Full Remote Alignment System (FRAS) Status and plans

Hélène Mainaud Durand, on behalf of WP15.4 members

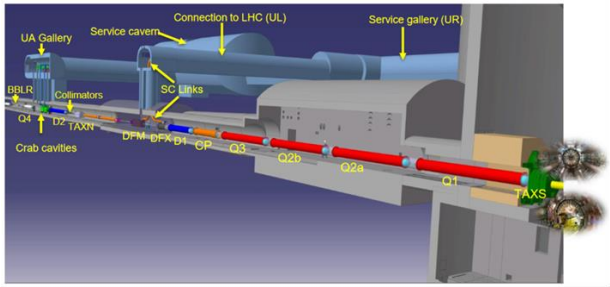
HL-LHC collaboration board, Vancouver, 27 September 2023

Outline

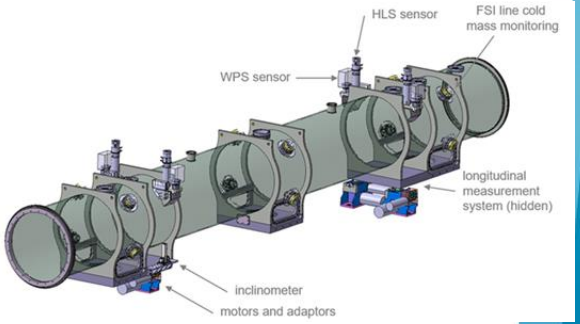
- A short reminder on Full Remote Alignment System (FRAS)
- Single Component Test : status
- Inner-Triplet String Test: status and next steps

Introduction to 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 YETS or LS
  - 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



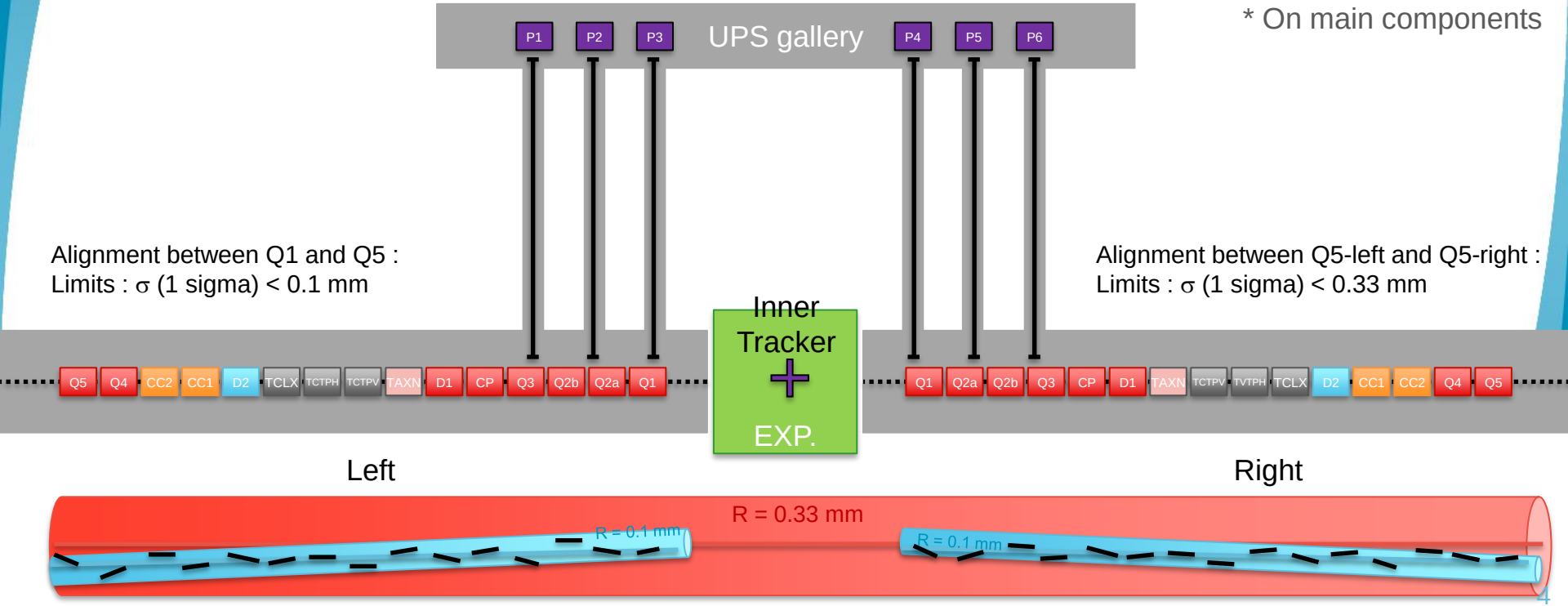
- All components from Q1 to Q5 will be:
  - Either equipped with sensors and motorized axes
  - Or **FRAS compatible**: they are static components that can absorb the displacements of their adjacent components.

Alignment requirements for the components

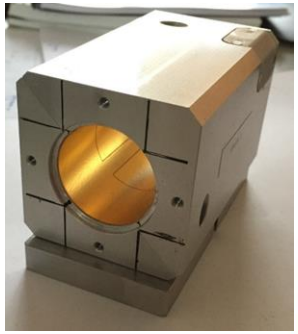
Alignment objectives (2023) for FRAS

- Position of the components cryostat along one side of the tunnel : +/- 0.1 mm *
- Position of the components cryostat along one side of the tunnel w.r.t the other side : +/- 0.33 mm *

* On main components

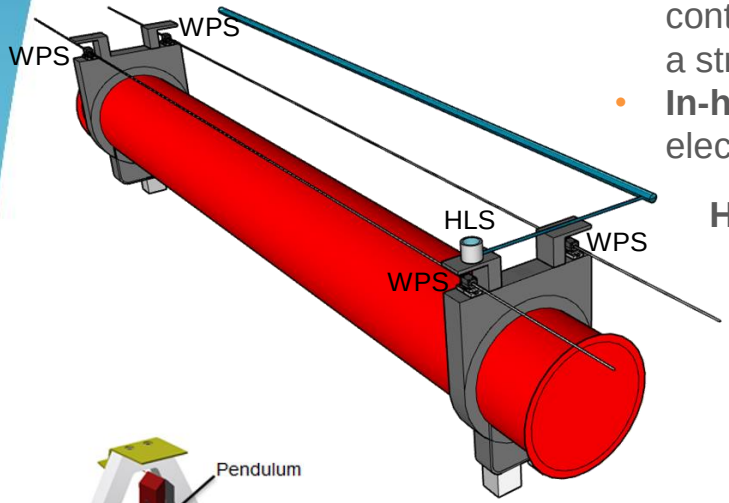


Solutions for Full Remote Alignment



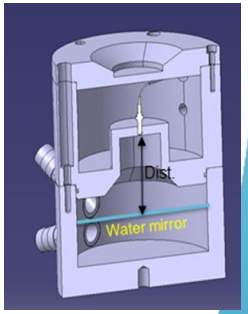
Wire Positioning Sensors (WPS):

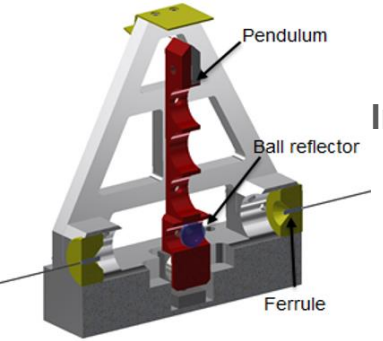
- Based on **capacitive technology**, performing continuous radial and vertical offset measurements w.r.t. a stretched wire, within a submicrometric resolution
- **In-house design** based on flexible polyimide PCB with electrodes printed on the surface and coated with gold



Hydrostatic Levelling Sensor (HLS):

- Based on the communicative vessel principle, performing vertical offset w.r.t. a water surface, within a submicrometric resolution
- **Frequency Scanning Interferometry (FSI) technology**
- Qualification under finalization



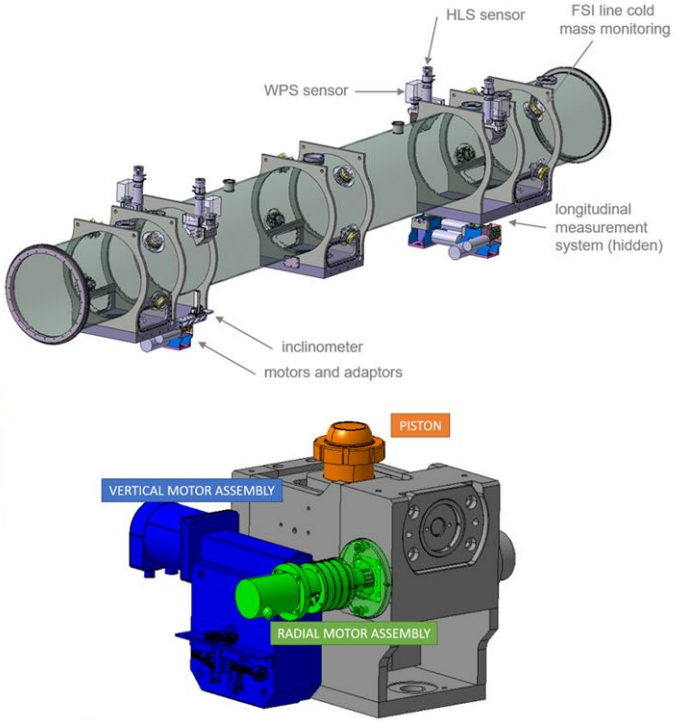


Inclinometers (in-house concept):

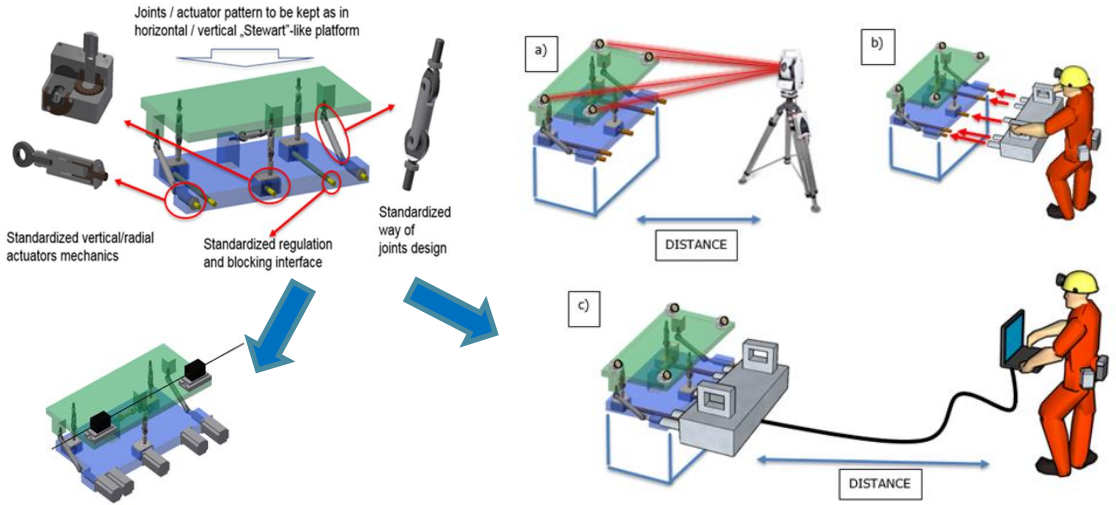
- Vertical pendulum measured either via **capacitive or FSI technologies**
- First tests: repeatability below ±10 µrad

Solutions for Full Remote Alignment

Alignment solutions for a heavy component (> 2 tons)



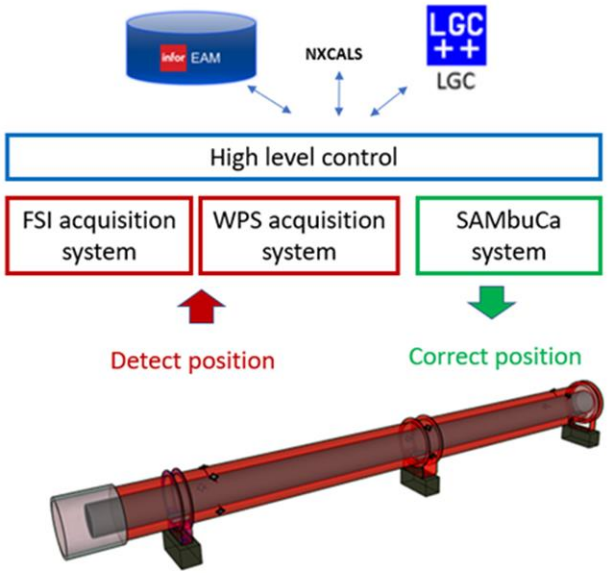
Alignment solutions for a light component (< 2 tons)



UAP platform **permanently** equipped with WPS sensors, inclinometers and motor assemblies

UAP platform **temporarily** equipped with plugged-in motor assemblies

Full Remote Alignment: control/command & acquisition aspects



Acquisition & control/command chain

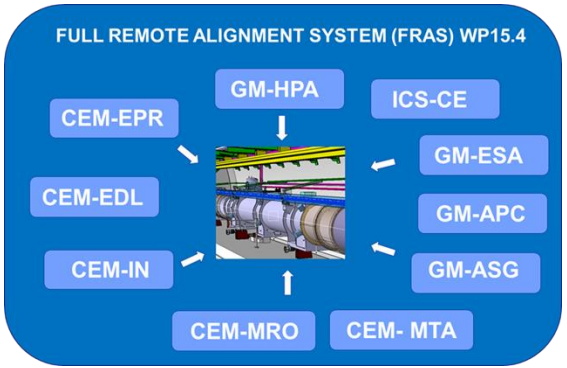
68 components

9 sensor systems

1150 sensors

344 motors

- **In-house designs**, with prototypes being qualified on the Single Component Test
- Collaboration between 3 groups of the BE department at CERN



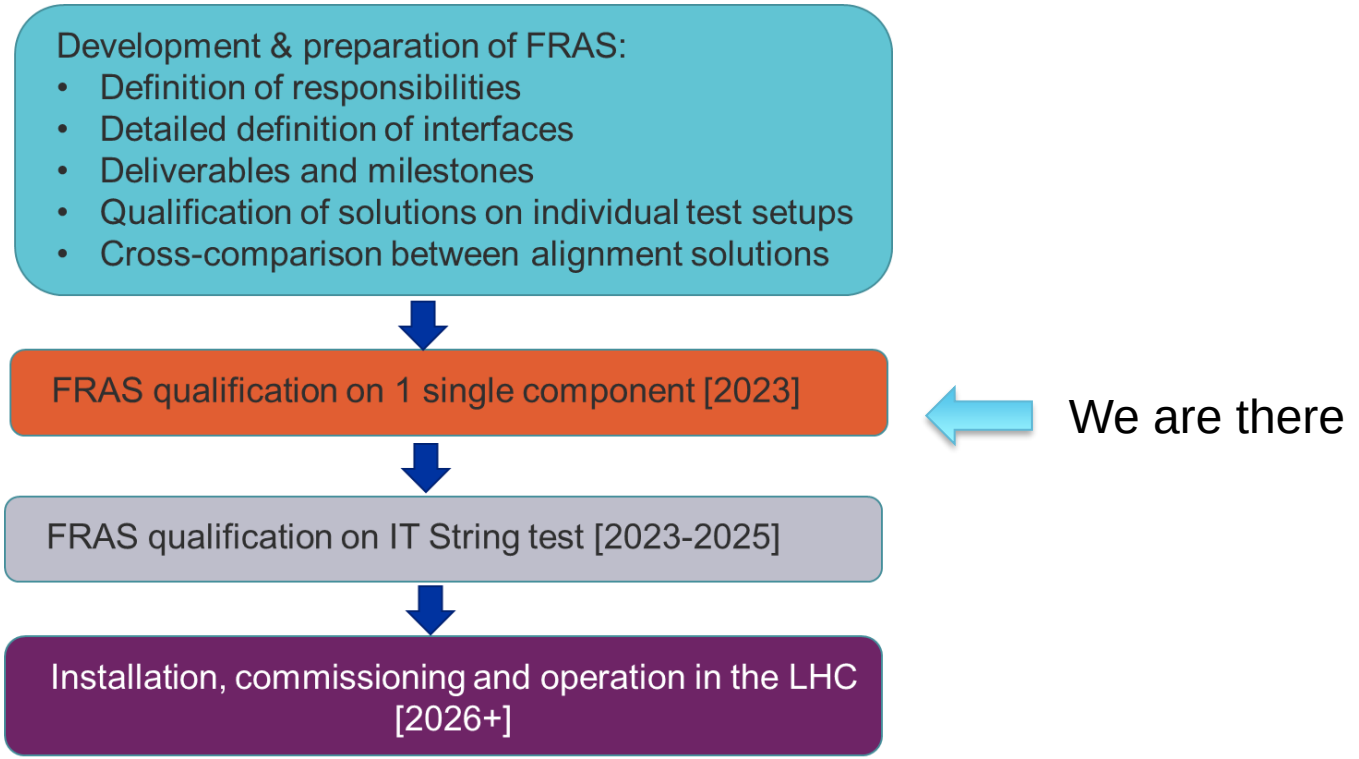
FRAS risk and safety assessment

FRAS must be operated and maintained without putting the LHC components or the persons intervening in the tunnel at risk.

- **Identification of the main failure modes and their consequences**, using the Failure Mode And Effect Analysis (FMECA):
  - Damage at an **interconnection bellow**
  - Damage of the HL-LHC components
  - Risk for personnel less critical as limited exposure time and all safety procedures already in place.

- **Development of control measures reducing the risk to an acceptable level**:
  - Use of standard IEC 61511-3
  - Application of **protection layers** to mitigate the risk of bellow damage during the displacements of 2 adjacent components: use of independent solutions based on different technologies to determine the 3D position of components and bellows
- **Corresponding document approved :** EDMS 2727128

FRAS qualification strategy

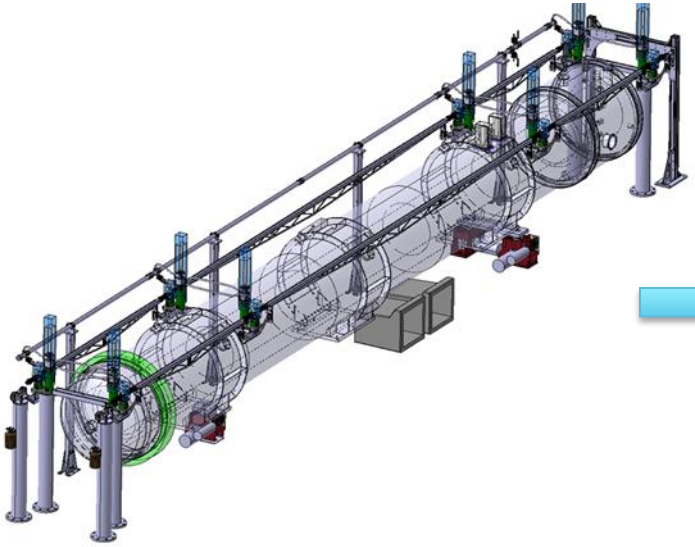


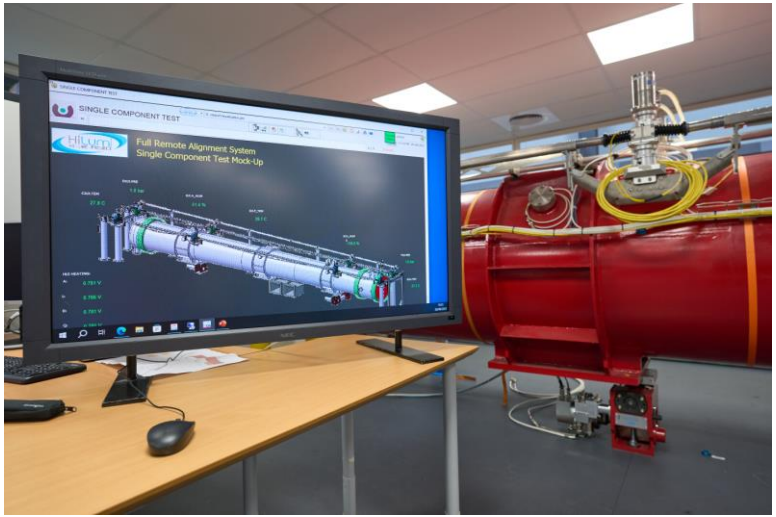
Outline

- A short reminder on Full Remote Alignment System (FRAS)
- **Single Component Test : status**
- Inner-Triplet String Test: status and next steps

Single Component Test - Objectives

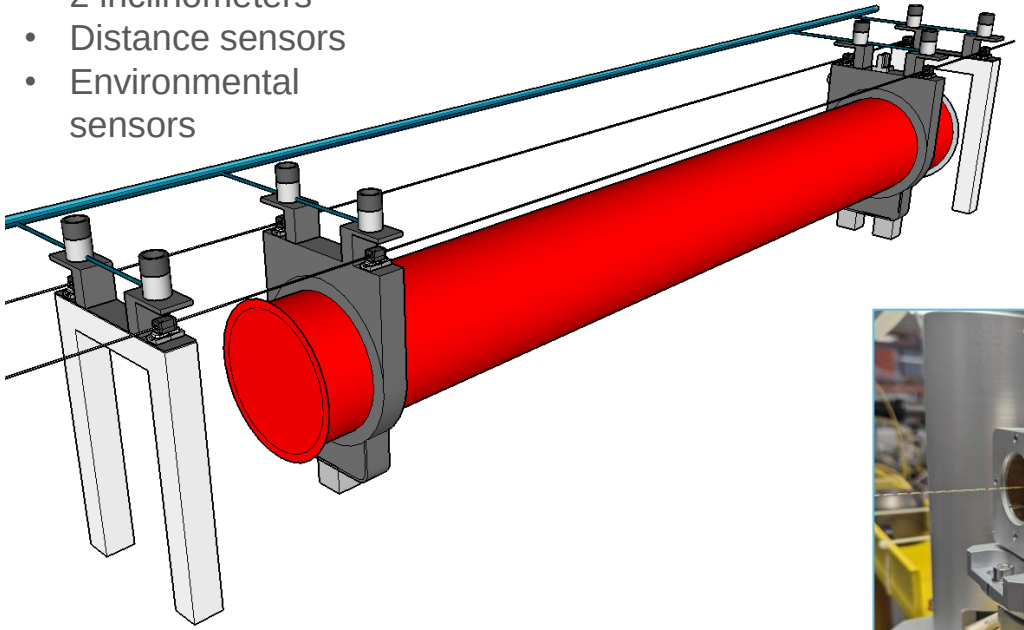
- To perform the individual and combined qualification of sensors, measurements systems, motorized adapters, data acquisition and alignment algorithms
- To provide the possibility to qualify the FRAS performance before the IT String Test
- To validate the interfaces between the 3 groups CEM, GM and ICS





Single Component Test - Sensors

- 8 HLS installed on 1 hydraulic network
- 8 WPS installed on 2 wires
- 2 inclinometers
- Distance sensors
- Environmental sensors

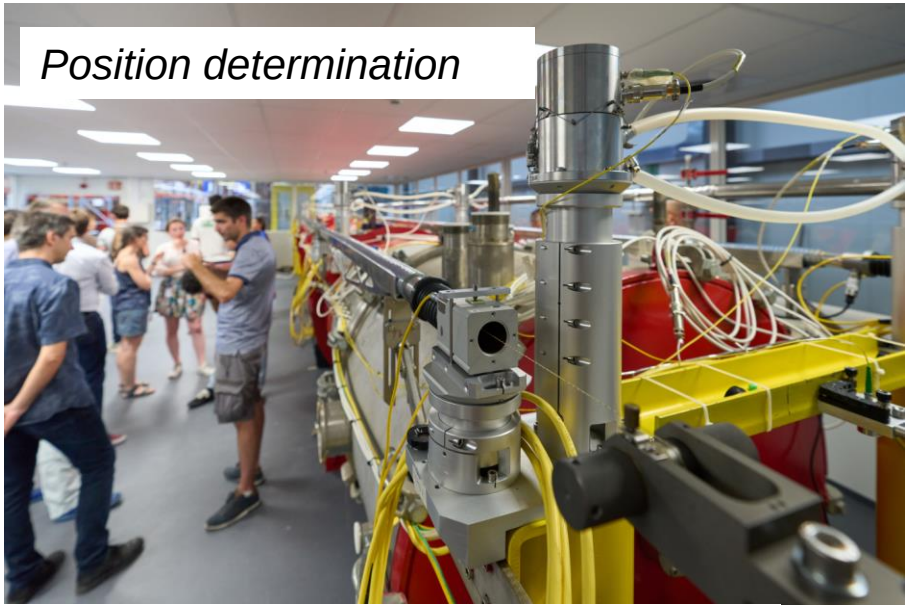


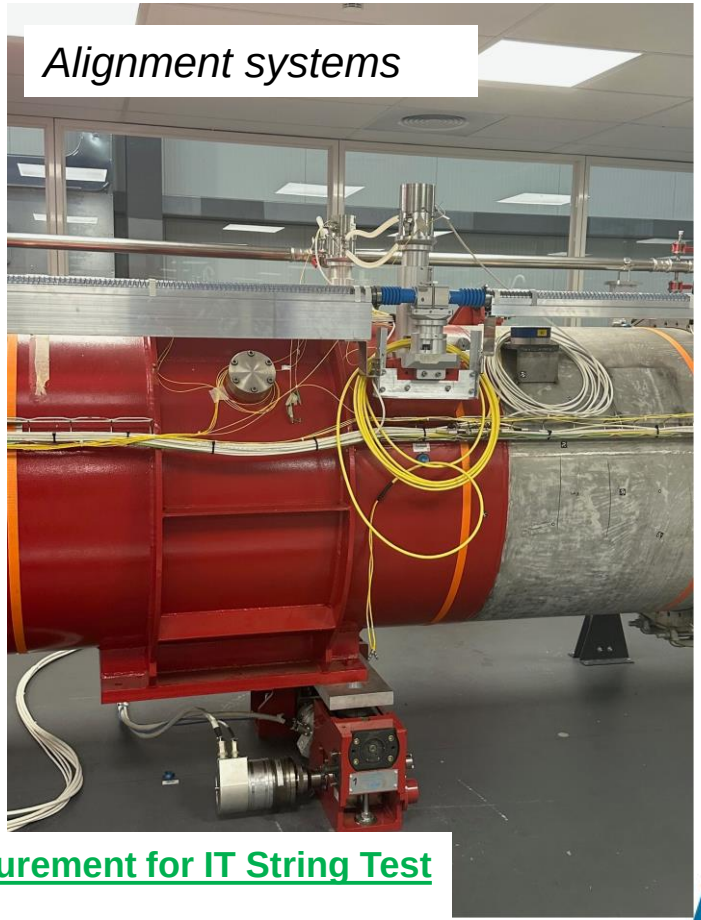
Inclinometer

Hydrostatic Levelling Sensor (HLS)

Wire Position Sensor (WPS)

Single Component Test – Position determination



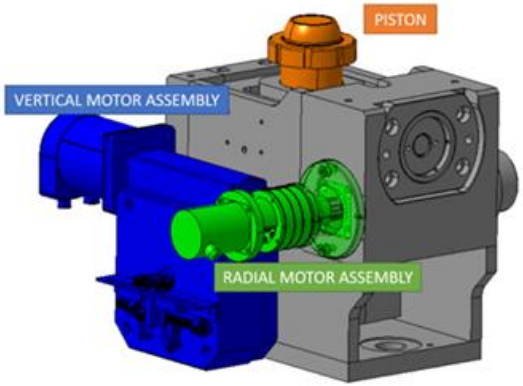


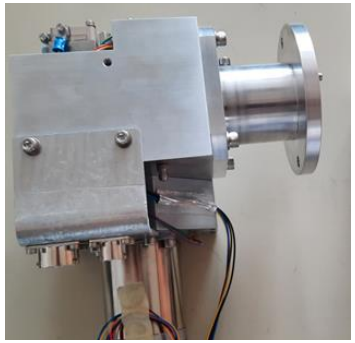
Accuracy (absolute position in R-general) :

- Radial position of TAP Magnet : 27 µm
- Vertical position of TAP Magnet : 17 µm
- Roll : 18 µrad

VERY GOOD RESULTS ACHIEVED! → Launch of procurement for IT String Test

Single Component Test - Adjustment





Radial assembly

Vertical motor assembly

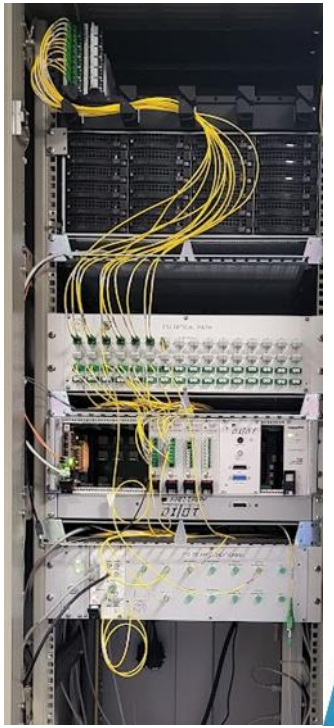
- 3 Gear trains for speed reduction and absolute position monitoring
- Epicycloid standard reduction for actuation
- Hydrostatic actuation based on polyurethane pastille

- Resolver implemented in absolute mode – ~350° for full adapter range (+/-2.5mm)
- Both types of motor assemblies qualified locally. Final qualification scheduled in October.

Single Component Test – Acquisition & control/command systems

- 24 channels FSI acquisition system developed and qualified.
- Software specification prepared and approved: **LHC-_-ES-0047**
- Low Level and High Level software under finalization – final qualification scheduled in November 2023.

Low Level controls



FSI acquisition system

- New in-house solution named **SAMbuCa** (Sensors Acquisition and Motion Control system) - EDMS 2274146

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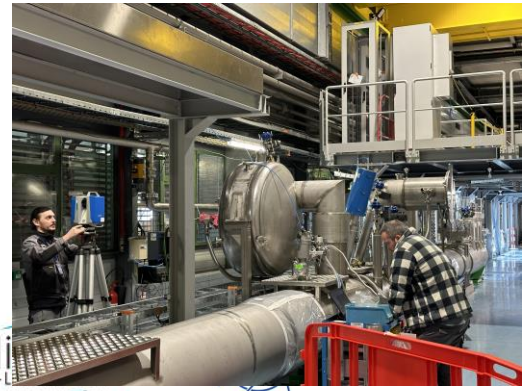
IT String Test status

Network determined



Cryo installation

Marking performed

Next steps

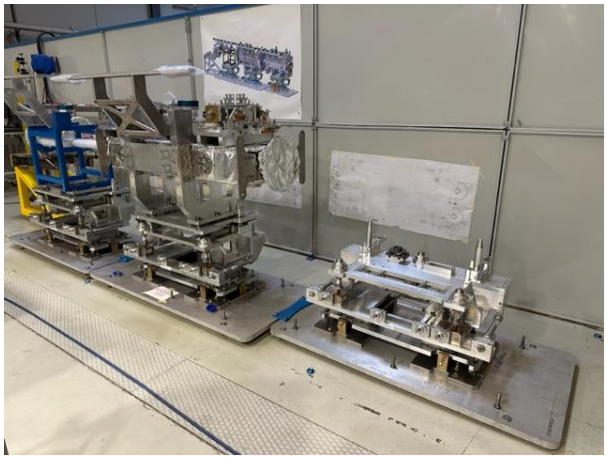
- SCT: Final qualification of low level and high level software (November 23)
- Procurement of mechanical equipment and sensors launched → control at reception, assembly and calibration
- IT-String Test:
  - Jacks installation & alignment
  - Components alignment
  - FRAS installation
  - FRAS local qualification
  - Final smoothing of components using FRAS

Other items from WP15.4

- Standard alignment of the collimator mock-up and final qualification of the Universal Adjustment Platform and sensors supports
- Fiducialisation measurements on-going
- A lot of work on-going on quality aspects: naming, preparation of databases, etc.
- Internal monitoring & assembly measurements of crab cavities :

  → *See presentation by V. Rude*
- Internal monitoring of MQXF :

  → *See presentation by V. Rude.*

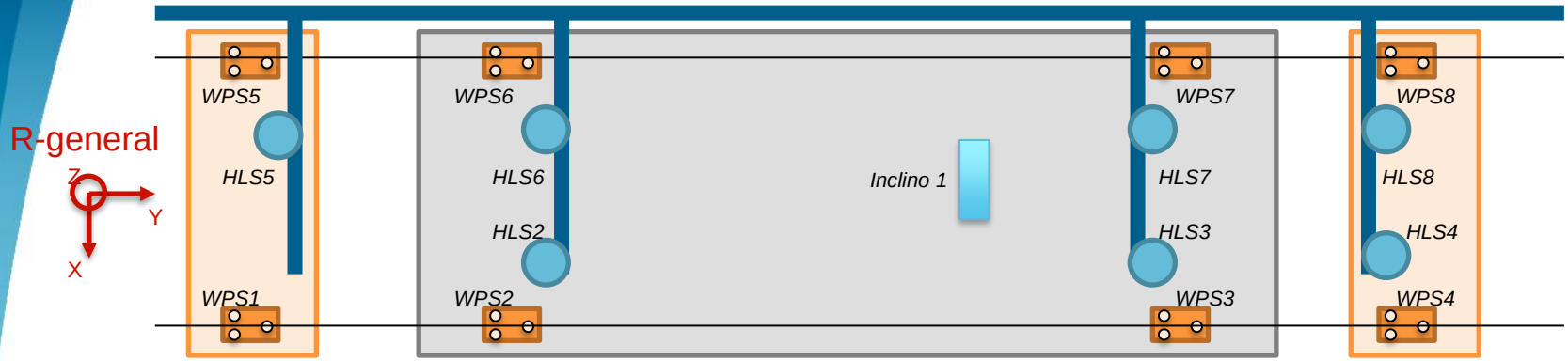


Summary

- The Single Component Test (SCT) confirms to be a very useful mock-up to qualify the hardware (motor assemblies, sensors) and software for the Full Remote Alignment System (FRAS) in order to be ready for the IT String Test.
- All sensors (except longitudinal sensors) have been qualified. Procurement launched for the IT String Test.
- All motor assemblies qualified on individual test benches; to be qualified through repositioning cycles on the SCT in October.
- Low-level and high-level software under finalization (final qualification expected in November 2023); they will have to be extrapolated to the control of the 6 components of the IT String Test.
- Once fully qualified on the SCT, a 1000 channels FSI acquisition system will be developed for the IT String Test.

Thank you very much!

3D calculation



3D calculation with :

- 8 / 8 : WPS
- 7 / 8 : HLS → Issue with sliding part ?
- 1 / 2 : inclinometer → issue with one sphere

FUV : 0.6 [1]

A priori precision WPS : 20 µm
A priori precision HLS : 20 µm
A priori precision inclino : 150 µrad

Accuracy (absolute position in R-general) :

- Radial position of TAP Magnet : 27 µm
- Vertical position of TAP Magnet : 17 µm
- Roll : 18 µrad

	Residual		A priori precision	
WPS1-WPS_rad	10	µm	20	µm
WPS1-WPS_vert	2	µm	20	µm
WPS5-WPS_rad	-10	µm	20	µm
WPS5-WPS_vert	-7	µm	20	µm
WPS2-WPS_rad	-12	µm	20	µm
WPS2-WPS_vert	-6	µm	20	µm
WPS3-WPS_rad	-5	µm	20	µm
WPS3-WPS_vert	13	µm	20	µm
WPS6-WPS_rad	12	µm	20	µm
WPS6-WPS_vert	11	µm	20	µm
WPS7-WPS_rad	5	µm	20	µm
WPS7-WPS_vert	-6	µm	20	µm
WPS4-WPS_rad	7	µm	20	µm
WPS4-WPS_vert	-8	µm	20	µm
WPS8-WPS_rad	-7	µm	20	µm
WPS8-WPS_vert	2	µm	20	µm
HLS5-HLS_vert	24	µm	20	µm
HLS2-HLS_vert	-11	µm	20	µm
HLS3-HLS_vert	4	µm	20	µm
HLS6-HLS_vert	6	µm	20	µm
HLS7-HLS_vert	-10	µm	20	µm
HLS4-HLS_vert	-10	µm	20	µm
HLS8-HLS_vert	-3	µm	20	µm
inclino 1	63	µrad	150	µrad