THE COMPACT LINEAR COLLIDER (CLIC) STUDY

1 Introduction

In this lecture we introduce the Compact Linear Collider (CLIC) accelerator study proposed and developed at CERN in collaboration with number of other institutes. The CLIC study aims at developing the technology based on the two beams acceleration method for a linear collider in the post-LHC era for physics in the multi-TeV centre of mass energy range and demonstrate its feasibility.

First we will give an overview of the CLIC scheme and some key physics processes expected. Then we will explain with more details the different parts of the accelerator complex and the R&D effort done all around the world. We will finish with the studies and projects at a medium and long term issue.

1.1 CLIC overview

The CLIC technology is based on the two beam acceleration method; where the overall layout for a centre of mass energy of 3 TeV is shown in Figure 1.

This acceleration method consists in extracting RF power from a low energy and high intensity electron beam (so-called Drive Beam) by Power Extraction and Transfer Structure (PETS). Each RF power structure accelerates electron and positron beams (so-called Main Beam) with accelerating gradients of 150 MV/m and are arranged in sectors providing an acceleration of ~ 70 GeV over 624 m.

To collide beams with a centre of mass energy of 3 TeV, which is the optimal energy, 2 × 22 sectors are needed [1]. The total length of the CLIC will be around 33 km. However, the collider could start operation at lower energy simply with a shorter length and then be upgraded in stages to reach the maximum energy of 5 TeV [2].

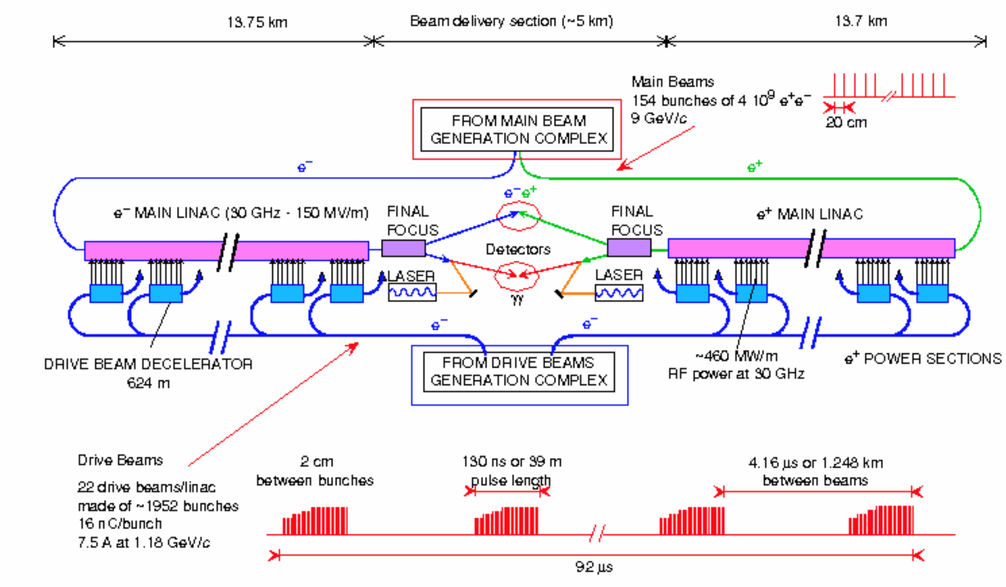


Figure 1: Overall layout of CLIC for a centre of mass energy of 3 TeV

The high RF frequency (30 GHz) of the accelerating structures has been chosen in order to operate at high accelerating gradient (150MV/m) at room temperature, in order to limit the overall length of the facility. Another advantage of the two beams acceleration scheme is that the linac is compact, is based on a modular design and has no active components such as modulators or klystrons. So, both linacs can be installed in the same small tunnel as shown in Figure 2. Therefore the cost of the linacs is moderate.

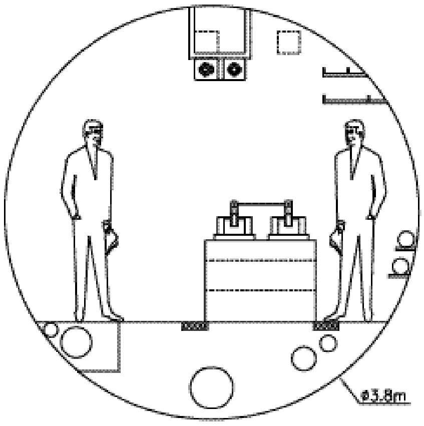


Figure 2: Tunnel cross-section

Major challenges have to be reached. Part of these challenges, that is the R&D on accelerating gradient, generation and conservation of low emittance, beam stabilisation and do physics measurement in high beamstrahlung regime, are independent of the acceleration technology. The other part that is, the efficient RF power production by two beams acceleration, the 30 GHz components with manageable wakefield and operating at high power, are specific to the CLIC scheme. All these R&D efforts will be presented in section 4.

1.2 Key physics processes

The goal of the linear collider experiment will be to probe the physics beyond the SM. The three main topics are : the origin of the particle masses (due to Higgs boson or not), the unification of the four fundamental interactions in a simple group framework and the understanding of the number of particle families and their weak mixing. Nevertheless the field of action of the linear collider will be larger to separate and understand the different theories beyond the Standard Model.

From 2000 onwards a CLIC physics study group identifies and investigates the physics potential of a facility operating at a centre of mass energy from 1 to 5 TeV. We will give you here some of the key processes extracted from its report [2].

1.2.1 Light and heavy higgses, Higgs potential

1.2.1.1 e+e- -> H -> μ+μ-

This process could be a good probe for a light Higgs from 120 to 150 GeV. The measurement of this branching ratio would be a test of the scaling of the Higgs with all the elementary particles. This can prove that the Higgs boson is responsible for the masse of each elementary particle.

1.2.1.2 e+e- -> H -> bbbar rare decay

It could be a good probe for an intermediate Higgs from 180 to 240 GeV. This measurement will ensure the Yukawa coupling to quark for Higgs masses set by the electroweak data.

1.2.1.3 Triple Higgs coupling

This is the most accessible coupling to reconstruct the shape of the Higgs potential to complete the study of the Higgs profile and to obtain a direct proof of the electroweak (EW) symmetry breaking mechanism.

As shown in Figure 3, the process e+e- -> WW νν->HHνν ->bbarbbar(or W+W-W+W-) νν could be a good probe for different masses of Higgs.

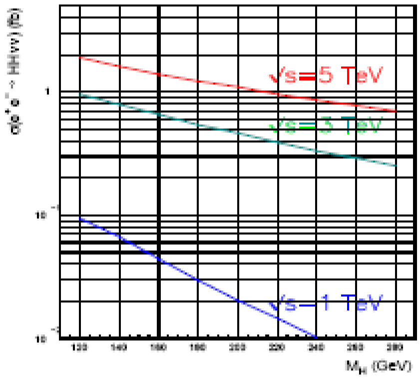


Figure 3 : Double Higgs production : cross section for e+e- -> HHυυ process as function of the Higgs boson mass for different centre of mass energy.

1.2.1.4 Heavy Higgs

The new physics can cancel the effects of a heavy Higgs, a good probe of this would be e+e- -> H e+e--> Xe+e- through a zz fusion. This channel is model independent, but the analysis will be a challenge to reconstruct and determine the energy of the very forward electrons close to the beam-beam effect background.

1.2.2 Supersymmetry

The supersymmetry is one of the most studied theories beyond the SM. It could unify fermions and bosons, connect gravity with the other interactions and be an essential ingredient of the string theory. In this theory quarks and leptons have scalar superpartners and there are five physical Higgs bosons.

The LHC has a discovery potential for squarks and gluinos. A linear TeV collider will be able to measure with a high accuracy the properties of light gluinos and spleptons. But, as shown in Figure 4 a multi-TeV collider will measure accurately the complete particle spectrum and determine :

- All the MSSM masses
- Mixing angle
- Couplings
- Spins …

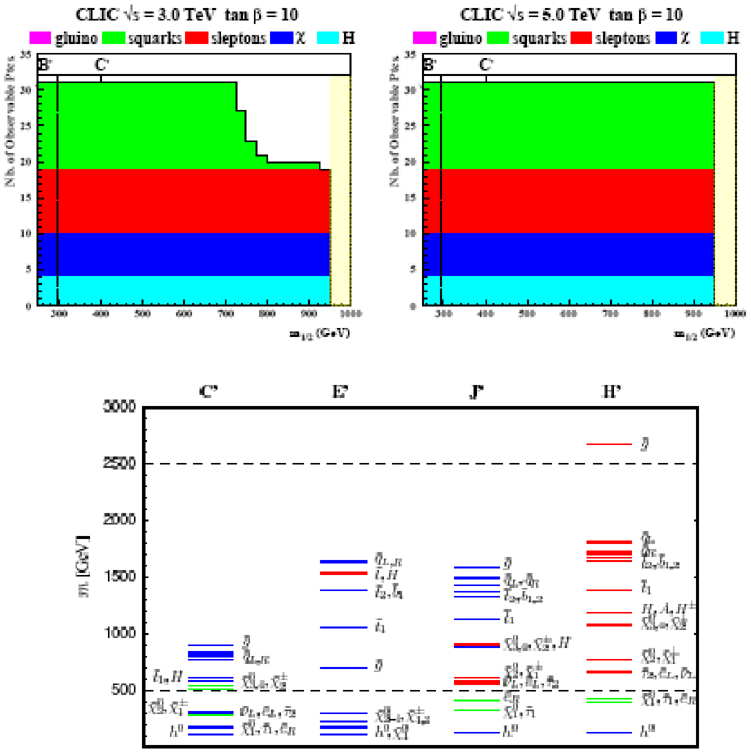


Figure 4 : Estimates the number of MSSM particles that may detectable as a functions of $m_{1/2}$ along the WMAP line B' and C' for a CLIC energy of 3 and 5 TeV(top). Examples of mass spectra, Sparticles that would be discovered at LHC, a 1-TeV LC and CLIC are shown as blue, green and red respectively.

Figure 5 shows that a high definition of measurement will determine all the soft-breaking parameters, test the unification at GUT scale or SUSY-breaking scale, pin down the SUSY-breaking mechanism and test the consistency of the model.

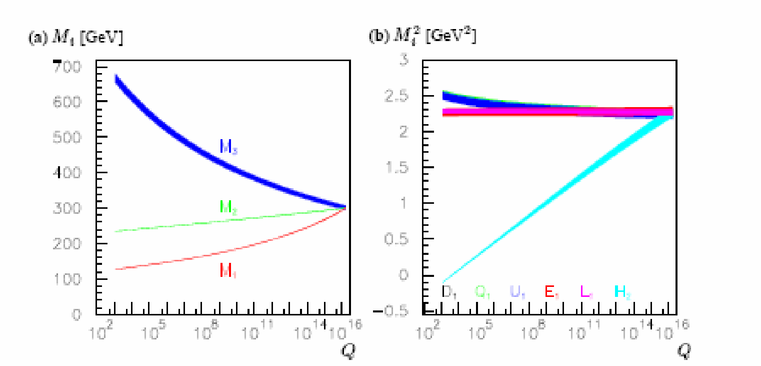


Figure 5 : Running of a gaugino mass parameters (a) and first generation sfermion mass parameters $M^2_{H,2}$ (b), assuming 1% errors on sfermion and heavy Higgs boson masses.

1.2.3 New Theories

Beyond the supersymmetry, and beyond the TeV scale, there is a wide range of scenarios. These scenarios could explain the EW symmetry breaking without a light Higgs boson, stabilize the SM if the supersymmetry doesn't exist or then embed the SM in a GUT. In the following paragraph, we will give some examples of these different theories.

1.2.3.1 Extra Dimensions

The hypothesis of the possibility that new spatial dimensions can be observed at high energy is motivated by the hierarchy problem and appears naturally in the string theory. The idea is that the world we see is in 4 dimensions but that the gravity can expand in 4+δ dimensions, in which the extra dimension could have a size from fm to mm scale.

- **The large extra dimension or ADD model**

The virtual Kaluza-Klein graviton deviate the SM parameters. The spectrum of the graviton excitation is nearly-continuous, due to the very weak interaction of the graviton. The signature will be obtained by the experimental missing energy.

- **Randall-Sundrum model**

The SM fields are on brane and the graviton is in the bulk KK. In this case the linear collider will be a KK factory, which will be observed thanks to their resonances (KK tower) in the e+e- -> μ+μ- cross sections (Figure 6). The properties of KKs (spin, BRs, etc…) will be measured.

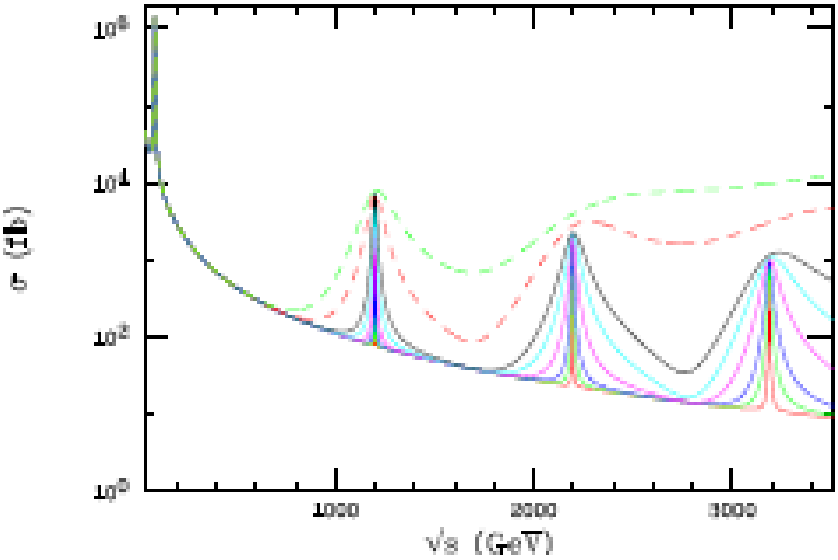


Figure 6 : KK graviton excitations in the RS model produced in the process e+e- ->μ+μ-. From the most narrow to the widest resonances.

- **Universal extra dimension model**

In this theory all the particles can go into the bulk. Each particle has a KK partner. The spectrum looks very similar to a SUSY spectrum. The measure of the spin of the particles will differentiate the two models.

1.2.3.2 Black Holes

Theoretically, it will be possible to generate micro black holes, the mass of which could be equal to the energy of the machine. This could allow the physicists to study the quantum gravity. Figure 7 shows that the decay process of the black hole is dominated by the Hawking radiation, so all the elementary particles should be produced democratically and spherically.

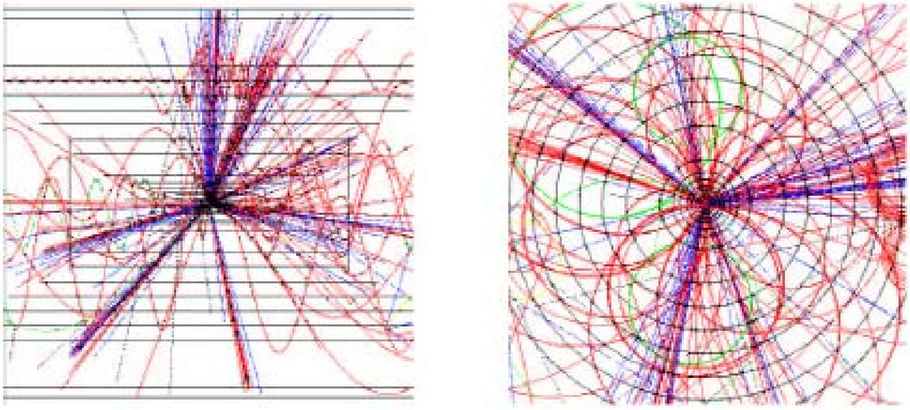


Figure 7 : Black hole production in a CLIC detector

1.2.3.3 New gauge theories

Several new theories predict the existence of new vector resonances. If the centre of mass energy is sufficient, the most observable manifestation will be a sudden increase of the e+e- ->ffbar cross section.

- **New resonances Z'**

The simplest SM extension of the SM consists in adding U(1) gauge symmetry breaking close to the Fermi scale. This introduces an extra Z' boson having the same coupling as the SM Z°.

One of the methods used to detect this new boson at a linear collider will be the same as the one used at LEP to detect the Z boson. Figure 8 shows the cross section for the dilepton final state will be measured with a centre of mass energy scan.

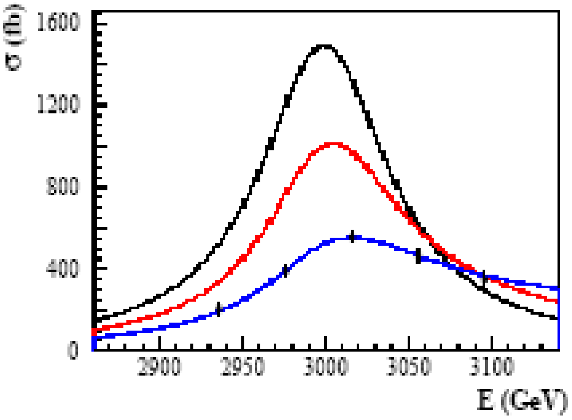


Figure 8 : *The Z'$_{SSM}$->l+l- resonance profile obtained by an energy scan.*

- **WW scattering**

In the scenario where the Higgs boson has a mass inferior to 700 GeV and its coupling with gauge bosons is not large enough, it is expected that the W^{+-} and Z° develop strong interactions at energy around 1-2 TeV. This interaction could generate an excess of events above SM expectations.

The study of the e+e- ->WWυυ where the W pairs decay in hadronic mode, 4 jets very collimated shown in Figure 9, will be a clean final state to detect the WW scattering.

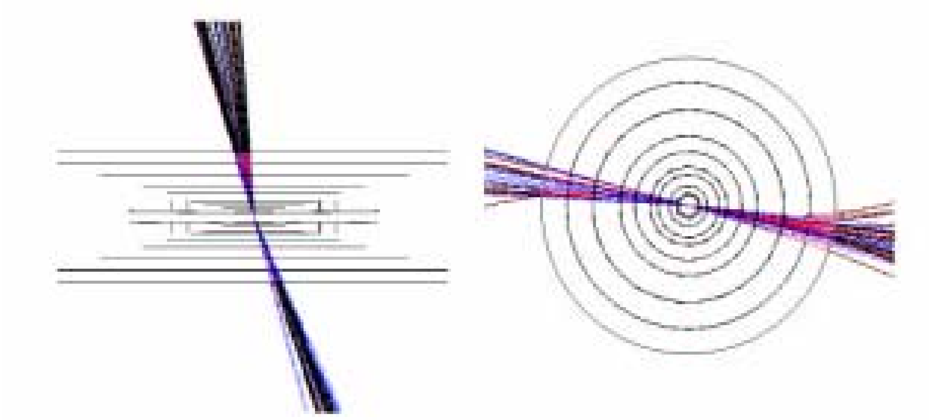


Figure 9 : Views of an event in the central detector, of the type
e+e- -> WWυυ -> 4 jets υυ, from a resonance with M_{WW} = 2 TeV

- **Little Higgs model**

In this mode, one of the Higgs boson is coupled with new heavy particles such as top quark T and gauge bosons Z_H and W_H. At the CLIC energy, the production of the heavy boson can be substantial. The mass of this boson can be determined thanks to the threshold behavior and the coupling thanks to the cross section rate.

1.2.4 QCD

Thanks to the γγ collision option, it will be possible to measure accurately:

- The total γγ cross section
- The photon structure
- The BKFL dynamics

2 Description of the CLIC

2.1 Parameters

The CLIC is a multi-TeV linear collider presently designed to perform e^+/e^- collision in the centre of mass at 3 TeV. It is based on a novel technology using high accelerating gradient of 150 MV/m. The “compact” collider overall length is ~ 33 km. This high gradient is at the technology limit. It requires the operation at 30 GHz in order to stay below the limits of the surface heating, the RF breakdown and the dark current capture.

The design luminosity is ~ 10^{35} $cm^{-1}s^{-1}$. The luminosity scales like the ratio of the wall-plug beam efficiency times the wall-plug power to the vertical emittance [3]. To keep the energy consumption at a reasonable level, say half a nuclear plant, the wall-plug to beam efficiency should be as high as possible. With the CLIC technology, a wall-plug beam efficiency of ~ 10 % is achievable. Therefore the normalized vertical emittance at interaction point (IP) should be ~ 10^{-8} rad.m.

The Table 1shows the main parameters for a CLIC with 0.5 TeV and 3 TeV centre of mass energy. The upgrade from 0.5 TeV to 3 TeV can be relatively easily done and built in stages thanks to the modular design of the RF accelerating structure.

Table 1 : Main parameters for a CLIC delivering 0.5 and 3 TeV in the centre of mass.

Center of mass Energy (TeV)	0.5 TeV	3 TeV
Luminosity (10^{34} cm-1s-1)	2.1	8.0
Mean energy loss (%)	4.4	21
Photons / electron	0.75	1.5
Coherent pairs per X	700	$6.8\ 10^{8}$
Rep. Rate (Hz)	200	100
10^{9} e± / bunch	4	4
Bunches / pulse	154	154
Bunch spacing (cm)	20	20
H/V ε_n (10^{-8} rad.m)	200/1	68/1
Beam size (H/V) (nm)	202/1.2	60/0.7
Bunch length (μm)	35	35
Accelerating gradient (MV/m)	150	150
Overall length (km)	7.7	33.2
Power / section (MW)	230	230
RF to beam efficiency (%)	23.1	23.1
AC to beam efficiency (%)	9.3	9.3
Total AC power for RF (MW)	105	319
Total site AC power (MW)	175	410

2.2 CLIC RF power source

Standard RF power sources based on modulators and klystrons as used in the SLC at SLAC are not available at a frequency as high as 30 GHz. Moreover, their cost would not be affordable due to the large number of necessary power stations. The CLIC RF cavities are fed with a dedicated and innovative power source. The power at 30 GHz is produced by a drive beam. The CLIC is a two beams accelerator, thanks to this new technology, the power source and the main linac are sitting in the same tunnel. The Figure 10 shows the layout of the CLIC RF power source. There is one RF power source for each main linac. The description of the main components is given in the following sections.

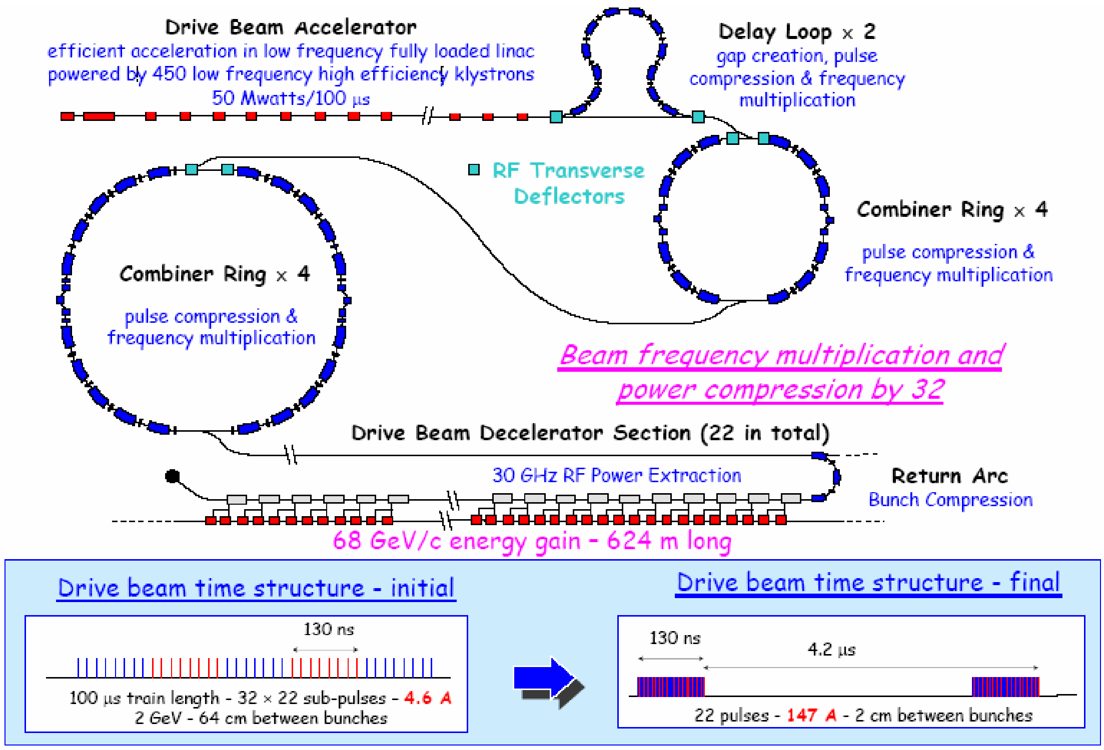


Figure 10 : Layout of the CLIC RF power source which produces the drive beam.

2.2.1 Introduction

The CLIC main beam operates with 130 ns long pulses at about 230 MW per accelerating structure at 30 GHz. An electron beam, the drive beam, is used to produce the power which is extracted trough resonant decelerating structures (PETS) towards the main beam. The drive beam combines very long RF pulses and transforms them in many short pulses with high power and higher frequency. The advantage of the electron beam manipulation as compared to RF manipulation in standard klystron technology consists in very low RF losses while transporting the beam pulses over long distance and compressing them to very high ratio. In the meantime, a frequency multiplication is obtained.

2.2.2 Description of the CLIC RF power source

The CLIC drive beam injector uses a thermionic gun, a bunching system and an injector linac to produce pulses of 92 μs with 8.2 A and about 43 000 bunches. The electron beam is accelerated by the drive beam accelerating linac from 50 MeV to 2 GeV. The traveling wave cavities, operating at 937 MHz, are fully loaded to increase the efficiency and are powered by 450 klystrons of 50 MWatts/pulses (multibeam klystrons).

The beam is sent into a delay loop (x2) and two combiner rings (x4, x4) to increase the beam frequency and to compress the power by a factor 32. The challenges of such beam manipulations are to preserve the bunch quality. The final r.m.s bunch length shall be 0.4 mm for 16 nC bunch charge. The beam is distributed in the delay loop and in the ring by RF transverse deflectors.

After this manipulation, the beam is sent trough transfer lines towards a return arc where a bunch compression system reduce longitudinally the bunches from 2 mm to 0.2 mm.

Finally, the 30 GHz drive beam is decelerated to produce RF power to feed the main linac. Each drive beam decelerator contains 500 PETS which shall feed 1000 main linac accelerating structure (250 modules). The 147 A drive beam is decelerated from 2 GeV down to 0.2 GeV before being dumped. Over a length of 624 m, the decelerated drive beam gives an energy gain of 68 GeV to the main beam. For a 3 TeV collider, 22 drive beams are required.

2.2.3 Power transfer efficiency

The power is a key parameter for a future linear collider; the total wall plug power is 300 MW for a CLIC complex at 3 TeV.

Figure 11 shows the power flow of the wall plug power to the beam. The wall plug power to RF efficiency is 40 %. The lowest transfer efficiency along the chain is constituted by the low frequency (1 GHz) klystron power production to the drive beam (65 %). The RF to main beam power efficiency is 25 %. The overall total wall plug to main beam power efficiency is 10 %.

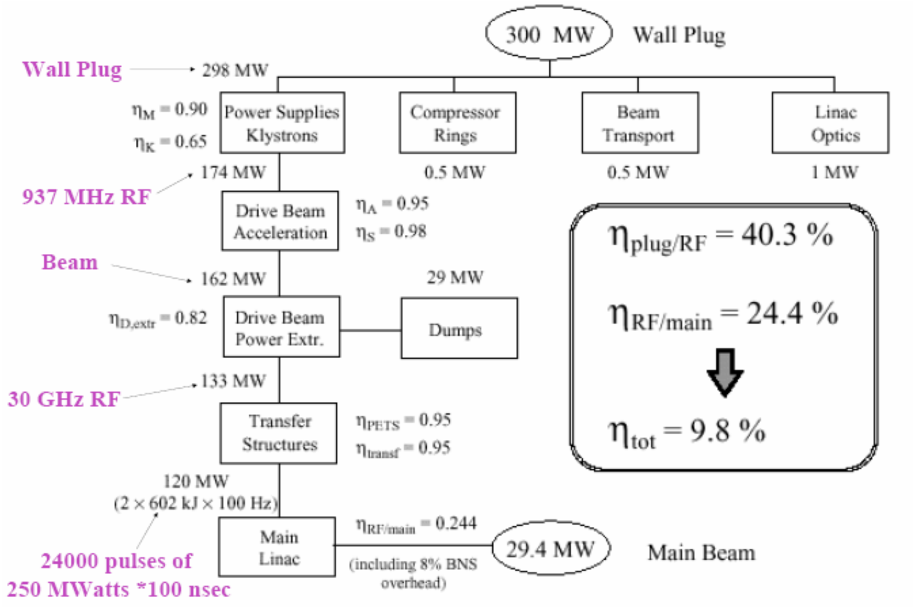


Figure 11 : The CLIC power flow from the wall plug to the main beam.

2.3 *CLIC Main beams Complex*

The main beams used for the physics studies are produced in a dedicated injector. The injector produces a positron and an electron beams with the required longitudinal and transverse dimensions. Afterwards, the energy of the bunches is increased in the accelerating module up to 1.5 TeV. A final focus system deflects and focuses the beams to the interaction point before being dump.

2.3.1 CLIC injector complex

Figure 12 shows a schematic of the CLIC injector complex. The electron source is based on RF photo-injector which produces 1 nC/bunch with 154 bunch/pulse. A pulse is 140 ns long, there are 100 pulses/s (100 Hz). At the exit of the injector linac, the electron beam enters the damping rings at 2.4 GeV.

The positron line is built with another electron source based on a RF photo-injector which produces 2.2 nC/bunch. The 154 bunch/pulse are sent to a e-/e+ converter at 2 GeV. For the sake of reliability a second positron source could be built close to the first one, but with an independent access. The positron beam is captured and accelerated to 2.42 GeV to enter the damping rings.

The beam emittance is reduced trough synchrotron radiation emission down to the damping ring equilibrium emittance. The positron beam needs a pre-damping ring because of its high initial transverse emittances. The energy of the damping ring is 2.4 GeV as a trade-off between fast cooling and small equilibrium emittances, and the bunch frequency 3 GHz.

At the exit of the damping rings, the bunch compressor reduces the rms bunch length from 3 mm to 30 μm. A first bunch compression is done at the exit of the damping ring and another one, after the transfer line at the entrance of the main LINAC at 9 GeV.

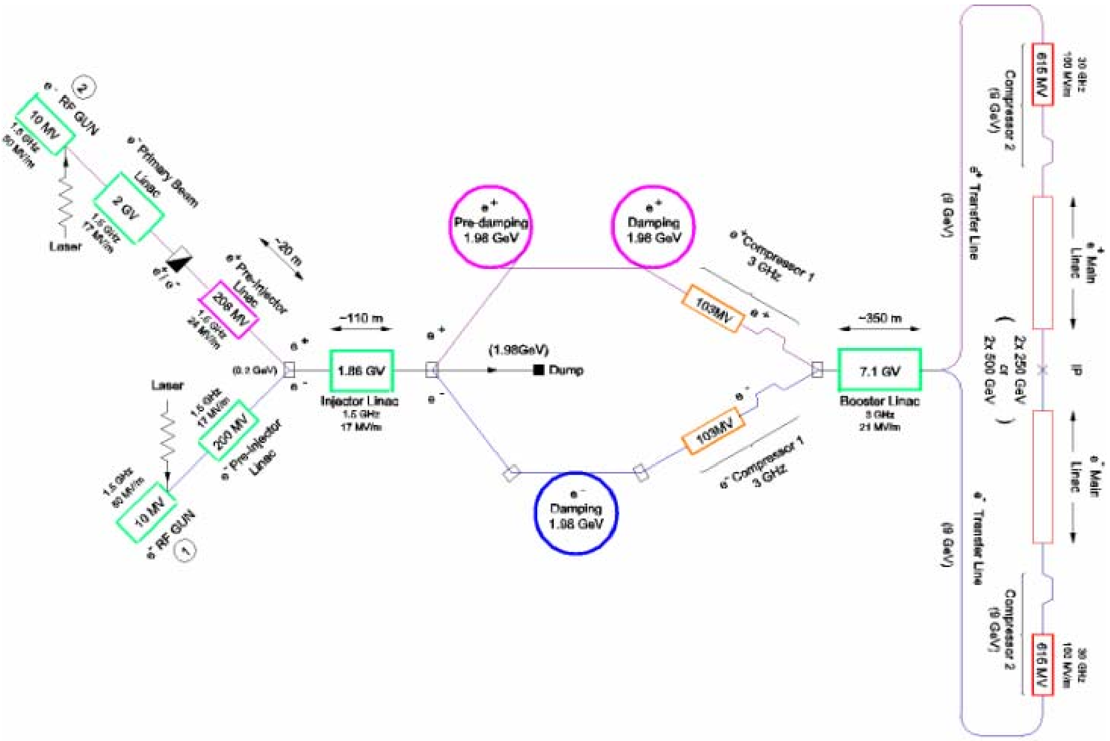


Figure 12 : The CLIC injector complex for the e^+ and e^- main beams.

2.3.2 Accelerating modules

Figure 13 shows a CLIC module of the main beam and the drive beam together with the tunnel cross section. The drive beam produces 230 MW at 30 GHz while decelerating from 2 GeV to 200 MeV. Using this power, the main beam of 1 A is accelerated from 9 GeV to 1.5 TeV at a gradient of 150 MV/m. The pulse of 100 ns contains 154 bunches of $4\ 10^9$ particles with 35 μm length. Each bunch is separated by 20 cm. To build a 3 TeV linear collider, 6000 modules/linac are required. During acceleration by the 24000 accelerating structures the beam emittance shall be preserved. For this reason, a transverse alignment tolerance of 100 μm is required to limit emittance blow up. To this mean, a concrete block to support the two beams and an active alignment system are used. A wire positioning system ensures a relative precision of 10 μm over 200 m. The simulations predict an increase of 20 % of the emittance along the main beam.

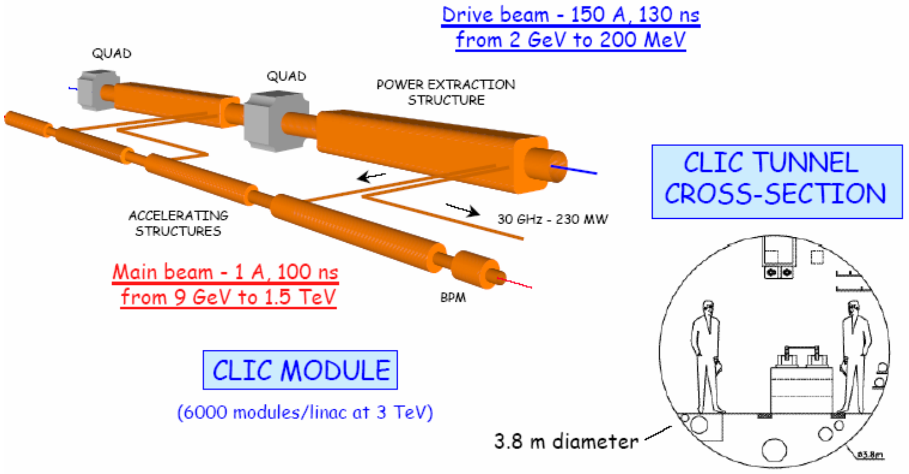


Figure 13 : CLIC accelerating module together with the CLIC tunnel cross section. The module shows the main beam and the drive beam.

2.3.3 Beam delivery system

The beam delivery system is divided into three subsystems : the collimation section, the chromatic correction section and the telescope of the final focus. At the IP, the beam will be transversally focused to 60 nm and 0.7 nm. Beamstrahlung is produced by the strong electromagnetic fields of the colliding bunches. The consequence is a luminosity spectrum and a background into the detectors due to the pair production [4]. After the collision, the beams are dumped in a dedicated area.

3 Achieved challenges and challenges to be reached

To perform collisions at the multi-TeV level, the accelerator community is facing several challenges. Some of the challenges are common to multi-TeV collider and are addressed by different laboratories, others are specific to the CLIC technology and are specifically addressed by the CLIC community. The challenges marked by a ∗ are currently addressed in test facilities.

The challenges common to multi-TeV linear colliders are :

- Accelerating gradient ∗
- Generation and preservation of ultra-low emittance beams
- Beam Delivery & IP issues such as nanometer size beams and sub-nanometer component stabilisation ∗
- Physics with colliding beams in high beamstrahlung regime

The challenges specific to the CLIC technology are :

- 30 GHz components with manageable wakefields ∗
- Efficient RF power production by Two Beam Acceleration ∗
- Operability at high power (beam losses) and linac environment (RF switch) ∗

4 Test Facilities

We discuss in this section the main test facilities or colliders which have studied or are studying challenges linked to the CLIC design.

4.1 ATF

The next generation of electron-positron linear colliders must collide multi-bunch trains of electrons and positrons with extremely small transverse and longitudinal emittances. This is an essential requirement for obtaining the desired collision luminosity. The ATF (Accelerator Test Facility) project was launched at KEK in 1990 as a test facility for investigating the technical feasibility of the low-energy portion of future linear collider (the damping ring), which is responsible for producing multi-bunch beams with extremely low emittance. One of the successes has been the achievement of vertical emittance below 5 pm, which was made possible through a variety of advanced tuning techniques and diagnostic systems, including a novel procedure for beam based alignment of the main quadrupoles. ATF achieved emittance very close to the 0.5 TeV design of CLIC (see Table 1).

4.2 SLC, FFTB

The SLAC Linear Collider (SLC) operated at Stanford in the 90's. The SLC is the only linear collider which produced physics. It gave majors contributions to the development and understanding of e+/e- source (photocathode and polarized electrons), damping ring, bunch compression, emittance preservation and final focus.

The Final Focus Test Beam at SLAC (FFTB) is a prototype linear collider final focus, designed to reduce the 46.6 GeV SLAC beam to a size of 2 microns by 60 nanometers. The FFTB has the horizontal and vertical demagnifications required by a future linear collider, and thus addresses all the same optical aberrations.

4.3 CTF Facilities

In order to study the principle of the CLIC based on the two beam acceleration scheme at high frequency, a CLIC Test Facility (CTF) has been set-up at CERN. The CTF started in the second half of the 80's and are still active today. The facilities are used to specifically address CLIC challenges. As far as the challenges were reached, the facilities increased in complexity from CTF1 to CTF3 today.

The CTF1 demonstrated that the generation of a high intensity drive beam with short bunches by a photo-injector, the production of 30 GHz RF power and the acceleration of a probe beam by 30 GHz structures were possible. The generation of 30 GHz RF power was tested in a prototype CLIC, 30 cm long, traveling wave section. 30 GHz pulses with a peak power of 60 MW were produced by the CLIC section. These power pulses were fed into a second identical CLIC structure to produce the high accelerating gradients. At the end of 1994 such pulses were used to test a prototype CLIC transfer structure. The high peak power is obtained with a train of 24 or 48 bunches, 333 ps apart, and a total charge of 80 nC (for 24 bunches) or 145 nC (for 48 bunches).

CTF2 was a real prototype, launched in 1996, of a two beam accelerator operating at 30 GHz. It was equipped with fully-engineered CLIC building blocks (modules) and with the CLIC active alignment system. The 10 m long, test section very similar to the CLIC drive and main linacs, produced up to 480 MW of peak RF power at 30 GHz and accelerated the beam up to 320 MeV.

Figure 14 shows the layout of the CTF3 facility presently under construction. This facility is a test of the drive beam generation, acceleration and RF multiplication by a factor 10. It is a small scale version of the CLIC RF power source.

With CTF3, at the level of the RF power source : fully-loaded operation of drive beam accelerator, combination of bunch trains with transverse RF deflectors, bunch "coding" with fast phase-switch and power production efficiency will be tested. At the level of the 30 GHz acceleration and components : nominal accelerating field of 150 MV/m with pulse duration larger than 130 ns, components, integration of components in modules and two-beam operation and beam loading compensation for multi-bunches will be tested.

After the CTF3 validation, at the level of the RF power source: operation at full current and energy with beam power handling, drive beam stability during deceleration and operation at full pulse length will remain to be validated. Finally, at the level of the 30 GHz acceleration : main beam stability during acceleration, emittance preservation, and others general issues for multi-TeV colliders (such as generation of ultra-low emittances, focusing and colliding very small beam and beam delivery section) will remain to be validated.

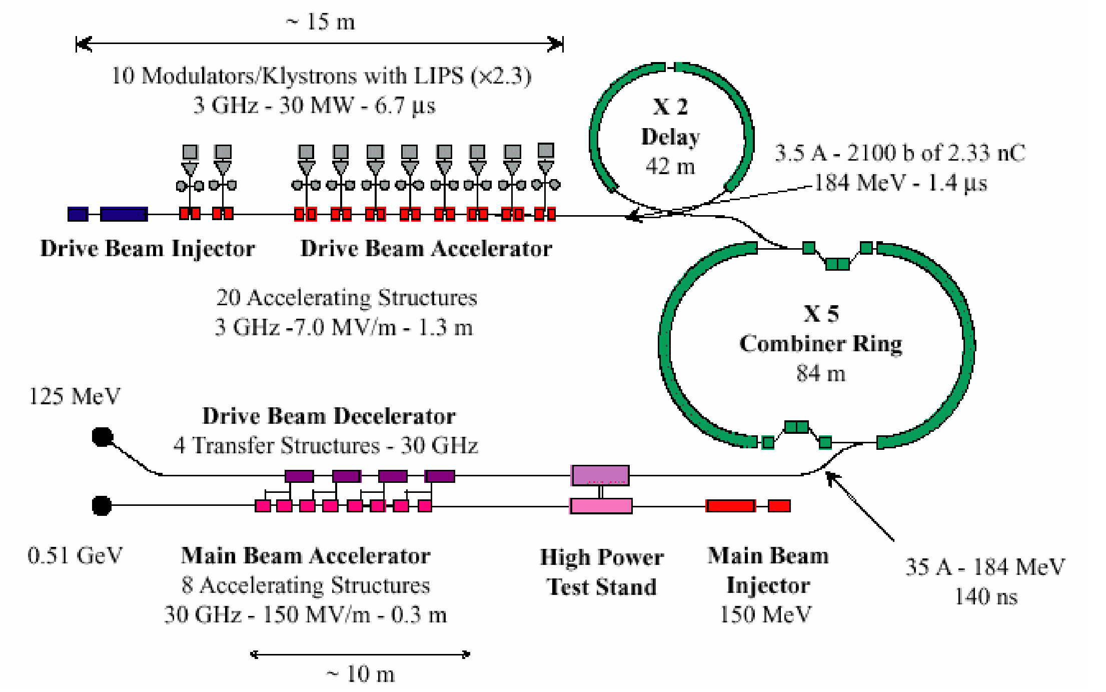


Figure 14 : Layout of the CTF3 defined to address the RF multiplication technology to be used in the CLIC power complex.

5 The CLIC position in the linear collider world

The Tevatron at FNAL or the LHC at CERN will discover the Higgs boson and the supersymmetric particles if they exist. A worldwide consensus is born to set out the scientific case for a 500 GeV e^+e^- linear collider, upgradeable to higher energy in the future and with options retained for special investigations with alternate beam particles and added polarization capability [5]. The statement has helped the International Linear Collider Steering Committee to define the scope of the baseline facility [6]. This committee has defined ranking R&D for linear collider studies (R1, R2, R3, and R4):

- R1: R&D needed for feasibility demonstration,
- R2: R&D needed to finalize design choices,
- R3: R&D needed before starting production,
- R4: R&D desirable for technical/cost optimization.

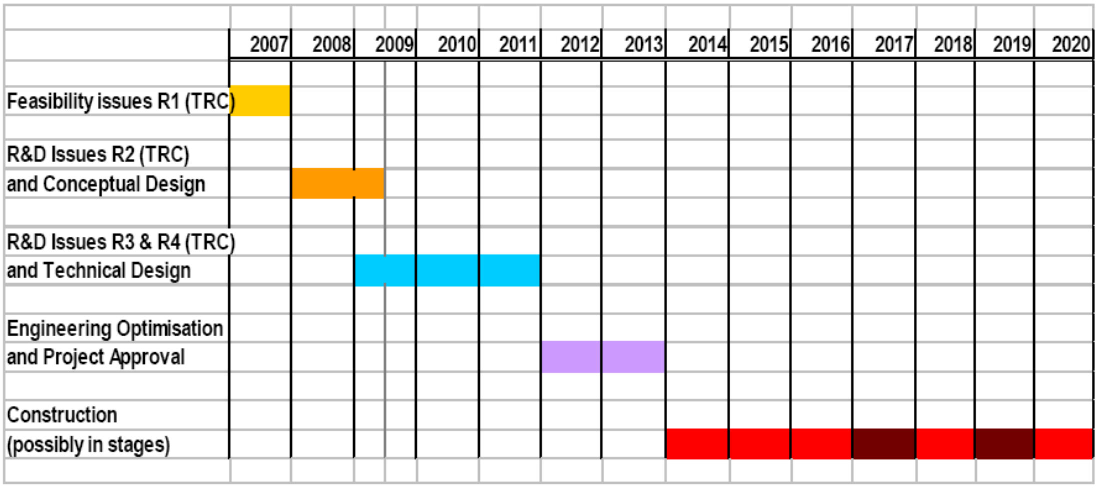
Two projects for a TeV class linear collider, using two different acceleration technologies (TESLA project with superconductive technology, NLC project with room temperature technology) have already demonstrated the R1 key issues.

An ITRP (International Linear Collider Technology Recommendation Panel) has been created to choose between these two technologies, in order to enable the international community to concentrate their efforts on one final design. Its recommendation for a superconducting technology has been endorsed by ICFA in Summer 2004.

For the TeV class linear collider, the first collision could start in 2015 and then run at the same time as LHC. It would give an important complementarity between the collected data.

Figure 15 shows the CLIC R&D and construction milestones. The CLIC specific issues R1 and R2 will be addressed in CTF3. The CTF3 project is divided in packing and will be done with extended collaboration. R1 shall be completed by 2007 and R2 by 2009.

The CLIC technology has a delay of about 5 years compared to the TeV class collider.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Feasibility issues R1 (TRC)	🟨													
R&D Issues R2 (TRC) and Conceptual Design		🟧	🟧											
R&D Issues R3 & R4 (TRC) and Technical Design			🟦	🟦	🟦									
Engineering Optimisation and Project Approval						🟪	🟪							
Construction (possibly in stages)								🟥	🟥	🟥	🟫	🟥	🟫	🟥

Figure 15 : CLIC R&D and construction milestones

The key issues common to each accelerator technology will be addressed by collaboration in the frame of a design study (EU framework program, 27 collaborating institutes). It could be completed by 2008.

By 2010, a technology evaluation and Physics assessment based on LHC results for a possible decision on Linear Collider funding with staged construction starting with the lowest energy required by physics could be done.

6 Long term scenarios

As shown in Figure 15, the CLIC will be possibly constructed in different stages and start with low energy physics facilities. We will show here the possible CLIC stages approach before the optimized stage at 3 TeV.

The first stage could be to construct an half CLIC section with energy of 68 GeV. This complex could be used to create an X-ray FEL demanding some adaptations to reduce the spread of energy and the emittance of the beam. Another application of this stage, shown in Figure 16, could be to create a QCD Explorer (QCDE) using collision between the electron beam CLIC stage 1 and the proton beam of LHC. This facility will give optimum luminosity (L $>10^{31}$cm^{-2}s^{-1}) with proton superbunches, which require LHC update. This will go beyond the measurement of HERA by 2 orders of magnitudes [7]. However, the location of this first stage will not be optimum for a future extension.

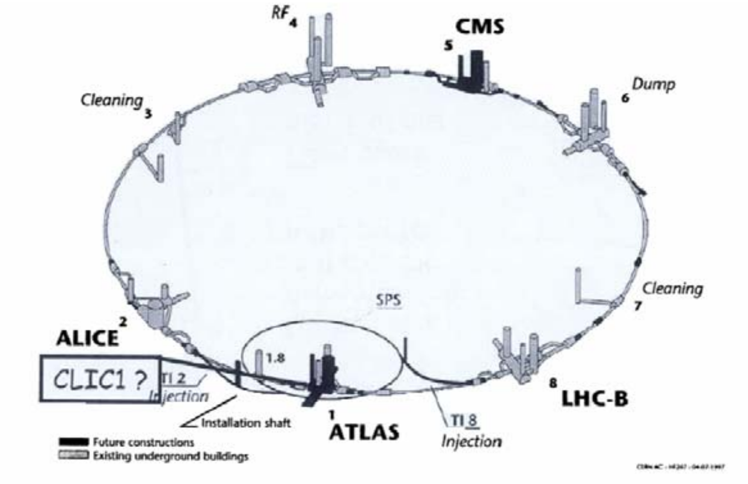


Figure 16 : Scheme of the QCD Explorer

The second facility is to build a Z and W factory using two linacs made up of one CLIC section. As shown in Figure 17, its total length will be of about 2 km. For the Z factory the centre of mass energy will be 90 GeV, obtained with two linac giving 45 GeV (gradient of 80 MV/cm) each. For the W factory the centre of mass energy will be 160 GeV, obtained with two linac giving 80 GeV (gradient of 157 MV/cm) each. The luminosity will be respectively 8 10^{33}cm^{-2}s^{-1} and 1.3 10^{34}cm^{-2}s^{-1}, if the accelerating structures can be powered at 200 Hz repetition rate.

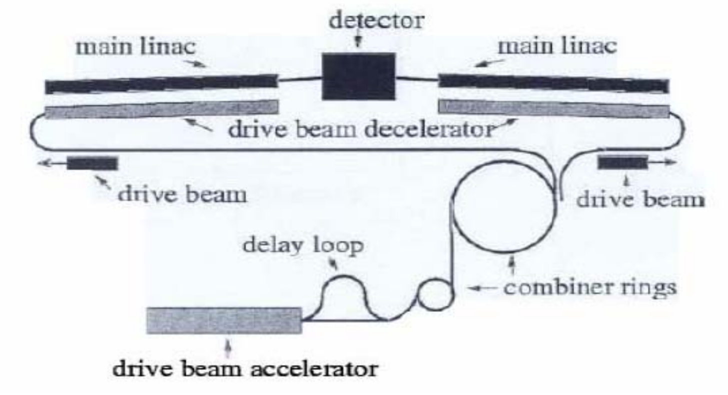


Figure 17 : Scheme of the Z and W factory.

The last and not the least possibility of using the first two sections of CLIC, is to build a low energy γγ collider with a centre of mass energy of 115 GeV, which will be a Higgs factory. Figure 18 shows the scheme of such a factory named CLICHÉ. With a γγ luminosity of 8.3 $10^{33}cm^{-2}s^{-1}$, CLICHÉ will be able to produce 20000 light Higgs bosons per year allowing to measure accurately the bbar, WW and γγ decays of the light Higgs [8].

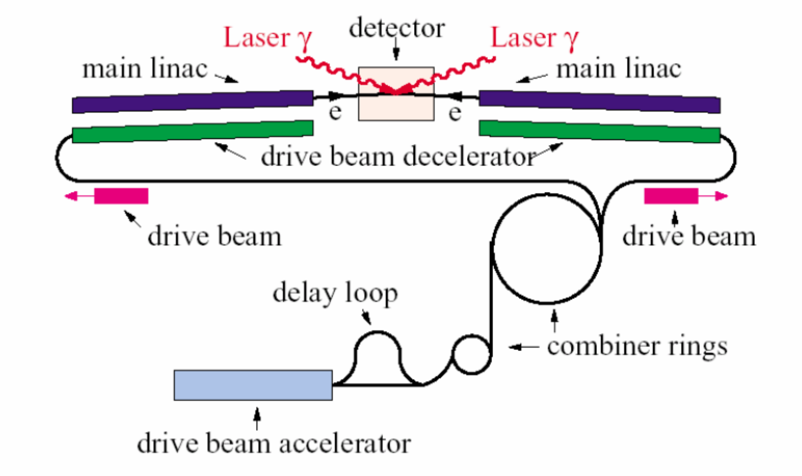


Figure 18 : Scheme of the light Higgs factory (CLICHÉ), the γγ collisions are obtained by back scattering on the electron beam.

7 Conclusion

The CLIC is a R&D study which is complementary to Super-Conducting technology recently down-selected by ITRP for a TeV Linear Collider and necessary in order to extend energy range of linear colliders in the future. It is the only possible scheme to extend linear collider energy into the Multi-TeV range.

The CLIC technology is not mature yet, and requires challenging R&D, but has very promising performances already demonstrated in CTF2.

The R&D key issues are clearly identified (ILC-TRC): on one hand there is the key-issues independent from the technology studied by 2008 in a wide collaboration of European Institutes (Design Study submitted to EU FP6 funding), and on the other hand there is the CLIC-related key-issues addressed in CTF3 (feasibility by 2007 and design finalisation by 2009) if extra resources can be found.

CLIC is complementary to the ILC as a safety net to the Super-Conducting technology in case of LHC results show that a sub-TeV energy range is not found attractive enough for Physics or as the technology for a second generation of Linear Collliders to extend their colliding beam energy into the multi-TeV range. Nevertheless it is possible to start the construction in stages with low energy applications.

Of course there is still a lot to be done before the CLIC technology can be operational and new ideas and challenging work in world-wide collaborations is needed. So YOU ARE ALL WELCOME to participate and make the CLIC scheme and technology a realistic tool in the best interest of Physics

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