Emittance scans for CMS luminosity calibration

Peter Tsrunchev[1], Olena Karacheban[2] on behalf of the CMS collaboration
[1]Sofia University, [2]CERN

Introduction

The Beam Radiation Instrumentation and Luminosity (BRIL) project at CMS operates 3 online luminometers – the Forward Beam Conditions Monitor (BCM1F), the Pixel Luminosity Telescope (PLT), and the Hadron Forward Calorimeter (HF). Each of them provides a mean value of the number of hits per orbit per bunch crossing μ, which is proportional to the instantaneous luminosity L. Fig. 1 shows μ values from the PLT during LHC fill 6241. Each luminometer is characterized by a visible cross section σ_{vis} which is the calibration coefficient between the detector rates R and luminosity

$$L = \frac{R}{\sigma_{vis}} \qquad (1)$$

The visible cross section is determined through a van der Meer (VdM) scan program conducted under special conditions (low pile-up, no crossing angle, high β^*) once a year. In it the two beams get scanned across each other in both the x and y axes of the collision plane. A Gaussian-like shape is fitted to each scan to get the convolved widths Σ_X and Σ_Y, along with the fitted peak rate values R_X and R_Y. The visible cross section is then calculated as:

$$\sigma_{vis} = \pi \Sigma_X \Sigma_Y (R_Y + R_X) \qquad (2)$$

Emittance scans

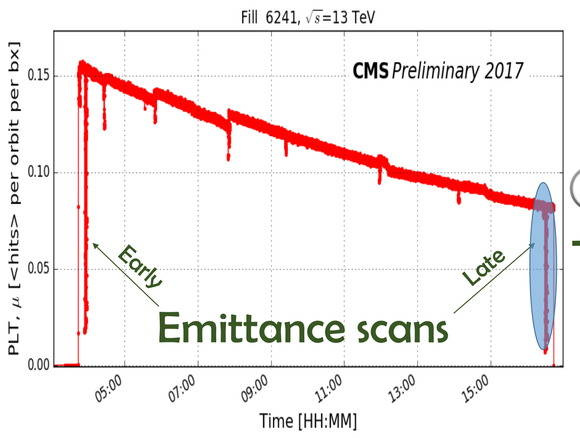

Fig.1. μ values for the PLT during the whole fill 6241.

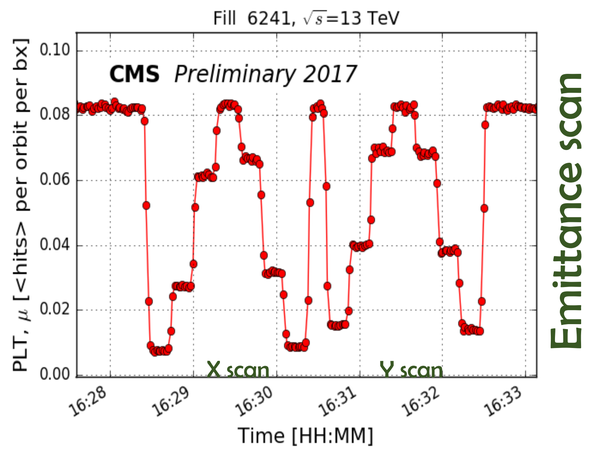

Fig.2. . μ values for the PLT during late emittance scan.

Fit

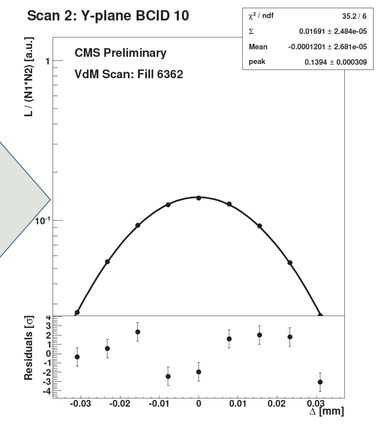

Fig.3. A Single Gaussian fit to emittance scan shape.

Since the start of 2017, at the beginning and end of each normal-conditions fill, a 7-9 step van der Meer-like scan is conducted (the big dips in μ on Fig. 1, also zoomed in on a "late" scan pair on Fig. 2). Each step is 10 seconds, making use of the detectors' fast readout systems. Data from each bunch for each of the scans gets fitted with a Single Gaussian shape (Fig. 3), then σ_{vis} is calculated using Eq.2 and the Single Bunch Instantaneous Luminosity (SBIL) is calculated using Eq. 1

Per-bunch measurements

These per bunch measurements (Fig. 4, Fig. 5) allow studies of train effects not present in normal VdM scans. Fitted peak positions (Fig. 6) can illustrate beam-beam kicks in the orbit, and were used by the LHC for beam dynamics studies and simulation benchmarking. Further collaboration with Beam Physics groups is needed to estimate the importance of this effect HL-LHC

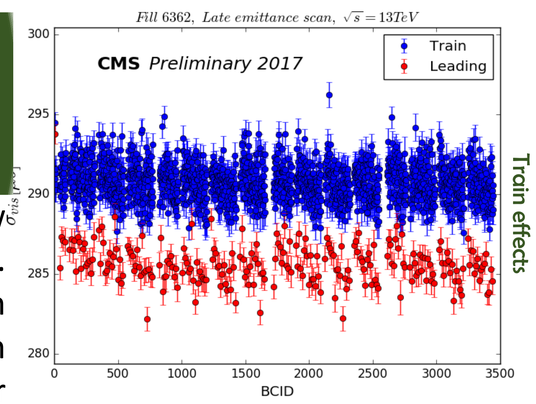

Fig.4. Visible cross-section as a function of bunch crossing (BCID) in Fill 6362 for PLT for leading and train bunches. Data from an early emittance scan is shown.

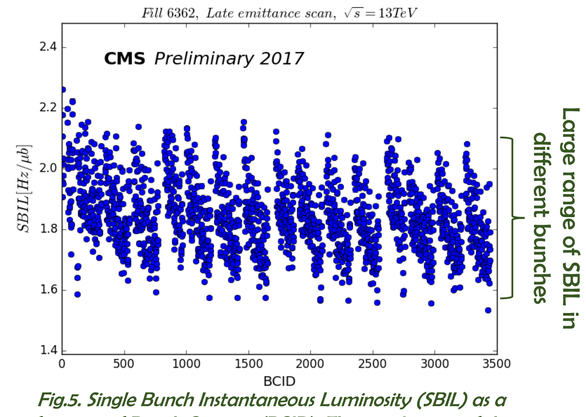

Fig.5. Single Bunch Instantaneous Luminosity (SBIL) as a function of Bunch Crossing (BCID). The usual range of the SBIL at the beginning of the fill is between 6 and 10 Hz/μb, while the SBIL range for the late scan strongly depends on the length of the fill..

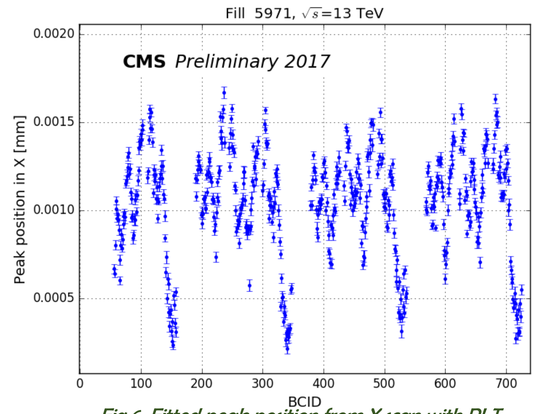

Fig.6. Fitted peak position from X scan with PLT measurements for several bunch trains.

Nonlinearity measurements

Plotting the σ_{vis} values from a single fill (Fig. 4) against the corresponding SBIL values (Fig. 5) shows a linear dependence between the two, illustrated with data from fill 6362 on Fig. 7. The dataset at SBIL=2 corresponds to the late scan, while the higher pile-up data is from the early scan. A data driven simulation shows this slope is linearly dependent on the nonlinearity in the detector rates. Emittance scans allow for a per fill nonlinearity measurement based on these fits (Fig. 8). A separate nonlinearity estimation can be made from a linear fit of cross section averaged over all the bunches in a fill versus the corresponding SBILs, shown on Fig. 9 for Si sensors of the BCM1F detector, which show very good linearity. This is done on a sets of fills with similar beam conditions. The results are consistent with each other when the per fill train and leading bunch estimates get weighted according to filling scheme.

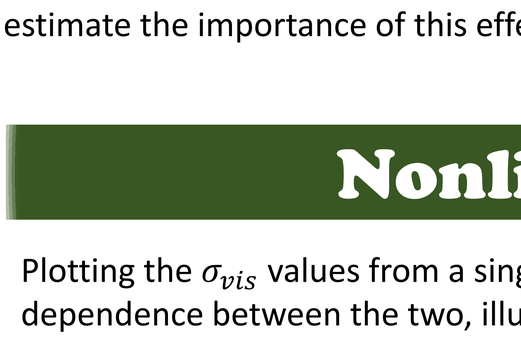

Fig.7. PLT visible cross section as a function of SBIL per bunch crossing in fill 6362

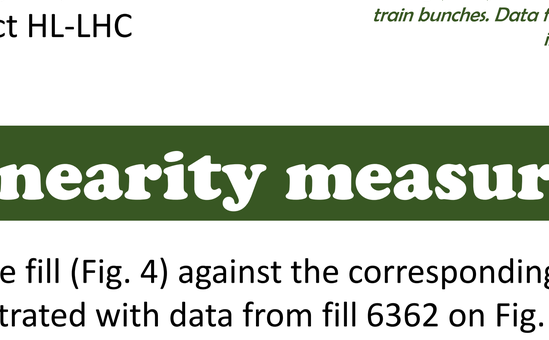

Fig.8. Slope of PLT visible cross section versus SBIL per Fill

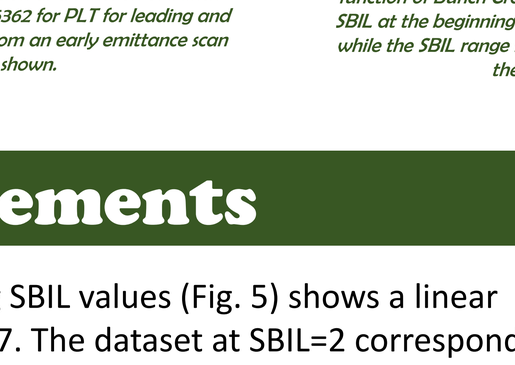

Fig.9. Average BCM1F Si sesonrs visible cross section as a function of average SBIL

Stability monitoring

Emittance scans are automatically analysed and the resulting measurements are displayed (plotted) on a web page serving as a quick reference check and as a long term stability monitor. Fig. 10 shows how emittance scan data shows stability issues – the highlighted areas correspond to periods where the PLT dropped in efficiency. Deficiencies were mitigated by raising the operational high voltage of the detector.

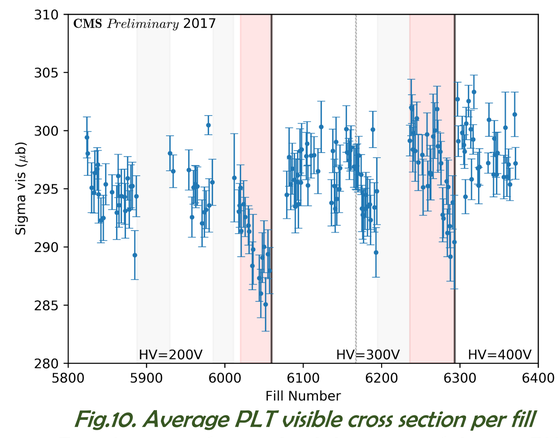

Fig.10. Average PLT visible cross section per fill Error bars signify standard deviation of the per BX measurements in the average

Emittance scans – summary

- Emittance scans are short van der Meer-like scans performed at the beginning and end of each fill at the LHC for diagnostics. In 2017, emittance scans were utilised by the BRIL project for calibration of the three online luminometers – BCM1F, HF and PLT thanks to their fast back-end electronics and readout systems
- Emittance scans can provide a nonlinearity measurement for each detector independently, supplementing comparison-based approaches of the past.
- Data from the scans is automatically analysed and results are posted to a web page for quick reference and long-term stability monitoring.
- Fitted peak position (mean value of Gaussian) can be used for bunch train structure studies involving beam-beam kicks in the orbit