BCM1F and Luminosity calibration

CMS Collaboration

Abstract

The Fast Beam Condition Monitor (BCM1F) provides a real time bunch-by-bunch luminosity measurement. The stability of the calibration and the linearity of the system is monitored with regular emittance scans. This note shows the stability and linearity results for 2017. The absolute calibration is obtained in a special Van der Meer (VdM) fill. To correct for non-gaussian beams, special beam imaging scans are performed. The orbit drifts during the VdM scan are studied and corrected for. The results for the 2017 beam imaging scan and the orbit drift are shown.
BCM1F and Luminosity calibration plots

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Introduction to the BCM1F detector

The Fast Beam Condition Monitor BCM1F consists of 10 poly-crystalline CVD 5 mm x 5 mm diamonds positioned 1.8 m on either side of the interaction point at a radius of 6.5 cm from the beam pipe. Each diamond is metallized with two 1.75 mm x 3.5 mm pads. Additionally 8 n-in-p silicon diodes of 2.5 mm x 2.5 mm are used to compare the detector performance of the two types of sensors and produce independent results with different systematic uncertainties. The signal is read out, shaped by a frontend ASIC, and converted to an optical signal which is then transmitted to the backend electronics in USC55. The data travels parallel paths: a discriminator path registers the time of signal pulses and transfers this information to dedicated fast readout electronics, while an ADC system captures full orbits for monitoring studies but is prevented from acting as data readout by a high deadtime.

CMS.BCM1F provides information on the condition of the beam and ensures that the inner detector occupancy is sufficiently low for data-taking. In addition to providing beam information, CMS.BCM1F also detects collisions and as such is used as a luminometer.
Luminosity during VdM scan

This plot shows the BCM1F luminosity during one of the scan pairs in the 2017 VdM fill (#6016). The separation of the beams in X and Y are shown in the lower plot for the same time. The separation is given by the nominal separation value of the beams. This is an introductory plot to explain how a VdM scan works.
A Van der Meer-like (VdM) scan, also called emittance scan, with 7 scan steps up to a beam separation of 3 sigma, is performed in every fill at operational conditions. The output of the VdM analysis is the visible cross-section or \( \sigma_{\text{vis}} \). While the result of these scans has limited precision, it is used as monitoring tool for relative stability. The plot shows the results of these scans performed at the start of stable beams (bunch luminosity > 5 Hz/\(ub\)) for the BCM1F detector for all high luminosity fills at 13 TeV during 2017 since fill 6016 (VdM fill).

The degradation is due to several factors: Radiation damage to optical hybrids, radiation damage to sensors, change in filling scheme and towards the end of the year it was necessary to change the operational HV of some of the sensors to avoid excessive noise. Hence the degradation is not explained by a single parameterization.
BCM1F linearity

The VdM-like scans during nominal operation are performed at different luminosities. The result shows a different detector efficiency at different Single Bunch Instantaneous Luminosity (SBIL), implying a non-linear detector response. A linear fit to the data is used to parameterize the non-linearity and the result is used correct the luminosity data. Shown here is the data between fills 6050 and 6150 since this was a period of relative stability. Only fills with more than 100 bunches are used.

SBIL is calculated from measurement itself. The calibration factor obtained in this particular scan is applied to the uncalibrated peak value of this scan. An average over the whole fill is used, since for the sigma_visible value also all bunches are averaged. While the calibration should be precise, the non-linearity can have some influence on the VdM result. This effect is however minor. By using SBIL calculated by other luminometers, the results on the non-linearity are similar within a few percent, which is well within the precision these short scan.
During the 2017 Van der Meer scan program in fill 6016, the CMS experiment performed a set of four Beam Imaging scans. In each scan, one beam is moved in steps across the other beam along one transverse direction. By measuring the positions of the interaction vertices during all steps with the CMS tracker system, the transverse proton densities of the two beams can be reconstructed. For a simultaneous fit of the data collected during all four scans, two-dimensional proton density models built from normal distributions are employed. The fit results are used to test the assumption of factorizable beam proton densities that is made in the Van der Meer calibration of the CMS luminosity measurement, and allow for a correction of deviations found.

The plots show the fit results for the data recorded for bunch crossing number (BCID) 2063 during the X-scan of the second beam as a two-dimensional pull distribution (left) and projected to radial and angular coordinates (right). The employed fit model is a normalized sum of three two-dimensional normal distributions with different weights, where the component with the smallest Gaussian widths gets a negative weight (called Super Double Gaussian fit model). The method of using a Super Double Gaussian fit has been shown in CMS-PAS-LUM-17-001. The pull distributions show a good agreement between the fitted model predictions and the recorded data.