Status of Clic Study Toward a Multi-TeV Linear Collider

Goal of CLIC study

Develop technology for a linear e+e- collider at 1-3 TeV c.m.

Collision energy for physics complementary to LHC.
3) for problems common with other linear collider projects close collaboration

2) interaction point issues specific to multi TeV collisions

- backgrounds at multi TeV interaction point
- particle identification at multi TeV interaction point

1) two beam/high frequency specific items like

- 30 GHz RF technology for main linac & drive beam decelerator
- drive beam generation & transport
- linac alignment and orbit correction methods

organization of study

drive beam as efficient & scaleable RF power source

cmp of CLIC

normal conducting, high frequency (30 GHz) accelerator for high gradients to keep total length reasonable
# CLIC Main Parameters

<table>
<thead>
<tr>
<th>Centre of mass energy</th>
<th>[TeV]</th>
<th>0.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam parameters at IP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect lumin. (with pinch)</td>
<td>$10^{34} \text{cm}^{-2} \text{sec}^{-1}$</td>
<td>L</td>
<td>1.0</td>
</tr>
<tr>
<td>Luminosity (within 1% Δp/p)</td>
<td>$10^{44} \text{cm}^{-2} \text{sec}^{-1}$</td>
<td>L</td>
<td>1.0</td>
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<tr>
<td>Average energy loss</td>
<td>[%]</td>
<td>$\delta_h$</td>
<td>4.4</td>
</tr>
<tr>
<td>Beamstrahlung parameter</td>
<td>[-]</td>
<td>Y</td>
<td>0.3</td>
</tr>
<tr>
<td>Linac repetition rate</td>
<td>[Hz]</td>
<td>$f_r$</td>
<td>200</td>
</tr>
<tr>
<td>Number of particles/bunch</td>
<td>$10^9 \text{e}^+$</td>
<td>$N_c$</td>
<td>4.0</td>
</tr>
<tr>
<td>Number of bunches/pulse</td>
<td>[-]</td>
<td>$n_b$</td>
<td>154</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>[m]</td>
<td>$\Delta_h$</td>
<td>0.20</td>
</tr>
<tr>
<td>Transverse emittances</td>
<td>$10^8 \text{radm}$</td>
<td>$\gamma \varepsilon_{x/v}$</td>
<td>200/2</td>
</tr>
<tr>
<td>RMS beam width</td>
<td>[nm]</td>
<td>$\sigma^*_x$</td>
<td>202/2.5</td>
</tr>
<tr>
<td>Bunch length</td>
<td>[$\mu$m]</td>
<td>$\sigma_z$</td>
<td>30</td>
</tr>
<tr>
<td>Beam power per beam</td>
<td>[MW]</td>
<td>$P_b$</td>
<td>4.9</td>
</tr>
</tbody>
</table>

## Main Linac

| RF frequency of main linac | [GHz] | $\omega/2\pi$ | 30 | 30 |
| Accelerating field (loaded) | [MV/m] | G | 150 | 150 |
| Total two linac length | [km] | $l_T$ | 5.0 | 27.5 |
| RF power at section input | [MWatts] | $P_s$ | 229 | 229 |
| RF pulse length | [$\mu$sec] | $\Delta_k$ | 0.130 | 0.130 |
| Number of structures/linac | [-] | $N_S$ | 6940 | 21470 |
| AC to beam efficiency | [%] | $\eta_{AC-B}$ | 9.8 | 9.8 |
| AC power for RF generation | [MW] | $P_{AC}$ | 100 | 300 |
power will be non-trivial and needs further investigation. Handling of 332 GW of instantaneous beam power and 40 MW of average beam power. BPM resolution \(\sigma \approx 5\) mm and pre-firing with \(\sigma \approx 100\) mm assumed.

(BPM resolution \(\sigma \approx 5\) mm and pre-firing with \(\sigma \approx 100\) mm assumed)

Beam dynamics issue in drive beam acceleration and decelerator seem to be ok.

Overall scheme will be tested in CTF3.

Read for 20 MW 937 MHz Klystron has started in industry prototypes of 30 GHz power extraction structures work very satisfactorily in CTF1.

Drive beam scheme with fully loaded drive beam Linac, combiner rings and split drive beam scheme.
RF Power Source - Overview
\[ V_{\text{acc}} \approx I/2 \]\n
- No power flows out to the load
- The copper situation
  - High efficiency
  - Structure
    - Loaded gradient still greater than zero at the end of the structure due to losses in copper
    - Unloaded gradient decreases
      - "Standard" situation

High current, short accelerating structures & low gradient

How to be \( \sim 100\% \) efficient accelerating with normal conductining structure? RF sources to the beam. The first thing to do is transfer efficiently the power from the low frequency.

*Fully-loaded Acceleration*
Bunch Phase Coding & Delay Loop

- Use every other bucket
- Switch from even to odd buckets to code the pulse
- Need a gap for the kicker rise time (clean extraction process)
- Want a continuous train of bunches in the accelerator (avoid beam loading transients)

RF Transverse deflectors - 468.5 MHz

Delay loop

Detecion - 468.5 MHz

Acceleration - 937 MHz

92 lus train length - 16 x 22 pulses - 15 A peak current

92 lus train length - 32 x 22 sub-pulses - 7.5 A current

Sub-pulse length 64 cm

Sub-pulse length 130 ns or 39 m

Pulse length 130 ns
Multi-turn Combination in Ring
Four-Turn Ring Injection

- Want a factor 4 pulse compression & frequency multiplication
- Use transverse RF deflector injection in a ring
The distance between pulses is $2l_{\text{main}}/N^2$.

Counter-flow distribution allows one to power different sections of the main linac with different drive beam pulses. The initial drive beam pulse length is equal to $2l_{\text{main}}$. In several $(N^2 = 22)$ drive beam pulses, each one powering a 700 m long section of TBA, instead of using a single drive beam pulse to power the main linac, the initial pulse is split.
Tests in CTF2 two-beam acceleration is a high impedance version used PET's. The one shown in this page: Transverse cross-section of a PET's model.
Ground motion support design, check if orbit correction algorithms can be found in presence of feedback. Algorithm methods design quarantine. Further study needed to investigate feedback methods.

However, low frequency motion with \( v < 100 \) Hz can be compensated by feedback, high frequency motion has usually small amplitudes.

\[
\text{With } (10 \text{ mm vibrations) luminosity reduced by 30%},
\]

tolerance of line quadrupoles. This introduces very stringent constraints of \( 1 \) mm on vibration amplitudes. To achieve this very strong focusing is needed. Together with the very small acceleration with little emittance growth.

Achieves \( \Delta x \approx 10 \text{lm orbit can be corrected by appropriate algorithms for } \Delta x \approx 0.5 \text{ pm and prealignment with active alignment syst.}

If BPM resolution \( \Delta x \approx \frac{\Delta x}{2} \) beam dynamics.

Main Linear - beam dynamics.
Fig. 2. Power spectra of vertical seismic vibrations measured in Russia (UNK, LEP tunnels), in Switzerland (LEP tunnel, CERN) [4] and in Finland (Hiddensee cave) in quiet conditions.

Power spectrum of ground motion:

- Quiet conditions
- Hiddensee cave, 18-08-94, 4 cm
- CERN LEP tunnel, 23-03-93, 1 cm
- Freilting UNK tunnel, 11-11-92, 2 cm

Motion \( \dot{\omega} \) for given frequency \( \omega \) shows power \( P(\omega) \) in \( \text{Hz}^2 \) / Hz
Recently damage in some of the structures used in CTF II observed.

Problems:

But design needs refinement to reduce local heating an to increase Q.

Test of aluminium model in ASSET gives promising results.

Preliminary design for multibunch structure with HOM dampers and dipole

multibunch operation.

These structures are without HOM support, which is mandatory for
6 GHz power prototypes. Structures built, 5 tested with beam so far.

30 GHz (10mm wavelength) structures

Techniques developed for machining & brazing of

Main Linac - accelerating structure
The CLIC braze/diffusion bond joint

Assembly in precision granite V-block

Vertical in brazing oven

Diamond machined on Diamond machined surface

Braze/diffusion bond

0.03 mm
TDS wakefield experiment at ASSET
Problems of RF breakdown & structure damage

until end 1999 believe that 30 GHz structures are "breakdown free" for RF pulse-length achievable with CTF II (15 ns), because no significant reflected power was observed. Then observation of mechanical damage in coupling cell.

Improved instrumentation shows now that in our pulse-length range RF energy is dissipated break down and only small amounts are reflected.

Seems that in our parameter regime maximum surface field is similar for single cell cavities travelling wave structures.

However, single cell cavities show no damage after breakdowns, travelling wave structures do.

R & D program:
• improve teststand vacuum conditions (presently $10^{-6}$-$10^{-7}$ mbar) now $10^{-9}$
• careful RF conditioning using emitted current information
• change structure geometry to reduce $E_{\text{surface}}/E_{\text{acc}}$ ratio
• investigate influence of group velocity
• improve surface cleanliness
• studies to understand breakdown mechanism (e.g. single cell experiments with different cavity materials, surface preparations etc.)
Structure damage in high field region
current emission (downstream of structure, upstream of structure)

RF power (incident, transmitted, reflected)
correlation between emitted current and missing RF energy
measurement of onset of RF breakdown as function of pulse-length

ratio $\frac{E_{\text{SURFACE}}}{E_{\text{ACCELERATION}}} = 2.8$ in CLIC structure
either this ratio or $E_{\text{SURFACE}}$ has to improve if we want to achieve CLIC goals
(with large uncertainty in calculations).

$\approx 4$ hadrons produced per bunch crossing by $\gamma - \gamma$ scattering.

controlled manner.

How to dump particles of opposite charge in a clean and

correspond to 20% of number of primary beam particles.

cohherent pair production: number of $e^+$ and $e^-$ produced

multi TEV problems at LEP.
Coherent Pair Creation

A photon can turn into a $e^+e^-$ pair in a strong external field

$$\frac{dN}{ds} \propto \frac{\exp\left(-8/(3\kappa)\right)}{(1 + 0.22\kappa)^{1/3}}$$

$$\kappa = \frac{\hbar \omega B}{mc^2 B_c} = \frac{\hbar \omega \gamma}{E_0}$$

<table>
<thead>
<tr>
<th>CLIC at $E_{CM}$ [TeV]</th>
<th>$n_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>700</td>
</tr>
<tr>
<td>1</td>
<td>$3 \cdot 10^6$</td>
</tr>
<tr>
<td>3</td>
<td>$6.7 \cdot 10^8$</td>
</tr>
<tr>
<td>5</td>
<td>$1.8 \cdot 10^9$</td>
</tr>
</tbody>
</table>
Hadrons

Hadrons can be produced by photon-photon collision
they can overlay interesting events
cross section is not measured at high energies

⇒ use parametrisation
here G. A. Schuler and T. Sjöstrand (pessimistic version)

\[ \sigma_H = 211 \text{ nb} \cdot \left( \frac{s}{\text{GeV}} \right)^\epsilon + 297 \text{ nb} \cdot \left( \frac{s}{\text{GeV}} \right)^{-\mu} \]
\[ \epsilon = 0.0808, \mu = 0.4525 \]
\[ E_{cm} \geq 5 \text{ GeV} \]

<table>
<thead>
<tr>
<th>name</th>
<th>TESLA [TeV]</th>
<th>NLC/JLC</th>
<th>CLIC</th>
</tr>
</thead>
</table>
| \(E_{cm}\) | 0.5 | 0.8 | 0.5 | 1.0
| \(N_H\) | 0.23 | 0.6 | 0.07 | 0.33 | 0.047 | 4.05 |

in TESLA it may possible to separate longitudinally
in normal conducting machines one may have to integrate over some bunch crossings
Configuration of 1999

Goals of CTF II:

Demonstration of Two-Beam Acceleration in CTF II

To develop and test CTF beam monitors
To test active alignment system in an accelerator environment
To develop and test the drive beam generation and transport
To design and construct a fully engineered representative CTF style test section
To study feasibility of two beam acceleration scheme at 30 GHz
30 GHz accelerating structure

30 GHz power extraction structure

(probe beam)

drive beam
system integration of 30 GHz booster/accelerator and active alignment are consistent with theoretical model measured drive beam deceleration, power transfer & main beam acceleration main beam has been accelerated by 60 MeV (limited by the drive beam charge) two beam acceleration at 30 GHz with structure of RF structures works high charge, tightly bunched drive beams can be generated, accelerated and CTF II has demonstrated: Summary two beam acceleration
End 2002, CTF II will be dismantled to make space for CTF3. Apart from this further experiments on coherent synchrotron radiation are planned. However, RF pulse length is limited to 15ns (CLIC design 120 ns).

Testing of 30 GHz structures: Peak power of more than 200 MW can be provided. 2001 & 2002 operation with a single extra long power extraction structure for high power.
(Laser for drive beam RF gun option)
SLAC (drive beam injector design)
(Thermionic guns and prebunchers)
LAL Orsay (combines ring and delay loop)
INFN Frascati (combines ring and delay loop)

Collaborations for CTE3

2003.

Forgseen in phases with interleaved beam experiments, from 2001 to

CTE3 has been approved by CERN management. Construction is

power $P > 240$ MW and pulse-length $T > 120$ ns

provide 30 GHz RF source to test prototype structures with nominal

and combiner ring

demonstrate drive beam generation scheme with fully loaded linac

goals:

CTE3
The NEXT CIC Test Facility
and provide the CTC nominal RF power and pulse length.

It will test the drive beam generation, acceleration, and RF multiplication by a factor 10.

It will be built at CERN. In the hall of the present LEPI-Injector complex (LPI).

CTF3 will be built at CERN. In the hall of the present LEPI-Injector complex (LPI).

The Next CTC Test Facility - CTF3
Successfully high power tested at nominal power levels

First CTF3 S-band drive beam accelerator structure with HOM dampers