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CONSOLIDATED LATTICE OF THE COLLIDER FCC-hh

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Abstract

The FCC-hh (Future Hadron-Hadron Circular Collider) is one of the options considered for the next generation accelerator in high-energy physics as recommended by the European Strategy Group. The latest changes brought to the lattice of the FCC-hh collider are commented: impact of the new intra-beam distance, efforts to increase the beam stay clear in the dispersion suppressors, tuning procedures, and updates on the insertions.

LAYOUT OF THE FCC-hh

The layout of the FCC-hh ring is shown in Fig. 1. It has only slightly changed compared to the one shown in Ref. [1, 2]. The total circumference of the FCC-hh ring is 97.75 km. The FCC-hh ring is made of 4 short arcs (SAR), 4 long arcs (LAR), 6 long straight sections of 1.4 km (LSS) and 2 extended straight sections of 2.8 km (ESS). The parameters of the ring are given in Table 1 [3].

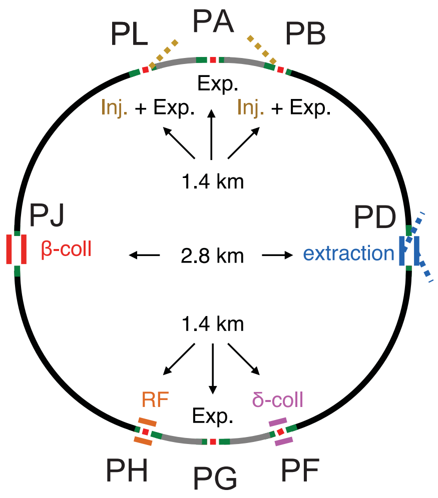

Figure 1: Layout of the FCC-hh ring.

The high luminosity interaction points (IPs) are located in the sections LSS-PA and LSS-PG. The value of L^* in the experimental insertion region (EIR) is 40 m [4]. Two additional IPs (with lower luminosity) are located in the sections LSS-PB and LSS-PL. These sections host the injection as well, which gives additional constraints [4, 5]. The beam H1, which runs in the clockwise direction, is injected into the section LSS-PB and the other one H2 into the section LSS-PL. The RF cavities are located into the section LSS-PH with a beam separation enlarged from 250 mm to 420 mm. This section is currently made of FODO cells (length: 219.292 m and phase advance: 72°). The extraction section is located in the section ESS-PD and enables the extraction of both beams in the same section [5]. The betatron and momentum cleaning sections are respectively located in the sections ESS-PJ and LSS-PF for both beams [6–8].

Table 1: Parameters of the FCC-hh Ring

Parameter	Value		Unit
	Baseline	Ultimate	
Energy	50		TeV
Circumference	97.75		km
LSS and ESS length	1.4 and 2.8		km
SAR and LAR length	3.4 and 16		km
β^*	1.1	0.3	m
L^*	40		m
Normalized emittance	2.2		µm
γ_{tr}	98.466	98.413	
Q_x/Q_y	109.31/ 107.32		
Q'_x/Q'_y	2/2		
Beam separation	250		mm
Beam separation (RF)	420		mm

UPDATES OF THE ARC CELLS

Since the systematic value of b_2 in the dipoles was too large (up to 50 units), the beam separation was enlarged from 204 mm [9, 10] to 250 mm. The dipoles have now a systematic b_2 component of 6 units at injection energy, and near 0 unit at collision energy. The integrated quadrupole strength is smaller. A direct consequence is to use shorter main quadrupoles (6.4 m against 7.2 m) and longer and weaker dipoles (15.81 T against 15.96 T) as given in Ref. [1].

The arc cell is 213.03 m long with a phase advance of about 90 degrees. The layouts of the arc half-cell, of the short straight section, and of the dispersion suppressor (DIS) are given in Fig. 2. Each FODO cell has 12 dipoles (MB), 12 b_3 correctors (MCS), 6 b_5 correctors (MCD), and 2 short straight sections (SSS). Each SSS contains one BPM, one sextupole, one quadrupole (MQ), one multipole corrector (trim quadrupole, skew quadrupole, or octupole), and one dipole corrector. The lengths of these magnets are optimized accordingly with the reachable maximum gradients [3, 11–13]. The total length of the SSS is 11.3 m. The distances between two MBs, between one MB and one SSS, between two elements inside SSS are respectively 1.5 m, 1.3 m, and 0.35 m. The parameters of the different arc magnets are given in Table 2. The optical functions and the geometrical apertures (at injection) in the arc cell baseline are shown in Fig. 3. The beam stay clear was computed with the last

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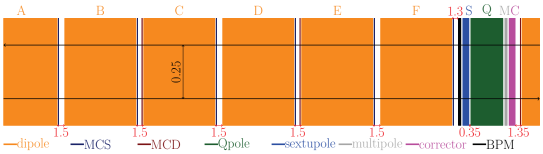
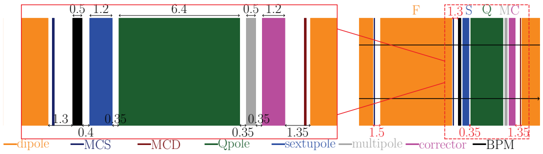
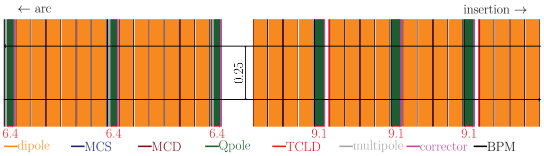


(a) Arc FODO half-cell



(b) Short Straight Section



(c) Dispersion suppressor

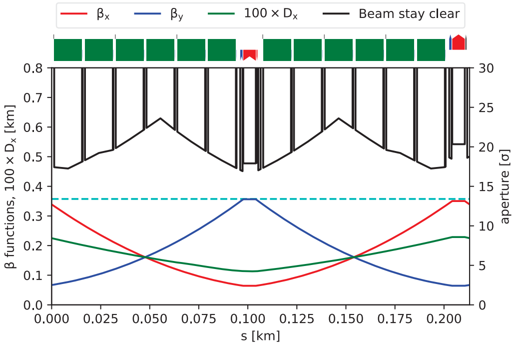
Figure 2: Layout of the arc FODO half-cell, SSS, and DIS.

Table 2: Parameters of Main Elements in the Arcs. Trim Quadrupoles, Skew Quadrupoles or Octupoles are not Present in all FODO Cells. Nevertheless, There are Always Two Multi-poles per Cell.

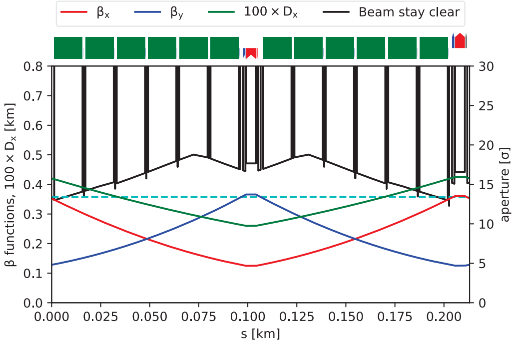
Magnet	Max. field	Length [m]
Main Dipole	16 T	14.187
Dipole Corrector	4 T	1.2
Main Quadrupole	360 T/m	6.4
Trim Quadrupole	220 T/m	0.5
Skew Quadrupole	220 T/m	0.5
Main Sextupole	7,000 T/m^2	1.2
Sextupole Corrector	3,000 T/m^2	0.11
Decapole Corrector	2.8×10^6 T/m^4	0.11
Main Octupole	200,000 T/m^3	0.5
BPM	-	0.5

version of the beam screen [3, 14] and taking into account the dipole sagitta and the misalignment tolerances [15].

An alternative to the arc optics is to use phase advances of 60° instead of 90° in the arc cells. The motivation is to reduce the needed integrated quadrupole gradient, to use shorter quadrupoles, and finally to use longer and weaker dipoles. By keeping a maximum gradient of 360 T/m, the quadrupoles can be shortened from 6.4 m to 4.5 m; the dipoles can be lengthened by 0.33 m and the dipole field can be reduced to 15.44 T. Another advantage is to reduce the maximum sextupole gradient thanks to larger dispersion functions. The maximum sextupole gradient is then 3200 T/m^2 for the ultimate lattice. Nevertheless, the correction schemes should be modified to work with this phase advance. The main issue is the reduction of the physical aperture at injection because of enlarged dispersion. At injection energy of 3.3 TeV, the physical aperture is only 12.3 σ, well below the target limit of 13.4 σ. Nevertheless, the beam stay clear is calculated with the assumption of straight dipoles. In the case of sector dipoles, the beam stay clear for this alternative becomes 15 σ, above the requirements of 13.4 σ.



(a) Baseline: 90 degrees per cell



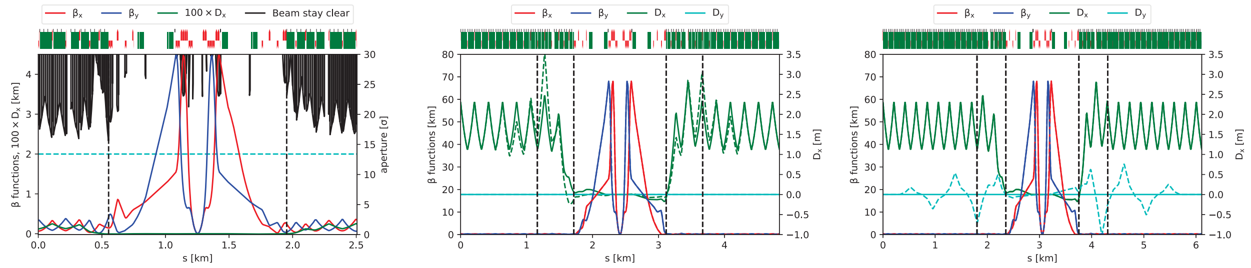
(b) Alternative: 60 degrees per cell.

Figure 3: Optical functions in the arc cells (respectively in blue β_x, in red β_y, and in green $100 \times D_x$) for the baseline with a phase advance of 90 degrees per cell and for the alternative with a phase advance of 60 degrees. The beam stay clear is shown in black at injection energy (3.3 TeV). The cyan horizontal line shows the specified target of 13.4 σ.

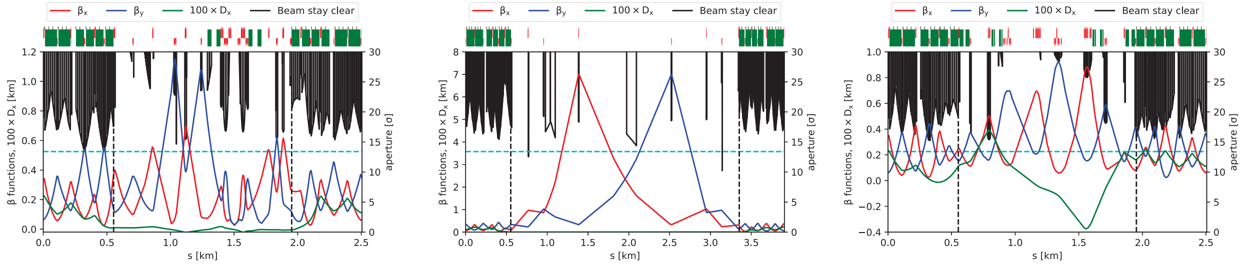
OPTICS OF THE FCC-hh RING

In Ref. [1], one dipole was removed at the middle of the LAR to save some space for the technical straight sections (TSS). The dispersion wave generated by the missing dipole was then damped by using trim quadrupoles from each side of the missing dipole. The technical straight section at the middle of the long arcs does not require any extra space in the lattice anymore. The long arcs are thus simpler: there is no more missing dipole. Currently, the chromaticity is corrected by two sextupole families distributed in the SAR and LAR.

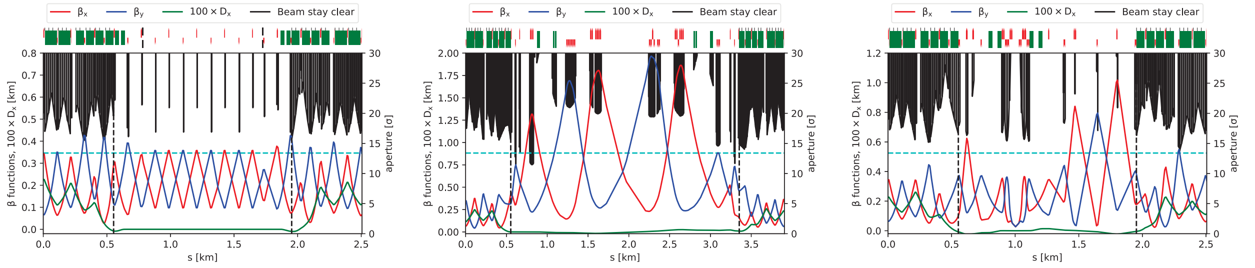
The tuning procedure has been slightly modified for the arc optics. The phase advances in the FODO cells are exactly 90° in the SAR whereas they are $90 + \epsilon_{x,y}$° in the LAR. The value of $\epsilon_{x,y}$, can now be adjusted differently for each LAR. By this way, the phase advance between PA and PG can



(a) LSS-PA-EXP at injection (b) LSS-PA-EXP at collision (c) LSS-PG-EXP at collision



(d) LSS-PB-INJ+EXP (e) ESS-PD-EXT (f) LSS-PF-COL



(g) LSS-PH-RFS (h) ESS-PJ-COL (i) LSS-PL-INJ+EXP

Figure 4: Optical functions in the high-luminosity IR (at injection and collision energies, dashed lines are when the crossing scheme is on), injection, extraction, momentum collimation, RF, betatron collimation, and low-luminosity IR sections at injection (respectively in blue β_x, in red β_y, and in green $100 \times D_x$). The beam stay clear is shown in black at injection energy (3.3 TeV). The cyan horizontal line shows the specified target of 13.4 σ.

be adjusted by keeping the global tune at the target value. Indeed, studies have shown that the dynamic aperture and machine stability are very sensitive to this value at collision [16, 17]. An alternative is to tune the insertions LSS-PH, hosting the RF, and the extraction section ESS-PD but this method has not been implemented yet.

Correction schemes are explained in Ref. [16, 18, 19] and will not be developed here. The SSC scheme is used with trim or skew quadrupole at the arc entrance in order to correct the spurious dispersion coming from the EIR [2, 20].

The DIS are similar to the ones used in LHC [21]. Like in HL-LHC, some space (5 meters) is saved for two 1-meter-long collimators to protect the arc entrances from the debris coming from the insertions (mainly experimental and cleaning ones [15]). The bottleneck of the beam stay clear was located into the DIS. Special care was taken in the matching procedures to keep the beam stay clear above the target value. The updated optics of the different main insertions are given in Fig. 4 for the ultimate parameters given in Table 1.

CONCLUSION

The consolidated optics of the FCC-hh ring has been presented. The last updates of the arc optics have been commented. The layout of the arc cell has been shown and has been updated in agreement with magnet specifications. The geometric aperture is within requirements. An alternative like 60 degrees per FODO cell has been shown.

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