Normal Conducting Magnets for RCS

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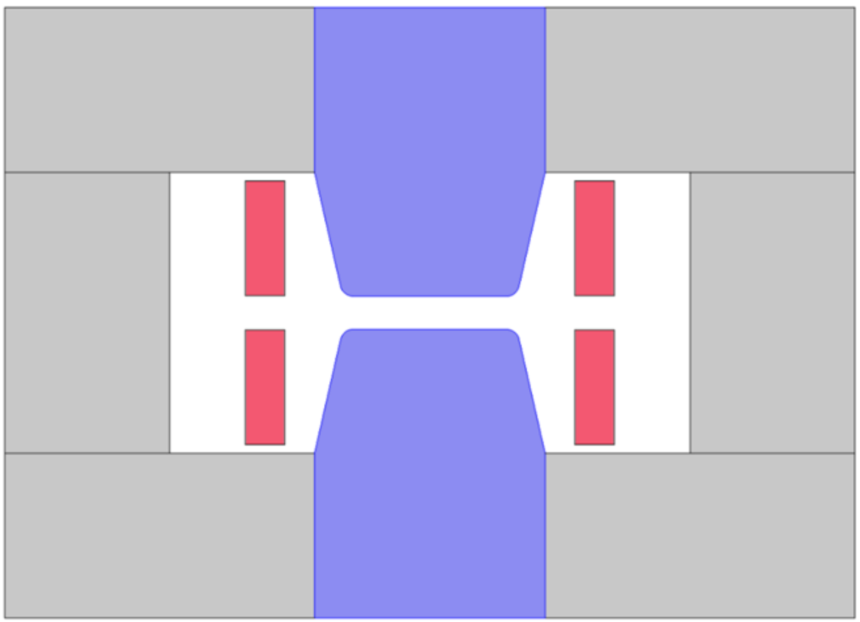
Design Concepts

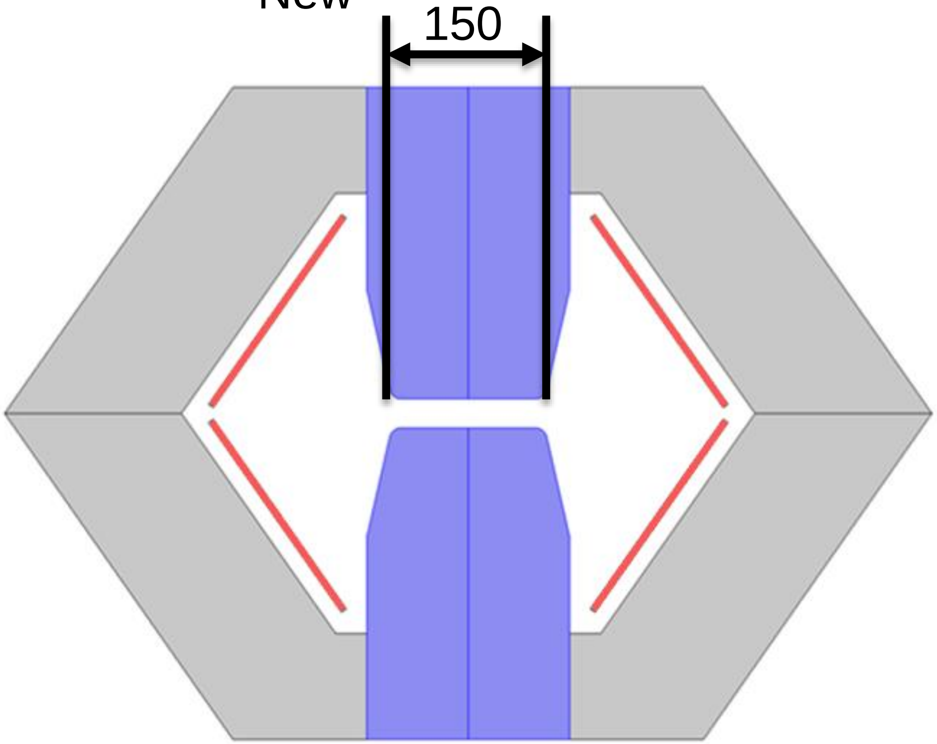
- Dipole Requirements
  - Good field region: 60x10 mm^2
  - Aperture: 60x25 mm^2
  - Ramp rate: 1 kHz
  - B > 1.5T
- Aims
  - Minimize losses
  - (First pass on engineering)
- Approach
  - Materials: intelligent combination of materials
  - Geometry excitation coil: minimize eddy current losses

Geometry Evolution

Old



New



3% SiFe

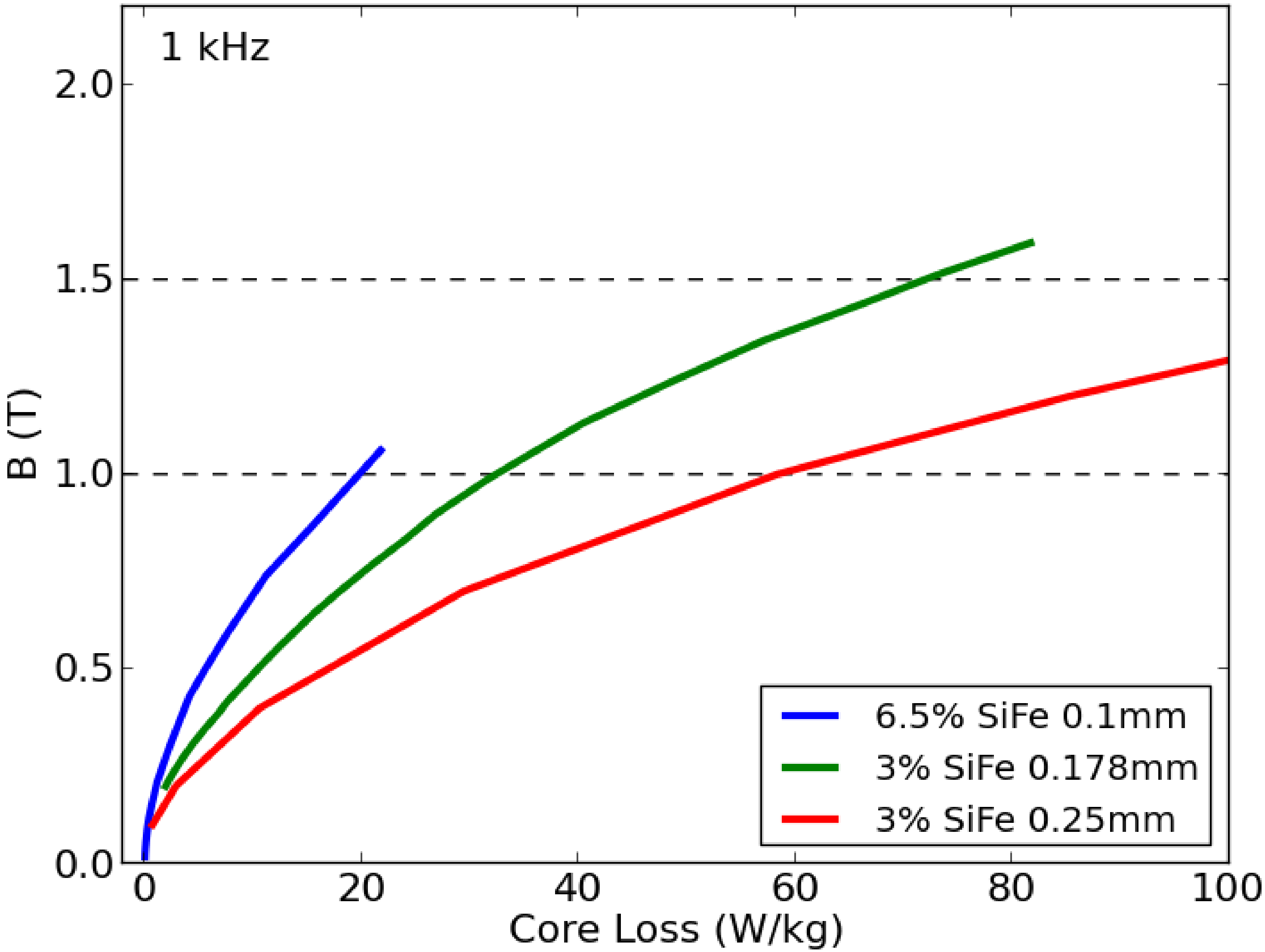
6.5% SiFe

Coil

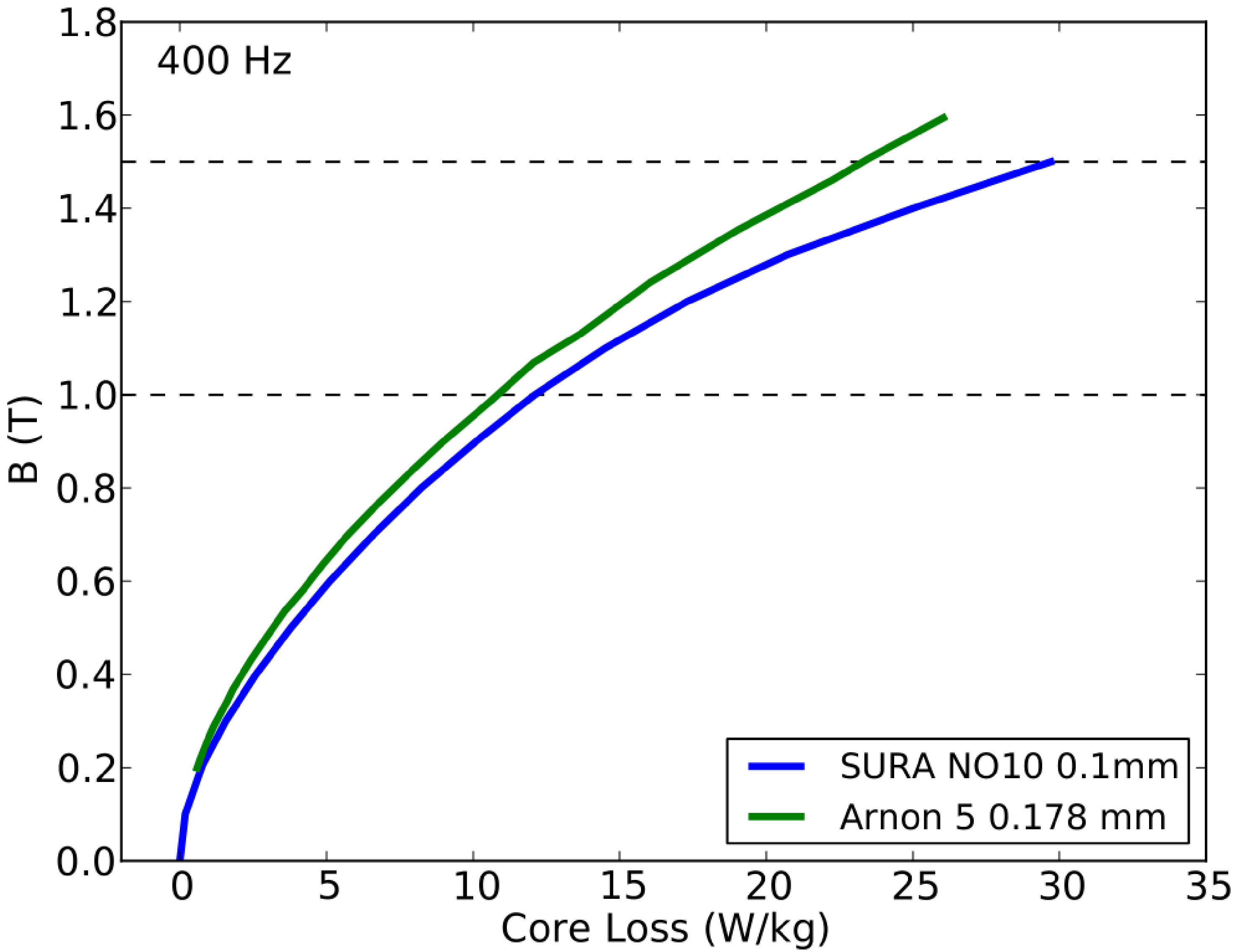
Better suppression of eddy currents

Minimized yoke volume

Materials - Core Losses

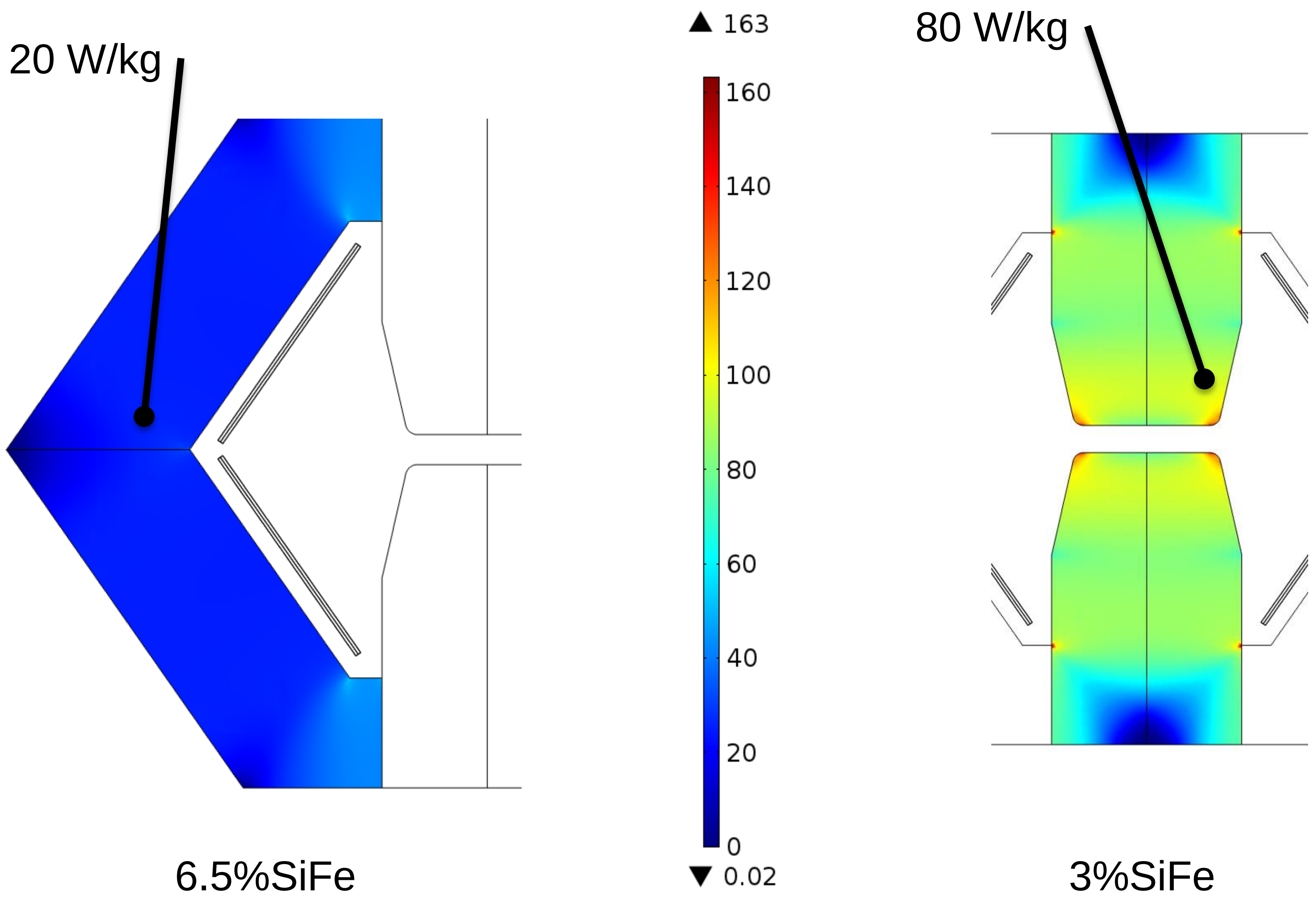


Lamination Thickness

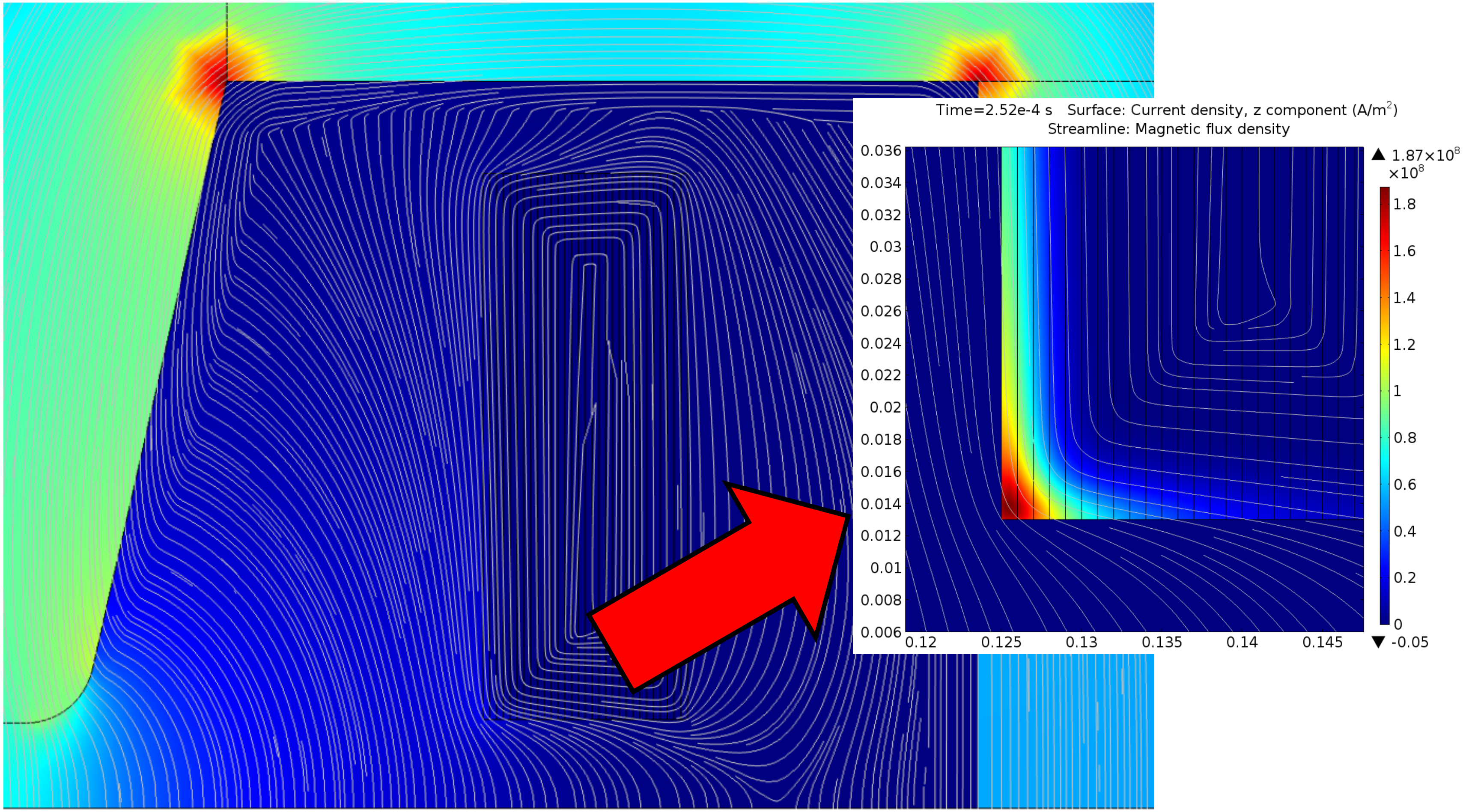


Power Dissipation Yoke

Average power dissipation: 1.57 kW/m



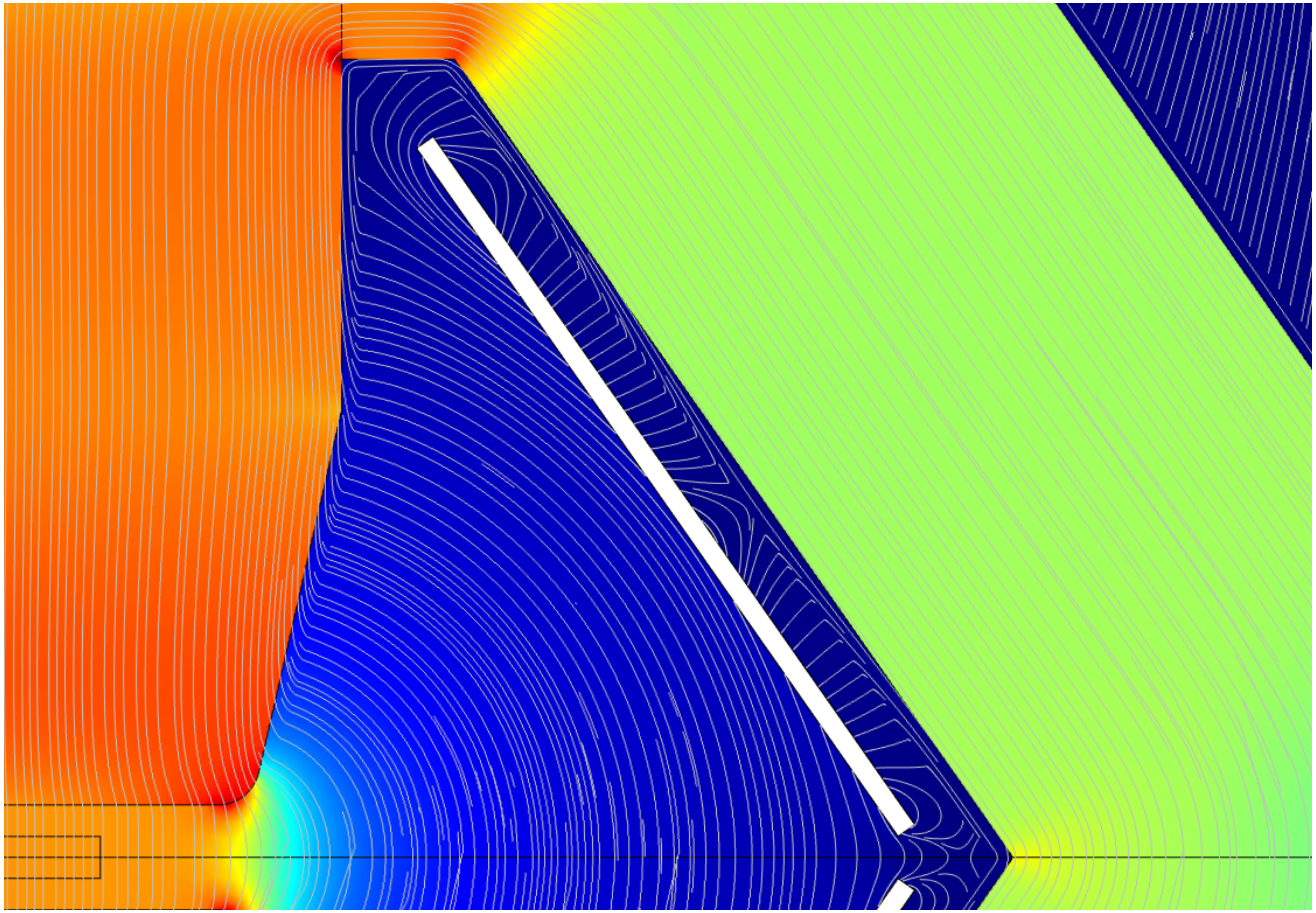
Old Geometry



Field lines not parallel to current sheets: high current density in corners of current sheets

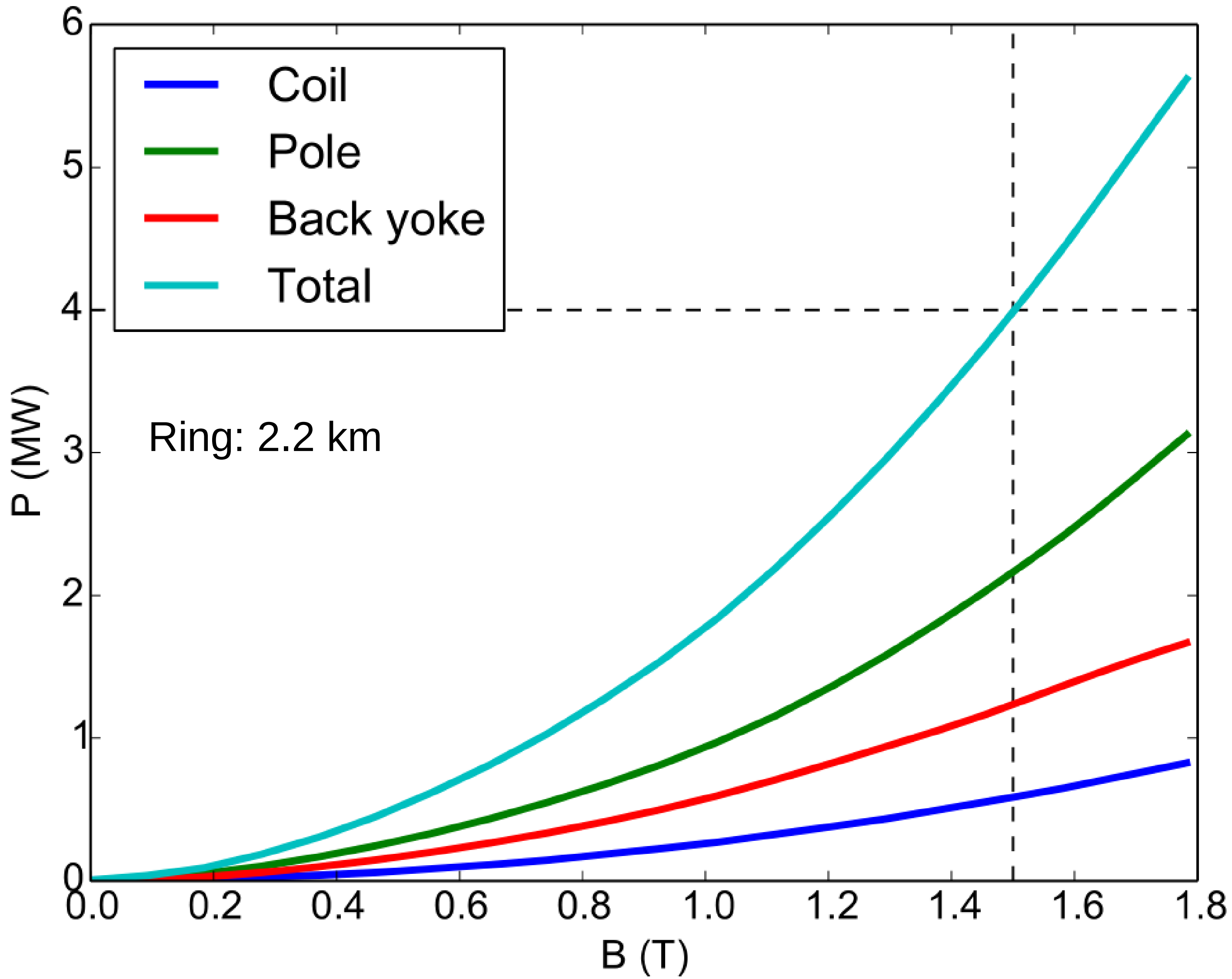
New Geometry

Coil loss: 250 W/m

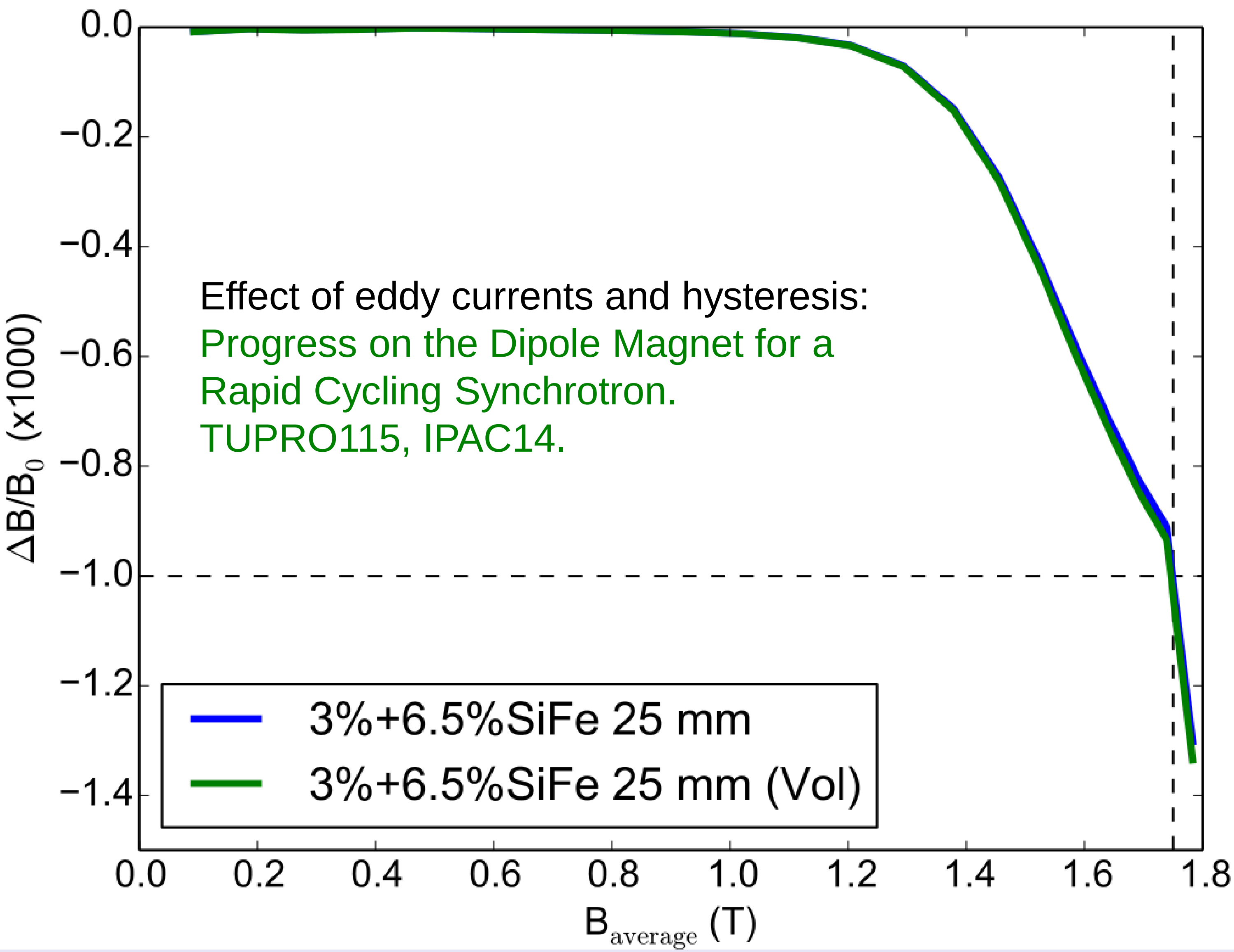


Field lines parallel to current sheet (reduction of eddy current losses by 30%)

Power Loss Contributions



Field Quality

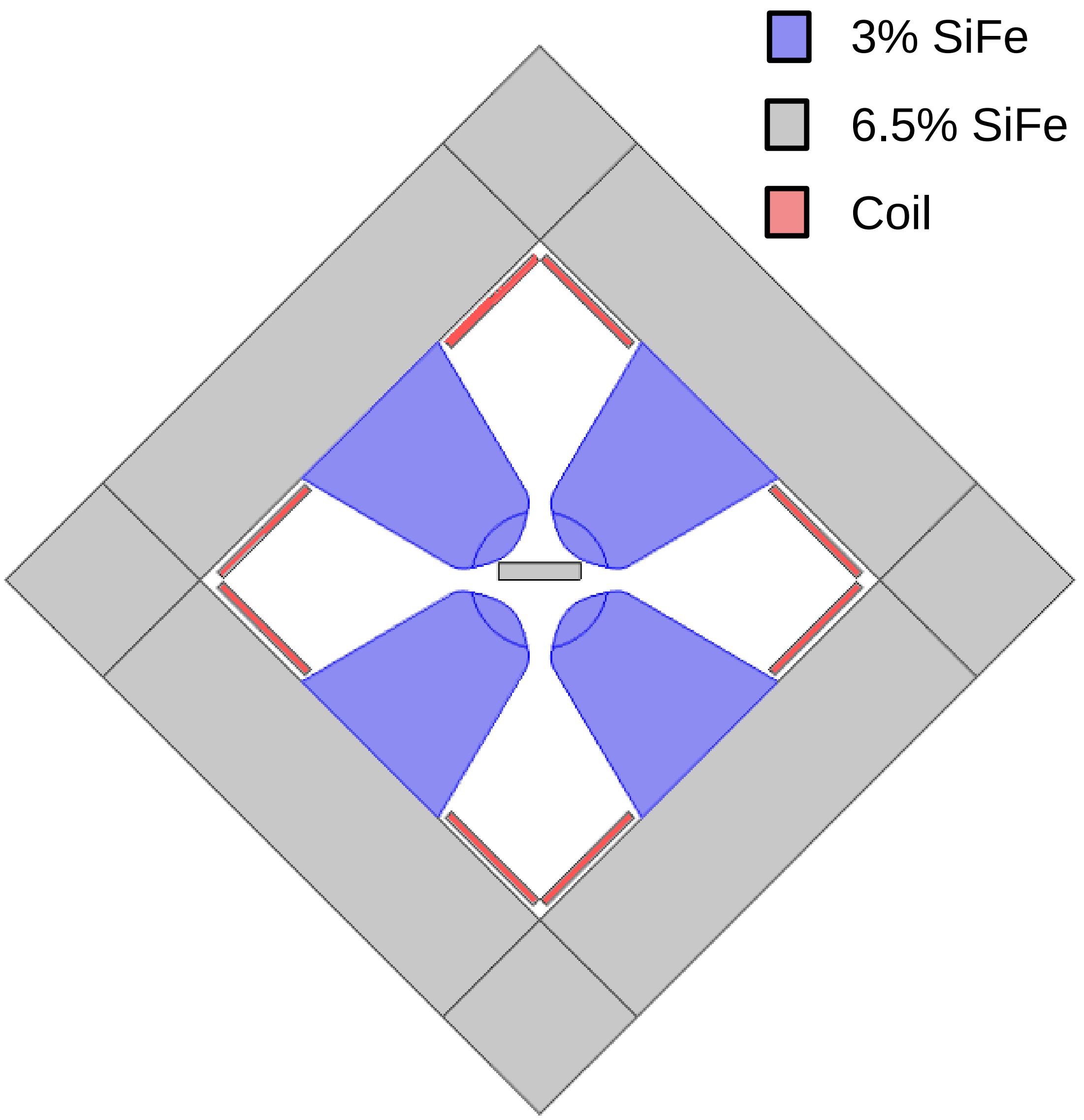


Specs

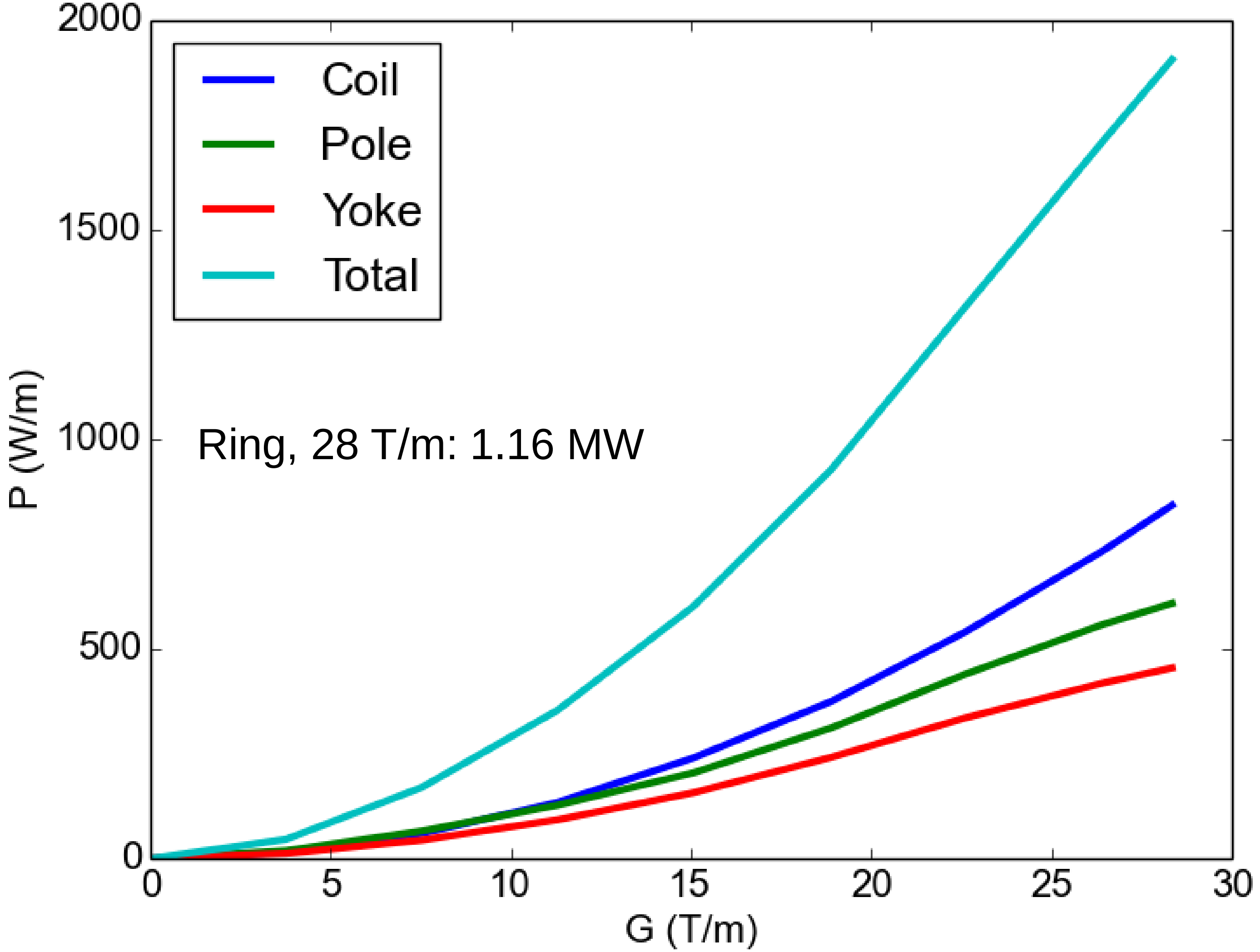
Machine Design	375-750 GeV	
Total Integrated Dipole Length	2200	m
Beam repetition rate	15	Hz
Yoke material	6.5%SiFe	
Pole material	3% SiFe	
Gap	25	mm
Good field region (h x v)	60x10	mm^2
Peak field Bmax	1.75	T
Field quality at Bmax	0.001	
Ramp rate (equivalent frequency)	1000	Hz
Power Loss Yoke (at 1.5T)	3.45	MW
Power Loss Coil (at 1.5T)	0.55	MW
Total Power Loss (at 1.5T)	4	MW
Stored energy	4200	J/m
Current per bus bar (4 bus bars)	15600	A*turns
Average peak current density cable	16	A/mm^2
DC resistance single cable	1.77E-05	Ohm/m
Voltage drop coil DC at 20 kA	0.353669	V/m
Voltage required to drive current	866	V/m
	(max dI/dt = 98017690 A/s)	
L (four PS per magnet)	8.84	uH

Quadrupole

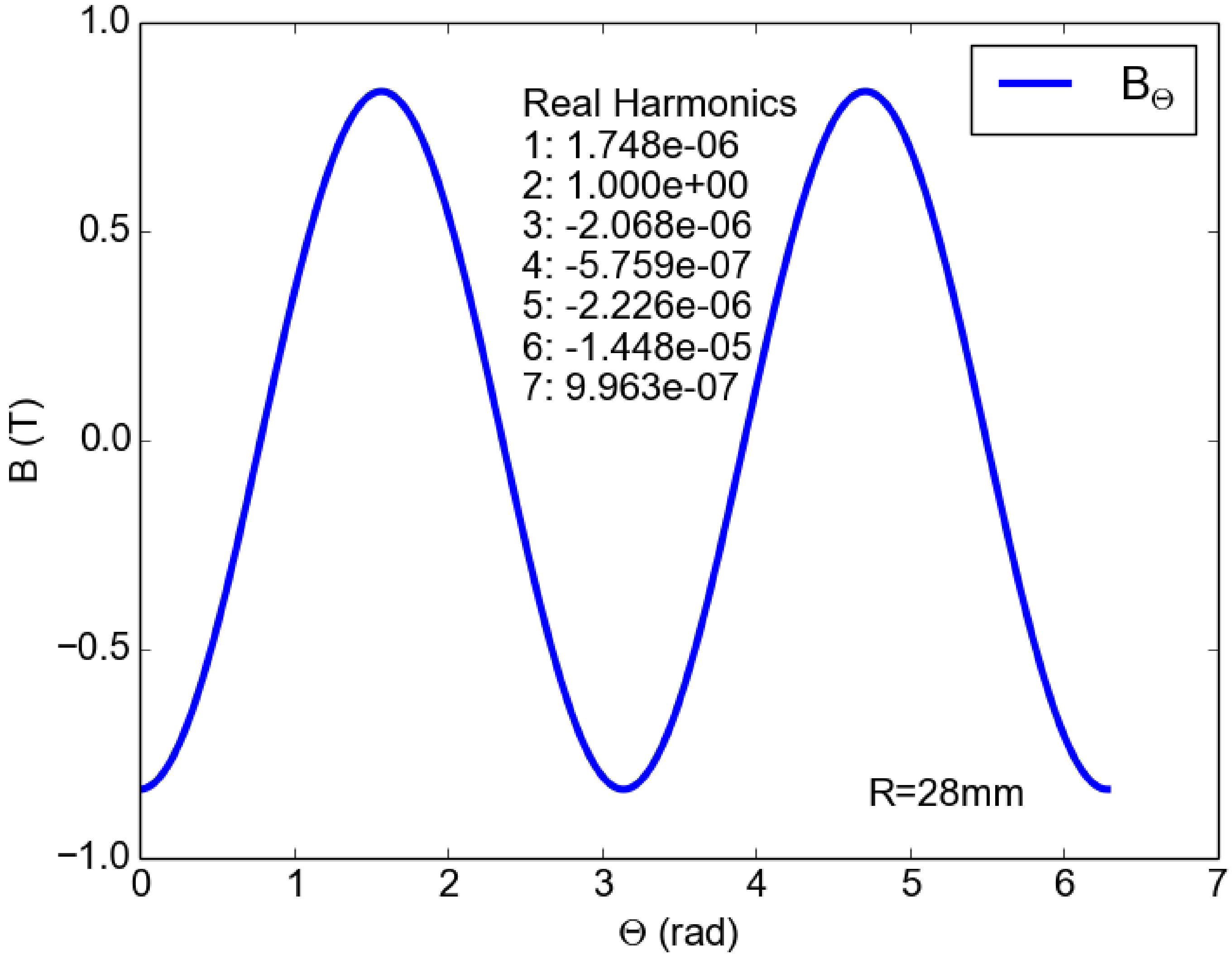
- Required gradient: about 30 T/m
- Good field region
  - 60x10mm^2
- Frequency: 1 kHz
- Pole: ‘ideal shape’
- Same design principles



Power Loss Quad



Field Quality



Conclusion

- Concepts for normal conducting magnets
  - Combine strength of two materials
  - Eddy current heating well understood
- Performance
  - Dipole field up to 1.75T
  - Gradient: 28.5 T/m
- Power losses
  - Acceptable losses at 1000Hz
- Future work
  - Minimize total loss (yoke + excitation coil)
  - Power Supply

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  - John Zweibohmer, Fermilab

Additional Slides

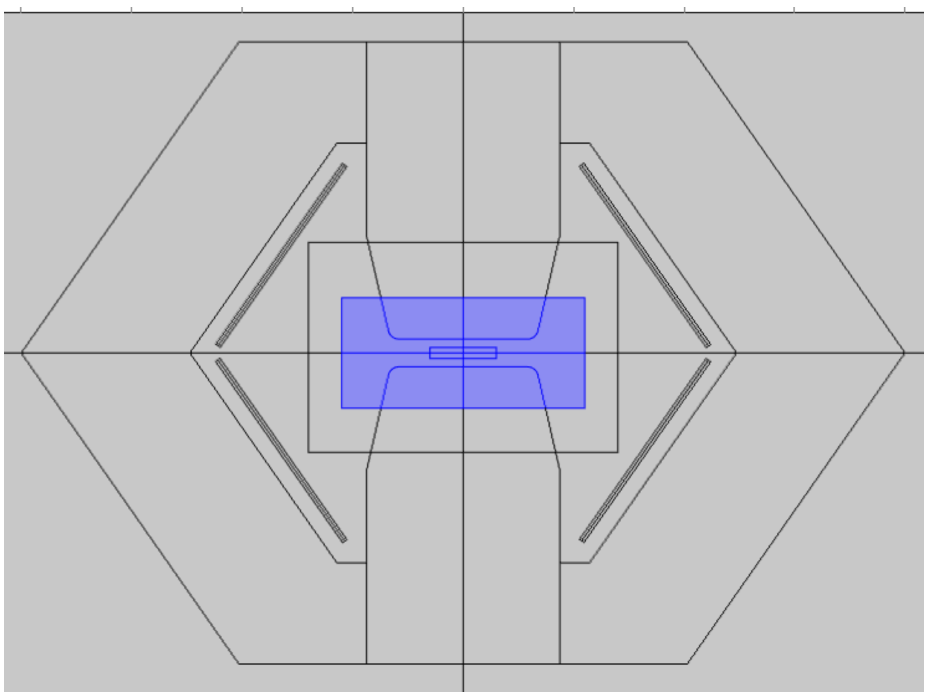
Superconducting Option

- Wall plug power superconducting version?
  - Not easy to answer – not enough data
- How good does a SC dipole have to be?
- Break even for SC version: 0.9 W/m
  - Normal conducting loss: 550 kW (2.2 km)
  - P_{300K} = 250 W/m
  - P_{4K}: 0.9 W/m (Carnot efficiency 280)
- Heat losses
  - Power leads: P_{4K} = 3-5 W
    (20 kA lead, CERN/NHMFL)
    - Need 8 for 2 m long magnet to keep voltage reasonable
  - Power loss conductor

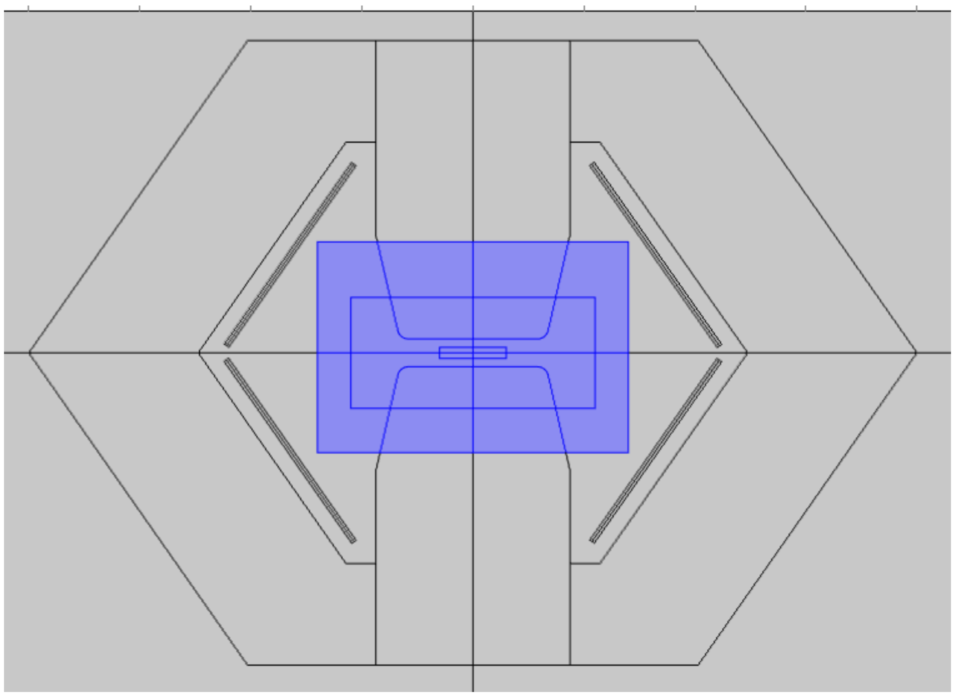
Magnetic Energy Distribution

Total: 4200 J/m (1.5T)

Percentage of magnetic energy in blue area:



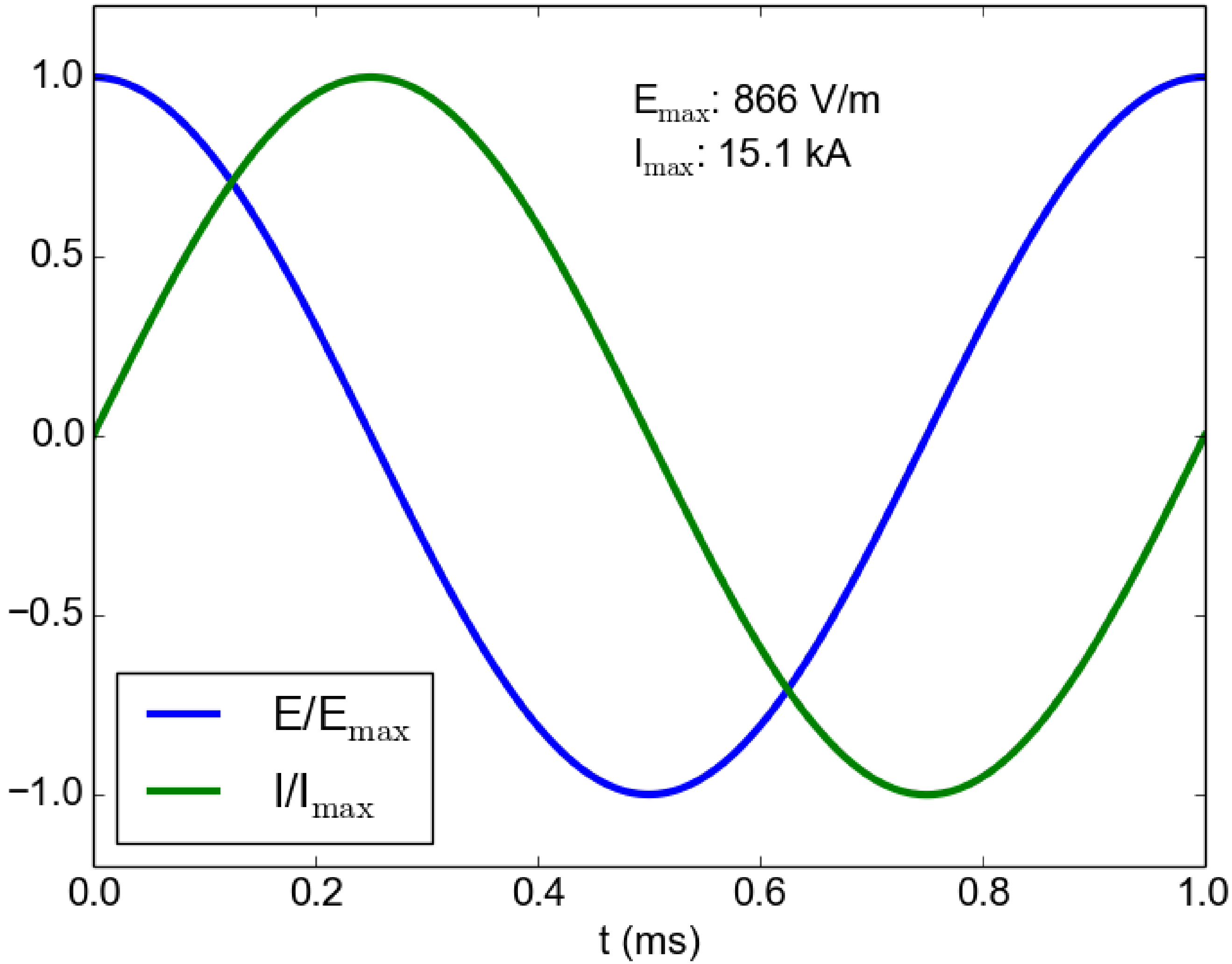
85%



92%

96% of magnetic energy are not in vicinity of coils

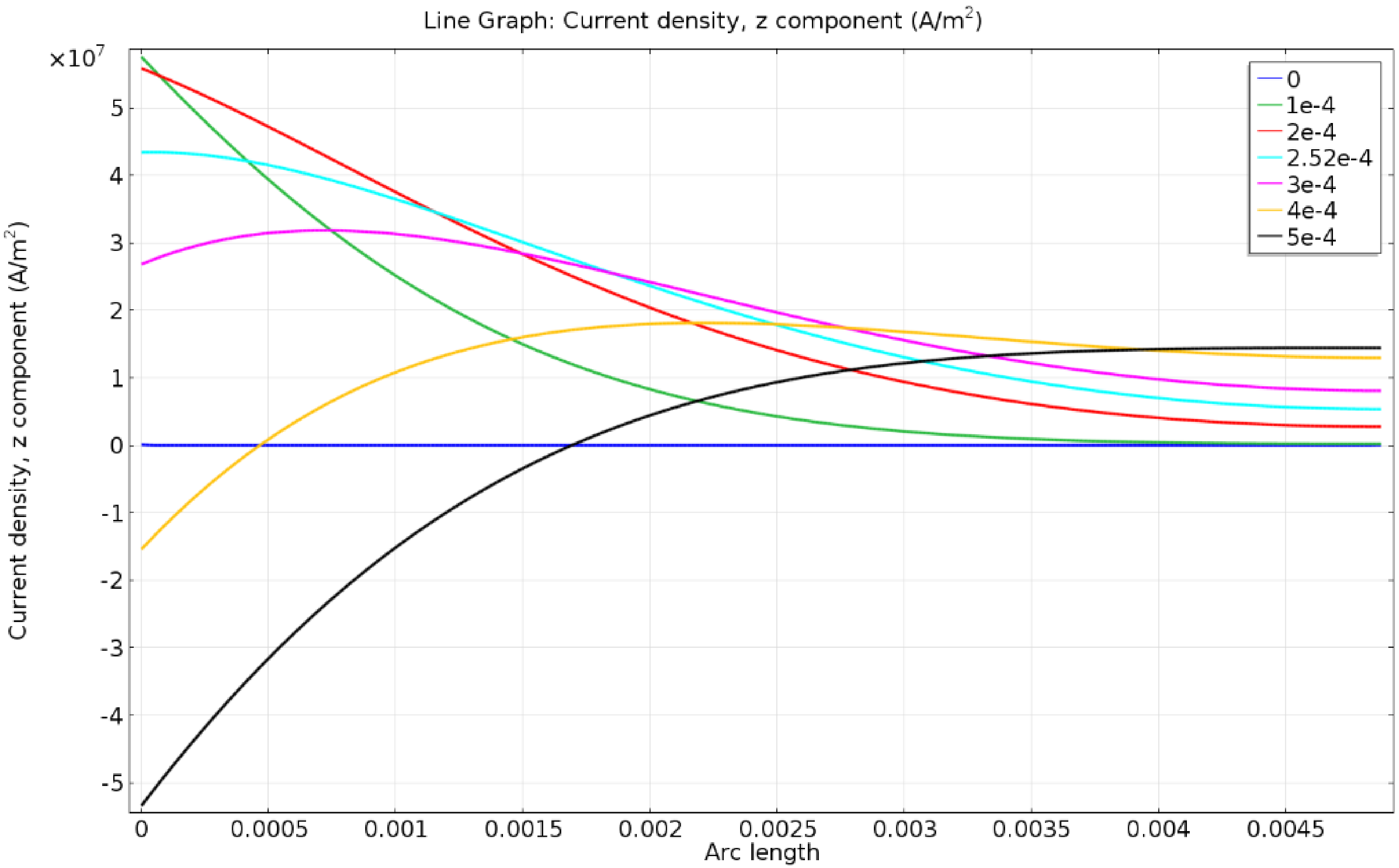
Excitation: Voltage Source



Excitation voltage

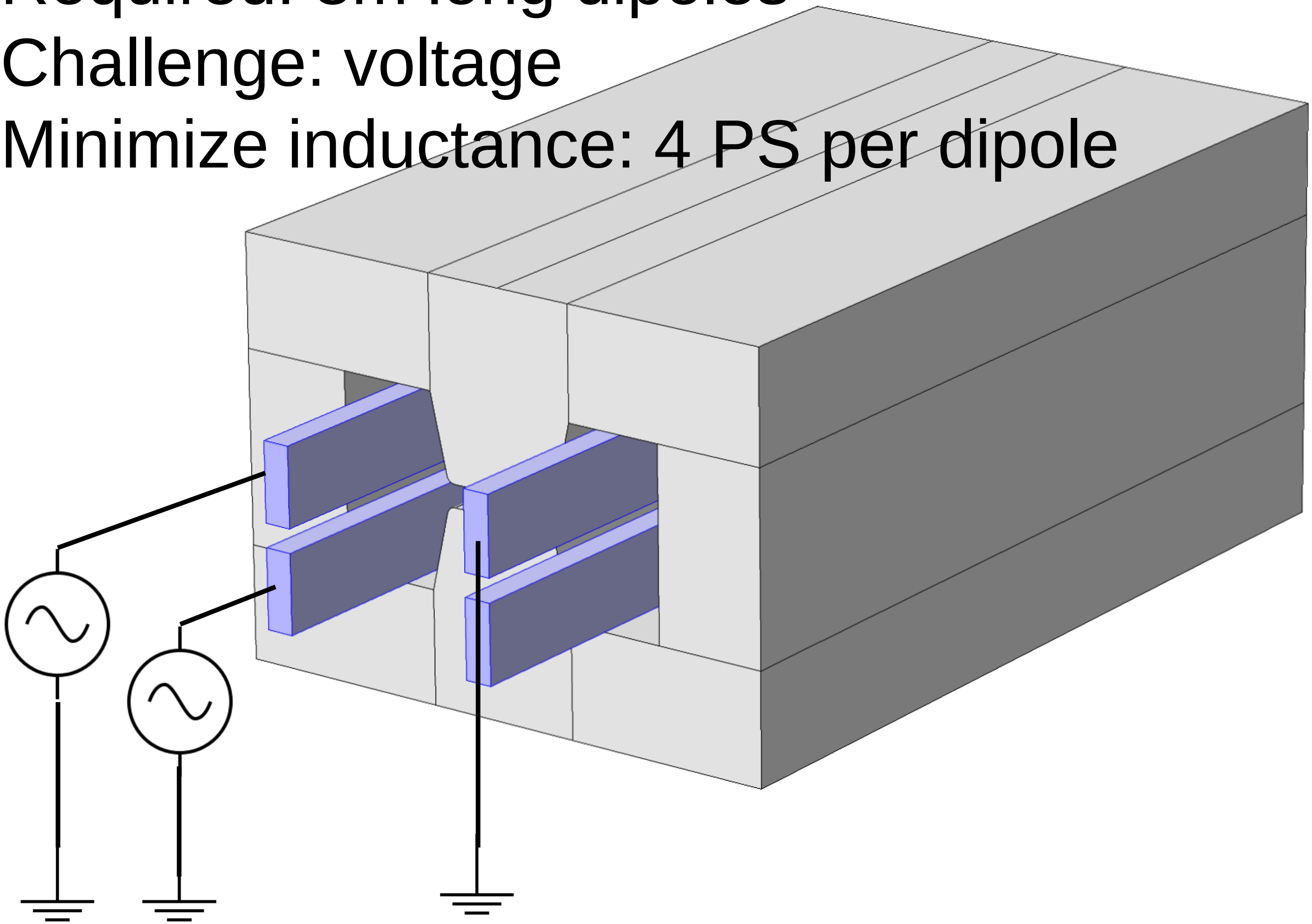
Current
(integrated J)

Current Density across sheets



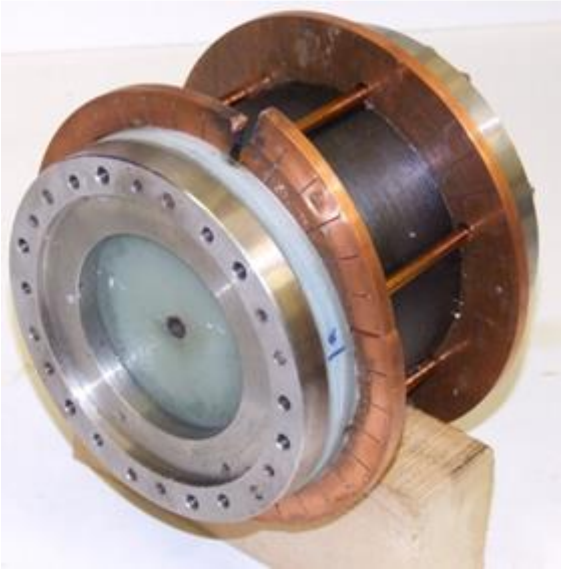
Power Supply

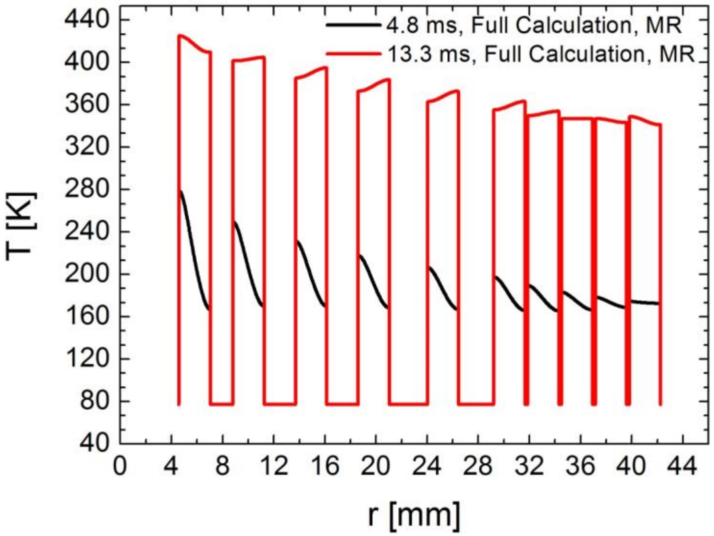
- Required: 8m long dipoles
- Challenge: voltage
- Minimize inductance: 4 PS per dipole



FEA: Eddy Current Simulation

- Technique developed ~10a ago
- Pulsed high field magnets (60-100T)
  - Normal conducting solenoids
  - 10 ms pulse
  - Operate at 77K
  - DOI:10.1109/TASC.2005.864485





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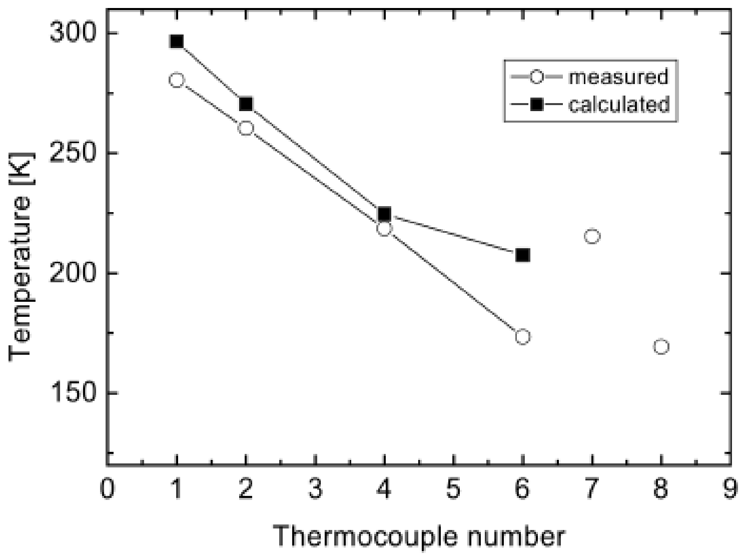
- Verified experimentally



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