The ATLAS Diamond Beam Monitor: Luminosity Detector at the LHC

Schaefer, D. M.^{a,*}, on behalf of the ATLAS Collaboration

^aCERN, Meyrin, Switzerland

Abstract

After the first three years of the LHC running, the ATLAS experiment extracted its pixel detector system to refurbish and re-position the optical readout drivers and install a new barrel layer of pixels. The experiment has also taken advantage of this access to install a set of beam monitoring telescopes with pixel sensors, four each in the forward and backward regions. These telescopes are based on chemical vapour deposited (CVD) diamond sensors to survive in this high radiation environment without needing extensive cooling. This paper describes the lessons learned in construction and commissioning of the ATLAS Diamond Beam Monitor (DBM). We show results from the construction quality assurance tests and commissioning performance, including results from cosmic ray running in early 2015.

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1. Introduction

The Diamond Beam Monitor (DBM) [1] collects data from the LHC collisions inside ATLAS [2]. The DBM has 4 tracking telescopes on either side of the pp collisions at $\eta \sim 3.2$ ¹ with 3 diamond and 1 silicon telescopes as shown in Figure 1. Each telescope consists of 3 layers of diamond/silicon sensors with FE-I4 readout chips. Each pair of telescopes is connected through a hitbus chip to allow specialized triggering and readout. The DBM FE-I4 data is readout as the 15th-stave of the Insertable b-Layer (IBL) [3], and a data stream using the hitbus data is used for luminosity estimates.

2. Construction and Installation

The FE-I4 readout has 26,880 readout channels in a matrix of 336×80 channels (rows $\times$ columns) and a pixel pitch of $50 \mu\text{m} \times 250 \mu\text{m}$ ($\eta \times \phi$). The pixel sensor is biased at $\sim 500 \text{ V}$ ($\sim 70 \text{ V}$) for diamond (silicon) to collect charge. The expected sustained trigger rate is around 300 kHz. Diamond does not need to be cooled, but operates at $0\text{--}10^\circ\text{C}$ to avoid heating other detectors as well increasing the stability of the FE-I4 readout. The evaporative cooling loops on the DBM allow the silicon telescopes to be run as low as -5°C if necessary.

Figure 1: The DBM at $\eta \sim 3.2$ in the ATLAS detector.

Figure 2: The module orientation in ϕ and r on A-side (left) and C-side (right) is shown in the ATLAS detector.

2.1. DBM Layout in the ATLAS Detector

The chip/sensor assemblies are glued to a flexible (flex) PCB, and the readout chip is wire bonded to the pads on the PCB. The PCB pads orient the readout channels as well as the online geometry shown in Figure 2. The rows (finer segmentation) are oriented in η , which corresponds to larger distance from the beamline. This was done to have better resolution on the z of tracks coming from the pp interactions. The columns are arranged in ϕ . The row numbering increases with increasing $|z|$ and $|\eta|$ as shown in Figure 3 because the detector is tilted by 10° to point toward the pp interaction point.

*Corresponding author

Email address: schae@cern.ch (on behalf of the ATLAS Collaboration)

¹ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

Figure 3: The module orientation in z is shown in the ATLAS detector.

The DBM geometry used in the offline reconstruction is validated with cosmic-ray data comparing hits in raw and reconstructed data.

3. Diamond vs Silicon and Luminosity Measurements

The run 2 Large Hadron Collider (LHC) instantaneous luminosity is expected to reach $2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ with 300 fb^{-1} integrated luminosity for run 2 plus run 3. The current diamond luminosity monitor on ATLAS called the Beam Conditions Monitor (BCM) will saturate near $L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. The DBM will improve over the BCM by adding 2.8×10^5 more channels, which allows the DBM to exploit the spatial configuration of hits/tracks.

With the very large dose of radiation delivered during run 2, the silicon will start to degrade. The advantage of diamond over silicon is that it is more than 3 times as radiation tolerant at all energies [4], and response stability is important for precise luminosity measurements.

3.1. Tuning Modules

Diamond has a lower pulse height for MIPs but also lower noise relative to silicon, so lower thresholds of $\sim 1000e$ are needed to achieve reasonable hit efficiency. Diamond also has a shorter charge collection time than silicon, which is advantageous for 25 ns spaced collisions at the LHC. The modules are currently tuned to 3000e, and the first step of tuning to 2500e is shown in Figure 4 with uniform calibration within 30e. The goal for the diamond sensors is to go as low as possible. The calibration is done with the Pixel data acquisition (DAQ) software [3], and the goal is a threshold of $\sim 1000e$.

3.2. Tracking and Luminosity

The z resolution of tracks along the beamline is expected to be $\sim 0.6 \text{ cm}$, which allows tracks from pp -collisions to be distinguished from those from non-collision beam background and beam halo. This allows the DBM to estimate the non-collision beam and cavern backgrounds by separating horizontal tracks from non-collision backgrounds from those pointing to the pp interaction point as shown in Figure 5.

The DBM hitbus chip allows for fast triggering at 300 kHz with OR or AND of the 3 sensor layers, and dedicated triggering on collision, non collision, and empty proton bunches. This gives a sample of colliding, non-collision, and cavern backgrounds, which can be used to estimate the non-collision backgrounds in the colliding bunches.

Figure 4: Threshold scan on diamond sensor at 2500e.

Figure 5: Cartoon of track discrimination between tracks originating from the pp interaction point or other.

The DBM selects an unbiased and informed sampling to obtain good statistics on all proton bunches including lower luminosity bunches. The informed sampling will target tracks that are consistent with the pp collisions in z . Pattern recognition was validated with DBM+IBL noise hits during commissioning.

4. Conclusion

The DBM is commissioned and ready for data taking. The cosmic-ray data was not sufficient to validate the DBM stand-alone tracking because of the vertical orientation of the DBM FE-I4's, which was not conducive to observing cosmic-ray tracks. Future data taking with collisions will validate the DBM stand-alone tracking.

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