DEPENDENCE OF BACKGROUND RATES ON BEAM SEPARATION IN THE LHC

Yngve Inntjore Levinsen *, Helmut Burkhardt †, R.B. Appleby ‡, Simon Mathieu White §

Abstract

To some extent, background and loss rates vary when beams are brought into collision in the LHC and when the beam separation is varied during luminosity scans. We have searched for these effects in the early LHC operation. The data are analysed and compared with models and simulations.

INTRODUCTION

The LHC includes four experimental regions. The collisions in each interaction region will result in scattered particles, some of which may be lost in another interaction region resulting in cross talk between the experiments. Proton colliding in one experiment with a small energy loss could survive in the beam for a short while, being lost around another experiment. Depending on optics, phase advance, aperture and so forth, the level of background arising from this cross talk can change significantly. As part of a larger effort to map out and understand the different background sources in LHC, we have been simulating and studying the cross talk as a function of the interaction rates in the different experiments.

Interaction region cross talk as potential source of background has been known for a while. Earlier studies on loss maps from collisions in the CMS interaction region already showed evidence for this effect [1], and motivated for a more dedicated study as presented here. The design luminosity of the LHC is $10^{-34}\,\mathrm{cm^{-2}\,s^{-1}}$, for the two high luminosity experiments ATLAS and CMS. The two other experiments, LHCb and ALICE were designed for luminosities which are several orders of magnitude below the LHC design luminosity. ALICE in particular will run at a nominal luminosity of about $10^{-29}\,\mathrm{cm^{-2}\,s^{-1}}$ up to a maximum of $3\times10^{-30}\,\mathrm{cm^{-2}\,s^{-1}}$, and will therefore be rather sensitive to cross talk from the high luminosity interaction regions [2]. The background is dependent on the specific machine parameters. A simulation tool is required to predict the background levels in a given setting. Of importance is the luminosity in each experiment, the positions of the tertiary collimators, and the phase advance between different elements (experiment to experiment, or experiment to a given aperture bottleneck upstream of other insertions).

Small angle elastic proton collisions in one experiment give an angular kick to the protons, acting as a transversal diffusion process. Since collisions are more probable in the centre of the beam, this will typically increase the betatron action of the colliding proton. As a result, one would expect a peak in losses from one experiment at locations which are at a phase advance

$$90 + \mathrm{atan}(\alpha/\beta) + 180\cdot n \tag{1}$$

degrees downstream of the collision point, where n is an integer and where the twiss parameters are taken at the point the potential loss points.

In addition, we also expect losses from proton collisions which result in a small energy loss. A proton will be lost from the stable rf-bucket for an energy loss of $\Delta E/E > 3.5\times10^{-3}$ but may still travel through one or several of the LHC arcs up to $\Delta E/E \approx 7\times10^{-3}$. This is included in our simulations. The dispersion around the experiments is small so that most of the off-momentum protons will be lost far from the experiments and not contribute much to the observed backgrounds.

We searched for signs of cross talk during luminosity scans. These scans are done for only one of the four interaction regions at a time. The duration of these scans is less than 30 min, which is short compared to the beam and luminosity lifetime (> 10 h), so that any changes in the observed background rates at the other interaction regions would be evidence for cross talk.

SIMULATIONS

A simulation has been set up, in similar manner to the beam-gas simulations [3, 4]. A detailed optics and aperture model is available. Sixtrack is used for tracking, providing the availability of high speed multiturn tracking of protons. Other residues from the collisions are not able to survive from one experiment to the next without getting lost.

DPMJET III is used to generate collision events. DPMJET can use internally PYTHIA and PHOJET. The framework developed for these background studies is highly modular, which means that other event generators can be tested.

In Figure 1, a simulated loss map from IP cross talk is shown for beam one (moving clockwise when seen from above). A detailed view around the IPs is shown in Figure 2. The beam energy is 3.5 TeV. For the simulations we assumed a β^* of 2 m in ATLAS and CMS, 3 m in LHCb, and 10 m in ALICE. This differs somewhat from the current machine, which has 2 m β^* commissioned in all four IPs.

* Univ. of Oslo, Norway and CERN
† CERN, Geneva, Switzerland
‡ CERN and Univ. of Manchester, United Kingdom
§ Univ. de Paris-Sud 11, France and CERN

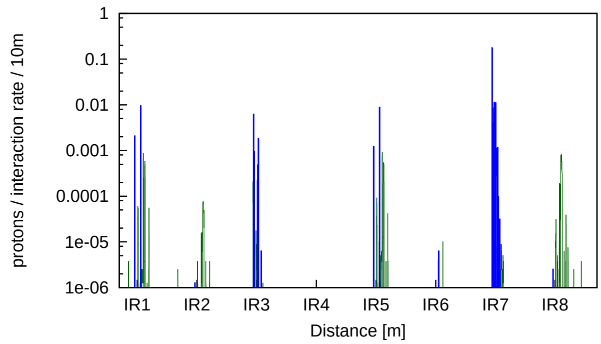


Figure 1: The loss map from beam one. Rates coming from different experiments are normalized to the squeeze optics at those experiments. The blue line show losses on collimators, whereas the green line shows losses on other aperture restrictions.

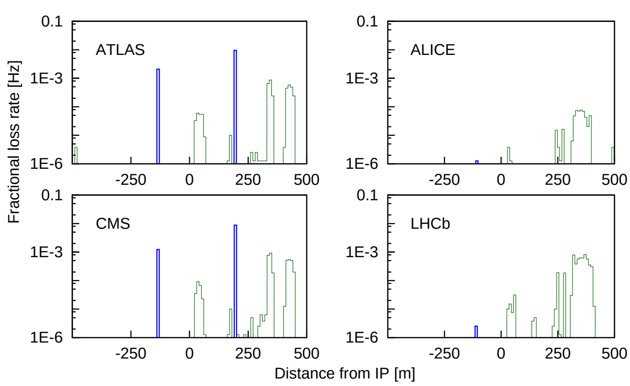


Figure 2: Detailed loss maps around the experiments. Losses downstream of the IP are for the most part coming from the IP itself. What is interesting are losses upstream of the IP, which can cause particle showers into the caverns.

Elastic and quasi-elastic collisions make up for a large fraction of the collisions in the insertion regions. For 3.5 TeV, about 28 % of the protons are found to be within an energy range which makes it possible to survive through one arc without being lost. About 10 % of the protons are found to survive for more than 100 turns after the collision. These numbers vary slightly for different machine settings. We are left with slightly less than 1/5 of the protons which are potentially contributing to the cross talk between the experiments.

LUMINOSITY CALIBRATION SCANS IN LHC

An application has been developed [5] to separate the beams locally in the insertions and obtaining the luminosity as a function of the separation of the two beams. This application has two purposes. First, it is used to optimize the luminosity. This is a quick procedure performed regularly during operation. The second purpose is to do calibration scan in order to obtain an estimate on the luminous region and then an estimate on the absolute luminosity. These scans are slower (in order to obtain sufficient statistics) and more points are required for a proper fit. An example of the resulting interaction rate on one of the collision rate monitors (BRANs) can be seen in Figure 3. The duration of a full scan depends on the available intensity. With an interaction rate on the BRANs of around 100 Hz that we had during this scan, a full scan took about 20 min.

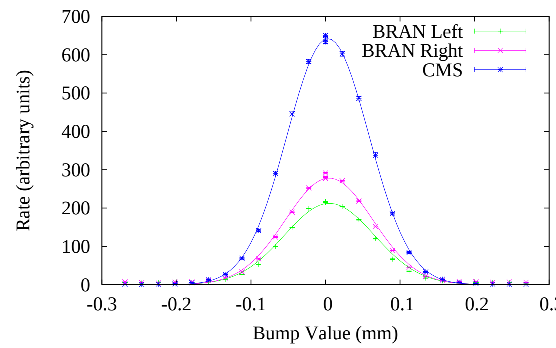


Figure 3: The interaction rate during a luminosity scan in CMS [6]. This full scan took about 20 min to finish.

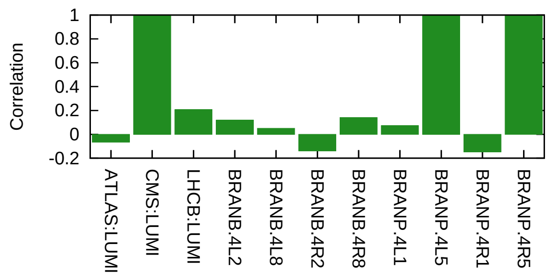
Because the luminosity scans give a particular signal to the luminosity as a function of time, it was considered worthwhile to search for correlations between this signal and background signals at other places in the machine.

In LHC there are many different detectors that could be used to search for cross talk. To study all signals in detail for all luminosity scans would be very time consuming. Hence one has developed an analytical tool that calculates the correlation between a specified signal (e.g. the signal from a BRAN) to all other signals selected. The correlation should then give a quick indication if there is something worth looking at. An example is given in Figure 4.

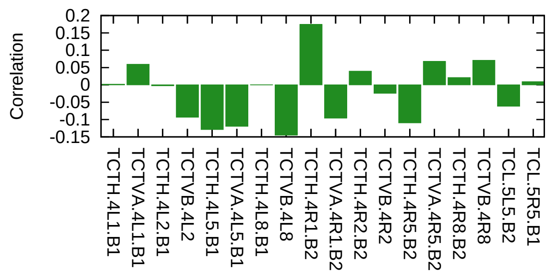
In the figure we observe that only the luminosity signals in the insertion itself show a clear correlation. Even the physics debris collimators (TCL R/L 5) do not see any signal variation. We expect that higher intensity would be required in order to study the IR cross talk in detail.

DISCUSSIONS AND OUTLOOK

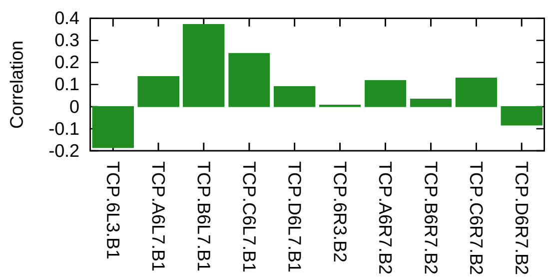
In the simulations, it is observed that a high fraction of the collisions in ALICE result in a proton hitting the TCTs in CMS and ATLAS for beam one and beam two respectively. This can be understood from the fact that the β^* is larger in ALICE than the other experiments, which means that γ^* is lower. Hence a given angular kick (which is dependent on neither β^* nor γ^*) will result in a larger betatron action for the proton collisions in ALICE than the other experiments. In addition, the TCTs are more relaxed when β^* is larger in a given IP, decreasing the fraction of the beam they are scraping.



(a) Luminosity monitors



(b) Tertiary collimators and physics debris collimators in IR5 (TCLs)



(c) Primary collimators

Figure 4: Table of correlation values from a horizontal scan in CMS. All signals are correlated to the BRAN left of CMS (downstream for beam 2). Of particular interest are the signals in Figure (a). For the collimators in Figure (b) and (c), the gas ionisation BLMs are used.

If it is correct that β^* is the dominating factor together with the phase advance, then this is good news. It means that the cross talk produced in an experiment will be reduced when we increase the squeeze in the originating experiment, counteracting the increased interaction rate. As we unsqueeze the low luminosity insertions, we will further reduce the incoming background at those experiments, because the TCTs are at a more relaxed position.

It is observed that the vertical phase advance in the simulation from ALICE to the vertical tertiary collimator in front of ATLAS is 78 degrees, and the maximum amplitude would be expected at 86 degrees. Hence, we are close to the maximum amplitude in addition to the fact that this is the first major aperture restriction beam two meet after the collisions in ALICE.

We are not observing significant cross talk in the LHC at the moment — which is good and as expected. We did a short simulation of the nominal 7 TeV machine, where we learned that one could expect a hit rate on the TCTs originating from cross talk up to about one order of magnitude less than that of the normal halo component. We are fairly confident that we now have the tools ready to both simulate IR cross talk and analyse the data that becomes available from the LHC.

REFERENCES

[1] R. W. Assmann and T. Weiler. IR cross talk simulations. Work in progress.

[2] V. V. Talanov. Simulation of machine backgrounds. *Workshop on Experimental Conditions and Beam Induced Detector Backgrounds*, 2008.

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

[4] Y. Inntjore Levinsen, R. B. Appleby, and H. Burkhardt. Beam-gas loss rates in the LHC. In *IPAC Kyoto*, number TUPEB072, 2010.

[5] M Lamont, R Alemany-Fernandez, H. Burkhardt, and S. M. White. Luminosity optimization and calibration in the LHC. CERN-ATS-2009-071.

[6] S. M. White, R. Alemany-Fernandez, H. Burkhardt, and M. Lamont. First luminosity scans in the LHC. In *IPAC Kyoto*, 2010.