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The aim of CERN Large Hadron Collider (LHC) is to collide protons and heavy ions with centre of mass energies up to 14 zTeV. In order to monitor and optimize the collision rates special detectors have been developed and installed around the four luminous interaction regions. Due to the different conditions at the high luminosity experiments (ATLAS and CMS) and the low luminosity experiments (ALICE and LHC-b) two very different types of monitors are used: a fast ionisation chamber (BRAN-A) and a Cd-Te solid state detector (BRAN-B respectively. Moreover, in order to cope with the low collision rates foreseen for the initial run, a third type of monitor, based on a simple scintillating pad, was installed in parallel with the BRAN-A (BRAN-P). This contribution illustrates the results obtained during the 2010 run with an outlook for 2011 and beyond.

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FIRST RESULTS OF THE LHC COLLISION RATE MONITORS*

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Abstract

The aim of CERN large hadron collider (LHC) is to collide protons and heavy ions with centre of mass energies up to 14 zTeV. In order to monitor and optimize the collision rates special detectors have been developed and installed around the four luminous interaction regions.

Due to the different conditions at the high luminosity experiments (ATLAS and CMS) and the low luminosity experiments (ALICE and LHC-b) two very different types of monitors are used: a fast ionisation chamber (BRAN-A) and a Cd-Te solid state detector (BRAN-B) respectively. Moreover, in order to cope with the low collision rates foreseen for the initial run, a third type of monitor, based on a simple scintillating pad, was installed in parallel with the BRAN-A (BRAN-P).

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INTRODUCTION

The ultimate aim of LHC is producing collisions inside the four experimental detectors: ATLAS, CMS, ALICE and LHC-b. This will allow the further understanding of the nature of matter and of the forces holding it together.

Looking more in detail there are differences in the way this should be done. ATLAS and CMS profit from the highest collision rate possible, while ALICE and LHC-b require the collision rate to be set and controlled at optimal levels. For ALICE the radiation damage sustained by the sub-detectors in case of long terms p-p luminosities above $10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is dangerous. For LHC-b the upper limit is defined by the requirement of not having more than one p-p interaction during the same bunch crossing. This limits the bunch luminosity to $1.8 \times 10^{29}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and thus the maximum luminosity to $5 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for 2808 bunches.

The luminosity, and thus the collision rate, of an accelerator depend on the parameters of the beams according to the well known Eq. 1

$$L = \frac{N_{b1} N_{b2} f_{rev} k_b}{2\pi\sqrt{(\sigma_{x1}^2 + \sigma_{x2}^2)(\sigma_{y1}^2 + \sigma_{y2}^2)}} \cdot \exp\left[-\frac{(\bar{x}_1 - \bar{x}_2)^2}{2(\sigma_{x1}^2 + \sigma_{x2}^2)} - \frac{(\bar{y}_1 - \bar{y}_2)^2}{2(\sigma_{y1}^2 + \sigma_{y2}^2)}\right] \quad (1)$$

where N_{b1}, N_{b2} represent the number of particles per bunch, f_{rev} is the revolution frequency, k_b is the number of colliding bunches, $\sigma_{x1}, \sigma_{y1}, \sigma_{x2}, \sigma_{y2}$ are the transverse beam sizes and $\bar{x}_1, \bar{y}_1, \bar{x}_2, \bar{y}_2$ are the transverse beam positions. Although there are monitors for the measurement of the various beam parameters entering in Eq. 1, it is difficult to extrapolate certain values to the interaction point, where no instrument can be installed, with sufficient accuracy, in particular the beam sizes and positions. It is for this reason that it is important to have collision monitors providing a relative measurement of the luminosity independently of the knowledge of the beam parameters.

DETECTORS

As already mentioned, there are three different types of collision rate detectors installed in LHC in order to cope with the full range of parameters. All these detectors are used to sample the rate of showers generated by neutral particles created in the collisions and emerging at very small angles ($\vartheta < 300\,\mu$rad). The fluctuations of the shower intensity are very broad. Several Monte-Carlo simulations have been performed over the years with the FLUKA code [1][2][3] in order to quantify this pulse height spectrum.

All detectors are capable of separating pulses coming from different bunch crossing and have a readout system operating at the bunching frequency of 40 MHz providing thus the bunch-by-bunch luminosity in addition to the average luminosity.

BRAN-A

This detector has been developed by Berkeley lab [4] and consists of a fast ionization chamber composed of 4 square quadrants in order to measure the centre of gravity of the impinging neutral flux in the transverse plane (x-y) allowing the calculation of the crossing angle at the IP. In order to achieve the bunch-by-bunch acquisition the chambers volume is rather small leading to very small signals.

A dedicated fast and very low noise pre-amplifier followed by a shaper has been developed [5]. The digital acquisition is accomplished by the DAB card developed at CERN, but with a dedicated firmware developed at Berkeley. The acquisition system can work both in counting mode, for low luminosity, and in pulse height mode, for high luminosity and high multiplicity (can be > 20).

The 4 ionization chambers are installed inside the neutral absorbers TAN, which protect the following superconducting elements of the machine from the neutral flux.

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BRAN-B

This detector is based on Cadmium Telluride sensors and is the result of several years of collaboration between CERN and CEA-LETI in Grenoble [6]. The detectors consist of an aluminum housing containing 10 polycrystalline CdTe disks of 17 mm diameter and 300 μm thickness distributed on two rows.

The CdTe disks are polarized at up to 300 V. The relatively large signals are directly fed to linear preamplifiers and finally acquired by a custom CERN-made counting VME board. Each CdTe disk is acquired separately in order to allow the calculation of the center of gravity of the shower.

BRAN-P

In order to provide a mean for tuning the collision rates for the first beams in LHC, where the fast ionization chambers were difficult to use, simple plastic scintillators have been produced and installed. The signals coming from the PMTs are directly fed to a modified version of the counting board developed for the BRAN-B. For luminosities of 10^{32} the lifetime of these detectors is expected to be a few days.

For this reason the detectors have been removed at the end of the 2010 run when degradation was already visible.

LHC OPERATION

During 2010 the main aim was to commission the LHC at 3.5 TeV per beam and proceed as fast as possible towards the high luminosity it was designed for. Nevertheless, several periods were dedicated to luminosity production in order to allow the four experiments to record events and start the search for new physics.

The maximum luminosity in 2010 was about 10^{32}. In 2011 the goal is to rapidly ramp up the luminosity up to 10^{33} at 3.5 TeV and then dedicate the remaining time to luminosity production. At the time of writing the maximum luminosity is already very close to 10^{33} and the stable physics period is about to start.

At this luminosity the pile-up of events in a bunch crossing is already considerable (about 10). A typical physics fill lasts between 10 and 20 hours during which the luminosity drops by about a factor 2.

RESULTS

All BRAN detectors have been in operation since the very first collisions in LHC. However at 450 GeV and with only small charge bunches the BRAN-A detectors were not usable.

As already mentioned the BRAN detectors are designed to provide only relative measurements and have no ambition to compete with the experiments. Their reliability and simplicity of use make them, however, very useful for setting up and optimizing the collisions, operation that is performed several times during a physics fill. Figure 1 show the evolution of the luminosity during a fill as measured by the BRAN detectors around IP5 and the CMS experiment.

Figure 2 shows the instantaneous bunch-by-bunch luminosity measured by the BRAN-B and the LHC-b experiment.

From the figures it is possible to observe several facts. First of all, the luminosity is tracked rather well by the BRAN detectors although some devices like the BRAN-A-Left at CMS show large non linearities. In the mentioned case the reason is the large pile-up coupled to the fact that a large counting threshold is used for that device due to a larger than normal noise level coming from some unidentified external source.

Pile-up should in general exhibit a saturation-like effect, but in this case, where the probability of detecting a collision during a bunch crossing is small due to the large threshold, the pileup has the effect of increasing this probability and thus the detector efficiency is increased for higher luminosities.

The usual, saturation-like, pile-up effect is observed for the more sensitive BRAN-B detectors although several actions have been taken to reduce the counting rate.

Although pile-up can be in principle compensated for, the ever changing complex bunching pattern complicates the correction algorithm and since linearity is not vital for this detector it has not been implemented yet.

The BRAN detectors have been successfully used also during the lead ions run at the end of 2010 where the luminosity is very small compared to protons, but the amplitude of the signals are much larger.

BRAN-A

The BRAN-A detectors required a bit longer tune-in time as the luminosity was too low for most of 2010. Nevertheless, they were ready for the 2011 run when the BRAN-P were removed. The overall performance of these detectors is good and they can now be operated both in counting or pulse-height mode.

Looking at Fig.1 it is possible to observe both results. The blue curve refers to the BRAN-A detector installed on the right of IP5 and is operated in pulse-height mode. This mode of operation is insensitive to the pile-up and therefore follows the luminosity much better. In this case the remaining error is due to non linearities of the analog signal processing, in particular the droop, which is not perfectly corrected and will require a little more tuning (visible especially in the bunch-by-bunch data).

The acquisition system of the BRAN-A detectors is rather complicated and contains a large number of tuning parameters both in the analog section and in the digital signal processing. The fine tuning is still under way as it is a rather time consuming process. All BRAN-A detectors will soon be used in pulse-height as this mode is more precise although a bit more noisy.

As mentioned the BRAN-A are composed of four independent quadrants allowing the calculation of the center of gravity of the shower and thus the crossing angle. The commissioning of this feature is currently under way.

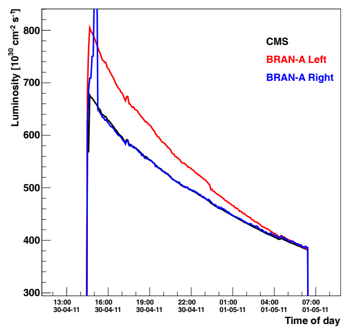

Figure 1: Luminosity readings during a fill. The curves from the CMS experiment and the two BRAN-A detectors around IP5 are normalized at the end of the fill. The quirks on the blue curve at the beginning of the fill are due to detector tuning. The BRAN-A-Right is operated in pulse-height mode, while the BRAN-A-Left is operated in counting mode

BRAN-B

Thanks to their simplicity the BRAN-B detectors were commissioned very rapidly even before the first collisions using beam loss signals. The detectors are composed of ten CdTe disks disposed on two rows. The idea was to use the ten signals to reconstruct the profile of the shower and extract the center of gravity for crossing-angle measurement.

Unfortunately, it has turned out that the calibration done on each CdTe disk during production is not reliable. This effect has two implications. Firstly the crossing angle measurement can not be done and secondly the luminosity measurement is very sensitive to the shower position. This problem is particularly important at IP8 since the LHC-b detector contains magnetic fields that are periodically switched modifying the crossing angle. The result is that the absolute calibration from one fill to the next is not reliable. Nevertheless, the crossing angle inside a given fill remains constant so that the relative measurement is still reliable.

Figure 2 shows the bunch-by-bunch luminosity measurement done by the LHC-b experiment and one BRAN-B detector at IP8. This shows the time resolution capability of the BRAN-B. The scatter of the points visible in Fig.3 is mainly due to statistical error (only 10 s integration time).

The pile-up problem is not present in the BRAN-B devices around ALICE as the luminosity there is kept on purpose low (around 10^{30} Hz/cm^2) and is small at LHC-b, where the luminosity is leveled at around few 10^{32} Hz/cm^2.

CONCLUSIONS

Twelve BRAN detectors of three different types have been installed around the luminous regions of LHC. All detectors have been commissioned during the 2010 run and 8 (4 BRAN-A and 4 BRAN-B) are presently routinely used in setting up the beams. The remaining 4 (BRAN-P) have been removed due to the expected radiation damage.

All detectors have been demonstrated to be reliable and track the variations of the luminosity sufficiently well (few percent deviations) to be used for tuning the machine. Some functionalities, like the crossing angle measurement, have not been commissioned yet and work is ongoing.

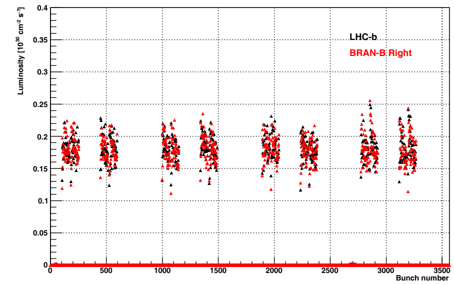

Figure 2: Instantaneous bunch by bunch luminosity readings for IP8.

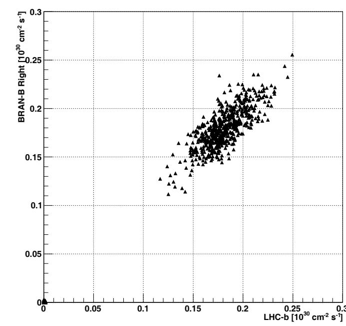

Figure 3: Scatter plot of bunch by bunch luminosity readings for IP8.

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