FEASIBILITY OF THE CLIC METROLOGICAL REFERENCE NETWORK

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INTRODUCTION

In the previous PhD thesis linked with the CLIC pre-alignment, the instrumentation and the network configuration had both been defined. But all the questions were not yet answered.

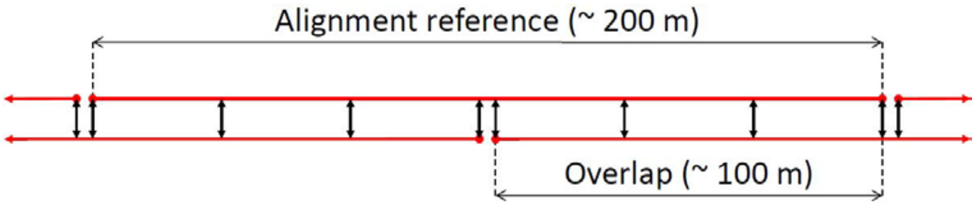
The main concept of the CLIC pre-alignment is based on the overlapping stretched wires. How is it possible to get a value of the uncertainties of one point, associated to one wire, with respect to another one, corresponding to another wire ? It is essential to answer this question which is close to the CLIC pre-alignment specifications: 10 µm along a 200 m sliding window.

This presentation shows the R & D made in order to answer this. It is based on the management of coordinate systems, from the sensors calibrations to the alignment references modelings.

MRN & PRE-ALIGNMENT

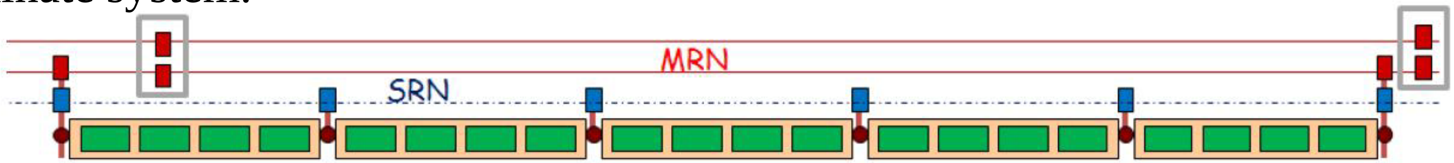
❑ THE OVERLAP PRINCIPLE

The MRN is designed to provide a linac long alignment reference by overlapping stretched wires.



❑ THE SUPPORT PRE-ALIGNMENT NETWORK (SPN)

The SPN uses the MRN to define the CLIC components positions in the general coordinate system.



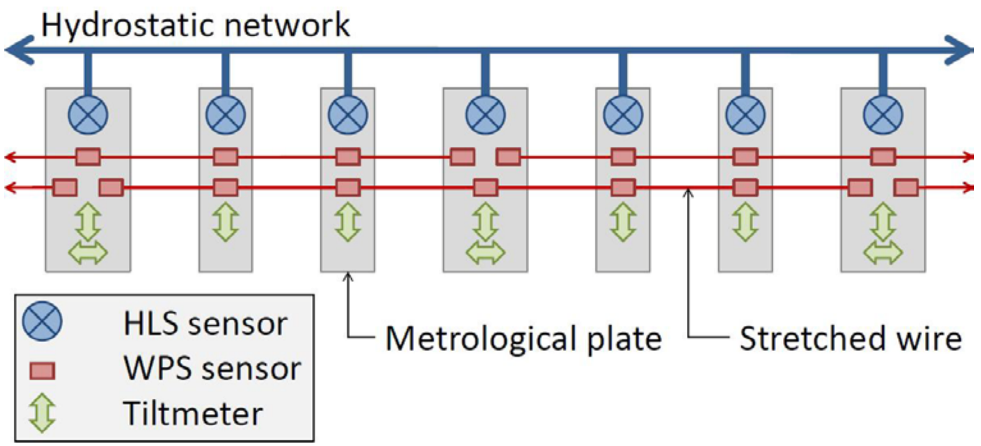
❑ THE FIDUCIALIZATION

The pre-alignment must ensure the beam axis of the CLIC components form a straight line along 200 m. The fiducialization defines the beam axis of the CLIC components in their coordinate system.

MRN & PRE-ALIGNMENT

❑ METROLOGICAL PLATES

The sensors are fixed on invar metrological plates. Their absolute calibration and the metrology ensure the geometry of the plate is known.

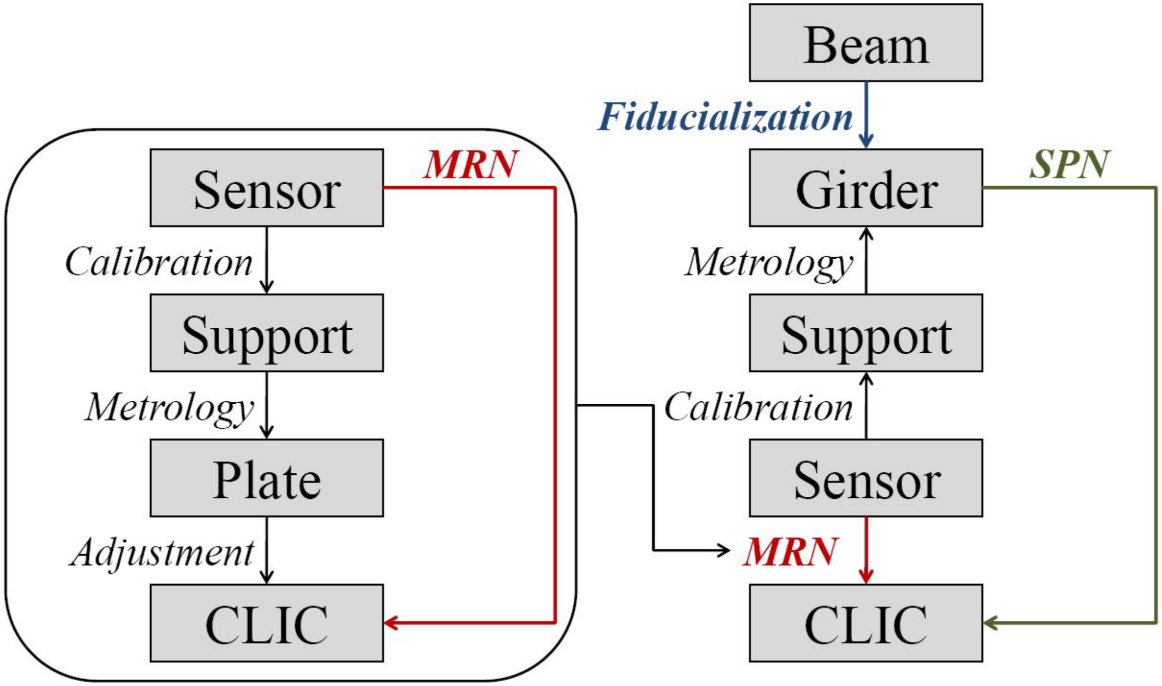


❑ PLATES IN THE GENERAL COORDINATE SYSTEM

The SPN requires the knowledge of the wires modeling parameters in the general coordinate system. A least-square adjustment will provide the positions and orientations of the plates as well as the wires parameters.

MRN & PRE-ALIGNMENT

❑ CLIC PRE-ALIGNMENT METROLOGICAL CHAIN

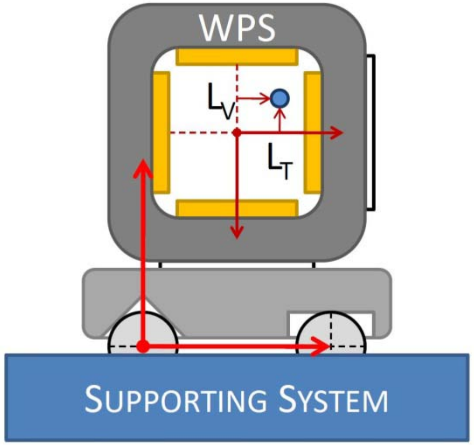


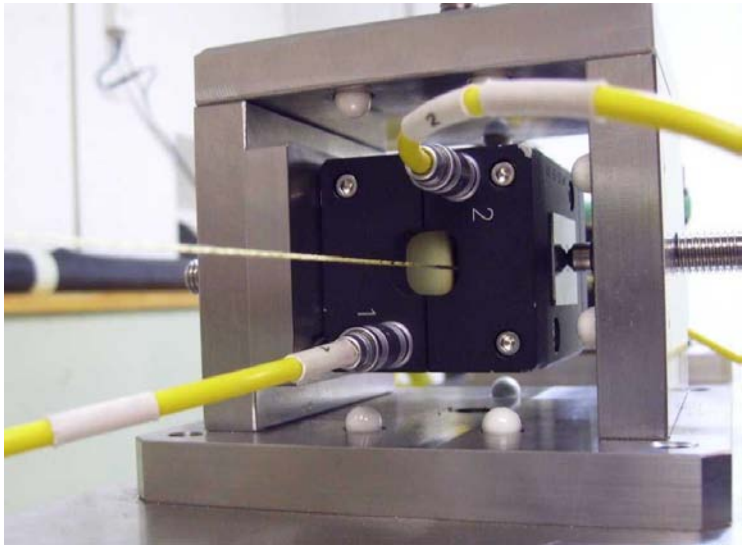
A WPS or a HLS sensor provides the coordinates of a measured point of a wire or a water surface in its inner coordinate system. The sensor calibration allows the definition of this point in the support coordinate system. And so on…

Sensors absolute calibrations

❑ Calibration parameters of the WPS

The coordinate system of the sensor has to be defined with respect to its centering system. Three parameters are relevant: the transversal and vertical offsets and the roll.





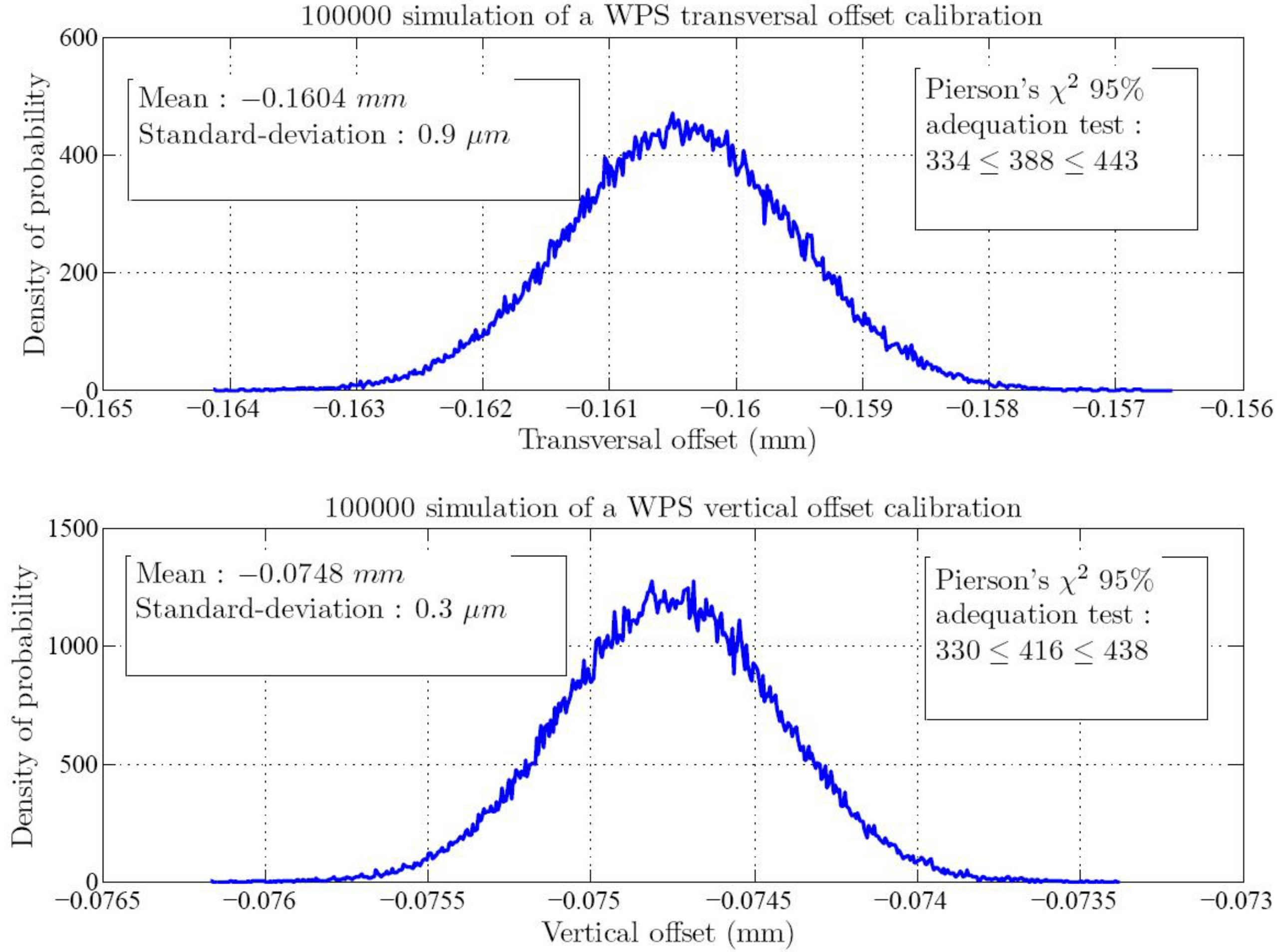
The sensor, mounted on different centering systems known according to each other, measures a constant point of the wire.

The main hypothesis of this calibration is false. On the different centering systems, the WPS does not measure a single point of the wire. This method prevent the calibration of the sensor roll.

SENSORS ABSOLUTE CALIBRATIONS

❑ CALIBRATIONS RESULTS OF THE WPS

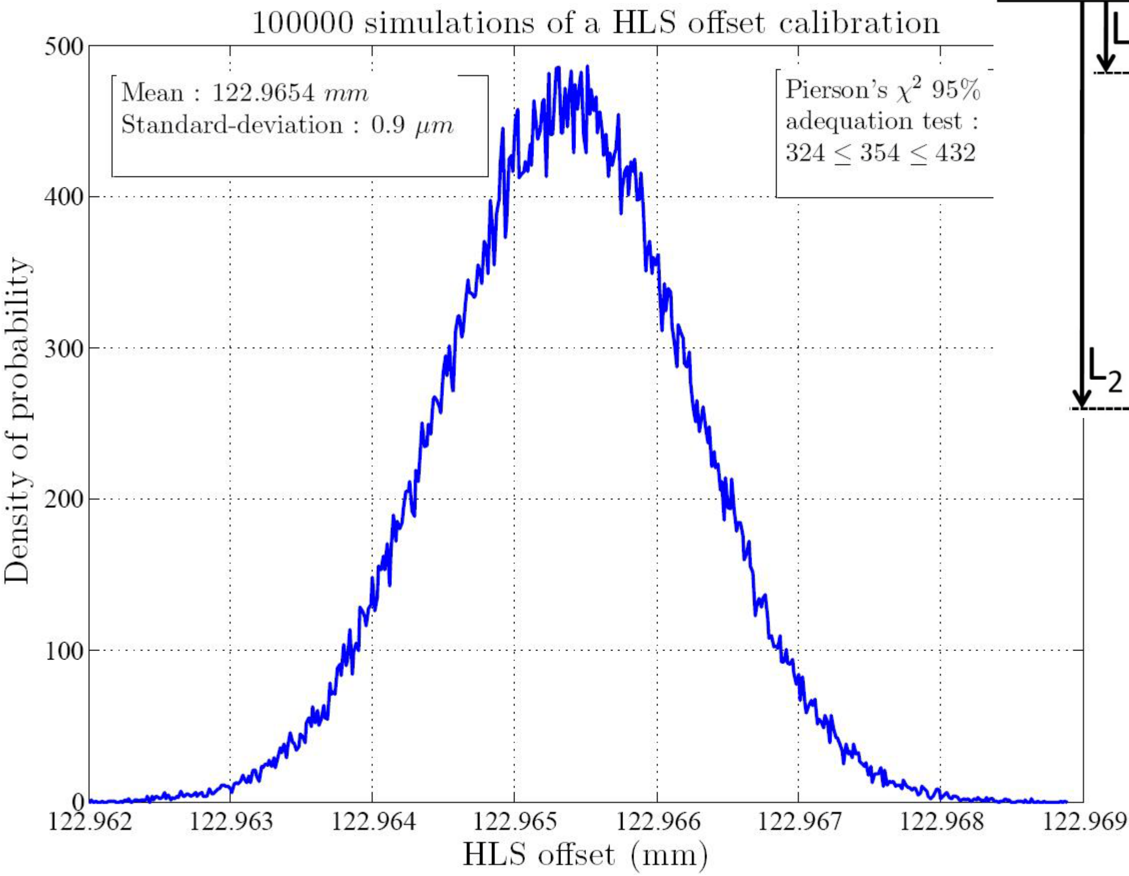
All the 17 calibrated sensors had the same offsets standard deviations.

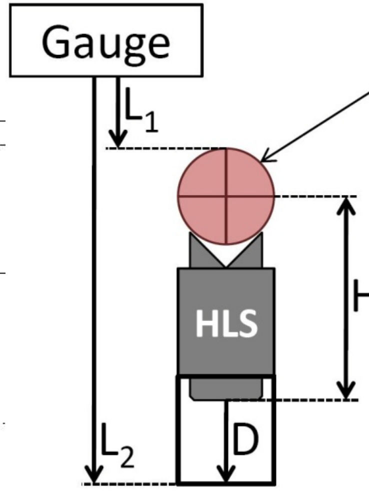


SENSORS ABSOLUTE CALIBRATIONS

❑ ABSOLUTE CALIBRATION OF THE HLS

7 sensors have been calibrated and simulated…





$$H = |L_2 - L_1| - \left(D + \frac{\Phi}{2}\right)$$

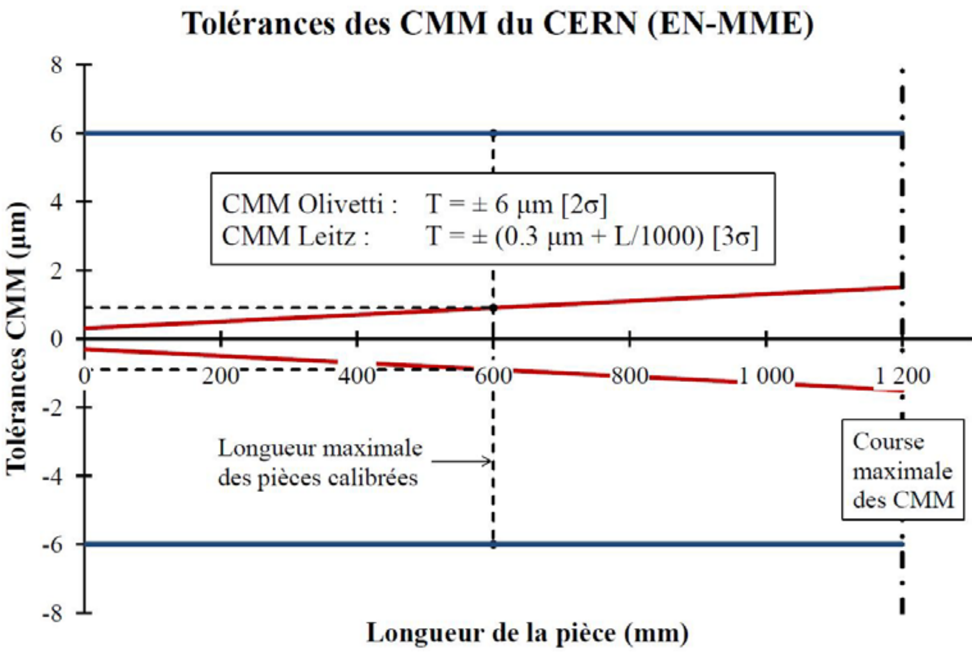
The calibration gauge has been checked in metrology : σ = 0.6 μm.

The sensors simulated offsets have the same standard deviation : 0.9 μm.

METROLOGICAL MEASUREMENTS

❑ COORDINATE MEASURING MACHINES AT CERN

A CMM provides the coordinates of points in a 3D system.



CERN is actually equipped with a 3 µm standard-deviation Olivetti CMM (1σ). In a few months, it will be equipped with a Leitz “Infinity”. The metrology uncertainties will become neglictable !

METROLOGICAL MEASUREMENTS

❑ CMM CALIBRATION OF THE PLATES

The invar metrological plates of the TT1 facility have been measured by the CERN Olivetti CMM.

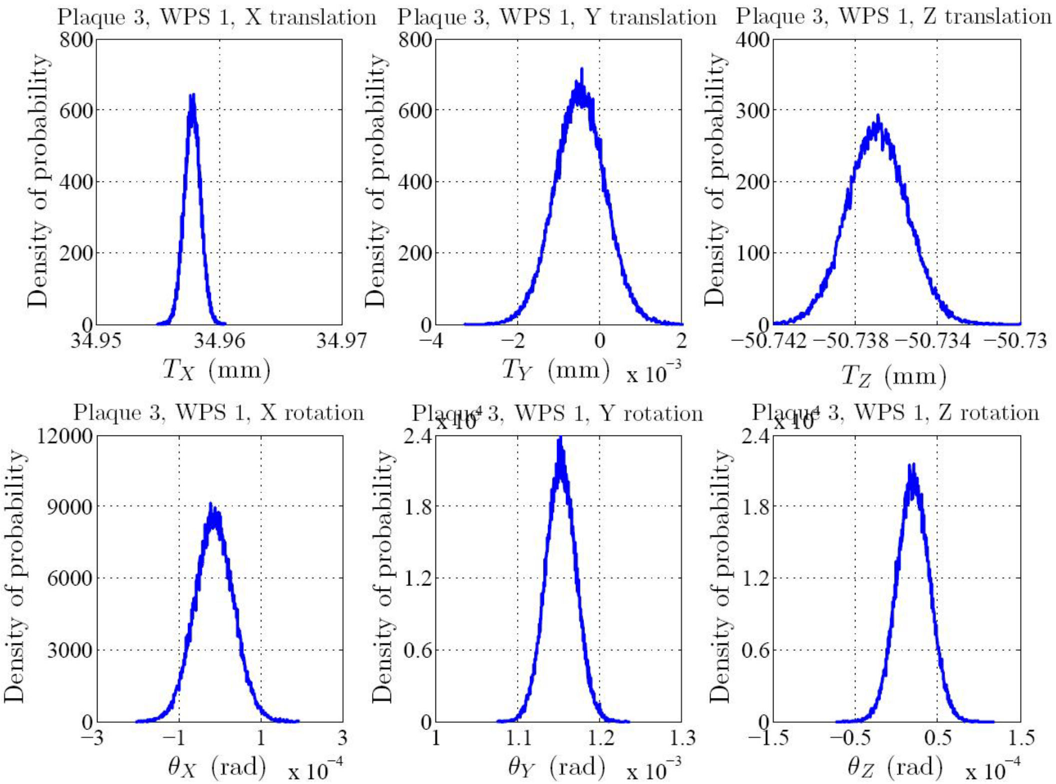
For each plate, the centers of the sensors centering balls and of survey reflectors are known in the same coordinate system.

Metrological measurements

❑ Plates results and simulations

	Tx	Ty	Tz
Mean (mm)	34.9578	-0.0005	-50.7369
STD (µm)	0.7	0.6	1.5
γ_1	316	315	336
χ^2	338	400	398
γ_2	422	421	446

	θx	θy	θz
Mean (mrad)	-0.013	1.153	0.020
STD (mrad)	0.047	0.018	0.020
γ_1	323	302	309
χ^2	409	341	345
γ_2	431	406	414



MODELING OF THE REFERENCES

❑ FINAL ADJUSTMENT EQUATIONS

Let us consider M as a point of a stretched wire or and hydrostatic surface, measured by a WPS or a HLS sensor. Thanks to the sensor calibration and the metrological definition of the corresponding plate, the coordinates of M in the plate system is known.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{CLIC} = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} + k.\left[R_Z(\alpha_Z)\times R_Y(\alpha_Y)\times R_X(\alpha_X)\right]\times \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{Plate} = \begin{bmatrix} f(Z) \\ g(Z) \\ Z \end{bmatrix}$$

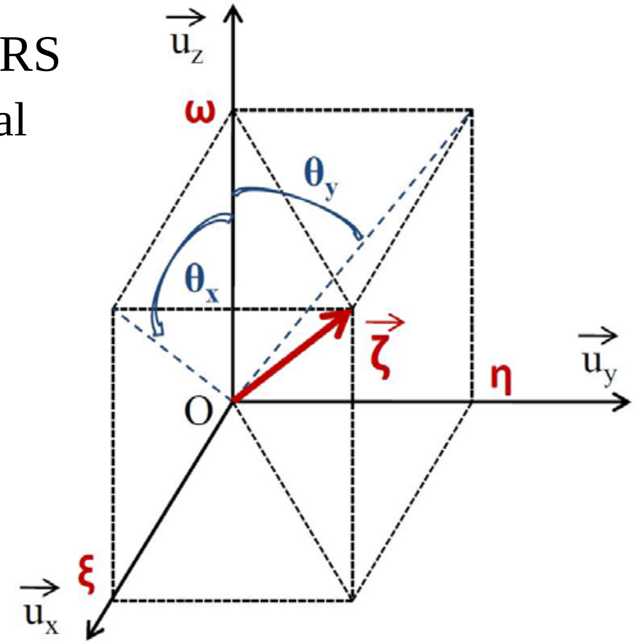
The coordinates of M in the CLIC system are given, on one hand, by a 3D spatial transformation (3 translations, 3 rotations and 1 scale factor). On the other hand, those coordinates are the results of the transversal and vertical modelings of the references.

The scale factor is fixed (0.001 : mm →m). The longitudinal parameters (T_Z, α_X and α_Y) are obtained from the survey measurements. The roll α_Z is provided by the tiltmeter. The functions f and g depend on the wires and water surfaces modelings.

Modeling of the references

Roll determination from tiltmeters

A double-axis tilmeter provides the angles of the vertical direction, projected on two orthogonal plans.



$$\begin{cases} \left[\vec{\varsigma}\right]_{Tiltm} = \begin{bmatrix} \xi \\ \eta \\ \omega \end{bmatrix} = \omega . \begin{bmatrix} \tan\theta_X \\ \tan\theta_Y \\ 1 \end{bmatrix} \\ \omega = \sqrt{1-\xi^2-\eta^2} = \dfrac{1}{\sqrt{1+\tan^2\theta_X+\tan^2\theta_Y}} \end{cases}$$

The roll of the plate α_Z is obtained by solving a matricial equation.

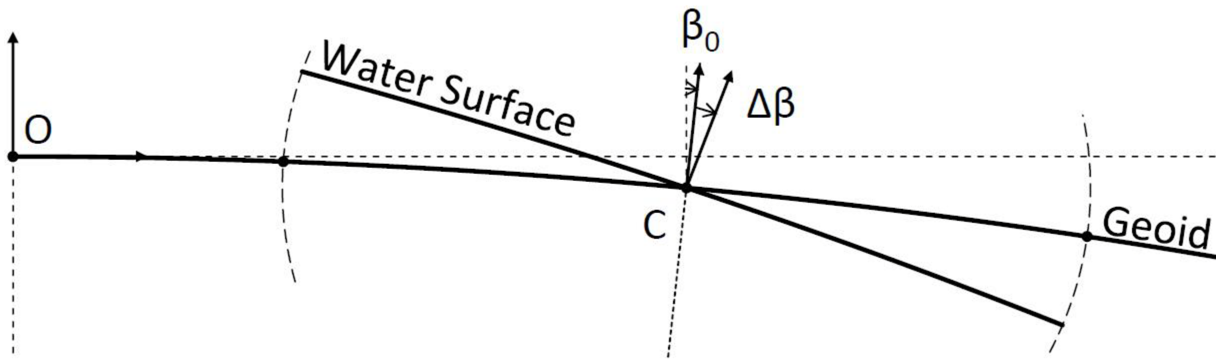
$$\left[\vec{\varsigma}\right]_{CLIC} = \begin{bmatrix} \Xi \\ H \\ \Omega \end{bmatrix} = \left[R_Z(\alpha_Z)\times R_Y(\alpha_Y)\times R_X(\alpha_X)\right]\times r\times\rho\times\begin{bmatrix} \omega.\tan\theta_X \\ \omega.\tan\theta_Y \\ \omega \end{bmatrix}$$

This is possible if the vertical deflection is known, if it's a double-axis tiltmeter and if the sensor and its support are calibrated (r and ρ rotations matrixes).

Modeling of the references

❑ Modeling function of a hydrostatic surface

The hydrostatic surface, measured by HLS sensors, follows the geoid.
It oscillates around the static part of the geoid because of the tides.



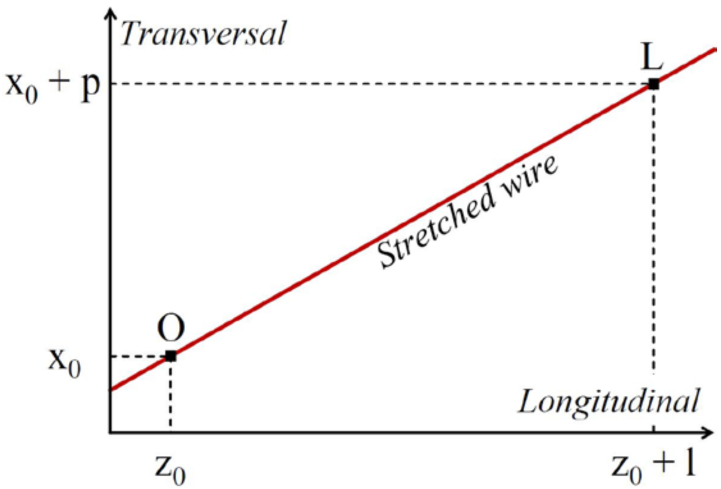
Z is the longitudinal axis of the hydrostatic network. Y is the vertical axis. C is the center of the network. The locale vertical direction, including the tides effects, along the Z axis is given by the angle $\beta_0 + \Delta\beta(t)$.

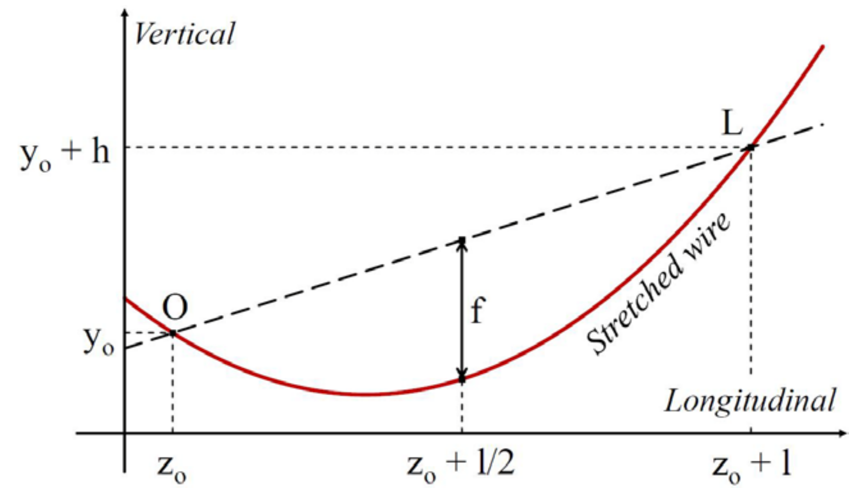
$$Y = Y_C - R_T.\cos(\beta_0 + \Delta\beta(t)) + \sqrt{R_T{}^2 - (Z - Z_C + R_T.\sin(\beta_0 + \Delta\beta(t)))^2}$$

This modeling considers an oscillating R_T radius circle around C by the angle $\beta_0 + \Delta\beta(t)$. The geoid studies should demonstrate if a circular modeling is efficient enough for a 200 m long hydrostatic network.

Modeling of the references

Modeling functions of the stretched wires





$$M \in \{Wire\} \Leftrightarrow$$

$$\begin{cases} Z_0 \leq Z \leq Z_0 + l \\ X = X_0 + \dfrac{p.(Z - Z_0)}{l} \\ Y = Y_0 + \dfrac{4f.(Z - Z_0)^2}{l^2} + \dfrac{(h - 4f).(Z - Z_0)}{l} \end{cases}$$

In transversal, the stretched wire is considered as a straight line. In vertical, it is a catenary, which is approximated by a 2nd order polynomial function.

MODELING OF THE REFERENCES

❑ IMPROVEMENT OF THE WIRES VERTICAL MODELINGS

The sag f depends on the linear mass of the wire q and its tension T. The catenary modeling is reliable if the ratio q/T is constant along the wire.

Today, we still don't know how to measure independently both of those parameters on a stretched wire. But the value of this ratio can be deduce from the oscillation frequency φ of the wire.

$$\frac{q}{T} = \frac{8f}{gl^2} = \frac{1}{4l^2\varphi^2}$$

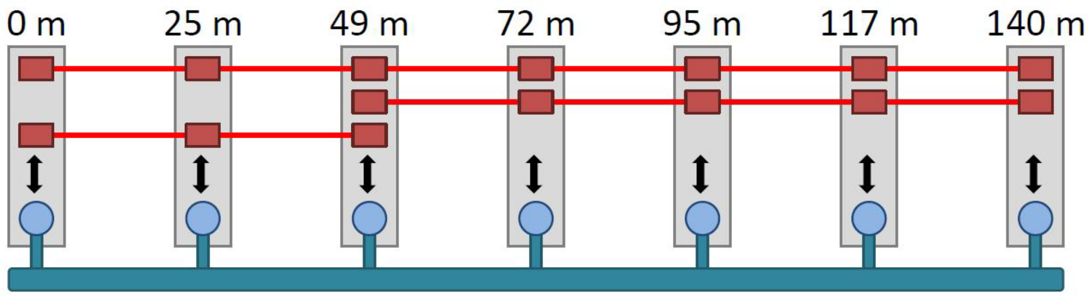
It has been shown this ratio was linearly dependant with the relative humidity. By measuring the frequency φ and the humidity gradient, it should be possible to compute corrections to the polynomial approximation.

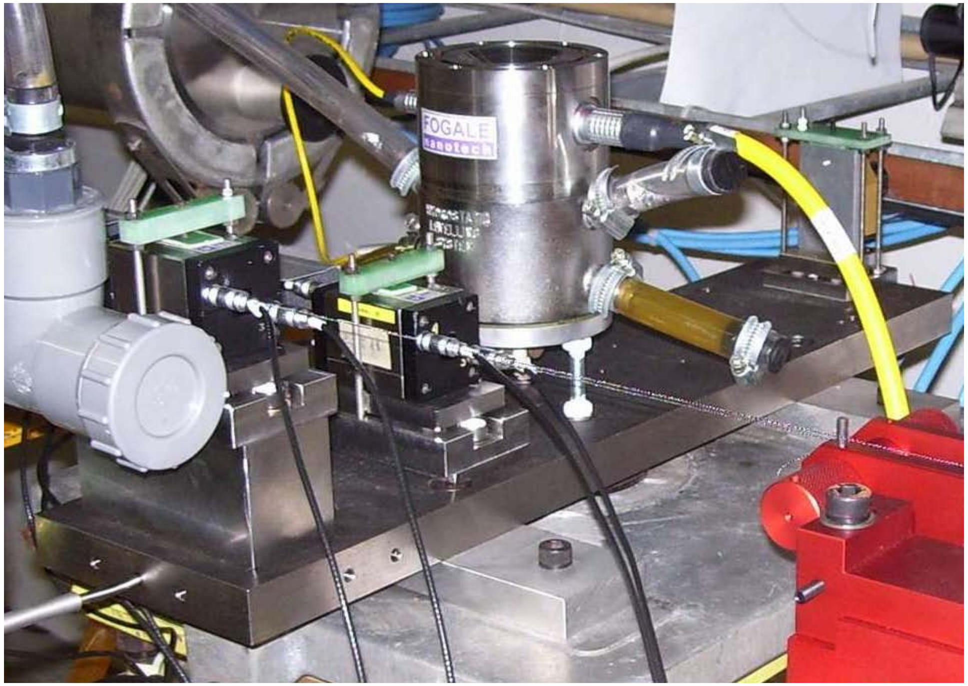
Then, by measuring the frequency, the sag could be removed from the unknown parameters list. And finally, it would be a way to check the physical state of the wire, a way to anticipate its breaking.

FINAL ADJUSTMENT

❑ THE TT1 FACILITY

It is a facility which reproduces the overlap principle along 140 m.





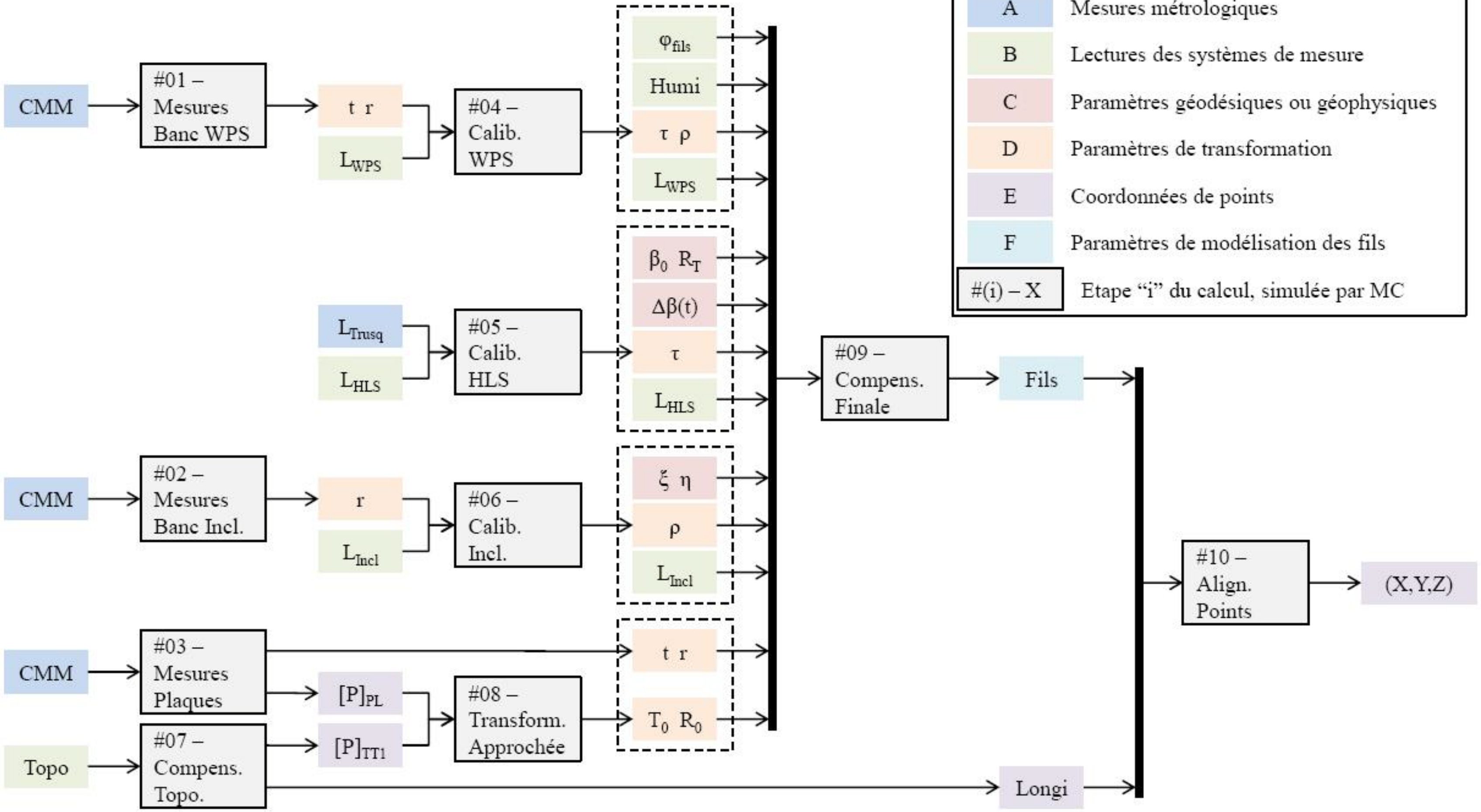
It is composed by 7 invar plates, 3 overlapping stretched wires, 1 hydrostatic surface and tiltmeters.

FINAL ADJUSTMENT

❑ GLOBAL DECOMPOSITION OF THE MRN

LÉGENDE

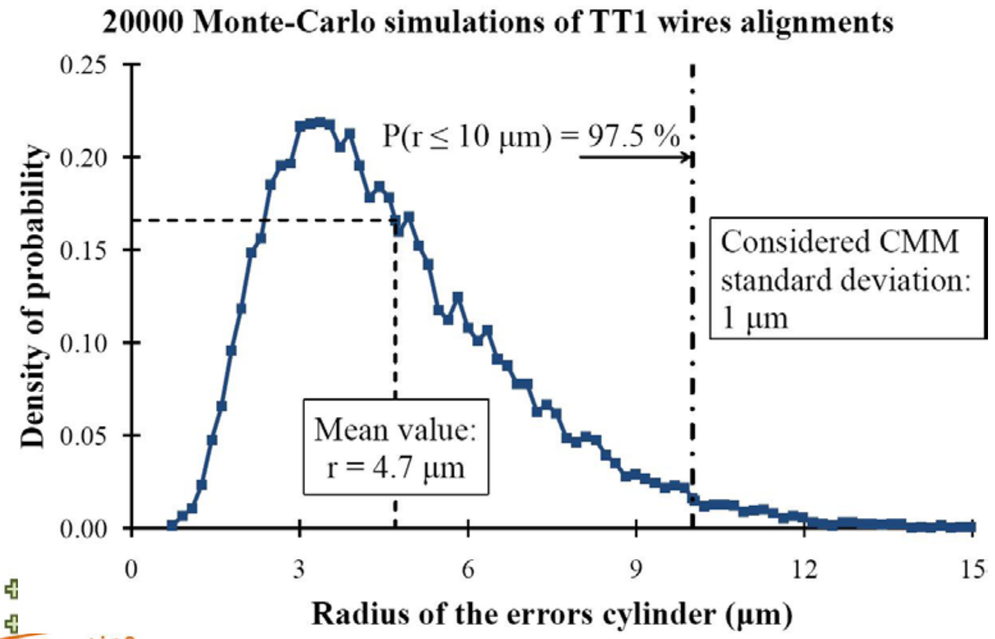
A	Mesures métrologiques
B	Lectures des systèmes de mesure
C	Paramètres géodésiques ou géophysiques
D	Paramètres de transformation
E	Coordonnées de points
F	Paramètres de modélisation des fils
#(i) – X	Etape "i" du calcul, simulée par MC

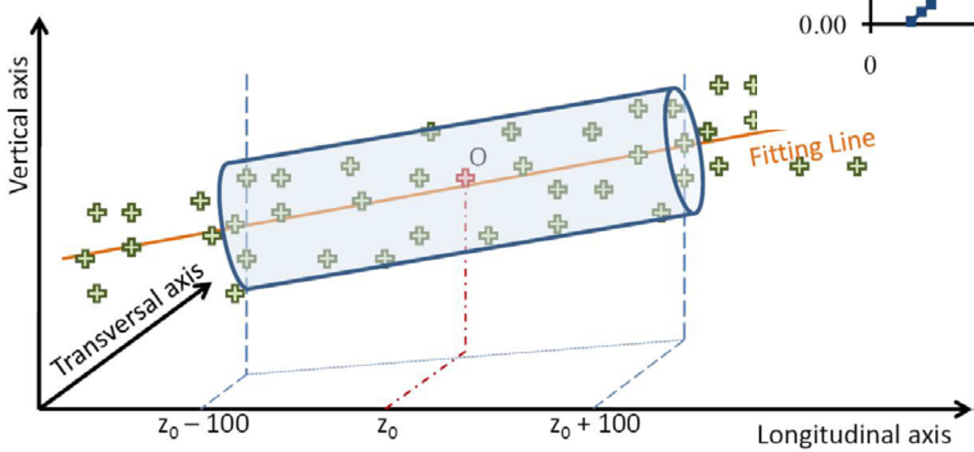


FINAL ADJUSTMENT

❑ SIMULATIONS OF THE TT1 140 M ERRORS CYLINDER

According to the pre-alignment specifications, we must ensure all the errors fit, along 200 m in a 10 µm error cylinder.

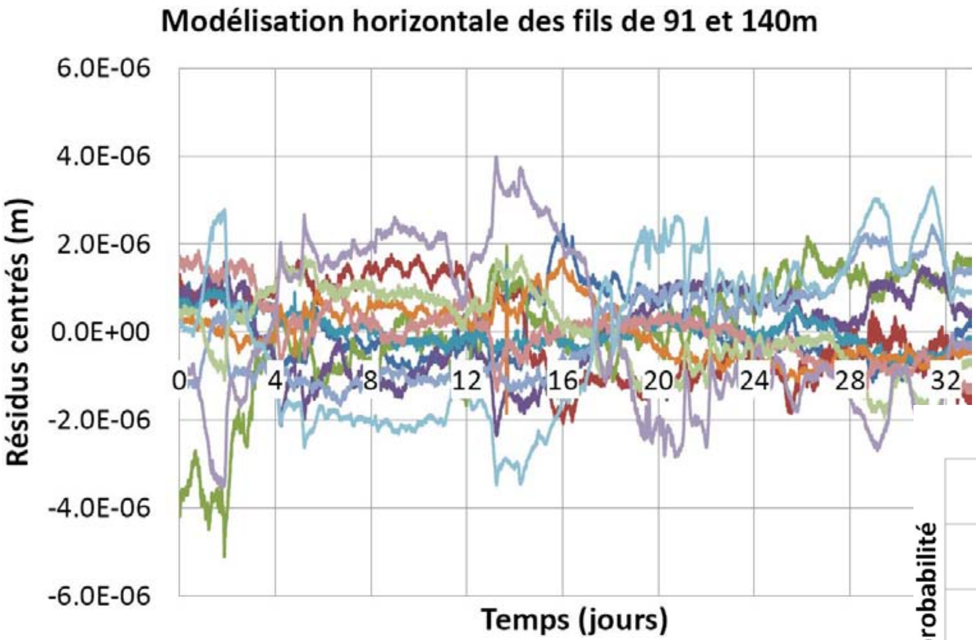




The TT1 simulations are showing that in 97.5 % of the cases, all the pre-alignment error along 140 m fit in a 10 µm cylinder.

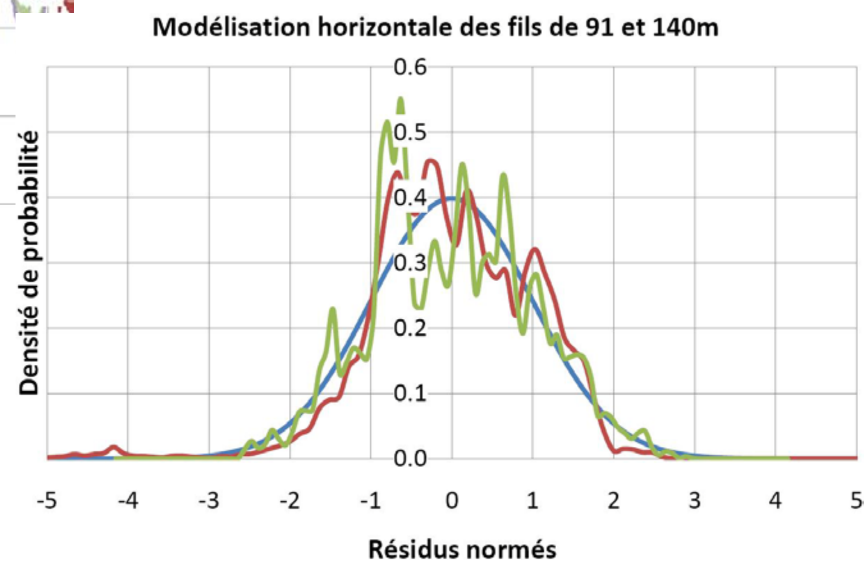
FINAL ADJUSTMENT

❑ TT1 EXPERIMENTAL PRECISION



In summer 2009, the measurements during 33 days have been computed.

The standard deviation of the residuals after adjustment was 2.1 μm !



The distribution of the centered residuals seemed close to the gaussian distribution (no Pearson's χ^2 adequation test done).

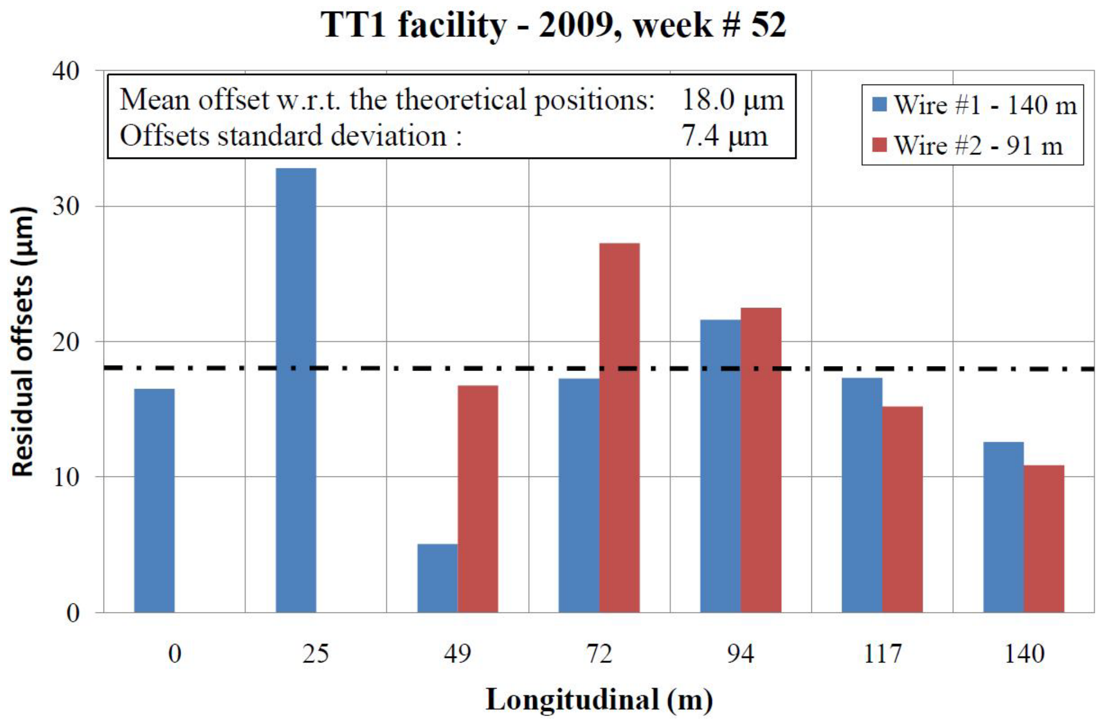
FINAL ADJUSTMENT

❑ TT1 EXPERIMENTAL ACCURACY

Unfortunately, if the final adjustment residuals have an excellent dispersion, their mean value are quite high (~ 50 µm).

A gross error detection has been made by a L1 adjustment. The gross errors were due to unglued balls.

But the new balls did not improve the results, because of the unknown rolls of the WPS interfaces…



Conclusion

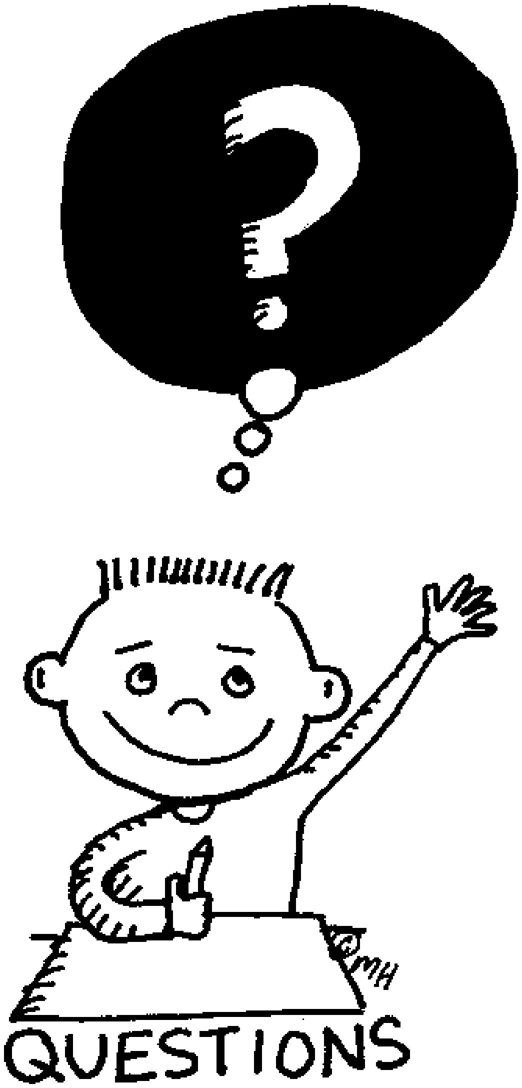
The management of coordinate systems in the CLIC pre-alignment seems efficient. The whole problem is now determined. All the involved parameters are detected and defined in the equations. Unfortunately, their uncertainties are not yet completely known, especially the WPS roll and the geoid data.

R & D still has to be done concerning those parameters. This is essential in order validate the simulation modeling of the TT1 facility with the experimental results. The last results are promising: 2.1 µm precision, 18 µm accuracy, i.-e. a factor 4 to the simulated one (4.7 µm) ! We are very close now !

A last effort has to be done. When it is, it will be possible to extrapolate the simulation modeling to the entire CLIC project, as a final step for the MRN feasibility studies.

ERRATUM :
Please replace in this presentation, slides 8 and 9, "*Pierson* χ^2 adequation test" by "*Pearson* χ^2 adequation test.

QUESTIONS ?



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