Magnetic Field Shaping Using High Temperature Superconducting Monoliths

L. Bromberg, J.V. Minervini, J.H. Schultz
MIT Plasma Science and Fusion Center

T. Brown, P. Heitzenroeder and M. Zarnstorff
Princeton Plasma Physics Laboratory

A. Boozer
Columbia University

Supported by Princeton University Subcontract Award Number S00828F

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

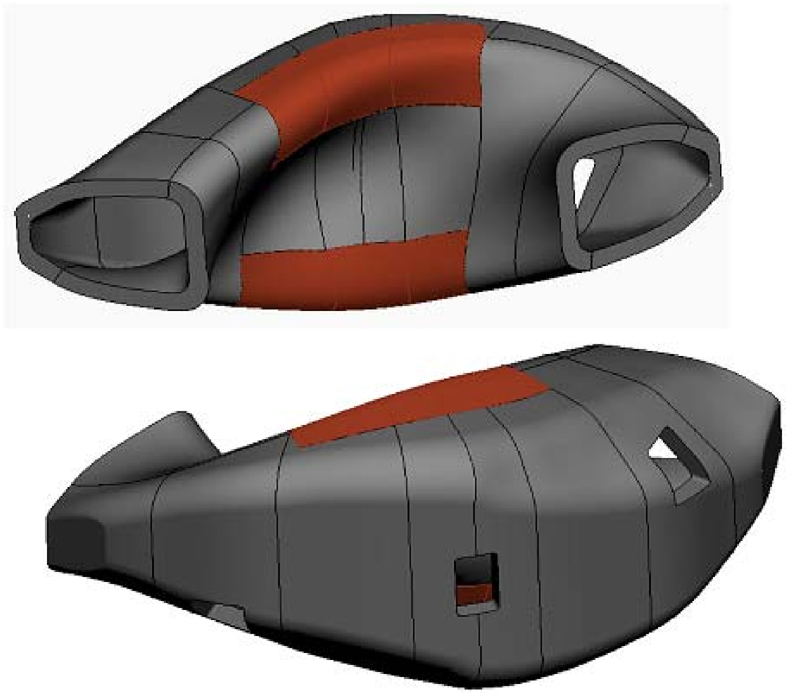
MIT PSFC

Topics

- Motivation of study
- High Temperature Superconducting (HTS) Materials
  - Properties
  - Availability
- Modeling
  - Toroidal ripple control (simple geometry)
  - Stellarator fields (complex)

Objectives of the concept

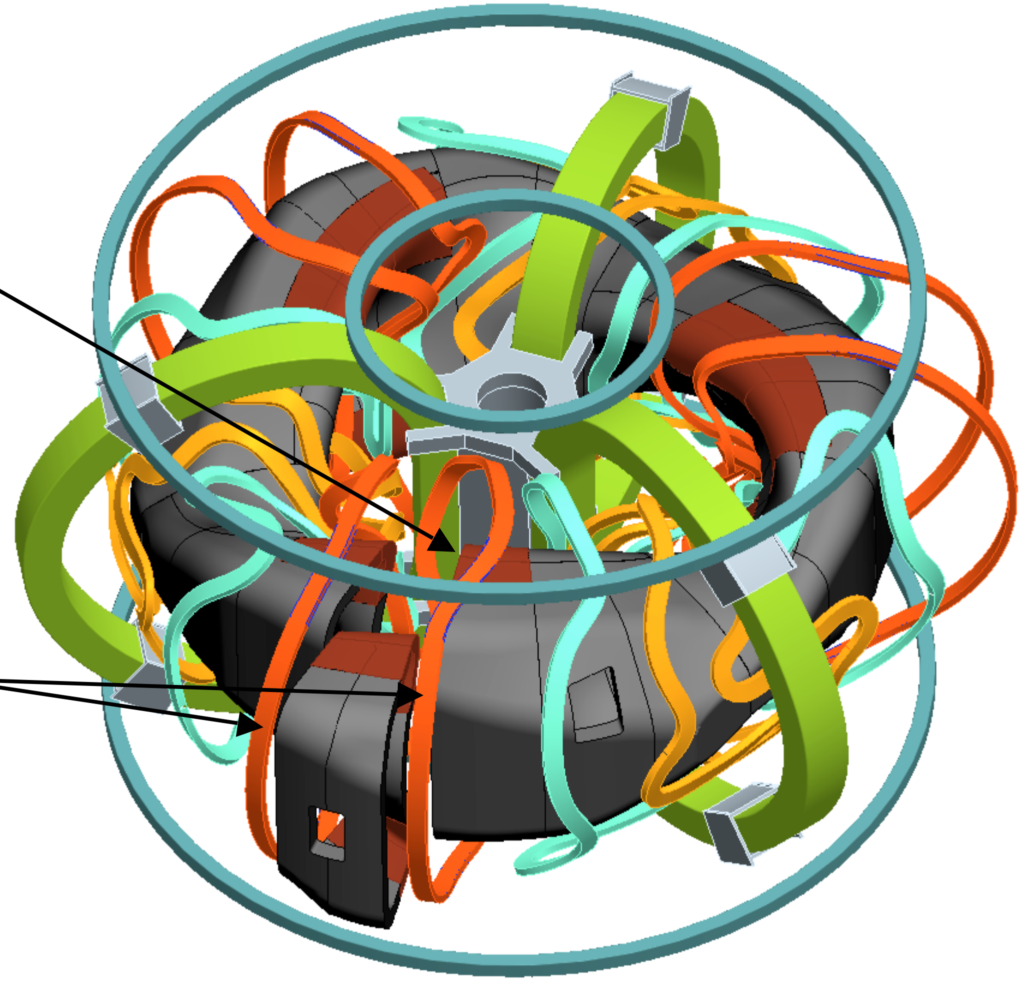
- Superconducting monoliths can be used to shield/trap magnetic fields
    - HTS monoliths can operate without flux jump because of high thermal stability
- Can superconducting tiles be used to modify fields generated from simple coils?
    - Simplify coil geometries for stellarators
    - Improved access



Improved access, simpler coils

Simpler coils in inboard side

Reshaped outer coil leg: more maintainable geometry



BULK HTS applications to Stellarator

- Well suited to the needs of stellarators
  - Passive elements
  - DC (*i.e.*, no AC fields, as in bearings)
  - Field exclusion, as opposed to field trapping
    - Stresses are compressive (as opposed to field trapping where large tension occurs)

- Issues:
  - Field creep
  - Homogeneity (may require adjustment in the field)
  - Large torques need to be supported

Availability of Bulk HTS

Nexans SuperConductors GmbH

- Available sizes
  - 40 X 40 X 16 mm^3
- Cost:
  - 300 €, 20 € /cm^2
- Available from other suppliers:
  - Cambridge University
    - 13 mm radius,10 mm tall
  - ATZ (Germany)
  - Japanese (ISTEC)
    - 100 mm radius, 10 mm tall

High-temperature superconductor bulk magnets that can trap magnetic fields of over 17 tesla at 29 K

Masaru Tomita*† & Masato Murakami*

NATURE | VOL 421 | 30 JANUARY 2003 | www.nature.com/nature

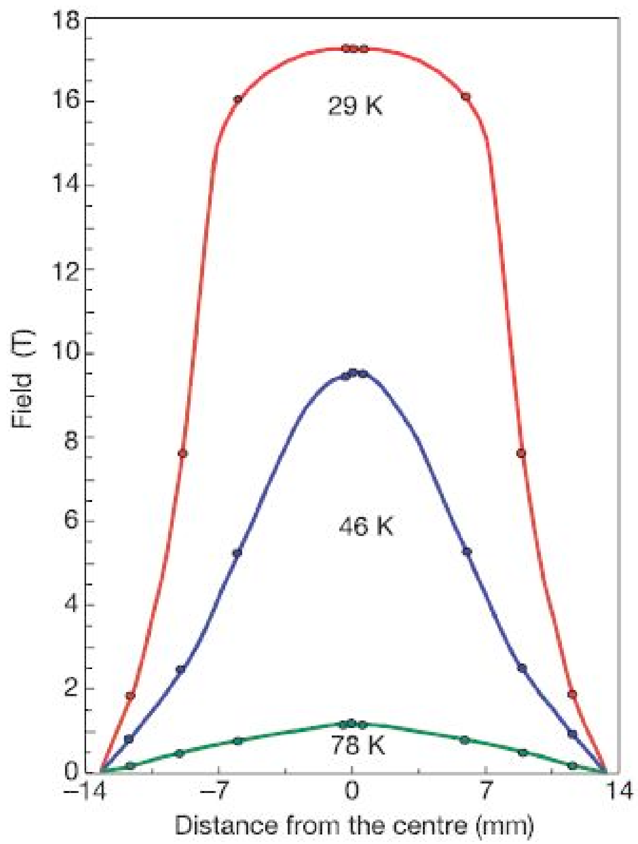
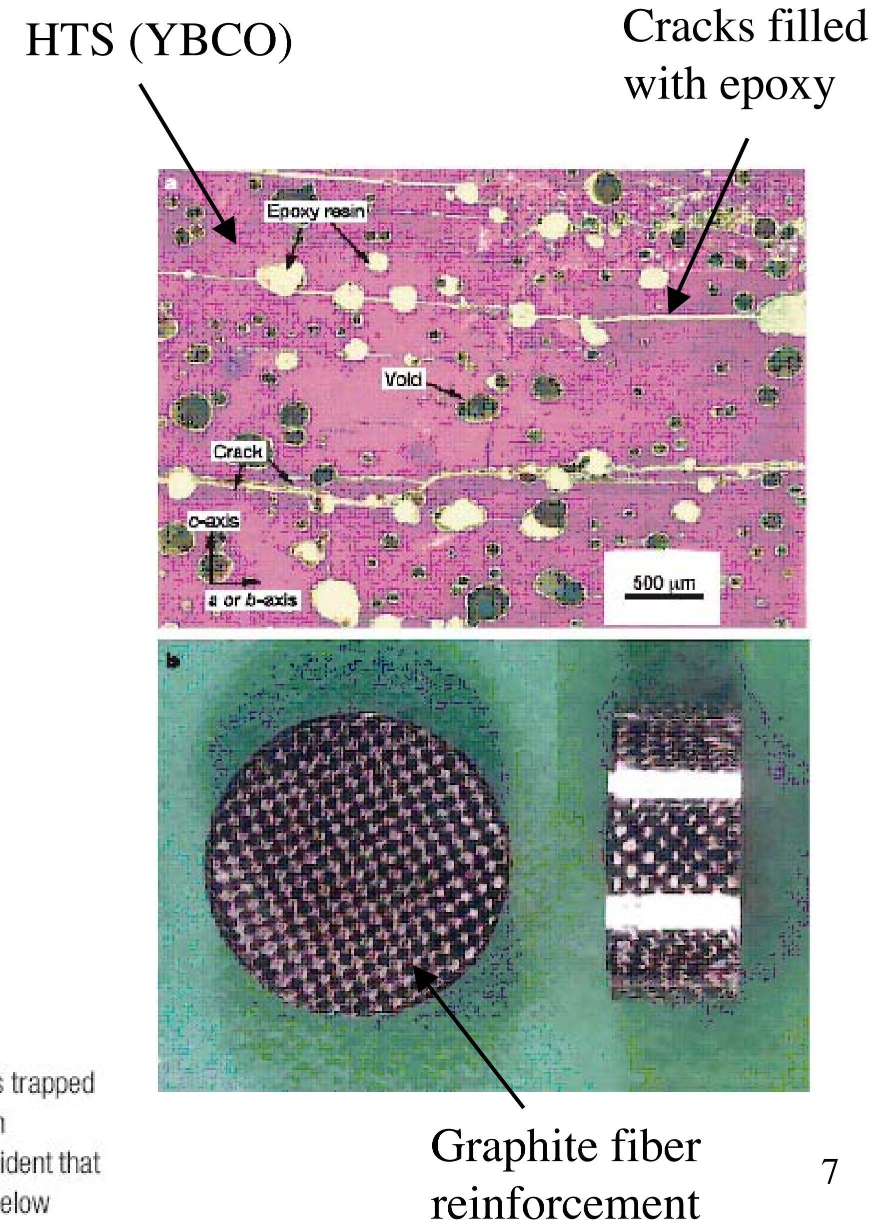
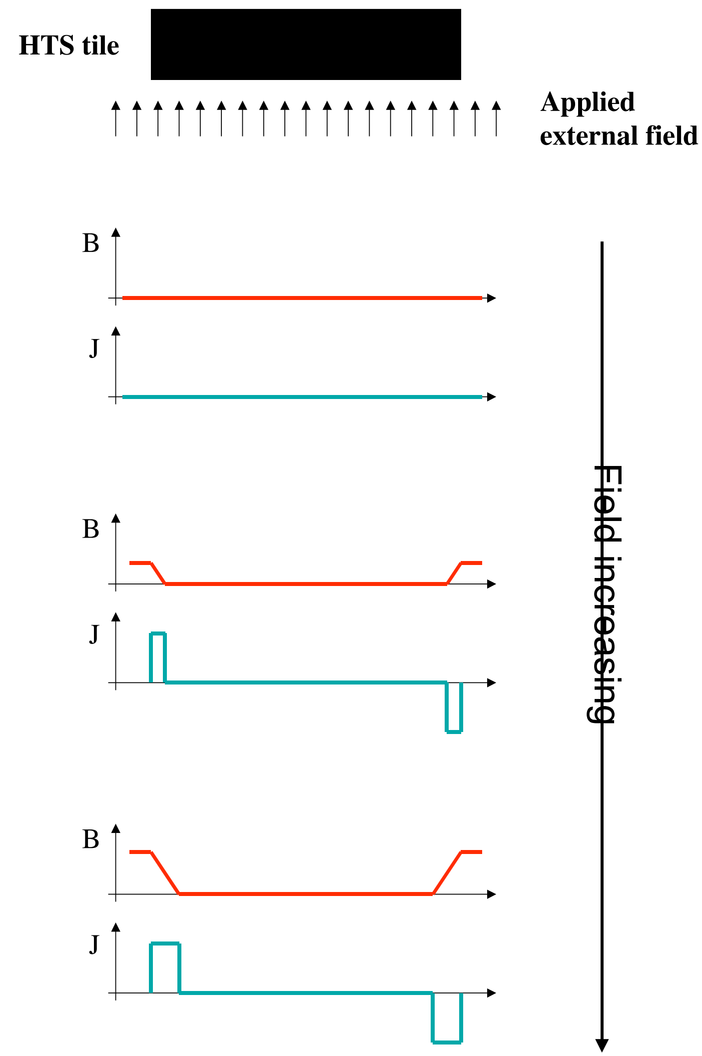


Figure 5 The effect of temperature on trapped-field distribution. The field was trapped between two 26.5-mm-diameter YBCO disks with carbon fibre wrapping, resin impregnation and embedded Al. Data are shown for 29 K, 46 K and 78 K. It is evident that the trapped field is saturated at higher temperatures, but that the field is far below saturation at 29 K, showing that much higher fields could be trapped.



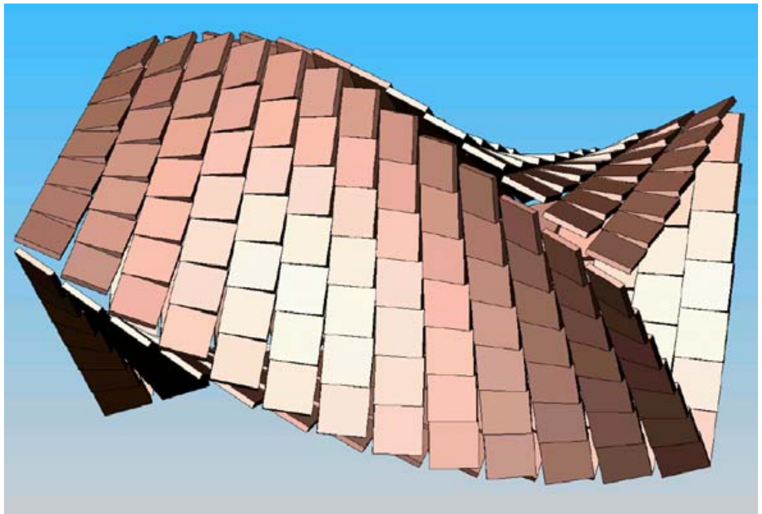
Modeling HTS monoliths

- The superconductor is always at critical conditions
- When field changes outside of the superconductor, currents (at critical conditions) will be generated on the surface to prevent changes in the interior
- Currents are a function of the local magnetic field (magnitude and direction, for ReBCO) and temperature



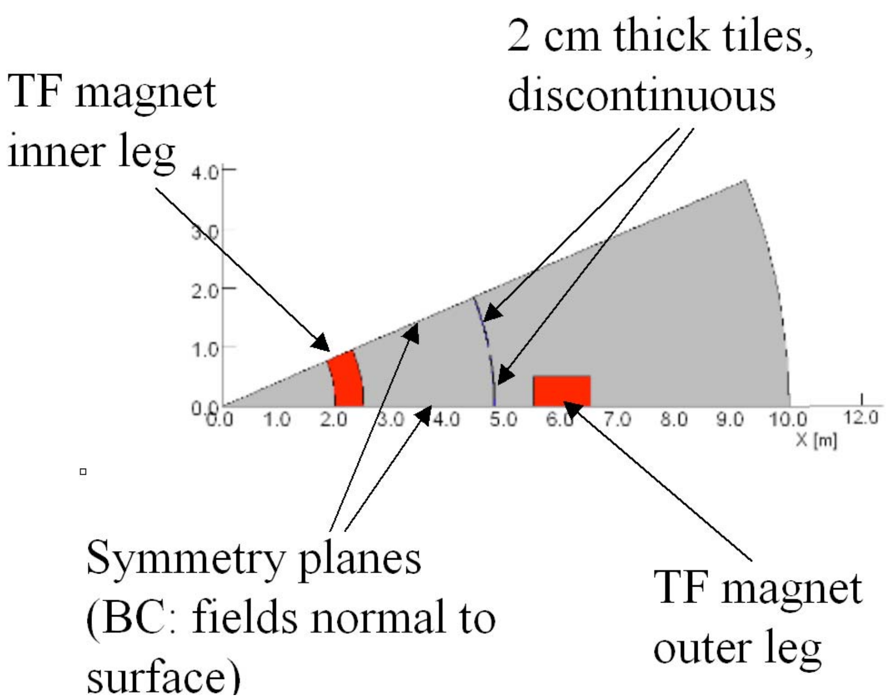
Modeling tokamaks/stellarators

- Bulk superconductor can be treated as perfect diamagnetic material
- Stellarator is complex 3-D geometry
  - To understand multiple tile performance started out analyzing 2-D geometry
  - Axial symmetry of set of coils that simulate a toroidal magnet at the midplane
  - Relevant to ripple reduction in tokamaks

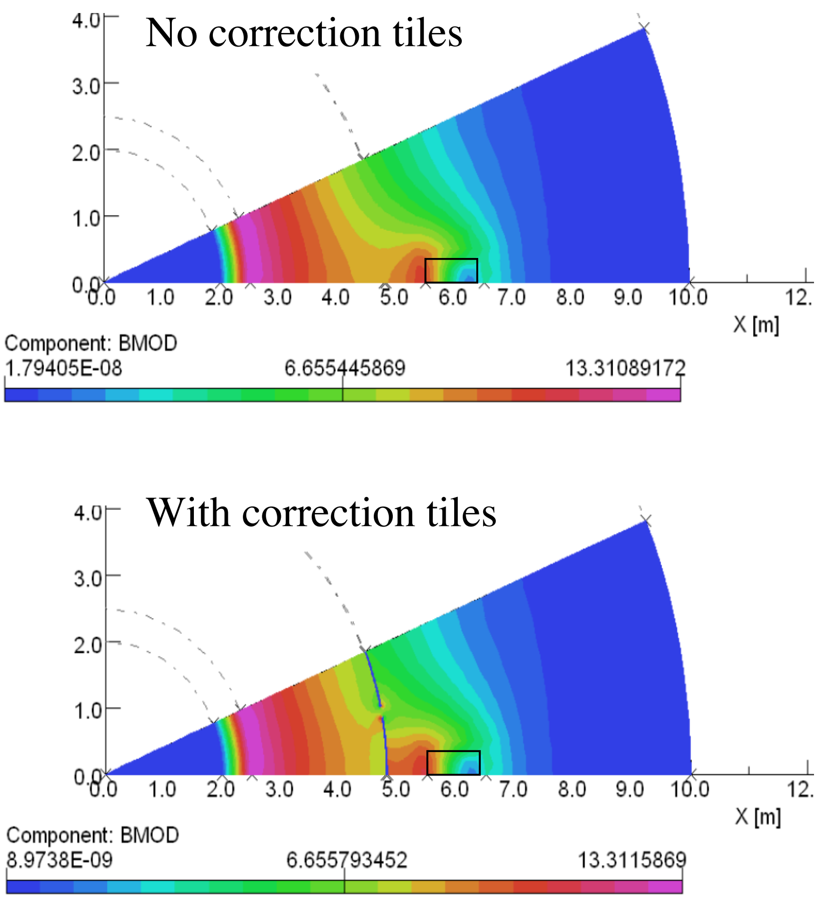


Simpler geometry: tokamak midplane 8-coil TF set

Midplane of tokamak

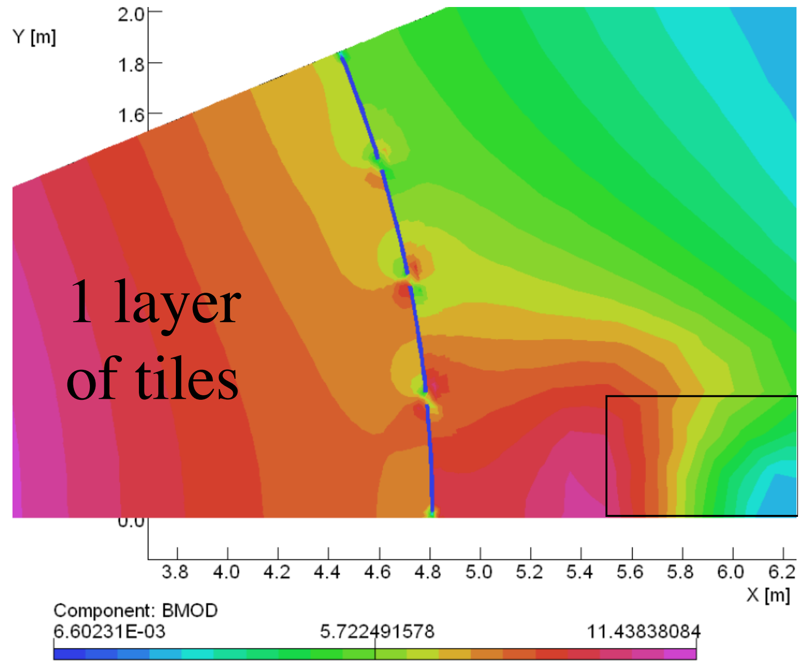


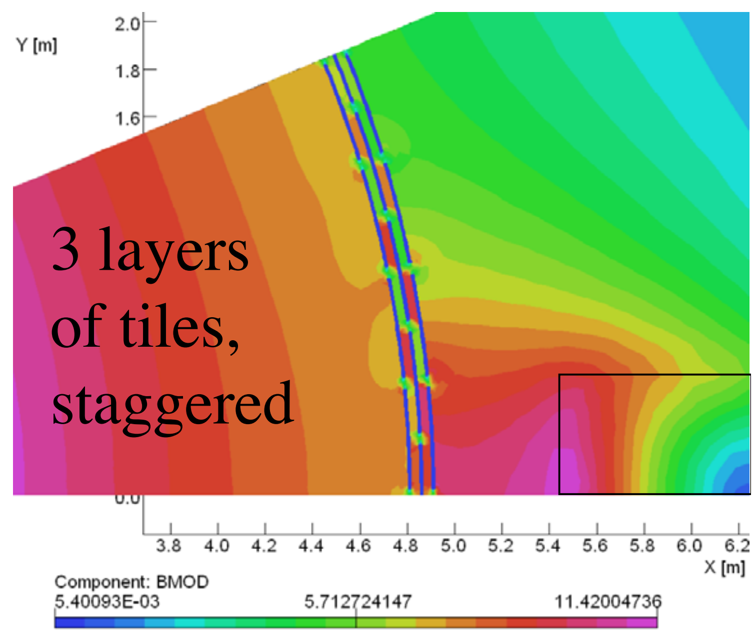
|B| contours on midplane



|B| contours

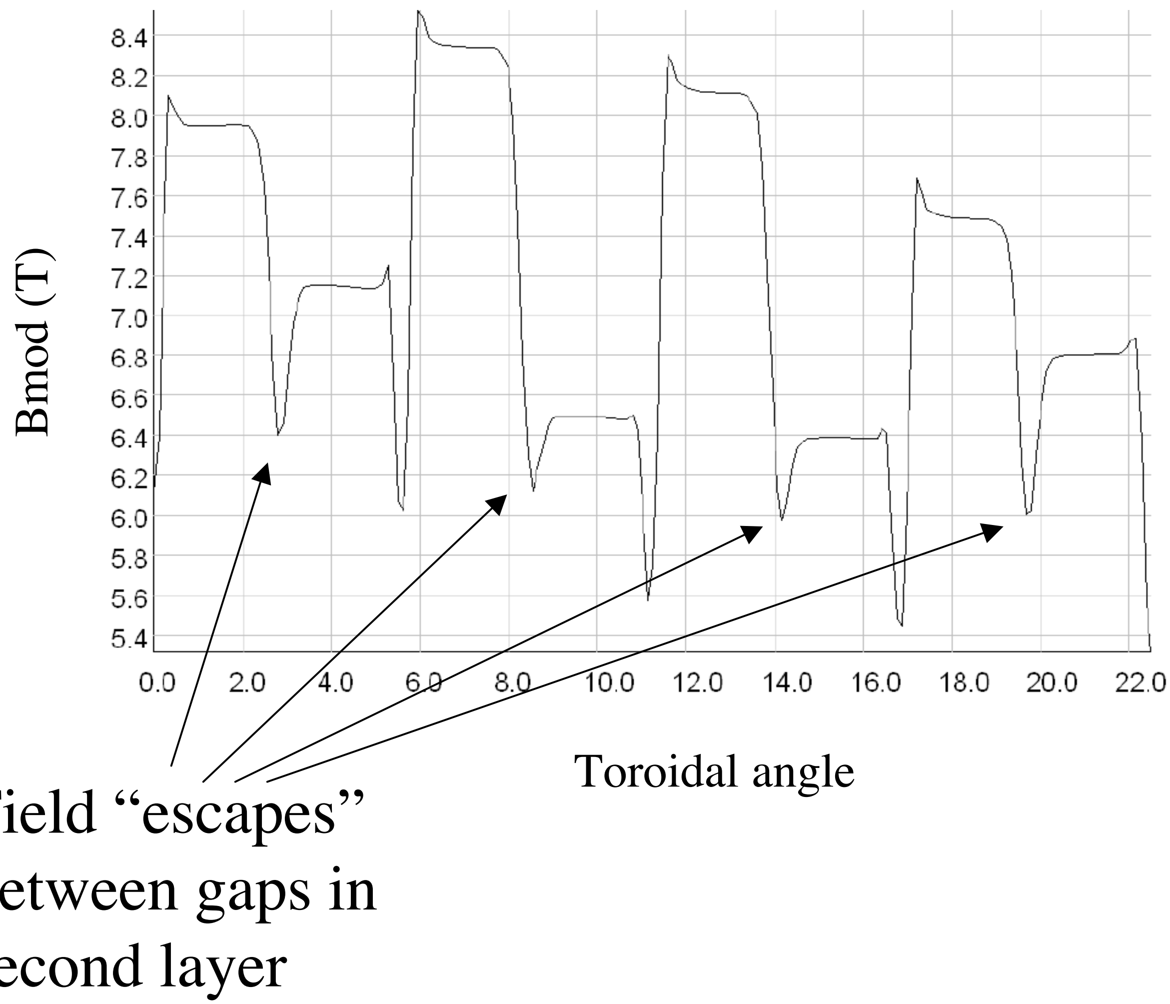
- Field escapes through gaps in the layers





- μ = 0.001
- Tiles
  - 0.02 m thick
  - Radial gap between layers =3 cm
  - 0.5^o toroidal gap (~ 4 cm)

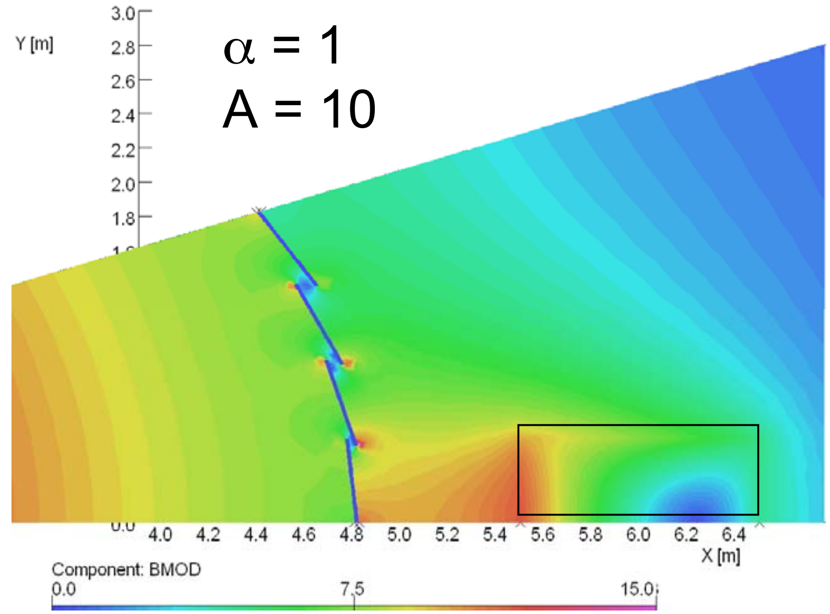
Field profile between first and second layers

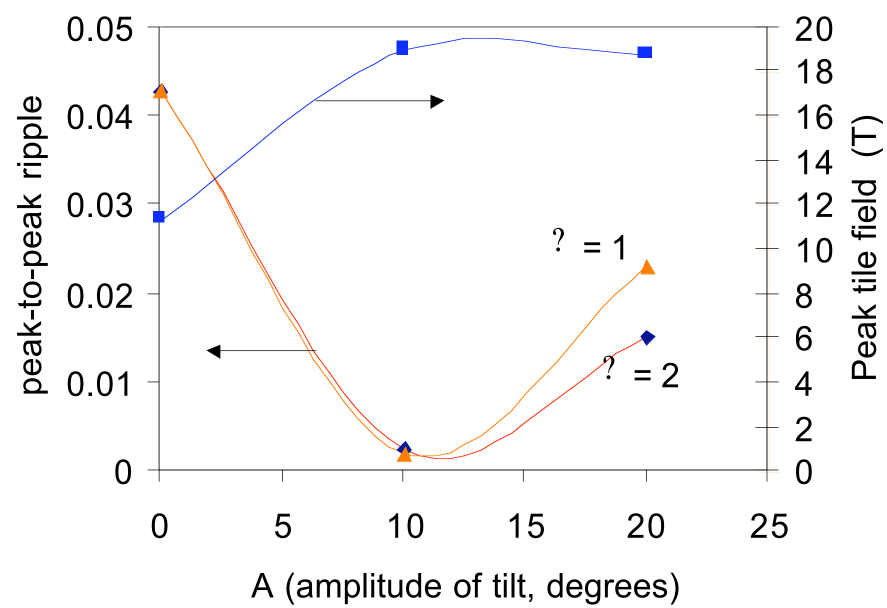


Improved Tile Orientation Eliminates Ripple

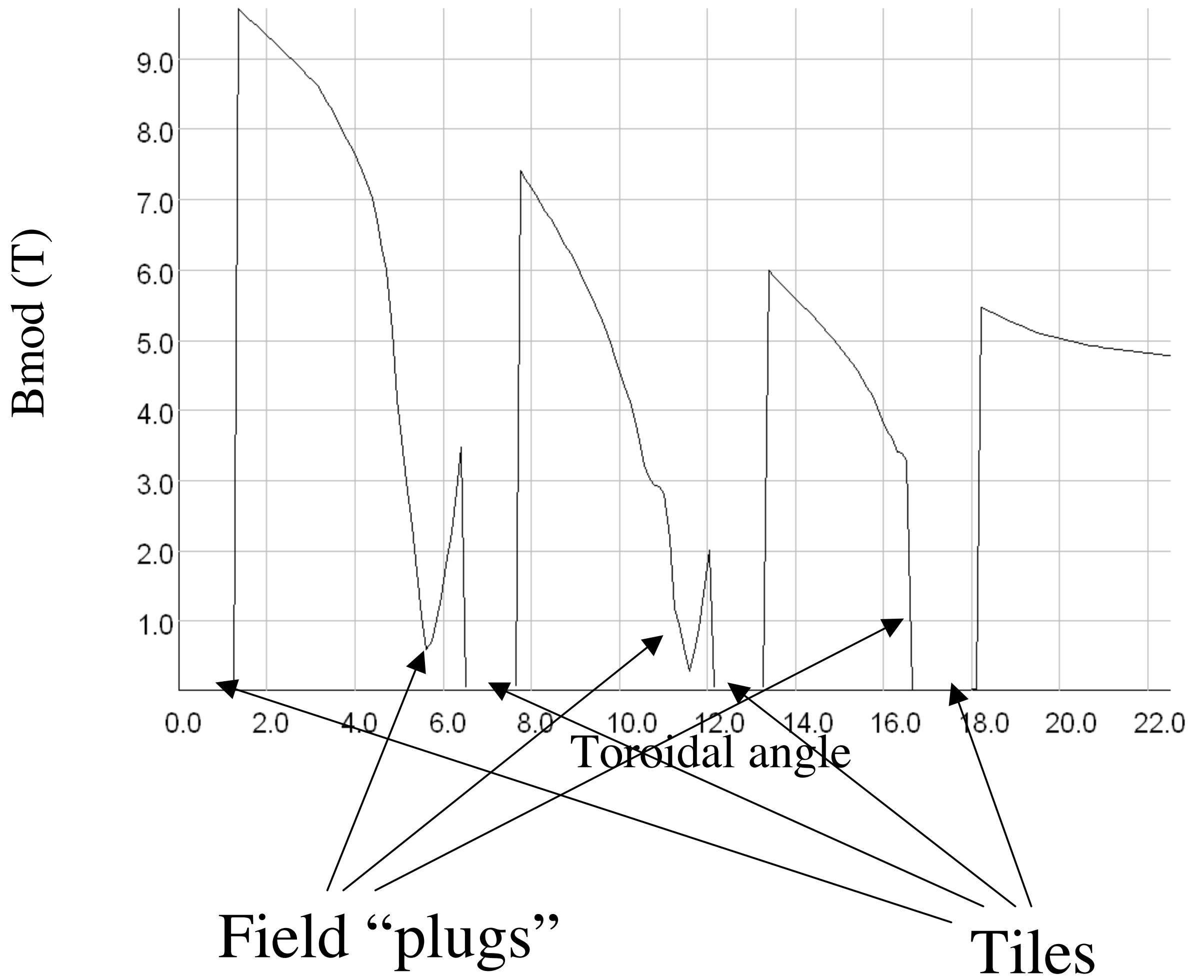
- Problem:
  - Field decays between gaps
  - Current in tiles small because small normal field (radial field)
- Solution:
  - Have tiles overlap
  - Tilt tiles so that they interact with toroidal field

Tilt ~ A $\sin(\alpha N \theta)$ (α = 1, 2)

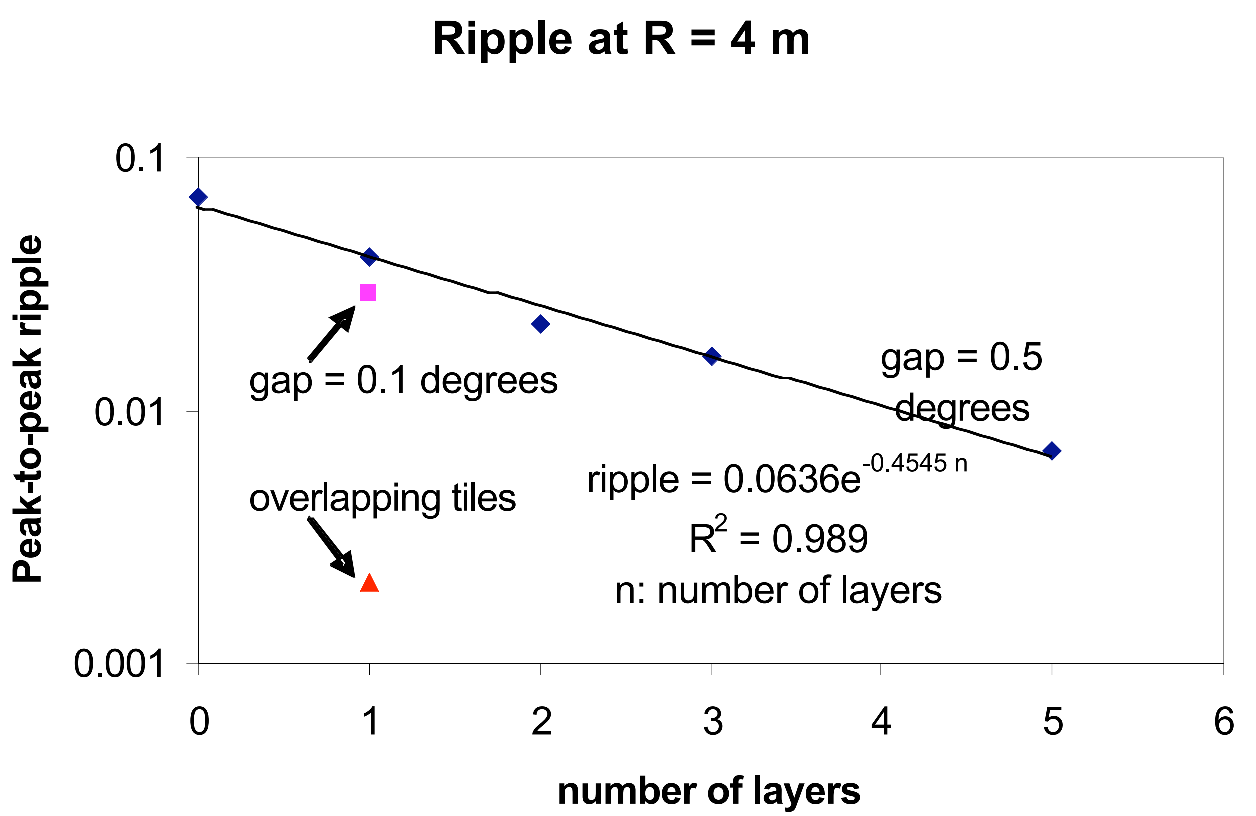




Field profile along R =4.81 m



Toroidal field ripple at 4 m



Summary

- Performed simple calculations on toroidally symmetric geometry to provide understanding on performance of tiles
- Ripple: scales exponentially with number of layers.
- Pucks do two things:
  - Eliminate the main magnetic field from its interior, resulting in large currents around the puck, not useful for ripple minimization or field shaping
  - Currents at the edges do provide for field management
  - For multiple tiles, adjacent tiles interact, making problem complex.
- Tilting/overlapping provides powerful control for field shaping
  - Location and orientation can be adjusted for optimization
- Started process for 3D model of stellarator-like geometry