MACHINE DETECTOR INTERFACE ALIGNMENT SYSTEM UPDATE

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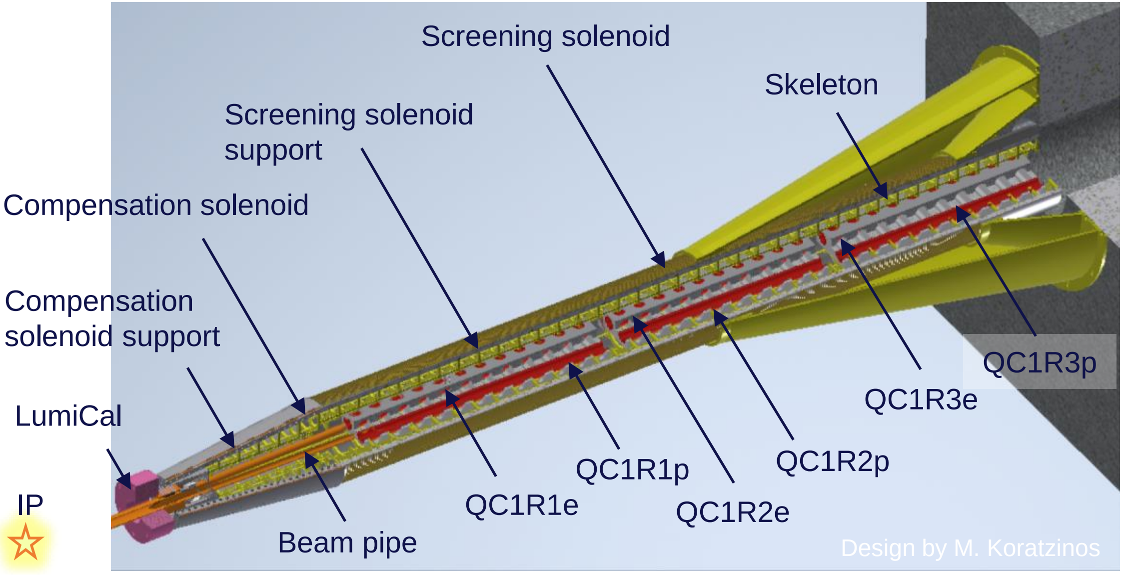
Why not just upgrade the sensors ?

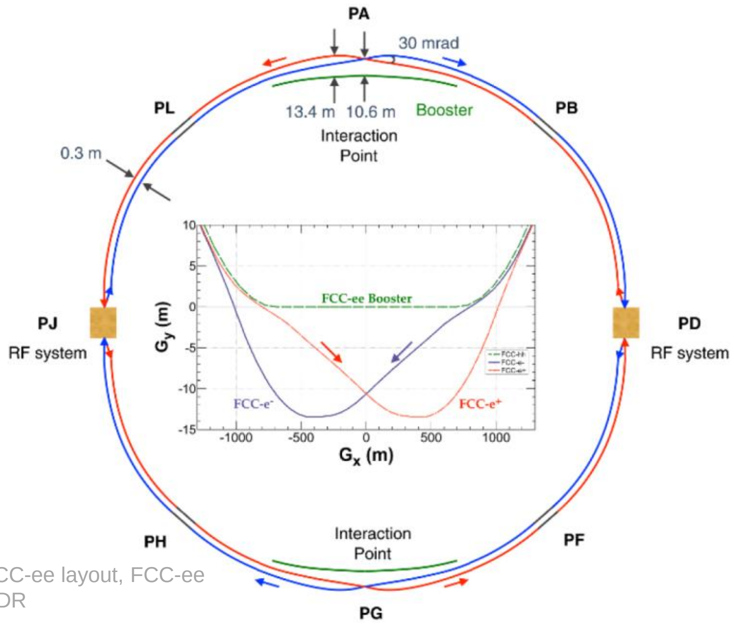
- Is it even possible to align, and monitor the alignment, of such MDI ?
- What is the plan to align , and monitor the alignment, of this MDI ?
- Can a re-adjustment system be

implemented in this complex MDI ?



Why do we need a precise alignment in the FCC-ee interaction region ?

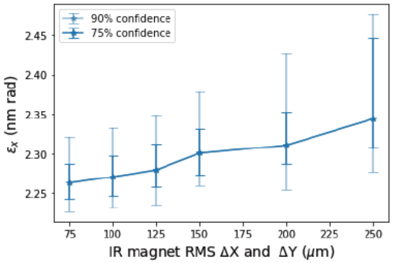
- Maximise performance in terms of integrated luminosity
- Maintain the related background at a tolerable level for the experiments (includes minimizing synchrotron radiation)
- Minimize emittance blow-up

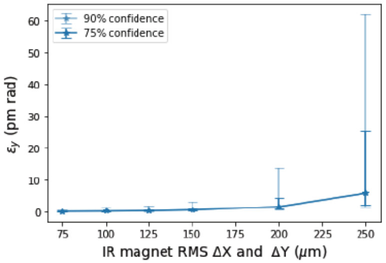


FCC-ee layout, FCC-ee CDR

IR magnets alignment - transverse misalignments (ΔX and ΔY)

Type	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	ΔS (μm)	$\Delta THETA$ (μrad)	ΔPHI (μrad)
IR quadrupole	varied	varied	250	200	100	100
IR sextupoles	varied	varied	250	200	100	100
All other magnets	as listed in Table on slide 7					

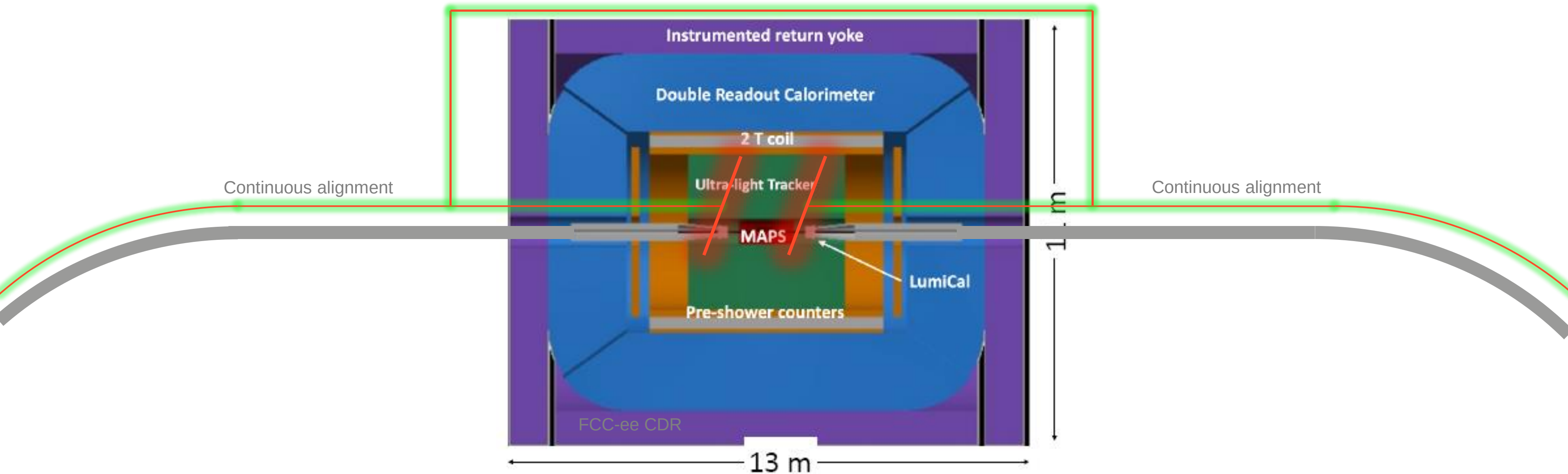




“Status and plans for optics corrections and emittance performance”,Tessa Charles, Bernhard Holzer, Katsunobu Oide, Frank Zimmermann and the FCC-ee optics team, FCC-week 2021

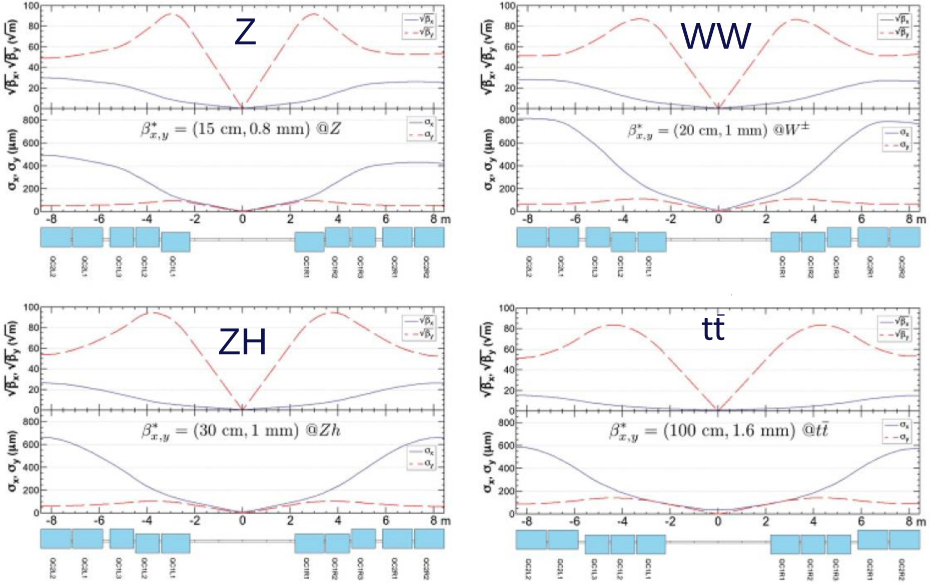
Why does it need to be more precise than in the rest of the machine ?

- Maintain the related background at a tolerable level for the experiments (includes minimizing synchrotron radiation)
- “Hole” in the machine => “hole” in the alignment -> align both side precisely so they collide

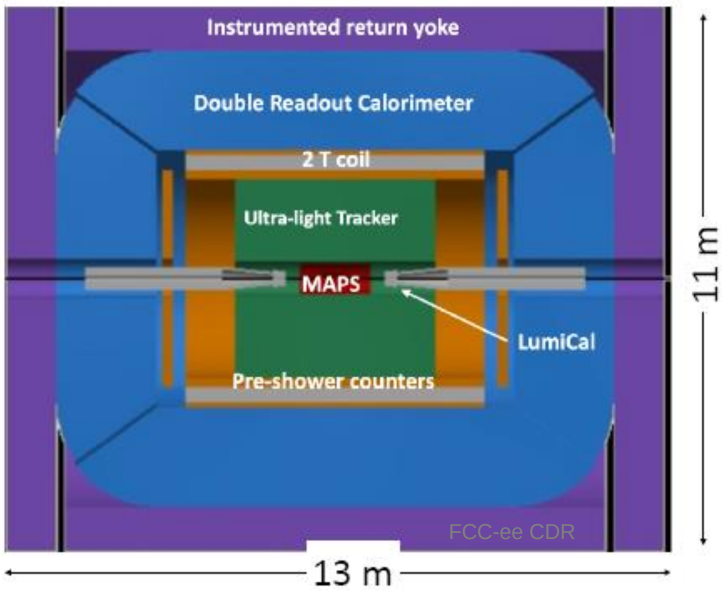


Why does it need to be more precise than in the rest of the machine ?

- Maintain the related background at a tolerable level for the experiments (includes minimizing synchrotron radiation)
- “Hole” in the machine => “hole” in the alignment -> align both side precisely so they collide
- Minimal beam size in the entire ring + collide as precisely as possible near the center of the experiment

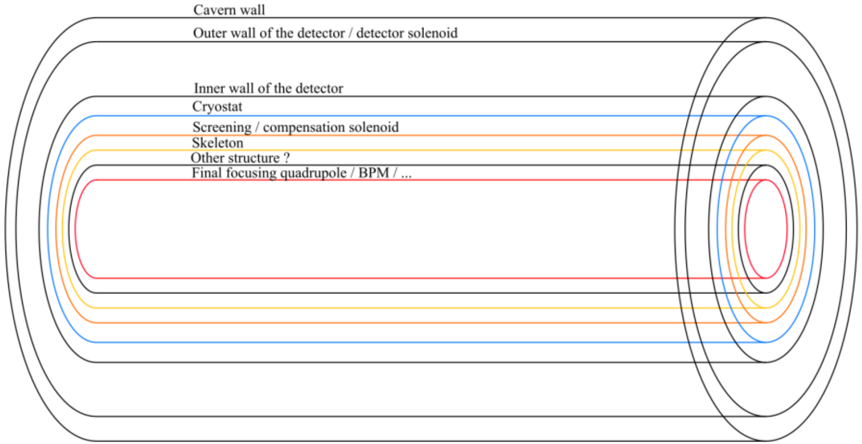


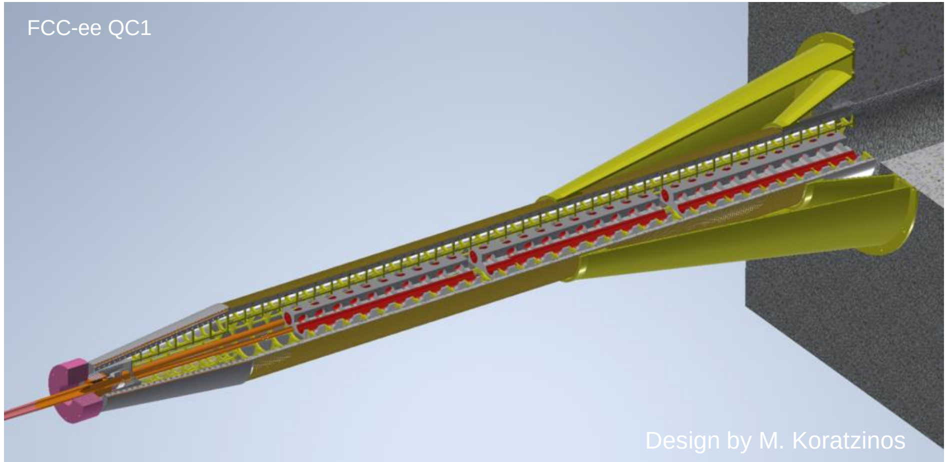
FCC-ee CDR

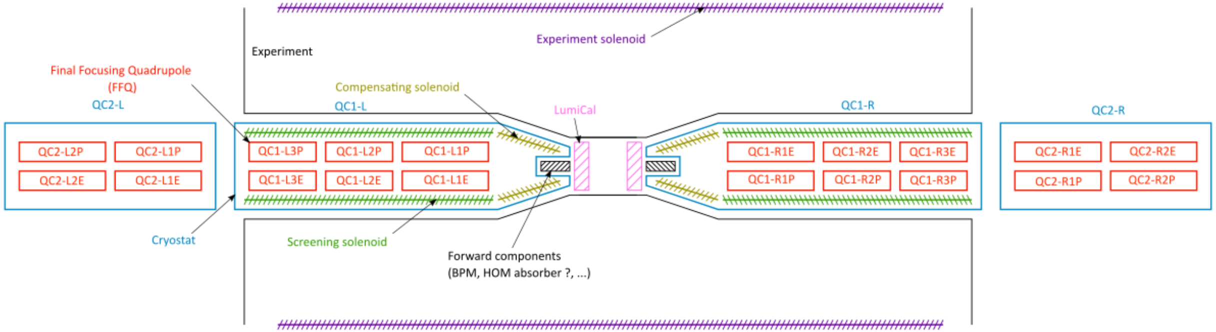


Why is this alignment difficult to do ?

➢ Design (lot of components to measure, layered design, very little space, design not definitive)







Why is this alignment difficult to do ?

- Design (lot of components to measure, layered design, very little space, design not definitive)
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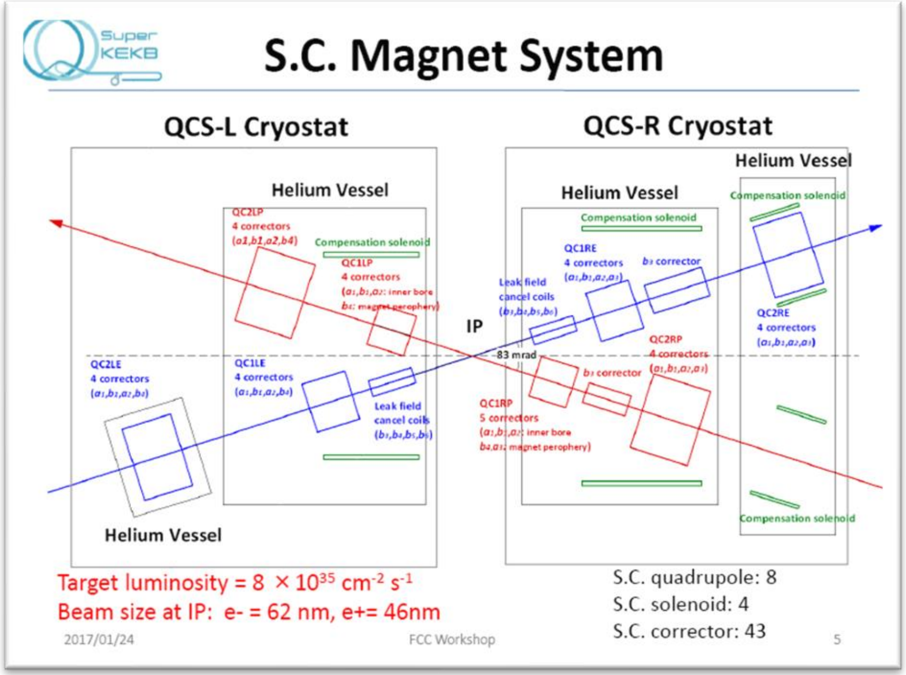
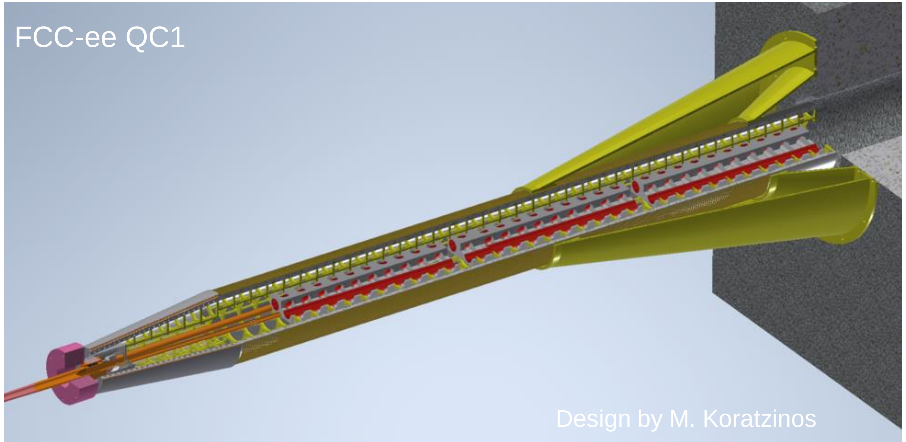




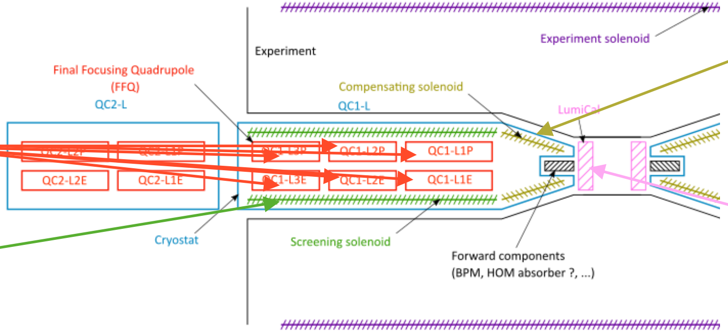
“Superconducting magnet system for SuperKEKB Interaction region”, Norihito Ohuchi, FCC workshop, 24/01/2017

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

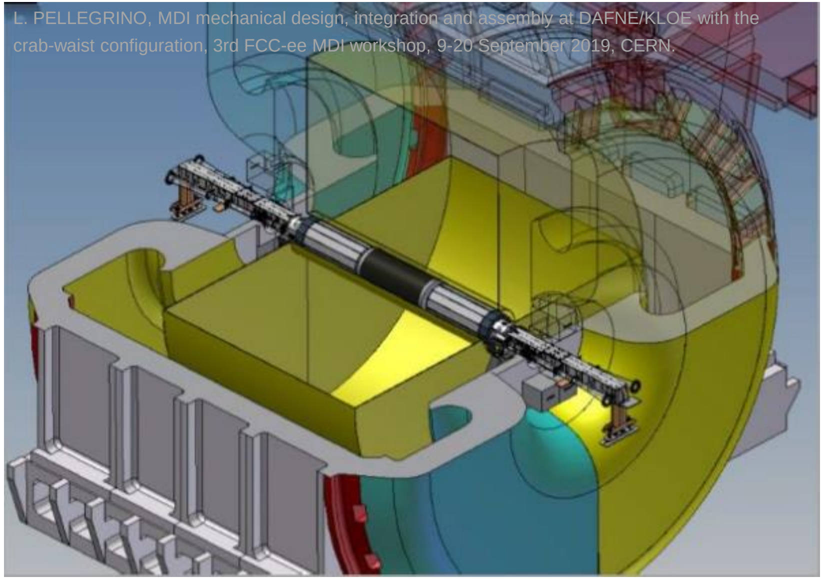
Misalignment tolerances include all possible error sources such as: manufacturing errors, assembly errors, deformation both during/after installation and during operation, magnetic field measurements, metrology measurement, reference network and alignment measurement, anticipated degradation in the alignment 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.

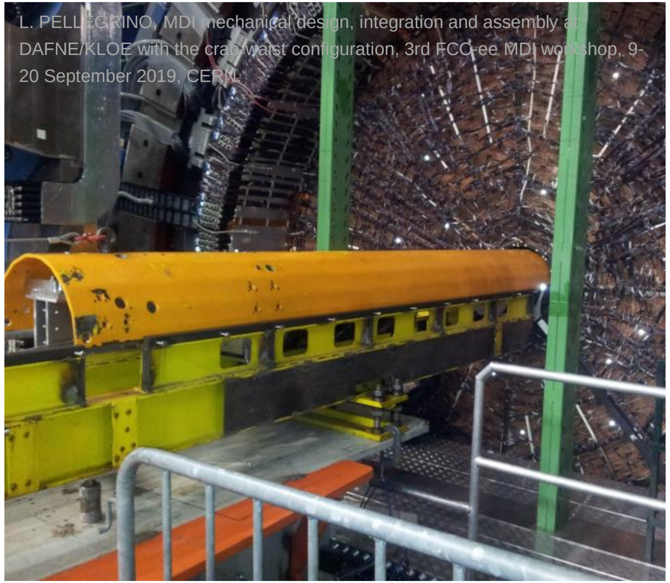
Alignment requirement at 30 µm => alignment precision <10 µm

Hasn’t it been done in the past ? Is there any similar MDI ?

- There are relatively similar MDI (DAFNE/KLOE, SuperKEKB/BelleII) but there are some differences :
  - DAFNE/KLOE different design, with a central pipe support, non cooled down final focusing quadrupoles, no alignment monitoring system, less stringent alignment requirement



L. PELLEGRINO, MDI mechanical design, integration and assembly at DAFNE/KLOE with the crab-waist configuration, 3rd FCC-ee MDI workshop, 9-20 September 2019, CERN.



L. PELLEGRINO, MDI mechanical design, integration and assembly at DAFNE/KLOE with the crab-waist configuration, 3rd FCC-ee MDI workshop, 9-20 September 2019, CERN.

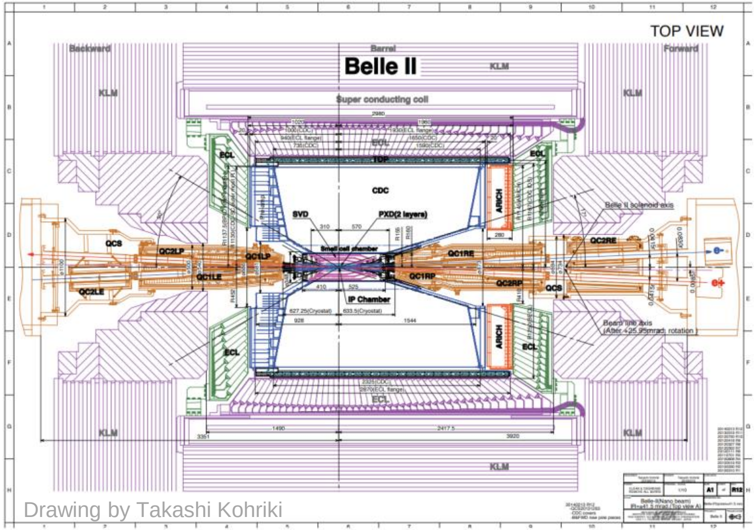
$L^* = 0.3$ m
$\theta_{cross} = 50$ mrad

Beam size :
$\sigma^*_x = 250\ \mu m$
$\sigma^*_y = 3.1\ \mu m$
$\sigma_z = 15$ mm

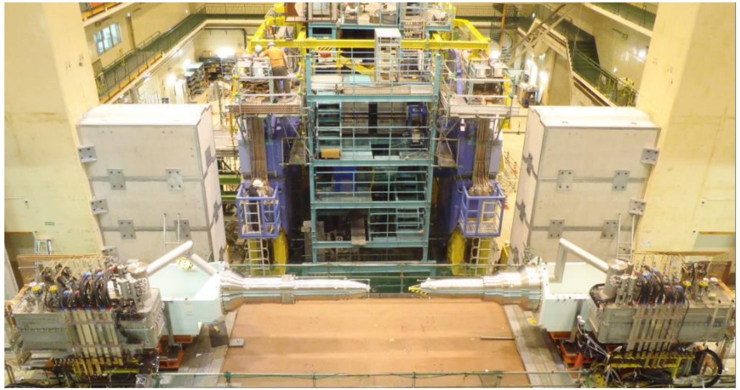
Alignment aim :
~ 100 µm

Hasn't it been done in the past ? Is there any similar MDI ?

- There are relatively similar MDI (DAFNE/KLOE, SuperKEKB/BelleII) but there are some differences :
  - DAFNE/KLOE different design, with a central pipe support, non cooled down final focusing quadrupoles, no alignment monitoring system, less stringent alignment requirement
  - SuperKEKB/BelleII : asymmetric MDI, cooled down final focusing quadrupoles, but no alignment monitoring system, less stringent alignment requirement



Drawing by Takashi Kohriki



N. Ohuchi, "Final-Focus Superconducting Magnets for SuperKEKB", IPAC 18, 01/05/2018

HER
$L^* = 1.22$ m
$\theta_{cross} = 83$ mrad

Beam size :
$\sigma^*_x = 10.7 \mu m$
$\sigma^*_y = 0.062\ \mu m$
$\sigma_z = 6$ mm

Alignment aim :
$\sim 100\ \mu m$

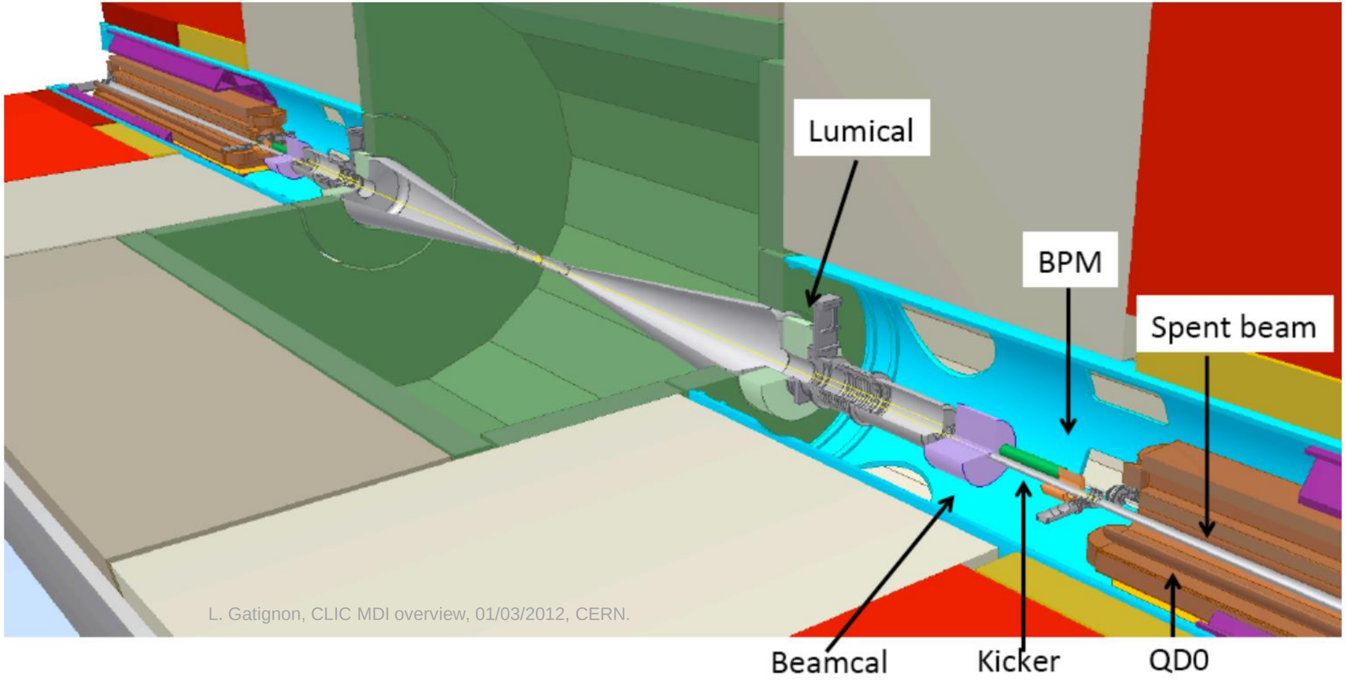
LER
$L^* = 0.76$ m
$\theta_{cross} = 83$ mrad

Beam size :
$\sigma^*_x = 10.1\ \mu m$
$\sigma^*_y = 0.048\ \mu m$
$\sigma_z = 5$ mm

Alignment aim :
$\sim 100\ \mu m$

Hasn't it been done in the past ? Is there any similar MDI ?

- CLIC and ILC planned to have similar MDIs:
  - CLIC : non cooled down final focusing quadrupoles, alignment monitoring system wanted, but none found so far, requirement more stringent than FCC



L. Gatignon, CLIC MDI overview, 01/03/2012, CERN.

L^* = 3.5 m 500 GeV
θ_{cross} = 20 mrad

Beam size :
$\sigma^*_x = 0.202\ \mu m$
$\sigma^*_y = 0.0023\ \mu m$
$\sigma_z = 0.072\ mm$

Alignment aim :
~ 10 µm

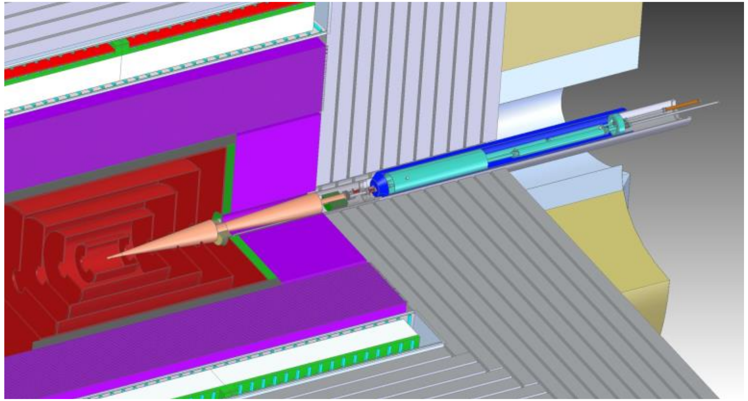
L^* = 3.5 m 3TeV
θ_{cross} = 20 mrad

Beam size :
$\sigma^*_x = 0.040\ \mu m$
$\sigma^*_y = 0.001\ \mu m$
$\sigma_z = 0.044\ mm$

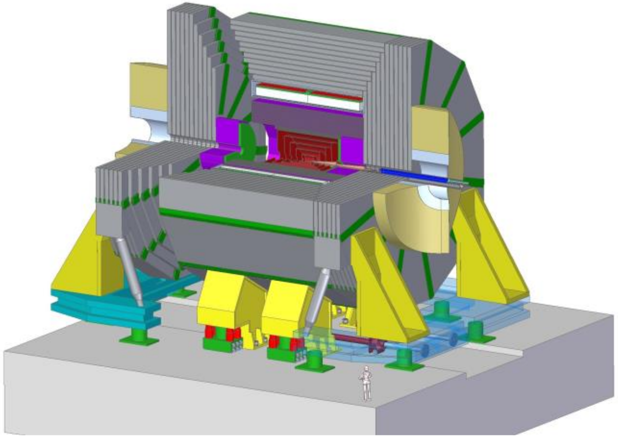
Alignment aim :
~ 10 µm

Hasn't it been done in the past ? Is there any similar MDI ?

- CLIC and ILC planned to have similar MDIs:
  - CLIC : non cooled down final focusing quadrupoles, alignment monitoring system wanted, but none found so far, requirement more stringent than FCC
  - ILC : cooled down final focusing quadrupoles (only one in the cryostat), alignment monitoring wanted but not found, requirement more stringent than



Marcel Stanitzki, The SiD Detector – Machine Backgrounds, 01/2020, Hong Kong



Marcel Stanitzki, The SiD Detector – Machine Backgrounds, 01/2020, Hong Kong

L* = 3.5 m 250 GeV
θ_{cross} = 14 mrad

Beam size :
$\sigma^*_x = 0.516\ \mu m$
$\sigma^*_y = 0.0077\ \mu m$
$\sigma_z = 0.300\ mm$

Alignment aim :
$\sim 20\ \mu m$

L* = 3.5 m 500 GeV
θ_{cross} = 14 mrad

Beam size :
$\sigma^*_x = 0.474\ \mu m$
$\sigma^*_y = 0.0059\ \mu m$
$\sigma_z = 0.300\ mm$

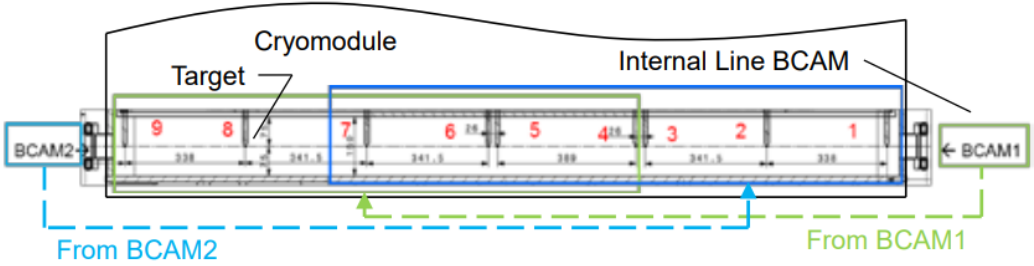
Alignment aim :
$\sim 20\ \mu m$

There is no existing alignment and monitoring that could be adapted to the FCC-ee MDI

Can existing sensors do the job ?


BCAM, Open Source Instrument

- Multiple difficulties with existing sensors :
  - Optical sensors are extremely fragile to radiations



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

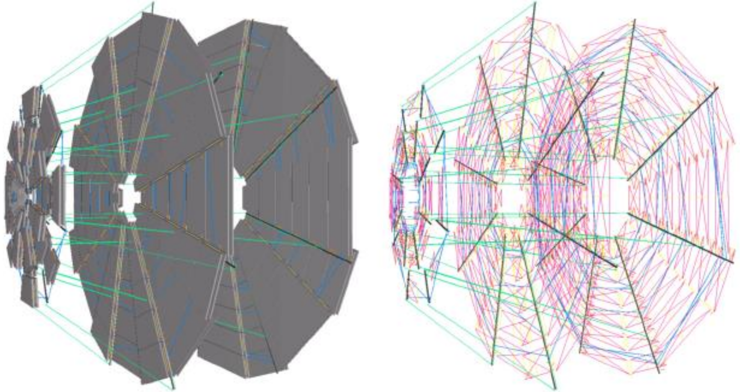


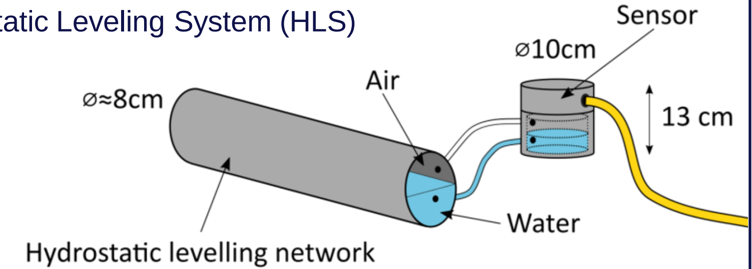
Fig. 2: Layout of the alignment system in one muon spectrometer endcap, with and without the precision chambers visible. Only the EI (left), EM (center), and EO (right) stations are shown, the EE station has been omitted. The several thousands of thin colored lines represent the alignment sensor lines: polar BCAMs (green), azimuthal BCAMs (blue), RASNIK proximity sensors (orange), in-plane RASNIKs (red), chamber temperature sensors (yellow). Shown as thick black lines are the alignment bars, inside which there are in-bar RASNIKs and temperature sensors (not visible). The different types of sensors are discussed in the following sections.

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

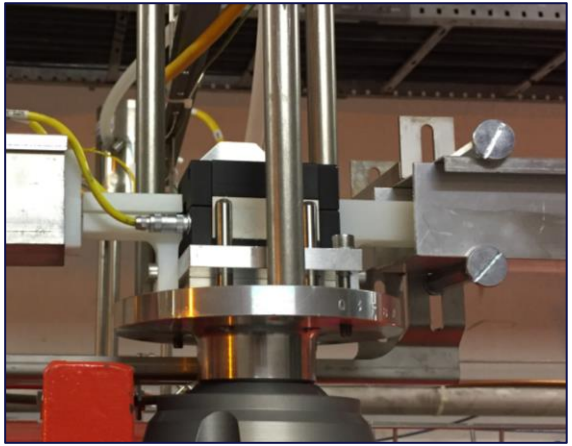
Can existing sensors do the job ?

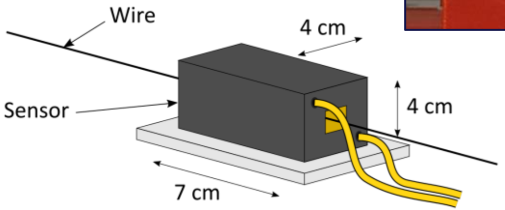
- Multiple difficulties with existing sensors :
  - Optical sensors are extremely fragile to radiations
  - Capacitive sensors systems require infrastructure to work (WPS and HLS) which can’t be implemented in the MDI

Hydrostatic Leveling System (HLS)



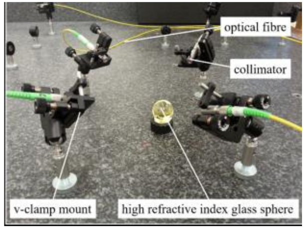
Wire Positioning Sensor (WPS)



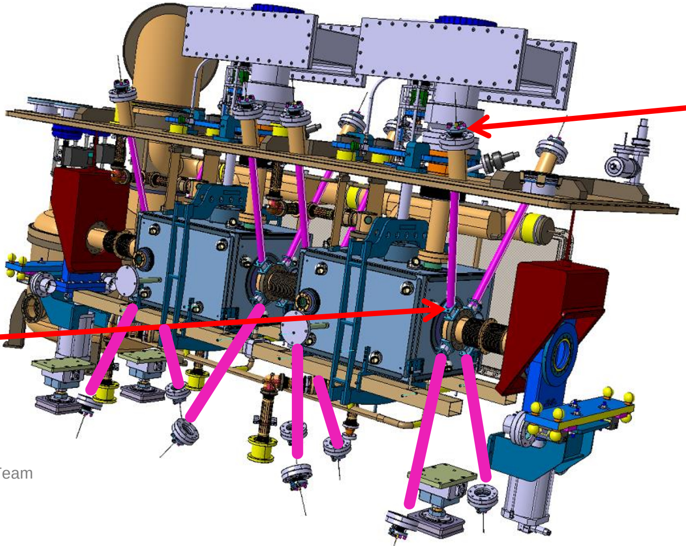


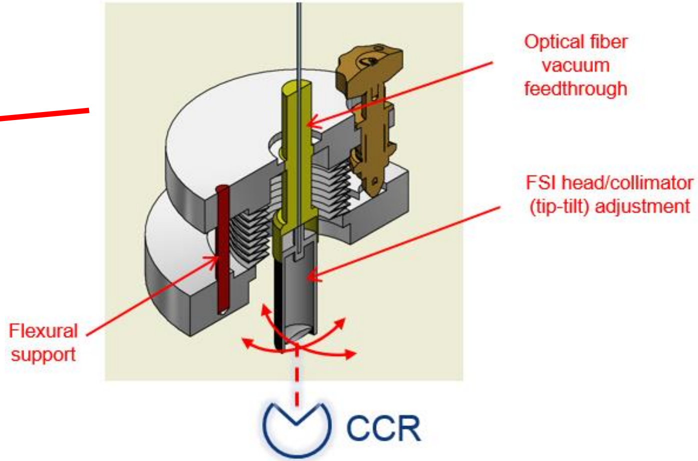
Can existing sensors do the job ?

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



- Multiple difficulties with existing sensors :
  - Optical sensors are extremely fragile to radiations
  - Capacitive sensors systems require infrastructure to work (WPS and HLS) which can’t be implemented in the MDI
  - Still early in the development of interferometric measurements (can’t be easily implemented in the MDI, especially regarding the space available).

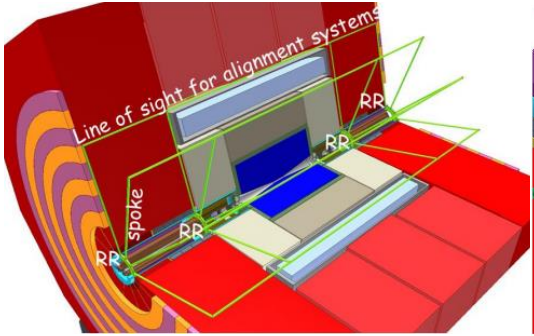


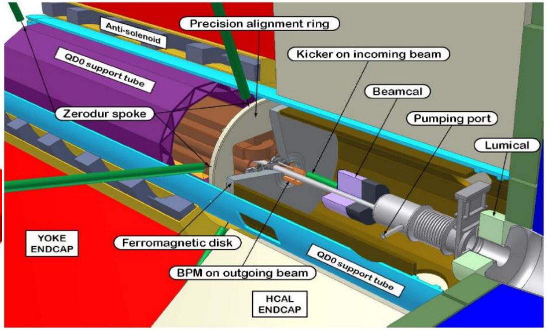


M. Sosin, A. Herty, J. Rutkowski on behalf of GM-HPA Team
WP15.4 Sensor review, 2021.07.06

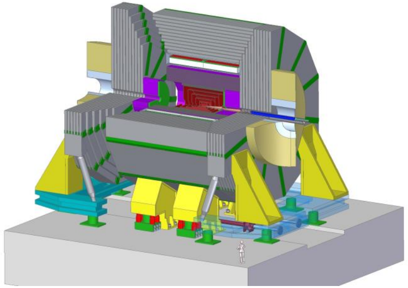
Can existing sensors do the job ?

➢ Underlined by the fact that CLIC and ILC didn't find any working system.

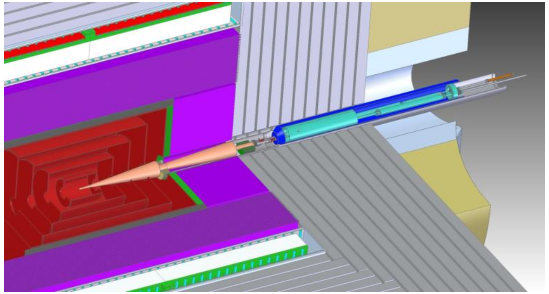




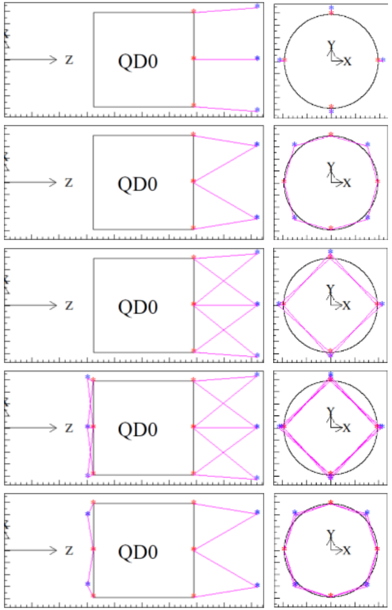
CLIC Machine Detector Interface, MDI mini workshop, HKUST IAS, Philip Burrows on behalf of Lau Gatignon, 2020



Marcel Stanitzki, The SiD Detector – Machine Backgrounds, 01/2020, Hong Kong



Marcel Stanitzki, The SiD Detector – Machine Backgrounds, 01/2020, Hong Kong



Riles K., Yang H-J., Chen T.,"Update on FSI R&D for SiD Tracking and Final Focus Magnet Alignment", SiD Workshop, SLAC, 14/12/2011

Existing sensors cannot be used for the alignment of the FCC-ee MDI

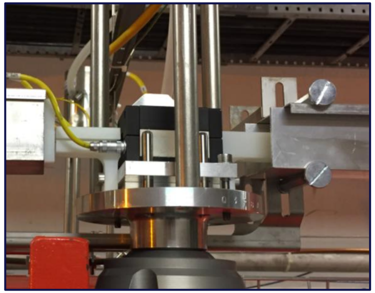
Why not just upgrade the sensors ?

- The problem is not due to the precision of the sensors (which is constantly improving).
- The problem comes from the sensor itself, the way it measures, the infrastructure required.

Why not just upgrade the sensors ?

- The problem is not due to the precision of the sensors (which is constantly improving).
- The problem comes from the sensor itself, the way it measures, the infrastructure required.
- Such thinking on an update of the entire infrastructure is only rarely done (usually there is no time and no need).

WPS in LEP



WPS in LHC

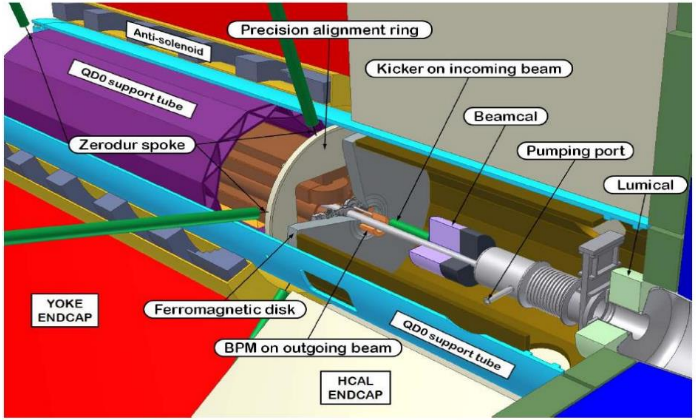
HLS and WPS have been used in LEP and they will be used in HL-LHC. Sensors are more precise, but the way of measurement is the same.

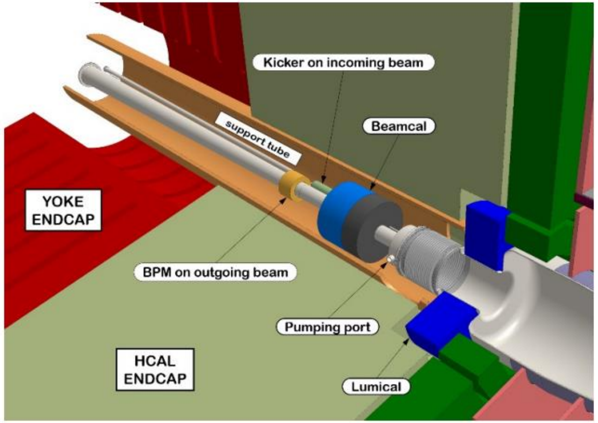
Is it even possible to align, and monitor the alignment, of such MDI ?

- Its seems mandatory and it is asked for the next generation colliders (HL-LHC, ILC, CLIC, FCC, CEPC)

Even though CLIC and ILC haven't found any solution so far.

CLIC Machine Detector Interface, MDI mini workshop, HKUST IAS, Philip Burrows on behalf of Lau Gatignon, 2020





Aicheler, Markus, et al. "The compact linear collider (CLIC)-project implementation plan." arXiv preprint arXiv:1903.08655 (2019)

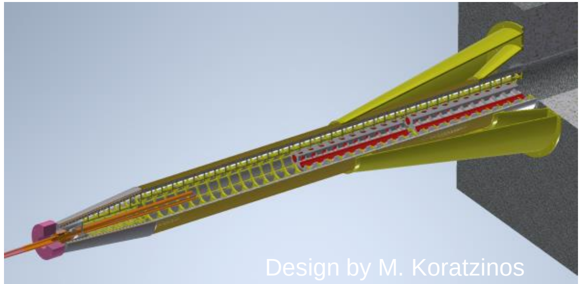
" Since the CDR [3], the final quadrupole QD0 has been moved from inside the detector (with $L* = 3.5$ m at 3 TeV or $L* = 4.3$ m at 500 GeV) to the tunnel floor outside the detector (using $L* = 6$ m for both 380 GeV and 3 TeV designs)."

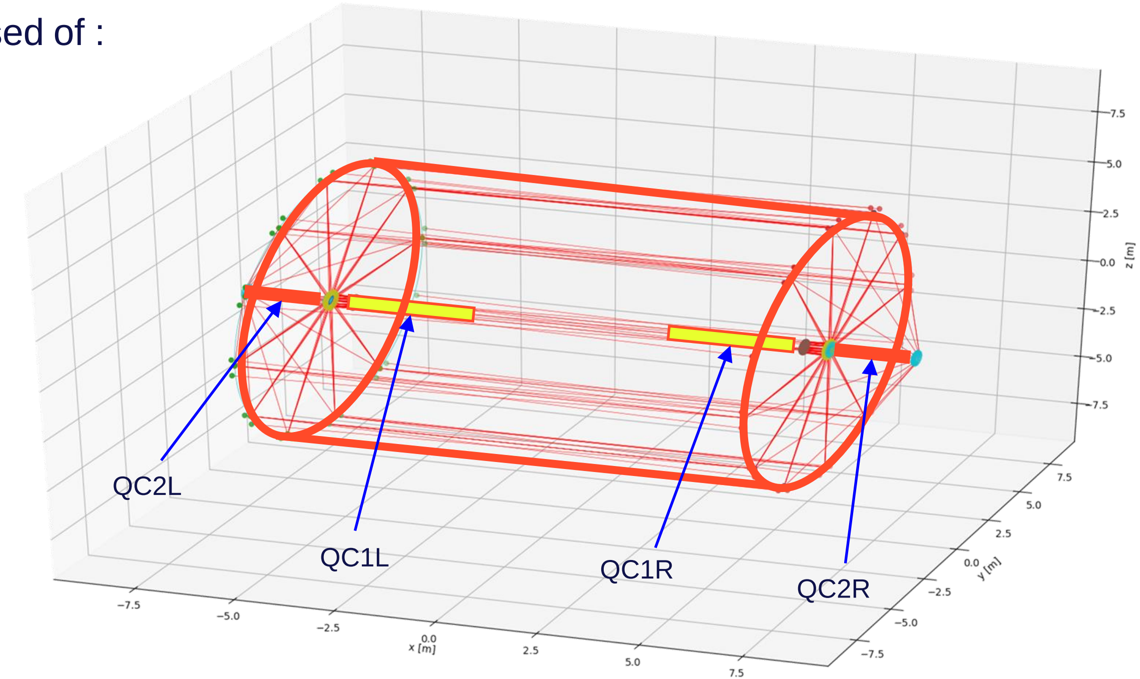
Aicheler, Markus, et al. "The compact linear collider (CLIC)-project implementation plan." arXiv preprint arXiv:1903.08655 (2019)

Not only due to alignment though

What is the plan to align, and monitor the alignment, of this MDI ?

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





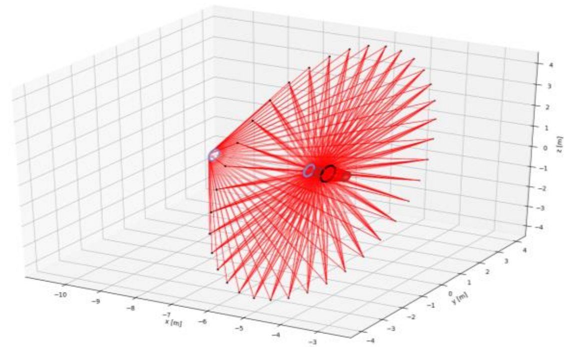
Goals :

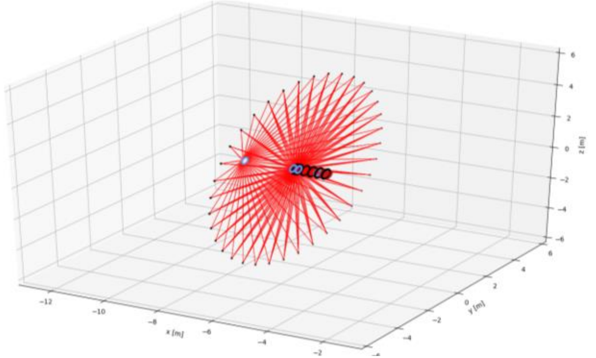
- Monitor an interface at the end of QC1 to retrieve the position of internal component (monitored thanks to the internal monitoring system).
- Monitor the alignment between QC1 and QC2.
- Monitor the alignment between the inner components and the experiment solenoid.
- Monitor the alignment between the two sides of the experiment.

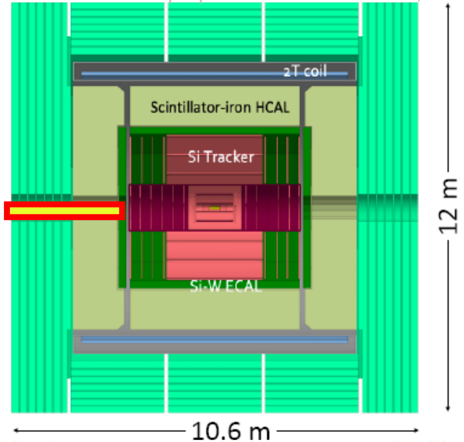
What is the plan to align, and monitor the alignment, of this MDI ?

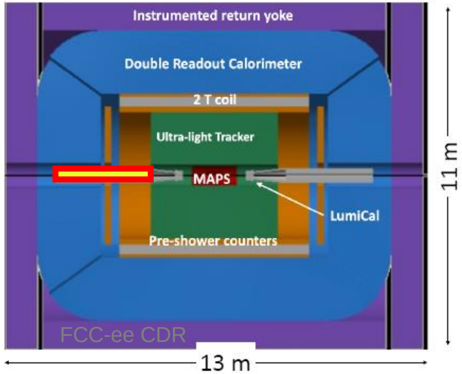
- Alignment and monitoring system composed of :
  - External alignment system

HOFFMAN, A. C., PARÈS, G., FRITZSCH, T., *et al.* Detector Technologies for CLIC. *arXiv preprint arXiv:1905.02520*, 2019.

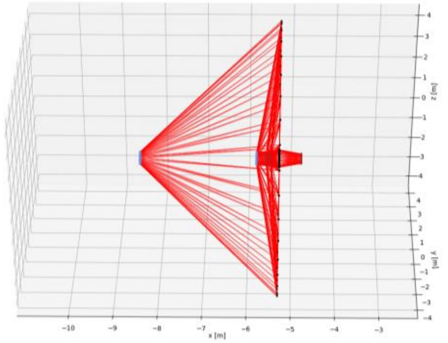




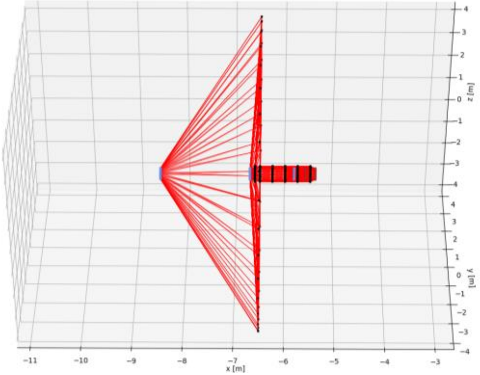




QC1 partly inside, QC2 entirely outside

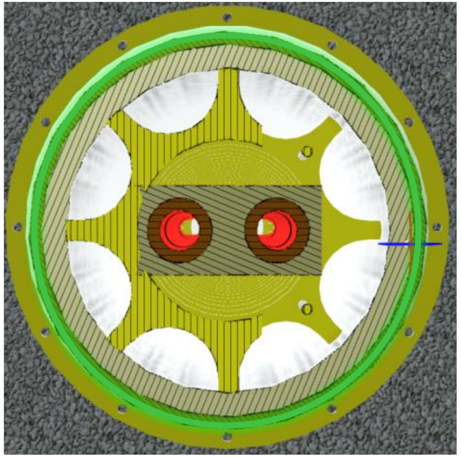


QC1 entirely inside, QC2 partly inside



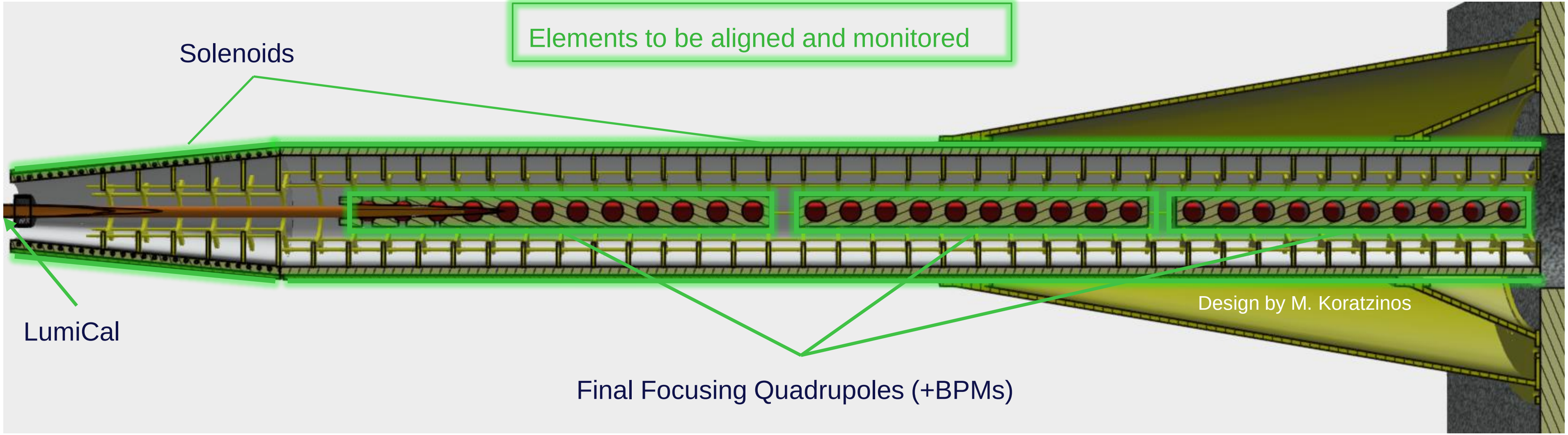
Optimal network : too much measurements, some (plenty) wont be possible.
Any update on the design would be much welcomed.

What is the plan to align, and monitor the alignment, of this MDI ?



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

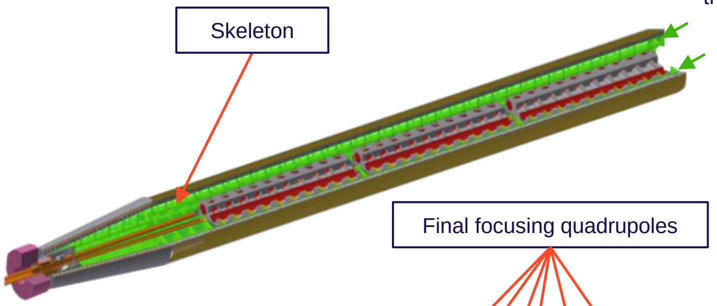
- Currently no existing system capable of such precise measurements (~ 10 µm) in harsh conditions
- Simulations on new systems are ongoing

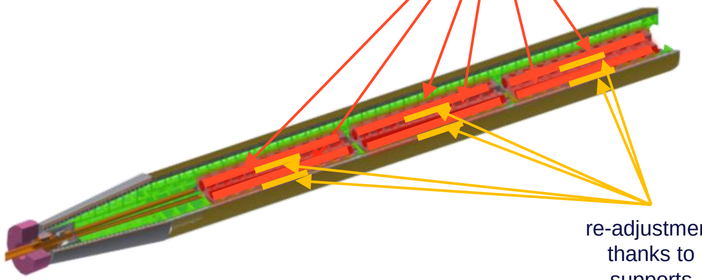


Can a re-adjustment system be implemented in this complex MDI ?

➢ Re-adjustment possibilities

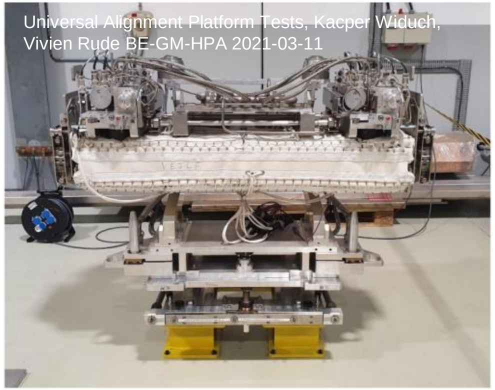
Does not need to be in real time and/or on all the inner components.

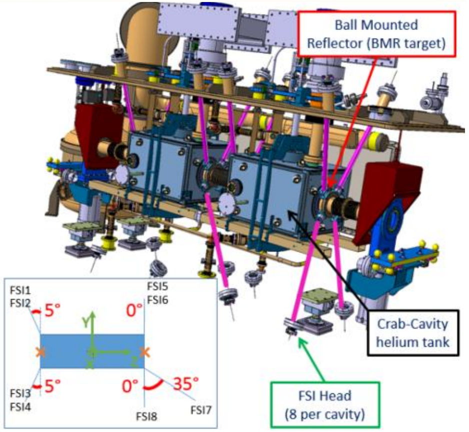




Some existing solutions

Not adapted yet
Some R&D required





Sosin, Mateusz, et al. Position monitoring system for HL-LHC crab cavities. No. CERN-ACC-2016-197. 2016.

Summary

- Alignment and monitoring in the MDI seems mandatory (it’s been asked for all the next generation colliders)
- Requirements are tighter in the MDI than in the rest of the accelerator (min. beam size, "hole” in the machine)
- It has never been done in the past (CLIC and ILC didn’t find any solution)
- Current sensors cannot be used in such situation (space constraints, tight requirements and harsh condition)

This MDI design is as elegant as it is complex and it represents a big challenge

but

- There is a strategy for the alignment and monitoring of the MDI
- Simulations of a new sensor are finished, results will follow

To be continued …

Thank you for your attention