The Compact Muon Solenoid Experiment
Conference Report

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Computation of Alignment and Calibration Constants in CMS

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Abstract

The CMS detector is a very complex apparatus with more than 70 million data acquisition channels. The full physics potential of CMS and the recorded data can only be exploited with precise calibration and alignment constants that have to be produced in an efficient way. The CMS Collaboration has set up an infrastructure for alignment and calibration based on dedicated skimmed data streams providing inputs which are specific to the various workflows computing these constants. A prompt calibration concept allows for the determination of the most time-dependent constants almost immediately after the data are recorded, thus following as fast as possible any change in the running conditions. The paper will introduce the basic concepts of the CMS alignment and calibration infrastructure, and present results from selected workflows.

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Computation of Alignment and Calibration Constants in CMS

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Abstract—The CMS detector is a very complex apparatus with more than 70 million data acquisition channels. The full physics potential of CMS and the recorded data can only be exploited with precise calibration and alignment constants that have to be produced in an efficient way. The CMS Collaboration has set up an infrastructure for alignment and calibration based on dedicated skimmed data streams providing inputs which are specific to the various workflows computing these constants. A prompt calibration concept allows for the determination of the most time-dependent constants almost immediately after the data are recorded, thus following as fast as possible any change in the running conditions. The paper will introduce the basic concepts of the CMS alignment and calibration infrastructure, and present results from selected workflows.

Index Terms—LHC, CMS, alignment, calibration

I. INTRODUCTION

THE central components of the Compact Muon Solenoid (CMS) is a superconducting solenoid of 6 m diameter, providing a magnetic field of 3.8 T. Within the magnet bore are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL) located. The inner tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$ and consists of 1440 silicon pixel and 15148 silicon strip detector modules. The ECAL consists of nearly 76000 lead tungstate crystals that provide coverage in $|\eta| < 1.48$ in the ECAL barrel region and $1.48 < |\eta| < 3.0$ in the two endcaps. A preshower detector consisting of two planes of silicon sensors interleaved with a total of three radiation lengths of lead is located in front of the endcaps. The HCAL covers the region $|\eta| < 3.0$ and is composed of layers of plastic scintillator within a brass/stainless steel absorber with a total of 10000 readout channels. Muons are measured in gas-ionization detectors embedded in the steel return yoke. The muon system comprises a total of 1600 cathode strip and drift tube chambers accounting for 840k channels. A detailed description of CMS can be found in [1].

II. OFFLINE WORKFLOW

The data recorded by the CMS experiment are transferred to the Tier0 at CERN and split up into three streams: the main physics data stream, a calibration, and an express stream. The calibration stream is designed to contain data at a high event rate but with a highly reduced event content, whereas the express stream constitutes only a subset of 10% of the

Fig. 1. Depiction of the data and work flows. The recorded data are transferred to Tier0 in three streams. Dedicated alignment and calibration datasets are produced from the reconstructed express and calibration stream data and transferred to the CERN Analysis Facility (CAF). On the CAF new conditions are calculated and used in the reconstruction of the physics stream data at Tier0.

physics stream. The express stream data are reconstructed with a low latency of one to two hours at Tier0 and allow for fast physics feed-back and data quality monitoring. The processing of the main data, the physics stream, can be delayed for up to 48 hours by buffering to allow for the production of new alignment and calibration constants from the data actually being processed. The reconstruction of a certain run hence uses constants produced from a subset of data from that exact run. Calibration and alignment workflows run on the CERN Analysis Facility (CAF) and use dedicated so-called AICaReco skims that are produced from both the reconstructed express and physics streams. Newly determined constants are uploaded to the conditions database and can be used in the prompt processing or a possible reprocessing of the data.

III. ALCARECO PRODUCTION

The data used by the alignment and calibration tasks contain just the minimum amount of information needed for a specific task. In the case of the ECAL calibration with photons from π^0 and η decays the used so-called AICaRaw streams are directly produced by the High Level Trigger (HLT) in order to keep events that are normally rejected by the physics trigger and at the same time maintain a high event rate for calibration. In contrast, the AICaReco skims used for tracker, muon system, ECAL and HCAL calibration as well as the

tracker and muon system alignment are produced from both the express and prompt processed streams by applying special filters and stripping of unneeded event content. The alignment and calibration framework provides a flexible mechanism to apply cuts and reduce the amount of data in the AICaReco streams. There are a total of 28 different AICaReco skims produced from the express and the prompt reconstructed data streams. Examples are

- Calibration and alignment of the strip tracker with tracks from zero and minimum bias events
- Muon system alignment with cosmic muons
- Muon system drift tube calibration with muons
- ECAL calibration with photons from π^0 and η decays
- HCAL calibration with isolated tracks

In the case of the express stream, production of the AICaReco skims starts with a low latency with respect to the start of a particular run. Fig. 2 shows the delay between the start of a run and the presence of the first subset of AICaReco data for data collected between June 27 and August 9, 2011. The minimum delay is of the order of one hour with the mean value being approximately 1.3 hours. The delay between the start of a run and the presence of the full AICaReco data is shown in Fig. 3 as a function of the duration of the run for the same data taking period as shown in Fig. 2. The data points shown in Figs. 2 and 3 show the results for the AICaReco skim dedicated to the alignment of the strip tracker with tracks from minimum bias events.

Fig. 2. Delay between the start of a run and the presence of the first AICaReco data for data collected between June 27 and August 9, 2011.

IV. CALIBRATION OF THE ELECTROMAGNETIC CALORIMETER

Data collected with the CMS detector in 2010 have been used to perform a channel-by-channel calibration of the ECAL barrel and endcaps. Photons from π^0 and η decays as well as the azimuthal symmetry of the average energy deposition at a given pseudorapidity are utilized to equalize the response of the individual crystals. The precision of the crystal energy response inter-calibration has been determined from pre-calibration constants, obtained from test beam and cosmic ray

Fig. 3. Delay between the start of a run and the presence of the full AICaReco data as a function of the duration of the run for data collected between June 27 and August 9, 2011.

Fig. 4. Combined crystal energy response inter-calibration precision obtained from data collected in 2010 as a function of the crystal pseudorapidity for the barrel (left) and the end caps (right).

data as well as laboratory light yield measurements, and the above mentioned data [2]. Fig. 4 shows the combined inter-calibration precision as a function of crystal pseudorapidity η for both barrel and endcaps. At $\eta < 1.0$ in the barrel the inter-calibration precision is approximately 0.5% and below 1% in the full η coverage of the ECAL barrel. In the endcaps the precision is $< 2\%$ in the η -region with overlap with the pre-shower detector and of the order of 3 – 4% elsewhere.

V. ALIGNMENT OF THE TRACKER

Based on data collected in 2011 the alignment constants of the CMS tracker have been updated. The used alignment algorithm performs a simultaneous fit of all alignment and track parameters using Millepede-II [3], [4]. The Millepede-II stand-alone 64bit Fortran90 computer program has recently been largely parallelized using OpenMPTM to improve turn-around time of obtaining new alignment constants. Studies have shown that the detector modules can not be assumed flat, i.e., sensors exhibit bowing and the sensors in composite detector modules have an inclination angle with respect to each other. In order to take these additional degrees of freedom into account in the alignment procedure, three additional alignment parameters per sensor have been introduced in order to describe the bowing. Moreover, the alignment parameters

of sensors in composite modules are determined individually. The total number of alignment parameters per sensor is hence nine (eight) in case of pixel (strip) sensors¹.

The rigid body alignment parameters, i.e. the position and orientation, of larger pixel structures, were also split into various time periods in order to take movements of these structures into account. In such a scheme, Millepede-II enables the determination of the alignment parameters for the larger pixel structures for each time period individually whereas alignment parameters for detector modules within the larger structures are determined from the full statistics.

For the 2011 tracker alignment a total of 200614 alignment parameters had to be determined. The used statistics corresponded to approximately 1 fb^{-1} with 15 million loosely selected muon tracks, 3 million low momentum tracks, 375000 muon pairs from $Z \rightarrow \mu^+\mu^-$ decays and 3.6 million tracks from cosmic muons recorded between LHC fills.

With the aforementioned performance improvements, number of alignment parameters and data sample, new alignment constants were produced within 9:50 hours using 8 threads on an Intel Xeon L5520 2.27 GHz workstation.

Fig. 5. Mean sagitta along the strips for all single sensor module for all sub-structures of the tracker.

Fig. 5 shows the mean of the determined sensor sagittas along the strip direction for the various sub-structures of the tracker. For the barrel pixel layer the mean sagitta is approximately $30 \mu\text{m}$. Under larger track incident angles, e.g. in the innermost barrel pixel layer and under shallow track angles, the sensor bending results in systematic residuals of over $100 \mu\text{m}$ at the edge of the sensors.

Taking the sensor bending and the inclination angle between sensors in composite module into account during the track reconstruction significantly improves the track quality. This can be seen in Fig. 6 where the χ^2 -probability of reconstructed cosmic tracks as a function of the tracks transverse distance to the beam line (d_0) is displayed for various module surface assumptions. The data points indicated by red triangles represent the result under the assumption that all modules are flat. With increasing d_0 and hence larger track incident angles the χ^2 -probability drops from about 0.5 to 0.2 at $d_0 = 70 \text{ cm}$. When assuming flat sensors and allowing for an inclination angle

Fig. 6. χ^2 -probability of reconstructed cosmic tracks as a function of the tracks transverse distance to the beam line (d_0) for various module surface assumptions.

between the sensors in composite modules (green triangles), the drop in χ^2 -probability is reduced. The largest improvement is seen when the reconstruction assumes curved modules (blue squares) and curved sensors (magenta circles) with a flat behavior of the χ^2 -probability up to $d_0 \approx 50 \text{ cm}$.

VI. SUMMARY

The CMS experiment has implemented an alignment and calibration infrastructure that allows for the determination of new running conditions in a flexible and efficient way. Data sets used to obtain new constants are designed to minimize data size and performance overheads by limiting the contents to the minimum needed for a particular workflow. The combined ECAL inter-calibration precision using data collected in 2010 is below 1% in the barrel region and 2% in the end cap region with pre-shower overlap. The recent addition of the sensor bowing parameters in the alignment framework significantly improves the quality of the track reconstruction. The computing performance improvements in the Millepede-II alignment algorithm allow for a fast turn-around even with of the order of 200000 alignment parameters and enable future systematic studies.

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¹six (five) rigid body parameters for the position and orientation of pixel (strip) sensors and three parameters for the sensor bowing