BEAM-GAS BACKGROUND OBSERVATIONS AT LHC

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Abstract

Observations of beam-induced background at LHC during 2015 and 2016 are presented in this paper. The four LHC experiments use the non-colliding bunches present in the physics-filling pattern of the accelerator to trigger on beam-gas interactions. During luminosity production the LHC experiments record the beam-gas interactions using dedicated background monitors. These data are sent to the LHC control system and are used to monitor the background levels at the experiments during accelerator operation. This is a very important measurement, since poor beam-induced background conditions can seriously affect the performance of the detectors. A summary of the evolution of the background levels during 2015 and 2016 is given in these proceedings.

INTRODUCTION

Non-collision backgrounds can adversely affect high energy physics experiments at colliders and include: cosmic-rays, detector noise and Beam-Induced Background[1] (BIB). Monitoring the latter during LHC operation is especially important, since excessive levels of BIB can impact detector performance seriously, particularly the inner trackers; or can mimic physics signals, such as fake jets in the calorimeters with associated missing transverse momentum, which must be understood and mitigated in physics analyses. Three sources of BIB have been identified [1]:

Inelastic beam-gas interactions occurring just upstream of the experiments (within long straight sections or the beginning of the arc), which can generate showers of energetic secondaries that penetrate the experimental caverns and reach the innermost sub-detectors. This is the dominant source of background at the LHC.

Beam halo losses in aperture restrictions, which can produce secondaries that reach the experiments. In the LHC the main contribution comes from the aperture restriction nearest to the experiments; the Tertiary Collimators (TCTs).

Elastic beam-gas scattering all around the ring. The scattered protons may eventually be intercepted by the beam cleaning insertions or the TCTs. In the latter case, their effect adds up to the beam losses in the TCTs.

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[1] Also known as Machine-Induced Background (MIB)

DETECTION METHODS

The main LHC experiments each monitor the BIB with dedicated sub-detectors, outlined below, which are typically triggered using the non-colliding bunches present in the physics-filling pattern of the accelerator. Every experiment sends certain background signals [2] to the LHC control room for online monitoring of the beam conditions. The data are stored in the accelerator logging database and displayed in the CERN Control Centre.

ALICE measures BIB using the ALICE Diffractive (AD) detector, a small-angle hodoscope consisting of two arrays of 8 cells of plastic scintillators of about $22 \times 22\,\mathrm{cm}^2$ and 2.5 cm thick each, installed asymmetrically at -18 m and +20 m on either side of the ALICE interaction point (IP). The background events rate associated to each of the two LHC beams are measured based on timing thanks to the wide arms and the good time resolution of the system [3]. The measured BIB rates were normalized to the beam intensity.

ATLAS primarily relies on the Beam Conditions Monitor (BCM) to measure BIB rates, using hits from two sets of four $8 \times 8\,\mathrm{mm}^2$ metalized diamond sensors with 680 ps timing precision [4]. The sensors are at a radius of 5.5 cm from the beam line and at ± 1.84 m from the IP, enabling independent identification of the incoming BIB from each beam, which arrives 12.3 ns earlier than the outgoing collision products. The BIB rates presented here are the online BCM trigger rates before prescale, normalized to the total intensity of the unpaired isolated bunches [5] used for the measurement.

CMS is equipped with the BCM1F detector [6], which comprises 24 single crystal diamond detectors (sCVD) of $5 \times 5\,\mathrm{mm}^2$ size with two readout pads per sensor, at 1.8 m on either side of the interaction point at a radius of 6.5 cm from the beam pipe. For the BIB measurement, all detector hits 12.5 ns prior to the arrival of collision products are counted. All non-colliding bunches and first bunches in all trains are averaged for the final background measurement. The result is normalized to the bunch intensities of the used bunches.

LHCb uses a dedicated beam and background monitoring system, commonly referred to as Beam Loss Scintillator (BLS) [7]. This is composed of a set of 6 scintillators and PhotoMultipliers (PMTs), 4 equipped with plastic and 2 with radiation-hard quartz radiators ($3 \times 4 \times 4\,\mathrm{cm}^3$) with quartz-window PMTs. The rate of BIB is measured from unpaired bunch interactions in LHCb, as a logical OR of the 6 scintillators/radiators, normalized to the intensity of the unpaired bunches themselves.

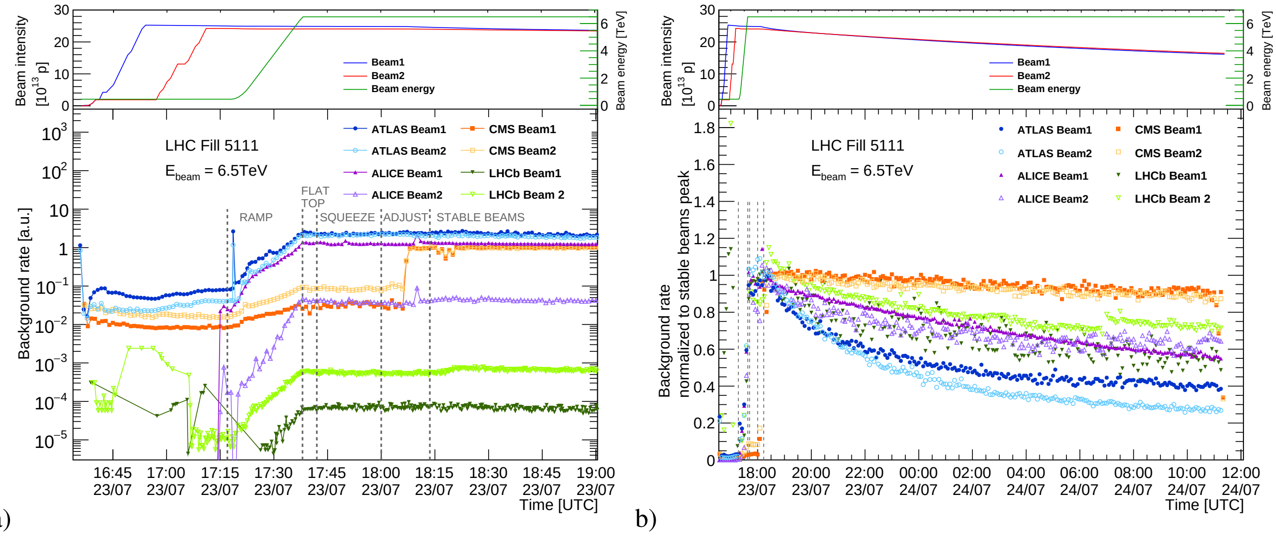

Figure 1: Background evolution during LHC Fill 5111 in 2016. Plot (a) shows the start of the fill, in which vertical lines indicate RAMP, FLATTOP, SQUEEZE, ADJUST and STABLE BEAMS. Plot (b) shows the BIB rates measured by each LHC experiment throughout the entire fill, normalized to the average value over the first ten minutes of STABLE BEAMS.

BEAM-INDUCED BACKGROUND VARIATION DURING A PHYSICS FILL

The LHC Fill 5111 in the 2016 pp run was selected by the LHC Background Study group as a typical example for comparison. The background rates provided by each of the four experiments are plotted in Fig. 1. Differences in absolute rates for each experiment and LHC beam are expected from the upstream gas pressures, beam optics and aperture restrictions; LHC simulations show they play a major role in the distribution of background reaching each experiment [8].

Fig. 1 a) shows in log scale the unnormalized rate of BIB at the start of LHC Fill 5111, from which several interesting features can be observed. All experiments see a similar increase in rate during the LHC beam energy RAMP. At FLATTOP and SQUEEZE the rates remain constant. During ADJUST to collisions a further increase is observed for CMS, with a temporary spike in rate in ALICE, while ATLAS and LHCb remain flat indicating the BIB measurement is insensitive to luminosity effects. It must be noted that the rates in Fig. 1 a) are not absolute and thus not directly comparable, mainly due to instrumentation effects, such as different sub-detector technologies, acceptance area, and different sub-detector locations relative to the beam line. Such instrumentation effects obscure the more subtle differences expected from simulation, however, the general variation in rates during the fill are observed.

In Fig. 1 b) the background rates have been normalized simply to the average rate in the first ten minutes of STABLE BEAMS. A gradual fall off in the background rates with beam intensity is typically observed over the duration of the fill. The ATLAS data show a rapid fall off because the BCM rates are normalized to the sum of unpaired isolated bunch intensities, and at the low radius of the BCM, the rates are dominated by residual beam-gas interactions close to the interaction region, where the beam pipe pressure is driven by the beam intensity [5].

BEAM-INDUCED BACKGROUND EVOLUTION IN 2015 AND 2016

The evolution of the rate of BIB reaching the LHC experiments during the pp run in 2015 and 2016 is shown in Fig. 2. Each data point represents the rate at the start of an LHC Fill, averaged over the first ten minutes of STABLE BEAMS, and normalized for each experiment as described above.

In general, the BIB rates in 2015 are higher and vary more than 2016. This is mainly due to the wider range of filling patterns at the LHC used in 2015. As the filling schemes became more stable in 2016, and after the initial scrubbing and recommissioning period, an overall reduction in rates is observed. Certain exceptions arise as a result of interventions in technical stops, and the dedicated pressure bump tests, in which the beam-pipe pressures upstream of the experiments were deliberately raised temporarily in a controlled fashion, to study the effects of beam-gas interactions on background rates. There are also detector specific reasons for the other features in the background rates, as explained below.

As is apparent in Figs. 2 a) & b), the beam 1 background rate (BKGD1) is constantly higher in ALICE due to the beam 1 injection region on the left side of IP2, and especially due to the TDI and TCDD beam stoppers [9]. In addition, due to the asymmetry of the AD detector, BIB arrive 13.4 (5.4) ns earlier than the collision signal on the left (right) side of AD when there are 25 ns spaced bunch trains, which implies different beam-gas trigger windows to not overlap with the collision trigger and a lower efficiency for BKGD2. The smaller BKGD2 rate observed in 2016 is due to lower gain applied on the AD PMTs.

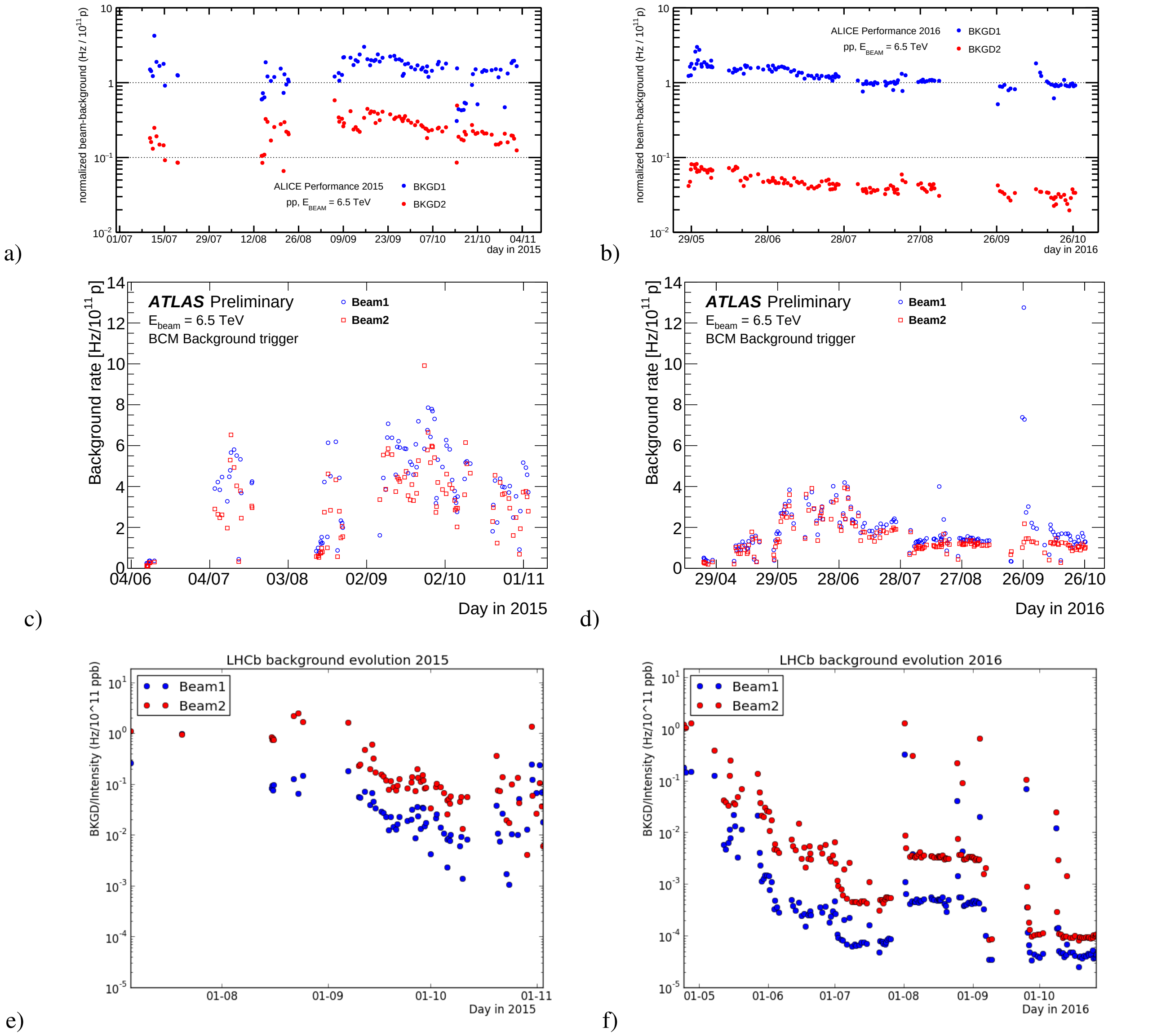

Figure 2: Beam-induced background evolution during 2015 (left) and 2016 (right) for ALICE (upper), ATLAS (middle) and LHCb (lower).

The evolution of ATLAS BCM rates is shown in Figs. 2 c) & d). A systematically higher rate of beam 1 than beam 2 is observed, which is consistent with previous studies [5]. An increased beam 1 background due to the pressure bump test [4] on 25/9/16 is apparent in subsequent LHC Fills (5332 to 5339), and is thought to be due to slow out-gassing of the beam screen in the triplet. Fluctuations of BIB rates related to the beam-screen temperature has been observed previously in run I, in fills subsequent to the quench of the superconducting triplet [5].

LHCb BIB rates are shown in Figs. 2 e) & f). The LHCb BLS system is located around 1.5 m upstream of the IP and while the response of the detector is in time with beam 2, it is about 5 ns shifted with respect to beam 1. For this reason the rates attributed to beam 1 are lower than beam 2.

CONCLUSION

A range of detection methods developed by the LHC experiments enable Beam-Induced Backgrounds to be continuously monitored, which is essential for smooth detector operation and BIB mitigation in the physics analyses. A first direct normalized comparison of the experimentally measured backgrounds during a typical fill reveals interesting features for further studies. The backgrounds measured so far in run II have tolerable, quite stable rates, and tests coordinated by the LHC Background Study group are helping to improve the understanding of measured backgrounds with respect to LHC simulations.

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