APPLICATION OF THE WIRE OFFSET MEASUREMENT TECHNIQUE IN THE FCC ALIGNMENT

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INTRODUCTION

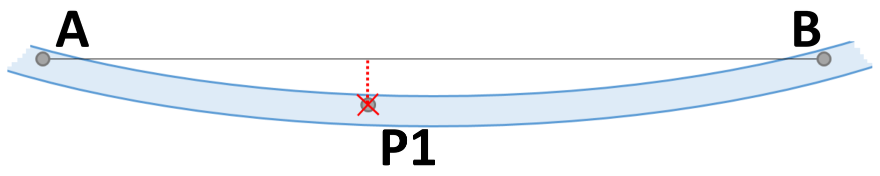
The surveying team uses several alignment methods, applying both permanent and temporary systems, in order to ensure a high precision alignment of the accelerators. The wire offset measurement or *écartometrie* is an alignment technique where offsets from the fiducials on the magnets to a stretched wire are measured using a measurement scale. This is a simple and fast technique which allows us to obtain reliable and precise measurements. One of the main advantages of this technique is the elimination of the influence of refraction that is linked to optical methods.

This poster shows the simulations and the results of tests which have been carried out in the LHC tunnel to study the feasibility and the accuracy of this method with longer wires.

WIRE OFFSET MEASUREMENT

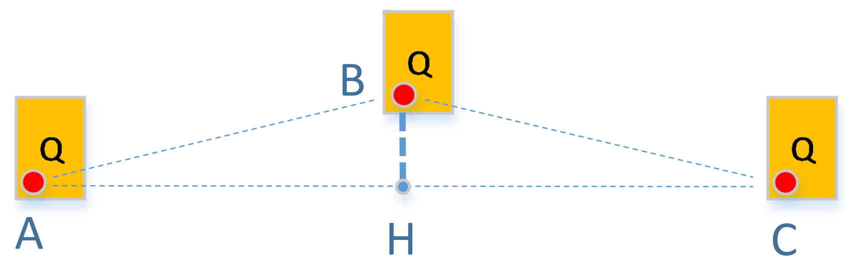
Principle

The measurement scale, or *écartometre*, measures the shortest distance between one point (P1) with respect to a line (AB). For that, two fixed points are needed, one at each end of the wire.



Relative Alignment Error

In order to calculate the relative alignment error between quadrupoles, the equation to calculate the distance between the quadrupole in the middle and the line defined by the neighbouring quadrupoles will be used.



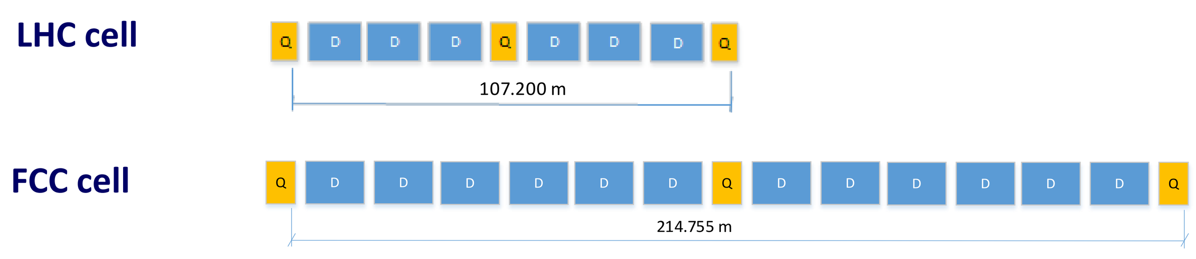
$$f(x) = \overline{BH} = \sqrt{\overline{AB}^2 - \left(\frac{\overline{AB}^2 + \overline{AC}^2 - \overline{BC}^2}{2 \cdot \overline{AC}}\right)^2}$$

$$\Sigma_y = J \cdot \Sigma_x \cdot J^T$$

J : Jacobian matrix
Σ_x : Variance-covariance matrix of the observations

LHC vs FCC

The alignment of the LHC using the wire offset measurement technique is carried out by covering three quadrupoles with one wire and making overlaps in order to have enough data.



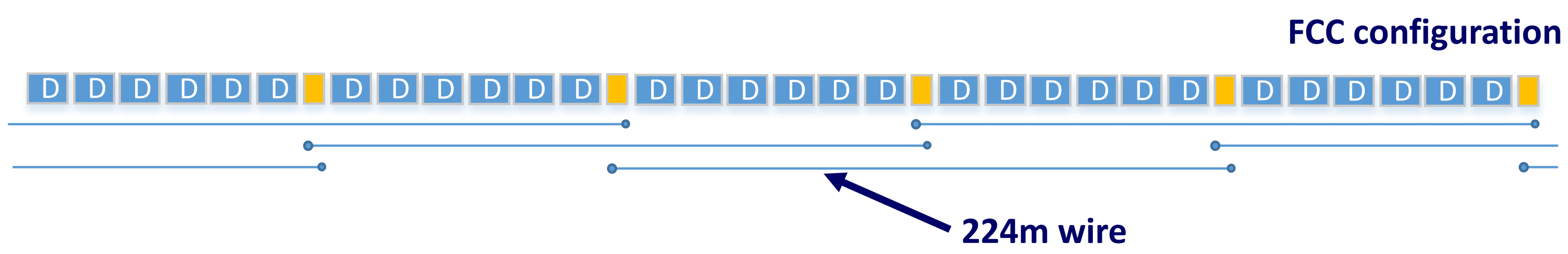
Goals:

- Test the feasibility of this alignment technique over longer distances.
- Study the effect of airflow in the tunnel.
- Validate the instruments.

SIMULATIONS

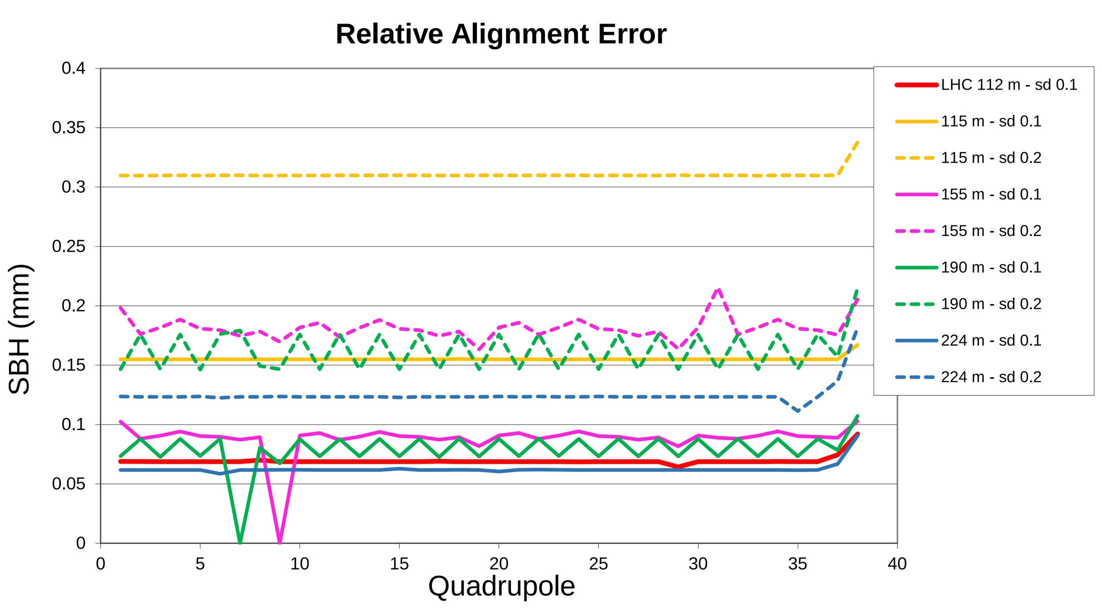
Configurations and Wire Lengths

- The simulated machine follows a **straight line** instead of a curved line.
- The distances between elements and their sizes have been created according to the **proposed dimensions**.
- The length of the simulated structures is 4 km ⟶ 20 cells in the FCC and 40 cells in the LHC.
- The networks are designed to measure every point of the dipoles at least twice, and the quadrupole points three times ⟶ Simulations with **four different wire lengths.**



Simulation Results

An analysis of the results is carried out to determine the best wire offset measurement design option.



Wire	SD obs (mm)	Mean ∑BH ($x10^{-7}$)	Mean SBH (mm)
115 m	0.1	0.24	0.16
	0.2	0.96	0.31
	0.4	3.85	0.62
155 m	0.1	0.08	0.09
	0.2	0.33	0.18
	0.4	1.28	0.36
190 m	0.1	0.07	0.08
	0.2	0.27	0.16
	0.4	1.09	0.33
224 m	0.1	0.04	0.06
	0.2	0.16	0.13
	0.4	0.63	0.25

	Wire	SD obs (mm)	Mean ∑BH ($x10^{-7}$)	Mean SBH (mm)
LHC	112 m	0.1	0.048	0.07
FCC	224 m	0.111	0.048	0.07

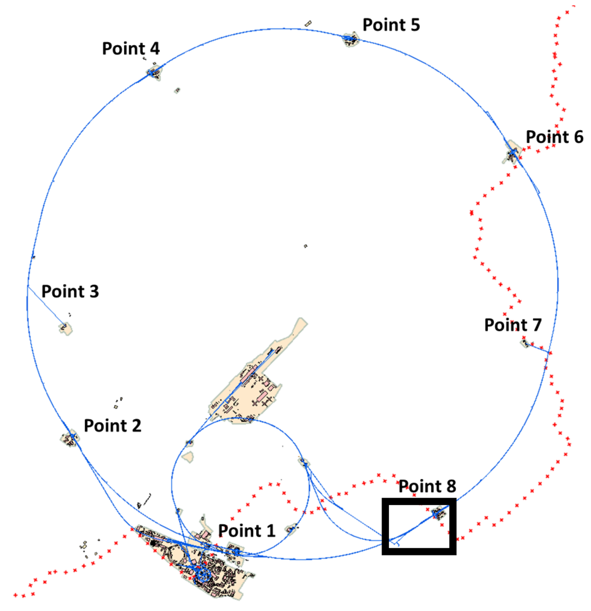
The only case whose resulting relative error is smaller than in the LHC case is the 224 m-wire with 0.1 mm standard deviation in the observations.

200 M-WIRE TESTS

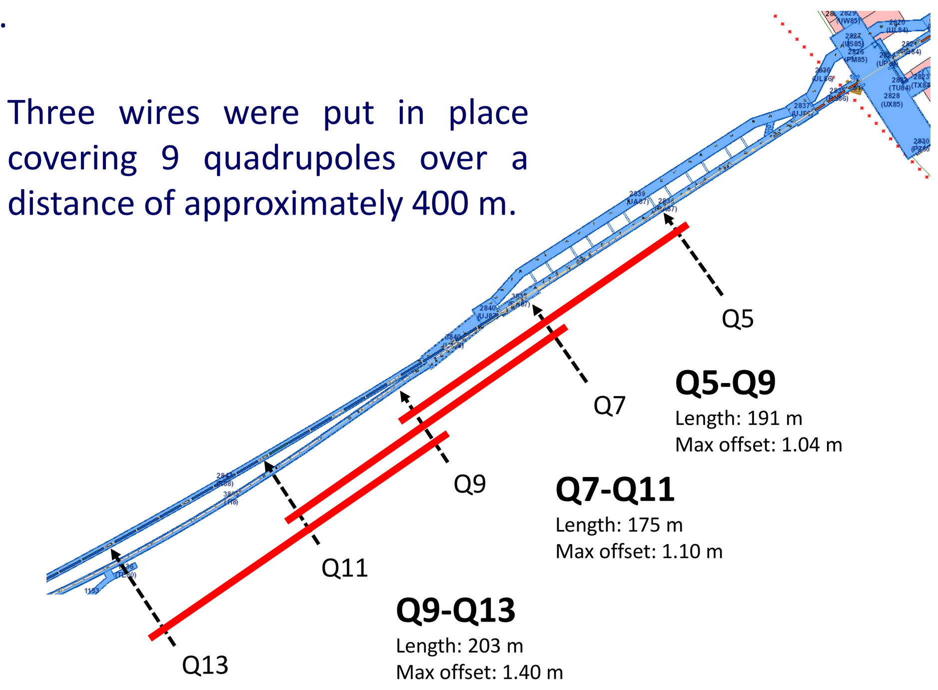
The measurement campaign took place at the end of the EYETS 2016-2017 and lasted for two weeks. The aim was to simulate the conditions of the FCC scenario in the LHC tunnel, to verify the methodology used in the LHC alignment and to test the instruments available to carry out the measurements.

LHC Tunnel

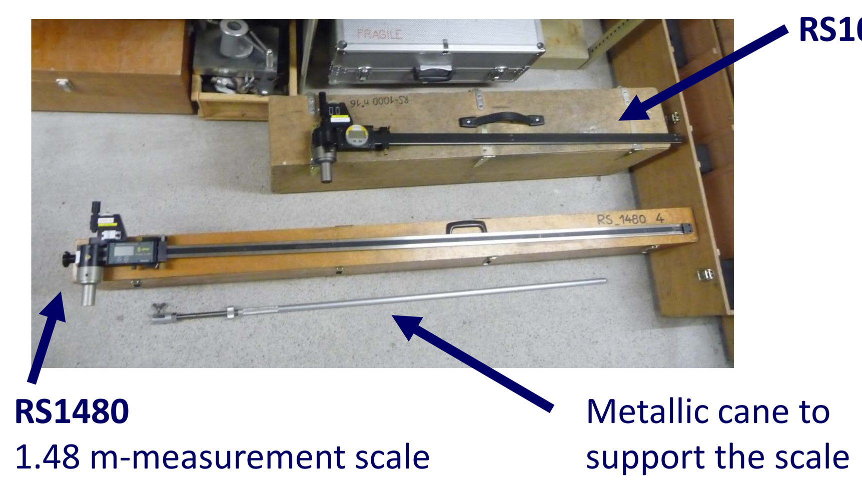
The area chosen to carry out the tests is sector 8-1, to the right of Point 8, where the last alignment of the machine was made a few months before these tests. Starting at the straight section to minimise as best as possible the radius of curvature of the tunnel.



Three wires were put in place covering 9 quadrupoles over a distance of approximately 400 m.



Instruments and Measurements



Wire offset measurements in the LHC tunnel

Supports at both ends of the stretched wire.

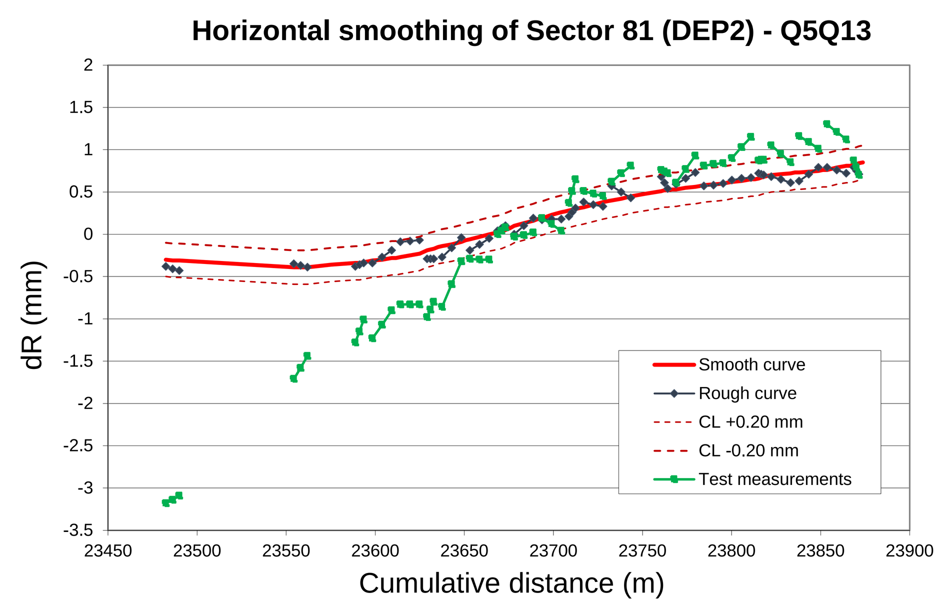
- Each wire was measured **twice** with the RS1480 to control the measurements and to detect potential errors sources.
- Some points were measured with the RS1000 to be able to compare the offsets taken with both instruments.
- The **ventilation** was reduced down to the minimum level.
- Measuring the wire from all points takes up to 2h30 when using the RS1480.

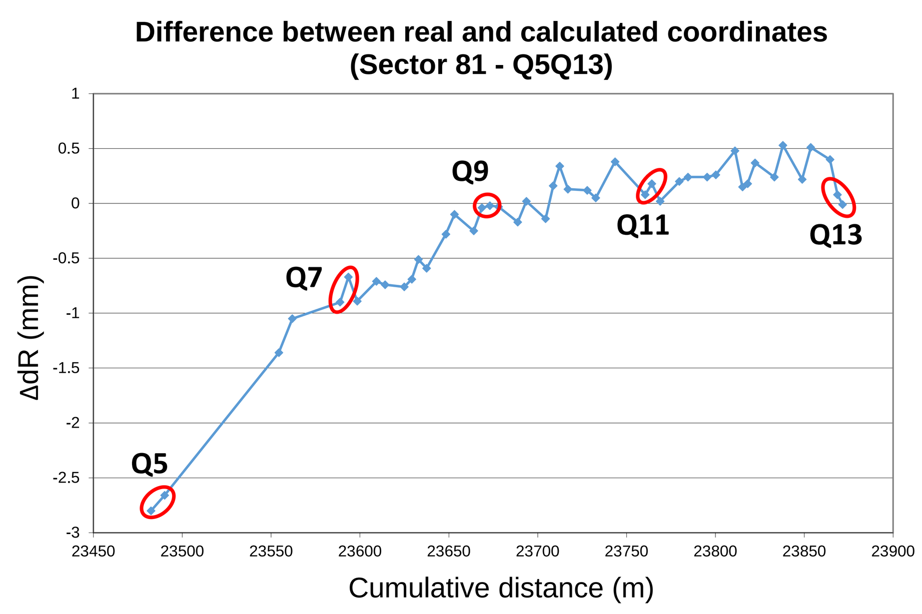
Results

Fixed point: Q9.E
Orientation: Q9.E - Q13.S

The **radial difference (dR)** is calculated with respect to the theoretical coordinates of the points.

The **dR difference (ΔdR ≡ dBH)** is the difference between the offsets calculated from both the real coordinates, and the coordinates calculated from the test measurements.





Larger differences between real and calculated coordinates were expected in elements before Q8 since they were not included in the last alignment campaign.

The calculated coordinates are mainly affected by the effects of the air current and the instrument.

Wire			SD obs (mm)	∑BH ($x10^{-7}$)	SBH (mm)
A	B	C			
Q5.S	Q7.S	Q9.S	0.1	0.10	0.10
Q7.S	Q9.S	Q11.S	0.1	0.08	0.09
Q9.S	Q11.S	Q13.S	0.1	0.10	0.10

CONCLUSION

- The **relative alignment error** calculated using simulated data is coherent with the resulting values obtained using actual data.
- It is possible to use the **same kind of wire** in order to cover longer distances.
- The **air current** has more influence on a 200 m wire (the wire was visually **vibrating** with a larger magnitude than for shorter wires), therefore it is more difficult to make consistent measurement.
- **Systematic errors** need further investigation.
- Working with the RS1000 is **much faster** and **easier** to use. The maximum offset in the FCC will generally be smaller than 0.80 m, therefore the shorter measurement scale could be use.
- The RS1480 will be used in case of larger offsets. A **calibration** of the instrument would be required.