HiLumi HL-LHC PROJECT

14th HL-LHC Collaboration Meeting

Qualification of the first Cold Powering System for the HL-LHC triplets

Amalia Ballarino for the WP6a

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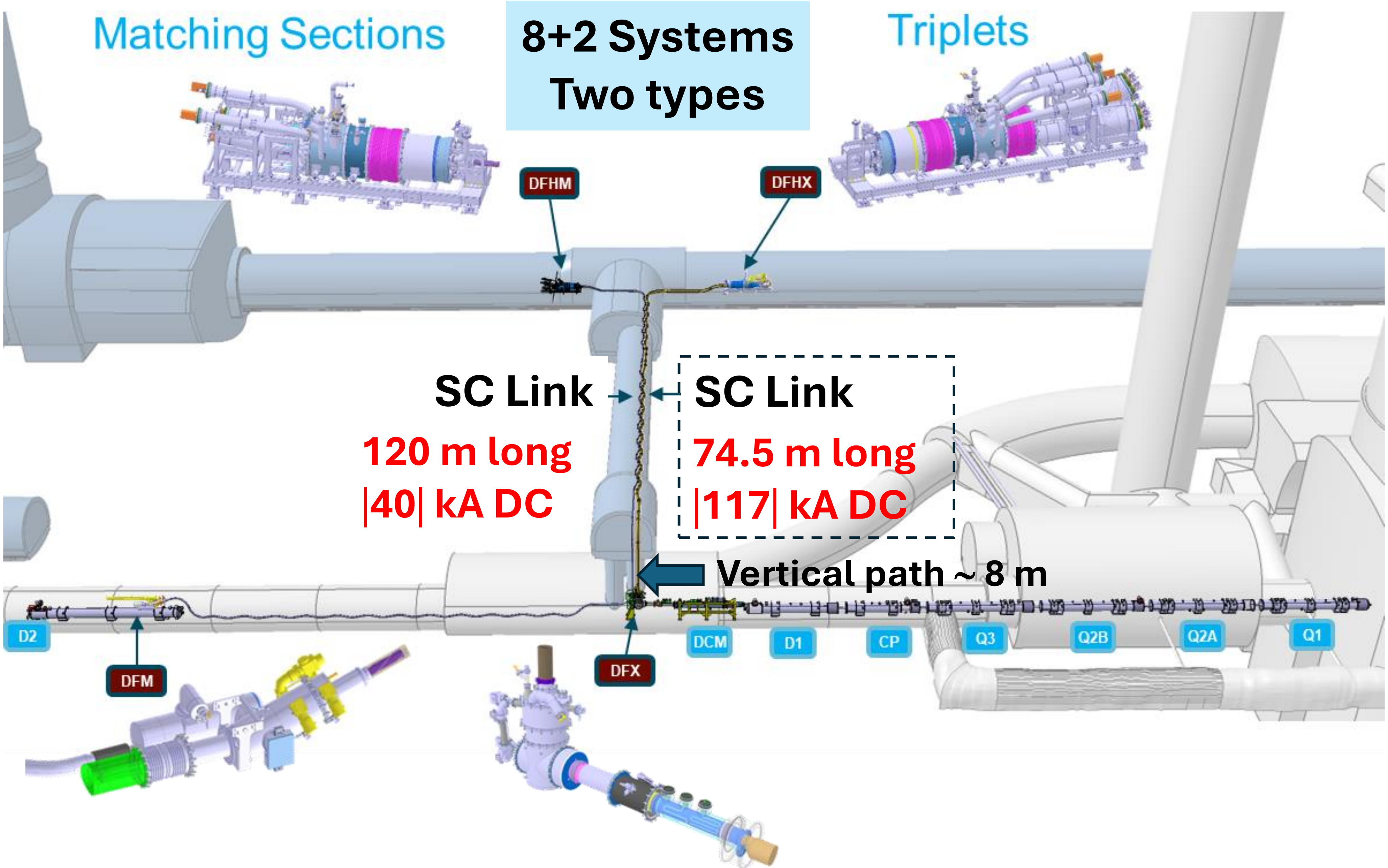
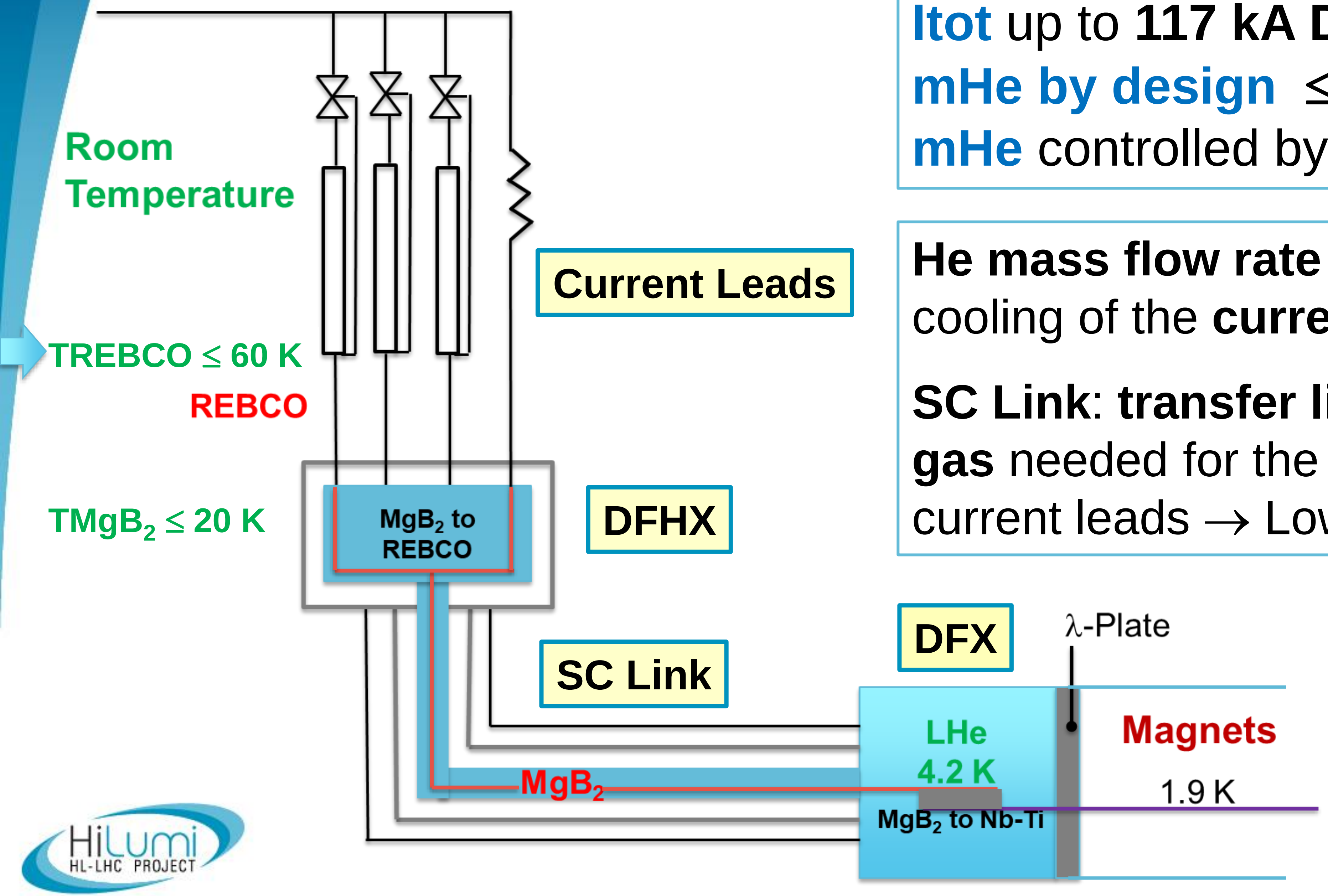
Powering the HL-LHC magnets



Cold Powering System for HL-LHC Magnets



Itot up to **117 kA DC**
mHe by design ≤ 5.5 g/s
mHe controlled by **TREBCO**

He mass flow rate imposed by the cooling of the **current leads**

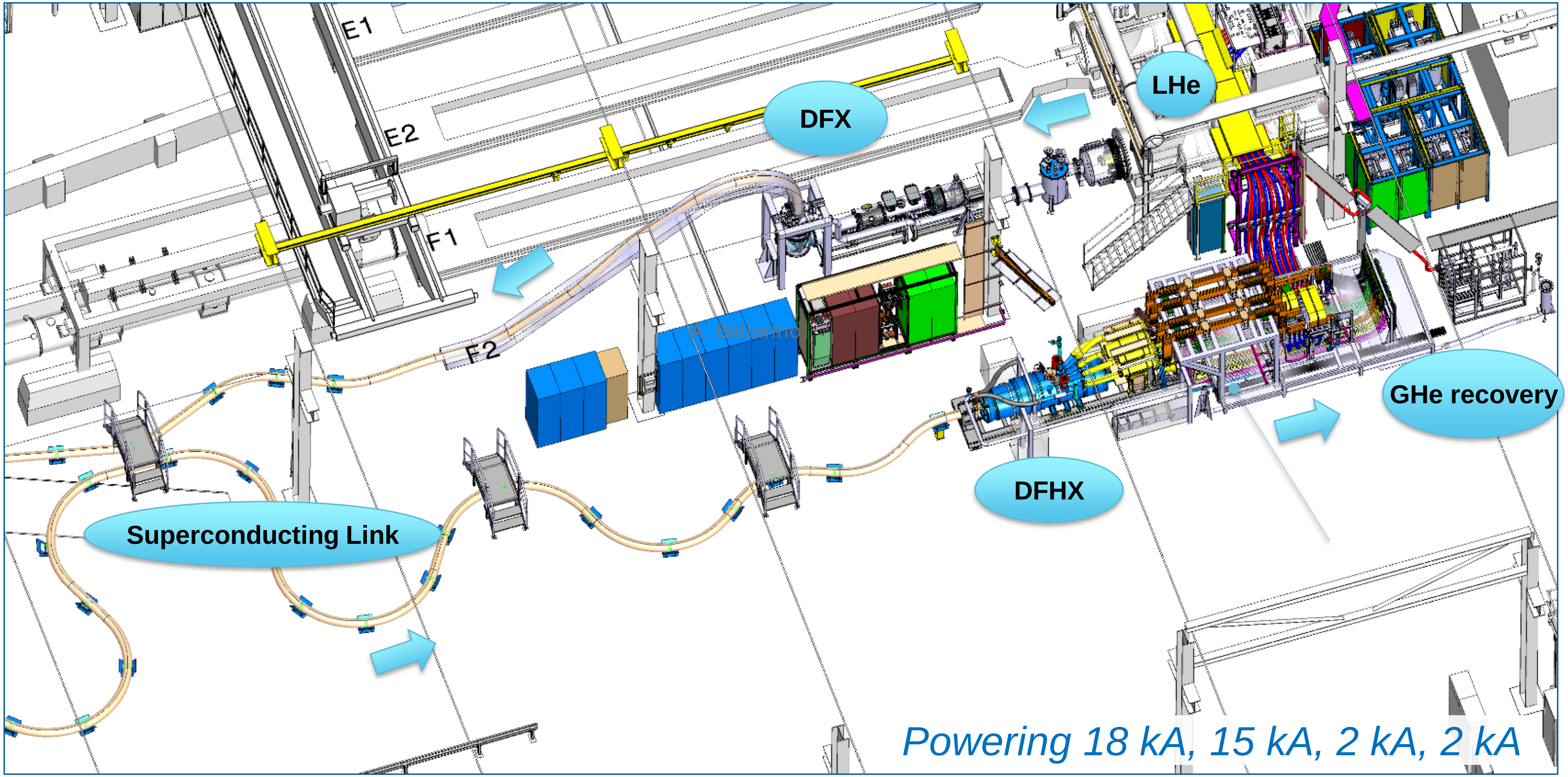
SC Link: **transfer line for the helium gas** needed for the cooling of the current leads → Low heat load cryostat

The Superconducting Link for HL-LHC

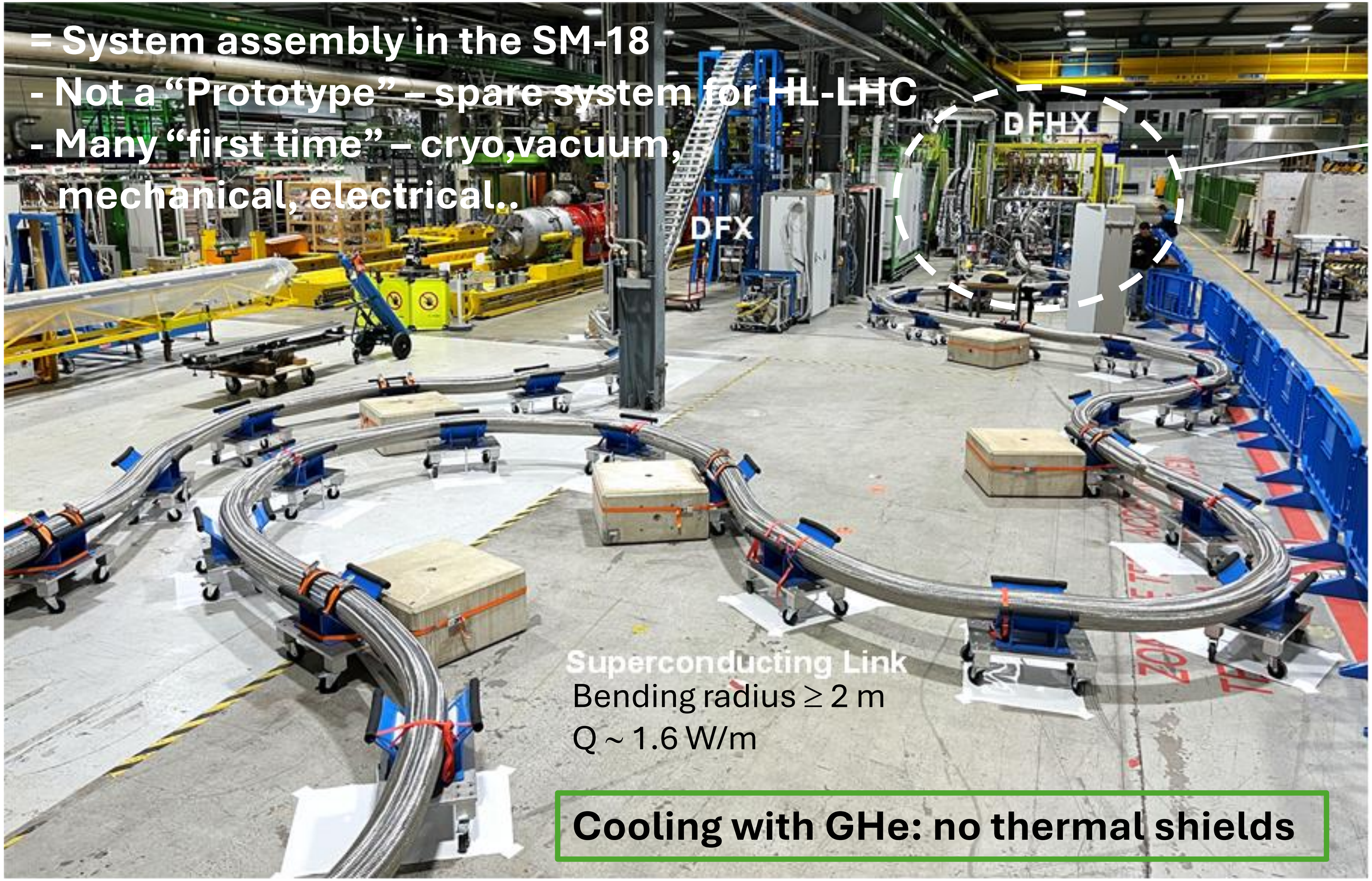
|117| kA @ 25 K
Φ ~ 90 mm, ~ 25 kg/m

MgB_2 wire produced at **ASG Superconductors**
Superconducting Link cryostat produced at **Cryoworld**
MgB_2 cabling performed at **ICAS/TRATOS**
REBCO cabling at CERN

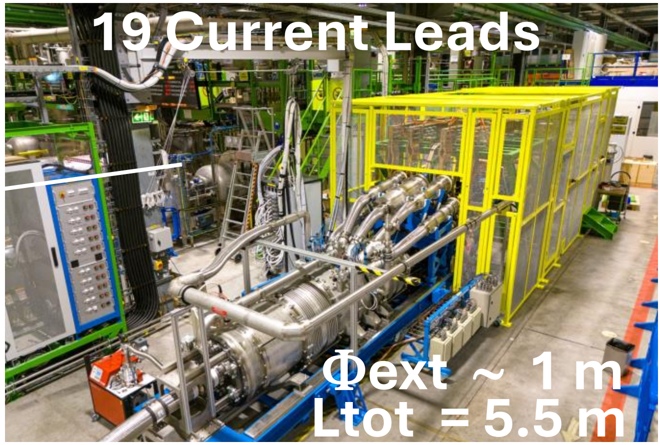
Cold Powering System in the SM-18

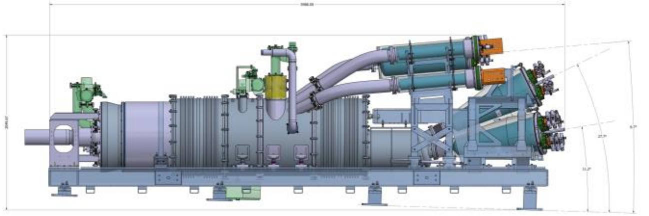


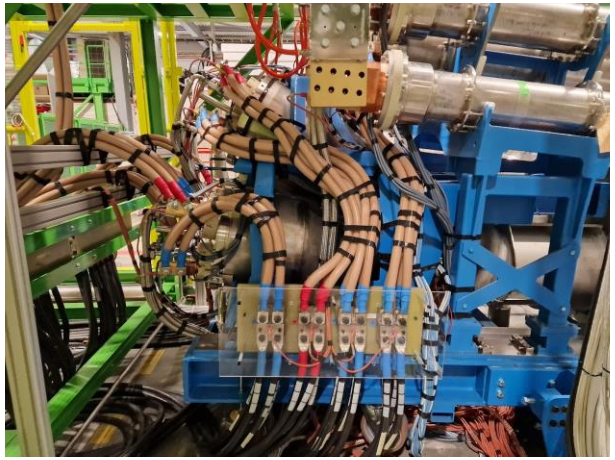
Cold Powering System in the SM-18



DFHX





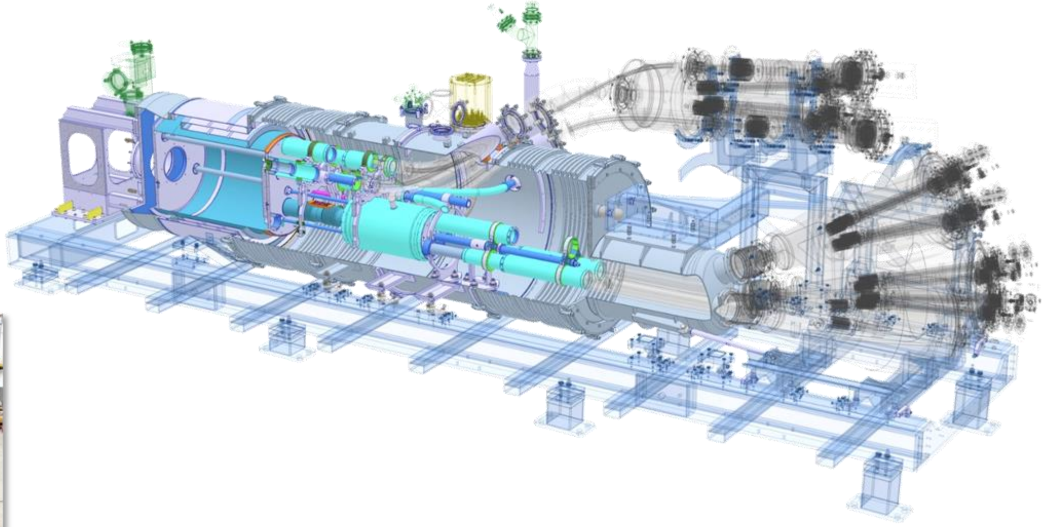


Instrumentation signals: 304 voltage taps and 105 temperature sensors

Contributions from our collaborators

University of Southampton - DFX

Uppsala University/RFR – Three components of DFHX

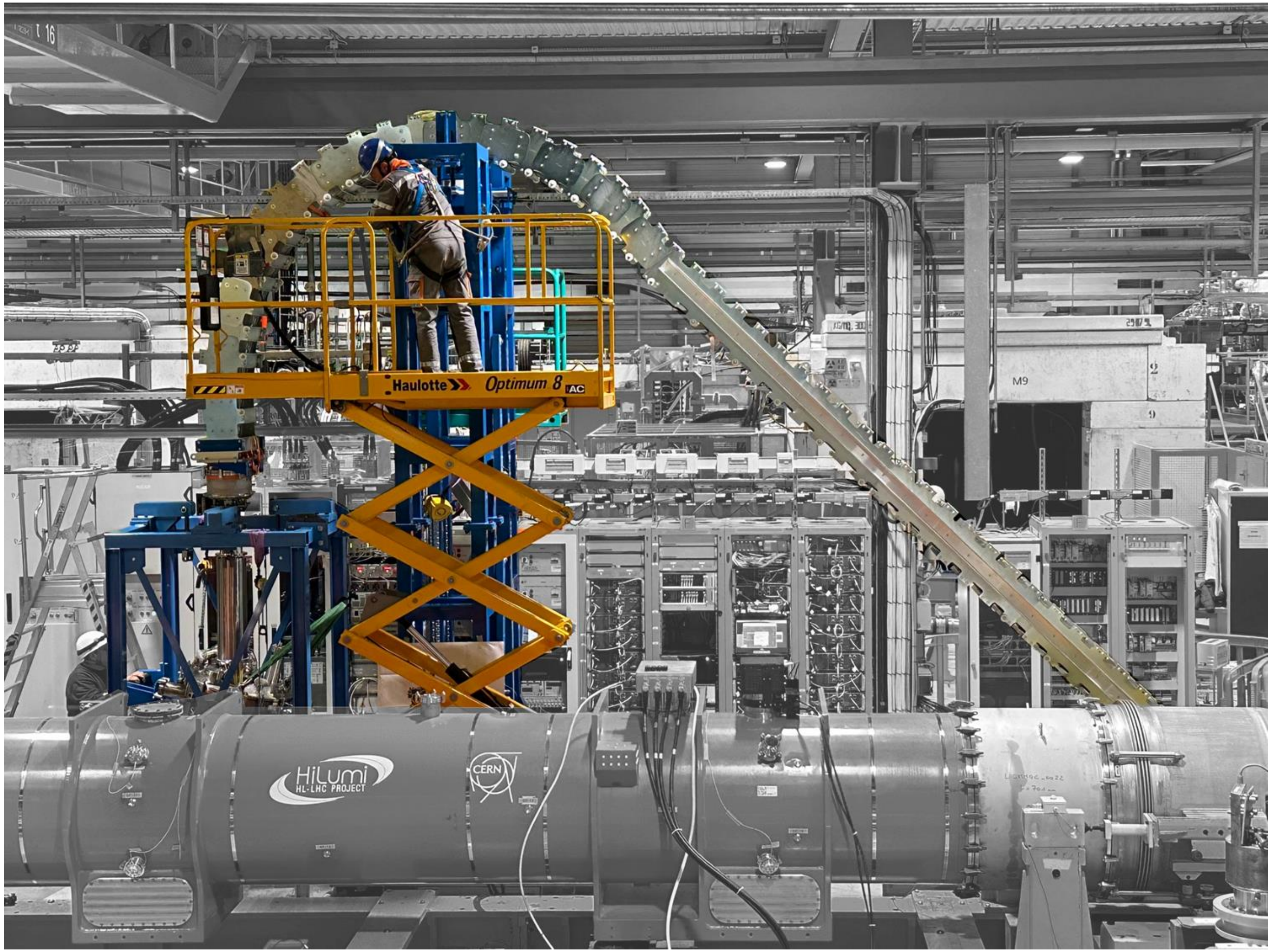


CERN Main Workshop

- Manufacturing/assembly of resistive parts of current leads
- Manufacturing of mechanical components of DFHX
- Welds in the SM-18

A successful collaborative effort

Vertical Path of Superconducting Link



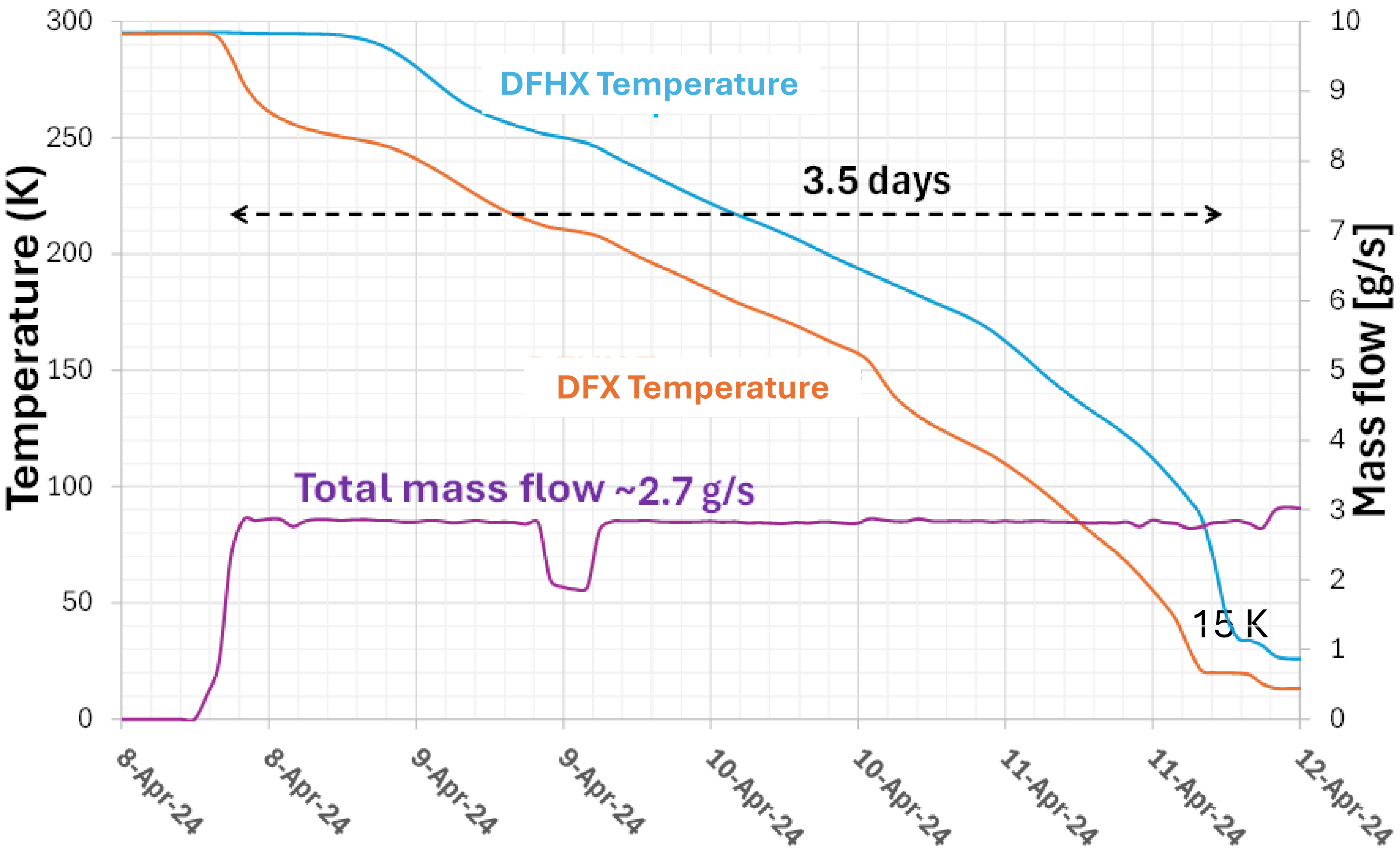
Cool-down

After the **pressure test** (4.6 bara) and the **leak test** (helium leak rate better than 1.0×10^{-8} mbar·l·s^{-1}), **cool-down** to nominal cryogenic conditions was performed

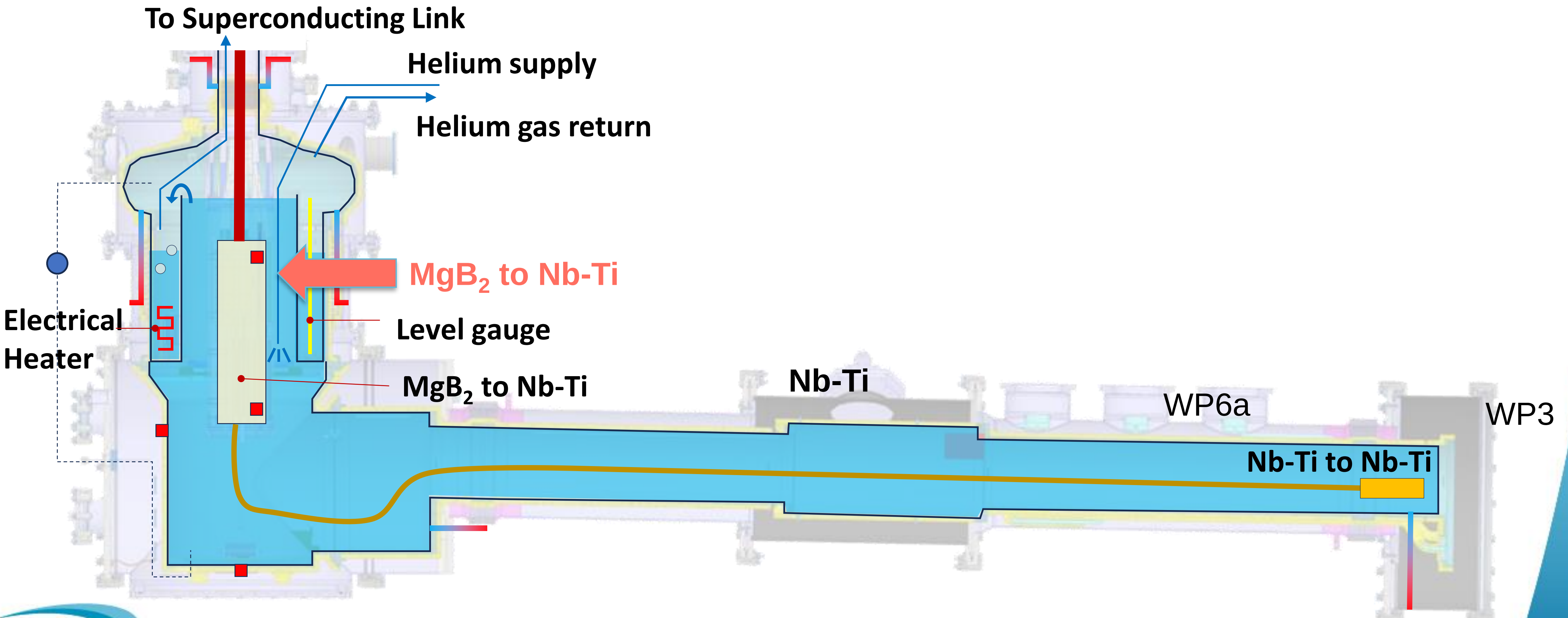
ΔT ≤ 50 K
from RT to 160 K

ΔT ≤ 70 K
from 160 K to 15 K

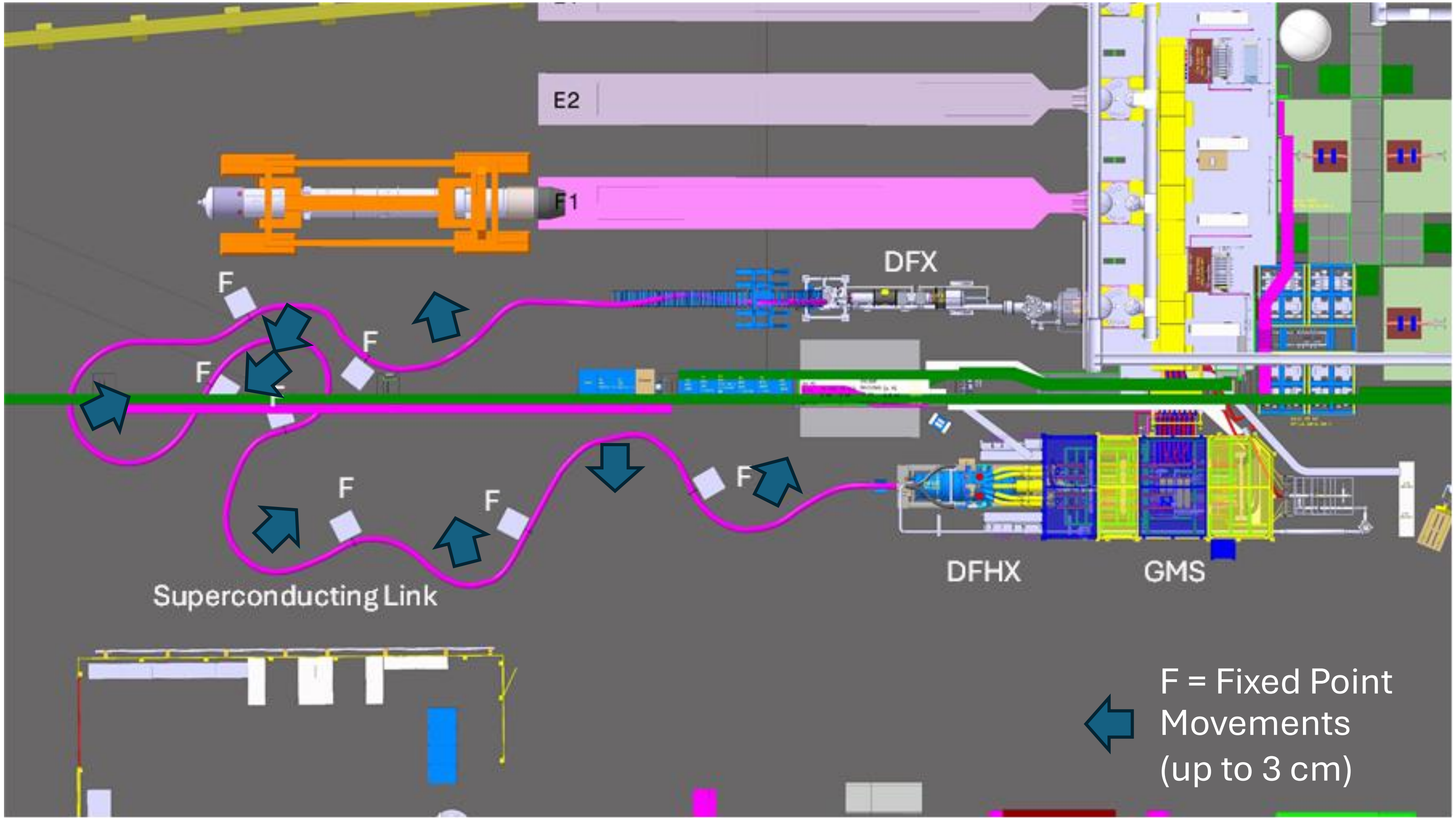
m = 2 g/s - 3 g/s



Layout of DFX

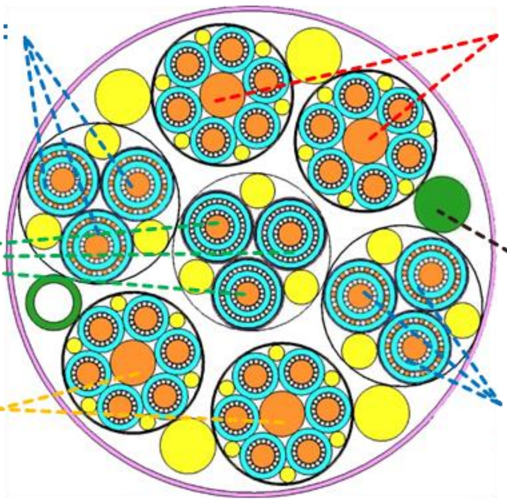


Dealing with Thermal Contractions



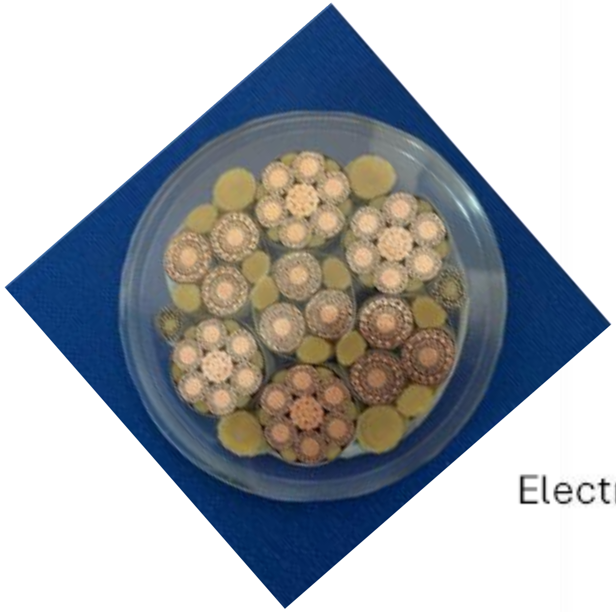
Two thermal cycles (from room temperature to cryogenic conditions) **followed by powering** of all circuits. Repetitive performance

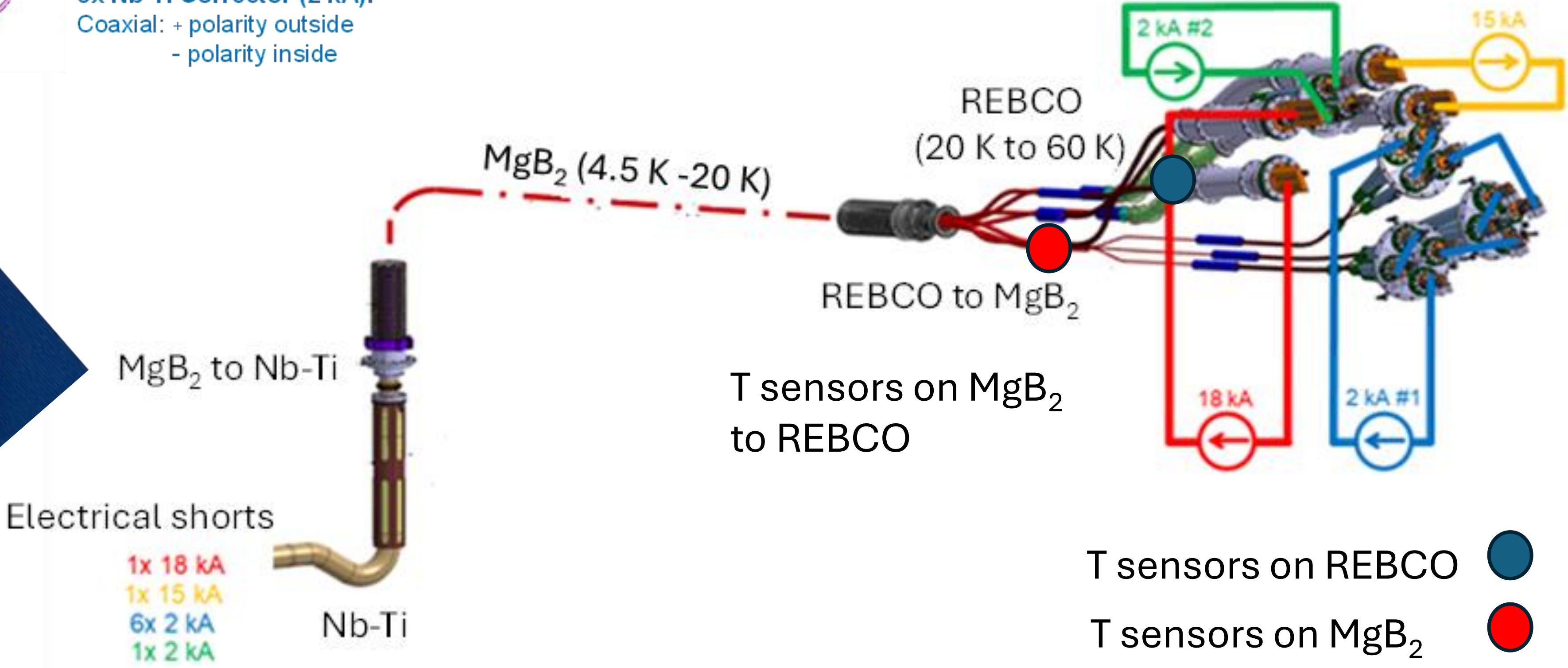
Powering Scheme



Four power converters:

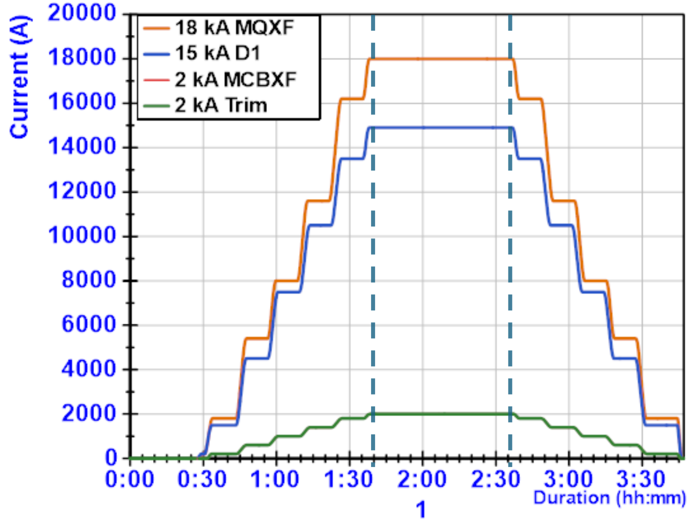
18 kA – $I_{HL\text{-}LHC}$ = 16.23 kA (Nb_3Sn quadrupole)
15 kA – $I_{HL\text{-}LHC}$ = 12.11 kA (Separation dipole)
2 kA – $I_{HL\text{-}LHC}$ = 2 kA (Trim)
2 kA – $I_{HL\text{-}LHC}$ = 1.74 kA (Correctors)

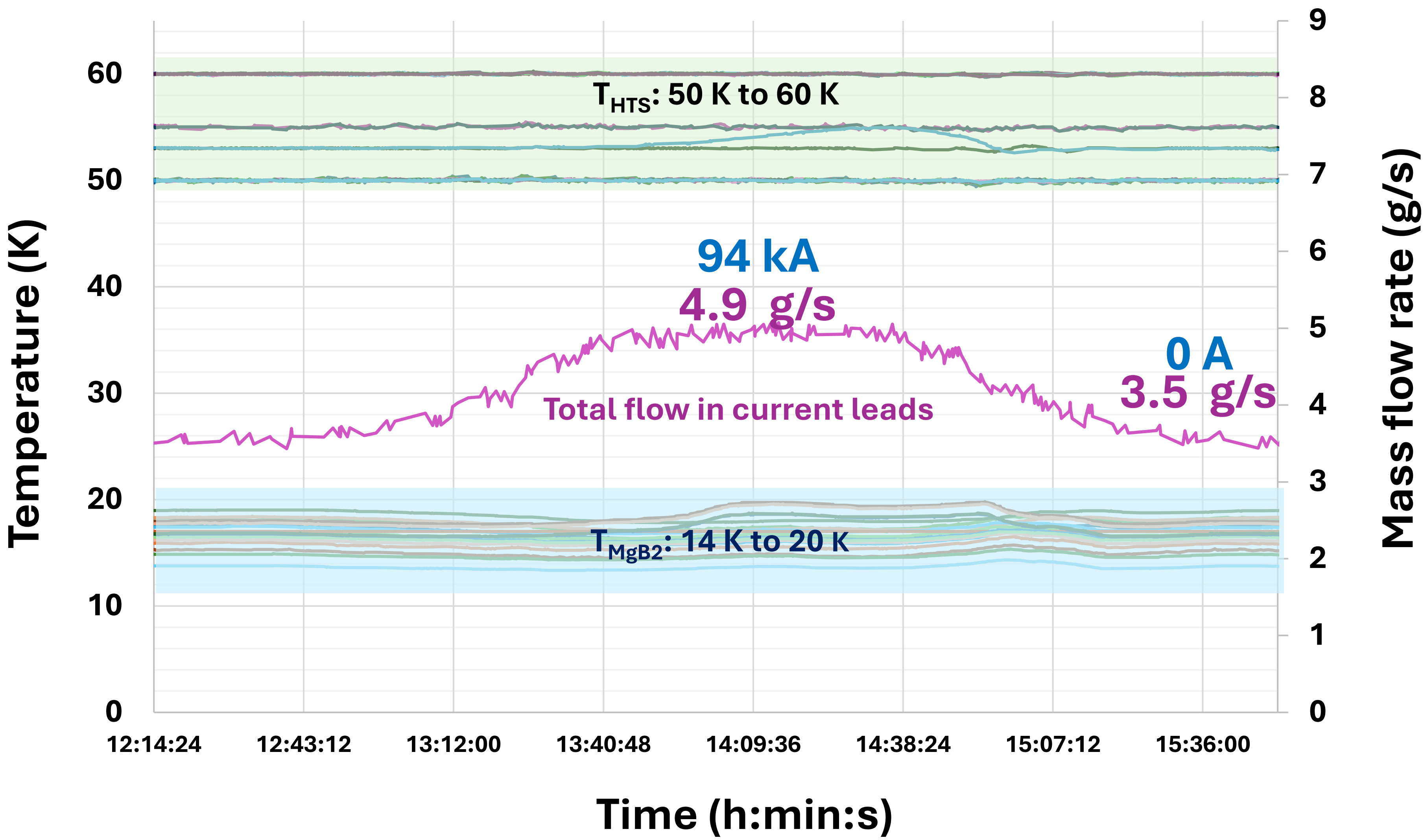




Maximum current delivered by the power converters: **94 kA**

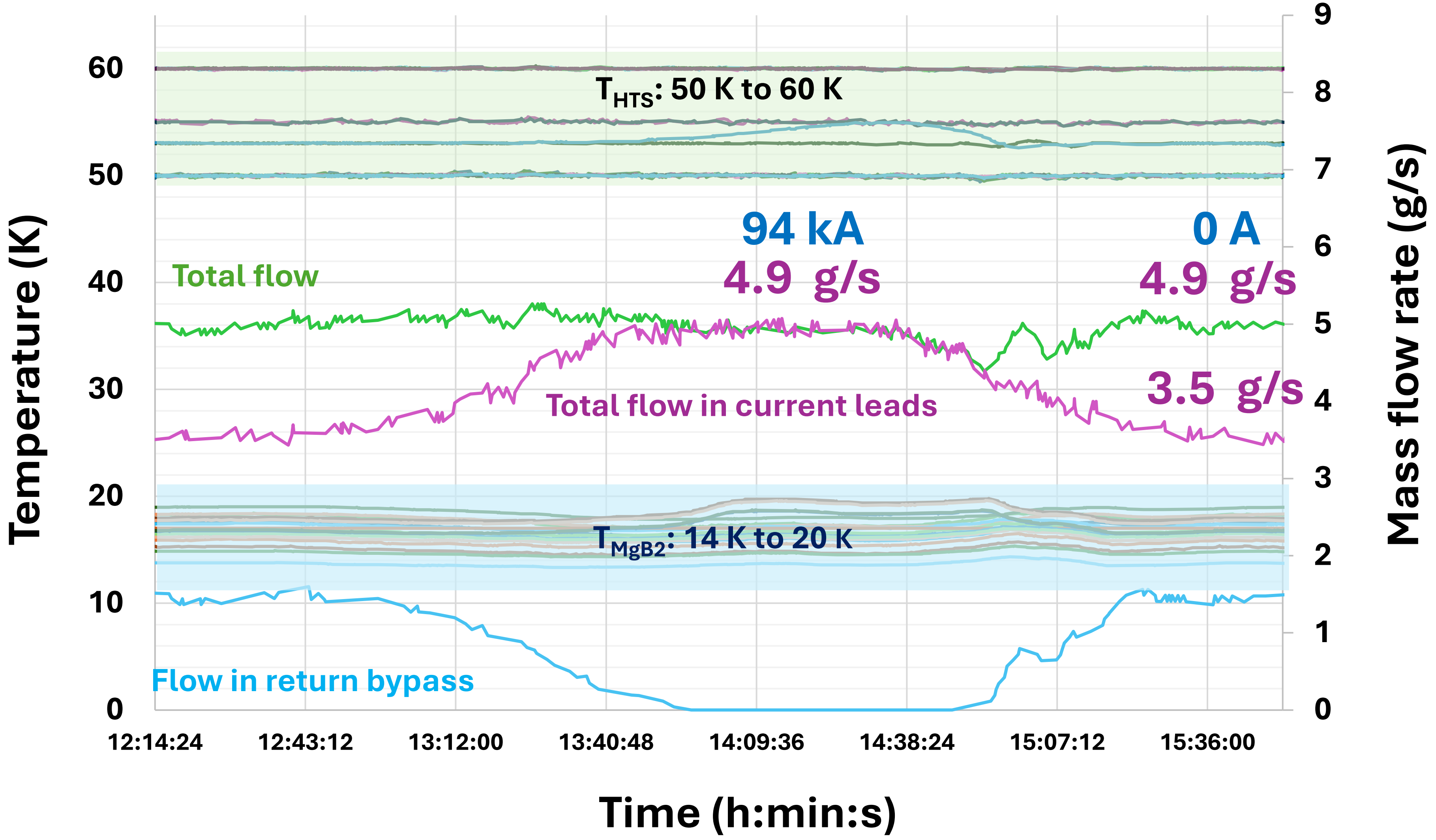
Cryogenic and Electrical Performance (1/2)





Mass flow rate dominated by requirement of optimized current leads: ~ 0.05 g/(s·kA)

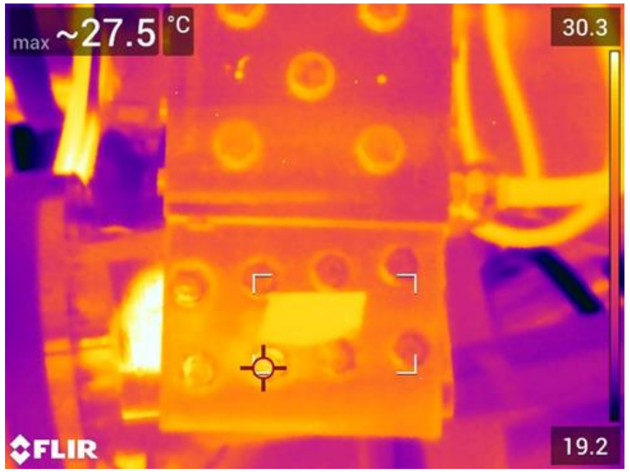
Cryogenic and Electrical Performance (2/2)



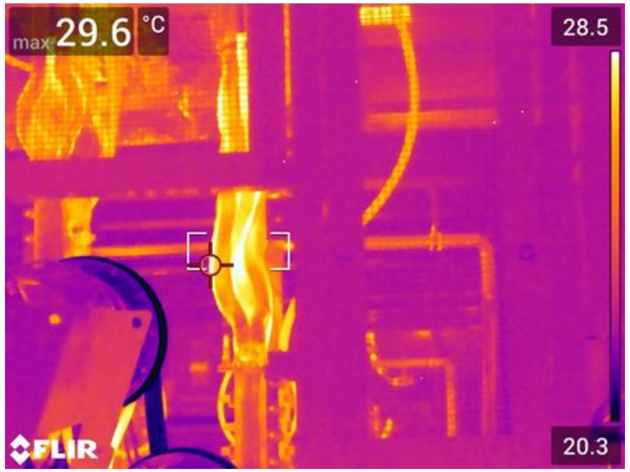
High voltage tests (2.3 kV among polarities and between each polarity and the ground) in nominal cryogenic conditions **successfully performed** (leakage currents < 10 μA)

Room Temperature Terminations

18 kA hold: ~2 h
Temp. increase: ~3 °C



18 kA hold: ~2 h
Temp. increase: ~5 °C



2 kA hold: ~2 h
No temp. increase

Maximum 5 °C increase at maximum current, no condensation during any operating condition (both at zero current and with current)

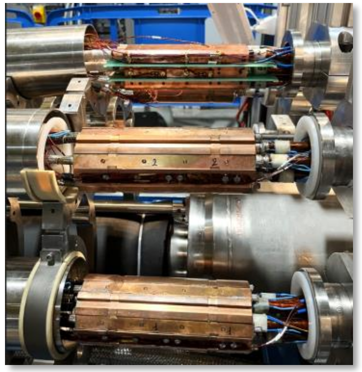
Splices

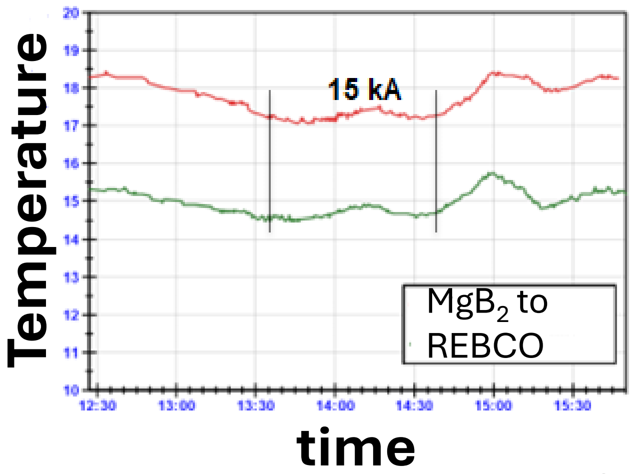
REBCO to MgB_2, GHe @ 20 K | MgB_2 to Nb-Ti, LHe @ 4.5 K | Nb-Ti to Nb-Ti, LHe @ 4.5 K

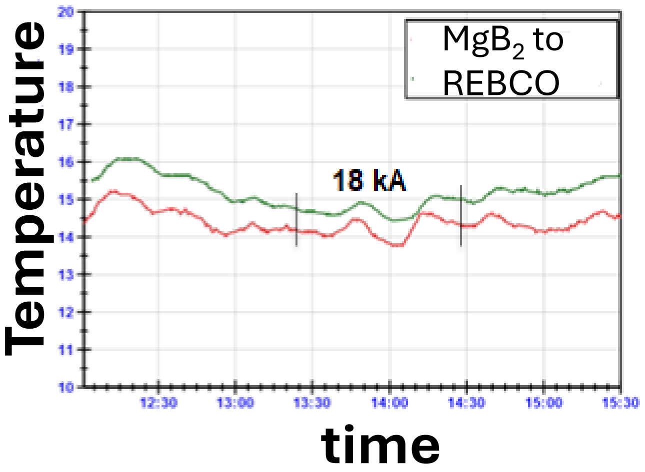
Circuit	REBCO to MgB_2 splices		MgB_2 to Nb-Ti splices		Nb-Ti to Nb-Ti splices	
	R_{splice} measured	R_{splice} expected	R_{splice} measured	R_{splice} expected	R_{splice} measured	R_{splice} expected
18 kA	1.4 ± 0.1 nΩ	1.5 - 2.2 nΩ	1.4 ± 0.1 nΩ	≤ 1.8 nΩ	0.9 ± 0.1 nΩ	≤ 2.0 nΩ
15 kA	1.7 ± 0.1 nΩ		1.4 ± 0.3 nΩ		0.9 ± 0.1 nΩ	
2 kA - Trim	4.3 ± 0.8 nΩ	4.5 - 6.5 nΩ	1.4 ± 0.2 nΩ	≤ 3.5 nΩ	1.2 ± 0.1 nΩ	
2 kA - Correctors	10.1 ± 1.1 nΩ	9.0 - 13.0 nΩ	2.4 ± 1.4 nΩ	≤ 6.0 nΩ	1.1 ± 0.3 nΩ	

Stable performance, no overheating, temperature of splices independent of current (± 1 K)

MgB_2 to REBCO







Transient Behavior

Successfully validated:

- **Cryogenic requirement during transients**
  Capability of operating **without liquid helium supply during 10 minutes** with MgB_2 to Nb-Ti splices immersed in liquid helium. Capability of producing **up to 10 g/s of GHe**

- **Electrical requirement (cross talks)**
  Absence of cross talk among circuits – via electro-magnetic coupling. Fast discharges (up to 100 A/s) of the 2 kA circuits do not trigger the quench protection system of any of the other circuits

- **High Voltage insulation**
  Each circuit tested at **5 kV** in air, **2.3 kV** in nominal cryogenic conditions, and **1.1 kV** in GHe at room temperature. Measured leakage currents 100 times lower than specified limit

Re-spooling/Transport of SC Link + DFHX

Compactness of DFHX and flexibility of the SC Link enable **assembly and qualification** of the Systems **at the surface** (before installation in the LHC underground)

See presentation of Y. Leclercq on Wednesday (WP6a in String)

Conclusions

- The **first Cold Powering System for the HL-LHC Triplets** has been **successfully validated**: cryogenic, electrical and mechanical performance all met design parameters. **Robustness** of the system in different operating modes was proven
- The system transferred up to **|94| kA** (maximum current delivered by power converters) **in DC mode** and in nominal cryogenic conditions: **MgB_2 @ 20 K** and **REBCO @ 60 K**. Operation of MgB_2 is up to 29 K and of REBCO up to 70 K (~ **10 K temperature margin**)
- Components of the Cold Powering Systems have been **industrialized.** They are today in an **advanced phase of series production,** and several series productions are completed (recently DFHX components)
- The system has been opened, re-spooled, transported and **installed in the String.** This was also a good exercise for what will have a to done for the tunnel installation


A phantastic team !

Thanks for your attention !

Acknowledgements:

O. Pirotte, R. Mauny and J. Gery from the **TE-CRG** group
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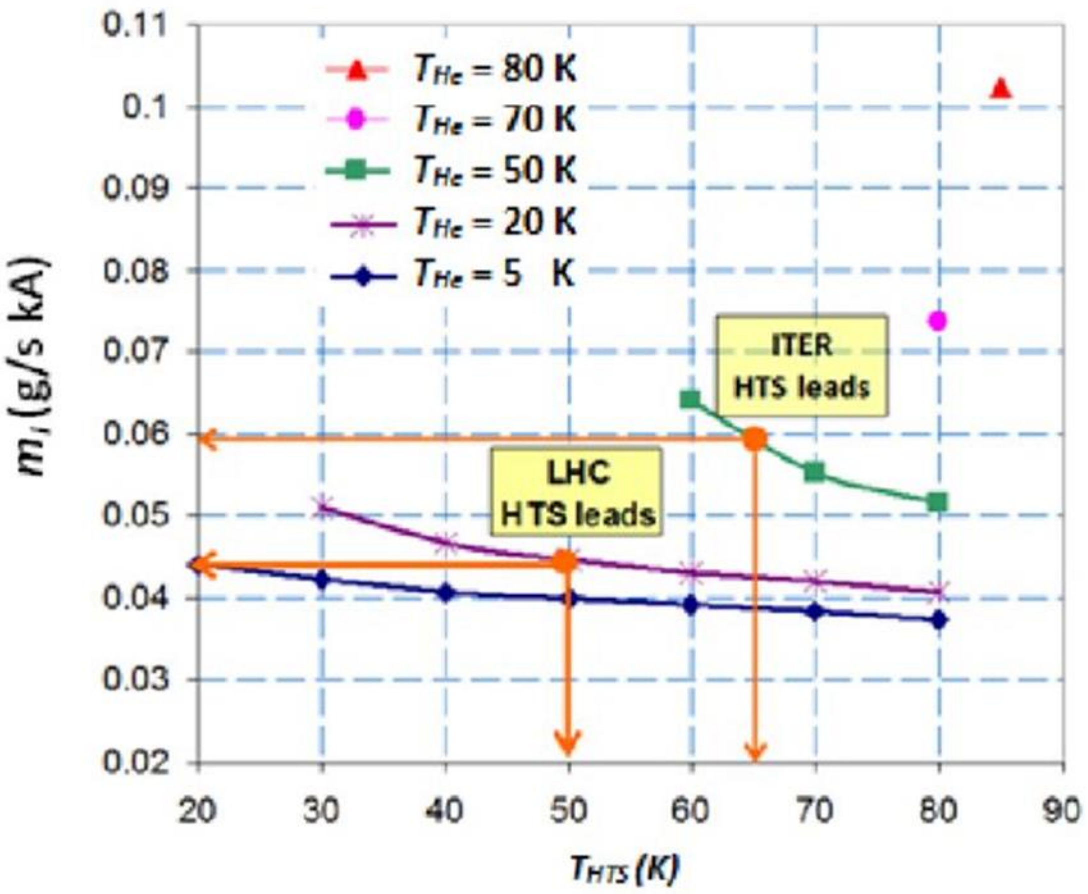
QPS and ELQA teams from the **TE-MPE group**
C. Bertone and E. Richards and the **EN-HE transport team**
Our collaborators: **University of Southampton** and **University of Uppsala**



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T_{He} = 80 K
T_{He} = 70 K
T_{He} = 50 K
T_{He} = 20 K
T_{He} = 5 K
ITER
HTS leads
LHC
HTS leads
m_l (g/s kA)
T_{HTS} (K)