Laser interferometer for cold mass displacement

H. Mainaud Durand,
On belhalf of Mateusz Sosin and Vivien Rude

8th HL-LHC collaboration meeting, 18/10/2018, CERN

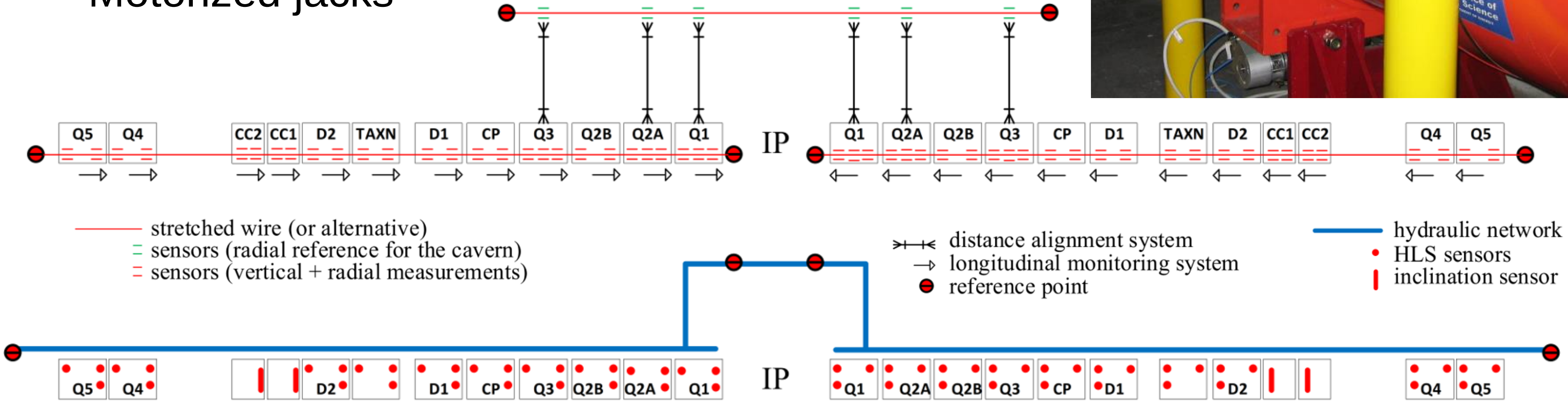
Alignment systems for HL-LHC

To determine the position of the cryostats

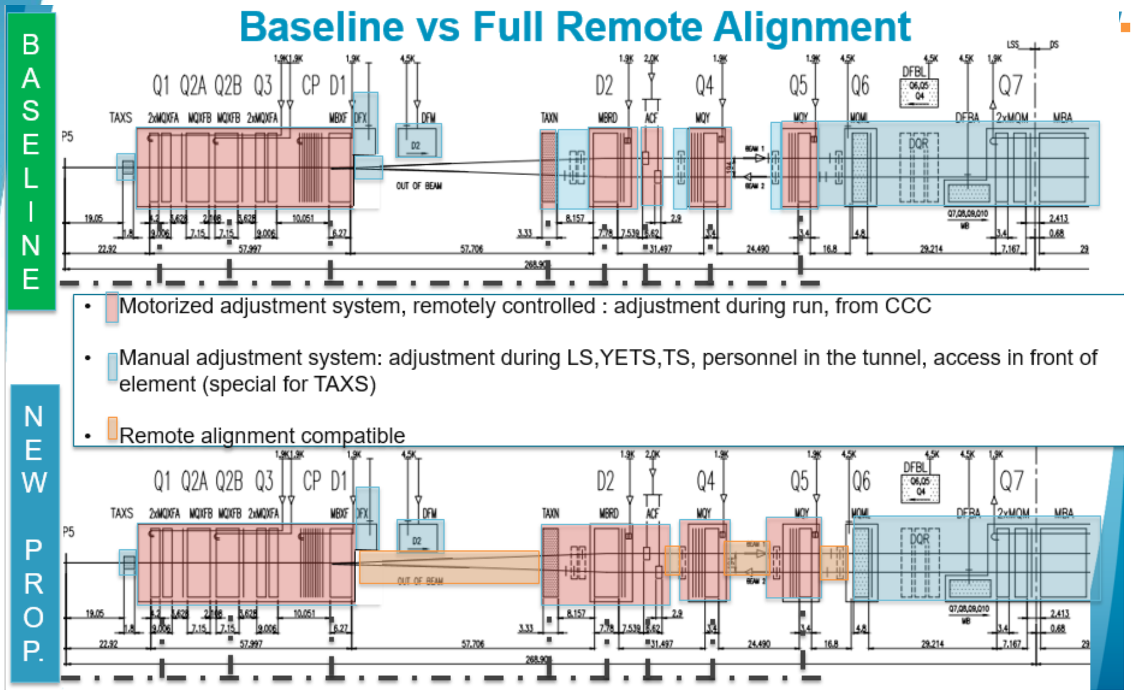
- Wire Positioning Sensors (WPS)
- Hydrostatic Levelling Sensors (HLS) (or rad-hard inclinometers)
- Sensors for the longitudinal position

To adjust the position of the cryostats

- Motorized jacks



Alignment systems



- The Full Remote Alignment
  - Can be deployed
  - It will be beneficial to reduce radiation to personnel
  - It will increase the window for machine optimization (larger margin in aperture margin and lower β^* reach)
  - Less pressure on orbit corrector system
  - Higher machine flexibility and reduced reaction time
  - It opens the possibility to re-optimize the Matching Section

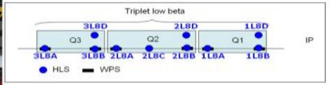
See presentation from P. Fessia

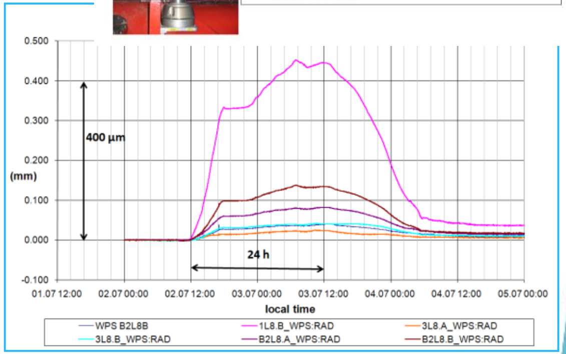
To monitor the position of the cold mass inside the Inner Triplet cryostat

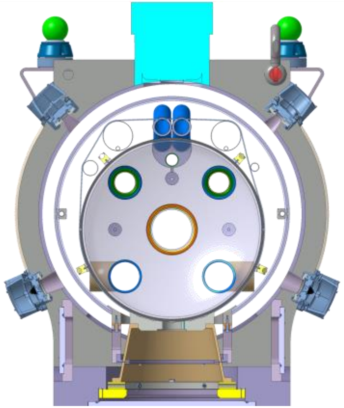
Why a system to monitor the cold mass displacement?

- 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)
- Strong interest from WP2 to know more accurately than in the LHC the longitudinal position of the cold mass

- 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

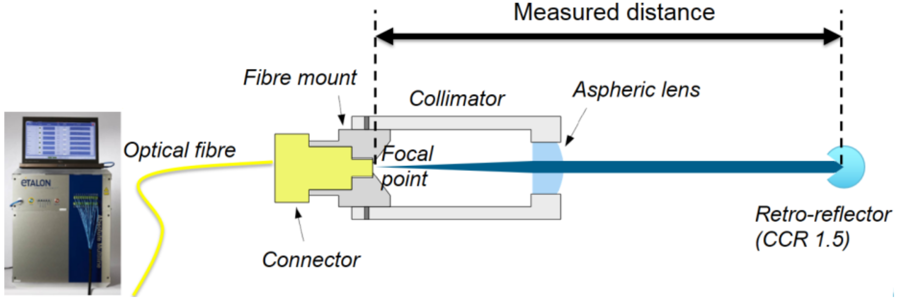






Introduction to laser interferometer

- FSI = Frequency Scanning Interferometry
  = absolute distance measurement



- $\Delta Phase\ (meas.) = \frac{2\pi}{c} * L_M * \Delta\nu$
- $\Delta Phase\ (\ ref.\ ) = \frac{2\pi}{c} * L_R * \Delta\nu$

$$\frac{\Delta Phase\ (meas.)}{\Delta Phase\ (\ ref.\ )} = \frac{L_M}{L_R}$$

Accuracy : 0.5 µm per meter

Outlook

- Qualification tests

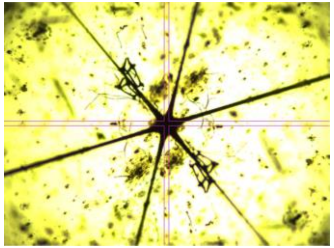
Validation on independent benches	→	Validation on Crab cavities in SM18 & SPS	→	Validation on a test magnet (Dipole)
Performance of one line FSI & study of an alternative - Irradiation tests - Thermal tests - Precision, accuracy,…		*Performance target at warm, vacuum, cold, and cross-comparison with other systems*		*Validation of performance* - Accuracy and precision - Long term stability - Cryo-condensation issues

- Cryo-condensation issue
- Next steps and summary

Pre-test achieved on FSI

- Validation of targets through irradiation and cold tests

10 MGy

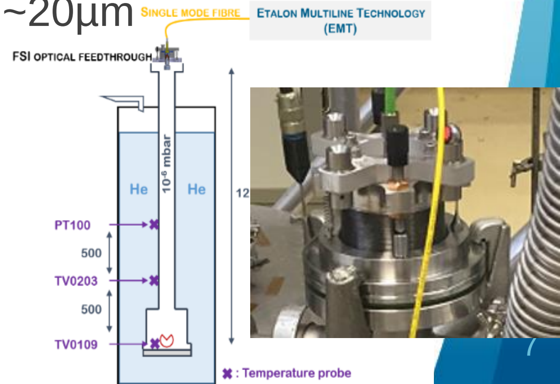


Liquid nitrogen test:
- No damage of targets
- No loss of performance

Radiation tests of BMRs :
- Ceramic BMRs and collimators validated with TID of 10MGy
- BMR mirror centricity lost ~20µm

- Validation of meas. chain (vacuum & cold tests)

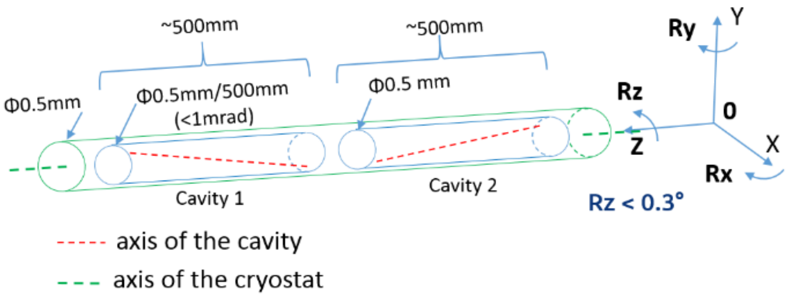
Liquid nitrogen test:
- No visible deformation of the feethrough
- Decrease of intensity but no impact on the measurements
- Comparison with AT401 measurements within 20 µm

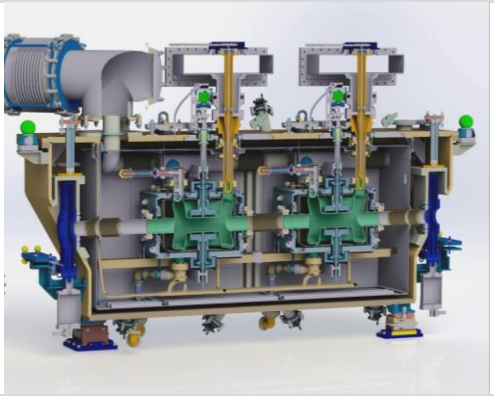


Crab cavities case

Alignment requirements (3σ):

- The cavities axes have to be included in a 0.5 mm diameter cylinder w.r.t. the cryostat axis,
- The cavities roll (Rz) w.r.t. the cryostat axis has to be lower than 5 mrad,
- The cavities pitch and yaw (Rx, Ry) w.r.t. the cryostat axis has to be lower than 1 mrad.

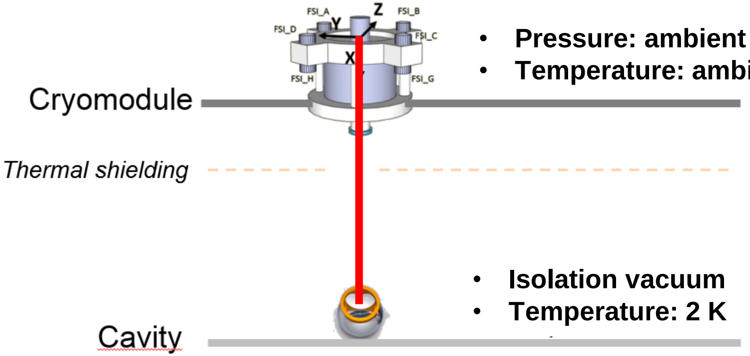




HL-LHC environmental conditions:

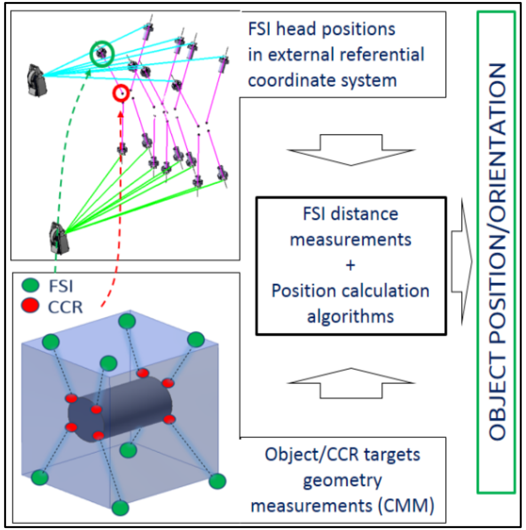
- Radiation → 10 MGy (beam pipe), 1 MGy (cryostat surface)
- Insulation vacuum: 10^{-6} mbar
- Temperature: 2 K

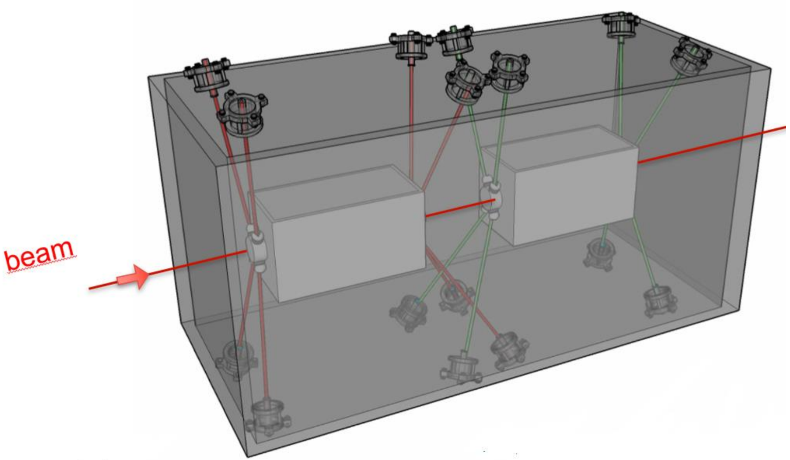
Crab cavities results



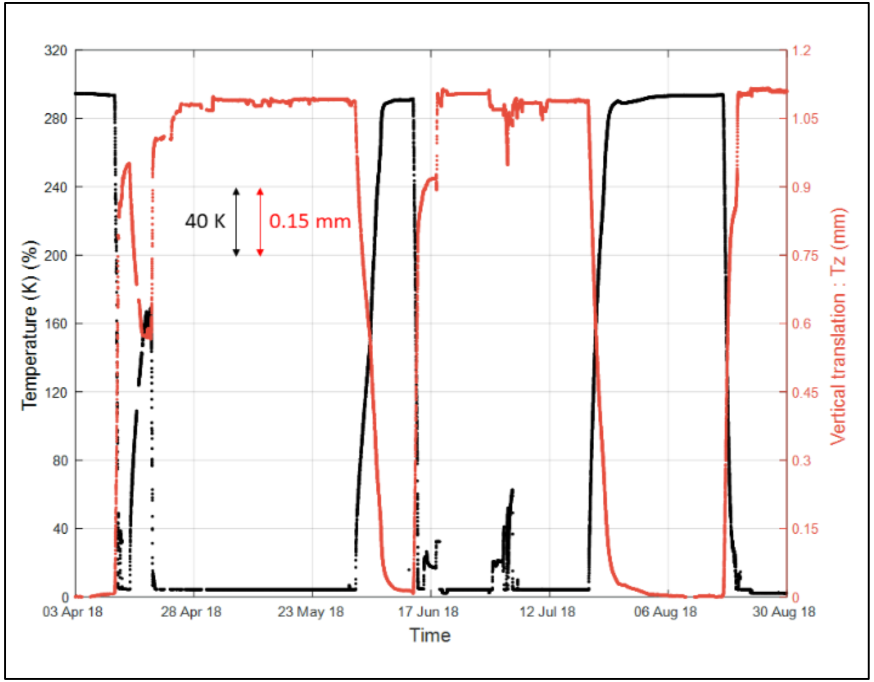
- **Pressure: ambient**
- **Temperature: ambient**

- **Isolation vacuum**
- **Temperature: 2 K**



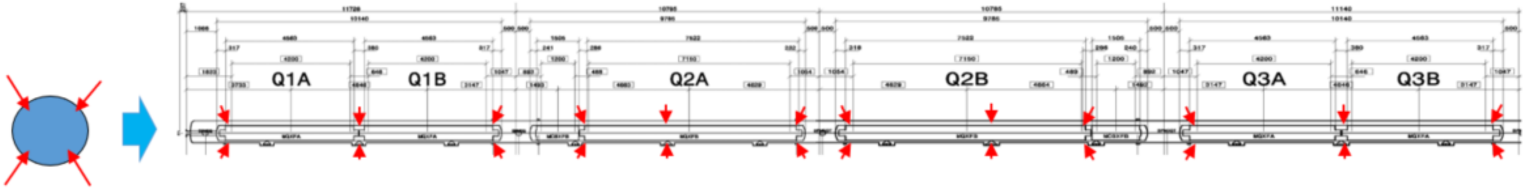


Crab cavities results

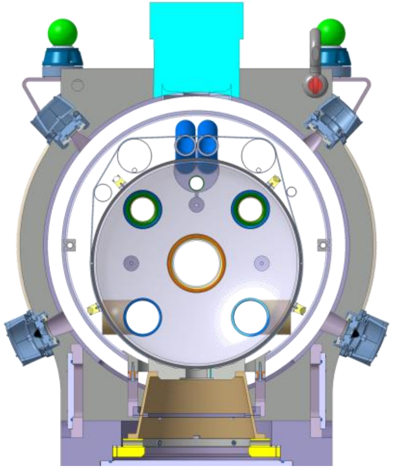


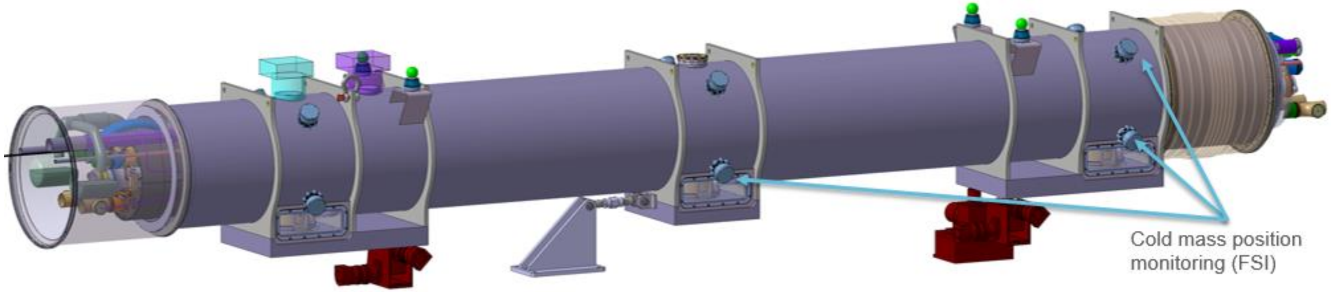
- ✓ Successful cross-comparison with other systems at warm, at cold, under vacuum
- ✓ Accuracy of the absolute position of crab cavities using FSI : ±0.05 mm
- ✓ Relative position: a few micrometers

Configuration for IT cold masses



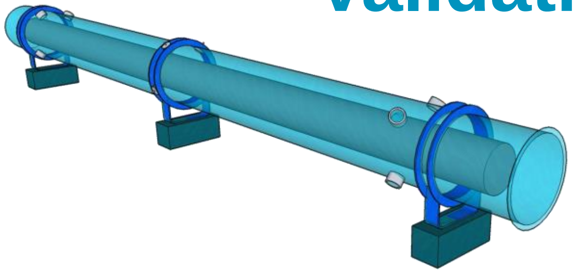
3 x 4 FSI heads
for each cold mass

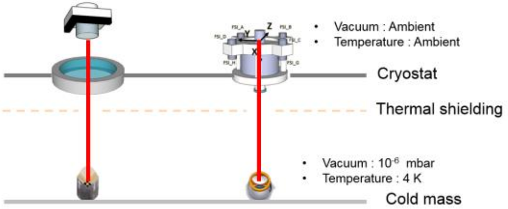


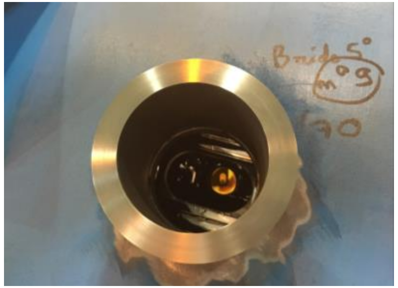


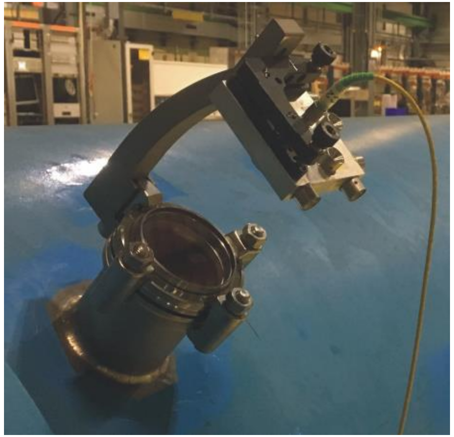
Courtesy D. Duarte Ramos

Validation on a dipole test

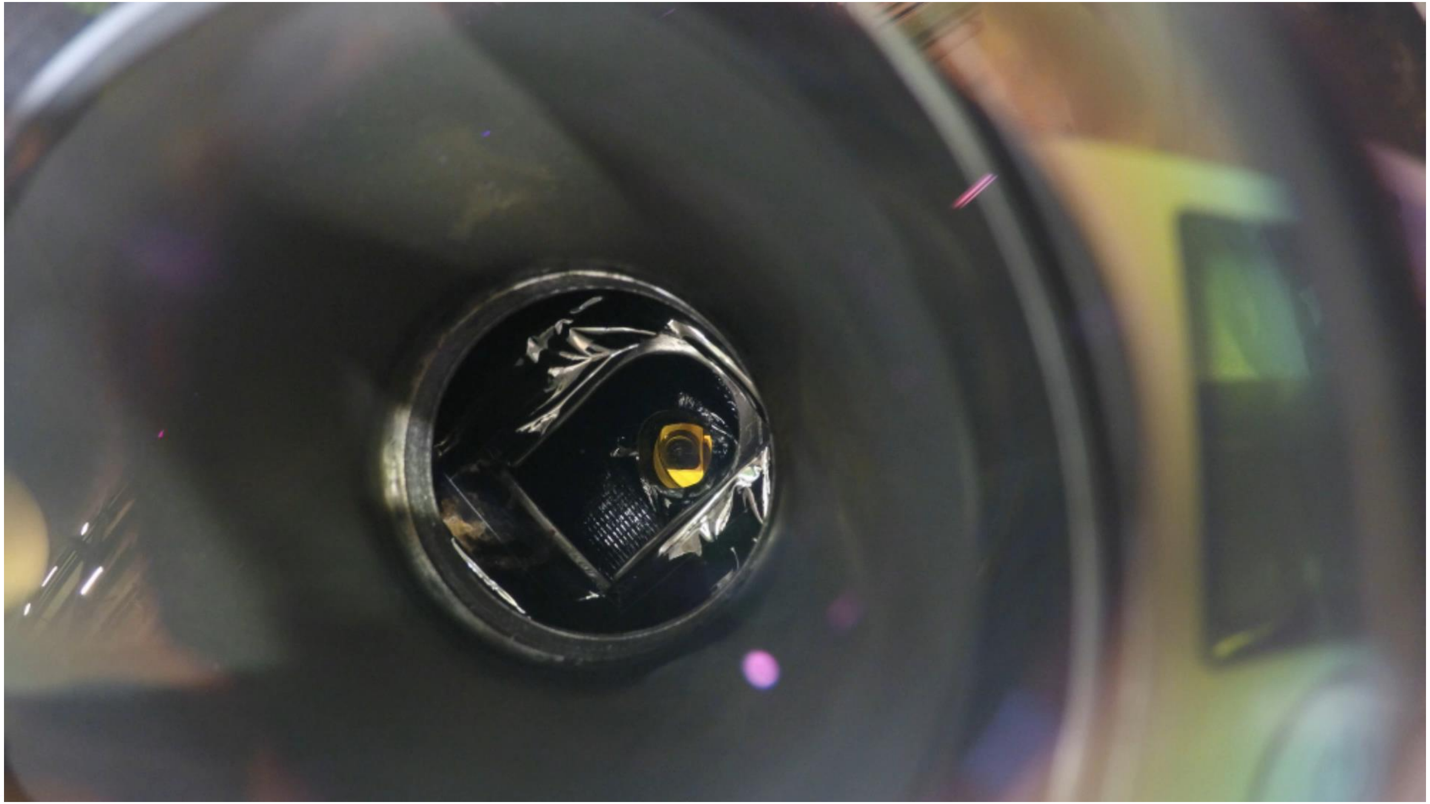








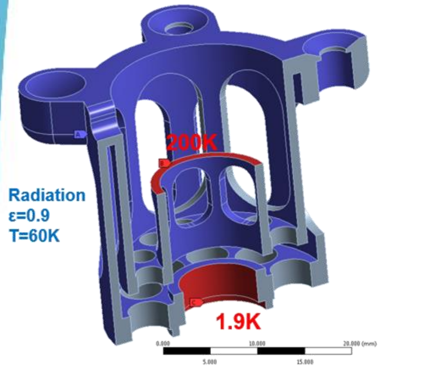
Cryo-condensation issue



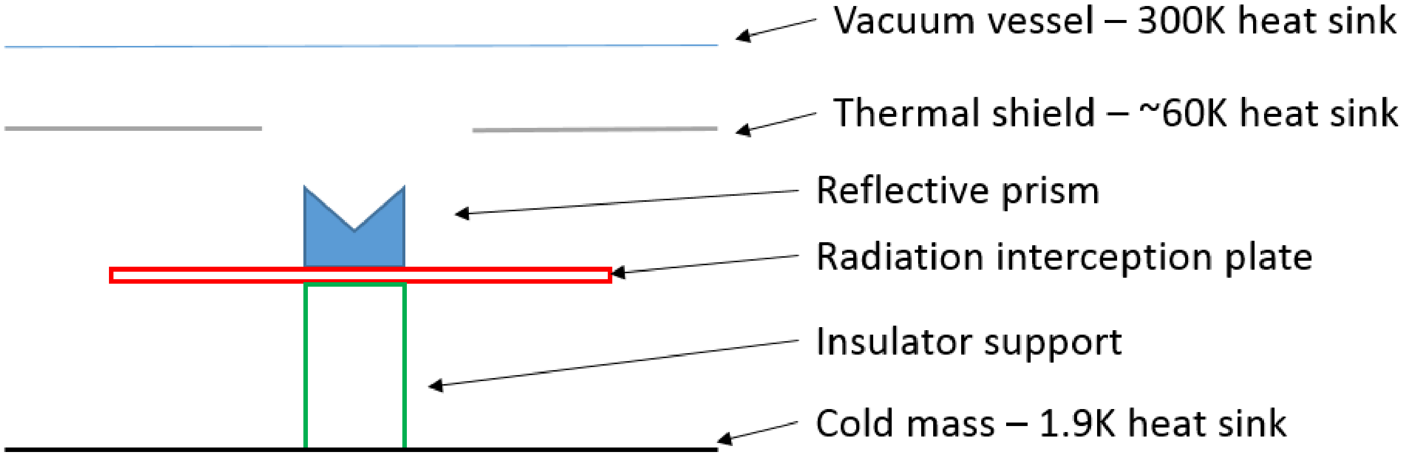
Cryo-condensation issue

How can we achieve a “heating” of the probes up to ~200K ?

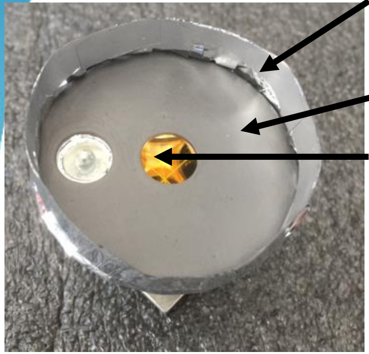
Permanent heating – by making sure that the probe stays at >=200K, no cryo-condensation should ever take place in principle. This could be achieved using the power radiated from the vacuum vessel (which is 300K “hot”).

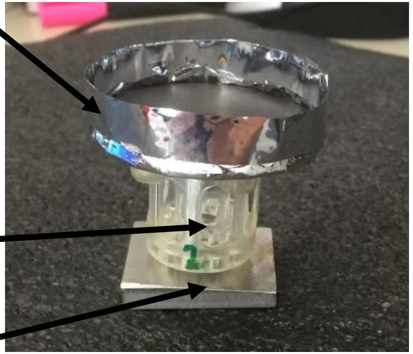


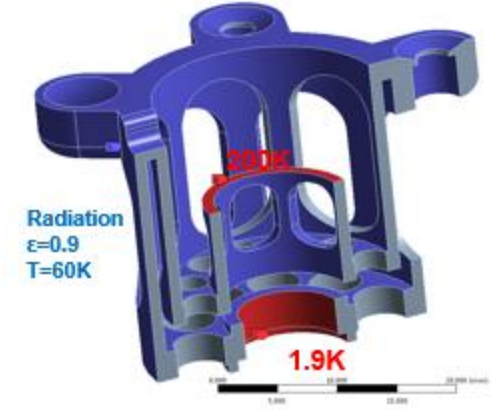
Courtesy F. Micolon



Thermal dissipation







	Power (mW)
Residual opening	60
Heat conducted by support	56
Total heat to CM	**116**

Courtesy F. Micolon

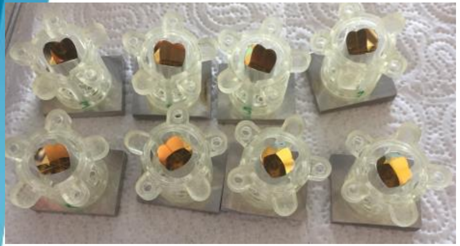
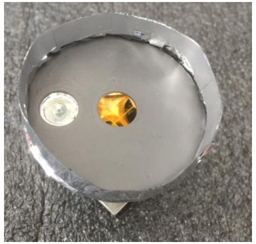
The FSI system is fitted with 12 holes per magnet – 48 holes per triplet:

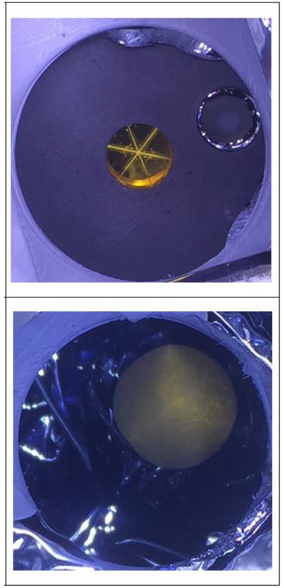
→ 48*0.116=5.57W (for TS holes Φ40mm)

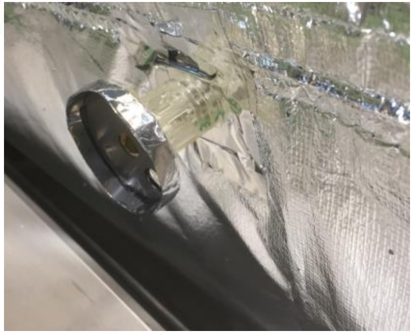
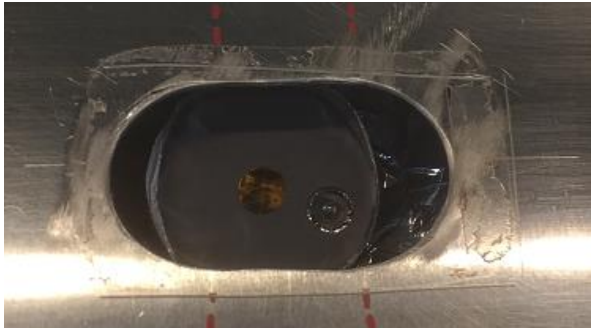
Thermal in-leaks additional operating cost is ~ 28kCHF for 10 years operation per triplet string

FSI thermal load budget discussed with WP9 and assessed as acceptable

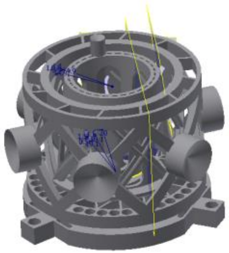
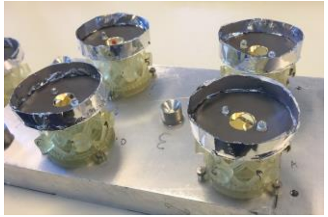
Cryo-condensation issue




- Next step: design of a more robust support, made of another material (Acurra Blue stone and then Accura 48).
- Installation and validation on the dipole (all viewports configuration)

Latest results

	October 2018 PHASE 4 293 K → 4 K	
Tx : radial (mm)	0.016 mm	+/- 0.138 mm
Ty : longitudinal (mm)	0.266 mm	+/- 0.126 mm
Tz : vertical (mm)	**-0.975 mm**	+/-0.045 mm
Rx : pitch (rad)	0.000012 rad	+/- 0.000009 rad
Ry : roll (rad)	0.000781 rad	+/- 0.002861 rad
Rz : yaw (rad)	0.000020 rad	+/- 0.000005 rad
F : scale factor	**-3109 ppm**	+/- 17ppm
Sag (radial)	-0.069 mm	+/- 0.024 mm
Sag (vertical	0.034 mm	+/- 0.042 mm

Successful test at 4 K of the new support of targets!
Cryo-condensation issue solved!

Summary

- All tests of validation of FSI system successful: individually, in the crab cavities, inside a dirty dipole
- Issue of cryo-condensation solved by the development of a new support of target, made of Accura 48, allowing the target to be at 200 K with an acceptable thermal dissipation.
- Tests still under way to decide on the targets and the configuration of feedthrough/viewport before the end of the year.
- Final validation will take place on the string test.

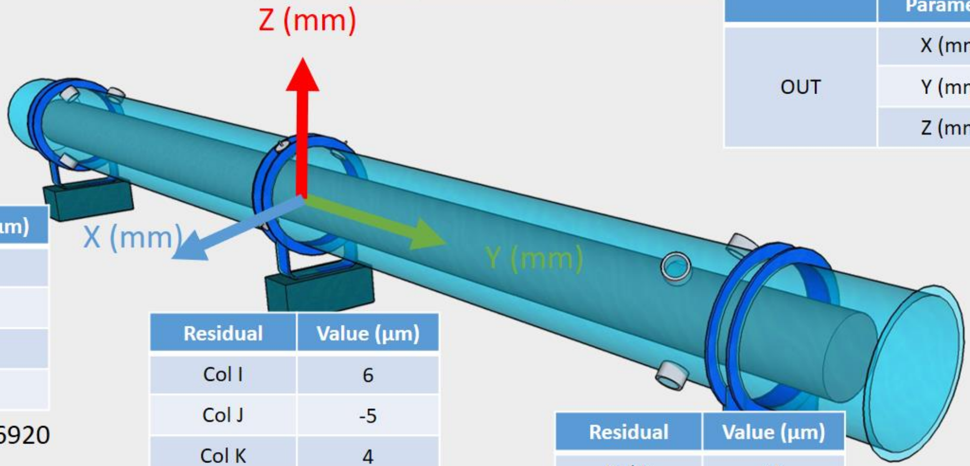
Thank you very much

Latest results per section

	Parameter	Value
IN	X (mm)	0.569
	Y (mm)	-6200.536
	Z (mm)	71.602

	Parameter	Value
CENTER	X (mm)	2.286
	Y (mm)	0.306
	Z (mm)	73.991

	Parameter	Value
OUT	X (mm)	4.053
	Y (mm)	4984.820
	Z (mm)	76.003



Residual	Value (µm)
Col A	39
Col B	-19
Col C	36
Col D	-31

Scale factor : 0.996920

Residual	Value (µm)
Col I	6
Col J	-5
Col K	4
Col L	-4

Scale factor : 0.997129

Residual	Value (µm)
Col E	12
Col F	-5
Col G	11
Col H	-9

Scale factor : 0.996903