RESULTS FROM THE LHC BRAN LUMINOSITY MONITOR AT INCREASED LUMINOSITIES*

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Abstract

The LHC BRAN luminosity monitors are used to monitor and optimize the luminosity in the LHC high luminosity interaction points IP1 and IP5. The Argon gas ionization chambers detect showers produced in the TAN absorbers by neutral particles emerging from *pp* collisions. The detectors have been operated during the 2010 run by counting the shower rate. Since the current 2011 run has a multiplicity of proton-proton collisions per bunch crossing near ten, the detector sees more than one collision per bunch crossing. Therefore, the operation of the detector has been switched to pulse height mode to detect the average shower flux per bunch crossing. This paper presents results of the recent pulse height mode operation, including the total and bunch-by-bunch luminosity as well as a determination of the crossing angle at these IPs. Comparisons with luminosity measurements from ATLAS and CMS detectors are also presented.

INTRODUCTION

The BRAN luminosity monitors for the high luminosity interaction points in the LHC (IP1 and IP5) are gas ionization chambers (Ar + 6%N_2) that detect the showers produced in the TAN absorbers by forward, neutral collision products produced in pp interactions [1-6]. Since the shower rate is proportional to the pp collision rate, the detectors provide a relative measurement of the luminosity. The detectors have been in operation since the beginning LHC operation to monitor and optimize the luminosities of IP1 and IP5 [7,8]. The system is designed to operate at 40 MHz to measure bunch-by-bunch luminosity at the LHC's nominal bunch collision rate. The device is also designed to withstand the extreme level of radiation (~1 GGr/yr) [9], two orders of magnitude higher than that seen by any previous detector.

The signal processing system is designed to detect both the rate (counting mode) and average intensity (pulse height mode) of the showers in the TAN absorbers. The counting mode is more precise at low luminosity but saturates when the shower production rate per bunch crossing approaches unity, in which case operation switches to the pulse height mode. The detectors were operated in the pulse height mode in 2010 [6-7], but the maximum multiplicity increased from about four to almost ten in 2011 so the pulse height mode has been commissioned in 2011.

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DETECTOR DESIGN

Argon ionization chamber

The system design is derived from the two main constraints: radiation hardness and speed. As a consequence, we adopted a gas ionization chamber built with only passive rad hard components such as metals and ceramics. The chamber is operated using a gas mixture of 94% Ar and 6% N_2 pressurized to 7 bar with a bias voltage of 1.2 kV to optimize the drift speed of the electrons produced by ionization.

An additional feature of the detector is the four-quadrant segmentation, which provides information of the center of mass of the shower and therefore gives an indication on the crossing angles.

Fluka Model

The system has been developed based on a detailed model using Fluka Monte Carlo simulator [10]. The model has provided a good estimation of the signal from the detector [11-13] by providing the calculated energy and intensity of the particles in the shower.

Figure 1 shows a model prediction of the ratio between the event rate of out detector and the *pp* collision rate of the experiment as a function of the multiplicity. This ratio is a measure of the effectiveness of counting events versus looking at the total intensity of the shower. The rate approaches zero for a high multiplicity but, depending on the threshold, the multiplicity may raise the rate while in intermediate values. A deviation from a flat line indicates the error of the counting mode. The multiplicity in the 2011 run ranges from about five to ten. The simulation predicts a visible change in the rate in such a range for 3.5 TeV and hence inaccuracy of the counting mode.

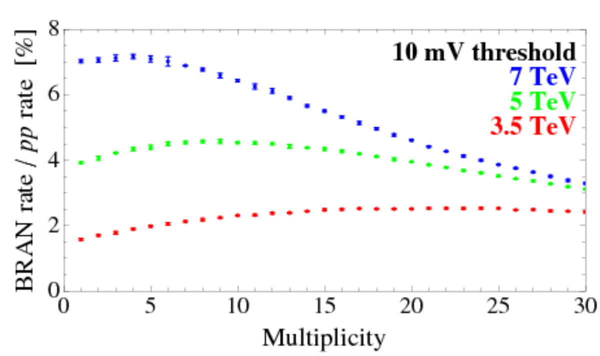

Figure 1: FLUKA model prediction of the ratio between the event rate of the BRAN luminosity monitor and *pp* collision rate at the interaction point. The derivative of the

rate represents inaccuracy of the counting mode.

LHC RUN IN 2011

Comparing the runs in 2010 and 2011, the beam energy remains at 3.5 TeV but the luminosity is increased by an order of magnitude from 2×10^{32} cm^{-2}s^{-1} to 2×10^{33} cm^{-2}s^{-1}, mainly due to the increase in the number of bunches, but also the further beta-squeeze and the increase in the beam brightness. Table 1 summarizes the machine parameters that impact the performance of out detector.

Table 1 – Main LHC parameters for beam collisions

	2010	2011	Nominal
Energy [TeV]	3.5	3.5	7
Luminosity [cm^{-2} s^{-1}]	2×10^{32}	3.5×10^{33}	1×10^{34}
Bunches/beam	368	1404	2808
Bunch Intensity	1×10^{11}	1.3×10^{11}	1.15×10^{11}
Emittance [μm]	2.5	2	3.75
Beta* [m]	3.5	1	0.55
Multiplicity	<4	<17	~22
Acceptance [%]	5	5	20

As one can see in Fig. 2, showing the luminosity production of the LHC in 2011, the rate of the integrated luminosity has made great improvements, meeting the stated 1 fb^{-1} goal for 2011 in May, and heading for several times that goal.

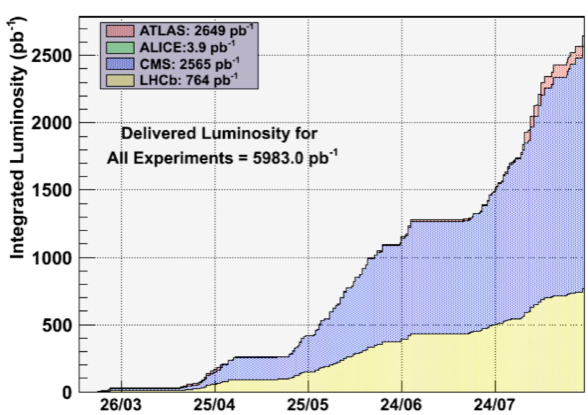

Figure 2: LHC integrated luminosity production.

OPERATING MODES COMPARISON

The large improvement in performance of the LHC has impacted the operation of the luminosity monitor. The luminosity monitor was operated in the counting mode during the 2010 run and measurements showed a very good agreement with the rates seen by the experiments [8]. However, when the multiplicity goes up to almost ten, the counting mode can have errors as large as 10% or even more, due to the intrinsic inability to count multiple events for the same bunch crossing. We therefore need to operate looking at the average intensity in the pulse.

For this transition phase, the systems are setup so that the detector on the left side of the IP operates in counting mode while the one on the right side runs in the pulse height mode. This allows us to monitor the data in both modes and manage the transition from counting to pulse height mode. Figure 3 shows the percentage differences in the performance of each of the four installed detectors from the respective experiments. We can clearly see that the ones in the pulse height mode have a much better agreement with measurements from the experiments. We should note that the detector on the right side of IP5 operates with a threshold much higher than that for the detector on the right side of IP1, due to environmental electrical noise. This also indicates that the accuracy of the counting mode also depends on the threshold and the accuracies of the detectors on the counting mode may be improved by adjusting their thresholds.

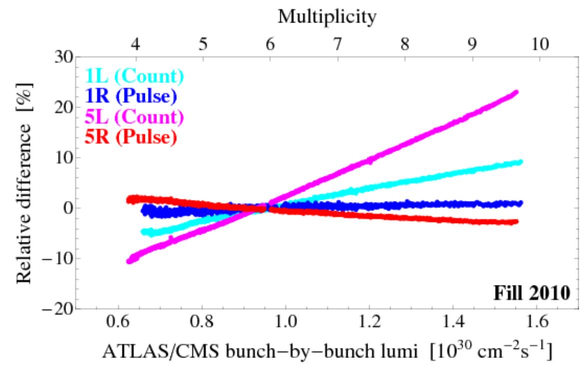

Figure 3: Correlation of luminosity rates (both counting and pulse height modes) with experiments.

Figure 4 gives a close look at the difference between the measurements from the luminosity monitors on the pulse height and from the experiments. The relative difference is about ±1%, meeting the device's specifications [1-6] for the multiplicity range of about four to ten, the operating range of the run in 2011.

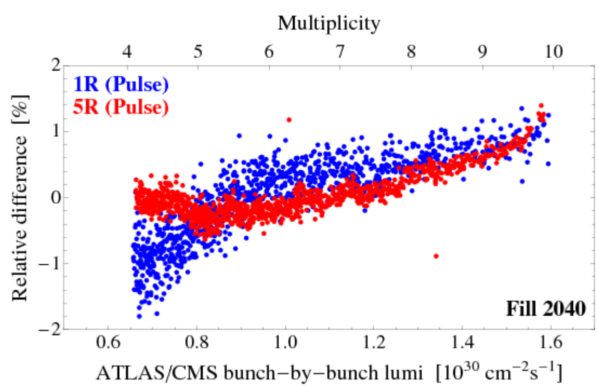

Figure 4: Correlation between experiments and pulse height measurements gives very good results

BUNCH-BY-BUNCH MEASUREMENT

The detector is designed to measure the bunch-by-bunch luminosity for the nominal operation with 25 ns bunch spacing. The capability of the bunch-by-bunch measurement for the operation with 150 ns bunch spacing is already demonstrated in 2010 [8]. During the current run, we demonstrated that the detector can provide bunch-by-bunch measurement for the operation with 50 ns bunch spacing as well.

Figures 5 and 6 show the bunch-by-bunch luminosities and emittances (averaged over two beams and two planes) measured with the detector at IP5 during a long store. The figures compare the measurements at the beginning (darker colors) and middle (lighter colors) of the fill. This is the fill where the emittance of one batch of Beam 2 is blown up at the injection and produces less luminosities compared to the other bunch pairs. We can clearly see the batch with the problem (bunch pairs ~500-750) in Figs. 5 and 6.

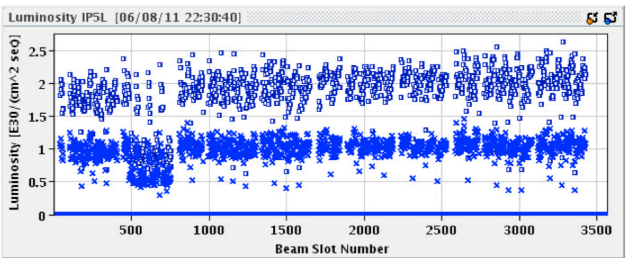

Figure 5: Full turn of bunch-by-bunch luminosities at CMS comparing the beginning (darker) and middle (lighter) of physics fill 2007. The emittance of a single batch of Beam 2 is blown up at the injection, leading to less luminosities for the bunch pairs ~500-750.

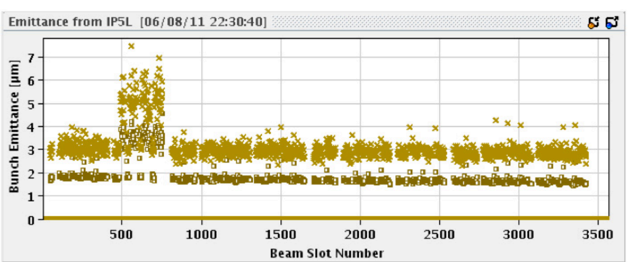

Figure 6: Full turn of bunch-by-bunch emittance (averaged over two beams and two planes) comparing the beginning (darker) and middle (lighter) of the physics fill. The data is from the same physics fill as Fig. 5.

RADIATION ENVIRONMENT

The integrated luminosity per year for the nominal LHC operation is 80-120 fb^{-1} [14]. The run in 2011 expects 4-5 fb^{-1}, which corresponds to ~50 MGy radiation dose to our detector in 2011. This is still a level below that we expect any damage in the detector components. However, we will be monitoring the detector performance for possible radiation damages in the future, as the integrated luminosity will continue to grow.

CONCLUSIONS

The BRAN luminosity monitor for the high luminosity interaction points of the LHC has been operational since the beginning of the LHC run and used to monitor and optimize the luminosities of IP1 and IP5. The instantaneous luminosity of the LHC has been increased to more than 2×10^{32} $cm^{-2}s^{-1}$ in 2011, increasing the maximum multiplicity of *pp* collisions per bunch crossing to about ten, and the pulse height mode of the luminosity monitor has been commissioned to cope with this increase. It is demonstrated that the detector in pulse height mode can provide the relative luminosity measurement with an accuracy of about ±1% with respect to the experiment for the multiplicity range of 4-10 per collision. We also confirm that counting mode shows an inaccuracy of ~10% or even larger for such a large range of the multiplicity, as expected.

As the LHC performance continues to improve, we plan to follow the detector's development: on one side, when signals become stronger we will be adjusting the data acquisition chain to match the available electronics. On the other as the total dose to the detector will start reaching higher values, we will be looking for the effects of activation of components as well as possible increase in background rates.

ACKNOWLEDGMENTS

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REFERENCES

[1] W. C. Turner, LBNL Note LBNL-42180, 1998.
[2] W. C. Turner *et at*., NIM A **461** (2001), p. 107.
[3] J. F. Beche *et al*., IEEE Trans. Nucl. Sci. Vol. **49** No. 1 (2002), p. 285.
[4] P. S. Datte *et al*., IEEE Trans. Nucl. Sci. Vol. **50** No. 2 (2003), p. 258.
[5] J. F. Beche *et al*., EPAC'06, p. 580.
[6] E. Bravin *et al*., PAC'07, p. 4171.
[7] A. Ratti *et al*., IPAC'10, p. 501.
[8] R. Miyamoto *et al*., PAC'11, WEPC030.
[9] N. Mokohov *et al*., LHC-Project-Report-633, 2003.
[10] G. Battistoni *et al.*, Hadronic Shower Simulation Workshop '06, p. 31 (2007); A. Fasso *et al*., CERN-2005-10, INFN/TC_05/11, SLAC-R-77, 2005.
[11] S. M. White *et al*., PAC'09, p. 3516.
[12] R. Miyamoto *et al*., IPAC'10, p. 498.
[14] H. S. Matis *et al*., PAC'11, MOP202.
[14] "LHC Design Report Vol. 1: the LHC Main Ring", edited by O. Bruning *et al*. (CERN, Geneva, 2004).