UGC Report on the TDR for the CMS Endcap Calorimeter\textsuperscript{1} Phase-II Upgrade


Process
Following LHCC approval in February 2018, the UCG held a “Kickoff Meeting” with CMS at CERN to begin its review of the project’s cost, schedule, manpower and 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 late March 2018. On April 11 the UCG review meeting took place at CERN, with a plenary session briefly recalling the main points of the overall project and going over global questions remaining from the interim meeting, followed by parallel sessions for in-depth scrutiny. The confidential preliminary “money matrix” was reviewed by the UCG “core team” and the chair of the LHCC.

Project Overview
The CMS Endcap Calorimeter system is a unique project in the CMS Phase II Upgrade program, since, in contrast to the other upgrades, it is a completely new system using a different technology than the current endcap calorimeter. The proposed detector is a highly granular calorimeter system using silicon and plastic scintillator tiles / SiPM - based active elements in an integrated electromagnetic and hadronic calorimeter system. The location of the transition from silicon to scintillator is driven by the expected radiation levels, with silicon used in the front and inner part of the detector due to its higher radiation hardness. The total silicon detector area is approximately 600 m\textsuperscript{2} (about 3 times the area of the CMS Silicon tracker) with 6M channels, making it the largest silicon project in the Phase II upgrades. The area covered by plastic scintillator is approximately 500 m\textsuperscript{2}, consisting of 400k individual tiles and SiPMs operated in a CO\textsubscript{2} cooled volume at \textdegree C. The upgrade project draws on technology from various areas, such as silicon trackers and highly granular calorimeter systems with silicon and plastic scintillator / SiPM readout developed and demonstrated by the CALICE collaboration, and is attracting new groups not previously involved in CMS calorimetry, both from within CMS and from CALICE.

Cost Situation
The project has an overall CORE cost of 67.2 MCHF, in agreement with the initial estimate of 64 MCHF given in the scoping document. The largest cost items are the silicon sensors and modules (26.0 MCHF), electronics and electrical systems (15.8 MCHF) and mechanical systems including cooling (11.4 MCHF). Overall, the cost is well justified and understood, with 50\% based on vendor quotes, including the silicon sensors, the single most expensive item, and close to 70\% in the quality factor 1 or 2 categories.

\textsuperscript{1} CERN-LHCC-2017-023; CMS-TDR-019
Schedule
Since no components of the current detector are reused, the construction schedule is driven by the installation date towards the end of LS3, with no constraints imposed by accessibility of detector elements during the construction phase. The project is currently transitioning from R&D to prototyping, with the bulk of the procurement and production activities in the years 2021 to 2023, and an installation of the two endcaps in the second half of 2025. The overall schedule is ambitious but not unrealistic, and at this point provides sufficient float to accommodate possible delays without jeopardizing the final installation date defined by the overall requirements of the CMS Phase II upgrade project. The installation schedule appears to be realistic, with sufficient personnel available to carry out the required work at the CMS site. In view of the ongoing design optimization and upcoming technical decisions, which may also have schedule implications, it is important that the schedule planning is closely monitored as the project proceeds.

Resources
The funds required by the project are covered at a level over 97% by expressions of interest of the participating funding agencies at this stage, with discussions with key contributors already in an advanced state. The institutional responsibilities are spread and matched to the expertise of the participating institutes, with multiple institutes relying on different funding agencies participating in all key subsystems. Six Module Assembly Centers (MAC) for the silicon modules and four Tile Assembly Centers (TAC) for the scintillator tile modules will be set up at different institutions and countries, involving a broad basis of the collaboration in the detector construction.

Surveys of the participating institutes indicate that the personnel required for the construction will be available at the centers at the level needed, with the potential to cover additional personnel to achieve an increased throughput to shorten production time in case of delays. Nevertheless, the overall large manpower requirements and the steep ramp-up of technical personnel in later 2020/early 2021 are of concern, and will need continued discussions of the project management with the participating institutes to allow for corrective actions and possible schedule adaptations in the case of shortfalls. Since this project draws on expertise from other areas within and outside of CMS it is important to understand the sharing of resources and possible conflicts in terms of requirements of expert personnel.

Risks
The main risks have been identified with appropriate ways to mitigate them. By installing additional equipment, the assembly centers are set up to allow a doubling of the throughput to meet the production schedule, if necessary.

Project Structure and Management
The overall project structure is established, with all key positions down to level 3 filled. The team draws from all major participating groups, and consists of experienced as well as less senior scientists and engineers, ensuring long-term coverage and succession planning. The interfaces between the endcap project and central technical coordination are well defined, in terms of both technical and financial responsibility.
Global Comments
At present, the project does not yet have well-structured quality assurance and quality control programs. This is understood by the collaboration, and the panel encourages the team to establish such an organization and the relevant procedures throughout the project in a timely fashion. In this context it should be noted that activities have already been undertaken to ensure the quality of the considered MAC and TAC sites by visits of the project management to the institutes planning to set up a center.

The final choice of the number of longitudinal layers is a key point for proceeding to the production stage of the CE-H absorber, and will be informed by simulation studies by the end of October 2018. The decision should be taken by the target date set by the collaboration. This will enable the mechanical design to move forward and avoid it getting close to the critical path. In this context, the benchmark studies for the final decision should be solidified and clarified, also considering redundancy in the event of a failure of complete layers.

The collaboration has presented a thorough test beam and laboratory test program establishing the performance of the system. In this context we want to stress the importance of system tests with at least two full cassettes with all electrical connections to investigate possible cross-talks between multiple cassettes. Likewise, the thorough testing of multiple layers of interconnected modules, modelling a multi-layer detector, is a key test to perform to understand possible effects only apparent when operating a larger system. It should be ensured that a sufficient number of modules of different types is available to perform these tests in parallel to the required qualification steps including sensor irradiation.

Subproject-specific Observations and Comments

Mechanical Systems
The team involved in the project demonstrates a high level of expertise, and the provided cost estimate is reasonable and well-motivated, based on quotes, past experience and extensive prototyping. The cooling system, which accounts for more than 50% of the total costs of the mechanical systems, is a key element of the overall project. It is well understood and designed by an expert team, with important components procured from industry.

To take into account ongoing optimization studies, the schedule for the design of the electromagnetic section of the endcap calorimeter should be aligned with the Project Readiness Review for mechanical systems foreseen for Oct. 2019, which should fit into the overall schedule without other modifications. At this moment, the overall schedule for the finalization of the design and for the construction and assembly is reasonable, motivated by prototyping and past experience. It is however important to finish the R&D and finalize the specifications for external elements to these systems in a timely fashion to keep the mechanical design moving forward.

The specifications of the stainless steel plates for CE-H should continue to be optimized to minimize the complexity of the production while preserving the integrity of the design. The optimization of shipping and handling of expensive and fragile elements of this upgrade, in particular of the assembled cassettes, is an important element in the risk mitigation.
Sensors and Modules
The activities in this area profit from the well-recognized and impressive expertise of the participating groups in the assembly of large batches of silicon modules for the CMS tracker and in the production of a large-scale prototype of a highly granular scintillator tile / SiPM hadronic calorimeter by the CALICE collaboration, on which the design of the scintillator part of the EC is based. The majority of the costs in this area are covered by a quote for the silicon sensors. At present, a large cost uncertainty still exists for the SiPMs, which however is only a small fraction of the overall sensor costs.

An important challenge is to identify vendors capable of producing 8’’ sensors with a process suitable for large-scale production of high quality sensors. A key element of risk mitigation is the availability of two vendors for silicon sensor production. In this area a strong effort is undertaken by the collaboration, which should continue with the goal to qualify two vendors for 8’’ sensors. It is important to ensure availability of sensors for all needed tests in the prototyping phase to perform irradiation and long-term system tests with the different sensor types. The committee was happy to see that a well-developed plan exists for the training and ramp up of the individual MACs, making use of dummies to ensure minimum loss of good sensors and other module elements for the training of personnel and development of procedures. The impact of ramp-up on the use of production spares is expected to be negligible.

As for the silicon sensors, the establishment of two or more vendors for the SiPMs is a key element to reduce risks, to firm up the cost estimate and to reduce costs by introducing competition. In this regard, the introduction of two specification levels, with differing radiation levels, in the outer and inner regions of the detector may open up additional possibilities for multiple vendors, and reduced cost. It should be noted that even in pessimistic scenarios for the SiPM price, the cost risk remains well controllable on the medium to low level. An important item for the individual tile option is the demonstration that the wrapping and handling of the large number of tiles with different geometries is indeed feasible with the required precision.

Since the module assembly is carried out at 10 sites, procedures for the knowledge transfer from the lead MAC / lead TAC to the other sites are important, with enough material (such as dummies) available for local training at the different sites early on.

Electronics, Trigger and Data Acquisition
The front-end electronics, data compression and transmission, clock transmission, back-end electronics and data acquisition are covered by experienced teams. The high level of integration and the complexity of the system require an excellent communication between the different actors and the central data acquisition of CMS.

A key element of the whole project is the HGCROC ASIC, whose development is on the critical path towards module production. The panel noted the interesting development to explore the option of using a single ASIC for both the silicon sensors and the SiPM readout, and encourages the collaboration to fully explore this possibility in a timely fashion. Possible drawbacks and associated risks of a single ASIC for the rather different signals from the two sensor types need to be fully understood for this decision. The schedule for the ASIC development appears reasonable, and a further iteration seems to be feasible if needed, without compromising the overall schedule of the project. Due to minimum order sizes, The yield for ASICs, such as those considered here, is usually high. For the HGCROC, a yield of 80% is assumed, which appears to be justified given previous experience of the team. Because the numbers of chips needed is much smaller for the Concentrator ASIC the yield can be as low as 50% without resulting in problems. For the HGCROC, a yield of 80% is assumed, which appears to be justified given previous experience of the team. Nevertheless, this
number should be closely watched to ensure a sufficient number of good ASICs is available for the production of the modules.

At present the need for a separate clock distribution system is being investigated. The decision on whether the clock signal given by LpGBT is sufficient for timing purposes should not be delayed beyond the currently foreseen timeframe of one year.

Electro-mechanical mockups exist to ensure that key components such as connectors meet the space constraints. These studies should conclude at the time of the decision on the number of detector layers to allow the overall mechanical design of the detector to proceed in a timely fashion.

Conclusions

The Calorimeter Endcap Upgrade project is in a good state at this point. The committee was impressed with the technical capabilities of the involved groups and the professionalism and enthusiasm of the project team. We wish to commend them for the quality of the documents and the answers to the questions of the committee, and for their open and constructive state of mind and responsiveness during the review process.

The cost, schedule, resources and risks appear appropriate. Since this project was solidified rather late in the overall planning process towards the Phase II upgrades of CMS, there are still important decisions to be taken to complete the design of the detector, such as the number and arrangement of the active layers in the electromagnetic and hadronic sections of the detector. The team is well aware of the required steps and the cost implications of these decisions are understood, giving confidence that the finalization of the detector design can proceed as required by the ambitious construction schedule. Nevertheless, the tight schedule, in combination with the decisions that still need to be taken on the path towards production, and the substantial personnel build-up required, make a careful oversight and frequent follow-up indispensable. The development and implementation of project-wide QA and QC programs is an important next step towards production.

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