

UCG Report on the Phase II Upgrade of the CMS Tracker¹

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Process

Following LHCC approval in September 2017 of the Tracker Upgrade TDR on its scientific and technical merit, 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 large number of questions, which were discussed in an interim Vidyo meeting, followed by a few additional questions. On Nov 27 at CERN we heard 4 hours of presentations from the TK group, followed by an afternoon of breakout sessions, and “homework” questions. The confidential preliminary “money matrix” was reviewed by the chairs of the UCG and LHCC.

Overview

This is a huge project: total cost CHF 112M (OT 67M; IT 23M; Common Systems 22M). Fortunately excellent infrastructure for integration and testing is already in place in the Tracker Integration Facility from the original Tracker, and the team is highly experienced. The cost estimate and cost risk are in reasonable shape. The design of the Outer Tracker (OT) is well advanced, with credible schedule and milestones.

The Inner Tracker (IT), however, is still in the R&D phase, and is critically dependent upon the RD 53A readout chip, which is still under development and behind schedule. The IT schedule is therefore more uncertain and the schedule risk is greater than usual for a TDR. Of particular concern, no milestones were presented until 2019. The IT group needs to improve scenario planning to cope with potential further issues with RD53A. Fortunately they are taking opportunities to exploit OT work when possible, such as QA procedures.

Our bottom line: we can recommend approval of this TDR, with the caveat that the IT is less advanced than ideal, and requires special monitoring.

General comments

The meeting opened with several plenary talks, the first of which was a summary talk on the status of the project. We were very surprised when the newly-proposed Barrel Timing Layer (BTL) was included, even though the LHCC had not yet received any written documentation. As such an addition could have significant implications on the tracker layout and performance, should CMS want it to go ahead, this would require a new scientific/technical assessment by the LHCC. Accordingly, the observations and recommendations of the LHCC in September and by the UCG in this report pertain to the Tracker Upgrade as presented in the TDR, and do not include the BTL.

Before start of construction, the Inner Tracker has a heavy research and development program with a very constrained timeline to finalize its design. The collaboration has fallen short to present

¹ CERN-LHCC-2017-009 ; CMS-TDR-014

a targeted program with identified resources and milestones to complete the R&D phase on schedule, and is urgently recommended to develop such a plan. Milestones for each design parameter should be established urgently, along with plans to cope with further delays or issues.

R&D Plans and resources, preparing for start of production

The OT is basically on track, but as in any such large project several issues need to be resolved before production can begin. The good news is that a vendor for the sensors has been qualified; the bad news is that the second vendor is still not qualified after several years. CMS is hopeful the situation can be positively resolved in 2018, but for now the inherent risks of a single vendor remain. The OT group has identified three vendors for the hybrids, but is still having to work with them on various problems, such as warpage, delamination, and cracked lines, to ensure reliability and yield in production; it is not obvious at this time how quickly this process will converge. OT module assembly is distributed among 9 sites, complicating the logistics, coordination and follow up QA/QC. Given the size and complexity of the project, and the number of production sites, local and global QA/QC is of paramount importance, and should be set in place as early as possible in the process (including R&D). It is also important to bring all the sites up to the same level of training, quality and management. That said, the plan is simpler than that of the original tracker, and the group is very experienced. A sufficient number of institutes are involved in testing and qualification, and regular training and workshops have been set up. If possible, we suggest that the module assembly jigs all be produced in the same place to facilitate uniformity. Correlated risks need to be carefully assessed, and mitigation plans developed in advance. A prime example is the impact on module production of delays in producing hybrids and other required components.

Several issues are delaying progress on the IT. As mentioned above the FE Chip (RD53A) is still in R&D phase, and constitutes the largest schedule and financial risk. Deciding whether a common chip for ATLAS and CMS is feasible, or that separate chips are necessary needs to be done in a timely way. Many sensor parameters are still open: pixel size, sensor thicknesses, biasing scheme, spark protection scheme. Thicknesses need to be specified to allow tests of bump bonding, etc. 3D sensors are under investigation for the innermost layer.

The schedule calls for placing the order for the sensors in 2020, while the final version of the PROC readout chip will be available only in Q3/2021. As a result many testing steps will have to be carried out with the initial version, to be submitted in July 2019. Careful understanding of whether the risks entailed are acceptable is of the highest importance to decide if this schedule is wise. Power systems also pose risks. Given the current problem discovered on the DC-DC converters for the IT, the impact on the schedule is not clear because the source of the problem has not yet been found, and the IT group will be heavily occupied until it is. In general, the IT project needs to define intermediate milestones that could help monitor progress towards readiness for production, and to ensure that the different institutes contribute the manpower to the level they have pledged.

DAQ, detector testing and commissioning, Data processing

The system commissioning is well thought through and is based on the experience with the present system. The TIF is a uniquely fertile and comprehensive test facility – a “secret weapon.” A plan for developing the test hardware and software is also in place

The resources needed for the upcoming task need to be further clarified and responsible institutions need to be clearly identified. The test systems distributed over all production and assembly sites need to be well supported during the assembly by a central team.

The data-processing team is capable and experienced, and realizes they need to work closely with the rest of the CMS systems (DAQ, L1 trigger, etc.) to assure data communication protocols are clearly defined.

Mechanical structures and Detector Integration

The complexity and density of services, and very tight tolerances present a challenge. The group relies on experience with the current tracker, and plans to validate the design of OT substructures in Aug. 2019, and the first production in Aug. 2021. All substructures will be built by Dec. 2023. For the IT, structures will be validated in May 2021 and built by Nov. 2023. Several risks in the schedule, quality and integration were described and their mitigations evaluated. The boundaries between the tracker project and CMS common infrastructure (TC) are well defined. One risk that was not listed in the tracker risk register refers to a delay in the convergence to a final design on time.

We are concerned about the schedule risk and other impacts of the possible timing detector layer on the envelope and the layout (and the physics performance), which might endanger the milestone of all substructure design validation (OT/IT.ME.3). The approval process of such a timing layer at a later stage must include a review of the engineering changes to the tracker.

The CERN group producing the CO₂ cooling plants will be heavily loaded. The TK cooling project cannot be easily split up into plant/transfer lines/on detector cooling infrastructure. Hence the work on all cooling aspects could fall to this central team. A plan for efficient involvement of external institutes in this project has to be established.

Organization/Management

The organization is designed to ensure communication with tracker operations, led by a committee of coordinators. It is unusual in that it melds the various OT and IT subsystems within this committee, instead of the more conventional approach where line responsibility mirrors the high-level WBS. Perhaps as a result, it was difficult to map the presentations of the coordinators onto the costs, schedule, resources and risks that we had to evaluate. And there was the unfortunate lack of communication concerning the status of the proposed Barrel Timing Layer.

Fortunately a good set of parallel sessions with the key people involved in design and R&D was very useful in providing the information we needed. Following the meeting we discussed organizational issues with CMS senior management, and were satisfied they and the Tracker Group will make whatever improvements are necessary to ensure success. Most tasks are covered, still a few gaps. As remarked before, the OT appears to be progressing well. A better plan and schedule are needed for operating the current IT, concluding PHASE II R&D, and transitioning to production. We are concerned that serious tensions and conflicts could develop between the IT-phase II design and testing efforts, and current IT operations when phase II prototyping and testing ramp up.

The management needs to be proactive in spotting in time and averting individual risks, and the several potentially dangerous correlated risks with other CERN entities: Support groups, **ATLAS**, LHC, etc. We were pleased to learn that the risk management group is engineer-intensive, and in which engineers have major input “bottom up.”

Conclusions and Recommendations

- The cost estimates and the current and planned resources are reasonable for this stage. However, this is an exceedingly complex project that requires intense project management to succeed. More detailed scenario planning to deal with possible delays is needed.
- The Outer Tracker schedule and risks are at normal levels, provided they continue to be proactively managed.
- The Inner Tracker is behind schedule, and needs to anticipate and prevent possible manpower conflicts with current tracker operations. However, there are no showstoppers that would cause us to deny or defer approval.
- A common CMS-ATLAS pixel readout chip would present an opportunity for reducing technical and schedule risks, and possibly cost. The feasibility study should be vigorously pursued and the current baseline plan of using different chips based on the same building blocks critically re-examined.
- The proposed Barrel Timing Layer and its impact on the Tracker need to be reviewed by the LHCC and UCG before it is approved. This is urgent if schedules are to be maintained.
- CMS, the LHCC and CERN management must closely monitor the funding situation and technical progress.
- We recommend Step 2 approval by the RB and RRB to allow resources to become available and MOU's to be signed, with the caveat that the IT requires special monitoring.