UCG Report on the TDR for the CMS Muon System Phase II Upgrade[1]

P. Bauer, A. Cardini, S. Dalla Torre, D. Denisov, F. Forti, H. Kroha, M. Martinez-Perez, L. Moneta, M. Morandin, P. Newman, A. Polini, O. Sasaki, F. Simon, A.J.S. Smith, D. Waters

Procedure

Following provisional LHCC approval in November 2017 pending information of the individual upgrades on the physics reach, which was subsequently provided and will be presented at the February 2018 LHCC meeting, the UCG held a "Kickoff Meeting" with CMS at CERN to begin its review of the project's cost, schedule, manpower and expected financial resources. The UCG then reviewed the cost appendix and sent CMS a list of questions, which were discussed in an interim Vidyo meeting in early January 2018. On January 24 the UCG review meeting took place at CERN, with a plenary session going over the main points of the overall project, and parallel sessions for in-depth scrutiny. The confidential preliminary "money matrix" was reviewed by the UCG "core team" and the chair of the LHCC.

Overview

The CMS muon system consists of four distinct detector systems: Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC) and Gas Electron Multiplier Detectors (GEM). The first three are existing systems which will be upgraded, while the GEMs are new detectors. A first GEM station (GE1/1, which is not part of the present TDR) will be installed in LS2. In the DT and CSC systems, the electronics will be upgraded. In the RPC system, the electronics will be upgraded and new improved detectors will be installed in the endcaps to augment the CSC chambers in that location. The GEM system extends the forward acceptance of the muon system, and augments the CSC system in high-rate regions.

Cost

The project has an overall CORE cost of 21.4 MCHF, an increase by 250 kCHF with respect to the original TDR estimate, and in good agreement with the cost estimate given in the scoping document. It should be noted that these costs do not include the 3.75 MCHF of CORE costs for the GE1/1 system to be installed in LS2. Overall, we find the costs well motivated, and with appropriate quality factors at this stage of the project. At present, 72% of the costs are at QF 1 or 2, with the most of the remaining items in QF 3 and 4 expected to reach QF 1 in early 2019, with the finalisation of the TDAQ TDR and with the availability of prototypes. Service and integration-related costs are expected to reach QF 1 after LS2, following tests to confirm the design.

Schedule

The schedule of the CMS muon upgrade is unusual in that it foresees a staggered installation schedule for the different components of the system. In part, this is driven by the inaccessibility of the rear elements of the endcaps during most of LS3. Work on the refurbishment of CSC on-detector electronics will be performed in LS2 (as well as the installation of GE1/1). The Year-end technical stops (YETS) 2021/22 and 2022/23 will be used for the installation of the GE2/1 and RPC detectors in the endcaps, while the DT front-end electronics, the back-end electronics and the ME0 detector will be installed in LS3. This installation schedule has the benefit of reducing the load on LS3, and results in a spreading of the funding profile of the muon upgrade, as well as providing upgrade benefits earlier, and is seen as a strength by the committee.

Since the individual upgrade projects are shorter in duration than typical phase 2 projects, the schedule floats are often also shorter. While this requires monitoring, as pointed out below for

[1] CERN-LHCC-2017-012 ; CMS-TDR-016

specific subsystems, it is not seen as a reason for concern since the built-in floats represent an adequate level of contingency considering the length of the individual activities.

Resources

All level 2 WBS items are well-covered in terms of funds foreseen in the preliminary money matrix reflecting the expressions of interest of the participating institutes, and available personnel is sufficient to cover the needs of the project. The management of the project is well structured, with well-established links between the different subprojects and clear lines of communication to central CMS management. All management positions are filled. An established process of risk management is in place, with clear assignment of responsibilities at the L3 level and monitoring and communication paths.

Institutional responsibilities are well-spread, with 18 out of 72 institutes contributing to more than one subproject, adding flexibility to the resource allocation. In all key areas, more than one funding agency is contributing. We note that there are new groups joining the upgrade project, taking visible roles with important contributions. These new groups are also adding new funding agencies to the project.

A recent survey of personnel at the institutes engaged in the upgrade activities matches well with the expected resource requirement extracted from the WBS, giving confidence in the resource planning. Since several sub-projects show steep ramp-ups in personnel needs, the personnel situation requires monitoring by project management, but we were ensured that the temporary increases in personnel can be well handled by the institutes. One concern is the possible impact of the increasing personnel demand for the upgrades on the operation of the existing detectors, which will need to be covered in parallel to the upgrade construction. The subproject leaders are confident that this does not present a significant problem.

The committee was pleased to note that an effort has been made to understand potential "single points of failure" represented by key experts, and that a strategy to train additional people in areas where such issues may materialise has been established. Overall, the committee was very impressed with the diversity of the leadership of the project.

Specific Issues

One issue that is specific to the Muon upgrade project in CMS is the use of gasses with substantial GWP (global warming potential), which are needed for the operation of the CSCs and the RPCs. Already today the consumption of these gasses presents a significant contribution to the operation costs, and for environmental reasons it is desirable to limit the emission of such gasses to a minimum. CERN requires the reduction of emissions by 30% by Run 3, and by 70% by Run 5. EU regulations may lead to a restriction or even to a ban of the use of these gasses. The affected projects invested considerable effort to develop a plan to be able to meet the requirements, as discussed in more detail below for the specific subsystems. The committee was pleased to see these activities. We also encourage the collaboration to continue their investigations of the consequences of a complete ban of the presently used gas mixtures, including the study of possible alternative gasses and a full understanding of the impact of using other mixtures on detector performance and longevity.

Subsystem-specific Observations and Comments

Drift Tubes (DT)

The DT project is in a good state. All participating institutes are represented in the project structure, and the team appears well-established. The costs, dominated by the FPGA for the on-detector electronics, are well justified, with appropriate quality factors at this point. The spending profile is covered by the participating funding agencies. The required personnel for the assembly of the minicrates is secured at the institutes. The estimate of the number of technicians required for installation appears conservative, and possibly not the full number will be needed in the detector hall. Securing the full number of qualified technicians may be an issue that needs to be monitored. The project schedule has in general sufficient levels of contingency.

One critical area in this respect may be the OBDT, where the production start is foreseen immediately after the results from the radiation tests are available. This essentially eliminates the possibility for considerable adjustments following the test results. This however is only a limited concern, since many of the OBDT components have already been radiation tested, or are designed for radiation levels substantially beyond the ones experienced in the DT environment. This applies also to the most critical component, the Microsemi FPGA, which is of interest beyond the DT project as well. Here, first encouraging radiation tests are already available and further studies are ongoing, resulting in an overall low risk for problems with the radiation hardness of the OBDT.

Resistive Plate Chambers (RPCs)

We found the report about iRPCs comprehensive and convincing. The estimates in terms of costs, quality factors and resources appear transparent and precise enough for the present state. The schedule of the project is tight, primarily due to the fact that it makes use of successive year-end technical stops (YETS) for installation. The staging of the installation allows to recover from possible delays of items, adding implicit contingency should it be needed. The early installation of some components provides the opportunity to gain operational experience with and understanding of the new systems.

The panel acknowledges the strategy to reduce the emission of gasses with a high environmental impact. In particular for the existing RPCs, the plan to significantly reduce the gas emissions by either repairing the chambers or disconnecting the few unrepairable ones, in conjunction with recuperation and abatement systems for the exhaust, appears promising. In this context we note that the new iRPC chambers will come from the same producer as the present RPC chambers installed in the endcaps, which did not show the leak issue experienced by the barrel chambers. Still, potential gas leaks are an issue that needs to be carefully monitored, with strategies for repairs in place should they be needed. In this context it is also essential that studies of alternative gas mixtures are carried out, although at present we are confident that the program to reduce the emissions will be sufficient and should be followed up with highest priority.

We see the development of new front-end ASIC as an essential and time-critical element of the project.
In this respect we acknowledge the strategy for setting up a diversified development and test program where the 2D vs 1D readout options and different chip technologies are validated.

Gas Electron Multipliers (GEMs)

Also the GEM system is in a mature state, with transparent cost estimates at appropriate quality levels. In contrast to the other systems, the GEMs are entirely new, and have a component to be installed in LS2 (the GE1/1 chambers). This results in well-justified differences in the project structure compared to the other three systems. The technical and managerial aspects, including schedules, are in general well assessed and under good control. 39 Institutions, with a total of 90 physicists are involved in daily activities. Since production of the GE1/1 detectors is ongoing, substantial experience exists in the team. This is demonstrated for example by the training of teams for the assembly in 2017, with currently four active sites operating one shift per day. More sites can be activated, up to a total of 7, if needed.

The committee takes particular note of key measures to mitigate the project risks, which are the experience from the GE1/1 project for critical items such as the front-end chip and the high voltage supply, and the good progress with the validation of a second vendor for large GEM foils from Korea. In this context, it is important to understand possible consequences for the substantial financial contributions from Korea if this validation is unsuccessful.

The schedule of the project is well structured, taking into account an equilibrated distribution of installation activities and use of personnel, and provides sufficient contingency in most areas. One critical area in this respect is ME0, which will be installed in the endcap. The installation schedule for ME0 is driven by the endcap calorimeter, resulting in a schedule contingency of 2 months only, the smallest one in the muon project. This contingency is relative to the last ME0 chamber only, and additional contingencies exists in the HGC schedule, so the associated risk is judged to be well controllable. To keep these risks small, a continuous monitoring and potential adjustment of the project schedule, also in relation to the endcap calorimeter schedule is of key importance.

Cathode Strip Chambers (CSCs)

The CSC project is well organized and the organization chart contains the required granularity. The interconnections and lines of responsibility are well defined. The matrix of responsibilities *vs* institutions closely follows the experience from the original construction.

Small changes in the schedule for the LS2 projects have been implemented since the first version of the TDR, leading to an extended prototyping phase (1 month more) motivated by some details learned during installation tests and minor integration issues. On the other hand, the optimization in the quality control procedure leads to additional contingency in the global schedule for LS2 projects. The schedule and the milestones for the LS3 projects are well defined.

The costs of the project are primarily concentrated in large expenditures in 2018 and 2019, with the 2018 part already secured. The quality factors of the cost estimates are good, with quotes available for the main items.

The personnel profile required for this project presents a rather strong anticipated ramp up in 2018 to be maintained until 2020 (at a level about a factor 4-5 larger compared to current levels). This personnel is dominated by physicists who in average devote 50% of the time to the project. We note that surveys of the participating institutions indicate that the needs can be met. In this context, we encourage the project management to ensure that a core component of the contributions is provided by persons spending substantially more than 50% of their time on the project.

The risks of the project are rather low, with the most significant issue being the use of a CF_4 – based gas mixture. We are pleased to note that significant effort is invested to mitigate this risk by working towards a reduction in emissions, consisting of a reduction in the CF_4 content of the gas mixture, improved recuperation efficiency and plans for an abatement system. We also strongly encourage the collaboration to continue their efforts to identify possible alternative gas mixtures, and to fully understand the longevity issues associated with running without CF_4.

Conclusions

The Muon Upgrade project is in a good state at this point. The committee found the involved groups technically capable and enthusiastic about the project, with a healthy fraction of young scientists taking on responsibilities. The cost, schedule, resources and risks appear reasonable. The spread-out installation schedule is a particular strength of this project, reducing the load on the LS3 schedule of CMS. A well-defined plan to deal with the critical item of the emission of gasses with high GWP exists. Its progress and success has to be closely monitored to ensure that the required reduction in emissions is met, and that contingency plans for working with different gasses are available if this becomes a necessity.

We recommend Step 2 approval by the RB and RRB to allow resources to become available and MOU's to be signed.