Cable model meeting

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  - MQXF voltage profile
  - Influence of boundary conditions
  - Influence of inter-strand contact resistance
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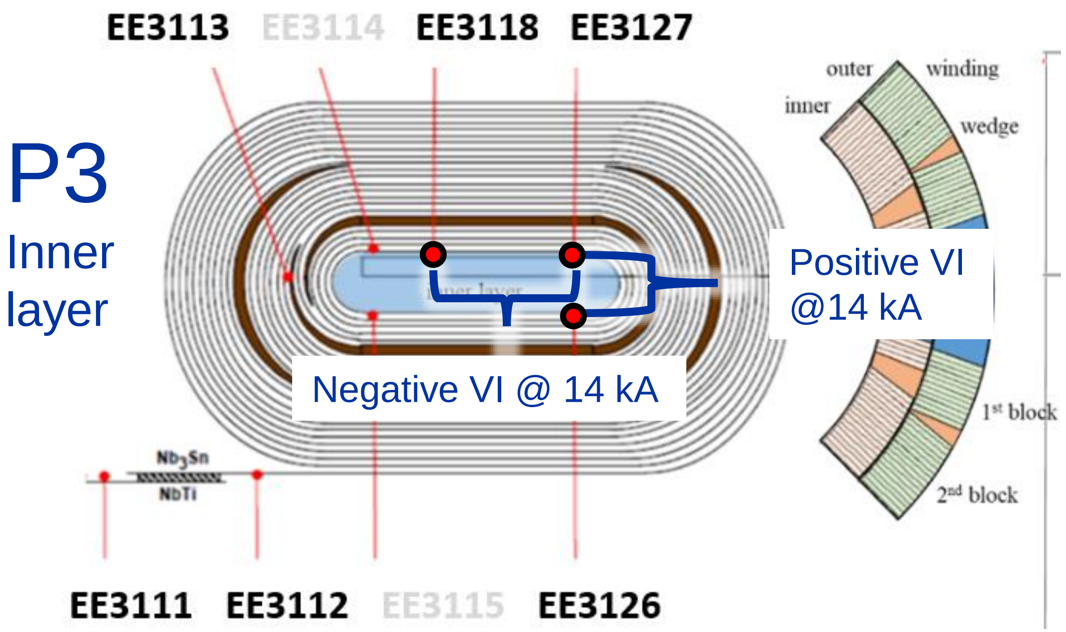
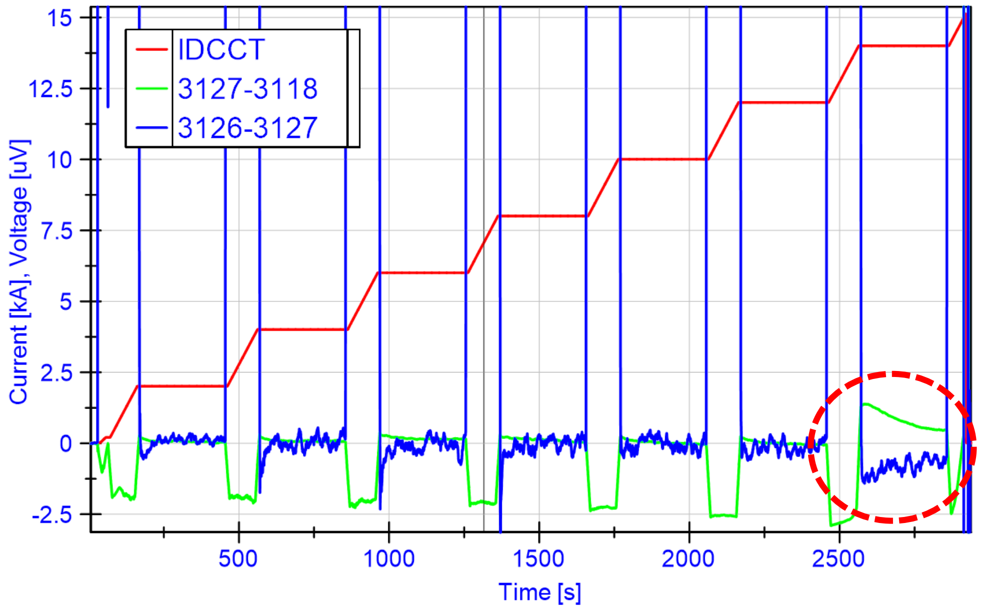
- **Proposal for experiment**

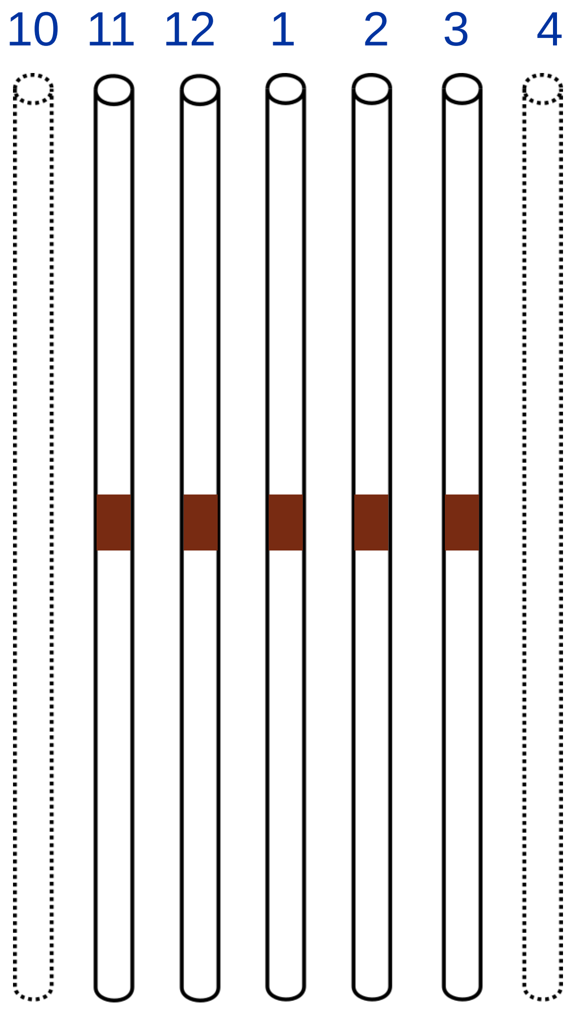
V-I measurement results

- Anomalous voltage signals on several segments at the 14 kA plateau:
  - **Negative** decaying voltage over the *straight* segment (3127-3118)
  - **Positive** decaying voltage over the *head* segment (3126-3127)





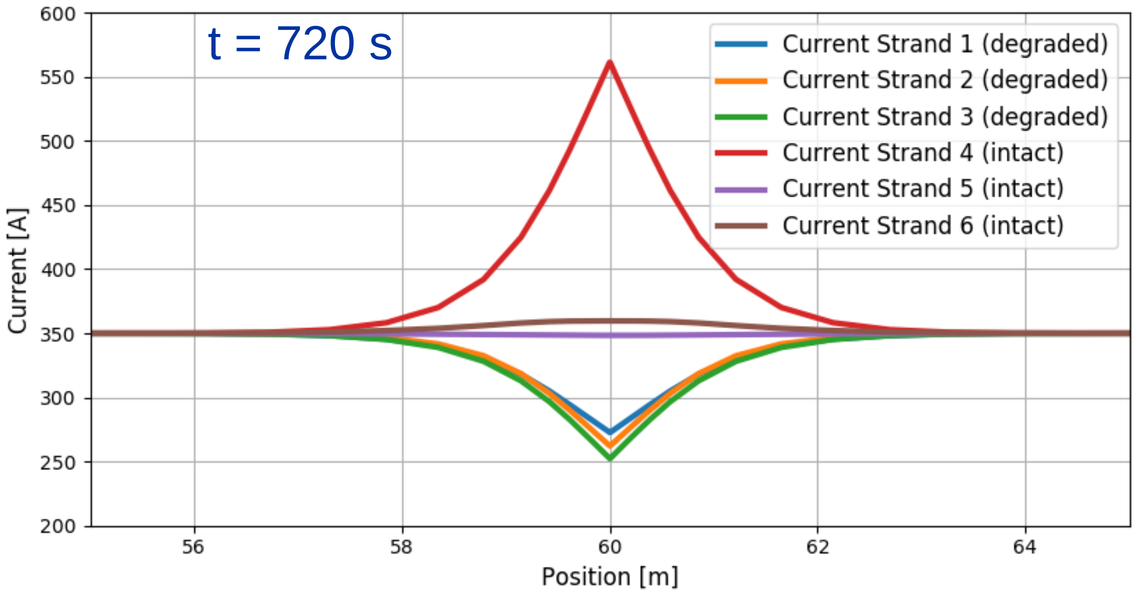
THEA model

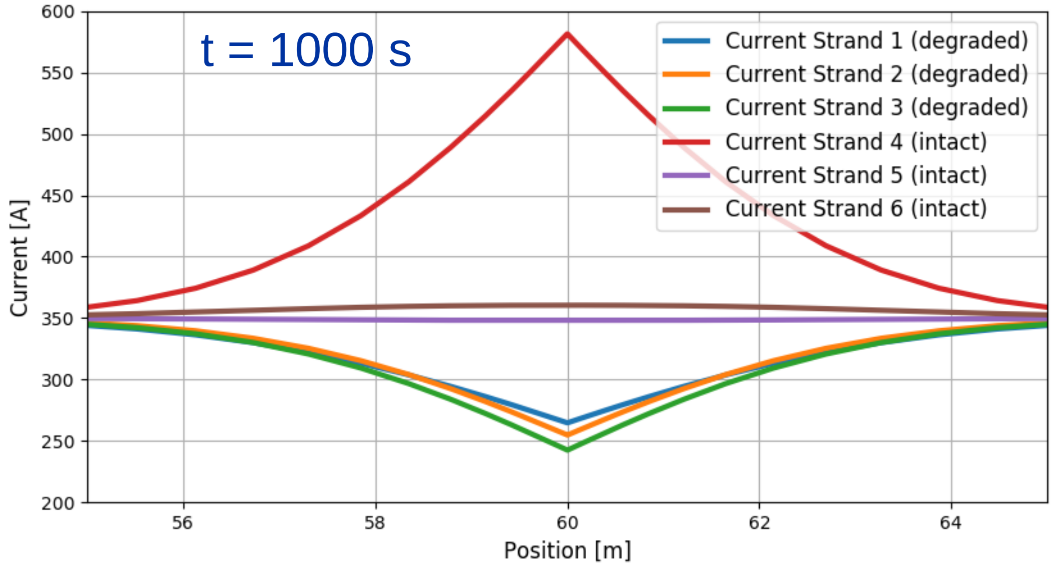


- **Sub-scale model consisting of 12 strands**
  - 120 m long cable
  - 5 degraded strands: 20 % remaining SC area, n-value = 20, L_{def} = 1 mm
- **Assumptions:**
  - Homogeneous magnetic field over the entire cable
  - Constant temperature: 1.9 K
  - Voltage taps measure one strand only
  - Inter-strand contact resistances:
    - R_a = 5 μΩ
    - R_c = 200 μΩ

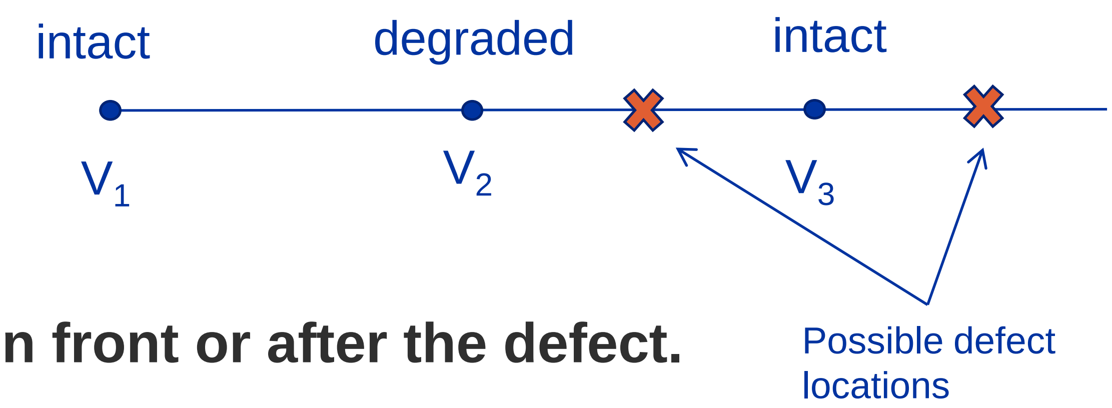
MQXF – current distribution

- **Simulation of V-I measurement, straight ramp to 14 kA, 20 A/s**
- **Current profile of degraded vs intact strands around defect**
- **Most of the current is taken up by <u>adjacent</u> strand**
- **As time progresses the profile expands → voltage decays**

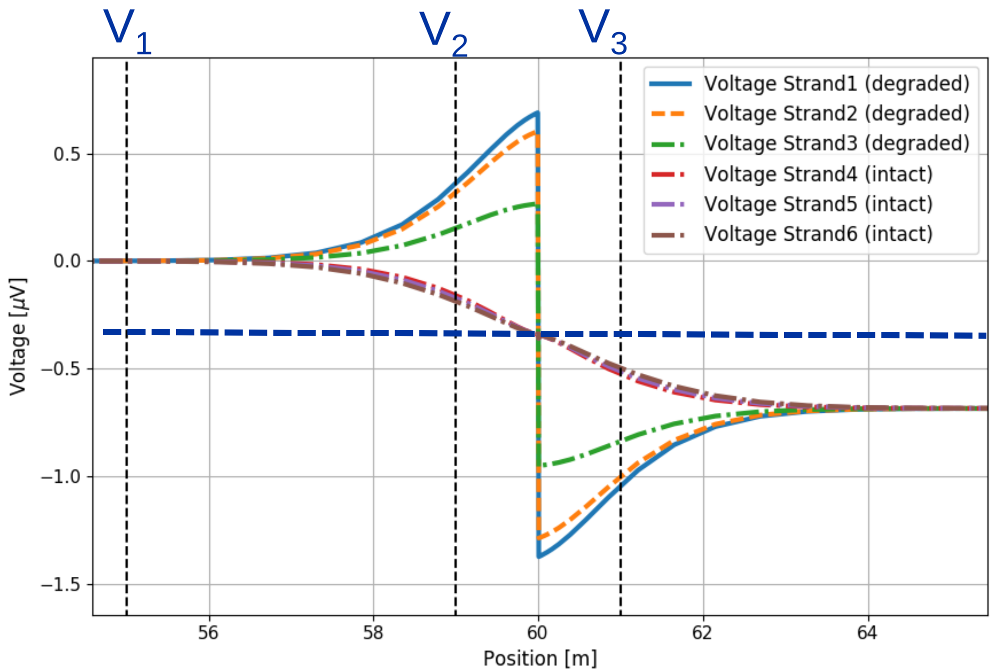


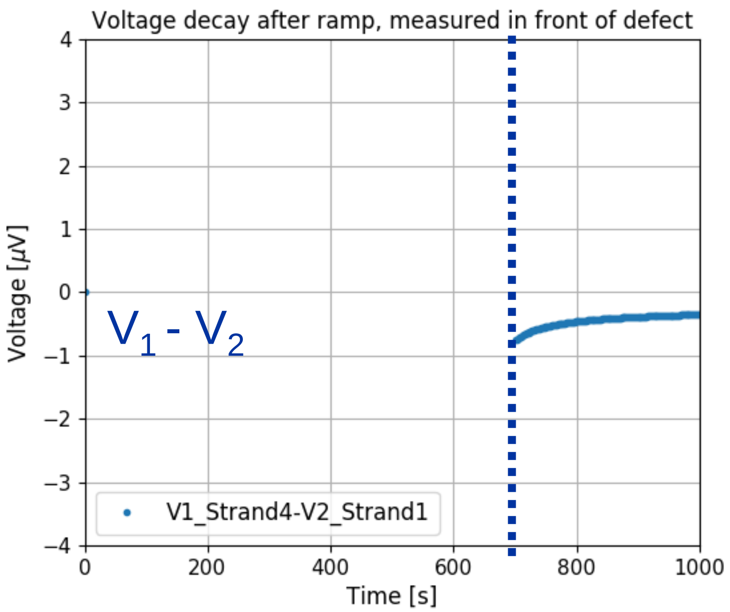


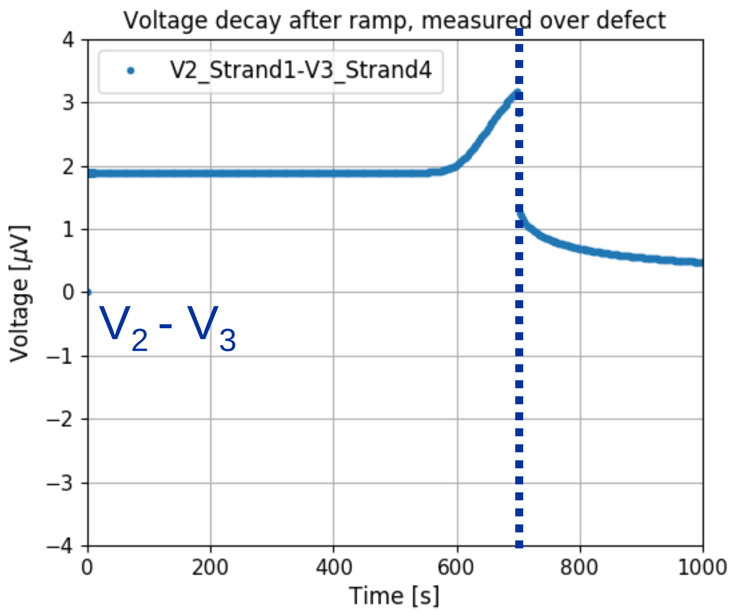
MQXF – Voltage profile



- **Voltage profile of degraded vs intact strands**
- **Negative voltage is possible when measuring in front or after the defect.**
- **Negative voltage *over* the defect is *not* possible with any combination of voltage taps**





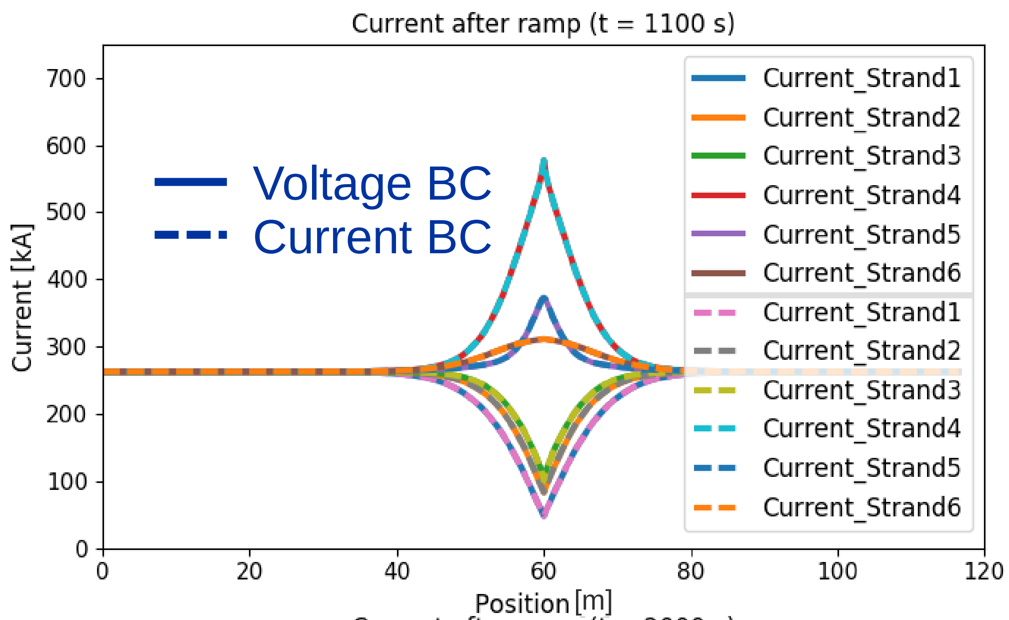


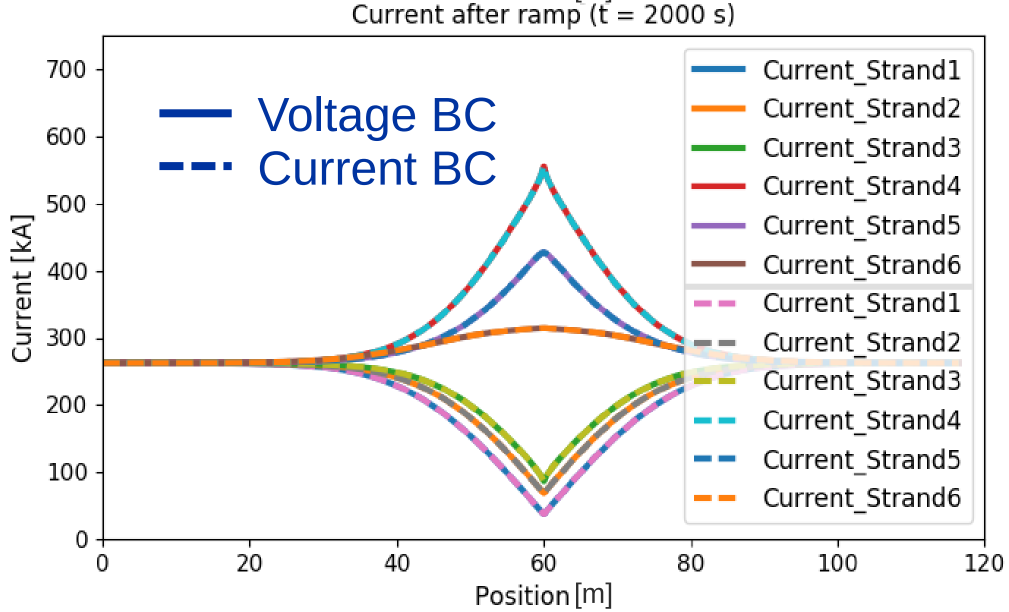
Conclusions – THEA model MQXF

- Decaying voltage signals can be explained by an inhomogeneous defect
- Negative voltage signal is possible when measuring next to the defect
- Negative voltage signals are not possible when measuring over the defect

Boundary conditions

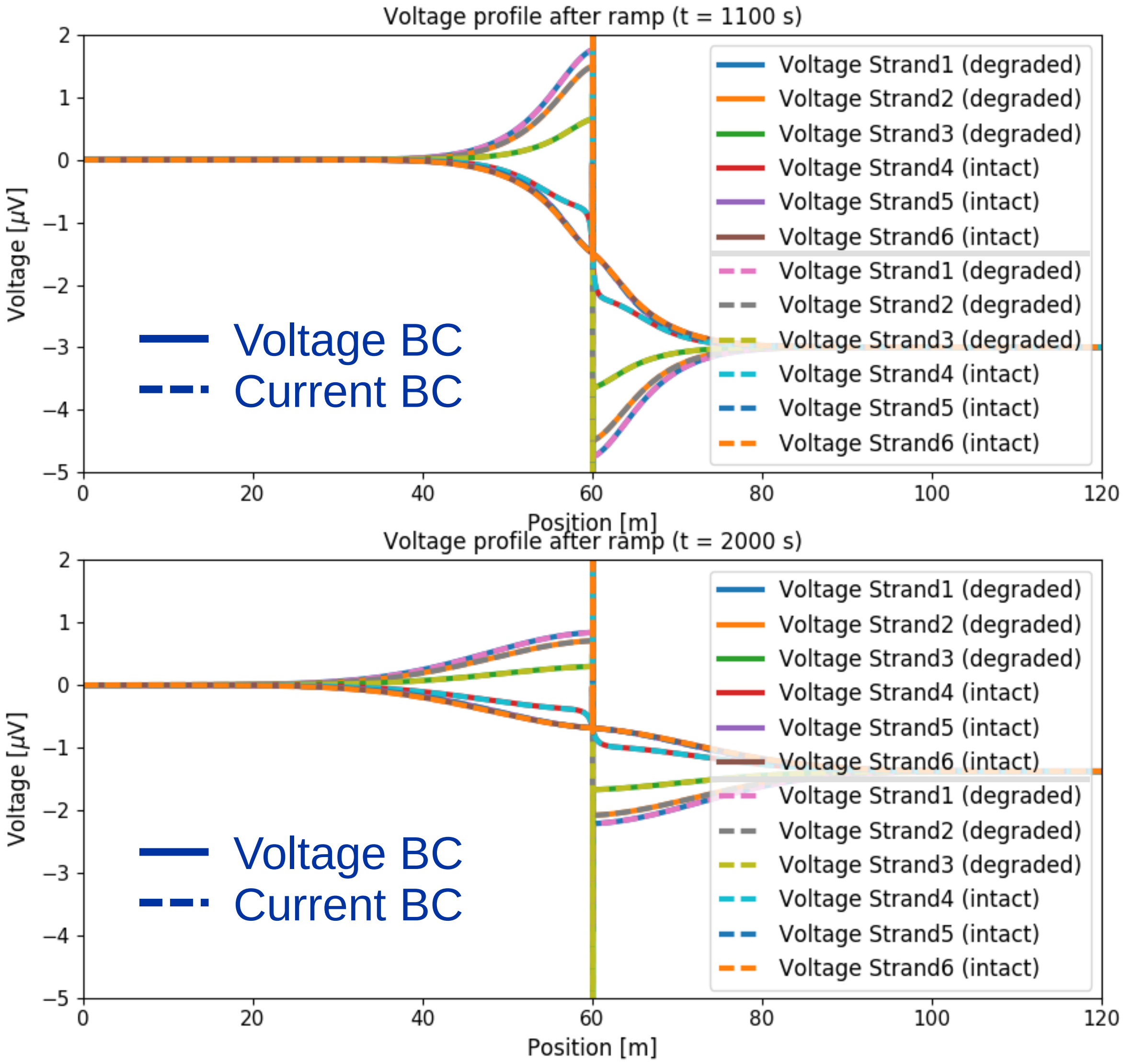
- **Influence of boundary conditions**
- **Model with 12 strands, length: 120 m**
- **Two simulations:**
  - Imposed voltage boundary conditions ——
  - Imposed current boundary conditions - - -
- **The results for both cases are an exact match**
  - BC’s are far enough away from defect to not make a difference





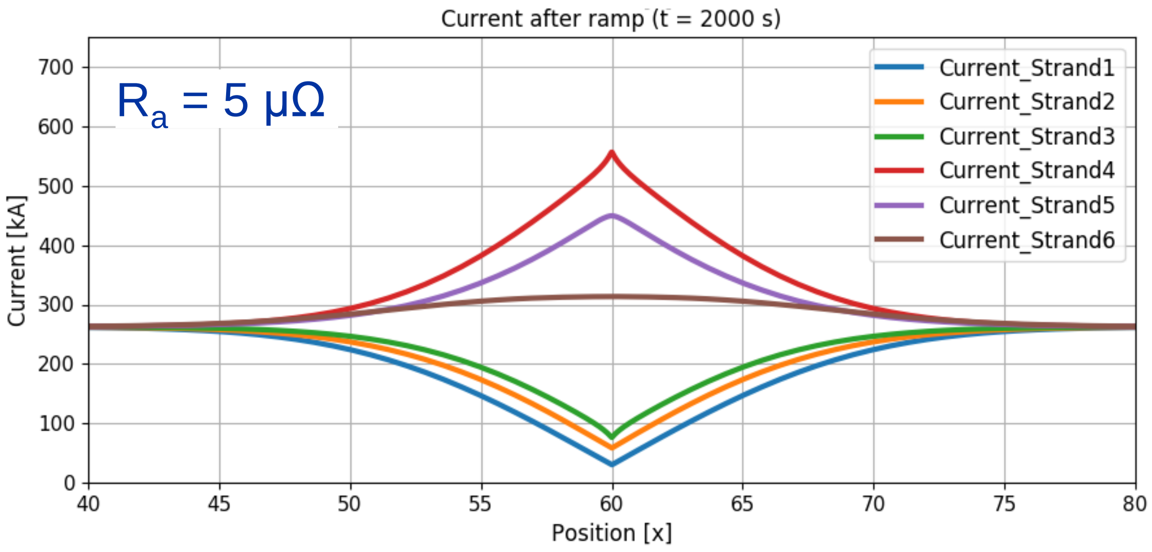
Boundary conditions

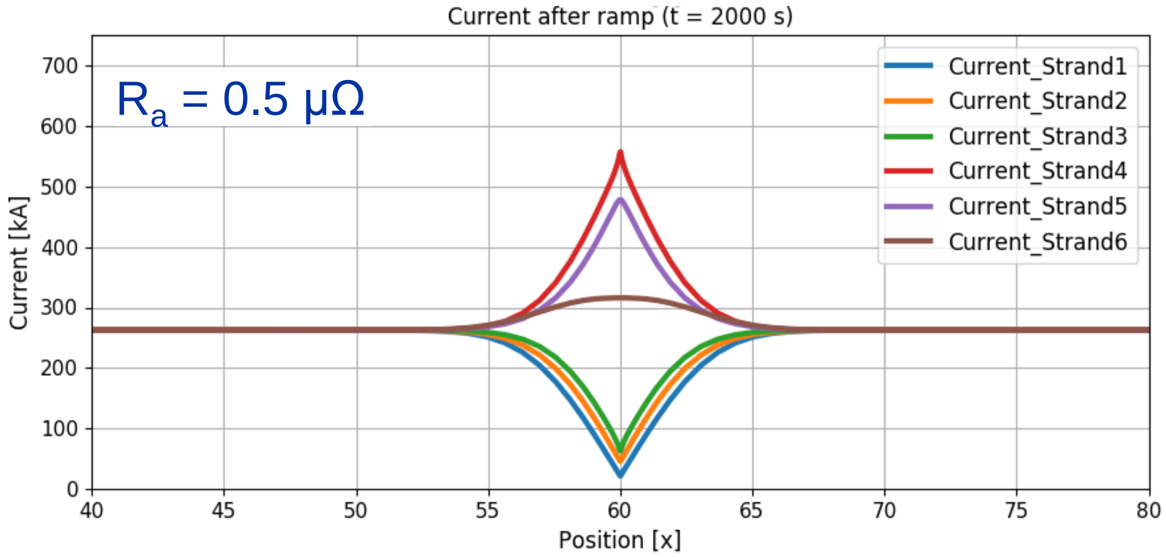
- **Voltage profile also matches exactly**
- **Conclusion:**
  - Boundary conditions at the joint do not play a role for sufficiently long models



Influence of R_a

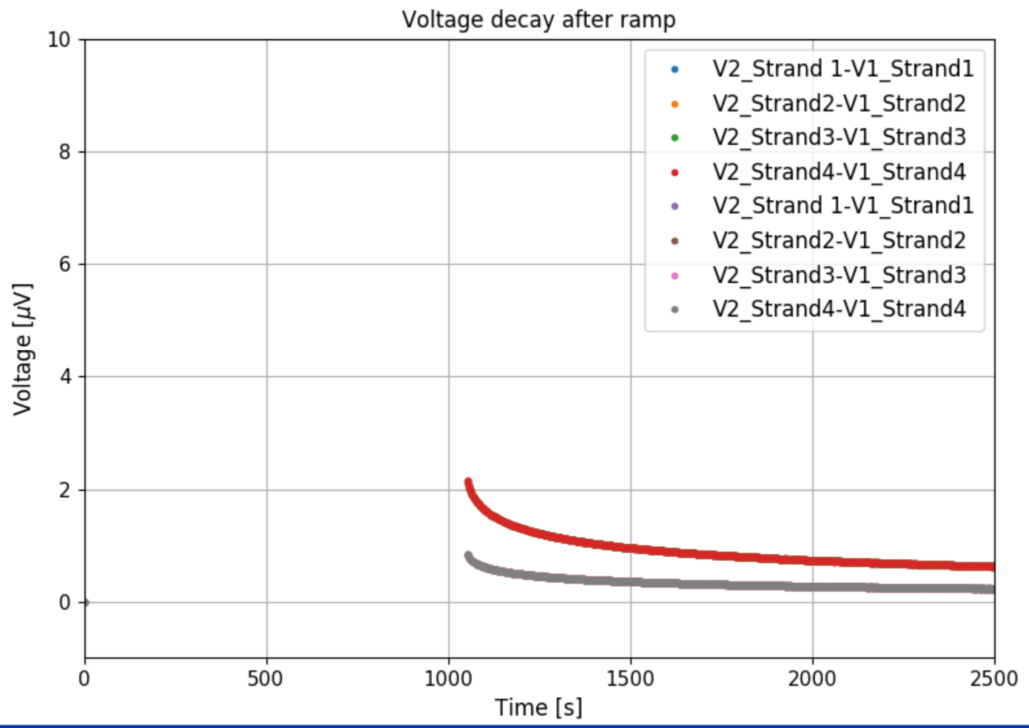
- **Current profile after 2000 s for a cable with R_a = 5 μΩ and R_a= 0.5 μΩ**
- **Reduced length scale of current redistribution for lower R_a**

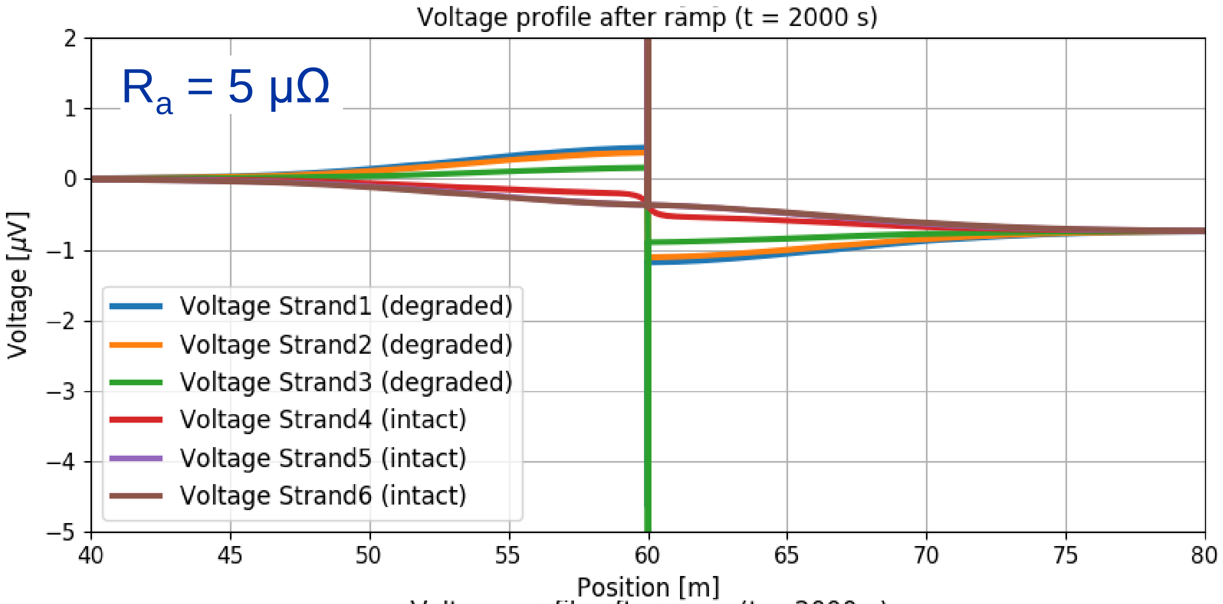


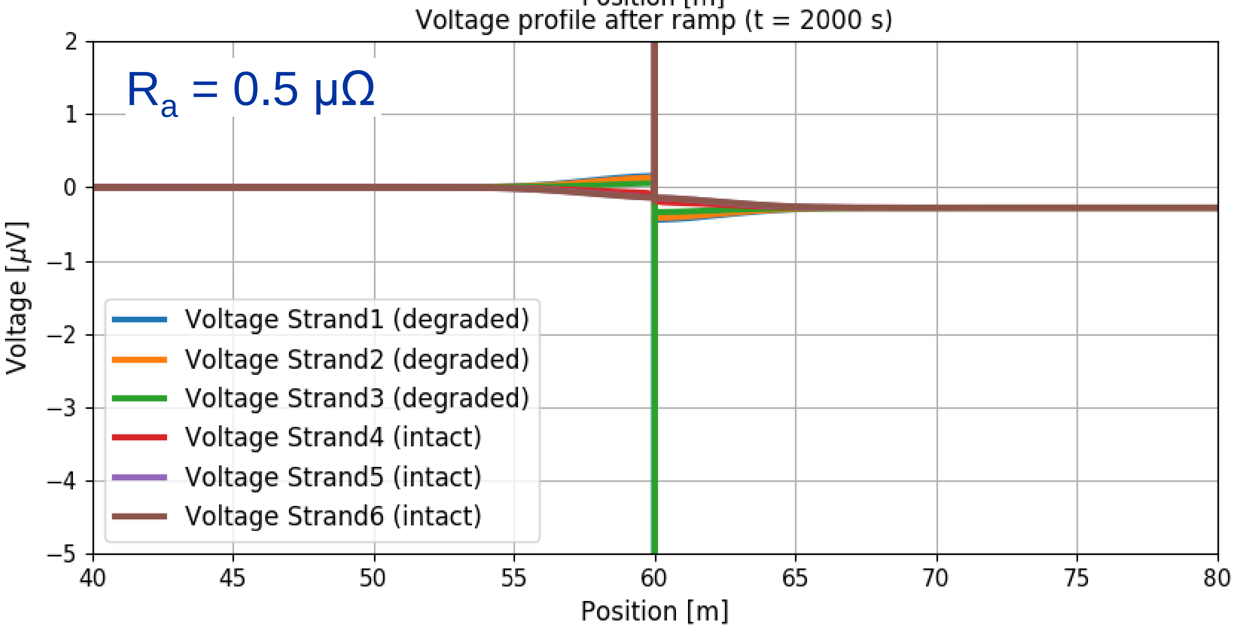


Influence of R_a

- **Voltage profile reduced in both amplitude and length**

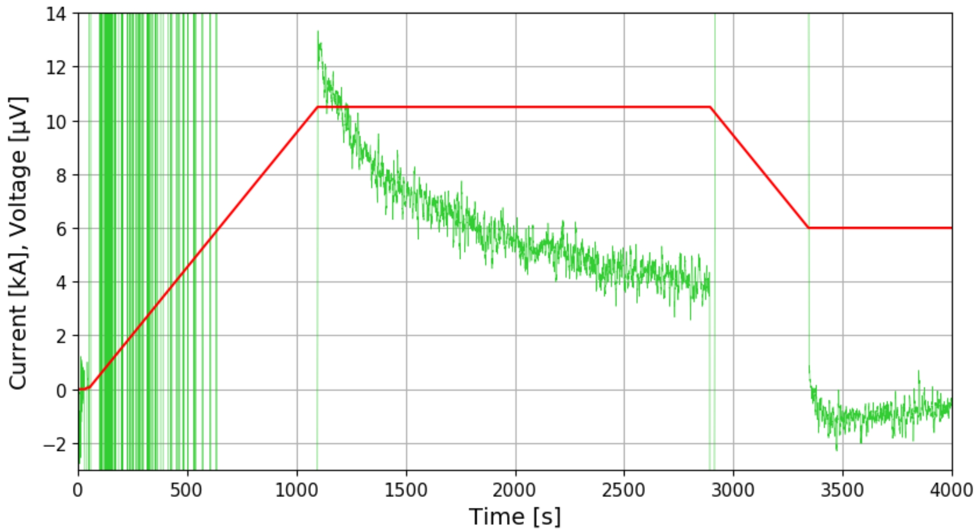


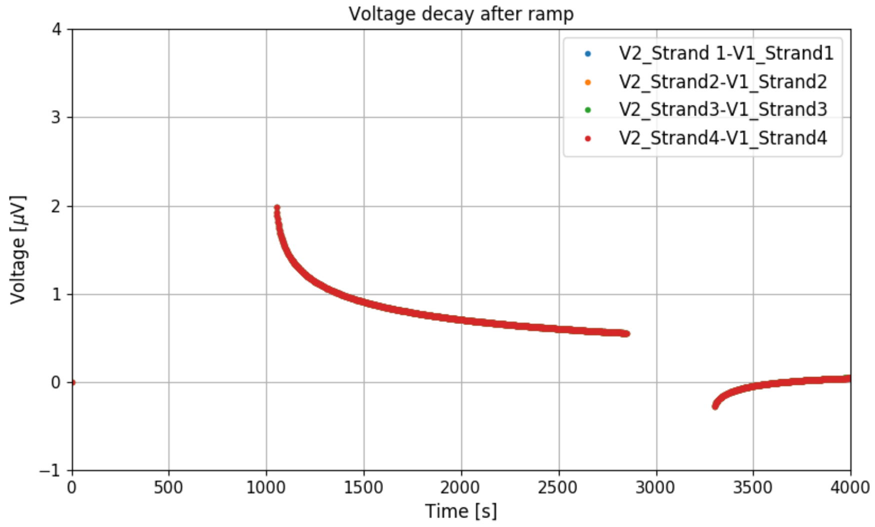




Results – 11 T dipole

- Sub-scale cable model of 16 strands
- 5 fully broken strands, R_a = 5 μΩ
- Continuous ramp to 10.5 kA → positive decaying voltage
- Ramp down to 6 kA → negative decaying voltage





Overview of anomalous features in V-I measurements

- **THEA model with a length of >100 m**
- **Inhomogeneous defect of 1 mm at the center**
  - A subset of strands is broken or degraded

Magnet	Anomalous feature	THEA model
11 T dipole/ MQXF	Voltage decay	OK
11 T dipole /MQXF	Time constant: ~ 10^2 seconds	OK
11 T dipole	Negative voltage after ramp down (full coil)	OK
MQXF	Negative voltage after ramp up (internal segment)	OK

Uncertainties of model

- **Results depend on uncertain parameters**
  - Inter-strand contact resistance
  - R_a is not precisely known and may vary longitudinally
  - R_c varies transversely since the core has a reduced width
- **No transverse or longitudinal variation in the magnetic field**
- **No temperature dependent effects**

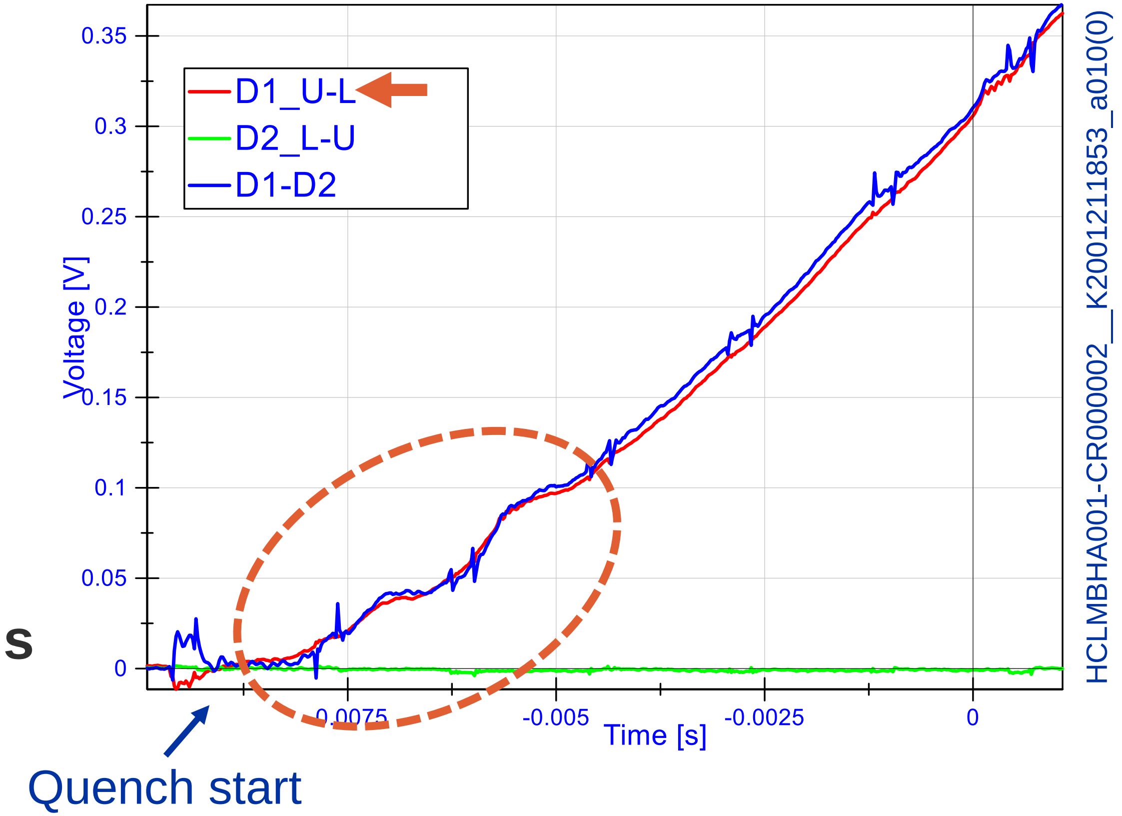
Early quench development – model proposal

- Some quenches in the *presumably* damaged coils showed interesting features during the **early stages** of the quench

- Variations in slope of coil voltage after quench

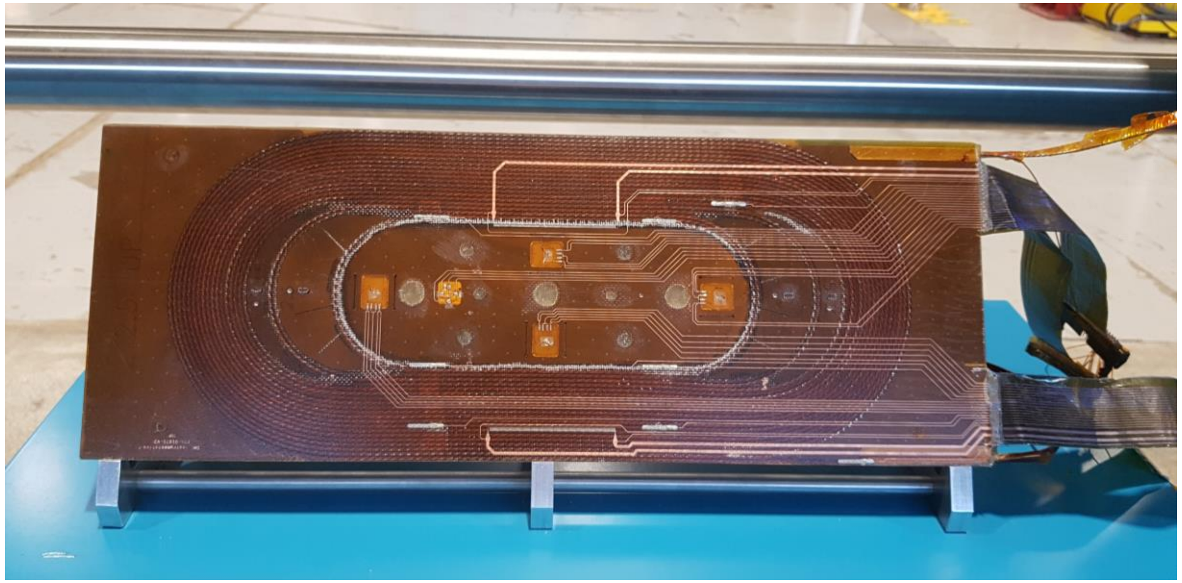
- Possibly the result of **inhomogeneous current distribution** at quench start

- Can this behavior be reproduced in a **short model** simulating only the **first few milliseconds** of the quench?



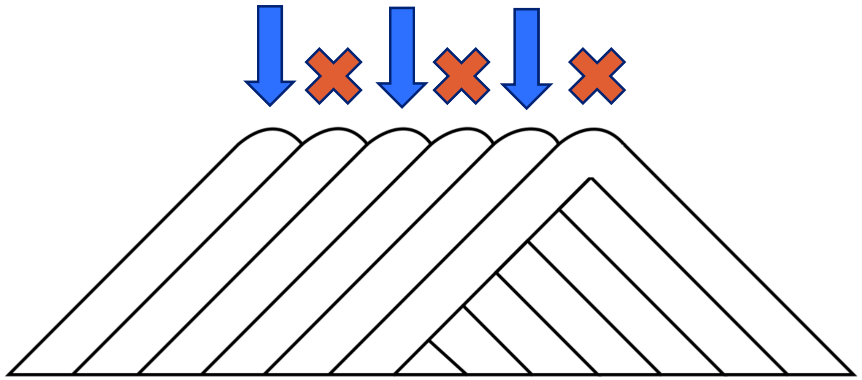
SMC magnets – proposal for experiments

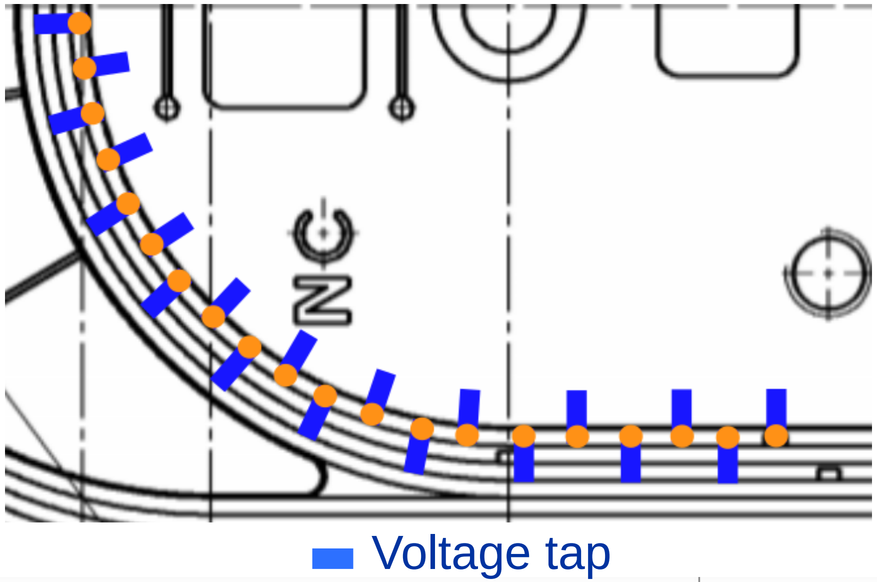
- **Leftover SMC magnets may be used to conduct experiments**
  - Double racetrack coils of ~60 meters length
  - 18/40 strand Rutherford cables of different types (cored vs. non-cored)
- **Introduce a local defect → break one or multiple strands**
- **Implement voltage taps on all strands at different locations**

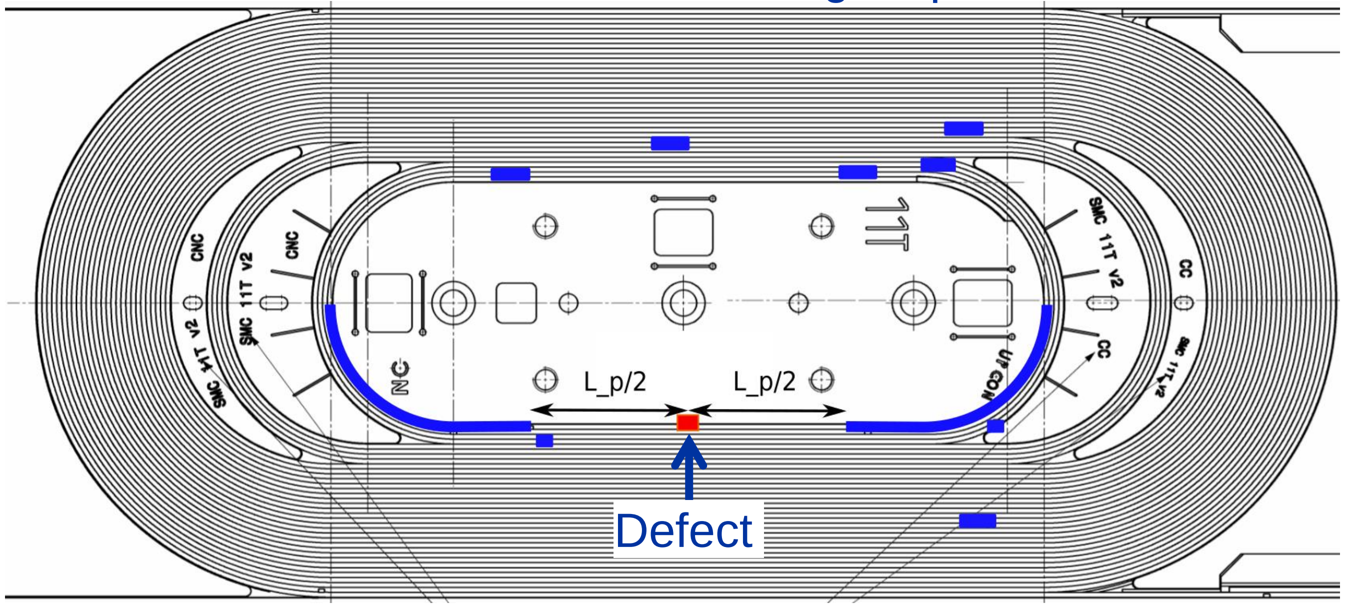


SMC magnet – voltage taps

- **Voltage taps can be implemented with measurement leads on a trace**
- **Voltage taps every other strand**
- **Longitudinal vs. transverse resolution**
- **Exploit symmetry of voltage profile**







SMC magnets – proposal for experiments

- **Model validation**
  - Match voltage levels on taps with THEA model
- **Study quench behaviour/location**
  - Quench behaviour on strand level
- **Ramp rate studies**
  - Quench location vs. defect location
  - Inverse ramp rate dependency
  - Very fast ramps possible