Choice of injector solenoid steel IR driven by tolerance stackup

Jay Benesch

Abstract

Tolerance stackup studies were undertaken on models of the low momentum injector solenoid (see TN-19-010). Tolerances used were chosen to be readily achieveable in a modern machining environment, 100 and 300 microns. IR of the steel plates in the solenoid was 38, 45 or 57.2 mm. The 38 mm version was added at Joe Grames's request. Before this study I advocated the 57 mm version as the focusing strength is flatter across the beam and concept is simpler. This study showed that the 45 mm IR is 2-3x **less** susceptible to manufacturing variance and produces about 60% more focusing strength (B^2) for the same current so that version is suggested. It can be used at all low momentum locations in the injector.

Results with 3A in 528 turns per coil.

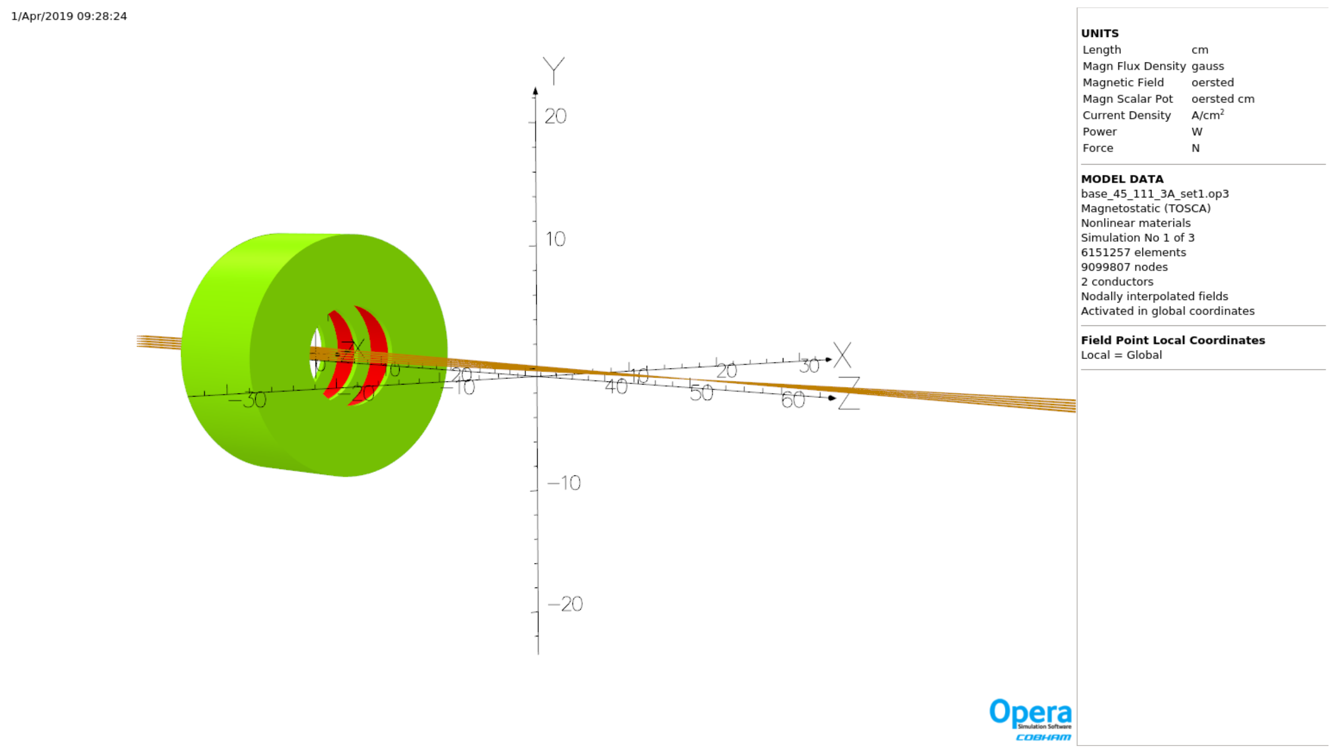
description	38 mm	**45 mm**	57 mm
integral B^2dL over [-30,30] at 3A at y=0 (G^2-cm)	394826	289004	173523
keV KE for 50 cm focal length, 1 cm square on axis, 3A	325	250	160
improvement factor over FA at 6 mm radius	4.83	5.64	7.33
improvement factor over FD [12-18 mm]	2.51	2.94	3.82
change due to 300 micron single coil move	0.5 ppt	0.9 ppt	2.1 ppt
change due to both coils moving 300 μm same direction	(not modeled)	none	none
change due to coils moving 300 μm opposite directions	1.1 ppt	1.8 ppt	4.2 ppt
non-concentricity of left coil vs other, steel, 300 μm	0.05 ppt	0.1 ppt	0.1 ppt
move left plate 100 μm with respect to coils, shell	0.4 ppt	0.7 ppt	1.8 ppt
0.001 of int(B^2) beyond z= (z=0 at center of 11 cm assembly)	10.2 cm	11 cm	13.5 cm
1% of peak B at z= (z=0 at center of assembly)	15.4 cm	17.5 cm	21.6 cm

While the change in focal length (∫ B^2dL) over radii of interest is 30% greater for the 45 mm option than the 57 mm option, the integral at 3A is 60% greater for the smaller aperture so the coils will run cooler. The tolerance for manufacturing error is much better in the 45 mm design and this will likely make their cost comparable to the 57 mm design for the same error budget. This might be allocated:

a. coils must be symmetric about center of central steel piece within 0.3 mm (1.8 ppt)
b. steel plates must be symmetric around central steel piece within 0.2 mm (2*2*0.7 ppt = 2.8 ppt
c. steel concentricity 0.1 mm should be easy due to copper mandrel machining
d. coil concentricity 0.3 mm should be achiveable in winding per specification

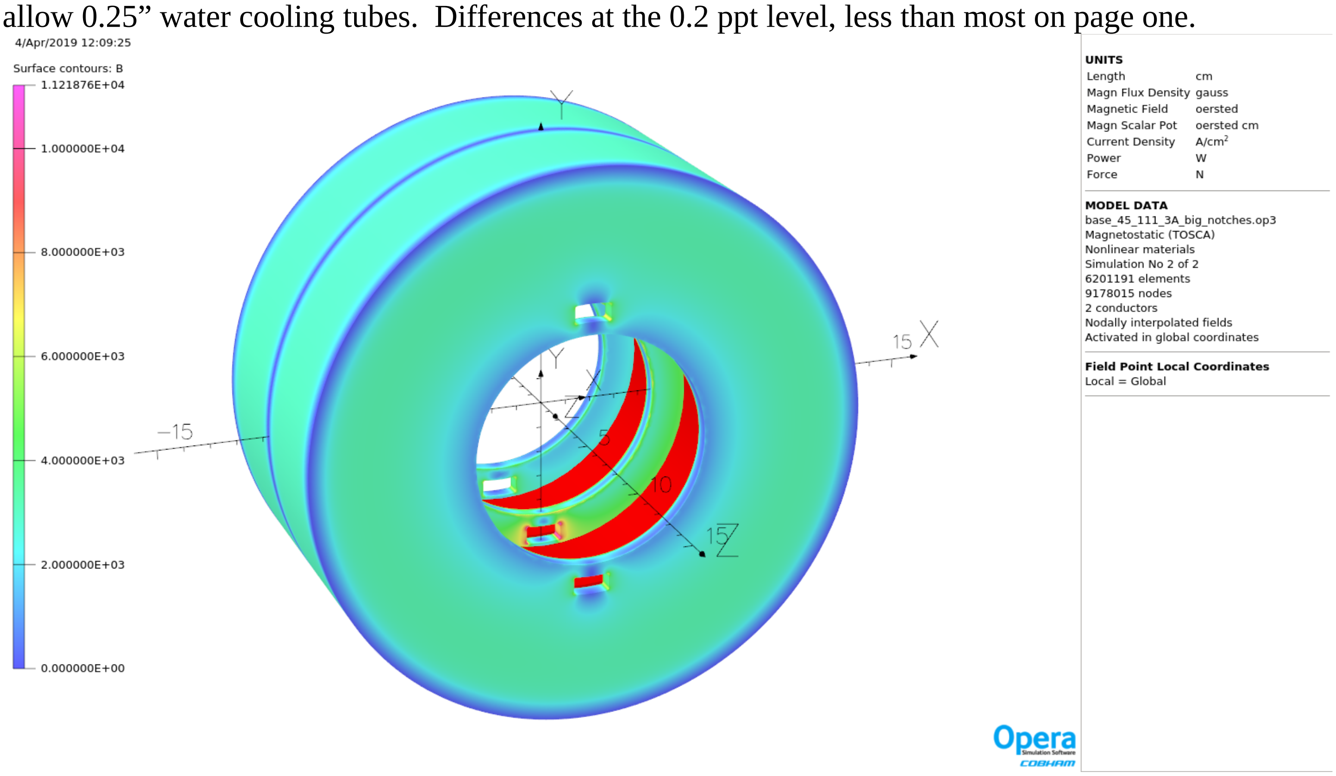
All the units should then be identical within 0.5%. If tighter grouping is desired, cut (b) in half and (a) by a third to get 0.26%. Given the 3x larger effect of steel offset to coil offset, it may be desirable to have three 8.75” diameter plates with two short steel 8.5” OD tubes, through bolted, so the plate separations can be measured after assembly. M3 or #4 threaded rod.

Resistance per coil ~2 ohm so with water cooling the 45 mm design should be fine for 375 keV.



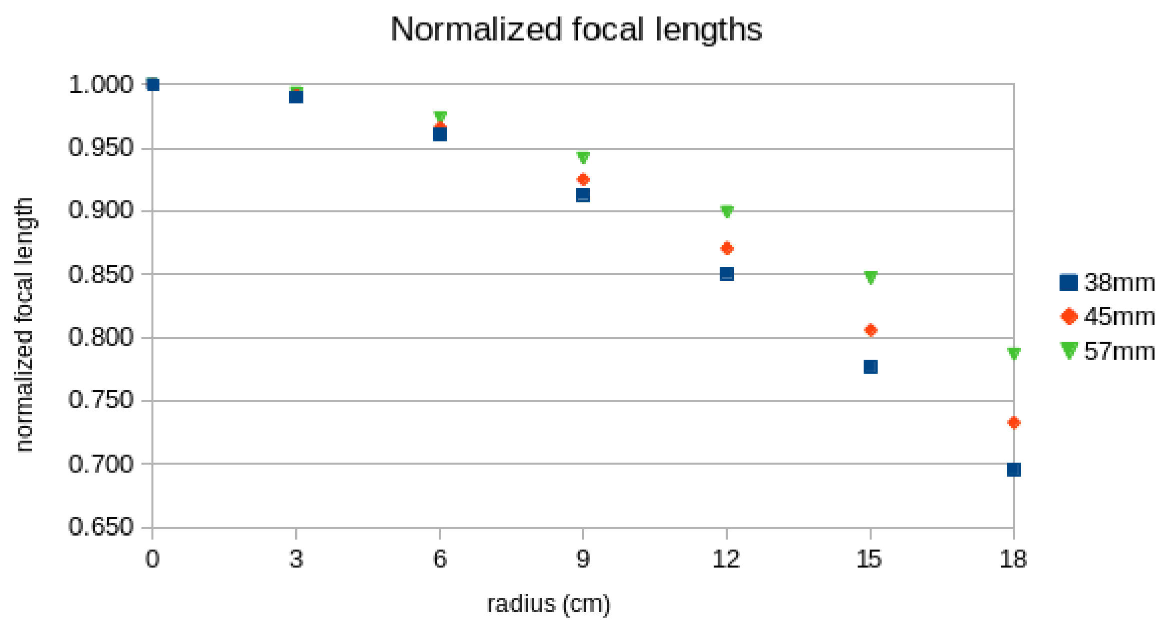
1 cm square bunch of 250 keV rays focused by the design with 45 mm IR on steel plates.

I checked difference in Fourier components of the design above vs that below, which has notches to allow 0.25” water cooling tubes. Differences at the 0.2 ppt level, less than most on page one.



Further discussion of plate IR

In my opinion the 45 mm IR is the best compromise for the injector. The beam centroid is steered within +-2 mm of the axis. Beam pipe is typically 1.5” OD, 1.38” ID, 17.5 mm IR. In https://logbooks.jlab.org/entry/3634406 the square root of emittance*betaX was 8 mm at 0I06. In https://logbooks.jlab.org/entry/3634414 the same value for Y is 3 mm. These were measured 12/3/2018. Even if one assumes the calculated size for X is incorrect, there are still only five times the y size from the possible centroid location to the wall. Given that transmission through the 6 mm diameter apertures placed at nodes of the beta functions is of order 90%, a more typical value of sigma may be 2 mm. There are a lot of particles out beyond 6 mm radius at anti-nodes, aka the solenoids, on the scale of the ppb helicity correlated position differences parity experiments are working towards. Resulting differences in beta functions will propagate through the machine. There are still many tens of ppb of particles out at the wall - and Pockels cell steering via helicity flip will change their number and how many get through the apertures. I assert that rather than reducing solenoid steel aperture to just over the OD of 2.75” CF flanges the CIS and injector groups should be working towards making 3.375” CF flanges and 2” OD tubing the standard in the low momentum region. This tube has 24 mm IR, adding over two sigma to cut-off. Remember also that A3 and A4 will be at 200 kV KE after the 2020 injector rework and so will also be intercepting particles. Maintaining equal beta functions for all particles out to large radius should be the goal. It should not be governed by the use by the initial injector group leader only of Varian Conflat sizes. MDC introduced intermediate sizes including 3.375” (2” tube) and 4.625” (3” tube) by the mid-70s. CEBAF's injector should use them in the rebuild.



Focal length is maximum in the center of the solenoid and decreases as one moves out towards the conductor. Chopper slits encompass r=[12,18]. For the 45 mm IR, span is 0.138. For the 38 mm IR, 0.155, an eighth larger. Varying Larmor rotation as a function of slit Z in the chopper drove the selection of the 45 mm IR for that location, see TN-19-010. I believe it to be a good compromise for all locations even though beta functions for halo particles will still progress differently from those in the core. A 46 or 48 mm radius might be a better compromise yet except in the chopper. The 46 mm IR yields a factor of 3.00 improvement over the FD at a cost of 4% of focusing strength.