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# Infrastructures and Monitoring of the on-line CMS computing centre

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## Abstract

This paper describes in detail the infrastructure and installation of the CMS on-line computing centre (CMSOLC) and its associated monitoring system. In summer 2007, 640 PCs acting as detector Read-out Units for the CMS Data Acquisition System (DAQ) were deployed along with 150 servers for DAQ general services. Since summer 2008, 900 PCs acting as DAQ Event Builder Units/Filter Units have been added and today, the CMSOLC has an on-line processing capability sufficient for a Level 1 trigger accept rate of 50 kHz. To ensure that these 1700 PCs are running efficiently, a multi-level monitoring system has been put in place. This system is also described in this paper.

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# I. INTRODUCTION

The Compact Muon Solenoid (CMS) experiment [1] at CERN's Large Hadron Collider (LHC) will search for new physics at the TeV scale such as the Higgs mechanism or Super-Symmetry. At its design luminosity of $10^{34}$ $cm^{-2}s^{-1}$ the LHC will provide proton-proton collisions at a centre-of-mass energy of 14 TeV with a bunch crossing frequency of 40 MHz. Each bunch crossing will give rise to about 20 inelastic collisions in which new particles may be created. Decay products of these particles are recorded by the sub-detector systems of CMS comprising on the order of $10^8$ readout channels. After zero-suppression, the total event size per bunch crossing is expected to be on average 1 MB. A highly selective online-selection process accepts on the order of $10^2$ events per second to be stored for offline analysis.

In CMS, this selection process consists of only two levels. The first level, the Level-1 Trigger [2] that is a dedicated system of custom-built pipelined electronics, reconstructs trigger objects (e.g. muons, electrons/photons, jets) from coarsely segmented data of the muon and calorimeter sub-detectors. Based on concurrent trigger algorithms which include cuts on transverse momentum, energy and event topology, it accepts interesting events at an average maximum rate of 100 kHz (minimum rejection ratio 1:400 bunch crossings).

All further steps of on-line event processing including the read-out, data transport to the surface and event-building at an aggregate data rate of 100 GB/s, high level trigger processing and data storage are handled by the CMS Data Acquisition (DAQ) System [3]. The $\sim 10^8$ readout channels are grouped into approximately 650 data sources by the Front-End Driver (FED) electronics. Full event data are buffered during the 3 µs latency of the Level-1 Trigger and pushed into the DAQ System upon a Level-1 accept. The event building process is implemented with a two-stage event building architecture [3]. The fully assembled events are passed to the filter farm which executes the high-level trigger decision based on reconstruction algorithms similar to the full off-line reconstruction. The rejection factor achieved by the filter farm is about 1:1000. Hence, about 100 events per second are sent to the central storage system in the Meyrin computer centre.

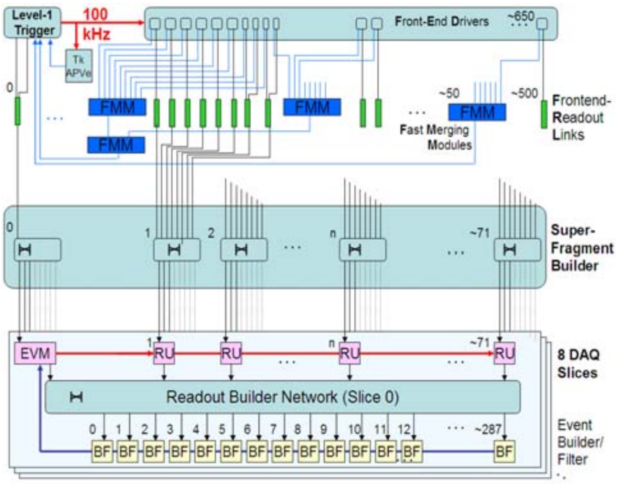


Figure 1: CMS DAQ block diagram

# II. CMS DAQ INFRASTRUCTURES

## A. *Civil engineering and racks*

The DAQ building on the CMS experimental site contains the general detector control room, the DAQ farm control room, a sub-detector control room, a conference room and the DAQ farm itself. Everything but the farm is located on the ground floor. The farm occupies the whole of the second floor (See figure 2).

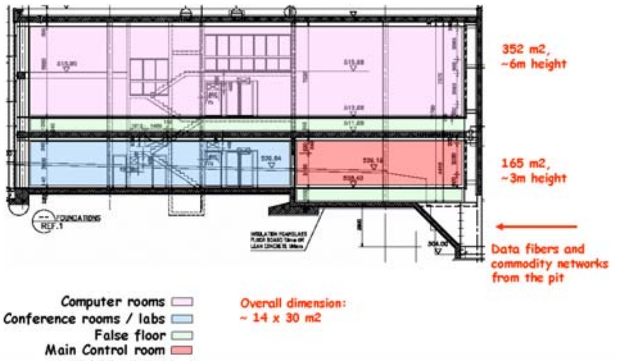


Figure 2: CMS DAQ building at experimental site

The computer room features a 1m deep false floor and has a total capacity of 180 racks for a maximum power dissipation of 800 kW. Currently 106 racks are installed which corresponds to a data processing capacity of a 50 kHz trigger rate. The remaining half will be equipped as the luminosity of the LHC ramps up. Nevertheless, the entire plumbing infrastructure has been installed for the full 100 kHz system.

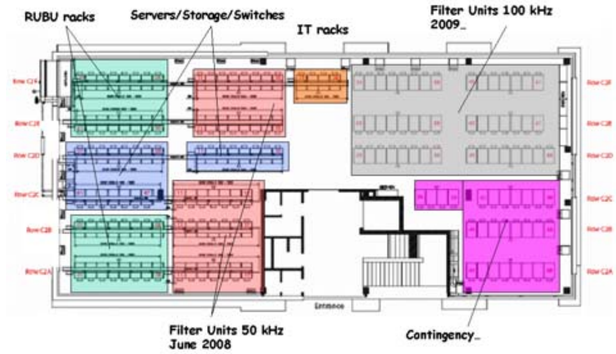


Figure 3: Rack layout in CMS computer room

In 2003, the total number of servers and their projected power consumption was estimated at ~140 racks and ~750 kW of dissipated power. The power density in the room is about 2 kW/m2 and depending of the PC type (readout unit or builder/filter unit), the power per rack ranges from 4 kW to 10 kW. Given such high power densities, custom designed water-cooled racks were chosen to remove the heat load from the servers.

After preliminary studies carried out within the "LHC PC Rack Cooling Project" [4], CMS purchased about 150 water cooled PC racks from CIAT [5] with the following features:

- 47 U high, 19 inch mounting standard
- 44 U usable internal space

- 60 cm x 90 cm footprint, 106 cm total depth
- 10 kW thermal capacity
- 2 $m^3$/h water flow, $\Delta T$ 4 °C.
- 3 fans, 2450 $m^3$/h air flow, front to back

To maintain a very low cost, minimal monitoring capabilities are implemented at the rack level comprising a fan failure signal per fan and a thermostat with a threshold at 40 °C.

The racks are arranged in group of 8 (7 when pillars were present) and placed according to the hot/cold aisle principle. Although this arrangement is not needed for cooling efficiency, it is practical for human access to the front faces of the PCs without being subjected to cold air blasts. The distance between rows of racks is 1.50 m front to front and 1 m back to back (see figure 3).

### *B. Cooling water and electrical power*

A cold water plant located next to the building provides the cold water for the racks. With the nominal inlet water temperature being 14 °C, it is important to control the air humidity in order to avoid condensation. Therefore, a 100 kW air conditioning unit is connected to the computer room in order to absorb daily heat fluctuations and control the air humidity, hence maintaining the air dew point below 12 °C.

The power distribution relies on a Canalis system feeding from the top each group of 8 or 7 racks. A Canalis power bar brings a maximum of 64 Amps on 4 phases in each rack for a maximum power of 14 kW. Each phase is equipped by a D-type breaker of 16 amps. For each phase there is a 10 outlet power distributor including a sequencer on 3 groups of outlets with a 200 ms delay between groups to prevent the phase breaker from tripping due to the inrush current when all servers are switched on at the same time.

### *C. Fire safety*

Eight smoke detection devices are installed in the room. The smoke input pipes are located above the racks at the air exhaust. If smoke is detected in the room, electrical power is cut and a water mist system from Marioff called HI-FOG [6] can be automatically activated. HI-FOG is a fire protection technology utilising high pressure to produce a fine water mist with average drop size of 50 - 120 µm, combining the extinguishing characteristics of water with the penetrative qualities of gases with no danger to people or the environment. Specific tests have been carried out and showed that running computers are not damaged and continue to perform their tasks when exposed to water mist.

### *D. Networks*

The different communication networks are laid in cable trays beneath the false floor. The cable trays are organized in three layers of 40 x 10 $cm^2$. The main networks are:

- The optical Myrinet switch-Readout Units (RU) network. This network distributes the data coming from the underground counting rooms to the RU machines

- The service network (copper). This network is used to access the machines for maintenance and monitoring purposes. For example, the IPMI (Intelligent Platform Management Interface) temperature monitoring process runs over this network.

- The data network (copper). This network is used to exchange data packets during the event building process between the RUs and the Builder Units/Filter Units (BU/FUs).

Exhaustive information about the network topology can be found in [7].

## III. CMS DAQ HARDWARE MONITORING

To ensure that the servers perform their tasks according to expectations, the environmental conditions and the servers themselves must be monitored.

### *E. Physical parameters monitoring*

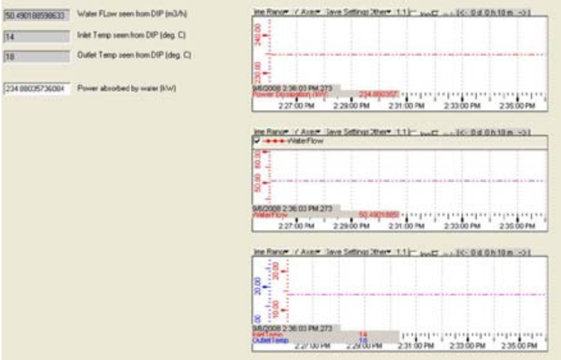
Physical parameters are monitored at the room level and at the server level giving detailed information about the operating parameters.

At the room level, the monitored values are the following:

- Temperature
- Relative humidity
- Inlet water temperature
- Outlet water temperature
- Water flow

Those values are provided by the air conditioning system and the cold water plant through DIP (Data Interchange Protocol)[8] which is a communication protocol developed at CERN that allows relatively small amounts of soft real-time data to be exchanged between very loosely coupled heterogeneous systems. Very low latency is not required for the monitoring of these systems. The data is assumed to be mostly summarised data rather than low-level parameters from the individual systems, e.g. cooling plant status rather than the opening level of a particular valve.

PVSS [9] applications have been developed in order to monitor the room level values as provided by the water plant and air conditioning unit. If any if these values are not within nominal ranges, an alarm notifies the DAQ group of the problem. A month history is stored in order to make correlations with other events if necessary. (See figure 4).



50.490188598633 Water FLow seen from DIP (m3/h)
14 Inlet Temp seen from DIP (deg. C)
18 Outlet Temp seen from DIP (deg. C)
234.880035736084 Power absorbed by water (kW)

Figure 4: PVSS panel for cooling water monitoring

The next level of monitoring for the physical parameters takes place inside the servers. The temperatures, voltages and fan rotation are monitored by the server sensors through IPMI [10]. The IPMI specification defines a set of common interfaces to a computer system which can be used to monitor system health and manage the system. IPMI operates independently of the operating system (OS) and allows administrators to manage or monitor a system remotely even in the absence of the OS. IPMI is functional even if the monitored system is not powered on. Alarms are triggered when the monitored parameters are out of nominal range and the parameter history is available.

In nominal cooling conditions, the internal temperature of the machines is close to 20 °C. In the case of cold water service interruption, the server internal temperature will start to rise. When it reaches 27 °C, a warning is issued on the server console. When it reaches 30 °C for RUs and BUFUs (called hereafter the soldiers) and 33 °C for the general services servers, a daemon, which checks the temperature every 5 minutes, powers off the machine in a graceful way. If all protection mechanisms failed, a hardware thermostat cuts the power supply at the Canalys level when rack internal temperature is above 40 °C. The different temperature thresholds for soldiers and servers are there to give priority to the servers over the soldiers. With the soldiers shut down, the room temperature ceases to rise, hence keeping the important servers on-line.

A latency of ~30-45 minutes has been observed between the cold water service interruption and first soldier graceful shutdowns. Up to now, graceful shutdowns of servers have never been observed.

As mentioned above, IPMI is used to retrieve the internal temperatures, voltages and fan speed. The IPMI module collects also warning and error messages generated by the system itself. For example, if the memory failed to correct an access error, a message will be logged and be available through the IPMI port. These kinds of messages allow problems to be discovered at an early stage. Every hour, a script reads new messages and stores them in the maintenance database.

### *F. Services monitoring*

Monitoring the physical parameters of servers is necessary but not sufficient to ensure that the machines are performing as expected. The services must also be monitored by dedicated tools. Nagios [11] has been chosen to perform the service monitoring. Nagios is a system and network monitoring application. It watches hosts and services defined by the user and sends alerts when things go bad and when they get better. Nagios has built-in modules for monitoring things like network services (SMTP, POP3, HTTP, NNTP, PING, etc.) or host resources (processor load, disk usage, etc.) A simple plug-in design allows users to easily develop their own service checks for specific needs. Depending on the server function, different sets of tests have been implemented. Amongst them are:

- Check if IPMI is accessible remotely
- Check if JOBCONTROL is running. This application is needed to integrate the server in the data taking process.
- Check if Kerberos authentication is working
- Check if the machine is reachable via Ping
- Check if Secure Shell (SSH) is running
- Check if SLP (Service locator protocol) is running.
- Check installation - if the Quattor (a CERN specific system administrative tool) [12] installations have completed successfully
- Check CPU load
- Check free space on disk partitions
- Check total number of running processes
- Check number of users logged-in
- Check if zombie processes are present

When a problem is detected by Nagios, system administrators are notified and corrective actions are scheduled.

### *G. Hardware maintenance tracking*

The total number of machines installed up to now is close to 2000, including the machines located in the underground counting rooms, and this number will grow along with LHC luminosity. We expect a total of 3000 machines in the near future. Given this considerable number, a database has been implemented to store the characteristics of each machine (i.e. serial number, physical location, system name, Network hardware addresses, interfaces, warranty duration, etc) and all warning/error messages collected through IPMI every hour. The user interface of the database allows the display of the last warning/error messages and related machine maintenance history. This database is also used to store hardware changes (e.g. change of location) and track the hardware interventions on the machines. Summaries and statistics can be made through the user interface.

### *H. What next?*

As already mentioned above, the next important milestone is to complete the CMS on-line computing facilities and reach the processing power needed to filter 100 kHz of Level 1 trigger rate. Before launching the tender for these additional filter units, some infrastructure must be completed: the false floor modification for one meter deep racks and the purchase and installation of new water-cooled racks with a thermal capacity of 16-18 kW. This increased thermal capacity is required for housing the next generation of multi-core multi-processor machines. These steps are scheduled for the beginning of 2009.

Regarding the computing services monitoring, the target is to continue to develop and customize existing management tools and integrate them into a single user interface that will be used for the different actions performed on a machine in the computing centre:

- Creation of a new machine or replacement of an existing machine.
- Operating system and software deployment and update
- Monitoring of the behaviour of the machine, and if needed automatic notifications of hardware or software problems
- Maintenance actions tracking
- Summaries and statistics production

## IV. SUMMARY

The on-line CMS computing centre, located at the surface of the experimental site, performs the event assembly (640 event fragments produced by the detector are assembled into a single event of ~1MB) and subsequently, executes the high level trigger algorithms (HLTs) in order to select the events to be stored for later off-line analysis.

The heavy infrastructures (false floor, water ducts, racks, power rails) were installed in 2005 and 2006. The cabling for the first batch of 800 servers (event builder PCs) started early 2007. The event builder PCs have been installed and commissioned in summer 2007. They are acting also as event filters as long as the data volume does not require dedicated PCs to run the HLT algorithms. About 900 servers for on-line event filtering have been installed this summer in view of the LHC start-up. Installation of an additional 1000 servers is foreseen for 2009 to reach the full processing power.

There is a three level monitoring system for all the machines: the first level is dealing with physical parameters (voltages, temperatures, fans) and maintenance/repair actions. The second level is monitoring the services provided by each server (ssh, tcp, presence of drivers, etc). The third level is looking at the application performances. Data retrieved by the three levels of monitoring are stored in a database.

## V. REFERENCES

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