Cross detector stability studies in Run-II CMS luminosity

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Abstract

In this report is made a short review on what is luminosity and how is it computed at the Compact Muon Solenoid (CMS) at the Large Hadron Collider (LHC). RAdiation Monitoring System for the Environment and Safety (RAMSES) data for 2017 was extracted from LHC logging database and cross-calibrated to the Hadronic Forward calorimeter Transverse Energy sum method (HFET) data. Plots for cross detector stability were obtained and analysed in order to exclude instability regions. Cross detector stability uncertainty was computed for 2017 and the LHC Full Run-II resulting in 0.5% for both cases.

Contents

1 Luminosity

The quantity that measures the ability of a particle accelerator to produce the required number of interactions is called the luminosity. It is the proportionality factor between the number of events per second and the cross section (1). The unit of the luminosity is $cm^{-2}s^{-1}$.

$$\frac{dR}{dt} = \mathcal{L}\,\sigma_p \tag{1}$$

The integrated luminosity is taken over the sensitive time (2). It is directly related to the number of observed events (3).

$$\mathcal{L}_{int} = \int_0^T \mathcal{L}(t')dt' \tag{2}$$

$$\mathcal{L}_{int}\,\sigma_p \;=\; number\ of\ events\ of\ interest \tag{3}$$

1.1 Colliding beams luminosity

In order to compute a luminosity for colliding beams experiments, the properties of both beams are taken into account. It is done a convolution using 3D distribution functions of the beams (Fig. 1).

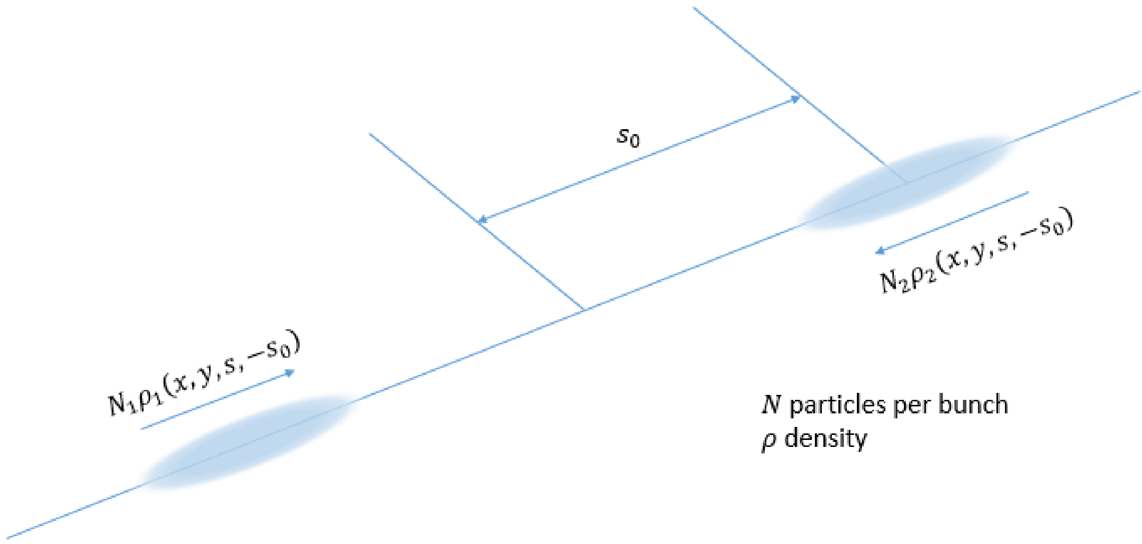


Figure 1: Schematic view of a colliding beam interaction.

In the case of bunched beams they are moving through each other, the overlap integral (4) depends on the longitudinal position of the bunches, so it is utilized the distance to the central collision point as the time variable $s_0 = ct$. A priori the beams have different distribution functions and different number of particles. For several bunches in a beam, N_b is the number of bunches per beam and f is the revolution frequency.

$$\mathcal{L} = N_1 N_2 f N_b K \int_{-\infty}^{+\infty} \rho_1(x, y, s, -s_0)\ \rho_2(x, y, s, s_0)\ dx\ dy\ ds\ ds_0 \tag{4}$$

$$\text{where } K = \sqrt{(\vec{v_1} - \vec{v_2})^2 - (\vec{v_1} \times \vec{v_2})^2/c^2}$$

1.2 Cross detector stability uncertainty

In order to get the luminosity, rate of event is measured in a detector obtaining a magnitude proportional to the luminosity. That factor of proportionality is called visible cross section of a detector and it is measured by doing Van der Meer Scans or cross calibration with other detectors. There are two kinds of uncertainties on luminosity measurements: time integration and normalization. Cross detector stability is among the time integration uncertainties and the source of it is that VdM Scan is made once a year and the calibration is not stable in that period of time. Therefore it has an impact on integrated luminosity.

2 The CMS Detector

The Compact Muon Solenoid (CMS) [1] is one of two general purpose experiments at the Large Hadron Collider (LHC) [2] at CERN, Geneva, Switzerland. To match the LHC physics program requirements, the CMS was designed to reach good resolution and to deal with high particle rates and radiation damage. In order to distinguish among different types of particles and reconstruct tracks several subsystems are built in cylindrical layers on top of each other around the beam pipe. Cylinders are closed with the end-cups to detect particles at small polar angle. Tracking detectors are positioned around the beam pipe, surrounded by calorimeters, a superconducting magnet and a muon detection system as the most outer part [3].

2.1 Luminosity measurement at CMS

The knowledge of the integrated luminosity requires stability over long periods of time. Combination of redundant measurements can lead to improved precision. For that reason, several luminometers along with algorithms to estimate instantaneous luminosity are used (Fig. 2).

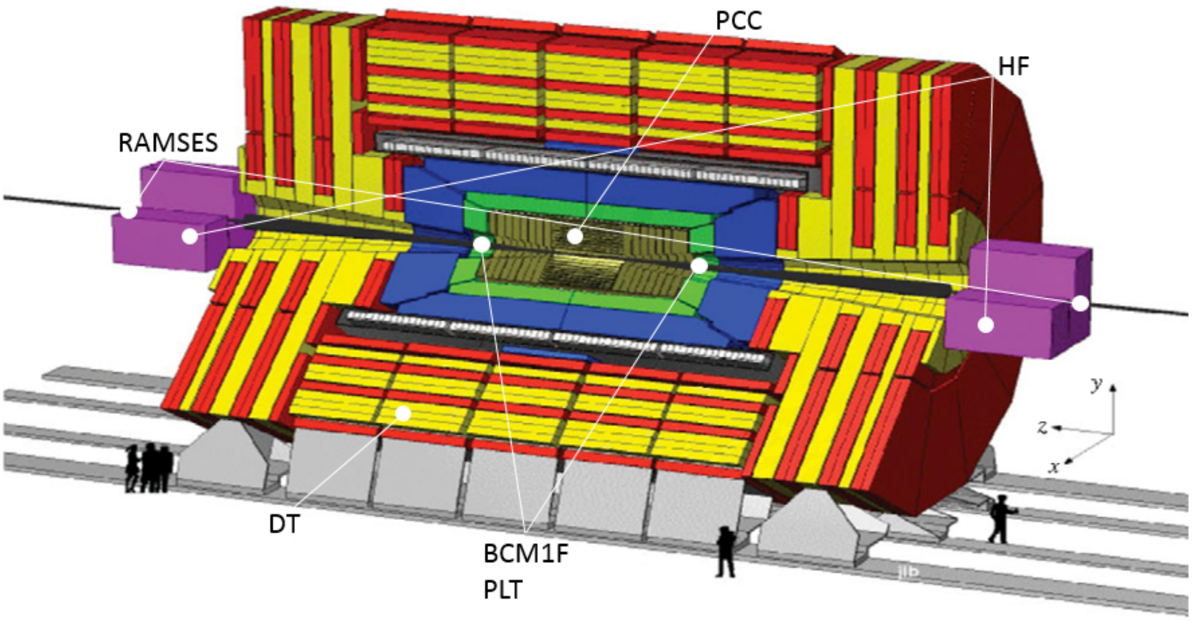


Figure 2: CMS luminometers.

Online luminometers:

- Hadronic Forward calorimeter, Transverse Energy sum method (HFET) and OCcupancy based method (HFOC).
- Pixel Luminosity Telescope (PLT).
- Beam Condition Monitor-Fast (BCM1F).

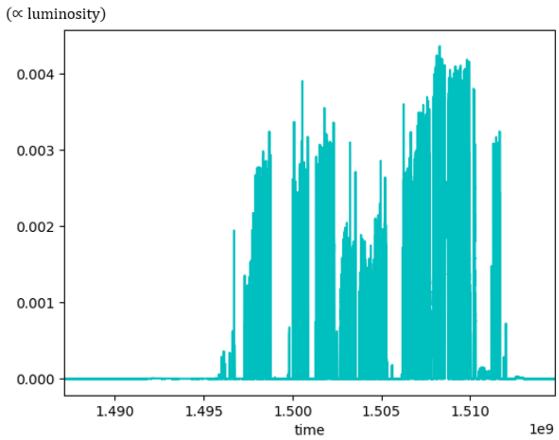
Offline luminometers:

- Muon Drift Tubes (DT).
- Pixel Cluster Counting (PCC or PXL).
- RAdiation Monitoring System for the Environment and Safety (RAMSES).

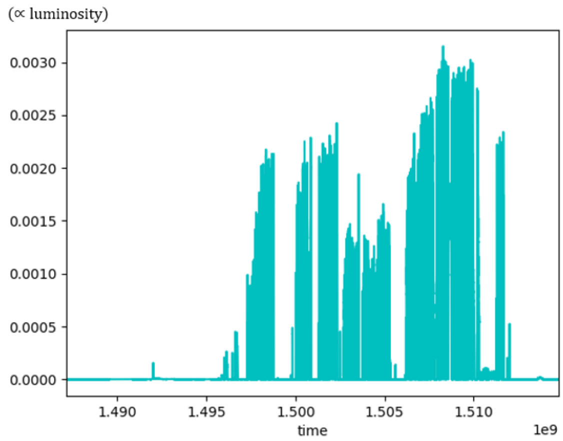
3 Results

3.1 Calibration of RAMSES 2017 data

The RAMSES data from 2017 was extracted from the LHC logging data base. It corresponds to the names "PMIL5514:DOSE_MEAS" and "PMIL5515:DOSE_MEAS", which were called RAMSES 1 and RAMSES 2 respectably. In Fig. 3 are shown the dependences of some magnitude assumed to be proportional to luminosity with time, in timestamps from UNIX, for RAMSES 1 and 2.



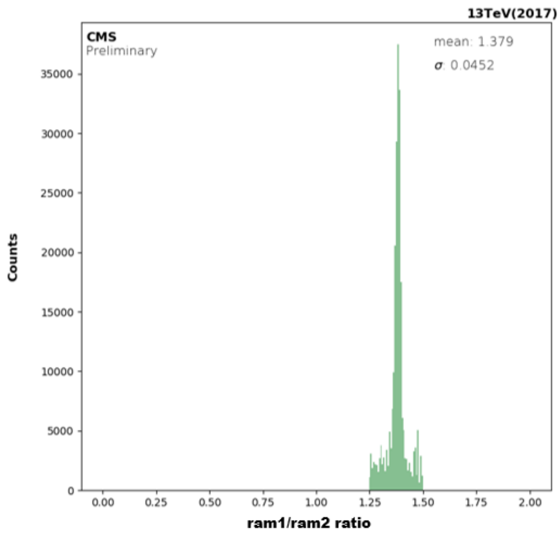
(a)



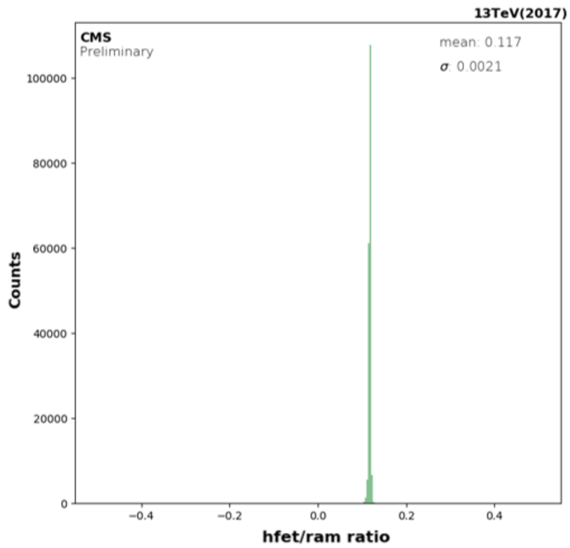
(b)

Figure 3: RAMSES data, (a) "PMIL5514:DOSE_MEAS", (b) "PMIL5515:DOSE_MEAS".

The mean ratio between RAMSES channels was calculated (Fig. 4a). Using this value, RAMSES 2 was normalized to RAMSES 1. After that, they were joined computing the mean value between both. Once done that, RAMSES mean was calibrated to HFET (Fig. 4b).



(a)

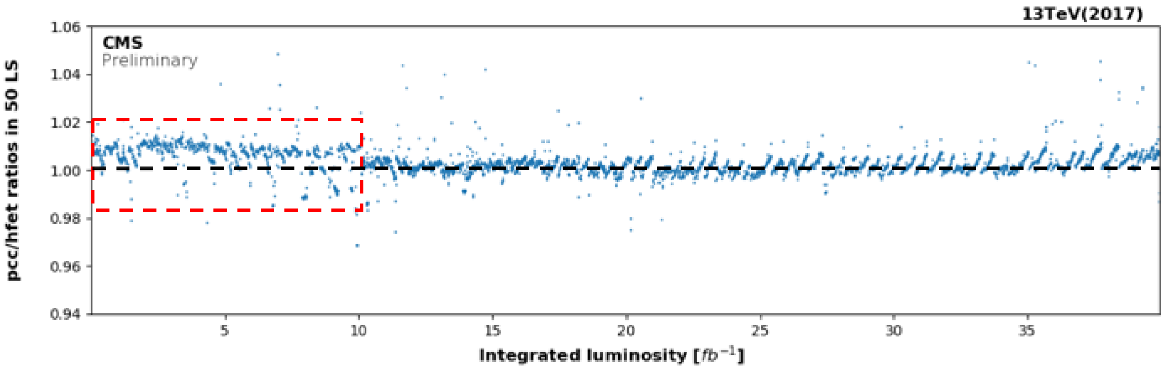


(b)

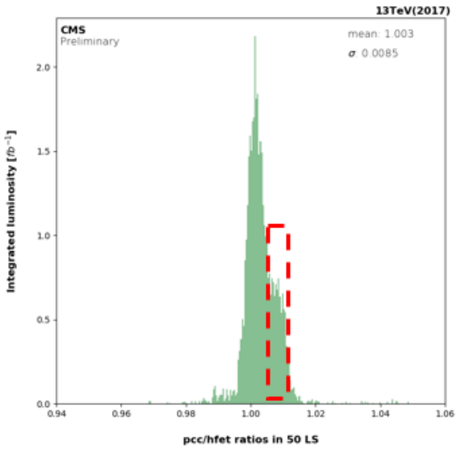
Figure 4: RAMSES data, (a) "PMIL5514:DOSE_MEAS", (b) "PMIL5515:DOSE_MEAS".

3.2 Cross detector stability in 2017

First we made the 2017 cross detector stability for PCC vs. HFET. We calculate the ratio between the two detectors along the year which corresponds to the integrated luminosity (Fig. 5a) and make a histogram of this ratio weighted to the luminosity of each point (Fig. 5b), this gives us information about the cross detector stability but it is not enough to identify which one is responsible for bad data points. HFET was used as the reference detector for having shown the best behaviour.



(a)



(b)

Figure 5: (a) Ratio PCC/HFET vs. Integrated Luminosity, (b) Ratio PCC/HFET histogram wighted to the integrated luminosity.

A shift can be seen at low integrated luminosity in Fig. 5a, but this kind of plot does not allow to distinguish which detector has bad behaviour.

There is a previous result for 2017 cross detector stability but uses only one detector pair. Our goal is to include the study of all available luminometers which is consistent with 2016 and 2018 method.

Using three detectors it can be deduced which of them is the source of the problem.

For example, in HFOC-PCC-HFET (Fig. 6) we can see the same shift at the beginning in HFOC/HFET, so it corresponds to HFET. It can also be seen that the mean value of HFOC ratios are 1.02. This is not a bad result considering PCC and HFOC had a completely independent calibration.

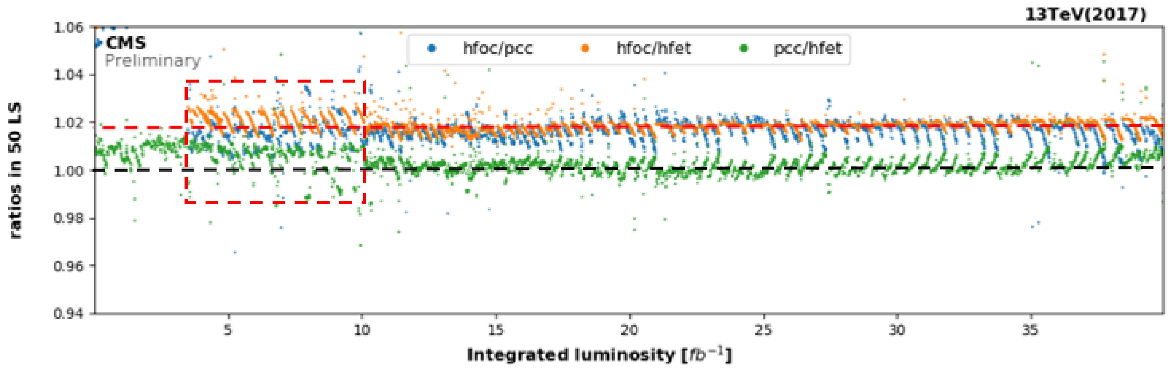


Figure 6: Ratios HFOC/PCC, HFOC/HFET and PPC/HFET vs Integrated luminosity.

Using a higher scale, we can see some instability regions at the beginning in HFOC (Fig. 7). In order to compute the cross detector stability uncertainty, we have to obtain the standard deviation of a histogram like the one in Fig. 5b. Instability regions increase the standard deviation, so its removal lowers the uncertainty. After done that, standard deviation in HFOC/HFET decreased from 0.0182 to 0.0027.

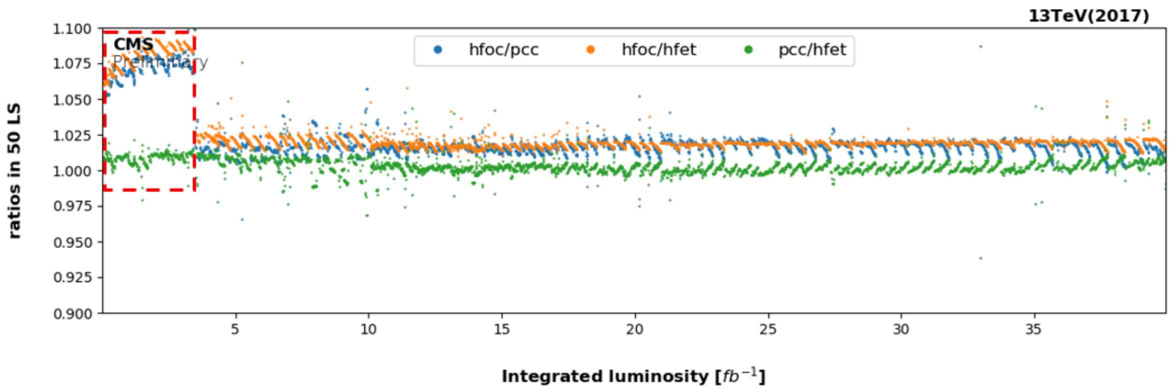


Figure 7: Ratios HFOC/PCC, HFOC/HFET and PPC/HFET vs Integrated luminosity.

The RAMSES data was formatted to be suitable for data processing. As mentioned before it was made an initial cross calibration to HFET. It is important to signalize that this is only a normalization, the behaviour of the data remains the same. It was compared with PCC and HFET using the same procedure that for HFOC. In Fig. 8 it can be observed several instability regions for this detector. Therefore, further investigation about this needs to be done.

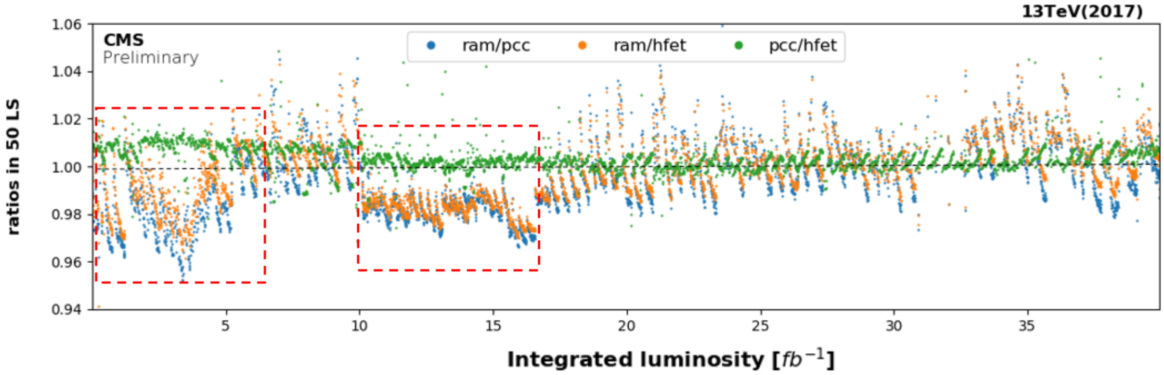


Figure 8: Ratios RAMSES/PCC, RAMSES/HFET and PPC/HFET vs Integrated luminosity.

We made a ranking of detectors standard deviation when compared to HFET (Table 1) and then calculate the ratio, normalized to one, of the best detector data and, if missing value, the second best and so on.

Table 1: Ranking of standard deviation for BEST/SECOND BEST analysis in 2017.

X/HFET	Standard Deviation
HFOC	0.0027
PCC	0.0051
PLT	0.0067
DT	0.0077
BCM1F-Si	0.0079
BCM1F-D	0.0155

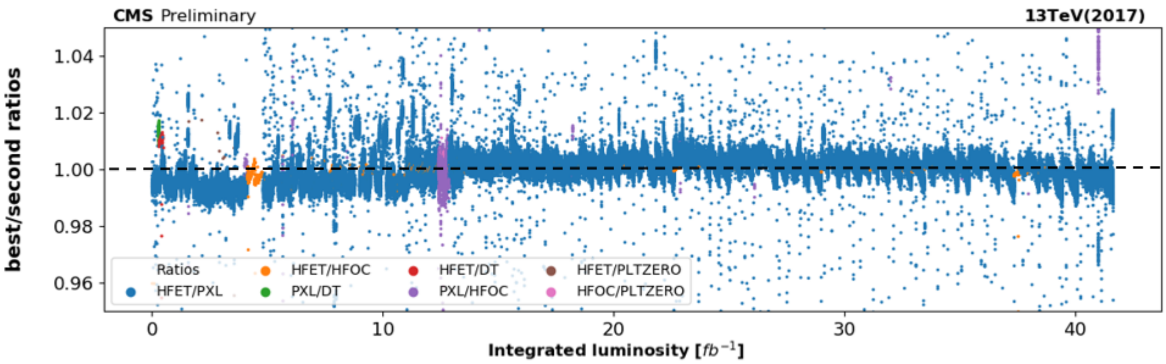


Figure 9: Ratio BEST/SECOND BEST vs Integrated luminosity in 2017.

From this we can evaluate the cross detector stability along 2017 (Fig. 9). The resulting uncertainty is 0.5%, when compared with the previous one is the same but this time using the same method as in 2016 and 2018 which allows us to calculate the Full Run II uncertainty.

3.3 Cross detector stability in Full Run-II

It was applied the same procedure but taking best/second best for 2016, 2017 and separately (Fig.). Since integral luminosity in full Run-II (137.19 fb^{-1}) was too high compared to the one in 2015 (3.80 fb^{-1}), this year was excluded from this analysis. The main contribution to the BEST/SECOND BEST analysis were PCC/HFOC for 2016 (pink), PCC/HFET for 2017 (green) and HFOC/PCC for 2018 (purple).

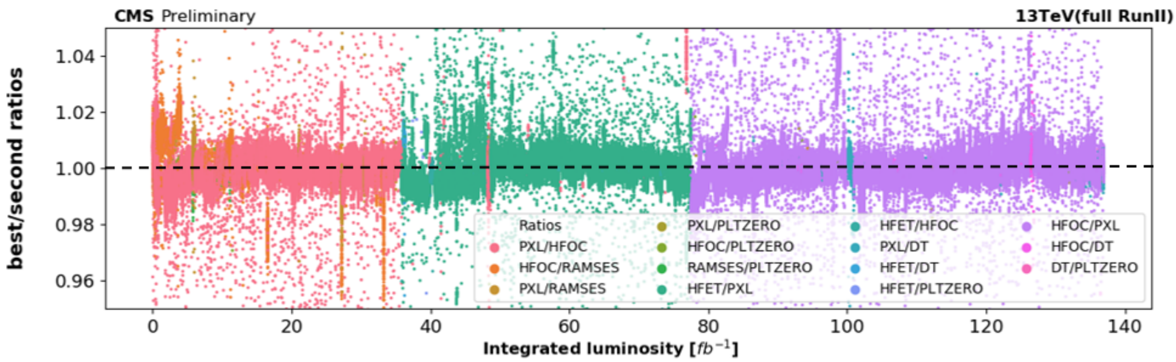


Figure 10: Ratio BEST/SECOND BEST vs Integrated luminosity in Full Run-II.

This gives us a uncertainty value of 0.5% for the full Run-II cross detector stability, which is a consistent result considering 2016, 2017 and 2018 were analysed independently and they show a similar behaviour.

4 Conclusion

It was made the RAMSES extraction cross-calibration to HFET. It was analysed the 2017 cross detector stability for every luminometer and was measured the uncertainty in that year. Also studies about the Full Run-II cross detector stability were made and it was computed the uncertainty in the whole period of time.

References

[1] The CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum., 3 (08):S08004, 2008.

[2] L. Evans and P. Bryant, LHC Machine, J. Instrum., 3 (08):S08001, 2008.

[3] O. Karacheban, Luminosity measurement at CMS, Doctoral Thesis 2017, Verlag Deutsches Elektronen-Synchrotrons.