Future Circular Collider

PUBLICATION

Recommended Accelerator follow-up R&D: Milestone M2.6

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MILESTONE REPORT

RECOMMENDED ACCELERATOR FOLLOW-UP R&D

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Abstract:

This milestone documents the gaps between the results of the particle collider conceptual design study and the level of detail required to enter a project construction preparatory phase. This document establishes a portfolio of suggested R&D topics related to the domain of particle collider design and associated technologies that need to be addressed with high priority in a follow-up project in order to come to a consistent and coherent design on which a project construction preparation can be based.

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TABLE OF CONTENTS

1. PARTICLE COLLIDER DESIGN 4

1.1. MOTIVATION 4
1.2. OBJECTIVES 4
1.3. DESCRIPTION OF WORK 5
1.4. COLLABORATION WITH UNIVERSITIES AND RESEARCH CENTRES 5
1.5. COLLABORATION WITH INDUSTRIAL PARTNERS 6

1. PARTICLE COLLIDER DESIGN

1.1. MOTIVATION

The EuroCirCol project has developed a complete layout, beam optics and conceptual design for a future circular energy frontier hadron collider (FCC-hh), aiming at providing proton-proton collisions at 100 TeV in the centre of mass. The feasibility of the collider optics, in particular for the experimental interaction region and other functionally relevant insertions (four interaction points, injection, extraction, collimation), has been verified using a diverse set of complementary analytical and simulation tools. The results have been documented in a conceptual design report volume (D1.5).

The FCC-hh design has been developed considering the needs of the hadron collider only. Those were considered the pivotal for the feasibility of a 100 km long particle collider. **Considering the long-term physics programme that such a research infrastructure can offer and making best use of the investments, a staged implementation is seriously being considered, in which at first a lepton collider is installed in the tunnel that would later host the hadron collider.**

While the principle feasibility of the energy-frontier hadron collider could be shown thanks to the EuroCirCol project, fitting a highest-luminosity lepton collider (FCC-ee) into the existing layout would currently only be possible with two electron-positron interaction points and with performance trade-offs. For this and other related reasons, the maximum theoretically attainable performance of such a lepton collider cannot be achieved with the current layout, which was chosen in view of the hadron collider only.

Consequently, an immediate priority for follow-up R&D is revising the current particle accelerator layout and its placement with the goal to arrive at a layout which optimally fits both particle colliders (proton-proton and electron-positron), which can potentially accommodate more than two lepton-collider interaction points, and which could possibly also be more cost effective in the first stage (e.g. by requiring less civil structures for the lepton collider than needed for the subsequent hadron collider).

Collimation needs for a lepton collider, transfer lines, injection and extraction insertions, have not been studied in detail so far. An optimization of such elements and their placement can affect the overall layout. Similarly, the length of the radiofrequency (RF) sections for the lepton collider needs to be reviewed, optimized, and possibly be shortened, depending on the progress with the R&D on thin-film superconducting RF cavities.

1.2. OBJECTIVES

The main objectives of future R&D are:

- ☐ Further, develop and optimise the design of FCC-ee both to maximize the performance for a given layout and investment scenario. Explore options with more than two experiments, study the minimum lengths and optimum placements of the other insertions, develop and validate a collimation and machine-protection scheme. Consolidate and optimize the FCC-ee injector complex by selecting the most suitable one from several different options and alternative configurations. Complete the detailed technical design of the experimental interaction region and its overall integration into the CERN technical infrastructure and into the region, considering the transnational context of the project.
- ☐ As a function of the adapted layout and placement, iteratively improve the design of FCC-hh in order reduce the cost and to ease the hardware requirements. The design needs to be compatible with a civil engineering infrastructure that can also host a luminosity frontier lepton collider. The staged implementation permits a review of the civil engineering structures in view of reducing the initially required capital investments (FCC-ee as first phase and FCC-hh as second phase). The layout should accommodate changes required for the lepton collider.

- Further develop the superconducting RF technologies including cavities and power sources that are cost effective and which permit reducing the length of the RF insertions by providing increased performance. Develop arc magnets for the lepton collider that are cost effective.
- Develop simulation tools and a modelling framework, which allow studying the vertical emittance, dynamic aperture and polarization for exactly the same machine with the identical errors and optics corrections.
- Define a common layout and tunnel design that optimally balances the requirements of the hadron and lepton facility, maximizes the performance, and minimize the cost of the lepton collider as a first step.

1.3. DESCRIPTION OF WORK

A number of different R&D activities will be required:

- Continue the design of the hadron collider ring as far as needed to ensure its consistency with the change proposals resulting from the lepton collider ring R&D.
- Optimise the design of the hadron collimation system to potentially reduce its length, up to the minimum length required for the lepton collider (e.g. by the lepton collider radiofrequency systems). This might call for a study of alternative collimation concepts.
- The civil engineering studies need to consider the host-state implementation requirements and constraints (layout, placement), the excavation materials management needs, the infrastructure and resource optimization needs, the project risks and the overall total cost of ownership for a combined FCC-ee and FCC-hh physics programme.
- Significant efforts will be required for studies of FCC-ee emittance tuning and beam polarization, including the development of beam diagnostics.
- Alternative lepton injector configurations will be compared in terms of performance, cost and risk. An optimum configuration must finally be selected.
- The integrated design of the FCC-ee experimental interaction regions should be completed, including magnetic systems, stability analysis and possible stabilization schemes.
- Lepton collider proto-collaborations need to be formed to propose experiment facilities and to create a long-term sustainable research infrastructure project.
- A business plan including capital and operation cost documentation together with funding scenarios that include CERN member states and global partners beyond this consortium need to be drawn up.

1.4. COLLABORATION WITH UNIVERSITIES AND RESEARCH CENTRES

From the beginning, this R&D programme will be a collaborative endeavour, which builds on the committed involvement of universities and research centres from around the world. The EuroCirCol H2020 project initiated a worldwide consortium to develop and explore a design of a future circular particle collider. Research institutes with established track records in the design and development of such systems need to further intensify their contributions for the next step of the study.

Concerning FCC-hh, work on the integrated optics design could be continued by CEA (France) and the collimation system by CERN.

For FCC-ee, work on emittance tuning and polarization could be carried out in collaboration with DESY (Germany) and PSI (Switzerland); on the positron source with IN2P3/LAL (France), BINP (Russia) and KEK (Japan); on the injector linac with PSI (Switzerland) and ELETTRA (Italy); on the damping ring with INFN-LNF (Italy) and CELLS/ALBA (Spain); on the top-up booster with CEA (France) and KIT (Germany); on the radiofrequency cavities with INFN-LNL (Italy) and JLAB (US);

on efficient RF power sources with CEA(France), IN2P3/IPN (France), ESS (Sweden/EIO), SLAC (US), Lancaster U. (UK), and MUFA (Russia); on the FCC-ee vacuum system with CAS-IHEP (China) and Izmir IT (Turkey); on the machine-detector interface and experimental detector integration with INFN-LNF (Italy), BINP (Russia and NBI (Denmark)); beam diagnostics with KIT (Germany), KEK (Japan) and CELLS/ALBA (Spain); and on feedback systems with Stanford U. (US) and U. Oxford (UK). The optimization for different numbers of IPs could be studied by BINP (Russia), KEK (Japan) and EPFL (Switzerland).

For host-state related implementation matters, collaboration with non-profit, public organisations such as CEREMA (France), CETU (France), BRGM (France), Montanistic University Leoben (Austria), Universities in Geneva, Lausanne and Zurich (Switzerland) are already in the process of being established.

In the near future, the consortium needs to be enlarged with additional academic partners, in particular universities and institutes in France, Germany, Italy, Switzerland, Spain, Denmark, Sweden, UK with a track record in the development of the aforementioned systems. The consortium also needs the involvement of academic partners outside the ERA, in particular United States, Japan, Russia, and China.

1.5. COLLABORATION WITH INDUSTRIAL PARTNERS

The design and development of accelerator radiofrequency systems, magnet systems, beam vacuum system, beam diagnostics, collimation system, and other ancillary equipment relies strongly on the capability to manufacture, install and operate a large number of devices that are fabricated with high precision and at acceptable cost. Therefore, industrial partners will be included at all stages of the R&D programme, from the development of fundamental technologies via the assembly and process-related activities to quality management, installation, maintenance and repair concepts. Co-development with industrial partners during the R&D phase prioritises the following key topics:

- The optimum production techniques and thin-film coating recipe for high-gradient, high-Q thin-film SC RF cavities;
- the cost-effective production of warm twin magnets for the FCC-ee arcs;
- the development of an economic beam vacuum system with integrated NEG pumping and of sufficiently low impedance;
- the optimum design of the interaction-region magnet systems;
- the development of adequate beam diagnostics;
- the optimisation of magnet and vacuum-system assembly;
- the optimisation of internal and external interfaces to improve assembly;
- testing, installation, maintenance and repair in view of high availability and good use of the assets.

Among the possible industrial partners are THALES (France), ScandiNova (Sweden), L3 (US), VDBTC (Russia), BRUKER (Germany), Linde (US and Germany), and IBM (Switzerland and US).

The aforementioned activities will include the definition of collaborative EC co-funded projects to increase the impact of transferring technological developments from research to industry. Such projects can have significant impacts on the competitivity of European companies by advancing the technologies, the know-how of the companies and by creating new markets, beyond the particle accelerator domain (e.g. RF power sources for industrial equipment, household appliances, industrial light, medical devices, security applications and much more).