CLIC Conceptual Design and CTF3 Results

D. Schulte for the CLIC team
IPAC 2011
# CLIC Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>centre of mass energy</td>
<td>$E_{cm}$ [GeV]</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>luminosity</td>
<td>$\mathcal{L}$ [10^{34} cm^{-2}s^{-1}]</td>
<td>2.3</td>
<td>5.9</td>
</tr>
<tr>
<td>luminosity in peak</td>
<td>$\mathcal{L}_{0.01}$ [10^{34} cm^{-2}s^{-1}]</td>
<td>1.4</td>
<td>2</td>
</tr>
<tr>
<td>gradient</td>
<td>$G$ [MV/m]</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>site length</td>
<td>[km]</td>
<td>13</td>
<td>48.3</td>
</tr>
<tr>
<td>charge per bunch</td>
<td>$N$ [10^9]</td>
<td>6.8</td>
<td>3.72</td>
</tr>
<tr>
<td>bunch length</td>
<td>$\sigma_z$ [$\mu$m]</td>
<td>70</td>
<td>44</td>
</tr>
<tr>
<td>IP beam size</td>
<td>$\sigma_x/\sigma_y$ [nm]</td>
<td>200/2.26</td>
<td>40/1</td>
</tr>
<tr>
<td>norm. emittance</td>
<td>$\epsilon_x/\epsilon_y$ [nm]</td>
<td>2400/25</td>
<td>660/20</td>
</tr>
<tr>
<td>bunches per pulse</td>
<td>$n_b$</td>
<td>354</td>
<td>312</td>
</tr>
<tr>
<td>distance between bunches</td>
<td>$\Delta_b$ [ns]</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>repetition rate</td>
<td>$f_r$ [Hz]</td>
<td>50</td>
<td>50</td>
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<tr>
<td>est. power cons.</td>
<td>$P_{wall}$ [MW]</td>
<td>240</td>
<td>560</td>
</tr>
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</table>
# Key Design Issues

<table>
<thead>
<tr>
<th>Main linac gradient</th>
<th>Accelerating structure</th>
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<tbody>
<tr>
<td>Drive beam scheme</td>
<td>Drive beam generation</td>
</tr>
<tr>
<td></td>
<td>PETS</td>
</tr>
<tr>
<td></td>
<td>Two beam module</td>
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<tr>
<td></td>
<td>Drive beam deceleration</td>
</tr>
<tr>
<td>Luminosity</td>
<td>Main beam emittance generation and preservation, focusing</td>
</tr>
<tr>
<td></td>
<td>Alignment and stabilisation</td>
</tr>
<tr>
<td>Operation and Machine Protection System (robustness)</td>
<td></td>
</tr>
<tr>
<td>Detector (experimental conditions)</td>
<td></td>
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</tbody>
</table>

Design and feasibility issues will be covered in CLIC Conceptual Design Report. In time for European strategy group.

Volume 1: Accelerator
Volume 2: Physics and experiments
Volume 3: Executive summary
Main Linac

- Maximise current to maximise efficiency/luminosity
- Strong focusing O(10%) quadrupoles
- Sensitive to imperfections
- 80% fill factor
Accelerating Structure

- Require breakdown probability 1% per pulse
  - \( p \leq 3 \times 10^{-7} \text{m}^{-1} \text{pulse}^{-1} \)

- Design based on empirical constraints
  - \( E_{\text{surf}} < 260 \text{MV/m} \)
  - \( \Delta T < 56 \text{K} \)
  - \( P/(2\pi a)\tau^{1/3} < 18 \text{MW/mm ns}^{1/3} \)

D. Schulte

W. Wuensch et al.
Achieved Gradient

Measurements scaled according to

\[ p \propto G^{30} \tau^{5} \]

Some input power as 100MV/m loaded

Tests at KEK and SLAC

<table>
<thead>
<tr>
<th>Simple early design to get started</th>
<th>More efficient fully optimised structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>No damping waveguides</td>
<td>T18</td>
</tr>
<tr>
<td>Damping waveguides</td>
<td>TD18</td>
</tr>
<tr>
<td></td>
<td>T24</td>
</tr>
<tr>
<td></td>
<td>TD24 = CLIC goal</td>
</tr>
</tbody>
</table>

CLIC RF team
N. Shipman

TD24: September 15th @ KEK
mid-November @ SLAC
Soon @ CERN
CLIC Power Source Concept

Drive Beam Accelerator
efficient acceleration in fully loaded linac

Drive Beam Decelerator Section (2 × 24 in total)

Combiner Ring × 4
pulse compression & frequency multiplication

Combiner Ring × 3
pulse compression & frequency multiplication

Delay Loop × 2
gap creation, pulse compression & frequency multiplication

RF Transverse Deflectors

CLIC RF POWER SOURCE LAYOUT

Drive beam time structure - initial
240 ns
140 μs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV - 60 cm between bunches

Drive beam time structure - final
240 ns
5.8 μs
24 pulses - 101 A - 2.5 cm between bunches

D. Schulte
**CLIC Test Facility (CTF3)**

<table>
<thead>
<tr>
<th>parameter</th>
<th>unit</th>
<th>CLIC</th>
<th>CTF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>accelerated current</td>
<td>A</td>
<td>4.2</td>
<td>3.5</td>
</tr>
<tr>
<td>combined current</td>
<td>A</td>
<td>101</td>
<td>28</td>
</tr>
<tr>
<td>final energy</td>
<td>MeV</td>
<td>2400</td>
<td>≈120</td>
</tr>
<tr>
<td>accelerated pulse length</td>
<td>μs</td>
<td>140</td>
<td>1.2</td>
</tr>
<tr>
<td>final pulse length</td>
<td>ns</td>
<td>240</td>
<td>140</td>
</tr>
<tr>
<td>acceleration frequency</td>
<td>GHz</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>final bunch frequency</td>
<td>GHz</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

- **Recycled infrastructure**
  - made it affordable
  - causes lots of headache

- **150 MeV e-linac**
- **Thermionic source**
- **Photo injector**
- **Experimental area**
- **Delay Loop**
- **Combiner ring**
- **15GHz deflector**
- **3GHz acceleration**
- **1.5GHz sub-harmonic buncher**
Drive Beam Linac

95.3% RF to beam efficiency
No instabilities
Phase switch works OK

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CLIC goal</th>
<th>CTF3 routine at end of linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse emittance</td>
<td>100μm</td>
<td>50-60μm</td>
</tr>
<tr>
<td>Pulse current</td>
<td>7.5e-4</td>
<td>5.4e-4</td>
</tr>
</tbody>
</table>

G. Sterbini, T. Persson
Cannot measure beam phase jitter accurately enough
- monitor being developed (Frascati)
- measure RF instead

<table>
<thead>
<tr>
<th></th>
<th>Tolerance</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Power</td>
<td>0.2%</td>
<td>0.21%</td>
</tr>
<tr>
<td>RF Phase</td>
<td>0.05°</td>
<td>0.07°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.035°)</td>
</tr>
</tbody>
</table>

Good CTF3 klystron
- pulse-to-pulse
- 10ns time slices
- with respect to local phase reference
Drive Beam Combination

29 A reached, routinely 25A

Significant increase of transverse emittance
Current jitter increases to O(1%)

Focus has been on current
• will now further improve beam quality

CTF3 specific issues need to be addressed and limits identified
• RF pulse compression
• Beam energy in combiner ring is 5% of that in CLIC
• Geometric emittance 20 times larger
• ...
• ...

CTF3 team

End of linac

Delay loop

After delay loop

In combiner ring
TBTS (two-beam test stand)
- power transfer to main beam
- module design

TBL (test beam line)
- drive beam stability during deceleration
PETS Breakdown Rate at SLAC (ASTA)

D. Schulte

No breakdown last $O(8 \times 10^6)$ pulses -> P about consistent with $p = 2.4 \times 10^{-7}/m/pulse$

A. Cappelletti et al.

Power
Energy/pulse

Test with on-off
In September

[Graphs and images showing power and energy trends over time]
TBTS: Two Beam Acceleration

CTF3 team

Maximum gradient 145 MV/m

Consistency between
- produced power
- drive beam current
- test beam acceleration
Installation and validation of first two prototype modules under way

Structure design modified slightly TD26

Stack of 8 ac. structures under assembly

G. Riddone et al.
Decelerator Design

Avoid losses
• 100A, 2.4-0.24GeV beam
• aperture ≈ 10σ
• large energy spread
• significant wakefields

Design and simulations are OK

≈ 1km
1000 quadrupoles
TBL: Drive Beam Deceleration

Goal is 50% deceleration

16 PETS maximum
4 PETS installed
4 to come in September
More next year

Up to 19A current
• optics understood
• no losses in TBL

Good agreement
• power production
• beam current
• beam deceleration

D. Schulte

S. Doebert et al.
Main Beam Emittances

<table>
<thead>
<tr>
<th></th>
<th>$\epsilon_x$ [nm]</th>
<th>$\epsilon_y$ [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping ring exit</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>RTML exit</td>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>main linac exit</td>
<td>660</td>
<td>20</td>
</tr>
</tbody>
</table>

$$\mathcal{L} = H_D \frac{N^2}{4\pi\sigma_x\sigma_y} n_b f_r$$

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$

Beam power

Luminosity spectrum

Beam Quality (+bunch length)
Emittance Generation

Damping ring design is consistent with target performance

Many design issues addressed
- lattice design
- dynamic aperture
- tolerances
- intra-beam scattering
- space charge
- wigglers
- RF system
- vacuum
- electron cloud
- kickers

CLIC @3 TeV would achieve 40% of luminosity with ATF performance
(3800nm/15nm@4e9)

Y. Papaphilippou et al.

ICFA Beam Dynamics Mini Workshop on Low Emittance Rings 2011
3-5 October 2011
Main Linac Alignment Concept

Pre-alignment $O(10\mu m)$
• with wire system
• detailed model in simulations
• BPM shown as example

Dispersion free steering
• aligns BPMs and quadrupoles

Move girders onto the beam
• use wakemonitors
• removes wakefield effects

BPM alignment errors

<table>
<thead>
<tr>
<th>Reference</th>
<th>10µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>5µm</td>
</tr>
<tr>
<td>Sensor-cradle</td>
<td>5µm</td>
</tr>
<tr>
<td>Cradle-BPM</td>
<td>5µm</td>
</tr>
<tr>
<td>BPM internal</td>
<td>5µm</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>14µm</td>
</tr>
</tbody>
</table>
• RMS error of 11μm found
  • accuracy is approx. 13.5μm
  • Target is 10μm

• More work remains to be done
  • Found two bad points due to mechanical problem
  • Stake-out error needs to be determined
Main design issues
- chromaticity
- non-linear effects
- synchrotron radiation
- tuning
- stability

Including 10μm RMS misalignments

Static imperfections:
- Goal is $L \geq 110\% L_0$
- with probability of 90%

Convergence is slow
- faster method is being developed

Need more complete imperfection modelling
- independent sides
- field errors
- dynamic imperfections during tuning
- realistic signals

Full tuning performance

R. Tomas,
B. Dalena et al.

Tests programme at ATF2 at KEK
Natural ground motion can impact the luminosity
• typical quadrupole jitter tolerance $O(1\text{nm})$ in main linac and $O(0.1\text{nm})$ in final doublet

-> develop stabilisation for beam guiding magnets
Active Stabilisation Results

<table>
<thead>
<tr>
<th>Luminosity achieved/lost [%]</th>
<th>A</th>
<th>B10</th>
</tr>
</thead>
<tbody>
<tr>
<td>No stab.</td>
<td>119%/2%</td>
<td>53%/68%</td>
</tr>
<tr>
<td>Current stab.</td>
<td>116%/5%</td>
<td>108%/13%</td>
</tr>
<tr>
<td>Future stab.</td>
<td></td>
<td>118%/3%</td>
</tr>
</tbody>
</table>

J. Snuverink, J. Pfingstner
Machine Protection/Operation

Machine protection concept
• inherently robust against fast failures
• detect slow failures

Most important example BDS collimation
• energy collimators supposed to take a pulse
• betatron collimators not

Concept for start-up developed
• based on CTF3/LHC experience

Concept developed to operate 3TeV-CLIC at lower energy for physics studies
• based on reduced beam current/longer pulses
• can cover factor 3 in energy
Outlook

Develop staged approach to project
• taking into account LHC and other findings
• e.g. start for Higgs and top then go up in energy

CLICO, a facility with real prototypes
• prototypes of hardware components at real frequency
• final validation of drive beam quality/main beam emittance preservation
• facility for reception tests

More technical design
• many workpackages defined

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<tbody>
<tr>
<td>Conceptual design &amp; preliminary cost estimation</td>
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<tr>
<td>Engineering, industrialisation &amp; cost optimisation</td>
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<tr>
<td>Project Preparation</td>
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<tr>
<td>Project Implementation</td>
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<td>?</td>
</tr>
</tbody>
</table>
Conclusion

Conceptual Design Report is converging

Key issues have been addressed
• very good progress
• more work remains on some

A road to the future is visible
• please join and help
• ILC-CLIC workshop in Granada, September 26-30
• CLIC workpackage meeting at CERN, November 3-4
Thanks

Thanks to the CLIC collaboration in general

Thanks in particular to:

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J.-P. Delahaye, S. Stapnes