Optimizing the FCC-hh Hadron Collider

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Abstract

The Future Circular Collider integrated project foresees, as a first stage, a high-luminosity electron-positron collider (FCC-ee) [1], which would afterwards be followed by a 100 TeV hadron collider (FCC-hh) [2] installed in the same tunnel. The interplay between measurements at the two collider stages maximizes the FCC physics results [3]. Here we propose a further optimisation of the hadron-collider accelerator design to improve performance, reduce overall length (and cost), and ensure continued compatibility with the FCC-ee lepton collider, as the design of the latter evolves.

Most of the major recent discoveries in particle physics (Z, W, and Higgs bosons, and the top quark) have required high-energy hadron colliders. In this context, increasing the mass reach by almost an order of magnitude and increasing the luminosity by a factor of 30 with respect to the LHC (a factor of 5 with respect to the HL-LHC) play a crucial role in being able to access a large range of new physics opportunities [3]. The conceptual design for a future hadron collider achieving these objectives, the FCC-hh, has recently been published.

The key technology of FCC-hh is high-field superconducting magnets. The FCC-hh Conceptual Design Report [2] assumes 16 T dipole magnets based on Nb_3Sn technology. The principle feasibility of such dipole magnets has been all but demonstrated, e.g. by a recent short model magnet at FNAL [5]. Primary aims for the hadron collider magnet R&D program include the development of highly performant Nb_3Sn wire – e.g. via the introduction of artificial pinning centers – determining the optimum magnet concept (e.g. cos theta, block coil, common coil, canted cos theta), reducing the cost of these magnets and ensuring an adequate field quality. In view of the time scale of the integrated FCC project and the potential development of HTS magnet technology over this period, also aspects such as the impact of higher main bending fields (i.e. higher than 16 T) or higher IR quadrupole fields on the machine design, beam dynamics and performance should be investigated. The interaction region could be further optimized with regard to radiation shielding, triplet correction and the possible use of HTS magnet technology.

The FCC-hh CDR foresees using the LHC at 3.3 TeV as injector for the FCC-hh. An attractive alternative, which could be further explored, is the injection from a new fast-ramping superconducting SPS, at an energy of, e.g. around 1.3 TeV.

The longest straight section of the FCC-hh, with a length of 2.8 km, is allocated for betatron collimation. Reducing the length of the collimation section, to e.g. 2.2 km, would be of interest to improve the symmetry and super-periodicity of the collider layout, and to possibly achieve a better match with the evolving layout of the lepton collider, that might conceivably feature more than two interaction points. Higher super-periodicity could also benefit the beam dynamics (dynamic aperture, beam-beam limit) of the hadron collider, which would need to be further investigated.

In parallel to the betatron collimation also the beam extraction section should be shortened (e.g. by installing a longer extraction septum, and more extraction kickers). The machine protection system and failure modes will need to be reevaluated for the new layout.

Presently, the transverse distance between the e^+e^- and pp collision points is about 11 m. The separation is due to the asymmetric interaction-region layout and the large crossing angle of the lepton collider. Reducing this distance, potentially also by "smart" changes in the FCC-hh layout (changing the end point of the arc and possibly integrating bending magnets into the final focusing systems, also allowing for a partly local chromatic correction), would be of interest to reduce the size of the detector cavern and to enable a modular approach for the detector construction, so that the FCC-ee detector, or portions of it, could later be expanded or converted into the FCC-hh detector [6].

Issues requiring further studies and accelerator optimization include the following:

1. Shortening the length of the betatron collimation system (presently 2.8 km).
2. Layout/geometry modifications to reduce the transverse distance between the FCC-hh and FCC-ee collision points; studies of the importance of super-periodicity and the associated tolerances.
3. Development of cost-efficient 16 T dipole magnets with acceptable field errors.
4. Studies and developments of alternative injector scenarios, e.g. injection from a superconducting SPS and elaboration of all the implications.
5. Optimization and review of the injector complex.
6. Machine protection and radiation issues (further optimisation of the interaction region; shortening of extraction section; failure scenarios; etc.).
7. Further RF design and development of FCC-hh crab cavities.
8. Design for maximum energy efficiency.

This list is certainly incomplete. Technical design contributions from the Snowmass and greater US community to these and other studies will be most welcome!
It is expected that, starting with the lepton collider FCC-ee, the new accelerator infrastructure would serve the world-wide particle-physics community in a synergetic and cost-effective manner throughout the 21st century, as envisaged in the Future Circular Collider integrated project plan [4].

References

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