Finite Elements Magnetic Analysis of the CLIC MDI region

Antonio Bartalesi

CERN TE-MSC-MNC

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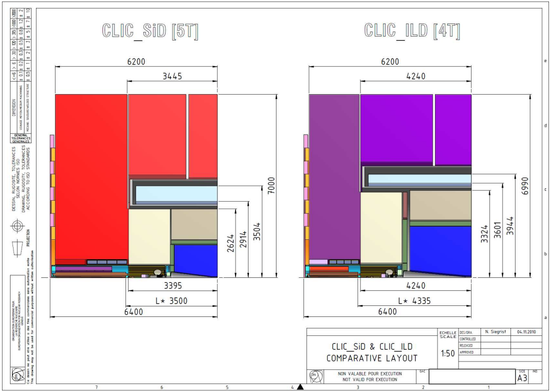
Thanks to the MDI team!

First of all I want to thank everybody who contributed to this work with:

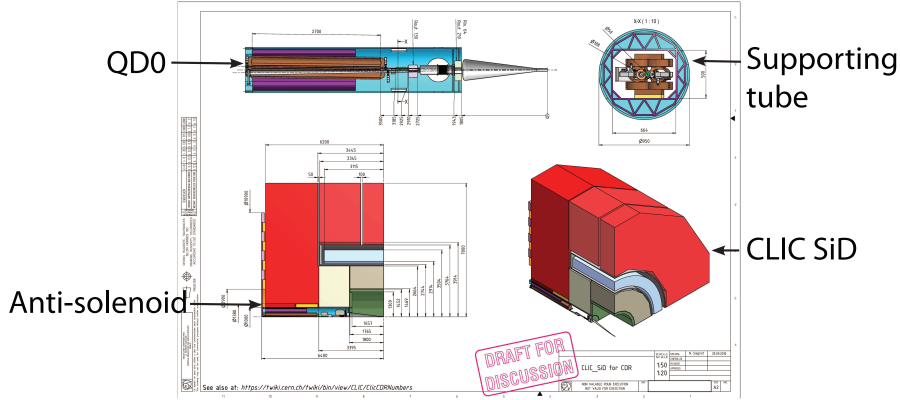
K.Artoos, P.Burrows, B.Dalena, H.M.Durand, K.Elsener, A.Gaddi, L.Gatignon, H.Gerwig, A.Hervé, A.Jeremie, M.Modena, D.Schulte, A.Vorozhtsov.

The proposed CLiC detectors



This work focus on the *SiD design only*. We want to be sure that the detector field do not put at risk the correct functioning of the iron dominated final focus quadrupole QD0.

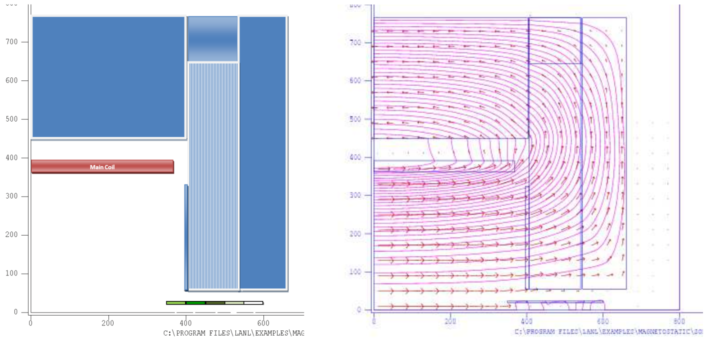
The CLiC SiD design



Here the most important dimensions are shown.
SiD detector develops 5 Tesla at the interaction point.

What we started from?

A ferromagnetic QD0 needs an active magnetic shielding to operate inside the detector.

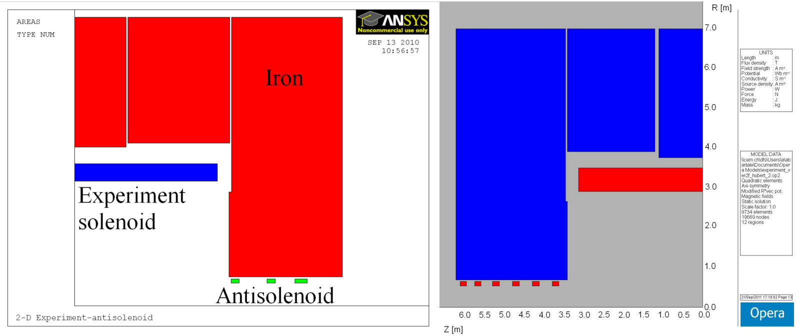


An *anti-solenoid* has been proposed since 2009[1].

[1]Detlef Swoboda, 6th MDI Meeting

How we started?

We started making a finite element model with Ansys™ and then we moved to Opera™.



Feasibility and beam dynamics impact were always considered while the integration process moved forward.

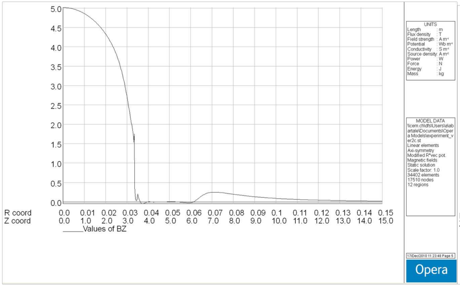
How we proceeded?

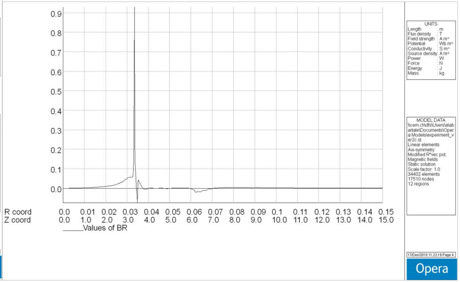
While other groups finalized their own designs (experiment layout, alignment etc. . .) we modified the anti-solenoid to minimize the resulting field in the region reserved for QD0:

- We studied anti-solenoids made of 3, 4, 5 and 6 coils.
- We investigated tapered or other complex shapes of the coils.
- Also we looked for the optimum currents to use in each coil.
- Finally we considered to have a ferromagnetic shield (a disc) or to use ferromagnetic materials for some nearby components.

Magnetic flux results

Here are some results dated 17th December 2010:

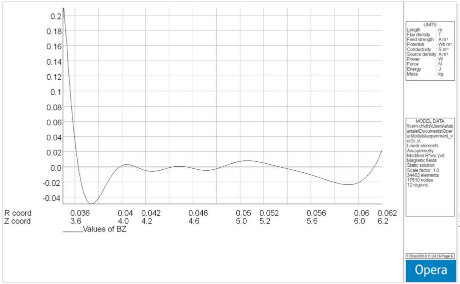


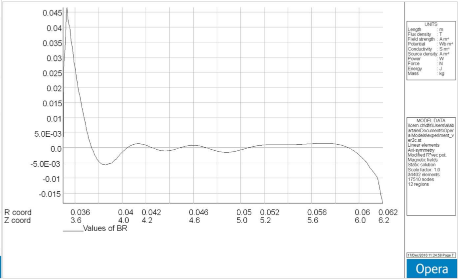


Bz and Br (in Tesla) on beam axis from IP to 10 m away.

A zoom in the QD0 region

From previous slide, here is a zoom in our region of mayor interest.



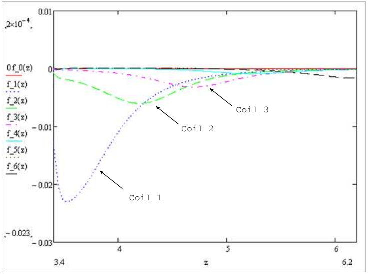


Such results were already considered acceptable from the beam dynamics group[2], however we kept on improving the anti-solenoid for a correct QD0 protection.

[2] As shown in B.Dalena, CLIC-note-886

Multi–dimensional minimization

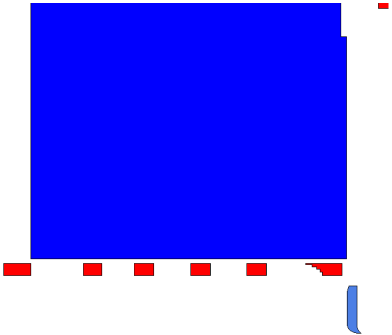
A routine to optimize the currents in the anti-solenoid to minimize the residual field on beam axis was set up.

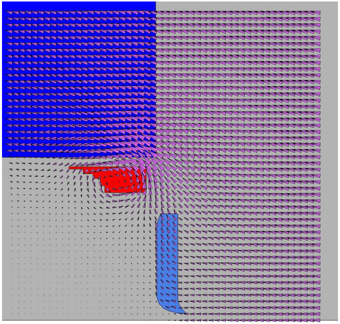


The magnetic contribution of each coil is multiplied by a variable, summed and integrated on the beam line.
The obtained parameter is then minimized in the 6 variables, to find the optimum value of current to have each coil.

Ferromagnetic disc

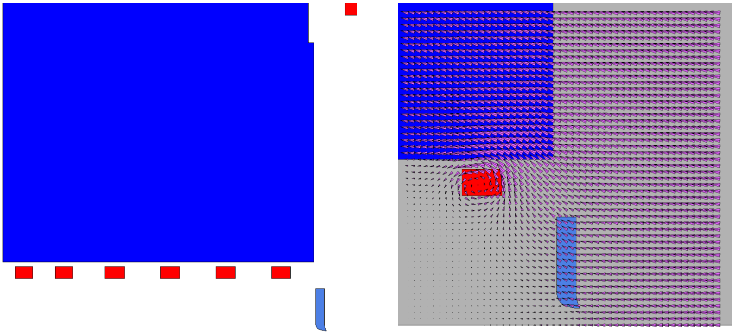
It was noticed that a ferromagnetic disc to be put in front of the QD0 region could improve the magnetic shielding.





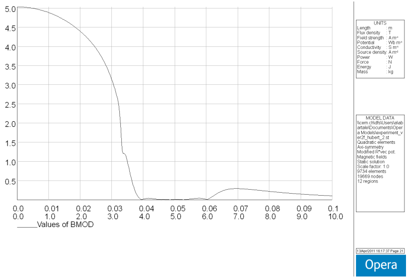
The second picture shows its benefit by means of a field map.

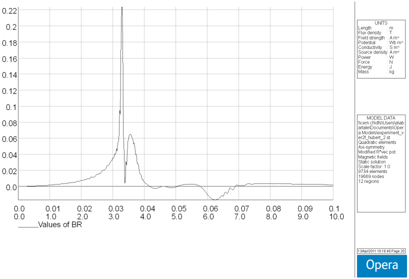
Where do we stopped?



Here is a picture of the latest version of the anti-solenoid obtained by a 2D model, with the resulting field map.
It is compliant to integration with all the surrounding system.

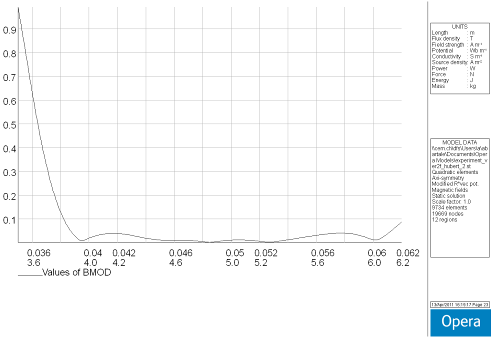
What we obtained?





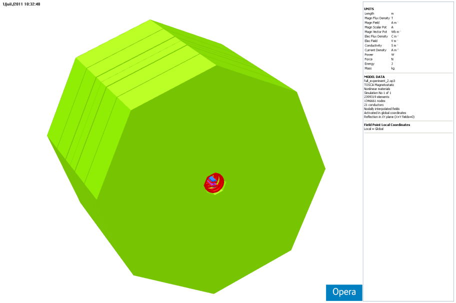
Shielding is working, even if we know that we could do better by taking some space from the neighboring systems.

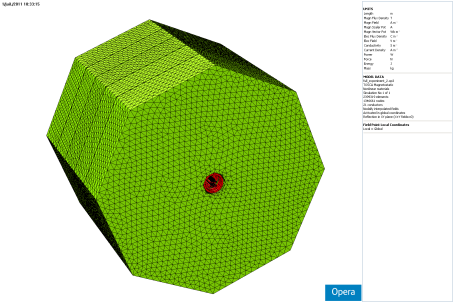
What we obtained in the QD0 region?



Even in the QD0 region results are good enough for this stage. Rather than improving furthermore the anti-solenoid design with this model, we preferred to proceed to the next step: 3D.

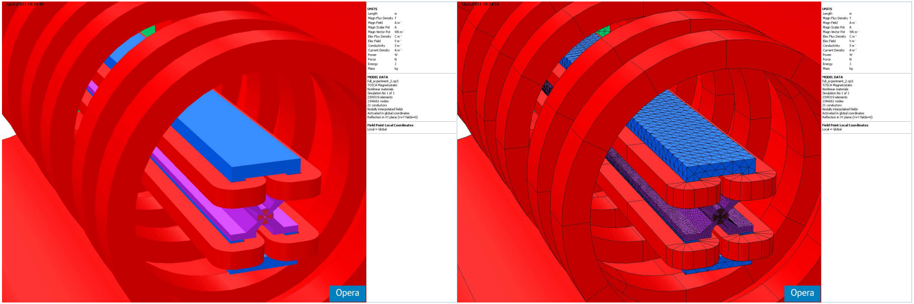
Overview





With a 3D model we can include QD0, which was not representable before. However, the simulation becomes much heavier.

Two worlds, one model



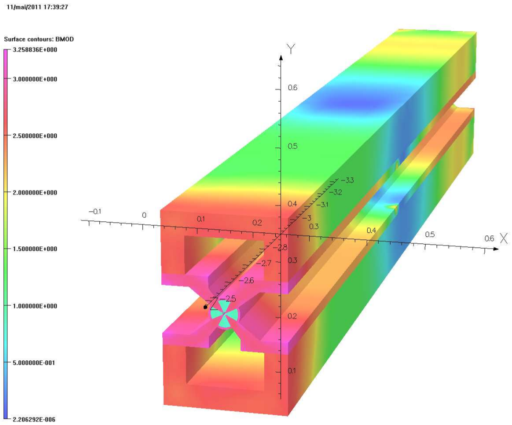
The mayor challenge is the scale difference:
Experiment outer radius = 7 m,
QD0 aperture radius = 4.125 mm.

Some features

Some informations about the model:

- a half of the experiment and a full QD0 are modeled.
- almost 2.5 million elements, some of them quadratic.
- around 4 hours of computation time.
- conductors, ferromagnetic regions and permanent magnets all at once.

First simulation



QD0 attracts a high amount of field:
new anti-solenoid parameters *are required*!

Back to the design phase

The anti-solenoid was refined using different techniques:

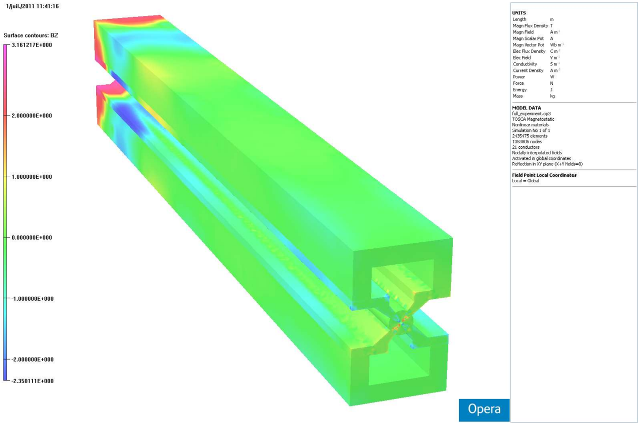
- Trial and error current adjustment.
- Trial and error coil shape adjustment.

There are some difference from the previous design phase:

- Ferromagnetic disc is not performing as without QD0: it was *removed*.
- QD0 iron regions are non linear: multidimensional minimization routine is *not applicable* anymore.

All the integration compatibilities were maintained, however.

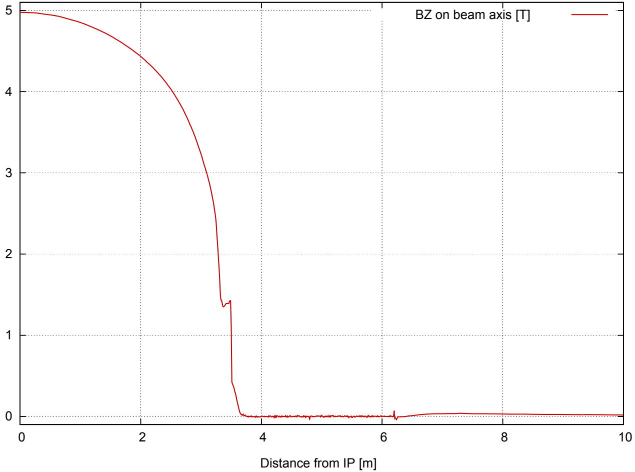
Residual field (BZ) inside QD0



Excellent performance of anti-solenoid,
still some issues due to saturation at the QD0 extremity.

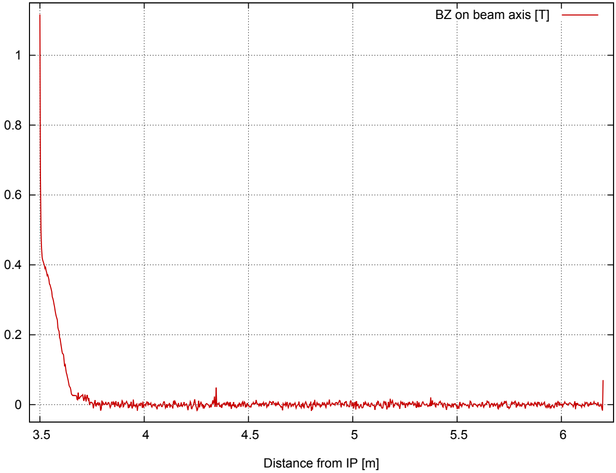
Bz on the beam line

Here is what we obtained in terms of Axial field:



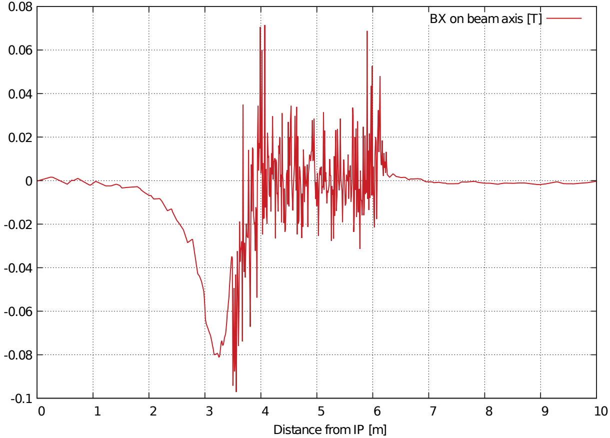
Zoom in QD0 region

Here is a zoom in the QD0 area:



Br on the beam line

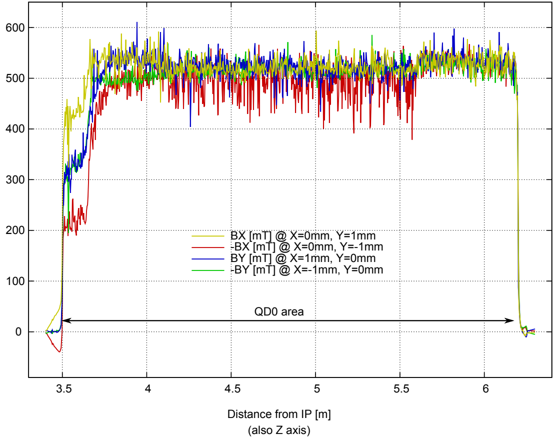
Here is the radial field:



Noise deriving from the finite element approximation is evident when the absolute value of BX are this low.

Effects on QD0 gradient

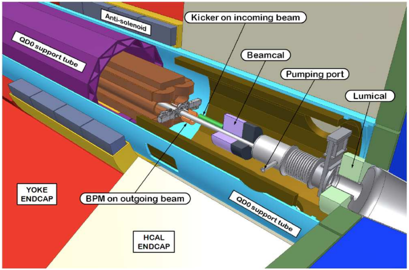
Now we have QD0 in the model, so we can evaluate its gradient:

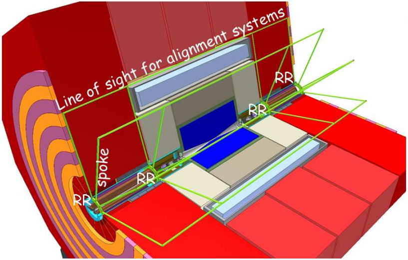


As anticipated, a degradation occurs in the extremity close to IP.

Can't we do better?

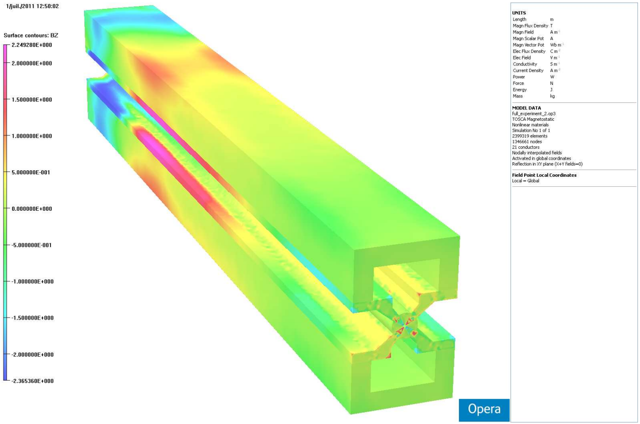
We can put integration aside for a moment and see what can we achieve.





The results that follow, in particular, are still compatible with the old space allocation (picture on the left) but incompatible with the latest pre-alignment design (on the right).

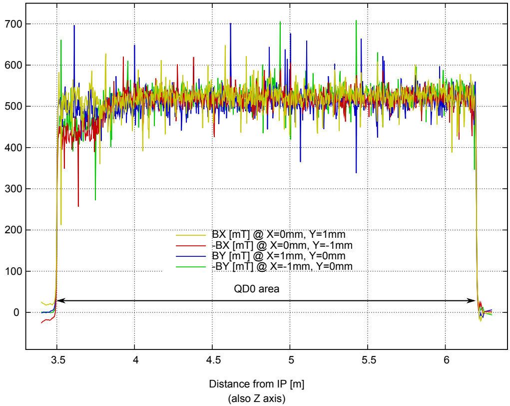
Residual field (BZ) inside QD0



Even better performance of the anti-solenoid, only a minor area of QD0 is perturbed.

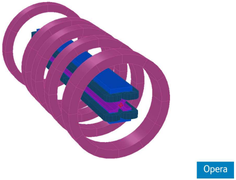
Effects on QD0 gradient

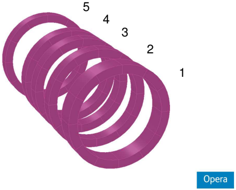
Here are the results in terms of gradient:



Degradation is reduced, but still present. So far, the only way we found to make it disappear was increasing L* by 30 cm.

Forces on the anti solenoid coils

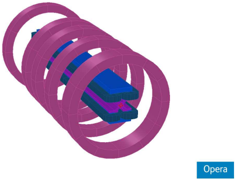


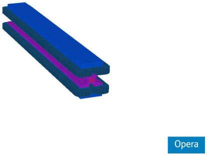


Coil number	FX kN	FY kN	FZ kN	MX kNm	MY kNm	MZ kNm
1	-331	-69	**7170**	-158	109	-359
2	-2.29	4.48	136	4.25	-1.89	0.208
3	-0.663	-7.46	107	-5.94	-1.47	-0.330
4	0.059	0.097	-1.41	-0.084	0.168	0.005
5	0.108	0.649	9.27	-0.018	0.011	0.031

It's impressive how forces on coil 1 never changed despite of one year of design iterations.

Forces and torques on QD0





	FX kN	FY kN	FZ kN	MX kNm	MY kNm	MZ kNm
QD0	-8.29	0.729	-5.73	-0.783	5.58	0.078

Those forces could be almost zero with a better shielding.

Our conclusions

From our simulations, we observed the followings:

- The anti-solenoid *works*: QD0 is substantially shielded.
- To have QD0 working as specifications, the anti-solenoid position *is imposed* by the problem itself, and it's slightly different from what we have now.
- Forces and torques are high, but we are also confident that they can be *handled* in the anti-solenoid and *drastically reduced* in QD0 with a better shielding.

Next steps?

What can we do next?

Integration we would like to cooperate with the MDI group to better define the space allocated for the anti-solenoid.

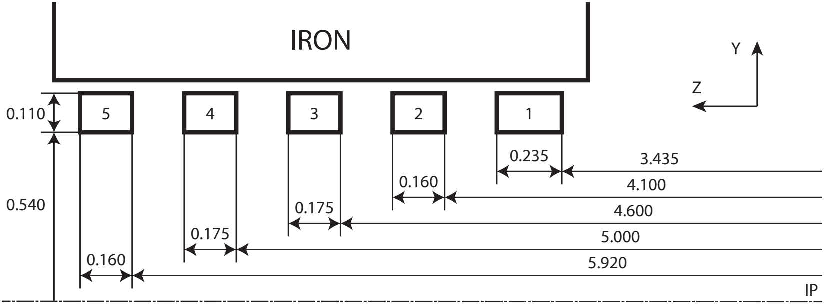
Simulations we are considering to split the 3D model in two parts to detail more the QD0 and better study its behavior when perturbed.

Transients a dynamic analysis is also foreseen, mostly to understand what can happen in case of a quench.

Questions and feedbacks are more than welcome!

Thank you!

Antisolenoid dimensions [m] and current densities



Section number	1	2	3	4	5	
Current density	80.0	23.5	15.0	3.8	2.0	$\frac{A}{mm^2}$

Those dimensions refer to our best 3D simulation and are compatible with the space we were given.