Comparison of the ATLAS and CMS Luminosity Measurements during pp Collisions in 2010 at $\sqrt{s} = 7$ TeV

B. Heinemann, UC Berkeley and Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

In this article a comparison between the determination of the luminosity from the two large multi-purpose LHC experiments, ATLAS and CMS, is made. The luminosities measured in some individual example LHC fills are compared directly. In addition comparisons between several physics cross sections are made and their agreement is quantified. It is found that the measurement of the luminosity is consistent between the two experiments within the uncorrelated uncertainties.

INTRODUCTION

In this article a comparison of the CMS and ATLAS luminosity and cross section measurements is presented with the aim of understanding if both experiments receive the same luminosity from the LHC. In the following sections we first briefly describe the methods used for calibrating the absolute luminosity with emphasis on the differences between ATLAS and CMS. We then compare directly the luminosity measured by the experiments before we compare the cross section measurements based on that luminosity. Finally we conclude.

METHODS USED FOR THE CALIBRATION OF THE ABSOLUTE LUMINOSITY

Both ATLAS and CMS determine the absolute luminosity calibration using dedicated van-der-Meer scans as reported in these proceedings [1, 2]. This calibrated luminosity is reported online to the LHC and it is used offline by physics analyses in both experiments. The results presented in this report all rely on the preliminary calibrations derived from the van-der-Meer scans from April and May 2010 where the overall precision was 11% on the luminosity measurement. 10% of this uncertainty is, however, due to the beam current measurement and correlated between the two experiments. The strictly uncorrelated part of the luminosity measurement is 4.2% for CMS and 4.7% for ATLAS. The uncertainty on the ratio of the ATLAS to CMS luminosity measurement is thus 6.3% and this will be used to evaluate the consistency between the two experiments.

A major difference between the two experiments is that ATLAS counts *events* while CMS counts *hits*. The ATLAS method is rather sensitive to pileup pp interactions but ATLAS has demonstrated that this can be corrected for with an uncertainty $< 0.5\%$. The CMS method is intrinsically less sensitive to pileup and CMS quotes an uncertainty on this better than 1%.

COMPARISON OF THE LUMINOSITY MEASUREMENTS BY FILL

Both ATLAS and CMS report the luminosity as measured online to the LHC via DIP and these values are stored in the `TIMBER` database. We analysed the 18 fills taken with stable beams between 1364 (Sept. 22nd) and 1418 (Oct. 14th). Fig. 1 shows this comparison for two example LHC fills. In fill 1418 the value of this ratio is stable at 1.02 and this is typical: for 16 of the 18 LHC fills the ratio is consistent with 1.02 ± 0.02. There were two cases where a larger difference was observed, e.g. in fill 1397 also shown in Fig. 1. In this particular fill the ratio is about 1.06 during most of the fill. However, at the end the ratio goes back to 1.02. The reason in this particular case is that CMS did not report any luminosity measurement at the start of the fill so that the LHC was not able to optimize the luminosity. At the end of the fill LHC did a beam optimization scan and after that the ratio returned back to the typical value of 1.02. The other case where a larger difference was observed is 1372 during which the so-called *hump* was present. We observe a much larger emittance growth than usual and an apparent correlation between the horizontal and vertical plane. It is possible that this causes then a real difference in the two experiments due to e.g. the crossing angles being in different planes. This is not yet understood quantitatively.

COMPARISON OF CROSS SECTION MEASUREMENTS

In this section we compare cross section measurements from ATLAS and CMS.

W and Z Boson Production Cross Sections

Both experiments have published measurements of the W and Z boson cross sections based on 0.3 pb^{-1} (ATLAS [3]) and 2.9 pb^{-1} (CMS [4]). The values are given in Table 1.

Considering only the uncorrelated uncertainties the resulting ratios for the ATLAS to CMS cross sections are $1.00 \pm 0.06(\mathrm{stat} + \mathrm{sys}) \pm 0.06(\mathrm{unc.lumi})$ for the W cross section and $0.88 \pm 0.09(\mathrm{stat} + \mathrm{sys}) \pm 0.06(\mathrm{unc.lumi})$ for the Z boson cross section. These ratios are in good agreement within the uncertainties. This comparison is as not yet probing the luminosity to a precision better than 10% but is expected to achieve a precision much better than 5% when the full 2010 dataset is analysed and experimental uncertainties of both statistical and systematic nature will be much improved.

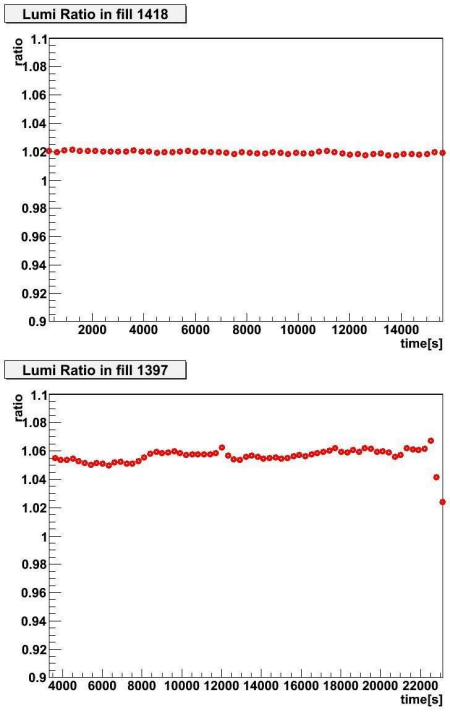

Figure 1: Ratio of the ATLAS to CMS instantaneous luminosity for LHC fills 1418 (top) and 1397 (bottom) as function of time during the fill.

Table 1: Cross sections for W and Z boson production as measured by the ATLAS and CMS collaborations. Also given is the ratio of the ATLAS to the CMS cross section measurement including only the uncorrelated uncertainties on the measurement. The ATLAS measurements are based on an integrated luminosity of 0.3 pb^{-1} and those of CMS are based on 2.9 pb^{-1}.

Experiment	$\sigma(W)$ (nb)
ATLAS	$9.96 \pm 0.55(\text{stat} + \text{sys}) \pm 1.10(\text{lumi})$
CMS	$9.95 \pm 0.29(\text{stat} + \text{sys}) \pm 1.09(\text{lumi})$
	$\sigma(Z)$ (nb)
ATLAS	$0.82 \pm 0.08(\text{stat} + \text{sys}) \pm 0.09(\text{lumi})$
CMS	$0.931 \pm 0.035(\text{stat} + \text{sys}) \pm 0.102(\text{lumi})$

Charged Particle Cross Section

During early LHC running another method was devised to allow for a direct comparion between the LHC experiments fill by fill by using the high statistics cross section of minimum bias interactions. While there exists no high precision theoretical prediction (as is the case for the W and Z boson cross sections [5]) for this process it can serve to compare the experiments fill by fill.

The ATLAS and CMS experiments have measured the cross section for events that have at least one primary charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ as this region ensures a high experimental acceptance in ATLAS, CMS and ALICE. Primary charged particles are defined as charged particles with a mean lifetime $\tau > 0.3 \times 10^{10}$ s either directly produced in pp interactions or from subsequent decays of particles with a shorter lifetime. The measurements are performed by selecting minimum bias interactions that have at least one reconstructed track and are corrected for any detector-specific effects such as the tracking and vertex efficiencies, the trigger efficiency, the pileup interactions etc. [6, 7, 8]. LHC fill 1089 taken in May 2010 was chosen for an initial comparison. The instantaneous luminosity in this fill was about 2.1×10^{28} cm^{-2}s^{-1} at the start and 1.3×10^{29} cm^{-2}s^{-1} at the end of the fill, and there was one bunch pair colliding in ATLAS and CMS. The average number of events per crossing is about $\mu = 0.1$. Both CMS and ATLAS did van-der-Meer-scans during this fill, and here only the part of the fill where no scan was performed is compared.

The rates of events are shown in Fig. 2. It is seen that the rate decreases as function of time due to the decrease in luminosity. It is also seen that the correction from the raw to the physical rate is about 10%. For the CMS measurement both the raw and the fully corrected rate is shown. For ATLAS the corrected rate is shown both with and without the pileup correction.

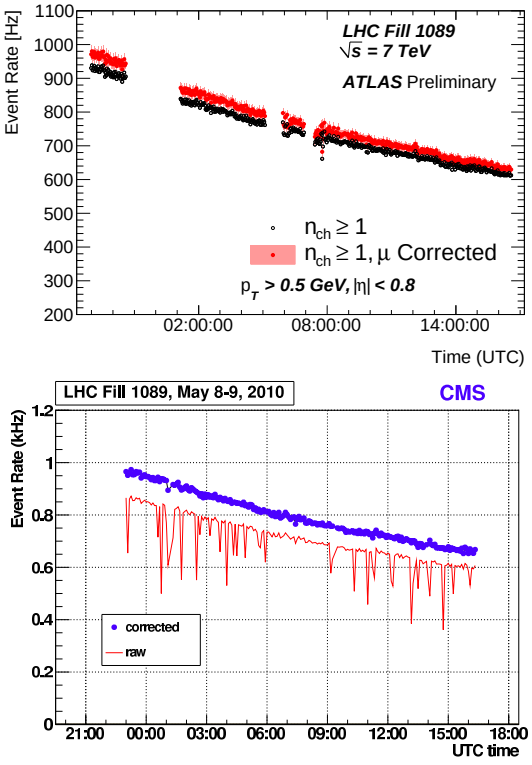

Figure 2: ATLAS (top) and CMS (bottom) measurements of number of events selected by the charged particle analysis. For ATLAS the corrected rate is shown with and without the correction for pileup. For CMS the raw and the fully corrected rate is shown. The dips in the raw CMS rate are due to deadtime and are corrected for in the final result. The overall deadtime correction for CMS integrated over the fill is well below 1%.

The overall correction factor (from raw to fully corrected) is about 10% at the beginning and 8% at the end of the fill: this time dependence is a result of the decreasing value of μ during the run, i.e. the decreasing pileup. In addition there are certain times when a much larger correction is applied due to significant deadtime. The overall correction factor for tracking, vertexing efficiency etc. is 1.040 ± 0.017 in ATLAS.

The cross section is shown for ATLAS and CMS in Fig. 3 after all corrections. ATLAS finds $\sigma_{ATLAS}(\mathrm{ChPart}) = 42.3 \pm 0.7(\mathrm{stat.+sys.})$ mb and CMS finds $\sigma_{CMS}(\mathrm{ChPart}) = 43.99 \pm 0.62(\mathrm{stat.+sys.})$ mb, and thus the ratio of the two cross sections is

$$R = 1.040 \pm 0.022(\mathrm{stat.+sys.}) \pm 0.062(\mathrm{unc.lumi}).$$

This assumes that all the expertimental uncertainties between the ATLAS and CMS measurement are uncorrelated as they are dominated by the understanding of the tracking efficiency. This ratio is again consistent with unity within the uncertainties quoted. Also, note that both measurements are flat vs time during this fill.

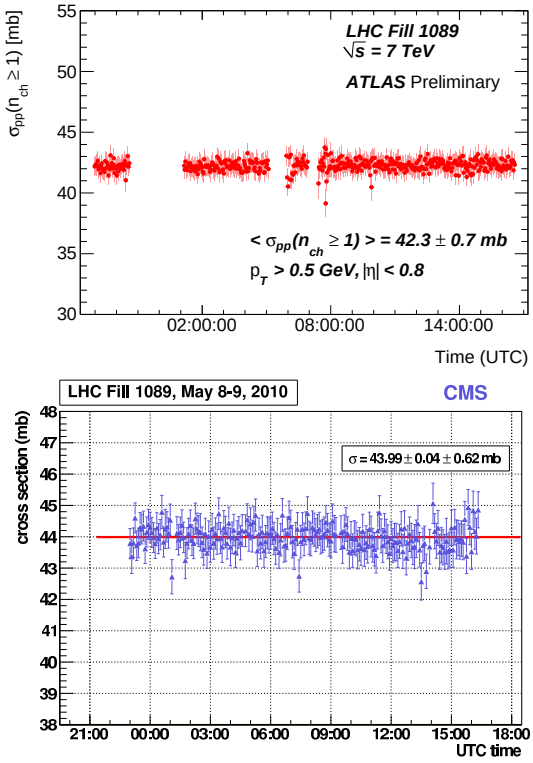

Figure 3: ATLAS (top) and CMS (bottom) measurements of the cross section for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ as function of time during LHC fill 1089.

CONCLUSIONS

A comparison between the CMS and ATLAS measurements for the luminosity has been presented. For most fills the two luminosity measurements agree to within 2%. The cross sections of W and Z boson production and of the production of events with a prompt charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ also agree to within the uncorrelated systematic uncertainties. It will be interesting to repeat this comparison when the uncertainty on the W and Z cross section measurements is improved using the full 2010 datasets. Also, since the time of writing these proceedings the luminosity precision has been improved significantly (e.g. to 3.4% by ATLAS [11]) using the van der Meer scan from October 2010, and the much improved understanding of the beam current uncertaunties [9, 10]. These comparisons should be repeated with the updated much more precise luminosity calibration.

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