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Qualification of the first MgB_2 and REBCO based Cold Powering System for HL-LHC

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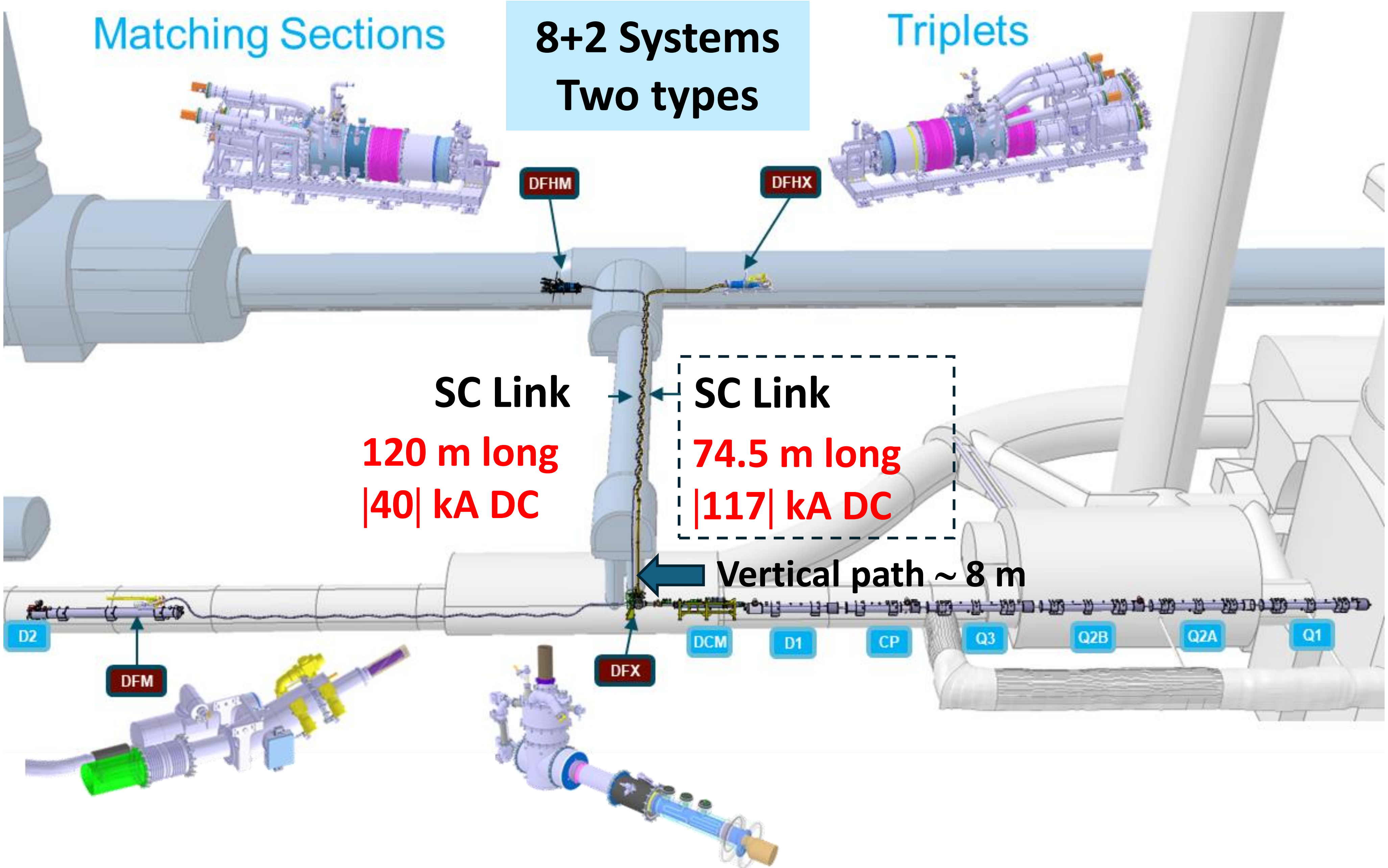
The HL-LHC Project

The main objective of HiLumi LHC Design Study is to extend the LHC lifetime by **another decade** and to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

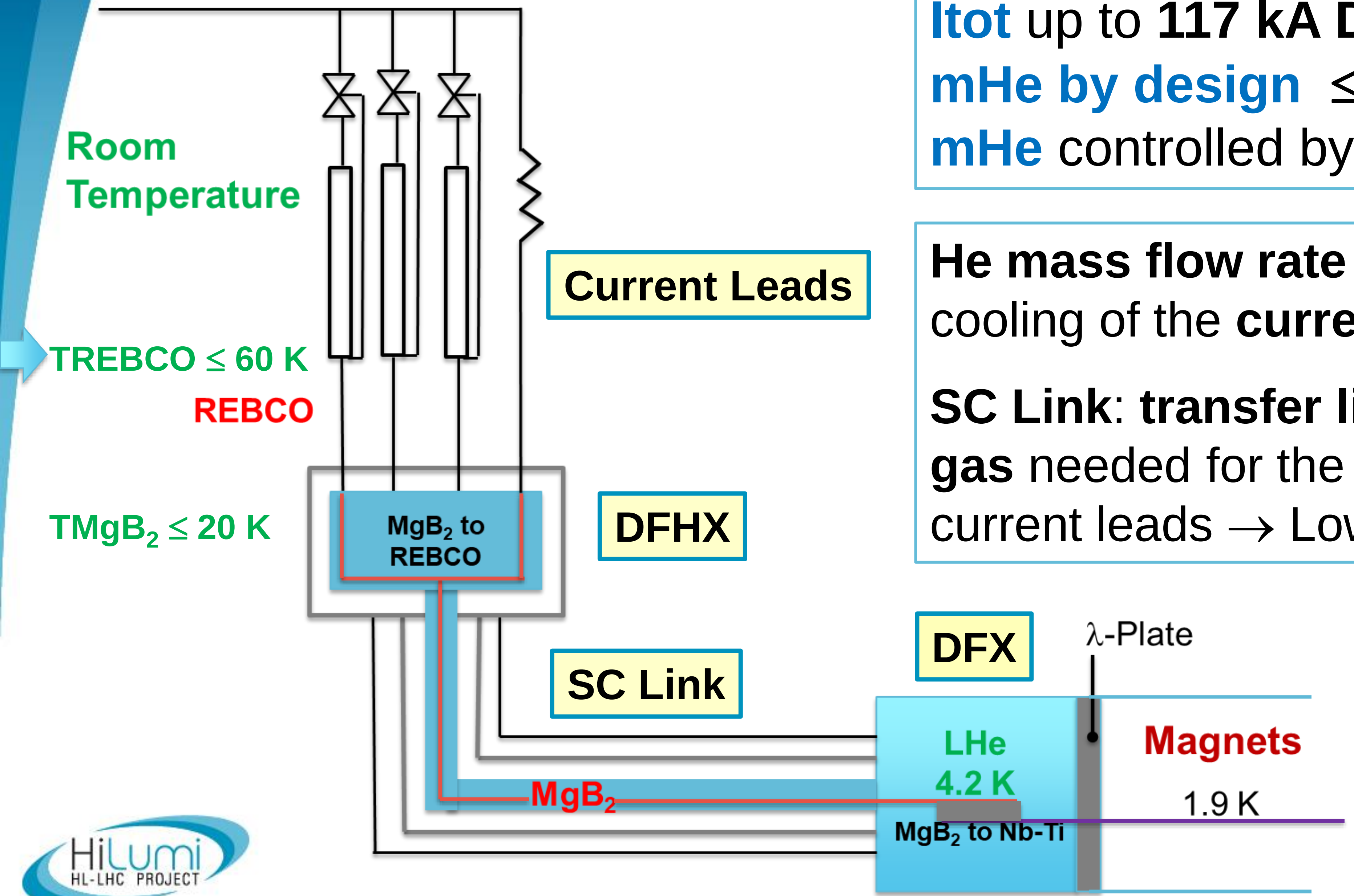
A peak luminosity of L_{peak} = $\mathbf{5 \times 10^{34}\ cm^{-2}s^{-1}}$ **with levelling**, allowing:

An integrated luminosity of $\mathbf{250\ fb^{-1}}$ **per year**, enabling the goal of $\mathbf{L_{int} = 3000\ fb^{-1}}$ twelve years after the upgrade.
This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Powering the HL-LHC magnets



Cold Powering System for HL-LHC Magnets



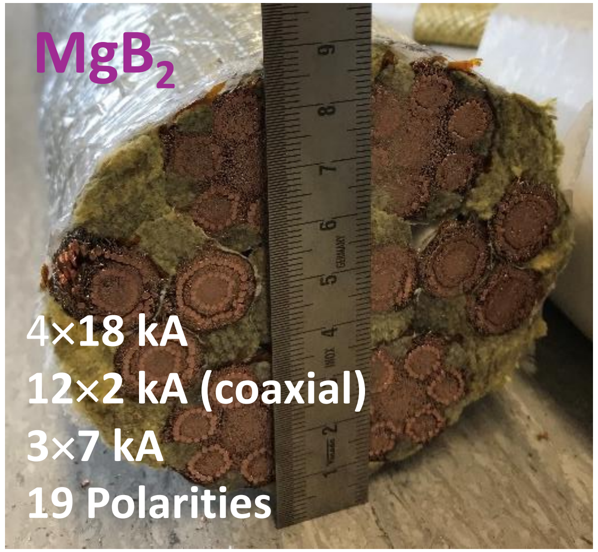
Itot up to **117 kA DC**
mHe by design ≤ 5.5 g/s
mHe controlled by **TREBCO**

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

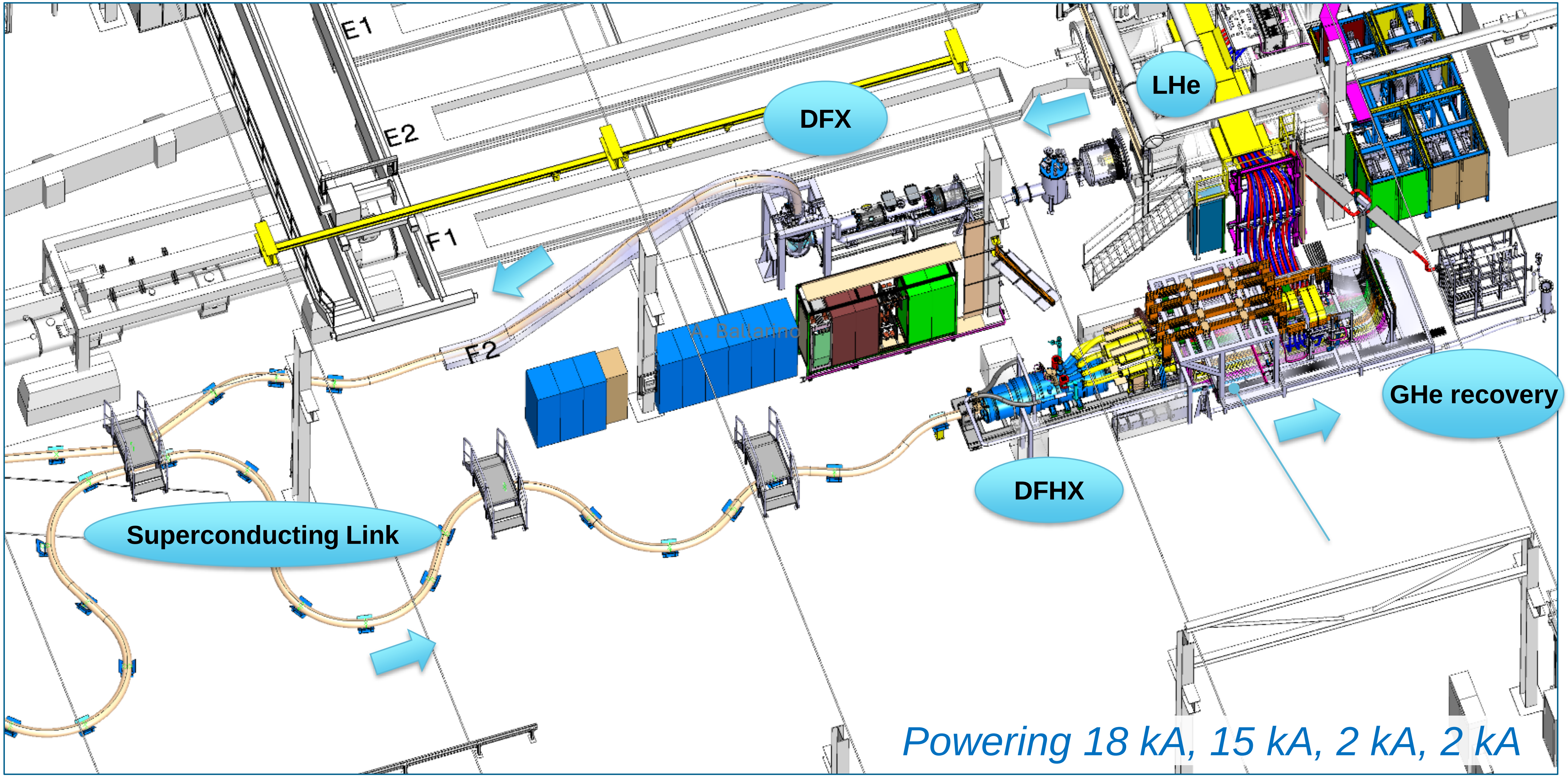
The Superconducting Link for HL-LHC

| 117 | kA @ 25 K
Φ ~ 90 mm, ~ 25 kg/m



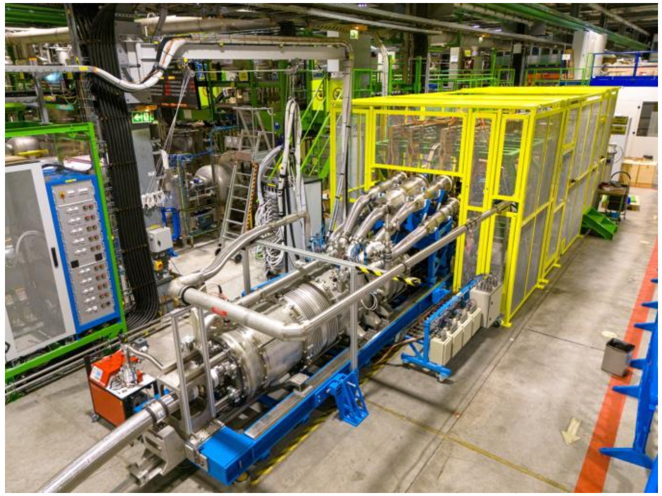
MgB_2 wire produced at **ASG Superconductors**
Superconducting Link cryostat produced at **Cryoworld**
MgB_2 cabling performed at **ICAS/TRATOS**

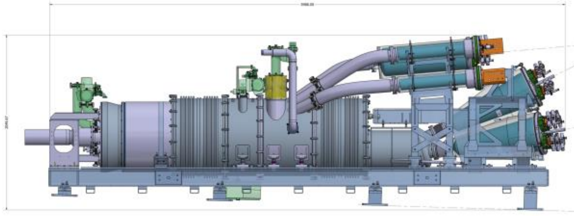
Cold Powering System in the SM-18



Cold Powering System in the SM-18

DFHX





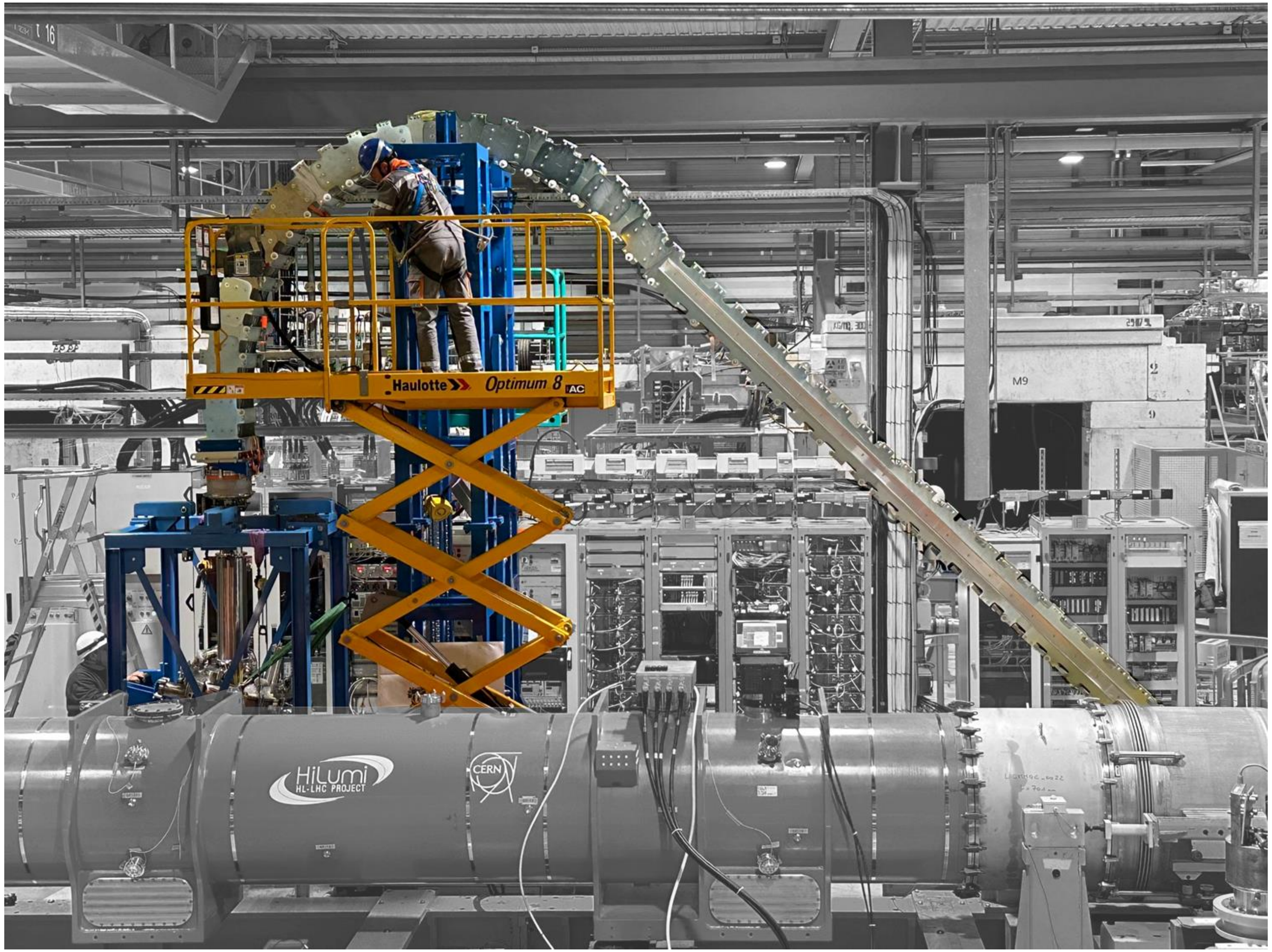
Ltot = 5.5 m

Φext ~ 1 m

19 Current Leads

Instrumentation signals: 304 voltage taps and 105 temperature sensors

Vertical Path of Superconducting Link



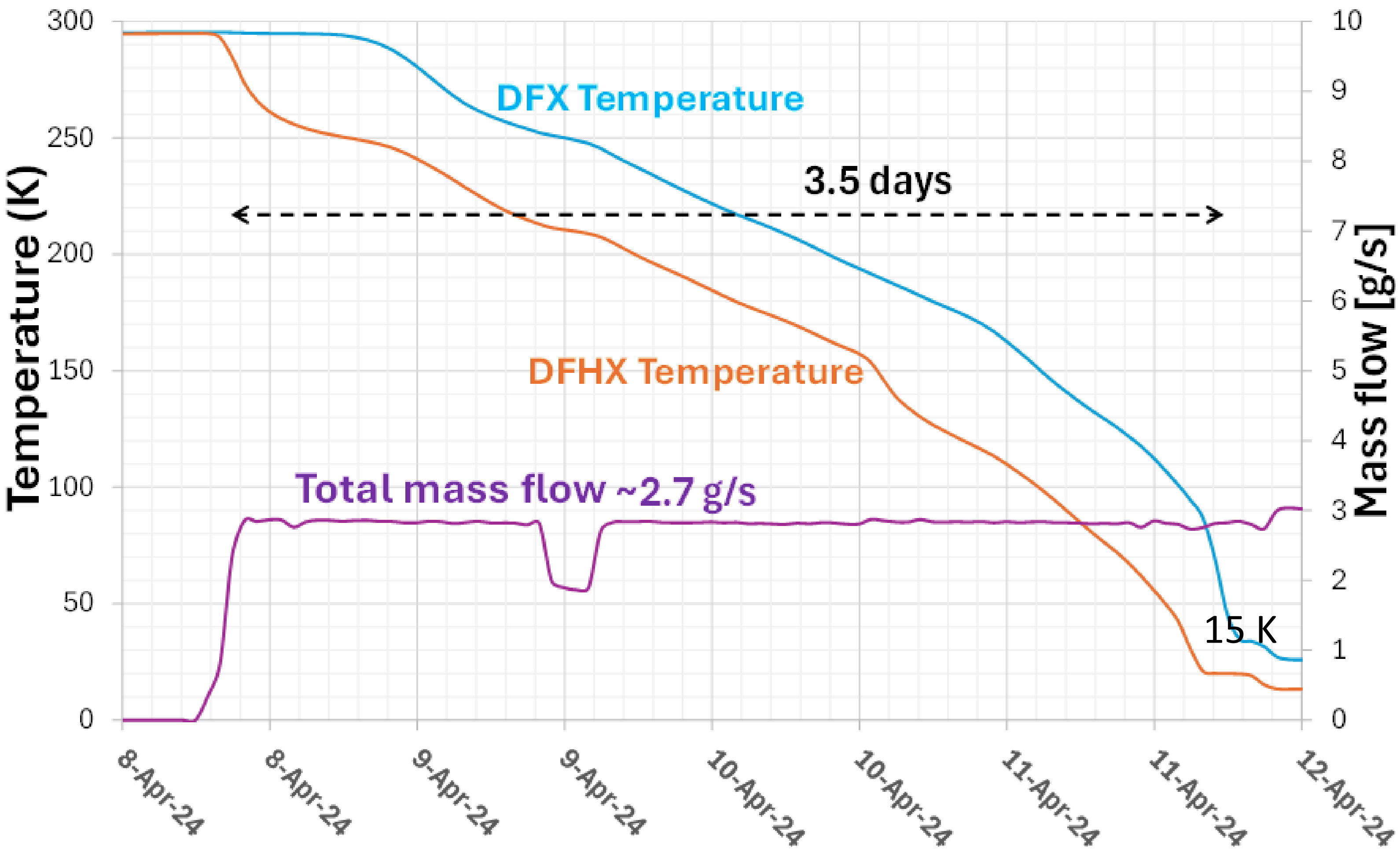
Cool-down

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

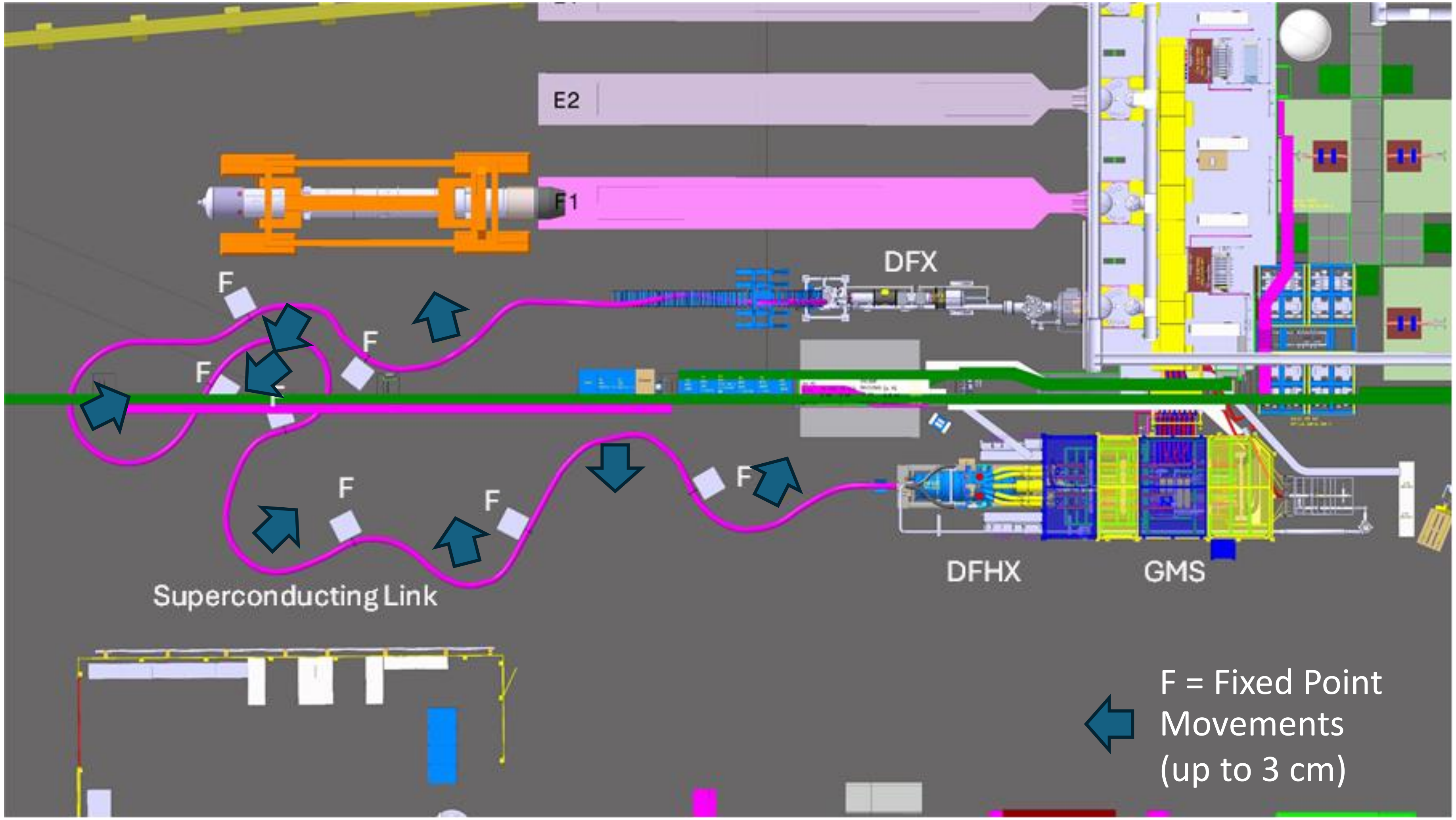
$\Delta T \leq 50$ K
from RT to 160 K

$\Delta T \leq 70$ K
from 160 K to 15 K

m = 2 g/s - 3 g/s

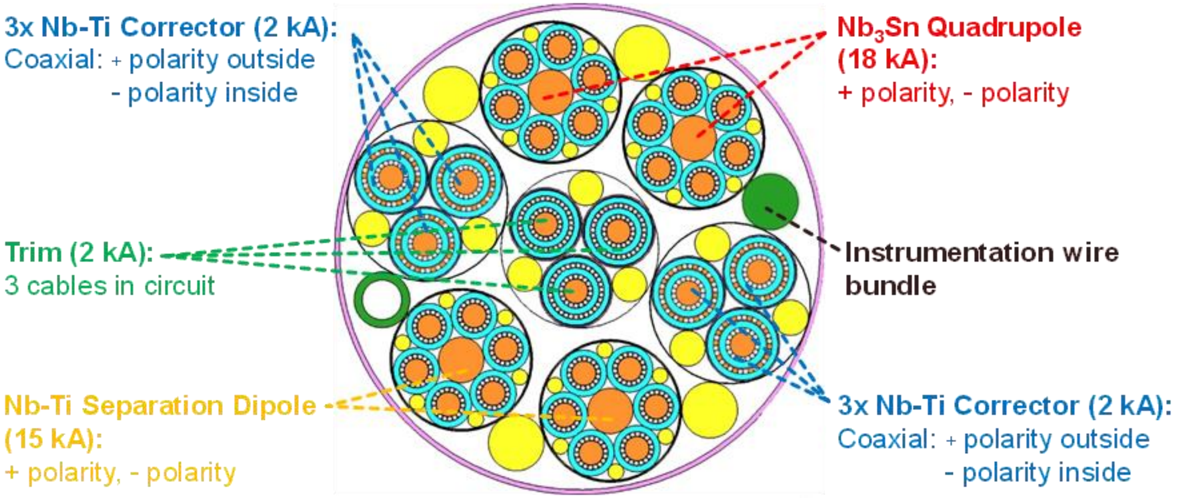


Dealing with Thermal Contractions



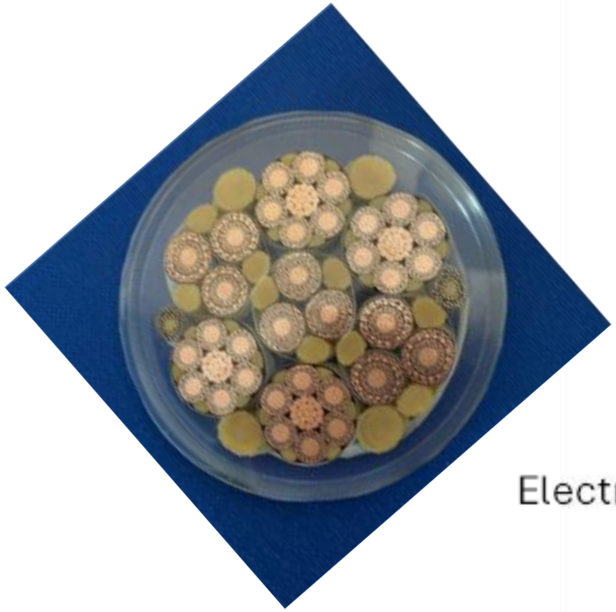
Two thermal cycles (from room temperature to cryogenic conditions) **followed by powering** of all circuits. Repetitive performance

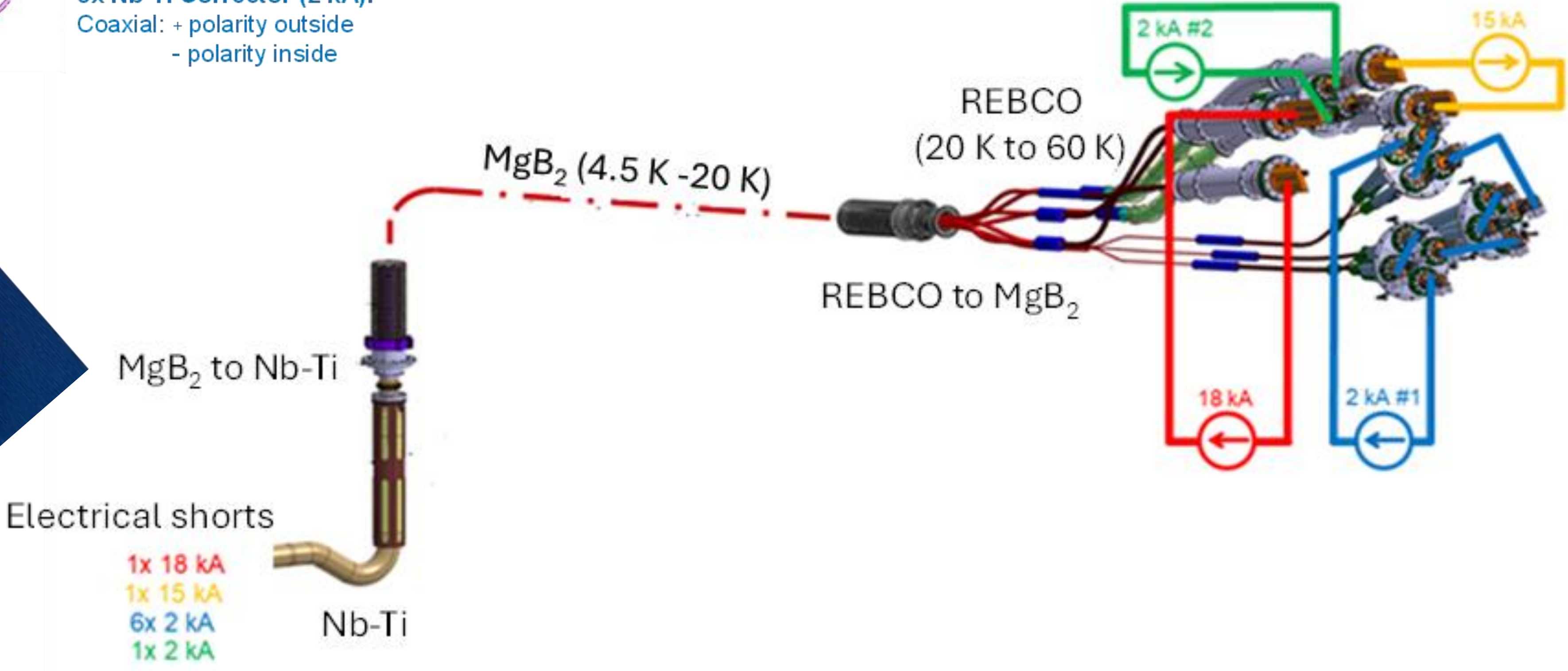
Powering Scheme



Four power converters:

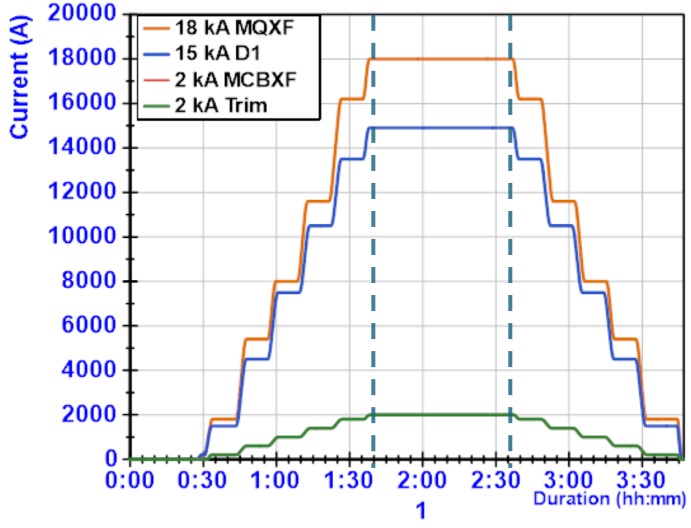
18 kA – I_{HL-LHC} = 16.23 kA (Nb_3Sn quadrupole)
15 kA – I_{HL-LHC} = 12.11 kA (Separation dipole)
2 kA – I_{HL-LHC} = 2 kA (Trim)
2 kA – I_{HL-LHC} = 1.74 kA (Correctors)

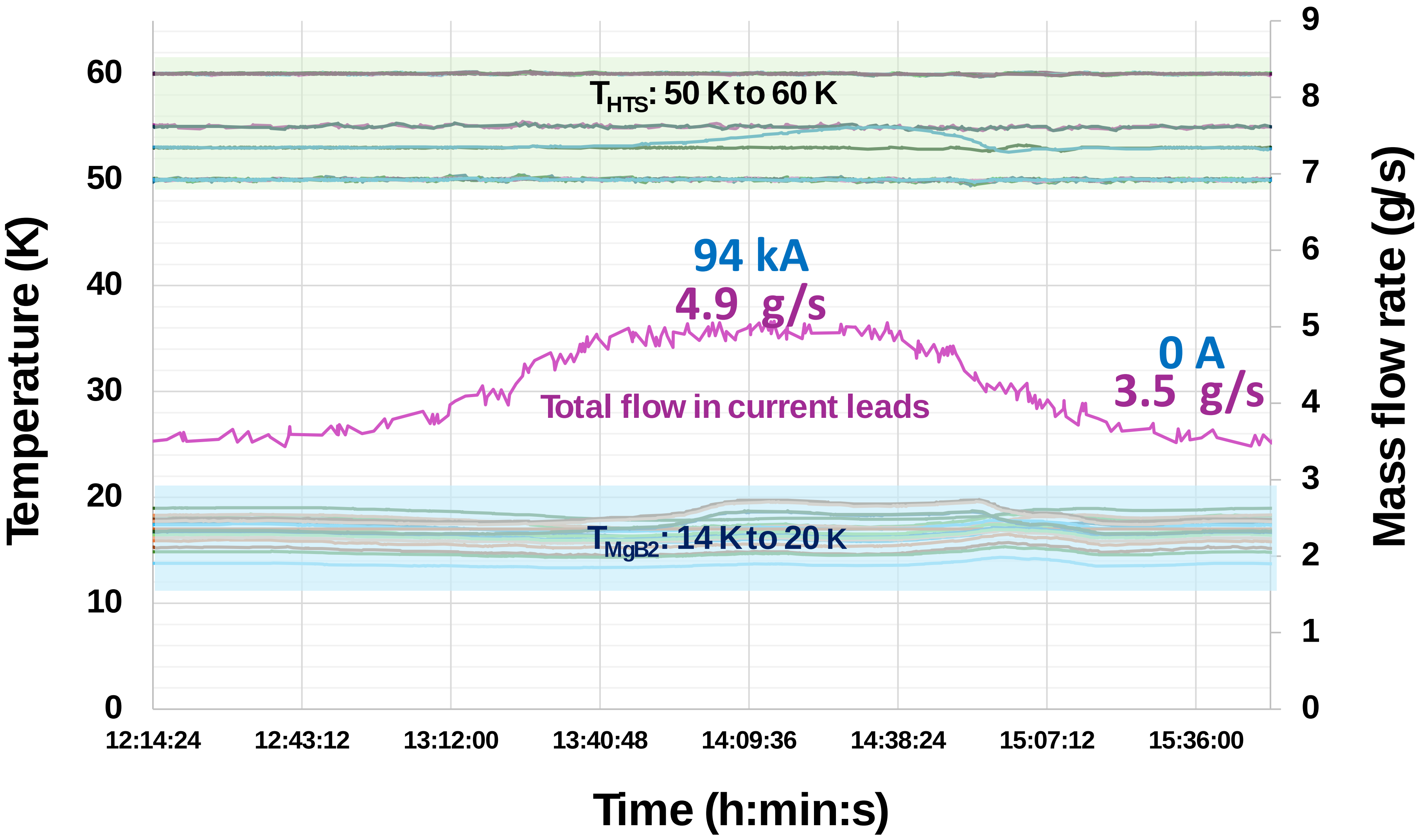




Maximum current delivered by the power converters: **94 kA**

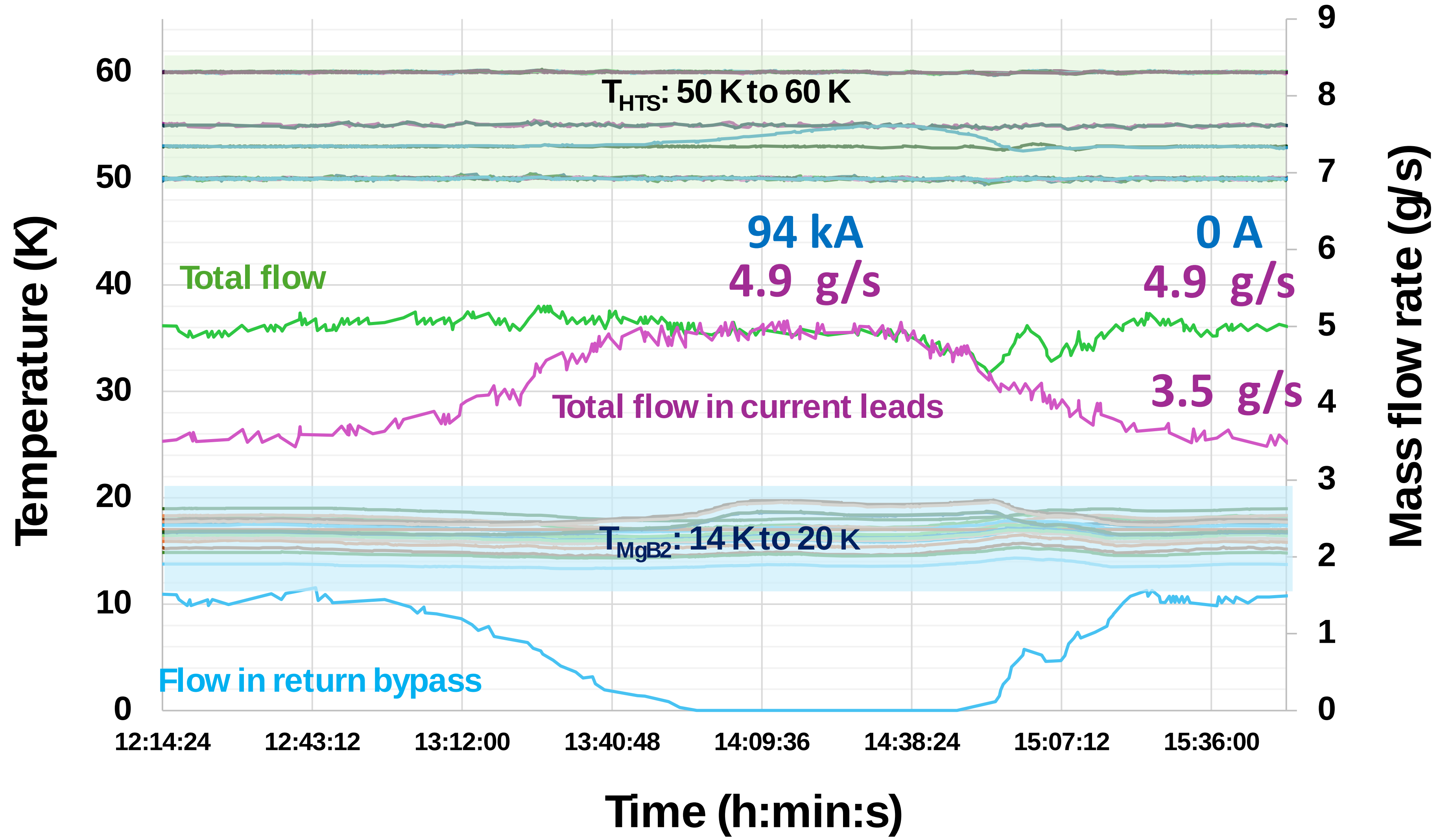
Cryogenic and Electrical Performance





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

Cryogenic and Electrical Performance



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)

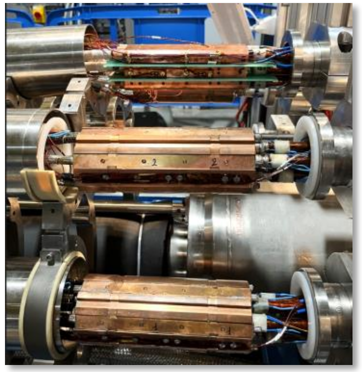
Splices

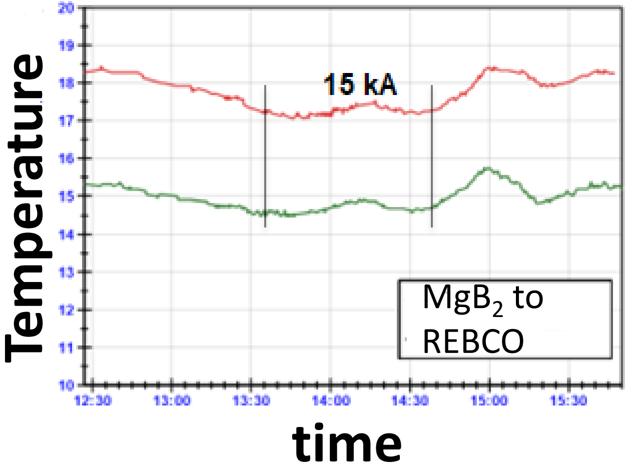
REBCO to MgB_2, GHe @ 20 K — MgB_2 to Nb-Ti, LHe @ 4.5 K — Nb-Ti to Nb-Ti, LHe @ 4.5 K

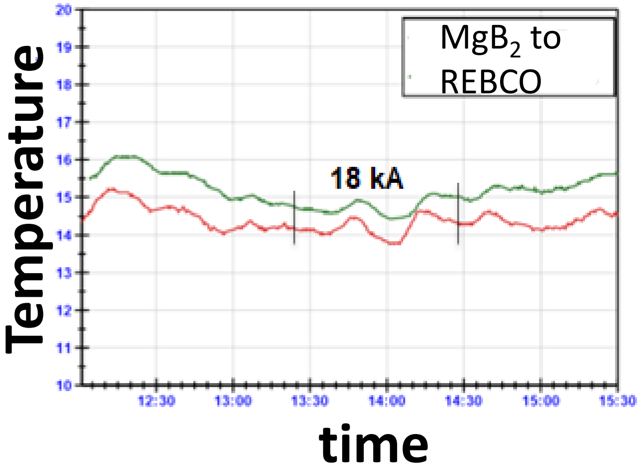
Circuit	REBCO to MgB_2 splices		MgB_2 to Nb-Ti splices		Nb-Ti to Nb-Ti splices	
	R_{splice} measured	R_{splice} expected	R_{splice} measured	R_{splice} expected	R_{splice} measured	R_{splice} expected
18 kA	1.4 ± 0.1 nΩ	1.5 - 2.2 nΩ	1.4 ± 0.1 nΩ	≤ 1.8 nΩ	0.9 ± 0.1 nΩ	≤ 2.0 nΩ
15 kA	1.7 ± 0.1 nΩ		1.4 ± 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**

Capability of operating **without liquid helium supply during 10 minutes** with MgB_2 to Nb-Ti splices immersed in liquid helium

- **Electrical requirement**

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

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 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**)
- About **1500 km of MgB_2 wire** has been procured for HL-LHC, and **20 km of REBCO tape** is being procured
- After an intense R&D at CERN, components of the Cold Powering Systems have been **industrialized.** It is today in an **advanced phase of series production. Installation in the LHC underground** is planned to start in **Q2 2027** – with completion by end 2027

Thanks for your attention !

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Layout of DFX