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Performance of the CMS electromagnetic calorimeter in Run II and its role in the measurement of the Higgs boson properties

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The characterisation of the Higgs boson discovered in 2012 around 125 GeV, and confirmed with the data collected in Run II, requires the precise determination of its mass, width and couplings. The electromagnetic calorimeter (ECAL) of the Compact Muon Solenoid Experiment (CMS) is crucial for measurements in the highest resolution channels, $\mathrm{H} \to \gamma\gamma$ and $\mathrm{H} \to 4$ leptons. In particular the energy resolution, the scale uncertainty and the position resolution for electrons and photons are required to be as good as possible. During Run II the LHC is continuously operating with 25 ns bunch spacing and increasing instantaneous luminosity. The calorimeter reconstruction algorithm has been adapted to cope with increasing levels of pile-up and the calibration and monitoring strategy have been optimised to maintain the excellent performance of the CMS ECAL throughout Run II. We show first performance results from the Run II data taking periods, achieved through energy calibrations using physics events, with a special emphasis on the impact on the measurement of the properties of the Higgs boson and on searches for new physics.

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1. Introduction

The CMS electromagnetic calorimeter [1] is composed of 75 848 lead tungstate scintillating crystals read by APD's in the barrel section and VPT's in the endcap regions. The energy resolution of the calorimeter is the most important parameter affecting the precision with which it is possible to measure the Higgs boson properties.

2. Energy reconstruction

The pulse shape from crystals is acquired after a trigger using ten samples at 40 MHz and modelled as a sum of one in–time pulse superimposed to up to 9 out–of–time ones. A fit to this model with binned templates extracted periodically from runs with only one bunch circulating in either LHC beam gives the pulse amplitude A_i for each channel i above threshold [2].

A clustering algorithm combines the signals from crystals in a variable $\eta - \phi$ window, where η is the pseudorapidity and ϕ the azimuthal angle of the channel. Superclusters are built out of clusters found in strips extending along ϕ: electrons, in fact, may radiate photons due to the 3.8 T magnetic field that bends their trajectory along this direction. The energy of neutral clusters compatible with being irradiated by an electron are identified and included in the supercluster. The uncorrected energy of clusters is then obtained as

$$E_{e,\gamma}^{raw} = GF_{e,\gamma}\sum_i c_i A_i + E_{ps}\,, \tag{2.1}$$

G being a conversion factor from ADC counts to energy, $F_{e,\gamma}$ taking into account the differences between electrons and photons. Intercalibration constants c_i are needed to equalise crystals response for different light output and readout efficiency. In the endcap regions, the energy deposited in a preshower detector E_{ps} is summed to the one measured by ECAL.

The values of c_i are periodically measured exploiting the symmetry in ϕ of the energy deposited in ECAL by minimum bias events in proton–proton collisions (ϕ–symmetry), as well as the invariant mass of photon pairs from π^0 and η decays [3][4].

As the crystal transparency varies with irradiation, the pulse amplitude must be corrected for this effect. The correction is derived by applying a time-dependent correction factor $S_i(t)$, obtained by monitoring the crystal transparencies by means of the injection of a laser pulse through optical fibres [5]. The response $R_i(t)$ of channel i at time t has been found to be related to $S_i(t)$ by

$$\frac{S_i(t)}{S_i(0)} = \left(\frac{R_i(t)}{R_i(0)}\right)^{\alpha_i} \tag{2.2}$$

where α_i has a small crystal-to-crystal variation with an average value of 1.52 or 1, for the two crystals suppliers. The transparency loss is strongly correlated with the delivered instantaneous luminosity of LHC, and crystals partially recover during periods of inactivity of the machine. The change in transparency depends on pseudorapidity η: it goes from less than 4 % at $|\eta| < 1.4$ to as high as about 0.7 at $|\eta| > 2.7$.

The performance of the algorhitm is measured from the ratio between the energy E and momentum p of reconstructed electrons [6]. Currently, such a ratio goes from an uncorrected value of 0.9401 ± 0.0069 to a corrected value of 1.0000 ± 0.0015.

Residual effects are taken into account by an η–dependent global scale factor $G(\eta)$, obtained by matching the dielectron invariant mass to the known Z^0 mass value. In the end, the corrected energy of a supercluster is given by

$$E_{e,\gamma} = G(\eta)F_{e,\gamma}\sum_i c_i S_i(t)A_i + E_{ps}\,. \tag{2.3}$$

Thanks to the outlined procedure, the resolution of the $\gamma\gamma$ invariant mass measurement at 125 GeV is as low as 2.4 GeV. The position resolution of a supercluster depends on the energy resolution, too. After a procedure aiming at the relative alignment between the calorimeter and the tracker, it is found that the resolution in the polar and azimuthal angles in the barrel is $\sigma_\eta = 1.2\times 10^{-3}$ and $\sigma_\phi = 2.6\times 10^{-3}$, and about twice as much in the endcaps.

Given the above mentioned figures, the Higgs boson mass, calculated by combining both the $H \to \gamma\gamma$ and the $H \to 4$ leptons channels, is $m_{\mathrm{H}} = 125.02^{+0.26}_{-0.27}(\mathrm{stat})^{+0.14}_{-0.15}(\mathrm{syst})$ GeV [8]. The production cross section with respect to the standard model prediction is $\mu = 1.16^{+0.15}_{-0.14}$ [9] and the spin and parity of the observed particle is $J^P = 0^+$ [10].

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