Overview of electrical test on HL-LHC prototype diode stack

- Introduction (Giorgio)
- Summary of electrical test at 300K/77K (Giorgio)
- Overview of electrical at SM18 (300K/4 K) (Gerard)
- Conclusion

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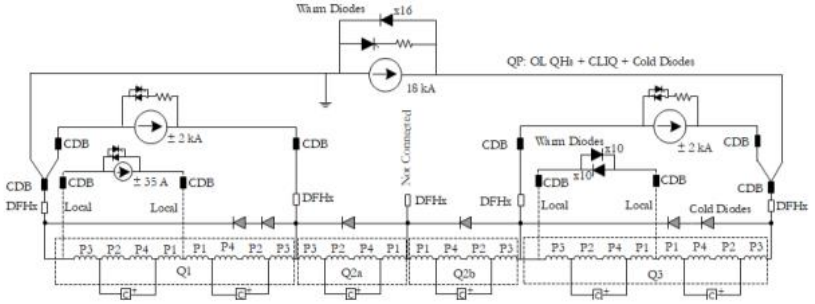
Introduction

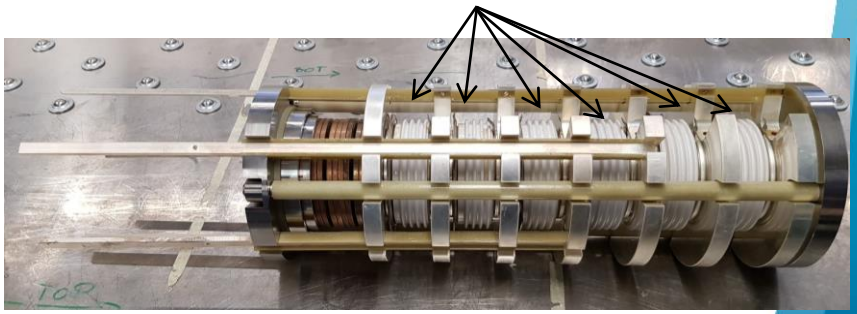
- Recall of electrical criteria for HL-LHC diodes:

Design criteria for HL-LHC IT cold diodes		
Dose tolerance (82-83m from IP, 3000fb^{-1}) [kGy]	30	
Fluence tolerance (82-83m from IP, 3000fb^{-1}) [n/cm^2]	2E+14	
Operating temperature [K]	1.9	
Turn-on voltage at 1.9 K [V]	< 15	
Reverse withstand voltage at 1.9 K [V]	> 200	
Maximum expected current [kA]	7	
Maximum Diode series resistance (7kA) [mΩ]	< 0.5	
Opening speed / reaction time [µs]	< 50	

- The HL-LHC Proto1 is equipped with standard LHC diodes, to be used in HL-LHC string only. For HL-LHC, the specific very thin base diodes (same dimensions, more radiation tolerant), will be used.



Standard LHC diode press-packs (6)



Prototype HL-LHC diode stack

Circuit parameters

- Electrical parameters of the circuit: worst case scenario with peak current of 7kA to 18kA for ~130 ms, MIIts <40 (Quench Protection studies from E. Ravaioli, EDMS 1760496).

EDMS NO.	REV.	VALIDITY
1760496	1.1	DRAFT

REFERENCE : LHC-DQ-ER-0001

Table 5. Simulated worst-case peak currents, thermal loads, and characteristic times in the circuit components (see Figure 1)

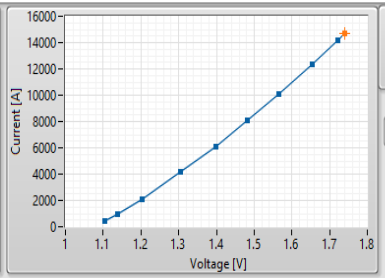
Circuit component	Peak current [kA]	Thermal load [$10^6 A^2 s$]	Characteristic time [ms]
Main power supply crowbar and leads	17.5	37.4	122
Q1 and Q3 trim power supply crowbar and leads	5.0	3.0	120
Q1a trim power supply crowbar and leads	3.7	1.3	95
Warm Diodes across Q3a	3.6	1.1	85
Main power supply reverse Diodes	1.0	0.015	15
Cold Diodes across Q1 and Q3	5.0	2.9	116
Cold Diodes across Q2a and Q2b	5.2	2.1	78

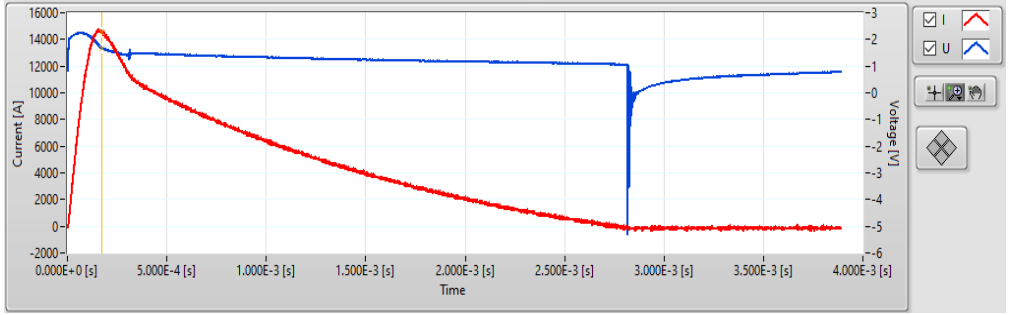
HL-LHC diode stack: electrical tests 300/80 K

The prototype stack was instrumented as for series production and standard set of measurements were performed, at 300K and 80K (LN2), in MPE lab.

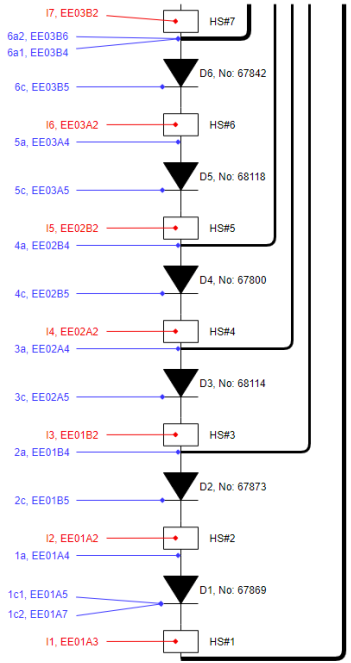
- Forward current measurement, up to 14.5kA:

I	U	I_detected	U_detected	DESIRED	DialogC	TEST_ID	P
435	1.103	435	1.103	500	1	8072	
960	1.139	960	1.139	1000	1	8072	
2098	1.203	2098	1.203	2000	1	8072	
4186	1.306	4186	1.306	4000	1	8072	
6119	1.399	6119	1.399	6000	1	8072	
8063	1.482	8063	1.482	8000	1	8072	
10083	1.567	10083	1.567	10000	1	8072	
12339	1.655	12339	1.655	12000	1	8072	
14141	1.722	14141	1.722	14000	1	8072	
14671	1.740	14671	1.740	0	1	8072	

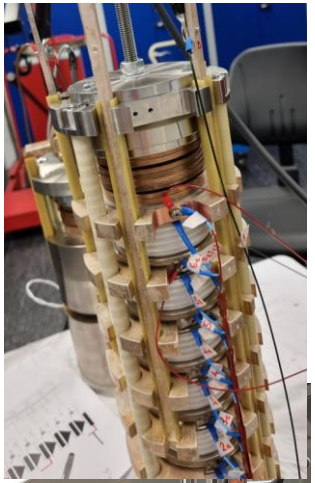




Example of diode 67842, at 77K



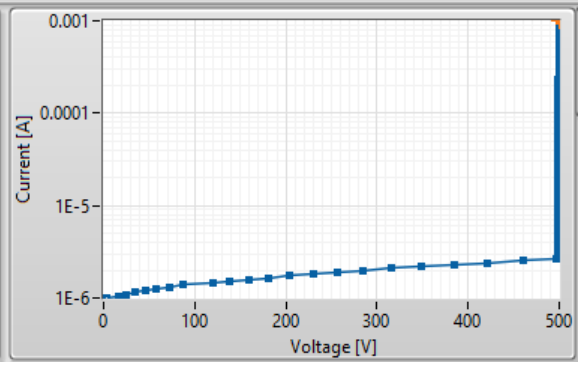
Schematic of HL-LHC diode stack



HL-LHC diode stack: electrical tests 300/80K

- Reverse blocking voltage @1mA:

I	U	I_
660.700E-6	499.5	-
691.800E-6	499.6	-
724.400E-6	499.6	-
758.600E-6	499.7	-
794.300E-6	499.7	-
831.800E-6	499.7	-
871.000E-6	499.8	-
912.000E-6	499.8	-
955.000E-6	499.9	-
1.000E-3	499.9	-



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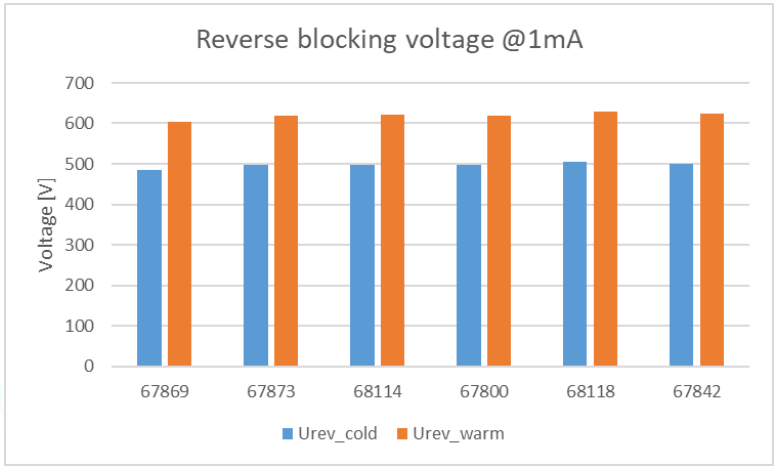

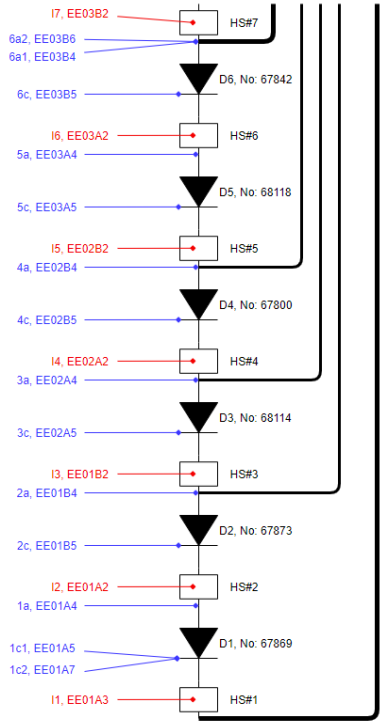

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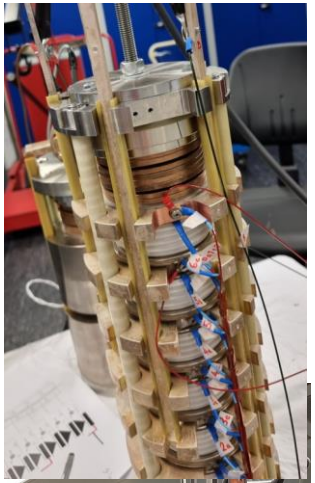
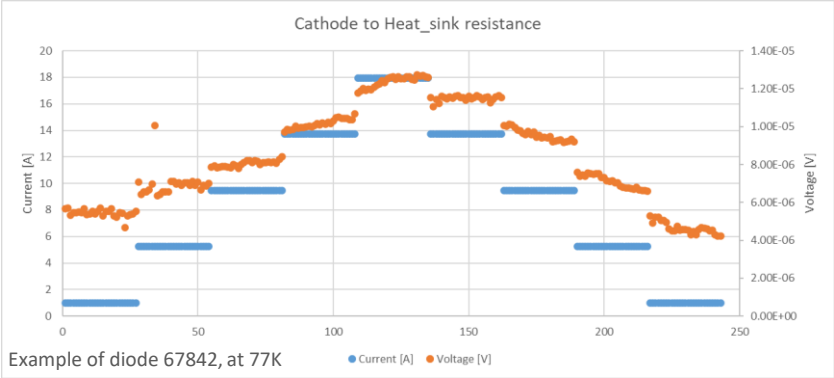
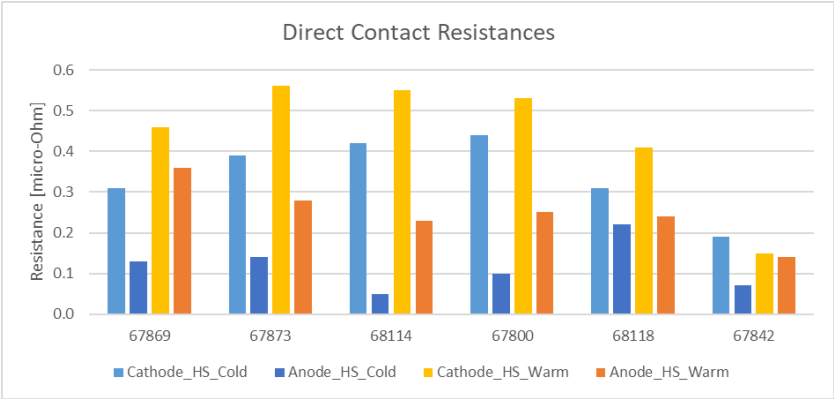
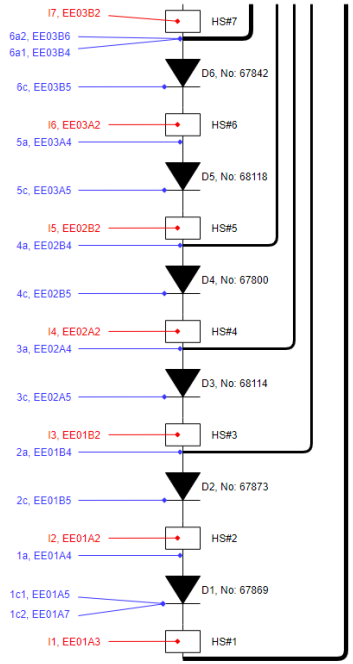


HL-LHC diode stack: electrical tests 300/80K

- Direct Contact Resistance: between diodes and heat sinks, < 1 uOhm







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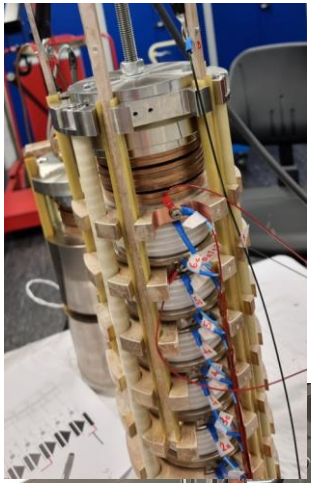

HL-LHC diode stack: electrical tests 300/4 K, in SM18

- The HL-LHC diode stack was prepared for cold test in SM18 and transported there.
- Additional instrumentation was installed on the first prototype to monitor temperature profile during powering tests.
- The goal of the test is to validate electrical performance of the stack at 4K, with high current pulses and thermal load:
  - Verify thermal load of the stack vs temperature excursion
  - Verify diode characteristics (Ufwd, Urev)
  - Monitor contact resistances
- See slides/reports from Gerard for overview of cold tests in SM18

HL-LHC diode stack: electrical tests 300/4 K, in SM18

- See slides/reports from Gerard for overview of cold tests in SM18

Conclusions

- The prototype HL-LHC diode stack, equipped with LHC standard diodes (same dimensions and similar electrical performances), with series instrumentation, has been tested at 300K and LN2. The electrical performance shows that the diode stack is mechanically sound.

- The electrical test at 4K showed very good performance w.r.t. to high current pulses and thermal load:
  - Current pulses of ~7.5 kA for more than 1 s.
  - Thermal load of about 50 Miits with temperature excursion < 60K
  - Electrical parameters of the diodes in line with LHC standard diodes.

- The proto1 was submitted to more severe conditions as it will be used in IT string without any problem. Therefore, it could be used, as it is in the IT String.

Thank you for your attention !

Circuit parameters, E. Ravaioli

- Electrical parameters of the circuit: worst case scenario with peak current of 7kA to 18kA for ~130 ms, MIIts <40 (Quench Protection studies from E. Ravaioli, EDMS 1760496).

Conclusion

#	Component	Max peak current [A]	Max thermal load [MIIt]
1	Main power supply crowbar and leads	17500	37.3
2	Q1 trim power supply crowbar and leads	3647	2.10
2bis	Q1/Q3 trim power supply leads	4888	2.83
3	Q3 trim power supply crowbar and leads	3805	2.21
4	Q1a trim power supply crowbar and leads	3534	1.14
5	Main power supply reverse Diodes	3511	1.12
6	Q3a Warm Diodes	4264	1.86
7	Q1 Cold Diodes	5396	2.13
8	Q2a Cold Diodes	5455	2.13
9	Q2b Cold Diodes	4239	1.83
10	Q3 Cold Diodes	1031	0.014

- These are the figures for the maximum identified **peak currents** and **thermal loads** in the main HL-LHC IT circuit components (magnets excluded), calculated for conservative worst-cases at ultimate current using STEAM-COSIM model (one PSPICE circuit + six STEAM-LEDET magnet models).
- The assumptions considered in these cases are more conservative than those adopted for magnet simulat This is by choice, since extremely conservative scenarios can be covered with limited requirements.
- Note EDMS 1760496 will soon be updated with these new values (once the last details of the circuit desig be finalized), and with the magnet simulation results presented at MCF in 2020.

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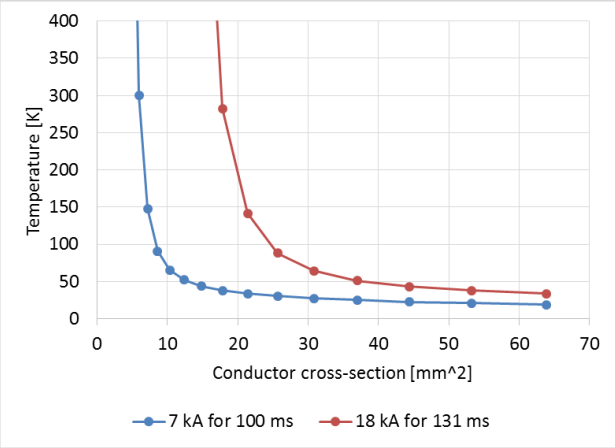
MQXF – Dimensioning of the cross-section of the Cold-Diode bus bar

Assumptions for Cold Diode worst considered case

- Initial temperature: 4 K
- Copper with RRR=100
- 0 magnetic field [no magneto-resistivity]



Case 1: Worst considered case:
worst-case that can realistically occur.

- Peak current: 7 kA
- Thermal load: 4.9 MIIt
- Equivalent time, i.e. Thermal load / (Peak current)^2 : 100 ms
- **Recommended Cu cross-section: at least 20 mm^2**

Case 2: Diode carrying the full 18 kA during the magnet discharge:
case where the diode needs to carry the full current for the entire magnet discharge time. One cannot see an operational scenario when this could happen, but since the cold diodes are dimensioned for this case, it is considered.

- Peak current: 18 kA
- Thermal load: 42.5 MIIt
- Equivalent time, i.e. Thermal load / (Peak current)^2 : 131 ms
- **Recommended Cu cross-section: at least 45 mm^2**