HiLumi HL-LHC PROJECT

Seminar at Uppsala University

HL-LHC Cold Powering Systems

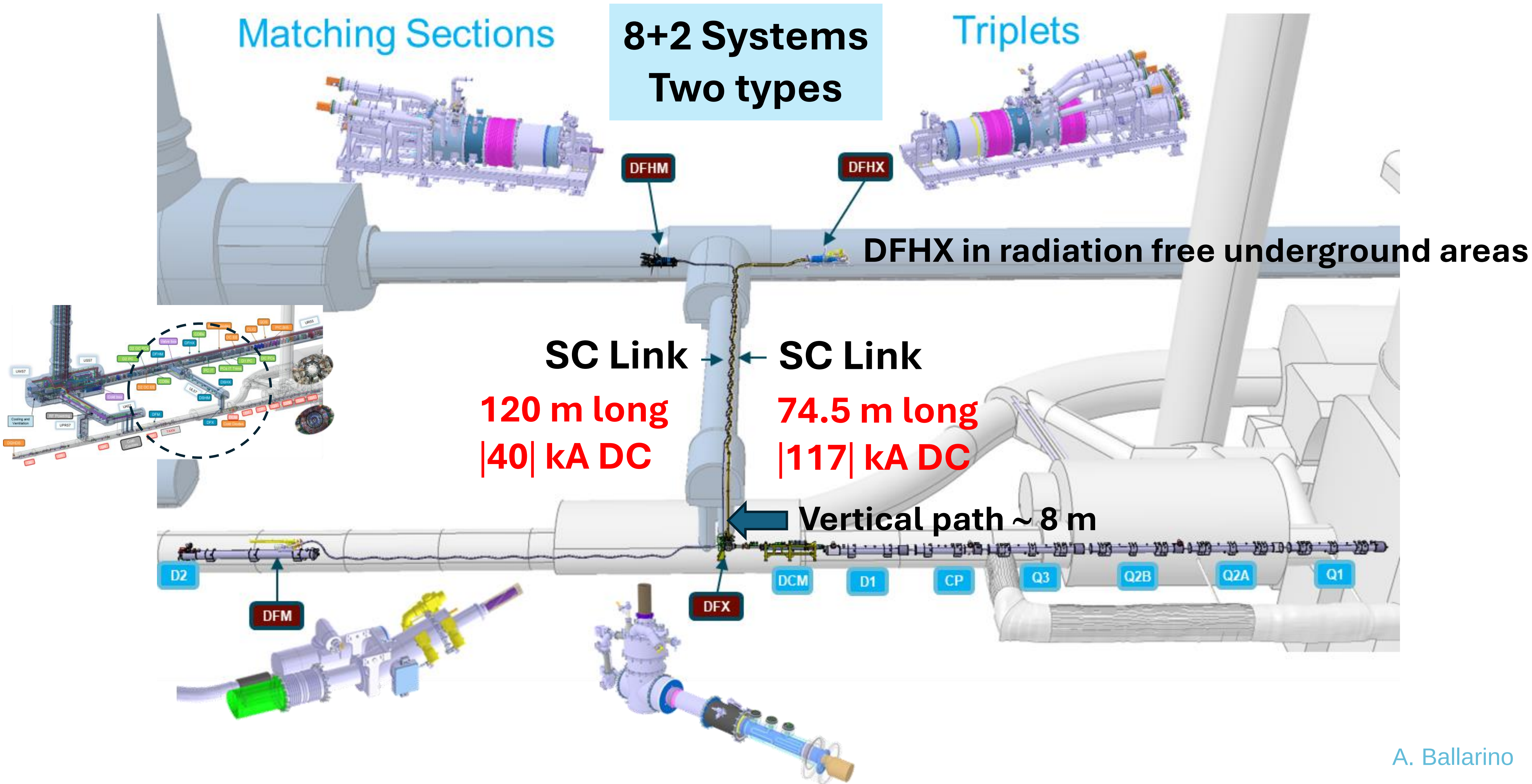
Amalia Ballarino, CERN

for the HL-LHC WP6a and all WP6a contributors

CERN

Uppsala, 9 December 2024

Powering the HL-LHC magnets



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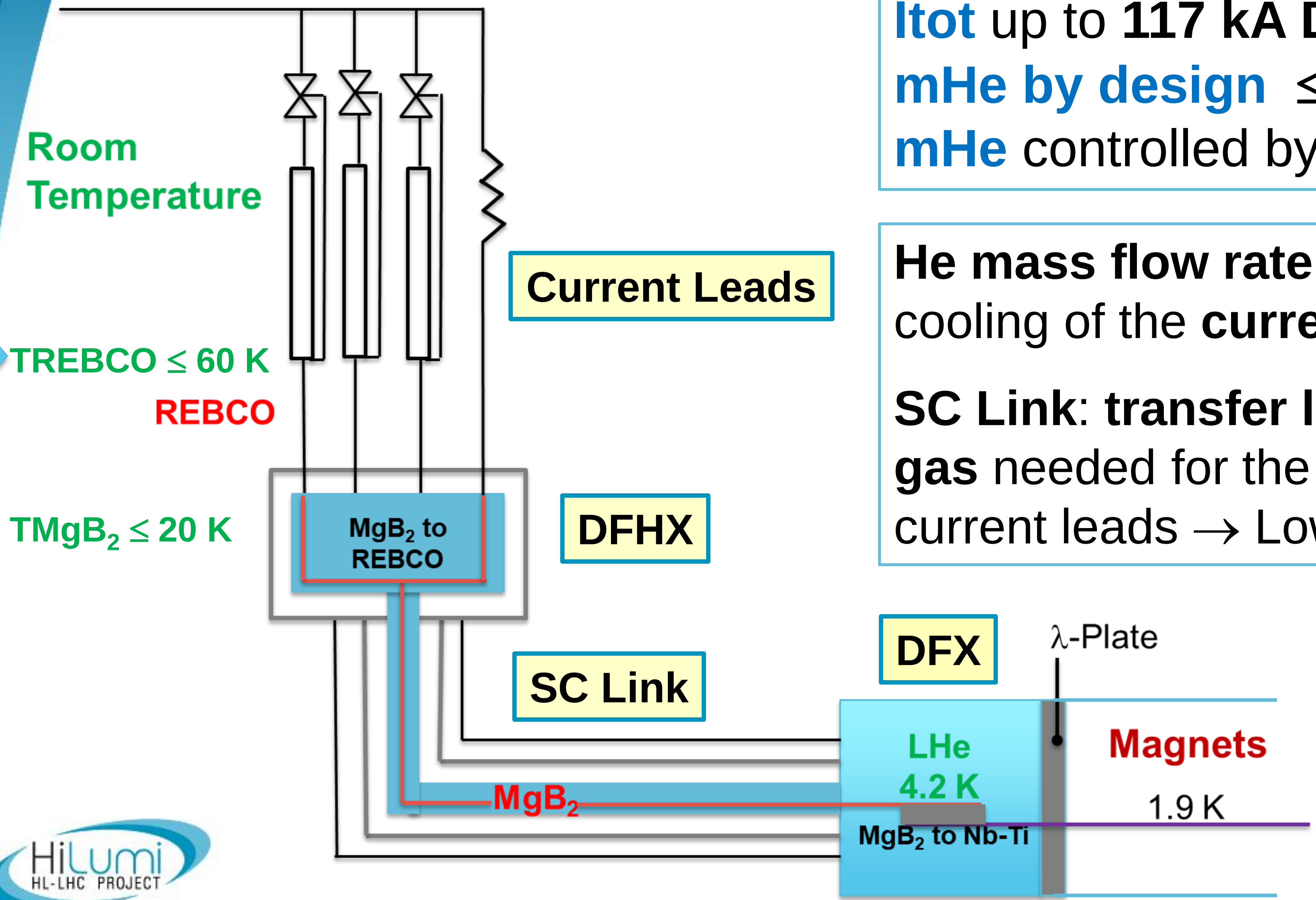
Powering the HL-LHC magnets



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

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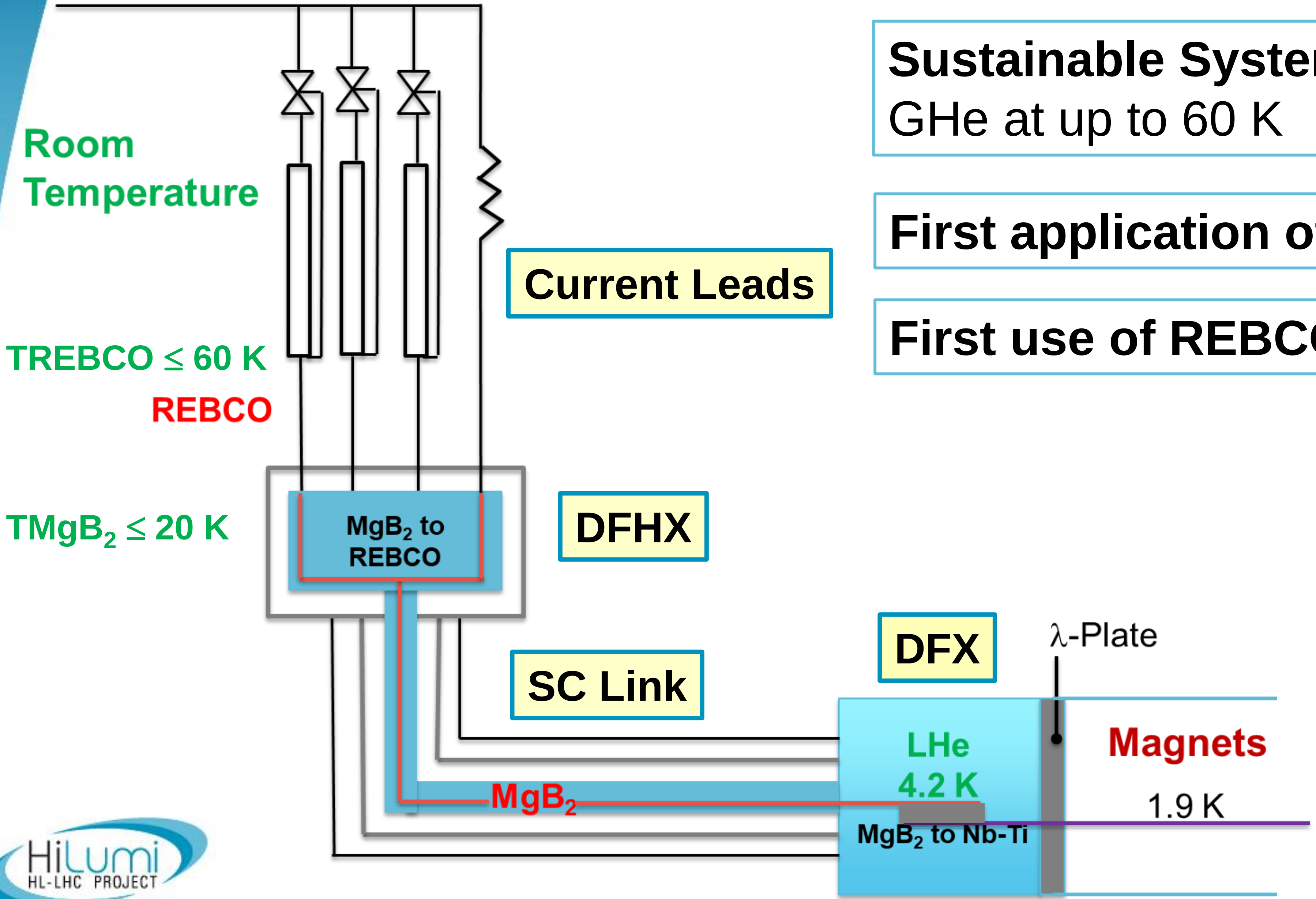
Powering the HL-LHC magnets

Sustainable System operated with GHe at up to 60 K

First application of MgB_2 round wire

First use of REBCO in an accelerator



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High Temperature Superconductors

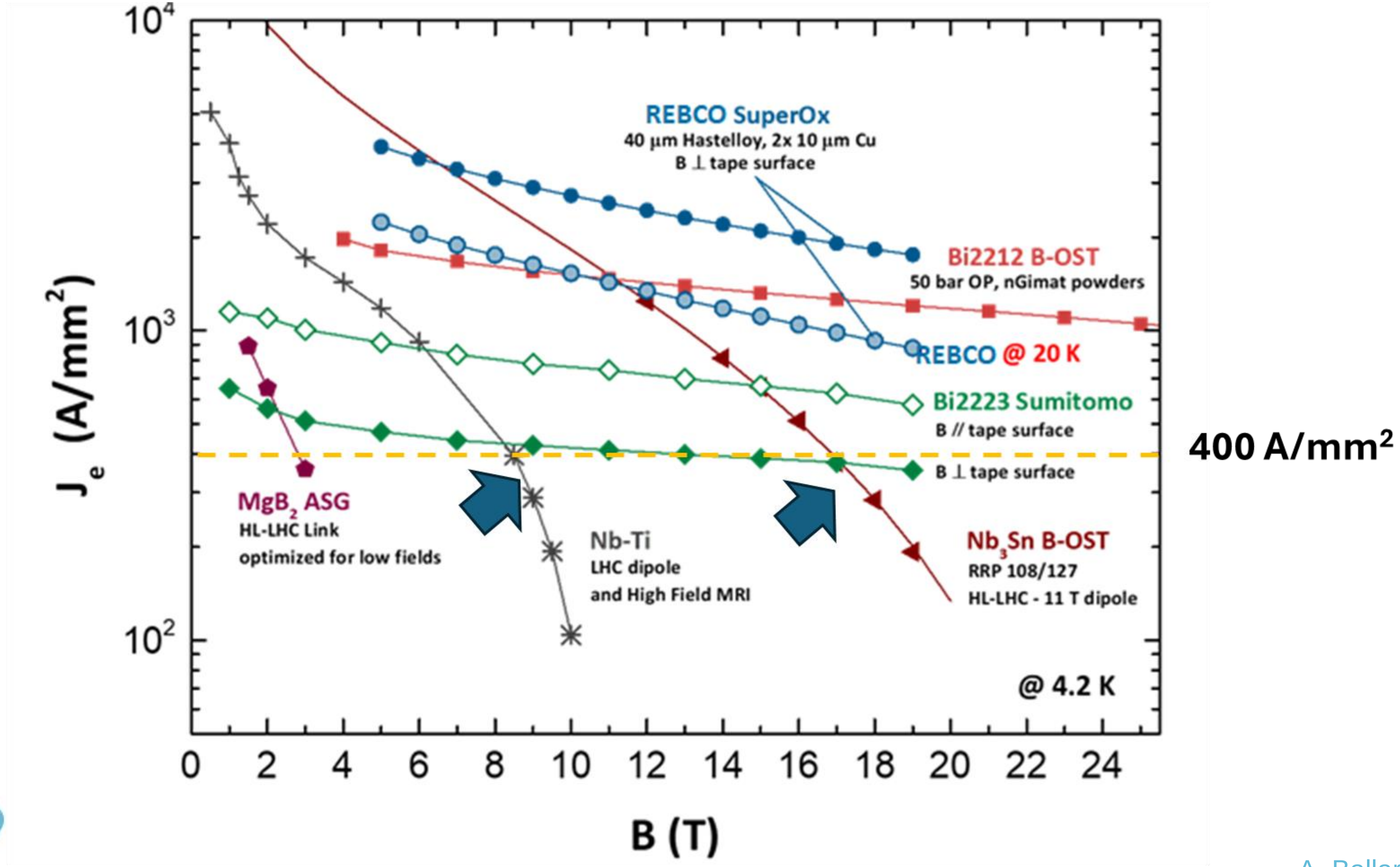
Operation above liquid helium temperature

- MgB_2 (year of discovery: 2001, **Tc ~ 39 K**)
  - **Low** and **medium field** applications (**4.2 K up to ~ 25 K**). A **sustainable alternative** to Nb-Ti

- **REBCO** (year of discovery: 1987, **Tc ~ 93 K**)
  - **Enabling technology** for **high (> 15 T) field** applications (high Jc, no training, no magneto-thermal instability, high MQE,...);
  - **Sustainable technology** for **low and medium field** applications at **higher temperatures** (above liquid helium and **up to liquid nitrogen**)

Higher operating temperatures: operational temperature margin, indirect or gas cooling

Superconductors: LTS vs HTS at 4.2 K



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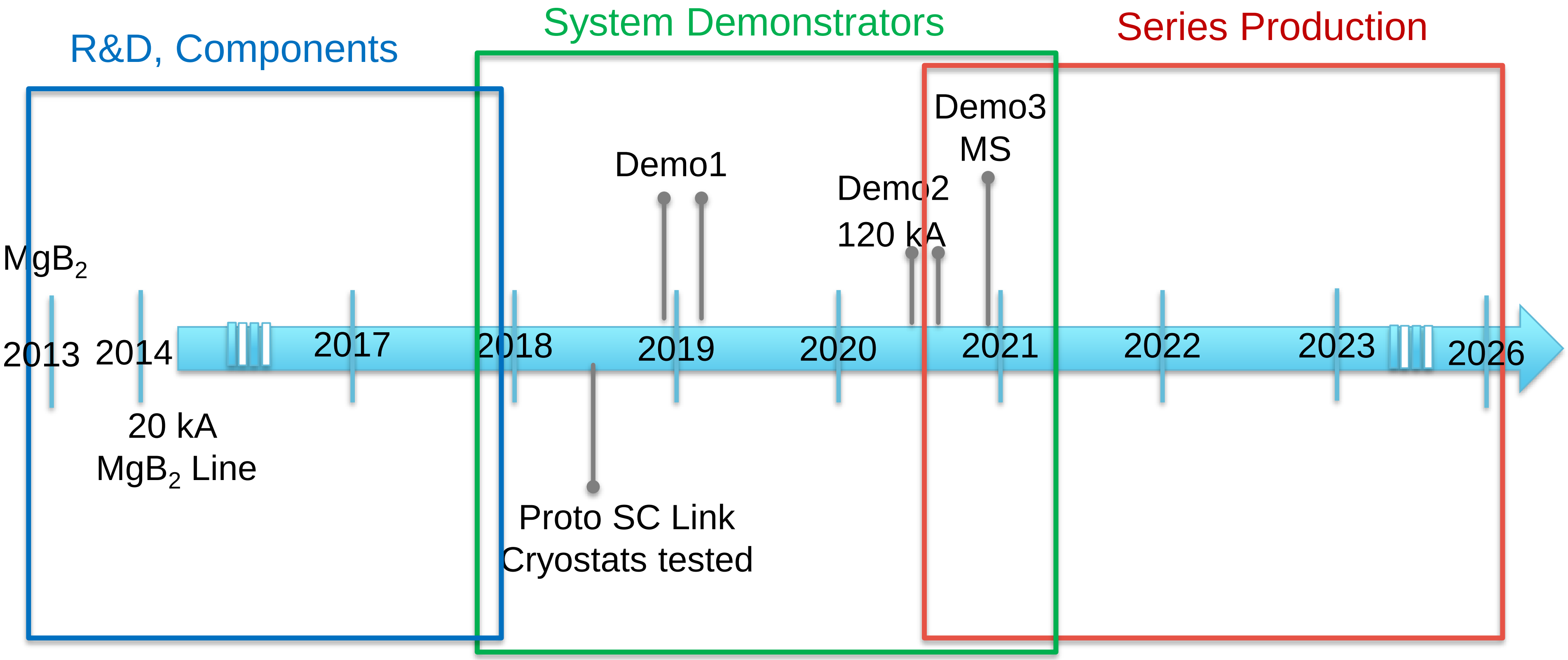
R&D Timeline and Key Developments



Today most of the series components have been produced

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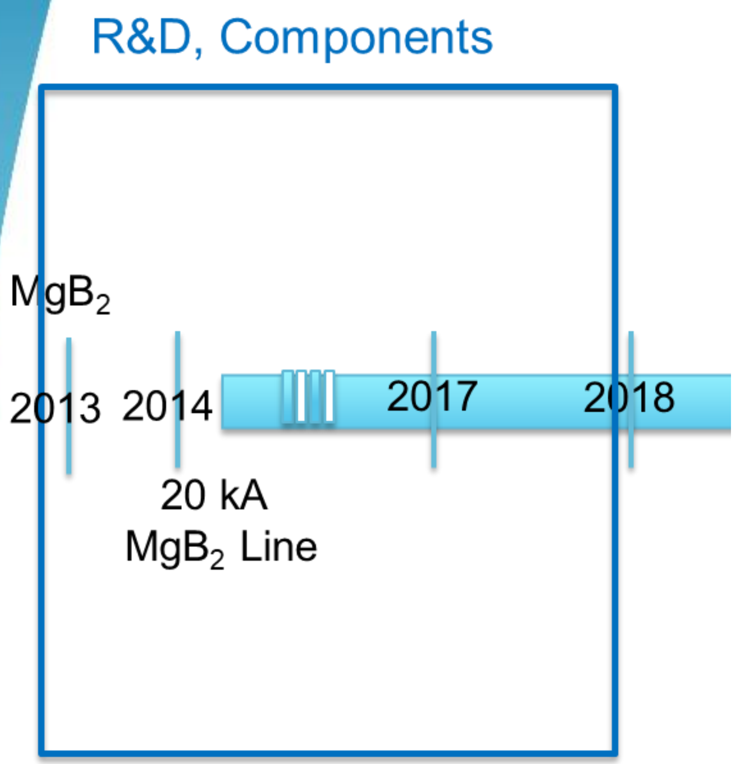
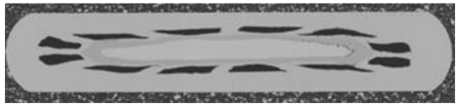
Key Developments



- **MgB_2 Wire** ASG SUPERCONDUCTORS

3.6×0.67 mm^2



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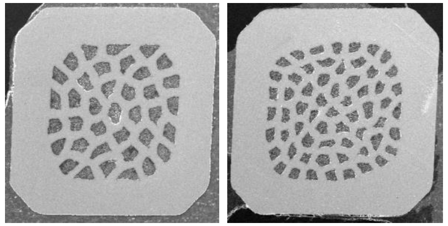

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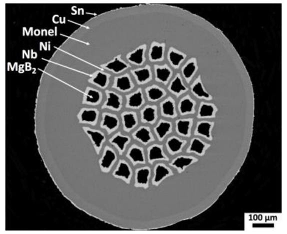
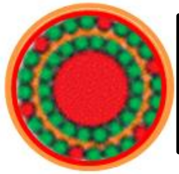
Φ = 1 mm



- **MgB_2 Cables at CERN**

20 kA @ 25 K
Φ~24 mm

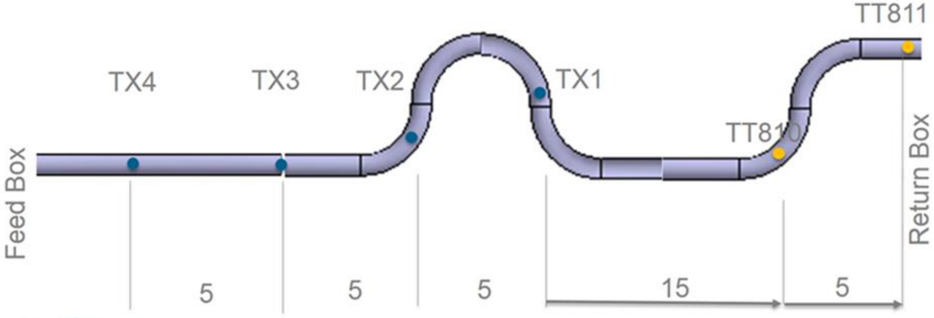


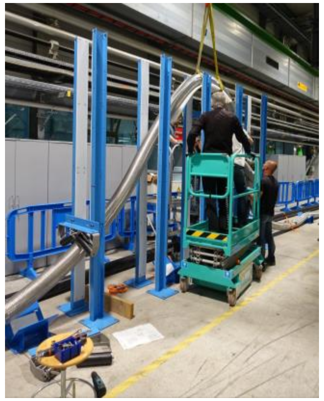
± 2 kA @ 25 K
Φ~11.5 mm

7 kA @ 25 K
Φ~10.5 mm

React & Wind Technology

- **2-Wall Flexible Cryostats**





Q < 1.5 W/m @ 4.5 K
RB ≤ 1.5 m
Δp ≤ 10 mbar with 10 g/s of GHe @ 25 K

Cryoworld, Criotec, Nexans

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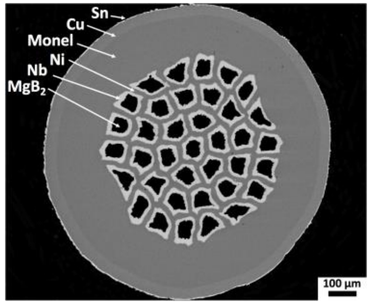
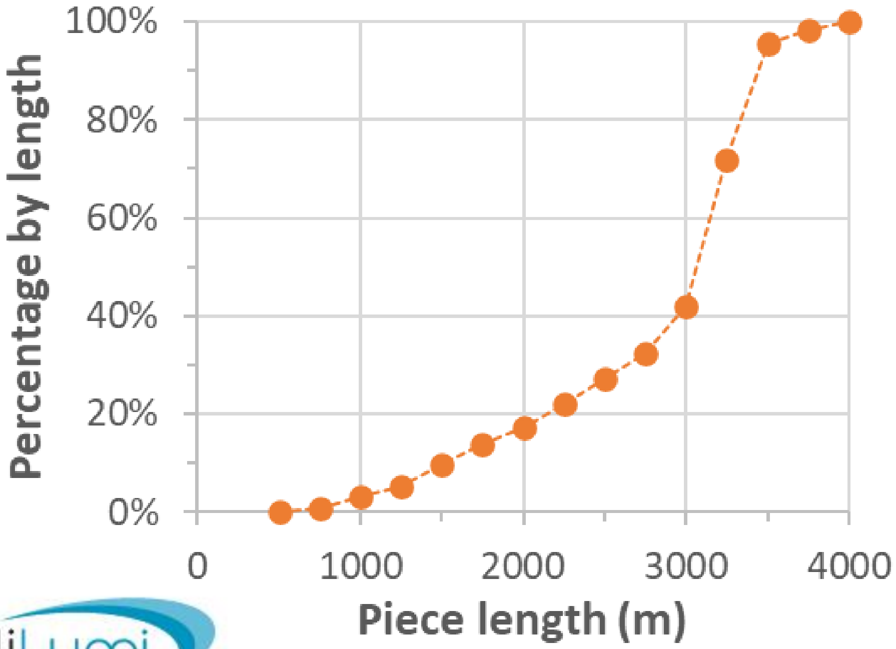
Key Developments – MgB_2



Φ = 1 mm
37 MgB_2 filaments
Tw = 100 mm

Average piece length 2435 m



Wire diameter	mm	1	± 0.2
Wire ovality	mm	≤ 0.015	
Cu fraction	%	≥ 12	
Cu coating	µm	≥ 30	
Filaments eq. diameter	µm	≤ 60	
Filaments Twist Pitch	mm	≤ 100	± 5
Tensile strain at RT *	%	≥ 0.28	
Bending radius after HT *	mm	≤ 100	
Unit Length	m	≥ 500	+1, -0
RRR (Cu)	-	> 100	
Ic(25 K, 0.9 T)	A	≥ 186	
Ic(25 K, 0.5 T)	A	≥ 320	
Ic(20 K, 0.5 T)	A	≥ 480	
n-value@ 25 K and 0.9 T	-	> 20	

Electrical performance within specification (Ic(20 K, 0.5 T) ≥ 480 A)

- **Mean I_c** ~ 20 % above specification
- Consistent trends between **supplier** and **CERN test data** (in different conditions)

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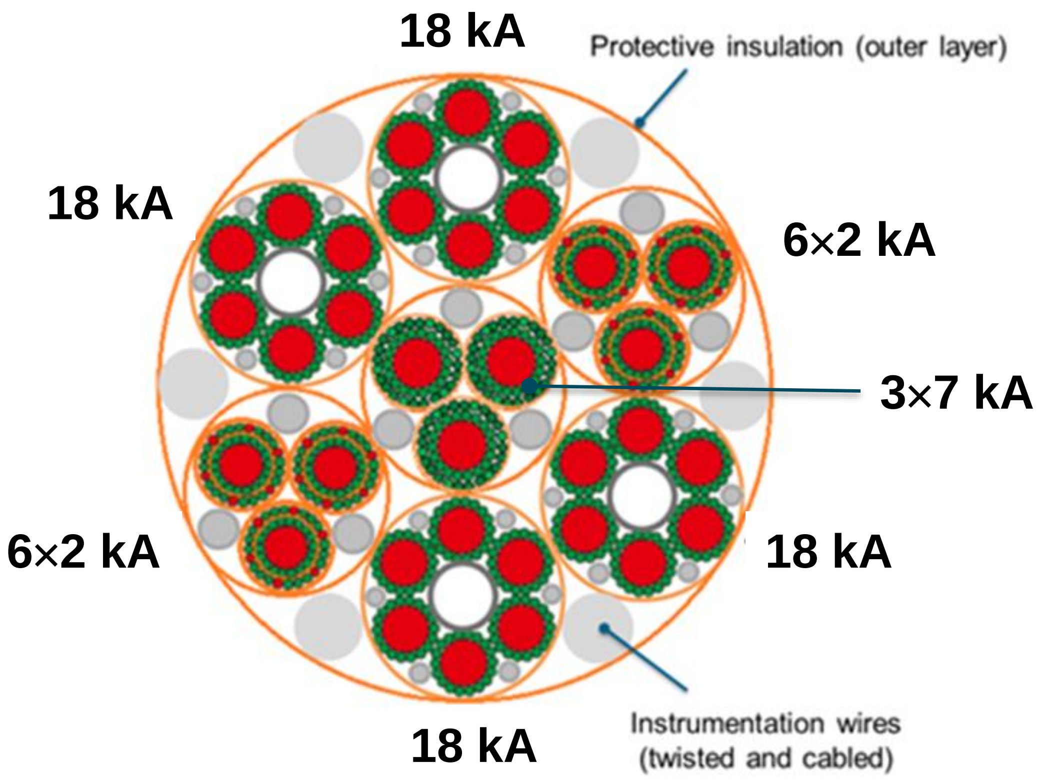
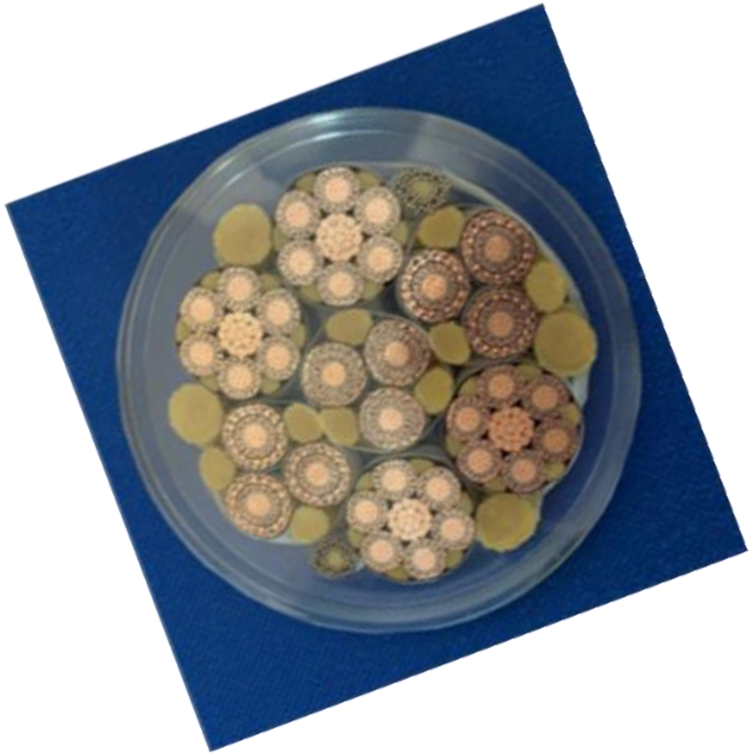
Key Developments





Itot ~ 120 kA, DC **Φ_{ext} ~ 90 mm**

Insulation voltage: **10 kV to 15 kV** in air

Total weight ~ 1.7 ton

Total length ~ 70 m

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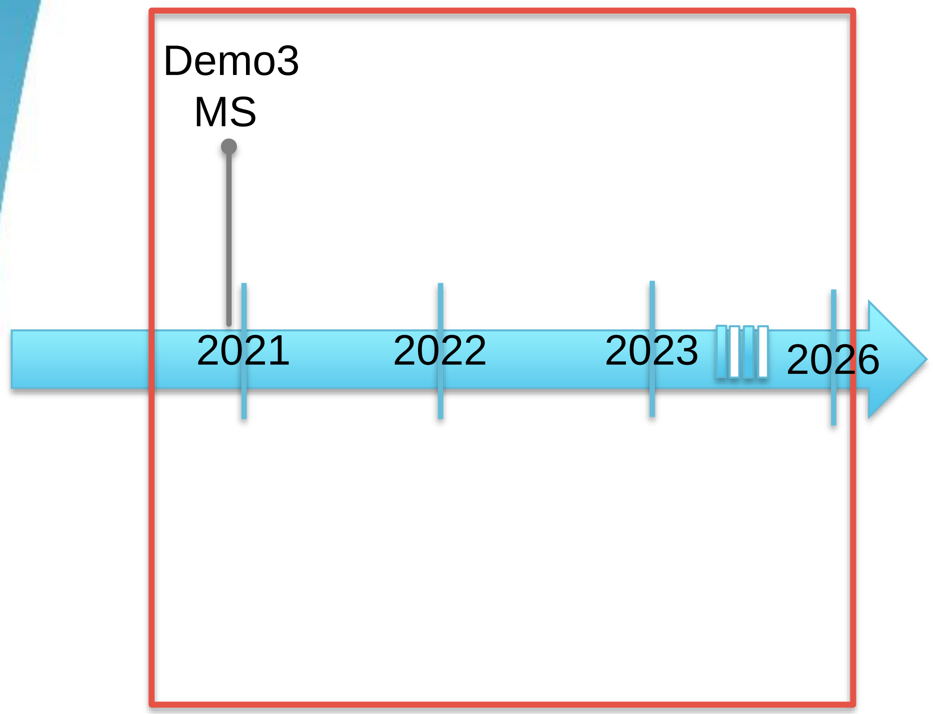
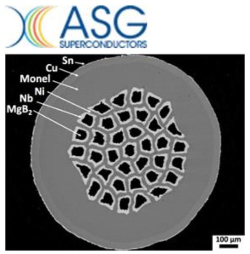
Series Production

Series Production



- **MgB_2 Wire**
  Series completed (1500 km)



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n-value@ 25 K and 0.9 T	-	> 20	

- **MgB_2 Cables** industrialized
  8 out of 10 units at CERN

- **2-Wall Flexible Cryostats** indutrialized
  Series completed

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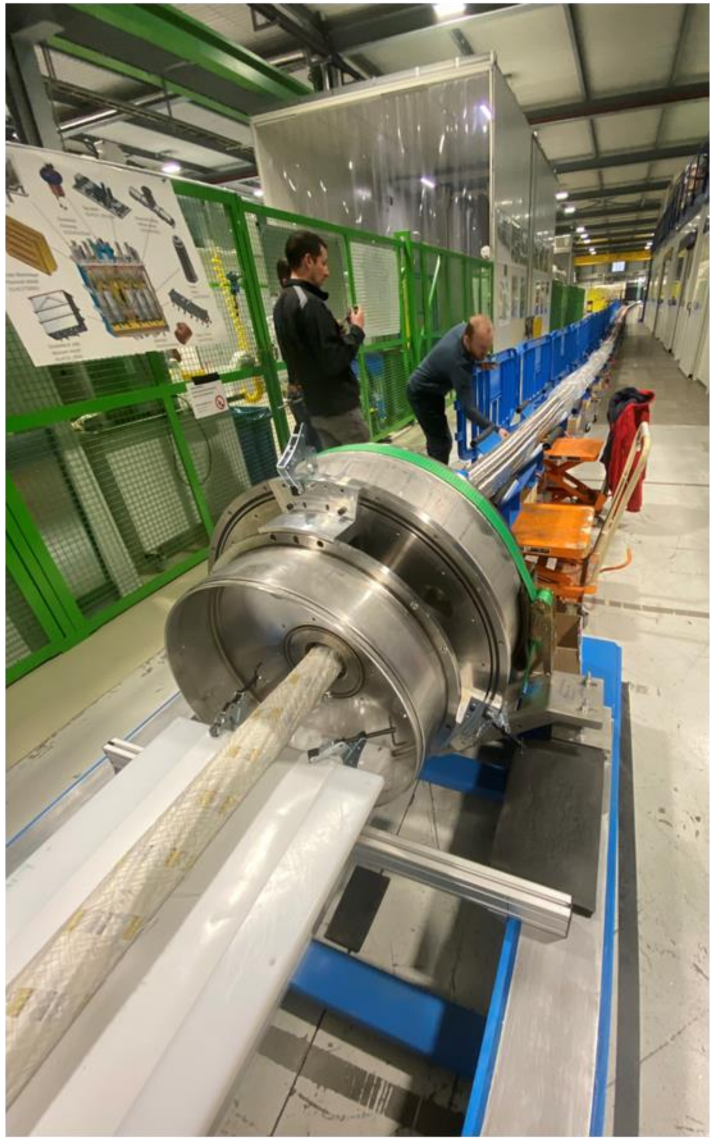
MgB_2 Superconducting Links



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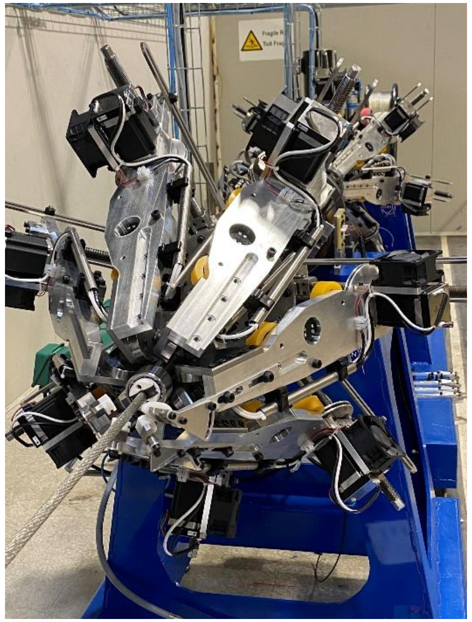
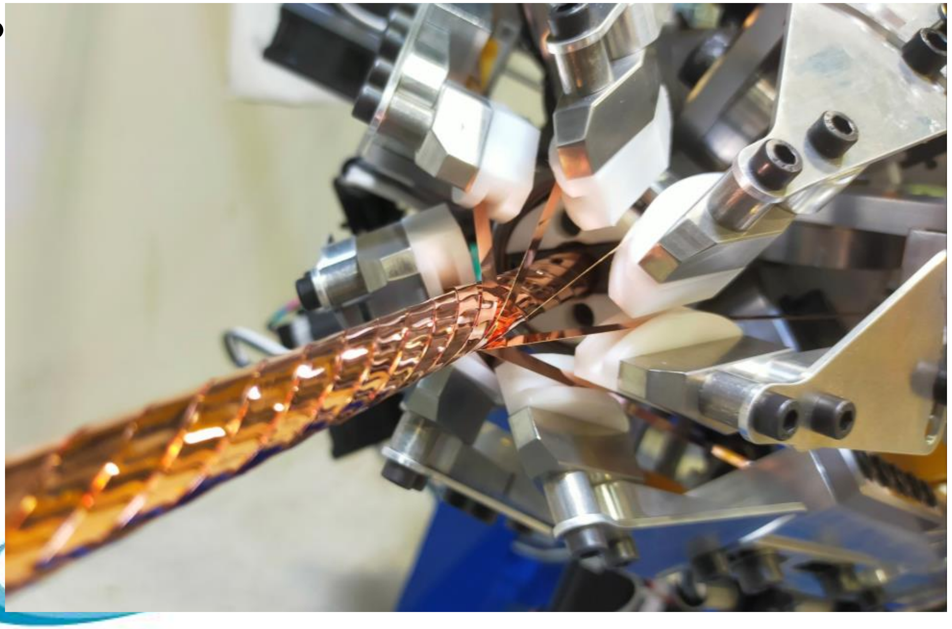
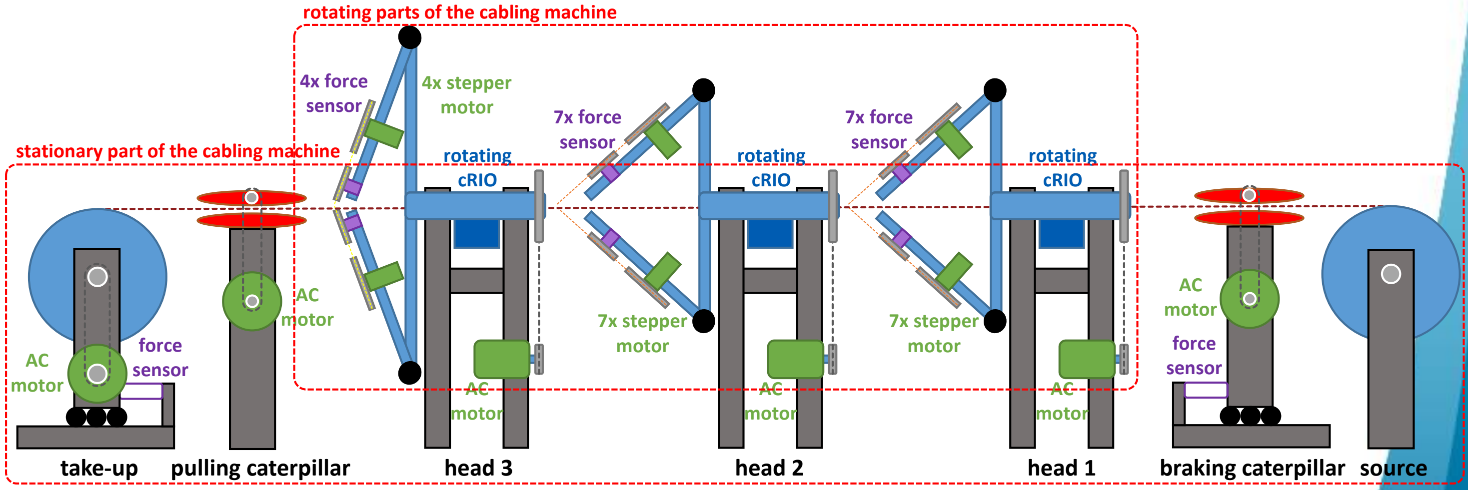
REBCO Cables

- **14 REBCO Tapes** helically wound on braided Cu core
- **Two layers** – each with 7 tapes, wound with opposite direction
- **Polyimide insulation**
- **3 kA @ 60 K and 0.5 T**
- Individual length of cables: 2 m – 3.5 m
-







REBCO Cables at CERN

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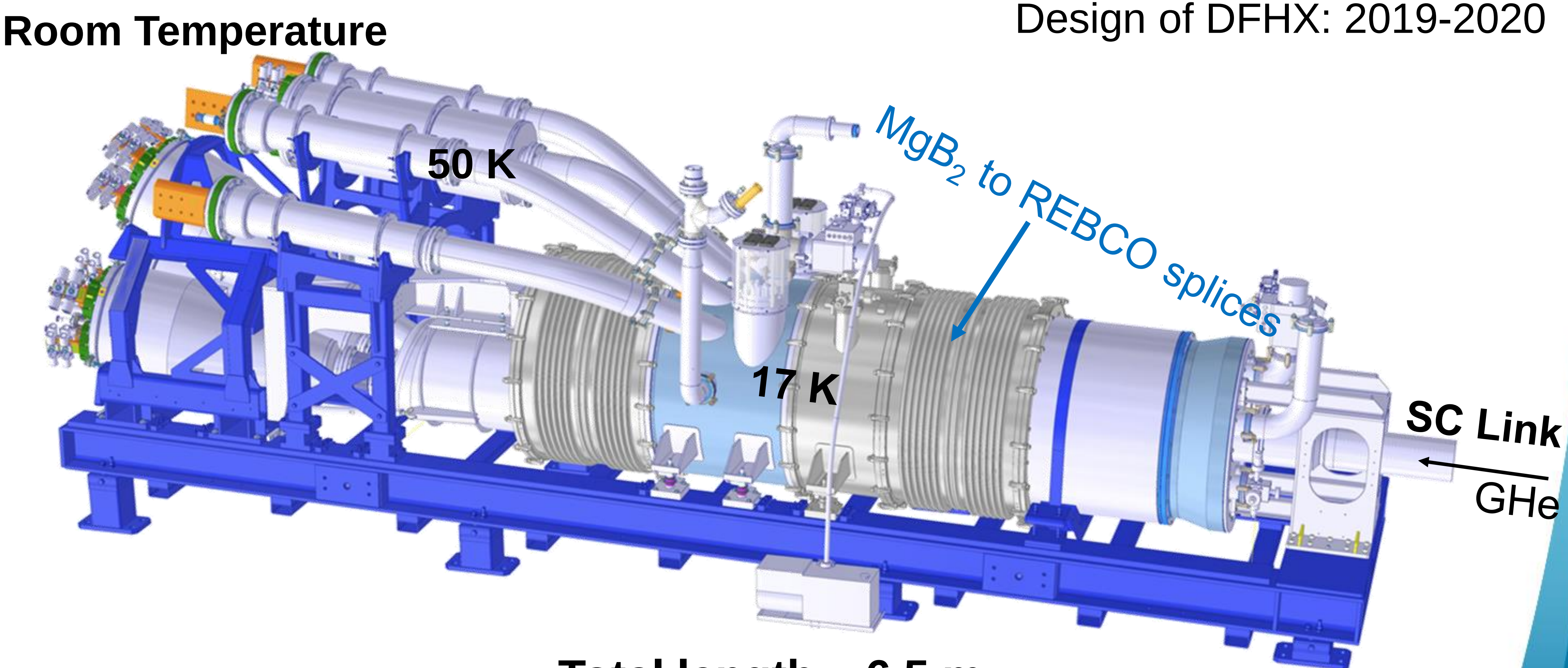
DFH: the warm termination of the SC Link

Design of DFHX: 2019-2020



Total length ~ 6.5 m

Very compact design (thanks to HTS and GHe)

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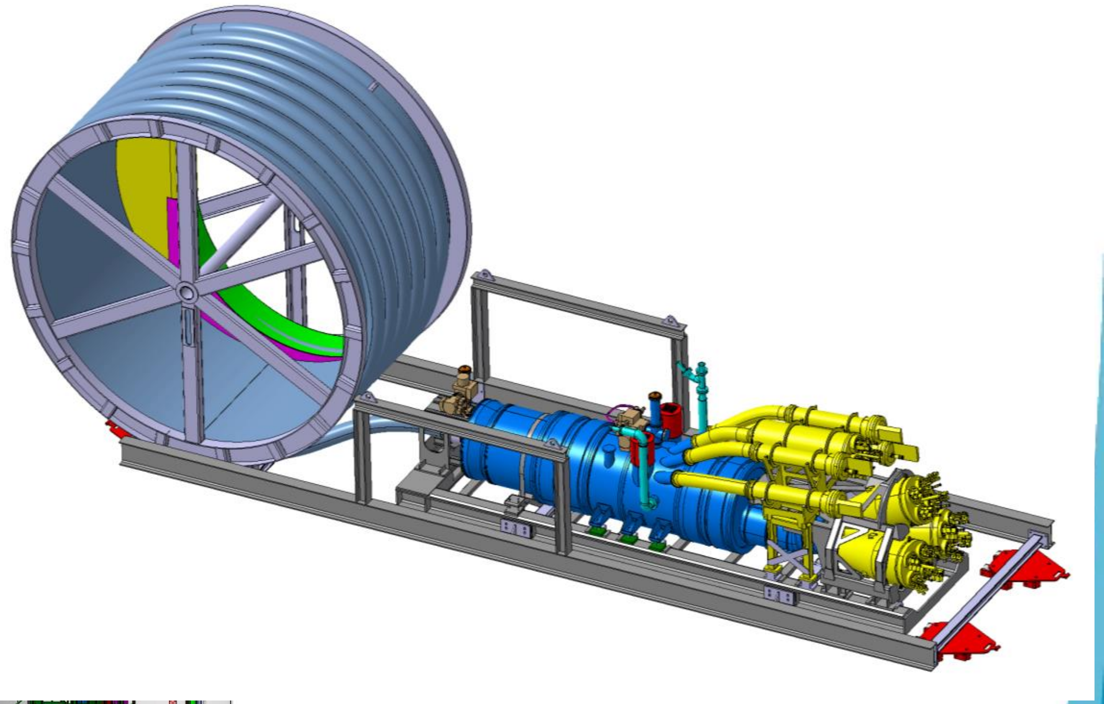
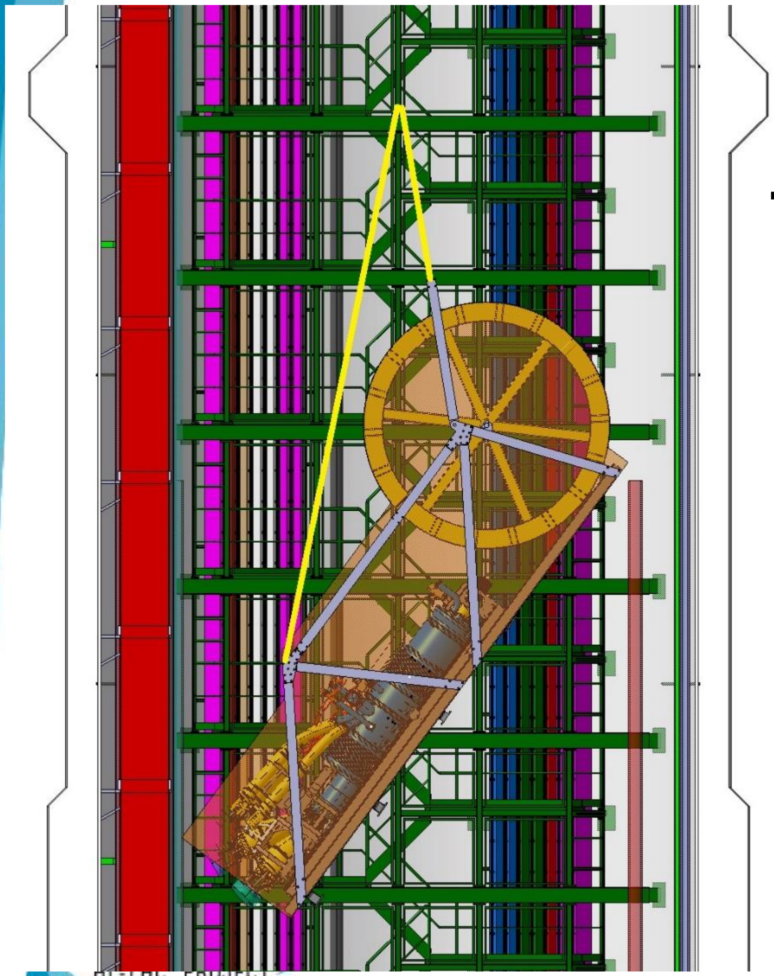
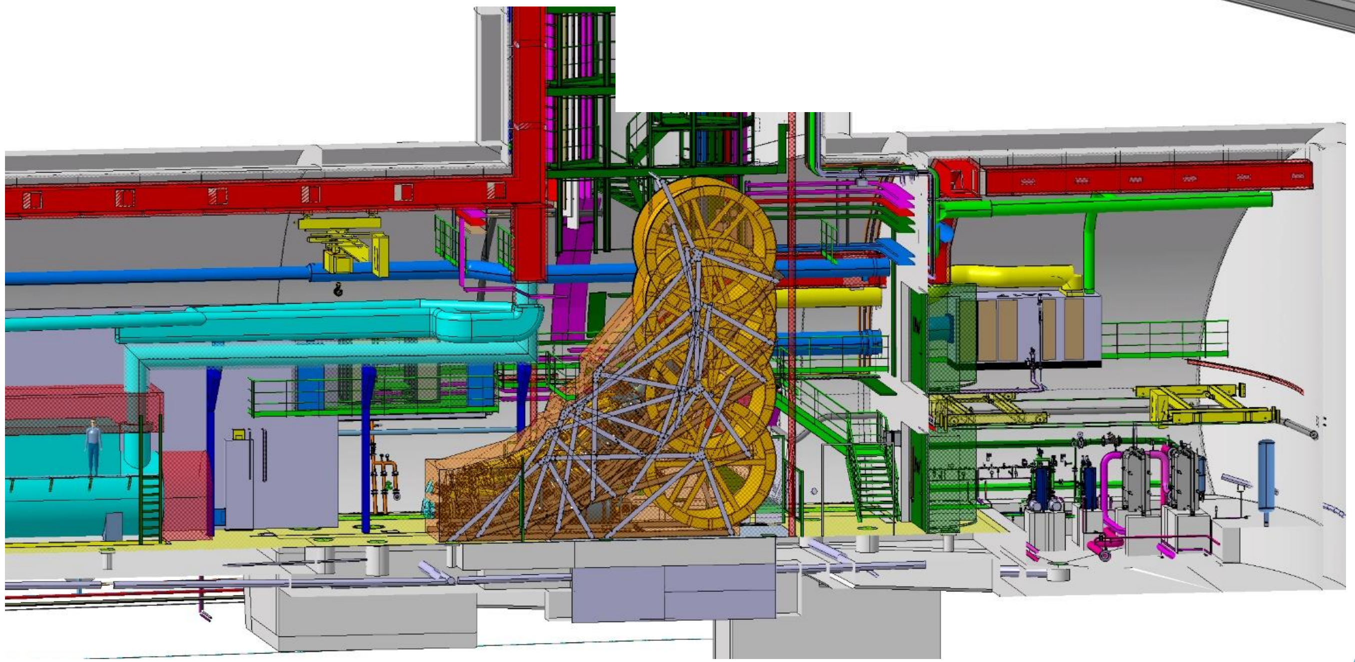
DFH Compactness for Integration

Transported and unspooled in the LHC underground **after full qualification** in nominal operating conditions





Total weight ~ 10 ton



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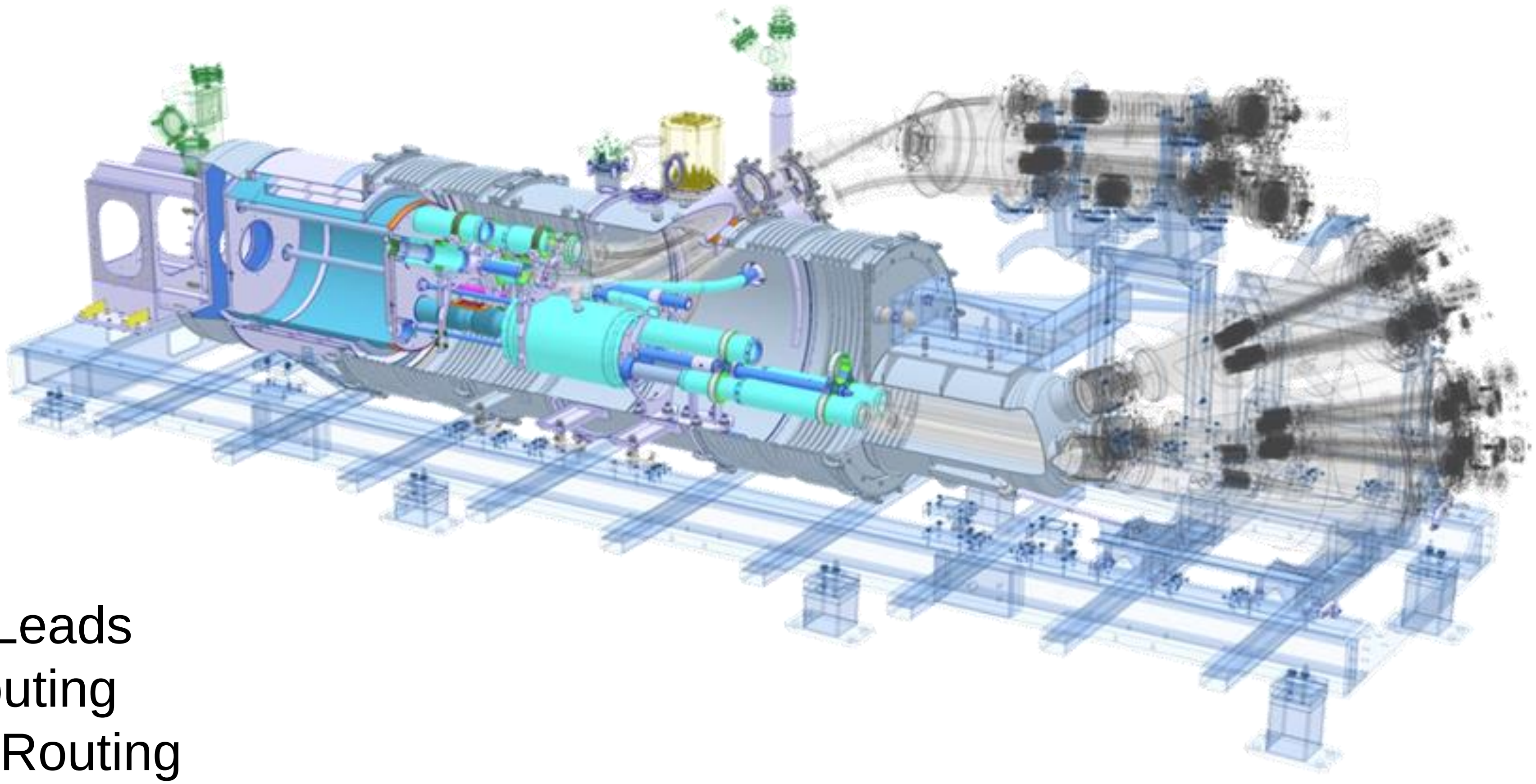
Complexity of DFHX



Current Leads
MgB_2 Routing
REBCO Routing
MgB_2 to REBCO High Current Splices in GHe
Temperature control, GHe distribution and control, Instrumentation

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DFHX and DFHM: a successful story CERN-Uppsala-RFR

- **Collaboration Agreement** between CERN and Uppsala University signed in **January 2022**
- **March 2022**: **Production Readiness Review** for DFHX an DFHM
- In **December 2024**, **all components** (4 DFHX and 5 DFHM) have been manufactured and **delivered to CERN**
- **Discussions** and preparation meetings **started in 2021**. RFR also manufactured mechanical components that are today part of the first DFHX

ADDENDUM No. 1

KE5162/TE/HL-LHC

to

THE MEMORANDUM OF UNDERSTANDING FOR COLLABORATION IN THE HIGH LUMINOSITY LHC PROJECT AT CERN

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN")

and

UPPSALA UNIVERSITY (the "University")

concerning

Collaboration in the construction of DFH series cryostats in the framework of the High Luminosity Upgrade of the LHC at CERN

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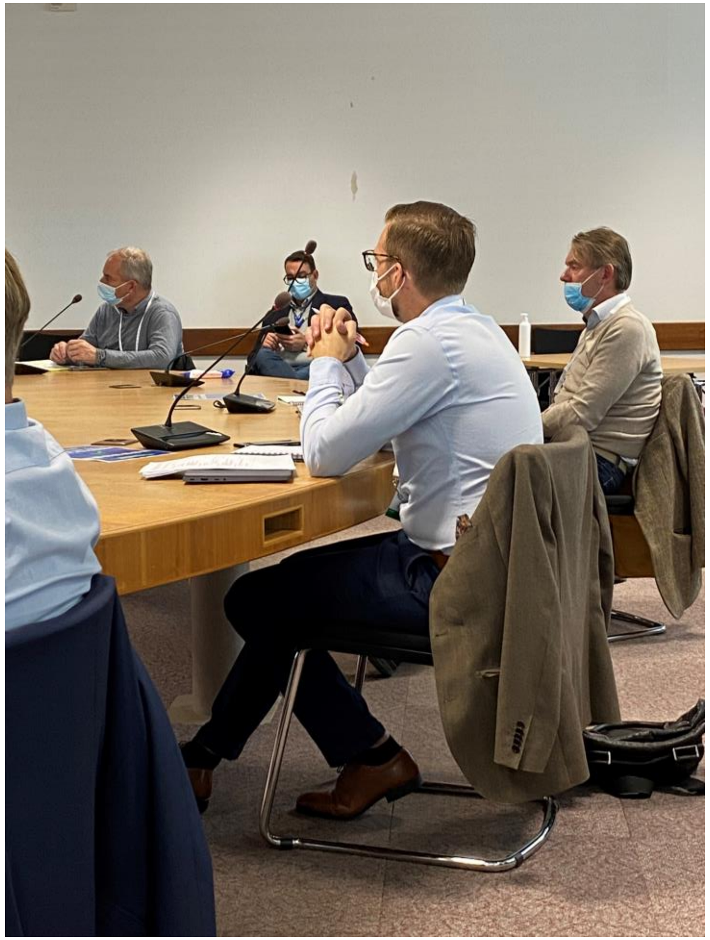
DFHX and DFHM: a successful story
CERN-Uppsala-RFR

Preparation Meeting at CERN, **September 2021**



DFHX and DFHM: a successful story
CERN-Uppsala-RFR

RFR at CERN
September 2022

DFHX and DFHM: a successful story
CERN-Uppsala-RFR

Visit of CERN at RFR, **December 2022**

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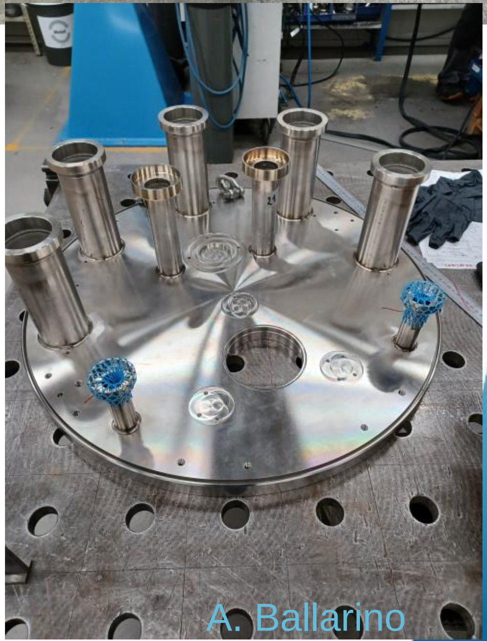
DFHX and DFHM: a successful story CERN-Uppsala-RFR

Delivery to CERN of **first series components**: **March 2023**



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DFHX and DFHM: a successful story
CERN-Uppsala-RFR

Visit of CERN at RFR, **April 2024** – Review of the schedule for the series

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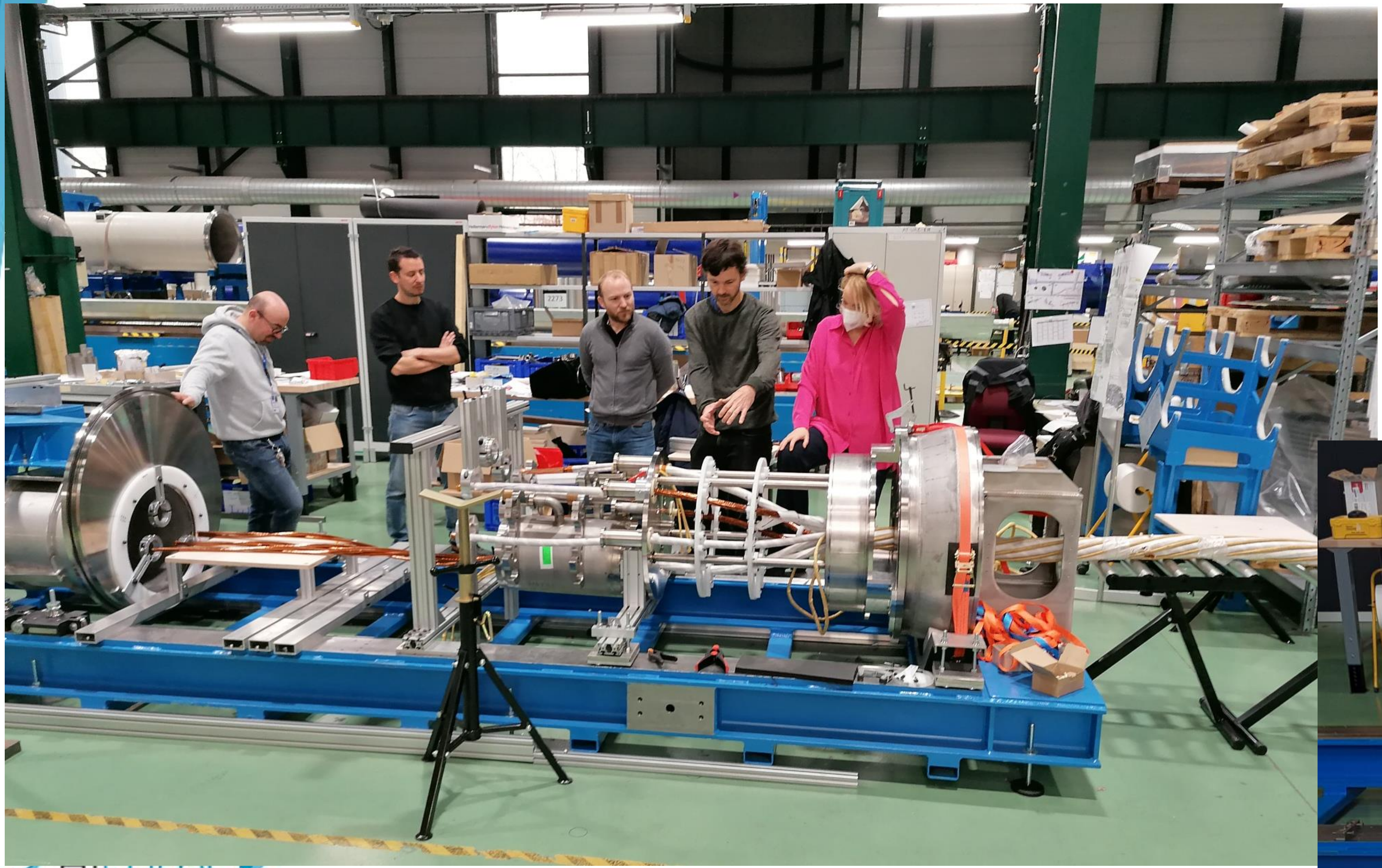
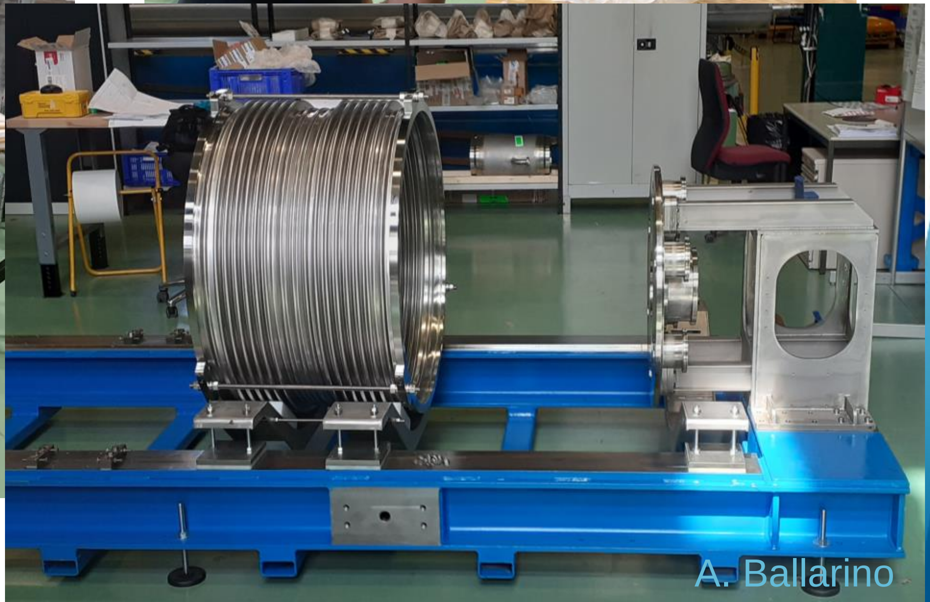
DFHX and DFHM: a successful story CERN-Uppsala-RFR

Start of the Assembly at CERN of the **first DFHX**





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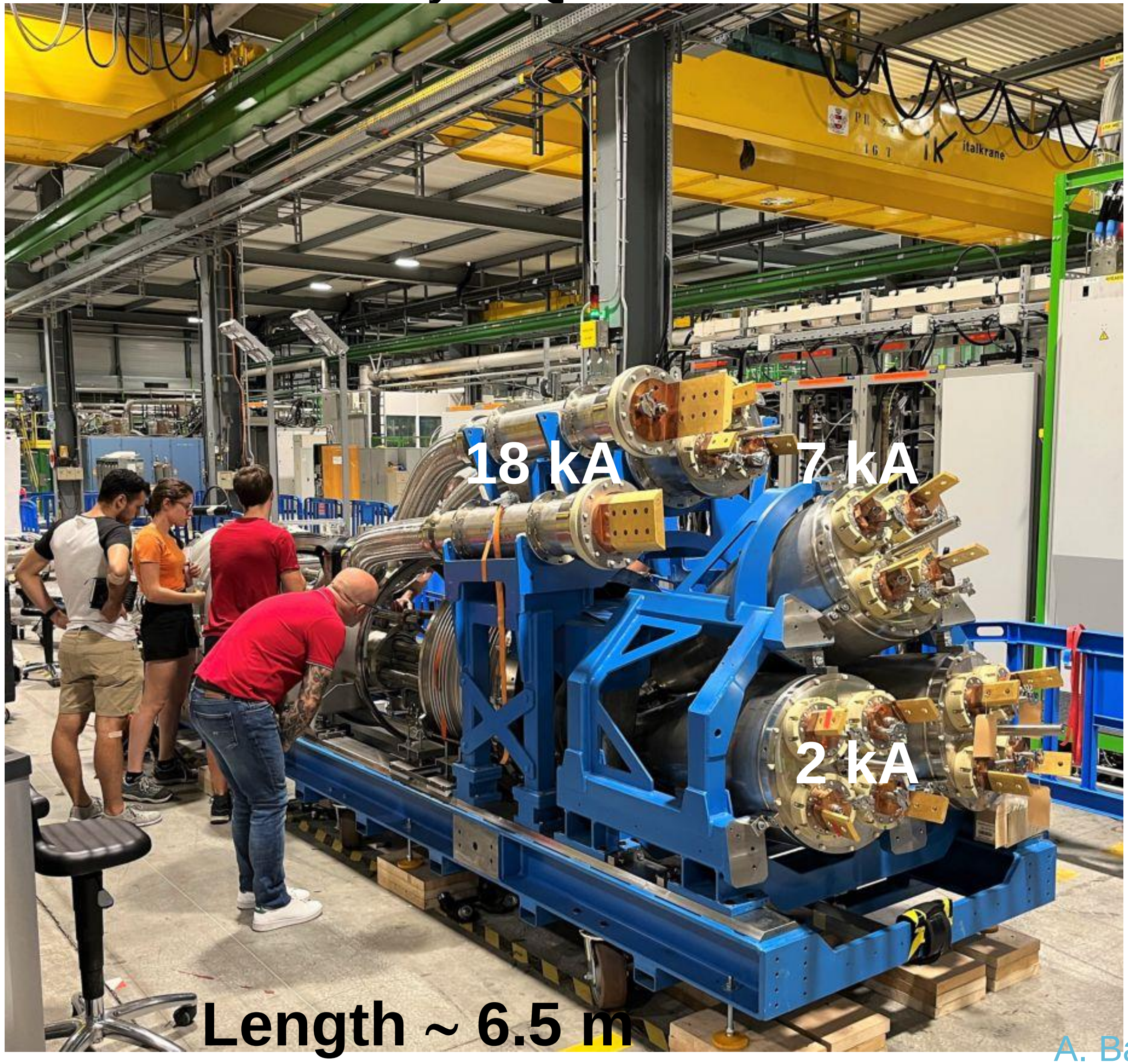
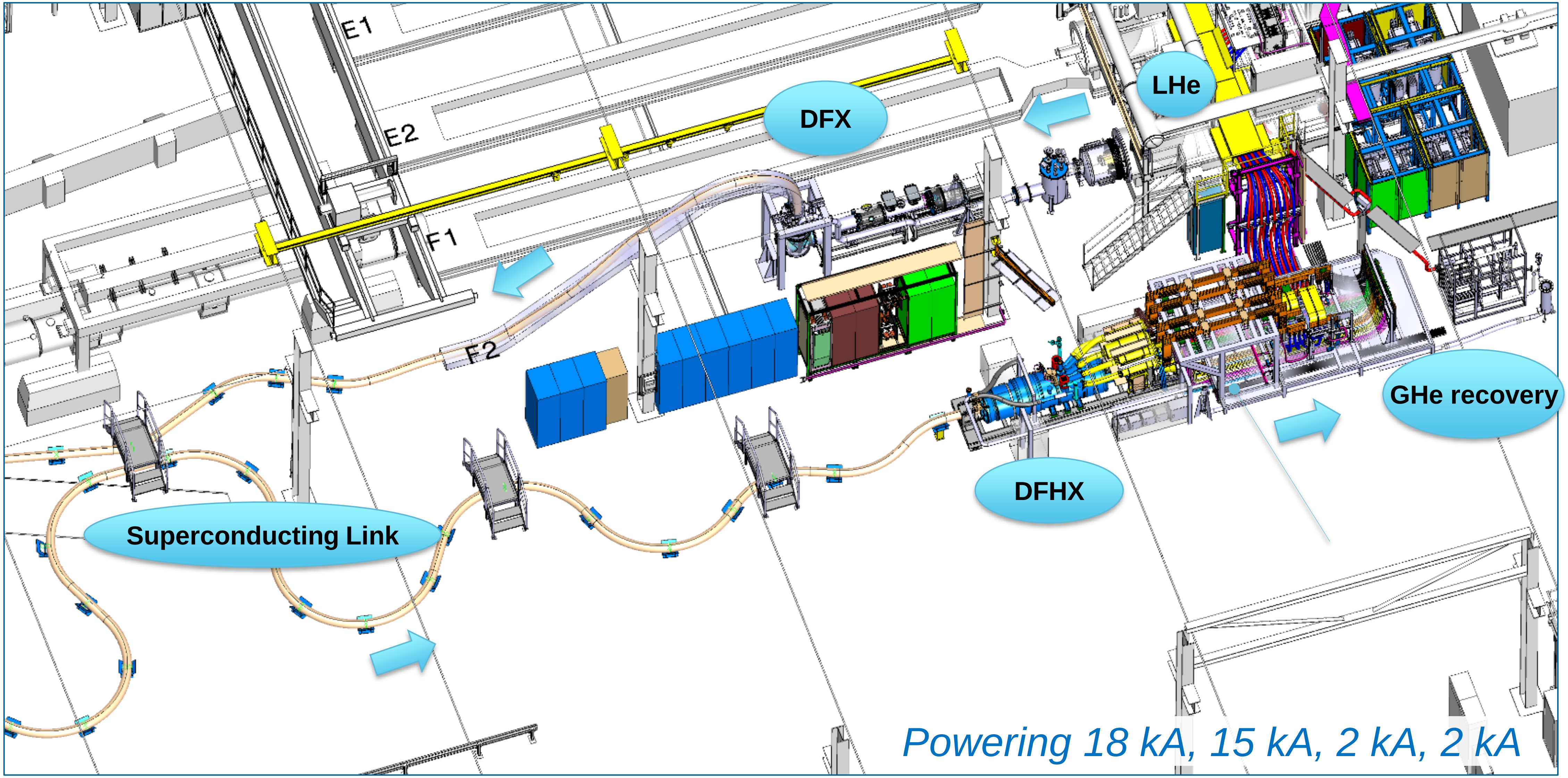
DFHX and DFHM: a successful story CERN-Uppsala-RFR

First DFHX becomes a reality – **Q3 2023**



Cold Powering System in the SM-18



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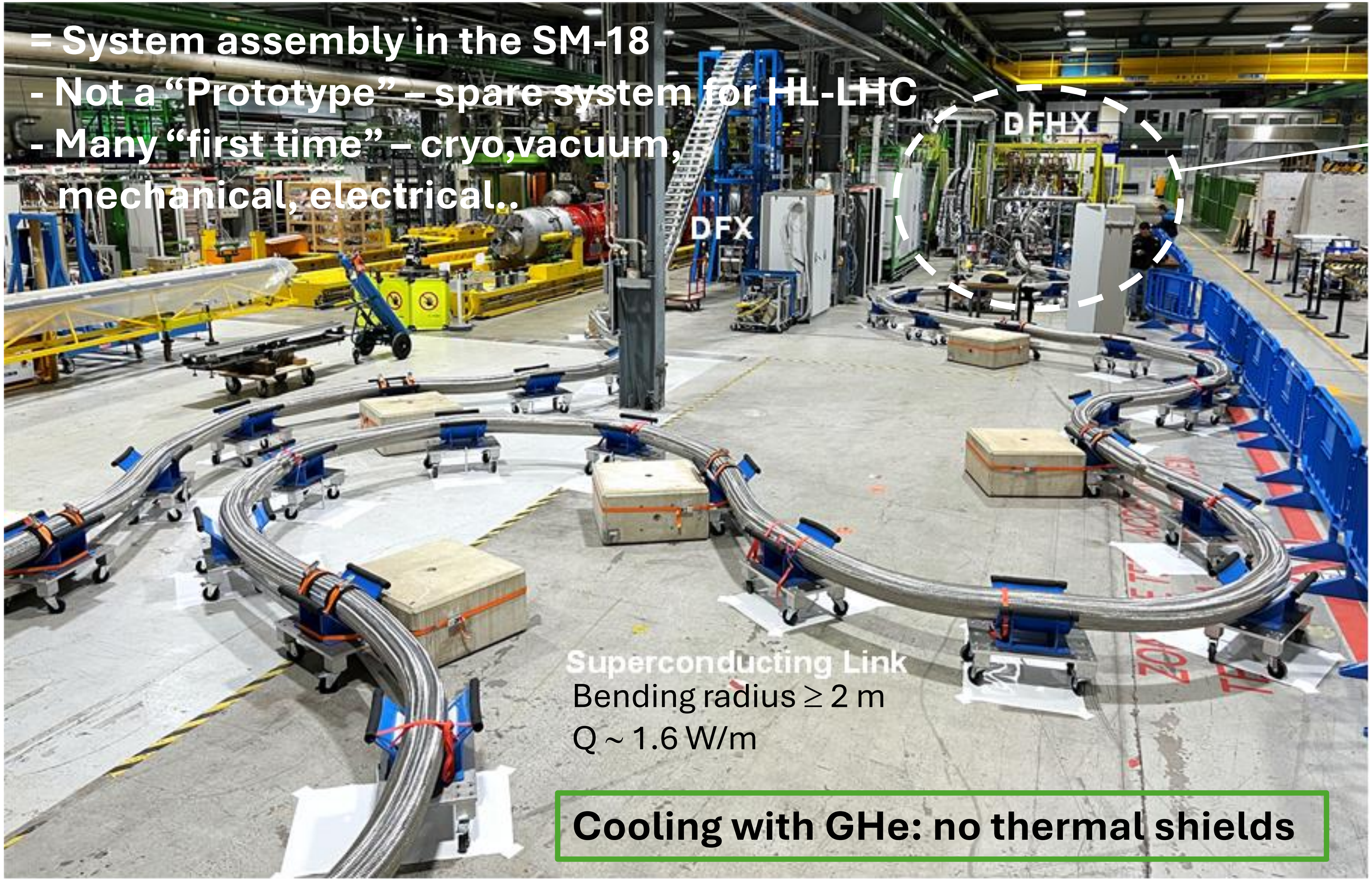
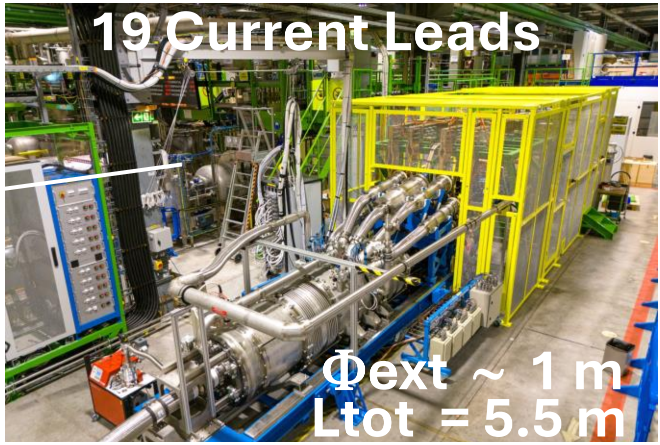
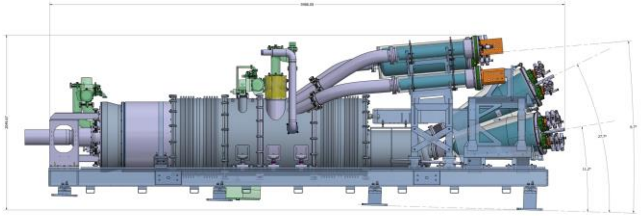
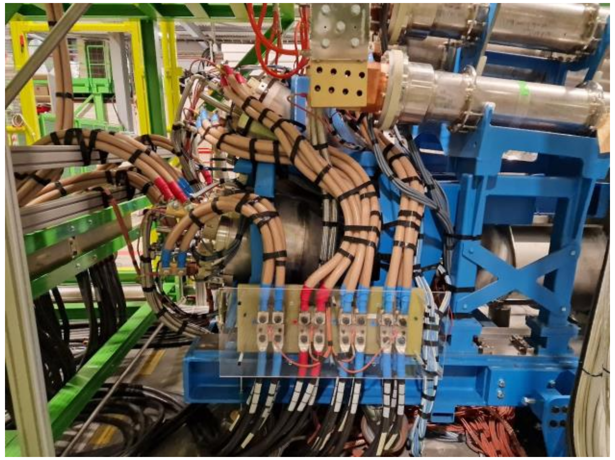


DFHX

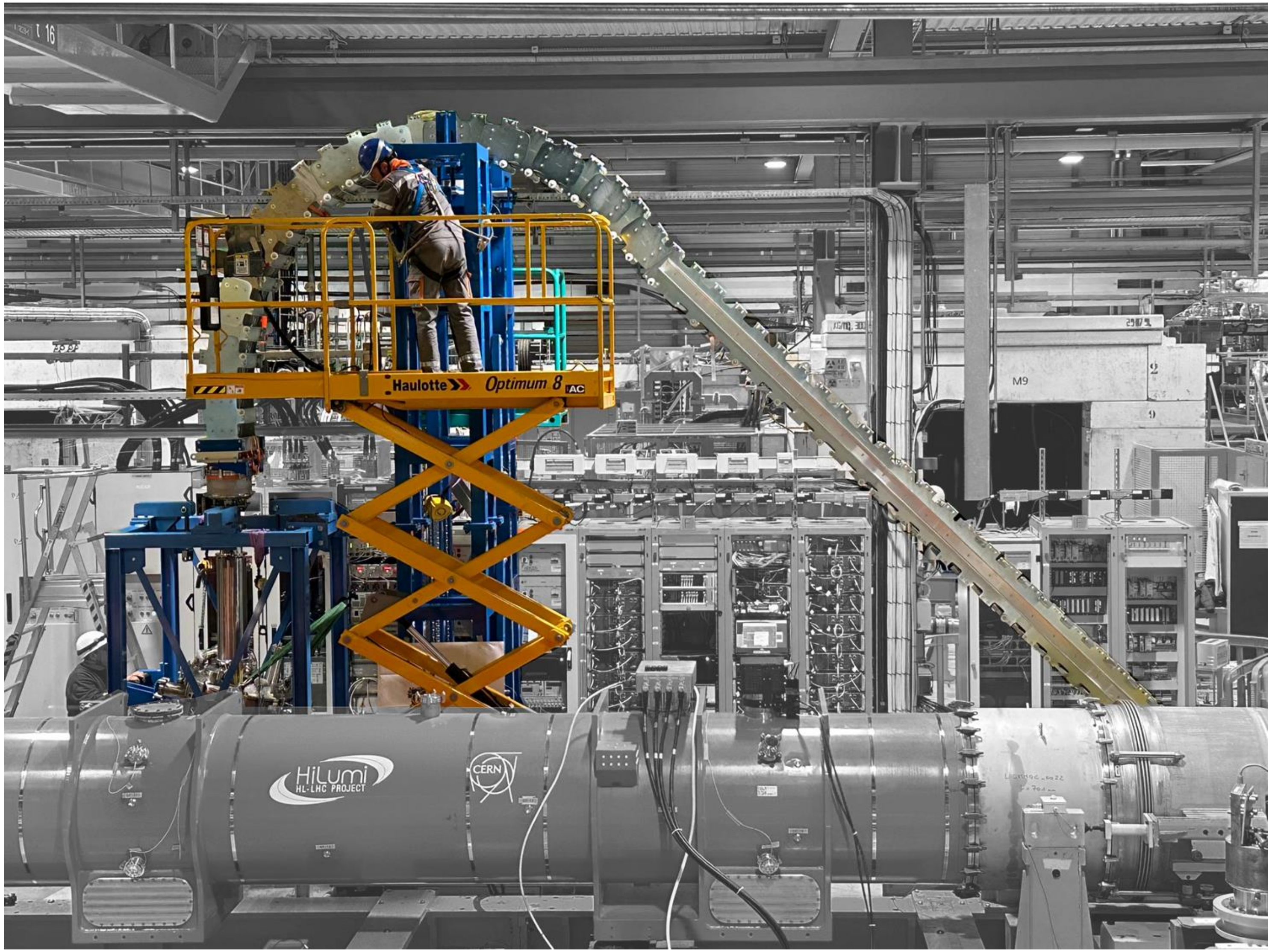






Instrumentation signals: 304 voltage taps and 105 temperature sensors

Vertical path of Superconduting Link



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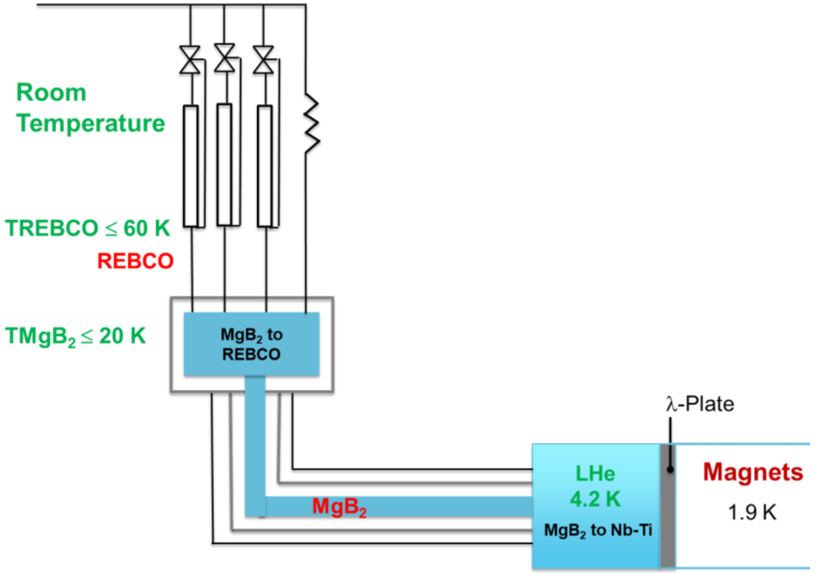
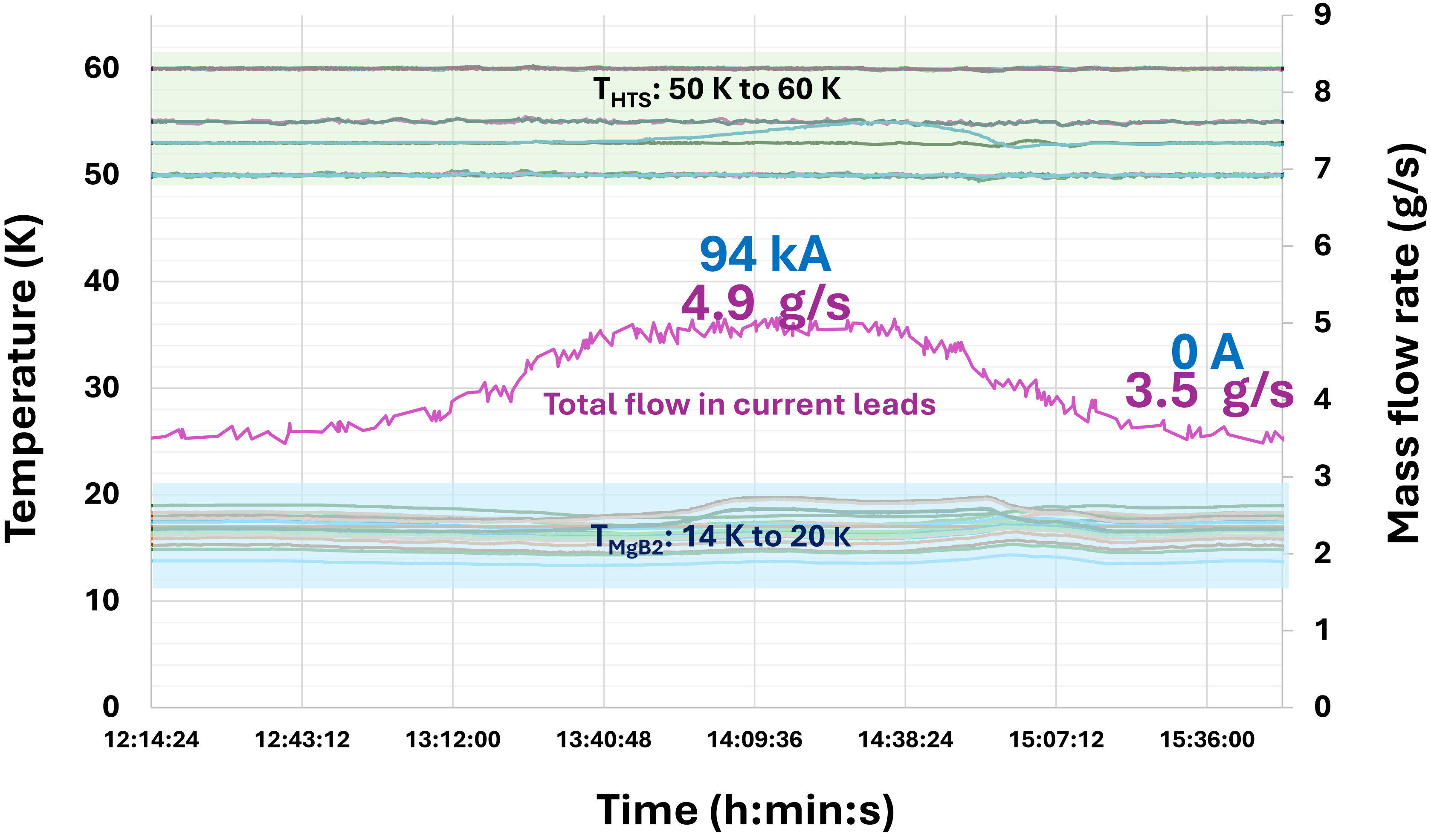
Cryogenic and electrical performance

All operating temperature in the desired range





World prima for highest DC current – over long distance, use of MgB_2, use of REBCO

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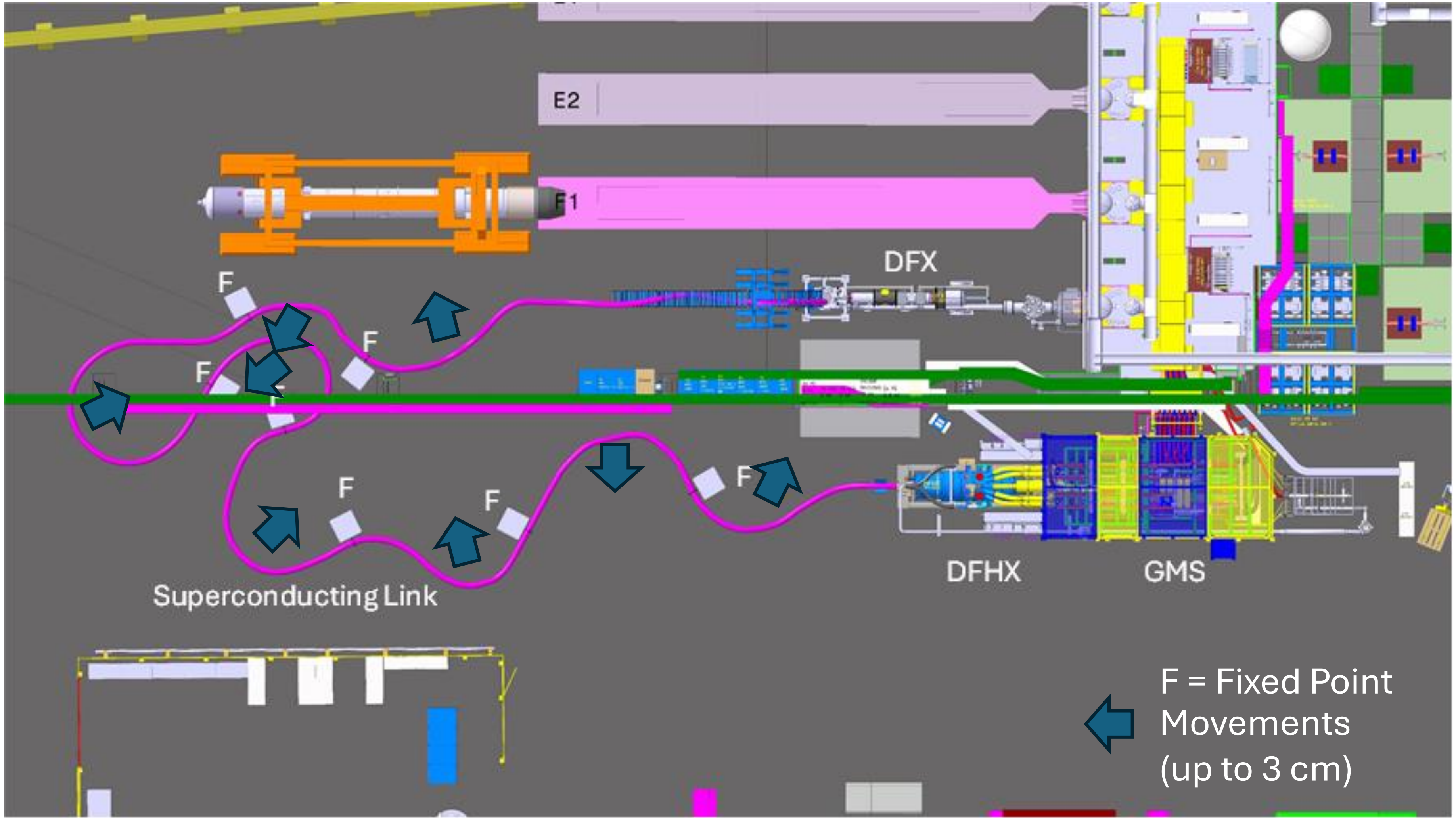
Dealing with thermal contractions



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

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Re-spooling and 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)

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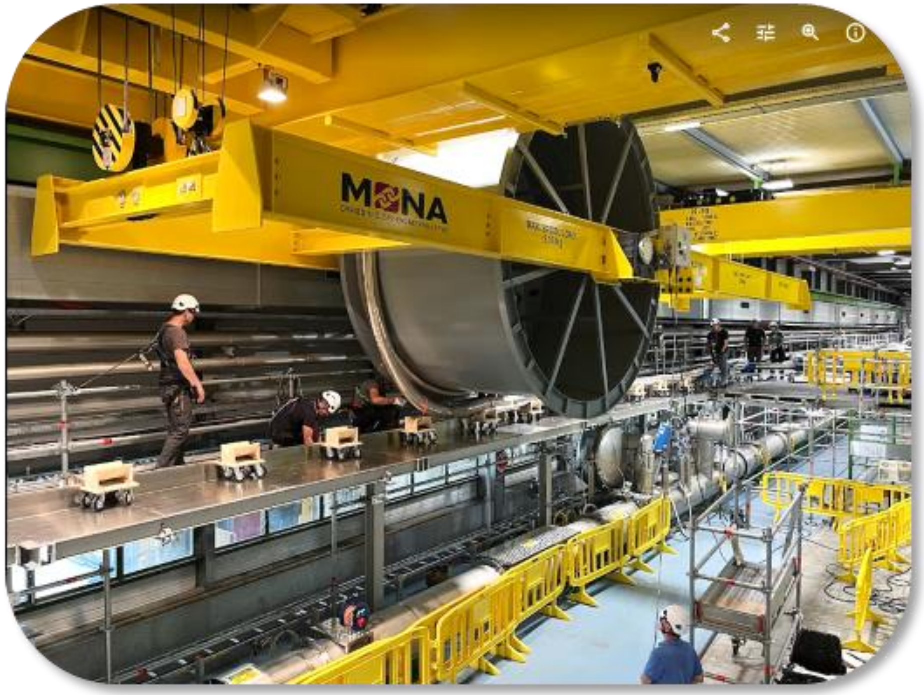
Installation in the String



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Conclusions

- The **first Cold Powering System for the HL-LHC Triplets** has been **successfully validated**: cryogenic, electrical and mechanical performance all meet design parameters. **Robustness** of the system in different operating modes was also proven

- Components of the Cold Powering Systems have all been industrialized. **Series production is almost completed**. Remaining work is the assembly and test at CERN of nine systems. This work is on-going and it is planned to be completed by end 2026. Installation in the LHC underground starts in Q2 2028

- The **DFHX and DFHM** are important and complex components of the Cold Powering Systems. **Many thanks to Uppsala University and RFR for the great contribution and for the excellent collaboration**

Thanks for your attention !