https://doi.org/10.1142/9789811280184_0029



# Chapter 29

# Vacuum challenges at the beam energy frontier

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## Introduction

Designing the vacuum system for a machine like the HE-LHC is a very challenging task, since it demands the vacuum designer to cope with synchrotron radiation (SR) critical energy and power at levels much higher than those of the LHC, and a linear photon flux (photons/s/m) 80% higher than that estimated for the FCC-hh,[1] see Table 1.

Table 1. Synchrotron radiation (SR) characteristics in the arcs of LHC, HE-LHC and FCC-hh.

| Parameter | LHC | HE-LHC | FCC-hh |
|---|---|---|---|
| Linear SR power (W/m) | 0.25 | 5.5 | 35 |
| Linear photon flux ($10^{16}$ photons/m/s) | 5 | 27 | 15 |
| Critical photon energy (eV) | 44 | 320 | 4300 |

A number of critical features of the design of the vacuum system for HE-LHC are discussed below.

## Beamscreen design

As the cold-bore diameter and the length of the dipoles are identical for HE-LHC and FCC-hh, the cross-section of the beam-screen (BS) studied so far are the same for the both accelerators. This way, the design optimisation and the experimental validation performed for the FCC-hh during the first dedicated study program funded by Horizon 2020[2,3] can be applied to the HE-LHC. It should be noted that contrary to the dipoles of FCC-hh which have a straight yoke and cold-bore, the HE-LHC must have curved yoke and cold bore like the LHC, since the beam orbit sagitta in the middle of the dipole would otherwise be 8.6 mm for a straight magnet, causing the beam halo to touch the BS, especially at injection energy when the beam cross-section is bigger. For comparison, the beam sagitta in the middle of an FCC-hh dipole is only 2.3 mm. This necessitated the creation of new 3D models for the Monte Carlo ray-tracing simulations of the SR and molecular density distribution as compared to FCC-hh.[2,4] The modelled lattice version is the "$23 \times 90$", with 3 dipoles and 1 quadrupole/corrector package in each half cell, $\sim$ 54 m-long.[1] The resulting molecular density profiles are qualitatively similar to those calculated for FCC-hh, with a $\sim$ 2 m long density spike corresponding to the position of a short SR absorber placed at the very end of the dipole which masks the dipole-dipole or dipole-quadrupole connection area, where the RF fingers inside the bellows

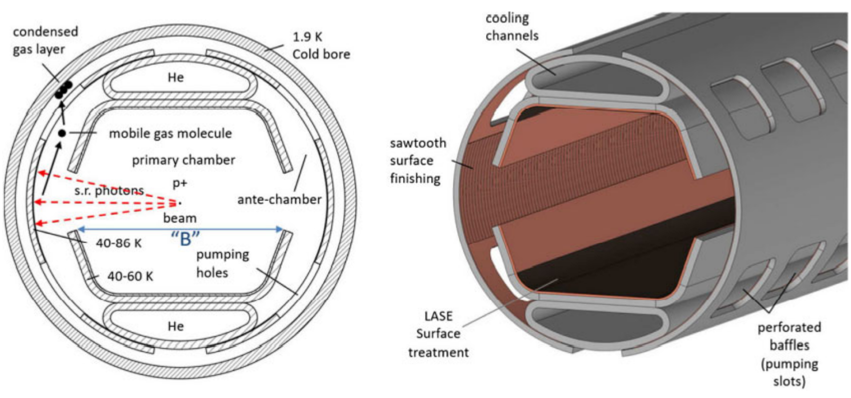


Fig. 1. Design of the HE-LHC BS. The main functions and parts are indicated, together with nominal temperature range of the different parts, presently under review. Width "B" is 27.55 mm. The pumping slots are much larger than those of the LHC, giving an effective linear pumping speed for $H_2$ of $\sim$ 900 l/s/m vs $\sim$ 480 l/s/m for the LHC. The vacuum behaviour of such a BS has been tested at KARA (formerly ANKA) light source, see Refs. 2–4. Only the primary SR photon fan is indicated, but low energy reflected photons can and will be scattered around the BS, finally irradiating all surfaces and generating photon stimulated desorption (PSD) of gas molecules everywhere on all surfaces of the BS. The aim is to minimize those generated on the inner surfaces of the BS in direct view of the beam.

and the beam-position monitor electrodes are placed, see Fig. 4.40 in Ref. 4. The Monte Carlo ray-tracing simulations for the gas density profiles show average values below the maximum allowed value of $1 \cdot 10^{15}$ $H_2$-equivalent molecules/$m^3$, corresponding to nuclear beam-gas scattering lifetime higher than 100 hours as required.

### Electron-cloud

In addition to the higher PSD generated by the SR fan, the HE-LHC is also challenging because of its high beam current, 1.12 A compared to the 0.5 A of the FCC-hh, making the electron-cloud (EC) countermeasures even more important. As shown in Refs. 1,3,4 experimental tests and calculations have been carried out extensively to make sure that the EC can be kept under control. The EC is currently one of the major problems with increasing the beam intensity in the LHC as it is a source of beam instabilities and an issue for cryogenic heat load.[5] Various surface treatments and thin-film deposition techniques have been proposed and validated experimentally, such as laser ablation and amorphous carbon coating of the BS internal surfaces.[3]

### Impedance

The resistive-wall impedance in such a narrow BS geometry is also a very important issue.[1] Several collaborations and tests have been set up recently to determine whether high-temperature superconductor (HTS) inserts could be fixed onto the 6 flat inner sides of the BS geometry.[6] A robust program of study using numerical simulations is under way,[6] as well as experimental validation using a light source beamline.[3]

### Ion-stimulated desorption

Another effect to take care of is ion-stimulated desorption (ISD), which is known to depend on several quantities, such as the gas composition, the beta functions, bunch spacing and separation, and applied pumping speed and beampipe conductance. The large linear pumping speed given by the pumping slots helps, keeping the molecular density low. In addition, tests at 80 K carried out at KARA light source[3] have shown that $\sim 90\%$ of the gas generated via PSD is hydrogen, with only the remaining 10% being

CO and $CO_2$. This should help keep the ISD effect under control, as per calculations carried out for FCC-hh.[4]

## Summary

The design of the HE-LHC vacuum system relies on the large body of literature generated for the vacuum system of FCC-hh. There are some features of the BS which are specific to the HE-LHC which will need to be tested and validated in the future, such as the use of HTS for minimizing the resistive-wall impedance. Additionally, the effect of an increased BS temperature and its effects on the cryogenic heat load, technology, and operating costs will need to be ascertained, with possible implications on energy saving and related operational costs, which are becoming more and more important.

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