Full Remote Alignment System (FRAS) for HL-LHC project

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10 October 2024

Outline

Introduction

- HL-LHC project
- FRAS

Status of development and qualification

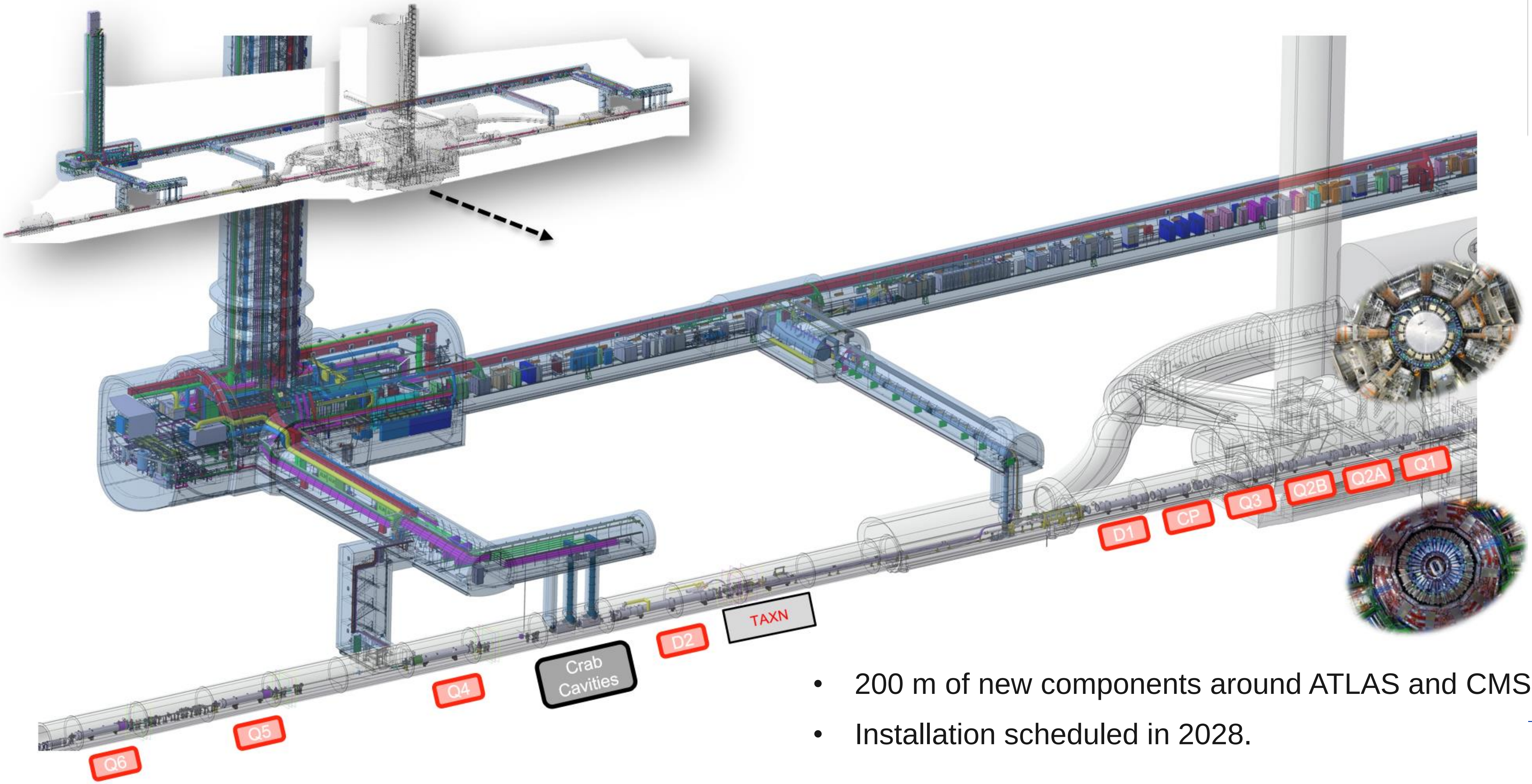
- Strategy
- Single Component Test facility & results
- Towards the Inner Triplet String Test

Alignment strategy

- LHC alignment
- Scenarios of alignment

Summary

Introduction to HL-LHC project



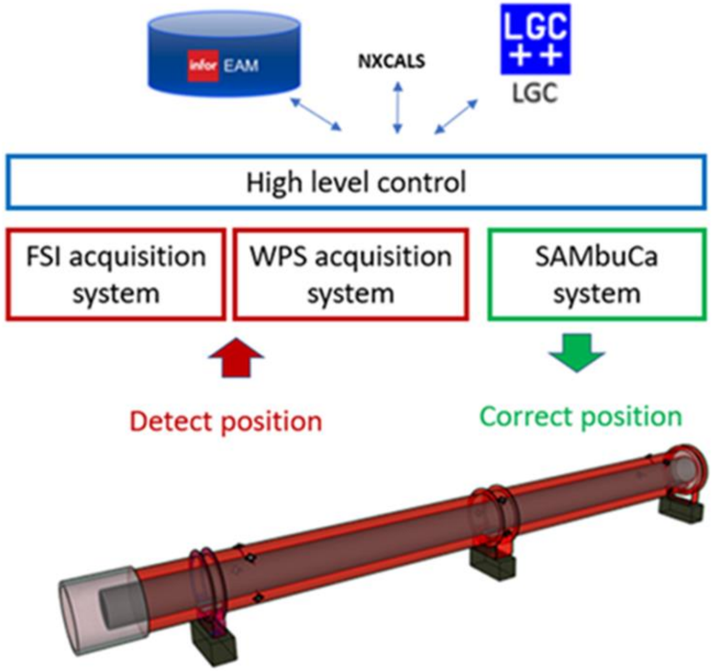
- 200 m of new components around ATLAS and CMS
- Installation scheduled in 2028.

Full Remote Alignment System (FRAS)

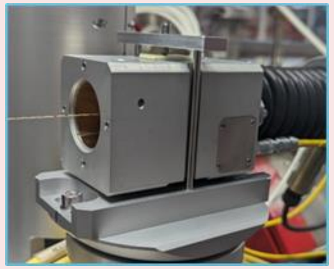
- It consists of alignment systems (alignment sensors, motorized adapters, their acquisition and control/command systems, associated software) allowing to determine the position of components and readjust them remotely within a range of ± 2.5 mm.
- **FRAS will provide:**
  - An important reduction of the dose taken by surveyors as no access in tunnel will be needed between technical stops or long shutdowns
  - A reduction in the mechanical misalignment, allowing to decrease the required correctors strength and to push the accelerator performance
  - A gain in aperture for several components
- **All components from Q1 to Q5 will be:**
  - Either equipped with sensors and motorized axes
  - Or FRAS compatible: they are static components that can absorb the displacements of their adjacent components.
- **From the lessons learnt:**
  - In-house developments → industrialized
  - Internal monitoring of the IT cold masses and crab cavities w.r.t. their cryostats
  - Follow-up of the available stroke of the bellows

Full Remote Alignment System (FRAS)

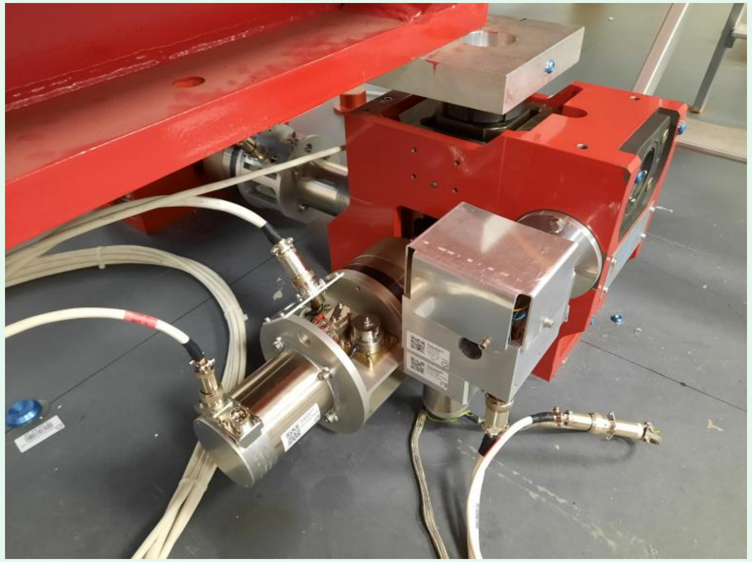
FRAS acquisition and control/command

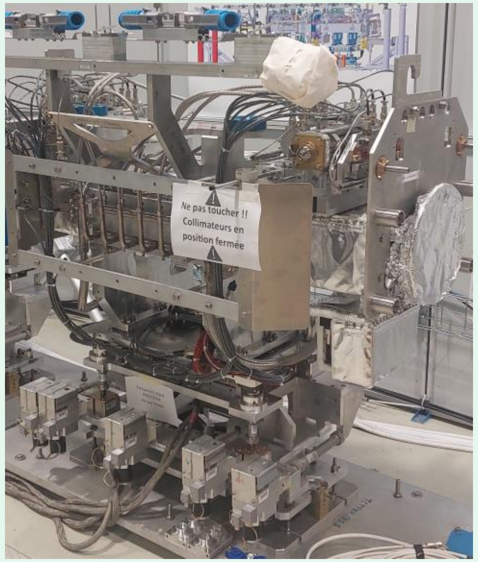


Position determination solutions



Adjustment solutions





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Development strategy

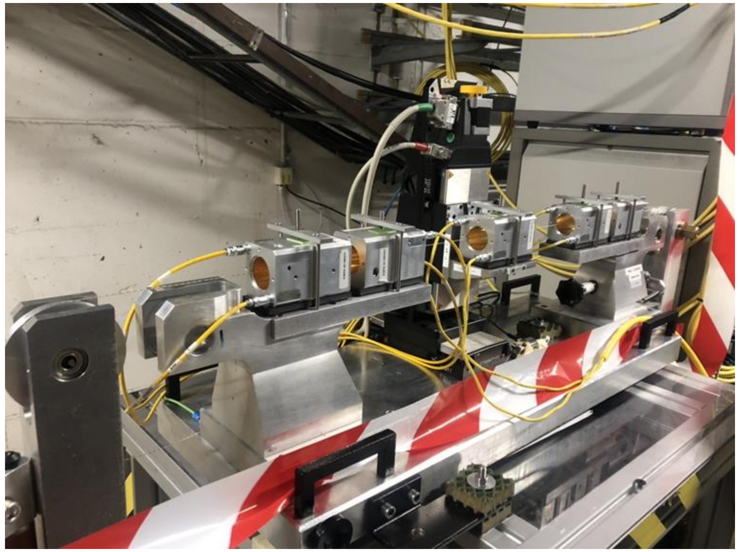
Development & preparation of FRAS:

- Definition of responsibilities
- Detailed definition of interfaces
- Deliverables and milestones
- Qualification of solutions on individual test setups
- Cross-comparison between alignment solutions

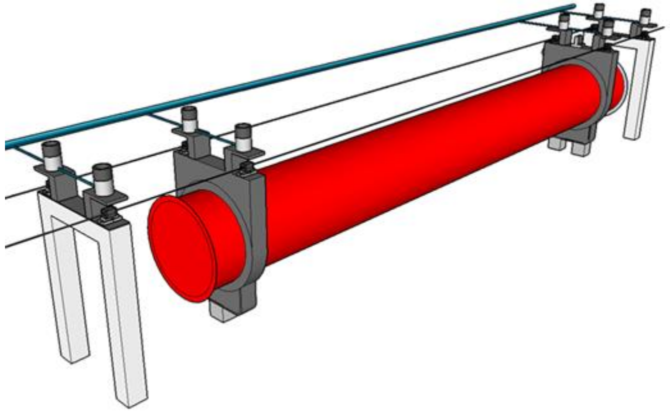
FRAS qualification on 1 single component [2023-2024]

FRAS qualification on IT String Test 2024-2025]

Installation, commissioning and operation in the LHC [2027+]



Single Component Test



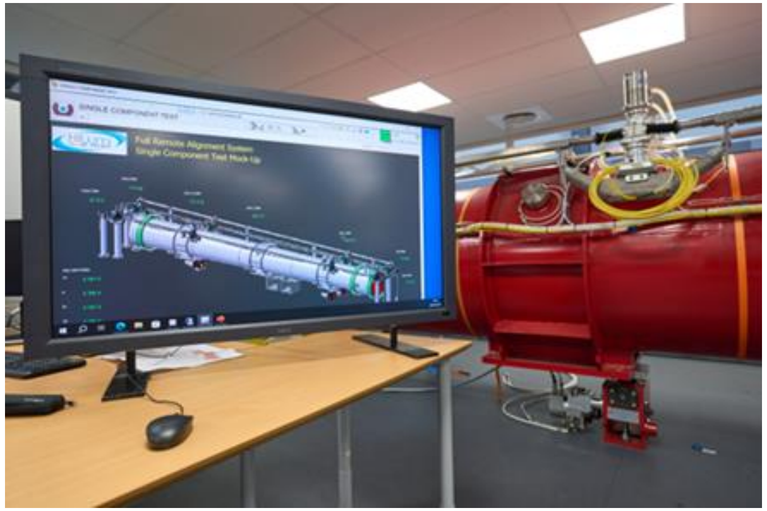
- ✓ 8 HLS
- ✓ 8 WPS
- ✓ 2 inclinometers
- ✓ Distance sensors
- ✓ Environmental sensors
- ✓ 3 vertical adapters
- ✓ 2 radial adapters

Objectives:

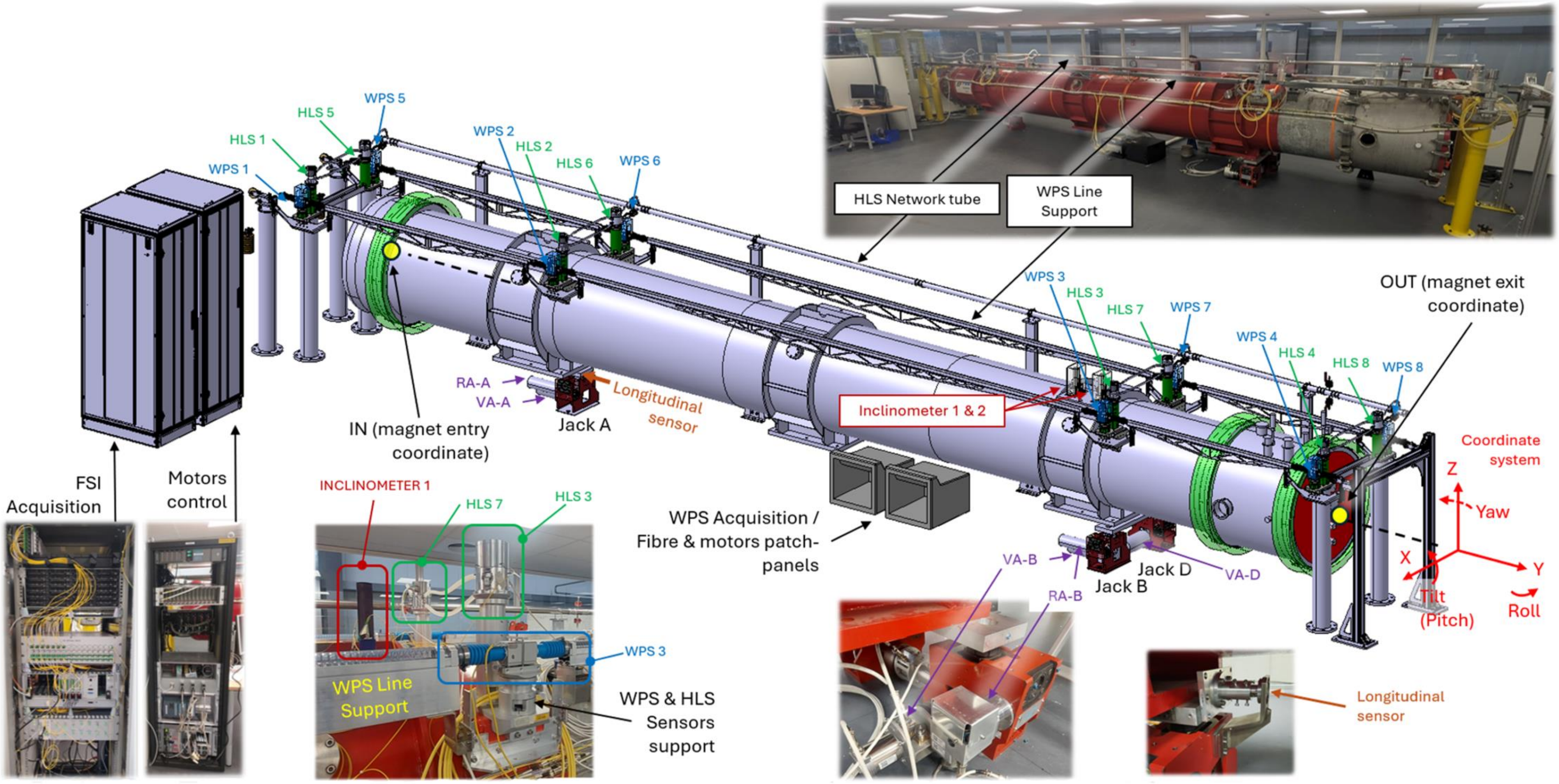
- To perform the individual and combined qualification of sensors, measurement systems, motorized adapters, data acquisition and alignment algorithms
- To provide the possibility to qualify the FRAS performance before the IT String Test
- To validate the interfaces as FRAS is developed as a collaboration between 3 groups at CERN

Configuration:

- A lot of redundancy
- Same software configuration than for the final solution



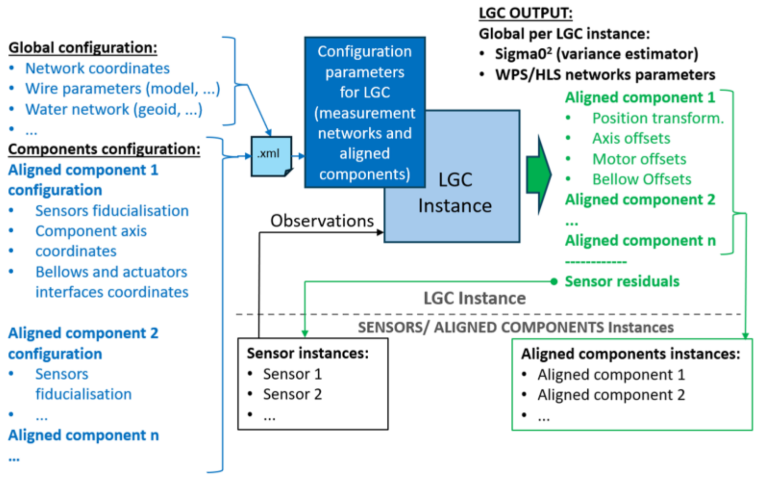
Single Component Test



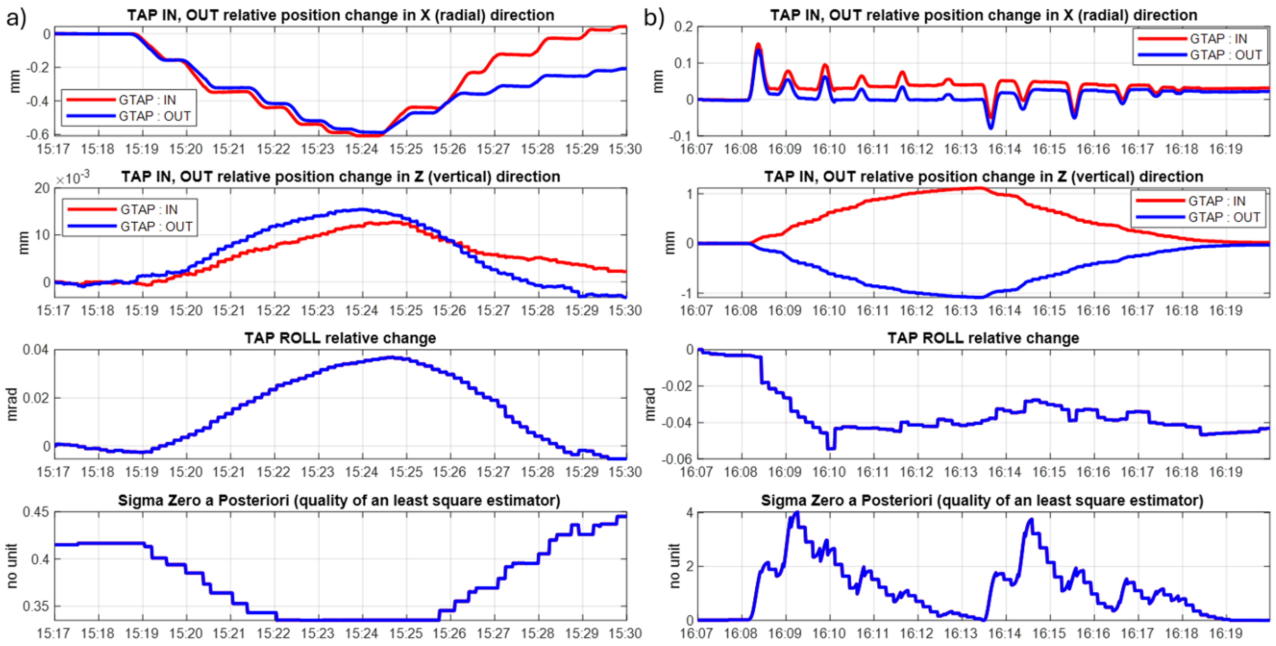
See IWAA 2024 paper from Mateusz SOSIN

Single Component Test

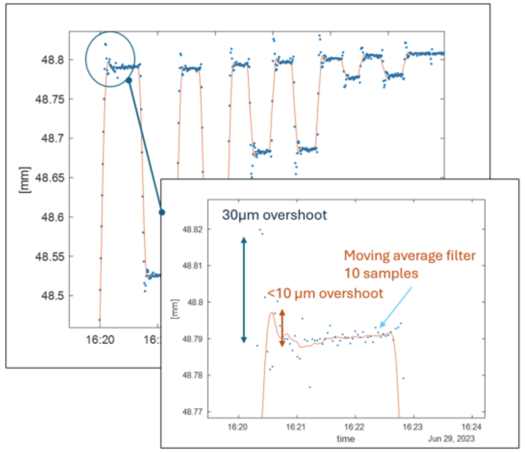
LGC instance interaction



Outcome of least square adjustment software test



HLS dynamic test

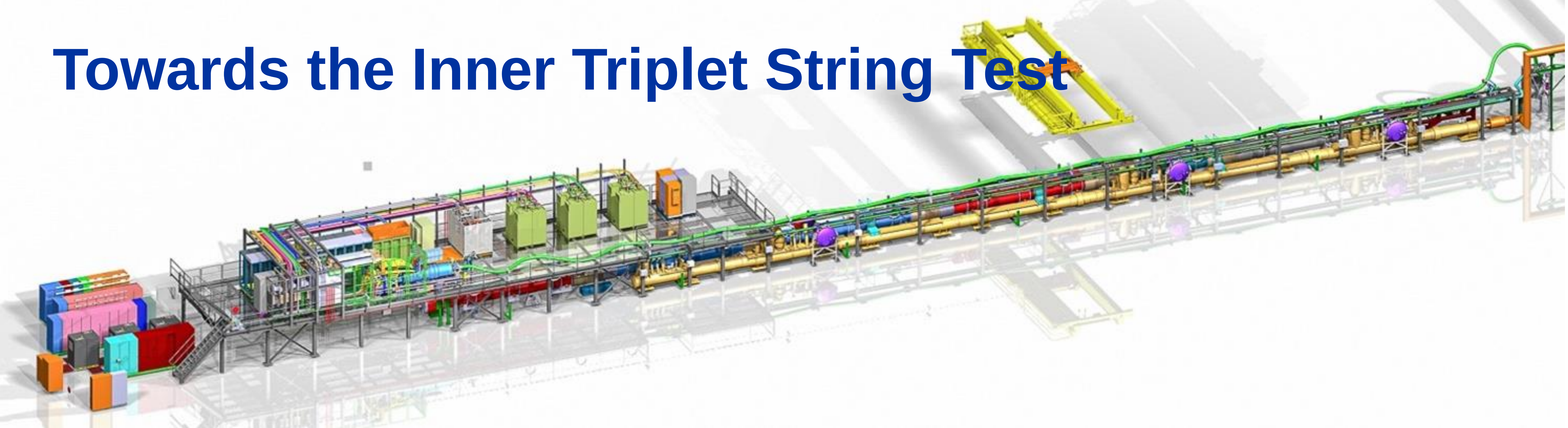


A lot of lessons learned:

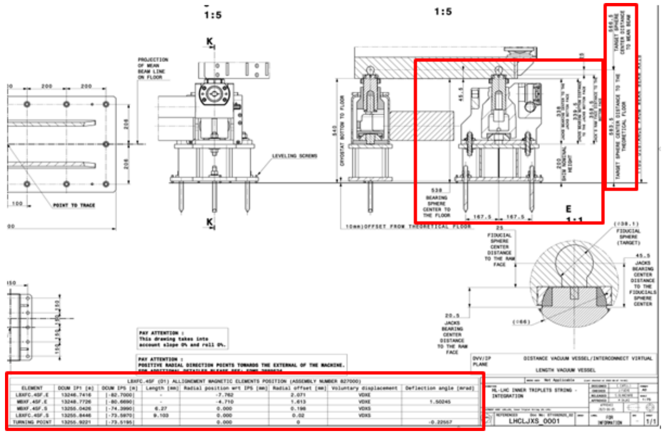
- On integration, installation procedures, networks routing, system design, procurement for series, etc.
- Not only a solution for system commissioning, but also a rehearsal platform for control system upgrades.

See IWAA 2024 papers from Guillaume KAUTZMANN and Mateusz SOSIN

Towards the Inner Triplet String Test



Installation drawings



Tracing

Jack position control

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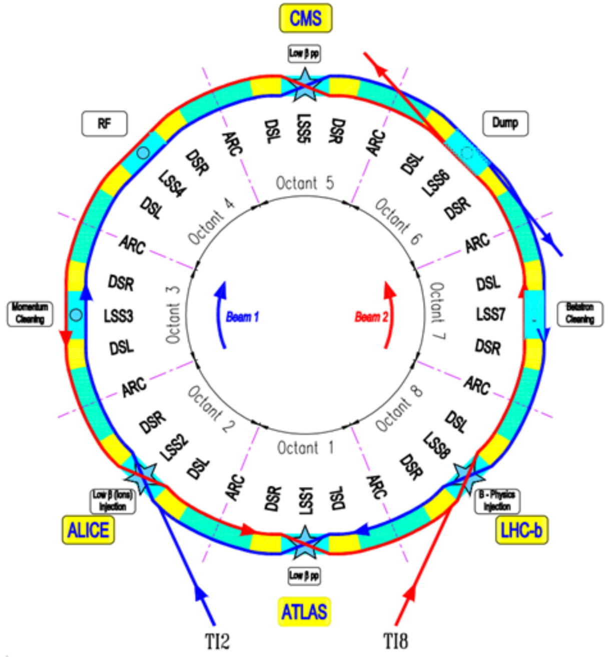
LHC alignment strategy

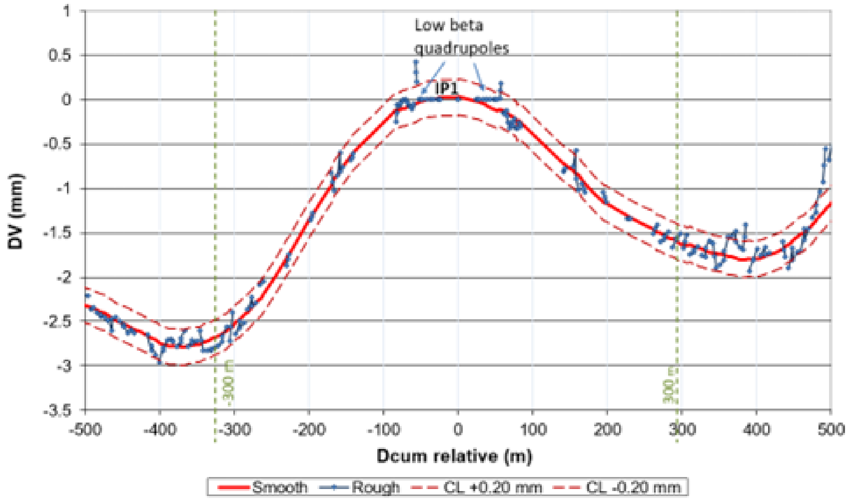


During Long Shutdown (LS):

- Full roll angle, vertical and radial measurement of all components, at cold, under vacuum.
- Smoothing process to minimize steps between adjacent components over sliding windows of 150 m.

During Run End Year Technical stops:

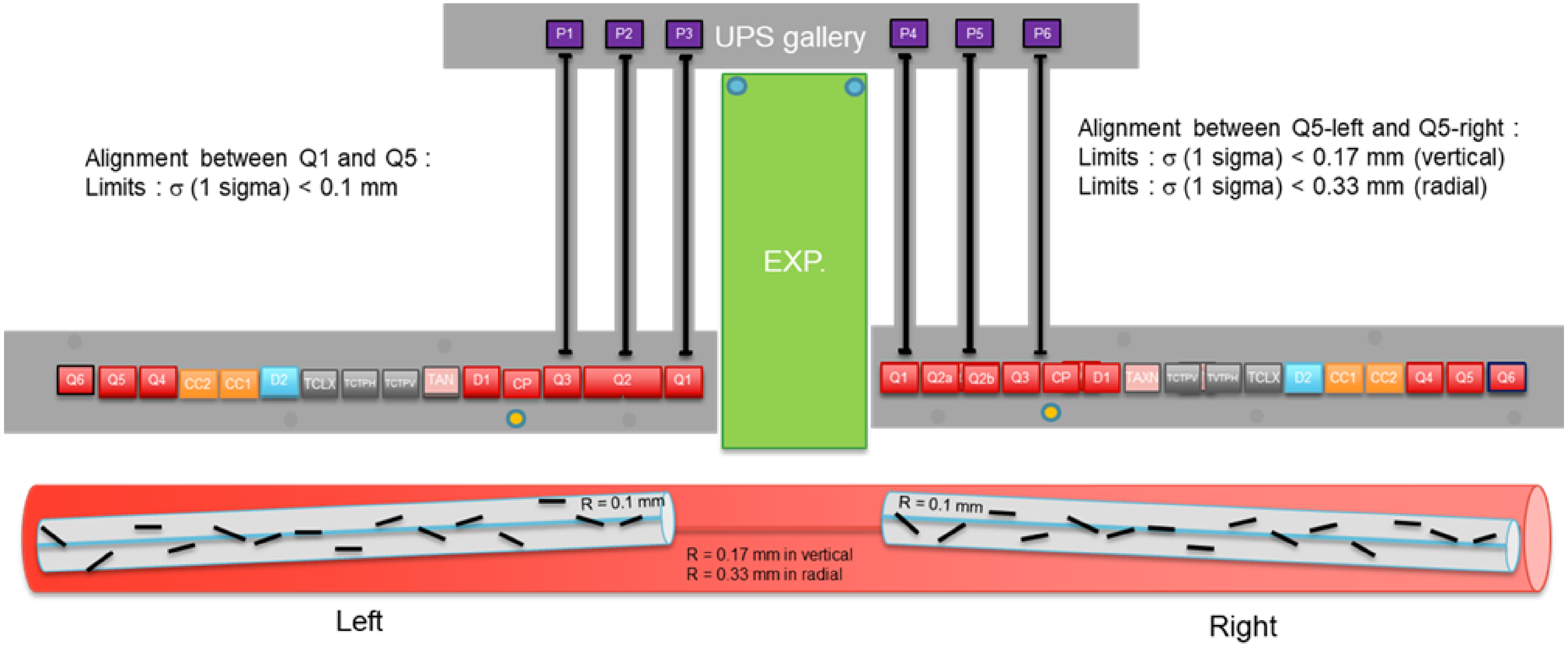
- Only a limited number of machine components are controlled in the less stable sectors,
- And the Long Straight Sections around the detectors.



See IWAA 2022 paper from Jean-Frédéric Fuchs

Alignment strategy

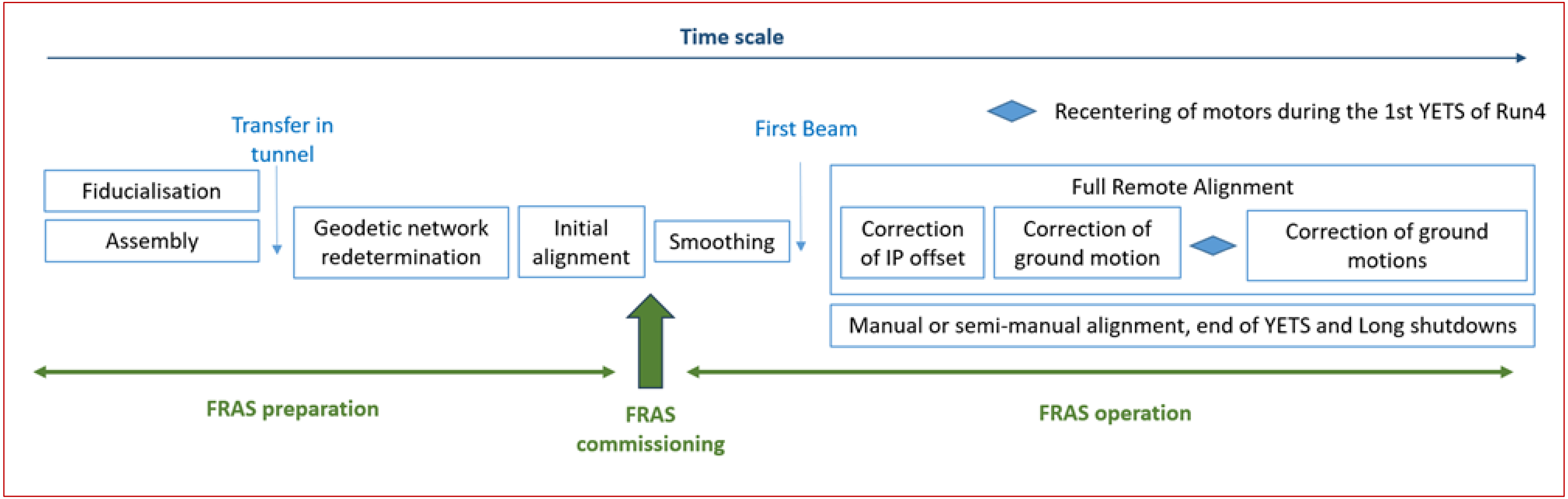
Alignment accuracy of FRAS equipped components in LSS1 and LSS5



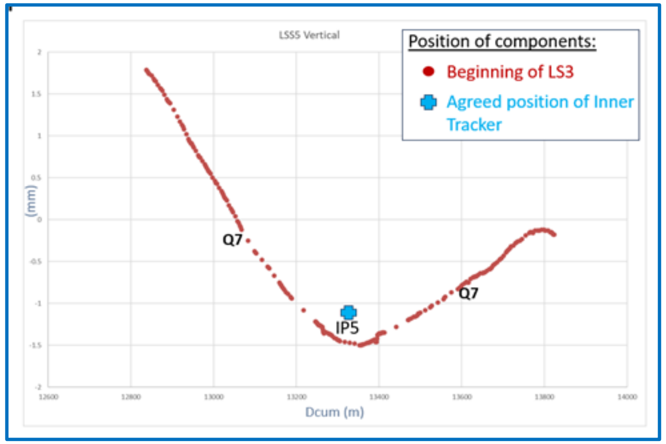
See IWAA 2022 papers from Vivien Rude and Hélène Mainaud Durand

Alignment strategy

FRAS life cycle overview

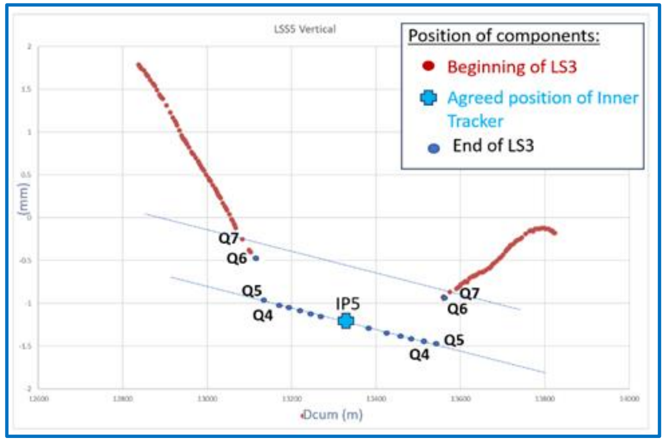


Alignment strategy



Step1:

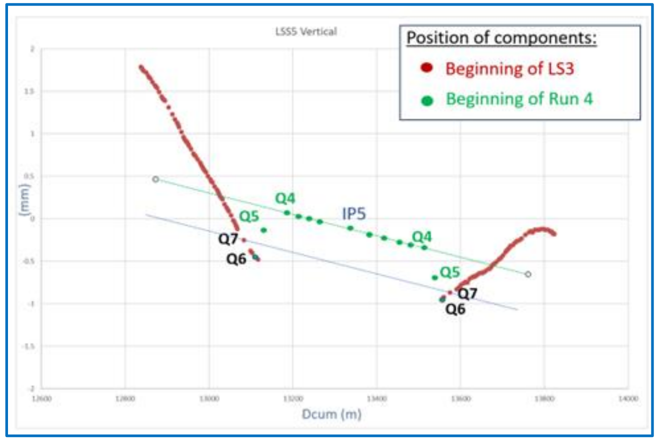
- Beginning of LS3, full measurement of LSS1 and LSS5 components, before their dismounting
- Considering past measurement + current position of the inner tracker: definition of the position of the future inner tracker for the ATLAS and CMS reference frames.
- Components Q6, Q7 and Q8 considered as fixed points



Step 2:

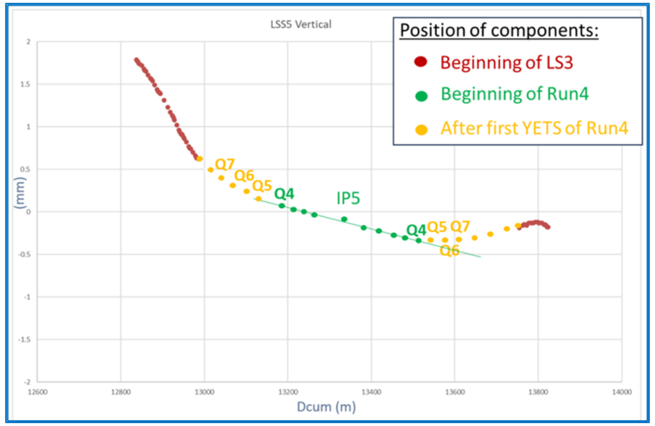
- New components installed and aligned along a straight line, parallel to the line formed by Q7L and Q7R, passing through the agreed position of the ATLAS and CMS inner tracker, both radially and vertically.
- Once components are in place, FRAS installation is launched
- Once component under cold conditions, final smoothing performed.

Alignment strategy



Step 3:

- Once the first beams have collided in the experiments after LS3, the real position of the ATLAS and CMS inner trackers w.r.t. the machine components will be determined.
- During the first technical stop of Run 4, the FRAS-equipped components will be displaced remotely along a straight line passing through the actual position of inner tracker and parallel to the line (Q7L-Q7R)
- As Q6 is considered fixed, Q5 will be displaced by only half of the requested offset.



Step 4:

- During the first Year End Technical Stop, while radiation levels are not too high, the LSS components not considered as static will be realigned and a smoothing between the LSS and the arc components will be performed.
- The measurements linking FRAS and arcs components will be performed using the Survey Train.

See IWAA 2024 papers from Patrick Bestmann and Florian Barcet

Summary

FRAS will allow the remote positioning of more than 70 components of the LHC, equipped with alignment sensors and supported by either motorized jacks or motorized platforms.

Once the alignment systems were qualified on dedicated test setups or benches, the first very important milestone was the qualification on one component of the full chain of acquisition and control/command.

Tests are coming to an end on this single component and have been the object of a lot of lessons learned, from the design or integration to the software.

In parallel, a general strategy has been prepared and is proposed for the alignment of these new FRAS equipped components, and all the other ones, including the detector part.

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