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Alignment challenges for a future linear collider

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OUTLINE

- ✓ Introduction: alignment tolerances achieved for the LHC
- ✓ Specifications for alignment of CLIC and ILC, and alignment challenges
- ✓ Solutions being studied
    - ○ Long range alignment system
    - ○ Short range alignment system
    - ○ Fiducialisation
    - ○ Case of the Machine Detector Interface area
- ✓ Conclusion

Introduction : state of the art

Steps of alignment of an accelerator

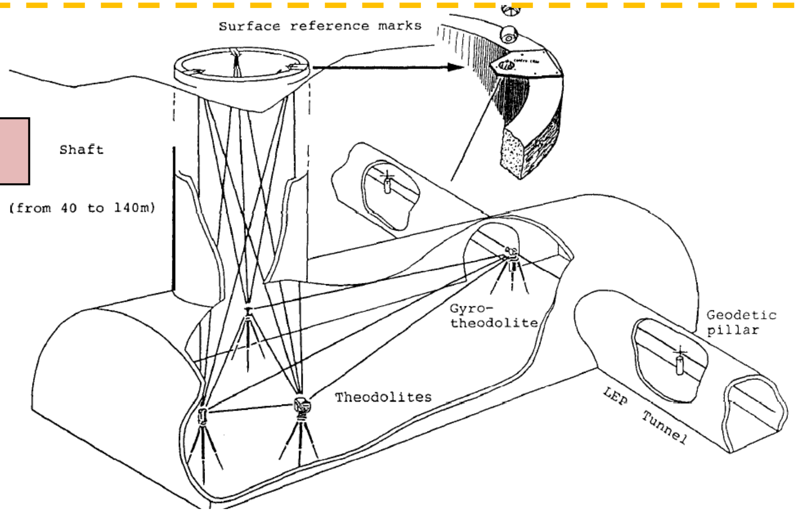
Surface

Installation and determination of the Survey network

Fiducialisation

Transfer of reference into tunnel

Installation and determination of the tunnel network



Absolute alignment

Relative alignment of the elements: smoothing

Injection of pilot beam

Implementation of beam based alignment and beam based feedbacks

Control and maintenance of the alignment

Monitoring and remote adjustment in remote areas

Underground

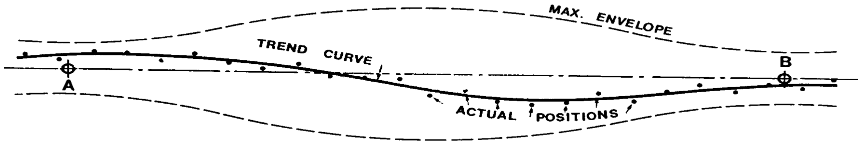
Introduction: state of the art (case of the LHC)

Fiducialisation

Operation during which the position of the fiducials is measured w.r.t. a reference axis (magnetic, mechanic)
➔ Uncertainty of measurement < 0.1 mm (1σ)

Absolute alignment

Initial alignment of each component w.r.t underground geodetic network ➔ uncertainty of measurement < 0.3 mm (1σ)



Relative alignment of the elements

Smoothing : relative position of components w.r.t to the trend curve ➔ uncertainty of measurement < 0.1 mm (1σ) over 150 m

Control and maintenance of the alignment

Monitoring and remote adjustment in specific areas

Monitoring of the relative displacements w.r.t a given reference time or position σ = a few microns using alignment systems and remote adjustment using motorized jacks

Specification for ILC & CLIC

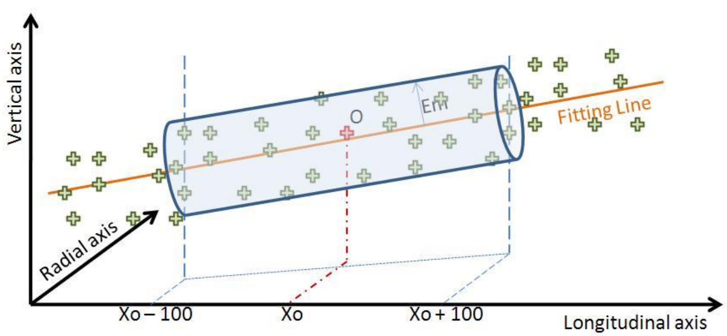
Above state of the art for ILC:

Area	Nb of beam	Error of misalignment on the fiducials (1σ)
Main linac	1	0.2 mm rms over 600 m
BDS	1	0.02 mm over 200 m

Fiducialisation: : 0.05 mm rms

Above state of the art for CLIC:

Special case of main linac and BDS



The zero of each component will be included in a cylinder with a radius of a few microns:

- ✓ 14 µm over 200 m (RF structures)
- ✓ 17 µm over 200 m (MB quadrupoles)
- ✓ 10µm over 500m (BDS and final focus components)

Adjustment required: step size below 1 µm

Alignment challenges for a future linear collider

Up to a few microns

Fiducialisation

Smoothing **replaced by** Active pre-alignment for CLIC

Active determination of the position for ILC

Long range alignment system

Stable alignment reference, known at the micron level

Short range alignment system

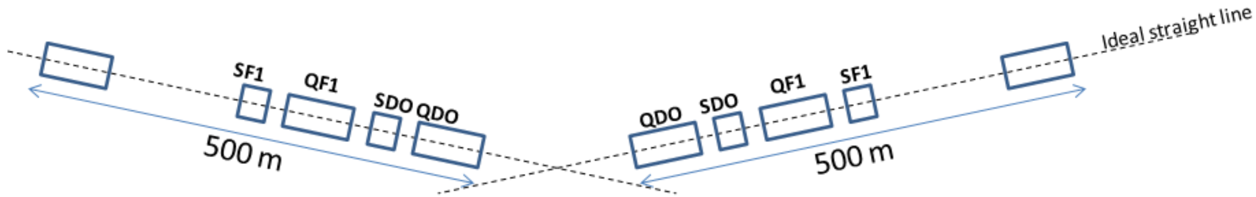
Submicrometric sensors providing « absolute » measurements

Fiducialisation at a micron level

Measure objects within a few microns

Submicrometric displacements along 3/5 DOF

Special case of MDI area

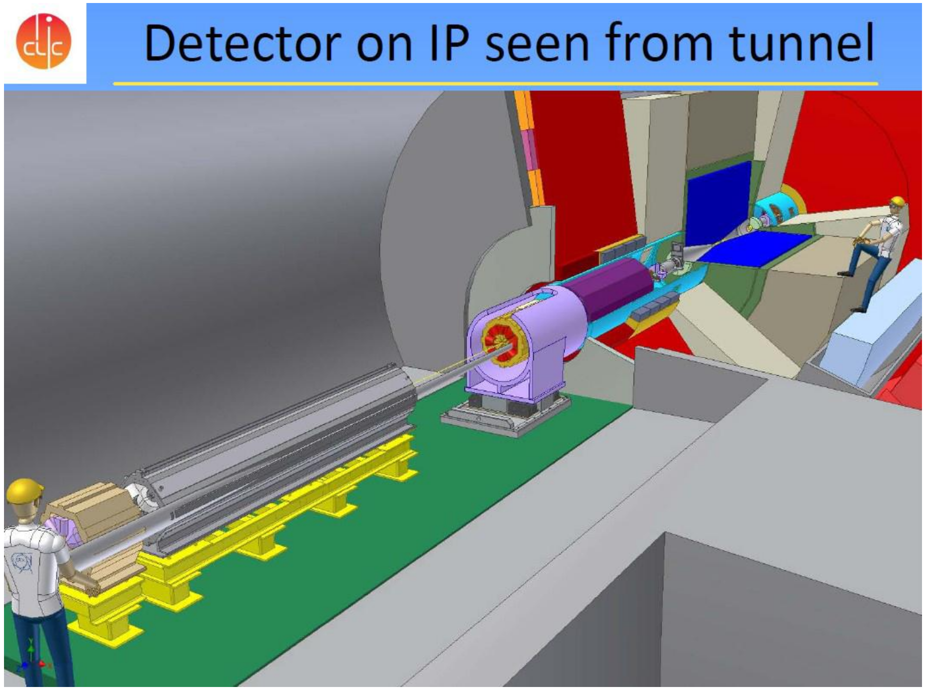


Requirements (CLIC):

- ✓ Determination of left reference line w.r.t right reference line : within ± 0.1 mm rms
- ✓ Monitoring of left reference line w.r.t right reference line : within a few microns
- ✓ Monitoring of the position of left QD0 / right QD0 within ± 5 μm rms

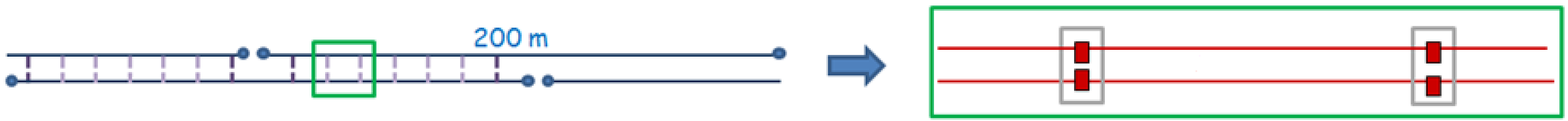
Taking into account:

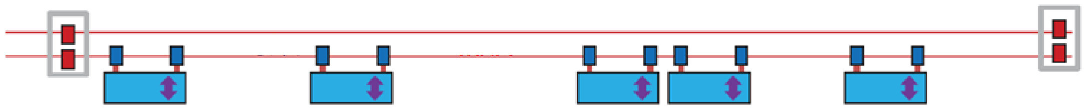
- ✓ Push pull detectors
- ✓ Last component (QD0) inside the detector (L*=3.5m)

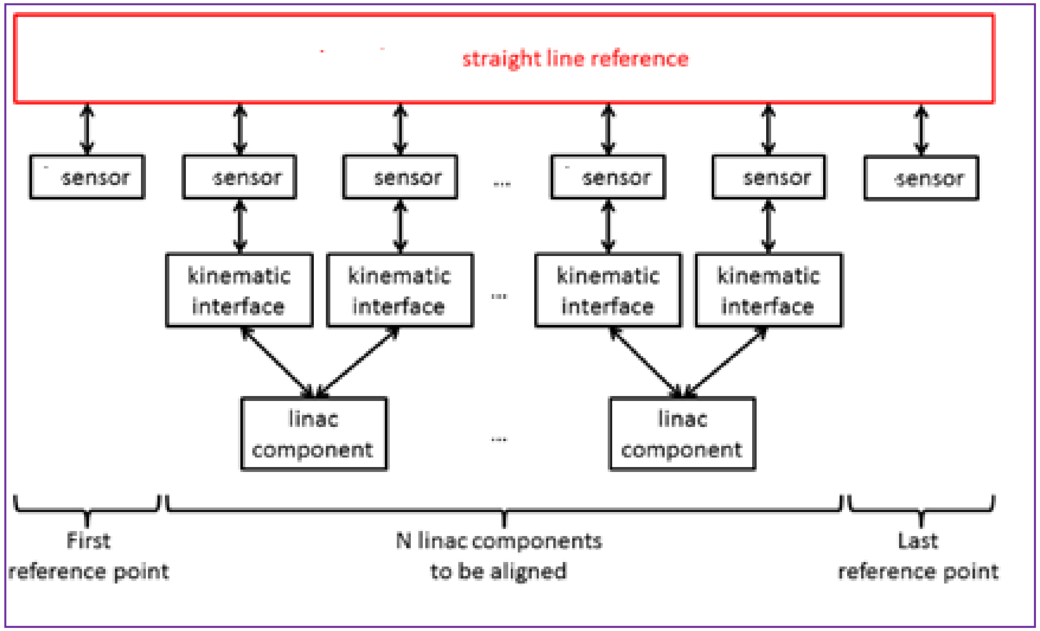


Long range alignment system

As it is not possible to implement a straight alignment reference over kilometers:
➔ use of overlapping references



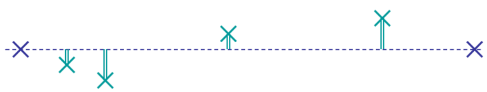




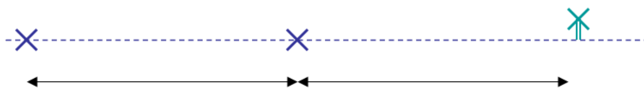
Long range alignment system

Reference over hundreds of meters

(n - points)



(3 - points)

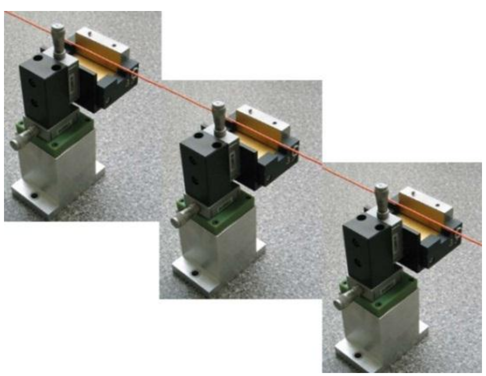


Stretched wire

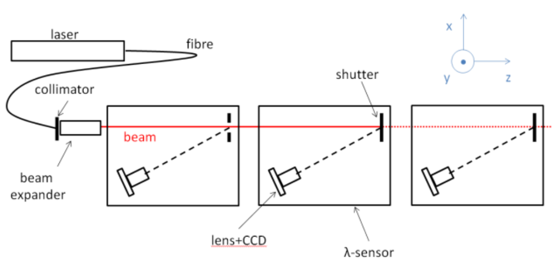
Laser beam under vacuum

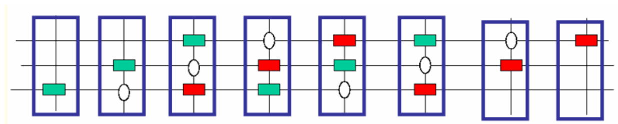
Λ-system

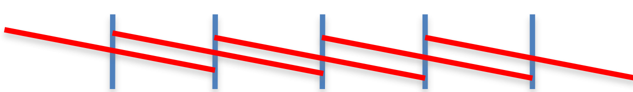
Raschain



Wire Positioning Sensors (WPS)







Solution consisting of overlapping stretched wires and WPS sensors chosen for CDR of CLIC and RDR of ILC

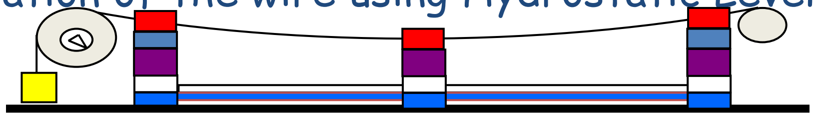
Long range alignment system

Stretched wire

Main issue: long term stability of a wire

(effects of temperature, humidity, creeping effects, air currents)

➔ Modelization of the wire using Hydrostatic Levelling Systems (HLS)



but only in the vertical direction

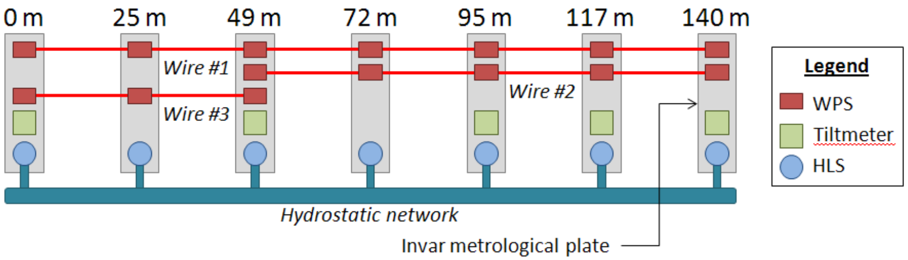
but HLS system follows the equipotential of gravity which needs then to be known

➔ studies undertaken concerning the determination of the equipotential of gravity

Subject of a PhD thesis:
« Determination of a precise gravity field for the CLIC feasibility studies »

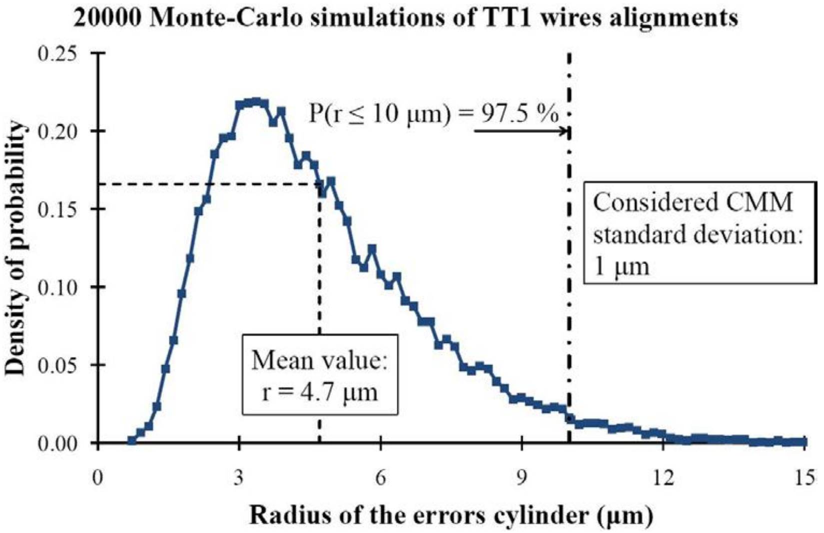
Long range alignment system

TT1 facility



One of the objectives ➔ to determine the precision and accuracy of a reference network consisting of overlapping stretched wires.

Simulations



Position & orientation of the metrological plates in the coordinate system of the tunnel

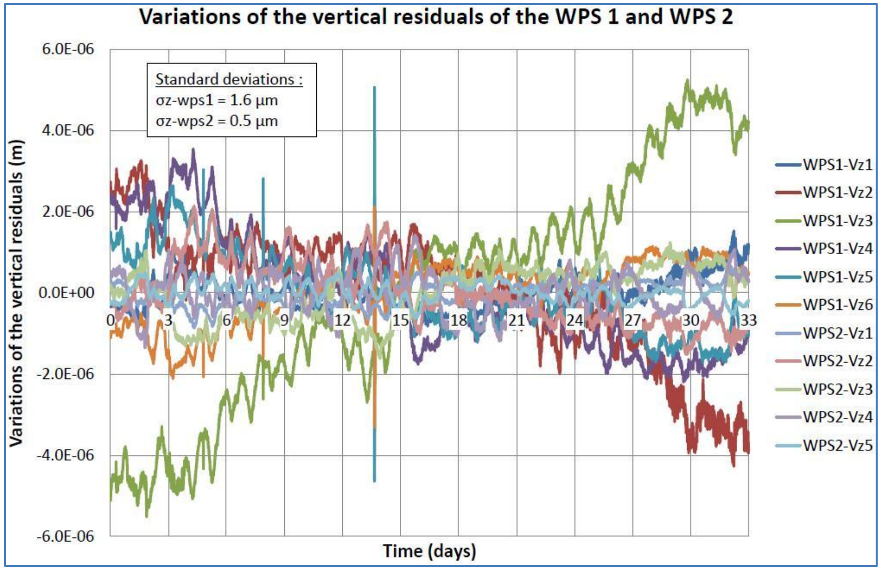
Monte Carlo method using theoretical readings of sensors

➔ in 97.5% of the cases, all the pre-alignment errors fit in a cylinder with a radius of 10 μm.

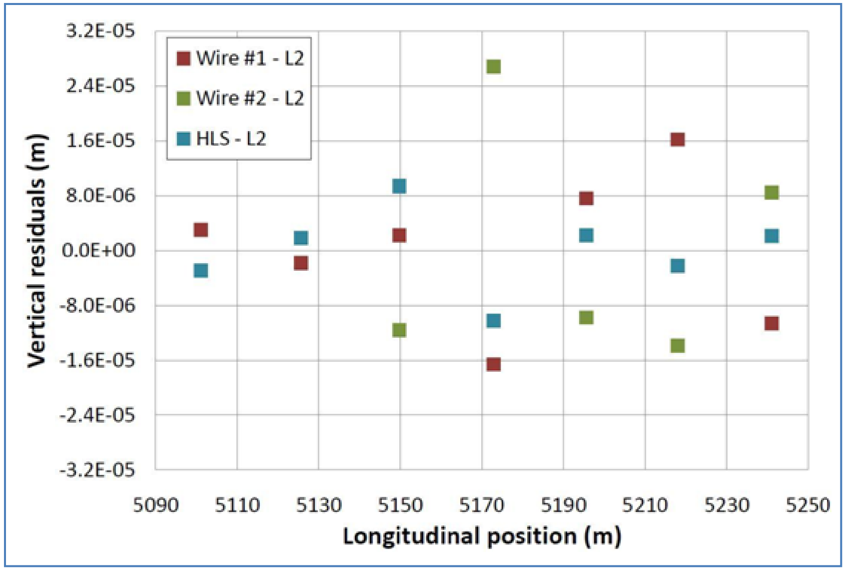
Long range alignment system

Results in TT1

- ✓ Precision on a 140 m wire: better than 2 microns over 33 days
- ✓ Accuracy: 11 microns in vertical, 17 microns in radial. Can be improved!



Vertical residuals of the 2 longest wires:
σ (wire 1) = 1.6 μm
σ (wire 2) = 0.5 μm

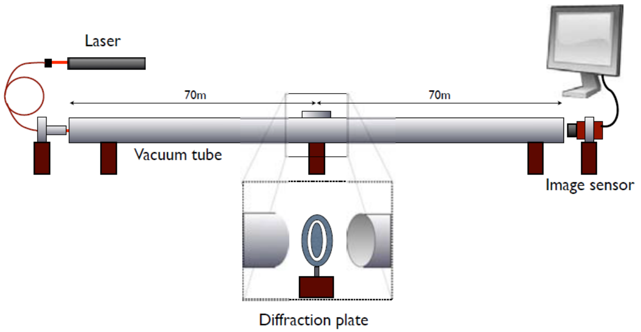


Accuracy of the TT1 network adjusted by the least squares method in vertical:
σ = 11 μm r.m.s (27 μm max. value)

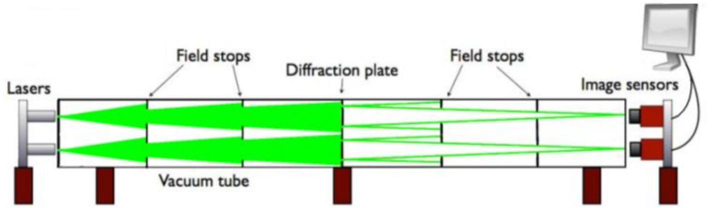
Long range alignment system

Development of laser based alternatives

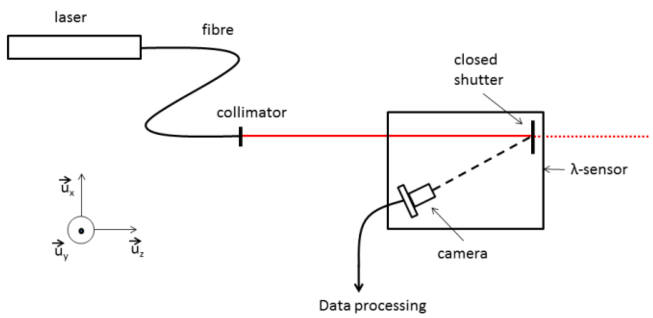
Latest achievements on RasDif:



- ✓ First configuration installed successfully in 2009
  - ○ Resolution below 0.1µm
  - ○ Appears to behave as a very precise seismometer
- ✓ Double configuration showed non coherent results
  - ➔ inter-comparison needed with WPS



Latest achievements on λ- system:



First simulations performed: angular orientation & repeatability of shutter should be better than 0.2 mrad and 12 µm in order to detect a micrometric displacement

- Basic laboratory experiments with low cost elements and simple methods done at short distance (about 2 m)
- Measurement repeatability within an interval of [−4 µm,4 µm] around the mean values
- Standard deviation less than 5 µm

Short range alignment system

WPS (Wire Positioning Sensor)

Requirements	
Precision	< 2 µm
Accuracy	< 5 µm
Range	10 mm x 10 mm
Radiation hard	

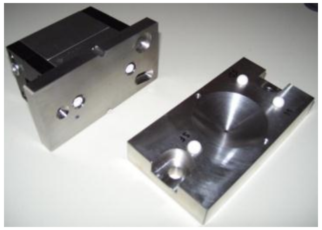
Issue: WPS sensor fulfilling the requirements

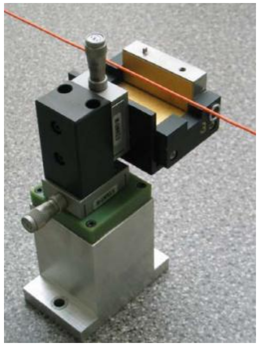
- ✓ « absolute measurements » (known zero w.r.t mechanical interface)
- ✓ no drift
- ✓ sub micrometric measurements

Upgrade of an existing WPS

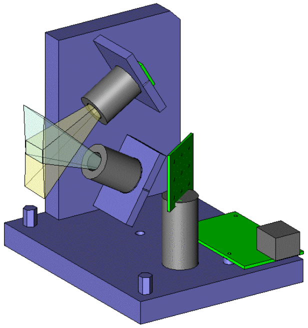
Development of a new WPS

Capacitive based WPS (cWPS)

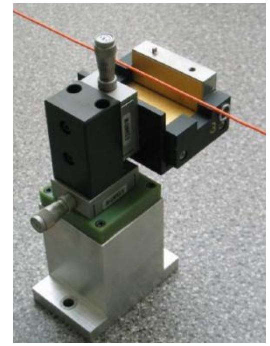


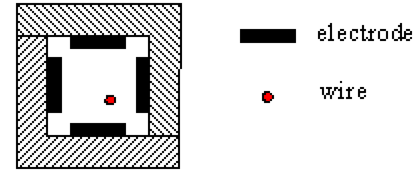


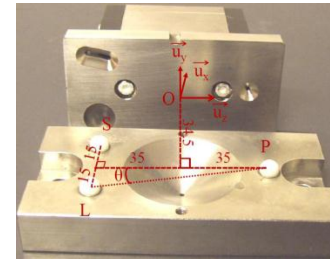
Optical based WPS (oWPS)



Short range alignment sensors







Sensors : cWPS

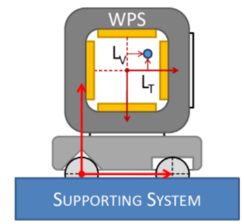
60 sensors installed in the LHC on the low beta triplets

- ✓ Rad Hard (sensors up to 300 kGy, Remote electronics up to 50 kGy)
- ✓ Resolution: 0.2 μm

But relative measurements only!

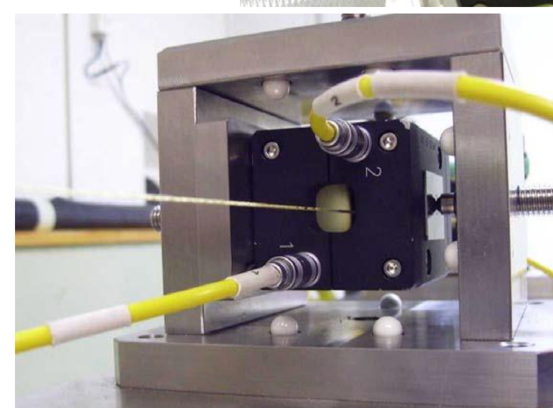
Latest achievements:

- ✓ An isostatic mechanical interface allowing a repositioning within 1μm and an absolute calibration has been developed
- ✓ A very accurate linearity bench
- ✓ An « absolute » bench
- ✓ Dedicated lab with a temperature stable within ± 1°C



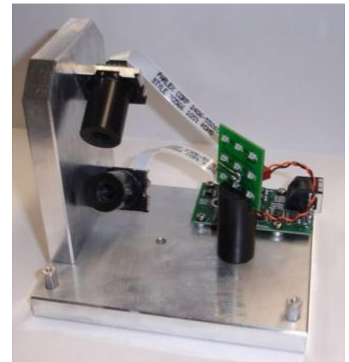
Status / current issues:

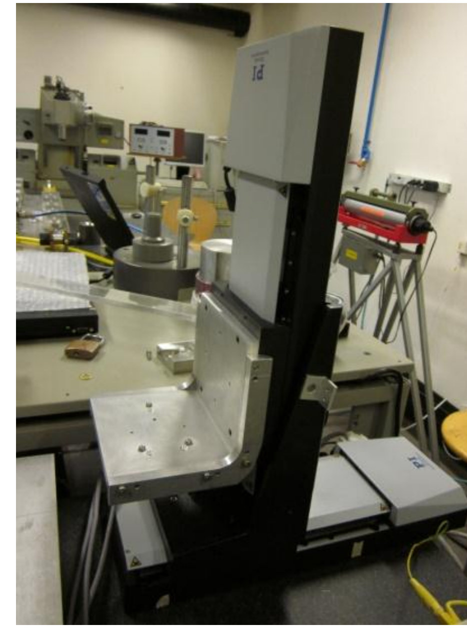
- ✓ Linearity depends of the generation of carbon peek wire used: < 5 μm over the whole range (better in middle range)
- ✓ Repeatability & interchangeability < 1μm
- ✓ Accuracy ("absolute calibration") of cWPS < 20 μm (bench recalibrated last week in the metrology lab).



Short range alignment sensors

Sensors : oWPS





Main characteristics (from the manufacturer)

- ✓ Resolution: < 0.1 µm
- ✓ Range : +/- 5 mm (along two axes)
- ✓ Repeatability: 2µm
- ✓ Accuracy : < 5µm
- ✓ Wire: Vectran

Latest achievements:

- ✓ A very accurate linearity bench
- ✓ A vectran wire (manufactured fiber spun from a liquid crystal polymer) visible to infra-red light and not antistatic ➔ silver plasma coated wire.

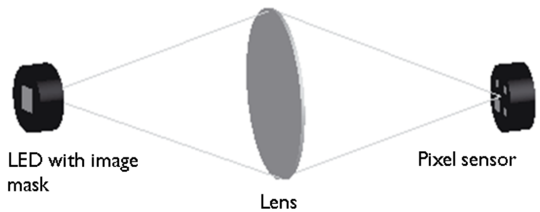
Status

- ✓ Resolution < 1 µm, interchangeability < 5 µm
- ✓ Noise problem to be solved
- ✓ Impact of temperature: ~ 6µm/°C to be corrected
- ✓ Absolute calibration to be controlled.

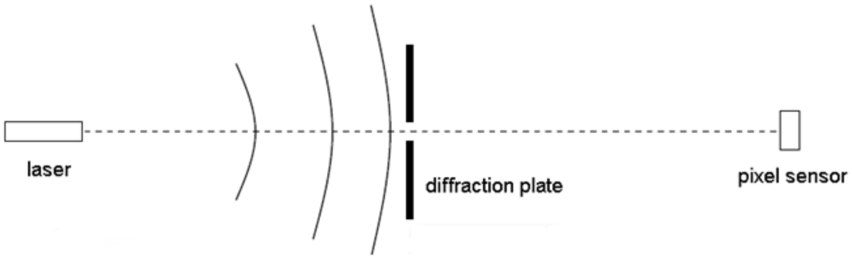
Short range alignment sensors

Sensors : RasChain

2 possibilities: RasNik versus RasDif



RasNik



RasDif

Status:

- ✓ Test setup to validate RasNik & Rasdif on 4 m
- ✓ First results: jitter and refractive bending of light ➔ thermal shielding needed
- ✓ Preparation of sensors for two beam modules and inter-comparison tests with other sensors

Fiducialisation

First solution: CMM measurements (dimensional control, pre-alignment of components on their supports, fiducialisation), but STATIC

MPE = 0.3 μm + L/1000 (L in mm)

Most accurate but for very short components
➔ Development of portable means

Micro triangulation

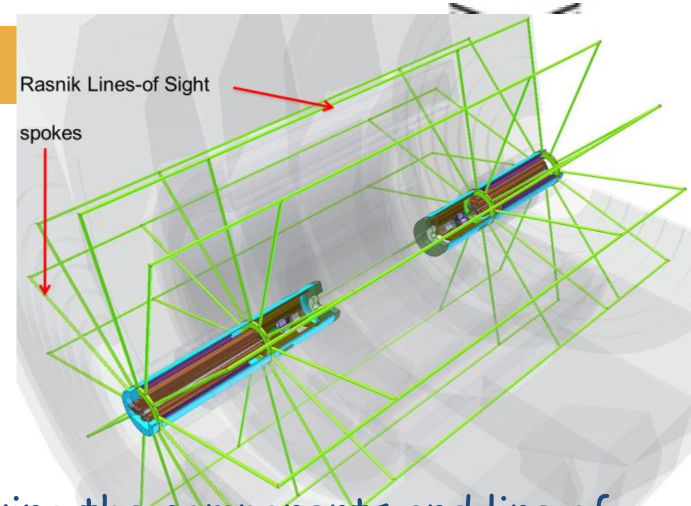
Romer arm

<u>Latest achievements:</u>

- ✓ Fiducials developed
- ✓ Several means developed and validated:
  - AT401 ~ 5μm @ 2m
  - Micro triangulation ~ 5μm @ 2m
  - Romer arm ~ 10 μm @ 2m
- ✓ Test of fiducialisation strategy:
  - Very precise for short objects on CMM
  - Accuracy ~ 20 μm on 2m long objects

Laser tracker: AT 401

Special case of MDI area

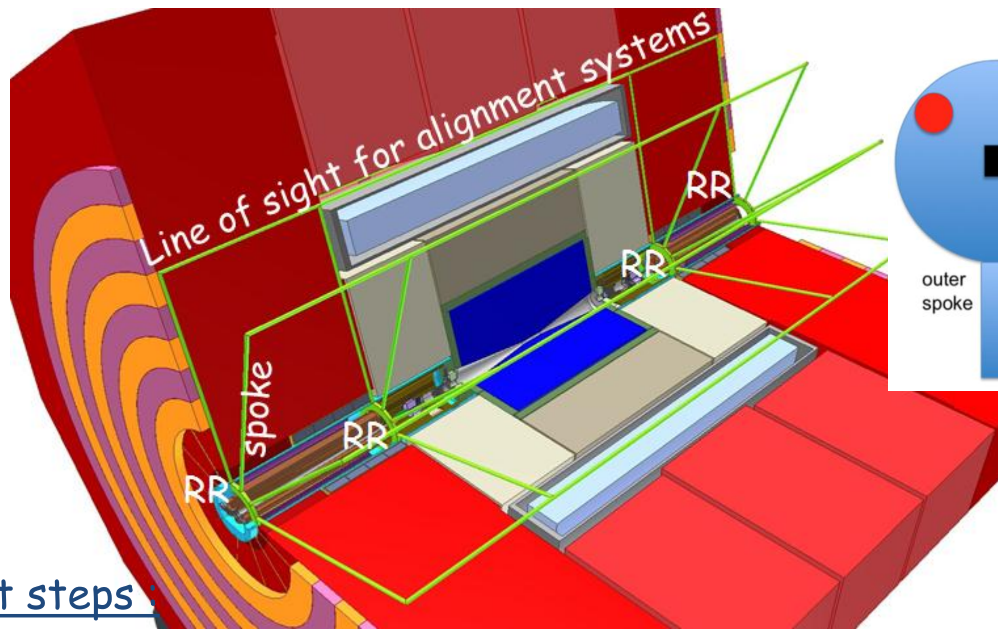


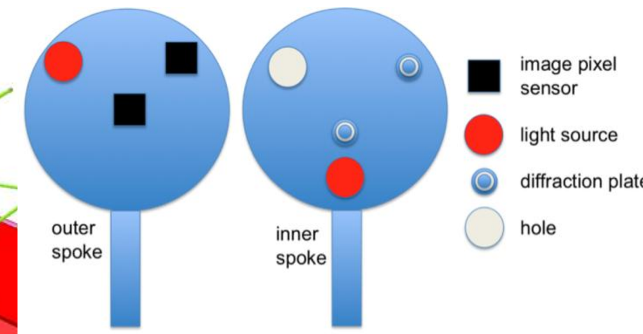
Monitoring on both sides of the detector:

No direct line of sight at the level of the beam

External line of sight at 3m in "dead space"

Spokes equipped at both ends by alignment sensors linking the components and line of sights





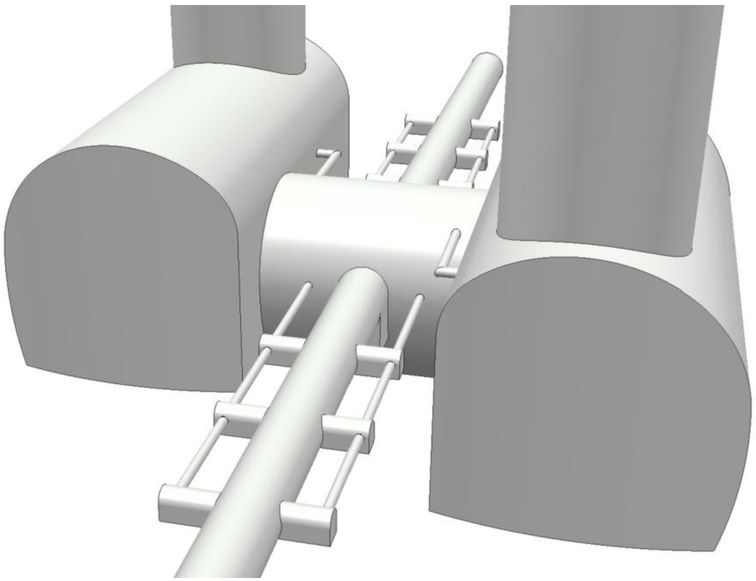
Status and next steps :

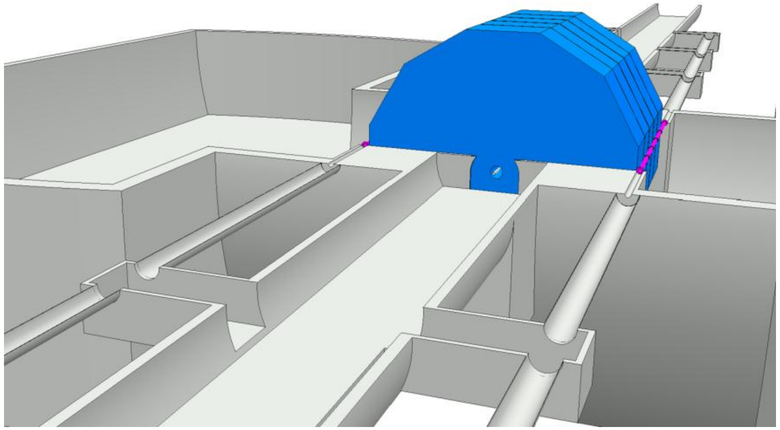
- ✓ A mock-up real size will be built @CERN to validate the whole concept
- ✓ Design ready

MDI area

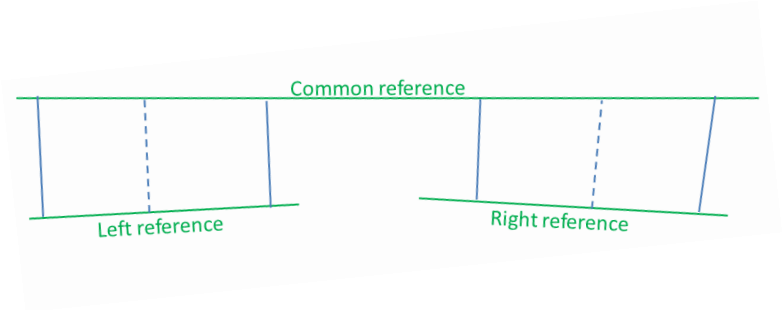
<u>Link between left and right sides:</u>

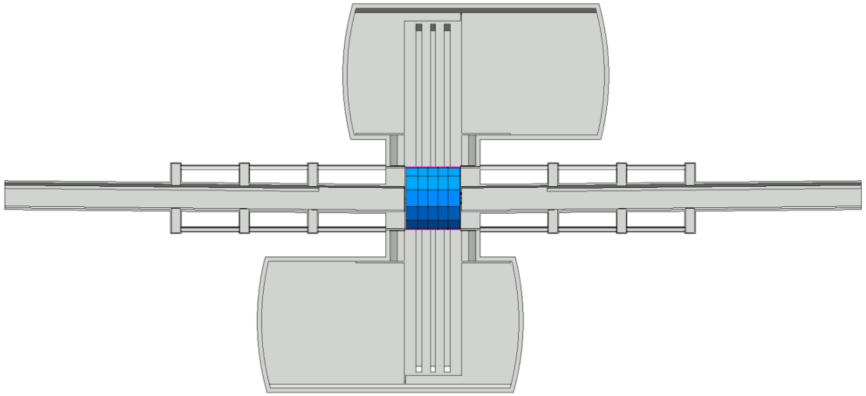
Parallel survey galleries





Laser system shielding coupled to the push-pulled detector





Next steps:

- Distance reference to reference : means to be developed
- N-point laser based alignment system over ~ 100 m to be developed

CONCLUSION

- In comparison with alignment requirements of the LHC, the alignment of linear colliders is a real challenge, with precision and accuracy of a few microns over several hundreds of meters, including the fiducialisation process.

- Solutions are under development concerning long range alignment system:
  - A stretched wire solution has been proposed for the RDR of ILC and CDR of CLIC.
  - Results from test setup have shown that an uncertainty in the determination of the position of a sensor over 140m is of the order of 11 µm.
  - Alternatives, based on laser beam under vacuum, are under development, first to validate the stretched wire solution, and why not to replace it.

- Short range sensors are under development as well, and the latest results show that an accuracy below 5 µm and a repeatability below 1µm are reachable.

- Fiducialisation at a micron level is a challenge too, with a level of difficulty depending of the size of the component. For very short components (length <1m), CMM are a must, but will need to be replaced by portable means that are under development and validation.