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Validation of the simulation of the CMS electromagnetic calorimeter using data

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Abstract

The CMS ECAL Collaboration developed a full 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 and of the electronics response. 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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Validation of the simulation of the CMS electromagnetic calorimeter using data

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Abstract

The CMS ECAL Collaboration developed a full 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 and of the electronics response. 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 CMS Collaboration [1] has reimplemented in recent years its simulation and reconstruction software in the new CMSSW framework. The simulation of the electromagnetic calorimeter ECAL is fully operational and it is now extensively used to simulate events for physics analysis and to develop new reconstruction and calibration algorithms. In this report the implementation of the ECAL simulation is discussed, together with its validation through the comparison with real data collected at testbeams in the past years.

2 The ECAL structure

The CMS electromagnetic calorimeter [2] is a homogeneous calorimeter made of $PbW0_4$ scintillating crystals. The $PbW0_4$ small radiation length (X_0 = 0.89 cm) and Molière radius (R_M = 2.2 cm) make ECAL a compact and highly granular calorimeter. Its layout is shown in figure 1. ECAL consists of a barrel covering the pseudorapidity region up to $|\eta| < 1.48$ and two endcaps, which extend the coverage up to $|\eta| < 3$. In front of the endcaps a preshower made of silicon strips is foreseen. The ECAL barrel has a modular structure and it is organized in 36 supermodules, each one consisting of 1700 crystals with slightly position dependent dimensions. The transverse granularity is $\Delta\eta \times \Delta\phi$ = 0.0175 × 0.0175. The crystals are quasi-projecting, with a 3 degrees angle between their axis and the line coming from the nominal vertex position both in η and ϕ. In the endcaps the crystals are arranged in four *dees*. The transverse granularity ranges from $\Delta\eta \times \Delta\phi$ = 0.0175 × 0.0175 to 0.05 × 0.05. The crystals are equipped with avalanche photodiodes in the barrel and vacuum phototriodes in the endcaps for the light yield measurement.

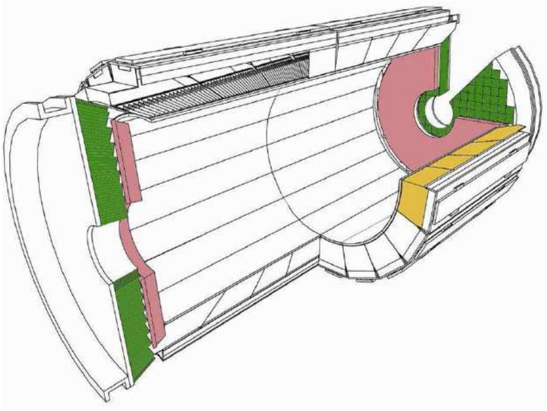

Figure 1: View of the CMS electromagnetic calorimeter.

The full calorimeter has been designed to achieve excellent energy resolution, which is needed to discover the Higgs boson through its possible electromagnetic decays.

3 The ECAL simulation

Three main tasks enter the ECAL simulation: the description of the detector geometry, the tracking of the generated particles in the magnetic field through the detector and the digitization, which mimics the output of the readout electronics. Everything is based on the Geant4 simulation toolkit [3], which provides a rich set of physics processes describing the electromagnetic and hadronic interactions in detail. Geant also provides tools for modelling the geometry and the interfaces required to retrieve informations from particle tracking through the detector.

The geometry description includes the geometrical properties of the detector components, their relative positions and the materials they are made of. The approach followed in CMS is the unification under a single architecture named Detector Description Database (DDD), which is also common to the reconstruction and the visualization software. In the DDD the full detector is represented as a multigraph structure in which the description is compactified. Such a structure can be translated into an expanded view, corresponding to a tree structure of volumes contained into higher level ones. XML is used as a language to encode the description itself through the DDD schema, then the implementation of volumes is done via C++ code. The porting to the CMSSW framework has been the occasion to revisit the ECAL geometry description. Both crystals and preshower strips are considered as sensitive devices. The description is now algorithmic and this allows for an independent alignement of the modules, which makes the setup more flexible. The current description is based on the latest drawings of ECAL and on the measurements of the weights of the different components done before the assembly of the detector. This concerns expecially passive materials such as cooling, electronic boards and cables, which are relevant as material in front of the hadron calorimeter. The visualization of one barrel supermodule is shown in figure 2.

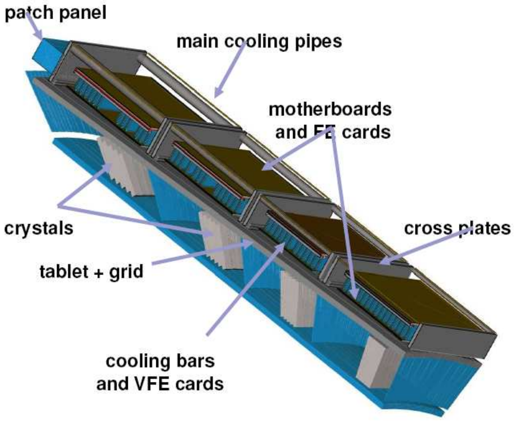

Figure 2: Visualization of an ECAL barrel supermodule based on the geometry description implemented in the simulation.

The description of particles going through the detector is based on Geant4 and an interface for the possible tuning of Geant objects at any simulation time is implemented. The physics list for the processes which are simulated is among the more relevant parameters to be set; up to now many physics lists for both electromagnetic and hadronic interactions have been tested (LHEP, QGSP, QGSP-EMV, QGSC..), together with different particle production cuts. The output of the ECAL specific code is the CaloHit, which summarizes the output of the detector response modeling and contains the information about the energy deposit, the bunch crossing, the timing, the sensitive detector and the Geant track originating the deposit itself. The CaloHit structure is largely in common with the hadron calorimeter software.
The physics processes happening when a particle impacts on the calorimeter are simulated in a simplified way. The scintillation light emission, the light propagation and absorption and the behaviour of the photodetectors are condensed in an effective conversion factor between the hit energy deposit and the average number of photoelectrons which are produced. The conversion factors are 2.25 and 1.8 photoelectrons/MeV respectively in the barrel and in the endcaps; these numbers include the excess noise factor (due to fluctuations in the detection and multiplication processes in the photodetectors) so that photostatistical fluctuations have the correct magnitude. The contribution to the constant term from non-uniformity in the light collection along the crystal is also included.

After the physics process simulation, the response of the electronics is reproduced in the digitization step. In the ECAL electronic chain a Multi Gain Preamplifier processes the signal coming from the photodetectors with three different possible gains ($\times 1$, $\times 6$, $\times 12$), then each signal is digitized by a multi-channel ADC operating at 40 MHz. The output of the digitization step is the ECAL Dataframe, a sequence of 10 time samples corresponding to the 10 ADC clock ticks plus the gain identifier. The output is simpler for the preshower, which only has three samples and one gain. In the simulation the gain switch mechanism, the gain hysteresis and the saturation (happening at 1.7 TeV in barrel and 3 TeV in endcap) are emulated. An accurate description of the noise of the electronics based on real data measurements is also implemented; to be as accurate as possible, pedestals and gain ratios are read from a database. As a last step, the signal is sent to the emulator of the trigger primitives and used for the selective readout mechanism in the crystals and for the zero suppression in the preshower [4]. The digitization software is now fully operational. Studies related to possible improvements in the algorithms to speed up the digitization itself and to improve the software performances are currently ongoing.

The output of the digitization is finally passed to the reconstruction software, which builds up reconstructed hits from all subdetectors and then produces higher order physics objects.

4 Simulation validation

The ECAL simulation is used to produce events for physics analysis and to develop new reconstruction and calibration algorithms. Also, simulated data are currently used to test in full CMS environment algorithms and strategies developed in the simplified testbeam setup (without magnetic field). A data driven and as faithful as possible simulation is therefore necessary to be ready for the CMS physics at startup. While a big effort is ongoing to compare the results obtained with different Geant4 versions and physics lists, a crucial aspect is also the validation of the simulation with real data as soon as they are available.

In summer 2006 some modules of the electromagnetic calorimeter were exposed to electron beams over a large energy range. To be able to compare the testbeam data with the simulation a dedicated description of the testbeam setup was implemented, which includes the description of both the detector and the beam line starting from the last bending magnet.

The validation of the simulation is carried on looking to simple variables which could spot basic problems and to more complex quantities, like resolution or linearity, to fully validate the agreement.

Studies are performed to validate the description of the transverse shape of the electromagnetic showers comparing the energy measured in a single crystal (E1) or in a matrix of 3x3 (E9) or 5x5 (E25) crystals in data and simulation. Figure 3 shows the trend of the ratio E1/E25 as a function of the pseudorapidity obtained on testbeam data and with simulation using two different Geant4 versions. The behaviour versus η is well reproduced, and this ensures the possibility to trust the simulation for calibration purposes. The simulation absolute value agrees within 1% with data. A shift is visible between the two Geant versions, which can be possible attributed to the different treatment of the multiple scattering. The validation versus new Geant releases is continuosly ongoing as soon as they are available; recent Geant releases show a quite stable behaviour of the considered quantities. Similar considerations also hold for the transverse shower shape trend versus the energy.

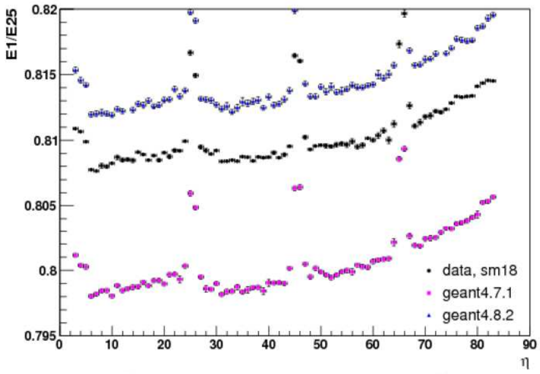

Figure 3: Ratio E1/E25 as a function of the crystal pseudorapidity. Data collected at the testbeam (black dots) are compared with simulation based on Geant 4.7.1 (pink dots) and Geant 4.8.2 (blue dots).

As an example of more complex quantity, in figure 4 the position resolution as a function of the beam energy is compared for testbeam data and simulation. The position is computed using ECAL via an energy weighted average of the positions of the crystals involved by the shower [5]. Data and simulation well compare in both the directions orthogonal to the beam.

The examples discussed in this section are part of a more extensive validation campaign based on testbeam data. Recently, a dedicated simulation has been also implemented to reproduce the conditions of the cosmics data taking which is currently ongoing after the integration of ECAL within CMS and the installation of the detector underground. Further tunings of the simulation will be possibly implemented profiting from the output of such upcoming validations.

5 Conclusions

The full simulation of the CMS electromagnetic calorimeter has been integrated in the CMS software framework and it is fully operational. An extensive validation using real data collected at testbeams is ongoing. A general good agreement between data and simulation is found.

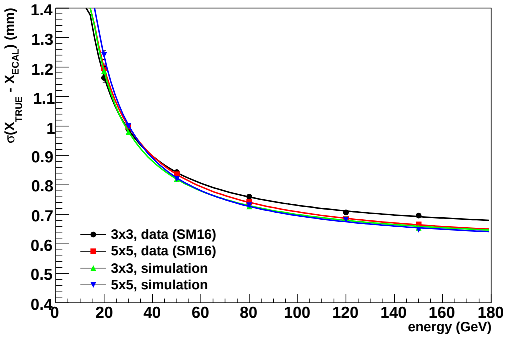

Figure 4: Position resolution as a function of the beam energy computed applying the same algorithm to testbeam data (black and red dots) and simulation (green and blue dots). Crystals belonging to a 3x3 or a 5x5 matrix around the crystal with maximum energy deposition are considered as contributing in the position reconstruction. The plot refers to the X coordinate (corresponding to η); similar results are obtained in Y (ϕ).

References

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[5] E. Meschi et al, *Electron Reconstruction in the CMS Electromagnetic Calorimeter*, CMS NOTE-2001/034