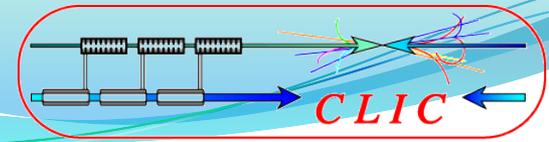# Modeling of the CLIC prealignment errors

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Introduction

The topic of this presentation is a part of the R & D performed to demonstrate the feasibility of the CLIC prealignment.

The CLIC prealignment systems have to be mathematically modeled. Then this model will be simulated. The results of the simulations will be compared to the results of a 140 m facility in the CERN TT1 tunnel.

These simulations will also allow the CLIC beam physics researches to model the impact of the prealignment errors on the beam emittance growths.

In this presentation, the CLIC prealignment strategy and the first simulations results are going to be briefly presented. Then the new model, which is under development, is going to be described.
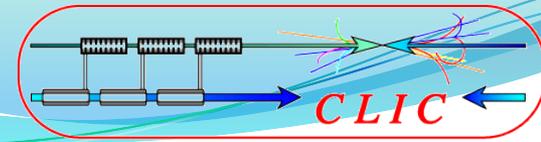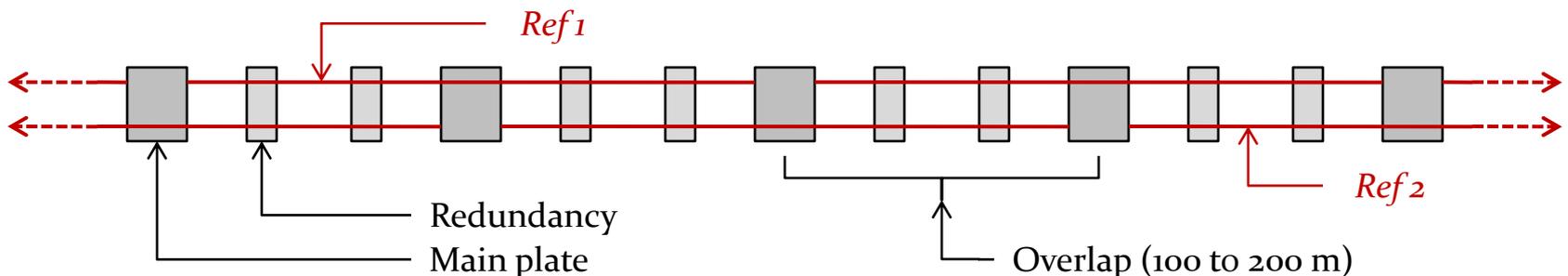
The propagation network

The CLIC components prealignment specifications are very tight. A simplified concept of the prealignment requirements is the tolerance of 10 μm along a 200 m sliding window.

The emittance growths due to the long distances misalignments must be limited. The prealignment has to ensure there is no perturbations, within a few microns, of the components positions with wavelengths smaller than 200 m.

The CLIC components must be aligned along straight lines. The ideal would be to use a 24 km reference straight line, according to which the CLIC is prealigned.

Ref 1

Redundancy
Main plate

*Ref 2*

Overlap (100 to 200 m)

Such a reference does not exist. The propagation network concept consists of building this line by overlapping references (LASER beams or stretched wires).
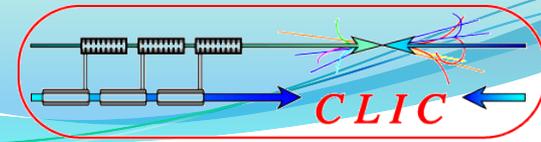
The overlapping references

There are two candidates, a LASER beam under vacuum and a stretched wire. Micrometric LASER alignment system are under development. But none of them is fully validated in the micrometric precision.
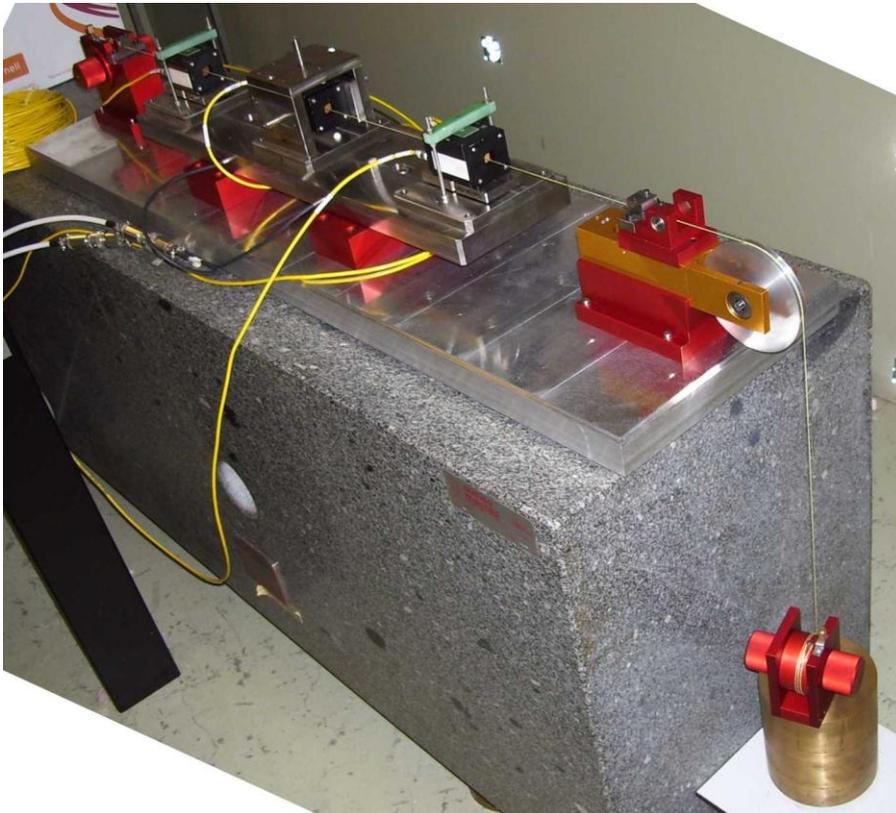
That why all the CLIC studies made at CERN concern the most achieved alignment system, the stretched wires.

The sensors (WPS, i.-e. Wire Positioning System) provide the transversal and vertical offsets to the wire.

The wire is modeled by a straight line in the horizontal plan and a catenary in the vertical one. This is the theoretical approach which still has to be proved in the micrometric scale.
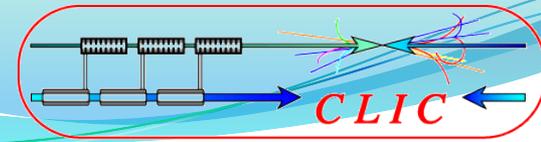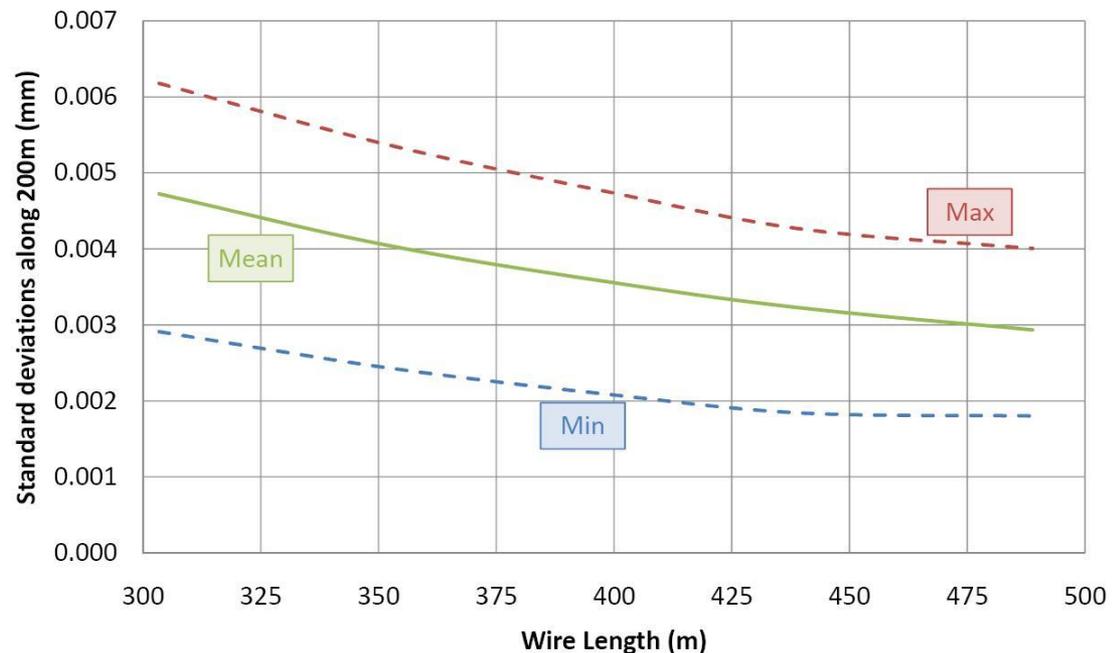
The first simulations

They have been performed with LGC (Logiciel Général de Compensation). They were based on the Monte-Carlo method. One CLIC linac (22 km) has been simulated.

The effect of the lengths of the wire on the 200 m deviation has been studied.

According to the simplified prealignment tolerance of 10 μm (3σ), the specifications seem to be fulfilled with wires longer than 425 m.

The beam physic simulations, based on these data, have shown that 400 m wires were able to limit the long distances emittance growths.

100 simulations along a 22 km linac, 6 pits

Max

Mean

Min

Standard deviations along 200m (mm)

Wire Length (m)

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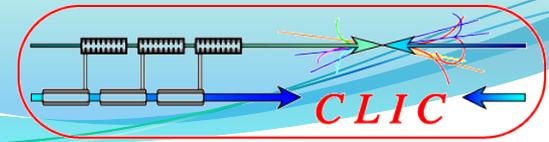
Reliability of the first model

The model used for these simulations was simplified in order to use the existing software. LGC has been developed by the CERN survey group to deal with the standard measurement systems. It was not designed for the CLIC constraints.

- There was no redundancy in the wire overlap,
- The wires were considered, in the horizontal and vertical plans, as straight lines,
- No systematic effect has been taken into account,
- No calibration parameter has been simulated.

Now a new model is required to go further in the prealignment feasibility studies and to improve the beam physic simulations. The specifications of this new model has been defined in collaboration with Daniel Schulte.

- Both of the CLIC linacs will be simulated at the same time,
- Redundancy in the overlap has to be implemented,
- The vertical shape of the wire will be modeled by a catenary,
- All the measurements will be simulated, including the calibrations,
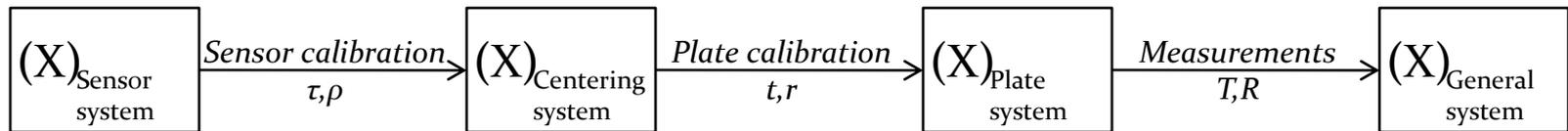- Possibility to add systematic effects in the wires overlaps.
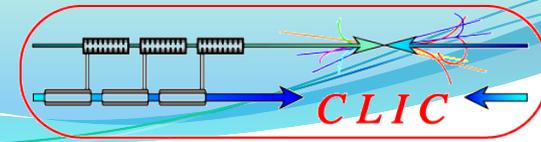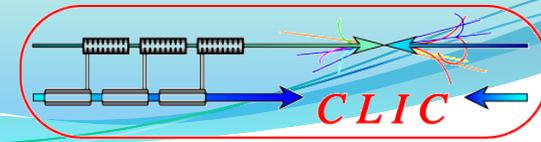
The propagation network modeling

The CLIC components are prealigned according to the propagation network which is composed by overlapping wires. Hence, the geometry of the wire used to prealign one component must be defined in a general coordinates system.

Metrological plates on which sensors are installed

Component to align
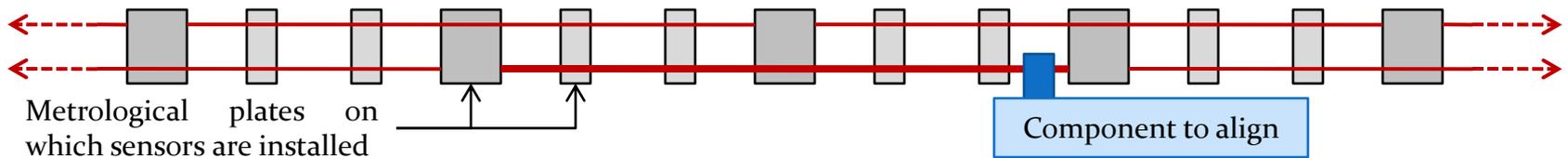
A WPS sensor is providing the position of one point of the wire in a local system. This system must be defined according to external references. If theses references are known in the general coordinates system, so does the measured point of the wire.

$$(X)_{\text{Sensor system}} \xrightarrow[\tau,\rho]{Sensor\ calibration} (X)_{\text{Centering system}} \xrightarrow[t,r]{Plate\ calibration} (X)_{\text{Plate system}} \xrightarrow[T,R]{Measurements} (X)_{\text{General system}}$$

Each of these transformations are defined by translations and rotations matrixes. The last transformation, to go from the plate to the general coordinates system, is given, initially by topometric measurements and, finally by the stretched wire.
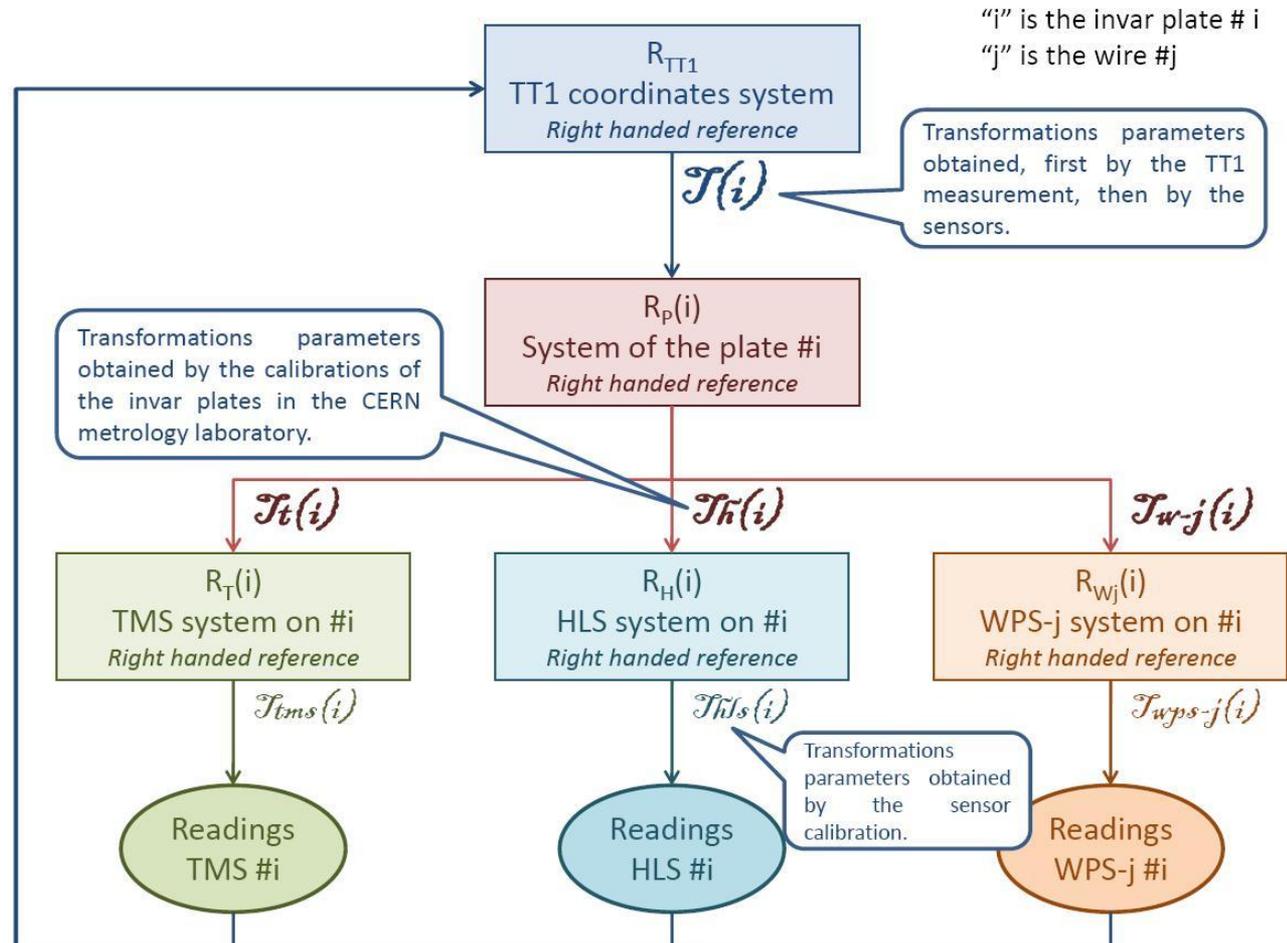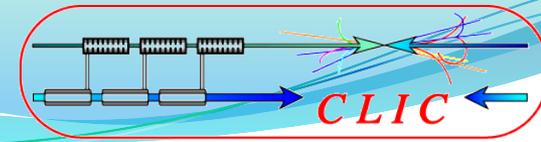
Dealing with coordinates systems...

Here is the same principle, explained for the TT1 facility.

The TT1 is a 140 m long facility designed to get the precision of the wires overlap. The layout is similar to the propagation network concept.

TMS : double-axis inclinometers
HLS : Hydrostatic levelling system
WPS : Wire positioning system.

"i" is the invar plate # i
"j" is the wire #j

Transformations parameters obtained, first by the TT1 measurement, then by the sensors.

Transformations parameters obtained by the calibrations of the invar plates in the CERN metrology laboratory.

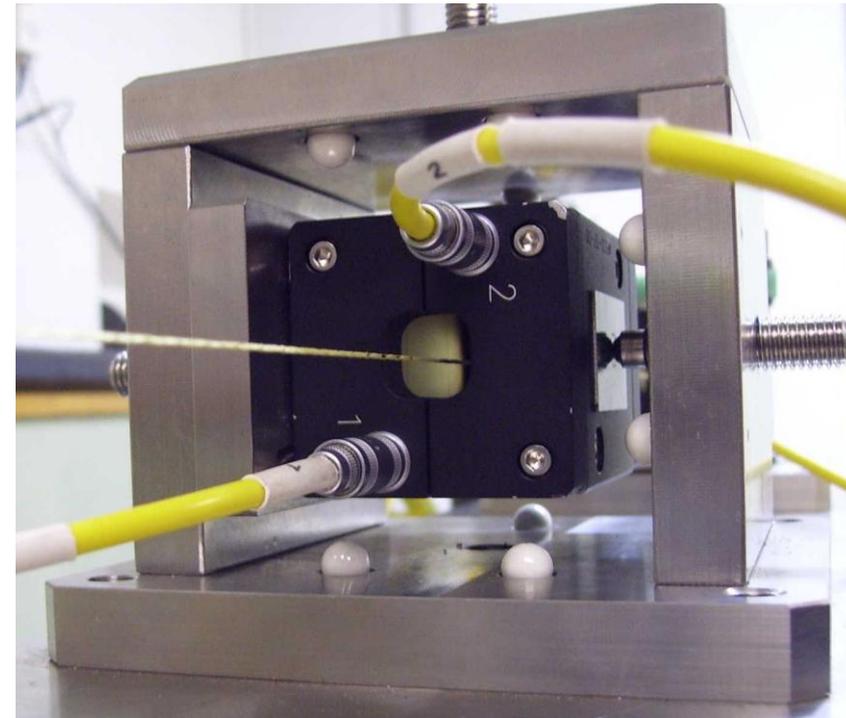Transformations parameters obtained by the sensor calibration.

The sensor zero calibration

The WPS sensor takes place on a three balls centering system. Where is the zero of the sensor according to these balls ?
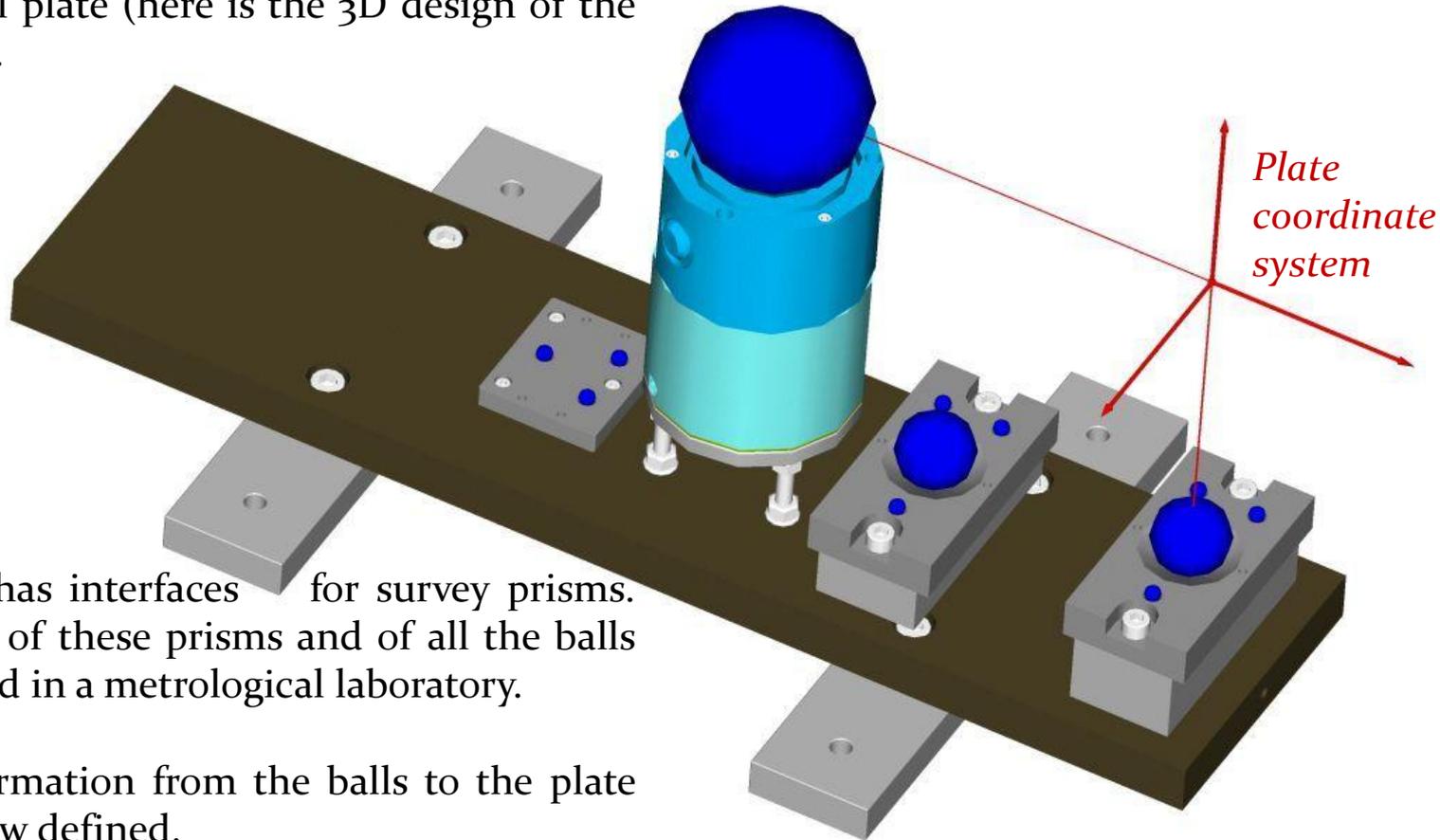

A calibration bench has been designed to answer this question. It should provide the translations, the rotations from the zero to the three balls system and the precision of these parameters.
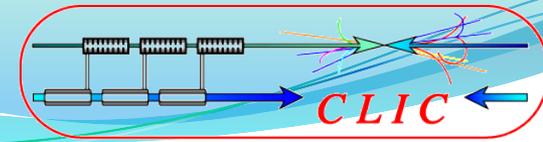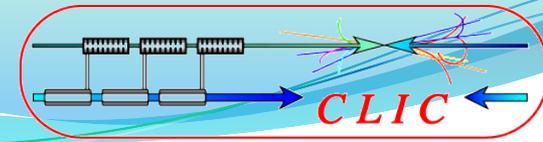
The plate calibration

The sensors centering systems are screwed on a metrological plate (here is the 3D design of the TT1 facility).

Plate coordinate system

Each plate has interfaces   for survey prisms. The centers of these prisms and of all the balls are measured in a metrological laboratory.

The transformation from the balls to the plate system is now defined.
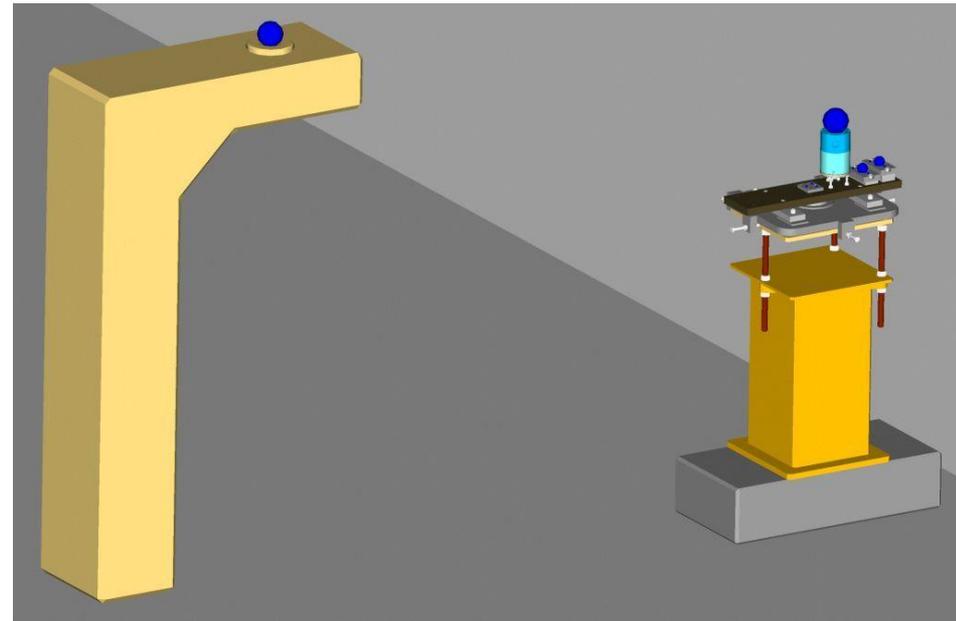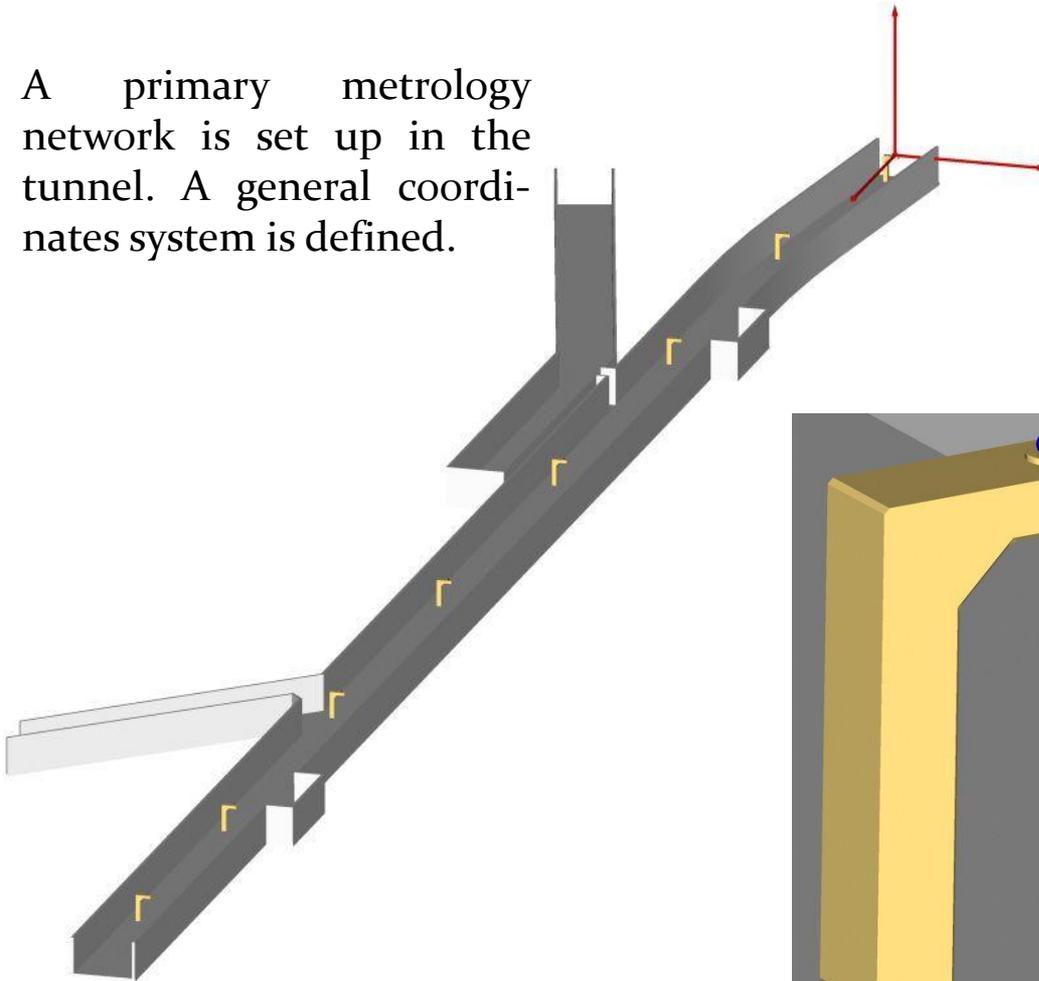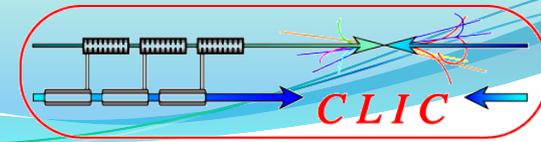
The general coordinates system

A primary metrology network is set up in the tunnel. A general coordinates system is defined.

The initial position of the plates according to this system is given by the topometric measurements.
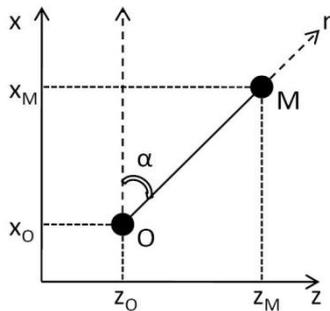
Approximates values of the transformations parameters are obtained.

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The topometric measurements

The devices used for these measurements are levelling systems, tacheometers and laser trackers. They measure angles (α, horizontal and β, vertical), 3D distances (d) or differences of level (h).
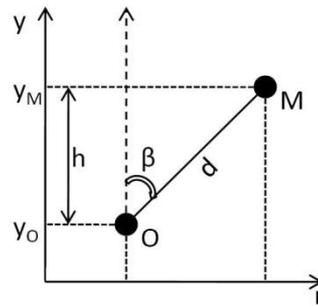
$$\alpha = \arctan \frac{z_m - z_o}{x_m - x_o}$$
$$d = \sqrt{(x_m - x_o)^2 + (y_m - y_o)^2 + (z_m - z_o)^2}$$
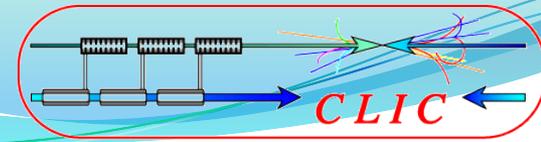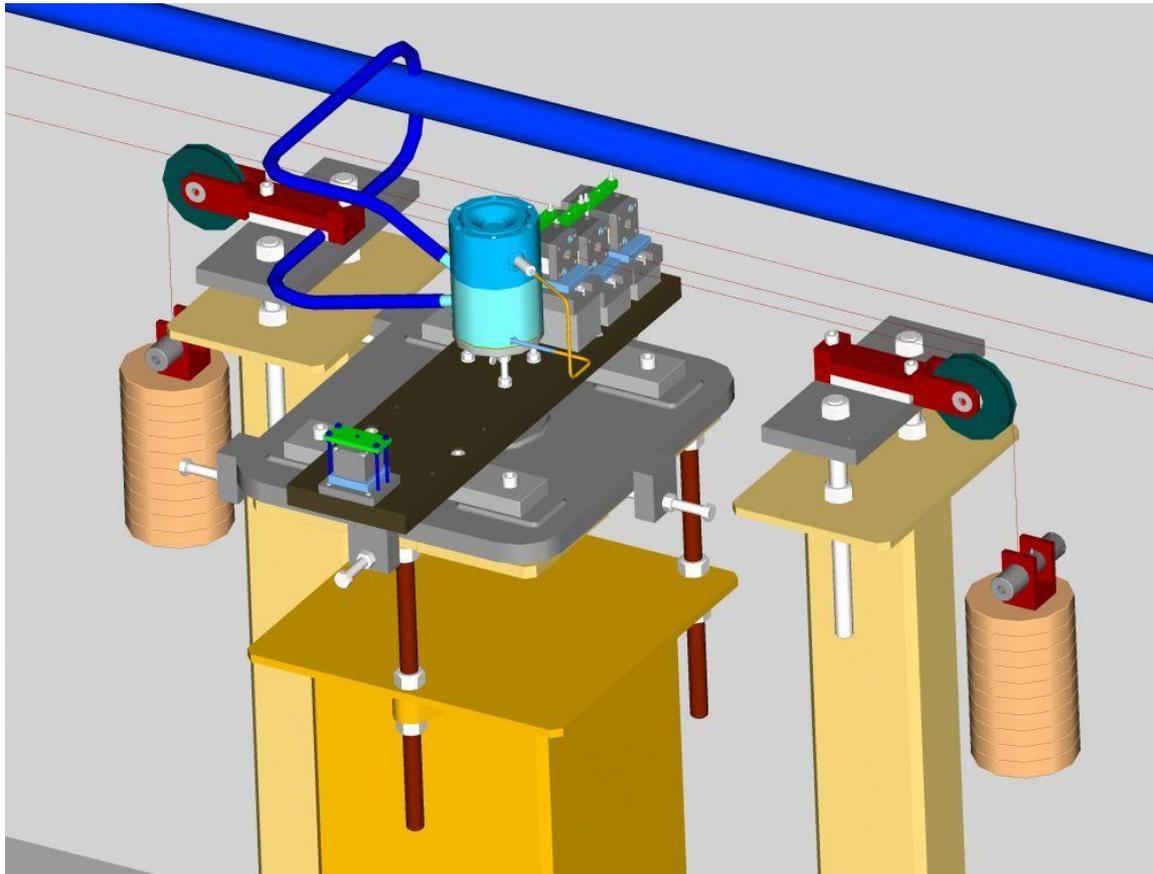$$\beta = \arcsin \frac{y_m - y_o}{d}$$
$$h = y_m - y_o$$

The precisions of these devices are very well known.

For the TT1 facility, the precision of the topometric measurements was 0.2 mm along the 140 m of the tunnel.
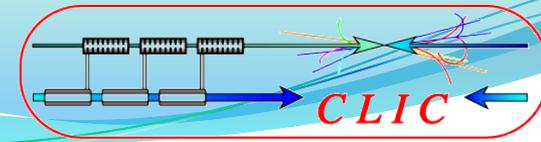
The sensors measurements

Three kind of sensors are used, inclinometers (TMS), hydrostatic levelling system (HLS) and WPS.

Thanks to their measurements, the transformation parameters of the plate should be defined more accurately . A 5 µm precision is expected.

The TMS gives the tilts of the plate and the HLS the vertical translation. The WPS provides the transversal and vertical translations.

Model of the sensors measurements

Thanks to the transformation matrixes, all the measured points of one wire are expressed in the general coordinates system. These points (F_i), in the theoretical approach, must belong to a straight line in horizontal and to a catenary in vertical (i.-e. an hyperbolic cosinus), approximated by a parabol.

The points measured by the HLS sensors belong to a water surface which follow an equipotential of gravity. If the tides effects are neglicted, all these points (H_i) have the same altitude.
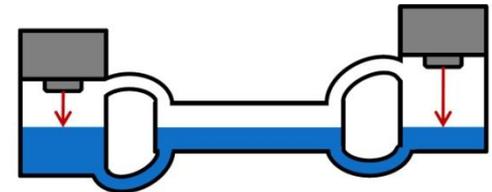
Hence the equations are :

$$\exists (a, b, c, d, e, h) \in \mathbb{R}^6 \forall i \in \{1..n\} \begin{cases} F_{i,x} &= a \cdot F_{i,z} + b \\ F_{i,y} &= c \cdot F_{i,z}^2 + d \cdot F_{i,z} + e \\ H_{i,y} &= h \end{cases}$$

After the adjustment of the points coordinates, the final values of the plates tranformation parameters are computed. The whole geometry of the propagation network is known.
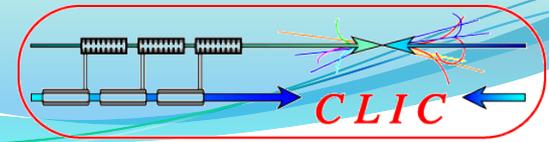
Conclusion

The simulations results of the first prealignment model were promising from the survey and beam physics points of view. The CLIC prealignment specifications seem to be reachable.

Now they require further investigations. The model has to be closer to the reality than before. The new model is in development. The different steps are mathematically defined. The different blocks presented here have now to be put together.

As soon as the algorithms are ready, the model will be simulated along a small distance and compared with the TT1 facility. Then it will be implemented for the whole CLIC project, i.-e. along 48 km.

This will be the last challenge. It will represent a large amount of data to compute (20000 equations for 12000 parameters).
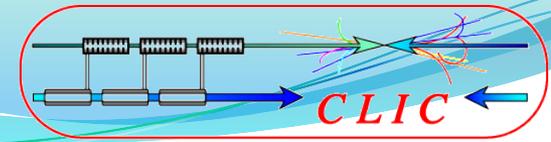
Thanks for your attention !

For further informations, a publication about the first model of the CLIC prealignment has been made for the PAC09 conference :

« PROPAGATION ERROR SIMULATIONS CONCERNING THE CLIC ACTIVE PREALIGNMENT », Th. Touzé, H. Mainaud-Durand and D. Missiaen.