Conclusions from the Linear Collider meeting in Lausanne April 2019.

The highest scientific priority in particle physics is to uncover phenomena that establish new physics addressing the shortcomings of the Standard Model (SM). Precision studies in e+e- collisions of the properties of the Higgs boson including its self-interaction, of the top quark, and of other processes, can elucidate the underlying dynamics of electroweak symmetry breaking and “point the way” to new physics Beyond the Standard Model (BSM). Direct searches for new phenomena that are difficult to observe in hadronic interactions can also be pursued. All of these studies could address fundamental questions such as the origin of mass and of the matter-antimatter asymmetry, and the nature of dark matter.

The most cost effective, fast, and versatile approach is construction of a linear e+e- collider (LC) facility starting from an initial energy and luminosity optimised for the targeted measurements. Such a facility will also provide physics guidance for future accelerators beyond the initial LC. The facility should provide the foundation for a long-term e+e- physics programme and hence be upgradable in the future with the same, improved, or new technologies to much higher energies, allowing improved precision and reach for SM and BSM physics. The LC should be pursued for construction start-up in about 5 years, aiming for operation by ~2035.

During the ESPP process important conclusions will be drawn concerning future projects and studies, which are crucial for a timely construction start-up of a LC project. This is a unique opportunity to move ahead quickly towards constructing a LC that fulfils the goals described above. Europe and CERN should play leading roles in this endeavour, wherever the LC is realised.

Background and justifications for a LC – summary of main points discussed

Electron-positron collisions provide clean conditions for very precise studies of the Higgs boson, the top quark, and other SM particles and processes, and for direct searches for new particles, exotic Higgs decays, and other BSM physics. The goal of precision studies is to discover deviations from SM predictions in the Higgs boson couplings and in other interactions, which point to new physics. This is complemented by the direct searches for new phenomena.

Higher-energy e+e- collisions would significantly improve the precision tests of the SM parameters and the sensitivity to BSM physics by opening new production channels and testing energy dependences. In this endeavour, beam polarisation also plays an important role. The higher energies allow direct measurement of the Higgs self-coupling – a critical fundamental property of the Higgs field – using two distinct production mechanisms, giving unique sensitivity to its SM or non-SM value.

A LC can be upgraded to reach higher energies, and the next phases could be adapted depending on the results obtained. Beyond increasing the linac-lengths, R&D is ongoing for higher gradients, for example by improving SCRF cavities or X-band accelerating structures. In the longer term a linear collider infrastructure can be adapted or reused to significantly reduce the cost, risk and implementation time of a future linear collider using a different technology. For example, new accelerator technologies, such as plasma wakefield or di-electric based acceleration, promise more compact and hence affordable linac upgrades towards much higher energies than are currently considered.

A particular strength of linear colliders is that they have close technological links to general accelerator advances and construction of smaller high-performance systems such as FELs and other light sources, which are used for applications outside particle physics. The investments in these smaller accelerators world-wide are significant and the benefits of having many areas of science pursuing the developments of similar tools cannot be overstated in terms of future capabilities. The European XFEL and LCLS-II are prime recent examples for SCRF; the SwissFEL and SACLA, using normal conducting C-band structures, are relevant examples for NCRF.

ILC and CLIC are at this point projects that can move forward quickly towards implementation, and be ready for expanding and deepening Higgs studies and Standard Model precision measurements within ~15 years, possibly overlapping with the HL-LHC programme. In both cases the resource requirements for the initial project stages are similar to those for the LHC construction.

Beyond the initial stage of a LC, benefitting from its physics guidance, the possibilities and opportunities for future colliders in particle physics extend beyond running or upgrading a LC. Examples are hadron and even muon colliders where R&D and developments are on-going but further work is needed for realistic implementation proposals. Any of these colliders can be built with designs fully optimized for their physics requirements, in parallel with an operating LC facility. In terms of future scientific perspectives, continuity and adaptability, this approach seems very attractive for our field.

More about the projects

The Compact Linear Collider (CLIC) project is proposed for implementation at CERN, and the International Linear Collider (ILC) is proposed for implementation in Japan[1]. Extracts of the abstracts and conclusions of the respective projects' input to the ESPP process are shown below, with links to much more information.

"CLIC is a TeV scale high-luminosity linear e+e- collider under development by international collaborations hosted by CERN. For an optimal exploitation of its physics potential, CLIC is foreseen to be built and operated in stages, at centre-of-mass energies of 380 GeV, 1.5 TeV, and 3 TeV, for a site length ranging between 11 km and 50 km. CLIC uses a two-beam acceleration scheme, in which normal-conducting high-gradient 12 GHz accelerating structures are powered via a high-current drive beam.

CLIC accelerator technology has reached a mature state and is increasingly being put to use in accelerator projects around the globe. The construction of the first CLIC energy stage could start as early as 2026 and first beams would be available by 2035, marking the beginning of a physics programme spanning 25–30 years and providing excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors.

CLIC represents a compelling opportunity for the post-LHC era."

CLIC, as presented in the ESPP input documents, is considered the best future collider option for construction at CERN (link): https://clic.cern/european-strategy

"The ILC, being proposed as an international facility in Japan, is an electron-positron linear collider with an initial energy of 250 GeV. The ILC accelerator is based on the technology of super-conducting radio-frequency cavities. This technology has reached a mature stage in the European XFEL project and is now widely used. The accelerator is upgradable to higher energies, 500 GeV and possibly 1 TeV, and also luminosity upgrades are considered. Running at lower energies, down to the Z-pole, has also been studied.

The international - including European - interest for the project is very strong. Europe has participated in the ILC project since its early conception and plays a major role in its present development covering most of its scientific and technological aspects: physics studies, accelerator and detectors. The potential for a wide participation of European groups and laboratories is thus high, including important opportunities for European industry. Following decades of technical development, R&D, and design optimisation, the project is ready for construction and the European particle physics community, technological centres and industry are prepared to participate in this challenging endeavour."

ILC in Japan running as a Higgs factory at 250 GeV, with upgrade possibilities, is an attractive implementation of a LC, with a strong European community eager to participate and contribute (link): https://ilchome.web.cern.ch/content/ilc-european-strategy-document

[1] The possibility of hosting an ILC technology based linear collider at CERN was discussed but this has not been studied in detail.