CLIC Status: The Compact Linear Collider

8th International Conference on New Frontiers in Physics, Crete
Andrea Latina, CERN
on behalf of the CLIC and CLICdp Collaborations
CLIC Status:
The Compact Linear Collider

- Project overview
- Physics reach
- Accelerator challenges
- Outlook

Compact Linear Collider
e^+e^- collisions up to 3TeV
http://clic.cern/

8th International Conference on New Frontiers in Physics, Crete
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Collaborations

http://clic.cern/

- CLIC accelerator design and development
- (Construction and operation of CTF3)

CLIC accelerator collaboration
~60 institutes from 28 countries

- CLIC physics prospects & simulation studies
- Detector optimization + R&D for CLIC

CLIC detector and physics
(CLICdp)
30 institutes from 18 countries
Compact Linear Collider (CLIC)

- **380 GeV** - 11.4 km (CLIC380)
- **1.5 TeV** - 29.0 km (CLIC1500)
- **3.0 TeV** - 50.1 km (CLIC3000)
# CLIC parameters

<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>
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<tr>
<td>Repetition frequency</td>
<td>$f_{\text{rep}}$</td>
<td>Hz</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Number of bunches per train</td>
<td>$n_b$</td>
<td></td>
<td>352</td>
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<tr>
<td>Bunch separation</td>
<td>$\Delta t$</td>
<td>ns</td>
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<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Pulse length</td>
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<td>ns</td>
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<tr>
<td>Accelerating gradient</td>
<td>$G$</td>
<td>MV/m</td>
<td>72</td>
<td>72/100</td>
<td>72/100</td>
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<tr>
<td><strong>Total luminosity</strong></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>
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<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>
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<tr>
<td>Main tunnel length</td>
<td></td>
<td>km</td>
<td>11.4</td>
<td>29.0</td>
<td>50.1</td>
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<tr>
<td>Number of particles per bunch</td>
<td>$N$</td>
<td>$10^9$</td>
<td>5.2</td>
<td>3.7</td>
<td>3.7</td>
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<tr>
<td>Bunch length</td>
<td>$\sigma_z$</td>
<td>$\mu$m</td>
<td>70</td>
<td>44</td>
<td>44</td>
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<tr>
<td><strong>IP beam size</strong></td>
<td>$\sigma_x/\sigma_y$</td>
<td>nm</td>
<td>149/2.9</td>
<td>$\sim$ 60/1.5</td>
<td>$\sim$ 40/1</td>
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<tr>
<td>Normalised emittance (end of linac)</td>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>nm</td>
<td>920/20</td>
<td>660/20</td>
<td>660/20</td>
</tr>
<tr>
<td>Normalised emittance (at IP)</td>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>nm</td>
<td>950/30</td>
<td>—</td>
<td>—</td>
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</tbody>
</table>

**Links:**

- CDR 2012: [https://cds.cern.ch/record/1500095](https://cds.cern.ch/record/1500095)
- Updated Staging Baseline 2016: [https://cds.cern.ch/record/1425915](https://cds.cern.ch/record/1425915)
- Project Implementation Plan 2018: [https://cds.cern.ch/record/1475225](https://cds.cern.ch/record/1475225)

**Source:** [http://dx.doi.org/10.5170/CERN-2016-004](http://dx.doi.org/10.5170/CERN-2016-004)
Updated CLIC Staging

<table>
<thead>
<tr>
<th>Stage</th>
<th>$\sqrt{s}$ [TeV]</th>
<th>$\mathcal{L}_{\text{int}}$ [ab$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.38 (and 0.35)</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Electron polarisation enhances Higgs production at high-energy stages and provides additional observables

Baseline polarisation scenario adopted:

electron beam ($\sim$80%, +80%) polarised in ratio (50:50) at $\sqrt{s}=380$GeV ; (80:20) at $\sqrt{s}=1.5$ and 3TeV

$\gamma\gamma$ collider using laser scattering also possible

Upgrades using novel accelerator techniques also possible

Staging and live-time assumptions following guidelines consistent with other future projects:

Linear vs Circular Colliders

\[ \Delta E \propto \left( \frac{E}{m} \right)^4 \frac{1}{R} \]
CLIC Physics

Issues not addressed by SM:
- origin of the weak scale interactions
- dark matter
- origin of matter/antimatter asymmetry

Many new studies focused on discovery prospects at CLIC
Exploring the physics landscape as broadly as possible

The CLIC Potential for New Physics

New!
Higgs coupling sensitivity

Full GEANT-based simulation studies including beam backgrounds of many channels at all 3 stages → global fit including correlations;

\[
\sigma(ZH) \sim g^2_{HZZ} \\
\sigma(ZH) \times BR(H \rightarrow VV/ff) \sim g^2_{HZZ} g^2_{HV/Hff} / \Gamma_H \\
\sigma(H, \overline{e}e) \times BR(H \rightarrow VV/ff) \sim g^2_{HWW} g^2_{HV/Hff} / \Gamma_H
\]

Precision \( \leq 1\% \) for most couplings
c/b/W/Z/g couplings significantly more precise than HL-LHC even after 380GeV stage
\( \Gamma_H \) is extracted with 4.7 – 2.5% precision

Higgs self-coupling requires high energy

Using \( M(HH) \) differential distribution:

\[
\Delta \lambda / \lambda = +11\% \\
\Delta \lambda / \lambda = -7\%
\]


Each energy stage contributes significantly
Top physics

- Intending threshold scan around 350 GeV (10 points, ~1 year) as well as main initial-stage baseline $\sqrt{s}=380\text{GeV}$
- Sensitive to top mass, width and couplings
- Observe 1S ‘bound state’, $\Delta m_t \sim 50$ MeV
- FCNC decays
- CP properties of $ttH$
- Cross-section and $A_{FB}$
- Couplings to Z and $\gamma$
- EFT interpretation

First study of boosted top production in $e^+e^-$

$e^+e^- \rightarrow t\bar{t} \rightarrow qqqqbb^-$

Hadronic decays of high-energy top quarks do not lead to 3 separated jets

$\rightarrow$ identify substructure

New!

arXiv 1807.02441: Top-quark physics at the CLIC electron–positron linear collider

in journal review

$\sqrt{s}=3\text{TeV}$

Hadronic decays of high-energy top quarks do not lead to 3 separated jets

$\rightarrow$ identify substructure

$\Delta m_t \sim 50$ MeV

Intending threshold scan around 350 GeV (10 points, ~1 year) as well as main initial-stage baseline $\sqrt{s}=380\text{GeV}$

- Sensitive to top mass, width and couplings
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CLIC challenges

- Key technologies have been demonstrated
- CLIC is now a mature project, ready to be built
CLIC layout – 380 GeV

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

Drive beam time structure - final
- 24 pulses - 101 A - 2.5 cm between bunches

Drive beam complex
- Klystrons: 472 units, 20 MW, 48 µs
- Drive Beam Accelerator: 1.91 GeV, 1.0 GHz
- Delay Loop: 73 m

Decelerators, 4 sectors
- BC2 to TA: 300 m
- e⁻ Main Linac: 190 GeV, 12 GHz, 72 MV/m, 3.5 km

Time Delay Line
- BDS: 2.2 km
- IP: 11.4 km

MAIN BEAM complex
- Spin Rotator: 359 m
- Booster Linac: 9 GeV
- Pre-injector e⁺ Linac: 0.2 GeV
- Primary e⁻ Linac for e⁺ production: 5 GeV
- Target
- Gun
- Pre-injector e⁻ Linac: 0.2 GeV
- DC Gun

Baseline electron polarisation ±80%

CLIC layout – 380 GeV

Drive beam time structure - initial
- 140 ns train length - 24 sub-pulses
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DRIVE BEAM
- 2.0 km
- Drive Beam Accelerator: 1.91 GeV, 1.0 GHz

Delay Loop: 73 m
- CR2: Ø140 m

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- BC2 to TA: 300 m
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Baseline electron polarisation ±80%

CAPTION
- CR: Combiner ring
- TA: Turnaround
- DR: Damping ring
- PDR: Predamping ring
- BC: Bunch compressor
- BDS: Beam delivery system
- IP: Interaction point
- ■: Dump
CLIC layout – 3 TeV

Baseline electron polarisation ±80%

Captions:
- **CR**: Combiner ring
- **TA**: Turnaround
- **DR**: Damping ring
- **PDR**: Predamping ring
- **BC**: Bunch compressor
- **BDS**: Beam delivery system
- **IP**: Interaction point
- **□**: Dump
Key accelerator challenges

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- 100 MV/m gradient in main-beam cavities
- Produce, transport, and collide low-emittance beams
- System integration, alignment and stability, engineering, cost, power ...
CLIC Test Facility (CTF3)
Accelerator challenges

Dr. Andrea Latina

Key challenges:

High-current drive beam bunched at 12 GHz
Power transfer + main-beam acceleration
~100 MV/m gradient in main-beam cavities
Low emittance generation
Alignment & stability

Drive beam quality:
Produced high-current drive beam bunched at 12 GHz

Examples of measurements from CLIC Test Facility, CTF3, at CERN.

CTF3 now the ‘CERN Linear Electron Accelerator for Research’ facility, CLEAR
Accelerator challenges

Demonstrated 2-beam acceleration

Key challenges:

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- ~100 MV/m gradient in main-beam cavities
- Low emittance generation
- Alignment & stability

$31\text{ MeV} = 145\text{ MV/m}$
Accelerator challenges

**X-band performance: achieved 100 MV/m gradient in main-beam RF cavities**

**Key challenges:**

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- ~100 MV/m gradient in main-beam cavities
- Low emittance generation
- Alignment & Stability
Accelerator challenges

Nano-beams

**Key challenges:**

- High-current drive beam bunched at 12 GHz
- Power transfer + main-beam acceleration
- ~100 MV/m gradient in main-beam cavities
- Low emittance generation

The CLIC strategy:

- Align components (10μm over 200m)
- Control/damp vibrations (from ground to accelerator)
- Measure beams well – allow to steer beam and optimize positions
- Algorithms for measurements, beam and component optimization, feedbacks
- Tests in existing accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)
Accelerator challenges

Key challenges:

High-current drive beam bunched at 12 GHz
Power transfer + main-beam acceleration
~100 MV/m gradient in main-beam cavities
Low emittance generation

Nano-beams

The CLIC strategy:

- Align components (10μm over 200m)
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Nano-beams
Towards industrialisation

Investigating paths to industrialisation

Baseline manufacturing technique: bonding and brazing

Alternatives: brazing as for SwissFEL machining halves

Target is structures that are low-cost & easy-to-manufacture
SwissFEL – C-band linac

- 104 x 2m-long C-band structures
  (beam $\rightarrow$ 6 GeV @ 100 Hz)
- Similar $\mu$m-level tolerances
- Length $\sim$ 800 CLIC structures
- Being commissioned
Upgrade proposal: XARA

- X-band Accelerator for Research and Applications
- The 4th CLARA linac is replaced by an X-band accelerating section to reach 1 GeV
- Novel FEL technology
- An EUV/soft x-ray FEL facility for ultra fast chemistry and biology, and a centre of accelerator R&D.

Compact, highly monochromatic X-ray source.
Complementary to X-ray tube and synchrotron light source.
Applications in cultural heritage, material science, medical, etc.

Electrons at CERN, overview

- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2x (bunches 3ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10

Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

Acc. R&D interests (see later): Overlaps with CLIC next phase (klystron based), future ring studies, FEL linac modules, e-beams for plasma, medical/radiation/detector-tests/training, impedance measurements, instrumentation, positioners and damping ring R&D
380 GeV Klystron option
Updated schedule: Construction + commissioning: 7 years

- Tunnel excavation TBM Good rock
  - Inner lining
- Survey works
- General services installation
- CV Installation works
- Electrical installation and cabling
- Machine transport
- Machine Installation
- Commissioning period
- Physics

CLIC 11km tunnel option - 380GeV - Drive Beam Option

System Commissioning @380GeV
Beam Commissioning @380GeV
Schedule

Updated schedule:
Construction + commissioning: 7 years, followed by 25–30 year physics programme

- Tunnel excavation TBM Good rock
- Inner lining
- Survey works
- General services installation
- CV Installation works
- Electrical installation and cabling
- Machine transport
- Machine Installation
- Commissioning period
- Physics

Graph showing integrated luminosity over years with peaks at 0.38 TeV, 1.5 TeV, and 3 TeV.
Civil Engineering and Infrastructure Studies

Important effort within:
- Civil engineering
- Electrical systems
- Cooling and ventilation
- Transport, logistics and installation
- Safety, access and radiation protection systems

Crucial for cost/power/schedule

Power Estimates

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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>380</td>
<td>168</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>1500</td>
<td>364</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>3000</td>
<td>589</td>
<td>46</td>
<td>17</td>
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</tbody>
</table>

From running model and power estimates at various states – the energy consumption can be estimated

CERN energy consumption 2012: 1.35 TWh

Further savings possible, main target damping ring RF
Will look also more closely at 1.5 and 3 TeV numbers next

Power estimate bottom up (concentrating on 380 GeV systems)
- Very large reductions since CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimisation, etc

CERN is currently consuming ~1.2 TWh yearly (~90% in accelerators)
Cost - I

Machine has been re-costed bottom-up in 2017-18
- Methods and costings validated at review on 7 November – similar to LHC, ILC, CLIC CDR
- Technical uncertainty and commercial uncertainty estimated

<table>
<thead>
<tr>
<th>Domain</th>
<th>Sub-Domain</th>
<th>Cost [MCHF]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Drive-Beam</td>
<td>Klystron</td>
</tr>
<tr>
<td>Main Beam Production</td>
<td>Injectors</td>
<td>175</td>
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<td>Damping Rings</td>
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<td>Beam Transport</td>
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<td>Drive Beam Production</td>
<td>Injectors</td>
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<td>Frequency Multiplication</td>
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<td>Beam Transport</td>
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<td>Main Linac Modules</td>
<td>Main Linac Modules</td>
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<td>Post decelerators</td>
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<tr>
<td>Main Linac RF</td>
<td>Main Linac Xband RF</td>
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<tr>
<td>Beam Delivery and Post Collision Lines</td>
<td>Beam Delivery Systems</td>
<td>52</td>
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<td>Final focus, Exp. Area</td>
<td>22</td>
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<td>Post-collision lines/dumps</td>
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<td>Civil Engineering</td>
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<td>Infrastructure and Services</td>
<td>Electrical distribution</td>
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<td>Survey and Alignment</td>
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<td>Cooling and ventilation</td>
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<td>Transport / installation</td>
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<td>Machine Control, Protection and Safety systems</td>
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<td>Machine Control Infrastructure</td>
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<td>Machine Protection</td>
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<td></td>
<td>Access Safety &amp; Control System</td>
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<tr>
<td><strong>Total (rounded)</strong></td>
<td></td>
<td><strong>5890</strong></td>
</tr>
</tbody>
</table>

CLIC 380 GeV Drive-Beam based: \(5890 \pm 1470\) MCHF;

CLIC 380 GeV Klystron based: \(7290 \pm 1800\) MCHF.
Other cost estimates:

Construction:
• From 380 GeV to 1.5 TeV, add 5.1 BCHF (drive-beam RF upgrade and lengthening of ML)
• From 1.5 TeV to 3 TeV, add 7.3 BCHF (second drive-beam complex and lengthening of ML)
• Labour estimate: ~11500 FTE for the 380 GeV construction

Operation:
• 116 MCHF (see assumptions in box below)
• Energy costs

- 1% for accelerator hardware parts (e.g. modules).
- 3% for the RF systems, taking the limited lifetime of these parts into account.
- 5% for cooling, ventilation and electrical infrastructures etc. (includes contract labour and consumables)

These replacement/operation costs represent 116 MCHF per year.
CLIC roadmap

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.
Working group for use of Novel Acceleration Technologies (NAT) – plasma with various drivers, dielectrics, etc (short chapter in Project Implementation Plan document)
  - Physics and accelerator parameters (luminosity in particular)
  - Consider status of various studies
  - Key challenges beam-quality, positrons, energy efficiency for suitable luminosities

Possible re-use of tunnel/infrastructure/drive-beams/injectors etc interesting for a LC infrastructure

The fact the actual effective ML might remain short (and hence possibly “cheap” and inter-changeable in a limited time) makes this long term perspective worth considering

Have not found any “constrains/guidance” from these very long term “hopes” that would impact the design of CLIC stages 1-3
  - CLIC is laser-straight and with a “reasonable” crossing angle likely to compatible with higher beam energies and the bunch separations needed for these technologies
CLEAR
CERN Linear Electron Accelerator for Research

80–220 MeV electrons
Bunch charge 0.01–1.5 nC

CLEAR started with beam in August 2017

Main activities:
CLIC & high-gradient X-band
Instrumentation R&D
VESPER irradiation test station
  Electronic components for space applications
    (with ESA)
  Medical applications (VHEE)
  Electronic components for accelerators and detectors
Novel techniques: plasma focusing and acceleration, THz radiation, dielectric structures

Open to proposals for user experiments
LC strategy discussed ahead of Granada. See summary (at link), extract below:

Conclusions from the Linear Collider meeting in Lausanne April 2019.

The highest scientific priority in particle physics is to uncover phenomena that establish new physics addressing the shortcomings of the Standard Model (SM). Precision studies in e+e- collisions of the properties of the Higgs boson including its self-interaction, of the top quark, and of other processes, can elucidate the underlying dynamics of electroweak symmetry breaking and "point the way" to new physics Beyond the Standard Model (BSM). Direct searches for new phenomena that are difficult to observe in hadronic interactions can also be pursued. All of these studies could address fundamental questions such as the origin of mass and of the matter-antimatter asymmetry, and the nature of dark matter.

The most cost effective, fast, and versatile approach is construction of a linear e+e- collider (LC) facility starting from an initial energy and luminosity optimised for the targeted measurements. Such a facility will also provide physics guidance for future accelerators beyond the initial LC. The facility should provide the foundation for a long-term e+e- physics programme and hence be upgradable in the future with the same, improved, or new technologies to much higher energies, allowing improved precision and reach for SM and BSM physics. The LC should be pursued for construction start-up in about 5 years, aiming for operation by ~2035.

During the ESPP process important conclusions will be drawn concerning future projects and studies, which are crucial for a timely construction start-up of a LC project. This is a unique opportunity to move ahead quickly towards constructing a LC that fulfills the goals described above. Europe and CERN should play leading roles in this endeavour, wherever the LC is realised.
A linear collider as part of an overall strategy

<table>
<thead>
<tr>
<th>2021-25</th>
<th>2026-30</th>
<th>2031-35</th>
<th>2036-40</th>
<th>2041-45</th>
<th>2046-50</th>
<th>2051-55</th>
<th>2056-60</th>
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<tbody>
<tr>
<td>HL LHC</td>
<td>LHC and HL LHC operation</td>
<td>Option: continue running</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LC prep phase and construction</td>
<td>LC initial stage operation</td>
<td>Option: continue running</td>
<td>Options: next stages, stop and possibly prepare for novel acc.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Proton (magnet) R&amp;D and acc. detailed design</td>
<td>Muon acc. R&amp;D towards CDR</td>
<td>Options: Circ. acc. prep &amp; construction (radius, techn, timeline tbd)</td>
<td></td>
<td></td>
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<tr>
<td>Novel acc, R&amp;D - 15 year horizon, move towards LC use?</td>
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<tr>
<td>Physics Beyond Collider (prep, construction, operation)</td>
<td>CEPC programme (not detailed)</td>
<td></td>
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</tbody>
</table>

Legend: Acc R&D  Constr.  Operating  Option for operation

HL LHC until ~2038
LC const. “ready”, affordable, provide opportunities for long term e+e- data
Acc. R&D opening for proton (possibly muon) colliders by/before 2050 – no 100 km constrain or wait for tunnel access (limited by R&D and funding)
PBC programme
CEPC development will unfold
Summary

• CLIC is now a mature project, ready for implementation
• The main accelerator technologies have been demonstrated
• The cost and implementation time are similar to LHC
• The physics case is broad and profound, and being further developed
• The detector concept and detector technologies R&D are advanced
• The full project status has been presented in a series of Yellow Reports and other publications: [http://clic.cern/european-strategy](http://clic.cern/european-strategy)

Thanks to all providing material - and more generally ALL contributors to the CLIC ESPP input/background documents, from which this material is drawn
Extra slides
Low emittance transport

1) Pre-align BPMs+quads accuracy $O(10\mu m)$ over about 200m

3) Use wake-field monitors accuracy $O(3.5\mu m)$ – CTF3

Stabilise quadrupole $O(1\text{nm})$ @ 1Hz

PACMAN, Marie Curie Action:
- vertical RMS error of 11µm
- i.e. accuracy is approx. 13.5µm

Emittance summary at Linac End:
- $(H; V) = (4.31; 3.21)\text{ mm mrad}$
- $(H; V) = (3.30; -)\text{ mm mrad}$
- $(H; V) = (2.75; 2.57)\text{ mm mrad}$ (35% in X, -20% in Y)

FACET

FERMI

Before correction:
- $(H; V) = (4.31; 3.21)\text{ mm mrad}$

After DFS:
- $(H; V) = (3.30; -)\text{ mm mrad}$

After DFS+WFS:
- $(H; V) = (2.75; 2.57)\text{ mm mrad}$
Final focus system

ATF2 @ KEK
Next phase

<table>
<thead>
<tr>
<th>Details</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main linac modules</strong></td>
<td>Final technical design, qualify industry partners, verify performance</td>
</tr>
<tr>
<td>Build ten prototype modules in qualified industries, two beam and klystron versions</td>
<td></td>
</tr>
<tr>
<td><strong>Accelerating structures</strong></td>
<td>Industrialization, manufacturing and cost optimisation</td>
</tr>
<tr>
<td>Around 50 structures incl. for modules above</td>
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</tr>
<tr>
<td><strong>Operating X-band test-stands, high efficiency RF</strong></td>
<td>X-band component tests, validation and optimization, cost reduction and industrially available RF units</td>
</tr>
<tr>
<td>X-band test-stands at CERN and collaborating institutes, cost optimized X-band RF</td>
<td></td>
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<tr>
<td><strong>Technical components</strong></td>
<td>Luminosity performance, costs and power, industrialization</td>
</tr>
<tr>
<td>Magnets, instrumentation, alignment, stability, vacuum</td>
<td></td>
</tr>
<tr>
<td><strong>Design &amp; Parameters</strong></td>
<td>Luminosity performance, risk, costs and power reduction</td>
</tr>
<tr>
<td>Beam dynamics studies, parameter optimization, costs, power</td>
<td></td>
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<tr>
<td><strong>Drivebeam studies</strong></td>
<td>Verification of the most critical parts of drivebeam concept, develop further the industrial capabilities for L-band RF systems</td>
</tr>
<tr>
<td>Drivebeam front end optimisation and system tests to around 20 MeV</td>
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</tbody>
</table>
Collider environment

Beam structure

Not to scale!

20 ms

156 ns

High bunch charge density

→ beam-related backgrounds

small effect at \( \sqrt{s}=380\text{GeV} \)

large effect at high energies

Precise timing required

for beam background rejection

1 ns in calorimetry,

5 ns in vertexing/tracking

High precision:

jet energy resolution

→ fine-grained calorimetry

momentum resolution

impact parameter resolution

\[
\sigma(E)/(E) \sim 3.5\% \text{ for } E>100\text{GeV} \\
\sigma(p_T)/p_T^2 \sim 2\times10^{-5}\text{ GeV}^{-1} \\
\sigma_0 \sim 5\oplus 15/(p[\text{GeV}]\sin^{3/2}\theta) \text{ \mu m}
\]

tt at \( \sqrt{s}=3\text{TeV} \)

CALICE / FCAL

CLICdp vertexing/tracking programme
Ultra low-mass vertex detector with 25\( \mu \)m pixels

Main tracker, silicon-based (large pixels and/or strips)

Forward region with LumiCal and BeamCal

Fine-grained calorimetry used for Particle Flow Analysis

End coils for field-shaping

Solenoid magnet \( B=4T \)

Return yoke (iron) with detectors for muon ID

Triggerless readout

Tracker spatial resolution: 7\( \mu \)m
Material: 1–2\% \( X_0 \) / layer

Vertex detector spatial resolution: 3\( \mu \)m
Material: 0.2\% \( X_0 \) / layer
\( \rightarrow \) forced air cooling

CLICdet

11.4 m