MUON DT UPGRADE

C. Fernández Bedoya on behalf of the CMS DT community

The muon Drift Tube (DT) system of the CMS (Compact Muon Solenoid) detector will undergo a program of upgrades accommodating to the LHC (Large Hadron Collider) schedule. Based on the present excellent performance of the system and on the expectations of an adequate operation of the detector at higher luminosity, upgrades for Phase 1 are focused on improving the reliability of the system and in particular of a few electronics parts. Accordingly, efforts are concentrated on consolidating two aspects: the Trigger Boards (TRB) and the Sector Collector (SC) electronics. For the Phase 2 upgrade, with luminosities exceeding up to a factor 10 CMS design parameters, the main concern is the reduction of the L1A (Level 1 Accept) trigger rates without imposing a significantly high transverse momentum cut. The status of the overall DT upgrade project is reviewed in the text.

INTRODUCTION

Muons are measured in CMS by means of three different technologies of gaseous detectors. In the barrel, where the magnitude of the residual magnetic field in the detector volume is negligible and the neutron background and muon rate are expected to be low, DT chambers are used [1]. The DT chambers are responsible for muon detection and, thanks to the about 2 T magnetic field present in the iron yoke, for a precise momentum measurement over a wide range of energies. The DT system also provides a reliable and robust trigger system with precise bunch crossing assignment.

The DT system is a wide area detector. Four stations of DT chambers are installed in the return yoke of the CMS magnet, which is segmented in five wheels of equal size along the beam line (the Z CMS axis). Each wheel is divided in 12 sectors each covering ~30º around the interaction point and each sector is organized in four stations of DT chambers going from inside to outside MB1, MB2, MB3 and MB4. There are 250 DT chambers in CMS, with a total of 172,200 channels.

The DT electronics (Figure 1) is divided in three levels: on detector electronics (Front-End, ROB and Trigger Boards) located in Minicrates at chamber level and hence, highly inaccessible; Sector Collector system in the racks on one side of the CMS wheels and the last stage located in the counting room which includes the regional muon trigger and the DDU (Device Dependent Unit) that connects to the CMS central DAQ.

1 PHASE 1 DRIFT TUBES UPGRADE

The DT upgrade plan has been staged to accommodate to LHC shutdowns and therefore it foresees an imminent action in the 2013-2014 shutdown where long term access to the detector is required for the TRB replacement in the Minicrates and the SC relocation from the periphery of the Yoke wheels to the CMS Counting Room. After this move of the SC electronics the next actions that include the redesign of the SC and the regional muon trigger electronics will therefore be decoupled from extended access to the cavern and can be performed at a later stage.

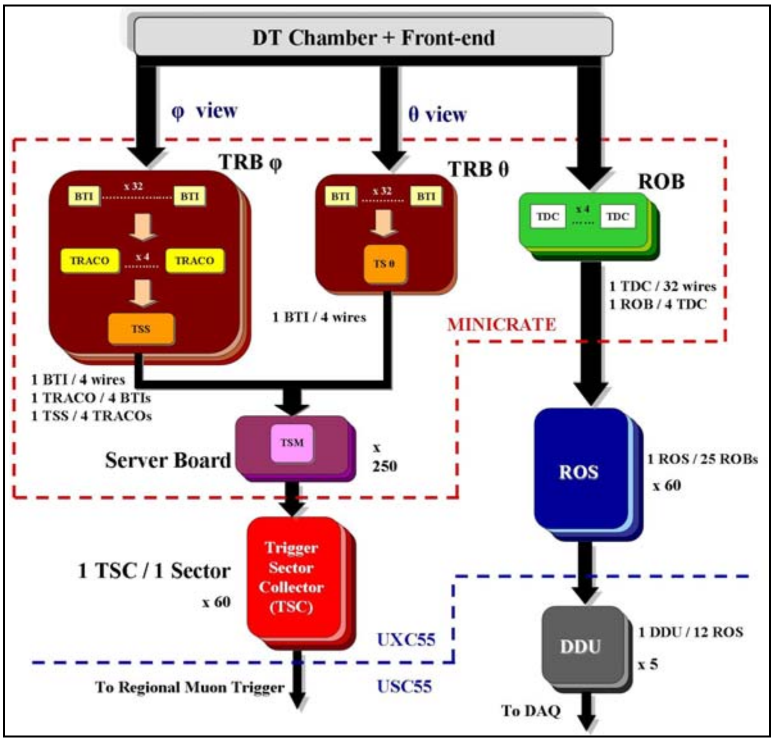

Fig. 1: A schematic view of the read-out and trigger electronics of the DT system.

1.1 Theta TRB replacement

Theta Trigger Boards (TRB) are housed inside the Minicrate and are built around the Bunch and Track Identifier (BTI) module. BTIs receive the signals from the chamber wires through the front-end electronics and generate a trigger at a fixed time after the passage of the muon by searching the coincident, aligned hits in the four equidistant planes of staggered drift tubes in each chamber superlayer. The association of hits is based on a meantime technique [2], which uses the fact that there is a fixed relation between the drift times of any three adjacent planes. Four silicone-topped BTI ASICs are mounted on a ceramic support to build a BTIM hybrid circuit (Figure 2). Eight BTIMs are placed on each Trigger Board.

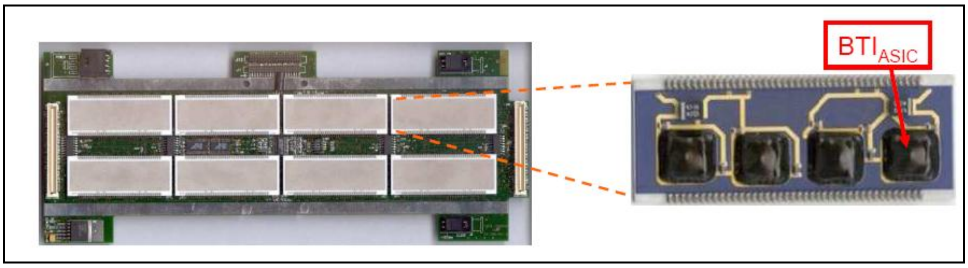

Fig. 2: Image of a Theta TRB and the BTIM with the silicone-topped BTI ASICs.

The motivation for the redesign of the theta trigger board is the lack of BTIM spares that at present are around 3%. The BTIM have suffered a high mortality (around 1%) during the production stages and during the commissioning phase, presumably due to thermal stress of the BTI ASIC bonds caused by continuous power cycles. Since the ATMEL 0.5 μm technology of the BTI ASIC is now obsolete, and further BTI spares cannot be produced, R&D has taken place in the last years to migrate the BTI algorithm to an FPGA which is suitable to operate under the environmental conditions expected in the detector.

The TRB are installed in a region that is not hostile in terms of radiation doses (around 0.4 Gy for 10 years of LHC operation) but subject to a substantial probability of Single Event Effects (fluence of 5 10^{10} p/cm^2 in 10 years of LHC operation). Accordingly, radiation tests have been performed in different FPGAs at the PSI with 60 MeV protons which lead us to identify the ACTEL A3PE3000 as a good candidate. Indeed, this device should also fit operation under ten times more luminosity than LHC.

Extensive timing optimization has allowed allocating the algorithm of up to four BTIs inside the logic of the FPGA, achieving an integration of eight devices inside one board. A final prototype is at present being designed while the last devices for power distribution are being identified.

After the final tests of the prototype that will take place by the end of this year, the final production will be ready to start, in order to allow replacement during the 2013-2014 shutdown. The plan is to replace all the theta TRB of one chamber layer (MB1 Minicrates) in all the wheels, i.e. 120 boards. From the substituted boards we can extract the BTIM to enlarge the number of functional TRBs, both theta and phi boards. The phi TRBs make use of the same BTIM, although they also include other ASIC, the TRACO [3], which makes a full replacement much more complex. Being the expected recovery efficiency of around 80-90% we can foresee to reach after the theta TRB replacement a comfortable number of 11% spare BTIMs that will insure safe operation for a long term.

The replacement of one full station in the system allows future modification of the trigger performance in a uniform way in the detector, taking advantage of the reprogramming capability of the FPGAs. As an example, the improvement in theta resolution has been studied and although for the moment the gain does not seem to make worth the extra modifications, the possibility is left open.

1.2 Sector Collector relocation

The Sector Collector [4], second level of DT trigger and read-out electronics, is located in the tower racks on one side of the CMS wheels. It is made of 10 VME crates 9U that host 60 ROS (Read Out Server) boards and 60 TSC (Trigger Sector Collector) boards with the main task of multiplexing the read-out and trigger signals in order to reduce the number of fibers to the counting room, due to the high cost of the optical links at the time of design.

The SC system has turned out to be a complex system, highly integrated, with large power consumption and not easily accessible. Therefore, it intrinsically becomes a weak point in terms of reliability of the system. It is worth noting that the impact of a failure in one module may handicap a large fraction of the detector (from one sector to half a wheel both in the read-out and in the trigger chain). A fast reaction is needed in order to minimize the impact of such failures; however, limited access to the CMS cavern, which is subject to technical stops in LHC operation and radiation protection issues, renders a significant fraction of the DT system useless in the meantime.

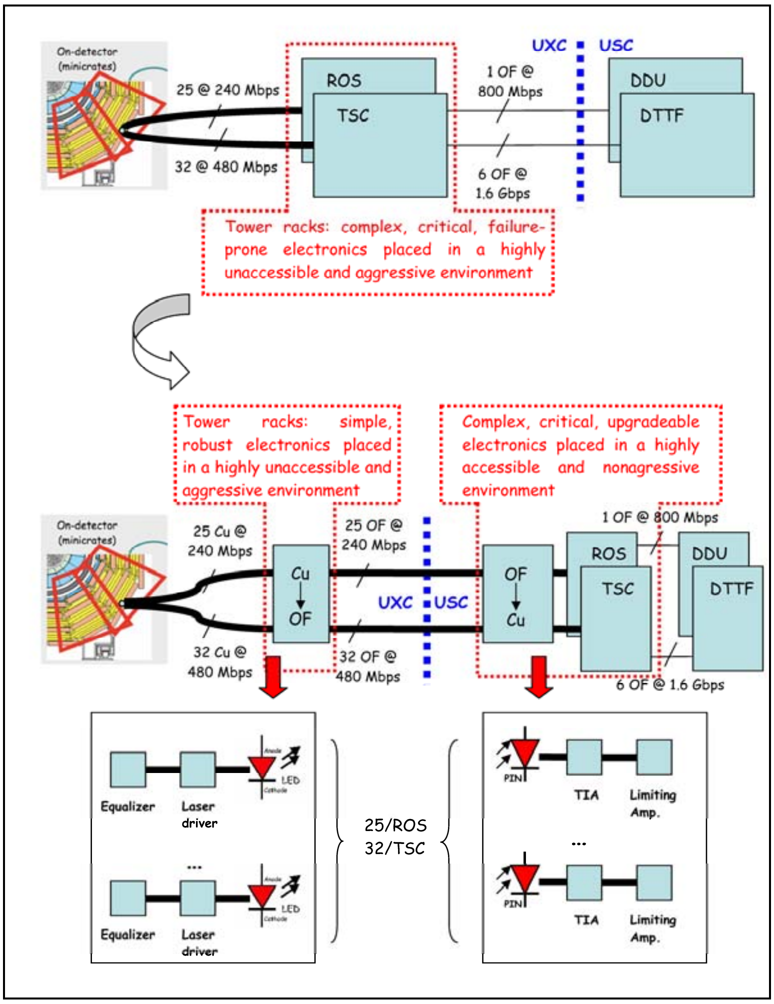

Fig. 3: Schematic view of the proposed upgrade for Sector Collector electronics. The top part of the figure shows the current situation, while the bottom part sketches the situation after the proposed upgrade.

On top of that, we envisage the redesign of the ROS board for detector occupancies at higher than nominal LHC luminosity and a future TSC that could be merged with the new regional trigger logic or even, with a phase 2 upgrade. Since optical links are a cost effective solution nowadays, relocating the SC in the counting room allows not only minimizing the risks of failures in the system but also opens possibilities for an optimal future upgrade.

Our plan is to replace the SC electronics by a simple copper to optical converter, the CuOF modules, which will translate each individual link into an optical signal that will be received at the counting room as can be seen in figure 3. Differential signals will be converted to optical links without adding further stages of deserialization and data decoding that will increase the latency of the link.

The read-out information is received from each ROB board in the Minicrate through an LVDS copper link, up to 40 meters long, at 240 Mbps. In addition, local trigger data (encoded information of position, transverse momentum and track quality) outputs from the Server Board in each Minicrate using serial LVDS running at 480 Mbps. The total number of copper-pair differential links is large, 3500. Nevertheless, even with present standard fiber cables (72 fibers per cable with 6 ribbons of 12 channels in an MPO connector) the total number of cables to be routed with an adequate mapping is 80, which is reasonable and within cost estimate.

At a first stage, due to the tight schedule, we will reuse the present ROS and TSC in the counting room, and for that, we will design a backward conversion optical to copper, the OFCu modules. Future ROS and TSC could then be installed at any time when ready.

Since minimizing the increase in L1A trigger latency is critical, ROS and TSC will be arranged in a different layout as compared to the present system. In particular, we will allocate all the TSC boards in 5 VME crates, instead of 10 as required at present, which will save us rack space near the regional muon trigger (the DTTF, Drift Tubes Track Finder) to which the TSC connects to. Since cable lengths are not a concern for the read-out part, the ROS boards will be located elsewhere. The architecture of the system foresees either case to maintain present TSC to ROS link that is used to read local trigger data within the data flow for debugging purposes during the commissioning stages.

2 PHASE 2 DRIFT TUBES UPGRADE

Operation of the Drift Tubes detector during LHC data taking has shown that the system performs very satisfactorily. Although based on drift tubes with a drift time of 400 ns, it has proven to provide a robust, efficient and pure trigger with synchronization and timing information well below 1 ns uncertainty. Extrapolations to a higher luminosity environment, up to 10^{35} cm^{-2} s^{-1}, show as a major point of concern an increase of the L1A trigger rate that will force the choice of a higher transverse momentum cut unless an improvement of the transverse momentum determination can be achieved.

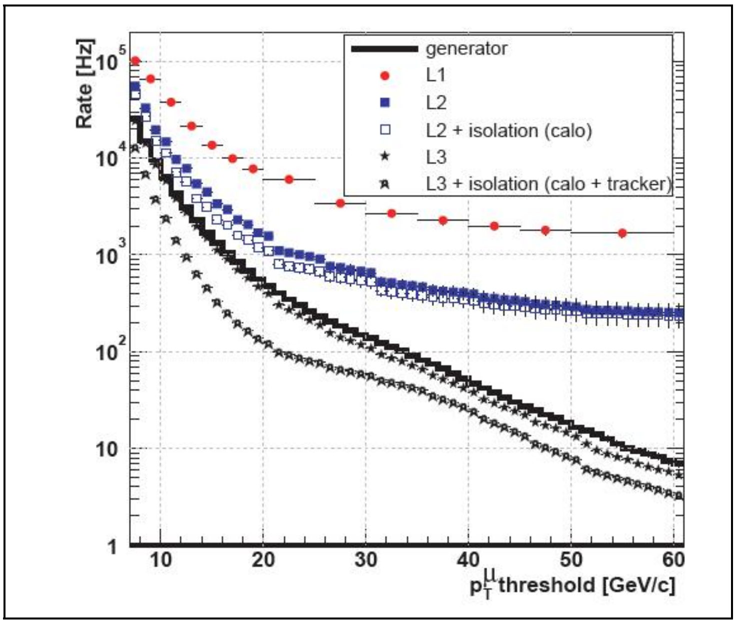

Fig. 4: HLT single-muon trigger rates as a function of the transverse momentum threshold for a luminosity of 10^{34} cm^{-2} s^{-1}. The rates are shown separately for Level-1, Level-2 and Level-3, with and without isolation applied at Levels 2 and 3. The rate generated in the simulation is also shown.

A big improvement in trigger rate control comes from the use of the tracker data that with a higher bending angle and reduced multiple scattering allows improving the transverse momentum resolution and limiting the feed through of mismeasured low momentum muons to high momentum. It can be seen in figure 4 how the effect in trigger rates becomes dramatic by using the tracker information at the High Level Trigger in CMS. Combination of the tracker data at Level 1 can therefore avoid applying very high transverse momentum cuts that will have significant impact in the CMS physics performance.

The basic idea is to associate the DT muon tracks with the level 1 tracker trigger primitives: stubs from stacked layers, cluster width or the format that upgraded tracker may provide. Present simulations are based in the following algorithm: φ and θ muon trigger primitives are found in DT chambers (in principle MB1, though MB2 could also be used for coverage inefficiencies) and they are extrapolated to the tracker layers. The φ bending angle measured in MB1 can be extrapolated to the φ deviation in the tracker layers by means of a linear relationship, which allows an easy hardware implementation. The size of the matching region depends on the primitive position, but in particular, on its transverse momentum. The list of tracker objects is extracted from this region and is matched to the DT track segments in order to filter out the low momentum tracks. With the selected candidates, the transverse momentum can be recomputed to achieve a higher transverse momentum resolution.

3 SUMMARY

The DT upgrade plans have been revised in the text, both for Phase 1, where solving technical aspects and setting the system up for future upgrades is the main priority but also for Phase 2, where the driven lines for an effective operation at higher luminosity are sketched.

TRB replacement and SC relocation, as main items of Phase 1 upgrade, have been advanced recently to the 2013-2014 shutdown, and although the schedule is tight, they are advancing well and seem to go along with the planning.

Phase 2 program will be based most certainly in solving the higher L1A trigger rate at high luminosity by means of improving the transverse momentum resolution. A big improvement should come from the use of the tracker data and simulations are being carried on in this direction.

References

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[2] F. Gasparini et al., "Bunch crossing identification at LHC using a mean-timer technique", 1993 Nucl. Instrum. Meth. A 336 91.

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