14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPL061

FCC-EE ARC HALF-CELL: PRELIMINARY DESIGN & INTEGRATION STUDIES, WITH IDEAS FOR A MOCK-UP

F. Carra#[1], L. Baudin[1], J. Bauche[1], K. Artoos[1], S. Atieh[1], A. Bertarelli[1], O. Brunner[1], O. Capatina[1], A. Chance[2], S. Chemli[1], J.P. Corso[1], J. Coupard[1], B. Dalena[1,2], M. Di Castro[1], J. Etheridge[1], C. Garion[1], S. Grillot[1], T. Guillén-Hernández[1], M. Guinchard[1], K. Hanke[1], C. J. Eriksson[1], R. Kersevan[1], R. Losito[1], H. Mainaud Durand[1], W. Niewiem[1], K. Oide[1], J. Osborne[1], A. Piccini[1], T. Raubenheimer[3], S. Rorison[1], C. Tetrault[1], M. Timmins[1], J.-P. Tock[1], F. Valchkova-Georgieva[4], L. Von Freeden[1], F. Zimmermann[1].
[1]CERN, Geneva, Switzerland
[2]Atomic Energy and Alternative Energies Commission, Gif-sur-Yvette, France
[3] SLAC National Accelerator Laboratory, Menlo Park, California, United States of America
[4]Foselev Suisse SA, 1214 Vernier, Switzerland

Abstract

During 2022, a dedicated study was undertaken at CERN, together with the FCC Feasibility Study collaborators, to propose a robust configuration for the FCC-ee arc half-cell. The proposed layout considers integration aspects of the elements in the arc cross section, both for the booster and the collider, as well as aspects related to powering, cooling and ventilation, supporting and alignment, optics, instrumentation, handling and installation. The interfaces between the arc elements and the straight sections have also been analysed. This paper summarizes the main conclusions of the assessment and reports the preliminary engineering analyses performed to design the supporting system of the booster and of the collider. A proposal for a possible mock-up of the arc half-cell, to be built at CERN in the next years, is also presented.

INTRODUCTION

The current layout of the FCC-ee considers a circumference of about 90 km [1]. 85% of these, *i.e.* about 77 km, are taken by the arcs, which count almost 3000 half-cells, in the FCC-ee Zh / $t\bar{t}$ configuration [2]. The arc half-cell is the most repeated region of mechanical hardware in the tunnel. For this reason, within the FCC Feasibility Study, the construction of a half-cell mock-up at CERN is proposed, with the goal of testing aspects related to fabrication, integration, assembly, transport, installation, alignment, stability, inspection and maintenance. The mock-up configuration will feature a tunnel region including the booster and the collider magnets and vacuum system, their supporting structures, as well as the main services.

Preliminary design and integration studies on the arc region were performed in 2022, with the goal of defining an optimized configuration in terms of integration, maintenance, safety, transport, support stability, radiation, and compatibility with an FCC-hh machine. This configuration can then be adopted as a baseline for the arc half-cell mock-up.

#federico.carra@cern.ch

BOOSTER-COLLIDER RELATIVE PLACEMENT IN THE ARCS

The placement of the booster and of the collider must be optimized in the radial and vertical directions of the tunnel's cross-section, with a hard constraint of a maximum tunnel diameter of 5.5 m, as well as in the azimuthal direction. Regarding the tunnel cross section, as also explained in [3], an optimized configuration with respect to those presented in [4] consists of placing the booster on top of the collider. This frees up more space for the services, especially the cooling and ventilation piping, the transport vehicles and the alignment system (Figure 1).

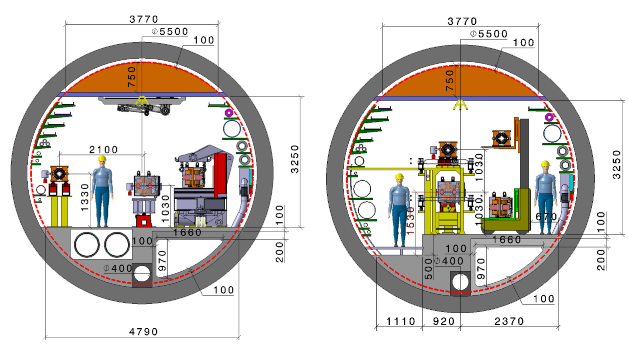

Figure 1. Configurations for the relative placement between booster and collider. Left: horizontal configuration. Right: vertical configuration.

On top of being more compact, the vertical configuration provides further advantages:

- Permits smaller tunnel diameters in the RF sections.
- Same basement configuration as FCC-hh.
- Easier access for handling and removal of booster magnets and Short-Straight Sections (SSS).
- Better from radiation point of view, as the highest dose is generated on the outer side of the tunnel, and this could be detrimental to the outer (booster) ring in case of a horizontal placement [5].

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPL061

A potential issue of the vertical placement of the booster is a poor dynamic stability: due to the longer lever arm ground-to-magnet, the booster would oscillate more, exceeding the tight dynamic positioning tolerances, particularly in the SSS region. Due to vibration cross-talk between booster and collider, it also worsens the collider stability. For this reason, a significant effort in design and simulations was made in 2022 to improve the supporting system and maximize the stability of the two accelerators.

DYNAMIC STABILITY AND VIBRATIONS

The first solution found to improve the booster stability in a vertical configuration is to minimize the height of its centre of mass, while allowing enough clearance with the collider underneath. This could be done by azimuthally shifting the SSS of the collider with respect to the SSS of the booster, keeping the cell periodicity (*i.e.* the shift azimuthally imposed to the booster SSS with respect to the collider SSS is maintained constant along the ring). In fact, the SSS is, for both machines, the bulkiest section of the arc. With the proposed modification, the SSS of the collider will be positioned, azimuthally, in correspondence of the small and compact booster dipoles, and *vice versa* (Figure 2).

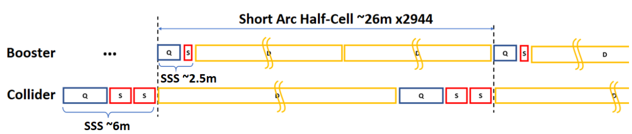

Figure 2. Azimuthal shift between booster and collider.

Moreover, several design iterations were performed to stiffen the supports of the booster. The evolution of the design is shown in Figure 3.

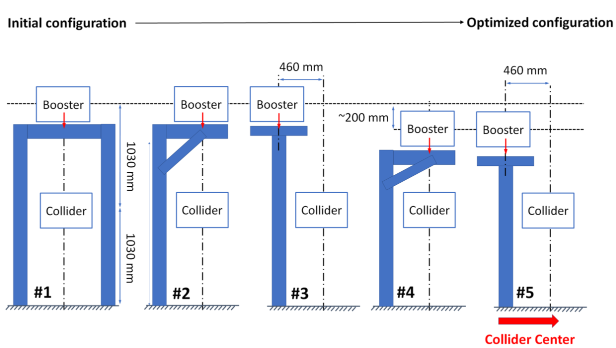

Figure 3. Principles of optimization of the booster placement and supporting system.

A summary of the evaluation process for the various supporting systems is given below:

1. Modal analysis and evaluation of the eigenfrequencies (results in Table 1).
2. Definition of a baseline based on the results of step 1.
3. Addition of the booster magnets to the model and evaluation of the transfer function ground to magnetic axis.
4. Random vibration analysis using as input a reasonable footprint of the expected ground motion, see for example [6].
5. Addition of the collider magnets to the model to evaluate vibrational crosstalk.
6. Comparison of the results of step 6, in terms of booster and collider oscillation, with the dynamic stability requirements (summarized in [7]).

Table 1. Natural frequencies of the booster support in different configurations.

Mode	Booster support configuration *(see Figure 3)*				
	#1	#2	#3	#4	#5
Longitudinal	7 Hz	18 Hz	24 Hz	21 Hz	29 Hz
Torsional	7 Hz	19 Hz	23 Hz	29 Hz	29 Hz
Flexural	14 Hz	36 Hz	41 Hz	40 Hz	54 Hz

The longitudinal mode is reported for reference, even though it is not particularly relevant for this study, as it does not generate vertical/horizontal displacements which would affect the dynamic stability of the supports. It should also be noted that, currently, the design of the booster magnets is very preliminary. For this reason, a conservative value for the mass of the booster magnets was assumed in the calculations (2.5 tons).

We are currently in step 3 of the evaluation process; however, the studies performed so far already allowed the construction of a 3D model of the arc half-cell, shown in Figure 4 (length is about 20 m). This model is based on the configuration #4, and will be updated to configuration #5 (better from stability point of view) if the ongoing integration study [3] will confirm that there is enough horizontal space for a 460 mm shift of the booster with respect to the collider.

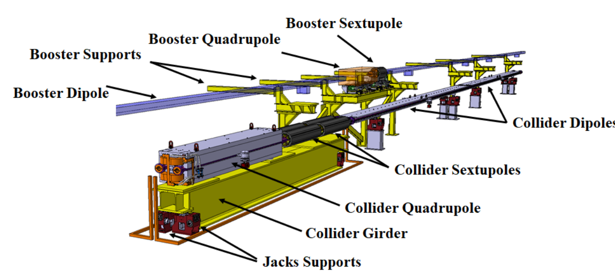

Figure 4. CAD model of arc cell, with focus on the Short Straight Section.

CONFIGURATION OF THE SHORT STRAIGHT SECTIONS

The principles for assembling, installing, aligning and maintaining the elements in the SSS of booster and collider on their supporting system were extensively analyzed.

The use of girders to support the common elements in the SSS provides significant practical advantages. The SSS elements, magnets and vacuum chambers can be pre-assembled and pre-aligned on a girder in a clean room outside the tunnel, with proper tools and environment. In this case, it is possible to design splitable magnets, allowing insertion of a single vacuum chamber before closing the upper half of the magnets. A single vacuum

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPL061

chamber for one SSS decreases the number of bellows, with important benefits on RF impedance [8], cost and reliability. The entire SSS module (girder + quadrupole + sextupoles and vacuum system) can then be transported as one single object to the tunnel, optimizing the transport and maintenance operations. “Hot spares” of SSS modules can be stored and rapidly prepared for installation in case of fault. Repair can then be done in proper conditions on surface. Finally, a pre-alignment on surface reduces the time to be spent in the tunnel for final alignment, with also positive effects on the beam-based alignment requirements (weaker trims if a good pre-alignment is already done).

A potential disadvantage of a girder is that, usually, it requires more space, vertically, than, for example, a supporting system with standard jacks for each SSS magnet. This means that the vertical position of the accelerators would be higher, with possible detrimental effect on the dynamic stability at the level of the beam axis. It is therefore important to maximize the girder stability by optimizing the design and materials, for example with biologically-inspired casting structures, damping materials and increased number of supports / wedges (Figure 5).

Figure 5. Top left: steel girder for SLS, courtesy M. Wurm (PSI). Top right: granite girder for SwissFEL, courtesy J. Wickstroem (PSI). Bottom: cast girder for PETRA IV [9].

ARC HALF-CELL MOCK-UP

The interest and goals for the construction of a physical arc half-cell mock-up were described above. A preliminary proposal for a mock-up configuration is given below, keeping in mind that cost-efficiency is an important parameter. The following considerations can be made:

- The mock-up should be considered a living, upgradable testing platform;
- The cross-section should be in a 1:1 scale (Ø5.5m);
- The functional length (*e.g.* length of the mock-up including functional systems) could be reduced with respect to a standard half-cell, however:
- Increasing lengths for the tunnel envelope can be explored to reproduce singularities in the ring such as vacuum sectorization, fire compartmentation, alcoves, diameter variations, interface with RF regions, etc.
- The SSS should be considered as the core of the mock-up in terms of functionality of its elements, allowing to test installation, alignment, static and dynamic stability, integration and maintenance.

A preliminary mock-up layout is sketched in Figure 6.

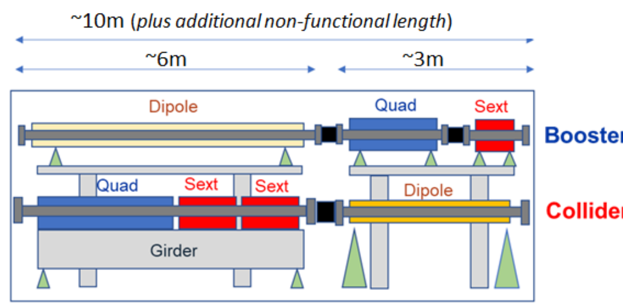

Figure 6. Preliminary proposal for an arc-half cell mock-up layout.

CONCLUSIONS

In 2022, a design and integration study was performed to optimize the configuration of the FCC-ee arc half-cell layout. In particular, the aspects related to the accelerator’s relative positioning, supporting principles, and stability, have been presented in this paper. A possible configuration for an arc-half cell mock-up at CERN was also proposed and discussed. The goal is to design, fabricate and install such mock-up to allow an important return of experience in view of the next update of the European Strategy for Particle Physics.

ACKNOWLEDGEMENTS

The authors express their thanks to the Arc Half-Cell Senior Advisory Committee (F. Bertinelli, P. Fessia, F. Lackner, P. Raimondi, J. Wickstroem) and M. Wurm, for the precious feedback and constructive discussions on the solutions presented in this paper.

REFERENCES

[1] M. Benedikt, “FCC Feasibility Study Status”. Presentation given at the FCCIS Workshop, https://indico.cern.ch/event/1203316, CERN, Geneva, Switzerland, 2022.
[2] T. Raubenheimer, “FCC Accelerator status and R&D beyond FCCIS”. Presentation given at the FCCIS Workshop, https://indico.cern.ch/event/1203316, CERN, Geneva, Switzerland, 2022.
[3] J.-P. Corso, K. Hanke, F. Valchkova-Georgieva, “Challenges and Solutions in the Integration Studies

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPL061

of the Future Circular Collider", submitted to IPAC'23, Venice, Italy, 2023.

[4] A. Abada, M. Abbrescia, S. S. AbdusSalam *et al.*, "FCC-ee: The Lepton Collider. Future Circular Collider Conceptual Design Report Volume 2", Eur. Phys. J. Special Topics 228, 261–623, 2019. https://doi.org/10.1140/epjst/e2019-900045-4.

[5] B. Humann, "Synchrotron radiation studies for the FCC-ee arc with FLUKA". Presentation given at the FCC Week 2021, https://indico.cern.ch/event/995850/, Online Event, 2021.

[6] K. Artoos *et al.*, "Ground Vibration and Coherence Length Measurements for the CLIC Nano-Stabilization Studies". Proc. PAC09, Vancouver, Canada, 2009.

[7] F. Carra, "Functional Specifications". Presentation given at the FCC-ee Arc Half-Cell Mock-up Meeting, https://indico.cern.ch/event/1224422/, 22nd November 2022.

[8] M. Migliorati, "Single-beam collective effects: overview and impedance update". Presentation given at the FCC Week 2022, https://indico.cern.ch/event/1064327/, Paris, France, 2022.

[9] S. Andresen, N. Meyners, D. Thoden, "Innovative and Biologically Inspired PETRA IV Girder Design". Presentation given at the 11th International Conference on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation, 10013/epic.5aa33692-9342-4ddc-8f6c-f5ef30815874, Online Event, 2021.