CLIC
THE COMPACT LINEAR COLLIDER

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Linear Collider Baseline

**LEP: 209 GeV**

next Electron-Positron Collider

- Centre-of-mass-energy:
  - 0.5 - 3 TeV
  - Luminosity: >2*10^{34}

**Physics motivation:**

"Physics at the CLIC Multi-TeV Linear Collider: Report of the CLIC Physics Working Group,“

CERN Report 2004-5

Storage Ring not possible, energy loss $\Delta E \sim E^4$

→ two linacs, experiment at centre

- total energy gain in one pass: **high acceleration gradient**
- beam can only be used once: **small beam dimensions at crossing point**

Boundary conditions: site length

Power consumption
In 1999 ICFA issued a statement on Linear Colliders, ..... that there would be compelling and unique scientific opportunities at a linear electron-positron collider in the TeV energy range. Such a facility is a necessary complement to the LHC hadron collider.

Two options: ILC - CLIC

Collaboration on common issues
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<tr>
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<th>ILC: Superconducting RF</th>
<th>CLIC: normal conducting copper RF</th>
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<tr>
<td><strong>500 GeV</strong></td>
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<td><strong>3 TeV</strong></td>
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<tr>
<td><strong>Accelerating gradient:</strong></td>
<td>31.5 MV/m</td>
<td>100 MV/m</td>
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<td></td>
<td>(35 MV/m target)</td>
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<tr>
<td><strong>RF Peak power:</strong></td>
<td>0.37 MW/m , 1.6 ms, 5 Hz</td>
<td>275 MW/m, 240 ns, 50 Hz</td>
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<td><strong>RF average power:</strong></td>
<td>2.9 kW/m</td>
<td>3.7 kW/m</td>
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<td><strong>Total length:</strong></td>
<td>31 km</td>
<td>48.4 km</td>
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<td><strong>Site power:</strong></td>
<td>230 MW</td>
<td>392 MW</td>
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<td><strong>Beam structure:</strong></td>
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<td><strong>Particles per bunch:</strong></td>
<td>20 * 10^9</td>
<td>3.7 * 10^9</td>
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<td><strong>2625 bunches / pulse of 0.96 ms</strong></td>
<td><strong>312 bunches / pulse of 156 ns</strong></td>
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<td><strong>Bunch spacing</strong></td>
<td>369 ns</td>
<td>0.5 ns</td>
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CLIC = Compact Linear Collider (length < 50 km)

CLIC parameters:
**Accelerating gradient**: 100 MV/m
RF frequency: 12 GHz

64 MW RF power / accelerating structure of 0.233m active length
→ 275 MW/m

Total active length for 1.5 TeV: **15’000 m**

Pulse length 240 ns, 50 Hz

**Efficient RF power production !!!!!**
The CLIC Two Beam Scheme

Individual RF power sources?
=> Not for the 1.5 TeV linacs

Two Beam Scheme:
Drive Beam supplies RF power

- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

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

Accelerating Structures

Power Extraction transfer Structure (PETS)

BPM

Main beam – 1.2 A, 156 ns
from 9 GeV to 1.5 TeV
CLIC Drive Beam Generation

Accelerate long bunch train with low bunch rep rate (500 MHz) with low frequency RF (1 GHz) to generate short (280 ns) trains with high bunch rep rate (12 GHz).
The Full CLIC scheme

CLIC 3 TeV

Not to scale!
Why 100 MV/m and 12 GHz?

Optimisation: (A. Grudiev)

Structure limits:
- RF breakdown – scaling
- RF pulse heating

Beam dynamics:
- Emittance preservation – wake fields
- Luminosity, bunch population, bunch spacing
- Efficiency – total power

Figure of merit:
- Luminosity per linac input power

Take into account cost model

after > 60 * 10^6 structures:
100 MV/m 12 GHz chosen, previously 150 MV/m, 30 GHz
CLIC Accelerating Module

- Main Beam
- Drive Beam
- COOLING CIRCUITS
- RF DISTRIBUTION
- ACCELER. STRUCTURE (BRAZED DISKS)
- BEAM INSTRUMENTATION
- VACUUM MANIFOLDS
- GIRDER
- ALIGNMENT SYSTEM
- INTERCONNECTIONS
- PETS (MINI-TANK)
- PETS (OCTANT)
Accelerating Structures

Objective:
• Withstand of 100 MV/m without damage
• Breakdown rate < $10^{-7}$
• Strong damping of HOMs

Technologies:
Brazed disks - milled quadrants

Collaboration: CERN, KEK, SLAC
Power Extraction : PETS

Special development for CLIC

- Travelling wave structures
- Small R/Q : 2.2 kΩ/m
  (accelerating structure: 15-18 kΩ/m)
- 100 A beam current

136 MW RF @ 240 ns per PETS
(2 accelerating structures)
0.21 m active length
total number : 35’703 per linac

Status:
CTF3: up to 45 MW peak (3 A beam, recirculation)
SLAC: 125 MW @ 266 ns

ref: Igor Syratchev
### CLIC Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CLIC 500 GeV</th>
<th>CLIC 3 TeV</th>
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<tbody>
<tr>
<td><strong>Center-of-mass energy</strong></td>
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<tr>
<td>Beam parameters</td>
<td>Conservative</td>
<td>Nominal</td>
</tr>
<tr>
<td>Accelerating structure</td>
<td>502</td>
<td>G</td>
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<tr>
<td>Total (Peak 1%) luminosity</td>
<td>0.9(0.6)·10^{34}</td>
<td>2.3(1.4)·10^{34}</td>
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<td>Repetition rate (Hz)</td>
<td></td>
<td>50</td>
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<tr>
<td>Loaded accel. gradient MV/m</td>
<td>80</td>
<td>100</td>
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<tr>
<td>Main linac RF frequency GHz</td>
<td></td>
<td>12</td>
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<tr>
<td>Bunch charge10^9</td>
<td>6.8</td>
<td>3.72</td>
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<tr>
<td>Bunch separation (ns)</td>
<td></td>
<td>0.5</td>
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<tr>
<td>Beam pulse duration (ns)</td>
<td>177</td>
<td>156</td>
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<td>Beam power/beam (MWatts)</td>
<td>4.9</td>
<td>14</td>
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<tr>
<td>Hor./vert. norm. emitt (10^{-6}/10^{-9})</td>
<td>3/40</td>
<td>2.4/25</td>
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<td>Hor/Vert FF focusing (mm)</td>
<td>10/0.4</td>
<td>8 / 0.1</td>
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<tr>
<td>Hor./vert. IP beam size (nm)</td>
<td>248 / 5.7</td>
<td>202 / 2.3</td>
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<tr>
<td>Hadronic events/crossing at IP</td>
<td>0.07</td>
<td>0.19</td>
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<tr>
<td>Coherent pairs at IP</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>BDS length (km)</td>
<td>1.87</td>
<td>2.75</td>
</tr>
<tr>
<td>Total site length km</td>
<td>13.0</td>
<td>48.3</td>
</tr>
<tr>
<td>Wall plug to beam transfert eff</td>
<td>7.5%</td>
<td>6.8%</td>
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<tr>
<td>Total power consumption MW</td>
<td>129.4</td>
<td>415</td>
</tr>
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</table>
CLIC Test Facility CTF3

Provide answers for CLIC specific issues

Write CDR in 2010

Two main missions:

Prove CLIC RF power source scheme:
- bunch manipulations, beam stability,
- Drive Beam generation
- 12 GHz extraction

Provide RF power for validation of CLIC components:
accelerating structures,
RF distribution,
PETS (Power extraction and Transfer Structure)

Demonstration of “relevant” linac sub-unit:
- acceleration of test beam
CTF3 Building Blocks

Infrastructure from LEP

- 150 MeV e-linac
- 30 GHz test stand
- magnetic chicane
- 3.5 A - 1.4 μs
- CLEX (CLIC Experimental Area)
- TWO BEAM TEST STAND
- PROBE BEAM
- Test Beam Line
- Delay Loop
- Combiner Ring
- 28 A - 140 ns
- total length about 140 m

Photo injector tests, laser

Infra 10 m
World-wide CLIC&CTF3 Collaboration

33 Institutes involving 21 funding agencies and 18 countries

Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University (Norway)
Patras University (Greece)
Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Uppsala University (Sweden)
DETECTORS & PHYSICS
CLIC Physics

- New physics expected in the TeV energy range
  - Higgs, Supersymmetry, extra dimensions,…?
- LHC will indicate what physics and at which energy scale
  - Is 500 GeV enough or is there a need for a multi-TeV machine?
- Even if multi-TeV is the final goal, CLIC will most likely operate over a range of energies (e.g. 0.5 – 3.0 TeV)
Heavy Mass SUSY Particles

e.g. $e^+e^- \rightarrow H^0A^0$ production

$e^+e^- \rightarrow H^0A^0 \rightarrow b\bar{b}b\bar{b}$

$m_{H^0A^0} \approx 1$ TeV
Yellow dots mostly from $\gamma\gamma$
$e^+e^- \rightarrow H^0A^0$ at 3 TeV

$H^0A^0 \rightarrow b\bar{b}b\bar{b}$

3 ab$^{-1}$

Black
without $\gamma\gamma$ background

Blue
with $\gamma\gamma$ background
+ 25 ns time stamping
Example of CLIC SUSY Search

Dilepton spectrum in neutralino decay

\[ \tilde{\chi}_j^0 \rightarrow \ell^+ \ell^- \rightarrow \ell^+ \ell^- \tilde{\chi}_1^0 + \tilde{\chi}_j^0 \rightarrow \tilde{\chi}_j^0 Z^0 \rightarrow \tilde{\chi}_j^0 \ell^+ \ell^- \]

Reach in parameter space

\[ \tan \beta = 10 \]

\[ m_{h'} (\text{GeV}) \]

CLIC 3 TeV

IHC
Extra Dimensions and SUSY have rather similar signatures at LHC. Clean final states and control of CM energy at CLIC allows separation. Example: pair produced KK muons and SUSY smuons: $\mu^+ \mu^- \, \sqrt{s}$

$$e^+ e^- \rightarrow \mu_1^+ \mu_1^- \rightarrow \mu^+ \mu^- \gamma \gamma$$

produced

$$e^+ e^- \rightarrow \tilde{\mu}^+ \tilde{\mu}^- \rightarrow \mu^+ \mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

reconstructed

Angular distribution of muon

M. Battaglia, AK Datta, A dRoeck, K Kong, K Matchev
In UED theories, TeV-scale Graviton resonances are predicted, decaying into $\gamma\gamma$, $gg$ or $f\bar{f}$ pairs. Cross sections are large.

\[ e^+e^- \rightarrow \mu^+\mu^- \]
# Indicative Physics Reach

Units: TeV (except $W_L W_L$ reach)

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>LHC</th>
<th>sLHC</th>
<th>LC</th>
<th>LC</th>
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<tbody>
<tr>
<td></td>
<td>14 TeV</td>
<td>14 TeV</td>
<td>0.8 TeV</td>
<td>5 TeV</td>
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<td></td>
<td>100 fb$^{-1}$</td>
<td>1000 fb$^{-1}$</td>
<td>500 fb$^{-1}$</td>
<td>1000 fb$^{-1}$</td>
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<tr>
<td>Squarks</td>
<td>2.5</td>
<td>3</td>
<td>0.4</td>
<td>2.5</td>
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<tr>
<td>$W_L W_L$</td>
<td>2$\sigma$</td>
<td>4$\sigma$</td>
<td>6$\sigma$</td>
<td>30$\sigma$</td>
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<tr>
<td>$Z'$</td>
<td>5</td>
<td>6</td>
<td>8†</td>
<td>30†</td>
</tr>
<tr>
<td>Extra-dim ($\delta=2$)</td>
<td>9</td>
<td>12</td>
<td>5–8.5†</td>
<td>30–55†</td>
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<tr>
<td>$q^*$</td>
<td>6.5</td>
<td>7.5</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>$\Lambda$compositeness</td>
<td>30</td>
<td>40</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>TGC ($\lambda_\gamma$)</td>
<td>0.0014</td>
<td>0.0006</td>
<td>0.0004</td>
<td>0.00008</td>
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</tbody>
</table>

† indirect search (from precision measurements)

Ellis, Gianotti, de Roeck  
Hep-ex/0112004 + updates
Motivation:

- Substantial CLIC accelerator effort towards Conceptual Design Report (CDR) for end 2010
- Include CDR chapters on the CLIC physics potential, CLIC detector concepts and their related technological issues

CLIC detector concept will be very similar to ILC concepts

A few challenging differences:

- Higher energy
- Increased background conditions
- Difference in time structure

Profit from many years of investment in ILC $e^+e^-$ physics/detector simulations, hardware R&D and detector concepts

LCD@CERN: Working together with the ILC detector concepts and with the linear collider detector technology collaborations to study modifications to the ILC concepts for CLIC energies and beam conditions.
Detectors

ILC: IDAG (International Detector Advisory Group
Physics and Experiments Board

LOI’s
CLIC Detector Issues

3 main differences with ILC:

• Energy 500 GeV => 3 TeV

• More severe background conditions
  • Due to higher energy
  • Due to smaller beam sizes

• Time structure of the accelerator
How is physics changing from LEP to CLIC?
CLIC Time Structure

Train repetition rate 50 Hz

CLIC: 1 train = 312 bunches 0.5 ns apart 50 Hz
ILC: 1 train = 2820 bunches 308 ns apart 5 Hz

Consequences for CLIC detector:
- Need for detection layers with time-stamping
  - Innermost tracker layer with ~ns resolution
  - or .... all-detector time stamping at the 10 ns level
- Readout/DAQ electronics will be different from ILC
  - Power pulsing has to work at 50 Hz instead of 5 Hz
Beam-induced Background

Background sources: CLIC and ILC similar
Due to the higher beam energy and small bunch sizes they are significantly more severe at CLIC.

Main backgrounds:

- CLIC 3TeV beamstrahlung $\Delta E/E = 29\%$ ($10 \times ILC_{value}$)
  - **Coherent pairs** ($3.8 \times 10^8$ per bunch crossing) $\leq$ disappear in beam pipe
  - **Incoherent pairs** ($3.0 \times 10^5$ per bunch crossing) $\leq$ suppressed by strong solenoid-field
  - $\gamma\gamma$ interactions $\Rightarrow$ hadrons (**2.7 hadron events per bunch crossing**)

- Muon background from upstream linac
  - More difficult to stop due to higher CLIC energy (active muon shield)
Tentative long-term CLIC scenario
Shortest, Success Oriented, Technically Limited Schedule

Technology evaluation and Physics assessment based on LHC results for a possible decision on Linear Collider with staged construction starting with the lowest energy required by Physics

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<td>Technical design</td>
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<td>Engineering Optimisation &amp; Industrialisation</td>
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<td>Construction (in stages)</td>
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<td>Construction Detector</td>
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Conceptual Design Report (CDR)
Technical Design Report (TDR)
Project
First
Future course of high-energy physics to be determined by results from LHC.

Although we do not yet know what the LHC will (or will not) find, many of the physics scenarios that have been studied would best be explored further with a high-energy e+e- collider.

CLIC will provide unique, high-precision physics at the energy frontier up to 3 TeV centre-of-mass energy.

- Provide access to heavy Higgs boson, supersymmetry and extra dimensions.

Prudent to have the widest possible technology available (CLIC and ILC) to make a choice when LHC results appear.

- In the meantime, CLIC and ILC teams are working together in studies of positron sources, damping rings, beam dynamics, beam delivery, interaction regions, detectors and costing.