Qualification of the round REBCO cables of the Cold Power Systems of HL-LHC

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Outline

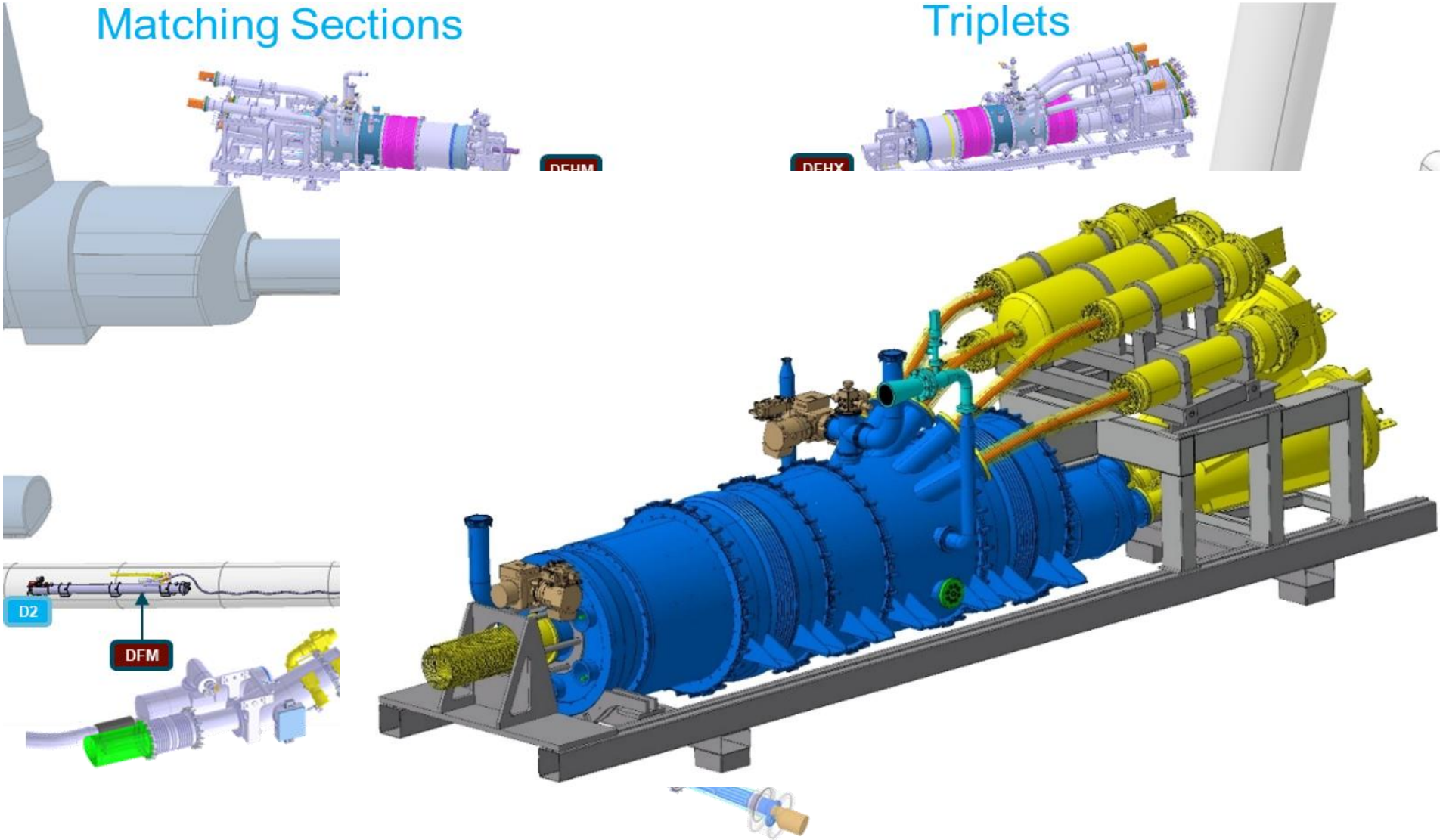
- Introduction
- Motivation
- Quality control
- Results
- Conclusions

Introduction

- The Cold Powering System for powering the HL-LHC magnets
- Superconductors used:

  NbTi, MgB_2, REBCO.
- MgB2 cables:
  - Length: approx. 100 meters.
  - Cooled by helium gas: 4.5 – 20 K.
- REBCO cables:
  - Length: 2.0 – 3.5 meters.
  - Cooled by helium gas: 20 – 60 K.

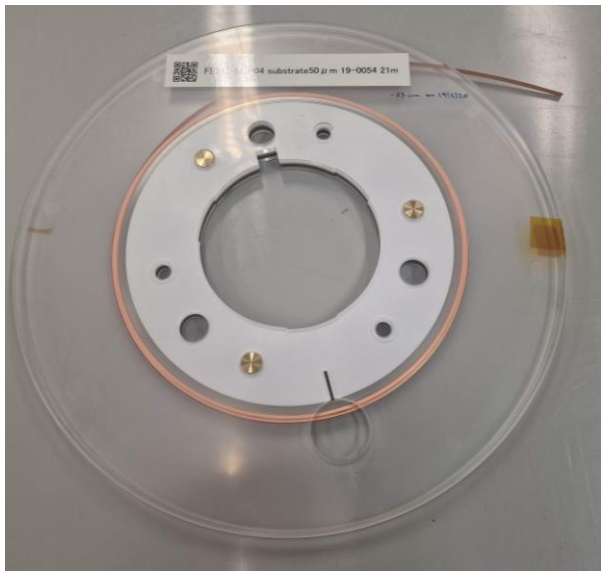
The Cold Powering of the HL-LHC magnets



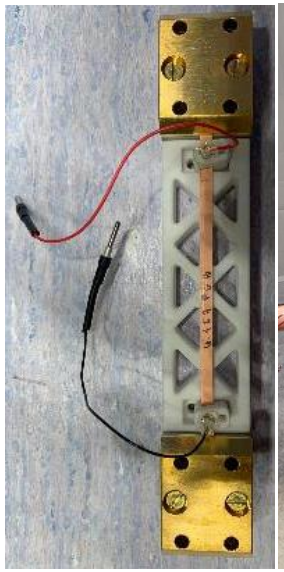
Quality control

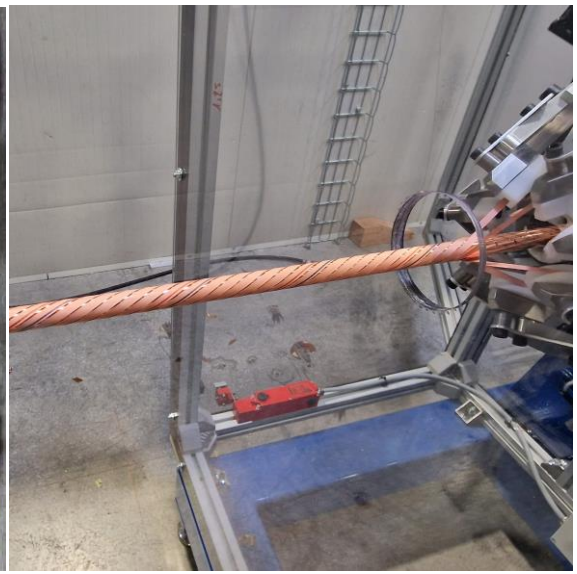
High Temperature Superconductor (HTS) cabling workflow

1. Procurement, quality control of HTS (QC I)
2. Cabling of HTS cables
3. Cutting into 2.5m – 3.5m cable pieces and dedicated 0.3m QC cable samples
4. Extraction of HTS tapes, QC measurement of extracted tapes (QC II)
5. Splicing of HTS cables
6. QC measurement of each cable at 77K, self-filed (QC III)
7. Acceptance of cable
8. Assembly of the current leads



Quality control of REBCO tapes



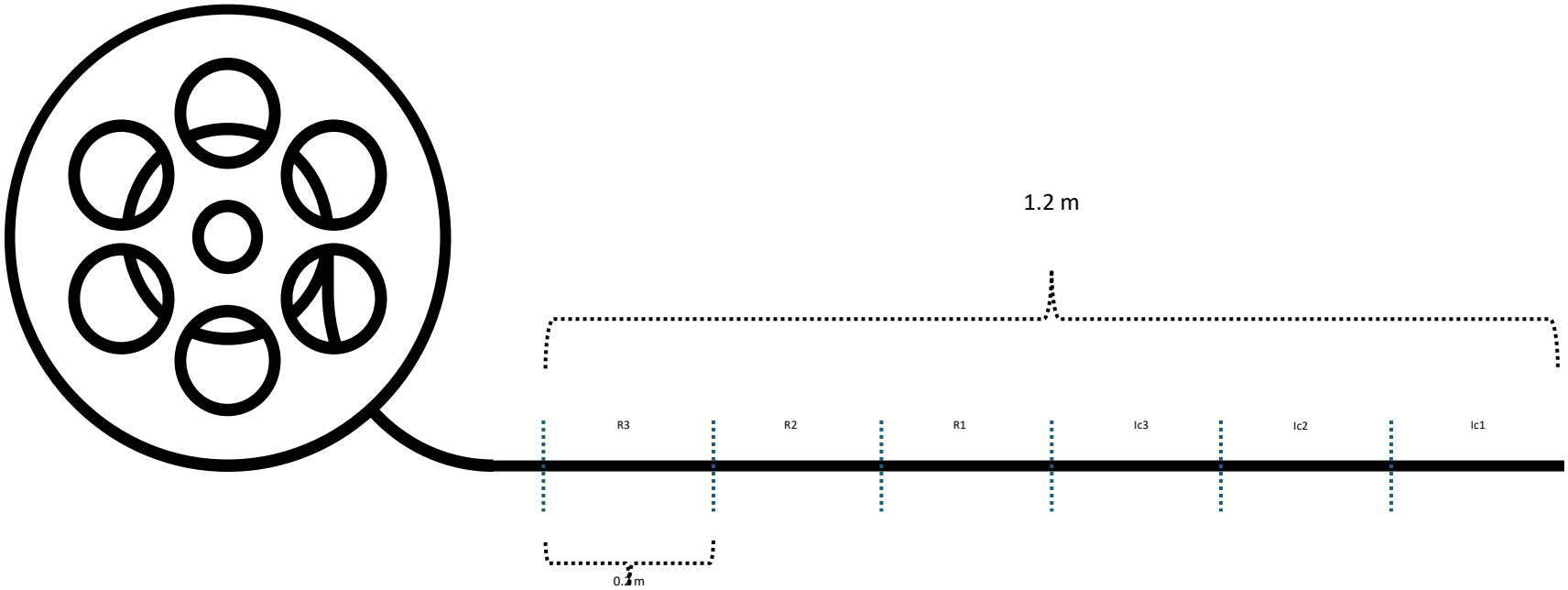


Fabrication and testing

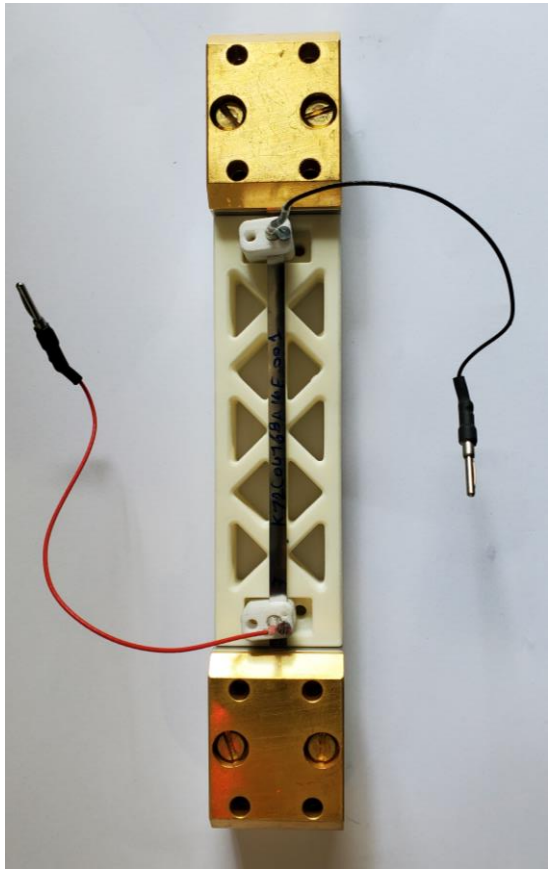
Current lead assembly

Testing and Qualification of HTS Samples (QC I):

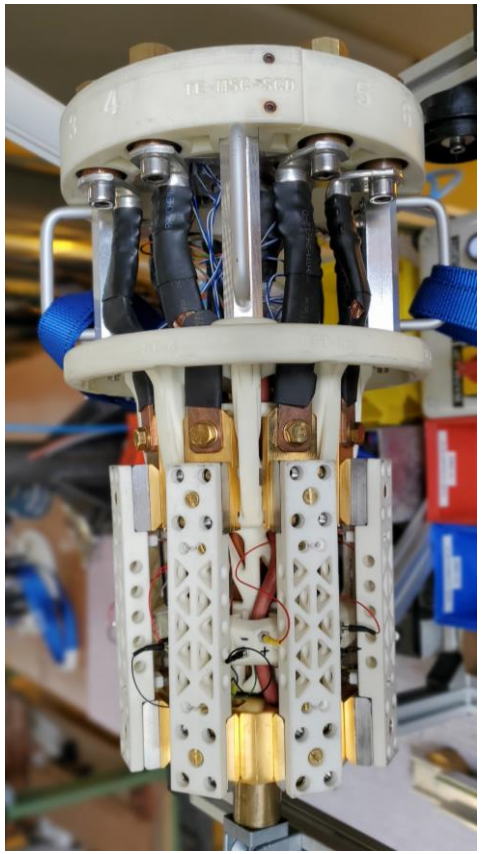
- Cutting 1.2 m (6 samples, 0.2 m each)
- 3 samples for critical current (Ic1, Ic2 and Ic3)
- 3 samples for internal resistance (R1, R2 and R3)
- Record in the database



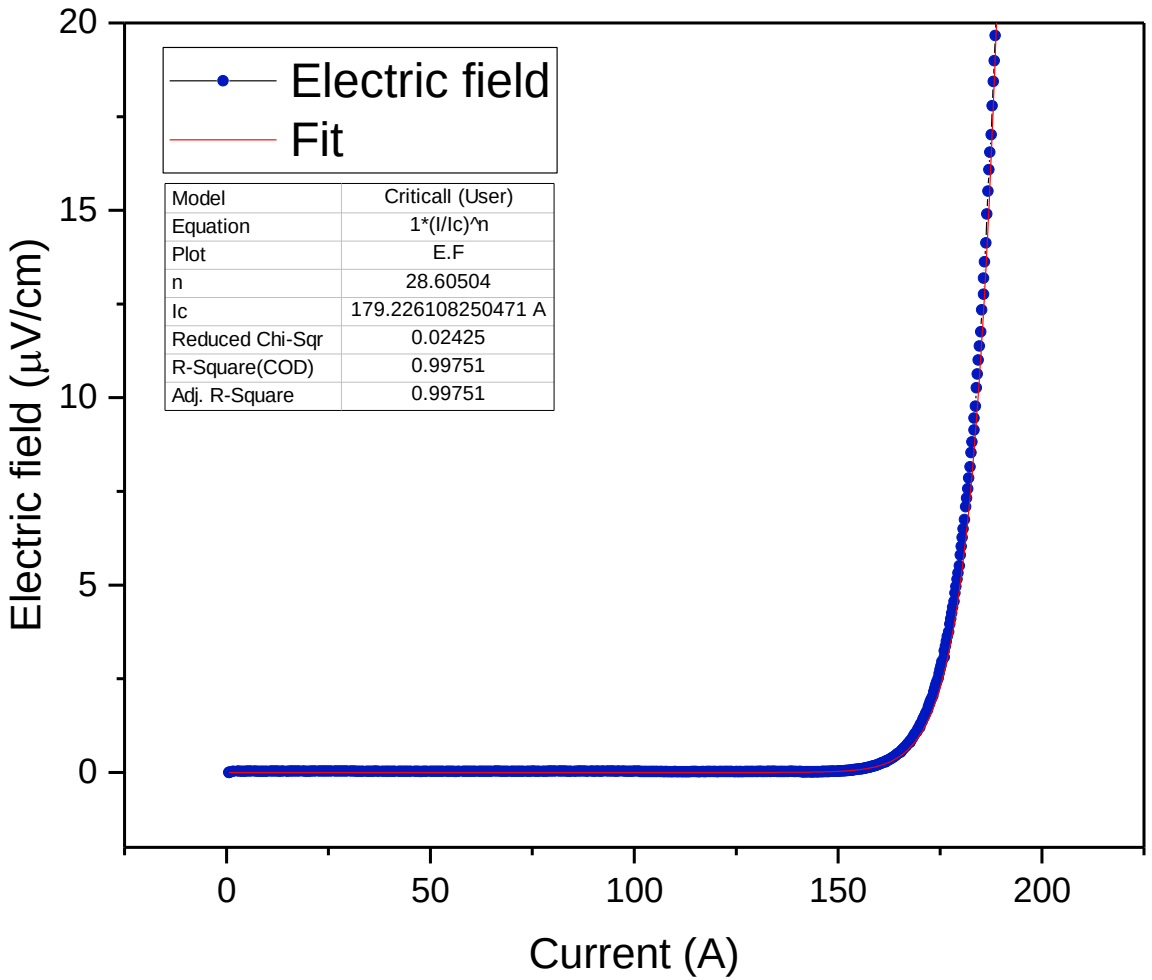
HTS Station



Sample Preparation



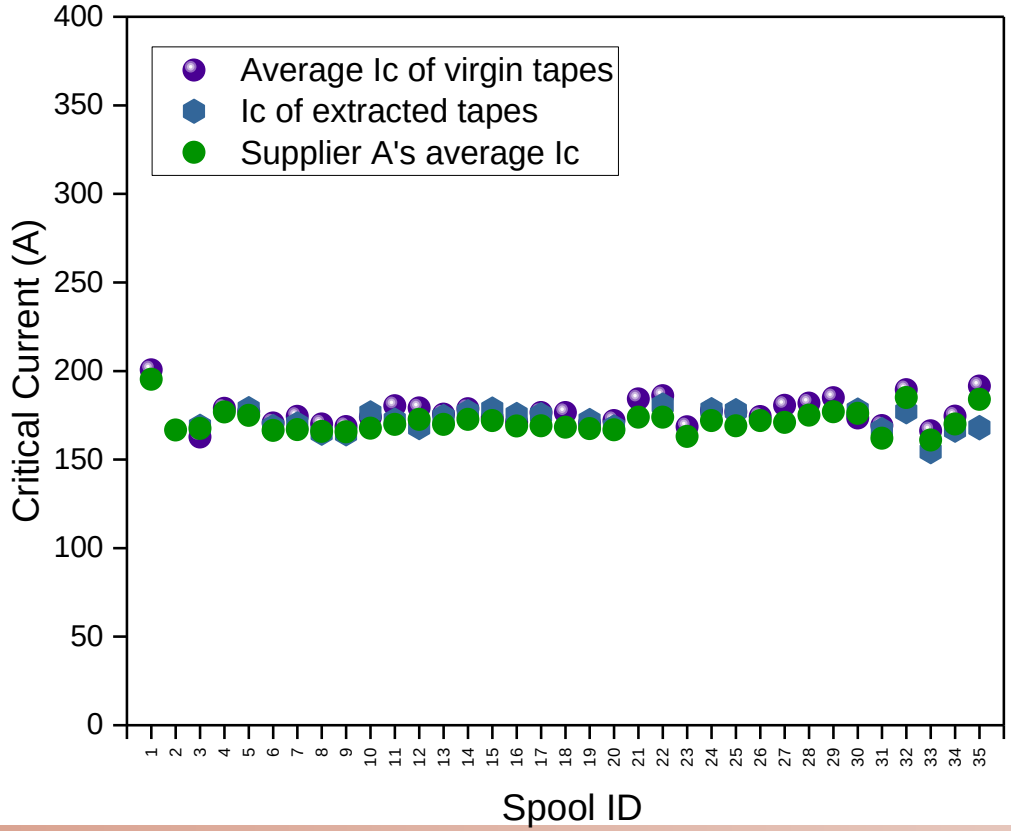
Sample Insert

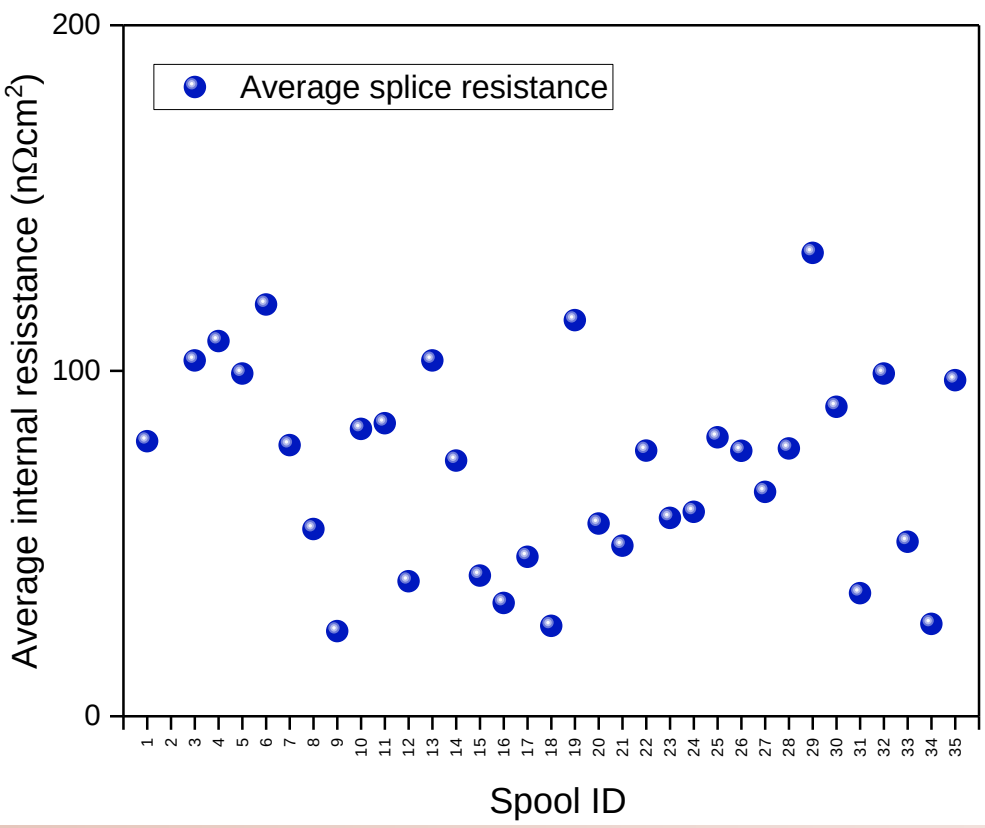


An exemplary curve of a virgin tape from the critical current measurements shows an Ic of 179.23 A with an n value of 28.60.

Internal Resistance

Why do we need internal resistance → to homogenise the splice resistance or all tapes in a cable

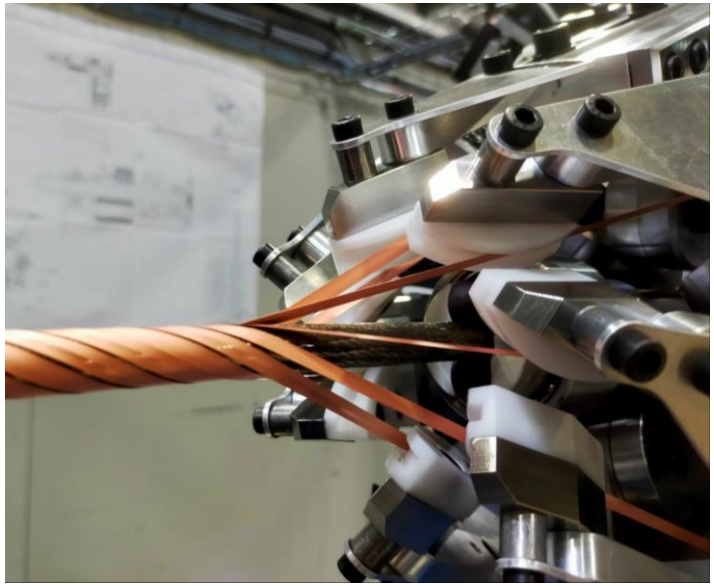




Fabrication of HTS cables at CERN

Cable configuration:

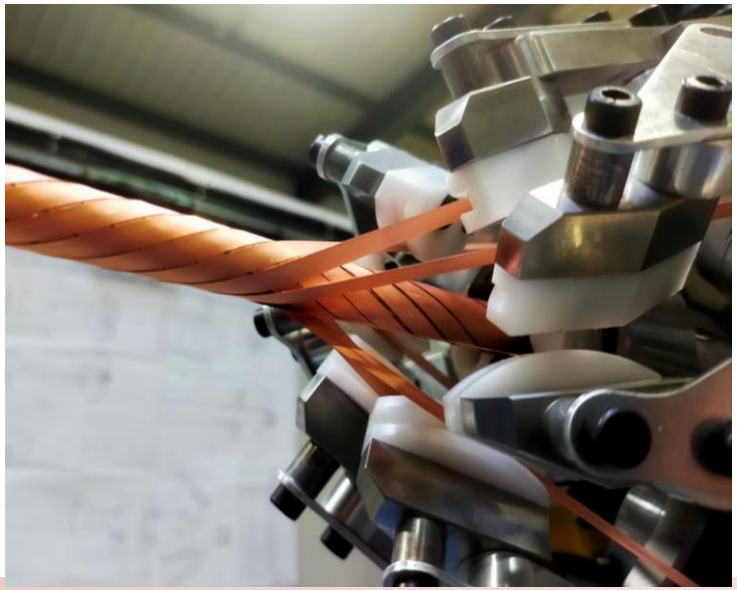
- REBCO tapes helically wound on a braided copper core.
- 2 layers with opposing winding directions with a copper layer between them.
- 7 tapes per layer.
- REBCO layer positioned towards the outside.
- Outer insulation layer of Kapton tape.



Circuit configurations:

- 2 kA circuit: 1 cable.
- 7 kA circuit: assembly of 2 cables.
- 18 kA circuit: assembly of 6 cables.
- Cable lengths:

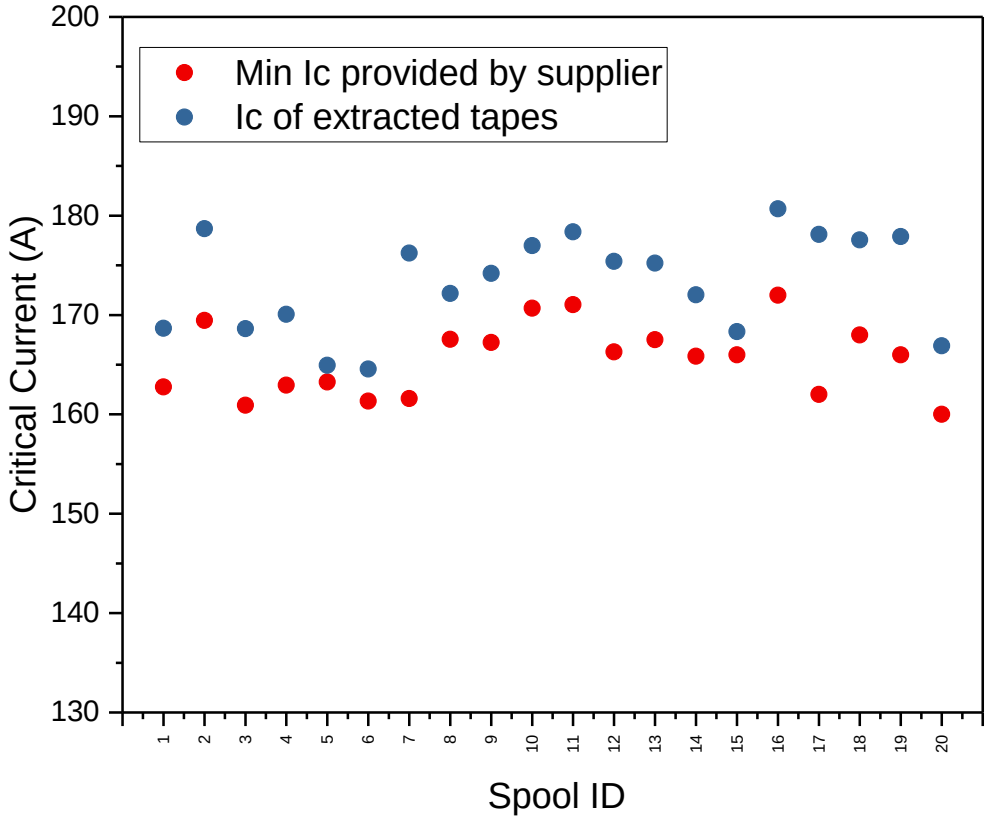
- Individual cable lengths: 2.0 to 3.5 meters.



Quality control of Extracted taps QC(II)

Testing Of extracted tapes (QC II):

- After cabling, cable is cut into the required 2.5 to 3.5m long pieces, and dedicated QC cable samples (0.3m) at the ends and between all cable pieces
- Extraction of all tapes and QC measurements: rejection of cable if extracted tapes show degradation (compare to min. Ic of used spool provided by supplier)
- If accebpted, cable pieces are terminated on both ends with the Cu tubes, each cable sample is measured in LN_2



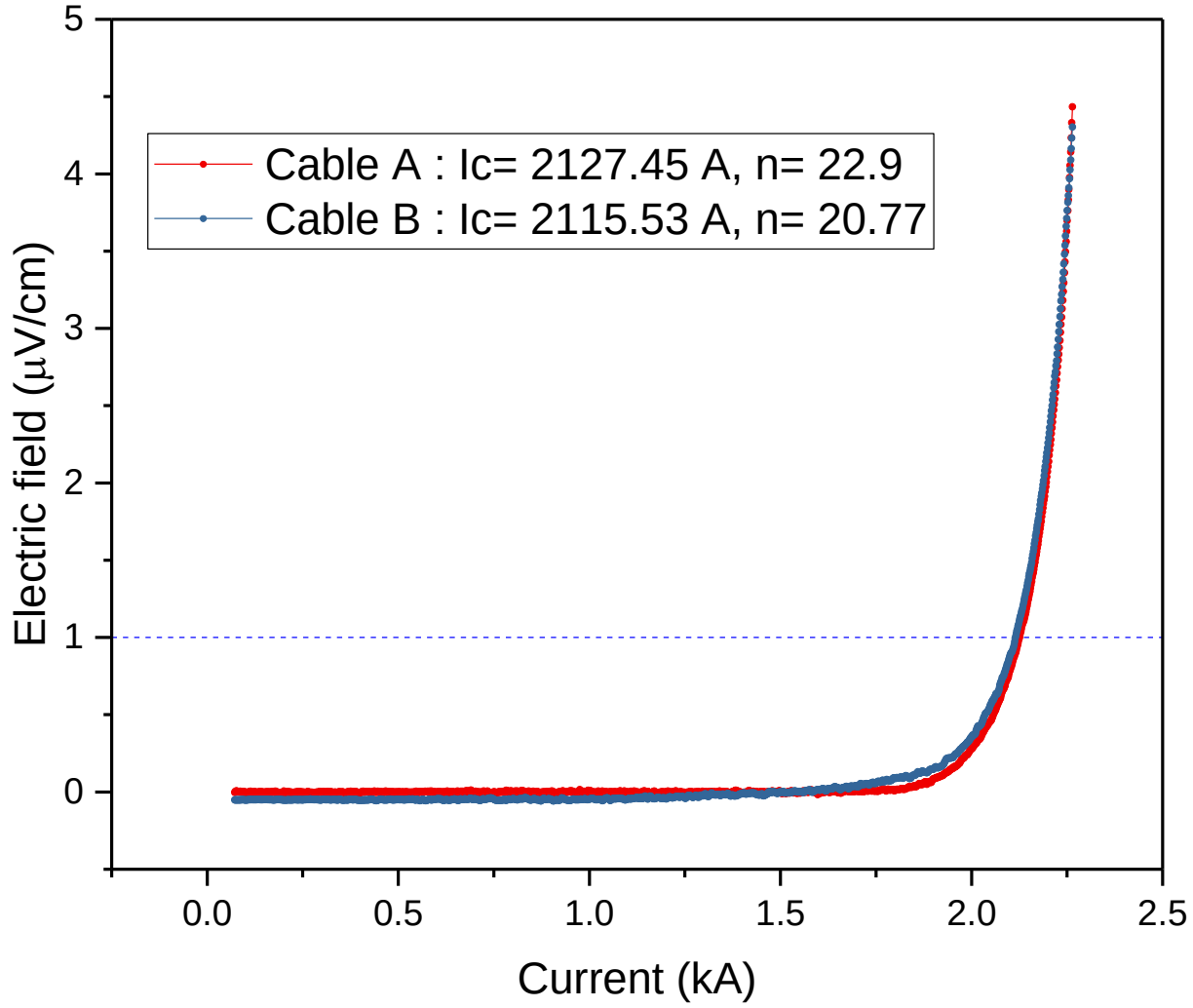
Cables

HTS Cable

Test in liquid nitrogen

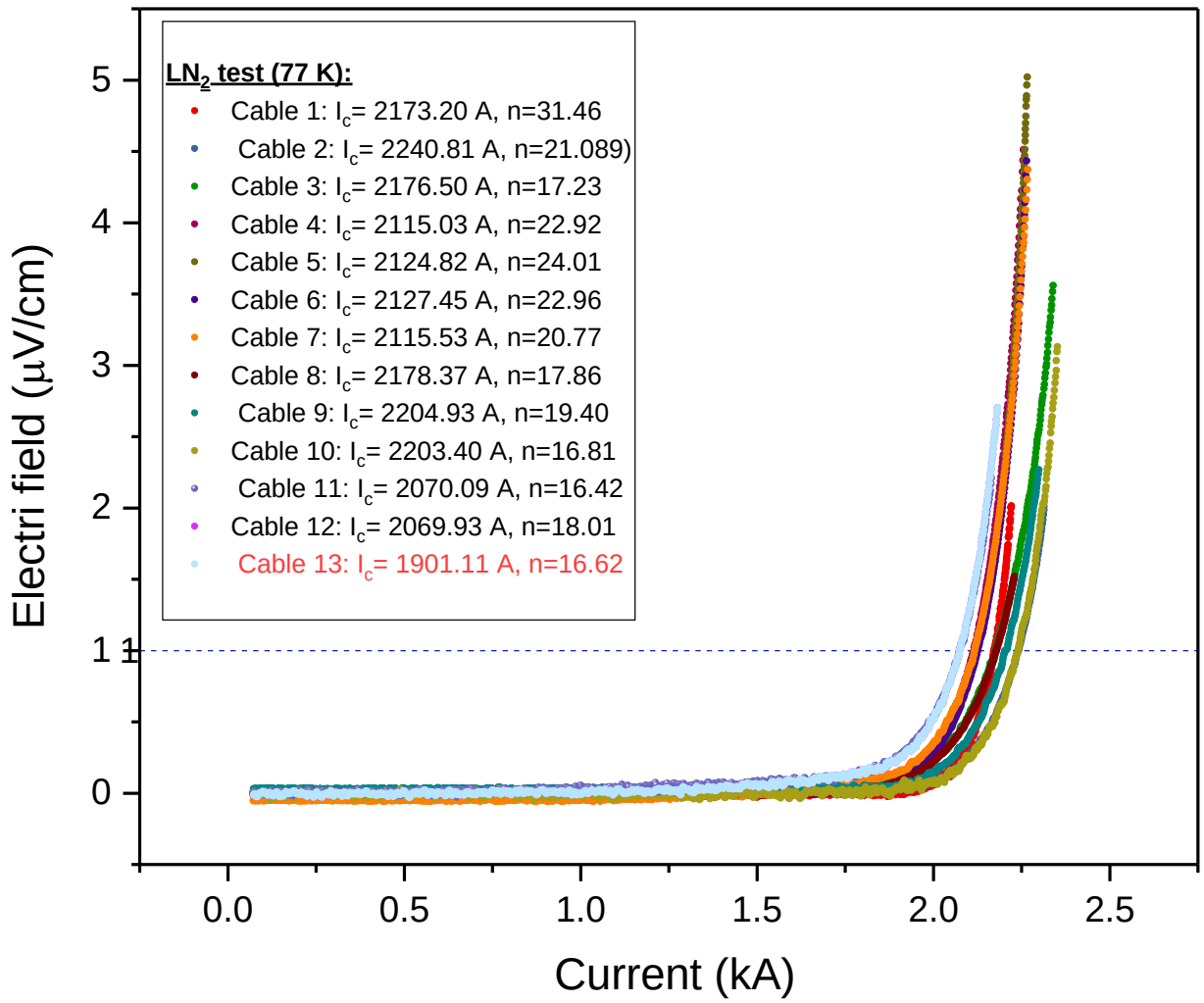
HTS cables tested in LN_2 (77 K) (QC III)

The critical current measurements of two consecutive cable from a single run, show very similar behaviour.

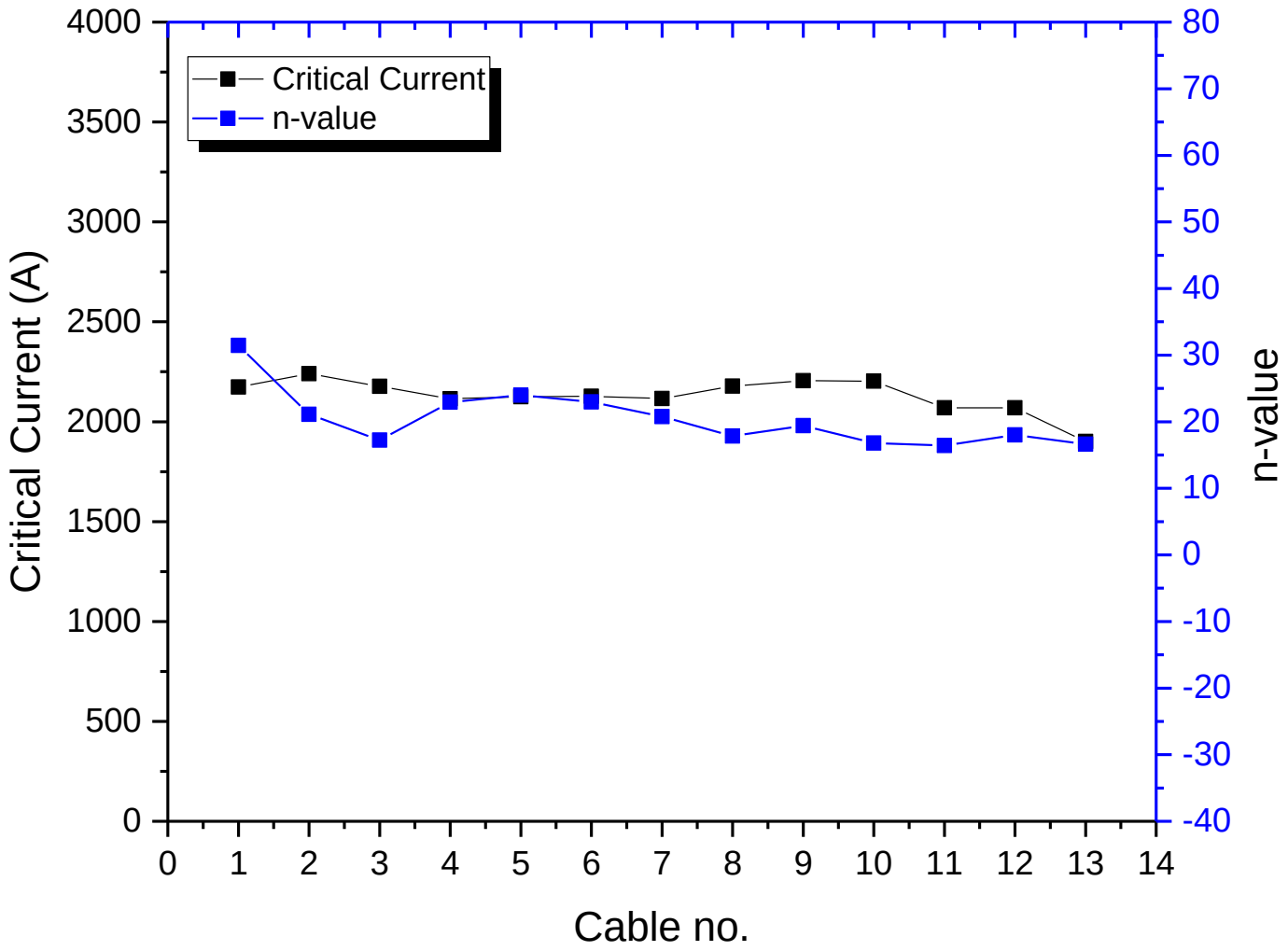


HTS cables tested in LN_2 (77 K)

The results include data from several cables (the minimum acceptance criteria of 1.9 kA (1 μV/cm) at 77 K).



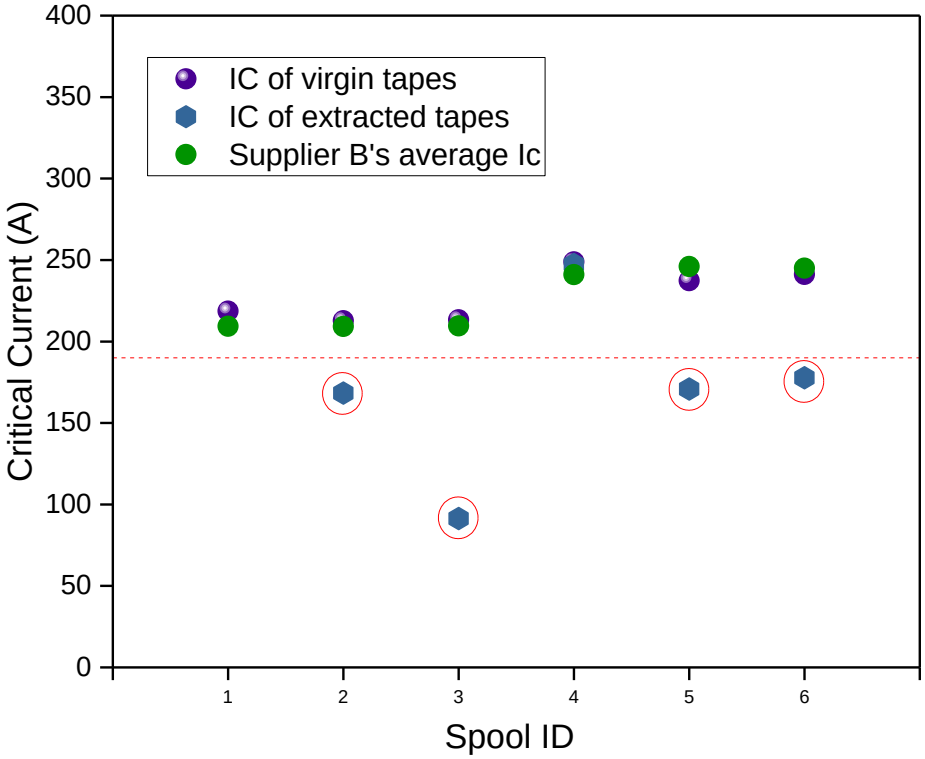
Critical current and n-values

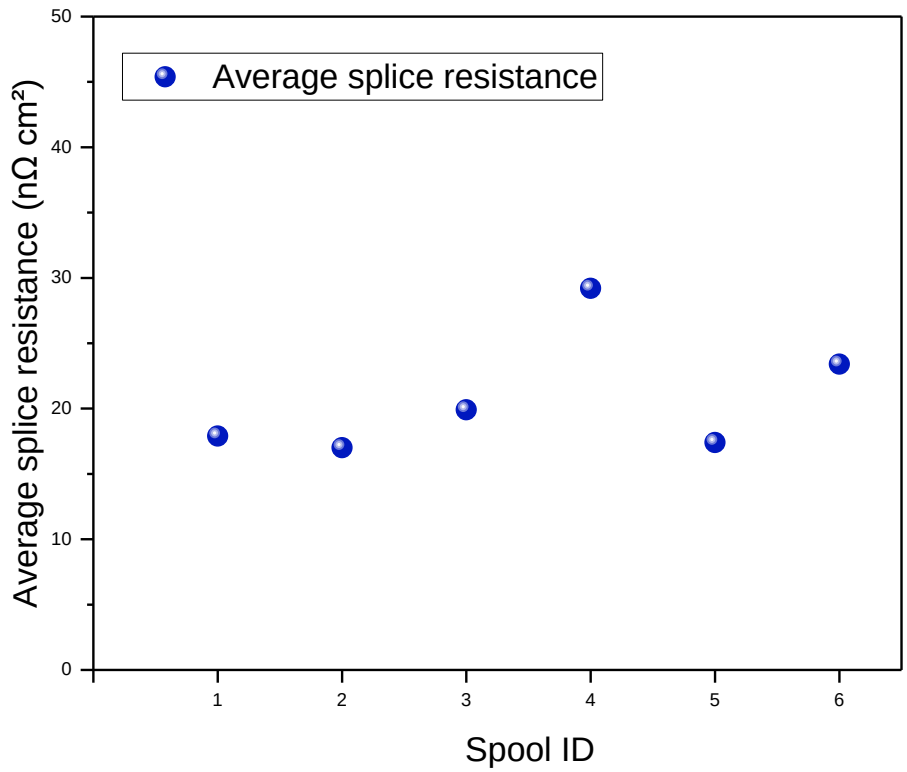


Recent Activities

Results Of REBCO tapes from Supplier B

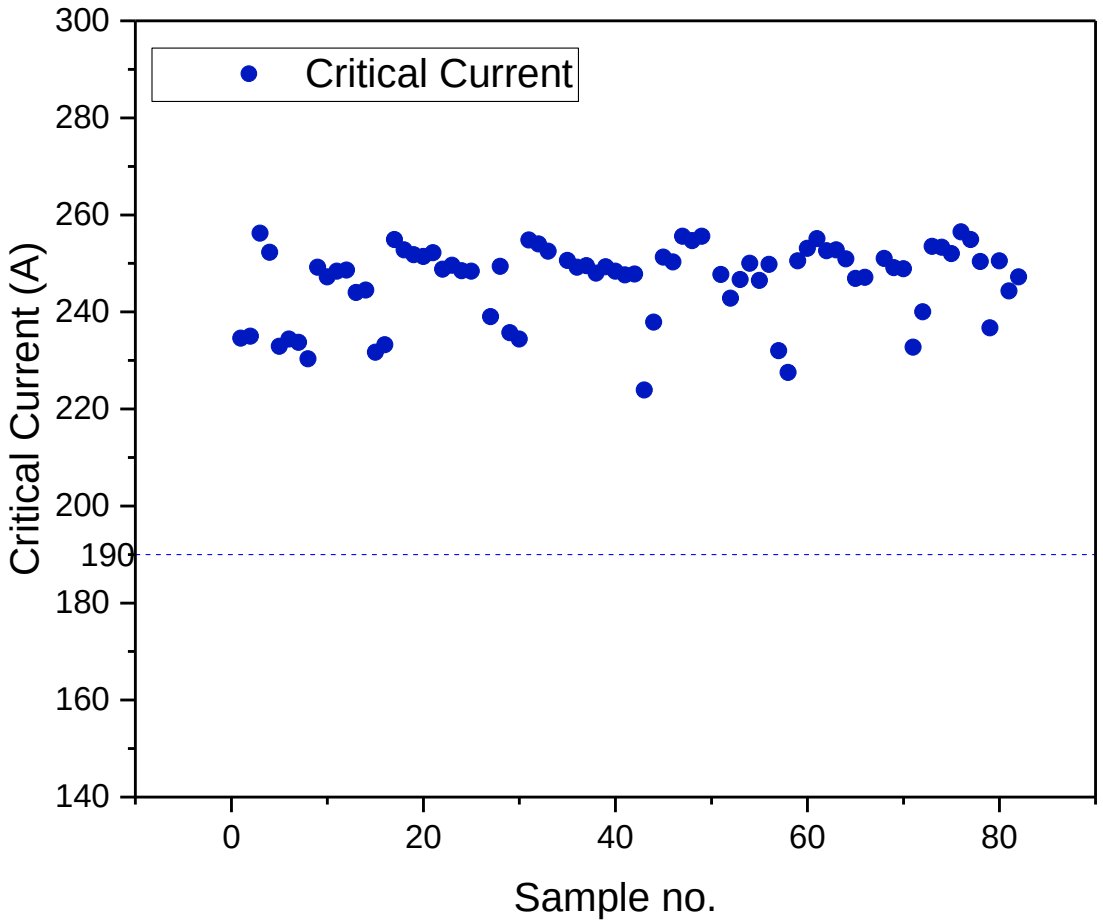
The Ic results from virgin wire are homogenous across length, lower internal resistance, but the extracted samples show degradation

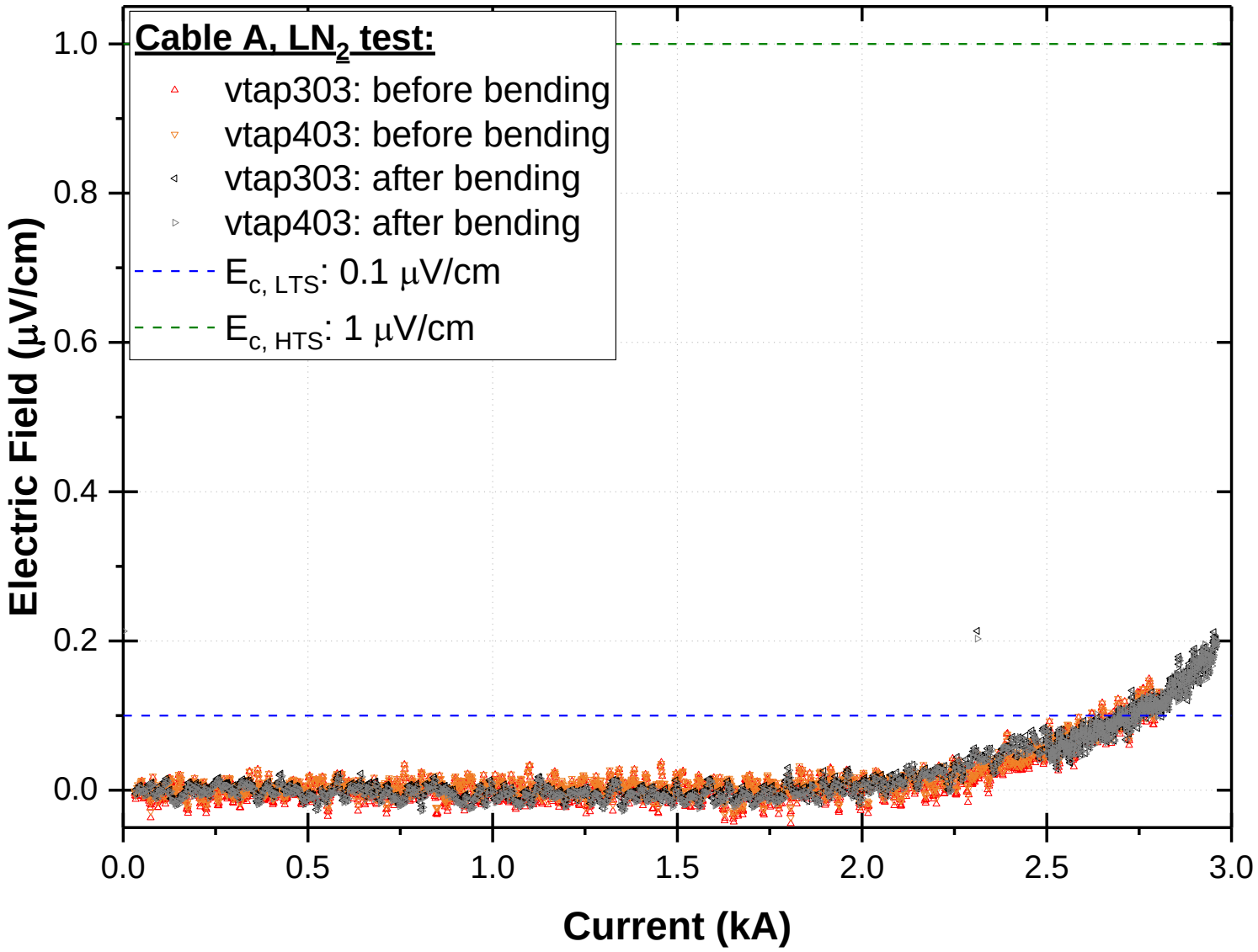




Cable with HTS inverted configuration (HTS layer facing inward)

The extracted tapes from a cable with HTS layer inverted configuration show no degradation (Specified criteria: 190 A at 77 K for 4mm wide tape)




Cable A, LN2 test:
vtap303: before bending
vtap403: before bending
vtap303: after bending
vtap403: after bending
Ec, LTS: 0.1 μV/cm
Ec, HTS: 1 μV/cm
Electric Field (μV/cm)
Current (kA)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Conclusion

Critical Role of Quality Control: Quality control of both virgin and extracted tapes and cables is ensuring the long-term reliability and performance of the cold powering systems.

Testing Protocols: Testing methods were employed to assess the quality of the tapes and cables. These protocols included critical current measurements and lap joint resistance measurements.

Meeting Project Requirements: The tapes and cables underwent comprehensive quality assessments to ensure they met the specific requirements of the project.

Long-Term Reliability: Ensuring high quality through stringent testing contributes to the long-term reliability of cold powering systems, which is essential for their practical deployment and operation.

Successful Prototype Operation: The prototype system operated highlighting the reliability and suitability of the selected materials.

Lessons for Future Development: Insights gained from the quality control process can inform future developments in HTS cable technology, improving designs(i.e. inverted configuration) and manufacturing processes.

Thank you

Cabling map with same resistance : an example

KX04Y45968A01U	40.12 nΩcm²
KX04Y31462A04U	39.048 nΩcm²
KX04Y45968A03U	46.12 nΩcm²

Cable length to produce:

Run °:	1019			Comment:									
Date:	15/03/2023												
Cable length to produce:		8.8	m										
	Head1 :				Head2 :				Buffer Head :			Head3 :		
Position:	HTS tape ref:	Length (cm):	Tension (N):	Position:	HTS tape ref:	Length:	Tension (N):	Position:	Buffer tape ref:	Length (cm):	Position:	Kapton tape ref:	Length (cm):
1	KX04Y45968A01U	1054	10	1	KX04Y31462A04U	1069	10	1	Cu 12 x 0.1mm	2429	1		3142
2	KX04Y45968A01U	1054	10	2	KX04Y45968A03U	1069	10				2		0
3	KX04Y45968A01U	1054	10	3	KX04Y45968A03U	1069	10				3		3142
4	KX04Y45968A01U	1054	10	4	KX04Y45968A03U	1069	10				4		0
5	KX04Y45968A01U	1054	10	5	KX04Y45968A03U	1069	10						
6	KX04Y45968A01U	1054	10	6	KX04Y45968A03U	1069	10						
7	KX04Y45968A01U	1054	10	7	KX04Y45968A03U	1069	10						
Total (cm):		7379.008				7481.94				2429.152			6283.2
Total (m)		148.61							24.29			62.83	

	Tape Id:	Head1:	Head2:	Total (cm)	Total (m)	All tapes total (m)
tape 1	KX04Y45968A01U	7379	0	7379	73.79	148.61
tape 2	KX04Y31462A04U	0	1069	1069	10.69	
tape 3	KX04Y45968A03U	0	6413	6413	64.13	

KX04Y45968A01U	40.12 nΩcm²
KX04Y31462A04U	39.048 nΩcm²
KX04Y45968A03U	46.12 nΩcm²