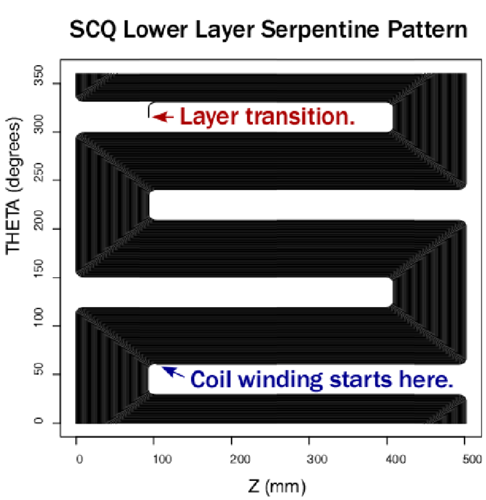
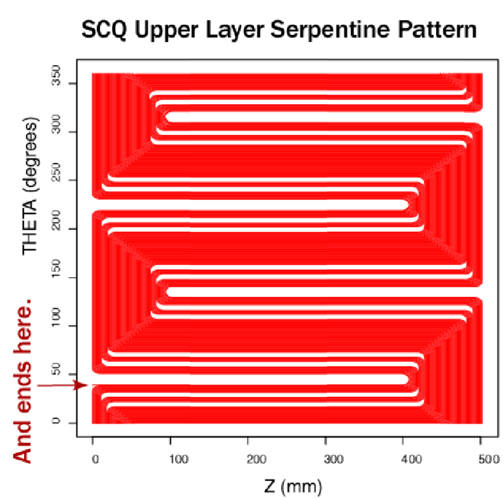
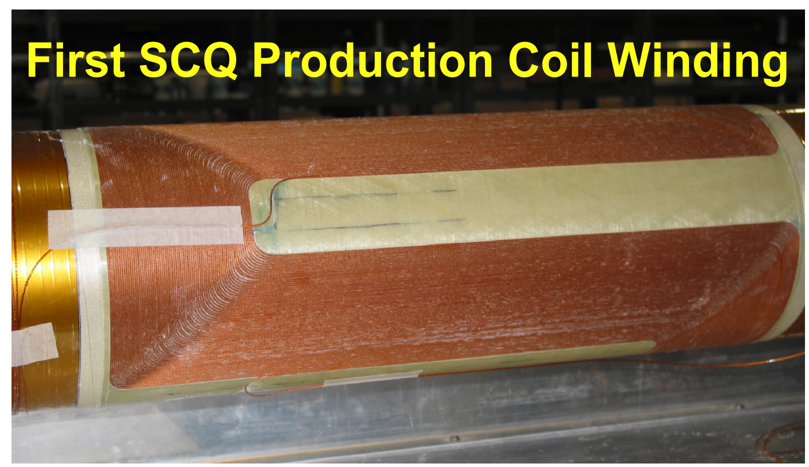
# Serpentine Style Coil Windings for BEPC-II IR Magnet Production

## Presented by

## Brett Parker/BNL-SMD



# Original Double-Layer BEPC-II Coil Winding Patterns for SCB and SCQ.

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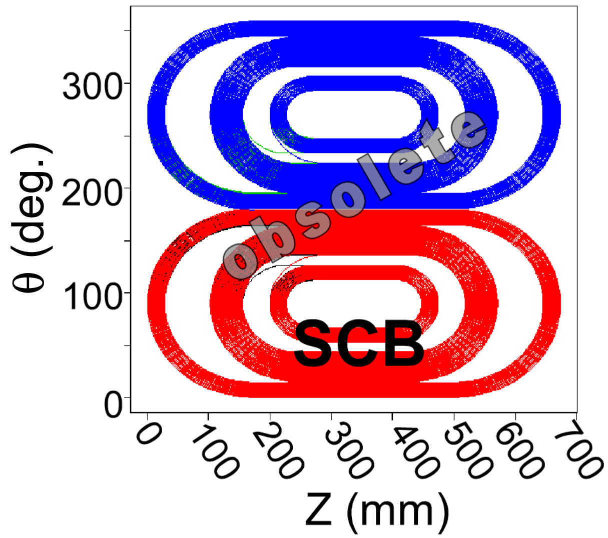
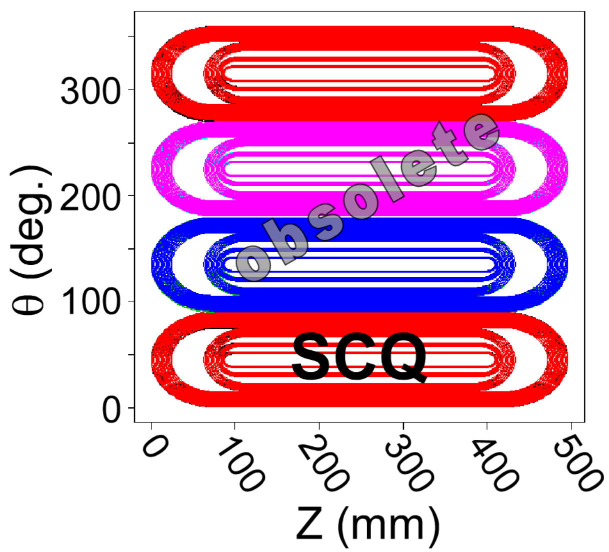



The plan had been to wind one coil pole and then stop winding to fill in gaps with G10 before adding new substrate and then continue winding the same pole in the second layer.

This was maybe not so bad for SCB where we would have had to stop/start twice but for the four double-layer SCQ we would have had sixteen stop/starts for each magnet.




Newly developed serpentine style winding allows us to wind all the poles for a given layer without stopping so that only when changing layers are stops required.

While important for efficient coil production, serpentine windings also naturally give good integral harmonics.

In order to ensure that coil production went smoothly we made two serpentine winding tests before the start of BEPC-II coil production.

# The Second Serpentine Style BEPC-II SCQ Coil Test Winding.

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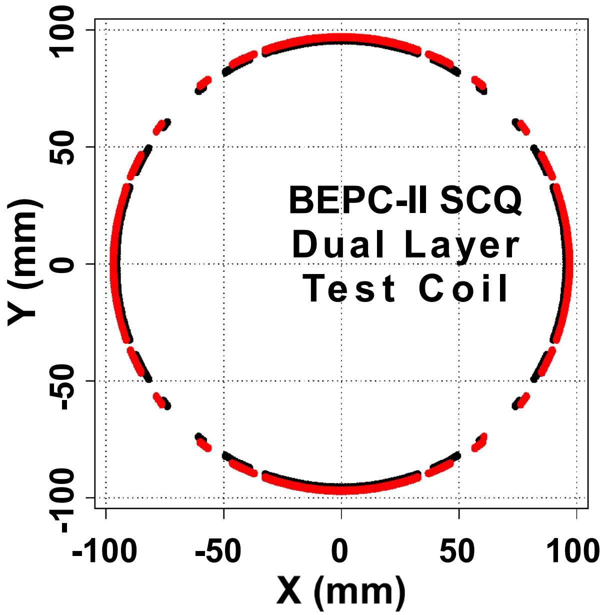


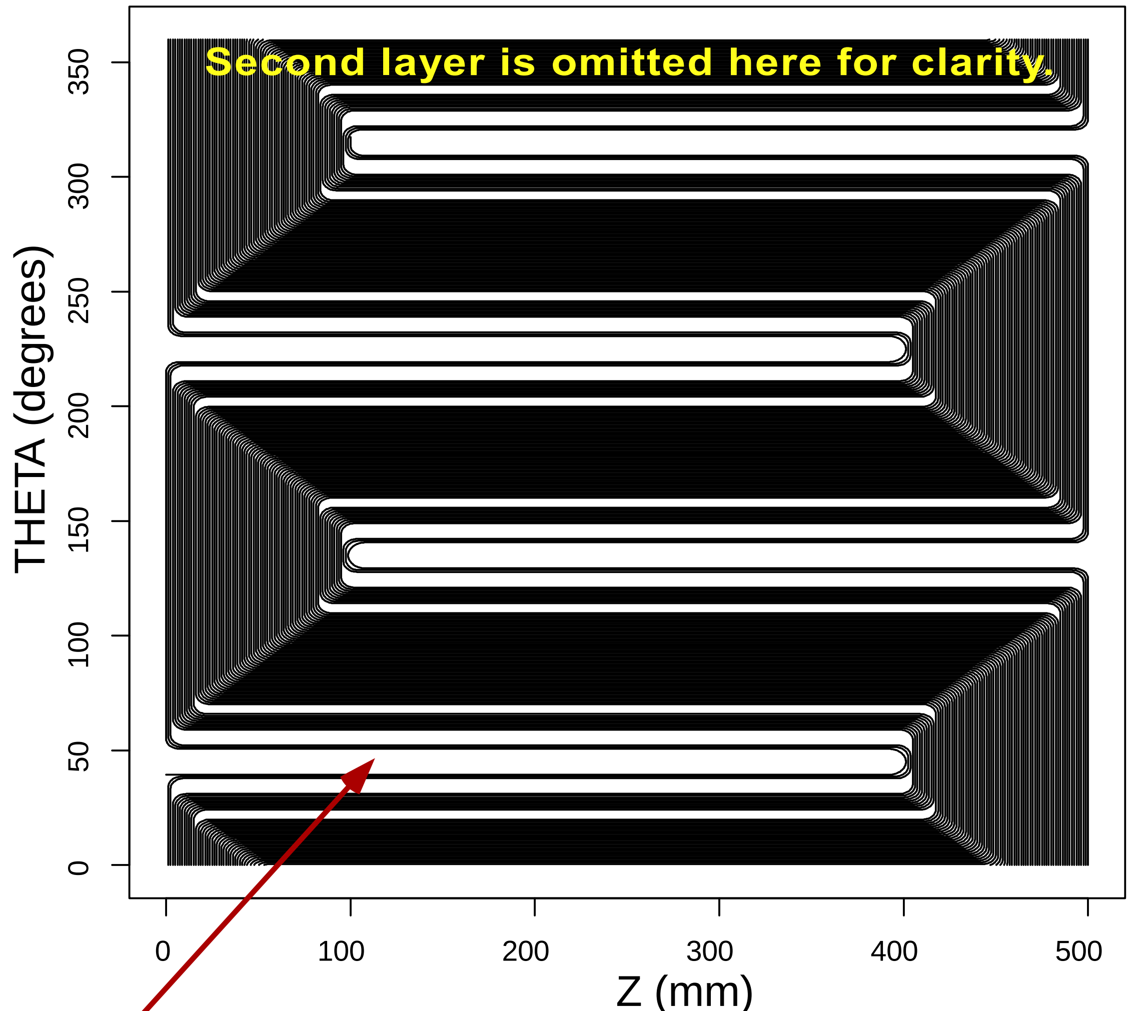


*The second serpentine test winding had features needed to achieve proper harmonics and went easily to 1000 A in operation.*

**A tube was placed here to bring current lead down and out via the gap in first layer.**

**Later refinements led to patterns that did not require tubes to get the leads out.**

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# Knowledge Gained with the Second Serpentine BEPC-II SCQ Test Winding.

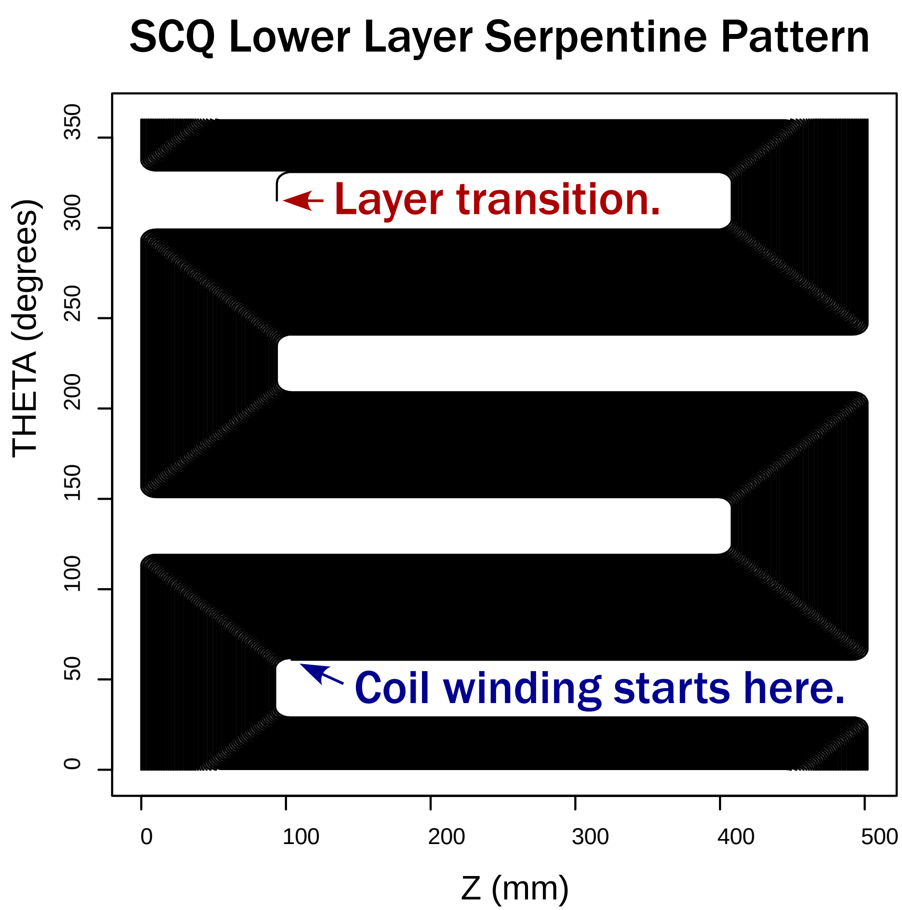
The field quality is generally very good - certainly far better than the first coil. The only notable harmonics are -3.7 units of skew sextupole, +2.1 unit of skew octupole and +1.5 unit of normal decapole (all at a reference radius of 50 mm). All other harmonics are about or below one unit. This field quality is similar to what we can typically achieve for a single layer coil.

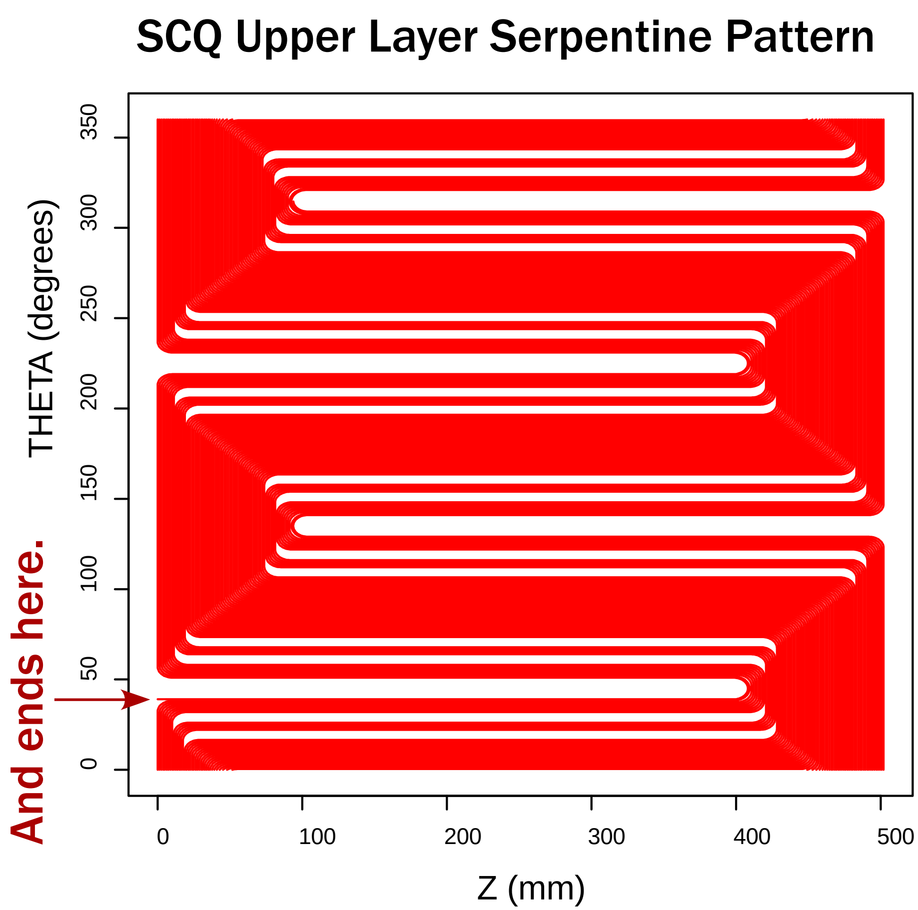
I believe this test coil can be declared a success as far as field quality goes. - Animesh Jain, 22 December, 2003.

**We also realized that changing the layer winding order allows us to bring out both leads together via the pole gap in the second layer.**

# Final “Tweaking” of the SCQ Coil Pattern.






**Harmonic tuning spacers are now only in second layer (gives better harmonics with fewer spacers & speeds up production).**

# Final “Tweaking” of the SCQ Coil Pattern.

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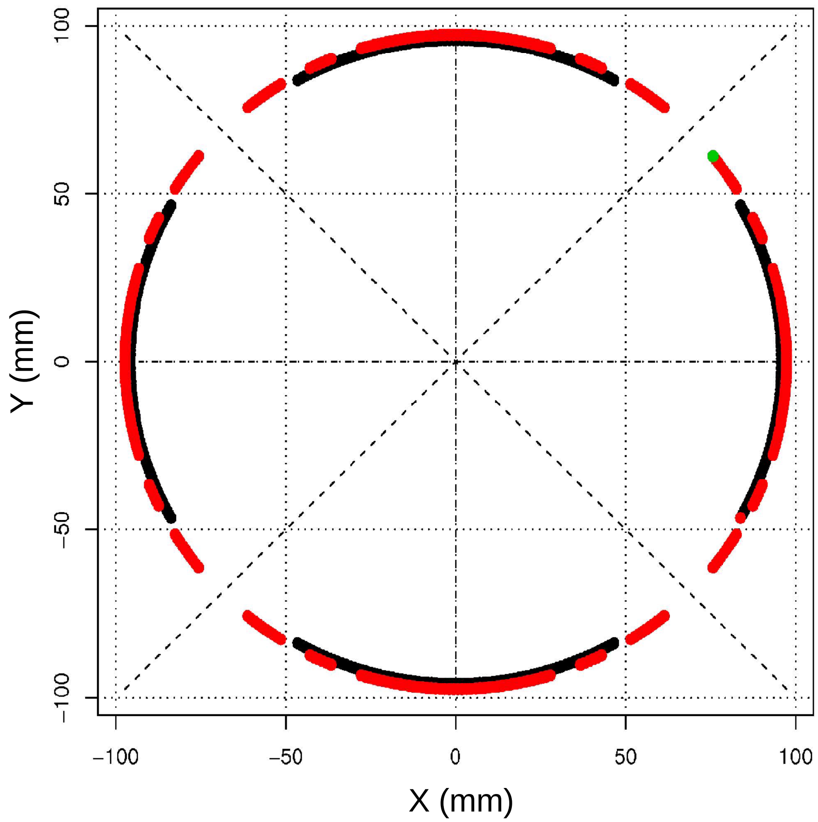
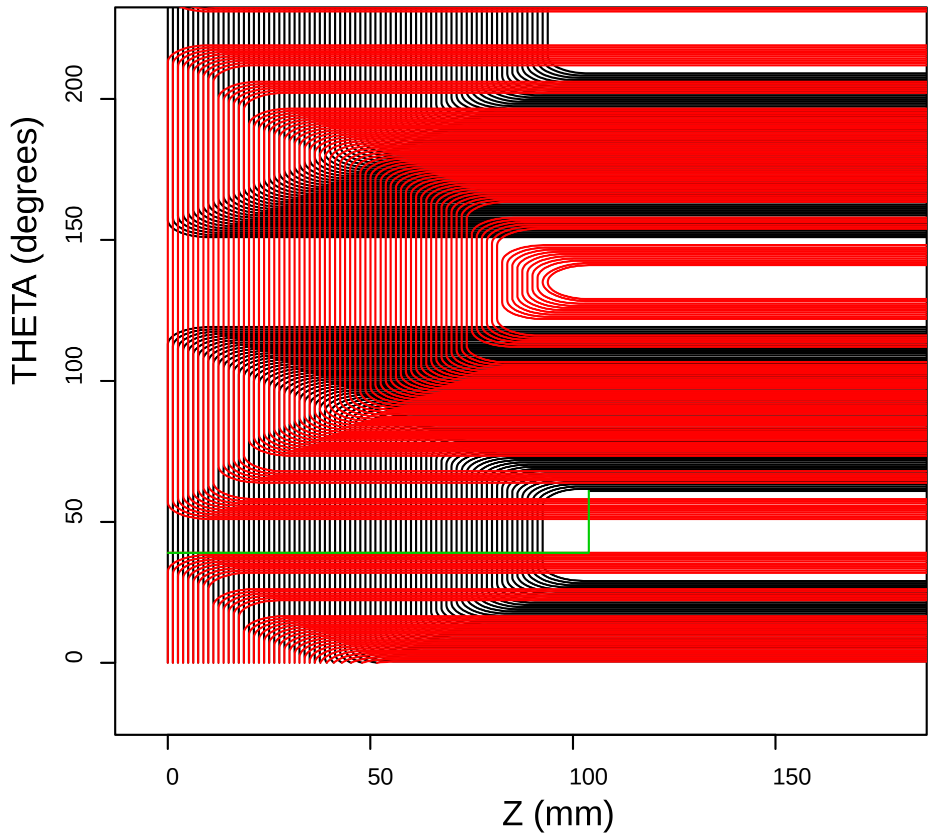
**SCQ First Double-Layer Cross Section**




**SCQ Serpentine: Close Up at Lead End**




Keeping the bottom layer pattern simple (no spacers) reduces the time the coil stays on the winding machine and we find good harmonic solutions with fewer total spacers. Starting winding at the pole allows the input lead to be brought out next to the exit lead in the gap in the second layer.

# The "Final" Multi-Layer SCQ Coil Pattern.

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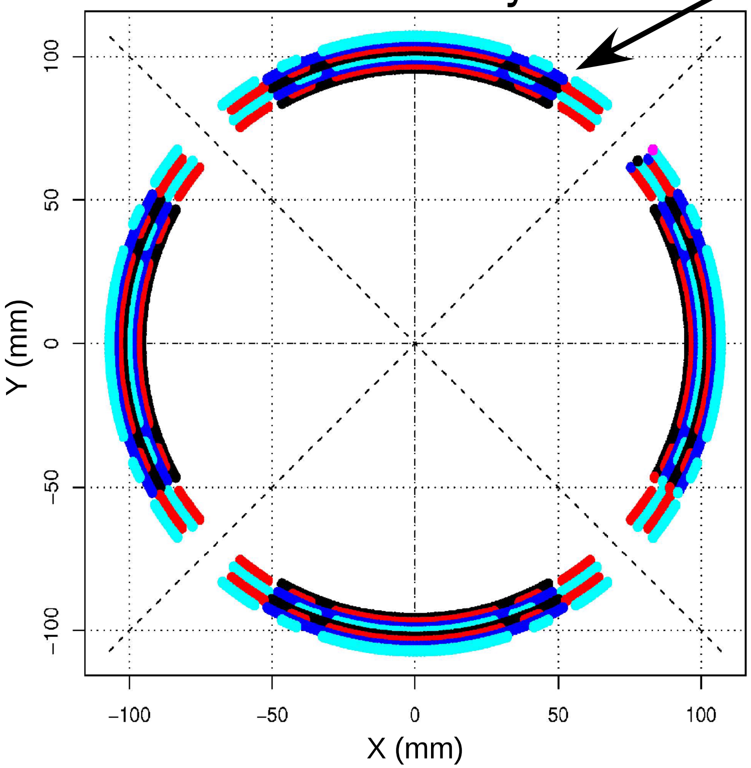
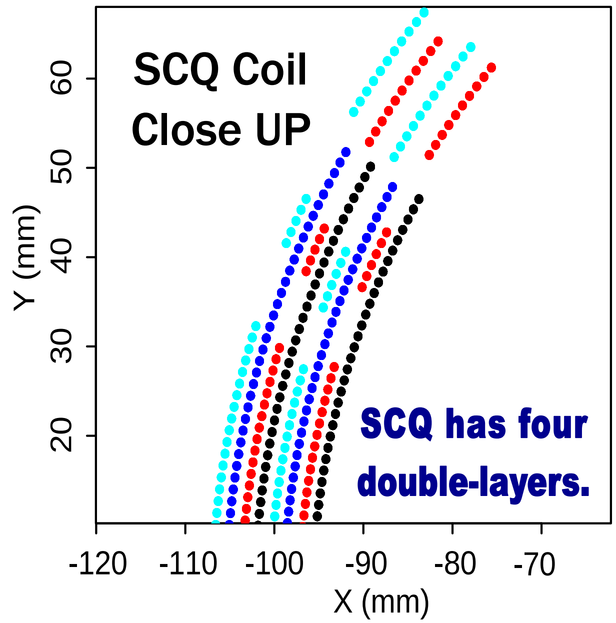
SCQ Final Cross Section with Four Double-Layers

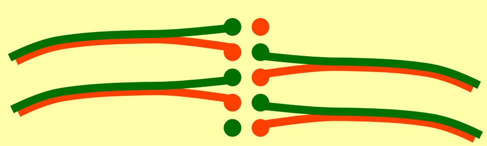



**Original SCQ pattern had two harmonic tuning spacers in every layer; present design only two in every other layer but achieves better solution. Since coil features now do not line up as much in different layers, result has reduced peak field.**




Each double-layer has two leads that exit next to each other from the coil pack. It is then a simple matter to make pigtail splices (wires alternating clockwise and counterclockwise azimuthally to save longitudinal space) to connect up the different layers. Thus these splices are done outside the main coil pack where they can be reliably made up.

**View towards coil lead end**

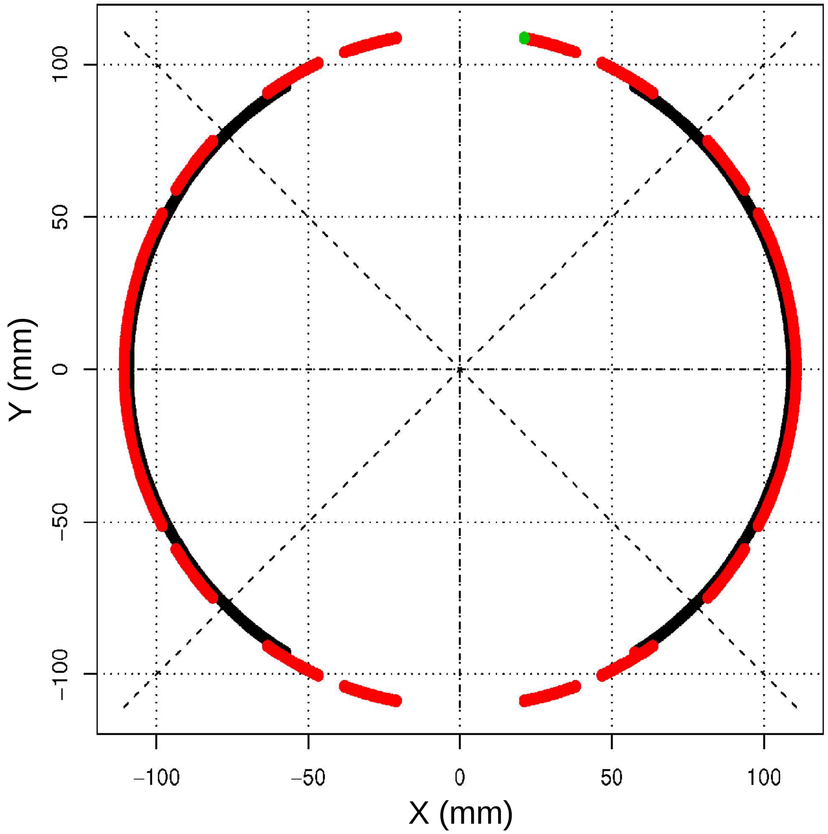


SCQ Wiring Schematic

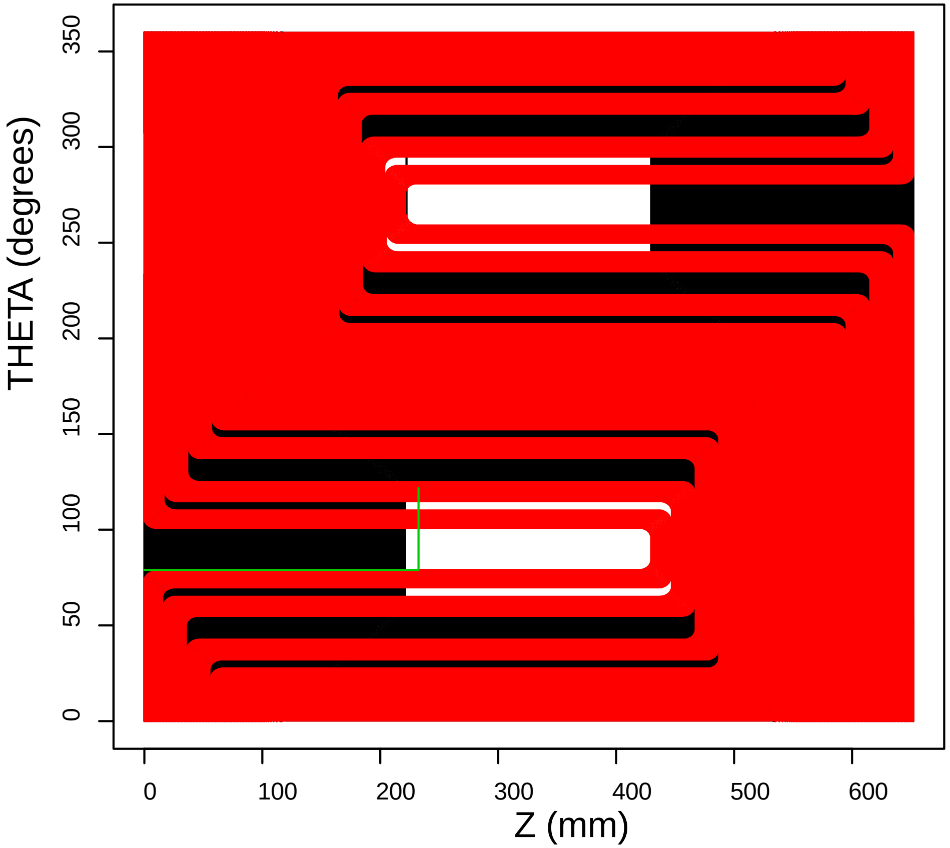
# The "Final" SCB Serpentine Coil Pattern.



SCB Final Serpentine Cross Section




SCB Final Serpentine Winding Pattern




Like SCQ the SCB coil is wound from seven strand cable. Here three spacers in the upper layer are sufficient to ensure good harmonics. Note that dipole ends are naturally longer than quadrupole ends so SCB has even less "straight section" than SCQ and has to be wound longer than SCQ in order to have the same magnetic length.

# The "Final" VDC Serpentine Coil Pattern.

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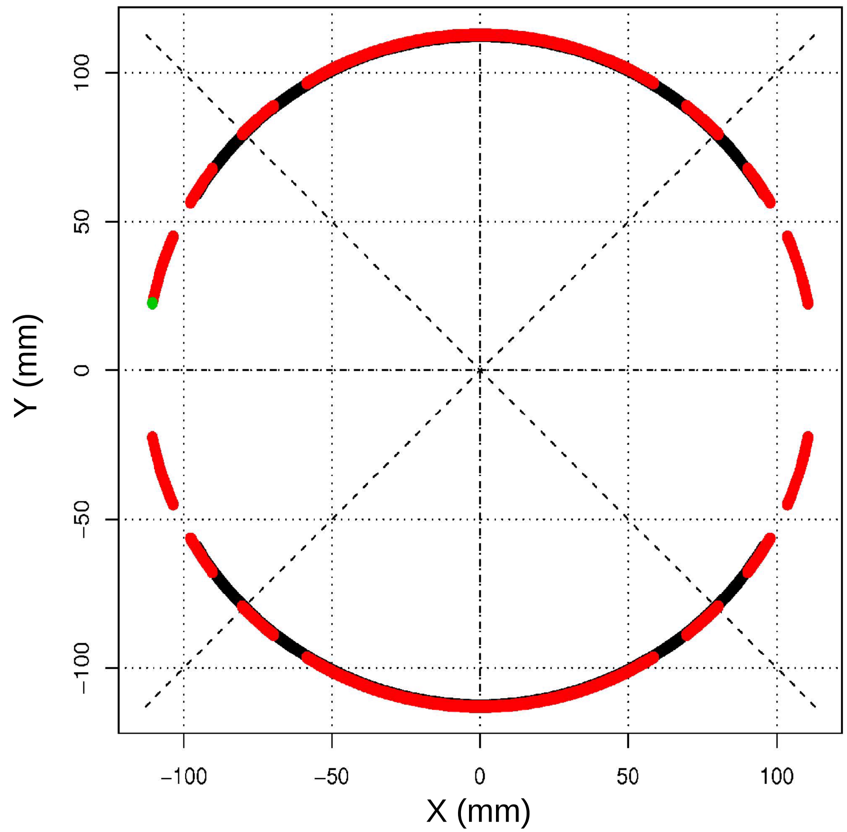
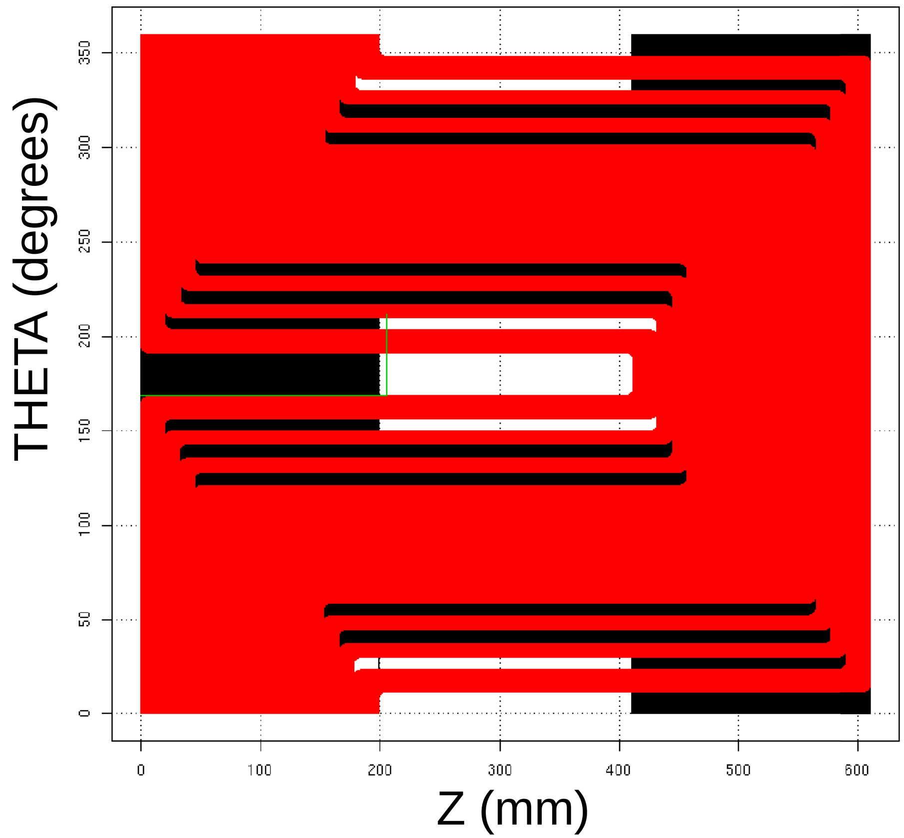
VDC Final Serpentine Cross Section

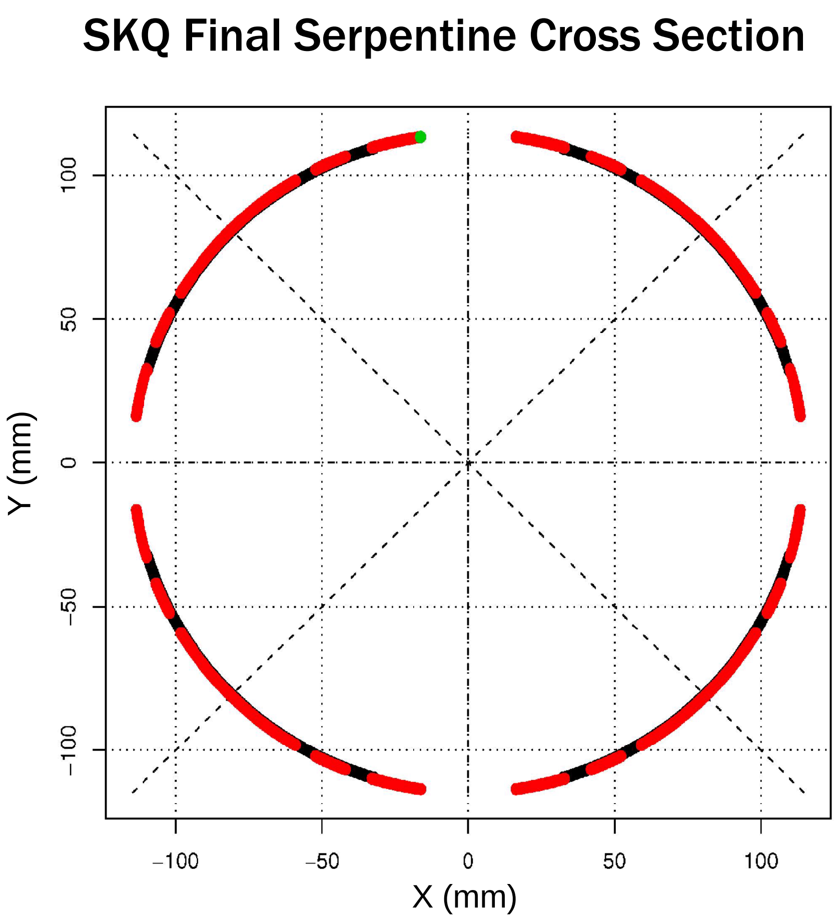


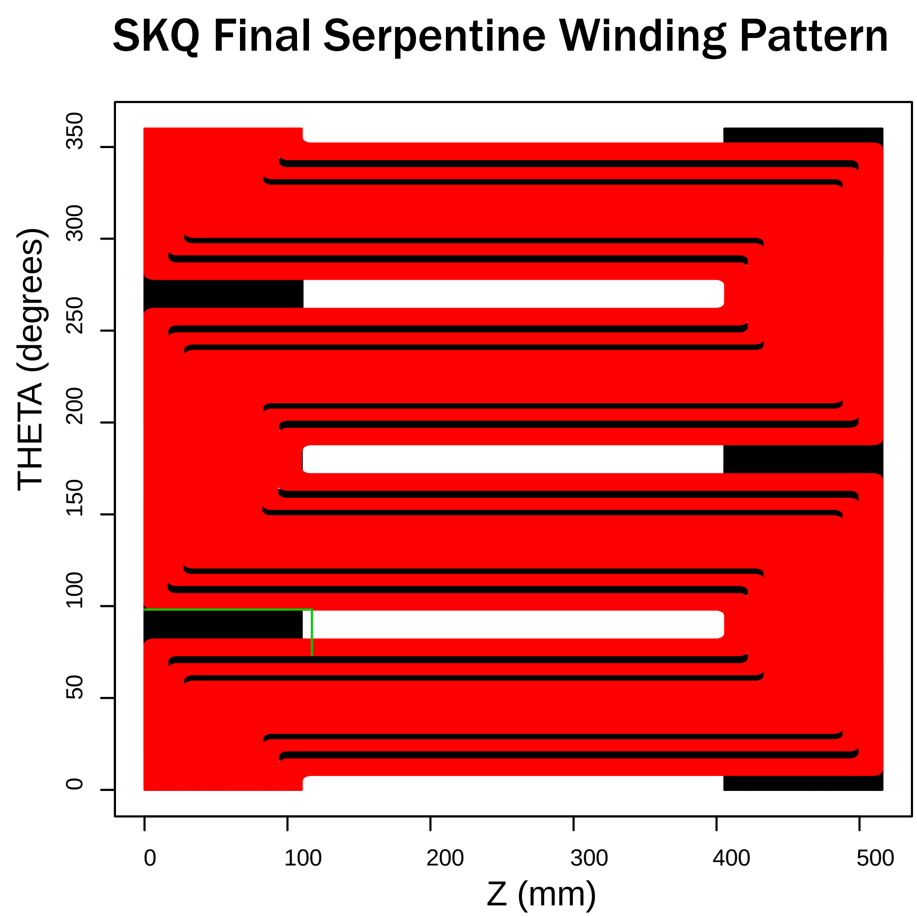

VDC Final Serpentine Winding Pattern




VDC is wound using single strand wire and as with SCB three spacers in the upper layer are adequate for tuning design harmonics. The actual winding pattern is a nested-serpentine, as was done for the NLC FF quadrupole, where the conductors in the second layer are constrained to lie in the "grooves" atop the lower layer turns. As was done for HERA-II, spacers are filled in with Nomex.

# The “Final” SKQ Serpentine Coil Pattern.




SKQ is also wound in a nested-serpentine pattern from single strand wire and only two spacers are needed in the upper layer for desired design harmonics.

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# BEPC-II Superconducting IR Magnet Coil Summary Table.

| BEPC-II Magnets 3-March-04 | B, G (T), (T/m) | $R_{in}$, $R_{out}$ (mm) | From IP (mm) | Coil Length (mm) | Magnetic Length (mm) | Operating Current (A) |
|---|---|---|---|---|---|---|
| SCQ | 18.744 | 95.1~108.1 | 958~1460 | 502 | 400 | 477 |
| SCB (HCD) | 0.543<br>0.056 | 108.5~111.8 | 644~1296 | 652 | 400 | 496<br>(51) |
| VCD | 0.059 | 111.9~113.5 | 904~1514 | 610 | 380 | 27 |
| SKQ | 0.937 | 113.6~115.2 | 951~1467 | 516 | 400 | 47 |

**Note: magnetic lengths and magnetic centers are kept the same as before; however, with Serpentine style windings the physical coil lengths and operating currents are now slightly different.**

# Start BEPC-II Superconducting IR Magnet Production: First SCQ Coil Pattern.

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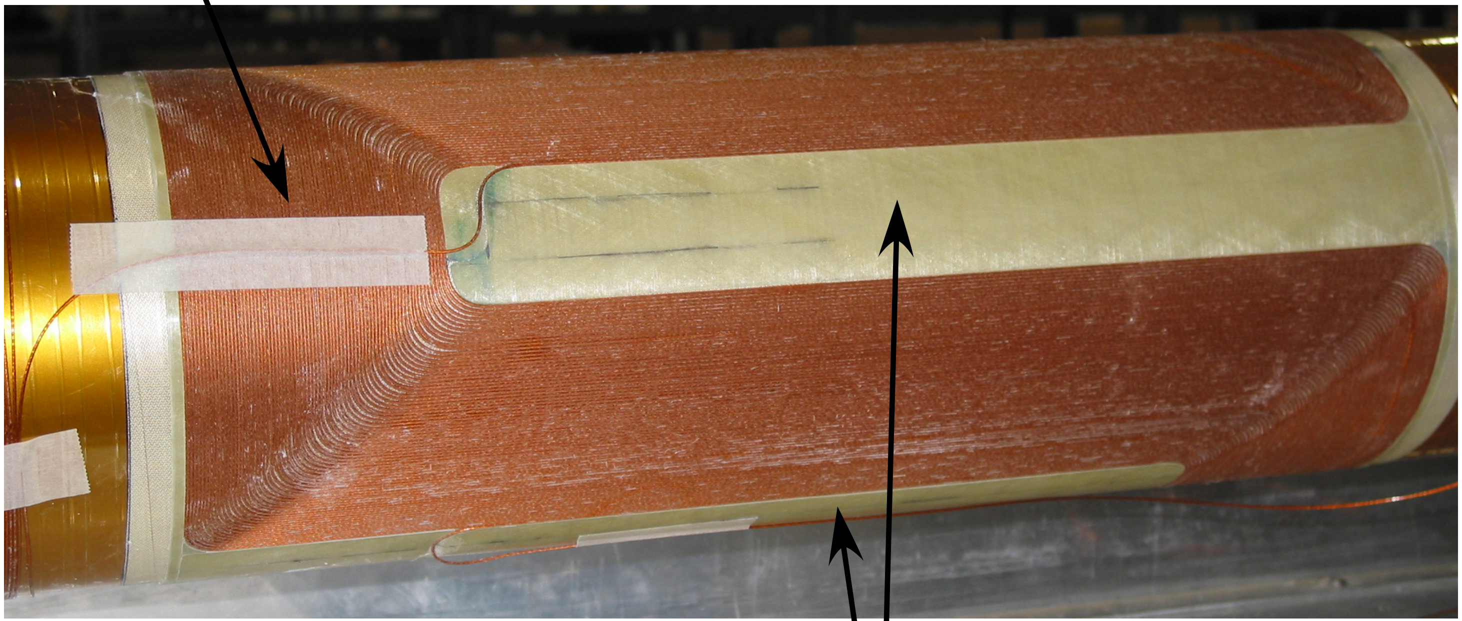
**When winding continues the second layer pattern will be open here (allowing the current leads to exit the coil pack).**



**Simple G10 spacers fill in pole regions.**

# BEPC-II Anti-Solenoid Design Status.

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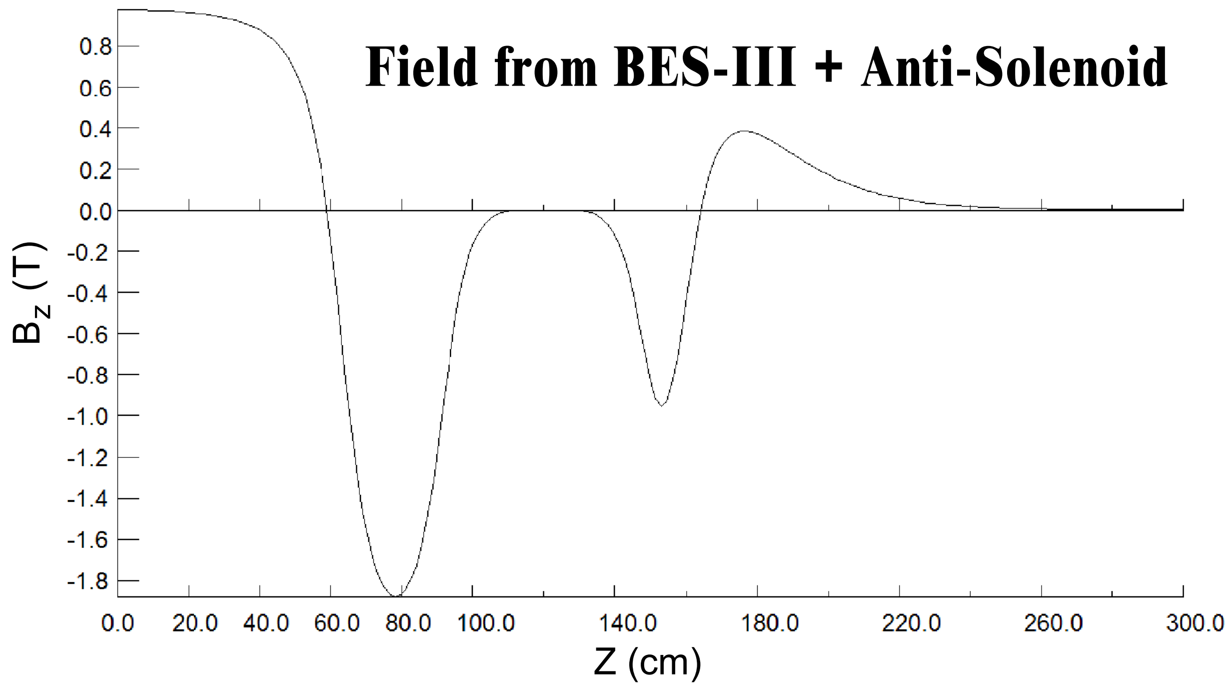
**732 turns for AS1**

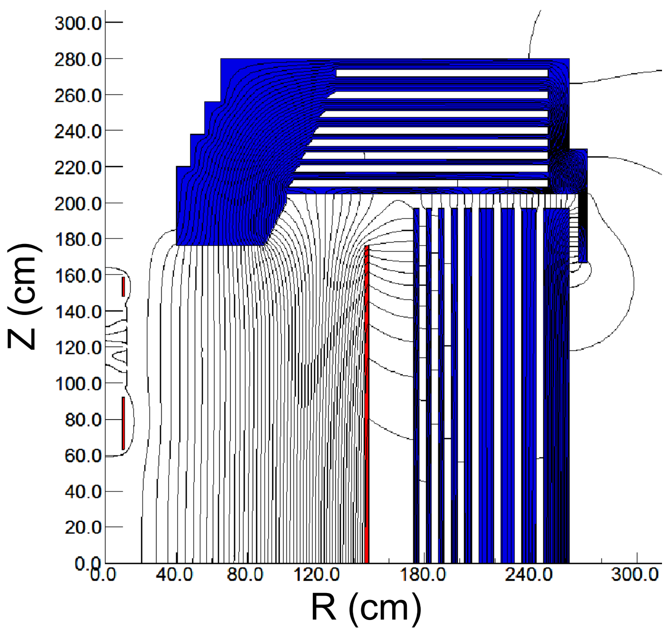
**316 turns for AS2**

**276 turns for AS3**

**1324 total (1272)**

**$I_{op}$ = 1078 A**




**Re-optimized Anti-Solenoid: Took turns away from AS3 to give more space for SCQ leads but was able to find solution with more turns in AS2 yielding 4% lower operating current and better Bz compensation. Expect to do final tweaking of anti-solenoid design once SCQ is wound.**