Alignment & internal metrology

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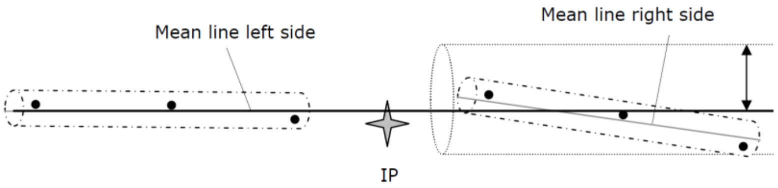
HL-LHC TCC meeting – 30/06/16

Outline

- Remote alignment & adjustment system for LHC
  - Constraints and requirements
  - Current solution
  - What has been achieved
  - Lessons learnt
- The improvements proposed for HL-LHC
  - New constraints and requirements
  - Baseline
  - Studies required

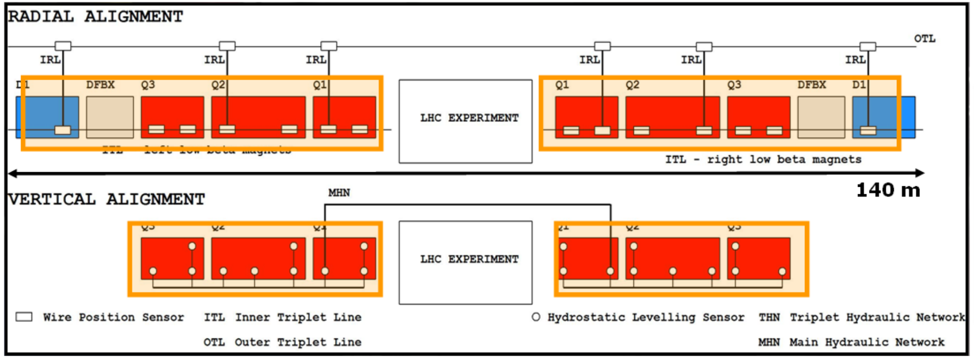
Constraints and requirements for LHC

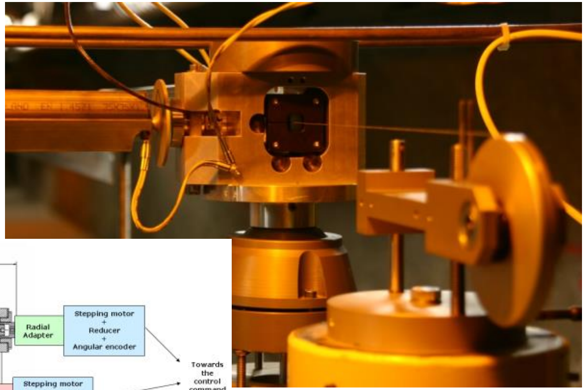
- Due to radiation: remote alignment (determination of the position + adjustment) of the triplet to reduce the doses taken by surveyors
- Alignment requirements for LHC (see LHC-G-ES-0016)
  - Final errors of alignment of one triplet w.r.t the main elements of the LSS: relative position of the fiducials within ±0.1 mm (1σ)
  - Relative determination of the position of quadrupoles inside the low beta triplet using alignment sensors: ± 3µm + 1µm/month
  - Error of the relative positioning of two inner triplets:
    - Radially : ± 0.2 mm from left to right (1σ)
    - Vertically: ± 0.1 mm (1σ)
  - Linking the experiment cavern to the tunnel: any fiducial mark of the cavern reference network w.r.t the «machine geometry» is expected to range from 0.5 mm to 1.2 mm rms.

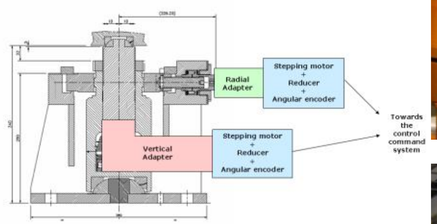


Current solution

- LHC case







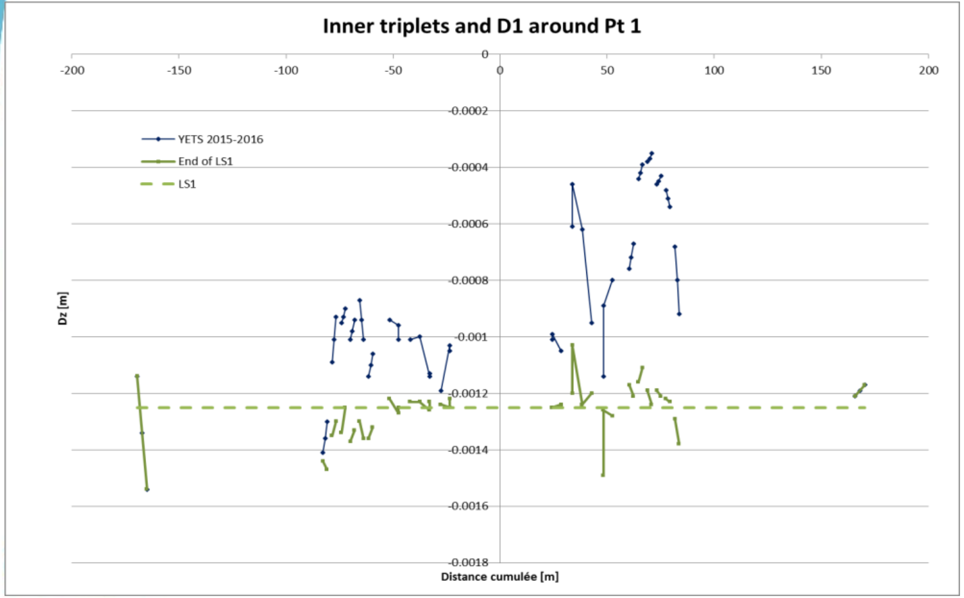
What was achieved:

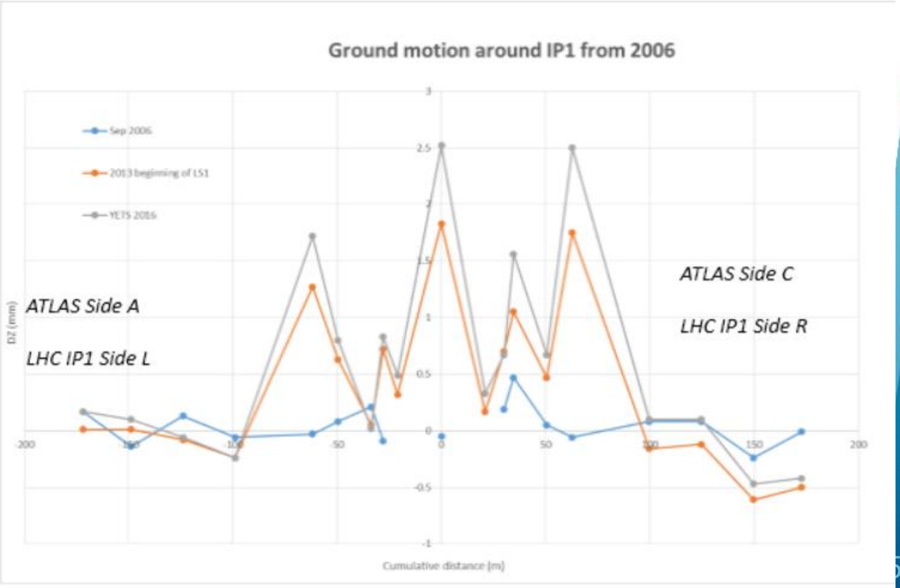
- Relative monitoring within a few microns accuracy
- Monitoring of left side vs right side: ± 0.15 mm
- Adjustment: resolution < 10 µm

Lessons learnt

- LSS1 and LSS5 are not so stable:
  - Important misalignments seen on D1
  - Long term data show that LSS are not stable up to Q5

LMC 24/02/2016, D. Missiaen

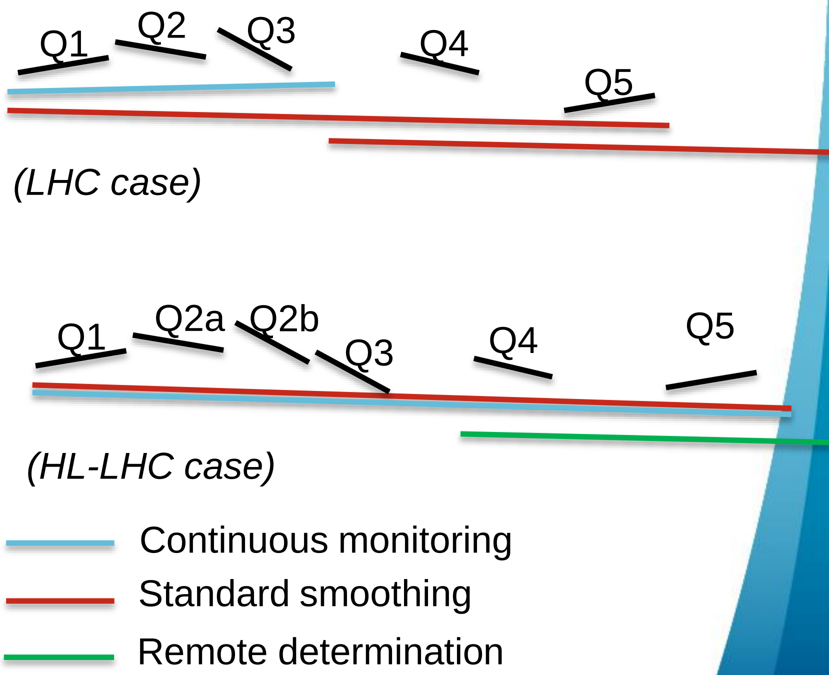




Lessons learnt

Final smoothing:

- Smoothing difficult to perform due to shielding, ventilation, permanent systems
- Extend the permanent wire up to Q5 to perform the smoothing remotely & improve the link between triplet & LSS
- Develop a remote method to determine the position of intermediary components & link the wire Q1-Q5 to the further components of LSS
- Extend the HLS system in a safer area

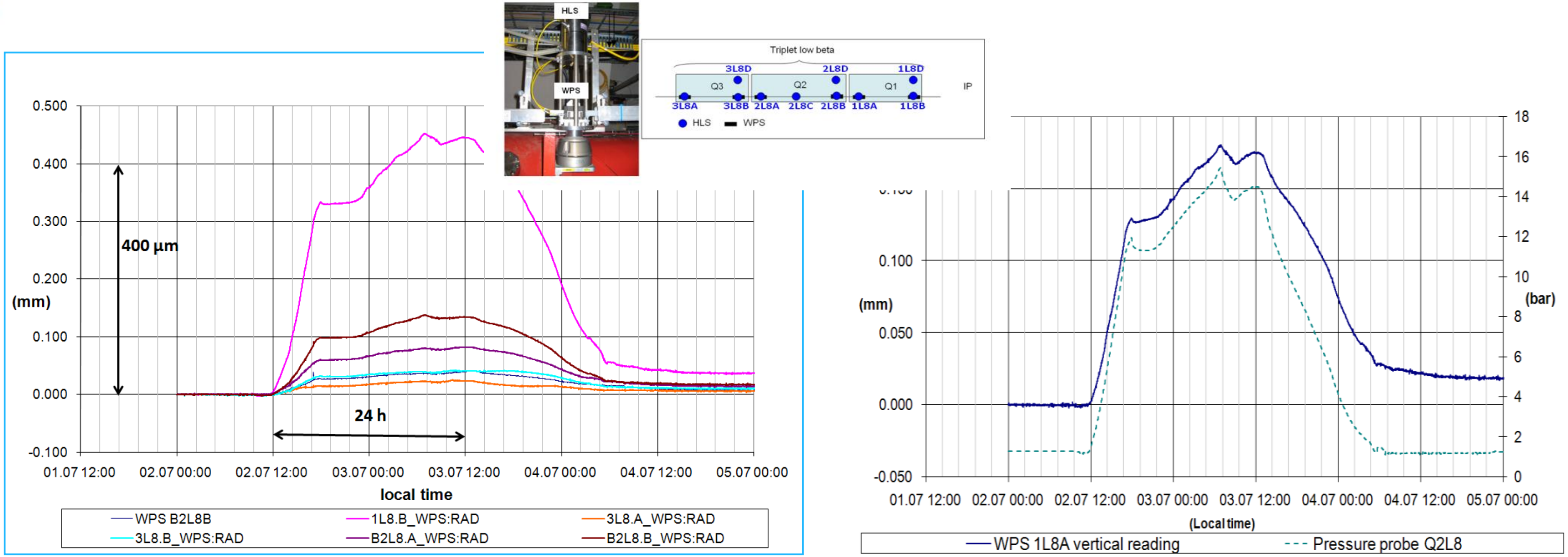


Lessons learnt

- Relative monitoring
  - Only 2 wires (out of 10 installed in the LHC) broke in more than 8 years
  - Fixation issues to solve (WPS on its support, support on the fiducial)
  - Integration to be improved for a better access to the interconnection, remote stretching of the wire
  - 3D scans of the area needed
  - Place for training needed
  - Integrate all the improvements on the WPS sensors carried out in the CLIC study

Lessons learnt

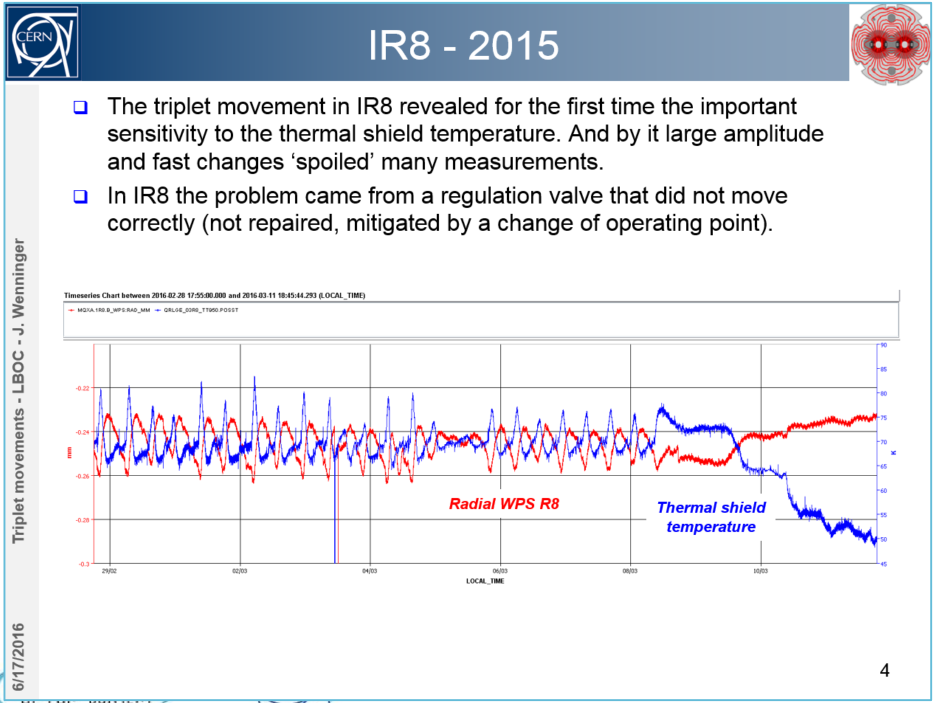
- Thanks to the sensors, some misalignment on the cryostat could be monitored

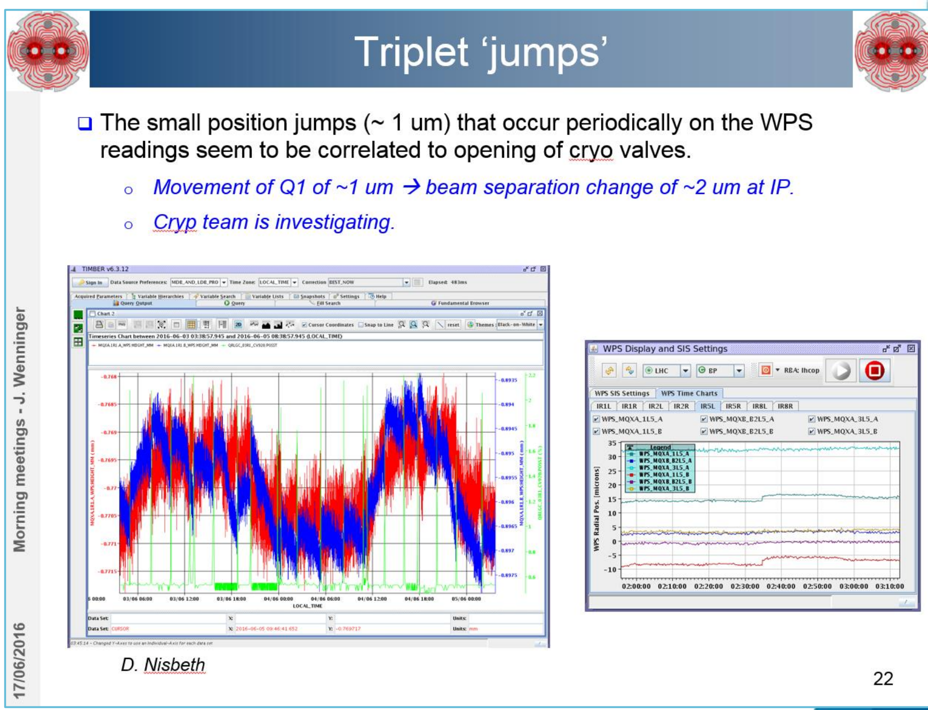


➔ a remote fine tuning of the alignment of the IT after the cool-down must be performed.

Lessons learnt

- Help for OP to diagnose problems, to check that there was no misalignment of the triplets during a TS

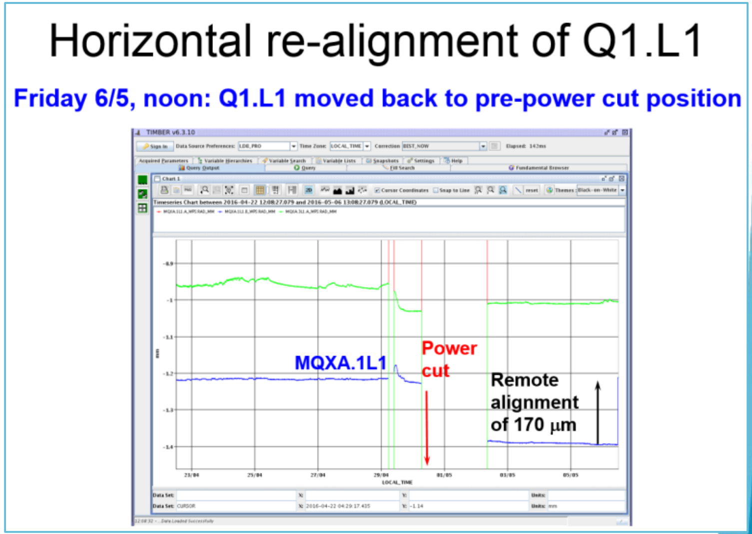




LBOC 17/06/2016, J. Wenninger

Lessons learnt

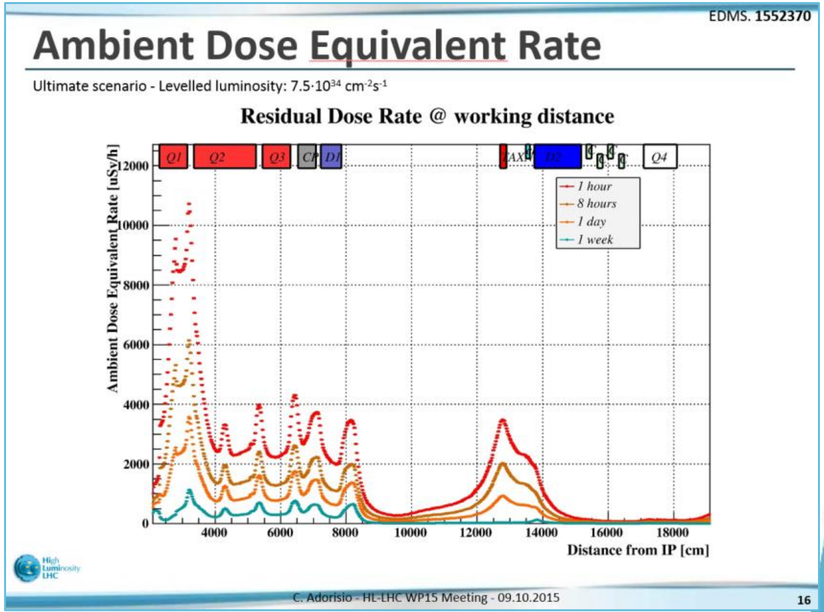
- Remote adjustment
  - Possibility to perform remote alignment of the triplet when beam is off
  - Hyper static configuration of all cryo-modules to be avoided (tie-rods, bumpers)
  - Monitoring of load applied on each jack very useful



LMC 11/05/2016, M. Giovannozzi

HL-LHC constraints

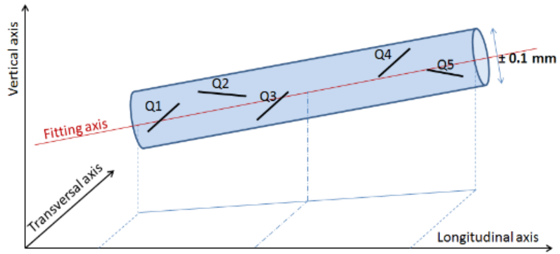
- Radiation & other safety requirements:
  - Remote alignment of components to reduce the doses taken by surveyors
  - Limit the exposition of surveyors to risks of a cryogenic accident, especially in the triplet area.

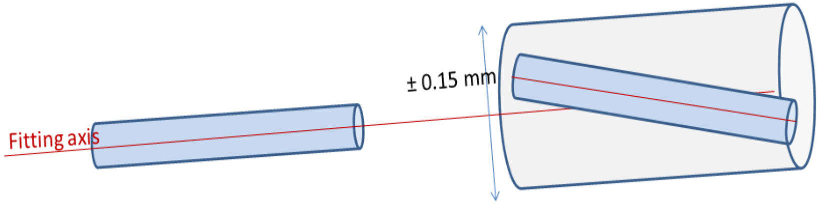


HL-LHC requirements

- Machine performance

CERN-ACC-2015-0014



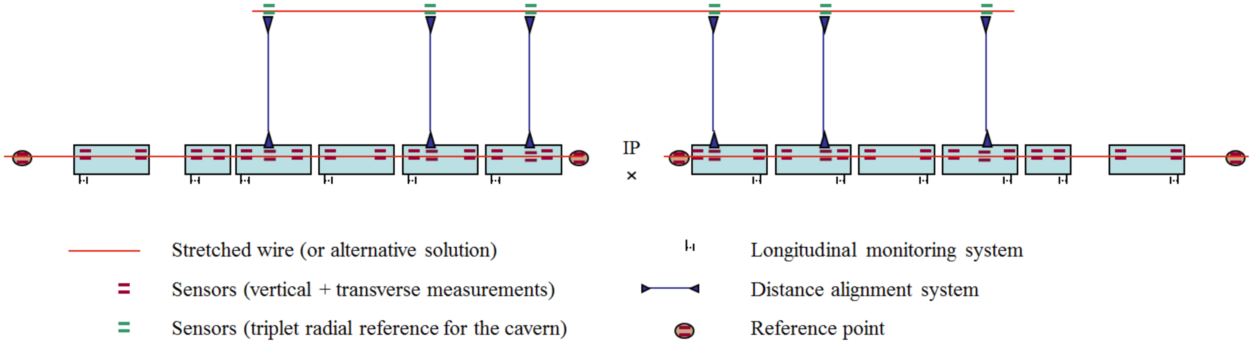


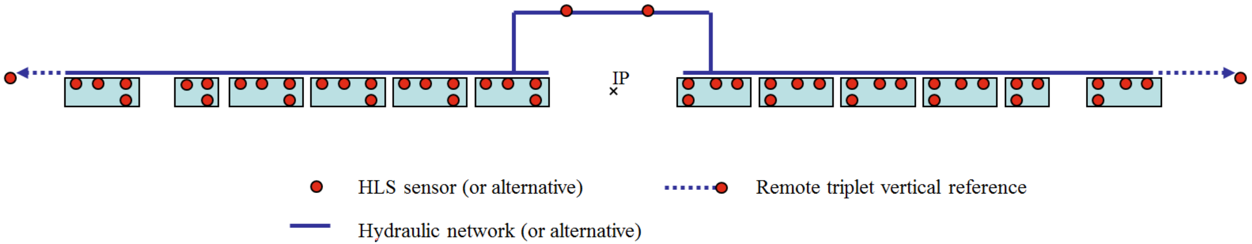
Transverse alignment error (1σ) $\pm\sqrt{(\pm 0.1)^2_{\text{fid}} + (\pm 0.1)^2_{\text{align, side}} + (\pm 0.15)^2_{\text{align, left/right}} + (\pm 0.17)^2_{\text{mis}}}\ \text{mm} = \pm 0.27\ \text{mm}$

- Remote adjustment of the position of the HL-LHC components from Q1 to Q5 according to 5 DOF (resolution < 10µm, stroke ± 2 mm TBC)

MONITORING OF THE RELATIVE POSITION

- HL-LHC





Why a monitoring above Q3?

- Required by machine performance
- Important misalignments seen on D1
- Long term data show that LSS are not stable up to Q5
- Radiation doses more important up to Q5 in HL-LHC
- Geometrical configuration of smoothing measurements to link the triplet to the remaining components of LSS has to be improved

Why a monitoring of cold-mass ?

- Fiducialisation budget of error very tight: ± 0.1 mm, including uncertainty of measurements, impact of transport, cold measurements vs warm measurements, internal constraints

- In the LHC, we know at the micron level the relative position of the cryostat, but not at the level of the cold mass, though there are mechanical constraints

- The supporting of IT cold mass will change and should be more stable, but will it be really the case at the micron level?

HL-LHC Studies

- Studies undertaken:
  - Remote determination (baseline)
    - How to stretch a wire remotely?
    - Design & integration of sensors supports, etc.
    - Upgrade of capacitive sensors remote electronics & cables
    - Development of HLS-Lines
  - Monitoring of the crab cavities inside their cryostat using Frequency Scanning Interferometry (FSI)
  - Study of alternatives (laser based alignment system, rad-hard inclinometer)

HL-LHC studies

- Other additional studies to be undertaken
  - Wire to wire measurements
  - Solution to measure intermediary components
  - Collimators case
  - Motorization of the jacks

- Schedule:
  - Test of some of the developments during LS2 on triplets 2 & 8
  - Pre-series to be tested on String Test 3

Summary

- Lessons learnt in LHC : the area between Q1 and Q5 is not stable, the remote alignment systems are really needed due to safety constraints and radiations, alignment requirements achieved except concerning the smoothing Q1-Q5.
- For HL-LHC, an extension of the alignment systems up to Q5 is proposed combined with a monitoring of the triplet cold-mass position. This is required by machine performance; it will limit the doses taken by surveyors (solving the smoothing issue between Q1-Q5) and it will provide a better understanding of the internal constraints
- R&D work is on-going concerning the monitoring of the crab cavities (to be applied on the cold mass monitoring), on the alignment sensors (study of low cost alternatives, remote stretching of wire, upgrade of capacitive sensors cables & electronics).

Thank you very much

Cold mass monitoring

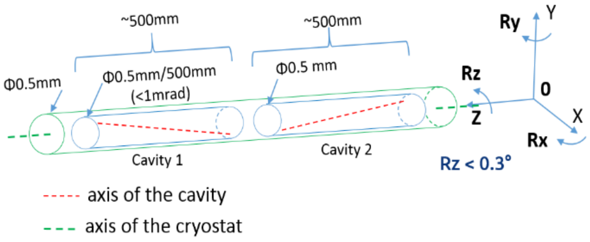
- Objective: propose, validate & integrate an alignment system to monitor the position of cold mass inside the cryostat (T°<3K, high level of radiations >1MGy, technical vacuum)

- Strategy:
  - Use of Frequency Scanning Interferometry (FSI), absolute distance measurement
  - Adapt the solution under validation for the crab cavities

- Space booked for electronics & acquisition

Specific cases: crab cavities

- Requirements (CERN-ACC-Note-2013-003):
  - The transverse rotation (roll Rz) of the individual cavities inside the cryostat should be inferior to 0.3 ° (3σ)
  - The cavity roll w.r.t longitudinal cryostat axis should be less than 1 mrad
  - The transverse displacement of cavities w.r.t each other inside their cryostat should not exceed 0.5 mm (3σ).



Specific cases: crab cavities

- Strategy:
  - Validation of FSI:
    - Simulations & validation of concept
    - Irradiation tests
    - Cold tests
    - Design & validation of a feedthrough
  - Comparison with AT401 & BCAM
    - In the calibration base: validation of the concept
    - In SM18 (vacuum & cold temperature)
    - In SPS