BEAM-GAS LOSS RATES IN THE LHC

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Abstract

We report on detailed simulations and first observations of beam-gas rates in the LHC. For the simulations, a set of comprehensive tools has been set up, which incorporate pressure maps, collimator settings, and beam optics. The simulations include both elastic and inelastic beam-gas events in the arcs and long straight sections of the LHC. This provides, amongst other things, realistic collimator loss distributions, fluxes of secondary particles into the experiments and multi-turn tracking of elastic event residues.

INTRODUCTION

LHC had its first collisions in November 2009, with a quickly following world record in collision energy at the end of the month. These days we are getting an instantaneous luminosity of about $10^{27}\,\mathrm{cm^2s^{-1}}$ without squeezed optics, at a collision energy of 7 TeV. From the initial pilot beam intensity of 5×10^9 protons/bunch and 1 bunch/beam, we eventually want to end up with the nominal intensity of 1.15×10^{11} protons/bunch and 2808 bunches/beam. The beams should eventually be strongly focused at the interaction points, further increasing the luminosity. These changes will not only change the luminosity, but the background as well. In order to get a good prediction of the signal to noise ratio and the protection of the machine, it is important to know how the different background sources scales with these changing parameters.

In this paper we will present the current status of our knowledge of the beam-gas background, i.e. background arising from protons in the beam colliding with the residual gas left in the beam pipe. This is a part of a larger effort to obtain the full picture of and scaling laws for background sources. We presented our simulation framework for distant beam-gas at PAC 09 together with V. Talanov [1]. In this paper we will present predictions for background rates from this simulation package, together with shower simulations for the long straight sections around ALICE and LHCb using Fluka. The predictions from the simulations are then compared to the early data that has currently become available from the LHC running. A more detailed presentation of these simulations for the LHC injection energy can be found in [2].

SIMULATIONS AND EXPECTATIONS

Input parameters

For the simulations, the nominal settings for 3.5 TeV is used. That includes a β^* of 10 m in ALICE, 3 m in LHCb, and 2 m in ATLAS and CMS. The external crossing angle is turned off, limiting the maximum number of bunches in the machine to 156 bunches/beam. The experimental magnets are set at full power, with inversed polarity in LHCb. The RF voltage is at nominal 16 MV.

Beam-gas by its nature depends linearly on the pressure, hence the pressure assumed is important. At 3.5 TeV, synchrotron stimulated desorption is assumed to be insignificant in the straight sections. In the arc, there is a slight increase in pressure from the purely static pressure maps. The H_2 equivalent pressure map can be seen in Figure 1.

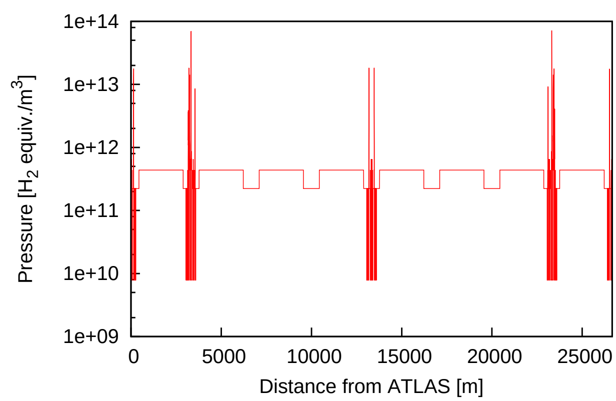

Figure 1: The H_2 equivalent pressure map used for the simulations. We see the four experimental regions, where a detailed simulated pressure map is available. The map starts at IP1, which is ATLAS.

LSS beam-gas

Beam-gas interactions in the long straight sections (LSS) of the experiments give a direct background source to the experiments. The elastic interactions contribute to the beam emittance growth, while the inelastic interactions generally produce forward hadrons and locally lost products at large angles. The forward hadrons (generally pions), and the resulting decay to muons, give the LSS beam-gas experimental background contribution.

The LSS beam-gas background to the LHC experiments was calculated using the simulated pressure map shown in Figure 1. A FLUKA geometrical model [3, 4] was constructed of the LSSs of the LHC, with a model of the magnetic elements, tunnel, shielding, collimators and all relevant mass distributions. The magnetic fields were included either through explicit field maps or ideal fields. Full details of the model for IR8 (LHCb) can be found in [3, 4]. The proton-gas molecule interactions are simulated using DPMJET and distributed in the LSS according to the pressure profile. Note the calculation is done in terms of hydrogen-equivalent pressure profiles. The resulting hadronic and EM showers give the background flux contribution into the experimental caverns. The particle showers are cut off at a kinetic energy of 20 MeV for all particles except neutrons, which are followed down to thermal energies.

The total rate of beam-gas interactions is obtained from the integral of the gas pressure profile in the LSS (up to the experimental interface plane) and the proton-hydrogen/proton-carbon nuclear cross section. Table 1 gives the total rates of LSS beam-gas inelastic interactions in the LSSs of LHCb and ALICE, assuming 2×10^{10} protons in the LHC and a pH inelastic cross section of 36 mb. The interface plane locations of LHCb are 2.1 m for beam 1 and 19.9 for beam 2, and 19.5 m on both sides for ALICE.

Table 1: LSS inelastic beam-gas interaction rates, assuming 2×10^{10} protons in the LHC.

LSS	rate [protons/s]
LHCb left	1.45
LHCb right	1.45
ALICE	1.25

The resulting LHCb MIB fluxes from beam-gas interactions in the LSS at 3.5 TeV beam energy are 3.3 charged hadrons/s and 0.2 muons/s for beam 1, and 5.9 charged hadrons/s and 0.5 muons/s for beam 2. Note the longitudinal location of these results differ due to the different location of the beam 1 and beam 2 interface plane for LHCb. The resulting MIB flux for ALICE beam 1 and beam 2 are 3.0 charged hadrons/s and 0.3 muons/s. These results are obtained for a proton fill of 2×10^{10} protons.

Distant beam-gas

Distant beam-gas provides additional background signal in form of protons hitting the tertiary collimators (TCTs) upstream of the final triplets in the insertion regions. As such, this background component does not have a clear signature that we see from the local beam-gas background. It will look more or less identical to the normal halo component, and will add on top of that signal. This will make distant beam-gas harder to disentangle than LSS beam-gas.

At the current beam energy we do not have dynamical contributions to the pressure. Hence, the beam-gas background is orders of magnitude below what we expect at nominal machine parameters. For nominal machine conditions, we have estimated based on simulations that the proton rate on the TCTs are on the order of MHz, and the simulated pressure maps gives a lifetime for the beam-gas component of about 1000 h. Calculations of beam-gas lifetime are further explained in [2]. This means that the distant beam-gas component can be expected to reach the same order of magnitude as the normal halo component.

Figure 2 shows a simulated loss map for 3.5 TeV. In this simulation we have used a β^* of 2 m in ATLAS and CMS, 3 m in LHCb and 10 m in ALICE. For the normalization to a rate, a bunch intensity of 9×10^{10} protons and 156 bunches per beam. The beam-gas lifetime is estimated to be on the order of 10^5 h, using the simulated pressure map for 3.5 TeV.

Table 2 gives the proton fluxes on the different TCTs, assuming the same parameters. The rates scale linearly with the total stored current for a given beam, so they can be rescaled to the actual intensity in the machine. The purpose of the TCTs is to protect the final triplets. As one decreases the β^*, the transversal beam size in the final triplets increases. Hence, the TCTs must be placed closer to the beam (in units of transversal beam size). That means that these rates would be higher for a β^* of 2 m in ALICE and LHCb, instead of 10 m and 3 m, respectively.

The proton rates in Table 2 must be transported to the experiments interface plane. This is done with the same FLUKA code that is used for the shower simulations of the inelastic beam-gas. From this one obtains a conversion factor in e.g. number of muons at the interface plane per proton at the different tertiary collimators. An example of such conversion factors for LHCb beam 1 can be found in [5].

EARLY DATA FROM LHC

As we see from Figure 2, the proton flux on the collimators is too low to be observed with the beam loss monitors at the moment. The experiments can still measure even single beam-gas events. This is done by measuring the trigger rate for bunches which are not colliding with a bunch in the other beam, what is defined as beam-empty trigger rates. The showers to the interface plane are then transported through the experimental cavern, and the expected trigger rate efficiency for the activated trigger scheme is calculated for the different background sources. This procedure is covered in [5] for the case of LHCb.

In the data following below we had a fill of three bunches in each beam, where there were two centred bunch col-

Table 2: Simulated rates in protons per second hitting the horizontal (H) and vertical (V) tertiary collimators for the 3.5 TeV parameters.

Experiment	Orientation	Rate [protons/s]	
		Beam One	Beam Two
ATLAS	H	40.4	46.2
	V	22.1	42.8
ALICE	H	2.54	2.87
	V	4.37	2.77
CMS	H	49.0	37.6
	V	54.1	30.3
LHCb	H	18.0	19.5
	V	14.4	46.0

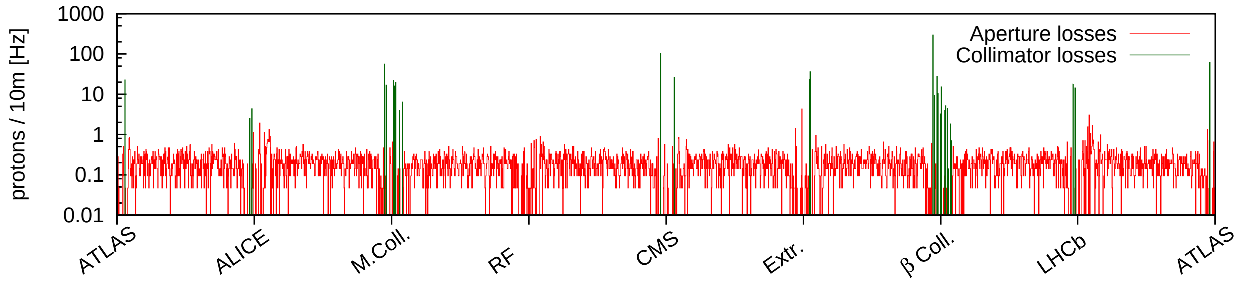

Figure 2: Simulated loss rates from beam 1 at 3.5 TeV. About 71 % of the events are lost locally, in addition to the losses shown here. The y-axis shows the number of protons hitting the aperture at the given location. Elastic hits on the collimators are not counted, the protons are then subsequently tracked until inelastic impact takes place.

lisions in each interaction point (IP). LHCb had for this fill an average trigger rate of 0.65 per second for beam-empty collisions for beam 1. With the trigger algorithm used, LHCb simulations show that this corresponds to a inelastic beam-gas rate of about 8 protons per second, to be compared with Table 1.

The bunch intensity for the non-colliding bunch was measured with the fast beam current transformer (BCT) and found to be about 9×10^9 over the course of the fill. Hence, the estimated rate of protons from inelastic beam-gas from our simulations is 0.65, one order of magnitude lower than measured. Betatron halo and elastic beam-gas do bring up the trigger rate slightly, but it is found that for the 3.5 TeV beam energy, inelastic beam-gas is the dominating background component in LHCb. Ignoring these components cannot explain the discrepancy, but they will result in a smaller difference between simulations and measurements. Background components can be significantly larger than expected, due to e.g. optics imperfections and misalignments that are not included in simulations.

We published an estimate for the beam-gas rates at 450 GeV in a note earlier this year [2], where we used a simplified pressure map based on measurements instead of simulations. Measured pressure levels should always be considered an overestimate, due to gauge outgassing, location of gauges etc.

The average pressure in the pressure profile we generated is close to one order of magnitude higher than the simulated pressure. If the average pressure is closer to our estimates pressure than the simulated pressure, that could explain some of the discrepancy between the simulated and measured trigger rate for this fill. It has always been stressed that the simulated pressure maps are order of magnitude studies, and that safety margins must be applied. The same pressure map simulations give a beam lifetime of about 1000 h for the nominal machine, whereas the lower limit requirement defined in the LHC design report is 100 h [6, 7].

SUMMARY

We have here presented an extensive framework for beam-gas background simulations in LHC. From this framework, we have estimated expected rate of background particles showering towards the experiments ALICE and LHCb for 3.5 TeV beam energy, in addition to providing a loss map for the rest of the LHC. The showers are compared to measured trigger rates for LHCb, and the simulations predict the trigger rates to be one order of magnitude lower than measured. This is not alarming for a first approach. We are pleased to see that we can already compare data with simulations at this early stage.

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REFERENCES

[1] Y. Inntjore Levinsen, H. Burkhardt, and V. V. Talanov. Simulation of beam-gas scattering in the LHC. In *PAC Vancouver*, May 2009.

[2] R. B. Appleby, Y. Inntjore Levinsen, and H. Burkhardt. LHC-Project-Note-429, CERN, Geneva, Feb 2010.

[3] R. B. Appleby and A Mereghetti. LHC-Project-Note-427, CERN, Geneva, Feb 2010.

[4] R. B. Appleby, G. Corti, M. Lieng, D Macina, and V. V. Talanov. LHC-PROJECT-Report-1180, CERN, Geneva, Jan 2010.

[5] M. Lieng, R. B. Appleby, G. Corti, and V. V. Talanov. In *IPAC Kyoto*, number MOPEC001, 2010.

[6] A. Rossi and N. Hilleret. LHC-Project-Report-674, CERN, Geneva, Sep 2003.

[7] O. S. Brüning, Paul Collier, P Lebrun, Stephen Myers, Ranko Ostojic, John Poole, and Paul Proudlock. *LHC Design Report*, volume 1. CERN, Geneva, 2004.