Modeling superconducting inhomogeneities of commercial REBCO tapes with a 1-D electro-thermal model comparing two different constitutive laws

Nicolò Riva **(EPFL, MIT)**, Francesco Grilli **(KIT)**, Bertrand Dutoit **(EPFL)**

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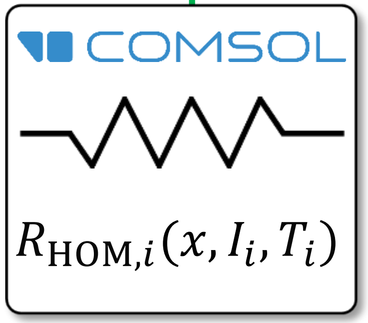
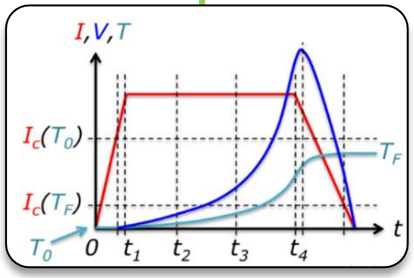
Outline

Motivations: accurate simulations



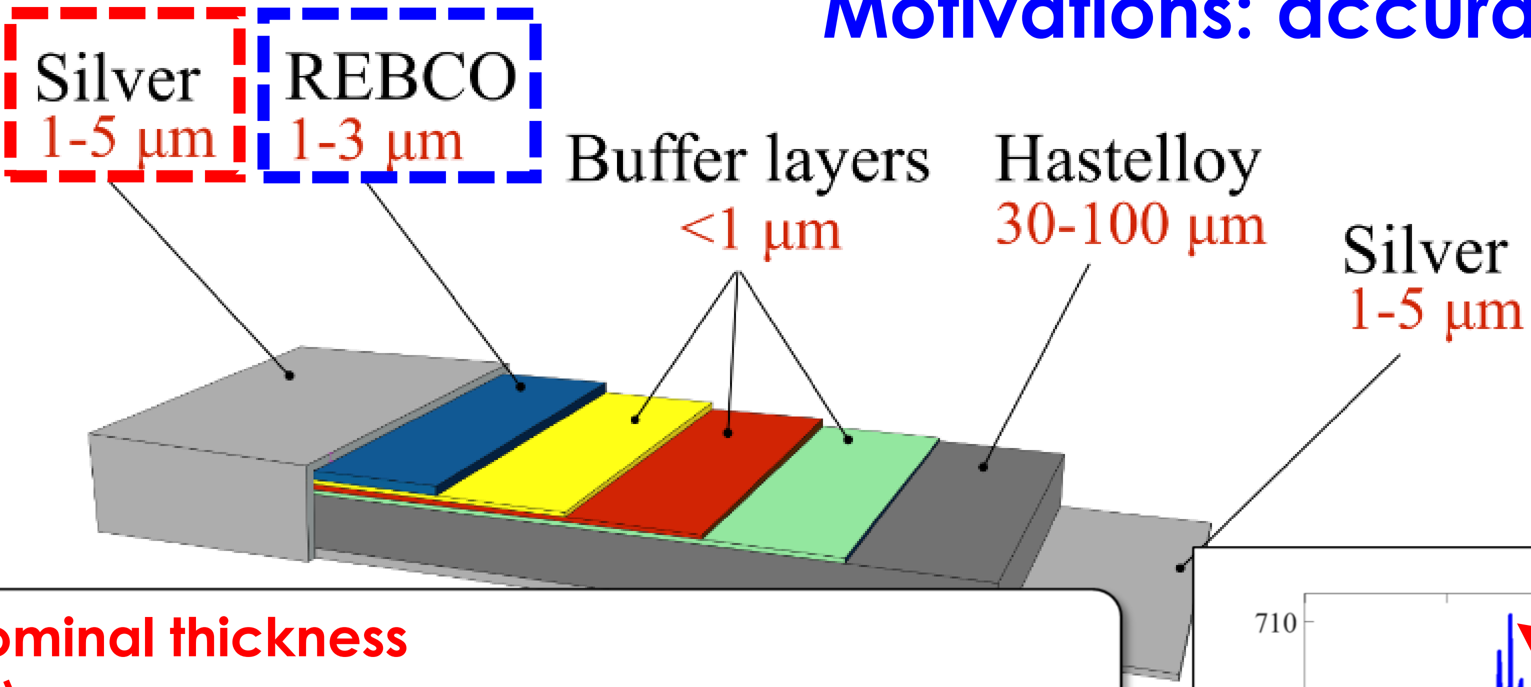
1-D electro thermal model

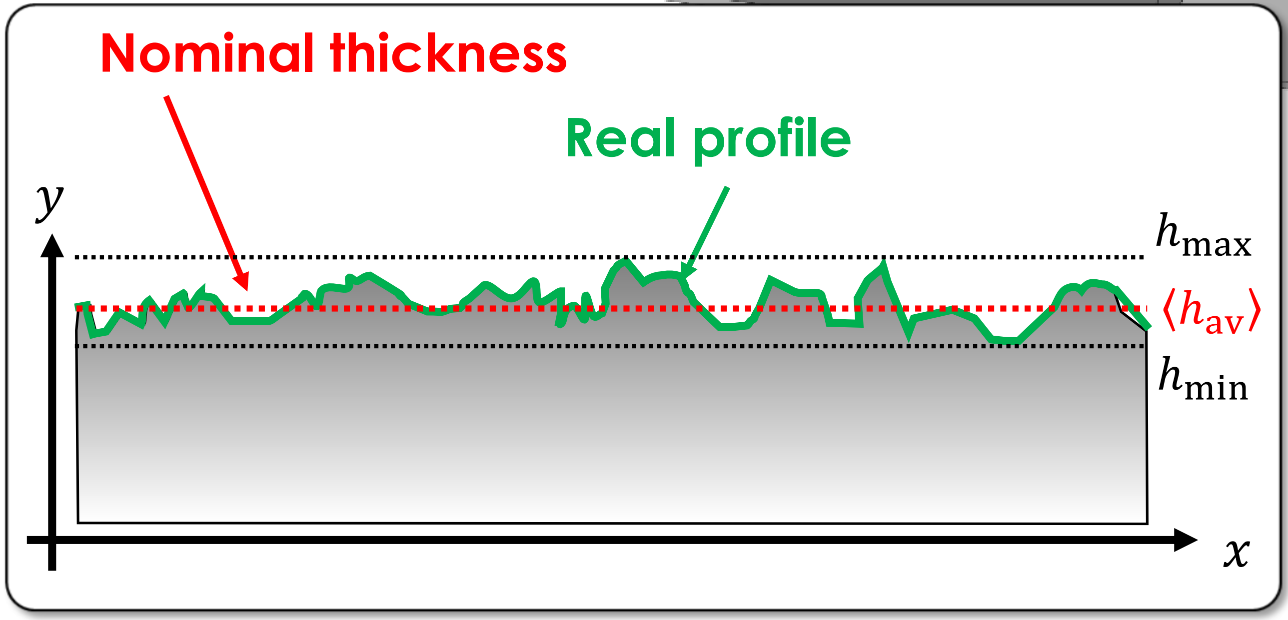


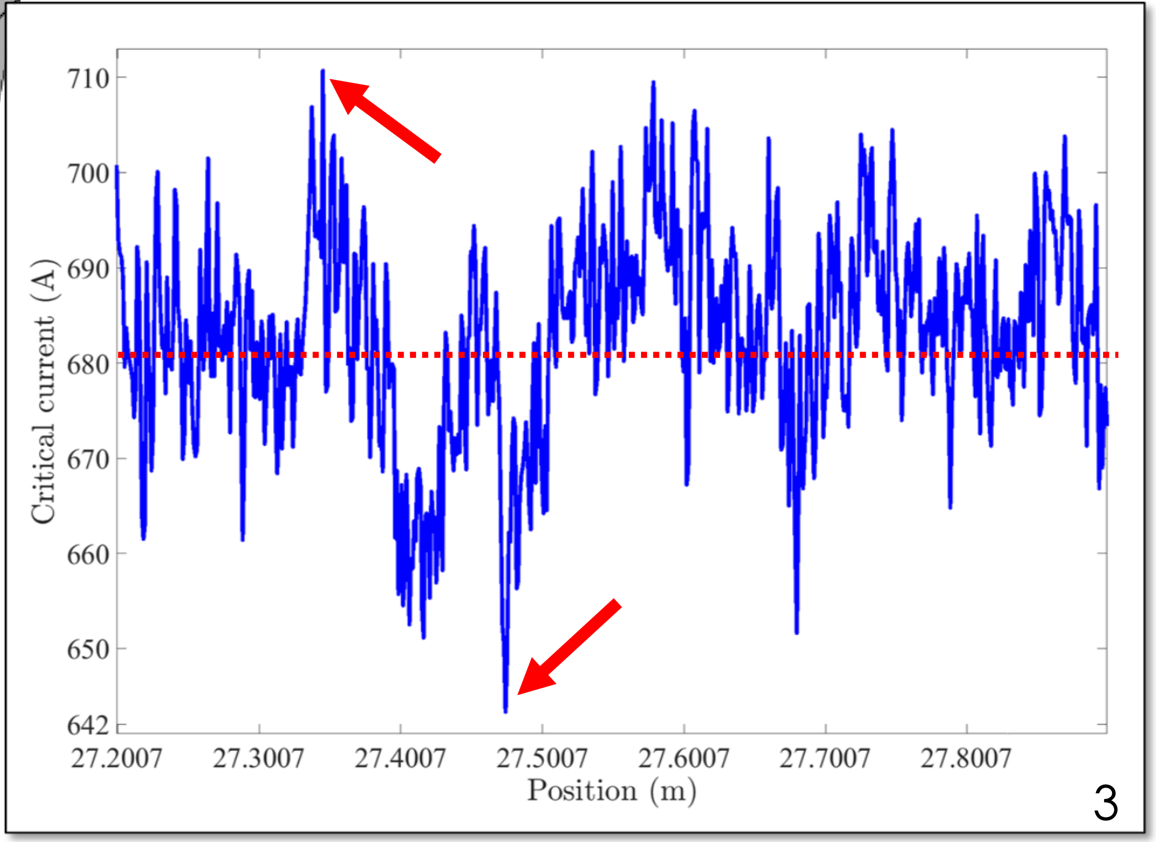
Results inhomogeneity+ constitutive laws

Conclusions & future work

Motivations: accurate simulations

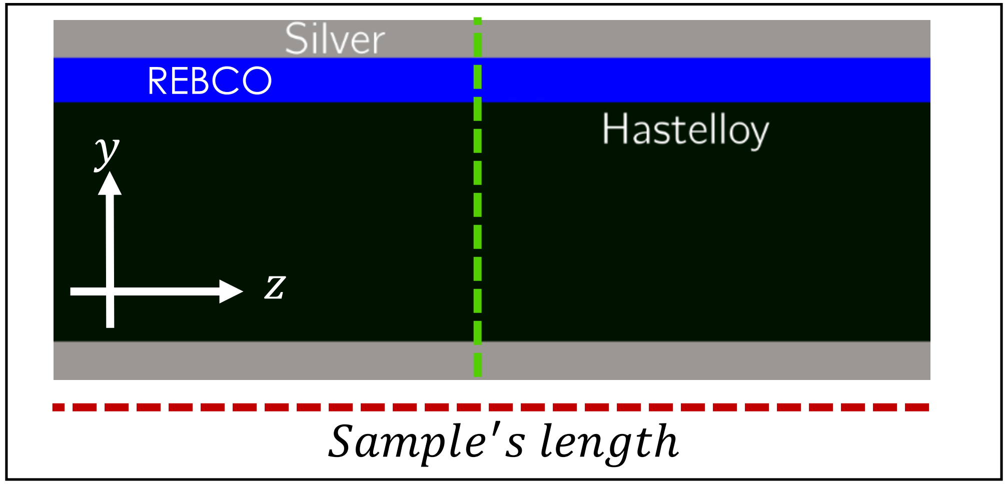


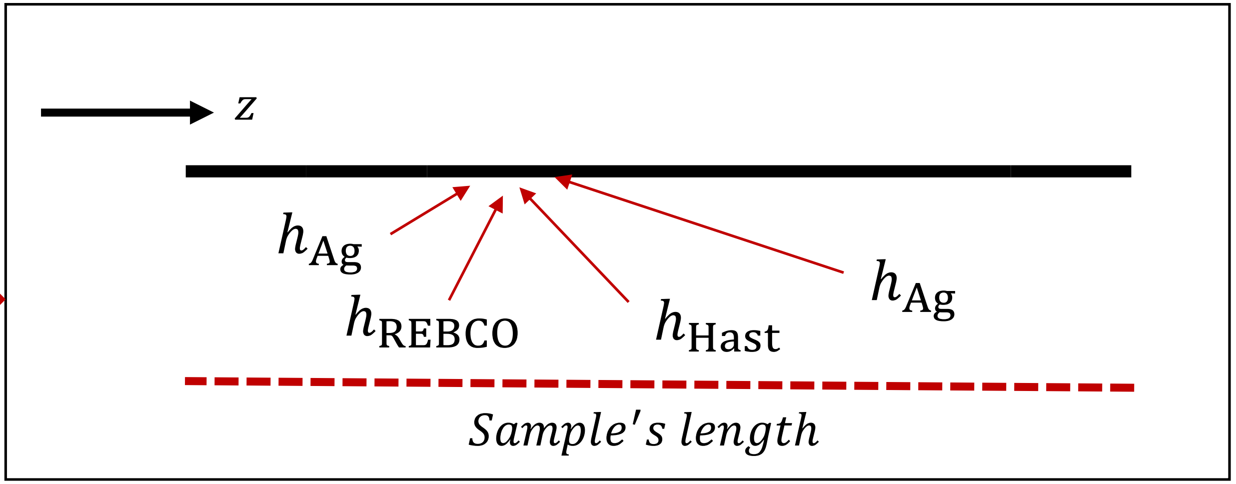




Step 1: Homogenized Heat Equation

COMSOL (ht)





Heat equation

$$\rho_{m,HOM}(T)C_{p,HOM}(T)\frac{\partial T(z,t)}{\partial t}+\frac{\partial}{\partial z}\left(-k_{HOM}(T)\frac{\partial T(z,t)}{\partial z}\right)=Q$$

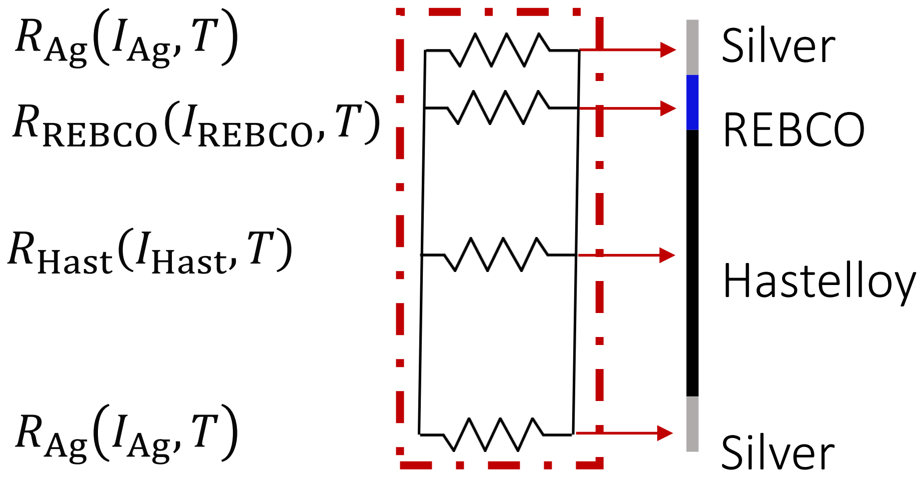
$$Q=EJ-\frac{2h\cdot(T-T_0)}{h_{tot}}$$

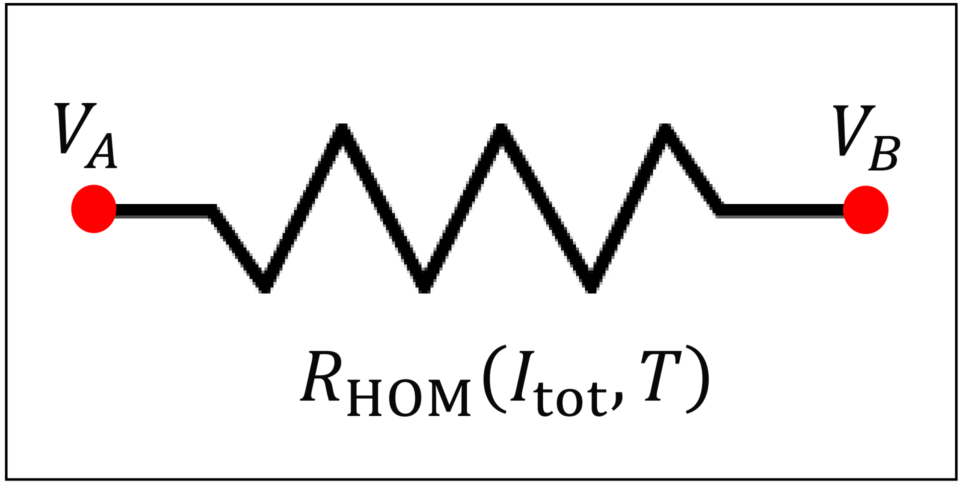
$$k_{HOM}(T)=\frac{\sum h_j k_j}{h_{tot}}$$

$$\rho_{m,HOM}(T)=\frac{\sum Vol_j\rho_{m,j}}{Vol_{tape}}$$

$$C_{p,HOM}(T)=\frac{\sum m_j C_{p,j}}{m_{tot}}$$

Step 2: Equivalent electric circuit for tapes COMSOL (cir)





Electric circuit

$$I_j(T) = \frac{V_B - V_A}{R_i(I_i, T)}$$

$$I_{REBCO}(t) = I_{tot}(t) - \sum_{j=1}^{n_{mat}} I_j(t)$$

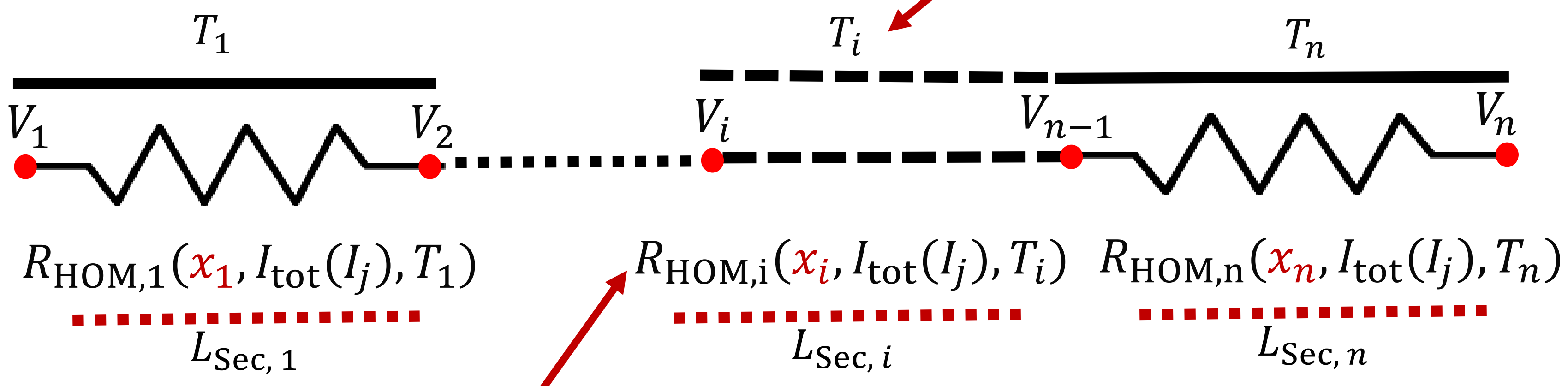
$$R_i(I_i, T) = \frac{\rho_{el,i}(I_i, T) \cdot L}{S_i}$$

$$\frac{1}{R_{HOM}(I_{tot}(I_j), T)} = \sum \frac{1}{R_j(I_j, T)}$$

Step 3: 1-D electrothermal model

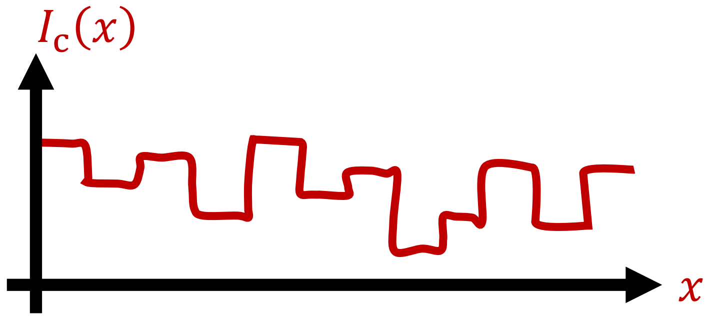
COMSOL

1-D Homogenized Heat Equation for n sections

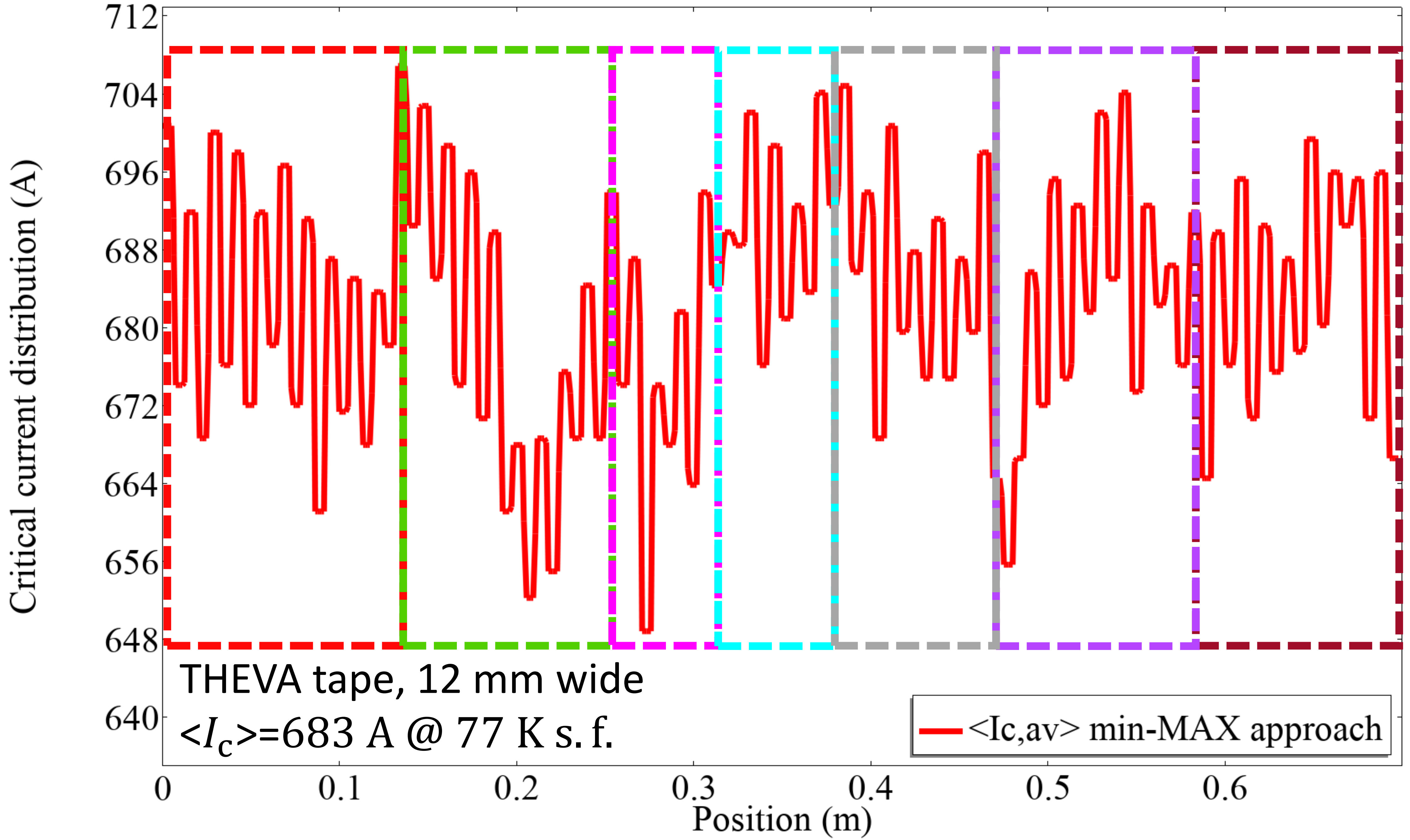


Equivalent electric circuit for n short tapes

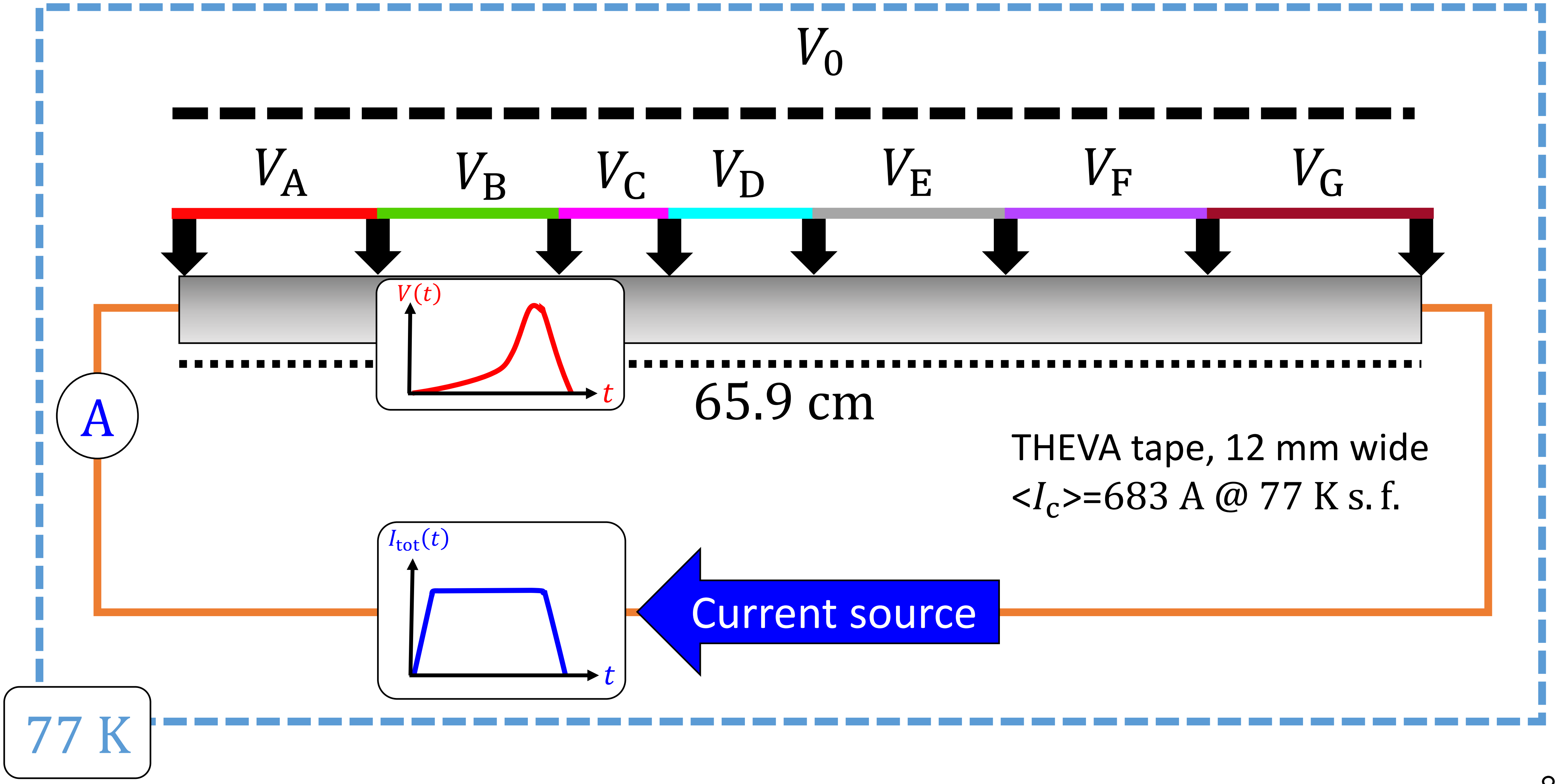
$$I_c(x) = \begin{cases} I_c(x_1) = 115\ \mathrm{A} & x_1 < x < x_2 \\ I_c(x_2) = 110\ \mathrm{A} & x_2 < x < x_3 \\ \quad\quad\quad\quad\quad\quad \dots & \\ I_c(x_n) = 122\ \mathrm{A} & x_{n-1} < x < x_n \end{cases}$$



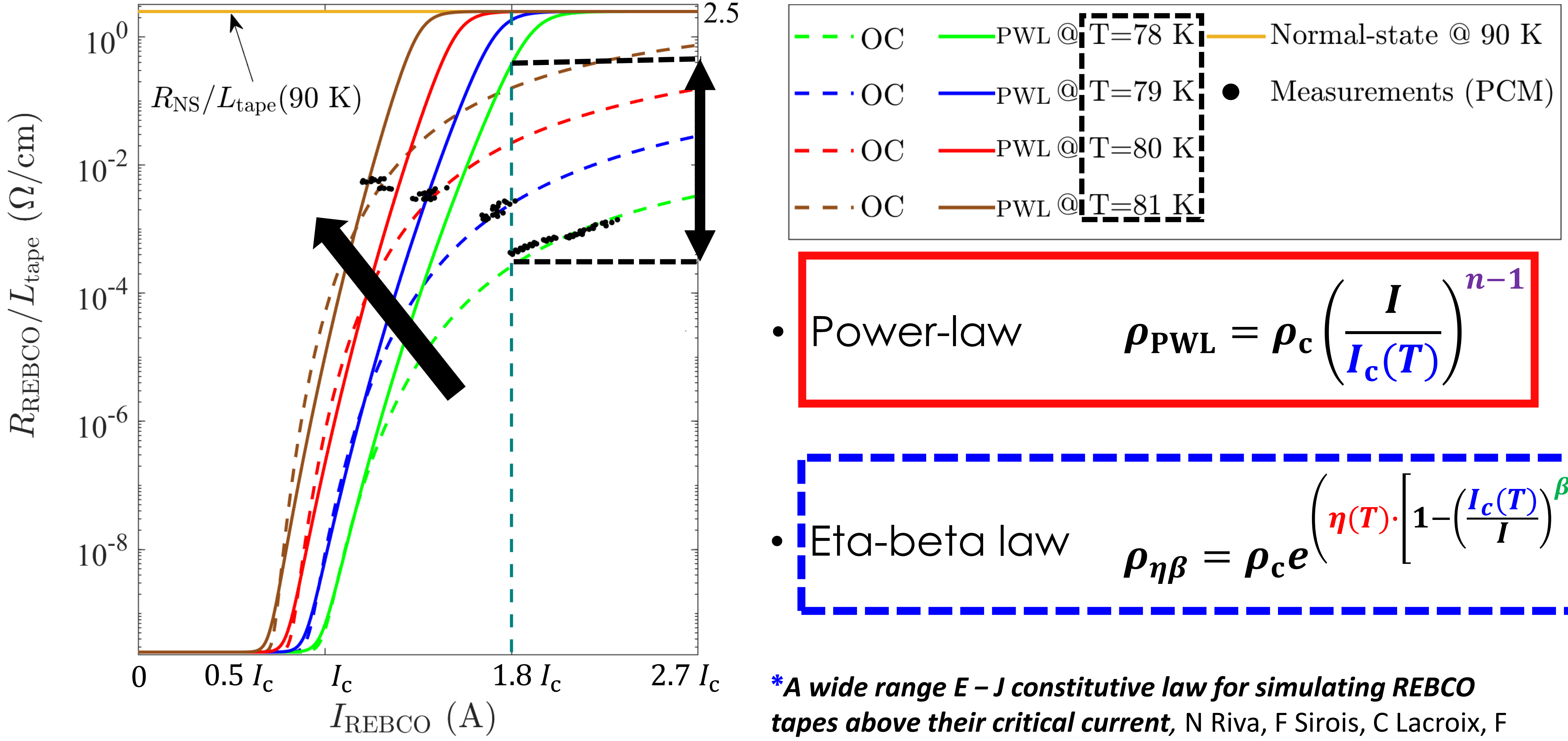
Inhomogeneity implementation (n = 100 resistors sections)



Validation & results: experimental measurements



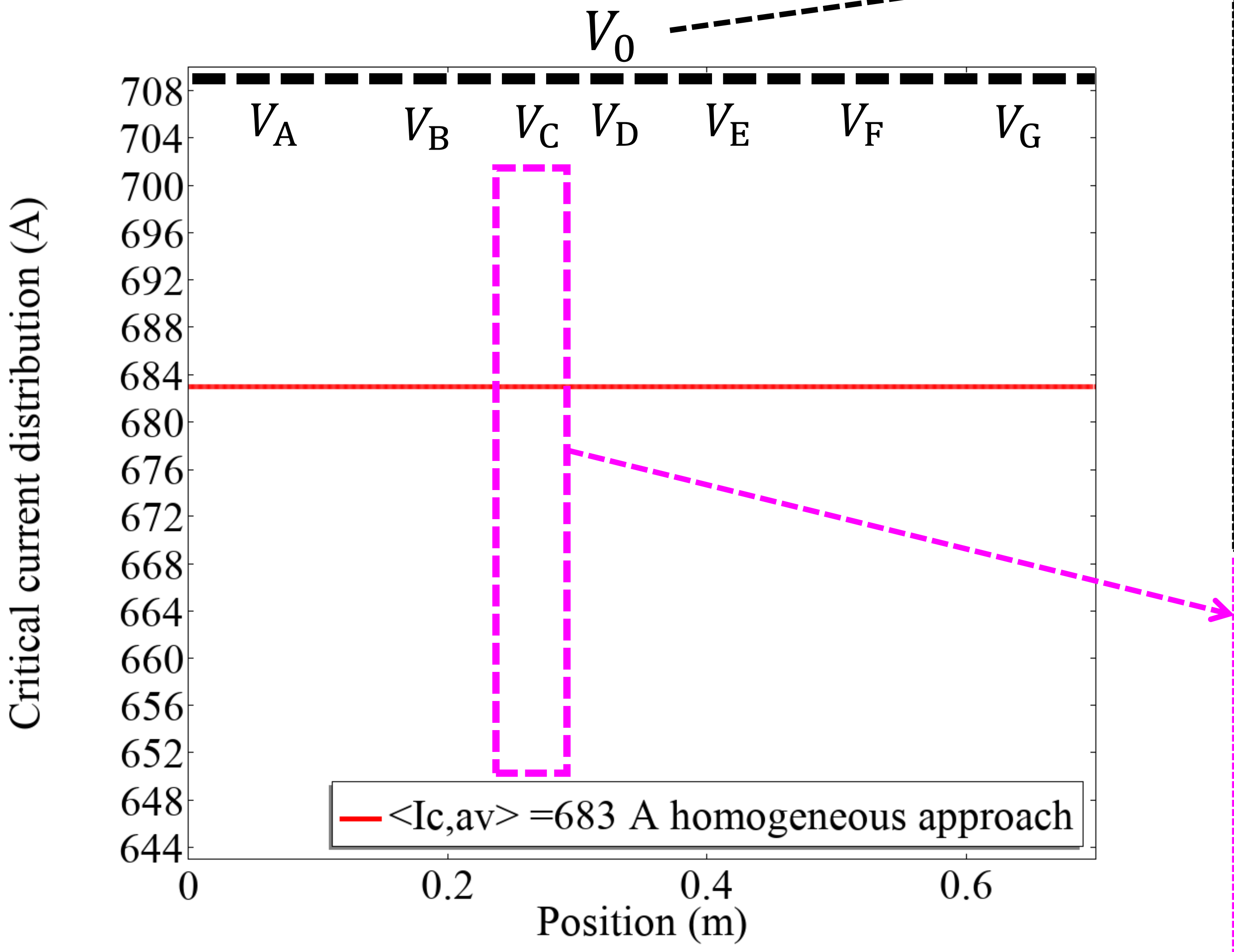
Validation & results: Choice of the constitutive law (power law vs eta-beta law*)

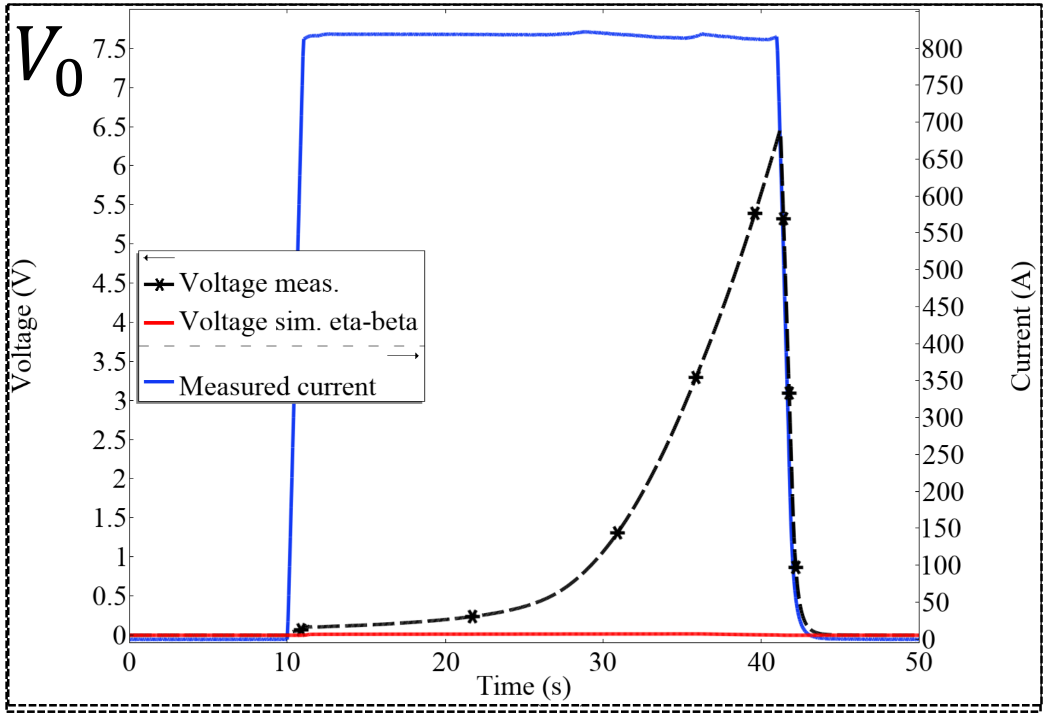


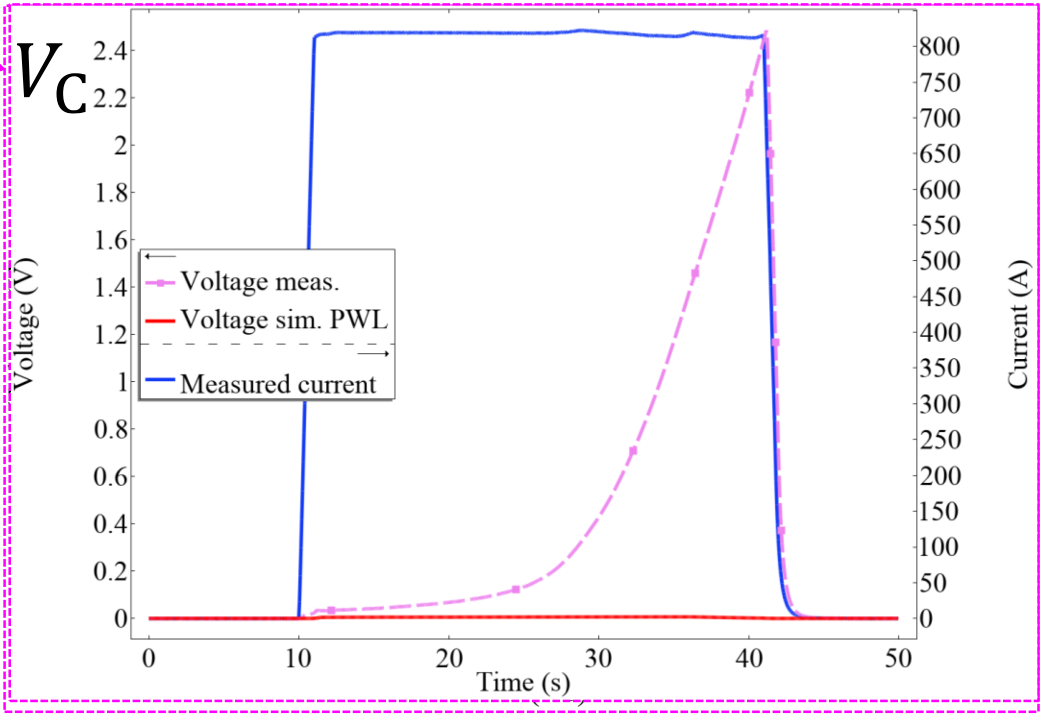
- Power-law $$\rho_{PWL} = \rho_c \left(\frac{I}{I_c(T)}\right)^{n-1}$$
- Eta-beta law $$\rho_{\eta\beta} = \rho_c e^{\left(\eta(T)\cdot\left[1-\left(\frac{I_c(T)}{I}\right)^{\beta(T)}\right]\right)}$$

****A wide range E – J constitutive law for simulating REBCO tapes above their critical current*,** N Riva, F Sirois, C Lacroix, F Pellerin, J Giguere, F Grilli and B Dutoit - *SuST.* **34 115014**

Voltage along the length (hom.)

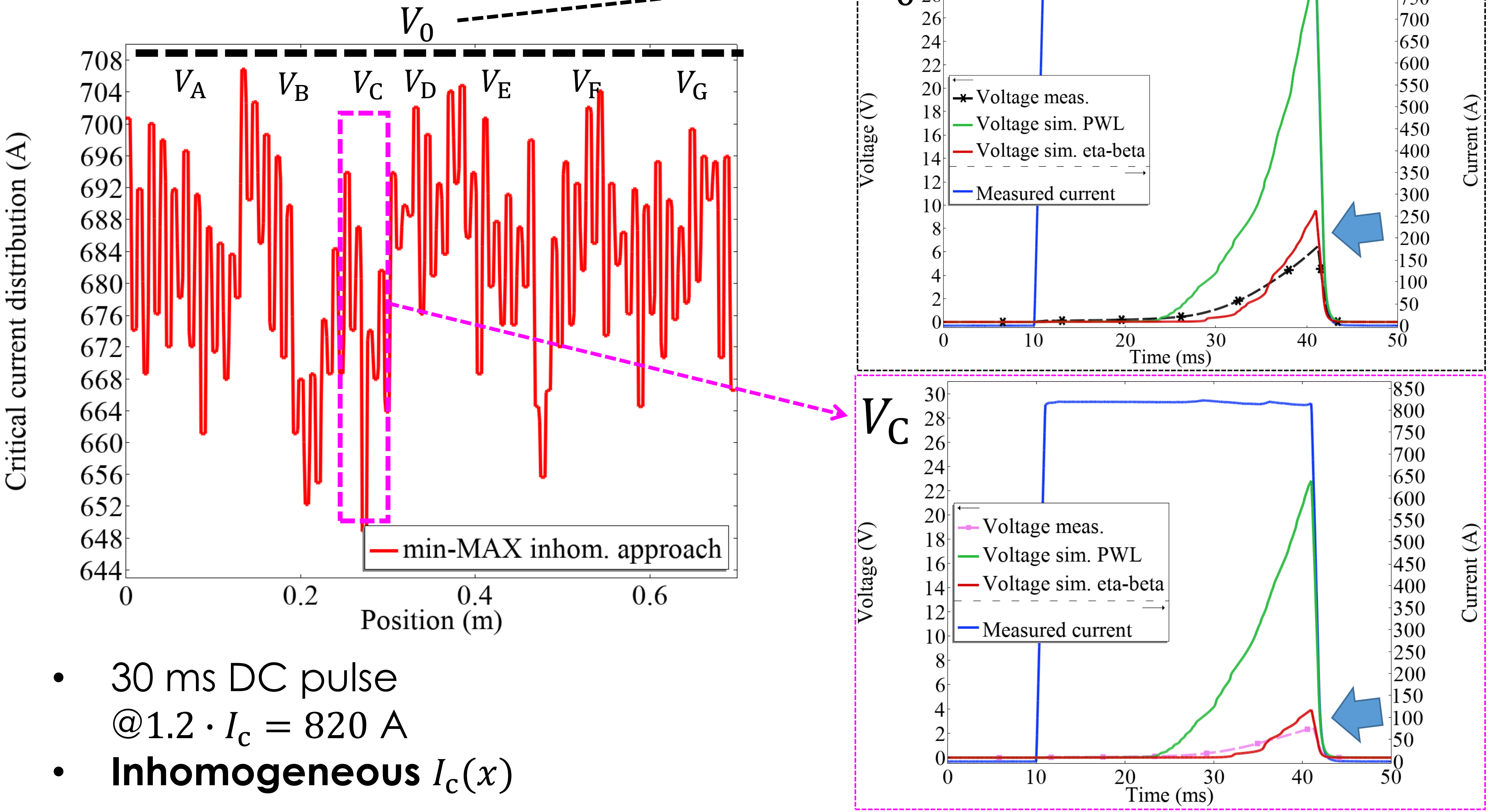






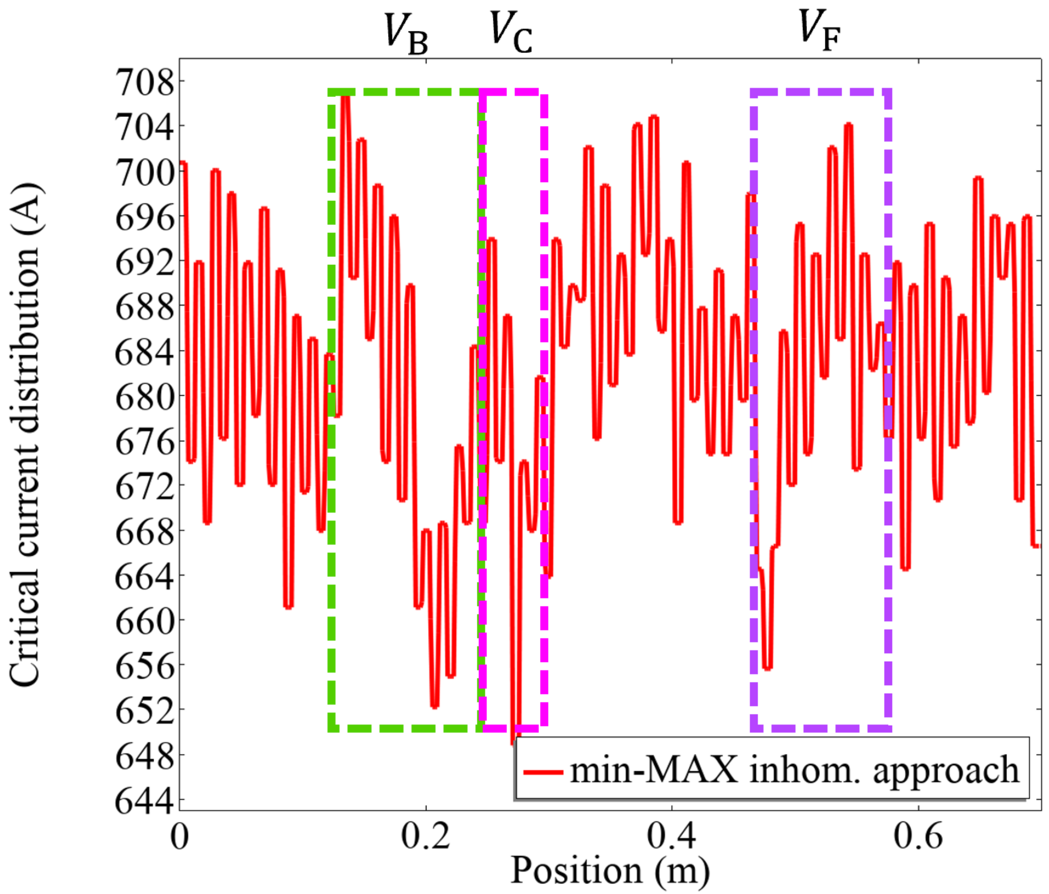
- 30 ms DC pulse @$1.2 \cdot I_c = 820$ A
- **Homogeneous** $I_c(x)$

Voltage along the length (inhom.)



- 30 ms DC pulse @$1.2 \cdot I_c = 820$ A
- **Inhomogeneous** $I_c(x)$

Temperature profile (inhom.)



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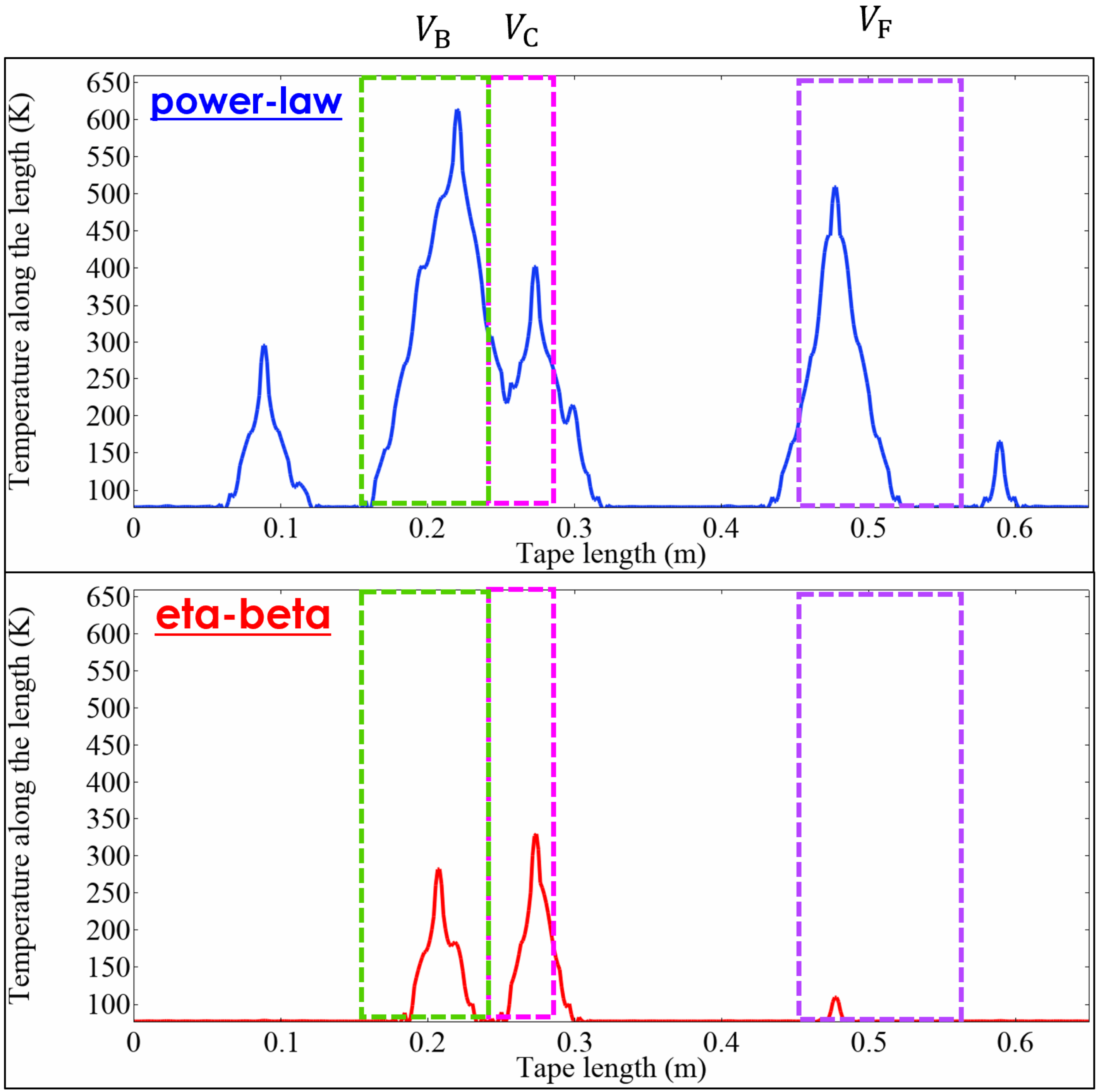
- **Inhomogeneous** $I_c(x)$



Conclusions…

1) Inhomogeneous $I_c(x)$ real data were used in a simple and computational efficient 1-D electrothermal model:
   A. Homogeneous $I_c(x)$ -> inaccurate simulations
   B. Inhomogeneous $I_c(x)$ -> eta-beta law better reproduces measurements than the power-law + realistic temperature profile along the tape length

2) Simple electrothermal model can be used to understand the role played in thermal runaways due to material inhomogeneity/defects

…and future work

- Improve agreement with measurements + further experiments
- Inhomogeneity layer thickness of materials (e.g., silver)
- Comparison with 2D/3D electrothermal models