9. Magnet protection:
components between magnet and electronics

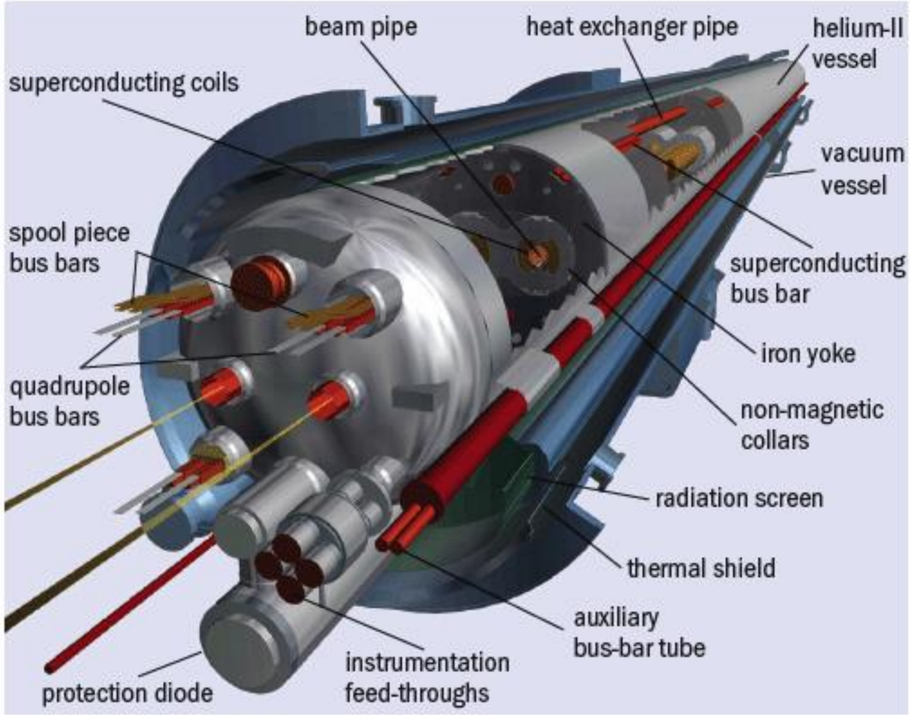
- ➔ Introduction
- ➔ Magnets Voltage taps
- ➔ Instrumentation Feedthroughs System
- ➔ Cables for quench detection
- ➔ Grounding concept for the magnet circuits

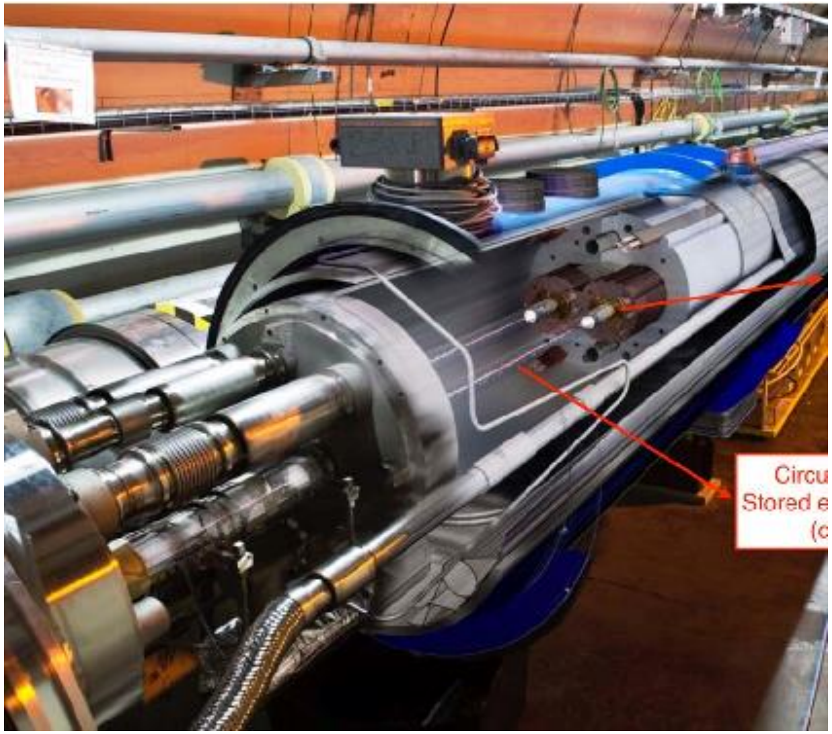
Introduction

- For the LHC, each cryomagnet assembly is made of a **main magnet** and several small **corrector magnets**.
- Each assembly is equipped with **quench heaters** and **voltage taps** for magnet **protection**, and some others voltage tap for **diagnostic**.
- Those cryomagnets are also equipped with **thermometers** and **cryoheaters** for diagnostic and control.
- Most of the cryomagnet also have a protection **by-pass diode** itself equipped with diagnostic **leads** and **voltage tap**.
- All the wires that connect these instruments are routed from the **cold mass** (operating at cryogenic temperature) to the **ambient environment** through an instrumentation feedthrough.
- The number of instrumentation wires serving each magnet assembly and passing from cold to ambient is between **36** and **40**.
- The connection between cryomagnet components and electronic devices is then assured through dedicated cables and connectors.

Introduction

LHC cryodipole cross-section

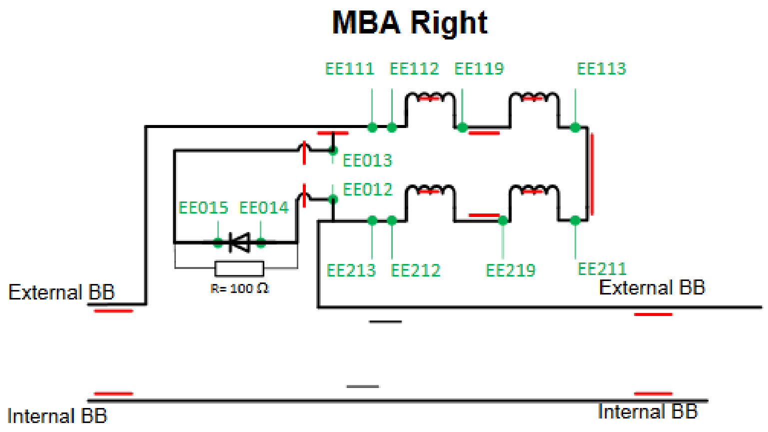




Magnet voltage taps

Redundancy:

- The voltage taps used for **protection** of the magnet are usually doubled (redundant). The one used for diagnostics are not.
- For redundant voltage tap, ideally they should be attached to the superconducting coil in a slightly different position (few cm)
- If critical joints are part of the magnet itself or part of the circuit, it is recommended to have voltage taps on each side of the junction.
- Schematic of LHC dipole v-taps:


MBA Right

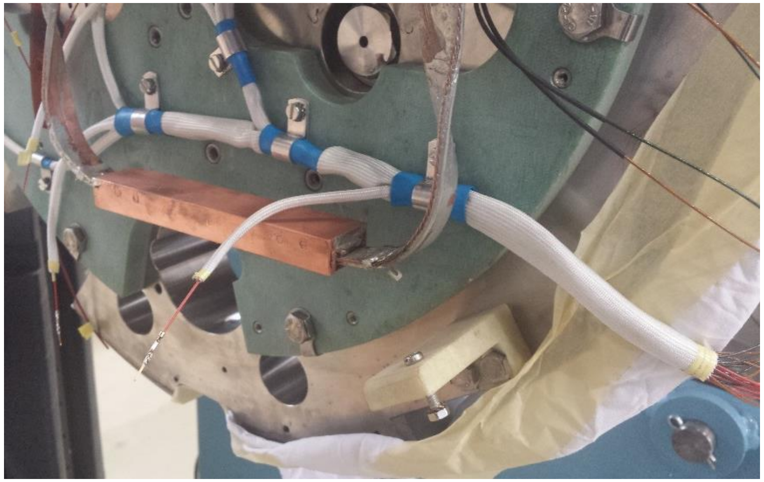
Bridge between Vtap EE025 (D21-C4) and Itap EE023 (D21-B2)
G. D'Angelo (29.10.2014)

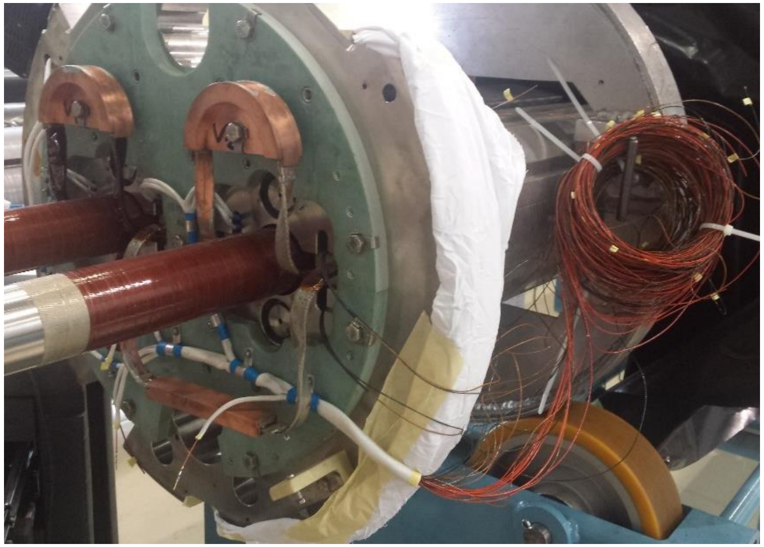
- In case of loss of a voltage tap, one could use a redundant V-tap, re-routed in warm part, into an interface box.

Magnet voltage taps

Contact fixation at superconductor:

- On the superconducting cable, the voltage tap is terminated by a **lug soldered** onto the superconducting cable.
- On the copper stabilisation and bus bars: they are made of different types of lug, depending whether it is a voltage or a current tap, **screwed** into the **copper**.
- The solder recommended is Sn 96.5 % - Ag 3.5 %.
- All the wires have their final length (6 m. for the main LHC dipoles)➔ **better reliability**!
- The voltage tap section is 0.155 mm2, copper, with polyimide insulator (high voltage class). The outer diameter is 1 mm.
- The voltage tap cables are stripped and their insulation is reinforced by an individual glass-cloth tube until they are grouped with others. After having soldered all these wires, the connections are insulated with the same type of insulation as the superconducting cables or bus bars.

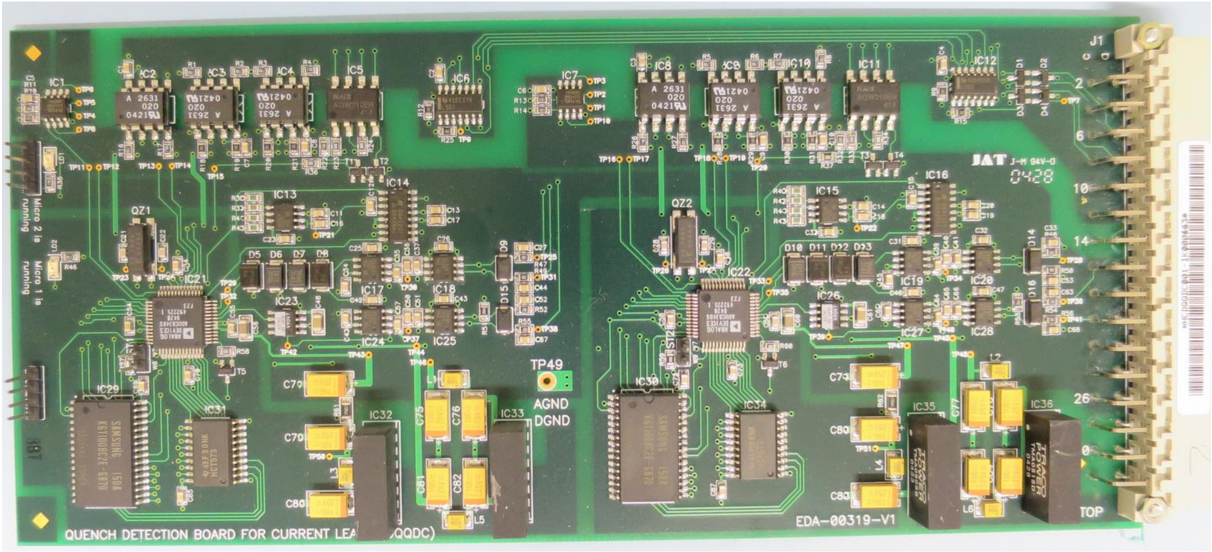


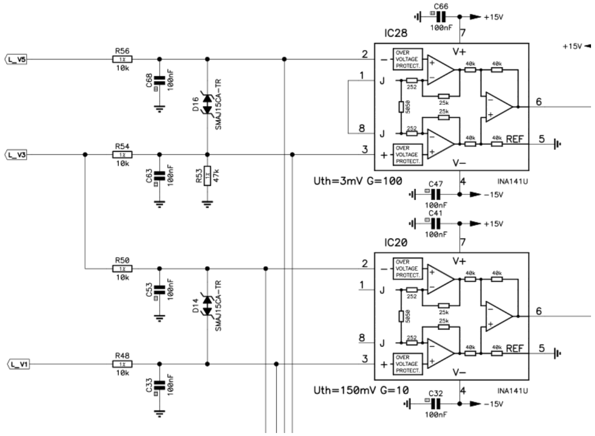


Magnet voltage taps

Voltage taps securing (current limiter):

- The magnet voltage taps and the current lead voltage taps are **without protective resistor** (except D1 to D4 magnets from Berkeley National Laboratory).
- The voltage taps are secured via the input stage of their electronics that may have a resistor that serves as a fuse in case of overcurrent.
- The advantage of having the protective device in the warm part, outside the cryostat, in the electronics would ease the intervention in case of failure

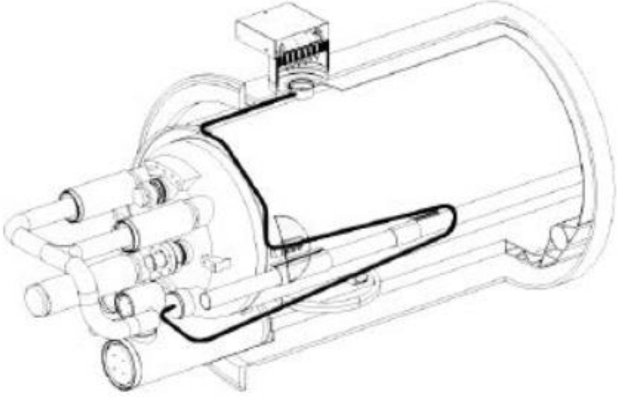




Instrumentation Feedthrough System

Definition of the IFS:

- For the LHC, each cryo-magnet assembly is made of the main magnet and several small corrector magnets. Each assembly is equipped with **voltage taps**, **quench heaters** and **cryogenic instrumentation**.
- All the wires that connect these instruments are routed from the **cold mass** (operating at cryogenic temperature) to the **ambient environment** through an instrumentation feedthrough.
- The number of instrumentation wires serving each magnet assembly and passing from cold to ambient is between **36** and **40**.
- An Instrumentation Feedthrough System (IFS) will **electrically** and **mechanically** connect the instrument wires to the outside of the **vacuum vessel.**



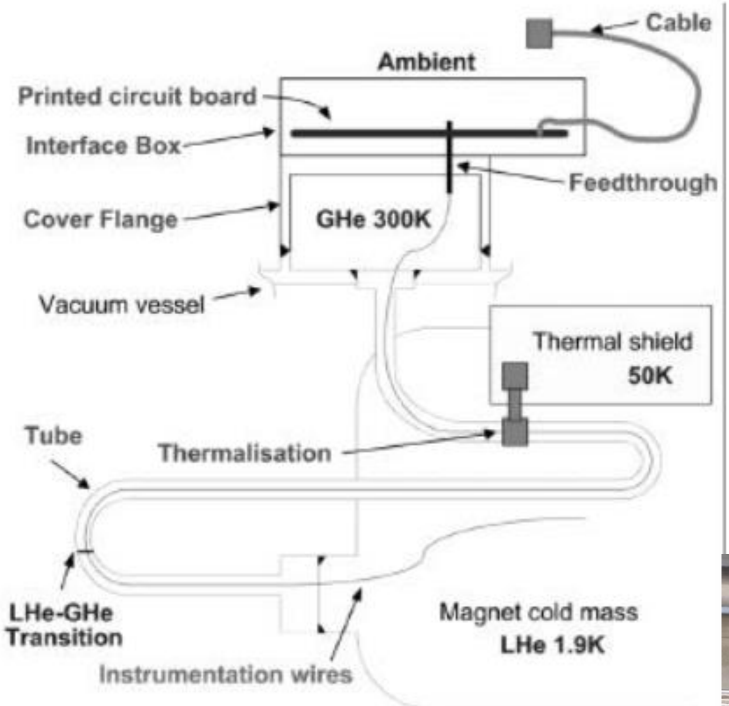
Instrumentation Feedthrough System

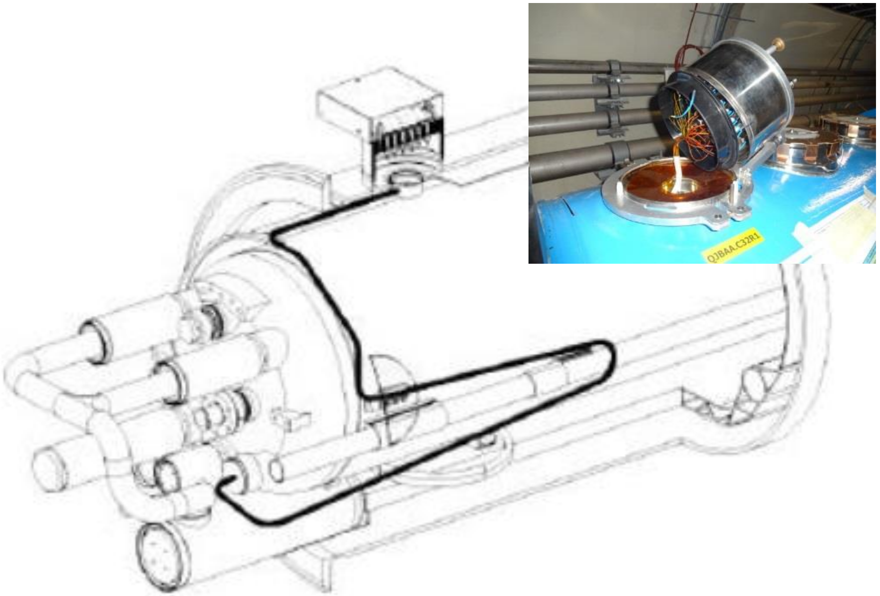
- The IFS has to satisfy several requirements: simplicity of integration, optimal access during tests and commissioning, voltage withstand and reliability during the lifetime of the machine.
- The heat load to superfluid helium must be minimized, and the long-term stability of the insulation vacuum should be preserved.
- The solution adopted has an open stainless steel tube housing the wires connected between the magnet and the outside of the vacuum vessel and terminated by a leak tight connector.

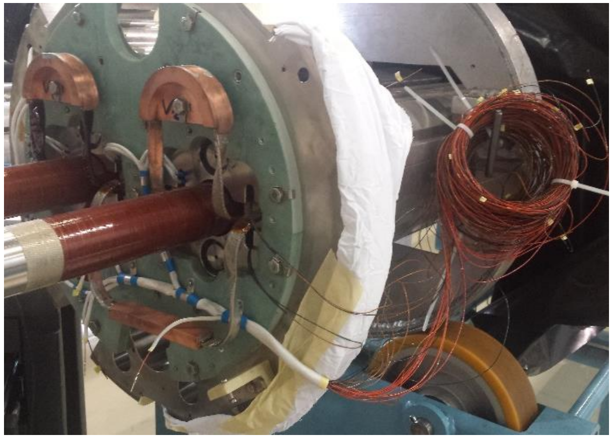
- Let’s see in details the IFS …

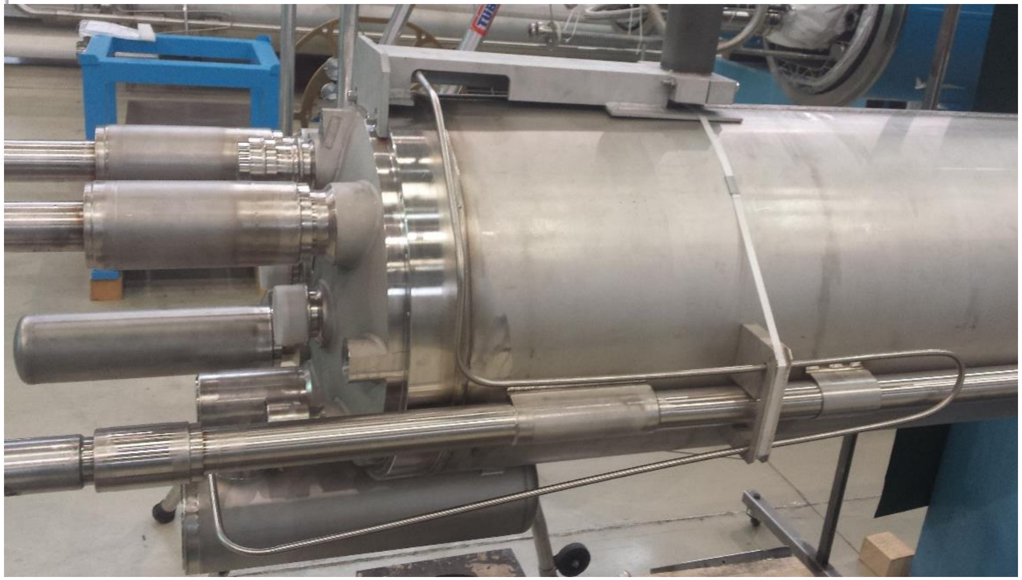
Instrumentation Feedthrough System

Principle and Design:



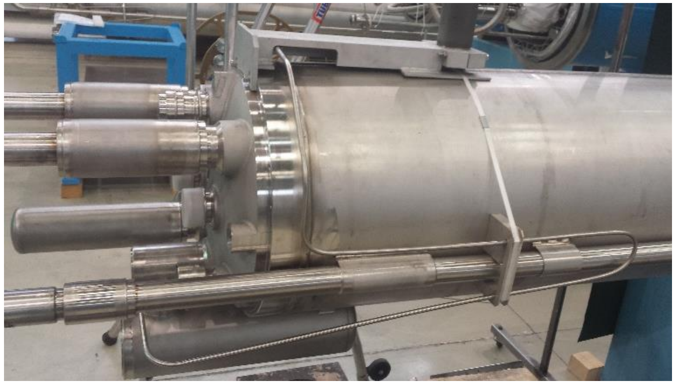


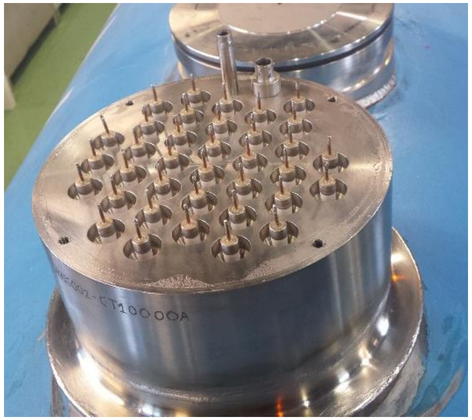


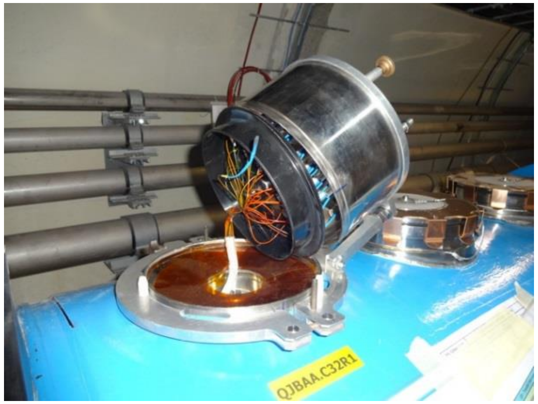


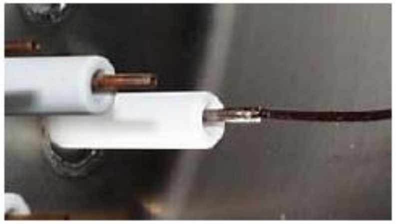
Instrumentation Feedthrough System

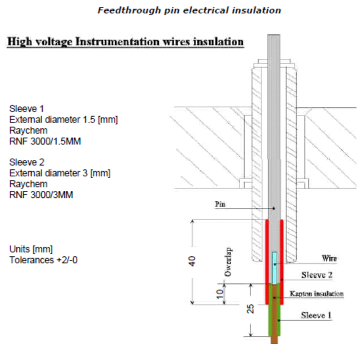
Some detailed view:











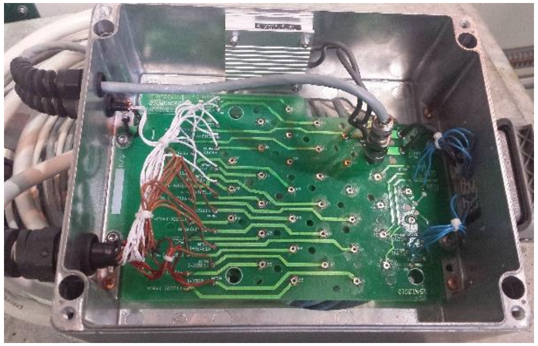
Feedthrough pin electrical insulation

High voltage Instrumentation wires insulation

Sleeve 1
External diameter 1.5 [mm]
Raychem
RNF 3000/1.5MM

Sleeve 2
External diameter 3 [mm]
Raychem
RNF 3000/3MM

Units [mm]
Tolerances +2/-0



Instrumentation Feedthrough System

The IFS has to satisfy several requirements:

- Lifetime:
  - In the baseline, the lifetime was of 20 years. The component used are meant to last even longer then that.
- Voltage withstand:
  - The **maximum voltage** are seen by the wires during **electrical tests**. These voltages are never exceeded during machine operation or failure conditions. The IFS should therefore fulfil higher specifications than the magnet itself.
  - The **worst dielectric** conditions are attained during the **cold tests**, at the warm part of the wires, when the breakdown voltage is decreased by the **presence of gaseous helium**.
  - At identical pressure, the breakdown voltage value in helium is a reduced by a factor of 6-10 as compared to the air: Paschen law. This factor was taken into account in the design of the voltage withstand value: 5 kV in the air
- Radiation hardness:
  - Radiation doses affect the functionality of organic material like the wire insulation, insulating support used to relieve the stress on the connections, and the feedthrough insulation material.
  - For the LHC, calculation of radiation doses for 20 years of operation were done as a function of the distance to the beam axes.
  - For the IFS, the maximum radiation dose was estimated at 14 kGy.

Instrumentation Feedthrough System

- Thermal performance:
  - The IFS has been designed to minimise the thermal load to the superfluid helium bath to which it is connected.
  - The thermal load is determined by the thermal conduction through the electrical conductor, by the free tube section and the ration between free and conductor cross-section. With high filling ratio of the tube, the thermal load is reduced to the one obtained by pure thermal conduction of the wire through the whole length.
  - The optimal situation is to maximize the length of the tube and aim at a filling ratio of the order of 70 %.
  - To limit the heat load at the 1.9 K level, the IFS tube is thermalized to a thermal shield operating around 50 K.
  - Finally, the retained parameters for the tube are a length of **3 m** and an internal diameter of **8 mm**, with **1mm** wall thickness.
  - The heat load of the IFS to the 1.9 K helium bath is of the order of 300 mW while it is about 500 mW to the screen via thermalization.

Instrumentation Feedthrough System

- Vacuum tightness:
  - The components concerned by the vacuum tightness are all the feedthroughs at the interface between the insulation vacuum and outside environment and the cold mass and the insulation vacuum .
  - For the different interfaces, we have the following parameters:

Interfaces	**LHC : Leak rate per feedthrough**
He to insulation vacuum	$< 10^{-11}$ Pa m3/s
Insulation vacuum to air	$< 10^{-9}$ Pa m3/s
He to air	$< 10^{-3}$ Pa m3/s

- Pressure withstand:
  - The component concerned by the pressure withstand is the entire IFS, and in particular its warm feedthrough. The IFS is submitted to the same pressure as the cold mass, to which it is connected.
  - Main pressure withstand parameters for the IFS:

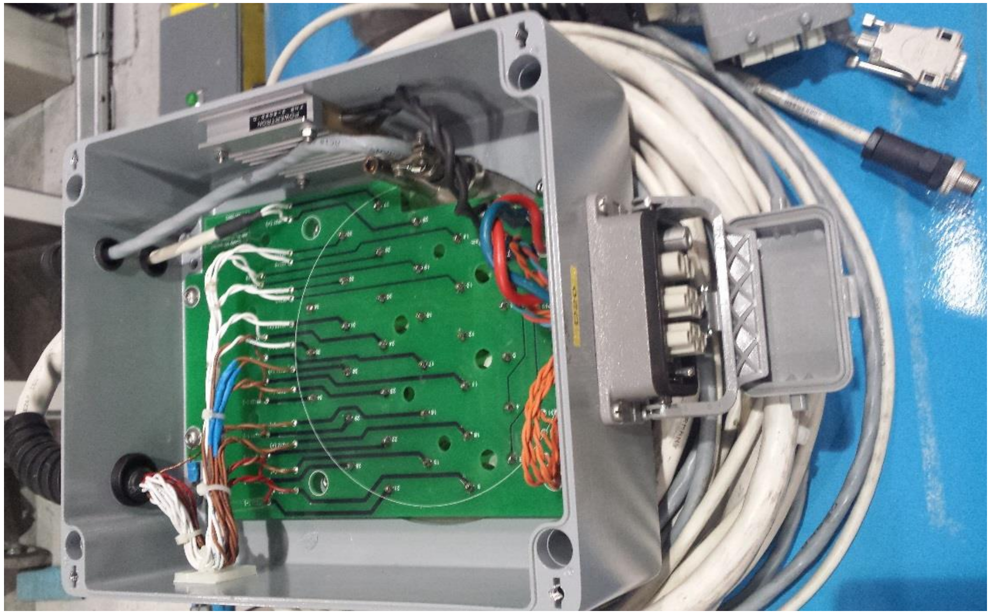
Pressure case	**IFS in the LHC**
Operating pressure	$1.3 * 10^{5}$ Pa
Maximum test pressure	$25 * 10^{5}$ Pa
Maximum rate of pressure rise	10^{7} Pa / s

Summary of the main parameters of the IFS:

Parameter	Limit	Unit
Radiation dose (worst case in interconnections area, about 10cm from beam axes)	14 000	Gy
Operating pressure	$1.3 * 10^5$	Pa
Maximum pressure after a quench	$20 * 10^5$	Pa
Maximum rate of pressure rises after quench	10^7	Pa / s
Maximum pressure test	$25 * 10^5$	Pa
Helium to atmosphere leak tightness	$< 10^{-3}$	Pa * m^3 /s
Insulating vacuum to atmosphere leak tightness	$< 10^{-9}$	Pa * m^3 /s
Helium to Insulating vacuum leak tightness	$< 10^{-11}$	Pa * m^3 /s
Voltage withstand at warm	5000	V
Voltage withstand at cryogenic condition	3100	V

Instrumentation Feedthrough System

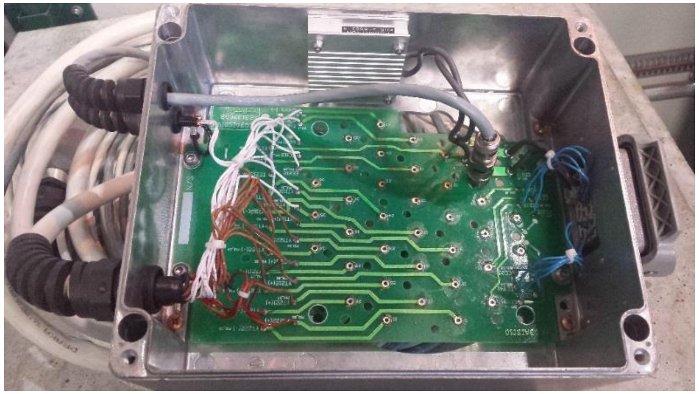
Final product:



Cables for quench detection

Type of cables between IFS and electronics:

- The cables used in the warm part for quench detection is made of multi-strand copper wires, with polyethylene insulation, twisted pairs hold into a copper screen with a polyolephine outer sheath.
- The section of the copper cable is of 0.5 mm2, and the average length of 10 meters (between 7.5 m. and 12 m. depending on the magnet type).
- The shielding the cables is connected at both ends.
- The connectors used are industrial one and robust: mostly “Harting” type HAN for excellent reliability, robustness, diversity and electrical characteristics.
- The shielding of the cables is connected to Ground at each termination to improve EMC .



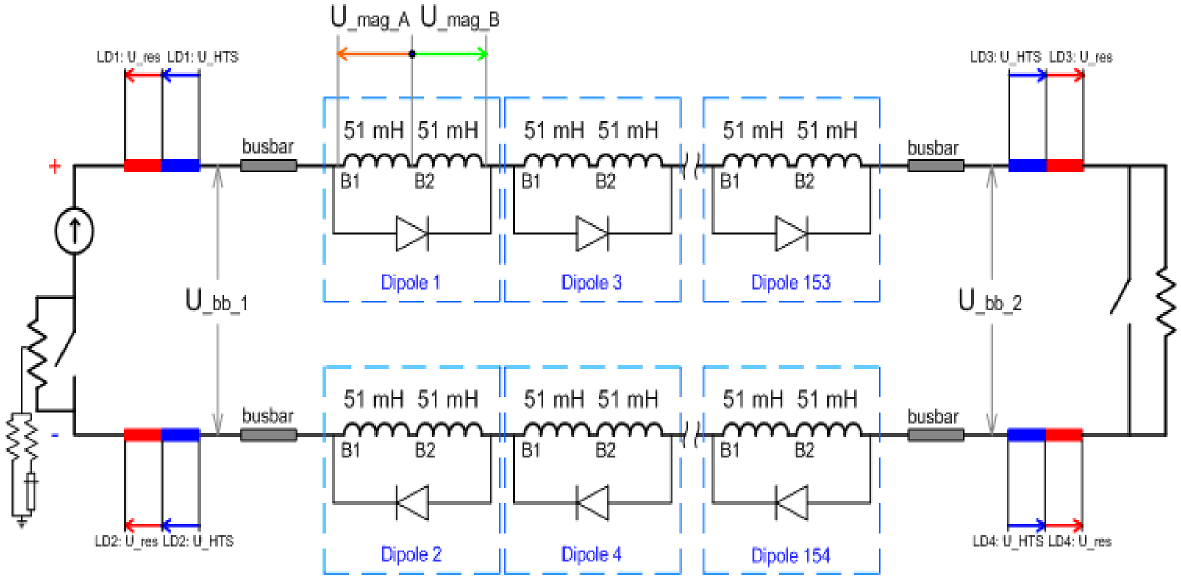
Connectors:
P10: Harting HAN
C10: FCT Electronix/Sub D Canon
C11: Phoenix Contacts

P10, C10, C11 cables,
Length between 7.5 and 12 m.

Grounding concept

Grounding concept for the magnet circuit:

- The superconducting magnets are fed in current by power converters, whose outputs are galvanically insulated from AC side.
- The DC side shall be grounded for safety reasons to limit the output common mode voltage, through an earthing circuit. No current is flowing through this link as long as no other earth path exists.
- The grounding of the circuit is usually done inside the power converter, except for the main dipole where it is done in the energy extraction switch.
- Simplified schematic of the main dipole circuit of the LHC:



Thank you for your attention !