CMS Upgrade MB Response to SLHC Document:

09.04: EMC immunity studies for CMS Tracker upgrade (Contact Person: Fernando Arteche)

We welcome this proposal and are pleased with this collaboration. We feel it is important to align this program closely with CMS needs and ongoing R&D. We suggest submission of a revised proposal that answers the specific requests below. Please also see the comments from the referees.

Specific requests for the revised proposal are:

1. Explain how noise propagation effects in the power network might be studied in a design where motherboards do not exist in the tracker, but are replaced by thin cables.
2. Explain how measurements on the circuits can incorporate the expected environment (e.g. a DC-DC converter on a carbon-fiber support structure). How will the effects of the eventual detector impedances be included in these measurements? What kind of facility (e.g. integrated test stand) would be needed for such measurements?
3. Explain how any testing facility (*e.g.* an integrated test stand) would be supported over the long term (*i.e.* 5 years).
4. Explain why a semi-anechoic chamber is needed for this measurement program.
5. Provide a plan showing how such measurements could be made collaboratively with the board designers to provide a more prompt feedback.
6. Explain how the guidelines will be propagated to the designers.
7. Clarify the relationship of ITA to CMS.
8. Explain how collaboration with Aachen and Fermilab might be developed.
9. Explain further the available resources (both funding and personnel).
10. Explain further on which tracker sub-system(s) the work will be performed (pixels, tracking/outer tracker, tracking trigger, all)?
11. Explain when would what kind of prototypes be needed for the testing? Will prototypes be available on a timescale compatible with the proposal? If these are not available on the timescale of the planned work, how will this R&D proceed?
12. Explain how the fibers for the sensors (WP4) would be brought into the tracker in case cable channels are not accessible?

Referee #1:

First of all, I think a focused effort in this area is really needed and the aim of the project is correct.

My main concern is that this R and D effort focuses too much on circuits and circuit boards and not on the integrated detector package. I feel that if the tracker upgrade proceeds with separate mechanical and electrical designs, we will end up with a device that will be as massive as the existing tracker if not more so. What I think we need is an integrated approach where the mechanical structures serve as mounting structures and shielding for the electronics.

Working package 1. This is a useful measurement but it does not really tell us the performance of the DC¬DC converter mounted in a carbon fiber support structure. In my view, the carbon fiber would serve as the mechanical support (no circuit board) and also provide shielding and probably power return (ground). What I think is needed is a facility to measure the performance of the converters in a rod. It would measure the noise between sensor modules on a rod and between adjacent rods. It would do this with conventional instrumentation (spectrum analyzers etc) and also with prototype readout electronics. I think that there would be at least 2 of these test stands - one on each side of the Atlantic.

Working Package 2. I do not believe that the mass constraints will allow any sort of circuit board to distribute power. Most likely, power will be sent over twisted pair mounted in some way on the carbon fiber support. Thus, this package becomes the same as the augmented package 1 described above.

Working package 3. I think that this is OK as it stands for initial development. It will eventually be integrated into the expanded version of work package 1. Given the high data rates required for the trigger, the design of the noise immunity of the FEE is likely to be iterative. That is, one will build a prototype system and measure its signal to noise as a function of frequency. If this is not adequate, then both the grounding and shielding and the design of the FEE will be reevaluated and new designs developed to address the noise problem. The FEE might be redesigned to increase its noise immunity but it is also possible that the structure may be modified to provide better grounding and shielding.

Working package 4. I don't know much about FBG sensors. I will comment that the noise contribution from the controls in the existing tracker was from the 40 MHz clock that is needed for the trigger rather than the monitoring and downloading. I think that this could be useful but it is not essential to the new tracker development.

I think that the proposal should be modified so that they will work in conjunction with Aachen and Fermilab to develop an integrated test stand. One of the first uses would be to mount a few DC-DC converters on a carbon fiber support and measure the noise performance. This clearly an expansion of the proponents efforts and it requires close collaboration with other institutions but it is what I think is needed.

Referee #2:

Discussion of content

The topic of this proposal is basically EMC measurements in view of a DC-DC conversion powering system. Four Work Packages (WP) are distinguished:

WP 1: Power network impedance effects on noise emissions. In this WP the conducted and radiated noise of DC-DC converter prototypes shall be measured with respect to the impedance of the power network connecting the DC-DC converter to source and load. For this purpose test stands for conductive noise will be developed. The radiative noise measurements will be conducted in a semi-anechoic chamber, as available at ITA. While tests of conductive noise of

DC-DC converters are being performed on various levels at several institutes (CERN, RWTH Aachen, Fermilab), systematic quantitative characterizations of the power distribution network have not yet been performed. Tests in shielded chambers have not been performed either and are known to be relative expensive, if the room has to be rented. It will certainly be useful to have access to such equipment, and measurements of the radiation of DC-DC converters in such a chamber would be a new and interesting contribution.

WP 2: Noise propagation effects in the ICB power network. In this WP the optimal design of "inter-circuit boards" (ICB) wrt. EMC is studied. To this purpose new methods of measurement to estimate the conducted current noise in the ICB shall be developed. These tests are meant to result in recommendations for the design of DC-DC converters, front-end electronics and the ICB. My impression is that the authors have in mind motherboards similar to those present in the current CMS tracker. However, in many new proposals such motherboards do not exist anymore but are replaced by thin cables. Furthermore, as the authors do apparently not plan to develop the power distribution network themselves, but rather intend to characterize existing prototypes, I wonder if realistic prototypes will be available on the timescale of the proposal.

WP 3: Noise immunity test in FEE prototypes. Tests of (hybrid? module?) prototypes will be conducted to understand their noise immunity. This will result in further recommendations for their layout. Here one has to acknowledge that designers of such components will also have a valid interest in characterizing their electronics and significant overlap could potentially be created.

WP 4: Validation of electromagnetic immune optical fiber sensors for temperature, magnetic field and strain monitoring; effect on the overall EM noise. Optical fiber sensors are proposed as sensors for temperature, magnetic field and strain. Their light weight and immunity to noise are mentioned as advantages. Their implementation (embedding) and the gain with respect to EMC will be studied. Such sensors have also been proposed in the context of the "Central European Consortium", by the same group (I. Vila). Not clear to me is how these new additional fibres will be brought into the tracker, as we assume today that the cable channels cannot be accessed. Other points to be addressed are radiation hardness, prize, complexity of off-detector electronics circuits, complexity of calibration, robustness wrt to mechanical stress.

<u>Focus of the proposal wrt. CMS needs</u>

The CMS tracker has chosen DC-DC conversion as baseline powering scheme, and clearly conductive and radiative noise is an important issue for this technology. To optimize the tracker electronics for immunity wrt. the noise emitted by converters is crucial and studies towards such immunity will be needed. My impression for the current proposal is, however, that the authors are somewhat detached from the current lines of thinking in the tracker community. The task could be more complex as the authors are anticipating, as 2-3 different subsystems have to be characterized (pixels, tracking, triggering), or a choice has to be made. Also, classical motherboards as the authors seem to have in mind are not foreseen in many proposals anymore, in order to save material. Another potential problem is that the authors plan to provide guidelines, but do not develop any component themselves. This is only useful if the engineers in charge of the components in question are willing to follow the proposed guidelines, and if the timescales fit (for example, the outer tracker readout chip is being designed already now).

Overlap with other groups
There is overlap with the CERN group, who performs also tests of the conductive and radiative noise emissions of their DC-DC converter ASICs. Furthermore there is overlap with the group at RWTH Aachen, who develops the converter PCBs and performs system tests with tracker structures with the goal to understand the noise coupling mechanisms. As mentioned above, tests in an anechoic chamber are not planned by other groups and could be beneficial. Also detailed modeling / simulation of CMS electronics is beyond the scope of at least the Aachen group and would be a useful contribution. There is no overlap for the optical fiber sensors.

Resources, people
This part of the proposal is not very concrete. What is the manpower behind this proposal? Are there groups behind the two authors? F. Arteche is certainly an expert in the field of noise measurements, and has performed noise measurements with CMS tracker structures before. His current institute (ITA) provides the facilities to conduct the proposed measurements, but it seems to be a commercial institute and is not part of CMS. This is an unusual situation and it should be clarified formally what are the consequences and how to deal with this. Concerning the proposed 2-year program and its schedule, WP1-3 seems to me optimistic but maybe possible for an experienced FTE. WP4 looks realistic to me.

Summary
The proposal has certainly overlap with the work of other groups, but extends this work significantly. Some care must be taken to integrate the proposed work into the CMS tracker R&D (e.g. within the Tracker Upgrade Electronics and Power Working Groups). I suggest the following points to be raised:

- Clarify the relationship of ITA to CMS.
- Detail further the available resources (both money & human)
- Detail further on which tracker sub-system(s) the work will be performed (pixels, tracking/outer tracker, tracking trigger, all)?
- When would what kind of prototypes be needed for the testing? Will prototypes be available on a timescale compatible with the proposal?
- How would the fibers for the sensors (WP4) be brought into the tracker in case cable channels are not accessible?

Referee #3:

1. Document form and layout

The document is far from being accurate and looks like having been written in a hurry. Without an a-priori knowledge of the EMC issues for the CMS upgrade, it would be very hard to even understand the objective of the proposal. Even with this knowledge, it is not easy to understand in practical terms the details of the work proposed.
I would strongly recommend the authors to rewrite the proposal with more care, especially if they intend to use it to present financial requests to their National Funding Agencies.

2. Aim of the project

The project proposal is divided in two areas: noise coupling mechanism and electromagnetic immune optical fiber sensors (OFS). I do not see such a strong link between the two issues to justify merging them into a single proposal. If the optical sensors in work package 4 could be useful for sensing purposes, their use does not remove with these optical ones in terms of EMC does not look as the major justification for an R&D on the OFS. I am not here objecting the validity of Work Package 4 in the proposal, I just think it should be a separate proposal from the one object of this review. I will therefore not comment in more details Work Package 4, for which I do not feel qualified, and recommend the authors to submit a separate proposal for that package.

For what concerns the main aim of the proposal, which is on EMC immunity studies, it is clear that a structured and coordinated R&D activity would be very beneficial in view of a SLHC CMS. This is particularly relevant since a new powering scheme, most likely based on switching DCDC converters on-detector, will be necessary for SLHC. A good understanding of the noise sources and coupling mechanisms since the early development phase of the SLHC CMS will allow for designing a solid and reliable detector system, able to work efficiently without excessive requirements from either power or signal distribution systems.

The aim of the project is therefore definitely appropriate for the needs of SLHC CMS. I wish to stress that, in line with what expressed in section 5 of the proposal, it is extremely important that the knowledge generated by R&D on EMC issues is immediately diffused to the full CMS community. System components are designed in a distributed way by a large number of individuals in different institutes: the best detector in terms of noise immunity can be built when all components are designed with EMC in mind.

It should be added that the document speaks about EMC rules to be applied, while it would be preferable to speak about “a set of recommendations and guidelines” that should be advertised widely. Again, the usefulness of the project lies in its capacity to transfer the generated knowledge to the community.

3. Details of the work packages

a. Work package 1

The study propose in WP1 is certainly interesting and relevant. Conducted noise from DCDC converter prototypes are characterized today with a test system with constant impedance at both input and output. This impedance not being necessarily matching the one in the final application, it is certainly interesting to:

- study and make a model of the real impedance in the application
- study the evolution of the DCDC noise when the input/output impedance is changed

For what concerns the radiated noise, which is also a relevant parameter, it is not clear why the proposal suggests performing radiated noise studies in a semi-anechoic chamber. Such chamber being generally used for far-field radiation, the authors should justify how its use would allow for investigating near-field noise coupling, which is the coupling mechanism that will dominate radiated noise pick-up in SLHC CMS.

Finally, it is regretful that the proposal does not detail how the study of the real impedance seen by the converters in the detector (to source and load) will be carried on. The SLHC CMS tracker being still in a very early stage, it looks very unlikely that any representative hardware (modules, hybrids) will be available for the study in the timeframe detailed for this WP in the proposal. Are the authors implying that such impedances are not strongly dependent on the detector configuration, and that a representative study can be done with a "generic" detector scheme?

b. Work package 2

This WP specifically attacks problems encountered in the past with the ICB. Nevertheless, to the best of my knowledge no ICB is foreseen to be used in the SLCH CMS outer tracker (for the possible trigger layers the design is not yet mature enough to conclude, but again it is possible that nothing like an ICB will be used). The relevance of this entire WP, as it is exposed in the reviewed document, is therefore questionable.

On the other hand, the general idea of studying how noise propagates in a complex system such as the CMS tracker is certainly valid. I would recommend the authors to reformulate this WP to make it more generally applicable to the SLHC CMS tracker, and to give sufficient details for the reviewers to understand how this work is practically going to be performed (which hardware is going to be used for the measurements? which type of measurements will be made?)

c. Work package 3

Measurements of noise immunity of hybrid/module prototypes are certainly necessary both to understand noise-coupling mechanisms (and correct the hybrid/module/ASIC design if necessary) and to define specifications for the power distribution system (such as optimum switching frequency, maximum level of conducted/radiated noise). Nevertheless, two objections can be raised to the formulation of this work package in the reviewed document:

- it is unlikely that hybrid/module hardware of the SLCH generation will be available in 6 months time. The time schedule for this WP looks therefore unrealistically optimistic
- Design and characterization of the hybrids/modules is (to my knowledge) planned to be done already in other institutes, for instance in Bristol and Aachen. Those 2 institutes are equipped with systems to characterize the noise immunity, and have certainly intention to carry on such tests. The document does not mention it explicitly, hence a doubt about possible duplication of efforts exist.

4. Conclusion and recommendations

The proposal concerns overall an R&D activity that is certainly relevant for the needs of a SLHC CMS. Its main interest in my opinion is in the following 2 points, over which one should build the R&D if approved and funded:

- it originates from an engineering institute where a specialized knowledge of EMC exists
- it aims at developing expertise to be advertised and transferred to the community via presentations at conferences, working groups, and redaction of recommendations/guidelines. It actually even suggests the exchange of information and collaboration across experiments (with ATLAS).

Although in its present form the proposal is not sufficiently documented and details of the proposed work are not clearly exposed, the above two points of interest prevail and I suggest to react positively to the proposal – maybe asking the authors to rework the proposal in light of the comments from the reviewers before final acceptance.

For what concerns the worry about duplication of effort, this is a risk that in fact exists and can be avoided only by a coordinated activity. Although some of the work in the proposal is already planned to be done by some Institutes, the added value of the proposal in my opinion is the addition of expertise from an engineering Institute specialized in EMC (which will bring personnel and dedicated equipment).

If well coordinated, this activity would allow EMC expertise to be developed in the Institutes where modules/hybrids are designed and tested and eventually to the whole community. This coordination effort cannot be confined within the powering group, since EMC widely spans across the full detector system. It should therefore be at the full electronics coordination level.