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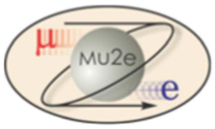

the
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project

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TD Engineering Document No.

Date: 2012-08-22

Alignment of the Transport Solenoid Magnetic Center Due to Coils Displacements (Magnetic Design Version 7)

Abstract

This document summarizes the results for the misalignments of the magnetic centre of the Mu2e Transport Solenoid in the hypothesis that the geometry of the solenoid is affected by some type of error.
In order to identify the magnetic centre of the solenoid, a low energy particle (1 MeV e^-) trajectory has been considered, and the displacements from this nominal track have been calculated in case of deformed geometry.
Two types of errors were studied: Systematic and Random.

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Circulated to:

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1. INTRODUCTION

The version 7 of the magnetic design of the Transport Solenoid (TS) is described in [1].

Respect to the nominal configuration, two types of geometrical errors can occur:

Systematic errors, due to thermal or mechanical stress; they usually affect all the coils of only one of the sections of the TS (TS1, TS2 etc.)

Random errors, due to building tolerances; they affect each single coil, that moves from its original position.

The effects of these errors on the magnetic field are studied in a separate document ([2]).

The aim of this work is to study the alignment of the magnetic centre due to coils displacements. In order to do that, the trajectory of a 1 MeV electron is used. Electrons of such energy have relatively small deviations from the centroid of the coils. This can be considered as the magnetic centre.

Figure 1 shows the displacements among the geometrical centre of the solenoid, the trajectory of 1 MeV electron in the nominal case and the trajectory in case some error is present. The proportions are exaggerated for major clearness of the picture.

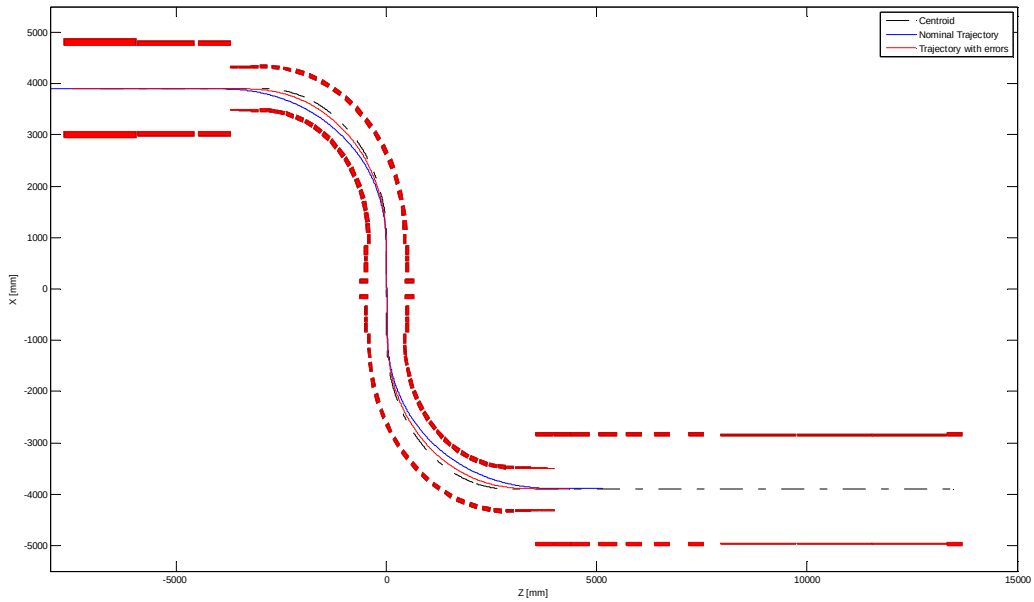

Figure 1 - 1 MeV trajectories inside the solenoid for nominal and deformed configurations

In Figure 2, the horizontal and vertical displacements with respect to the centroid of the coils are shown, for the nominal configuration. The vertical black lines identify the different sections of the TS (from TS1 to TS5). The particle is supposed to be, at initial time, in a point on the centroid of the PS close to the location of the production target with initial speed parallel to the centroid itself.

The tracking is repeated when the coils are off the nominal position and the horizontal and vertical differences with respect to the nominal are computed along the trajectory.

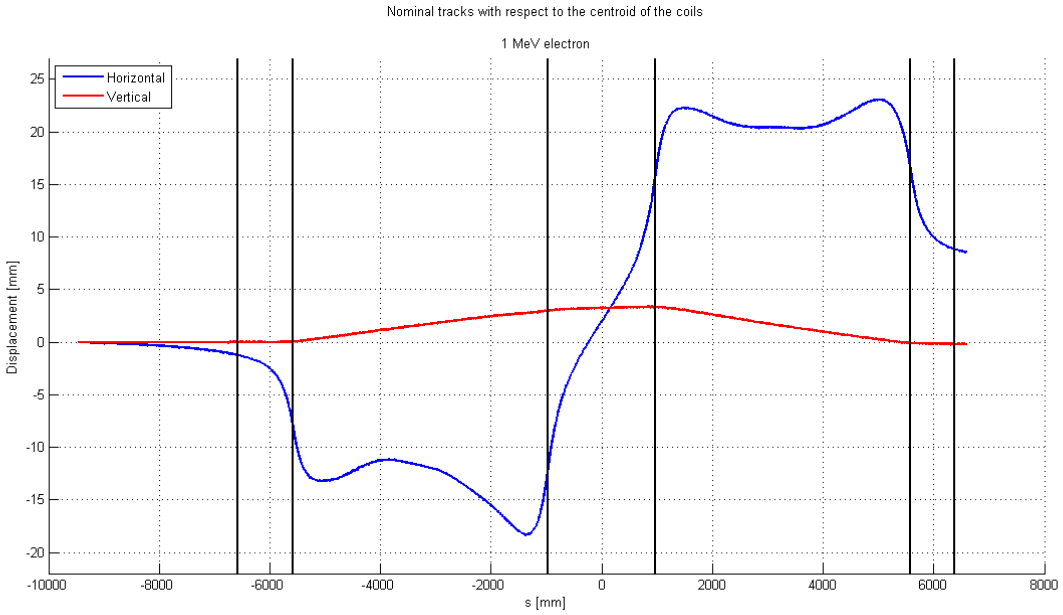

Figure 2 – Displacements of the nominal trajectory with respect to the solenoid central line

In case of random errors, the trajectory calculation is repeated 100 times, with different individual displacement directions every time. The maximum displacements of the coils are fixed in each case.

The results are presented in terms of horizontal and vertical displacements with respect to the nominal trajectory.

The coordinate system used for the following analysis is the same of reference [1].

2. RANDOM ERRORS

The random errors taken into account are the same of document [2].

For each of the considered configurations, vertical or horizontal displacements from the nominal trajectory are represented as the mean over 100 cases with error-bars of width equal to one σ of standard deviation.

Radial, longitudinal and vertical translations and Pitch and Yaw rotations are considered.

When only horizontal displacement plots are presented, it is implied that the vertical displacement is negligible, and vice versa.

Figure 10 and Figure 12 show the displacements, chosen among 100 cases, for the configuration that, in each of the two cases (ΔP=10 mrad and ΔP=5 mrad), give the largest vertical displacement from the nominal trajectory.

It is possible to notice that in both cases the maximum displacement is almost three times larger than in the one in the error-bars plot (Figure 11 and Figure 13); this is due to the fact that the error-bars represent 1σ of the distribution. This is true for all the random cases studied.

2.1. TRANSLATIONAL

2.1.1 RADIAL DISPLACEMENTS

2.1.1.1 ΔR = 10 mm

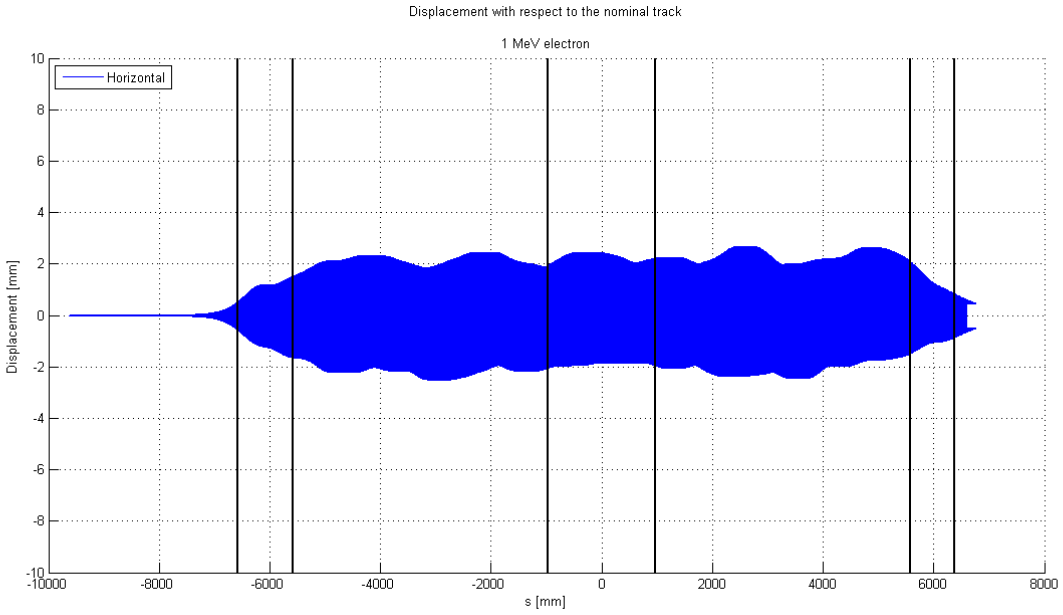

Figure 3 - Horizontal displacement with respect to the nominal track

2.1.1.2 ΔR = 2 mm

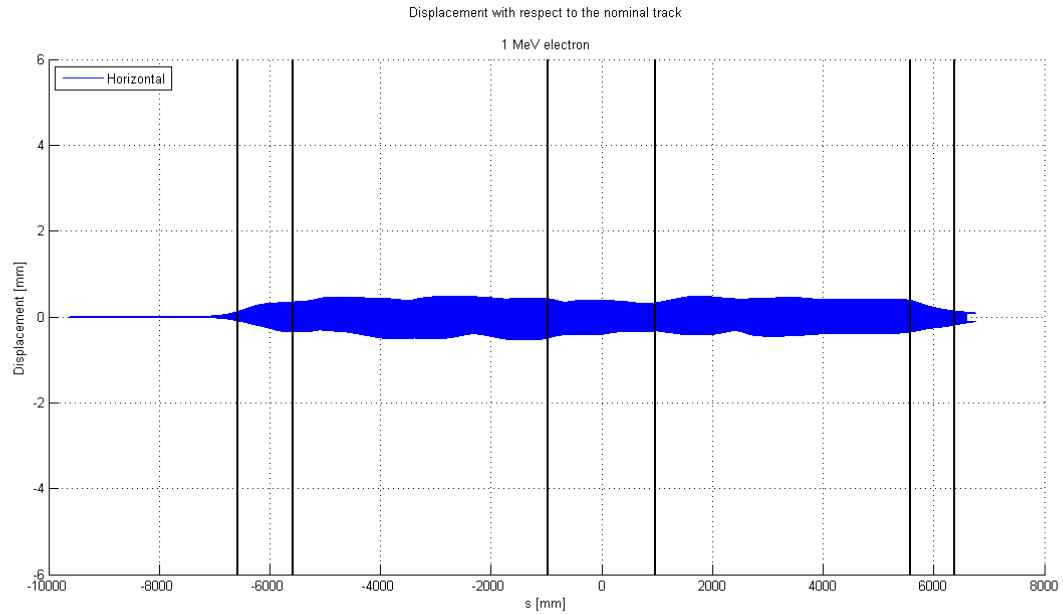

Figure 4 - Horizontal displacement with respect to the nominal track

2.1.2 VERTICAL DISPLACEMENTS

2.1.2.1 ΔV = 10 mm

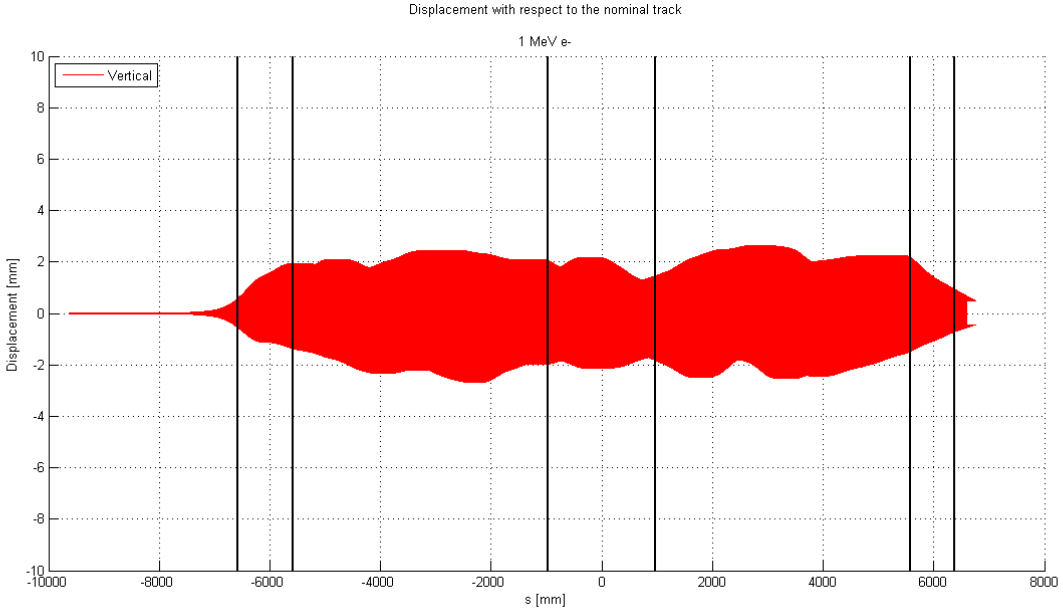

Figure 5 - Vertical displacement with respect to the nominal track

2.1.2.2 ΔV = 2 mm

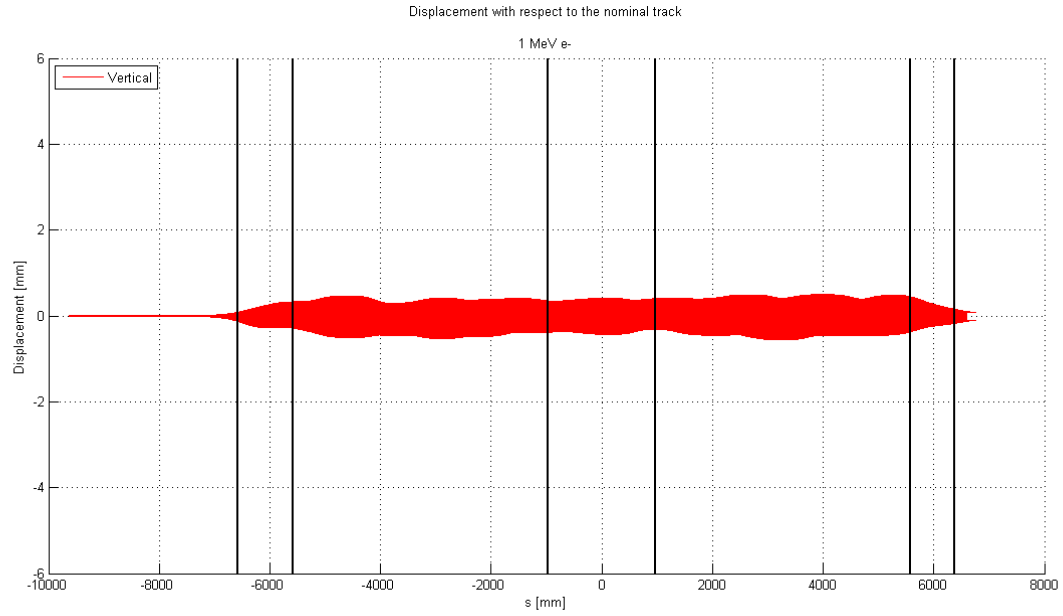

Figure 6 - Vertical displacement with respect to the nominal track

2.1.3 LONGITUDINAL DISPLACEMENTS

2.1.3.1 ΔL = 10 mm

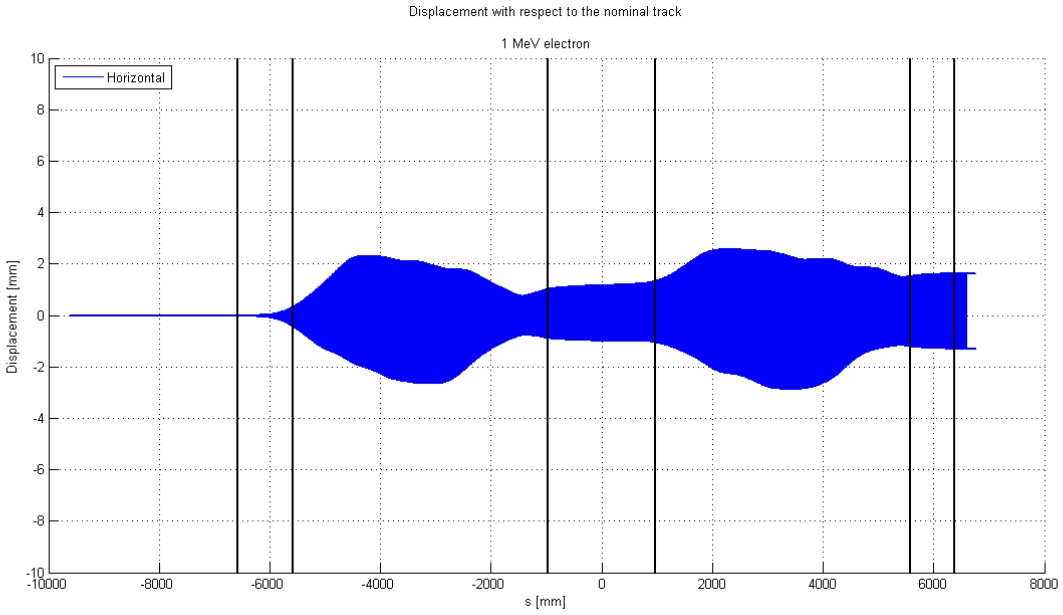

Figure 7 - Horizontal displacement with respect to the nominal track

2.1.3.2 ΔL = 2 mm

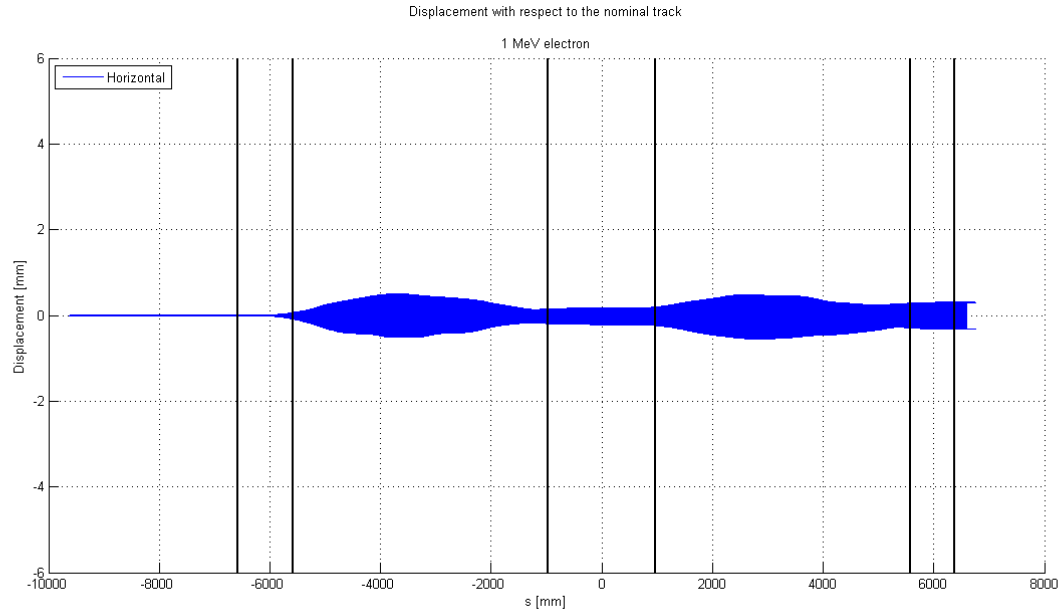

Figure 8 - Horizontal displacement with respect to the nominal track

2.2 ROTATIONAL

2.2.1 PITCH ROTATION

2.2.1.1 ΔP = 10 mrad

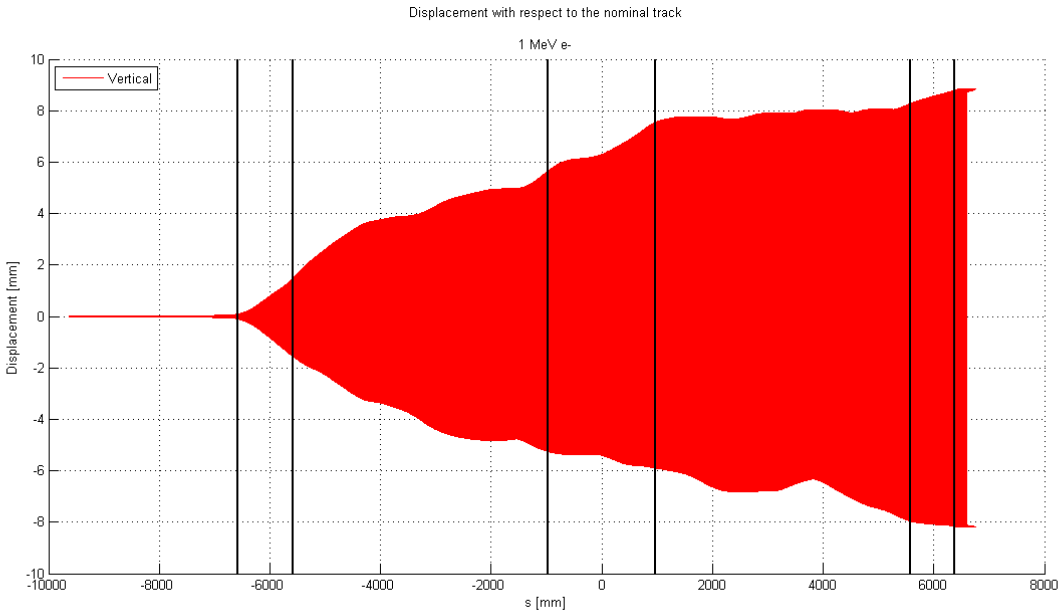

Figure 9 - Vertical displacement with respect to the nominal track

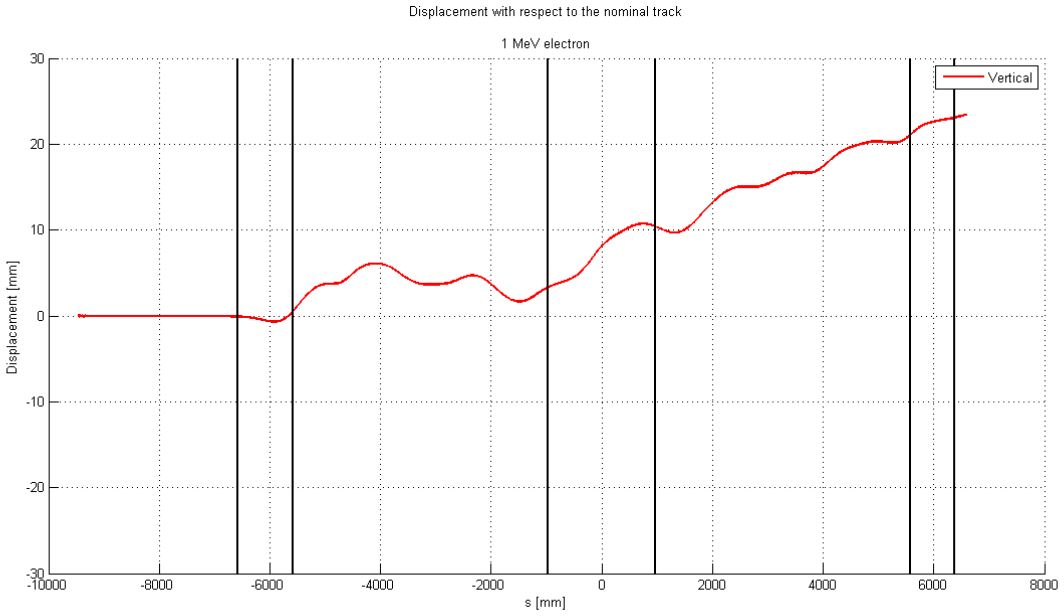

Figure 10 - Vertical displacement for the configuration that gives the largest displacement in TS5

2.2.1.2 ΔP = 5 mrad

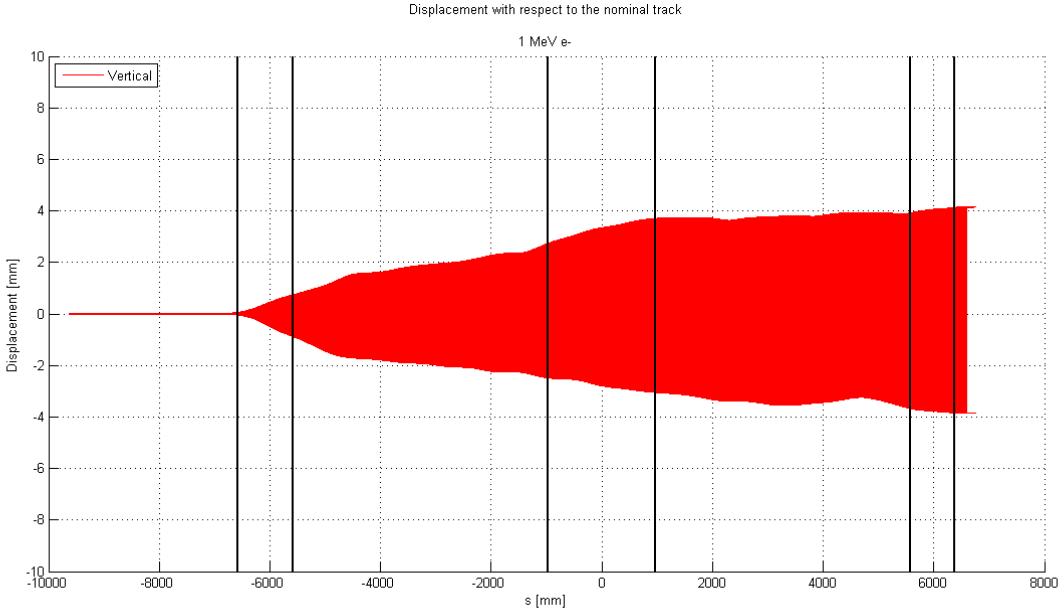

Figure 11 - Vertical displacement with respect to the nominal track

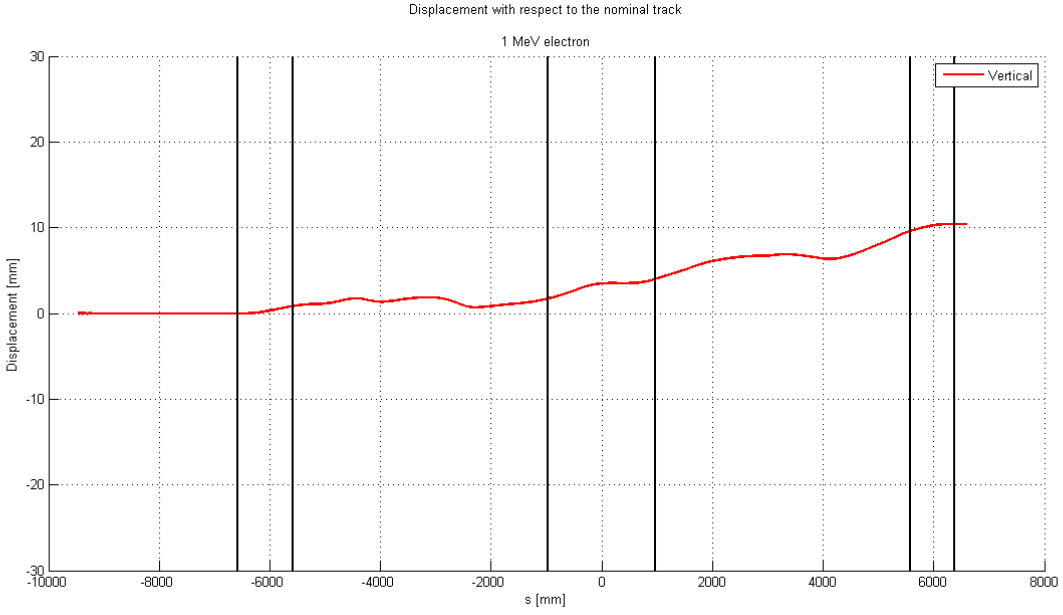

Figure 12 - Vertical displacement for the configuration that gives the largest displacement in TS5

2.2.1.3 ΔP = 2 mrad

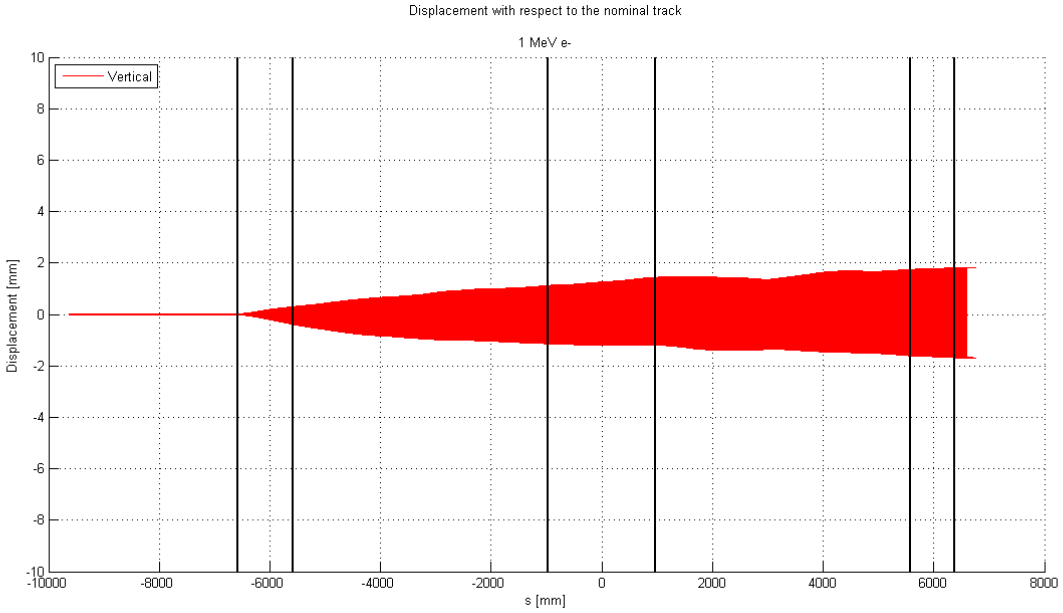

Figure 13 - Vertical displacement with respect to the nominal track

2.2.2 YAW ROTATION

2.2.2.1 ΔY = 10 mrad

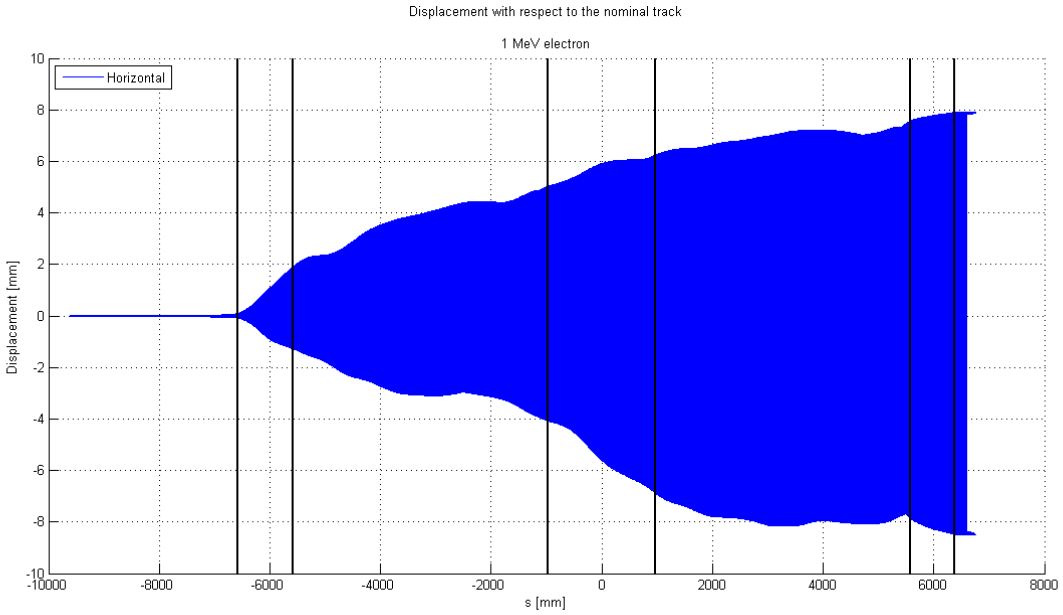

Figure 14 – Horizontal displacement with respect to the nominal track

2.2.2.2 ΔY = 5 mrad

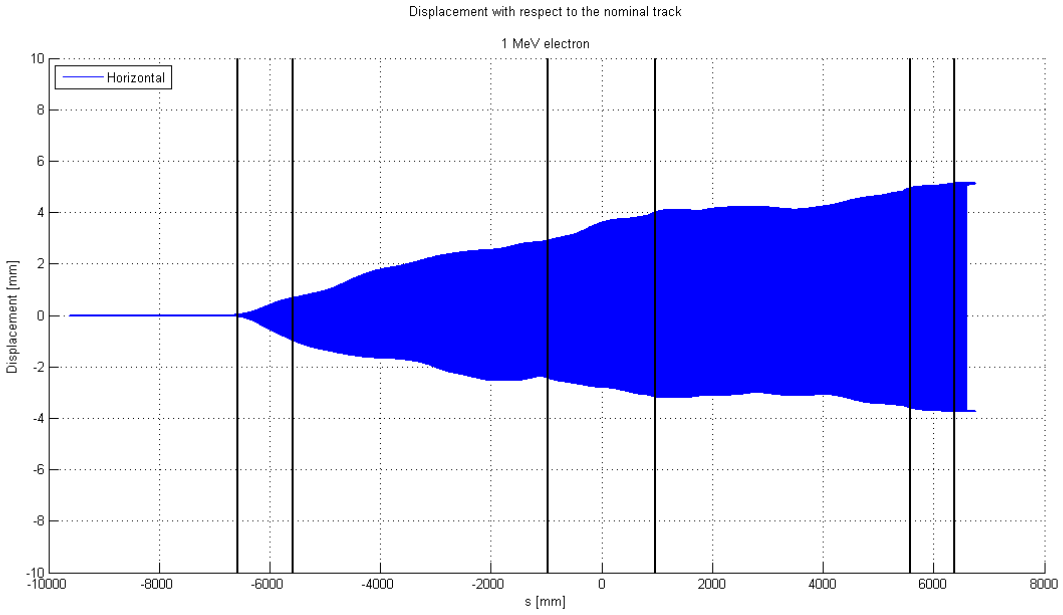

Figure 15 - Horizontal displacement with respect to the nominal track

2.2.2.3 ΔY = 2 mrad

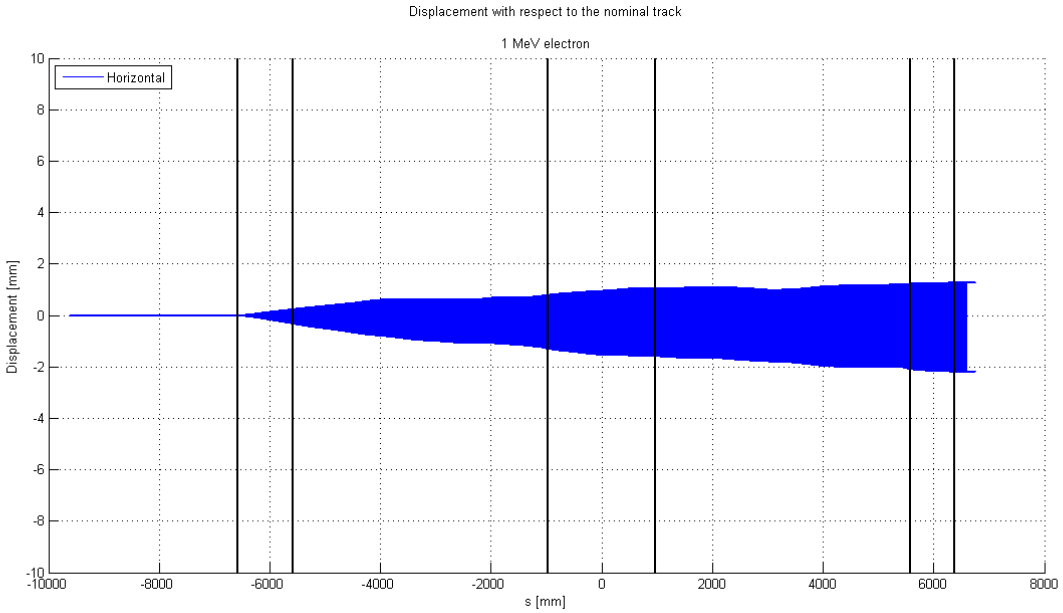

Figure 16 - Horizontal displacement with respect to the nominal track

3. SYSTEMATIC ERRORS

As the most critical sketches of the solenoids are TS1 (where the field is maximum) and TS3 (because off the presence of the gap), the study of systematic errors is mainly focused on these two sections.

When only horizontal displacement plots are presented, it is implied that the vertical displacement is negligible, and vice versa.

3.1 CASE 1 – TS1 IS BENT 1° TOWARDS +X

Figure 17 describes the type of geometrical deviation taken into account. Here the represented bending angles have been taken much higher than 1° for major clearness of the picture

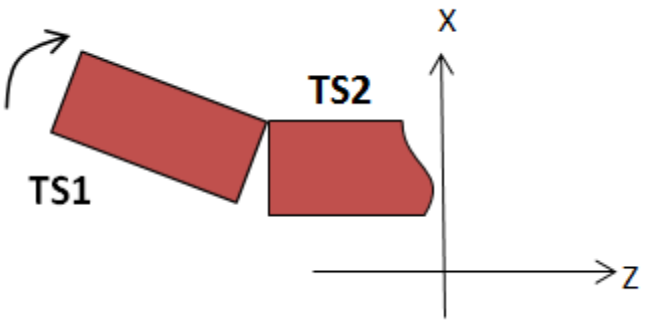

Figure 17 - TS1 bent towards +x

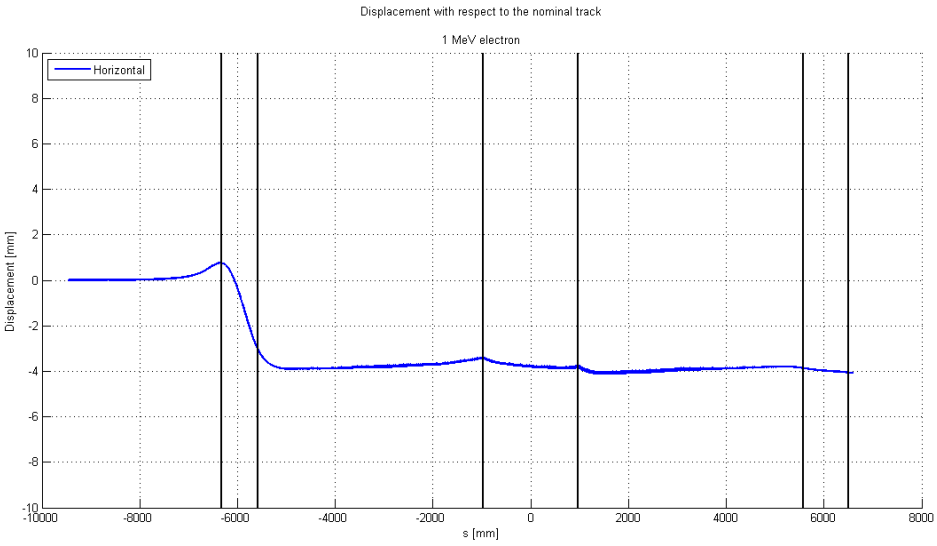

Figure 18 - Horizontal displacement with respect to the nominal track

3.2 CASE 2 – TS1 IS BENT 1° TOWARDS –X

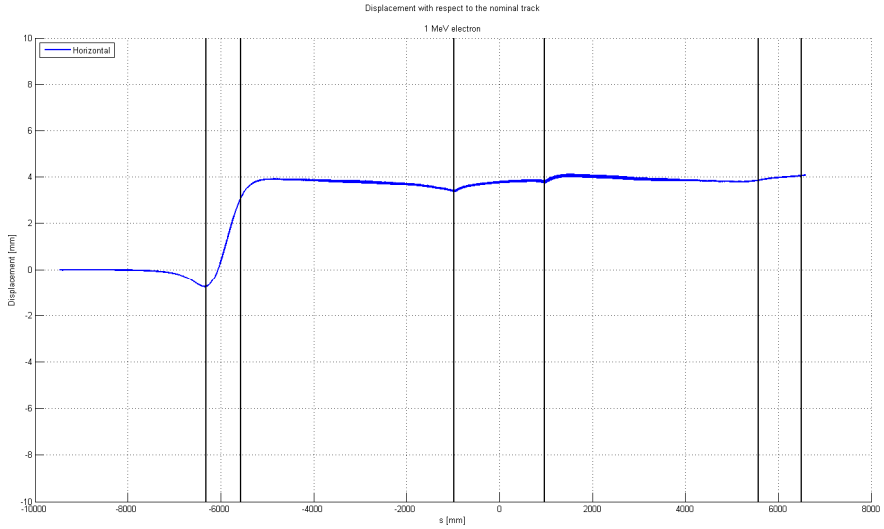

Figure 19 - Horizontal displacement with respect to the nominal track

3.3 CASE 3 - TS1 IS BENT 1° TOWARDS +Y

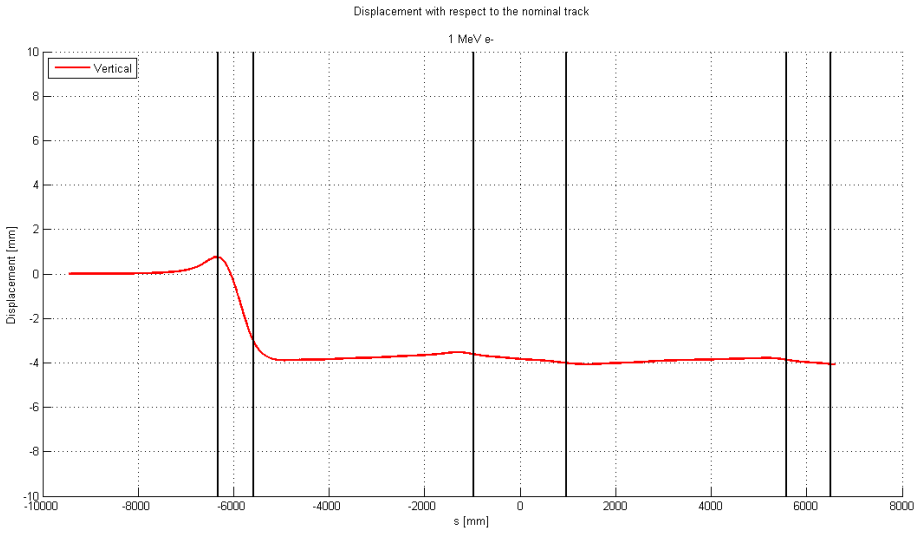

Figure 20 - Vertical displacement with respect to the nominal track

3.4 CASE 4 – TS1 IS DISPLACED 10 mm IN +Z DIRECTION

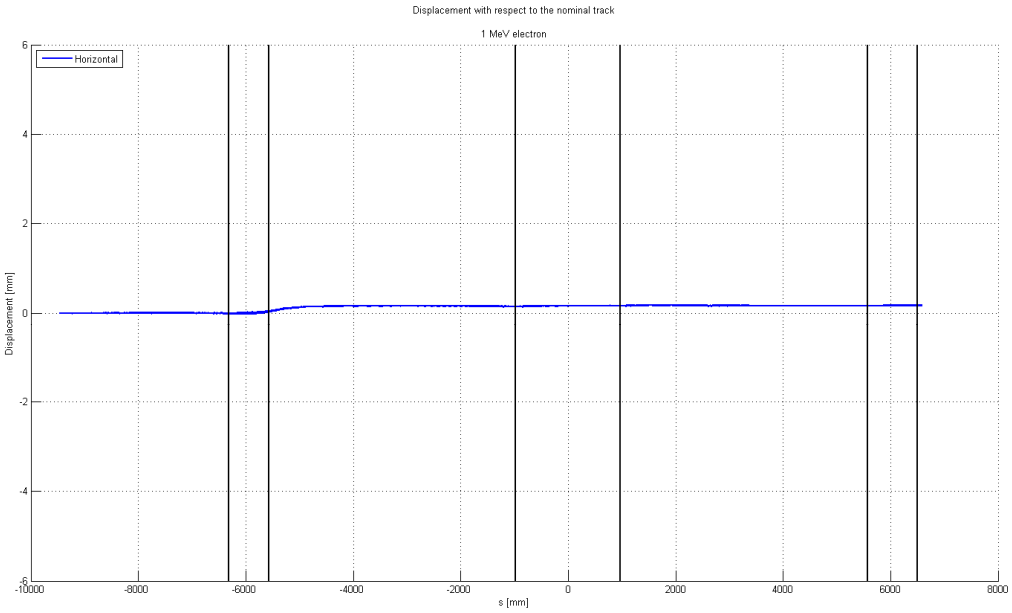

Figure 21 - Horizontal displacement with respect to the nominal track

3.5 CASE 5 – TS1 IS DISPLACED 10 mm IN -Z DIRECTION

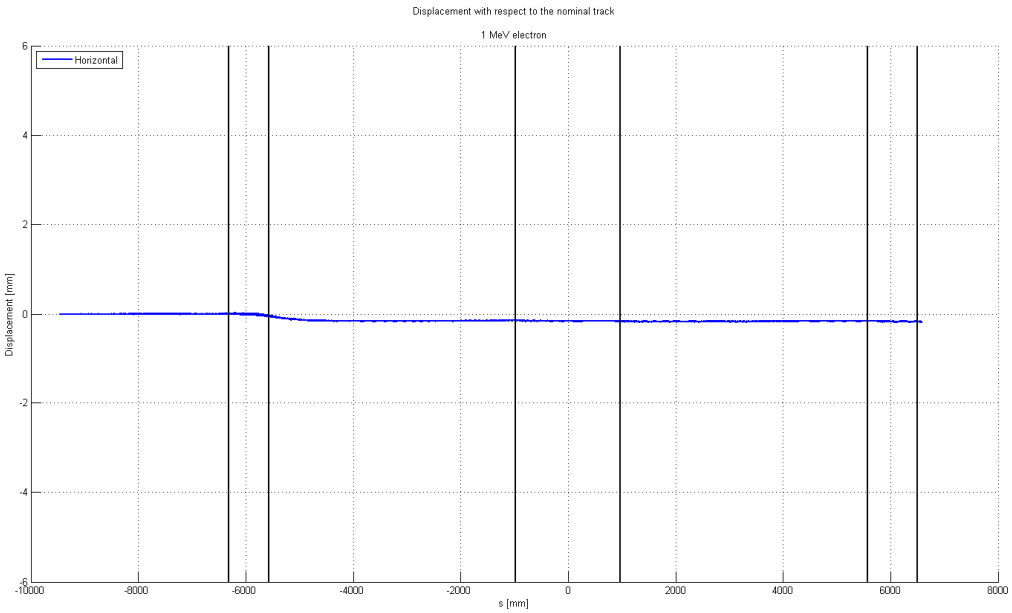

Figure 22 - Horizontal displacement with respect to the nominal track

3.6 CASE 6 – TS1 IS DISPLACED 10 mm IN +X DIRECTION.

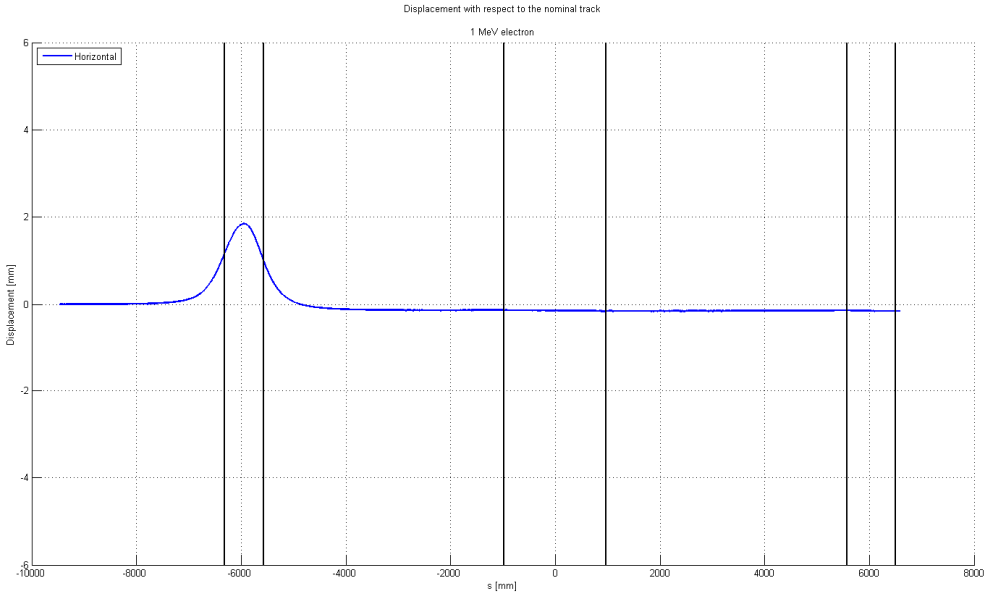

Figure 23 - Horizontal displacement with respect to the nominal track

3.7 CASE 7 – TS1 IS DISPLACED 10 mm IN -X DIRECTION.

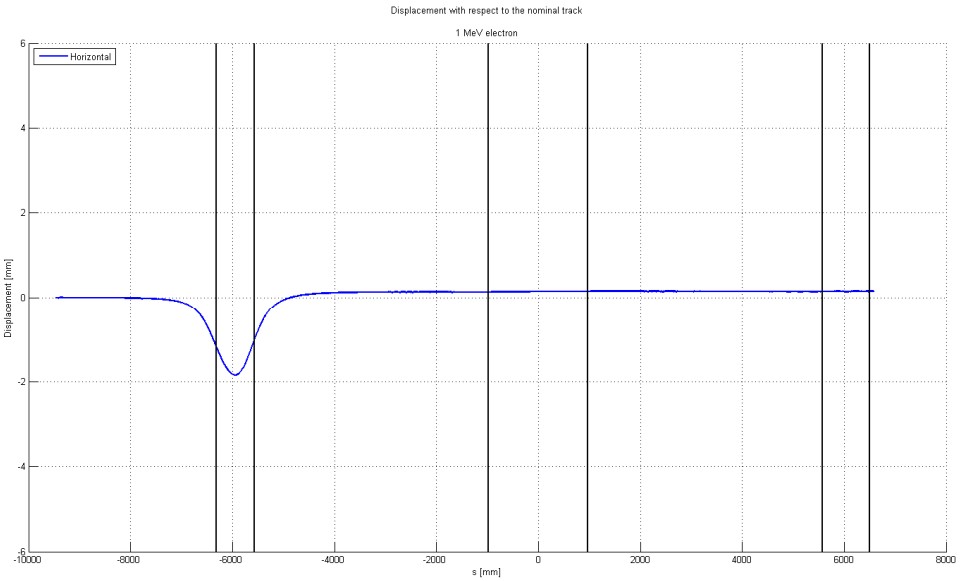

Figure 24 - Horizontal displacement with respect to the nominal track

3.8 CASE 8 - TS3u COILS ARE MOVED 10 mm IN -X DIRECTION, TS3d COILS ARE MOVED 10 mm IN +X DIRECTION.

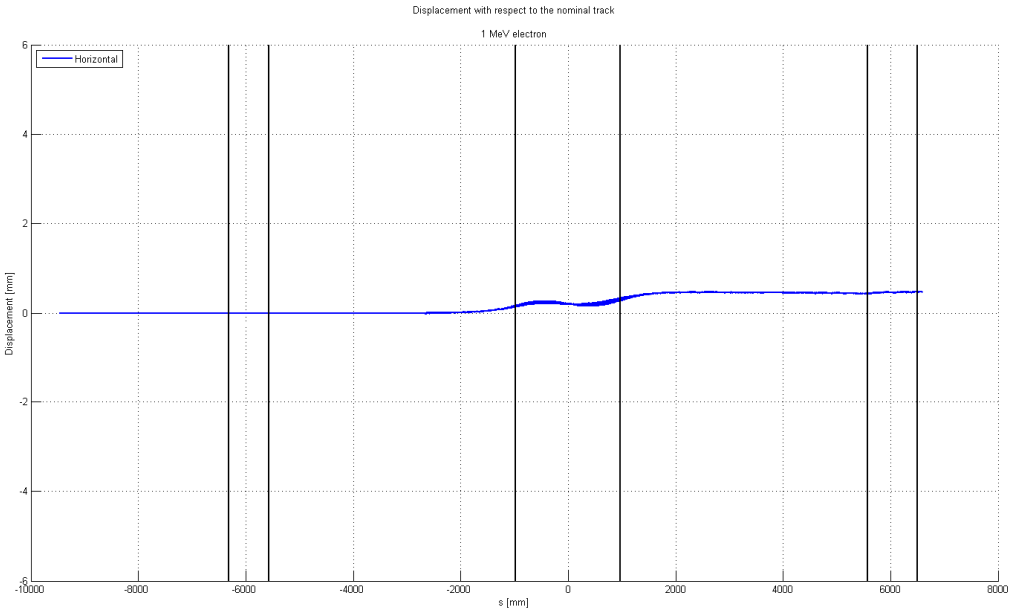

Figure 25 - Horizontal displacement with respect to the nominal track

3.9 CASE 9 – TS3u COILS ARE MOVED 10 mm IN +X DIRECTION, TS3d COILS ARE MOVED 10 mm IN -X DIRECTION.

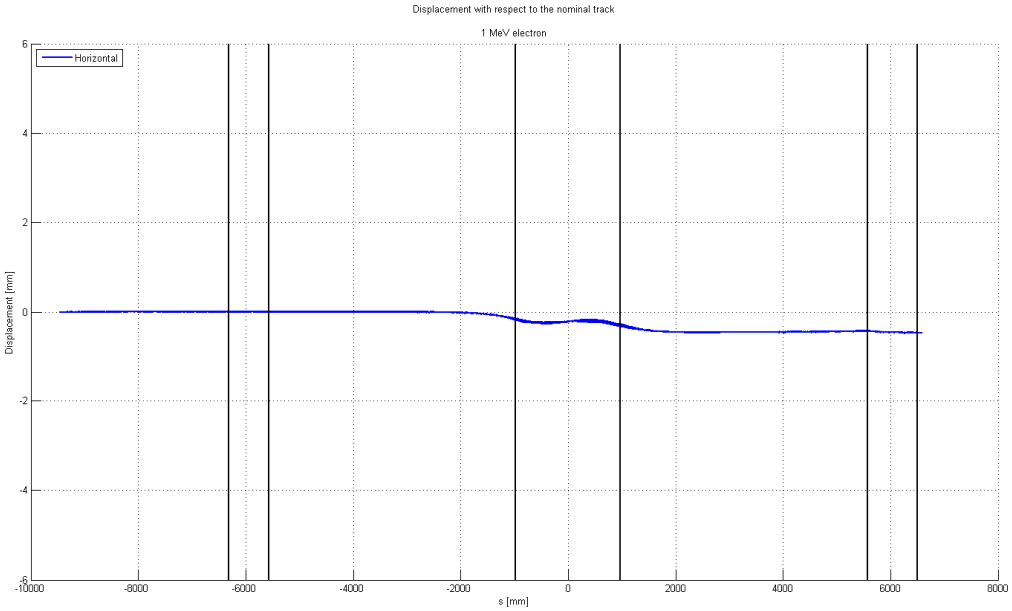

Figure 26 - Horizontal displacement with respect to the nominal track

3.10 CASE 10 – TS3u IS BENT 1° TOWARD –Z, TS3d IS BENT 1° TOWARD +Z

Figure 27shows the deformation in exam; as usual, the angles in the picture are emphasized respect to the ones in the calculation.

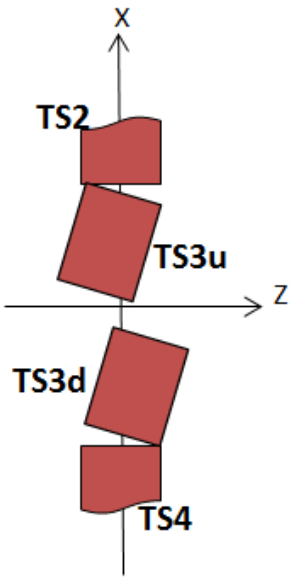

Figure 27 - TS3u bent toward -Z; TS3d bent in the opposite direction

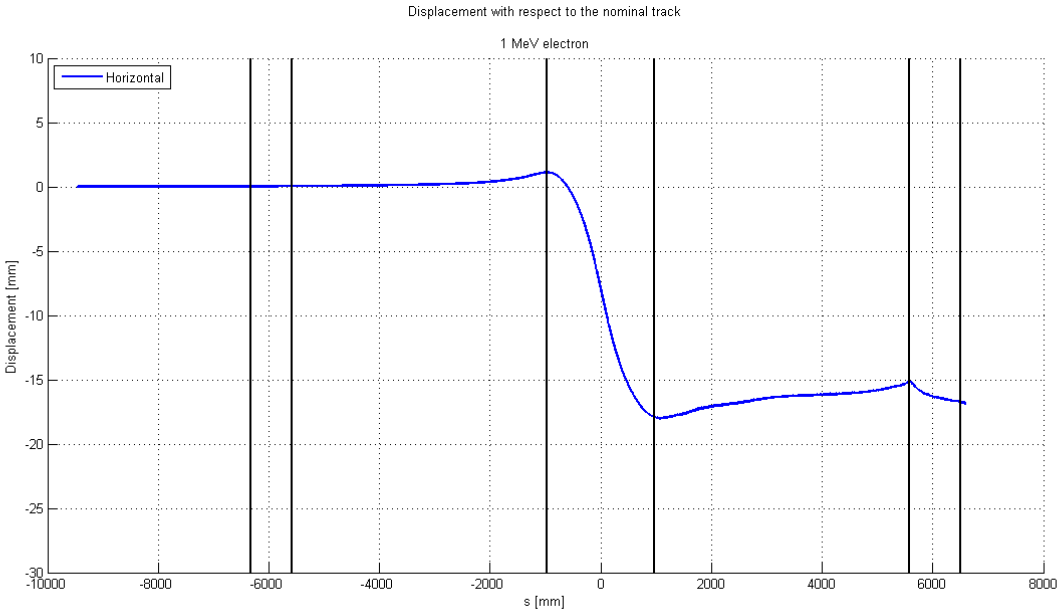

Figure 28 - Horizontal displacement with respect to the nominal track

3.11 CASE 11 – TS3u IS BENT 0.5° TOWARD –Z, TS3d IS BENT 1° TOWARD +Z

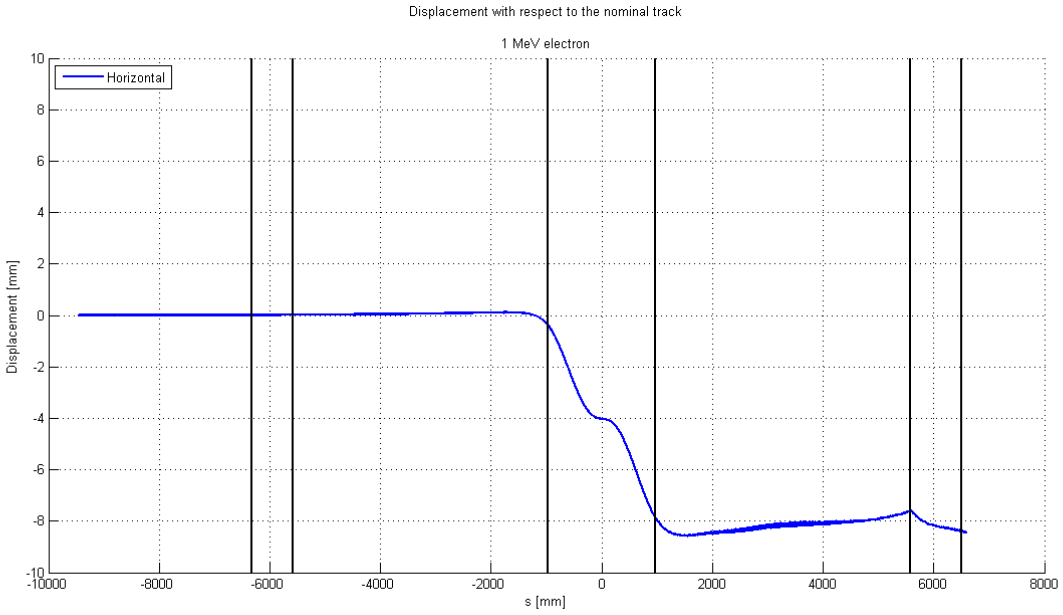

Figure 29 - Horizontal displacement with respect to the nominal track

3.12 CASE 12 – TS3u IS BENT 1° TOWARD +Y, TS3d IS BENT 1° TOWARD +Y

Figure 30 shows the geometrical deviation considered, with emphasized angular displacements

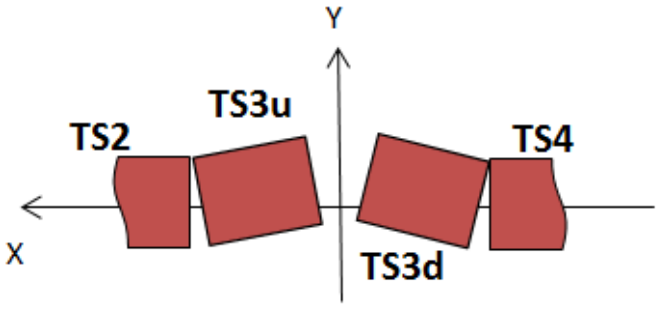

Figure 30 - TS3u and TS3d bent toward +Y

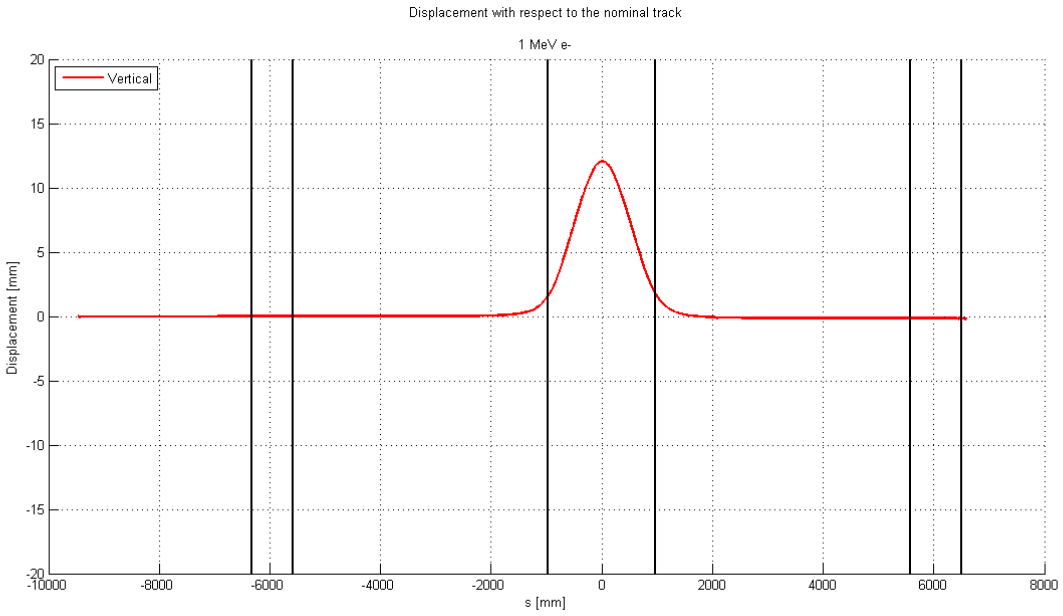

Figure 31 - Vertical displacement with respect to the nominal track

3.13 CASE 13 – TS3u IS BENT 0.5° TOWARD +Y, TS3d IS BENT 0.5° TOWARD +Y

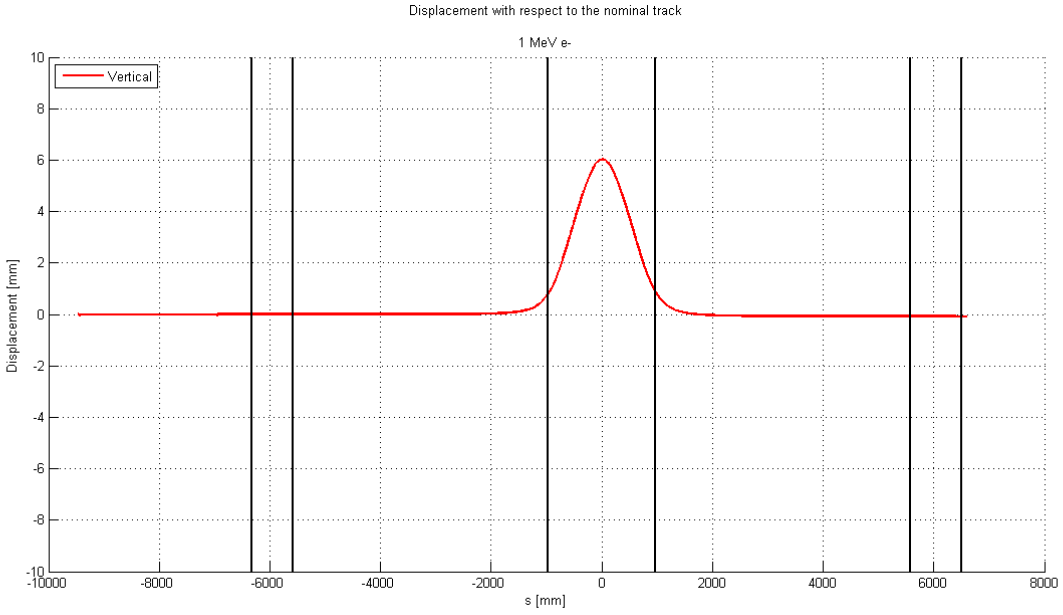

Figure 32 - Vertical displacement with respect to the nominal track

3.14 CASE 14 – TS3u IS BENT 1° TOWARD -Y, TS3d IS BENT 1° TOWARD -Y

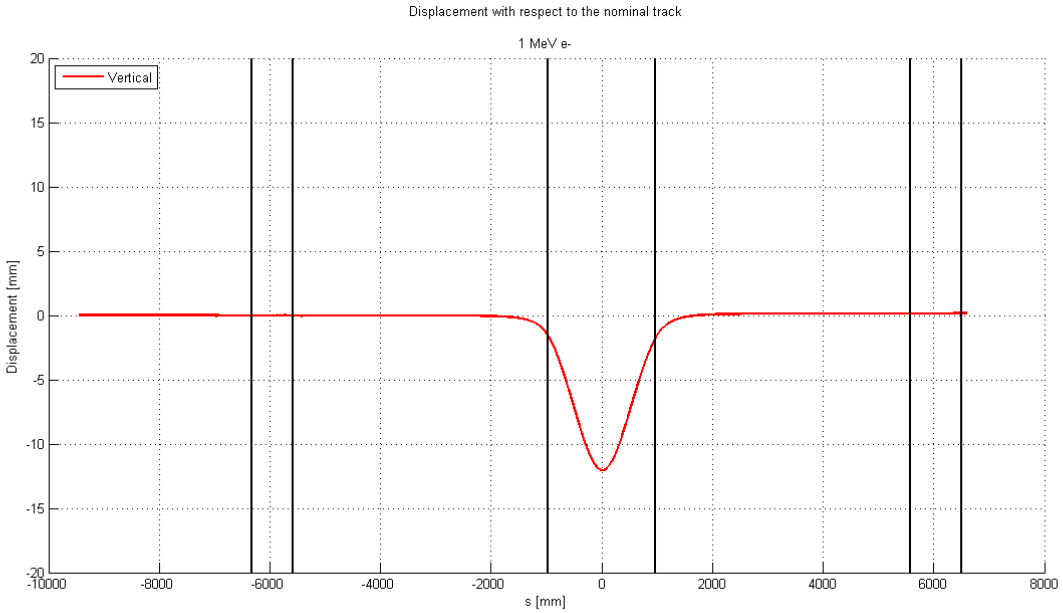

Figure 33 - Vertical displacement with respect to the nominal track

3.15 CASE 15 – TS3u IS BENT 0.5° TOWARD -Y, TS3d IS BENT 0.5° TOWARD -Y

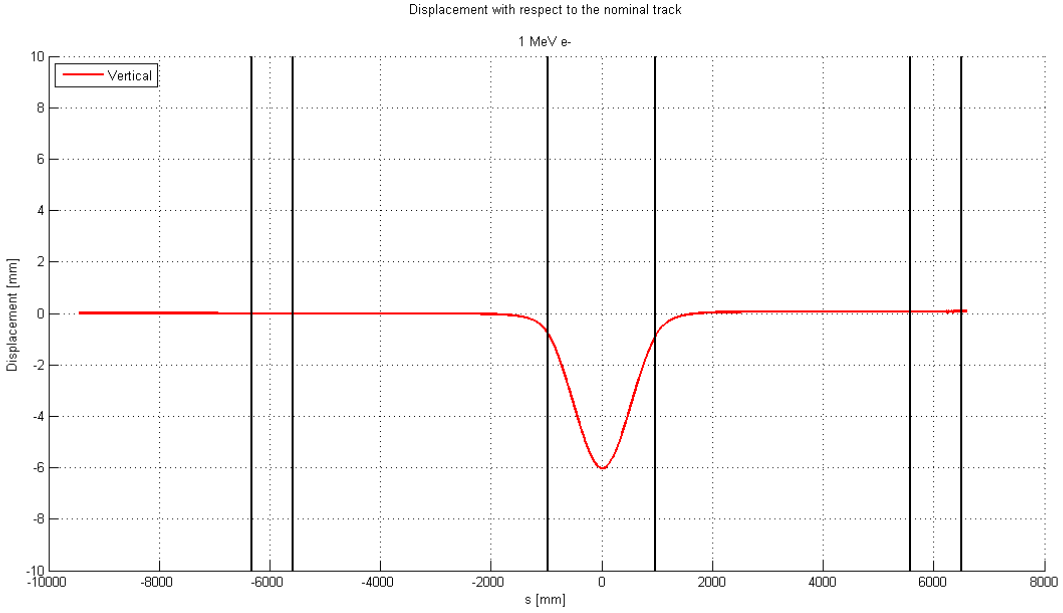

Figure 34 - Vertical displacement with respect to the nominal track

3.16 CASE 16 – TS3u IS BENT 1° TOWARD +Y, TS3d IS BENT 1° TOWARD –Y

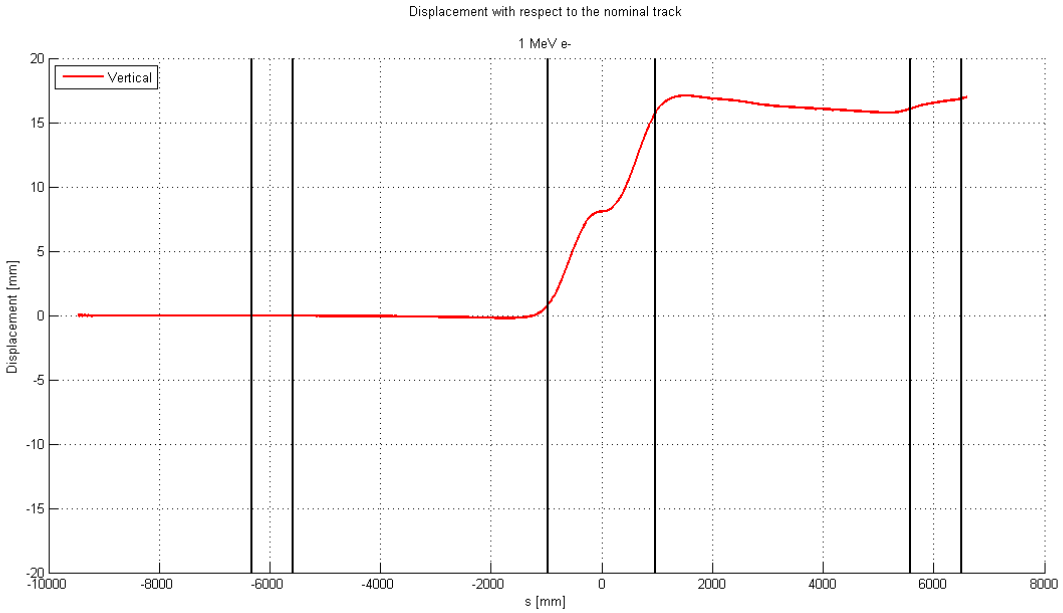

Figure 35 - Vertical displacement with respect to the nominal track

3.17 CASE 17 – TS3u IS BENT 0.5° TOWARD +Y, TS3d IS BENT 0.5° TOWARD –Y

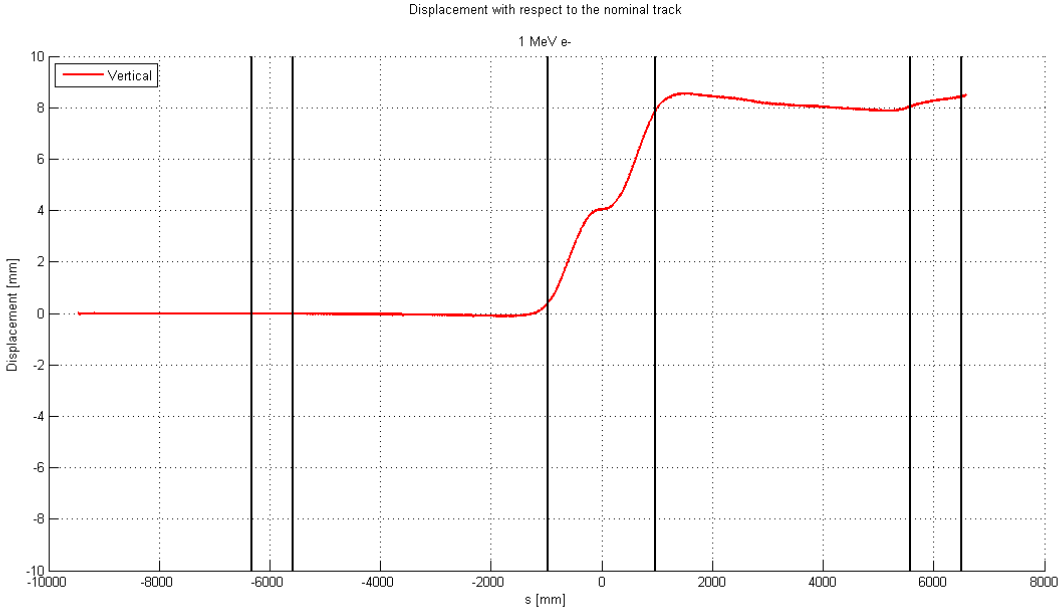

Figure 36 - Vertical displacement with respect to the nominal track

3.18 CASE 18 – TS3u IS BENT 1° TOWARD -Y, TS3d IS BENT 1° TOWARD +Y

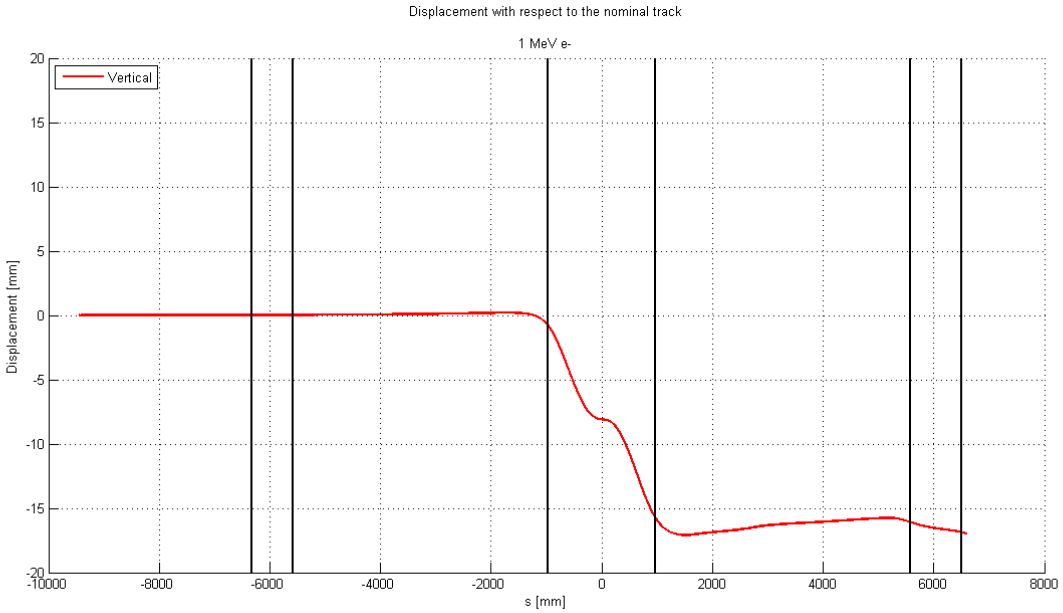

Figure 37 - Vertical displacement with respect to the nominal track

3.19 CASE 19 – TS3u IS BENT 0.5° TOWARD -Y, TS3d IS BENT 0.5° TOWARD +Y

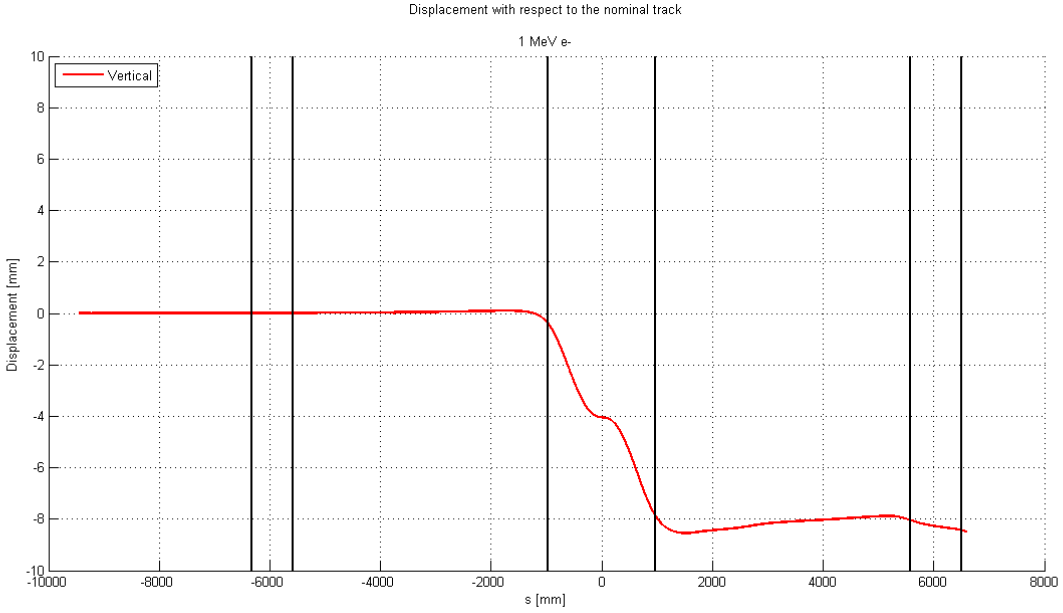

Figure 38 - Vertical displacement with respect to the nominal track

3.20 CASE 20 – TS5 IS BENT 1° TOWARDS +X

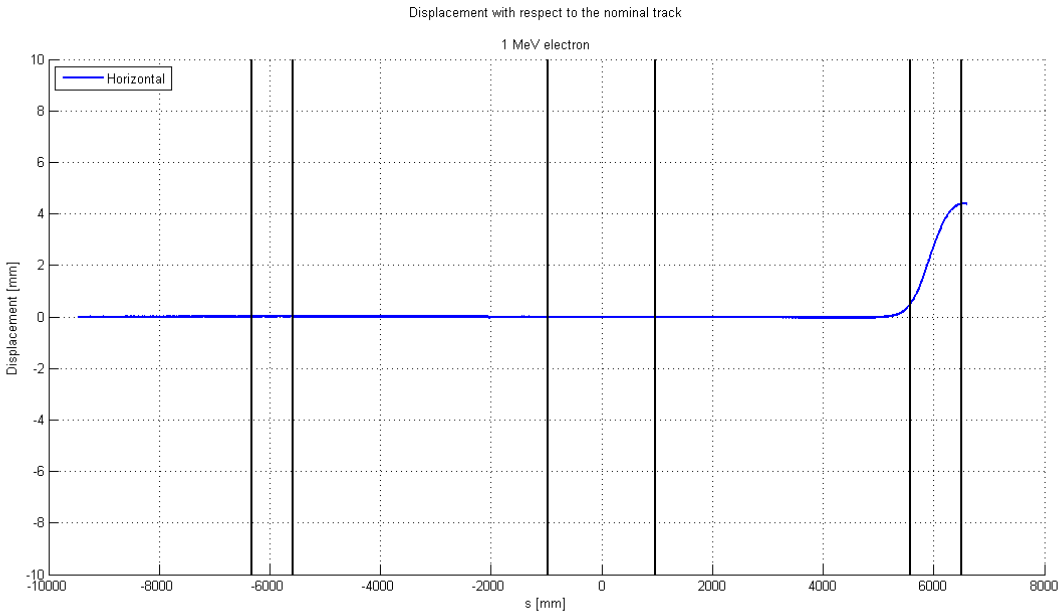

Figure 39 -Horizontal displacement with respect to the nominal track

3.21 CASE 21 – TS5 IS BENT 1° TOWARDS –X

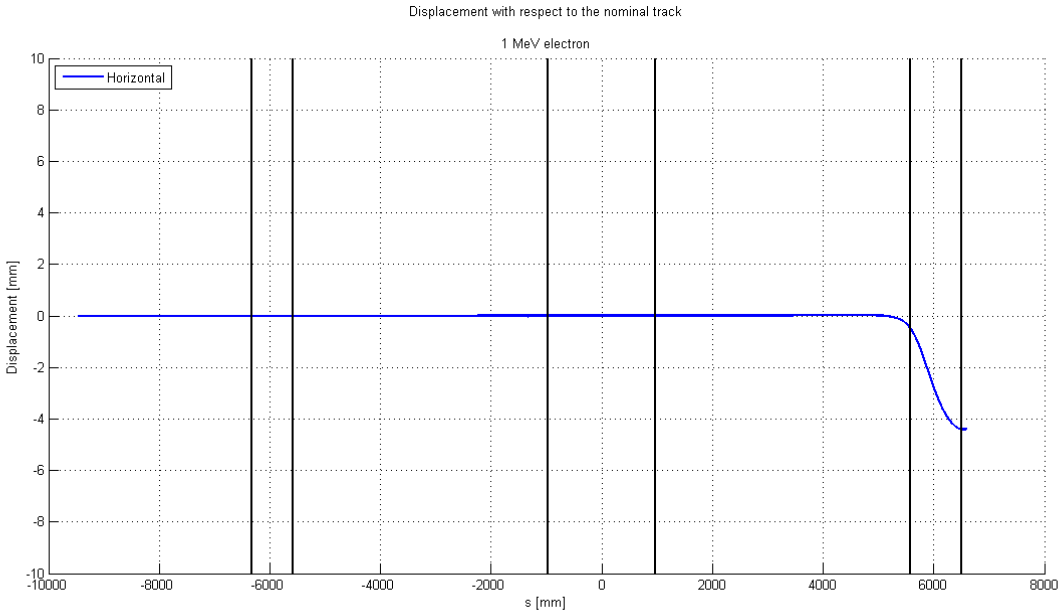

Figure 40 - Horizontal displacement with respect to the nominal track

3.22 CASE 22 – ESTIMATED RADIAL DISPLACEMENTS APPLIED TO TSu AND TSd

Figure 41 represents the estimated module for the radial displacement of the first 25 coils of the solenoid (TSu) from the mechanical analysis of the support structure of the coils [3].

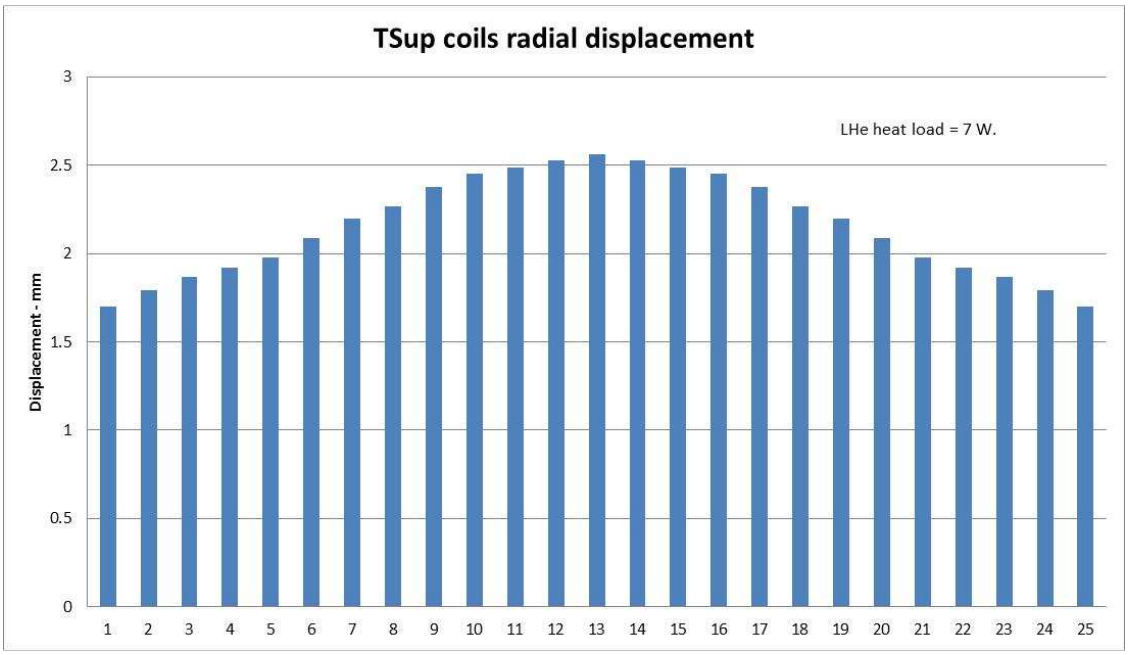

Figure 41 - Estimated radial displacements for the first 25 coils

These displacements were applied to the second part of the TS (coils 26-50) as well, but in opposite direction. The described movements are summarized in Figure 42

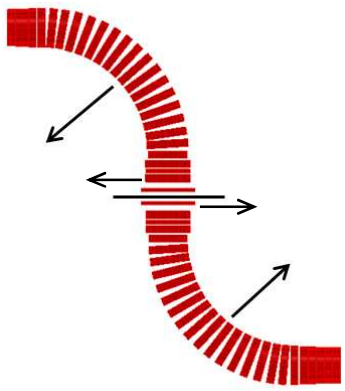

Figure 42 - Coils radial displacement directions

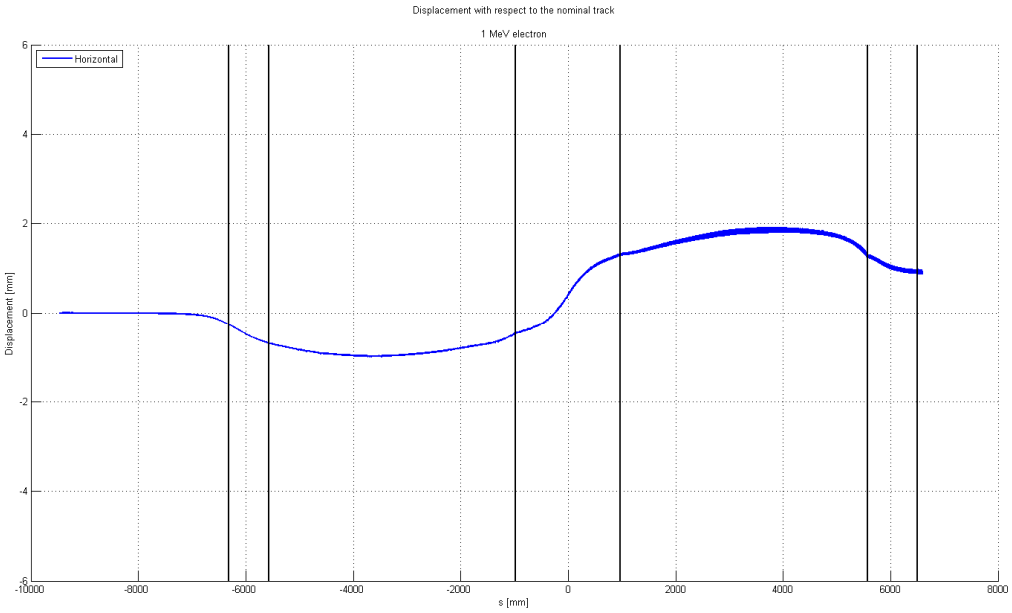

Figure 43 - Horizontal displacement with respect to the nominal track

4. CONCLUSIONS

A study of the trajectories of 1 MeV electron through TS magnetic field has been done. Different deformed geometries have been examined and two types of errors have been considered: Random and Systematic.

The values of the errors studied in the present work are often higher than the ones expected in the reality.

The results show that the most critical configurations, in terms of random errors, are those obtained giving random pitch or random yaw rotation angles to each of the coils.

Regarding systematic errors, some of the configurations considered introduce an offset in terms of displacement from the nominal trajectory. Particularly, the worst cases are those having TS3u and TS3d bent in opposite directions toward one of the axis.

5. REFERENCES

[1] M. Lopes, "Mu2e Transport Solenoid Magnetic Design (Magnetic Design Version 7)", Mu2e-docDB-1233

[2] M. Lopes, G. Moretti “Tolerance studies of the Mu2e Transport Solenoid (Magnetic Design Version 7)”, Mu2e-docDB-2156

[3] G. Ambrosio et al., "Mu2e TSu Design Study", Mu2e-DocDB-2075