OVERVIEW OF THE FCC-EE ALIGNMENT AND MONITORING STUDY

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CERN BE-GM-HPA

Many thanks to :
Manuela Boscolo, Francesco Fransesini, Hélène Mainaud Durand, Mateusz Sosin, Michel Noir, Bartlomiej Pudlo, Jürgen Gutekunst, Guillaume Kautzmann, Okan Dag

Overview

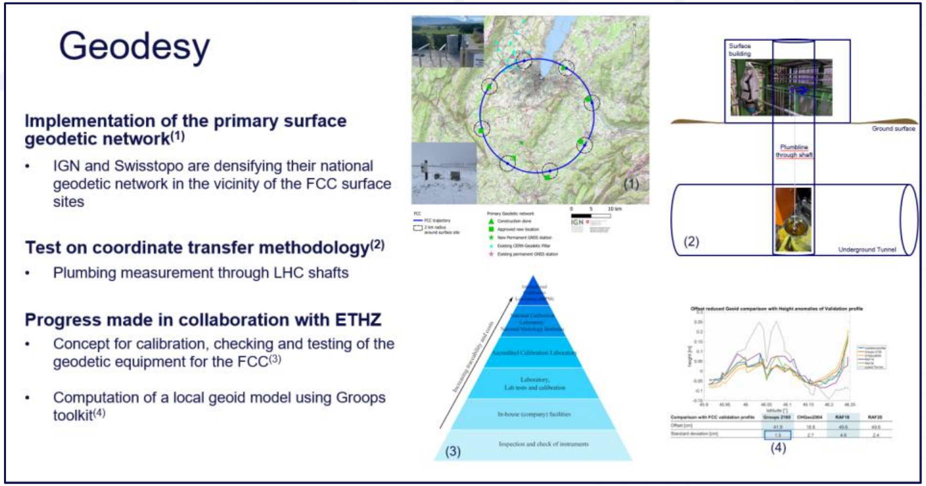
- Disclaimers
- Update on the work done for the alignment and alignment monitoring in the arcs
- Update on the situation in the MDI
- Conclusion

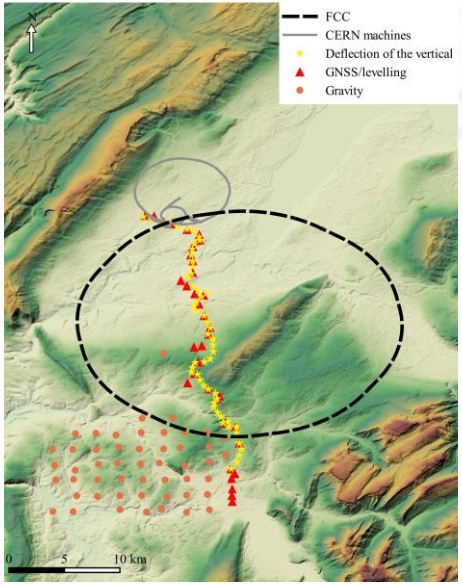
Disclaimer 1

This presentation will cover the work performed toward the alignment in the tunnel (both arc and the MDI).

But the alignment process starts from the surface, with GNSS, levelling, gravity measurements …

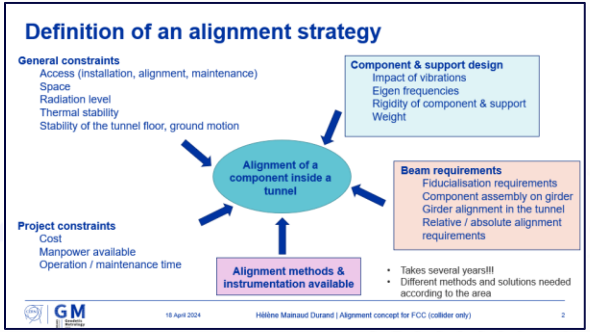
These aspect have been covered by Benjamin Weyer’s presentation, on Tuesday morning.





Disclaimer 2

This presentation will cover only the work done so far, which is only a fraction of what's needed for such project. For a more complete overview, please see Helene Mainaud Durand's presentation here (Geodetic Metrology group leader at CERN) :



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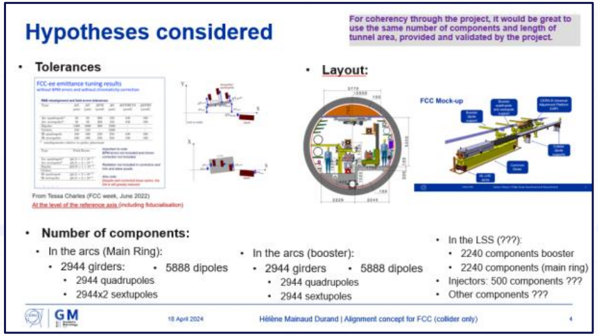

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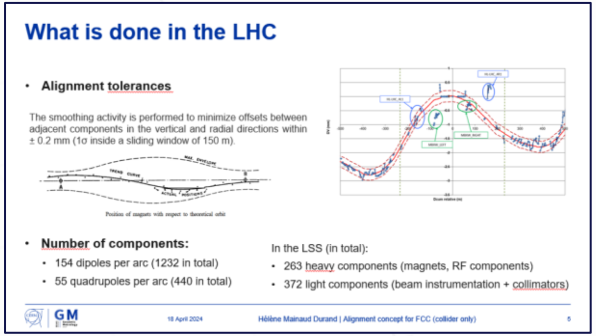

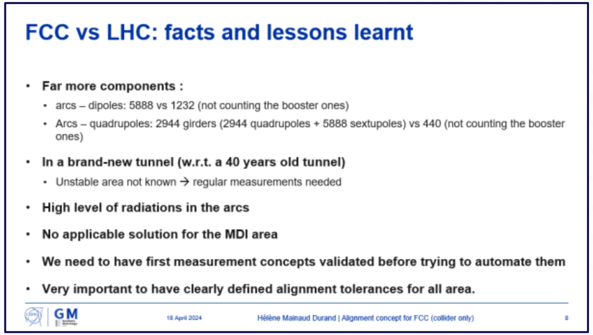

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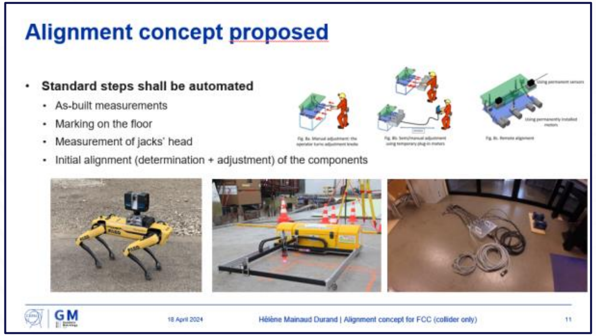

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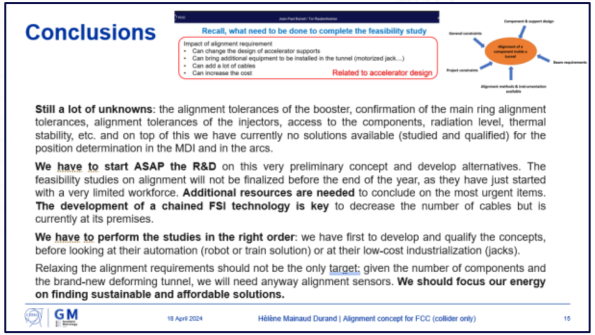


Focus of the work done

FCC and LEP/LHC are very similar, the main difference (regarding alignment) is the size and all that results from this (even though alignment requirements, component shape, support, stability and many others deriving from these are non-negligible).

First goal is to study the alignment error propagation as it impacts :

- Marking
- Initial installation
- Monitoring
- Adjustment
- Resources
- Cost
- Time spent

Over the entire lifespan of the machine

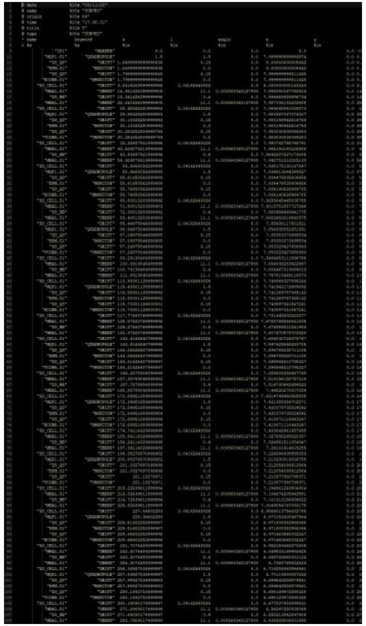
Ongoing simulations

One big challenge : We have two (or even three) objects being increasingly more detailed and mature, but without a clear link between them yet.

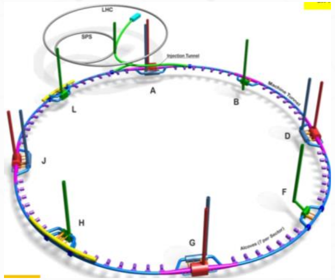
But as surveyors we are asked to locate the machine in the tunnel with very demanding precisions.

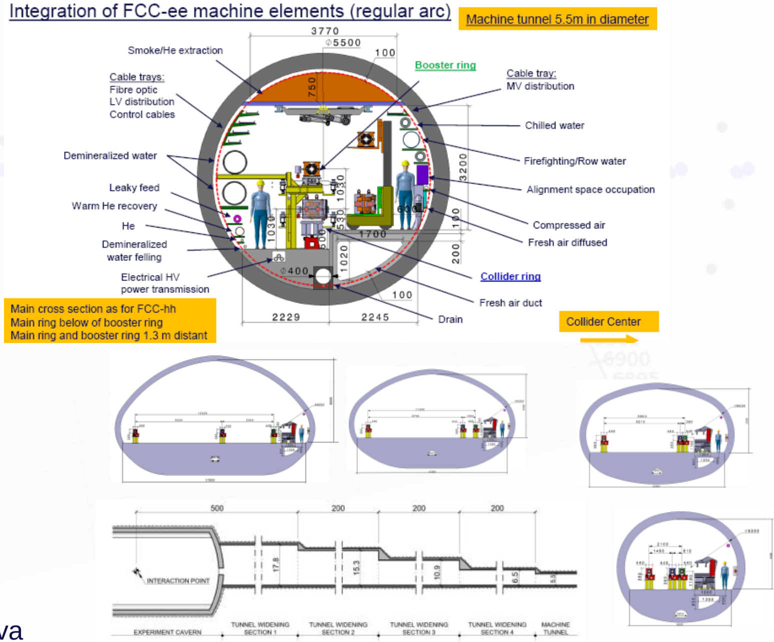
Collider optics layout

Booster optics layout



Tunnel integration

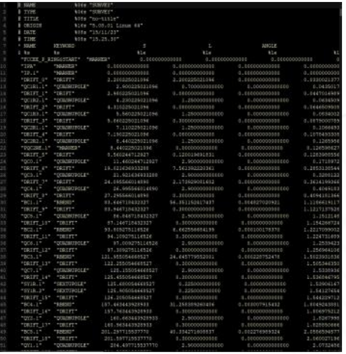




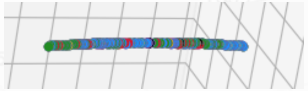
F. Valchkova-Georgieva

The current process for the simulations

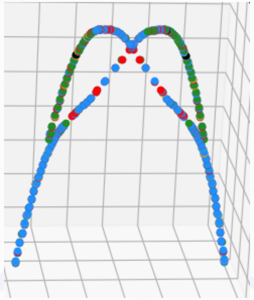
.tfs file



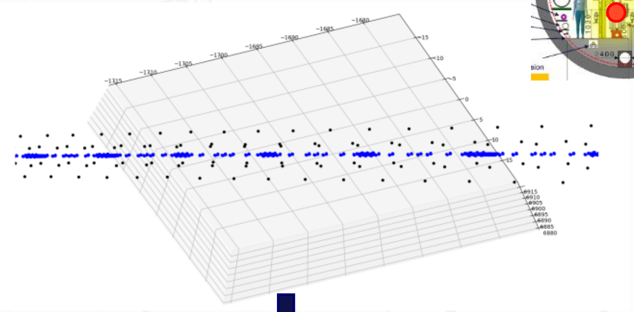
Entry and exit points for all the components

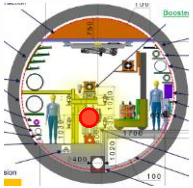


Trajectory



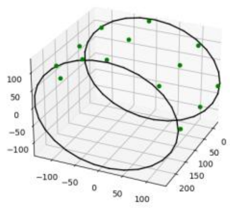
Generation of the tunnel around that trajectory



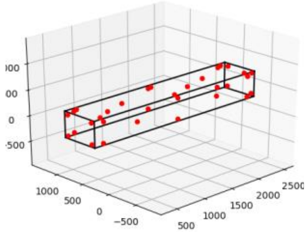


Simulation of fiducial locations on the components

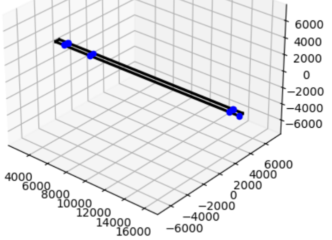
Sextupole



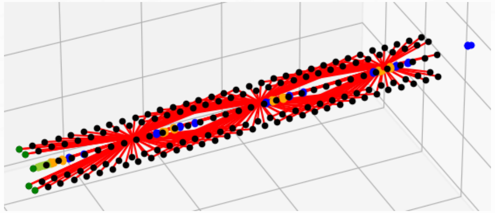
Quadrupole



Dipole

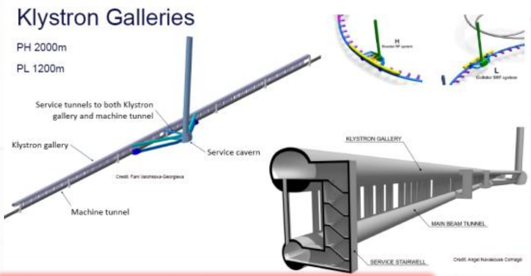


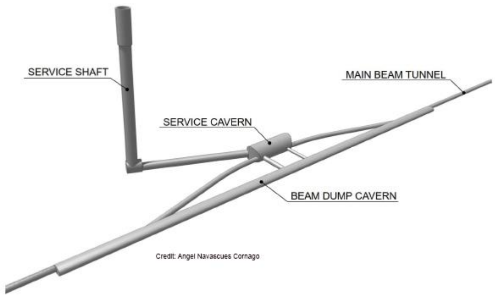
Generation of measurements (between measuring instrument, tunnel walls and components)



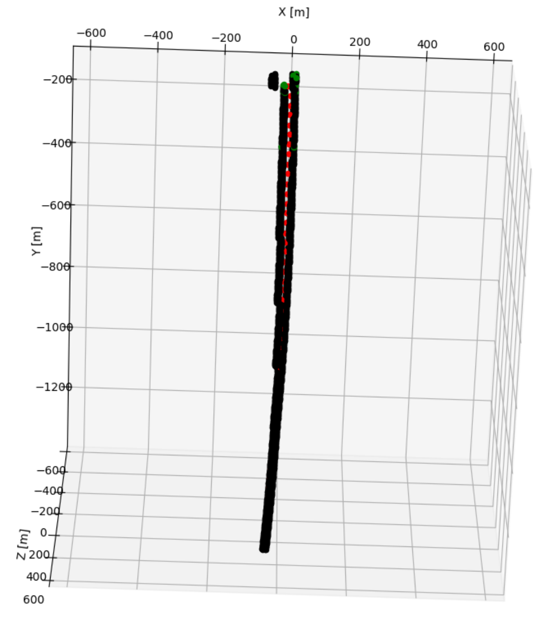
Tunnel point network is different depending on the location

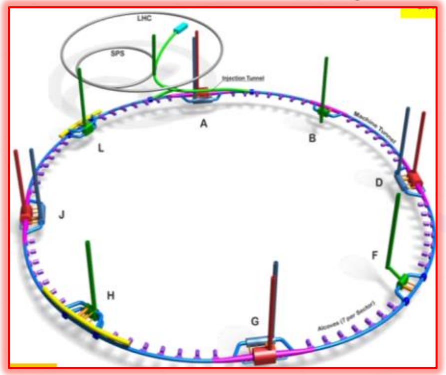
F. Valchkova-Georgieva

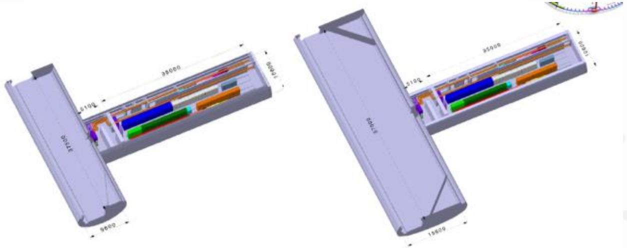




Reference points in the tunnel around the IP

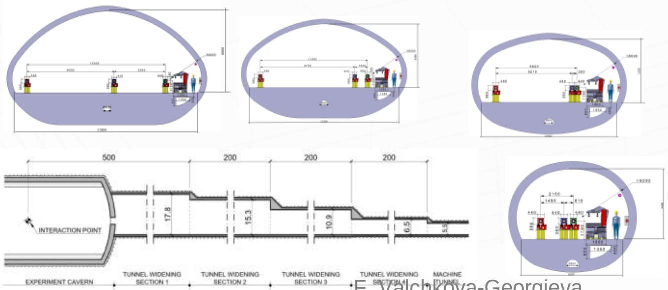






Small transport Layby with standard FCC Alcove

Big transport Layby with standard FCC Alcove



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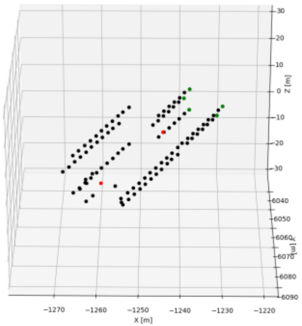
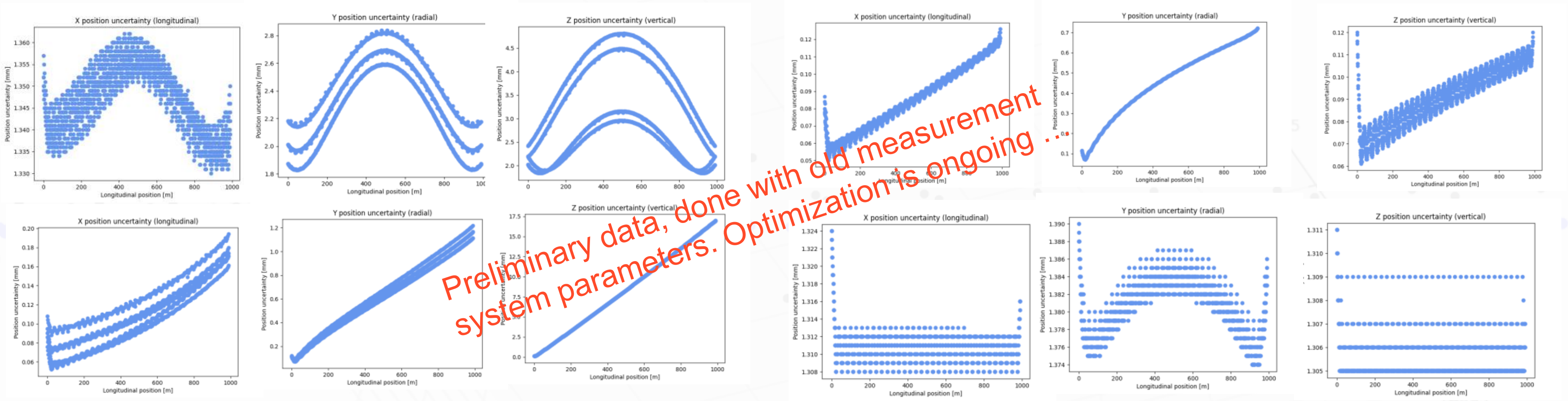
Reference points in the tunnel at an alcove



Status

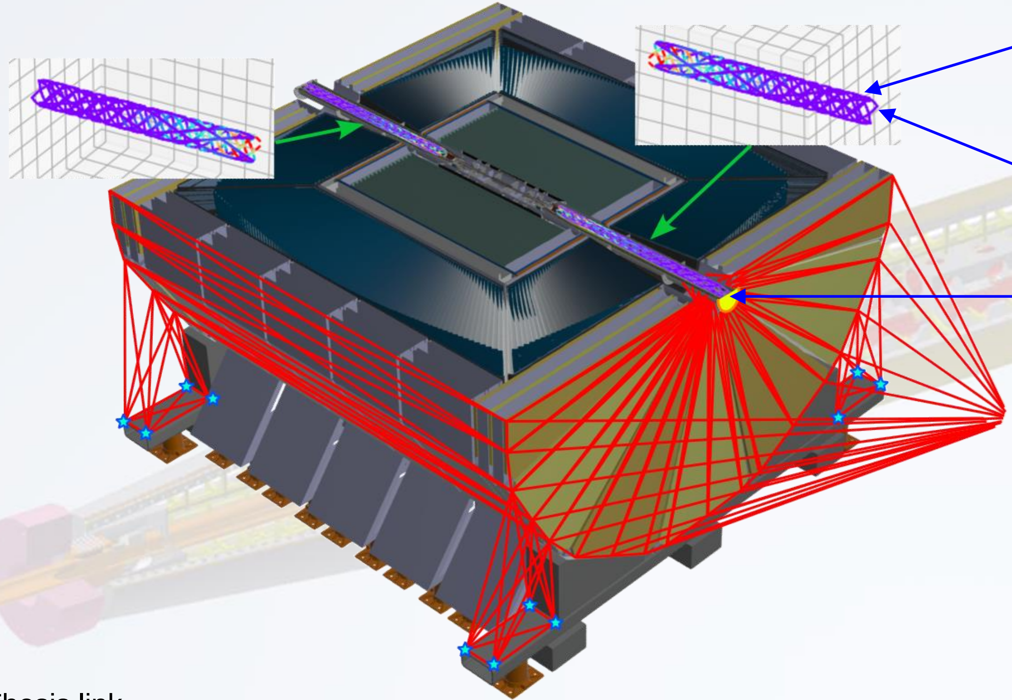
A code has been created to get the position uncertainty of points and/or components depending on a set of tunable parameters (tunnel geometry, point network density, measurement system characteristics …).

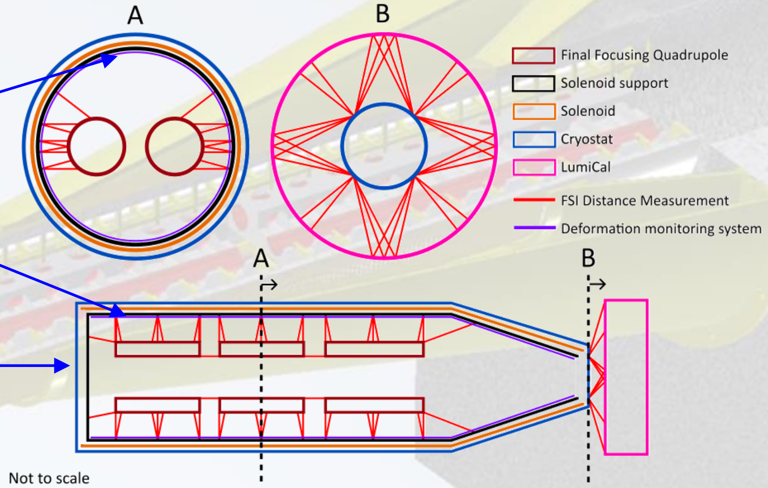


Upgrade of the current adjustment software is required as it cannot compute more than 2 km of tunnel at once.

Temporary solutions are used to perform simulations, but the challenge needs to be addressed.

MDI



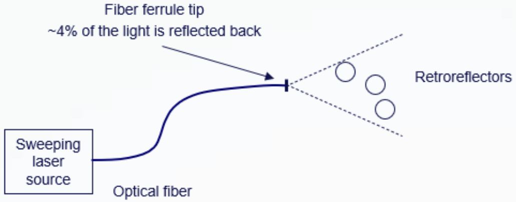


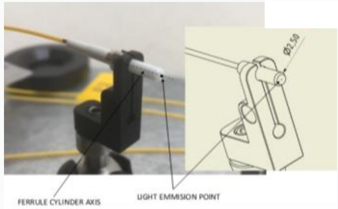
Thesis link

MDI

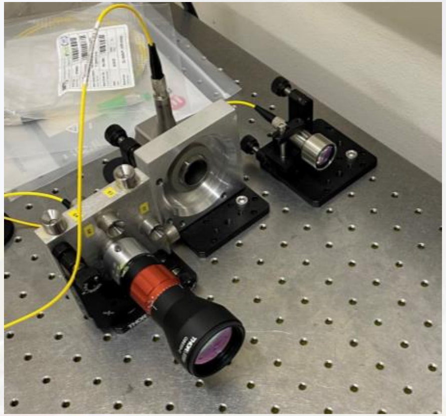
External alignment and monitoring system

Permanent network of interferometric distance measurements based on Frequency Scanning Interferometry (FSI).

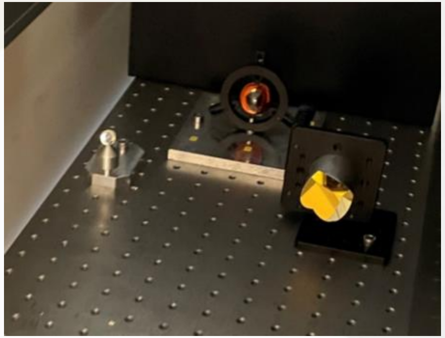




Sosin, M., et al. "Frequency sweeping interferometry for robust and reliable distance measurements in harsh accelerator environment." Applied Optical Metrology III. Vol. 11102. SPIE, 2019.

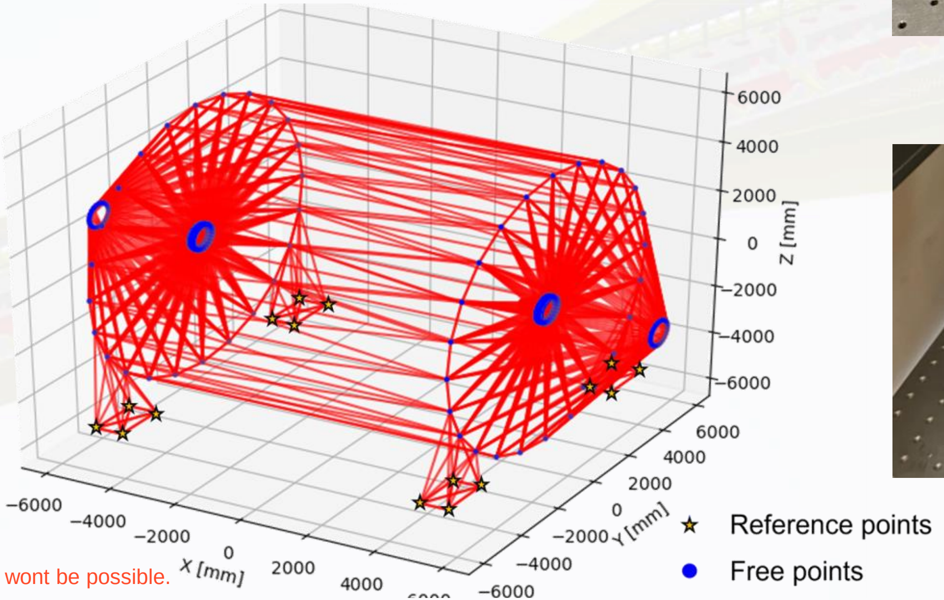


R&D on optics and reflectors



Goals :

- Monitoring of the interface at the end of QC1
- Monitor the alignment between QC1 and QC2.
- Monitor the alignment between the inner components and the experiment solenoid.
- Monitor the alignment between the two sides of the experiment.



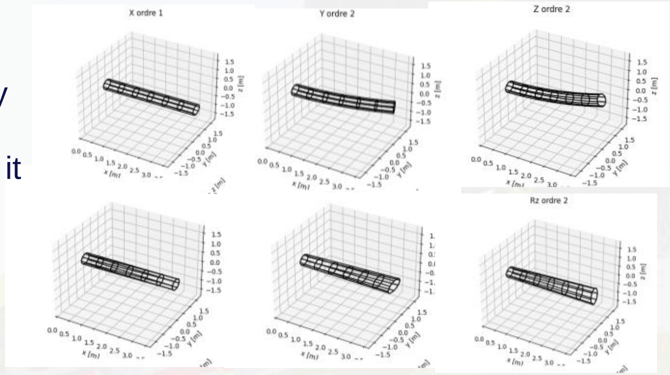
Optimal network : too much measurements, some (plenty) wont be possible.
Any update on the design would be much welcomed.

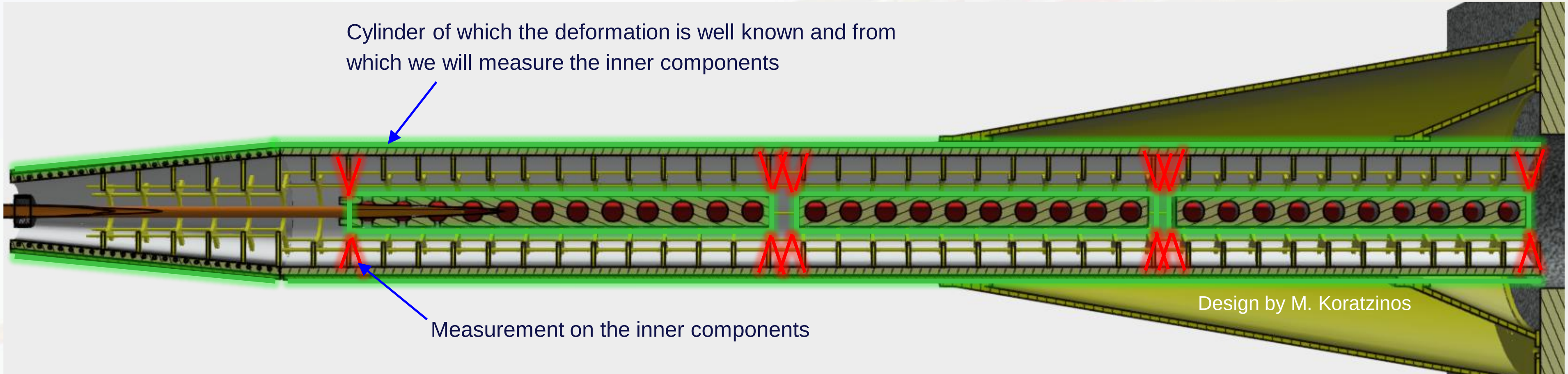
Thesis link

Internal alignment system

- Goal : monitor the deformation extremely precisely over the length of the assembly
- Create a network of points accurate enough so another system can measure from it onto the inner components
- Deformation monitoring system + distance measurement system

Deformation models



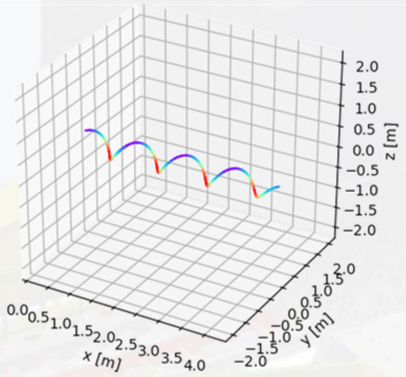


- Measurement system waiting for design update.

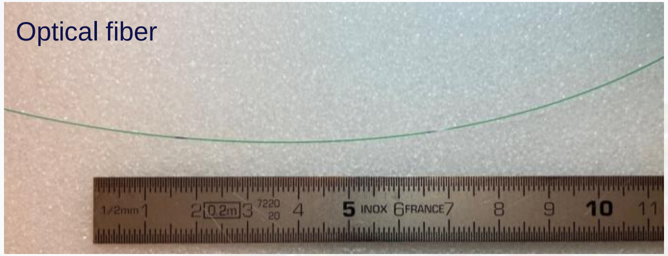
Thesis link

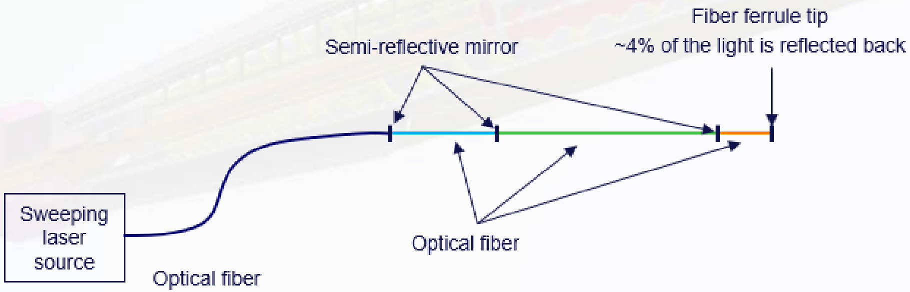
Deformation monitoring

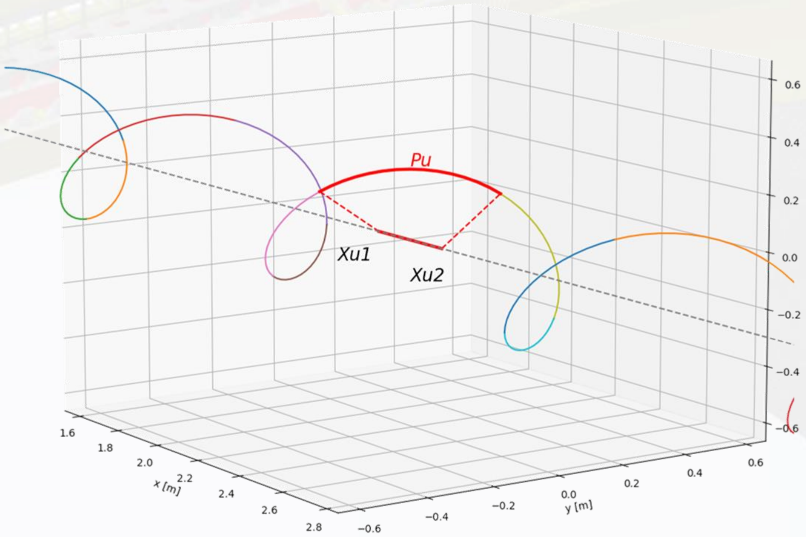
https://iopscience.iop.org/article/10.1088/1361-6501/acc6e3



- Optical fiber placed in a helix shape, separated in portion by semi-reflective mirrors, which can be simultaneously and independently measured
- Helixes defined by their length, radius, step, number and position of portions
- Technology used : In-line multiplexed and distributed FSI measurement (in development at CERN)







Deformation monitoring

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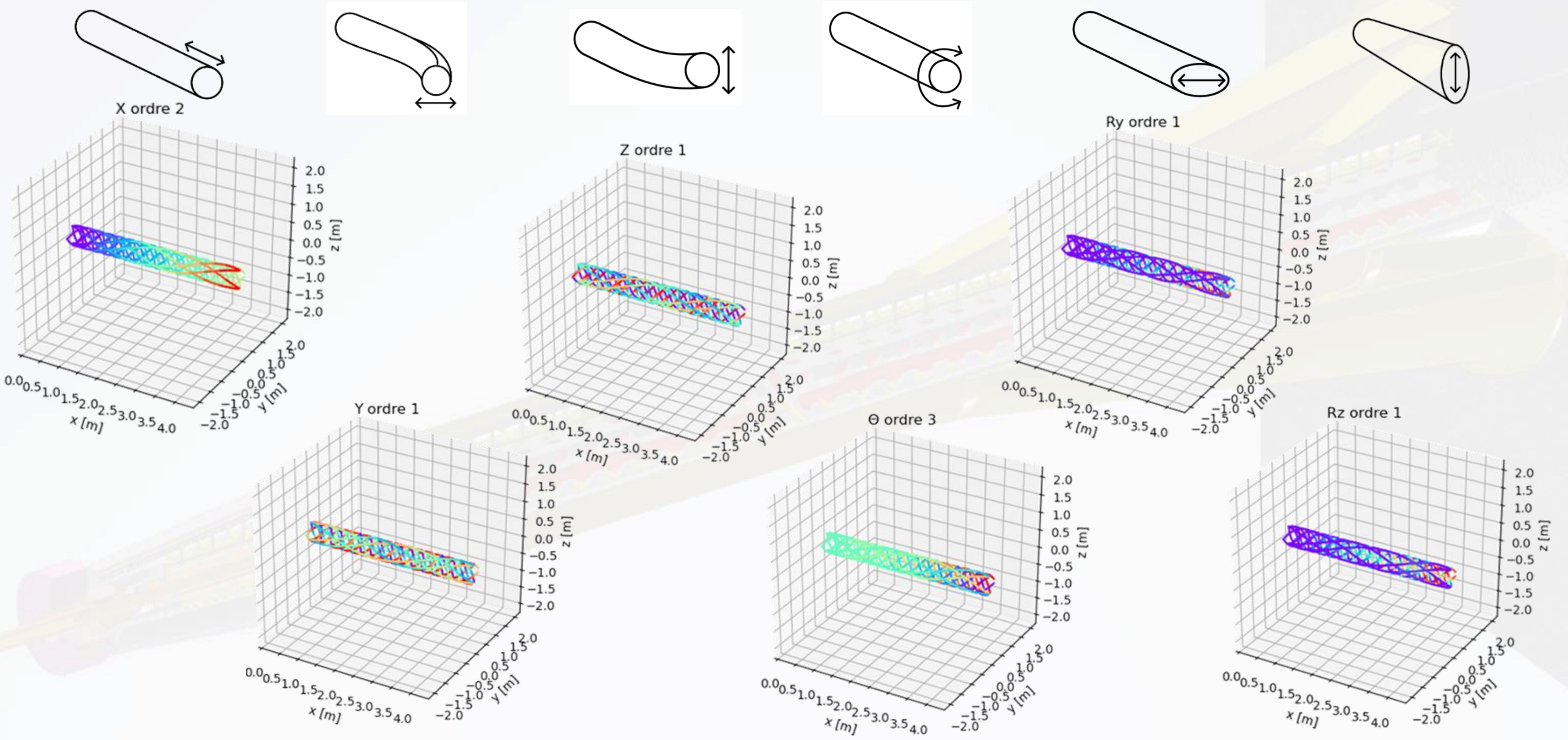
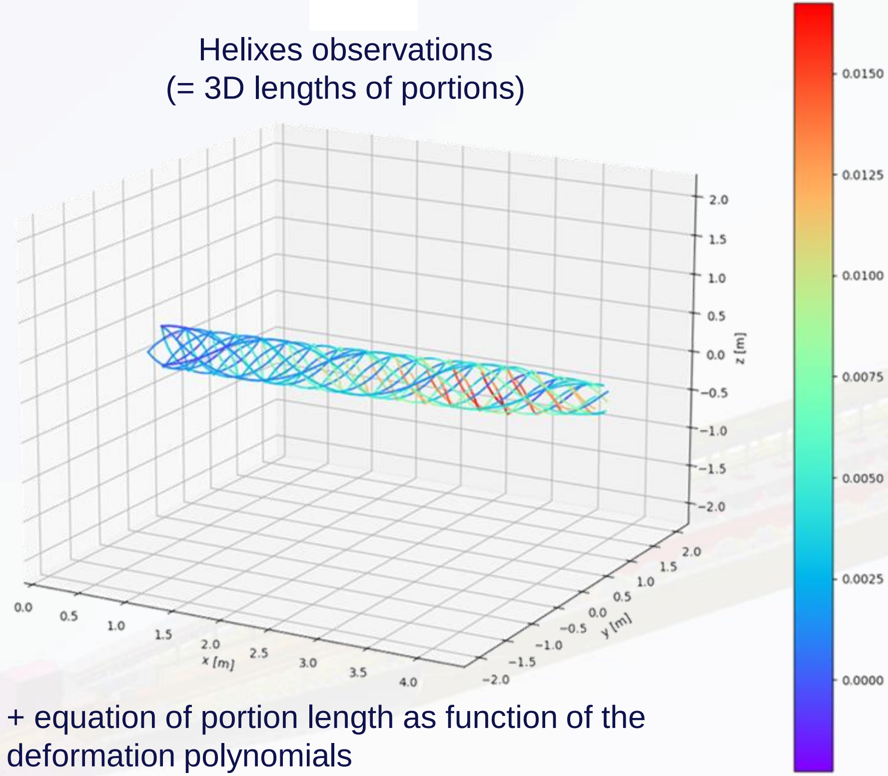


Deformation monitoring

https://iopscience.iop.org/article/10.1088/1361-6501/acc6e3

Cylinder deformations

Helixes observations
(= 3D lengths of portions)



Least square adjustment

$$P_x(t) = \sum_{i=1}^{n} a_i t^i$$

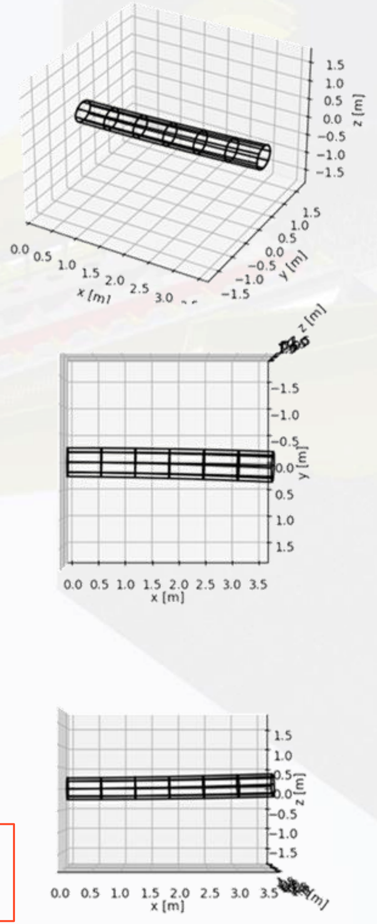
$$P_y(t) = \sum_{i=1}^{n} b_i t^i$$

$$P_z(t) = \sum_{i=1}^{n} c_i t^i$$

$$P_\theta(t) = \sum_{i=1}^{n} d_i t^i$$

$$P_{ry}(t) = \sum_{i=1}^{n} e_i t^i$$

$$P_{rz}(t) = \sum_{i=1}^{n} f_i t^i$$



+ equation of portion length as function of the deformation polynomials

Total : 3600 measurements and ≈ 3 cm^3 space taken by the sensing system in the assembly.

Simulations shown micrometric accuracy
To be confirmed by a prototype

Deformation monitoring

First prototype

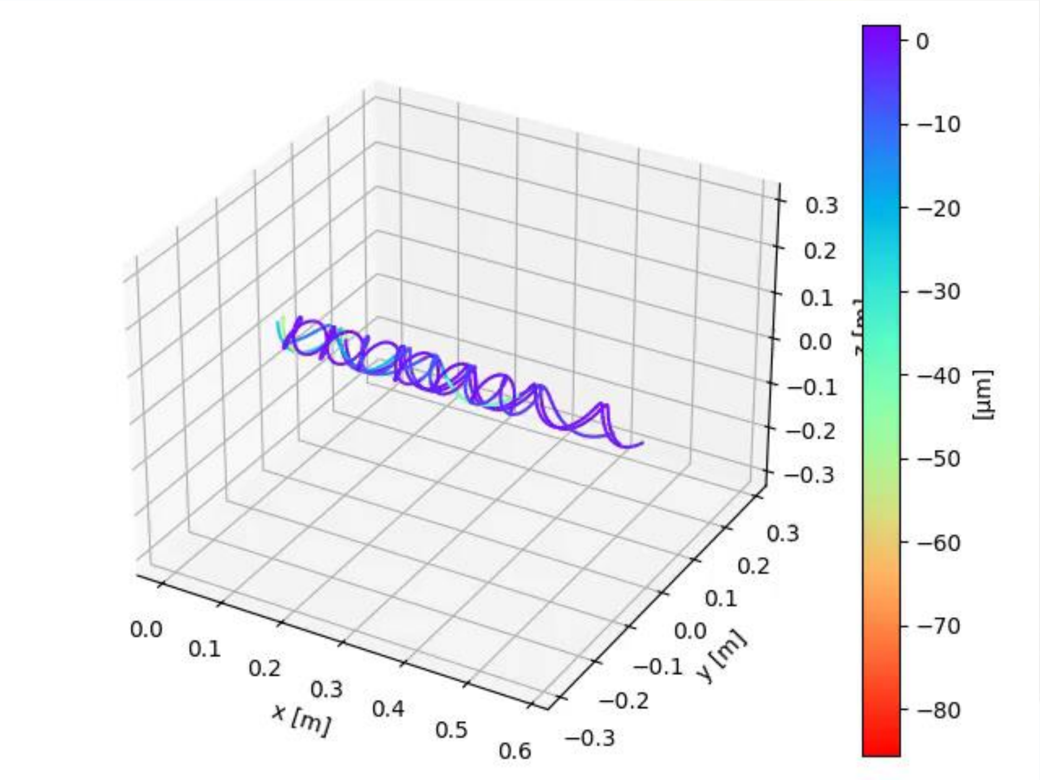
Deformation monitoring

The goals of the prototype were:

- Establish a process for the assembly of the 'big' prototype (1/2 scale)
- Study the difficulties during the positioning/gluing
- Study the 'as-built' result and deal with real data
- Get ready for the next prototype, a 2m long tube

This prototype was not meant for deformation testing.

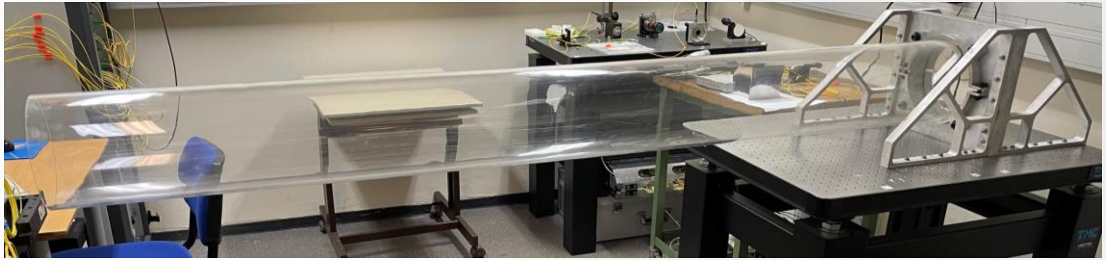
8 hours measurement
Shrinkage of the fibres due to the curing of the glue

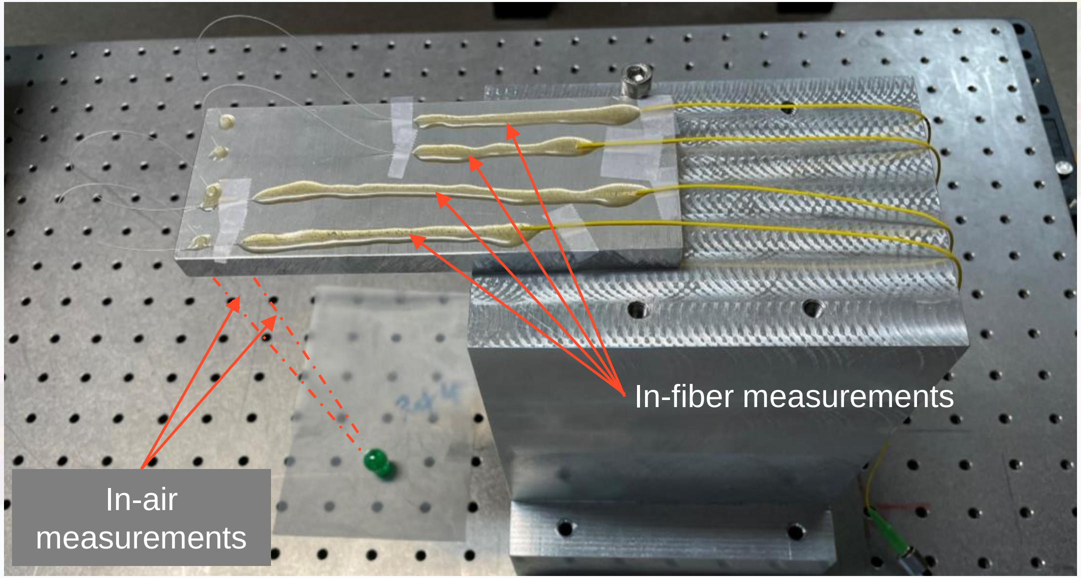


Deformation monitoring, next steps :

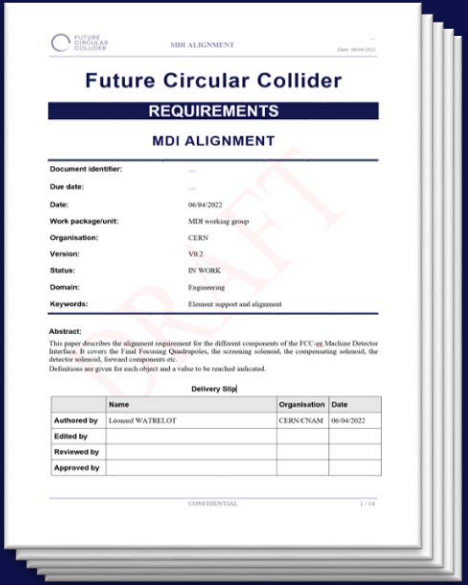
- Assemble the 2m long prototype
- Implement distance measurement from the tube towards components inside
- Perform deformations
- Crosscheck using different sensor systems (laser tracker, probe sensor)

Parts getting ready for a 2m long tube deformation study





Thank you for your attention


MDI ALIGNMENT

Future Circular Collider

REQUIREMENTS

MDI ALIGNMENT

Document identifier:	---
Due date:	---
Date:	06/04/2022
Work package/unit:	MDI working group
Organisation:	CERN
Version:	V0.2
Status:	IN WORK
Domain:	Engineering
Keywords:	Element support and alignment

Abstract:

This paper describes the alignment requirement for the different components of the FCC-ee Machine Detector Interface. It covers the Final Focusing Quadrupoles, the screening solenoid, the compensating solenoid, the detector solenoid, forward components etc.

Definitions are given for each object and a value to be reached indicated.

Delivery Slip

	Name	Organisation	Date
Authored by	Léonard WATRELOT	CERN/CNAM	06/04/2022
Edited by			
Reviewed by			
Approved by			

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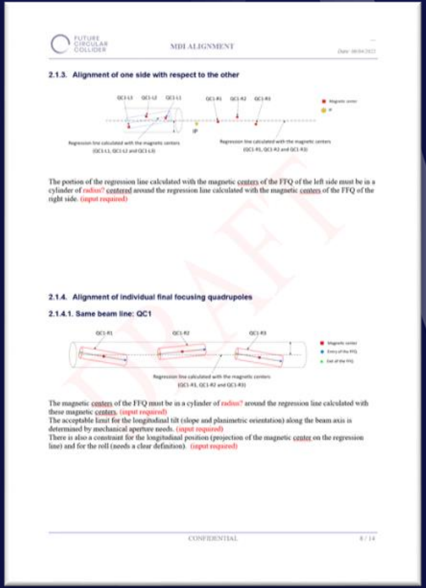
MDI ALIGNMENT

2.1.3. Alignment of one side with respect to the other

The portion of the regression line calculated with the magnetic centers of the FFQ of the left side must be in a cylinder of radius? centered around the regression line calculated with the magnetic centers of the FFQ of the right side. (input required)

2.1.4. Alignment of individual final focusing quadrupoles

2.1.4.1. Same beam line: QC1

The magnetic centers of the FFQ must be in a cylinder of radius? around the regression line calculated with these magnetic centers. (input required)

The acceptable limit for the longitudinal tilt (slope and planimetric orientation) along the beam axis is determined by mechanical aperture needs. (input required)

There is also a constraint for the longitudinal position (projection of the magnetic center on the regression line) and for the roll (needs a clear definition). (input required)

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Additional subjects needed to be looked at :

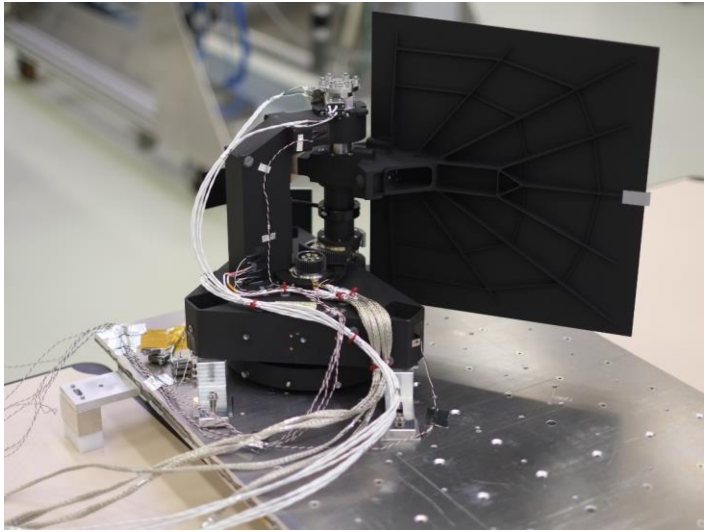
- Tunnel marking
- Magnet support
- Adjustment solutions
- Magnet deformation
- Automatisation
- Alignment data storage and handling
- ...

I’m still trying to gather alignment requirements

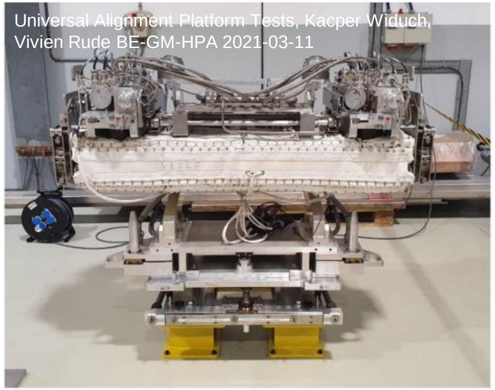
Re-adjustment system

- Interest of having a system able to move one or multiple element without requiring to disassemble the entire QC1 ?
- Not necessary to be accurate at 10 µm, a system able to correct major displacements ~0.2 mm to 1mm (due to transport, gravity deformation, movement during cool down, intense magnetic fields …) would be already extremely convenient.
- Not necessary to work at cryogenic temperatures only at room temperature would be already extremely convenient.
- Not necessary to be able to work during the run of the machine, during shut downs would be already extremely convenient.

The EUCLID VIS Read-out Shutter Unit, which will operate in space



Larchevêque, C., et al. "The Euclid VIS read-out shutter unit: a low disturbance mechanism at cryogenic temperature." *arXiv preprint arXiv:1801.07496* (2018).



Universal Alignment Platform Tests, Kacper Widuch, Vivien Rude BE-GM-HPA 2021-03-11

A lot of possibilities are open, from the system working only at warm temperature allowing a re-adjustment to the 0,1mm level of major components at the end of shut downs, to the system able to realign in real time and during the run of the machine the cold components to the micrometer level.

Systems to work in these conditions exist, the difficulty is to <u>quantify their advantage compared to a loss of luminosity due to any misquantified misalignment value or to the need to dismount, disassemble, realign, reassemble and remount the assembly.</u>