

Finite Elements Magnetic Analysis of the CLIC MDI Region

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Considering the current CLIC SiD detector design and the machine parameter L^* , the final focus quadrupole QD0 will be placed *inside* the experiment itself. This configuration is very challenging from an integration point of view.

Among several other aspects, the iron-dominated QD0 will need an active magnetic shielding to avoid undesired interactions with the magnetic field generated by the main solenoid of the detector.

This shielding will be provided by a superconducting anti-solenoid, and this paper aims to describe the method used to design such device, the results obtained and the issues still to be solved.

1 Introduction

There are two proposed detectors for CLIC: the SiD and the ILD designs, both represented in figure 1. The SiD [1] is considered to be the most challenging one, due to its higher magnetic field of 5 T at the Interaction Point (IP), therefore the following study focuses on the SiD design only.

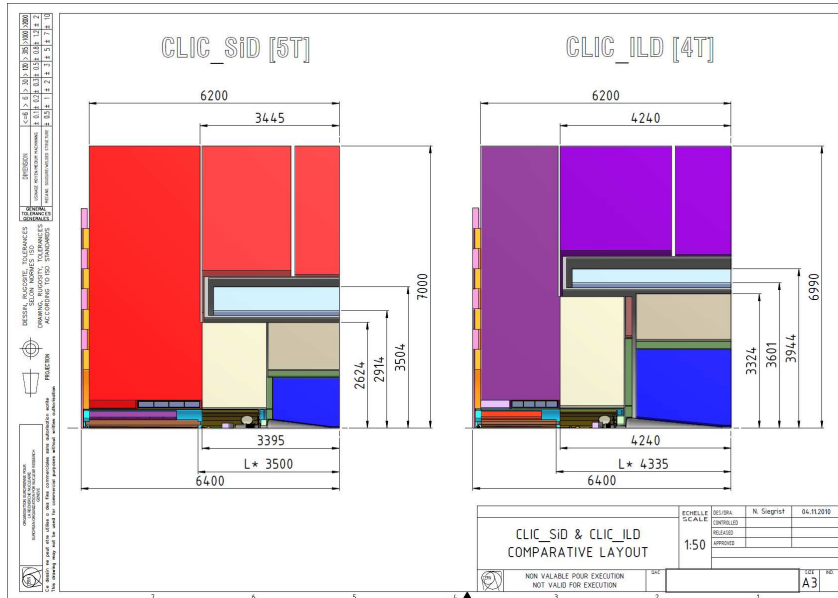


Figure 1: The SiD and ILD designs overview

With an L^* value of 3.5 m, the normal conducting final focus lies *inside* the boundaries

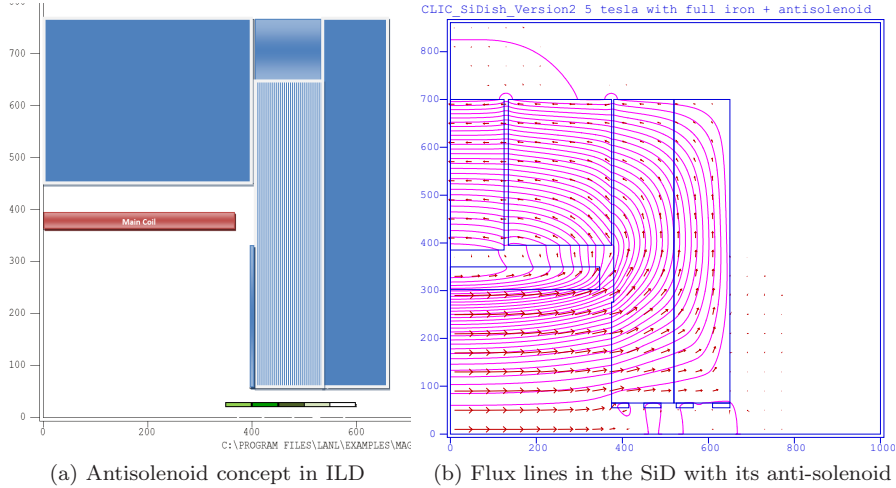


Figure 3: The first anti-solenoid layouts

3. To be integrated in the Machine Detector Interface (MDI) region.

The number of coils, their dimensions and currents were set as the output of this study.

2 The two-dimensional model

As a first approximation, a 2D axial-symmetric FEM model was considered the best choice to represent the MDI region. In fact, even if QD0 could not be included in this kind of simulation, it was possible to use such model to reduce the magnetic field in the final focus region and evaluate both the forces and the stresses acting on the anti-solenoid. However, since a 3D simulation was considered fundamental, it was planned and performed later.

The first model was set up using Ansys by Ansol, mainly to evaluate forces and stresses after performing a magnetic simulation. Once found out that magnetic precision was more relevant than stress calculation, that software was abandoned in favour of Opera2D by Vector Fields. Figure 4 shows the very first and the very last designs proposed.

The first anti-solenoid was designed for an L^* of 3.8 m, and consisted in 3 superconducting coils, the current densities were $1.14 \cdot 10^8$ A/m², $3.67 \cdot 10^7$ A/m² and $6.00 \cdot 10^6$ A/m² for coil 1, 2 and 3 respectively. Results in terms of magnetic field along the beam line are shown in figures 5a and 5b, while the maximum axial force was $7.0 \cdot 10^6$ N, on coil 1.

2.1 Design evolution of the 2D model

The first magnetic results obtained were satisfying, but many integration issues still needed a solution. The most important changes that occurred in the evolution of the MDI were the setting of L^* to 3.5 m with the consequent detector re-dimensioning; the necessity to reserve a space of at least 40 mm around the anti-solenoid coils for their cryostat, and finally the setting of the maximum current density for the anti-solenoid to $8 \cdot 10^7$ A/m².

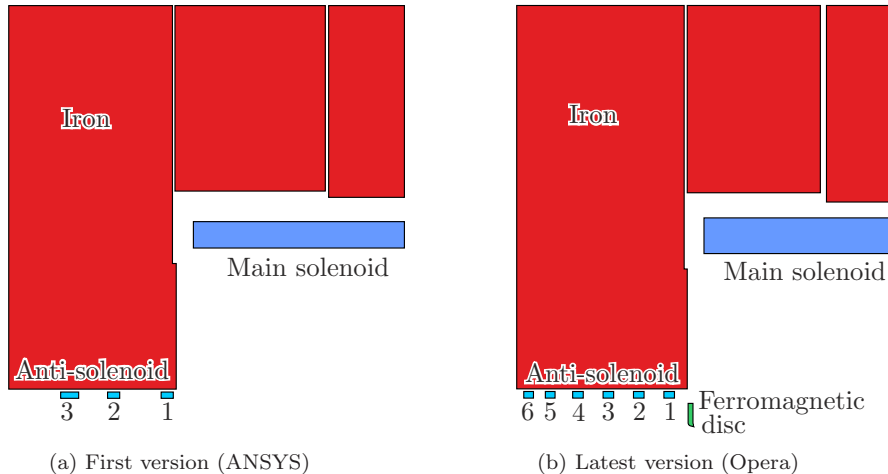


Figure 4: Two finite element models schemes

To improve the shielding, anti-solenoids made by different numbers of coils were studied, and also the coils shapes were continuously changed. At some point, it was introduced a ferromagnetic disc to be placed in front of the QD0 region, as shown in figure 4b, and it was also defined a numeric routine to iteratively find the coil currents which minimize the remaining magnetic field in the QD0 region and on the beam axis.

2.2 Results of the 2D models and conclusions

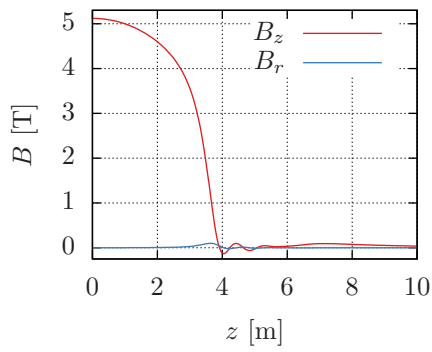
Figures 5c and 5d show the best results ever obtained in terms of magnetic field with a 2D model. However, due to integration issues, that design was discarded in favour of a less performing one, which gave the results represented in figures 5e and 5f.

Once reached this stage, the integration issues were considered solved, the remaining magnetic field minimized and the forces under control. It was then clear that only a 3D simulation could add some more information, and in particular a 3D simulation was the only way to introduce the QD0 magnet in the analysis and study its magnetic interactions with both the detector main solenoid and the anti-solenoid.

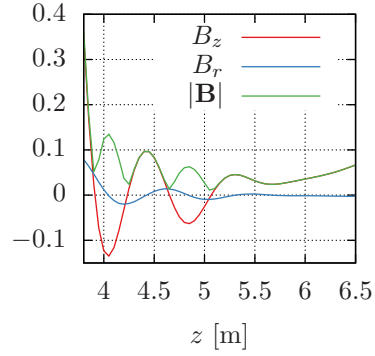
3 The three-dimensional model

The main challenge of the 3D model is the scale difference of the various components (Figure 6a). In the same model there are in fact objects as big as the iron end-cap, with a radius of 7 m, and object as detailed as the final focus, with an aperture radius of just 4.125 mm. Furthermore, it was possible to use only one plane of symmetry to simplify the model, which consisted in a half of the detector plus a full QD0 and an anti-solenoid (Figure 6b).

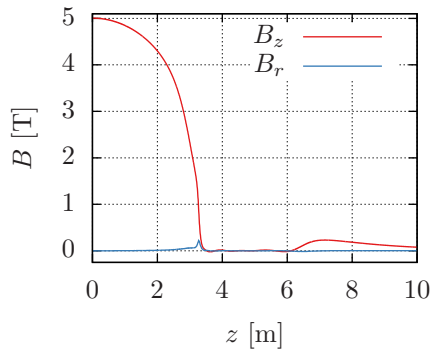
The magnetic simulation included non linear iron regions, coils and even the permanent magnets blocks which are proposed in the QD0 hybrid design [3].



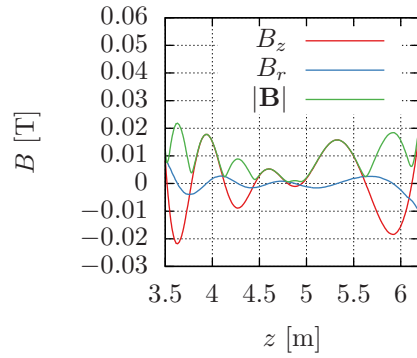
(a) From the IP to 10 m (Ansys)



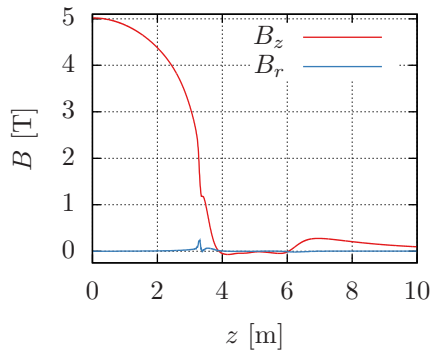
(b) In the QD0 region (Ansys)



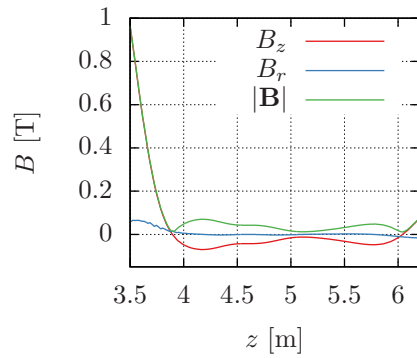
(c) From the IP to 10 m (Opera, best result)



(d) In the QD0 region (Opera, best result)



(e) From the IP to 10 m (Opera, integrated)



(f) In the QD0 region (Opera, integrated)

Figure 5: Axial, radial and overall magnetic field on the beamline

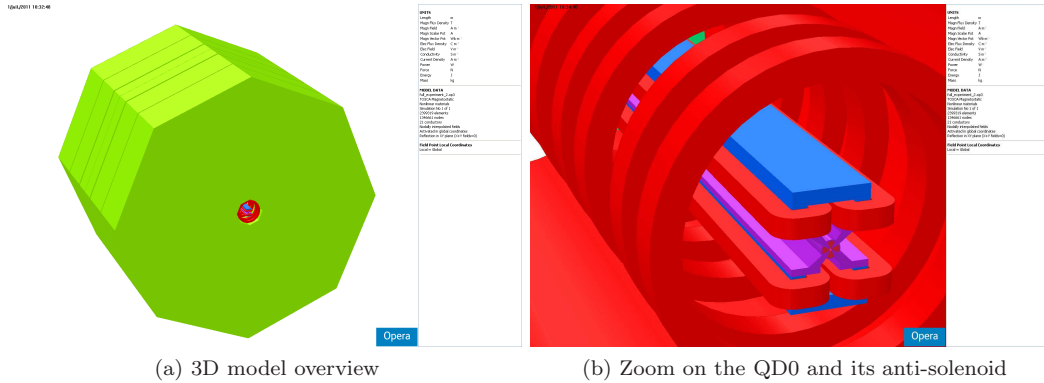


Figure 6: The 3D model

3.1 Design evolution of the 3D model

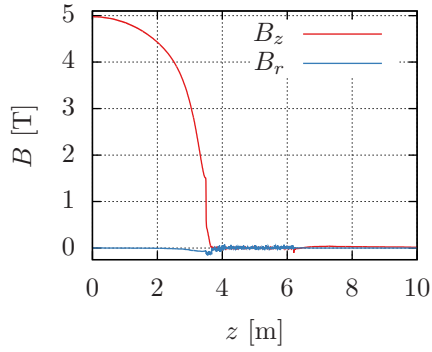
The anti-solenoid defined during the previous 2D analyses didn't perform as before once QD0 was introduced, and too much magnetic field was attracted by its poles and yokes. Then it was necessary to adapt the currents and also reposition slightly some of the anti-solenoid coils, to shield the magnet properly. This was done with a trial and error procedure, since the routine that was set up for the 2D model was based on the superposition of effects and became unusable due to the non linear behaviour of QD0. Finally, the ferromagnetic disc effect was overcome by the presence of the magnet, so it was removed.

3.2 Results of the 3D model

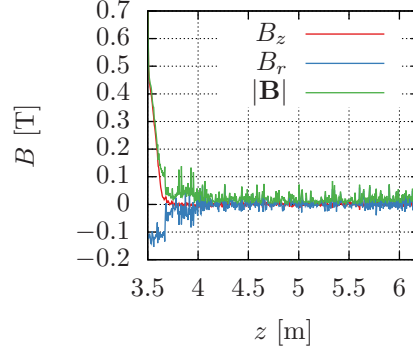
Magnetic field on the beam axis was highly reduced as the ferromagnetic QD0 *shielded* the beam line. Figures 7a and 7b show the remaining field on the beam line. However, since QD0 was simulated, it was also possible to evaluate directly its performance in terms of gradient developed. Figure 7c shows the gradient calculated at 1 mm from the magnetic axis in four different directions, labelled coherently with the beam coordinate system. Some losses are present in the first part (the expected gradient was 535 T/m). Forces on the anti-solenoid were the same as the first 2D analysis and forces on the QD0 were present and highly related to the shielding efficiency. With the best integrated design the maximum force on the QD0 was roughly 5 KN, in the axial direction towards the IP.

3.3 A last non integrated version

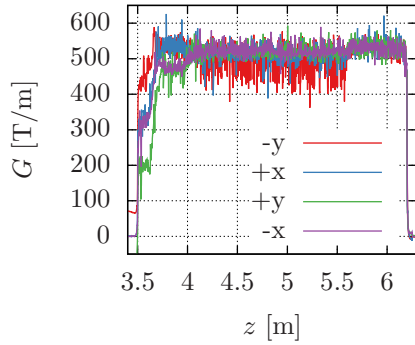
Since the QD0 performance was still not satisfying, it was decided to put aside integration and try to define a better anti-solenoid. The latest design investigated was not compatible with the pre-alignment system [4], since the first coil was closer to the IP, but it was not interfering with the Hadronic Calorimeter or any other system. Figure 7d shows the improvements in terms of gradient. Losses were reduced, as the first part (about 30 cm) of QD0 worked at 95%. The only solution found so far to achieve 100% of the QD0 gradient was to increase L^* by 30 cm.



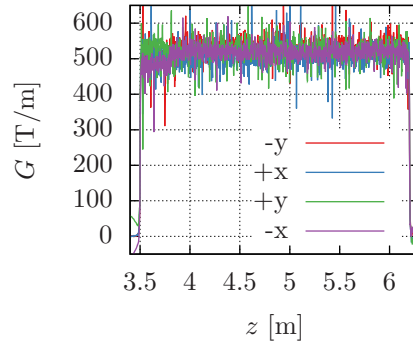
(a) Field on the beamline from the IP to 10 m



(b) Field on the beamline in the QD0 region



(c) QD0 gradient at 1 mm radius



(d) QD0 gradient at 1 mm radius in the best case

Figure 7: The 3D results

3.4 Conclusions and next steps

This study points out that the anti-solenoid *can* shield the QD0, even if this will require some additional space, or a slightly bigger L^* . This will also reduce the forces acting on the magnet, while in the anti-solenoid forces are still relevant and instability issues may occur. As next steps, transient analyses, further integration and better FEM models are foreseen.

References

- [1] A. Gaddi. Main solenoid progress. LCWS11, 2011.
- [2] D. Swoboda. CLIC Spectrometer Magnet Interference. 6th MDI meeting, 2009.
- [3] M. Modena. QD0 and short prototype status. LCWS11, 2011.
- [4] H. Mainaud Durand. BDS alignment progress. LCWS11, 2011.