OPERATIONAL RESULTS FROM THE LHC LUMINOSITY MONITORS*

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Abstract

The luminosity monitors for the high luminosity regions in the LHC have been operating to monitor and optimize the luminosity since 2009. The devices are gas ionization chambers inside the neutral particle absorber 140 m from the interaction point and monitors showers produced by high energy neutral particles from the collisions. It has the ability to resolve the bunch-by-bunch luminosity as well as to survive the extreme level of radiation in the nominal LHC operation. We present operational results of the device during proton and lead ion operations in 2010 and make comparisons with luminosity measurements by AT-LAS and CMS.

INTRODUCTION

The Large Hadron Collider (LHC) at CERN can accelerate proton and lead ion beams to 7 TeV and 547 TeV respectively and produce collisions of these particles. Luminosity measures performance of the LHC and is particularly important for experiments at the high luminosity interaction points (IPs), ATLAS (IP1) and CMS (IP5). To monitor and optimize the luminosities of these IPs, BRAN (Beam RAte Neutral) detectors [1, 2] have been installed and operating since the beginning of the 2009 run [3].

The neutral particle absorber (TAN) protects the D2 separation dipole from high energy forward neutral particles produced in the collisions [4]. These neutral particles produce electromagnetic and hadronic showers inside the TAN and their energy flux is proportional to the collision rate and hence to the luminosity. The BRAN detector is an Argon gas (mixed with 6% of Nitrogen) ionization chamber installed inside the TANs on both sides of IP1 and IP5 and monitors the relative changes in luminosity by detecting the ionization due to these showers. When the number of collisions per bunch crossing (*multiplicity*) is small, the shower rate inside the TAN is also proportional to the luminosity. Hence, the detector is designed to operate by measuring either the shower rate (*counting mode* for low and intermediate luminosities) or the average shower flux (*pulse height mode* for high luminosities). The detector is also designed 1) to survive the extreme level of radiation (~1 GGy in the nominal condition), 2) to resolve the showers from each bunch crossing (40 MHz in the nominal condition) and measure bunch-by-bunch luminosity, and 3) to have four independent square shaped channels, each occupying a quadrant, making the detector sensitive to the crossing angle [1, 2].

During proton operation in 2010, the beam energy was 3.5 TeV and the multiplicity did not exceed four. Because the counting mode is still effective in such a condition [5], the BRAN was operated in the counting mode in 2010. This paper presents measurement results of the BRANs during the operation in 2010 (mainly proton operation) and makes comparisons with luminosity measurements by the experiments. Operation of BRANs have been supported by efforts of numerical simulations [5, 6]. Recent results of the simulations are also presented in this proceedings [7].

TOTAL LUMINOSITY

Proton Operation

Figure 1 shows the luminosities at IP1 and IP5 during one cycle (*fill*) of the proton beams, measured by the BRANs and the experiments. The *left* and *right* sides of an IP are defined by an observer inside the LHC ring. The luminosities of the BRANs are the scaled shower rates calibrated against the experiments. We can see good agreements among the BRANs and experiments.

Figure 2 compares the raw shower rates of the BRANs to the proton-proton (*pp*) collision rates of the experiments for the data of Fig. 1. The collision rates at the IPs are estimated with the measured luminosities and the 72 mb inelastic *pp* cross section [8]. The differences among the BRANs are due to different materials in front of the BRAN inside the TAN [7] and also cable attenuation. We note that
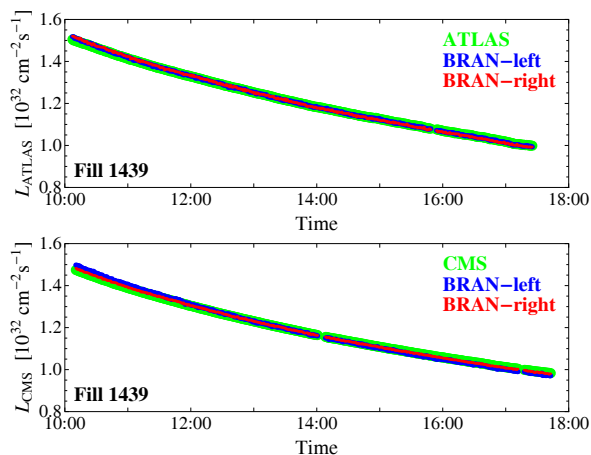

Figure 1: Luminosities at IP1 and IP5 measured by the BRANs and experiments.
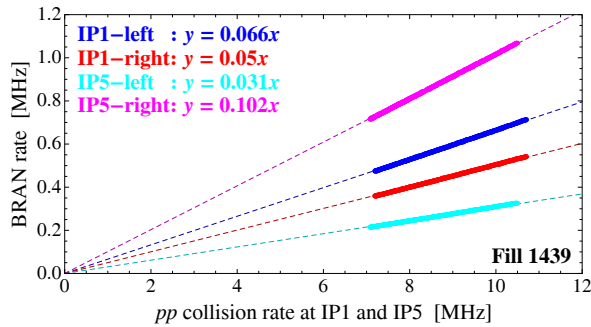
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Figure 2: Shower rates observed by the BRANs vs. the *pp* collision rates at IP1 and IP5.

the detector on the left side of IP5 has been suffering from 100 kHz noise and operating with a higher threshold than other three detectors, making the counting rate of this detector smaller than the rest. A recent simulation predicted about 5% of *pp* collisions are detected by the BRAN [7] and the measurements are consistent with this prediction.

Figure 3 shows relative differences between the measured luminosities of the BRANs and experiments for the same data of Figs. 1. We can see that the BRANs have small systematic errors of about ±1%, except for the detector on the left side of IP5 with the noise issue. The cause of these systematic errors may be the multiplicity of *pp* collisions but this is still under investigation. The goal for the precision of the BRAN is 1% in relative measurements, assuming a reasonable averaging time, and this was achieved for the typical luminosity level of 10^{32} cm^{-2}s^{-1} in 2010.

Lead Ion Operation

Although the BRANs were designed mainly for proton operation, they were also operated during lead ion operation in November 2010. During the lead ion operation, the
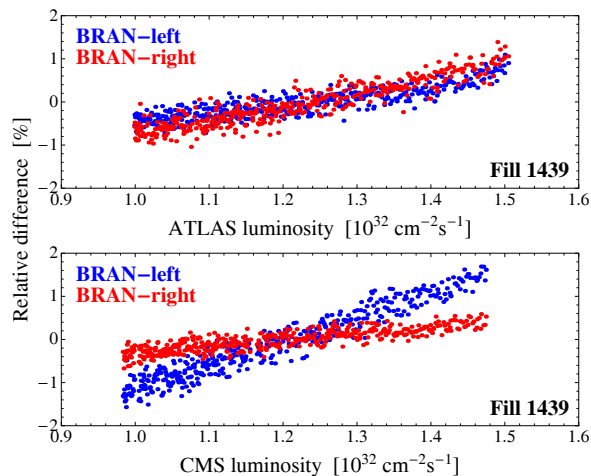

Figure 3: Relative differences between the BRANs and experiments. The systematic errors are on the level of the target precision (1%) except the one on the left side of IP5.
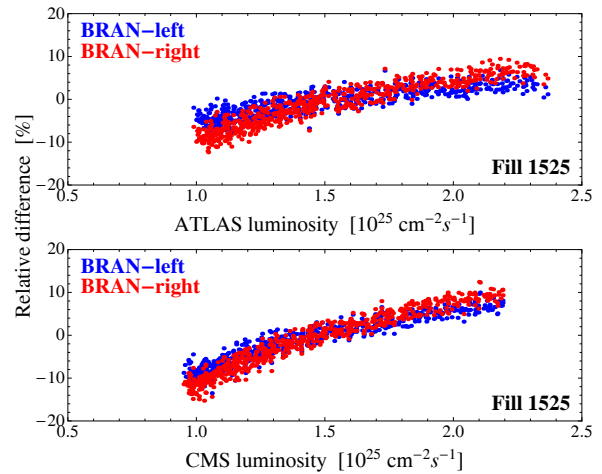
Figure 4: Relative differences for the lead ion operation. Systematic errors (±10%) are much larger than the proton operation in Fig. 3.

luminosity was on the order of 10^{25} cm^{-2}s^{-1}, corresponding to the collision rate of several kHz, which is two to three orders of magnitude smaller than proton operation (Fig. 2). Figure 4 shows the relative differences between the BRANs and experiments for one lead ion fill. Compared to proton operation in Fig. 3, the BRANs have larger systematic errors of about ±10%. We have not fully investigated the cause of these systematic errors.

BUNCH-BY-BUNCH LUMINOSITY

Figure 5 shows a snapshot of the bunch-by-bunch luminosities at IP5 measured by the BRAN and CMS. The data was taken for one proton fill with 150 ns bunch spacing and 348 colliding bunch pairs at IP5. Each data point shows the average value and the standard deviation of measurements taken over 10 minutes. We can see good agreements between the two measurements. The lower part of Fig. 5 shows the histogram of the relative differences for all 348 bunch pairs. The standard deviation of the difference is 1.0%. Figure 5 shows a snapshot at the beginning of the fill, where the total luminosity is about 2×10^{32} cm^{-2}s^{-1}, and the standard deviation of the relative differences remains at the same 1% level up to the end of the fill after about 12 hours, where the luminosity has decreased to about 1×10^{32} cm^{-2}s^{-1}. We conclude that, if the scale is properly calibrated, the BRANs in counting mode can provide a 1% level of precision not only for the total luminosity but also for the bunch-by-bunch luminosities for the conditions of proton operation in 2010.

INTERACTION AREA

The luminosity is inversely proportional to the cross sectional areas of the beams at the IP and so the luminosity measurement, together with the bunch intensity measurement, provides information of the size of the beams. If all
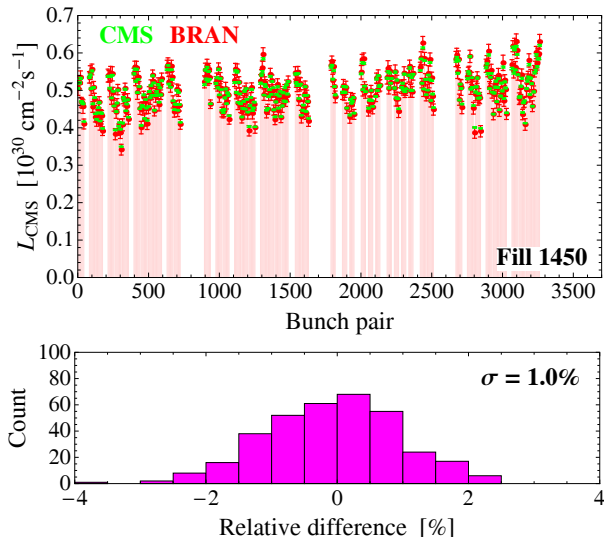
Figure 5: A snapshot of the bunch-by-bunch luminosities measured by the BRAN and CMS (upper) and the histogram of the relative differences (lower).

the bunches in both beams have an identical round Gaussian shape, the luminosity L is given by

$$L = \frac{fkn^2}{4\pi\sigma^2}F = \frac{fkn^2}{8\pi\sigma_L^2}, \qquad (1)$$

where f is the revolution frequency, k is the number of colliding bunch pairs, n is the bunch intensity, F is the geometrical reduction factor due to the crossing angle (0.92 for 200 μrad during proton operation in 2010), σ is the RMS beam size at the IP, and σ_L is the RMS size of the luminous region observed by the experiment. Figure 6 shows an evolution of the RMS beam size at IP5 during one proton fill, where we observed slightly larger beam size growths than other fills. The RMS beam size σ is reconstructed based on Eq. (1) with the luminosity of the BRAN, L, and the size of the luminous region measured by CMS, σ_L. We can see a good agreement between the two measurements. When a linear fit is applied to the correlation of the two measurements, the proportionality coefficient and r^2 are 0.9968 and
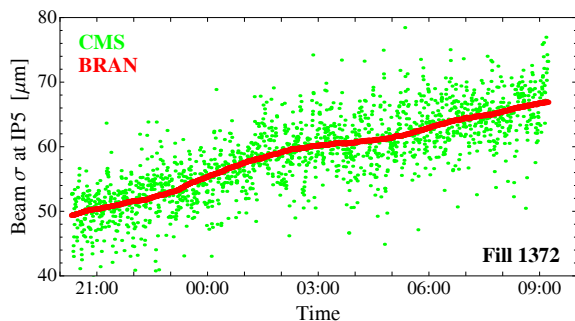
0.9954 respectively, which are consistent with the accuracy of the BRAN (Fig. 3). We can also see that the measurement based on the luminosity has smaller fluctuations than that from the luminous region but it can only observe the average over two planes and two beams.

CROSSING ANGLE

During proton operation in 2010, the LHC ran with a full crossing angle of 200 μrad at IP1 (vertical) and IP5 (horizontal). The asymmetry ratios (up-down for IP1 and left-right for IP5) among the quadrant channels of the BRAN were recorded during some proton fills and compared with measurements of beam position monitors and a predictions of a simulation. Preliminary analysis [7] indicates that the detector is sensitive to crossing angles but a more quantitative analysis of these measurements is underway.

CONCLUSIONS

The BRAN luminosity monitors for IP1 and IP5 have been in operation since 2009. Their measurements have been available online in the control room and used to monitor and optimize the luminosities at these IPs. We demonstrated in the conditions of proton operation in 2010 that the BRAN could provide the total and bunch-by-bunch relative luminosities with about 1% precision, which has been the design target. The BRAN was also tested during the lead ion operation where large systematic errors of about $\pm10\%$ were observed. The BRANs were used in the counting mode until 2010, but as the multiplicity of collisions per bunch crossing approaches ten during proton operation in 2011, they will be operated in the pulse height mode.

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Figure 6: Evolution of the effective beam size at IP5, reconstructed from the luminosity of the BRAN and the luminous region of CMS.

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