LHC and HL-LHC collimation system optimization

H.Garcia[1], S.Boogert[1], S.Radaelli[2]

[1] Royal Holloway UNiversity of London. United Kingdom
[2] CERN, Geneva, Switzerland

Abstract

Machine related backgrounds arise mainly either from the halo that accompanies the core beam or from accidental losses due to individual events. Particles at large displacements from the core can impact on beam-line apertures, including collimators, and then exit the beam-pipe downstream. Looking towards the initial LHC upgrades, an optimization of the layout of the LHC collimation system to minimize beam related backgrounds in the ATLAS detector at CERN is required. Moreover optimizing the LHC injection region to minimize activation in that region is very important.

LHC and HL-LHC

The Large Hadron Collider (LHC) at CERN is designed to collide protons with an unprecedented energy of 7 TeV and a total stored energy of about 362 MJ per beam. The LHC is a 27 km synchrotron that consists of 8 straight sections, called Insertion Regions (IR) and 8 arcs. Thousands of superconducting magnets guide the two beams. Each IR houses either one of the four main LHC experiments where the beams collide, or other equipment: the accelerating radio-frequency (RF) system is installed in IR4, the beam extraction takes place in IR6, and injection in IR3 and IR8. IR3 and IR7 are dedicated to the collimation system.

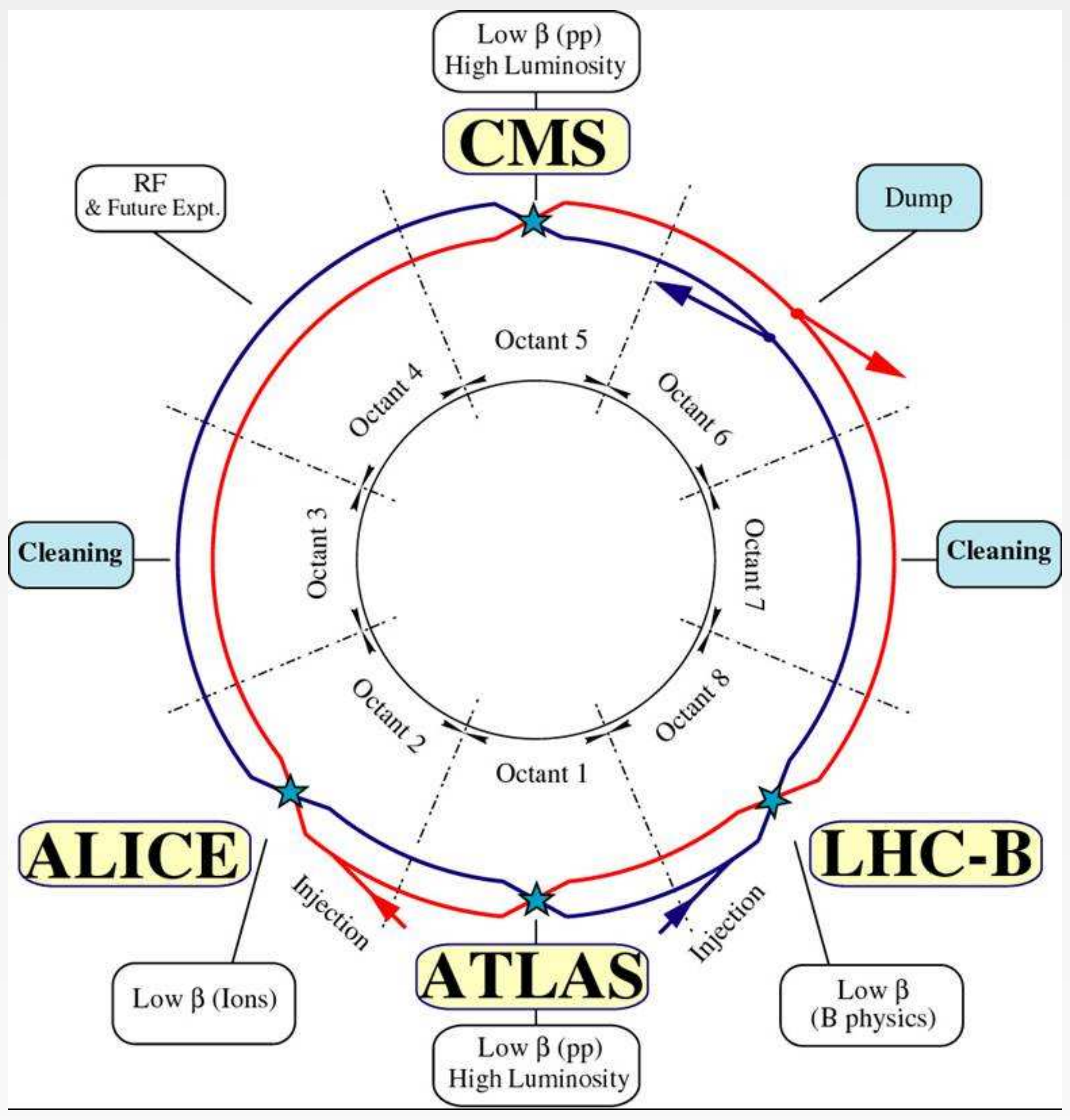

FIGURE 1: Schematic layout of the LHC.

Because of the high stored energy the LHC beams are highly destructive and beam losses can cause quenches of superconducting magnets and possibly material damage. Therefore, all beam losses need to be controlled. For this purpose, a multi-stage collimation system has been installed in order to intercept unavoidable beam losses in a safe way.

The HL-LHC

The HL-LHC is an upgrade of the present LHC with the aim to achieve an integrated luminosity of 3000 fb^{-1} in 10 years thanks to an increase in peak luminosity of about a factor 10. The optics design will follow the Achromatic Telescope Squeezing (ATS) [2] scheme in order to decrease the β function at the IP to the 15 cm. This optics reconfiguration and the fact that the beam power will increase by almost a factor 2 implies a review of the whole collimation system to determine whether the current LHC collimation system is enough or a new design is required.

LHC and HL-LHC beam paameters

Parameter	2011	2012	Nom.	HL-LHC
Beam energy [TeV]	3.5	4	7	7
N. of bunches	1380	1380	2808	2808
Bunch intensity (10^{11} p)	1.2	1.4	1.15	2.2
Peak stored energy [MJ]	112	146	362	693
Horizontal and vertical β^* [m]	1.5/1.0	0.6	0.55	0.15
Peak luminosity [10^{34}cm^{-2}s^{-1}]	0.35	0.77	1.0	7.4

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LHC Collimation

The halo collimation is achieved by several stages, with the primary collimators, called TCP, closest to the beam, followed by secondary collimators (TCS) and active absorbers (TCLA). A three-stage system is installed both in IR7 for betatron cleaning and IR3 for momentum cleaning. In addition, there are other collimators in most of the other IRs. Tertiary collimators (TCTs) provide local protection of the quadrupole triplets in the final focusing system. They are also important for decreasing the experimental background [3].

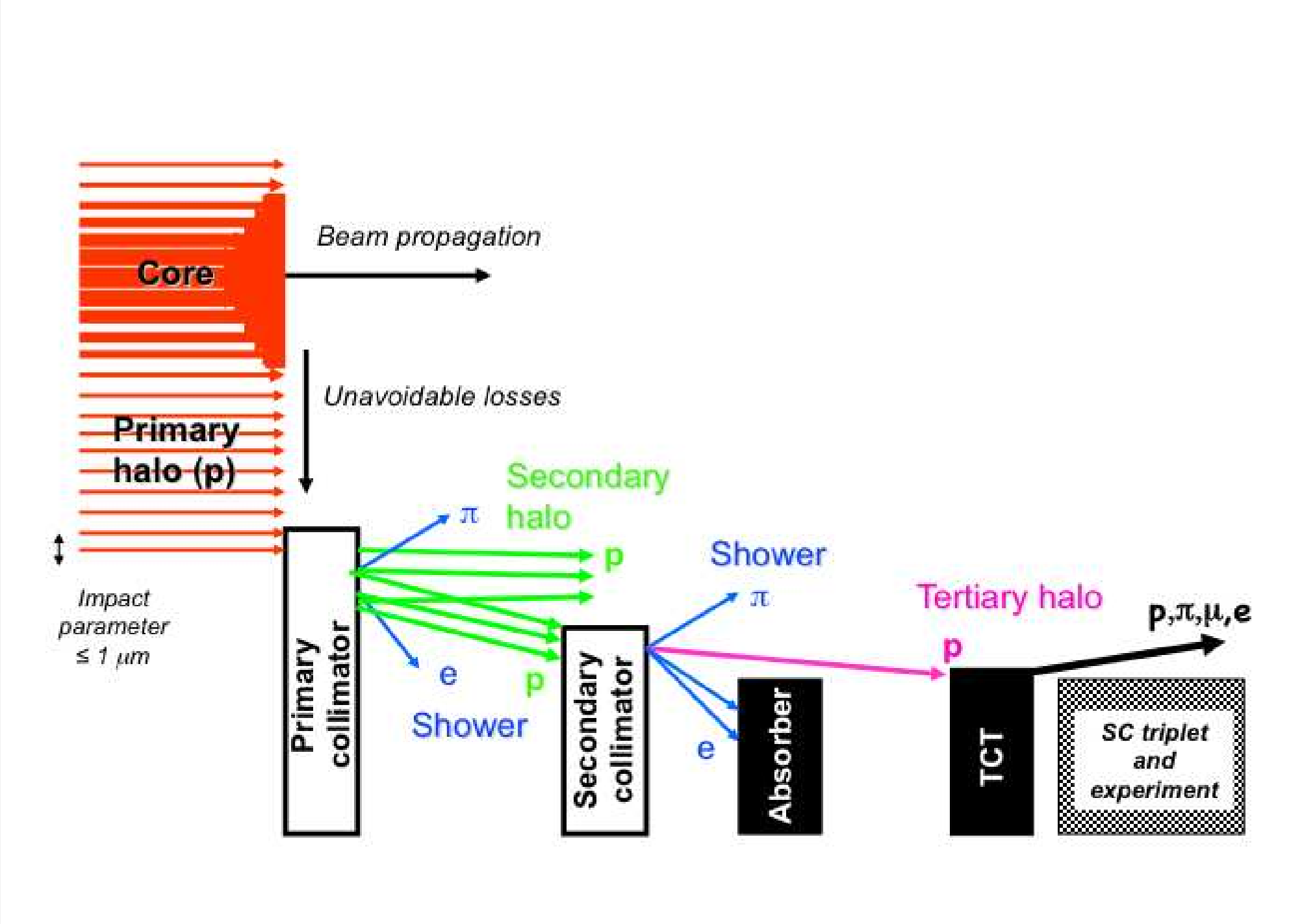

FIGURE 2: Scheme of the collimation principle.

In spite of a sophisticated design, a small number of protons, initially hitting the TCPs are not absorbed by the cleaning system. Instead, they leave the cleaning insertion on a perturbed trajectory and are possibly lost on the downstream machine aperture. The effectiveness of the collimations depends on their longitudinal placement in terms of betatron phase advance and dispersion. The collimation performance is usually quantified in terms of the local cleaning efficiency η, which is defined as the ratio of the local losses $N_{\rm loc}$ over a distance Δs to the total losses on collimators $N_{\rm tot}$:

$$\eta = \frac{N_{\rm loc}}{N_{\rm tot}\Delta s} \qquad (1)$$

The beam losses along the ring are usually represented with the beam loss patterns like the one shown in where in black are represented losses in the collimators, in red the losses in warm magnets and in blue the losses in superconducting magnets. Ideally the collimation system would intercept all the particles and no blue spikes would appear. In reality, some losses occur in the cold magnets. Therefore, the level of losses in these regions must be kept under a certain limit to avoid enough energy deposition to create a quench in the magnet.

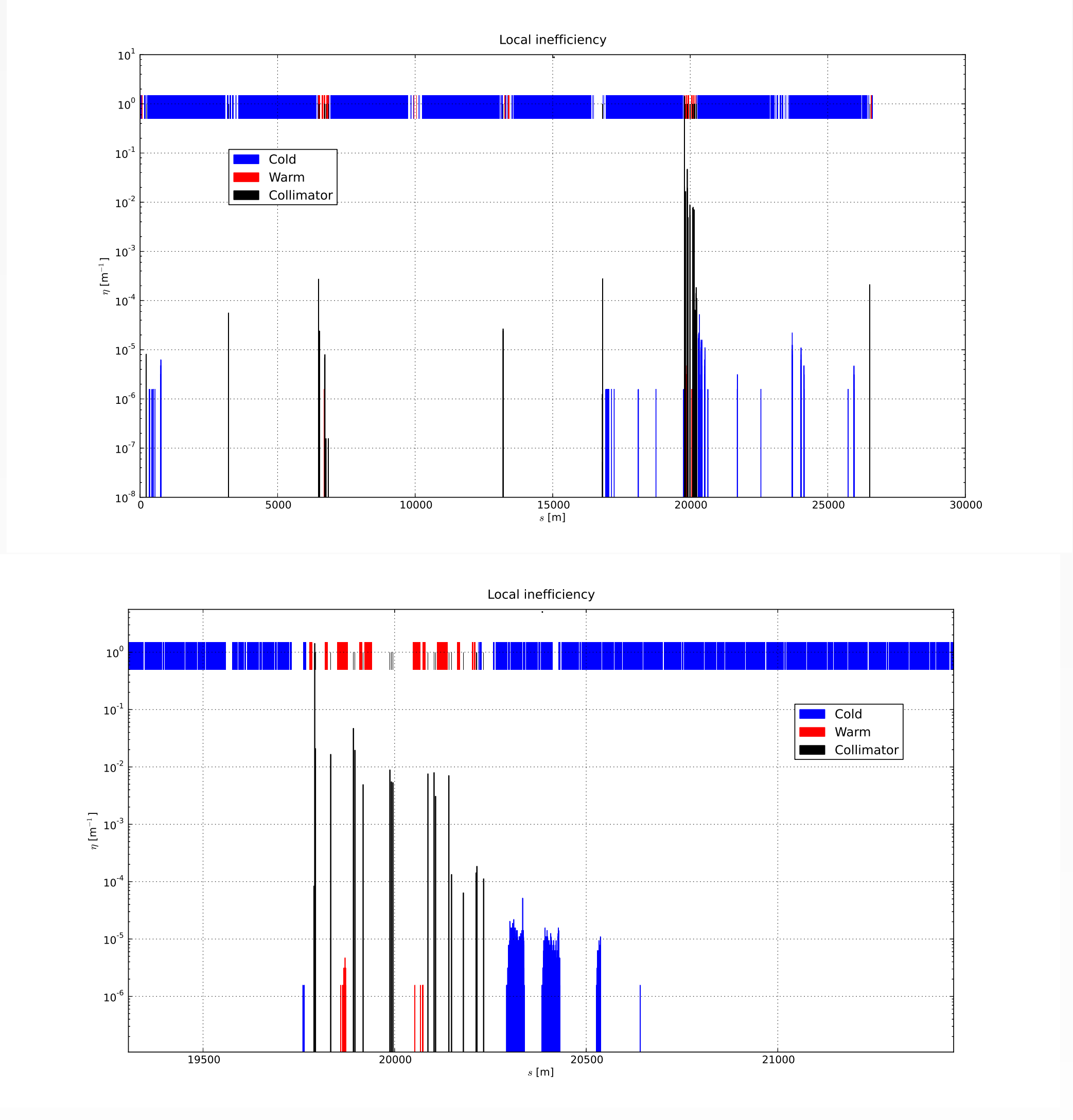

FIGURE 3: Beam loss distributions around the HL-LHC according to simulations simulations performed with SixTrack for Beam 1 and horizontal collimation. Detail of the betatron cleaning section.

To simulate the cleaning of the collimation system we use SixTrack. It is a multi-turn tracking code that accounts for the six-dimensional phase space in a symplectic manner. A particle is considered lost either when it hits the aperture or if it interacts inelastically inside a collimator.
In order to achieve satisfactory statistics to resolve losses below the quench level, we usually track at least $6.4 \cdot 10^6$ protons for 200 turns.

IR1 collimation optimization

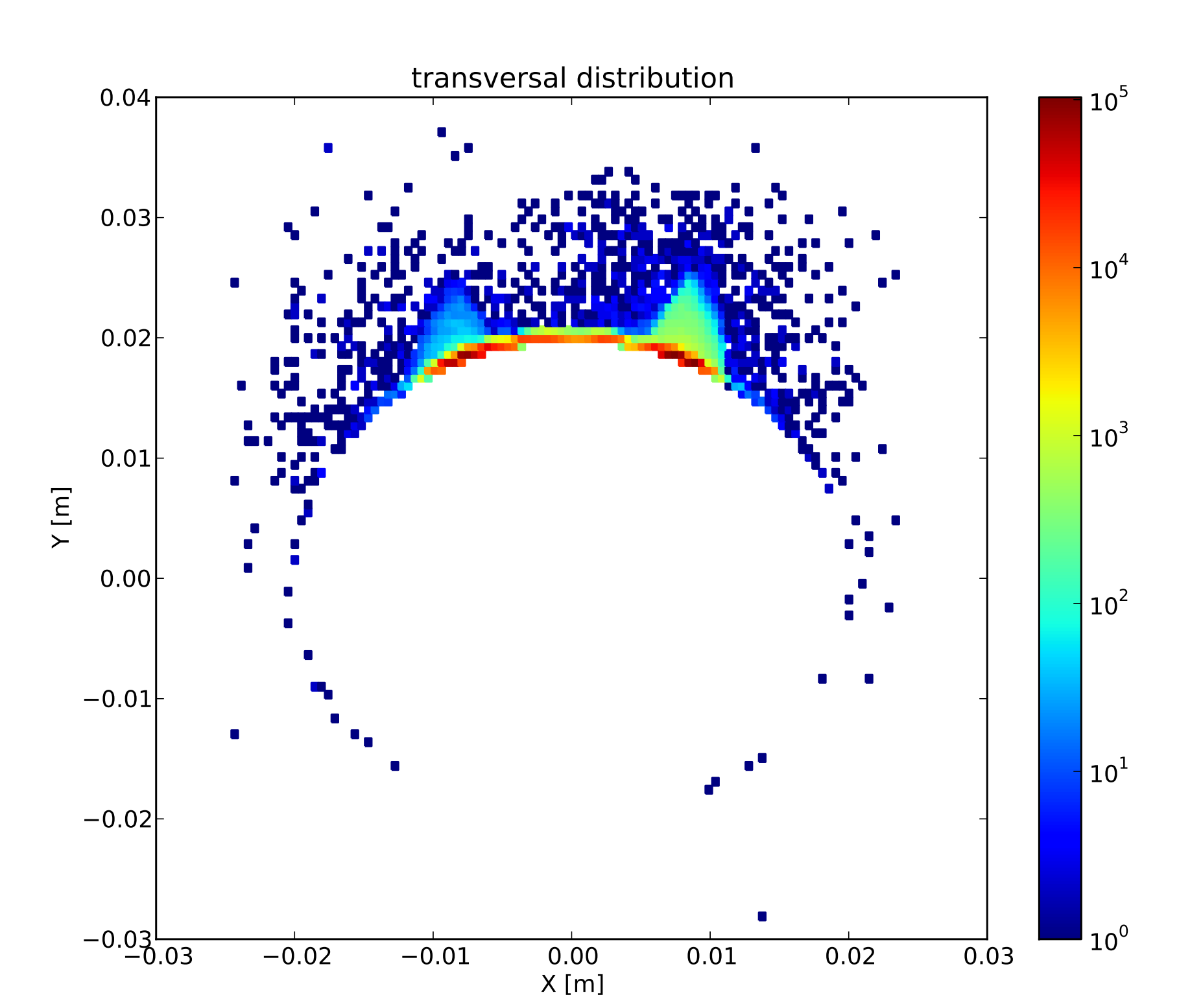

FIGURE 4: Loss map of in the Q2 region for an aperture of 20 mm.

BDSIM

BDSIM is a Geant4 and C++ based particle tracking code which seamlessly tracks particles in accelerators and particle detectors, including the full range of particle interaction physics processes in Geant4. The code has been used to model the backgrounds of the International Linear Collider (ILC), the Compact Linear Collider (CLIC), the Accelerator Test Facility 2 (ATF2) and more recently the LHC.

Geometric Library

The simulation of the physical elements of the beamline (bending magnets, quadrupoles, sextupoles,...) was initially relatively simple, with the geometry of such elements based on cylindrical bodies representing the magnet body, beam pipe and vacuum chamber. Recently, a more detailed geometry for the magnetic elements is being implemented.

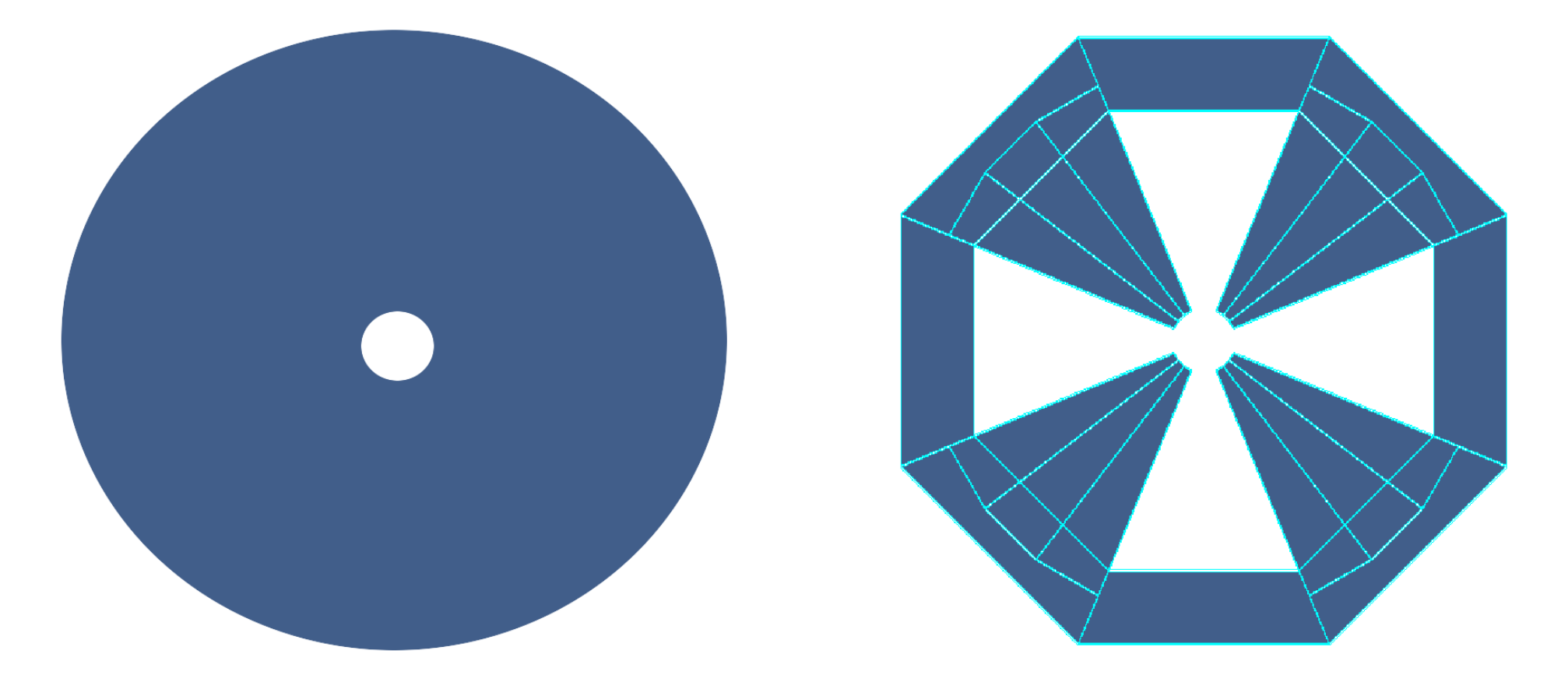

FIGURE 5: Evolution of the geometry of a quadrupole from its original design (left) to the more detailed design (right).

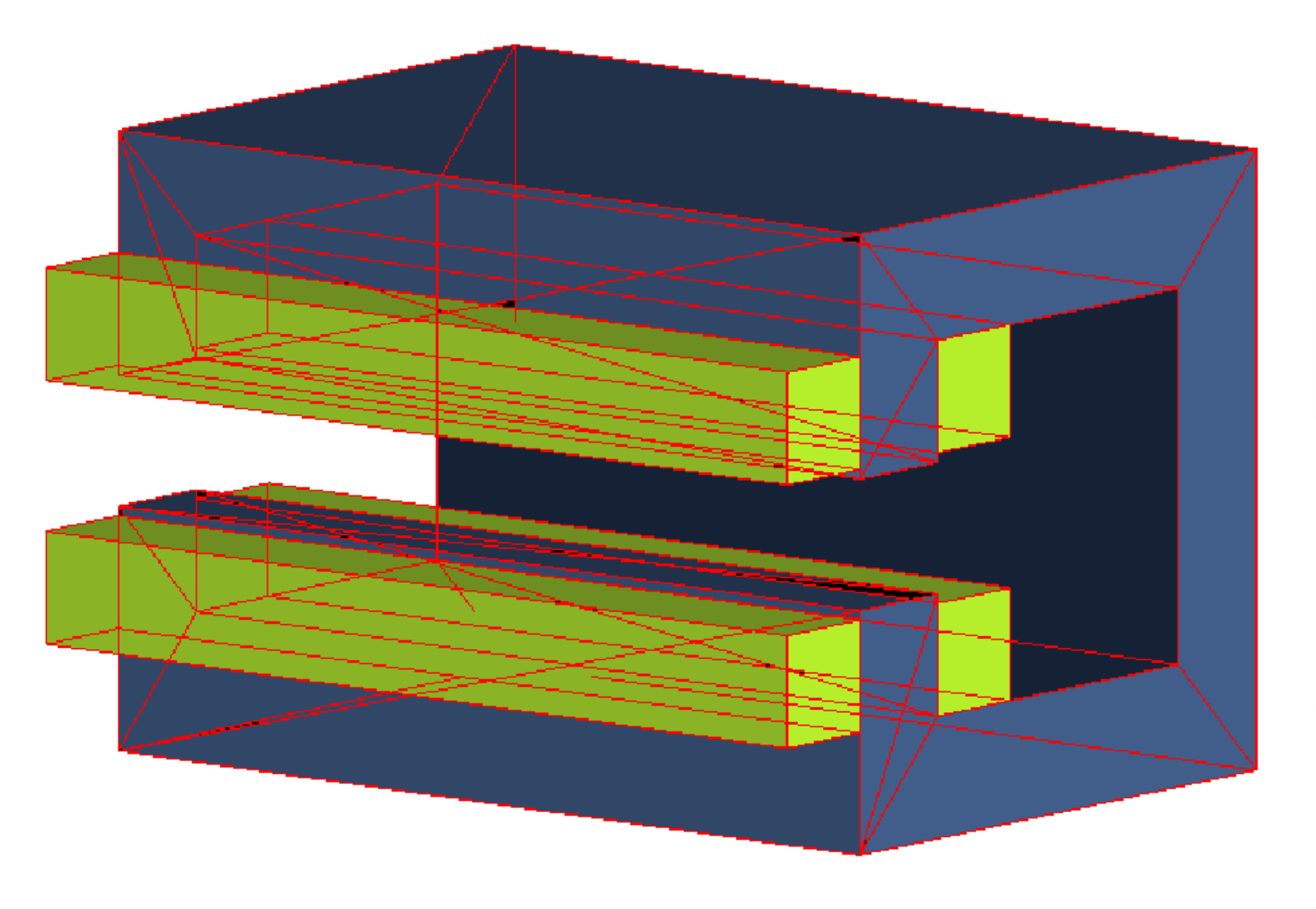

FIGURE 6: 3D view of the new C-dipole geometry generated in Geant4. The detailed geometry will make simulations more realistic.

References

[1] R.Bruce et al. "Simulations and measurements of beam loss patterns at the CERN Large Hadron Collider", to be published.

[2] S.Fartoukh, "Achromatic telescopic squeezing and applications to the LHC and its luminosity upgrade", Phys.Rev.ST.AB, **16**, 111002 (2013).

[3] R.Bruce et al. "Sources of machines-induced background in the ATLAS and CMS detectors at the CERN Large Hadron Collider", CERN-ACC-2014-0021 (2014).