depth and the power dissipation. In addition, a system for the data transfer to the back-end electronics has to be developed.

Also of high priority, but not covered for the moment, is the design of GamCal and an estimate of its potential for a fast feedback beam-tuning system.

4.6 COIL AND RETURN YOKE

The basic layout of the ILD detector has always followed the strategy of tracking in a magnetic field. The ILD detector design therefore asks for a 4 T field in a large volume, with a high field homogeneity within the TPC volume and with a reduced fringe field outside the detector.

The parameters of the ILD magnet being very similar to the CMS ones (c.f. [127], [128]), basic designs of both magnets are similar. An anti DiD (Dipole in Detector) is also added in the design, which allows to compensate the effect of the crossing angle for the outgoing beam (and pairs) behind the I.P.

4.6.1 Physics Requirements

The main requests from the physics for the ILD magnet are a solenoidal central field of nominal 3.5 T and maximum 4 T, in a volume of 6.9 m in diameter and a length of 7.35 m with the following requests:

- A high integral field homogeneity:

$$| \int_0^{2.25m} (B_r/B_z)\, dz \,| \leq 10\ mm; B_r = B_x(x/r) + B_y(y/r)$$

  within the TPC volume, which is a cylinder 3.6 m in diameter and 4.5 m long. This high homogeneity requests incorporating compensation windings.

- A fringe field in the radial direction less than 50 G at R = 15 m to not magnetically perturb the second detector when in operation on the beam line.

- A yoke instrumented for the detection of muons and for tail catching (see section 4.7).

4.6.2 Magnet Design

The magnet consists of the superconducting solenoid, including the correction coils, and of the iron yoke, one barrel yoke in three pieces and two end-cap yokes, also in two pieces each. The anti DiD is located outside the solenoid.

Concerning the correction coils, it seemed practically simpler and less space consuming to incorporate them into the main winding, by adding extra currents in appropriate locations of the winding.

The cross section of the ILD detector magnet is shown on Figure 4.6-31. Its main geometrical and electrical parameters are given in Table 4.6-8.

The coil is divided into five modules, electrically and mechanically connected: there are three central modules, 1.65 m long each, and two external modules, 1.2 m long each. All modules consist of a four-layer winding.

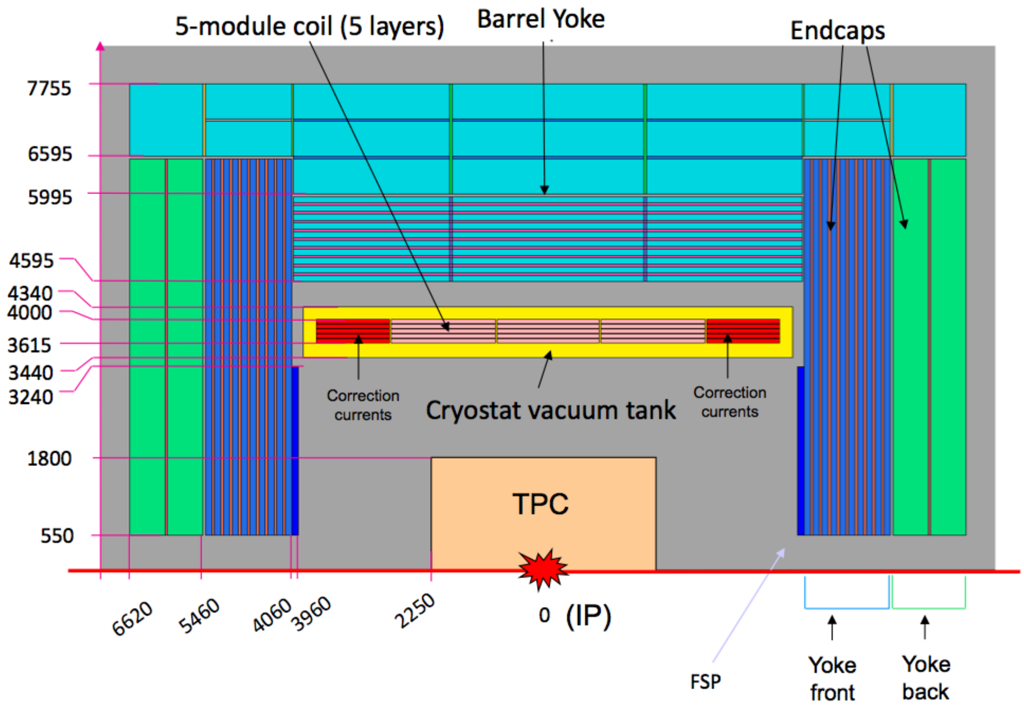

FIGURE 4.6-31. Cross section of the ILD magnet.

Cryostat inner radius (mm)	3440	Maximum central field (T)	4.0
Coil inner radius (mm)	3615	Maximum field on conductor (T)	5.35
Coil outer radius (mm)	4065	Stored energy (GJ)	2.0
Cryostat outer radius (mm)	4340	Stored energy/ cold mass (kJ/kg)	12.2
Barrel yoke inner radius (mm)	4595	Nominal main current (kA)	18.2
Barrel yoke outer radius (mm)	7755	Nominal correction current (kA)	15.8
Coil length (mm)	7350	Ampere-turns main coil (MAt)	1.52
Cryostat length (mm)	7810	Ampere-turns correction coils (MAt)	1.36
Yoke overall length (mm)	$6620 * 2$		

TABLE 4.6-8
Main geometrical and electrical parameters

The nominal main current, 18.2 kA for a central field of 4.0 T, runs through all the turns of the solenoid. An extra correction current of about 15.8 kA is added in the turns of the four layers of the two external modules to get the integral field homogeneity.

The barrel yoke has a dodecagonal shape. It is longitudinally split into three parts. In the radial direction, the inner part of the yoke is made from 10 iron plates of 100 mm thickness, with a space of 40 mm between each to house detectors for tail catching and muon detection. Three thicker iron plates of 560 mm each with 40 mm spaces for muon detectors form the outer part of the barrel yoke. The weight of the barrel yoke is around 7000 t.

The end-cap yokes, also of dodecagonal shape, have a similar split structure, with 10 iron plates of 100 mm thickness in the inner part, with a space of 40 mm between each to house the tail catcher and muon detectors, and two external thick plates, each 560 mm thick, to make up the total iron thickness. A 100 mm thick field shaping plate (FSP) will be added inside each end-cap to improve the field homogeneity. The weight of each end cap yoke is around 3250 t and thus the total weight of the yoke is around 13400 t.

The main design challenge of the yoke endcaps is to contain the magnetic forces themselves. A weight equivalent of ≈18.000 t pulls at each endcap. A FEM analysis shows that if the endcaps are constructed in radially fixed segments (c.f. figure 4.6-32) the deformation of the endcaps due to the magnetic force could be less than 3 mm; alternative designs which lead to comparable small deformations are also under study. These deformations are far smaller than e.g. at CMS where the endcaps are deformed by ≈16 mm during the powering of the magnet.

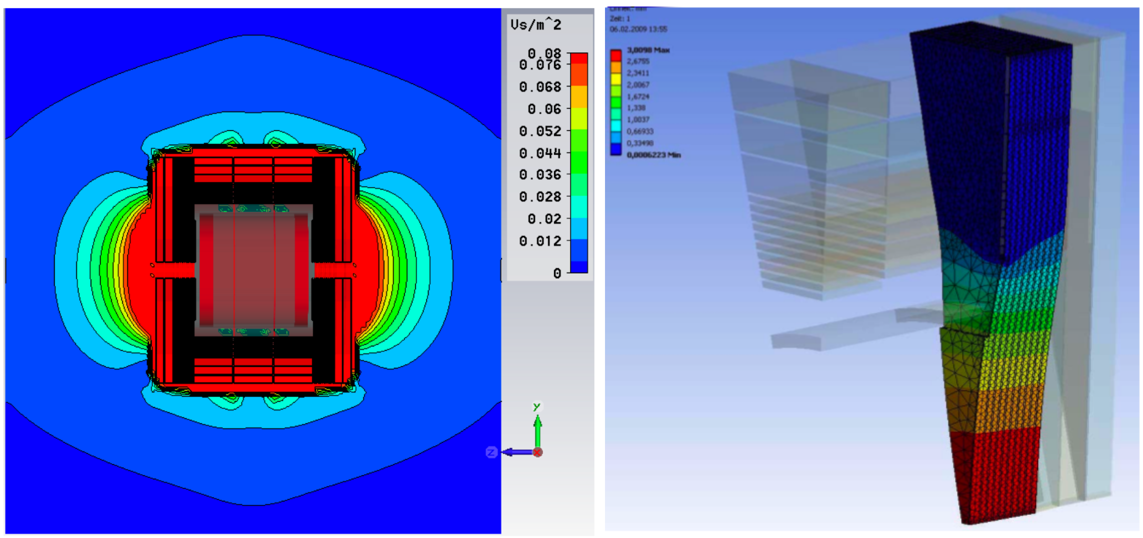

FIGURE 4.6-32. Strayfields outside the yoke (left). Deformation of an endcap segment (right).

4.6.3 Magnetic Field

The calculated integral field homogeneity, with the nominal values of the main and correction currents given in table 4.6-8 meets the requirement (maximum value of 7 mm at 4 T). Note that the effect of the anti DiD is not taken into account in this calculation.

With the yoke structure described, the calculated fringing field is ≈40 Gauss at 15 m in the radial direction and therefore fulfils the requirements (c.f. figure 4.6-32).

4.6.4 Technical Aspects

As several technical aspects are quite similar for the ILD and CMS magnets, the experience gained during the construction of the CMS magnet will be of great help for ILD.

The conductor will consist of a superconducting cable coextruded inside a low electrical resistivity stabiliser and mechanically reinforced by adding high-strength aluminum alloy. Two different conductors will be necessary, using different superconducting cables and different ratio of mechanical reinforcement, but with the same overall dimensions.

The winding will be done using an inner winding technique. The magnetic forces will be contained both by the local reinforcement of the conductor and by an external cylinder. The coil will be indirectly cooled by saturated liquid helium at 4.5 K, circulating in a thermo-siphon mode.

The central barrel yoke ring will support the vacuum tank. Internal sub-detectors will be supported on rails inside the vacuum tank.

4.7 MUON DETECTOR

The identification of leptons is an important part of the physics programme at the ILC. For muons above a few GeV, the instrumented iron return yoke is used as a high efficiency muon identifier. The clean environment of an electron-positron Linear Collider allows for a muon system design that is much simpler compared to the ones that have been developed for the hadron colliders. There is no need to trigger on muon tracks; instead the clean nature of the events at the ILC allows the linking of track candidates from the inner detectors with tracks in the muon system.

In addition to its muon tagging ability the system will be instrumented to allow for a limited calorimetric performance. In this way it can act as a tail catcher, tagging late developing showers and thus improving the energy measurement.

A muon is most easily identified by a track in a muon detector behind significant material. At the ILD, the muon system is reached by muons with a momentum above about 3 GeV. The strong central magnetic field will keep lower energy particles from reaching the muon system. The main challenge then for these type of muons is the joining of a signal in the calorimeter with a track segment outside the coil. Multiple scattering in the calorimeters and the coil will have a large impact on this, and the efficiency of association will increase with momentum. At lower momenta, the signal in the calorimeter will be used to identify muons. In particular inside jets this is difficult, and more in - depth studies are needed within ILD to reach strong conclusions.

4.7.1 Conceptual Design

The muon system in ILD will cover a large area of several thousand square meters. The detectors therefore need to be reliable, easy to build, and economical. Signals from the detectors should be large so that simple readout systems and cable routings can be used to the readout modules. The detectors should have a reasonable temporal and spatial resolution. Searches for long-lived particles and tagging of cosmics and beam halo muons requires that a few nsec time resolution be achievable. Since multiple scattering is significant, spatial resolutions in the range of cm are sufficient. Occupancies are low, so that both strip and pixel devices can be considered. The efficiency and reliability of muon identification somewhat depends on the iron longitudinal segmentation as do calorimetric performances. Mechanical construction and practical considerations indicate that plate thickness cannot be below 10 cm. For the ILD design, the total thickness needed to close the magnetic flux is ≈ 275 cm (see 4.6). It is instrumented with 10 layers of detector with 10 cm thick absorber plates in between, and a few layers at larger distance in the remainder of the yoke.

Both gas detector and extruded scintillator strips can in principle fulfill the requirements. Plastic Streamer Tubes (PST) or Resistive Plate Chambers (RPC) are candidates for the gas detector. However, RPCs tend to be preferred over PSTs due to their reduced cost and