OPERATIONAL RESULTS OF THE LHC LUMINOSITY MONITORS UNTIL LS1*

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Abstract

The monitors for the high luminosity regions in the LHC have been operating since 2009 to help optimizing the LHC's luminosity. The devices are gas ionization chambers installed inside a neutral particle absorber 140m from the Interaction Point (IP) and monitor showers produced by high energy neutral particles from the collisions. They have the capability to resolve the bunch-by-bunch luminosity as well as to survive the extreme level of radiation during the nominal LHC operation. The devices have operated over a broad range of luminosities, from the initial 10^{-2} Hz/μb until the levels well in excess of 10^3 Hz/μb† reached in 2012. We present operational results of the device during proton and lead ion operations until the LS1 shutdown, which include runs at 40 MHz bunch rate and with *p-Pb* collisions.

INTRODUCTION

The BRAN (Beam RAte of Neutrals) detectors measure the relative luminosity at the IR1 (ATLAS) and IR5 (CMS) interaction regions of the LHC. The detectors are comprised of fast ionization chambers sporting a wide dynamic range installed at either side of the Interaction Points IP1 and IP5. It measures the neutrons and photons flux from *p-p, p-Pb* and *Pb-Pb* collisions in the forward direction [1]. During the final part of the LHC run before the LS1 shutdown we were able to validate the detector performance with 40 MHz collision rate during the LHC operation with 25 ns bunch trains and with the accelerator colliding protons with lead ions generating asymmetric collisions.

BRAN DESCRIPTION AND OPERATION

We developed a gas ionization chamber, using Argon mixed with 6% of nitrogen, allowing for bunch-by-bunch monitoring in an extremely high radiation environment (180 Gr/yr) at the nominal LHC operation.

The detector consists of six parallel layers each divided into four quadrants for possible collision rate monitoring during LHC operation with non-zero collision angles. Image charges of the electrons produced in the ionization process are collected and integrated by a fast front-end amplifier, followed by a shaper and a digitizing system. This signal processing chain has been designed to support the nominal 40 MHz bunch rate.

† 1 Hz/μb = 10^{30} cm^{-2} s^{-1}

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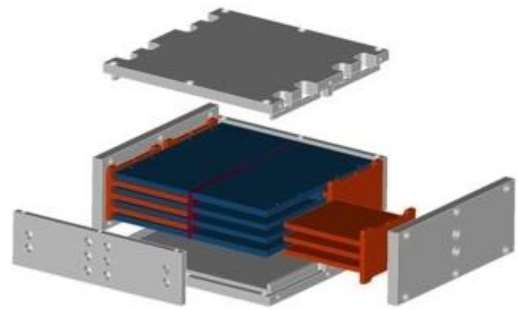

Figure 1: Exploded view of the detector.

The BRAN data is archived in the LHC data in two different ways. On the left side of the IR (viewed from inside of the LHC ring), a collision is declared every time the voltage exceeds a threshold during a bunch crossing. This method, called "Counting Mode", works well at low luminosity but saturates as the intensity increases. In the second method, called "Pulse Height Mode", the average pulse height of the signal generated from each collision is recorded. "Pulse Height Mode" is linear at higher luminosities, but is tends to be dominated by system noise at low luminosity when the signal from the collisions is smaller or comparable to the level of the noise from the ambient and the readout system.

OPERATIONAL RESULTS

Contribution to LHC Operations

Since the early days of the LHC commissioning, the BRAN has been a reliable tool for operating the machine and configuring the IPs for optimized collisions. The device is used in every production run to bring the beams in collisions and through the beta squeeze, leading to the production mode configuration of the LHC (stable beams) when the experiments publish their luminosity values. Previous comparisons between the BRAN and the results reported by the experiments have shown a very good (~1%) agreement [2].

The LHC has operated during most of the proton runs up to LS1 with a 50 ns bunch spacing and an energy up to 4 TeV per beam. On the other hand, the machine has also operated with more than 50% higher bunch charge, and an emittance significantly smaller than nominal, resulting in peak luminosities up to 7x10^{33} cm^{-2}s^{-1}. The BRAN responded without problems to the challenge posed by the bigger amount of pileup effects resulting from the improved machine performance.

Monitoring 40 MHz (25 ns) Collisions

During the last weeks of the run the LHC collided trains of bunches separated by the design time interval of 25 ns. This allowed both the experiments and the accelerator to test and validate their systems at this higher bunch rate. Collision data at 40 MHz rate were recorded at the BRAN detectors. Bunch-by-bunch data is shown in Figure 2; the absence of a pileup signature demonstrates the ability of the detector to resolve the nominal 40 MHz collision rate.

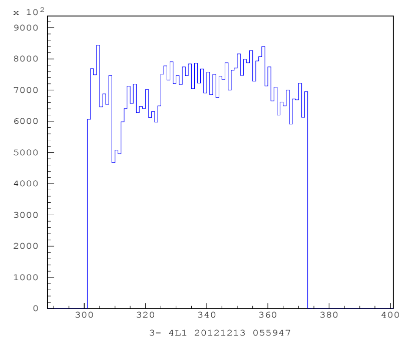

Figure 2: Data collected at 40 MHz bunch rate collisions.

In this occasion we also analyzed the analog signals in the data stream. Figure 3 shows a cumulative histogram of the BRAN peak response measured after the pre-amplifier and shaper on a single quadrant of the detector.

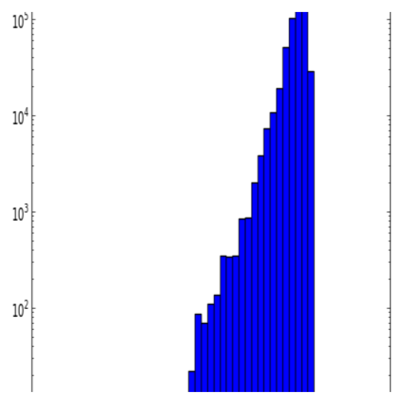

Figure 3: Pulse height distribution of the analog signal from one quadrant.

The data presented here was accumulated during a low-occupancy 25 ns LHC run. As a result the mean number of proton collisions per crossing was < 1. Given the rate of proton collisions per crossing is Poisson distributed, this leads to an approximate factorial-based dropoff in the histogram distribution. We see something more smooth, however, as one must also factor in material effects, the distribution of trajectories of the particles from the interaction and the response of the detector itself.

Monitoring Proton on Lead Collisions

In another novel configuration implemented during its last run before LS1, the performance of the four detectors at both sides of the IP1 and P5 interaction regions was assessed during the accelerator operation with *proton on Lead (p-Pb)* collisions. Results collected at the even side of IP1 are shown in Figures 4, 5 and 6 for both the Pulse height and counting modes of operation. The asymmetry of the distributions generated by the vertical crossing angle is clearly visible. Similar results were collected in IP5 where the asymmetry is in the horizontal plane.

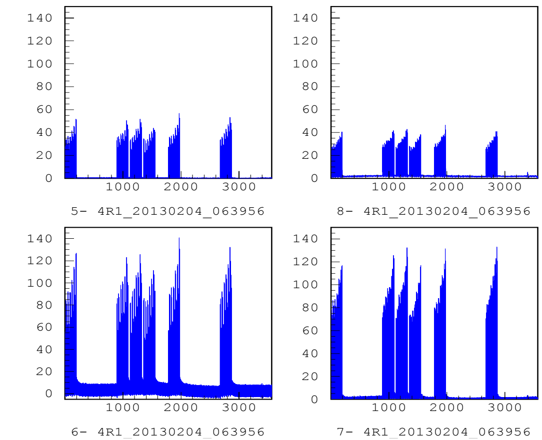

Figure 4: PH-mode in ATLAS with *p-Pb* operation. The plot is taken on the detector at the Right side of the IP which captures the shower from the Lead beams.

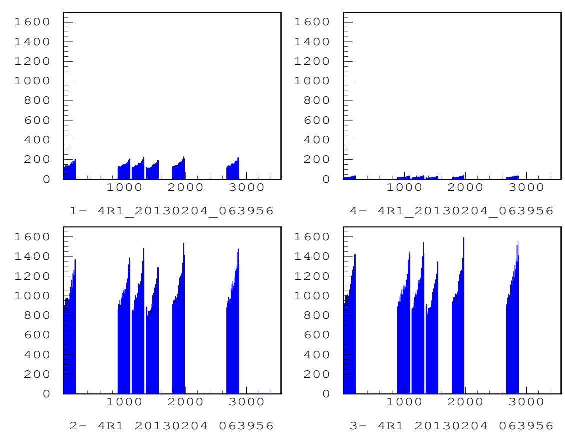

Figure 5: Counting mode in ATLAS in *p-Pb* operation.

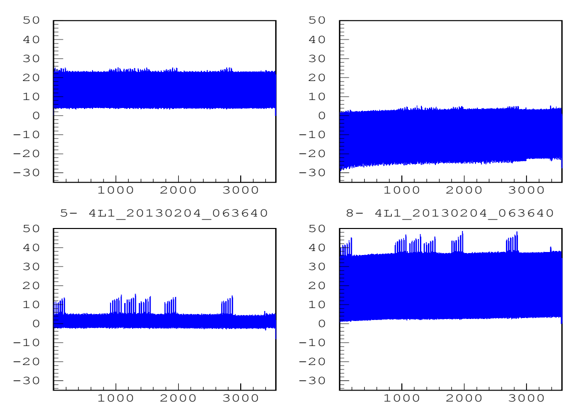

Figure 6: Pulse height mode in ATLAS in *p-Pb* operation. The plot is taken on the detector at the Left side of the IP which captures the shower from the Proton beams.

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The comparison between signals from the Right and Left side detectors shown in Figures 4 and 6 indicates that the shower from the *Lead* beam is approximately 18 times stronger than the corresponding shower from the *Proton* beam.

SYSTEM MODELING

We developed a FLUKA [3-4] model of the BRAN and integrated it into the LHC's model of the IP. The full detail of the beam line is included up to the TAN absorber which shields the first LHC dipole from the forward neutral particles produced at the IP and houses the BRAN. The geometry of the TAN is shown in Figure 7.

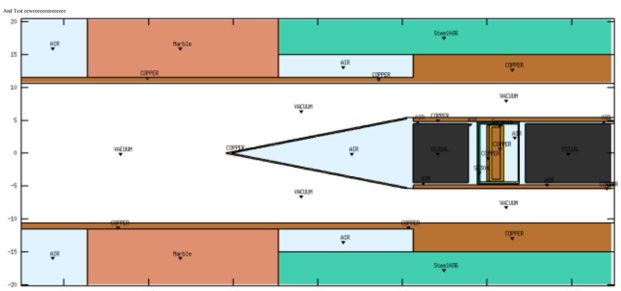

Figure 7: Top view of the BRAN in the CMS TAN. The color white indicates the regions of vacuum.

Using the DPMJET [5] option of FLUKA, we have simulated the *p-p, p-Pb* and *Pb-Pb* reactions over the expected operating range of the LHC. Figure 8 shows the shower formation for *p-p* (which is dominated by gamma ray showers) and *Pb-Pb* (dominated by neutron showers). The simulations showed how the energy is deposited in the detector as a function of energy and crossing angle of the beams.

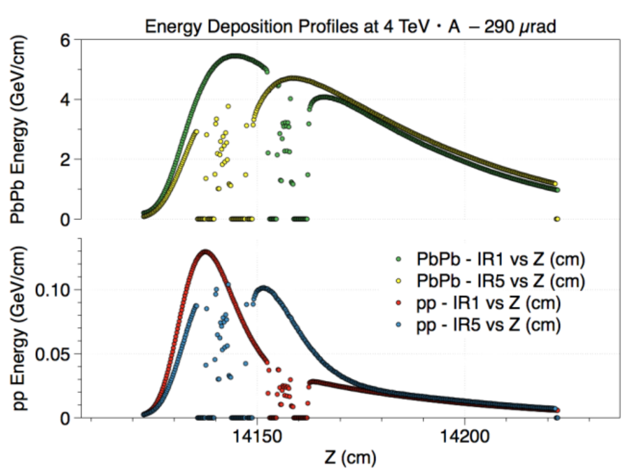

Figure 8: Energy deposited in the TAN for *p-p* and *Pb-Pb* collisions. The region in the center for each detector is where the BRAN is located. The different material in from of the BRAN produces the difference between the shower depositions between the IR regions.

Figure 9 shows the relative amount of energy in the BRAN for different combinations of colliding particles. When the LHC collides *p* on *Pb*, the signal strength from the BRAN is close to a factor of twenty higher on the side that the *Pb* beam approaches and is in good agreement with the observations from the BRAN reported here, comparing the data from Figures 4 and 6.

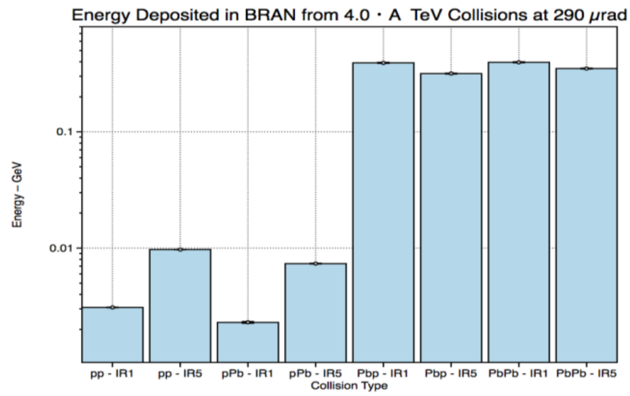

Figure 9: Comparison of the amount of energy deposited in the detector with *p-p*, *p-Pb*, *Pb-p* and *Pb-Pb* collisions.

CONCLUSIONS

With the LHC run at a 40 MHz bunch rate, the BRAN has now demonstrated the ability to meet all of its specified requirements. The only challenge that the device is left to face when the run will resume is its level of radiation hardness. The device has so far not shown any sign of performance deterioration up to the radiation levels reached by the LHC.

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