Proposal of test setup

- **Status of the study**

The Compact Linear collider (CLIC) study is a site independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron-positron linear collider in the post-LHC era for physics up to the multi-TeV center of mass colliding beam energy range (nominal 3 TeV).

The next milestone of this project is a Conceptual Design Report (CDR) that must be ready end of 2010. In this report, the feasibility of CLIC technology will be demonstrated, a design of a linear collider based on CLIC technology will be proposed and an estimation of its cost will be given.

The pre-alignment of the CLIC components is one of the key issues: the components must be pre-aligned w.r.t a straight line within a tolerance of 10 microns over a sliding window of 200m, along the whole linacs. The solution proposed in the CDR is based on overlapping stretched wires and Wire Positioning Sensors (WPS). This solution has some drawbacks: its cost, the difficulties in its installation and maintenance, the sag of the wire is a limiting factor and will require modelization using HLS systems which perform measurements w.r.t the geoid (which then must be determined within an accuracy never reached before).

- **Introduction to the CLIC requirements concerning pre-alignment** :

  **The components to be aligned**

  In order to optimize the production of sufficient RF power for this high gradient, CLIC relies upon a two-beam-acceleration concept: The 12 GHz RF power is generated by a high current electron beam (drive beam) running parallel to the main beam. This drive beam is decelerated in special power extraction structures (PETS) and the generated RF power is transfered to the main beam.

![CLIC module layout](image)

Figure 1: two beam acceleration concept
Each component (MB quad, MB quad BPM, DB quad, RF structure, PETS) must be pre-aligned within a few microns, w.r.t a straight line, along a sliding window of 200 m, along the 20 km of each linac.

In order to simplify this pre-alignment, several components will be aligned on one girder or support:

- Along the Drive beam (DB): DB quad and PETS will be pre-aligned on 2 m long girders.
- Along the Main beam (MB): MB quad (and its associated MB quad BPM) will be pre-aligned on an interface plate (0.5 m, 1 m, 1.5 m, 2 m), RF structures will be pre-aligned on girders (0.5 m, 1 m, 1.5 m, 2 m)

Repositioning strategy

In order to simplify the pre-alignment, DB and MB girders will be inter-linked with their extremities, based on a so-called cradle. This arrangement allows a movement in the transverse girder interlink plane within three degrees of freedom in the radial and vertical direction. The non critical longitudinal direction will not be actively aligned and therefore a guiding will mechanically exclude uncontrolled movements. The cradle will be supported by three micrometric jacks (two vertical and one radial).

The DB and MB must be pre-aligned independently, with respect to a common straight reference.

The BPM and MB quad are mounted on a common support (interface plate), and pre-aligned independently of the MB girders, according to 5 degrees of freedom (longitudinal position will be adjusted manually). Before each MB quad and BPM, the chain of girders is stopped by an additional cradle.

Alignment strategy

The alignment strategy consists of a combination of 2 types of metrological networks: propagation and proximity networks. As it is not possible to implement a straight reference over 20 km, overlapping references will be use, of at least 200 m, with an uncertainty of measurement of a few microns. This propagation network, will allow precision propagation on long distances. In addition, a proximity network will be attached every x m (x to be defined: depending on the configuration and propagation error) to the propagation network. This proximity network will provide a high precision alignment (a few microns over short distances), between adjacent components, and will consist of low cost pre-alignment sensor assemblies.
But along the main linac, the distance between two adjacent pre-alignment sensor assemblies will not be regular, due to the sequence of modules.

**Sequences of modules**

Each main linac will consist of sequences of 2m long modules. There are 5 types of modules, depending on the length of the MB quad: from the type 0, with no MB quad along the main beam, the type 1 with a 0.5m long MB quad to the type 4 with a 2m long MB quad.
Per linac, the number of modules is the following:

- Type 0: 8374
- Type 1: 154
- Type 2: 634
- Type 3: 477
- Type 4: 731.

The sequence of modules is shown in the diagrams below. At the very beginning of the linac, there is an alternation of modules of type 0 and of type 1. After 600m, the sequence becomes one module type 2 after two modules type 0. After 5000m from the beginning of the linac, the sequence becomes one module type 3 after four modules type 0. The second part of the linac towards the IP consists of sequences of 9 modules type 0 between two modules type 4.
Integration of the alignment solution

As the module is particularly crowded by a lot of systems (RF, vacuum, beam instrumentation,...), some space was already booked for the alignment solution: between the two beams, space was booked for the propagation network, on the other side of each beam, some additional space was booked for a proximity network (which would not need vacuum pipes).
Budget error

Two types of budget error can be considered:

- Achievable and realistic data: better than 15 µm (r.m.s) (where we are now with the stretched wire solution), which is the basis for all the beam dynamics simulations.

- Target for development: 3 µm (r.m.s)

Considering the accelerating structures, the pre-alignment budget error (achievable and realistic data) is the following:

**Accelerating Structure Alignment**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Inherent accuracy of reference</th>
<th>10 µm</th>
<th>1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref. to cradle</td>
<td>Sensor accuracy and electronics (reading error, noise,..)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>2</td>
<td>Link sensor/cradle (supporting plates, interchangeability)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Cradle to girder</td>
<td>Link cradle/girder</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Girder to AS</td>
<td>Link girder/acc. structure</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>5b</td>
<td>Inherent precision of structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>14 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Tolerance</td>
<td></td>
<td>40 µm</td>
<td>3σ</td>
</tr>
</tbody>
</table>

**Beam-Based Alignment**

6) relative position of structure and BPM reading: 5 µm | 1σ

Figure 8: budget error concerning RF structures

Considering the MB quad and PBM, the pre-alignment budget error is the following:

**Quadrupole Alignment**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Inherent accuracy of reference</th>
<th>10 µm</th>
<th>1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref. to cradle</td>
<td>Sensor accuracy and electronics (reading error, noise,..)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>2</td>
<td>Link sensor/cradle (supporting plates, interchangeability)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Cradle to Q</td>
<td>Link cradle/quadrupole</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>7a</td>
<td>Inherent precision of quadrupole</td>
<td>10 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>17 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Tolerance</td>
<td></td>
<td>50 µm</td>
<td>3σ</td>
</tr>
</tbody>
</table>

**BPM Alignment**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Inherent accuracy of reference</th>
<th>10 µm</th>
<th>1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref. to cradle</td>
<td>Sensor accuracy and electronics (reading error, noise,..)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>2</td>
<td>Link sensor/cradle (supporting plates, interchangeability)</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Cradle to BPM</td>
<td>Link cradle/quadrupole BPM axis</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>8a</td>
<td>Inherent precision of quadrupole BPM axis</td>
<td>5 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>14 µm</td>
<td>1σ</td>
</tr>
<tr>
<td>Tolerance</td>
<td></td>
<td>40 µm</td>
<td>3σ</td>
</tr>
</tbody>
</table>

**Beam-Based Alignment:**

8c) relative position of quadrupole and BPM reading: 10 µm | 1σ

D. Schulte

Figure 9: budget error concerning MB quad
Concerning the Drive Beam, the tolerances are not clearly defined yet, but should be slightly relaxed w.r.t those of the Main Beam (a budget error of 20 microns for the DB quadrupole).

Summary

The most complicated scheme is at the beginning of the linac where there is an alternation of type 1 and type 0 modules, as summarized on the diagram below. For a better understanding, proximity and propagation networks are decoupled on each side of the beam.
Some first longitudinal dimension data:

Figure 12: Longitudinal dimension data
One proposal to be discussed:

- **Hypotheses considered**
  - Validation of the pre-alignment systems must be performed via an inter-comparison as no measurement standard exists.
  - Issues are the following:
    - Comply with the budget error:
      - Determination of the zero of the components w.r.t support reference / girder axis
      - Determination of the support reference /girder axis w.r.t mechanical interface of the pre-alignment sensor assembly
      - Determination of the zero of each pre-alignment sensor assembly w.r.t the mechanical interface
      - Accuracy and precision of the pre-alignment sensor assembly
      - Stability and determination of the pre-alignment reference
  - Integration in the module environment
  - Cost of the pre-alignment solution
- **Facilities “available”:**
  - Test module program
    - 4 modules in lab (one type 4, one type 1, two types 0) [2011-2012]
    - 3 modules in CLEX (one type 4, one type 1, one type 0) [2012-2014]
  - TT1 tunnel (140m horizontal tunnel) [2010-2012]
  - TZ32 tunnel [500m tunnel in slope] [> 2012]

- **Proposal:**

  To validate the proximity solution during the test module program. In this program, the modules type 0, 1 and 4 have been chosen, being quite representative of all module types. The sequence of modules 0-0-1-4 will be tested in lab, with dummy RF structures and quad, with real mechanical functions and interfaces, and real sub-systems (pre-alignment, supporting, stabilization, cooling and ventilation). The sequence of module 0-1-4 will be tested in CLIC Experimental Area environment (CLEX) with beam. The lab facility will allow testing the proximity solution with real components, real inter distances, in the two beam configuration (drive beam + main beam). The CLEX facility will allow to validate the fiducialisation with the beam based alignment, and the good running order of the pre-alignment devices under a severe environment (radiations + magnetic fields).
This validation on short range would allow:

- To deal with the integration issues (book the space needed for the alignment systems)
- To deal with the environment issues (noise, CEM from other equipment in lab, radiation/magnetic fields in CLEX)
- To have a better idea of costs
- To validate the procedure of pre-alignment, the schedule foreseen
- To test the proximity pre-alignment systems on a real sequence of modules.
- To validate the concept of short range measurements on a real size mock-up and to get a better idea of all technical problems needing to be solved
- To validate the use of such alignment system with the repositioning solution, to validate the algorithm of repositioning.

To validate the combination of the propagation and proximity solutions over a range of at least 100m (in the TT1), and 400m (in the TZ32 tunnel), performing an inter-comparison between solutions.

This validation on long range would allow:

- To confirm the propagation error of the different solutions
- To compare the different solutions and to conclude on their precision
- To validate the concept of propagation / proximity networks and especially the links between both networks

These two proposals will be detailed below.

- **Test modules in lab and CLEX**

  The layout of these test modules, from the pre-alignment point of view is the following:
The integration of all the sub systems has just started. The longitudinal distances between all the components are not frozen yet.

These test modules are foreseen to validate the solutions proposed for CDR, that is why it foreseen to integrate WPS sensors for the pre-alignment. It would be also a great opportunity to test another proximity solution, which needs then to be defined.

- **Setup in TT1 / TZ32**

**Objectives:**

Plates will act as CLIC component supports (see fig. 10). Each plate has its own system of reference (to be defined later), w.r.t which the mechanical interfaces of each pre-alignment sensor assembly has been determined.

The position of each plate will have to be computed in the general system of reference of the test setup mixing the measurements from proximity / propagation pre-alignment systems of different technologies.

**Details:**

- Definition of the general system of reference:
  - Longitudinal orientation given by the straight line crossing the centers of the reference systems of the first and last plate along the 100 m.
  - Origin: center of the system of reference of the first plate
- All plates will be pre-aligned along 6 DOF, using standard geodesic means, within +/- 0.1 mm.
- The plates Ref. S. and Ref. E. are considered as references.
- The plates Ref. S. and Ref. E. can be displaced accurately according to 3 DOF (transverse and tilt).
- The position of the zero of each intermediate plates is then computed with respect its theoretical position (offset / theoretical) using the measurements from the alignment systems.
- The comparison of the offsets computed from the different alignment systems will give an idea of the accuracy of the alignment systems: the comparison between offsets should be within a few microns if all alignment methods fulfill the requirements.
- The precision of each alignment method will be determined while displacing the reference plates.

Components to be aligned:

- They must be representative of the layout foreseen for CLIC:
  - 3 DOF
  - Non regular distances
  - Short distances (0.5m – 2m)
  - Not too expensive
  - Could be installed either in TT1 or in TZ32
- They must allow the evaluation of the propagation errors concerning the proximity system
- The two reference points can be displaced accurately.

Layout

Figure 14 : Proposal of long range setup

if needed according to the simulations on error propagation.
Components

Two types of invar plates (like in TT1), acting as a CLIC support:

- **Propagation network**

![Figure 15: plate including the propagation network](image1)

- **Proximity network**

![Figure 16: plate with no propagation network](image2)

- **Next steps**

  - To discuss these proposals
  - To agree on the test facility proposal and define the objectives
  - To propose a workplan and dispatch the responsibilities.