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The iron geometry of RHIC dipoles

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1 Introduction

This note reports on the results of applying to short RHIC dipoles the same analysis that has already been applied to full length "DRG" dipoles [1]. Design parameters for these dipoles may be found in Table 1. After appropriate generalization, the same software has been applied to all dipoles - including DRG magnets. More documentation and data can be found in directories associated with this software [2].

Parameter	DRG	DR8	D5I	D5O	D96
Mag length (design) [m]	9.4407	9.4407	6.9160	8.6984	2.9494
Optical angle [rad]	.038924	.038924	.028515	.035864	.012161

Table 1: Dipole design parameters.

Quantitative details of the best fit to the iron geometry of each magnet model are presented in the following section, "Iron geometry". A brief discussion of the average locations of cold mass (and, for DRG magnets, beam tube fiducials) naturally follows. Fiducial data are presented in the section "Fiducial geometry".

2 Iron geometry

Figure 1 shows the assumed geometrical model that is fit to Northrop-Grumman sagitta data, measured at several places on the cold mass iron. The iron is assumed to have a central region tracing a constant radius arc, with a straight section of identical length on both ends. "IRON_STRAIGHT", the optimum length of the straight ends, is the only free variable in the model.

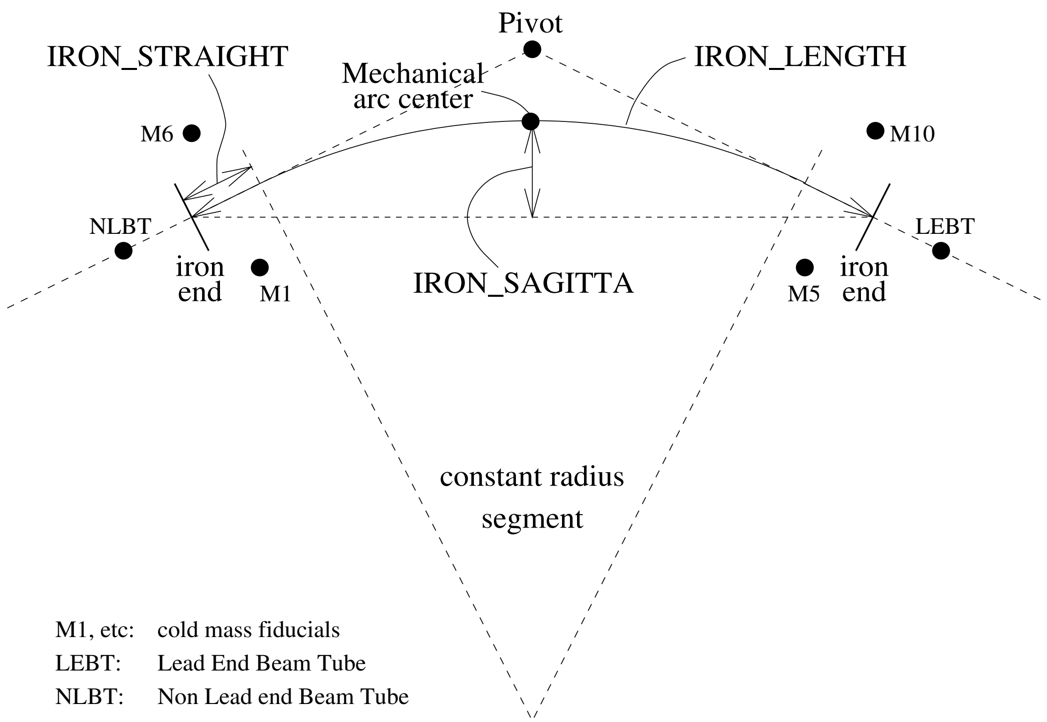

Figure 1: Basic features and parameters of the model of the iron geometry.

The solid line in the figure represents the center line of the iron, as built. The dashed lines that converge on the "Pivot" represent extrapolations of the ideal design orbit, proceeding from the outside to the inside of the magnet. Only in an ideal world will these dashed lines match smoothly to the ends of the iron center line curve. In the real world it is possible, necessary, and desirable to adjust the radial location of the "Mechanical center point" of the iron, relative to the pivot. In what follows, this offset is adjusted to place the injected beam in the center of the iron, on average, as well as possible.

Parameter	DRG	DR8	D5I	D5O	D96
IRON_STRAIGHT [m]	.85	.85	.85	.85	.40
Mechanical radius [m]	236.297	236.297	233.543	236.276	181.644
Injection radius [m]	242.108	242.108	243.025	242.849	243.278
Storage radius [m]	242.565	242.565			244.241
Mechanical angle [rad]	.033926	.033926	.023496	.030798	.013330
Optical angle [rad]	.038924	.038924	.028515	.035864	.012161
Iron length [m]	9.7165	9.7165	7.1871	8.9766	3.2212
Iron sagitta [m]	.0484	.0484	.0261	.0411	.0067
Mag length (design) [m]	9.4407	9.4407	6.9160	8.6984	2.9494
Mag length (inject) [m]	9.4238	9.4238	(6.9298)	(8.7095)	2.9584
Mag length (store) [m]	9.4416	9.4416			2.9701
INSTALL_OFFSET [in]	.050	.050	.020	.020	-.020
Injection offset [m]	.046242	.046265	.024558	.039008	.004971

Table 2: Geometrical parameters of the average dipole data, for each dipole style. Parentheses imply that only warm data are available.

Table 2 lists various quantities that are either input to, or output from, the iron model for magnet style. The "mechanical radius" is the radius of the iron arc, derived from known values of IRON_STRAIGHT, the total "iron sagitta", and the "iron length". For future reference, note the low value of the mechanical radius of the D96 dipoles. Also note that the parameters for DRG and DR8 dipoles are (deliberately) identical, with the sole exception of a very minor difference in the "injection offset" (discussed below).

"Injection radius" and "storage radius" are the radii necessary to achieve the fixed design optical angle in the measured magnetic length available. When no cold measurements are available, the warm magnetic length is used to calculate the injection radius, while the storage radius is left blank.

The "mechanical angle" is derived from the mechanical radius and the known iron arc length, while the "optical angle" is the design quantity that is found, for example, in the optics database.

"INSTALL_OFFSET" is the optimum value of the deliberate radial offset of the iron, relative to the design injection trajectory. It is chosen to (approximately) minimize the RMS offset of the injected beam relative to the center of the iron. For DRG and DR8, this also fortuitously moves the average location of the beam tube into a more weld-able position. No beam tube data are available for the other (shorter) magnet models. A positive displacement moves the magnet away from the center of RHIC.

"Injection offset" is the radially outward displacement of the injection arc center (NOT the mechanical arc center), relative to the vector average of the cold mass fiducials, averaged over all available dipoles of a particular dipole style. This parameter is used to help tell the surveyors where to put the magnets. The values in the Table use fiducial data recorded in Table 3, below, which is yet to be discussed.

3 Sagitta and centerline plots

Figures 2, 3, 4, 5, and 6, each show a "sagitta" plot and a "centerline" plot. Data points with error bars on the sagitta plot represent Northrop-Grumman data. The first and last data points have no error bars by construction. They are close to the iron ends, but not exactly at them, so that the iron sagitta reported in Table 2 is not quite the same as the maximum in this plot. Note that the horizontal and vertical scales of the sagitta plots vary greatly between magnet styles.

The plot scales are held constant in the centerline plots, so that orbit deviations can be directly compared between magnet styles. The quantity plotted is the location of the iron centerline relative to the injected orbit, which is conceived as being fixed in space. Hence a positive radial installation offset raises the curve. Each centerline plot includes a rectangular box, which represents the iron length in the horizontal, and a centerline deviation range of $\pm$ 1 mm in the vertical. Inspection reveals that, in all cases, the iron centerline is everywhere within this box, after an appropriate installation offset has been added.

The only slight surprise in all these plots is in the case of D96, by far the shortest of all RHIC dipoles. As already noted, the difference between mechanical radius and injected beam radius is unusually large in this magnet. It is said to be difficult to accurately bend such a short magnet. Nonetheless, the injected beam is as well centered in D96 dipoles as in the other magnet styles.

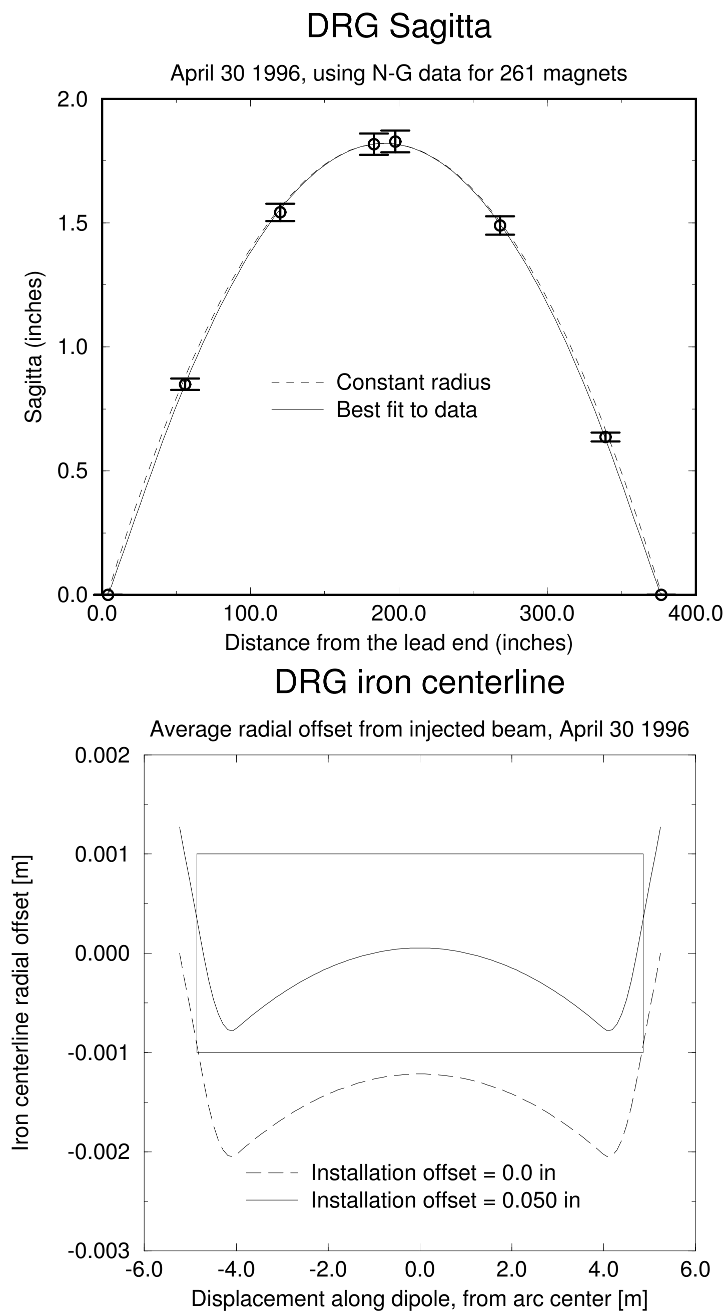

Figure 2: Sagitta data and fit, and centerline offset, for DRG dipoles.

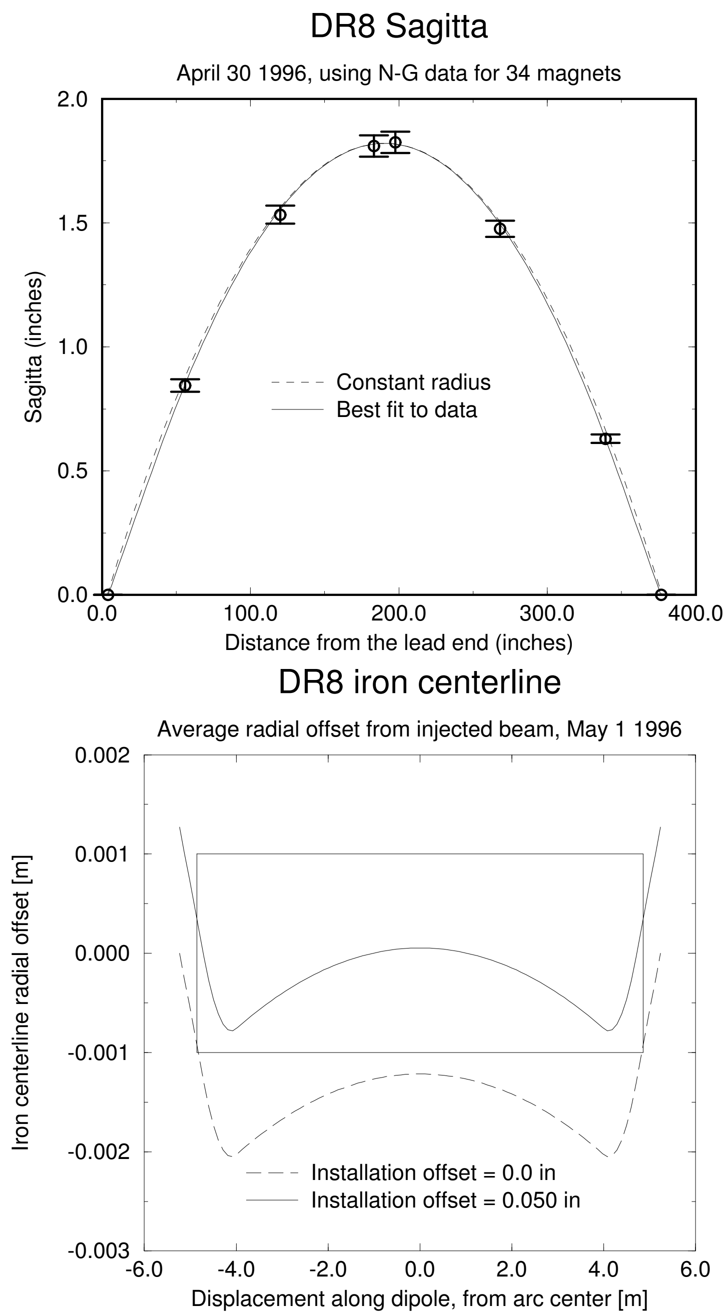

Figure 3: Sagitta data and fit, and centerline offset, for DR8 dipoles.

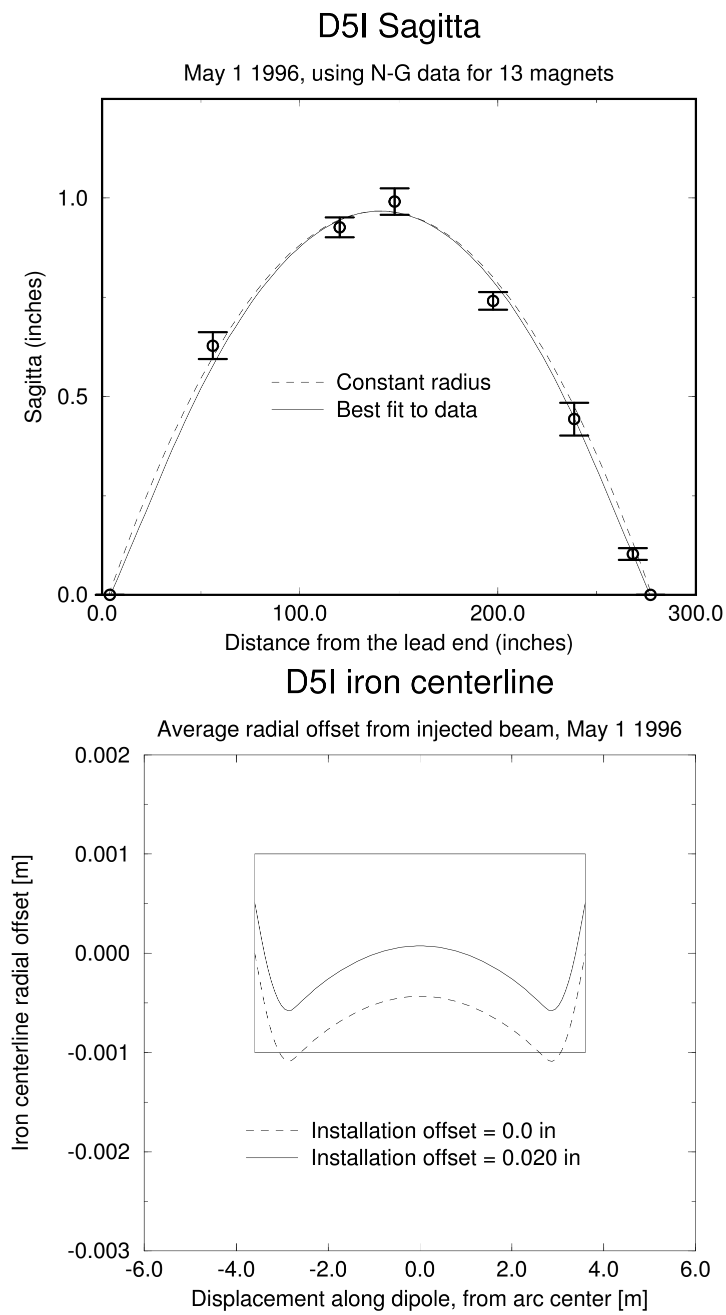

Figure 4: Sagitta data and fit, and centerline offset, for D5I dipoles.

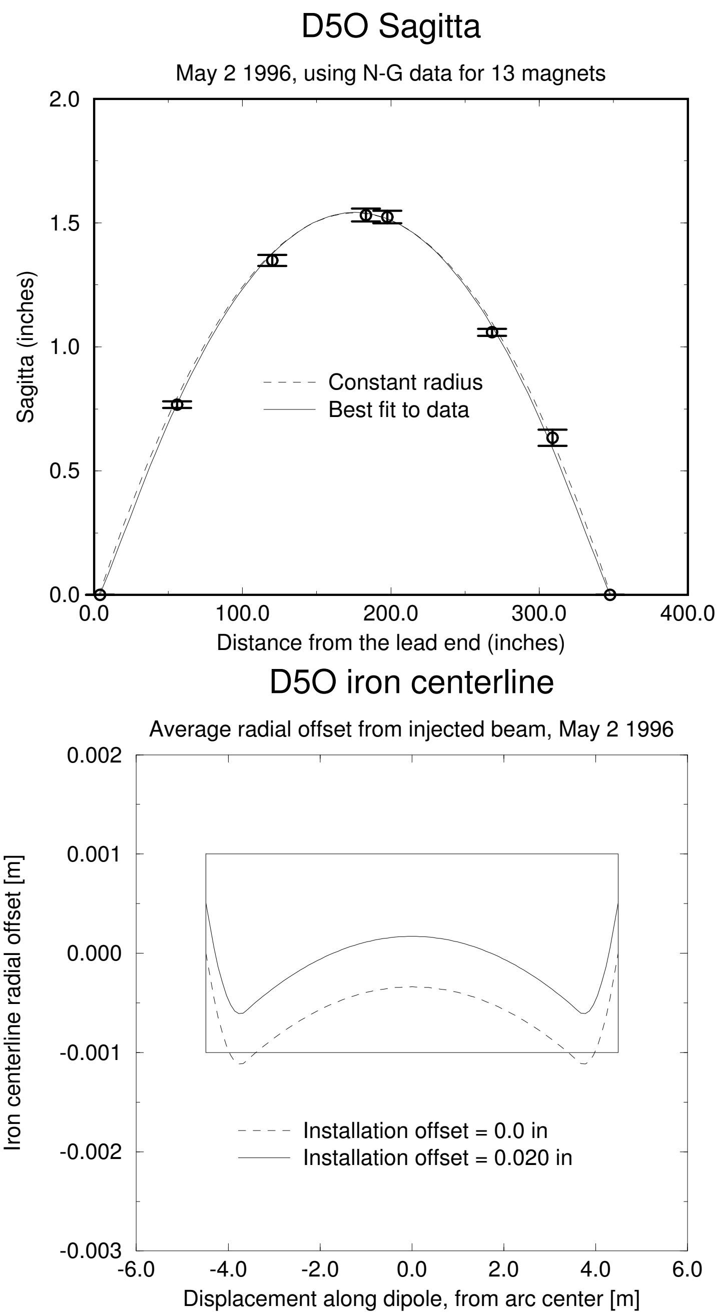

Figure 5: Sagitta data and fit, and centerline offset, for D5O dipoles.

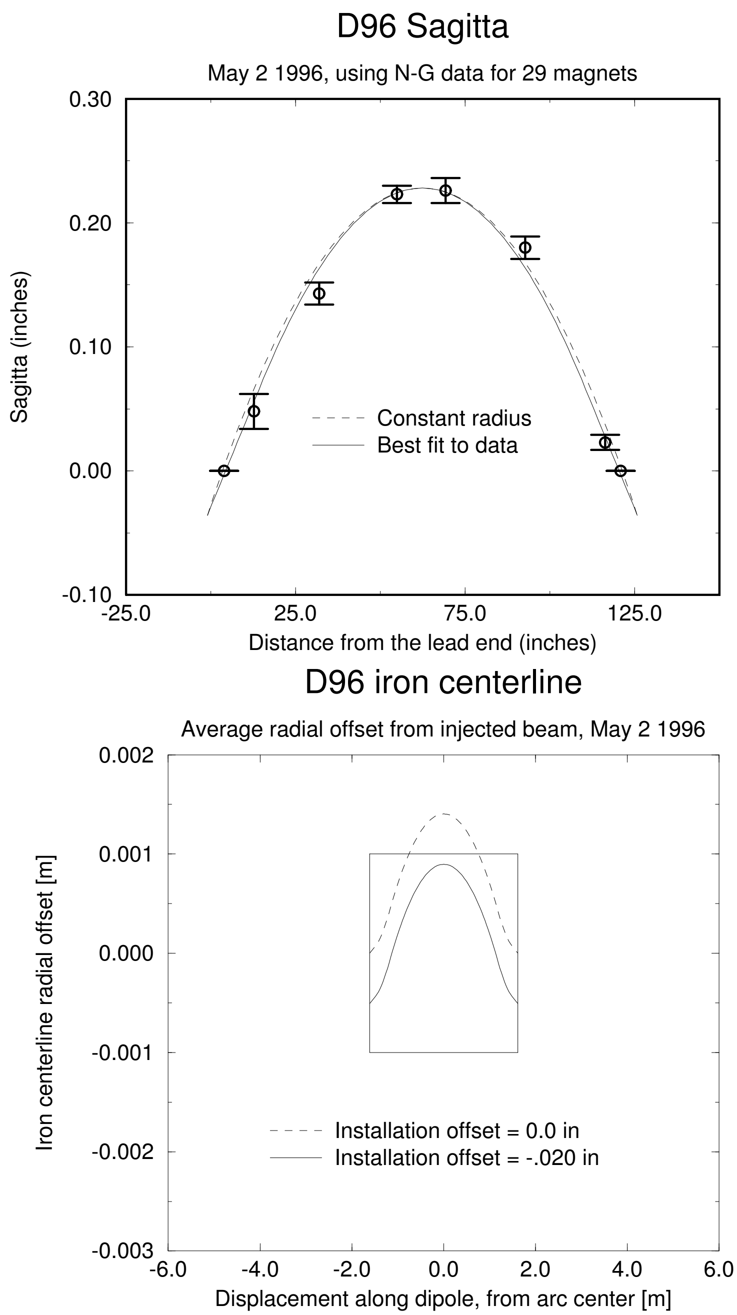

Figure 6: Sagitta data and fit, and centerline offset, for D96 dipoles.

4 Fiducial geometry

Figure 7 shows the two local coordinate frames that are used in the software. The “symmetric” coordinate frame is used for all internal calculations. Some external results are reported in the “MANCAT” coordinate frame that is extensively used by the surveyors. Note that cold mass fiducial marker M1 is at the origin of the MANCAT system, and fiducial M5 is on the Y axis.

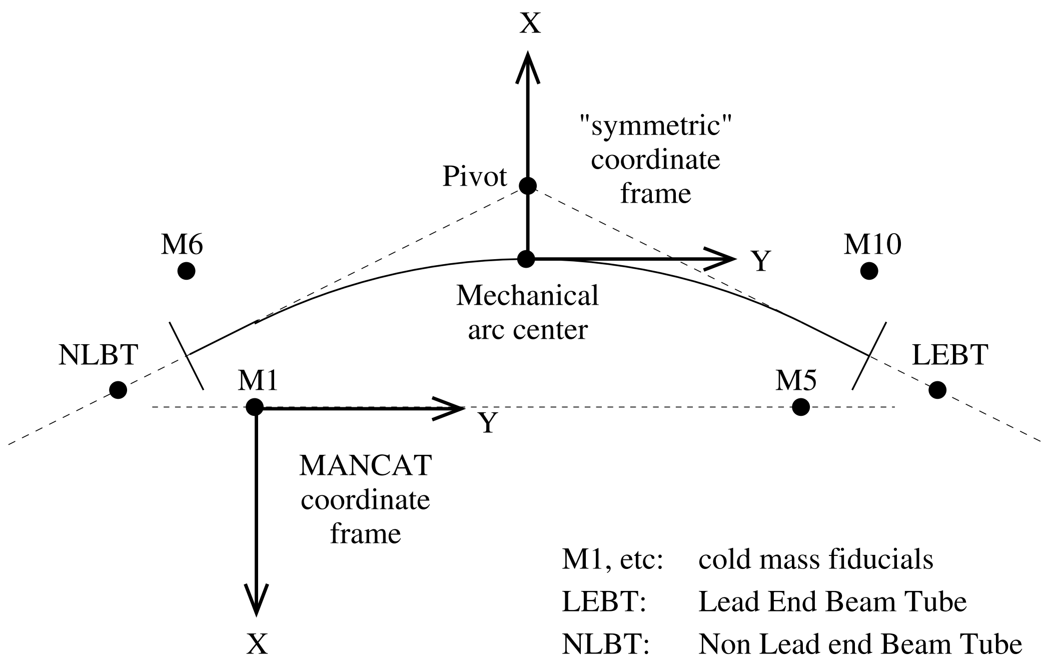

Figure 7: Origins and orientations of the two local coordinate frames, the “symmetric” frame and the “MANCAT” frame.

Figure 8 shows details of the surveying cold mass fiducials that are found at the end of the iron, and which are crucial in the correct installation of a dipole. Data is available for all such iron fiducials on all dipoles. Data is also available for Beam Tube fiducial targets "NLBT" and "LEBT", but only for DRG dipoles. The three quantities "FID_R_OFF", "FID_S_OFF", and "TUBE_S_OFF" determine where the 6 symmetrically placed fiducials are located in the computer model. One set of three variables is optimized for each magnet style, to best match the measured average fiducial locations.

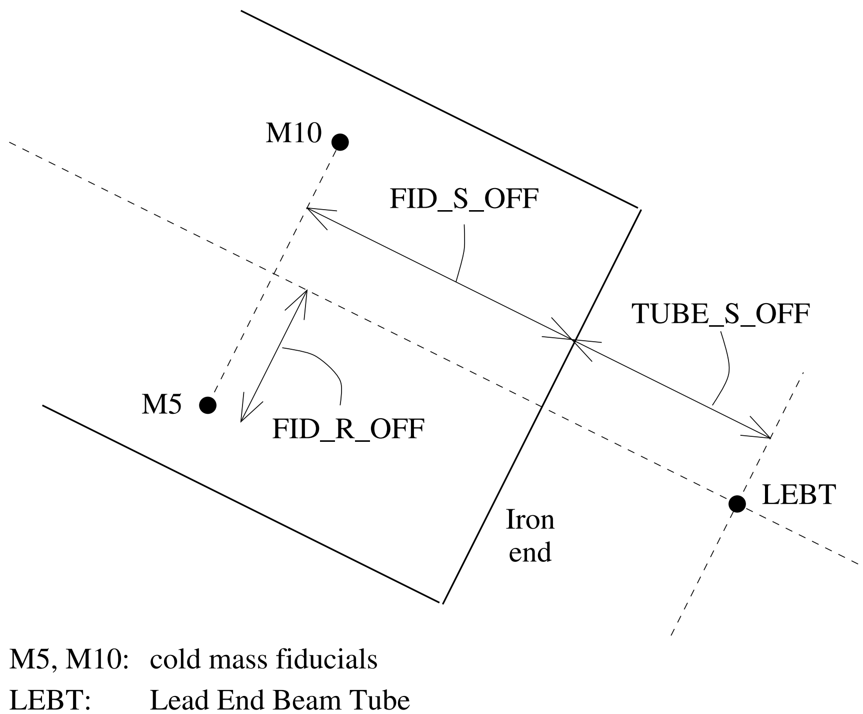

Figure 8: Detail of the location and parameterization of the cold mass fiducials on the iron of a dipole and, where available, of the Beam Tube target fiducials.

Table 3 lists the fiducial geometry parameters for each style, and the resultant symmetrized average fiducial locations in the MANCAT coordinate frame. Beam tube data is available only for DRG magnets. Note that the optimum values for FID_R_OFF and FID_S_OFF are slightly different for DRG and DR8 styles, leading to the slight difference in the injection offset values that are recorded in Table 2.

Parameter	DRG	DR8	D5I	D5O	D96
FID_R_OFF [m]	.12202	.12200	.12210	.12205	.12202
FID_S_OFF [m]	.12476	.12426	.12495	.12485	.12494
TUBE_S_OFF [m]	.37201				
M5.y [in]	372.529	372.569	272.996	343.413	116.916
M6.x [in]	-9.607	-9.605	-9.614	-9.609	-9.608
M6.y [in]	-0.163	-0.163	-0.113	-0.148	-0.064
M10.x [in]	-9.607	-9.605	-9.614	-9.609	-9.608
M10.y [in]	372.692	372.732	273.109	343.561	116.980
LE Beam Tube x [in]	-4.472				
LE Beam Tube y [in]	392.166				
NL Beam Tube x [in]	-4.472				
NL Beam Tube y [in]	-19.637				
Mechanical Pivot x [in]	-8.479	-8.479	-6.766	-7.898	-5.157
Mechanical Pivot y [in]	186.265	186.284	136.498	171.706	58.458

Table 3: Symmetrized average fiducial locations in the MANCAT coordinate frame, where M1.x, M1.y, and M5.x are zero by definition.

Finally, it should be noted that the enumeration of cold mass fiducials on D96 dipoles is different from the other dipole styles. Figure 9 shows the correct labeling, which is ignored in the contents of Table 3 for the sake of convenience.

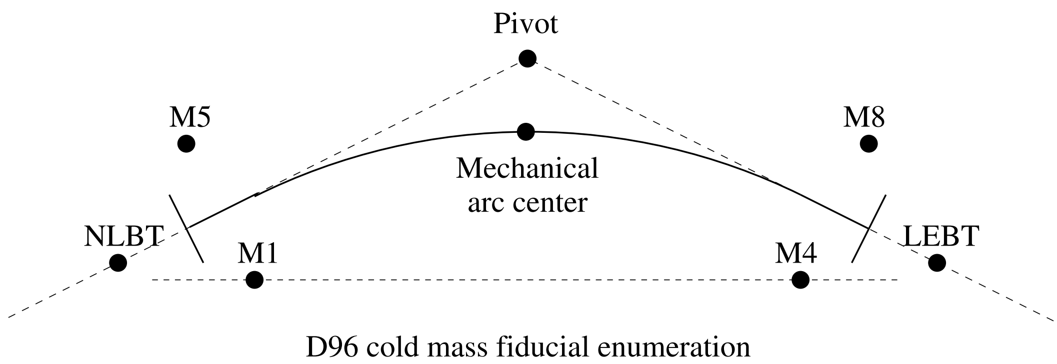

Figure 9: D96 eps.

5 Conclusions

Although the final delivery of short dipoles from Northrop-Grumman has not (quite) occurred yet, there is sufficient data available for the average iron geometry of each magnet style to be accurately derived, as built.

Slightly different installation offsets are optimum for the average magnet of each style. These offsets are part of the surveyors system of orienting magnets at installation. The surveyors also take into account the deviations that individual magnets have from the average magnet.

The worst case systematic shift of the injection orbit, relative to the iron centerline, is less than 1 mm. This accuracy is more than adequate for RHIC operations.

Acknowledgments

It would not have been possible to perform the analysis reported here without the help of Steve Tepikian, Dejan Trbojevic, and Jie Wei,

References

[1] S. Peggs, S. Tepikian, D. Trbojevic, J. Wei, "The Warm Iron Geometry of the 'Average' RHIC Dipole", RHIC/AP/62, July 1995.

[2] See the directory "/rap/horst/drg_geom", and others beneath it, for more information and data.