# The ATLAS Beam Condition and Beam Loss Monitors

I. Dolenc* on behalf of ATLAS BCM and BLM group

*Jožef Stefan Institute,*
*Jamova cesta 39, 1000 Ljubljana, Slovenia*
**E-mail: irena.dolenc@ijs.si*

The primary goal of ATLAS Beam Condition Monitor (BCM) and Beam Loss Monitor (BLM) is to protect the ATLAS Inner Detector against damaging LHC beam incidents by initiating beam abort in case of beam failures. Polycrystalline Chemical Vapour Deposition (pCVD) diamond was chosen as the sensor material for both systems.
ATLAS BCM will provide real-time monitoring of instantaneous particle rates close to the interaction point (IP) of ATLAS spectrometer. Using fast front-end and signal processing electronics the time-of-flight and pulse amplitude measurements will be performed to distinguish between normal collisions and background events due to natural or accidental beam losses. Additionally, BCM will also provide coarse relative luminosity information.
Second system, the ATLAS BLM, is an independent system which was recently added to complement the BCM. It is a current measuring system and was partially adopted from the BLM system developed by the LHC beam instrumentation group with pCVD diamond pad sensors replacing the ionisation chambers.
The design of both systems and results of operation in ATLAS framework during the commissioning with cosmic rays will be reported in this contribution.

*Keywords*: ATLAS, Beam Condition Monitor, Beam Loss Monitor, diamond detectors

## 1. Introduction

If there is a failure in an element of the LHC accelerator the resulting beam losses could cause substantial damage to the experiments. The LHC experiments have decided to develop their own protection systems in addition to those provided by the LHC. The aim of the Beam Condition Monitor (BCM) and Beam Loss Monitor systems in ATLAS to detect early signs of beam instabilities and initiate a beam abort if needed. Additionally, ATLAS BCM will also provide a coarse relative luminosity measurement as a

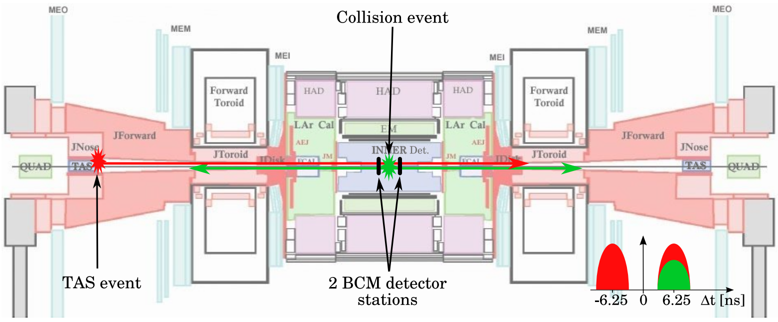


Fig. 1. ATLAS detector with two BCM detector stations at $\pm z_{bcm}$. Particles from interactions (green line) reach both stations simultaneously at time $\Delta t = z_{bcm}/c$ after interactions. Particles from anomalous event like beam hitting the TAS collimator (red line) reach left station $|\Delta t| = z_{bcm}/c$ before interactions at the IP occur.

complementary information to LUCID, the ATLAS main luminosity monitor.

## 2. ATLAS BCM

The ATLAS BCM principle of operation is shown in Fig. 1. There are 2 detector stations placed around the interaction point (IP) at $z_{bcm} = \pm 1.84$ m. Collisions at IP give signals in both stations simultaneously (*in–time hits*) every proton bunch crossing (25 ns). While particles originating from background event at $|z|$¿$|z_{bcm}|$ hit the nearest station at a time $\delta t = 2z_{bcm}/c \sim 12.5$ ns before the station on the other side (*out-of-time hits*), which corresponds to 1/2 of the time difference between two consecutive bunch crossings (BCs). Thus, the *out-of-time* hits can be used to identify the background events on the bunch-by-bunch basis while the *in-time* hits can be used to monitor the luminosity. There are four BCM detector modules on each side of IP, placed symmetrically around the beam pipe (Fig. 2) with sensors located at r$\sim$55 mm. They are mounted at $45^o$ towards the beam pipe in order to increase the average particle path through sensors and thus the signal by $\sqrt{2}$. Short description of the system is provided in the following section, for details see[1,2] and refernces therein.

### 2.1. *Detector modules and read-out chain*

Polycrystalline chemical vapour deposition (pCVD) diamonds were chosen for the sensor material due to their radiation hardness and fast signals.

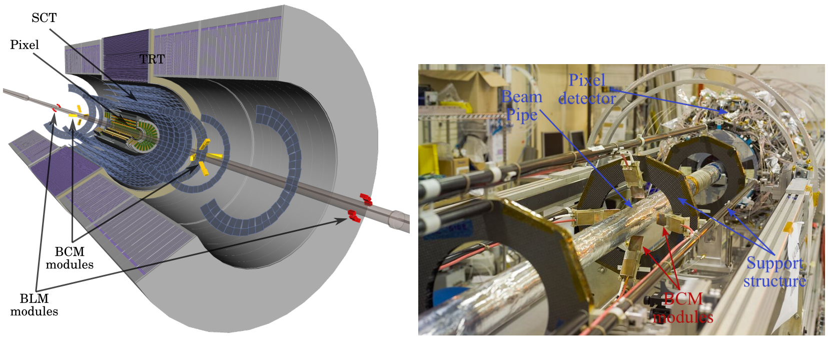


Fig. 2. The BCM and BLM detector modules in their intended position inside the ATLAS Inner Detector (left), as visualised by the ATLAS event display VP1.[3] BCM modules are mounted on the Beam Pipe Support Structure (right).

Diamond sensors also exhibit very low leakage current which allows operation at room temperature without cooling. Sensors are $\sim$500 $\mu$m thick with $1\times1\,\text{cm}^2$ surface and $8\times8\,\text{mm}^2$ contacts. To achieve high and narrow signal pulses the sensors are operated close to the charge carrier saturation velocity, at bias voltage of $\pm$1000 V.

To increase the signal amplitude two diamond sensors are mounted in a stack and read out in parallel (Fig. 3). The front–end electronics is based on a 2 stage current amplifier. With 200 MHz at the readout mean rise time and FWHM of BCM analogue signals were measured to be 1.4 ns and 2.9 ns respectively while a typical signal-to-noise ratio (S/N) for minimum ionising particles (MIPs) at $90^o$ incidence was measured to be 7–7.5.

Analogue signal from detector modules is routed to the region where lower radiation levels are expected[a]. Here, electronics based on the NINO chip[4] is used to digitise the signals. The NINO chip serves as amplifier and discriminator with time-over-threshold capability. The width of the resulting digital output signal (rise time $\sim$1 ns, jitter $\sim$25 ps) is correlated to the amplitude of the input signal.

To optimise S/N the analogue signals are first filtered through a 200MHz $4^{\text{th}}$ order low-pass filter. To increase the NINO chip dynamic range the input signal charge is split in 2 channels (high and low gain channel) in ratio of 1:11. The NINO output signals are transmitted to the ATLAS USA15 service cavern for further processing. This is done by two Xilinx FPGA

[a]Around 10 Gy in 10 years of ATLAS operation, while at sensor location $\sim10^{15}$ particles/cm$^2$ and ionisation dose of $\sim$0.5 MGy are expected.

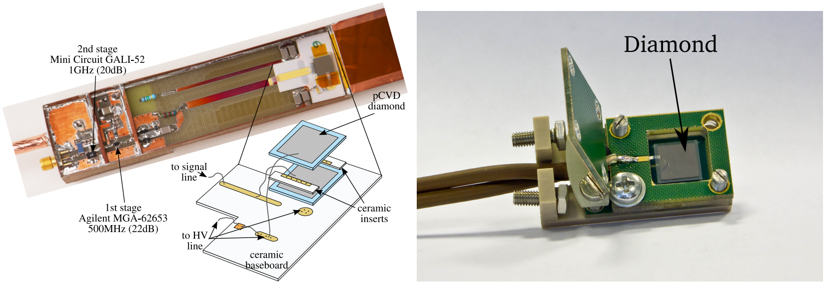


Fig. 3. Left: BCM detector module with the two FE amplifier stages and pCVD diamond sensors. Right: BLM detector module.

based units that sample received signals with a frequency of 2.56 GHz, resulting in 64 samples of 390ps width for each BC. The raw data and rising edges with corresponding pulse widths are stored in 2 separate cyclic buffer. Both buffers can be read out to the LHC post mortem system in case of a beam abort. Coincidences between high multiplicity of low gain and high gain channels are searched for in order to trigger a beam abort.
The median S/N of the BCM system for MIPs at $45^o$ incidence was estimated to be $\sim$9 for high gain channels. Timing resolution was measured to be better then 800 ps.

### 2.2. *Commissioning with cosmic rays*

In the November 2008 ATLAS Inner Detector collected combined cosmic data with two different triggers. One utilised the Resistive Plate Chambers[5] (RPC) of the Muon system while the other used the fast-OR mechanism of Transition Radiation Tracker[6] (TRT). For each trigger signal (Level1 Accept), BCM sends processed data (signal widths and rising edged positions) of 31 consecutive bunch crossings (BCs). Figure 4 shows the distribution of RPC and TRT triggered BCM signal positions over the recorded 31 BCs. Superimposed is a fit to a Gaussian signal and a random background. The TRT plot exhibits narrower Gaussian peak which can be explained by a known lower jitter of this trigger. Extracted fit parameters show that 1 million TRT triggered events resulted in $\sim$9 true BCM hits and 10 million RPC triggers were required to get 9 true BCM hits while the estimated probability for a fake BCM hit in one BC is around $10^{-7}$.
BCM also participated in the June 2009 ATLAS cosmic data taking. The timing plots for the random and IDCosmic triggered events are shown in Fig. 4. The IDCosmic trigger selected events that gave a track in ATLAS

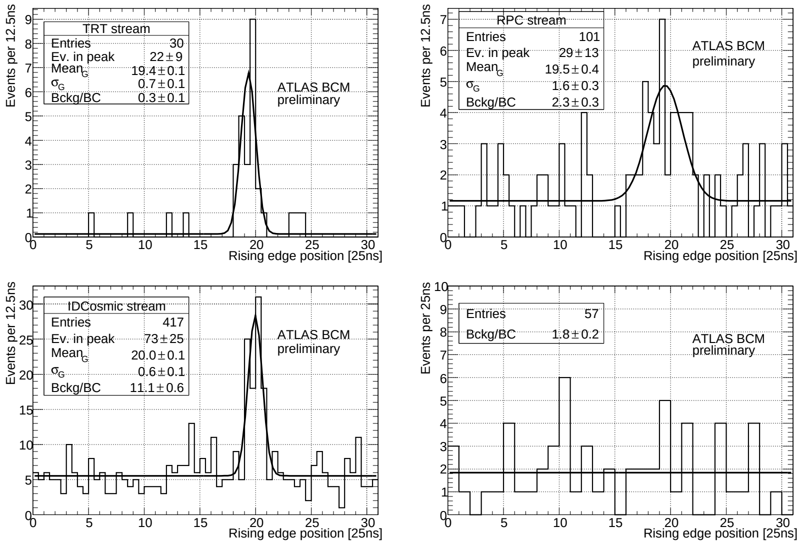


Fig. 4. Timing distribution of TRT, RPC, IDCosmic and random triggered BCM hits collected during ATLAS cosmic data taking The time scale is in units of BCs.

Inner Detector at trigger Level2. Analysis shows that 1 million IDCosmic triggers gave around 6 true BCM hits. The probability for a fake hit in one BC was found to be 7–8 times higher then in 2008 Cosmic run due to the lower threshold settings in 2009 run.
Figure 5 shows the timing distributions over the BCM channels. Most of the BCM hits are on the high gain channels. For those channels one can also observe lower contribution to the signal peak for the BCM modules on side C which can be attributed to the fact that the two ATLAS shafts are not of equal size.

## 3. ATLAS BLM

The ATLAS Beam Loss Monitor (BLM) is an independent system which was recently added as a backup to the BCM. Its readout is based on the BLM system developed for the LHC machine[7] with $8{\times}8\text{mm}^2$ and $500\,\mu$m thick pCVD diamond sensors packed in shielded module boxes (Fig. 3) replacing the ionisation chambers. The ATLAS BLM consists of 6 module boxes on each side of IP (Fig. 2). They are mounted on the Inner Detector End Plate at $z{=}\pm345\,$cm with sensors at $r{=}6.5\,$cm. For each module the system will provide measurement of radiation induced current in sensors,

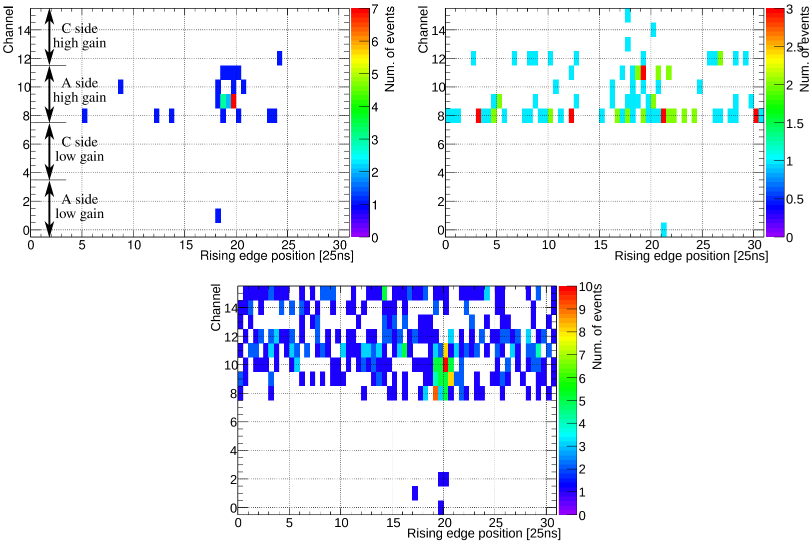


Fig. 5. Timing distribution over BCM channels of TRT (top left), RPC (top right) and IDCosmic (bottom) triggered BCM hits collected during ATLAS cosmic data taking.

integrated over different time constants ranging from 40 $\mu$s to 84 s. If any of the readings for two modules on the same side of IP exceeds a predefined threshold the system will abort the LHC beams.

## References

1. W. Trischuk et al., JINST, **3**, P02004 (2008)
2. I. Dolenc, *Development of Beam conditions monitor for ATLAS experiment*, Ph.D. thesis, University of Ljubljana, 2008
3. T. Kittelmann et al., *The Virtual Point 1 event display for the ATLAS experiment*, CHEP 2009, Prague, Czech Republic, 21-27 Mar 2009 to be published in JPCS
4. F. Anghinolfi et al., Nucl. Instr. and Meth. A **553**, 183-187 (2004)
5. The ATLAS collaboration, *T*he ATLAS Experiment at the CERN Large Hadron Collider, JINST **3**, 1-422 (2008)
6. *T*he TRT Fast-OR Trigger, to be published in ATLAS note
7. C. Zamantzas, *The Real–Time Data Analysis and Decision System for Particle Flux Detection in the LHC Accelerator at CERN*, Ph.D. thesis, Brunel University, 2006