

# The Sector Collector of the CMS DT Trigger system: Installation and Performance

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## Abstract

Drift Tubes chambers are used for muon detection in the central region of the CMS experiment at LHC. Custom electronics is used for reconstructing muon track segments and for triggering the CMS readout. The trigger Sector Collector modules collect muon segments identified by the on-chamber devices, synchronize the data received from different chambers and convert from LVDS to Optical for transmission to the off-detector electronics. Installation and integration tests were developed for tuning both firmware and hardware of the Sector Collector system: results are reviewed. The system performance during CMS data taking with cosmic rays is discussed.

## I. DRIFT TUBE TRIGGER SYSTEM

### A. The Drift Tube detector

Drift Tubes (DT) chambers are installed in the central part (“barrel”) of the CMS experiment [1], they are used both for muon track reconstruction and trigger purposes. Chambers are embedded in the return yoke of the magnetic field. The “barrel” iron yoke is segmented in 5 elements (wheels) along the beams direction and in  $30^\circ$  azimuthal sectors in the transverse plane. Four chambers are installed in any sector at increasing distance from the beam pipe; they provide transverse momentum ( $P_t$ ) measurement using the track bending in the CMS magnetic field. Schematic layout of the DT system for one wheel is shown in Figure 1.

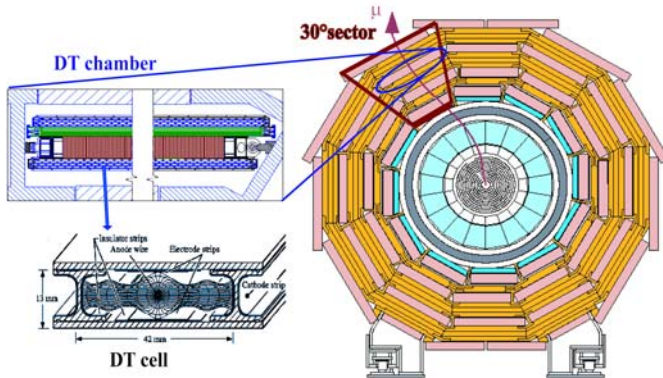


Figure 1: Cross section of a CMS wheel. Schematic designs of DT chamber and cell are also shown.

Each DT chamber is composed by several layers of drift tubes, performing track segment reconstructions with mean-timer technique [2]. 250 DT chambers are installed in the CMS barrel (4 in most of sectors, 5 in the bottom and top ones of each wheel).

## II. CMS LEVEL-1 TRIGGER SYSTEM

The CMS level-1 trigger is designed with custom pipelined electronics, so every collision ( $BX = 40$  MHz bunch crossing frequency) is analyzed with no dead time. Goal of the Level-1 Trigger System is to select interesting events, in order to reduce the total rate of accepted events to less than 100 kHz. If a given event is accepted, a Level-1 Accept signal is issued to the sub-detectors and raw data are transmitted to the following CMS trigger level, called HLT.

### A. DT Trigger Electronics Overview

Goals of the DT-based muon trigger are to perform muon identification,  $P_t$  measurement and assignment to the correct BX. The electronics is organized in a logical tree structure.

First processing stages are installed on the detector, into aluminium boxes mounted on each DT chamber, called Mini-Crates. They have to reconstruct and select two track segments per chamber having higher  $P_t$ . Main requirements of the Mini-crate electronics are reliability and radiation tolerance, so that ASICs and pASICs technology have been preferred and redundant designs have been implemented [3].

Following processing stages are performed by track-finder electronics [4]. They are implemented on several custom VME boards which are installed in the underground counting room (UXC), which is separated from the detector hall with a several meters wide concrete wall. Their major tasks are to match segments among DT chambers and select 4 higher  $P_t$  muons in the whole barrel.

The Sector Collector (SC) system perform link between local trigger (on-detector) and track-finder (in UXC) electronics.

## III. THE SECTOR COLLECTOR SYSTEM

### A. System Overview

The SC system, connecting on-detector and UXC electronics, has been designed following a sector-wide

segmentation. Any SC processing unit receives trigger data from the Mini-crates within a given azimuthal sector, synchronizes and transmits them (after properly remapping) to the track-finder electronics. SC units are located in VME crates hosted on the CMS towers (the metallic structures surrounding the detector, see Figure 2). Each Mini-crate delivers its output through 2 copper FTP cables using serial LVDS transmission (480 Mbit/s). Every SC unit receives data from 4 (5 in the top and bottom sectors of each wheel) Mini-Crates and send the output to the track-finder electronics through optical links. Sector output is transmitted through 6 optical links (GOL chips @ 1.6 Gbit/s). 2 crates per wheel are foreseen (lodged in the same rack); they host both SC units and read-out electronics devices.

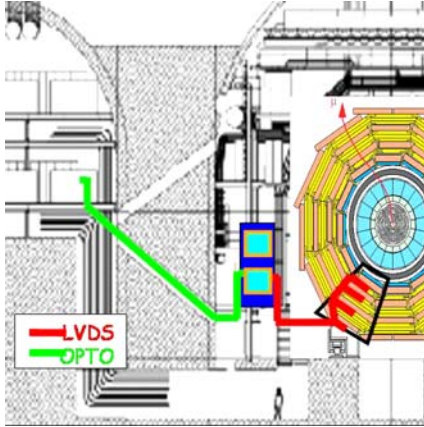


Figure 2: View of CMS underground halls. Sector crates location and trigger data path from the detector to the underground counting room are shown.

### B. Hardware Implementation

The SC unit is implemented with a 9U VME board (see Figure 3). Five piggy boards are plugged in: four of them are equipped with LVDS receiver electronics (LVDS-RX boards) and one (Opto-TX) with optical transmitters. Each LVDS-RX receives trigger data from one Mini-crate (2 cables – 2 separate LVDS channels). In the top and bottom sectors of every wheel, the outer DT chamber is split in two separate ones, so that a special 4-channel receiver board has been produced.

The output optical links are connected to the track-finder electronics, through the Optical receiver cards (Opto-RX), installed on the same crates in UXC. 84 Optical receiver cards (Opto-RX) are being installed, 60 of them receiving trigger information relative to the transverse CMS coordinates (1 Opto-Rx per sector); 24 receive information relative to the longitudinal CMS coordinates, wedge-wide grouped (2 receivers per wedge).

A complete hardware description can be found in [5]. Main features are:

- Implementation of the processing devices with Flash-based Actel ProAsicPlus300 devices (radiation tolerance required);
- On-board FPGAs programming through custom VME-to-Altera Jtag interface;

- Independent piggy board power supplies; LVDS-RX and Opto-Tx can be powered off in case of failure with I/O lines isolation;
- Spying of portions of trigger data that can be injected in the data acquisition stream;
- I2C internal bus for reading temperature and current sensors;
- Configurable custom JTAG chain for accessing ICs on the piggy boards (configuration, boundary scan, spying ...).

In the Opto-Rx cards Altera StratixGX devices, with 8 embedded gigabit transceivers, are used.

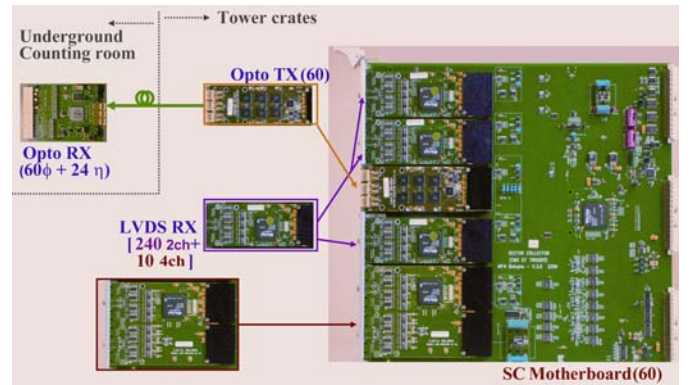


Figure 3: Implementation of the Sector Collector.

### C. Synchronization tools

Most important task of the SC system is to perform timing alignment of trigger data received from the chamber electronics within each sector; moreover, hardware tools have been provided in order to ease synchronization between sectors and wheels. DT trigger system has several sources of de-synchronization, inducing both fine (phase of signals) and coarse (several BX skew) de-synchronization among chambers and sectors data:

- Unrelated clock phases for different Mini-Crates (however each Mini-Crate behaves as a global synchronous device) ;
- Length of copper cables from Mini-crates to SC (ranging from 10 m minimum to 40 m maximum);
- Optical fiber skew: measurement of the propagation delay for all installed final fibers gave a maximum skew less than 20 ns.

Several hardware features have been implemented to take care of de-synchronization sources:

- delay lines on the clock used to sample the SC input (32 steps – 1 ns/step, 1 delay line per LVDS-RX) and automatic confront between received and re-calculated parity bit; the check is performed on each LVDS cable independently;
- 0-to-7 BX pipeline on every single Mini-crate input;
- 0-to-3 ¾ BX pipeline (¼ BX step) on the Opto-Rx output.

### D. Drift Tube Technical Trigger

A Technical Trigger based on DT has been developed during the SC commissioning. Its purpose is to provide a trigger signal suitable for debugging purposes. It is shown in Figure 4. Looking at the CMS official trigger path, the output of the SC units is fed into the track-finder devices and then sent to next selecting devices (Sorters). A Technical Trigger signal is built with the SC outputs taken at the track-finder input. Each track-finder checks its input data, received from the connected SC, and delivers a Technical Trigger bit signal if at least one chamber has valid triggers. Then, a cabled logic is used to perform (anti)coincidences. For instance, simple coincidences between upper and bottom sectors in the same wheel can be used to trigger on muons from cosmic rays when cross the CMS inner detectors.

Several V976 C.A.E.N. modules are used to implement the required cabled logic. The DT Technical Trigger has not been yet integrated within the CMS trigger but it was extensively used in DT local data-taking during sub-detector commissioning.

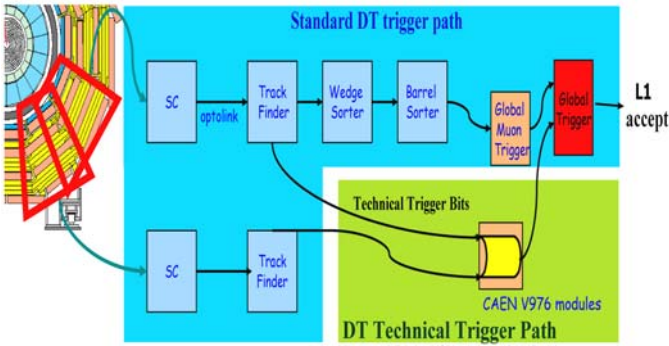


Figure 4: Description of the DT technical trigger w.r.t. the standard DT trigger implementation. In this figure a simple connection with two adjacent sectors is shown.

## IV. SECTOR COLLECTOR PERFORMANCE

SC production and pre-installation tests were described in [5].

The system commissioning was performed with long data-taking both with random triggers and with muons from cosmic rays. First, each sector were instrumented with final connections and tested stand-alone, then several sectors were integrated in the official CMS data-taking campaigns, called Global Runs. Their aim was to gradually integrate CMS sub-detectors and perform global data-taking both with cosmic muons and technical triggers (random...). Participation of DT trigger electronics increased from few sectors (June '07) to the full system (during last August '08 Global Run). More than 250 millions of events from cosmic rays have been taken.

During Global Runs the Sector Collector performance were studied in order to achieve an overall DT trigger synchronization as well as with other CMS sub-detectors.

### A. DT Trigger System Synchronization

The DT trigger synchronization procedure has been tested with cosmic muons but it's very similar to the one that will be done with LHC beam.

First, for each Mini-crate the best clock phase has to be found. Details can be found in reference [6] where methods used for the best tuning with respect to the LHC beam phase are reviewed.

Then, a scan on the SC input has to be done, by varying the phase of sampling clock on each cable and finding (through parity bit check) the best value for the correct data sampling (Figure 5).

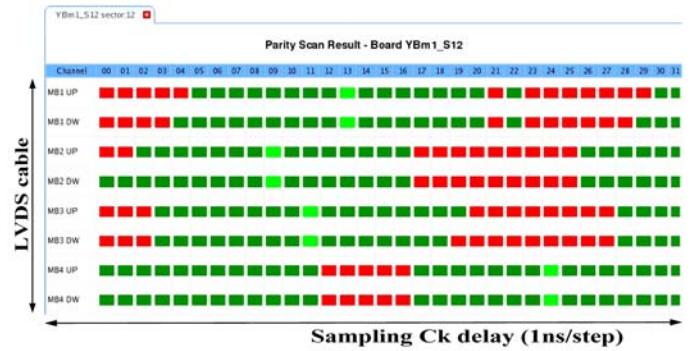


Figure 5: Screenshot get with the SC control software, showing an example of scan in order to find the best phase of the input sampling clock.

Next step is performed using the spied data of a SC boards. Spy registers are acquired when a fixed DT chamber into a sector has triggered; the trigger distribution vs BX shows peaks in other chambers, due to the correspondent muon which crosses (and induces a trigger in) more than one chamber. Pipelines on each station output are used to align peaks in time (Figure 6).

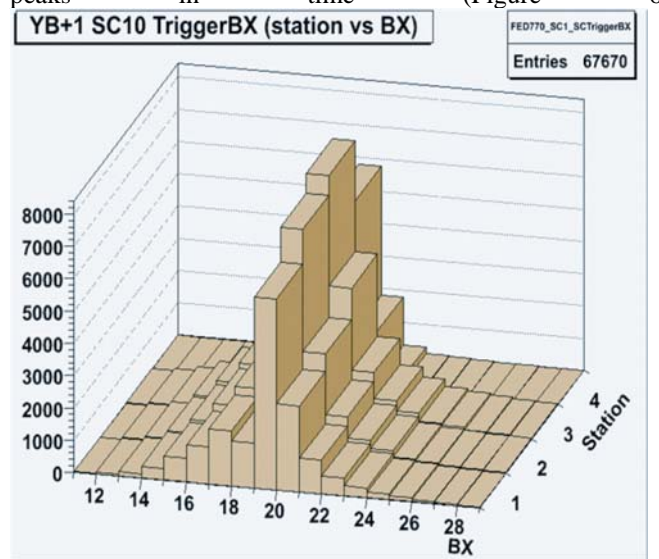


Figure 6: Number of triggers vs. bunch crossing number for each station within a given sector. Example of the plots used for coarse timing synchronization.



Finally, pipelines on Opto-RX cards are used to align data coming from nearby sectors (analyzing coincidences in the spy registers on the Track-Finder input) See Figure 7 for an event display showing a reconstructed muon track crossing chambers in nearby sectors.

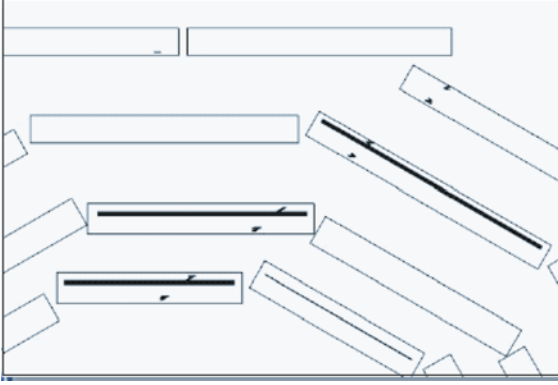


Figure 7: event display showing a reconstructed tracks of a muon which crosses nearby sectors.

### B. DT Technical Trigger

The Technical Trigger has been extensively used in order to acquire data triggered by muons from cosmic rays, since they don't point to the interaction point. By requiring coincidences between triggers on top and bottom sectors of the same wheel a sample of events having muons crossing the inner tracking system has been selected. An event display can be viewed on Figure 8. In this run the CMS magnetic field was set to 3 T. Track bending is visible.

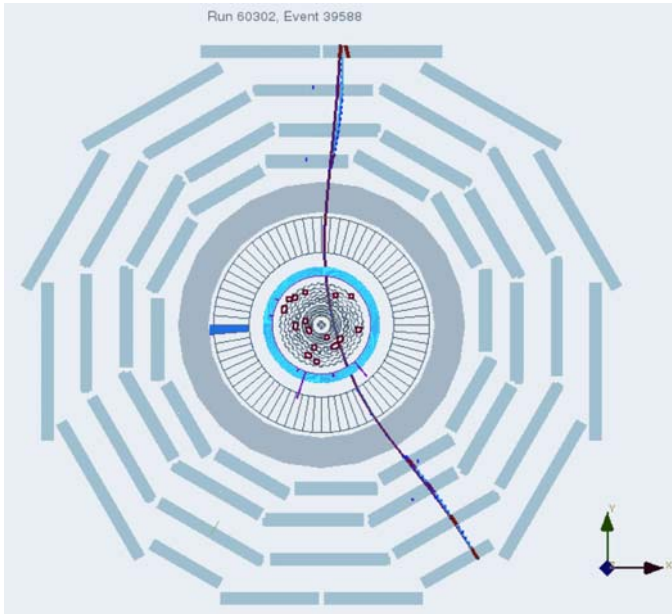


Figure 8: event display of a cosmic muon track triggered with DT and crossing both muon and inner-tracking sub-detectors. CMS magnetic field was set to 3 T for this run.

Using the Technical Trigger can be useful even during beam data-taking. By accepting all single chambers triggers the contribution expected at trigger rate from cosmic muons will be less than 300 Hz ( $\sim 260$  Hz has been measured in the last Global Run). At low luminosities the contribution due to muons produced in collisions will be still acceptable. For instance, when  $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$  the trigger rate obtained with a global OR of all single chamber triggers will be about 500 Hz. Such a rate will allow a data sample useful for DT synchronization to be taken in few hours.

## V. CONTROL SOFTWARE

During the SC commissioning, control software has been developed starting from the custom applications used during the system production and tests at the Bologna laboratory. Its major goal is to be integrated in the CMS software platform, properly designed in order to integrate all CMS trigger applications in a common framework.

The control software has to:

- Retrieve the hardware configuration parameters from database;
- Perform automatic power on of piggy boards;
- Load configuration parameters on hardware;
- Monitor hardware status (error flags, temperatures, current drawing...);
- Export monitored data to a “conditions” database;
- Provide user-friendly panels, showing system health.

The software has been implemented in the CMS Trigger Supervisor project **Error! Reference source not found.**: a common framework designed for set up, operate and monitor the CMS trigger devices and the information exchange with the CMS Run Control and the global monitoring system. It provides facilities for customizing single applications (called “cells”), their communications (via SOAP protocol), connections with databases and graphical user interfaces for managing cells via http client.

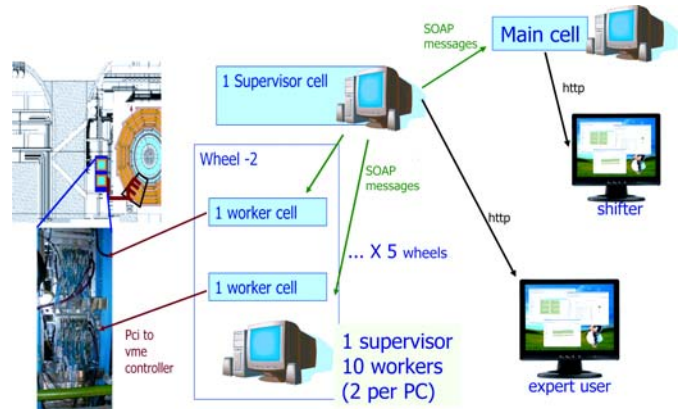


Figure 9: Overview of the implementation of the Control Software for the SC system.

The overview of the implementation of the SC control software within the trigger supervisor has shown in Figure 9. Modularity requirements led to a two layer system. One Supervisor cell acts as interface with the CMS central TS

application, as well as access point for any task performed by expert. Supervisor cell automatically manages 10 workers in parallel, each one performing hardware operations with a given VME crate.

As an example of the software performances, the configuration of the whole SC system takes  $\sim 30$  s from scratch (the so-called “cold start”, which needs all piggy boards to be powered on) and less than 1 s to only configure hardware (“warm start”).

Screenshot of one of the user-friendly panels implemented is shown in Figure 10, as seen from HTML browser. Information on the temperature sensors vs. time are provided with useful views (one panel per crate, one plot per board, one coloured tick per sensor).

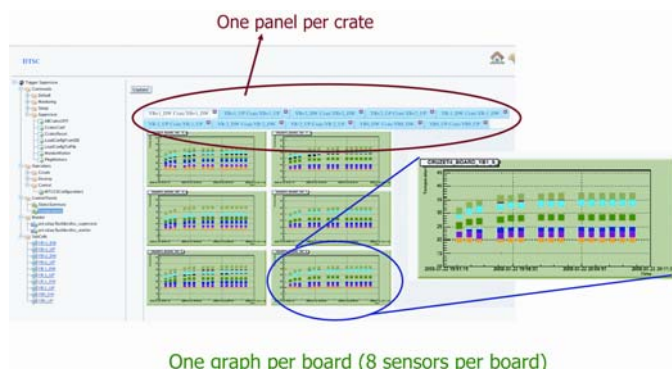


Figure 10: SC control software – screenshot showing panel for on-line temperature monitoring.

A similar panel is shown in Figure 11, where a summary of the status of all boards in the system is summarized. Faulty boards are represented with red boxes. Buttons in the top of the web-page are used to select hardware features to be checked against faults, in order to provide easy diagnostic.



Figure 11: SC control software – screenshot showing panel for on-line monitoring of board faults.

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