Editors' note

Understanding the origins of the Universe and how it works and evolves is the present mission of a large community of physicists of many nations and specialities. It calls for a large-scale vision, involving general relativity, astrophysics, and cosmology, together with the detailed basic understanding provided by particle physics; these disciplines work hand in hand, with the help of several other research fields. Presently, particle physics stands at an important moment in its history. With the discovery of the Higgs boson, the matrix of interactions and elementary particles that is called the 'Standard Model' (SM), is complete. Yet the Higgs boson itself, and how it breaks the electroweak symmetry, remains a fascinating subject requiring verification at the next order of precision, typically at percent, or even per-mille, accuracy. Furthermore, several experimental facts are not accounted for by the SM; let us mention: (i) the baryon asymmetry of the Universe, (ii) the nature and origin of dark matter, and (iii) the origin of neutrino masses. These have no unique, if any, explanation in the SM and yet will require answers from particle physics.

Particle physics exploration must continue… but we no longer have a guiding scale.

How can this exploration be carried out? Which next tool is needed? Going to higher and higher energies is an obvious idea. It has worked well for the Standard Model particles so far, because they all have roughly the same strong and electroweak couplings. It is far from evident, however, that the new phenomena or particles, required to explore these questions, will behave in the same way—the opportunity to explore much smaller couplings or much higher scales must be kept in mind. Here, the role of precision measurements, the search for extremely rare decays of known particles, for small violations of the SM symmetries, and for direct production of super-weakly coupled objects is in order. A broad search strategy is thus needed.

With this in mind, and armed with the recommendation of the European Strategy in 2013 that Europe should be in a position to "propose an ambitious post-LHC accelerator project at CERN", the FCC collaboration has elaborated a strategy of circular colliders fitting in a new facility of 100 km circumference. It will start with a high-luminosity e^+e^- electroweak factory, FCC-ee, and culminate in a proton collider, FCC-hh, of more than 100 TeV collision energy. Additional options of heavy-ion collisions and e–p scattering are foreseen and, possibly, muon collisions. This strategy offers, by way of synergy and complementarity, a thorough study of the Higgs boson, as well as unmatched capabilities of high-energy exploration, precision measurements, and sensitive rare process searches [1]. The FCC Conceptual Design Report (CDR) has been prepared and released [2–4]. This powerful exploratory project will, right from its first step as a Z factory, explore completely uncharted territory in terms of precision and sensitivity. Moreover, it constitutes an extraordinary challenge for theory. The theoretical community has responded with enthusiasm to the challenge; already several workshops have gathered an increasing number of contributions.

In this report, we collect theory contributions to the 11th FCC-ee meeting held in January 2019 at CERN [5], completed by a few invited guest contributions. The report is a kind of community white paper, rather than a conventional conference report. It collects, coherently, the contributions from 86 scientists, representing the state of the art in 2019 and envisioning the additional needs of future lepton colliders. We are grateful to Jens Vigen from CERN. Due to his efforts in the final productions, the document meets the highest editorial standards.

The collective interactions of all of us, in one way or another, at the meeting in January 2019 and for several months after, make the backbone of the final write-up. Nevertheless, for the convenience of the reader, we decided to retain a sectional structure for the bulk of the document, with individual bibliographies for the sections.

The volume follows the report [6] on the FCC-ee workshop in January 2018 [7], which focused on the theory needs for the Tera-Z, the first stage of the FCC-ee, working in the Z boson mass range. The purpose is to document existing studies and also to motivate future theoretical studies, enabling by their predictions a full exploration of the experimental potential of the FCC-ee.

It has become evident that a significant work must be accomplished, both in multiloop calculations in the Standard Model and also in projects beyond the Standard Model. Documentation of these requirements became highly desirable to complement the submitted Conceptual Design Report. The present report exemplifies both the well-advanced status of phenomenology for the FCC-ee and, at the same time, the need for further mathematically well-founded deepening of the technologies for precision measurements. In this respect, it is a necessary addition to the FCC CDR.

From a scientific point of view, the FCC is the most challenging collider project for the next few decades [8]. We see it as our duty and pleasure to prepare such a frontier project and to sustain CERN's leading role in basic research worldwide. The goals must be set as high as possible, i.e., at the level of the statistical uncertainties, because *this precision genuinely equates discovery potential.*

We thank all participants of the workshop for their engagement with presentations and in the discussions during the workshop, and the authors of the report for writing such excellent contributions. The exploratory potential of the FCC-ee can be fully exploited only if the talent and efforts of accelerator builders and experimenters is met by theory. The message is: we are working on it.

From this quest for the unknown, driven by curiosity, history shows that there is a return for all of us, scientists or not [9–11].

The editors.

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