Talk outline

• The work plan – issues, organization & timescale
• Recent R&D results
  • High-gradient structures
  • CTF3
• Other R&D activities
  • Beam physics
  • Technical issues
• Conclusion
Aim of the CLIC study:

- develop technology for e-/e+ linear collider with the requirements:
  
  ✓ $E_{CM}$ should cover range from ILC to LHC maximum reach and beyond $\Rightarrow E_{CM} = 0.5$-3 TeV,
  ✓ $L > \text{few } 10^{34}\text{ cm}^{-2}$ with acceptable background and energy spread
  ✓ Design compatible with maximum length $\sim 50\text{ km}$
  ✓ Affordable
  ✓ Total power consumption $< 500\text{ MW}$

Physics motivation:

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

Present goal:

Demonstrate all key feasibility issues and document in a CDR by 2010
X-band high-gradient and CLIC R&D for future colliders

The CTF3 – CLIC world wide collaboration

Ankara University (Turkey)  
BINP (Russia)  
CERN  
CIEMAT (Spain)  
Cockcroft Institute (UK)  
Gazi Universities (Turkey)  
IRFU/Saclay (France)  
Helsinki Institute of Physics (Finland)  
IAP (Russia)  
IAP NASU (Ukraine)  
Instituto de Fisica Corpuscular (Spain)  
INFN / LNF (Italy)  
J.Adams Institute, (UK)  
JINR (Russia)  
JLAB (USA)  
KEK (Japan)  
LAL/Orsay (France)  
LAPP/ESIA (France)  
NCP (Pakistan)  
North-West. Univ. Illinois (USA)  
Oslo University (Norway)  
PSI (Switzerland),  
Polytech. University of Catalonia (Spain)  
RRCAT-Indore (India)  
Royal Holloway, Univ. London, (UK)  
SLAC (USA)  
Uppsala University (Sweden)
CLIC/CTF3 Collaboration
http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

• 27 institutes involving 17 funding agencies from 15 countries

• Organized as a HEP Detector Collaboration

• Started as CTF3, recently extended to CLIC R&D in view of CDR and beyond

CLIC / ILC Collaboration
http://clic-study.web.cern.ch/CLICStudy/CLIC_ILC_Collab_Mtg/Index.htm

• Focusing on subjects with strong synergy between CLIC & ILC

• Making the best use of the available resources

• Identifying and understanding the differences due to technology and energy (technical, cost….)

• Preparing together the future evaluation of the two technologies by the Linear Collider Community made up of CLIC & ILC experts
CLIC organizational chart

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm
Work Plan until 2010:

- Demonstrate feasibility of CLIC technology (R&D on critical feasibility issues)
- Design of a linear Collider based on CLIC technology
- Estimation of its cost (capital investment & operation)
- CLIC Physics study and detector development
  [http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html](http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html)

Conceptual Design Report to be published in 2010 including:

- Physics, Accelerator and Detectors
- Results of feasibility study
- Preliminary performance and cost estimation

R&D Issues classified in three categories:

- critical for feasibility: fully addressed by specific R&D to be completed before 2010 results in CDR
- critical for performance: being addressed now by specific R&D to be completed before 2015 first assessments in CDR results in Technical Design Report (TDR) with consolidated performance & cost
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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<tbody>
<tr>
<td>R&amp;D on Feasibility Issues</td>
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<td>Conceptual Design</td>
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<td>R&amp;D on Performance and Cost issues</td>
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<tr>
<td>Engineering Optimisation &amp; Industrialisation</td>
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<tr>
<td>Construction (in stages)</td>
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<tr>
<td>Construction Detector</td>
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</tbody>
</table>

CLIC Parameters and upgrade scenario

- **1st phase:** Initial operation
  - Energy: 500 GeV
  - Parameters: conservative

- **2nd phase:** Luminosity increase
  - Energy: 500 GeV
  - Parameters: nominal

- **3rd phase:** 0.5 to 3 TeV energy upgrade
  - Energy: 3 TeV
  - Parameters: conservative

- **4th phase:** Luminosity increase
  - Energy: 3 TeV
  - Parameters: nominal
## CLIC Parameter Table

<table>
<thead>
<tr>
<th>Center-of-mass energy</th>
<th>CLIC 500 GeV</th>
<th>CLIC 3 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerating structure</td>
<td>502</td>
<td>G</td>
</tr>
<tr>
<td>Total (Peak 1%) luminosity</td>
<td>0.9 (0.6)·10^{34}</td>
<td>2.3 (1.4)·10^{34}</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Loaded accel. gradient MV/m</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Main linac RF frequency GHz</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Bunch charge 10^9</td>
<td>6.8</td>
<td>3.72</td>
</tr>
<tr>
<td>Bunch separation (ns)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Beam pulse duration (ns)</td>
<td>177</td>
<td>156</td>
</tr>
<tr>
<td>Beam power/beam MWatts</td>
<td>4.9</td>
<td>14</td>
</tr>
<tr>
<td>Hor./vert. norm. emiss (10^{-6}/10^{-9})</td>
<td>3/40</td>
<td>2.4/25</td>
</tr>
<tr>
<td>Hor/Vert FF focusing β^* (mm)</td>
<td>10/0.4</td>
<td>8 / 0.1</td>
</tr>
<tr>
<td>Hor./vert. IP beam size (nm)</td>
<td>248 / 5.7</td>
<td>202 / 2.3</td>
</tr>
<tr>
<td>Hadronic events/crossing at IP</td>
<td>0.07</td>
<td>0.19</td>
</tr>
<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>
</tr>
<tr>
<td>Total power consumption MW</td>
<td>129.4</td>
<td>415</td>
</tr>
</tbody>
</table>
What matters in a linear collider?

Energy reach

\[ E_{cm} = F_{\text{fill}} L_{\text{linac}} G_{\text{acc}} \]

- High gradient

Luminosity

\[ L = \frac{n_b N^2 f_{\text{rep}}}{4 \pi \sigma_x \sigma_y} \times H_D \propto \eta^{AC}_{\text{beam}} \frac{P_{AC}}{E_{cm}} \frac{\delta_{BS}^{1/2}}{\varepsilon_y^{1/2}} \]

- Acceleration efficiency
- Generation of small emittance damping rings
- Conservation of small emittance wake-fields, alignment, stability
- Extremely small beam spot at Interaction Point beam delivery system, stability
The small emittance challenge
The small beam size challenge
The CLIC way to a multi-TeV linear collider - Basic features

• High acceleration gradient (100 MV/m)
  ✓ “Compact” collider - overall length @ 3 TeV < 50 km
  ✓ Normal conducting accelerating structures
  ✓ High acceleration frequency (12 GHz)

• Two-Beam Acceleration Scheme
  ✓ Cost effective, reliable, efficient
  ✓ Simple tunnel, no active elements
  ✓ Modular, easy energy upgrade in stages

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

Main beam – 1 A, 160 ns
from 9 GeV to 1.5 TeV
CLIC Layout 3 TeV

Drive Beam Generation Complex

Main Beam Generation Complex

booster linac, 9 GeV, 2 GHz

e injector, 2.4 GeV

Main & Drive Beam generation complexes not to scale
CLIC Layout  500 GeV

Drive Beam Generation Complex

- 326 klystrons
- 33 MW, 29 µs

Drive beam accelerator
- 2.37 GeV, 1.0 GHz
- 1 km

Delay loop
- 1 km

Main Beam Generation Complex

- Booster linac, 9 GeV, 2 GHz
- 365 m

- e+ injector, 2.4 GeV
- 365 m

- e injector 2.4 GeV
- 365 m

- e DR 365 m
### Table of CLIC feasibility issues

<table>
<thead>
<tr>
<th>SYS TEMS (level n)</th>
<th>Critical parameters</th>
<th>Feasibility issue</th>
<th>Performance issue</th>
<th>Cost issue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structures</strong></td>
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<tr>
<td><strong>Main beam acceleration structures</strong></td>
<td>Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate</td>
<td></td>
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<tr>
<td><strong>Decelerator structures</strong></td>
<td>Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability</td>
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<tr>
<td><strong>Drive Beam</strong></td>
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<tr>
<td><strong>Validation of drive Beam</strong></td>
<td>- production</td>
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<td></td>
<td>- phase stability, potential feedbacks</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- MPS appropriate for beam power</td>
<td></td>
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<tr>
<td><strong>Two Beam</strong></td>
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<tr>
<td>Test of a relevant linac sub-unit with both beams</td>
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<tr>
<td><strong>Beam Physics</strong></td>
<td>Preservation of low emittances (main linac + RTML)</td>
<td>Absolute blow-up Hor: 160nradm Vert: 15 nradm</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Stabilization</strong></td>
<td>Main Linac and BDS Stabilization</td>
<td>Main Linac: 1 nm vert (&gt;1 Hz) BDS: 0.15...1 nm vert (&gt;4 Hz) depending on implementation of final doublet girder</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Operation and reliability</strong></td>
<td>Commissioning strategy</td>
<td>Handling of drive beam power of 72 MW</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
CLIC accelerating structure optimization

- Takes into account RF break-down limitations for peak surface field, power and pulse length
- Input from beam dynamics & beam-beam effects at collision
- Based on parametric total cost model

- Find structure parameters (aperture, length, group velocity) with optimum cost
- Calculate cost and performance (Luminosity/power)
- Final choice of parameter is a compromise between cost, performance and other practical considerations

A. Grudiev et al.
EPAC ‘06
CLIC accelerating structure requirements

- Loaded average accelerating gradient \( \geq 100 \text{ MV/m} \)

- Breakdown rate at nominal gradient \( \leq 2 \times 10^{-7} \) per meter @ 3 TeV c.m. (1% luminosity loss)

- RF to beam efficiency in the 20 – 30% range @ 3 TeV

- Long range wake at 2\(^{\text{nd}}\) bunch crossing \( W_{t,2} \leq 0.27 \times 10^{-6} \text{ V/pC/mm/m} \cdot \frac{E_{\text{acc}}}{N} \)

<table>
<thead>
<tr>
<th>Structure</th>
<th>CLIC G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency: ( f ) [GHz]</td>
<td>12</td>
</tr>
<tr>
<td>Average iris radius/wavelength: ( \langle a \rangle / \lambda )</td>
<td>0.11</td>
</tr>
<tr>
<td>Input/Output iris radii: ( a_{1,2} ) [mm]</td>
<td>3.15, 2.35</td>
</tr>
<tr>
<td>Input/Output iris thickness: ( d_{1,2} ) [mm]</td>
<td>1.67, 1.00</td>
</tr>
<tr>
<td>Group velocity: ( v_g^{(1,2)}/c ) [%]</td>
<td>1.66, 0.83</td>
</tr>
<tr>
<td>N. of reg. cells, str. length: ( N_s, l ) [mm]</td>
<td>24, 229</td>
</tr>
<tr>
<td>Bunch separation: ( N_s ) [rf cycles]</td>
<td>6</td>
</tr>
<tr>
<td>Luminosity per bunch X-ing: ( L_{b,x} ) [m(^{-2})]</td>
<td>( 1.22 \times 10^{34} )</td>
</tr>
<tr>
<td>Bunch population: ( N )</td>
<td>( 3.72 \times 10^9 )</td>
</tr>
<tr>
<td>Number of bunches in a train: ( N_b )</td>
<td>312</td>
</tr>
<tr>
<td>Filling time, rise time: ( \tau_f, \tau_r ) [ns]</td>
<td>62.9, 22.4</td>
</tr>
<tr>
<td>Pulse length: ( \tau_p ) [ns]</td>
<td>240.8</td>
</tr>
<tr>
<td>Input power: ( P_{in} ) [MW]</td>
<td>63.8</td>
</tr>
<tr>
<td>( P_{in}/Ct_p^{1/3} ) [MW/mm ns(^{1/3})]</td>
<td>18</td>
</tr>
<tr>
<td>Max. surface field: ( E_{\text{surf}}^{\max} ) [MV/m]</td>
<td>245</td>
</tr>
<tr>
<td>Max. temperature rise: ( \Delta T^{\max} ) [K]</td>
<td>53</td>
</tr>
<tr>
<td>Efficiency: ( \eta ) [%]</td>
<td>27.7</td>
</tr>
<tr>
<td>Figure of merit: ( \eta L_{b,x}/N ) [a.u.]</td>
<td>9.1</td>
</tr>
</tbody>
</table>
X-band high-gradient R&D - activities

- Structure construction (high precision machining, tolerances, material studies...)
- Power Extraction & Transfer Structures (PETS) development
- Development of high-power RF components
- Breakdown theory and simulation
- Basic physics experimental studies
  - Single-cell and short constant impedance structures
  - Waveguide breakdown experiments
  - Pulsed-power heating experiments
- Full Accelerator Structure Testing

pulsed-power heating testing (SLAC)
X-band high-gradient R&D - collaborating Institutes

CERN: Structure design & fabrication, high-power testing.

SLAC: High-power testing, pulsed-surface-heating testing, test structure fabrication.

KEK: Test structure fabrication and high-precision machining. High-power testing starting.

Cockcroft Institute: Structure and beam dynamics simulations planned.

PSI: Interest in structure design, breakdown theory and high-power testing.

Helsinki Institute of Physics: Precision mechanical engineering. Breakdown simulation.

Uppsala University: Two-beam test stand beam-lines, instrumentation and experiments. Breakdown experiments.

CIEMAT: Test-PETS and RF components.

Gycom/Nizhniy Novgorod: High-power RF components.

Pakistan: Two-beam test stand hardware.

Dubna: Pulsed surface heating experiment.

DAPNIA, SACLAY: Superconducting-level cleaning. Planned test accelerating structure fabrication, wakefield monitor, high-power testing.

US High-gradient collaboration: Many common subjects.
High-power RF facilities

Testing of RF components:

Accelerating structures
PETS
RF components

SLAC NLCTA (3 RF stations)
Klystron Lab (4 RF stations)

Operational
11.4 GHz
Up to 300 MW @ 400ns

KEK Nextef
X-band Klystron Test Station

Operational
11.4 GHz
Up to 100 MW @ 400 ns

CERN 12 GHz Test Stand
(CEA-DAPNIA)

Under construction
start beginning 2010
12 GHz
50 MW @ 1.5 μs
**Structure T18_vg4.2**

- designed by CERN
- built at KEK,
- assembled and bonded in SLAC
- tested at SLAC (NLCTA).

![RF BKD Rate vs. Gradient for 230ns Pulse](image)

- **After 250hrs of RF conditioning**
- **After 500hrs**
- **After 900hrs**
- **After 1200hrs**

**RF to beam Efficiency - temp stabilised (%)**

- **ILC design 1.3 GHz Pulsed SC**
- **NLC design 11.4 GHz**
- **CLIC design 3 TeV**
- **CLIC design 500 GeV**

**CLIC design 3 TeV**

- **T18vg2.4 11.4 GHz 2008**

**CLIC design 500 GeV**
Next steps

**T18**

- Tested
- 105 MV/m, 230 ns, 2x10^{-7}/(mxpulse)

**Supporting tests:**
- Quadrant fabrication
- CD10
- Choke mode CD10

**TD18**

- Add damping
- Move to design iris range

**CLIC G**

- Undamped
- Move to design iris range and add damping
- Add damping
- Full prototype with damping

**CLIC G**

- Move to design iris range

**Today**

**early 2009**

**late 2009**
Drive Beam Accelerator
efficient acceleration in fully loaded linac

Combiner ring × 4
pulse compression & frequency multiplication

Drive Beam Decelerator Sector (24 in total)

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

Combiner ring × 3
pulse compression & frequency multiplication

Power Extraction

Drive beam generation

Drive beam time structure - initial
240 ns
140 μs total 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 – 100 A – 2.5 cm between bunches
X-band high-gradient and CLIC R&D for future colliders

CTF3 – Layout

- DRIVE BEAM LINAC
- CLEX
- COMBINER RING
- DELAY LOOP

- 4 A – 1.2 μs 150 Mev
- 30 A – 140 ns 150 Mev

10 m
X-band high-gradient and CLIC R&D for future colliders

CTF3 – R&D Issues - where

- Fully loaded acceleration
- Bunch length control
- Recombination x 2
- Recombination x 4
- Bunch compression
- Phase-coding
- Structures 30 GHz
- Structures 12 GHz
- Two-beam acceleration
- Deceleration stability
- PETS on-off
- Structures DB generation
- Structures PETS on-off
- Structures DB decelerator
- CLIC sub-unit
X-band high-gradient and CLIC R&D for future colliders

CTF3 – R&D Issues - when

- Recombination $\times 2$
- Bunch length control
- Fully loaded acceleration
- Phase-coding
- Structures $30\,GHz$
- Structures $12\,GHz$
- Deceleration stability
- PETS on-off
- Two-beam acceleration
- 2008
- 2009
- 2010
Drive Beam linac – high current, full beam loading operation
Delay Loop – beam current multiplication x 2, hole creation

Beam current measured:

- before DL
- in DL
- after DL

Graph showing beam current over time with markers for different conditions.
Fast vertical beam instability in CTF3 solved by new deflectors with strong damping of the vertical deflecting mode and larger hor./vert. detuning

Old RF deflectors

New RF deflectors (INFN-Frascati)
Bukit in Aluminium – very fast conditioning to nominal power (1 day)
Without the losses from the fast vertical beam instability (plus improved optics control and tuning tools) it is now possible to circulate the 3 A beam with very small losses for hundreds of turns.

Bunch re-combination of a 3 A beam with factor four current increase had been demonstrated – 12 A reached.

(DL still by-passed, and limited by RF pulse length)
Most of the hardware has now been installed!
Progress only possible through successful collaboration between 27 international institutes.

Technical programme is on track:
- CTF3 on schedule
  - full beam loading
  - bunch phase coding and Delay Loop operation
- First results on recombination on Combiner Ring
- All machine components installed (apart from TBL)
### X-band high-gradient and CLIC R&D for future colliders

#### Matching critical issues & test facilities

<table>
<thead>
<tr>
<th>SYSTEMS (level n)</th>
<th>Critical parameters</th>
<th>Crucial design choice or feasibility</th>
<th>Performance issue</th>
<th>Cost issue</th>
<th>Relevant Facilities [also valid for ILC]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structures</strong></td>
<td></td>
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</tbody>
</table>
| Main beam acceleration structures  
Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate | 100 MV/m  
240 ns  
3·10⁻⁷ BR/(pulse*m) | X | X | X | CTF2&S (2005-2010)  
Test Stand (2009-2010)  
SLAC/NLCTA  
SLAC/ASTA  
KEK/NEXTef |
| Decelerator structures  
Demonstrate nominal PETIS with damping features at design power, with design pulse length, breakdown rate on/off capability | 136 MV  
240 ns | X | X | | CTF3 (2005-2010)  
CTF3/TBTS (2008-2010)  
CTF3/TBL (2009-2010)  
SLAC ASTA |
| **Drive Beam**     |                     |                                     |                   |            |                                       |
| Validation of drive beam  
- production  
- phase stability, potential feedbacks  
- MPS appropriate for beam power | 0.2 degrees phase stability at 12 GHz | X | X | | CTF3 (2005-2010)  
CTF3/TBL (2009-2010)  
X-FEL  
LCLS |
| **Two Beam**       |                     |                                     |                   |            |                                       |
| Test of a relevant linac sub-unit with both beams | NA | X | | | CTF3/TBTS (2008-2010) |
| **Beam Physics**   |                     |                                     |                   |            |                                       |
| Ultra-low emittances  
- Generation of low-emittances (damping rings) | Hor: 500 nradm  
Vert: 5 nradm | | | | ATF [2008-10]: 3000/12  
CESRTA: Electron Cloud  
NSLSII: Hor 2000 nradm  
SLS: Vert 10 nm |
| - Preservation of low emittances (main linac + RTML) | Absolute blow-up  
Hor: 160 nradm  
Vert: 15 nradm | X | X | | Beam simulations  
LCLS  
SCSS |
| - Beam focusing to small dimensions (BDS) | Hor: 40 nm  
Vert: 1 nm | | | | ATF2 (2006-2012)  
Hor: 200 nm  
Vert: 36 (20) nm |
Small emittances from Damping Rings

- Present CLIC DR design for 3TeV achieves goals for transverse emittances with a 20% - 30% margin (380 nm horizontal and 4.1 nm vertical)

- Conservative DR output emittances (2.4 μm horizontal, 10 nm vertical) for CLIC @ 500GeV scaled from operational or approved light source projects (NSLSII, SLS)

* geometrical emittances
Damping Rings

- **CLIC damping ring design**
  - Racetrack, 365 m long, $E = 2.4$ GeV
  - Arcs filled with TME cells
  - Straights filled with 2 m-long **superconducting damping wigglers** (2.5 T, 5 cm period)
  - Output emittance strongly dominated by IBS

- **Work in progress**
  - SC wiggler **prototype** to be built and tested at ANKA
  - IBS **theory**, numerical tools
  - Pre-damping rings optics design
  - Radiation absorption protection, vacuum chamber design and impedance budget
  - Design of HOM free high frequency RF cavities
  - Collective effects evaluation (electron cloud and fast ion instability)
  - Injection and extraction elements
  - Diagnostics and feedback
  - Route from 500GeV to 3TeV
Beam Delivery System

- Convergence to an optimized BDS design – meet requirements on paper
- Recent proposal for a larger $L^*$ solution (relax final doublet alignment tolerances)
- The challenge remains to verify tuning in realistic simulations with dynamic effects
- Lots to learn from ATF2 experience
- ATF2 ultra-low betas proposal: demonstrate CLIC-like chromaticities

Peak Luminosity has been optimized by varying dispersion, betas, adding decapoles (CLIC-Note-735).
X-band high-gradient and CLIC R&D for future colliders

ATF & ATF 2

<table>
<thead>
<tr>
<th>Project</th>
<th>Status</th>
<th>$\beta_y^*$ [mm]</th>
<th>$L^*$ [m]</th>
<th>$L^<em>/\beta_y^</em>$</th>
<th>$\xi_y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFTB</td>
<td>Design</td>
<td>0.1</td>
<td>0.4</td>
<td>4000</td>
<td>17000</td>
</tr>
<tr>
<td>FFTB</td>
<td>Measured</td>
<td>0.167</td>
<td>0.4</td>
<td>2400</td>
<td>10000</td>
</tr>
<tr>
<td>ATF2</td>
<td>Design</td>
<td>0.1</td>
<td>1.0</td>
<td>10000</td>
<td>19000</td>
</tr>
<tr>
<td>ATF2 pushed</td>
<td>Proposed</td>
<td>0.05</td>
<td>1.0</td>
<td>20000</td>
<td>38000</td>
</tr>
<tr>
<td>CLIC 500GeV</td>
<td>Design</td>
<td>0.2</td>
<td>4.3</td>
<td>21500</td>
<td>35000</td>
</tr>
<tr>
<td>CLIC 3TeV</td>
<td>Design</td>
<td>0.09</td>
<td>3.5</td>
<td>39000</td>
<td>63000</td>
</tr>
<tr>
<td>ILC</td>
<td>Design</td>
<td>0.4</td>
<td>3.5</td>
<td>8750</td>
<td>15000</td>
</tr>
<tr>
<td>ILC pushed</td>
<td>Design</td>
<td>0.2</td>
<td>3.5</td>
<td>17500</td>
<td>30000</td>
</tr>
</tbody>
</table>
Beam Emittance Conservation

- Emittance budget:
  - $\varepsilon_y \leq 5$ nm and $\varepsilon_x = 550$ nm after damping ring
  - $\Delta \varepsilon_y \leq 5$ nm in transport to main linac
  - $\Delta \varepsilon_y \leq 10$ nm in main linac
  - $\varepsilon_x = 660$ nm before the beam delivery system (growth mainly in RTML)
  - BDS budget: 20% spot size increase in the vertical plane
    - includes design, static and dynamic effects
    - requires 90% of the machines to perform better than the target

- Emittance budget is respected in simulations

- Tolerances are derived, iteration with experts of technical systems started
  - Alignment & stabilization
  - Magnets
  - Correctors
  - Instrumentation

- Feedback studies ongoing
- Benchmarking between codes and with beam tests
CLIC Technical Committee (CTC)  
(created in spring 2008)

• General objective:


• Specific responsibility:

• Set-up and keep updated an overall CLIC Work Breakdown Structure (nomenclature, components specs, documentation).

• Review the ensemble of technical equipments in the present CLIC design in terms of: Components specifications, technical feasibility, fabrication and industrialization, integration (machine/tunnel), machine-detector interface, installation, schedule, cost.

• Identify technical key issues requiring specific R&D or prototyping in view of the CDR, assess present R&D program and propose prioritized R&D.

• Suggest possible improvements aiming at improving the performance to cost and risk ratio.

• Elaborate for the CDR a baseline scenario and schedule, a CLIC baseline complex and possible options for improved performance and/or reduced cost.
Stabilization & Alignment

- **LEP ground motion during 1 year**: 300 µm – 1 mm
- **Ground motion due to Lunar cycle (tides)**: Several µm
- **7 sec hum**: 100 nm, CLEX
- **10 nm, CLEX**

**Correction with beam-based feedbacks** (limited by \( f_{\text{REP}} \))

**Slow motion** \( f_{\text{CUT}} \approx 1 \text{ Hz} \)

**Fast motion**

**Mechanical stability of magnets**

**Geophones**

**Accelerometers**

**Cultural noise**

**Acoustic noise becomes very important**
Stabilization

Vertical spot size at IP is ~ 1 nm \((\text{size of water molecule})\)

Stability requirements for a 1% loss in luminosity

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Ix</th>
<th>Ly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linac (4000 quads, f &gt; 1 Hz)</td>
<td>5 nm</td>
<td>1 nm</td>
</tr>
<tr>
<td>Final Focus (4 quads, f &gt; 5 Hz)</td>
<td>5 nm</td>
<td>0.1 nm</td>
</tr>
</tbody>
</table>

Need active damping of vibrations

CERN vibration test stand \((2001-2003)\)
Stabilization

- Extensive work done between 2001 and 2003 concerning CLIC stabilization

- From 2004 to 2007:
  - Work continued only at LAPP-Annecy, France
  - At CERN beam dynamic studies, update of stabilization requirements

- Collaboration between several Institutes started in 2008:
  - [http://clic-study.web.cern.ch/CLIC-Study/CLIC_Stabilisation/Index.htm](http://clic-study.web.cern.ch/CLIC-Study/CLIC_Stabilisation/Index.htm)
  - LaViSta (LAPP, Université de Savoie-SYMME)
  - CERN (TS, AB)
  - JAI- Oxford University
  - CEA-DSM-IRFU-SIS
  - Information exchange with DESY, SLAC
Two-Beam module studies

• Module design and integration have to be studied for different configurations. Potential advantages and drawbacks are being evaluated for each configuration.

• Integration of the systems in terms of space reservation has been done for all the module types and detailed design started for the main systems, such vacuum, cooling, alignment, stabilisation …

• Important aspects of cost are raised and basic parameters provided for other areas of the study.

• Goal: build prototype → test with beam of a few modules in CTF3 from 2010

Drive beam

Main beam

20760 modules (2 m long)
71460 power prod. structures PETS (drive beam)
143010 accelerating structures (main beam)
Other technical Issues presently under investigation

- Civil Engineering
- Magnets
- Diagnostics
- Alignment & survey
- Vacuum
- Cooling & Ventilation
- Transport & Installation
- Radiation & Safety
- Cost & Schedule
Civil Engineering

CERN sample site (in conjunction with ILC site studies)

IP under CERN Prevesin site
Phase 1: 0.5 TeV extension 13 km
Phase 2: 3 TeV extension 48.5 km
Planning

Based on LHC experience
Consistent with 7 years construction for phase 1
CLIC08 Workshop

All of the R&D activities I have presented (and some I didn't have the time to) were reviewed & discussed recently in the 2nd CLIC Workshop (CERN, 14-17 October 2008)

http://project-clic08-workshop.web.cern.ch/project-clic08-workshop/

Participation actually larger than present CLIC/CTF3 collaboration:

215 (registered) participants from 57 Institutes of 18 countries

Next CLIC Workshop tentatively scheduled for October 13-16, 2009
CONCLUSIONS

• CLIC design and R&D on all CLIC feasibility issues on schedule for completion of CDR by 2010 including:
  • Concept of accelerator and detector
  • Feasibility results
  • Preliminary performance and cost

• R&D on complementary issues (performance and cost) to be completed and reported in a TDR with consolidated performance and cost by 2015
  • Consolidate/extend CTF3 in the medium term (2010 – 2012)
  • Identify, plan and execute complementary CLIC R&D in other facilities world-wide (ATF, ATF2, Cesr-TA, light sources...)
  • Increase RF testing capabilities (New X-band sources, transform CTF3 in RF factory)
  • Start development-industrialization of components (DBA klystrons, structures, etc...) at nominal parameters
  • Reflection started on facility, possibly first step (re-usable) – toward CLIC on 2015 time scale

• CLIC/CTF3 multi-lateral collaboration strong of 27 institutes from 15 countries extremely efficient and fruitful
  • Importance of CLIC/ILC collaboration
A lot still to be done before the CLIC technology is mature enough to be considered for a future Linear Collider

…but also a lot of recent progress
Reserve
X-band high-gradient and CLIC R&D for future colliders

- **TBA**
  - 6.5 GeV, 1.2 A
- **DBA**
  - 0.2 GeV, 101 A
  - 0.48 GeV, 4.2 A
- **CALIFES type injector**
  - 0.2 GeV, 1.2 A
- **DB Turn around**
  - 0.48 GeV, 101 A
- **Compression**
  - 2 x 3 x 4

All components nominal and re-usable for CLIC
To be decided in 2010-2011 in light of first physics results from LHC, and
designed and R&D results from the previous years. This programme could most
probably comprise:

- An LHC luminosity increase requiring a new injector (SPL and PS).

The total cost of the investment over 6 years (2011-2016: 1000-1200 MCHF + a
staff of 200-300 per year. Total budget: ~200-250 MCHF per year.

- Preparation of a Technical Design for the CLIC programme, for a possible
construction decision in 2016 after the LHC upgrade (depending on the ILC
future).
  Total CERN M + P contribution + ~250 MCHF + 1000-1200 FTE over 6 years.

- Enhanced infrastructure consolidation: 30 MCHF + 40 FTEs from 2011.

N.B.: Over the period 2012-2016. Effective participation of CERN in another large
programme is envisaged: the ILC, which has not yet been approved.
This still requires a confirmed and assured level of financial support and Design.
This support is currently being sought. It might be achieved if ILC is
approved or if a new, more ambitious level of activities and support is envisaged in the
European framework.

N.B.: Expect additional significant contribution
from outside CERN, up to the same level.
The CLIC Technology-related key issues as pointed out by ILC-TRC 2003

**R1: Feasibility**

- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- R1.3: Design and test of damped ON/OFF power extraction structure

**R2: Design finalization**

- R2.1: Developments of structures with hard-breaking materials (W, Mo…)
- R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system
- R2.3: Test of relevant linac sub-unit with beam
- R2.4: Validation of drive beam 40 MW, 937 MHz Multi-Beam Klystron with long RF pulse
- R2.5: Effects of coherent synchrotron radiation in bunch compressors
- R2.6: Design of an extraction line for 3 TeV c.m.

* Feasibility study done – need development by industry.

N.B.: Drive beam acc. structure parameters can be adapted to other klystron power levels
# 500 GeV comparison Table

<table>
<thead>
<tr>
<th>Center-of-mass energy</th>
<th>NLC 500 GeV</th>
<th>ILC 500 GeV</th>
<th>CLIC 500 GeV Conservative</th>
<th>CLIC 500 GeV Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (Peak 1%) luminosity</td>
<td>2.0(1.3)·10³⁴</td>
<td>2.0(1.5)·10³⁴</td>
<td>0.9(0.6)·10³⁴</td>
<td>2.3(1.4)·10³⁴</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>120</td>
<td>5</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Loaded accel. gradient MV/m</td>
<td>50</td>
<td>33.5</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Main linac RF frequency GHz</td>
<td>11.4</td>
<td>1.3 (SC)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Bunch charge 10⁹</td>
<td>7.5</td>
<td>20</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>Bunch separation ns</td>
<td>1.4</td>
<td>176</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Beam pulse duration (ns)</td>
<td>400</td>
<td>1000</td>
<td>177</td>
<td></td>
</tr>
<tr>
<td>Beam power/linac (MWatts)</td>
<td>6.9</td>
<td>10.2</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>Hor./vert. norm. emitt (10⁻⁶/10⁻⁹)</td>
<td>3.6/40</td>
<td>10/40</td>
<td>3 / 40</td>
<td>2.4 / 25</td>
</tr>
<tr>
<td>Hor/Vert FF focusing (mm)</td>
<td>8/0.11</td>
<td>20/0.4</td>
<td>10/0.4</td>
<td>8/0.1</td>
</tr>
<tr>
<td>Hor./vert. IP beam size (nm)</td>
<td>243/3</td>
<td>640/5.7</td>
<td>248 / 5.7</td>
<td>202/ 2.3</td>
</tr>
<tr>
<td>Soft Hadronic event at IP</td>
<td>0.10</td>
<td>0.12</td>
<td>0.07</td>
<td>0.19</td>
</tr>
<tr>
<td>Coherent pairs/crossing at IP</td>
<td>10?</td>
<td>10?</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>BDS length (km)</td>
<td>3.5 (1 TeV)</td>
<td>2.23 (1 TeV)</td>
<td>1.87</td>
<td></td>
</tr>
<tr>
<td>Total site length (km)</td>
<td>18</td>
<td>31</td>
<td>13.0</td>
<td></td>
</tr>
<tr>
<td>Wall plug to beam transfer eff.</td>
<td>7.1%</td>
<td>9.4%</td>
<td>7.5%</td>
<td></td>
</tr>
<tr>
<td>Total power consumption MW</td>
<td>195</td>
<td>216</td>
<td>129.4</td>
<td></td>
</tr>
</tbody>
</table>

[http://clic-meeting.web.cern.ch/clic-meeting/ComparisonTable.html](http://clic-meeting.web.cern.ch/clic-meeting/ComparisonTable.html)
Alignment studies in CTF II

Tolerance of CLIC pre-alignment: ± 10 μm transverse position over 200 m
(enough to send a pilot beam, and start beam-based alignment)

Full system Tested in CTF II:
In a closed loop, the elements were maintained w.r.t wire within a ± 5 μm window and operated reliably in a high radiation environment.
**Active pre-alignment**

Some of the issues:
- Integration of active pre-alignment system in modules
- Mechanical tolerances of components on girder
- Tests on longer distances than CTF II
- Influence of gravity
- New methods (performance, cost)

*Red Alignment System from NIKHEF (RASNIK)*
Full beam-loading acceleration in TW sections

RF in

No RF to load

No beam

High current beam

“short” structure - low Ohmic losses

most of RF power (≥ 95%) to the beam
Beam combination/separation by transverse RF deflectors
Beam combination/separation by transverse RF deflectors
X-band high-gradient and CLIC R&D for future colliders

CTF3 Preliminary Phase (2001-2002)

Beam structure in linac – 4 pulses

streak camera measurement

Beam structure after combination (factor 4)

Bunch spacing

6.6 ns

420 ns

333 ns

Pulse Length 6.6 ns

Beam Peak Current 1.2 A

A first ring combination test was performed in 2002, at low current and short pulse, in the CERN Electron-Positron Accumulator (EPA), properly modified

Bunch spacing

83 ps

6.6 ns

total length 1.3 ms - Peak Beam Current 0.3 A
Preliminary phase results

Streak camera images of the beam, showing the bunch combination process