



13th HL-LHC Collaboration Meeting

Status of WP6A, industrialization and tests

Amalia Ballarino for the WP6a

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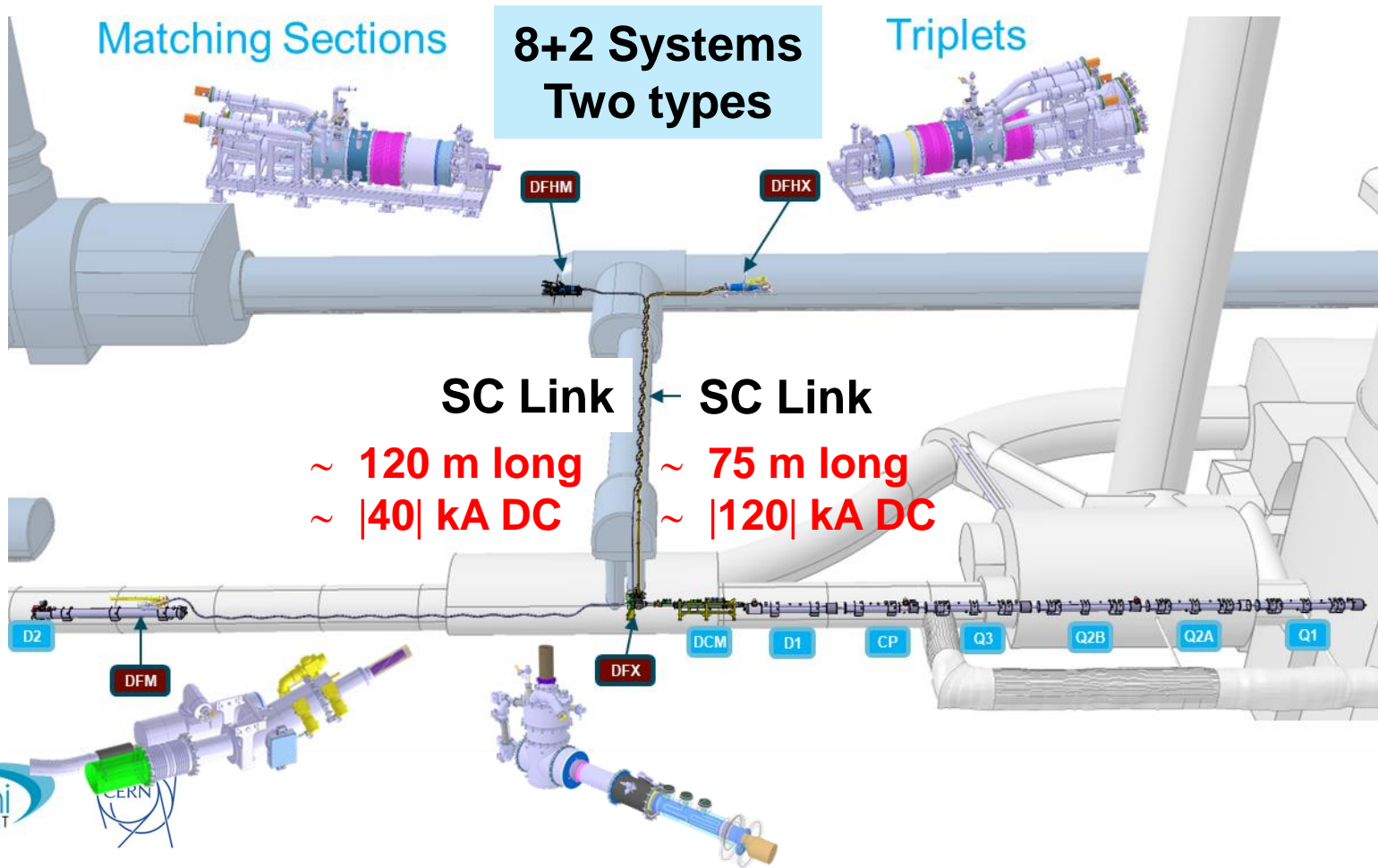
Y. Yang, W. Bailey, **University of Southampton**

T. Ekelof, R. Santiago, **Uppsala University**

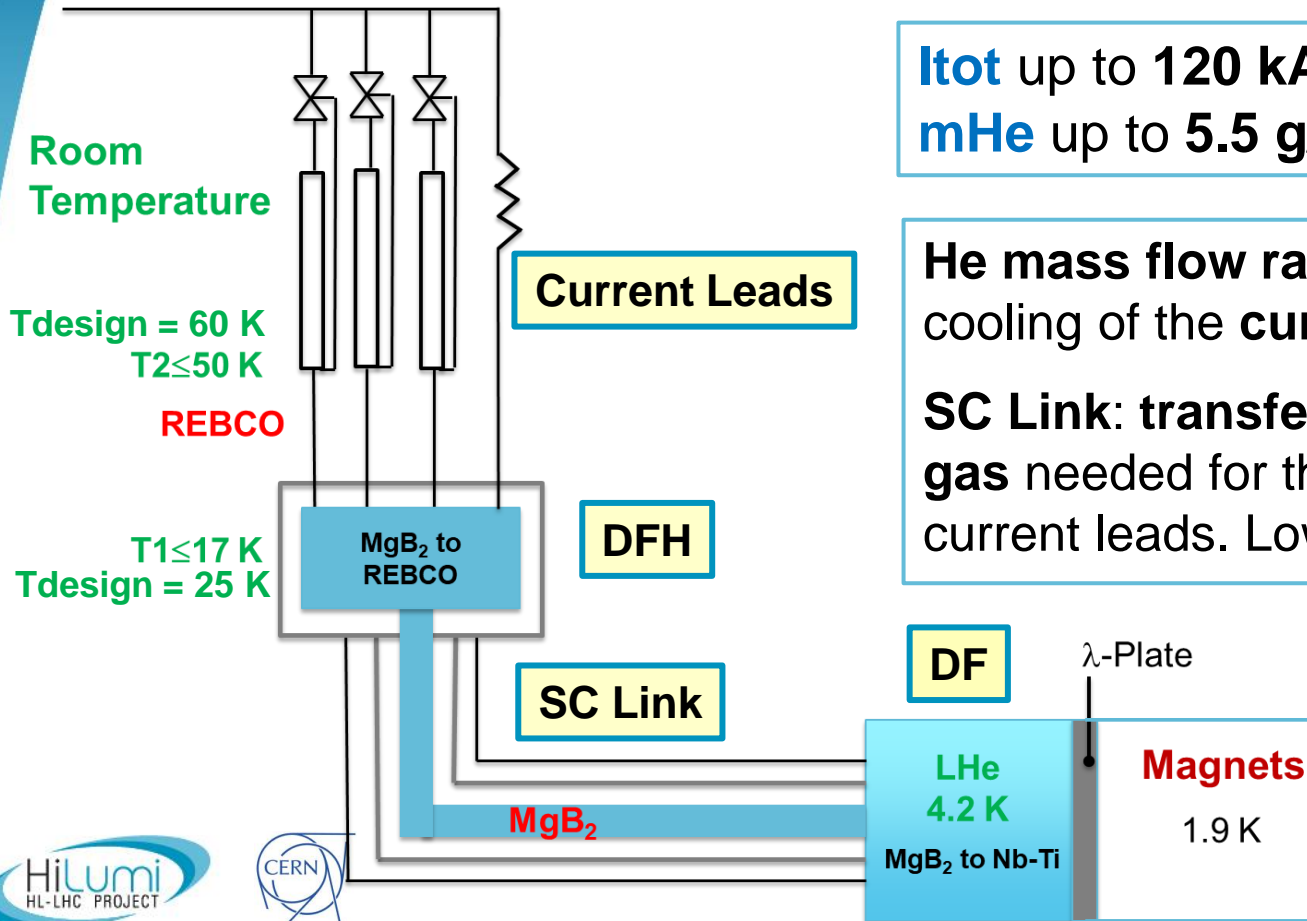


Vancouver (Canada), 25-28 September 2023

Powering the HL-LHC magnets



Powering the HL-LHC magnets

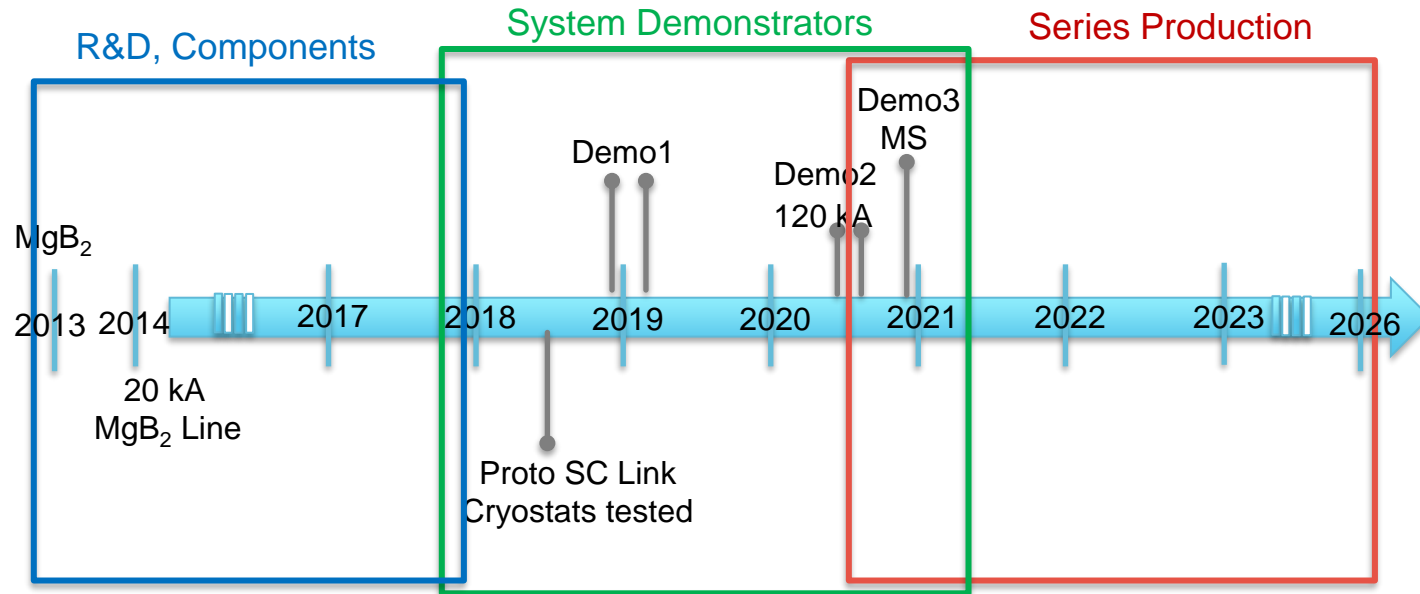


I_{tot} up to 120 kA DC
 $m\text{He}$ up to 5.5 g/s

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**

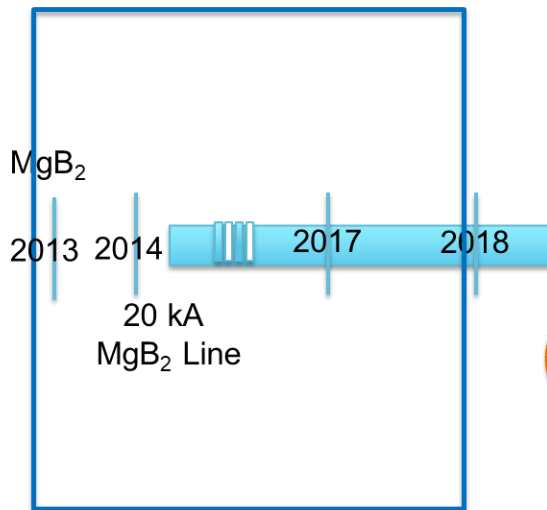
R&D Timeline and Key Developments



We are today in an advanced phase of industrial production

R&D: Components

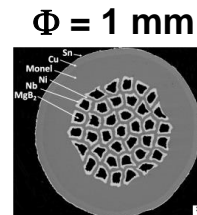
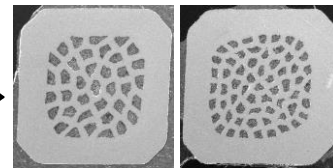
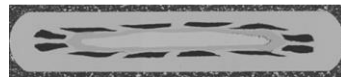
R&D, Components



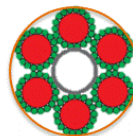
- MgB₂ Wire**



3.6×0.67 mm²



- MgB₂ Cables**



20 kA @ 25 K
Φ~24 mm



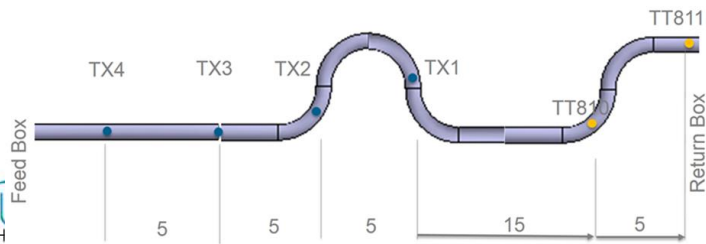
± 2 kA @ 25 K
Φ~11.5 mm



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

R&D: System Demonstrators

2 × 18 kA Current Leads



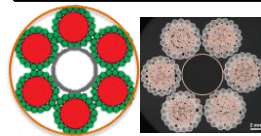
- **Demo 1**

L=20 m

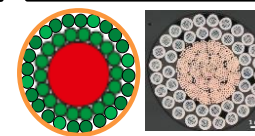
20 kA

25 K

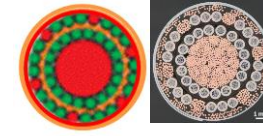
20 kA @ 25 K
 $\Phi \sim 24$ mm



7 kA @ 25 K
 $\Phi \sim 10.5$ mm



± 2 kA @ 25 K
 $\Phi \sim 11.5$ mm



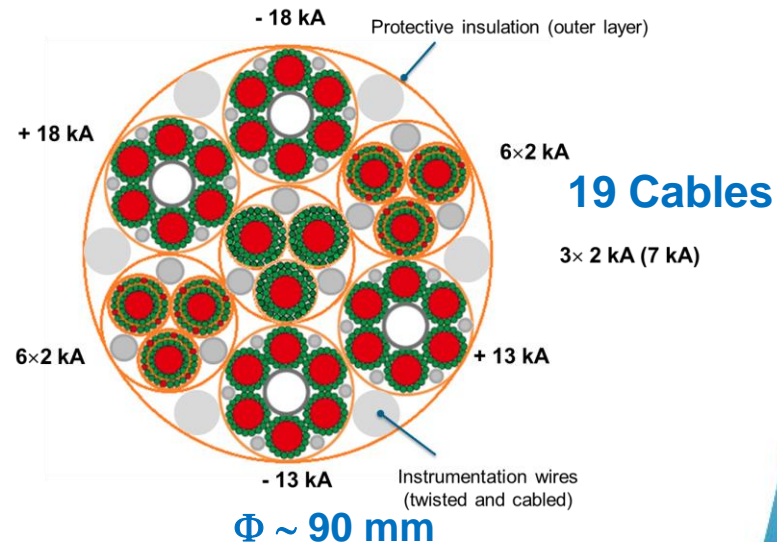
- **Demo 2**

- **Demo 3**

L=60 m

|120| kA

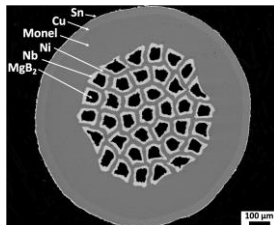
25 K



Prototype MgB₂ cable (60 m long) industrialized at ICAS

After Demo 3, start of series production

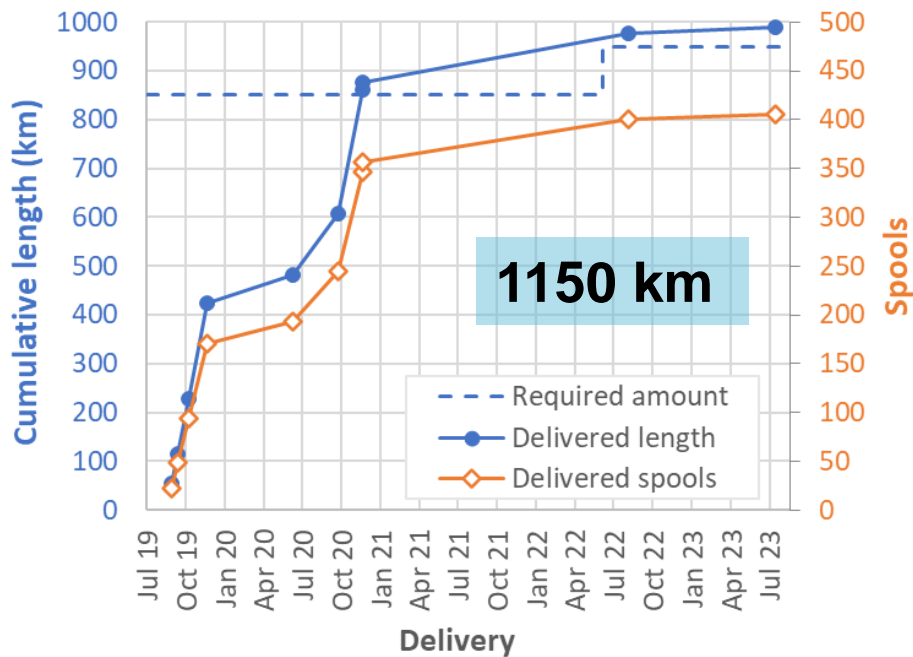
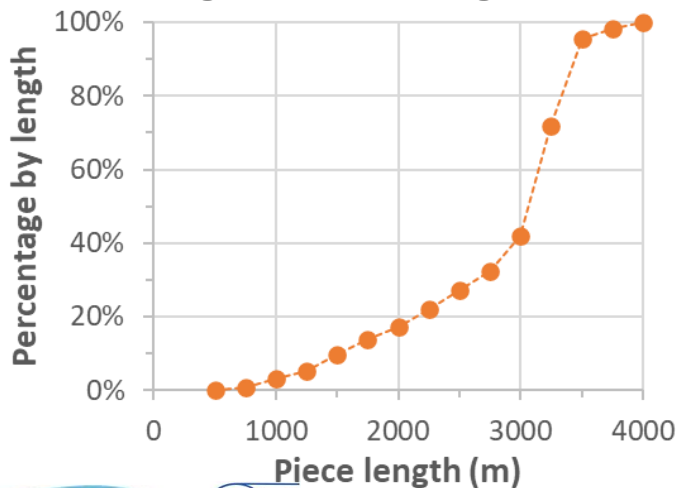
MgB₂ Wire – Series Production (1/2)



$\Phi = 1 \text{ mm}$
 37 MgB₂ filaments
 Tw = 100 mm

Total production of **1150 km** of
 MgB₂ wire **completed** at ASG
 Superconductors

Average piece length 2435 m



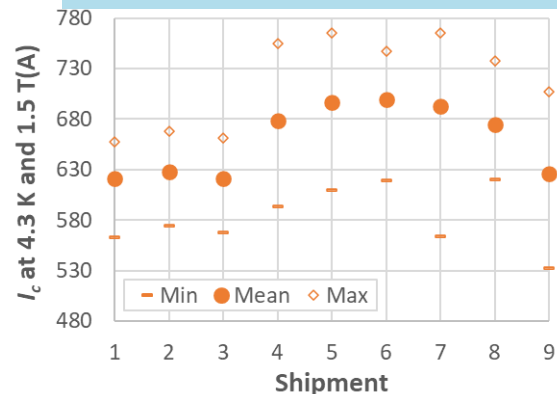
MgB₂ Wire – Series Production (2/2)

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	
I _c (25 K, 0.9 T)	A	≥ 186	
I _c (25 K, 0.5 T)	A	≥ 320	
I _c (20 K, 0.5 T)	A	≥ 480	
n-value@ 25 K and 0.9 T	-	> 20	

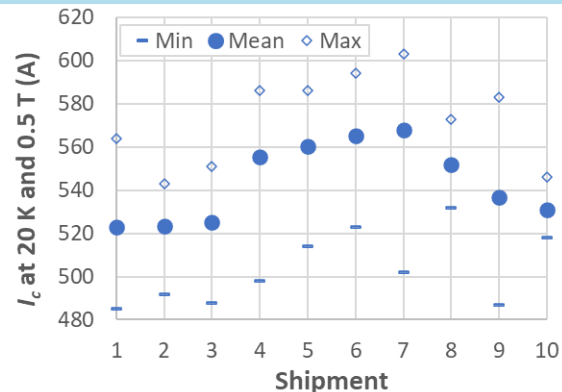
Electrical performance within specification (I_c(20 K, 0.5 T) ≥ 480 A)

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

CERN data, parallel field

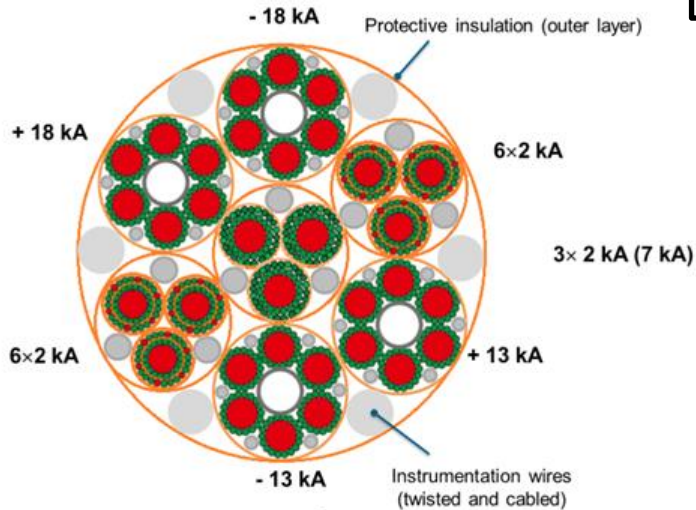


Supplier data, perpendicular field



MgB₂ Cables

|120 | kA @ 25 K, $\Phi \sim 90$ mm



18 kA @ 25 K, $\Phi \sim 24$ mm



Insulation voltage: 15 kV -10 kV

Weight ~ **1.7 ton**

Length ~ 75 m



2-Wall Flexible SC Link Cryostats (1/2)



2-Wall Flexible SC Link Cryostats (2/2)

Series production will be **completed by end of October 2023** – with the delivery of the last two units

PM1, SX1, SX2, SX3, SM1, SM2 & SM3 at CERN in Flex building (B947)



Cryostat	Status	Delivery
PX1	Used in SM18 - Approved	09.2022
PM1	Stored in Flex - Approved	09.2022
SX1	Stored in Flex – Approved	02.2023
SX2	Stored in Flex – Approved	02.2023
SX3	Stored in Flex – Approved	06.2023
SM1	Stored in Flex – Approved	09.2023
SM2	Stored in Flex – Approved	06.2023
SM3	Stored in Flex – Approved	09.2023
SX4	Being manufactured at Cryoworld	10.2023
SM4	Being manufactured at Cryoworld	10.2023



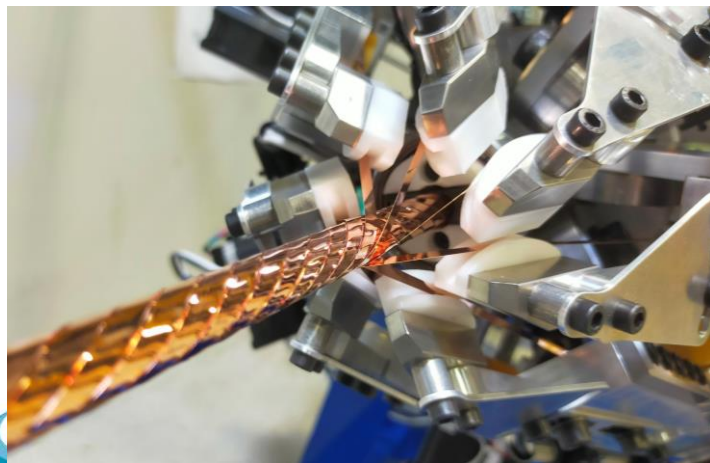
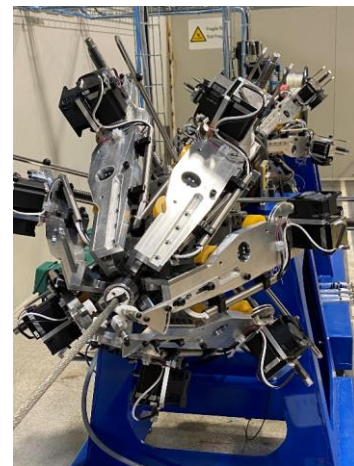
Eight out of ten series cryostats have been produced by **Cryoworld**

MgB₂ Superconducting Link

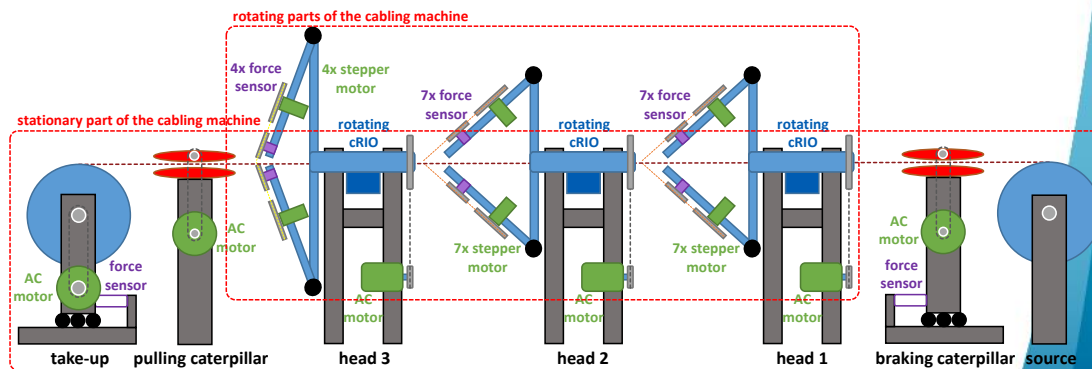


REBCO Cables (1/2)

- **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
- **~ 1 km of REBCO cable**



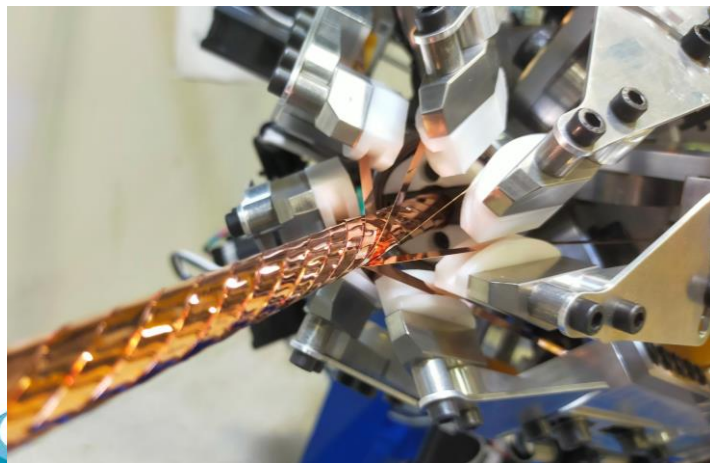
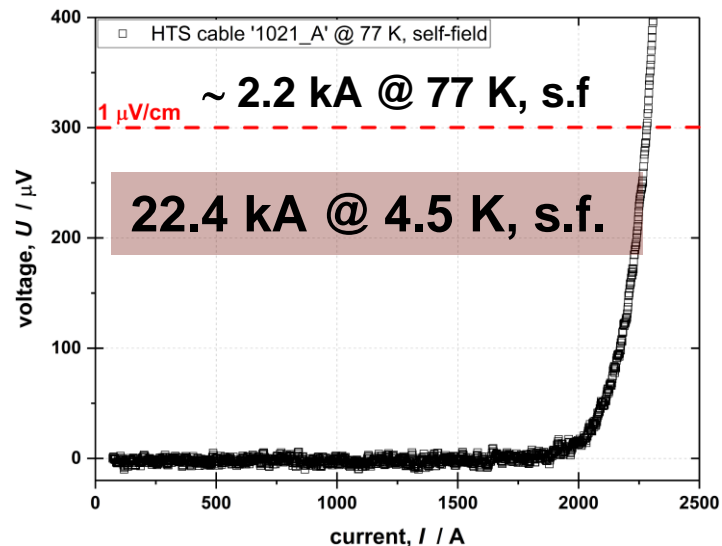
A Ballarino



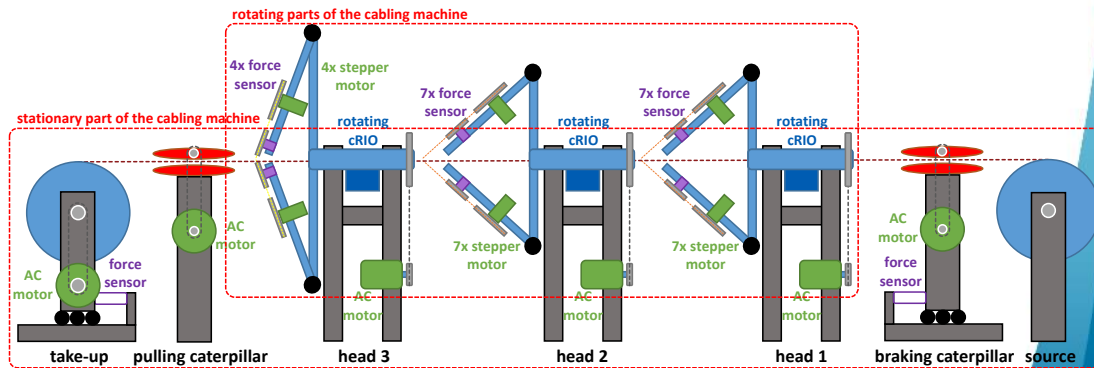
REBCO Cables at CERN

REBCO Cables (2/2)

- **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
- **~ 1 km of REBCO cable**



A Ballarino

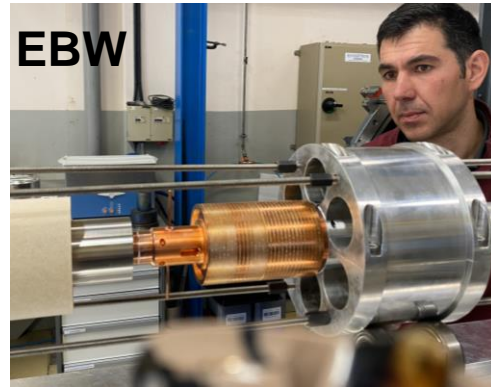


REBCO Cables at CERN

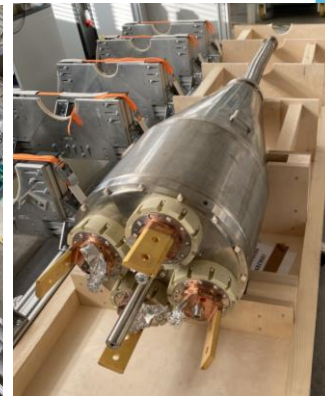
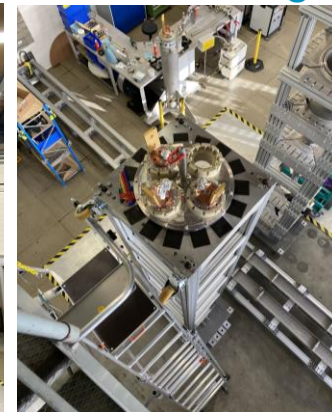
HTS Current leads

CERN Main Workshop

- Produced at CERN all **19 current leads** needed for the Prototype System (4×18 kA, 12×2 kA, 3×7 kA) + 4×0.6 kA
- Procured all raw material and completed **manufacturing of ~ 70 %** of the **series** components – in the CERN Main Workshop
- Launched **procurement** of the **REBCO HTS tape**

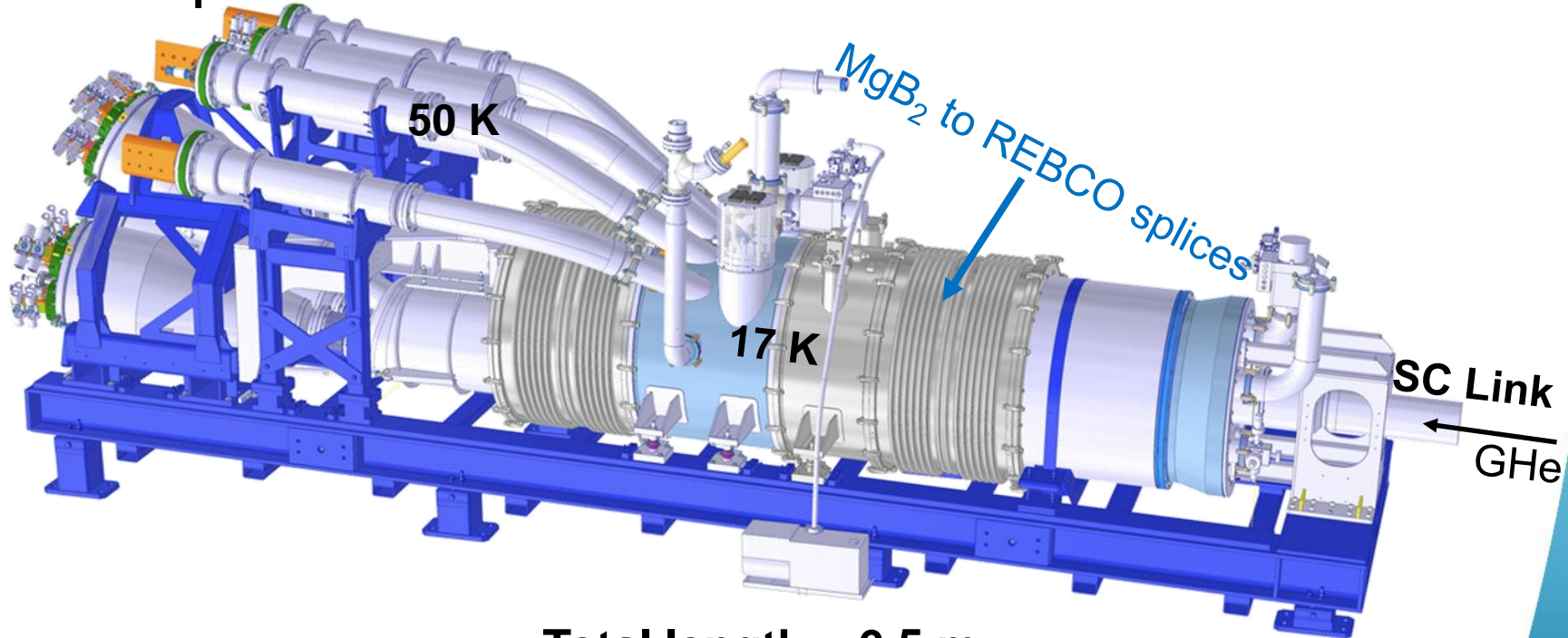


CERN Building 288



DFHX Cryostat– Warmer SC Link side

Room Temperature

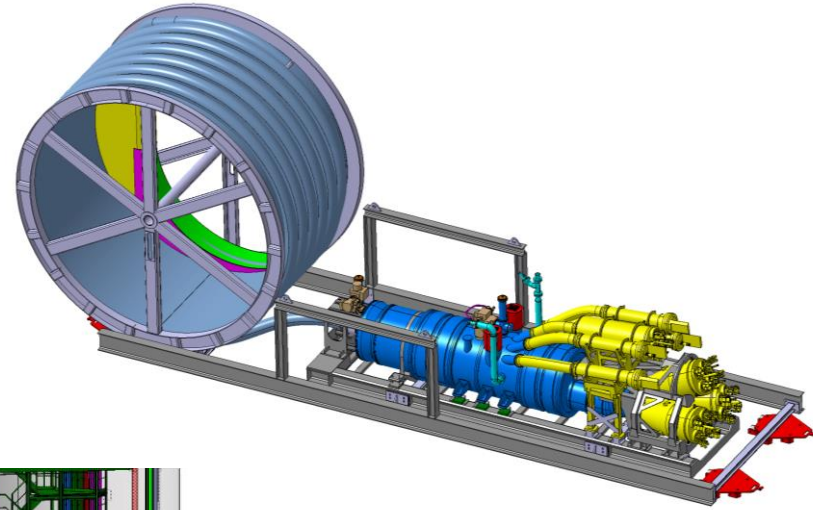


Total length ~ 6.5 m

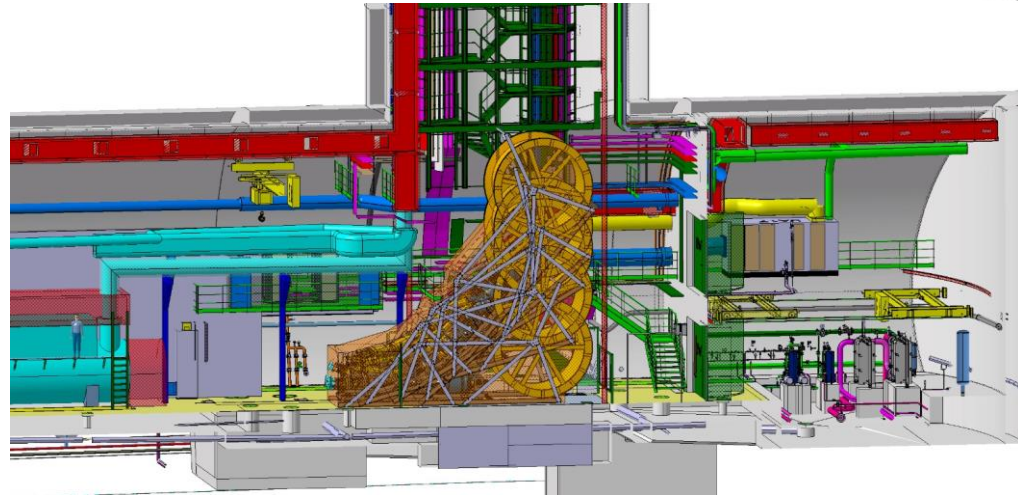
Very compact design

Installation in the LHC underground

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

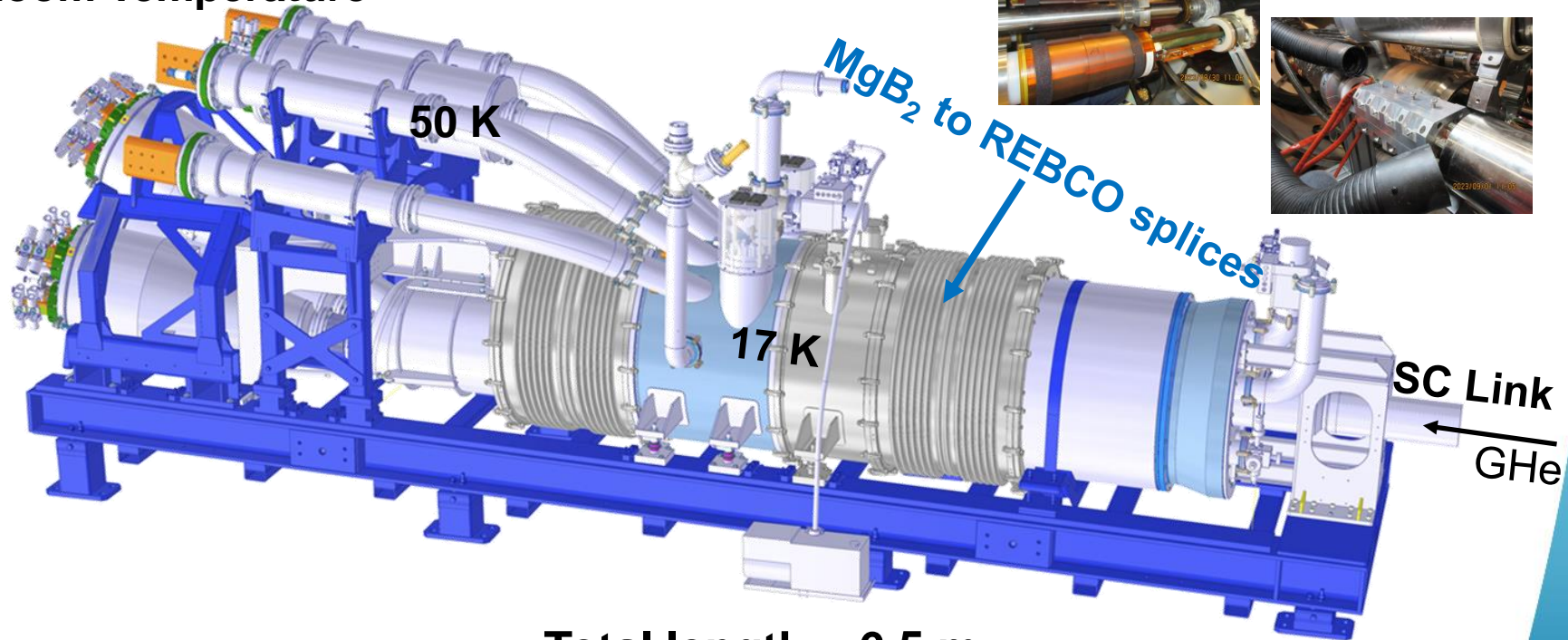


Total weight ~ 10 ton



System Design – Warmer SC Link side

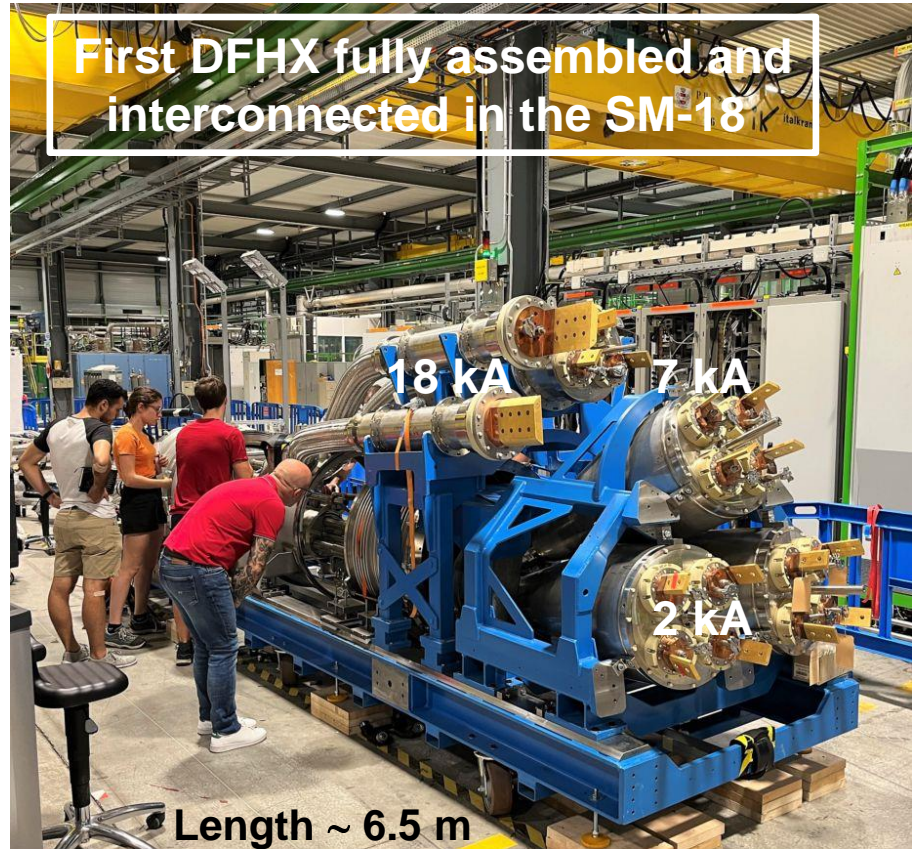
Room Temperature



Total length ~ 6.5 m

Very compact design

System Design – Warmer SC Link side



DFHX: Uppsala University



Cryostat	Status	Delivery
DFHX1 (P)	Used in SM18 - Approved	12.2021
DFHX2	Stored in Flex - Approved	06.2023
DFHX3	QA doc in review @ WP6a	09.2023
DFHX4	In Production	15.11.2023
DFHX5	In Production	30.11.2023
DFHM1	In Production	21.12.2023
DFHM2	In Production	08.01.2024
DFHM3	In Production	22.01.2024
DFHM4	In Production	28.02.2024
DFHM5	In Production	28.02.2024

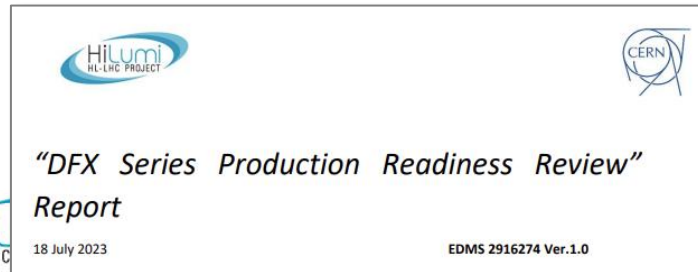
Production at Uppsala University and RFR

- **Uppsala University: first series delivery** (second DFHX cryostat) took place in June 2023
- **Second series cryostat** (third DFHX cryostat) completed and approved for delivery
- Production of the **series DFHX** on schedule to be **completed before end 2023**
- Production of the **series DFHM** completed in February 2024

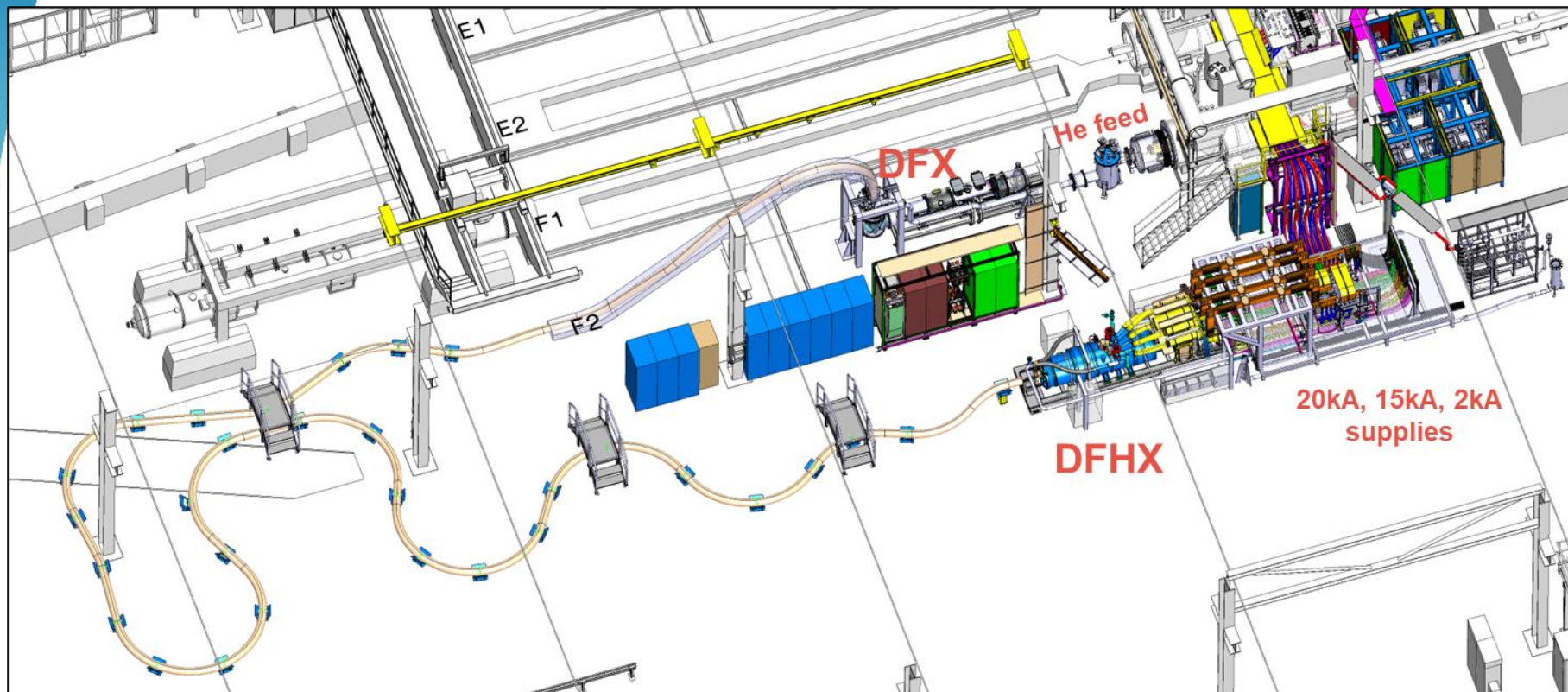


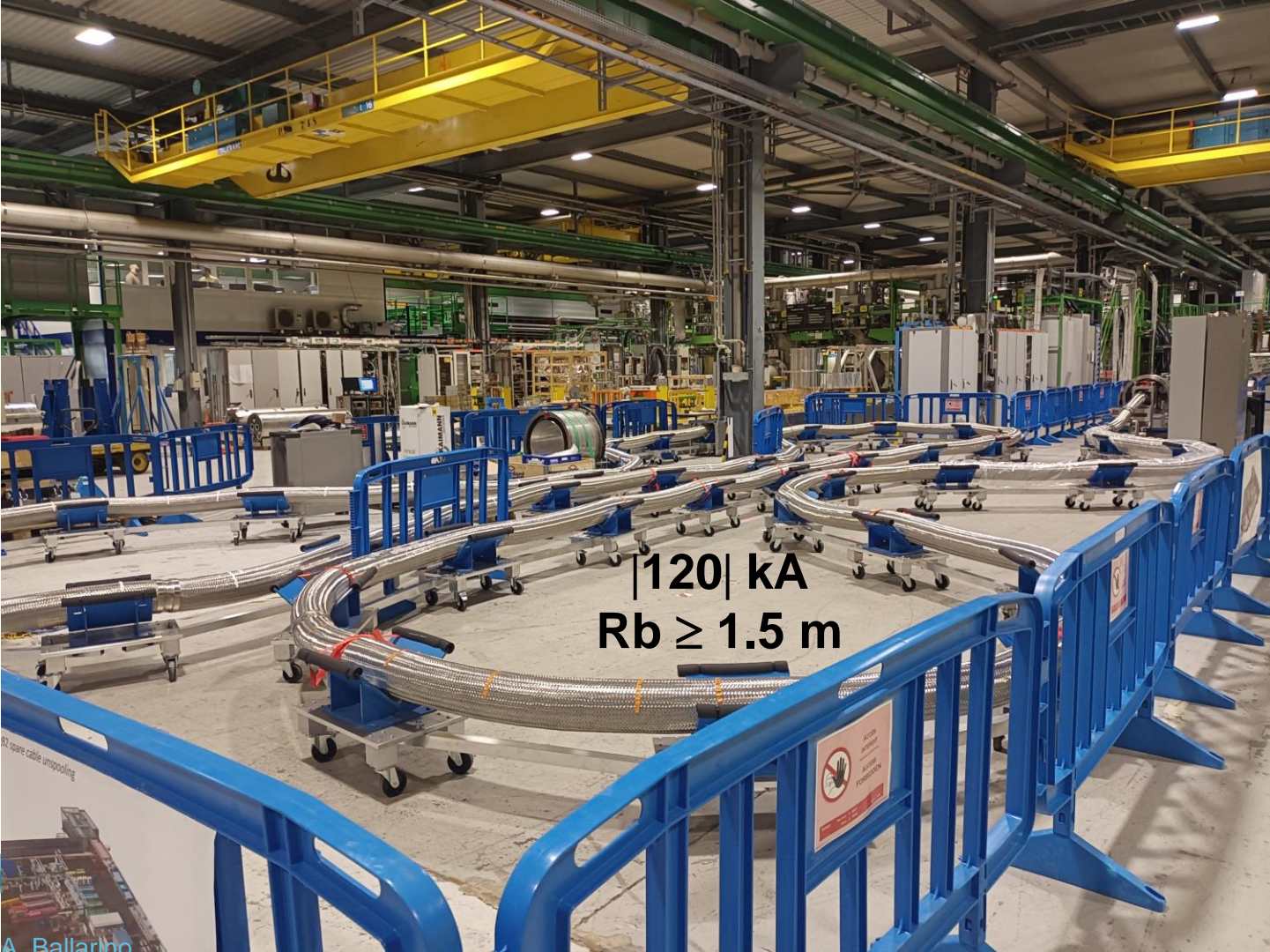
DFX: University of Southampton

- **UK1: pre-series (spare) DFX unit** delivered in March 2022. Production at LTi Metaltech
- **UK2 for series production.** PRR for DFX series production at Puma on the 7th of July 2023
- About 80% of raw material for series procured. First **delivery** (second unit) in **October 2023** (completion of DFX production in January 2024)



Prototype System assembly in Cluster F2/SM-18

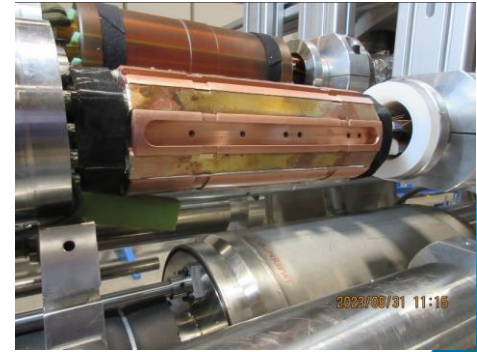




|120| kA
 $R_b \geq 1.5 \text{ m}$

2x spare cable unpooling

Prototype System assembly in Cluster F2/SM-18

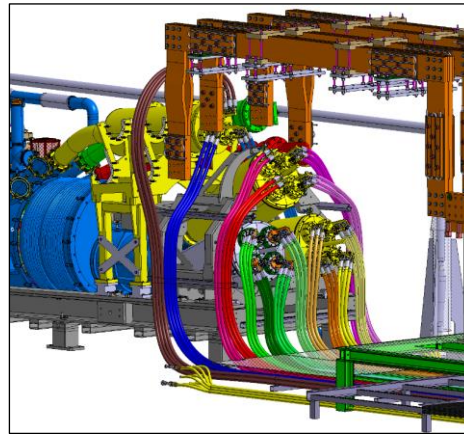


Cluster F2 Upgrade



IP2 cage installed (EN/ACE)

- Panels removed to facilitate ACC cabling works
- Cage interlocks by TM team
- ACC cables with overlength visible



Dedicated chassis (courtesy WP16) to simulate CL flag positions to prepare ACC in advance of DFHX installation.



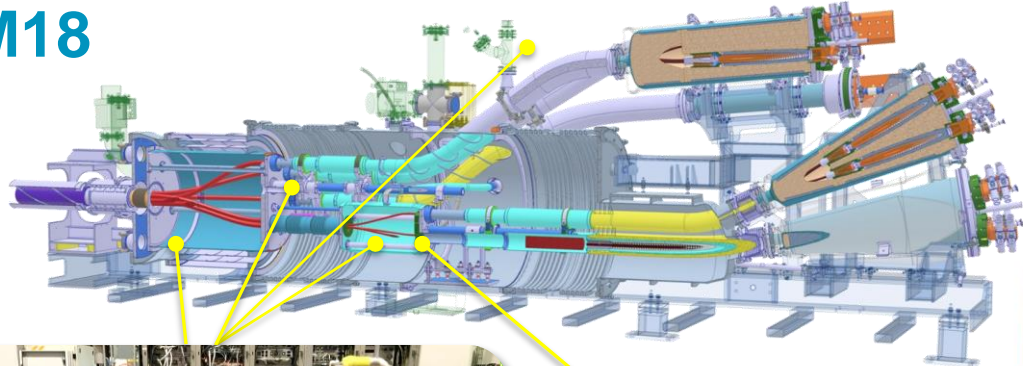
Chassis installation & positioning by WP6a team.
EN/EL cable terminations this week



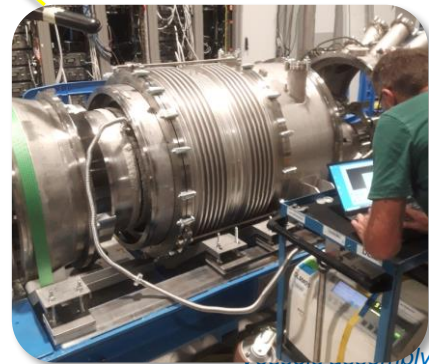
Prototype System @ F2 – SM18

COMPLETED MILESTONES

- **Q4-2022**
 - Unspool flexible cryostat
 - DFHX transport to SM18
- **Q1-2023**
 - Weld Flexible cryostat to DFHX + QC
 - MgB2 Cable pulled into flexible cryostat & HV test
 - 1st Cable shuffling & Fixed point
- **Q3-2023**
 - HV test & Shuffling box assembly
 - IFS instrumentation routing & testing
 - 2kA cable shuffling
 - Vacuum Vessels Components assembly
 - 12 x 2 kA current leads assembled & soldered
- **07.2023**
 - Helium circuits welding & Leak tested
 - Instrumentation feedthroughs installed & QC
- **08.2023**
 - 2kA splices instrumentation & insulation
 - 7kA & 18 kA current leads assembly
- **09.2023**
 - Qualification of SCLink insertion tooling
 - 7kA & 18kA Current leads installed & soldered



Shuffling box welding & QC

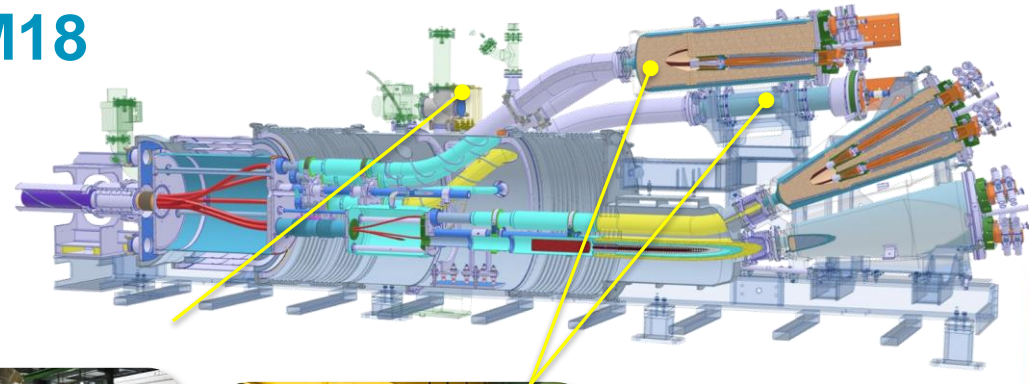


Safety & cold return lines welding & QC

Prototype System @ F2 – SM18

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 - 2kA splices instrumentation & insulation
 - 7kA & 18 kA current leads assembly
- 09.2023
 - Qualification of SC Link insertion tooling
 - 7kA & 18kA Current leads installed & soldered



Instrumentation routing & QC



18kA current leads installation

SCLink insertion tooling qualification



ALL splices, insulation, instrumentation in DFH completed

Getting ready for transport



Conclusions

- Assembly of **Prototype System** being completed in the SM-18. **Tests** in the SM-18 in early **November 2023**. This is a **spare Cold Powering System** for the HL-LHC Triplets – it incorporates all features/interfaces of the series systems
- Construction of **Cluster F2** - for test of Prototype System and series systems – completed on-time
- **Series production** in industry, at the collaborators' sites and at CERN well advanced and **on track**

Aknowledgments

- The **CERN Main Workshop**, the CERN cryogenic (**GRG**) and vacuum (**VSC**) groups, the CERN installation and transport teams (**WP15**), the quench protection team (**WP7**)
- Our collaborators (**Uppsala University** and **University of Southampton**) and their contractors (**LTi Metaltech**, **RFR Solutions**, **Puma Engineering**)
- Industrial contributors (**ICAS**, **Cryoworld**, **ASG Superconductors**)
- The CERN **HL-LHC Project Office**
- The CERN **TE management**



Thanks for your attention !

