Performance Studies of Minimum Bias Trigger Scintillators in LHC Run 3

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Abstract

The Minimum Bias Trigger Scintillators (MBTS) system provided the primary triggers for selecting events from low energy or low interaction rate runs, such as first collisions, calibration scans and heavy ion runs. During the Long Shutdown 2 (2019-2022), the MBTS were completely replaced with the 32 new counters. Since 2022, the MBTS have been commissioned with cosmic rays and LHC Run 3 collisions events. This project proposes a study of the performance of each counter in terms of efficiency and radiation damage effects using the data taken by the ATLAS detector in 2022.

1 Introduction

1.1 ATLAS detector

The ATLAS detector allows detection and precise measurements of different types of particles produced in the collisions delivered by the Large Hadron Collider (LHC). Charged particles are reconstructed in the central pseudorapidity range $|\eta| < 2.5$ using information from the Inner Detector (ID) surrounding the interaction point and placed in the 2 Tesla magnetic field. The innermost part of ID, the pixel detector, consists of several layers of silicon pixel sensors arranged into a cylindrical barrel and two sets of disks on both sides of the barrel. Similar layouts also have the silicon strip sensors of the Semicondictor Tracker (SCT) placed directly after the pixel detector. Tracks found in these two detectors may be extended to the Transition Radiation Tracker (TRT), which is the outermost part of the ID. The electromagnetic and hadronic calorimeters, placed farther away from the interaction point and covering the range $|\eta| < 4.9$, are used to measure the energy of jets and high-p_T particles. Muons with $|\eta| < 2.7$, which traverse all the above mentioned detectors without stopping, are registered in the Muon Spectrometers. The components of ATLAS detector are shown on Fig. 1.
In addition there are several smaller components providing specific signals needed by the trigger system or used in some special measurements. One of them is the Minimum Bias Trigger Scintillators detector (MBTS). Several more small detectors are located at large distances from the interaction point. The ALFA detector using scintillator fibres is installed at ± 237 m and ± 241 m. The ATLAS Forward Proton detector (AFP) is slightly closer, at ± 205 m and ± 217 m. Each of its arms has two stations, which comprise 4 planes of silicon pixel sensors and a Time-of-Flight detector. Both ALFA and AFP detectors are placed very close to the beam and are used to measure particles emitted at very small angles. Closer to the interaction point is the detector of the LHCf experiment located at ± 140 m and measuring photons emitted in the ranges $8.81 < |\eta| < 8.99$ and $|\eta| > 10.96$ using calorimeters. [1]

1.2 Minimum Bias Trigger Scintillators detector

The MBTS detector is situated near the interaction point inside the ATLAS detector, at a distance of approximately 3.6 m along the beam pipe (see Fig. 1). It's primary purpose is to provide a minimum bias trigger for the ATLAS experiment. MBTS are mounted on the inner face plate of the electromagnetic endcap calorimeters. There are 32 polystyrene scintillator counters of 2 cm thick each, organized into two disks with one on each side of the ATLAS detector (A and C). The scintillators are installed on the inner face of the end-cap calorimeter cryostats at z = 3560 m such that the disk surface is perpendicular to the beam direction. Each disk is divided into an inner and an outer ring respectively covering the radial regions (153, 426) mm and (426, 890) mm. The

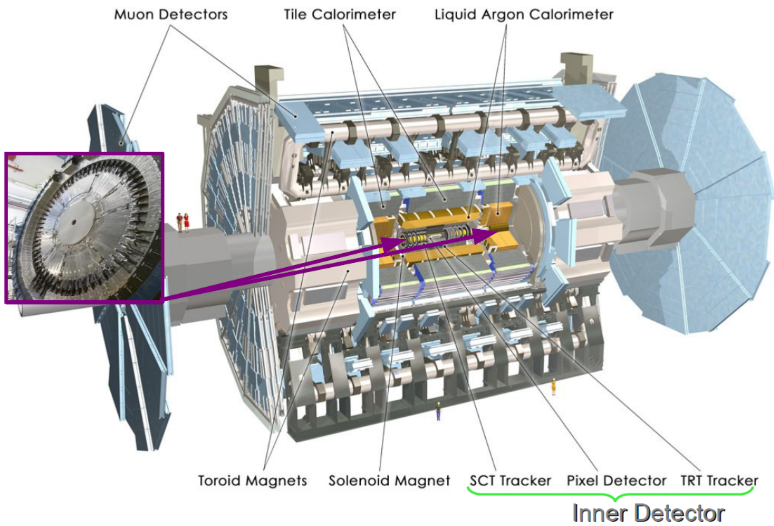
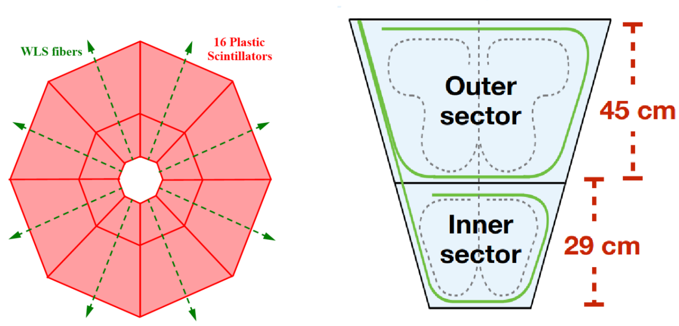


Figure 1: ATLAS detector including the position of MBTS

outer counters pseudorapidity acceptance (η) is $2.08 \leq |\eta| \leq 2.78$, while the acceptance for inner counters is $2.78 < |\eta| < 3.75$. [2]

Both inner and outer rings are organized into eight independent ϕ sectors, $2\pi/8$ radians wide each. These sectors are placed such that the first sector has its edges at $\phi = 0$ and $\phi = \pi/4$. Light emitted by each scintillator counter is collected by wavelength-shifting (WLS) optical fibers. WLS are embedded in grooves at the edges of the counters and are grouped at the center of the module between the two pieces of scintillator. These optical fibers guide the emitted light to photomultiplier tubes (PMTs), which are read out through the same electronics that is currently used to read out the Tile hadronic calorimeter (TileCal). Connection between MBTS modules, counters and PMTs are showwn in Table 1 and 2. MBTS structure is shown on Fig. 2. In 2019, MBTS were replaced with radiation-hard green scintillators for the inner counters and standard blue scintillators for the outer counters (see Fig. 3).

The MBTS signals, after being shaped and amplified in such a way that the pulse amplitude is proportional to the amount of energy deposited in the counter, are fed into leading edge discriminators and sent as 25 ns NIM pulses to the Central Trigger Processor (CTP). The total charge collected as well as the arrival time of the signals are recorded. An MBTS hit is defined as a signal above the discriminator threshold. At the CTP input, the 32 MBTS signals are stretched to 200 ns and the hit multiplicity is calculated for each side independently. [3]



(a) (b)

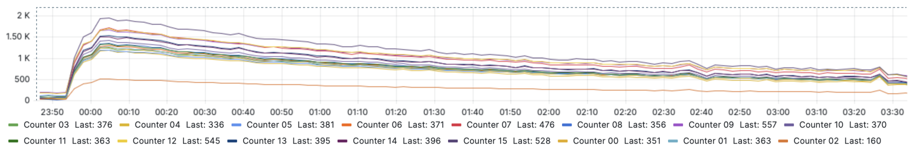
Figure 2: MBTS disk structure. (a) Layout of one of the two MBTS disks. 16 plastic Scintillators and WLS fibers are shown. (b) Inner and Outer sectors of MBTS disk.

(a) (b)

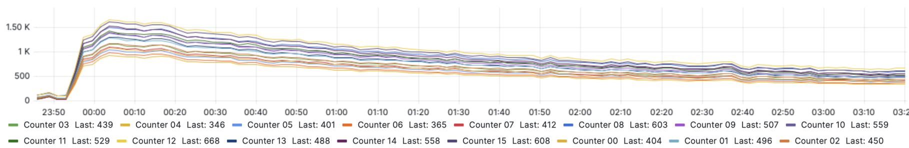
Figure 3: MBTS scintillators. (a) standard blue scintillator, (b) radiation-hard green scintillator

2 Event rate selection

Particle collisions occur at an extremely high rate in accelerators like the LHC, producing an enormous amount of data. A two-level trigger system was used by ATLAS in Run 3 to reduce the event rate from a maximum raw rate of 40 MHz to 1 kHz, which is written to disk. The L1 trigger (L1) is the initial stage of event selection in ATLAS detector. It's a hardware-based system designed to quickly decide whether an event is interesting enough to be recorded for further analysis. It uses a subset of calorimeter and muon sub-detector information to accept events at a rate below 100 kHz. If an event meets this criteria, it is "triggered" and sent for further analysis at higher levels of the trigger system, reaching a decision within a latency of less than 2.5 µs.[4]
The High-Level Trigger (HLT) is the second stage of event selection in the ATLAS experiment. It reduces the accepted event rate to 1 kHz on average depending on the data-taking conditions. Unlike the Level 1 trigger, which operates with hardware-based algorithms and makes quick decisions, the HLT



(a) A side



(b) C side

Figure 4: Rates dependence as a function of time for all counters. Plots include period from 19.07.22 23:50 to 20.07.22 3:30.

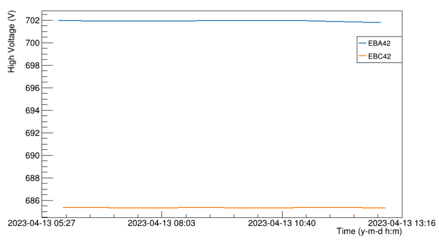
involves more sophisticated software-based algorithms that analyze the event data in more detail. Since the HLT has access to more information and operates with more advanced algorithms, it can be more selective in choosing events of interest. However, due to the increased computational complexity of the HLT, it operates with a longer processing time compared to the Level 1 trigger, with typical event decision times of 40 µs. [5]
L1 and HLT rates for the MBTS counters can be seen on Fig. 4.
The MBTS counters operated at a constant High Voltage (HV), with values ranging between 600 to 700 V for different counters. HV as a function of time for some MBTS cells are shown on Fig. 5.

Table 1: Connection between modules and counters for MBTS inner cells

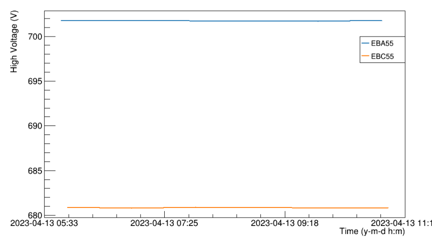
A side			**C side**		
Counter	Module	PMT	Counter	Module	PMT
A00	EBA57	PMT5	C00	EBC57	PMT5
A01	EBA58	PMT5	C01	EBC58	PMT5
A02	EBA39	PMT5	C02	EBC39	PMT5
A03	EBA40	PMT5	C03	EBC40	PMT5
A04	EBA41	PMT5	C04	EBC41	PMT5
A05	EBA42	PMT5	C05	EBC42	PMT5
A06	EBA55	PMT5	C06	EBC55	PMT5
A07	EBA56	PMT5	C07	EBC56	PMT5

Table 2: Connection between modules and counters for MBTS outer cells

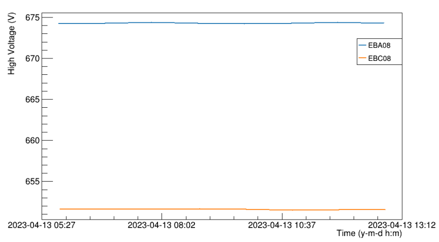
A side			**C side**		
Counter	Module	PMT	Counter	Module	PMT
A08	EBA03	PMT13	C08	EBC03	PMT13
A09	EBA08	PMT13	C09	EBC08	PMT13
A10	EBA20	PMT13	C10	EBC19	PMT13
A11	EBA24	PMT13	C11	EBC24	PMT13
A12	EBA43	PMT13	C12	EBC43	PMT13
A13	EBA46	PMT13	C13	EBC45	PMT13
A14	EBA54	PMT13	C14	EBC54	PMT13
A15	EBA59	PMT13	C15	EBC59	PMT13



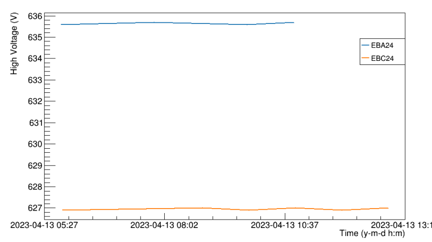
(a) Cell 05



(b) Cell 06



(c) Cell 09



(d) Cell 11

Figure 5: HV dependence on Time for cell 05, 06, 09 and 11. Blue lines show A side, orange lines show C side. Plots include period from 13.04.23 5am to 13.04.23 1pm. As can be observed, it't almost constant over the given period. Connection between modules and counters for MBTS cells are presented on Table 1 and Table 2.

3 Degradation of MBTS system

The LHC operation affects the performance of the MBTS. Prolonged exposure to intense radiation causes a decrease of the optical transmission of the scintillating tiles and of the WLS fibres causing large MBTS signal reductions.

The average total ionising doses are 0.61×10^3 Gy/fb^{-1} for inner counters and 0.83×10^2 Gy/fb^{-1} for outer counters. The degradation of the MBTS system has been determined using laser and MB data collected during pp collision runs. The PMTs were operated at 500 V. The MBTS response was obtained normalising the measured MB currents to ATLAS instantaneous luminosity. [6]
Fig. 6 shows the response variation of the inner and outer counters as a function of total ionasing dose, integrated luminosity and time. Conversion factor (α) is defined as:

$$\alpha = \frac{I}{L_{int}},$$

where I is PMT current that is measured as:

$$I = \frac{< ADC >}{Gain},$$

and L_{int} is integrated luminosity. Luminosity values were obtained using ATLAS luminosity calculator[7]. The relative variations of the PMT responses as measured by the Laser system are also shown.

4 Results and Conclusions

In this work, two sides (A and C) of MBTS counters have been observed. Monitoring of MBTS rates have been performed, with a specific focus on L1 and HLT rates over time. The results illustrate a trend in rates, decreasing from 2 kHz to 500 Hz throughout the day. HV at which MBTS counters operated, have also been checked and found to remain constant during the operating period.
By the end of 2022, the inner and outer MBTS counters have lost almost 40% of their response. Degradation of the counters is primarily influenced by the properties of scintillators rather than the performance of PMTs. New radiation-hard scintillators for inner counters have demonstrated an ability to endure higher ionizing doses and degrade much slower than the standard outer scintillators even with taking into account that they are closer to the beam line than outer ones.
Results of this project were presented during TileCal Trigger meetings [8][9] and during TileCal week on 11 of October [10].

5 Acknowledgements

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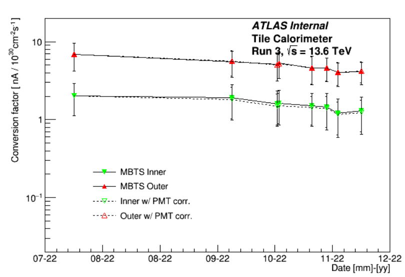
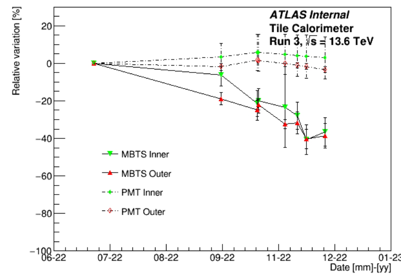


(a)



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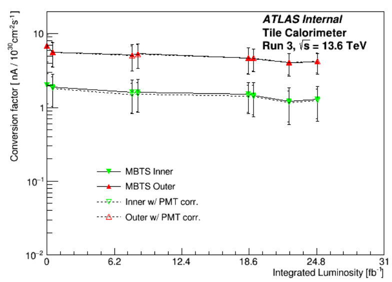

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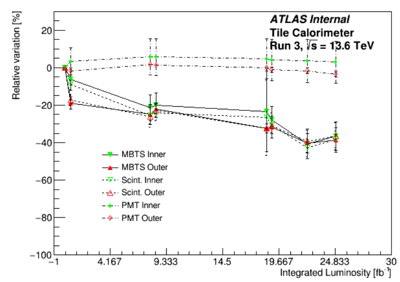
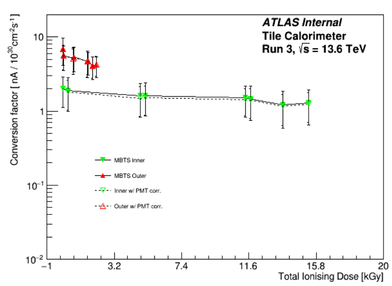
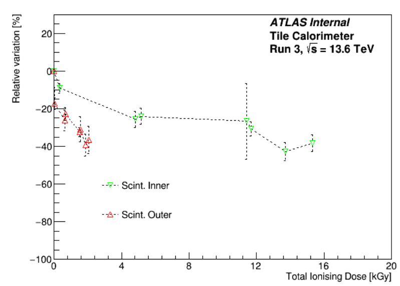


(d)



(e)



(f)

Figure 6: Response ((a), (c), (e)) and relative response variation ((b), (d), (f)) of the MBTS inner (green triangles) and outer (red triangles) counters as a function of Time ((a), (b)), integrated luminosity ((c), (d)) and total ionizing dose ((e), (f)) during Run 3. MBTS corresponds to full response (scintillators and PMTs). The green (red) diamond-shaped markers show the relative response of the PMTs and scintillators of the inner (outer) counters.

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