Contribution ID: **127** Type: **not specified**

Calibration of the CMS hadron calorimeters using proton-proton collision data at $\sqrt{s}$ = 13 TeV

Friday, 19 March 2021 12:20 (20 minutes)

Methods are presented for calibrating the hadron calorimeter system of the CMS detector at the LHC. The hadron calorimeters of the CMS experiment are sampling calorimeters of brass and scintillator, and are in the form of one central detector and two endcaps. These calorimeters cover pseudorapidities $|\eta| < 3$ and are positioned inside the solenoidal magnet. An outer calorimeter, outside the magnet coil, covers $|\eta| < 1.26$, and a steel and quartz-fiber Cherenkov forward calorimeter extends the coverage to $|\eta| < 5.19$. The initial calibration of the calorimeters was based on results from test beams, augmented with the use of radioactive sources and lasers. The calibration was improved substantially using proton-proton collision data collected at $\sqrt{s}$ = 7, 8, and 13 TeV, as well as cosmic ray muon data collected during the periods when the LHC beams were not present. The present calibration is performed using the 13 TeV data collected during 2016 corresponding to an integrated luminosity of 35.9 fb^{-1}. The intercalibration of channels exploits the approximate uniformity of energy collection over the azimuthal angle. The absolute energy scale of the central and endcap calorimeters is set using isolated charged hadrons. The energy scale for the electromagnetic portion of the forward calorimeters is set using $Z \to e^+e^-$ data. The energy scale of the outer calorimeters has been determined with test beam data and is confirmed through data with high transverse momentum jets. In this paper, we present the details of the calibration methods and accuracy.

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Session Classification: Calorimetry

Track Classification: Calorimetry