THE CLIC STUDY: TAKING THE LEP LEGACY TO THE MULTI-TEV FRONTIER

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With the completion of the Lep-2 operation, the exploration of the high energy frontier in e^+e^- physics is most likely to be inherited by a linear collider (LC). In fact, the E^4_{beam} scaling of the beam energy loss in circular storage rings makes them no longer a viable choice for collision energies beyond about 300 GeV. A rich harvest of physics results should become accessible at centre-of-mass energies $\sqrt{s} \simeq 500$ GeV, that can be obtained with super-conducting RF structures, as proposed by the Tesla project [1], or also with X-band warm cavities [2]. If the electro-weak symmetry breaking is realised through the Higgs mechanism, whose onset is manifested by the existence of an elementary Higgs boson, a 500 GeV LC at high luminosity will promote Higgs physics into the domain of precision measurements. In the study of the Higgs sector, the LC may thus become to the Lhc, the equivalent of what Lep has been to the $Sp\bar{p}S$, in the study of the Z^0 and $W^\pm$ bosons.

If the Higgs field is indeed responsible for the masses of the Z^0 and $W^\pm$ bosons, that Lep has measured so accurately, as well as for those of the fermions, a further exploration of the TeV frontier will become necessary to fully probe its structure and nature and to understand the mechanism that stabilises the electro-weak scale giving $v \simeq 250$ GeV $\simeq 10^{-17} \times M_{Planck}$. Furthermore, in order to precisely test the nature of signals that may be observed at the Lhc, by the end of this decade, and to extend the probe for new physics beyond its reach, a lepton collider able to deliver collisions at energies in the multi-TeV range will be required. This motivates the development of new techniques of particle acceleration, beyond those presently considered for a TeV-class LC.

The Clic project, carried out at Cern since 1987, aims at developing and validating the two beam acceleration scheme to provide e^+e^- beams colliding at $\sqrt{s}$ energies from 0.5 TeV, or lower energies if the need would arise, up to 5 TeV [3]. While promising to open a new domain for experimentation at e^+e^- colliders, Clic also presents new challenges compared to any other e^+e^- collider project, due to its different regime of operation. In order to balance the $1/s$ fall of s-channel cross sections, experimentation at multi-TeV energies requires a luminosity of the order of 10^{35}cm^{-2}s^{-1}. In the Clic scheme, the necessary RF power is generated at 30 GHz, by means of a high intensity, low energy drive beam, extracted by copper transfer structures and transferred to the main beam . The 30 GHz choice allows to operate with a larger gradient, thus minimising the linac total length and therefore its cost. However, since at 30 GHz the cavity aperture is only ∼4 mm, the wake-field generation becomes more important, compared to lower frequencies, and the beam emittance needs to be preserved by a careful choice of the parameters and by enforcing tighter alignment tolerances. At the same time, at $\sqrt{s}$ = 3-5 TeV, e^+e^- collisions take place in a regime of large beamstrahlung ($\Upsilon >> 1$) where the luminosity is expected to increase with the RF frequency and to be independent of the accelerating gradient [4]. In this regime the luminosity spectrum is significantly broadened by the energy loss suffered by the electron and positrons in the intense field generated by the incoming beam.

The design luminosity is achieved with a bunch charge, corresponding to only one tenth of that accelerated at LEP but focused to a spot four orders of magnitude smaller, in the horizontal and vertical planes, at the interaction point.

The definition of the CLIC physics programme still requires essential data that is likely to become available only after the first years of LHC operation and, possibly, also the results from a LC operating at lower energies [5]. At present we thus have to envisage several possible scenarios for the fundamental questions to be addressed by HEP experiments in the second decade of this new century.

If new particles will have been observed, either at the LHC or in lower energy e^+e^- data, CLIC has the potential to complement the probe to their nature. In the case of an elementary Higgs boson, even after the LHC and a 500 GeV LC will have studied in details its properties, the ultimate test that the observed boson is the manifestation of the scalar potential responsible for electro-weak symmetry breaking will come from the determination of the triple and, possibly, the quartic self-couplings as can be obtained at a high luminosity multi-TeV e^+e^- collider. If Supersymmetry is realised in Nature, signals for supersymmetric partners of the known particles should be observed at both the LHC and in lower energy e^+e^- collisions. Beyond discovery, it will be crucial to accurately study the properties of all these particles (masses, couplings and quantum numbers), to understand the underlying model of symmetry breaking and to determine the theory parameters. This will likely require e^+e^- data at $\sqrt{s}$ energies in excess to 1 TeV.

A striking manifestation of new physics in the multi-TeV region will come from the sudden increase of the $e^+e^- \to f\bar{f}$ cross section signalling the s-channel production of a new particle. There are several scenarios predicting new resonances in the mass range of interests for CLIC. A first exemplificative category of New Physics, yielding such signatures is represented by additional gauge bosons like a Z'. These are common to both Grand Unification inspired E_6 models and to Left-Right symmetric models. Further, Kaluza-Klein excitations of the graviton, of Z and γ gauge bosons, or both, are a distinctive feature of models of quantum gravity with extra-spatial dimensions. Finally, models with strong symmetry breaking may be characterised by the appearance of resonances at the TeV scale in WW scattering. If such new states would become directly observable at CLIC, the study of electroweak observables around the resonance will be required to precisely determine their nature and couplings. Even if no new particle will be directly produced, the comparison of precision electro-weak data to the Standard Model (SM) predictions has the potential to open a window that extends the linear collider sensitivity to new physics to scales far beyond the centre-of-mass energies. This study would essentially reproduce the LEP physics programme at energies beyond the TeV frontier and will significantly profit of the availability of polarised beams to enhance the sensitivity to deviations from the SM couplings. In particular CLIC could probe the existence of new gauge bosons, of extra dimensions and of other new phenomena in terms of contact interactions up to scales of order 30 TeV to 200 TeV. This sensitivity will investigate a new mass scale, well beyond that explored at the LHC and will require to compute SM predictions for electro-weak observables with a comparable accuracy to that achieved at LEP energies.

While considering experimentation at a multi-TeV collider, it is also important to verify to which extent extrapolations of the experimental techniques, successfully developed at LEP and being refined in the studies for the TESLA project, are still applicable. This has major consequences on the requirements for the experimental conditions at the CLIC interaction region and for the definition of the CLIC physics potential. Now, there are two main issues relevant to the applicability of techniques developed at LEP/SLC in the multi-TeV regime. These are: i) the increased boost of hadronic jets and ii) the large accelerator induced backgrounds, mostly from $\gamma\gamma \to$ hadrons and pairs and the broad luminosity spectrum. The LEP experience has taught us that the reconstruction of multi-fermion final states is best achieved by combining the independent response of the tracking and calorimetric detectors using an energy flow algorithm while the parton flavour can be efficiently identified using the precise determination of particle trajectories in the vertex detector. As the jet collimation increases, the di-jet separation decreases and the heavy hadron decay distance is enhanced by the large boost at multi-TeV energies, this reconstruction techniques will need to be re-optimised in particular in few parton final states.

The physics potential of a multi-TeV linear collider still needs to be explored in full details. However, a first recognition of the main anticipated physics signatures shows that many of the concepts and techniques developed at LEP are likely to still provide a direction for probing the next energy frontier beyond the LHC.

References

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