Perspectives on International Superconducting Linear Colliers (ILC) to the Next Century
Part A: High Luminosity Higgs Factory and Top Factory

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Introduction

Over the last few years, strong statements [1] from ICFA indicate general agreement within the World High Energy Physics (HEP) community that an electron-positron collider Higgs factory is one of the highest priorities for the field as the next HEP machine. In June 2020, the European Strategy for Particle Physics Report [2] offered strong support for ILC hosted by Japan, expressing their wish for European participation. Other paths to the Higgs Factory are the FCCee [3] or CLIC [4] in Europe, and CEPC [5] in China, all in the CDR stage with further development needed. With a TDR completed some years ago [6], ILC remains the most technologically ready and mature of all possible Higgs factory options for an expeditious start. In the years after its TDR completion, ILC technology is being used on a large scale to establish a rich experience base with new accelerators such as LCLS-II [7] in the US and SHINE[8] in China.

In this LOI (Part A) and in an accompanying white paper, we compare the different Higgs Factory options in terms of cost, AC power, luminosity, and technological readiness. We indicate how recent advances in SRF allow the ILC baseline luminosity to be upgraded by a factor of 6, to be competitive with the proposed FCCee, but at substantially lower cost [9]. We are therefore interested in a detailed discussion of this matter during the Snowmass process.

In addition to the Higgs and Top Factories discussed here, an equally strong physics attraction of ILC is the inherent energy upgradability of the superconducting linear collider to TeV and multi-TeV energies, offering clean e^+e^- physics *to the next century*. In the second part of this LOI (Part B to Snowmass Group AF4) and in an accompanying white paper, we discuss the energy upgradability paths of ILC to the multi-TeV energy domain. And again, we express our interest in a detailed discussion of this matter during the Snowmass process.

Proposal

The most significant development supporting the expeditious launch of ILC is that the cost of starting at 250 GeV as a Higgs Factory [10, 11] has dropped considerably from the original TDR estimate for the 500 GeV machine, with bottoms-up cost evaluations, further substantiated by the experiences of the European XFEL [12] and LCLS-II. At 17.5 GeV, European XFEL is an SRF linac based on ILC technology that has been operating for a few years. 4 – 8 GeV XFELs at SLAC (LCLS-II/ LCLS-II-HE) and SHINE in China based on ILC technology are now under installation or construction. There have been significant worldwide developments in SRF technology, with the establishment of infrastructure as well as a significant industrial base in the Americas, Asia and Europe. ILC SRF technology has enabled several new accelerator projects around the world. Demonstration experiments at ATF2 [13] in Japan have established confidence in ILC IP parameters, and demonstration experiments [14] at CESR (Cornell) have established confidence in damping ring parameters.

A key area of further development for the ILC Higgs Factory is achieving higher Q values with the invention of new techniques of Nitrogen Doping [15], Nitrogen infusion [16] and Two-Step baking/Cold Electropolishing [17]. Nitrogen doping has already been applied to the LCLS-II, although at medium gradients (16 – 18 MV/m) for CW operation. In this proposal (and a following white paper), we explore how higher Q values (2×10^{10} at 31.5 MV/m) can lead to a 6× Luminosity Upgrade Stage. The ILC Higgs Factory already discusses a ×2 luminosity upgrade option. Here we explore the 6x luminosity upgrade to be competitive with the luminosity/detector proposed by FCCee. The availability of polarized beams increases the effective ILC luminosity by another factor of 2.5 [10], compensating for the single detector of ILC, versus two detectors for FCC-ee. Polarization is one of the merits of linear colliders over circular machines.

In our approach to a future luminosity upgrade for ILC250 we choose to keep the main beam parameters (such as bunch charge, bunch length, beam emittances, final focus properties) the same as for the baseline ILC250, so that the final collision spot size, beam disruption, and backgrounds of ILC remain unchanged. Instead we raise the beam power by a factor of 6. The higher *Q* opens the option of increasing the RF pulse length (and so the beam-on duty cycle) allowing the population of the RF pulse with twice the number of bunches (2,624 instead of 1312) at the same bunch spacing in the linac as for the 250 GeV baseline, which helps to better preserve emittance in the linac. We increase the repetition rate of the pulses from 5 Hz to 15 Hz to give corresponding luminosity increase of a factor of 6. (These increases can also be staged to first aim for x4 luminosity.) The white paper will discuss how to address the corresponding challenges for additional RF power, cryogenic power, damping rings, damping time reduction, positron source, and beam dumps for higher beam power. Finally, we present parameters of the energy upgrade to a 380 GeV Top Factory.

Summary

As indicated in Table 1, with the potential of a 6x luminosity upgrade, the ILC Higgs Factory is the least expensive option with the capital cost, lowest AC power (operating cost) and the baseline ILC has the earliest possible for physics start. The potential for 6 x luminosity upgrade makes ILC the highest luminosity candidate at the lowest cost. The upgrade to Top Factory also has the most attractive luminosity, cost and AC power.

Table 1 compares the parameters costs, luminosities, and AC power for ILC baseline, ILC luminosity x 6, FCCee, CEPC, and CLIC (380 GeV). Capital costs are for the accelerator only, and do not include Labor, Detectors, operations, and contingency. The cost for the starting ILC Higgs factory (5.5B) is consistent with the ILC TDR amended by Japan [10]. For the Top Factory, the additional linac is based on a gradient of 40 MV/m at *Q* = 2x10^{10}. Additional details for the parameters will be given in the white paper.

	ILC Baseline Higgs	6× Luminosity upgrade Higgs	ILC Top	FCCee Higgs	FCCee Top	CEPC Higgs	CLIC (380) (Higgs & Top)
Energy [GeV]	250	250	380	240	365	240	380
Luminosity [×10^{34}]/IP	1.35	8.1	4	8.5	1.5	3.0	1.5
Total capital cost	5.5 B ILCU	+2.3 B ILCU	+1.5 BILCU	10.5 BCHF	+1.1 BCHF	12^ BCHF	6 BCHF
Start Construction	2024	2038	2045	2038^^		2022	2026
Start Physics	2033	2040	2047	2048	2053	2030	2035
Total AC power [MW]	132	+135	157	308	364	270	170
Tunnel length [km]	20	+0	+5	100	+0	100	11.4
Av. Gradient [MV/m]	31.5	31.5	34.4	10	10	20	72

^ The CEPC CDR estimates cost is China will be 30 – 50% less than Swiss based Costs

^^ As per European Strategy Report

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