The Compact Muon Solenoid Experiment
Conference Report

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28 June 2010 (v3, 08 August 2010)

CMS Silicon Strip Tracker Monitoring

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Abstract

The CMS Silicon Strip Tracker is the largest detector of its kind ever operated, with a silicon surface area of about 200 m² of silicon surface. The Silicon Strip Tracker is the sub-detector with the highest number of detector modules within the CMS experiment.

Given the complexity of the device, a variety of tools were developed and are used to determine the status of the detector in real time and allow for data qualification and corrective actions when needed.

In this paper we describe the monitoring techniques that are used to safely operate the detector and assess the state of its calibration.

Presented at RT2010: 17th IEEE NPSS Real Time Conference

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I. INTRODUCTION

THE CMS experiment [1] at the LHC [2] features the largest Silicon Strip Tracker (SST) ever built, composed of 15148 detector modules with about 9.3 M readout channels. The detector is designed to endure more than 10 years of operations, without maintenance, as access conditions are extremely difficult. Such constraints on a large system, together with the need for high quality data, make real-time automatic analysis of the operational status mandatory.

Monitoring the commissioning and the data acquisition is a challenging task for which many applications were developed to improve safety, data quality, efficiency and optimization of the detector calibration.

II. SYSTEM ARCHITECTURE

The detector modules need to be programmed after each power-up to set their working parameters. The control signals are handled by 46 Front-End Controller [3] VME-9U boards sitting in the counting room, which communicate over optical fiber via 356 token-rings with the Communication and Control Units (CCU) [4] chips, deployed inside the detector. Each CCU controls from 3 to 15 detector modules.

The clock of the token ring protocol is locked to the LHC clock and the synchronous signals (like the trigger) are encoded in it as missing clock ticks. The clock is recovered at the modules with the use of PLLs [5].

At every trigger the strip signals are multiplexed by the front-end electronics and the analogue signal is transmitted by Linear Laser Driver (LLD) [6] via 36392 optical fibers [7] to the far-end readout ADCs hosted by 440 Front End Drivers (FED) [8] VME-9U boards in the counting room.

During normal data taking the FEDs communicate via SLINK-64 with the central CMS data acquisition system [9], where the event building and filtering is performed. This allows the transmission of events at rates up to approximately

140 kHz. Data can alternatively be read out via VME, for detector commissioning and calibration. The event readout rate is limited to approximately 10 Hz in this case.

The power supply to the control units and modules and the high voltage for the silicon sensors is provided by approximately 4000 power supply channels via lines controlled by sense wires, which also carry the connection for environmental hard-wired probes deployed inside the detector. The Detector Control system records the functional parameters of the Power Supply System, reads the environmental probes and handles the detector safety.

All the applications handling this system use the same database infrastructure to archive the configuration parameters, environmental probe measurements, etc.

III. DETECTOR CONTROL AND SAFETY SYSTEMS

Detector safety is the primary concern during operations and is taken care of by the Detector Safety System (DSS) [10], which is completely stand-alone. It is based on 9 PLC systems reading the environmental data in real time and handling hardware interlocks. The DSS analyzes about 1000 hard-wired probes monitoring temperature and humidity and reacts in real time against possible overheating or condensation.

In order to reduce the detector dead time it is necessary to efficiently report the detector status to the operators and also activate an automatic error recovery system whenever this is possible and safe.

Both these tasks are taken care of by the Detector Control System (DCS). This controls the power supply systems in a hierarchical finite state machine, collects and displays more than 1 million operating parameters and also provides display for the auxiliary services (cooling plant, dry gas, thermal screen). In case the conditions of the system approach the pre-defined safety margins, the DCS will fire software interlocks, turning off the small subset of power supplies where the problem occurred before an DSS interlock would intervene, resulting in a wider power cut.

The detector modules contain chips that monitor voltages and some temperature probes. These are read by the FEC through the “slow control”. A dedicated data stream provides a sampling of these values every 2 minutes to the control system, which integrates this information with the hard-wired probes to provide a more detailed monitoring.

The control software is implemented in the PVSS environment. It is based on a finite state machine with around 3000 nodes arranged in 140 basic units in a tiered structure matching the hardware and is distributed across 11 PCs. The system works in the CMS protected network, which can be accessed only with authentication. A graphical user interface allows access to details from every single channel and measurement

Fig. 1. The DCS GUI allows access to details from every single channel and measurement withing a few clicks from the main panel. It reports the status of the subsystems and the functional status of the control system itself.

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IV. SYSTEM COMMISSIONING AND CALIBRATION

In order to bring the SST into an operational state, a number of parameters must be set, both in the detector devices and in the readout electronics. Tuning these parameters is commonly referred to as *commissioning*.

The SST was commissioned for the first time in June-July 2008, and completely re-commissioned in 2009 to allow for the re-calibration after the working temperature of the cooling system was moved from 11 °C to 4 °C.

The first step of commissioning allows the relative synchronization of all channels by adjusting the phase of the LHC clock delivered to the front-ends by programming the PLL delays. This is important because signal amplitude is attenuated by as much as 4% per nanosecond of mis-synchronization. With this procedure the timing spread was reduced to an RMS of 0.7 ns [11].

The readout is also calibrated by measuring the optical line gains and tuning the LLD amplification for individual fibers, to optimize the use of the FED ADCs. Additionally a software calibration is obtained by using the nominal correspondence of a tick mark to a charge deposit of 175 000 e^- . The estimated systematic uncertainty is 5%, attributable to the sensitivity of the tick mark amplitude to variations in the LV power supply and environmental temperature [12].

The signal baseline and the shape of the CR-RC pulse from the APV25 [13] pre-amplifier and shaper are also tuned to compensate for non-uniformities in the fabrication process and environmental conditions (and later on also irradiation).

Finally, the timing of the trigger was also adjusted to be synchronous with the passage of the particles, with a precision of approximately 1 ns.

On top of that, prior to any data taking and also periodically, the baseline and noise of each channel is measured with a dedicated procedure, and this information is passed to the

Fig. 2. Distribution of the link gain measured with the calibration signal amplitude, after the proper gain setting was chosen for each laser. A very small fraction of the links ($\sim 0.16\%$) are out the nominal range.

FEDs to tune their zero-suppression algorithm. The channel gain measurement is also performed periodically, to monitor for possible variations. Figure 2 shows, for example, the distribution of the measured optical line gains after the LLD tuning was performed.

There are 8 main setting parameters and a number of control variables per module, resulting in about 200,000 parameters that must be checked for the control system. The noise distribution is also analyzed for each of the 9 million channels to check for non-Gaussian tails. All these parameters are computed with a dedicated system [14] and can be visualized through an interactive GUI, which also allows parameters to be correlated, selection criteria for problematic elements to be graphically defined and information relating to them to be properly logged.

V. DAQ SYSTEM MONITORING

The SST DAQ system is distributed across 36 controlling PCs and is implemented in C++ using the CMS framework: XDAQ. This system is continuously monitored during operations in order to identify possible system failures.

Each PC can run one or more applications to control FECs, FEDs, retrieve the configuration parameters from the database, store the local data, etc. Every application implements a message sender class which allows prioritized messages (qualified as DEBUG, INFO, WARN, ERROR, FATAL) to be posted via TCP/IP to a special error message collector application. The messages contain a code to identify the sender, the nature of the message, the hardware part to which it is related and a verbal description. These messages are collected in a local file, stored to database, grouped by source and displayed online through an AJAX web interface. The latency of this system varies with the load of messages, and is typically of the order of few seconds. This allows the identification in real

time of any single problem (most typically the interruption of communications with a device) and intervene in case of problems, reducing the dead time. It is also used to later perform a statistical analysis of the collected errors.

During data taking a number of monitoring elements are also recorded to the database (time needed for configuration, errors, temperatures, etc...) and periodically harvested. These periodic checks allow the stability of the whole system to be assessed.

VI. SPY CHANNEL

In the normal data taking scheme the VME bus for the FED is only used to configure the boards, mainly programming each channel's baseline and noise values and the thresholds to identify an incoming data packet. The zero-suppressed data are sent to the central DAQ via the SLINK-64 bus. The commissioning runs, nevertheless, are recorded reading out the data via the VME bus: this way the event building process can entirely be handled within the cluster of nodes assigned to the SST, without (otherwise massively) interfering with the CMS central DAQ [14].

The VME readout mechanism can also be used during normal operations, in parallel with the standard readout, in order to monitor the actual data stream read by the FED boards, after the digitization. This is called the *spy channel*. For each incoming data packet the raw data are available inside the FED FPGAs, but are normally discarded after the data has been re-packed (see Figure 3). Along with the clock line a pre-arm synchronous signal can be sent that triggers the copy of the data corresponding to the next trigger in the front-end buffers into a reserved area in the FEDs' memory. This signal is not sent again until the whole triggered event is readout through the VME bus and stored. This mechanism allows unobtrusive access to the front-end raw data stream during physics runs, retaining event synchronicity, even though an event rate of ~ 1 Hz is only possible.

By properly programming the pre-arm phase with respect to the LHC orbit cycle, it is possible to capture either physics triggers or events with guaranteed no collisions. This is useful to calibrate the SST performance under nominal operation conditions, with and without collision data, monitor how calibration constants change with time, trigger rate temperature and also to validate and evaluate the performance of FED noise suppression algorithms.

This system is currently in place during standard operations, and is used to validate the front-end data handling. It can also be used to monitor in real time variations in the signal gain and channels' pedestal and noise, thus reducing the need of periodic dedicated maintenance operations and increasing dramatically the frequency of monitoring for these quantities.

VII. DATA QUALITY MONITORING

The Data Quality Monitoring (DQM) in CMS is performed in a coherent way throughout the subsystems, within the standard analysis software framework.

Each subsystem can define its own monitoring elements, which are computed on-line (on a fraction of the events)

Fig. 3. Raw data as seen by the spy channel: the full data frame is available, allowing to measure each channel's baseline and noise, as well as the signal response prior to the zero-suppression. The link gain can be measured by the digital header amplitude.

Fig. 4. Signal/Noise distribution for clusters correlated to a track in the Inner Barrel $300 \mu\text{m}$ -thick detectors. Each cluster charge was rescaled to the perpendicular incidence angle equivalent, using the track's information.

and off-line on the whole collected dataset. The monitoring elements (which are typically 1-dimensional or 2-dimensional plots) are built using the quantities derived by the standard CMS reconstruction (such as tracks, the associated hits, the released charge, etc.). Some examples are the distribution of the signal amplitude for hits associated to a track (shown in Figure 4), the number of tracks found per event and their polar and azimuthal distributions.

While the data taking is ongoing the updated histograms are displayed through a common web interface, and can also be automatically checked against some reference plots representing "normal" data taking conditions.

In order to cope with the high granularity of the SST the monitoring histograms are computed also for small segments of the detector, leading to the definition of approximately 300 000 detailed histograms and some SST-specific tools to display the information (more details can be found elsewhere [15], [16]).

The fast feedback available through the on-line DQM allows prompt triggering of actions to aimed to recover the detector functional status as soon as possible, thus increasing the

Fig. 5. Example of a monitoring implemented: the on-module delay chip settings are analyzed. A simple linear dependence is expected and fitted. The residuals of this fit are shown to the user. An automatic cut identifies the outliers (marked red/dark here). The list of IDs of the suspect modules is also provided.

data taking efficiency and quality. The thorough data sample analysis performed off-line, is used to perform data quality certification.

VIII. WEB DATABASE INTERFACE

Most applications use the database as a back-end: it records all the parameters monitored by the DCS (after the small dead-band oscillations are filtered out), the SST configuration parameters, the results of the calibration analyzes, etc.

During the initial phase of SST operations it was clear that a number of monitoring operations would have been frequently repeated and that the monitoring items would have evolved together with the experience of operations. It was thus felt there was a need for a simple tool for the data retrieval and display (and simple analysis) which also allows the creation of new analysis templates with minimal effort. For this purpose a web applications was designed and implemented using the AJAX technique called WBMTools.

On the user side this appears as a list of monitoring pages. Each one is linked to a database query, where the user can change predefined parameters (like the period of time under analysis), and to a ROOT macro, which analyzes the query results and outputs an arbitrary number of plots and tables to the web interface (see Figure 5).

On the developer's side (which can be restricted for safety), the web interface allows the query and the input parameters to be defined and automatically creates the skeleton ROOT macro to analyze the result, leaving to the developer the task of defining and filling the desired histograms and plots.

This tool reduces the length of the development cycle with respect to the available alternatives and widens the potential pool of template developers. To the date more than 40 monitoring tasks are performed within this framework.

IX. CONCLUSIONS

For all the individual sources of information a clear set of monitorable elements was identified and is periodically checked. Some elements are verified for each data taking run, such as those computed within the Data Quality monitoring, the error messages produced by the DAQ and the functional status of the services reported by the DCS together with the main environmental information. Some other elements are collected through the web database interface and other similar tools. The results are checked daily or weekly and their implications are reported to the SST community, which can take informed decisions on the actions needed, if this is the case.

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