Quench Protection of the HL-LHC Hollow Electron Lens Superconducting Solenoid Magnets

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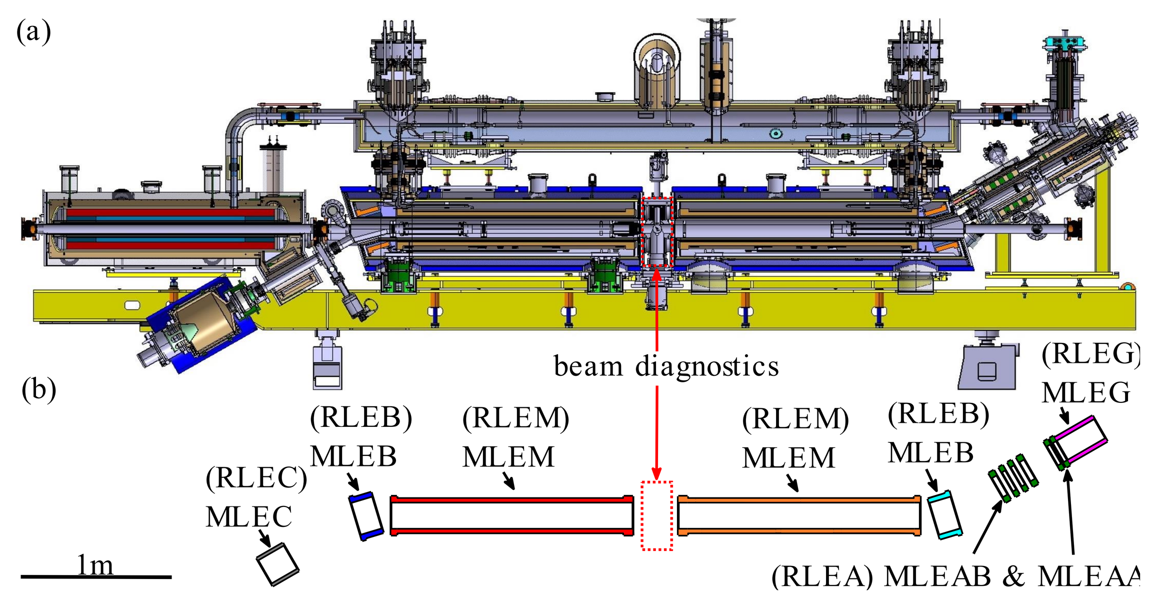
Introduction

- Installation of two Hollow Electron Lens (HEL) systems is a part of the High-Luminosity LHC (HL-LHC) project.
- The systems aim for a controlled depletion of hadron beam tails and an enhanced hadron beam halo collimation.
- Quench protection method selected to comply with the allowed limits of 500 V maximum peak voltage-to-ground and 120 K maximum coil temperature.
- Quench simulation tools were combined with uncertainty quantification methods.



	Unit	RLEM	RLEB	RLEA	RLEG	RLEC
Type*		CSM	SSM	CSM	SM	SM
Nominal current, I_{nom}	A	300	335	(9-)300	350	120
Inductance** at I_{nom}	H	11.321	1.182	0.971	0.919	0.477
Stored energy** at I_{nom}	kJ	615.8	66.3	49.6	30.3	2.4
Number of circuits in unit	-	2	2	1	1	1
Power converter type		HL-LHC600A-10V	LHC600A-10V	LHC600A-10V	LHC600A-10V	LHC600A-10V
Circuit type	-	600-A	600-A	600-A	600-A	120-A

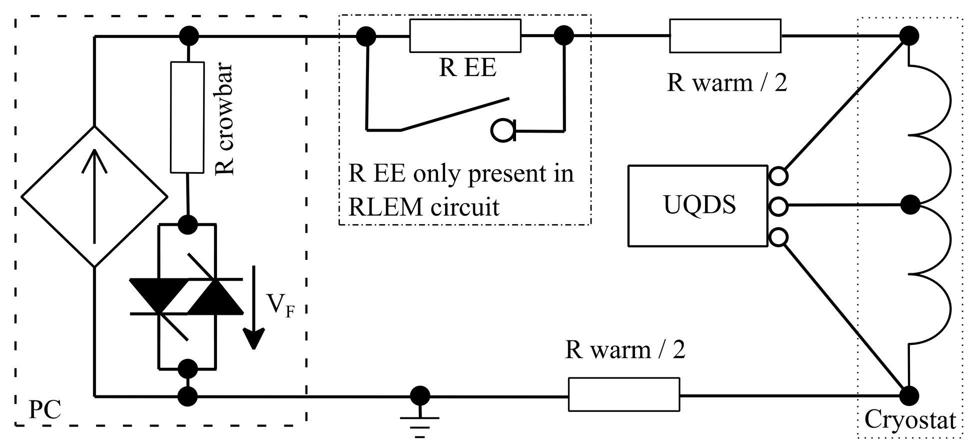
* CSM – Compensated Solenoid Magnet, DSM – Distributed Solenoid Magnet, SM – Solenoid Magnet. ** mean value

- Each HEL unit has 22 independently powered circuits, with up to 615.8 kJ of stored energy per circuit.
- Only solenoid circuits considered here. There is 5 types as shown in the table above.
- Energy extraction (EE) is going to be used in the RLEM circuit and benefits of it are shown below.

Simulations

- Powering and protection use the technology available for the HL LHC. The schematic for circuits shown on the right.
- Quench detection with CERN's Universal Quench Detection System (UQDS) used for measuring the resistive voltage component with the middle voltage tap.
- All solenoid magnets are designed with the same rectangular Nb-Ti/Cu superconducting (SC) composite wire (Cu:SC 4:1)
- No metal structures are included in the quench simulations i.e. no iron yokes and ferromagnetic shields, no formers, cryoshields or cryostat structures. The coils are assumed adiabatic. Inter-filament coupling currents loss was included.
- The quench simulations performed using the STEAM-LEDET[1] code are combined with uncertainty quantification methods available in the DAKOTA[2] software.

[1] https://cern.ch/steam/LEDET [2] https://dakota.sandia.gov/

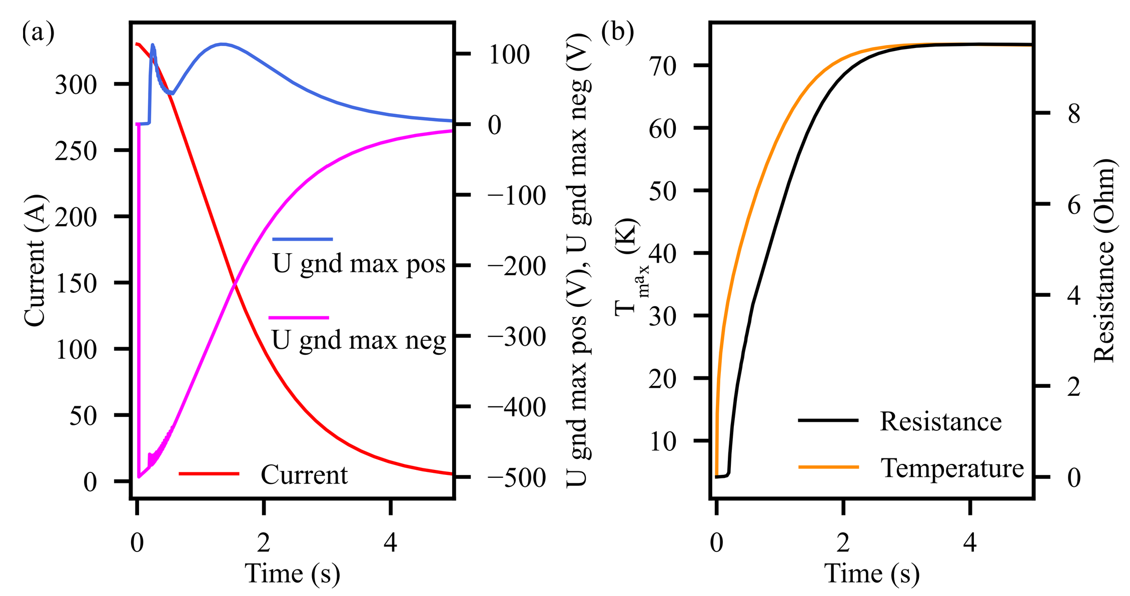


- For the uncertainty quantification, 6000 quench simulations were performed with independent, randomly distributed inputs in the ranges specified in the table on the right.

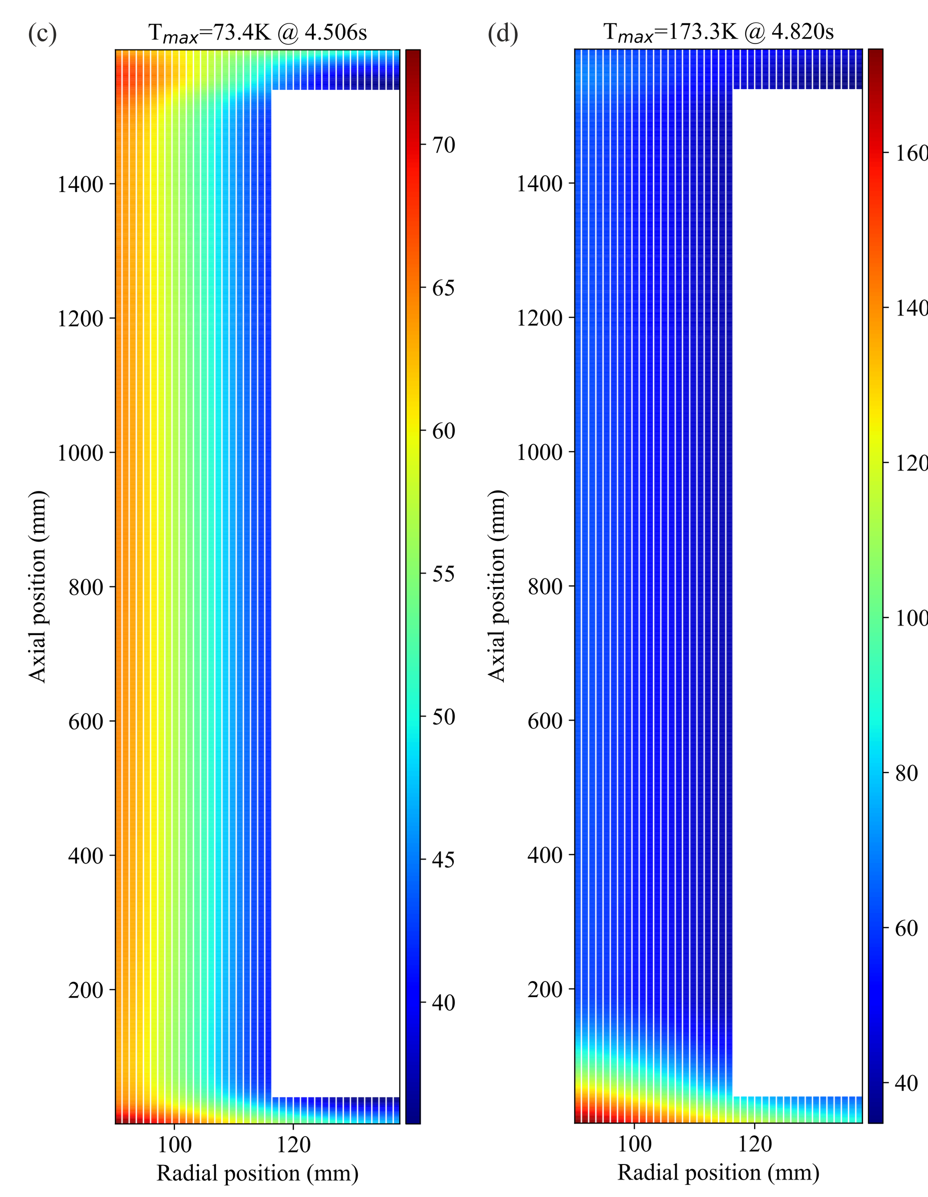
	Name	Nominal	Range		Unit
Wire	RRR	100	80	220	-
	Twist pitch length	50	40	100	mm
	I_c, 4 T, 4.2 K	750	750	900	A
	Bare wire height	1.61	1.60	1.62	mm
	Bare wire width	1.01	1.00	1.02	mm
Magnet	Bath temperature	4.2	4.1	4.5	K
	Quench initiation turn	1	first	last	turn
	Pre-Preg thickness	150	135	195	µm
Circuit	R warm 600-A circuit	9.0	8.1	9.9	mΩ
	R warm 120-A circuit	54.0	48.6	59.4	mΩ
	R crowbar 600-A circuit	50	0	55	mΩ
	R crowbar 120-A circuit	80	0	88	mΩ
	Crowbar voltage V_F	1.0	0.9	1.1	V
	EE voltage in RLEM	500	475	500	V
Detection	Detection threshold	100	95	105	mV
	Discrimination time	10.0	9.5	10.5	ms

Results

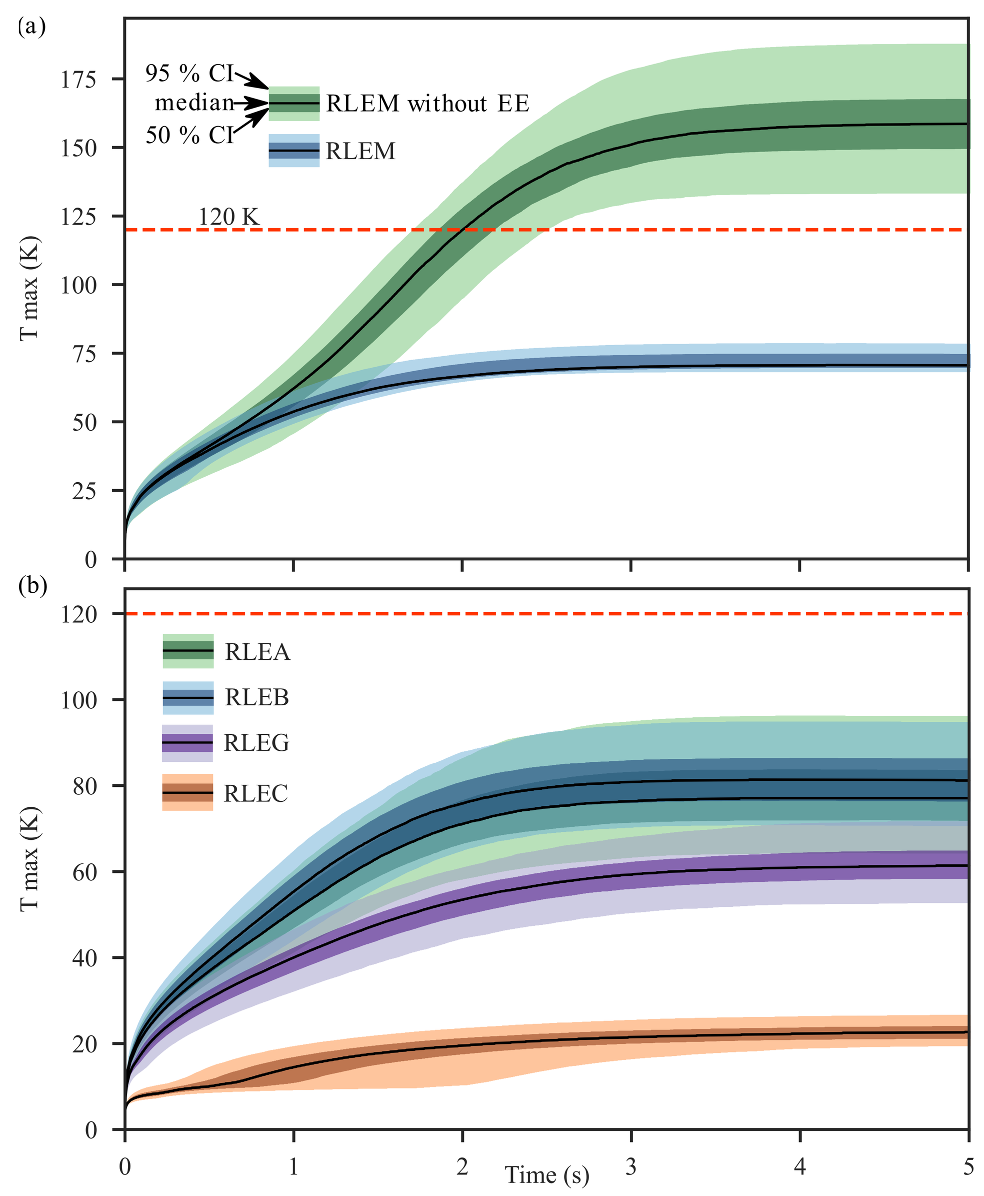
- With the EE, quench-back dominates the quench behaviour and the temperature distribution in the largest stored energy solenoid circuit (RLEM).
- The uncertainty quantification (UQ) provides a comprehensive assessment of quench characteristics of the circuits and a range of insights on the quench behaviour of the circuit. Examples of UQ outputs are shown on the right.



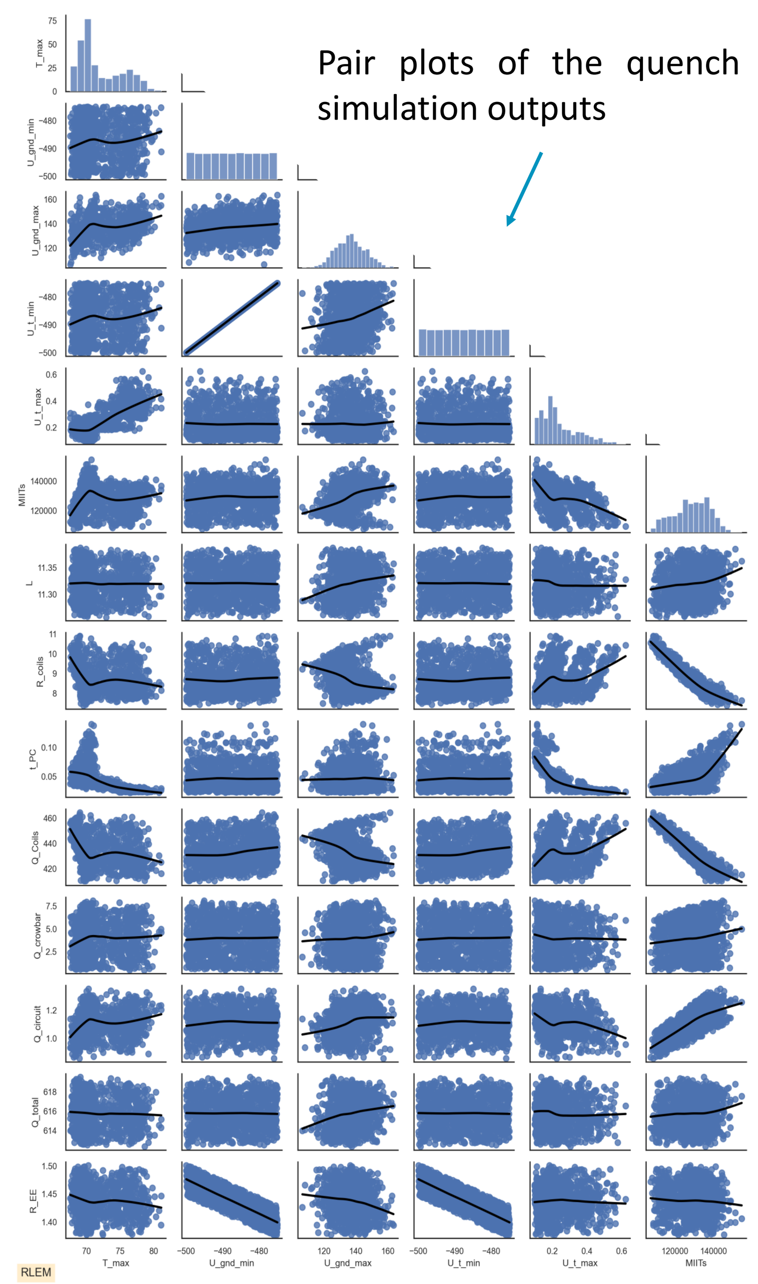
Quench at nominal values for the RLEM circuit



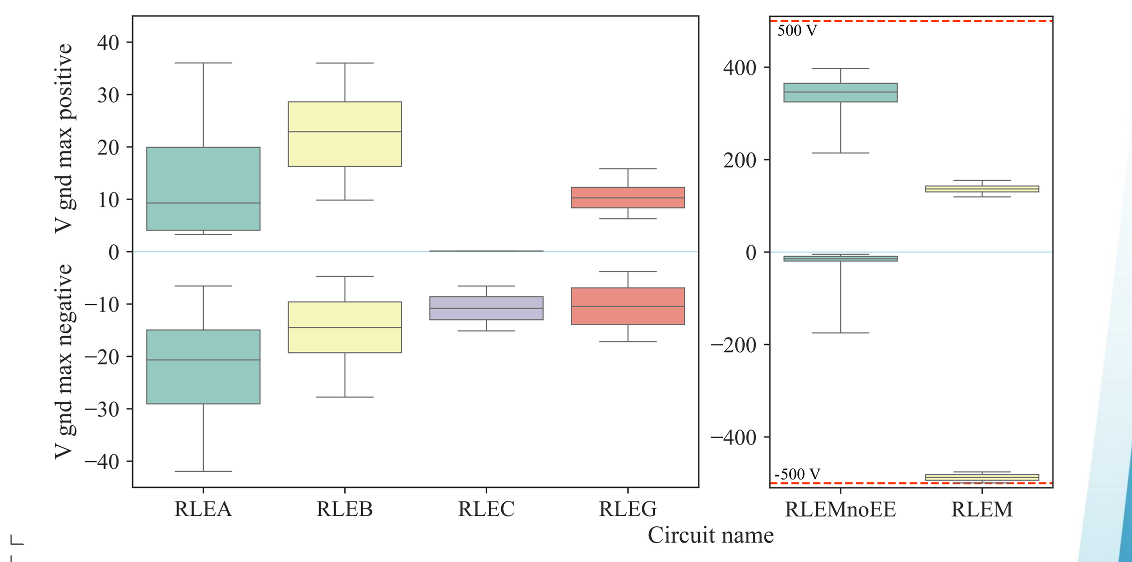
Temperature distribution in the MLEM with and without EE



Median and 95% CI plots of maximum temperature of the coils



Pair plots of the quench simulation outputs



Box and whisker plots of maximum voltages to ground