STATUS OF THE BEAM OPTICS OF THE FUTURE HADRON-HADRON COLLIDER FCC-HH

A. Chancé*, D. Boutin, B. Dalena, J. Payet, CEA, IRFU, SACM, Centre de Saclay, F-91191 Gif-sur-Yvette, France,
B. Holzer, R. Martin, D. Schulte, CERN, Geneva, Switzerland

Abstract

Following the recommendations of the European Strategy Group for High Energy Physics, CERN launched a design study for possible future circular collider projects, FCC, to investigate their feasibility for high energy physics research. The study covers three options, a proton-proton collider, a circular e+/e- collider and a scenario for e-p collisions to study deep inelastic scattering. The present paper describes the beam optics and the lattice design of the Future Hadron-Hadron Collider (FCC-hh). The status of the first order and second order optics of the ring will be shown for collisions at the required centre-of-mass energy of 100 TeV cm.

LAYOUT OF THE FCC-hh RING

The current layout (see Fig. 1) of the FCC-hh ring consists of a ring with 2 high-luminosity insertions and 2 low-luminosity insertions. The target circumference is 3.75 times the one of LHC, i.e. 99.97 km. The FCC-hh ring is made of 4 short arcs (SAR), 4 long arcs (LAR), 6 long straight sections (LSS) and 2 extended straight sections (ESS). The parameters of the ring are given in Table 1. The high luminosity interaction points (IPs) are located at the IPA and IPG (in the named sections LSS-PA[PG]-EXP on the layout). The optics of these interaction regions is assumed to be antisymmetric and is presented in [1] for the former value of $L^* = 36$ m and in [2] for the current value of $L^* = 45$ m. In order to mitigate the beam-beam effects, the crossing angles in IPA and IPG are not in the same plane at the collision. The lower luminosity IPs are located at the IPF and IPH (in the named sections LSS-PF[PH]-EXP). At the current state of the study, these insertions are made of FODO cells. The insertion sections and the RF cavities are located at the IPB and IPL (LSS-PB-INJ and LSS-PL-RFS on the layout) for the first beam H1 which runs in the clockwise direction. The order is reverse for the second beam H2. As the beam separation must be enlarged to 420 mm for the RF cavities, a chicane is added at the entrance and at the exit of these sections. These sections are made of FODO cells. The cell length is enlarged to 300 m to enable the insertion of an injection septum [3]. The extraction and the betatron collimation are respectively located at the IPD[J] for H1[H2] whereas the momentum collimation section is located in the other ESS at the IPJ[D]. The extraction [4], the betatron and momentum collimation sections [5] are scaled from the LHC with the factor $k = \sqrt{\frac{50}{7}}$ for the betatron functions and the distances. The factor k is derived from the ratio of the centre-of-mass energy at collision between the LHC and FCC-hh. By multiplying all distances by this factor, we keep then the same gradient in the quadrupoles. The derivative of the dispersion is divided by this factor. The dispersion suppressors (DIS) are similar to the ones used in LHC. The advantage of this configuration is a good filling factor by keeping a good flexibility [6]. Special care has been taken to have a dispersion lower than in the momentum collimation section in the DIS upstream in order not to spoil the collimator hierarchy.

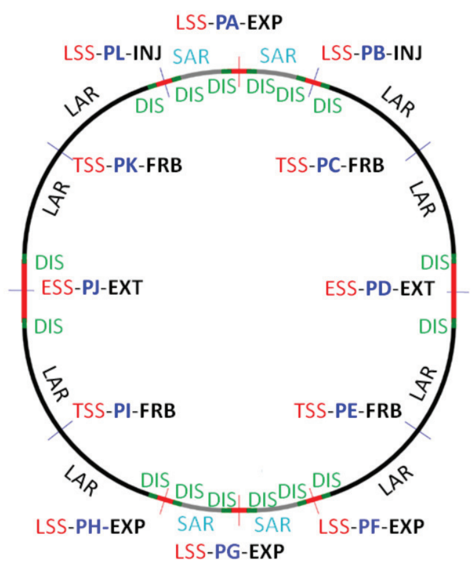


Figure 1: Layout of the FCC-hh ring.

Table 1: Parameters of the FCC-hh Ring

Parameter	Value Baseline	Value Ultimate	Unit
Energy	50		TeV
Circumference	99.171		km
LSS and ESS length	1.4 and 4.2		km
SAR and LAR length	3.6 and 16		km
β^*	1.1	0.3	m
L^*	45		m
Normalized emittance	2.2		μm
γ_{tr}	99.580	99.469	
Q_x/Q_y	111.31/ 108.32		
Q'_x/Q'_y	2/2		
Beam separation	250		mm
Beam separation (RF)	420		mm

* Corresponding author: antoine.chance@cea.fr

ISBN 978-3-95450-147-2

OPTICS OF THE FCC-hh RING

The optics of the different main insertions and of the whole ring are given in Fig. 2 and Fig. 3 for the baseline parameters given in Table 1. The FODO cells of the arcs are optimized to have the largest filling ratio [6, 7]. The current parameters of the FODO cell are summed up in Table 2. The phase advance in the FODO cells is exactly 90° in the SAR whereas it is 90°+$\epsilon_{x,y}$ in the LAR. The value of $\epsilon_{x,y}$, is adjusted to tune the whole ring. Because of the large number of FODO cells in the LAR, the value of $\epsilon_{x,y}$ stays small.

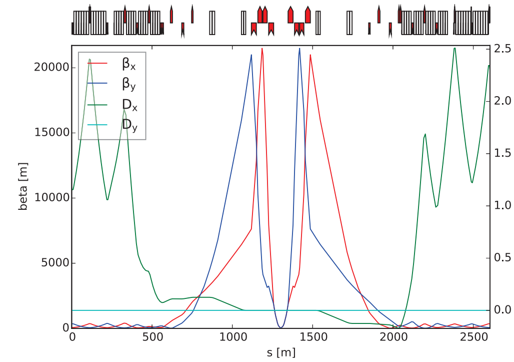
A dipole is removed at the middle of the LAR to save some space for the technical straight sections (TSS). To cancel the dispersion wave generated by this missing dipole, another dipole is removed downstream at the phase advance of about 180 degrees (two FODO cells far away). Since the phase advance is not exactly 90°, there is a residual dispersion beating which is canceled in the DIS downstream. The phase advance between the IPs A and G and the first focusing/defocusing sextupole of the SAR is respectively adjusted to 90° modulo 180° in the horizontal/vertical plane. In the current design, the chromaticity is corrected by two sextupole families distributed in the SAR and LAR. In the future, more advanced schemes like the ATS [8] will be studied.

Table 2: Parameters of the Arc FODO Cell

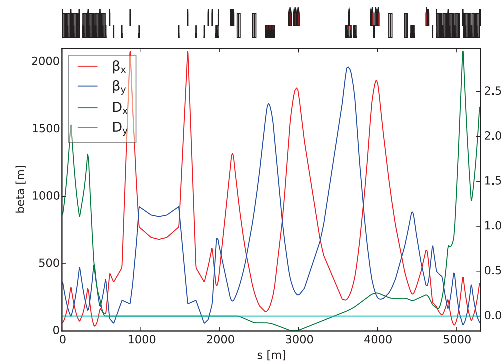
Parameter	Value	Unit
Cell length	213.895	m
Cell phase advance H/V	90	deg
Number of dipoles per cell	12	
dipole magnetic length	14.3	m
dipole maximum field	15.9	T
quadrupole magnetic length	6.29	m
quadrupole maximum gradient	359	T/m
sextupole magnetic length	0.5	m
sextupole maximum gradient Baseline/Ultimate	8140/16030	T/m^2
dipole-dipole spacing	1.36	m
quadrupole-dipole spacing	> 3.67	m
quadrupole-sextupole spacing	1.0	m

CORRECTION OF THE SPURIOUS DISPERSION

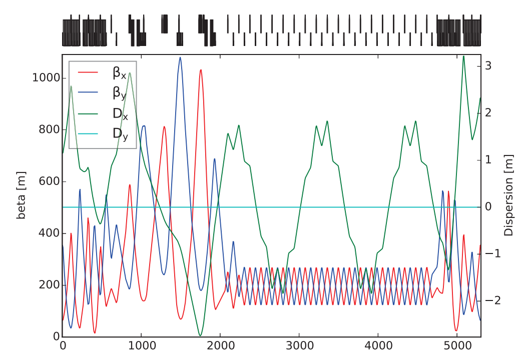
While colliding, the two beams cross with an angle which can reach values up to $P_{\mathrm{Xing}} = \sqrt{\frac{\epsilon_N}{\gamma\beta^*}} \times n_{\mathrm{Xing}}$ where n_{Xing} is the half-crossing angle in sigmas. It is fixed to 7.6, corresponding to an angle of $P_{\mathrm{Xing}} = 46.6\ \mu$rad for the baseline [2]. The orbit excursion in the triplet generates a residual dispersion, which must then be corrected. The studied correction scheme is similar to the one used for HL-LHC [8]: the entrance correctors and exit correctors of the SAR are switched on. The phase advance between the used correctors and the IPs A and G is near 90° modulo 90°. The closed orbit in the SAR quadrupoles generates a dispersion wave which corrects the spurious dispersion. The angles in the correctors are then adjusted to cancel the dispersion at the IPs B, F, H and L. The β beating is finally corrected in the DIS upstream of the left SAR and downstream of the right SAR around the IPs A and G. The chromaticity created by the closed orbit in the SAR is corrected by the sextupoles in the LAR. Before and after correction, we obtain then the closed orbit and the dispersion shown on Fig. 4. The maximum closed orbit in the arcs reaches values up to 8.6 mm/10.9 mm in the



(a) LSS-PA-EXP



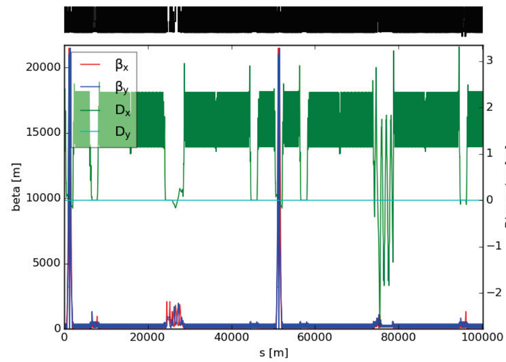
(b) ESS-PD-EXT



(c) ESS-PJ-EXT

Figure 2: Optical functions for the baseline configuration of the insertion regions: experimental section, the betatron and momentum collimation section.

ISBN 978-3-95450-147-2



(a) FCC-hh ring

Figure 3: Optical functions for the baseline configuration of the whole ring.

horizontal/vertical plane. The maximum angle in the correctors is respectively 24.4/24.5 μrad for a horizontal/vertical crossing angle. In the current state, these values are much too large and some solutions must be taken to mitigate these values. The length of the SAR could be enlarged to make the correction more efficient and thus to reduce the needed closed orbit in the SAR. Applying the ATS scheme by using every other sextupole will be investigated in a future study.

CONCLUSION

A status of the first and second order optics of the FCC-hh ring has been given. The correction of the spurious dispersion has been investigated. The proposed scheme is to use the correctors at the entrance and at the exit of the short arcs to generate a perturbation of the closed orbit and then a mitigation of the residual dispersion. In the current state, the amplitude of the orbit in the arc quadrupoles for the spurious dispersion correction cannot be accepted. Some actions must be undertaken to mitigate the orbit like longer short arcs. The correction of the chromaticity is made by two sextupole families. In the future, more advanced schemes like the ATS will be tested to see the impact on the second order terms like the Montague functions.

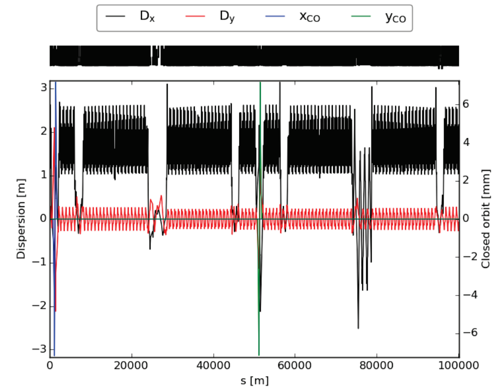
ACKNOWLEDGEMENT

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

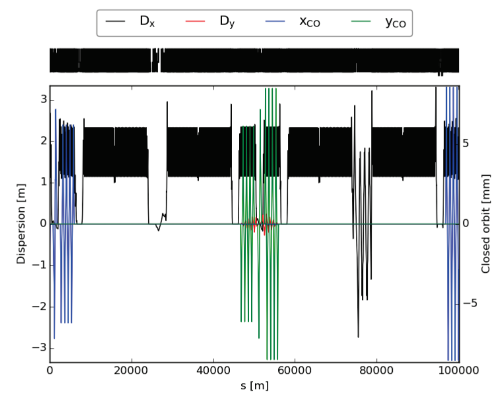
REFERENCES

[1] R. Martin, R. Tomás, and B. Dalena, "Interaction Region for a 100 TeV Proton-Proton Collider," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 1996–1998.

[2] A. S. Langner, "Developments on IR baseline design." presented at the FCC week 2016, Rome, Italy, April 2016, unpublished.



(a) Before correction



(b) After correction

Figure 4: Closed orbit and dispersion in the ring before and after correction of the spurious dispersion in presence of the crossing scheme.

[3] W. Bartmann *et al.*, "Beam Transfer to the FCC-hh Collider from a 3.3 TeV Booster in the LHC Tunnel," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 3901–3903.

[4] T. Kramer *et al.*, "Considerations for the Beam Dump System of a 100 TeV Centre-of-mass FCC hh Collider," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 2132–2134.

[5] J. Molson, P. Bambade, S. Chance, and A. Faus-Golfe, "Simulation of the FCC-hh Collimation System." presented at IPAC'16, Busan, Korea, May 2016, paper TUPMR054, this conference.

[6] A. Chance *et al.*, "First results for a FCC-hh ring optics design," Tech. Rep. CERN-ACC-2015-0035, CERN, Geneva, Apr 2015.

[7] B. Dalena *et al.*, "First Considerations on Beam Optics and Lattice Design for the Future Hadron-Hadron Collider FCC-hh," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 2466–2468.

[8] S. Fartoukh, "Achromatic telescopic squeezing scheme and application to the lhc and its luminosity upgrade," *Phys. Rev. ST Accel. Beams*, vol. 16, p. 111002, Nov 2013.