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# RADIATION MONITORS AS A VACUUM DIAGNOSTIC IN THE ROOM TEMPERATURE PARTS OF THE LHC STRAIGHT SECTIONS

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## Abstract

In the absence of collisions, inelastic interactions between protons and residual gas molecules are the main source of radiation in the room temperature parts of the LHC long straight sections. In this case the variations in the radiation levels will reflect the dynamics of the residual pressure distribution. Based on the background simulations for the long straight section of the LHC IP5 and on the current understanding of the residual pressure dynamics, we evaluate the possibility to use the radiation monitors for the purpose of the vacuum diagnostic, and we present the first estimates of the predicted monitor counts for different scenarios of the machine operation.

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# RADIATION MONITORS AS A VACUUM DIAGNOSTIC IN THE ROOM TEMPERATURE PARTS OF THE LHC STRAIGHT SECTIONS

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## *Abstract*

In the absence of collisions, inelastic interactions between protons and residual gas molecules are the main source of radiation in the room temperature parts of the LHC long straight sections. In this case the variations in the radiation levels will reflect the dynamics of the residual pressure distribution. Based on the background simulations for the long straight section of the LHC IP5 and on the current understanding of the residual pressure dynamics, we evaluate the possibility to use the radiation monitors for the purpose of the vacuum diagnostic, and we present the first estimates of the predicted monitor counts for different scenarios of the machine operation.

## OBJECTIVES OF THE STUDY

The radiation environment in the Long Straight Sections (LSS's) of the LHC is defined by the sources of a different nature. During collisions, the main source of the secondaries in the LSS's are the $p$–$p$ interactions in the IP. When the beams do not collide, the principle source of radiation is the proton interactions with residual gas atoms. In this case the resulting radiation levels depend on residual gas density and composition, and the variations in the radiation levels in the LSS reflect the dynamics of both spatial and temporal distribution of the residual gas pressure. If these variations are sufficiently large, radiation monitors (Figure 1) installed in the LSS's can be used as a vacuum diagnostic to monitor the gas pressure and to detect local pressure bumps.

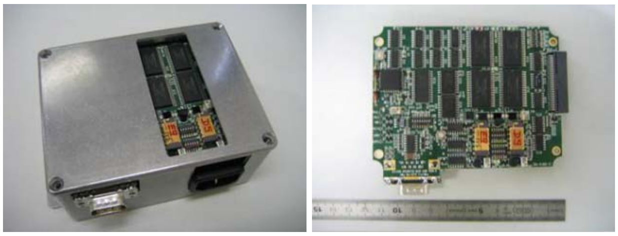

Figure 1: Radiation monitor for the LHC (left) and without the cover (right). The scale is in centimeters.

The main objective of the present study is to evaluate the gas density profile in the room temperature part of the LSS via variation in the radiation levels. Namely the pressure monitoring is required in the LHC experimental insertions IR1 and 5 in the regions from the IP to the TAS, from the TAS to Q1, from D1 to the TAN, from the TAN to D2, from Q4 to Q5, from Q5 to Q6 and from Q6 to Q7, where the existing radiation monitors can be used for diagnostics (Figure 2).

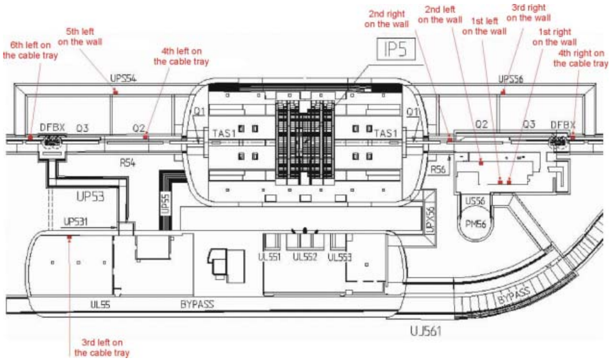

Figure 2: Locations of the radiation monitors in the long straight section of the LHC interaction point IP5.

The vacuum chambers are coated with a non evaporable getter (NEG) coating, which, being activated at 100$^o$ C, provides a large distributed pumping speed. Expected average gas densities and pressure in the IR 1& 5 and IR 2& 8 before and after conditioning with nominal beam [1] are given in Table 1. The average hydrogen equivalent gas density in the LSS's is estimated to be $10^{13}$ $H_2$ mol/m$^3$ that equals $4\times10^{-10}$ Torr. Despite a vacuum gauge is located every 30 m, due to the large pumping speed, the vacuum pressure is only known in the vicinity of the gauge ($\sim$ 1 m) so almost 93 % of the vacuum chambers will operate under an unknown pressure. Radiation monitors could provide additional vacuum diagnostics such as estimates of the pressure profile along the NEG chambers, compared between the IR's, and also could indicate when the NEG needs to be reactivated and if this has been done correctly.

## NEG COATED CHAMBERS AND ASSUMED PRESSURE PROFILES

The NEG coating pumps all the gases with the exception of hydrocarbons and noble gases. In the normal operation the gas density in the NEG vacuum chambers is dominated by $CH_4$, which density in the LSS's is estimated to be in the range $2\times10^{11}$ to $2\times10^{13}$ $CH_4$ mol/m$^3$ with the equivalent $H_2$ gas density in the range from $10^{12}$ to $10^{14}$ $H_2$ mol/m$^3$. In the simulations we consider a pressure bump due to $H_2$ or CO desorption induced by the beam or due to a leak. Due to the large $H_2$ pumping capacity of the NEG, a $H_2$ pressure bump can remain "local" therefore not being detected a few meters away. Despite the limited NEG capacity (one monolayer for the CO), a CO flux of $3\times10^{-5}$ Torr.l/s i.e. a pressure of $5\times10^{-8}$ Torr saturates a 7 m long, 60 mm di-

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Table 1: Average gas densities and pressure levels in the experimental regions of the LHC [4].

| | **IR1 & 5** | | | | **IR2 & 8** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Start-up** | | **After conditioning** | | **Start-up** | | **After conditioning** | |
| | Density [mol/m$^3$] | Pressure [Torr] | Density [mol/m$^3$] | Pressure [Torr] | Density [mol/m$^3$] | Pressure [Torr] | Density [mol/m$^3$] | Pressure [Torr] |
| $H_2$ | $8\times10^{12}$ | $2\times10^{-10}$ | $3\times10^{12}$ | $10^{-10}$ | $5\times10^{12}$ | $2\times10^{-10}$ | $10^{12}$ | $4\times10^{-11}$ |
| $CH_4$ | $2\times10^{13}$ | $6\times10^{-10}$ | $2\times10^{11}$ | $6\times10^{-12}$ | $2\times10^{13}$ | $7\times10^{-10}$ | $2\times10^{11}$ | $6\times10^{-12}$ |
| CO | $3\times10^{12}$ | $8\times10^{-11}$ | $3\times10^{11}$ | $8\times10^{-12}$ | $2\times10^{12}$ | $6\times10^{-11}$ | $10^{11}$ | $3\times10^{-12}$ |
| $CO_2$ | $4\times10^{12}$ | $10^{-10}$ | $6\times10^{11}$ | $2\times10^{-11}$ | $4\times10^{12}$ | $10^{-10}$ | $3\times10^{11}$ | $9\times10^{-12}$ |
| $H_2$ equivalent | $2\times10^{14}$ | $5\times10^{-9}$ | $10^{13}$ | $4\times10^{-10}$ | $2\times10^{14}$ | $6\times10^{-9}$ | $7\times10^{12}$ | $2\times10^{-10}$ |

ameter getter coated vacuum chamber in 10 h [2]. So, a CO pressure of a few $10^{-9}$ Torr ($\sim 10\ldots100$ times higher than the average CO density) can also exist "locally" in a getter coated chamber before being detected a few meters away after more than 100 h. We estimate the variation of radiation levels for the case of a rectangular 5 m long pressure bump which is 10, $10^2$, $10^3$ and $10^4$ times the base density of $CH_4$, i.e. of $10^{13}$, $10^{14}$, $10^{15}$ and $10^{16}$ $H_2$ mol/m$^3$.

## BEAM-GAS BACKGROUND SIMULATION

To evaluate the performance of the radiation monitoring for the purposes of the vacuum diagnostics, the predicted level of the background due to potential pressure bump in the LSS has to be compared with the background levels from the two other sources of radiation in the straight section. These sources are the background due the $p$–$p$ interactions in the IP and the beam-gas background due to the proton losses on residual gas in the LSS vacuum chamber, along the Beam 1, coming from the interaction point.

We consider the beam-gas background in the insertion region IR5 and use the detailed model of the simulations, developed to estimate the machine induced background in the forward physics detectors in the IR5 due to the beam–gas losses along the outcoming for the IP5 LHC Beam 1 [3]. The pressure profile for the IR5 was taken from [4] for the "after machine conditioning" period with 2808 bunches and nominal bunch intensity. The calculations are performed for the LHC collision optics 6.5 with the $\beta^* = 0.55$ m in the IP5, and also for the injection optics and energy.

In the model of the LSS structure we introduce a "virtual" cylinder of 1 m radius and centered at the beam, with the outer surface composed of the 1mm layer of $SiO_2$, to imitate the sensor of the radiation monitor installed above the magnet line (Figure 3). This virtual cylinder had the length of 220 m in horizontal plane, covering the distance between the IP5 and the center of the Q5–Q6 drift chamber. We consider the 5 m long pressure bump at the exit of the D1 along the Beam 1, with the $H_2$ equivalent density level of $10^{16}$ mol/m$^3$ ($H_2$ pressure of $3\times10^{-7}$ Torr). The estimates for the lower pressure values can be obtained from these results by a simple proportion.

The results of the simulation for the flux density $f(s)$ of the hadrons with the E > 20 MeV are given in Figure 4 as a function of the distance from the interaction point IP5, normalized on the surface of each cylindrical scoring cell so its azimuthal dependence was discarded. The green curve on the plots shows the flux density longitudinal distribution for the case of the LHC collision optics at 7 TeV and residual gas pressures for the nominal machine filling scheme. Two blue curves give the same distributions for the injection and collision energy (with the corresponding optics) for the case when only 5 m of the vacuum chamber at the D1 exit in the TAN direction were filled by the residual gas with the $H_2$ equivalent density level of $10^{16}$ mol/m$^3$.

At both collision and injection energies there are two distinct peaks in the flux density distributions. The first peak is located at the D1 exit, around the location of the pressure bump itself, and represents the inelastic component of the background which gives the contribution to the radiation environment close to its point of production. The second downstream peak is around the front surface of TAN and is formed by the products of the secondary cascades initiated in this region by the elastic part of the losses at the point of the pressure bump. In this case the inner diameter of the TAN vacuum chamber serves as an aperture limitation for the particles deflected at relatively small angles in the primary proton interaction on the nuclei of residual gas. At the D1 peak both at 450 GeV and 7 TeV the obtained estimates for the flux density in the case of pressure bump are factor $\sim 100$ higher than for the nominal case. At the TAN peak for 7 TeV beam the values for both cases are another order of magnitude larger then for the D1 location while in

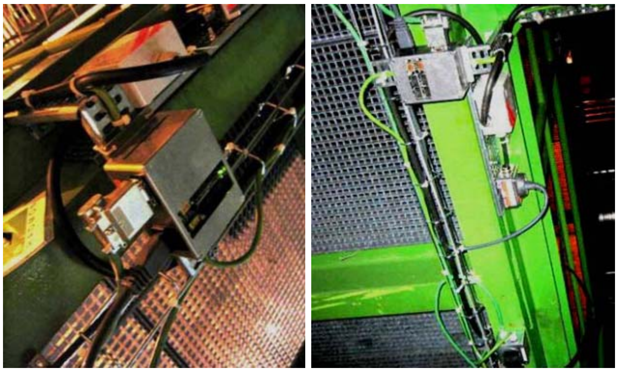

Figure 3: Radiation monitor installed in the UX85 area of the LHCb experiment.

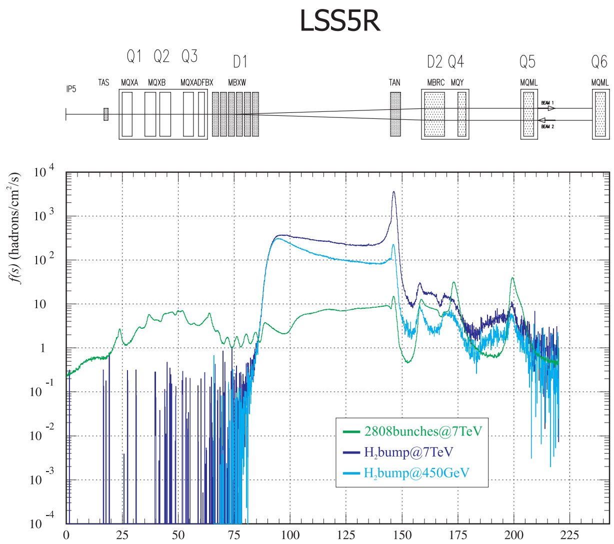

Figure 4: Hadron flux density $f(s)$ in the LSS of the IR5 as a function of the distance from the interaction point IP5, the three cases considered.

the case of the injection energy the second peak is about two times lower then the first one. The absolute values for hadron flux density at these peaks for the case of the pressure bump of $10^{16}$ $H_2$ equivalent mol/m$^3$ are given in Table 2, and both locations can be considered as the most favorite from the vacuum diagnostics point of view, either at injection or at top LHC energy.

## RADIATION MONITORING

The maximal difference for the levels of the beam–gas background between nominal operation and pressure bump cases in Table 2 is a factor of $\sim 200$, for the hadron flux density at the TAN peak at 7 TeV. The difference between the level of the nominal beam–gas background and the predicted background level in the LSS's from the *p–p* interactions in the IP can be estimated to be factor $10^3 \ldots 10^4$ (basing on [5]) for the maximum luminosity of $10^{34}$ cm$^{-2}$/s in the IP5. This means that the radiation monitors will be able to detect a variation of the radiation levels induced by a modified pressure profile either in the absence of colliding beams, when there will be no background from to the *p–p* interactions, or in the case of the luminosity in the IP5 at least two orders of magnitude lower then the maximal one (eg. $\leq 10^{32}$ cm$^{-2}$/s), for the TAN peak to become visible.

The most sensitive part of the radiation monitors are the sensors that measure the hadron flux. High energetic hadrons with energies above 20 MeV can create ionization in the reverse bias junctions of CMOS transistors arranged in a Static RAM (random access memory) cell. If the transistors are used in a standard SRAM cell, the contents of this cell can change from logic '0' to logic '1' (a count). Under a flux density of $10^6$ hadrons/cm$^2$/s the monitor will register 1 count per second [6]. This means that $\sim 10$ minutes would be needed to register a few counts at top energy in the region of TAN assuming the simulated flux density of 3200 hadrons/cm$^2$/s for a CO pressure of $4\times10^{-8}$ Torr (equivalent to the $H_2$ density of $10^{16}$ mol/m$^3$).

Table 2: Hadron flux density [particles/cm$^2$/s] at D1 and TAN peaks for the three studied cases.

| **Nominal** | | **$H_2$ bump 7 TeV** | | **$H_2$ bump 450 GeV** | |
|---|---|---|---|---|---|
| D1 | TAN | D1 | TAN | D1 | TAN |
| 4 | 14 | 340 | 3200 | 300 | 210 |

In the present simulation the scoring of the hadron flux was performed at the distance of 1 m from the beam line which corresponds to the positioning of the monitors either on the closest tunnel wall or on the floor. Placing the monitors on the support at the closest distance to the D1–TAN vacuum chamber of $\sim 20$ cm reduces the surface of the scoring zone, increasing the flux density by a factor of 25, and enables to gain significantly in the number of counts, decreasing the time of the flux measurement.

The same estimate can be made for the monitoring during injection, ramp and squeeze. In order to have a significant sensitive diagnostic for the vacuum in the LSS, various monitors should be positioned close to D1 and TAN and close to the beam pipe. The variation of the count rate during injection, ramp and squeeze should provide the required diagnostic information. Assuming that filling the machine will take 1 hour at an average rate of 300 hadrons/cm$^2$/s and that ramp and squeeze will take 20 minutes at an average rate of $10^3$ hadrons/cm$^2$/s, the fluence during a turnaround between physics would be $2.3\times10^6$ hadrons/cm$^2$ which would produce a sufficient number of counts.

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