CMS Upgrade MB Response to SLHC Document:

10.03: R&D of the Detector Systems for Stage One of the High Precision Spectrometer Project

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The Upgrade MB advises CMS management that this R&D proposal describes the correct program to prepare this project with the revisions requested below. However, in order to approve this proposal CMS Management should determine that it has a positive view of and an interest in HPS.

The proposal should separate off the R&D for Phase 2 more clearly and specify more exactly what is needed for Phase 1. The proposal should more clearly explain how the proposed schedule for design and installation would be met, given the time taken by the TOTEM collaboration for its design and installation. A critical issue is to resolve whether there will be a refurbished station at 220 m or a new station at 240 m and to understand whether the long-term plans of TOTEM conflict with the operation of this station. Another important issue is whether this system can operate and do physics at luminosities above 10^{34}.

Please see the comments from the referees.

Specific requests for the revised proposal are:

1. Explain how the proposed R&D plan meets the requirements of the layout, design and schedule of the stage 1 detector and how the stated personnel resources are sufficient to realize this plan. Explain the differences, advantages, complementarity, sharing of resources and duplication of effort (if any) between the ATLAS and CMS R&D projects.

2. Explain what electronics would be used with the stage 1 detector. What electronics (including transducer) and DAQ would be used with the GasToF and QUARTIC?

3. Provide more details about the plan for and use of the SiPMs, specifically, radiation testing, operating parameters (high voltage, signal amplification) and electronics. Explain why the stage 1 detector should not use the MCP-PMT, leaving the SiPMs for later.

4. Explain how the development of the prototype reference clock system, including test beam satisfies the proposed schedule. Explain the plans for the SLAC scheme.

5. Provide more details on the exact R&D required, plans and timelines for the Planar and 3D pixel systems and the overall Trigger & DAQ. These need more technical detail and information about personnel.

6. Provide more details on the schedule, including (a) what would be required for a single installation instead of 2 stages and (b) contingency plans, e.g. is it possible to install the stage 1 detectors during the annual technical stop?

7. Explain the radiation levels expected at the detector locations, how these are determined and how measurements can be made to verify them.

8. Provide more details about operation at higher luminosity and use of multi-hit events, including the implications for the HPTDC chip.

9. Provide a risk assessment for the installation at 420 m and 240 m on the nearby machine elements.

10. Explain the influence on the timing resolution of beam effects (momentum spread, optical errors, drift, etc.) and the RF clock imperfections (jumps, drifts, etc.) and how these will be monitored (e.g. monitored reference clock, etc.).

11. Explain the plan for deploying appropriate beam position monitors and loss monitors on the moving beam-pipe system. Provide more detail about the installation, functioning and risks of the Hamburg Pipe and NCC.

12. Explain the need for R&D on 3D detectors given the R&D on Planar Detectors.

13. Provide a plan to use LHC data to validate the simulation results.

14. Provide a set of milestones for the project along the lines suggested by the referees.

In addition, we request you to address the detailed comments on the proposal from the referees below.

Referee #1:

General:
According to the schedule presented, Stage One will be installed in 2012-13. So, this R&D will have a very limited time before the detector would get installed. Not having seen the requirements, proposed layout, and design of the Stage One detector, it's a bit difficult to judge whether the R&D plan would really be adequate. For example, there was a plan for the Moving Pipe but we were not presented how the detector itself would be attached to the pipe. How is the grounding and shielding done? The R&D proposal is really a collection of goals for different WPs and activities with little details on how they plan to accomplish their goals.

Comments on the WPs:

WP1: Timing detector system

QUARTIC issues: good progress has been made and the R&D plan is solid. However, it is not clear what electronics that they would propose to use for the Stage One detector. The electronics used in the test beam were commercial items and might not be compatible with the rest of the sub-detectors and the DAQ system.
GasToF: good progress but I am surprised by the statement that only by Winter 2011 would the detectors be tested with 300m long signal and HV cables to study the possibility of long-distance monitoring and using initially (??) a common DAQ system. Is the plan to eventually use two separate DAQ systems, one for each side? Again, there was no mention of the electronics for this system.

SiPM: I am not sure whether this could be done in time for Stage One since radiation damage studies have yet to be carried out. Since SiPM needs very different high voltage bias and signal amplification, the powering and front-end electronics would be very different. I think the best approach should be to focus on MCP-PMT as the baseline for Stage One and the R&D for SiPM is more appropriate for later stages.

Common issues: there was no mention of what electronics to be used for the timing detectors. For sure, radiation damage studies would be important. It'd also be useful to test all the detectors with the near-detector electronics in the test beam before and after irradiation.

Prototype reference clock system:
This is the most critical part of the timing Detector system. The full system test is planned to happen only in a test beam in Fall 2011. This may be a bit late, particularly it also depends on improving the time resolution of the HPTDC chip under WP5. There it was stated that a prototype of the high resolution TDC card based on this chip is targeted only for end of 2011.

WP3: Planar pixel detector system
The plan is very vague. There are only two types of barrel pixel modules, 2x8 and 1x8. Both types of modules seem to be too large for this purpose. There could be some single chip modules but this would be readout using carrier PCBs and special test system. It is not clear that there's much in common with the CMS pixel DAQ system. One of the requirements is that the pixel detector has to be edgeless or no dead area around the edges which is certainly not the case for the current pixel modules. I don't see an easy way to bypass this limitation.

WP4: 3D pixel detector system
It'd seem to me that a better bet or strategy is to use single chip 3D devices for the Stage One. There are already some working single chip 3D devices mated to CMS readout chips available. These devices are edgeless and could offer some initial operation experience before Stage 2.

WP5: Trigger and DAQ systems
I don't understand item 3) which said exploratory studies of Stage two HPS240 L1 trigger electronics based on uTCA system and reviewing situation on the context of new pixel ROC. The new pixel ROC would be pretty much like the current ROC in terms of trigger capability (cluster counting). Even though I know nothing on the proposed trigger for HPS240, I don't see how the new pixel ROC would have an impact.

Referee #2:

This document proposes R&D activities to be carried out within the next 18 months, aiming towards the development and installation of the HPS (High Precision Spectrometer) detectors. The physics case for the HPS has been reviewed elsewhere, with the conclusion that these detectors would bring a very valuable addition to the CMS physics programme.

Two major installation stages are foreseen, with the possibility of installing "stage-one" detectors at 240 m, during the 2012 shutdown. The document is meant to address issues related to the first stage (see e.g. the title and the abstract). However, some activities are described, that are relevant only for the stage-two detectors (e.g. 3D pixels in WP4; studies for a trigger electronics based on muTCA in WP5; then some ambiguities can remain, regarding the options that are considered for the stage-one detectors). While I agree that these studies should start as soon as possible and, as such, be part of an 18-month R&D programme on HPS, I suggest that the document be more explicit.

Besides that, the proposal is clear, there will be an interesting physics outcome from these HPS detectors at 240 m, the R&D project is attractive, and I see no showstopper. The R&D looks appropriate and not excessively duplicated. The proposal presents a clear plan towards a demonstration of a timing reference system with a resolution better than 10 ps. The mechanical aspects (moving pipe system) will be worked out in close collaboration with the CERN EN-MEF group. This seems to represent quite a lot of work, and resources should be effectively deployed as soon as possible, following an agreement between the CMS management and the relevant CERN groups, if the goal of 2012 is to be met.

Here are my main comments and questions:

- In case you miss the 2012 opportunity to install the stage-one detectors: could the installation take place during a yearly technical stop, how much time is needed in total?

- Radiation levels at 240m and 420m: it is of course crucial to have a good idea of the constraints that radiation will put on the detectors and on the electronics. We could make measurements with the current beams, now that the machine does operate in relatively stable conditions. This would be helpful to benchmark the simulations. Some simple devices can probably be installed at these locations, if not already present.

- Tracker: the document should spell out better what are the plans for the stage-1 tracker: what aspects need to be studied in view of adapting the CMS pixel modules? Is there any specific R&D needed in WP3? Besides the R&D aspects, a few more details regarding WP3 could be added in this proposal (e.g. what are the plans to face the O(100) fb^{-1} that the stage-one tracker would be exposed to, between 2012 and ~ 2016).

- WP4: this is an R&D for stage-two (and is presented as such), and not in "the preparation of stage one". If the scope of the document is extended to describe an 18-month programme of R&D, relevant both for the stage-one detectors and for the preparation of stage-two, I suppose you will extend the description of WP4, with time lines, as done for WP1.

- What are the options that are being considered for the stage-one QUARTIC? Should the R&D decide between single- and multi-channel MCP-PMTs, or also between SiPMs? I assume that the SiPM studies are rather aimed towards stage-two, since the timescale is tight, if you want to have a prototype tested and ready to install by 2012 (already the selection of the SiPMs that will be used is likely to take some time, since radiation hardness may be a serious issue as stated in the document).

- The SiPMs studies are mentioned only in the context of QUARTIC. I understand indeed that the lifetime issue of MCP-PMTs will be (at high luminosities) more a concern for QUARTIC than for GASTOF. However, in case SiPMs appear to be a viable solution for QUARTIC, GASTOF may investigate whether SiPMs could be an option as well for them, for the stage-two detectors, and compare the pros/cons with the other options based on multi-anode MCP-PMTs.

- the TDC chip: is there any additional R&D needed regarding the TDC electronics that will be used for QUARTIC ? if single-channel MCP-PMTs are used for the stage-one detector, and if the current HPTDC chip is used (25 ps resolution), the time measurement would be limited by the electronics.

- The updated HPTDC for stage-two: are there some requirements that you would like to set on the specifications of the upgraded HPTDC chip that is being designed by the CERN group ? You may want to influence the design of the chip, if not too late, such that you can easily use it for your detectors. E.g. for HPS and its ATLAS counterpart, you may have some radiation hardness demands on that chip, that are more stringent than for other applications like the TOF of Alice.

- A question regarding physics and multi-hit events at high luminosity: further physics studies should tell under which conditions multi-hit events can be used for physics. Indeed, the requirements on the detectors at high luminosity are quite different depending on whether:
    - one simply needs to "tag" the multi-hit events, in order to reject them in the analyses (leading of course to a non negligible loss in statistics);
    - these events are kept in the analyses, i.e. a precise timing measurement is needed for the two (or more ?) protons.

- In the appendix, for WP5: from the text, it looked like more people were involved here.

Referee #3:

First of all comments on the specific 3 questions asked, then more detailed comments on the proposal WPs below.

The R&D is appropriate for the needs of CMS at SLHC (i.e. focused):

The R+D is clearly for future sub-detectors which give interesting physics reach beyond that of the currently installed detector. Therefore the physics case is strong. This physics is not accessible by the present CMS detector as built - though it clearly has a large overlap with the current TOTEM physics programme, though the proposed kinematic regime of this proposal extends beyond that of TOTEM. This R+D is appropriate if these physics goals fall within the CMS remit for the SLHC.

The programme as outlined in the proposal is focused towards the steps needed to be able to build the detectors described in the proposal. Some aspects may have been overlooked.

It was raised previously by the CMS FP420 review panel, and I think should be reiterated here that the option for detectors at 420m is not a zero-risk option for LHC operation, due to the requirement of replacing the connection cryostat with a novel design.

The effect of the proposed HPS240 and HPS420 stations on nearby machine elements (especially quenchable items such as downstream magnets and the connection cryostat) should also be evaluated.

The timescale of the R+D programme proposed is short compared to that needed by TOTEM to design and install.

The R&D is not excessively duplicated (ie we don't have too many people have working on the same topics):

It is clear that the answer here depends in the first instance upon whether there is a TOTEM physics programme for SLHC. It mentions early in the proposal that for the stations at ca. 240m, there are two options - a refurbished TOTEM or the detector proposal as outlined here. If both exists, then clearly this R+D is excessively duplicated.

It should also be noted that an active 220m TOTEM station would probably have a disastrous impact on the performance of the 240m station (ref: LHC project notes 386 and 397 ; R. Appleby et al, Paper TH5RFP031, Proc. PAC 2009).

I would therefore strongly suggest that clarification is sought from the CMS management on this issue.

In any event, the opportunity should not be missed to capitalise on operational knowledge obtained by TOTEM during the present running period to influence the design. This aspect is completely missing from the proposal.

The programme is ambitious - and there is some redundancy built into this programme, with several options presented in particular in relations to extracting optimal timing measurements. There are 3 places where there is redundancy in the R+D:
- Timing detectors
- Tracking detector
- Reference timing signal

For the timing detectors, the choices are potentially complementary, and fairly near to the specs of the required final devices. For the tracking detector, the standard barrel pixel modules should certainly be pursued. The 3-D pixel choice is high risk, though as stated an interesting possible first application. It is not mentioned in detail here, but presumably the people proposing to work on these are already involved in similar work packages for other proposals, and so it does not detract from the work package proposed and allows a potentially interesting option. For the reference timing signal, I believe that several approaches would be complementary, though a strategy should be converged on soon.
In summary - this seems reasonable and not excessively duplicated.

The number of people on each work package seems to be rather limited - especially as it is probably correct to assume that all named persons will only dedicate part of their time to this research. For a successful delivery of the stated R+D goals, the reviewer suspects that additional collaborators will need to be sought. As stated in the answer to the first question - the timescale is ambitious.

We would also like your input on suggested milestones or check-points where progress and plans for continuation should be reviewed.

Here are the suggestions for possible milestones/check-points:

For all 3 aspects where there is redundancy in the R+D (timing and tracking detectors, and reference timing signal), milestones should be made for a technology choice. There is a potential here for the alternative technology choices to distract from each other, so clear milestones for technical designs should be made.

Strict milestones should be set for the simulations of the signal and background at the proposed stations. These should include:
- validation of the simulations (to TOTEM simulation and to a variety of data)
- evaluation of impact of HPS stations on surrounding machine equipment
- evaluation of background
- evaluation of signal reconstruction

The installation, successful and safe operation and physics utilisation of the HPS240 should be demonstrated before the riskier HPS420 is approved.

An effective L1 triggering strategy needs to be demonstrated for HPS420.

Comments on proposal:

General:

It should be noted that some of the work packages as presented in the proposal were entirely lacking in detail. In contrast WP1 seems to comprise the majority of effort. As such it is not possible to assess them to an equal degree - they are reviewed as presented in the proposal as it stands.

Concept of timing - as detailed in the final report of the FP420 collaboration - a key aspect is the association by precision timing of a tagged scattered proton to an individual primary vertex on an event-by-event basis. This is assumed to be absolutely linear (by assumption of perfect beam dynamics), i.e. the desired time resolution of 10ps gives an associated vertex resolution of 2mm. This should certainly be the case for the ensemble, on average. However, I found no detailed discussion of migrations possible due to momentum spread, optical errors, drift, etc. Naively I might expect these not to be completely negligible, in the context of a requirement of 10ps timing resolution. If these have not yet been studied and demonstrated to be negligible, I would suggest an appropriate beam simulation (e.g. MAD) to show that timing migrations are well under control.

Considering ALARA, and that all near-beam-pipe work and all work in the LHC tunnel comprises a level of risk, a strong case needs to be made why HPS240 needs both a stage 1 and stage 2 installation.

WP1: Timing detector system

- The goals for both timing detectors seem realistic and easily achievable.

Reference timing:
- Recommend ensuring that the design includes a return path/feedback for the reference clock, as continual monitoring of jitter will be needed to ensure stability.
- Note that whilst the design as presented requires only a reference clock to each station, I suspect that a deeper understanding of the timing will be necessary to actually operate and understand the detector.
- To understand the beam timing at least 3 signals are needed: RF clock, and timing from both beams (eg BPTX or similar).
- The level of understanding presently reached on the timing in CMS indicates that the jitters and uncertainties are far larger than the precision needed here. During a fill, measurements on an ensemble of measurements indicate that jumps of 60-100ps and drifts of >200ps during a fill are frequent.
- Present understanding of the timing in CMS means that effects as small as 20ps can be seen, but only by highly averaging (i.e. not on a per clock cycle) and these effects cannot be precluded to be systematic. All of these numbers are much smaller than the level of precision that the RF system expects to provide.
Therefore would strongly recommend any effort on providing this reference clock:
- to envisage including the RF clock and Beam timing in the measurements to anticipate the need for them later.
- To coordinate this with the present and future efforts on understanding beam timing in CMS.

WP2: Moving beam pipe.

- It is not clear whether dedicated beam position monitors are foreseen at these locations. As a conservative measure, recommend that they should be considered as part of the baseline design.

- Loss monitors are vital for calibrating and assessing collimator position in terms of sigma from the beam. No mention is made whether dedicated loss monitors will be installed or whether the detectors themselves will provide these calibrations.

WP3 and WP4: Tracking detectors.

- Details of what these work packages comprises (beyond a very general description) are lacking.
- The case for what the R+D for WP4 is trying to achieve for the HPS detectors above and beyond what WP3 provides is not made in this proposal as it stands now.
- Note, in the context of using pixel readout paths, that spares of many of these standard items are very low (especially optical components). This is presumably only a problem for items considered for 2012 and before. It may be safe to assume that in the timescale of 2016, alternative items might already be available.

WP5: Trigger and DAQ

- Use of real data, as detailed here, to evaluate trigger strategy essential to determine whether it is realistic.
- For HPS420, key event discriminant is HPS420 hits + vertex tag. Neither is available at L1. Need to demonstrate that relevant physics can be triggered on efficiently with L=10^34 trigger.

WP6: MC studies.

- Details given of this work package are quite limited.
- Key point that I believe is missing is validation of the simulation results with LHC data. There are sufficient data from the present run (from various detectors) - and these should be used to validate and lend confidence to the simulation results. Lessons learned from TOTEM should be incorporated here. TOTEM simulation results should be used as a benchmark for development of simulations.
- Much of the geometry and simulation should already be implemented for TOTEM
- Activation of the HPS stations with intense beam (and subsequently a handling policy) is not mentioned.
- There will be a tertiary collimator installed at ca. 150m probably in 2016 for the outgoing beam. It should be determined that this collimator has no effect upon the HPS stations, particularly the HPS 240m station.

Referee #4:

Physics and Technical Issues

Generally speaking, this is a very good proposal, which addresses studies of new physics in areas that have only recently been explored in some detail. The particular advantage is that knowledge about the decay products of a final state emerging through central exclusive production is not required and that good mass resolution of that state can be achieved per event.
Luminosities beyond 10^{34} $cm^{-2}s^{-1}$ and the subsequent problems have not been addressed in this proposal.

For CMS two stages are proposed. For the first stage, to be operational after the 2012 shutdown, detectors at ± 240 m from IP5 are foreseen. For the second stage, to be operational after the 2016 shutdown, more detectors and a new connecting cryostat between warm and cold LHC sections should be installed at ± 420 m.

There is some risk in the installation and functioning of the Hamburg pipe, which involves movable parts and interlock and other safety issues. The NCC, of which a design already exists, is also a system that needs to be carefully planned and executed. I believe that a detailed safety assessment report is necessary for the installation, connectivity and operation of both components. A plan B to quickly switch back to LHC operation without HPS in case of any failure is needed. Beam monitors and other safety equipment, with adequate software, must be included in sufficient number to prevent any accident that could have a large impact on the entire LHC program.

The two types of proposed ToF counters seem already to be able to fulfill the specifications. Their complementarity is also a nice feature. It is acknowledged that achievements in this area have been excellent during the last year or so. Several options for the reference timing are available. Details on the evaluation and prototyping plans of the SLAC scheme have been given. This solution may however, turn out not to be totally adequate, therefore more details on the fallback options could have been given. The reference timing system seems currently to be the part of the proposal that needs a significant amount of work in the next months.

The detector pocket production and subsequent laser welding carries more risk than producing the beam pipe in one piece by electro-erosion. Therefore we look forward to seeing this technique being used for the final HPS prototype.

The joint efforts on 3D tracking with the CMS pixel group, but also with ATLAS and Medipix, are encouraging. WP3, the work package for the planar pixel detector system, presently seems to lack technical detail and perhaps manpower.

The studies of trigger and DAQ issues are well presented and reasonable. The plan to use mTCA technology is compatible with the rest of CMS.
Monte Carlo simulation studies could benefit from more manpower and more detailed plans.

It is in our opinion better to plan for a setup separated from TOTEM in the ± 240 m region instead of refurbishing their 220 m area, as it is indeed preferred by the proponents.

Concerning timing, it is crucial that Stage One is ready for installation by the start of the long LHC shutdown in 2012.

Resources & Management Issues

A similar project, jointly prepared by ATLAS and CMS members, exists also for the ATLAS forward regions. Whilst it is always preferential to have more than one experiment studying similar topics, it may be impossible for reasons of budget and manpower restrictions, but also

due to the possibly limited capacity of a small number of available LHC and other technical experts from CERN as well as short installation and commissioning times. Probably the same experts will be involved in both experiments. The cost is expected to be less than one percent of CMS. I believe it is reasonable to assume that it can be met, if necessary with the contributions of new collaborators.
Although the potential size of the collaboration, as it can be deduced from the proposal, may just be sufficient, it should be better quantified, both in numbers and in actual availability, given that most collaborators will also be involved in other projects.

Recommendations

- The CMS Management should approve the R&D outlined for this project and should interact formally with the concerned LHC and technical groups of CERN.

- Demonstrate quickly that a critical mass of dedicated collaborators, including CERN technical staff, is achieved, commensurate with the different stages of the project.

- Work on the reference timing system should have priority.

- Work out clearly the differences, advantages and complementarity with respect to the ATLAS project.

- The project is well focused and compatible with the needs of CMS. Duplication of effort in the ATLAS and CMS projects and in the technical studies for the experimental setup is, however, to be absolutely avoided.

- Milestone Spring 2011:

Final configuration of timing detectors,
Feasibility of cheap SiPMs,
Feview the timing reference clock system.

- Milestone Summer 2011:

Prototype of the moving pipe system ready,
Risk analysis report ready,
Review Monte Carlo studies.

- Milestone Spring 2012:

Readiness review of complete Stage One system.

- Milestone end 2012:

Complete system available and tested as far as possible.