Conceptual Design of the Positron Capture Solenoid

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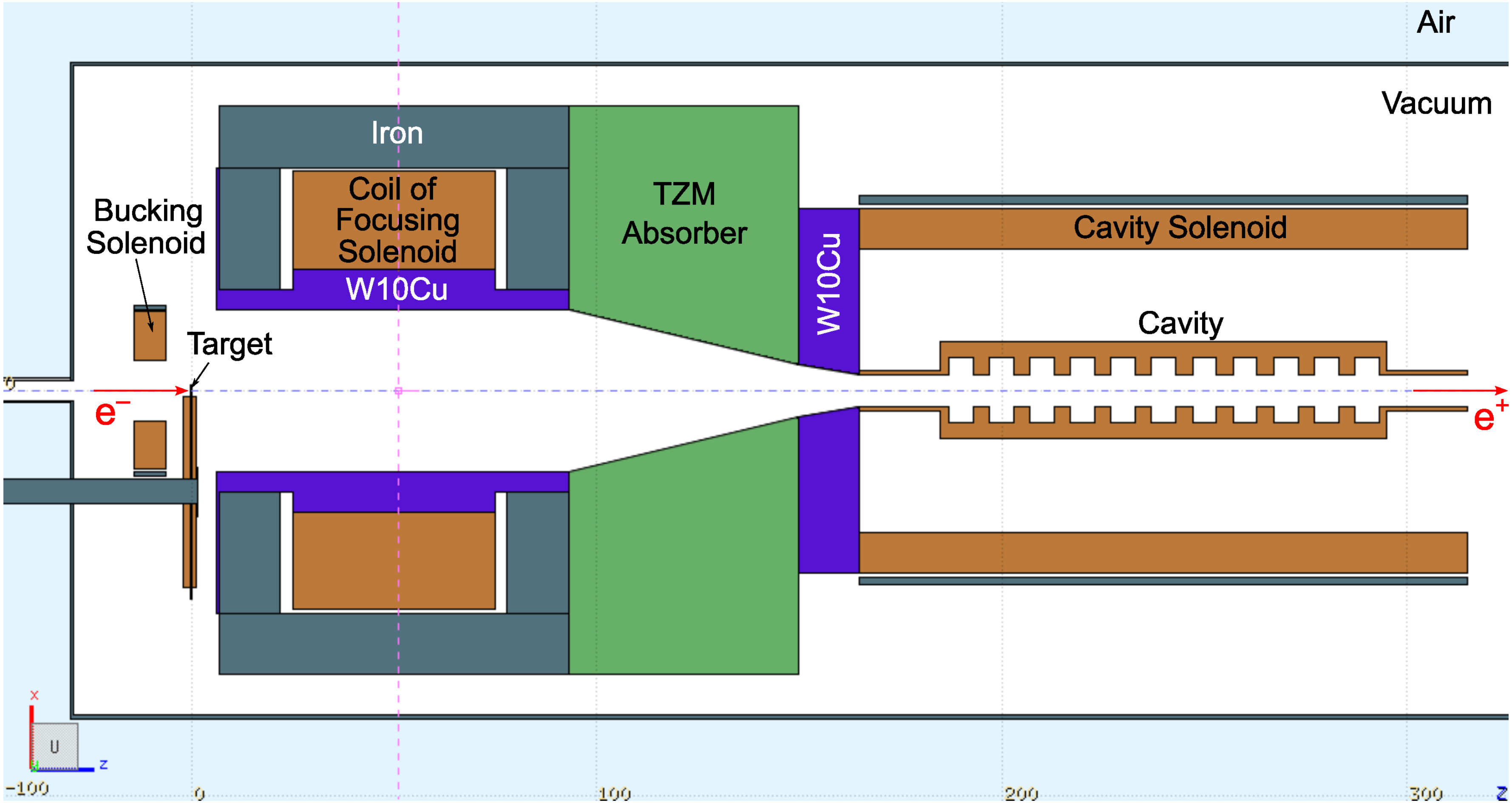
Background

- This work was begun 4Q23 beginning with an idealized concept by Andriy Ushakov presented 11 October 2023.
- This is NOT an engineered design: magnetics and heat transfer were considered.
- Eight hollow conductors from Luvata were examined. Assumed insulation increased conductor envelope by 1 mm aka 25 micron glass half-lapped and vacuum-epoxy potting. https://www.luvata.com/products/hollow-conductors
- Resistive heating and cooling were evaluated for coil configurations possible within the steel envelope in accompanying spreadsheet using https://www.pressure-drop.com/Online-Calculator/ Two examples are shown below.

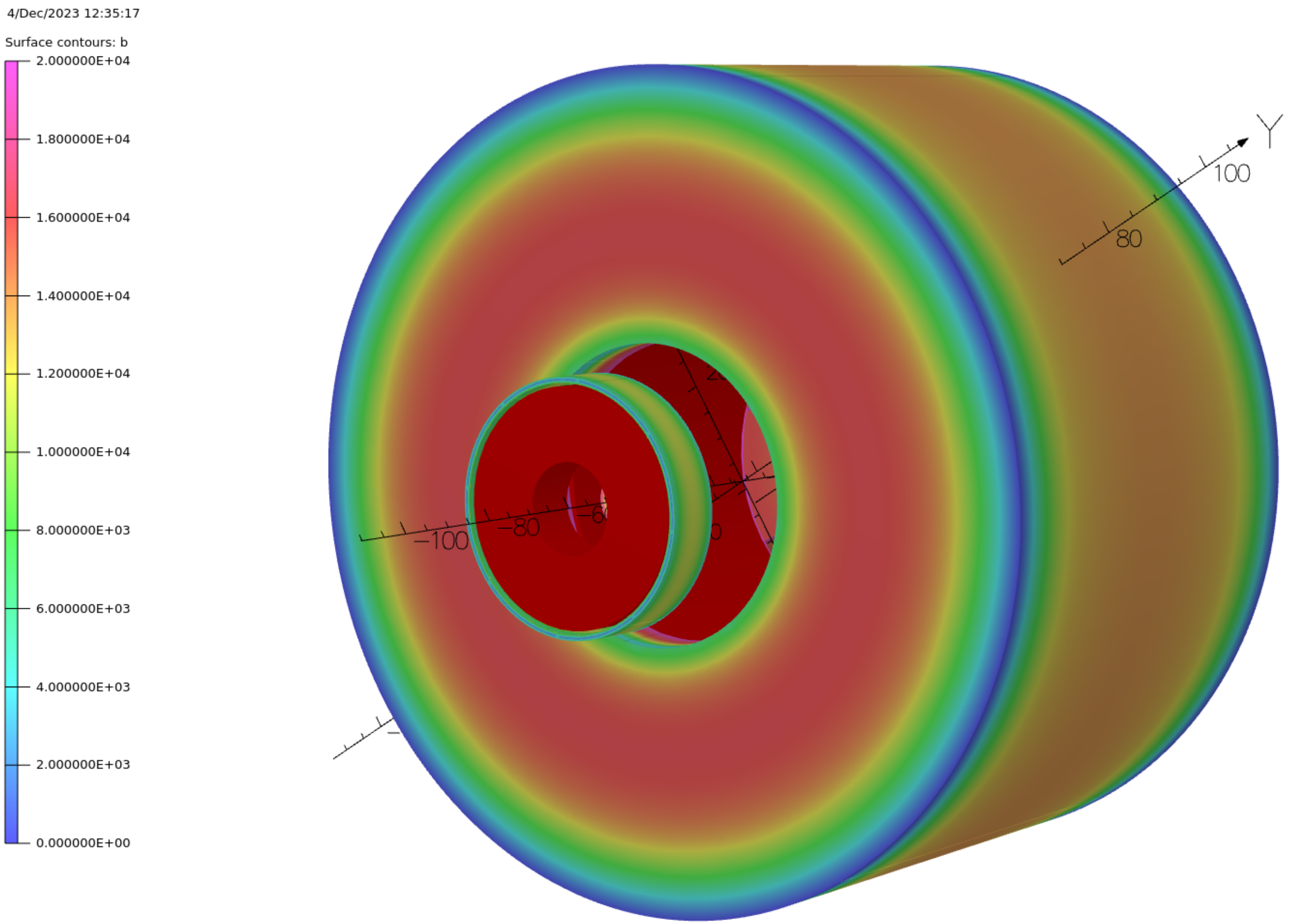
Andriy's IPAC paper Figure 1



Basics

- Coils total ~54 cm long, 60 cm ID, 108 or 111 cm OD
- Steel inside Z 56 cm
- Steel 15 cm ends, IR at ends 25 cm, steel cylinder 15 or 20 cm thick
- Target assumed at Z = -50 cm, 7 cm from end of steel.
- Small bucking solenoid ends at Z=-57 cm, 7 cm from target. This is intended to zero the field at the target so the emerging positron/electron beam is NOT magnetized as this complicates later optics.

Field on surface of steel, 1.3 T central field



Model with compensation solenoid centered at Z=-61.5 cm. Capture solenoid center at Z=0, conversion target at Z=-50. 7 cm clearance on either side of target.

Requirements

- Sami Habet analyzed the requirements for capturing positrons centered about three energies: 6 MeV, 19 MeV and 60 MeV.
- At 6 MeV, 1.27 T solenoid 6 cm long optimal (unpolarized)
- At 19 MeV, 1.3 T solenoid 25 cm long (unpolarized)
- At 60 MeV, 1.3 T solenoid 50 cm long (polarized)
- Only the last condition can be met with a conventional conductor. ~0.9 T possible for second. All might be possible with a segmented superconducting system; I have not explored that option.

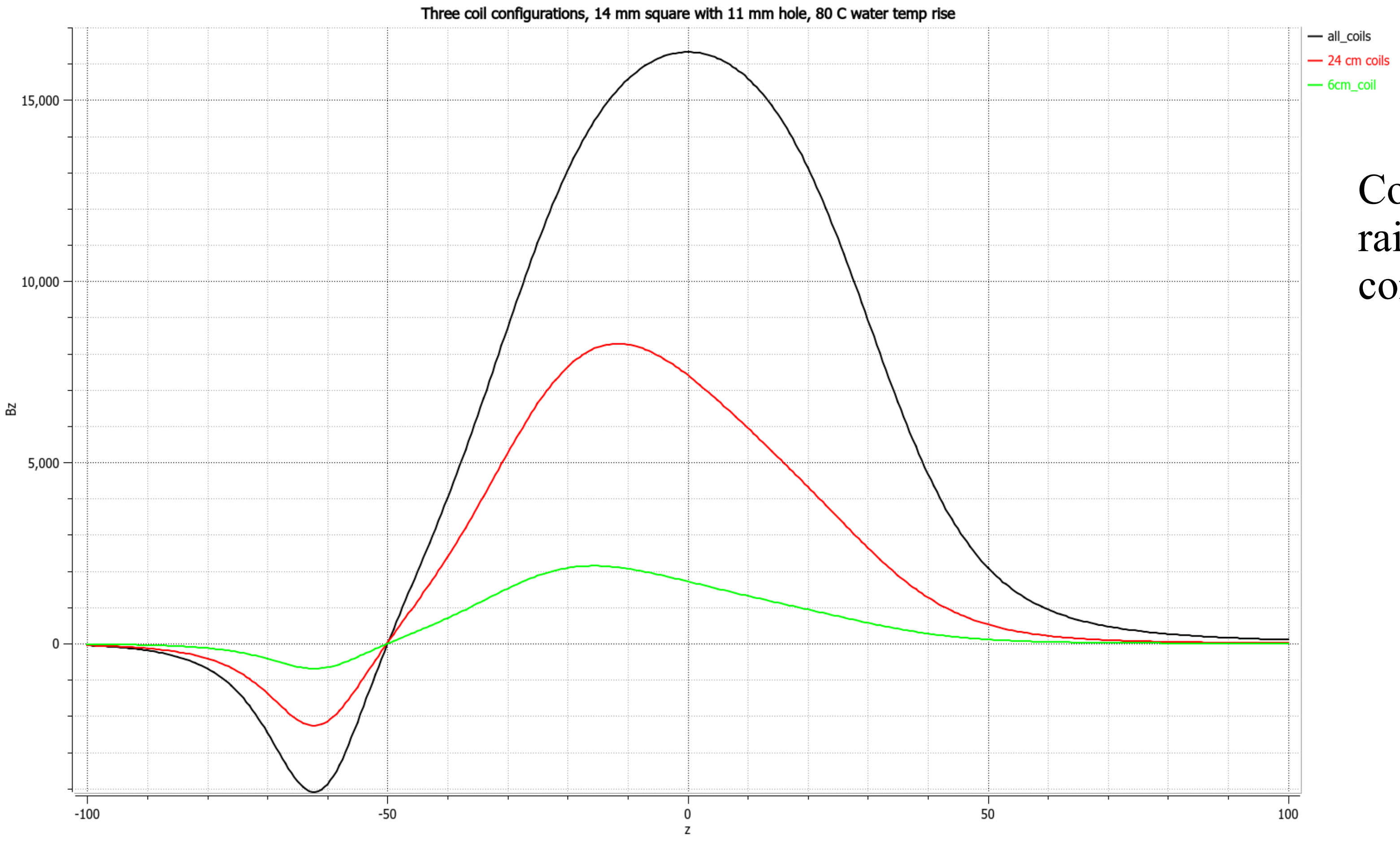
How requirements drove models

- Solenoids and cavity will become activated. W10Cu and TZM will become very hot and would have to be removed to swap solenoids.
- Moving the cavity will be difficult due to waveguide to RF power gallery upstairs so the magnet and the target would have to be moved downstream.
- Given activation, remote material handling equipment would be needed to remove the long system, install the shorter magnet and its shielding, and move the target downstream.
- The models therefore have three coils within the steel, ~6 cm long, 17-18 cm long and ~30 cm long, to a total of 54.0 or 54.4 cm. One, two or three are energized in what follows.

Additional assumptions

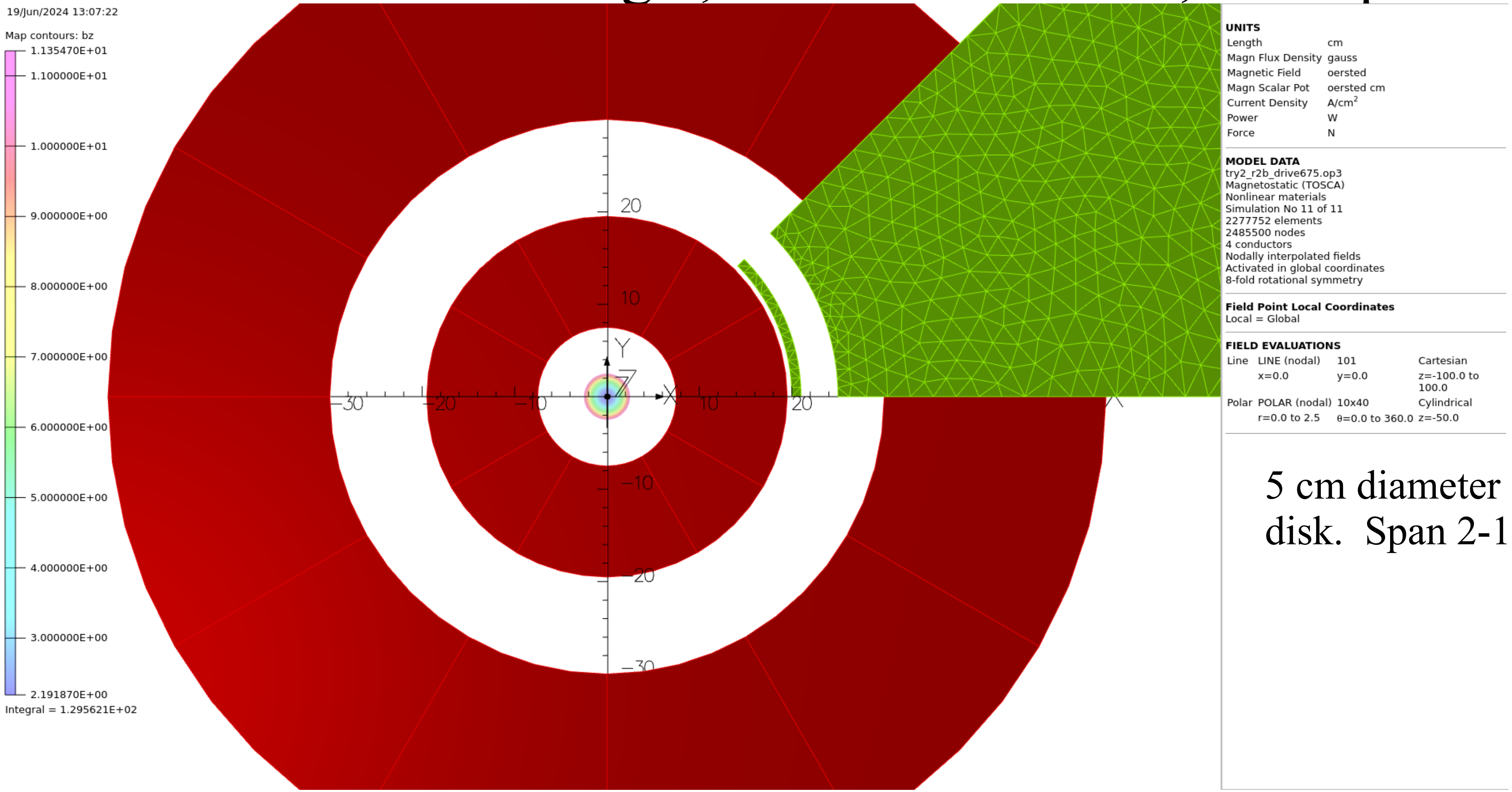
- The main coil is to be fabricated from double pancakes wound radially with water and current connections at the OD. See GTS coil for an example. The gap between coil OD and steel ID is intended to accommodate the water and current connections; it may be increased. The steel at OD in second model is 20 cm thick so a longitudinal slot may be machined in it to pass the water lines and current leads.
- The field capability of each model is limited by how much water can be pushed through each double pancake by 20 bar water.
- I assume a chiller producing 4 C water at 20 bar at the coil entrance; perhaps 25 bar at the exit of the chiller installed outside the LERF.

14 mm square conductor with 11 mm hole



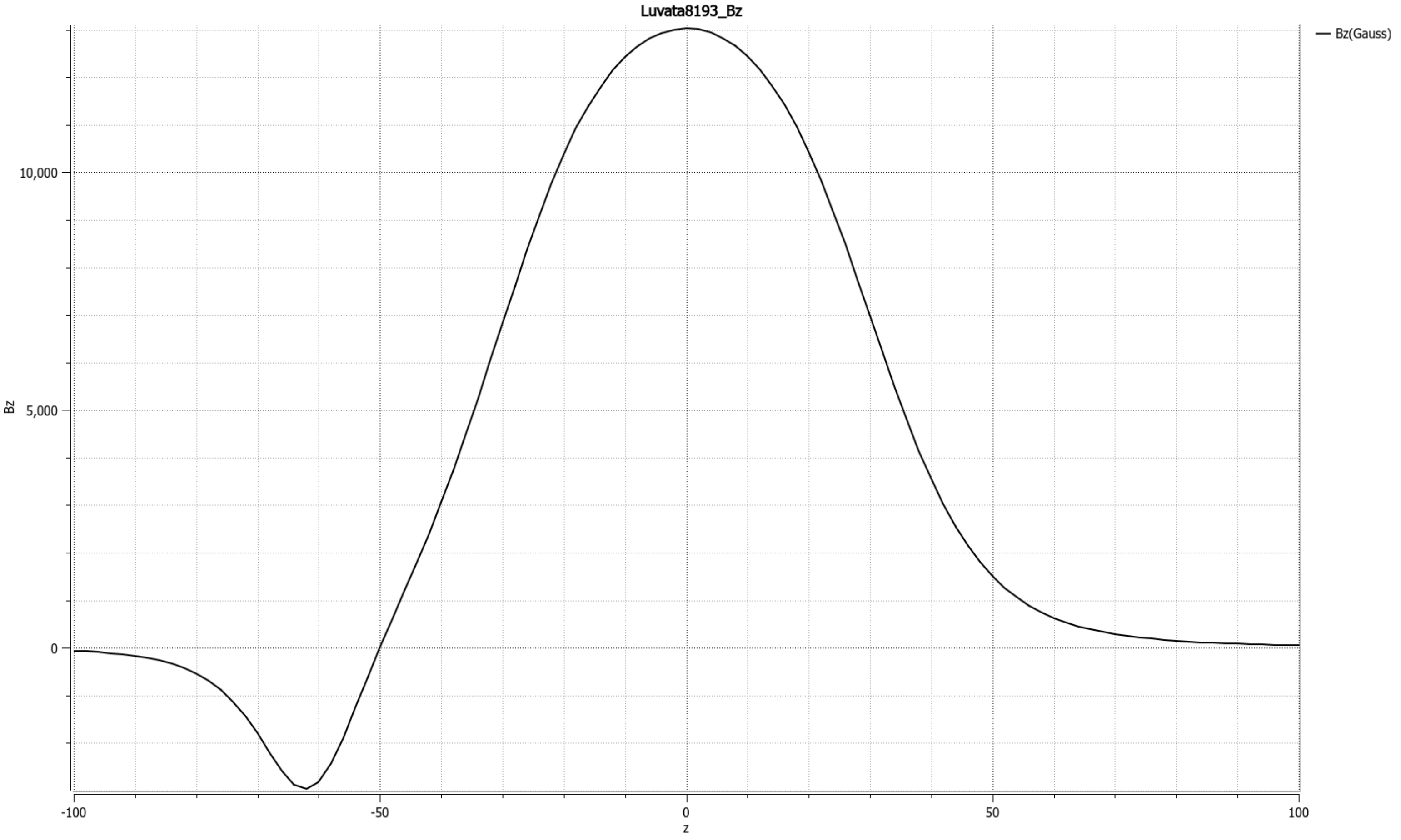
Coil current railed in three configurations

Field at conversion target, 14 mm conductor, 1.3 T peak



5 cm diameter disk. Span 2-11G

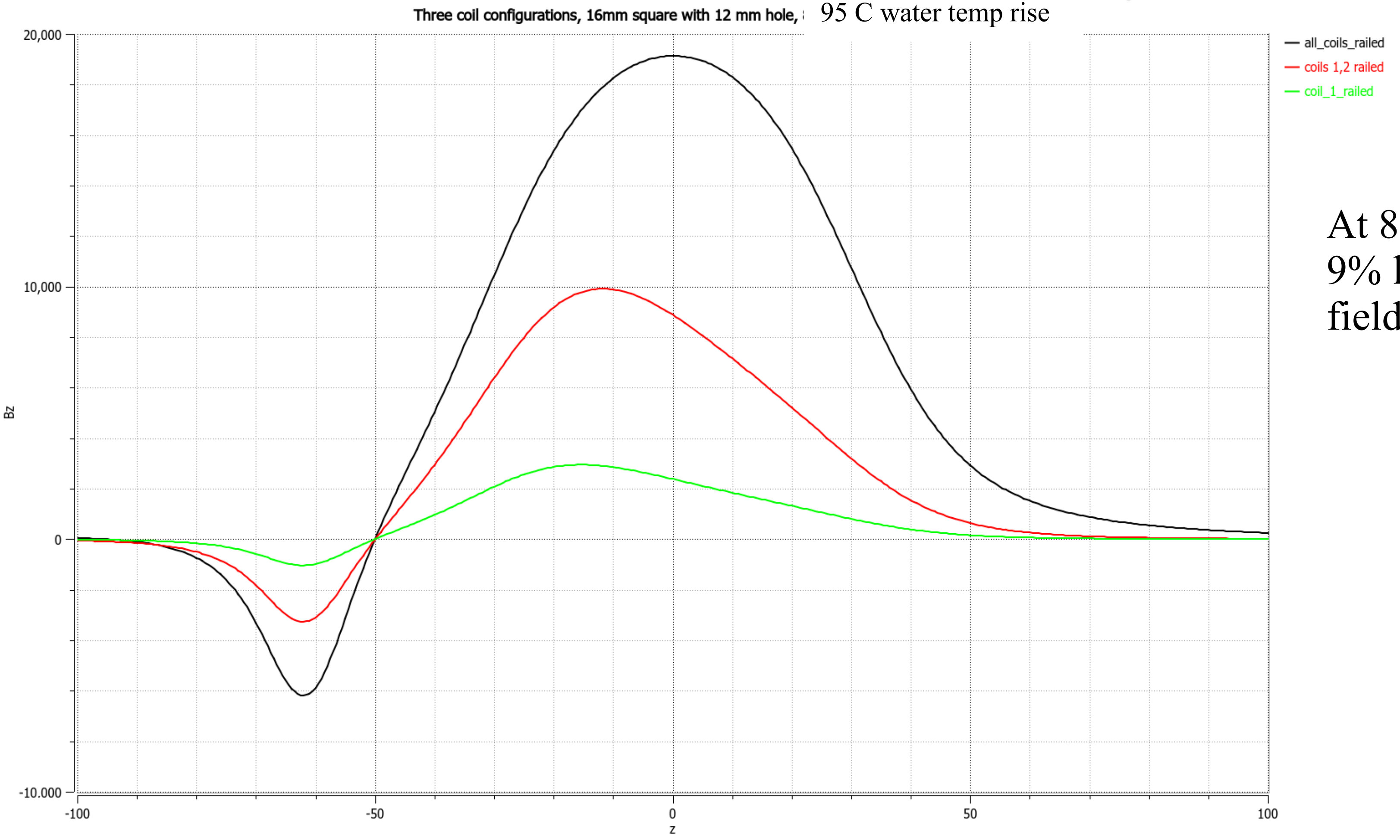
14 mm conductor current adjusted for 1.3 T peak field



16 mm square conductor, 12 mm hole

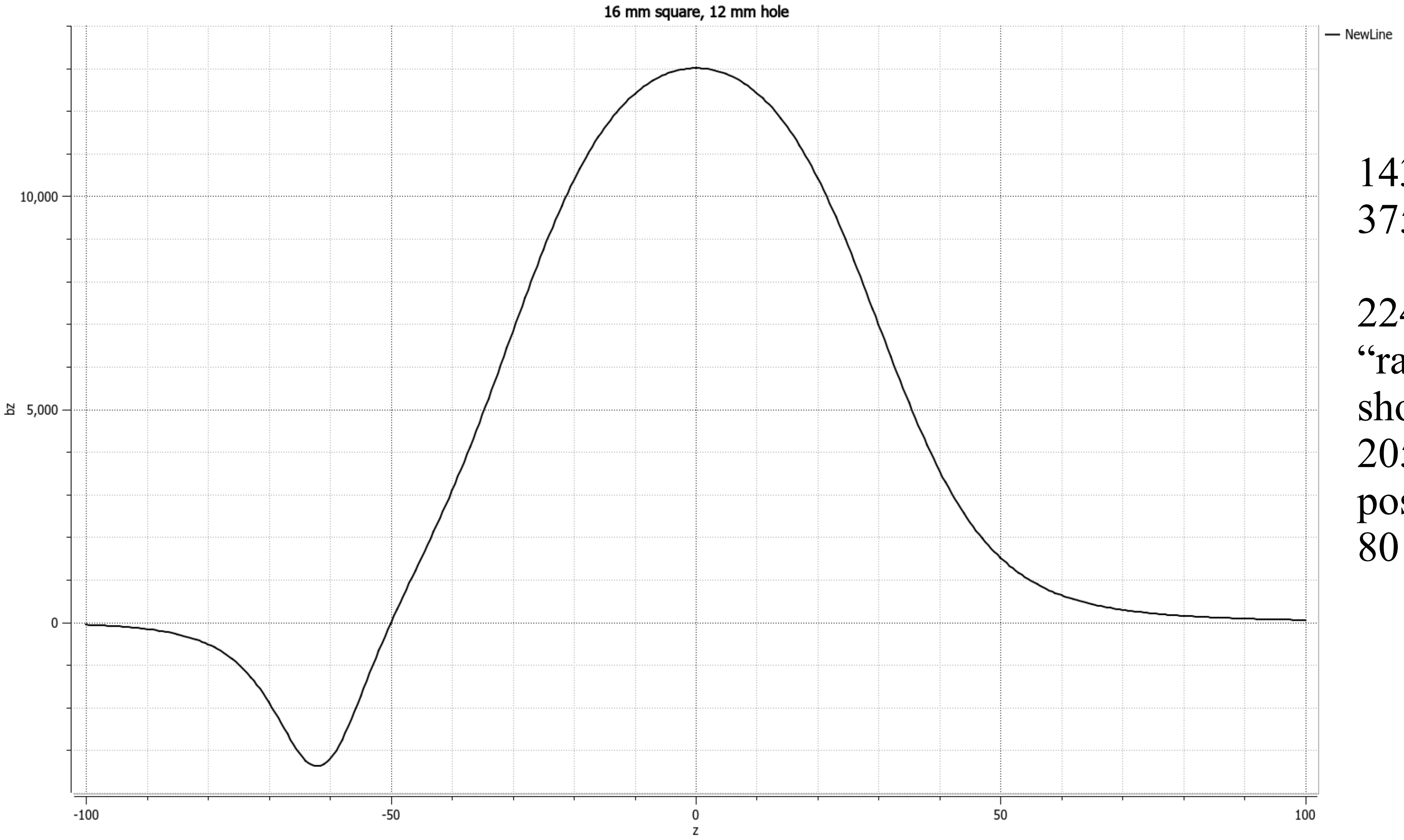
- Since the 11 mm hole did not allow enough water flow to approach the second requirement I tried a 16 mm square conductor. Coil envelope is slightly larger. Turns count is lower and current higher.
- My initial power calculation for this conductor was incorrect: 19 bar water would suffer a temperature rise of 95 C when the current is railed in the next slide. Fields will be 9% lower than shown.
- Three coils are 6.8 cm, 17 cm and 30.6 cm long. Two coils each 27.2 cm long would be more practical.

16 mm conductor, three coil configurations



At 80 C rise, 9% lower fields

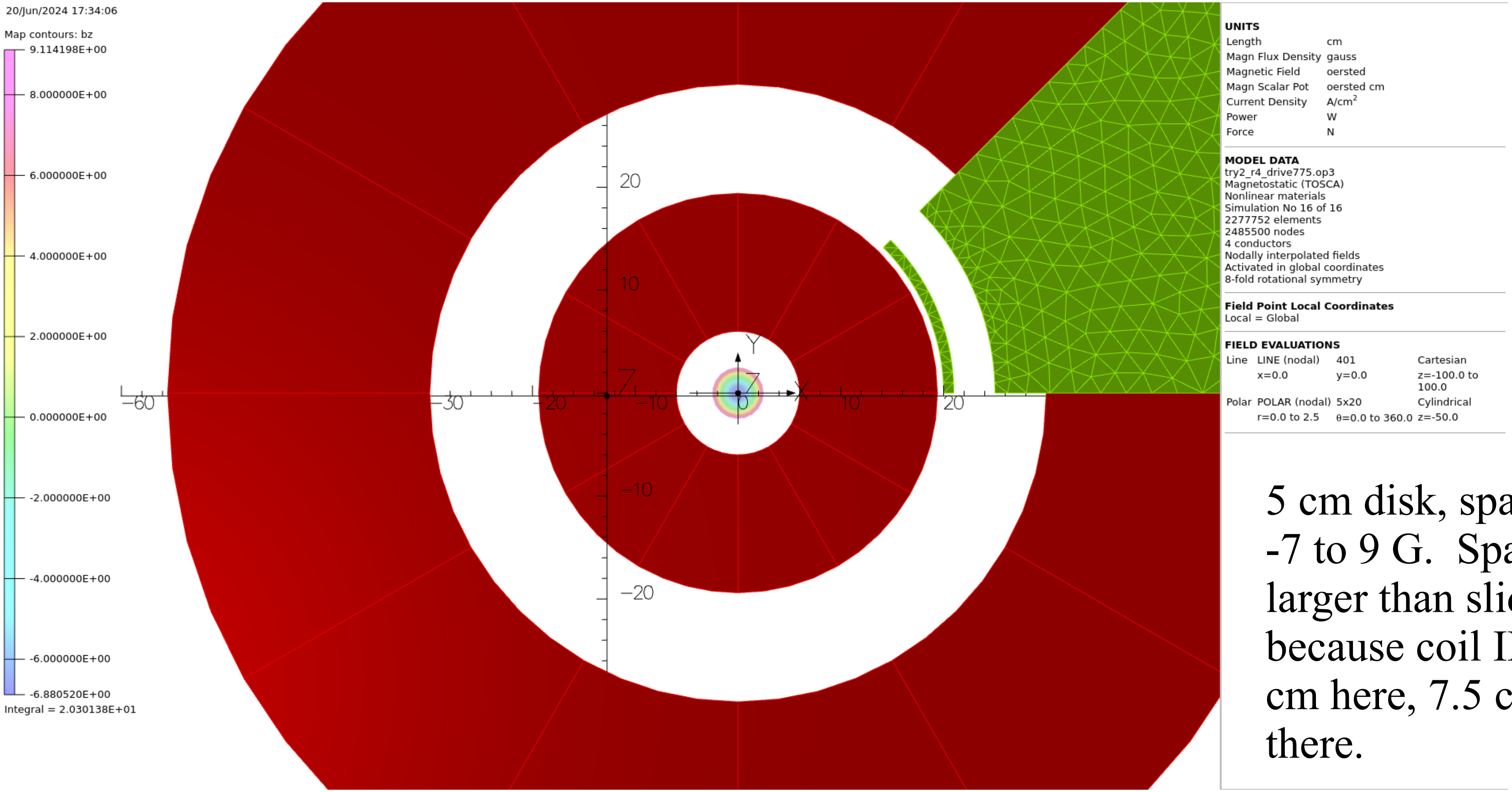
16 mm conductor, 1.3 T with all coils on



1430 A, 260 V
375 kW

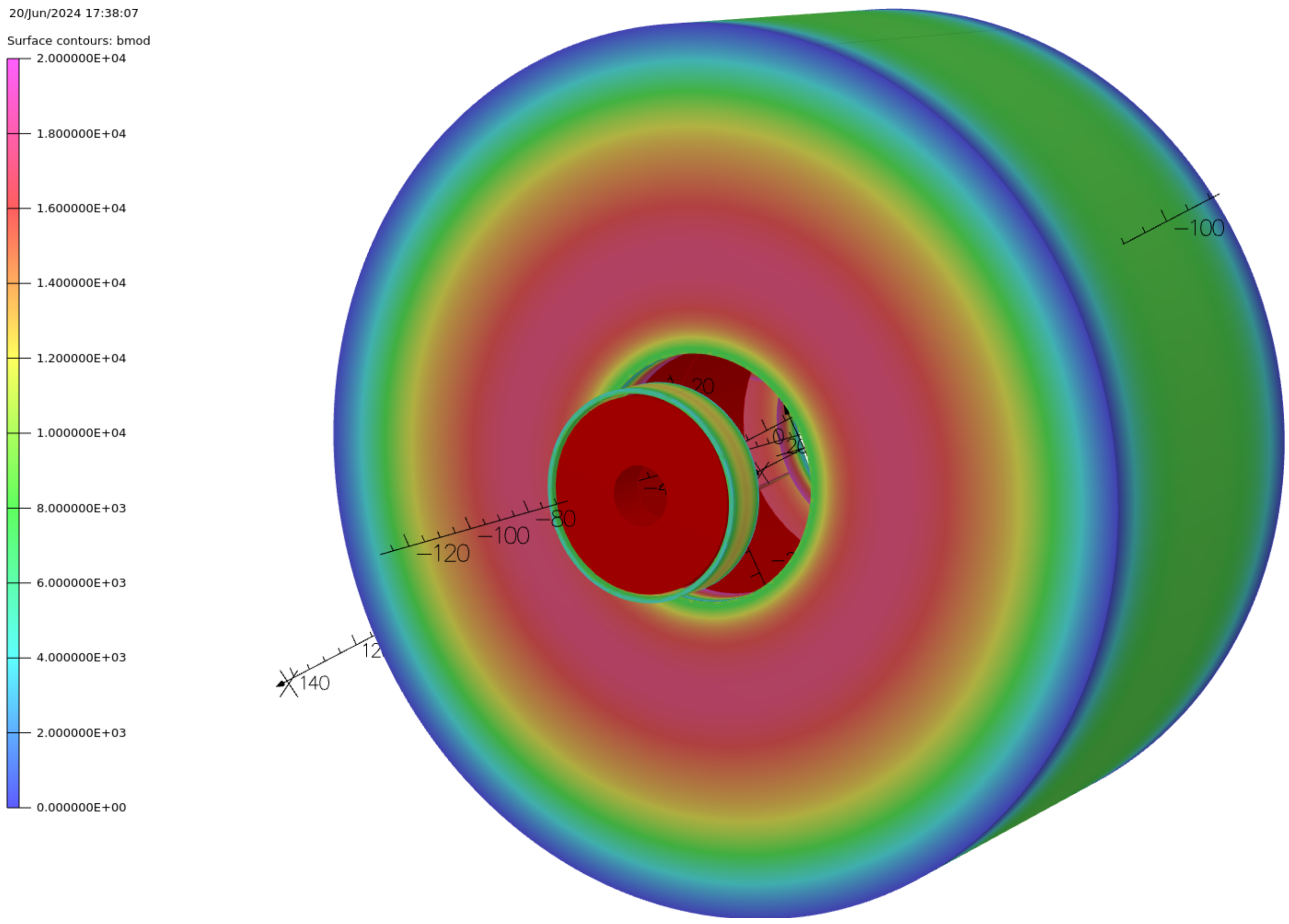
2240 A for the "railed" fields shown earlier.
2050 A, 190 V possible with 80 C rise.

Field at conversion target



5 cm disk, span -7 to 9 G. Span larger than slide 10 because coil IR 6 cm here, 7.5 cm there.

16 mm conductor, 1.3 T, field on steel surface



UNITS

Length	cm
Magn Flux Density	gauss
Magnetic Field	oersted
Magn Scalar Pot	oersted cm
Current Density	A/cm^2
Power	W
Force	N

MODEL DATA
try2_r4_drive775.op3
Magnetostatic (TOSCA)
Nonlinear materials
Simulation No 16 of 16
2277752 elements
2485500 nodes
4 conductors
Nodally interpolated fields
Activated in global coordinates
8-fold rotational symmetry

Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS

Line	LINE (nodal)	401	Cartesian
	x=0.0	y=0.0	z=-100.0 to 100.0
Polar	POLAR (nodal)	5x20	Cylindrical
	r=0.0 to 2.5	θ=0.0 to 360.0	z=-50.0

Thicker end plates would help if the rotating target mechanism allows.

Bucking solenoid

- Fall 2023 thought was to use the same conductor as main magnet and drive in series. Segmenting the main precludes that.
- Coil in 16 mm model is assumed to be wound of heavy film insulated #4 solid conductor, 0.536 cm MMC. 16 turns by 25 layers.
  Error: layer count must be even so both leads are on same side.
  Realized 6/21, too late to change.
- Current 190 A for 1.3T central field, resistance 0.25 Ω, power ~9 kW.
  Side area 1070 cm^2 so an upstream side cooling plate should suffice.
  ID and OD cooling possible. Downstream side unlikely to be available due to target mechanism.

Conclusions

- Capture solenoid engineering and fabrication effort will be dominated by cooling requirement.
- It is possible to compensate the field of the capture solenoid so the positrons are created in near-zero field. The spinning copper rotor with tungsten target will still generate eddy currents. Field at exit of capture solenoid is non-zero.
- The Physics Division Magnet Group should be consulted about a segmented superconducting magnet with iron return (versus self-shielded) since the iron is useful for radiation shielding and the self-shielding coil would also have to be segmented.

Notes re final engineering design

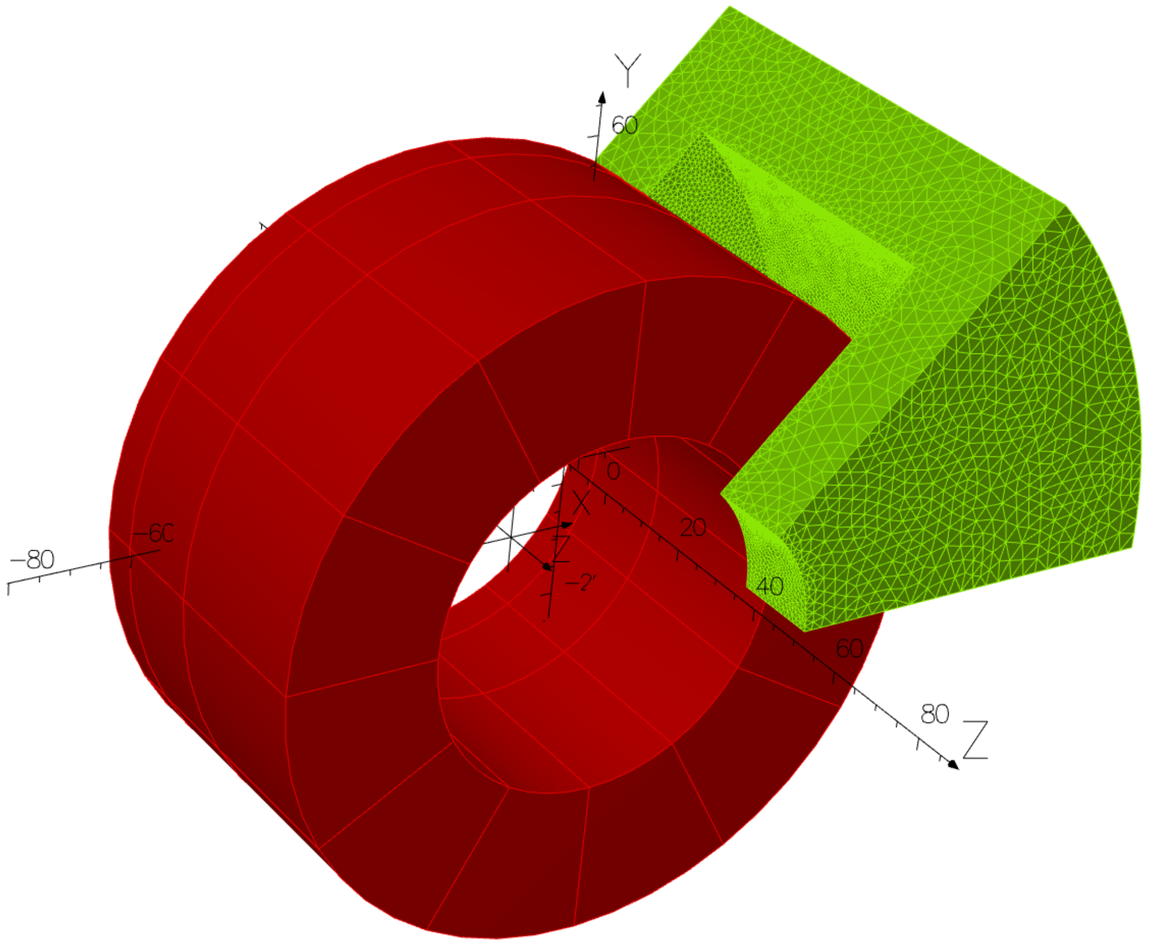
- Stored energy of system is ~230 kJ. Derived inductance 0.23 H.
- Magnetic pressure ~9 atm, effect on dimensions not calculated.
- Thermal expansion not calculated.
- Heat transfer within bucking solenoid not calculated.

References

- Solenoid Magnet Design by D. Bruce Montgomery, © 1969
- Rough conceptual design for positron capture solenoid

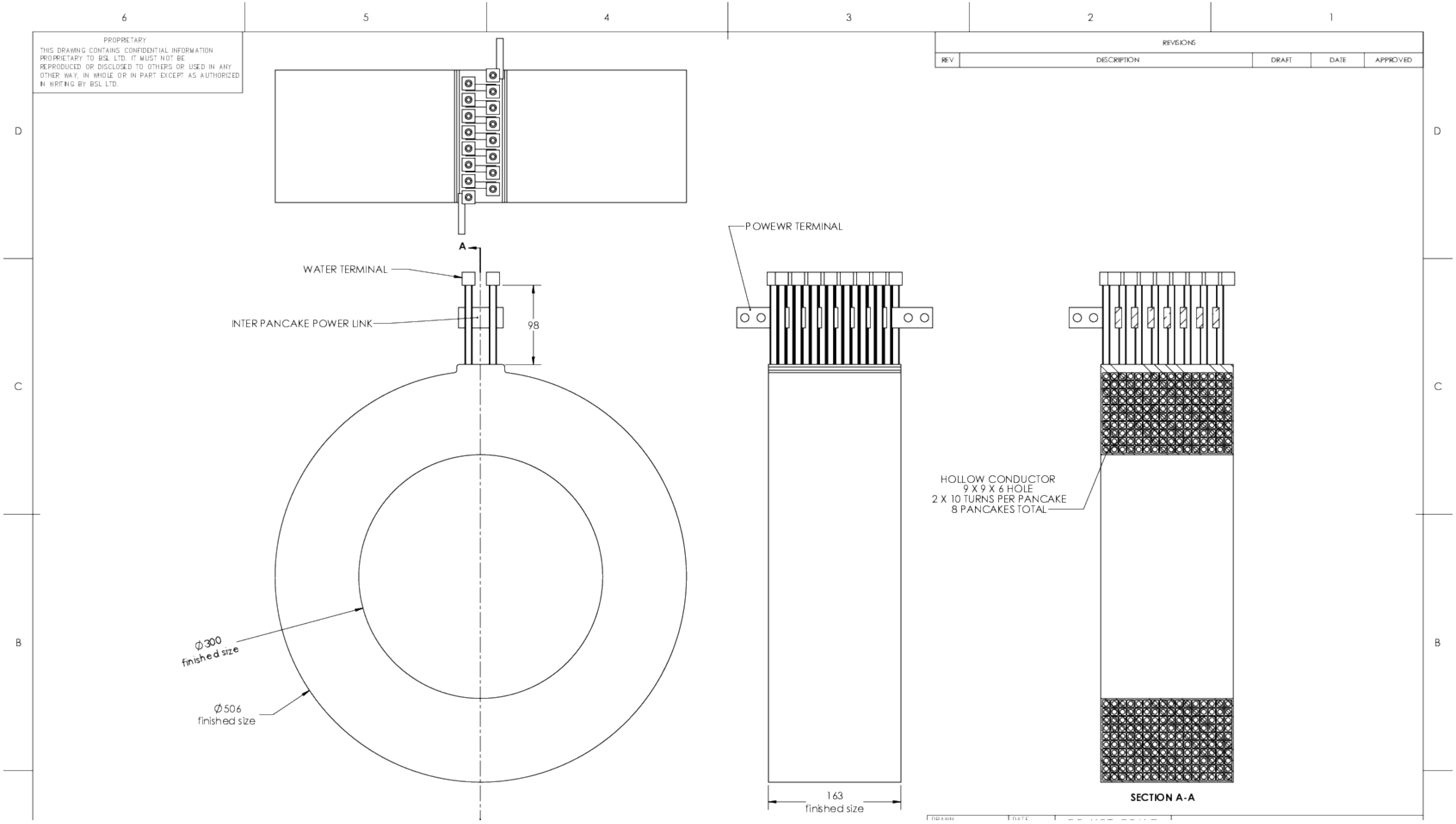
  https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-277909/23-067.pdf
- Second iteration on positron capture solenoid

  https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-278905/23-077.pdf



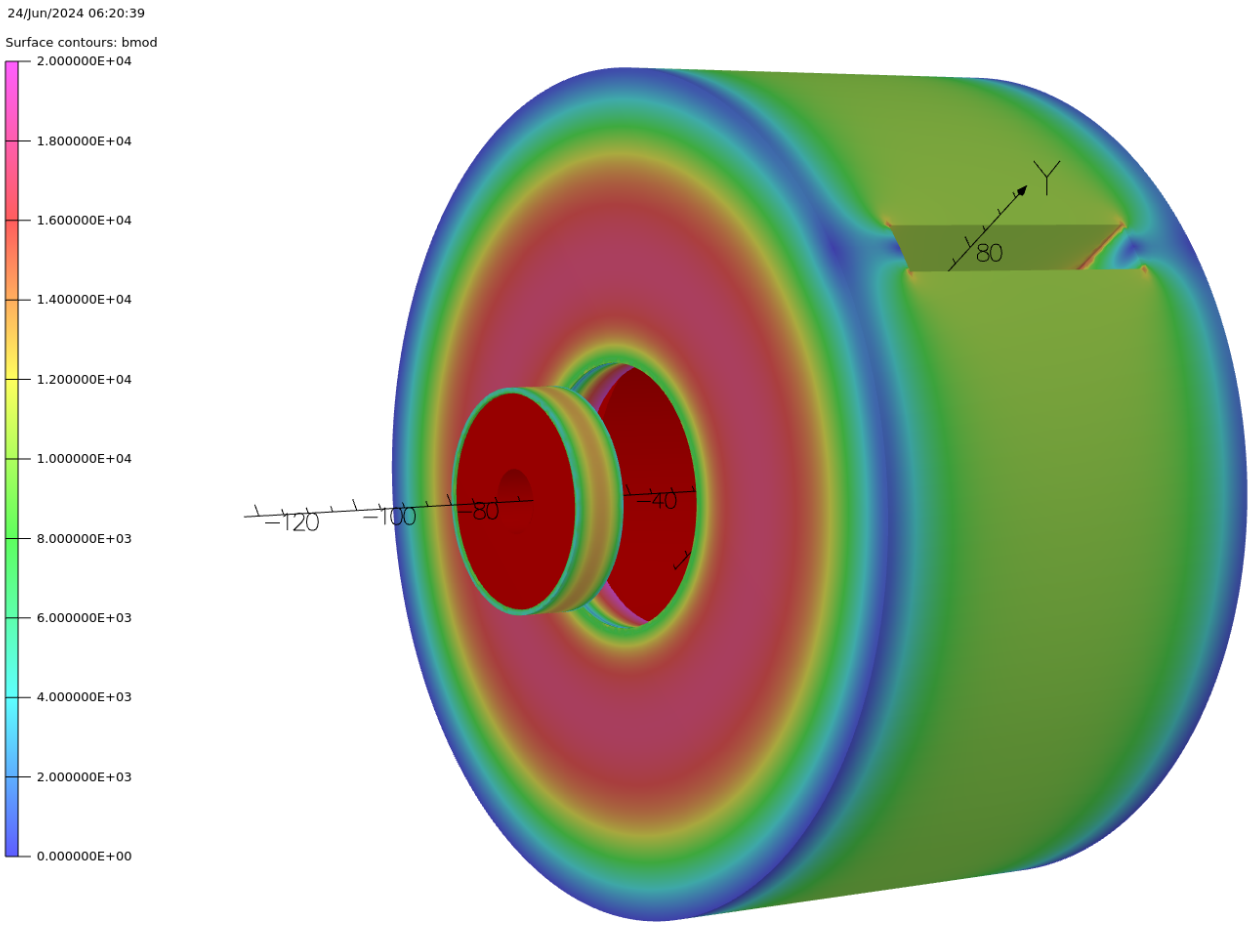
Three coils shown.

GTS drawing from preferred vendor (who was too expensive)

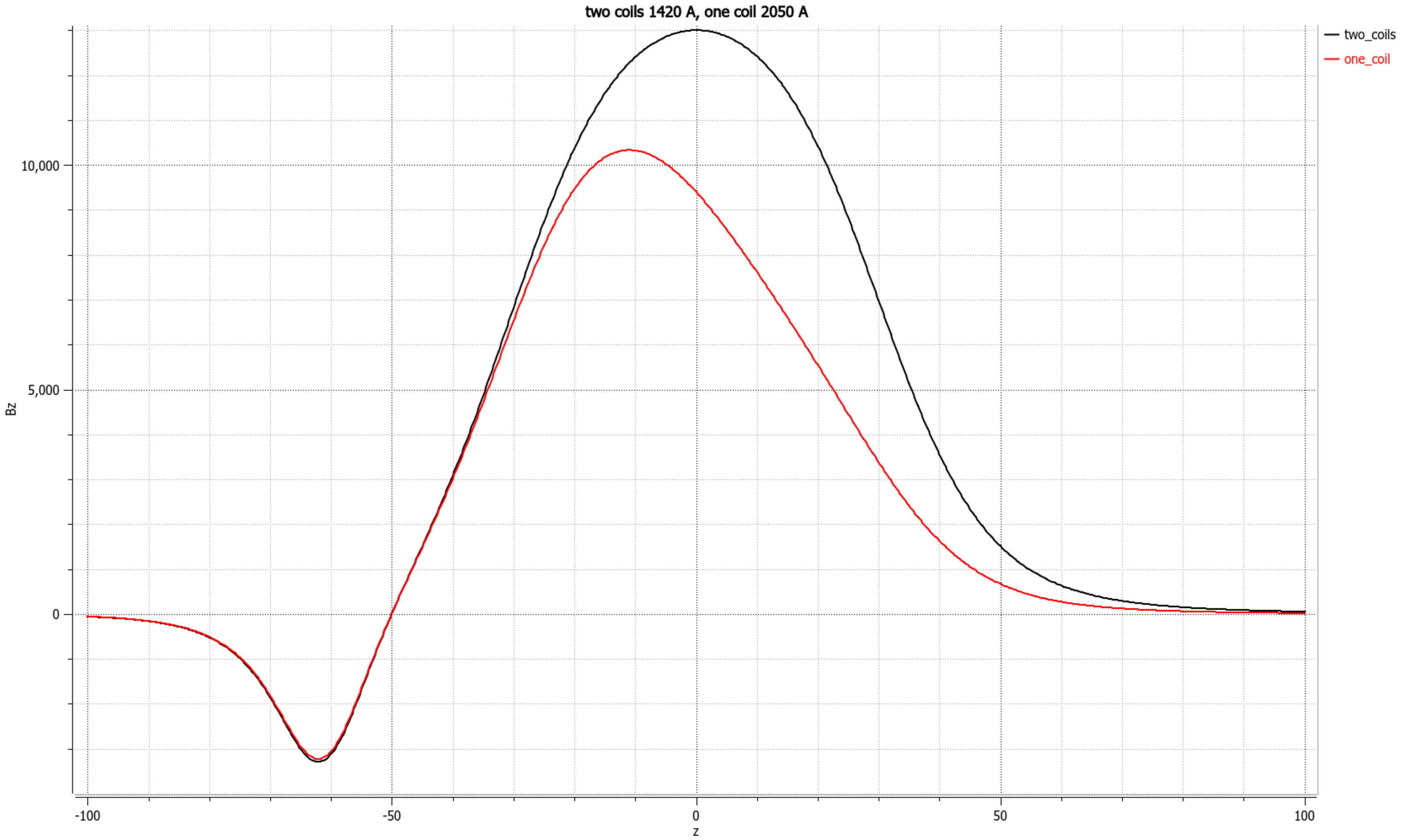


Model with slot, two half-coils

26 layers
in bucking
solenoid



Slotted model, two configurations



One coil active, downstream end