FCC-EE MDI ALIGNMENT AND MONITORING STRATEGY

Léonard WATRELOT
PhD student, CERN BE-GM-HPA section, SMI, CNAM (Conservatoire National des Arts et Métiers)

Mark JONES (CERN) and Stéphane DURAND (GeF, CNAM)

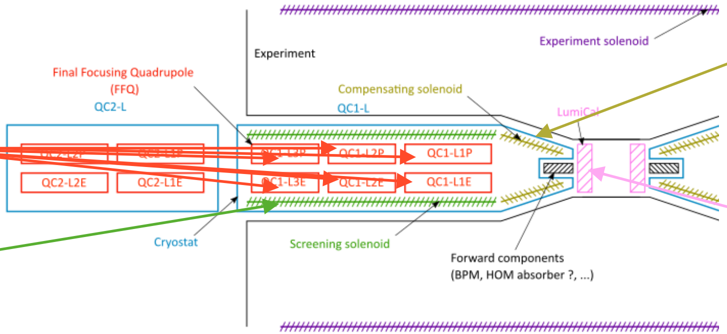
Many thanks to :
Manuela Boscolo, Michael Koratzinos, Hélène Mainaud Durand, Mika Masuzawa, Luigi Pellegrino, Mateusz Sosin and Vivien Rude

Why is this alignment difficult to do ?

- Design (lot of components to measure, layered design, very little space, design not definitive)
- Conditions (cryogenic temperature, radiations, magnetic fields)
- Requirements (very tight alignment requirement, especially on Final Focusing Quadrupoles, BPM, Screening and Compensation solenoids, and LumiCal)

FFQ : Alignment tolerance at 30 µm + Monitoring

Screening solenoid : Alignment tolerance at ~100 µm + Monitoring



Compensation solenoid : Alignment tolerance at ~100 µm + Monitoring

LumiCal
Alignment tolerance at 50 µm w.r.t. the IP (longitudinal) + Monitoring

Misalignment tolerances include all possible error sources such as: manufacturing errors, assembly errors, deformation both during/after installation and during operation, magnetic field measurements, metrology measurement, reference network and alignment measurement, anticipated degradation in the alignment over time as a function of ground motion and other effects.

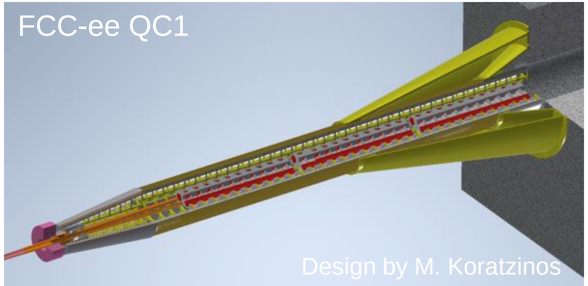
Experience from previous accelerator projects indicates that a reasonable assumption for the relative radial alignment precision can be derived by applying a factor 1/3.

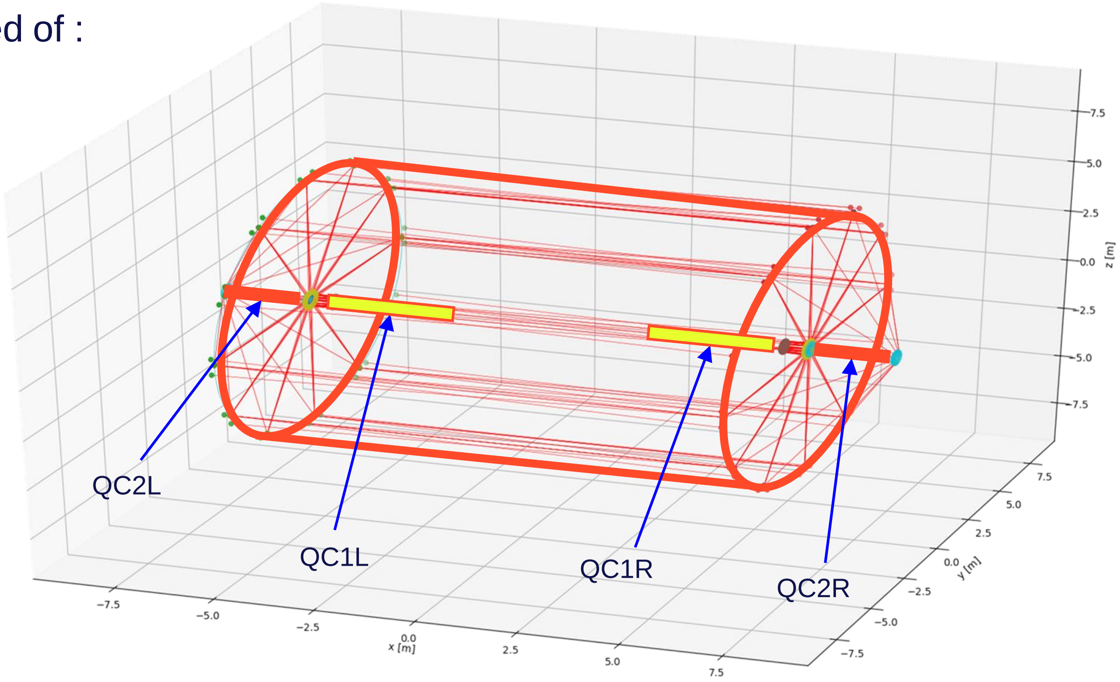
Alignment tolerance at 30 µm => alignment precision required <10 µm

No solution from other MDI

Proposition of a strategy for the alignment and monitoring of the MDI

- Alignment and monitoring system composed of :
  - External alignment system
  - Internal alignment system





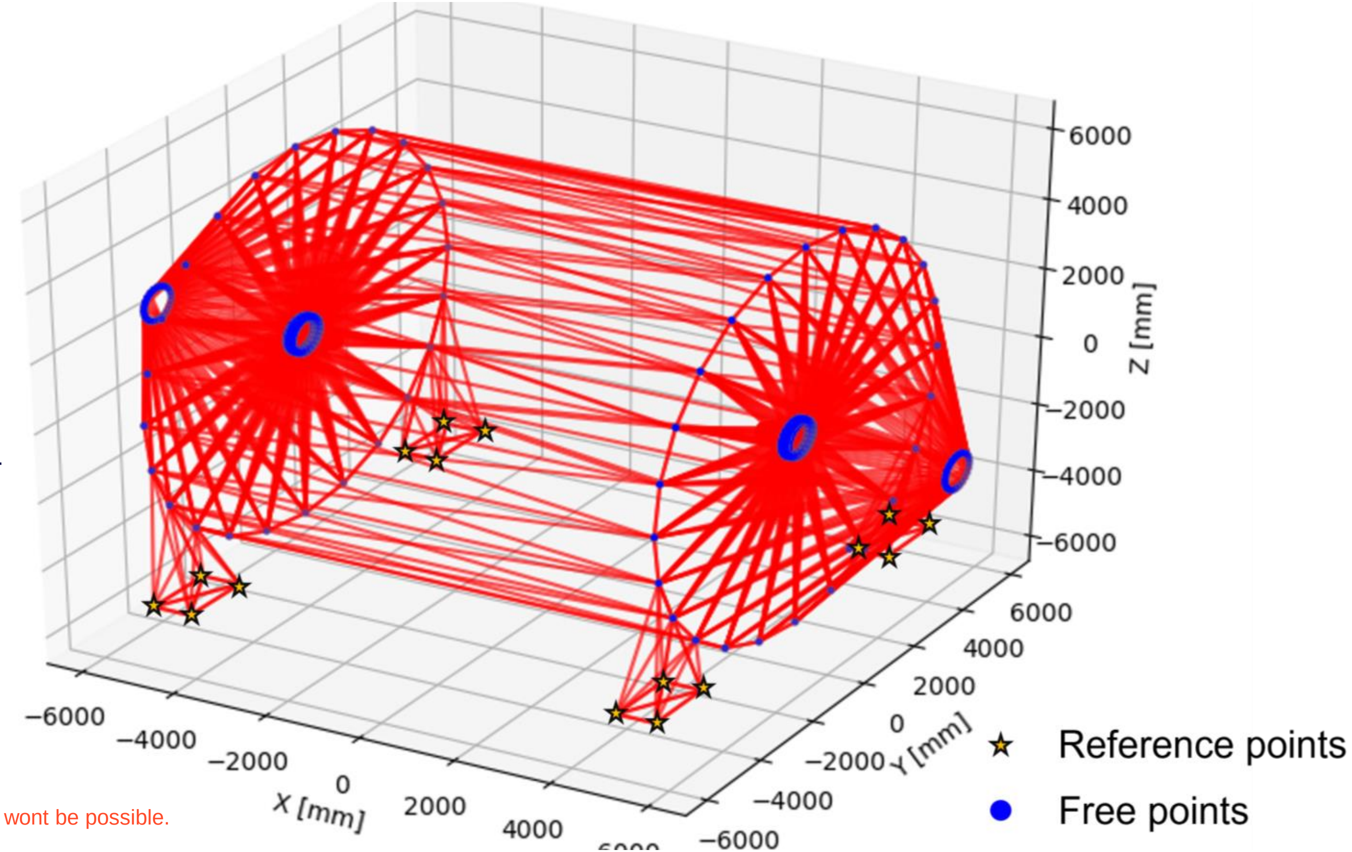
Internal alignment is very challenging !!!

External alignment and monitoring system

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

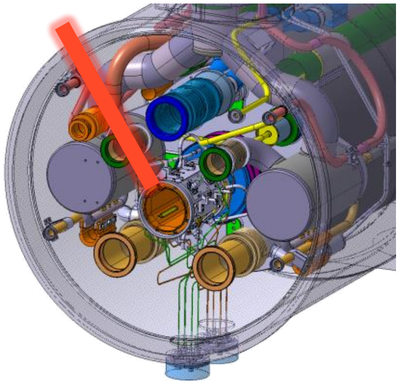
Goals :

- 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.

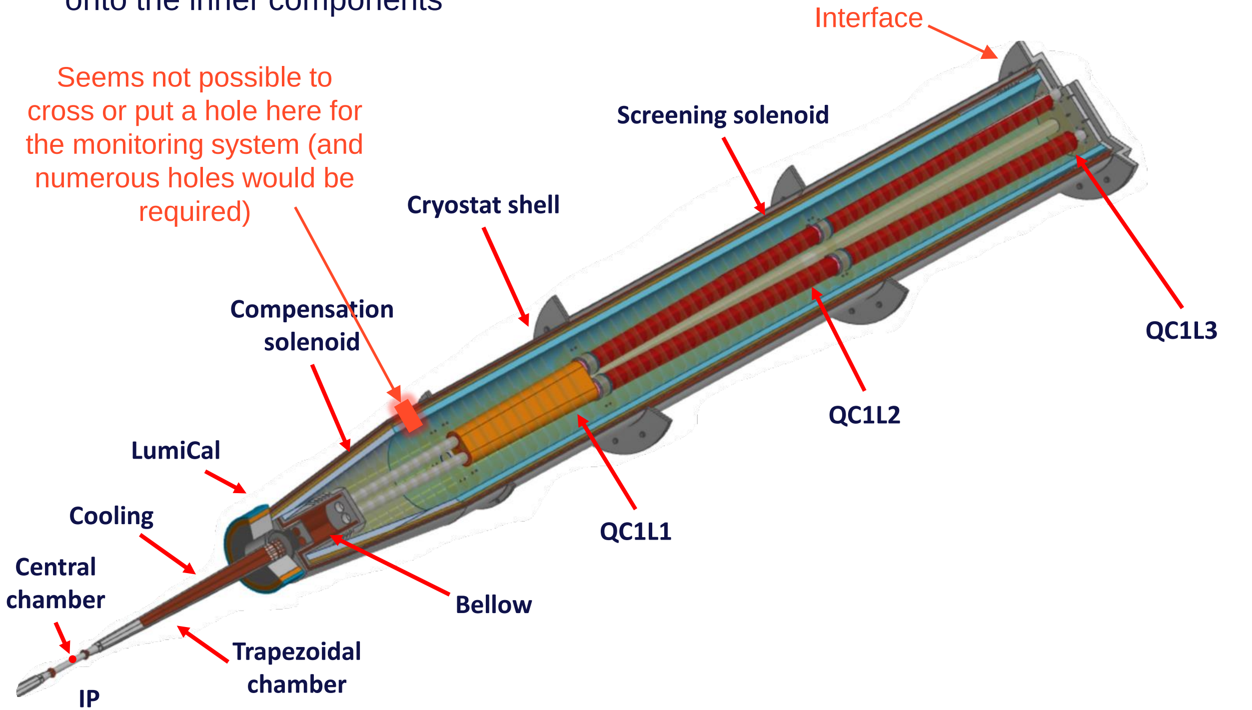


Optimal network : too much measurements, some (plenty) wont be possible.
Any update on the design would be much welcomed.

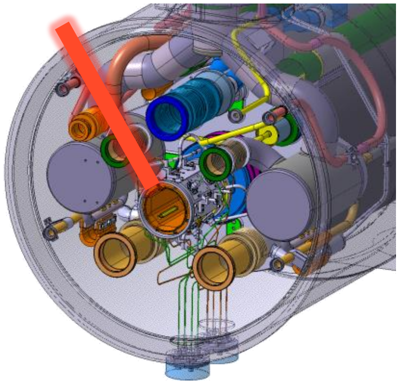
Internal alignment system



- 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



Internal alignment system



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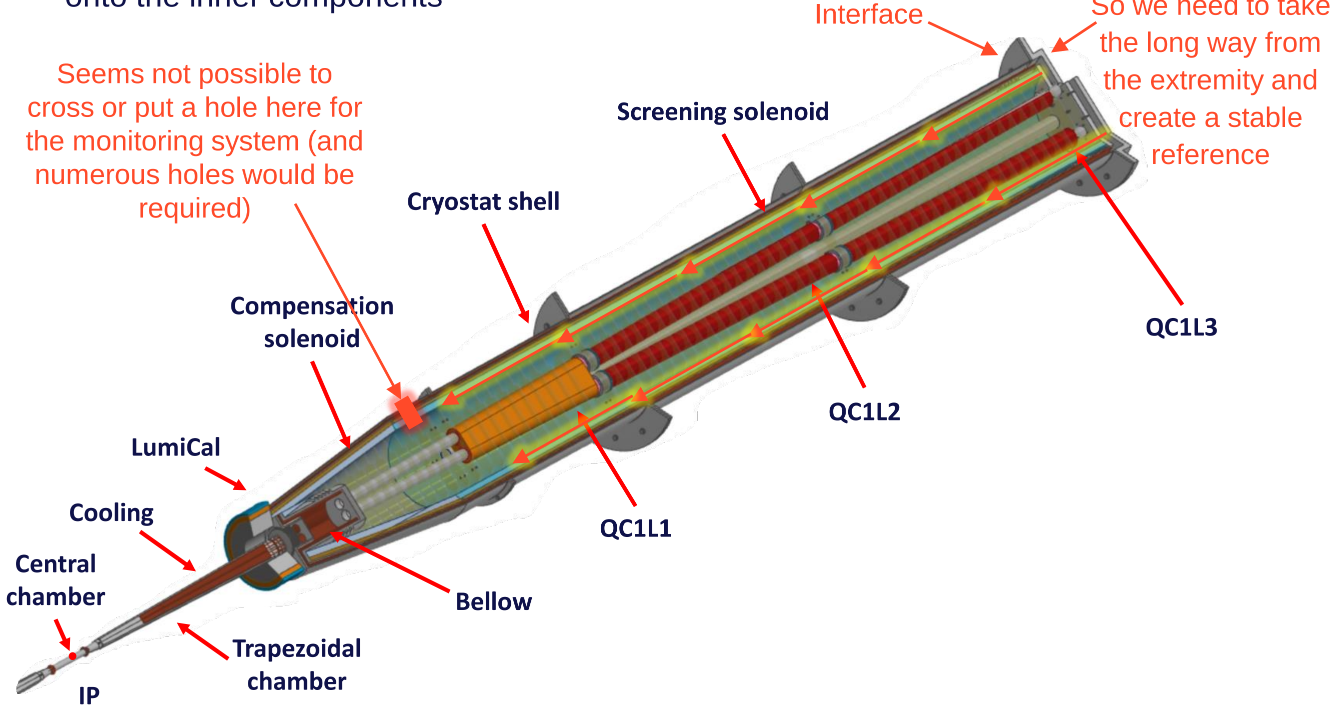
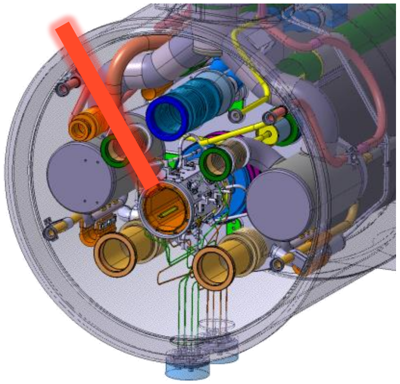


Internal alignment system



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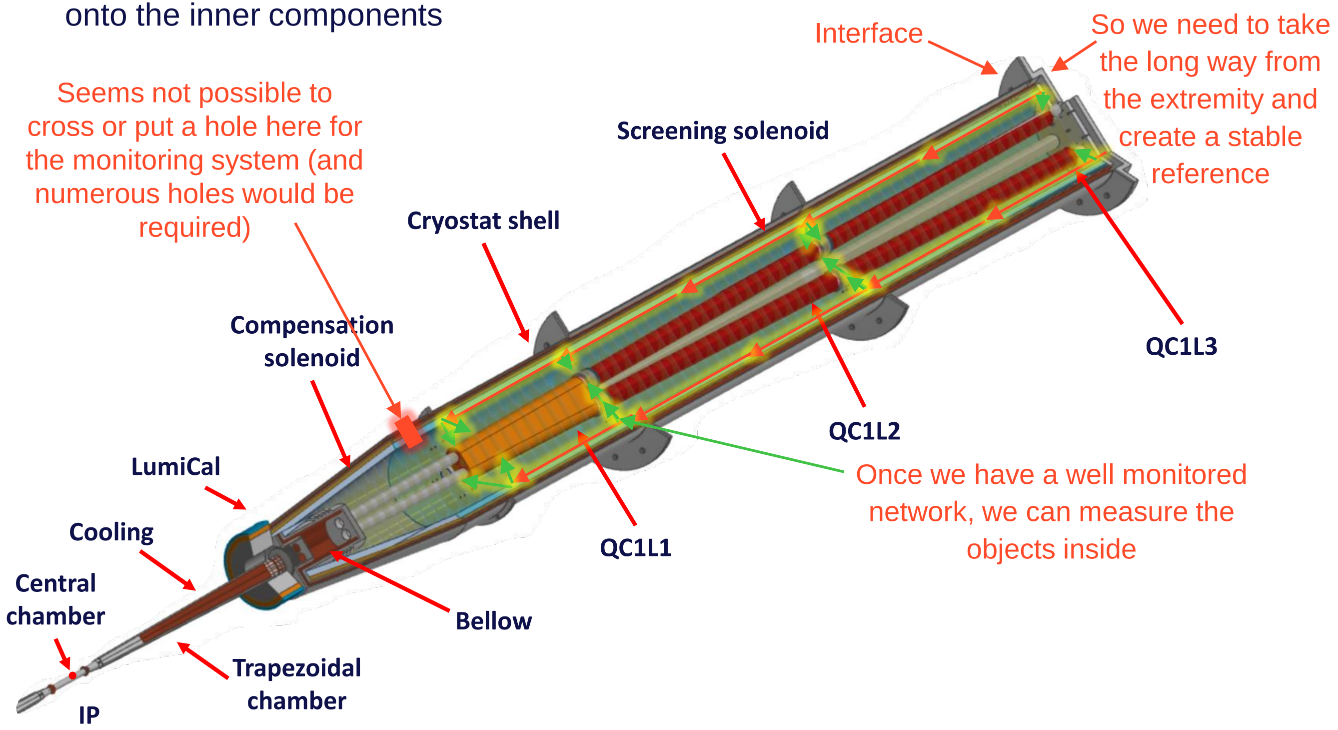
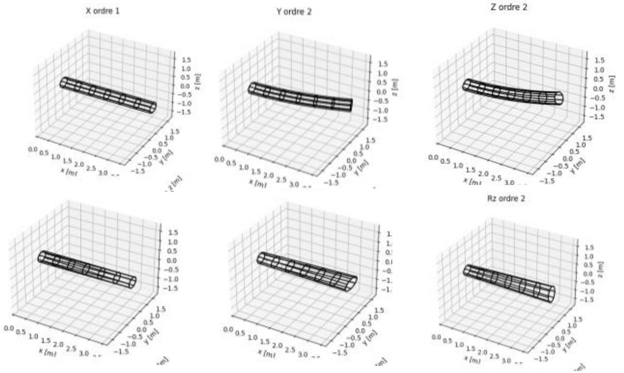
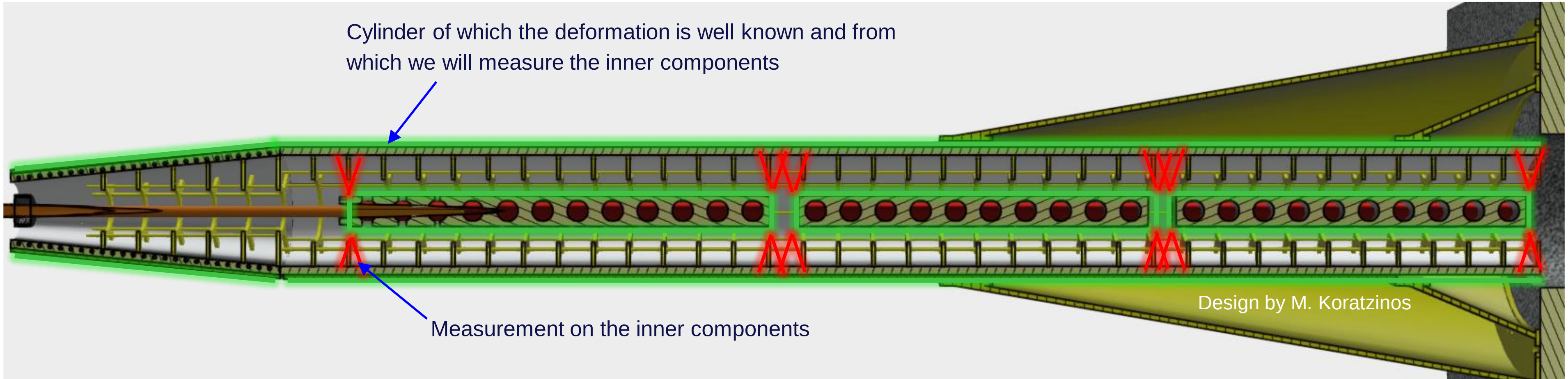


Internal alignment system

Deformation models



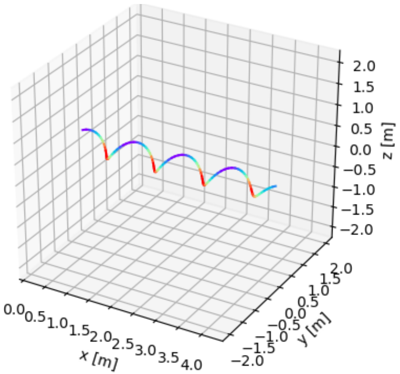
- ➢ Goal : monitor the deformation extremely precisely ove the length of the assembly
- ➢ Create a network of points accurate enough so another system can measure from it onto the inner components
- ➢ Deformation monitoring system + distance measurement system



- ➢ Measurement system waiting for design update.

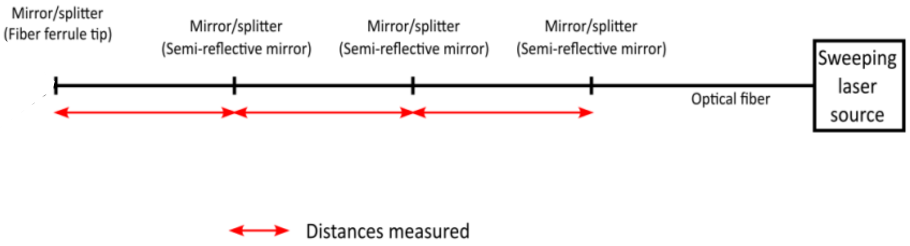
Deformation monitoring

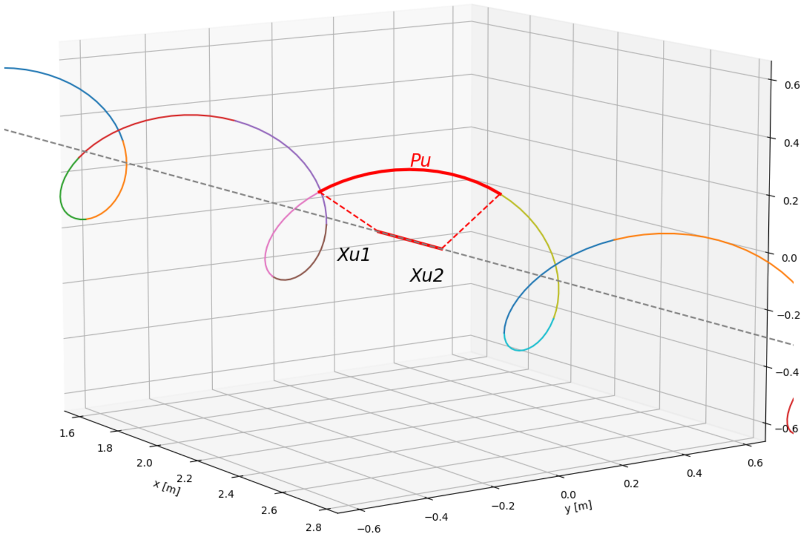
https://iopscience.iop.org/article/10.1088/1361-6501/acc6e3



- 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

- Two technology available for such measurements :
  - SOFO (Surveillance d'Ouvrage par Fibre Optique) (locked at a prototype state)
  - In-line multiplexed and distributed FSI measurement (in development at CERN)





Deformation monitoring

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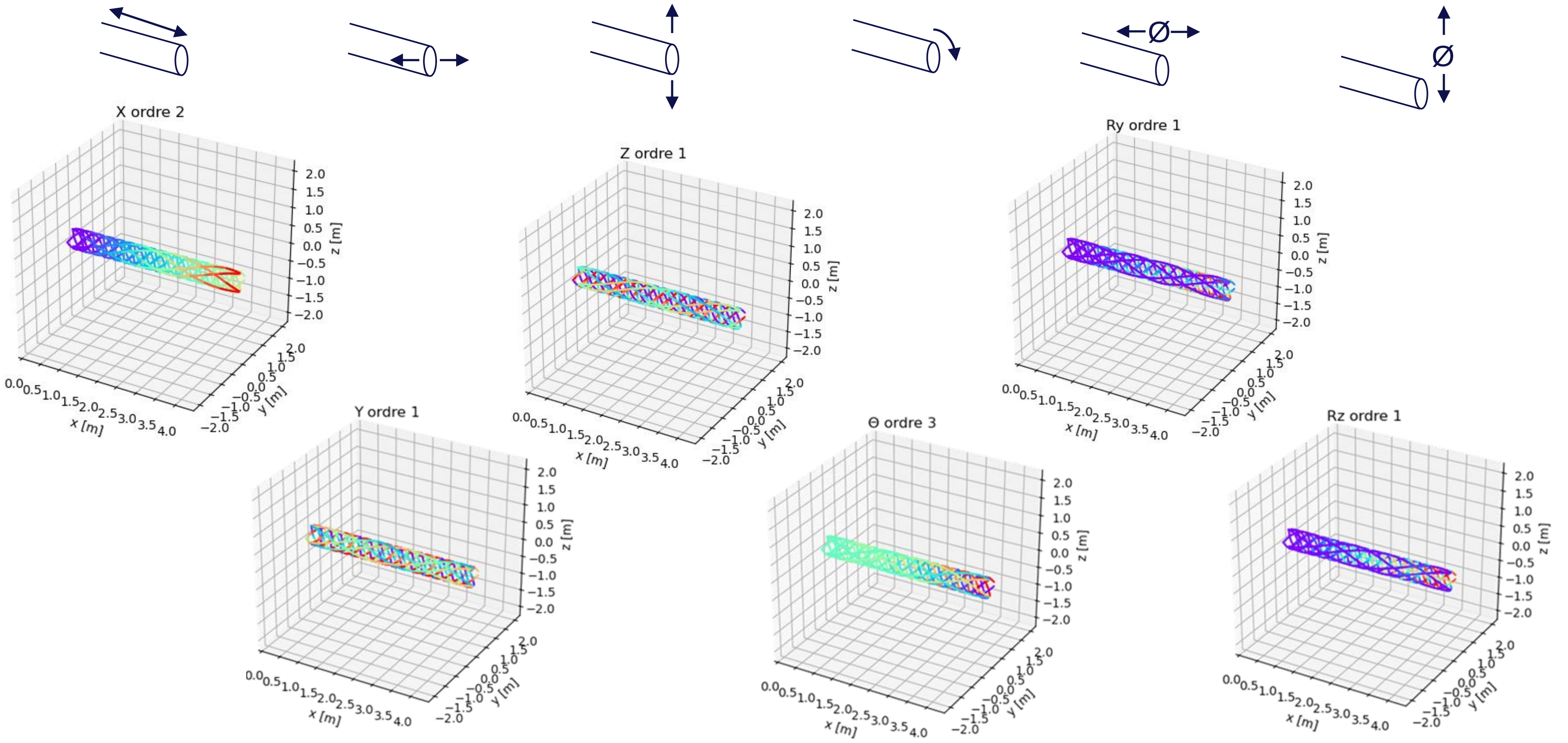

Deformation monitoring

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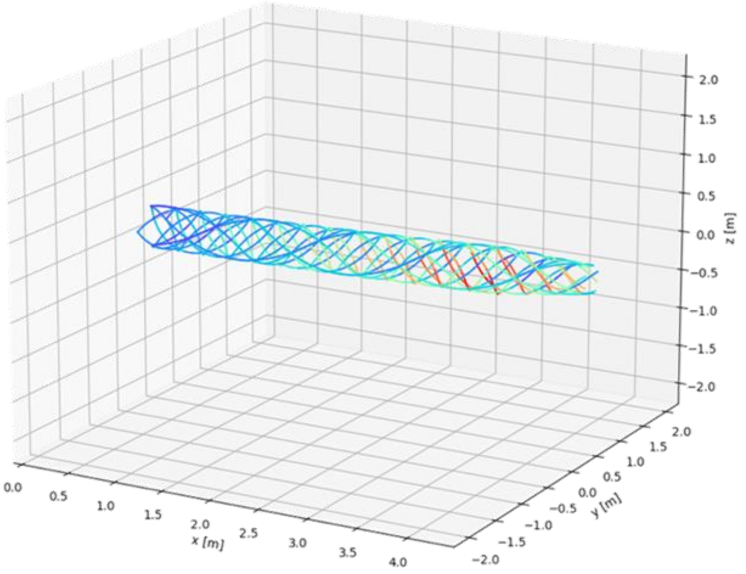
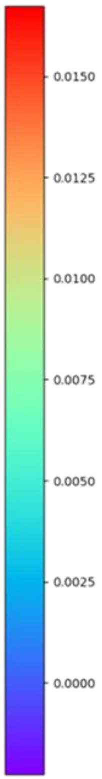
Helixes observations
(= 3D lengths of portions)





+ equation of portion length as function of the deformation polynomials

Least square adjustment

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

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

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

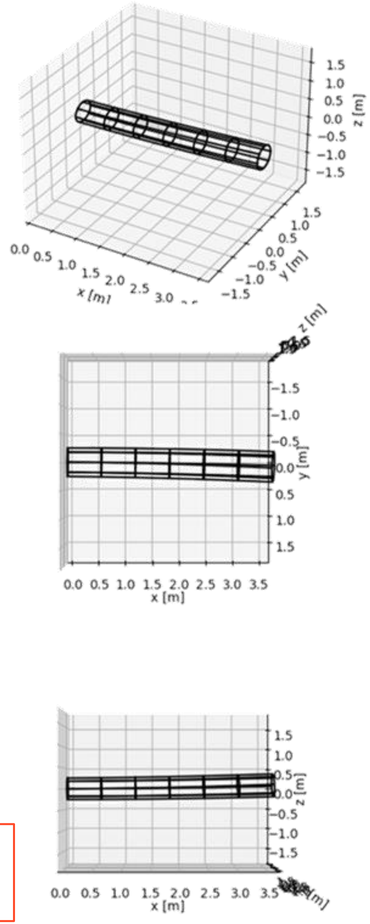
$$P_\theta(t) = \sum_{i=1}^{n} d_i t^i$$

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

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

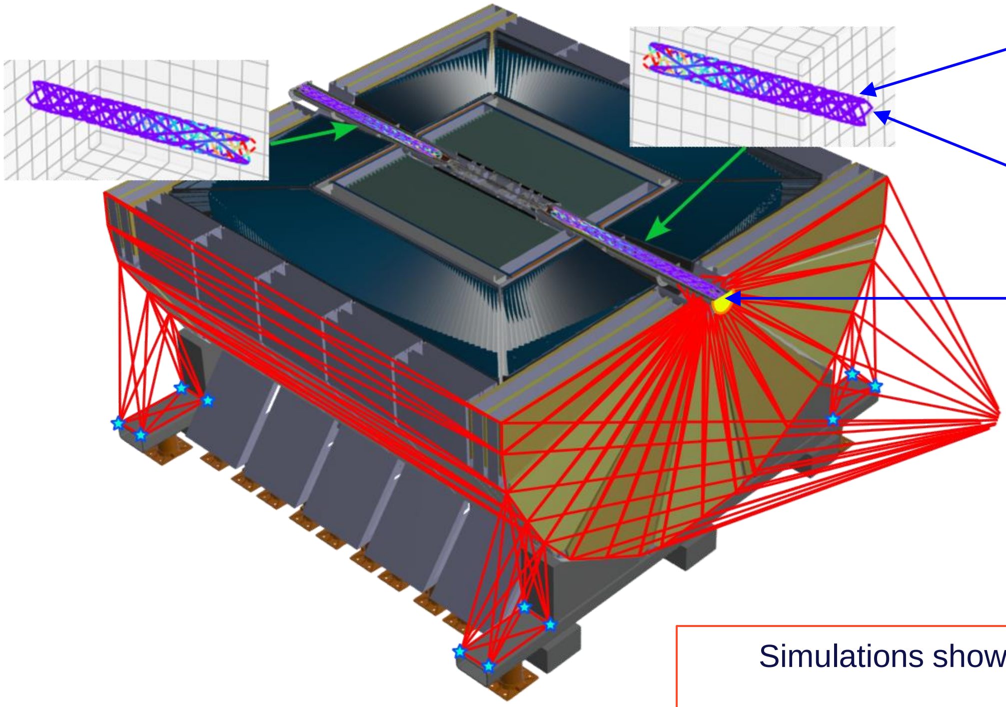
Deformations parameters

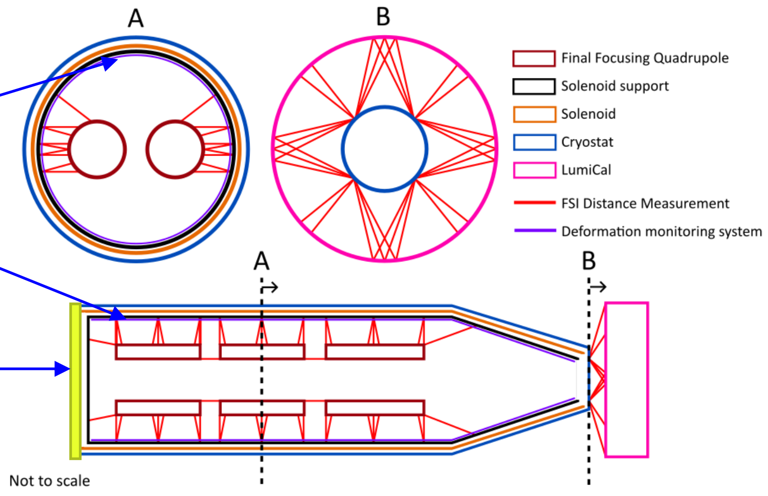
Cylinder deformations



Simulations shown micrometric accuracy
To be confirmed by a prototype

Full alignment and monitoring system

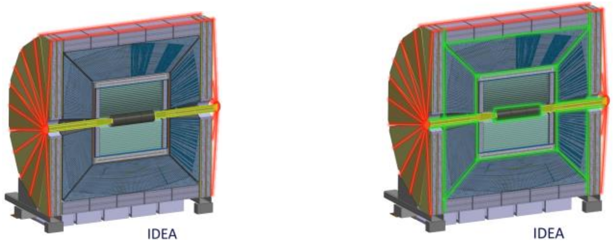




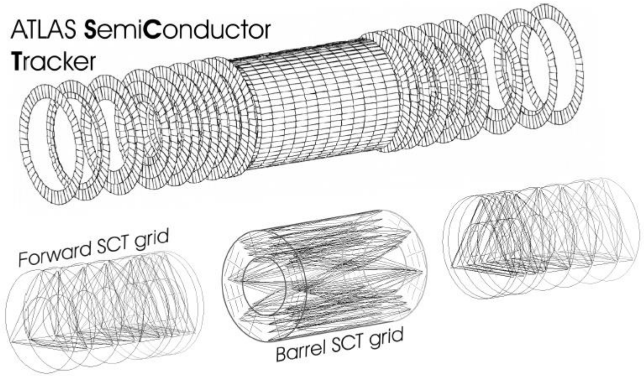
Simulations shown micrometric accuracy for the alignment between final focusing quadrupoles on both sides.
To be refined with upcoming updates of the detector design.

Alignment strategy proposal

The MDI alignment system could be seen as a standalone backbone, on which sub-system alignment systems could connect.

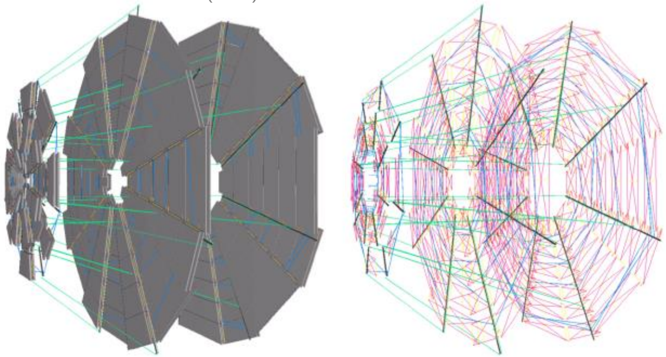


Gibson, S. M., et al. "Monitoring the heart of ATLAS using Frequency Scanning Interferometry." Proceedings of the Eighth International Workshop on Accelerator Alignment, CERN, Geneva. 2004.



- Layout of the alignment system in the silicon detector modules in the ATLAS SemiConductor Tracker.
- Use of Frequency Scanning Interferometry.
- Relative alignment of the detector parts up to bellow 50µm

Aefsky, S., et al. "The optical alignment system of the ATLAS muon spectrometer endcaps." Journal of Instrumentation 3.11 (2008): P11005.



- Layout of the alignment system in one muon spectrometer endcap.
- Use of optical alignment systems.
- Relative alignment of the detector parts up to bellow 100µm

⇒ Thanks to the detectors it is possible to measure the position of the IP and/or the position of the beam (relatively accurately with respect to the detector part)
⇒ This could be linked with the alignment system installed on the accelerator, allowing to link the position of the IP, the LumiCals and the FFQ.
⇒ Would be a win-win to link with relative measurement the machine and the detector (especially for the dense FCC-ee MDI).

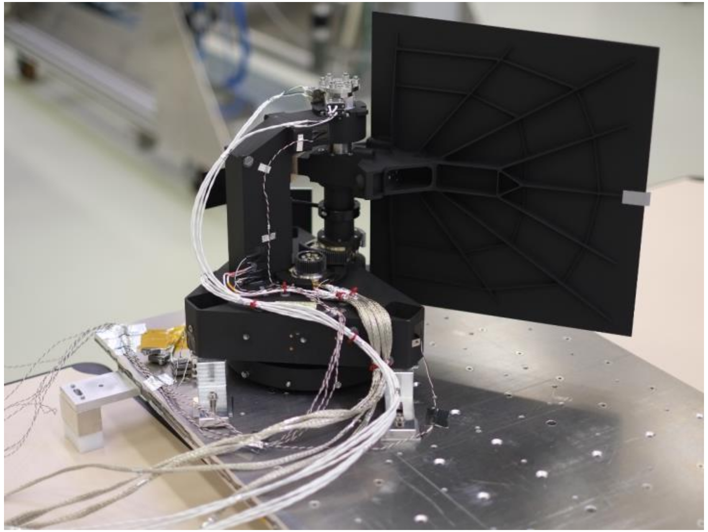
Re-adjustment system

- ➢ 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.

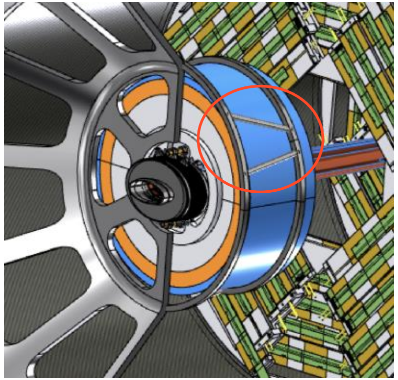
A lot of possibilities are open, from the system working only at warm temperature allowing a re-adjustment to the 0,1mm level of major components at the end of shut downs, to the system able to realign in real time and during the run of the machine the cold components to the micrometer level.

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.

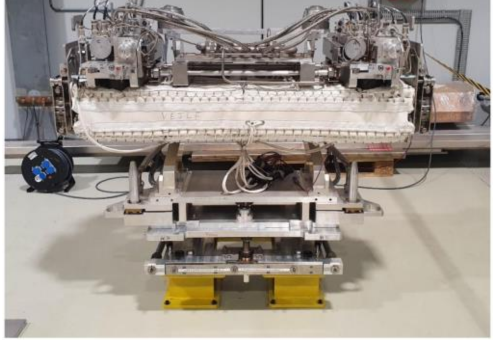
The EUCLID VIS Read-out Shutter Unit, which will operate in space



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

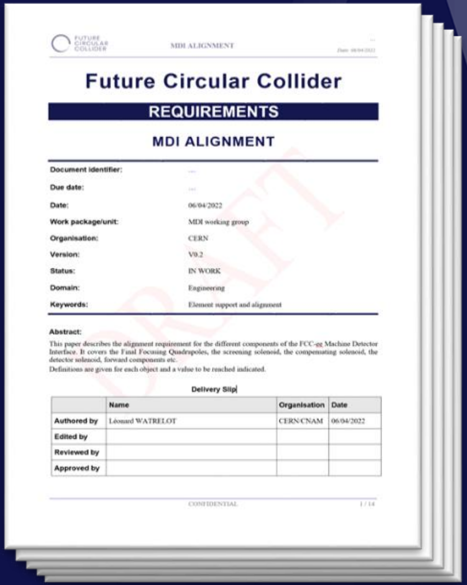


Fabrizio Palla's presentation of yesterday



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

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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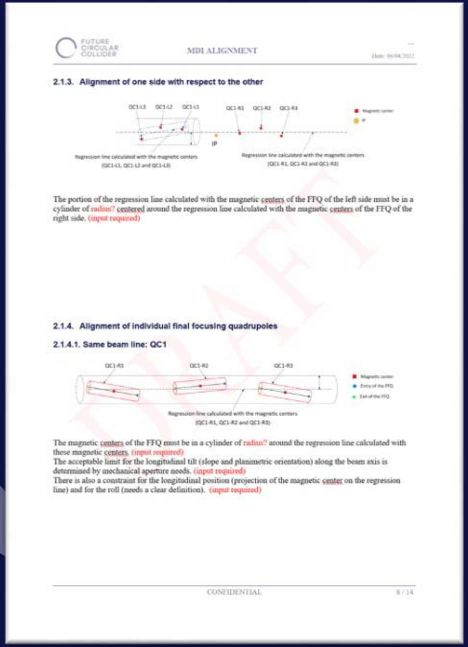

MDI ALIGNMENT

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)

CONFIDENTIAL

- "Internal misalignment should be better than 30µm",
M. Koratzinos, "CCTFF quad design status", MDI workshop, 30/01/2018

- "Final Focusing quads misalignment (QC1_1-QC1_3 and QC2_1-QC2_2) (if not respected, beams do not collide):
  - Geodesy : transverse shift of FF quads with sigma xy= 25µm
  - vibrations : transverse shift of FF quads with sigma xy= 0.1µm

IR BPM misalignment (if not respected, beams do not collide) :
  - geodesy : transverse shift of BPM with sigma xy= 25µm
  - vibrations : errors of BPM reading with sigma xy= 0.1µm

The beam parameters are destroyed after correction of 25 µm IR BPM misalignments
S.Sinyatkin, "Orbit errors at the FCC-ee due to the FF quadrupoles displacements"

- "Measurement of the component's position inside the detector is needed",
A. Bogomyagkov, A. Krasnov , E. Levichev , S. Pivovarov , S. Sinyatkin, BINP, "Summary and comments on Machine Detector Interface", MDI workshop 09-20 september 2019

- " The distance between the two calorimeters has to be measured to 110 µm",
M. Boscolo, "Summary of the 2nd FCC-ee MDI workshop", Workshop on the mechanical optimization of the FCC-ee MDI, january 30 to february 9 2018, CERN

- "Internal to LumiCal : assembly and metrology/ alignment of Si readout pads to ~1.5µm radial precision External to LumiCal : need very high precision : distance LumiCal/ nominal IP to be controlled/ measured to ~50µm level",
M. Boscolo, "FCC-ee MDI design as outcome of the first week of MDI workshop and goal of this week workshop", Workshop on the mechanical optimization of the FCC-ee MDI, January 30 - February 9 2018, CERN quoting Mogens Dam/ NBI Copenhagen

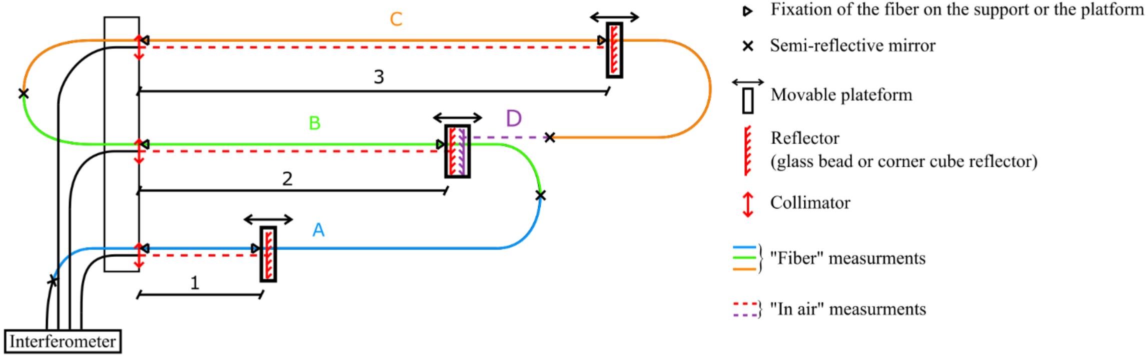
- "Alignment accuracy of SC magnets = 100µm"
M. Boscolo, CEPC workshop MDI design highlight (24th MDI meeting)

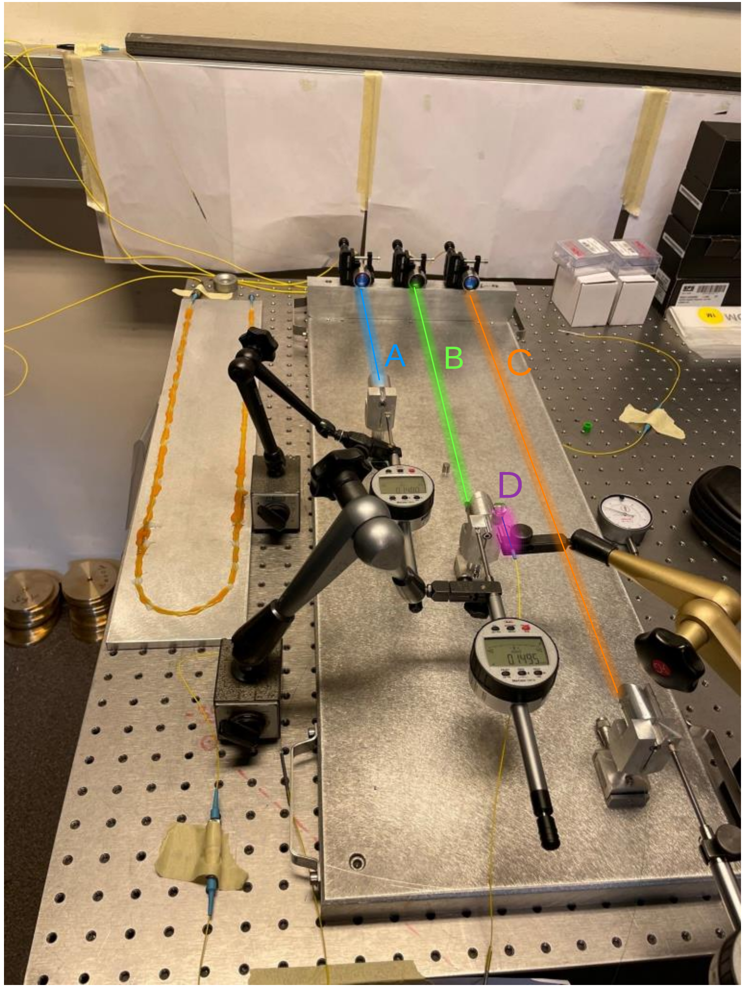
- "For a 1mrad tilt of the detector solenoid (wrt the rest of the system – beam, screening and compensation solenoid) the corresponding uncorrected distortion is unacceptably large."
Mike Koratzinos

- "IR quadrupoles and sextupoles (75µm in radial and longitudinal, 100µrad roll), BPM (40µm in radial and 100µrad for the roll relative to quadrupole placement)."
Summary of emittance tuning results, Tessa Charles, 20/10/2020

In-line multiplexed and distributed FSI prototype and first tests

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





- A bench has been assembled
- 3 independent measuring portions + “regular” in-air measurement at the end
- Verification thanks to regular FSI measurements
- “Stability bench” made by gluing a fiber to an aluminium plate

In-line multiplexed and distributed FSI prototype and first tests

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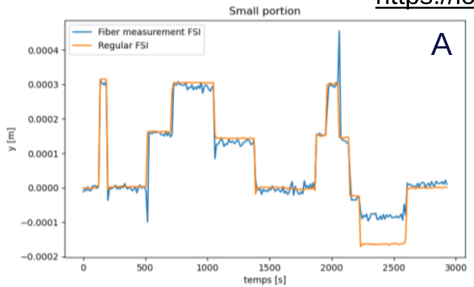
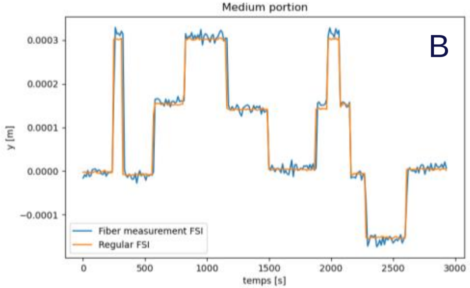
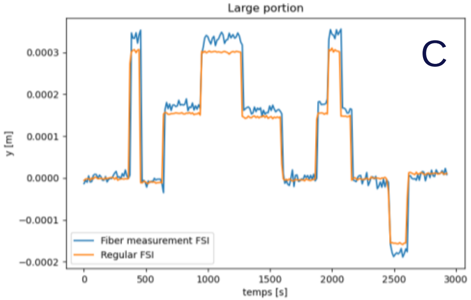
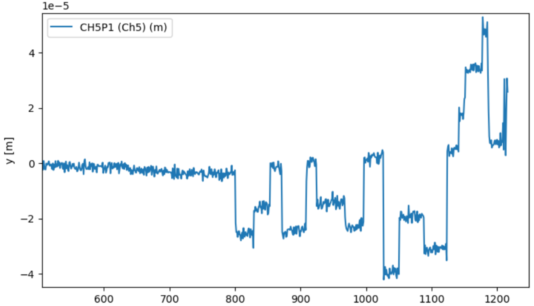
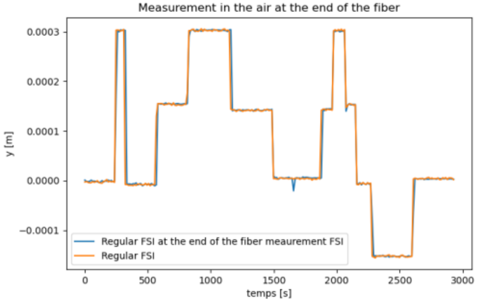
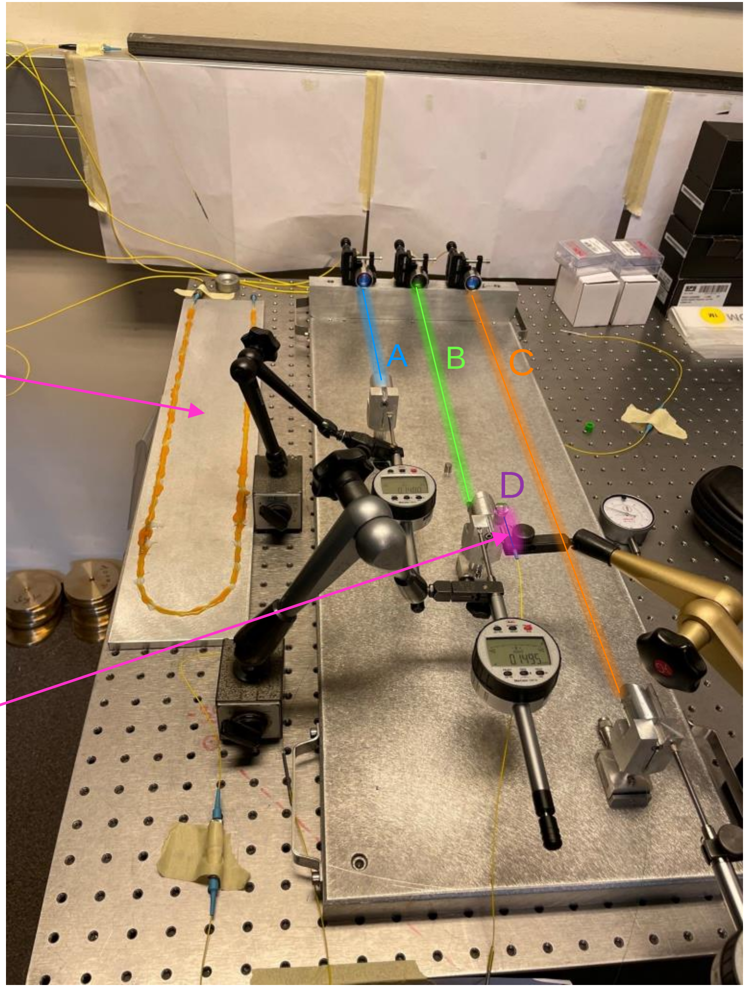






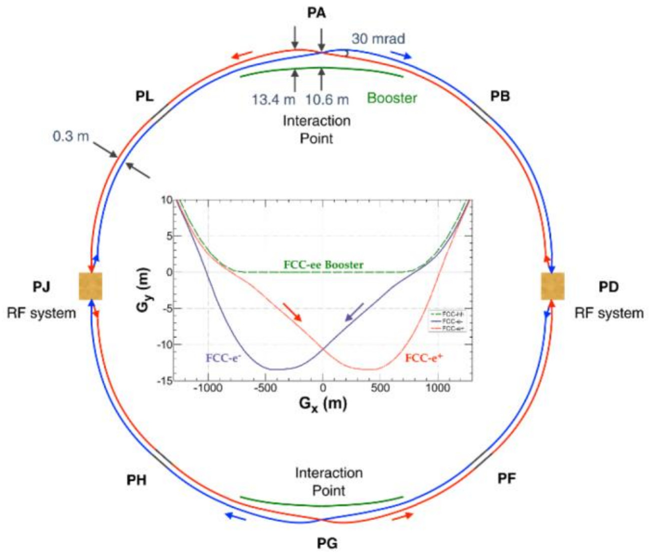


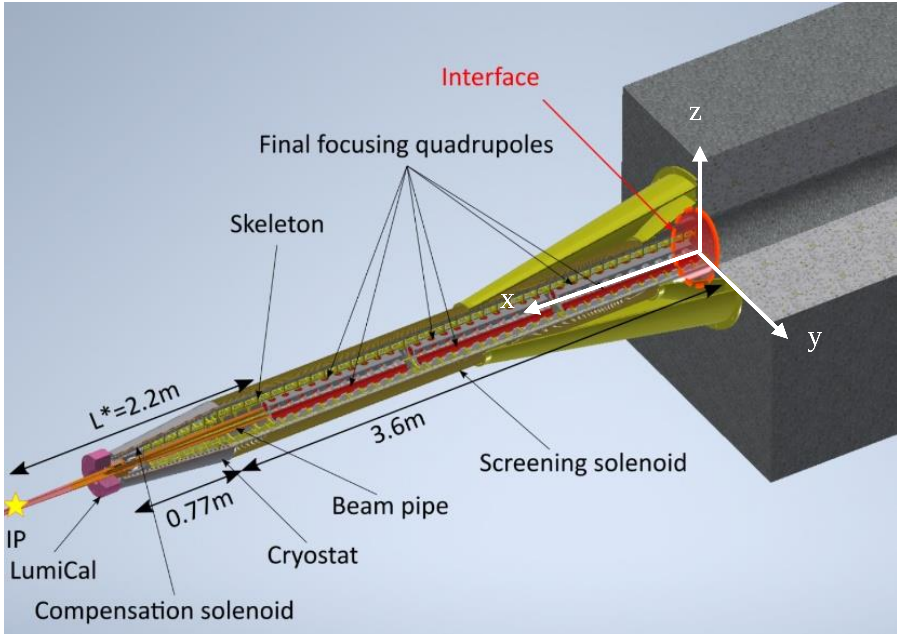




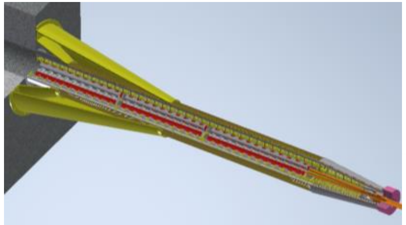
Coordinate system definition

Deformations are defined in the (O, Ox, Oy, Oz) Euclidean system linked to the interface plate, shown in Figure 11. The origin of this system is the centre of the plate, the Ox is perpendicular to the plate (and ideally is the bisector of the crossing angle between the two beams), Oy is the intersection of the plane of the plate and the plane formed by the incoming and outgoing beams and Oz is the last vector in order to form an oriented orthogonal system.





Deformation model

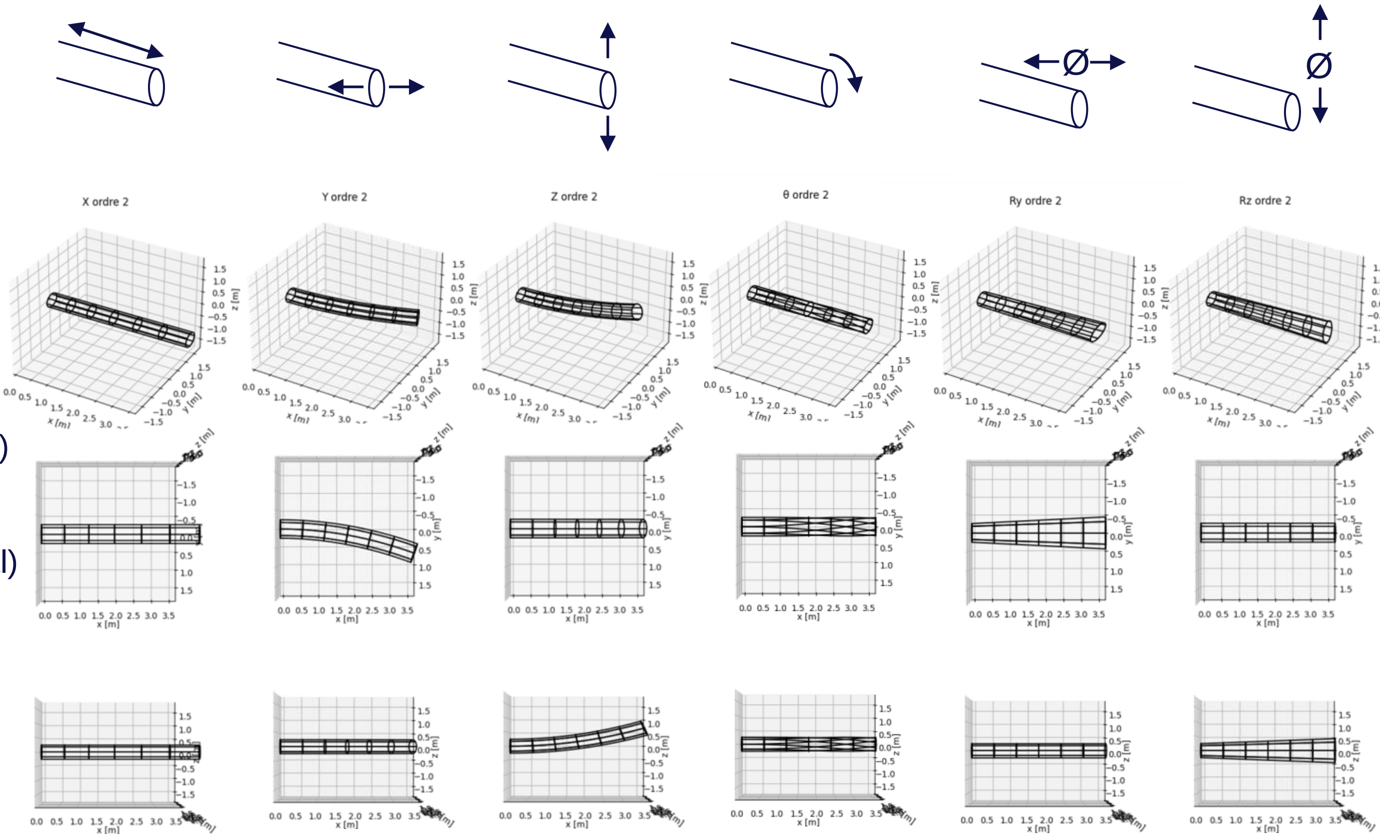


- Polynomial (classic model, easy to manipulate)
- 6 polynomial of degree 4
  - Elongation
  - Radial deformation (horizontal)
  - Radial deformation (vertical)
  - Torsion
  - Radius deformation (horizontal)
  - Radius deformation (vertical)

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

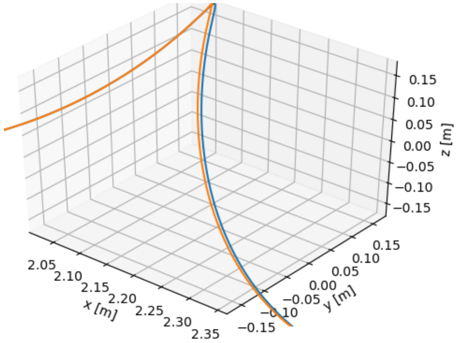
$$P_y(t) = \sum_{i=1}^{n} b_i t^i \qquad P_{ry}(t) = \sum_{i=1}^{n} e_i t^i$$

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

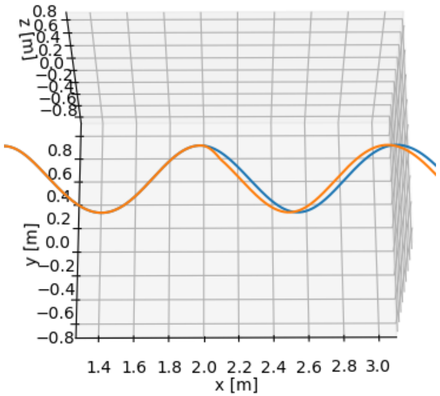


Deformation monitoring system : additional implementation

Helix installation error models



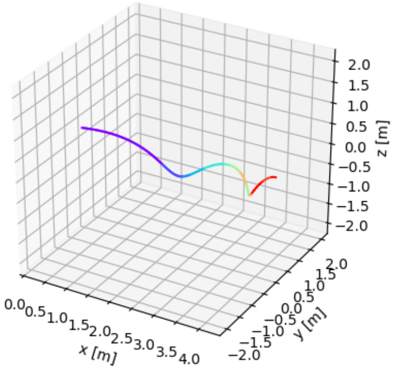
Punctual step error, but catches with theoretical position



Punctual step error implying a offset for the rest of the helix length

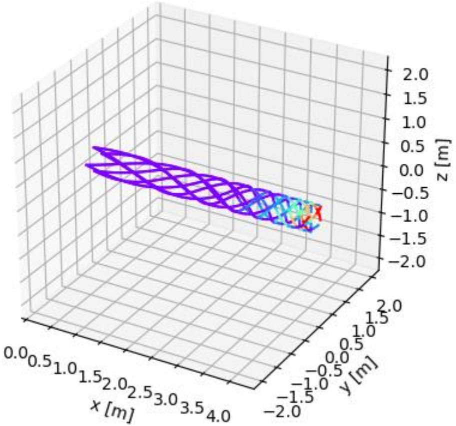
Easily seen in the least square adjustment residues (lot of redundancy)

Variable step helixes



Ex : Smaller step as it goes forward inside the detector

Allow to choose where to have more dense or more precise measurements



Model implemented and working

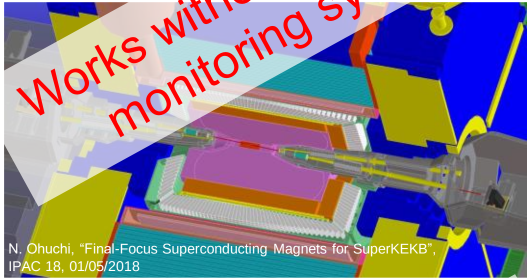
Additional tests to be done (comparison between full variable step network, hybrid variable and fix step network, full fixed step network)

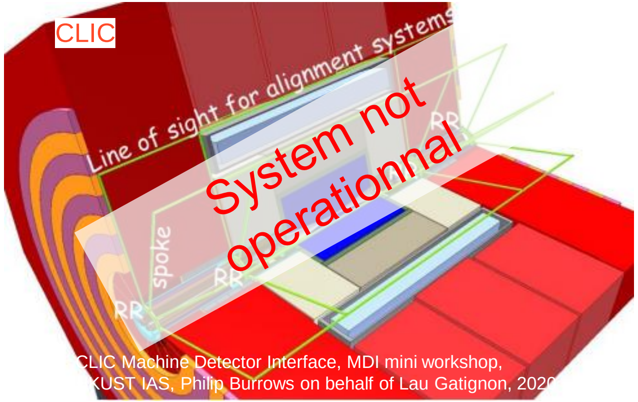
Similar existing MDIs

DAΦNE/KLOE
SuperKEKB/Belle II
LHC/ATLAS

MDIs of project colliders

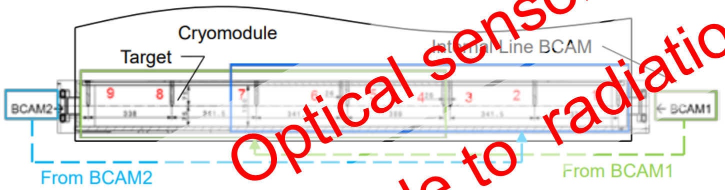
HL-LHC
CLIC
ILC





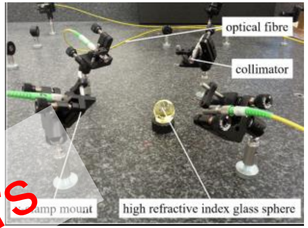
Can existing sensors do the job ?

Optical sensors
Sensible to radiations



HIE-ISOLDE alignment and system, technical design and project status, J.-C. Gayde, 2012.

BCAM, Open Source Instrument



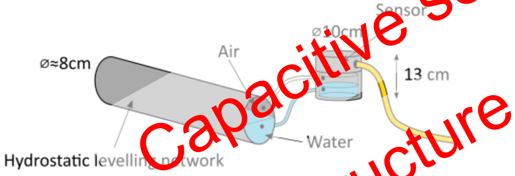
Gayde, J-Ch, and Kamugasa, S., "Evaluation of Frequency Scanning Interferometer Performances for Surveying, Alignment and Monitoring of Physics Instrumentation." (2018): WEPAF069.

Interferometric sensors
Early design, require space but none available

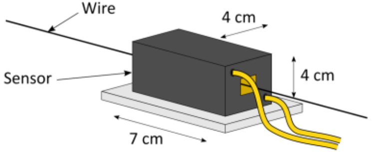
M. Sosin, A. Herty, J. Rutkowski on behalf of GM-HPA Team WP15.4 Sensor review, 2021.07.06

Hydrostatic Leveling System (HLS)

Capacitive sensors
Infrastructure required but no space available



Wire Positioning Sensor (WPS)



- ➢ Underlined by the absence of solution for the CLIC and ILC projects