CMS Upgrade MB Response to SLHC Document:

09.05: Prototyping stacked modules for the L1 track trigger (Contact Person: Geoff Hall)

It is our intent to recommend this proposal for approval with some requested revisions. These revisions and plans for reviews, *etc*. should be made with agreement of Tracking Project Management. Please see the comments from the referees.

Specific requests for the revised proposal are:

1. Provide more details about the R&D plan deliverables and milestones and specifically the *primary* institutional responsibilities and time-scales for these. These details should also include intermediate steps towards some of the listed milestones, *e.g*. smaller test scale structures with "test" chips on them.
2. Provide more prioritization of the activities in the proposal. First priority activities should include demonstration of interconnect technology, sensor development, module evaluation (especially power, cooling and mass) and power studies involving the data transmission and optical links. Second priority activities should include off detector electronics and beam tests.
3. Provide a set of milestones for the program specifically for when the project should be reviewed, *e.g*.
   - Delivery of substrate design.
   - Measurement of interconnection and/or bump-bonding yields.
   - Delivery of a TFEA (or ROC and assembler) design and calculation of the power required.
   - Delivery of a module prototype.
   - Testing of a module prototype (including its triggering capability).
4. Provide more information about the linkage of sensor development to other R&D efforts.
5. Provide a plan for convergence of the two design concepts.
6. Provide more details on how cooling issues will be addressed.
7. Provide more details about industrial involvement and how this will be financed.
8. Provide a set of benchmarks for module evaluation: electrical (including noise immunity), mechanical, thermal and more details of a testing program involving beam tests and interfacing to off-detector electronics for the needed measurements. These benchmarks should make clear if they are satisfied only with direct measurement or if simulation will be used for part of the determination.
9. Provide a plan to address following items within the first year of the proposal:
   - Details of the data traffic between various ASICs (ROCs).
   - Details of the data buffering needed.
   - Simulating data rates, traffic, and number of hit pixels and buffer sizes, including such effects as charge sharing, track inclination, multi-tracks within jets and variation with rapidity.
   - Simulating the trigger performance requirements on z (vertex) resolution, cut-off momentum, robustness against missing hits, chips, modules,
   - Details of the substrate design and positioning accuracy required for TFEA chip bump-bonding

- How charge sharing will be handled.

10. Provide details of how input from other (non-sensor) R&D projects will be integrated into the program:
    - DC-DC Converters (especially noise from using these).
    - Cooling technologies
    - GBT Links
    - Others?
11. Provide a high-level budget estimate with a plan to provide more budget information after one year.

Referee #1:

It seems clear that either of the two proposals is intended to expand to become the level 1 trigger enabled upgrade of the CMS tracker if successful.

I think it would be technically possible to collaborate with the CMS HCAL with the early off-detector electronics (or just simply steal; the so-called "HCAL front end control server" module could be used for test beams and such).

I cannot find anything else sticking out that would need comments other than that a more detailed budget estimate (actually any budget at all...) should be asked for by, say, the end of the year as suggested under 4.4 Funding and Resources.
Thus, to my taste, approved with the above request.

Referee #2:

Proposal 09.05 is very appropriate for the needs of CMS at SLHC. It is innovative, without being over-aggressive in terms of proposed technologies. The investigated concepts are clearly described and explained, and have been discussed and presented to CMS on several occasions before. It is good that they are now summarized in a formal proposal. Unfortunately, the project-implementation aspects of the proposal are still vague and in some cases even unclear. How will so many participants and institutions be structured into an efficient project? The activity matrix in section 6 is for instance a good indication of a still poorly focused program with too many institutions involved in too many tasks. In such conditions, there is in my opinion a risk that the collaboration forming around this R&D project results in fact in a mini-tracker collaboration operating within the official tracker collaboration. The signature of the proposal by many key people in the tracker upgrade management structure may also result in conflicts of interest when it comes to reviewing the results of the R&D and compare them with alternative projects.

The proposal highlights 7 topics for R&D. These are all necessary, but could be prioritized:
- Off detector electronics and beam tests for instance could be set as second priority, and should be carried out by fewer institutes to maximise efficiency.
- Sensor developments should be very tightly linked to other R&D efforts in this area, as duplication of effort could be avoided in this case. - The module development topic is insufficiently detailed in section 5 of the proposal. Only power and assembly issues are mentioned, but this topic should become, together with the ASICs, the core of the project.

Cooling is only briefly mentioned for instance, but is a crucial ingredient to the success of the design. Also, two design concepts are proposed, but no convergence path is sketched. Finally, how is industry going to be involved and what resources are available to fund these costly industrial developments?
- Module evaluation is key to the successful completion of the R&D project, but is unfortunately described in only 4 lines in section 5.7. This deserves more attention. In particular, the definition of a set of benchmarks (electrical, mechanical, thermal,...) would be useful to focus the project. The module evaluation topic could be enlarged to include off-detector electronics and beam tests.

In conclusion, I recommend to endorse this proposal with the above caveats, but suggest that CMS (or the CMS tracker management) establish a solid framework to steer it, together with proposal 09.03. A panel of independent reviewers, a set of benchmarks, a jointly accepted timeline are instruments that will prepare the tracker collaboration to the evaluation phase that will follow the R&D projects.

Referee #3:

The proposal is based on the two layer design (Pt-layers) which is well accepted as the best candidate for a L1 tracker trigger. Two module designs are proposed. Both seem visible and qualify for an R&D program. I suggest to approve the proposal and ask the authors for more details within one year. These should include more concrete information about the data traffic between the various ASICs (ROCs).

Personally I have a slight preference for the 2nd design (referred to as 2.3). It is much more elegant but also technically more challenging. It requires development of the substrate between the two layers which should provide all the needed interconnects. The substrate is not explained much in the present proposal. The TFEA chips will have to be positioned very accurately on the substrate in order for the bump-bonding to work efficiently.

For neither of the two design the authors explain how the charge sharing will be handled. The proposed sensors will collect electrons, therefore the Lorenz angle will be large and will induce charge sharing between the 100 micron wide pixels. Another problem which is mentioned only briefly is the data buffering needed for hits generated from tracks in jets. Simulations will be needed to estimate the data rates, number of hit pixels per column and the buffer sizes.

Below I answer the specific questions.

1) The RD is appropriate for the needs of CMS at SLHC (ie focused)?
Yes, very much. Tracker L1 trigger is central to triggering at SLHC.

2) The RD is not excessively duplicated (ie we don't have too many people have working on the same topics)?
There is some overlap with the previous proposal for a L1 tracker trigger by R.Lipton et al. (09.03). However, considering that this is a very new and ambitious task some duplication of the R&D effort is justified.

3) Of the R&D proposed, (a) which are the highest priority?
- the ASCIs, the ROC&Assembler for 2.2 and the TFEA for 2.3.
- the interconnects, especially the implementation of the "Local trigger links" through the substrate in 2.3.
- testing of the TFEA position accuracy needed for bump-bonding to work correctly (2.3).
- power issues including the power needed for the data transmission and the optical components.

(b) which can be identified as generic (e.g. independent of the specific tracker design selected)?
- power related studies
- the planar substrates and the interconnection yield in 2.3.
- the ASIC design in 90 nm technology.

(c) which need input from simulation in order to proceed?
(1) Simulation of the data traffic between the two Pt layers needed to perform an efficiency track trigger. This should include effects like:
- charge sharing between pixels induced by the Lorenz angle and the track inclination,
- multi tracks within jets,
- tracks at large rapidity where the crossing of the two layers happens at a different z.
(2) Simulations needed to establish the size of the data buffers/pipelines to hold data in the ROC peripheries.

(d) which need input from other R&D (not included in the proposal) in order to proceed?
(1) DC-DC converters for powering.
(2) GBT links

4) Suggested milestones or check-points where progress and plans for continuation should be reviewed.
(1) For design 2.3:
- a more concrete design of the substrate between the 2 layers,
- the interconnection yield and the bump-bonding yield,
- the TFEA design and power required,
- a module prototype and testing of its trigger capabilities.
(2) For design 2.2:
- the ROC and Assembler design and the power required,
- the design of the interconnect between the 2 layers.
- the module prototype and testing.

Referee #4:

The proposed high luminosity sLHC upgrade will pose very challenging problems for trigger and detector design. There is general agreement that the current sLHC model of luminosities of 10^35 with 25 ns bunch spacing will require a track-based trigger. Such a device would be required to handle and filter huge amounts of data, with minimal power consumption and low mass. This note proposes the development of a Pt module to provide initial momentum filtering of hits. The group also proposes to design and simulate the front-end electronics and data flow, off-detector electronics, sensors and assemble and evaluate prototype modules.

The Pt module proposal focuses on commercially available technology for the module and includes many other aspects needed for fabrication of a trigger layer. Ultimately this will provide an option that can be compared to the vertically integrated modules for functionality, mass, and cost. This proposal envisions two options. The first is a design which transmits encoded hit information across a multi-via structure to a bottom side correlator chip near the edge of the module. The second uses chips mounted on a central printed circuit-like support which communicate locally through the substrate. Both designs assume digital transmission of hit information from chip-to-chip. The vertically integrated module proposed by another group includes an option to send analog information from top to bottom through an interposer, using one layer of chips on the bottom sensor. The vertically integrated proposal also assumes smaller z segmentation on the bottom layer. This is at the cost of unproven technology and the development of an "interposer", which provided connection between the layers. Many of the issues addressed by the two proposals are similar, and active collaboration among the proponents would clearly benefit CMS.

To answer the specific questions:

1) The RD is appropriate for the needs of CMS at SLHC (ie focussed)

If the track trigger problem is to be solved while retaining the physics capabilities of the experiment a toolbox has to be developed which will allow the proper decisions on physics and engineering tradeoffs to be made when a Phase II TDR is written. There is some time for this, and considerable uncertainty about both the evolution of the machine and that physics which will need to be addressed, but the R&D to set the landscape of choices needs to begin now. As such I view the scope of the proposed activities appropriate.

2) The RD is not excessively duplicated (ie we don't have too many people have working on the same topics)

The stacked module paradigm has emerged over the last few years as a model well suited to the requirements of a CMS track trigger. This proposal is intended to explore a module design based on commercially available technologies. This is in contrast to the "vertically integrated" proposal, which is intended to explore new technologies which are not yet widely commercially available. As such the two proposals can be viewed as complementary, each with a different technology as a focus. The VI proposal may fail due to cost, technical issues, lack of commercialization of the technology, or problems with yield.

Given this, I strongly encourage both options to be pursued. However there is also clear overlap in the overall goals and in specific areas like system architecture, ASIC design, sensor development, thermal modeling etc. The Pt Module design is correlated with – but not necessarily directly linked to work on ASICs, system architecture, and simulation. Parallel, possibly divergent developments in these areas within CMS would likely be counterproductive.

Formal merging of the efforts may be premature. However coordination is important. I note that there are a number of people who are on both proposals. Perhaps one or more of these people can

take on the task of coordinating the work of the two groups, making sure there is not too much overlap and linking specific efforts. Subtasks, like thermal modeling and ASIC functional block design might profitably be shared among these groups. There should be a plan within CMS to merge or reorganize the efforts on a time scale well before the Phase II TDR.

3) Of the R&D proposed,
(a) which are the highest priority?
Although the technology is considered "commercial" the size, scale, and density of interconnects is probably unique. Thus demonstration of the interconnect technology should be a high priority. Since the problem is one of scale and complexity, as opposed to specific technology R&D it is not clear how this will be addressed incrementally without full-scale chip and sensor development. It would be useful to have the collaboration comment on this.
Another priority will be development of an understating of module power, cooling, and associated mass. Studies of noise using DC-DC converters are part of this proposal. Simulation work needs to be done in parallel as noted in question 3c.

(b) which can be identified as generic (e.g. independent of the specific tracker design selected)?
The module design assumes Pt-layers, but could be implemented with a variety of overall tracker designs, including both the hybrid and long barrel designs.

(c) which need input from simulation in order to proceed?
Simulation will clearly be needed to understand the functionality of proposed trigger systems. There are a number of simulation realms which are relevant. Physics simulation will be needed to define the cut-off momentum as well as the rejection achieved. These are crucial parameters for the design and must be understood in the context of the physics goals for SLHC. Unfortunately those of us without precognition don't know what those will be. The best we can do is make a guess at a reasonable menu. Another important parameter to be informed by simulation is the required z resolution. Any trigger which correlates multiple objects will benefit from improved separation of vertices. This needs to be quantified by simulation for a few examples. As mentioned in the proposal, simulation of the actual circuitry to provide an estimate of power consumption and required bandwidth are important in informing the overall design of the system.
Another important design issue is redundancy. How robust is the design for triggering and tracking if hits, chips, or modules are missing?

(d) which need input from other R&D (not included in the proposal) in order to proceed?
As mentioned above the work needs to be informed by the ongoing track trigger simulation. In addition R&D on cooling and power distribution are very important to understanding module mechanical design and chip power limits. Progress on optical communication is important to accommodate the very high data rates envisioned with acceptable power consumption.

4) Suggested milestones or check-points where progress and plans for continuation should be reviewed.

The decision on which module option to pursue for prototype construction is a candidate milestone. Clearly the production and testing of a Pt module is the most important milestone.

The development of a carefully understood model for the data flow, mechanical design, and mass of the module are also important check-points.

The proposal lacks detail on time scale, milestones, and specific deliverables. Given the complexity of a full Pt module and associated ASICs fabrication of a full scale prototype module appears ambitious. Do the proponents plan to produce smaller scale test structures with either "mechanical" chip prototypes or low cost, large feature size test chips? It would also be useful to define which of the items to be "understood" on the R&D list (digital logic, data rates and power, mechanical and electrical integration, functionality) require hardware prototyping as opposed to computer simulation. The off-detector electronics are not specifically called out in the R&D goals. What are the expected deliverables for that group?