EIR key component functional design specifications for perliminary Baseline: Milestone M3.4

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MILESTONE REPORT

EIR KEY COMPONENT FUNCTIONAL DESIGN SPECIFICATIONS FOR PRELIMINARY BASELINE

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Abstract:

Report on the list of key accelerator elements for the collider experimental insertion region and its functional design properties, based on the existing preliminary EIR design baseline. The report indicates also the foreseen quantities and constraints on the infrastructure (e.g. experiment cavern and machine-detector-interface elements) so to permit coming to an overall cost estimate of the collider.

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Delivery Slip

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TABLE OF CONTENTS

1. LIST OF KEY ACCELERATOR ELEMENTS FOR THE COLLIDER EIR

1.1. MAGNETS

The final focus triplet is central to the performance of the collider. FCC-hh features two high luminosity EIRs and two low luminosity EIRs with individual magnet parameters each. Furthermore the high luminosity EIRs have a baseline design with round beam that require crab cavities to compensate the luminosity reduction due to crossing angles, and an alternative design compatible with flat beam in case crab cavities cannot be realised. The relevant magnet parameters for the single aperture triplet magnets are shown in Table 1 to 3

Table 1: Baseline triplet parameters of the high luminosity EIRs.

Magnet	Length [m]	Maximum Gradient [T/m]	Inner coil diameter [mm]	Number	Shielding thickness [mm]
Q1	14.3	130	164	8	35
Q2	12.5	105	210	16	35
Q3	14.3	105	210	8	35

Table 2: Alternative triplet parameters of the high luminosity EIRs.

Magnet	Length [m]	Maximum Gradient [T/m]	Inner coil diameter [mm]	Number	Shielding thickness [mm]
Q1	15.0	108	193.2	8	44
Q2	15.0	112	193.2	12	33
Q3	15.0	98.5	193.2	8	24

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Table 3: Triplet parameters of the low luminosity EIRs

Magnet	Length [m]	Maximum Gradient [T/m]	Inner coil diameter [mm]	Number	Shielding thickness [mm]
Q1	10.0	265	64	8	10
Q2	15.0	270	64	8	10
Q3	10.0	260	64	8	10

The cryostats of the triplet quadrupoles will have to be designed so they can support thick and consequently heavy shielding inside the coil apertures. It should be noted that the required number given in the tables corresponds to the number of magnets needed for operation, it does not include a spare policy nor replacements that might become necessary due to radiation damage. However, simulations of collision debris suggest that the low luminosity triplet can withstand the whole integrated lifetime luminosity of 5 ab^{-1}, while the high luminosity triplets have to be exchanged not more than once per 30 ab^{-1} if at all. The latter will depend on the survivable dose of the coil insulator, as well as the effectiveness of several mitigation strategies currently being worked on. These strategies include regular changes of the crossing plane and a specifically designed Q1 magnet. The crossing plane alternation will require a hardware exchange of the crab cavities.

In addition to the triplet, the high luminosity EIRs have four double aperture matching quadrupoles on each side of the IP. The low luminosity EIRs use adjacent injection section to match the optics, so they only include 4 matching quadrupoles on one side of the IP and two on the other side.

Table 4: Parameters of the matching section quadrupoles

Magnet family	Length [m]	Maximum gradient [T/m]	Aperture diameter [mm]	Number
MQY	9.1	200	70	8
MQYL	12.8	260	60	8
MQML	12.8	300	50	8
MQM	14.3	400	50	8

Not included in Table 4 are the magnets of the injection section as indicated in Figure 1, or the dispersion suppressors. The possible maximum gradient of the MQM magnets is currently being reassessed. It should be possible to replace the 8 MQM type magnets by 12 shorter and slightly weaker quadrupoles.

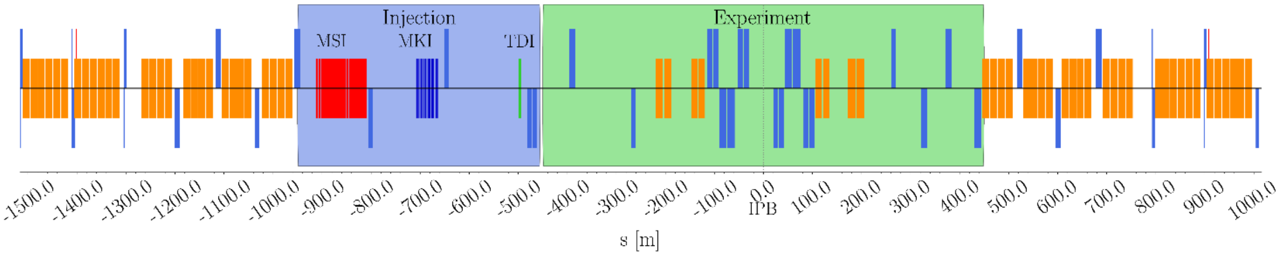

Figure 1: Layout of the low luminosity EIR. Only the experimental part (highlighted in green) is considered in this report

Behind the triplet region, the two counterrotating beams are separated by single aperture dipoles D1 and then brought back into parallel orbits with double aperture recombination dipoles, D2. In the case of the high luminosity EIRs, normal conducting dipoles, similar to the MBXW and MBW designs of the LHC, were chosen because of the radiative environment and because they can provide better field quality. In the low luminosity EIRs, space is limited because the straight section is shared with the injection. Consequently, superconducting dipoles with ambitious field strengths were chosen.

Table 5: Magnet parameters of the high luminosity EIR separation and recombination dipoles

Magnet	Length [m]	Field strength [T]	Aperture diameter [mm]	Number
D1	11.3	2	170	16
D2	11.3	2	91	16

Table 6: Magnet parameters of the low luminosity EIR separation and recombination dipoles

Magnet	**Length [m]**	**Field strength [T]**	**Coil aperture diameter [mm]**	**Number**
D1	12.5	12	100	8
D2	15.0	10	60	8

Orbit corrector magnets are required in the EIRs to provide crossing angles at the interaction points and to keep residual orbit excursions low. In the triplet regions, single aperture orbit correctors with nested coils (horizontal/vertical deflection) are needed. The high luminosity EIR features 3 of these magnets per side and per IP. Furthermore 5 double aperture orbit correctors per side, per IP are needed. The low luminosity EIR lattice does not yet have all correctors installed. Assuming a similar need as in the high luminosity EIR and excluding the orbit correctors placed in the injection section, a **total of 24 single aperture, nested coil orbit correctors** and **34 double aperture orbit correctors** are required.

In the high luminosity EIRs a single aperture, non-linear corrector package is required on each side of the IP, including skew quadrupole, sextupole, skew sextupole, octupole, skew octupole and dodecapole correctors. **In total, 4 corrector magnets of each kind** are needed, in addition to **4 double aperture skew quadrupole correctors.**

1.2. BEAM POSITION MONITORS

The high luminosity EIR features 3 aperture BPMs in the shared triplet region per side and per IP as well as 4 BPMs in the matching section per side, per IP and per beam. Assuming similar numbers again for the low luminosity EIRs and excluding the injection section, **a total of 80 BPMs** is needed.

1.3. CRAB CAVITIES

Initial studies with crab cavities show that a crab voltage of 12 MV per beam on either side of each high luminosity IP is needed to provide full crabbing in ultimate optics, corresponding to **96 MV in total**. Half of this voltage must be horizontally deflecting in one EIR, the other half vertically deflecting in the other EIR. For optics beyond ultimate parameters, the crab voltage increases up to 8x18.5 MV. Following a direct scaling from the HL-LHC lattice, 20 m of space were allocated for the crab cavities on each side of the two main IPs. No detailed studies on number of cavities or cryostat design were done yet. It should be noted that a radiation mitigation strategy to protect the triplet is to change the crossing plane on the two main IPs at least once during the lifetime. This will also require an exchange of the crab cavities (horizontally/vertically deflecting). Since IPA and IPG will always run with different crossing planes, it should be possible to simply exchange the hardware between the two main IPs during a shutdown. This should be taken into account when designing the cryostats and RF connections. If this proves to be impractical, parts of the required hardware will have to be doubled.

2. INFRASTRUCTURE

2.1. MACHINE-DETECTOR-INTERFACE

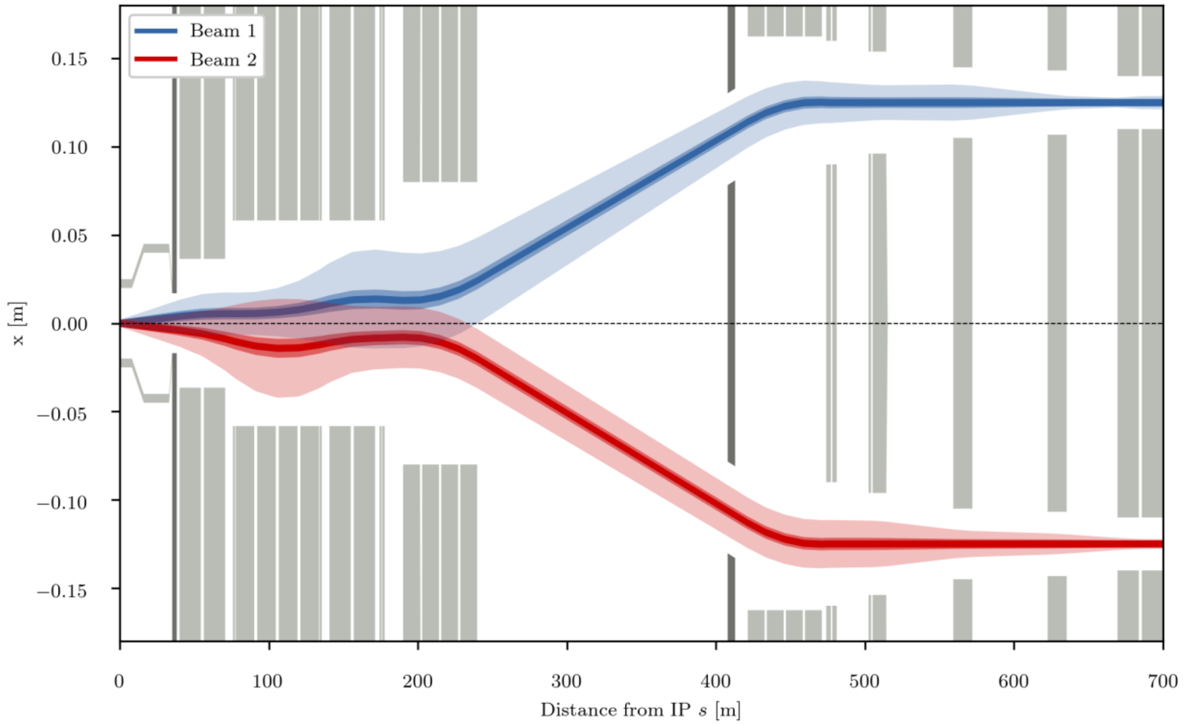

Figure 2: High luminosity EIR apertures. Magnets are depicted in light gray, absorbers in dark gray. At s<40 mthe detector beam pipe is shown.

The only machine-detector interface elements considered so far are the experimental beam pipe and absorbers for the collision debris of the high luminosity EIR. The material and shape of the experimental beam pipe are mandated by the needs of the detector. It comprises of a 0.8 mm thick beryllium beam pipe with 40 mm aperture diameter extending to 8 m on either side of the interaction point, followed by an 8 m long conical aluminum beam pipe with an inner diameter increasing to 80 mm. From s = 16 m to s = 33 m a straight Al beam pipe with 80 mm diameter is needed, after which a short conical cone reduce the aperture to the 34 mm diameter of the TAS absorber. For the low luminosity EIR, no beam pipe requirements are known so far.

The absorbers include the TAS placed before the first final focus quadrupole to capture most of the secondary particles, as well as the TAN, situated in front of the recombination dipole D2, protecting it from neutral particles from the IP. Studies of the collision debris suggest that TAS and TAN will be exposed to 26 kW and 112 kW of radiation power respectively (**values per element** with **4 TAS and 4 TAN elements required in total**). The study also found 6 kW heat load in the cold mass of the triplet and 45 kW in the cold shielding of the triplet magnets (values per side, per IP). Adequate cooling facilities to compensate these heat loads must be available.

In the case of the low luminosity EIR, a simple tungsten mask is sufficient to protect the triplet magnets. As the D2 recombination magnet is superconducting, a TAN will also be required, but no studies on heat load or needed specifications have been done so far.

2.2. EXPERIMENTAL CAVERNS AND TUNNEL

The dimensions of the experimental caverns are governed by the needs of the experiments. A cavern length of 66 m is required for the opening of the detectors. Apart from the beam pipe, no accelerator elements are currently foreseen to be placed inside the cavern.

For the HL-LHC, caverns housing the klystron galleries are foreseen few meters above the crab cavities. For the baseline FCC-hh design, similar cavities will be required. No further details on requirements of technical galleries, access galleries or similar infrastructure have been collected so far.

2.3. POWER SUPPLIES

At this point, only a general estimates of the magnet power supplies can be given. In the case of the matching quadrupoles it is safe to assume that all magnets and both apertures per magnet are individually powered. The exception is Q7 (MQM magnet family) which consists of two submagnets due to length constraints. Consequently **56 matching quadrupole power supplies are required in total** for all the matching sections. Specifications of the power supplies like current and power cannot be given at this point.

In the case of the triplets and separation/recombination magnets the technical details have not yet been addressed. It should e.g. be possible to power the D1/D2 dipoles together with a single power supply. Similarly, a single triplet could have a single main power supply but this would require additional trim power supplies. Additionally both triplets of one IP could be powered together.

Further power supplies will be required for orbit correctors and non-linear corrector magnets close to the triplets in the high luminosity EIRs. Seeing that the single aperture orbit correctors have nested coils while the double aperture orbit correctors have two independently powered apertures, a **total of 116 orbit corrector power supplies**.
For the **non-linear and skew correctors 32 power supplies** are foreseen.

3. CONCLUSIONS

Specification for the magnets in the EIRs are provided, together with the required numbers, not including spares or replacements. Estimates for the expected replacements of the triplet magnets are given. Requirements for the crab cavities are provided in terms of crab cavity voltage.

The machine relevant machine-detector interface is currently limited to the detector beam pipe and absorbers. The energy deposition from collision debris on the absorbers and cold mass requires an adequate cooling system.

The experimental cavern layout is given by the detector design, no requirements from the machine are imposed. However the crab cavities are expected to require galleries for the klystrons, similar to HL-LHC.

First estimates for the minimum number of magnet power supplies and beam position monitors are provided.

4. REFERENCES

Baseline triplet magnets, crab cavity voltage:

R. Martin et al., “Experimental Insertions”, FCC week 2018, https://indico.cern.ch/event/656491/contributions/2923542/

Alternative triplet magnets:

Jose Abelleira et al., “Flat beam alternative”, FCC week 2018, https://indico.cern.ch/event/656491/contributions/2930727/

Energy deposition, heat load and survivable dose:

F. Cerutti et al., “Beam loss studies in IP”, FCC week 2018, https://indico.cern.ch/event/656491/contributions/2930726/

Low luminosity IR:

M. Hofer et al., “3.3 TeV beam injection into combined experimental and injection FCC machine insertions”, FCC week 2017, https://indico.cern.ch/event/556692/contributions/2484269/

5. ANNEX GLOSSARY

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

ATS	Achromatic Telescopic Squeezing
BPM	Beam Position Monitor
c.m.	Centre of Mass
DA	Dynamic Aperture
DIS	Dispersion suppressor
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
IR	Interaction Region
LHC	Large Hadron Collider
LLIR	Low Luminosity Interaction Region
LAR	Long arc
LSS	Long Straight Section
MBA	Multi-Bend Achromat
MIR	Main Interaction Region
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	Superconducting Super Collider
TSS	Technical Straight Section