Luminosity Measurements at CMS using DT Phase 2 Demonstrator

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Introduction

The CMS Beam Radiation Instrumentation and Luminosity (BRIL) group is in charge of the measurement of luminosity, beam conditions and radiation fields at the CMS experiment. The project operates and develops new detectors and techniques for measuring luminosity under phase 2 of the LHC upgrades [1].

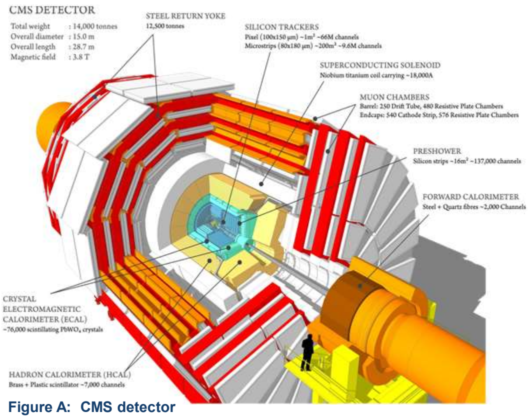


Figure A: CMS detector

Luminosity is one of the most important performance parameters of an accelerator. CMS has at least four detectors in charge of delivering this kind of measurements.

What is Luminosity?

- ✓ In a simplified manner, it is defined by eq. 1 as the number of events detected per unit time. It depends on the number of bunches (n), number of protons (N), machine frequency (f) and the beam width parameters ($\sigma_x\sigma_y$).
- ✓ Luminosity ($\mathcal{L}$) can be related to the number of collisions inside an accelerator in a given amount of time. If the cross section (σ) of a physics process is known, the luminosity can be used to compute the rate (R) of that process (eq 2).

Generally, accelerators tend to maximize their integrated luminosity. This translates into more data available for offline analysis.

$$\mathcal{L} = \frac{nN^2 f}{2\pi\sigma_x\sigma_y} \quad (1)$$

$$R = \dot{N} = \frac{dN}{dt} = \sigma\,\mathcal{L} \quad (2)$$

Luminosity at the LHC

- ✓ The LHC particle beam is arranged into discrete packets of protons called **bunches.**
- ✓ The beam can circulate for several hours under normal operating conditions. However, it degrades as time passes.
- ✓ The point where the two rotating beams collide is called the interaction point (IP)

The LHC usually operates with around 2500 bunches of protons that circulate in each ring inside the machine.

Each bunch is 25 ns apart from each other and each of them contain roughly 100 billion protons.

This means that the time to complete one orbit is

$$1\,orbit = 3564 \cdot 25\,ns = 89\,\mu s,$$

where 3564 is the total number of spaces for a bunch.

We define a lumi nibble (NB) as the time it takes to complete 4096 orbits: $1\,\mathrm{NB} = 4096\,orbits = 0.36\,\mathrm{s}$

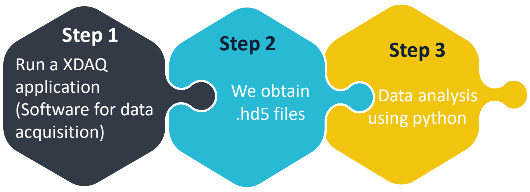
- In order to increase the probability of producing and observing rare events, a large number of collisions is required.
- Each crossing of beams produces about 1 MB of raw data. Given that the crossing rate is 40 MHz, this adds up to the unmanageable amount of 1 TB of data per second. This is the reason a trigger system is required.

Luminosity measurements at CMS

One of the ways CMS will measure the luminosity during LHC Phase II is by using the rates of muon trigger primitives, that is the Drift Tubes (DT) luminometer.

The tests that are currently being carried out during RUN 3 are called DT demo.

How to extract this information?



Preliminary plots

Figure B illustrates the mean number of hits of each bcid recorded by all the channels or boards of the DT system. On the other hand, this also shows that the board 0 is more efficient compared to the others.

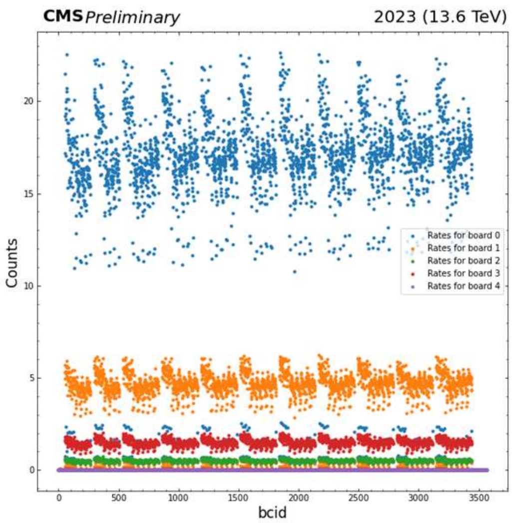


Figure B: Average number of hits for each bunch crossing

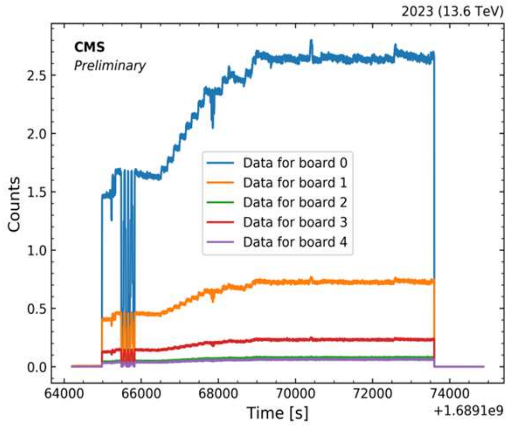


Figure C: Raw rates from DTLumi system (normalized by number of aggregated orbits) during Fill 9063

Figure C illustrates raw rates (muon trigger primitives) measured by multiple channels of DT Phase II demonstrator during Stable beams Fill 9063. The rates correlate with measured luminosity by other BRIL dedicated systems and follow the change in the machine status and beam parameters (e.g., beta*, leveling, optimization, and emittance scan).

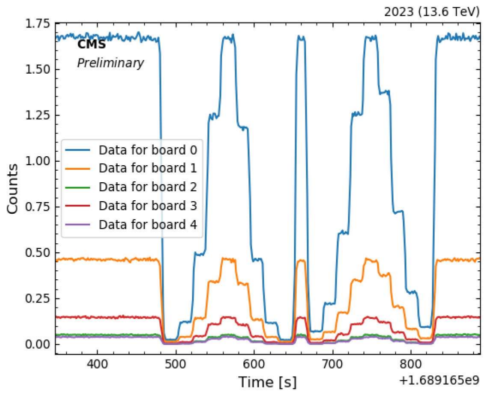


Figure D: Raw rates during emittance scan performed by LHC (Fill 9063)

Figure D shows raw rate of DT system during an emittance scan, which is used to calibrate the detector (to convert raw rates to luminosity $Hz/\mu b$). For example, for board 0, the maximum number of counts, approximately 1.75, is the point when head-on collisions take place.

Then, when the beams are separated, the number of counts decrease almost to zero. After that, the beams are moved to extract beam shape (profile), which helps us to perform calibrations.

Conclusions

We executed the XDAQ application chain to retrieve trigger primitives data from DT (demo system) and analyzed this information using python tools. We have found that there are background contributions to the luminosity observables up to the 10%.

We confirmed the validity of DT demo rates in emittance scan data with respect to other luminometers used by BRIL.

As an outlook to this project, It is important to include the online suppression of these backgrounds and to perform an initial calibration with emittance scan data.

Acknowledgements: The CMS collaboration and BRIL research group.

References

[1] Pompeo Marco Zanetti, G. (2016). Study of the performance of the CMS Pixel Luminosity Telescope
[2] Tsrunchev, P. (n.d.). Luminosity measurements at CMS