CMS Upgrade MB Response to SLHC Document:

08.07: Proposal for a First Level Trigger based on Tracking
(Contact Person: Fabrizio Palla)

It is our intent to recommend the Trigger Design and Associative Memory parts of this proposal for approval. Please see the comments from the referees.

Specific requests before final approval are:

1. Provide more details on plans to determine the dependence of the design on detector parameters *(e.g.* thickness, pitch, n-type vs. p-type, *etc*.)

2. Explain the plan for simulation of this particular trigger design.

3. Explain the plan for determining a design that will work in the overlap and forward regions and whether these regions might require inter-module data transmission.

It is important that this R&D program provide a proof of viability of this design that includes an implementation in FPGAs in place of Associative Memories. It is also our expectation that this R&D program address these issues with high priority:

1. Explain the number of outer tracker layers required to construct tracks.

2. Explain the volume of data required to transport and process to make the trigger primitives we well as the maximum data rate for the trigger processor.

3. Explain the effects of charge sharing between strips, cross talk and noise on the p_t resolution.

4. Explain how multiple clusters per region per crossing are transmitted and tagged.

5. Comment on the feasibility of hit correlation between 2 layers.

6. Comment on the anticipated material budget for this design.

7. Explain the how the geometric alignment would be accomplished and its accuracy.

8. Explain how this system would interface to the DAQ, TTC and Control channels.

We do not recommend the LiNbO3 modulator links for approval at this point due to concerns that the modulator size, material budget, temperature sensitivity, light polarization sensitivity, reflections at multiple connectors, drive voltage, power per bit, SEU immunity, switching voltage and associated noise at GHz rates may not be compatible with the design of the new tracker and the level of effort involved in this part of the R&D program, given there is also a focused link development project.

Referee #1:

This proposal is actually three independent activities which should be judged separately, as none depends crucially on the other.

1. Trigger based on cluster width determination.

It is important to investigate this further to understand how feasible it is, and the limits to its applicability. In particular, since the scheme depends on certain detector parameters (thickness and pitch, n- or p-type polarity, in particular), it will be important to evaluate the robustness of the method to variations in the detector parameters, including radiation damage effects. These could be crucial if a different sensor choice than optimal is imposed, for example for cost or radiation damage reasons.

It is also important to evaluate an implementation in the forward region. Since the scheme relies on operation at large radius, endcaps are the only way of extending the acceptance to higher eta values. It is far from obvious how to build trigger layers using this concept in the endcaps and a demonstration that this is possible by simulations is vital if it is to be accepted.

It could be worthwhile carrying out beam tests, as proposed, but care will be needed to emulate sufficiently well the SLHC conditions, to avoid incorrect conclusions.

The chip development could be wasted if this scheme is not finally adopted so this should be undertaken cautiously, especially as there could be other opportunities for ASIC design contributions to the upgraded Tracker.

2. LiNbO3 modulator links

This is not a new idea and was studied in the early days of LHC R&D. It was rejected on the same grounds which would still undermine it for tracker applications: the modulators are extremely large and would be hard to place inside the tracker, and contribute a significant amount to the material budget, at least locally. They require a relatively high voltage to switch, and this must be now applied at GHz rates, which is a concern, both to provide, and to avoid switching noise.

The alternative modulators appear to be considered less feasible being less well developed commercially.

The teams involved have a modest record in link development, and I think they underestimate considerably the effort required to make a viable study, at the level of detail required.

My recommendation is to reject this part of the proposal, unless the proponents could already answer the criticisms in a convincing manner and were able to return with a more substantial proposal. The effort and cost involved in prototyping I believe to be considerable and is not justified unless there is a very significant chance that these links would be exploited in the future.

3. Associative memories

The AM approach has been used before, so does not require proof, but not in the L1 application required for CMS which has far more stringent time constraints than the CDF application and probably cannot be guided in the same way. It is probably not crucial to the cluster trigger. In addition, the number of layers of information required to construct tracks seems to be larger than

likely to be possible and therefore requires a radical design of the new outer tracker with several layers providing trigger information, and discarding lower pT track information.
It should be demonstrated why a more flexible FPGA-based system does not have advantages over a hard-wired AM approach.
It is worth studying this approach further but only with modest investment of resources, until there is some convincing evidence that the method is viable and cost effective. What needs to be understood better is the robustness of the method as the number of contributing layers varies and how effective it can be in the congested SLHC environment. There should be proof that the required latency can be achieved, without building a significant system, preferably by simulations and calculations. Edge effects at azimuthal boundaries should be explained.

Overall, the proposal lacks a list of deliverables and milestones, and a better plan should be developed. Costs will be a consideration for the funding agencies and it should be made clear that CMS has not endorsed any estimates at this stage.

Referee #2

Ch. 1 & 2: Introduction and trigger architecture

The proposed scheme with local data reduction and global pattern matching across a limited number of tracking layers (3) appears to be an interesting and feasible solution for a CMS track trigger that fully merits an in depth feasibility study.

Detailed physics and detector simulations are clearly the highest priority tasks to make a serious evaluation of the proposed scheme and indentify possible problems (mass, crosstalk, charge sharing, noise, etc.). The criticality of the mass of the preceding tracking layers must be carefully evaluated to determine a realistic mass budget for this and cross check this with reality (always underestimated). The effects of an increased mass of the proceeding layers must also be understood.

It does not seem trivial to use the proposed scheme for the end caps. More details of a viable solution for this should be worked out within such a study.

Ch 3: Local data reduction

The use of local data reduction (~70%), based on cluster width, is important for the proposal. It could though be worth also to evaluate an option without such a local cluster reduction. This would imply ~3 times more data to transport/process, which may not be out of reach using parallel optical links and high performance processing devices (FPGA's or AM) available in 10 years time.

A schedule critical item in the realization of such a potential project will be the development, verification, production, etc. of an appropriate low power and low noise front-end chip. Such a front-end implementation is not really considered in detail in the proposal, whereas other implementation parts, that may be less schedule critical, are proposed to be implemented and tested. Making a clustering and data reduction ASIC in a rather old technology (0.35um) does not seem to be among the highest priority tasks for such an architecture evaluation, as such a basic digital function should not pose major implementation challenges.

Ch 4: Trigger readout

The emphasis given to the use of 10Gbps links maybe not necessarily be the optimal choice. SEU immunity of very high speed link serializers is a difficult and critical point. Lowest power per bit is not necessarily obtained at the highest possible link speed. An end of rod module can if needed most likely accommodate multiple link drivers at more moderate speeds. Very compact parallel optical links can be made from fiber ribbon links. Mapping of optical link technology from commercial telecom applications to high energy physics, with major radiation and SEU problems, is a very complicated and time consuming issue.

The use and development of low power high speed electrical links, for local data collection in the detector, is interesting for many tracking trigger applications and can only be encouraged.

The proposed option of using a shared trigger data path and normal readout data path could turn out to problematic at the system level. In an approach with multiple lower speed links it seems relatively straight forward to allocate one of these links for the normal readout path.

Figure 10 refers to the use of internal busses. Real busses are unusable for high speed signals and it is proposed to use a scheme with unidirectional point to point high speed serial links only.

It is proposed to study in detail the possible use of different types of optical modulators. The possible use of VCSEL lasers does somehow not appear. VCSEL's have shown very good radiation tolerance and is available from multiple sources.
The use of optical modulators in telecom is motivated by their strong drive to maximize the speed (e.g. 40Gbps) of their long distance fiber networks. For HEP applications we do not really have the same constraints. In the use of optical modulators the major power consumption is most likely not the optical modulator itself but the electronics needed to drive it (driver, high speed serializer, etc.).

The development of a radiation hard and SEU immune multi Gbps link serializer and driver is a major undertaking. The initial use of commercial link transmitters may therefore tend to underestimate the design effort that will eventually be needed to map this into a fully radiation hard and SEU immune link

Ch 5: Off-detector electronics

If it is proven possible to driver the required cluster information off the detector on a reasonable number of optical links, there is probably little doubt that technologies will be available in ~10 years time that can perform the required pattern processing and matching. The use of a custom made associative memory is a possible option that though requires significant time to be developed, tested, produced and verified. The use of an alternative scheme fully based on high end FPGA's available in 5-10 years time should also be seriously evaluated. In locations where commercial devices can be used, it is often seen that custom developed systems, when finally available, will not perform much better than the latest generation of commercial devices (FPGA's). It seems premature to embark in a particular implementation at this early stage in the basic evaluation of the proposed trigger scheme.

Summary remarks:

The simulation studies of the proposed detector and trigger system is clearly the most urgent task to get started to verify the basic scheme proposed.

An appropriate front-end chip will also be vital to estimate total mass in such a system (power, cooling, noise, etc).

The particular optical link to use on the end of the rod is clearly a key part of the proposed solution but does not seem urgent to study in detail in a first evaluation phase of the project.

If the required signals can be brought off detector there is probably little doubt that technologies will be available in 10 years time can process this large amount of data with short latency. It is recommended to study alternative architectures and implementation options for this before going into a specific implementation based on a given ASIC.

Referee #3:

Proposal 08.07 is well prepared and well presented, at least in terms of track trigger models, scenarios and algorithms. In these areas, the project is well described and the work plan is well documented. Unfortunately, the same cannot be said of electronics and links where only very general concepts are shown with too little detail to seriously judge the soundness of the proposal. At the other end of the spectrum, an electronics system-overview is missing, giving the impression that this is an isolated development for a specific functionality. How is this system linked to the DAQ, TTC and Control channels? How is compatibility with other developments maintained? Why would the tracker need a specific system for the trigger path, or is it proposed to use it for the other functions as well? These questions should be answered before CMS blesses what looks like a very independent venture. Diversity should definitely be encouraged, but only in a well understood collaborative environment.

Now to some details in section 4:

- The requirements listed in section 4.1 differ from what seems to be commonly understood: the quoted radiation hardness is probably only applicable to outer barrel regions and is missing the ionizing dose component (which might be most relevant to the proposed technology), the low and narrow operating temperature range does not allow operation or testing in warm conditions, the quoted density is very low and imprecise.
- The proposed MZModultator approach is quoted to result in lower power dissipation inside the detector (when compared to a directly modulated laser). This should be quantified as no

indication is given on the power dissipation of the modulator driver. - No mention is made of the polarization sensitivity of MZModulators. Will special fibers be needed to maintain the polarization of the incoming CW light?
- With a typical Vpi x L value of 10Vcm, how can one expect to have a small size LiNbO3 device operated with a driving voltage compatible with deep submicron CMOS technologies validated for radiation tolerance? - What are the plans to design a modulator driver in a radiation tolerant process?
- How will the Vpi voltage be supplied if it differs from the standard front-end ASIC supply voltage?
- What is the temperature sensitivity of Vpi and Vmod. How is it foreseen to control Vpi over the whole operating range (temperature, polarization, radiation dose,...)
- a discrete mention of a custom MZModulator development is made. What impact would this have on project cost, timescales and risk? Does it mean that existing devices do not fit the requirements? - Will non-LiNbO3 technologies be available on a timescale compatible with SLHC phase 2, with what margin of certainty?

To conclude, a word of caution. In the mid-1990's, the RD23 collaboration investigated MZModulators and EAModulators in great depth with industrial partners. Reports are still available at http://rd23.web.cern.ch/RD23/#Documents.

Near the end of the RD23 project, CMS decided that directly modulated lasers were the right choice for LHC. No one ever regretted this choice, which resulted in a simple system that could be produced in large volume. One should be cautious before entering such an adventure again, and make sure that significant changes have occurred to justify reopening closed doors.

Referee #4:

The basic idea to reduce the data flow from the detector to the off-trigger processor using data from one single layer only is appealing. If proven feasible it reduces the problematic interconnections between modules and the off-detector electronics and reduces material budget. However, in the overlap regions between modules some kind of data transmission to neighboring modules might be needed to avoid introducing geometrical inhomogeneities.

The proposed cluster width (CW) method seems in principle able to provide a measure of the incident angle. However, as also stated in the document, a number of uncertainties must taken into account. Depending on sensor type charge sharing between strips will occur in different ways, with two extremes; charge all on one strip or charge proportionally distributed. Additionally, other effects as mentioned in the document (cross talk, noise, flat sensor) will have an effect on the pt measurement. In addition to the afore mentioned imprecisions of the CW the geometrical influence where parts of the silicon sensor will be inclined with respect to a straight line from the interaction point has an influence on the selection of high pt tracks. In conclusion only a pt cut-off margin with a degraded pt resolution can be established but not a clear pt cut. This will spoil the cleanness of the triggered data samples. It should be stated whether this would be compatible with the overall physics trigger performance in CMS. If these drawbacks of the pt measurement method are acceptable for the CMS physics trigger performance the implementation of the CW method seems to be a method of data reduction with reduced interconnectivity which merits detailed evaluation. Requirements stated in the document are: flexibility, robustness and significant operation margin. These parameters are important and they should be defined more clearly in order to evaluate whether the CW method fulfills them. Many of the effects degrading the pt measurement cannot be simulated to the required precision and thus it will be mandatory to experimentally prove the feasibility of the CW method.

At the same time it is worthwhile to enlarge the scope of evaluation from the single layer CW method to a method involving two layers, where hit correlation between two layers would be attempted. This would reduce the requirements on position resolution and might deliver a clearer cut on pt. Furthermore it could reduce the background as one of the weak points of the CW method is the background suppression. Of course neighboring modules in different layers would need to interchange data, but with a reduced position resolution and data rate. Whether this is possible in principle depends on the physical implementation scheme and required material budget. The specification on geometrical implementation and required material budget have not been addressed in the document. In order to follow the research for a trigger scheme these parameters should be studied and margins set as soon as possible in order to exclude/include alternative methods and study realistic electro-mechanical implementation schemes.

In general the immediate need seems to be on defining a parameter space firstly on the detector parameters (material budget, position resolution, required pt resolution, trigger efficiency) and at the same time studying the CW algorithm and possible alternatives. Only, in a second phase can an electronics implementation, such as briefly described in fig. 5 be evaluated. In order to reduce the cost in material budget but also in reliability issues it seems appropriate to avoid duplication of read-out structures for the trigger and data path. The approach for the pattern recognition to use associative memories is elegant. The implementation feasibility will depend on the actual number of patterns and the way overlap regions will be handled. At that time the overall latency requirement for this trigger system should be estimated. One of the drawbacks using predefined patterns compared to classic track finding algorithms is that at the time of the startup any geometric misalignment would require that the patterns be calibrated first. The system would not be available for operation at startup time where the trigger might be especially useful.

Also it should be considered that in any case a powerful FPGA processor needs to be employed to distribute the data accordingly to the associative memories. As progress in FPGA development is very fast and FPGAs become more and more suited to store patterns using combinatorial logic facilities it is worthwhile investigating an approach employing FPGA processors only. In general the presented proposal is well described and shows the direction the studies should take. The next steps should be clear definition of the simulation studies, definition of parameter space and study of possible physical detector and electro-mechanical implementation schemes. At this point one should not limit the research to one method of measurement for data reduction.