Overview of WP15.4 inside the HL-LHC project

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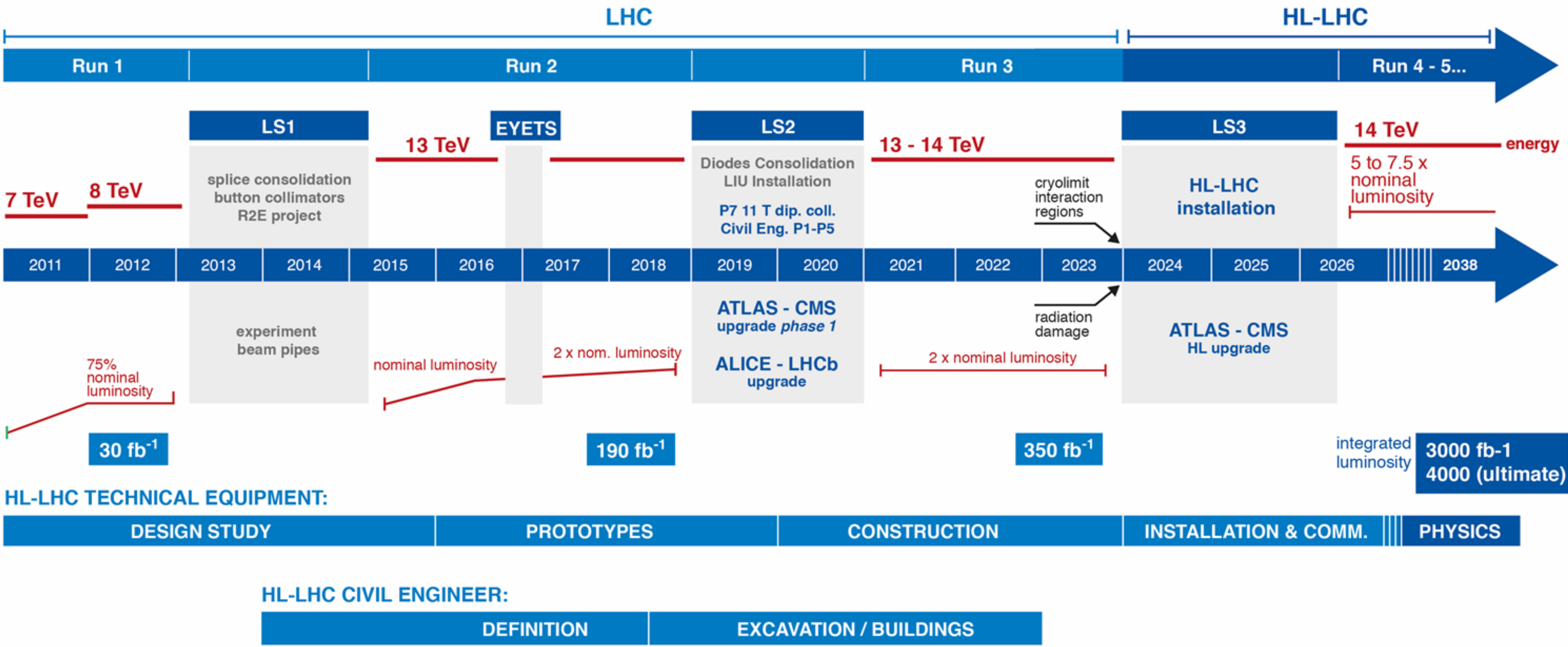
Review of HL-LHC alignment and Internal Metrology (WP15.4)

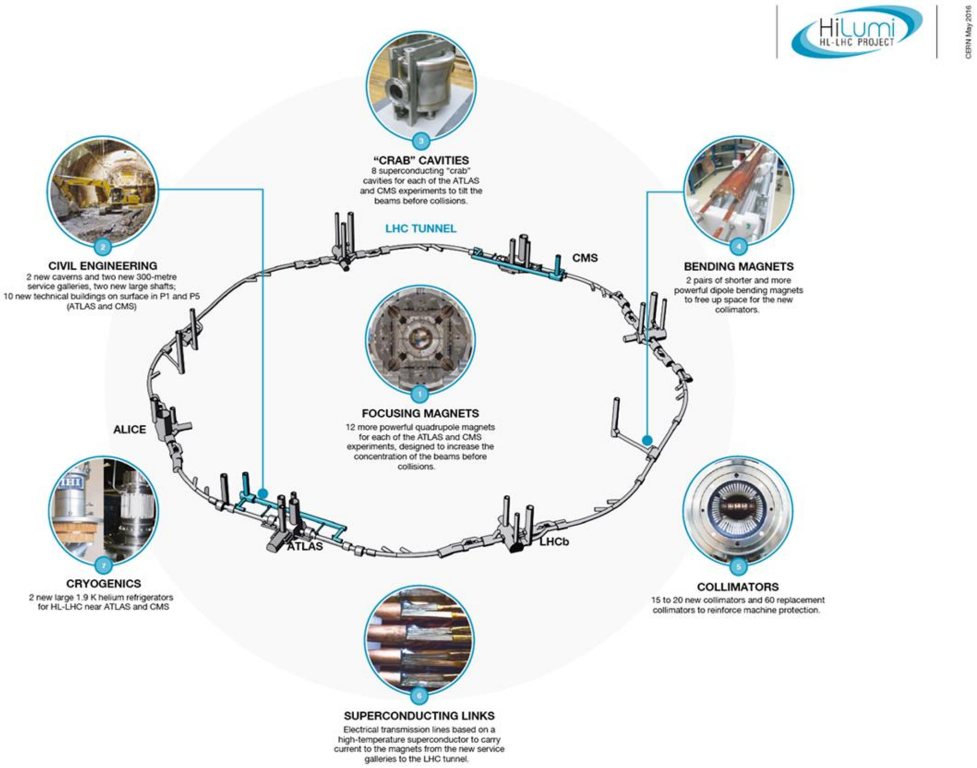
Outline

- Introduction to WP15.4
- What was achieved in the LHC & lessons learnt
- HL-LHC context
- HL-LHC alignment strategy
- What will not be covered during the review
- What will be covered

LHC / HL-LHC Plan



The HL-LHC Project

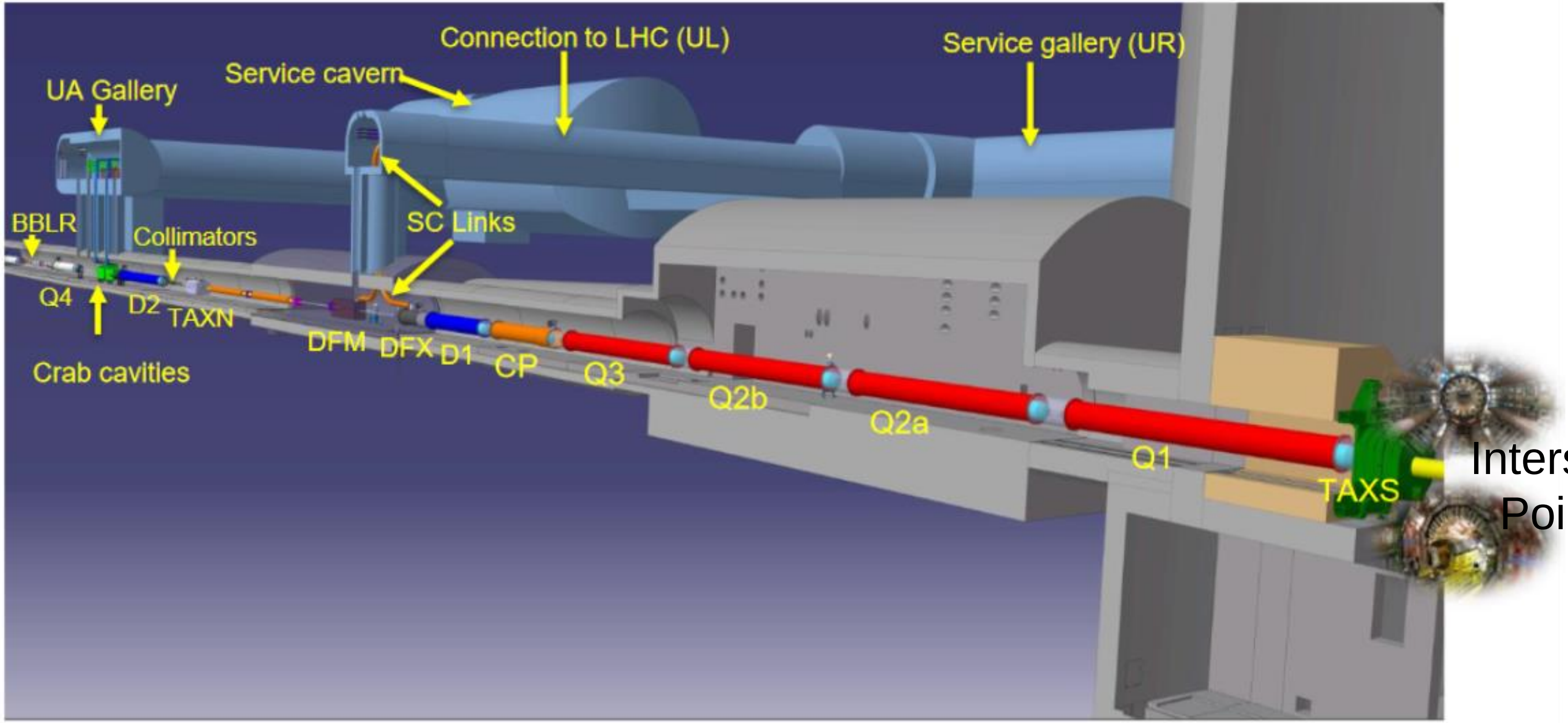


Impact on Alignment & internal metrology:

- ✓ New surface buildings and new underground galleries:
  - Redetermination of the geodetic network
  - Determination of the LSS azimuths in the LHC
  - Follow-up of geodetic aspects of civil engineering
- ✓ New components (to be installed in LS2 and LS3)
  - Internal metrology
  - Assembly measurements
  - Fiducialisation measurements
  - Marking
  - Pre-alignment
  - Smoothing
  - Permanent monitoring & remote adjustment solutions
- ✓ Development of new alignment solutions:
  - For the internal monitoring of components inside their cryostat
  - For the permanent monitoring
  - For the remote adjustment

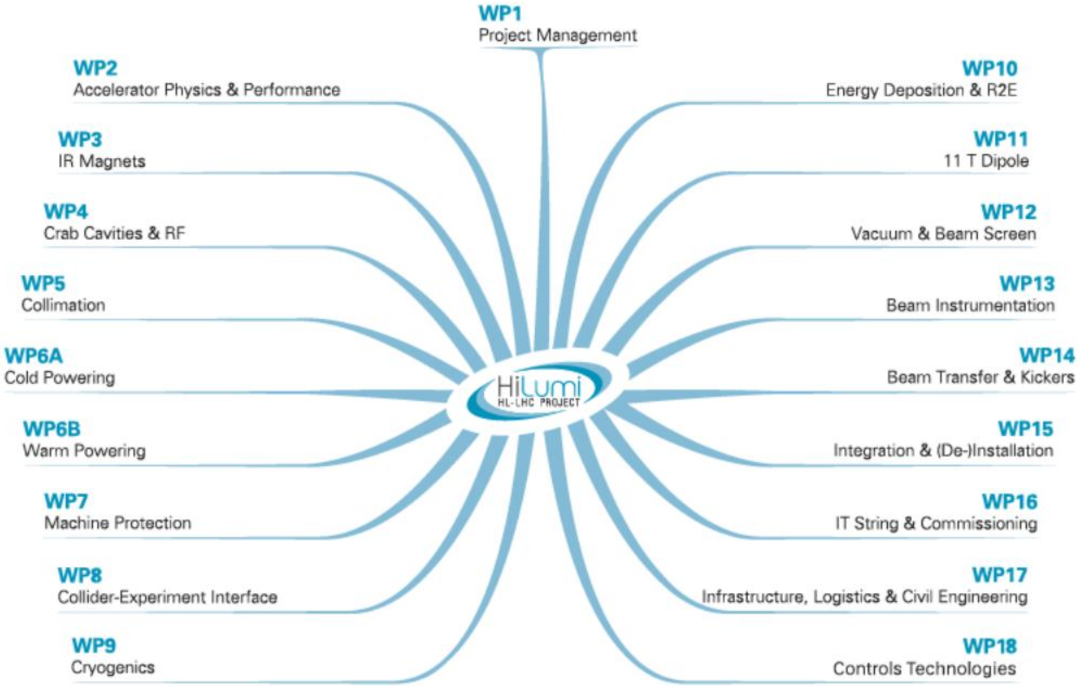
Major intervention on more than 1.2 km of the LHC

The tunnel and HL-LHC major components



Intersection Point (IP)

Introduction to WP15.4



WP15.1: Integration
WP15.2: Installation
WP15.3: De-Installation
WP15.4: Alignment & internal metrology

Introduction to WP15.4

Mandate of WP15.4:

- Cover all geodetic aspects of the project
- Perform the alignment of the components of the beam lines & specific components in MDI area
  - Using standard means when possible
  - With specific alignment systems (sensors & actuators)
- Cover the internal metrology aspects
- Carry out the as-built measurements needed in all newly equipped area

Introduction to WP15.4

All tasks related to alignment & internal metrology for HL-LHC divided into 4 WPs:

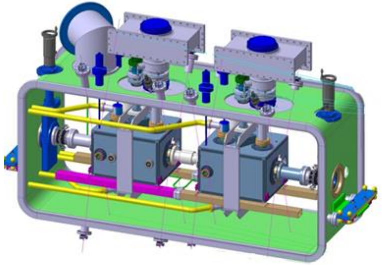
- Internal metrology
- Monitoring of the position of the inner triplet magnet cold mass & crab cavities w.r.t their cryostat
- Standard alignment
- Remote determination of the position and readjustment of the components

WP 15.4.1	WP 15.4.2	WP 15.4.3	WP 15.4.4
Internal metrology	Internal monitoring	Standard alignment	Remote alignment

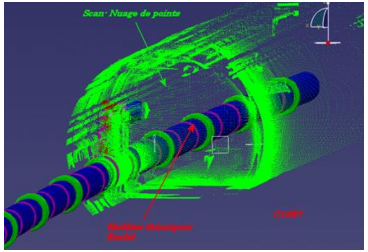
Introduction to WP15.4

WP 15.4.1

WP 15.4.2



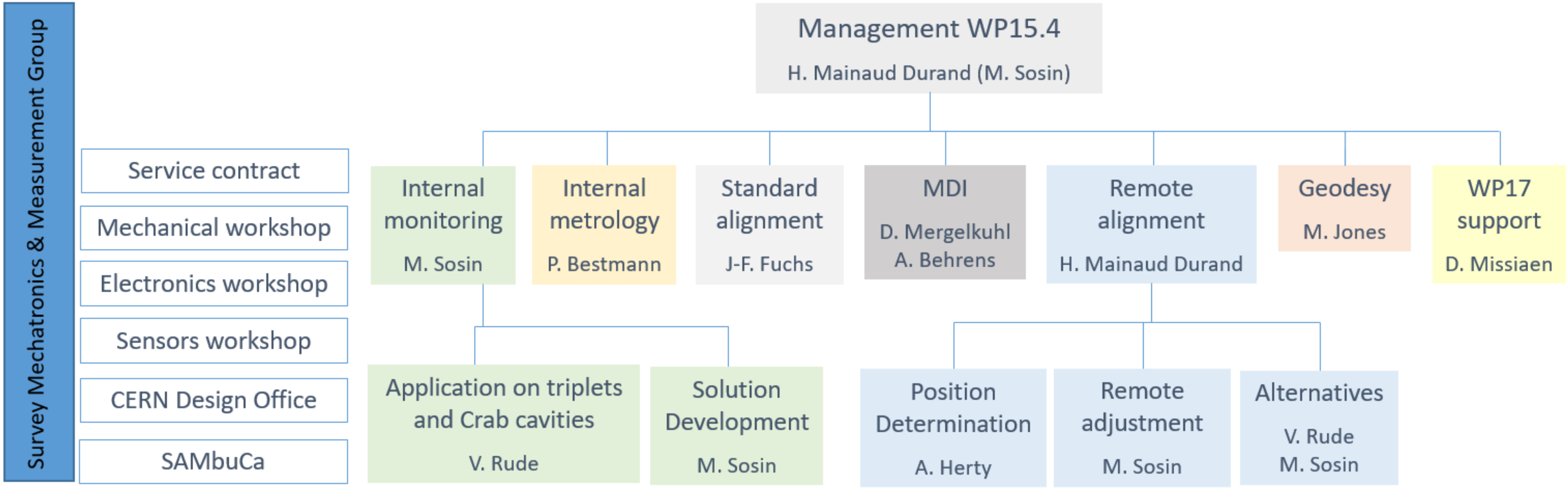
WP 15.4.2



WP 15.4.2

WP	Activity	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
15.4.1	Internal metrology (fiducialisation)	LS2 components + prototypes			LS3 components: pre-series and series						
15.4.2	Internal monitoring (Inner Triplet & Crab cavities)	R&D and solution validation		Implementation on prototypes		Validation on String test	Implementation on pre-series, series				Operation
15.4.3	Geodetic studies	Geodetic studies									
	Support to WP17			Support to WP17							
	Standard alignment	Preparation meetings		Standard alignment during LS2		Standard alignment of String Test		Preparation	Standard alignment during LS3		
15.4.4	Monitoring & positioning	Validation of alternatives		Integration; String Test preparation, installation, analysis			Procurement, calibration, validation		Installation & validation		Operation

Introduction to WP15.4



What was achieved in the LHC

Fiducialisation

Within +/- 0.1 mm ? (1σ)

Initial alignment

Smoothing

Within +/- 0.1 mm (1σ)

Beam

Monitoring of the relative position

Re-adjustment if needed

Within a few µm

Smoothing

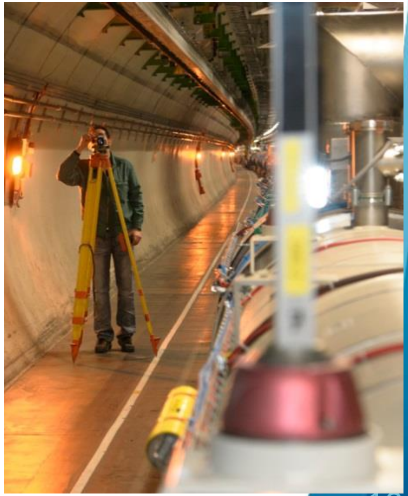
Fiducialisation

Determination of the magnetic axis / geometric axis with respect to external fiducials

What was achieved:

- Cold measurements performed at Fermilab (IT quadrupoles)
- Warm measurements performed at CERN, with an uncertainty of measurement of ± 0.05 mm
- Stability of the cold mass inside the cryostat ????

What was achieved in the LHC



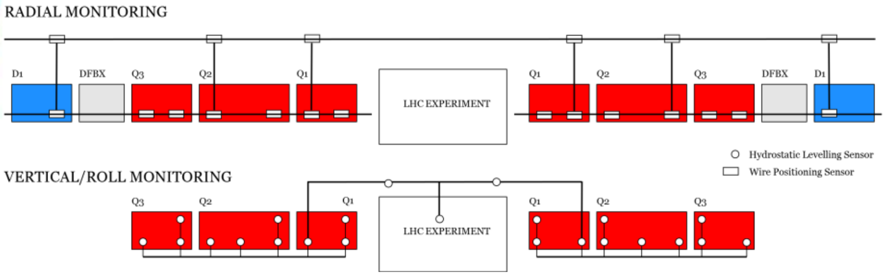
Smoothing

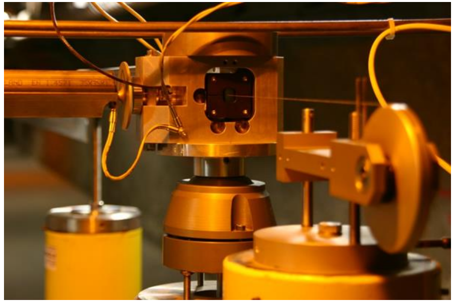
- Final errors of alignment of one triplet fiducials w.r.t. main elements of the Matching Section: ± 0.1 mm (1σ) requested but not achieved in radial.
- For all other main components of the Matching Sections: smoothing of ± 0.15 mm (1σ) over 110 m. Achieved.

What was achieved in the LHC

Monitoring of the position of the fiducials

Re-adjustment if needed





What was achieved:

- Monitoring within a few microns accuracy
- Adjustment: resolution < 10 µm

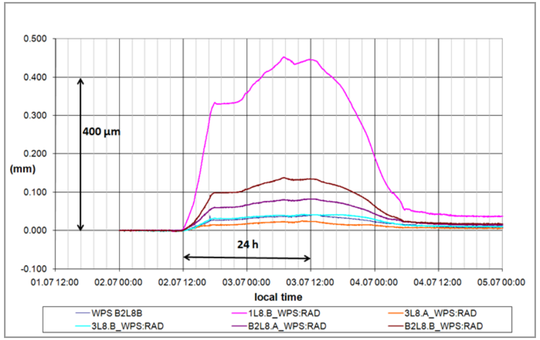
Issues met on motorized jacks:

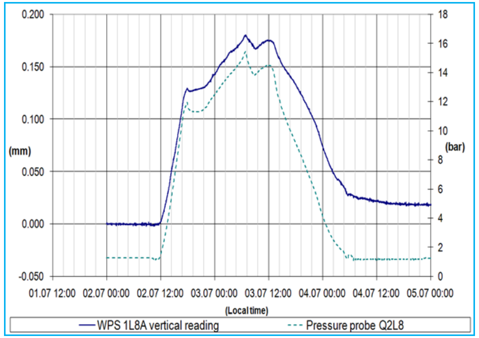
- Motorized jacks used outside the limits of what was specified from the loads and stroke point of view: jacks in contact with their longitudinal stop, creating slip/stick effect
- Leading to an unpredictable behavior of the triplet during remote adjustment
- As a consequence: loss of weight on jacks and risk to displace remotely the jacks transversally

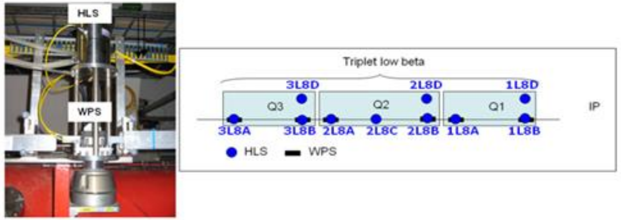
What was achieved in the LHC

From the operation point of view

- Important misalignments seen due to mechanical stresses caused during cool-down → remote fine tuning very interesting when no access is possible anymore







- Two ways to solve displacements of cryostats:
  - Remote alignment using WPS readings and motorized jacks
  - Magnetic corrections

Lessons learnt

Fiducialisation

- Warm and cold measurements should be performed at CERN
- As it seems difficult to develop a supporting system of cold mass + transport restraints for the magnet guaranteeing no displacement of the cold mass during transport, the monitoring of the position of the cold mass inside the cryostat w.r.t the fiducials will be needed.
- Straightness of the cold mass, position of vacuum pipe and position of fiducials have to be controlled during the manufacturing

Initial alignment and smoothing

- Smoothing difficult to perform due to shieldings, ventilation, permanent systems in the area
- Improve link between triplet and LSS
- Extend the permanent wire up to Q5
- Extend the HLS system in a safer area

Lessons learnt

Remote alignment

- Performance of the alignment systems:
    - Only 1 wire (out of 10 installed in the LHC) broke in more than 8 years (because of cabling team)
    - A lot of progress was achieved on the WPS sensors thanks to the CLIC studies where «absolute» sensors are needed: e.g. the position of the sensor coordinate system is known with respect to the component to be aligned
- 3D models of this area absolutely needed
- A place of training before going down is needed too.

Outline

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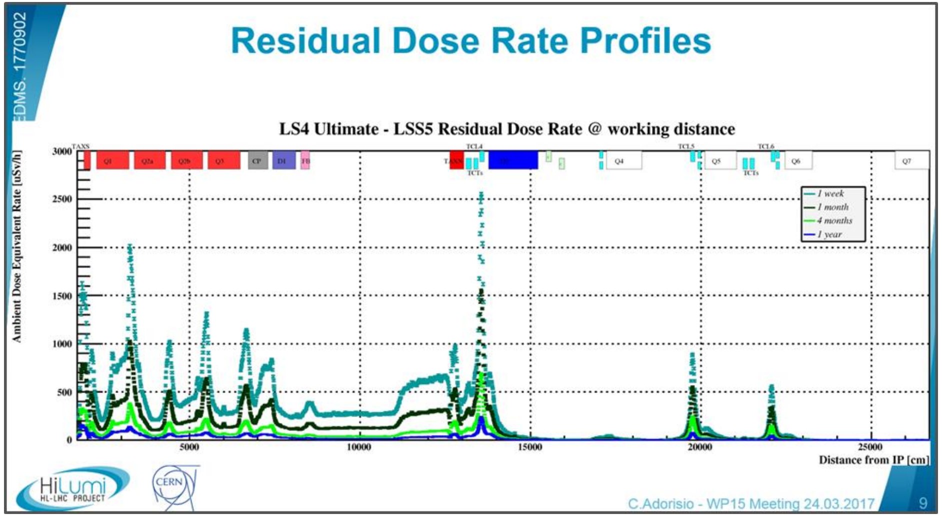
HL-LHC context

High radiation levels



Maximum Total Dose at 60 cm below the beam (jack location) for “ultimate HL-LHC”: less than 2 MGy.

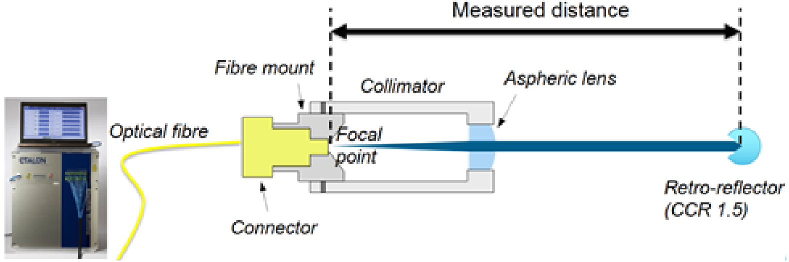
Ground motion: 0.3 mm/year max. per year, (except in a very specific area: 0.7mm/y)

New galleries could result in additional ground motion, but this is very difficult to estimate

Solution proposed for internal monitoring

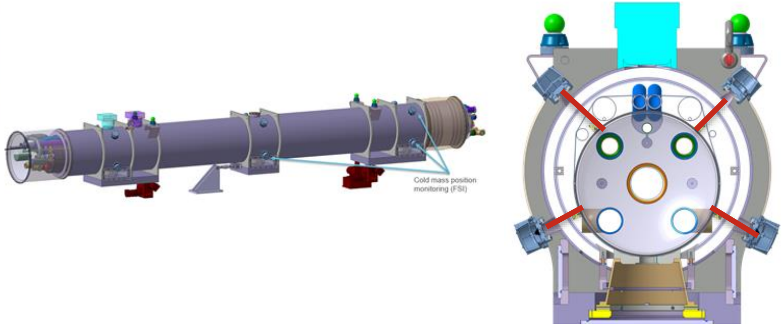
- From the LHC experience: we know at the micron level the position of the cryostat, but not what happens inside → difficult to correlate with beam.
- Displacements up to ± 0.5 mm (3σ) seen on the LHC dipoles after transport (EDMS 677511)

- Decision to include in the baseline the internal monitoring of the inner triplet cold masses using laser interferometer (less «invasive» solution)
- Validation of the commercial solution based on Frequency Scanning Interferometry (FSI), providing absolute distance measurements.



Solution proposed for internal monitoring

- Monitoring of the position of one or several components inside a vacuum vessel using absolute distance measurement between an optical collimator (located on the cryostat) and a target (located on the internal component), with no contact.
- Measurement context:
  - Technical vacuum: 10^{-6} mbar,
  - Total Ionizing Dose : 5 MGy max. at the level of the component, 1 MGy max. at the level of the cryostat,
  - From ambient temperature (cryostat) to cryogenic temperature (2K) (component).

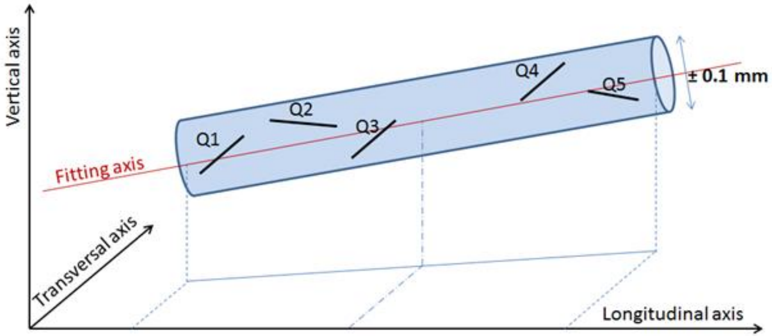


Position of the cold mass inside the IT quadrupoles

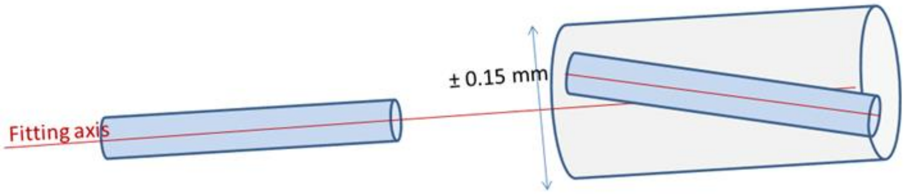
Position of the two crab cavities inside their cryostat

Alignment solutions: towards FRAS

- Alignment = determination of position + adjustment
- Considering the environment, ground motions, alignment requirements from beam dynamics: decision to perform the remote alignment of all the main components of a LSS (using sensors for the position determination and motors for the remote adjustment), based on the LHC solutions applied on the LHC inner triplets.



Mechanical axes of the magnets included in a cylinder with a radius of 0.1 mm

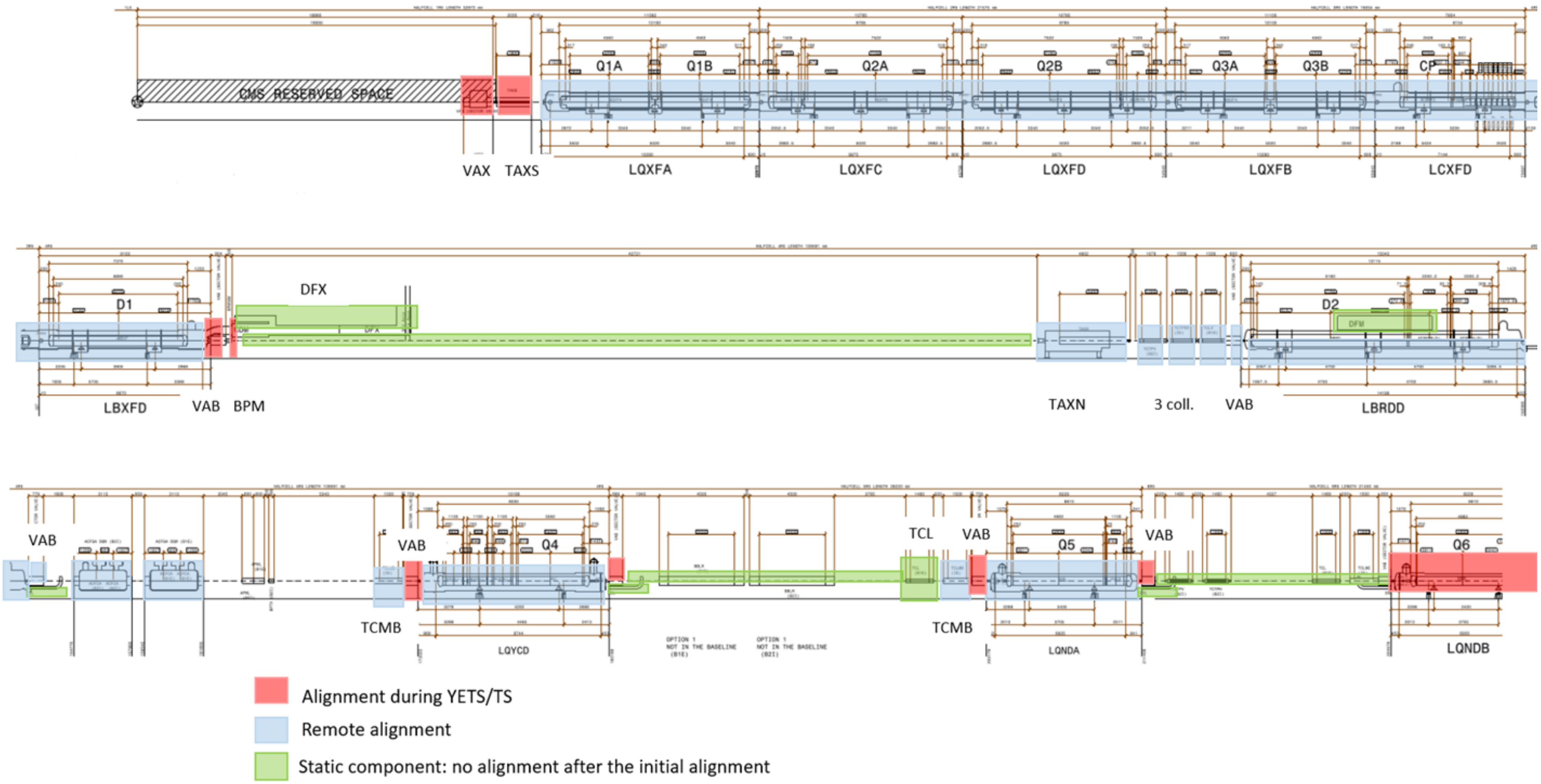


Mean axis of right side included in a cylinder with a radius of 0.15 mm around the mean axis of left side

Towards Full Remote Alignment System

- Remote alignment foreseen initially only for the main components
- Considering the uncertainty in the position of the inner tracker w.r.t. machine after the first installation and other components that might need a remote alignment considering the high level of radiations, a deeper study was launched to propose the Full Remote Alignment System.
- The components were classified into 3 types:
  - Components needing a remote alignment
  - Components to be aligned at the end of a YETS or LS
  - Components to be measured at the end LS (static components that will never need an adjustment)

FRAS: summary

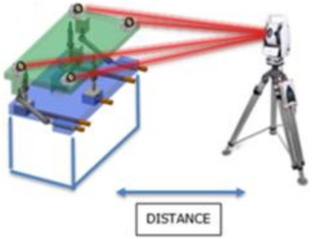


Solution proposed for the position determination

- Measure the position of components using Laser tracker and permanent targets

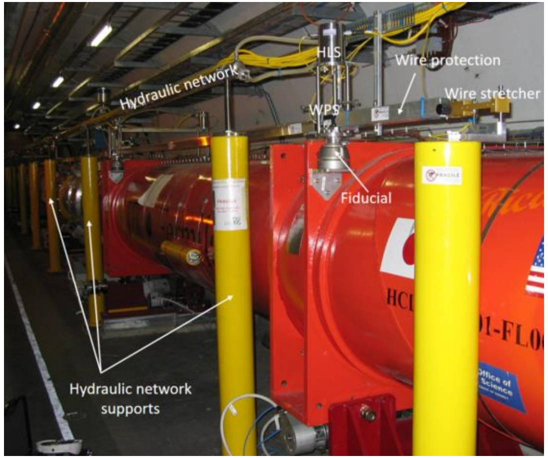
Laser tracker

Glass sphere



- ✓ Only at the end of YETS and LS
- ✓ In the tunnel

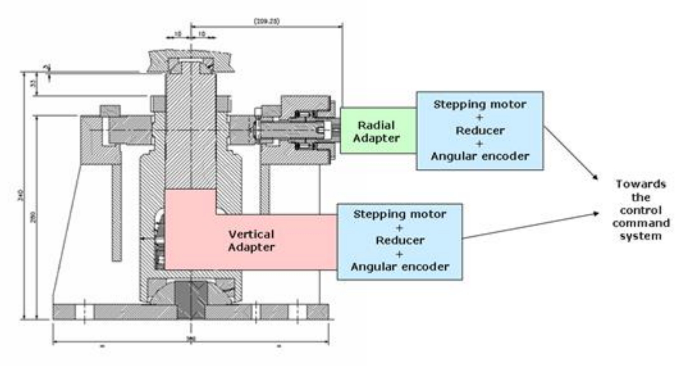
- Measure the position using permanent sensors installed on the cryostat



- ✓ Continuous and remote measurements
- ✓ From the CCC

Solution proposed for the adjustment solution

- For components with a weight above 2t: jacks, with motorization when needed



- For components with a weight below 2t: platforms, with motorization when needed

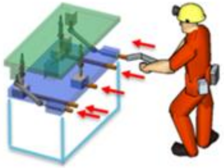


Fig. 8a. Manual adjustment: the operator turns adjustment knobs

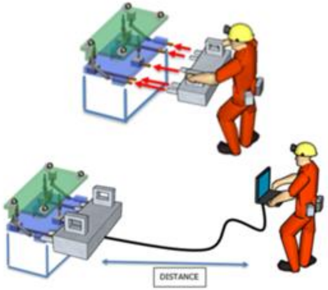


Fig. 8b. Semi/manual adjustment using temporary plug-in motors

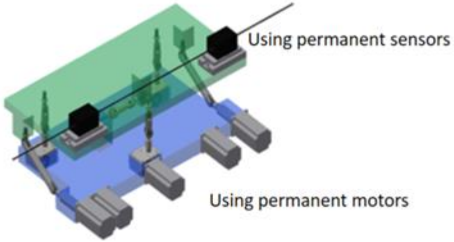


Fig. 8c. Remote alignment

Mandate and scope of the review

- Mandate : to review the alignment solutions foreseen for HL-LHC, with a focus on the internal metrology, the monitoring of inner triplet cold masses and crab cavities inside their cryostat and Full Remote Alignment System
- Scope of the review:
  - To examine the soundness of the proposed solutions individually and as a global system
  - To verify that all requirements from equipment owners and machine operation are duly covered
  - To check that the interfaces between WP15.4 and the other WPs are clear
  - To check the readiness of the solutions proposed and evaluate the associated risk if any
  - To evaluate the related test plan, acceptance criteria and the overall schedule
  - To examine the procurement strategy, identifying possible risks
  - To put in evidence possible integration issues and safety aspects

What will not be covered during the review

- Geodetic aspects
- Fiducialisation and internal metrology for HL-LHC components to be installed during LS2
- Standard alignment activities (determination of the underground geodetic network, marking, jacks heads alignment, initial alignment w.r.t. geodetic network, smoothing)
- 3D scans
- R&D on train measurements

What will be covered during the review

Introduction to FSI systems	*Mateusz Sosin*
30/7-018 - Kjell Johnsen Auditorium, CERN	09:25 - 09:55
FSI qualification and results	*Vivien Rude*
30/7-018 - Kjell Johnsen Auditorium, CERN	10:05 - 10:35
FSI choices and next steps	*Helene Mainaud Durand*
30/7-018 - Kjell Johnsen Auditorium, CERN	11:05 - 11:25

Internal monitoring

Internal metrology crab	*Vivien Rude*
30/7-018 - Kjell Johnsen Auditorium, CERN	13:40 - 14:00
Internal metrology/fiducialisation on other HL-LHC	*Patrick Bestmann*
30/7-018 - Kjell Johnsen Auditorium, CERN	14:10 - 14:40
Stratey concerning magnetic measurements, at cold, at warm	*Lucio Fiscarelli*
30/7-018 - Kjell Johnsen Auditorium, CERN	14:50 - 15:10

Fiducialisation aspects

What will be covered during the review

Talk	Speaker	Location	Time
Aperture and beam dynamics advantages for the machine	*Riccardo De Maria*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	15:40 - 16:00
Vacuum: review of limitations in moving the components under vacuum and	*Jan Hansen*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	16:10 - 16:20
Cryo: review of the limitations in moving the components under vacuum and	*Serge Claudet*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	16:20 - 16:30
RF: review of the limitations in moving the components under vacuum and cold	*Rama Calaga*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	16:30 - 16:40
BI requirements	*Michal Krupa*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	16:40 - 16:50
HL-LHC Long Straight Section layout	*Maria Amparo Gonzalez De La Aleja Cabana*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	17:10 - 17:25
Full Remote Alignment & MS optimization	*Paolo Fessia*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	17:25 - 17:40
Full Remote Alignment spec and interfaces	*Helene Mainaud Durand*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	17:50 - 18:10

Talk	Speaker	Location	Time
Radiation to electronics considerations	*Giuseppe Lerner et al.*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	08:45 - 08:55
RP considerations	*Cristina Adorisio*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	08:55 - 09:05
Safety considerations	*Christelle Gaignant*	*30/7-018 - Kjell Johnsen Auditorium, CERN*	09:05 - 09:15
Machine protection and operational aspects		*30/7-018 - Kjell Johnsen Auditorium, CERN*	09:30 - 09:45

Full Remote Alignment System (FRAS)

What will be covered during the review

Adjustment solutions

Jack requirements and motorization strategy	*Mateusz Sosin*	
30/7-018 - Kjell Johnsen Auditorium, CERN	10:00 - 10:20	
Jacks for the HL LHC magnets	*Vittorio Parma*	
30/7-018 - Kjell Johnsen Auditorium, CERN	10:30 - 10:50	
5DOF/6DOF Platform		
30/7-018 - Kjell Johnsen Auditorium, CERN	11:20 - 11:50	
Motors control and commands	*Paul Peronnard*	
30/7-018 - Kjell Johnsen Auditorium, CERN	12:00 - 12:20	
System reliability and radiation hadness/ maintenability	*Mateusz Sosin*	
30/7-018 - Kjell Johnsen Auditorium, CERN	12:30 - 12:50	

Position determination solutions

Requirements & solutions, status of integration	*Andreas Herty*
30/7-018 - Kjell Johnsen Auditorium, CERN	14:00 - 14:30
Status of developments (cWPS, iHLS, inclinometer, sensors data acquisition	*Mateusz Sosin*
30/7-018 - Kjell Johnsen Auditorium, CERN	14:40 - 15:10
Algorithm and uncertainty of measurements	*Vivien Rude*
30/7-018 - Kjell Johnsen Auditorium, CERN	15:15 - 15:35
Status of automatic platform measurements	*Helene Mainaud Durand*
30/7-018 - Kjell Johnsen Auditorium, CERN	15:50 - 16:10

Perspectives and conclusions

What is foreseen on string test	*Andreas Herty*
30/7-018 - Kjell Johnsen Auditorium, CERN	16:15 - 16:35
Summary of schedule foreseen for each WP, Resources and material (HMD)	*Helene Mainaud Durand*
30/7-018 - Kjell Johnsen Auditorium, CERN	16:40 - 17:10

Conclusion

- WP15.4 includes a large variety of activities in the survey and alignment field, from the internal metrology to the development of new methods of measurements through geodetic aspects. It concerns components to be installed during LS3, but also during LS2.
- This review will address the activities that are the more risky from the technical and cost aspects, as requiring new developments or interacting with a lot of different work packages of the HL-LHC project.

Thank you very much!