Status and Future Prospects for CLIC

- Introduction
- CLIC design
- CLIC Test Facility (CTF 3) results
- Outlook and Conclusions

Steffen Döbert, LINAC 08, 29.9-3.10, 2008, Victoria, Canada
CLIC = Compact Linear Collider (length ~ 50 km)

Goal: Design for a 3 TeV $e^+e^-$ linear collider

ICFA: 'LC is necessary to complement LHC physics'

→ ILC (0.5 TeV) or CLIC (3TeV) depending on LHC results

European strategy for particle physics

‘to be well positioned to push the energy frontier,
R&D on CLIC should be intensified
as well as on high performance magnets and on high intensity neutrino facility’

Present:
Mandate at CERN for a feasibility study with a CDR in 2010
What is so special about CLIC

High-Frequency and High-Gradient normal conducting rf:
Accelerating gradient: 100 MV/m
RF frequency: 12 GHz

Two beam scheme:
Low-energy high-current drive beam
High-energy low-current main beam
Sophisticated drive beam generation (high Q rf pulse compression using the beam)

Power extraction structure:
136 MW, 0.21 m long

Drive beam – 100 A, 240 ns from 2.4 GeV to 240 MeV

Main beam – 1.2 A, 156 ns from 9 GeV to 1.5 TeV

Main accelerator structure:
64 MW input power, 0.23 m long
Not to scale!
## CLIC 3 TeV parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-of-mass energy</td>
<td>3 TeV</td>
</tr>
<tr>
<td>Peak Luminosity</td>
<td>$5.9 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$</td>
</tr>
<tr>
<td>Peak luminosity (in 1% of energy)</td>
<td>$2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Loaded accelerating gradient</td>
<td>100 MV/m</td>
</tr>
<tr>
<td>Main linac RF frequency</td>
<td>12 GHz</td>
</tr>
<tr>
<td>Overall two-linac length</td>
<td>41.7 km</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>$3.72 \cdot 10^9$</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>0.5 ns</td>
</tr>
<tr>
<td>Beam pulse duration</td>
<td>156 ns</td>
</tr>
<tr>
<td>Beam power/beam</td>
<td>14 MW</td>
</tr>
<tr>
<td>Hor./vert. normalized emittance</td>
<td>660 / 20 nm rad</td>
</tr>
<tr>
<td>Hor./vert. IP beam size bef. pinch</td>
<td>40 / 1 nm</td>
</tr>
<tr>
<td>Total site length</td>
<td>48 km</td>
</tr>
<tr>
<td>Total power consumption</td>
<td>389 MW</td>
</tr>
</tbody>
</table>
New Main Beam accelerating structure

Structure optimization taking into account:
Rf constraints, Beam dynamics, collider performance and cost

<table>
<thead>
<tr>
<th>Structure</th>
<th>TD24vg1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency: $f$ [GHz]</td>
<td>12</td>
</tr>
<tr>
<td>Average iris radius/wavelength: $&lt;a/\lambda&gt;$</td>
<td>0.11</td>
</tr>
<tr>
<td>Input/Output iris radii: $a_{1,2}$ [mm]</td>
<td>3.15, 2.35</td>
</tr>
<tr>
<td>N. of reg. cells, str. length: $N_c$, $l$ [mm]</td>
<td>24, 229</td>
</tr>
<tr>
<td>Bunch separation: $N_s$ [rf cycles]</td>
<td>6</td>
</tr>
<tr>
<td>Filling time, rise time: $\tau_f$, $\tau_r$ [ns]</td>
<td>62.9, 22.4</td>
</tr>
<tr>
<td>Pulse length: $\tau_p$ [ns]</td>
<td>240.8</td>
</tr>
<tr>
<td>Input power: $P_{in}$ [MW]</td>
<td>63.8</td>
</tr>
<tr>
<td>Max. surface field: $E_{surf}^{max}$ [MV/m]</td>
<td>245</td>
</tr>
<tr>
<td>Max. temperature rise: $\Delta T_{max}$ [K]</td>
<td>53</td>
</tr>
<tr>
<td>Efficiency: $\eta$ [%]</td>
<td>27.7</td>
</tr>
</tbody>
</table>

See Poster, THP062, A. Grudiev
Prototype accelerating structure

Collaboration between KEK, SLAC and CERN

High Power test of T18_VG2.4_disk [1]

Frequency: 11.424 GHz
Cells: 18+2 matching cells
Filling Time: 36 ns
Length: active acceleration 18 cm
Iris Dia. a/λ: 0.155~0.10
Group Velocity: vg/c: 2.6-1.0 %
Phase Advance Per Cell: 2π/3
Power for <Ea>=100MV/m: 55.5 MW
Unloaded Ea(out)/Ea(in): 1.55
Es/Ea: 2

CLIC goal: trip rate < 3 \times 10^{-7}/m

→ Proof of principle!
No HOM damping yet

See Poster, THP061, TUP057
Deceleration structure
Power Extraction and Transfer Structure (PETS)

Special development for CLIC

- Travelling wave structures (136 MW for 240 ns per structure)
- Small $R/Q: 2.2 \, \Omega/m$ (accelerator: 15-18 \, \Omega/m)
- High group velocity $v_g/c = 48\%$
- 0.21 m active length (≈ 36000 needed per linac)
- 100 A beam current

Status:
RF power testing at SLAC and with beam in CTF3 at the end of 2008

ref: Igor Syratchev
CLIC module

- Main Beam
- Drive Beam
- Transfer lines

Components:
- Vacuum Manifolds
- COOLING CIRCUITS
- RF DISTRIBUTION
- ACCELER. STRUCTURE (BRAZED DISKS)
- BEAM INSTRUMENTATION
- CRADLES
- ALIGNMENT SYSTEM
- INTERCONNECTIONS
- PETS (MINI-TANK)
- PETS (OCTAN1)
Generating ultra low emittance beams:

CLIC has two damping rings each for $e^+$ and $e^-$
output DR: $\gamma\epsilon_x=381 / \gamma\epsilon_y= 4.1 \text{ nm rad}$
for $4.1\times10^9$ particles at 2.4 GeV
Key issues: high field wiggler, $e^-$-cloud

Preserving ultra low emittance beams:

Beam size at Interaction Point (rms): $\sigma_x = 40 \text{ nm}$, $\sigma_y = 1 \text{ nm}$

Jitter tolerances

<table>
<thead>
<tr>
<th></th>
<th>Final Focus quadrupoles</th>
<th>Main beam quadrupoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>$\sim 0.2 \text{ nm} &gt; 4 \text{ Hz}$</td>
<td>$\sim 1 \text{ nm} &gt; 1 \text{ Hz}$</td>
</tr>
<tr>
<td>Horizontal</td>
<td>$2 \text{ nm} &gt; 4 \text{ Hz}$</td>
<td>$5 \text{ nm} &gt; 1 \text{ Hz}$</td>
</tr>
</tbody>
</table>

Proof-of-principle: quadrupole stabilized to $< 0.5 \text{ nm}$ in vertical plane
CLIC Test Facility; CTF3

Facility to demonstrate critical issues for CLIC

150 MeV e-linac

30 GHz test stand

3.5 A - 1.4 μs

magnetic chicane

PULSE COMPRESSION
FREQUENCY MULTIPLICATION

CLEX (CLIC Experimental Area)
TWO BEAM TEST STAND
PROBE BEAM
Test Beam Line

Delay Loop

Combiner Ring

10 m

Photo injector tests, laser

28 A - 140 ns

total length about 140 m
CTF3 vs CLIC

CTF3 is scaled down from CLIC and uses existing infrastructure:

Main goals:
- Demonstrate CLIC drive beam generation
- Demonstrate 12 GHz rf structure with two beam acceleration
- Demonstrate stable and efficient deceleration with test beam line

<table>
<thead>
<tr>
<th></th>
<th>CLIC</th>
<th>CTF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Beam energy</td>
<td>2.4 GeV</td>
<td>150 MeV</td>
</tr>
<tr>
<td>compression / frequency</td>
<td>24 (Delay Loop + 2</td>
<td>8 (Delay Loop + 1</td>
</tr>
<tr>
<td>frequency</td>
<td>Combiner Rings)</td>
<td>Combiner Ring)</td>
</tr>
<tr>
<td>multiplication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive Beam current</td>
<td>4.2 A*24 ➞ 101 A</td>
<td>3.5 A*8 ➞ 28 A</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>1 GHz</td>
<td>3 GHz</td>
</tr>
<tr>
<td>train length in linac</td>
<td>139 µs</td>
<td>1.5 µs</td>
</tr>
<tr>
<td>energy extraction</td>
<td>90 %</td>
<td>~ 50 %</td>
</tr>
</tbody>
</table>
Fully loaded drive beam linac

Proof of one of the major CLIC features: Full Beam Loading

Drive Beam accelerating structure:

RF to beam transfer: 95.3 % measured

RF power at output of accelerating structure

Linac routinely operated with full beam loading

See Poster, TUP081, A. Dabrowski
Phase coding with sub-harmonic buncher's

one of three buncher cavities

1.5 GHz

Switching transient about 7 bunches

140 ns sub-pulse length
odd buckets
even buckets
20 cm between bunches
1.6 μs train length - 3.5 A current

140 ns pulse length
140 ns pulse gap
odd even buckets
10 cm between bunches
1.6 μs train length - 7 A peak current
Delay Loop, First Results

circumference 42 m (140 ns)

isochronous optics

wiggler to tune path length
(9 mm range)

CT.BPM 515
5.8 A + 0.5 A

CT.BPM 430
3.3 A

Designed and built by INFN Frascati
Combiner Ring

Artist view of TL1, CR and TL2 in the former LPI building

4 trains - \( I_o \) peak current

1 train - \( 4 \times I_o \) peak current
Combiner Ring, first results

Optics studied and first recombination trials:

- Linac current lower than nominal
- DL bypassed (no holes, missing factor 2)
- Losses during recombination (instability...)

See Poster, TUP056, P. Skowronski
CLIC experimental area (CLEX)

existing building

Drive Beam, 150 MeV, 30 A, 140 ns

Decelerator test, TBL

Two beam acceleration, Two Beam Test Stand (Upsalla University)

Probe Beam, 180 MeV (CEA-Daphnia)

Installation of equipment from 2007 - 2009

Beam in CLEX since August

See Poster, TUP004, F. Peauger
Test beam Line (TBL)
Decelerator experiment

• High energy-spread beam transport decelerate to 50 % beam energy

• Driven Beam stability
• Stability of RF power extraction total power in 16 PETS: 2.4 GW

• Alignment procedures 5 MV/dltni (30 A) PETS
• Alignment procedures 5 MV/diace/lti (30 A) per PETS

150 MV output Power
1 standard cells 16 total

PETS development: CIEMAT
BPM: IFIC Valencia and UPC Barcelona
CLIC long term scenario

Shortest, Success Oriented, Technically Limited Schedule
(Jean-Pierre Delahaye)

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility issues (Accelerator &amp; Detector)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conceptual design and cost estimation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design finalisation and technical design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering optimisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project approval &amp; final cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction accelerator (poss. staged)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction detector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CDR  TDR  Project approval  First Beam
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-of-mass energy</td>
<td>500 GeV</td>
</tr>
<tr>
<td>Peak luminosity (in 1% of energy)</td>
<td>$1 \times 10^{34}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Loaded accelerating gradient</td>
<td>80 MV/m</td>
</tr>
<tr>
<td>Main linac RF frequency</td>
<td>12 GHz</td>
</tr>
<tr>
<td>Overall two-linac length</td>
<td>8.8 km</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>$6.8 \times 10^9$</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>0.5 ns</td>
</tr>
<tr>
<td>Beam pulse duration</td>
<td>177 ns</td>
</tr>
<tr>
<td>Beam power/beam</td>
<td>4.9 MW</td>
</tr>
<tr>
<td>Hor./vert. normalized emittance</td>
<td>3000 / 40 nm rad</td>
</tr>
<tr>
<td>Hor./vert. IP beam size bef. pinch</td>
<td>221 / 2.8 nm</td>
</tr>
<tr>
<td>Total site length</td>
<td>12.8 km</td>
</tr>
<tr>
<td>Total power consumption</td>
<td>126 MW</td>
</tr>
</tbody>
</table>
Conclusions

- Consistent and realistic parameter set for CLIC
- Conservative 500 GeV parameters and staged construction to 3 TeV under development
- Feasibility demonstration well advanced
- Drive beam partly demonstrated
  - full beam loading, bunch phase coding, delay loop operation,
  - first results on combiner ring
- Proof of principle for the accelerating structure
- Feasibility demonstration and CDR by 2010
- Very strong and growing collaboration for CTF3 and CLIC
CLIC / CTF3 collaboration

24 collaborating institutes

Ankara University (Turkey)
Berlin Tech. Univ. (Germany)
BINP (Russia)
CERN
CIEMAT (Spain)
Finnish Industry (Finland)
Gazi Universities (Turkey)
IRFU/Saclay (France)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
J. Adams Institute, (UK)
JASRI (Japan)
JINR (Russia)
JLAB (USA)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
LLBL/LBL (USA)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University
PSI (Switzerland),
Polytech. University of Catalonia (Spain)
RAL (England)
RRCAT-Indore (India)
Royal Holloway, Univ. London, (UK)
SLAC (USA)
Svedberg Laboratory (Sweden)
Uppsala University (Sweden)
Reserve slides
CTF3 collaboration

CTF3 – Collaborations

INFN-LNF CIEMAT
BINP LURE CERN
NWU LAPP Uppsala

INFN-LNF CERN

CERN NWU
PSI Uppsala

CEA-DAPNIA
CERNI LAL

RRCAT
TSL
CERN

CEMRT
UPC IFIC
CERN

CERN LAL
SLAC

IAP

Uppsala
CERN

R.Corsini
New Main Beam accelerating structure

Structure optimization taking into account:
Rf constraints, Beam dynamics,
collider performance, cost

<table>
<thead>
<tr>
<th>Structure</th>
<th>TD24vg1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency: $f$ [GHz]</td>
<td>12</td>
</tr>
<tr>
<td>Average iris radius/wavelength: $&lt;\alpha/\lambda$</td>
<td>0.11</td>
</tr>
<tr>
<td>Input/Output iris radii: $a_{1,2}$ [mm]</td>
<td>3.15, 2.35</td>
</tr>
<tr>
<td>N. of reg. cells, str. length: $N_c$, $l$ [mm]</td>
<td>24, 229</td>
</tr>
<tr>
<td>Bunch separation: $N_s$ [rf cycles]</td>
<td>6</td>
</tr>
<tr>
<td>Filling time, rise time: $\tau_f$, $\tau_r$ [ns]</td>
<td>62.9, 22.4</td>
</tr>
<tr>
<td>Pulse length: $\tau_p$ [ns]</td>
<td>240.8</td>
</tr>
<tr>
<td>Input power: $P_{in}$ [MW]</td>
<td>63.8</td>
</tr>
<tr>
<td>Max. surface field: $E_{surf}^{max}$ [MV/m]</td>
<td>245</td>
</tr>
<tr>
<td>Max. temperature rise: $\Delta T^{max}$ [K]</td>
<td>53</td>
</tr>
<tr>
<td>Efficiency: $\eta$ [%]</td>
<td>27.7</td>
</tr>
</tbody>
</table>

![Graph showing various parameters](image)

- $P_{in} = 63.8$ MW, $P_{load} = 11.9$ MW
- $\tau_f = 22.4$ ns, $\tau_r = 62.9$ ns, $\tau_p = 240.8$ ns
- $E_{surf}^{max} = 245$ MV/m
- $\Delta T^{max} = 53$ K
- Efficiency $\eta = 27.7$%