CST PARTICLE STUDIO® Mesh variation and impact on magnetic field and beam trajectory simulations

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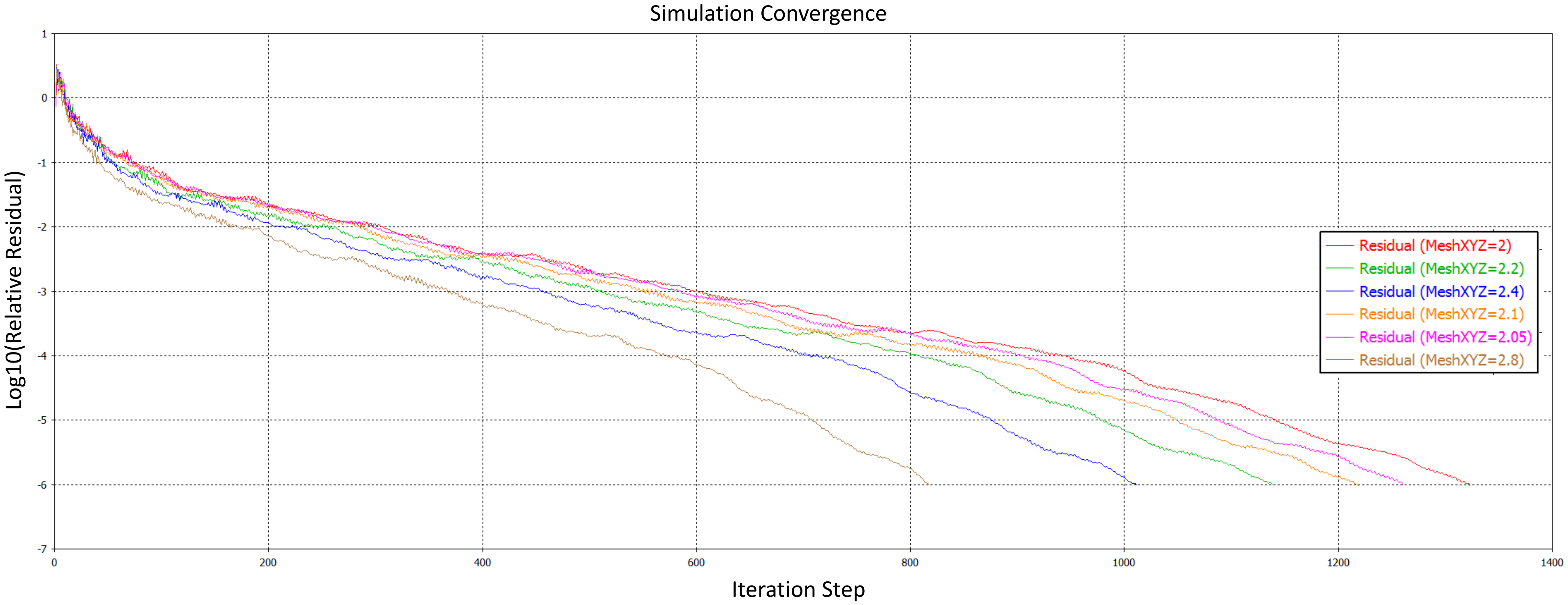
Objectives

- Study the effect of the mesh on:
  - The magnetic field of the HEL at LHC flat energy
    - The electron beam trajectory for the given magnetic field

A finer mesh requires more iterations, and therefore more time, to achieve convergence. A mesh study can help us to find a compromise between computational resources and accuracy of the results.



Overview

- Simulations broken down into several stages

1. Magnetic field simulations (magnetostatic solver)
   a) Set boundary box big enough to include return field lines (ran three different scenarios)
   b) Parametrize *magnetic* mesh size and vary uniformly in XYZ from 2.8 mm to 2 mm (does not run below!)
      - Find whether magnetic field converges to a given value
2. Electron beam tracking simulations (tracking solver).
   a) Reduce boundary box to the minimum necessary
   b) Keeping the *tracking* mesh equal, apply the magnetic fields obtained in Step 1 as inputs to the tracking solver
   c) For a given input, vary tracking mesh

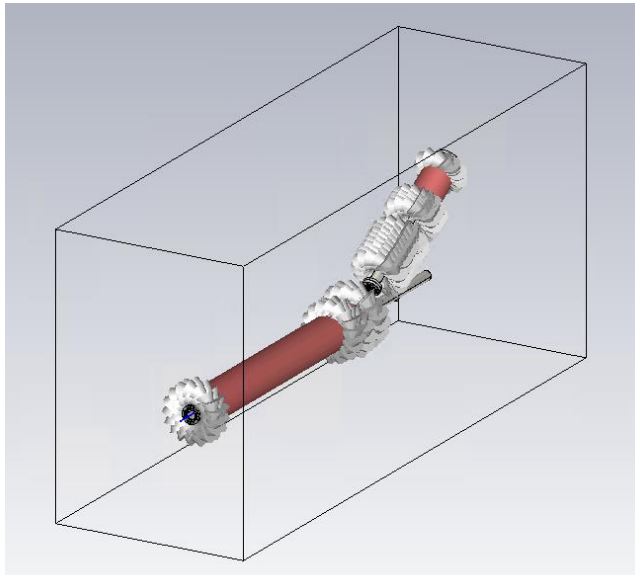


Fig. 1. Boundary box used for magnetic field simulations

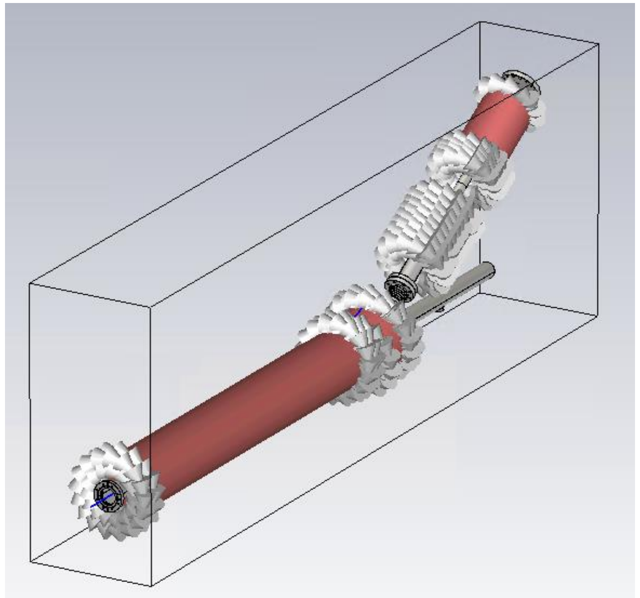
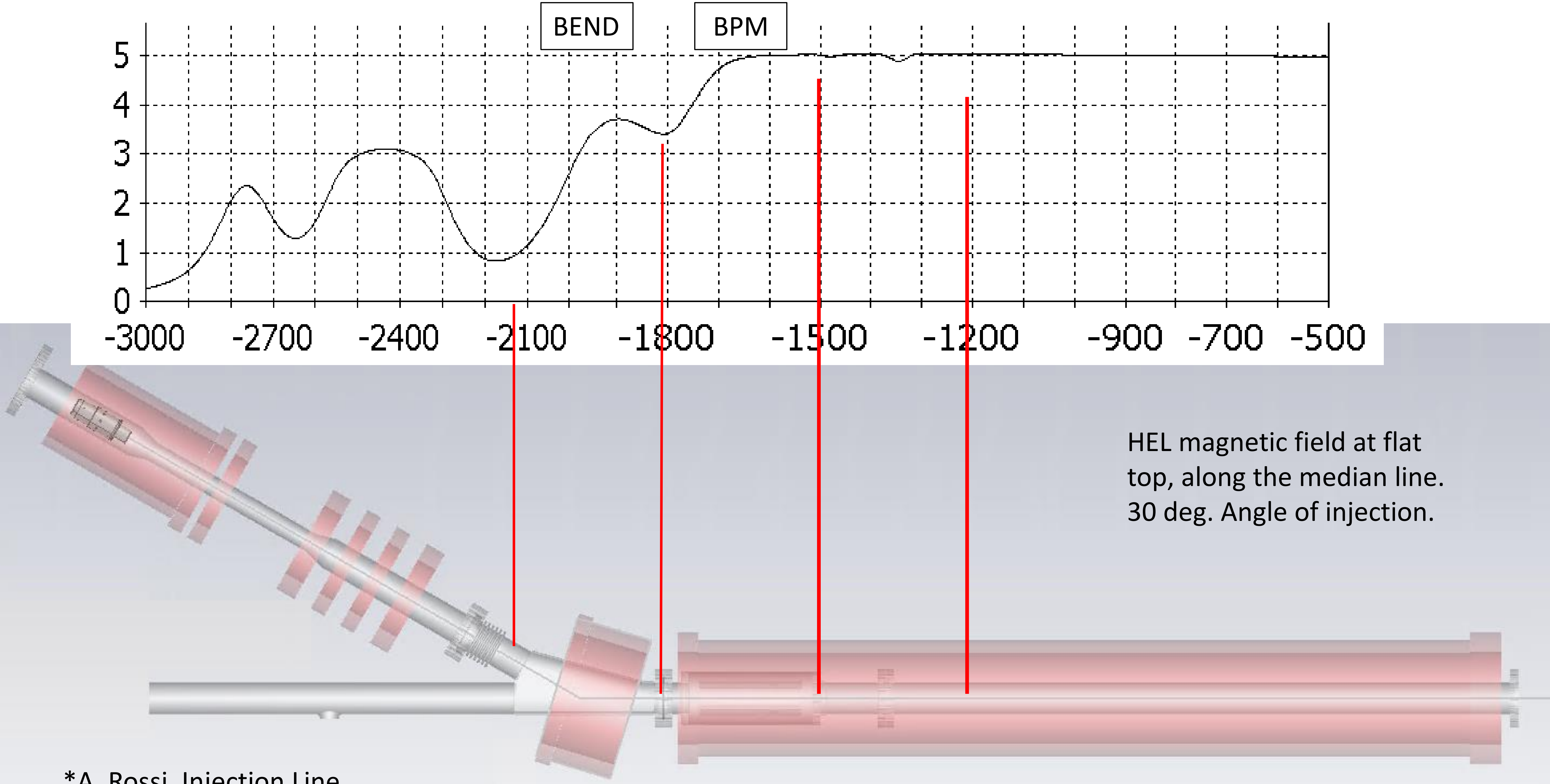


Fig. 2. Smaller boundary box used for tracking simulations



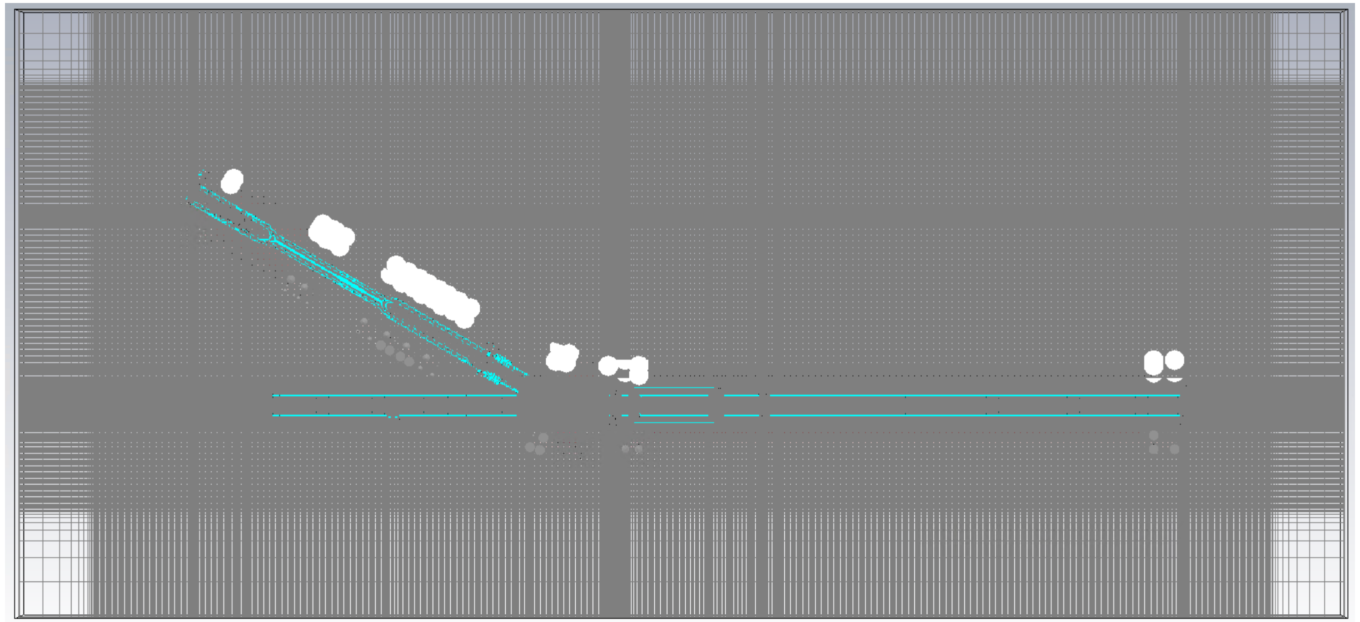
HEL magnetic field at flat top, along the median line. 30 deg. Angle of injection.

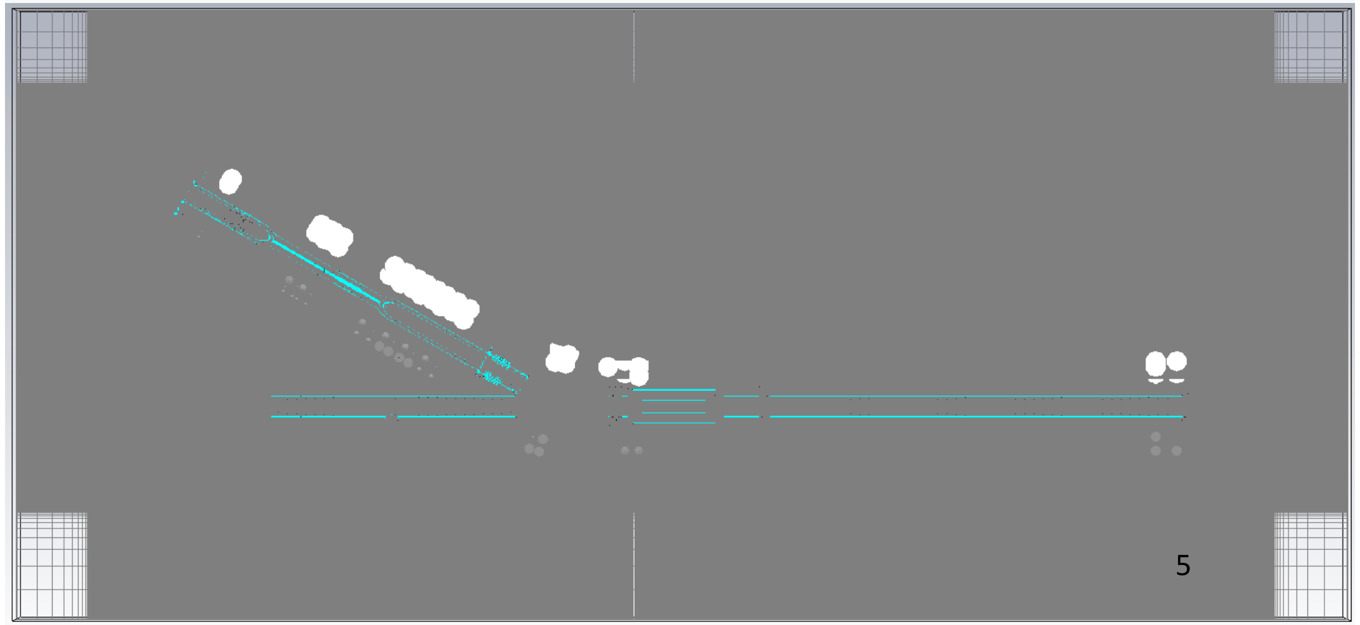
*A. Rossi, Injection Line studies, e-beam meeting #1

1. Magnetic field simulations

a. Parametrize mesh size and vary from 2.8 mm to 2.0 (reference mesh size)

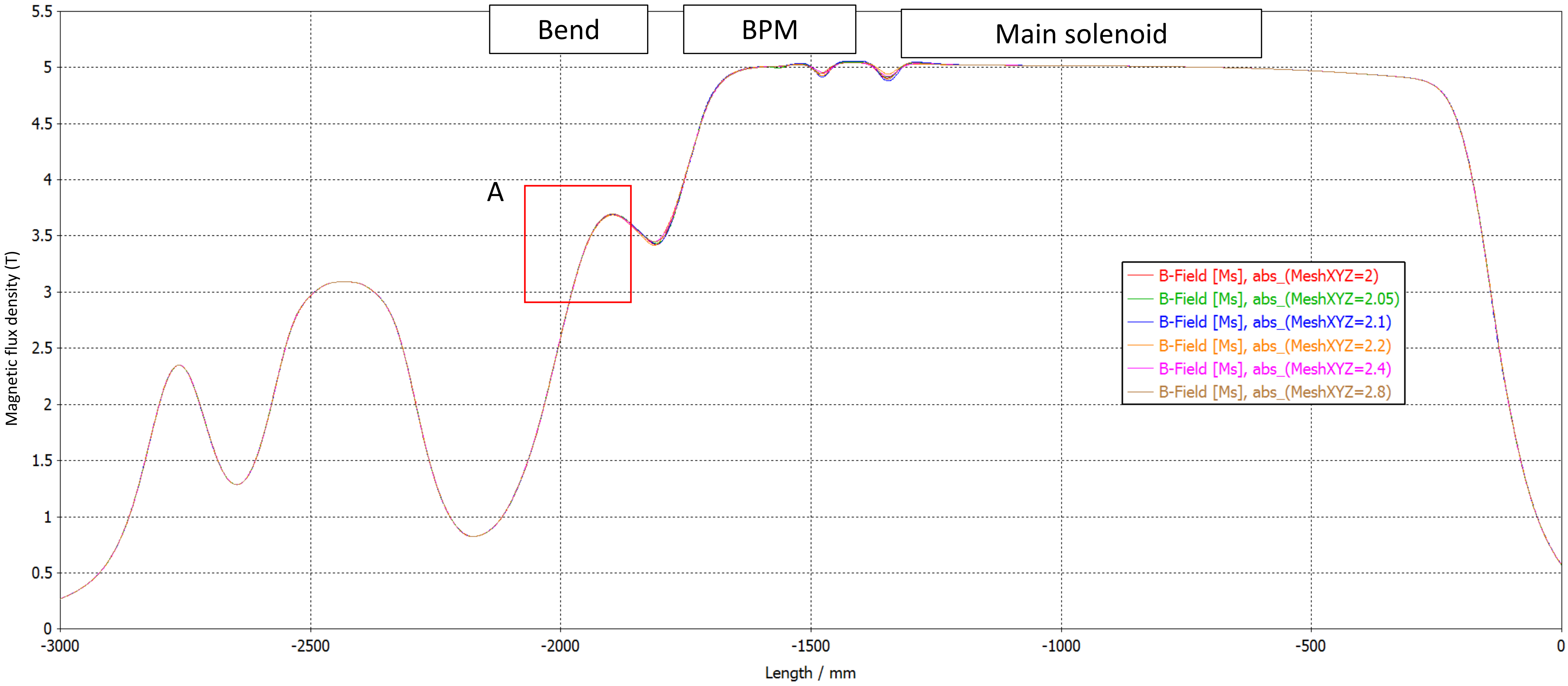
Mesh size	Number of cells	Time to run
2.8	125,302,320	6 h
2.4	200,945,664	11 h 40 min
2.2	252,132,656	17 h 13 min
2.1	302,036,280	24 h
2.05	317,726,866	27 h
2.0	**343,687,344**	**28 h**





1. Magnetic field simulations

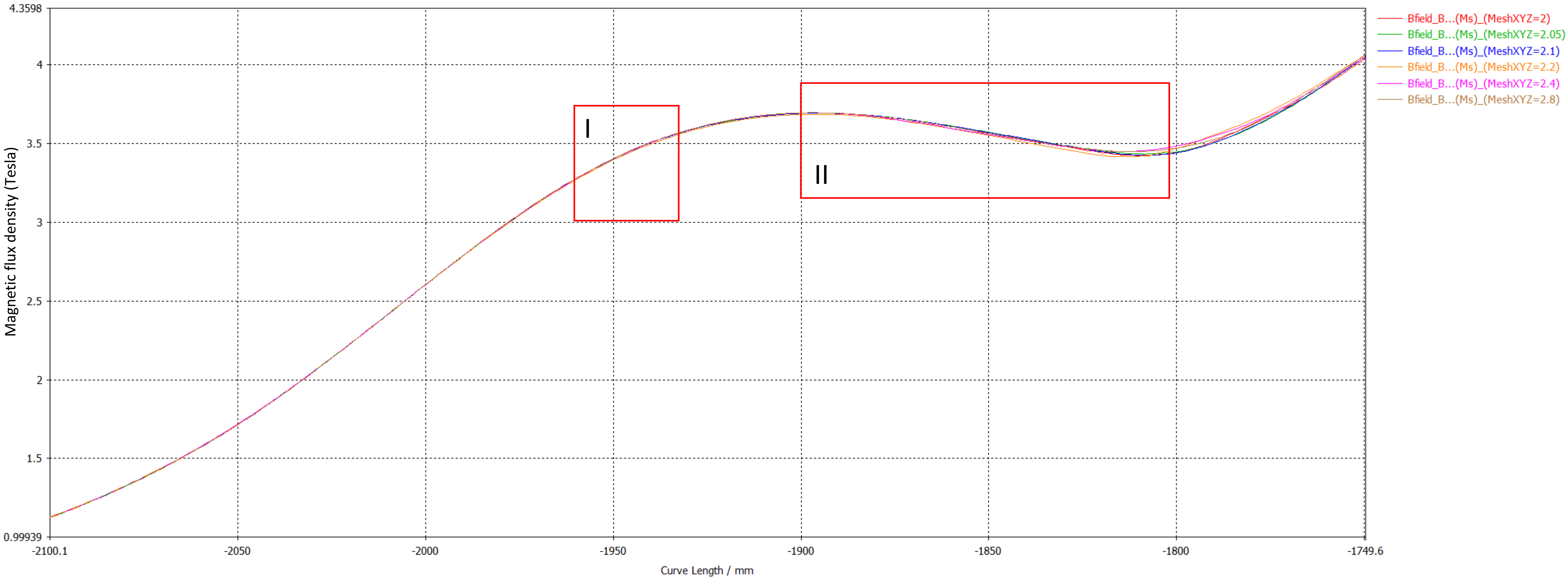
b. Find whether results converge towards a given value



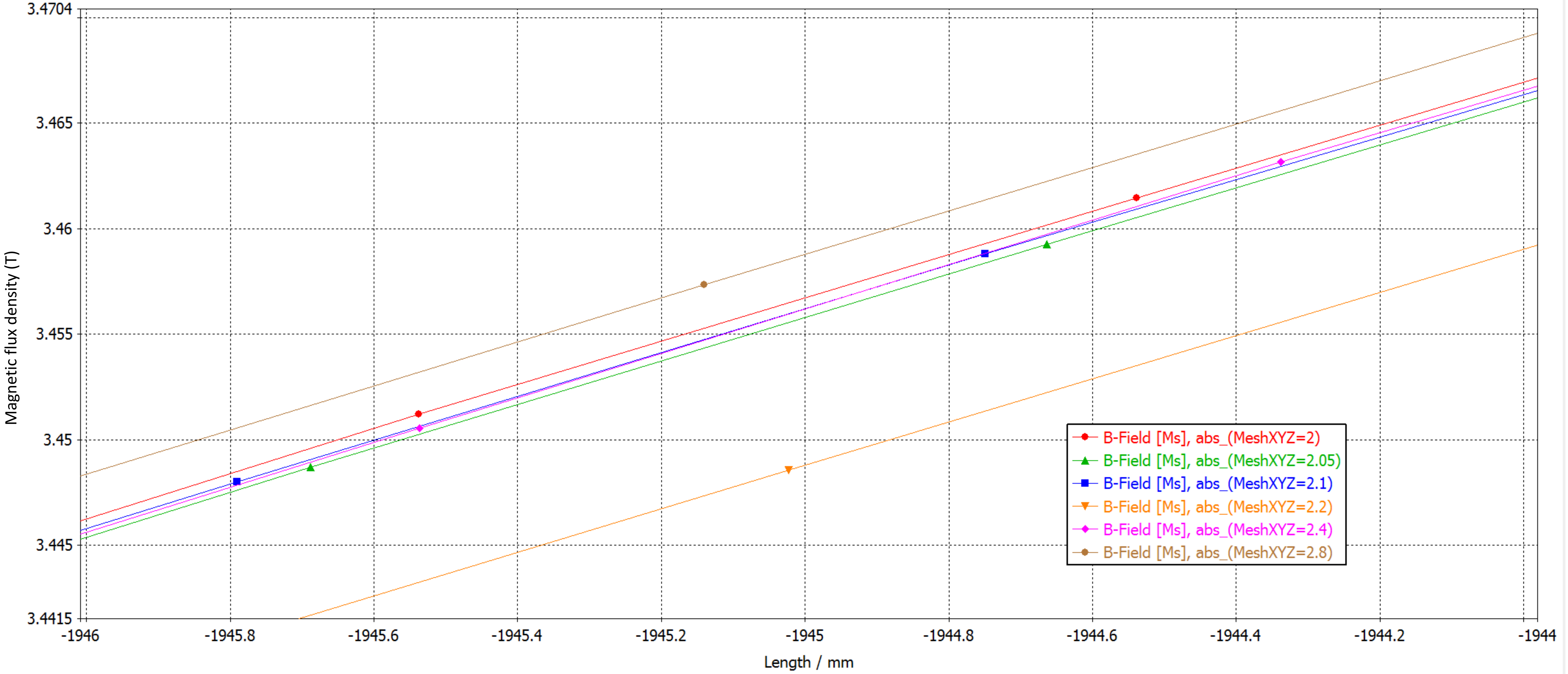
- Differences noticeable just after bend and during/after BPM

Let's look in detail to see if results converge or there is a trend…

Magnetic field through the bending magnet, before the BPM

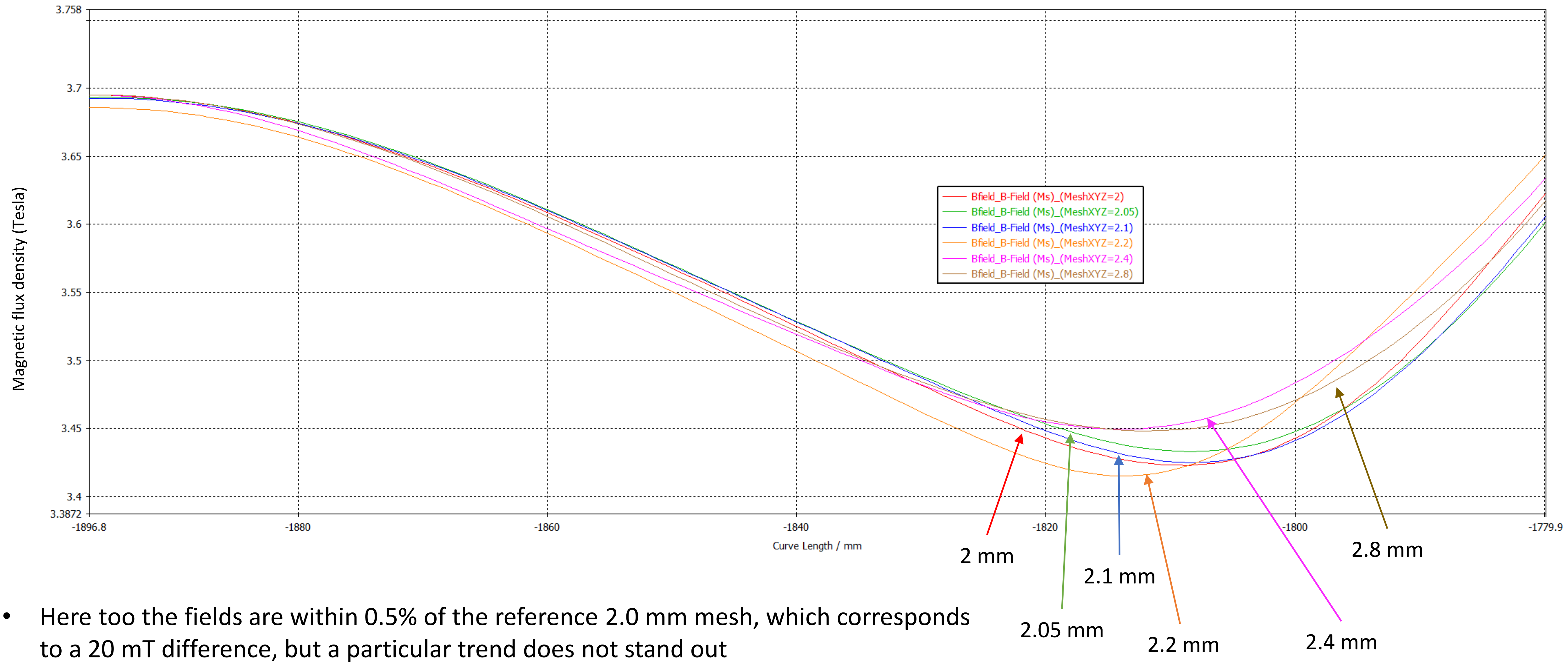


Magnetic field through the bending magnet, before the BPM and main solenoid (I)



- At this given location, the results obtained with meshes 2.0, 2.05, 2.1, and 2.4 are all within 0.02% or 1 mT
- The field obtained with a 2.2 mm mesh is 8 mT lower than the reference field, and for the 2.8 mm mesh, the field is 2 mT higher, however, there is no trend and these small differences here can lead to very large differences later on

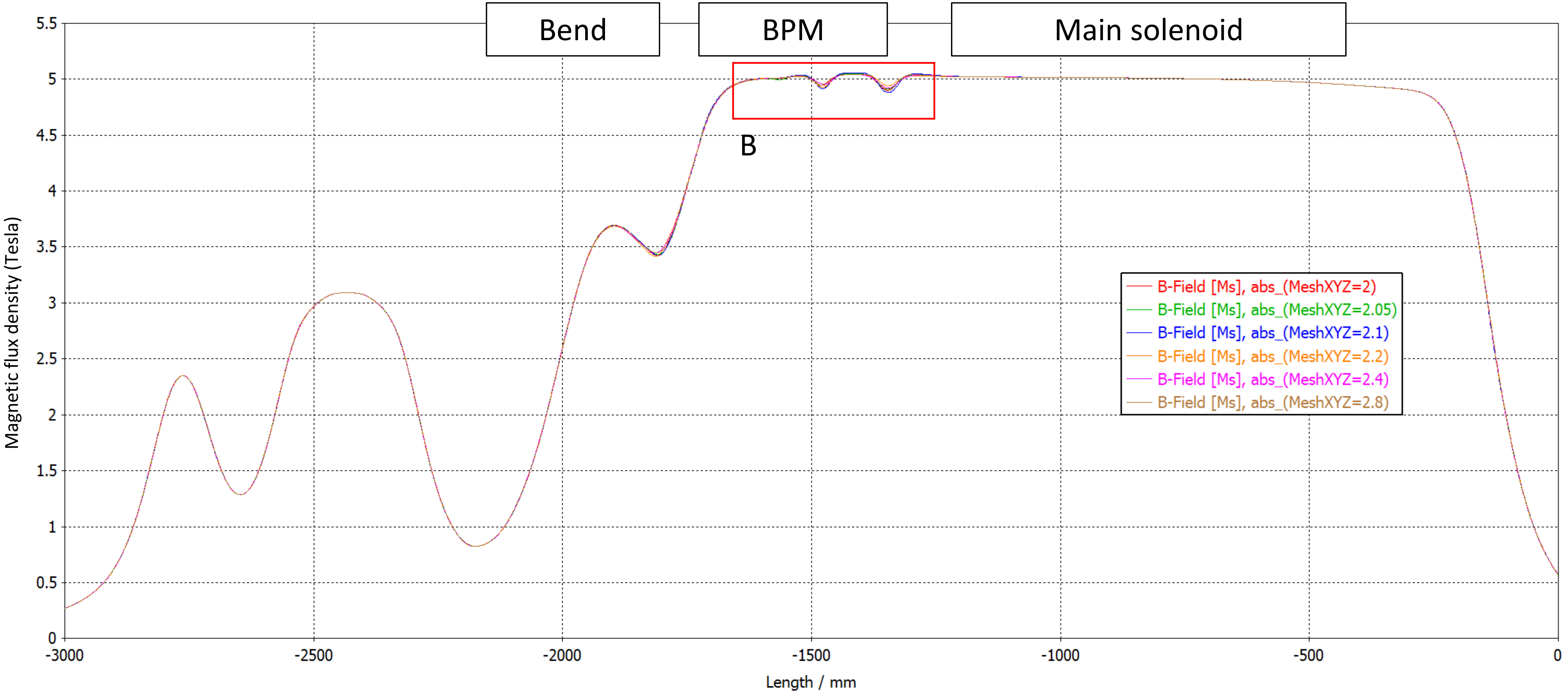
Magnetic field through the bending magnet, before the BPM and main solenoid (II)



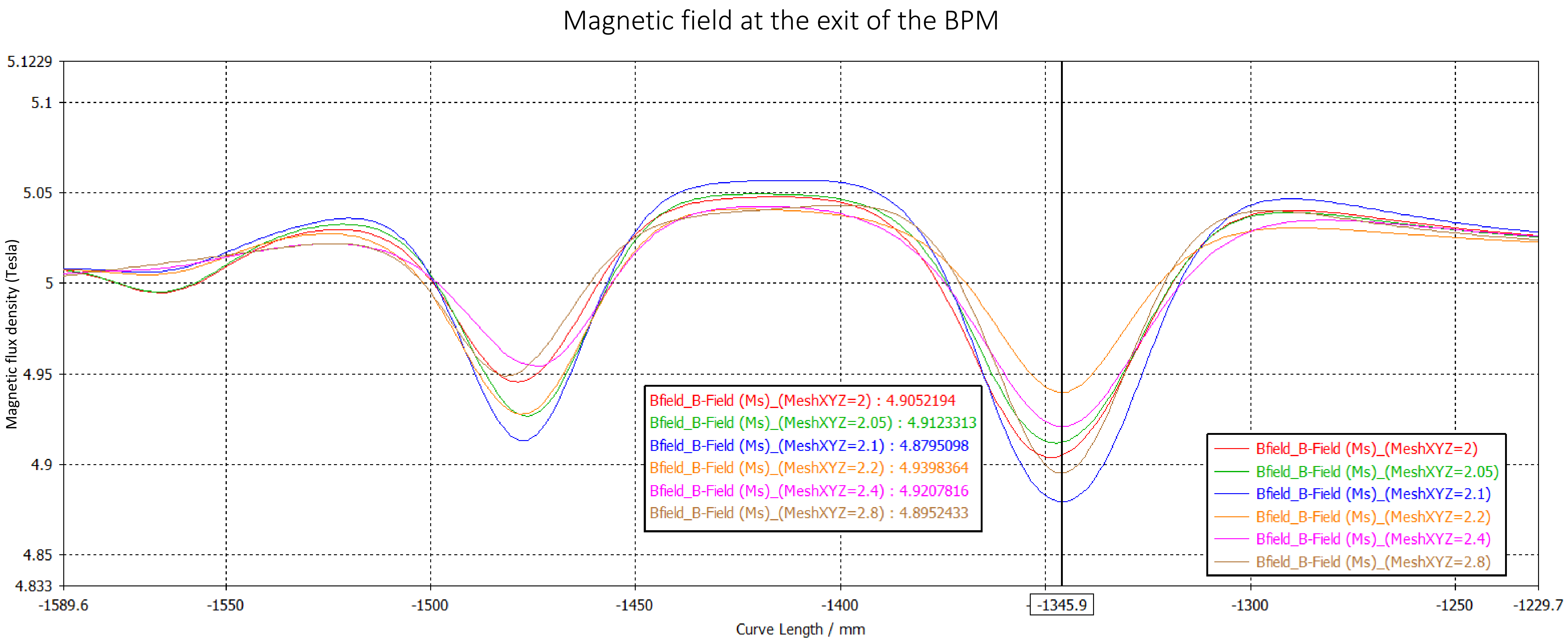
- Here too the fields are within 0.5% of the reference 2.0 mm mesh, which corresponds to a 20 mT difference, but a particular trend does not stand out
- The largest difference is found with the 2.4 mm mesh, where the field differs by 29 mT

1. Magnetic field simulations

b. Find whether results converge towards a given value



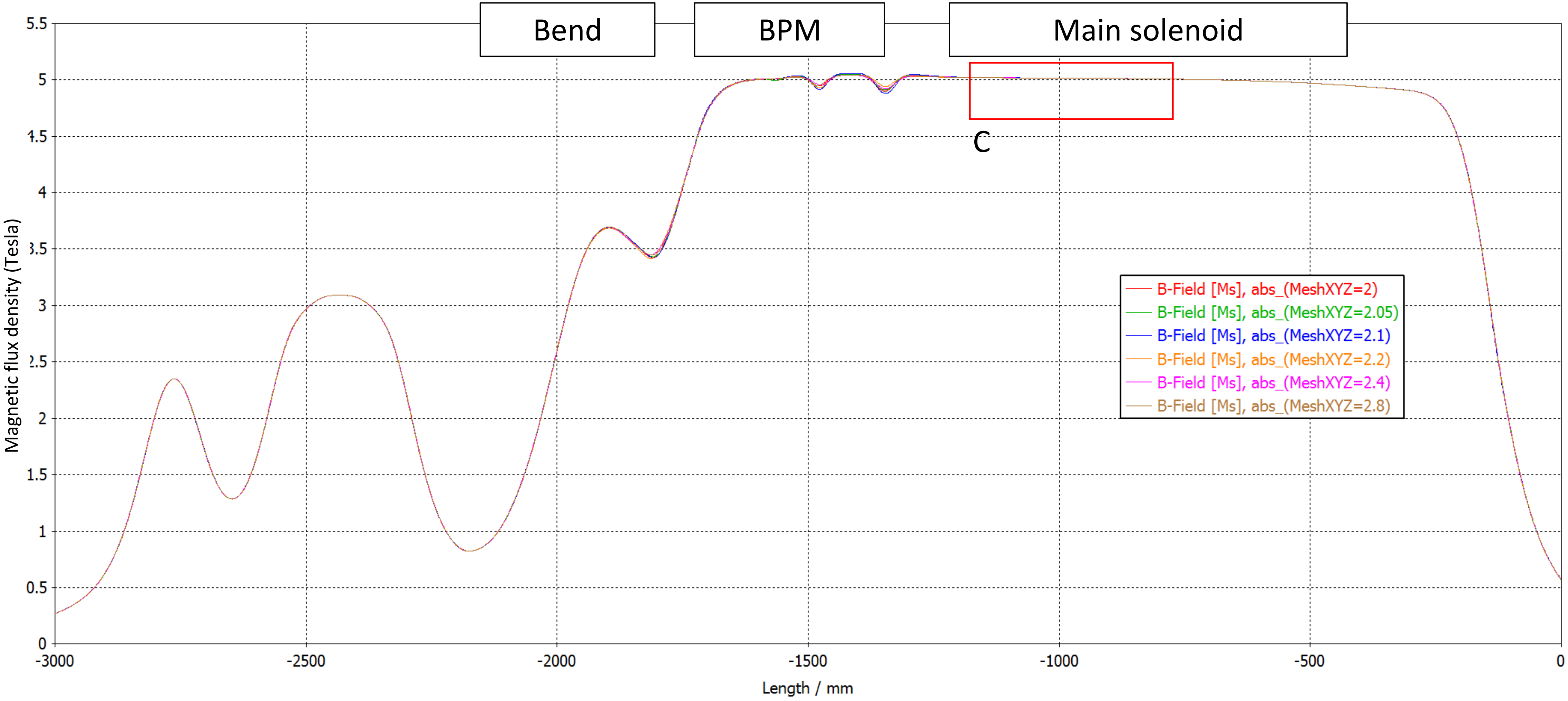
- In the second half and exit of the BPM we observe two perturbations and differences in the magnetic field which could be caused by interference from the BPM
- We should run a simulation replacing the BPM with a smooth beam pipe and investigate whether the differences are an artefact of the structure or not



- Largest difference compared to reference mesh is 0.7% or 0.03 T (2 mm vs 2.2 mm mesh)
- All fields again very similar, but again, no clear trend or pattern, in this case the 2.1 mm and 2.2 mm meshes are at the extremes where as through the bending magnet, it was the 2.
- Next step: run a simulation replacing the BPM with a smooth beam pipe and investigate whether the differences are an artefact of the structure or not

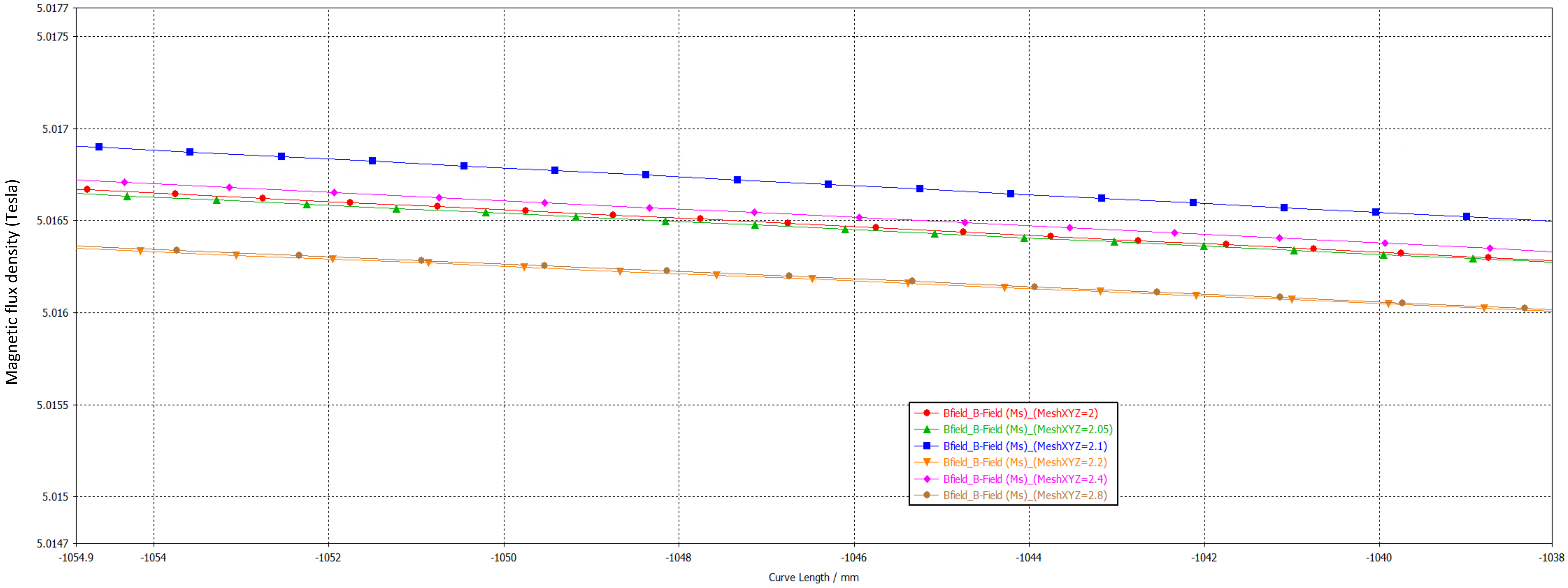
1. Magnetic field simulations

b. Find whether results converge towards a given value



- In the second half and exit of the BPM we observe two perturbations and differences in the magnetic field which could be caused by interference from the BPM
- We should run a simulation replacing the BPM with a smooth beam pipe and investigate whether the differences are an artefact of the structure or not

Magnetic field along part of the main solenoid, after the BPM



- The field through the main solenoid does seem to converge
  - (At this location) towards a value of 5.0166 T, with differences between the reference mesh and the other meshes of 0.006% or 0.2 mT
- Difference is insignificant, however, note that now, the field obtained with 2.2 and 2.8 mm meshes are almost identical, whereas through the bend they were at the extreme max. and min.

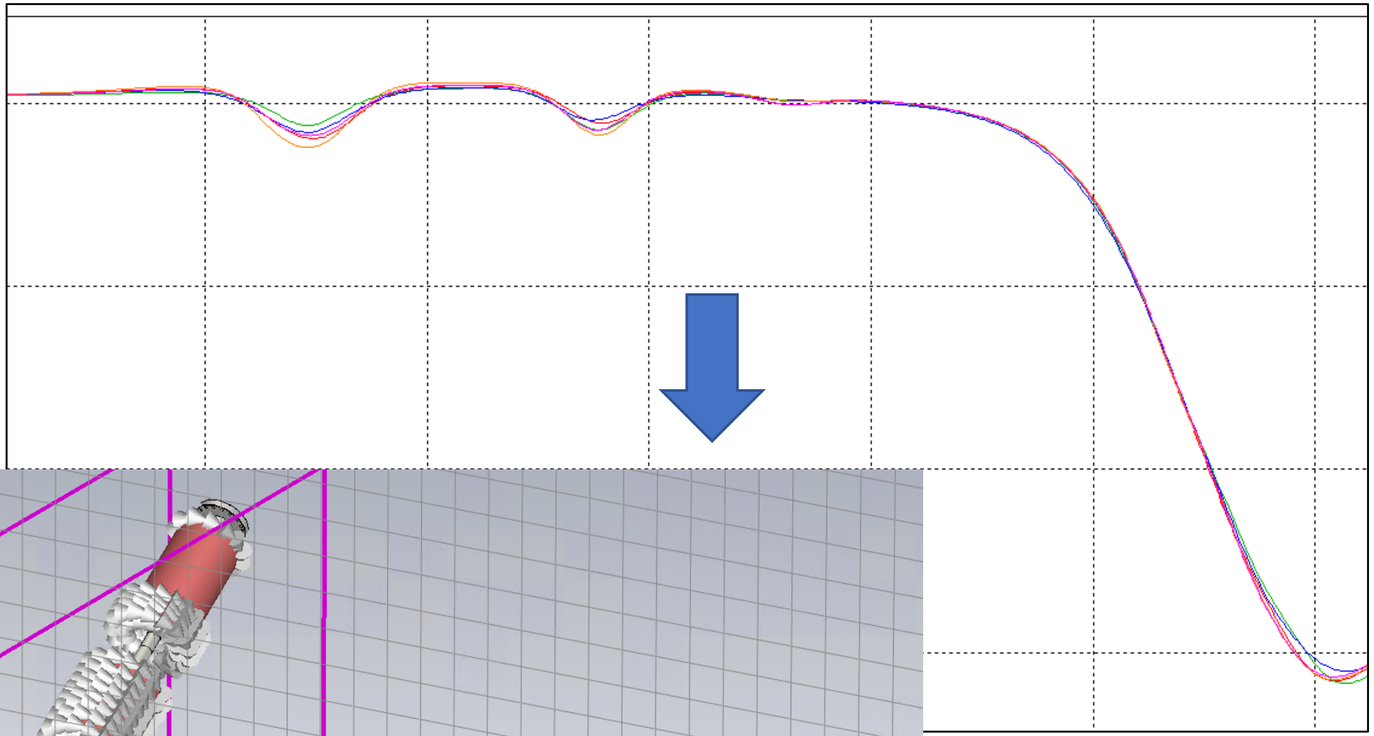
Conclusion (I)

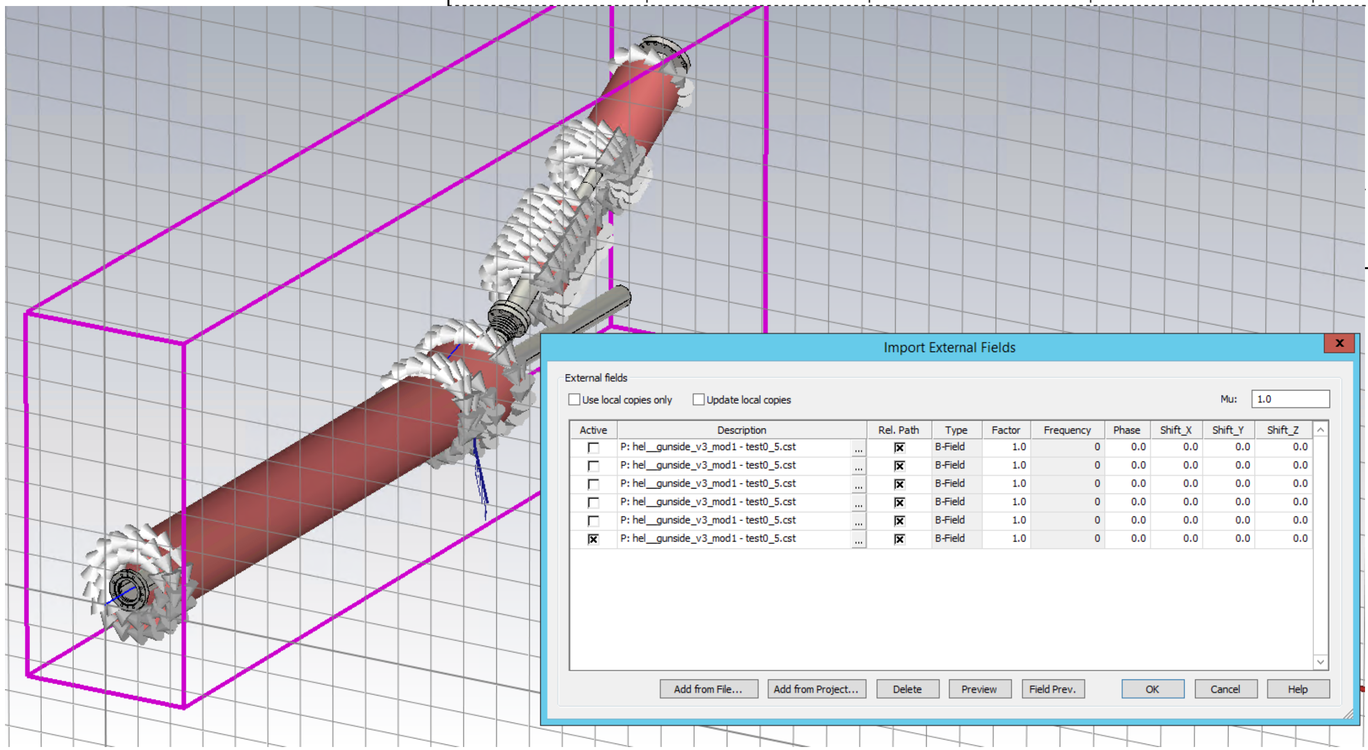
- The field values calculated with different mesh sizes are relatively close. This can still lead to large differences in particle trajectory.
- The results obtained with the 2.0, 2.05 and 2.1 mm meshes are closely linked but there is no clear overall pattern or trend towards convergence

Electron beam tracking simulations

Mesh used for
magnetic field

Magnetic Mesh size	Number of cells
2.8	125,302,320
2.4	200,945,664
2.2	252,132,656
2.1	302,036,280
2.05	317,726,866
2.0	343,687,344

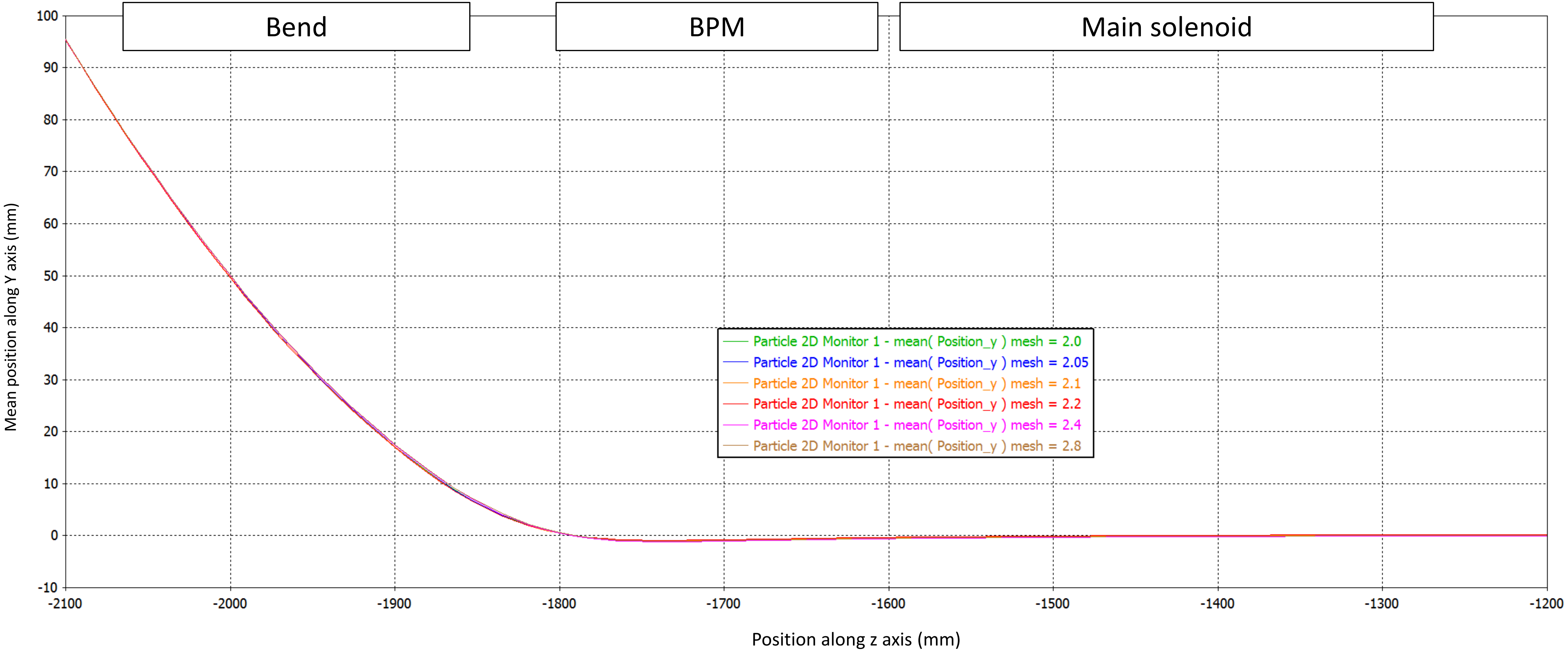


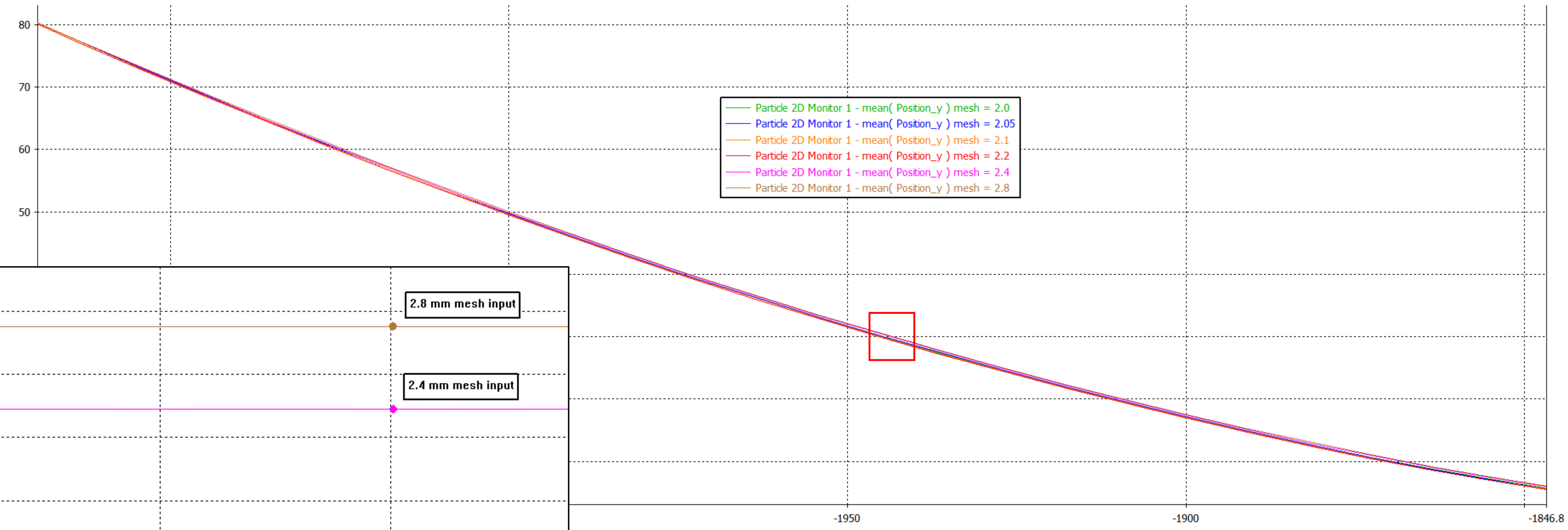


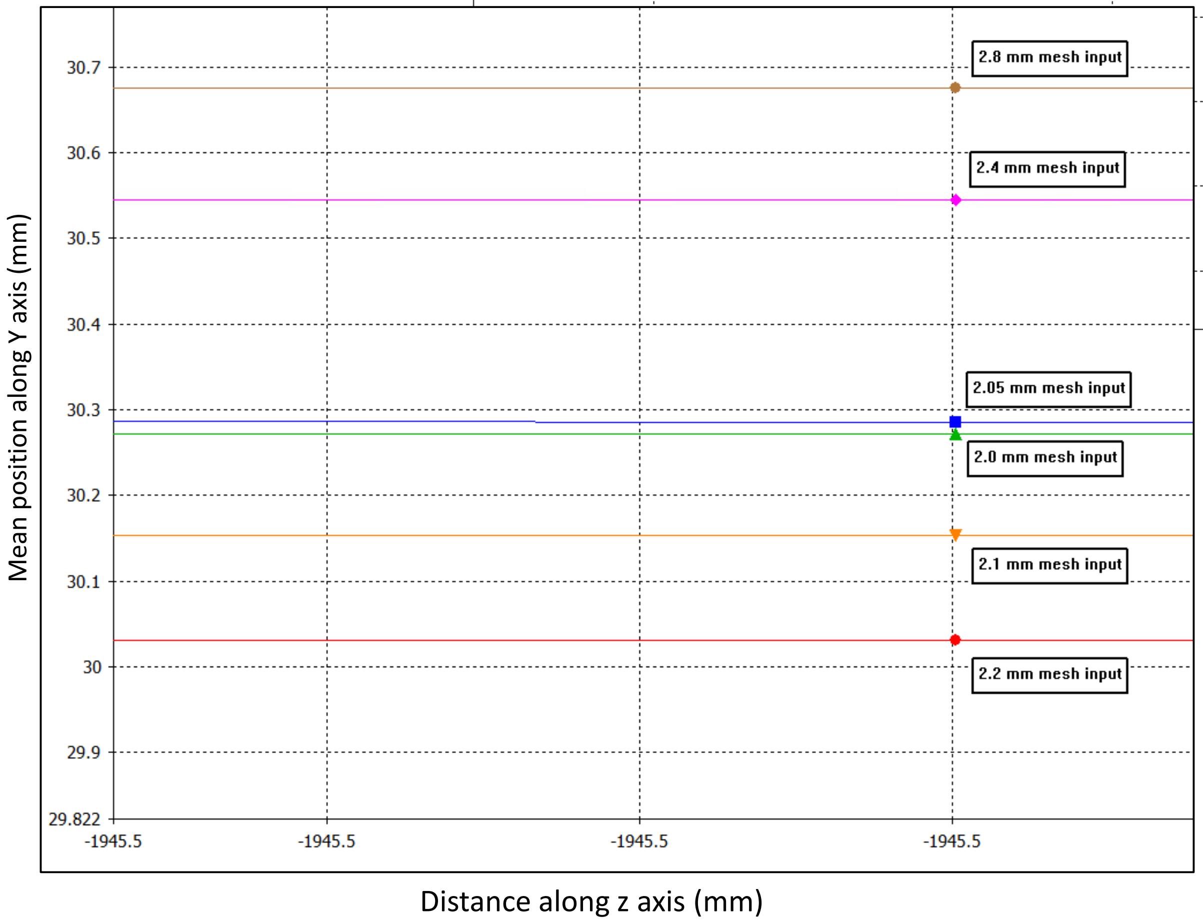
- 2 mm tracking mesh: 166,692,174 cells

* Boundary box reduced with respect to magnetic simulations

Beam centroid trajectory from beginning of bending magnet to main solenoid

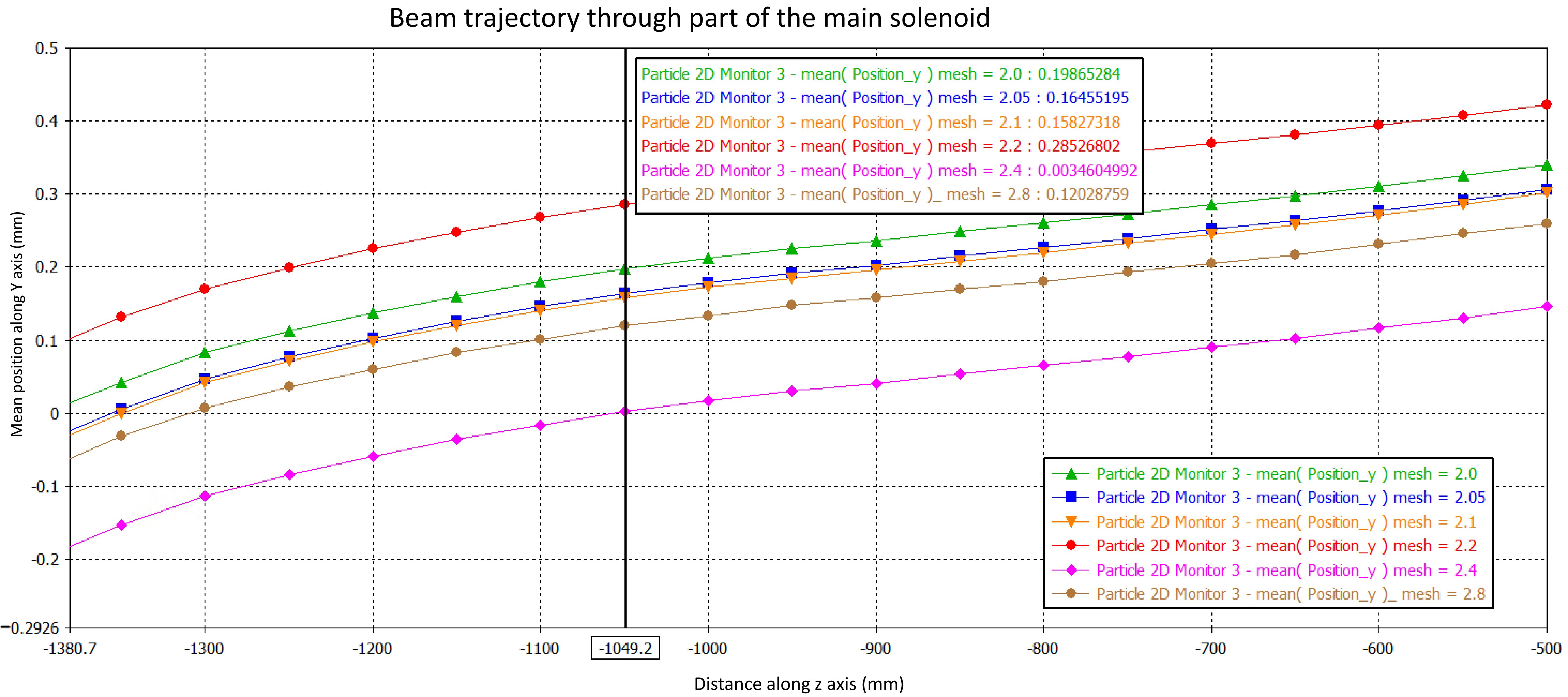




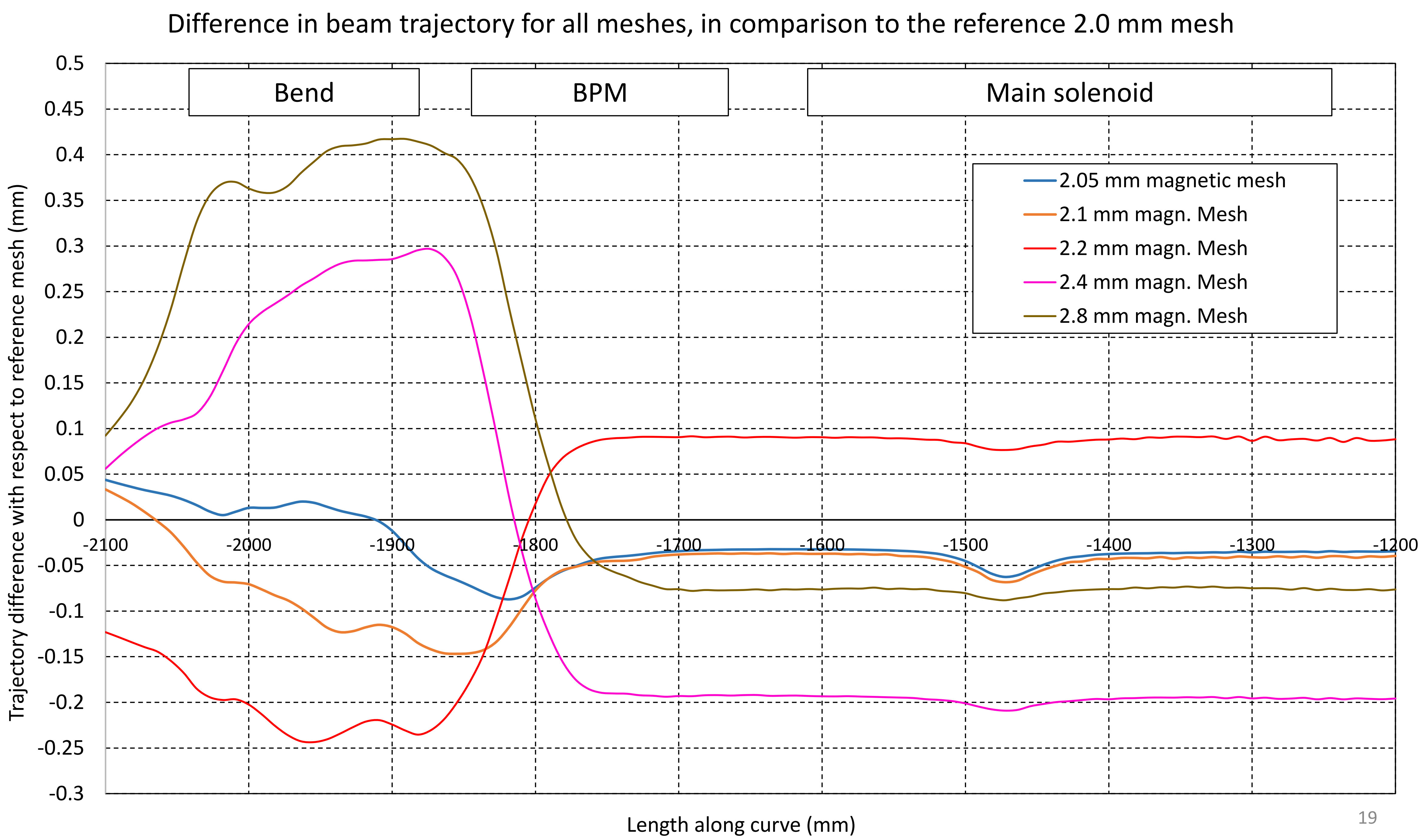


- In slide 8, we looked at the field in this particular location, the highest magnetic field was obtained with a 2.8 mm mesh, and the lowest with a 2.2 mm mesh – this reflects on the trajectories

- The difference in trajectory is of up to 1.3% or **400 microns** (2.0 vs 2.8 mm mesh) as compared to a beam sigma of ~300 microns
- For the 2.05 and 2.1 mm meshes, the differences are in the order of 0.05% and 0.4% respectively, which entails a difference of 14 microns and 110 microns respectively.



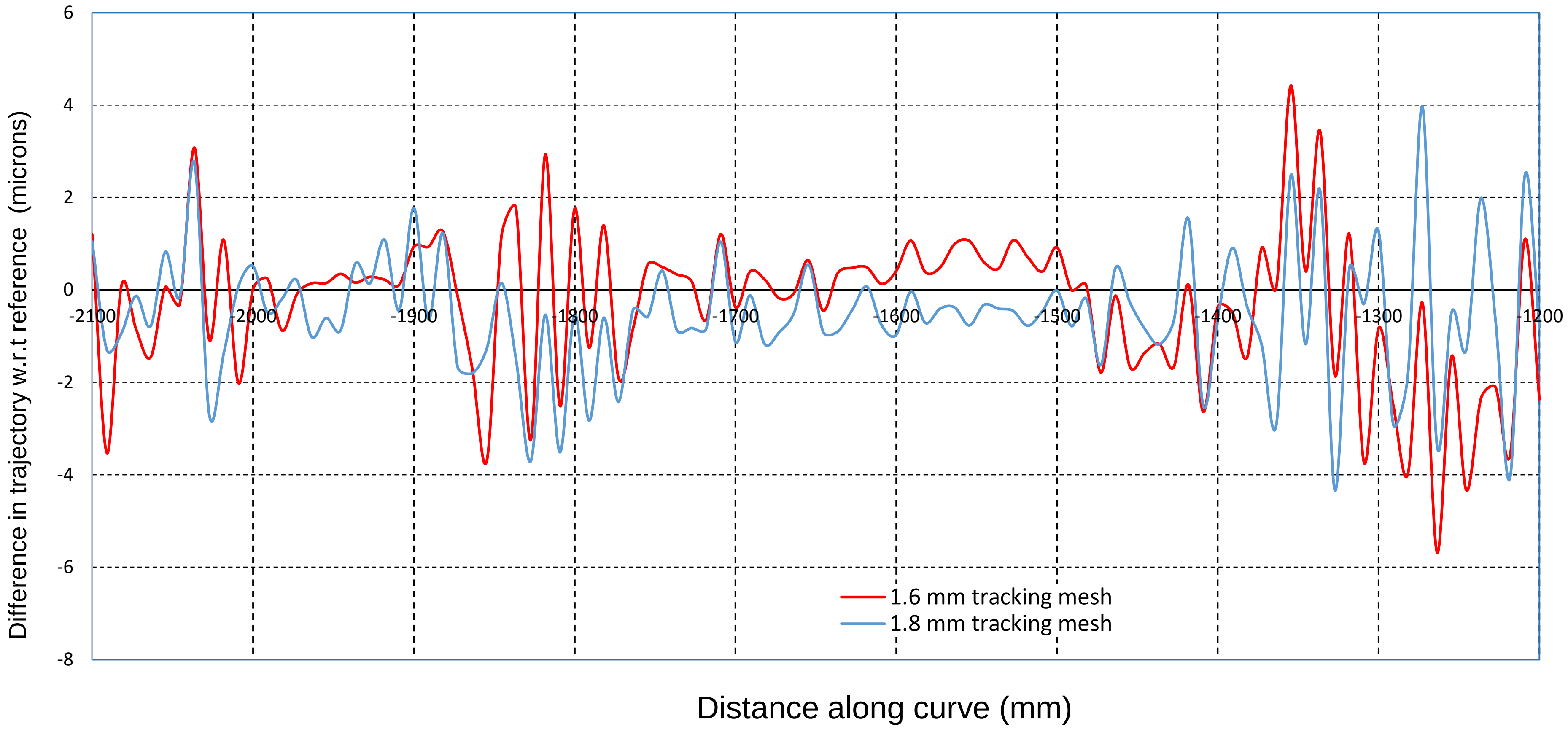
- The trajectories obtained with two finer meshes (2.05 and 2.1 mm) differ by 34 and 40 micrometres with respect to the reference mesh
- The results for the coarser meshes, 2.2, 2.4 and 2.8 do not follow a particular patter and the differences are 86, 195 and 78 microns respectively



Difference in beam trajectory for all meshes, in comparison to the reference 2.0 mm mesh
Bend
BPM
Main solenoid
2.05 mm magnetic mesh
2.1 mm magn. Mesh
2.2 mm magn. Mesh
2.4 mm magn. Mesh
2.8 mm magn. Mesh
Trajectory difference with respect to reference mesh (mm)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-2100
-2000
-1900
-1800
-1700
-1600
-1500
-1400
-1300
-1200
Length along curve (mm)

Mesh variation – Tracking simulations

Tracking Mesh size	Number of cells
2.0	166,692,174
1.8	225,229,884
1.6	332,342,640



* Bounding box reduced with respect to magnetic simulations

Conclusions and Future Work

- There is no clear convergence pattern for magnetic calculations, with the 2.2, 2.4 and 2.8 mm meshes being somewhat erratic
- However, the results obtained with the 2.0, 2.05 and 2.1 mm meshes are encouraging and can give us some “confidence intervals” or resolution to take into account in future calculations or simulations
  - Time-permitting, it might be a good idea to carry out simulations with meshes between 2.0 and 2.1 mm.
- Using a mesh larger than 2.2 mm for magnetic calculations may lead to inaccuracies in the order of those outlined before, but it should be noted that the simulations now need to be repeated with an iron shield that will lengthen the time of computation considerably.
- Changing the mesh during the *tracking* simulations does not have a noticeable effect on the calculated beam trajectory

- Other future work:
  - Look at the transverse distribution of the beam
  - Use smooth beam pipe instead of BPM for magnetic field calculations
  - Addition of iron shielding