A new "5 MeV" dipole

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Introduction

Drawing 27100-D-0001, Beam transport recirculator 5 MeV dipole magnet, is the assembly drawing for what we call the "5 MeV dipole". As the drawing name implies, it was initially designed for the injector recirculation experiment. It was then re-oriented and used to direct beam left to either the 5 MeV beam dump for energy measurement or the Mott polarimeter. For beam to CEBAF, BdL was set to zero, straight ahead. Finally, for the PEPPo experiment with a new beamline to the right, the magnet was rotated so the pole faces were normal to the CEBAF NL axis, allowing for roughly equal field inhomogeneity to all off-normal beam lines. The field inhomogeneity is insufficient for the approved bubble chamber experiment, so I was asked to design a replacement. Since there will be a new cryounit capable of providing beam of 16 MeV KE in 2015, it seems to me prudent to put enough steel in the magnet to provide for bending this beam since the increase is only 0.85cm in thickness.

Models

The TOSCA model of the existing 5 MeV dipole is shown in figure 1. The model of the proposed new model is shown in figure 2. The pole width increases from 4" to 14 cm to increase the region with field flat to better than 0.1% by 3 cm. There is no tolerance for pole parallelism on 27100-D-0001. The pole separation is given as "1.068" +- 0.015" assembly variance". This is fine for a one-time recirculation experiment but intolerable for a magnet intended to measure energy. The existing coil is 350 turns of #17 wire, random wound directly on the pole pieces. Joe Grames was not able to locate piece part drawings, only the assembly drawing.

Pole gap now will be 2.65-2.70 cm. The pole faces should be flat and parallel to 20 microns at the outside. This may require grinding the parts, but they are small so the expense will not be too great. Steel should be annealed for stress release before machining. If fabricated in six pieces steel stock is assumed to be 1.125" with final thickness at least 2.75 cm. Top and bottom plates of the magnet shall be full width with ground inner surfaces. The shorter side plates shall be ground top and bottom only, the mating surfaces, to set the pole separation. Pole pieces shall be ground top and bottom so the parallelism and spacing requirements may be met. If a magnet vendor has a piece of low carbon steel 3" x 10" x 10" the entire yoke could be machined/ground as a unit, cut into two pieces 12.5 cm long, assembled with slide fit pins for registration, and secured with two bolts on each joint. The dimensions in the model are minimum material condition: 2.70 cm gap, 2.75 cm thick steel sections. If one is starting from 3" x 10" x 10" stock the outer dimensions can grow as long as the outside surfaces are flat and parallel/perpendicular to 100 microns. Three or four threaded holes for mounting will later be specified for the bottom. Pole corners have a 1 cm radius to keep the stress in the conductor under 10%.

Coils are to be wound of #14 square copper wire with heavy film insulation, 14 layers of 14 turns each. The maximum material condition of the insulated conductor is 0.177 cm square so this results in a maximum coil size of 2.478 cm square exclusive of any interlayer or external fiberglass. Coil pockets are 2.75 cm square in the model, which should suffice when fiberglass is added. If more volume is needed, ask. Hmm, I suppose the coil pockets are maximum material condition. If the stock is larger than needed to accomodate 2.75 minimum steel thickness, coil pocket may be increased. Coils may be wound directly on the poles or or separate forms. In the latter case a slide fit over the poles is preferred and the manufacturer should provide some sort of coil spacer which will keep the coils rigidly seated in the pocket. The coils may be a bit larger and wrapped in EPDM rubber http://en.wikipedia.org/wiki/EPDM_rubber A coil spacer will still be required.

	x=0	x=1	x=2	x=2.5	x=3	x=3.5	x=4
1965 amp-turns	-27279.9	-27277	-27264.3	-27251.5	-27234.1	-27205.4	-27159.4
BdL ratio to x=0		0.9999	0.9994	0.9990	0.9983	0.9973	0.9956

Table 1. BdL values for z=[-20,20] along indicated x locations, y=0. 320 A/cm2 used in the coil; this is twice the requirement for a 9.1 MeV KE electron at 25 degrees bend. Ratios of BdL(x=0)/BdL(x_other) are shown in the bottom line of the table. As seen in figures below, the beam in in high homogeneity regions for most of its path.

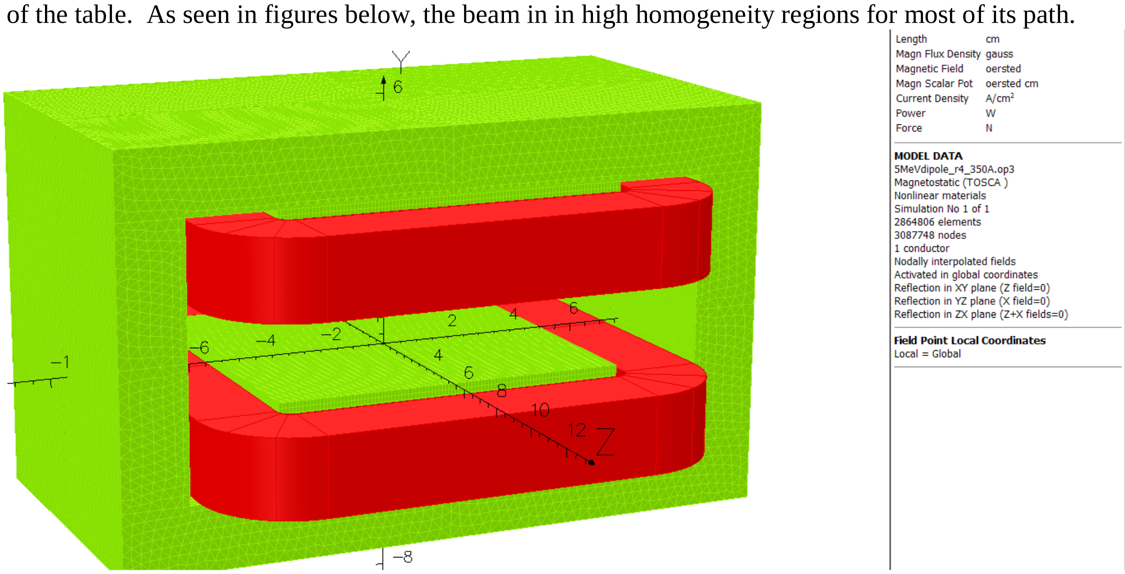

Figure 1. Original 5 MeV dipole

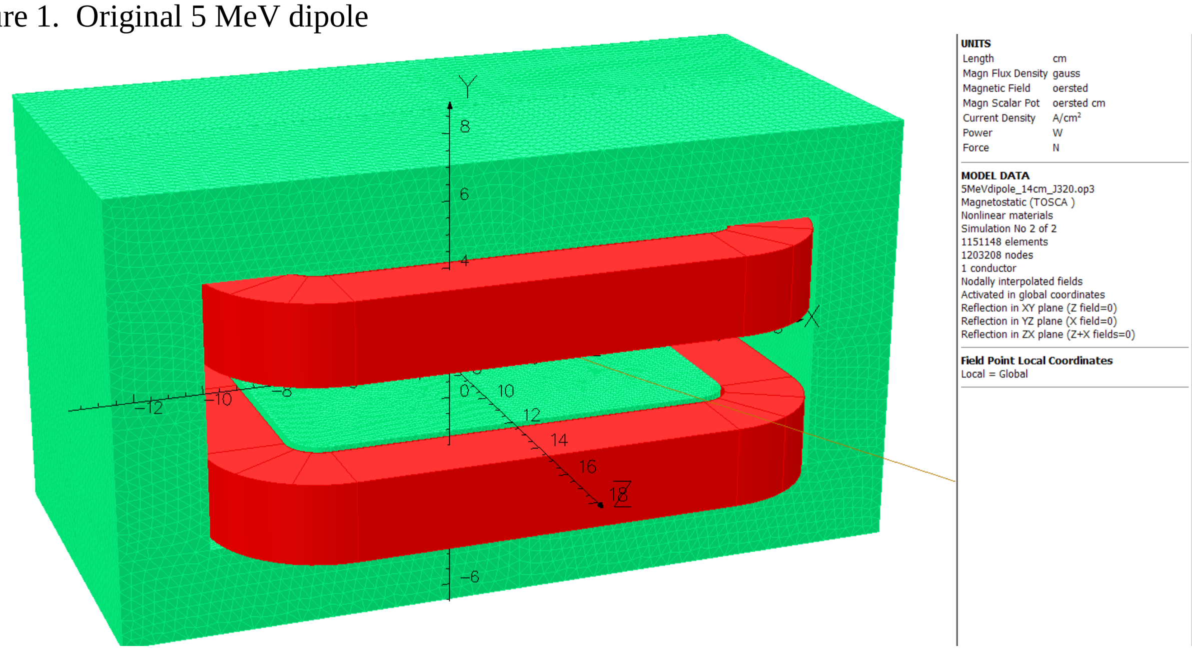

Figure 2. Proposed 5 MeV dipole 14 cm wide poles vs 4", 12.5 cm long vs 4"

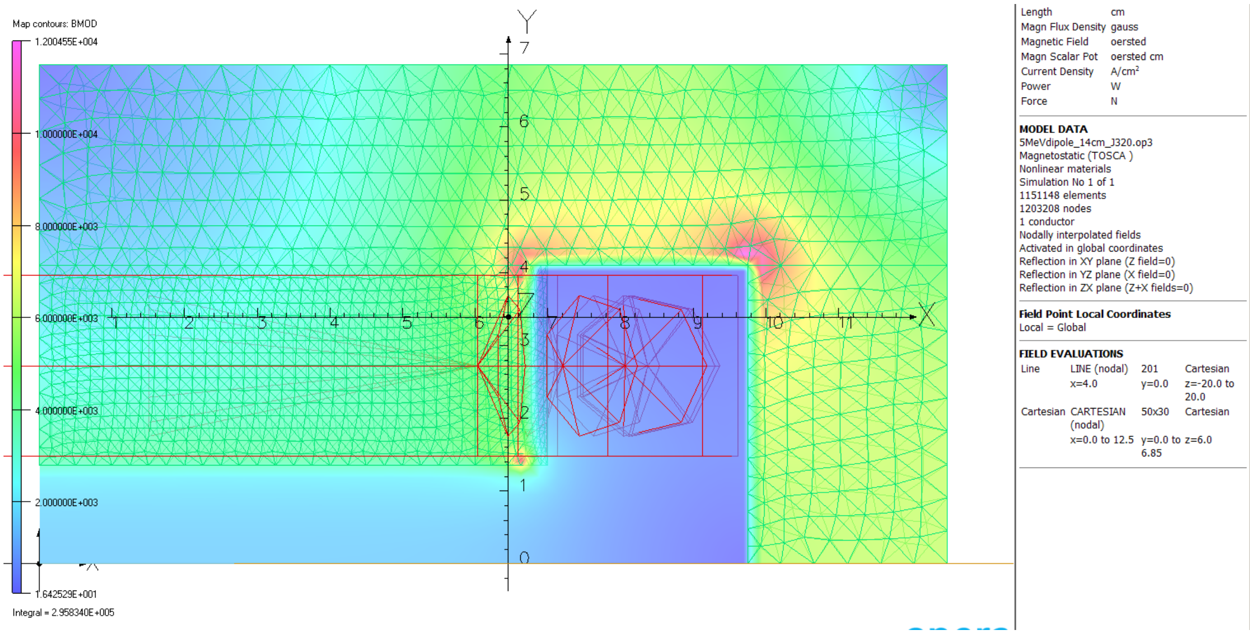

Figure 3. Bmod at z=6 cm so one can see the field peak in the radiused pole as well as in the return steel. J=320 A/cm^2, which will bend a 19 MeV KE electron 24.7 degrees.

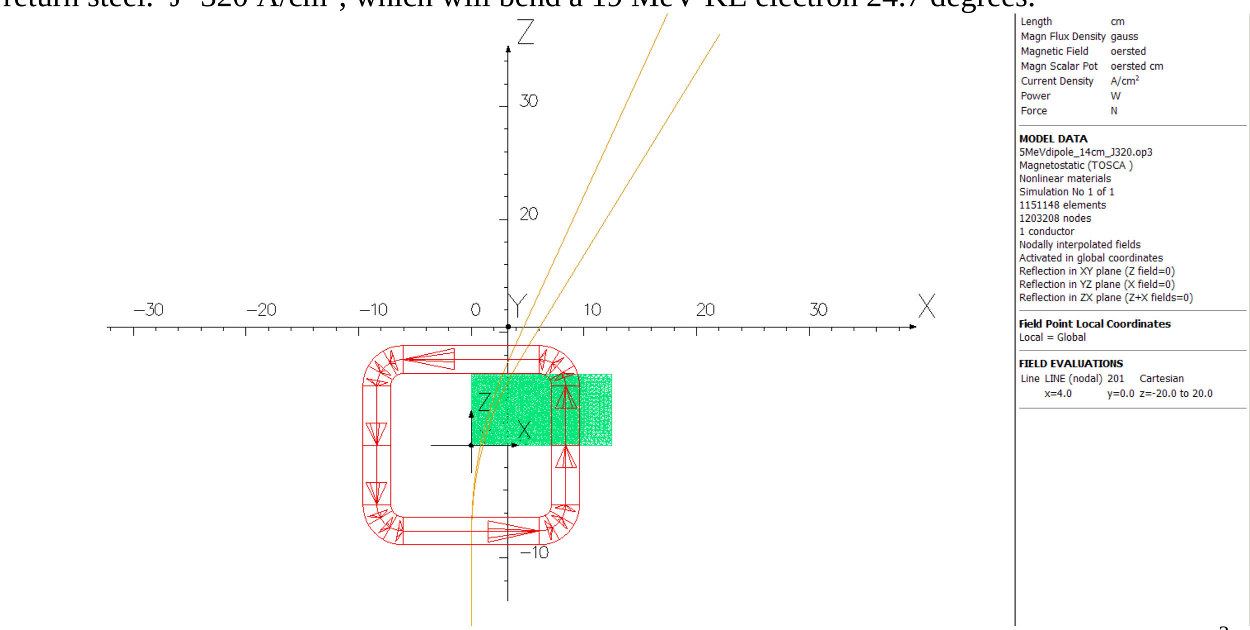

Figure 4. Trajectories of 15 MV KE (outer) and 19 MV KE (inner) in model with J=320 A/cm^2. Angles measured between z=15 and z=35 cm are 31.6 and 24.7 degrees respectively. This magnet has lots of excess capacity and could be shortened to 10 cm pole length from 12.5 cm pole length if 3"x10"x8" stock is available and 3"x10"x10" stock is not. 10.025 A in the conductor, ~1.7 ohms, so ~170W. 733 cc in coil pair, so ~0.25 W/cc. This shouldn't be an issue for convective cooling. Certainly half the current, one fourth the power, won't be.

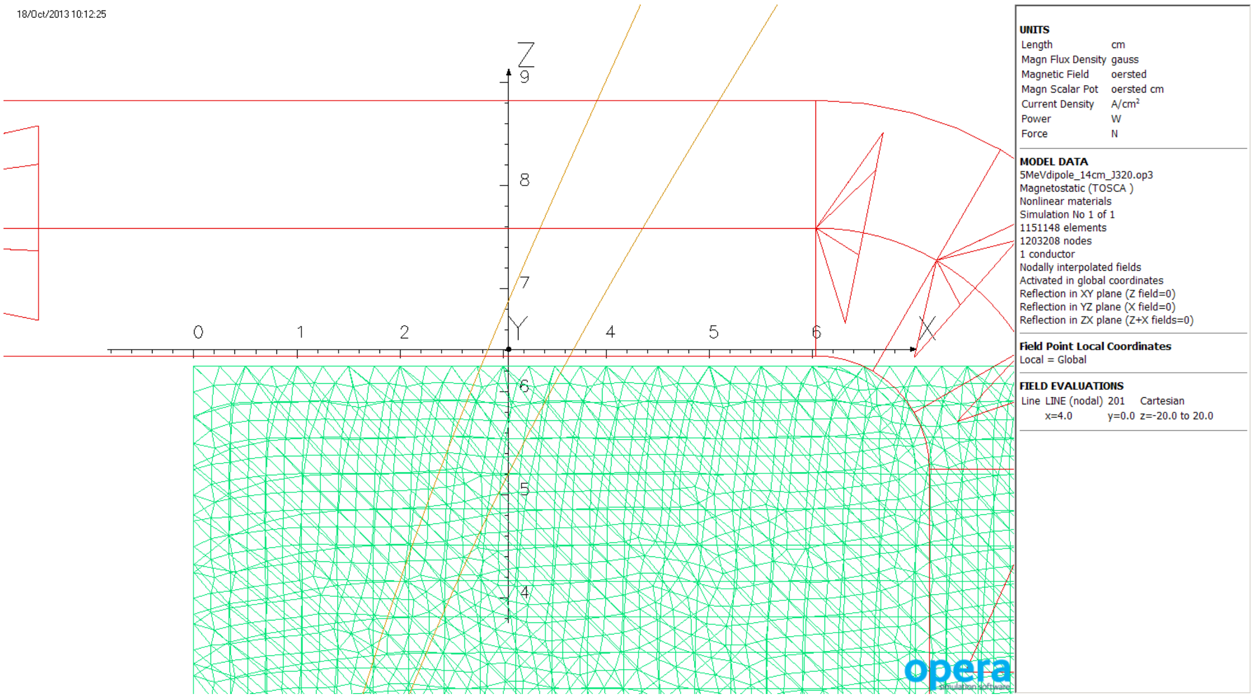

Figure 5. Close-up of trajectories in figure 4 so one can see where the particles cross the steel and coil boundares.

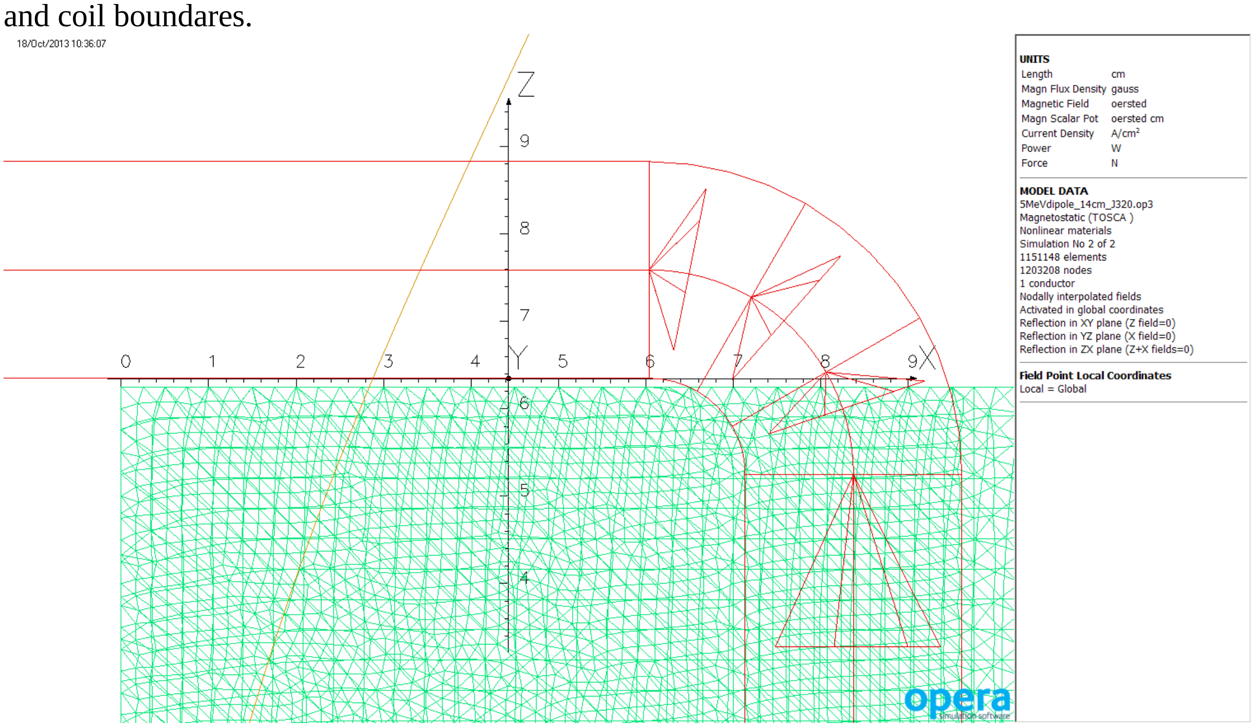

Figure 6. Trajectory of a 9.1 MV KE electron in a model with half the current density, 5.012 A in the conductor.

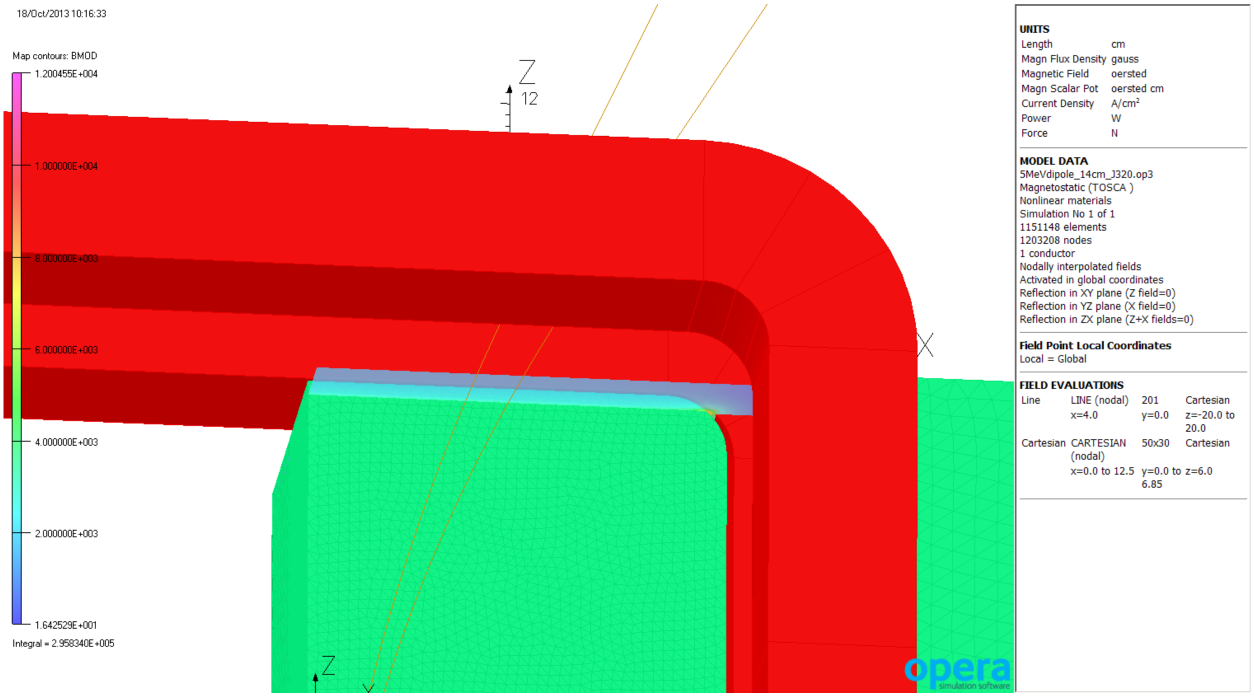

Figure 7. Bottom view of model showing pole corner radius and ~1mm spacing to coil in the model. The Bmod plane view of figure 3 is seen sticking out of the pole in this view, as are the trajectories of figure 5.

Steel dimensions in model, with no symmetry assumed, unlike most of figures above:

part	x1	x2	y1	y2	z1	z2
poleT	-7	7	1.35	4.1	-6.25	6.25
poleB	-7	7	-1.35	-4.1	-6.25	6.25
top	-12.5	12.5	4.1	6.85	-6.25	6.25
bottom	-12.5	12.5	-4.1	-6.85	-6.25	6.25
sideL	-12.5	-9.75	-4.1	4.1	-6.25	6.25
sideR	9.75	12.5	-4.1	4.1	-6.25	6.25

as discussed on page 1, pole faces should be flat and parallel within 20 microns. Spacing may be 2.65-2.7 cm. Top surface of top plate and bottom surface of bottom plate shall be referenced to the pole datums parallel and flat to 50 microns (preferred), 100 microns (allowed if cost reduction > 5%). Pole Z faces shall be perpendicular to pole face datums at 100 microns. If magnet is machined in two halves from 3" stock instead of from six pieces of 1.125" stock, AbsVal(y2) may increase from 6.85 to 7.5 cm to reduce machining. Overall width may also increase from 25 cm to 25.4 cm. Coil pocket may grow from 2.75 cm square to 2.9 cm square if convenient for manufacturer as long as steel thickness remains 2.75 cm minimum throughout top and side. Coil envelope increase for manufacturing convenience would drive pocket changes.

Possible issue: The vacuum chamber was designed with the angled arms referenced to the center of a magnet 4" long. There is room for a 5" long magnet on the chamber and the final angles will be OK but the region where the four arms diverge may show a closer approach than is desired. As mentioned in the figure 4 caption, the magnet has lots of excess capacity and so could be shortened to 10 cm pole length without issue. Coil current and heating will go up 25% and 56%, but this should still be OK. Someone needs to check the geometry. I can supply the numbers for the particle tracks shown in figure 4 with modest effort, tweeking the energy to get closer to 30 and 25 degrees.