PROCEEDINGS OF SCIENCE

Measurements and identification strategies for non-collision backgrounds in ATLAS experiment

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During nominal LHC collisions, protons can interact with residual gas in the beam pipe or with upstream collimators, producing showers of background particles known as Beam-Induced Backgrounds . These particles do not originate from the real proton–proton interaction point. Beam-Induced Beams can significantly impact detector performance and mimic signals in the searches for missing energy or for certain types of new physics, such as neutral long-lived particles. The ATLAS Non-Collision Background group plays a key role in developing tools to identify and reject these backgrounds. The characteristic features of Beam-Induced Background, as observed by the ATLAS Beam Conditions Monitor, the inner detector or as fake jets in calorimeters, are studied in detail in order to identify them and estimate their residual contribution.

As a part of this effort, series of dedicated pressure bump tests were performed during LHC Run 2 by introducing local pressure bumps at different locations with a gas density higher by orders of magnitude than during normal operation. The rates of beam-gas events are then estimated from the pressure measurements and pressure bump profiles obtained from calculations.

In this contribution, an overview of the origins of Beam-Induced Beam, the ATLAS Beam-Induced Beam online monitoring system, the pressure bump tests, and recent results based on measurements from LHC Run 2 data are provided.

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1. Introduction and motivation

Unconventional signals in searches for physics beyond the Standard Model in the ATLAS [1] detector using p–p collisions might include unconventional tracks and displaced jets [2] that are very similar to fake jets that arise from radiative energy losses of high-energy muons traversing the calorimeters due to beam-induced background or cosmic background. Non-collision background (NCB) signatures constitute an important source of background for these analyses, and their contribution must be well estimated. NCB can cause a trigger by themselves due to large energy deposits or they can overlap with a collision event and together form a signature leading to a trigger. The two principal Beam-Induced Beam (BIB) observables monitored in the ATLAS experiment are hits in the dedicated Beam Conditions Monitor (BCM) located close to the beam pipe and fake jets observed at radii of up to several metres. These proceedings present a summary of the BIB and the characteristic features used to identify it in the ATLAS inner detector and calorimeters. The pressure bump tests and recent results based on measurements from LHC Run 2 data are also provided.

2. Non-collision backgrounds

There are three main sources of NCB: protons scattering on residual gas molecules can create showers of secondary particles (beam gas), protons escaping the beam core and impacting on limiting apertures, e.g. collimators (beam halo) and cosmic-ray muon background due to high-energy muons produced in the atmosphere and traversing the ATLAS detector. The former two are referred to as beam-induced backgrounds (BIB) and are illustrated in Figure 1.

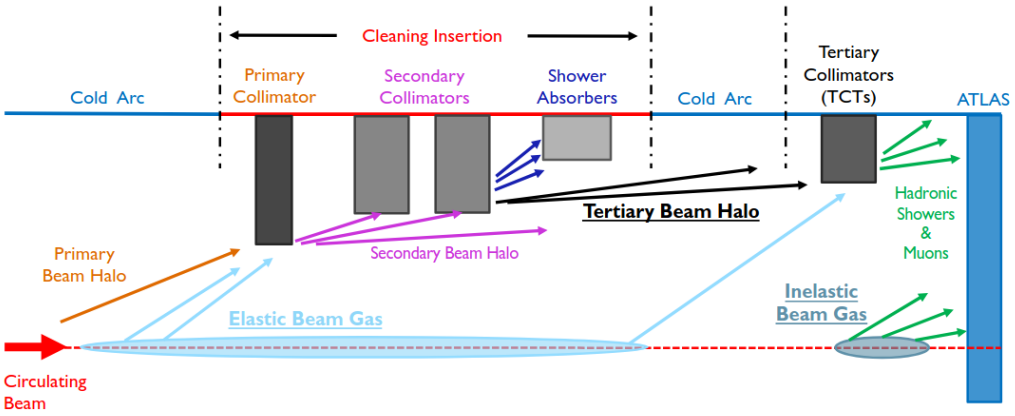

Figure 1: Schematic illustration of the sources of BIB reaching the ATLAS detector: nearby inelastic beam-gas collisions, tertiary beam halo losses on the TCT and protons deflected by elastic beam-gas collisions and hitting the TCT. The Figure is taken from Ref. [3].

3. Beam-indiced background signatures in the Beam Condition Monitor

The Beam Condition Monitor (BCM) sub-detector is used to monitor luminosity and BIB levels. It consists of two detector stations with four diamond modules each.

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The BIB trigger signature in the BCM, illustrated in Figure 2, is formed by a coincidence of an early hit before the nominal collision time in any of the four sensors on one side and an in-time hit aligned with the arrival time of collision products in any sensor on the other side of the interaction point (IP).

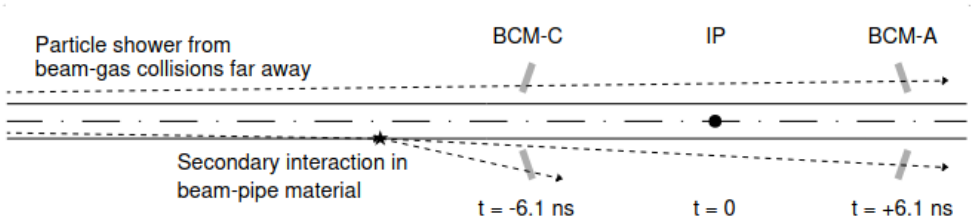

Figure 2: Illustration of the BIB trigger signature in the BCM.The trigger can be fired either by a single particle traversing a module on both sides of the IP or by two different particles. Figure is taken from Ref. [5].

4. Non-collision background signatures in the inner detector and the calorimeters

The ATLAS SemiConductor Tracker (SCT) [6] is a silicon-strip tracking detector which forms part of the ATLAS inner detector. The tracker is made up of a central barrel and two identical end-caps.

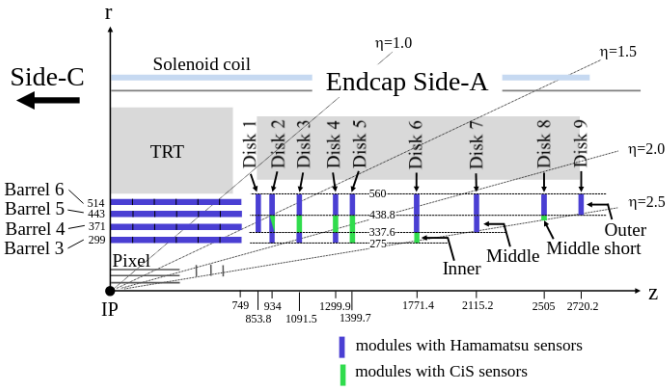

Figure 3: A schematic view of one quadrant of the SCT. The numbering scheme for barrel layers and endcap disks is indicated, together with the radial and longitudinal coordinates in millimetres. Figure is taken from Ref.[6].

The time difference between the hit counts recorded in the upstream endcap and those in the downstream endcap of the SCT creates an asymmetry. The z-asymmetry shown in Figure 4 (left) is the difference between the number of hits in endcap A and endcap C, normalised by the total number of hits in both endcaps and it is expected to be more pronounced for sub-detectors that are further away from the IP. The distribution of the time of the leading calorimeter clusters vs. pseudorapidity shown in Figure 4 (right) for events from crossings between unpaired isolated bunches without any primary vertex, exhibit a clear band structure.

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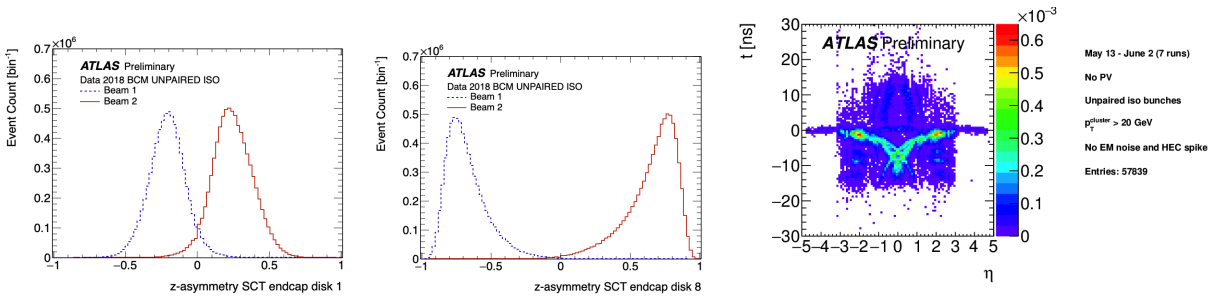

Figure 4: The z-asymmetry in SCT endcap disk 1 and 8 (left) and pseudorapidity vs timing distribution in calorimeter clusters (right). Figure is taken from Ref. [4].

5. Pressure bump test

FLUKA Monte Carlo simulations [7] can be used to predict the ATLAS detector efficiency to detect a beam-gas event as a function of its position along the z axis [8]. A series of dedicated pressure bump tests [5] were performed during the LHC Run 2, and the sensitivity of ATLAS to beam-gas events at various well-defined locations were quantified. The pressure bumps were created at four different z locations between 19 m and 151 m by heating Non-Evaporable Getter (NEG) cartridges such that some of the gas they had absorbed was re-injected into the LHC beam vacuum, resulting in a detectable increase of the BIB.

Figure 5 shows a schematic summary of the measurement, analysis and simulation procedures for the pressure bump test.

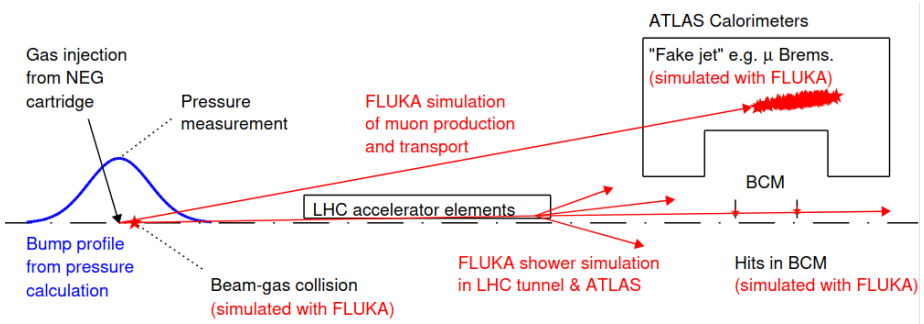

Figure 5: Schematic illustration of the pressure bump test. Figure is taken from Ref. [5].

6. Background measurements

The gas injection causes localised pressure bumps. The observed background is parameterised as a function of the change of local pressure as:

$$B = C + \omega(z_i)\Delta P(z_i) \tag{1}$$

with $\omega(z_i) = \frac{\Delta B}{\Delta P(z_i)}$, where $\omega(z_i)$ represents the ratio between the additional background rate ΔB observed by ATLAS and the change of local pressures $\Delta P(z_i)$ reported by vacuum gauges at locations z_i where i refers to the four pressure bump locations. C is the pedestal BIB level from

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beam-halo losses and from beam-gas interactions in the absence of the pressure bump with a minor contribution from cosmic-ray muons for fake jets.

Figure 6 shows the observed BCM and fake-jet background rates from beam-2 pressure bumps at 58 m and 151 m in LHC fill 6239, together with the BIB predictions from the pressure parameterisation defined in Equation 1. Data in the shaded regions are used to determine the parameters C and $\omega(z_i)$ needed to produce the BIB predictions. The pressure parameterizations follow closely the measured BCM backgrounds, except for a minor overshoot on the rising edge of the 58 m bump and a slightly faster return to the initial level. Excess jet rates are clearly resolved for these distant pressure bumps, even though the pedestal level is rather noisy.

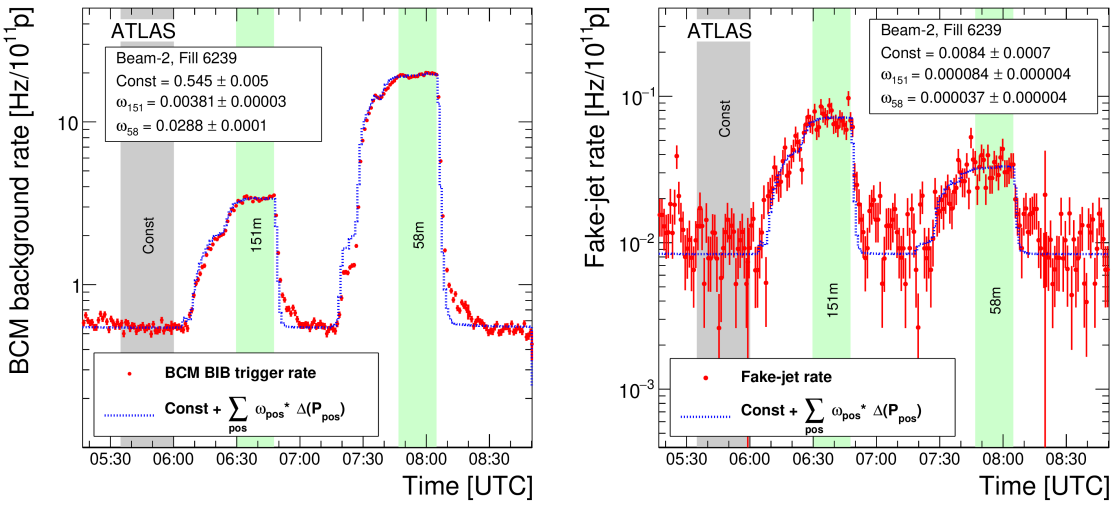

Figure 6: BCM background rate (left) and fake-jet rate (right) at 58 m and 151 m for beam-2 in LHC fill 6239. The data are shown with red markers while BIB predictions from the pressure parameterisation are shown with blue dotted lines. Figure is taken from Ref. [5].

7. Conclusion

Understanding non-collision background events is an important task for providing feedback to the LHC accelerator, to ensure good quality recorded data, and to provide estimates for physics analyses. Several dedicated pressure bump tests were undertaken during LHC Run 2 in order to determine the sensitivity of the ATLAS beam-induced background (BIB) monitoring system to beam-gas events. A very good correlation between the pressure measured at the bump location and the BIB rates seen in ATLAS is observed, i.e. the BIB rate can be fitted with a linear combination of a constant term and the local pressure changes.

NCB can be an issue during LHC operations. The successful benchmarking of the simulation methods provides important information for the study and optimization of future accelerator configurations such that the background in the experiments can be minimised.

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