ALIGNMENT OF THE INTERACTION REGION AT FCC-ee

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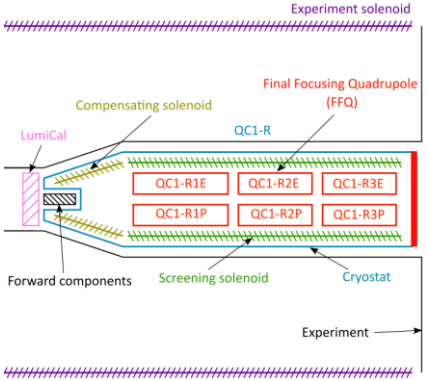
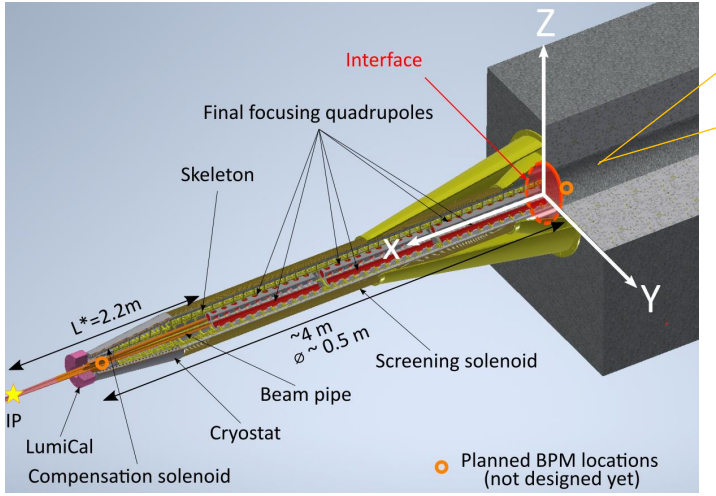
Many thanks to :
Manuela Boscolo, Francesco Fransesini, Hélène Mainaud Durand, Mateusz Sosin, Michel Noir, Fabrizio Palla, Bartlomiej Pudlo, Jürgen Gutekunst, Okan Dag

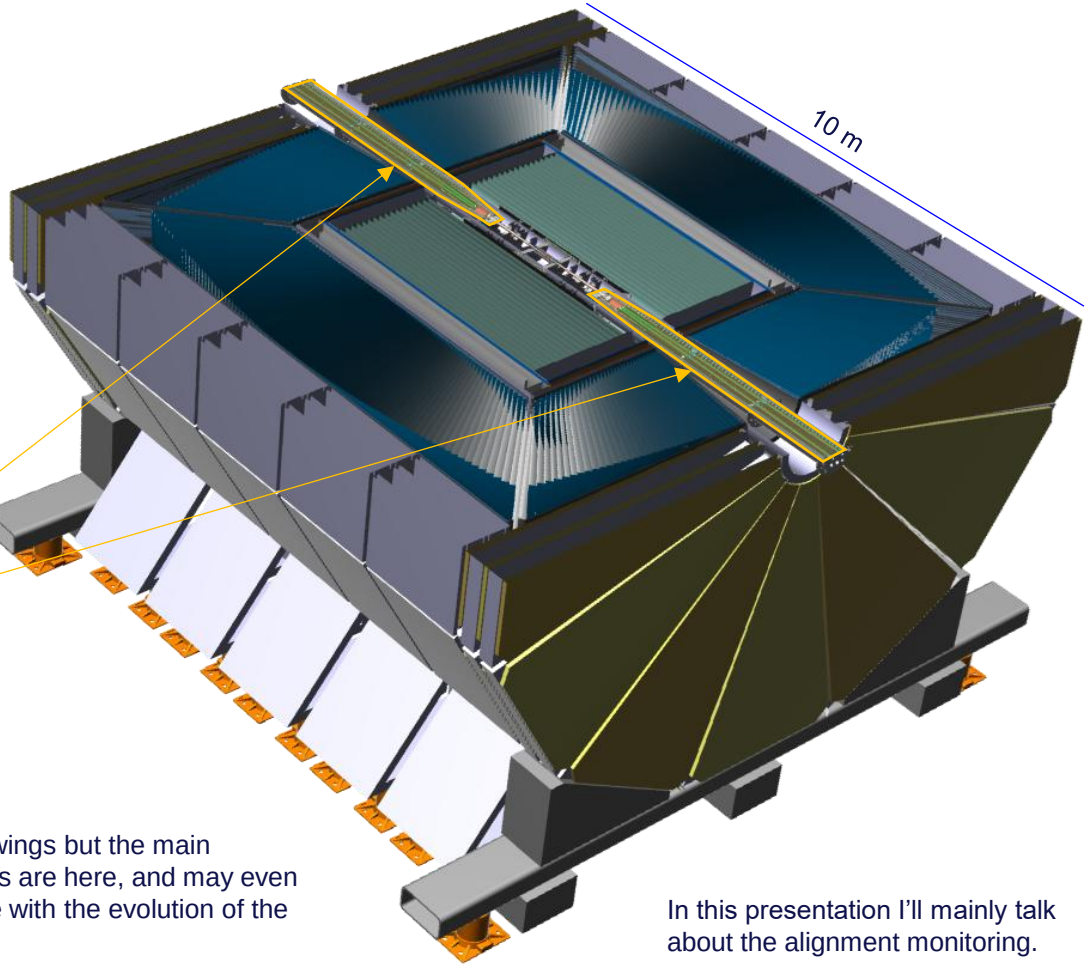
Overview

- The FCC-ee MDI situation
- External monitoring system
- Deformation monitoring system
- MDI alignment Mock up

Reminder of the FCC-ee MDI region





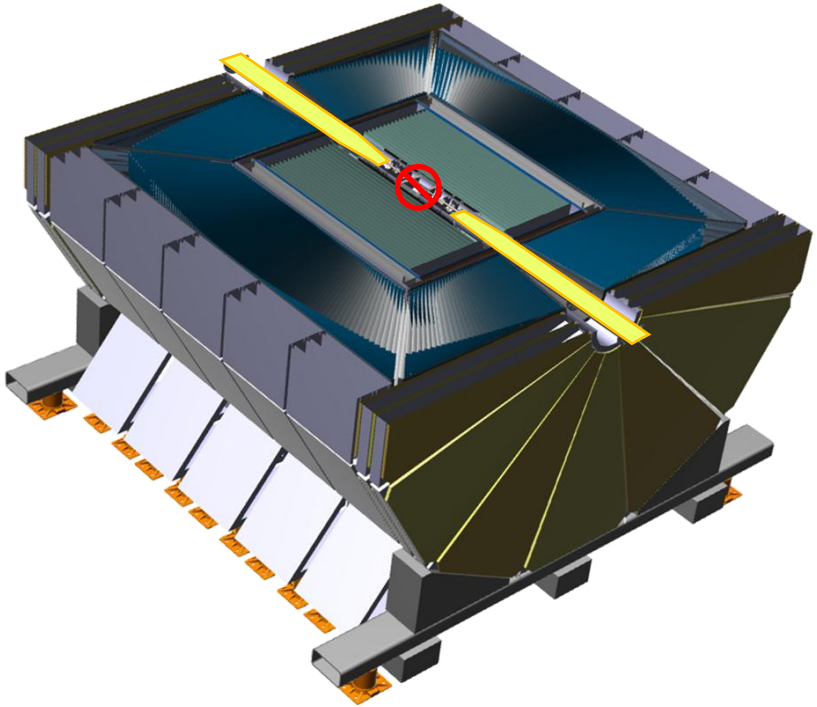


Old drawings but the main problems are here, and may even increase with the evolution of the design.

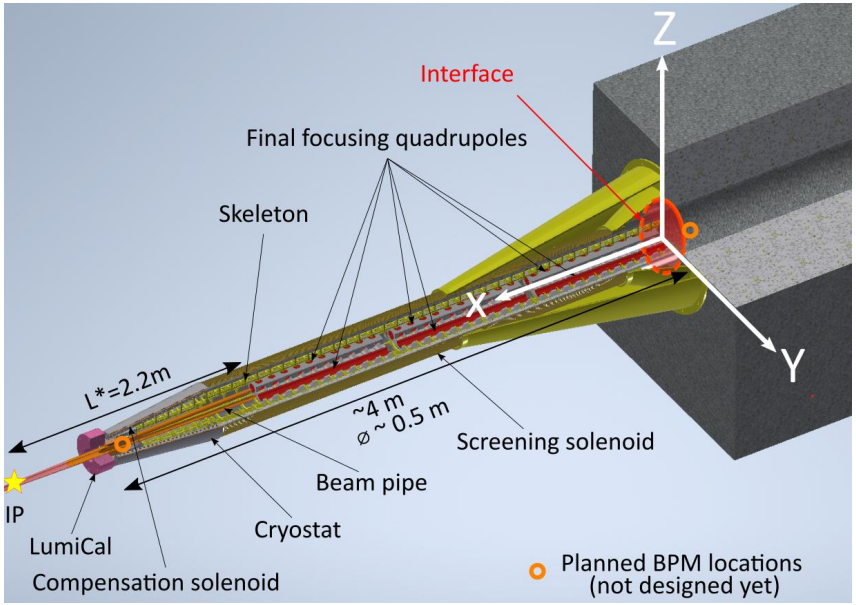
In this presentation I'll mainly talk about the alignment monitoring.

The alignment monitoring of the MDI separated in two sub-challenges:

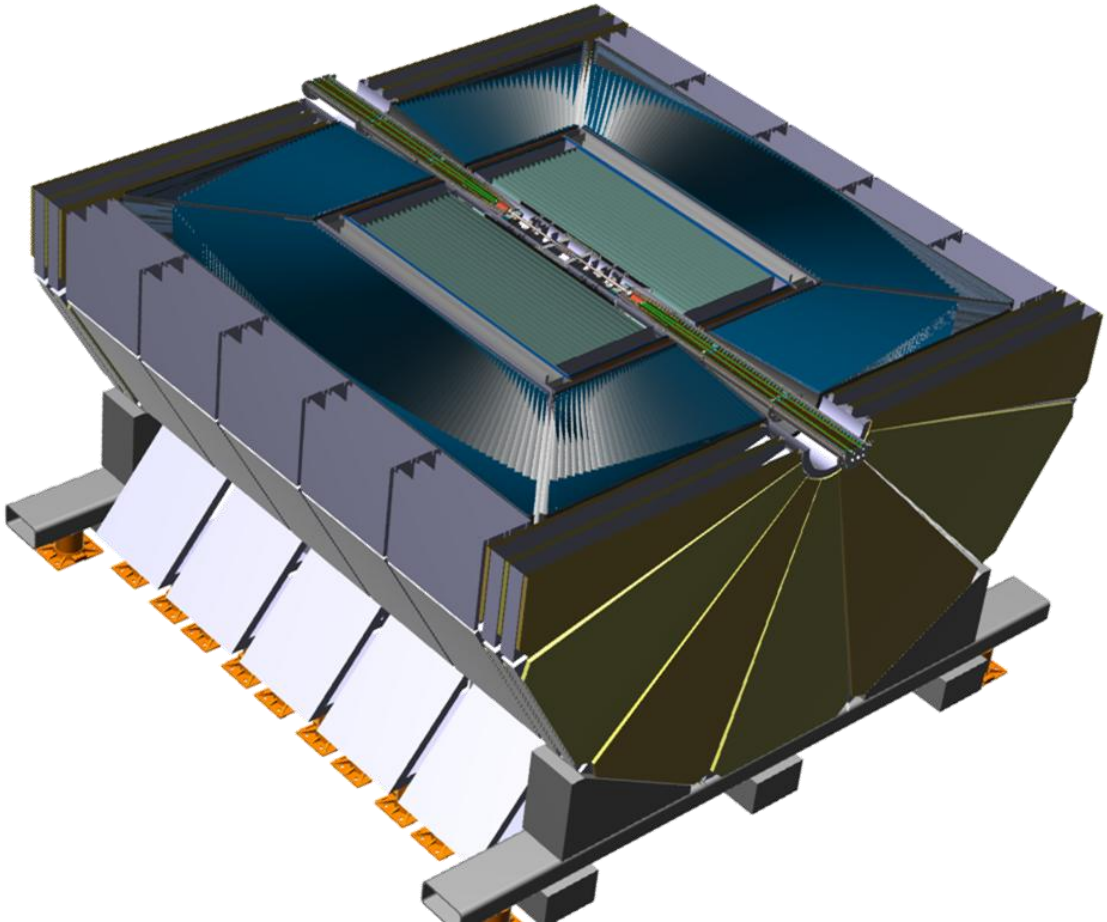
The complexity to link both sides of the MDI, as no line of sight will be available between the two assemblies.



The complexity to monitor the position of the final focusing quadrupole in such a long, narrow and crowded space.



First : the link between both sides of the detector



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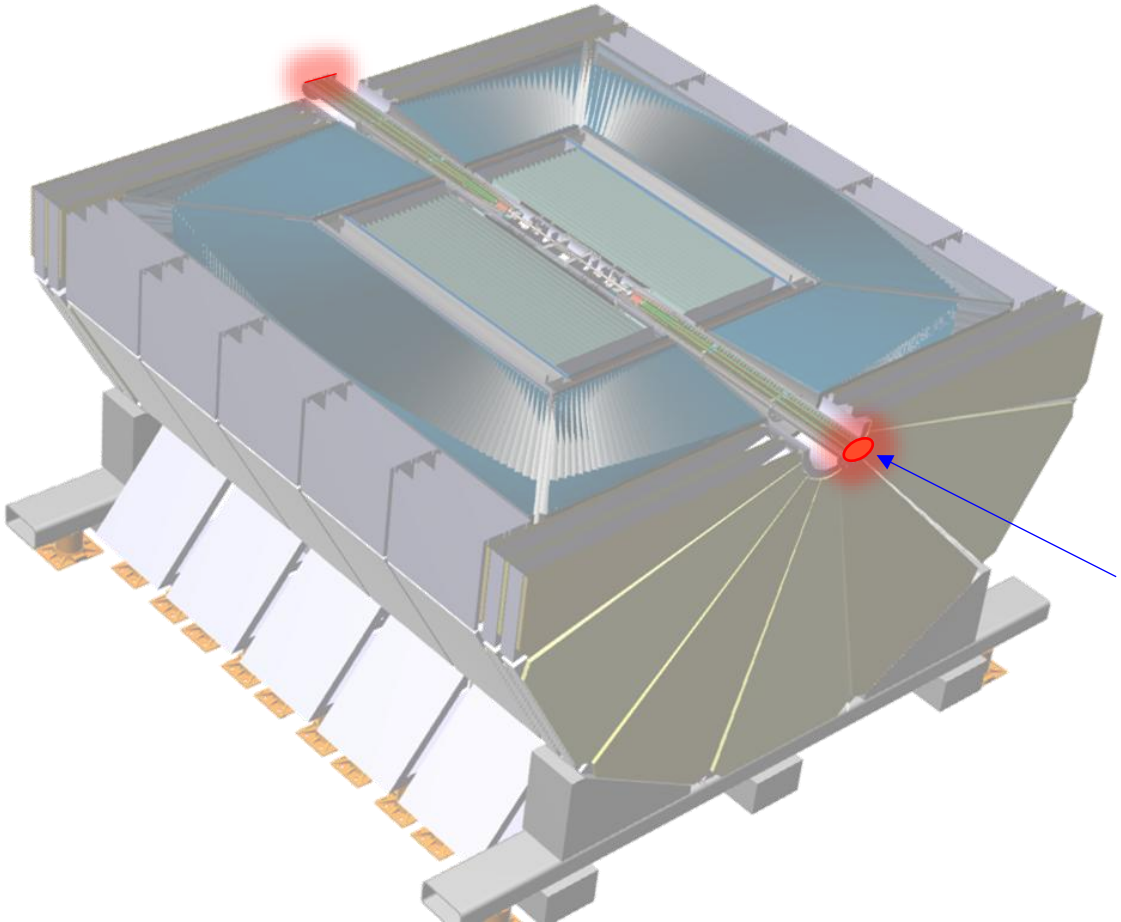
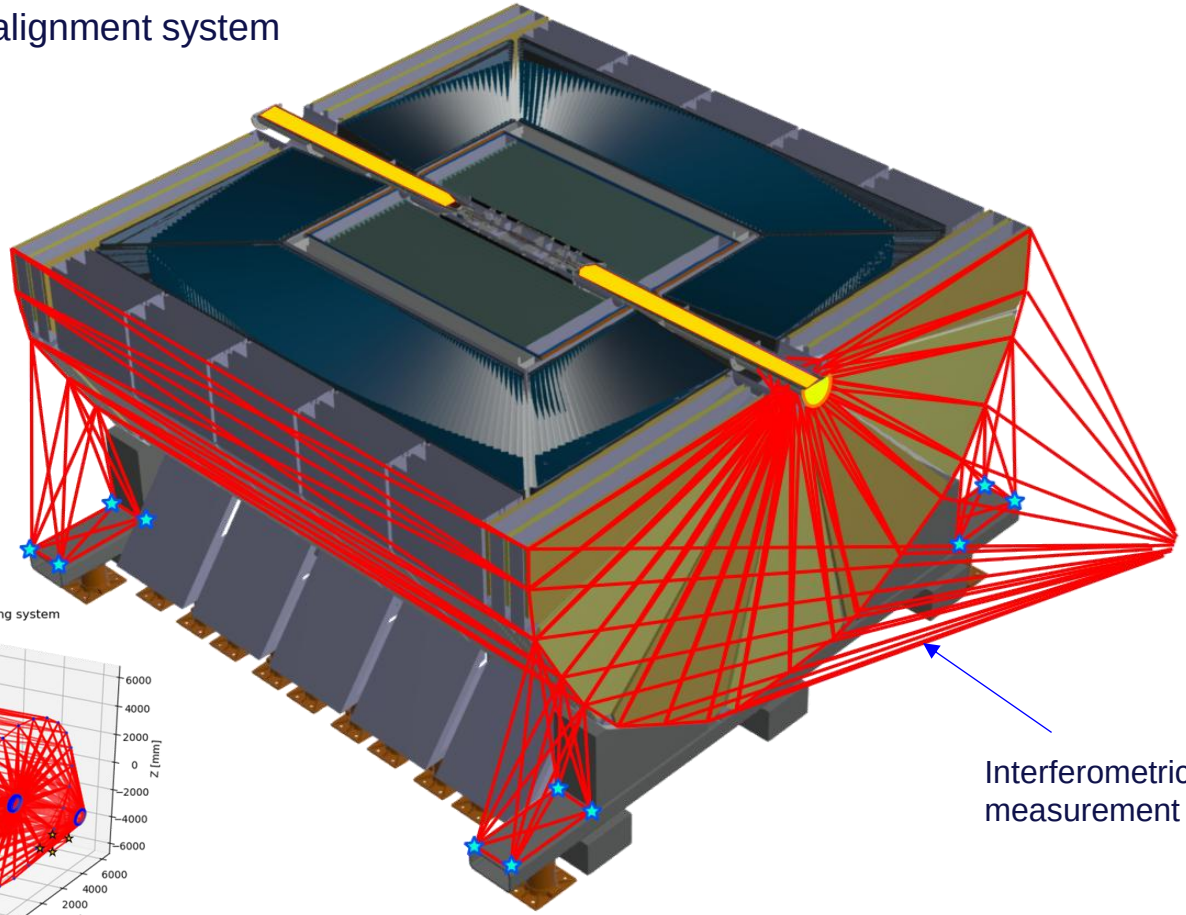
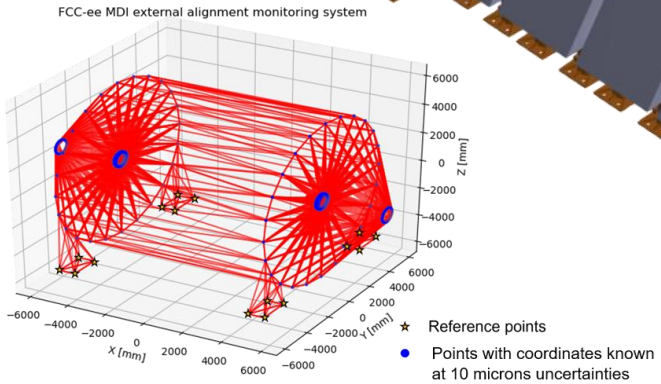


The only accessible part of the assembly, that can be monitored from outside of the detector

First : the external alignment system



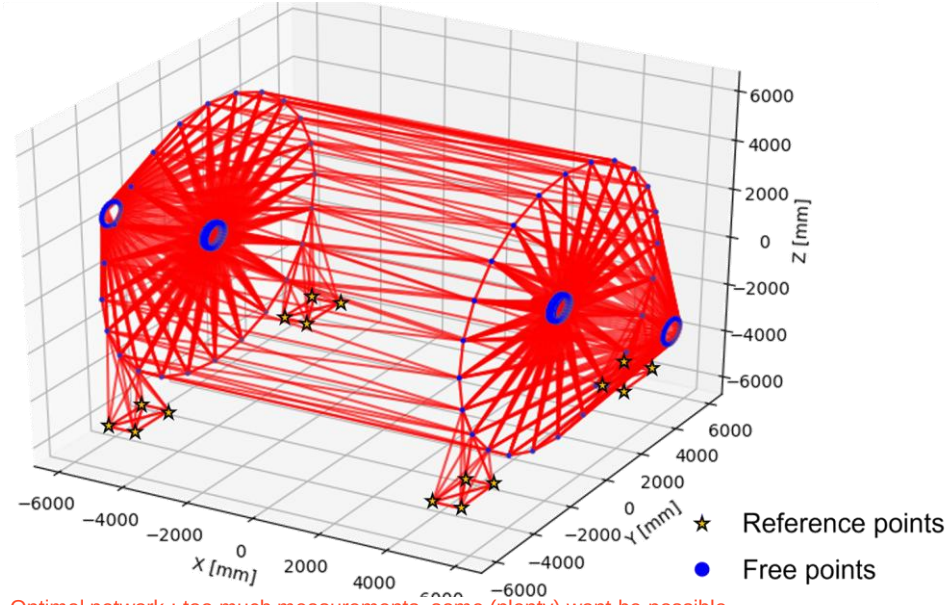


Interferometric distance measurement network

External alignment system

Simulations

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

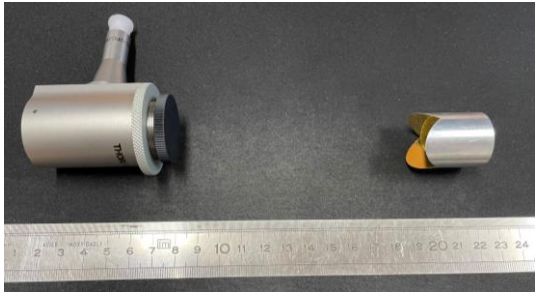


Optimal network : too much measurements, some (plenty) wont be possible.
Updates on the design are followed carefully.

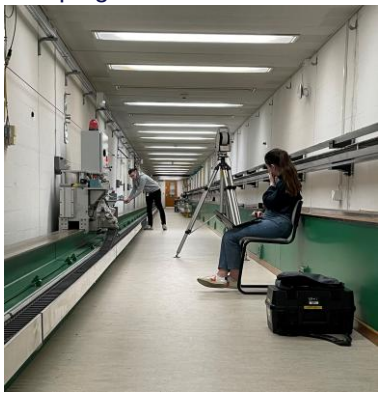
Thesis link

Hardware R&D

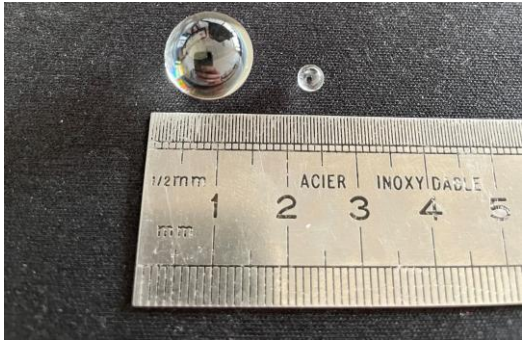
Collimator and Corner Cube retroreflector



FSI long range validation campaign

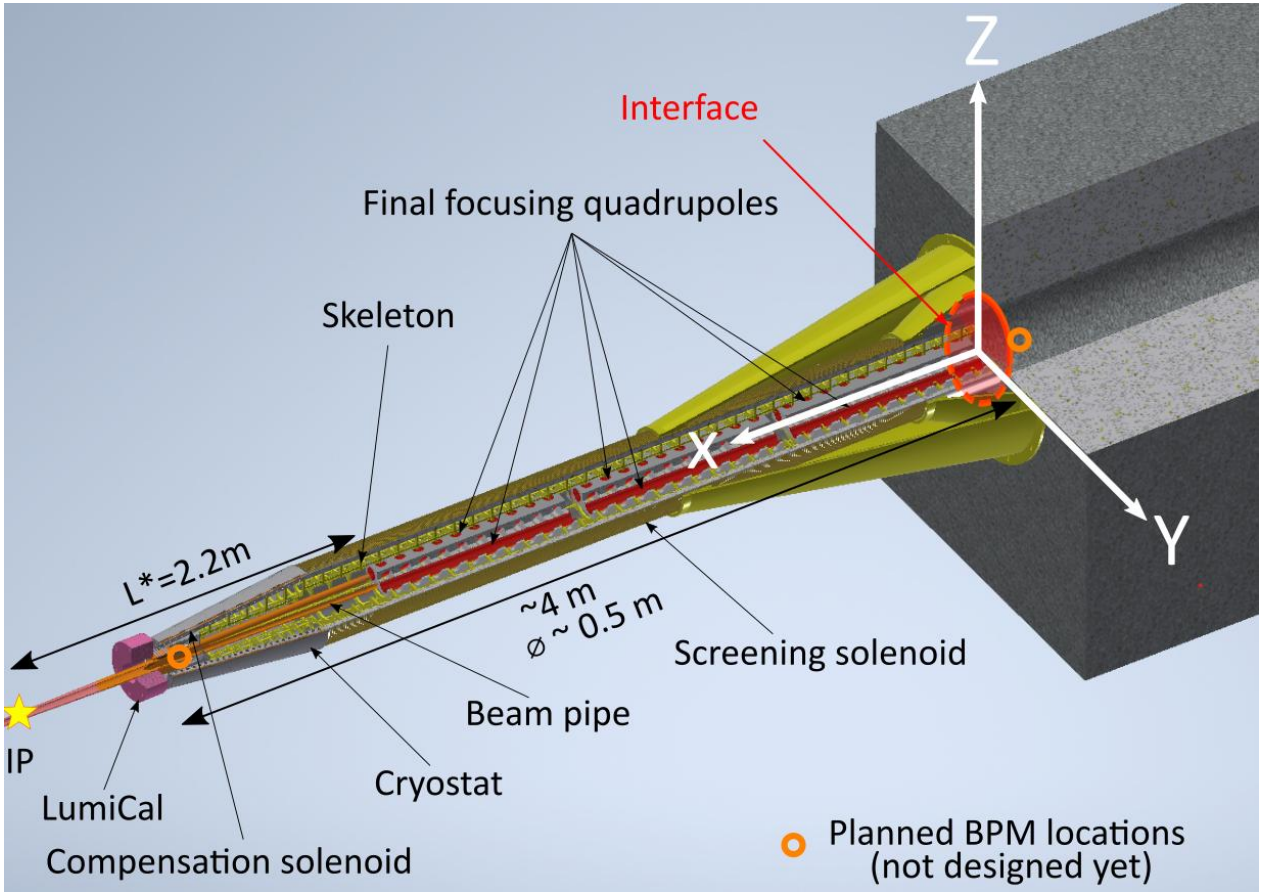


Glass beads



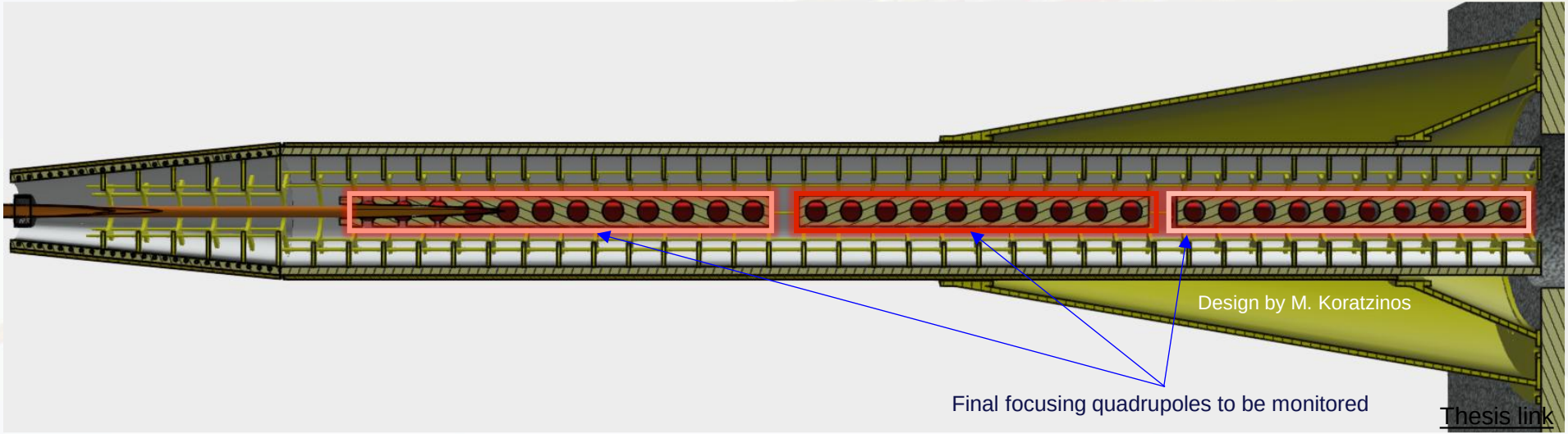
Glass bead supports

Second: internal alignment system



Second: internal alignment system

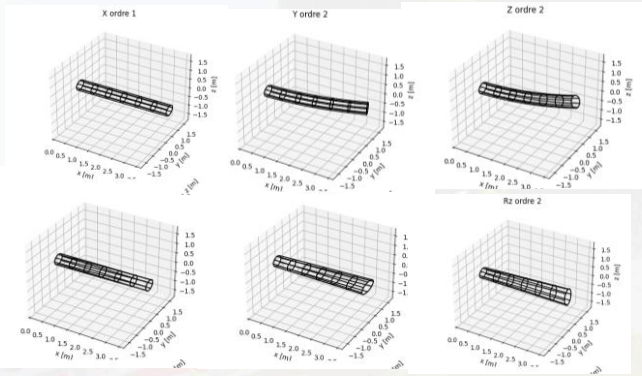
- Goal : monitor the final focusing quadrupoles to around 30micron uncertainty
- Challenge : extremely bad configuration (long, narrow and crowded cylinder), and no physical reference to stay precise.

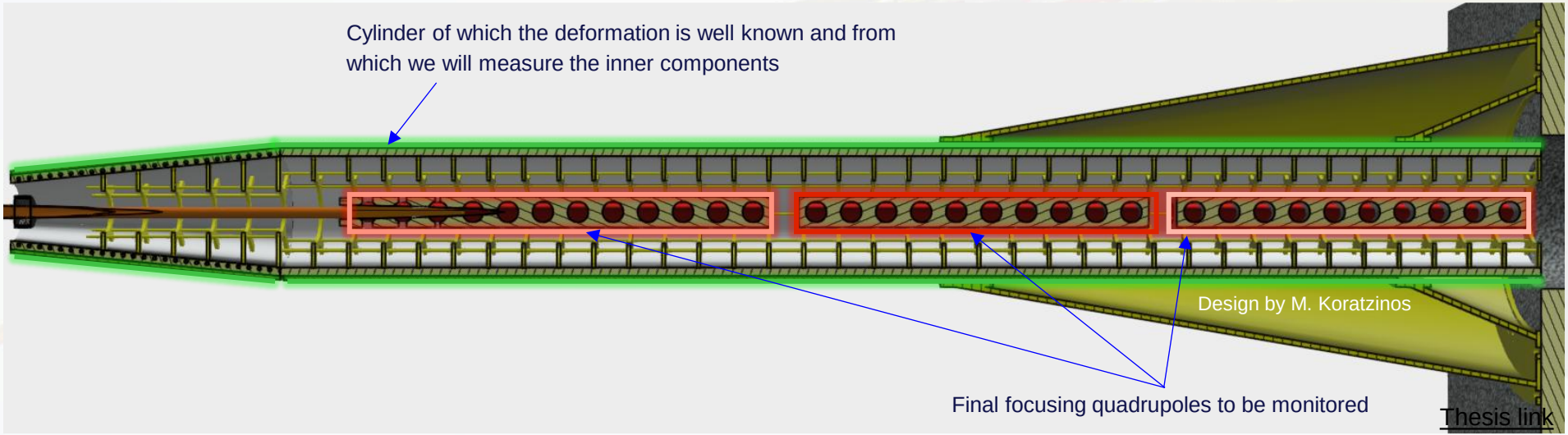


Second: internal alignment system

- Goal : monitor the final focusing quadrupoles to around 30micron uncertainty
- Challenge : extremely bad configuration (long, narrow and crowded cylinder), and no physical reference to stay precise along that configuration
- Proposition : monitor the shape of the support of the screening solenoid (a cylinder)

Deformation models





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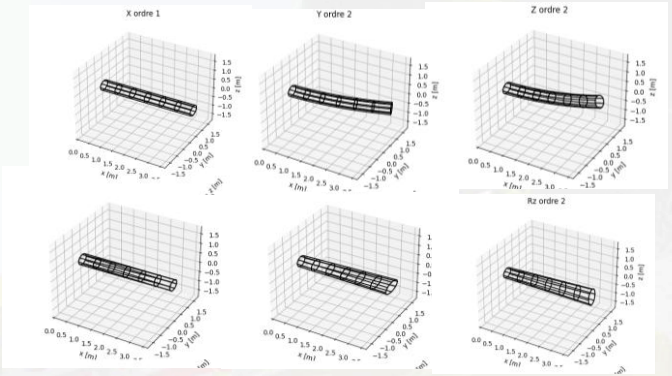
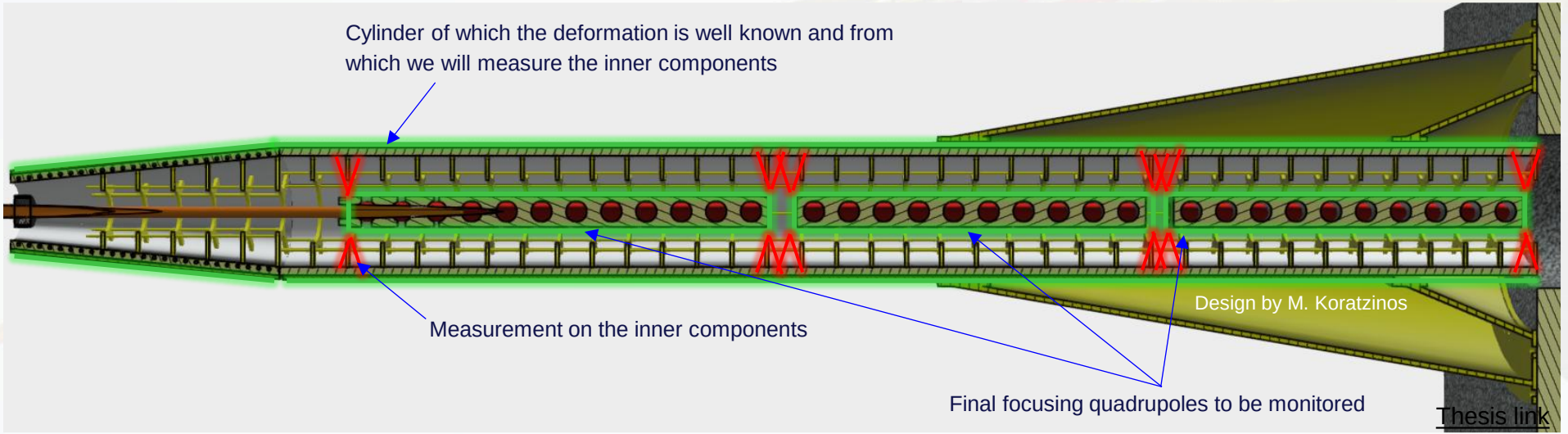
- Challenge : extremely bad configuration (long, narrow and crowded cylinder), and no physical reference to stay precise along that configuration
- Proposition : monitor the shape of the support of the screening solenoid (a cylinder)
- And then measure from that known shape towards the final focusing quadrupoles

Deformation models

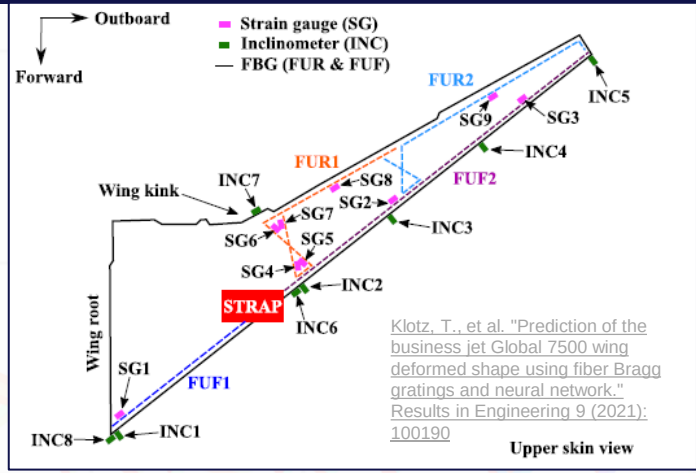




Deformation monitoring

Structural monitoring already exists in civil engineering and industry.
Multiple technologies can perform such measurements.

But there are only doing 1D measurements (discrete or distributed), while we want top perform 3D deformation monitoring.



Klotz, T., et al. "Prediction of the business jet Global 7500 wing deformed shape using fiber Bragg gratings and neural network." Results in Engineering 9 (2021): 100190

Inaudi, Daniele. Fiber optic sensor network for the monitoring of civil engineering structures. Diss. Verlag nicht ermittelbar, 1997.

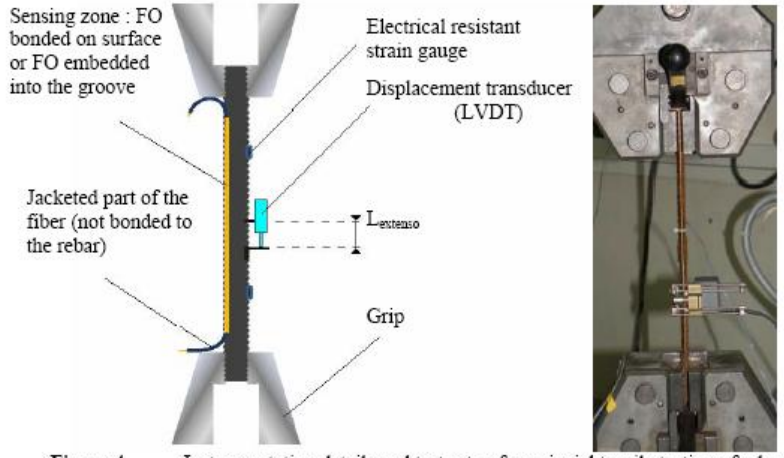


Figure 4. Instrumentation details and test setup for uniaxial tensile testing of rebar

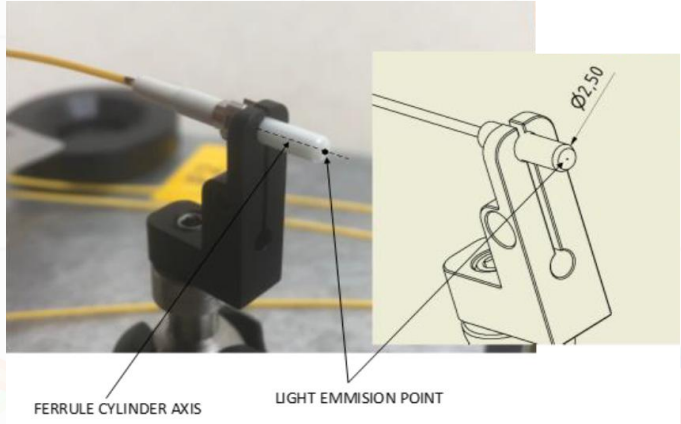
Quiertant, Marc, et al. "Deformation monitoring of reinforcement bars with a distributed fiber optic sensor for the SHM of reinforced concrete structures." NDE. 2012.

Deformation monitoring

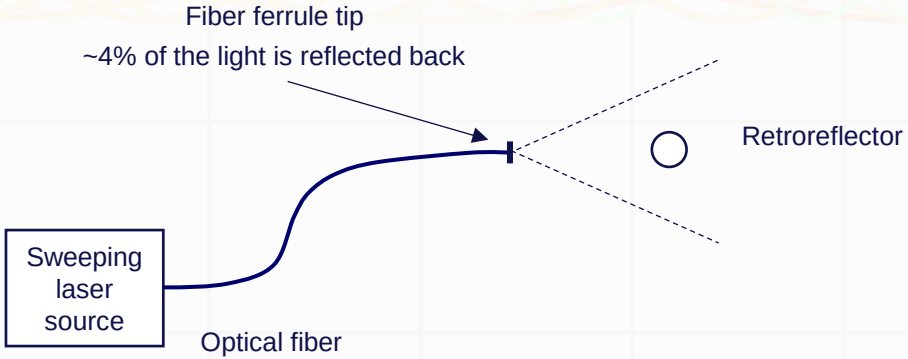
Existing solutions are not entirely adequate, so we investigated the FSI technology.

The Frequency Scanning Interferometry :

- Currently used to perform distance measurements in air



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.



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The Frequency Scanning Interferometry :

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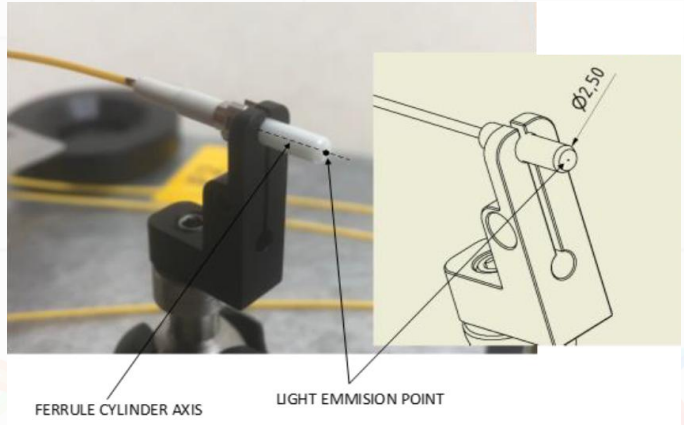
- Based on a Michelson interferometer



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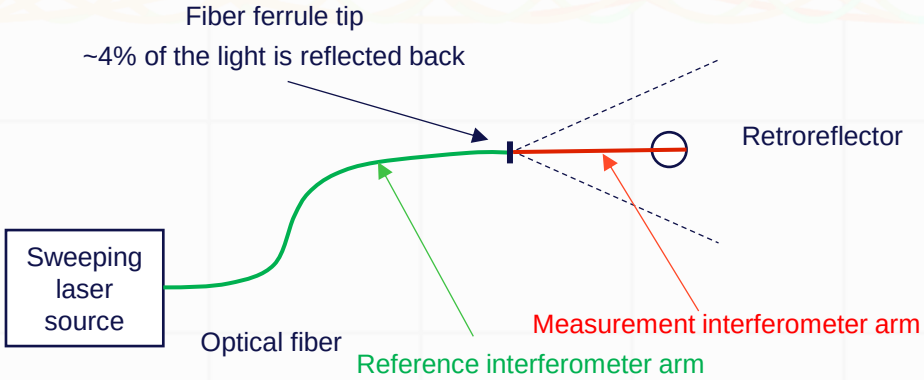

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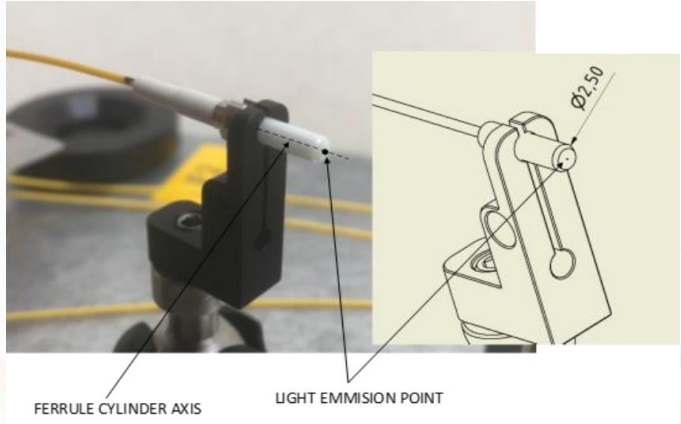
- The sweeping of the laser frequency allows for an absolute distance measurement



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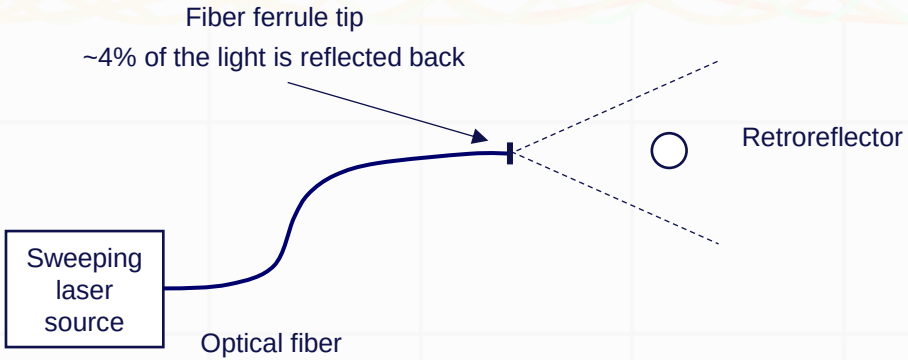

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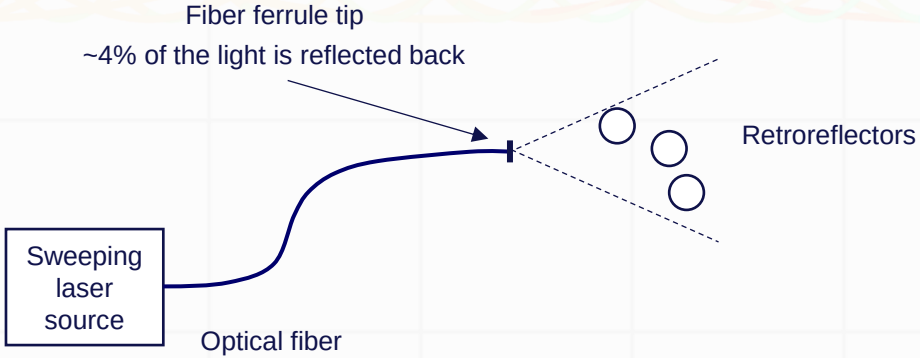
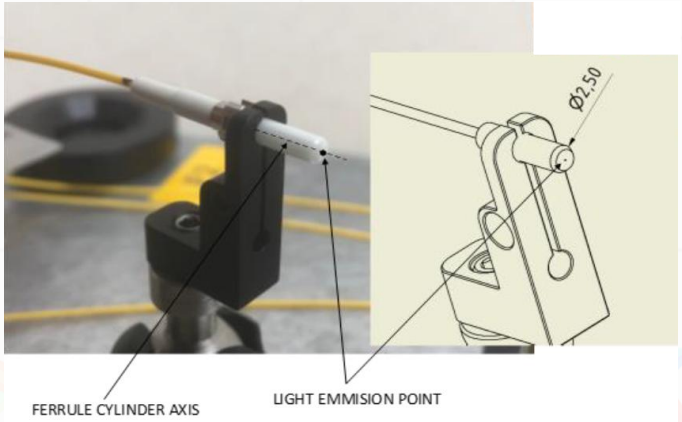
- Based on a Michelson interferometer
- The sweeping of the laser frequency allows for an absolute distance measurement
- Capable of multi-target measurements (only condition is to have different distances measured)

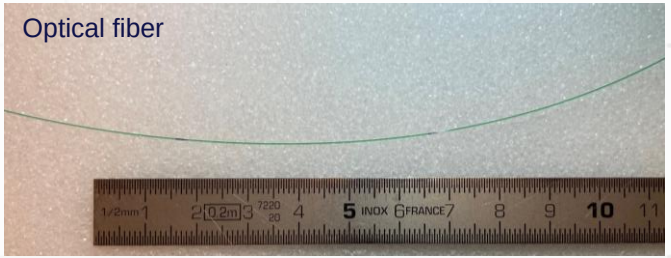




Sosin, M., et al. "Frequency sweeping interferometry for robust and reliable distance measurements in harsh accelerator environment." Applied Optical Metrology III. Vol. 11102. SPIE, 2019.

Retroreflectors commonly used

Deformation monitoring



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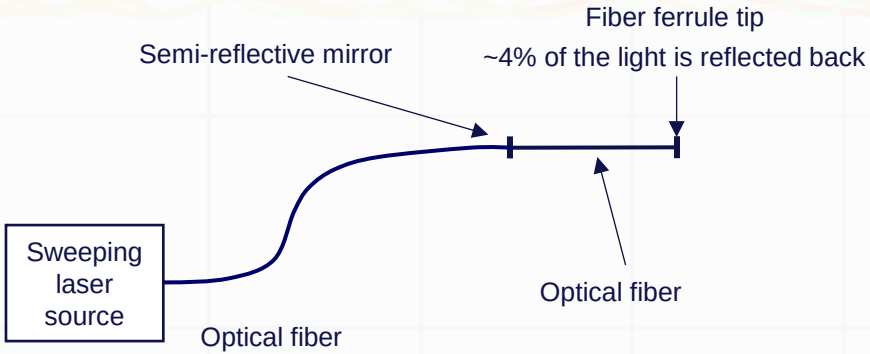
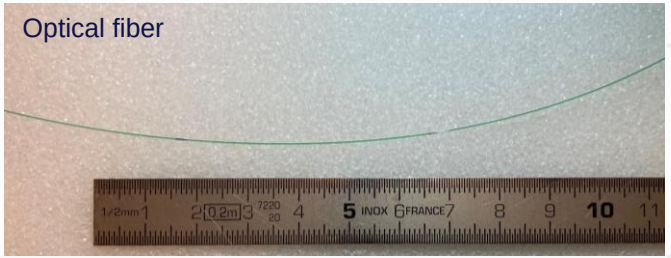
The Frequency Scanning Interferometry development: Measurement of an optical fiber cavity



Deformation monitoring



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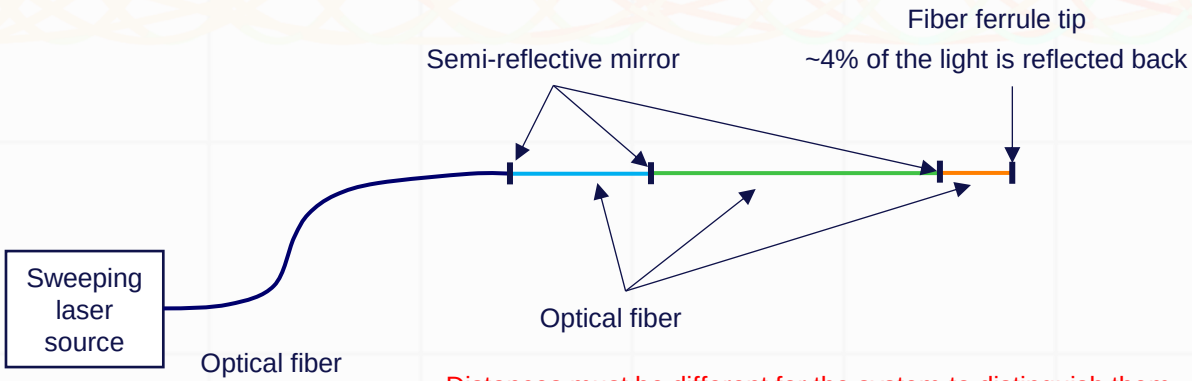
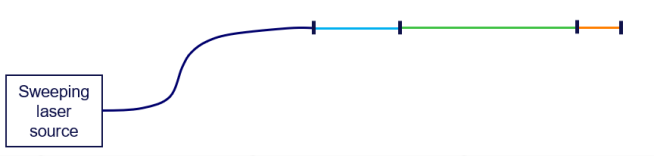


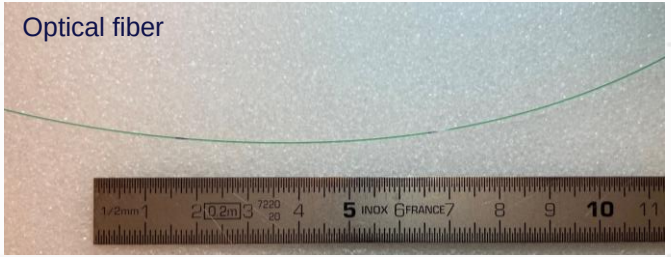
Distances must be different for the system to distinguish them

Watrelot, Léonard, Mateusz Sosin, and Stéphane Durand. "Frequency scanning interferometry based deformation monitoring system for the alignment of the FCC-ee machine detector interface." Measurement Science and Technology 34.7 (2023): 075006.

Deformation monitoring

The idea was to use the developed FSI to perform what we wanted: precise 3D deformation monitoring of a cylinder.





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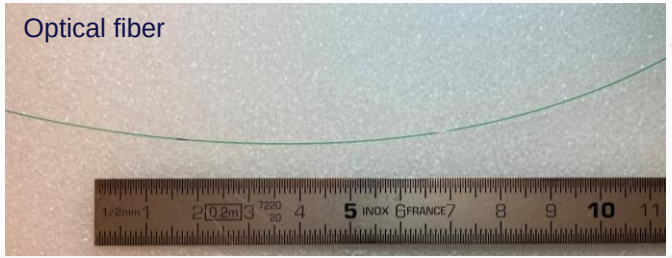

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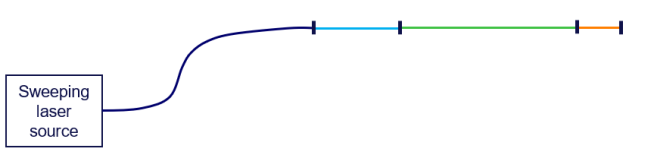
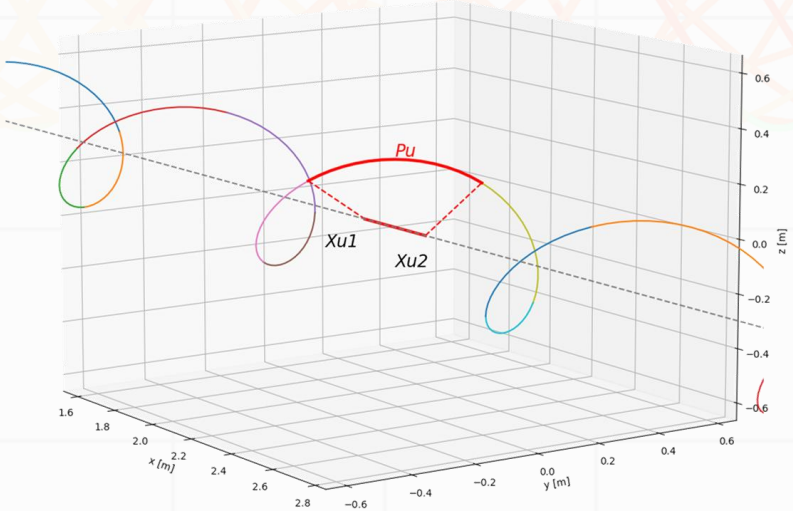
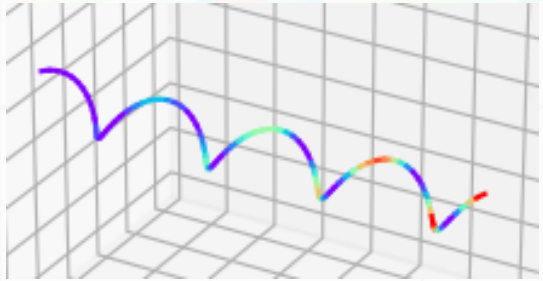


By gluing the fiber to the support in a helix shape it is possible to monitor the deformations.





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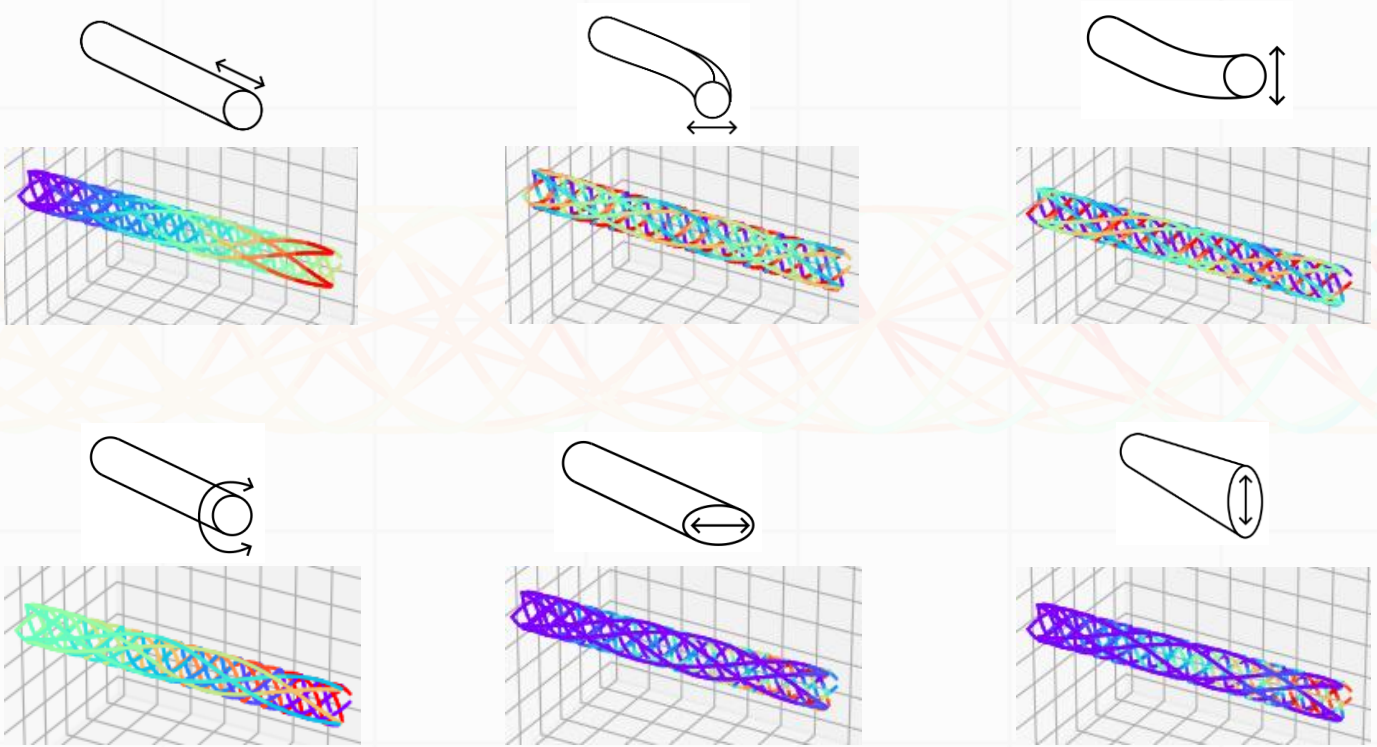
Deformation monitoring: “in-fiber” helix measurement

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



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Deformation monitoring

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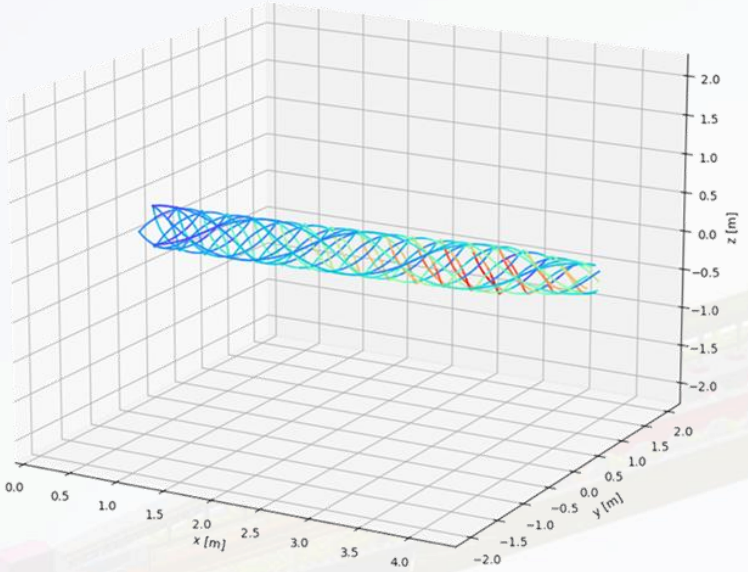
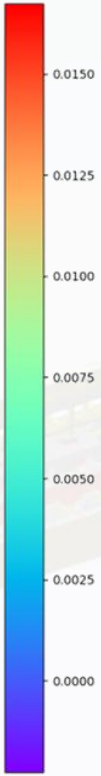
Cylinder deformations

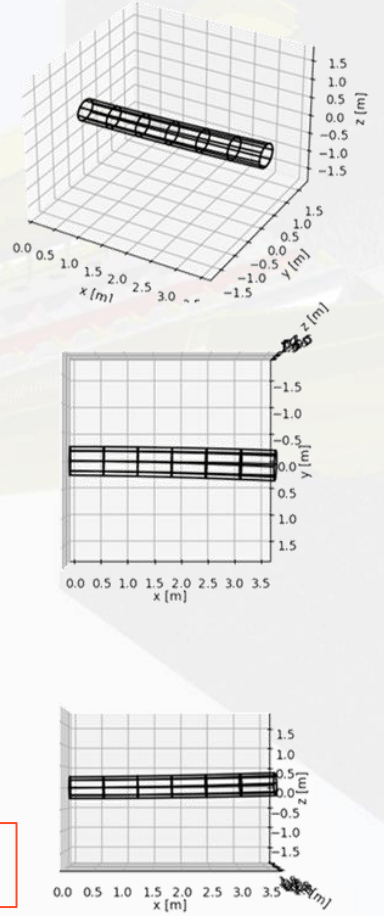
Helixes observations
(= 3D lengths of portions)



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.

Thesis link

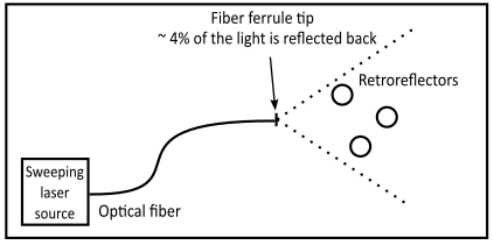
Simulations shown micrometric accuracy
To be confirmed by a prototype

Deformation monitoring

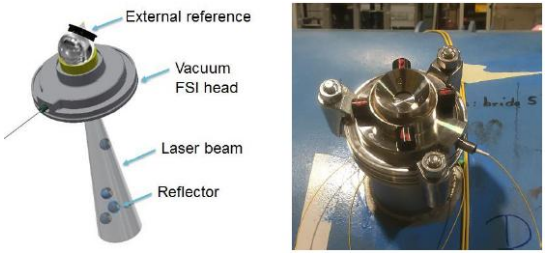
https://iopscience.iop.org/article/10.1088/1361-6501/acc6e3

While the in-air FSI measurement is clearly established and starts to be widely used at CERN …

Current use of the FSI



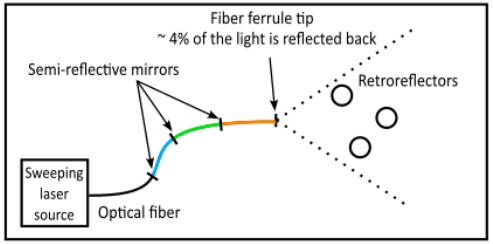
Example of a FSI head prototype measuring on the cold mass from the cryostat



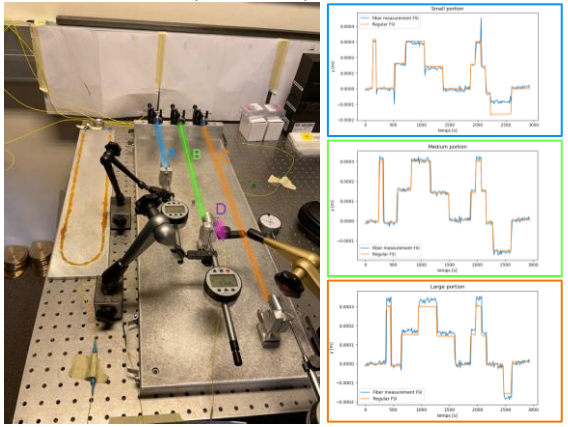
Sosin, M., et al. "Frequency sweeping interferometry for robust and reliable distance measurements in harsh accelerator environment." *Applied Optical Metrology III*. Vol. 11102. SPIE, 2019.

… the In-Lined Multiplexed and Distributed FSI measurement is only at its first prototypes.

Multiplexed measurements performed for the FCC



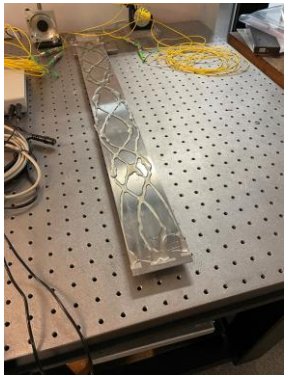
First prototype for the In-lined Multiplexed and Distributed FSI (cf. article)

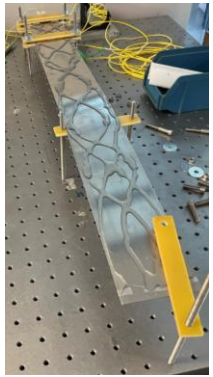


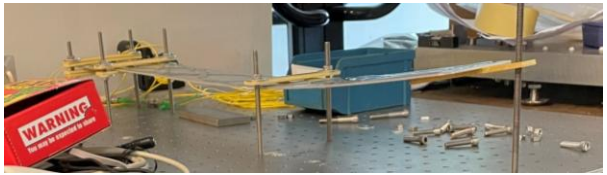
Thesis link

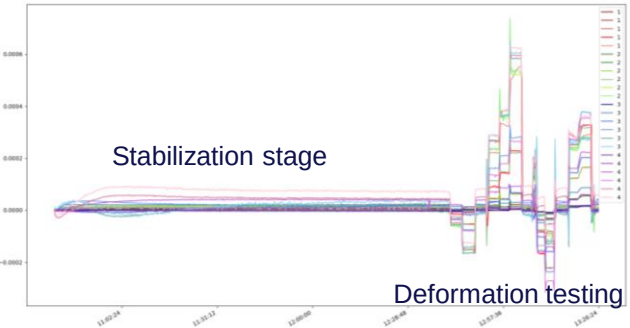
Latest and ongoing prototypes

Sensor glued on an aluminum plate



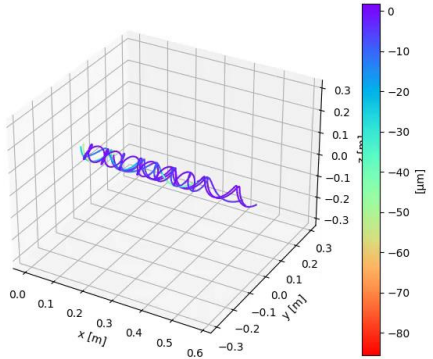


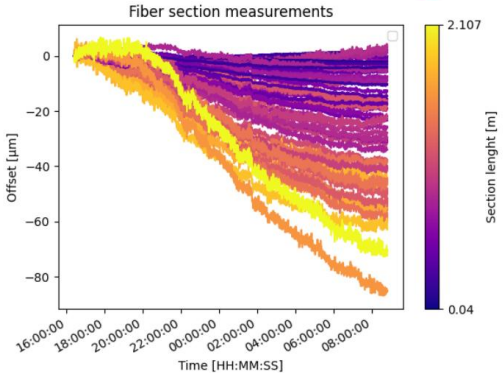




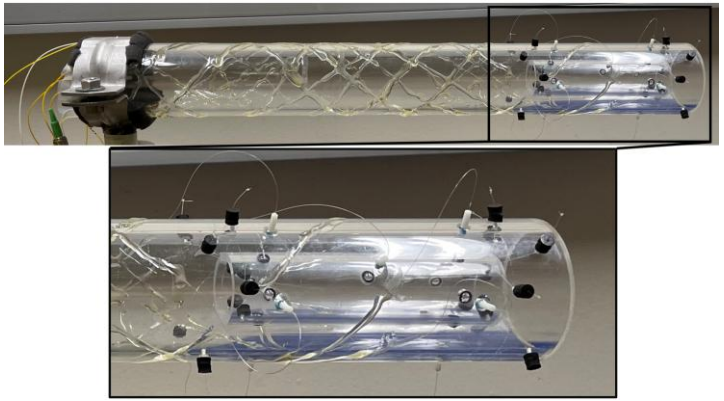
First prototype with helix fibers

Monitoring of the glue curing

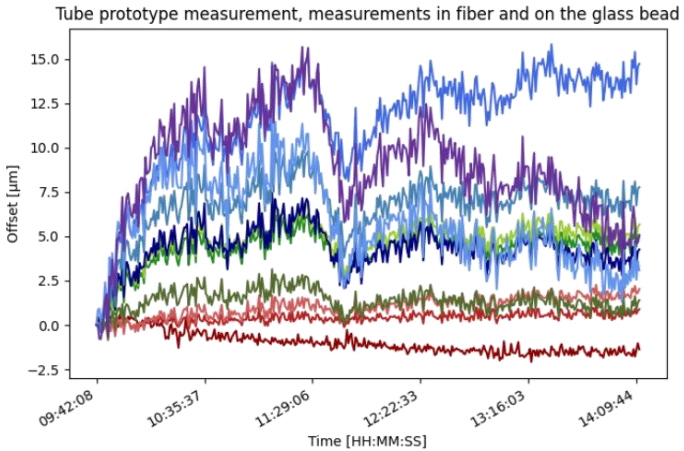




Prototype implementing the fiber measurement and the FSI measurement on reflector



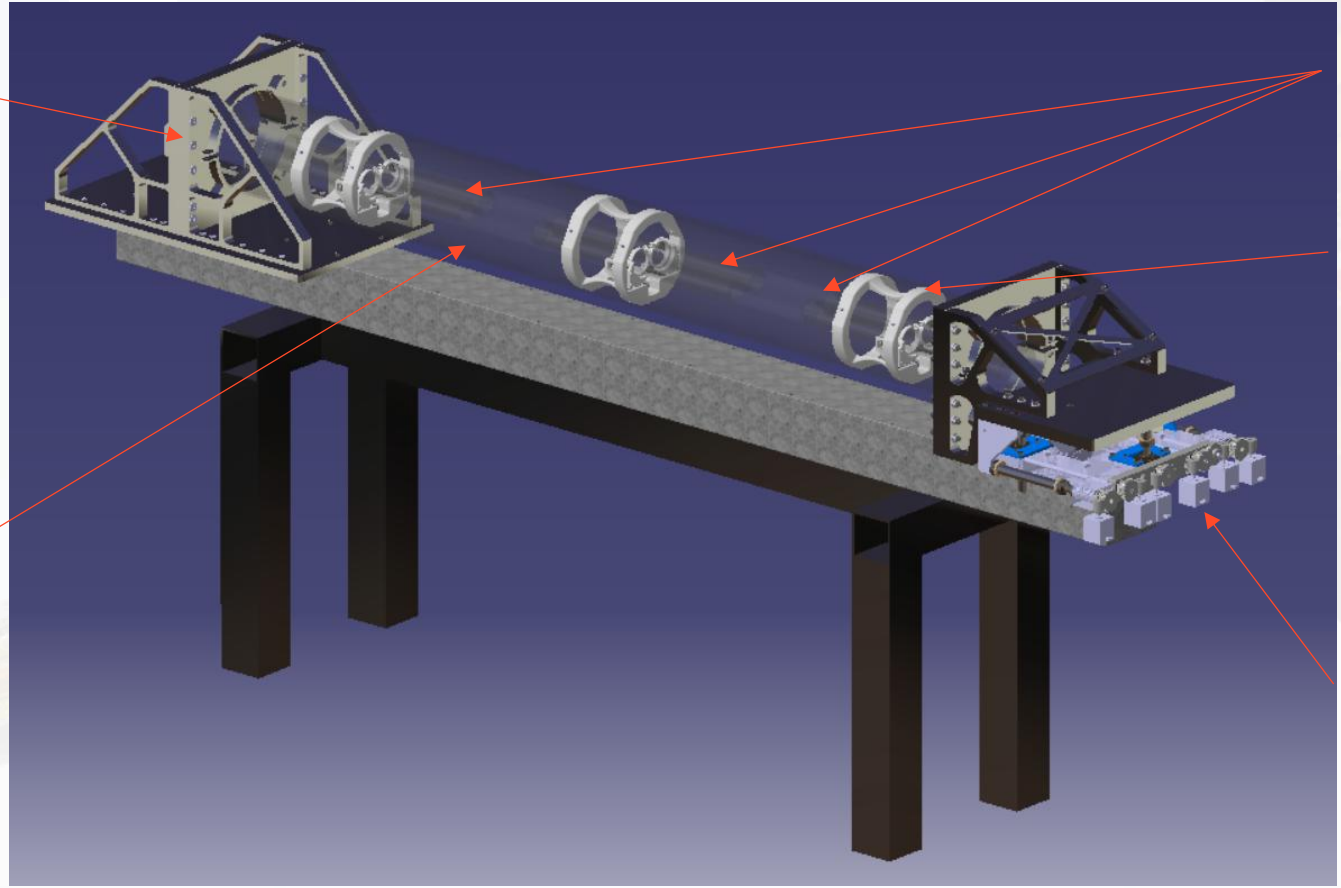
Measurements performed by a single fiber



MDI alignment monitoring mock-up: design and goal

Stable support, simulating the support outside the detector

2m long plastic tube, simulating the support of the screening solenoid on which the fibers will be installed



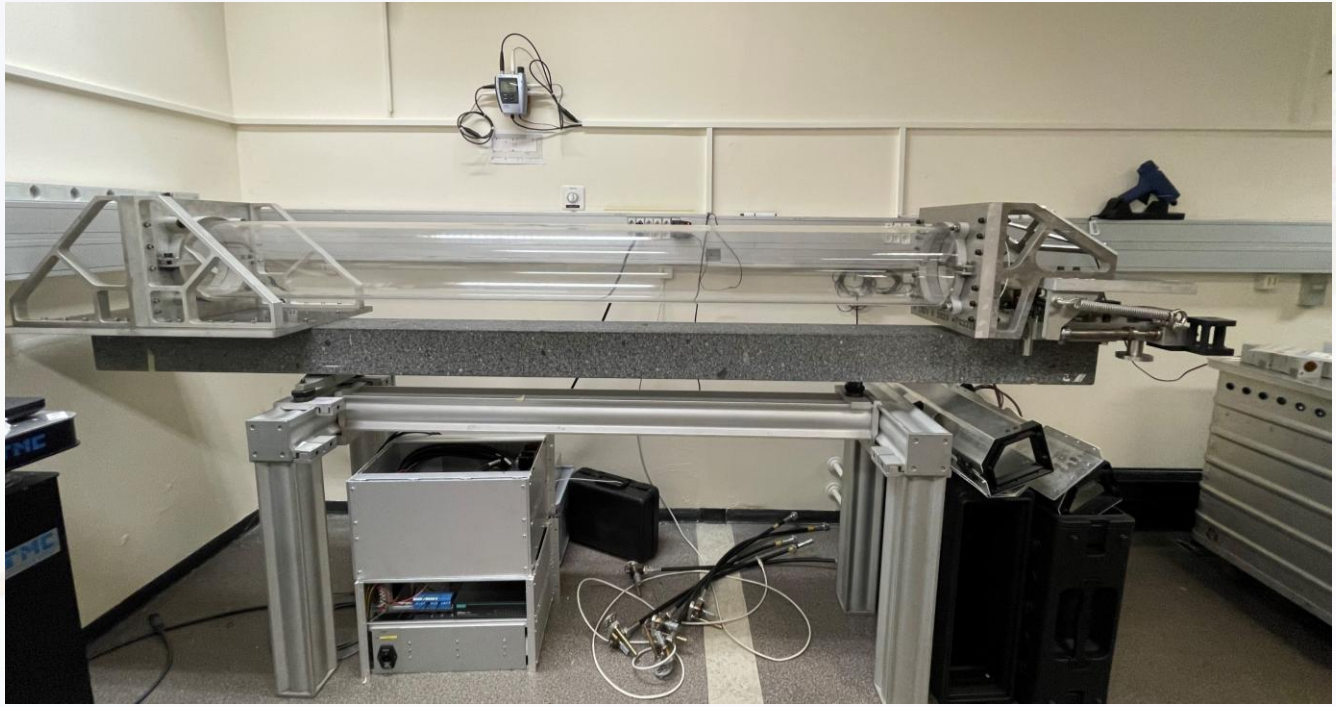
6x Smaller plastic tubes simulating the final focusing quadrupoles

3D printed supports and motorised kinematic mounts for the simulated final focusing quadrupoles

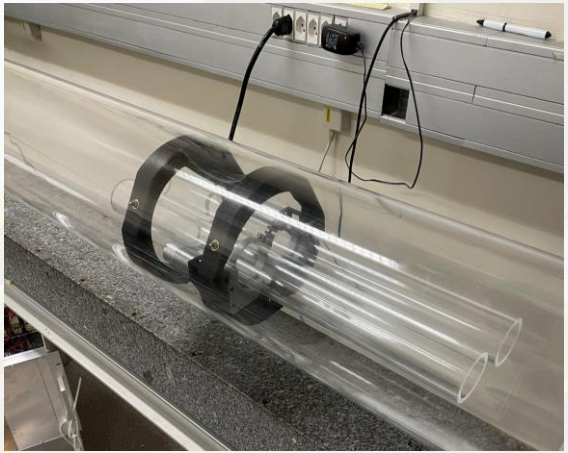
Very precise movable plate (Universal Adjustement Platform) to induce deformations

MDI alignment monitoring mock-up: first assembly

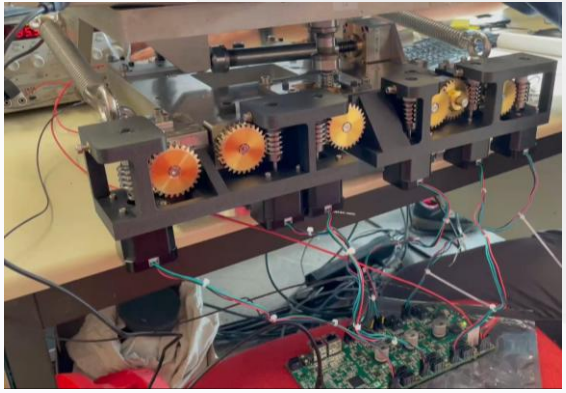
First assembly of the alignment monitoring mock-up.
UAP is being updated.
Initial deformation tests to be done using a dummy cylinder.



3D printed supports for the smaller cylinders

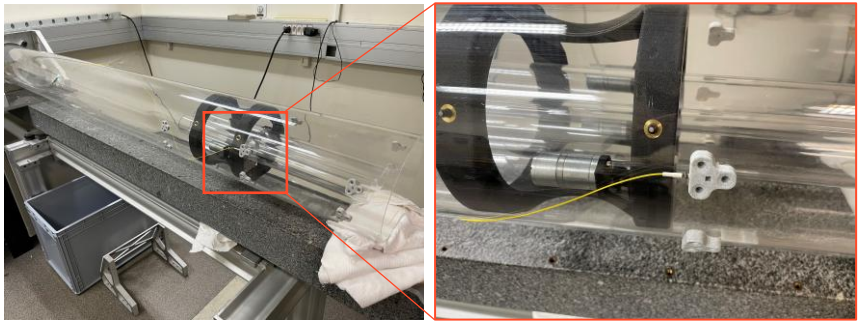


New controls and gears for the UAP



MDI alignment monitoring mock-up: FSI heads preparation

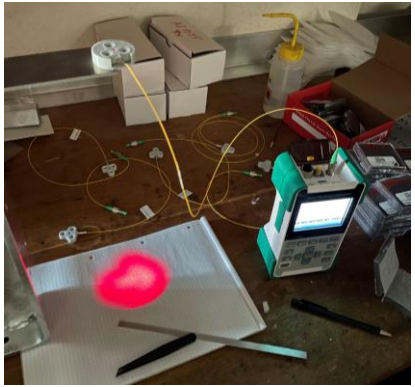
Preparation of FSI heads that will perform the classic “in-air” measurement towards the final focusing quadrupoles.



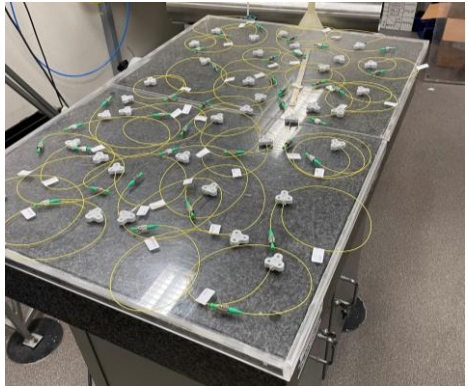
Calibration of all measuring heads thanks to a calibration bench

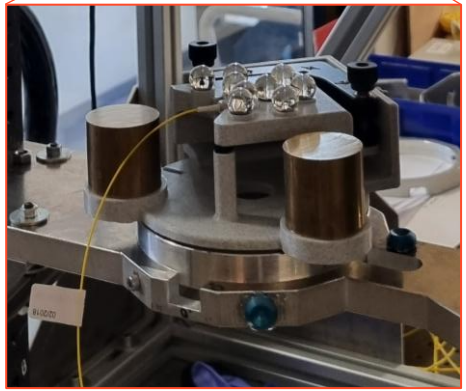
Gluing of the magnets

Installation of the prisms and checking the measuring cone



Gluing of the prisms, ready for the calibration



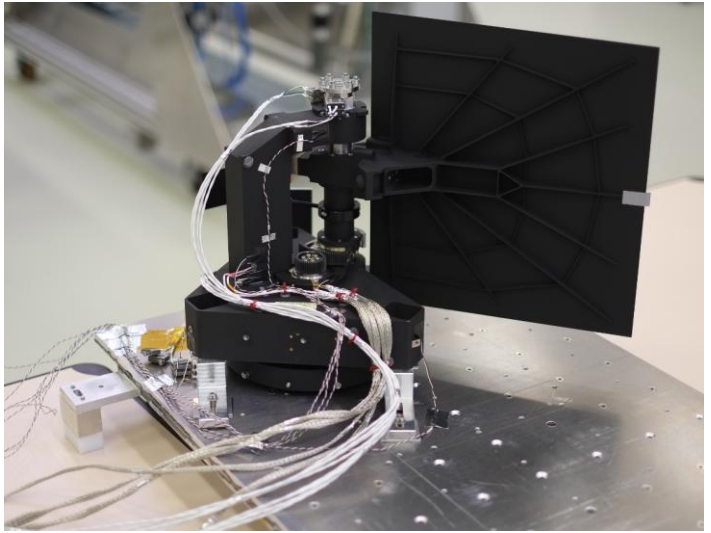


Thank you for your attention

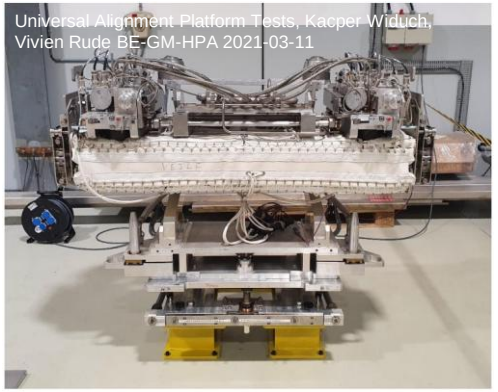
Re-adjustment system

- 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).



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 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.