MEMORANDUM

From: FCC Physics and Experiments Design Study; M. Benedikt, A. Blondel, P. Janot, M. Mangano
To: Snowmass conveners
Object: Participation to the 2020-2021 Snowmass Study

Introduction

The Future Circular Collider (FCC) physics, experiment and detector study groups are happy to get involved with the 2020-2021 Snowmass Study and welcome contributions from its participants. The FCC project is presented in the FCC CDRs [1][2][3][4], and in the contributions to the European Strategy [5][6][7][8][9][10] and in the recent physics workshop [11]. Further official FCC results, expected to be produced as time develops, will be summarized in one or several Snowmass contributions in 2021.

A general introduction to the FCC is given in a recent *Nature* article [12]. The FCC project comprises a first step consisting of a high-luminosity e^+e^- collider with centre-of-mass energy varying from 90 to 365 GeV, starting at the end of HL-LHC, to be followed in the 2060's by a 100 TeV pp collider including a program of ion-ion collisions and an e-p collider option. The FCC, making use of the complementarities and synergies of the lepton and hadron colliders, is an exceptionally powerful facility for Higgs studies. The FCC offers unmatched opportunities for direct production of new particles, both at feeble couplings and at high masses, with the lepton collider Z factory on the one hand, and the 100 TeV hadron collider on the other. It is also unique for electroweak physics both in neutral and charged currents, for QCD precision studies, and for the detailed exploration of heavy quark and lepton flavour properties. The unique features of the circular e^+e^- Higgs, Electroweak and Flavour factory are compared with those of the linear colliders in Ref. [10].

The FCC has recently received a 4-years grant from the European Union in support for a Design Study (FCC-IS) of the preparation of implementation of the infrastructure and lepton collider as first step of the FCC project. The task of the FCC physics, experiments and detector studies in the next 5 years is to deepen the studies, identify the detector requirements to match the much reduced experimental statistical uncertainties, promote the suitable detector R&D, and work towards establishing global experimental FCC-ee proto-collaborations by 2026/27.

Contact persons

The contact persons from the FCC physics and experiments studies to the Snowmass study frontiers are as follows:

- Overall contact: Markus Klute, plus Alain Blondel, Patrick Janot and Michelangelo Mangano
- Energy Frontier: Patrizia Azzi and Gregorio Bernardi (FCC-ee), Michele Selvaggi (FCC-hh), Christophe Grojean (Phenomenology)
- Frontiers in Rare Processes and Precision Measurements: Stéphane Monteil (b and c physics) and Mogens Dam (τ physics)
- Theory Frontier: Matthew McCullough
- Instrumentation Frontier: Mogens Dam and Franco Bedeschi
- Computational Frontier: Luc Poggioli

Software support can be obtained from the FCC software group (see C. Helsens and G. Ganis in [14]) who will be happy to integrate software contributions.

New results and challenges

Although a considerable amount of information is already included in the documents cited above and in the Physics Briefing Book [13] prepared by the European Strategy Preparatory Group, we would like to bring the following to your attention.

The FCC-ee accelerator design and luminosity figures are considered solid for the baseline configuration with two interaction points (2IP). The operation of detectors on the FCC-ee was shown to be feasible. A 4IP configuration is being studied, with the aim of delivering a total luminosity of a factor 1.7 higher for the same collider power consumption as that of the 2IP baseline. A "mono-chromatization" scheme is under study to make it possible to achieve the detection of $e^+e^- \rightarrow H$ production in the s channel.

The exceptionally large event samples expected at the FCC colliders constitute a challenge for detector design and construction quality, and also for computing. The FCC design study is relatively new in these respects. Considerable improvement and optimization of the detectors and of the running mode can be expected, thus offering numerous opportunities for ingenuity and creativity, to which we are happy to invite the Snowmass participants.

We can give two recent notable examples here.

1) Improved investigations [9] of the centre-of-mass energy calibration for the Z resonance scan lead to uncertainty estimates reduced to $\pm$ 25 keV on the Z width, $\pm$ 3.1 x 10^{-6} on $\sin^2\theta^{eff}_{lept}$, and a direct measurement of $\alpha_{QED}(m_Z)$ with a $\pm$ 3 x 10^{-5} relative precision. Improved analysis, instrumentation and monitoring might reduce these experimental errors even more.
2) Further investigation of the double Higgs production at FCC-hh [15] has led to an improved expected statistical precision of O($\pm$2%) with the full exposure, implying that the 10% precision mark should be reached very early (2-5 years) in the life of FCC-hh.

A set of "case studies" is being compiled in view of establishing a list of benchmarks and detector requirements, and will be contributed as one or several LOIs in the near future. Many other opportunities exist, to be identified and studied by the Snowmass participants.

Theoretical Challenges

All future lepton colliders proposed for the High Energy and Precision Frontier set stringent demands on theory to match the experimental precisions [16]. The most ambitious, broad-reaching and demanding of them is FCC-ee. This tremendous challenge is also an opportunity for the theory community to play an essential role in a combined precision calculation and measurement campaign, which could eventually lead to far-reaching constraints or discovery. It was concluded in Ref. [17] that the challenge can be tackled by a distributed collaborative effort in academic institutions around the world, provided sufficient support is available. We certainly encourage the Snowmass study to consider this essential endeavour in its future planning.

With our best wishes for a successful SNOWMASS 21!

References

[1] M. Mangano et al., "FCC Physics Opportunities - Future Circular Collider Conceptual Design Report Volume 1," The European Physical Journal C, 79, pp 1-161, (2019).
[2] M. Benedikt et al., "FCC-ee: The Lepton Collider - Future Circular Collider Conceptual Design Report Volume 2," The European Physical Journal Special Topics, 228, pp 261–623, (2019).

[3] M. Benedikt et al., “FCC-hh: The Hadron Collider - Future Circular Collider Conceptual Design Report Volume 3,” The European Physical Journal Special Topics, 228, pp 755–1107, (2019).
[4] “Physics at FCC: overview of the Conceptual Design Report”, FCC CDR presentation symposium, CERN 4-5 March 2019, https://indico.cern.ch/event/789349/
[5] M. Benedikt, et al., “Future Circular Collider - European Strategy Update Documents: The Lepton Collider (FCC-ee)”, https://cds.cern.ch/record/2653669, Jan. 2019.
[6] M. Benedikt, et al., “Future Circular Collider - European Strategy Update Documents: The Hadron Collider (FCC-hh)”, https://cds.cern.ch/record/ 2653674, Jan. 2019.
[7] M. Benedikt et al., “Future Circular Collider - European Strategy Update Documents: The FCC integrated programme (FCC-int).”, https://cds.cern.ch/record/2653673, Jan. 2019.
[8] N. Alipour Tehrani et al., “FCC-ee: Your Questions Answered”, Contribution to the European Strategy Update workshop, Granada, Spain, May 13-16, 2019, arxiv:1906.02693v2
[9] A. Blondel et al., “Polarization and Centre-of-mass Energy Calibration at FCC-ee’’, Contribution to the European Strategy Briefing Book, arxiv:1909.12245.
[10] A. Blondel and P. Janot “Circular and Linear e+e− Colliders: Another Story of Complementarity”, Contribution to the European Strategy Drafting Session in Bad Honnef, Germany, January 20-24, 2020, arxiv:1912.11871v2
[11] “The Third FCC Physics and Experiments Workshop”, https://indico.cern.ch/event/838435/
[12] M. Benedikt et al., “Future Circular Colliders succeeding the LHC”, Nature Phys. 16 (2020) 4, 402-407
[13] B. Heinemann, et al., “Physics Briefing Book: Input for the European Strategy for Particle Physics Update 2020”, arXiv:1910.11775.1.
[14] C. Helsens and G. Ganis, “FCC Software status”, and “Needs and status of implementation of benchmark channels” in [11]
[15] M. Mangano, G. Ortona and M. Selvaggi, “Measuring the Higgs self-coupling via Higgs-pair production at a 100 TeV p-p collider”, arXiv:2004.03505
[16] A. Blondel et al., “Standard Model Theory for the FCC-ee Tera-Z stage”, CERN Yellow Rep. 3 (2019), DOI: 10.23731/CYRM-2019-003, BU-HEPP-18-04, CERN-TH-2018-145, IFJ-PAN-IV-2018-09, KW 18-003, MITP/18-052, MPP-2018-143, SI-HEP-2018-21 arXiv:1809.01830
[17] A. Blondel, A. Freitas, J. Gluza, S. Heinemeyer, S. Jadach, P. Janot, T. Riemann, “Theory Requirements and Possibilities for the FCC-ee and other Future High Energy and Precision Frontier Lepton Colliders”, Input to the European Strategy Particle Physics 2020, arXiv:1901.02648v1