Predicting Critical Current as a Function of Magnetic Field in High Temperature Super Conductors

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Introduction: The Alcator C-Mod Tokamak at the Plasma Science and Fusion Center (PSFC) produces high performance research grade plasmas with temperatures approaching 100 million degrees centigrade for studies in fusion energy. This device uses strong magnetic fields made by powerful electromagnets to confine this very hot plasma. Higher fields give better confinement and higher fusion power, so the PSFC is exploring paths to achieve the highest possible field. New advances in REBCO high temperature superconducting (HTS) tapes could provide that path. One important criteria in designing a superconducting coil is the ability to predict the critical current (Ic) – the current above which the conductor becomes normally resistive. Critical current is a function of magnetic field strength, and COMSOL has been used along with data provided by the manufacturer to predict the magnetic field and critical current for a coil made with REBCO tapes.

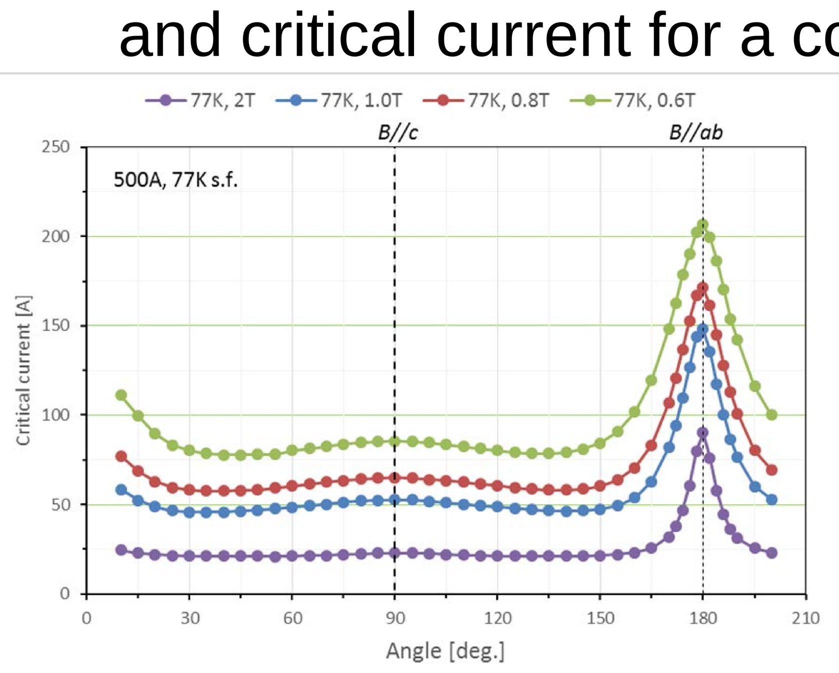


Figure 1: Manufacturer supplied (SuNAM) data on critical current of HTS tapes as a function of field and field angle at 77K

This data is input to COMSOL as an interpolation table which is called to define the current in each turn

*Note this data was supplied in Aug.2015 and the tape's performance may have been improved since then

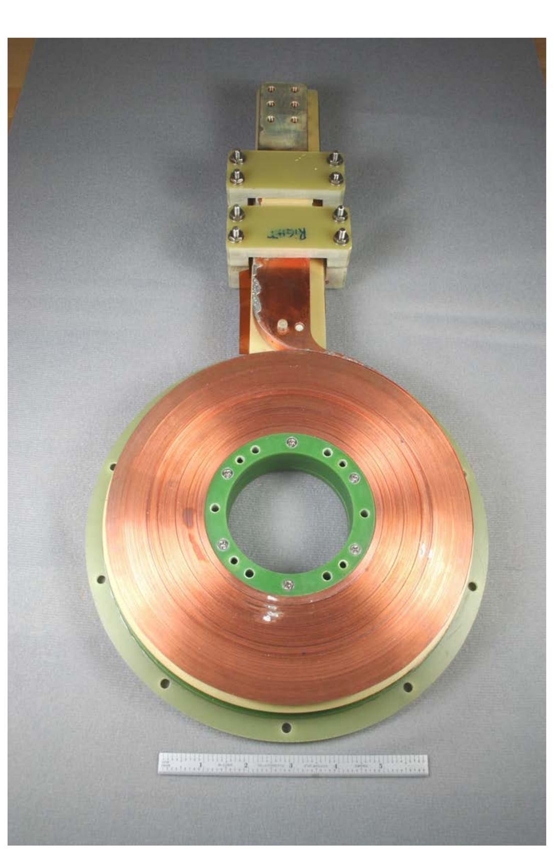
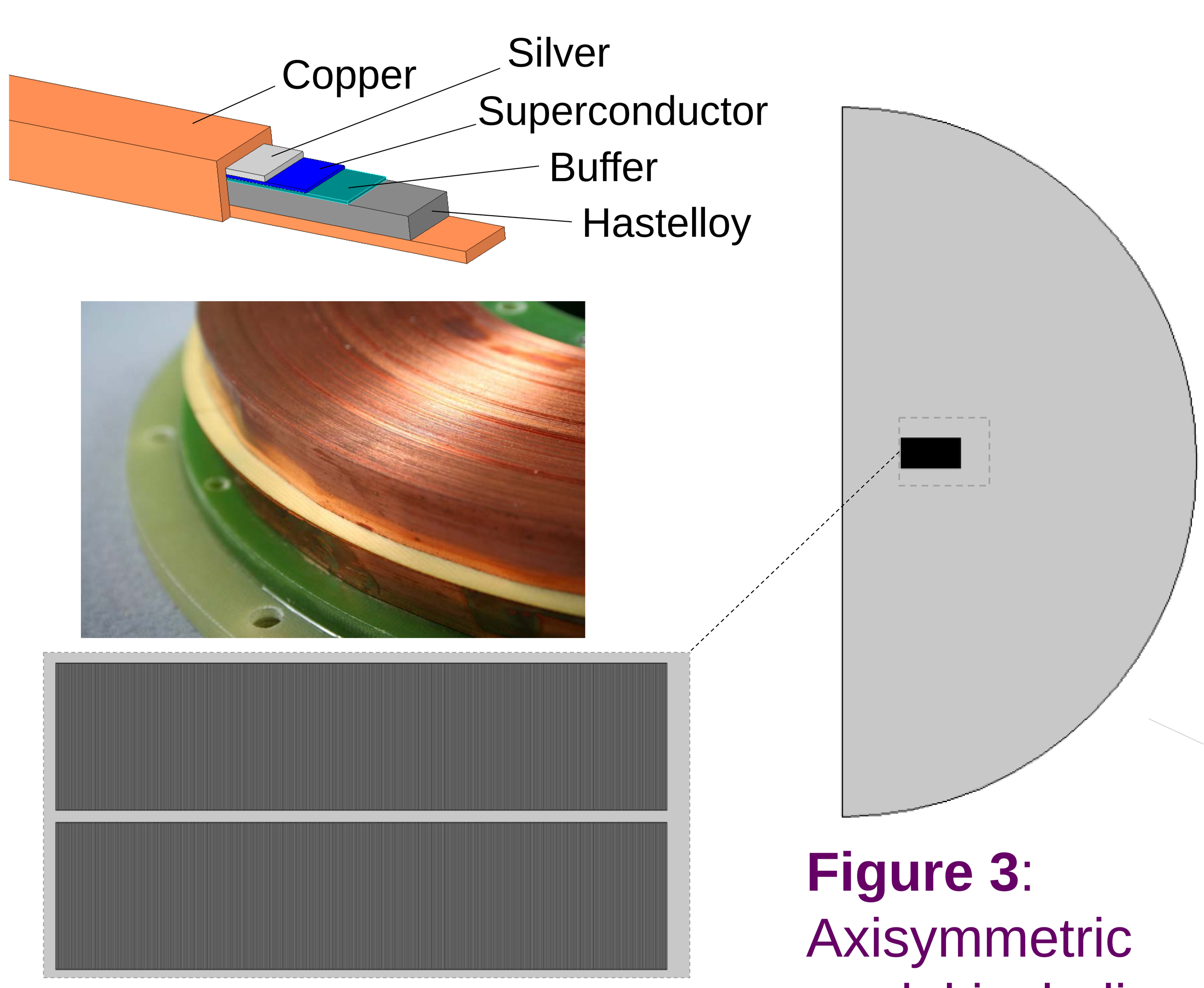


Figure 2: HTS double pancake coil made to test tapes with no turn-to-turn insulation



475 individual turns modeled in coil

Figure 3: Axisymmetric model including coil and air volume

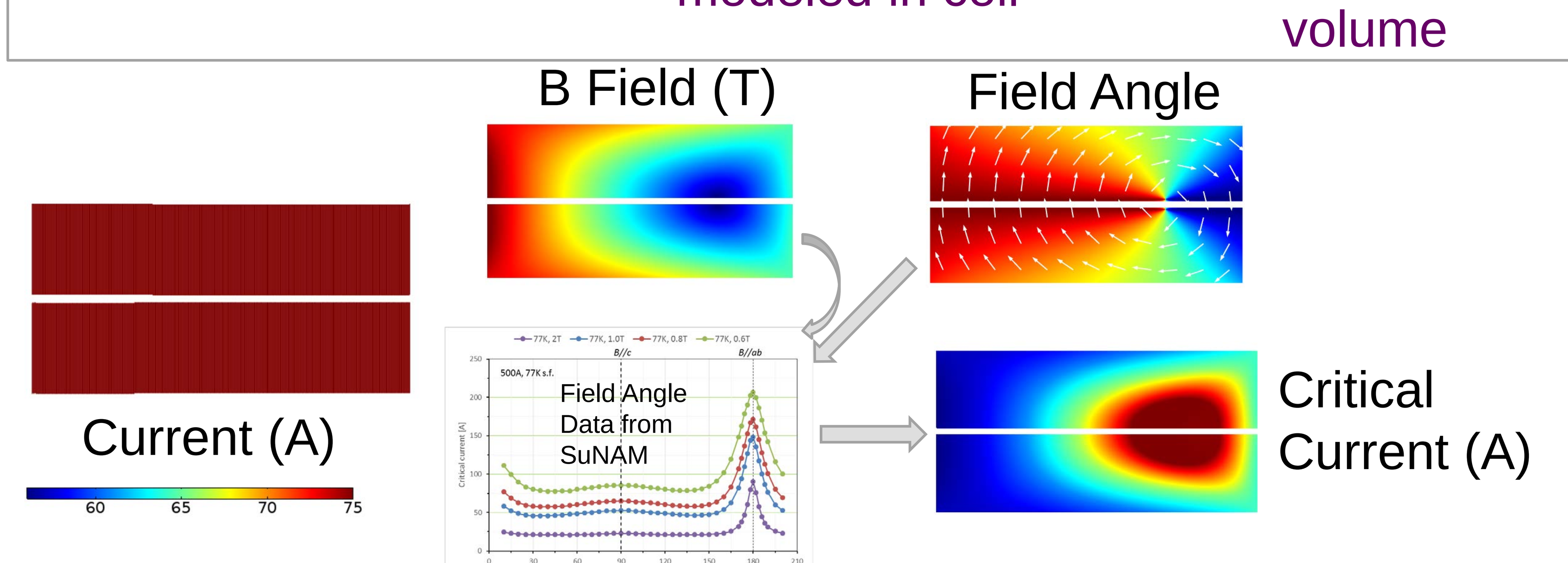


Figure 4: Model Procedure:
Initial Current applied as Surface Current
Run mf model to determine fields, Calculate field angle
Feed Resultant field and field angle into Interpolation table.
If input current > Ic, reduce current to Ic and re-run
Repeat until converged

Follow this procedure for:
I_Initial= 75A 100A 125A

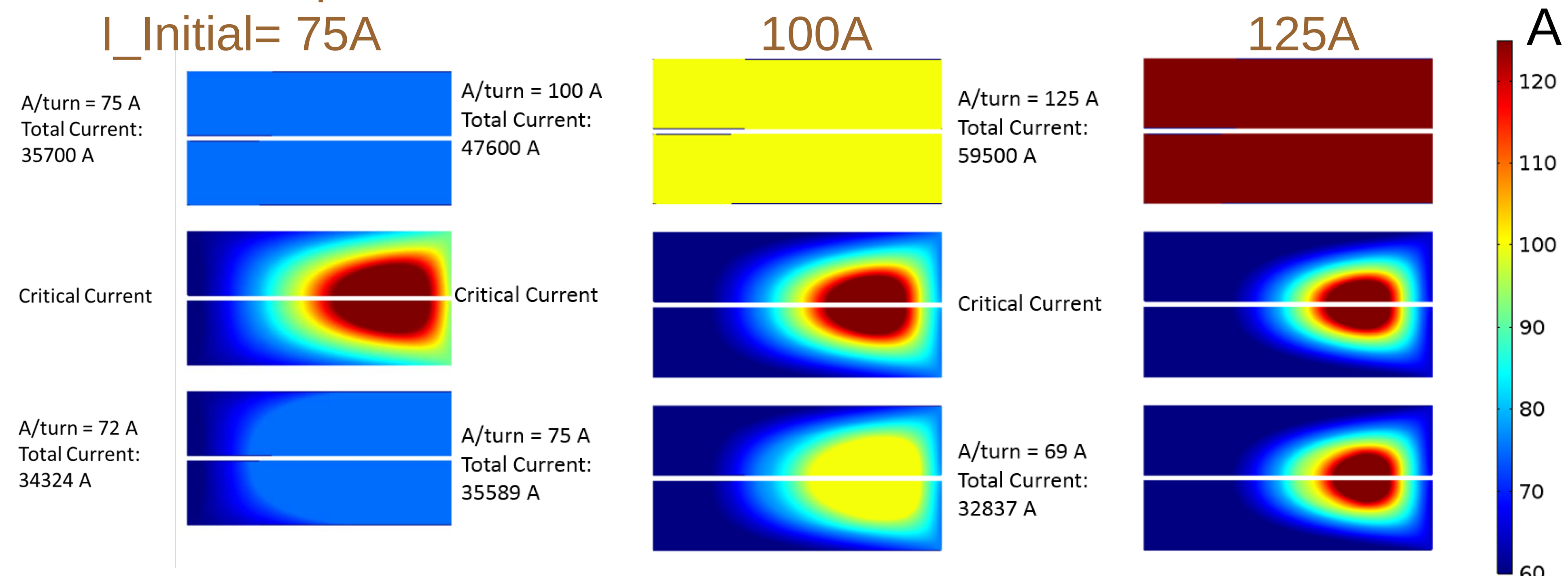


Figure 5 shows how the critical current due to field and field angle reduces the current in the coil.

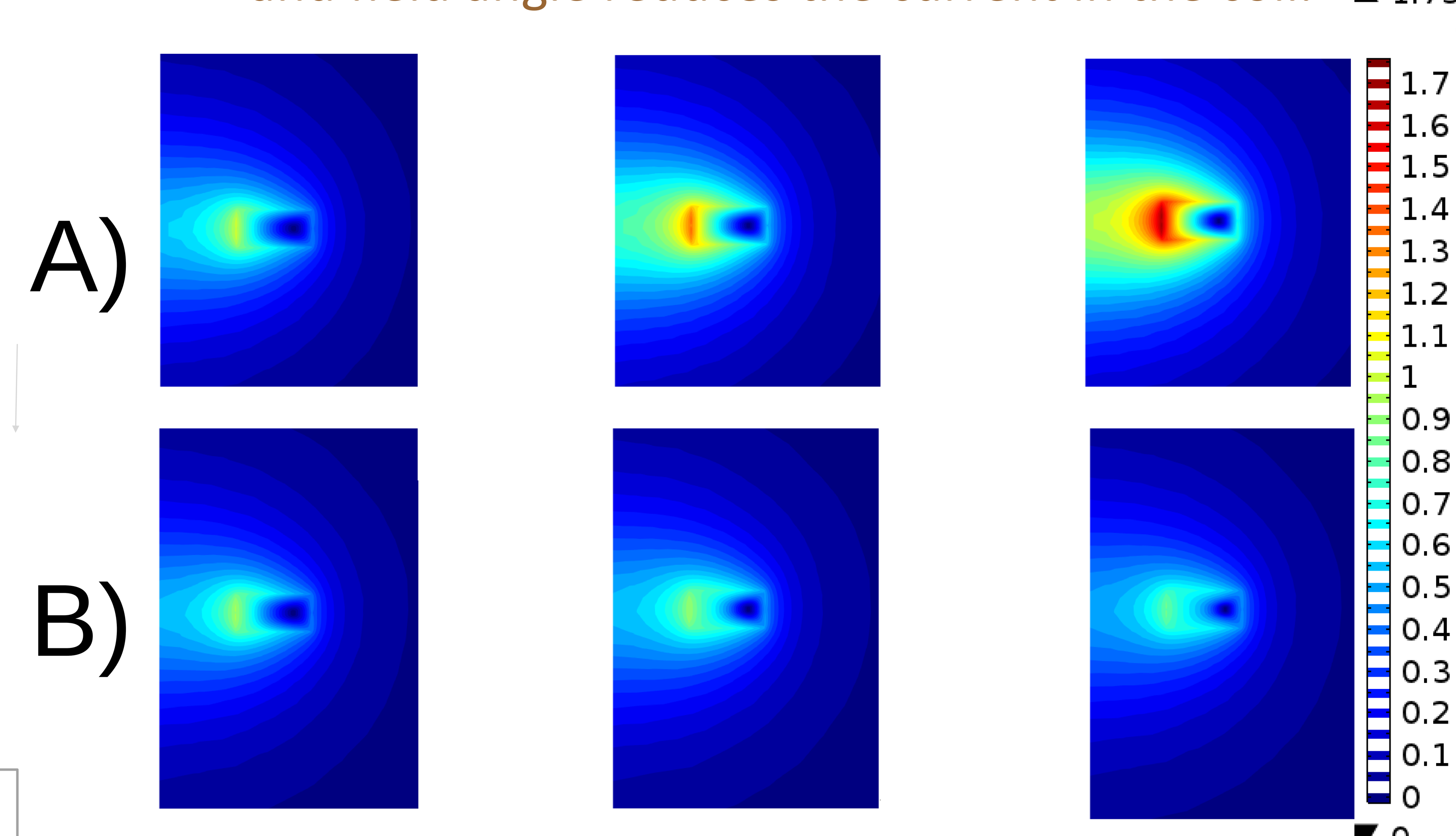


Figure 6: Reduction in field due to reduction in current
A) Magnetic Fields with Initial Current
B) Magnetic Fields with Final Current after critical current is applied

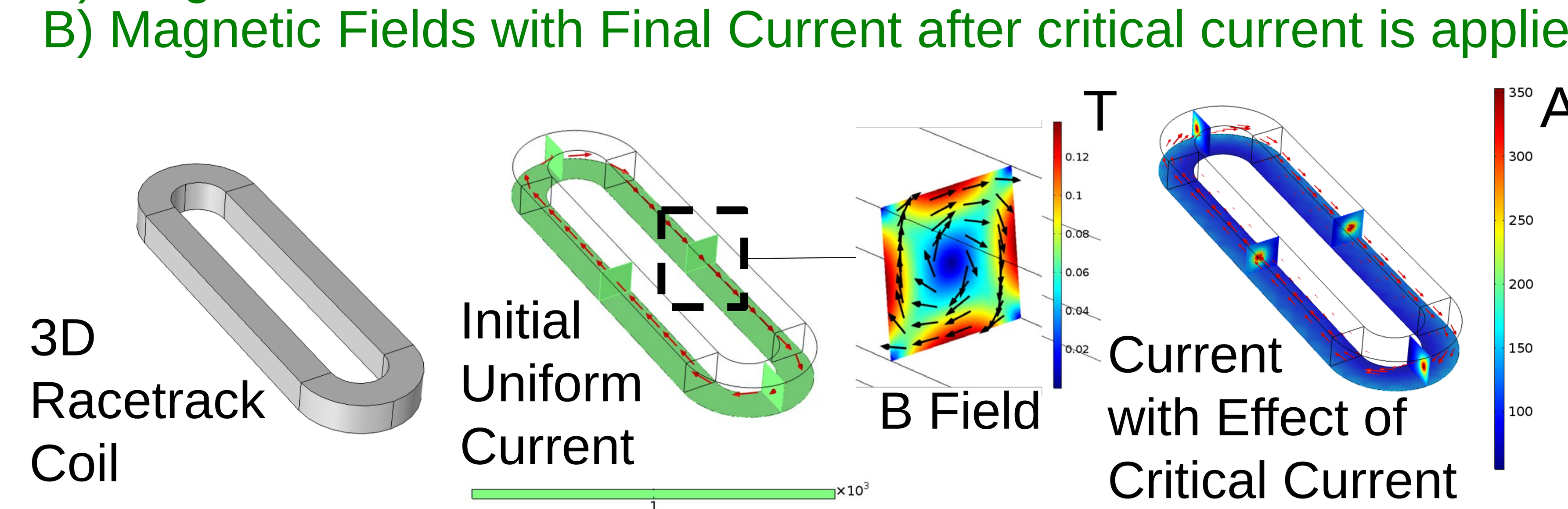


Figure 7: This technique has also been extended to 3D Models

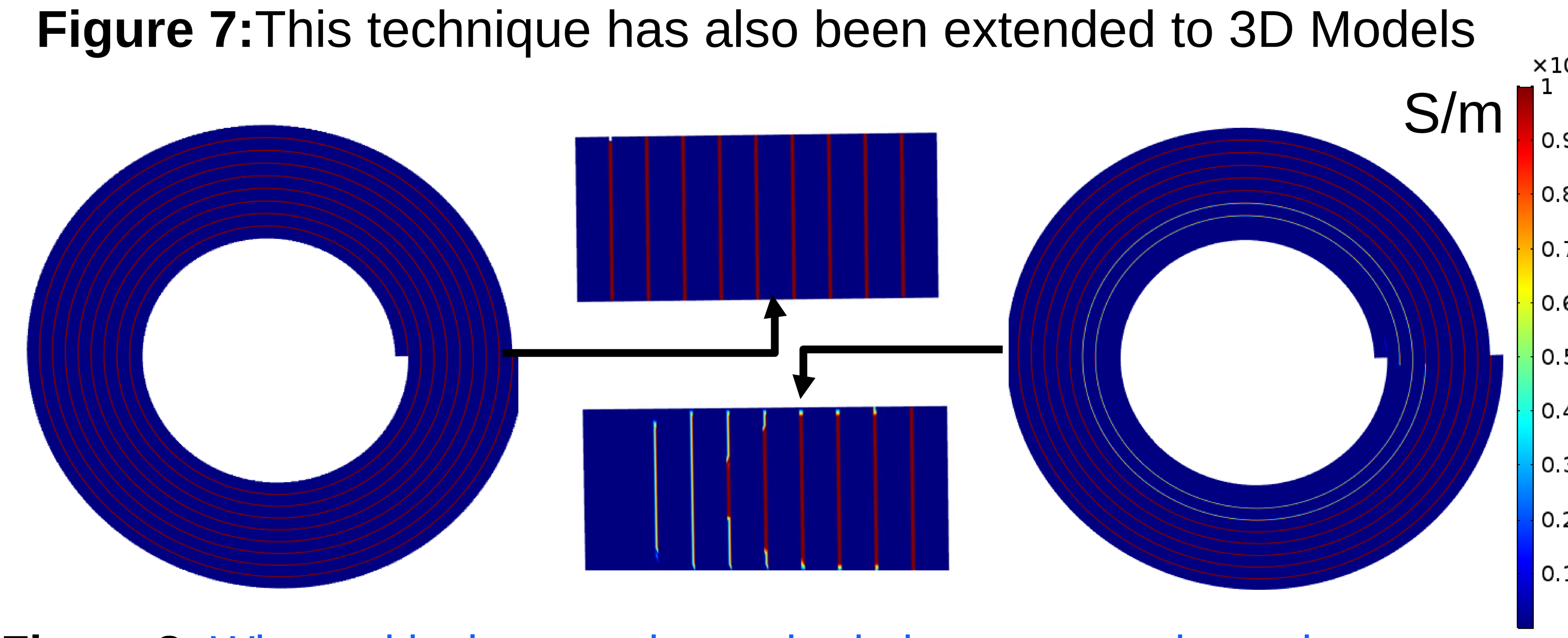


Figure 8: When critical current is reached, the superconductor becomes normally resistive. In a simple model of the pancake coil in Figure 2, once Ic has been exceeded, a switch statement is used to reduce the conductivity of the HTS to that of the hastelloy substrate (shown above). At this point, current will follow the least resistive path and can jump through the copper stabilizer to the next turn.

Conclusions: Models predicting the critical current due to field and field angle for coils with HTS tapes have been created. These models can predict when the superconductor will go normal and what current can be carried by the coil.