Connecting and Integration of the Instrumentation in the Magnets

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HL-LHC Magnet Circuit Instrumentation Day 2023

Outline

- Instrumentation sensors installation and wires connection, routing and testing
- IFS flanges overview and validation
- Documentation of magnet instrumentation

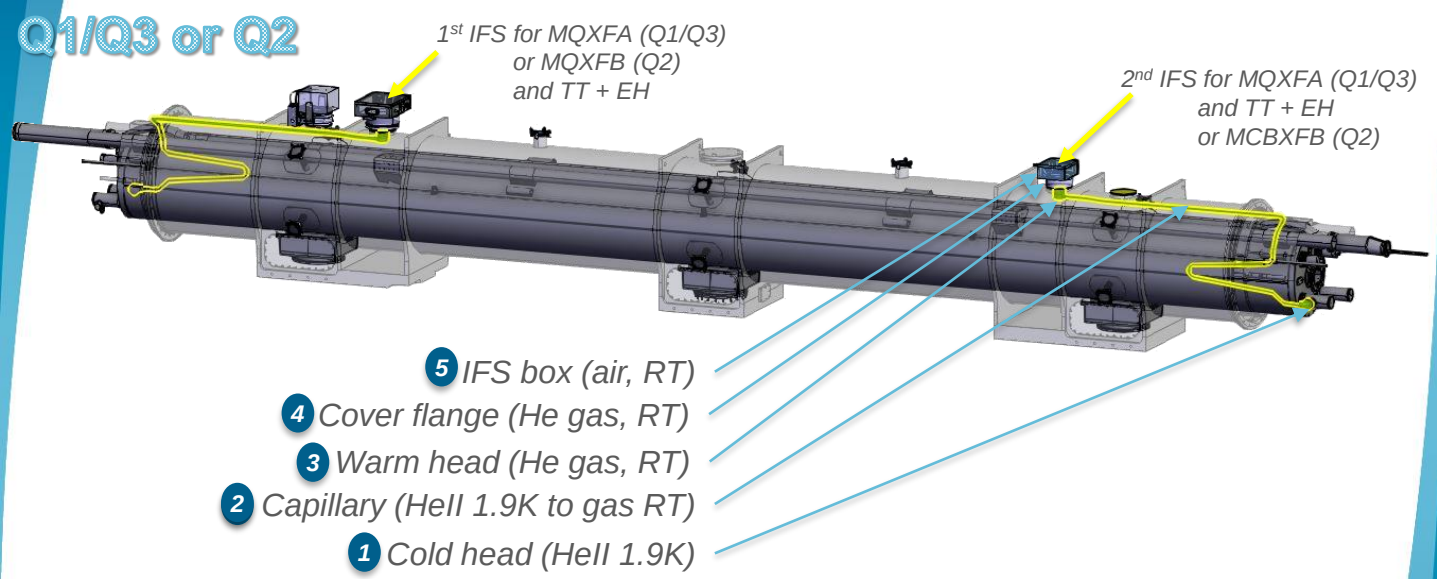
What kind of instrumentation and associated wire types are inside the cold masses?

Instrumentation Feedthrough System (IFS):

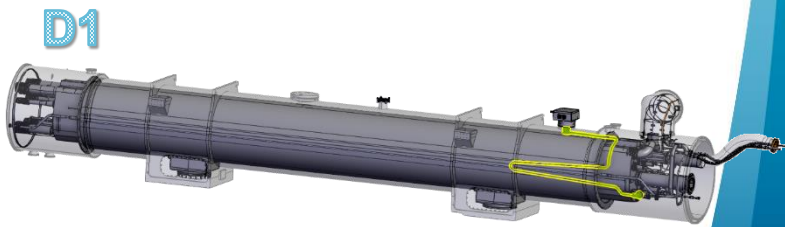
- *Electrical and mechanical connection of the instrument wires between the magnets in liquid helium and the outside of the vacuum vessel (RT)*
- *Simplicity of integration*
- *Optimal access during testing and commissioning*
- *To withstand Voltage and sustain reliability during the lifetime of the machine*
- *Minimized heat load to superfluid helium*

Electric		Cryogenic		Mechanic
Voltage taps	***(EE)*** ***AWG26***	***Temp. sensors***	***(TE or TT)*** ***AWG30***	*Strain gauges*
Quench heaters	***(YT)*** ***AWG18***	***Cryo-heaters***	***(EH)*** ***AWG20***	*Optical fibres*
Current taps	*(EE)* ***AWG20***	*Level sensors*	*(LE)* ***AWG30***	*Pressure sensors (PT)* ***AWG30***

Signal routings and component designations



2 IFS for MCBXFA and HO corr.
and TT + EH



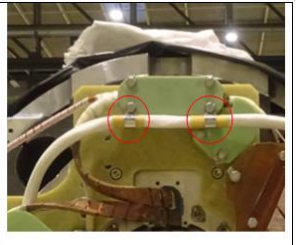
1 IFS for MCBXF and TT + EH

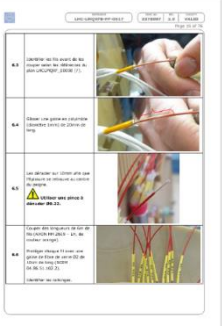
Voltage Tap Wire Installations and Connections

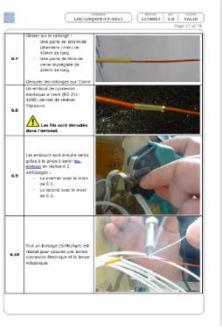
LHC-LMQXFB-FP-0017 (edms 2378097) Chapters 6, 8.2, 8.4 & 8.5

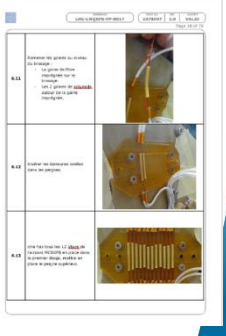
8.2.2	Appliquer du MOB 39 au pinceau sur les prises de potentiel et le câble.	
8.2.3	Braser les prises de potentiel avec un fer à souder réglé à 280/300°C. ⚠ **Positionner la panne sur la prise de potentiel.** ⚠ **La température ne doit pas dépasser les 300°C.**	
8.2.4	Nettoyer les pièces à l'éthanol. **Renseigner l'étape dans l'étape X.3.2.3 de la fiche de suivi [6].**	

8.4.7	Avec un fer à souder régler à 250°C, braser la pin sur la cosse avec de l'étain / Argent en mettant en contact la panne sous l'attache afin de faire fondre l'étain / argent déjà présent. ⚠ **Une fois en fusion et la pin noyée, retirer le fer à souder.**	
8.4.8	Nettoyer la brasure avec de l'éthanol, du scotch brite puis avec un chiffon non peluchant.	
8.4.9	Avec le service électrique, iidentifier les fils des prises de potentiel conformément au plan LHCLMQXF_E0008 [7]. **Renseigner l'étape X.3.2.6 de la fiche de suivi [6].**	

8.10.4	Fixer la gaine aux positions indiquées ci-contre : - Envelopper les fils avec de la gaine de fibre imprégnée. - Installer une attache Ø10 (ref. RS 226-9012). - Installer une rondelle Nordlock M6 (serrage à 6.3 N.m). 	

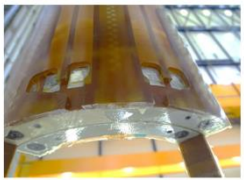


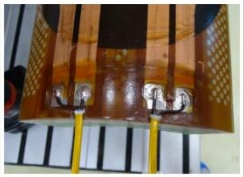




Quench Heater Wire Connections to the Strips

LHC-MQXFBC-FP-0017 (edms 1726065) Chapters 6.22

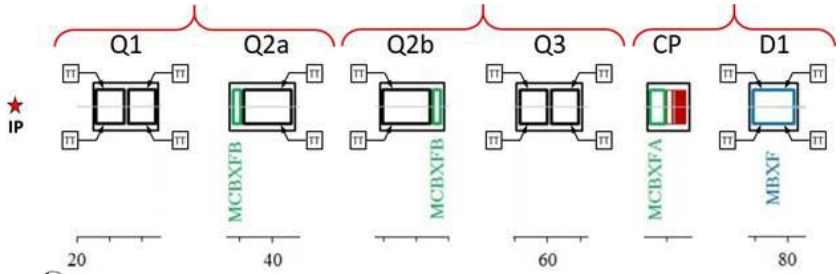
6.22.26	**Accès aux zones étamées couche externe CC et COC** Enlever les patchs de scotch démoulant en prévision du contrôle électrique.	 

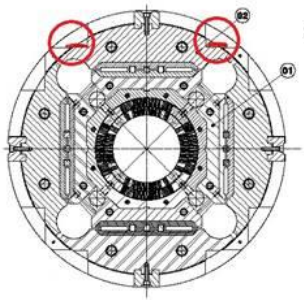
6.22.36	**Protection des câbles CC et COC** Protéger les câbles avec une chaussette textile et un tube en poly imide : **CC** : • 2 fils QH dans une chaussette, • 2 fils QH plus 1 fil Vtap dans une deuxième chaussette. **COC** : • 2 fils QH dans une chaussette, • 2 fils QH dans une deuxième chaussette.	 CC  COC

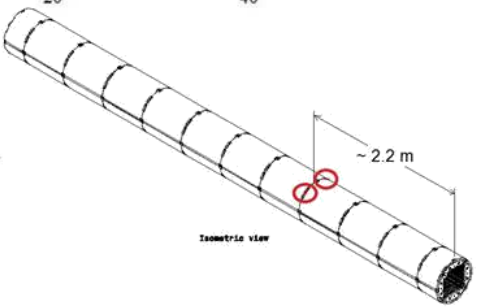
6.22.38	**Remplissage à l'Eccobond CC et COC** Injecter de l'Eccobond. Si nécessaire, boucher les trous précis avec de l'adhésif démoulant pour que l'Eccobond remplisse complètement la cavité. **Signer et remplir la fiche de suivi, pour la couche externe : §G.9.3.17 selon** [2]	 
6.22.39	**Polymérisation** Laisser polymériser 24h.	

Temperature sensors (TT)

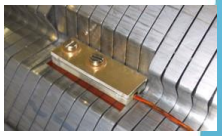
- 16 CERNOX thermometers will be installed in triplet string,
- 64 wires (Ø 0.255mm) to be routed outside the cryostats via IFS capillaries to the cover flanges,
- 2 AWG 30 (4 twisted wires Ø 1.6 mm) per capillary except in the Corrector package,
- Signals routed through the IFS capillary to connected LV feedthrough,
- Fermilab requested four additional temperature sensors to better monitor the temperature gradient in the Q1/Q3 cold mass assembly and to maintain the gradient between the magnet ends during cold tests.



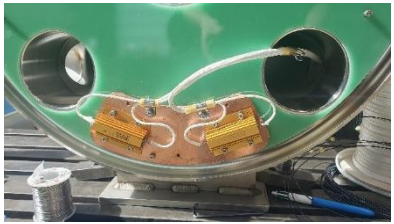




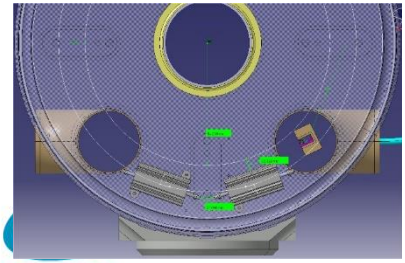
- *Sensors screwed on the laminations according to installation guide LHC-QIT-AP-0002.*
- *Wires routed via the same grooves, between the laminations and the aluminium shells, and glued at the level of the accessible slots.*
- *Extra-length added between the glued points to compensate the differential in thermal contraction between the wires and the yoke.*

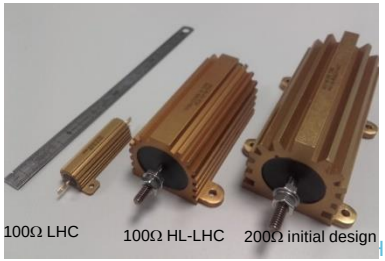


Cryo-Heaters (EH)

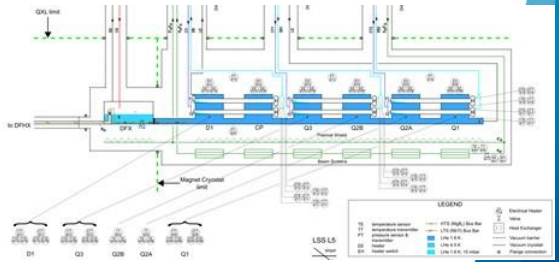


- Cryo-heaters in the liquid helium bath of the cold masses are primarily used for the cryo-plants preparation and ramp-up prior to the rise of the collision-induced heat load due to beam collisions. In addition they allow the helium boil off in a reasonable timescale during the cold mass emptying.
- 16 Cryo heaters 100Ω (Vishay RH100) will be installed in triplet string, 2 associated each main magnet in the cold mass,
- 100 Vdc, 1 A ⇨ 100 W each
- Signals routed through the IFS capillary connected to HV feedthrough (for standardisation purpose)
- Relocation at minimum 220mm from the beam axis for RP purpose, in direct contact with the end cover,
- 2 AWG 20 per resistance,
- 20mm minimum between the heaters and instrumentation wires that should be protected by a glass fibre sleeve insulation.



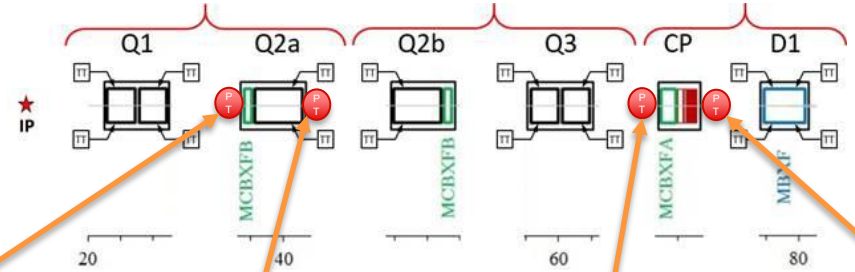


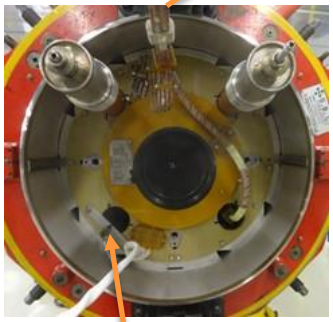
100Ω LHC 100Ω HL-LHC 200Ω initial design

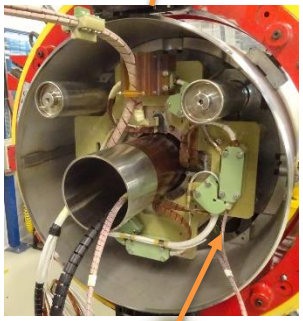


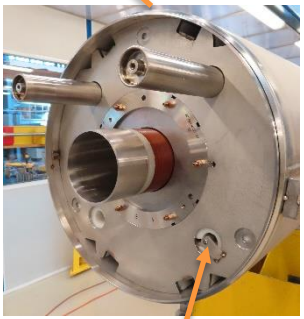
Pressure Sensors (PT)

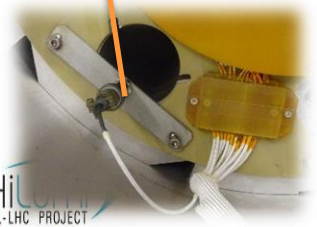
Only for the string test to measure the pressure waves











Situation inside the cold mass, routing upstream to the cold head

LHC-LMQXFB-FP-0017 (edms 2378097) Chapter 8.10
LHC-LMQXF_E-FP-0003 (edms 2648033)



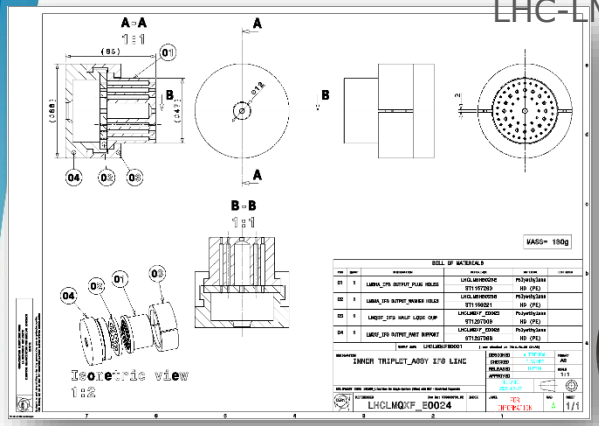



Cables are fixed at either end.

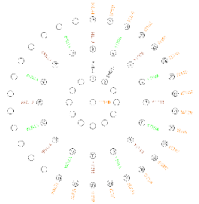
Along their path, they are wrapped in a fibre glass sleeve, guided inside supports that do not overly constrain them. In between two supports cables must have a certain freedom of liberty due to over length.
The cable supports have been replaced with St St units to avoid eddy current related buckling.

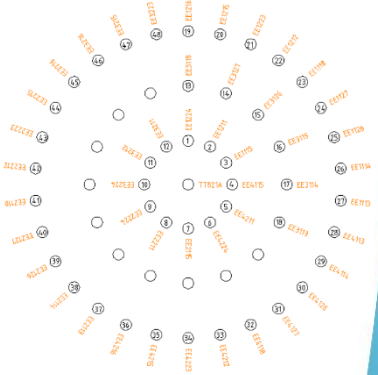
IFS Barrel Pieces and Labelling

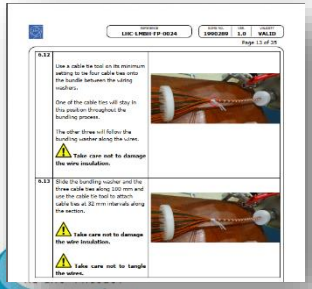
LHC-LMQXFB-FP-0023 (edms 2378105) Chapter 7.10 to 7.16

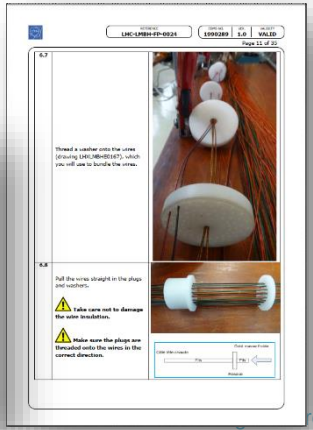


Drawings LHCLMQXF_E0024
The layout is such that there is no ambiguity on the wire positioning.
The drawing mentioned in the following slide will associate the wire Id (EE, YT, EH…) to the passage number.









Standardized barrels were supplied to FNAL and KEK so that all HL-LHC cold masses are all equipped.

Repair procedure is described in the spare slides.

IFS Capillary Installation Procedure

LHC-LMQXFB-FP-0023 (edms 2378105)

Bending procedure detailed in spare slides

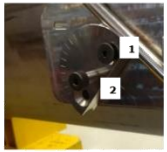
10. Cintrage des tubes IFS (Op X.24.5 du MIP [1])

10.1 Cintrage du capillaire MQXFB

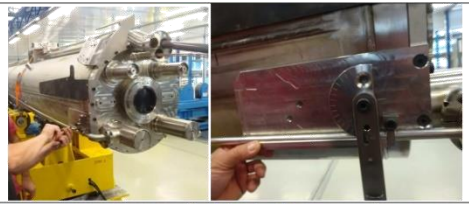
Le cintrage est réalisé avec l'outil de cintrage HCLMQXF_T0018 [18].

Le plan HCLMQXF_T0151 [19] décrit les opérations précisément. Les photos ci-dessous montrent les mêmes opérations pour aider (le numéro à gauche fait référence au numéro de l'opération du plan).

Pour installer les demi-lunes de cintrage, approcher la vis de la demi-lune sans la serrer (1), approcher la vis d'axe sans la serrer (2) puis bloquer la vis de la demi-lune.



1

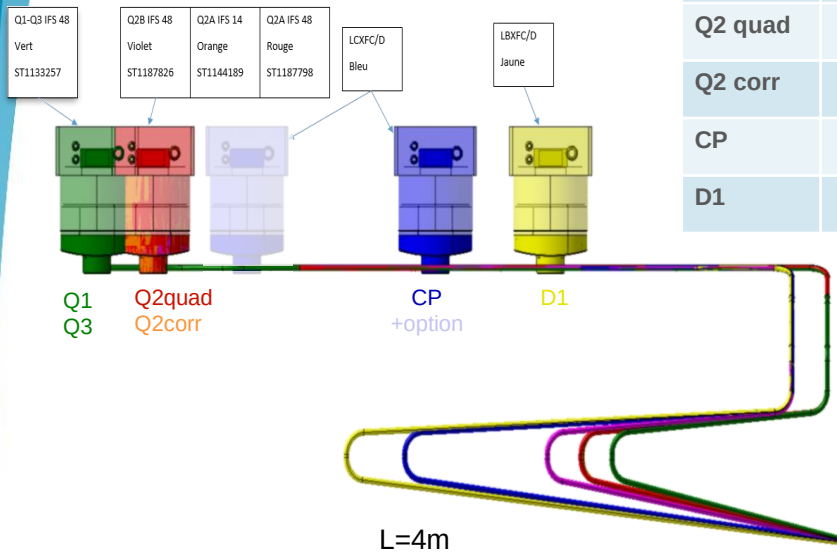


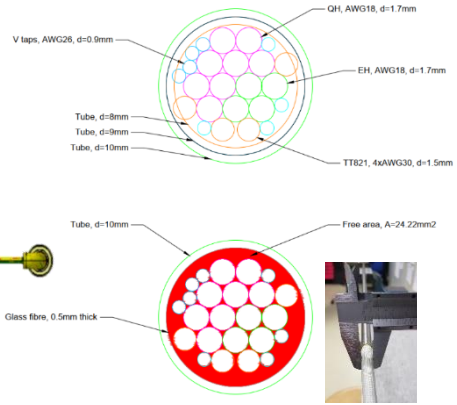
2

3

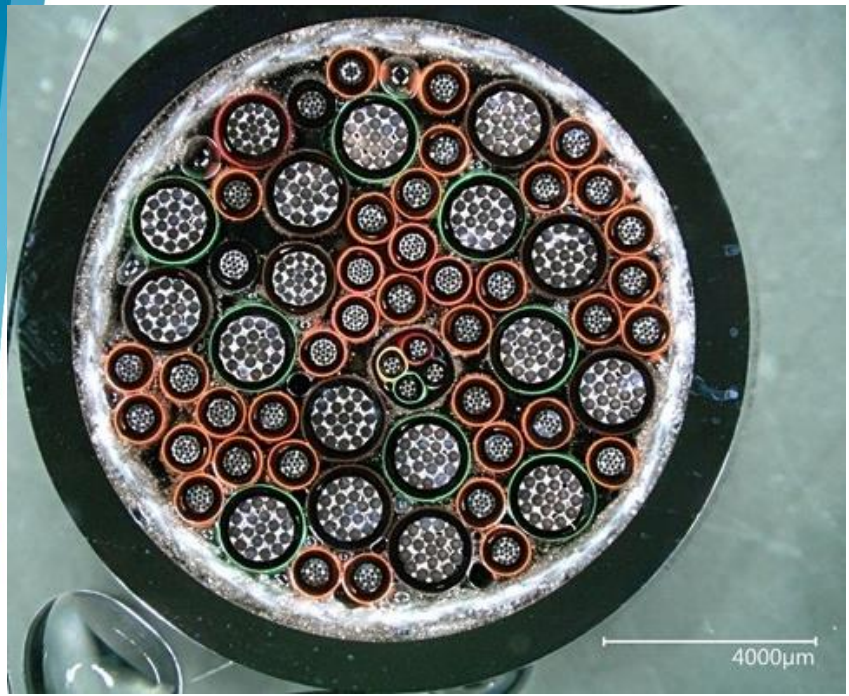
HL-LHC cold masses IFS Capillaries Integration, Dimensioning and Standardization

IFS capillary	Wires qtty	Wire qtty (Not V-Tap)	Ø	DWG
Q1/Q3	40 or 41	20	14/12	LHCLMQXF_E0026
Q2 quad	40	20	14/12	LHCLMQXF_E0027
Q2 corr	14	0	10/8	LHCLMQXF_E0028
CP	TBC	4	14/12	LHCLMCXFE0002
D1	36	28	12/10	LHCLMBXFE0025





Overview of the IFS capillary cross section



IFS capillary section for 11T type A cold mass (LMBHA)
Ø14/12

40 V taps
16 QH
2 I taps
2 EH
1 TT (4 wires)

AWG26: V-tap

AWG18: QH

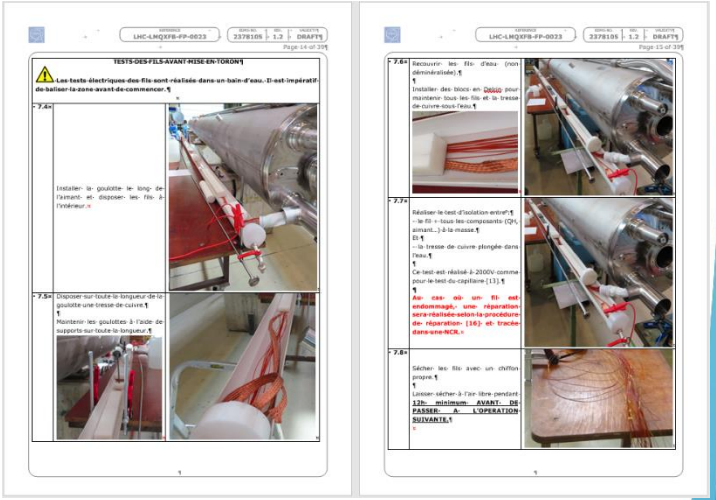
AWG30: TT

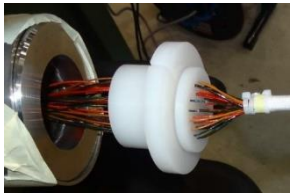
AWG20: EH
or I taps

Instrumentation wires insulation test immersed in water prior to the capillary insertion

LHC-LMQXFB-FP-0023 (edms 2378105) Chapter 7.4 to 7.70

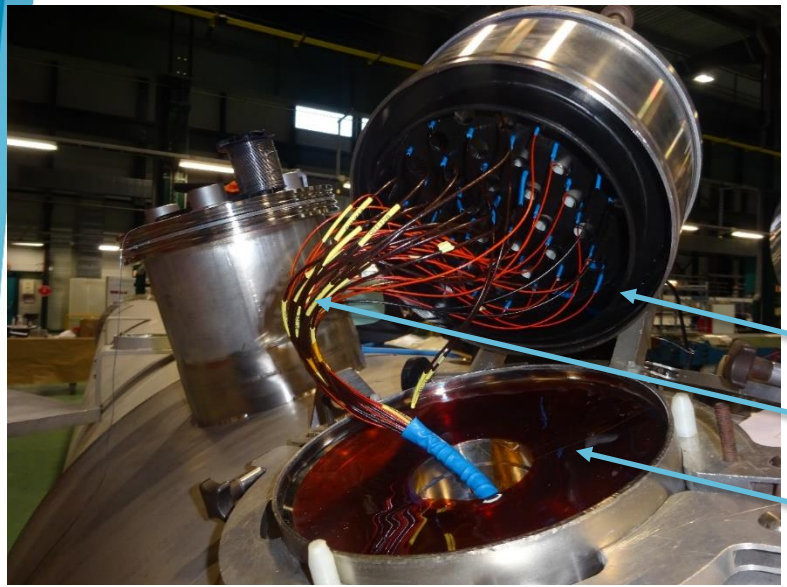
Technical note of the development edms 2900678





- *All wires (V-taps, QH, cryo-heaters) are immersed into tap water (not demineralized) inside a PVC gutter. They are connected to the positive terminal.*
- *A copper strip connected to the negative terminal is soaked in the same bath.*
- *2kV are applied between the poles.*
- *In case of failure, an NCR is opened for documentation follow-up, repair instructions are given in TE-MSC-LMF-QA-ELE-Réparation-IFS (EDMS 1430439)*

Connections between the warm head and the cover flange

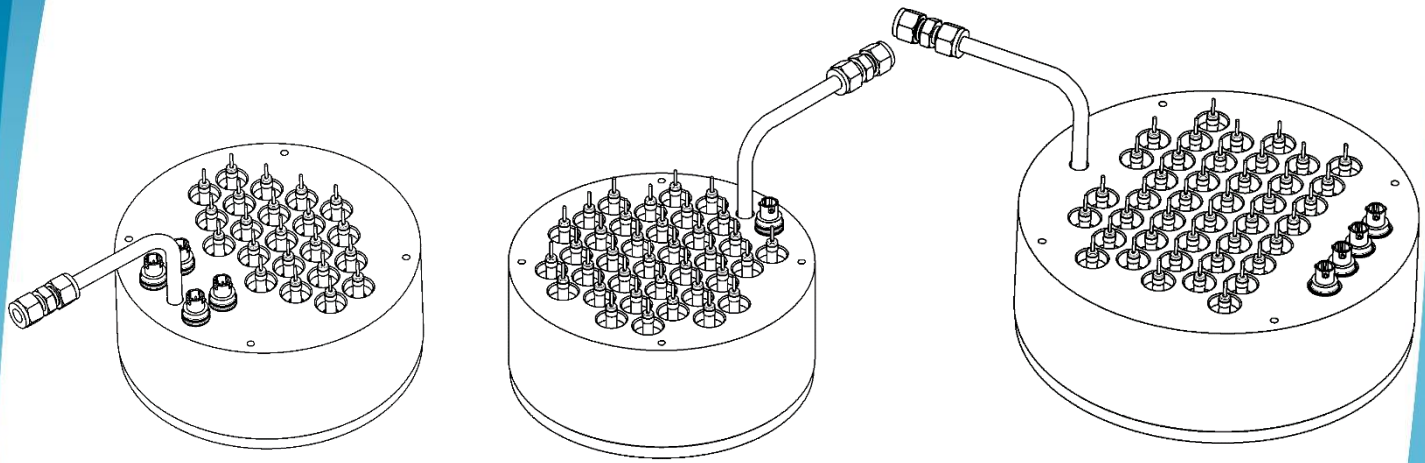


Careful positioning of the cover flange upon the cryostat flange

Positioning tool for cover flange tack welding

IFS Cover Flange Overview

3 types: S, M (LHC like), L



LHCLMQXF_E0020
S type: 22 HV pins
4 LV feedthroughs

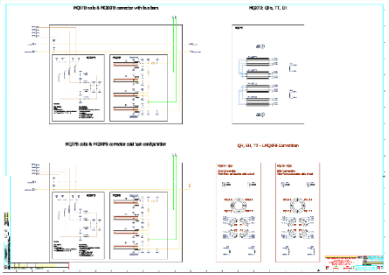
LHCLMQXF_E0053
M type: 36 HV pins
1 LV feedthroughs

LHCLMQXF_E0020
L type: 42 HV pins
4 LV feedthroughs

The cover flanges are validated by di-electrical test of each individual feedthrough at 5kV to ground and all others, and a pressure/leak test at 25bar at the manufacturer premises. Electrical tests are repeated during reception tests at CERN and before installation on the cryostat.

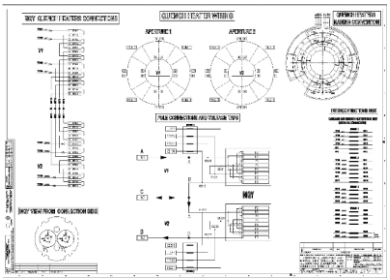
Documentation of magnet instrumentation
General Instrumentation Layouts

- From Q1 to D1: LHCLMQXF_E0001 & LHCLSXID0001



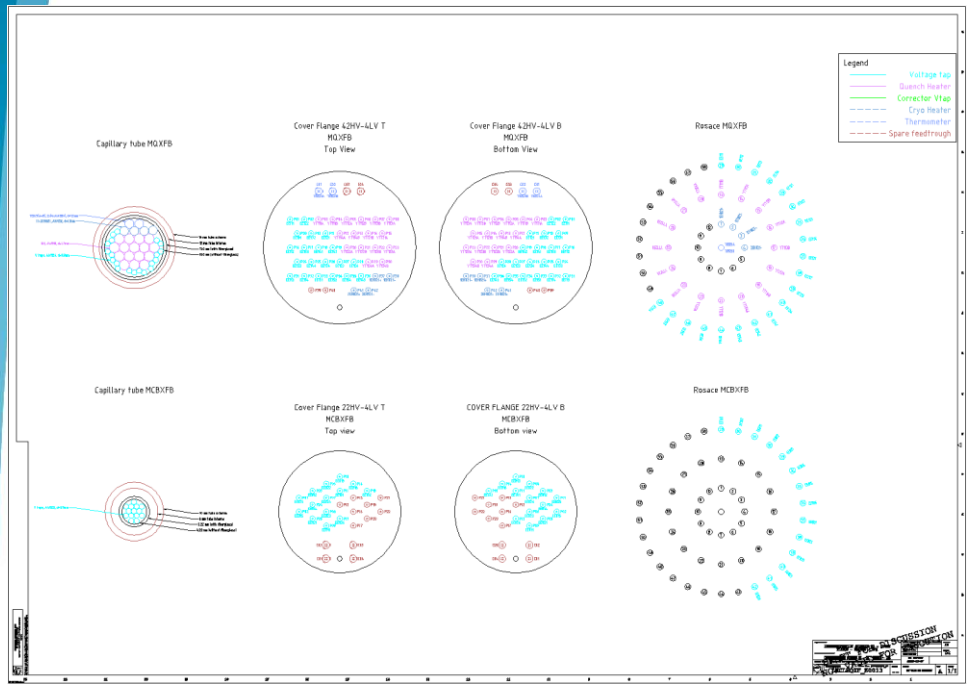
  - Q1/Q3 cold masses: LHCLMQXF_E0015
  - Q2 cold masses: LHCLMQXF_E0008
  - CP cold masses: LHCLMCXFE0001
  - D1 cold masses: LHCLMBXF0023&24

- For Matching Sections: LHCLSDIM0001&LHCLMBRDE0001



  - D2 cold masses: LHCLBRDE0001
  - Q4 cold masses/MQY: LHCLMQ_Z0154
  - Q4 cold masses/MCBYs: LHCLMQ_Z0152
  - Q5 cold masses/MQM: LHCLMQ_Z0127
  - Q5 cold masses/MCBC: LHCLMQ_Z0153

HL-LHC Cold masses Instrumentation Schemes
IFS Capillary, Barrel and Cover Flange Layout

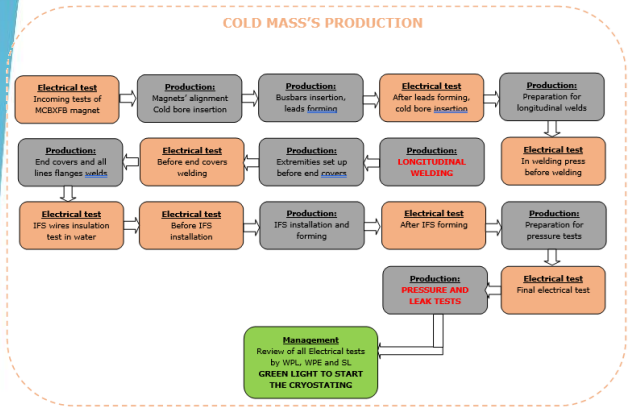


- *Q1/Q3: LHCLMQXF_E0011*
- *Q2: LHCLMQXF_E0013*
- *CP: LHCLMCXFE007*
- *D1: LHCLMBXFE0031*
- *D2: LHCLMBRDE0001*

Documentation of magnet instrumentation
Electrical Tests Report Templates

Flowchart of the electrical tests throughout the production

2.3 Electrical tests during cold mass's production



- Q2: LHC-LMQXFBE-FP-0001 (edms 2447487)
- CP: LHC-LMCXFE-FP-0005 (edms 2680542)
- D2: LHC-LMBRDE-FP-0005 (edms 2642966)
- D1: on-going developments

3.2.4 Electrical test before end covers welding

This electrical test is carried out before end covers welding once the cold mass extremities are set up.

Objet	COLD MASS (LMQXFB)		
When	Before end covers welding		
Template	LHC-LMQXFB-FP-0010		
Measurement	**TBD**	**what**	**Comments**
Resistance	Yes	• Magnet MQXFB • Magnet MCBXFB • Vtaps • Cliq cable • QH • Thermometer • Cryogenic heater	
Inductance	Yes	• Magnet MQXFB • Magnet MCBXFB V, H	1, 10, 100, 1k, 10k (Hz) (sweeping)
Capacitance	Yes	• Magnet MQXFB/All • Magnet MCBXFB V, H, V&H/All • Each QH in final configuration/All	100, 1k, 10k (Hz) (sweeping)
Discharge	Yes	• Magnet MQXFB	1000V then 2500V finally 2nd time 1000V
Insulation [GΩ] (magnet MCBXFB)	Yes	• Magnet MCBXFB, V /All • Magnet MCBXFB, H /All	200V
Insulation [GΩ] (magnet MQXFB)	Yes	• Magnet MQXFB/All • QHs/All • Cold bore/All • Not connected bus bar/All	500V (this test is performed twice, firstly, before all leak tests then after all leak tests to ensure they did not damage the coil)
Leak current [µA]	Yes	• Cold bore/All • Magnet MQXFB/All • QHs/All • Not connected bus bar/All	2000V 2000V then 3700V

BACK TO FLOWCHART

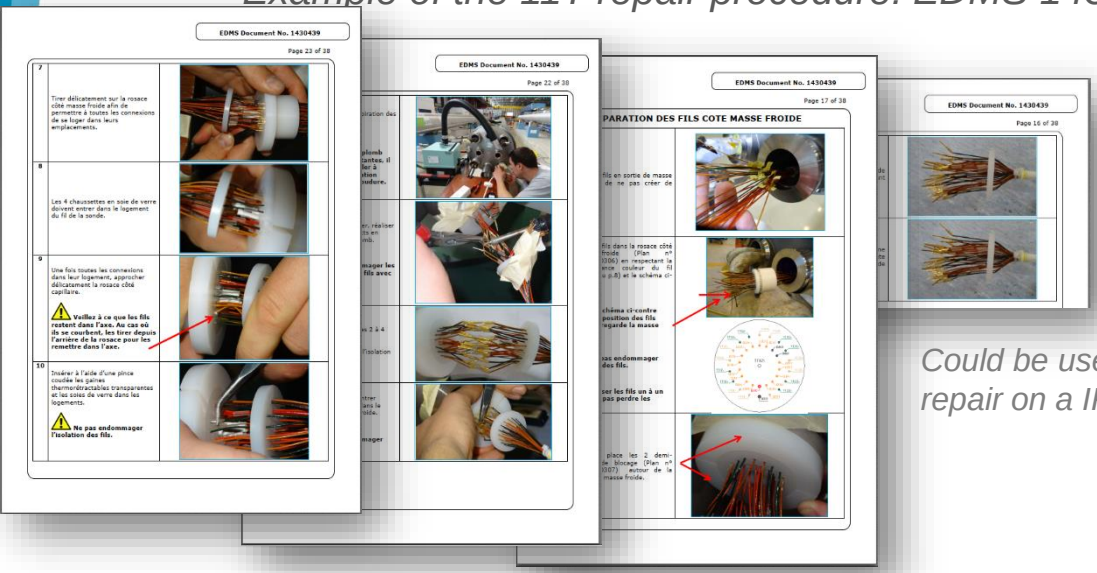
Summary

- Instrumentation layout was well defined with the different stakeholders:
  - WP7 to define V-tap quantities and distribution for magnet protection,
  - WP9 for the cryo-heater and temperature sensor locations, considering the magnets inertia and radiation protection issues,
  - EN-MME for mechanical and CRG for pressure sensors.
- Axon wires qualified during LHC fabrication are reused for HL-LHC and are stored as standard components in the CERN stores.
- Connection procedures are derived from LHC production except for the quench heaters.
- Assembly, validation and test procedures are well documented in edms, CDD and now PLM. New procedures were developed to qualify wire insulation before and after insertion inside the capillary tube.

Spare slides

Repair procedure

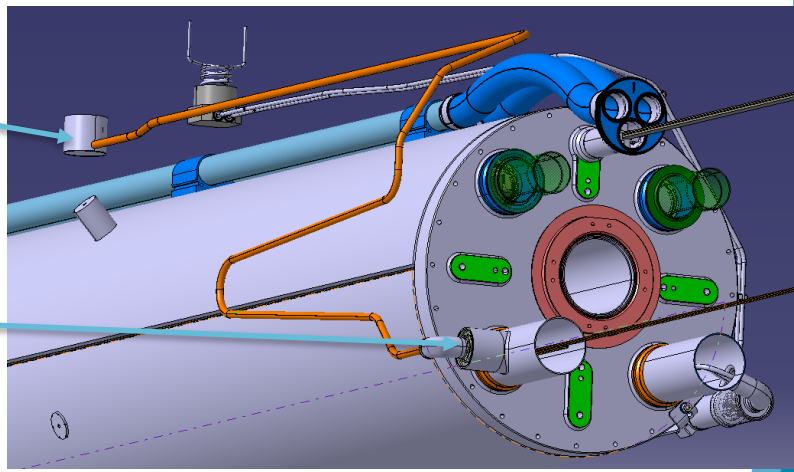
Example of the 11T repair procedure: EDMS 1430439



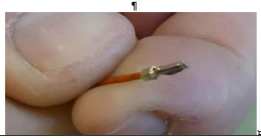
Could be used as baseline for any repair on a IFS capillary.

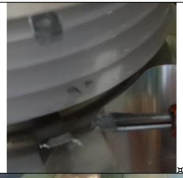
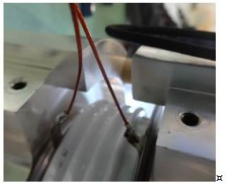
*As the wires are theoretically fixed within the **IFS capillary** the excess wires after the exit from the warm head alleviate any stress placed on the soldered joints to the cover flange feedthroughs.*

Same applies on the other side from the cold head to the pins connected along the leads, the quench heaters, the cryo heaters or the temperature sensors.

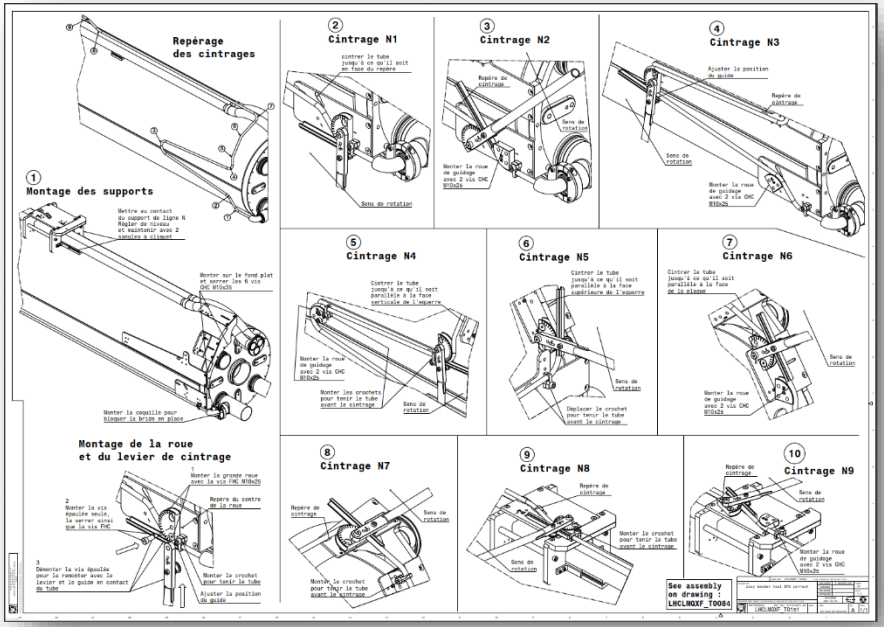


Diode V-taps connection

11	Sertir sur les 2 fils les pins BERG avec la pince à serir FCI. **Ne pas endommager l'isolation des fils.** Réaliser un autocontrôle des sertissages (tenue mécanique, pas de brin cassé, isolation du fil...). **Renseigner l'étape d'autocontrôle du sertissage (Fiche de suivi [8]).**	 
12	Couper les extrémités des pins Berg à la pince coupante. **Ne pas endommager l'isolation des fils.**	 

13	Enduire les contacts de la diode et les pins avec du Mob39. **Port de gants Nitrile obligatoire.**	
14	Etamer les contacts de la diode et les pins avec de l'étain / Argent (Ag4/Sn96). **Port de gants Nitrile obligatoire.**	 
15	Braser les pins sur les 2 contacts de la diode. **Port de gants Nitrile obligatoire.** Réaliser un autocontrôle des brasages (pas de surchauffe, collage...). **Renseigner l'autocontrôle de brasage des fils Vtaps (Fiche de suivi [8]).**	

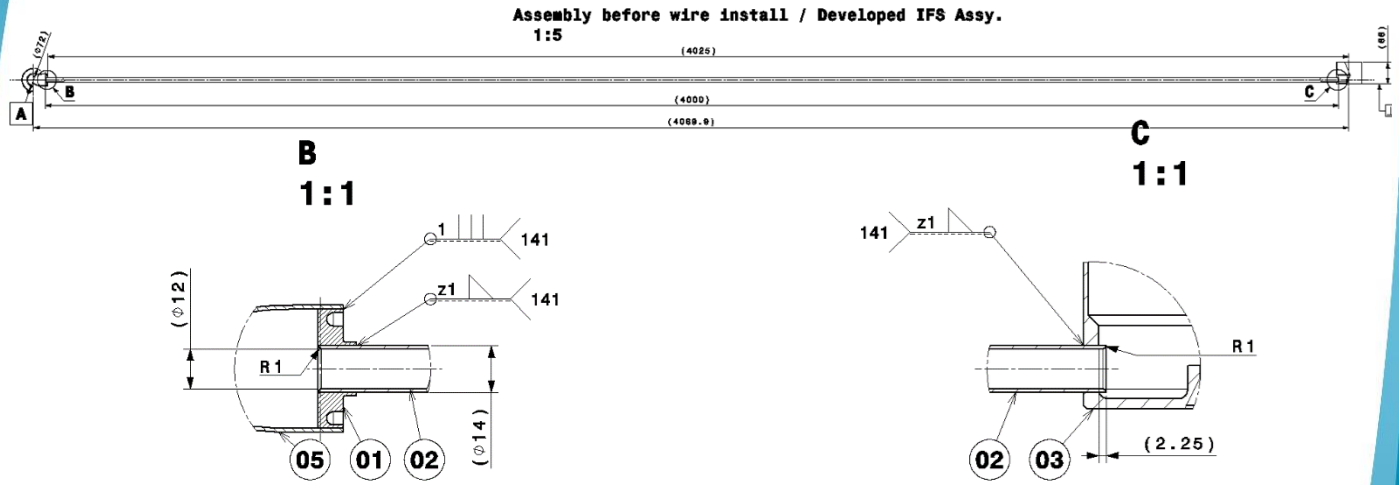
Forming sequence and procedure



LHCLMQXF_T0151

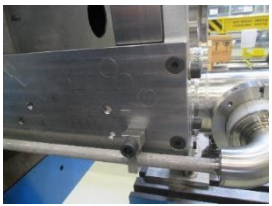
Written procedure will follow

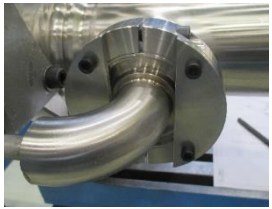
Capillary preparation



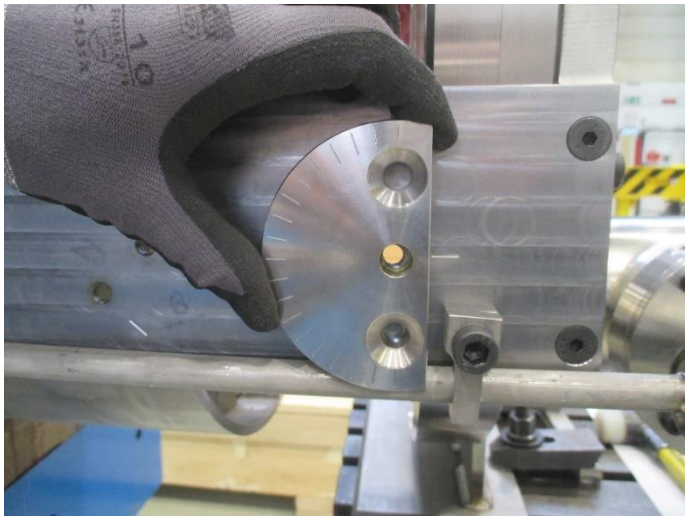
Internal face chamfered and surface dressed to remove sharp edges
Care to be taken when welding to prevent penetration and therefore reduction of the internal diameter of the tube (inspection conducted with an endoscope).
Previously reaming was required post welding.

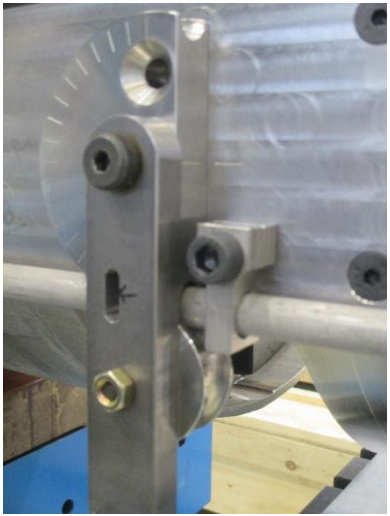
Prepared capillary installation



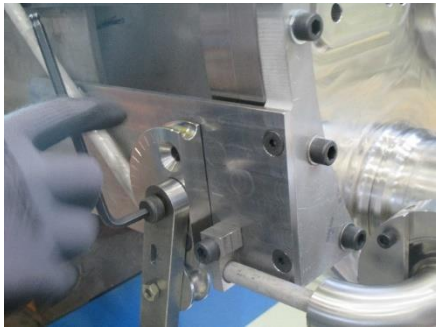


Bending shapes installation

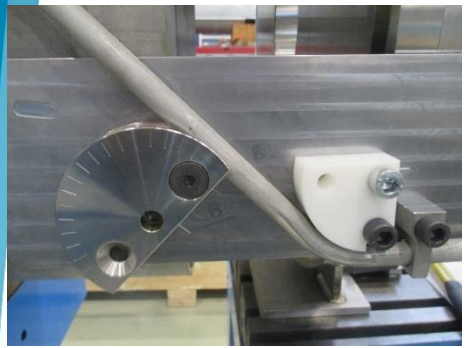
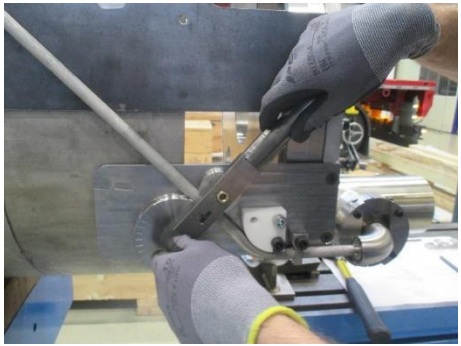


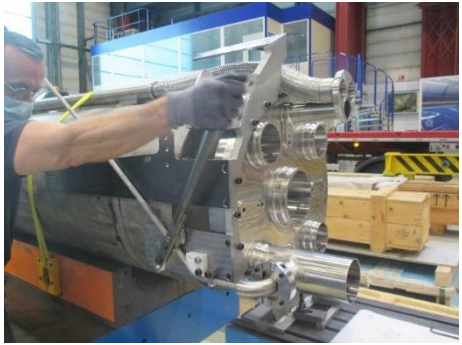
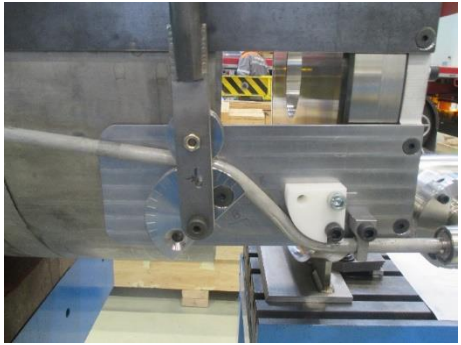


Bending



Bending

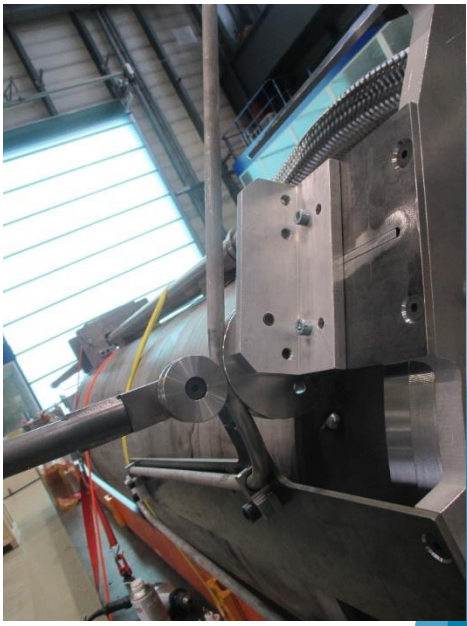

Bending



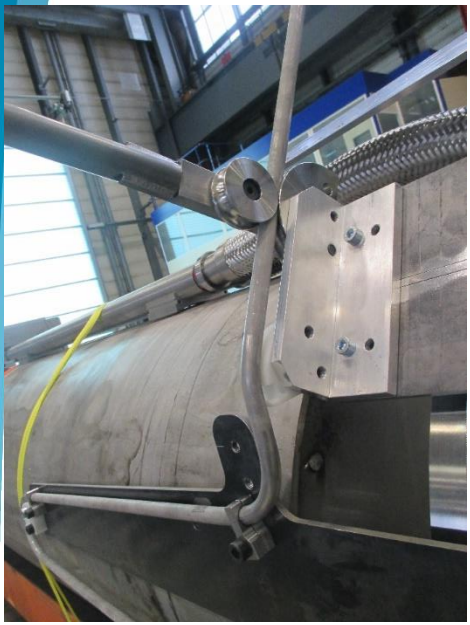



Bending

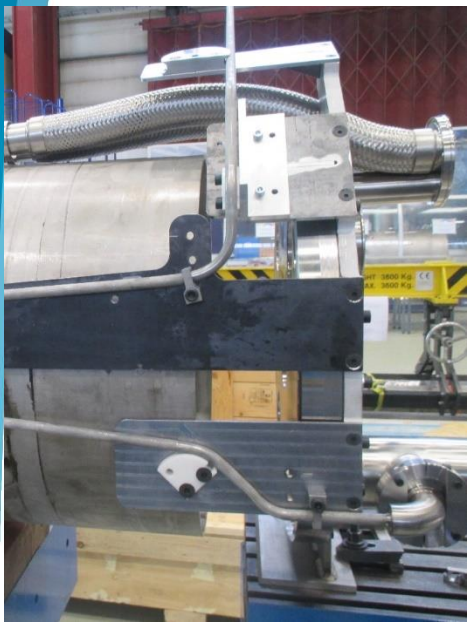
Bending



Bending

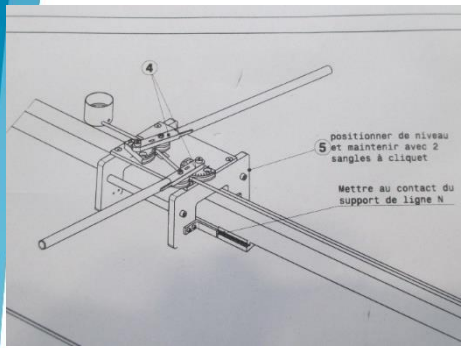


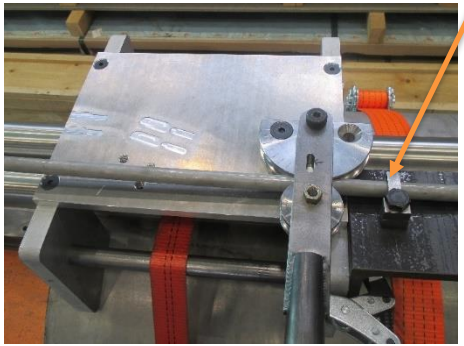
Bending

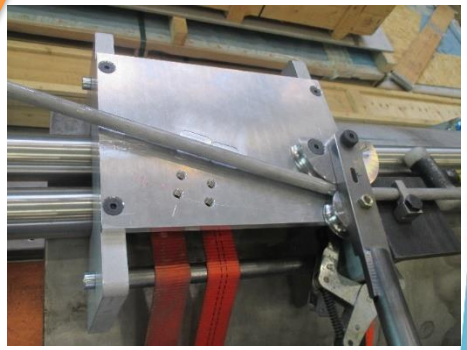


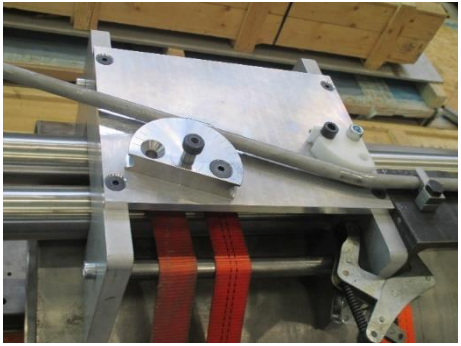
To be reinforced

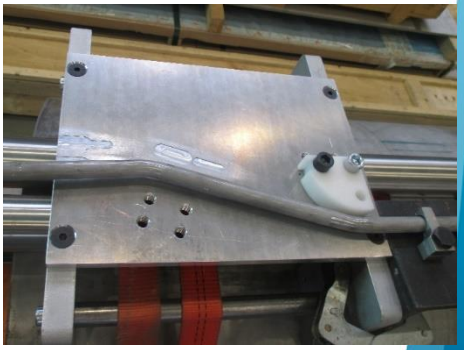
Bending


4
5
positionner de niveau et maintenir avec 2 sangles à cliquet
Mettre au contact du support de ligne N


Stiffening to be enhanced

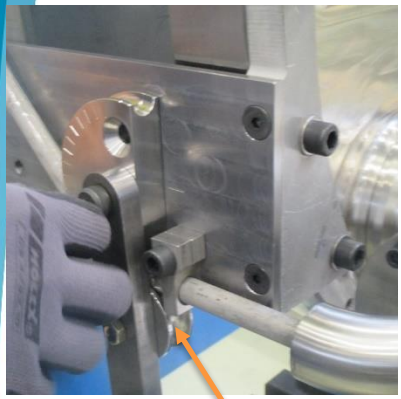


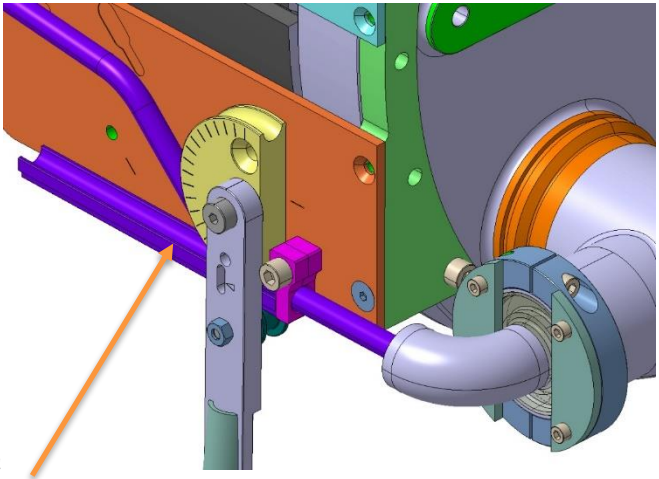


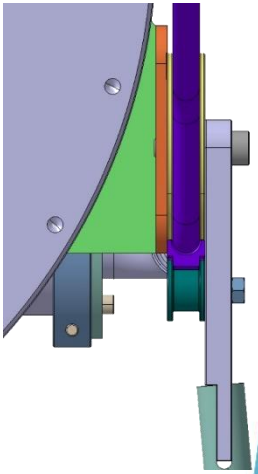


Lubrification while forming

On going improvements

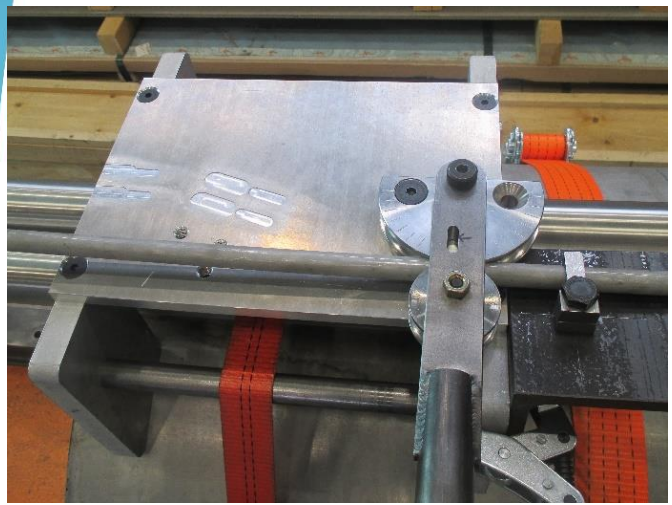


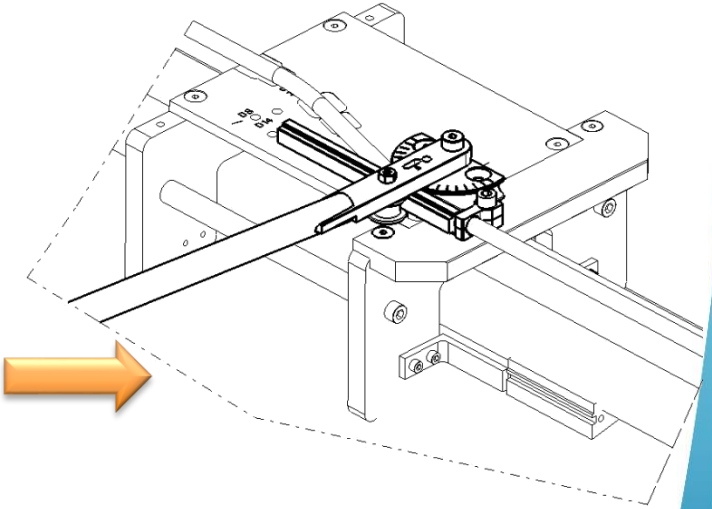




Forming wheel exchanged for a die a pusher wheel

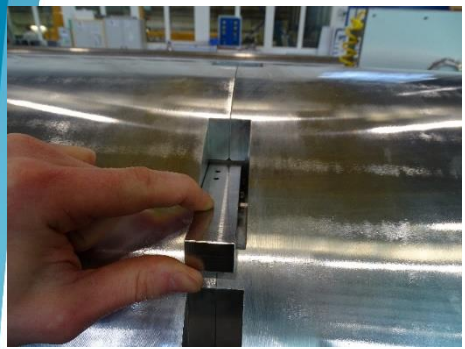
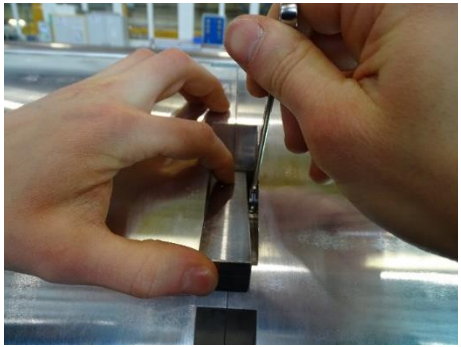
Capillary holding piece on top

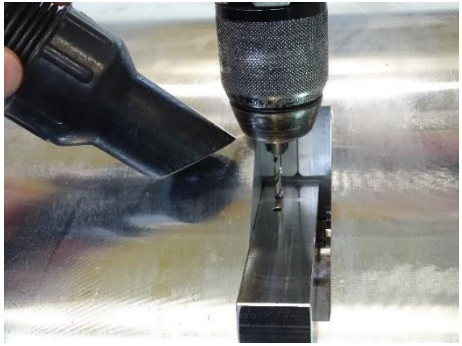
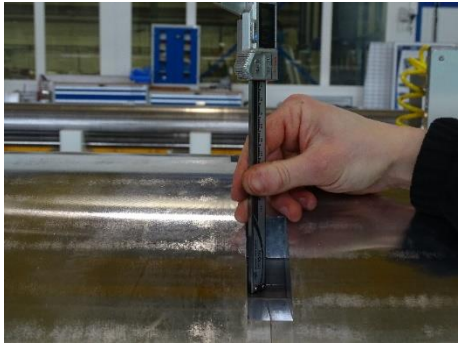
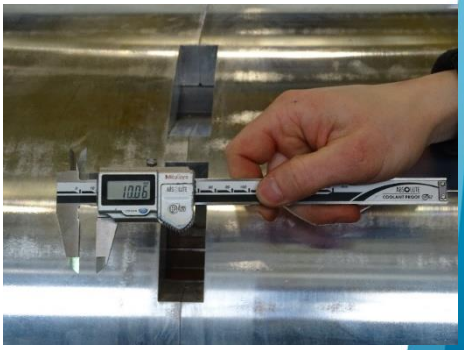




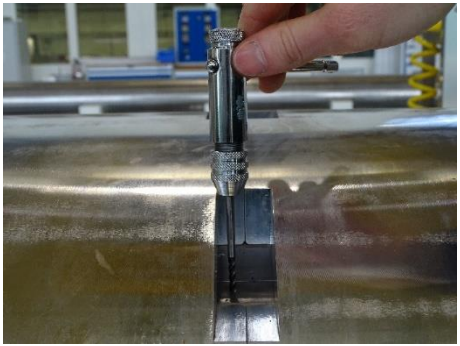
Tooling

Drilling the Ø2.6mm holes

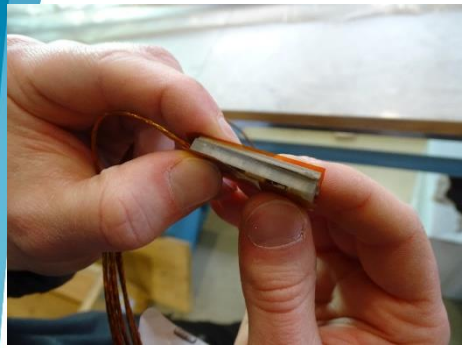



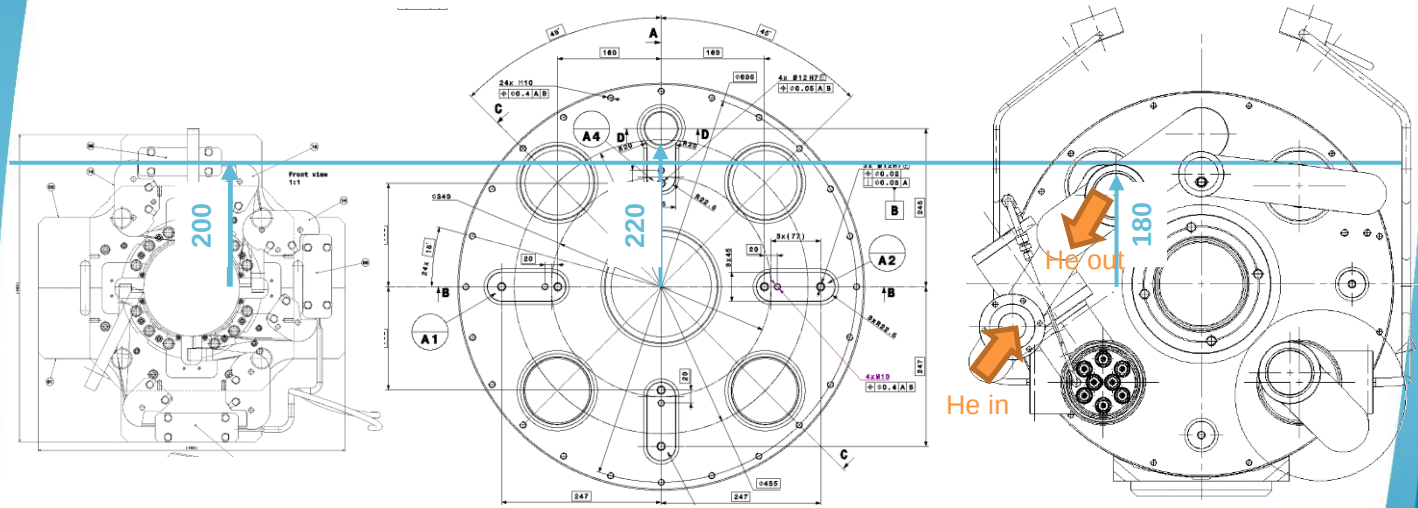
Taping M3

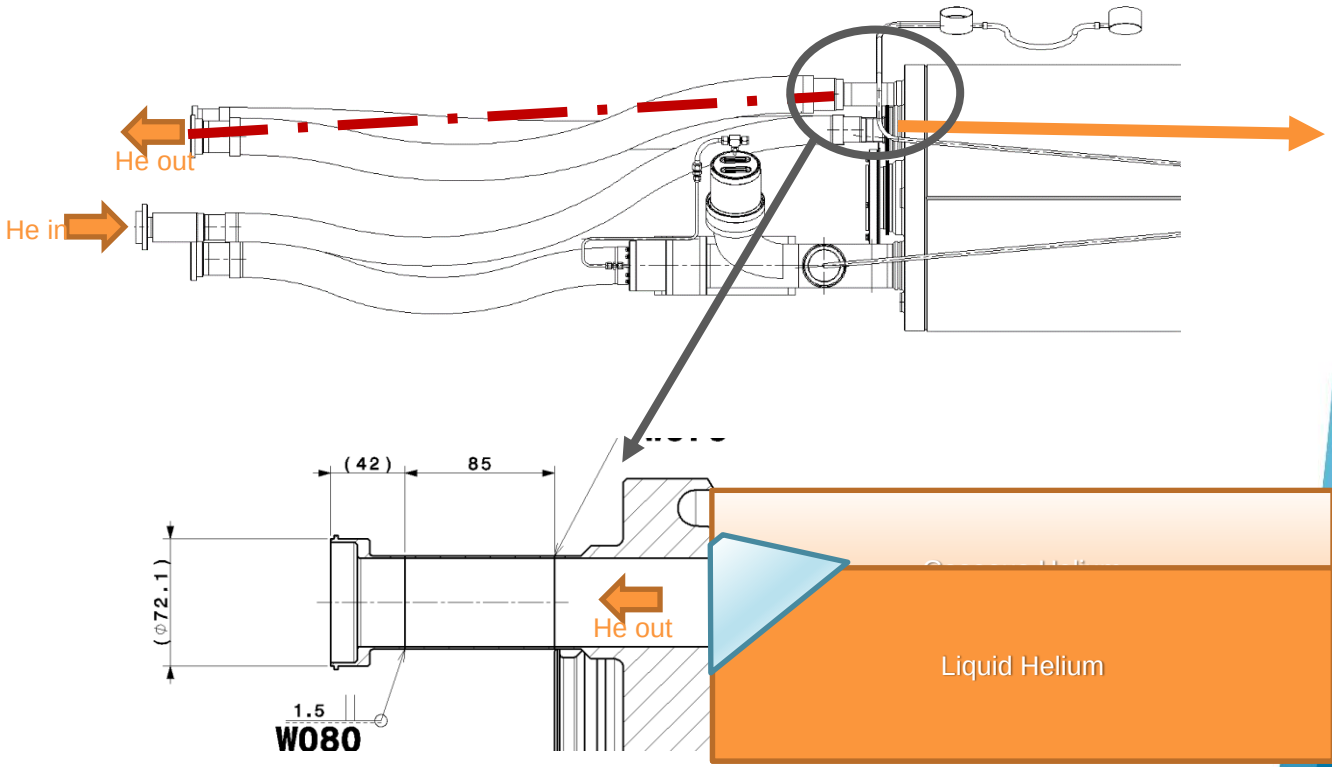


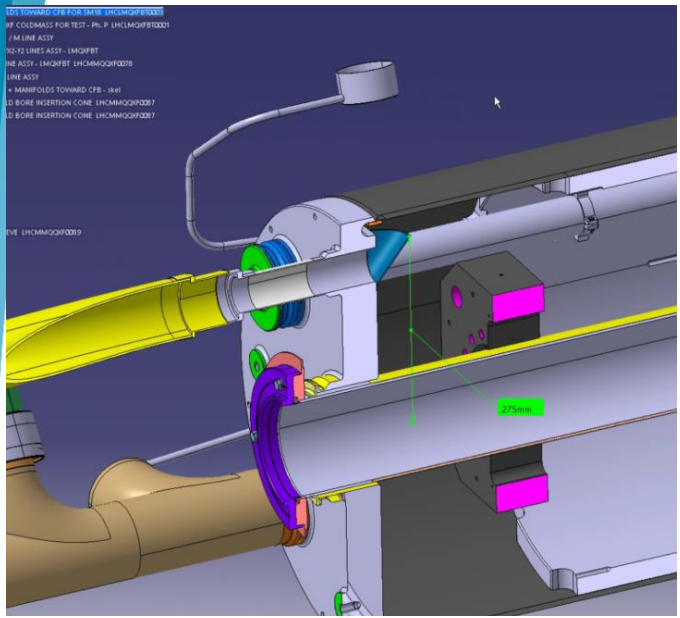
T sensor fixation

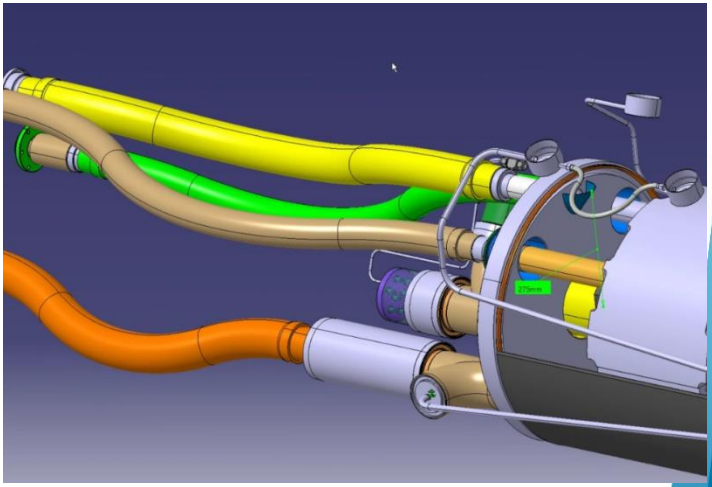


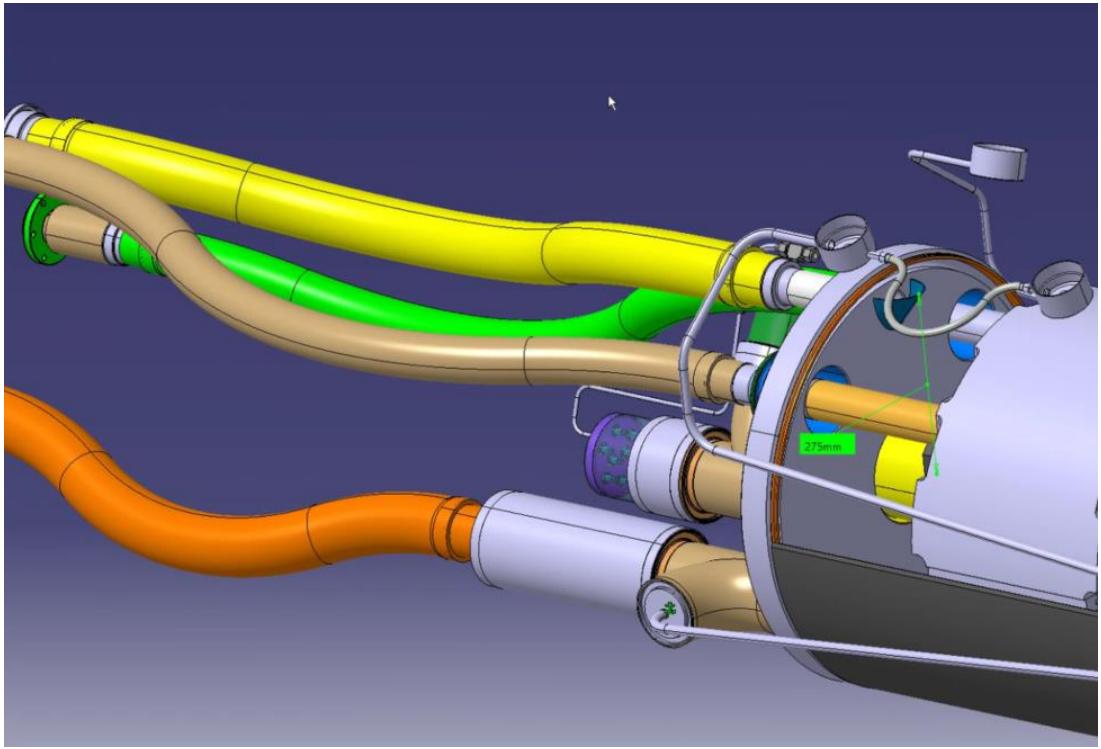


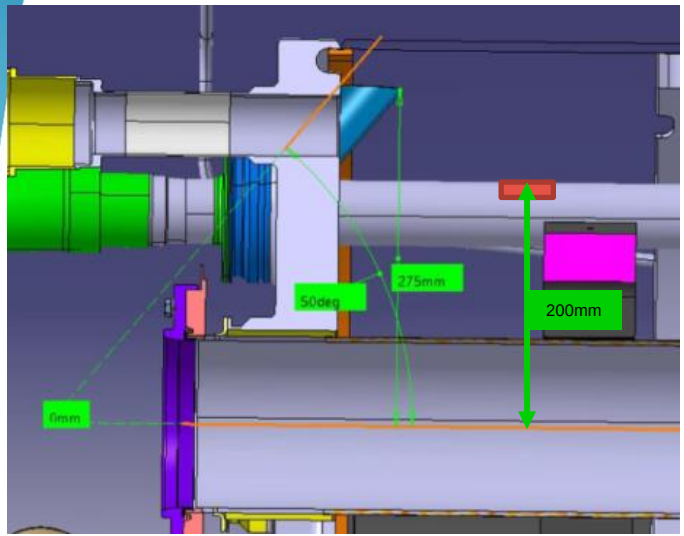

200
220
180
He out
He in

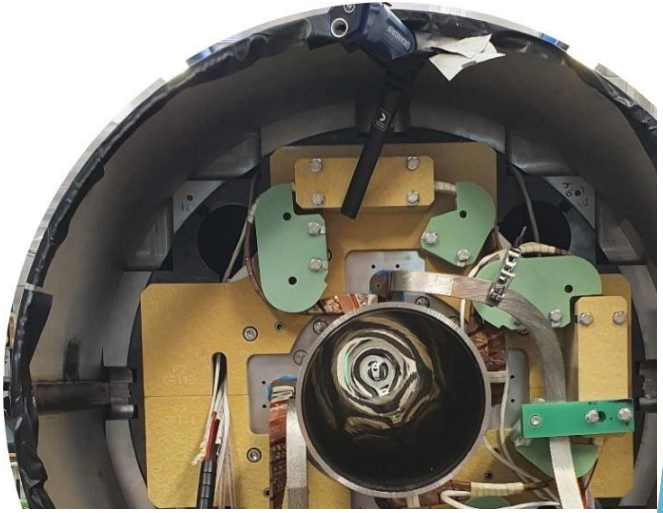

He out
He in
(42)
85
(φ72.1)
He out
1.5
W080
Liquid Helium


275mm




275mm





Minimum level height towards magnet axis: 200mm + Z_1
Maximum level height towards magnet axis: 275mm – Z_2

Integration in the tunnel with WP15

https://indico.cern.ch/event/1031564/

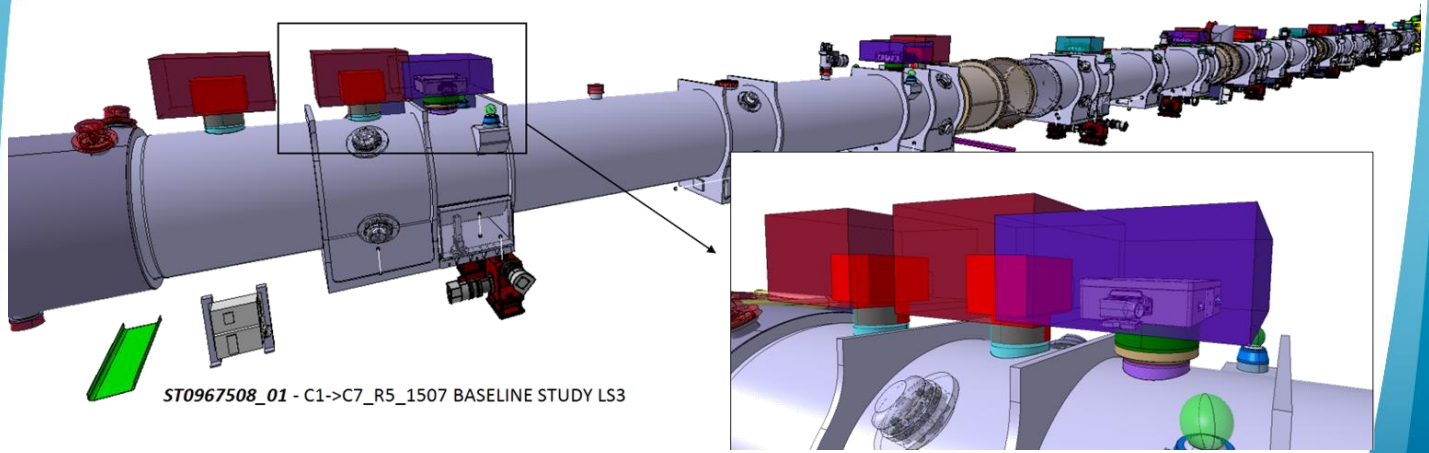
Recent updates: INTEGRATION MODELS

Maquettes d'integration:
- Juste la machine HL-LHC : ***ST0967508_01*** - C1->C7_R5_1507 BASELINE STUDY LS3
- Machine + tunnels + tous les services (maquette lourde, je vous conseille d'ouvrir en Preview):
ST0966906_01 - HL_IP5_R_1506_INTEGE. LS3

Orientation des boites à vérifier avec vous. Pour l'instant, j'ai toujours mis les connecteurs « principaux » côté passage/ côté QRL, et le pitch tube toujours orienté en axe faisceau.

Position of each box according to LHCQBAIS0127 drawing

(provided by T. Sahner)



ST0967508_01 - C1->C7_R5_1507 BASELINE STUDY LS3