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The commissioning and first results on the performance of the CMS Preshower Detector

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The commissioning and first results on the performance of the CMS Preshower Detector

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Abstract. The Preshower is the first part of the CMS endcap electromagnetic calorimeter, as seen by the particles. It is composed of 2 layers of lead absorbers followed by silicon sensors of a total surface of 17 m^2, the biggest ever built. The use of the silicon strip sensors improves the spatial accuracy of the incidence position of electromagnetic showers. This allows an additional rejection of background (e.g. neutral pions) to new physics, such as the two-photon SM Higgs decay. In this article, the results from first commissioning, the performance with first LHC beams and first in-situ calibration with charged particles are described.

1. The CMS Preshower detector

The electromagnetic calorimeter (ECAL) of CMS comprises a barrel and two endcaps ("EE") based on lead tungstate ($PbWO_4$) scintillating crystals, with a silicon-strip preshower ("ES") in front of each EE [1].

One of the main physics goals of CMS is to discover Higgs particle. If Higgs has mass less than 150 GeV, the easiest way to detect it in CMS is via its decay to two high-energy photons. However, neutral pions can mimic high-energy photons when they decay into two closely-spaced lower energy photons that the ECAL picks up together. In the endcap regions, where the angle between two photons from the π^0 decay is likely to be small enough to cause the problem. Therefore, a highly-segmented ES is placed in front of EE to prevent such false signals.

The ES covers $1.653 < \eta < 2.6$ and has two layers: lead radiators ($2X_0$ and $1X_0$, respectively) initiate electromagnetic showers from incoming electrons/photons whilst silicon strip sensors placed after each radiator measure the energy deposited and the transverse shower profiles. Each silicon sensor measures 63×63 mm^2, with an active area of 61×61 mm^2 divided into 32 strips. The nominal thickness of the silicon is 310 μm. They are grouped into "ladders" of 7, 8, or 10 sensors. The ES front-end electronics can operate in two modes: High Gain ("HG") is used for calibration purposes and low-energy collision running, including 7 TeV; Low Gain ("LG") has a higher dynamic range more suitable for higher energy collision runs.

2. Commissioning

After the installation finished in the first half of 2009, the most important thing was to check that all connectivity at the detector side for high and low voltage power lines, optical fibres and control cables was correct and functional, prior to "closing" CMS. Data were taken using a local DAQ system based on the XDAQ framework (CMS standard) [2, 3] and analyzed by CMS Data Quality Monitoring framework. The results of the commissioning were that all cables and fibres were correctly connected and the vast majority of the detector channels were functioning perfectly. Analysis of the noise performance in HG and LG modes was also performed. The average intrinsic noise is around 5.6 (2.5) ADC counts for HG (LG) meeting with beam test performance [4].

3. Preshower Operation during LHC collisions

3.1. Timing alignment

For every ES channel, the electronic response is sampled at -5, 20 and 45 ns relative to the arrival of the trigger signal. Reconstruction of the particle arrival times is extracted by fitting the digitized amplitude samples to the known pulse shape obtained from beam test [4].

The first step of ES time alignment was the adjustment of the digitization phase of the phase locked loop ("PLL") in steps of 1.04 ns, which is common to a varying number of strips, between 192 and 320 depending on the ladder type. The PLL settings were estimated using the ES geometry and cable length. Collision data were then used to fine-tune the PLL phase adjustment for the whole ES. Figure 1 shows the synchronization of the relative phase for 7 TeV collision events, before and after fine-tuning of the PLLs.

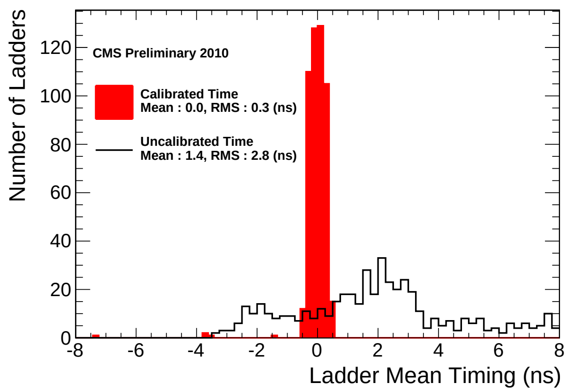

Figure 1. Synchronization of the relative phase between Preshower readout electronics (at the level of "ladders") and the passage of particles through the sensors, before and after fine-tuning.

3.2. Preshower status

Of the 4288 silicon sensors forming the ES, 9 are classed as "dead" due to hardware problems that occurred after installation. In addition, a few strips (23 out of 137216 total) are classed as noisy. The total percentage of fully-functional strips is 99.79%.

4. Data-MC comparisons of observables

4.1. Occupancy

The ES occupancy is calculated as the percentage of strips with a reconstructed energy greater than four sigma of the noise. This threshold corresponds to 32 keV of energy deposited in the strip in HG mode. Figure 2(left) shows how the occupancy varies with pseudo-rapidity (η, averaged over all ϕ), whilst fig. 2(right) shows the variation with azimuthal angle (ϕ, averaged over all η), both compared with simulation, where absolute values of the MC occupancies have been normalized to the data. The ϕ variations are due to the X-Y geometry of the ES and are well-simulated in MC.

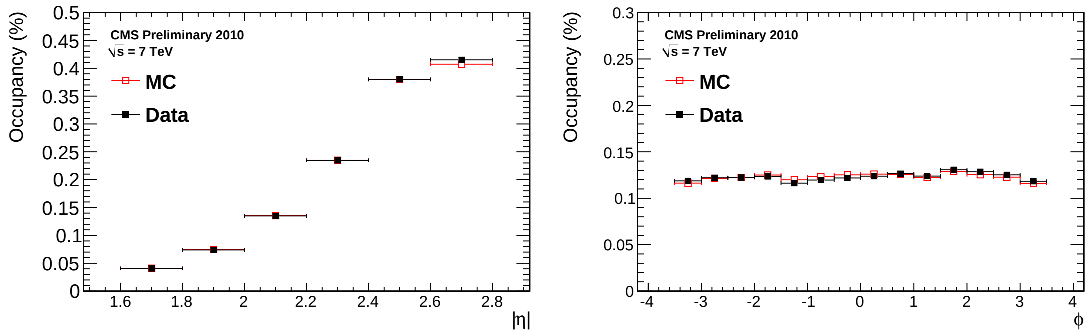

Figure 2. Preshower occupancy as functions of pseudo-rapidity (left, averaged over all ϕ) and azimuthal angle (right, averaged over all η).

4.2. Energy deposits on ES planes

Algorithm for clustering the energy deposits of incoming particles for the endcaps is done in three steps.

- Firstly, "basic clusters" (BC) of groups of crystals are formed around seed crystal having $E_T > 1$ GeV
- Then, we extrapolate their paths back to the centre of the collision and build the ES cluster around the intersected strip on each ES plane. The ES energy in MIPs is then converted to GeV and added to the EE BC energy.
- The endcap clusters are then further grouped into "superclusters" (SC), which are extended in ϕ, thus minimizing the cluster containment variations due to the strong magnetic field.

Figure 3 shows the ES cluster energies for each plane for 7 TeV minimum bias events for both data and MC. The ES clusters are associated to ECAL superclusters with raw transverse energy larger than 2 GeV and $1.7 < |\eta| < 2.5$. Figure 4 shows the energy ratio of the second to the first ES plane. These distributions show good agreement between data and simulation.

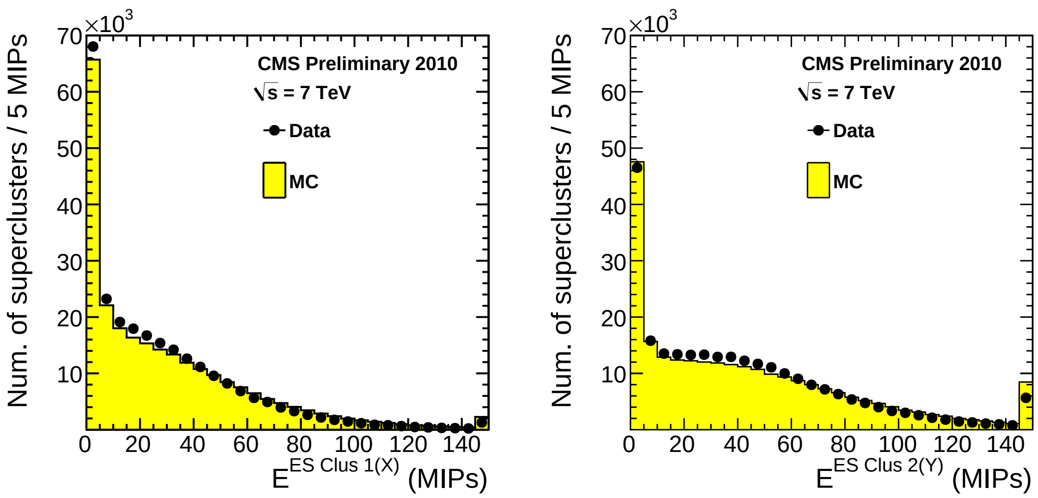

Figure 3. Energy deposited in each of the two ES planes for supercluster raw transverse energy larger than 2 GeV. Overflows are added to the last bin.

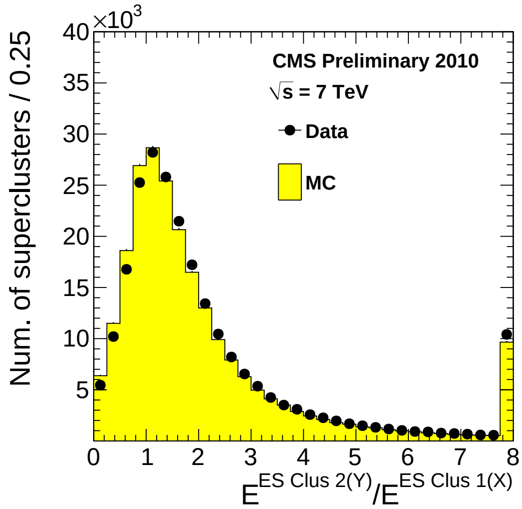

Figure 4. The ratio of the energy deposit associated with a supercluster on the second ES plane to the first one for supercluster raw transverse energy larger than 2 GeV. Overflows are added to the last bin.

5. Alignment between ES and EE

The ES disks are supported by a conical structure attached to the backplate of the endcap hadron calorimeters. This backplate also supports the EE Dees, so relative alignment between the EE and ES should be very good by design. EE clusters with $E_T > 2$ GeV, with no isolation or electron/photon identification requirements, were used as the source of this study, with position measurements being made in the EE and the ES. Note that the accuracy of these position measurements is rather poor due to the low E_T of a majority of the superclusters, but is sufficient for a first alignment. The same study was made with MC, assuming perfect alignment. The "out of the box" mis-alignment is less than half a millimetre in all planes. Figure 5 shows the alignment between the EE and ES for one of the ES planes.

6. First ES in-situ calibration with charged particles

The ES is a sampling calorimeter and essentially counts the number of charged particles passing through the silicon. The particles used to calibrate the ES are currently pions, with momentum greater than 1 GeV and an average momentum of 6.1 GeV. This means that they are nearly minimum ionizing, so for simplicity we refer to them as "MIPs". The design-goal accuracy of the channel-by-channel calibration is set to 5%. This corresponds to a contribution of about 0.25% to the overall EE+ES energy resolution for high-energy electrons since only 5% of a photon or electron energy is deposited in ES. There are two main sources of response variation (sensor-to-sensor and channel-to-channel) at the start-up: sensor thickness and gain uniformity of the electronics. Prior to their installation, all ES silicon modules were pre-calibrated with cosmic rays for at least 16 hours in the laboratory. The accuracy of the pre-calibration is estimated to be about 2.5%.

The first in-situ ES MIP calibration has been carried out by using the charged tracks with momentum greater than 1 GeV pointing to the ES from 7 TeV minimum bias events. Figure 6(left) shows the energy distribution for a silicon sensor. The distribution is fitted by a Landau function convoluted with a Gaussian function. The MIP-equivalent energy for this sensor is 47.2 ADC counts. For each sensor, the "MIP" value is defined to be equal to the fitted peak position. The distribution of the measured MIP values for all sensors having at least 1000 hits (currently

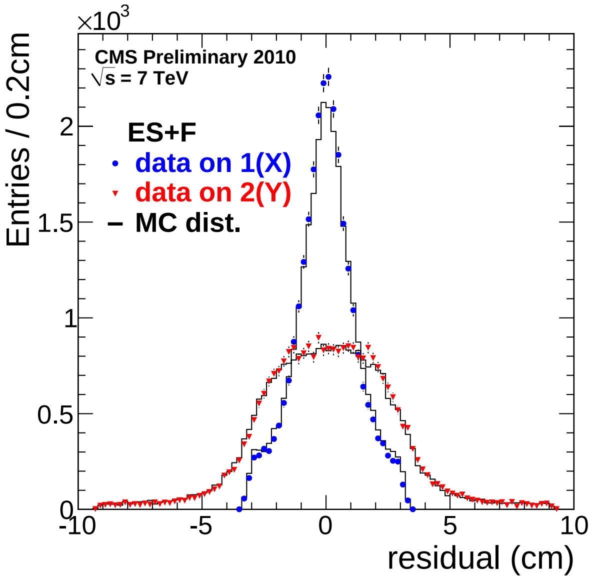

Figure 5. Alignment between ES and EE for one of the ES planes for both data and MC. The "out of the box" alignment is better than a millimetre.

3792 out of 4288 sensors) is shown in Figure 6(right).

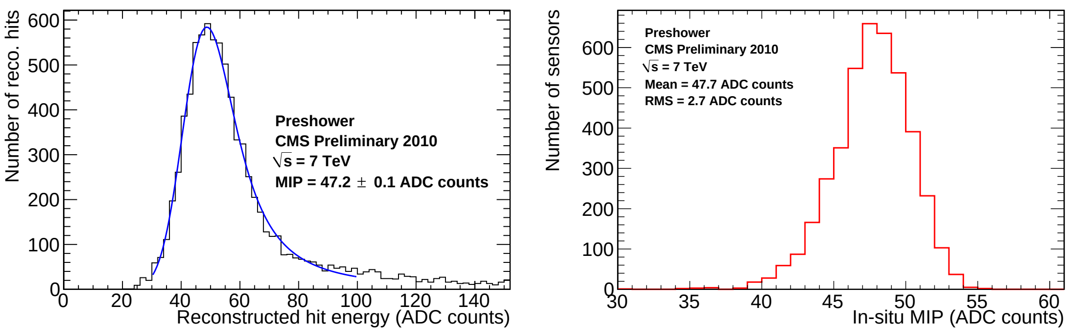

Figure 6. Energy distribution for a silicon sensor, requiring tracks with $p > 1$ GeV pointing to the ES (left). Distribution of measured MIP values for all ES sensors having at least 1000 hits. (right)

After in-situ calibration and measurement of the noise of each channel, an estimation of the signal to noise for single ionizing particles can be made. The design specification of the ES was to have an S/N ratio for single particles of about 8 for HG mode. The observed ratio, as shown in Figure 7 is between 9 and 11.

Figure 8(left) shows the correlation between sensor "MIP" values obtained from in-situ calibration and pre-calibration. The residuals plot is shown in Figure 8(right). The offset is due to the different particle momentum spectra and operating temperature in the two cases. The precision of in-situ calibration is then estimated to be about 2.2% which is better than the design-goal target.

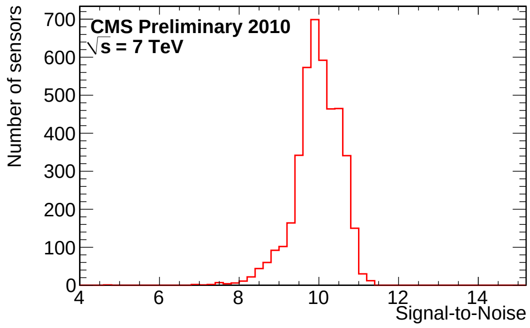

Figure 7. ES signal to noise ratio for single particles.

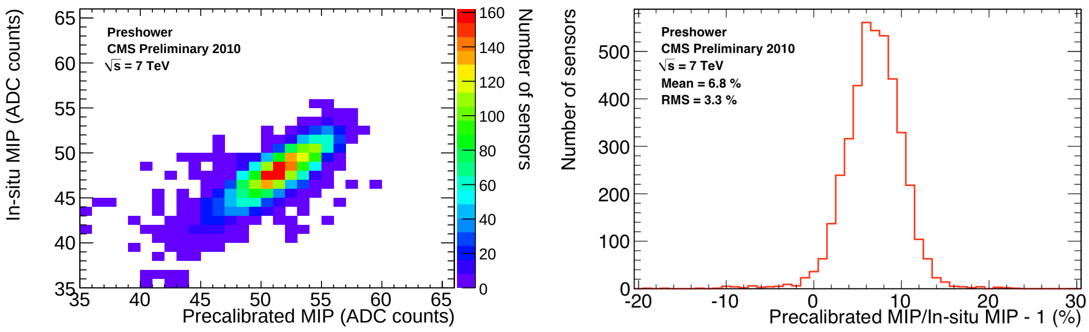

Figure 8. ES MIP values measured in CMS compared to those measured using cosmic rays in the laboratory (left). Residuals between the in-situ MIP calibration and pre-calibrations (right).

7. Summary

The CMS Preshower detector was installed and commissioned successfully in CMS in the first half of 2009. The results from first commissioning confirmed all connectivity in place and expected noise performance. Throughout the first data taking periods of the LHC, the CMS Preshower has been operational and 99.79% of channels are funcationing perfectly. The first collisions at 7 TeV have provided the opportunity to test our understanding of the basic observables, such as occupancy and energy clustering. Good agreement between data and simulation has been shown for these observables. The alignment between ES and EE is better than half a millimetre. First in-situ calibration with charged particles has been carried out, achieving required accuracy.

References

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