MCBRDP1 test results

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Contents

Contents

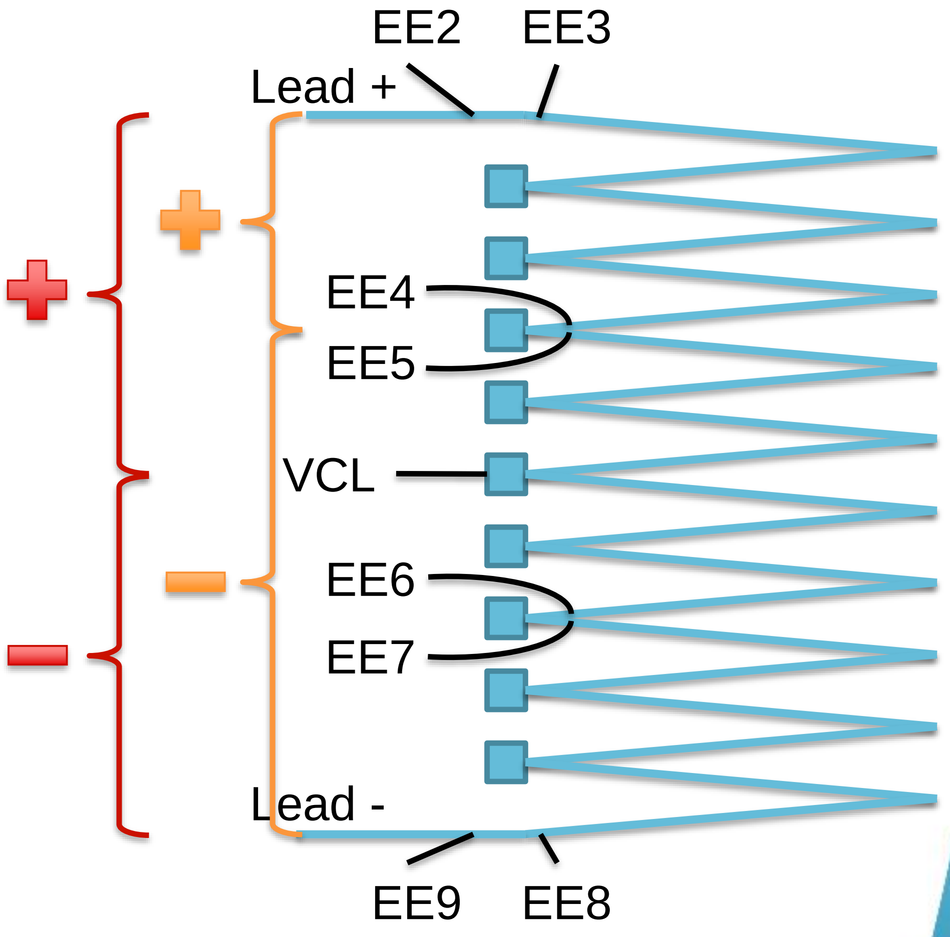
- Test setup
  - Quench detection
  - Quench protection & energy extraction
- Test results
  - Training & endurance
  - Protection studies
  - Inductance measurements
  - Splice resistance
  - RRR
- Conclusions

Test setup

- MCBRDP1 with two individually powered apertures
- One standard LHC 600 A power converter rack with two converters
- One standard LHC 600 A energy extraction rack with two switches and two 700 mOhm resistors

Quench detection (per aperture)

- QDS setup (baseline):
  - 2.3(EE3-EE5) – (EE5-EE8)
  - Trigger after 4 ms @ 100 mV
- Potaim setup:
  - (EE3-VCL) – (VCL-EE8)
  - Trigger after 10 ms @ 50 mV



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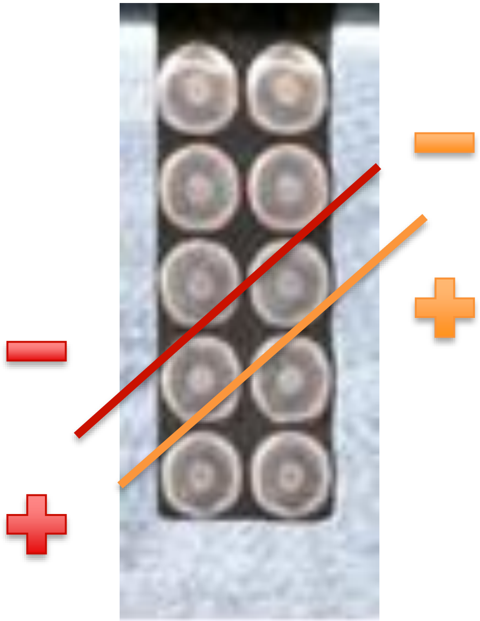

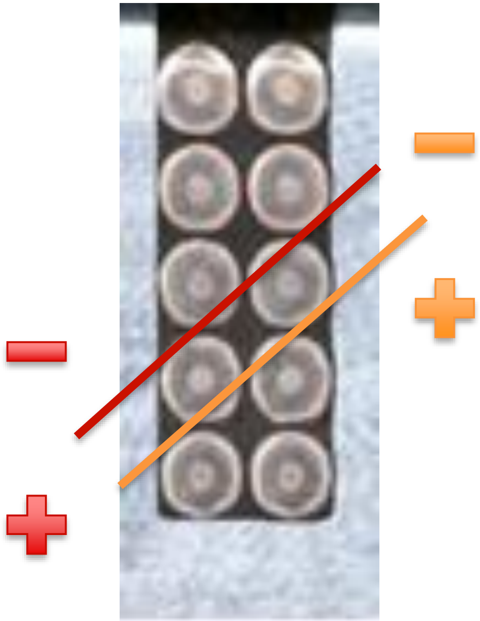

Quench protection

- Baseline: 0.7 Ohm resistor
- We also used other energy extractions:
  - 2x Metrosil varistor (#1) designed for <400 V at 460 A
  - 2x 0.15 Ohm resistor
  - 2x Metrosil varistor (#2) designed for <475 V at 470 A
    - Brought from England during the tests after we saw some problems
  - Thanks to Bozhidar Panev & MPE-EE, and Jeff Robertson & M&I Materials for their help

Contents

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  - Quench detection
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  - Training & endurance
  - Protection studies
  - Inductance measurements
  - Splice resistance
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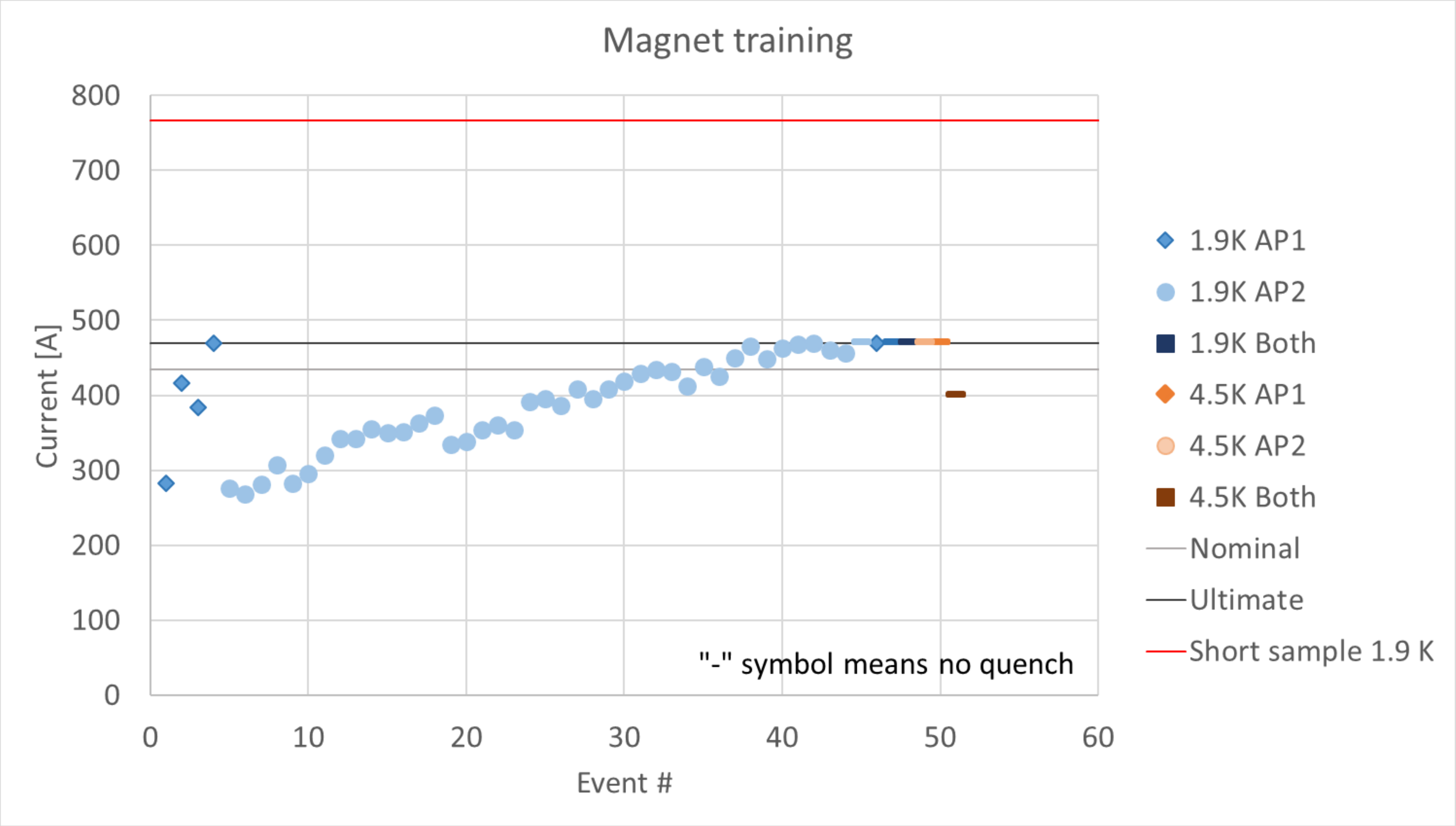
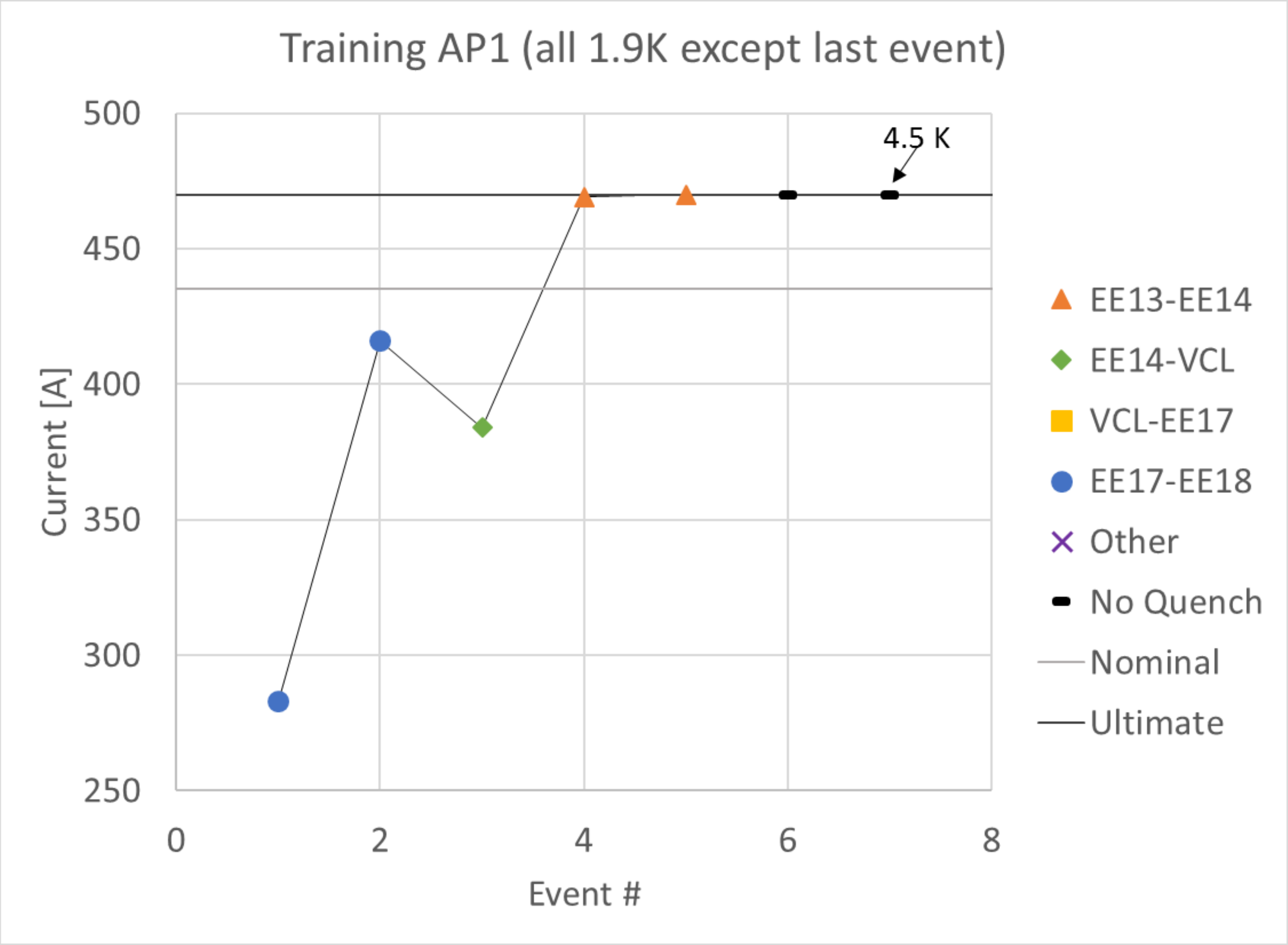
Training



- Both apertures have the first quench at ~280A (37% ss)
- Fast training in AP1
- Slow training in AP2
- No additional training with both apertures
- No additional training at 4.5K
- More details in the next slides

Training AP1



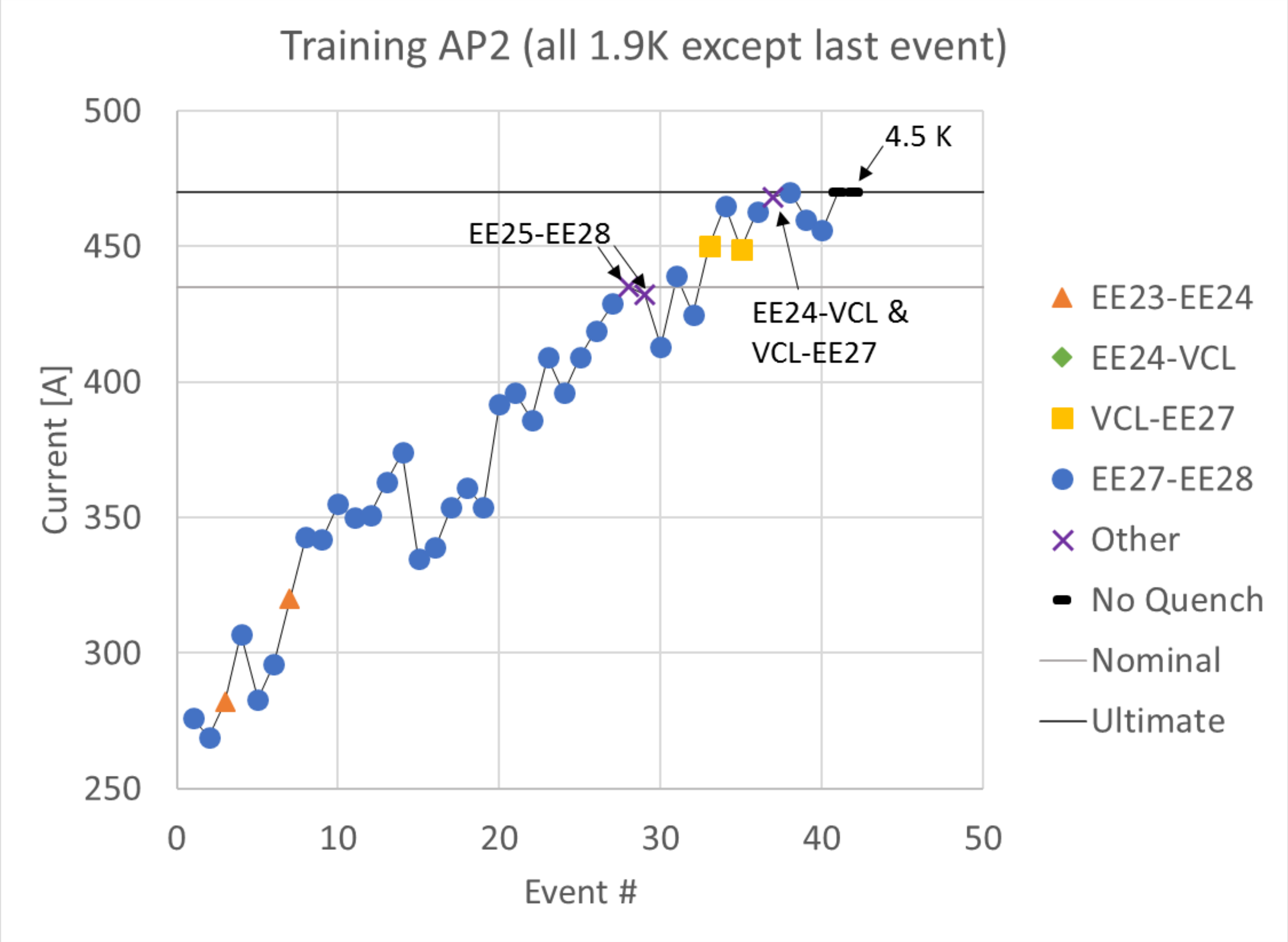
- Three quenches to nominal current
- Two last quenches within 1 A of ultimate current (in the decelerating ramp)
- No precursor in any quench
- Afterwards: held 2 h at ultimate current

- Protection: first two quenches above maximum allowed QI (hotspot temperature ~350 K)
    - More on this later

Shallow

Deep

Training AP2



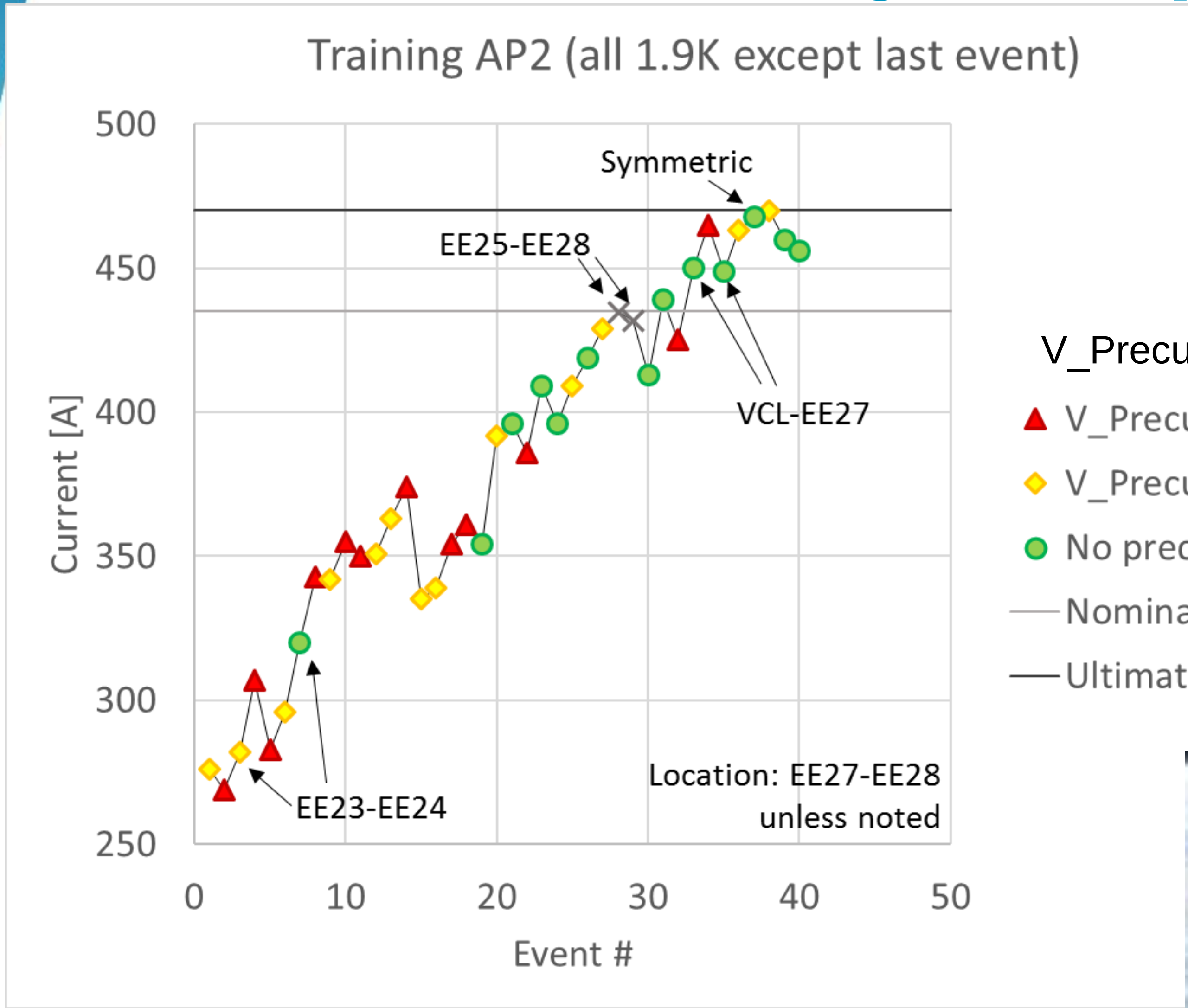
- Very long training, mostly on EE27-EE28
- After 32 quenches: no quench below nominal
- After 40 quenches training finished to ultimate current
- Held 2h at ultimate

- Quench #37 is symmetric

Shallow

Deep

Training AP2: precursors

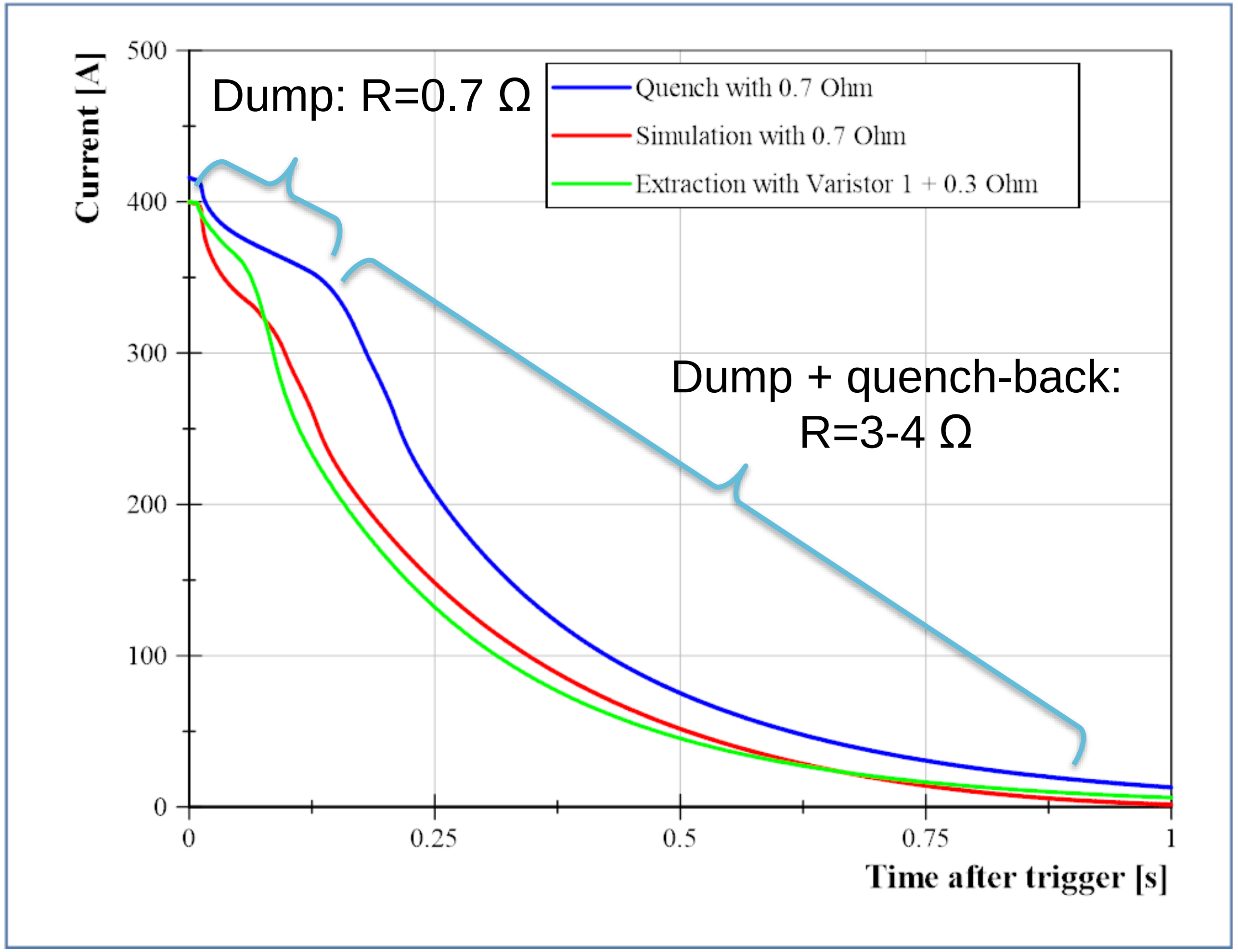


- Large precursors mostly in the first half of the training
- No precursors mostly in the second half
- Location statistics:

	Total	Large prec	Small prec	No prec
EE23-EE24	2	0	1	1
EE24-VCL	0	0	0	0
VCL-EE27	2	0	0	2
EE27-EE28	33	12	12	9

Contents

Protection studies

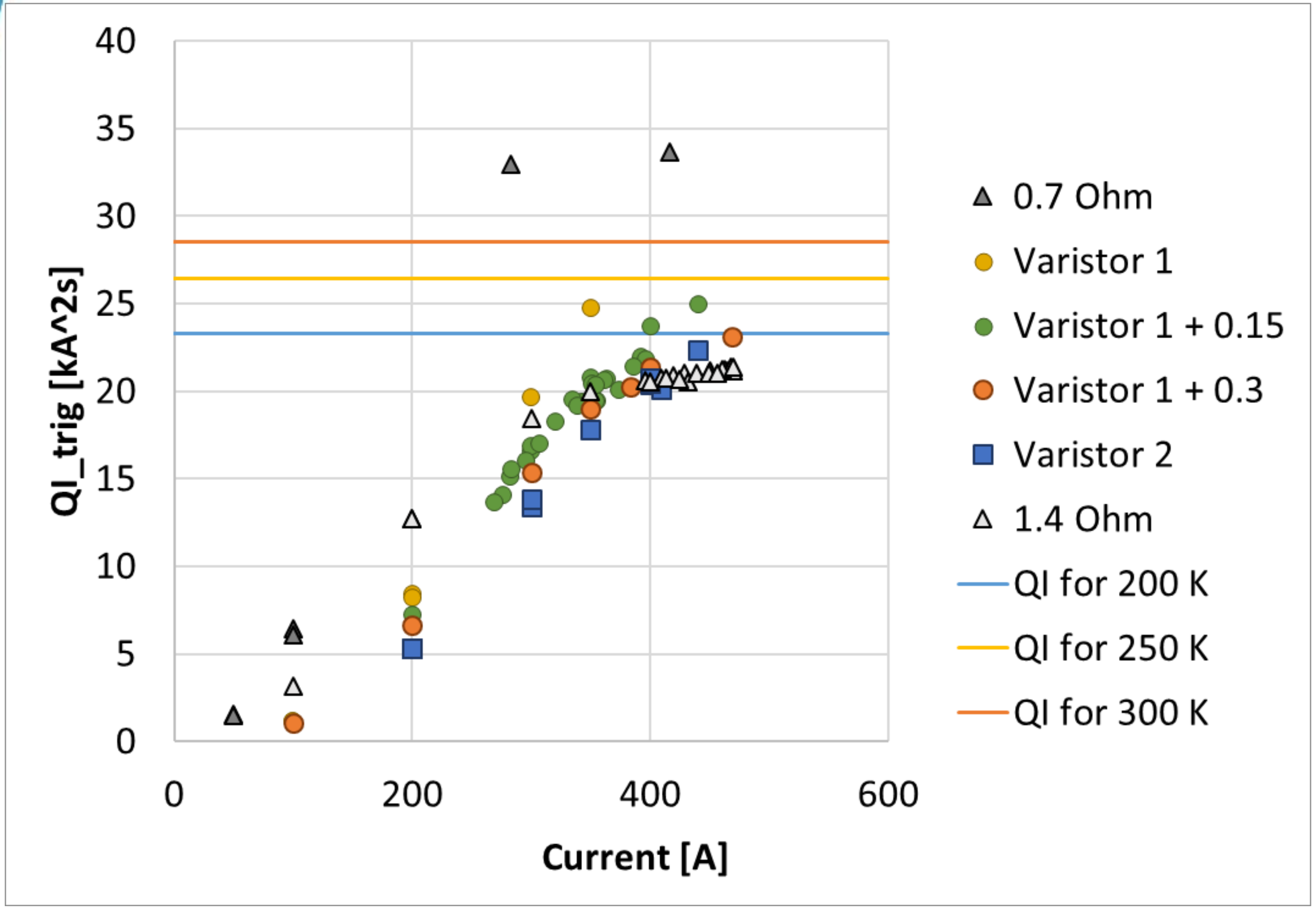


- All results presented in this section are at 1.9 K

- The expected current discharge is much slower than expected (quench-back starts later)
- With the baseline energy extraction (0.7 Ohm) we cannot keep the hotspot temperature below 200 K
  - We had two quenches at ~350 K

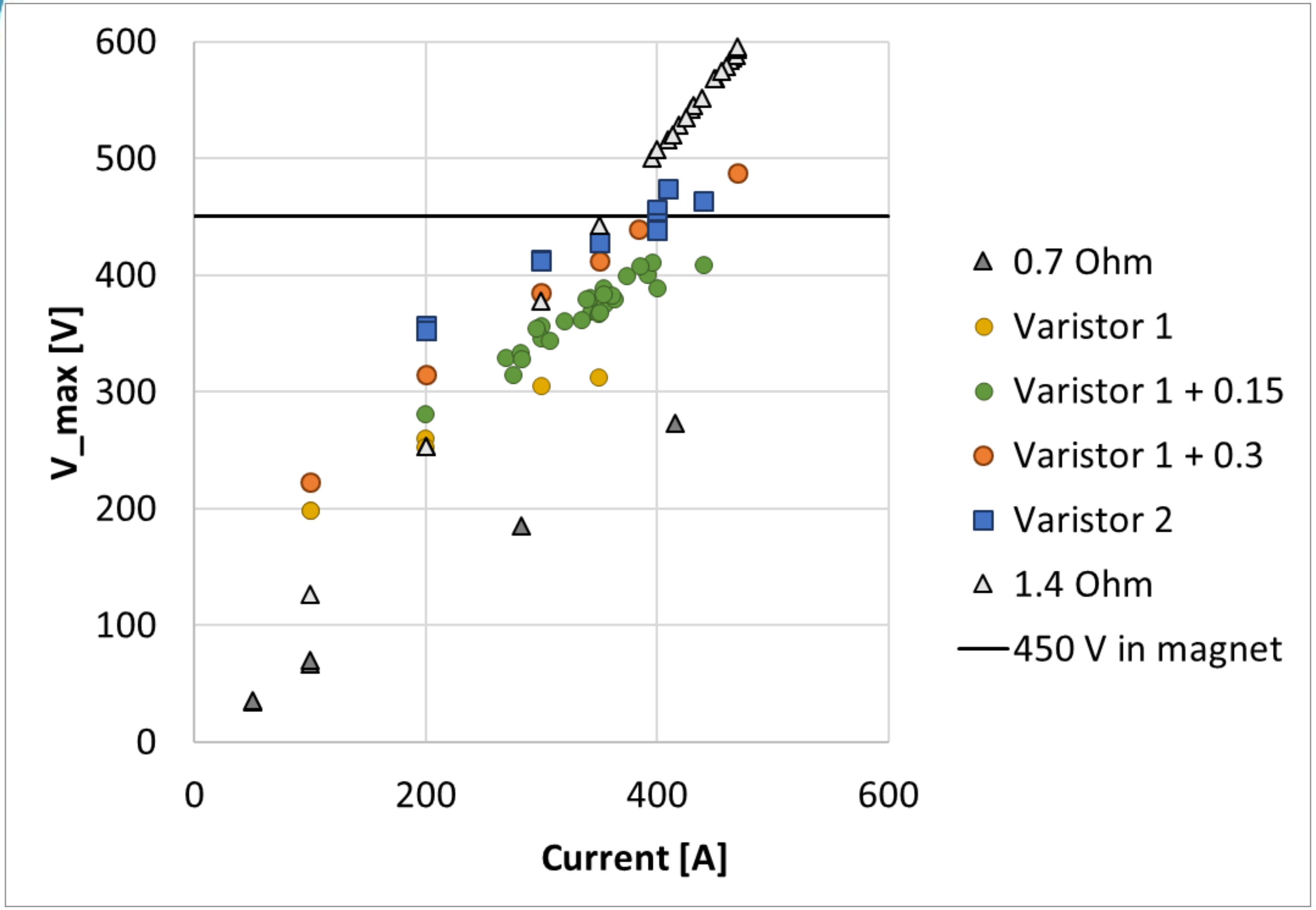
- We looked at several energy extraction setups to optimize discharge:
  - No more than ~200 K hotspot
  - No more than ~450 V in switch

Protection: QI from trigger vs current



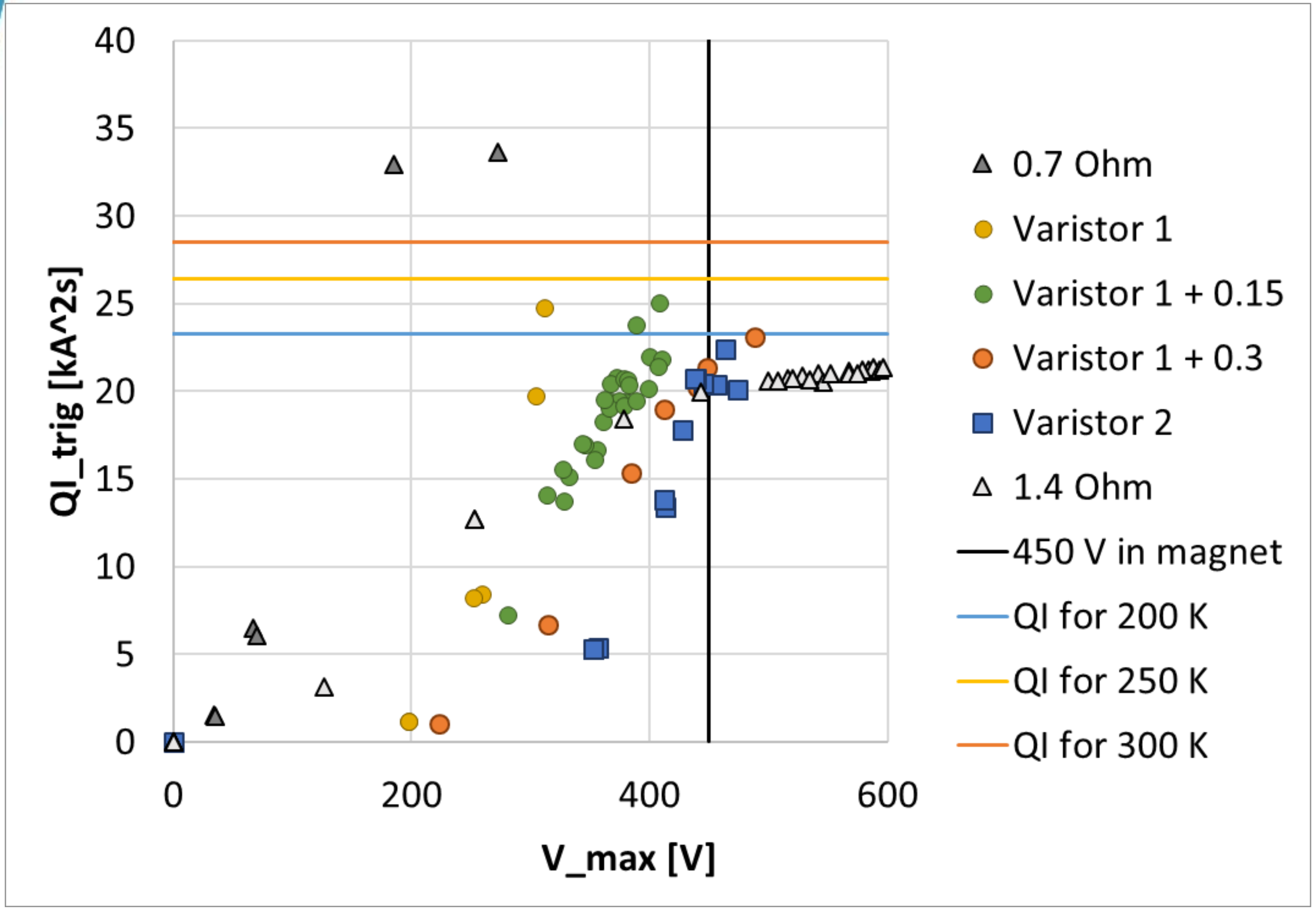
- Quench detection typically adds 4 kA^2s
- We can get to low QI with:
  - Varistor 1 + 0.3 Ohm resistor in series
  - Varistor 2
  - 1.4 Ohm (2x 0.7 Ohm resistors)
- Maximum voltage in the switch (450 V) limits the options

Protection: max magnet voltage vs current



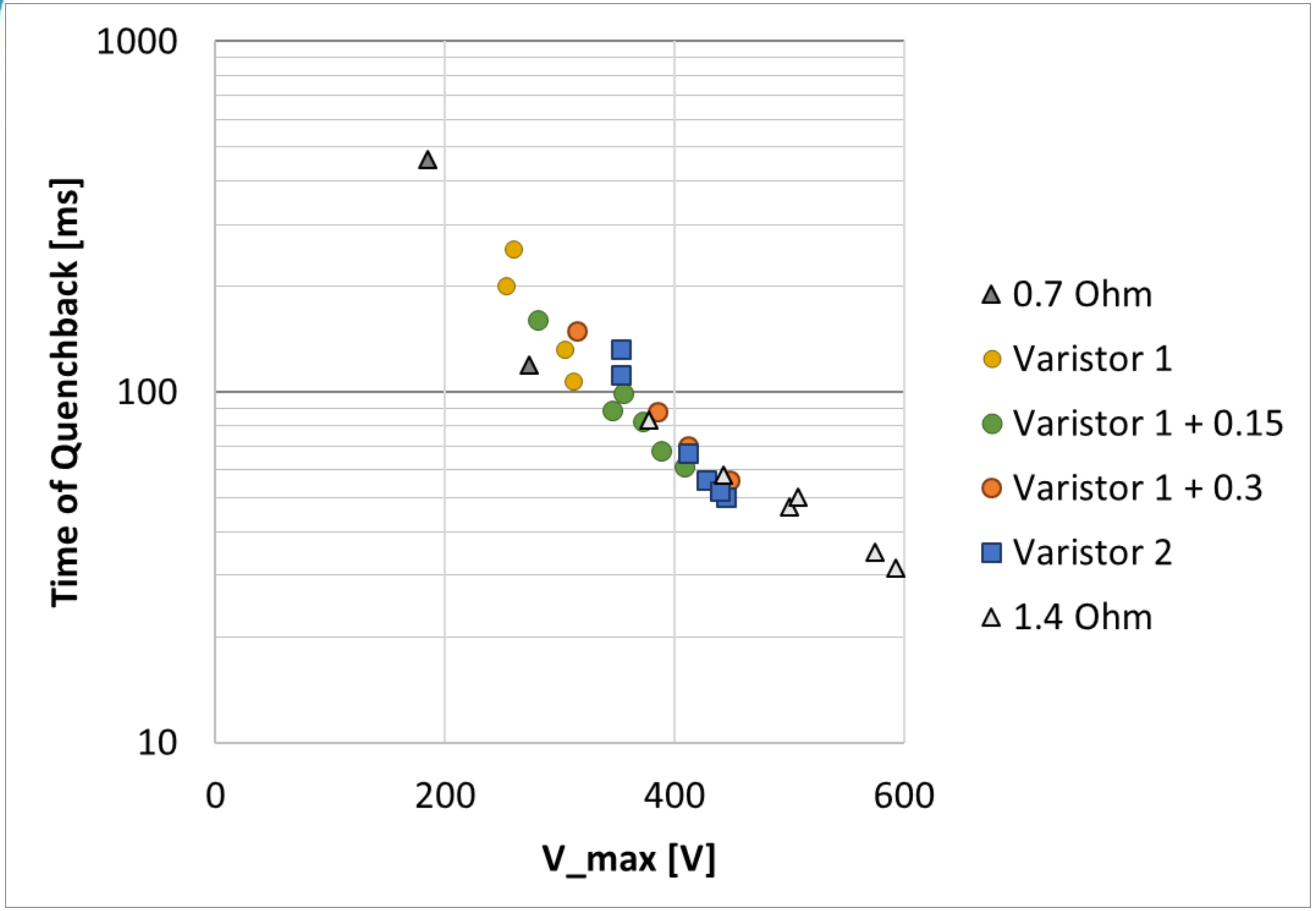
- The two original protection options (0.7 Ohm, Varistor 1) had too low maximum voltage, making the discharge too slow
- Varistor 1 + 0.3 Ohm and Varistor 2 have slightly too high voltage beyond 400 A
    - The Varistor specs could be better adapted to our needs
    - Increasing its temperature lowers the discharge voltage
- 1.4 Ohm is two switches in series, effectively duplicating the maximum allowed voltage

Protection optimization space

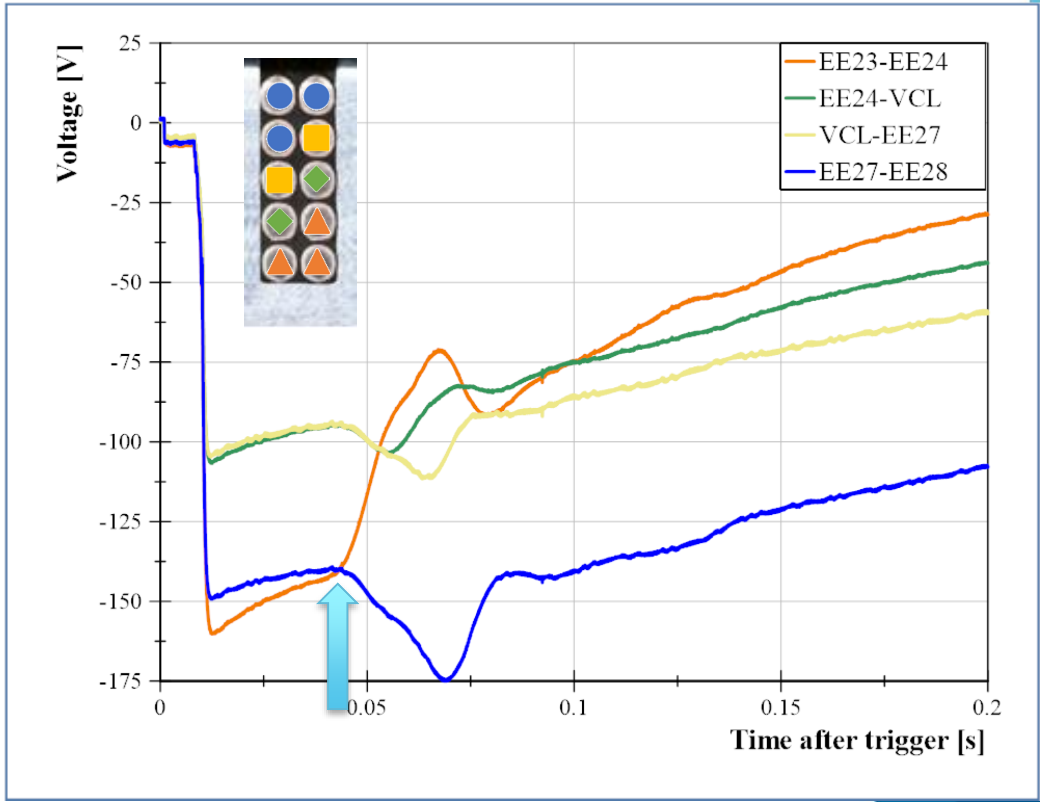


- This plot shows the results compared the limits:
  - Maximum QI for a limited hotspot temperature
  - Maximum voltage for the switch
- If we cannot stay within the limits, change the limits:
  - Use two switches for 2x max voltage (SM18)
  - Different switch components for optimized discharge voltage

Max voltage effect on quench-back start



- Quench-back start time determined from segment voltage after trigger
- QB starts in deeper strands
- QB start time mainly depends on the maximum voltage of the discharge



Contents

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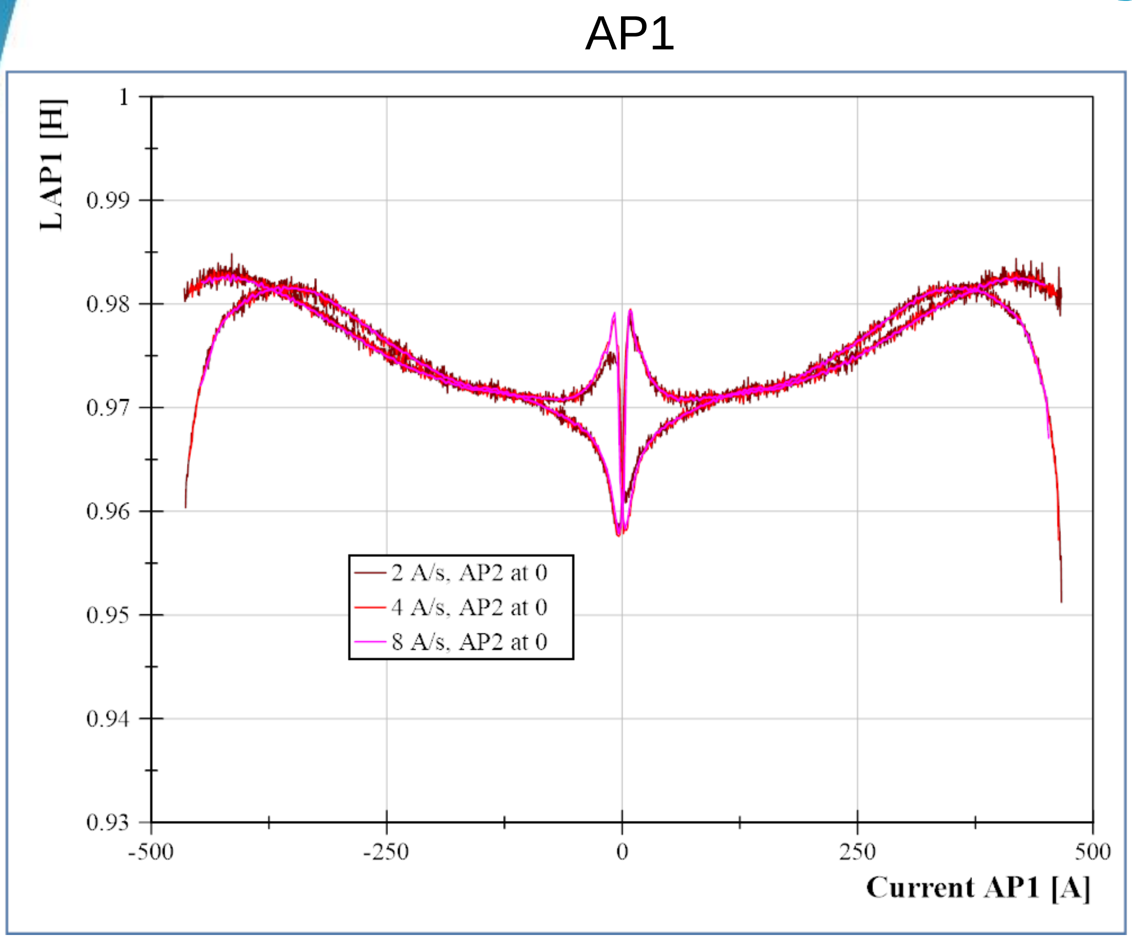
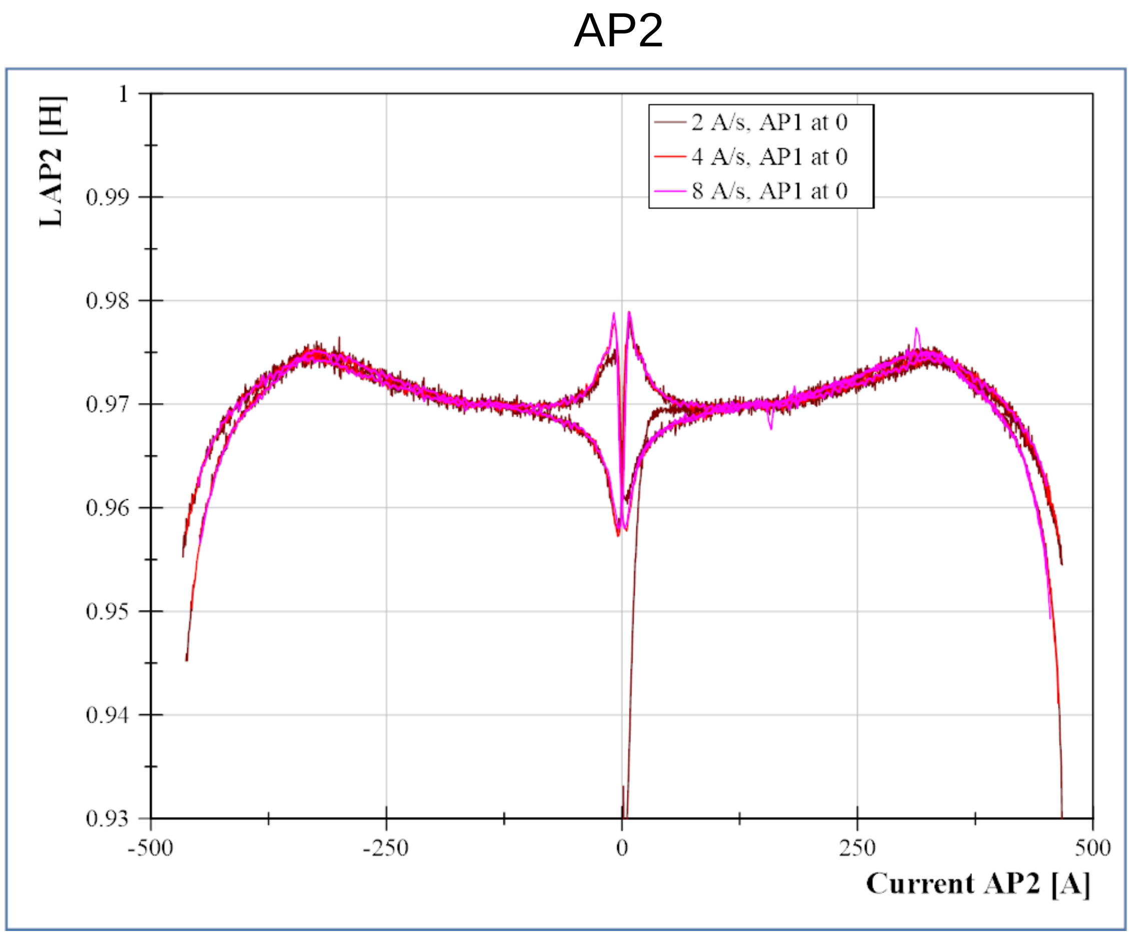
Inductance: only one AP powered

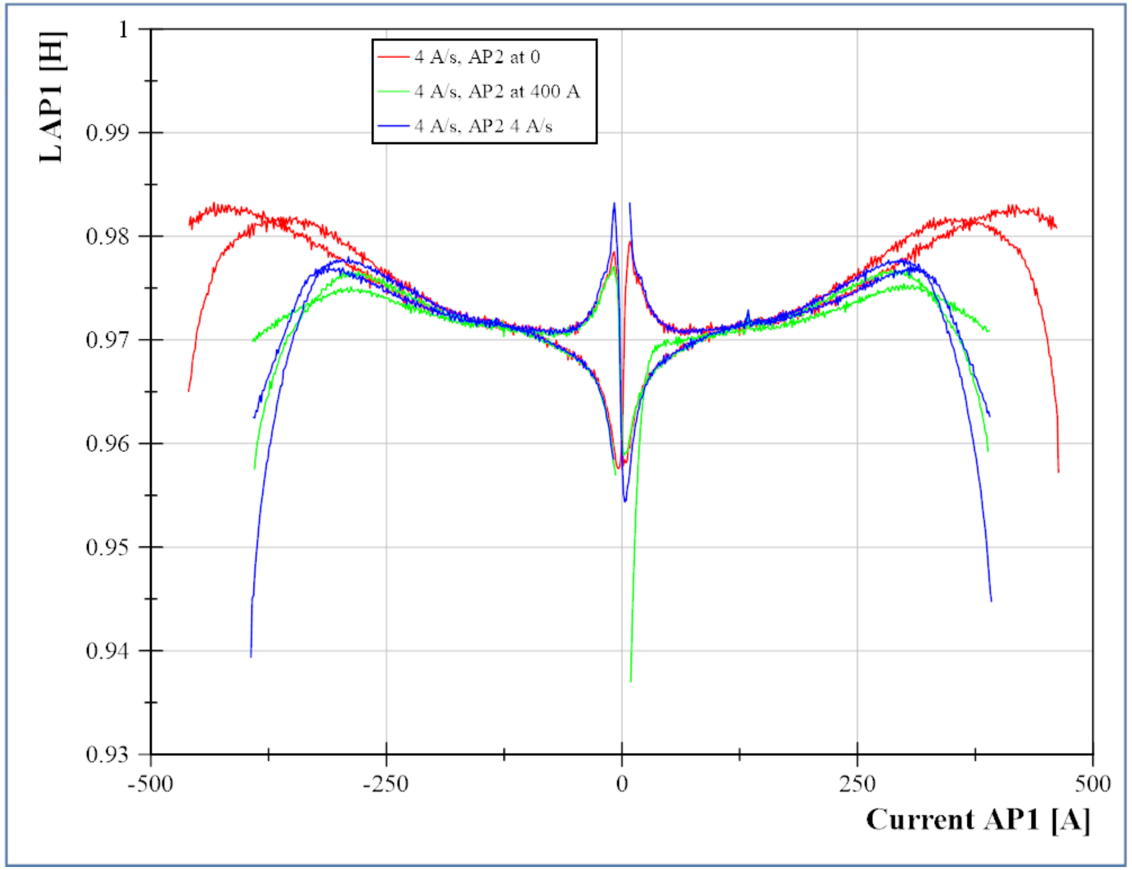




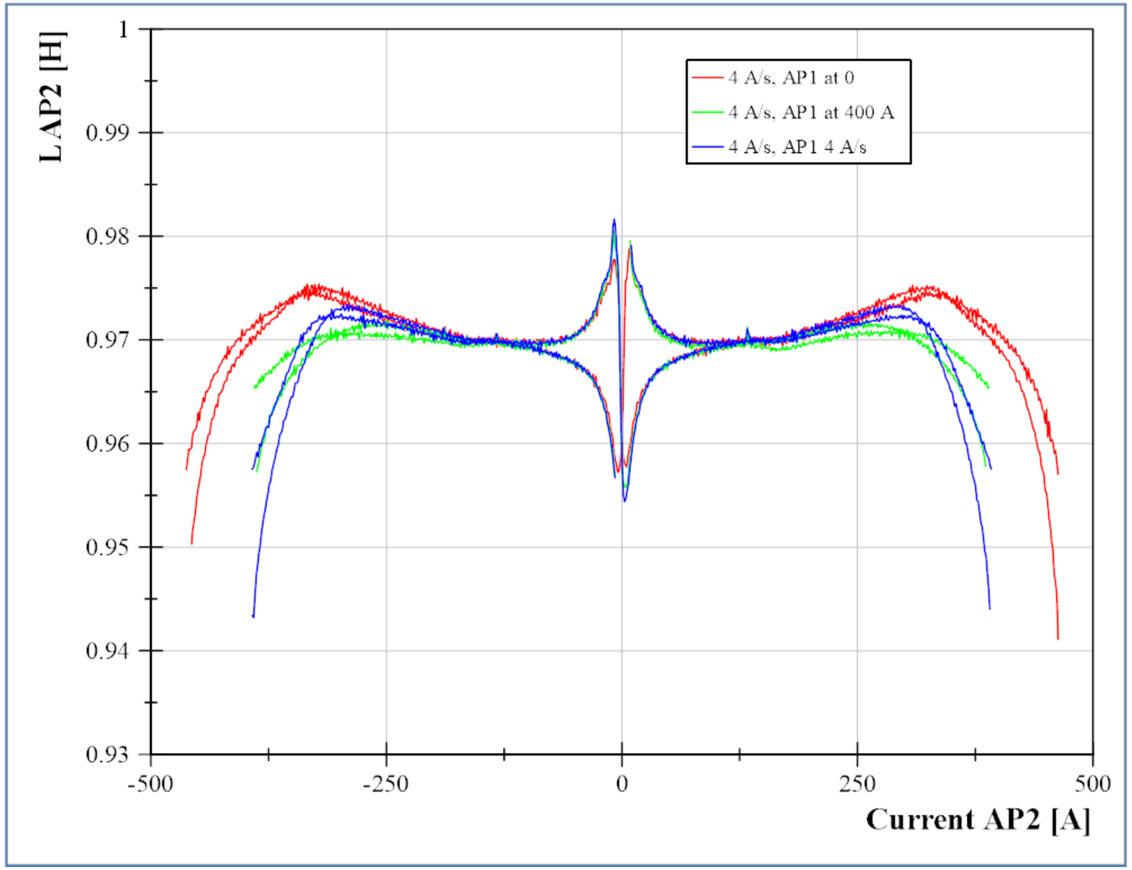
Inductance is much larger than expected 800 mH
Inductance does not depend on ramp rate between 2--8 A/s

Inductance: both APs powered

AP1

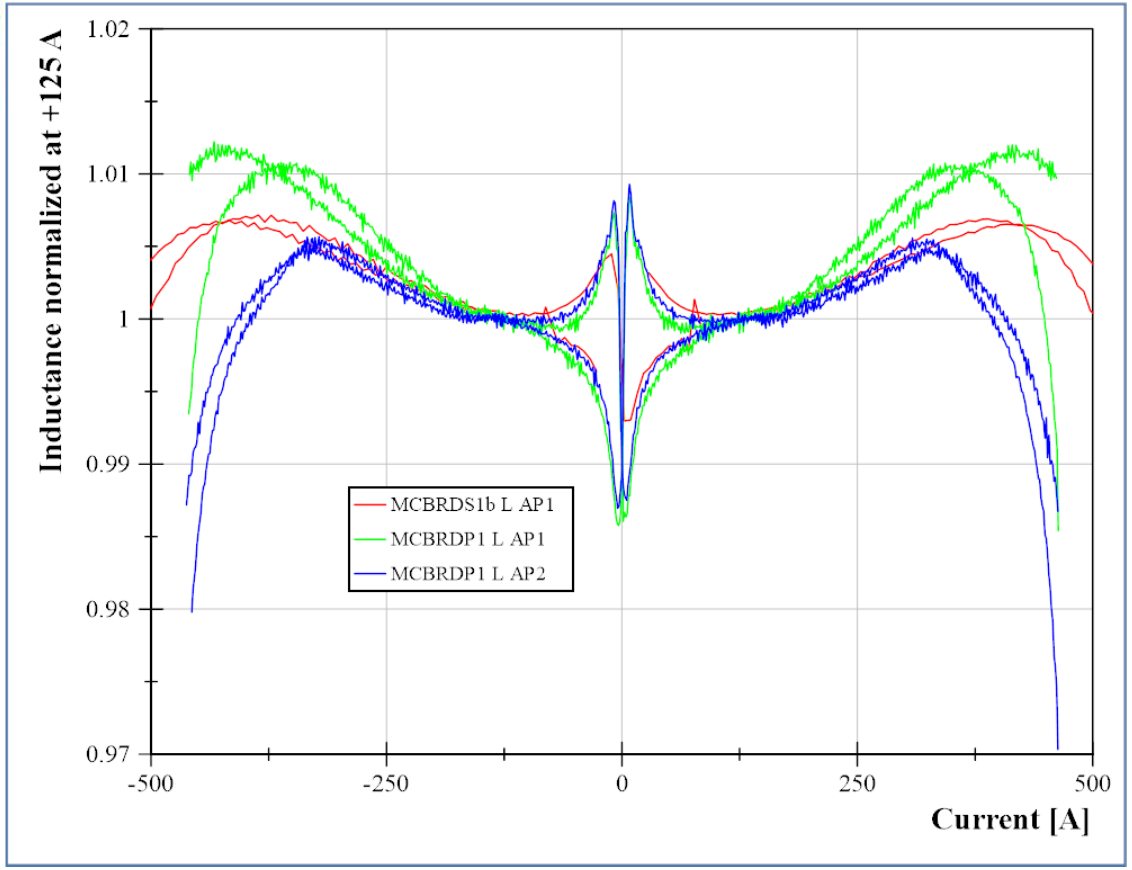


AP2



Inductance decays earlier when both apertures are powered

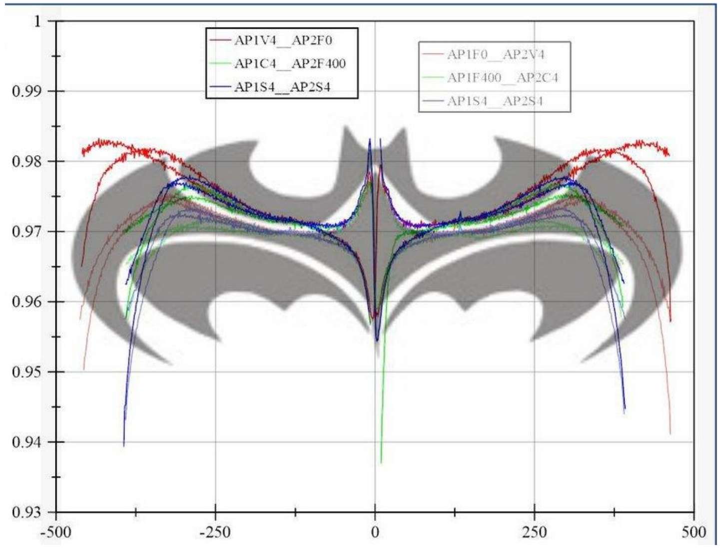
Inductance comparison with short model



- Each aperture powered alone at 4 A/s
- Inductance normalized to the value at +125 A

- AP1 in model very similar to AP2 in prototype
  - Do they have the same orientation?
- Inductance reduction starts later in model
  - Many differences: distance between apertures, iron yoke design

- It looks like the Batman sign



Contents

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Splices resistance & RRR

	V taps	Resistance [nOhm]	Error [nOhm]
AP1	EE14--EE15	5.38	0.06
	EE16--EE17	5.03	0.07
AP2	EE24--EE25	6.55	0.02
	EE26--EE27	6.62	0.04

- Individual splice resistance (5-6.6 nOhm) similar to that of model (5-10 nOhm)
- Average splice resistance measurement too noisy, will repeat for the second cooldown

Segment	RRR
EE13-EE14	235
EE15-EE16	233
EE17-EE18	221
EE23-EE24	230
EE25-EE26	233
EE27-EE28	235

- RRR values (220-235) lower than the short models (~260)

Contents

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Conclusions & future plans

- **Training** to ultimate current:
  - Good in AP1 (3 quenches to nominal, 5 to ultimate)
  - Very slow in AP2 (40 quenches to ultimate current). Mostly in the shallower three wires of the winding, where all quenches with precursor but one were originated.
  - No further training at 4.5 K
- **Protection**:
  - Baseline protection not adequate for hotspot temperature < 200 K
  - Need to optimize the protection systems
  - Onset of quench-back (at given temperature) mostly determined by voltage
- Other results:
  - **Inductance**: much larger than expected (1 H instead of 0.8 H)
  - **Splices resistance**: individual OK (5-6.6 nOhm), average data too noisy
  - **RRR**: lower than models (220-235 instead of 260)
- **Future**:
  - Second test (in 1-2 weeks): training memory verification, splice resistance measurement and full magnetic measurements

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