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Electron and photon performance with the CMS detector at $\sqrt{s} = 8$ TeV

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Abstract

The performance of the electron and photon reconstruction and selection with the CMS detector at $\sqrt{s} = 8$ TeV is presented. Selection criteria and efficiency measurements in data and simulation are shown. The electron and photon energy scale calibration and resolution are also discussed, with particular emphasis on their role in Higgs analyses.

Keywords: LHC, CMS, performance, electron, photon

1. Introduction

Several physics processes under study at the LHC are characterized by the presence of electrons or photons in the final state. The performance of identification algorithms applied to these objects is therefore crucial for the physics reach of the CMS experiment.

Moreover, electron and photon energy needs to be measured with good resolution and high accuracy in terms of the absolute energy scale. This is especially important for the studies of the Higgs boson in the four lepton and two photon decay channels, as well as in the studies of the W and Z bosons.

2. Electron and photon identification

Promptly produced electrons and photons can be separated from jet background by means of several discriminating observables, based on the measurements of the inner tracker and the electromagnetic (ECAL) and hadronic (HCAL) calorimeters. These variables can either be used separately, by applying requirements on their values, or be combined into one discriminant by multivariate techniques.

The shape of the electromagnetic shower in the ECAL is a very important handle for background rejection. Energy deposits in the ECAL crystals are grouped into superclusters. The most commonly used supercluster variables used for identification are constructed as follows:

- $\sigma_{i\eta i\eta}$: the second moment of the log-weighted distribution of crystal energies, calculated in the 5 x 5 matrix around the most energetic crystal in the supercluster and rescaled to units of crystal size. The choice of the η direction is needed to avoid distortions from the opening up of the charged energy flow in the magnetic field. This variable takes in average larger values for the background of neutral mesons decaying to two collimated photons, that are reconstructed as a single supercluster.
- R_9: the energy sum of 3 x 3 crystals centred on the most energetic crystal in the supercluster divided by the total energy of the supercluster. This variable is peaked close to 1 for electrons and photons that have not undergone significant energy loss in the tracker material in front of the ECAL (Fig. 1). It typically takes lower values for the background.

The amount of energy flow surrounding the electron or photon candidate provides further discrimination from the jet background. Isolation variables are most commonly calculated in the framework of the Particle-Flow (PF) event reconstuction. The PF al-

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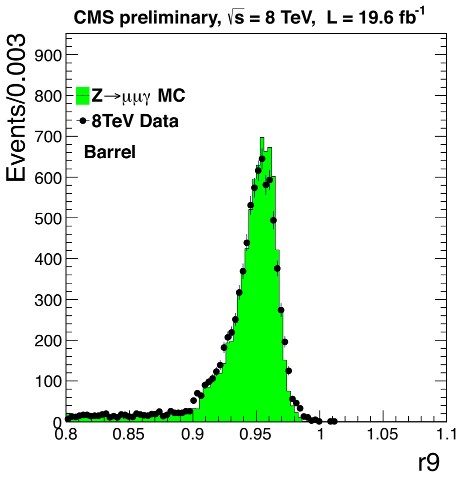

Figure 1: The distribution of the R_9 variable for pre-selected photons in data and Monte Carlo simulation of the $Z \to \mu\mu\gamma$ process for ECAL barrel. The R_9 shape in the simulation is corrected by a linear transformation derived from $Z \to ee$ [1].

gorithm combines information from all subdetectors and exploits optimally their granularity to provide an unambiguous interpretation of the event in terms of particle candidates. Isolation sums are calculated separately for charged hadrons, neutral hadrons and photons in a cone centered on the electron or photon candidate.

Electron and photons energy deposits are expected to be almost fully contained in the ECAL. A relatively large energy deposit in the HCAL, located in close vicinity of an ECAL supercluster, is an indication of the candidate to belong to the jet background. A requirement is therefore applied on the ratio of the energy reconstructed in the HCAL tower behind the ECAL supercluster, to the supercluster energy.

Additional discriminating variables are available for electrons from the Gaussian-Sum-Filter (GSF) track fit [2]. Requirements on track quality parameters and compatibility between the extrapolated track impact point on the ECAL surface and the position of the ECAL supercluster are applied.

The agreement of data and simulation for the electron and photon identification efficiency is assessed using samples of electrons from Z decays with the tag-and-probe technique and radiative Z decays (Z→ $\mu\mu\gamma$) [1, 3]. Figures 2 and 3 show that the simulation accurately predicts the distribution of multivariate discriminants based on the quantities described above.

A specific set of identification requirements has also been developed for electrons with high transverse momentum, and is used mainly in searches for new physics.

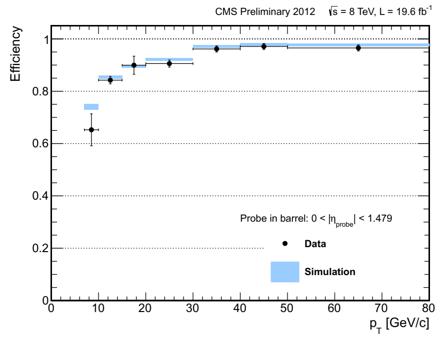

Figure 2: Efficiency in data and in a Drell-Yan Monte Carlo sample for the multivariate electron selection as a function of the electron p_T. Both statistical and systematic errors are included [3].

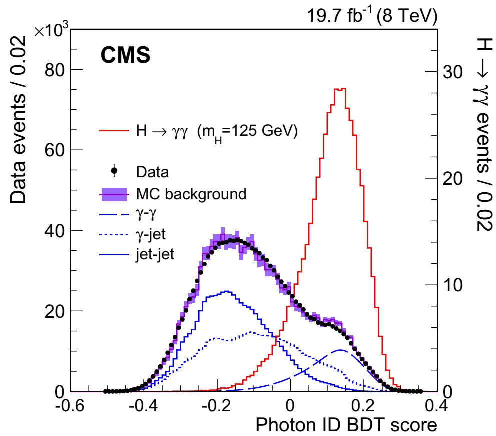

Figure 3: Photon identification BDT score of the lower-scoring photon of diphoton pairs with an invariant mass in the range $100 < m_{\gamma\gamma} < 180$ GeV, for events passing the Higgs analysis preselection in the 8 TeV dataset (points), and for simulated background and Higgs boson signal events [4].

3. Energy scale and resolution

The measurement of photon energy is based on the energy collected by the ECAL supercluster. Corrections are applied to account for several detector effects. The most important ones are the variation of the ECAL response due to changes in crystal transparency, the intercalibration of the ECAL channels, the partial containment of the electromagnetic shower in the ECAL supercluster, the interaction with the tracker material upstream of ECAL and the energy deposits from pileup interactions.

An accurate photon energy measurement is especially important in the analysis of Higgs boson decays in photon pairs [4]. A multivariate regression technique is used to obtain the best estimate of the photon energy, as well as the energy uncertainty. Electrons from Z decays (Fig. 4) are used to simultaneously calibrate the absolute energy scale in data and tune the energy resolution in the simulation.

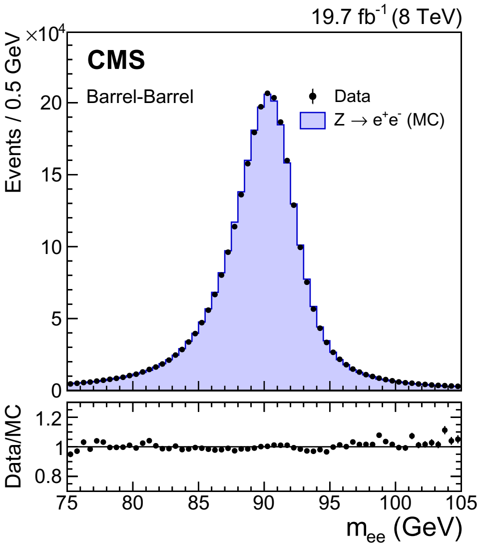

Figure 4: Invariant mass of e^+e^- pairs in $Z \to ee$ events in the 8 TeV data (points), and in simulated events (histogram), in which the electron showers are reconstructed as photons, and the full set of photon corrections and smearings are applied [4].

The dominant systematic uncertainties in the diphoton invariant mass measurement are induced by those in the linearity of the energy scale and in the simulation of differences between electrons and photons. They amount in total to about 0.15 GeV.

In the case of electrons, the ECAL supercluster energy measurement is complemented by the GSF track fit, which provides a better resolution at low transverse momentum. These two inputs are combined by a multivariate regression (Fig. 5). The agreement of energy scale in data and simulation is checked in different detector regions using samples of electrons from Z, J/ψ and Υ decays.

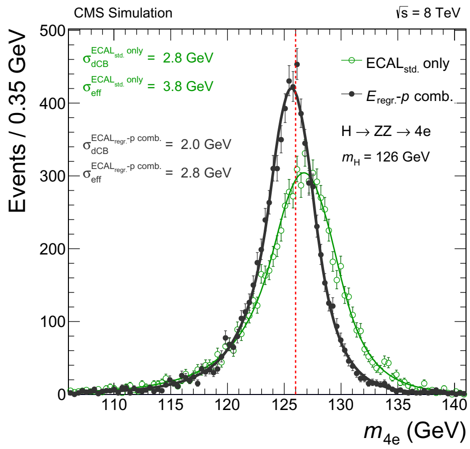

Figure 5: Expected four-lepton mass distribution from $H \to ZZ \to 4e$ for $m_H = 126$ GeV using ECAL-only electron momentum estimation (green open points), and using the regression-based combination with the track momentum (black full points) [5].

4. Summary

The CMS experiment has achieved an excellent performance in reconstructing and selecting electrons and photons produced in proton-proton collisions at the LHC, and in measuring their energy. The selection efficiency and the energy scale and resolution have been measured, and the simulation has been found in good agreement with data. These achievements have played an important role in the discovery of the Higgs boson with LHC Run 1 data.

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