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Document-148989

BL4N 45 Degree Bender Design

Document Type: Design note

Release: 01 **Release Date:** 2017–11–17

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History of Changes

Release number	**Date**	**Description of changes**	**Author**
01	2017–11–17	First release	Thomas Planche

Keywords: Beamline 4-North, BL4N, Dipole, Bender, Magnet, 45 degree

Contents

1 Scope

In this document we present:

1. the requirements of the ARIEL 500 MeV proton Beamline 4 North (BL4N) [1] 45 degree benders;
2. a suggested design;
3. the requirement for data obtained from the manufacturer, including magnetic measurement data.

2 Magnet Requirements and Design Constraints

Two identical 45 deg. bending magnets are to be built [1]. The basic magnet requirements and the design constraints are listed in table 1:

Bending angle	45 deg.
Edge angle	22.5 deg.
Maximum proton energy (corresponding rigidity $B\rho$)	500 MeV (3.637 T.m)
Full gap height	77.7 mm
Maximum power consumption (per magnet)	30 kW
Field quality requirement: Relative field flatness along magnets center ± 25 mm Relative integral flatness (see section 4.3)	 $\leq 5.10^{-4}$ $\leq 10^{-4}$
Clearance to west wall (see drawing TBP1845, section 3.1)	≥ 100 mm
Maximum magnet height (perpendicular to bending plane)	1000 mm
Magnitude of stray field along the electron beam path (see section 4.4)	$\leq 3.10^{-4}$ T

Table 1: Magnet requirements and design constraints.

From the rigidity and bend angle in table 1, the required field integral is:

$$\int_{-\infty}^{+\infty} B\mathrm{d}l = B\rho\ [\mathrm{T.m}] \times \text{bending angle [rad]} \simeq 2.856\ [\mathrm{T.m}]. \tag{1}$$

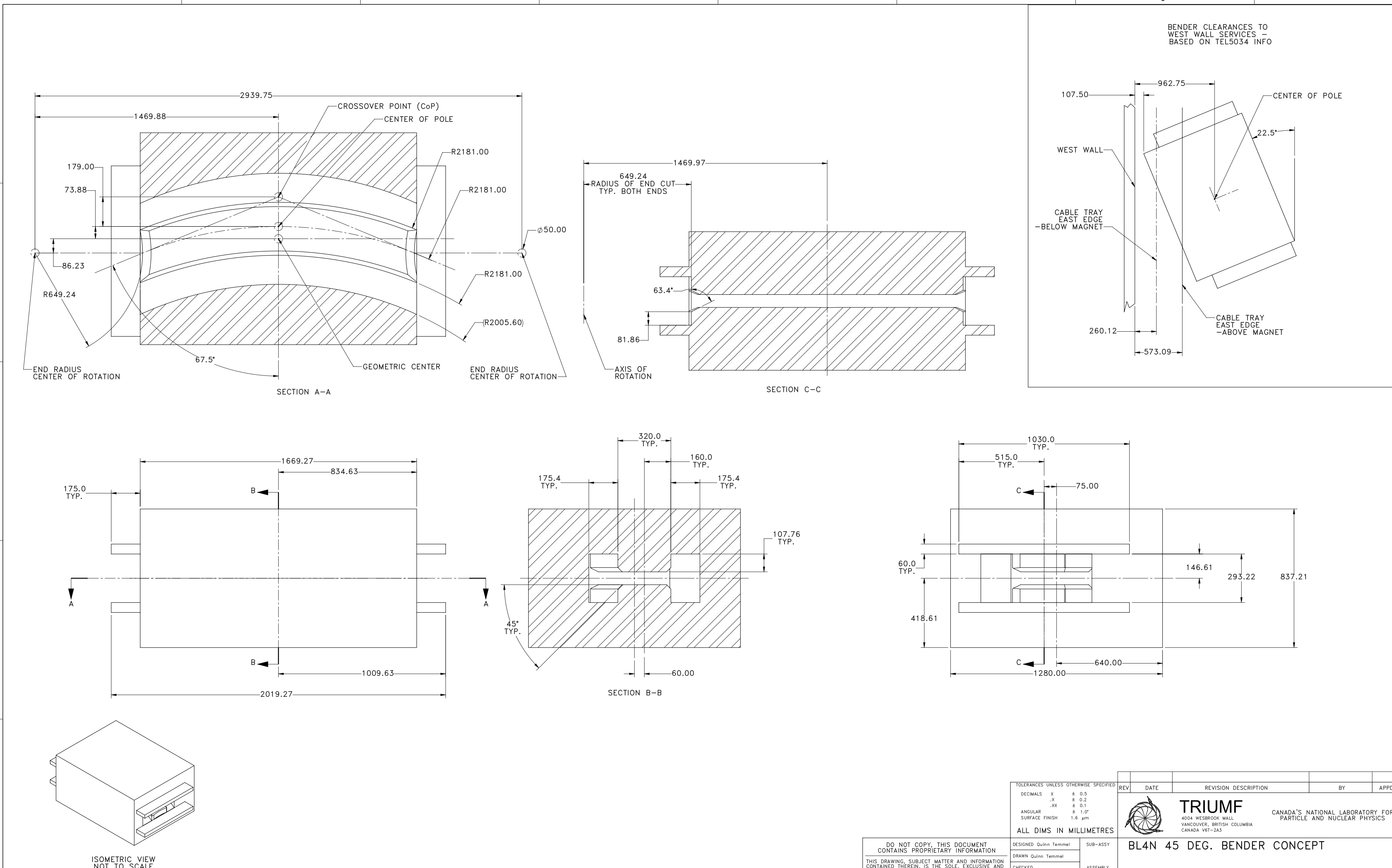
Note: the increment dl is taken along the proton path.

Between the two 45 degree benders of beamline 4N, the second one (4NMB10) drives the space constraints. This magnet will indeed be install above the existing electron beamline, and will come close to the ARIEL tunnel west wall (see figs. 2 and 3).

3 Proposed Design

3.1 Design Parameters

The design presented in this section is only a suggested design: the manufacturer is free to propose another, as long as it meets the requirements and constraints listed above. Geometric parameters of the iron yoke are give in drawing TBP1845:



REV	DATE	REVISION DESCRIPTION	BY	APPD

TOLERANCES UNLESS OTHERWISE SPECIFIED
DECIMALS X ± 0.5
.X ± 0.2
.XX ± 0.1
ANGULAR ± 1.0°
SURFACE FINISH 1.6 μm

ALL DIMS IN MILLIMETRES

TRIUMF
4004 WESBROOK MALL
VANCOUVER, BRITISH COLUMBIA
CANADA V6T–2A3
CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

DESIGNED Quinn Temmel
DRAWN Quinn Temmel
CHECKED
WPN # WPN–4436
TRACKING # P–179
SUB–ASSY
ASSEMBLY

BL4N 45 DEG. BENDER CONCEPT

SCALE 1:10
DATE 2017–07–04
THIRD–ANGLE PROJECTION
DWG NO. TBP1845
SIZE D
SHEET 1 OF 1
REV

Additional parameters of our design are given in Table 2. A schematic view

Magnetic field at the center of the magnet	1.63 T
Ampere turns per coil	53200 A.turn
Coil cross section	98 mm×155 mm

Table 2: Additional parameters of our proposed design.

of the coil is presented in fig. 1.

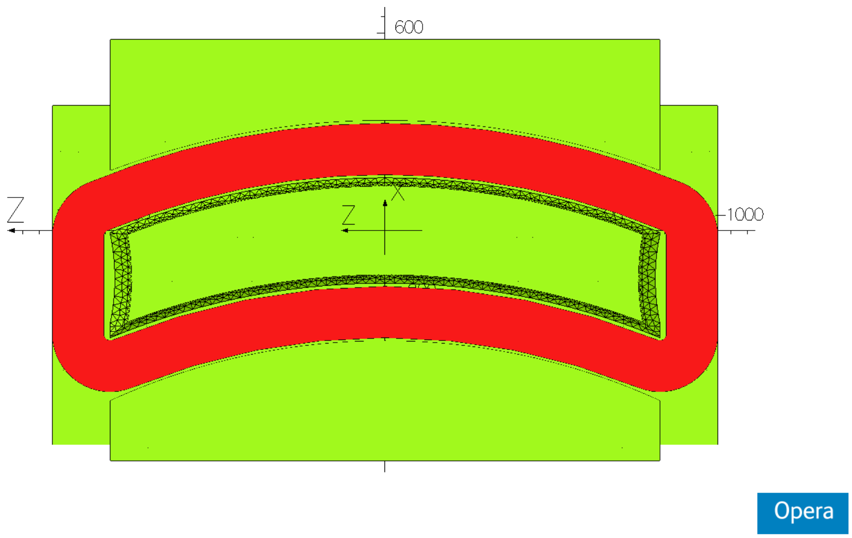


Figure 1: Top view of the coil used in our `OPERA-3D` model.

3.2 Magnet Footprint

The clearance to the west wall is just over 100 mm (see drawing TBP1845 and fig. 2). The clearance to the electron beamline below the second magnet is about 300 mm (see fig. 3).

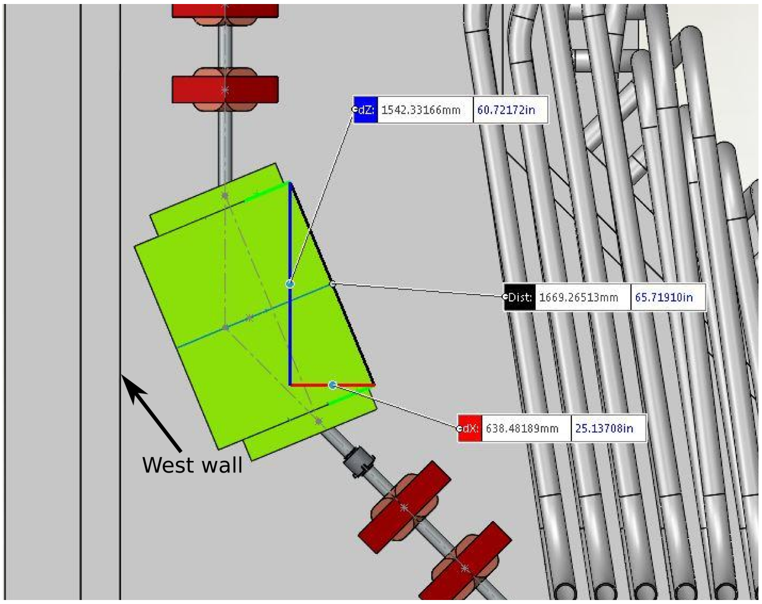


Figure 2: Top view of the 4NMB10 bender, showing the location of the nearby proton beamline quadrupole, and the location of the ARIEL tunnel west wall.

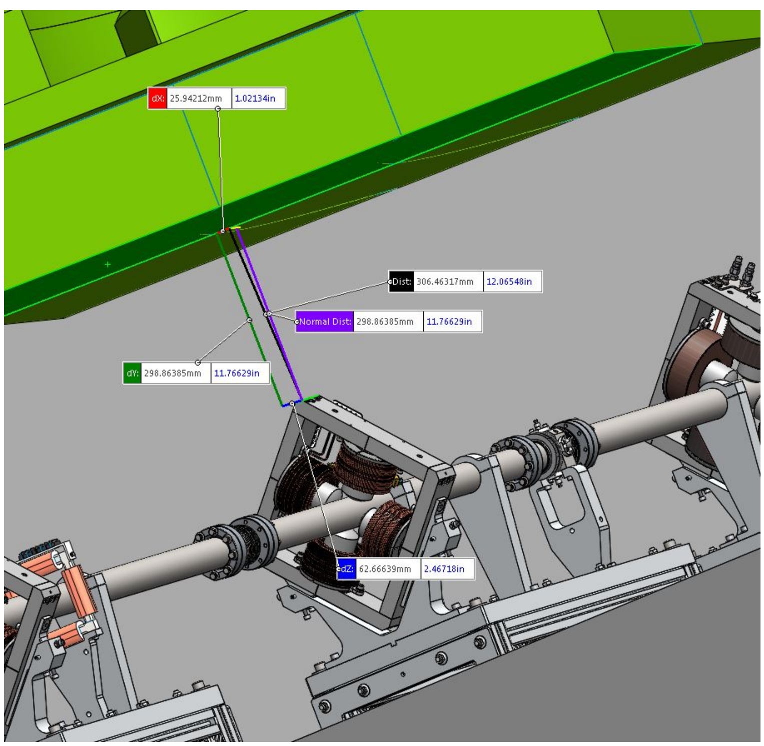


Figure 3: Isometric view of the bottom of the 4NMB10 bender showing the vertical clearance to the electron beamline components.

3.3 Achieved Field Quality

The proposed geometry was simulated using`OPERA-3D`. The resulting relative transverse field flatness at the center of the magnet is of the order of 4.10^{-4} of ± 25 mm (see fig. 4). The relative flatness of the field integral is better that 6.10^{-5}.

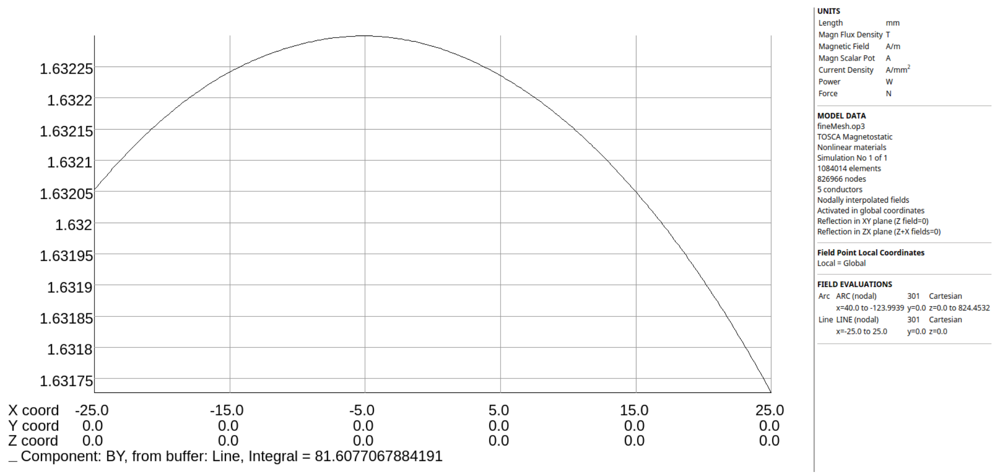


Figure 4: Magnetic field along the magnet center (section A-A of drawing TBP1845). The zero corresponds to the location of the magnet center.

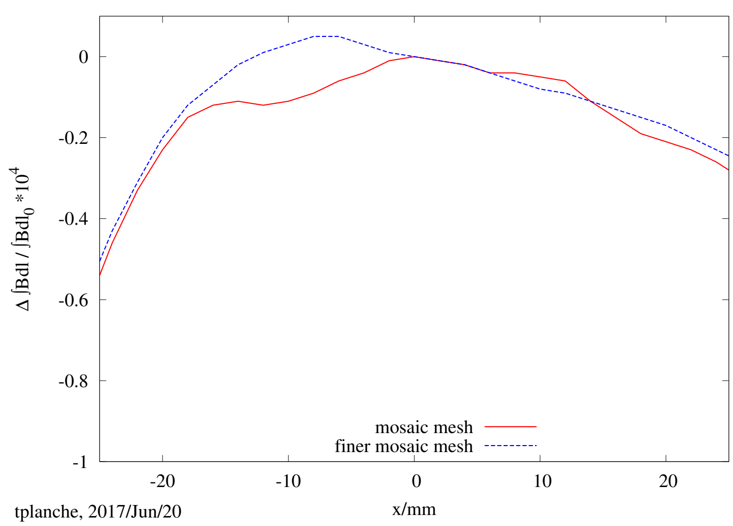


Figure 5: Relative flatness of the field integral measured along trajectories described in section 4.

We used `COSY-INFINITY` to calculate sextupole aberration coefficients along several trajectories around the reference trajectory. Over the transverse extend of our "good field region" (i.e. $\pm 25\,\mathrm{mm}$), the <angle | position^2> aberration coefficients are found to be smaller all much smaller than $0.87\,\mathrm{rad/m}^2$, as recommended in Ref. [2].

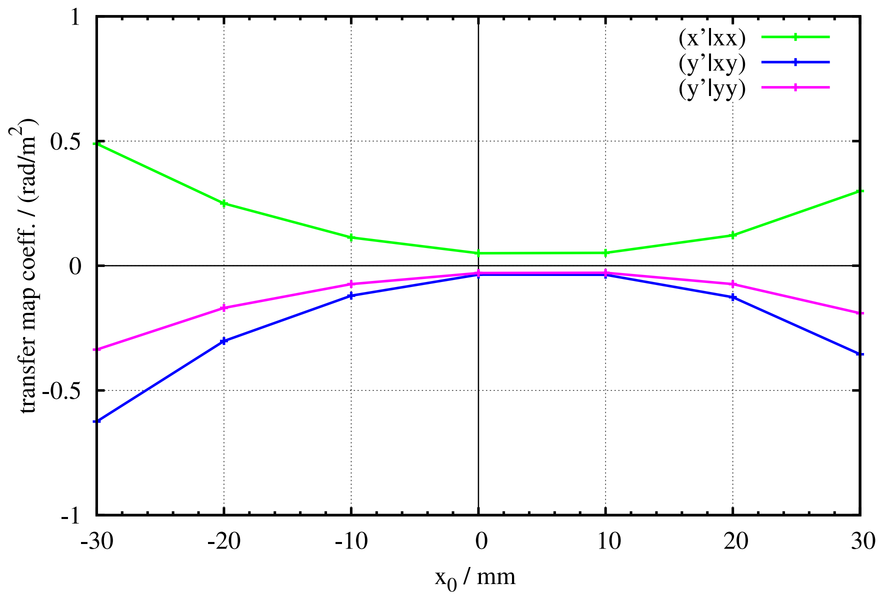


Figure 6: Dominant sextupole aberration coefficients calculated by `COSY-INFINITY`, as a function of the offset of the reference trajectory measured at the center of the magnet ($x_0 = 0$ corresponds to the magnet center).

3.4 Achieved Stray Field Magnitude

The magnitude of the stray magnetic field along the trajectory presented in section 4.4 is shown in fig. 7

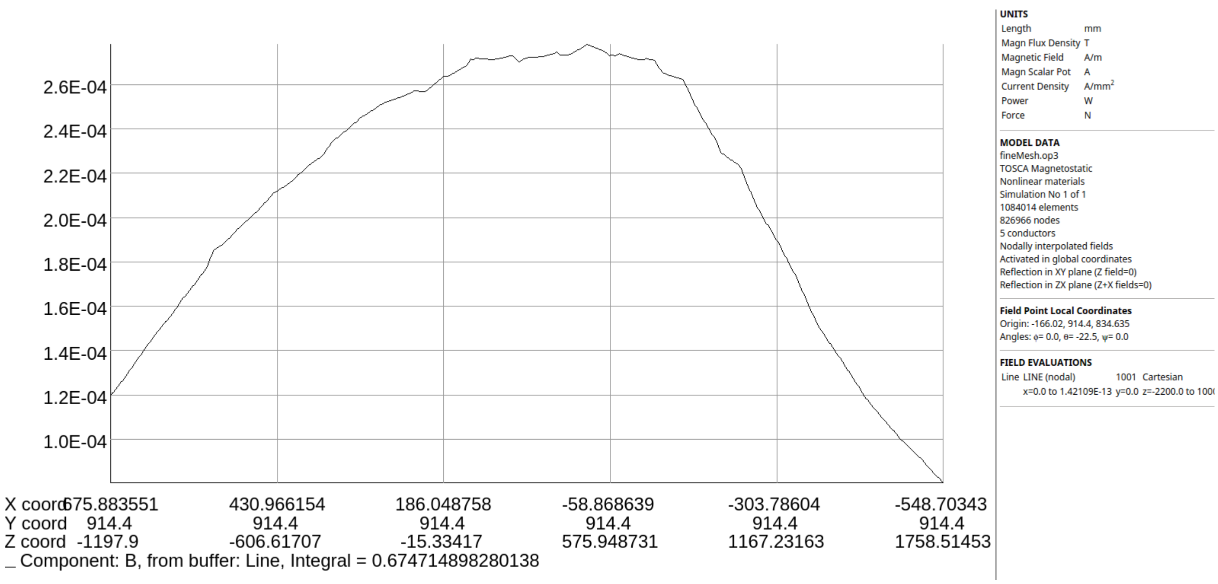


Figure 7: Magnitude of the stray magnetic field along the electron beam axis.

4 Required Magnetic Measurements

All required magnetic measurements are to be done along the magnet geometrical mid-plane.

4.1 Field strength at the magnet center

- It shall be checked that the field at the magnet center can reach the nominal field, and run continuously for three hours.

- We require a calibration (B vs. I) curve, giving vertical component of the magnetic field at the center of the magnet for at least 25 different currents while the magnet is ramped up to the maximum current, then at least 25 more points when the magnet is ramped down to zero current. Immediately after, we require the same measurement to be repeated with the opposite polarity.

4.2 Field flatness along the magnet center

- The vertical component of the magnetic field shall be measured ± 25 mm around the magnet center, with a step size of 5 mm, moving perpendicularly to the beam trajectory. This measurement is used to verify the field flatness (see table 1).

4.3 Field mapping and integrals

- The vertical component of the field shall be mapped with a step size no greater than 15 mm;

- The vertical component of the field shall be mapped along the reference trajectory. The reference trajectory is a 45 deg. arc of radius = 3.637/[nominal field of the magnet in Tesla], extended by a 700 mm tangential straight line on each side. This measurement is used to verify that the required field integral can be reached (see eq. (1))

- The measurement is repeated along the same trajectory shifted transversely in steps of 5 mm, over ± 25 mm. This measurement is used to verified the integral flatness (see table 1).

4.4 Stray Field Measurement

- Measure the **3 components** of the stray field along the electron beam axis: 914.4 mm below the mid-plane, along the beam exiting axis (see fig. 8).

- for the stray field measurement the step size shall be no greater than 50 mm.

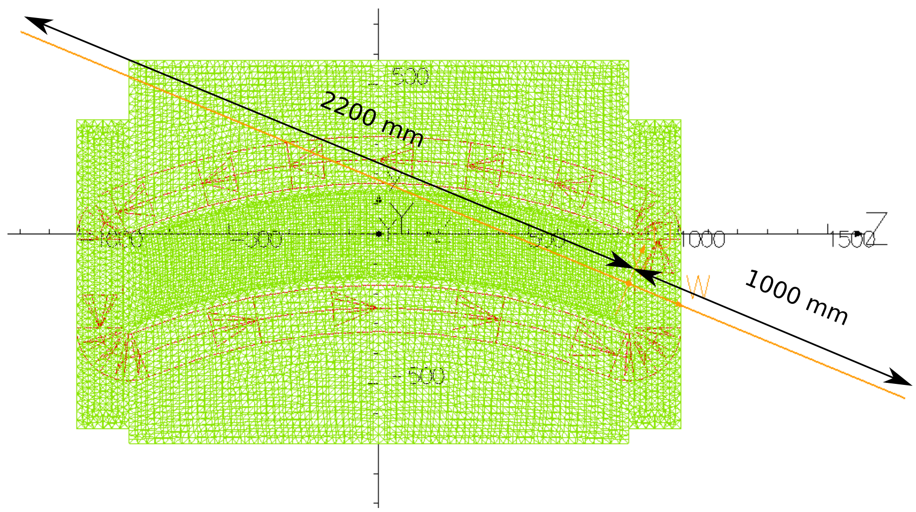


Figure 8: The yellow solid line represents the trajectory along which the stray field shall be measured.

5 Required Data

- TRIUMF requires a copy of all the measured data, including field components and coordinates (indexed against the physical dimensions of the magnet) for each measurement point.
- We require a copy of magnet design drawings, Solidworks model and also magnet simulations (`OPERA-3D` preferred).

References

[1] Y.-N. Rao, R. Baartman, Beam Line 4 North (BL4N) Optics Design, Tech. Rep. TRI-DN-13-13, TRIUMF (2013).

[2] Y.-N. Rao, Spec for BL4N 45 deg dipole magnets, Tech. Rep. TRI-BN-15-24, TRIUMF (2015).
URL http://lin12.triumf.ca/text/design_notes/b2015_24/sext_spec_on_dipole.pdf