Linear $e^+e^-$ collider case study
Goals of the case study

• Review the baseline 380 GeV CLIC design and propose R&D programs to:
  • Reduce the risk
  • Reduce the cost
  • Reduce the power consumption
  • Maximise luminosity

• Reliable, cheap, energy efficient super collider...
Proposal: Camel Collimator for CLIC

- **Considering cylindrical collimator:** a pipe in centre of a cube along the S coordinate (2 jaws are band together without gap)
  - CLIC operation (one collision optic) might not necessarily require variation in the collimators aperture (the optic does not change in the collimators)

- **Lighter absorber with low Z and low density material instead of Ti-Cu:**
  - Carbon-Fibre Composite (CFC) or Molybdenum-Graphite Composite

  - Reduction in cost by reducing the number of collimators (almost 1/3)
  - Easy to handle and align along the line
  - Potentially shortening the system length
  - Might help in Muon reduction (in case of MoGr)
  - Minimizing the Wakefield effect by tapering the edges

  → Disadvantage: not necessarily but maybe increment of the total power in the collimator
RF Optimization

Lower gradient means larger aperture and reduced wakefields:

$$W_\perp(z \ll z_0) \approx \frac{Z_0 c}{\pi a^4 z}$$

<table>
<thead>
<tr>
<th></th>
<th>100 MV/m</th>
<th>72 MV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a/\lambda$</td>
<td>0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>$W_{\text{transverse}}$</td>
<td>2.15</td>
<td>1</td>
</tr>
</tbody>
</table>

Increase gradient at higher energies when the beam is more rigid.

$P_{\text{loss}} = 25 \text{ MW}$

$P_{\text{in}} = 64 \text{ MW}$

$P_{\text{out}} = 12 \text{ MW}$

1 ns power feedback

RF power profile from the drive beam

Synchronization with beam
Use of Permanent Magnets

- Main beam linac 1700 quadrupoles
- Drive beam linac 7000 quadrupoles (1/m)
- Gradients comfortably within reach (23 T/m)
- Considerable operation cost savings if alternation of permanent and EM quads possible (e.g. 50 % at least for drive beam)
- Replace SC wigglers in DR with permanent magnets
Luminosity Measurement Optimization using diamond feedback systems

- R&D of CVD Diamond Detectors recommended for luminosity measurement feedback due to:
  - Radiation-hardness -> 10 MGy
  - Fast Readout signal ~ nanoseconds
    - Time resolutions ~30 ps
  - Ability to detect
    - Single particle
    - multi-particle
    - shower cascades
  - high-intensity beam losses
Luminosity Measurement Optimization using diamond feedback systems

- Position CVD Detectors after the interaction point to measure outgoing beams and calculate luminosity
- Radiation-hardness makes them ideal for this region in which high losses can be expected
- Fast response times allows for real-time measurements and feedback into the steering system
If investment is directed towards R&D on klystrons, efficiencies could increase →

- L-band: $\eta = 0.7 \rightarrow \eta = 0.9$
- X-band: $\eta = 0.5 \rightarrow \eta = 0.7$

Traditional way: decreasing the bunch length by increasing the accelerating voltage of the Klystron

- Limitation: Voltage

New way: use the space charge and the Klystron cavity to stimulate an oscillation of the core of the bunch

- Effect: periphery electrons can be connected to the bunch
R&D on Klystron Efficiency

- Comparison
Dual experiment CLIC with combined $e^+e^-$ beams

Original CLIC layout

- **Beam 1**
  - $e^-$-bunches
  - RF voltage
  - **e$^-$-source**
  - Damping ring(s)
  - Booster linac
  - Main linac

- **Beam 2**
  - $e^+$-bunches
  - **e$^+$-source**
  - Damping ring(s)
  - **experiment**
  - **delay line**
  - **beam splitter / recombiner (dipole magnet)**

Combined-beams CLIC layout

- **Beam 1**
  - $e^+$-bunches
  - **e$^+$-source**
  - Damping ring(s)
  - **experiment**
  - **delay line**
  - **beam splitter / recombiner (dipole magnet)**

- **Beam 2**
  - $e^-$-bunches
  - **e$^-$-source**
  - Damping ring(s)
  - Booster linac
  - Main linac
Dual experiment CLIC with combined $e^+e^-$ beams

• Appealing benefits
  • Two experiments
  • More stable beams – self stabilisation (?)
  • Shorter RF pulse

• Inspiring challenges
  • Beam quality
  • 0 A beam diagnostics
  • More complex
  • Beam synchronization
  • Extra beam lines
  • Beam split into two experiments
  • Reduced luminosity or more RF power
Beam-based coherent CLIC motion monitoring

- 11 km long, 10 m wide tunnel = ~ 100 000 m² area
- ~ 20 000 BPMs on “three” beamlines
- BPM spatial coverage = 1 BPM / 5 m²
BEAM ALIGNMENT

- Improve the magnet position stability: YES
- Improve the pre-alignment of the beam components: YES
- Improve the beam-based alignment procedures: YES
- Improve the beam-based feedback system design: YES
  - An active stabilization system exists which corrects magnet motion but needs to be improved.
  - Pre-Alignment performance low (BPM, quadruple and module offset, cavity tilt) requires more efficient technics like dispersion free steering for BPM offset.
  - Dynamic imperfections: ground motion, RF amplitude and phase jitter, magnet power supply ripple lead to direct luminosity loss.
  - Displacement of final doublet (FD) causes similar displacement of the beams at the IP (L*=6 m).
  - Stability of FD requires a fraction of nanometer accuracy.
  - Luminosity is directly related to the gain on beam stability (static and dynamic): gain \( \propto \varepsilon_y \) and \( 1/\varepsilon_y \propto L \).
  - The idea is to predict the beam trajectory and to correct misalignment in advance.
  - Valid for both static and dynamic imperfections.

<table>
<thead>
<tr>
<th>Location</th>
<th>Design limits ( \Delta \varepsilon_y ) [nm]</th>
<th>Static imperfect. ( \Delta \varepsilon_y ) [nm]</th>
<th>Dynamic imperfect. ( \Delta \varepsilon_y ) [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping ring exit</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>End of RTML</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>End of main linac</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Interaction point</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Sum</td>
<td>6</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>
GROUND MOVEMENT FEED FORWARD SYSTEM

Latent

$X_{bg,1} \rightarrow X_{bg,2} \rightarrow X_{bg,3}$

Observed

$X_{bg,1} \downarrow \quad X_{bg,2} \downarrow \quad X_{bg,3}$

- Offline Learning - slow
  - Learn the model
  - Unsupervised machine learning problem
GROUND MOVEMENT FEED FORWARD SYSTEM

Latent

\[ X_{bg,1} \rightarrow X_{bg,2} \rightarrow X_{bg,3} \rightarrow X_{bg,4} \]

Observed

\[ X_{bg,1} \rightarrow X_{bg,2} \rightarrow X_{bg,3} \rightarrow X_{bg,4} \]

- **Offline Learning** - slow
  - Learn the model
  - Unsupervised machine learning problem

- **Online Predictions** - fast
COST SAVINGS

- clicstarter

An error occurred. In order to save:
- Funding goal cannot exceed CHF 100,000,000.