upgrade Technical Design Reports for approval by the LHCC. The Inner Tracking System (ITS) TDR is recommended for approval after passing the UCG review successfully. The Trigger & Readout Upgrade TDR will be considered in the June 2014 LHCC meeting, where also the cost review will be conducted. During the March 2014 LHCC session, ALICE submitted the TPC Upgrade TDR for review by the LHCC. The cost review of the ITS took place before the LHCC meeting. After a full assessment of the costs in preparation for the UCG review, ALICE has found that the total project cost has increased to 13.3 MCHF from the TDR value of 12.0 MCHF, which is largely attributed to external labour. The Committee sees no major concerns. Project management and all groups involved have good experience from past involvement in the current inner tracking system and new groups bring fresh expertise to the project. The UCG was impressed by the level of detail the collaboration provided during the review. The cost and manpower estimates were found to be reasonable and the ITS was recommended for approval.

LHCC 118, 4-5 June 2014

To-date ALICE has submitted three Technical Design Reports (TDRs) for approval by the LHCC. The Inner Tracking System (ITS) TDR is recommended for approval after passing the UCG review successfully.

LHC 119, 24-25 September 2014

The LHCC has received Technical Design Reports on a new Inner Tracking System (ITS) and on a replacement of the Time Projection Chamber (TPC) read-out and a Technical Design Report for the Readout and Trigger System. Two additional Technical Design Reports, one for the Muon Forward Tracker (MFT) and one for the Online Offline (O2) System, are under preparation. The submission of the MFT Technical Design Report is planned for November 2014 and the O2 Technical Design Report for the June 2015 LHCC session.

The ITS is a complete replacement of the current inner tracking detectors with a seven-layer MAPS pixel detector having a total active area of 10.3 m², with 25 Giga-pixels. Of the four sensor architectures that were being pursued, the ALICE Collaboration has dropped the ASTRAL and CHERWELL2 options. The back-end electronics has been designed to be fully compatible with the two remaining architectures, MISTRAL and ALPIDE. The former is optimised for the outer layers and is not compatible with the inner barrel lay-out. MISTRAL sensors have pixels of $36 \times 62 \, \mu \text{m}^2$, an integration time of 20 µs and power density of about 100 mW/cm². The ALPIDE architecture has $28 \times 28 \, \mu \text{m}^2$ pixels, 4 µs integration time and a power density of 40 mW/cm². Prototypes of both architectures are being characterised in the laboratory and by using test beams and show good performance. It is expected that the sensor architecture will be common between the ITS and MFT. The MFT consists of five disks with two detection planes per disk. Both air-cooling and water-cooling are being considered for the MFT.

The ALICE Collaboration reported the status of its upgrade programme in a talk at the Detector Upgrade Review meeting as well as in the regular meeting with the LHCC referees. Work on the Inner Tracking System (ITS) upgrade (approved by the LHCC and UCG) is proceeding well, with a final decision between the ALPIDE and MISTRAL MAPS technologies to be made in early 2015, based on test beam results at the PS and the SPS. The read-out and trigger upgrade was discussed by the UCG at the September LHCC meeting and is presented in Section 7 above. The muon
forward tracker Technical Design Report is expected for the November LHCC meeting. The online/offline software upgrade Technical Design Report is expected in mid-2015.

**LHCC 120, 19-20 November 2014**

Two of the five expected ALICE TDRs are by now endorsed by LHCC and UCG: the new Inner Tracking System (ITS) and the upgrade of the Readout and Trigger System. The TPC TDR submitted in April 2014 is still under review and ALICE continues to conduct a substantial R&D program. Testing of prototypes of the Inner Readout Chamber (IROC) is underway at the PS and SPS. ALICE intends to submit an addendum to the TDR summarizing the results of their R&D efforts before the end of January 2015. This addendum will also include the decision on the readout chamber technology.

**LHCC 121, 4-5 March 2015**

Upgrade projects
The Inner Tracking System (ITS) upgrade project was approved in 2014, but the sensor technology choice is still pending. The pixel chip has been down-selected to two fully-compatible CMOS chip options: ALPIDE and MISTRAL-O. ALPIDE is the baseline option, while MISTRAL-O is optimized for the detector outer layers. Full validation is expected by end 2015

Inner Tracking System
The Inner Tracking System (ITS) upgrade project was approved in 2014, but the sensor technology choice is still pending. The availability of the pixel chip is the critical path item for both the ITS and the Muon Forward Tracker (MFT). The pixel chip has been down-selected to two fully-compatible CMOS chip options: ALPIDE and MISTRAL-O. The ALPIDE chip is the current baseline option, although a full validation of both architectures will take until the end of this year.

**LHC 122, 3-4 June 2015**

The LHCC carried out an in-depth review of two ongoing ALICE upgrade projects. Inner Tracking System (ITS) For the Inner Tracking System (ITS), the ALPIDE pixel chip architecture has been chosen as the baseline for all detector modules, while the development of the alternative MISTRAL-O, and in particular the outer barrel data management unit, is continued as a potential backup solution for the outer layers. After the successful test of p-ALPIDE-1, a second full-scale prototype (p-ALPIDE-2) was delivered in April 2015 to be used for full integration in the inner and outer modules. The p-ALPIDE-3 is intended to be the last prototype before pre-series production and will contain all final elements, including the 1.2 Gb/s high-speed output link. It is expected to be delivered in August 2015, on time for the Engineering Design Review in October 2015. The design of the Flexible Printed Circuit (FPC) and the assembly tooling for the Inner/Outer Barrel are being finalized. The contract for six Module Assembly Machines has been awarded to IBS (NL). Installation procedures including integration of FPC, power cables and cooling pipes are being studied on a 3D mock up. A first prototype Readout Unit will be ready in September 2015 for the production readiness review. The LHCC recognizes the progress made on the ITS and congratulates the team for their competence and for the good management of the project

**LHC 123, 23-24 September 2015**

Inner Tracking System (ITS) The ALPIDE-3, common to both the ITS and Muon Forward Tracker (MFT) upgrades, was supposed to be delivered in August 2015 according to the ITS in-depth review in June 2015. Due to a delay the delivery is now expected for mid-October 2015. Since extensive tests have been already performed on the chip this delay should not affect the overall schedule of either upgrade.
LHC 124, 2-3 December 2015

Good progress was reported on the ALPIDE read-out chip for the new Inner Tracking System (ITS), with the choice of architecture being made and the chip exceeding all specifications. Nearly all aspects of production have been addressed and technical solutions have been found and procedures established. The schedule is considered to be aggressive but feasible.

LHCC 126, 25-26 May 2016

The Engineering Design Review (EDR) for the ITS (inner tracker) HIC and Staves took place in May 2016, with a positive outcome. The committee concluded that the component designs, assembly set-ups and initial results on early HIC prototypes and staves look generally convincing, and that there are strong and experienced teams involved. It stated that there are no show-stoppers at this point.

LHCC 127, 21-22 September 2016

The LHCC carried out an in-depth review of the upgrades of the ALICE experiment. The experiment is to be commended for having made impressive progress in all areas of the upgrade, which seems to be well on track. Pre-production devices of the final version – 10 – of the ALPIDE chip were received only shortly before the LHCC meeting. Many tests have already been carried out, including some beam tests. The results to date indicate that the chip meets all specifications. Validation is on-going and the production readiness review (PRR) is scheduled for October 2016. The collaboration is very much encouraged to fully characterize the chip even if it implies a modest delay of the PRR. Small samples of hybrid integrated circuits (HIC) and staves for both the inner and outer barrel of the inner tracking system (ITS) have been produced.

4. Report on the LHCC review of the ALICE Muon Forward Tracker TDR

LHCC 122, 3-4 June 2015

The LHCC also received the ALICE Muon Forward Tracker (MFT) Technical Design Report

On 22 May 2015 the LHCC received an Addendum to the ALICE Muon Forward Tracker (MFT) Technical Design Report for the Upgrade Cost Group (UCG), describing the organization of the project, the budget estimation, the schedule, and the manpower available in the project. Given the moderate cost of the MFT of 3.05 M€, the project will not be reviewed by the UCG. Instead the LHCC ALICE referees conducted a small-scale cost and manpower review.

The LHCC is mostly satisfied with the document but has slight concerns regarding the organizational structure and the list of milestones requiring further discussion between the LHCC and ALICE.

The project benefits from a large technical overlap with the planned upgrade of the ITS and the synergy is being effectively leveraged. The additional risks different from the ITS ones are connected with funding and installation plans.

The overall cost estimate and the spending profile is sound. The responsibility for detector construction and funding is shared between four French institutes contributing to 72% of global, and to 87% of material costs. In particular, the rest of material costs are 70% of the Indian contribution. Such an asymmetric subdivision of funding and duties contains implicit risks that should be mitigated by developing a contingency plan against potential problems with fund securing.

The milestones provided are limited to Engineering Design (EDR) and Production Readiness (PRR) Reviews. A better defined set of milestones between the PRR and commissioning is needed. This will be particularly helpful in reviewing the man-power profile. In several cases participating
institutions made no man-power commitment beyond 2017 and thus several numbers have only been estimated. The associated risk needs to be evaluated.

As an outcome of this in-depth review the referees will formulate a set of questions for the ALICE Collaboration for a second iteration of the document.

**LHC 123, 23-24 September 2015**

Following the review of the cost, manpower, milestones, and schedule for the Muon Forward Tracker (MFT), the LHCC recommends for approval the ALICE MFT Technical Design Report. Due to its relatively low cost, the MFT cost review was conducted by the LHCC referees and not by the UCG.

Based on the review of the Technical Design Report for the Muon Forward Tracker (MFT) Upgrade and the Addendum for the UCG, intensive discussions with the proponents have taken place concerning in particular its organizational structure and the list of milestones. Due to its relatively low cost, the MFT cost review was conducted by the LHCC referees and not by the UCG. The LHCC referees thank the ALICE Collaboration for the extremely fruitful interactions between LHCC meetings. New tables for manpower and milestones have been included in the document. The improved and updated set of milestones is particularly helpful in reviewing the corresponding manpower profile and the critical path for some components common to the ITS upgrade.

Formal funding approval in France of the contribution of IN2P3 is still missing. However, the ALICE Collaboration received informal confirmation that the requested contribution for the MFT upgrade fits perfectly in the strategy of the IN2P3 for the LHC upgrade.

In addition, new countries have joined the project and SUBATECH, Nantes has recently obtained an additional grant so that the funding of the project has a safety margin. Most contributions from smaller partners in the upgrade have already been guaranteed and allocated.

Following the review of the cost, manpower, milestones, and schedule for the MFT, the LHCC endorses the ALICE MFT upgrade and recommends it for approval. The LHCC referees urge ALICE to monitor closely a few strategic items in the upgrade, namely the uncertainty about electronic engineers from Clermont-Ferrand after 2016, the still asymmetric subdivision of funding and duties among the partner institutions and the crucial approval in France of the IN2P3 funding.

**LHCC 124, 2-3 December 2015**

The Technical Design Report and the UCG addendum of the MFT were approved by the LHCC in September 2015. Funding for the project is almost exclusively through the French funding agencies, IN2P3 and CEA (IRFU at Saclay).

Since the previous LHCC meeting, CEA funding has been allocated and the IN2P3 included the MFT budget in their overall funding envelope for experiments at the LHC. The ALICE groups expect the Memorandum of Understanding with IN2P3 for the MFT project to be signed within the next few weeks.

The discussion with ALICE on the ITS and TPC upgrades is a part of the LHC Upgrade section (see Section 5).

**LHCC 127, 21-22 September 2016**

The muon forward tracker (MFT) project has implemented a new management structure and has developed a new project plan, resulting in a new schedule and milestones. A common ITS-MFT strategy is adopted where possible. The LHCC welcomes the new organizational structure and successful exploitation of synergies with the ITS. The laser soldering for the HIC has been
abandoned and wire-bonding is the new baseline, as was done for the ITS. For the MFT, the chips are interconnected to an aluminium flexible printed circuit (FPC). It is suggested to consider developing a copper FPC as a possible backup in case of persistent problems with the aluminium based FPC. Electrical tests are on-going and an EDR for ladder production is planned for September 2016. The project, including the overall mechanical design, is progressing well.

5. Report on the LHCC review of the ALICE Offline-Online Computing System (O2) TDR

Review Panel: C. Diaconu, A.J.S. Smith, T. Ullrich

LHCC 122, 3-4 June 2015

The Committee received the ALICE Online-Offline Computing System (O2) Technical Design Report and is currently reviewing the document.

The LHCC heard a report from the UCG, concentrating on the ALICE Phase-1 upgrades of the Time Projection Chamber (TPC) and Online-Offline (O2).

On 20 April 2015 the LHCC received the ALICE Online-Offline Computing System (O2) Technical Design Report and is now in the process of reviewing the document. ALICE plans to completely redesign the online computing system to address the major challenge of sampling the full 50 kHz Pb-Pb interaction rate after LS2. This upgrade will also include the continuous trigger-less read-out of several detectors, most prominently TPC, ITS, and TOF among others. The total data throughput amounts to 1.1 TB/s of which 1 TB/s originates from the TPC alone. ALICE plans to reduce this unprecedented data rate by adopting an entirely new strategy where calibration and reconstruction are performed online, and only the post-reconstruction results are stored while the raw data are discarded. This implies a much tighter coupling between online and offline computing systems. In a first step the raw data flux is reduced to 500 GB/s by processing of subdetector specific data (e.g. TPC cluster finding), in ~250 FPGA-based First Level Processors (FLPs). Around 1500 Event Processing Nodes with around 100k CPU cores augmented by 5000 GPUs will perform global processing such as track finding and first calibration. In synchronous data processing mode during LHC runs, the Compressed Time-Frames (CTF) constitute a data rate of 90 GB/s that is locally stored. In asynchronous mode, these data are further refined with improved calibration (“physics grade”), primary vertex finding, track-to-vertex association, and event extraction. This asynchronous data processing is not limited to the O2 facility but can also be undertaken at the Tier-0 and Tier-1 Grid facilities. Only the CTF and Analysis Object Data (AOD) are written to permanent storage. Tests presented in the Technical Design Report show that an overall data compression factor of 14 is feasible (20 for TPC). While various technology options for input-output, data processing, disk storage (60 PB), and fast networking have already been evaluated and found adequate, ALICE is looking carefully at future technology with the clear strategy for late procurements to maximize performance and lower the costs.

The O2 facility will be located at LHC Point 2 and will require two counting rooms of which one is currently available. One additional computing room will be needed on the surface. The facility will need a total power of 2.5 MW requiring major upgrades to the LHC Point 2 infrastructure. The same is true for the required cooling capacity of 2.4 MW. ALICE estimated that four professional FTEs need to be added to the existing workforce for facility maintenance.

A new project for a Virtual Analysis Farm based on OpenStack is being prepared in order to replace the present proof-based farm. ALICE released the Technical Design Report for the Online-Offline (O2) computing system for the Phase-1 upgrade.
LHCC 123, 23-24 September 2015

Based on the review of the Technical Design Report for the Online+Offline (O2) Upgrade, intensive discussion with the proponents, and following the endorsement of the Upgrade Cost Group (UCG), the LHCC recommends for approval the ALICE O2 Technical Design Report defined by the requested budget. In making this recommendation, the Committee is expecting that ALICE will secure the funds asserted in the Technical Design Report and that the O2 computing arrangements are also acceptable to the WLCG. Moreover, the implementation of O2 involves several CERN support groups and might require additional personnel, infrastructure and/or costs not covered in the cost presented in the Technical Design Report. A clear agreement on the division of these responsibilities between ALICE and CERN should be reached prior to the actual implementation of the project.

The main goal of the ALICE O2 upgrade is a complete redesign of the online computing system to address the major challenge of sampling the full 50 kHz Pb-Pb interaction rate after Long Shutdown 2 (LS2). This upgrade will also include the continuous trigger-less read-out of several detectors, most prominently the TPC, ITS, and TOF. The project is complex, addresses heterogeneous data acquisition systems, which are adapted for a trigger-less read-out. The upgrade involves large amounts of manpower, most of which is devoted to high level tasks in online and offline computing. In addition, a strong link to physics is needed, for instance for the monitoring of the physics performance of the implemented algorithms. Given this high level of specialization, the qualification of the human resources participating on the project is a critical parameter and needs careful management.

Based on the review of the Technical Design Report for the Online-Offline (O2) Upgrade, intensive discussion with the proponents, and following the endorsement of the Upgrade Cost Group (UCG), the LHCC endorses the ALICE O2 Technical Design Report defined by the requested budget and recommends it for approval.

Analyzing the enormous amount of recorded data will be challenging and a viable solution is presented in the Technical Design Report. The LHCC looks forward to seeing it discussed and implemented within the WLCG and with the WLCG-ALICE sites. This assumes that it stays within the respective allocated budget for offline/analysis computing and is discussed by the Computing Resources Scrutiny Group (CRSG). The LHCC notes that potential changes of the analysis strategy may still be possible, depending on the feedback from the WLCG and the Grid facilities. Any changes in the analysis strategy and planning are not expected to affect significantly the overall objectives and effectiveness of the O2 project itself.

The implementation of O2 involves several CERN support groups, personnel, and infrastructure. A clear agreement on the division of these responsibilities between ALICE and CERN should be reached prior to the actual implementation of the project.

The Online-Offline (O2) project was reviewed by the LHCC and UCG. The technical and organizational aspects of the required computing resources in the O2 project have to be discussed and coordinated with CERN IT Department, the WLCG, and the other experiments, and will be monitored by the LHCC. ALICE has started the work on O2, including the exploration of a new technology for parameter storage and the streamlining of the software development process.

LHCC 124, 2-3 December 2015

The Online-Offline (O2) discussions with CERN services have been concluded successfully and no unexpected costs were identified in the project.

The remaining items around the Online-Offline (O2) upgrade project were clarified, including an increase of the bandwidth from Point 2 to the Tier0, the compatibility with the WLCG development and the projected resources evolutions at CERN.
The main goal of the ALICE O2 upgrade is a complete redesign of the online computing system to address the major challenge of sampling the full 50 kHz Pb-Pb interaction rate after Long Shutdown 2 (LS2). In the O2 Technical Design Report, ALICE presented a well-developed design for a drastic reduction of the data volume, from 1.1 TB/s to 90 GB/s. The project was approved by the LHCC in September 2015. The UCG report emphasized that in making this recommendation it was assumed that the O2 computing arrangements are acceptable to the WLCG. It was further commented that the implementation of O2 involves several CERN support groups, personnel, and infrastructure and requested a clear agreement on the division of these responsibilities between ALICE and CERN to be reached prior to the actual implementation of the project. The O2 Technical Design Report was approved by the Research Board, under condition that the issues listed in the UCG report are resolved.

The LHCC takes note of the positive results of the meeting held on 16 October 2015 between ALICE and representatives of the IT Department and WLCG, clarifying the compatibility of both, (i) the overall O2 architecture with the WLCG, and (ii) the GRID resource evolution with the assumptions presented in the Technical Design Report. The agreement on the precise amount of disk/tape storage available on the GRID in the years 2018-2020 will be discussed with the Computing Resource Scrutiny Group at a later stage of the project.

The O2 operation also implies the upgrade of the network bandwidth from the experiment site to the Tier-0, as well as from CERN to the Tier-1 sites. While requests for the latter will be discussed in the near future, the cost for the bandwidth increase to the Tier-0 is being established.

On 6 October 2015, the CERN Directorate convened a meeting with the four LHC experiments to examine the global requirements for the operation of online/offline computing after the LS2.

In a series of meetings between ALICE and CERN services, it has now been verified that the O2 cost breakdown in the Technical Design Report is complete and the budget for services and infrastructure is adequate.

The costs of the fibre optic network from the new detectors (Inner Tracking System (ITS), Muon Forward Tracker (MFT) and TPC) to the computing farm, and the additional electrical power (2.5 MW) needed for the O2 operation have been evaluated by the EL group of the CERN Engineering Department (EN-EL) and are covered with proper contingency by the O2 budget as specified in the Technical Design Report. In particular, the electrical power increase can be obtained with the installation of two standard CERN transformers of 2 MVA, possibly during the YETS in 2016.

A new computer room (CR0) is needed to install part of the computer and storage system. The most convenient choice is the purchasing of a commercial Modular Data Center (MDC) that includes cooling, racks and power distribution and limits the requests to CERN services to the connection to the electrical and water distribution networks. ALICE plans to complete a first market survey and the purchasing of 20-30% of the total capacity in year 2016. The acquired lab could be moved to the experimental site (Point 2) in year 2018 when 10% of the computing system will be installed. Full deployment of the computing room and of the computer and storage facilities is scheduled for year 2020.

**LHCC 127, 21-22 September 2016**

The development of the O2 framework is proceeding well. A first implementation of the data quality control framework, including the condition and calibration database, has been implemented. The system is subjected to systematic benchmarking to characterize the different software elements. The dynamic deployment system (DDS) has been released and is being tested. An O2 development cluster has been deployed to demonstrate workflow management, and evaluate all the tools. The TPC simulation software is being refined for the upgraded detector. The approach to quickly enable O2 developers to become productive is very much supported. It is recommended that as many O2 elements as possible are used in the beam test campaigns and that the whole framework is used for the simulation and verification of beam test results. The
LHCC recommends that a decision be made as soon as possible by CERN management on the new data centre in Prevessin.

**LHCC 128, 30 November – 1 December 2016**

For the O2 upgrade, ALICE is proposing to initially purchase one container to evaluate the cooling needs, pending the decision on the new computing centre. This is a relatively small fraction of the total cost and expected to be cost-neutral with respect to the final solution. A decision on this procurement should be taken in consultation with the CERN management. A prompt decision on the possibility of a new CERN computing centre in Prevessin is essential for the execution of this project.

The LHCC recommends that a decision on the computing centre should be taken as soon as possible by the CERN management to avoid delays on the O2 overall schedule.

The O2 upgrade is on the critical path and it becomes increasingly urgent for CERN to confirm its plans for a new computing centre in Prevessin for ALICE and LHCb. ALICE proposes the purchase of one container to proceed with the evaluation of the cooling needs. This decision is expected to be cost-neutral with respect to the final solution.

**LHCC 129, 22-23 February 2017**

Setting up of a Development Lab for the O2 project is a priority. The purchase of one container as proposed by ALICE is waiting for the PCC (Prevessin Computer Center) tender. ALICE is evaluating with CERN-IT the alternative to move the development phase, or part of it, to the Meyrin CC.

ALICE is working on the baseline and the alternative PCC project for the O2 processing farm. A competitive tender for the baseline project of the O2 computer center as proposed in the TDR was carried out together with LHCb and the Neutrino Platform. The project is being finalized to be presented to the Finance Committee in June 2017 together with the alternative of the new computing center in Prevessin, proposed by CERN for the IT department and the upgraded farms of ALICE and LHCb.


**LHCC 115, 25-26 September 2013**

ATLAS has presented four Phase 1 upgrade Technical Design Reports for approval by the LHCC. The Muon New Small Wheel (NSW) and Fast Track Trigger (FTK) were recommended for approval, while the LAr Calorimeter and Trigger/DAQ Technical Design Reports are scheduled for detailed consideration in December 2013.

**LHCC 117, 5-6 March 2014**

The LHCC heard a report from the Upgrade Cost Group (UCG). The UCG reviewed the ATLAS New Small Wheel (NSW; CERN-LHCC-2013-006), the LAr Calorimeter (CERN-LHCC-2013-017) and the Trigger/DAQ (CERN-LHCC2013-018) Technical Design Reports.
The ATLAS NSW project aims to ensure the performance of the muon tracking and trigger capabilities in the forward ATLAS region as the LHC luminosity increases during Phase 1 and Phase 2. The project consists of 32 muon stations, each one composed of 8 Small-strip Thin-Gap Chambers (sTGC) and 8 Micromegas detectors assembled together. The UCG findings are: a) all needed information on costing, manpower and risks was provided by ATLAS; b) No major concerns were reported for the sTGC; c) the front-end electronics are not yet fully designed and d) to ensure quality and schedule, the LHCC should monitor progress frequently, especially for the Micromegas construction. The UCG recommends to the LHCC approval of the ATLAS NSW cost estimate.

The ATLAS upgrades are on track. Several groups are engaged in the muon New Small Wheel construction preparations and a test beam effort at Fermilab will occur in the coming month.

**LHCC 125, 2-3 March 2016**

The upgrade for the muon New Small Wheel (NSW) is making good progress for the mechanics, engineering and alignment systems, however, several problems have been encountered in the production of both chamber types, leading to a very critical schedule for installation in LS2 with no contingency at this point. The LHCC encourages the ATLAS management in getting the project on track in particular through a mobilization of the muon community, and by working out time contingency scenarios in case of non-recoverable schedule delays.

Progress with the muon New Small Wheel (NSW) upgrade is significantly delayed. There have been problems with production of both the Micromegas and small strip Thin Gap Chamber (STGC) detectors. Corrective action has been taken but there is almost no remaining contingency if the NSW is to be installed in LS2. The LHCC expressed concern about the slippage in schedule of the Phase-I upgrade projects, in particular the NSW.

**LHC 126, 25-26 May 2016**

The Phase-I upgrade projects status was reviewed. All projects are progressing. For the muon New Small Wheel (NSW) upgrade progress has been made in production of both the Micromegas and small strip Thin Gap Chamber (STGC) detectors, as well as in the readout electronics. The schedule remains extremely tight, and there is almost no remaining contingency if the NSW is to be installed in LS2. There remain concerns about progress with the LAr readout upgrade serialiser ASIC chip. The LHCC will continue to monitor closely the Phase-I upgrade projects, in particular the NSW.

Phase-I upgrades are progressing well, however with delays in several areas:

- NSW: There are concerns about delays on chamber production and readout chips. The schedule situation is difficult but well managed by the project leader. Additional support from CERN on logistics and procurement would be welcome.

**LHC 127, 21-22 September 2016**

Substantial progress has been made in all areas for the construction of the NSW; however the schedule remains very tight, in particular in view of recent problems with one industrial vendor, which need to be addressed urgently.

**LHC 128, 30 November – 1 December 2016**

Phase-I upgrade The ATLAS Phase-I upgrade projects are on track, with major concerns only in the area of the muon New Small Wheel. The NSW Micromega detectors are delayed, with the
production of the readout PCBs becoming a bottleneck again. For the sTGCs the cathode board production had resumed but had to be stopped again due to quality issues. An internal review of the project status and schedule options is foreseen for the beginning of 2017, followed by an in-depth LHCC Phase-I review at the February meeting.

The LHCC strongly encourages ATLAS to carry out a full risk assessment and evaluate the possible scenarios that could evolve in case the foreseen installation schedule for the NSW cannot be kept.


LHCC 116, 4-5 December 2013

The UCG reviewed the ATLAS Fast Tracker (FTK) (CERN-LHCC-2013-007). The project consists almost entirely of electronics and aims to provide a global track reconstruction within 100 µs after each Level-1 trigger. The UCG findings are: a) conceptual design is reaching completion; b) costs estimates are based on industry quotes and previous experience; c) the total engineering manpower (about 7 FTEs spread over several part-time engineers) appears low; and the Associative Memory Chip (AM) ASIC is behind schedule due to the challenging 65 nm technology. The delay in the AM chip is the main risk of the project, although only significant further issues will affect the 2016 run and have an impact on the physics. The cost risk is considered to be low. The UCG recommends to the LHCC approval of the FTK cost estimate. To assist the RRB SG in tracking the project, ATLAS should produce a resource-loaded schedule showing the number of necessary people and their expertise.

LHCC 123, 23-24 September 2015

For the Fast TracKer (FTK) system the production prototype AM chip will be tested in late 2015. All boards have passed their production readiness reviews and several boards are either in fabrication or about to be fabricated. A vertical slice test will be done before the end of 2015 using pre-production prototype components. It is hoped to have a fully running system with production components by autumn 2016 (i.e. with a 6-month delay).

LHCC 124, 2-3 December 2015

The ATLAS experiment reported on the status of the Fast Track Trigger (FTK) and the Phase-1 Trigger-DAQ upgrade. The FTK is a system of custom electronics that does global track reconstruction in the pixel and silicon strip detectors after every Level-1 trigger, that is, at 100 kHz. By adding the FTK to the current trigger architecture, the experiment is able to retain its physics capabilities within the 100 kHz Level-1 bandwidth. The rapid pattern recognition and track fitting allows global track reconstruction of all tracks with \( p_T > 1 \text{ GeV}/c \) to be done in about 100 µs, thus providing the tracks at the beginning of Level-2 event processing. The pattern recognition uses content addressable memory (CAM) custom chips, which store the 109 patterns. With this architecture all patterns see each hit almost simultaneously. The FTK architecture is based on massive data parallelism, with all silicon hits, from both the pixel and strip detector, transferred to the FTK at each bunch crossing. The readout chain consists of the following elements: the Input Mezzanine (IM), Data Formatter (DF), Auxiliary (AUX) card, Associated Memory Board (AMB), a Second Stage Board (SSB) and the Front-End – Level-2 Interface Card (FLIC). A key element is the AM06 chip in 65nm technology that holds 128k patterns. The chip was submitted for production in June but there were issues with the packaging, which has caused schedule delays. Test sites are up and running and are exercising the system with the AM05 chip.
Production versions of all boards are expected for June 2016 and the barrel coverage should be installed by July 2016. The overall schedule of the FTK with respect to the schedule presented at the 2014 winter LHCC meeting is about 8 to 9 months late. The LHCC takes note of the delays and regrets that the ATLAS experiment is unable to take advantage of the FTK at the originally scheduled early date.

8. Report on the LHCC review of the ATLAS Phase-I LAr Calorimeter TDR


LHCC 117, 5-6 March 2014

The physics motivation behind the ATLAS LAr Calorimeter upgrade is to maintain the Run I electromagnetic calorimeter rates at future higher Run III luminosities without raising thresholds. This can be achieved by increasing the transverse and longitudinal granularity of the existing LAr calorimeter using new electronics. The UCG findings are: a) information provided on costing, manpower and risk is based on prior experience and current costs, and is reasonable and consistent; b) the performance should be carefully studied to prevent deterioration in detector performance from increased noise, e.g. resolution in missing $E_T$; and c) the critical choice of the analog-to-digital converter for the LAr Trigger Digitizer Board (LTDB) is still to be made. The UCG recommends to the LHCC approval of the ATLAS LAr Calorimeter upgrade cost estimate.

LHCC 119, 24-25 September 2014

The LAr Calorimeter power supplies have been refurbished by the manufacturer and all are now working. The 4-sample read-out has been commissioned for up to 100 kHz read-out. The Tile Calorimeter repair campaign is completed and residual problems remain with only one barrel drawer. The Cs calibration system has been consolidated against leaks.

LHCC 122, 3-4 June 2015

The ATLAS experiment also presented a comprehensive overview of the plans for the Phase-2 upgrade. The ATLAS experiment has submitted five Technical Design Reports (TDRs) for the Phase-1 upgrade that set the path for the Phase-2 upgrades. The LoI for the Phase-2 upgrade described its major components: the full replacement of the inner tracker, major upgrades to the Trigger/DAQ (TDAQ), upgrades of the LAr calorimeter electronics based on streaming of all data off-detector with 40/80 MHz digitization rate and upgrades to the Tile Calorimeter and muon electronics. An extensive programme of optimization has been carried out post-LoI, based on the Phase-1 TDRs. The current “reference design” for ATLAS is, as for CMS, optimized for ultimate luminosity conditions including running at PU=200. The proposed TDAQ architecture is based on a split Level-0/Level-1 trigger architecture. A Level-0 latency of 6 $\mu$s is foreseen and a Level-1 latency of 30 $\mu$s. This will allow the introduction of Level-1 Track Associated Memory (AM)-based track finding driven by Level-0 Regions of Interest (ROIs). It also enables a highly-performant Level-1 Calorimeter trigger based on Level-0 ROIs and the availability of full calorimeter data.

The Fast Tracker (FTK) will be strengthened, enabling 100 kHz reconstruction of all tracks with $p_T > 1$ GeV. The HLT processing farm is specified for a maximum output rate of 10 kHz. Prototype trigger menus have been run and seem to be able to meet the physics goals.

A clear plan for upgrading the LAr calorimeter front-end and back-end electronics is being developed, which allows moving to a digital 40/80 MHz streaming output which also provides ROI-based finely segmented data to the Level-1 Calorimeter trigger.
The LAr calorimeter system is working well; the long-observed low-noise bursts have been found to be correlated with the LAr purity monitor high-voltage system. Two Tile Calorimeter modules have had to be turned off, and one is at 50% high voltage. It is planned to repair two of these modules during the YETS. The Tile Calorimeter muon trigger is being commissioned ready for 2016 operations.


The TDAQ feature extractor boards are progressing. The electron board lay-out has been completed and the jets and global boards will be sent for fabrication by the end of 2015. The accumulated delay is about 5 months.

The ATLAS experiment also presented the status of the Trigger/DAQ (TDAQ) Phase-1 Upgrade. This upgrade is motivated by the requirement to maintain thresholds within the 100 kHz Level-1 bandwidth to improve the performance of the Level-1 single object triggers. For the calorimeter, this is achieved by the use of 'Super-Cells' and increase of the digitization precision. One (Δη×Δφ) = (0.1 × 0.1) trigger tower will map into 10 super cells, with readout for each of the four longitudinal layers and four azimuthal readout segments for layers 2 and 3 each. This will enable the implementation of very effective shower shape variables at the trigger level, which provides for a more effective identification of electrons, photons and leptons, sharpens the electromagnetic, jet, and ET-miss efficiency turn-on curves and allows for an event-by-event pileup subtraction. Also the tau-identification would see considerable improvement. The trigger hardware consists of a Jet Feature Extractor (jFEX) module, an electromagnetic FEX (eFEX), and a global FEX (gFEX). Prototype test modules are available and are being tested. The layout for the jFEX modules is on-going and the boards will be manufactured in the first quarter of 2016. Production issues have hampered the production of eFEX modules, but new boards are expected in early 2016. The gFEX prototype modules will be submitted for production at the end of 2015. The speed of the LA-L1Calo link is not yet defined. Tests are foreseen in the timeframe of January to March 2016 before a decision will be taken.

The Phase-I upgrades are well under way, with the TDAQ upgrade already completed.

10. Report on the LHCC review of the ATLAS Forward Proton (AFP) TDR

The LHCC recommended for approval the ATLAS Forward Proton (AFP) Detector Technical Design Report, subject to its approval at the next ATLAS Collaboration Board and by the LHC Machine Committee (LMC).
ATLAS submitted the final draft version of the Technical Design Report for the Forward Physics (AFP) project; an almost-complete draft was considered at the March 2015 LHCC meeting. The project calls for installation of a single arm in the 2015 winter shutdown, which appears very ambitious. In practice both arms could be installed together during the 2016 winter shutdown. The LHCC recommended for approval this Technical Design Report, subject to its approval at the ATLAS Collaboration Board (expected within 2 weeks). As the AFP interferes potentially with the LHC Machine operation, approval is also required from the LHC Machine Committee (LMC) with documentation and approval via Engineering Change Requests (ECRs) for any beamline changes.

**LHCC 123, 23-24 September 2015**

Following approval by the ATLAS Collaboration Board and endorsement by the LHC Machine Committee (LMC), ATLAS plans to install one arm of the ATLAS Forward Physics (AFP) detector during the upcoming Year-End-Technical- Shutdown (YETS).

A van der Meer scan was performed with ALFA in preparation for \( \beta^* = 90 \text{m} \). One station apparently caused 'UFO's and had to be retracted; if beam-loss monitor thresholds can safely be increased it may be possible to restore this station. The ATLAS Forward Physics (AFP) received Collaboration approval after the previous LHCC meeting and was presented to the LHC Machine Committee (LMC) with documentation and approval via Engineering Change Requests (ECRs) for any beamline changes. It is planned to install one arm during the upcoming Year-End-Technical-Stop (YETS).

**LHCC 124, 2-3 December 2015**

The AFP (ATLAS Forward Proton) detector trigger cables and services for both arms will be installed in the YETS, and at least one station will be instrumented for 2016 operations.

**LHCC 125, 2-3 March 2016**

The LHCC heard that one arm of the ATLAS Forward Proton detector has been installed, with cabling and services already installed for both arms. The next arm will be installed in the next YETS.

**LHCC 126, 25-26 May 2016**

The newly installed first arm of AFP has been integrated into the ATLAS DAQ. The ALFA detector observes a large increase in radiation dose when AFP is in beam. AFP will only be inserted for a few fills for commissioning in 2016.

AFP has been integrated into the ATLAS DAQ system without latency penalty and diffractive proton data have been recorded. With AFP in-beam, ALFA has observed a significant increase in radiation dose to its electronics.

**LHCC 127, 21-22 September 2016**

With AFP in-beam, ALFA is unable to run at high luminosity due to knock-on backgrounds.

**LHCC 129, 22-23 February 2017**

EYETS work is proceeding according to plan, with activities including refurbishments of calorimeter cooling loops, the replacement of a few muon chambers with broken wires, and the installation of the second arm of the AFP detector. Continuous operation of both arms is foreseen in standard high luminosity pp running in 2017.
LHCC 130, 10-11 May 2017
The second arm of the AFP system has been installed. Both arms will be operated continuously in standard high-luminosity pp fills in 2017.

11. Report on the LHCC review of the CMS Phase-I Hadron Calorimeter TDR

LHCC 122, 3-4 June 2015
The CMS hadron calorimeter is also ready for data taking.

The second main element of the upgrade is the proposed high-grained end-cap silicontungsten calorimeter (HGCAL) followed by a backing hadron calorimeter (HE). The proposed HGCAL has 28 longitudinal Si/W segments, forming the electromagnetic section, followed by 12 depth segments of a silicon-brass front hadron calorimeter. It is completed by a 12 segment scintillator/brass backing hadron calorimeter.

LHCC 124, 2-3 December 2015
The hadron calorimeter exhibited loss of synchronization in the forward calorimeter electronics for a small fraction of the data.

The LHCC carried out an in-depth review of the Phase-I upgrades of the CMS Hadron Calorimeter (HCAL, the Trigger and the Pixel detector. The upgrade of the electronics for Hadron Calorimeter (HCAL) consists of an upgrade of the front-end and of the back-end. The new back-end electronics replaces the VMEbased system with a µTCA-based system and is the same for the different HCAL subdetectors (Hadronic Forward (HF), Hadronic Barrel (HB), Hadronic End-cap (HE), and Hadronic Outer (HO)). It only differs in firmware implementation. This upgrade is going very well. The new electronics has been exercised with data for all four subsystems; for the HF, HB and HE it has already been implemented in the trigger for data taking, albeit at a lower readout speed. Plans for the HO are being developed, as are plans for the higher (4.8 Gb/s) readout speed.

The upgrade of the front-end is lagging. For the HF 144 QIE cards, holding the new QIE10 chips, and 470 Versatile Link Dual Transmitter (VTTx) cards are needed. The production and testing of the QIE cards is a major bottleneck and the throughput is limited by the VTTx availability; currently only 26 VTTx modules out of the 470 required are available. These issues limit the quadrant scale test and QIE card calibration. Furthermore, the required re-work of the PMT boxes does not fit in the 2015/16 YETS. Due to the hardware availability and firmware issues and the lack of time for the PMT rework, the Collaboration has decided to defer the HF front-end electronics installation effectively by one year to the Year-End Technical Stop (YETS) of 2016/2017.

The upgrade of the front-end for HB and HE consists of replacing the HPDs with SiPMs and the associated readout electronics. This gives better photon sensitivity and allows for better longitudinal segmentation. Most of the elements of the upgrade are on schedule, but the production and testing of the QIE (and VTTX) cards is on the critical path, as is the Clock Control Module; the SiPM Bias control is also near the critical path. The schedule for installing the HE upgrade during the YETS, in parallel with the HF upgrade, is tight and close monitoring is recommended. The HB upgrade is scheduled for installation in Long Shutdown 2 (LS2) and its schedule has significant float. The LHCC congratulates the experiment on the success of the back-end upgrade and takes note of the schedule constraints for the front-end upgrade. It regrets that the experiment will be unable to take advantage of the front-end upgrade earlier.
**LHCC 125, 2-3 March 2016**

The hadron calorimeter had several maintenance tasks performed and demonstrated partial recovery of the radiation damage between December 2015 and February 2016 (~5%) in the end portion of the calorimeter.

**LHCC 127, 21-22 September 2016**

Several new detector elements, some of them part of the Phase I upgrade, have successfully been integrated into the data taking, including the upgraded Level 1 trigger, new readout for hadron calorimeters, and the CT-PPS.

**LHCC 128, 30 November – 1 December 2016**

CMS efficiently integrated new elements, some of them part of the Phase I upgrade, into the data collection, including the upgraded Level 1 trigger, new readout for hadron calorimeters, as well as CT-PPS. This enhanced CMS ability to collect data with high efficiency up to luminosities of 1.5 x 10^{34} cm^{-2}s^{-1}. Various special runs have been collected during 2016. The pPb run was in progress at the time of the LHCC meeting and CMS collected data with high efficiency.

**LHCC 129, 22-23 February 2017**

The forward hadron calorimeter (HF) upgrade with new multi-anode PMTs has been successfully installed and is now in the commissioning stage. The installation of SiPMs as an upgrade of the hadron endcap calorimeter (HE) has been postponed, taking into consideration the technical risks of the installation and the radiation aging of the current detector.

The forward hadron calorimeter (HF) upgrade with new multi-anode PMTs has been successfully installed and is now in the commissioning stage.

12. Report on the LHCC review of the CMS Pixel Detector Upgrade TDR

**LHCC 124, 2-3 December 2015**

Due to significant delays in the procurement and qualification of critical components, the production schedule for the Pixel Detector upgrade is extremely tight.

The CMS Collaboration plans on replacing the current pixel detector in the YETS in 2016/2017 with a new pixel detectors, which has four layers in the barrel region and three disks each for the forward and backward regions.

With the scope of the upgrade defined, major efforts are now directed toward R&D with the goal to have Technical Design Reports (TDRs) for various sub-systems ready, starting with the TDRs for the Pixel Detector and Outer Tracker upgrades in early 2017. Both of these systems require a substantial design, construction and assembly time.

**LHCC 125, 2-3 March 2016**

The upgrade of the CMS Pixel detector, also foreseen for the EYETS 2016/17, is making steady progress, although delays in module assembly and the production of the read-out chip lead to a critical schedule. The LHCC recommends the management to closely follow the development of...
these projects. A decision is expected by the next LHCC on what can be installed in the upcoming shutdown

**LHCC 126, 25-26 May 2016**

There is great progress and currently a good chance for installation during the coming EYETS, but the schedule is still very tight. The decision to proceed or not with the pixels installations this year will be made following an enhanced Engineering Design Review scheduled on June 16-17, 2016.

**LHCC 128, 30 November – 1 December 2016**

A key activity during the EYETS is the replacement of the pixel detector. The barrel pixel detector has an impressive near 100% channel yield. The disks are all at CERN with some issues remaining to be resolved, most notably some damaged cables. These issues will be investigated in the coming weeks. The installation has been exercised and all resources for the installation have been secured. Although the schedule is very tight, the collaboration is confident that the pixel detector can be installed as scheduled.

Impressive progress has been made on the new pixel detector to be installed during the EYETS, with a very high probability that the detector can be installed as foreseen.

**LHCC 129, 22-23 February 2017**

The beam line in CMS will be re-aligned vertically by ~1mm to give more uniform illumination of the pixel detector using a magnetic orbit bump, although a full mechanical realignment will be needed during LS2.

EYETS activities are progressing as planned with shutdown activities centred on the installation of the new pixel detector. CMS expects to be ready for beam as planned by May 1st, 2017.

Both barrel and forward pixel detectors have been delivered to CMS and extensively tested. Installation of the new detectors into CMS is expected late February and early March.

The LHCC congratulates CMS on the excellent progress made in particular in getting the pixel detector ready for installation in time for the on-going EYETS.

The beam line in CMS will be re-aligned vertically by ~1mm to give more uniform illumination of the pixel detector using a magnetic orbit bump, although a full mechanical realignment will be needed during LS2.

EYETS activities are progressing as planned with shutdown activities centred on the installation of the new pixel detector, but also including the installation of various HLLHC upgrade prototypes. CMS expects to be ready for beam as planned by May 1st, 2017.

On the Phase-I upgrades both barrel and forward pixel detectors have been delivered to CMS and extensively tested. Installation of the new detectors into CMS happened in late February and early March. The forward hadron calorimeter (HF) upgrade with new multi-anode PMTs has been successfully installed and is now in the commissioning stage. The installation of SiPMs as an upgrade of the hadron endcap calorimeter (HE) has been postponed to the 2017/18 YETS, taking into consideration the technical risks of the installation and the radiation aging of the current detector. The LHCC congratulates CMS on the excellent progress made in particular in getting the pixel detector ready for installation in time for the on-going EYETS.
The upgrade of the Forward Hadron Calorimeter involving the installation of new multi-anode PMTs had already been achieved by the February session of the LHCC. The Hadron Endcap Calorimeter upgrade has been postponed to the 2017/18 YETS, however keeping one new readout box in place for 2017 running to gain experience with the new electronics.

13. Report on the LHCC review of the CMS Phase-I Level 1 Trigger TDR


Submission of Technical Design Reports for VELO and Particle Identification expected for December 2013

The LHCB experiment presented the decision, taken during their recent technical design review, to employ the micro-channel based pixel sensor technology as the baseline for the upgrade of the Vertex Locator (VELO) detector. Two pixel sensor designs, using micro-channel cooling or using pocofoam cooling, and two strip sensor designs, again one using micro-channel cooling and one employing TPG cooling blocks, were considered. All options show improved performance over the current detector. The pixel option with micro-channel cooling represents the lowest material budget before the first measurement and has close to 100% uniformity with slightly better tracking efficiency. The integrated micro-channel cooling has been tested with hydrophobic bonds up to a pressure of 700 bar and techniques have been developed for soldering cooling connectors to withstand this pressure. Good progress is being made on the development of the read-out chip, the VELOPIX, which is based on the TimePix3 chip. The Committee would like to congratulate the experiment on the impressive amount of advanced R&D and is looking forward to a continued optimisation of the overall detector, which clearly holds the promise to deliver a wealth of high-precision data.

The LHCB upgrade is progressing according to schedule. Out of the 42 expected, 34 milestones have been reached, where three of the missed milestones so far were not on the critical path.

Major steps were taken in the previous months with the choice of technology for the upgrade of the Vertex Locator (VELO) and Ring Imaging Cherenkov (RICH) detectors and with a continuous effort to complete the Technical Design Reports (TDRs). The VELO and Particle Identification (PID) TDRs, incorporating the RICH, Calorimeter and Muon detectors, should be ready for December 2013, while the TDRs for the Tracker (UT, CT) and Low Level Trigger (LLT) are expected for March 2014. In the meantime, the LHCB Collaboration is still growing by adding the Kurchatov Institute (Russia) as a new Associate Member. At present, the Kurchatov Institute provides a strong technical contribution to the Fibre Tracker and there is great potential for this
Institute becoming a new strong member. From the financial point of view, negotiations with Funding Agencies proceed well. Many members have responded positively, while negotiations are still in progress with the United Kingdom, USA and Russia.

For the VELO upgrade, LHCb selected the micro-channel-cooled Pixel technology. The decision was approved by the Collaboration in July 2013 after a dedicated Upgrade Technology Review (VUTR) at end of May 2013 and related upgrade meetings and technical boards. Four options were compared with the same upgrade simulation tools, equivalent foil thicknesses and minimum inner radius. In contrast to the current VELO, all options have integrated cooling. The material budget was similar between options with the Strips, which, however, showed a worse \( \phi \)-dependence than Pixels due to overlapping foils at large angle. The impact parameter resolution and the efficiency were in all cases better than the current VELO, with the Pixels showing better performance than the Strips. On the other hand, the Strips show a secondary vertex resolution that is 20% better by having the first measured point slightly closer than the Pixels. However, this translates, via dilution, to a 15% statistical advantage and has still to be weighed by the difference in tracking efficiency. The decision on the Pixels was supported by all the Collaboration and was based essentially on two considerations: a) radiation effects have small impact on the efficiency and resolution and b) the track reconstruction performance was much faster than in the Strip option (7.6 ms/event to 2.8 ms/event). The report of VUTR referees indicated no show-stopper for any solution but encouraged to work on sensor prototyping and radiation hardness and recommended to make a risk assessment for the micro-channel cooling. The VUTR referees also observed that the VELO upgrade construction schedule is very tight. Since then, much progress has been made. The module lay-out has been improved and design of cooling connectors and the connectors’ fixture are complete. Many tests were carried out such as that for the performance of micro-channel cooling and for the read-out via Timepix-3 chips. Prototyping of sensor and bump-bonding have been also carried out. A dedicated electronic review is planned for November 2013.

**LHCC 116, 4-5 December 2013**

The LHCC received the Vertex Locator (VELO) (CERN-LHCC-2013-021) and Particle Identification (PID) (CERN-LHCC-2013-022) Technical Design Reports just prior to the Committee's December 2013 meeting. Initial discussions have taken place and further evaluation will follow to reach a conclusion at the LHCC meeting in March 2014.

The LHCb experiment submitted the TDR on the Vertex Locator (VELO) upgrade (CERN/LHCC-2013-021), which had been discussed extensively at the previous LHCC meeting. After extensive evaluation of four options, the Collaboration proposes to replace the current VELO detector with a lightweight hybrid pixel detector capable of 40 MHz readout at a luminosity of \( 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1} \). Cooling will be provided by evaporative CO2 circulating in micro-channel cooling substrates. The detector contains 41 million \( 55 \mu m \times 55 \mu m \) pixels, read out by the custom developed VeloPix front-end ASIC. Track reconstruction speed and precision is enhanced relative to the current VELO detector even at the high occupancy conditions of the upgrade, due to the pixel geometry and a closest distance of approach to the LHC beams of just 5.1 mm for the first sensitive pixel. The new detector has close to 100% uniformity. The integrated micro-channel cooling has been tested with hydrophobic bonds up to a pressure of 700 bar and techniques have been developed for soldering cooling connectors to withstand this pressure. Although the VELO upgrade construction schedule is very tight, a dedicated team is making steady progress and continued optimisation of the overall detector is expected.

The VELO TDR upgrade (CERN-LHCC-2013-021) includes a clear presentation of requirements, physics performance and design specifications together with a list of R&D results. The technology choice of micro-channel-cooled pixels looks mature and the technical items are well detailed. The LHCC will do a more detailed review of this TDR in the next month and will meet with LHCb to go through a set of dedicated comments and questions. The plan is to work for approval in time for March 2014 meeting. The PID TDR (CERN-LHCC-2013-014) is well structured. It consists of RICH,
Calorimeter and Muon systems. Some minor adjustment is still needed, such as to extend the description of the physics performance by adding a few significant measurements or plots based on this upgrade. Also for this TDR, much of the R&D has been carried out and many technical details reported. The LHCC observes that there is a risk/opportunity in cost saving for RICH-2 due to the still pending options of higher curvature lenses or larger area photomultipliers. The LHCC plans to proceed for approval with the same strategy as the one adopted for the VELO TDR.

LHCC 117, 5-6 March 2014

The UGC reviewed the LHCb Vertex Locator (VELO; CERN-LHCC-2013-021) and Particle Identification (PID; CERN-LHCC-2013-022) Technical Design Reports. • The LHCb VELO is a completely new silicon detector to provide improved track reconstruction at higher occupancies. The UCG findings are: a) the project is very ambitious in scope and only four years available to replace the current VELO in one single step; b) the cost estimates are reasonable; c) to ensure success of the project the LHCC must closely monitor the funding situation; and d) the RF foil is very demanding and critical for the project. The UCG recommends to the LHCC approval of the LHCb VELO upgrade cost estimate.

The VELO and PID TDRs have been scrutinized carefully by the Committee. A dedicated set of questions and technical details were posed to the Collaboration in January 2014. The LHCb Collaboration sent formal replies separately for each TDR to the LHCC before its March 2014 session, clarifying the situation in a convincing manner. The VELO TDR addresses all concerns that arise from such an ambitious project. It presents a convincing technology and describes well the physics motivations and detector requirements. Moreover, it states mitigation paths for which risks are high and elaborates on the remaining R&D to be completed. A number of options are left open for the final technology choices but the associated R&D programme is sound. All risk issues that come to mind are addressed. The PID TDR contains three, nearly independent sections for the RICH, the Calorimeter and the Muon Systems. The overall system is well described and the physics performance is well motivated. The most demanding upgrade concerns the RICH system. Technical choices are well explained. The bulk of the cost arises from the replacement of the Hybrid Photon Detectors (HPDs) with Multi-anode Photomultipliers (MaPMTs). There are options with larger areas MaPMTs or lenses in the RICH-2, which hopefully can be implemented to save cost. The upgrade of the Calorimeter and Muon systems mostly consists of a replacement of the readout electronics that poses no major concerns. For both TDRs, the cost details are clearly stated. A dedicated review on cost was carried out by the newly formed UCG. The LHCC conclude that both the VELO and PID TDRs are of very high quality. The LHCC congratulates the LHCb Collaboration and recommends for approval the VELO and PID Technical Design Reports.

LHCC 121, 4-5 May 2015

Vertex Locator (VELO): Detector half-planes have been rotated by 45-degrees, compared to configuration presented in the Technical Design Report, to mitigate tight tolerances during insertion. The changed geometry required a new foil design. Machine impedance studies are ongoing. The LHCC encourages the experiment to prepare a document in common agreement with the machine.

Design of the VeloPix ASIC (based on TimePix3) is ongoing at full speed and with a rather aggressive schedule. Availability of VeloPix will drive the VELO project schedule.

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LHCC 122, 3-4 June 2015

Progress on the Vertex Locator (VELO) is also proceeding very well. A study on the longitudinal impedance of the VELO RF foil was performed yielding $\text{Im}(Z_{\text{long}})=3.5 \, \text{m}$Ω while the impedance for LHC is $\text{Im}(Z_{\text{long}})=90 \, \text{m}$Ω. The LHCb VELO group has good cooperation and mutual understanding with LHC impedance and vacuum experts. LHC experts continue with simulation studies with support of LHCb to minimize the longitudinal impedance since it is correlated with the path length of the image currents. The sensor EDR took place 1-2 June 2015. The VELO group had performed an intense test beam activity in the last weeks producing many positive results. They tested 11 different sensors from two manufacturers before irradiation and after irradiation with proton and neutron beams. The analysis is ongoing and results on efficiency and charge collection were shown at the EDR. The module design was chosen, selecting the singlepoint support with features of the carbon-fibre support design.

LHCC 123, 23-24 September 2015

The upgrade of the Vertex Locator (VELO) system is also progressing very well. Two Engineering Design reviews (EDRs) were held in June 2015. The first one was dedicated to sensors. Remarks were raised on: (i) the Parylene coating for HPK p-on-n sensors that prevented reaching the operational bias at 1 kV and (ii) the presence of hot spots on the corners of Micron sensors. To address these remarks, pre-series with rounded corners were procured. Their tests in a test beam are in progress. The Production Readiness Review for the sensor is expected in the second quarter of 2016. The second Engineering Design Review was dedicated to the VELOPIX ASICS. Much progress was made to combine all technical elements and launch the final verifications before submitting the first chip version planned for the end of 2015. During the summer 2015 a workshop also was held to review all aspects of the VELO mechanics. An RF foil of $\frac{1}{2}$ meter has been designed and built. The Engineering Design Review on mechanics will take place at the end of 2016.

LHCC 125, 2-3 March 2016

Work on the VELO upgrade is continuing. The VELOPIX submission was delayed. Though no major issues exits, it is a complex chip requiring many details to be worked out and time-consuming simulations to be performed. Submission will start no later than end of April to produce a fully functional chip. A detailed plan for reabsorbing the delay is in place. A lot of activity has been on microchannel cooling. One crucial piece is the cooling connector. A pressure test with a stiffener on the back was completed successfully. In addition, creep tests were performed at elevated temperature and pressure. While one slit was fine after 150 h, the other slit broke after 54h. It was found that the creep developed at a void place. Hence care must be taken with the soldering procedure. Other tests involved the safety system and feed-throughs. The LHCC acknowledges that the VELO upgrade is a complex enterprise and that present delays – 13 – can be compensated in the overall schedule. Nevertheless, the timeline is tight. Thus, the LHCC will closely monitor the progress on the VELO upgrade.

LHCC 126, 25-26 May 2016

The upgrade of the detectors overall is progressing well. The PRR for sensors for the VELO detector has been postponed to September 2016 to implement some minor modifications to improve their performance, which is well justified. The prototype sensors perform very well.
**LHCC 127, 21-22 September 2016**

- Progress on the VELO is mixed. PRRs for sensor and cooling substrate were delayed.
  - The VeloPix was received. Initial tests show full functionality. To explore the full ASIC performance, necessary tests with the full electronic chain including sensors in a test beam are planned for 11/16.
  - New improved sensors were received from Hamamatsu. Sensors from Micron are expected. The sensor PRR is scheduled for 10/16 to select one type. The module design was finalized.
  - All prototypes for electronics and readout integration exist and tests look fine. - An improved RF foil prototype is in production.
  - Mechanics is on the critical path. LHCb will allocate 1.5 FTE mechanical engineers and 1 FTE to help with implementing important modifications. The mechanics EDR is planned for 11/16.
  - The microchannel cooling plates developed a delay, because zero bids were received for the tender. LHCb started negotiations with LETI to do a multi-phase process; first step: estimate bonding quality yield (10/16); second step: obtain full-size cooling plate (3/17). As plan B LHCb considers to use embedded pipes in milled pocofoam. The design proposed in 2013 was tested and is compatible with the mechanical design but degrades the impact parameter resolution by 20%. LHCb will follow both approaches in parallel. Another issue may consist of solder residues in corners of microchannels.

**LHCC 128, 30 November – 1 December 2016**

The phase-I upgrades are generally progressing well. UT, SciFi, Calo, RICH and muon system upgrades have entered the construction phase. Areas of concern are the UT and the VELO. The slippage in the UT schedule means that the SALT128 production is now on the critical path. The issues related to the microchannel cooling of the VELO are still unsolved. LHCb has scheduled a comprehensive review for 30/01/17-01/02/17 with focus on critical aspects, organization of construction and preparation for installation.

**15. Report on the LHCC review of the LHCb Phase-I Particle Identification TDR**


**LHCC 115, 25-26 September 2013**

Submission of Technical Design Reports for VELO and Particle Identification expected for December 2013

**LHCC 116, 4-5 December 2013**

The LHCC received the Vertex Locator (VELO) (CERN-LHCC-2013-021) and Particle Identification (PID) (CERN-LHCC-2013-022) Technical Design Reports just prior to the Committee’s December 2013 meeting. Initial discussions have taken place and further evaluation will follow to reach a conclusion at the LHCC meeting in March 2014.

The LHCb experiment also submitted the TDR for the upgrade of the Particle Identification Detector (PID) (CERN-LHCC-2013-022), which contains upgrades to three key subdetectors making up the particle identification system: the Ring Image Cherenkov (RICH) detector, the calorimeter and the muon system. The upgrades to each sub-detector were presented. Due to the
unacceptably high occupancies in the RICH1 detector, the aerogel will be removed and the performance will be largely retained through a redesign of the optics. The opto-electronics read-out chain will be adapted to sustain a 40 MHz read-out at a luminosity of $2 \times 10^{33}$ cm$^{-2}$ s$^{-1}$. The current Hybrid Pixel Detectors (HPDs) have the readout ASIC, which is limited to 1 MHz read-out rate, integrated in the device and will need to be replaced. The baseline new photodetector is a 64 pixel MAPMT with single photon sensitivity, average photoelectron yield of 40, pixel size less than 3 mm and time resolution better than 25 ns. A total of 1920 (2560) MAPMTs are required for the RICH1(2) detector(s). This spatial resolution is not needed for the RICH2 detector and the Collaboration is encouraged to develop other cost-effective options. Custom read-out ASICs, the CLARO and MAROC chips, are in development.

LHCC 117, 5-6 March 2014

The UGC reviewed the LHCb Vertex Locator (VELO; CERN-LHCC-2013-021) and Particle Identification (PID; CERN-LHCC-2013-022) Technical Design Report:

The ATLAS PID upgrade increases the read-out rate from 1 MHz to 40 MHz and applies a new software trigger. The front-end electronics of all systems, and in some cases whole detection systems themselves, must be replaced. The UCG findings are: a) to ensure success of the project the LHCC must closely monitor the funding situation; b) the Ring Image Cherenkov-1 (RICH-1) must be re-designed to fit within the same volume; c) the RICH-2 Hybrid Pixel Detectors (HPDs) are to be replaced by 1” Multi-anode Photomultipliers (MaPMTs) with new front-end electronics and lenses. The UCG recommends to the LHCC approval of the LHCb PID upgrade cost estimate.

LHCC 121, 4-5 March 2015

For the Particle Identification (PID) detectors, no concern exists for the Calorimeter and Muon systems where the main choices have been made and many Engineering Design Reviews are planned for the coming months.


LHCC117, 5-6 March 2014

In preparation for the March session of the LHCC, the Committee received two TDRs. The ALICE experiment submitted the TDR for the Time Projection Chamber (CERN-LHCC-2013-020) and LHCb presented the Tracking TDR (CERN-LHCC-2014-001). The Committee congratulates both experiments on the submission of these wellwritten TDRs. The LHCb Tracker upgrade consists of the replacement of two existing systems: the Trigger Tracker (TT), and the three downstream tracking stations T1, T2 and T3 (TStations). The silicon-strip-based TT will be replaced with a new silicon-strip-based Upstream Tracker (UT). The T-stations, currently using straw tubes for the outer stations and silicon strips for the inner stations, will be replaced with a single scintillating fibre technology. The upgrade is motivated by the 40 MHz readout requirement. The upgraded detector is fast enough for pattern recognition in the HighLevel Trigger (HLT). Furthermore, occupancies and radiation damage can be kept in check with the upgrade and the overall performance improved. A track finding efficiency exceeding 99.9% is targeted for the upgrade. The formation of a track trigger, using the magnetic field between the Vertex Locator (VELO) and UT will also be made possible with this upgrade, with a momentum measurement of $\Delta p/p \sim 15\%$, allowing for a drastic reduction in the number of candidate tracks passed to the fibre tracker. The UT consists of four all-silicon planes in the X-UV-X configuration at the same $z$-
locations as the TT. Three types of silicon sensors will be used: 10 × 10cm² silicon strip sensors with 190 µm pitch in the outermost region, and sensors with half the pitch and some with half the length surrounding the immediate area around the beam. All sensors are individually read out with the SALT chip. The opening for the beam is kept as small as possible to keep B-meson reconstruction inefficiency <6% for Bs reconstruction. The well-established stave concept, with embedded CO2 cooling, is used for assembly with sensors on either side of the stave. This assures full coverage and significant reduction in material budget in the far forward region. The Fibre Tracker has three stations with four 4 detection planes (X-UV-X) each. The stereo stations have the same 5 degree stereo angle as the UT. There are twelve fibre modules per detection plane. The fibre-ends at the equator are mirrored and each module has separate readout of the top and bottom segment. Each module end – top and bottom – has 16 Silicon Photomultiplier (SiPM) arrays, with each array having 128 channels that read out the fibre mats. The detector has to satisfy a stringent set of requirements. The photodetectors and fibres have to withstand a radiation dose up to 80 Gy and 35 kGy, respectively. The photodetectors will be cooled down to −40 ºC to maintain efficiency and to minimize radiation damage. A resolution of better than 100 µm in the bending plane is required with a mass budget of less than 1% X0 per detection layer. The baseline solution for the readout of the SiPMs uses the PACIFIC ASIC and a dedicated FPGA for clustering of the fibre hits. Bandwidth utilization is optimized using a “concentrator” chip, which enables readout of the 590k channels at 40 MHz. The upgrade of the LHCb Tracker is well motivated given the anticipated degradation of the performance of the current detector and to ensure compatibility with the overall upgrade to 40 MHz of the whole detector including the High Level Trigger (HLT) triggering capability.

LHCC 118, 4-5 June 2014

The LHCC heard a report from the Upgrade Cost Group (UCG). LHCb The UCG reviewed the LHCb Tracker Upgrade Technical Design Report (CERN-LHCC-2014-001). The Tracker Upgrade consists of the Upstream Tracker (UT) and Scintillating Fibre Tracker (SciFi) detectors. The UT is made of 4 planes constructed using staves with silicon on both sides, partially overlapping in the x-direction to ensure full coverage and with a higher segmentation in the region surrounding the beam pipe. The UCG findings are: a) the UT group is experienced and uses wellknown techniques; b) the risk of employing large numbers of undergraduates in the production is low and manageable, but this needs to be monitored through the project; and c) the schedule seems tight but feasible with the main concern being the schedule for the front-end electronics. The UCG recommends to the LHCC approval of the LHCb Upstream Tracker cost estimate. To ensure quality and schedule the LHCC should monitor progress of the electronics development & production and LHCb should request a quote from the firm Micron for the silicon. The SciFi consists of three stations downstream of the LHCb magnet, each station made of four fibre layers each and read out by silicon PMTs. The detector is built up from 144 modules, 1,150 fibre mats and 10,000 km of fibres, representing an unprecedented scale. The findings of the UCG are: a) the estimates of the cost and manpower are reasonable; b) the requested spending profile matches the schedule; c) the fibre acceptance and mat assembly pose major challenges; and d) the cost of replacing the inner region is not known. The UCG recommends to the LHCC approval of the LHCb SciFi cost estimate. Furthermore, LHCb should a) establish comprehensive QC/QA programmes and tools that are the same for each site; b) obtain a quote from KETEK for the SiPMTs to allow comparison with Hamamatsu; c) resolve remaining cost uncertainties; d) provide a cost estimate for replacing the inner region; and e) protect against currency fluctuations in dealing with vendors from Japan.

Upgrades: The preparation of the LHCb upgrade proceeds as planned. The major milestone of delivering Technical Design Reports (TDRs) for all systems was achieved. The TDRs for the Vertex Locator (VELO) and the Particle Identification (PID) systems were approved in March 2014 and the TDR for the Tracker systems was approved in June 2014. The LHCC has just received the TDR for the Online and Trigger. After the TDR completion, the upgrade money matrix is being frozen.
and LHCb plans to present it officially to the next Resource Review Board (RRB) in October 2014. Concerning funding, the negotiations with Funding Agencies proceed well. Italy has given approval. The Netherlands and the USA have taken their decision but an official statement is expected only for the end of June 2014. The UK has also formalized its decision that should be publically released for the beginning of July 2014. Germany is moving forward with its process that should be completed before the end of the summer. France, Russia and Brazil showed also a positive trend in the approval process and will soon clarify their contributions.

The Tracking TDR was received by the LHCC in March 2014, and has been reviewed by the Committee. The TDR clearly describes the two systems contributing to the overall tracking for LHCb, the UT (or Upstream Tracker) and the SciFi (Scintillating Fibre Tracker) systems. Together with the VELO, the upgraded tracker grants a high reconstruction efficiency, a low ghost rate and good tracking precision up to the luminosity regime of $2 \times 10^{33}$ cm$^{-2}$ s$^{-1}$. A set of comments and questions were posed to the Collaboration in April 2014. The LHCb Collaboration sent formal replies well in advance of the June 2014 LHCC session. The answers were clarifying the Committee’s minor concerns. As a final comment, the LHCC observes that, although the direct comparison between the current and upgraded tracker in the same high luminosity running conditions shows a very large improvement on performances, some loss of efficiency (2% for long tracks and from 8% to 10% for downstream reconstructed tracks) is observed with respect to the current detector at today’s luminosity. The Committee understands that this has been obtained with a very first version of a fully-renewed tracking reconstruction and that there is plenty of room for improvements. The Collaboration will keep investigating this in detail and the Committee looks forward to receiving a status report on further progress as the project proceeds. The cost details are clearly shown and a dedicated review on cost and schedule was carried out by the UCG. The LHCC concludes that the Tracking TDR is of very high quality. The Committee congratulates the LHCb Collaboration for this great achievement and recommends the TDR for approval.

17. Report on the LHCC review of the LHCb Phase-I Trigger and Online TDR


LHCC 118, 4-5 June 2014

The LHCC received the LHCb Trigger and Online Upgrade Technical Design Report (CERN-LHCC-2014-016). The Committee would like to congratulate the experiment on the submission of another well-written Technical Design Report (TDR).

The trigger upgrade has seen an important evolution since the presentation of the Letter of Intent in 2011. At that time a nominal luminosity of $1 \times 10^{33}$ cm$^{-2}$ s$^{-1}$ had been assumed, targeting a gain of a factor of two in trigger efficiency for hadronic final states by removing the hardware level trigger and providing an input rate to the High Level Trigger (HLT) of 5-10 MHz with an overall output rate of 20 kHZ. After submission of the Framework TDR in 2012 the baseline luminosity increased by a factor of two and three trigger options were pursued: a pure software HLT, a hardware assisted FPGA-based trigger, and a Low Level Trigger (LLT) in conjunction with an HLT. With the recent technology decisions for the various upgrade components, and the selection of a bi-directional event builder with the read-out electronics located on the surface, the Collaboration converged on a purely software-based HLT trigger, reconstructing tracks at the full inelastic collision rate. The hardware LLT emulated in software is kept as backup option. All tracks with $p_T > 500$ MeV will be reconstructed online at the full 40 MHz collision rate. Particle identification based on Ring Image Cherenkov (RICH) detector algorithms and a Kalman filter will be run on a subset of events at 1 MHz. An efficiency of nearly 99% compared to offline is predicted with no $p_T$ or lifetime bias. The full tracking is estimated to take only 40% of the online CPU budget of 13 ms per event. It should be noted that a data volume of approximately 4 TBytes/s is
processed and reduced to an output rate of 2 GBytes/s with an event size of 100 kBytes. The limitation on the output rate is given by offline computing resources. Studies show that large gains in efficiency can be obtained for inclusive b-decay and exclusive charm-decay modes for increased output bandwidth, which in turn of course requires additional resources.

A compact online system is obtained by locating all components in a single location and the decision has been taken to locate the online system on the surface. This requires long (~300m) optical links to bring the data to the processing centre. Various optical fibres have been tested and the most cost-effective solution meeting the requirements has been chosen. About 8800 versatile links are foreseen. The read-out network will rely on data-centre technology exploiting I/O and memory performance of modern server PCs. The online architecture essentially consists of a two-layer system. The event builder, a farm of about 500 PCs, forms the first layer; the second layer is the even filter, which is a CPU farm of up to 4000 PCs. A critical element is the custom made PCIe40 board, which contains up to 48 bi-directional optical I/Os (Gigabit Bidirectional Triggers, GBTs), which handles data rates up to 100 Gbit/s. This board is the universal building block for the DAQ, the Experiment Control System (ECS) and the Timing and Fast Control (TFC). The architecture is scalable and resources can be added as needed. Modest extrapolation of Moore's law has been used to estimate the resources required and, for example, 1000 nodes of the type available in 2020 will allow 13 ms for event processing for the HLT. Equipment will be bought as late as possible to optimally use new technologies. For the ECS only evolutionary changes are foreseen. The upgrade of the trigger and online system is quite aggressive, but elegant cost-effective solutions have been found to achieve the physics goals and the project is well organized.

LHCC 119, 24-25 September 2014

Upgrades Preparation of the LHCb upgrade proceeds as planned. The LHCC discussed the LHCb Online and Trigger Upgrade Technical Design Report (CERN-LHCC-2014-016), completing the list of Technical Design Reports for the LHCb upgrade. The Technical Design Report was submitted by the LHCb Collaboration two weeks prior to the June 2014 session of the LHCC, being the result of a long series of meetings and reviews that allowed the Collaboration to select the final technology choices. The Technical Design Report describes the new Online that works with a bi-directional Event Building (EB) based on a 500 PC server and a bi-directional router running at 100 Gbits/s. The read-out unit uses PCI express and the implementation needs an Event Builder farm located in the surface building with long-distance (300 m) transmission fibres bringing the data from the detector front-end electronics. This scheme takes advantage of the high bandwidth cost-effective data centre technology to perform a full event building at 40 MHz. The HLT system is a fully software-based system for which its conceptual scheme and the event selection have been tuned on the high performance upgraded tracking system to achieve a dedicated tracking at 30 MHz with an Event Filter Farm (EFF) of 1000 servers. After the tracking reconstruction and track selection, the new HLT also applies particle identification and inclusive/exclusive selection at 1-2 MHz allowing to reach much higher efficiencies than in the current detector. Baseline storage on disk occurs at a rate of 20 kHz. This performance is estimated by reconstructing simulated events and assuming a 6-fold CPU improvement from now until 2019. The LHCC considers that the fully-software choice provides high flexibility to the system and will allow the experiment to adapt the trigger quickly to evolving conditions. A detailed list of comments, suggestions and general questions on this Technical Design Report was sent to the LHCb Collaboration in mid-August 2014. Replies were received a few weeks before the September 2014 LHCC session and found to be satisfactory. The only point under debate is the foreseen possibility to have a final data through-put higher than the baseline 20 kHz. Although more physics is achievable with a larger through-put, the Committee expects to hear more details in future LHCC sessions with refinement of the physics reach and dedicated integrated discussion of the related computing model. The LHCC concludes that the Online and Trigger Technical Design Report is of very high quality. The cost and manpower estimates are reasonable and the UCG recommends approval so resources become available. The Committee congratulates the LHCb Collaboration.
for this achievement and recommends the LHCb Online and Trigger Upgrade Technical Design Report for approval. The recommendation was presented to the Research Board by the LHCC Chairman in September 2014, and the Research Board approved the Technical Design Report.

The LHCC concludes that the LHCb Online and Trigger Upgrade Technical Design Report (CERN-LHCC-2014-016) is of very high quality. The Committee congratulates the LHCb Collaboration for this achievement and recommends the LHCb Online and Trigger Upgrade Technical Design Report for approval. The recommendation was presented to the Research Board by the LHCC Chairman in September 2014, and the Research Board approved the Technical Design Report.

References:
All documents are publicly available in CDS: http://cds.cern.ch

UCG Reports and TDRs

1. ALICE Phase-I Readout and Trigger System TDR
   CERN-LHCC-2015-014; UCG-012
   CERN-LHCC-2013-019; ALICE-TDR-015

2. ALICE Phase-I Time Projection Chamber TDR
   CERN-LHCC-2015-015; UCG-013
   CERN-LHCC-2013-020; ALICE-TDR-016
   CERN-LHCC-2015-002; ALICE-TDR-016-ADD1

3. ALICE Phase-I Inner Tracking System TDR
   CERN-LHCC-2014-013; UCG-009
   CERN-LHCC-2013-024; ALICE-TDR-017

4. ALICE Muon Forward Tracker TDR
   CERN-LHCC-2013-024; ALICE-TDR-018

5. ALICE Online-Offline (O2)Computing System TDR
   CERN-LHCC-2015-018; UCG-014
   CERN-LHCC-2015-006; ALICE-TDR-019

6. ATLAS Phase-I New Small Wheel TDR
   CERN-LHCC-2014-008; UCG-004
   CERN-LHCC-2013-006; ATLAS-TDR-020

7. ATLAS Phase-I Fast Tracker TDR
   CERN-LHCC-2014-007; UCG-003
   CERN-LHCC-2013-007; ATLAS-TDR-021

8. ATLAS Phase-I LAr Calorimeter TDR
   CERN-LHCC-2014-010; UCG-006
   CERN-LHCC-2013-017; ATLAS-TDR-022

9. ATLAS Phase-I TDAQ System
   CERN-LHCC-2014-009; UCG-005
   CERN-LHCC-2013-018; ATLAS-TDR-023
10. ATLAS Forward Proton (AFP)  
   CERN-LHCC-2015-009; ATLAS-TDR-024

11. CMS Phase-I Hadron Calorimeter  
   CERN-LHCC-2012-015; CMS-TDR-10

12. CMS Pixel Detector Upgrade  
   CERN-LHCC-2012-016; CMS-TDR-011

13. CMS Phase-I Level 1 Trigger  
   CERN-LHCC-2014-006; UCG-002  
   CERN-LHCC-2013-011; CMS-TDR-12

14. LHCb Phase-I VELO  
   CERN-LHCC-2014-011; UCG-007  
   CERN-LHCC-2013-021; LHCb-TDR-013

15. LHCb Phase-I Particle Identification  
   CERN-LHCC-2014-012; UCG-008  
   CERN-LHCC-2013-022; LHCb-TDR-014

16. LHCb Phase-I Tracker  
   CERN-LHCC-2014-017; UCG-010  
   CERN-LHCC-2014-001; LHCb-TDR-015

17. LHCb Phase-I Trigger and Online  
   CERN-LHCC-2015-013; UCG-011  
   CERN-LHCC-2014-016; LHCb-TDR-016

Minutes of the LHCC meetings

- LHCC 116, 4-5 December 2013
- LHCC 117, 5-6 March 2014
- LHCC 118, 4-5 June 2014
- LHCC 119, 24-25 September 2014
- LHCC 120, 19-20 November 2014
- LHCC 121, 4-5 March 2015
- LHCC 122, 3-4 June 2015
- LHCC 123, 23-24 September 2015
- LHCC 124, 2-3 December 2015
- LHCC 125, 2-3 March 2016
- LHCC 126, 25-26 May 2016
- LHCC 127, 21-22 September 2016
- LHCC 128, 30 November – 1 December 2016
- LHCC-129, 22-23 February 2017
- LHCC-130, 10-11 May 2017