ESTIMATES OF RESIDUAL GAS DENSITY IN THE LHC

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Abstract

A short review on estimates of residual gas density in the LHC is presented. Results, presented for stable beam, are strongly dependent assumptions surface properties and beam operating configuration (beam current, energy, etc.) and represent only a 'snapshot' in time for the machine. Constant particle losses are not included at present and constitute a future study.

INTRODUCTION

Beam-gas interactions along the experimental insertion regions (i.e. between two arcs) have been indentified as one of the main sources of background noise to the experiments in the LHC [1], [2] during physics runs.

In the LHC the main gas species are expected to be hydrogen (largely dominant in the cold arcs), methane, carbon monoxide and dioxide. The presence of water should be negligible, given that room temperature sections are conditioned (baking and NEG activation), and that the water will have an extremely low vapour pressure in the cold sections.

In this paper estimates of residual gas density in the LHC are presented. Depending on the specific period of operation, the residual gas density varies with gas sources – mainly ion, electron and photon-induced gas desorption – which depend on the surface properties and on the operating configuration. On the one hand beam vacuum chamber preparation i.e. ex-situ cleaning, in-situ baking (or activation in the case of NEG surfaces), and particle bombardment, influence the gas induced desorption yields. On the other hand the beam current and energy will determine the total ionisation rate, the photon (synchrotron radiation) energy spectrum and flux to the wall, and, the electron flux and energy to the wall.

This paper details some of these dependences and present estimates made for stable proton beam (negligible beam losses) in the ATLAS interaction region, for initial beam operations and including thermal outgassing of the tertiary collimators before the Inner Triplets. The expected density in the arcs and during ion operations is also discussed.

It should be noted that if regular beam losses are expected during physics operation, their effect should be studied and added to the present calculations. Moreover, any other operating configuration should be analysed case by case, depending on the history of the machine at that moment in time.

VACUUM CALCULATIONS

The gas sources included in the simulations code (VASCO [3]) are thermal outgassing and dynamic effects, i.e. beam induced desorption phenomena: ion, electron and photon induced molecular desorption. In the case considered, the vacuum is "stable" (no pressure run away is expected due to the very high distributed pumping and low desorption), and electron cloud build up is neglected.

The results are presented in form of gas density per gas species and hydrogen equivalent gas density, i.e. weighted by the nuclear scattering cross sections as follows:

$$n_{H_2 equiv.} = n_{H_2} + \frac{\sigma_{CH_4}}{\sigma_{H_2}} n_{CH_4} + \frac{\sigma_{CO}}{\sigma_{H_2}} n_{CO} + \frac{\sigma_{CO_2}}{\sigma_{H_2}} n_{CO_2}$$

$$\frac{\sigma_{CH_4}}{\sigma_{H_2}} = 5.4;\ \frac{\sigma_{CO}}{\sigma_{H_2}} 7.8;\ \frac{\sigma_{CO_2}}{\sigma_{H_2}} = 12$$

Variation of input parameters with surface conditions and beam operations configuration

As highlighted before, the parameters determining the residual gas density strongly depends on surface conditions and beam operations. Both thermal outgassing and induced desorption yields may vary by several order of magnitudes depending on surface conditions, i.e. whether the surfaces was in situ baked/activated or if it has been bombarded by particles. Particle flux to the wall, and their incident energy, change with machine operating configuration (mainly beam intensity and energy) and history. Some examples, amongst many others, are given in the following (see talk transparencies for more data)

- NEG properties as a function of activation/venting cycle (aging), and of amount of gas pumped [4].
- Evolution of photon induced gas desorption with accumulated dose - total number of photon impinging on the surface [5].
- Evolution of electron induced gas desorption with accumulated dose - total number of electron impinging on the surface [6].
- Dependence of photon induced gas desorption with photon critical energy [7].

- Dependence of electron induced gas desorption with electron incidence energy [8].

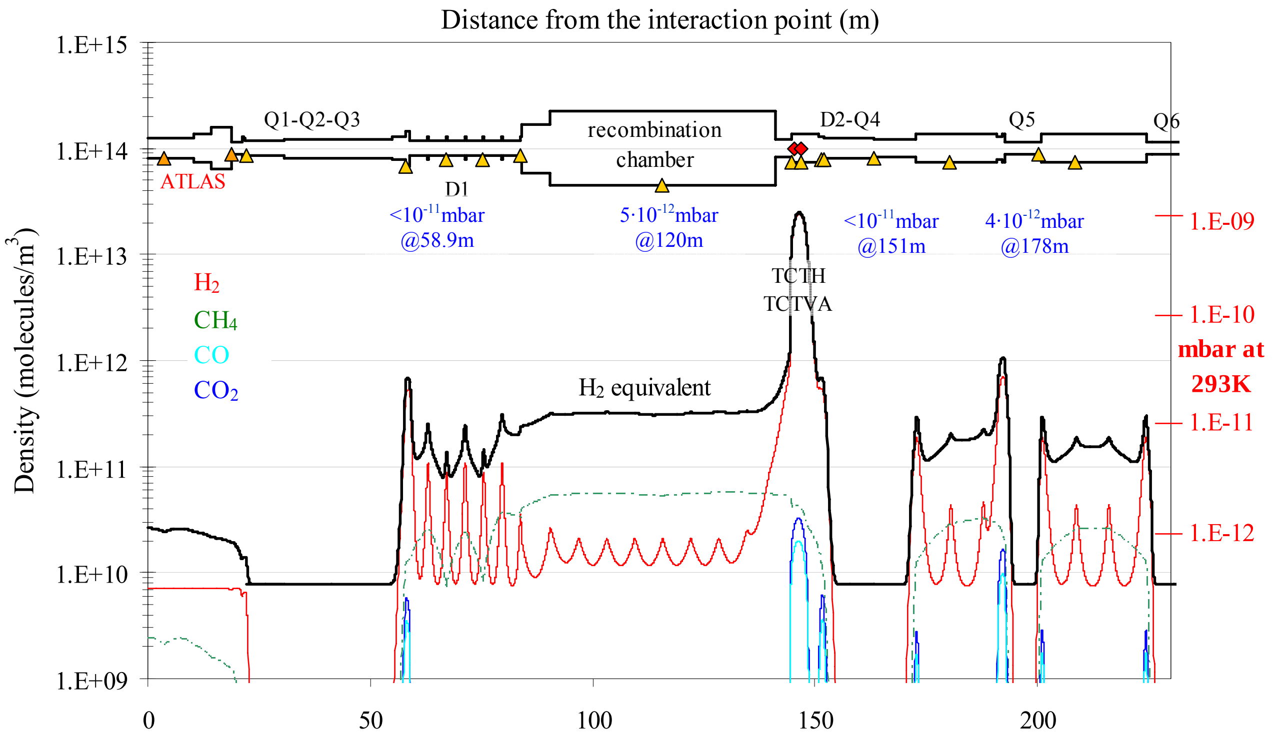

Figure 1: Residual gas density for the main gas species in the ATLAS interaction region as a function of distance from the interaction point for beginning of LHC operations. The region being symmetric, only the right hand side is shown. On the right hand side of the plot, a vertical scale for pressure (mbar) is given for 293K (room temperature). The values given in blue print are the pressure reading at the specified location at the beginning of April 2008.
Conversion factors: 1.E11 molec/m^3 ~ 4.5.E-12 mbar at 293K; ~ 2.7 E-14 mbar at 2K

Machine layout and assumptions

The layout considered [9] includes cold magnets (working at 1.9K or 4.5K) and room temperature sections. The cold magnets are equipped with a beam screen (cooled at 5 to 20K), which intercepts synchrotron radiation, thereby reducing heat load on the cold bore, and pumps gas thus avoiding ion induced pressure instability and guaranteeing a low background pressure. The beam screen distributed pumping works both via cryo-sorption on its own surface and via perforated holes onto the cold bore surface. In the calculations, cryo-sorption on the beam screen is neglected. The room temperature sections are, for most of their length, coated with Non Evaporable Getter. NEG coating is employed to prevent electron multipacting, given the low secondary electron yield after activation at a temperature between 160 and 200ºC for 2 hours, and to ensure low desorption and the gas pumping necessary for ion induced desorption stability and low background pressure. All room temperature sections are being baked-activated. In the calculations presented, NEG pumping is assumed to be 1/10 of a "freshly" activated NEG, i.e. of a NEG surfaced activated for the first time and never exposed to air.

RESULTS

Insertion regions

Residual gas density estimates presented so far [9, 10], are for stable beam, i.e. assuming no particle losses. Furthermore, they do not include the effect of collimators, introduced in the experimental interaction regions only at a later stage. Thermal outgassing has been fully characterised for each collimator installed in the machine [11]. After baking, it is dominated (by 90% or more) by hydrogen. Dynamic effects have been measured in the SPS with an unbaked graphite collimator In that case, as it was presented during the workshop [12], the pressure at the collimator varied from about 1. to 5.E-09 mbar, with hydrogen being the main gas. In the case of the experimental regions, the TCTH and TCTVA tertiary collimators, installed to protect the Inner Triplets from quenching, are made out of tungsten and are baked. The experience accumulated in the HERA operation show no effect due to proton losses on tungsten collimator, when the base pressure is in the order of 1.E-8 mbar [13]. A similar behaviour is expected in the LHC experimental interaction regions. The residual gas density for the ATLAS insertion region is plotted in

Figure 1, for the beginning of LHC operations, including collimator outgassing. In 2008, the proton beam will be composed by 43 bunches of few E10 proton per bunch at 5 TeV. With respect to earlier scenarios (Figure 2 for the CMS interaction region, 44 bunches, 1.5.E11 p/b at 7 TeV, as calculated in [9]), the photon flux is reduced by about a factor of 50. In the first case (as shown in

Figure 1), dynamic effects can be neglected, and the major contribution to density will be given by thermal outgassing.

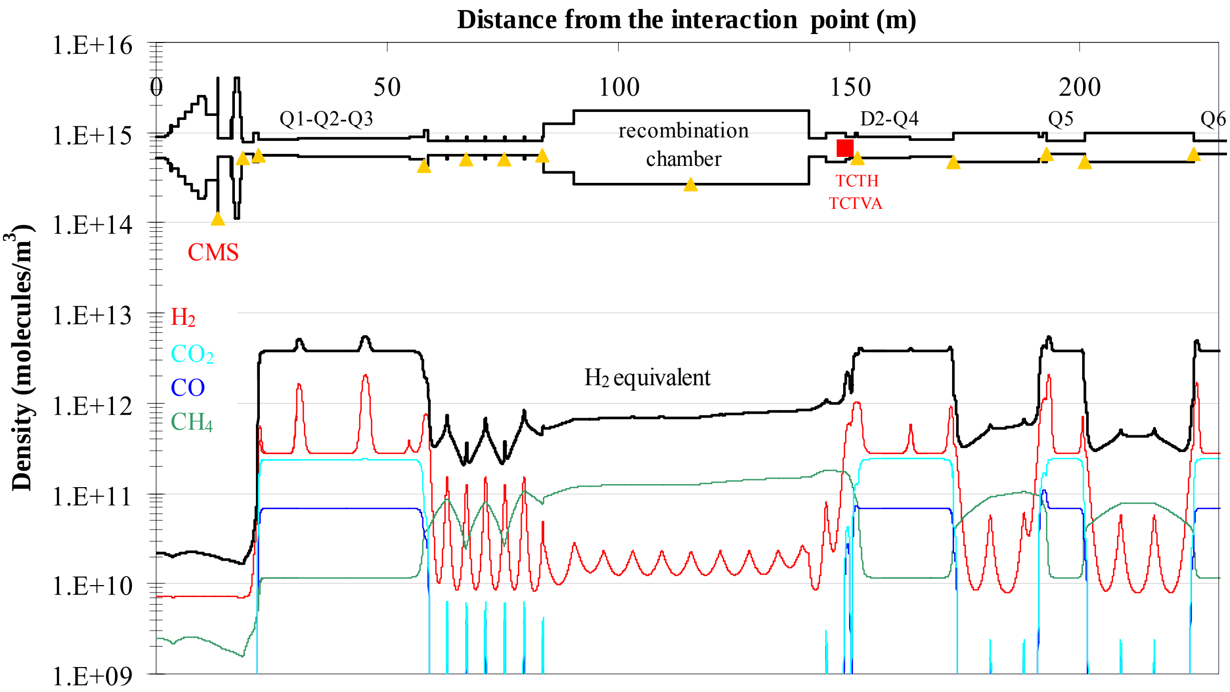

Figure 2: Residual gas density for the main gas species in the CMS interaction region as a function of distance from the interaction point for beginning of LHC operations. 44 bunches – 1.5.E11 proton/bunch at 7 TeV

The results presented in Figure 2, show the effect of beam operating configuration, in this case increasing synchrotron radiation, which cause the gas density to increase. The results, though, did not include the effect of the tertiary collimators, which should be comparable, as discussed before, to the contribution given by thermal outgassing, as calculated in

Figure 1.

Arcs

The gas density in the arcs can be estimated assuming, as for the cold magnets in the experimental insertion regions, the beam screen pumping only via holes (very conservative). In this case, for the same beam parameters, the photon critical energy will be about 3 times as in the experimental insertion regions, and the photon (and photoelectrons) flux about 10 times as much. The induced gas desorption yields for photon and photo-electron can be taken about the same values for similar history. With these hypotheses, the density expected in the arcs will be ≤ 20 times the one estimated in the cold sections of the insertion regions. The value given for the LHC design of 1.E15 hydrogen molecules/m^3 (corresponding to 100h beam lifetime) will nevertheless be the upper limit for background calculations.

Ion operations

Estimates for ion operations were presented in [14] and are expected to be in all operating configuration very close to the density calculated for thermal outgassing only. In this case in fact, gas sources other than thermal outgassing can originate only from beam losses, given the fact that

- Residual gas ionisation can be neglected and at ion estimated energy ~ 2eV no gas desorption is expected;
- Synchrotron radiation desorption can be neglected at critical energy ~ 2.8eV;

- No photoelectron or electron multipacting is expected due to low beam current and long bunch spacing.

In the case of ion beam losses, desorption yields are expected to be in the range of ~ 1.E5 molecules/ion [15] for each gas species considered (H_2, CH_4, CO and CO_2). Assuming beam screen holes pumping only (as done before), the continuous ion loss rate leading to the maximum density for 100h beam lifetime would be about 2.E6 ions/turn, which in reality corresponds to a beam lifetime < 2s. Furthermore, even in the case of localised losses as high as quench limit (estimated to 200x100 beam lifetime if lost over one second), pressure recovery would take < 1s. In conclusion, vacuum not expected to be limiting factor to beam lifetime for ion operations.

DISCUSSION AND CONCLUSIONS

Estimates of residual gas density for LHC operations were presented, given emphasis to their dependence on beam operating configuration and surface conditioning (i.e. machine history), and to how they represent only a 'snapshot' in time. Contribution of collimator outgassing in the insertion regions of ATLAS and CMS was calculated. Similar values are to be evaluated for the other experimental insertion regions, even if values are not expected to be very different.

The estimates where carried out for stable beam, assuming no continuous losses. If this assumption is to be reviewed, the effect of such losses should be analysed and added to present values.

Further comments:

- The vacuum group will be working close to the operation to learn how to use information on beam lifetime to renormalise the pressure estimates.
- In the event of a He leak in the arcs, it is expected to have a magnet quench before any effect of pressure can be seen [16]. BLM will be likely to give some useful information, and one should learn if beam lifetime can give an early warning on leaks in general.
- Possible cause of accident in the vacuum system would be fast temperature gradients opening leaks (in LEP, with beam at 80GeV due to synchrotron radiation hitting aperture restrictions), or damage caused by loss of beam.
- HOM are not expected, at present, to give temperature rise in the experimental regions, according to estimates (L. Vos) made at time of design and to measure introduced to prevent it : Cu coating, conical transition, RF contact, RF screen for pumps. This matter under investigation.
- Residual gas density can be computed case by case, working in close collaboration with operations, to establish machine history, and to study machine behaviour with particle losses.

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