FEASIBILITY STUDY OF MONITORING THE POPULATION OF THE CERN-LHC ABORT GAP WITH DIAMOND BASED PARTICLE DETECTORS*

O. Stein, CERN, Geneva, Switzerland and University of Hamburg, Germany†
F. Burkart, B. Dehning, R. Schmidt, C. Buhl Sørensen, D. Wollmann, CERN, Geneva, Switzerland

Abstract

At the end of a physics fill and in case of a failure, the LHC beams must be extracted and transferred through a 750 m long line to the beam dump block. During the rise of the extraction kickers to their full strength a particle-free abort gap, with a length of 3 µs in the LHC filling pattern, is required to prevent beam losses that could lead to substantial quenching of magnets, with a risk of damage. Therefore the particle population in this abort gap, which is mainly due to un-bunched beam, is monitored. Above a certain threshold an active cleaning by excitation of betatron oscillations with the transverse feedback system is initiated. This paper describes a novel method of monitoring the abort gap population using diamond particle detectors for detecting the interactions of beam in the abort gap with neon gas, injected in the beam pipe. Two different layouts of the system and the expected interaction and detection rates are discussed.

IMPORTANCE OF THE ABORT GAP FOR THE LHC MACHINE PROTECTION

Due to the high stored energy in the LHC beams (362 MJ per beam at nominal energy) an uncontrolled, complete beam loss will cause serious damage in the accelerator components along the beamline. Therefore, in case of beam instabilities, machine failures or end-of-physics runs, the circulating beams have to be extracted and dumped in a controlled manner. For this purpose the dumping system, consisting of deflection magnets, the dump-line and the dump-block at the end, is installed separately for the two beams in point 6 of the LHC. This system is capable of dumping the beam safely without harming the machine.

In case of a beam abort the 15 kicker magnets (MKD) will be triggered to deflect the beam into the dump-line. The kicker magnets have a rise time of maximum 3 µs, the nominal bunch spacing in the LHC is 25 ns (50 ns). Bunches passing the kicker magnets whose fields are rising will experience a deflection smaller than it is needed for a proper extraction. These diverted bunches continue traveling on a wrong trajectory. This can result in beam losses which lead possibly to damage or quenches in the downstream magnets.

The LHC filling pattern contains a 3 µs long (ideally) particle-free gap, the so-called Abort Gap (AG), to ensure safe beam aborts. The extraction kicker magnets are synchronised to the abort gap to minimise the particle losses during the rise of these magnets.

Due to unbunched beam particles can accumulate in the abort gap. Therefore it is necessary to monitor the abort gap population continuously and if necessary induce countermeasures. One method to reduce the AG population is to excite the betatron oscillation of the particles in the gap with the LHC transverse damper system which are then lost on the collimators in point 7. This Abort gap Cleaning (AGC) method was used for abort gap cleaning, during Run 1.

Monitoring the Abort Gap Population

The main instrument to monitor the abort gap population at the LHC is the synchrotron radiation monitor (BSRA). This monitor detects the synchrotron light which is emitted when the particles pass the super conducting (sc) D3 magnet and the adjacent sc-undulator close to point 4. Due to mechanical problems in the BSRA setup the system was not always operational and no other redundant system existed to allow a continuous monitoring of the AG.

In case of a BSRA failure the AGC was switched on regularly which lead to shorter beam life time of the LHC beams.

Therefore, an additional system for monitoring the AG beside the BSRA would add a layer of redundancy.

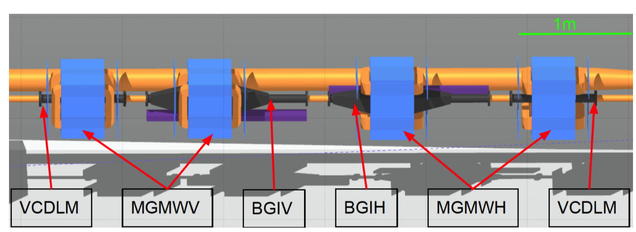

Figure 1: 3D-model of the BGI main components used for FLUKA simulations. VCDLM, 80 mm 316L drift tube. MGMW H/V, dipole. BGI H/V, vacuum chamber with BGI assembly. The second beam pipe can be seen in the background.

MONITORING THE ABORT GAP POPULATION WITH BEAM GAS INTERACTIONS

The beam gas ionisation monitors (BGI), one for each beams, are installed close to point 4 in the LHC. The original purpose of this device is to measure the transverse beam size [1].

* Work sponsored by the Wolfgang Gentner Programme of the Federal Ministry of Education and Research, Germany

† oliver.stein@cern.ch

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The BGI consists of two special shaped vacuum chambers (horizontal and vertical BGI, see Fig. 1) for each beam. In these chambers a pressure bump can be created by introducing neon gas.

The particles of the beam collide with the neon gas atoms in the BGI and create secondary showers. By measuring the rate of the showers (f_r), the beam intensity can be deduced if the neon gas pressure is known.

Calculation of the Beam Neon Gas Interaction Rate

Assuming the neon (Ne) gas profile as an equal distribution over the length (s_{tot}) of the BGI and treating the neon as a ideal gas (number of neon atoms A_{ne}) the interaction probability (P_i) per proton can be calculated by using the parameters shown in Table 1.

Table 1: Relevant LHC Parameters [2]

Parameter	
Numb. of Ne atoms (A_{ne})	1.98×10^9
Cross sec. Ne at 7 TeV (σ_{ne})	383.7 mb
Length of the Ne gas profile (s_{tot})	550 cm
Nominal neon gas pressure	8.8×10^{-8} mbar
tolerable AG population	10^9 p /3 µs
nominal LHC bunch intensity	1.15×10^{11} p
LHC revolution frequency	11245 Hz
max. num. of bunches per beam	2808
nominal bunch spacing for run 2	25 ns

$$P_i = \sigma_{ne} A_{ne} s_{tot}$$
$$P_i \approx 4.22 \times 10^{-13}$$

With this value the interaction rate with an AG population of 1×10^9 particles is $f_r \approx 4.7$ Hz.

Prolonging the Measurement Time by Taking Interbunch Collisions into Account

With the assumption that the particle population between nominal bunches is similar to the abort gap population, the collisions of intra bunch particles with the gas can be measured and then taken into account for the AG population calculations.

With the maximum number of proton bunches per beam, the estimated time occupied by one bunch (bunch signal and its decrease $\approx$ 10 ns) and the revolution frequency, the available time for measurements ($t_m \approx 61$ µs) and so the increased collision rate $f_{ir} \approx 97$ Hz can be estimated.

Correct Detector Positioning Reduces Beam-beam Cross Talk

The LHC beams are so close that beam losses of the second beam, especially from passing nominal bunches, can induce signals in the measurements of the first beam (cross-talk). To minimise these signals in the inter-bunch measurements a carefull positioning allows temporal matching of the bunched beam losses from both beams, see Fig. 2.

Two Detector Setup Allows Background Reduction

Even with the reduced cross-talk, the loss signals from the second beam and the losses of the first beam upstream of the BGI can cause unwanted signal in the measurements. For measuring the background level a second dBLM will be placed upstream of the BGI. The detector will be located at a position where the bunched-beam losses of the second beam arrive at the same time as the losses from the first beam like it is done for the first detector. The distance between both detectors is 7.48 m. Due to the relatively short distance between the detectors it is assumed that the background levels for both detectors are in average comparable.

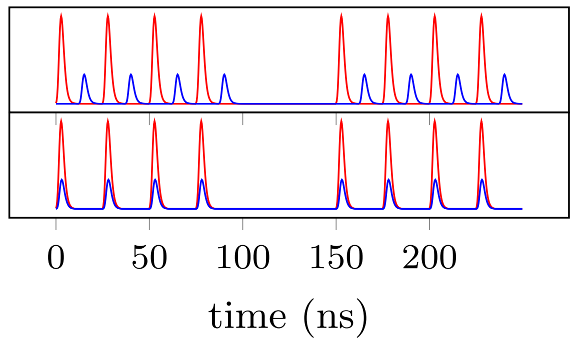

Figure 2: Example for loss signals of unmatched (top) and matched (bottom) beam losses of both beams, primary beam in red.

FAST DIAMOND BASED BEAM LOSS DETECTOR

To realise the above mentioned AG monitor setup a detector with a high time resolution ($t_{res} \leq 20$ ns) and ideally the ability of detecting single particles is a precondition.

Diamond based particle loss detectors (dBLM) which were already used at the LHC and in the CMS experiment during the first run have the required characteristics [3]. The active detector medium is a single crystalline CVD (Chemical Vapour Deposition) diamond.

Table 2: Characteristics of the dBLM for AG Monitoring

Parameter	
Crystal struct.	single crystalline CVD
Active volume	$5 \times 5 \times 0.5\,\text{mm}^3$
Efficiency	> 95 %
Time resolution	$t_{res} \approx 5$ ns
Single particle det.	yes

FLUKA SIMULATIONS FOR OPTIMAL DETECTOR POSITION AND GEOMETRIC FACTORS

FLUKA simulations were performed to determine the optimal detector position for a maximal signal of the beam gas interactions and a minimal influence of the cross-talk.

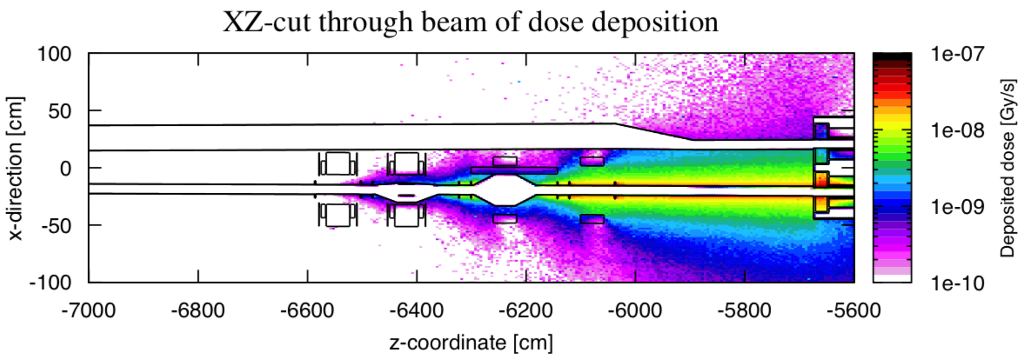

Figure 3: Beam losses due to beam neon gas interactions in the BGI.

Figure 3 shows that the maximum signal is downstream of the BGI close to the beam pipe. Due to very small incidence angles of the lost particles from the second beam on the first beam pipe, the pipe provides a large shielding effect which is shown in Fig. 4. This determines the vertical position of the detector at $y = 0$ cm in the shade of the beam pipe [4] [5].

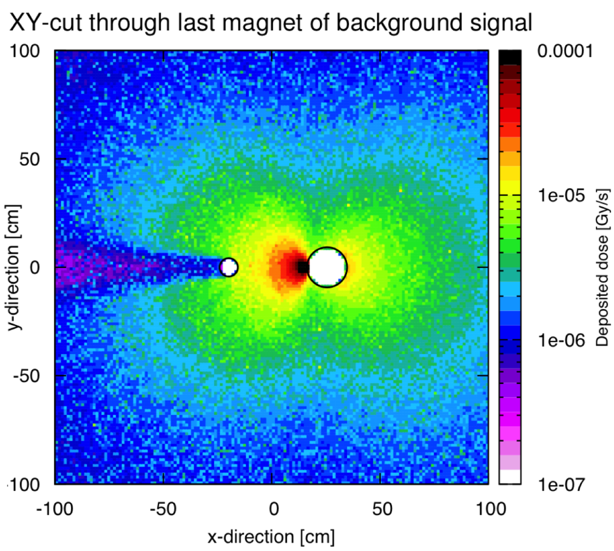

Figure 4: Beam pipe shields the cross-talk from the second beam. Detector position in the vertical plane at $y = 0$ cm.

For calculating the geometric factor (g_f) to determine the ratio between beam gas collisions and the detection rate a detailed detector model with an estimated efficiency of 95 % was used for the FLUKA simulations. With the above mentioned detector position the geometric factor can be determined to:

$$g_f = 0.03$$

ESTIMATED DETECTION RATES FOR NOMINAL BEAM OPERATIONS

By taking the geometric factor, the linear dependency of the collision rate, the gas pressure and the abort gap population into account, the detection rate over several orders of magnitude of AG population intensities can be calculated, see Fig. 5.

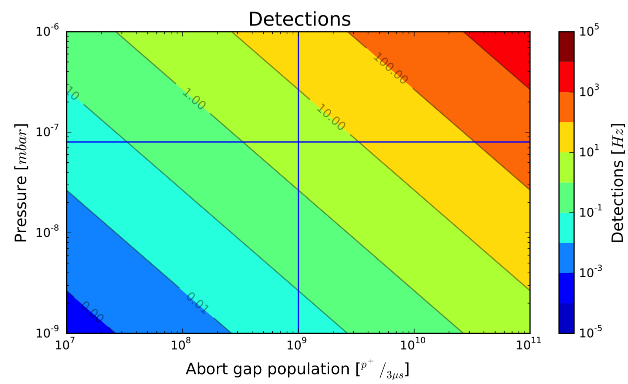

Figure 5: The detection rate increases linearly with the AG population.

The detection rate with a gas pressure of 8.8×10^{-8} mbar and an AG population of 1×10^{9} particles is about 2.85 Hz.

Data Acquisition and Integration Time

Histograming units will be used with a bin-width of 1.6 ns for the data acquisition. Long integration times ($\approx$ 1 min) during stable machine operation will help to reduce the statistical error of the measurements.

CURRENT STATUS OF THE AG MONITOR SETUP AT LHC

The proposed detector setup has been installed on both beams for the next LHC run. During the commissioning phase of the LHC measurements will show if the calculated values match the taken data.

The thresholds for the histogram units and the integration time will be determined during first tests with beam during the LHC commissioning phase in Spring 2015.

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