CMS Upgrade MB Response to SLHC Document:

09.07: US CMS Plans for Phase 1 SLHC Upgrade

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It is our intent to recommend this proposal for approval with some requested revisions. Please see the comments from the referees for additional specific revisions.

Specific requests for the revised proposal are:

1. Provide more details on the process for selecting amongst the multiple options for the forward pixels.

2. Improve the presentation of the HCAL simulation work and provide a figure of merit for the H/E rejection.

3. Clarify the source of the improved resolution in the calorimeter trigger position as improved processing of the existing trigger tower transverse granularity and not a change in the calorimeter trigger primitive granularity. Correct the luminosity range over which the present trigger is expected to work to 1 x 10^{34}. Explain the assumptions involved in revising the global trigger that are inherent in the trigger proposal.

4. Discuss the dependence of the tracking trigger performance on the layers used for the tracklets.

5. Provide more details on how the various parts are integrated with the overall CMS upgrade plans with more explanation about the division of responsibilities between US and non-US groups. Although needed for all subsystems, specifically this is requested for the HCAL, Trigger and DAQ.

6. Provide more details on the risks and fallback options associated with the HCAL R&D program.

Referee #1:

Forward pixel detector:
The proposal gives a flexible plan in view of different projections of the rise of luminosity, and integrated luminosity in particular. It is clear that at some point difficult management decisions may be needed balancing the cost of keeping open multiple options against the risk resulting from the closure of options. The ideal of flexibility must not be used to avoid decisions that are difficult for reasons other than an uncertain future.

CSC muons

Seems well thought out.

HCAL:
By far the largest item is the front-end (FE) upgrade. Although the FE upgrade is presented as a series of individual items, they fit together well and make a coherent picture. The simulation work is rather poorly presented, explained and justified. A background rejection figure of merit for the H/E cut would help.

Trigger:
Significant typo on page 89: "10^32" -> "10^34". Plans for Calorimeter trigger upgrade seem well motivated. Has getting the full granularity information from ECAL to the trigger been ruled out for all phases of the upgrade- Concerning the possibilities of track/calorimeter matching at Level-1 for electron triggers, I have the impression that the degradation in performance if the tracklet is not made from the *first* layers of material in the tracker (before conversions and brems) has not yet been fully appreciated (current simulation results - offline reconstruction in non-upgraded CMS - suggest that the degradation would be severe).

DAQ:
Seems well thought out.

Referees #2 & #3 (combined):

General Comments:

The overall Phase 1 US upgrade plan is well motivated and matches the general needs and requirements of CMS in the first phase of the SLHC. The overall timeline of the proposed upgrade projects is also aligned with CMS planning. For some of the proposed projects the time line is straight forward (e.g. the CSC upgrade) while other parts need to remain flexible and depending on the LHC schedule. Many of the discussed detector projects already benefit from strong to very strong US participation.

However, the US upgrade plan would benefit from a more detailed integration of the proposed US efforts with overall CMS. In particular, for some of the proposed upgrade projects in the HCAL and Trigger part, strong and well-defined collaboration with non-US groups will be required to guarantee the success of the project (see comments on individual upgrade projects for more details). It is not evident from the provided document if the required high-level of alignment with the corresponding planning of project collaborators has already been established.

Overall we do not see any unnecessary duplication of work within CMS on the proposed projects. However, concerning detail work the proponents of these upgrade projects have to work closely with the management of the subdetectors to ensure that duplications or inefficiencies will not happen throughout the upgrade.

Comments on individual upgrade projects:

This part of the review evaluates the individual projects that are described in the US CMS Phase 1 Upgrade Plan document.

Upgrade plan for the pixel detector:

The pixel detector system was conceived several years ago. Although the installed pixel system (barrel and end caps) fulfils the present requirements, there are several reasons that justify the development of a replacement system:

• First, the inner layers of the pixel detector have a limited lifetime and will seize functioning after a few years of standard LHC operation or an integrated luminosity of about 200 – 300 fb^{-1}. From a physics performance point of view, it is more than desirable to replace these detector layers rather than restrict analysis to the remaining outer layers. Due to the large uncertainty in the LHC schedule, this date might be as late as 2016. Nevertheless, the appropriate R&D should be pursued without delay.

• For the construction of the present pixel detector, the available technology of the time of the design was used. Technologies have further developed; with the proposed R&D, a significantly improved pixel system could be realized. The R&D proposal aims for an improved system with three forward pixel discs instead of two and four barrel pixel layers instead of three. The technologies under investigation could provide a significantly improved detector with many additional advantages, such as lower material budget, simpler module design, and largely improved radiation hardness of the sensors. The physics performance of CMS—in particular, the vertex reconstruction, tracking efficiency, and resolution—would clearly benefit from such a new pixel system.

The proposal foresees an R&D program to develop the needed components such as CO2 cooling, single type detector modules, an improved PSI chip, optical links, radiation hard sensors, etc. The proposed plan remains flexible and foresees, depending on the timescale, the installation of slightly modified detector elements or a completely new pixel system. Under the present circumstances, this is the correct way to ensure a continuous working pixel system for CMS.

The US R&D efforts described in the proposal are embedded well into the overall tracker collaboration effort for the pixel upgrade. The development of new pixel components needs to be a common effort of the barrel and end cap consortia. The R&D on the different components is pursued in working groups. The tracker management will avoid possible duplications.

Upgrade plans for the CSC muon detector:

To improve the performance of the end cap muon system, two upgrades are proposed:

• Completion of the CSC muon system by adding chambers ME4/2. In the current configuration, the CSC trigger has three muon chambers available in the rapidity range of 1.2 to 1.8 and can therefore select only two out of three stations, severely limiting the triggering capability in the case of high background rates. After an installation of chamber ME4/2, the triggering capability will be significantly improved by selecting three out of four stations. This upgrade would be

clearly beneficial for CMS. The construction of ME4/2 should proceed as long as expertise is available and the original CSC collaboration is still operational.

• Equipment of the ME1/1 chambers with new front-end boards to recover triggering and reconstruction capability over the rapidity range of 1.5 to 2.4. The ME1/1 chambers are exposed to the highest particle rates. The present analogue cathode front-end boards suffer at high rates, causing dead time and a degradation of the position resolution. The proposed new digital front-end boards would eliminate these problems. Furthermore, by installing new boards, the cathode channel ganging (rapidity interval 2.1 - 2.4) could also be removed, thus improving the muon identification. Restoring triggering and muon identification in this region by replacing the electronics with newly developed digital DCFEB boards is highly desirable. The two upgrade proposals for the CSC system are linked by the analogue electronic boards becoming available from the ME1/1 chambers for the installation in ME4/2.

The proposed R&D and construction of CSC chambers can only be done with the US-CSC collaboration. No duplication of efforts is anticipated.

Upgrade plan for the Hadron Calorimeter (HCAL):

The main goal of the HCAL upgrade plan for Phase 1 is to maintain and improve operation of the HCAL for physics. Therefore, the front-end electronics and trigger/readout receiver back-end electronics upgrade is mandatory to ensure that the current HCAL technology can continue to be used. Furthermore, installing longitudinal segmentation capability in the HCAL barrel and endcap would add additional reconstruction functionality and thus is desirable. The Phase 2 upgrade plan mainly focuses on R&D projects that study the impact of increased luminosity on the HCAL performance and evaluate the impact of radiation damage on the forward and endcap calorimeters. Since this review concentrates on Phase 1, we will not discuss this further.

• The Phase 1 front-end electronics upgrade of HCAL consists of adding longitudinal segmentation functionality as well as increasing the ability to determine the shower arrival time. It is anticipated that the existing front-end electronics infrastructure will be used for these upgrades. This implies that HPDs cannot be utilized for the longitudinal readout (four layers), so it is proposed to use SiPMs in the HB and HE instead. The shower arrival timing functionality in all detectors will be achieved by logical timing of a fast-discriminated pulse.

• The Phase 1 back-end upgrade plan proposes to rebuild VME cards in order to increase trigger granularity and trigger bandwidth. It is foreseen to benefit from the technology advances in electronic crate capabilities as well as in FPGAs.

The goal of the Phase 1 upgrade is to preserve the physics performance of the HCAL in the difficult SLHC environment. The authors plan to achieve this through significant upgrades of the front- and back-end electronics of HCAL. While the overall plan is well-motivated, several items of the HCAL Phase 1 plan require substantial R&D efforts (see page 85 of the document for further details). The provided upgrade plan lacks a comprehensive risk evaluation as well as fallback options for many of the important R&D projects. Although the general scope and

usefulness of the projects is well-documented, the impact of a potential negative outcome of the R&D work on the overall HCAL Phase 1 upgrade is often not evaluated in detail.

The HCAL project is US-dominated; however, given the significant scope of the upgrades and its potential implication on the CMS physics performance, it is necessary to coordinate the US effort with non-US HCAL partners as well as with other upgrade projects like Trigger and DQM. The present document provides only a very crude idea of how this important integration process will be executed.

The US HCAL upgrade plan is well-motivated but would benefit from more detailed risk evaluation and fallback option scenarios for several of the proposed R&D projects. It would also benefit from a comprehensive integration plan on the US HCAL effort and general CMS.

Upgrade plan for the Trigger:

In the first sentence of the trigger proposal, the authors claim that the present CMS trigger will work well up to $10^{32}s^{-1}cm^{-2}$ but will need significant modification to operate above LHC design luminosity. If this statement is true, then the following proposed improvements are important not only for the upgrade but also to achieve the required trigger performance at the LHC design luminosity of $10^{34}s^{-1}cm^{-2}$. Trigger upgrades for the regional calorimeter and the end cap muons are proposed:

• Rebuilding of the regional calorimeter trigger using the new -TCA technology. Concerning the isolation criteria, the interplay between calorimeter and track trigger is not optimal. The proposed implementation of an isolation bit as input to the global muon trigger would significantly improve the trigger capability. It is further proposed to increase the trigger tower granularity of the calorimeter to 0.087 η x 0.087 ϕ.

• Installation of new muon port cards for the end cap muon trigger and new trigger motherboards for CSC chambers ME1/1 to expand triggering to high rapidity (->2.1). The improvement program for the new muon port cards aims to increase the capability of the system to handle a larger number of trigger primitives (Local Charged Tracks) to about 10 per bunch crossing. Implementing these upgrades would remove a known bottleneck in the trigger.

The current CSC trigger uses a reduced granularity of only 0.05x2.5o. Increasing this granularity might become necessary for the Phase 2 upgrade when triggering information becomes also available from the silicon tracker.

The development of a new regional calorimeter trigger needs to be aligned with the partner in the regional and global calorimeter trigger collaboration to avoid duplication of work. Furthermore, it would be desirable to further detail some of the proposed requirements, like the increase in trigger granularity. The CSC trigger is a US project, so no duplication of work by other groups is expected.

Both projects need to be well-coordinated and agreed upon in the trigger collaboration. A change in one place of the system may cause subsequent incompatibilities. For instance, in Table 9, a

full replacement of the global trigger is indicated. While this might not be necessary for the Phase 1 upgrade, it must be understood under which circumstances and time schedule such a project will be pursued and by whom.

Upgrade plans for the Data acquisition system:

Proposal to install a fully functioning DAQ test system in building 904 to develop, integrate, and test new components needed for the future upgrade of the CSM DAQ system.

This effort needs to be an integral part of the R&D CMS DAQ upgrade plan. Developments and investments to be done in agreement with DAQ collaboration.