FCC-ee compensation scheme: consolidation

M. Koratzinos

MDI meeting

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Introduction

- Moving towards the TDR, we need to consolidate (update and improve the compensation scheme as presented in our CDR
- One major change is to find an extra 5mm of space for the cryostat. That means that the compensating solenoid needs to be made 5% smaller…
- …increasing the emittance blow-up…
- So, I then tried to re-optimise to gain what was lost (or even a bit more)

Many thanks to Katsunobu for patiently helping me in my debugging sessions, for checking my results and providing valuable feedback

Role of compensation

- According to our CDR, the role of the compensation scheme is to satisfy (amongst others) the following conditions:
  1. Total integral of Bdl seen by the beam should be close to zero (*)
  2. Field in the vicinity of QC1L1 < ±50mT (**)
  3. Emittance blow up should be as small as possible

(*) tunable by changing the current of the compensating solenoid: I stop iterations if better than 10^{-3} Tm. CDR states that emittance blows up by 0.1pm for a 10^{-3} Tm mismatch in compensation

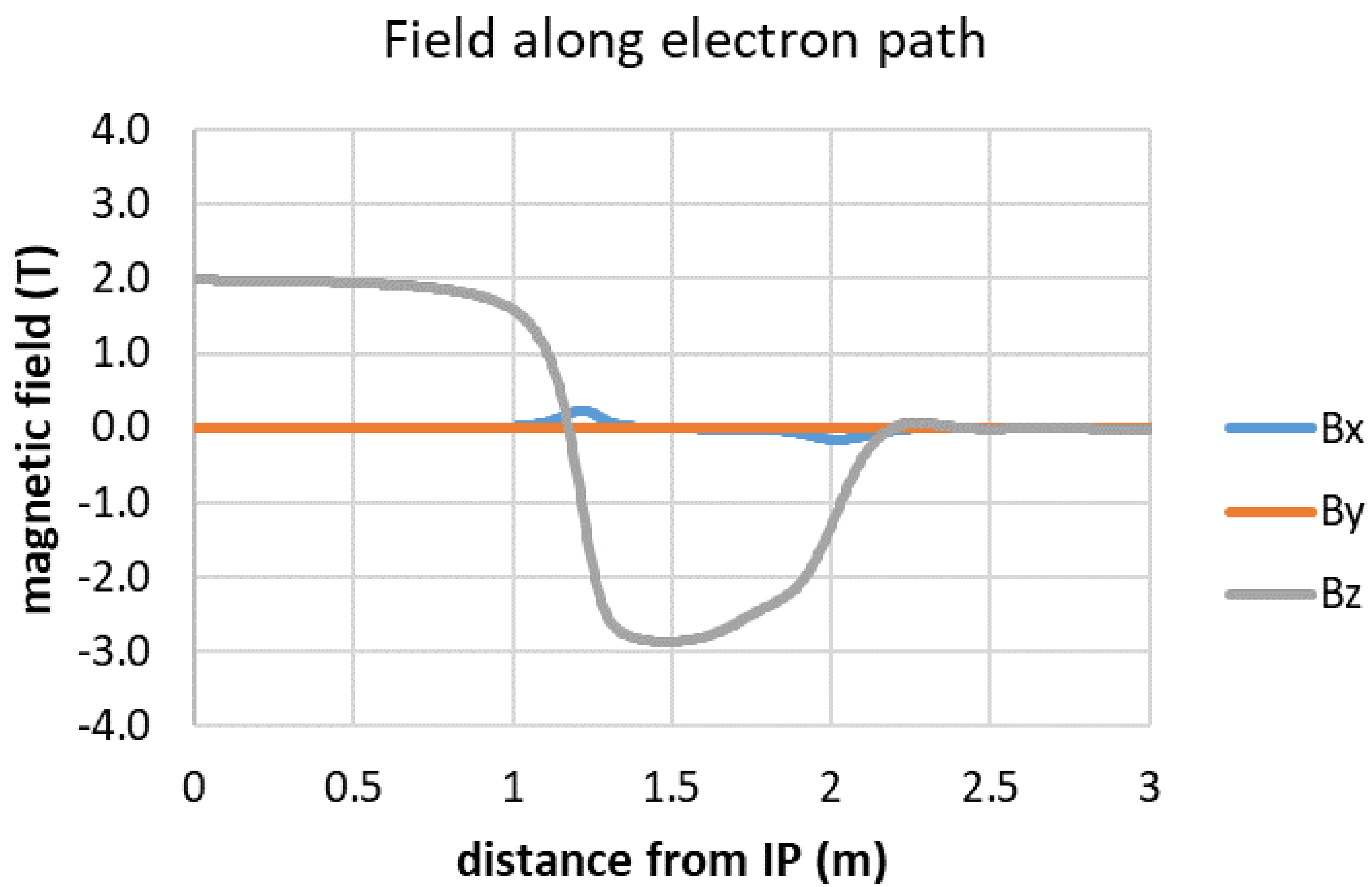
(**) this is not investigated at depth. Could be too stringent

Emittance blow-up only important for the Z running

Improvements over CDR

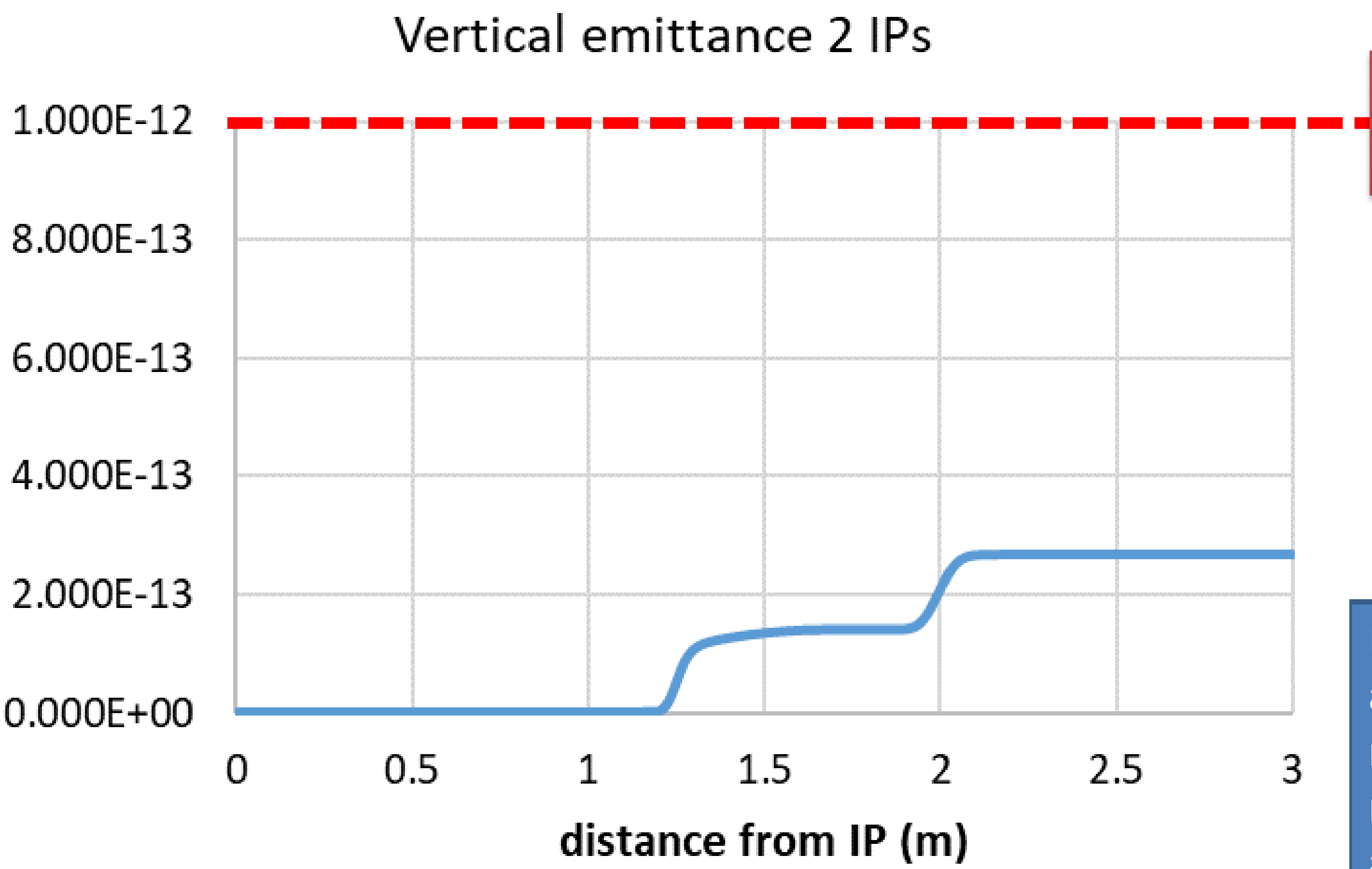
- The outer radius of the coils has been reduced so as to leave 5mm for the cryostat
- the compensating solenoid starts 5mm further downstream
- The screening solenoid and compensating solenoid are 5mm apart
- Now both coils have variable pitch → great for optimising
- The exact shape of the coil is now exported directly from the magnet optimization program. Before, the coil was a cylindrical envelope.
- Reminder: CDR number for the emittance blow-up for 2IPs at the Z: 0.4pm

Field profile



Note that I have concentrated in the region ± 3m from the IP. The zero field region actually extends to ±5m, but I do not have the return yoke design. For this analysis it is safe to assume that the field after ± 3 m is zero.

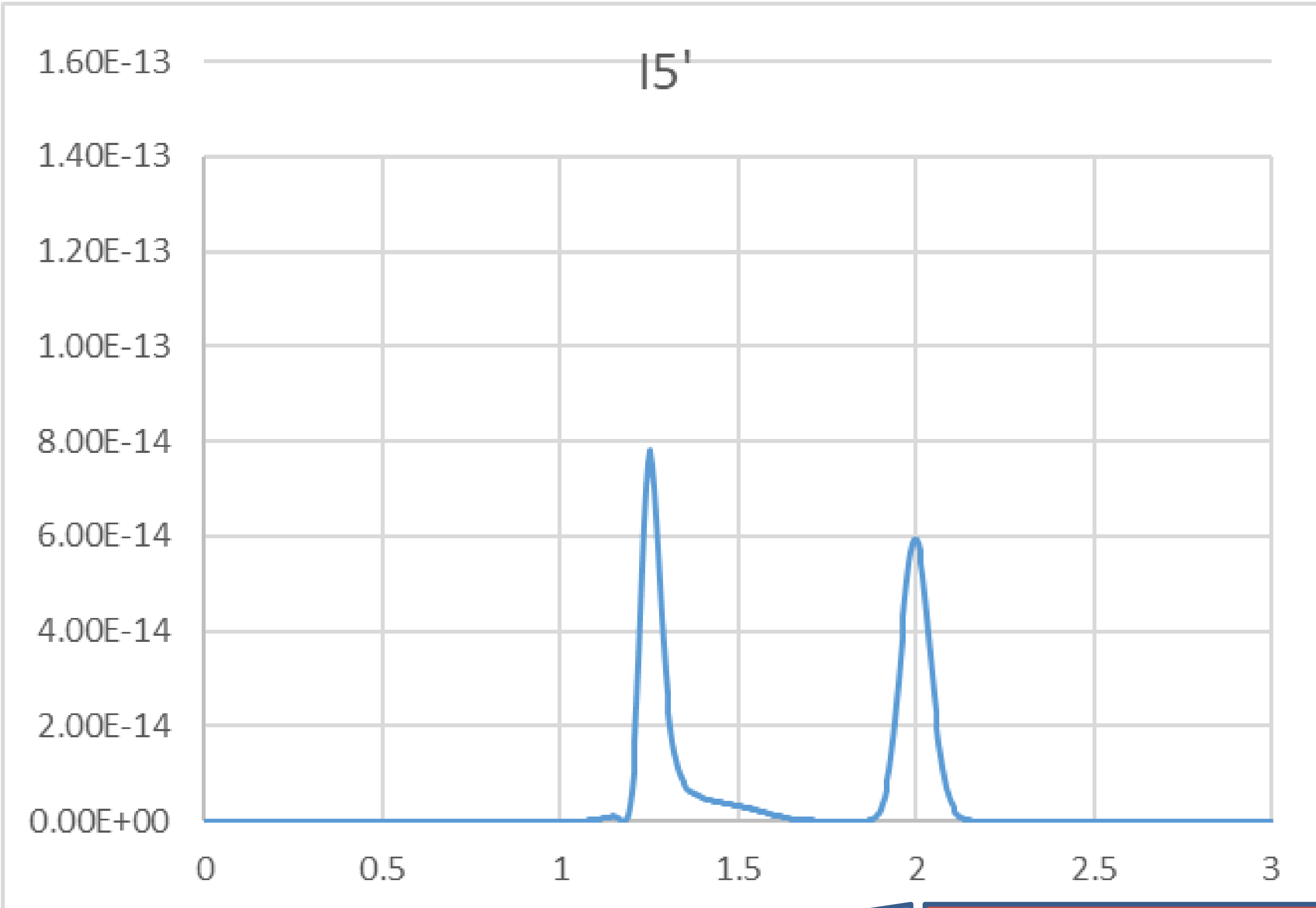
Vertical emittance blow up at the Z



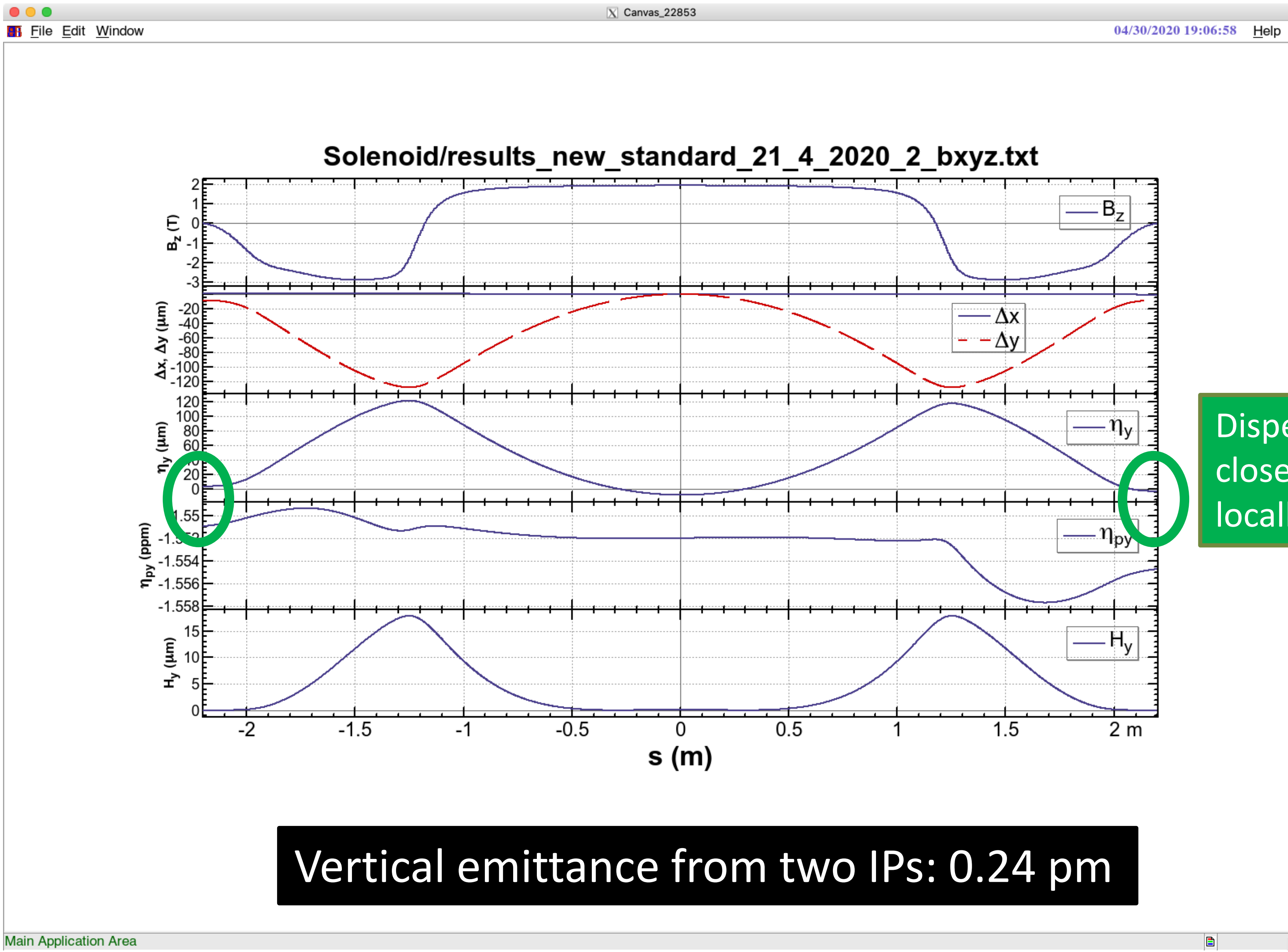
Total emittance budget

Emittance blows up at the edges of magnetic elements mainly. My simple analysis gives a total of 0.27 pm for 2 IPs

where emittance grows



SAD results



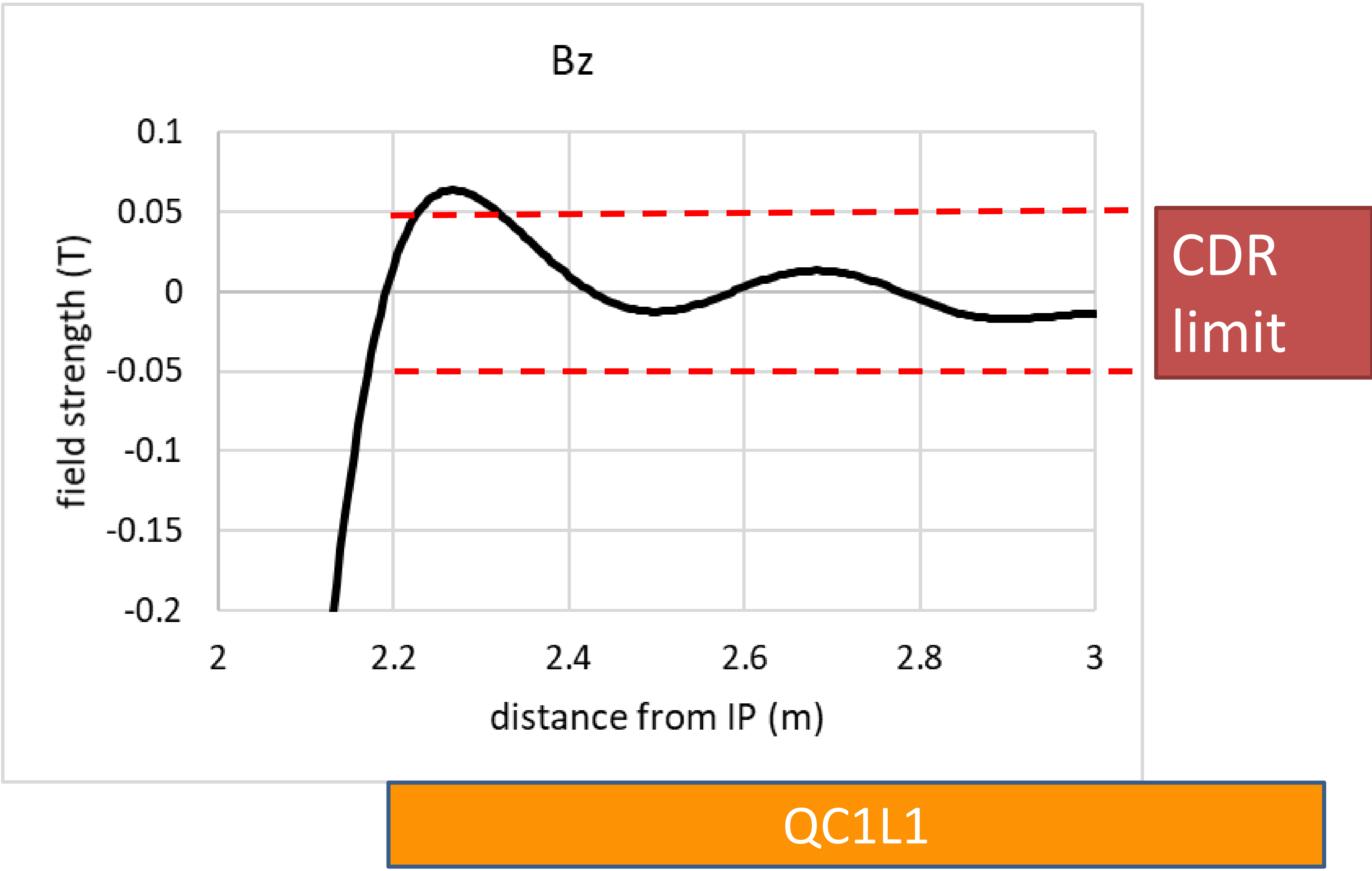
Dispersion closes locally

Vertical emittance from two IPs: 0.24 pm

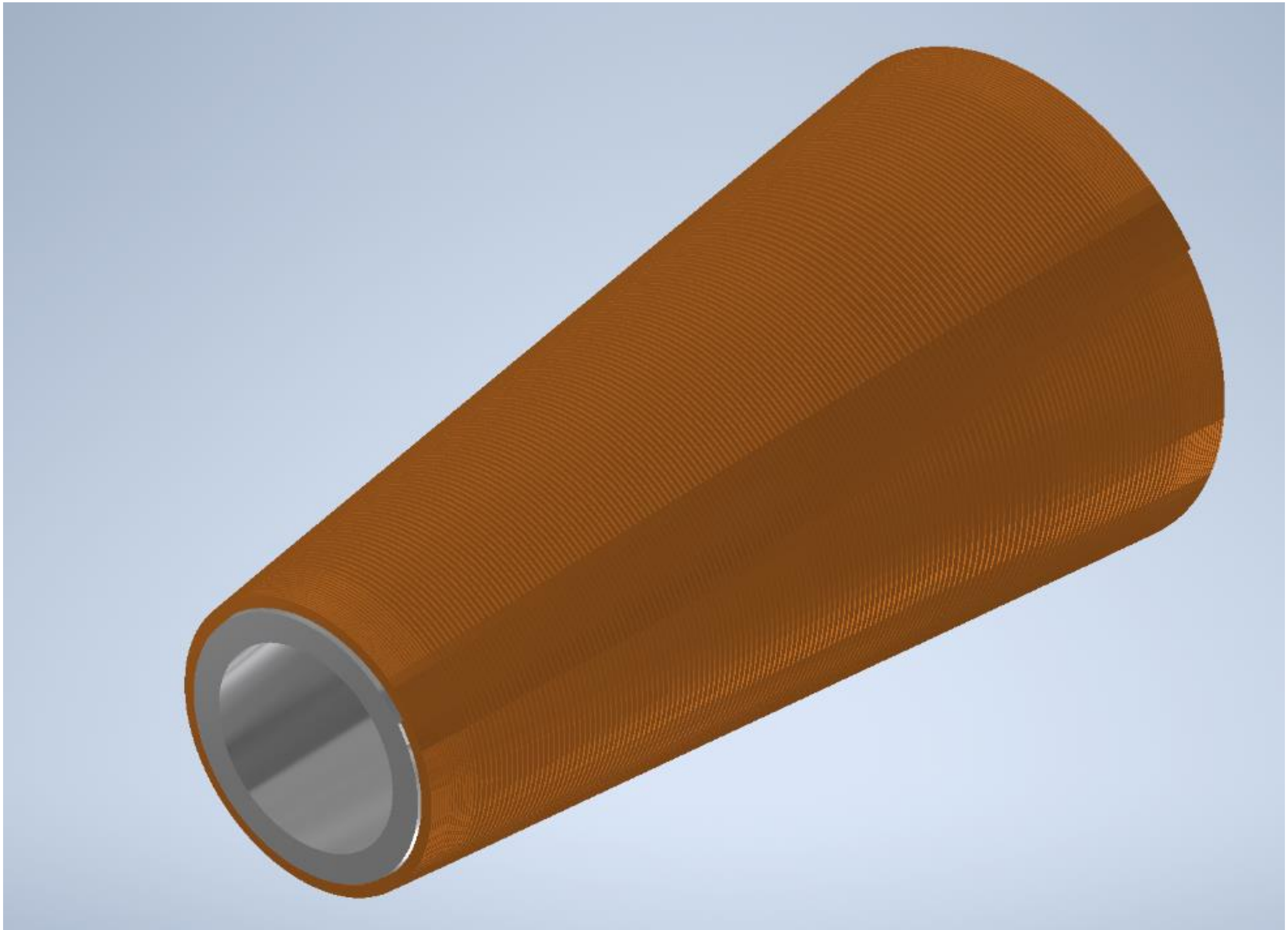
A note on dispersion leak

- Our initial CDR conditions are insufficient to ensure that no dispersion leaks out
- We need the extra condition that $\int B_x ds = 0$ on top of the condition of $\int B_z ds = 0$.
- Since I have two degrees of freedom (the current in the compensation solenoid and the current in the screening solenoid) I can actually make both integrals arbitrary close to zero in principle (I have not mathematically proven this!)
- In practice, I have managed a $\int B_x ds = (few) \times 10^{-5}$ and $\int B_z ds = (few) \times 10^{-3}$ (which is easy to improve further if needed)

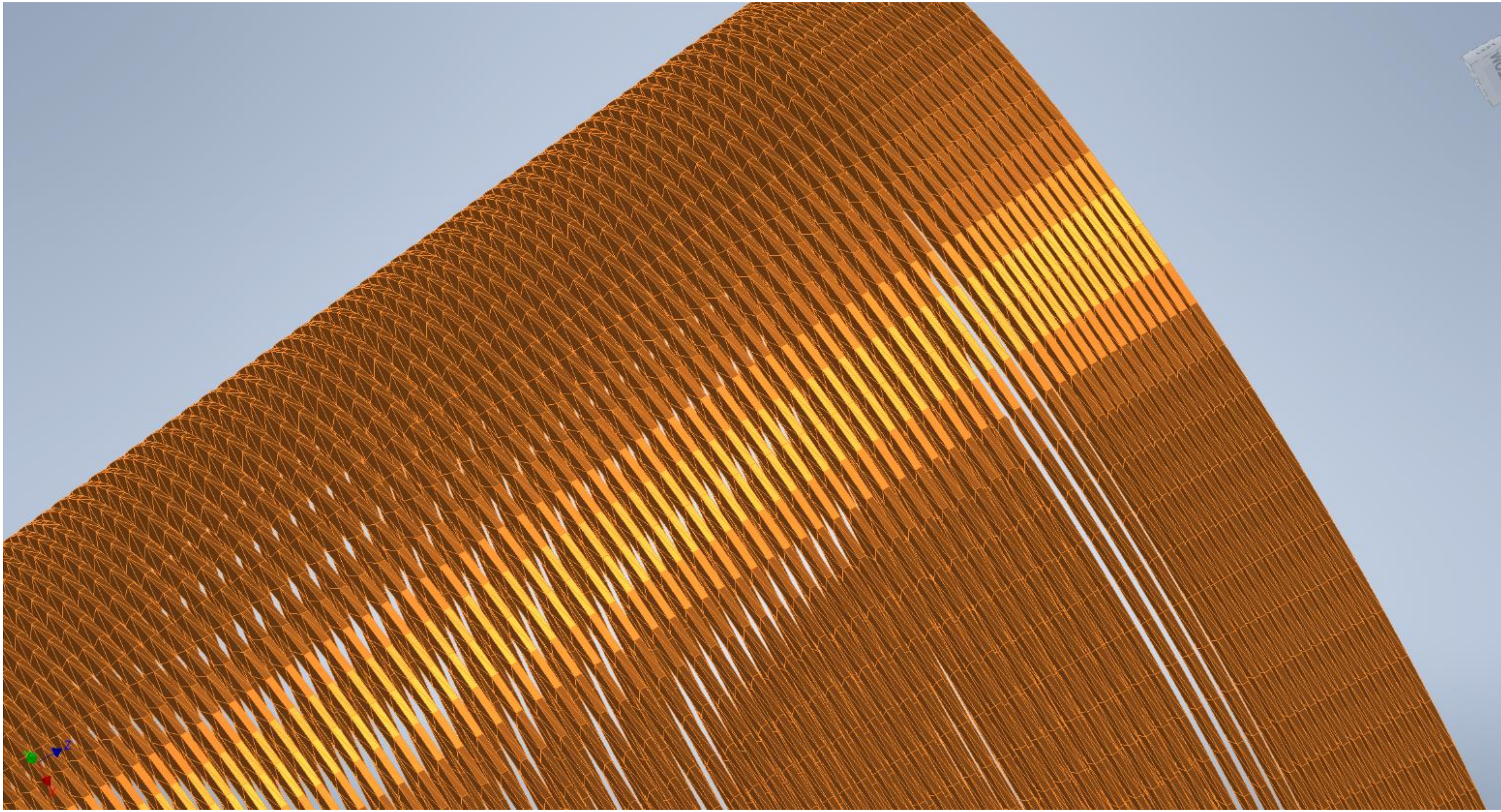
Field in the vicinity of QC1L1



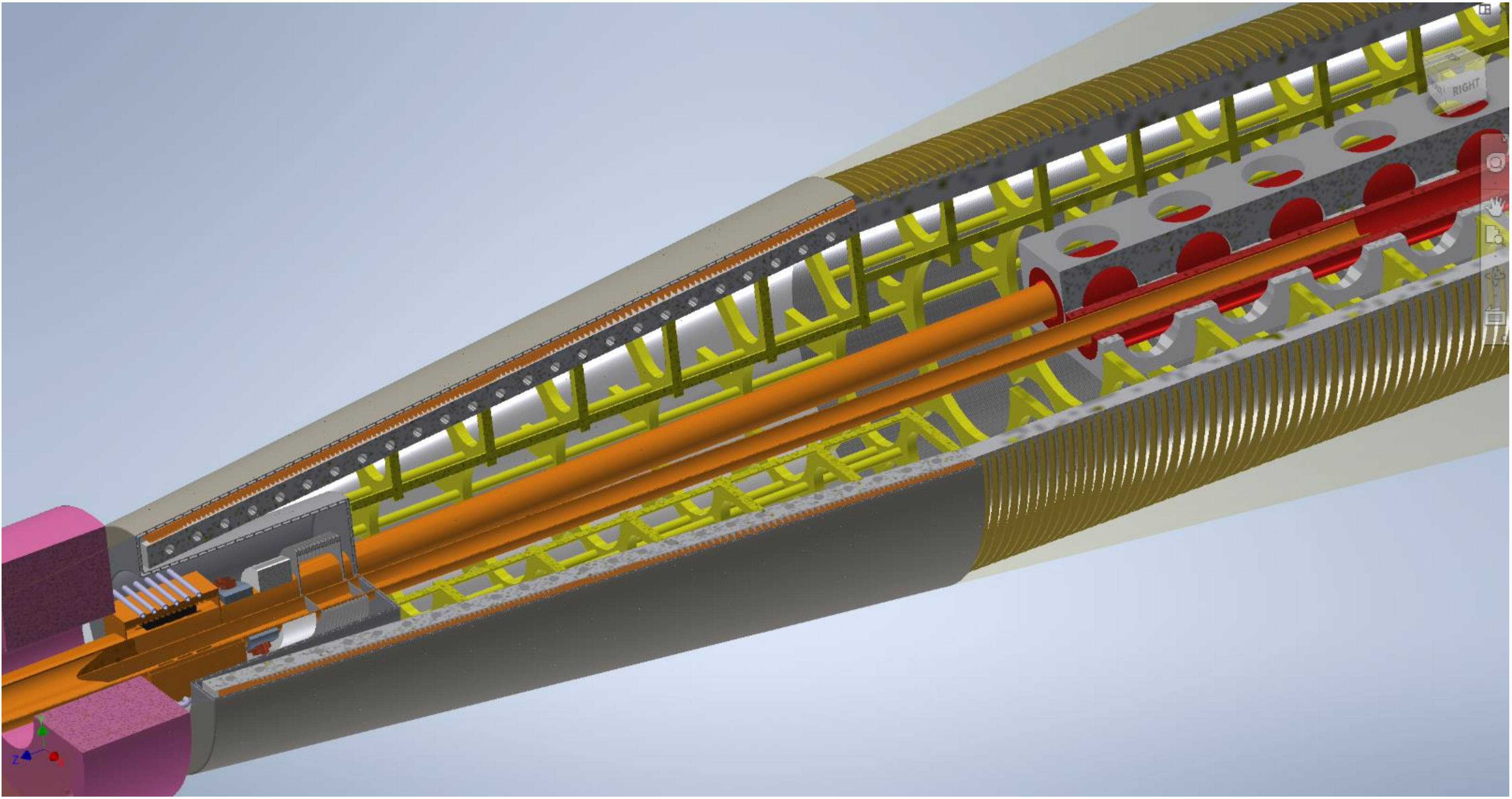
Export to CAD – compensating solenoid wire



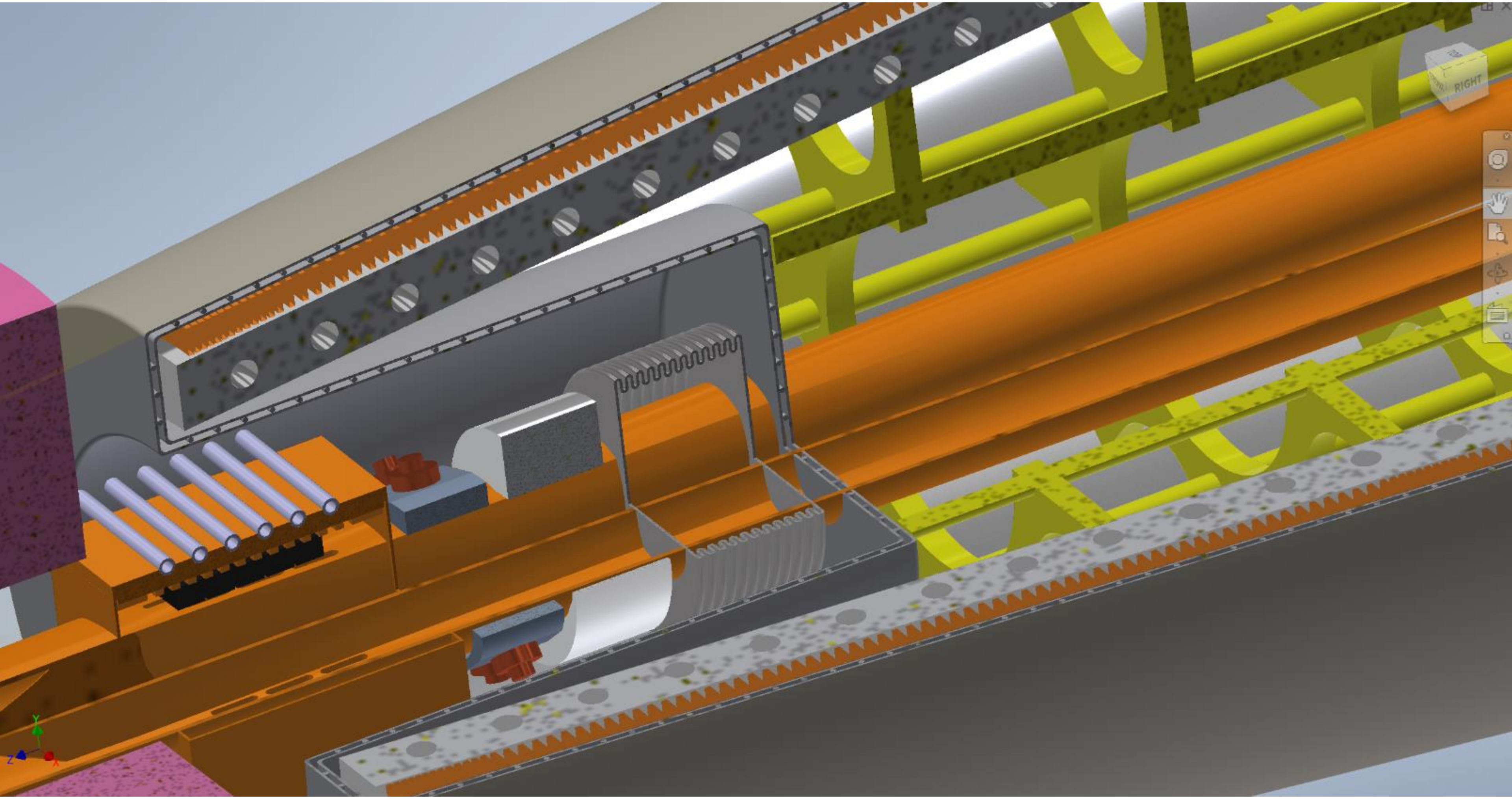
Individual wire is exported



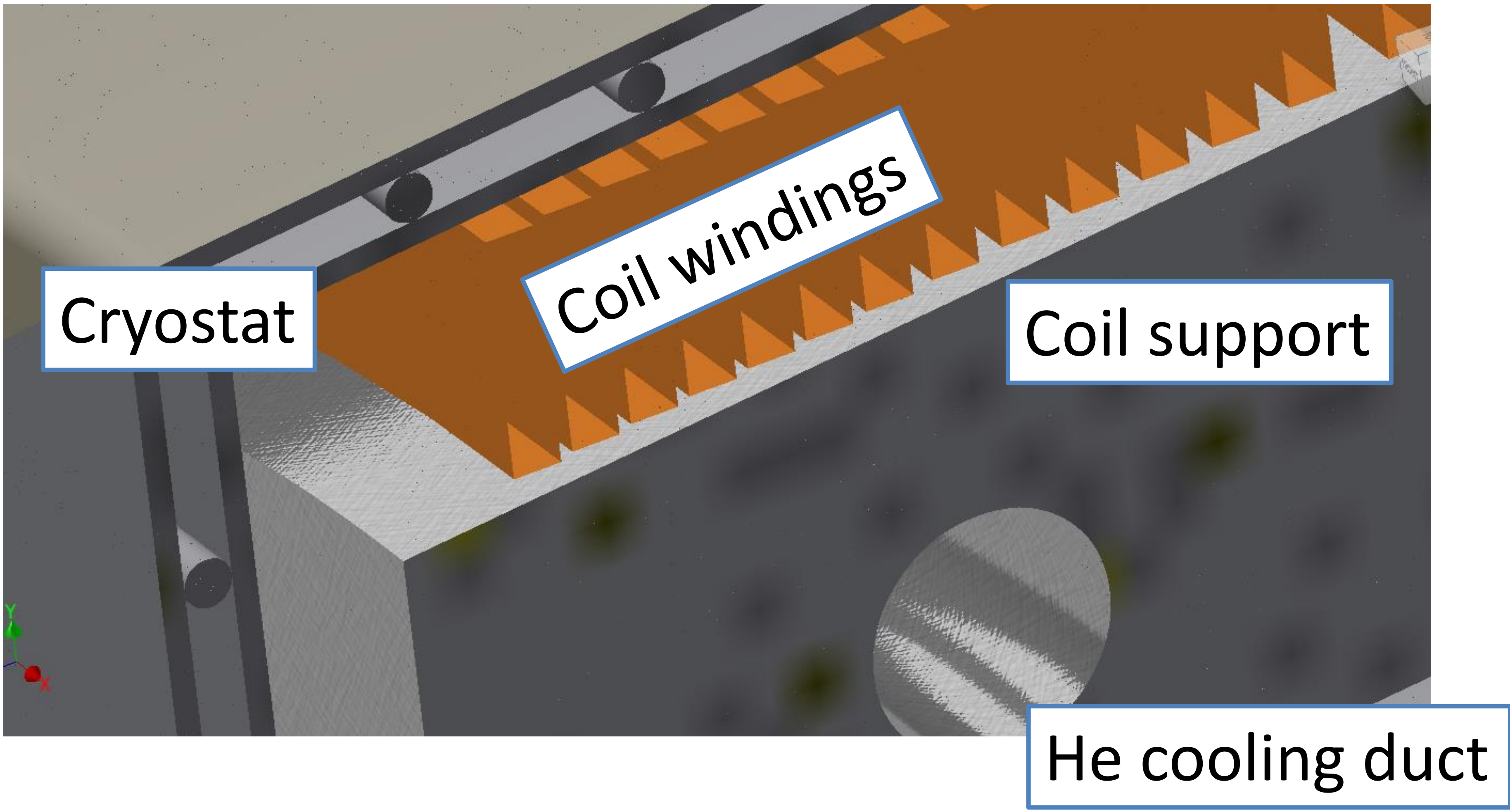
The full assembly



Front of the compensating solenoid



Front of the compensating solenoid



Misalignment analysis

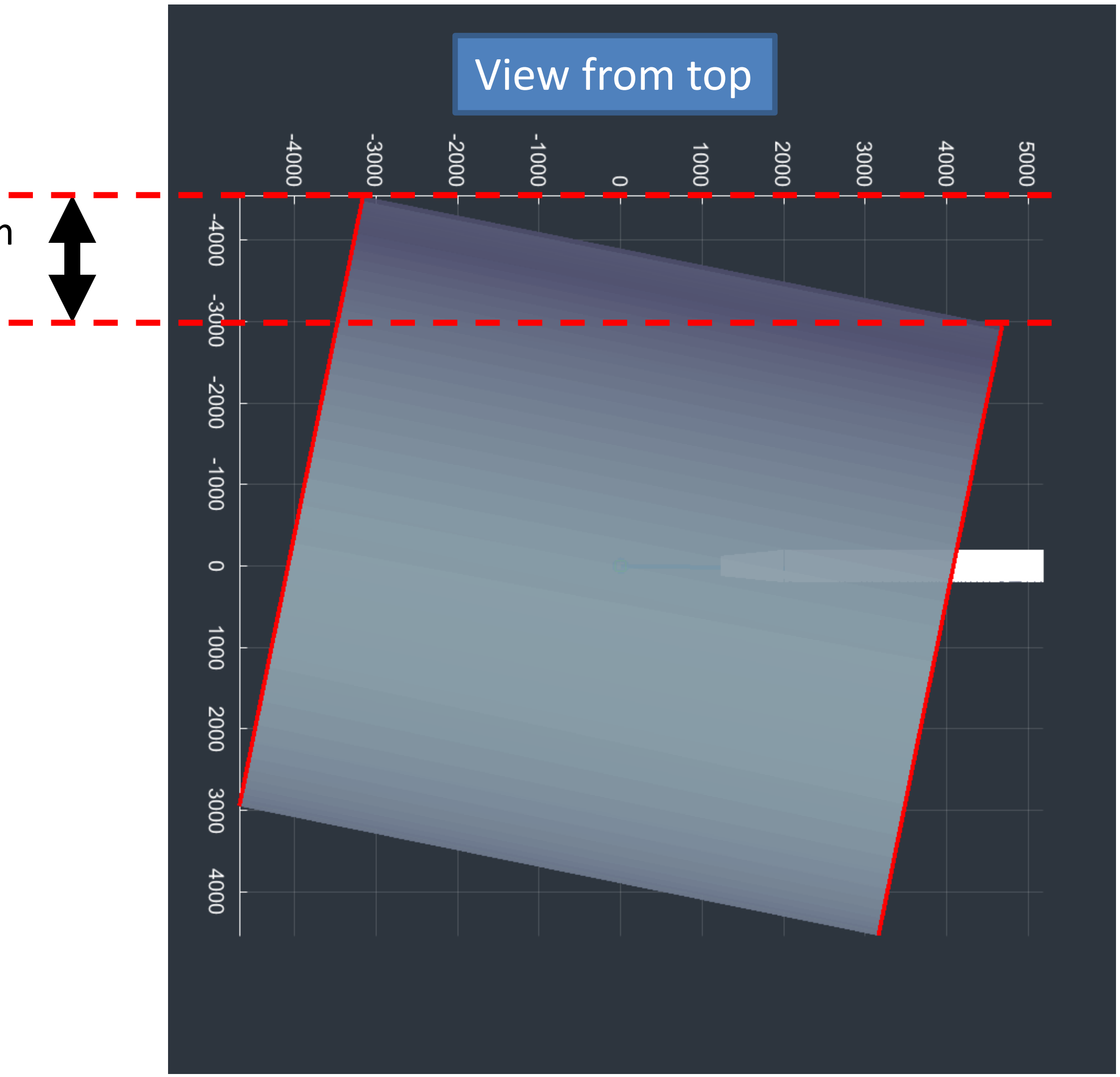
- How sensitive is the compensation system to component misalignment?
- I have moved the screening solenoid and the compensation solenoid individually by:
  - 200 µm in x, y, z
  - 100 µrad in theta and phi
- The results show that the emittance changes only by 5%
- The biggest change came when misaligning horizontally, so that the edge of the solenoid became closer to the beam
- This was verified by SAD

Misalignment of the detector solenoid

- But this is not the end of the story…
- The detector solenoid is huge and, of course, will also suffer alignment issues
- I have used 10mm of alignment in x, y and z for the detector solenoid
  - No major emittance blowup
- I have used 1mrad tilt misalignment
  - 1mrad in theta has a large effect (20% in emittance)

Misalignment in theta

(1mrad in 10 m → 10 mm)



Misalignment exaggerated 20 times

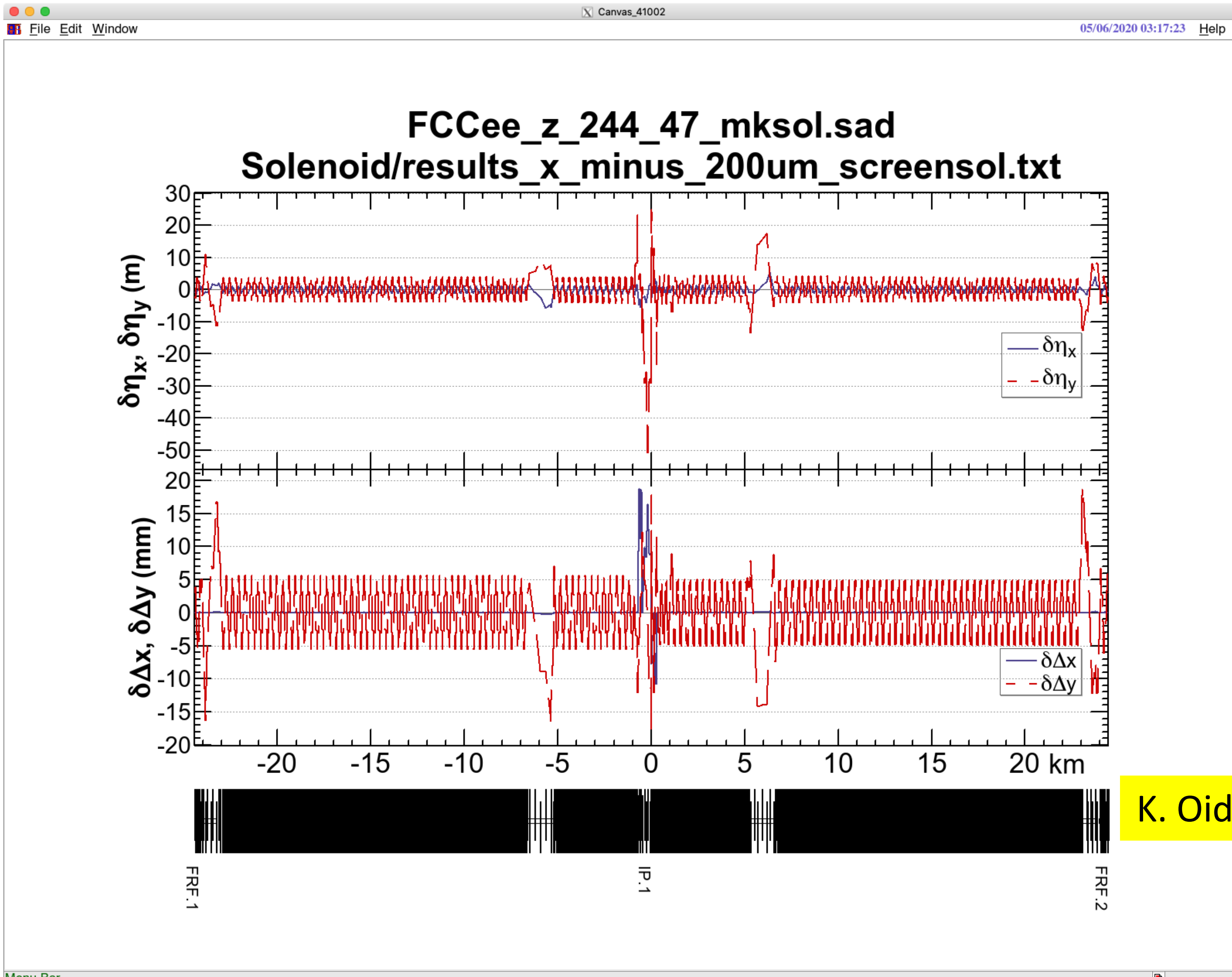
Equivalent to increasing the beam angle from 15 to 16mrad for one beam (and a decrease to the other)

Detector solenoid tilt

- So, any tilt of the detector solenoid generating a horizontal magnetic field component, generates a huge vertical orbit and dispersion all over the ring, see figure of next slide. This makes the entire ring unstable.
- So we need an orbit/dispersion correction for this. A very primitive correction on orbit/dispersion/coupling using dipoles on QC{12}* and skew quads on a few sextupoles around the IP, have given a much better orbit/dispersion as the second figure two slides down. The resulting vertical emittance is 0.288 pm (20% larger than the perfectly aligned case). This number depends on which correctors are used.
- In the actual machine, the measurement of dispersion and coupling at the IP will be difficult, so the final number might be worse than this. Anyway this kind of study should be done under the global correction by Tessa.

K. Oide

1 mrad tilt of defector solenoid - uncorrected



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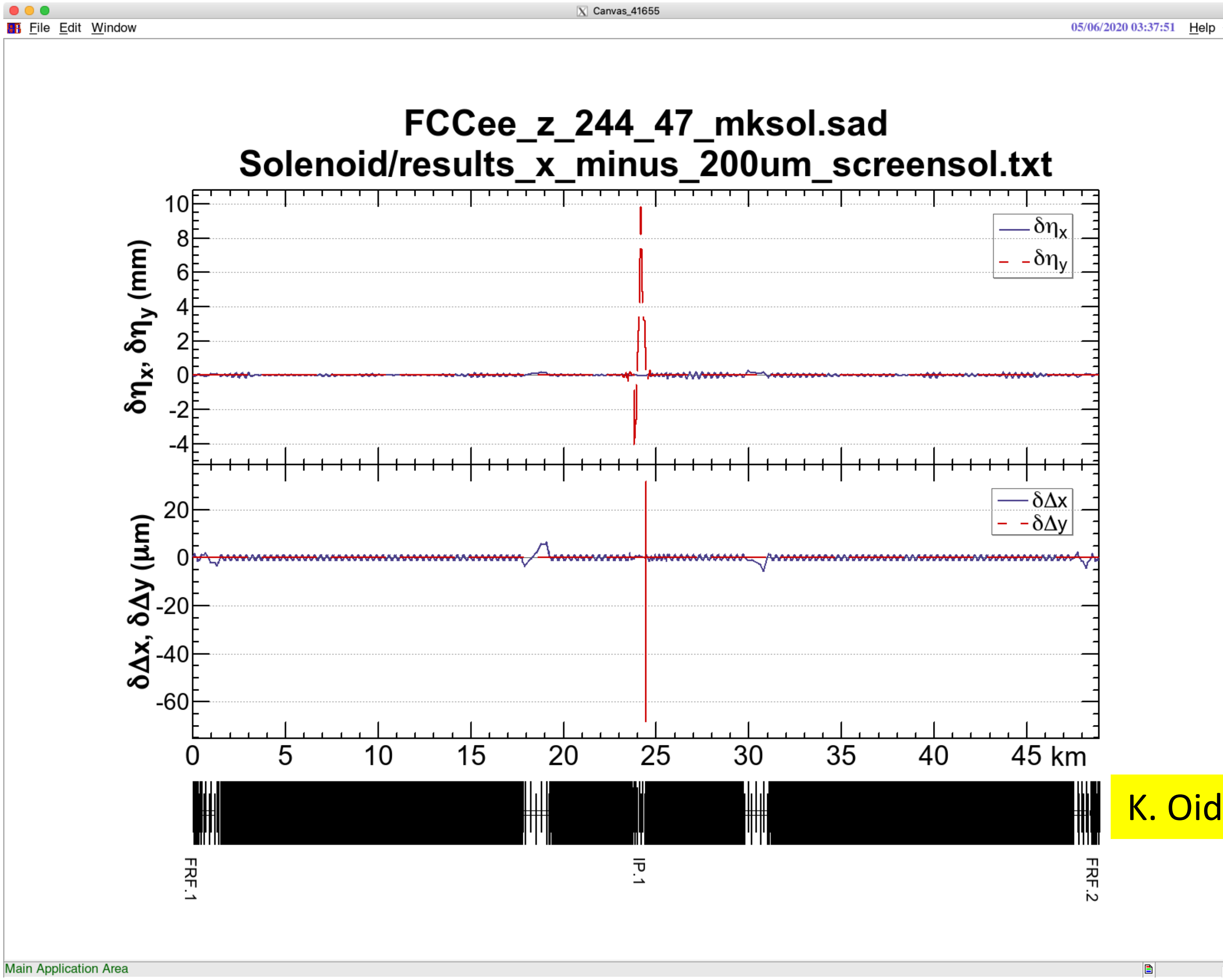
After correction

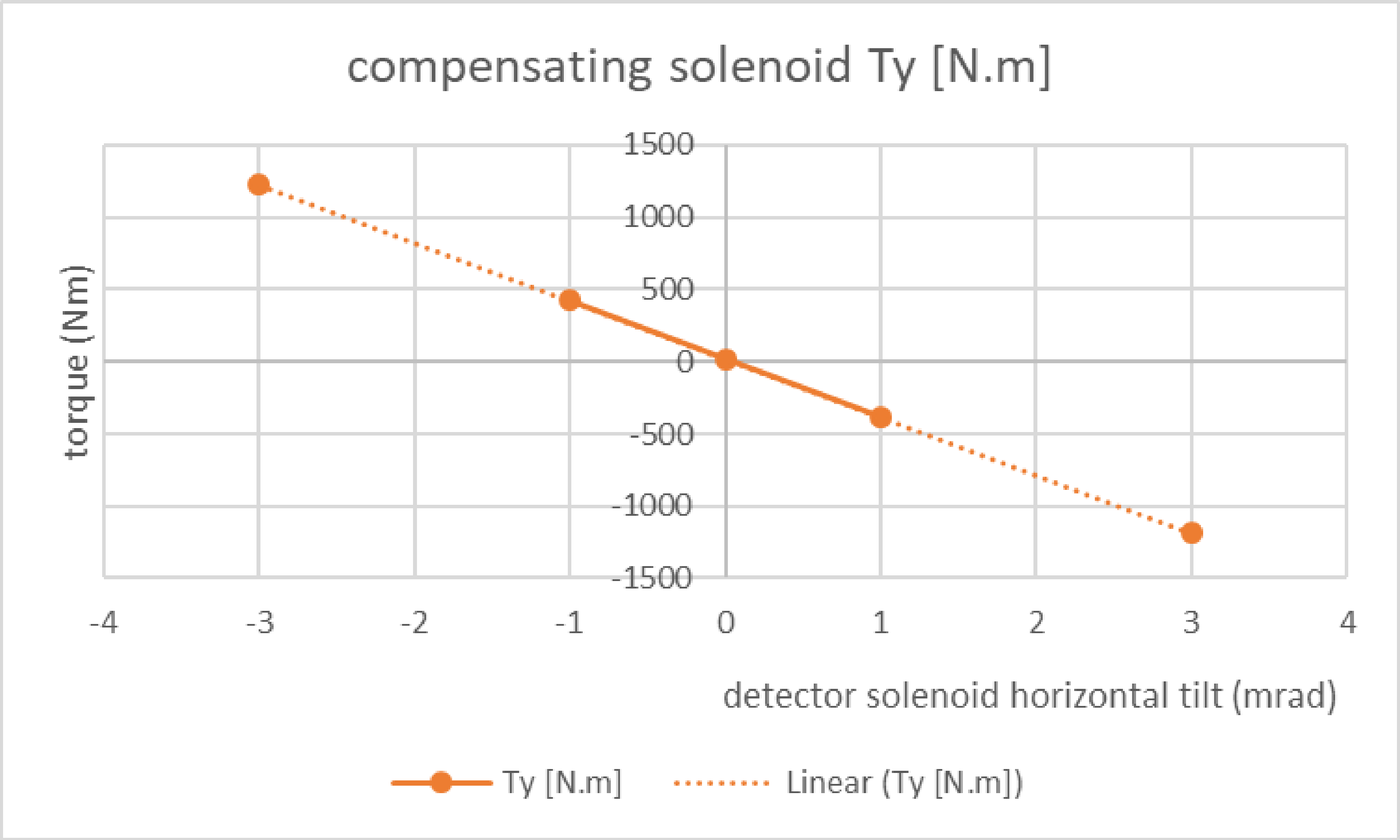


K. Oide

Is there a way to align the solenoids?

- Is there a way to align the real fields of the solenoids without relying on skew correctors or survey data (which for such a huge object will not be extremely accurate)?
- Yes, by using the fact that misaligned solenoids exhibit sizable torque.
- We need some hardware for that (sensors) and to develop a method, but I think it is doable.
- We would then have an aligned detector solenoid/compensating elements system.
- We still need to align this to the beam

Torque on comp. solenoid as a function of detector sol. tilt



- About 400Nm per 1mrad => possible to adjust to 50microrad

How well are current detector solenoids aligned?

- I have looked at the paper from the CMS detector solenoid survey.
- The CMS solenoid is bigger than the one we envisage for FCC-ee
- The results are from a pure mechanical survey, no strain gauges to measure torque as suggested here.
- In CMS there is an extra element which I am not yet modelling: the return yoke. So in CMS the solenoid can be misaligned with respect to the iron yoke

c.f. CMS survey

CMS-SG-UR-0018
EDMS : 659178

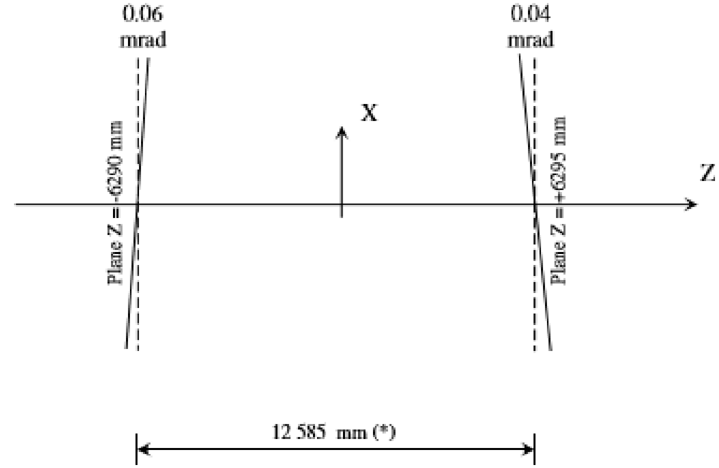
CMS

FINAL POSITION OF THE COIL

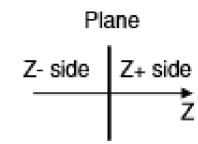
CERN SX5 – 07TH OCTOBER 2005

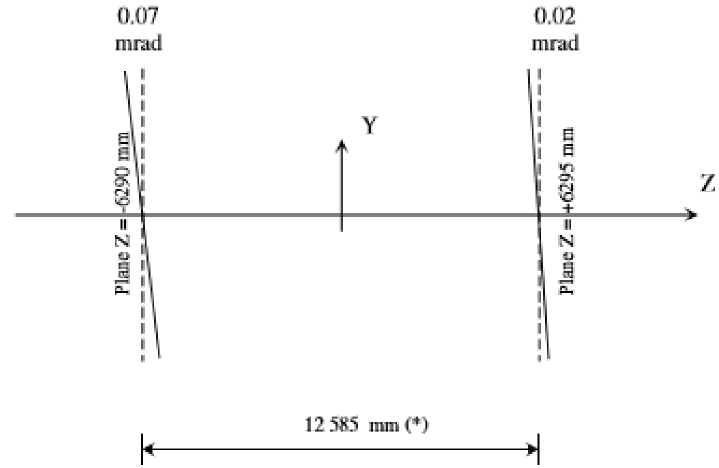
Numbers are around the 50μrad value:

- In X there is a 20 μrad tilt
- In y there is a 50 μrad tilt
- (this is more like a distortion than a tilt)



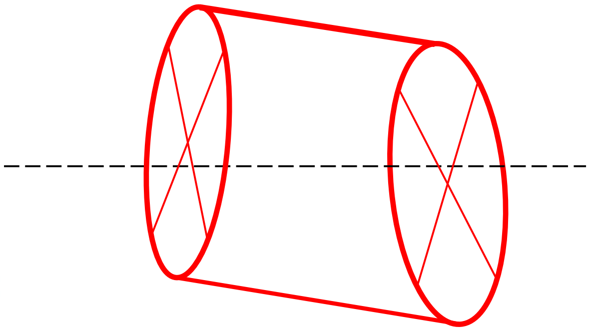
Angles and distances between mean planes
View in XZ plane with Y=0





Angles and distances between mean planes
View in YZ plane with X=0

CMS survey



- From the centre of circles fitted at the two extremities of the coil, the tilts are:
  - 140 µrad in x
  - 90 µrad in y

4.2 Best-fit circles calculation:

- On Z+:

Co-ordinates of the centre of the circle - in Calculated Co-ordinate Axis

BP	**X (m)**	**-0.0006**
	Y (m)	**0.0013**
	Z (m)	**6.2952**

Radius of the circle

Rad (m) **3.452** sig R 0.2 mm

- On Z-:

Co-ordinates of the centre of the circle - in Calculated Co-ordinate Axis

BM	**X (m)**	**0.0012**
	Y (m)	**0.0024**
	Z (m)	**-6.2902**

Radius of the circle

Rad (m) **3.451** sig R 0.5 mm

Extrapolating from CMS survey

- We can assume that we can mechanically align the detector solenoid with respect to the beam to 100 μrad
- We need to see how this affects Tessa's analysis

Summary - compensation

- A new optimization of the compensation scheme has been performed
- Now everything fits inside the 100mrad cone, including the cryostat
- Emittance blow up from two IPs according to the optics analysis: 0.24pm at the Z (compared to 0.4pm quoted in our CDR) therefore, ** this will not be a bottleneck if we need to go to 4IPs! **
- Realistic representation of the solenoids, down to the individual cable
- This is a complex analysis, I probably could not have done it if not for COVID19…

Summary - alignment

- A misalignment analysis of the compensation components has been performed and the scheme is stable to misalignments of 200 microns and tilts of 100 μrad
- A tilt of the detector solenoid of 1mrad yields a large dispersion and orbit distortion
- There is a way to avoid such tilts by measuring torque
- Prior art indicates that we can limit detector solenoid tilt to 100μrad using survey methods
- (we need to keep in mind that, although not discussed directly here, we need to have a number of strategically placed correctors to give us enough degrees of freedom to deal with all misalignment and imperfections ➔ we need a corrector strategy)
- (We also need an alignment strategy and specs, Tessa is working on this, we will give input for the MDI region)