CLIQ and Quench Heaters performance in MQXFAP1

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With many contributions by E. Ravaioli - CERN

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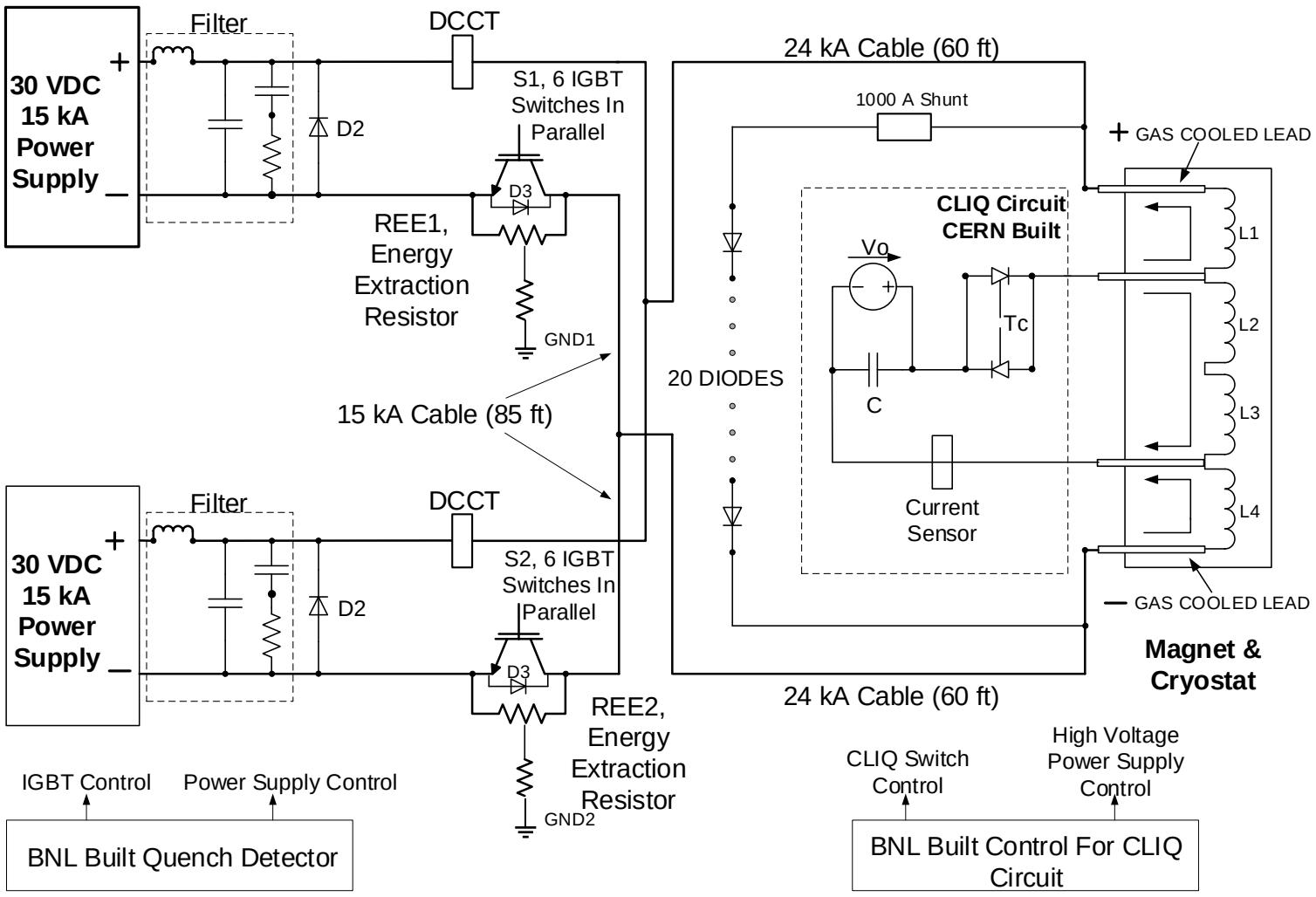
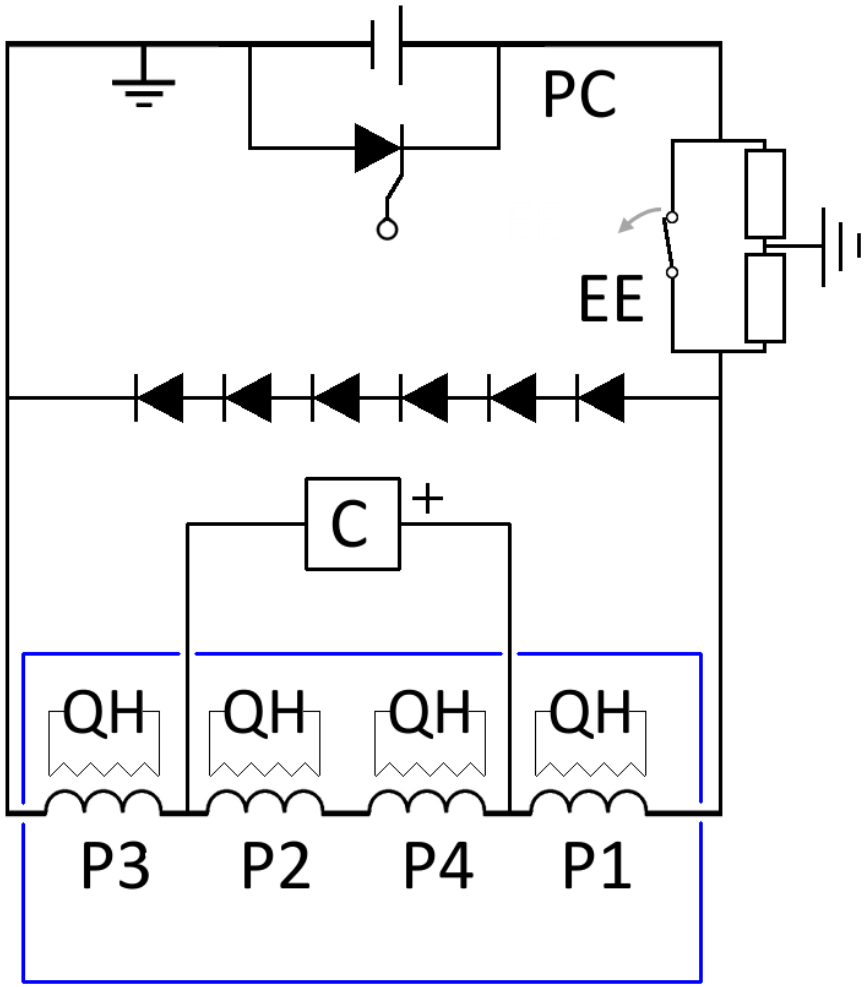
Outline

- MQXFAP1 quench protection system
- Heaters performance
- CLIQ performance
- Conclusions

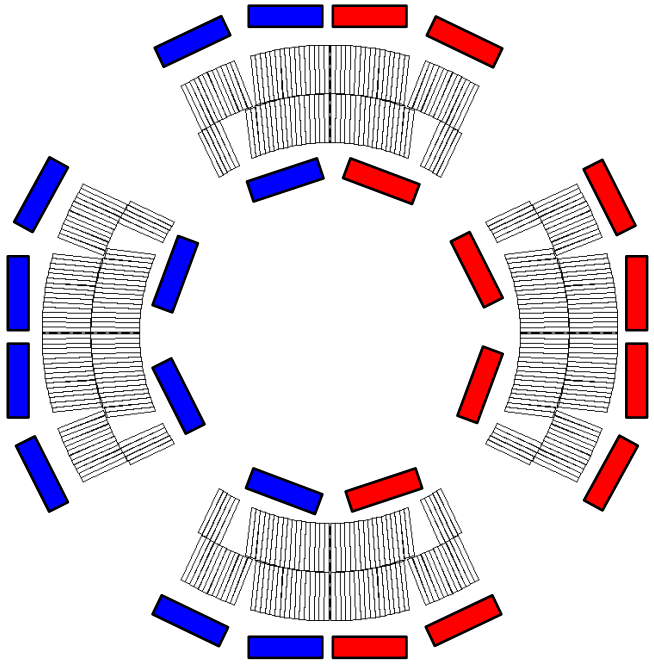
MQXFAP1 Protection system



MQXFAP1 Protection system



- Dump resistor: 37.5 mΩ
- OL heaters: 16 strips (HF and LF per each half coil)
- IL heaters: 8 strips (one per half coil)
- CLIQ: 40 mF, 500 V



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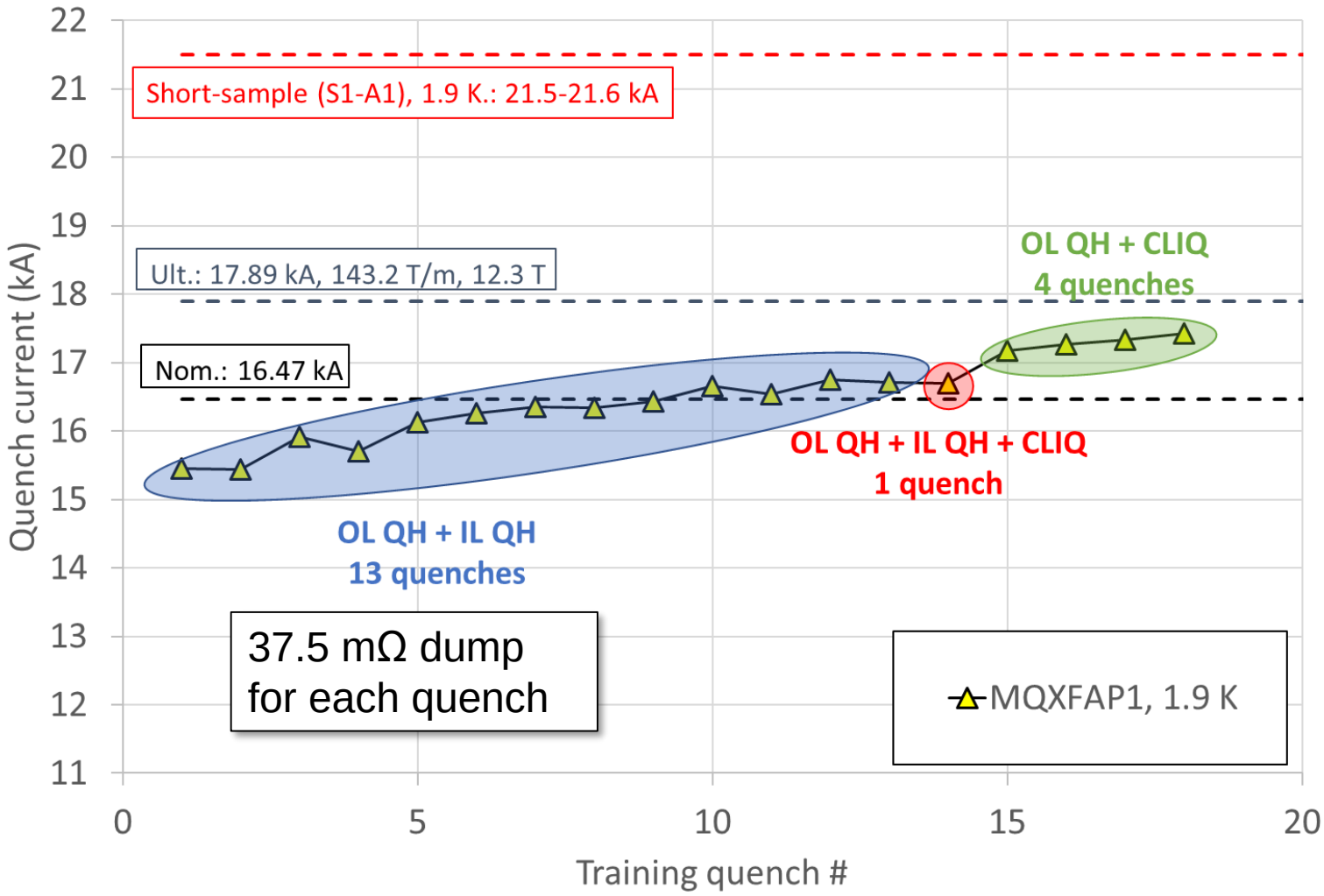
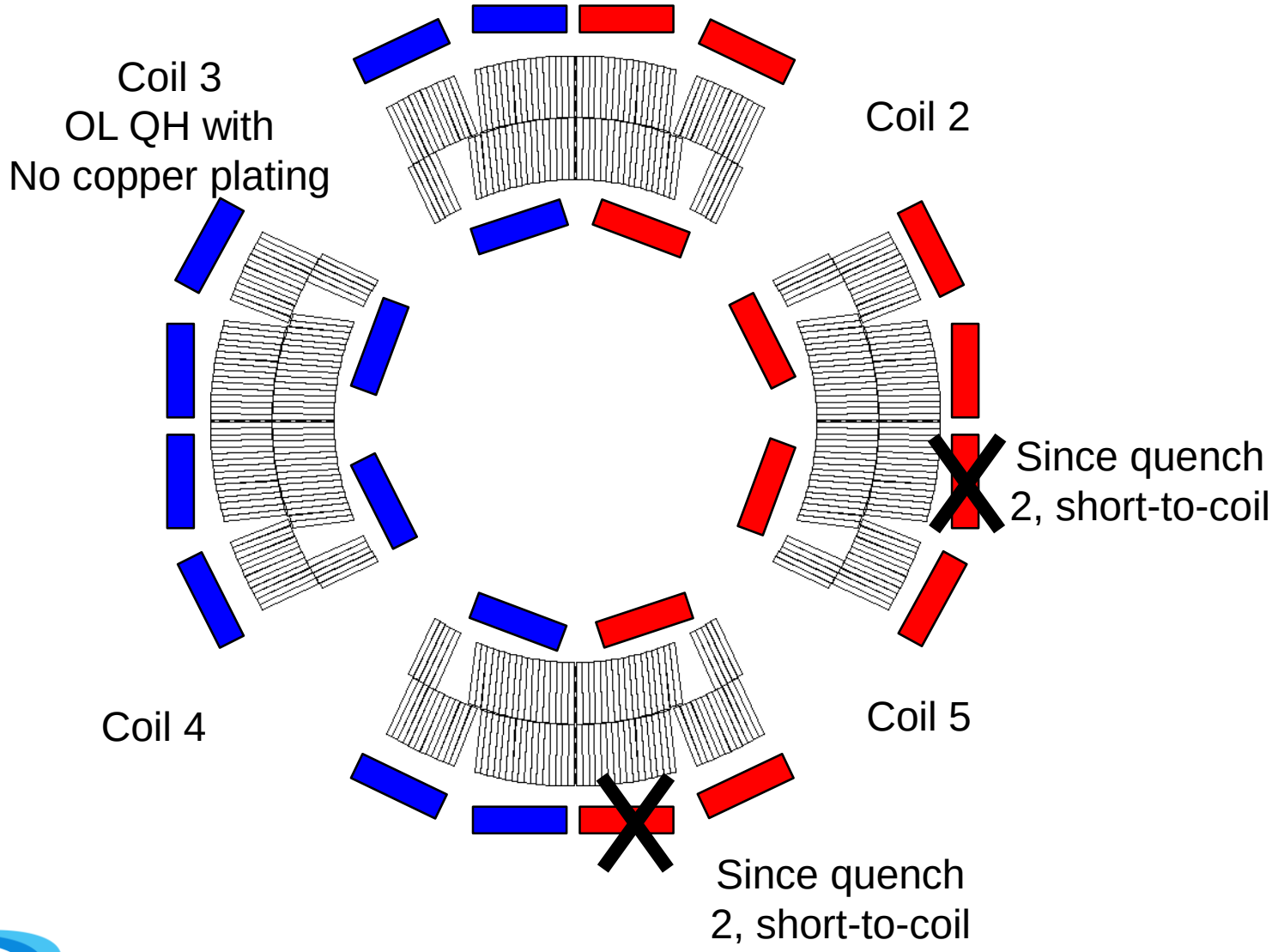


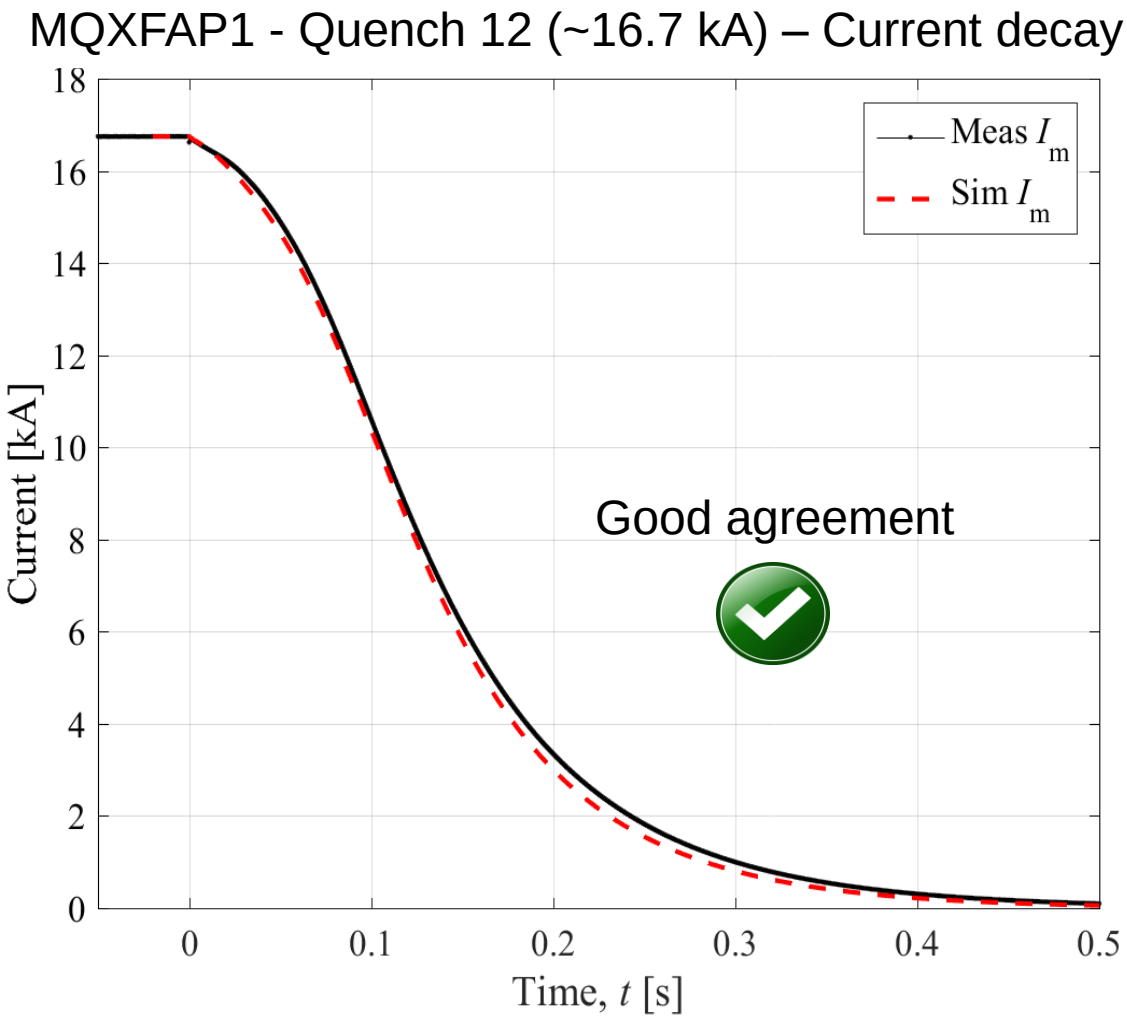
MQXFAP1 Protection system



Assumptions for simulations:

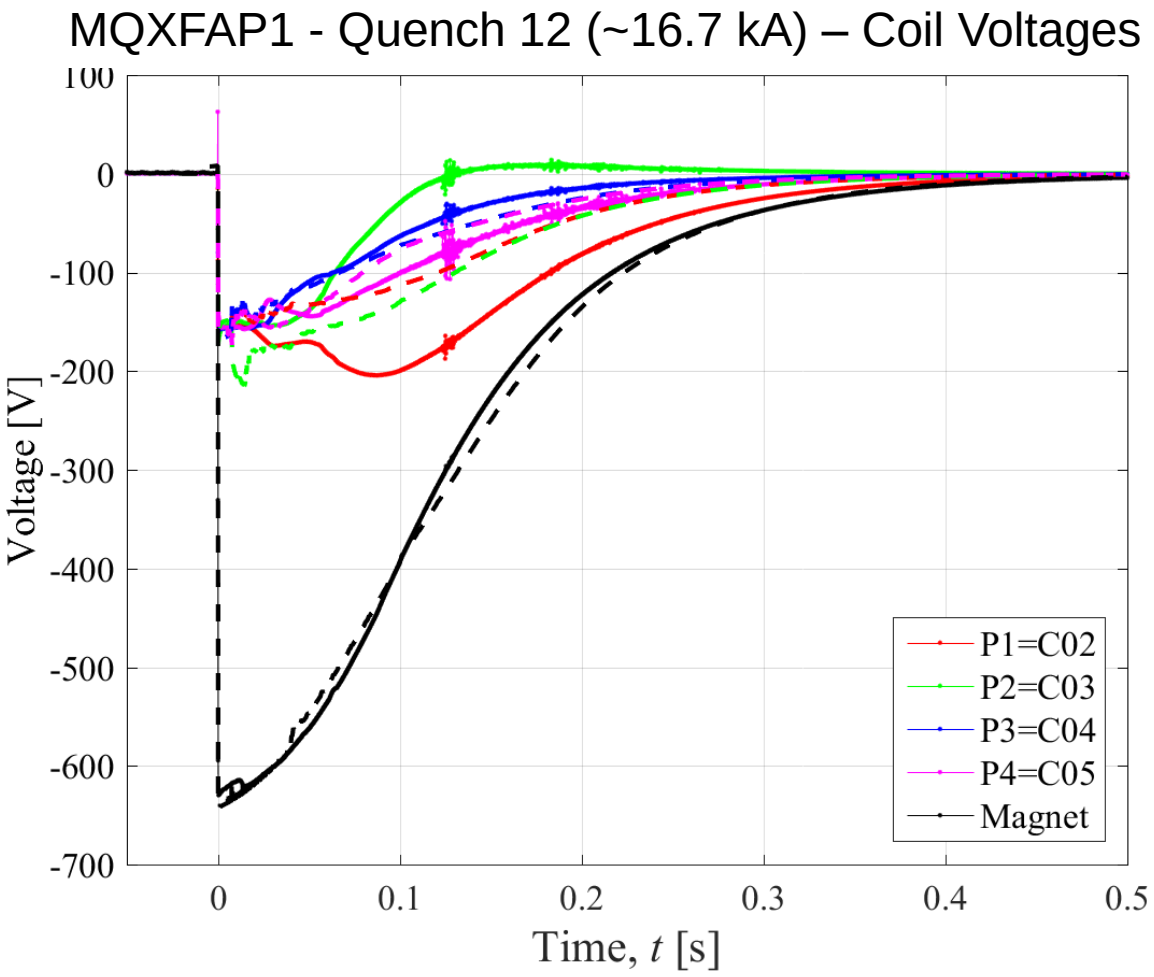
- Simulation software: LEDET
- 2D thermal model for the quench heaters
- Disconnected heaters not fired
- Coil 3 OL heaters at 25 % of nominal power (no Heating Stations)
- Measured RRR for each coil
- Measured Jc for each coil
- Protection parameters as at BNL facility
  - Validation time: 4 ms
  - Voltage threshold: 150 mV (at high current >8000 A)
  - Switch opening time: <1 ms

Quench Heaters performance



- Detection time: ~6.5 ms
- Validation time: 4 ms
- Switch delay time: ~1 ms
- Voltage threshold: 150 mV
- MIITs: 29.5
- HST: 275 K

Quench Heaters performance



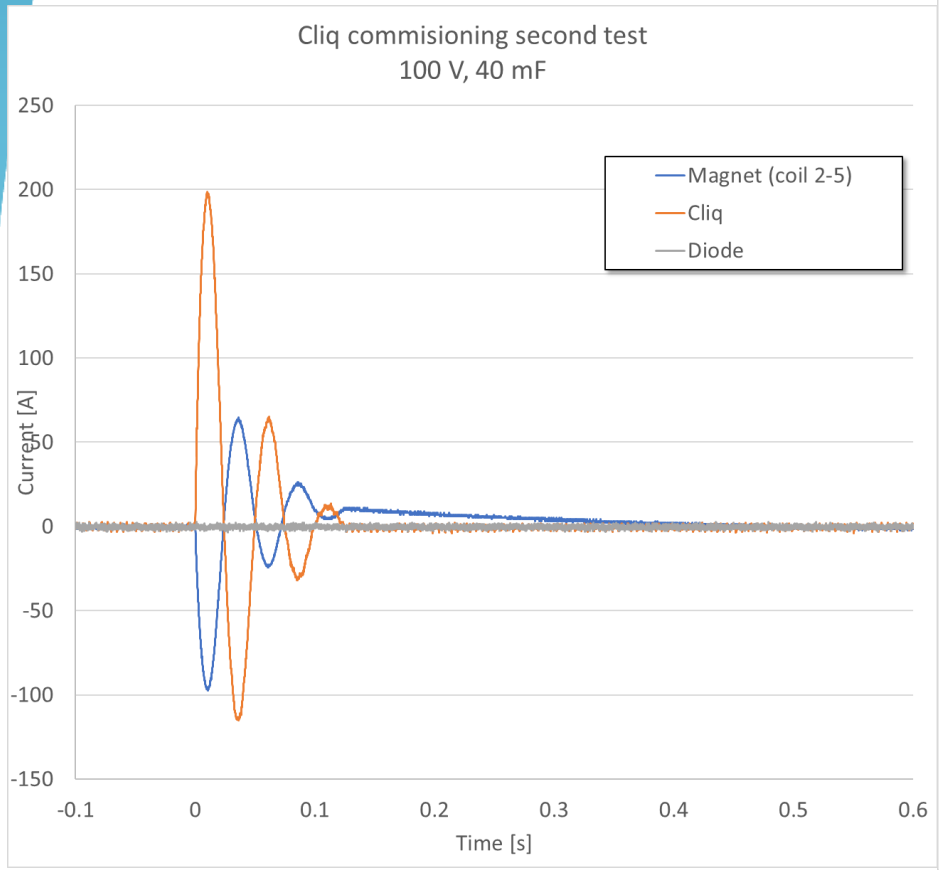
- Total voltage shows good agreement
- Coil 4 and 5 show good agreement
- Coil 2 and 3 show a slight disagreement, but in opposite direction
- It is difficult to go into more details, due to saturation of voltage taps.
- Proposal for the future: is it possible to duplicate some of the voltage taps signals (one with amplification, one without)?

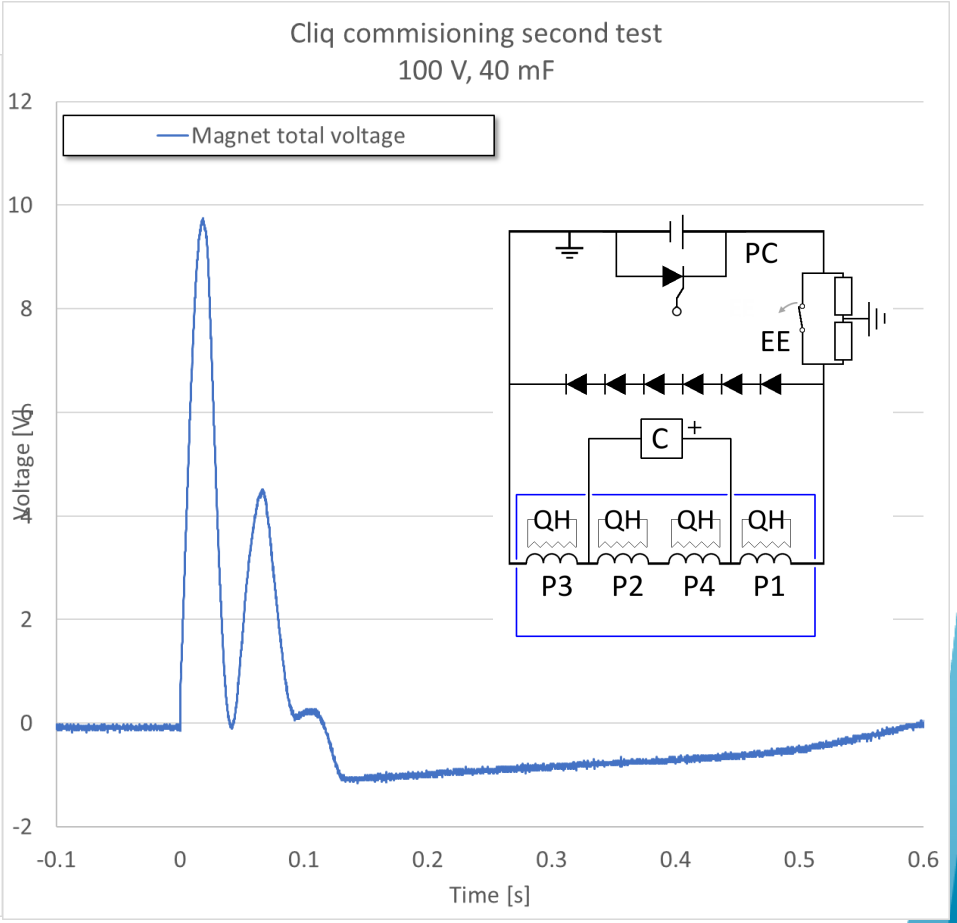
CLIQ performance

CLIQ commissioning tests

Test #	Magnet current [kA]	CLIQ charging voltage [V]	OL-H	IL-H	EE	Trigger
1	0	50	No	No	Yes	Manual
2	0	50	No	No	Yes	Manual
3	0	100	No	No	Yes	Manual
4	0	100	No	No	Yes	Manual
5	2	100	No	No	Yes	Manual
6	2	500	No	No	Yes	Manual
7	5	500	No	No	Yes	Manual
8	~16.7	500	Yes	Yes	Yes	Quench

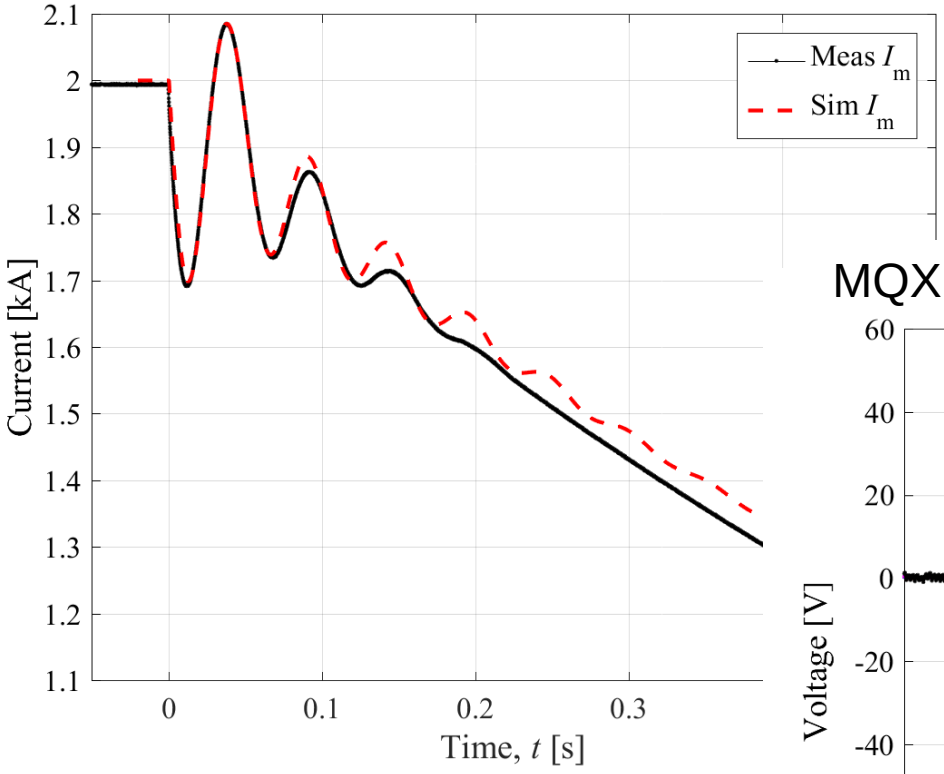
CLIQ performance



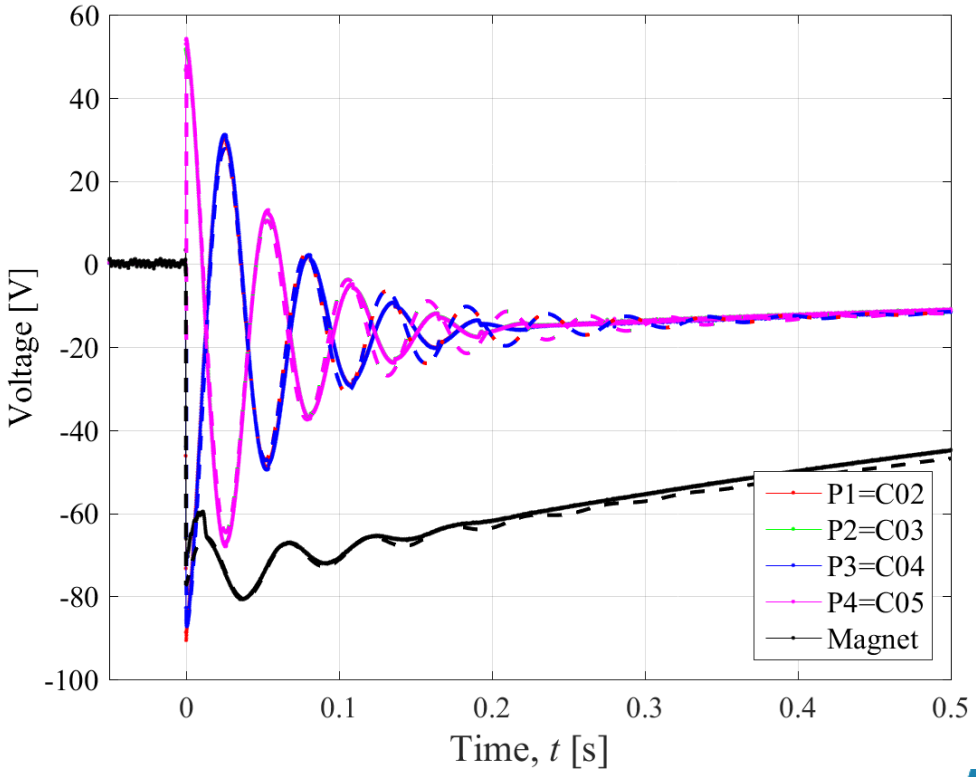


CLIQ performance

MQXFAP1 – CLIQ commissioning, 2 kA, 100 V



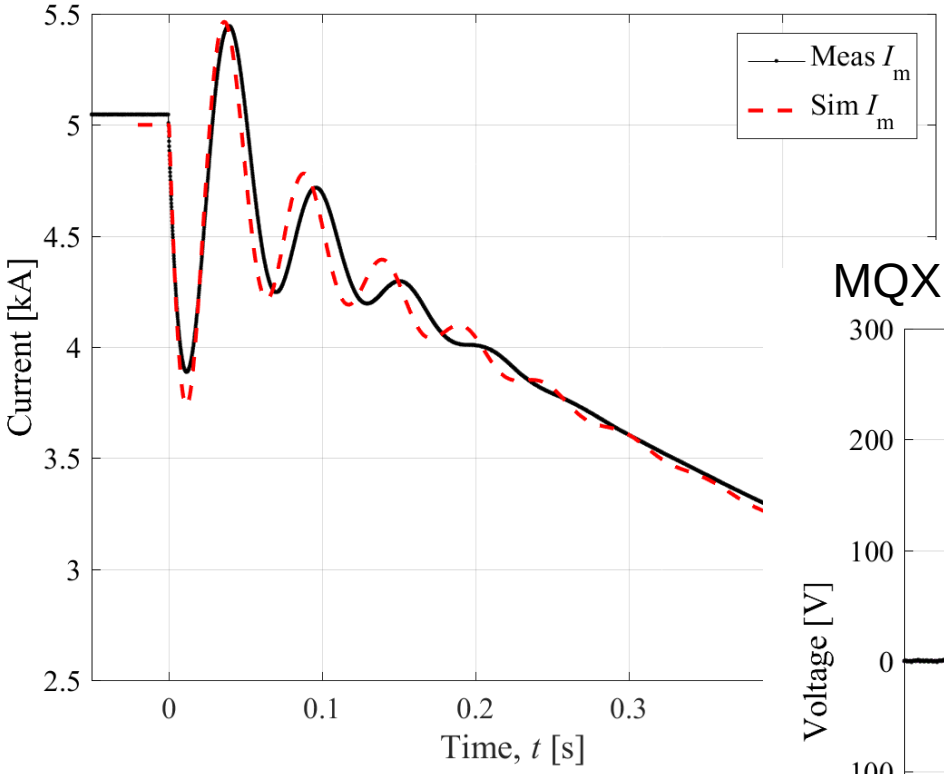
MQXFAP1 – CLIQ commissioning, 2 kA, 100 V



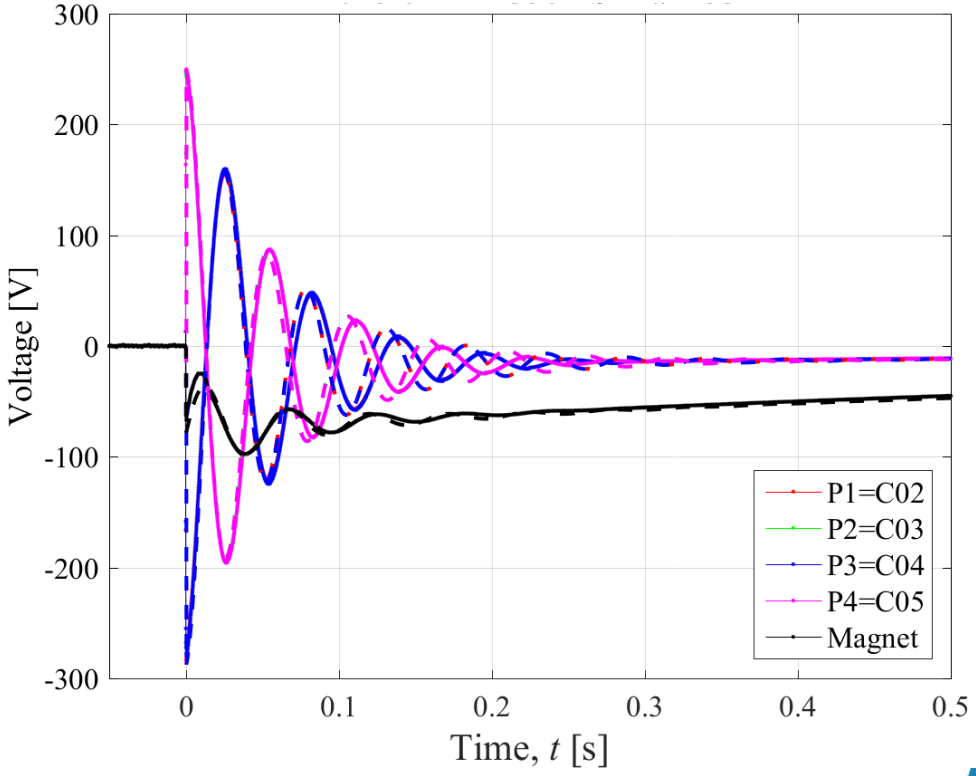
Good agreement

CLIQ performance

MQXFAP1 – CLIQ commissioning, 5 kA, 500 V

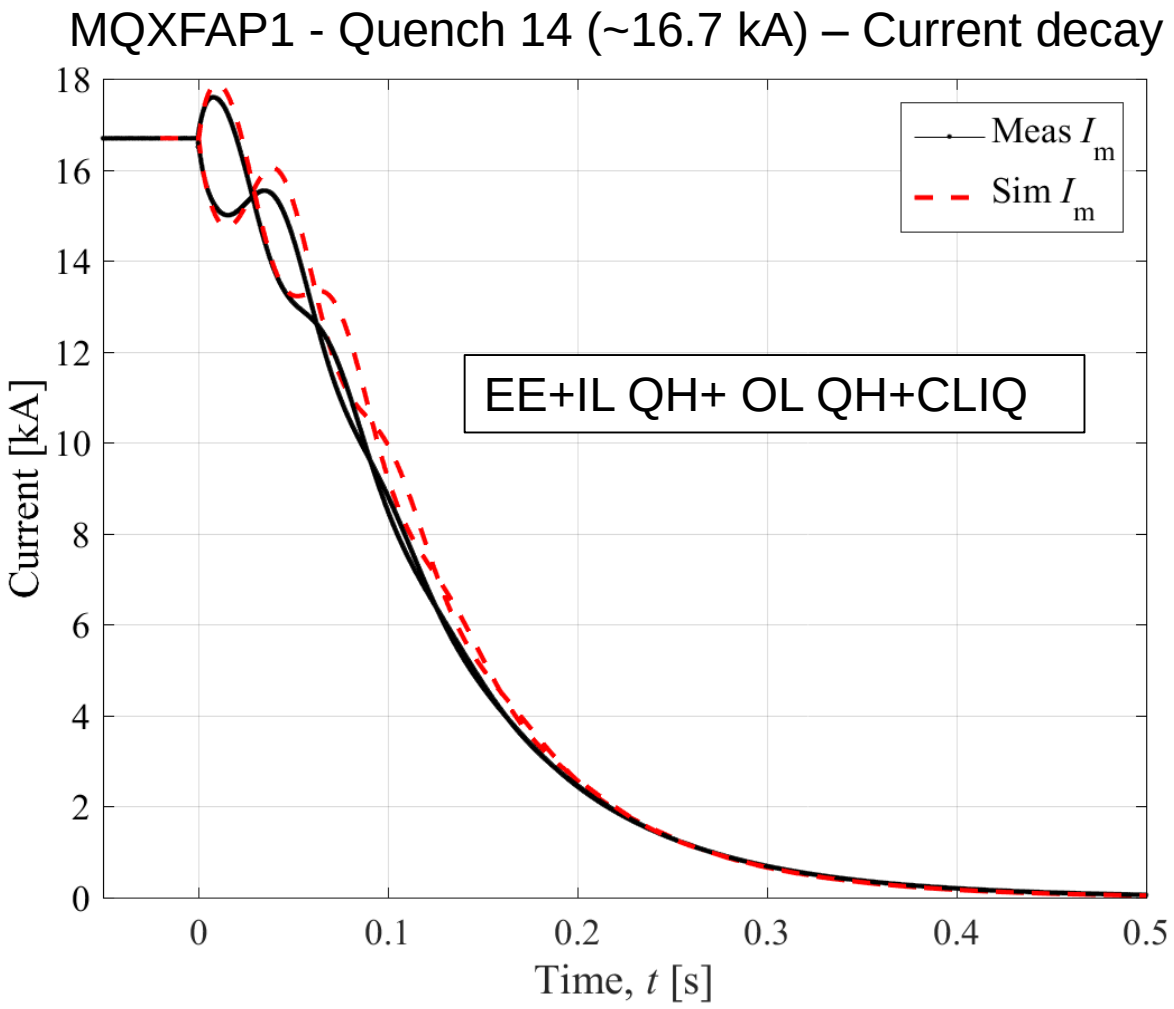


MQXFAP1 – CLIQ commissioning, 5 kA, 500 V



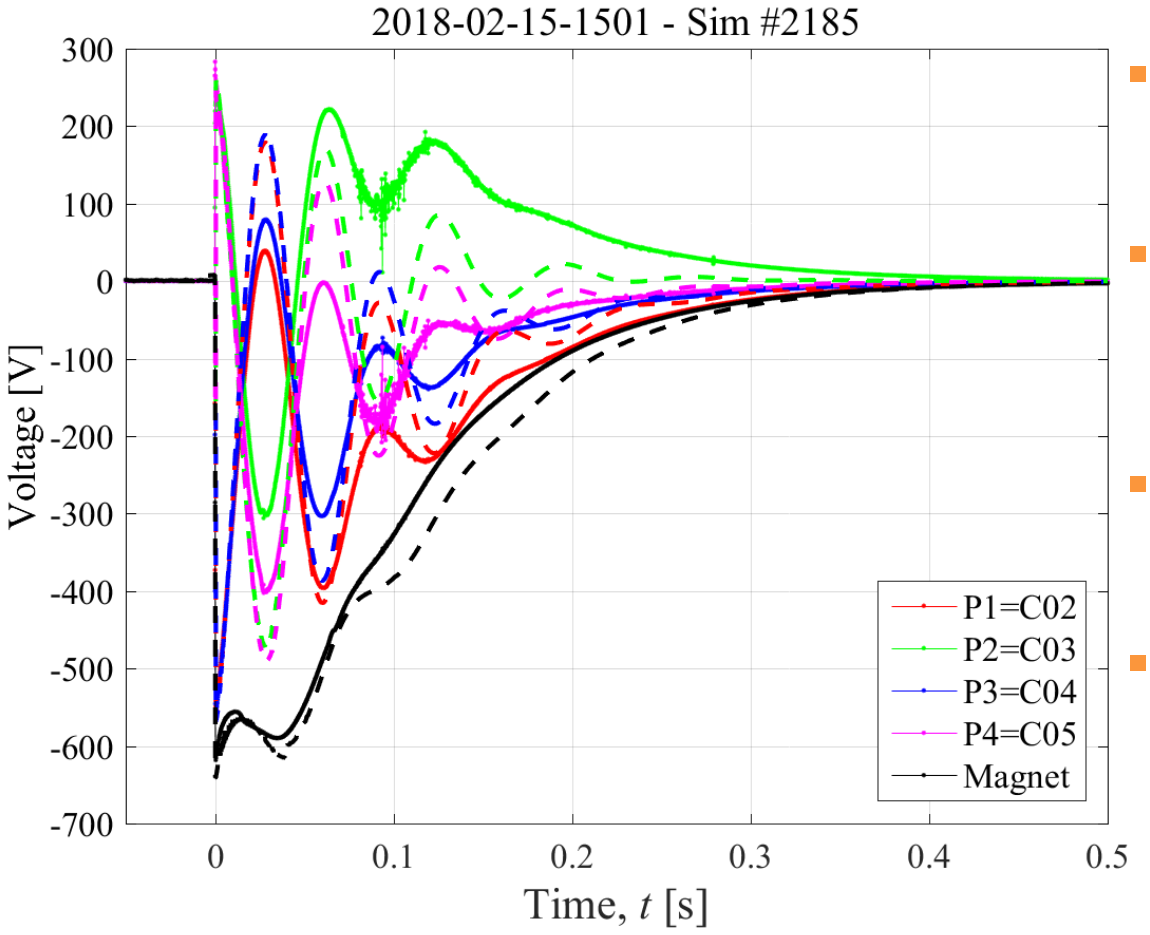
Good agreement

CLIQ performance



- Detection time: ~6.5 ms
- Validation time: 4 ms
- Switch delay time: ~1 ms
- Voltage threshold: 150 mV
- MIITs: 25.2
- HST: 220 K

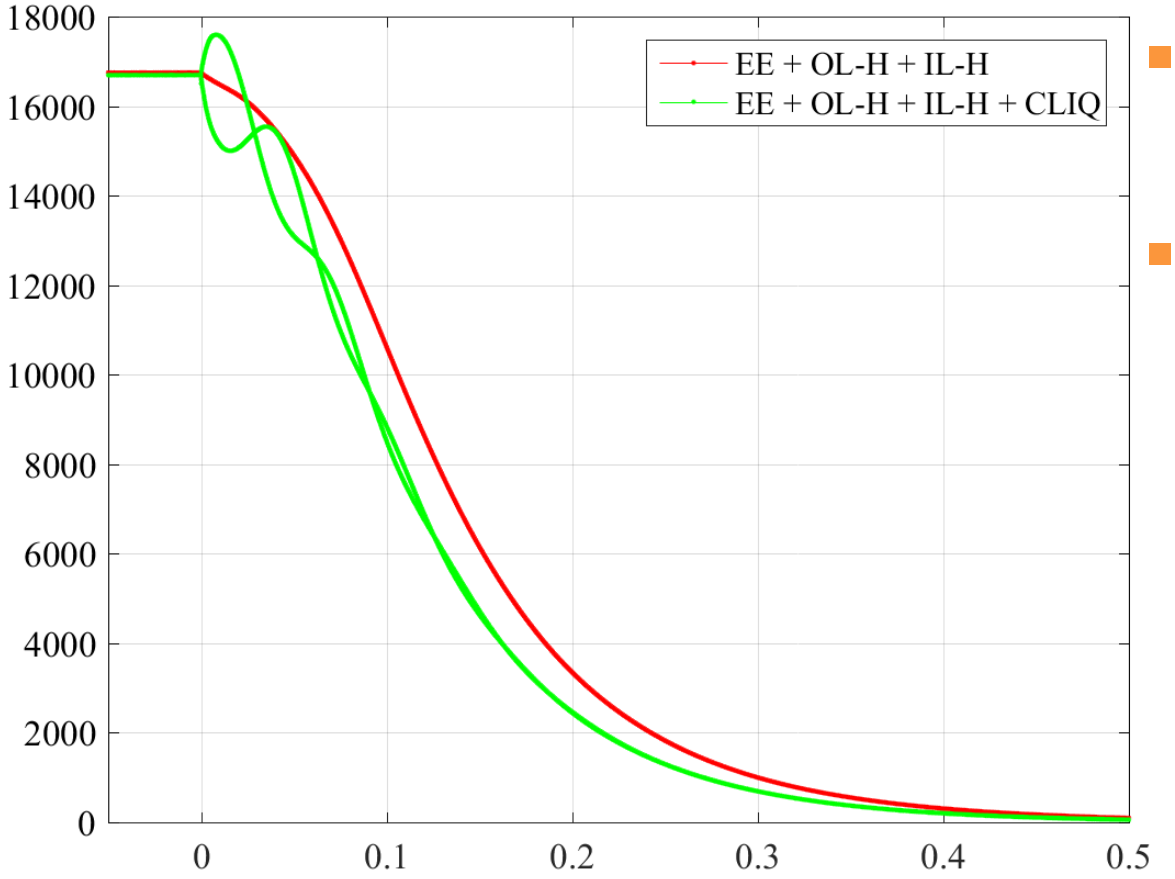
CLIQ performance



- Total voltage shows a nice agreement
- Coil 4 and coil 5 voltages show a general agreement
- Coil 2 and 3 show some disagreement
- Difficult to have more details due to voltage taps signal saturation

CLIQ performance

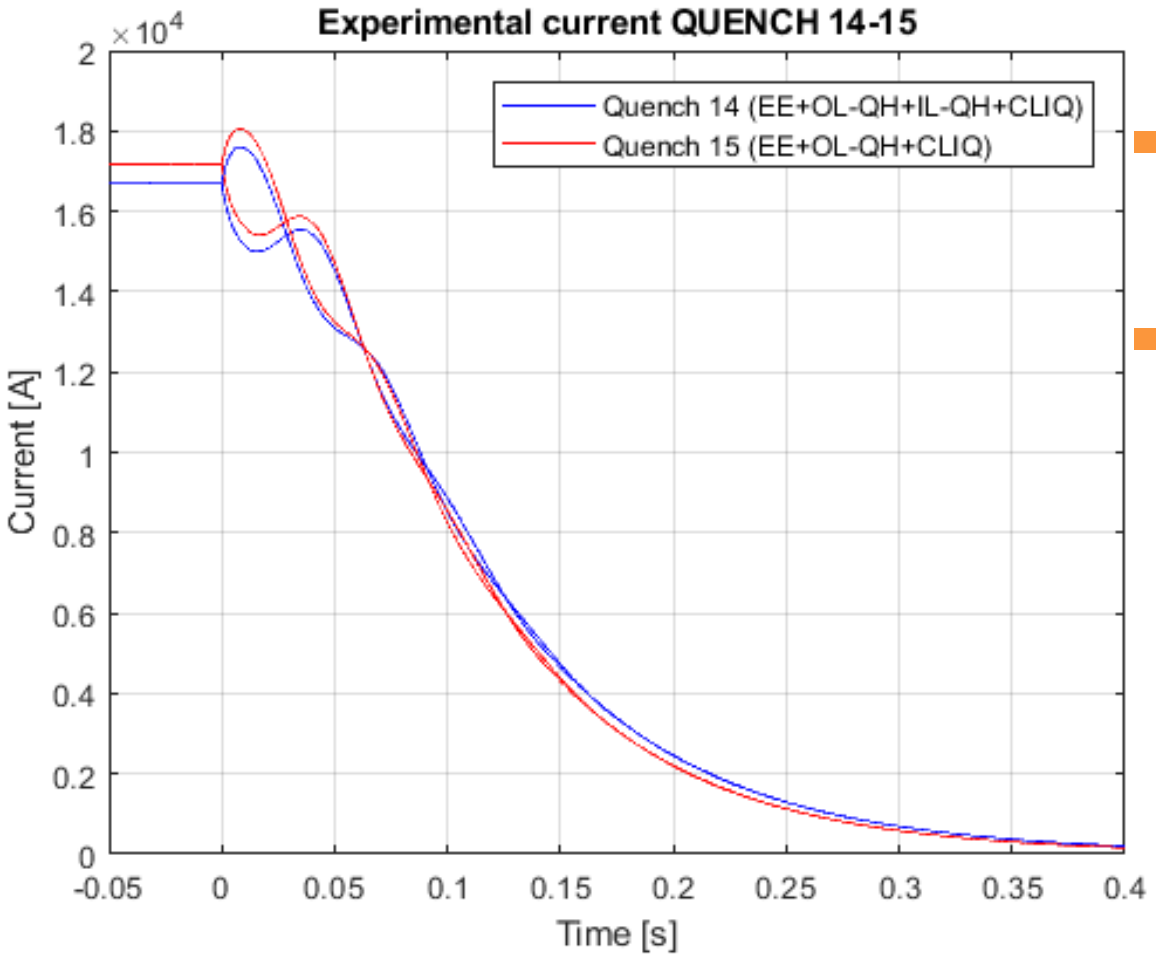
MQXFAP1 – Comparison quench 12 /Quench 14 (~16.7 kA) – Experimental measurement



- MIITs/T quench 12: 29.5 MA^2s / 275 K
- MIITs quench 14: 25.1 MA^2s / 220 K

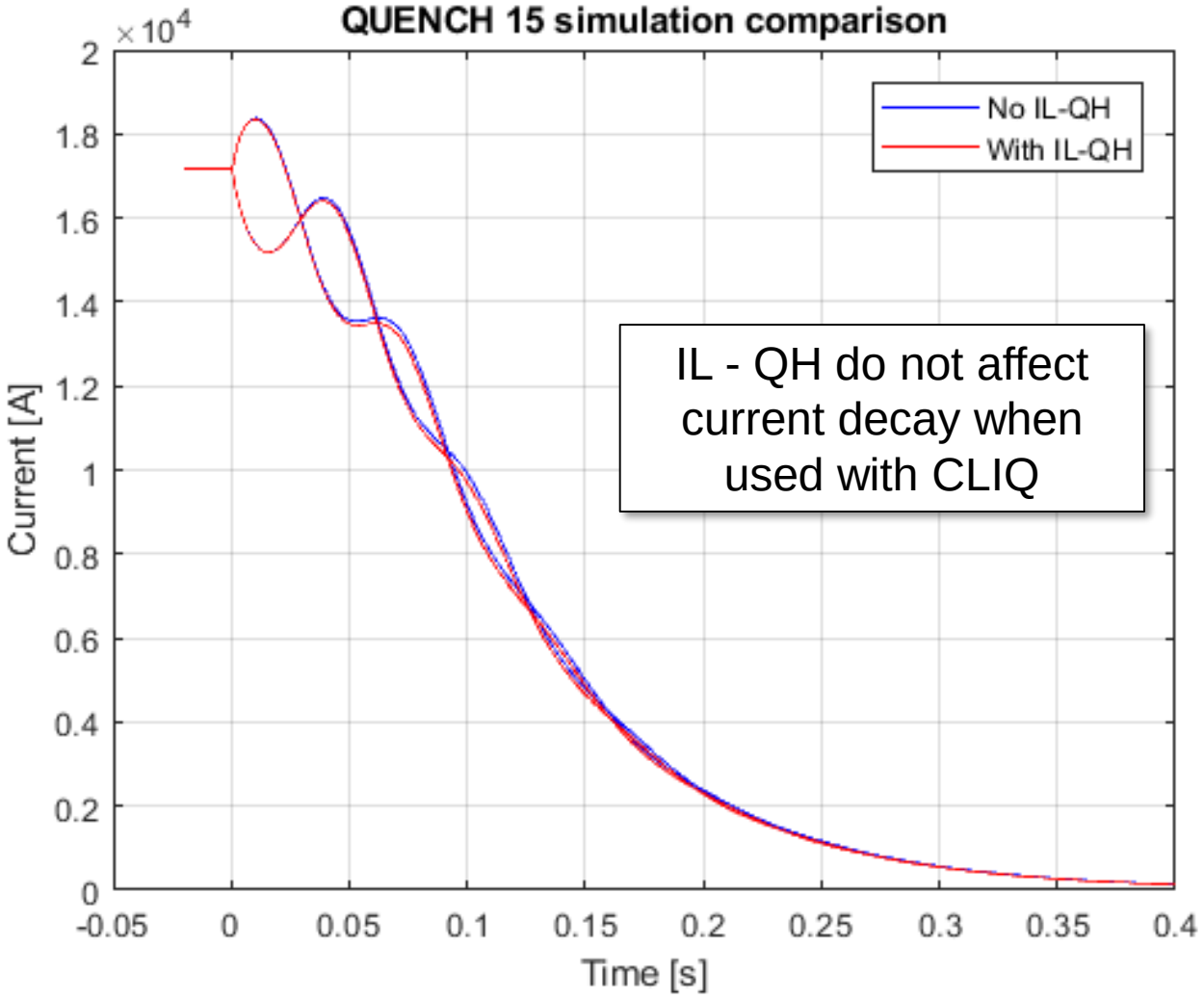
Using CLIQ reduces MIITs of **~15 %**

CLIQ performance

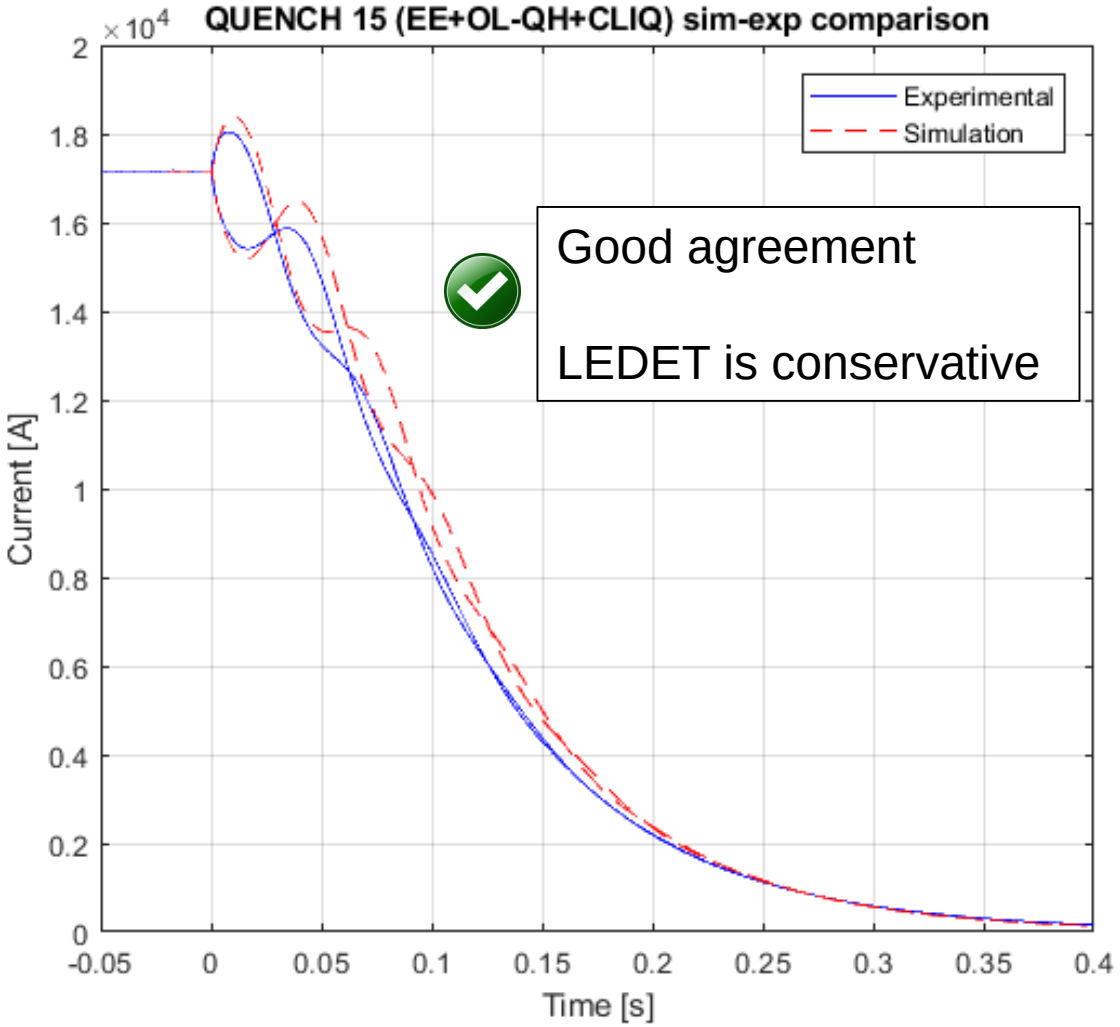


- MIITs/T quench 14: 25.1 MA^2s / 220 K
- MIITs/T quench 15: 25.4 MA^2s / 225 K

CLIQ performance



CLIQ performance

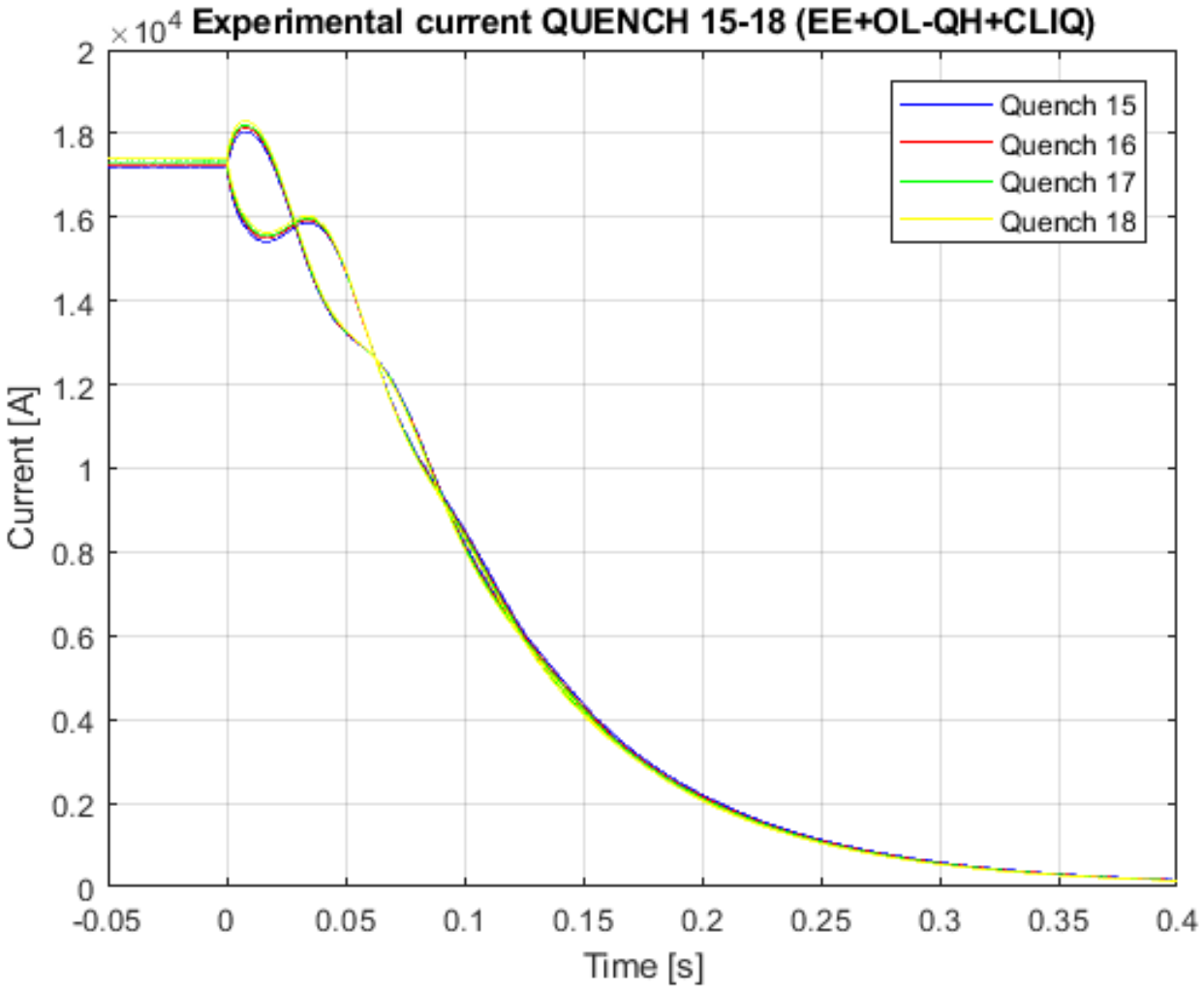


- Sim MIITs: 27.85 MA^2s
- Exp MIITs: 25.4 MA^2s

CLIQ performance

- Quench 15, 16, 17 and 18 were performed using CLIQ, dump resistor, OL quench heaters, and no IL quench heaters
- Results are similar to what shown before
  - Good agreement btw measured current decay and simulations
  - MIITs are almost independent on the presence of IL quench heaters
- After quench 18, due to a short to ground, the test campaign was stopped

CLIQ performance



CLIQ performance

- Comparison of experimental and measured MIITs in all quenches with CLIQ

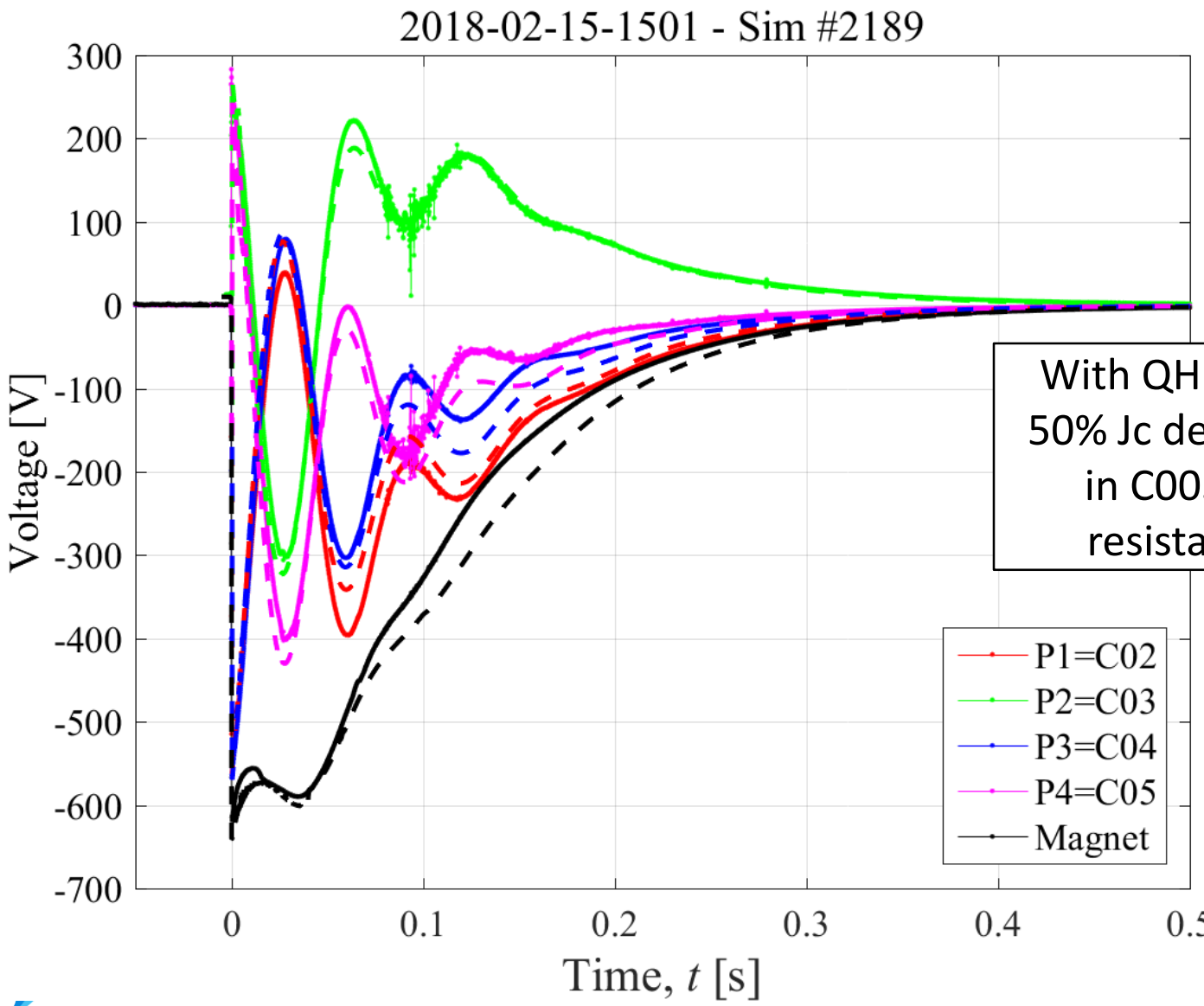
Quench	Current [A]	MIITs (simulated)	MIITs (measured)
14	16693	27	25.1
15	17167	27.85	25.4
16	17262	27.9	25.45
17	17326	27.95	25.49
18	17426	28.0	25.55

Conclusions

- Since CLIQ was commissioned during the MQXFAP1 test campaign, IL quench heaters were used until CLIQ reliability was demonstrate in quench 14
- The 37.5 mΩ dump resistor always present to extract some energy
- Therefore the lay-outs were:
  - IL quench heaters + OL quench heaters + dump (first 13 quenches)
  - CLIQ + OL quench heaters + dump (last 4 quenches)
  - Quench 14 has been performed with dump, OL heaters, IL heaters and CLIQ for the commissioning of CLIQ
- The reliability of simulations has been validated on experimental measurements
- The protection with EE, CLIQ and OL heaters shows a decrease of the MIITs of ~15 % respect to EE, IL and OL heaters
- The presence of dump resistor increases the efficiency of the protection system (in particular of CLIQ).
  - EE extract ~20 % of the stored energy (LEDET simulation).
- Based on simulations validated during this test, the maximum temperature of the magnet in nominal scenario is: 250 K @I_{op}

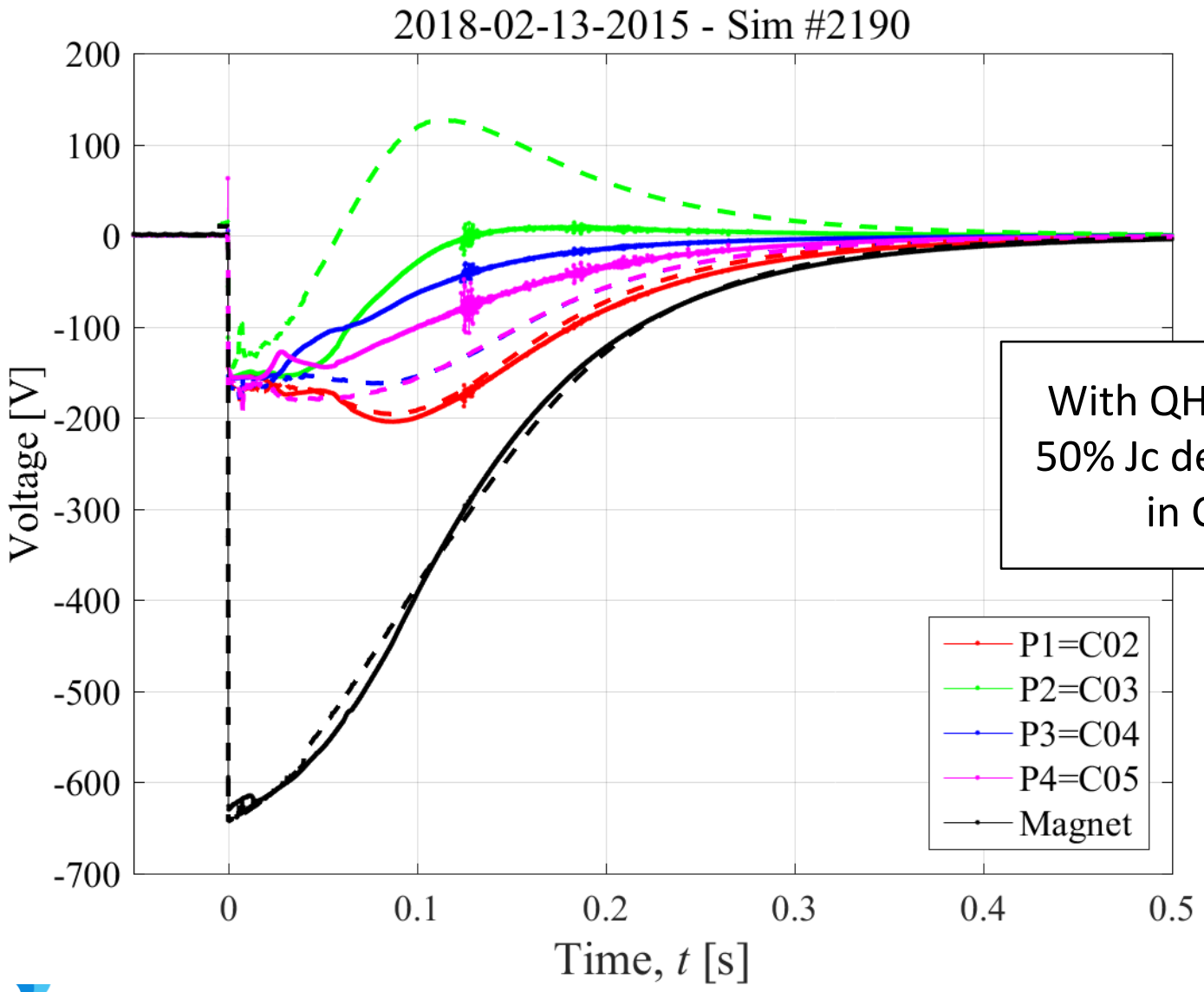
Backup slides

Backup slides



With QH on C003, 50% Jc degradation in C003, CLIQ resistance x3

Backup slides



With QH on C003, 50% Jc degradation in C003

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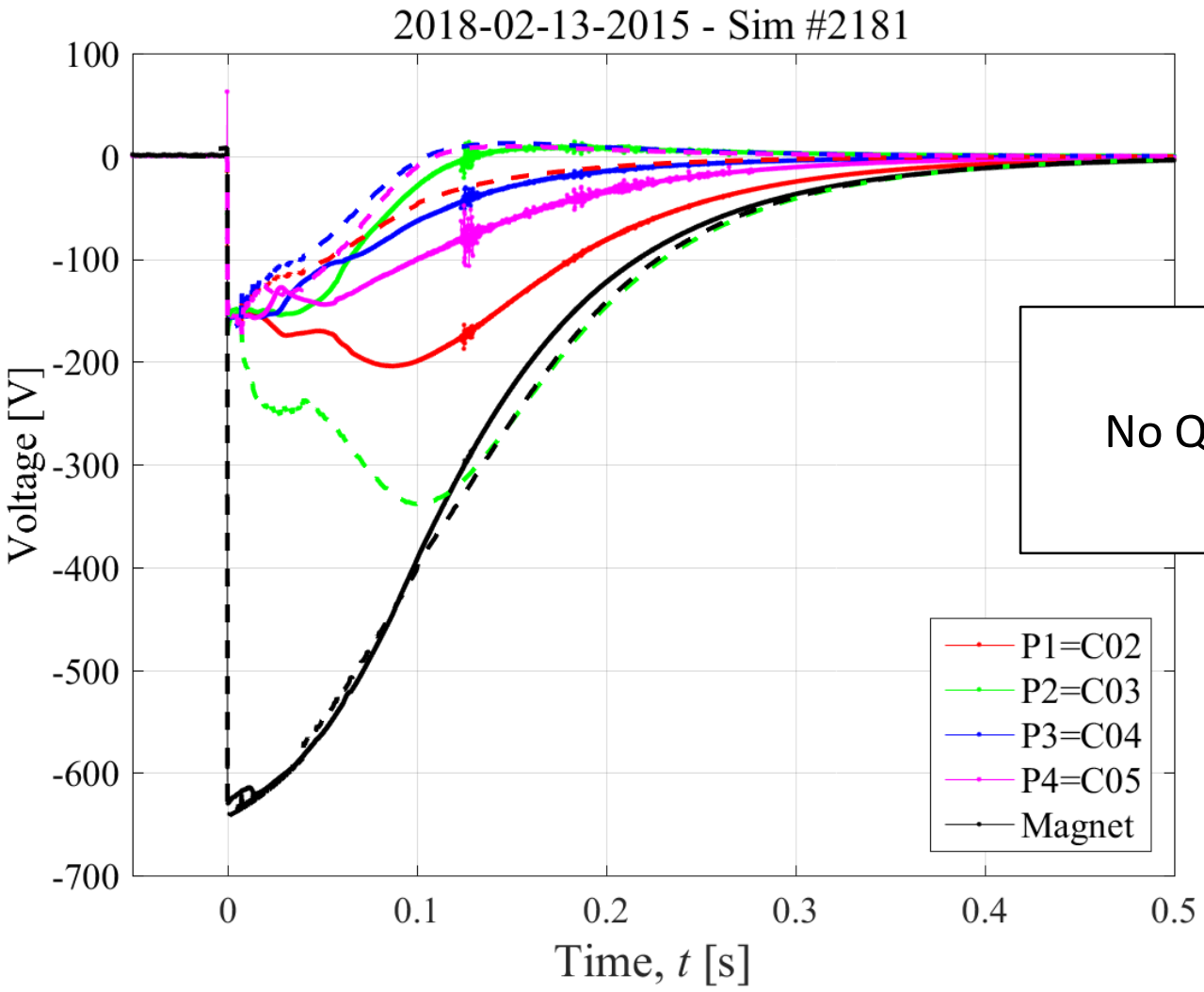

No QH in C003