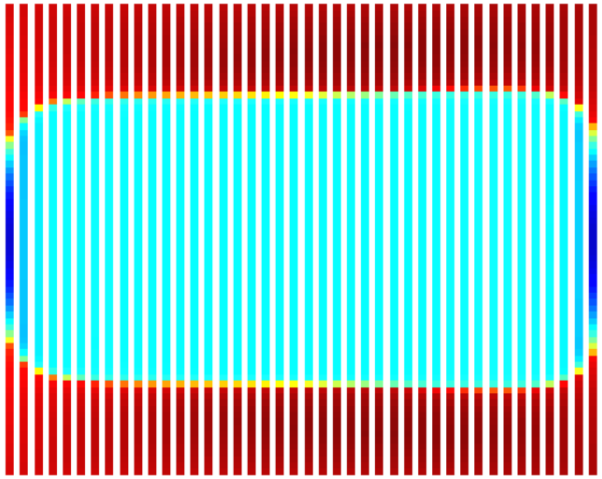
Field and Voltage transient behavior in REBCO HTS coils : Comparison between Experiments and modelling



Université Grenoble Alpes : B. Rozier, J. Vialle, P. Tixador
*Tohoku University : **A. Badel**, K. Takahashi, T. Okada, S. Awaji*

Outline

- Ongoing projects - Motivation
- Modelling approach
- Single tape pancake: BOSSE SMES Project @ CNRS Grenoble, France
- Double tape pancake: 30 T upgrade @ HFLSM, Tohoku University, Japan
- Summary

Cases under study : 2 ongoing projects

- In CNRS Grenoble : BOSSE Project

  12 T, 192 mm bore solenoid (1 MJ SMES)

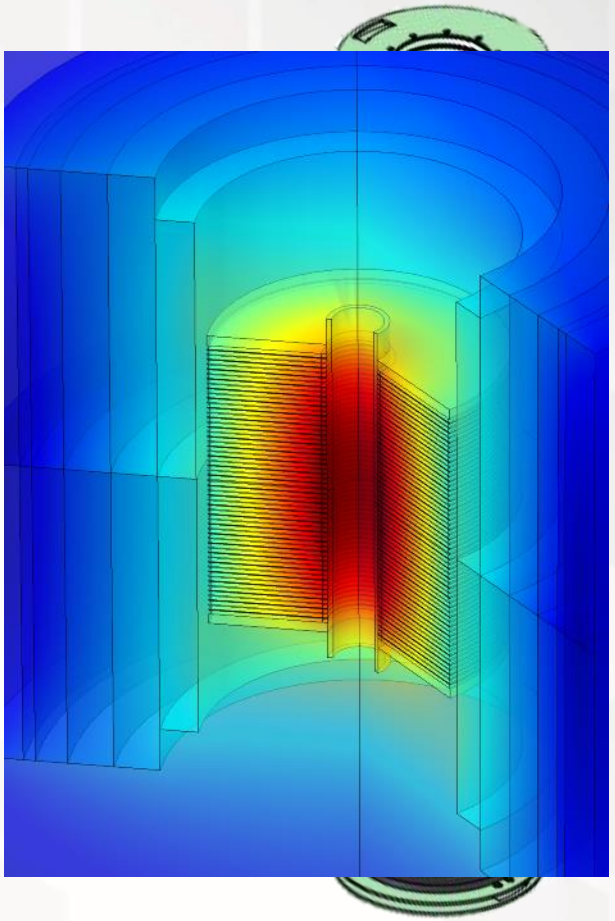
  12 mm single tape conductor

- In HFLSM, Tohoku Uni. : REBCO Insert upgrade
  30 T CSM

  16 T in 14 T LTS background

  4 mm width, 2 tapes co-wound face-to-face

Prototypes (full or subscale) tested in self field and background field, at 4.2 K LHe



Protection of insulated REBCO magnets

- HTS magnet do not really quench, they dissipate locally

  We need to detect local dissipation before thermal runaway occurs

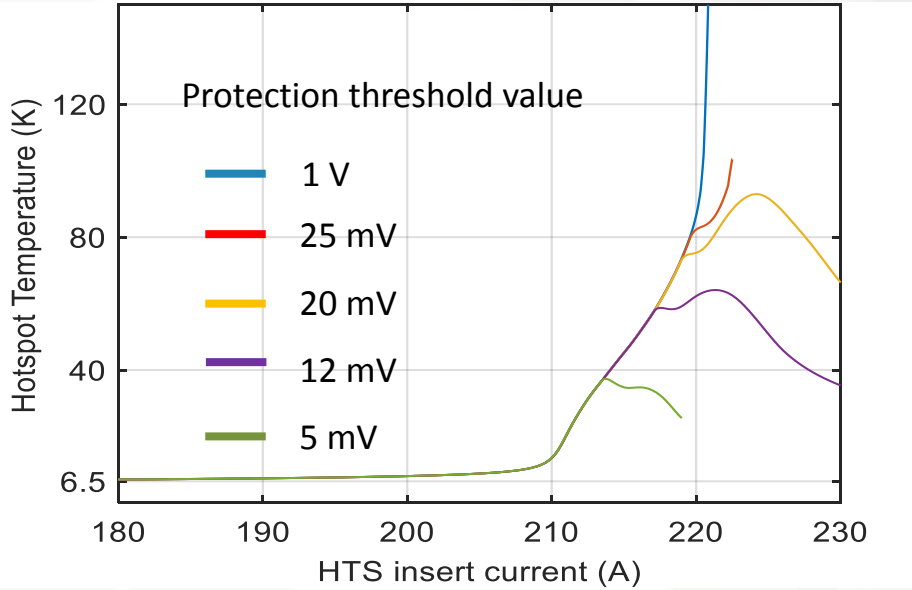
- Model taking into account statistical tape properties fluctuation :

  Help determine appropriate threshold values

- Low detection threshold :

  risk of false positive due to

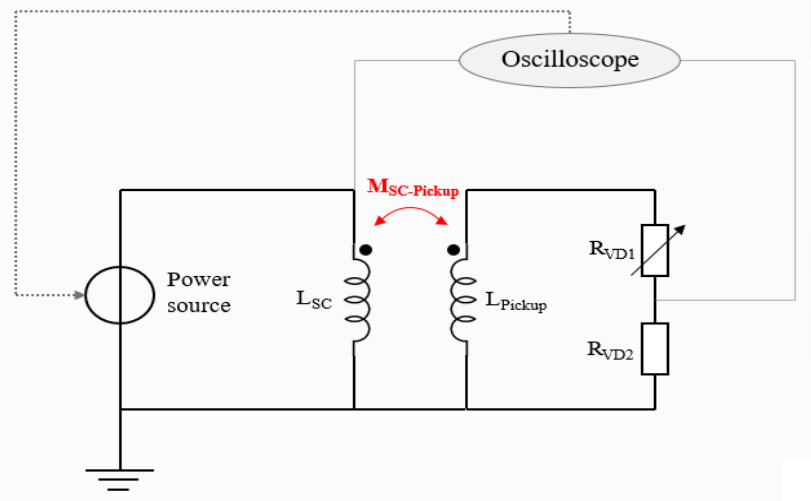
  Noise and Transient electromagnetic behavior

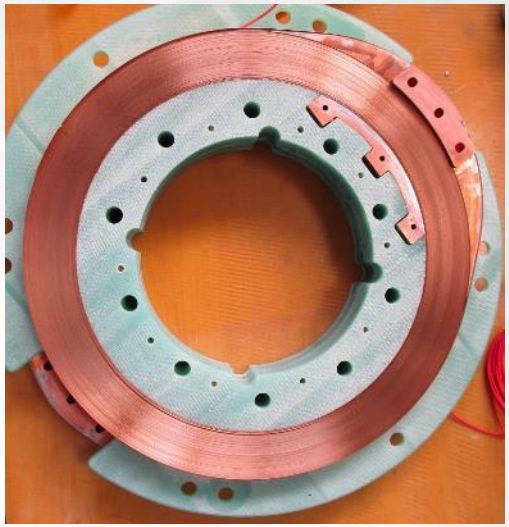


Modelling of the 25 T CSM REBCO insert behavior
Badel et al, IEEE TAS 29(5), 4600605, 2019

BOSSE proto DP : Observed voltage transient behavior

- Noise and inductive voltage removed by compensation coil





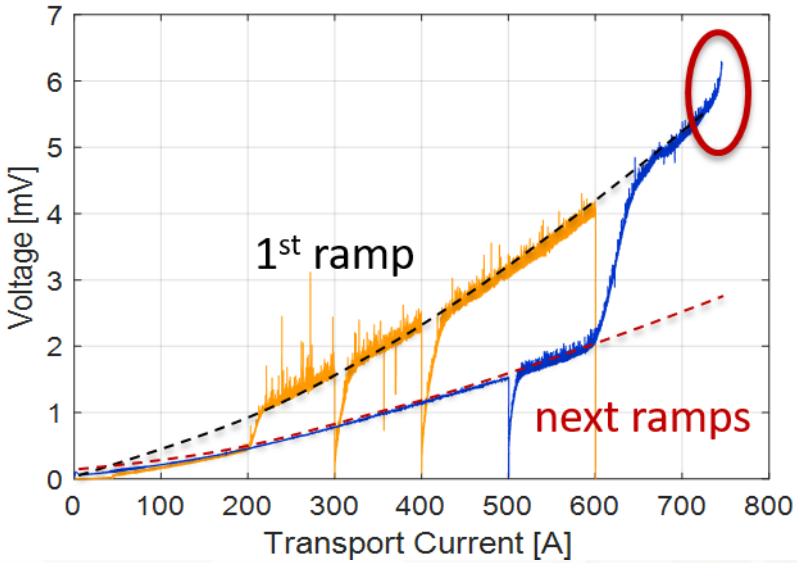
- The residual signal is due to

transient electro-magnetic phenomena

Much higher in magnitude
than our desired threshold !

✓ Noise filtering OK

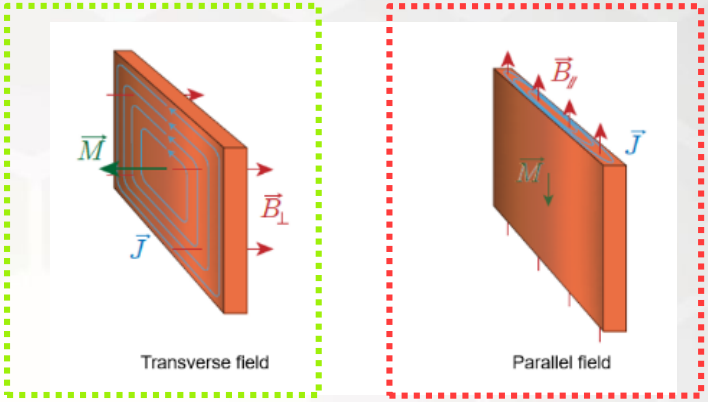
❑ We need to predict transients !

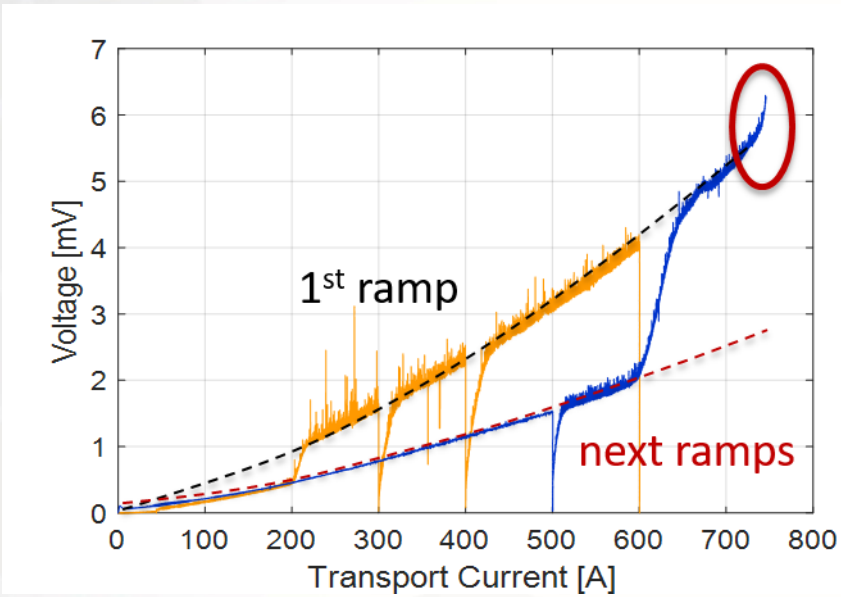


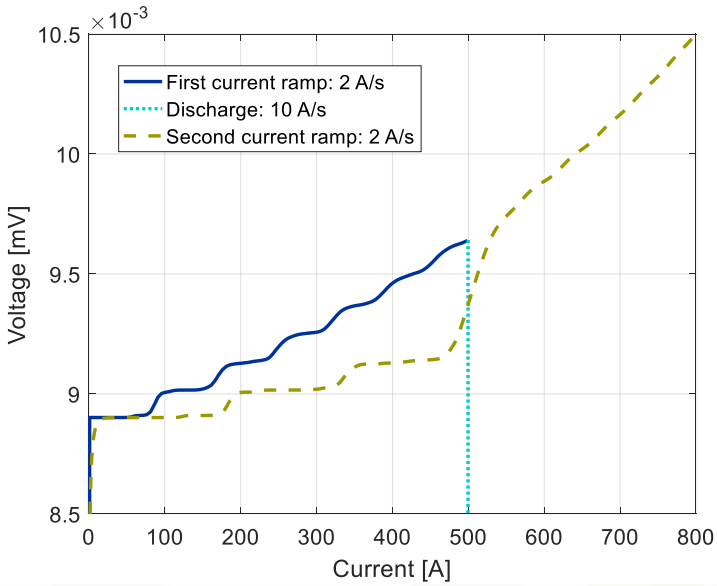
Electromagnetic transient studies

Approach

- 2D Axisymmetrical model, thin sheet hypothesis
- Integral method : mesh only active regions
- E(J) relationship : power law with Jc(B,Theta) @ 4.2 K
- External field due to outsert and /or other coil elements easy to include



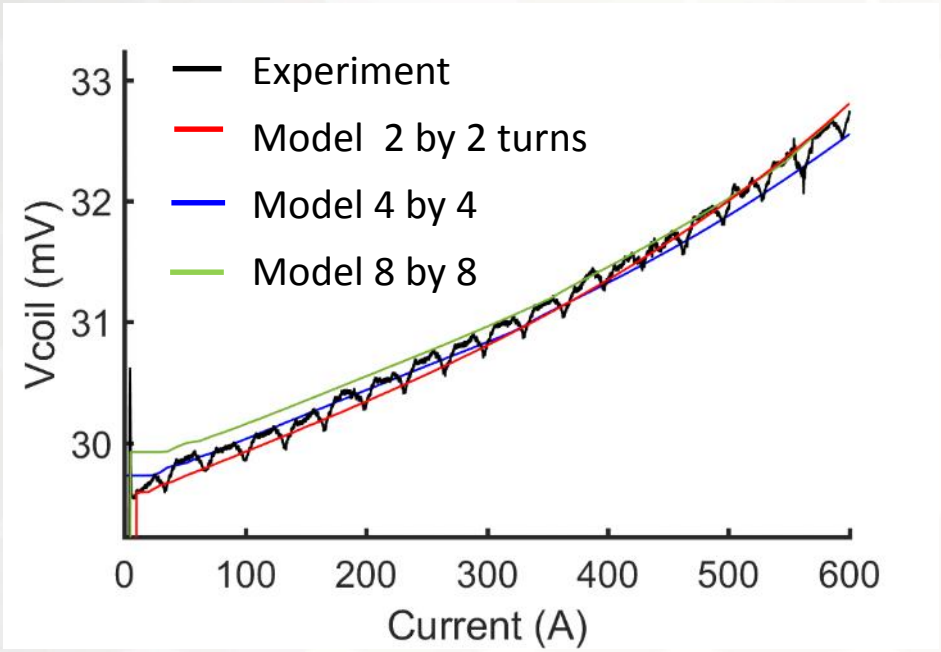


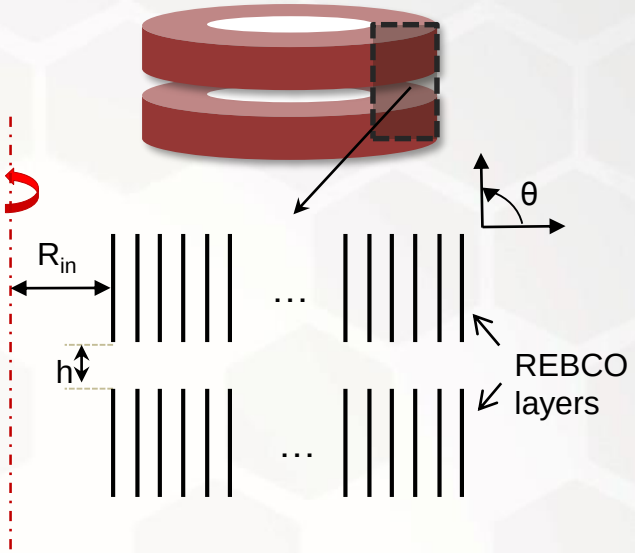


Rozier et al, IEEE TAS 29(5), 4702105 , 2019

Transient Voltage on single tape DP from BOSSE project

- Coil Description :
  - Double pancake
  - 12 mm width REBCO tape (SuperOx)
  - Top : 150 turns / Bottom : 168 turns
  - R_{in} = 96 mm / h = 4 mm

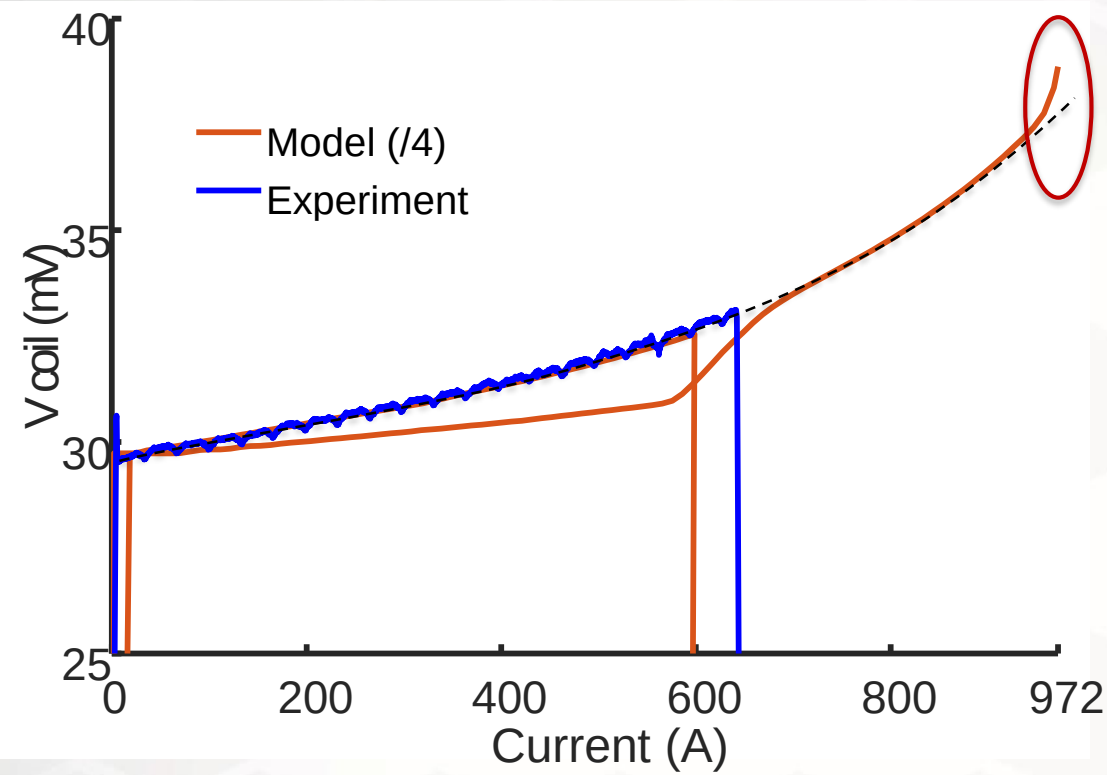


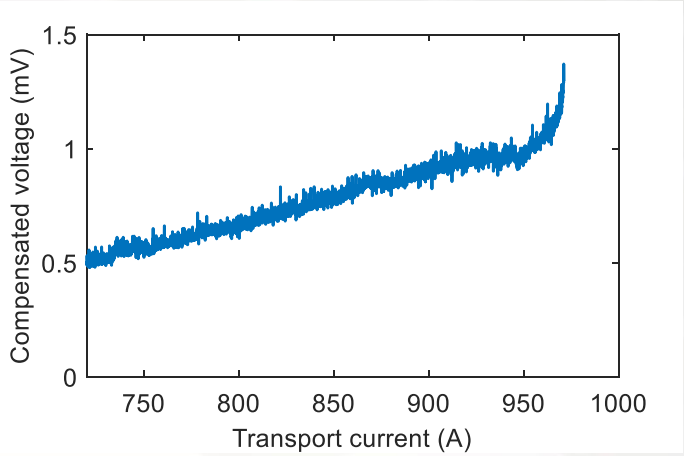


- Fit the experiment with 72 % of short sample Ic
- Reduced model acceptable

Transient Voltage on single tape DP (2)

- Axisymmetrical model = homogeneous conductor





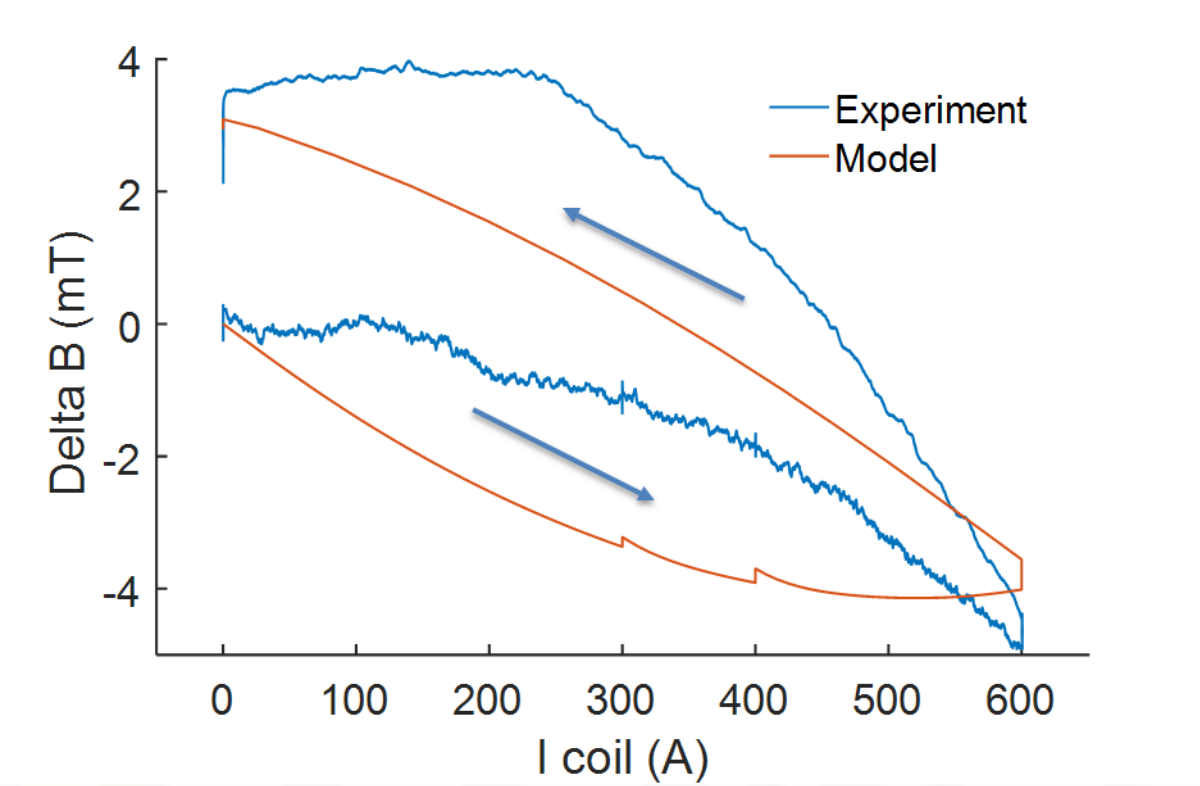
This coil effectively reached its limit at 973 A

Using very slow ramp

Fitting of Voltage drift curve in "safe" low current region predict expected Ic in practical operation

Field non-linearity on single tape DP from BOSSE project

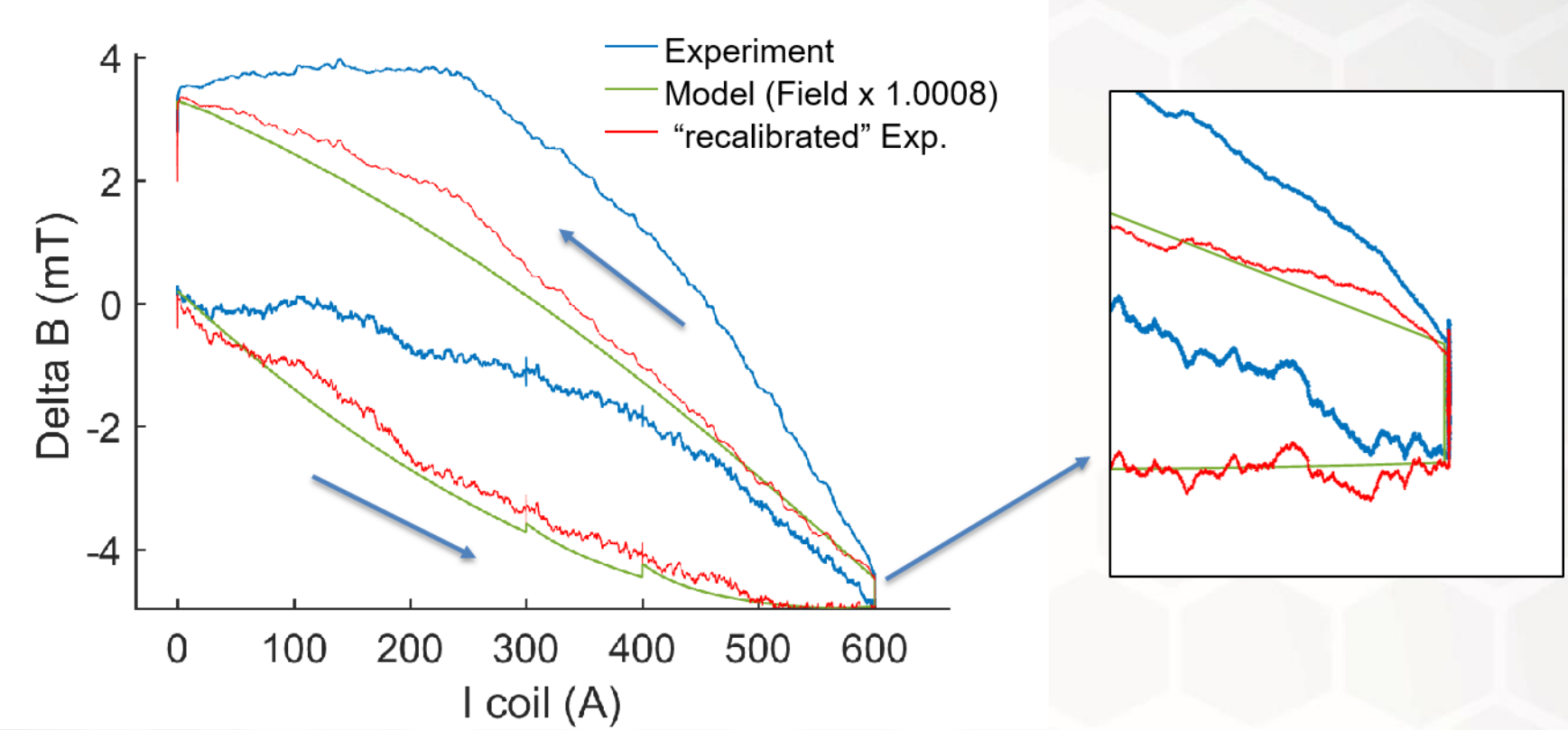
Hypotheses : Hall sensor linear, geometry as designed



600 A ≈ 1 T center field (4.5 T on inner turn)

Field non-linearity on single tape DP from BOSSE project

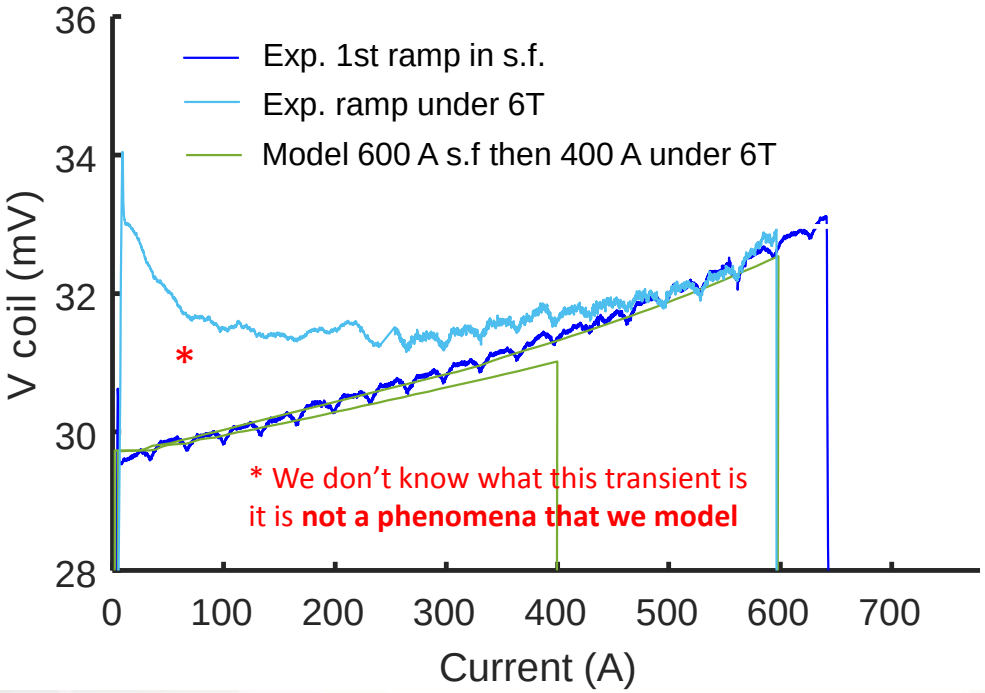
Re-calibrated hall Sensor data (by mean value of cycle)

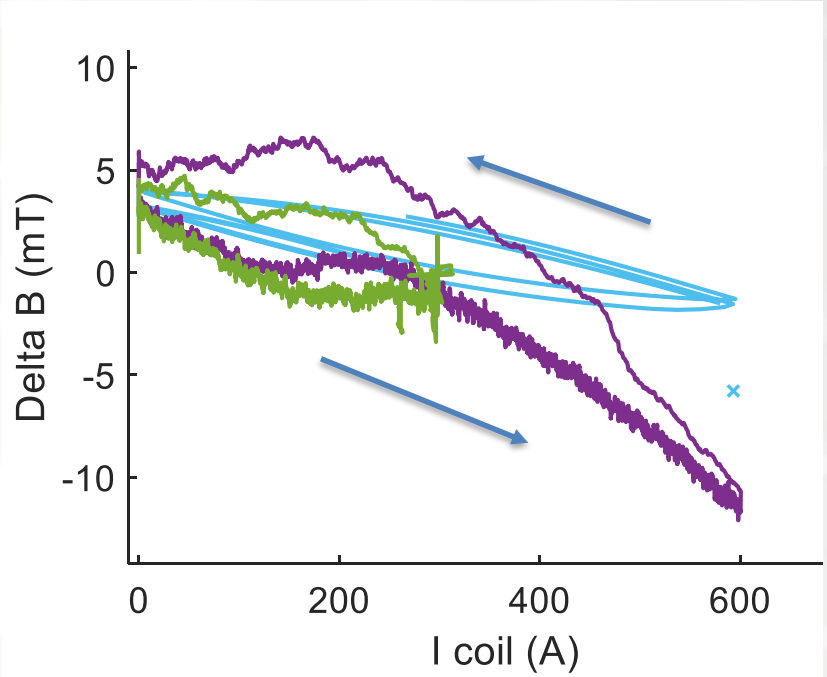


- ✓ Width of the hysteresis loop
- ✓ Field drift at plateau, Zero field drift

Single tape DP in 6 T background field

- The external field is very homogenous : there *should* be no major change





❑ Under 6 T we reach up to 0.3 % elongation : hoop stress enlarge the coil, lowering the field

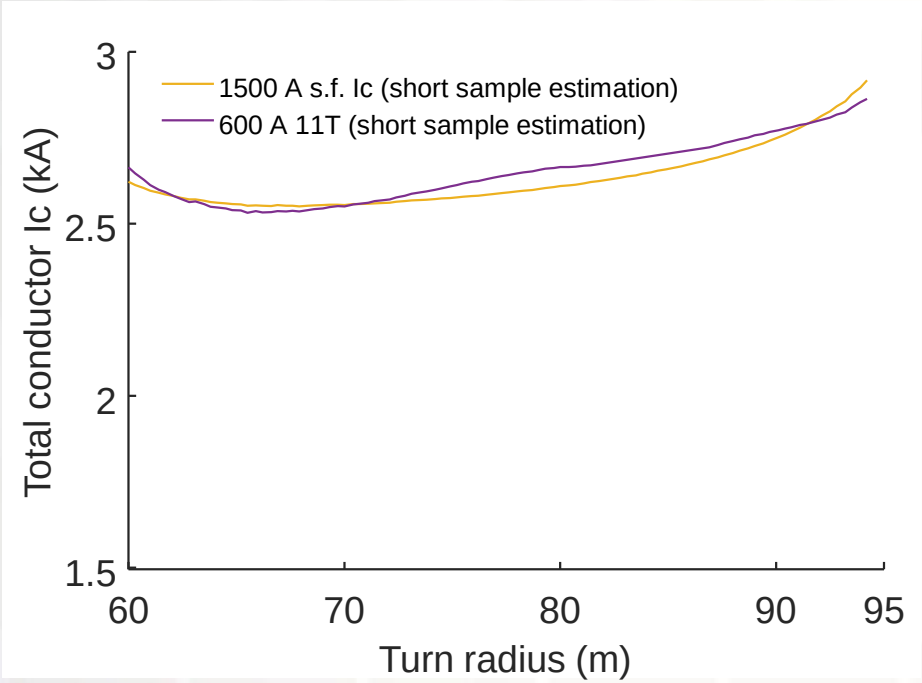
❑ Loop looks "compounded" : missing phenomena, other deformation effects ?

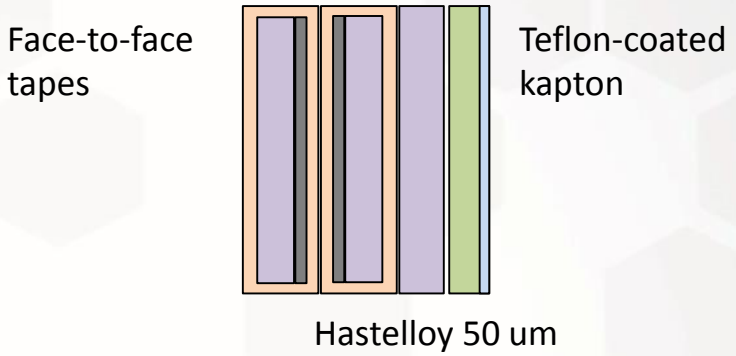
30 T CSM two tape co-wound prototype DP

Idea : mitigate the defect risk by putting to tapes in parallel

Are we sure that the current can flow in both tapes ? Can redistribute locally ?

Toshiba 2018 prototype : Co-wound Hastelloy reinforcement, teflon-coated isolation, impregnated



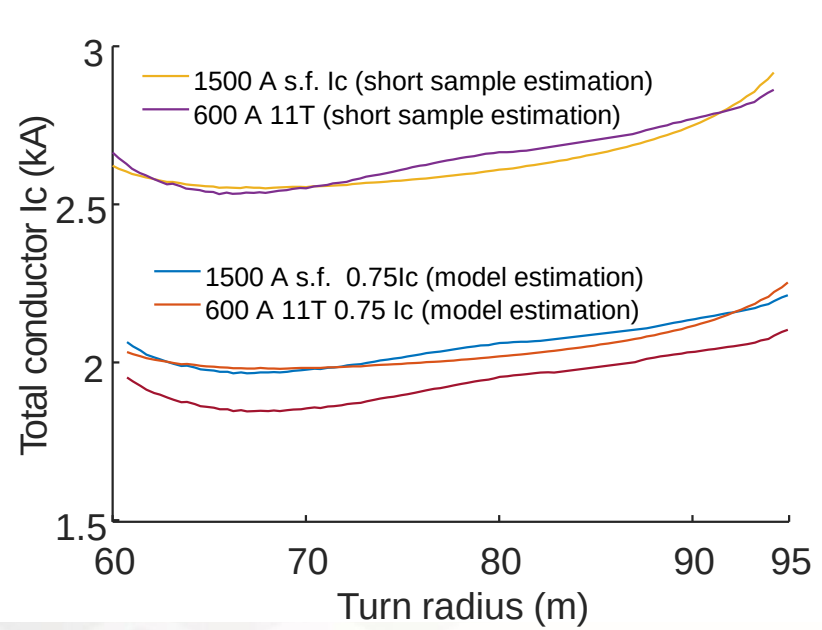


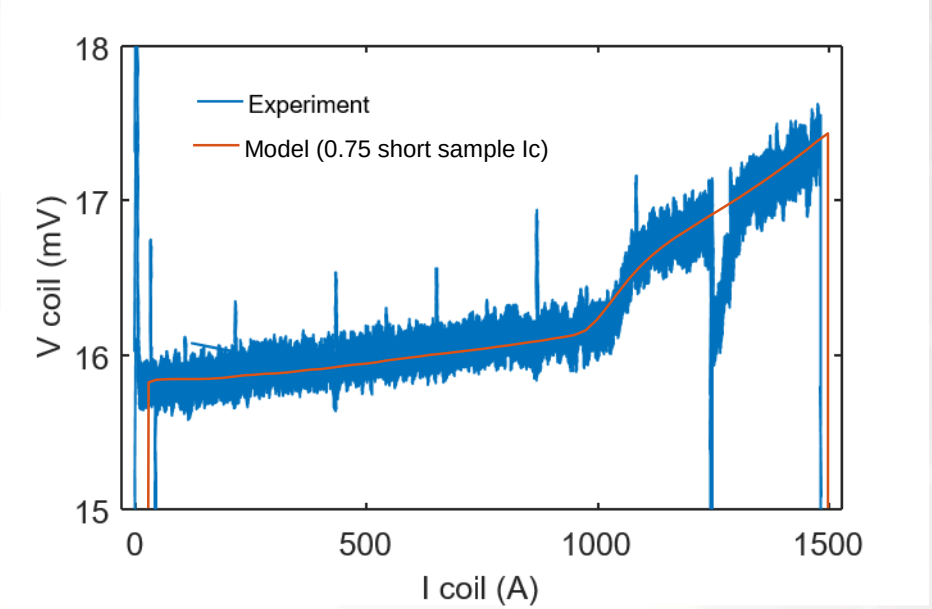
- 1500 A operating limit : current leads
- 600 A under 11 T : stress limit

We can model the two layers in parallel for each turn assuming perfect contact

Transient voltage in two tape co-wound DP

- Transient similar to single tape DP : Model matches with 75 % of short sample Ic





Voltage transient modelled with two tape in parallel or a single « super tape » hypothesis very close

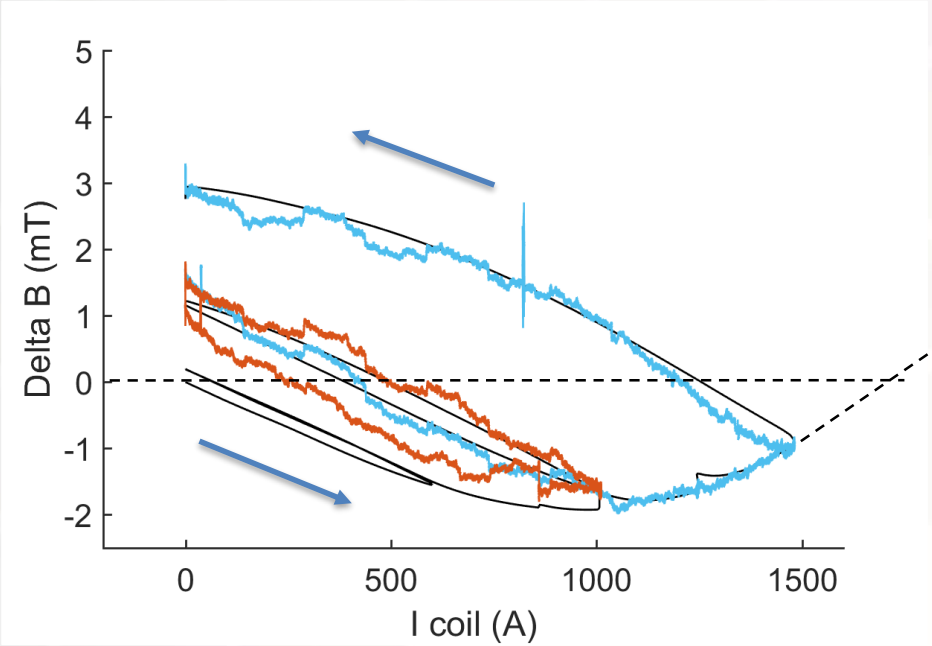
much lighter model : real time calculation ?

- Operation close but below critical current : we could not confirm the limit

What does the field transient say ?

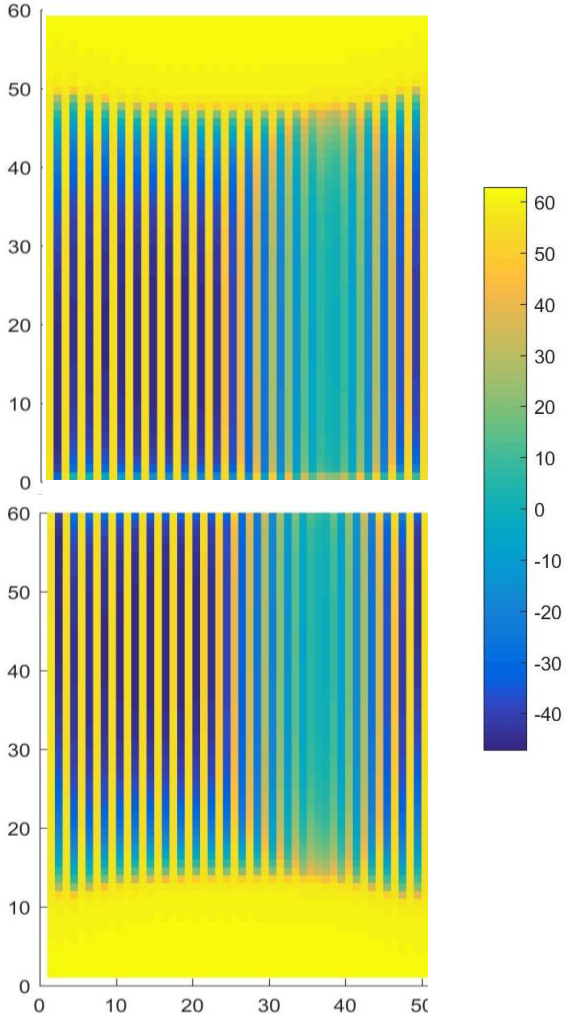
Field non-linearity in two tape co-wound DP

- Center field 2.5 T for 1500 A, recalibrated data



- Two competing effect :
  magnetization in width vs tape coupling
- Dominant “single tape” behavior
  but quantitatively much smaller
- Insight about current limit ?

Current distribution for I = 600 A



Summary

- Electro magnetic model : Calculate the expected voltage transient

  Any deviation should trigger a preventive discharge – Possible real time execution

- Works well in self field, gives inaccurate results in background

  We neglect a phenomenon (mechanics, but not only ?)

- A two tape co-wound pancake was tested successfully.
  Impossible to confirm its limit, but the model can help estimate the overall quality

- Experimental results on two tape co-wound DP are in good agreement with well-coupled hypothesis model

  Large sensitivity to tape-to-tape distance

We need to develop the comparisons on many test cases with other teams

Thank you !