Three more 15 degree bends and a BD/BJ replacement

Jay Benesch

Abstract

JLab Center for Injector and Sources (CIS) asked that the power draw for the previous design be reduced by increasing the wire size. Accordingly, the wire size was increased from AWG 18 to AWG 17, lowering resistance ~20%. Turns count is still 72. Coils are a bit thicker and wider. Hexagonal close pack of maximum material condition single film wire assumed in sizing coil. An Opera model with steel cylinder was created and six cases each were run with the BH properties of the steel set to 1010 and to air. The exact same mesh was thus used for both sets of simulations. For a 200 keV KE beam, 2.21 A and 6 W for air return case and 1.37 A and 2.3 W for steel return case. The modified coil form drawing is JL0087295.

Coil models

HELICALEND WIDTH=0.9 THICKNESS=1.13 H1=5 H2=5 R1=4.1 R2=1.13 ALPHA=23.1 BETA=90

HELICALEND WIDTH=0.9 THICKNESS=1.13 H1=5 H2=5 R1=5 R2=1.13 ALPHA=44 BETA=90

Steel (air) tube 6.35 cm OR, 0.15 cm wall aka 5" OD, 0.06" wall

Discussion

Much of the discussion in https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-202064/19-034.pdf carries over. I repeat here figure 2 showing psi rotation.

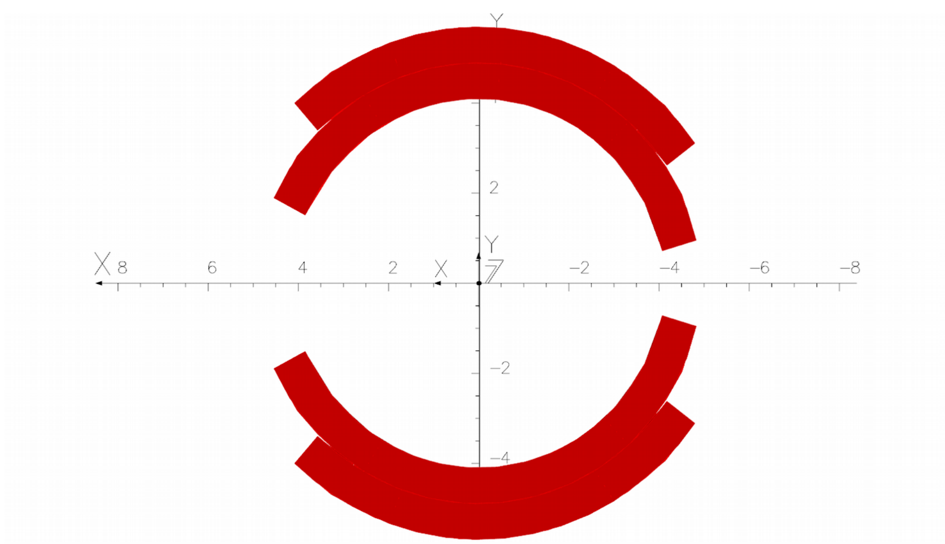

Figure 1. View from -Z, aka looking downstream, with +0.1 radian psi rotation applied to the coils. This is much larger than optimum. It is included to orient the author and reader.

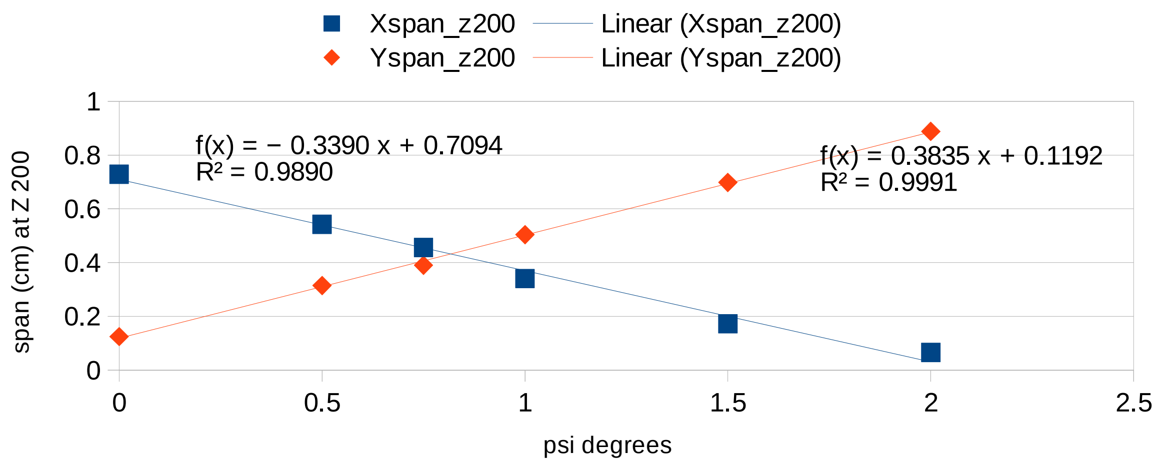

Figure 2. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. Air return. X span corrected for 7.5° angle. The lines intersect at 0.82° rotation of coils in same manner as figure 1.

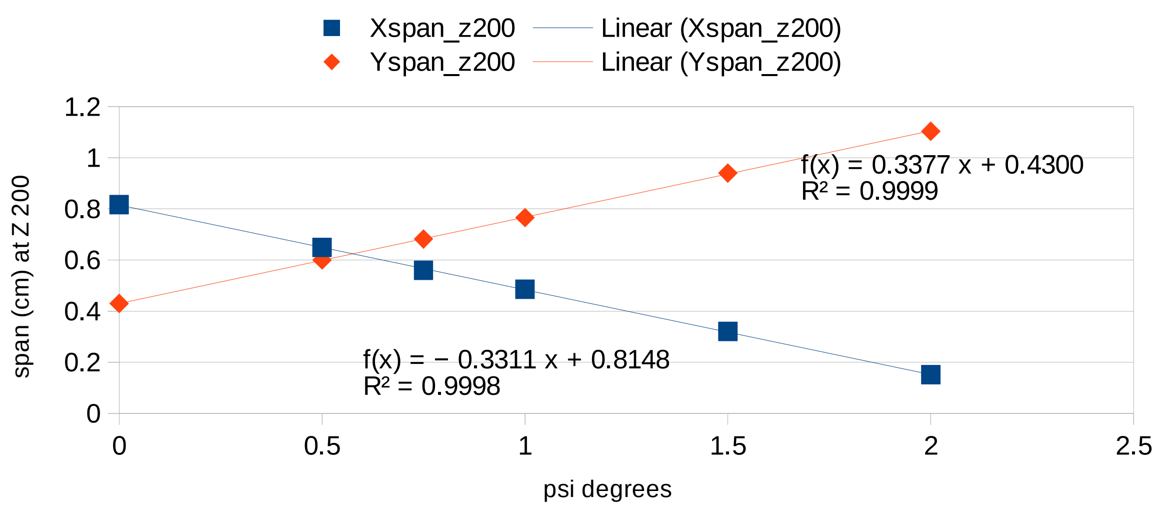

Figure 3. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. Steel return. X span corrected for 7.5° angle. The lines intersect at 0.575° rotation of coils in same manner as figure 1.

The models were evaluated with 3A aka 216 AT. For the air return case, electron energy of 332 keV KE resulted in split sagitta with 7.5° entry and exit angles. Displacing the orbit so entry and exit are on axis instead of 1.8 mm offset did not affect the results given the size of the coils. For the steel return case, 685 keV KE produced Figure 3. Again sagitta was split but a couple of offset checks showed that central entry woul give the same focusing results. Calculated resistance of the full coil set assuming nominal wire resistance at 20 C, 5.054 Ω/1000', is 1.23 Ω. This resistance was used to calculate the power values in the Abstract. The coil will equilibrate at higher temperature in the tunnel but the power will still be lower than that for AWG 18.

Perhaps more changes

Sarin Philip asked me October 21 about designing a replacement for the DB magnet as they have been thermally damaged by running up to 6A in CEBAF, roughly twice the maximum used in the FEL. Traces have bubbled the circuit boards, indicating heat not radiation. The DB is ~4.5" long. The coil former for this dipole is 4.42" long. The steel tube is 5.5" long but could be shortened to 4.75" without loss of central B field. The DB field map shows 927 G-cm at 10A. The fields for this dipole are shown below. Air return integral 590 G-cm, iron return integral 942 G-cm, both at 3A.

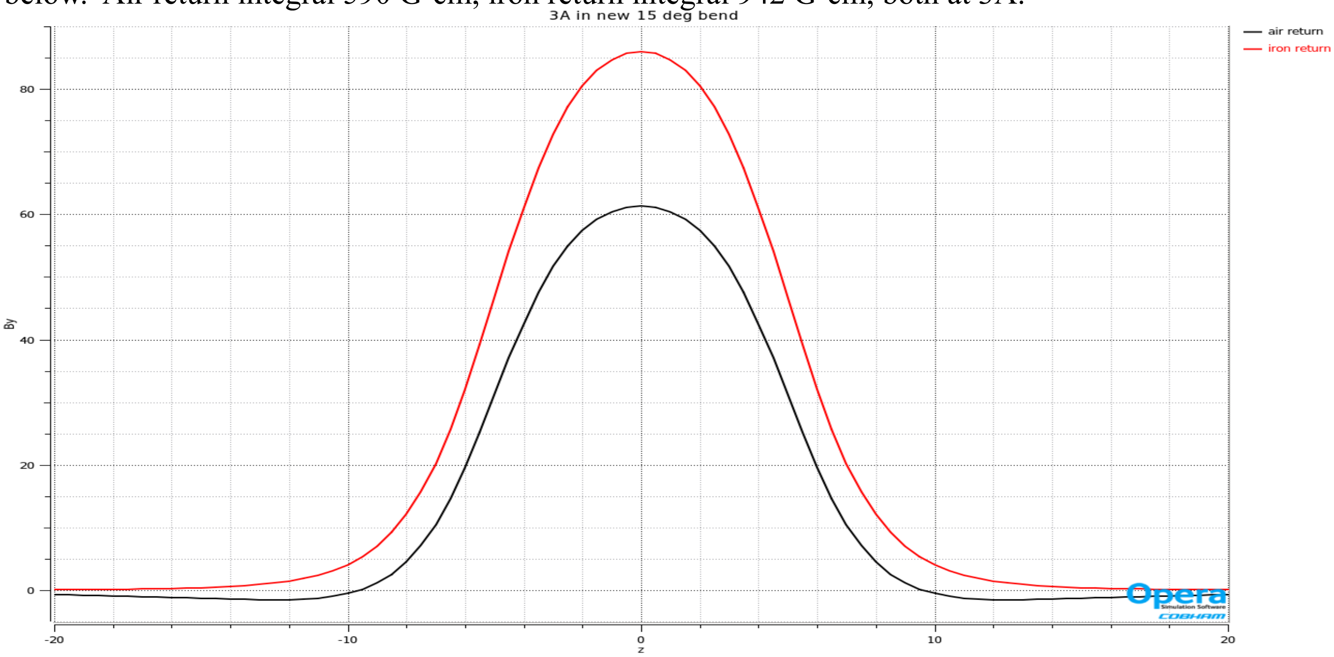

Figure 4. By along Z axis for air return (black) and iron return (red) versions, 3A.

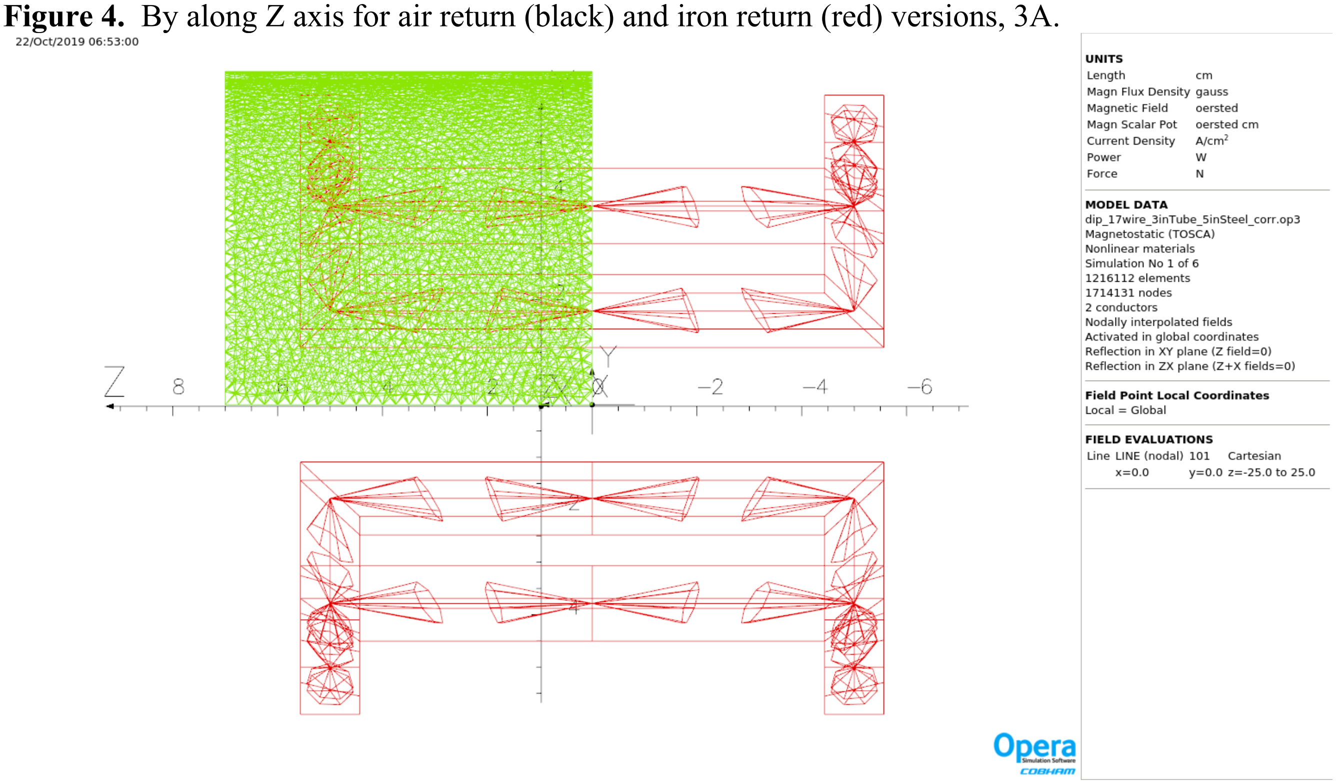

Figure 5. Section, viewing from +X, of model less air. This shows extension of (green) steel beyond end of the coils. 5.5" is available in the injector so I used it.

I designed the coils above using single film 17 AWG copper because that insulation is ample for 30 V power supply and there's no radiation at 200 keV KE. Diameter at maximum material condition 0.0475”. If these are to replace the DB and DJ units in high radiation areas by the C100s, heavy film is more appropriate. Diameter 0.0482” nominal, 0.0488” max material. I should increase the coil transverse sizes by 2.7% (0.0488/0.0475 -1) to 0.925 cm by 1.16 cm and solve the models again, alas. Resistance will increase but remain under 1.3 Ω at 20C. Higher in the tunnel but still not an issue for the trim cards.

Heavy Film Coil models

HELICALEND WIDTH=0.925 THICKNESS=1.16 H1=5 H2=5 R1=4.1 R2=1.16 ALPHA=23.1 BETA=90

HELICALEND WIDTH=0.925 THICKNESS=1.16 H1=5 H2=5 R1=5.025 R2=1.16 ALPHA=44 BETA=90

Steel (air) tube 6.35 cm OR, 0.15 cm wall aka 5” OD, 0.06” wall

drive factor for 3A*72T=216 AT is 1.00652 given J 200 A/cm^2 in 0.925 by 1.16 cm^2 section

Steel Length

For use near the C100s, 12 cm steel length vs 14 cm as above is preferable. A model with this length produces 951 G-cm at 3 A along axis vs 941 G-cm with 14 cm steel and 593 G-cm with air return.

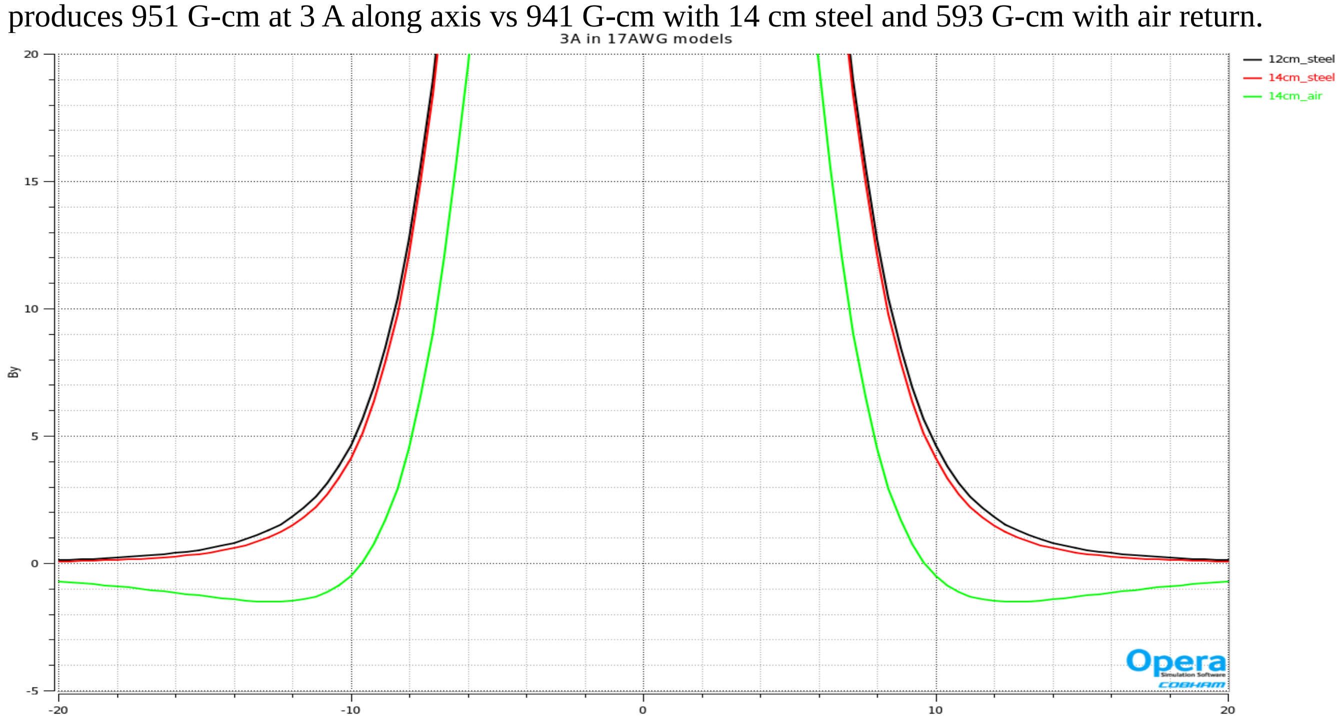

Figure 6. End fields from models with air return (green), 14 cm long steel return (red) and 12 cm steel return (black). There is a perhaps a 0.5G difference between the last two at Z=10cm. 12 cm length seems viable. Peak field is 86 G for both steel-return cases, as in figure 4.

It appears impossible to procure a 5” OD 0.06” wall steel tube in the USA today. I have found a source for metric tubing 130 mm OD with 2.5 mm (or 3mm) wall. I am running a model with 2.5mm wall.

Figure 6 made me wonder about By(Z) when the BdLs for air and iron return are the same.

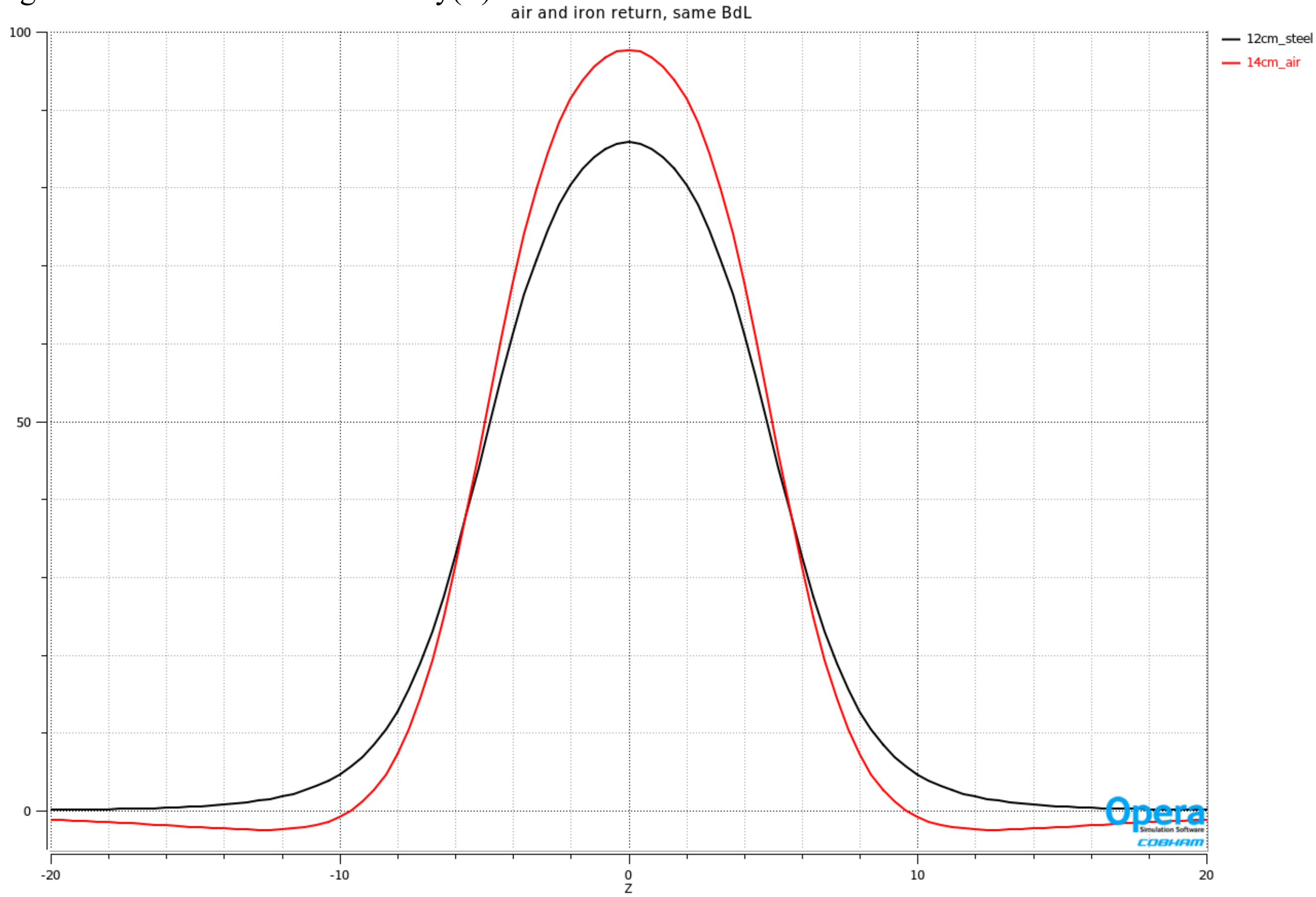

Figure 7. By(z) for air return model with 949 G-cm plotted with 12 cm steel return at 951 G-cm. Profiles differ more than I expected. This explains why the initial offsets needed to split sagitta differ by 2 mm.

The source found for metric tubing is
Spahr Metric, Inc., Fastener & Steel Distributor, 421 McGhee Road, Winchester, Virginia 22603
Seamless Round Carbon Tube E235, M130 x 3mm wall x 3m length $917.00
six to eight week delivery
Item # 019508-130.03.0124.0, 130mm o.d. x 124mm i.d. metric round tube on
http://metric-steel.spahrmetric.com/viewitems/tubing/metric-round-tubing?pagesize=200&pagenum=4

Tube would be turned to 125 mm ID to get needed precision to fit over coil form.

The meshes for the air return model with 17 AWG heavy film differs from that used with the 12 cm long metric steel tube since it matches the 5” OD, 14 cm long, 1.5 mm wall steel tube's mesh. Since the air outside the coils to 8 cm radius has 0.25 cm mesh, including the region that would be the 5” tube if B(H) weren't set to air, the mesh difference should not matter.

There is a sufficient stock of BD/BJ coils (~40) in the FEL that it is unlikely that this design will be used outside the injector for some years. It follows that only two copies for the injector will be purchased initially. Whether the steel sheath will be included is TBD.

Danny Machie found two sources for 5” OD 0.125” wall steel tube. Since the tolerance on round tube is relatively loose, 0.7mm on the metric tube above for instance, and the inch steel tube is about 2/3 the cost of the metric, Danny recommends that the 0.125” tube be purchased and bored out to, say, 0.1 mm tolerance. I have accordingly prepared models with 6.35 cm OD, 2 mm wall steel tube.

Sources for inch tubes:

https://www.metalsdepot.com/steel-products/steel-round-tube-dom

https://www.speedymetals.com/c-8242-round-tube.aspx?thickness=5

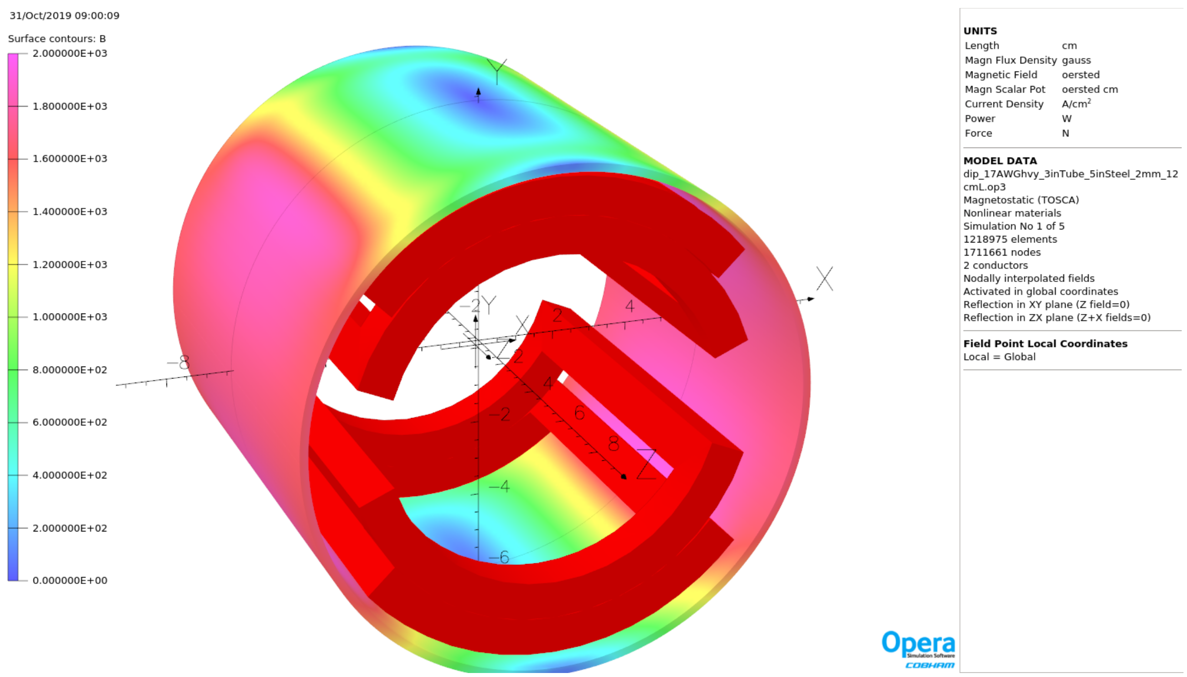

Figure 8. Field in 5” OD, 2 mm wall steel with 3 A in the 72 turns/coil of 17 AWG heavy film. The two halves of the steel should be oriented so they meet top/bottom, in the low field region.

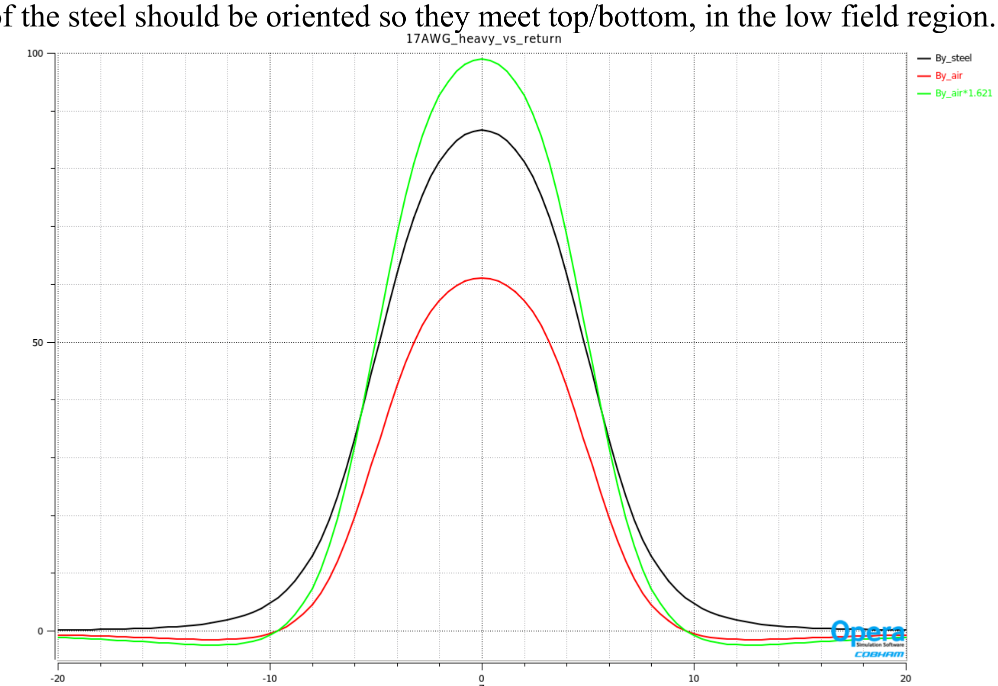

Figure 9. Field along Z axis of model with 3A with steel return (black), air return (red) and 1.621*air_return (green). BdL (G-cm) 593.1 air return, 961.5 steel return. Steel is 12 cm long.

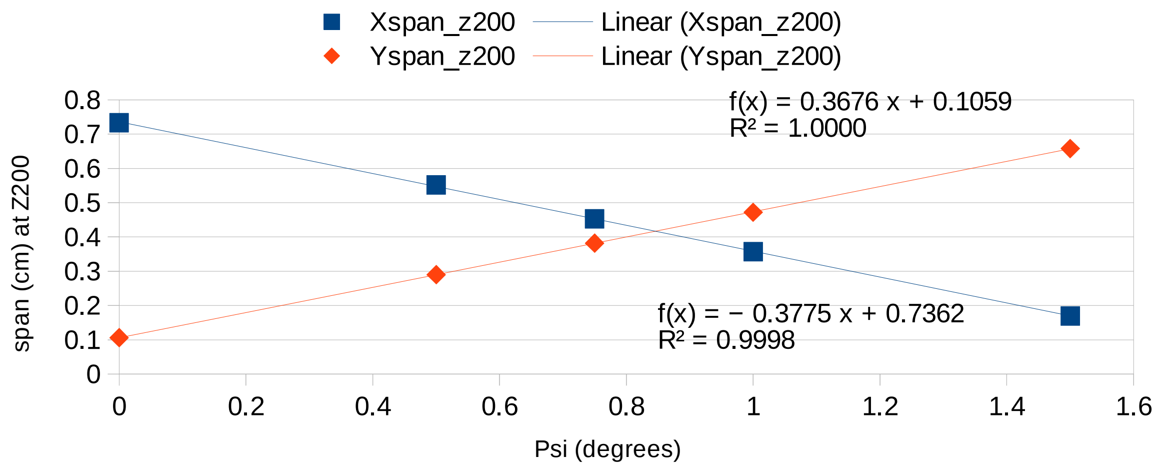

Figure 10. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. Air return. X span corrected for 7.5° angle. The lines intersect at 0.85° rotation of coils in same manner as figure 1.

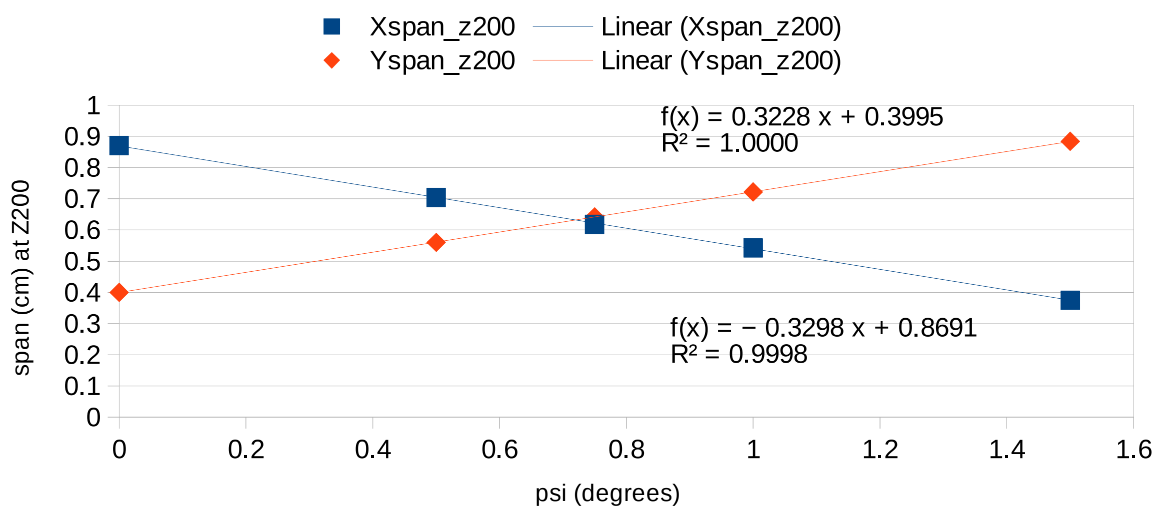

Figure 11. X and Y spans at Z=200 cm of array initially (z=-40) 1 cm square. Steel return 12 cm. X span corrected for 7.5° angle. The lines intersect at 0.72° rotation of coils in same manner as figure 1.

The source of the difference in optimum angle between figures 3 and 11 is not clear to me. Figures 2 and 3 measurements split the sagitta while figures 10 and 11 have on-axis entry and exit. The shorter (12 cm fig. 11 vs 14 cm fig. 3) steel return likely has more of an effect. Figure 12 on the next page, with 11.2 cm steel return, is ambivalent with respect to that hypothesis.

Resistance of the this assembly at 35C is 1.31 ohms. Power dissipated for 200 keV beam deflection with air return should be 6.45 W (2.22A). For steel return, 2.35 W (1.34A). Length per calculation 244'. I wouldn't count on a 250' spool to be sufficient, but I might try it given that calculations were done for maximum material condition wire.

One last change

It occurred to me that it would be a lot easier to assemble the steel half-annuli to the coil in Z if the two were closer to the same length. The coil is 111.6 mm long maximum material condition so I ran a set of models at steel 112 mm (vs 120 mm immediately above). As in the shift from 140 mm to 120 mm, BdL increased slightly. 3A now deflects a 715 keV KE beam through 15°. I did not run air return models as the difference in mesh would be insignificant. For this condition, see figure 10. For steel return, see below. Power dissipation for steel return at 35C, 200 keV KE, 2.3 W.

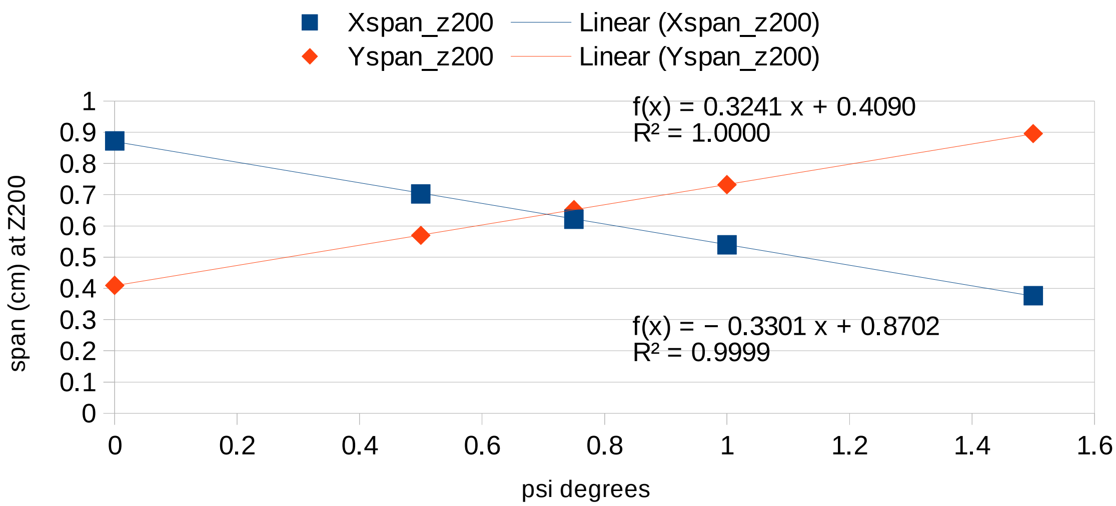

Figure 12. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. 112 mm steel return. X span corrected for 7.5° angle. The lines intersect at 0.705° rotation of coils in same manner as fig. 1.

Conclusions

Three designs for the 15 degree bend which will fit on the new 3" injector vacuum tube were presented. The design on this page is preferred as it is shortest (4.41") and compatible with higher radiation areas due to the use of 17 AWG with heavy film insulation. The BD/DJ circuit board correctors are 4.75" long and produce 928 G-cm with 10A. 10A will also cause the traces to lift off the board as that has happened with 6A. The design above produces 968 G-cm with 3A, 12W with steel return. With 6A, 47 W in steel return, 1936 G-cm. Given that the ex-FEL has about forty each of BD/DJ correctors, it is likely that quite a few more will have to fail due to radiation or thermal damage before units of this design are purchased to replace them. This design fits over the body of a BPM, 2.75" OD, but not the region with the SMA connectors. There is a BD/DJ set which does fit over the SMAs, one in each linac. Half of that could be replaced with a magnet fabricated as discussed here.

Two units should be purchased for the injector.

Drawing title: CEBAF Injector 200 keV Gun Y Chamber Dipole Coil Fixture
Drawing number: JL0087295

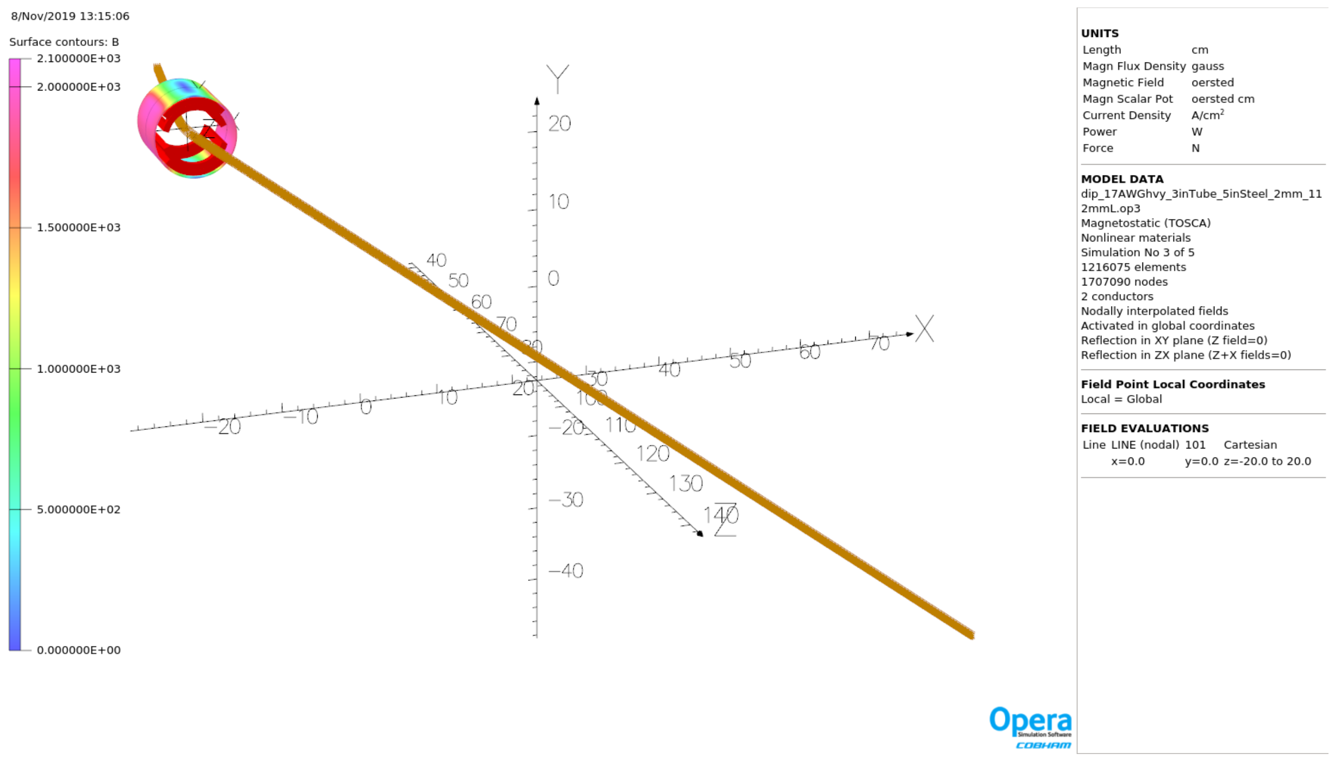

Figure 13. 1 cm square array through magnet with 112 mm steel and 0.75° coil rotation. Not optimum per figure 12, but not bad.