Introduction: emittance scans

The number of hits per bunch crossing (BX) follows a Poisson distribution. The probability of a certain number of hits is described by

\[ p(n) = \frac{\mu^n e^{-\mu}}{n!} \]

where \( \mu = -\ln(1 - p(0)) \) is the mean number of hits per BX. The occupancy per channel is low, this is a good method to determine the mean value of the number of hits per orbit per bunch crossing \( \sigma \) for luminosity calculation.

Luminosity calibration

A single Gaussian function is used to fit the emittance scan shapes. The peak rate in X (\( R_x \)) and Y (\( R_y \)) is obtained from the fit and used to calculate the cross-section also called sigma visible (Sigma\( \sigma \), \( \sigma_{vis} \)).

\[ L = \frac{\mu}{\sigma_{vis}} \]

\( \sigma_{vis} \) values are used for luminosity calibration and to monitor the stability and linearity of BRIL detectors.

Per bunch crossing \( \sigma_{vis} \) measurement

Two algorithms are used for nonlinearity measurement: one based on transverse overlap width in X and Y obtained from CMS emittance scans. Two independent analyses of emittance scans are launched: a Python-based offline framework and an online XDAQ-based application. Results are published on the monitoring web-pages in real-time for the XDAQ-based analysis and typically within 15 minutes for the Python-based framework, which has however the advantage of being re-usable.

Emittance scans for CMS luminosity calibration


1CERN, 2Soft University, 3Vilnius University, 4University of Tennessee Knoxville, 5DESY-Hamburg, 6Padua University, 7Princeton University

Abstract

Emittance scans are short von der Meer type scans performed at the beginning and at the end of LHC fills. The beams are scanned against each other in X and Y planes in 7 displacement steps. These scans are used for LHC diagnostics and since 2017 for a cross check of the CMS luminosity calibration. An XY pair of scans takes around 3 minutes. The BRIL project provides to the LHC three independent online luminosity measurement from the Pixel Luminosity Telescope (PLT), the Forward calorimeter (HF) and the Fast Beam Condition Monitor (BCM). The excellent performance of the BRIL detector front-ends, fast back-end electronics and CMS XDAQ based data processing and publication allow the use of emittance scans for linearity and stability studies of the luminometers. Emittance scans became a powerful tool and dramatically improved the understanding of the luminosity measurement during the year. Since each luminometer is independently calibrated in every scan the measurements are independent and ratios of luminometers can be used as a final validation for 2017 data. Two independent analyses of emittance scans are launched: a Python-based offline framework and an online XDAQ-based application. Results are published on the monitoring web-pages in real-time for the XDAQ-based analysis and typically within 15 minutes for the Python-based framework, which has however the advantage of being re-usable.

BRIL luminometers

Pixel Luminosity Telescope (PLT).

Fast Beam condition monitor (BCM1F).

6 BCM1F sensors and dedicated ASICs mounted on PCB.

Stability and nonlinearity monitoring

\( \sigma_{vis} \) obtained in all early emittance scans performed in 2017 operation, show in Fig.6, were used to monitor the efficiency of the PLT detector. The downward trends highlighted in pink show decreases in efficiency which were mitigated by an increase of the operational high voltage (HV). Time of the HV change is indicated with black lines. Technical stops and machine development periods are highlighted in light green. The gray vertical line points to the time of the filling scheme change from 8 bunches filled 4 bunches to 4 bunches filled 8 bunches. The smaller dips along the fill correspond to beam optimizations, which are performed to find the position where beams collide head-on or after a crossing angle change.

As early and late scans cover wide range of SBIL, a nonlinearity measurement is done for every fill. An example of linear fits of the \( \sigma_{vis} \) as a function of SBIL is shown in Fig.7 for leading and train bunches in red and blue respectively. One point of the plot corresponds to one of 3564 bunch crossings (BCID) in an orbit. A nonlinearity correction is applied for leading and train bunches separately taking into account the fraction of each type in a particular fill. In the (BB4e) filling scheme, the fraction of leading bunches is not negligible as it was for long bunch trains. Therefore emittance scans became a powerful tool to deliver nonlinearity corrections.

Summary

CMS emittance scans were run on a regular basis in 2017 at the beginning and at the end of fills. These short scans completed in 3 min became a powerful tool for luminosity calibration, stability and nonlinearity monitoring. Two independent applications are used for analyzing emittance scans. They show a +0.2% agreement and allow fast and easy access to analyzed data.