UCG Report on the CMS Phase II Upgrades

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Introduction: At the June LHCC meeting it was agreed that the ATLAS and CMS scoping documents, for MChF 275, 235, and 200 configurations, must be evaluated in time for the October RRB meeting**.** Numerous LHCC/UCG interactions with the experiments took place to accomplish this. As we received them, we reviewed outlines and preliminary versions of the document, including a schedule and spread sheets for costs and manpower. Vidyo meetings with CMS took place on July 6 and August 7, interspersed with Email exchanges. We have received marvelous cooperation.

Phase II is completely new ground for the UCG, as our Phase I efforts dealt entirely with complete, LHCC approved TDR's, whereas here we have a multistage approval process (CERN issued the document describing the process last week). At this step we focus on conceptual designs, cost methodology, past experience, etc., leaving details for the TDR's. The goal is to evaluate as well as possible the costs and schedules for the "Reference Detectors," as this is where the experiments have put the lion's share of their efforts. We leave it to the LHCC report to address the impact of de-scoping scenarios.

General Observations:
In sharp contrast to the original construction, the Phase II upgrades are based on years of experience with successful detectors: evolution *vs* going where no-one had gone before. The CMS reference detector cost estimate is CHF 265 M**.** Cost estimates are remarkably mature, applying an appropriate level of conservatism, and provide a firm basis for our reports to the RB and RRB. *The level of R&D and prototyping to be completed by CMS before the TDR's is relatively large. (Though not part of the core costs, this is of critical importance.)* We are therefore encouraged that CMS are assessing the uncertainty level of their cost estimates by employing industrial-like assignment of quality flags (QF 0 through 5) for unit costs and for number of required units, and have risk analyses and mitigation strategies underway. CMS is actively exploring opportunities to combine procurements with other experiments for "big ticket" items like silicon, power supplies, etc. The funding outlook is guardedly optimistic, with substantive, relatively encouraging interactions in progress with the FA's, in much greater detail than at this stage of original construction. Large uncertainties remain, however, and it will take a lot of time to secure commitments. Fortunately there appears to be an almost complete match of interests with needs.

We conclude that the CMS Phase II upgrade project is ready to proceed to detailed detector design, and to receive the funding necessary to establish a baseline cost and schedule for construction.

Detector System Summaries:

1. Trigger/DAQ – CHF 24 M
Costs are based on an extrapolation from 2013 to 2025, with a large uncertainty but also the possibility for gains in processing power by implementing new architectures. Part of this cost could be covered by M&O A money for the normal replacement of the farm after 4-5 years. (A common policy on this should be decided for both experiments.) The High Level Trigger constitutes 11 MCHF of the TDAQ budget.

2. Tracking – CHF 112 M
The Tracker dominates the cost of the Phase-II upgrade, with Pixels at CHF 23M and the Outer Tracker at CHF 89M. The project builds on extensive prior expertise, and estimates based on preliminary vendor quotes. The Sensor modules comprise ~ 50% of overall project cost, with 54% and 41% quality flag 1 or 2 (highest levels of confidence) for Pixels and the Outer Tracker, respectively. Importantly, CMS is working to qualify a second vendor for all tracking module

components (sensors, bump-bonding, hybrids, flex circuits, …). The Outer Tracker uses a well-known technology with which the collaboration is very experienced. High density flex circuit technology is critical for pT module and track trigger design – historically this has been a risky enterprise.
Though very conservative cost estimates have been used for these items, they are in line with other experiments and hence not overly conservative.

3. High-Granularity Calorimeter – CHF 75M
The upgrade project consists of a complete replacement for the crystal end cap calorimeter and the BE electronics. The EE and FH employ state-of-the-art silicon readout technology; the BH, conventional scintillator readout. In contrast to the tracker situation, the Si cost is highly dependent on specifications. The readout technology has been intensively developed for the ILC for over 15 years, with the largest cost driver being the silicon sensors: > 50% of the HGC cost. Fortunately the cost estimate is based on close-to-final design and vendor quote (QF =1 for both the unit cost and quantity). Cooling, based on CO2 cooling technology, is the 2nd largest cost driver at 14% of the HGC cost. Brass dominates the cost of the BH, with estimates based on past experience. The main current risks result from relying on a single source for the Si wafers and the associated vulnerability to exchange rates, even though HPK has an excellent track record of delivering quality sensors at cost. As mitigation CMS are working closely with two potential additional vendors, one European, the other US based, with encouraging results so far. There are also risks of cost increases for the raw material and/or machining and assembly of the brass for the HE. Here CMS is working with several companies in case one company cannot perform the work for expected cost.

We note that even though the silicon readout calorimeter is well developed, this is the first time such technology is to be used at such a large scale and in such a hostile environment. A wafer size of 6 in is assumed for the costing, but there are encouraging possibilities and a preliminary quote for 8 in wafers, which could reduce the *total* HGC cost substantially. The collaboration and cooperation with CALICE has been beneficial, and will likely continue to be so, at least for the initial R&D phase

4. CMS Muons – CHF 25M
The core costs (MCHF) are divided among DT electronics: 6.1; CSC electronics: 3.7; GEM GE11 and GE21: 7.9; RPC RE31, RE41 extensions: 2.3; and ME0 extension to η 3.0: 4.5. The baseline cost looks reasonable (mostly QF 1-2). The DT electronics upgrade is the least certain, because prototypes are still to be designed and built. (QF 3-4 vs QF 1-2 for the rest of the muon upgrade). All in all, the project looks in good shape at this point.

5. CMS Infrastructure – CHF 25M
Current estimates are necessarily of limited precision, based mainly on experience during CMS construction and LS1. Approximately 63% of the project is still at QF4, with the other 34% at QF3 after receiving engineering input. The largest items are tech support (8.9M), infrastructure (6.1M) and engineering integration (3.2M). These estimates need to be continuously refined as more information becomes available to reach QF1 quality.

Recommendations:
1. We encourage CMS to summarize all infrastructure activities in a coherent reference document.
2. Given the recent problems with the cryogenic system for the CMS solenoid, an in-depth assessment of ageing equipment in all critical components should be pursued with high priority.
3. The boundaries of responsibility between the collaboration and the host laboratory should be clearly defined and agreed