Results on various aspects of the performance of the CASTOR calorimeter in LHC Run 2 are presented. This includes the alignment, calibration and triggers of the detector. The intercalibration of the gains of the fine mesh PMT’s using beam-halo muons is discussed, this in combination with results of a study on the noise and baseline. Two methods on obtaining gain correction factors for reweighing the gains between different high voltage settings are compared. Results on the efficiency of a CASTOR jet trigger are compared for LHC Run 2 collision data and Monte Carlo event generator predictions.
Results on CASTOR Performance during LHC Run 2

CMS Collaboration
contact: hn-cms-castor@cern.ch

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CASTOR: forward non-compensating sampling Cherenkov calorimeter
Successfully took data during startup Run 2 (B=0T only)

Content:
- Results on CASTOR alignment. Improved alignment w.r.t. Run 1
- Pedestal signal spectrum analysis, improved w.r.t. Run 1
- Single channel beam halo muon spectrum for intercalibration of CASTOR
- Pull distribution on gain correction factors obtained by complementary analysis methods
- Run 2: CASTOR jet triggers applied for first time. Trigger efficiencies are displayed
Alignment CASTOR during LHC Run 2 (B=0T)

Figure: Illustration of the global fit result of the CASTOR position for data taking during LHC Run 2 pp collisions with $\sqrt{s} = 13$ TeV (B=0T). The nominal positions of the infrared sensors (gray) are shown as well as the reconstructed positions (green). The measured distances of the sensors with respect to the beam pipe are shown as lines attached to the round markers. The results shown here represent the face of CASTOR pointing towards the CMS interaction point, where the solid black lines indicate the inner boundary of the two independent halves. The distance to the interaction point is about 14 m. The precise alignment of CASTOR is very important since small changes have a large impact on the acceptance in units of pseudorapidity.
**Pedestal Signal Spectrum noisiest Capacitor (B=0T)**

![Pedestal Signal Spectrum noisiest Capacitor](image)

**Figure:** Pedestal signal spectrum for a typical CASTOR channel for cathode/last dynode Voltage of 1800/100 V (black, with Gauss fit), 1500/80 V (pink) and HV off (blue). The noise distribution and its statistical width depend strongly on the HV setting. The mean and width of the Gaussian are taken from the noisiest capacitor for each channel for determining the noise level. The 1800V setting was used for collecting muon events. At 1800V the fitted RMS averaged over all channels is 2.9 while the mean statistical RMS is 3.4.
CASTOR is equipped with fine mesh PMT’s (Hamamatsu R5505 and R7494)

3 Noise contributions in pedestal signal spectrum at 1800 V:
- Electronic noise: \(\approx 3 \text{ fC}\), no dependence on Voltage
- Thermal photoelectrons: \(\approx 100 \text{ fC}\)
- Discharges: max. \(5 \cdot 10^3 \text{ fC}\)

For the baseline and noise per channel in Run 2, parameters from a fit of the electronic noise were used instead of the statistical RMS, since the latter is a large overestimation of the noise!

An 8 \(\sigma\) tower cutoff from pedestal analysis: \(\approx 1.4 \text{ GeV}\).
Figure: Signal spectrum for a typical CASTOR channel after an offline isolated muon event selection. The overlaid noise distribution is measured from non-colliding bunch data. The model line corresponds to a mesh-type PMT (CASTOR uses the Hamamatsu R5505 and R7494) with an average number of photoelectrons $\langle n_{PE} \rangle$ of 0.5. The selection threshold used to identify channels above noise is shown as vertical line. The average signal of the muon spectrum in all channels is used to estimate the relative gain of all channels to intercalibrate CASTOR.
Data Collection and PMT Simulation

- Muon events were collected with a dedicated CASTOR trigger during circulating beam periods of the LHC pp $\sqrt{s}=13$ TeV run (B=0T), and subsequently analysed offline.

- Offline selection criteria:
  - Veto events with more than 1 tower above tower threshold
  - Require one sector with minimally 3 channels above channel selection threshold (see vertical line in figure) in different longitudinal regions

- The noise spectrum and tower threshold cutoff was determined from randomly selected events from non-collision bunch data.

- A simple PMT toy model (assuming only Poissonian fluctuations) is fitted to the data and describes the data reasonably well. The fit optimises to an average of $\approx 0.5$ photoelectrons per event. This explains why a peak in the muon signal spectrum is not observed in data and simulation.
Gain Correction Factors for CASTOR Channel (B=0T)

Weighted Difference Gain Corr Fact. LED and Survey

\[ \Delta G_{\text{corr}} = \frac{(G_{\text{corr}}^\text{LED} - G_{\text{corr}}^\text{Survey})}{\sqrt{\sigma_{G_{\text{corr}}^\text{LED}}^2 + \sigma_{G_{\text{corr}}^\text{Survey}}^2}} \]

Intersection good channels

Figure: Pull distribution with Gauss fit of gain correction factors determined by a dark box PMT survey (in laboratory) and statistical analysis of LED and pedestal spectrum analysis (in situ). For both methods a different fraction of CASTOR channels gives reliable gain estimates, the comparison is therefore done for the intersection of channels were both methods were reliable. The properties of the fit to the pull distribution indicate both methods yield consistent results on the gain correction factors.
Additional Information Gain Correction Factors (I)

Correcting Gains from Muon to Physics Voltage

- Two high voltage recipes applied at CASTOR during beam periods:
  - $G(hv_{phys})$: Custom gain recipe optimised to maximal dynamic range for collision data taking
  - $G(hv_\mu)$: Recipe with maximal gain values for collecting muon data during circulating beam periods

- Two methods to determine gain correction factors:
  - Dark box PMT characterization (B=0T only):
    characterise electronic gain in lab by dark box measurement for various Voltage values. Parameterise electronic gain by $G_e(V) = c \cdot (V)^k$
  - Statistical analysis: obtain gain correction factors by evaluating $\frac{G(hv_{phys})}{G(hv_\mu)}$. Obtain $G$ by statistical analysis LED and pedestal spectrum
Additional Information Gain Correction Factors (II)

Statistical Method vs Dark Box Survey

- Survey and statistical method give consistent results on gain correction factors.
- Errors on gain correction factors for Survey (1%) smaller than for statistical method (17%). Likely due to serial measurement and fit. Only for B=0T.
- Statistical method works as well in situ and at $B \neq 0$T!
CASTOR Medium Jet Trigger Efficiency (B=0T)

Figure: Trigger efficiency of CASTOR Medium Jet Trigger in LHC Run 2 zero bias pp $\sqrt{s} = 13$ TeV data and a Pythia 8 Monte Carlo minimum bias event sample (B=0T). The efficiency is defined as the fraction of events with an offline reconstructed leading jet that cause a jet trigger. The Medium Jet Trigger fires on CASTOR sectors above 850 GeV. The trigger becomes fully efficient in data and MC above a reconstructed jet energy of $\approx 1900$ GeV. In data the trigger fires on raw detector signals on which no gain corrections have been applied yet, causing the differences in efficiency between data and Monte Carlo.