The CLIC Accelerator Project Status and Plans

ICHEP, Seoul, July 2018

Daniel Schulte
For the CLIC collaboration
CLIC Introduction

CLIC: Compact Linear Collider

CLIC aims to provide multi-TeV electron-positron collisions with high luminosity at affordable cost and power consumption.

2012 CDR: Shows feasibility of 3 TeV design

2013 - 2019 Development Phase
Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase
Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase
Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions
Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start
Ready for construction; start of excavations

2035 First Beams
Getting ready for data taking by the time the LHC programme reaches completion
CLIC Staged Scenario

Plenty of physics at low centre-of-mass energies

Energy and luminosity targets from Physics Study Group

<table>
<thead>
<tr>
<th>Stage</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$\mathcal{L}_{\text{int}}$ (fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>380</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>3</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

Top above threshold Higgs via Zh and WW fusion

Study top at threshold

To be updated with more input from LHC and stage 1

Implementation in stages
Plenty of physics at low centre-of-mass energies

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<td>3000</td>
</tr>
<tr>
<td>4</td>
<td>1500</td>
<td>3000</td>
</tr>
</tbody>
</table>

Top above threshold
Higgs via $Zh$ and WW fusion

This is being reviewed
Consider larger integrated luminosity
Could further improve physics results

Implementation in stages

Road map for CLIC Staged Scenario
Developed optimised first energy stage
Upgrade to higher energies included
Developed optimised first energy stage
Upgrade to higher energies included

140 μs train length - 24 × 24 sub-pulses

4.2 A - 2.4 GeV - 60 cm between bunches

240 ns

Drive beam time structure - initial

BC2
e− main linac, 12 GHz, 72 MV/m, 3.5 km
time delay line
BDS
1.9km
IP
BDS
1.9km
e+ main linac
TA
11 km
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

Drive beam time structure - final

240 ns

24 pulses - 101 A - 2.5 cm between bunches

5.8 μs

decelerator, 4 sectors of 878 m
CLIC at 380 GeV

- **CIRCUMFERENCES**
  - Delay loop: 73 m
  - CR1: 293 m
  - CR2: 439 m

- **ACCELERATORS**
  - CR2: 2.0 GeV, 1.0 GHz
  - Decelerator: 4 sectors, 878 m
  - 446 klystrons, 20 MW, 48 μs

- **CONFIGURATION**
  - **e⁻ LINAC**
    - TA to CR2: 12 GHz, 72 MV/m, 3.5 km
  - **e⁺ LINAC**
    - TA to CR1: 2.86 to 9 GeV

- **COMPONENTS**
  - CR: combiner ring
  - TA: turnaround
  - DR: damping ring
  - PDR: predamping ring
  - BC: bunch compressor
  - BDS: beam delivery system
  - IP: interaction point
  - BC1: booster linac
  - Dump

- **DISTANCES**
  - 11 km
  - 2.5 km

- **INJECTORS**
  - e⁻ Injector: 2.86 GeV, 427 m
  - e⁺ Injector: 2.86 GeV
Two-beam Module Concept

100 A drive beam
1.7 A main beam

Straight references

100 A drive beam
1.7 A main beam

3 dB E-plane HYBRID

CHOKE-MODE FLANGE

LOAD

2.2m
time: 0 0.0 ns
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre-of-mass energy</td>
<td>$\sqrt{s}$</td>
<td>GeV</td>
<td>380</td>
<td>1500</td>
<td>3000</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>$f_{rep}$</td>
<td>Hz</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Number of bunches per train</td>
<td>$n_b$</td>
<td></td>
<td>352</td>
<td>312</td>
<td>312</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>$\Delta t$</td>
<td>ns</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Accelerating gradient</td>
<td>$G$</td>
<td>MV/m</td>
<td>72</td>
<td>72/100</td>
<td>72/100</td>
</tr>
<tr>
<td>Total luminosity</td>
<td>$\mathcal{L}$</td>
<td>$10^{34}$ cm$^{-2}$s$^{-1}$</td>
<td>1.5</td>
<td>3.7</td>
<td>5.9</td>
</tr>
<tr>
<td>Luminosity above 99% of $\sqrt{s}$</td>
<td>$\mathcal{L}_{0.01}$</td>
<td>$10^{34}$ cm$^{-2}$s$^{-1}$</td>
<td>0.9</td>
<td>1.4</td>
<td>2</td>
</tr>
<tr>
<td>Main tunnel length</td>
<td></td>
<td>km</td>
<td>11.4</td>
<td>29.0</td>
<td>50.1</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>$N$</td>
<td>$10^9$</td>
<td>5.2</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Bunch length</td>
<td>$\sigma_z$</td>
<td>$\mu$m</td>
<td>70</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>IP beam size</td>
<td>$\sigma_x/\sigma_y$</td>
<td>nm</td>
<td>149/2.9</td>
<td>~ 60/1.5</td>
<td>~ 40/1</td>
</tr>
<tr>
<td>Normalised emittance (end of linac)</td>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>nm</td>
<td>—</td>
<td>660/20</td>
<td>660/20</td>
</tr>
<tr>
<td>Normalised emittance</td>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>nm</td>
<td>950/30</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Estimated power consumption</td>
<td>$P_{wall}$</td>
<td>MW</td>
<td>252</td>
<td>364</td>
<td>589</td>
</tr>
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Drive Beam Scheme Performance

CTF3 measurements:
- RF to drive beam efficiency > 95%
- Current multiplication factor 8
- Most of beam quality
- 145 MV/m X-band acceleration

Detailed simulations of drive beam performance in CLIC

Arrival time with feedback

Current stability affected by very low CTF3 energy, 3 x larger beam and delay loop design different from CLIC

<table>
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<tr>
<th>Parameter</th>
<th>CLIC goal</th>
<th>CTF3 measured</th>
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<td>Arrival time</td>
<td>50 fs</td>
<td>50 fs</td>
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<td>Current after linac</td>
<td>$0.75 \times 10^{-3}$</td>
<td>$0.2-0.4 \times 10^{-3}$</td>
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Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.

CTF 3 stopped operation
New facility is online: CLEAR
CERN Linear Electron Accelerator for Research
Several klystron-based test stands exist that test structures (X-boxes).

Structure performance is reproducible.

Further optimisation ongoing of structure production for industrialisation.

CLIC Structure Development
Components are mounted accurately on movable girders.

Overlapping wires provide accurate position information.

Wake monitors in each structure measure beam offset (3.5 μm).

Magnets are stabilised mechanically to nm against ground motion and vibrations.

In addition to high accuracy optimisation for cost.
CLIC technology for CLIC and different applications

- EU co-funded FEL design study
- SPARC at INFN-LF
- ...

INFN Frascati advanced acceleration facility
EuPARXIA@SPARC_LAB

Eindhoven University led
SMART*LIGHT Compton Source
Develop klystron-based alternative
Expect comparable cost for first energy stage
But increases faster for high energies

Optimised structure

Novel high efficiency klystrons

Novel pulse compressors

Novel distribution system

Daniel Schulte
CLIC, ICHEP, Seoul, July 7, 2018
Beam Quality for Luminosity

- Production of low-emittance beams in damping ring
  - Similar to existing light sources

- Quality preservation in transport
  - Minimisation of imperfections
  - Optimised lattice design
  - Sophisticated beam-based tuning

- Focusing of beam in beam delivery system
  - Advanced lattice design
  - Advanced tuning
  - Test at FFTB and ATF2

ATF2 at KEK
Beam size (41 nm) is close to target (37nm)
Goals bring cost and power consumption down: “reasonable cost”: $O(6 \text{ GCHF})$
Reasonable power $< O(200 \text{ MW})$

CERN energy consumption 2012: 1.35 TWh

Initial value for 380 GeV (MCHF of Dec 2010)

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main beam production</td>
<td>1245</td>
</tr>
<tr>
<td>Drive beam production</td>
<td>974</td>
</tr>
<tr>
<td>Two-beam accelerator</td>
<td>2038</td>
</tr>
<tr>
<td>Interaction region</td>
<td>132</td>
</tr>
<tr>
<td>Civil engineering etc.</td>
<td>2112</td>
</tr>
<tr>
<td>Control &amp; operation</td>
<td>216</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>6690</strong></td>
</tr>
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Improvement of cost and power is ongoing
Detailed bottom up estimate
Already savings, seems we meet goal
Can re-use previous systems and components

Just add more linac and drive beam pulse length

At 3 TeV add one drive beam
Started exploration of novel acceleration methods for high-energy upgrades
• Make sure CLIC is consistent with this

Plasma-based acceleration demonstrated gradients of 50 GV/m
Dielectric structures could lead to reduced cost

Main challenges
• Preservation of beam quality has to be explored theoretically and experimentally
• Efficiency and beam stability
• Many technical challenges

Might be possible to reuse drive beam
Conclusion

Important progress toward the EU strategy

• Much improved technical maturity
• Normal conducting FELs are prototypes, e.g. Swiss FEL
• Further optimising 380 GeV first energy stage
• Work on further stages, including considerations of novel technologies
• Project Implementation Plan by end of 2018

Many thanks to L. Evans, S. Stapnes, W. Wuensch, Ph. Burrows, I. Syratchev and the CLIC team
Reserve
Main Linac Imperfection Mitigation

Components are mounted accurately on movable girders

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Overlapping wires provide accurate position information

Wake monitors in each structure measure beam offset (3.5 μm)

Components are mounted accurately on movable girders

Optimised lattice design
Sophisticated beam-based alignment, e.g. dispersion free steering (i.e. different energy beams)
Redesign CLIC modulators and klystrons
Aim: increase efficiency from 62% to 90%
⇒ Less power consumption
⇒ Also important cost saving
Shorter tubes, no oil in modulator, ...
⇒ Important cost saving

Permanent magnets
Use tunable permanent magnets where possible
• Drive beam quadrupoles
• Strongest permanent magnet developed in UK

\[ \eta_{Total} = 0.9 \]

New module design
Reduce cost of mechanical system and control

Main beam injector
e.g. halved power for positron production