ILC vs CLIC

....cosa si perde e cosa si guadagna.

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CLIC aim:
develop technology for $e^-/e^+$ collider with $E_{CMS} = 1 - 5$ TeV

Physics motivation:
"Physics at the CLIC Multi-TeV Linear Collider: report of the CLIC Physics Working Group,"
CERN report 2004-5

Present mandate:
Demonstrate all key feasibility issues by 2010
CLIC technology for Multi-TeV Linear Colliders

- **High acceleration gradient** (150 MV/m)
- "Compact" collider—overall length ≈ 33 km
  - Normal conducting accelerating structures
  - High acceleration frequency (30 GHz)
- **Two-Beam Acceleration Scheme**
  - RF power generation at high frequency
  - Cost-effective & efficient (~ 10% overall)
  - Simple tunnel, no active elements
  - "modular" design, can be built in stages
  - Easily expendable in energy

Overall layout for a center of mass energy of **3 TeV/c**
# The CLIC main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>3 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of mass Energy (TeV)</td>
<td>0.5 TeV</td>
<td>3 TeV</td>
</tr>
<tr>
<td>Luminosity ($10^{34}$ cm$^{-1}$s$^{-1}$)</td>
<td>2.1</td>
<td>8.0</td>
</tr>
<tr>
<td>Mean energy loss (%)</td>
<td>4.4</td>
<td>21</td>
</tr>
<tr>
<td>Photons / electron</td>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>Coherent pairs per X</td>
<td>700</td>
<td>$6.8 \times 10^8$</td>
</tr>
<tr>
<td>Rep. Rate (Hz)</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>$10^9$ $e^\pm$ / bunch</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Bunches / pulse</td>
<td>154</td>
<td>154</td>
</tr>
<tr>
<td>Bunch spacing (cm)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>H/V $\varepsilon_n$ ($10^{-8}$ rad.m)</td>
<td>200/1</td>
<td>68/1</td>
</tr>
<tr>
<td>Beam size (H/V) (nm)</td>
<td>202/1.2</td>
<td>60/0.7</td>
</tr>
<tr>
<td>Bunch length (μm)</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Accelerating gradient (MV/m)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Overall length (km)</td>
<td>7.7</td>
<td>33.2</td>
</tr>
<tr>
<td>Power / section (MW)</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>RF to beam efficiency (%)</td>
<td>23.1</td>
<td>23.1</td>
</tr>
<tr>
<td>AC to beam efficiency (%)</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Total AC power for RF (MW)</td>
<td>105</td>
<td>319</td>
</tr>
<tr>
<td>Total site AC power (MW)</td>
<td>175</td>
<td>410</td>
</tr>
</tbody>
</table>
Luminosity vs Collision Energy
Tentative long-term CLIC scenario

Shortest and technically limited schedule

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.
From April 2000 - in response to a growing interest in the physics potential of a multi-TeV e+e- collider - a CLIC Physics Study Group has been set-up in order to:

1) Identify and investigate key processes that can help to optimize the machine design:
   - luminosity spectrum,
   - accelerator induced background,
   - beam-beam background

2) Explore the physics program for CLIC and define a concept of the detector

3) Make a comparative assessment of the CLIC physics potential

http://cern.ch/CLICphysics/

Report summarizing the physics potentials of a facility at a centre-of-mass energy from 1 to 5 TeV with luminosities in the order of $10^{35}$ cm$^{-2}$ sec$^{-2}$.

"Physics at the CLIC Multi-TeV Linear Collider": CERN-2004-005
“synchrotron radiation” in the field of the opposing bunch “Beamstrahlung”

creates $e^+e^-$ pairs background in detector

smears out luminosity spectrum

~50% of the luminosity is within 1% of energy
Momentum spread after collision increases with colliding beam energy. Substantial luminosity from particles within small momentum spread.
Experimentation at CLIC: beamstrahlung becomes more severe

- forward coverage
- backgrounds
- precision of scans
- short bunch spacing (0.7 ns) challenges detector time resolution

lineshape scan of a 3 TeV dilepton resonance at CLIC
Physics case for multi-TeV $e^+e^-$ at CLIC

**Physics highlights:**

1. rare Higgs decays
2. improve on Higgs self coupling + extend mass range
3. more complete SUSY spectrum
4. extending mass reach new resonances, scans
5. study resonances of strong EWSB if within kinematic reach
Completion of the Higgs sector

Larger cross section @ 3 TeV:
can measure rare decay modes

\[ \sqrt{s} = 3000 \text{ GeV} \]
\[ \sqrt{s} = 500 \text{ GeV} \]
\[ \sqrt{s} = 350 \text{ GeV} \]
Higgs self coupling @ 3 TeV

Advantage of larger rates in HH#ν#ν:
* improve precision on $\lambda_{HHH}$ for light H to $\sim 10\%$ or better ($m_H = 120$ GeV)
* sensitivity on $\lambda_{HHH}$ for heavier H in WWWWW#ν#ν to $\sim 15\%$ ($m_H = 240$ GeV)

+ Direct production of heavy H,A,H± up to 1.2 TeV (at CLIC(3000))
Constraining Triple-Gauge Coupling

$\Delta k_{\gamma}$

$\Delta \lambda_{\gamma}$

0.0004 at 0.8 TeV  
0.00013 at 3 TeV
STRONG EWSB:
WW Resonance Observable @ 3 TeV

Can establish its existence beyond any doubt if < 1 TeV:

\[ ee \rightarrow H ee \]

Find resonance in strong WW scattering if > 1 TeV:

\[ ee \rightarrow H \nu \nu \]
If the Higgs is light ... 

There must be new physics below 1000 TeV ...
Extrapolate to high energies: \[ V(H) = -\mu H^2 + \lambda |H|^4 \]

114 GeV < \( m_H \) < 130 GeV: 
\( V(H) \) unstable for \( \Lambda < 10^7 \) GeV

130 GeV < \( m_H \) < 180 GeV: 
valid extrapolation to \( M_{\text{GUT}} \)

\( m_H > 219 \) GeV: 
conflict with EW data
SUSY at CLIC

CLIC can reach higher mass SUSY particles:

Dilepton spectrum in neutralino decay

\[
\begin{align*}
M_{\tilde{\chi}_1^0} &= 660 \text{ GeV}, \\
M_{\tilde{\mu}_L} &= 1150 \text{ GeV} \\
M_{\tilde{\chi}_2^0} &= 540 \text{ GeV}, \\
M_{\tilde{\chi}_1^0} &= 290 \text{ GeV}
\end{align*}
\]
Reach in the *mSugra* parameter space

\[ \tan \beta = 10 \]
SUSY : LHC vs ILC and CLIC

LHC almost `guaranteed’ to discover supersymmetry if it is relevant to the mass problem

LC observes complementary sparticles
Sparticle detectability along one WMAP line

**LHC $\tan \beta = 10$**

**LC $\sqrt{s} = 0.5$ TeV $\tan \beta = 10$**

**LC $\sqrt{s} = 1.0$ TeV $\tan \beta = 10$**

**CLIC $\sqrt{s} = 3.0$ TeV $\tan \beta = 10$**

**CLIC $\sqrt{s} = 5.0$ TeV $\tan \beta = 10$**
CLIC could measure Kaluza-Klein excitations

Angular distribution in graviton decay

[Graph showing direct-channel resonances]

[Plot showing the angular distribution of graviton decay]
<table>
<thead>
<tr>
<th>Process</th>
<th>LHC</th>
<th>LC</th>
<th>SLHC</th>
<th>CLIC 3, 5 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squarks</td>
<td>2.5</td>
<td>0.4</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>Sleptons</td>
<td>0.34</td>
<td>0.4</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>New gauge boson Z'</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Excited quark q*</td>
<td>6.5</td>
<td>0.8</td>
<td>7.5</td>
<td>3</td>
</tr>
<tr>
<td>Excited lepton l*</td>
<td>3.4</td>
<td>0.8</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Two extra space dimensions</td>
<td>9</td>
<td>5–8.5</td>
<td>12</td>
<td>20–35</td>
</tr>
<tr>
<td>Strong WLWL scattering</td>
<td>2σ</td>
<td>-</td>
<td>4σ</td>
<td>70σ</td>
</tr>
<tr>
<td>Triple-gauge Coupling (TGC) (95%)</td>
<td>.0014</td>
<td>0.0004</td>
<td>0.0006</td>
<td>0.00013</td>
</tr>
</tbody>
</table>

Integrated luminosities are 100 fb–1 for the LHC, 500 fb–1 for the 800 GeV LC, and 1000 fb–1 for the SLHC and CLIC. Most numbers given are TeV, but for strong WLWL scattering the numbers of standard deviations, and pure numbers for the triple gauge coupling (TGC).
summarizes discussion

THE HIGH ENERGY FRONTIER I

R.-D. Heuer, DESY
Orsay, 01/02/2006
1. What is the *physics* case for upgrades or new machines if LHC provides a null result?

2. Clear statements (ECFA, ACFA, HEPAP, ICFA, GSF,…) in 2001-2004 that a Linear Collider of up to at least 500 GeV, upgradeable to 1 TeV, should be the next major project and requires timely realization. Has the *physics* case changed since then?

3. Is there a clear *physics* case for multi-TeV lepton colliders *now*? At which energy?

4. What is the *physics* case for SLHC/DLHC? Which priority?

5. Muon Collider: any *physics* reason to discuss it (already) *now*?
3. Is there a clear physics case for a multi-TeV lepton collider now? At which energy?

Our current knowledge does not indicate a clear case for multi-TeV collisions need input from the LHC (and ILC) to set the scale

need for continued accelerator R&D (CLIC)
2. Consensus statements in 2001-2004 that a Linear Collider of up to at least 500 GeV, upgradeable to 1 TeV, should be the next major project and requires timely realization. Has the physics case changed since then?

Unanimous view: physics case has not changed since 2001

- Physics case for 400 (500) GeV is solid (see ECFA statement)
- Technology is at hand

we are ready to go for it (GDE timescale)
In how far should the decision about ILC construction be connected to LHC results?

The bulk of the discussion was directed to this question with differing opinions.

**YES:** discussion of scenarios with limited ILC sensitivity

**NO:** Clearly outspoken (not only from the young generation): coupling the ILC to LHC results leads to many drawbacks

- Time line is not well defined (moving target)
- Can lead to discouragement and tensions (what precisely should one demand to see in the LHC data?)
In how far should the decision about ILC construction be connected to LHC results?

Crucial to push ahead with ILC preparations for construction (GDE)

Upgrade / options depend on LHC+ILC(phase 1) findings (need flexibility)

Added value from concurrent running of LHC and ILC
1. What is the physics case for upgrades or new machines if LHC provides a null result?

Null result = no Higgs, no new physics

Catastrophic scenario (would be very interesting), does not invalidate the physics case for the ILC
Precision measurements at the ILC (and possible discoveries) will be crucial in this case
ILC input important for future road map