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Progress on quench measurements on high current MgB_2 cables

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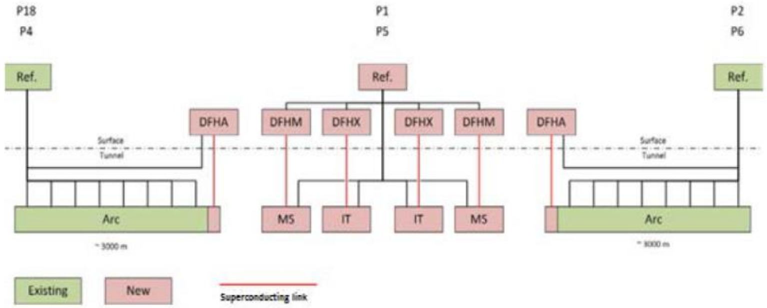
Outline

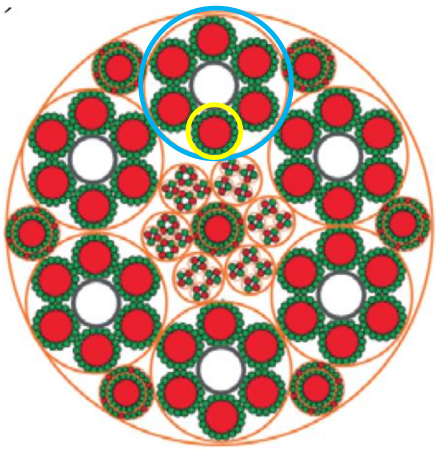
- Introduction
- Experimental setup
- Measurement results
  - Electrical characterization of the cable
  - Minimum quench energy
  - Normal zone propagation velocity
  - Transverse propagation
- Hot-spot temperature and protection

Introduction

- Superconducting Links based on MgB_2 cables cooled with helium gas will be used to power the magnets of the inner triplets and matching sections at IP1 and IP5
- Each Link will contain cable assemblies
- 20kA-rated cables will feed the low-β* inner triplet quadrupoles
- In this work we investigate the quench behaviour of an 18-strand cable → sub-unit of the 20kA and 3kA cables



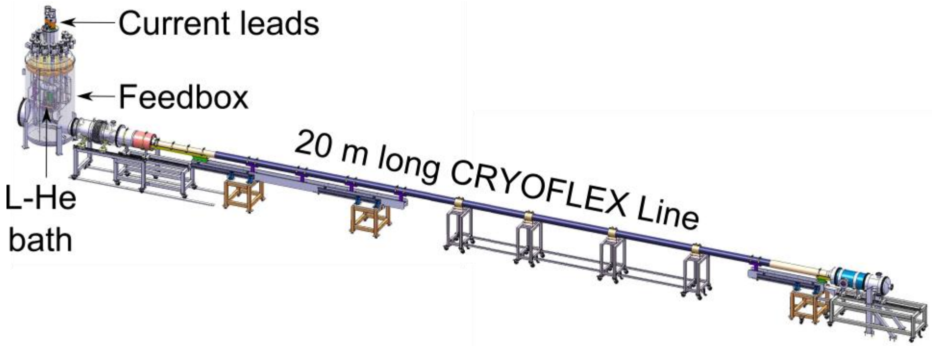
SC Links at P1 and P5

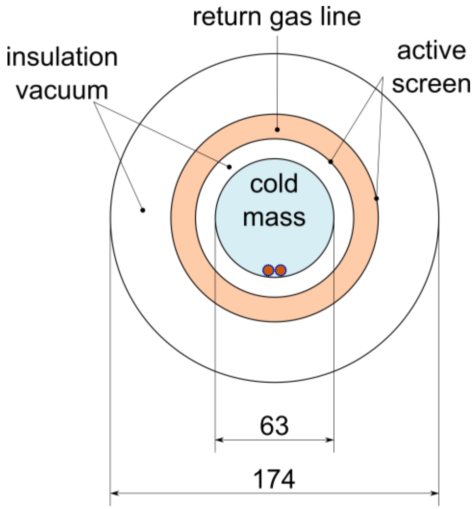


SC Link baseline configuration for inner triplets

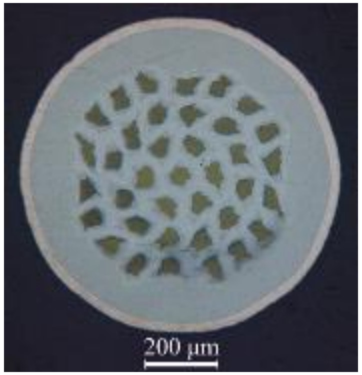
Test station

- Length: 20 m
- Temperature: 5-70 K
- He gas flow: 0.5-10 g/s



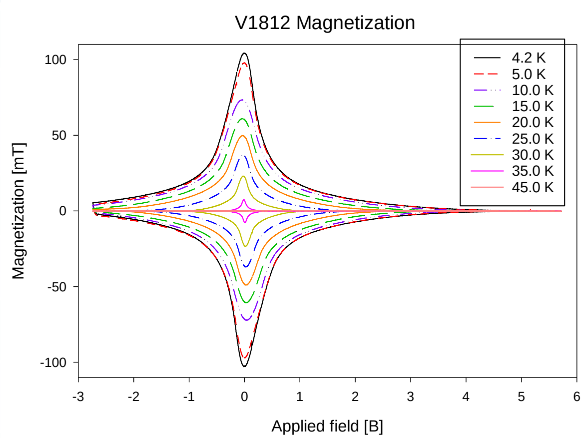


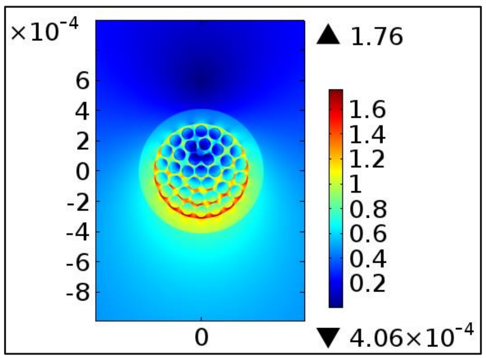
MgB_2 conductor



- Ex-situ round wire produced by Columbus Superconductors
- $J_c(T,B)$ curves obtained by combined magnetization and transport current measurements

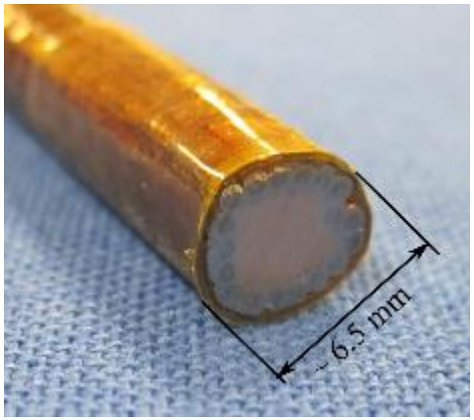
Wire parameters	
Wire diameter	0.87 mm
Number of MgB_2 filaments	37
Volume fractions	
MgB_2	14.6 %
Niobium	16.5 %
Nickel	20.8 %
Monel	37.6 %
Copper	10.5 %

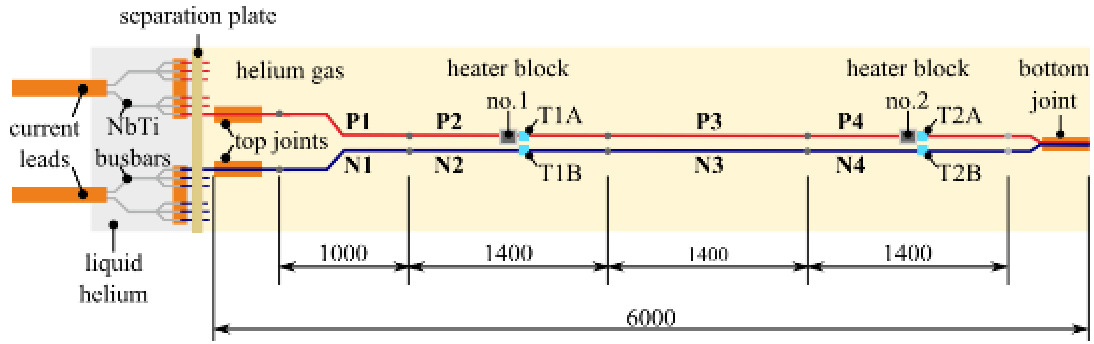


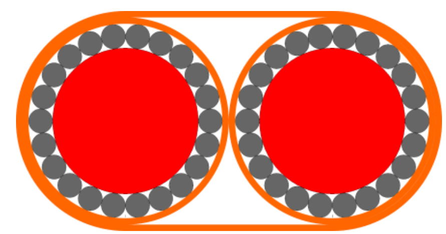


P. Alknes

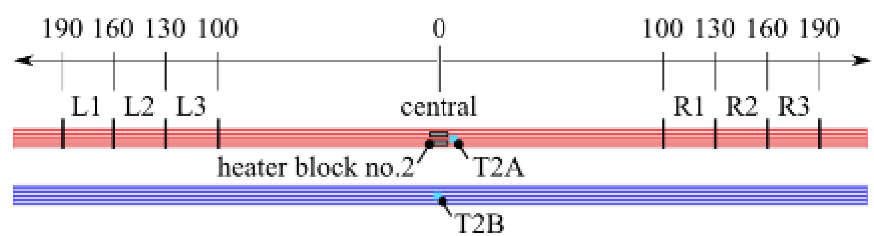
Cable assembly





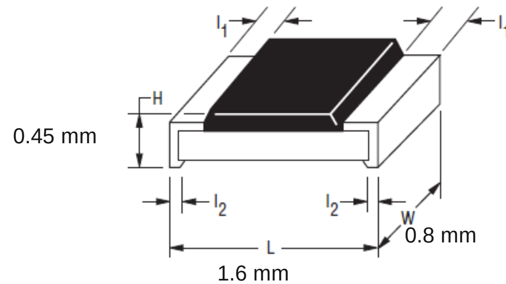


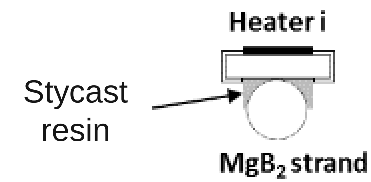
Cable parameters	
Cable diameter	6.5 mm
Number of MgB_2 strands	18
Cable twist pitch	400 mm
Copper braid cross section	12 mm^2 (RRR 80)
Cable insulation	200 µm per polarity (400 µm on portions P2/N2)

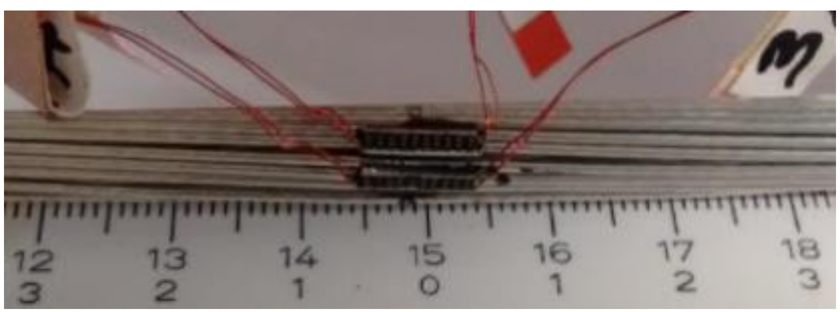


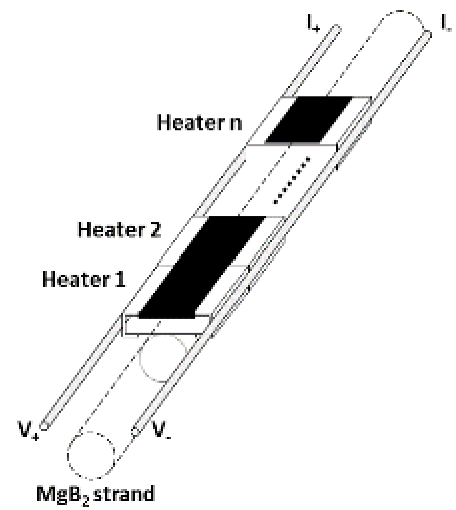
Heaters for quench trigger

- *Heater block*: two sets of Surface Mount Device Resistors (SMD-R) connected in series → best compromise in terms of size, power and robustness
- Each set has ten 10Ω parallel-connected resistors (8mm length)
- Power: up to 10W per resistor for pulses shorter than 100 ms



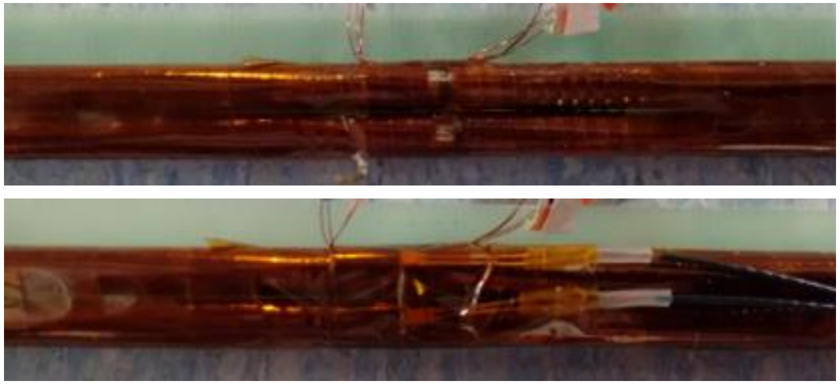


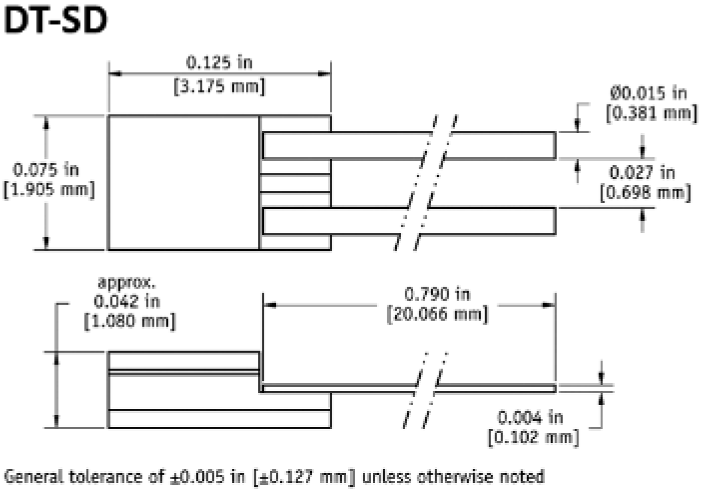




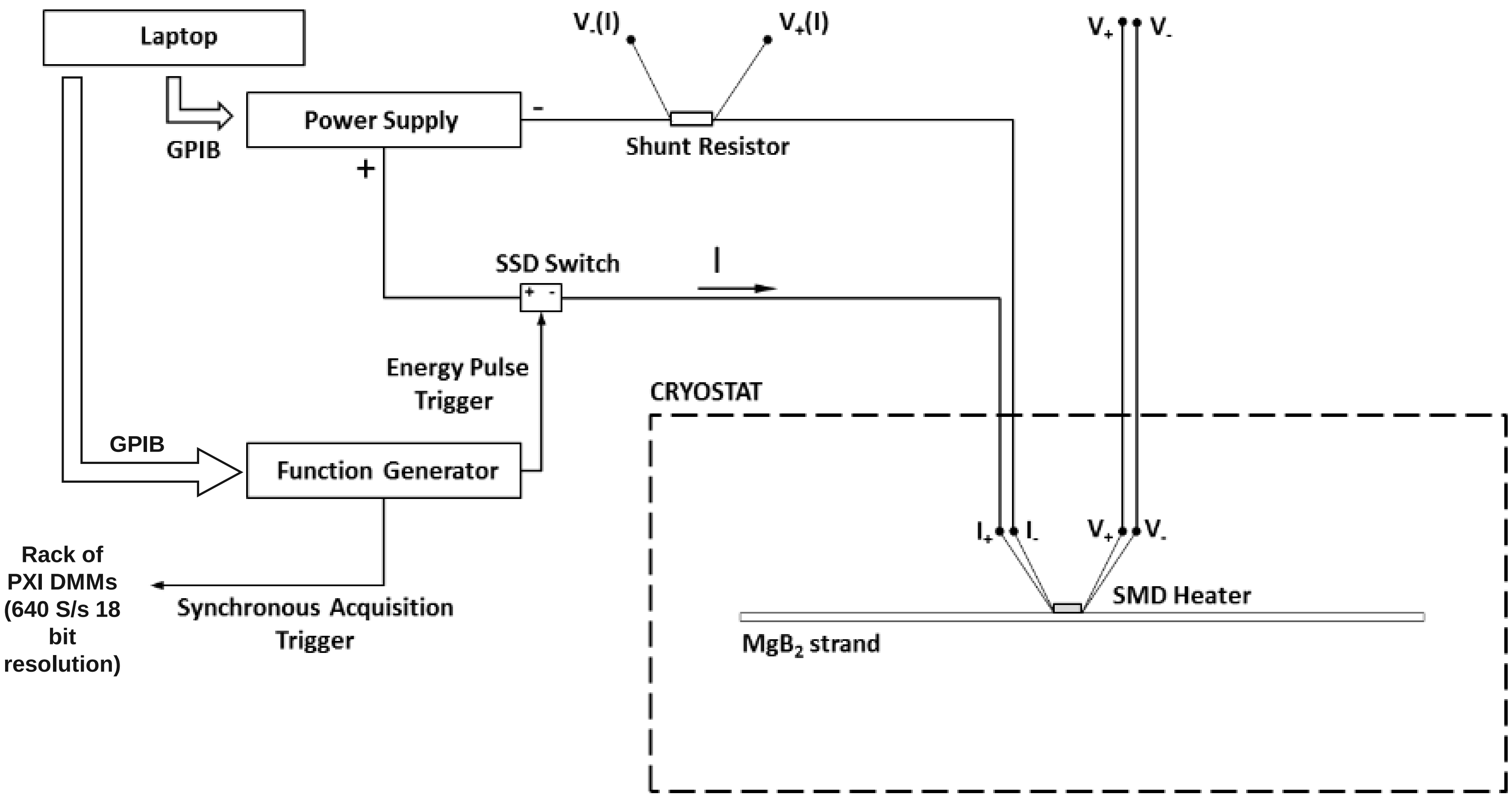
Temperature measurement

- Lakeshore DT-670 silicon diode sensors installed in correspondence of the heater blocks (±0.5 K resolution)
- Contact with cable by local removal of insulation and application of thin layer of Apiezon® thermal grease
- Used to monitor cable temperature before Ic measurements and hot-spot evolution



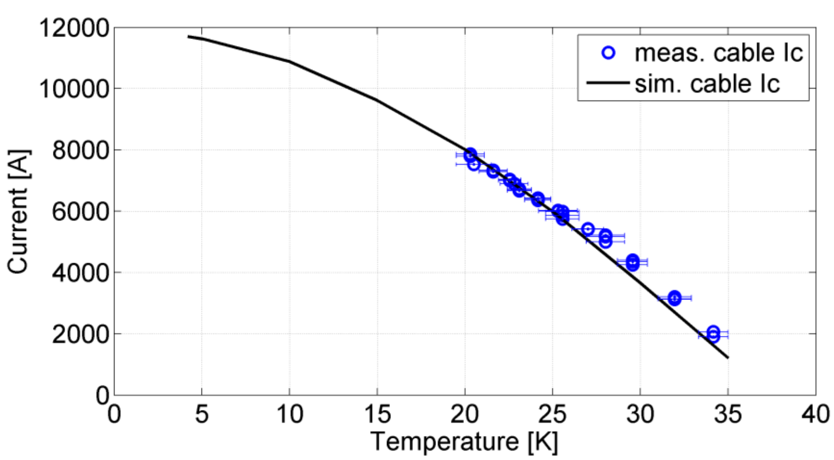


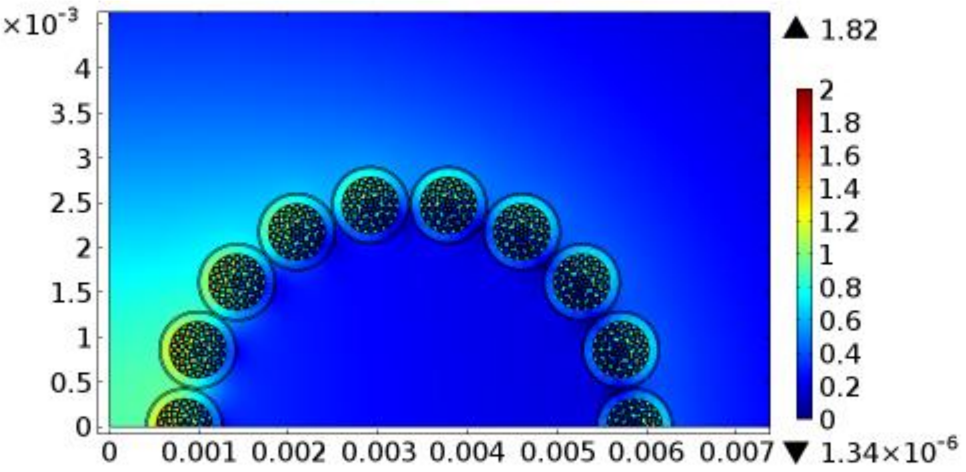
Electrical scheme for quench measurements



Electrical characterization of the cable

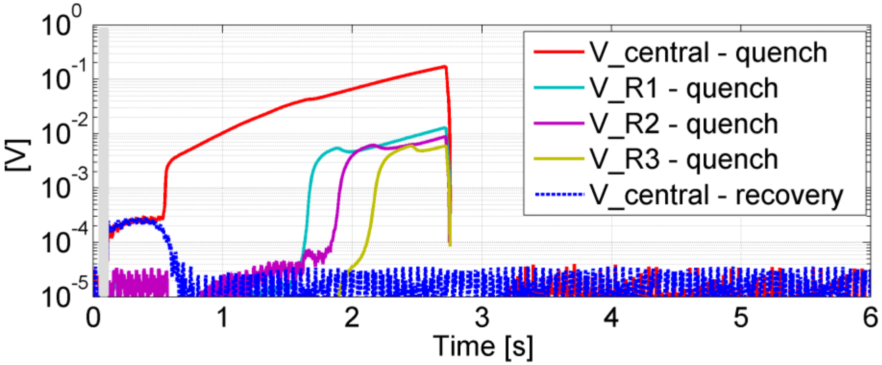
- Cable I_c measured at standard criterion of 1 μV/cm after temperature stabilization (±1 K variation along the cable length)
- Measurements performed with a mass flow rate between 1 and 2 g/s
- Error bars from temperature oscillations (measured during 10 minutes-long period before Ic measurements) and sensor resolution; three measurements per operating temperature
- Joint resistances: 18-21 nΩ for top joints, 12-14 nΩ for bottom joint

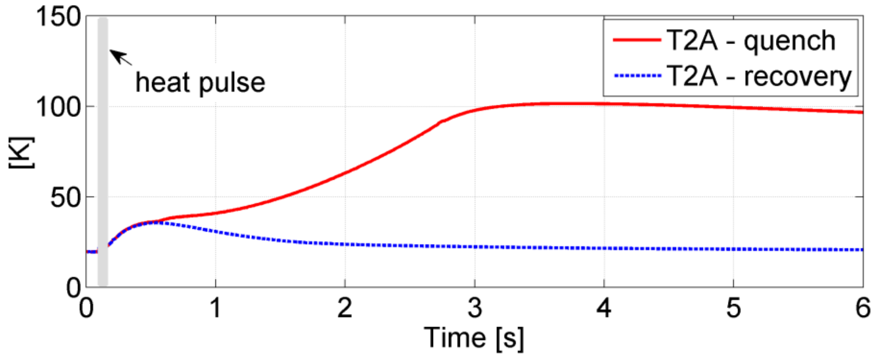


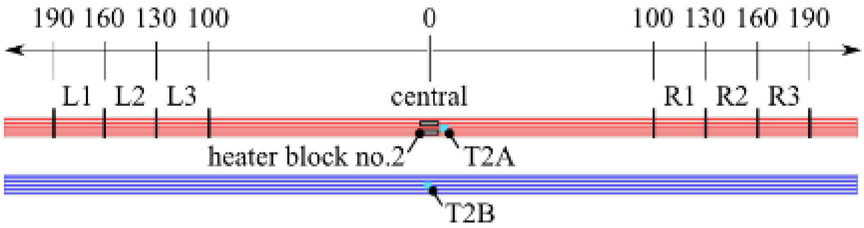


Quench measurements: procedure

- Quench triggered via a 50ms square current pulse feeding the chosen heater block
- In case of recovery, no voltage appears across the lateral cable portions → minimum propagating zone is shorter than 100 mm



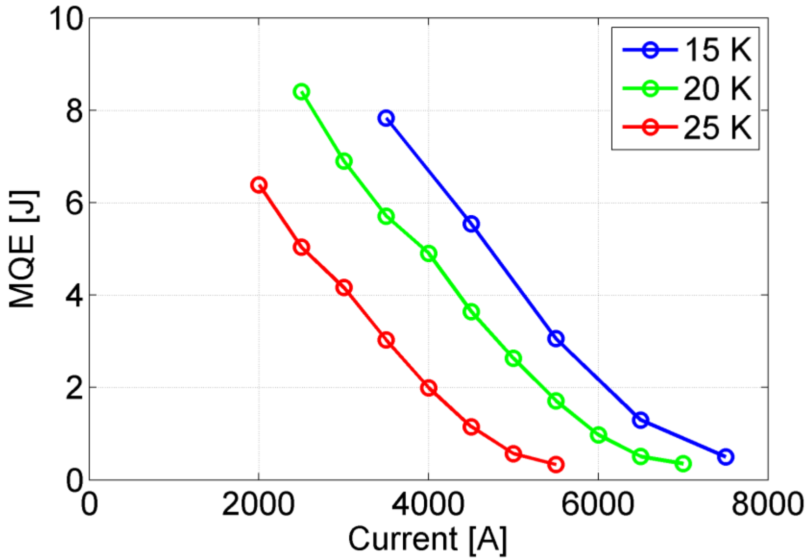




Measurement performed at 20 K, 3000 A

MQE measurements

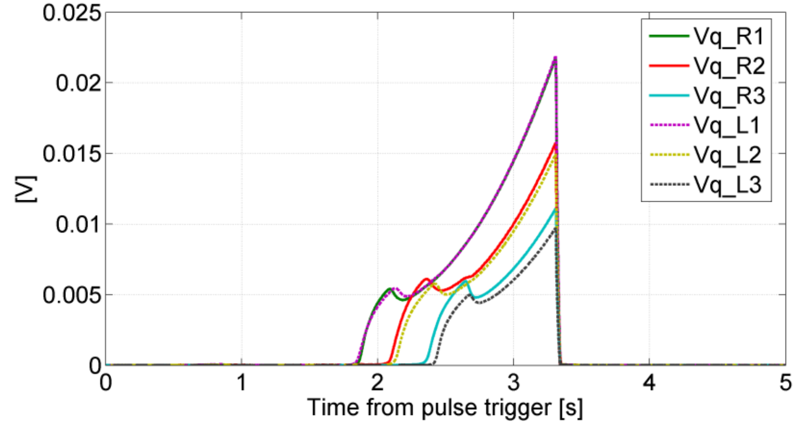
- Energy deposited in the heater block was increased incrementally up until a quench occurred (5% increase steps)
- Both minimum quench energy (MQE) and maximum recovery energy (MRE) finally checked starting from a virgin state of the cable to eliminate effects of uneven current distribution among the strands
- As $I_{op}/I_c \rightarrow 1$ the MQE curves flatten, in accordance with a model taking into account finite-n-value transition of the superconductor[1]

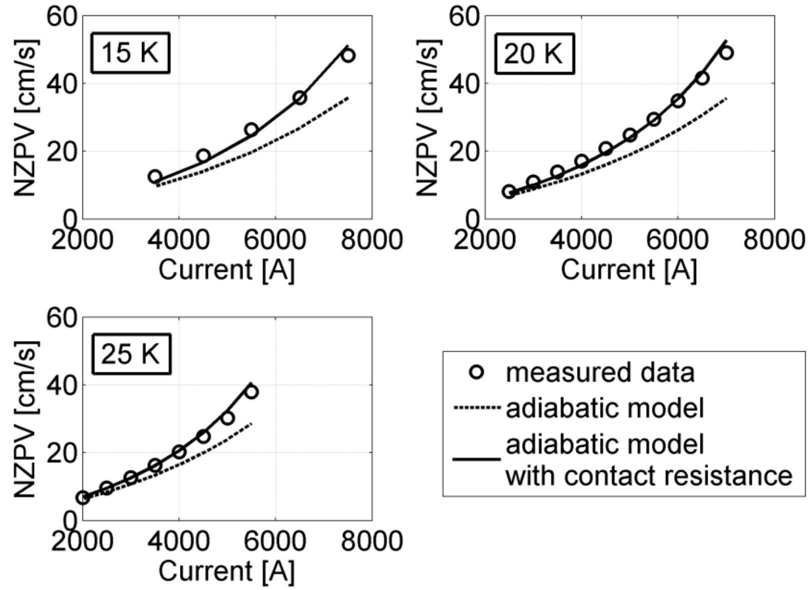


[1] Y. Yang, "Thermoelectrical studies", Deliverable Report D6.5, Hi-Lumi LHC Work Package 6

NZPV measurements

- Voltage traces present a bump pointing to current redistribution between MgB_2 strands and central copper braid
- The macro-strand adiabatic model fails to predict the measured values (errors up to 28%)
- Good fit obtained with a model which takes into account the contact resistance between the MgB_2 strands and the Cu braid[2] (error < 8% with best-fit conductance value $G_c = 2{\cdot}10^8$ S/m) → measurements ongoing
- At 3 kA NPVZ = 7.3-12.6 cm/s for T = 5-25 K

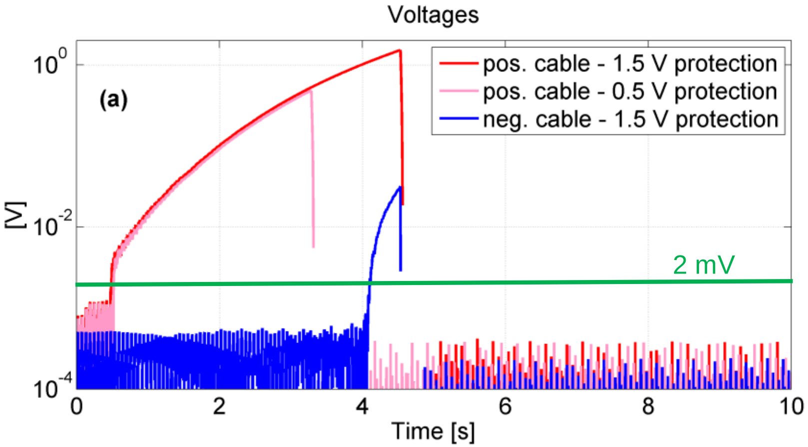




[2] M. Calvi et al., “Analytical model of thermo-electrical behaviour in superconducting resistive core cables”

Transverse propagation

- If the propagation is sufficiently long, a quench on a cable might induce the resistive transition of an adjacent cable by transverse heat transfer through respective insulation layers and interstitial helium gas
- Quench delay between pos/neg cables measured at 2 mV voltage threshold
- Data point to a minor impact of thicker insulation layer



Measurement performed at 15 K, 3000 A

Quench delay between positive and negative cable			
T [K]	Current [A]	Delay with 200 µm insulation thickness per cable [s]	Delay with 400 µm insulation thickness per cable [s]
15	3000	3.6	4.0
20	3000	3.4	3.8
25	2000	5.9	6.7
25	3000	3.1	3.3

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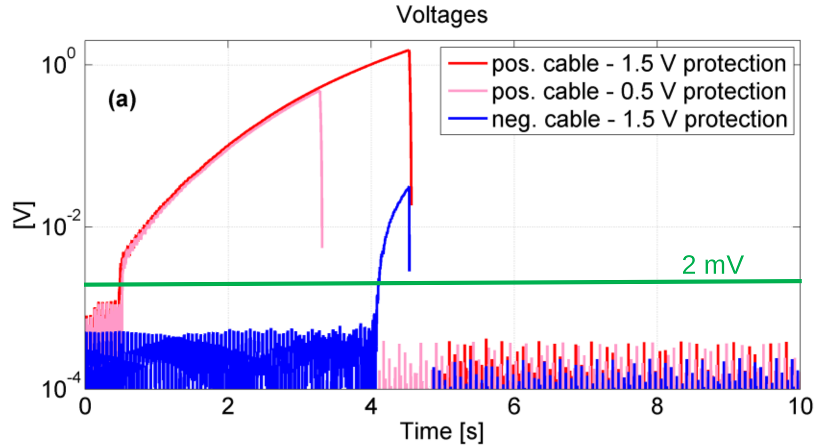
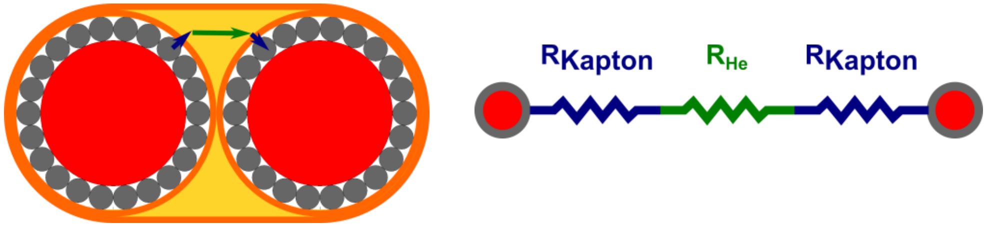
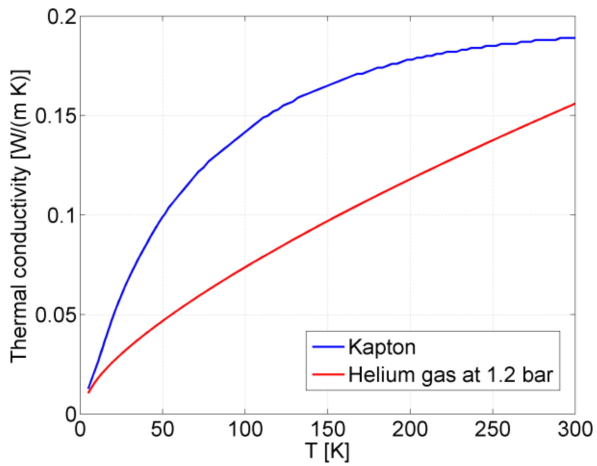


Measurement performed at 15 K, 3000 A





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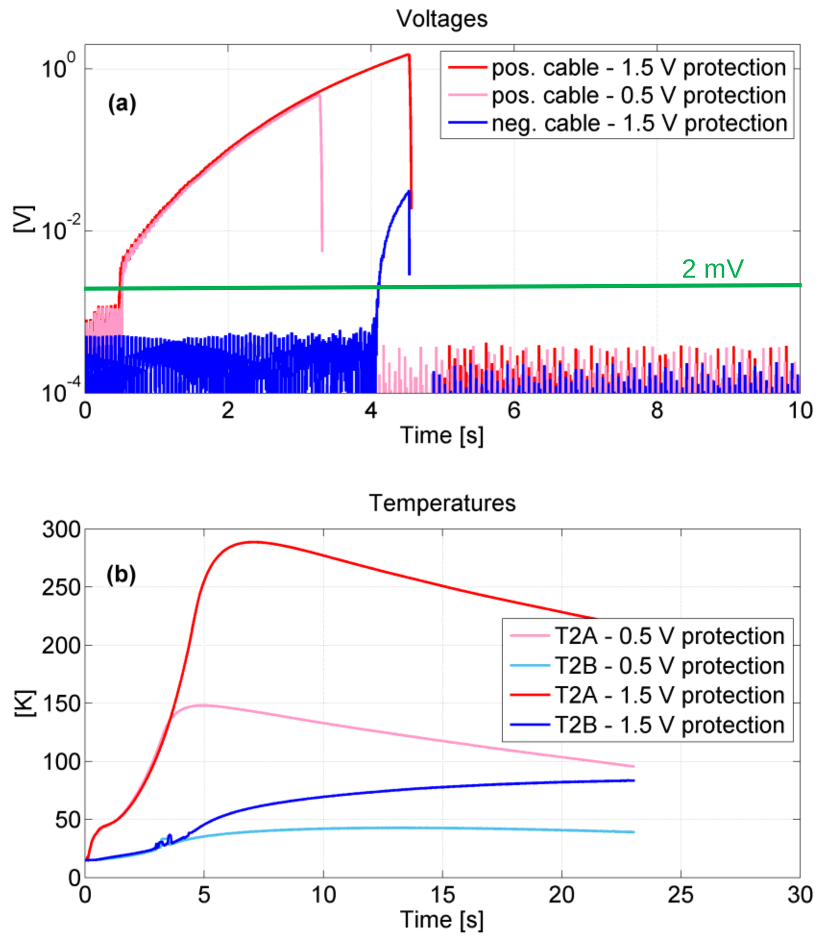
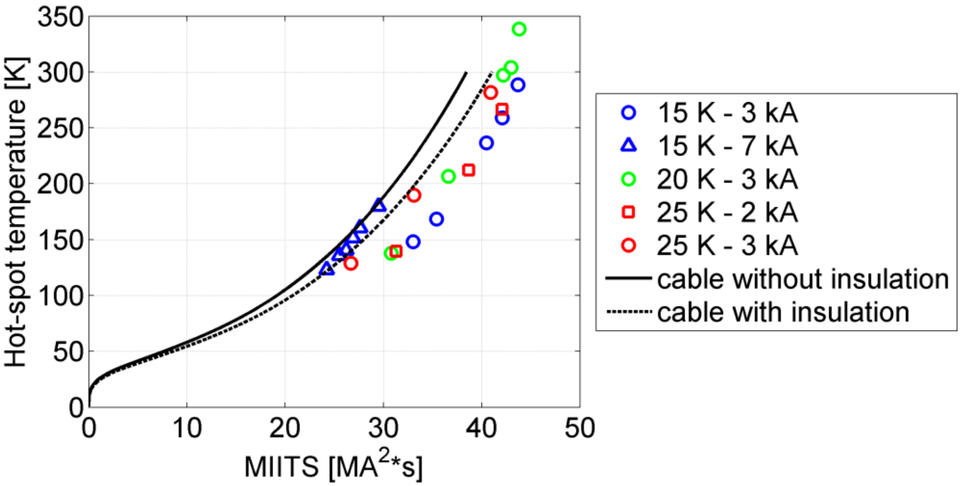
- Data point to a minor impact of thicker insulation layer
- Further experimental verification in multi-circuit cable assembly configurations is planned



Measurement performed at 15 K, 3000 A

MIITS and protection

- MIITS varied by changing the voltage threshold of the QPS
- Lower current → lower NZPV → longer propagation time at given voltage threshold → more important contribution of helium cooling on hot-spot temperature evolution
- Max hot-spot temperature reached T_{hs}~340 K with no degradation of cable Ic
- 25 K, 3 kA, 100 mV detection threshold → 15 MIITS of "quench capital" before detection → final T_{hs}~150 K with 3s time constant of the circuit



Conclusions

- Established an experimental setup and procedure for quench propagation measurements
- The measured values of MQE confirm a significant stability margin
- Measured values of the NZPV are in the order of 10 cm/s
- Voltage traces and comparison of NZPV data with simulations point to an effect of current redistribution between the MgB_2 strands and the copper core mediated by the electrical contact resistance
- Experimental data show that transverse quench propagation between adjacent cables can be avoided for sufficiently short propagation times

  → additional modelling and experimental verification in multi-circuit assembly
- The measurements show that quench detection and protection of high-current MgB_2 cables is feasible with acceptable voltage threshold and hot-spot temperature values in the operating conditions investigated