Proposed Main Injector Quad Offsets and Dipole Correctors Currents for the Current NuMI Extraction Geometry

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Introduction

The NuMI Lambertsons are planned to be installed during this summer's shutdown, currently scheduled for late August. Before these can be installed, a finalized extraction and beamline geometry needs to be agreed upon so that the stands and Lambertson flanges may be constructed. This note is to describe a set of quadrupole displacements and dipole corrector strengths that will define the geometry such that the flanges may be constructed and the dipoles installed. These displacements and corrector currents are dependent on the reduction of the present H608, H610, and H612 corrector 120 GeV/c levels to approximately zero. An initial installation scheme and corrector currents will be discussed.

The extraction and beamline geometry has been defined in the NUMI Primary Beam Design Report by S. Childress, et.al. in Oct 2002. In order to obtain the closed orbit and extraction position and angle that was specified by the design with correctors only, the correctors would have to run at greater than 30 Amps. At the time of that report the dipole corrector power supplies had a maximum of 18 A. Therefore, the only choice was to split the correction between transverse quad displacements and corrector strength. This lead to rather large quad displacements of approximately 4mm at some locations. This also lead to quad displacements at the upstream section of MI60 which implied active dipole correction on all ramps and energies to smooth back to zero. This, in and of itself, is not bad since the orbit could be smoothed to compensate the offsets and keep the beam centered through the upstream RF section.

Since the Design Report, a new 30 amp power supply has been developed by EE Support for use with the NuMI beamline dipole correctors. Utilizing these supplies can significantly reduce the need for quad displacements. **This solution will limit the design currents of the correctors to 20 Amps., leaving some room for margin**.

The extraction geometry (i.e. relative positions of the extraction elements) is close to that used for the design report. The Lambertson offsets and roll angles match what was used in the design report. Table 1 lists the elements, the fields, and approximate bend angles, and the orientation used here (and the design report). The offsets listed are not actually used in the simulation, but are values suggested to keep the beam approximately centered in the aperture (especially for V100) based upon design extraction trajectories. These will be used in generation of magnet cross section plots. Positive offsets are to the outside and up.

The beam position and angle, relative to the MI60 straight section, exiting the extraction c-magnet will be (approximately) maintained to the values described in the design report. (*the extraction geometry at 608 may not be quite the same in my model, but close enough* *for now*).Table 2 lists the horizontal and vertical positions/angles at the entrance and exit of the first Lambertson, LAM60A; the exit of the last Lambertson, LAM60C; and the exit of the C-magnet, V100 for the nominal extraction geometry.

Table 1. Kicker and Lambertson Field and position

Magnet	Field [kG]	Angle [mr]	dX [mm]	dY [mm]	Rotation
K602 (3 modules)	1.9558	0.000316	0.0	0.0	None
LAM60A	5.32419	3.72	2.0	-1.5	145 mr clockwise
LAM60B	10.73425	7.50	2.0	00.0	20 mr clockwise
LAM60C	10.73425	7.50	2.0	0.0	none
V100*	10.028	8.4	17u / 15d	30u / 80d	none

* the pitch values are only approximate and the physical geometrical constraints will dictate the actual installed pitch.

Table 2. Extraction positions a

	X [mm]		X' [mr]		Y [mm]		Y' [mr]	
	Design	Proposed	Design	Proposed	Design	Proposed	Design	Proposed
LAM60A in steel	19.112	19.946	0.921	0.776	0.0	0.0	0.0	0.0
LAM60A out steel	22.444	22.868	1.459	1.311	5.16	5.13	3.335	3.66
LAM60C out steel	18.066	18.258	-0.773	-0.773	93.295	92.16	19.633	19.51
V100 out steel	14.90	15.06	-0.774	-0.778	187.5	182.54	28.03	27.88

Flattop Momentum

One of the major operational scenarios will be combining the NuMI and pbar stacking cycles. The current pbar stacking cycle has a momentum off set of 0.42% to produce the necessary pbar bunch spacing for the Debuncher. The proposed solution incorporates the same momentum offset currently used on the pbar stacking cycle into the solution. Figure 1 shows the current flattop orbit in the Main Injector due to a positive 0.42% momentum offset. Here, positive positions are to the outside of the ring. Figure 2 shows the MAD orbit position (from 601 to 622) due to the same momentum offset. Note the position change is toward negative x. This is due to the fact that protons travel in a counterclockwise direction and the right-hand coordinate system has positive-x to the radial inside.

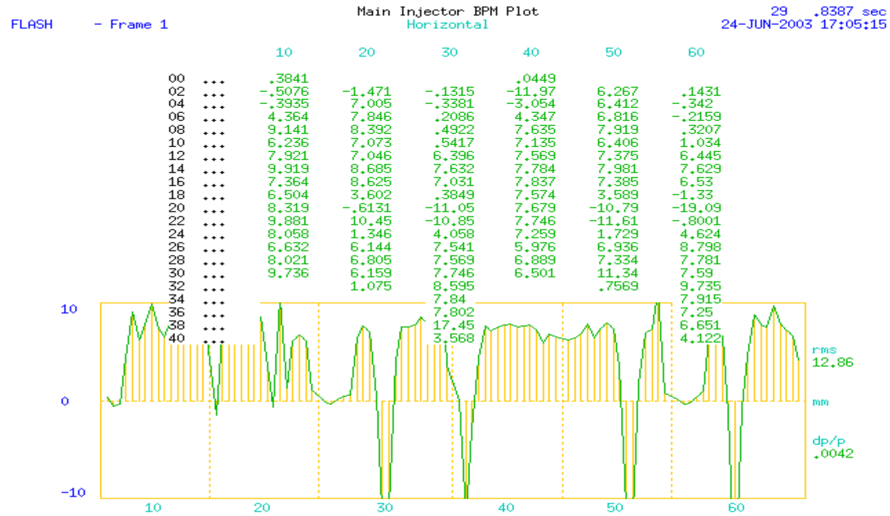

Figure 1. Current extraction orbit for pbar production

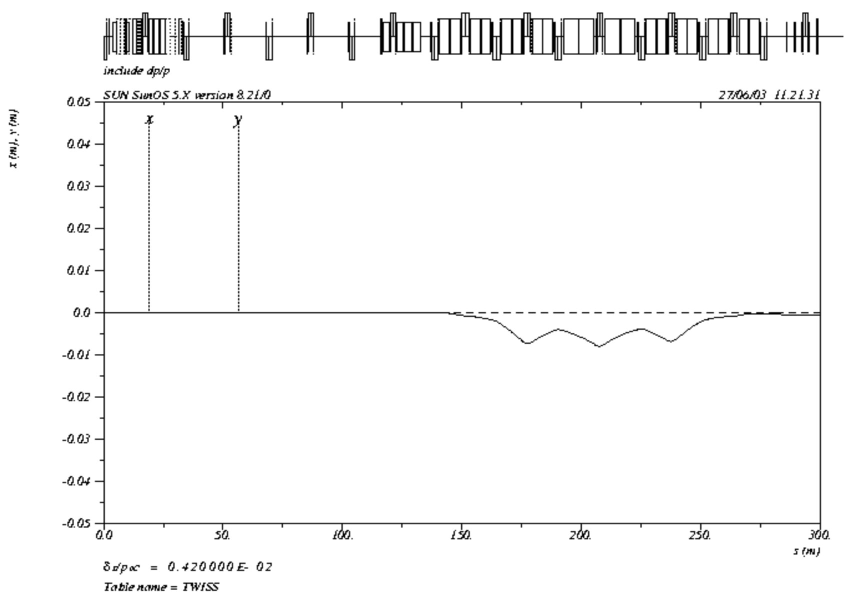

Figure 2. MAD simulation due to a positive 0.42% momentum offset. Positive-x is to the inside of the ring. Vertical scale is +/- 50 mm.

Closed Orbit

The closed orbit around the Lambertsons must be steered to the inside of the machine to avoid the Lambertson septa (4 mm thick) which is centered 2 mm to the radial outside. The circulating beam must always stay to the inside of the ring. The position of the closed orbit at extraction time was defined (in the design report) to be approximately 22 mm inside. If this orbit bump were to be done with just correctors, it would require greater than 30 amps. As in the original design, the quadrupoles around the Lambertsons are displaced. In this proposal the offsets were reduced almost by a factor 2 to keep the corrector currents at 20 amps or below. Table 3 lists the “approximate” offset for the quads at 606 thru 612 as calculated from dx = $\vartheta/(K_1 L)$ where L for IQB and IQE is 2.1176 m and IQD is 2.93040 m, and K_1 for the QF bus is 0.04068 $m^{-2}$and the "actual offsets used in the lattice file. Here the IQB and IQE are the quad types for the 84 inch quads and the IQD are the quad type used at the interface to the dispersion suppressor. Figure 3 shows the closed orbit around the Lambertsons due only to the "actual" quad off sets listed in Table 3.

Table 3 Approximate quad displacements as calculated from the kick the adjacent corrector and actual displacements used in simulation (in bold)

quad	β [m]	Ψ [2p]	ϑ [ur]	Approx ΔX [mm]	**Actual ΔX [mm]**
Q606	56.7	0	-129.26	-1.5	**-1.5**
Q608	59	.254	-185.61	-2.15	**-2.154**
Q610	43.1	.234	-199.06	-1.67	**-1.62**
Q612	41.3	.29	-209.06	-1.75	**-1.95**

To get the desired orbit displacement around the Lambertosn's and extraction positions, the correctors at H606/608/610/612 were adjusted. The goal was to keep the maximum current of any corrector to 20 amps or less. Figure 4 shows the orbit due to the added dipole correctors. Table 4 lists the required angle and current to generate a 22 mm (resultant) closed orbit displacement at HP608 and HP610. Additionally, the mult ratio for the closed 4 bump is listed. The 4 bump mult ratios will need to be changed from their current values because the corrector at 608 will be moved from its current location due to the installation of the Lambertsons.

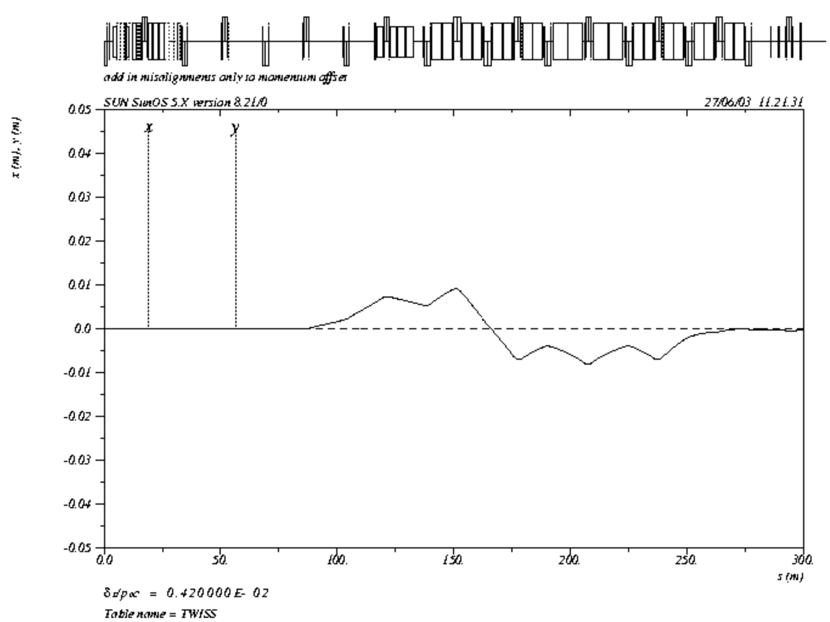

Figure 3. Orbit due to quad displacements around the Lambertsons as listed in Table 3 and the 0.42% momentum offset. Vertical scale is +/- 50 mm.

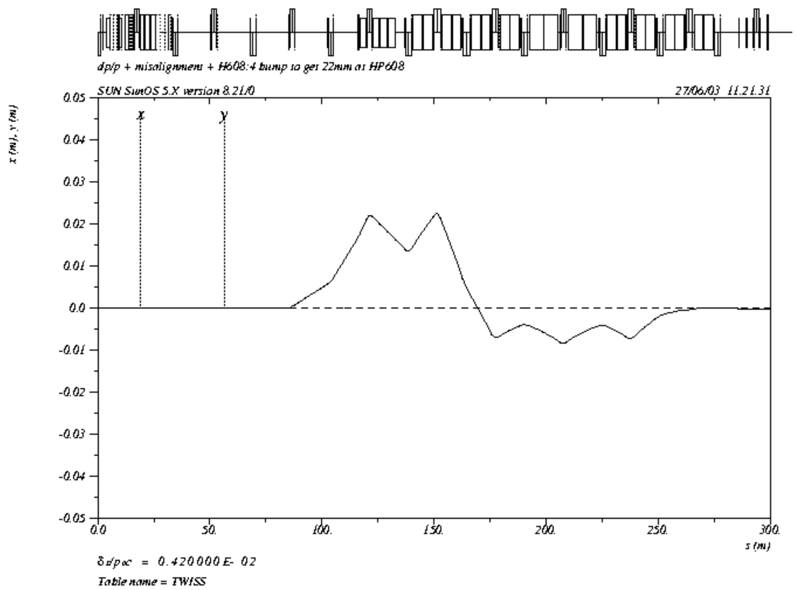

Figure 4. Closed orbit bump around the Lambertsons with both quad displacements and dipole correctors. Vertical scale is +/- 50 mm.

Table 4 Required corrector strength for Lambertson bump in the presence of reduced quad displacements

corrector	ϑ [ur]	Current [Amps]	Mult ratio
H606	240.74	13.5	1.0
H608	290.52	16.3	1.2068
H610	349.38	19.6	1.4513
H612	356.05	20	1.479

One of the goals of this solution is to remove the quad off sets in the upstream section of the MI60 straight and reduce the magnitude of the offsets around the Lambertsons. Since the Kickers (located at 602) are 270 degrees upstream of the Lambertson, the orbit undergoes a maximum excursion at 90 and 270 degrees in phase. The excursion at 90 degrees peaks at Q604 and must be reduced with a counterwave three bump H602:H604:H606. The extraction Lambertson's are located at the 270 degree excursion where the beam will be extracted . Since the kickers must kick to the inside, the counterwave three bump must move the beam to the outside. Figure 5 shows the result of adding in the H604:3 bump to 15mm to the outside and Table 5 shows the corrector strengths and mult ratios required for this bump.

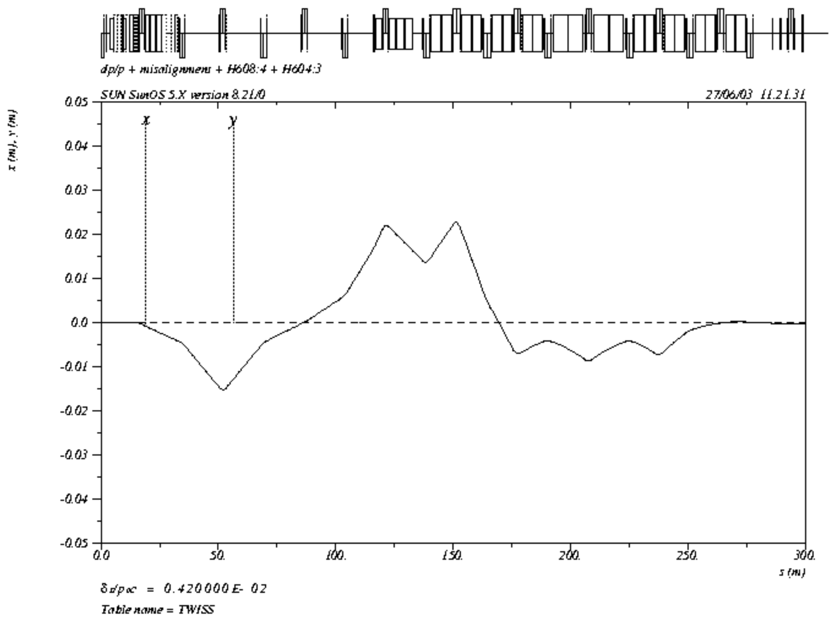

Figure 5. Closed orbit through the MI60 straight section in presence of 0.45% momentum offset. Shown is the 15 mm bump to the outside at 604 (dipole corrector only) and the 22mm excursion at 608 and 610 (due to quad displacement and dipole corrector). Vertical scale is +/- 50 mm.

Table 5 Required corrector strength for 15 mm kicker compensation bump at HP604.

corrector	ϑ [ur]	Current [Amps]	Mult ratio
H602	-276.36	-15.5	1.0
H604	- 14.89	-0.84	0.0538
H606	-276.16	-15.5	0.9993

The new 30 amp supplies were installed at 602 and 606 and in Feb 2003 these were tested to about 24 amps on a stacking cycle. At 24 amp the three bump produces about a 24 mm local closed orbit bump. Additional detail on these new supplies is discussed in MI Note 0297: Comments on Current NuMI Extraction Geometry.

Extraction Orbits

Figure 6 shows an enlarged plot in the region between 601 to 608 for the circulating beam orbit (a) and the extraction orbit (b).

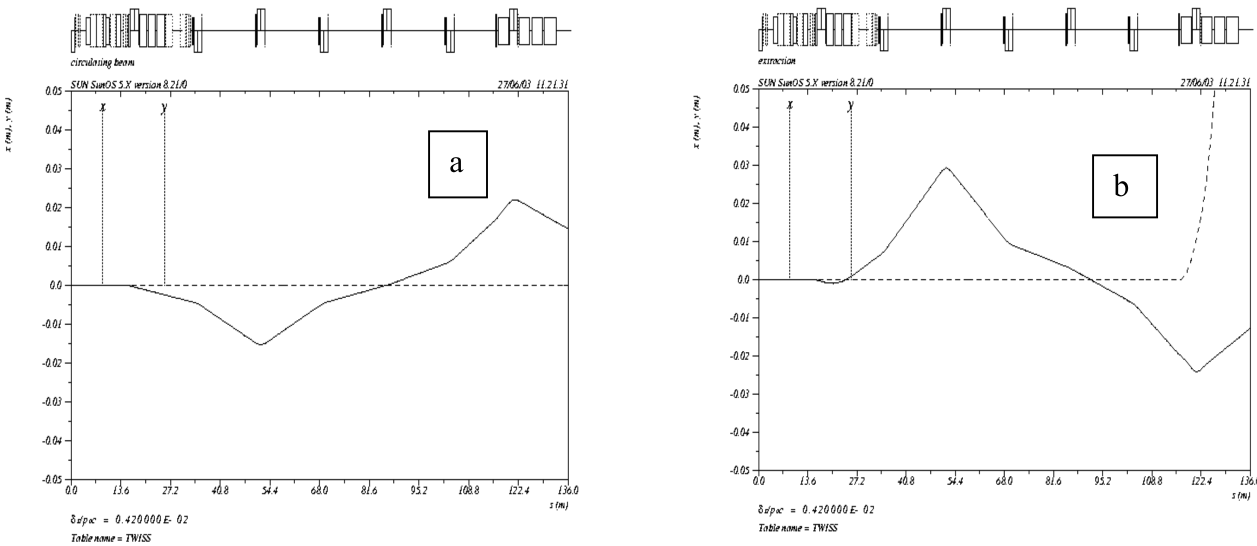

Figure 6: The two plots show the circulating beam (a) and the extracted beam (b) orbits due to the quad displacement, dipole corrector bump, and extraction kicker. Vertical scale is +/- 50 mm.

Initial Lambertson Installation, Quad Moves, and Corrector Currents

The NuMI ultimate operational beam positions, quad offsets and corrector currents have been defined which maximizes the beam-steel distance for circulating and extracted beams. However, the present corrector currents at the 608 to 612 locations must be reduced to keep the corrector currents below the trip level of 30 amps. A revised set of corrector currents has been determined which keeps the circulating beam at a distance from the Lambertson septa similar to MI52. The position at HP608 and HP610 are set to 15 mm inside. These corrector settings are shown in Table 6. These settings can be used without any modification to existing corrector strength. Note: these corrector settings assume the Lambertsons are installed and the corrector H608 in moved upstream as planned. The orbit, defined by the quad moves and corrector strengths are shown in Figure 7.

Table 6 Corrector strengths for Lambertson bump in the presence of reduced orbit excursion

corrector	ϑ [ur]	Current [Amps]	Mult ratio
H606	128.1	7.2	1.0
H608	129.4	7.27	1.009
H610	182.2	10.24	1.422
H612	148.1	8.32	1.156

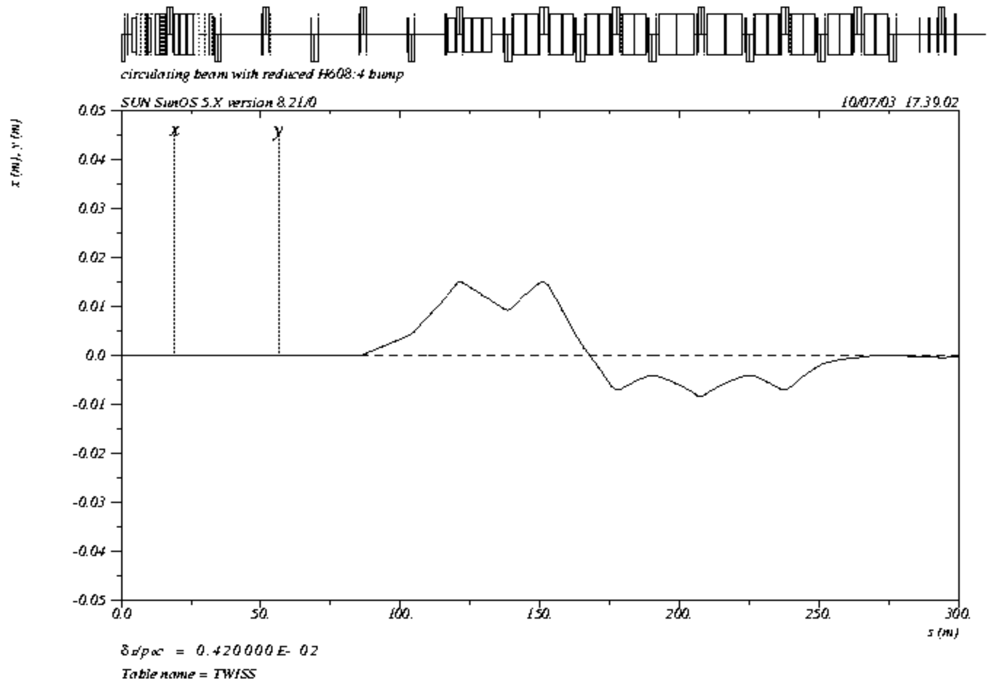

Figure 7: Horizontal orbit due to reduced corrector strengths and nominal quad offsets to be used during initial Lambertson installation. The positions at HP608 and HP610 are set to 15 mm to the inside.

Cross Sections

The next five figures (8 thru 12) show the cross section of the magnets and the circulating and extracted beam profiles for the scenario presented here. Additionally, the beam envelope for the reduced Lambertson bump for circulating beam is shown. The cross sections are taken at the upstream and downstream ends of LAM60A, Q608, LAM60B, LAM60C, and V100. As can be seen all Lambertsons are parallel to the straight section. The profiles are for 95% normalized emittance of 20 π-mm-mr and are shown entering and exiting the magnet steel, coil regions, drifts, etc. so there are multiple profiles only a short distance apart.

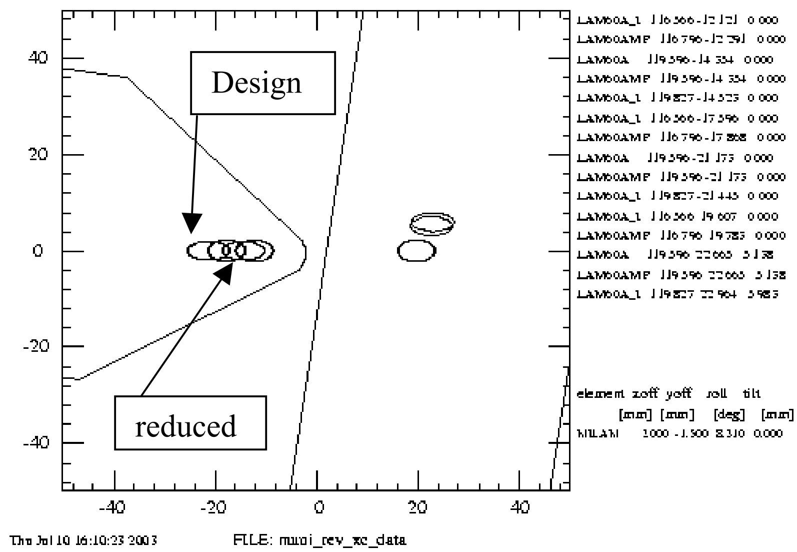

Figure 1. Profiles at LAM60A at entrance and exit of magnet. Positive-x it to the outside. The Lambertson is shown with a displacement of dx = 2 mm and dy = -1.5 mm. Scale is +/- 45 mm.

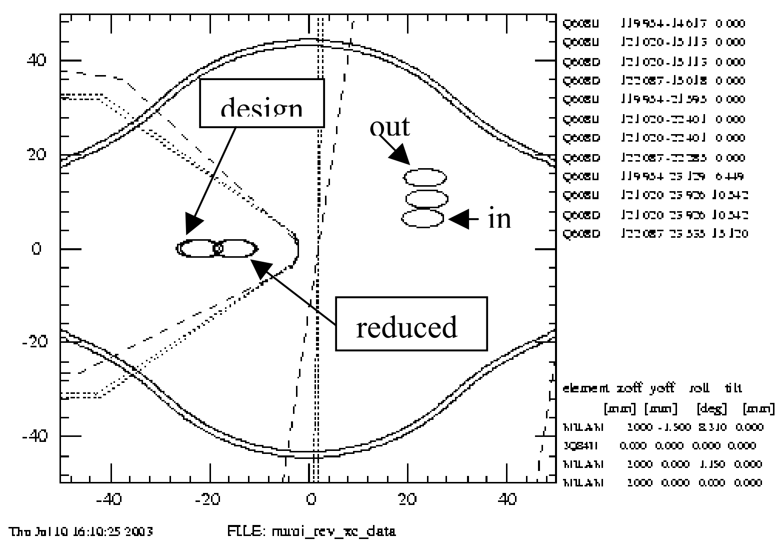

Figure 2. Circulating and extracted profiles at entrance and exit of Q608. Positive-x is to the outside. Also shown are the apertures for the three Lambertsons with the offsets described in the Design Report. NOT SHOWN is the –2.15 mm quad displacement. Scale is +/- 45 mm. Both the nominal design bump amplitude and the reduced bump amplitude of circulating beam are shown.

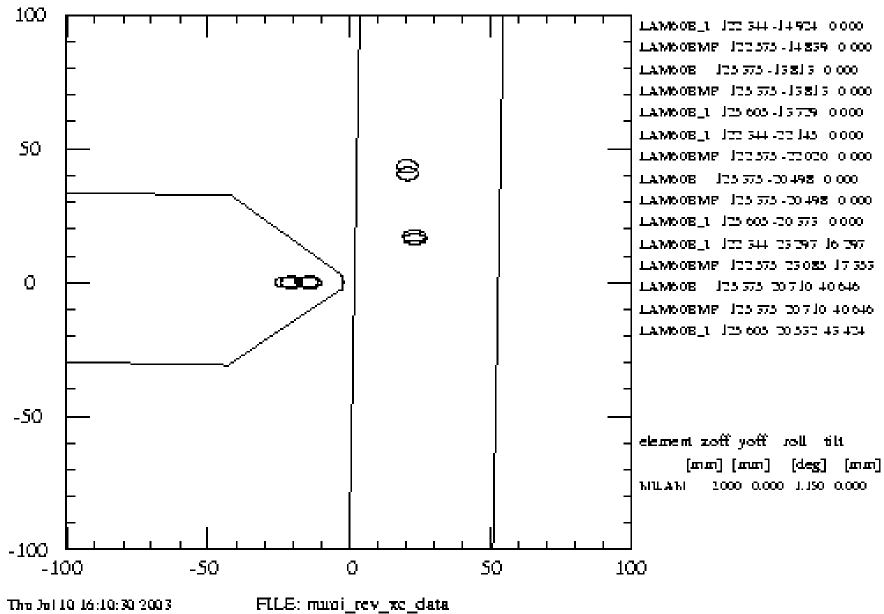

Figure 3. Profiles at LAM60B at entrance and exit of magnet. Positive-x it to the outside. The Lambertson is shown with a displacement of dx = 2 mm and dy = 0 mm. Scale is +/- 100 mm.

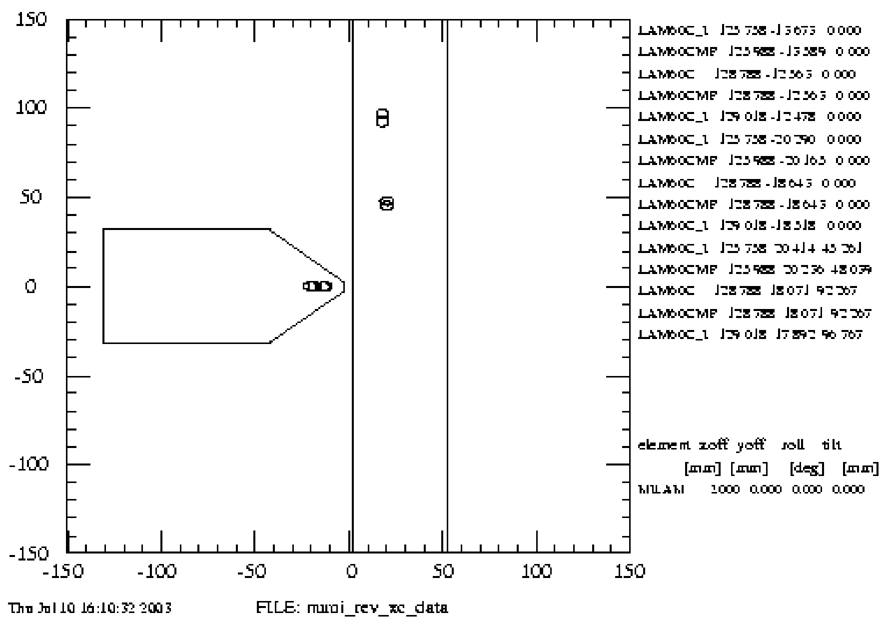

Figure 4. Profiles at LAM60C at entrance and exit of magnet. Positive-x it to the outside. The Lambertson is shown with a displacement of dx = 2 mm and dy = -1.5 mm. Scale +/- 150 mm.

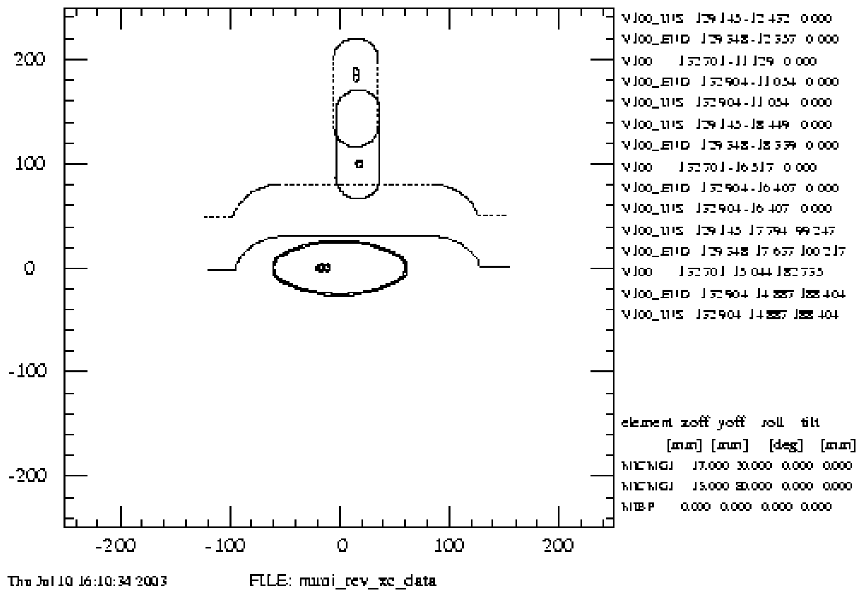

Figure 5. Profiles at V100 at entrance and exit of magnet. Positive-x it to the outside. The c-magnet is shown with an upstream displacement of dx =+17 mm and dy = +30 mm and downstream displacement of dx = +15 mm and dy = +80 mm. Scale is +/- 250 mm.

<u>Summary:</u>

A set of quad offsets have been proposed (and accepted July 29,2003) which reduce the quad displacement by almost a factor of 2 around the Lambertsons and <u>eliminate</u> the quad offset at Q602. These are found in the last column of Table 3 under "Actual" displacements and produce an 8 mm orbit distortion at Q608. The currents required for generating about a ~15 mm bump at H608 and H610 on top of the orbit distortion from the quad offsets (of about 8mm) were defined with a maximum current of 20 A as shown in Table 4. The currents for a 15 mm bump at Q604 are defined in Table 5. A set of three bump ratios for the H604:3 mult and a set of four-bump ratios for H608:4 were defined . Again, these offsets and currents are dependant on reducing the existing current levels of H608, H610, and H612.

Given the present currents of about 10 amps in the correctors H608 and H612, the amplitude of the four-bump, H608:4 was reduced by factor of two from about 15 mm to about 7 mm. When this bump is added to the 8 mm bump using the quad displacements the resultant is to produce an effective orbit displacement ay 120 GeV/c of about 15 mm. This is similar to the orbit displacements at MI52. The corrector settings are given in Table 6. This reduced bump amplitude will allow the installation of the Lambertsons and re-alignment of the quads during the Summer 2003 Shutdown and assure enough orbit control to steer around the Lambertsons with the new dipole corrector 30 A power supplies. The design and reduced bump amplitudes beam cross sections are shown on the magnet cross section plots.