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PUBLICATION

Preliminary EIR design Baseline: Deliverable D3.2

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DELIVERABLE REPORT

PRELIMINARY EIR DESIGN BASELINE

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Abstract:

Description of the EIR baseline design including a list of beamline elements (type, description, quantity, physical element characteristics). Estimates of the achievable performances at the interaction points. Description of the assumptions taken, requirements and constraints imposed onto the infrastructure and infrastructure services.

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Delivery Slip

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TABLE OF CONTENTS

1. EIR BASELINE DESIGN

The FCC-hh Experimental Interaction Region optics features SC triplets with distance between the IP and the first quadrupole equal to L*=40m. This distance has recently been changed from the previous value (of 45m) in order to achieve the overall optimization balance between the total length of EIR and the length of other sub-systems of FCC-hh.

1.1. MAIN EIR BASELINE DESIGN

The EIR optics now has two versions which have different triplets, based on different approaches to their optimization. The performances of the two designs appear quite similar at this stage of the studies. The first design, which is presently considered the baseline is shown in the figure below. The total length of the main EIR baseline optics is 1.4km.

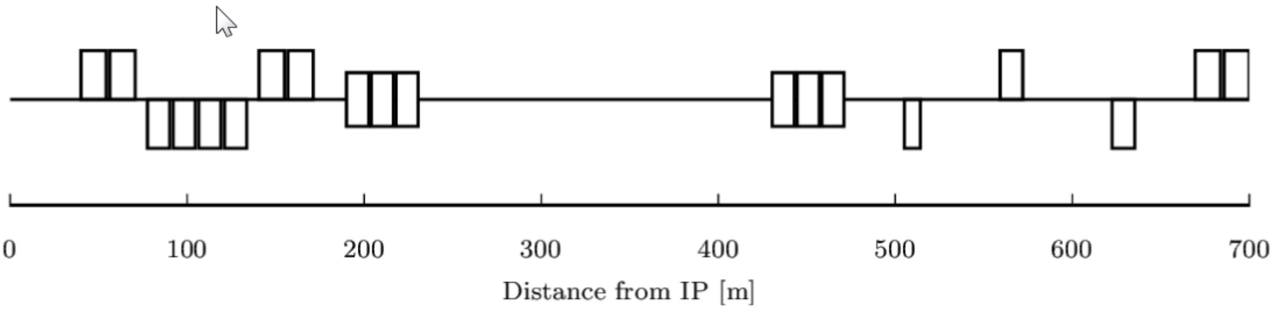

Figure 1: EIR layout of the main baseline (R. Martin et al, https://indico.cern.ch/event/656067/)

The parameters of the triplet corresponding to the baseline shown in Figure 1 are shown in the table below.

Table 1: Triplet parameters of the main baseline EIR optics

Magnet	Length [m]	Maximum gradient [T/m]	Inner Diameter [mm]	Number
Q1	14.3	130	164	8
Q2	12.5	105	210	16
Q3	14.3	105	210	8

The optics of the main baseline EIR optics is shown below in Figure 2.

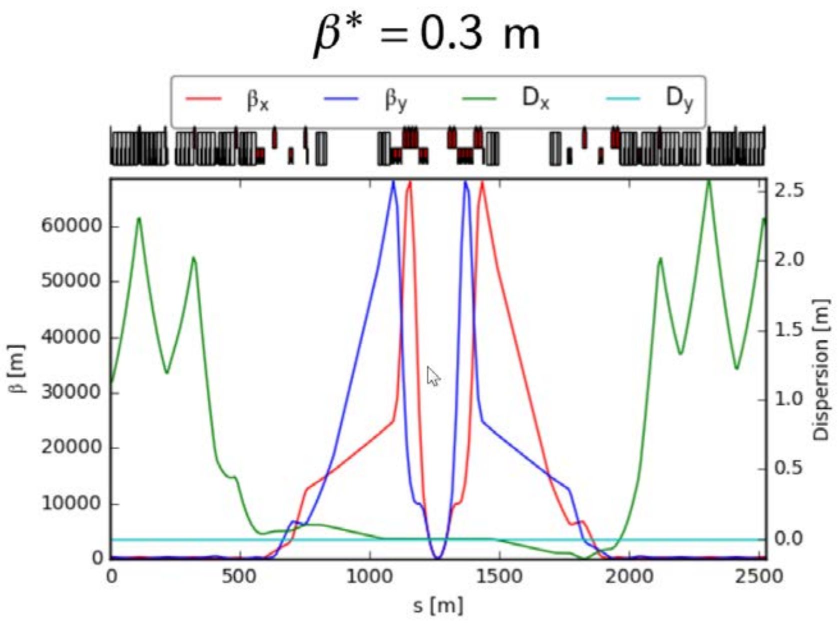

Figure 2: Twiss functions of the main baseline EIR optics

The optics includes space of 20 m reserved for crab cavities. The quadrupoles of the SC triplet include internal shielding, sufficient for ensuring their radiation protection. The separation dipoles (shown in Figure 1) are assumed to be normal conductive.

1.2. ALTERNATIVE EIR BASELINE DESIGN

The alternative EIR baseline has a different triplet, optimized with slightly different constraints. The performance comparison of the two designs is presently ongoing, and should be finalized for the Conceptual Design Report. The triplet in this case, in contrast to the previous 2-4-2 layout (which corresponds to the number of sub-units of Q1, Q2 and Q3 quads), corresponds to the 2-3-2 layout as shown in Table 2 below.

Table 2: Parameters of the triplet of the alternative EIR baseline. L. van Riesen-Haupt et al (https://indico.cern.ch/event/660616/)

Quadrupole	Sub Quads	Length	Coil Radius	Shielding	$k \times m^2$	Gradient	Aperture
Q1	2	15 m	96.5 mm	44.2 mm	0.000647	108 T/m	41 mm
Q2	3	15 m	96.5 mm	33.2 mm	-0.000674	112 T/m	52 mm
Q3	2	15 m	96.5 mm	24.2 mm	0.000590	95 T/m	61 mm

Moreover, the triplet is optimized in this case in such a way, that each quadrupole has the same radius of the coil and same length, so that each of the quadrupoles can be identical (except for shielding thickness) easing the manufacturing process. The optics of this design is shown in Figure 3 below.

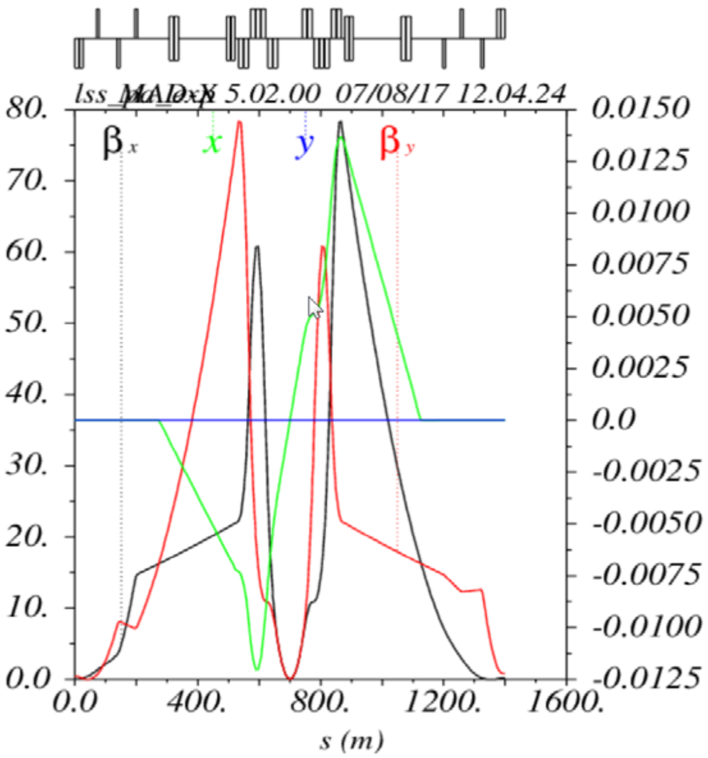

Figure 3: Optics of the alternative baseline of EIR

1.3. LOW LUMINOSITY EIR DESIGN

The optics of low-luminosity EIRs, where FF is co-located with injection, has to take into account requirements arising in particular from the need to protect cold elements from miss-kicked injected beams, which impose additional constraints on phase advance and reduce optics flexibility.

The optics design that accommodates all known requirements features L* of 25m, which was suggested by the detector design group, and beta* of 3m. The triplet layout and its parameters are shown in Figure 4 below.

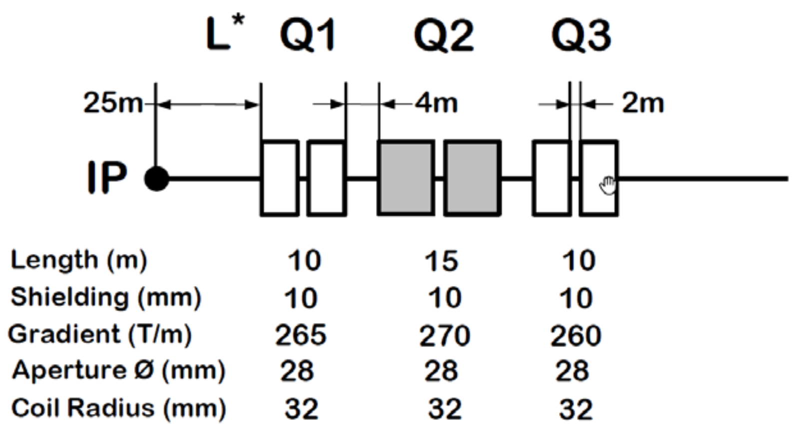

Figure 4: Layout of low luminosity EIR triplet and its main parameters, M. Hofer et al (https://indico.cern.ch/event/660616/)

2. IR PERFORMANCE ESTIMATES

Performance of EIR is estimated from a number of points of view. First of all, EIR optics is evaluated from the point of view of beta* reach, i.e. the smallest beta function that still provides that the required beam-stay-clear of 15.5 sigmas, taking into account the triplet apertures as well as the inner triplet shielding, and the needed crossing angle value. Next, the energy deposition studies are performed in the triplet, to ensure that the triplet shielding and the target absorbers provide adequate lifetime of the triplet. Next, the adequacy of nonlinear correctors and the ability to maintain large enough Dynamic Aperture (DA) is evaluated and optimized. The beam-beam studies as well as their effects on luminosity and on DA are them performed, together with evaluation of the methods to mitigate beam-beam effects. Backgrounds, such as synchrotron radiation or beam losses, including cross-talk between IPs (via muons or scattered protons), is then evaluated. As many of these evaluation steps are cross-dependant, the design process involves many iterations of design optimization. Below, we briefly summarize the main performance characteristics of the presented designs.

2.1. KEY PERFORMANCE CHARACTERISTICS

The main baseline EIR optics can safely reach beta* of 0.3m as specified by the "ultimate" design parameters and can also reach beyond that, namely down to beta* 0.2m, using the "thick" shielding option of 38mm that leaves 15.5 sigmas of beam stay clear.

The alternative baseline EIR have similar beta* reach – the nominal "ultimate" 0.3m as well as beyond – 0.2 m beta* which is reached with beam stay clear of 16.4 sigma. This design was also optimized for the so-called "flat beam" option. This has beta* of 0.15 x 1.2 meters and would not rely on use of crab cavities. The beam stay clear in this case is 20.2 sigmas.

The optics of the low luminosity EIR with beta* of 3m, with half-crossing angle of 19 μrad and with the triplet parameters shown in Figure 5 can achieve beam stay clear of about 15 sigma.

The energy deposition studies, performed for both designs have shown that the triplets can survive at least one or likely several high luminosity runs (one high luminosity run corresponds to 5 inverse attobarns), which is based on the present limit of 30 MGy dose. This is illustrated in Fig. 4 below. There are still some spikes of the dose in the beginning of some quadrupoles of the triplet, which could be further minimized out with some additional inter-quad shielding, if necessary.

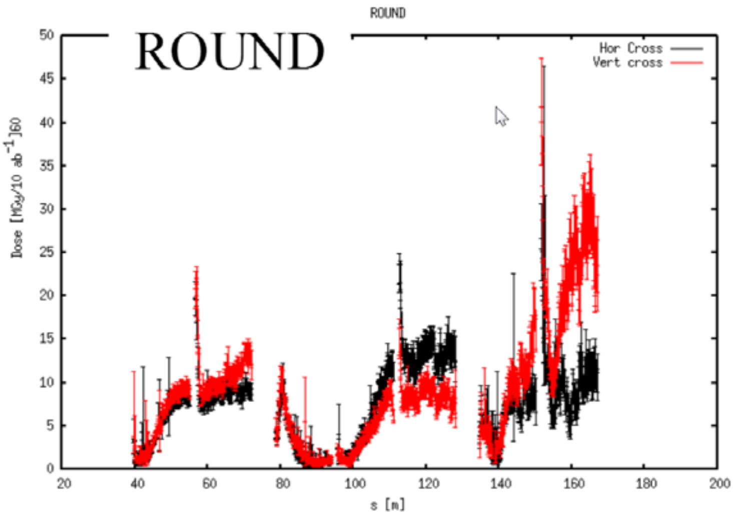

Figure 5: Example of energy deposition for alternative EIR baseline, for round optics and for two high luminosity runs (10 ab-1) J. Abelleira et al (https://indico.cern.ch/event/660616/)

The additional experiments are separated from the main experiment in insertion A by short arcs. These arcs need to be long enough to avoid that important background from the experiment in A reaches the other experiments. Hence, the relevant cross-talk between EIRs, via elastic and inelastic protons, and via muons, has been studied. It was found in particular that the proton cross-talk, while manageable, has implications on the collimation system design, which is being taken into account. The muon cross-talk, with the present separation between the nearest EIRs, was found negligible.

Background from synchrotron radiation (SR) photons emitted by protons in and on the way to the EIRs has been studied. It was found that while the SR power emitted in the last four bending magnets upstream the IP is of the order of 100 W, the fraction of this power that enters the experiment area, defined as the space between the TAS absorbers, is only around 10 W, out of which only about 1 W is expected to hit the +-8 m long inner Beryllium pipe. Most of the photons will be absorbed in this pipe, while just less than 1 photon per bunch with an energy of the order of 1 KeV will traverse the Be pipe towards the experiments, making this background source not a concern.

Optimization of dynamic aperture (DA) of FCC-hh have been performed ongoing, taking into account errors in the main dipoles of the arcs as well as nonlinear errors in the EIR inner triplets and possible nonlinear corrections in EIR. From one hand, there is good understanding now how the DA depends on the overall ring optics and phase advance between IPs, allowing to achieve large enough DA without and with nonlinear correctors. From the other hand, the recently modified design of the main dipoles (with reduce inter-beam distance) increased the errors by about an order of magnitude, making DA not sufficient at injection and requiring another iteration of design with the magnet team, which is ongoing.

Dynamic aperture has been studied for the full FCC optics of the previous version together with beam-beam effects. For these studies only two main EIRs have been taken into account. Assuming an alternating horizontal and vertical crossing scheme to profit from the passive compensation of the long-range tune and chromaticity shifts, it was found that the DA of 6-7 sigmas is ensured for a half crossing angle of 90-100 μrad resulting in a separation of 14.5 sigmas at the first long-range encounter. These results confirm the baseline scenario choices but highlight the fact that no margins are left for the negative effects of multipolar errors, Landau octupoles spread, high chromaticity operation and for the two low luminosity EIRs. Detailed studies of the beam-beam effects, including the most recent optics with L* of 40m, as well as for the flat optics (that lacks the passive compensation and thus would require a slightly larger crossing angle), for the low luminosity EIRs, as well as long-range beam-beam compensation with octupoles, are ongoing.

3. CONCLUSIONS

The FCC-hh EIR has been designed and its performance meet the expectations imposed by the overall parameters of the collider. The team is performing final design optimization and comparison of design alternatives and is getting ready to document the state of the design in FCC CDR.

4. REFERENCES

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- 22 Jun 2017, https://indico.cern.ch/event/648418/
- 27 Jul 2017, https://indico.cern.ch/event/656067/
- 01 Sep 2017, https://indico.cern.ch/event/660616/
- 21 Sep 2017, https://indico.cern.ch/event/667293/
- 06 Oct 2017, https://indico.cern.ch/event/664239/

EuroCirCol meeting

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- TUPVA040, A. Seryi at al, Overview of Design Development of FCC-hh Experimental Interaction Regions - http://inspirehep.net/record/1626415
- TUPVA002, A. Chance et al., Updates on the Optics of the Future Hadron-Hadron Collider FCC-hh - http://inspirehep.net/record/1626340
- TUPVA043, L. van Riesen-Haupt, A Code for Optimising Triplet Layout - http://inspirehep.net/record/1627008
- TUPVA041, L. van Riesen-Haupt, A. Seryi, R. Tomas, Exploring the Triplet Parameter Space to Optimise the Final Focus of the FCC - http://inspirehep.net/record/1626416
- TUPVA003, B. Dalena et al, Advance on Dynamic Aperture at Injection for FCC-hh
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- TUPVA037, J. Abelleira, L. van Riesen-Haupt, FCC-hh Final-Focus for flat-beams: parameters and energy deposition studies - http://inspirehep.net/record/1626435
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- TUPVA027, J. Barranco, et al., Study of Beam-Beam Long Range Compensation With Octupoles - http://inspirehep.net/record/1626433

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Interaction region design driven by energy deposition, Roman Martin, Maria Ilaria Besana, Francesco Cerutti, Andy Langner, Rogelio Tomás, Emilia Cruz-Alaniz, and Barbara Dalena Phys. Rev. Accel. Beams 20, 081005 – Published 30 August 2017
https://journals.aps.org/prab/issues/20/8

5. ANNEX GLOSSARY

SI units and formatting according to standard ISO 80000-1 on quantities and units are used throughout this document where applicable.

Acronym	**Definition**
ATS	Achromatic Telescopic Squeezing
BPM	Beam Position Monitor
c.m.	Centre of Mass
DA	Dynamic Aperture
DIS	Dispersion suppressor
EIR	Experimental Interaction Region
ESS	Extended Straight Section
FCC	Future Circular Collider
FCC-ee	Electron-positron Collider within the Future Circular Collider study
FCC-hh	Hadron Collider within the Future Circular Collider study
FODO	Focusing and defocusing quadrupole lenses in alternating order
H1	Beam running in the clockwise direction in the collider ring
H2	Beam running in the anti-clockwise direction in the collider ring
HL-LHC	High Luminosity – Large Hadron Collider
IP	Interaction Point
IPA/IPG	Interaction Points housing the two main experiments
LHC	Large Hadron Collider
LAR	Long arc
LSS	Long Straight Section
MBA	Multi-Bend Achromat
Nb_3Sn	Niobium-tin, a metallic chemical compound, superconductor
Nb-Ti	Niobium-titanium, a superconducting alloy
RF	Radio Frequency
RMS	Root Mean Square
σ	RMS size
SAR	Short arc
SR	Synchrotron Radiation
SSC TAS	Superconducting Super Collider Target Absorber Secondaries
TSS	Technical Straight Section