CONCEPTUAL DESIGN CONSIDERATIONS FOR THE 50 TeV FCC BEAM DUMP INSERTION

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Abstract

Safely extracting and absorbing the 50 TeV proton beams of the FCC-hh collider will be a major challenge. In the preliminary concept two extended straight sections (ESS) are dedicated to beam dumping system and collimation. The beam dumping system will fast-extract the beam and transport it to an external absorber, while the collimation system will protect the superconducting accelerator components installed further downstream. The high stored beam energy of about 8.5 GJ per beam means that machine protection considerations will severely constrain the functional design of the ESS and the beam dump line geometry, in addition to dominating the performance specifications of the main sub-systems like kickers and absorber blocks. The general features, including concept choice, optics in the ESS and beam dump line, passive protection devices, layout and integration are described and discussed.

FCC BEAM PARAMETERS

The European Strategy for Particle Physics started a design study for a potential high-energy frontier circular collider at CERN for the post-LHC era, the so-called Future Circular Collider (FCC) [1]. Two extended straight sections (ESS) each with a length of 4.2 km will be used to host the most critical systems concerning machine protection: extraction and collimation. A table with the main beam parameters of the FCC hadron accelerator can be found in Table 1.

Table 1: FCC Beam Parameters

Beam momentum	3.3 - 50 TeV/c
Number of bunches	10600
Bunch intensity	1E11
Stored beam energy	8.5 GJ

GENERAL LAYOUT OF THE EXTENDED STRAIGHT SECTION

In the baseline for the extended straight section the extraction system is followed by the betatron collimation system on one beam. The momentum collimation is located on the other beam. This is schematically shown in Fig. 1. The disadvantage of this solution is the impact of momentum collimation showers on the sensitive kicker elements on the other beam. An alternative configuration is shown in Fig. 2. In this case both extractions will be located in the same straight section. Betatron and momentum collimation will be placed in the opposite ESS.

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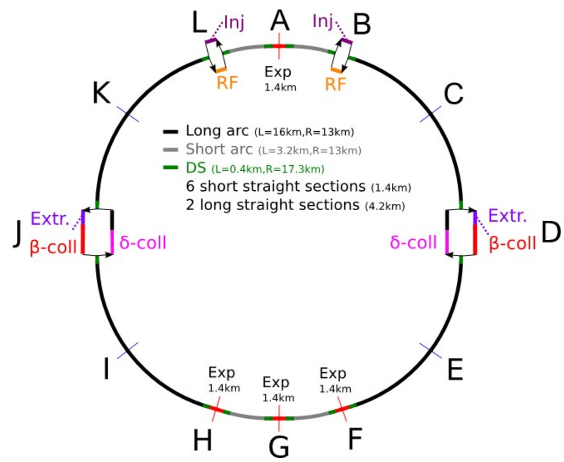

Figure 1: Initial baseline concept of the FCC ring with extraction and collimation in the same ESS (J and D).

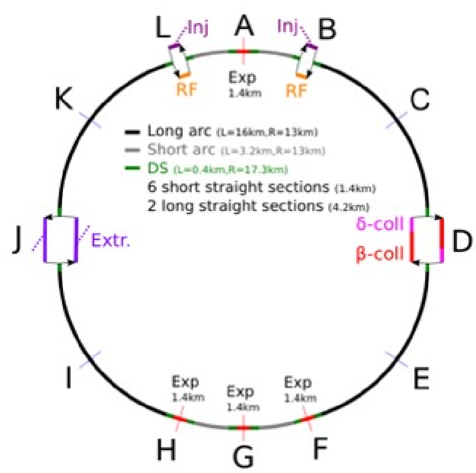

Figure 2: Alternative layout with both extractions in the same straight section (J). Betatron and momentum collimation will be placed in the opposite ESS (D).

DESIGN OF THE EXTRACTION

The design of the extraction system is driven by the required protection against failure cases, e.g. asynchronous beam dump. As the impact of only a single bunch at 50 TeV in present LHC absorber materials can cause localized material damage it is required for non-sacrificial absorbers to separate bunches in the O(mm) on the absorbers for a given beam size of a few 100 μm. These requirements push the septum as far downstream as possible to get more distance to the extraction kicker. In addition the optics of the extraction has to be pushed to high beta functions in both planes at the

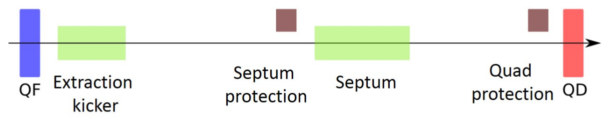

Figure 3: Schematic layout of the extraction system. The extraction kicker and the septum are marked in green, extraction protection absorbers for septum and QD are marked in brown, in addition the focussing (QF) and de-focussing (QD) quadrupole magnets are shown.

absorbers. For safe beam operation at least two absorbers are needed, the septum protection to protect the septum blade and the QD protection to protect the superconducting quadrupole magnet further downstream. A schematic layout is shown in Fig. 3. The extraction kicker and the septum are marked in green, the absorbers are marked in brown, in addition the focussing (QF) and de-focussing (QD) quadrupole magnets are shown [2].

Extraction Kickers

As the bunch separation on the absorbers plays a major role in case of a failure, the rise time of the extraction kicker should be as short as possible. For FCC extraction the field rise time is assumed to be in the order of 1 μs. The extraction kicker system has a total length of ~ 120 m and provides a total deflection angle of 0.13 μrad at top energy. This moderate deflection and the highly segmented system (~ 300 units) of low complexity helps for reaching a very short rise time and a small beam perturbation in case of single module failure [3]. Small beta function in the bending plane of the kicker would open the possibility not to retrigger the full system in case one of the 300 units is pre-firing, as the beam would only get a distortion of ~ 1 sigma from the kick of a single module. This option would significantly reduce the probability of an asynchronous beam dump. The corresponding pulse generator might be placed close to the magnet in the tunnel, therefore the influence of showers from the momentum collimations system onto the highly sensitive controls electronics is currently under investigation. The results will give an estimate for the required shielding, or show the necessity to locate the dump system in a separate ESS from the collimation systems.

Septum

The baseline for the septum is a high-field Lambertson with 2 T. In case of normal conducting technology this element will have a huge power consumption. A staged approach with ~ 10 m normal conducting followed by a superconducting septum is under study. The septum blade thickness will be in the order of 25 mm. The integrated field of 400 Tm (2.4 mrad deflection) will assume full clearance of the quadrupole cryostat (500 mm diameter) further downstream. Investigations are ongoing to use a triple chamber quadrupole to pass the extracted beam through the cryostat which would significantly reduce the kick strength for the septum.

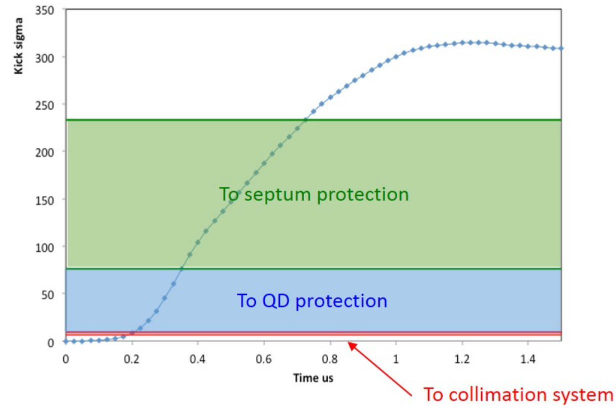

Figure 4: Schematic of the load on the different elements in the case of an asynchronous beam dump as a function of kick angle. The bunches will be swept across the collimators, quadrupole and septum protection absorbers.

Passive Protection Elements

During an asynchronous dump, which can arise e.g. from a failure of the synchronization system, a filled abort gap or an extraction kicker module pre-fire and a retrigger of the remaining kickers, the bunches will be miskicked and swept across collimators and absorbers. The load on the different elements as a function of the kick angle is schematically shown in Fig. 4. The survival of an asynchronous dump is a dominant consideration in the design of FCC extraction insertion. As a 25 ns bunch contains 0.8 MJ energy, with a density of 100 MJ/mm^2 (factor 25 higher than LHC) at extraction optics. There is a clear need for physical protection devices (septum and QD) to intercept swept bunches and prevent damage for the downstream accelerator components. Ideally these absorbers survive a beam impact but a sacrificial design will be considered as well. The septum protection will be placed ~ 10 m upstream of the septum blade. To protect the first quadrupole after extraction an absorber will be installed ~ 10 m upstream of the QD. The need for additional protection elements to protect further downstream quadrupoles is currently under study [4].

Optics

As mentioned above, the optics design for extraction is mainly driven by the requirement of high beta at the absorbers of min. 800 m and a low beta function in bending plane (below 250 m) at the extraction kicker. The option of further increasing the beta function at the absorbers would envisage using large aperture quads and, if needed, ramping optics between injection energy (big beam size, less critical for absorbers) and flattop (smaller beams, most critical for absorbers). The optics for the extraction is shown in Fig. 5. The matching from the arc optics can be possibly shifted in the dispersion suppressor. The cell after the extraction can be used for additional absorbers and for matching the optics to the requirements of the collimation system.

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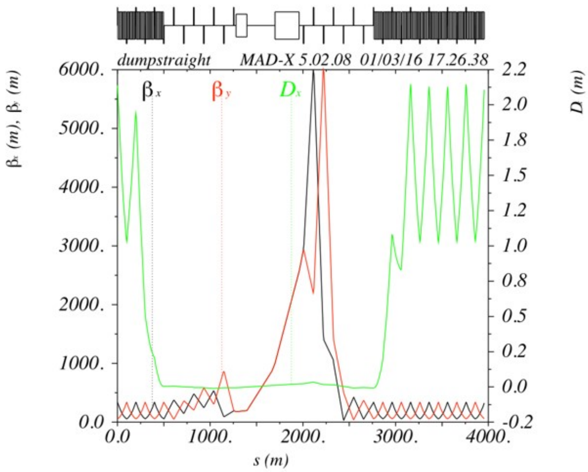

Figure 5: Optics for extraction with high betas at the absorbers and low beta function in the bending plane of the extraction kicker.

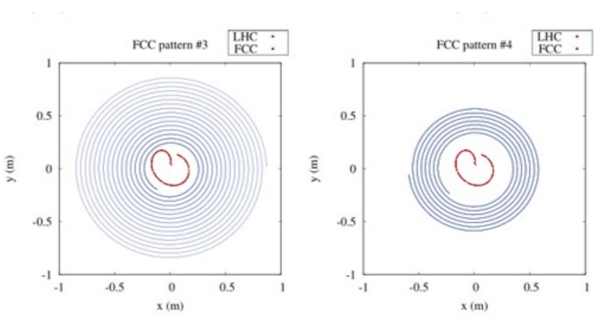

Figure 6: FCC dilution pattern (blue) in comparison the LHC ones (red). The one on the left side uses a fixed frequency of the dilution kicker, the right one uses a frequency sweep in the dilution kickers, leading to a reduced maximum kick strength but a higher complexity of the system.

Dilution Kicker Requirements and Beam Dump Line

To reduce the energy deposition density on the beam dump block the bunch impact positions have to be swept. This requires a highly demanding dilution kicker system [3]. FLUKA simulation showed that the bunches must be separated by min. 1.8 mm and neighboring branches of the spiral by ~ 4 cm [5]. This leads to a maximum deflection of ~ 60 - 70 cm on the beam dump block. Examples of the dilution pattern on the dump are shown in Fig. 6. A typical LHC dilution pattern is shown in red, the blue dots indicate an FCC dilution pattern. The one on the left side uses a fixed frequency of the dilution kickers, where as the right one uses a frequency sweep in the dilution kickers, leading to a reduced required maximum kick strength but a higher complexity of the system. Options to ease the hardware requirements by implementing an over-focussing quadrupole in the dump line are under study. For a feasible kick strength of the dilution kickers the assumed dump line length is about 2.5 km.

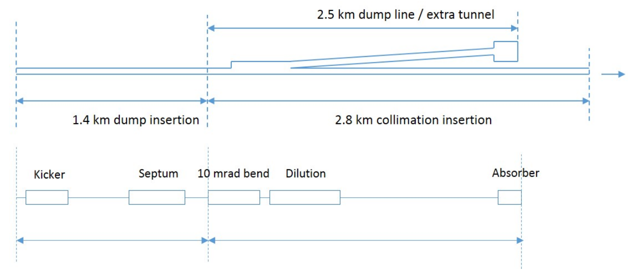

Figure 7: Integration of the extraction system in the ESS. A bending magnet in the dump line downstream of the septum bends the extracted beam into an extra dump tunnel with a length of 2.5 km. The MKBs will be placed in this tunnel.

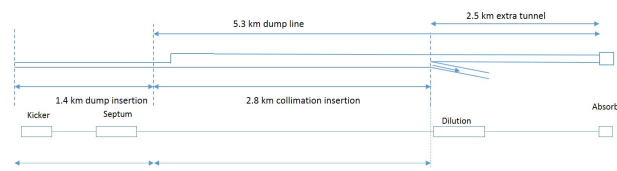

Figure 8: Alternative option for integration without bending magnet. The dump line will go through the collimation area going to an extra dump tunnel at the beginning of the arc.

INTEGRATION

In the ESS extraction this is followed by the betatron collimation. Two options for integration are shown in Fig. 7 and 8. In the first option a bending magnet in the dump line bends the extracted beam into an extra dump tunnel with a length of 2.5 km. The MKBs will be placed in this tunnel providing extra shielding to the MKB electronics. In the second option the dump line will go through the collimation area to an extra tunnel at the beginning of the arc. Also in this case the MKBs will be placed in the extra tunnel.

CONCLUSION

A preliminary conceptual design of the FCC-hh dump system has been investigated, with technically feasible subsystem parameters. The absorber limits drive the design. The requirements for the extraction kicker were reduced, due to the fact that the challenge lies in reliability. The optics were designed for absorbers and asynchronous beam dump. Beam dilution on the dump block leads to a challenging dilution kicker system. Radiation to electronics plays a major role for the integration of the elements in the tunnel, and will probably require a new layout with the dump system completely separated from the collimation systems. Further studies concerning impact of radiation to kicker electronics, damage limits for protection devices and additional absorbers further downstream are needed. In addition the optimization of dilution patterns and integration of collimation and extraction in the ESS will be continued.

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