The Compact Muon Solenoid Experiment
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Emulating the Level-1 Electromagnetic Trigger Response Using an Offline Database. Procedure for Populating This Database from the Online Information.

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The configuration of the electromagnetic hardware trigger requires 5 million parameters stored into an Online Master Data Storage database (OMDS). This poster will present the procedure used to transfer the parameters from the OMDS to the Offline database which is used to perform the validation tests with the Level-1 Trigger emulator.

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Emulating the Level-1 Electromagnetic Trigger Response Using an Offline Database. Procedure for Populating This Database from the Online Information.

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Abstract—The Level-1 Trigger plays a major role in the CMS experiment allowing the reduction of the raw event rate at the Large Hadron Collider. Its decision is based on information from the electromagnetic and hadronic calorimeters as well as the muon detectors. The electronics of the electromagnetic calorimeter generate and deliver basic quantities called “Trigger Primitives” which correspond to local energy deposits created by electromagnetic showers. In order to ensure the correct generation of the trigger primitives by the electronics, special software called an emulator has been implemented. It is able to reproduce the ECAL trigger functionalities at the bit level using the same inputs and identical output format. It is configured in exactly the same way as the hardware.

The configuration of the electromagnetic hardware trigger requires 5 million parameters stored into an Online Master Data Storage (OMDS) database. This paper will present the procedure used to transfer the parameters from the OMDS to the Offline database, which is used to perform the validation test with the Level-1 Trigger emulator.

I. INTRODUCTION

THE Compact Muon Solenoid (CMS) [1] is one of the four large detectors installed at the Large Hadron Collider (LHC) of the European Organization for Nuclear Research in Geneva. The LHC is a proton-proton collider with a nominal beam energy of 7 TeV and the design luminosity $L = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$. Its principal goal is to elucidate the nature of electroweak symmetry breaking for which the Higgs mechanism is presumed to be responsible [2].

The CMS detector was designed to be sensitive to the proposed energy scale at the LHC and to observe the cocktail of particles produced during the collisions by covering a large area around the interaction point and incorporating multiple types of sub-detectors. The different parts of CMS: tracker,

muon detector, electromagnetic (ECAL) and hadron (HCAL) calorimeters were designed with specific purposes and have the capability of isolating and reconstructing the interesting events. The selection of the interesting events is managed by the CMS trigger system composed of Level-1 (L1) and High Level (HLT) trigger stages. The L1 trigger uses information from the ECAL, HCAL and the muon detector.

The ECAL [3], [4] is a hermetic, homogeneous calorimeter comprising 61200 lead tungstate (PbWO_4) crystals mounted in the central barrel part, closed by 7324 crystals in each of the two endcaps. It has been optimized for the observation of the Higgs boson in its two photons decay mode.

After presenting briefly the CMS trigger system and in particular the ECAL trigger system we will focus on the ECAL trigger emulator and its configuration from the database. This last process includes the Online to Offline transfer from the Online database into the Offline database and allows the configuration of the ECAL trigger electronics and its emulator using the same consistent set of condition data.

II. CMS TRIGGER SYSTEM

The CMS trigger system is organized in two basic levels: L1 trigger and HLT. The L1 trigger [5] consists of custom developed and largely programmable electronics. It includes three main parts: the muon trigger, the calorimeter (ECAL and HCAL) trigger and the global trigger. Each of these triggers plays a specific role for identifying the detected particles (up to 4 isolated or non-isolated electromagnetic objects, electrons or photons, 4 tau-jets, 4 central or forward jets) and for providing the total transverse energy and the missing transverse energy. The L1 trigger reduces the rate of accepted crossings to below 100 kHz.

The HLT is a large computer farm [6] running programs developed within the CMS software framework. It performs the event selection by applying a set of filters in progressive stages.

While the L1 trigger is making its decision, the full high-precision data of all detector channels are stored in the detector front-end buffers, which are only read out if the event is accepted. All the events accepted by the L1 are sent to HLT that decreases the event rate to the order of 100 Hz.

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III. ECAL TRIGGER PRIMITIVES

The main role of the ECAL part of the L1 trigger electronics is to produce the trigger primitives (TPs) involved in the identification of the electromagnetic showers. The TPs are computed for each bunch crossing and for each ECAL trigger tower (TT) by the On-Detector electronics, the Front End Card [7]-[9]. Then they are integrated with the detector readout and Off-Detector electronics, the Trigger Concentrator Card [10] (TCC), located in the electronics cavern. They include basic quantities like the transverse energy, the information about the compactness and the time of the creation of the electromagnetic shower, and the trigger tower flag. The ECAL trigger primitive algorithm [11] applied for the calculation of these quantities takes as input the digital signals from 5 crystals grouped together in an entity, called a “strip”. Each of the 5 signals of one strip are linearized and summed in order to produce the strip signal. A filter is then applied to measure its amplitude and finally only the maximum is kept. The signals of the 5 strips of one tower are summed to obtain the total transverse energy by trigger tower.

The algorithms for the barrel and the endcap parts are different. Indeed, the ECAL barrel and endcap crystals are not organized in the same way. Due to geometrical considerations in the detector, the signals must be managed differently for the barrel and the endcaps. For the barrel, the front-end card produces, for each trigger tower, one signal for each strip. Then the 5 strip signals are summed to produce one signal per TT that is sent to the TCC. In the endcap case, the strip signal is given directly to the TCC.

The different processes in the algorithms use parameters like the gain and linearization constants, the weight values needed in the filter, and the look-up table used to reduce the dynamic range of the transverse energy from 10 to 8 bits. There are 14 types of parameters (related to the crystals, strips or trigger towers). In total, we obtain around 5 million parameters depending on the detector configuration. Some of these parameters, like the pedestals, will be changed on a daily or weekly basis, the calibrations will be changed on a monthly basis, the bad towers on a weekly basis, and the rest of the parameters will probably remain unchanged. The parameters used for the hardware configuration are stored in the CMS Online database.

IV. ECAL TRIGGER EMULATOR

A. Presentation

The ECAL trigger emulator is a simulation program written in C++ and integrated into the CMS software framework (CMSSW). It reproduces at the bit level the generation of the trigger primitives by the ECAL trigger electronics. The main role of the emulator is to simulate the trigger response and to validate the trigger operation by comparing the simulated and generated trigger primitives.

In order to be modular and closer to the electronics, the emulator’s code is organized in two parts: a framework and a set of algorithms, different for the barrel and the endcap parts.

As with the electronics, the emulator gets as input the digitized data coming from the front-end electronics (Fig. 1), processes it using the algorithms, and produces trigger primitives. The software algorithms (linearization, summation of the linearized signals to obtain the strip pulse, peak finding, formatting the transverse energy) correspond to the algorithms used in the electronics and presented in section III of this paper.

Fig. 1. Comparison between the trigger primitives generated by the electronics, and those calculated by the emulator.

The commissioning of the TPs was done with cosmic ray events. This was considered to be a “severe test of the ECAL trigger” [11]. It consists of comparing the electronics and emulated TPs. The standard plots produced by the ECAL data quality monitoring (DQM) consist of separate (ϕ, η) matrices for the barrel and for the endcap parts (see Fig. 2). The TPs are compared for each trigger tower, and, if they match, the corresponding TT is marked in green on the ϕ - η plot. The hatched zones correspond to masked trigger towers.

The same procedure of comparing the electronics and

Fig. 2 Map of the ECAL barrel showing the comparison between the hardware response and simulated trigger primitives. The green color indicates a perfect match. The cross-hatched areas show the masked trigger towers.

emulated TPs has been used since the start of data taking at the LHC. The standard plot for these data is shown in Fig. 2.

B. Configuration from the Offline Database

The calculation of the ECAL trigger primitives needs a total of around 5 million parameters that make the use of the database mandatory. The use of the database will allow the

parameters for each run to be accessible even after the run is finished. This is also a more robust and safer way to store the parameters compared to the previously used ASCII file.

The parameters needed for the configuration of the ECAL hardware are stored in the Online Master Data Storage database (OMDS). The Ecal Supervisor reads these values, configures the hardware, and logs into the OMDS which configuration was used. Data are written in the OMDS via CMSSW C++ libraries and transferred to the Offline database

Fig. 3. The Ecal Trigger workflow.

via an Online to Offline process (O2O). The ECAL trigger emulator is then configured from the Offline database using the same set of parameters as the ECAL trigger electronics (Fig. 3). This eliminates difficulties in comparing the emulator and the ECAL trigger primitives by ensuring that the emulator and the hardware were configured in the same way [12].

We will present now in more detail the ECAL part of the OMDS and the Offline database, as well the O2O jobs.

V. ONLINE TO OFFLINE TRANSFER PROCEDURE

All the calibrations and conditions data needed to configure the detectors as well as for different validation and analysis procedures are stored in the CMS databases. There were two major requirements that constrained the model of the condition databases' architecture. The first one was the need to allow the CMS experiment to work autonomously without any network connection to the outside world. This required developing an independent database at the CMS experiment location P5. The second was the need to have a database format compatible with the condition data from the CMS

software. Figure 4 presents the CMS database design corresponding to all these requirements.

The online database, OMDS, contains the relational tables. There are two offline databases: ORCON (Offline ReConstruction Online subset) installed at the online network and ORCOFF (Offline ReConstruction Offline subset) situated at the CERN Tier-0 Meyrin site. ORCOFF is the offline master database optimized for the offline usage [2]. ORCON is identical to ORCOFF and is used for the offline needs within the online network. The condition data are transferred from OMDS to ORCON by the O2O procedure, and then the data are streamed automatically to ORCOFF.

A. Online Master Data Base

The Online Master Data Storage database contains the configurations and conditions data. The part of OMDS that contains the configuration parameters is divided into three parts: the run configuration database, the front-end configuration database and the Trigger Configuration database. We will present the trigger configuration database.

The trigger configuration database has a main table that contains a label specific to each object, called the **TAG**, and an associated number, called the **VERSION**. It also contains a list of all the keys used to configure the specific ECAL trigger objects: pedestals, LUT, linearization coefficients, weights, bad trigger towers, and bad crystals. The time at which a configuration is inserted into this table is automatically logged by the database. It is also possible to enter a description of the information in this table.

Each object in the trigger configuration database that has been mentioned above has an "info table" and a "data table". The info table is used in the browser to give information to the experts about what this object represents and when it was written. The data table contains the parameters.

More complex objects like the weights or the LUT have a third table, called a "group table". These objects may all have the same value for each crystal or may have different values for each strip. In order to manage these values, they are saved by group. One table shows the group each strip belongs to and another table contains the data for each group.

The trigger configurations are filled by the trigger experts using the C++ libraries to read the most recent pedestals taken and the most recent calibrations available. The bad trigger towers and bad crystals are written in an xml file. They are loaded in the database via an XML parser that calls the same C++ libraries. A special editor allowing a visual masking of the noisy towers was developed, as well as a similar configuration editor for the trigger configuration database.

The trigger configuration database is read by the Ecal Trigger Supervisor via a set of Adapters that make use of the TStore libraries [5]. The Ecal software has wrapped these libraries in order to have a cache mechanism and be faster at configuration time.

The OMDS includes also a Condition database that contains all the information about the ECAL status and calibrations

Fig. 4. CMS condition databases architecture.

when taking data in CMS. The condition data are written periodically into the condition database.

B. Offline Data Base

The Offline database is used by the CMS simulation and offline reconstruction programs. While in the Online database complete freedom was left to the various sub-detectors to design the specific database schema in order to optimize the various applications for fast reading when configuring the CMS experiment electronics, in the Offline database design a different method has been adopted. In fact, since the beginning, a common approach for all the sub-detectors has been adopted in order to ensure portability and simple maintenance.

The CMS experiment uses POOL-ORA [13] libraries to write the objects into the Offline database. These libraries allow the reading of the database in the C++ CMSSW environment as if they were objects. The use of a common approach for the Offline database and the decision to transfer to the Offline database only the objects that are useful for the simulation and the offline reconstruction has been a winning strategy. In fact the OMDS is larger than 1 TB, while the Offline database is only about 35 GB large after two years of cosmics and beam data taking.

The drawback is that complex applications have had to be designed in order to transfer the relevant data from the Online to the Offline database and for some of these applications, like the specific ECAL L1 trigger, the timing of the transfer program is critical. Indeed, the ECAL trigger objects have to be in ORCON before the data quality monitoring and the trigger emulator program are launched, so that they can read them when they start.

In Table I we present the ECAL trigger primitives objects of the Offline database and the specific purpose they have in the calculation of the ECAL trigger primitives. The Offline database objects correspond to parameters used by the emulator algorithms. We have an object for each of the ECAL trigger parameters, the pedestals, the linear constants, physics constants, sliding window, crystal status, and tower status. The parameters that are stored by group in two OMDS tables are represented by two objects in the Offline database. This is the case for the weights, the LUT, and the barrel Fine Grain values. The Fine Grain parameters for the barrel and for the endcap parts are represented by different objects. This is due to the difference in barrel and endcap electronics cards as discussed in section III.

C. Online to Offline Jobs

The condition data stored in OMDS are transferred into the ORCON database by PopCon [14] (Populator of Condition Objects) applications, also called O2O procedure. PopCon is a part of CMSSW. It provides the possibility to encapsulate the data stored in the relational tables of OMDS as POOL-ORA objects to be stored into the Offline database.

We use the PopCon libraries to write fourteen O2O jobs, one for each ECAL trigger primitive's condition object (Table I). The jobs are launched by the ECAL data acquisition when it finishes its configuration. If there are no new parameters in

TABLE I. ECAL TRIGGER PRIMITIVES CONDITION OBJECTS IN THE OFFLINE DATABASE

Legend: a) by crystal, b) by strip, c) by trigger tower, d) by group, e) by detector ECAL barrel and endcap

Trigger primitives objects	Application
EcalTPGPedestals (a)	Make the ADC value
EcalTPGLinConst (a)	proportional to the E _L
EcalTPGPhysConst (e)	To calculate the energy in GeV
EcalTPGSlidingWindow (b)	For the output format of the TPs
EcalTPGLutIdMap (d)	1024 parameters to compress
EcalTPGLutGroup (c)	the energy value to 8 bits
EcalTPGWheightIdMap (d)	To evaluate the energy,
EcalTPGWeightGroup (b)	5 weights for each strip
EcalTPGCrystalStatus (a)	To mask the trigger towers and
EcalTPGTowerStatus (c)	crystals that are not working
EcalTPGFineGrainTowerEE (c)	
EcalTPGFineGrainEBIdMap (d)	Used to calculate the Fine Grain
EcalTPGFineGrainEBGroup (c)	Veto Bit
EcalTPGFineGrainStripEE (b)	

OMDS, no data are transferred. We test this condition by comparing the tag and the version of the new data with the last transferred data. The time scale used for launching the O2O jobs is the following: the Central Data Acquisition (DAQ) sends a configuration message to ECAL with a configuration key and the number of the next run; the ECAL DAQ configures and writes the configuration key into OMDS and makes the correspondence with the current run number; the ECAL DAQ launches the O2O jobs, the program transfers the data corresponding to the configuration key and the run numbers that are stored in a special ORCON table; the ECAL DAQ communicates to the central DAQ that it is correctly configured; the central DAQ sends the command "start run" with the same run number to ECAL; the ECAL trigger emulator then starts to process the data and finds in the ORCON database the conditions with the current run number and the right trigger configuration.

This mechanism ensures the consistency of the configurations of the ECAL hardware and emulator.

VI. CONCLUSION

We presented the workflow allowing the configuration of the ECAL trigger emulator so that it can be used online to monitor the ECAL trigger hardware. This emulator, developed for the simulation of the ECAL trigger response and for the validation and monitoring of the ECAL trigger hardware, is

now configured from the CMS Offline database. After having discussed the Online database structure used for the ECAL hardware configuration and the corresponding Offline structure used by the emulator, we described the Online to Offline procedure. This new procedure is used to transfer the condition data stored in the Online database into the Offline database. It is routinely used with success for the ECAL hardware validation since the first LHC collisions.

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REFERENCES

- [1] The CMS Collaboration, CMS Technical Proposal, CERN LHCC 94-38 (1994).
- [2] The CMS Collaboration, CMS Physics, Technical Design Report, Volume I: Detector Performance and Software, CERN/LHCC 2006-001, CMS TDR 8.1, 2 February 2006.
- [3] CMS Collaboration, "The Electromagnetic Calorimeter Technical Design Report", CERN/LHCC 97-33 (1997).
- [4] The CMS Collaboration, The CMS experiment at the LHC 2008 JINST 3 S08004.
- [5] The CMS Collaboration, The Trigger and Data Acquisition Project, Vol. I: The Level-1 Trigger, CERN LHCC 2000-038 (2000).
- [6] The CMS Collaboration, The Trigger and Data Acquisition Project, Vol. II: Data Acquisition and High-Level Trigger, CERN LHCC 2002-26 (2002).
- [7] M. Hansen, The new readout architecture for the CMS ECAL, 9th Workshop on Electronics for LHC Experiments, Amsterdam, The Netherlands, 29 Sept-3 Oct 2003, pp. 78-82, CERN-LHCC-2003-055 p. 78.
- [8] T. Romanteau et al., A Real Time Electronics Emulator with Realistic Data Generation for Reception Tests of the CMS ECAL Front-End Boards, CMS-CR-2005-029.
- [9] C. Collard, CMS ECAL Front-End boards: the XFEST project, 11th Workshop on Electronics for LHC and Future Experiments, Heidelberg, Germany, 12-16 Sep 2005, pp. 231-235 Detector and Experimental Techniques, CMS-CR-2005-030 ; CERN-CMS-CR-2005-030.
- [10] P. Paganini, Tests of the Boards Generating the CMS ECAL Trigger Primitives: from the On-Detector Electronics to the Off-Detector Electronics System, CMS-CR 2004-066, 2004.
- [11] P. Paganini (on behalf of the CMS Collaboration), 2009 *J. Phys.: Conf. Ser.* **160** 012062.
- [12] CMS Collaboration, Performance of the CMS Level-1 trigger during commissioning with cosmic ray muons and LHC beams. JINST 5 T03002, 2010.
- [13] M. De Gruttola et al., Persistent storage of non-event data in the CMS databases, Jan 2010. 20 pp. JINST 5:P04003, 2010.
- [14] M. De Gruttola et al., First experience inoperating the population of the condition databases of the CMS experiment, International Conference on Computing in High-Energy Physics Conference (CHEP 2009), Distributed Processing and Analysis track, 23-27 March 2009, Prague, Czech Republic.