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FCC-hh FINAL-FOCUS FOR FLAT-BEAMS: PARAMETERS AND ENERGY DEPOSITION STUDIES*

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Abstract

The international Future Circular Collider (FCC) study comprises the study of a new scientific structure in a tunnel of 100 km. This will allow the installation of two accelerators, a 45.6–175 GeV lepton collider and a 100-TeV hadron collider. An optimized design of a final-focus system for the hadron collider is presented here. The new design is more compact and enables unequal β^* in both planes, whose choice is justified here. This is followed by energy deposition studies, where the total dose in the magnets as a consequence of the collision debris is evaluated.

THE FCC HADRON COLLIDER

The FCC hadron collider (FCC-hh) is being studied by the EuroCircol project [1]. The new hadron collider will have two counter rotating beams of 50 TeV each. Figure 1 shows the most recent version of the FCC schematic layout, indicating the four Experimental Interaction Regions (EIR) [2] . Two high luminosity experiments are envisaged at Interaction Points A and G (IPA & IPG) and two Low-Luminosity Interaction Regions, at IPB & IPL.

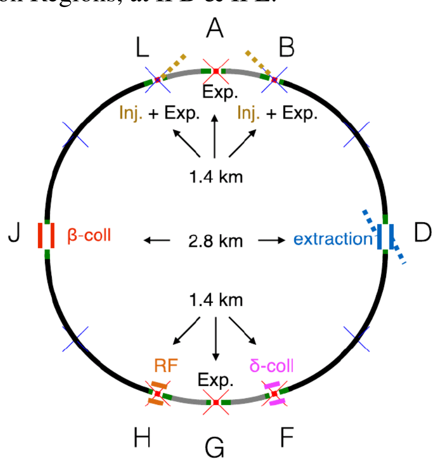

Figure 1: FCC schematic layout, showing the 8 straight sections with their respective length [3]. The total length of the machine is 97.75 km.

FCC-HH FINAL FOCUS SYSTEM

We describe here the work done on the optimization of the final-focus for the main EIR [4]. The final-focus is based on a superconducting triplet and aims at a β^* in the range 0.3 – 1.1 m. The baseline design of the final-focus [5,6] allows for an instantaneous luminosity up to 20 $\cdot 10^{34}$ cm^{-2}s^{-1}. With regard to the integrated luminosity, which is relevant for physics production and for the triplet survival in terms of long term damage, a total of 20-30 ab^{-1} are envisaged.

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ALTERNATIVE FLAT OPTICS

The parameter choice which led to the new final-focus design [7] is presented here. This new design is an alternative to the baseline design. Besides the search for a shorter triplet by means of new optimization techniques [8], the optics is aimed at providing a flat optics. A flat beam optics can increase the luminosity while keeping $\sigma_x^*\sigma_y^*$ and normalized separation [9]. But in addition to that, at 50 TeV, the emittance damping times are on the order of the beam operation. The equilibrium emittance can increase the beam-beam parameter above the maximum tolerated level, making necessary an emittance blow up by means, of, for example, noise injection [10]. However, this reduces the full potential luminosity gain through the consequent beam size reduction. On the other hand, a flat beam optics can reduce the tune shift, so that the emittance compensation to keep ξ below the limit is not needed anymore.

The comparison between the different optics versions is shown in Table 1. This alternative optics can provide flat beam collisions with a β^* ratio of 5. The total tune shifts in Table 1 have been estimated as [11]:

$$\xi = \frac{N r_p}{2\pi\epsilon_N\sqrt{1+\phi^2}}, \tag{1}$$

for round beams and

$$\xi = 2max(\xi_x, \xi_y). \tag{2}$$

for flat beams, where ξ_x and ξ_y represent the horizontal and vertical tune shifts, respectively:

$$\xi_x = \frac{r_p}{2\pi\gamma_r}\frac{N\beta_x^*}{\sigma_x^*\sqrt{1+\phi^2}\left(\sigma_y^* + \sigma_x^*\sqrt{1+\phi^2}\right)}, \tag{3}$$

$$\xi_y = \frac{r_p}{2\pi\gamma_r}\frac{N\beta_y^*}{\sigma_y^*(\sigma_y^* + \sigma_x^*\sqrt{1+\phi^2})}. \tag{4}$$

Here r_p represents the classical radius of the proton and $\sigma_{x,y}^*$ the beam size at the IP. The Lorentz factor is represented as γ_r. For the round beam optics, it has been assumed that the main contribution to the total tune shift comes from the two main EIR, each of them with the beams crossing at different planes: one is horizontal while the other is vertical. The reason for that is the beam-beam compensation scheme.

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Table 1: FCC Parameter Comparison: Bunch Population, Normalized Emittance, Number of Bunches, Horizontal and Vertical Beta Functions, Full Crossing Angle, Piwinski Angle, Geometric Luminosity Reduction Factor, Maximum Total Tune Shift, Initial Luminosity, Peak Luminosity and Average Luminosity per IP

		Optics	
	nominal (round)	ultimate (round)	alternative (flat)
$N[\cdot 10^{11}]$		1.0	
$\epsilon_N [\mu m]$		2.2	
n_b		10600	
σ_s [cm]		8	
β_x^* [m]	1.1	0.3	1.0
β_y^* [m]	1.1	0.3	0.2
θ [μrad]	92	176	96
ϕ	0.55	2.0	0.6
S	0.88	0.45	0.86
$\xi[\cdot 10^{-3}]$	10	11	12
$L[\cdot 10^{34} cm^{-2} s^{-1}]$	5	20	12
$L_{peak}[\cdot 10^{34} cm^{-2} s^{-1}]$	16	30	20
$L_{int}[fb^{-1}/day]$	6	9	8

However, the beam compensation does not work for flat beams and different methods must be used, as for example wire compensation. Therefore, the tune shift for flat beams has been estimated as Eq. (2), assuming that the crossing takes place in the same plane for both IPs. With regard to L_{int}, it has been estimated from simulations taking into account emittance damping and particle burn out. Here the crossing angle has been chosen to get the same for the same normalized separation for round and flat beams. However, recent findings indicate that the separation must be increased for flat beams [12]. This will be taken into account for future studies.

We can see that the flat beam optics leads to a similar values of the integrated luminosity with respect the round, $\beta^* = 0.3$ m optics. The advantage comes here from the lower peak luminosity, that reduces at the same time the event pile up. This and the fact that the initial luminosity is lower, enables a more stable physics production.

TRIPLET AND SHIELDING

The final-focus triplet (Q1-Q2-Q3) has been optimized by reducing its total length [7] and by minimizing the total accumulated dose on the superconducting coils profiting from the flat-beam scenario. As the maximum quadrupole length has been established as 15 m, Q1 and Q3 consists on two units and Q2 on three, so that they can provide the total required focusing power. In these simulations a continuous shielding between the magnets has been assumed. The impact of the split on energy deposition is still to be studied, and it is likely to introduce an increase of the dose at the entrance of each module. The main parameters of the final-focus quadrupoles for this particular alternative design are shown in Table 2.

Table 2: Quadrupole Parameters of the Alternative Final-Focus Triplet: Gradient, Inner Radius (absorber), Absorber thickness and Inner Coil Radius

quadrupole	Q1(×2)	Q2(×3)	Q3(×2)
g [T/m]	106	-111	97
r_i[mm]	46.7	57.7	66.7
Δ_{abs} [mm]	44.2	33.2	24.2
r_c [mm]	98.3	98.3	98.3

A cross section of Q1 is shown in Fig. 2. The absorber, which is located inside the beam pipe, is made of tungsten and its purpose is to shield the coils from the collision debris. The inner radius (r_i) has been calculated to allow for a minimum Beam Stay Clear (BSC) of 21σ. Thanks to the fact that the maximum $\beta-$function decreases moving from Q3 to Q1, r_i can be reduced in Q2 and Q1 while keeping the minimum BSC for the whole triplet. This left additional space to place a thicker absorber. This is not the case for the nominal round optics, where the maximum value of the beta-functions in each quadrupole is approximately the same, especially for Q2 and Q3.

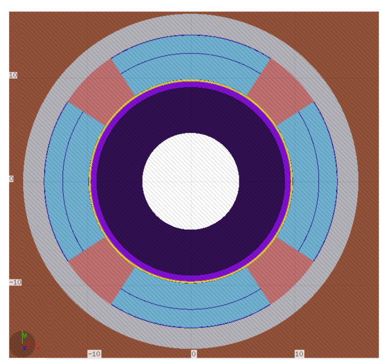

Figure 2: Transverse cross section of inner part of the Q1 in FLUKA model.

ENERGY DEPOSITION STUDIES

The debris coming from the *pp* collisions has been simulated with FLUKA [13, 14] in order to guarantee the triplet survival during the quadrupole life. This was done following the previous energy deposition studies on the baseline triplet [15, 16]. Figure 3 shows the results of the total dose received by Q3 on the alternative triplet. We can see that the transverse dose distribution is not symmetric. For the vertical crossing the peak dose is located on the upper side of the coil. This is due to the fact that in the simulations the collisions take place with a downward vertical crossing angle. The collision debris particles impact Q1 mainly at

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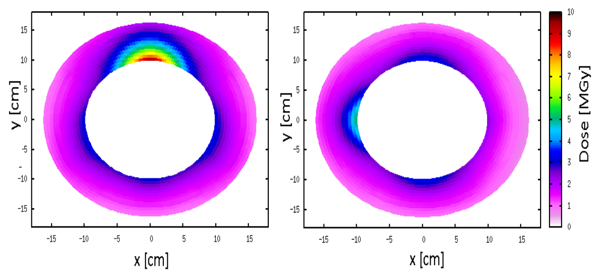

Figure 3: Transverse cross section of the Q3 dose profile on the coils for the vertical (left) and horizontal crossing (right).

-90 degrees, but, because of the effect of the magnetic field of the triplet quadrupoles, the angular position of this peak changes along the triplet and it appears at 90 degrees in Q3. For the horizontal crossing the situation is very similar, with the peak dose in the left part of the magnet coil.

Figure 4 shows the maximum dose in the triplet along the longitudinal axis. In order to decouple the dose from the integrated luminosity, it is normalized to 10 inverse attobarn. The maximum normalized dose is shown for each crossing scheme. The results are very similar for both schemes, with the exception of Q3, where the vertical gets more dose.

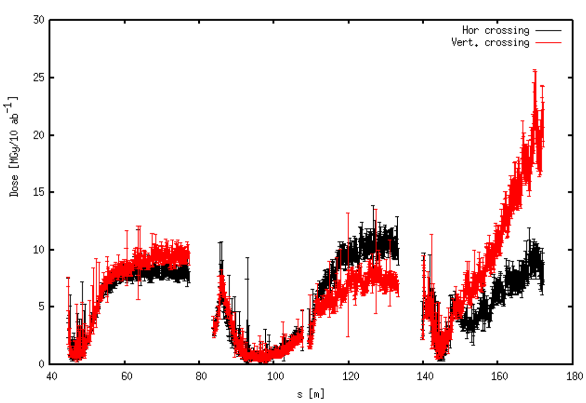

Figure 4: Peak dose profile in MGy per 10 inverse attobarn in the alternative flat optics.

Round optics

This triplet has been optimized for flat optics, but it is also capable of performing the ultimate round optics in Table 1, by only rematching to the arc [7]. A different set of simulations was done for this configuration, whose results are summarized in Fig. 5. In this case, the maximum peak dose is higher than for flat-beams due to the larger crossing angle, as this influences the spread of the collision debris.

Dose mitigation

For Q1-Q3 and the flat-beam configuration, the maximum peak dose is below 15 MGy. For Q3 the dose is higher. The reason is that the absorber is thinner as the β is larger than for the other quadrupoles.

Due to the fact that the peak dose is found to be at different angular positions of the transverse plane (Fig. 3), it can be reduced by alternating the crossing scheme [15]. This can be done by establishing collisions in each plane 50 % of the time. This is shown in Fig. 6 for the flat and round simulations. The maximum peak dose is found to be below 15 MGy for the flat optics, and below 25 MGy for the round one. Further reductions could be done, if needed, like alternating the orientation of the vertical crossing (that cannot be done for the horizontal plane). In any case the energy deposition studies show an acceptable dose, specially for the flat beam optics, which is below 45 MGy for the whole foreseen data-taking of 30 ab^{-1}.

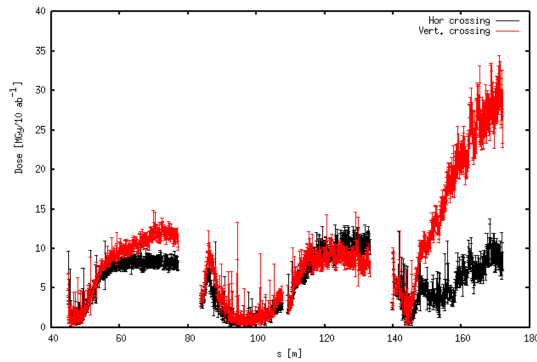

Figure 5: Peak dose profile in MGy per 10 inverse attobarn in the alternative flat optics for the round configuration.

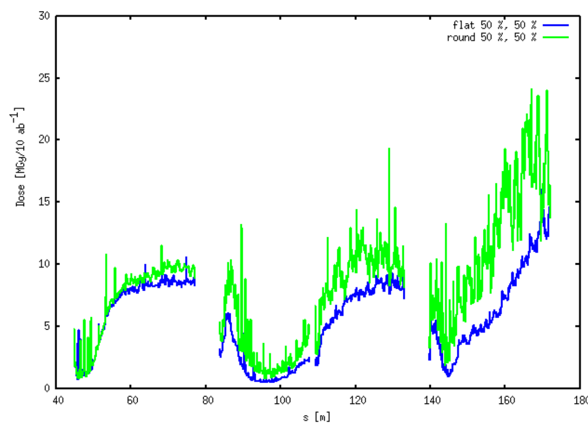

Figure 6: Peak dose profile in MGy per 10 inverse attobarn combined.

CONCLUSION

A choice for a first FCC flat optics parameters is made. In particular, it offers a significant reduction in L_{peak} with respect to the ultimate optics, as well as a more stable physics production with a minor loss in integrated luminosity and without any need, in principle, for tune shift control. The new triplet can provide the required parameters for the flat optics, as well as those needed for the round optics. It was optimized for the flat-beam performance, and it offers the lowest dose for this scheme, which can be further improved by alternating crossing plane. This is a very promising option for the FCC-hh final-focus optimization, and it will be worked in the future.

ACKNOWLEDGEMENT

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REFERENCES

[1] EuroCircol Collaboration, http://www.eurocircol.eu

[2] A. Seryi *et al.*, "Overview of Design Development of FCC-hh Experimental Interaction Regions", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper TUPUA040, this conference.

[3] A. Chancé *et al.*, "Updates on the Optics of the Future Hadron-Hadron Collider", presented at IPAC'17, Copenhagen, Denmark, May 2017, TUPVA002, this conference.

[4] A. Langner *et al.*, "Developments on IR baseline design", presented at FCC Week'16, Rome, Italy, May 2016.

[5] R. Martin, "IR/FF optics", EIR WP3 meeting,4 April 2017, https://indico.cern.ch/event/627884/.

[6] R. Martin, M. I. Besana, F. Cerutti *et al.*, "Interaction Regiom Design driven by Energy Deposition", submitted for publication, 2017.

[7] L. van Riesen-Haupt *et al.*, "Exploring the Triplet Parameter Space to Optimise the Final Focus of the FCC-hh", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper TUPVA041, this conference.

[8] L. van Riesen-Haupt *et al.*, "A Code for Optimazing Triplet Layout", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper TUPVA043, this conference.

[9] J.L. Abelleira, "Optics Designs of Final-Focus Systems for Future LHC Upgrades", Ph.D. thesis, EPFL, Lausanne, Switzerland, 2014, pp. 40–41.

[10] M. Benedikt, D.Schulte, and F. Zimmermann, "Optimizing integrated luminosity of future hadron colliders", Phys. Rev. ST Accel. Beams **18**, p. 101002, Oct. 2015.

[11] J.L. Abelleira, "Optics Designs of Final-Focus Systems for Future LHC Upgrades", Ph.D. thesis, EPFL, Lausanne, Switzerland, 2014, pp. 22–23.

[12] J. Barranco García *et al.*, "Beam-Beam Studies for FCC-hh" presented at IPAC'17, Copenhagen, Denmark, May 2017, paper TUPVA043, this conference.

[13] A. Ferrari, P.R. Sala, A. Fassò, and J. Ranft, "FLUKA: a multi-particle transport code", Rep. CERN-2005-10, INFN/TC 05/11, SLAC-R-773, Oct. 2005.

[14] G.Battistoni *et al.*, "Overview of the FLUKA code", Annals of Nuclear Energy, vol. 82, pp. 10-18, Aug. 2015.

[15] M.I. Besana *et al.*, "Assessment and Mitigation of the Proton-Proton Collision Debris Impact on the FCC Triplet"', in *Proc. IPAC'16*, Busan, Korea, May 2016, paper TUPMW004, pp 1410-1414.

[16] R. Martin *et al.*, "Radiation Load Optimization in the Final Focus System of FCC-hh", in *Proc. IPAC'16*, Busan, Korea, May 2016, paper TUPMW018, pp 1462-1466.

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