Full Remote Alignment System (FRAS) Status

Mateusz Sosin, on behalf of WP19

14th HL-LHC Collaboration Meeting, Genoa, 7-10 October 2024

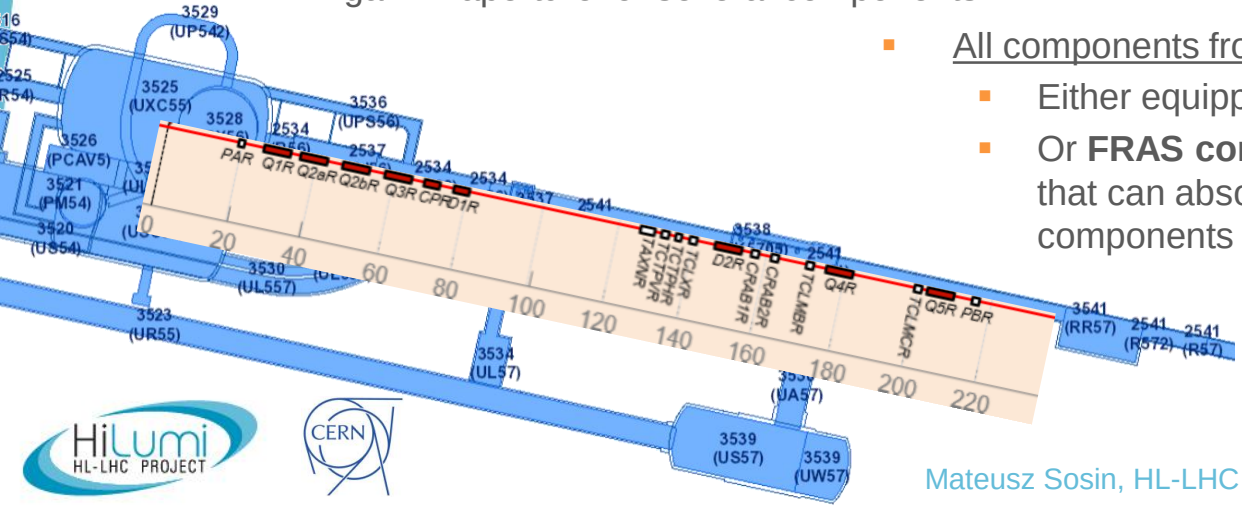
Outline

- A short reminder on Full Remote Alignment System (FRAS)
- Single Component Test : status
- Inner-Triplet String Test: status and next steps
- Other activities from WP19

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



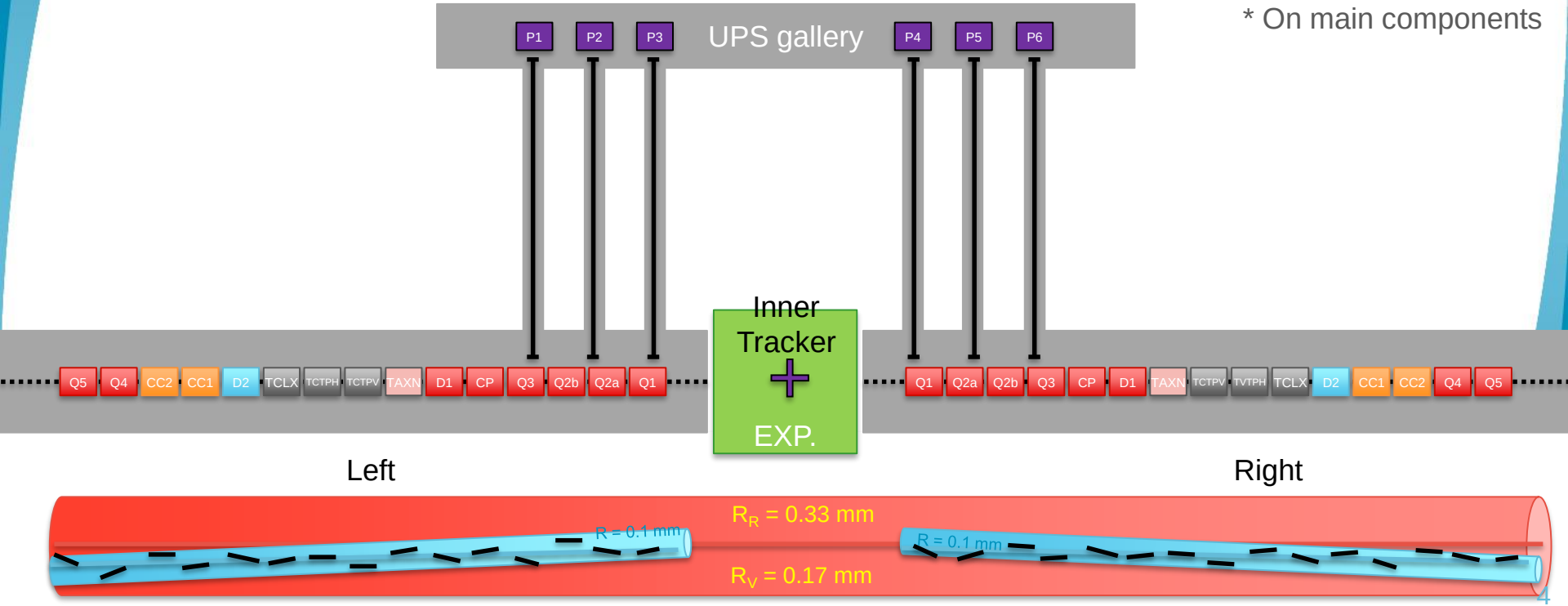
- All components from Q1 to Q5 will be:
  - Either equipped with sensors and motorized supports
  - Or **FRAS compatible**: they are static components that can absorb the displacements of their adjacent components

Alignment requirements for the components

Alignment objectives (2024) 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 : +/- 0.17_V / 0.33_R 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 micrometric resolution

Frequency Scanning Interferometry (FSI) technology:

Hydrostatic Levelling Sensor (HLS):

- Based on the communicative vessel principle, performing vertical offset w.r.t. a water surface, within a submicrometric resolution

Internal monitoring heads and targets:

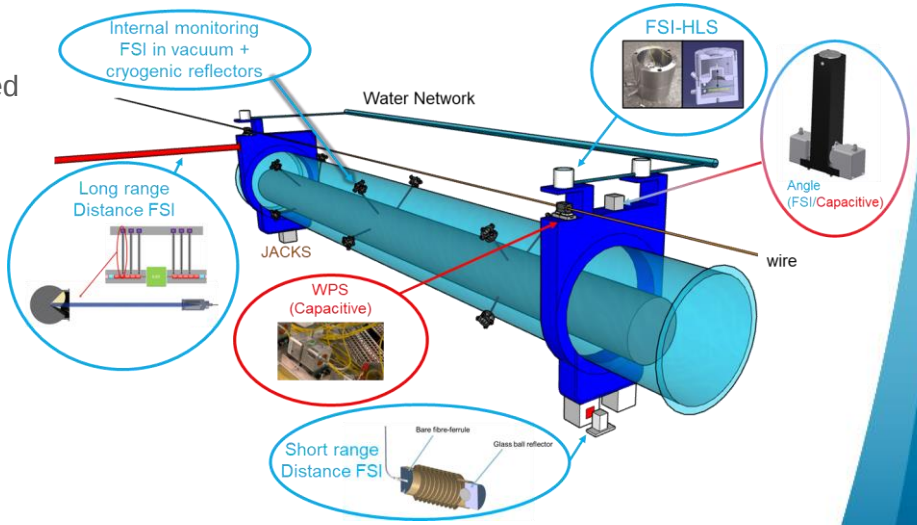
- Measuring distances between vacuum vessel and targets located on the magnet cold masses/CRAB cavities

Distance sensors (~15m long and short distance)

- Radial position transfer through UPS galleries and monitoring of longitudinal position of components

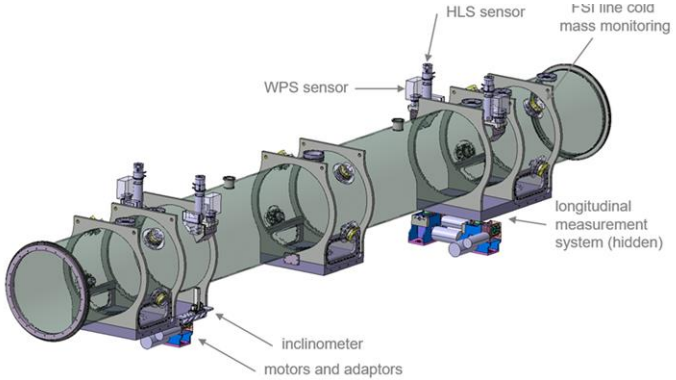
Inclinometers – FSI / capacitive:

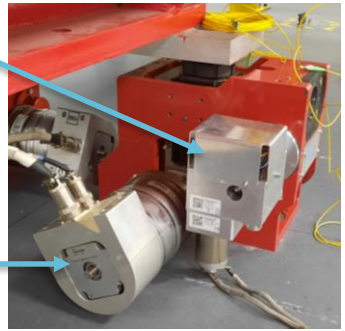
- Measuring components Roll angle.
- Repeatability below ±10 µrad



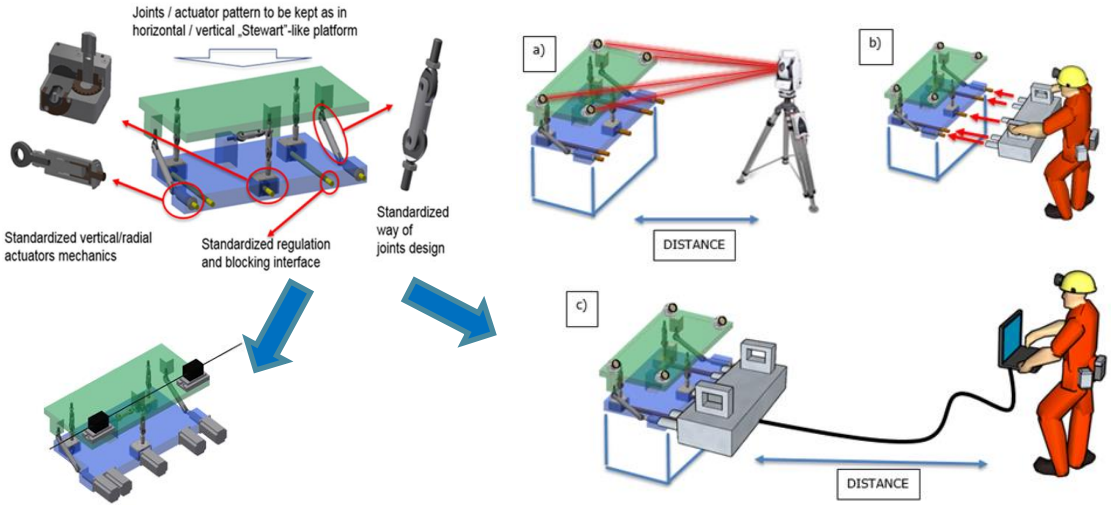
Solutions for Full Remote Alignment

Adjustment solutions for a heavy component (> 2 tons)





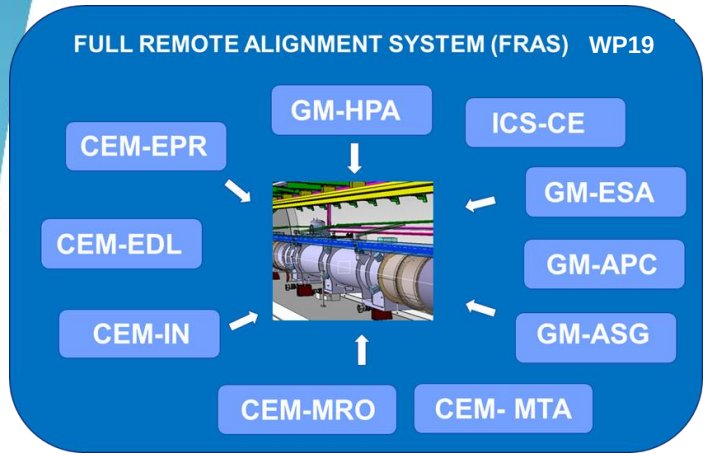
Adjustment solutions for a light component (< 2 tons)

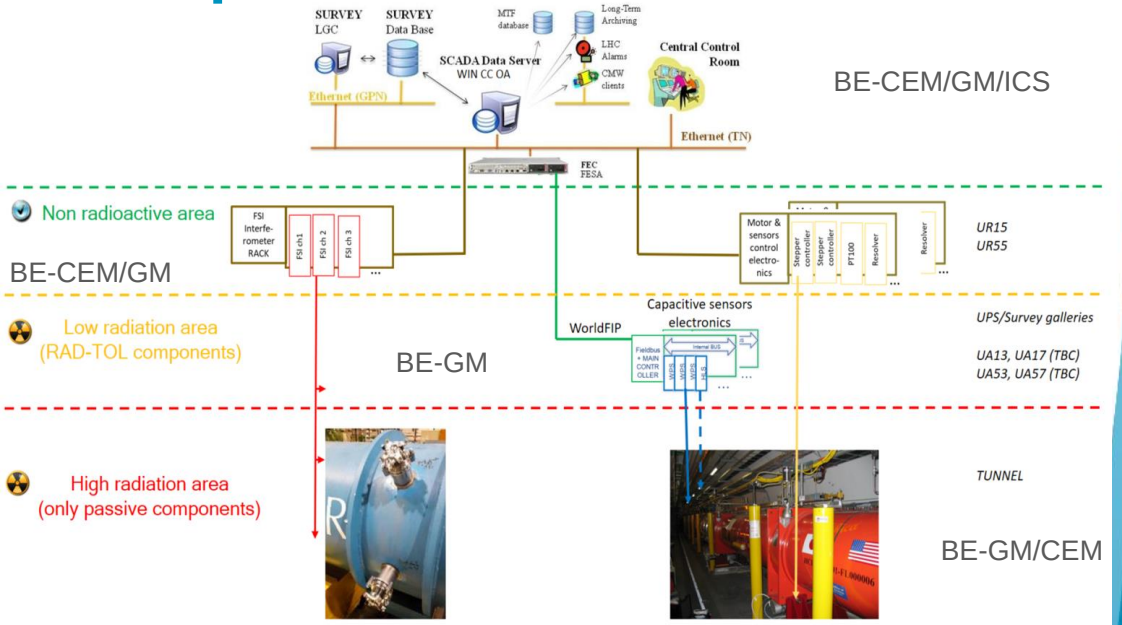


UAP platform **permanently** equipped with WPS sensors, inclinometers and motor assemblies

UAP platform **temporarily** equipped with plugged-in motor assemblies (or adjusted manually)

Full Remote Alignment: control/command & BE groups collaboration aspects





68 components

1150 sensors

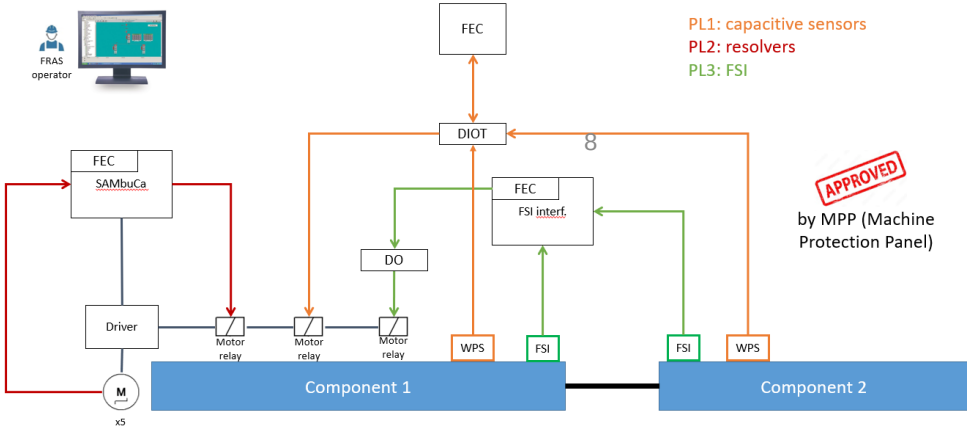
344 motors

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

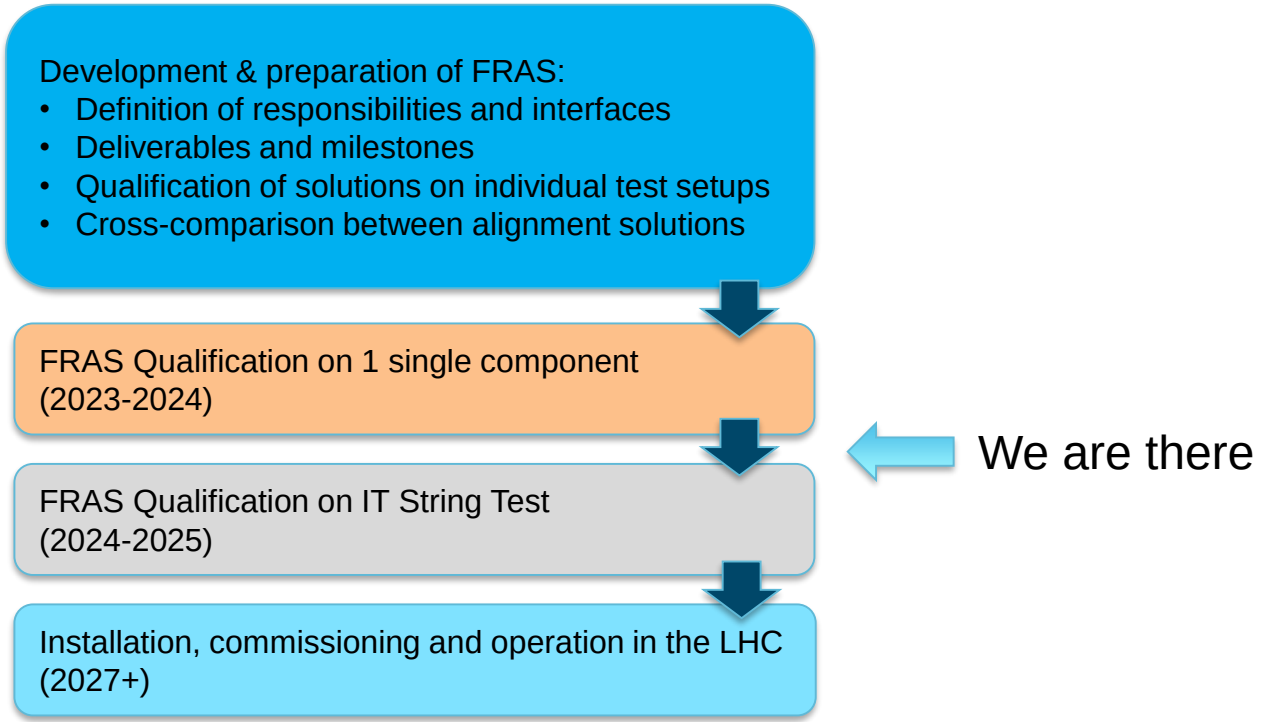
FRAS risk assessment and protection layers

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

- Main failure modes and their consequences identified (bellows damage, …)
- Alternative solution to *Safety Instrumented system* following the standards **IEC 61511**
- Reliability information is obtained by operational experience at CERN, with many (**conservative**) assumptions.
- According to the data handled, the **tolerable risk** is accomplished if the alignment activity remains within **less than 11 full days (motors ON)** per year
- Corresponding document approved: EDMS 2727128



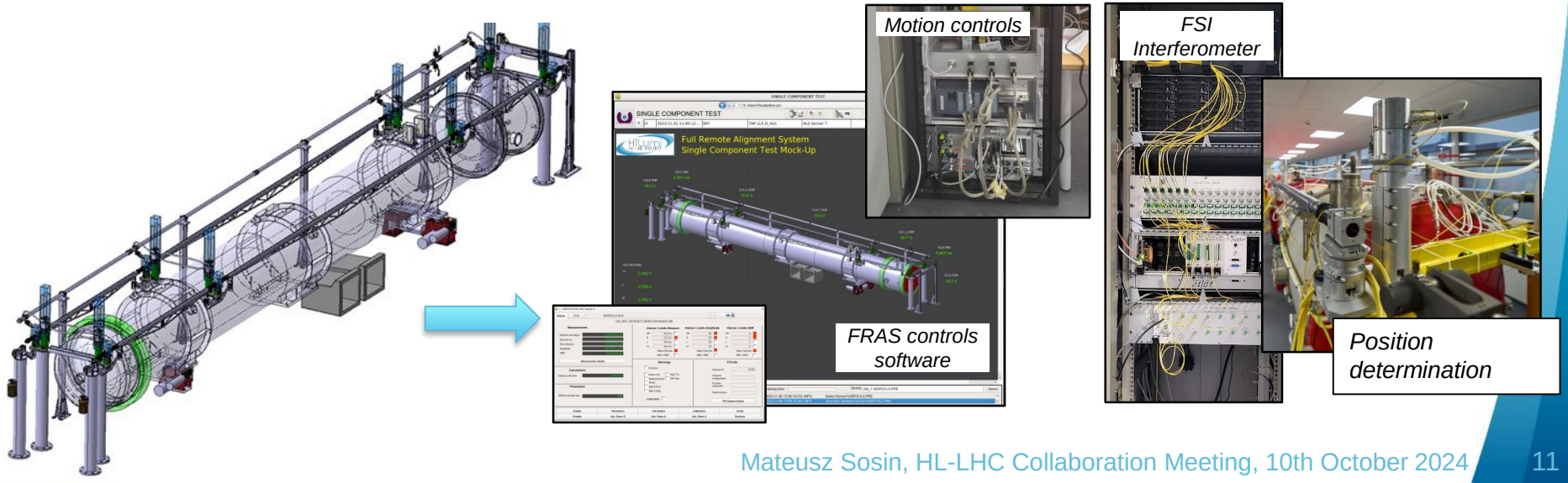
FRAS qualification strategy



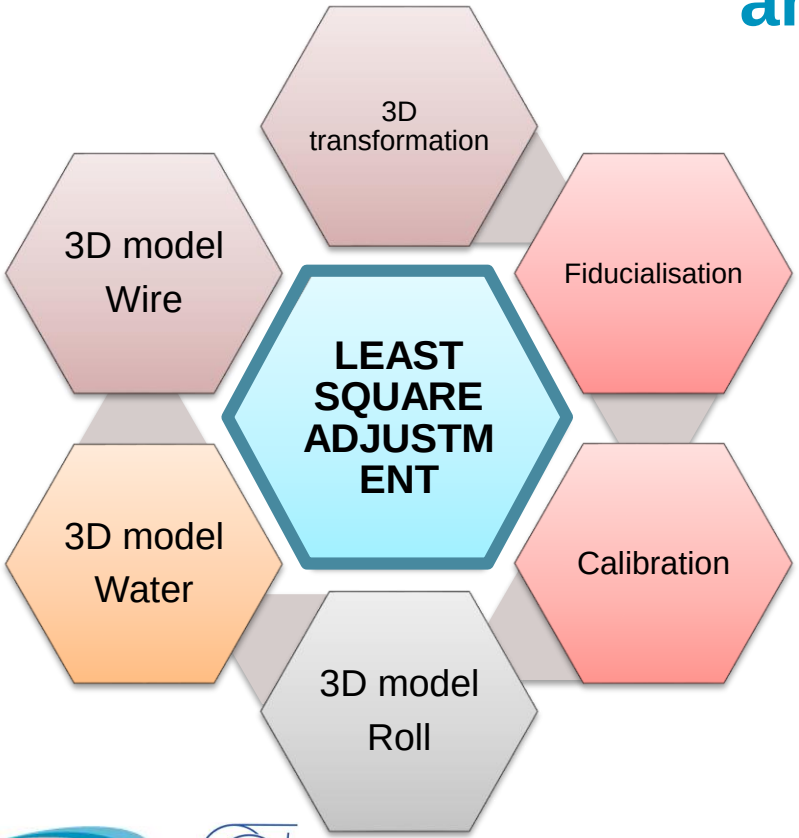
Single Component Test : status

Single Component Test (SCT) - 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 and prepare the IT String Test
- To validate the interfaces between the 3 groups CEM, GM and ICS



SCT for FRAS least square adjustment and data structures validation



Observations :

- WPS, HLS, Inclinometers

Main Parameters :

- Fiducialisation, calibration, etc.
- 3D positions of the components
- Positions and Sags of the wires
- Heights of the water networks

Dedicated real time LGC (*Logiciel General Compensation*) software package being developed

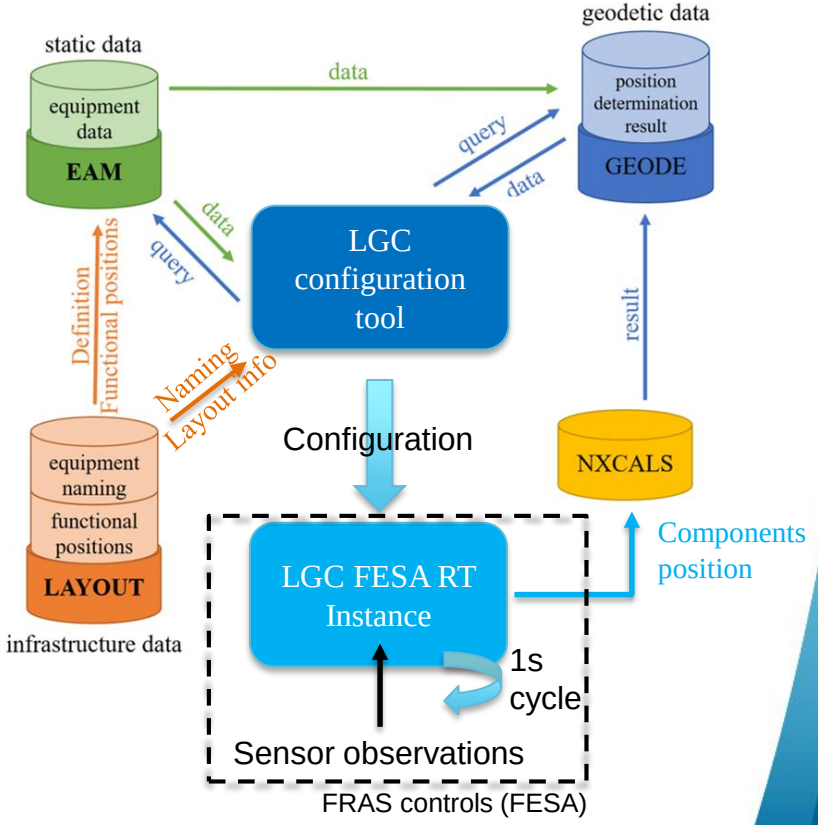
For 4 IP Sides → 288 sensors ≈ 35 000 parameters only for WPS sensors

~100 000 config. parameters for FRAS

SCT for FRAS least square adjustment and data structures validation

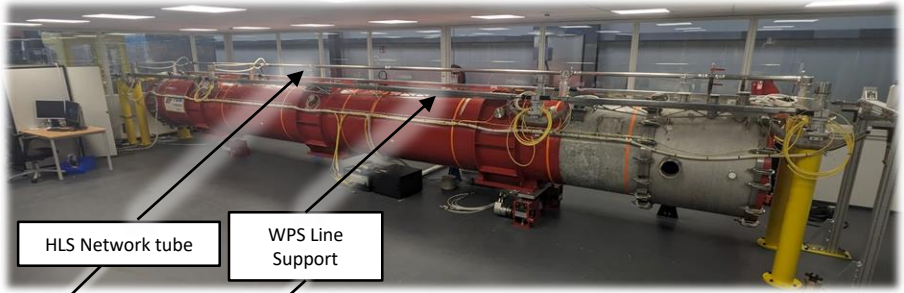
Tests of assets structures and QA approach

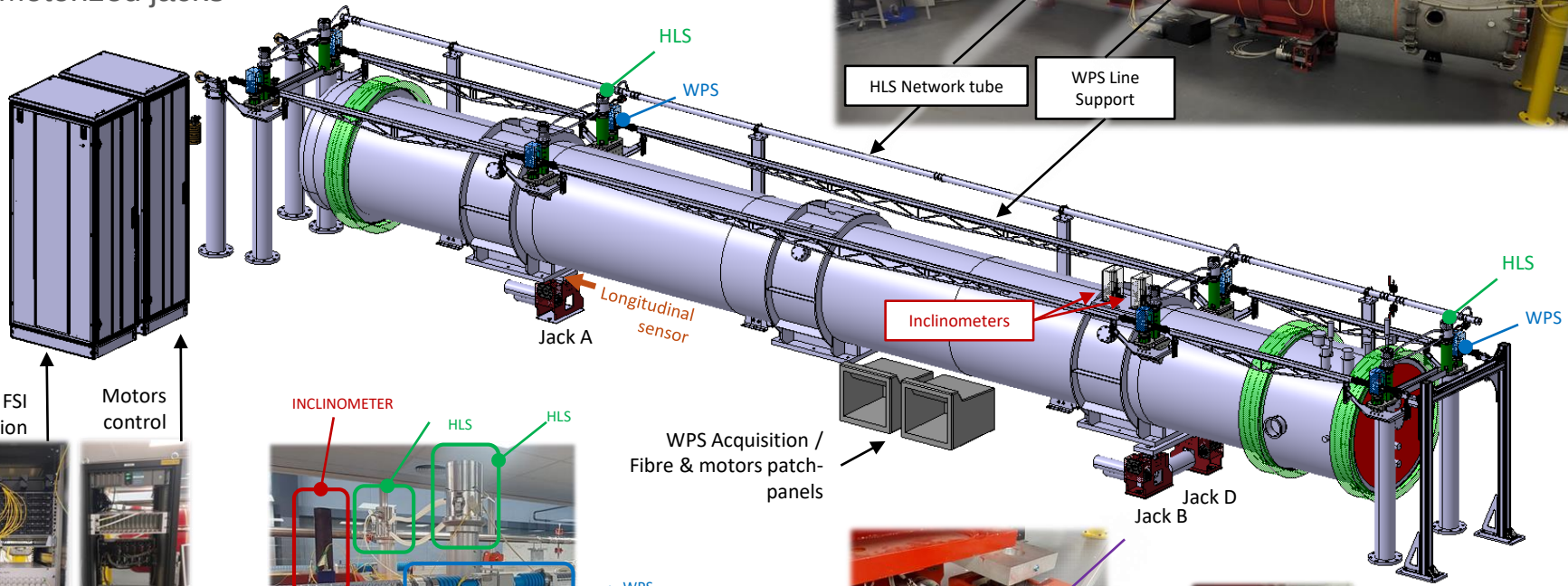
- Integration of FRAS related data in various Databases (for 1 component at first)
  - InforEAM (assets management, fiducialisation, calibration)
  - Layout DB (Infrastructure layout, functional pos.)
  - Survey DB (storage for geodetic points and magnets assemblies
- Tests of automatic configuration generation tools (to limit human error factor)
- Upgrade of data structures before IT String deployment



SCT mock-up

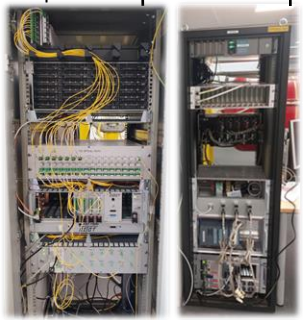
- 8 HLS installed on 1 hydraulic network
- 8 WPS installed on 2 wires
- 2 inclinometers; Distance sensors
- Environmental sensors
- Motorized jacks

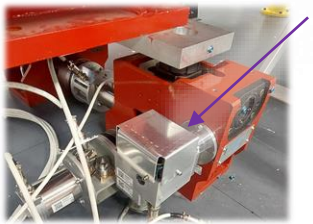


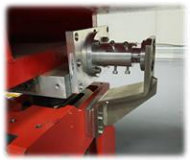


FSI Acquisition

Motors control



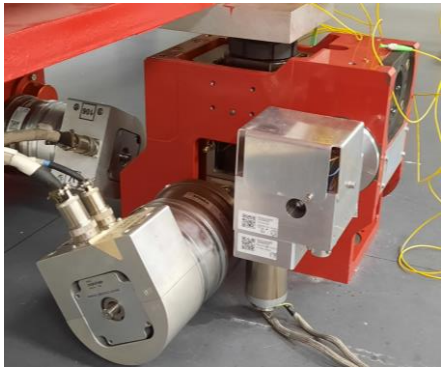




SCT – results

SCT as rehearsal platform of systems integration and installation:

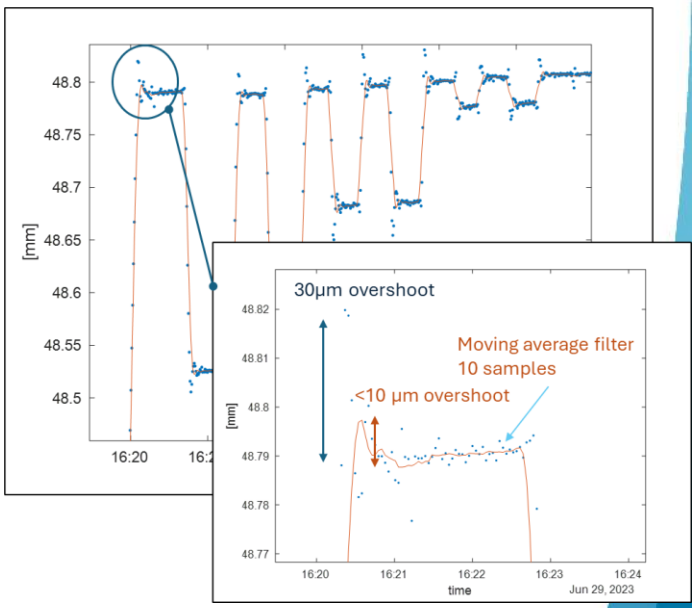
- Updates in WPS line supporting bars, HLS network and fibre ducts design
- Upgrades and validation of installation procedures for supports, jacks, HLS & WPS system components, cables/fibres routing and handling.
- Commissioning of first prototypes of HL-LHC FSI acquisition rack 64 channel modules (1/4 of full 256 ch rack)
- Commissioning and calibration of WPS sensors installation
- Motorized adapters <5 minutes quick installation time (ALARA principle) validated

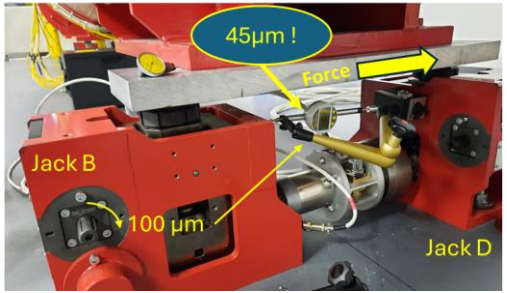


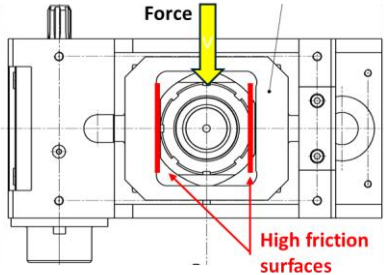
SCT – results

Dynamic tests of FRAS sensors and motorized jacks cycling:

- FSI HLS sensors tested under ‘extreme’ motion conditions. Water behaviour and sensors reading check in transition states
- FSI interferometer works well @ 5s cycle
- FSI Inclinometers, longitudinal sensors and WPS response tested – no issues
- Jacks behaviour checked in real conditions
  - Micrometric adjustment resolution confirmed
  - Issue with interference fit friction in “longitudinal” jack detected – fitting tolerances changed in HL-LHC production series

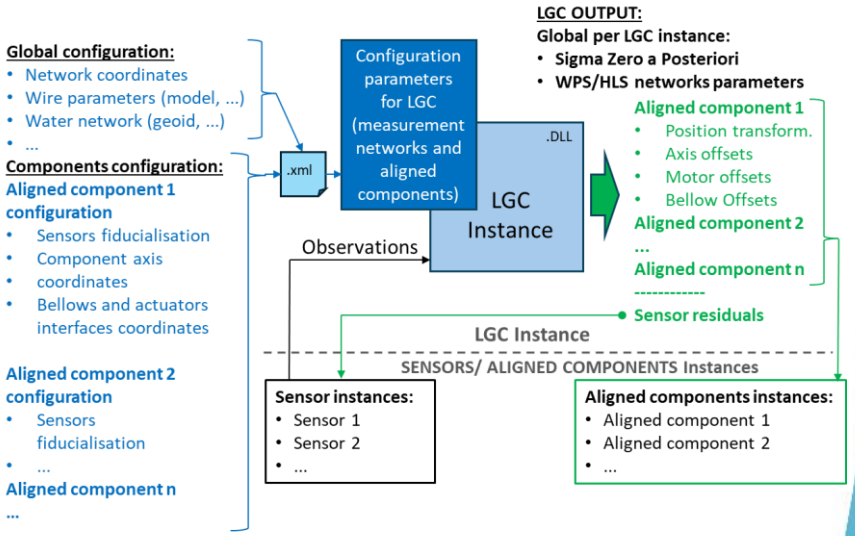






SCT– results - LGC position determination

- **The LGC software real time operation (external position monitoring) was validated on 1 component**
  - Radial and vertical position of TAP Magnet: ~30 µm
  - Roll: 35 µrad
  - LGC correct response during transition states (motion)
- FRAS data structures in InforEAM, GEODE DB were upgraded according to future needs



VERY GOOD RESULTS ACHIEVED! → Ready for extrapolation of software to IT String and Internal Monitoring features

SCT– status and next steps

- **Mock-up will be used as main rehearsal platform for FRAS software final implementation and tests before IT String and HL-LHC**
  - Continuous testing and upgrades of FRAS software blocks and software generation tools
    - Data acquisition and sensor software blocks upgrades (e.g. 1s data acquisition of FSI interferometer)
    - Finalization of safety layers implementation and tests
    - Tests of internal monitoring implementation - much more complex due to cryostat deformations issues identified during 2023/24
  - Preliminary validation of IT String software, before commissioning in Q1 2025
- **The tests performed in SCT allowed for launch procurement of IT String FRAS equipment**
- **SCT will be used for training of WP19 personnel before FRAS commissioning during LS3**

Inner-Triplet String Test: status and next steps

WP19 progress on IT String Test

- **Survey traced:**

Pillars, Beamline + parallel line, Beam pts, Jacks, Anchors, DFX/DCM and Jumpers

- **Jack installation and position control**

Q1 – Q2a – D1 done (Q2a installed)

- **Water network installation**

Main water pipe installed and validated.

- **Sensors acquisition, GYPOS Racks**

Equipment installation in progress (WPS and FSI racks): WPS cables commissioned and tested – big work due to cables complexity.

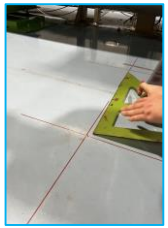
FSI optical modules and data acquisition commissioning ongoing

- **GYPOP patch racks**

Equipped with HLS heating and Motors patch. Waiting for their installation on Magnet Line to be equipped with fibre patch-panels

- **Optical Fibre pulling**

Postponed to end of October ‘24



WP19 progress on IT String Test

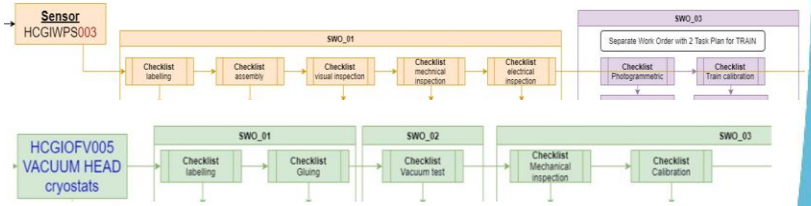
IT String equipment reception, assembly and checks:

- FSI targets and supports (ready – used for cryostating)
- FSI heads (ready, calibration)
- HLS line components (ready, installed)
- Sensor supports, WPS line support (ready)
- Pillars (ready)
- FSI Interferometer parts (ready, commissioning ongoing)
- HLS Sensors (assembled, to be calibrated)
- WPS Sensors and acquisition (validation pending)
- Motorized adapters (procurement pending) – Q1 2025
- Sambuca - motor controls (being validated) – readiness Q1 2025

WP19 progress on IT String Test

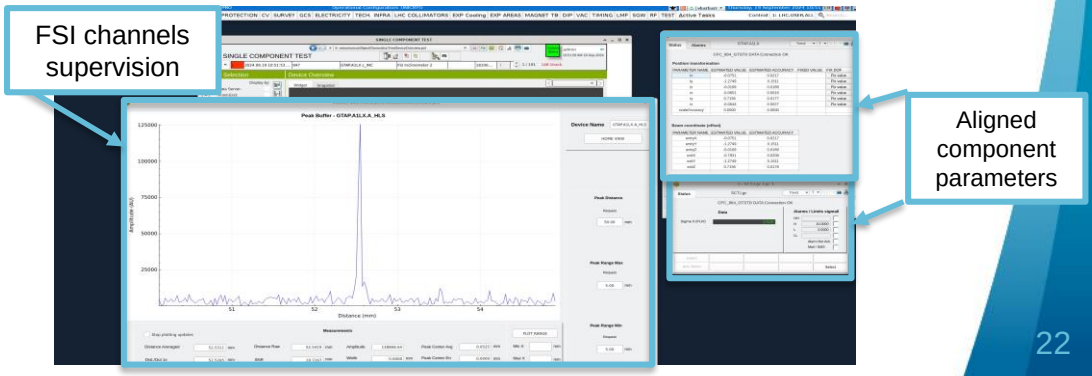
Data structures:

- Functional positions defined in Layout and published in EAM. Assets for FRAS systems ready - going through dedicated workflow for assembly, checks before installation and calibration
- EAM Custom fields on magnets implemented



Software:

- FESA/SCADA signal acquisition hardware and sensors objects are ready. To be deployed in Oct '24 for sensors commissioning
- External position monitoring is ready, but internal monitoring part need to be finalized (Nov/Dec '24)
- Motion controls blocks – Q1 2025
- Safety functions readiness - Q1 2025
- Commissioning of FRAS software on IT String – Q1 2025



IT String - Next steps

- Final qualification of control software on SCT
- Procurement of mechanical equipment and sensors ongoing → control at reception, assembly and calibration

- **IT-String Test (Q4 2024 – Q1 2025)**:
  - Finalize jacks installation & alignment
  - Components alignment
  - FRAS installation
  - FRAS local qualification
  - Commissioning of FRAS software
  - Final smoothing of components using FRAS

Other activities from WP19

- Standard alignment (external position monitoring) of the collimator mock-up and final qualification of the Universal Adjustment Platform:
  - FRAS sensor systems for Bld. 927 collimator mock-up being finalized
  - Infrastructure (pillars, cables) ready
  - Motorized adapters ready and validated on dedicated test bench
  - Mock-up FRAS commissioning Q4 2024

- Fiducialisation measurements (various components) on-going
- Internal monitoring of MQXF and crab cavities → *See presentations by V. Rude*
- FRAS Engineering Specification – presented for comments during WGA meeting (see EDMS 2964085)
- HL-LHC FRAS components procurement strategy discussed with H. Garcia Gavela and IPT

Summary

- **SCT have been (and is still) crucial to FRAS preparation for IT String Test and HL-LHC testing and upgrades**
  - All sensors and sensor software have been qualified
  - Motorized adapters qualified. Jack issues corrected
  - The internal monitoring software and safety layers software to be finalized, before IT String Commissioning in Q1 2025.
  - 6-components extrapolated software tests planned

- Quality Assurance for FRAS component assets and geodetic data structures as very important aspect
- FRAS preparation progress is in line with arrival of IT String magnets
- Sensors and equipment ready to be installed when component will be on jacks and infrastructure.
- FRAS HL-LHC procurement strategy discussed with H. Garcia Gavela and IPT

Thank you very much!

Big Thanks to all HL WP-s FRAS Stakeholders for fruitful collaboration in the FRAS implementation on various HL-LHC equipment.

Special Thanks to three groups of Beams Department, being a part of WP19: the Geodetic Metrology group, the Controls Electronics and Mechatronics group and the Industrial Control Systems group, for their efforts in FRAS development.