EXPLOITING THE UNDESIRED: BEAM-GAS INTERACTIONS IN THE LHC

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Abstract

The vacuum inside the LHC pipes has a key role in correct operation of the accelerator. The interaction of the beam with residual gas in the pipes can lead to the loss of the beam itself and damage accelerator components. Nevertheless, beam-gas interactions can be exploited to indirectly measure the gas pressure inside the beam pipe, detecting the secondaries produced. The showers generated are detected by Beam Loss Monitors, whose signals depend on the gas pressure. This technique would also allow to punctually measure the gas pressure in sections of the accelerator where vacuum gauges are not frequent, such as the arcs. The problem has been addressed by means of FLUKA simulations and the results have been benchmarked with direct measurements performed in the LHC in 2011.

INTRODUCTION

Beam-gas interactions are an undesired presence in particles accelerators. They are not only a source of background for the experiments, but are also a threat to the proper operation of the accelerator. Indeed, the induced secondary radiation can damage the electronics and cause a beam loss.

Nevertheless, it could be possible to exploit them to localize a vacuum leak along the accelerator. An increase in the gas density inside the beam pipe, would lead to an increase of the secondary radiation induced by the beam gas interaction. If this radiation could be detected, it would allow to localize the leak position with an higher precision than the one allowed by the vacuum gauges. This technique would be particularly useful in areas where the BLMs are more frequent than vacuum gauges, such in the case of Large Hadron Collider (LHC) arcs.

We have investigated the feasibility of this procedure by means of `FLUKA` simulations [1, 2]. First, we have evaluated the absorbed radiation dose in the Beam Loss Monitors (BLMs), located next to the dipoles and the quadrupoles in the LHC tunnel, and extrapolated a relation between the gas pressure in the beam pipe and the BLMs reading. Secondly, we have compared the relation between the gas pressure and the BLMs readings to benchmark our hypothesis.

The `FLUKA` geometry [3] used for this simulations extends from cell C7.L7 up to the cell C13.R7, for about 800 meters. The interaction of beam 1 protons with residual gas present in the beam pipe has been simulated sampling a point along the beam axis and forcing the interaction between the beam proton and the gas assumed to be hydrogen. The sampling is uniform inside each considered element or section.

Three simulations have been performed with different momentum of the proton beam: 450 GeV, 3.5 TeV, and 7 TeV respectively.

PRESSURE-DENSITY RELATION

`FLUKA` results are provided per primary interaction and can be scaled with the density of the gas molecules. Nevertheless, this quantity cannot be directly compared with the measured gas pressure. The two quantities are related by the equation $P = NkT$, where N is the number of gas molecules per unit volume, k is the Boltzmann constant, and T is temperature of the gas. Assuming N in m^{-3}, k in JK^{-1} ($k = 1.38 \cdot 10^{-23}$ JK^{-1}), T in K, and dividing by 100, the gas pressure is given in mbar.

The conversion into density of the pressure measured by the vacuum gauges in the LHC depends on the gauges location. While the temperature of the beam screen is of few Kelvins, the vacuum gauges measure the pressure at 300K, therefore a conversion factor has to be applied. For gauges directly connected to the beam pipe the conversion is given by the ratio of the temperatures, while for those connected through more pipes it is given by the square root of the ratio [4].

RESULTS

We have estimated the absorbed radiation dose in the BLMs located all along the LHC IR7 Dispersion Suppressor. The results of the `FLUKA` simulation for absorbed dose are provided in GeV g^{-1} per primary interaction and have been transformed into μGy-s^{-1} using the formula:

$$D = D' \cdot C_{G2J} \cdot \rho \cdot \sigma \cdot L_{sampling} \cdot I \cdot 10^6 \qquad (1)$$

where D is the absorbed dose rate in μ Gy-s^{-1}, D' is the `FLUKA` result in GeV g^{-1} per primary interaction, C_{G2J} is the conversion factor to transform GeV to Joule, ρ is the gas density inside the beam pipe given as number of H_2 equivalent molecules per m^3, σ is the cross section for a proton-H_2 inelastic interaction, $L_{sampling}$ is the sampling length ($\sim$ 350 m), and $I = n_b p_b \nu$ is the beam intensity given as function of the number of circulating bunches n_b (nominally 2808), the number of protons per bunch p_b (nominally 1.15 $\cdot 10^{11}$), and the bunch revolution frequency ν (nominally 11.245 kHz). Equation (1) can then be summarized

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as:

$$D = D' \cdot \rho \cdot n_b \cdot 5.51 \cdot 10^{13} \qquad (2)$$

where the dependence on the gas density and the number of circulating bunches is explicit. Weighting over all the BLMs reading it is possible to generate the plots of the absorbed radiation dose in the BLMs as function of the gas density (and of the gas pressure). The plot for non-directly connected vacuum gauges, and for different beam energies and different number of circulating bunches is shown in Fig. 1. In the plot is also indicated the sensitivity of the BLMs, about 1 μGy-s^{-1}.

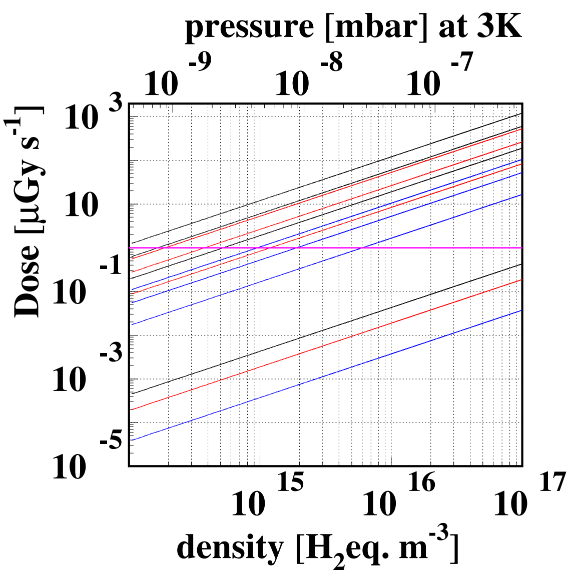

Figure 1: Absorbed radiation dose in the BLMs as function of the gas density. The colors indicate different beam energy: 450 GeV is blue, 3.5 TeV is red, and 7 TeV is black. The four lines of the same color refers to a different number of circulating nominal bunches, from top to bottom 2808 (nominal), 1404, 444, and 1. The resolution of the BLMs is indicated by the magenta line. The conversion to non-directly connected vacuum gauges reading is also shown.

BENCHMARKS

Finally, we have compared the predictions based on the results of our simulations with real measurements. Here we show two examples.

Fill 1733 has been on the 24th April 2011 (week 16). Beams were circulating with 480 bunches and 3.5 TeV momentum. Vacuum spikes took place in cell C4R8, with peak of almost $4 \cdot 10^{-7}$ mbar. Cell C4R8 is in the warm section where non directly connected vacuum gauges are used, namely VGPB.120.4R8.X.PR and VGPB.231.4R8.X.PR. Looking at Fig. 1 we would expect the nearby BLMs to measure almost an hundred of μGy-s^{-1}. Indeed, BLMQI.03R8.B2E10_MQXA reports a value of 89 μGy-s^{-1}. The correlation between vacuum gauges and the corresponding BLM reading is shown on the top of Fig. 2.

Fill 1894 has been on the 6th June 2011 (week 25). Beams were circulating with 1236 bunches and 3.5 TeV momentum. An increase in the pressure inside the beam pipe has been detected in cell C5R4, up to $3 \cdot 10^{-9}$ mbar with peaks about a factor four larger. Cell C5R4 is in the warm section were non directly connected vacuum gauges are used, namely VGPB.1175.5R4.R.PR and VGPB.1175.5R4.B.PR. On the base of Fig. 1 a BLM reading of few μGy-s^{-1} would be expected, with similar peaks. BLMEI.05R4.B1I10_BSRTM and BLMEI.05R4.B2E10_BGI have actually measured a few μGy-s^{-1} signal in correspondance of the increase in pression, in agreement with our predictions. The timing of the spike is also corresponding, while their values show some disagreement from the prediction. The correlation between vacuum gauges and the corresponding BLM reading is shown on the bottom of Fig. 3.

CONCLUSIONS

We have investigated the possibility to use beam-gas interactions induced radiation measured by BLMs to estimate the gas pressure in the LHC beam pipe. The first results of this technique look very interesting and more work is on going to refine it. Particular care is needed when dealing with transition zones from cryogenic to room temperature pipe and from NEG (Non Evaporable Getter) coated pipe to non NEG coated pipes (and to both viceversa). In these transitions the gas density changes and the effect on downstream shower could be non negligible. Last, it is important to note that a constraint on this technique comes from the BLMs sensitivity that limits the pressure that can be measured.

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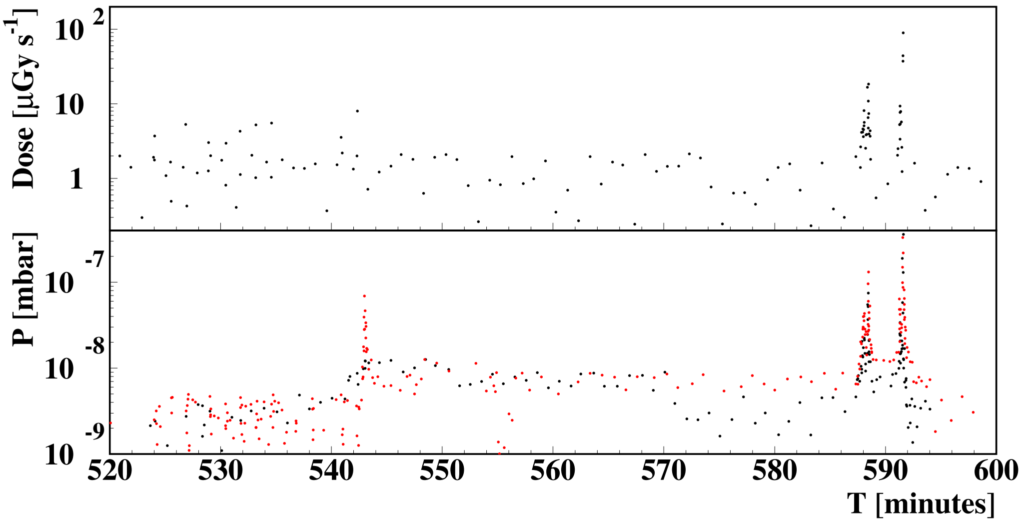

Figure 2: Benchmark for fill 1733. On top, dose measured by BLMQI.03R8.B2E10_MQXA. On the bottom, pressure measured by VGPB.120.4R8.X.PR (black) and VGPB.231.4R8.X.PR (red). Both are shown as function of time from the beginning of the fill.

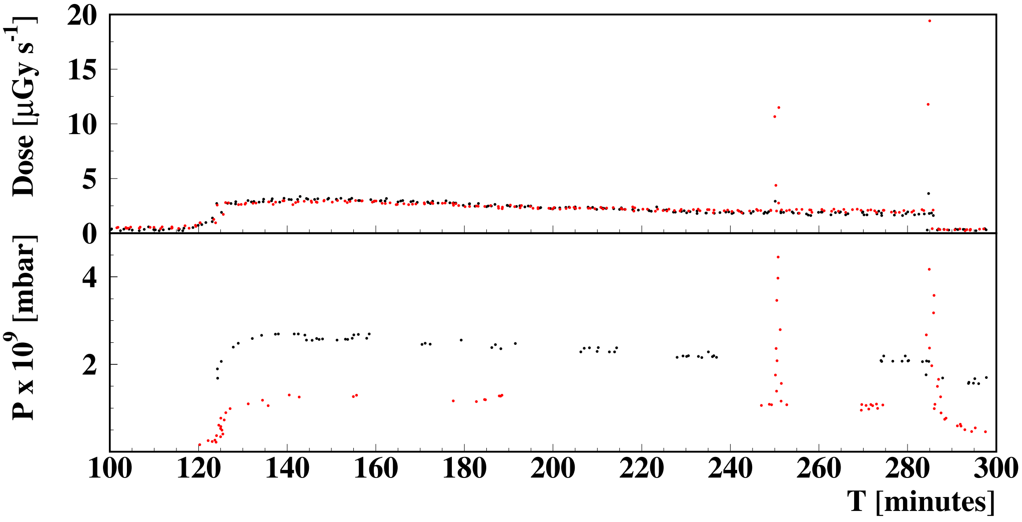

Figure 3: Benchmark for fill 1894. On top, dose measured by BLMEI.05R4.B1I10_BSRTM (black) and BLMEI.05R4.B2E10_BGI (red). On the bottom, pressure measured by VGPB.1175.5R4.R.PR (black) and VGPB.1175.5R4.B.PR (red). Both are shown as function of time from the beginning of the fill.