Booster Extraction Using Pulsed Magnets at 8 Gev

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INTRODUCTION

The effects of "edge focusing" from dipole magnets have been known for many years. The real impact however, of edge focusing from the Extraction straight Dogleg magnets and the injection Orbit Bump magnets on the Booster lattice was completely unsuspected until a few months ago[1]. The first of these magnets was put into the Booster over a quarter of a century ago[2]. The true magnitude of the effect was discovered when models of these magnets were inserted into MAD in an effort to develop a truer Booster lattice model[3]. The deleterious effects on the lattice were immediately obvious. Experiments have been done which have demonstrated that the effects predicted by MAD are in fact correct and that huge gains in Booster performance can be realized by removing these magnets (especially the Doglegs at the extraction straights) from the machine[4].

PULSED EXTRACTION CONCEPT

This idea for extracting the 8 Gev beam from the Booster without the use of the present pulsed septum and dogleg dipoles was originally proposed by Chuck Ankenbrandt. I have modified it somewhat in a manner which simplifies the geometry and magnet construction. Although these magnets have edge focusing strengths similar to the existing Doglegs they only occur at 8 Gev and the effects on the lattice are quite tolerable. It uses a set of pulsed magnets configured to operate as a local 3-bump, which for this write-up I am presuming to be built as thin septum magnets similar to the present extraction pulsed septums. The principal idea behind this scheme is that shortly before the beam is to be extracted the 3-bump will be pulsed on. As the amplitude of the 3-bump reaches its maximum the circulating beam will be skimming just beneath the septum of the center magnet. At that time the extraction kickers will be pulsed and the beam will be kicked across the septum and continue on out of the machine. All of the necessary bend angle required to miss the downstream "D" is provided by the first magnet of the 3-bump. The vertical apertures of these magnets are all larger than the apertures of the Defocusing Gradient magnets upstream and downstream of the extraction straight section. They do not appear as an aperture to the beam until they are pulsed just before the beam is extracted, at which time the center magnet septum will become a 40π–mm-mR limiting aperture as the current pulse (and the bump amplitude) approaches its maximum. Two slightly different versions of this scheme will be presented.

There are slightly over 5 meters of space available in the straight section to insert these magnets. Of the 5 meters I am using 4 meters for the magnets leaving 1 meter available for the necessary mechanical connections. The upstream and downstream magnets are 1 meter in length and the middle magnet is 2 meters. I expect that the 2-meter middle magnet will actually be made with two 1-meter magnets so that once again we have a double dogleg configuration. The magnets will be constructed without curvature. This is done to reduce the effects of marginal fields near the extreme edges of the poletip and to reduce construction difficulties and costs.

The present extraction geometry for the MI8 beam line at Long 3 is shown in Figure 1. The elevation of the beam at the MP02 bend center is the kicked beam elevation, not the circulating beam elevation.

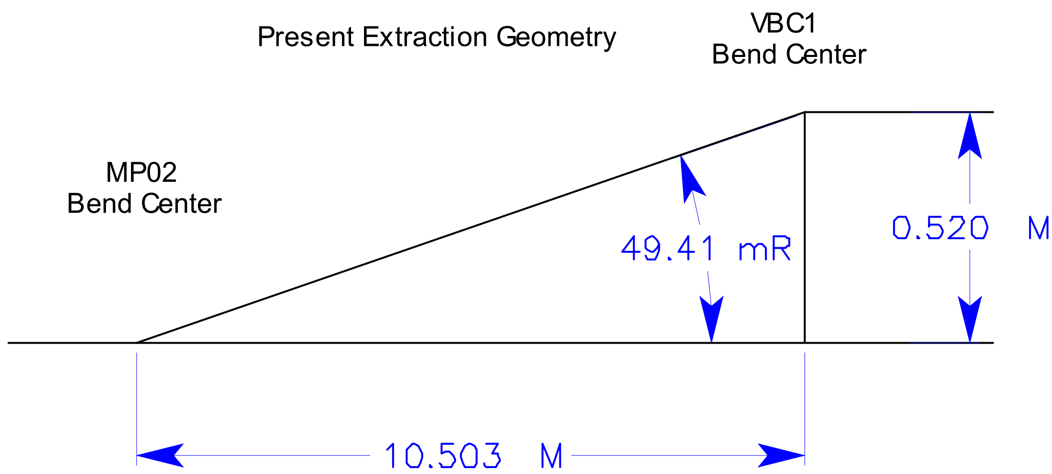

Figure 1

PROPOSED GEOMETRY #1

The 1st proposed geometry for the new system is shown below in Figure 2. The beam elevation at Magnet 1 bend center is the elevation of the kicked beam at extraction time. Note that the position of the bend center of Magnet 1 is ~1.5 meters upstream of the present septum in Figure 1.

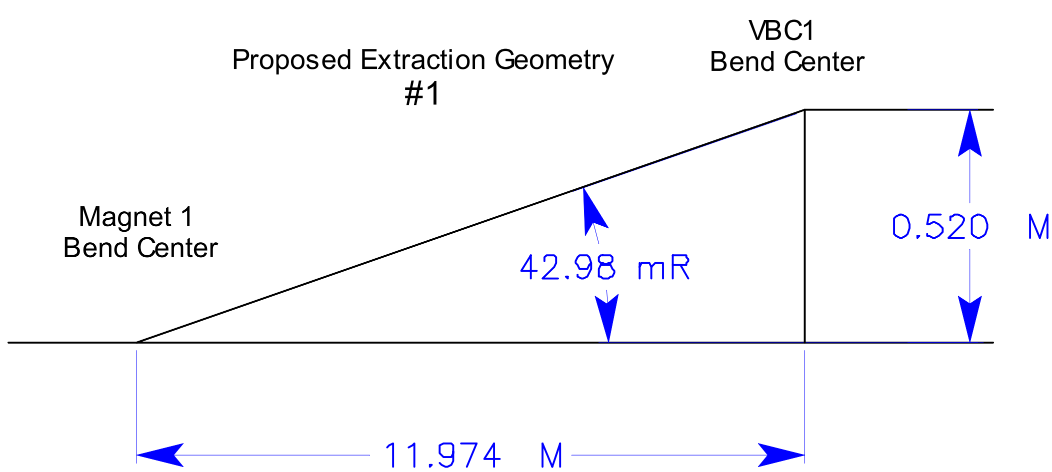

Figure 2

With this angle of 42.98 mR the inside edge of the extraction septum magnet will be positioned above the Booster centerline at 37.3mm. The "D" magnet poletip is at 28.486 mm so the septum is completely shadowed by the gradient magnet (see figure 6). Also, as illustrated above, the 42.98 mR beamline is designed to intersect the bend center of the VBC1 magnet so that no other vertical bends are required to match into the MI8 beam line. This is the simplest extraction geometry possible. Given a 1-meter long magnet for the 1st bend center, the field required to achieve this angle is 1.303 Tesla.

The required poletip width of the septum is given by the sum;

W = ½ "D" Magnet Aperture + Septum Position + Sagitta

W = 28.48 + 37.301 + 42.99 = 108.771 mm >> 110 mm

The parameters for this magnet are;

Length	1 meter
Bend Angle	42.98 mR
Poletip width	110 mm
Poletip Gap	57.15 mm
Inductance	2.488 uHenry
Peak Field	1.303 Tesla
Peak Current	58.64 kAmps
Nominal Pulse Width	530 uSec
15 Hz RMS Current	3.835 kAmps
Peak Magnet Voltage	0.96 kVolts

It is assumed in this write-up that the 4 magnets of the 3-bump will be operated in a series circuit. Further, the other three magnets will be built identically to the septum magnet although this is not absolutely required except from the very practical requirement that the 4 magnets are identical in strength and that the pulsed fields track exactly. The required power supply parameters are;

Total Load Inductance	9.952 uH
Peak Current	58.64 kAmps
Pulse Width	530 uSec
15 Hz RMS Current	3.706 kAmp
Power Supply Voltage	3.835 kVolt

The straight section layout for geometry #1 is below in figure 3. Note that the position of the 8 Gev orbit is 4.171 mm below the vertical centerline of the machine. This is necessary to make room in the magnet aperture to kick the beam sufficiently to clear the ~5mm septum. The amplitude of the required kick is one beam width plus the septum thickness as illustrated in figure 3. It will be necessary to use a programmable 3-bump to move the beam to this vertical position. The present BEXBMP system will work or it is possible the standard ring dipoles can be used for this purpose. Removing the BEXBMP magnet would clear about another foot of longitudinal space in the straight section.

Booster Extraction Geometry
#1

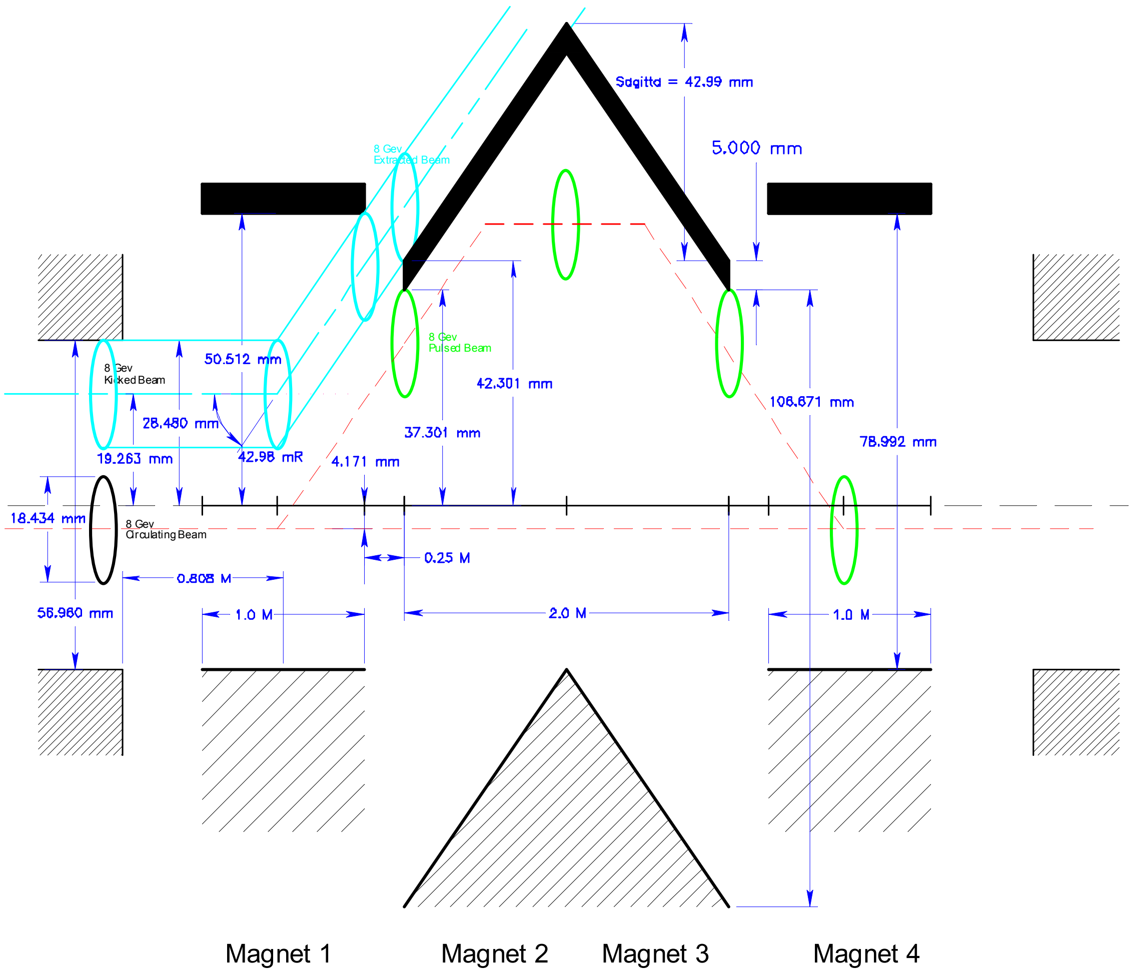

Figure 3

PROPOSED GEOMETRY #2

The geometry proposed above is the simplest achievable from the point of view of matching into the MI8 beam line. It is possible to reduce the extraction angle further but this means that some additional bend will be required or that the VBC1 magnet would have to be moved downstream and the whole upstream end of the MI8 beam line would have to be rebuilt. While this may be possible it is not pleasant to consider. The 2nd proposed geometry uses the minimum extraction angle possible and is defined by setting the inside edge of the septum so that it is just hidden by the "D" magnet poletip. If the extraction angle is made any smaller the septum will begin to protrude into the vertical aperture of the machine. In this geometry the extracted beam will miss the top of the downstream "D" magnet so that no other bends are required to extract cleanly from the Booster but to match to VBC1 some additional bending will have to be installed.

The 2nd proposed geometry for the new system is shown below in Figure 4. Once again the beam elevation at Magnet 1 bend center is the elevation of the kicked beam at extraction time.

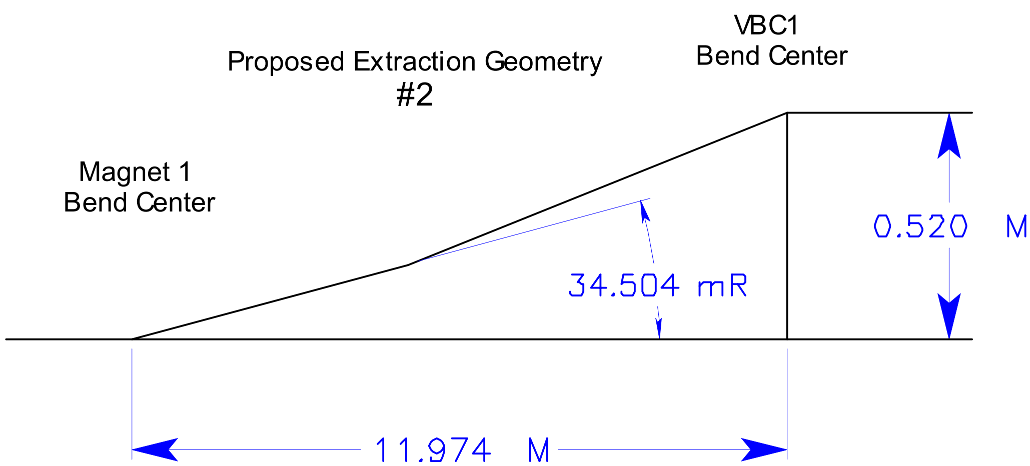

Figure 4

With this angle of 34.504 mR the inside edge of the septum will be positioned above the Booster centerline at 30.934 mm (see figure 7). The "D" magnet poletip is at 28.486 mm so the septum is still completely shadowed by the gradient magnet. Given a 1-meter long magnet for the 1st bend center, the field required to achieve this angle is 1.022 Tesla.

The poletip width of the septum is given by the sum;

W = ½ "D" Magnet Aperture + Septum Position + Sagitta

W = 28.48 + 30.934 + 34.507 = 93.921 mm >> 95 mm

The parameters for this magnet are;

Length	1 meter
Bend Angle	34.504 mR
Poletip width	95 mm
Poletip Gap	57.15 mm
Inductance	2.149 uHenry

Peak Field	1.022 Tesla
Peak Current	46 kAmps
Nominal Pulse Width	452 uSec
15 Hz RMS Current	2.681 kAmps
Peak Magnet Voltage	0.765 kVolts

It is assumed that the 4 magnets of the 3-bump will be operated in a series circuit. Further, the other three magnets will be built identically to the septum magnet. The required power supply parameters are;

Total Load Inductance	8.596 uH
Peak Current	46 kAmps
Pulse Width	452 uSec
15 Hz RMS Current	2.681 kAmp
Power Supply Voltage	3.06 kVolts

The straight section layout for geometry #2 is below in figure 5.

Booster Extraction
Geometry
#2

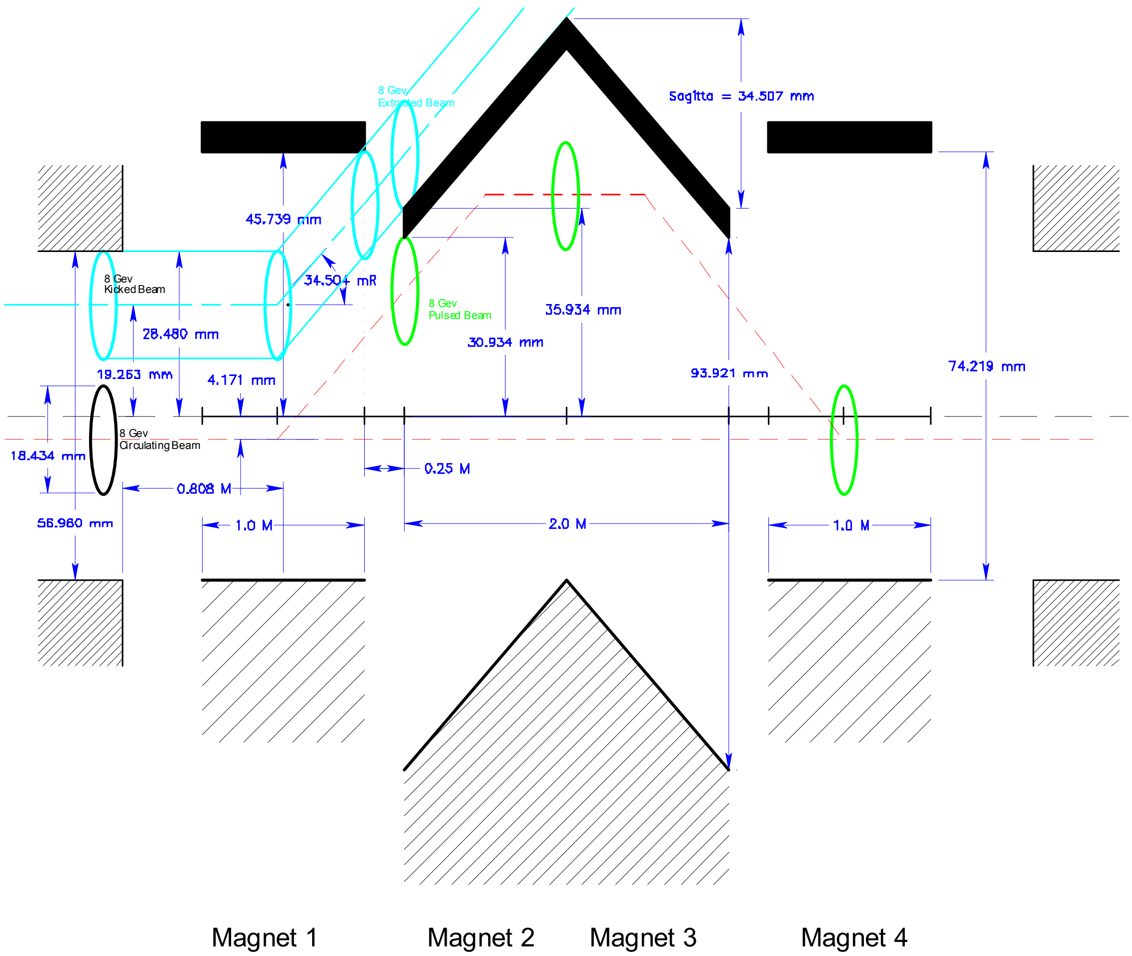

Figure5

As illustrated in figure 4 the 34.504 mR beam will not intersect the bend center of the VBC1 magnet so that additional vertical bending is required to match into the MI8 beam line. Where can the additional bend required to match the beam trajectory to the bend center of VBC1 be placed? The nominal bend of VBC1 is currently ~50 mR (see figure 1). The maximum bend that VBC1 can accommodate is ~57 mR. If a 57 mR bend is projected backward from VBC1 it will intersect the 34.504 mR beam near the end of the long straight section (above the corrector package) where there is insufficient clearance to put another bend magnet. Obviously the additional bend cannot be placed downstream of the long straight because VBC1 could no longer make the required bend. It would appear that the only reasonable place to put the additional bend is just downstream of the extraction septum above the 4th magnet of the bump. If the design is done properly (another reason for all the magnets to be built as thin septum type magnets) there should be room to put in a small cross section DC powered "C" magnet of sufficient strength. The bend angle of this magnet will be ~12.6 mR (0.444 T*M) if its bend center is placed at the bend center of the 4th magnet of the extraction bump. The bend angle of VBC1 is then increased from near 50 mR to ~53 mR.

The major gain with this geometry is that there is significant reduction in the pulsed power requirements and heating of the magnets but there will be the added expense of another magnet and power supply and the mechanical constraints are harder to achieve.

CONCLUSION

Experiments have shown that removal of the Extraction Straight Section Dogleg magnets from the Booster will significantly enhance Booster performance. They suggest that we will be able to accelerate intensities of >5e12 protons per pulse at >90% efficiency and will dramatically reduce radiation damage to machine components , residual radiation levels and personnel exposures[4]. The method proposed above is just one way to achieve this goal. It may not be the only way but is an extension of previously proven magnet and power supply designs with likely fewer R&D requirements.

References

1) A. Drozhdin - MAD lattice results with injection ORBMP magnets modeled. Jan 16, 2003.

2) B. Brown - The first set of Doglegs was installed at L-13 in the spring of 1978, the second set was installed at L-3 in the mid-1980s for extraction to PBAR.

3) A. Drozhdin - MAD lattice results with DOGLEG magnets modeled. Jan 23, 2003.

4) Booster Experiment - The extraction septum at L-13 was removed and the Doglegs at L-13 turned off. Acceleration efficiency was increased by ~10% and acceleration losses reduced by ~50%.

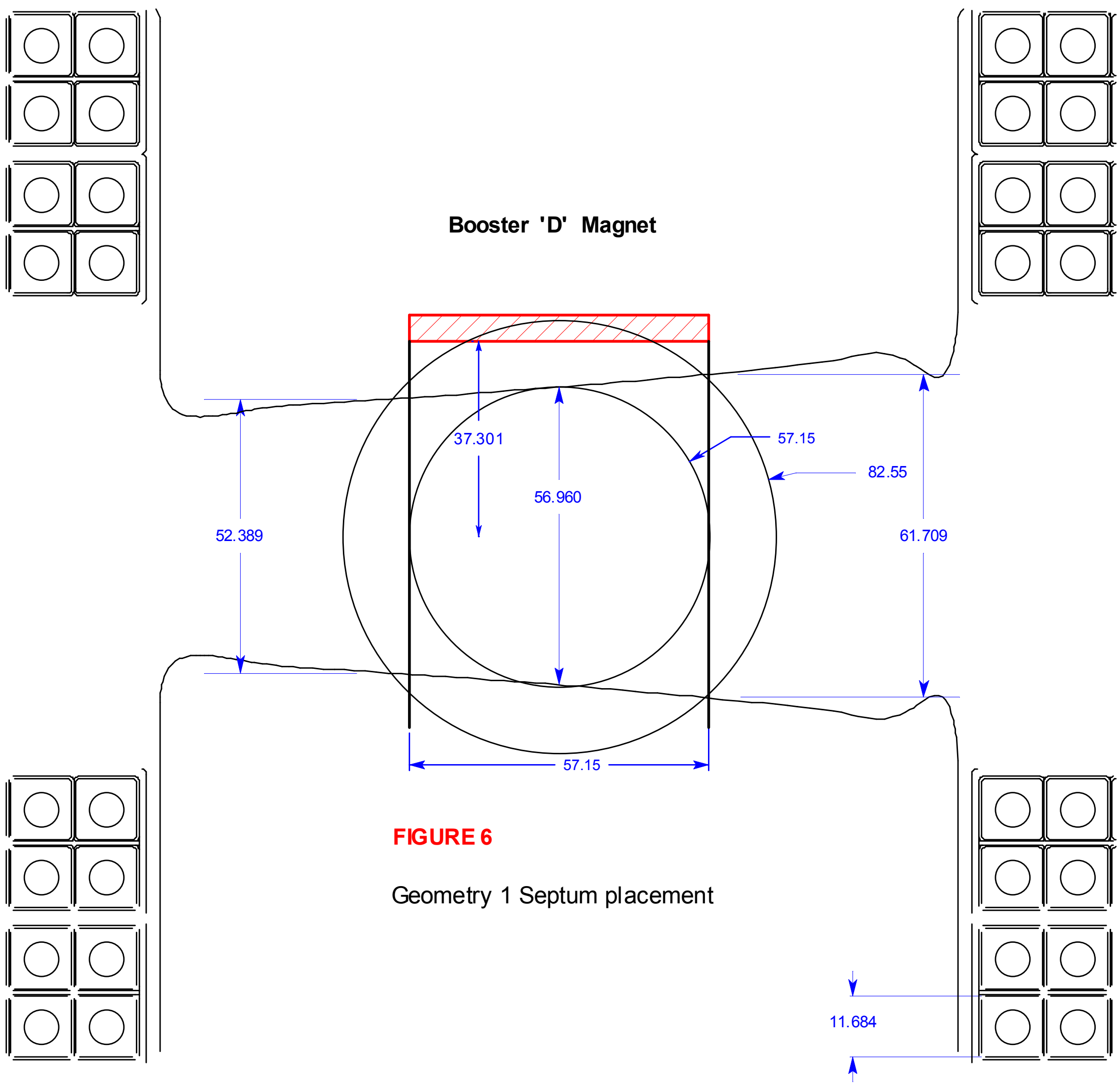

FIGURE 6

Geometry 1 Septum placement

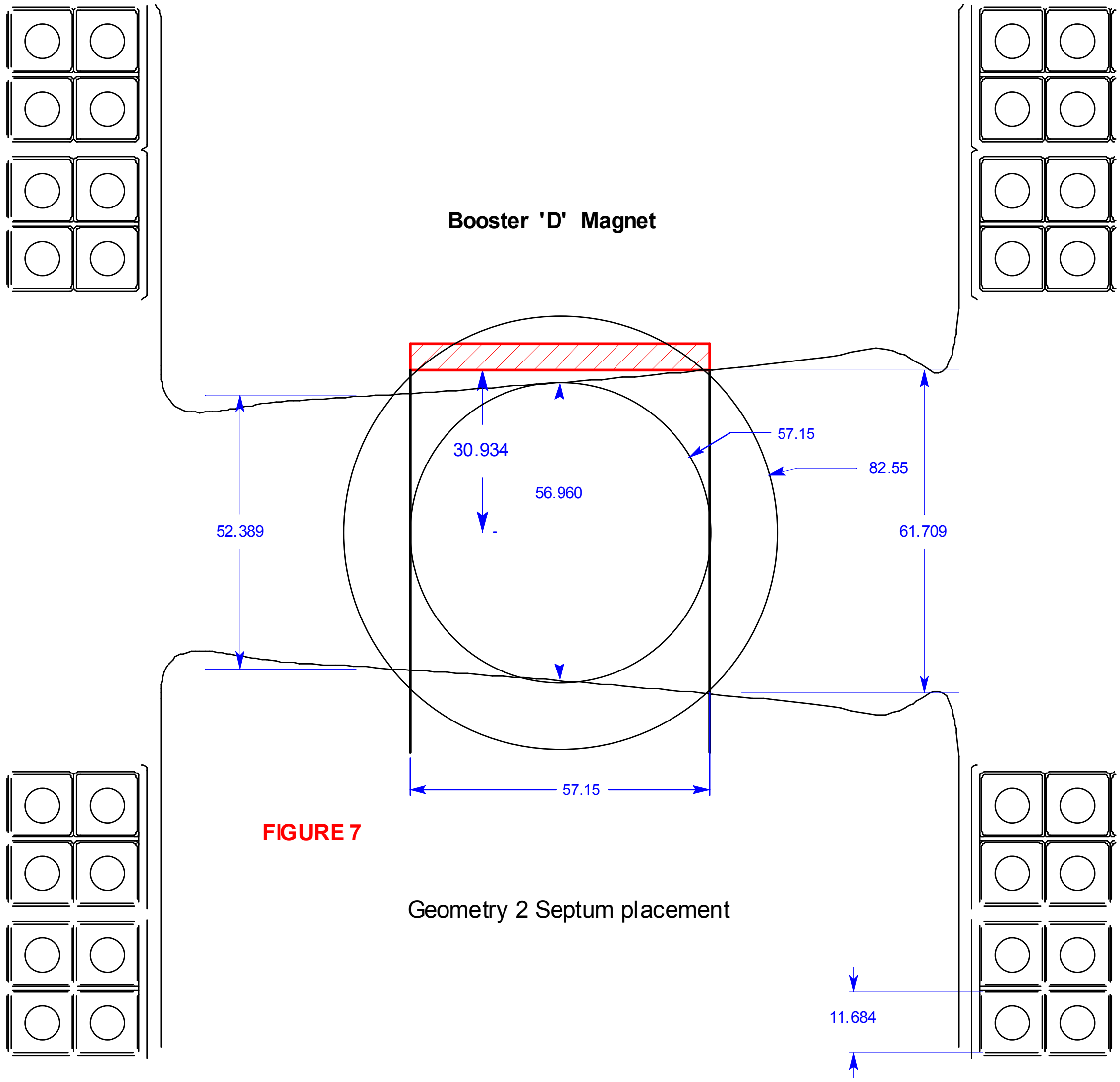

FIGURE 7

Geometry 2 Septum placement