TECHNOLOGICAL CHALLENGES OF CLIC

THE PREALIGNMENT OF THE COMPONENTS

INTRODUCTION

Why is CLIC prealignment a challenge?

- ✓ Tolerance of ± 10 μm never required before
- ✓ Necessity of an active prealignment to correct for perturbing effects (normal seismic ground movements, cultural noise, human and industrial activity, consequences of temperature variations)
- ✓ « Active » means a prealignment controlled by sensors and corrected by micro movers.

OUTLINE

- ✓ Technical evolution of measurement tools for alignment
- ✓ Alignment systems for continuous measurements
- ✓ CLIC prealignment solution

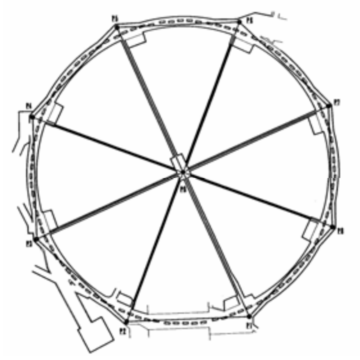
TECHNOLOGICAL EVOLUTION OF MEASUREMENT TOOLS FOR ALIGNMENT

TECHNOLOGICAL EVOLUTION

Proton Synchrotron in 1959 → first challenge:

Tolerances of the magnets alignment: 0.6 mm (radial plane)
0.3 mm (vertical plane)

First computers had just appeared
Angle measurements by theodolite (T3)
Distance measurements by invar wires
Levelling by Wild N3 level (σ: ± 0.3mm/km)



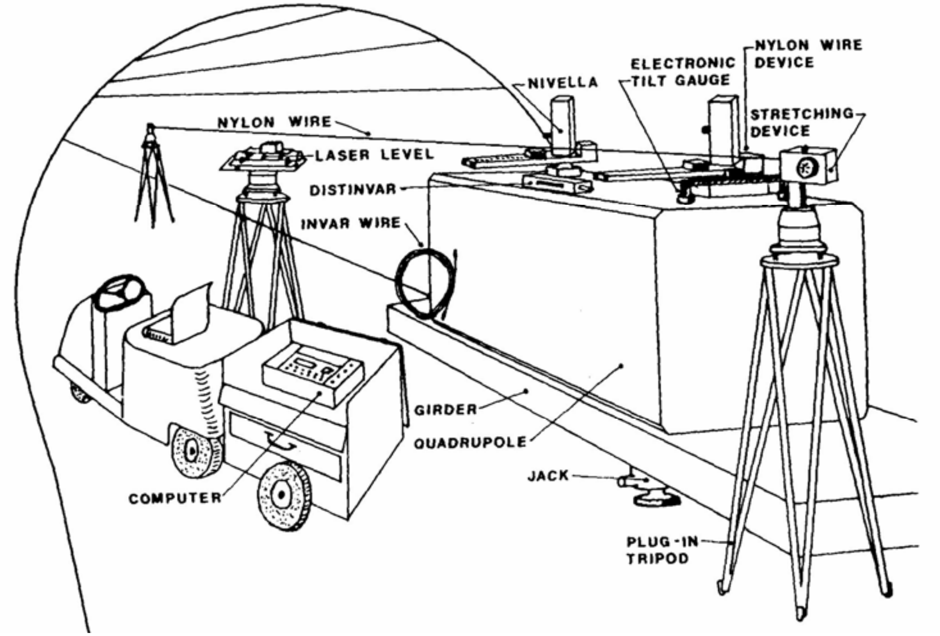
Intersecting Storage Ring (ISR) in 1966

Distinvar (invented by the CERN Survey Group in 1961) coupled with more sophisticated computers (σ: ± 0.015mm on short distances)

Super Proton Synchrotron (SPS) in 1972

Offset measurement device (invented by the CERN Survey Group) σ: ± 0.05mm
→ Measurements of small angles were replaced by offset measurements

TECHNOLOGICAL EVOLUTION



Large Electron Positron Synchrotron

Automation of these devices.

Large Hadron Collider (LHC)

Some tolerances:

First positioning of each magnet w.r.t. geodetic network: σ: ± 0.3mm

Final positioning (smoothing): σ: ± 0.1 mm

Combination of TDA + offset measurement devices + digital levels

Some lessons from the past:

- ✓ An optimum design for the alignment of a collider is a function of tools, methods and care
- ✓ The smoothing is the step on which the emphasis must be laid.
- ✓ Smoothing of all these colliders, σ_{maxi}: ± 0.1 mm over ≈ 100 m

… Factor greater than 10 of improvement for the CLIC

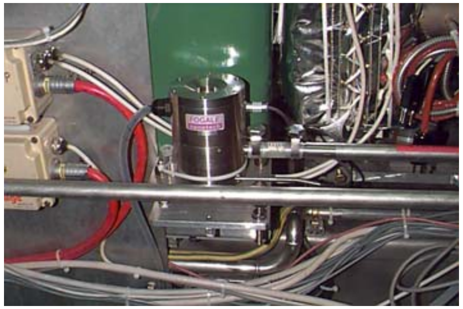
ALIGNMENT SYSTEMS AND THEIR PERTURBING EFFECTS

ALIGNMENT SYSTEMS

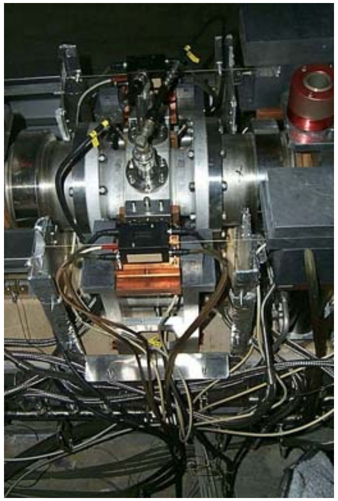
Tolerance of CLIC prealignment: ± 10 μm over 200m

→ need for alignment systems with the following characteristics:

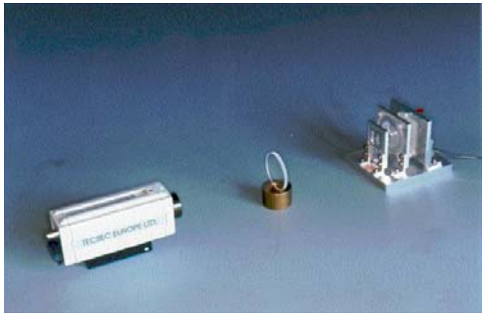
- high resolution
- continuous measurements
- working in severe environment (strong electro-magnetic fields and radiations)



Hydrostatic Levelling System (HLS)

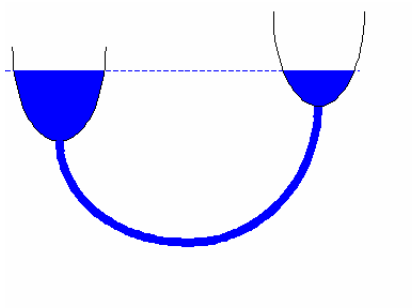


Wire Positioning System (WPS)



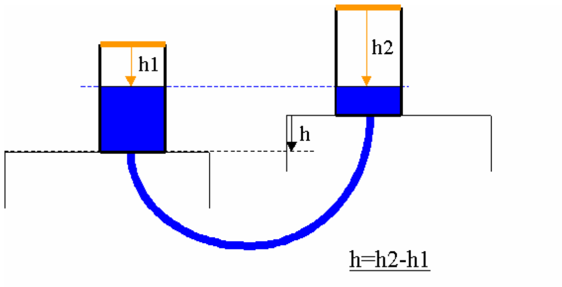
Red Alignment System from NIKHEF (RASNIK)

ALIGNMENT SYSTEMS : HLS



- ✓ Based on the principle of communicating vessels
- ✓ Water network = reference frame
- ✓ A sensor is fitted to each vessel – to determine the distance to the free surface of the water

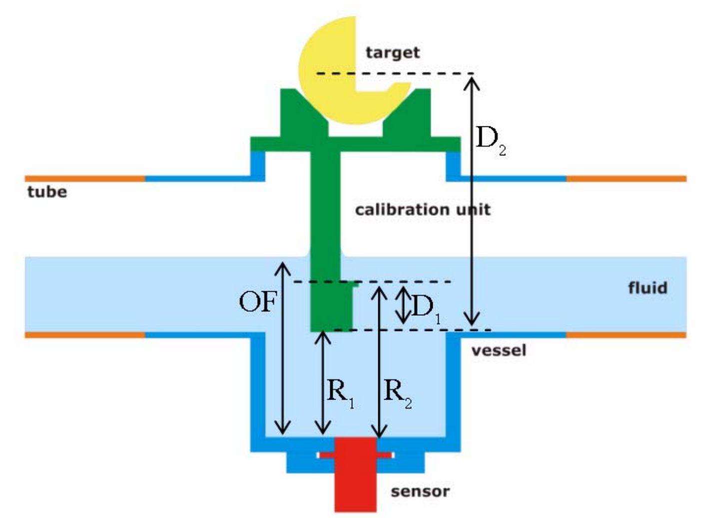
Capacitive technology



$$C = \frac{\varepsilon_o \varepsilon_r S}{d}$$

Resolution: 0.2 µm
Range: 5mm
Repeatibility: 1 µm
Bandwidth: 10 Hz

Ultrasonic technology



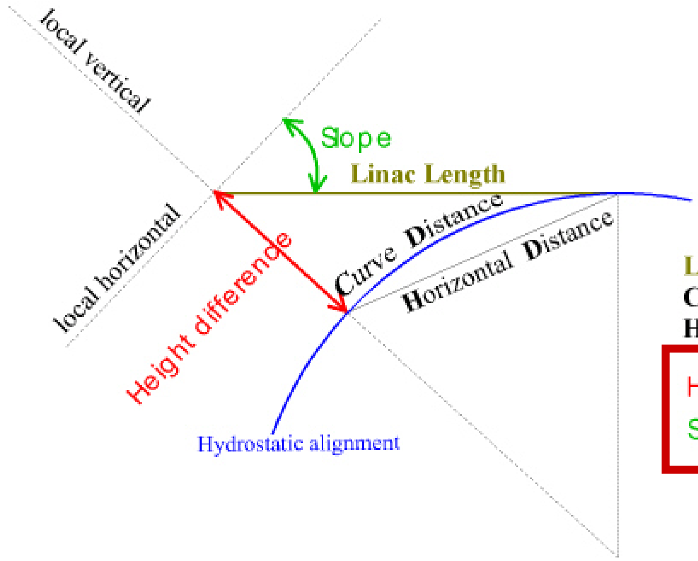
Resolution: 3 µm
Under development (DESY)

ALIGNMENT SYSTEMS : HLS

Measurements w.r.t an equipotential surface in the earth's gravity field

→ First approximation: spherical surface.

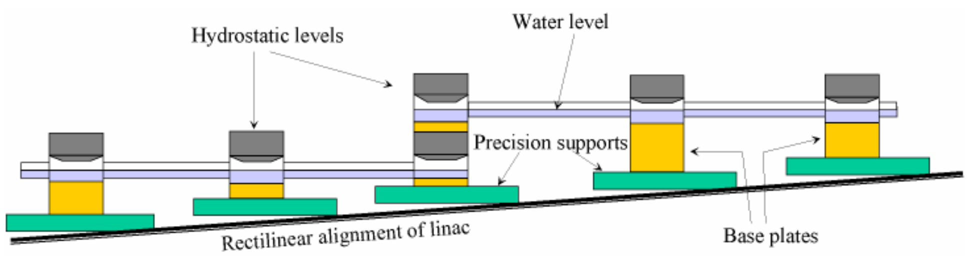
The components have to be aligned along a straight laser line…



LL = 17 770.939 m
CD = 17 770.893 m
HD = 17 770.887 m

Height difference = 24.799 m
Slope = 2.791 mrad

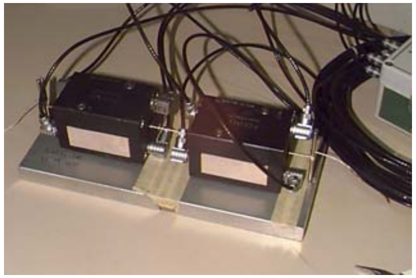
A solution: several hydrostatic lines…

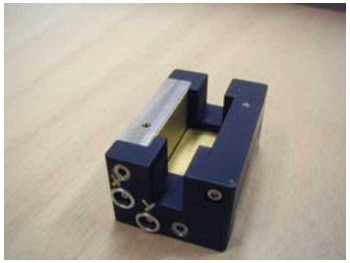


ALIGNMENT SYSTEMS : WPS

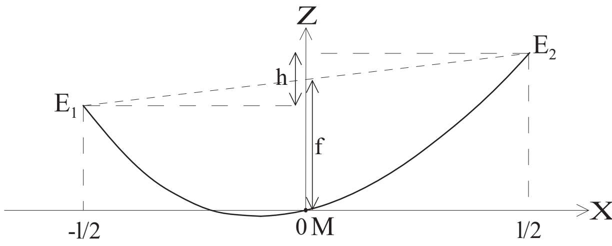
- ✓ Based on a capacitive technology
- ✓ Reference frame = stretched wire (carbon peek)
- ✓ Bi axial measurement device

Resolution: 0.2 μm
Range: 10 x 10 mm
Repeatibility: 1 μm
Bandwidth: 10 Hz

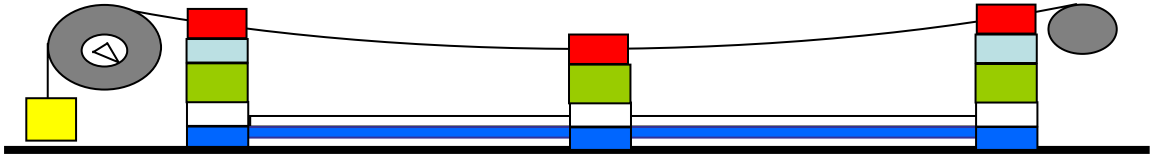




- ✓ In the horizontal plane: wire = straight line
- ✓ In the vertical plane: wire = catenary



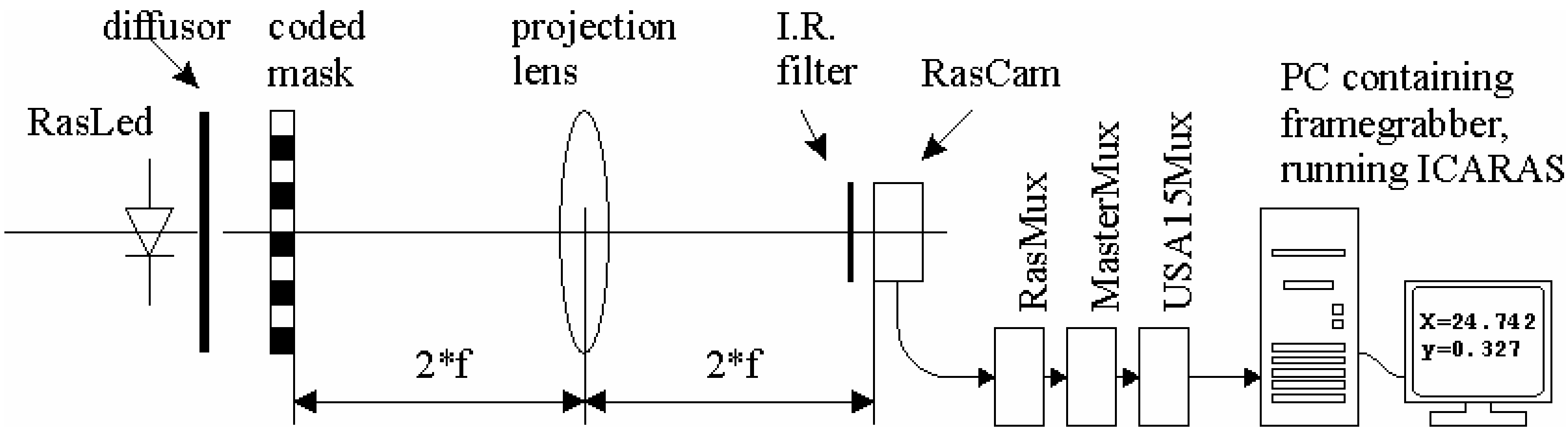
Modelization of the wire: to know very precisely and accurately the difference in height of 3 points along the wire



$$Z = \frac{4f}{l^2}(X + \frac{lh}{8f})^2 - \frac{h}{16f}$$

First tests: modelization within σ: ± 5 μm (on 50 m)

ALIGNMENT SYSTEMS : RASNIK



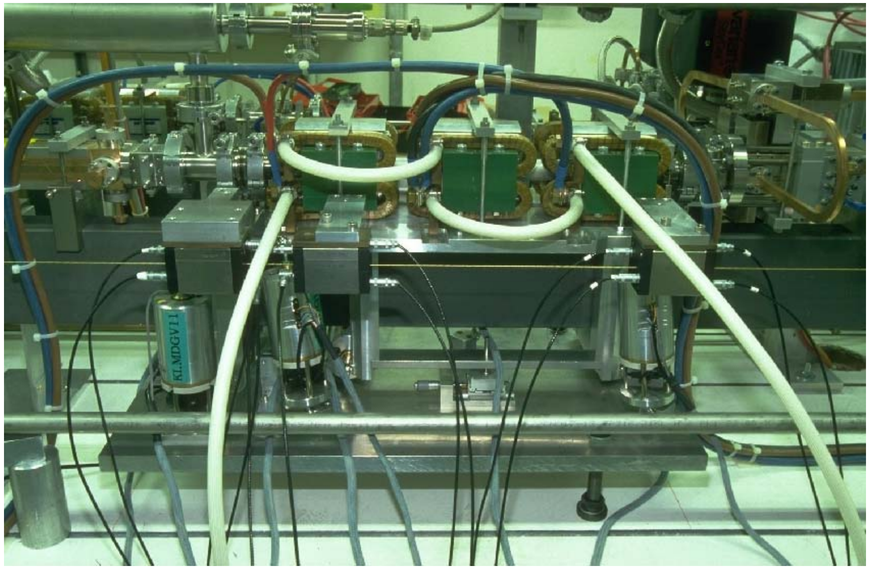
- ✓ Resolution: 0.01µm
- ✓ Range: 5mm
- ✓ Uncertainty of measurement with 2.f = 2.5 m : 1 µm

- ✓ Developed by NIKHEF
- ✓ Light rays nearly insensitive to gravity
- ✓ But limited by the medium over long distances

ALIGNMENT SYSTEMS : PREVIOUS APPLICATIONS

All these alignment systems have already been used sucessfully :

- ✓ L3 detector for RASNIK system
- ✓ LEP low beta quadrupoles for HLS system
- ✓ LEP spectrometer for WPS system
- ✓ WPS + HLS tested on CTF2



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

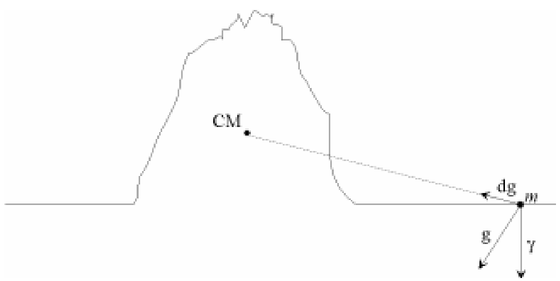
For CLIC: a new parameter … the dimension
Perturbation of gravity and its consequences

ALIGNMENT SYSTEMS : INFLUENCE OF GRAVITY

The metrology network must allow the rectilinear alignment of each of the 2 linacs.

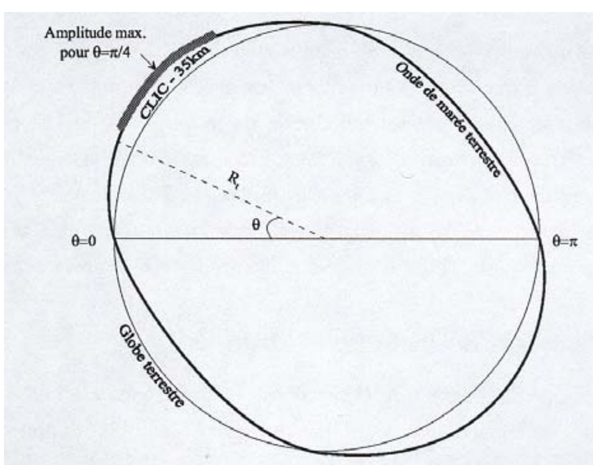
The reference frames (wire and water surface) are sensitive to gravity:

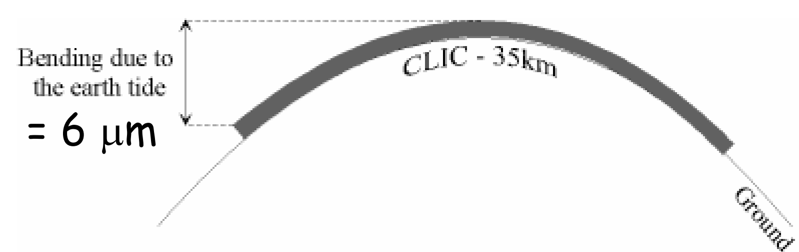
- ✓ the curvature of the earth, the altitude, latitude
- ✓ the distribution of mass in the neighbourhood



Maxi. deviation of the vertical: 15″ at CERN

- ✓ The attraction of moon and sun





In the most unfavourable conditions:
Maxi. Amplitude: ± 40 cm
Period of elementary component with largest amplitude: 12h

ALIGNMENT SYSTEMS : INFLUENCE OF GRAVITY

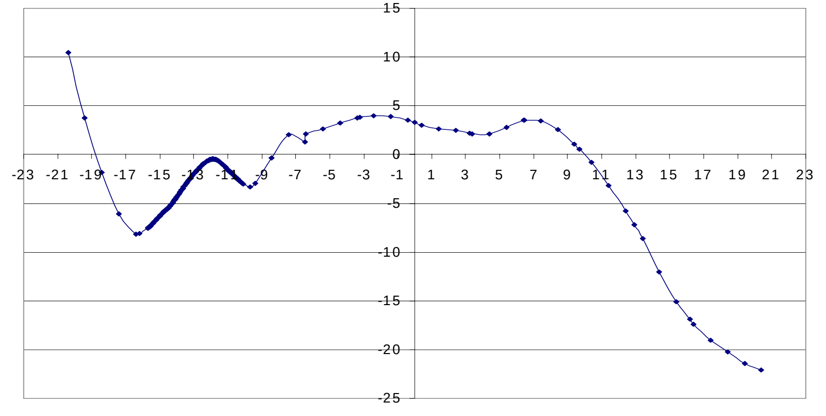
Influence on the WPS system:

The non uniformity of the gravitational field due to combined effect of latitude, altitude and the deviation of the vertical may deform the wire significantly (up to 15µm) but can be corrected (theoretical result to be confirmed by experiment).

Influence on the HLS system:

- ✓ HLS affected by oceanic and earth tides, but corrections can be applied
- ✓ Effect of nearby masses

Example of a 40 km geoid profile



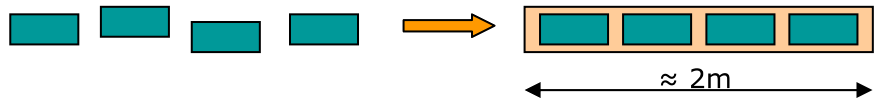
Uncertainty of the determination of the geoid will be strictly added to the vertical alignment uncertainty.

A knowledge of the geoid within a few microns is very unusual in gravimetry.

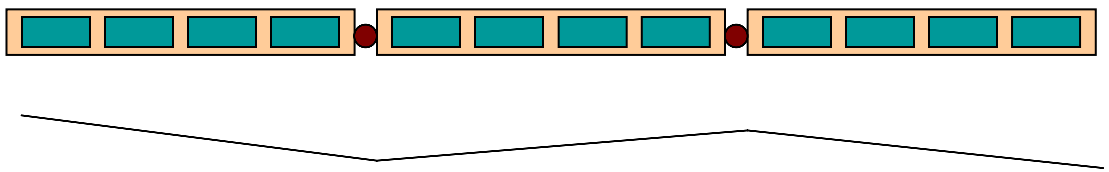
TOWARDS A SOLUTION FOR THE CLIC PREALIGNMENT

A SOLUTION FOR THE CLIC PREALIGNMENT

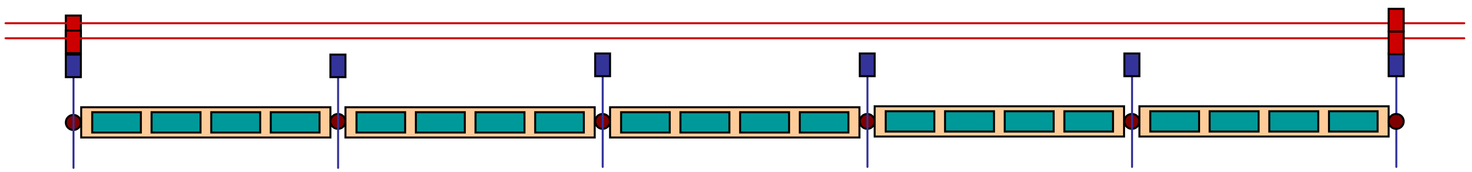
- ✓ To prealign a number of components on a girder



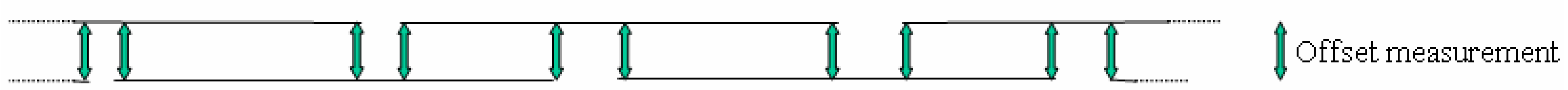
- ✓ To link all the adjacent girders by a common articulation point (3° of freedom)



- ✓ To associate the sensors of a first « proximity » metrological network to each articulation point, with a standard deviation of a few microns on several meters.



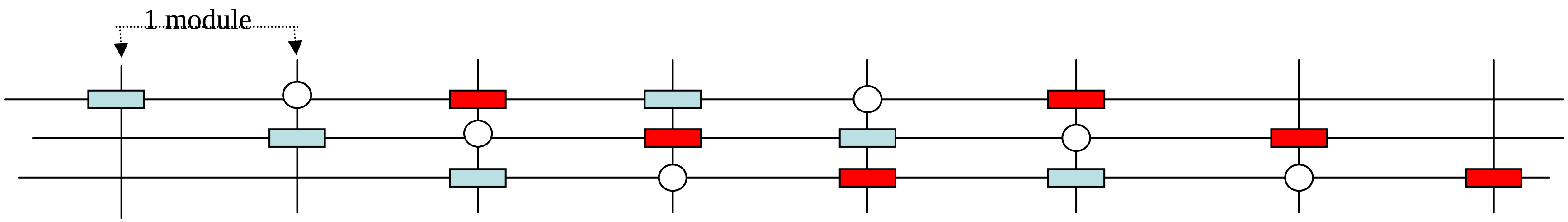
- ✓ To associate a second metrological network every x articulation points. This network allowing precision propagation on long distances, made of reference lines of more than 100m, overlapping on half on their length.



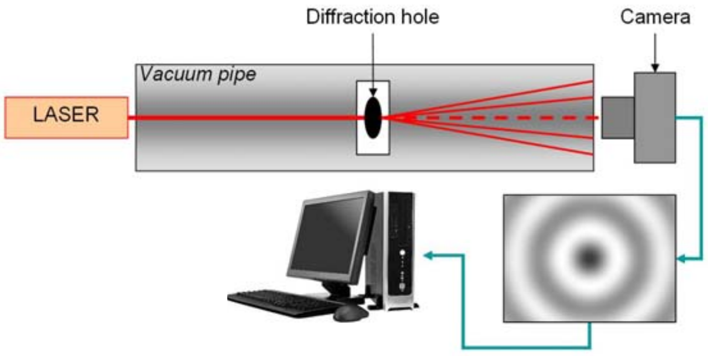
A SOLUTION FOR THE CLIC PREALIGNMENT

Two solutions are explored regarding the metrological networks:

- ✓ In both cases: proximity network = RASNIK



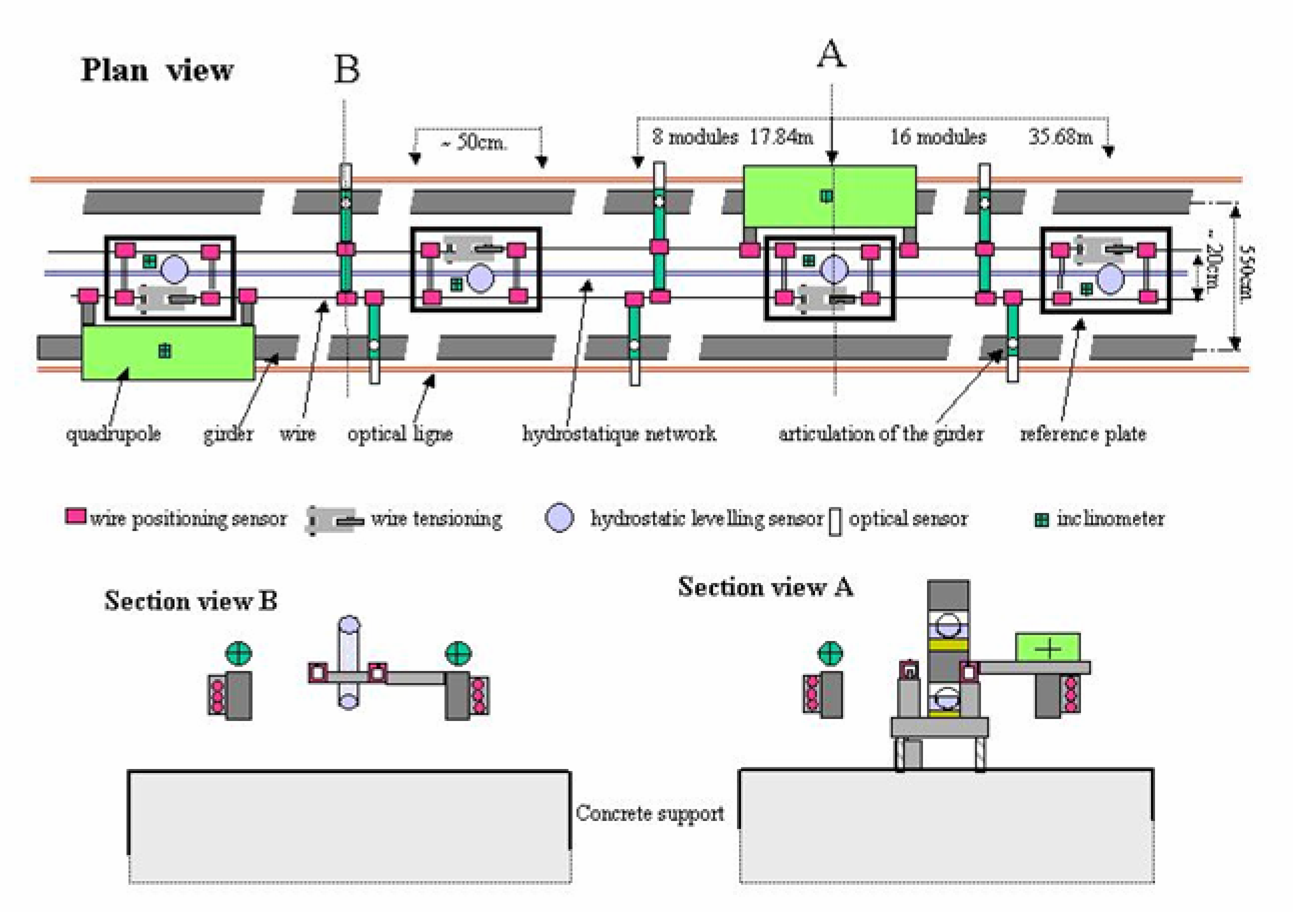
- ✓ Regarding the propagation network:
  - Solution 1: WPS system: overlapping stretched wires (100 m)
  - Solution 2: optical system named « RASCLIC », under collaboration frame with NIKHEF



- ✓ To provide transverse positional data on targets distributed over 100m, with an uncertainty of measurement better than 5μm.
- ✓ Straigth line = laser line between source and detector
- ✓ First idea: target with a hole in order to determine the center of the diffraction pattern

A SOLUTION FOR THE CLIC PREALIGNMENT

Example of configuration of solution 1



A SOLUTION FOR THE CLIC PREALIGNMENT

Simulations:

Principle:

- ✓ To assign simulated values to a network of observations
- ✓ To determine the network as if it had really been measured
  → software LGC++ developed by CERN Survey Group.

Hypotheses:

- ✓ Length of a wire: 100m
- ✓ A priori accuracy of the RASNIK CCD observations: 2μm
- ✓ A priori accuracy of offset measurements (wire): 5μm
- ✓ A priori accuracy of vertical measurements (wire): 8μm
- ✓ A priori accuracy of levelling observations: 7μm

Results:

- ✓ According to the configuration, articulation points prealigned with a standard deviation comprised between ± 8 and 14 μm on a sliding window of 200m.
- ✓ Hypotheses to be confirmed with a mock up under installation

CONCLUSION

The prealignment of the transverse components of a linac which is 14 km long, with a tolerance of ± 10 μm will be another great step forward compared to all that has already been previously achieved.

Some unknowns still need to be solved:

- ✓ The prealignment of the components on the girders and the link with the alignment systems
- ✓ Better knowledge of the perturbing effects for the HLS and WPS
- ✓ The possibility of determining the geoid with sufficient precision
- ✓ Another method to modelize the wire
- ✓ The development of the RASCLIC solution.

We are on the right course:

- ✓ Development, validation of new alignment systems
- ✓ Development of new methods: overlapping stretched wires
- ✓ First results of simulations are promising

Special thanks to Williame COOSEMANS