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The detailed simulation of the CMS detector

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Abstract

The CMS Collaboration developed a detailed simulation of the detector which is integrated in the software framework CMSSW. The simulation is based on the Geant4 tool for the description of particles interactions with the detector material. Care is given to the detailed description of the detector geometry. The simulation software is fully operational and it is currently under validation using real data from testbeams and from commissioning with cosmic rays.

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1 Introduction

The experiments which will take data at the Large Hadron Collider will make use of Monte Carlo samples to generate large amounts of signal and background events for physics analyses and to develop and validate methods for the detectors calibration, for efficiency and resolution estimation and so on. Having an accurate, faithful and data driven simulation is therefore really important. The CMS Collaboration [1] [2] has recently reimplemented its simulation, reconstruction and analysis software in the new CMSSW framework. The porting of the code was the occasion for a revision of several packages of the software. In this report the implementation of the full simulation is discussed, together with its validation through the comparison with real data collected at testbeams and during the commissioning with cosmic rays.

2 The simulation chain

The simulation inputs are collision events produced by some events generator. Several general-purpose generators are currently interfaced to CMSSW (Pythia [3], Alpgen [4], ...) and generator configuration cards embedded in full configuration files are implemented, as well as particle guns. The format of the Monte Carlo events throughout CMSSW is a wrapper around generator information recorded in the HepMC format.

The CMS full simulation is based on the Geant4 simulation toolkit [5] which provides a rich set of physics processes describing electromagnetic and hadronic interactions in detail. Geant4 also provides tools for modelling the full geometry and the interfaces required for retrieving information from particle tracking through the subdetectors. It also allows the description of the magnetic field. The Geant4 functionality is interfaced to the core of CMSSW through one single module coming with a set of parameters which are configurable at run time. Among them, one of the most relevant is the physics list for the processes to be simulated. Many physics lists for both hadronic and electromagnetic interactions have been tested (LHEP, QGSP, QGSC...) together with different particle production cuts. An interface for the possible tuning of the Geant4 objects at simulation time is also implemented.

The detector description involves the geometrical properties of the components, their relative positions and the materials description. The approach followed in CMS is the unification under a single architecture implemented via a Detector Description Database (DDD) [6]. In this package the detector is represented as a multigraph structure with a compactified description; such a view can be translated into an expanded one with a tree structure of volumes. XML is used as a language to encode the description itself through the DDD schema, but the whole structure is actually independent of the language used for the practical detector implementation.

The simulation is currently implemented for all the central subdetectors including the field map for the 4T solenoid. The porting to the new framework was also the occasion to revisit the detector geometry implementation: all the subdetectors are updating their geometry to the latest engeneering drawings of the detector, both for sensitive regions and for dead materials. Forward subdetectors have been also ported to the new framework and their simulation is currently being tested.

During the low luminosity and high luminosity phases of its operation, the LHC accelerator will produce respectively an average of about 3 and 20 inelastic pp collisions per bunch crossing that will pile-up on top of the signal collisions. Both in-time and out-of-time pile-up with respect to the trigger are taken into account in the simulation. At present signal and pile-up events are simulated in different streams and then merged at the hit level through a dedicated mixing module. A new project is on the way to mix real data pile-up with simulated events, to get a more realistic description of the underlying events.

The mixing module provides the input for the digitization module, which constitutes the simulation of the electronic readout. Care is given to all the details of the electronics, according to the different subdetector configurations. Fluctuations in the energy deposits are taken into account; also, an accurate description of detector noise, drift times, cross talk and any other detector characteristic is simulated. Where needed zero suppression algorithms are also implemented. The digitization software has been ported to the CMSSW framework for all the subdetector and it is fully operational. Most of the work is now related to possible improvements in the algorithms in order to speed up the digitization itself and to improve the software performances. The goal of the digitization is providing an output as close as possible to the real data coming from CMS. Such an output is then passed to the reconstruction software, which builds up reconstructed hits for all subdetectors and then produces higher level physics objects.

3 Simulation validation

A data driven and as faithful as possible simulation is important to be ready for the CMS physics at startup and a big effort is therefore currently ongoing to validate the simulation output versus the available data. In recent

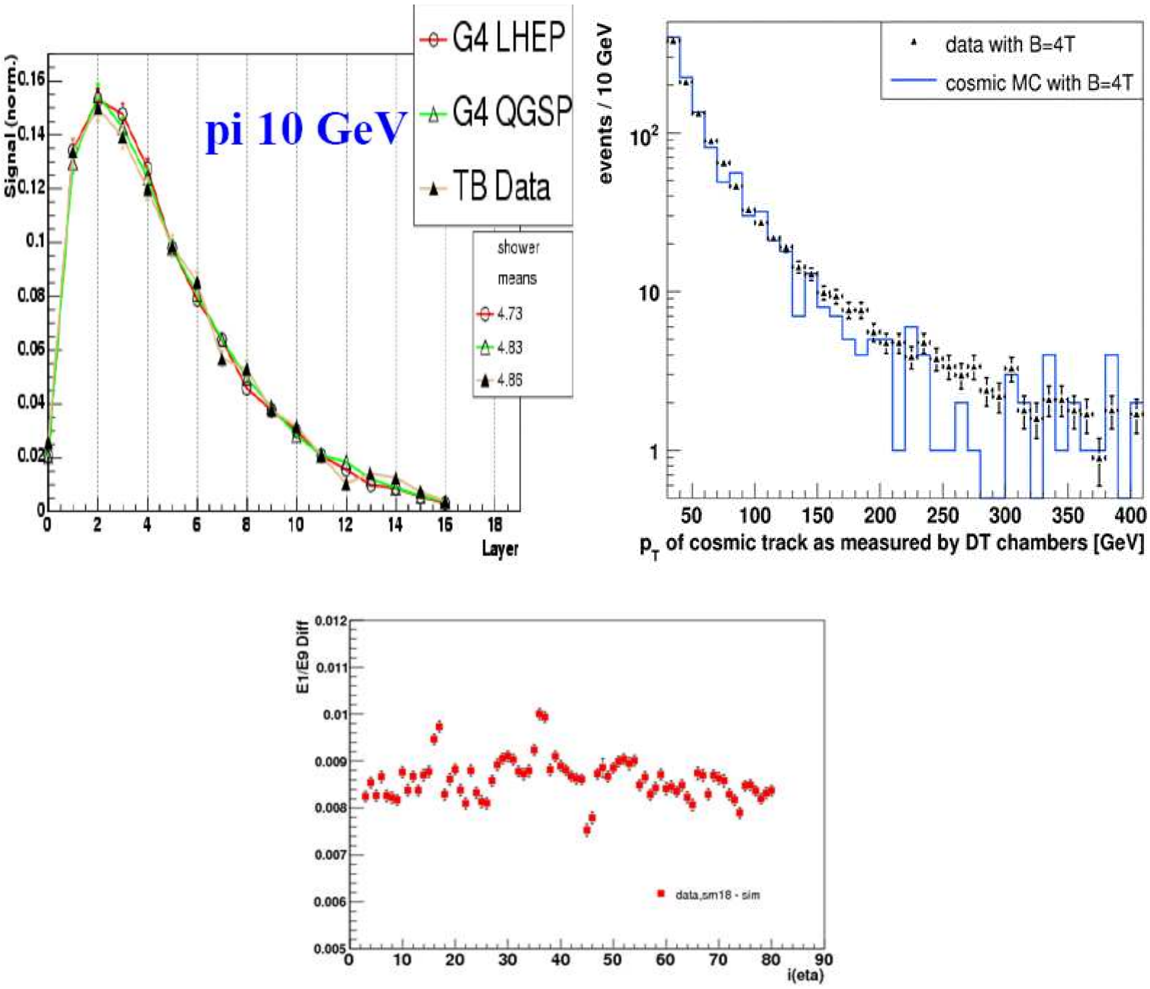

Figure 1: Validation of the CMS simulation versus data. On the top left, pions shower profile in HCAL: comparison between two different Geant4 physics lists and testbeam data; right, muons transverse momentum in drift tubes: comparison between cosmic rays collected during the commissioning and simulation. On the bottom: difference between the transverse profile of electromagnetic showers in ECAL with simulated electrons and data collected at testbeam.

years modules of both the electromagnetic and hadron calorimeters have been exposed to testbeams with pion and electrons over a large energy range and a detailed comparison with dedicated testbeam simulations is currently ongoing. The output from the tracker simulation is being compared with the data collected during a cosmic data-taking run during summer 2006 and at the Tracker Integration Facility at CERN. Also, the response to cosmic data during the commissioning of the muon detectors is being compared with the simulation exploiting a dedicated cosmic rays generator. In general a good agreement between data and simulation is found and an effort is ongoing to understand the remaining discrepancies. Some examples are shown in figure 1. The tuning of the simulation and digitization of the various subdetectors is on the way profiting from the output of such validations in order to better match the real data; also, feedback from these validations is provided to the Geant4 Collaboration.

A dedicated effort is also devoted to comparing the results obtained with different Geant4 versions and physics lists and to validate one software release versus another.

4 Conclusion

The full simulation of the CMS detector has been integrated in the new CMSSW framework and many of its components have been improved. The simulation software is fully operational and it is currently under validation using real data from testbeams and from commissioning with cosmic rays.

References

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