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EMBD : MB0 Analyzer Magnet

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History of Changes

Release Number	Date	Description of Changes	Author(s)
1	2012/07/05	Initial Release	T. Planche

Contents

1 Basic Magnet Requirements

Magnet type	H-frame rectangular dipole
Bending angle	60°
Maximum electron energy (corresponding rigidity $B\rho$)	15 MeV ($5.17\ 10^{-2}$ T.m)
Full gap height	53.2 mm
B_{max}	≥ 0.344 T
Field quality requirement: sextupole components	≤ 20 rad.m^{-2}

Table 1: Basic magnet requirements.

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

$$\int_{-\infty}^{+\infty} B\mathrm{d}l = B\rho\ [\mathrm{T.m}] \times \textit{bending angle}\ [\mathrm{rad}] \simeq 5.42\ 10^{-2}\ [\mathrm{T.m}]. \qquad (1)$$

The increment $\mathrm{d}l$ is taken along the electron path.

2 Constraints

This magnet will be part of an extremely congested beam line, which implies that the major design constraints are its insertion length and width. The other design constraints are listed in Table 2.

Maximum power consumption	700 W
Steel magnetization	≤ 1.4 T
B(I) linearity over the whole range	within $\pm$ 2%
Fringe field extent: remaining field at 0.2 m from the magnet center	 $\leq$3 G
Remanent field	≤ 20 G
The vacuum chamber must fit	see vacuum chamber design (Fig. 9)

Table 2: Design constraints.

3 Parameters of our Design

3.1 Summary Table

Coil	
Ampere turns	7550 A.t
Minimum inner dimensions [mm] (Given by the pole dimensions, see Fig. 2)	124 × 124 (x×y)
Maximum outer dimensions [mm] (Given by the yoke, clamp and pole dimensions, see Fig. 2 & 3)	230.4 × 202 × 107 (x×y×z)
Pole dimensions (see Figs. 1 & 3)	
Pole width (**pw**)	124 mm
Pole length (**pl**)	124 mm
Pole height (**ph**)	107 mm
Chamfer height (**chh**)	5 mm
Chamfer angle (**cha**)	30 deg.
Yoke dimensions (see Figs. 1 & 3)	
Magnet width (**mw**)	298.4 mm
Return yoke thickness (**yt**)	34 mm
Magnet height (**mh = 2*ph + 2*yt** + gap)	335.2 mm
Field clamps (see Figs. 1, 3 & 5)	
Clamp thickness at the top (**clt**)	12 mm
Clamp thickness at the bottom(**cltb**)	3 mm
Clamp cut angle (**cca**)	4.5°
Clamp width (**clw**)	124 mm
Magnetic connection clamp-yoke thickness (**cct**)	20 mm
Magnet length (**ml**) (see Fig. 1)	226 mm

Table 3: Detailed parameters of our design.

Detailed parameters of our design are given in Table 3. According to `OPERA-3D` simulations, this design satisfies all the requirement and constraints listed above. Illustrative views of the model are shown in Fig. 1, 2, 3 , 4, 5, and 6.

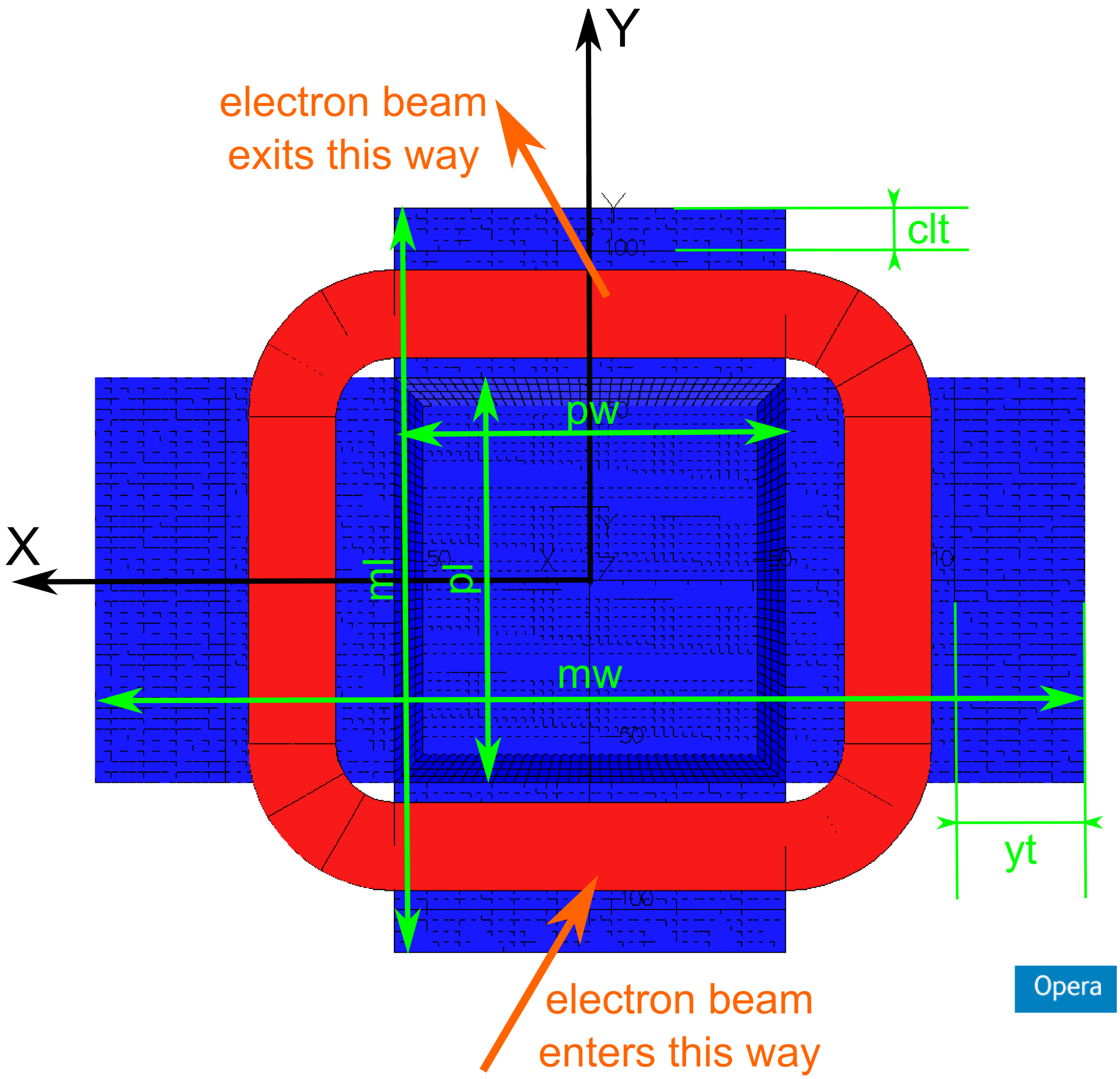

Figure 1: `OPERA-3D` model: plan view of half of the magnet. Steel volumes are in blue, coil is in red.

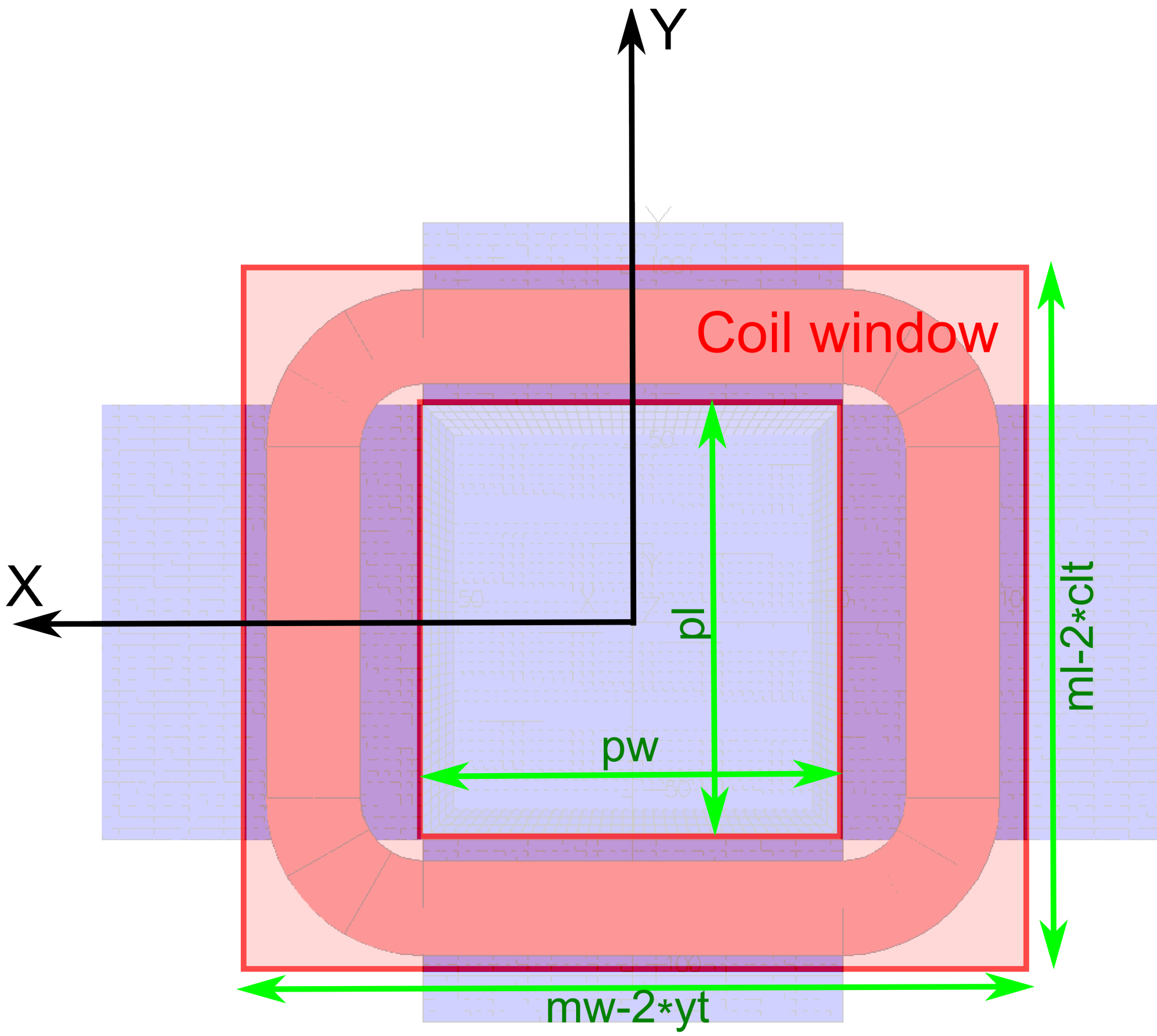

Figure 2: Schematic showing maximum dimensions **mw-2*yt** and **ml-2*clt**, and minimum dimensions **pw** and **pl**.

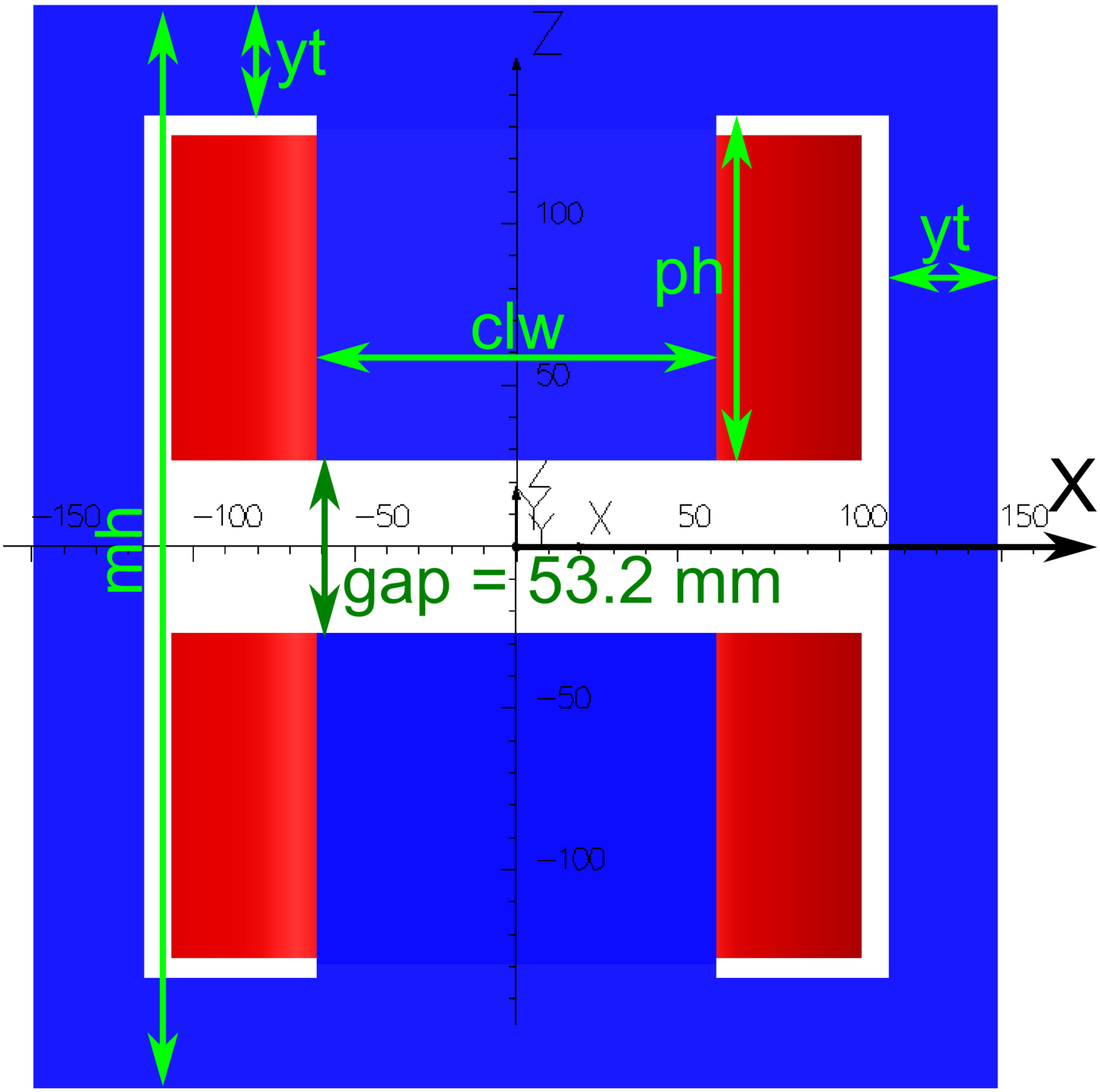

Figure 3: `OPERA-3D` model: front view of the whole magnet. Steel volumes are in blue, coils are in red.

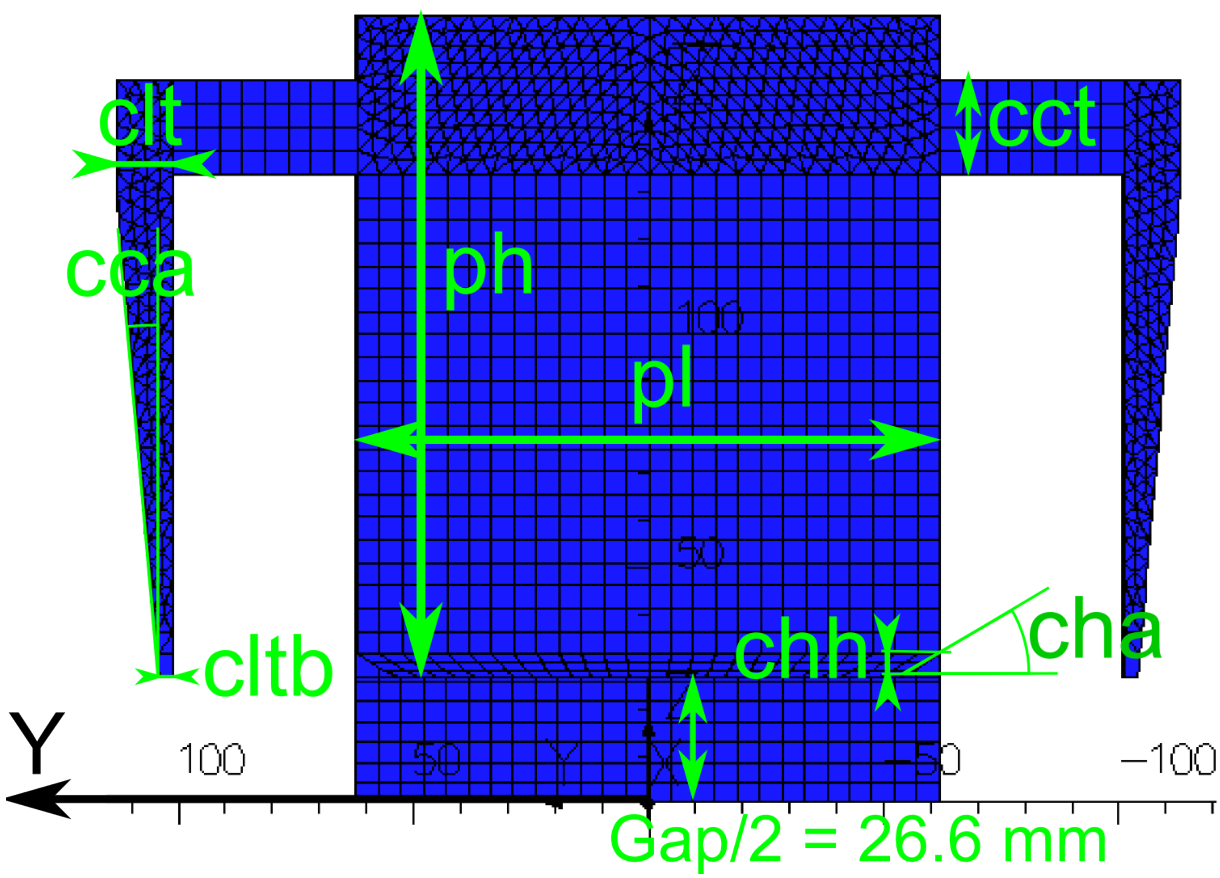

Figure 4: `OPERA-3D` model: Side view of one quarter of the magnet. Only steel volumes are shown. The mesh is also shown (black lines).

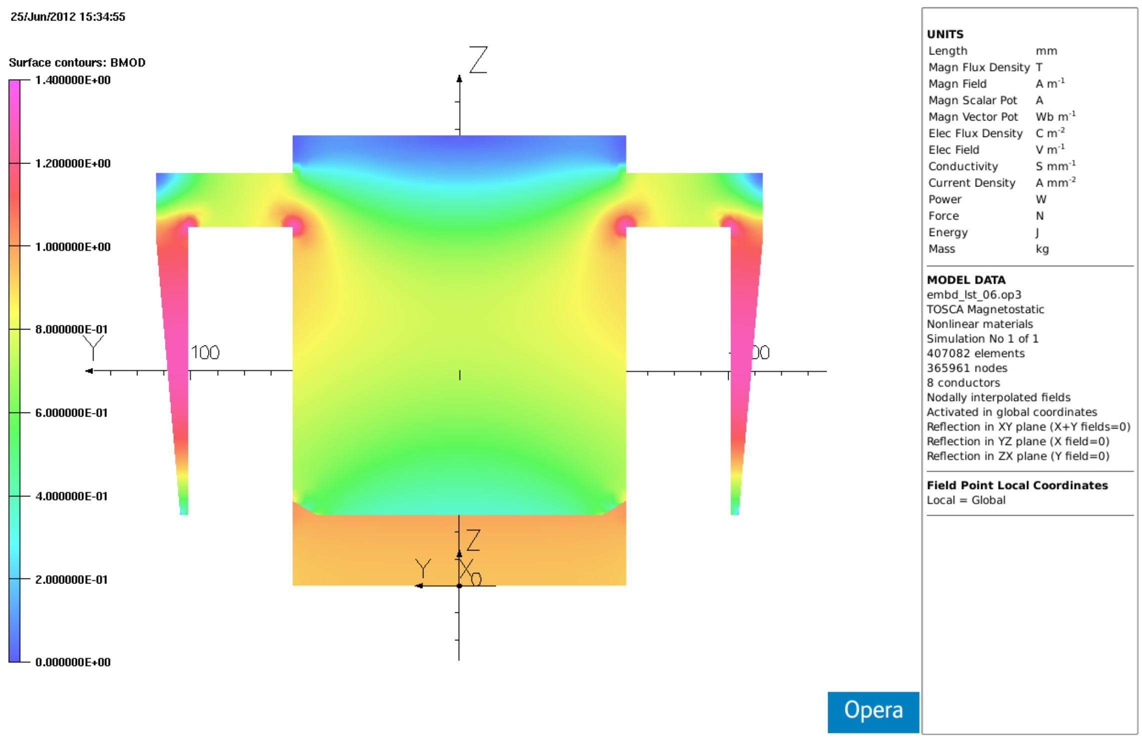

Figure 5: `OPERA-3D` model: Side view of one quarter of the magnet, showing field level in the steel.

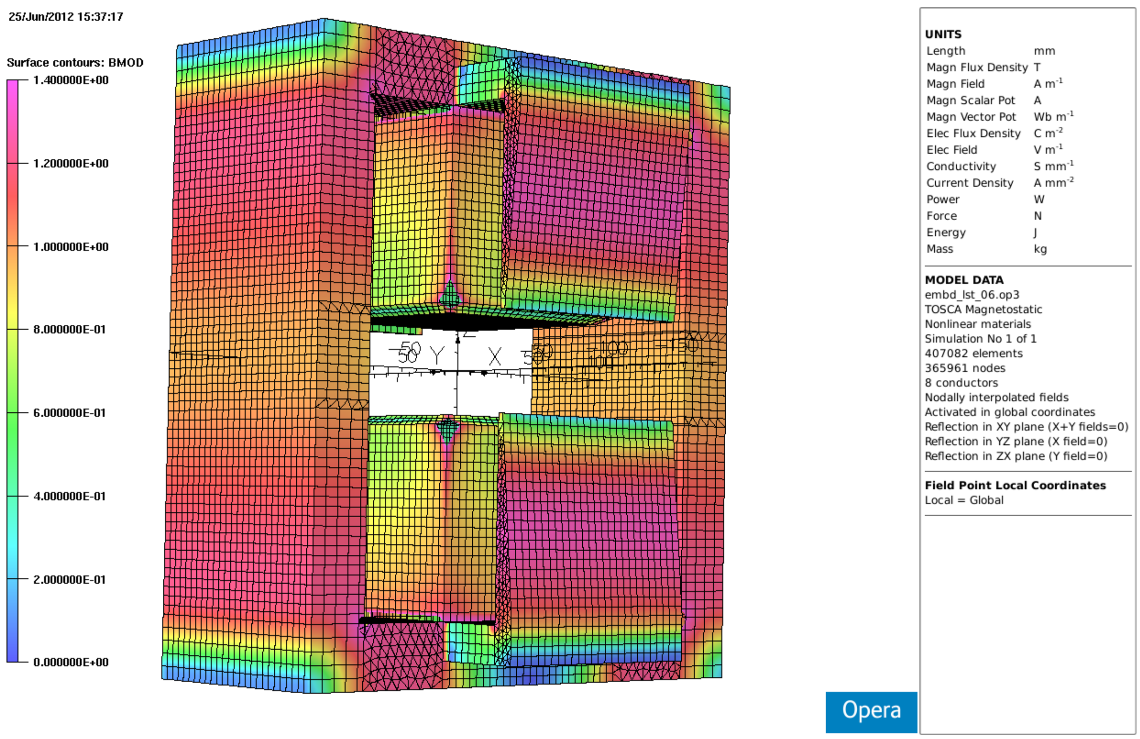

Figure 6: 3D view of the model showing the field level on the surface of the steel + mesh.

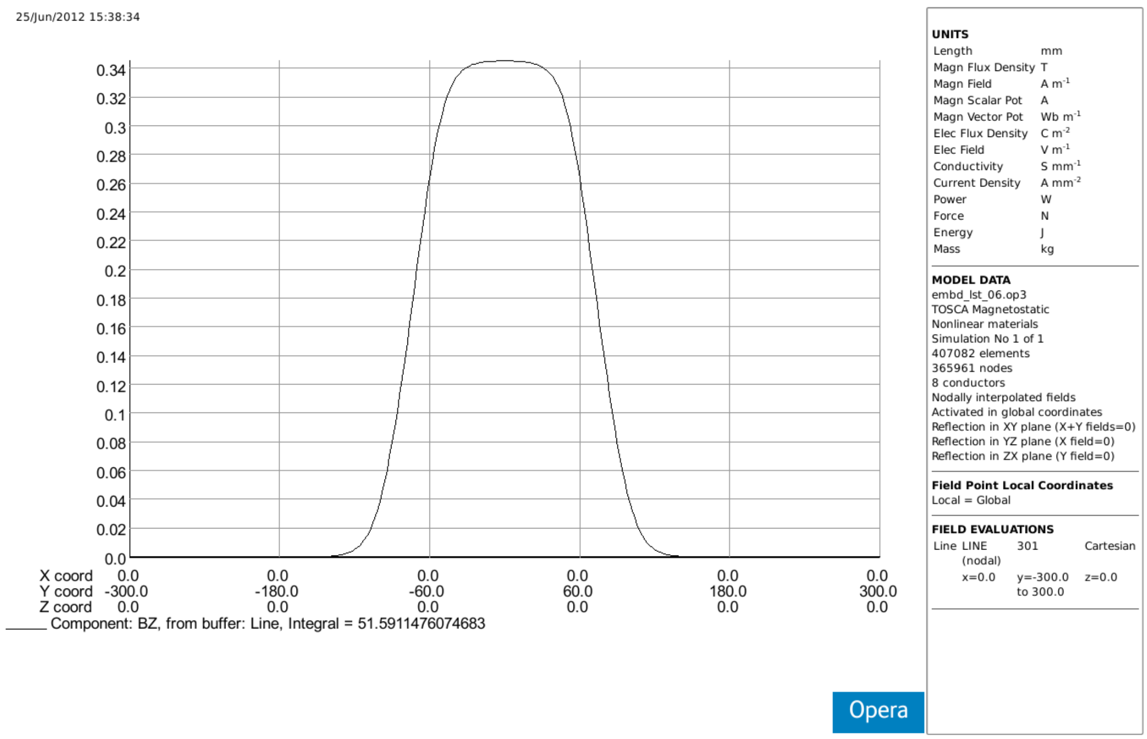

Figure 7: From our OPERA-3D model: vertical component of the magnetic field along the y axis (at x=0 & z=0).

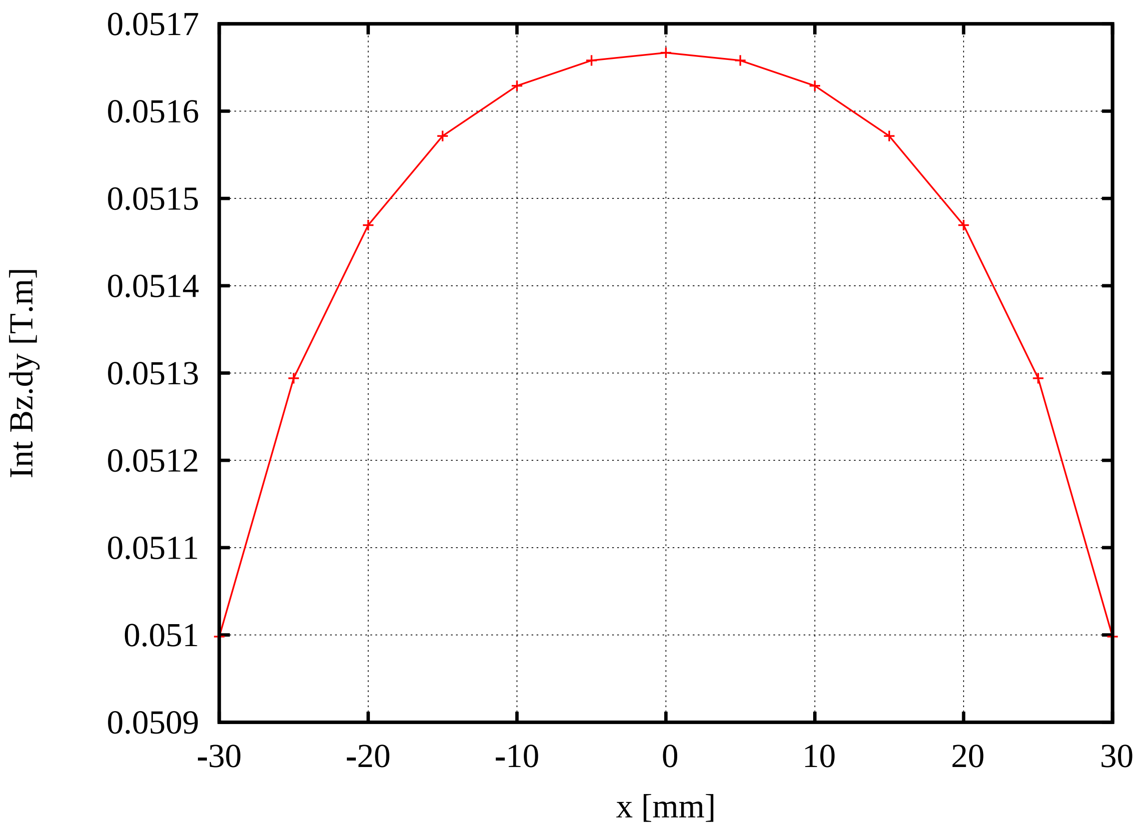

Figure 8: $\int B_z \mathrm{d}y$, along straight lines, as described in Fig. 17 (see Section 4.2).

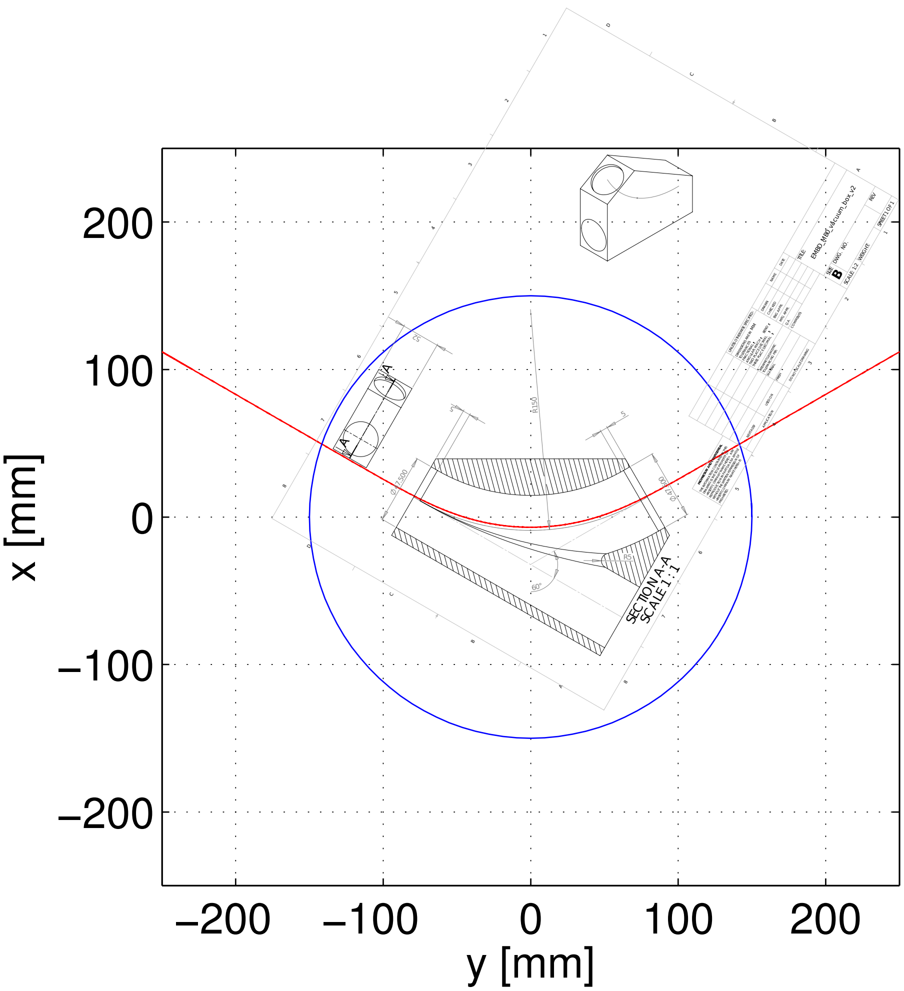

Figure 9: Reference trajectory plotted over a 2D drawing of the vacuum chamber.

3.2 Coil Parameters

The required Ampere-turns per coil were initially estimated using the relation:

$$\mathrm{NI}_{\mathrm{per\ coil}} = \frac{1}{2}\left(\frac{B_{max}\ [\mathrm{T}]\ \cdot\ full\ gap\ [\mathrm{m}]}{4\pi 10^{-7}}\right) \simeq 7280\ [\mathrm{A.t}] \tag{2}$$

The `OPERA-3D` model of this design used in fact 7550 A.t to produce the required amount of field.

3.3 Pole Dimensions

The pole dimensions given above (Table 3) were chosen as follows:

- ◇ The pole length results in the required field integral for a maximum field (in the mid plane) of about 0.344 T.
- ◇ The pole width results in the required field quality (Table 1).
- ◇ The chamfers are wide enough to avoid saturation of the steel.
- ◇ The pole height results from the coil height used in our model (+6 mm margin left between the coil and the yoke).

3.4 Field Clamps Dimensions

The field clamps are used to meet the required field quality, as well as to satisfy the constraint related to the fringe field extent. The clamp dimensions given above (Table 3) were chosen as follows:

- ◇ Field clamp width equal to the pole width. This has been found to be close to the optimum from the point of view of the field quality.
- ◇ The Field clamp thickness keeps the maximum field in the clamps below 1.4T (see Fig. 5).

3.5 Return Yoke Dimensions

The return yoke dimensions given above (Table 3) were chosen as follows:

- ◇ The return yoke has been made thick enough to keep the field in the steel well below 1.4 T (see Fig. 6).
- ◇ The distance between the pole and the return yoke (set equal to the gap height) comes from a trade-off between the field quality and the magnet transverse size.

3.6 Steel Properties

The BH curve used in this model is shown in Fig. 10. This BH curve was created at TRIUMF (by Paul Reeve), from the measurement of several samples of AISI 1010 steel.

However, we strongly recommend to build the magnet out of AISI 1006 steel, in order to minimize the remanent field. We have checked using OPERA-3D that the difference in term of field quality using either AISI 1010 or 1006 BH curves is negligible.

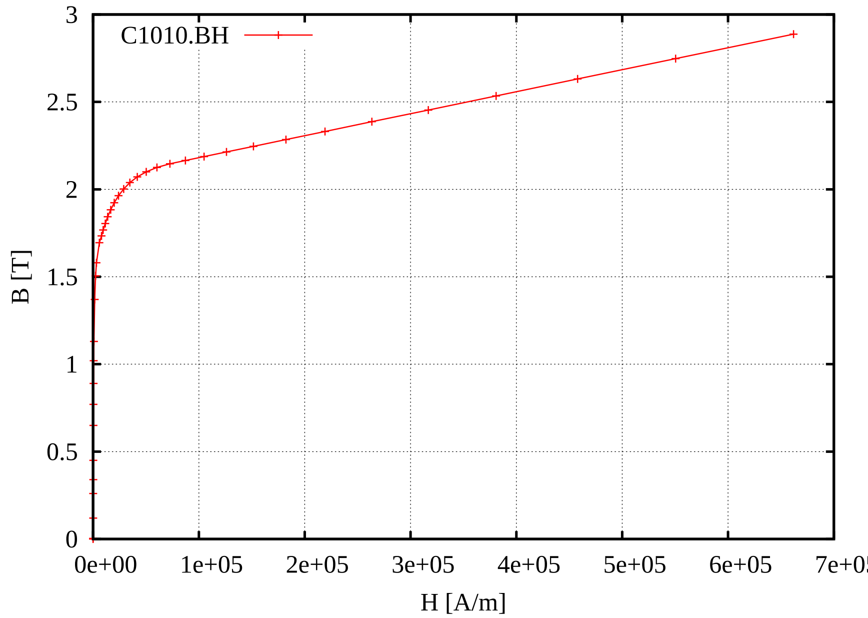

Figure 10: BH curve used in our model (AISI 1010 steel).

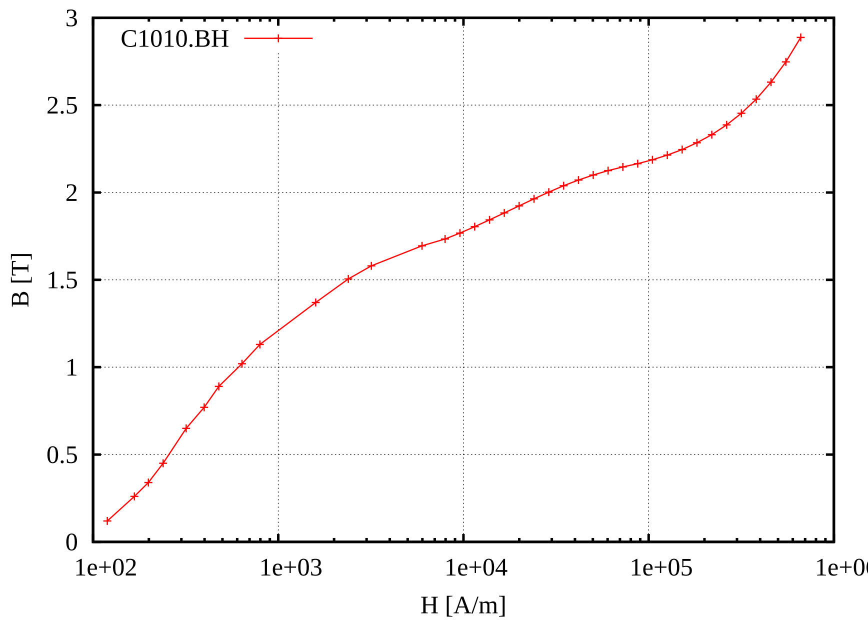

Figure 11: Same as Fig. 10 but with a log scale.

3.7 Field Quality from the OPERA-3D Model

A 2D field map of the magnet mid-plane has been extracted from the model. The field maps covers an area of ±100 mm in X and ±250 mm in Y, with a step size of 5 mm in both directions. We used this field map in COSY INFINITY version 9 [1] to track particles entering the magnet at an angle of 30°. This way we obtained the transfer map coefficients, calculated around these orbits, as a function of the initial particle coordinate x_0. Results are presented in Fig. 12. One can see on this figure that the sextupole components are minimum for $x_0 \simeq 112$ mm, and values are smaller than required (in Table. 1).

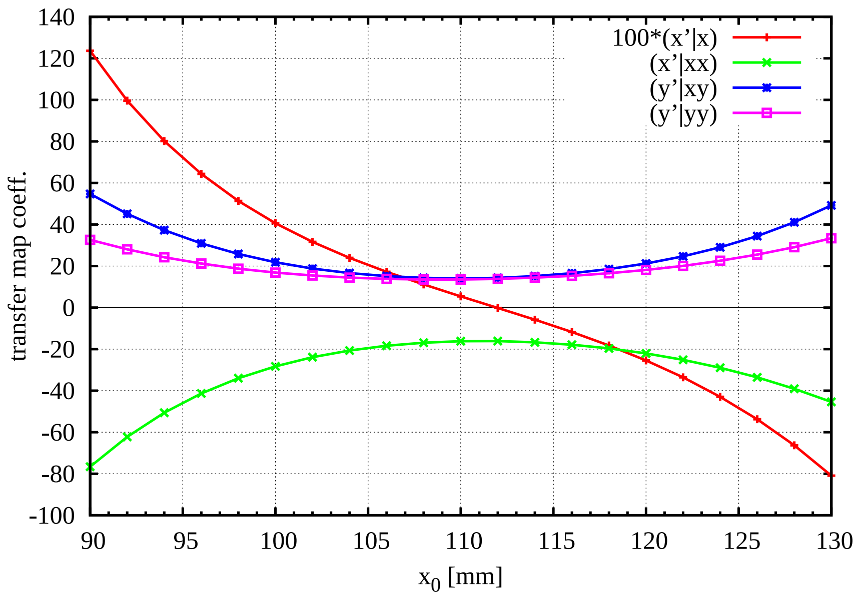

Figure 12: Quadrupole component and major sextupole components calculated around trajectories entering the field map at x_0, with an angle of 30°. The units system used for the coefficient is m & rad.

The trajectory starting from $x_0 = 112$ mm is our reference trajectory (see Fig. 13). The magnetic field seen by the particle along this trajectory is shown in Fig. 14. The transfer map calculated (to the second order) around this trajectory is presented in Table 4.

3.8 B(I) curve

The relation between Ampere.turns and field value at the center of the magnet in our model is presented in Fig. 15

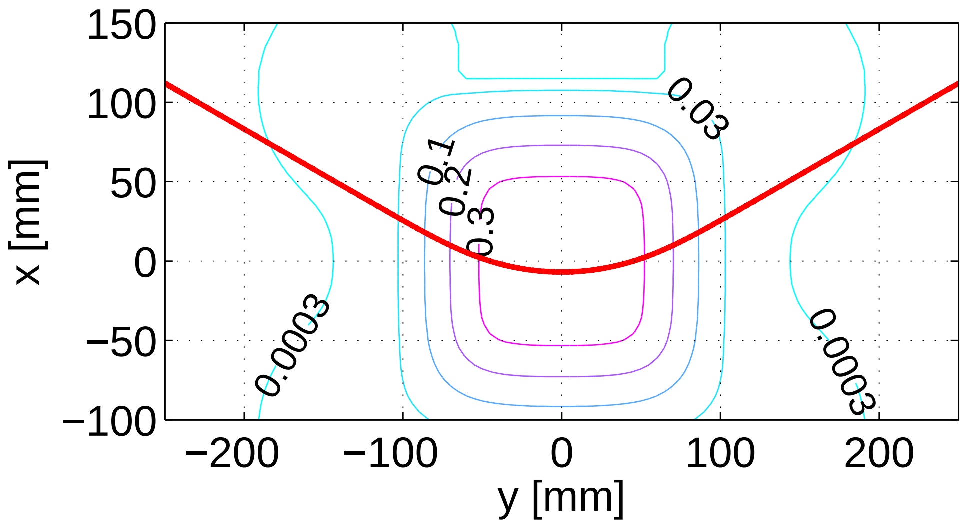

Figure 13: Red line: the reference trajectory. Contours represent the absolute value of the magnetic field from the 2D-field map (in Tesla).

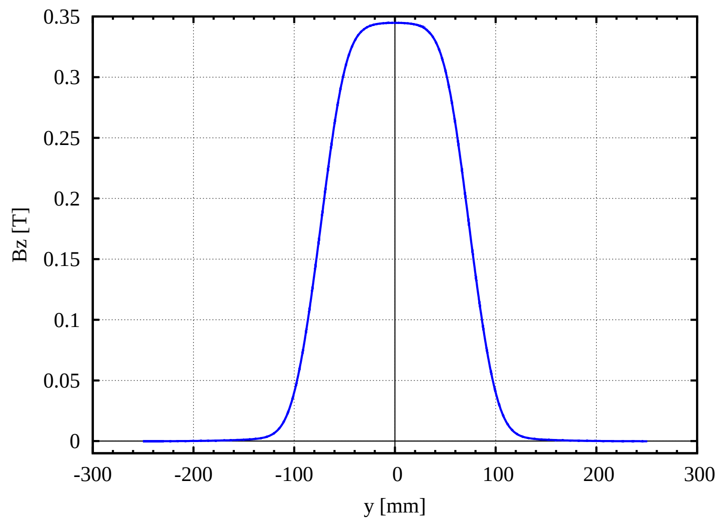

Figure 14: Field **seen by the particle** along the reference trajectory. (Note: only the vertical component of the field is non-zero, since the reference trajectory lies in the mid-plane).

x	x'	y	y'	l	(x|x'|y|y'|l| δ_k)
0.9998766	-0.5442868E-03	0.000000	0.000000	1.122080	100000
0.5270910	0.9998365	0.000000	0.000000	0.2953042	010000
0.000000	0.000000	-0.3866025	-4.452385	0.000000	001000
0.000000	0.000000	0.1913337	-0.3831033	0.000000	000100
0.000000	0.000000	0.000000	0.000000	1.000000	000010
-0.2961706	-1.122057	0.000000	0.000000	-0.2840783E-01	000001
-4.247186	-16.09139	0.000000	0.000000	-0.4505884	200000
-3.334045	-8.469503	0.000000	0.000000	-0.8534102	110000
-0.4382918	-0.5651808	0.000000	0.000000	-0.3991146	020000
0.000000	0.000000	7.423010	14.31533	0.000000	101000
0.000000	0.000000	3.216882	3.767841	0.000000	011000
0.8220823	13.76487	0.000000	0.000000	-5.900696	002000
0.000000	0.000000	1.897509	7.412405	0.000000	100100
0.000000	0.000000	0.4984164	0.6876011	0.000000	010100
0.9895635	5.582331	0.000000	0.000000	-1.270271	001100
0.8543390	0.9012438	0.000000	0.000000	-0.3828995E-02	100001
-0.3492662	-0.3790184	0.000000	0.000000	-0.1735653E-03	010001
0.000000	0.000000	1.332120	1.132977	0.000000	001001
0.4041205	1.072654	0.000000	0.000000	-0.2037752	000200
0.000000	0.000000	0.4016847	2.745297	0.000000	000101
0.3230196	0.3476293	0.000000	0.000000	-0.1156089	000002

Table 4: Second order transfer map calculated by `COSY INFINITY` around the reference trajectory. The units system used for the coefficient is m & rad.

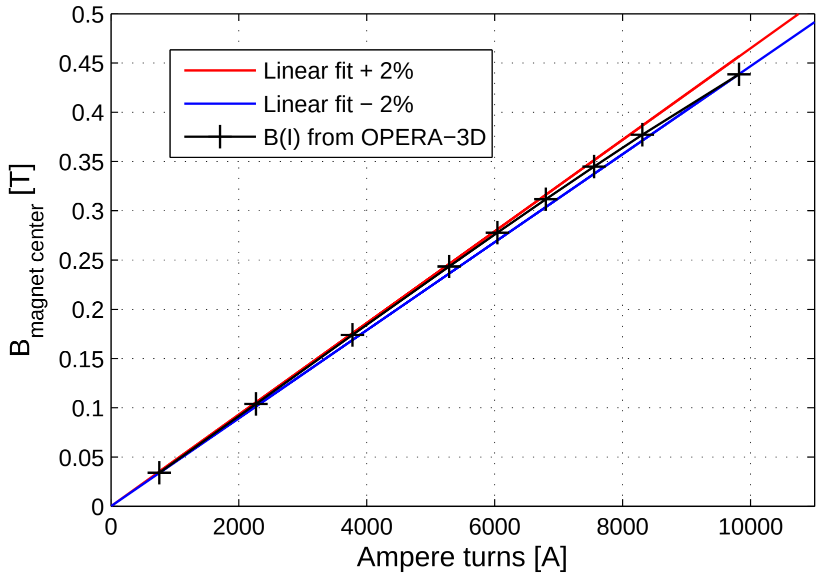

Figure 15: Field value at the center of the magnet, function of the Ampere.turns (per coil).

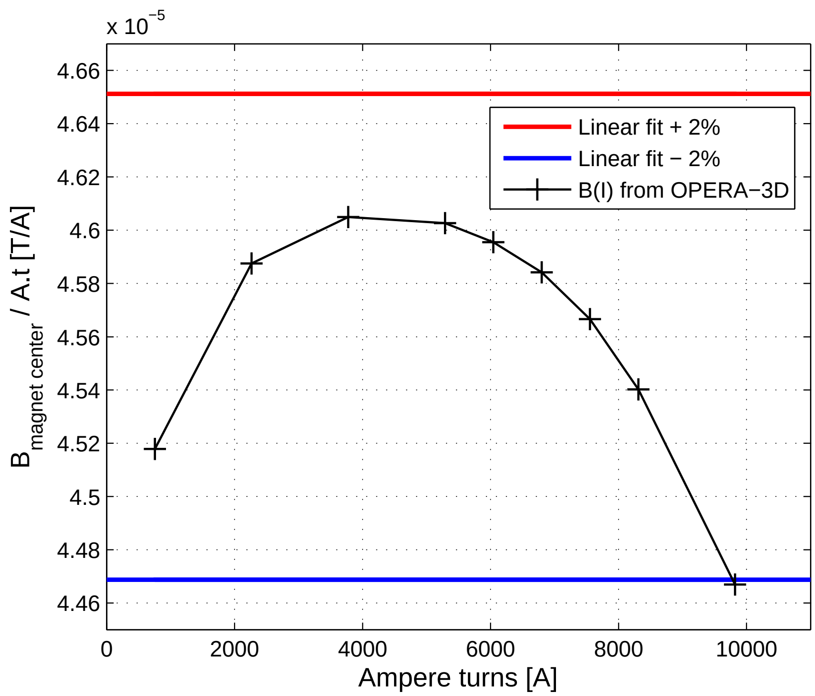

Figure 16: Same as Fig. 15, but for convenience we plot here B/Ampere.turns.

4 Tolerances & Field Measurement Specifications

4.1 Mechanical Tolerances

Tight tolerances ($\sim 100\ \mu$m) must be specified only on the following part:

- ⋄ poles flatness,
- ⋄ straightness of the pole edges crossed by the beam,
- ⋄ shape chamfers,
- ⋄ parallelism between the pole edges and the clamps,
- ⋄ flatness of the face of the clamps facing the beam.

4.2 Field Measurement

4.2.1 Field strength at the magnet center

- ⋄ It must be checked that the field can reach 0.344 T, and stand in for more that a couple of hours.
- ⋄ We also wish to have a calibration curve, giving vertical component of the B field at the center of the magnet for different currents (B(I) curve). We might want to do this measurement (and only this one) ourselves, at TRIUMF.

4.2.2 Field integrals

Proposed measurement procedure:

- ⋄ Find the actual location of the magnetic mid-plane.
- ⋄ Check that the field integral, in the mid-plane, along a straight line passing by the center of the magnet exceeds the expected value of 51.66 T.mm (see Fig. 8).
- ⋄ In this plane, measure field integrals along straight lines as described in Fig. 17, from x = -30 mm to x = +30 mm with one measurement every 10 mm. The field integrals measured along these lines must be identical within ± 0.8%.

If the field integrals satisfy this condition, **and** if the magnet is build according to the specified mechanical tolerances, then the field quality satisfies our requirements.

References

[1] K. Makino, M. Berz, Cosy infinity version 9, Nucl. Instr. and Meth. A 558 (1) (2006) 346 – 350, proc. of ICAP 2004. doi:10.1016/j.nima.2005.11.109.

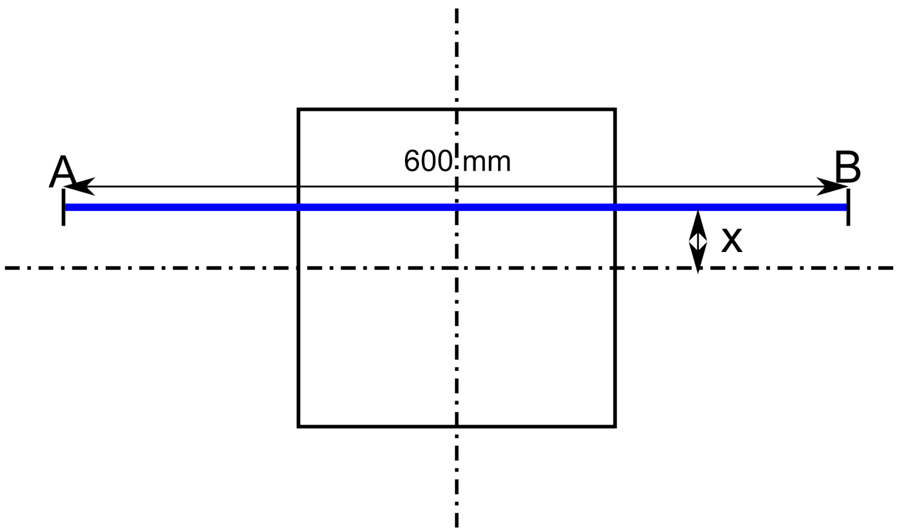

Figure 17: Schematic description of the trajectories along which the field integrals will be measured.