Overview of WP6A electrical requirements and instrumentation

J. Fleiter on behalf of WP6a

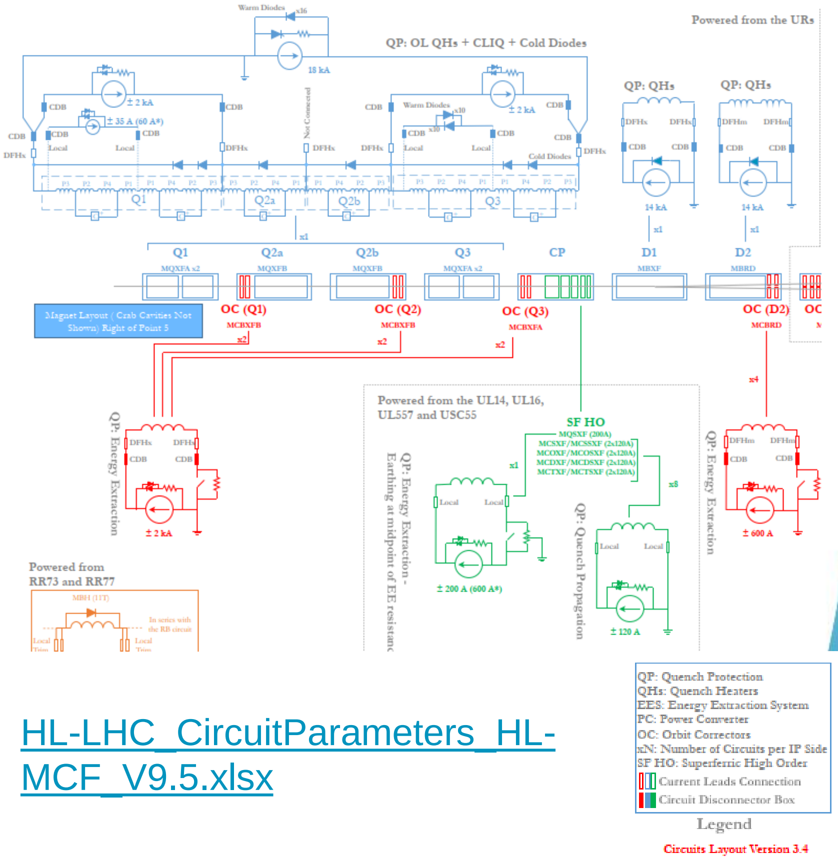
12th Annual HL LHC meeting 19-22 Sept 2022

Outline

- Current rating and dielectric insulation of circuits
- Current leads naming and attribution to circuits
- Current leads heating system
- Instrumentation of WP6a
  - Electric protection of circuits
  - Cryogenic
  - Vacuum
- Instrumentation feedthrough system of SC Link
- Instrumentation splitting modules of SC Link

Current rating of electrical circuits of WP6a

- **Inner triplets (9 circuits)**
  - **MQXF main** 2 x **18 kA**
  - **MQXF trim** 3 x **2 kA** **(3x7 kA AC)**
  - **D1** 2 x **18 kA**
  - **MCBXF** 12 X **2 kA**
- **Matching Section (5 circuits)**
  - **D2** **2 x 18 kA**
  - **MCBRD** **8 x 0.6 kA**



[HL-LHC_CircuitParameters_HL-MCF_V9.5.xlsx]()

Operating temperature of cold powering systems

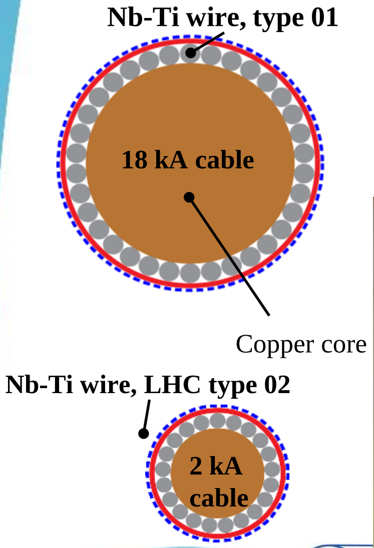
- **Operating temperature**
  - 4.5 K — Nb-Ti bus bars, NbTi/NbTi splices, MgB_2/NbTi splices
  - 4.5 - 17 K — MgB_2 cable (~100 m long)
  - 17 -50 K — HTS cables
  - 50-300 K — Resistive heat exchanger of leads
  - 300 K — Warm terminal of current leads
- **Cooling scheme (LHe or GHe)**
  - DFX => LHe, 4.5 K @ 1-2 bar
  - Sc Link, DFHX and current leads => GHe 5-300 K @ 1-2 bar

Sc cables of cold powering systems

NbTi bus bars

~7 m long

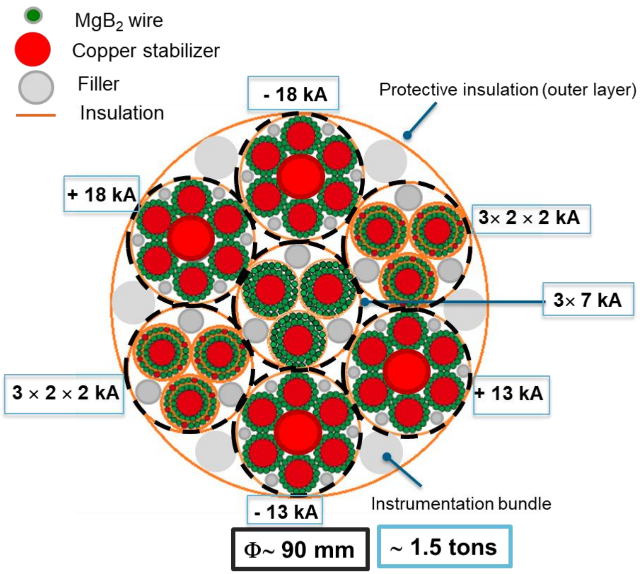
0.825 and 1 mm OD LHC strands



MgB_2 cables

~70-140 m long

1 mm OD strands

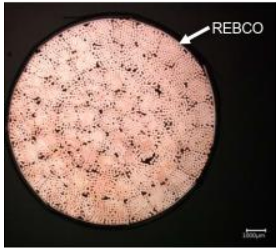


IT MgB_2 cable assembly

HTS cables

~3 m long

REBCO tapes 4 mm x 0.01 mm



3 kA sub cable

Electrical Insulation and transients

- Electrical components (Sc cables, Instrumentation, splices…) designed and produced to fulfill circuit insulation and transient requirements.
- **Dielectric insulation of components tested prior to installation.**

EDMS 1821907

Rating (kA)	Worst case voltage to ground during operation (V)	Acceptance tests of components to ground (V)		Insulation test voltage of system to ground (V)		Leakage current per component (μA)	Test duration (s)
		RT	NOC	RT	NOC		
18	900	4600	2300	460	1080	≤10	30
7	900	4600	2300	460	1080	≤10	30
2	540	3160	1580	316	648	≤10	30

RT → Room Temperature NOC → He gas @ RT, 1 bar

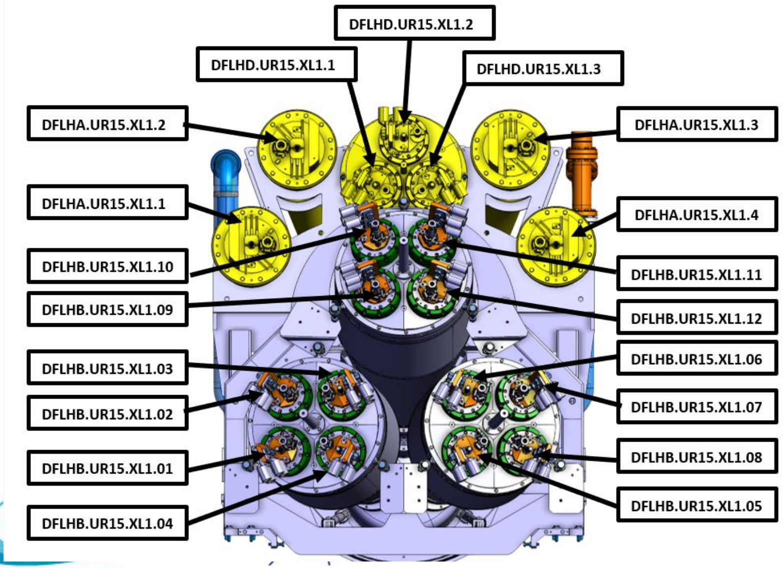
EDMS 1821907

Rating (kA)	MIITs ($MA^2 \cdot s$)	dI/dt (kA/s)	τ_n (no quench of magnets) (s)	τ_Q (quench of magnets) (s)	Equivalent time (s)
18 (*)	32	250	130	0.2	0.1
7	5	250	130	0.2	0.12
2 (**)	1	20	20	0.5	-

Current lead position codes and circuit assignments IT

- **Position codes** and **circuit assignments** defined in EDMS 2450769
- **Naming** follows the general rules for naming of **HL-LHC equipment**

Current lead assignment for Inner Triplets of Point Left 1



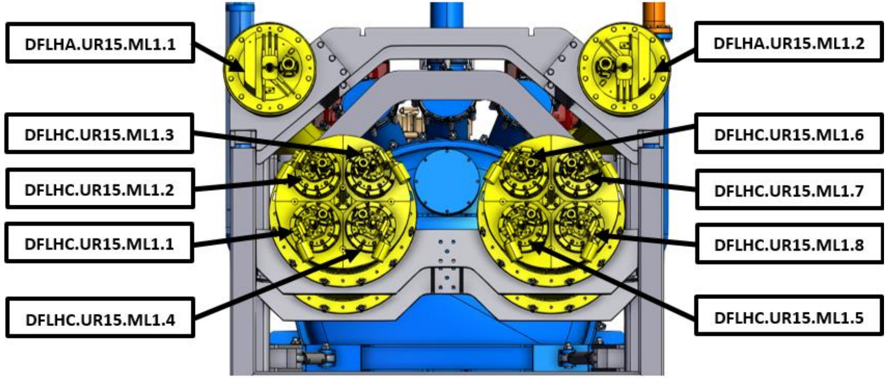
Current lead assignment for Inner Triplets of Point 1

Current lead functional position code	Type	Circuit assignment	Current lead functional position code	Type	Circuit assignment
DFLHA.UR15.XL1.1	A	RQX.L1.NEG	DFLHA.UR15.XR1.1	A	RQX.R1. NEG
DFLHA.UR15.XL1.2	B	RQX.L1.POS	DFLHA.UR15.XR1.2	B	RQX.R1. POS
DFLHA.UR15.XL1.3	B	RD1.L1. NEG	DFLHA.UR15.XR1.3	A	RD1.R1. NEG
DFLHA.UR15.XL1.4	A	RD1.L1. POS	DFLHA.UR15.XR1.4	B	RD1.R1. POS
DFLHD.UR15.XL1.1	B	RTQX1.L1. POS	DFLHD.UR15.XR1.1	B	RTQX1.R1. POS
DFLHD.UR15.XL1.2	NC	Not connected	DFLHD.UR15.XR1.2	NC	Not connected
DFLHD.UR15.XL1.3	A	RTQX3.L1. NEG	DFLHD.UR15.XR1.3	A	RTQX3.R1. NEG
DFLHB.UR15.XL1.01	A	RCBXV1.L1. POS	DFLHB.UR15.XR1.01	A	RCBXV1.R1. NEG
DFLHB.UR15.XL1.02	B	RCBXV1.L1. NEG	DFLHB.UR15.XR1.02	B	RCBXV1.R1. POS
DFLHB.UR15.XL1.03	A	RCBXH1.L1. NEG	DFLHB.UR15.XR1.03	A	RCBXH1.R1. NEG
DFLHB.UR15.XL1.04	B	RCBXH1.L1. POS	DFLHB.UR15.XR1.04	B	RCBXH1.R1. POS
DFLHB.UR15.XL1.05	A	RCBXV2.L1. NEG	DFLHB.UR15.XR1.05	A	RCBXV2.R1. POS
DFLHB.UR15.XL1.06	B	RCBXV2.L1. POS	DFLHB.UR15.XR1.06	B	RCBXV2.R1. NEG
DFLHB.UR15.XL1.07	A	RCBXH2.L1. NEG	DFLHB.UR15.XR1.07	A	RCBXH2.R1. NEG
DFLHB.UR15.XL1.08	B	RCBXH2.L1. POS	DFLHB.UR15.XR1.08	B	RCBXH2.R1. POS
DFLHB.UR15.XL1.09	A	RCBXV3.L1. POS	DFLHB.UR15.XR1.09	A	RCBXV3.R1. NEG
DFLHB.UR15.XL1.10	B	RCBXV3.L1. NEG	DFLHB.UR15.XR1.10	B	RCBXV3.R1. POS
DFLHB.UR15.XL1.11	A	RCBXH3.L1. NEG	DFLHB.UR15.XR1.11	A	RCBXH3.R1. NEG
DFLHB.UR15.XL1.12	B	RCBXH3.L1. POS	DFLHB.UR15.XR1.12	B	RCBXH3.R1. POS

Current lead position codes and circuit assignments MS

- **Position codes** and **circuit assignments** defined in EDMS 2450769
- **Naming** follows the general rules for naming of **HL-LHC equipment**

Current lead assignment for Matching Sections of L1



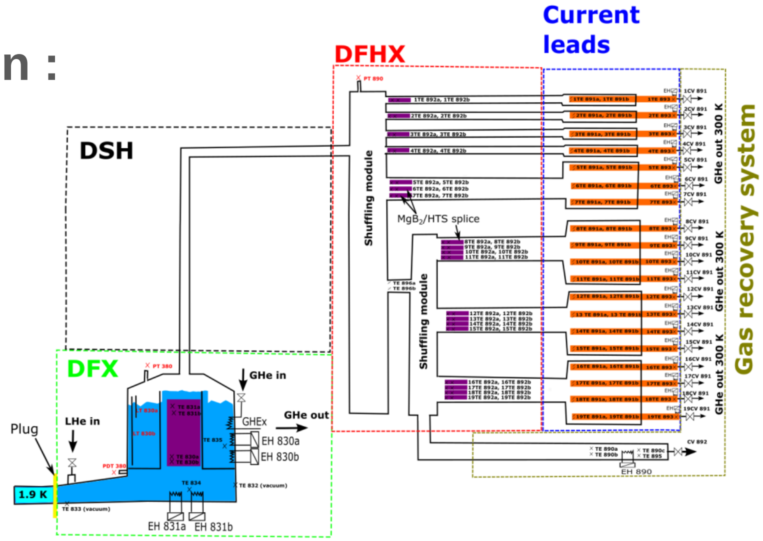
Current lead assignment for Matching Sections of P1

Current lead functional position code	Type	Circuit assignment	Current lead functional position code	Type	Circuit assignment
DFLHA.UR15.ML1.1	A	RD2.L1.NEG	DFLHA.UR15.MR1.1	A	RD2.R1.POS
DFLHA.UR15.ML1.2	B	RD2.L1.POS	DFLHA.UR15.MR1.2	B	RD2.R1.NEG
DFLHC.UR15.ML1.1	A	RCBRDV4.L1B1.POS	DFLHC.UR15.MR1.1	A	RCBRDV4.R1B1.NEG
DFLHC.UR15.ML1.2	B	RCBRDV4.L1B1.NEG	DFLHC.UR15.MR1.2	B	RCBRDV4.R1B1.POS
DFLHC.UR15.ML1.3	A	RCBRDH4.L1B1.NEG	DFLHC.UR15.MR1.3	A	RCBRDH4.R1B1.NEG
DFLHC.UR15.ML1.4	B	RCBRDH4.L1B1.POS	DFLHC.UR15.MR1.4	B	RCBRDH4.R1B1.POS
DFLHC.UR15.ML1.5	A	RCBRDV4.L1B2.POS	DFLHC.UR15.MR1.5	A	RCBRDV4.R1B2.NEG
DFLHC.UR15.ML1.6	B	RCBRDV4.L1B2.NEG	DFLHC.UR15.MR1.6	B	RCBRDV4.R1B2.POS
DFLHC.UR15.ML1.7	A	RCBRDH4.L1B2.POS	DFLHC.UR15.MR1.7	A	RCBRDH4.R1B2.POS
DFLHC.UR15.ML1.8	B	RCBRDH4.L1B2.NEG	DFLHC.UR15.MR1.8	B	RCBRDH4.R1B2.NEG

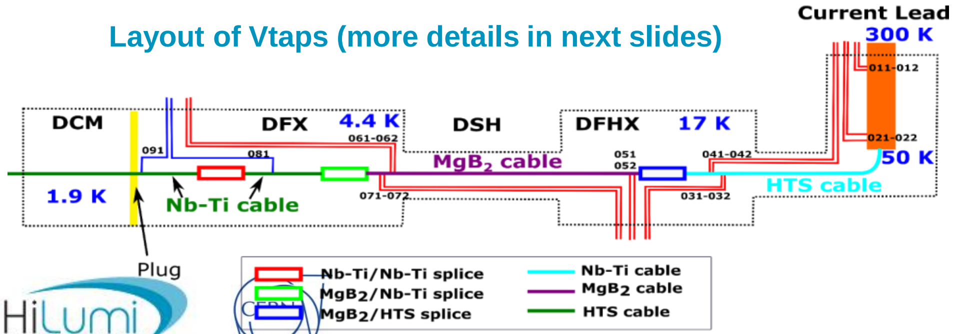
SC Link electrical instrumentation

- Each Sc Link equipped with specific instrumentation for a safe and controlled operation:
  - Electrical protection of circuits
  - Cryogenic control
  - Vacuum control
- Instrumentation of each Sc Link defined in :
  - Matching section EDMS 2512704
  - Inner Triplet EDMS 2591698

Layout of CRG instrumentation (more details in next slides)



Layout of Vtaps (more details in next slides)

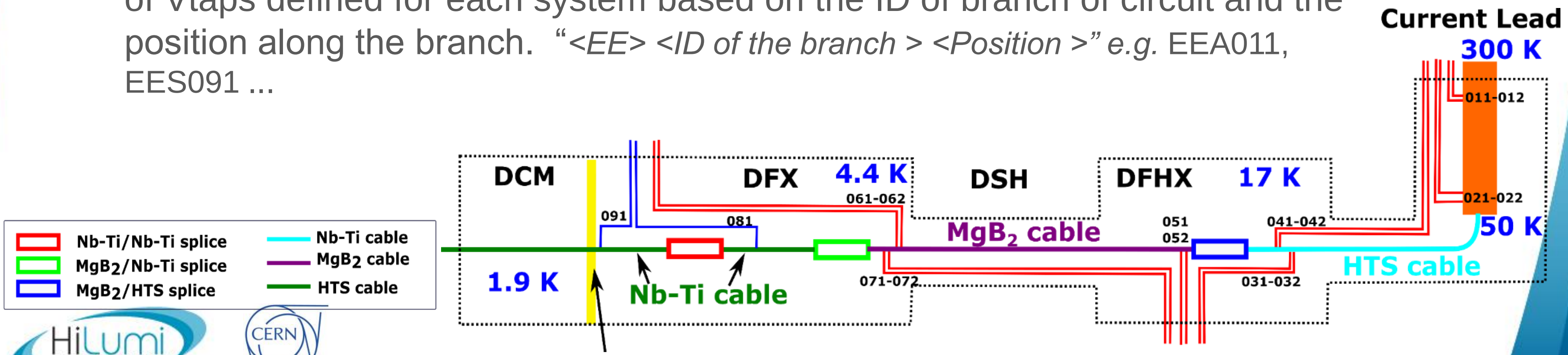


SC Link electrical instrumentation

- **Each branch of circuits** equipped with **16 Vtaps** for the **protection and monitoring** of: **Current lead** heat exchanger, **SC cables** (HTS, MgB_2, NbTi), **Splices** (HTS/MgB_2, MgB_2/NbTi and NbTi/NbTi)

- Same layout of Vtaps for all branches of circuits (0.6-18 kA)

- **Naming of Vtaps** defined in EDMS 2512704 and 2591698: a unique ID of Vtaps defined for each system based on the ID of branch of circuit and the position along the branch. “*<EE> <ID of the branch > <Position >” e.g.* EEA011, EES091 ...

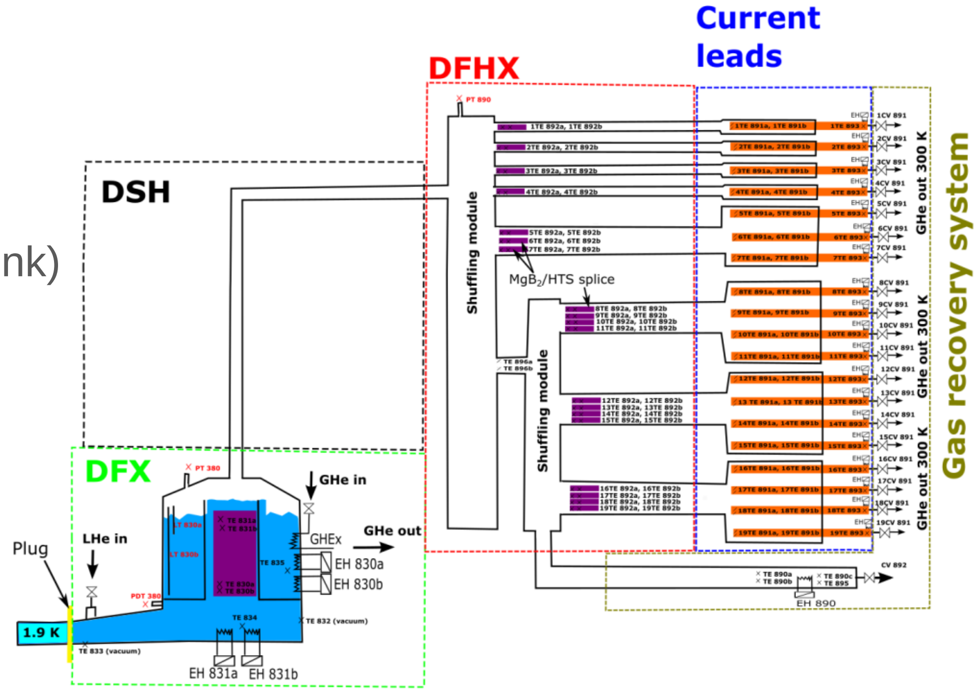


HL-LHC Circuit Voltage Taps Layout of SC Link (EDMS 2411822)

HiLumi HL-LHC PROJECT
CERN

SC Link cryogenic instrumentation

- For a safe operation of SC Link system, during nominal operation but also during transients, dedicated instrumentation is required:
  - Temperature transducers
  - LHe level gages
  - Pressure gages
  - Heaters
  - He control valves (not part of SC Link)
- More details in next slides



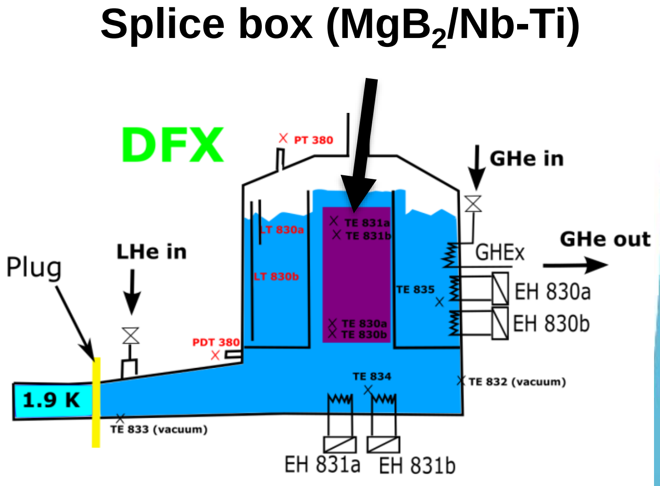
P&I Diagram of IT String =>EDMS 2244008

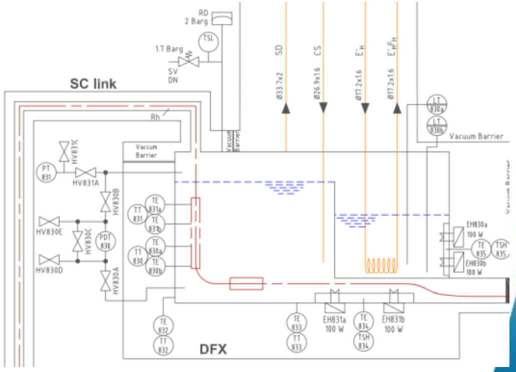
Engineering Specification: Instrumentation of the Cold Powering System EDMS 2512704 and 2591698

Cryogenic instrumentation of DFX

Cryogenic instrumentation of DFX :

- **8 Thermal transducers (TT)**
  - 2 in vacuum attached to He vessel (Cernox)
  - 4 in the splice box (He vessel) (Cernox)
  - 2 temperature sensors attached to the resistive heaters
- **5 Heaters**
  - 1 GHe/LHe Heat exchanger
  - 2 resistive Heaters in external bath
  - 2 resistive Heaters in the lower bath
- **1 He pressure gage**
- **1 He delta P gage** to measure level of liquid in the fountain
- **Two LHe level** transducers
- **Cryo control valves** are part of cryo jumper



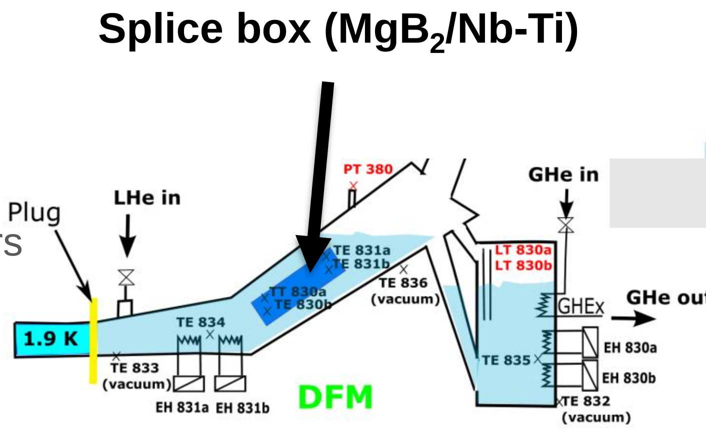


HL-LHC IT STRING SQXL - P&I DIAGRAM, EDMS 2244008

Cryogenic instrumentation of DFM

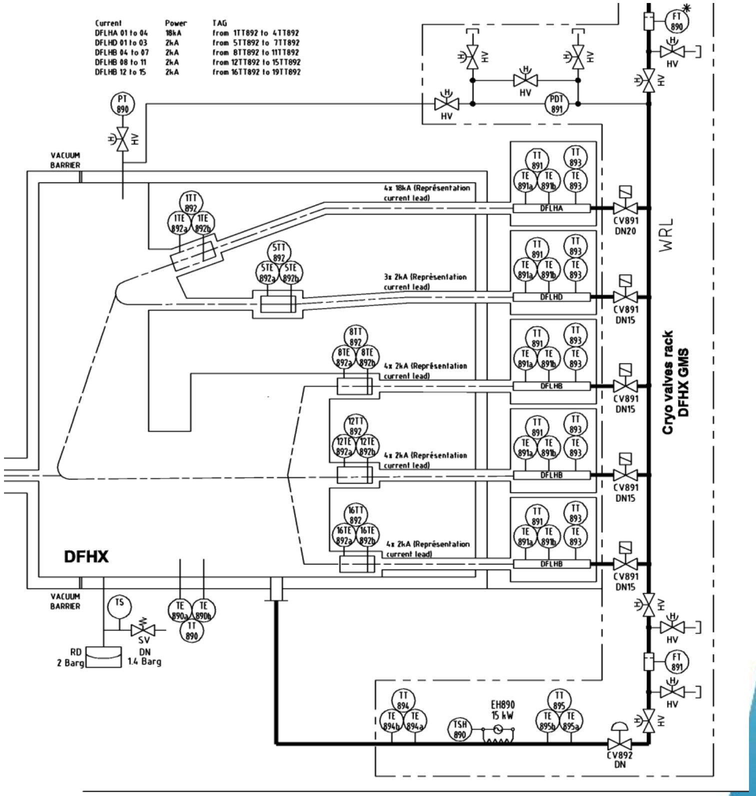
Cryogenic instrumentation of DFM :

- **9 Thermal transducers (TT)**
  - 3 in vacuum attached to He vessel (Cernox)
  - 4 in the splice box (He vessel) (Cernox)
  - 2 temperature sensors attached to the resistive heaters
- **5 Heaters**
  - 1 GHe/LHe Heat exchanger
  - 2 resistive Heaters in external bath (includes 1 spare)
  - 2 resistive heater in the lower bath (includes 1 spare)
- **1 He pressure gage**
- **Two LHe level** transducers
- **Cryo control valves** are part of cryo jumper



Cryogenic instrumentation of DFH and leads

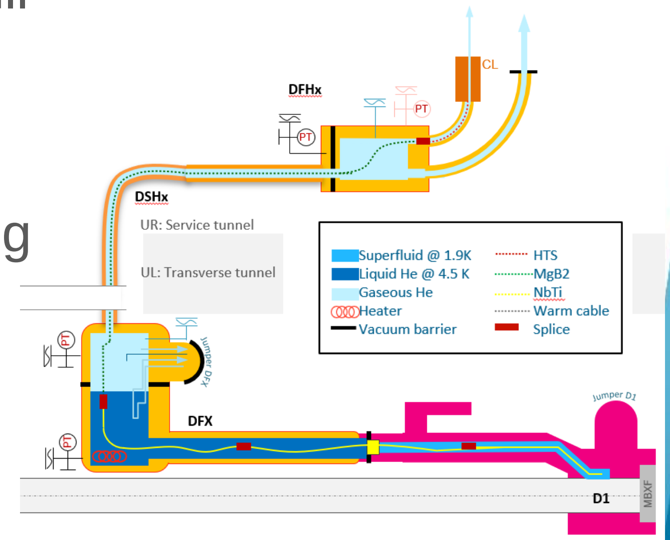
- **Instrumentation of DFH**
  - **1 active** and **1 spare Thermal Transducers** (TT) Cernox per MgB_2/HTS splice
  - **1 active** and **1 spare Thermal Transducers** (TT) Cernox In GHe
  - **1 He pressure gage**, external to He tank
- **Instrumentation of current leads**
  - **Two active and one spare Thermal transducers (PT 100) per current lead**



HL-LHC IT STRING SQXL - P&I DIAGRAM, EDMS 2244008

Vacuum instrumentation

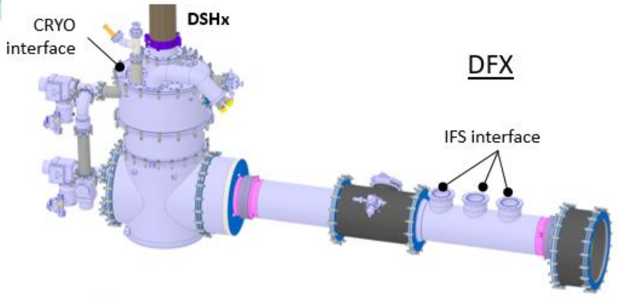
- The cold powering chain of each SC Link system is made of three vacuum volumes as defined in EDMS1824906: **DFX(M)**, **DSH** and **DFHX(M)**
- The DFX(M) and DFHX(M) vacuum vessels will be equipped with vacuum ports (EDMS 2157597) use to plug pumping units and/or vacuum instrumentation
- All the vacuum instrumentation (Pirani, Penning and membrane gauge) will be external to the DFX vacuum vessel (attached to ports)
- => **no wiring in the vessel for vacuum instrumentation is required**

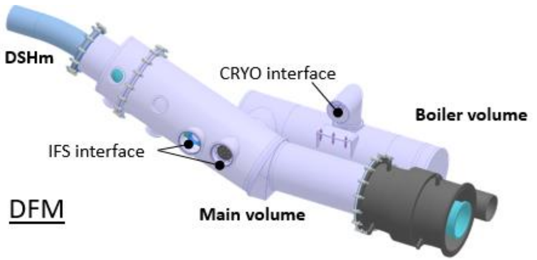


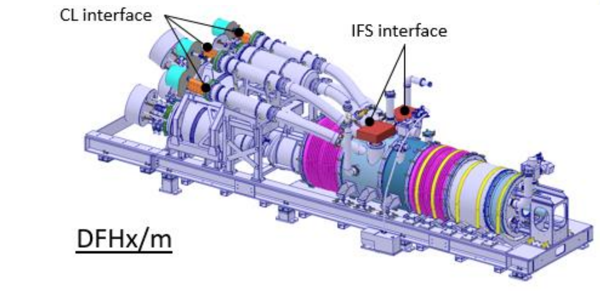
EDMS1824906

Instrumentation Feedthroughs of SC-Link systems

- Feedthroughs located at three specific locations:
  - **DFX(M)**: Vtaps, temp probes, LHe level gage and heaters
  - **DFHX(M)**: Vtaps and temp probes
  - **Current leads:** Vtaps and temp probes
- Instrumentation feedthrough systems of WP6a **designed, constructed** and **tested** accordingly to voltage requirements EDMS 1821907





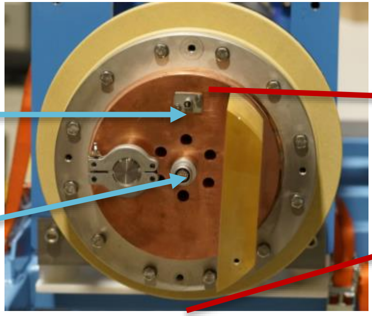


Instrumentation Feedthroughs of DFHX(M) and current leads

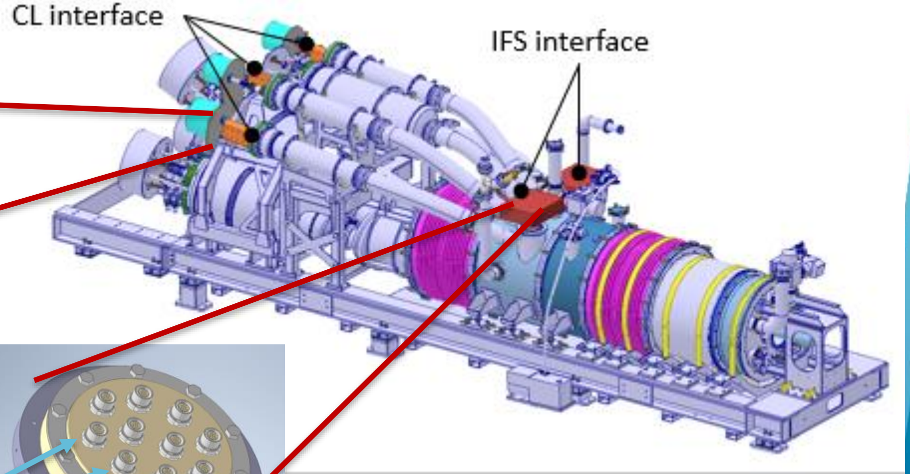
- **Each HL-LHC Current leads** equipped with one Fischer connector and a 4 pin Lemo connector **as for LHC**
- **Feedthroughs of DFHX(M)** composed of multiple Fischer connectors (one connector per branch of circuit, Vtaps and TT) mounted on an insulating flange.

Lemo connector

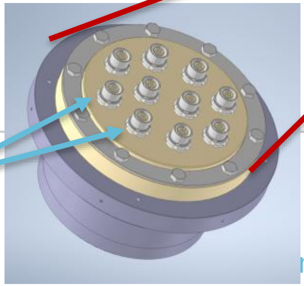
Fischer connector



Feedthroughs of current leads



Fischer connectors

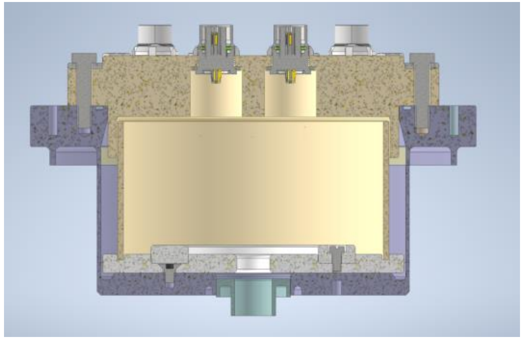


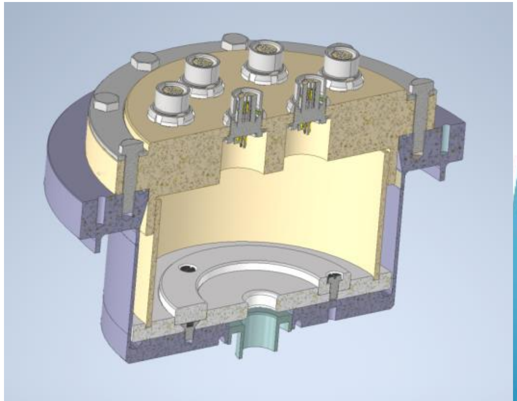
Feedthroughs of DFHX(M)

HiLumi HL-LHC PROJECT

Design of feedthroughs of DFHX(M)

- Vtaps and TT equipping same branch of circuits regrouped in dedicated connector (same electrical potential ~+/- 10 V in transients)
- TT of GHe regrouped on a separate connector
- A total of 20 connectors required for DFHX, 11 connectors for DFHM
- Leak tight Connectors of type Fischer S105A058 distributed among two insulated flanges (PEEK, with O-ring seal)
- Connector insulation (in air) :Pin to pin 1.6 kV, Pin to body 1.4 kV
- Clearance and creepage distance between body of connectors (14 mm air, 56(66) mm Ghe)



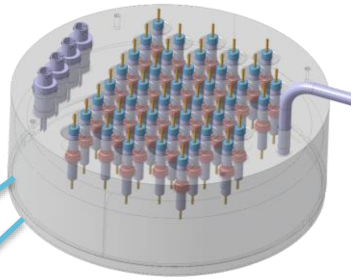


MCF meeting #105, June 2022, https://indico.cern.ch/event/1170478/

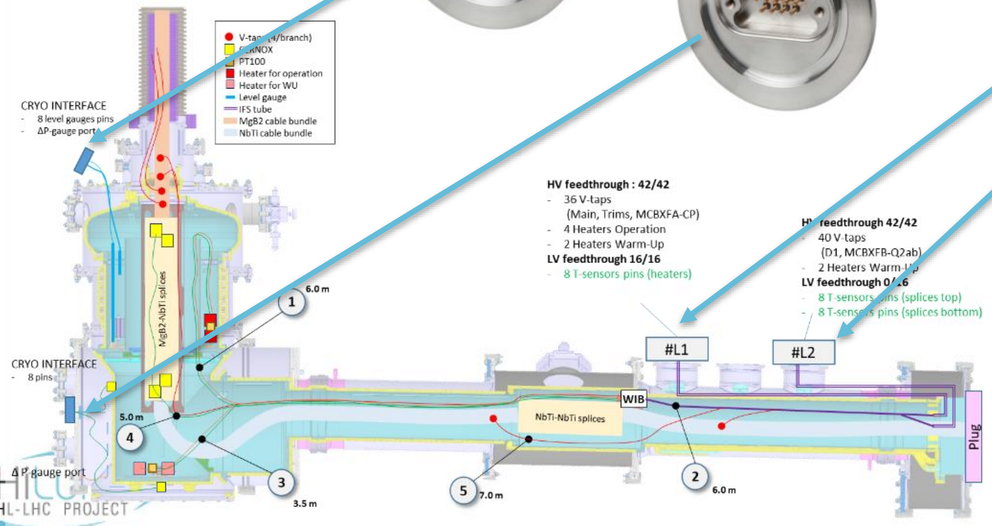
Instrumentation Feedthrough of DFX

- **Feedthroughs of DFX(M):**
  - **HL-LHC cryo-magnet IFS (L-Type)**
  - **SubD connector mounted on Iso-K flange for LHe level gage**
  - **SubD connector mounted on Iso-K flange for TT in vacuum**

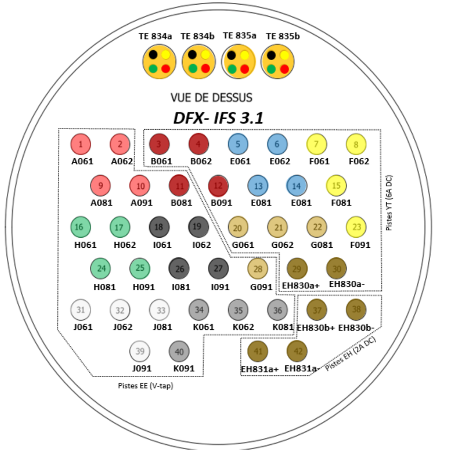
L Type IFS of DFX



SubD IsoK flange



Pinout of L Type IFS

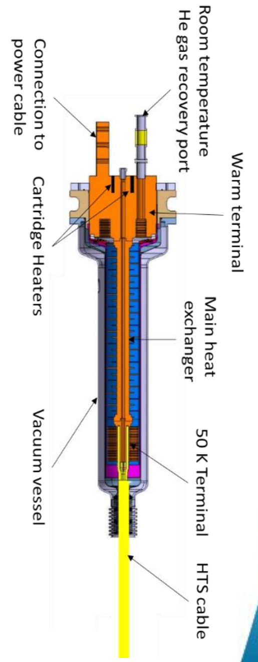


HL-LHC PROJECT

Heating system for current leads

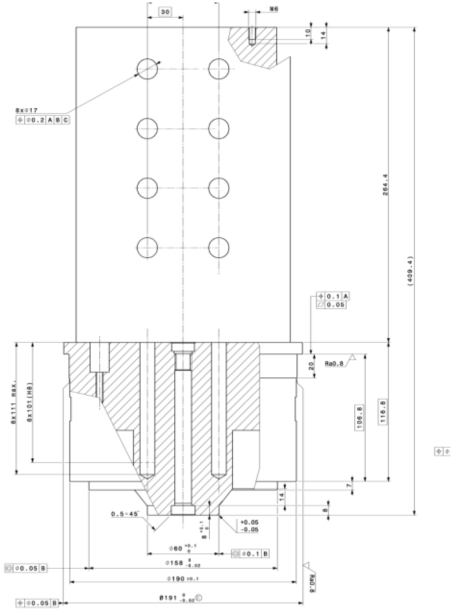
- For a **safe operation** of the **HL-LHC current leads**, each of them will be **equipped** with a **dedicated heating system to avoid the formation of condensation and ice that would lead to gas leakage or degradation of HTS current leads**.
- Functional specification defined in EDMS 2770173

- **Each** heating **system shall**:
  - **Maintain** the warm terminal of the leads to **300 K** (+/- 3 K) during the entire operational cycle of machine
  - **Set point** could be **monitored** and **changed remotely**
  - Provide sufficient **dielectric insulation** to HL LHC circuits (~3 kV)
  - **Deliver a power** (48V) ranging between **125 W** and **1.8 kW**
  - Being made of components quickly replaced with reliable connectors
  - Restart and get back in control mode after power cut
  - Having appropriate electrical protection to limit shut down only to faulty elements/components

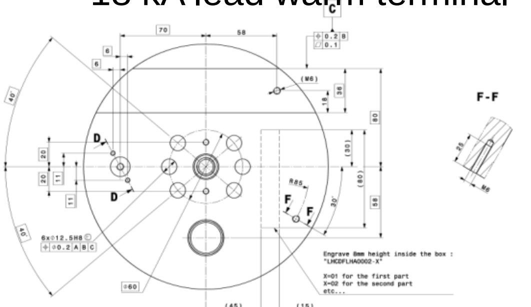


Resistive heaters for the current leads

	Type of lead	Number of leads per system	Technical drawing of warm terminal of the leads	Diameter of cartridge heater	Length of cartridge heater	Number of cartridge heater per lead	Power and voltage of each Heater
Inner Triplet	18 kA	4	LHCDFLHA0002	12.5 mm	100 mm	6	300 W/ 48 V
	7 kA	3	LHCDFLHBP0025	6.5 mm	50 mm	2	125 W/48 V
	2 kA	12	LHCDFLHBP0025	6.5 mm	50 mm	2	125 W/48 V
Matching Section	18 kA	2	LHCDFLHA0002	12.5 mm	100 mm	6	300 W/ 48 V
	0.6 kA	8	LHCDFLHBC0001	6.5 mm	50 mm	1	125 W/48 V



18 kA lead warm terminal

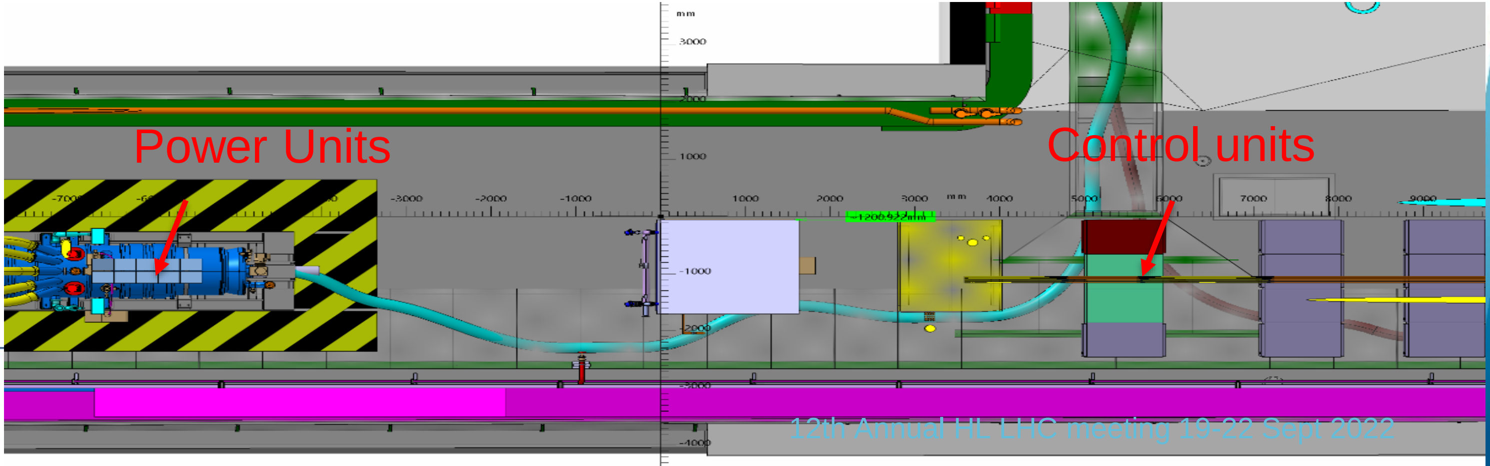


More details on the Heating system of the leads in presentation of G. D'Angelo.

CARTRIDGE HEATER of CURRENT LEADS

Integration of Heating system in the HL-LHC machine

- Integration of components :
  - Power units next by current leads, installed on top of the DFHX and DFHM in individual box
  - Resistive heaters mounted on current leads, with wiring running of cable trays installed on top of the DFHX and DFHM
  - Control units installed ~15 m from the current leads in dedicated racks



THERMOSWITCH of CURRENT LEADS

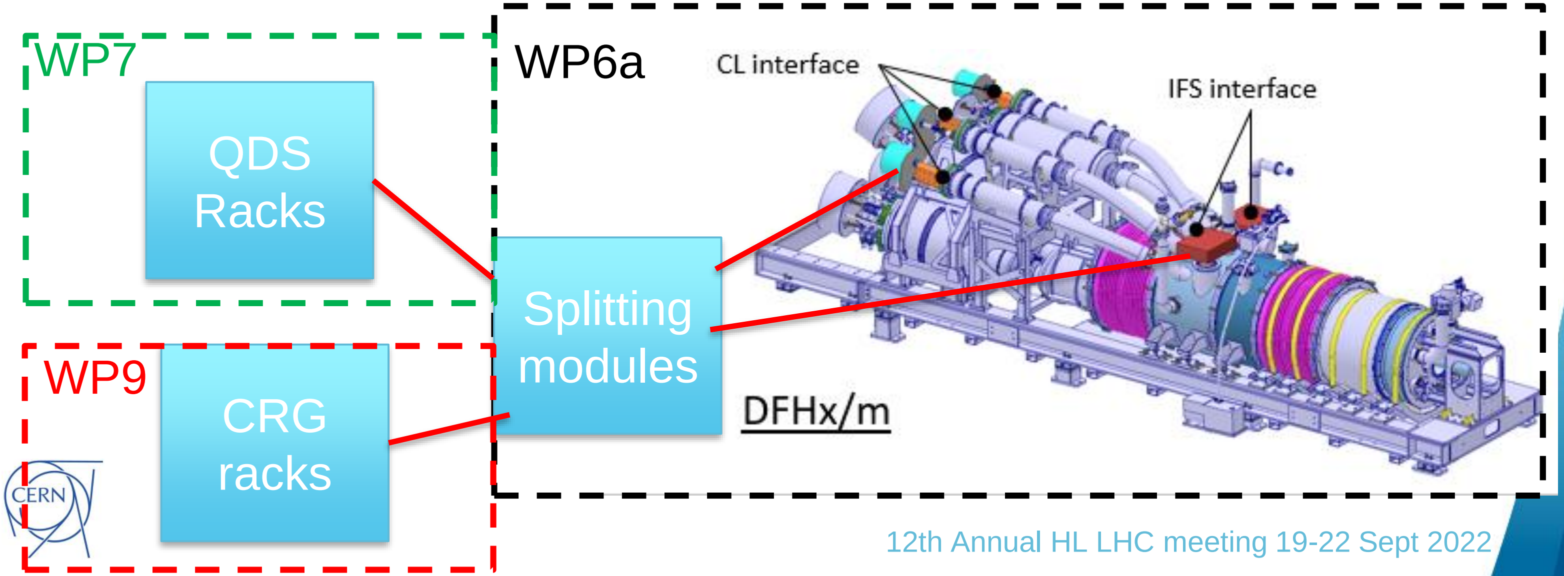
- Each current lead will be equipped with a thermoswitch that will triger a discharge of the circuit if temperature of lead is exceeding 60 degC in operation
  - The type chosen is open by raising temperature.
  - They are insensitive to shocks, accelerations and vibrations.
  - Dielectric holding between the HTS C.L. and the inner parts of the thermostat: 3.5 kV
  - Nominal voltage : 250V
  - Nominal current : 6A
  - Signals from Thermoswitch will be collected by the means of a dedicated proximity equipment:
    - 19 Thermoswitch for IT
    - 10 Thermoswitch for MS

SPLITTING MODULES OF SC LINK

- External splitting module (proximity equipment) are required to route in dedicated cables instrumentation signal of Sc Link to cryo and electrical protection racks
- Splitting modules will be located close by the DFHX(M) and DFX
  - Splitting module of DFX/DFM under responsibility of WP7 (see presentation of G. D’Angelo
  - Splitting module of DFHX/M under responsibility of WP6a, described in next slides

SPLITTING MODULES OF DFHX AND DFHM

- Instrumentation cables of CL and IFS of DFHX(M) will be collected in the proximity equipment
- Connectors of Proximity equipment: Harting type
- Interface among WP at the level of output connectors of splitting modules
- One proximity equipment for four branch of circuits: 5 PE for IT, 3 PE for MS
- Functional spec of proximity equipment drafted in Sept 2022.



Splitting modules of DFHX and DFHM

- Specification drafted in Sept 2022, that defines for each connector (input and output):
  - Connector ID
  - Type of connector
  - Type of cable
  - Pinout

Pinout of output connector for CRYO

Sensor ID	Signal	Source signal		Conn PE-XCRG-01		
		Conn ID	PIN	Type	Con. Pin ID	Cab. con. ID
1TE892a	U+	PE X4-01	7	Rack: 09 16 072 3101, Cable: 09 16 072 3001, EMC: 09 62 816 0301	V+	1
1TE892a	U-	PE X4-01	8		V-	2
1TE892a	I+	PE X4-01	9		I+	3
1TE892a	I-	PE X4-01	10		I-	4
1TE892b	U+	PE X4-01	11		V+	5
1TE892b	U-	PE X4-01	12		V-	6
1TE892b	I+	PE X4-01	13		I+	7
1TE892b	I-	PE X4-01	14		I-	8
1TE891a	U+	PE X5-01	7		V+	9
1TE891a	U-	PE X5-01	8		V-	10
1TE891a	I+	PE X5-01	9		I+	11
1TE891a	I-	PE X5-01	10		I-	12
1TE891b	U+	PE X5-01	11		V+	13
1TE891b	U-	PE X5-01	12		V-	14
1TE891b	I+	PE X5-01	13		I+	15
1TE891b	I-	PE X5-01	14		I-	16
1TE893	U+	PE X6-01	1		V+	17
1TE893	U-	PE X6-01	2		V-	18
1TE893	I+	PE X6-01	3		I+	19
1TE893	I-	PE X6-01	4		I-	20

List of output connectors of the splitting module of DFHM

List of output connectors of the splitting module of DFHM						
Vtaps/ Temperatre sensors	Current leads/ leg of circuit	Signals		Connector ID		Cable
		Nb of wires for Vtaps	Nb of wires for Temp probe	Connector ID	Connector Type	
Temp	DFLHA.UR_.M_.1	-	20	PE-MCRG-1	11 x |Rack: 09 16 072 3101| |cable : 09 16 072 3001| | EMC: 09 62 816 0301|	20x DRAK A HV
	DFLHA.UR_.M_.2	-	20	PE-MCRG-2		
	DFLHC.UR_.M_.1	-	20	PE-MCRG-3		
	DFLHC.UR_.M_.2	-	20	PE-MCRG-4		
	DFLHC.UR_.M_.3	-	20	PE-MCRG-5		
	DFLHC.UR_.M_.4	-	20	PE-MCRG-6		
	DFLHC.UR_.M_.5	-	20	PE-MCRG-7		
	DFLHC.UR_.M_.6	-	20	PE-MCRG-8		
	DFLHC.UR_.M_.7	-	20	PE-MCRG-9		
	DFLHC.UR_.M_.8	-	20	PE-MCRG-10		
	None (TT832A/TT832B)	-	8	PE-MCRG-11		
Vtaps	DFLHA.UR_.M_.1 DFLHA.UR_.M_.2 - -	16	-	PE-MMPE-01a	6 x |1 x 09 14 016 0371| |4 x 09 14 008 3101| |1 x 09 30 016 0318|	NE36
		16	-	PE-MMPE-01b		NE36
	DFLHC.UR_.M_.1 DFLHC.UR_.M_.2 DFLHC.UR_.M_.3 DFLHC.UR_.M_.4	32	-	PE-MMPE-02a		NE36
		32	-	PE-MMPE-02b		NE36
	DFLHC.UR_.M_.5 DFLHC.UR_.M_.6 DFLHC.UR_.M_.7 DFLHC.UR_.M_.8	32	-	PE-MMPE-03a		NE36
		32	-	PE-MMPE-03b		NE36

Conclusion

- Current leads named and attributed to circuits
- List of instrumentation for safe cryogenic, electrical and vacuum operation of the SC Links system defined
- Instrumentation feedthroughs of SC Link defined
- The functional specification for current leads heating system was defined, it is developed by WP7.
- Safety thermoswitch will equip each HTS current lead that will cut off the power converter if the temperature reaches 60ºC.
- Splitting module for DFX(M) and DFHX(M) are being designed. The one of DFX(M) is with WP7. Interfaces are defined, the detail design of DFHX(M) splitting module will be completed by Q2 2023.

Thanks for your attention