Response of the HL-LHC triplet cryostat to base excitation induced vibrations: status and plans

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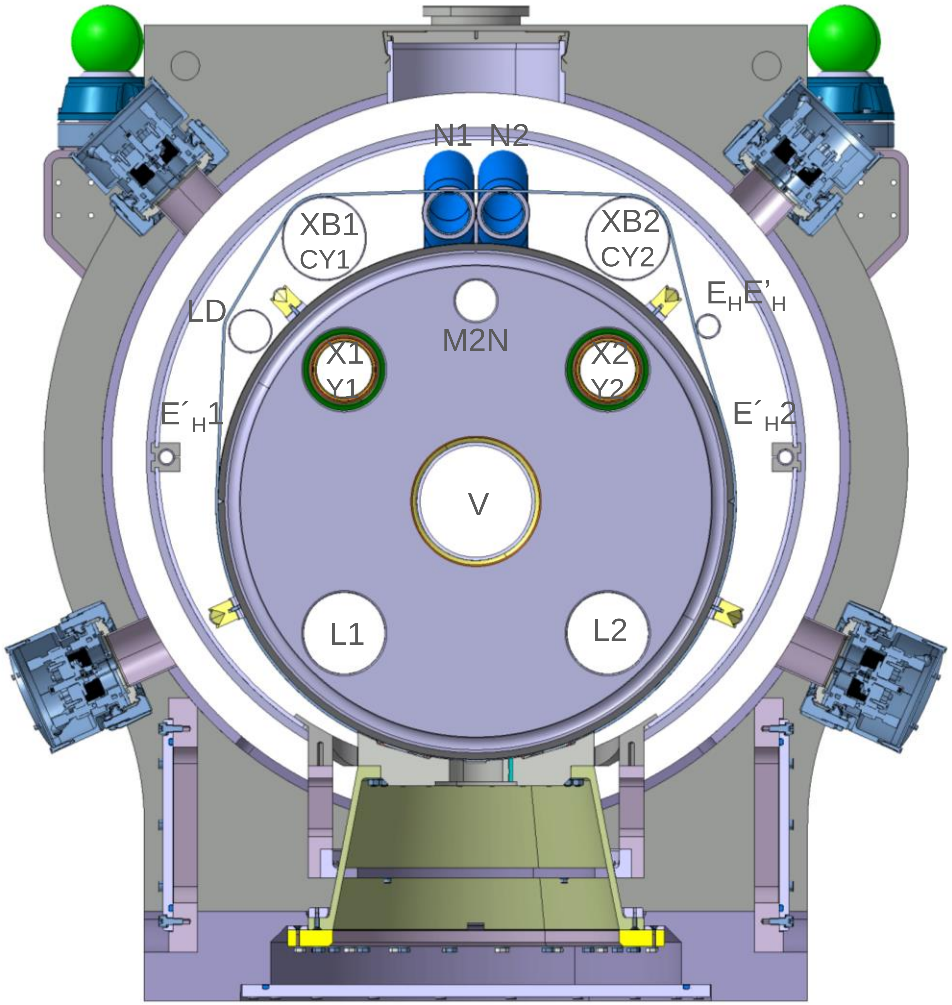
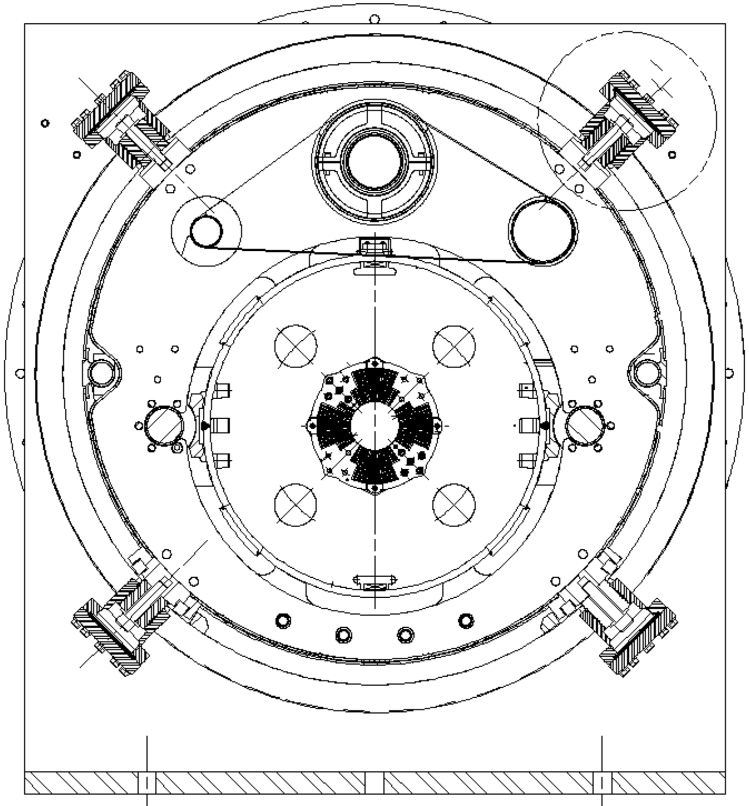
Cryostat for HL-LHC triplets



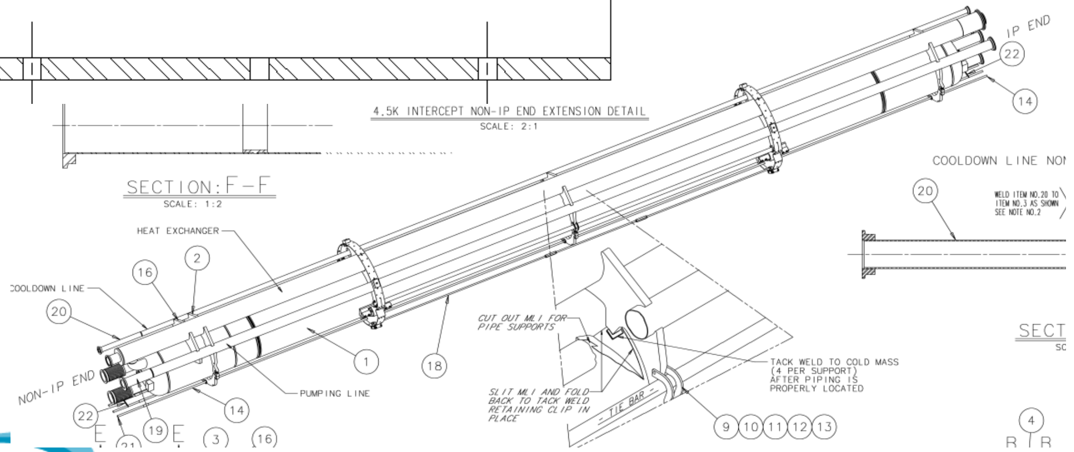
Cross section as seen from IP

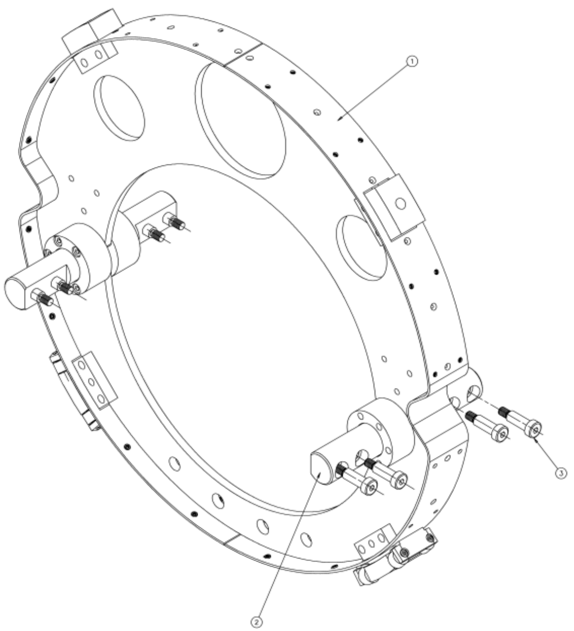
- Cold mass supported on GFRE columns:
  - Base principle of LHC arcs
  - Better return of experience than spider supports of LHC triplets
- New configuration designed for larger cold mass (Ø630 mm) plus cryogenic lines inside cryostat, but identical diameter of vacuum vessel
- Increased stiffness of supports for better alignment stability
- New assembly procedure and tooling
- Integration of cold mass position monitoring system (Q1, Q2a/b, Q3)

LHC Triplet cryostat

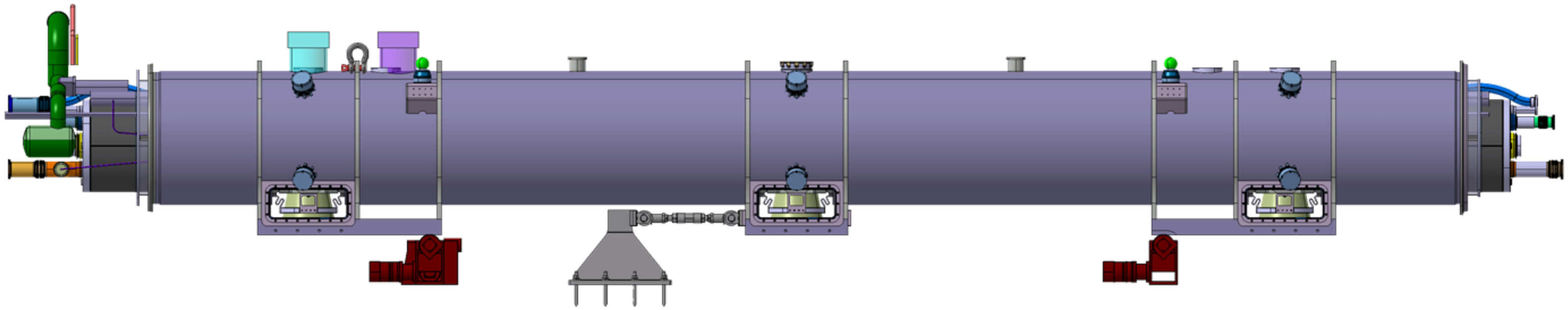


- Standard LHC 914 mm diameter vacum vessel
- 490 mm diameter cold mass. About 60% of HL-LHC cold mass linear weight.
- Heat exchanger outsider the cold mass
- “Spider” supports. Later reinforced with longitudinal restraint bars for strength against pressure loads





Cryostat supports



Longitudinal anchor for Q1 and D1: tie rod designed to hold vacuum and quench loads (longitudinal)

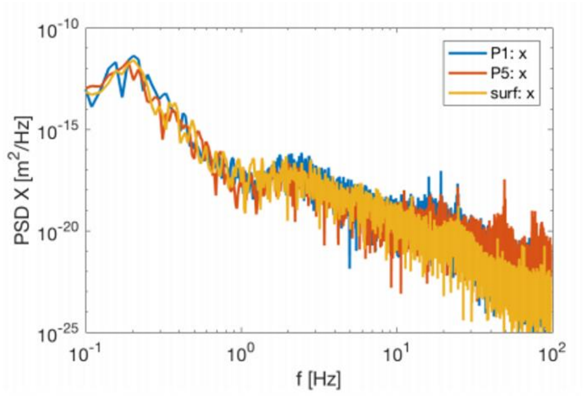
Alignment jacks on three points (isostatic) with remote actuation

Note: LHC triplet cryostats are different as they have a system of tie-rods at the interconnects to resist vacuum force and bumpers for internal pressure loads. At this stage it is assumed that interconnects are, in any case, decoupling enough the cryo-assemblies such that small displacement dynamic behaviour is not affected.

Response to random base excitation

Random excitation: at a given frequency the **amplitude** of the excitation constantly changes, but its **average** value tends to remain relatively constant. It follows a Gaussian distribution.

This gives the ability to characterise a random excitation as a statistical process: **Power Spectral Density** plots (units mm^2/Hz for displacement, mm/s^2/Hz for acceletation, N^2/Hz for force).



Frequency Response Function: Can be obtained from a finite element model of the cryo-assembly through a modal analysis followed by a harmonic analysis.

$$H(\omega) = A(\omega) - iB(\omega)$$

$$|H(\omega)| = \sqrt{A^2 + B^2} = \frac{a_{out}}{a_{in}}$$

$$\frac{\mathrm{Im}[H(\omega)]}{\mathrm{Re}[H(\omega)]} = \frac{B}{A} = \tan\phi$$

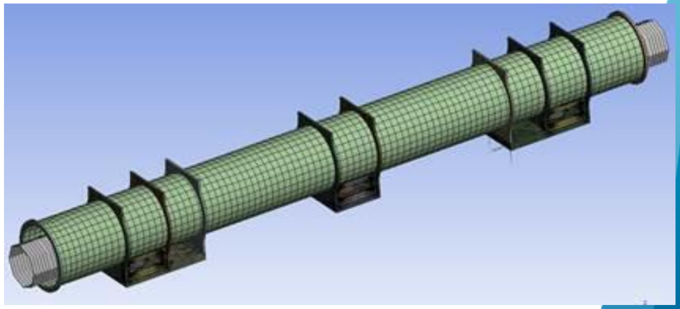
Response of the system to a single input:

$$RPSD(\omega) = |H(\omega)|^2 . PSD(\omega)$$

Spectral density response

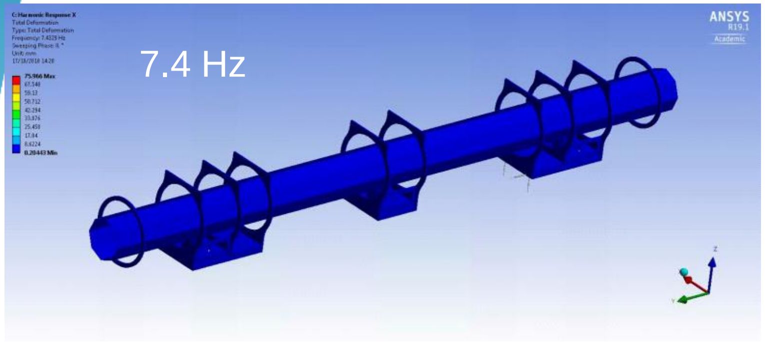
Spectral density input

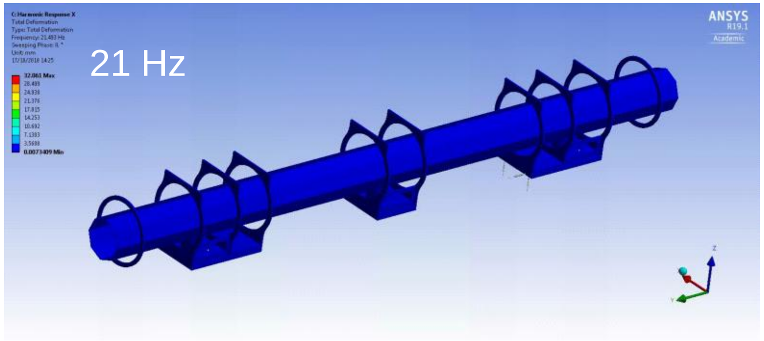
$$RMS = \sqrt{\int_0^\infty RPSD(\omega) d(\omega)}$$

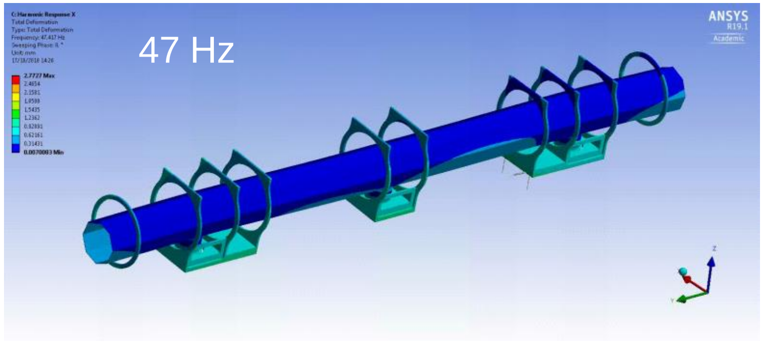


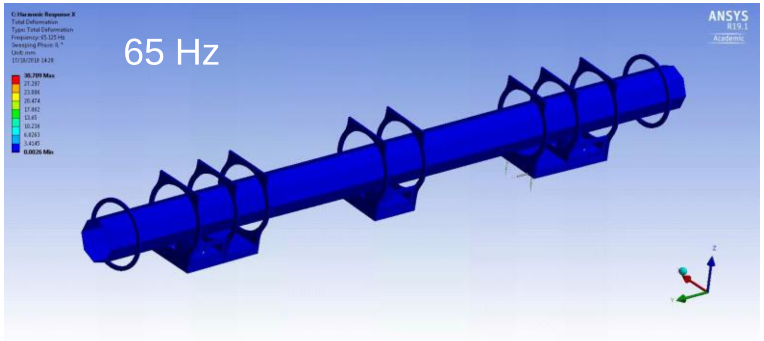
FE model of HL-LHC Q2 cryoassembly.
Jacks modelled as springs (not visible).

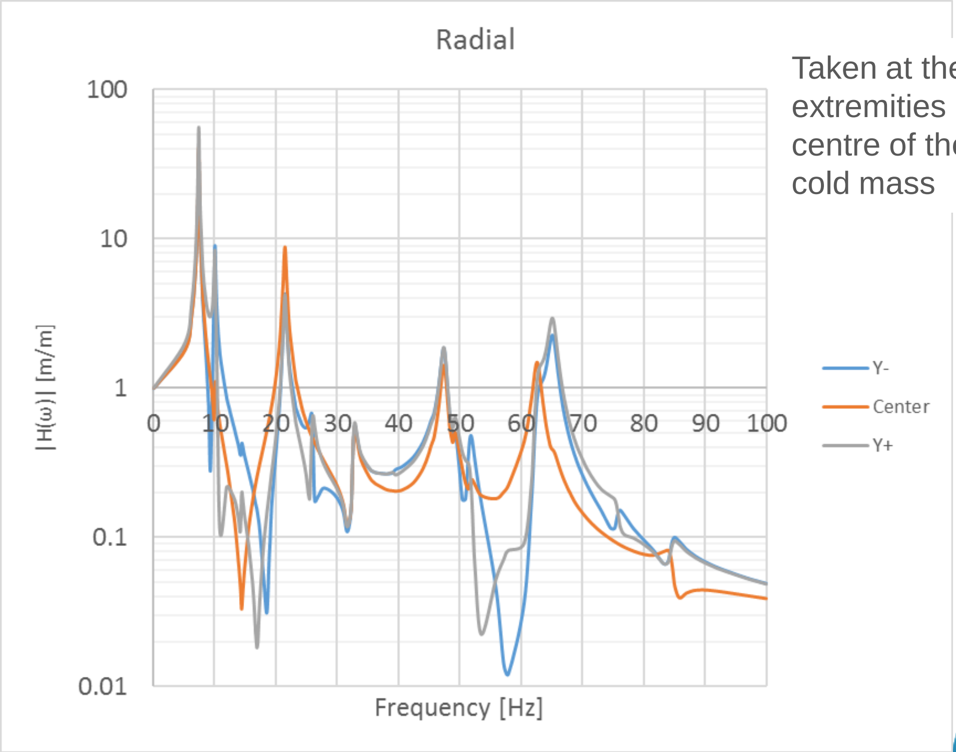
HL-LHC Frequency Response Function: Radial







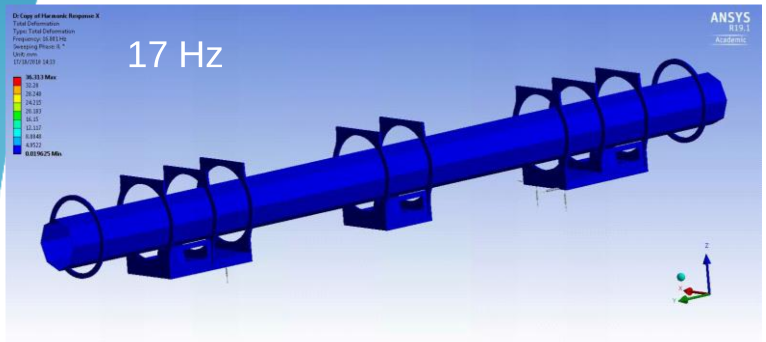


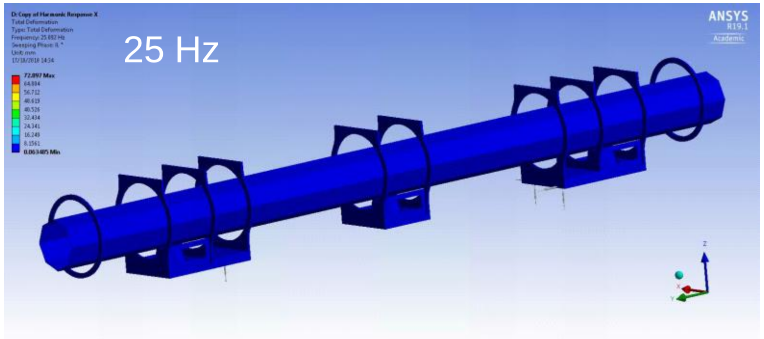


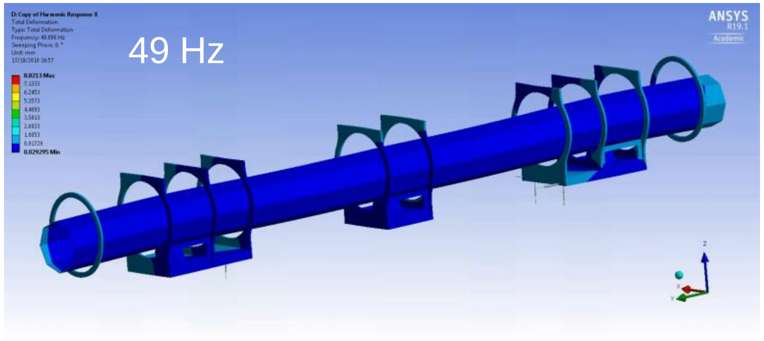
Taken at the two extremities and centre of the cold mass

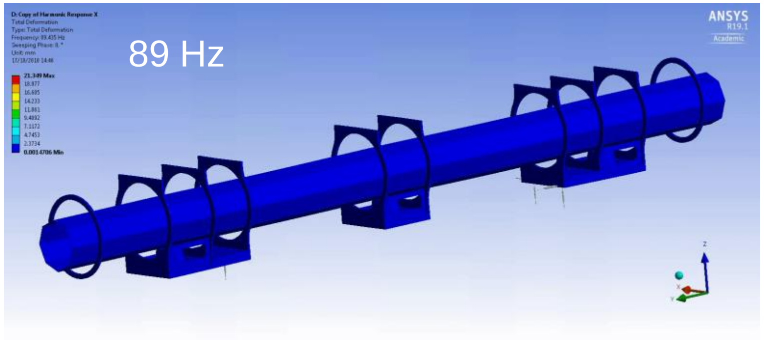
Assuming 1% overal damping ratio. NOTE: Amplification at ressonance ponts are highly dependent on damping: measurements on real cryo-assemblies are necessary.

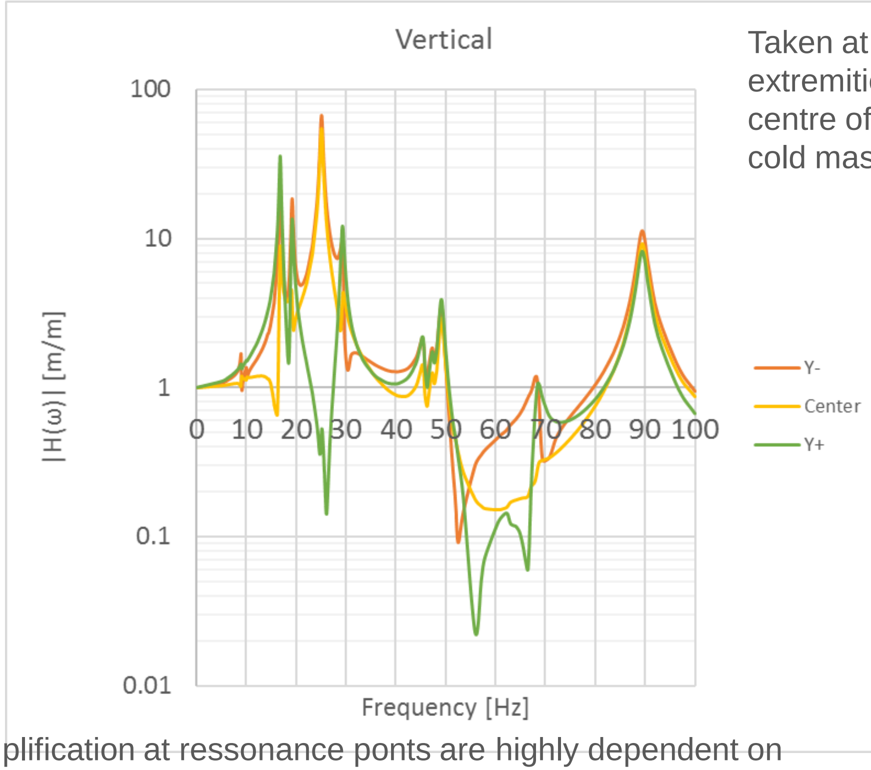
HL-LHC Frequency Response Function: Vertical











Taken at the two extremities and centre of the cold mass

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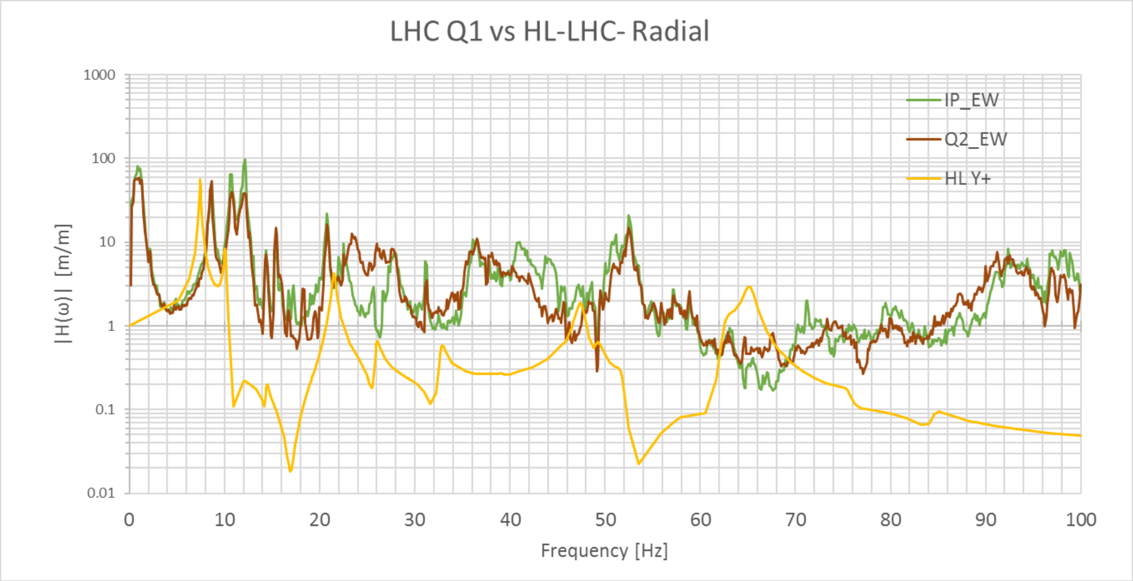
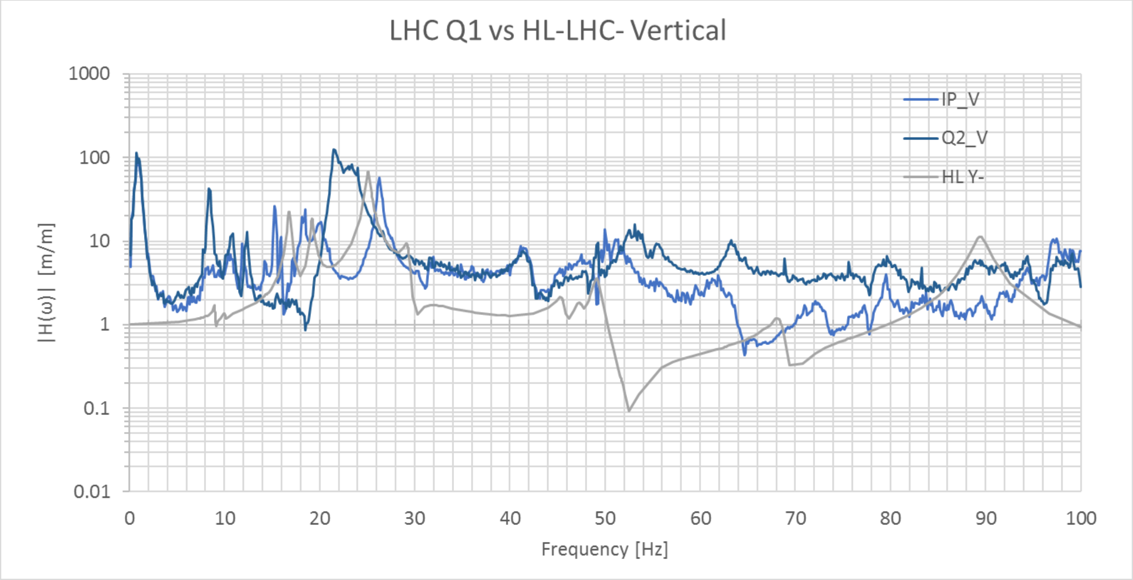
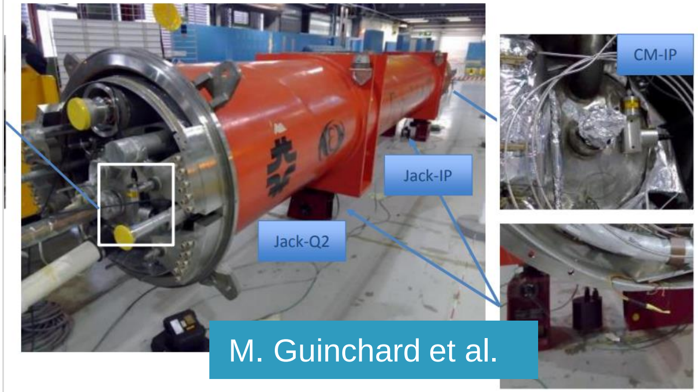
HiLumi HL-LHC PROJECT

Comparison with measurements on LHC Q1



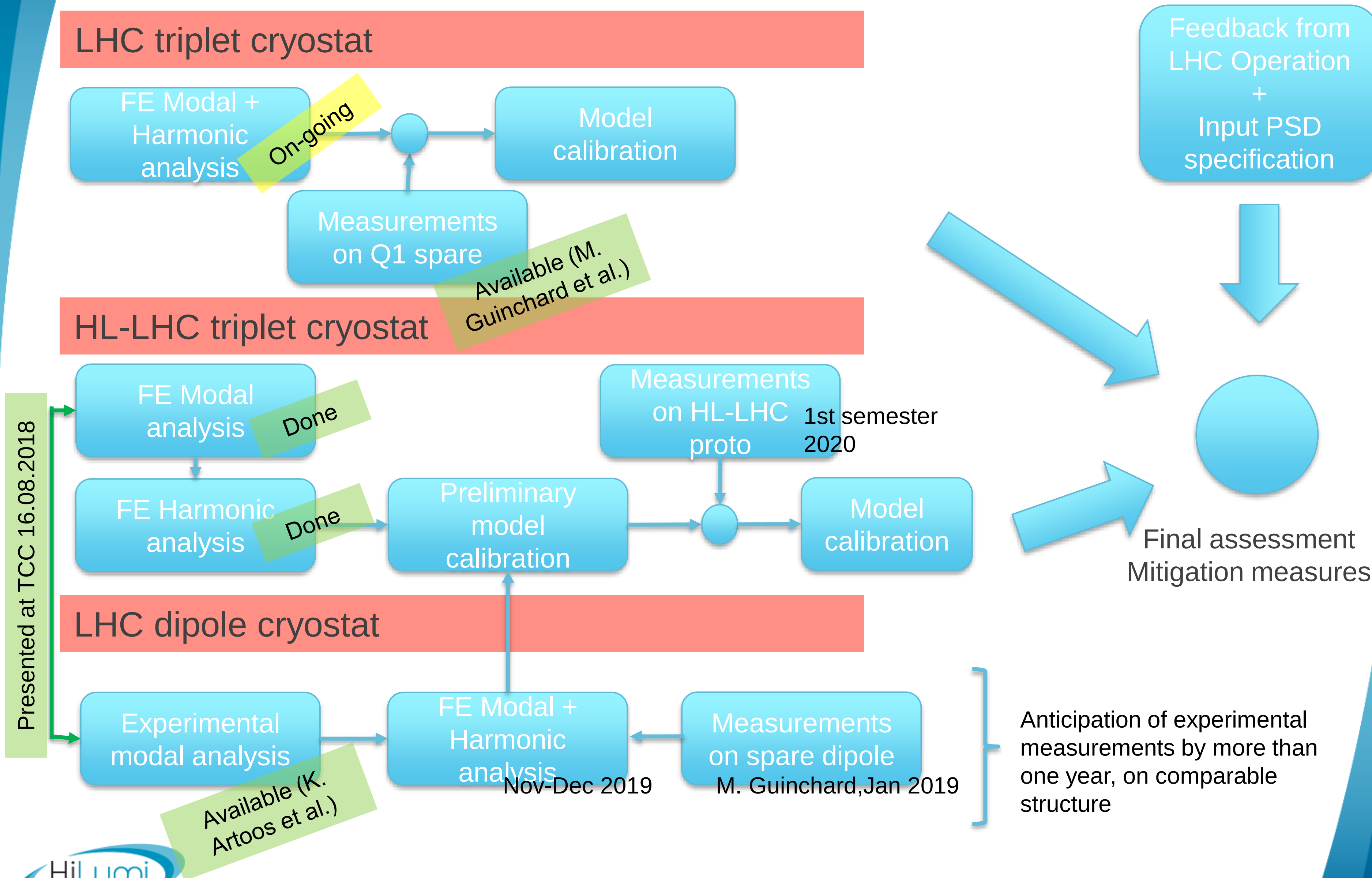




- Comparable resonant frequencies despite substantially different structure
- Significant difference observed on attenuation frequencies for radial excitation
- On-going work on a model of LHC Q1 cryoassembly will give us a better understanding of the differences between LHC and HL-LHC

HL-LHC PROJECT

Status and plans



Conclusion

- On-going work on FE modeling. Results on FE analysis of LHC Q1 available soon.
- Planned measurements on **LHC dipole** cryo-assembly by EN-MME (2019) and on HL-LHC prototypes (2020).
- HL-LHC FE model combined with measurements on LHC dipole cryo-assembly should allow us to **anticipate** the behaviour of **HL-LHC** cryo-assembly by at least one year wrt availability of the first prototype.
- So far FE harmonic analysis of HL-LHC cryostat indicates that dynamic behaviour of HL-LHC and present LHC triplet is somewhat **comparable** despite a different cold support structure and cold mass weight.

Thank you