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CONSIDERATIONS FOR A QD0 WITH HYBRID TECHNOLOGY IN ILC

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Abstract

The baseline design of the QD0 magnet for ILC, the International Linear Collider, is a very compact superconducting quadrupole (coil-dominated magnet). A prototype of this quadrupole is under construction at Brookhaven National Laboratory (USA). In CLIC, the Compact Linear Collider under study at CERN, we are studying a different conceptual solution for the QD0. This is due to two main reasons: all the magnets of the Beam Delivery System will need to be stabilized in the nano-meter range and extremely tight alignment tolerances are required. The proposed solution, now baseline for CLIC, is a room temperature hybrid quadrupole based on resistive coils and permanent magnet blocks (iron-dominated magnet). In this paper we present a conceptual design for a hybrid solution studied and adapted also to the ILC project. A super-ferric configuration (superconducting coils with warm iron poles) is also proposed to make the cross section compatible with the layout of both experiments. This design matches the compactness requirement with the advantages of stability and alignment precision, aspects also critical for ILC in order to achieve its design luminosity. Some final focus optics design considerations for this solution are also presented.

INTRODUCTION

For both ILC experiments (SID and ILD) the QD0 final focus quadrupole baseline design is a Super-Conducting (SC) coil-dominated combined function magnet [1]. This design is very advantageous in terms of magnet compactness, being very limited the available space for the QD0 inside the hadronic calorimeter end-cap (i.e. a cylinder aligned on the incoming beam axis with a diameter of 376 mm in SID and 600 mm in ILD [2]).

On the other hand the SC solution shows some possible disadvantages linked to two other crucial requirements:

- The magnet will need an extremely accurate and precise alignment (in the range of 50 µm);
- In order to preserve the beam luminosity, the source of possible vibrations (i.e. ground motion and any technical noise) must be minimized.

Concerning the first requirement, alignment accuracy and high precision seem not evident with a SC magnet design, where the only accessible element for the final alignment is the external cryostat, inside which the magnetic axis may move as a function of temperature.

With respect to the second requirement, a coil-dominated magnet cooled by LHe could be impacted by vibrations induced by the cooling system. Furthermore, it seems not possible to eventually implement an active stabilization system on a cryostated SC magnet that is by definition a multi-layers assembly. In fact, the cold mass support design will require optimizing the thermal characteristics (ex. lightness and thermal insulation performances), while the stabilization needs will require optimizing the mechanical and structural aspects (ex. stiffness and modal vibrations of the cold mass supports).

In the CLIC project, the design boundary conditions for QD0 are slightly different. Independent of the magnet design choice, the QD0 will require an active stabilization in the sub-nanometer range to achieve the specified luminosity. This aspect was at the base of the development of a “hybrid” iron-dominated design [3], i.e. based on resistive coils + permanent magnet (PM) blocks. Figure 1 shows a recently realized prototype.

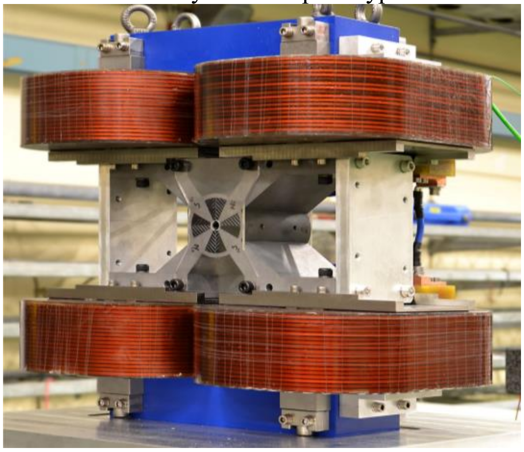

Figure 1: CLIC QD0 short prototype.

One main advantage of this solution is that the monolithic quadrupole core is fully visible and accessible for both the alignment and the stabilization system functions. The coils are designed to operate at a very low current density j (about 1 A/mm^2 at the maximum required gradient of more than 550 T/m) avoiding in this way the necessity of an active water cooling system. The magnet and its ancillary systems will thus be a fully “passive” object, with no potential sources of vibrations.

All the cross-section parameters (dimensions, gradient, ampere-turn, etc.) of the short prototype are fully representative of the “full-size” magnet. A complete magnet will be manufactured assembling several “short” central modules (i.e. Permandur core and SmCo inserts) on full-size return yokes and coils.

THE NEW PROPOSED DESIGN FOR QD0

Within the strengthening collaboration and synergy between CLIC and ILC through the Linear Collider

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Collaboration (LCC), we are evaluating and presenting here a new conceptual design for a “hybrid” ILC QD0 design in two versions:

1. a resistive coils design
2. a new SC coils design proposal.

The first version (with resistive coils) derives from the mentioned above new quadrupole concept developed for CLIC. In the case of ILC the conceptual design is very similar but adapted to the ILC QD0 parameters (gradient, aperture, geometry, etc.).

The ILC Final Focus layout requirements

Figure 2 shows the main geometric parameters for the QD0 Interaction Point (IP) and QD0 layout for ILC.

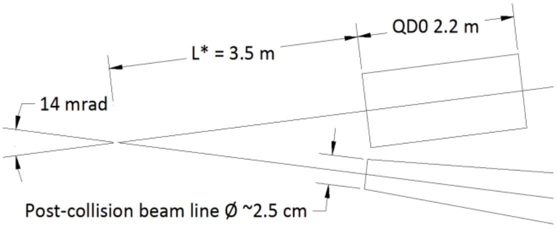

Figure 2: Layout of the ILC interaction region.

The other basic parameters needed to define the 2D cross-section are:

- the required magnetic gradient: 124 T/m
- the magnet bore aperture: 20 mm.

This corresponds to a 1.24 T field at the pole.

The ILC QD0 “warm” version design

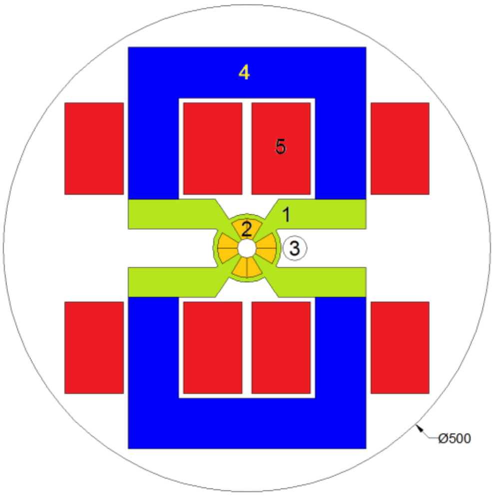

Figure 3: ILC QD0 conceptual cross-section.

Figure 3 depicts the magnet conceptual cross-section. The main components are: the monolithic core part in Permendur (1); the eight SmCo PM inserts (2); the post-collision line chamber (3); the return iron yokes (4), the four EM coils (5). The magnet would fit in a cylindrical envelope of 500 mm diameter.

In Figure 4 are shown the results of the magnetic calculations (done with Opera-2D/ST® code) for a quadrant of the ILC QD0. The star-like line contour in the magnet bore identifies the required “good field region”, where ΔG/G is ≤ 0.01% (gradient homogeneity).

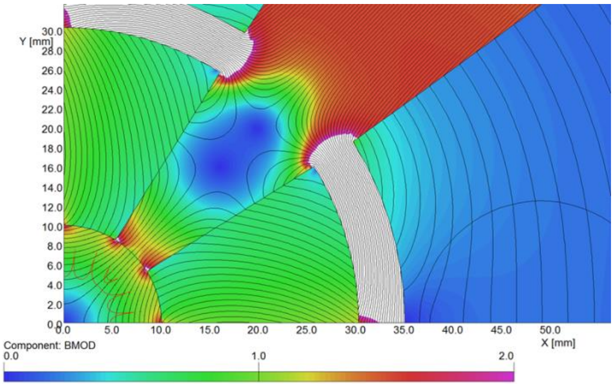

Figure 4: ILC QD0 magnetic calculation plot.

The cross section geometry is optimized to provide the best field quality at the nominal gradient (~127 T/m provided by 5000 ampere-turns). This is shown in Table 1 where we list the magnetic field multipole components for different operating gradients that can be obtained by adjusting the current in the coils.

Table 1: Magnetic Field Multipole Components Produced at Different Working Points (R_{ref}= 3 mm.)

NI[A]	0	1250	2500	3750	5000
G [T/m]	34.494	42.807	68.333	98.196	127.299
b6	63.206	46.397	20.332	7.049	0.021
b10	0.219	0.166	0.083	0.041	0.022
b14	-0.001	0.000	0.001	0.001	0.001
b18	0.027	0.020	0.009	0.003	0.000

The ILC QD0 “super-ferric” version

This new alternative design could combine the positive aspects of the two solutions under study for ILC and CLIC. In case of needing even more compactness, the use of a SC coil design and the use of permanent magnet blocks could further reduce the magnet cross section.

This improvement can be done preserving the presence of a warm monolithic quadrupolar core structure that will thus remain accessible for the alignment and for any eventual passive or active stabilization system.

In this context we have investigated a simple SC coil configuration utilizing standard Nb-Ti wire available from industry. Figure 5 depicts the conceptual cross-section for the super-ferric version. The required 5000 ampere-turns are carried by 9 turns of “F24” type Nb-Ti wire from the company Bruker with a cross-section of 1.8 mm^2 and with 24 Nb-Ti filaments [4].

The cryostat conceptual design is now being defined and no major critical aspects are identified so far. The conceptual design takes advantage of the recent experience at CERN with the manufacturing of the Fast Cycling Magnet super-ferric prototype [5], where similar performances were successfully achieved for very

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compact cryostat dimensions. Figure 5 depicts the conceptual cross-section of the super-ferric version. The cryostat assembly (7) with its intermediate shield @75K (6) will be composed by two halves assembled around the coil packs composed by the 9 SC wire turns wound around the 4.5 K LHe cooling circuit pipe (5). Thermal shields and coil casings will be covered by a low emissivity surface protection (no multi-layer insulation presence).

In this version the magnet would fit in cylindrical envelope of 300 mm diameter.

First calculations show that, with a protection resistance of 200 mΩ, in case of quench the coil temperature will remain acceptable in the range of 30 K.

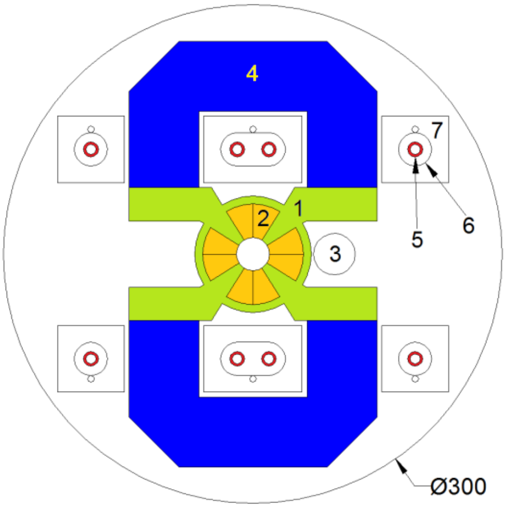

Figure 5: ILC QD0 super-ferric option conceptual design.

Beam Optics Layout considerations

The use of a normal conducting QD0 would not require extra correcting coils like in the superconducting case to generate dipolar and other multipolar components since the same effect could be generated using movers and the field quality expected for such magnet should be good enough to not require these correction coils. Beam steering and correction by nano-positioning movers is an aspect under study for the CLIC Main Beam. A dedicated research line on this subject is on-going within the PACMAN Marie Curie program recently started at CERN [6]. Achievements on this aspect could be profitable also to ILC and CLIC MDI magnets.

Consideration on SD0

The ILC MDI layout includes a sextupole element SD0 placed upstream to the QD0. Table 2 shows the main optic parameters for such magnet. The magnet is placed still inside the experiment end-cap region.

Table 2: ILC SD0 Main Optics Parameters

Length	Minimum Aperture	Sextupolar Strength	Distance from IP
600 mm	6 mm (diam.)	5420 T/m^2	6.85 m

CERN is studying a hybrid design for SD0 magnet that will provide similar advantages as QD0 [7]. Similarly to what proposed here for the QD0, a super-ferric version of SD0 could be also proposed as alternative to the superconducting baseline.

Consideration for the Antisolenoid

The use of hybrid magnets in the MDI region will imply the presence of an antisolenoid in order to shield the QD0 PM blocks from the magnetic field generated by the experiment detector solenoid. This aspect was studied in details for CLIC [8] and no major drawbacks appear in integrating an antisolenoid within the supporting tube of the MDI region. For the most tight layout (SiD case), as shown in Figure 6 the whole integrated design (QD0/antisolenoid/supporting tube) must be included in a cylinder with diameter of 432 mm.

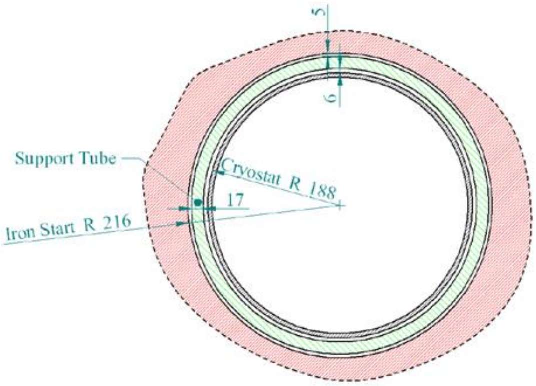

Figure 6: MDI support tube cross-section (SiD experiment layout).

CONCLUSION

An alternative design for the ILC Final Focus QD0 quadrupole was presented. Two versions are under study: a "warm hybrid version" (resistive coils + PM inserts based on the QD0 baseline design under study for CLIC Project) and a "super-ferric hybrid version" where the resistive coils are replaced by a very compact cryostat hosting SC coils composed by 9 turns of industrially available NbTi superconducting wire.

These designs would be more advantageous in terms of alignment and stabilization of the QD0 magnet, a critical aspect to preserve the design luminosity of the collider.

Concerning beam optic and MDI layout aspects, further studies should cover the design and integration of the SD0 and of an antisolenoid needed to shield the PM inserts from the experiment detector magnetic field.

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