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RECENT UPDATES OF THE LAYOUT OF THE LATTICE OF THE CERN HADRON-HADRON FUTURE CIRCULAR COLLIDER

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Abstract

The Future Circular Collider (FCC) study comprises two accelerators, namely a high-energy lepton collider (FCC-ee) and an energy-frontier hadron collider (FCC-hh). Both rings share the same tunnel infrastructure, analogous to the LHC that reuses the LEP infrastructure. We present the current design status of FCC-hh, updated from the Conceptual Design Report (CDR), with recent developments including the new designs of the combined injection and dump insertion, combined injection and RF insertion, new collimation insertions, and the optimisation of the arc cells and dispersion suppressors to increase the dipole filling factor.

GENERAL LAYOUT OF THE PROPOSED FCC-hh RING

Since the publication of the CDR, intense efforts have been devoted to placement studies, to refine the results presented in [1]. These aim to determine an optimal tunnel layout that complies with the multiple constraints imposed by geological, territorial, and environmental factors. Additionally, within the framework of FCC-ee studies, it emerged that implementing four experimental interaction points is an interesting option worth investigating. Beam dynamics considerations impose a symmetric positioning of the four experimental points. Hence, to allow sharing of the experimental caverns between the FCC-ee and FCC-hh, the same principle should also be applied to the FCC-hh lattice. As a result, a new layout [2], shown in Fig. 1, is being studied, with a circumference of 91.17 km. The proposed layout has an appealing side effect, as only 8 access points (instead of 12 as in the CDR baseline) are present, with a non-negligible impact on the civil engineering works and costs.

The length of the straight sections has also been revised: a short straight section, 1.4 km as in the baseline CDR lattice, is used for the experimental points (located in PA, PD, PG, and PJ); a long straight section, 2.160 km, is used to house the key accelerator systems. Currently, it is proposed to install the beam dump in PB, the betatron collimation in PF, the momentum collimation in PH, and the RF system in PL. These preliminary assignments should be confirmed by detailed studies that also evaluate the feasibility of the optics required for the various systems.

The total length of the arcs is 76.93 km, and, unlike the baseline configuration, all the arcs now have the same length. The reduced arc length implies that the collision energy falls short of 100 TeV by approximately 8 TeV, assuming 16 T for the field of the arc dipoles. The length of the FODO cell remains unchanged, still comprising twelve dipoles.

The rearrangement of the experimental points affects the design of the injection and transfer lines. The LHC-like configuration, in which injection is performed in the same straight section as the secondary experiments are installed, has to be dropped because it would lead to very long transfer lines. Therefore, the current layout envisages the combination of injection with beam dump (in PB) and RF (in PL). Then, to save tunnel length, it is proposed that the transfer lines run in the FCC-hh ring tunnel starting near PA to the injection point (see Fig. 1). The transfer line magnets for this solution would be rather relaxed in terms of magnetic properties, profiting from the favourable ratio of injection to collision energies.

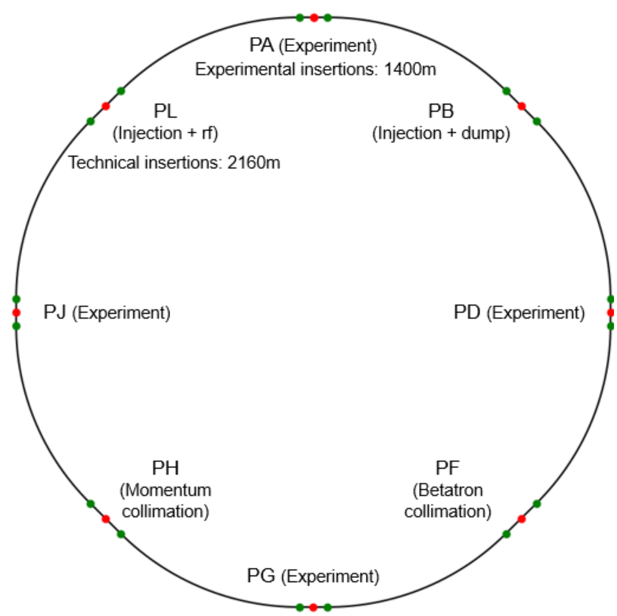

Figure 1: Layout of the FCC-hh ring with four collision points. The red circles indicate the interaction points or the middle of the straight sections. The green circles indicate the end of the straight sections.

INSERTIONS

Experimental Insertions

The current layout is very similar to that reported in [1]. The four experimental insertions are all identical in terms of layout and optical parameters, all reach the nominal value of $\beta^* = 30$ cm at collision, as shown in Fig. 2, and 10 m at injection, and are very similar in terms of dispersion.

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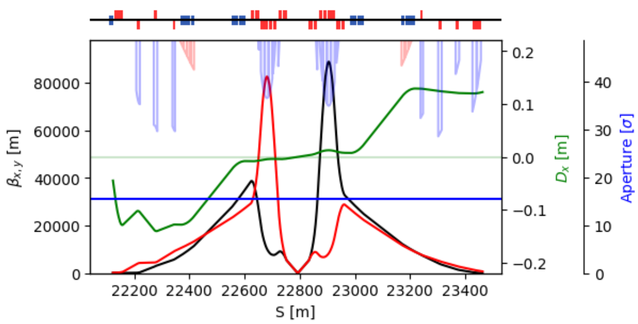

Figure 2: Optical parameters of experimental insertions, and available beam aperture of cold elements (blue) and warm elements (red) for $\beta^* = 30\,\mathrm{cm}$. The blue line represents the target aperture value at collision energy.

Collimation Insertions

The original layout presented in [1], heavily inspired by that of the LHC collimation insertions [3], has been reviewed in depth. This was needed due to the shortening of the insertion and also due to recent developments in the optics of the LHC betatron collimation insertion [4]. The main change is the increase of the beta-values. Note that in the case of the collimation insertions, the optics are a key ingredient, but the assessment of the actual performance is carried out by means of dedicated simulations evaluating the efficiency of the collimation system. The results of these are discussed in [5]. Another important change is the review of the geometry of the dogleg magnets that originated from the LHC design. Due to recent studies [6], weaker deflections are needed, which is very helpful in the design of a compact layout. Furthermore, the decision has been taken to keep the inter-beam distance constant along the insertions, which makes the optics for the two beams identical. The optical functions and the beam aperture at injection energy[1] are shown in Fig. 3. At collision energy, the optics remain the same and the beam aperture is above the target of 15.5 σ for all elements.

Injection and Dump Insertion

The total straight section length of 2160 m does not allow the injection and dump systems to be placed sequentially. However, since the optical constraints for these systems are similar, we propose to overlay them by imposing the constraints of 90° phase advance between kickers and protection absorbers. Figure 4 shows the optical functions (top). The optics design is symmetric to allow for extraction of both beams. The injection and extraction elements for the clockwise beam are shown in the bottom part. The location of the injection system within the extraction optics generates a phase advance between the septum and the kicker that is more favourable than in the CDR design [1], almost halving the required kick angle. This optimisation is particularly important in the event of a misfiring of the injection kicker, when the full pulse-length equivalent of bunches will have

[1] The nominal injection energy is 3.3 TeV, with an alternative option considering 1.3 TeV [1].

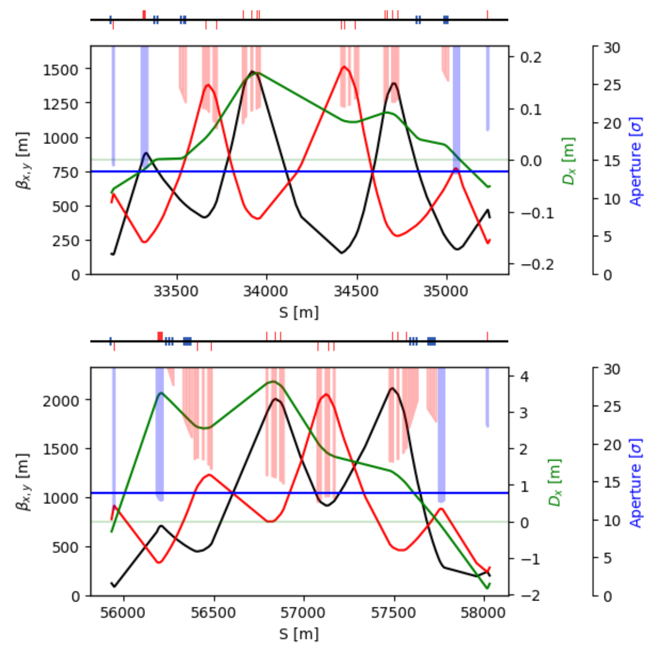

Figure 3: Optical parameters of the insertion housing the betatron collimation system (top) and momentum collimation system (bottom) and available beam aperture of cold elements (blue) and warm elements (red). The blue line represents the target aperture value at injection energy.

to pass through the extraction system before being dumped onto a dedicated absorber. To cope with these trajectories, it is important to have injection and extraction systems that deflect the beam in the same plane (currently the vertical one). This gives a favourable sequence of quadrupole deflections for the failure scenario trajectories. Compared to the CDR design, the hardware requires an increase in the apertures of the extraction kicker of approximately 5 mm (from 16 mm to 21 mm) and of approximately 27 mm of the quadrupole downstream of the extraction kicker. A careful design of the protection of the extraction septum is needed. The reduced length of the straight section will probably require the extraction channel to pass through the cryostat of the quadrupole downstream of the septum. Full validation of this design requires a careful analysis of the failure scenarios of both systems, considering specific hardware design features, as well as the global machine protection implications of these failure scenarios.

Injection and RF Insertion

The injection of the counter-clockwise beam is planned to occur in IPL, where the RF system is also located. Although the injection design in IPB is driven by mitigation of failure scenarios, due to the limited space available, the optics design for injection of the counter-clockwise beam is driven by keeping the hardware design of the kicker, septum, and absorber the same. The two doglegs, which are needed to increase the inter-beam distance and enable the installation of the RF cavities in the central part of the insertion, are

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implemented to be achromatic. The injection of the counter-rotating beam is performed on the right side of the insertion, and the hardware parameters of the septum and kicker magnets are the same as the systems installed in PB. In terms of injection in PB, the counterclockwise beam is injected into the outer magnetic channel. The optical functions and the beam aperture at injection energy are shown in Fig. 5.

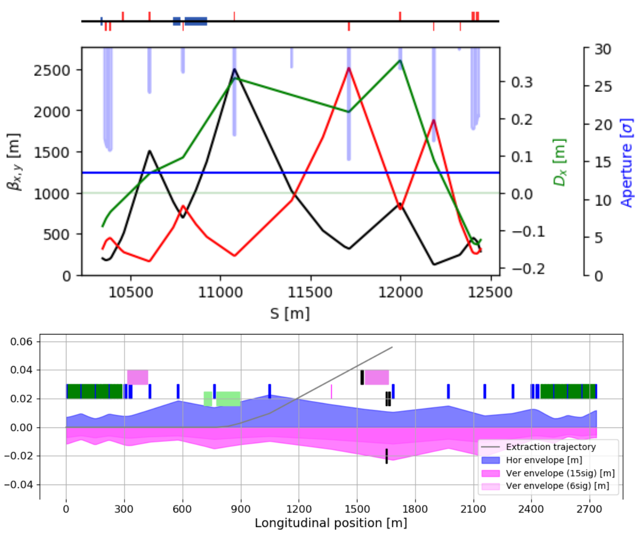

Figure 4: Top: Optical parameters of the insertion housing the clockwise beam injection and beam dump systems, and available beam aperture. The blue line represents the target aperture value at injection energy. Bottom: Layout of the PB insertion (kickers in green and the septa in magenta). The injection is on the left and takes place upstream of the extraction. The larger 15σ envelope represents the circulating beam and the smaller 6σ envelope is relevant for the design of the extraction channel.

DEVELOPMENT ACTIVITIES

This paper is the starting point for a new layout that should include several novelties. Based on new considerations of placement options and compatibility of RF harmonic number with that of the injector, the circumference of FCC-hh should be further reduced to the final planned value 90.66 km. It is planned to achieve this by shortening the technical insertions from 2.160 km to 2.032 km, which implies re-examining the layout and optical solution found so far. The situation of the insertion housing the dump and injection systems is particularly challenging.

The regular cell in the arcs is planned to be stretched to comprise 16 dipoles, thus providing a higher dipole fill factor [7]. The layout of the dispersion suppressor will also be further optimised to adapt to the new arc configuration and possible changes to the insertion optics.

Important changes are also envisaged for the experimental insertions. It is proposed to implement a radial displacement of the collision point to make it coincident with that of the FCC-ee rings. This should optimise the cavern size, fully shared between the two machines, and might enable reusing FCC-ee detector components in FCC-hh. Radial displacement should be obtained by changing the local arc geometry, carefully considering the impact on geometry and optics. The new local arc geometry should be optimised to follow, as much as possible, the geometry of the FCC-ee rings to minimise the need for new tunnels. The regular arc optics will be perturbed by these changes, and a new solution will need to be found. It is also planned to review the internal layout of the experimental straight sections, replacing the normal-conducting D1 separation dipole with a superconducting version, inspired by what is planned for HL-LHC [8], also reviewing the properties of the D2 separation dipole.

Sections of the transfer lines installed in the ring tunnel are being studied in terms of integration and hardware design. The dipole and quadrupole fields are relatively relaxed, which enables the possibility of using normal-conducting magnets or even permanent magnets, which would have clear advantages over normal-conducting devices.

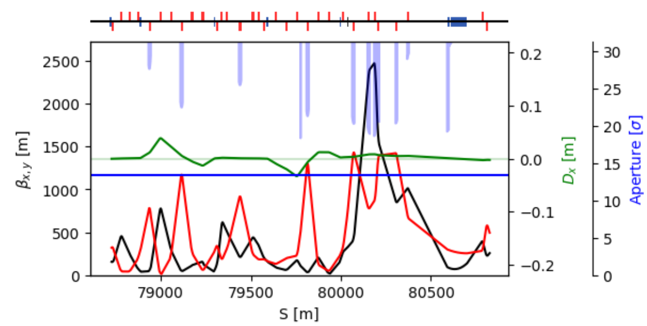

Figure 5: Optical parameters of the insertion housing the counter-clockwise beam injection and RF systems, and the available beam aperture. The blue line represents the target aperture value at injection energy.

CONCLUSIONS AND OUTLOOK

Several new developments of the FCC-hh layout have been presented and discussed here, and many more are in the process of being considered and implemented in an updated version of the layout. This layout could then be used to resume beam dynamics simulations. It is also worth mentioning a parallel line of research consisting of developing a new optics and layout using combined-function magnets [9–11]. This approach has two main advantages: the first being the increase of the dipole fill factor even with respect to longer FODO cells; the second being the absence of arc quadrupoles, which is an important aspect in terms of magnet construction and overall costs. The beam dynamics aspects of the combined-function layout, which are essential for establishing the feasibility of this approach, are currently being investigated.

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