1 Magnet

1.1 Basic Design Considerations

The magnetic field must deflect charged particles such that their momenta can be obtained with sufficient resolution: $\delta p/p$ =1%-1.5% (σ). On the other hand, lepton identification with the RICH detector requires a nearly field free region around the target. Furthermore, a large momentum range of p=0.1 GeV/c - 1.5 GeV/c (see chapter *Design Principles*) must be accepted simultaneously within a large solid angle ($\theta = 20^0$ - 85^0, all azimuthal angles).

The large momentum range leads to a non-focusing spectrometer with a transverse momentum kick p_T^{field} below 100 MeV/c. The latter corresponds to a product of magnetic field times path length of less then 0.34 Tm. Assuming a magnetic field region of 0.5 m in order to keep the spectrometer compact, the magnetic field still stays below 0.7 T. For such a design, the required momentum resolution can be obtained only by keeping multiple scattering in the magnetic field region as small as possible. The contribution of multiple scattering to the momentum resolution amounts to

$$\delta p = 13.6\ \text{MeV/c} \cdot \sqrt{(d/L)}$$

where d specifies the width of the field region and L the radiation length.

A momentum resolution of 1% resulting from multiple scattering only requires an effective thickness d/L=0.5%. In this value the contribution from the detectors to measure the deflection of the particle must be included. It can be achieved only by filling the volume between the detectors with helium.

A transverse kick below 100 MeV also puts constraints on the position resolution of the particle detectors. At 1 GeV/c the deflection angle amounts to about 5.7^0. A simple model calculation assuming two sets of two detectors spaced by 0.3 m shows that a position resolution of better then 150 μm is required in order to obtain a momentum resolution of 1% at 1GeV/c.

1.2 Field Geometry

Both toroidal and solenoidal field geometries were investigated:

- For a solenoidal field geometry a field free region around the target needed for the RICH detector can be only approximated by (superconducting) correction coils. At small polar angles the field direction is nearly parallel to the particle direction reducing the transverse kick provided by the field in the region were the largest particle momenta occur.

  Outside the spectrometer, the field lines are occupying a large volume with a high magnetic field and corresponding problems (high field energy, shielding of photomultipliers). This can be avoided by a massive iron yoke, which would constitute a strong source of background due to secondary particle production. A more detailed discussion of a solenoidal field configuration is contained in the HADES LOI[1].

- The toroidal field geometry avoids these problems. Since the shadow of the coils can be aligned with the detector frames, no additional loss of solid angle is caused by the coils.

  Although the field strength is rather low, superconducting coils are necessary in order to obtain a compact coil construction. A non-superconducting spectrometer shadowing about the same solid angle as a superconducting one (including heat shields and vacuum chamber) would result in a power consumption of about 10 MW. Although such a concept might be technically feasible, the operating cost would compensate the cost reduction for the construction within less than 2 years.

1.3 The Superconducting Toroid

In the following a design of a superconducting toroid is shortly discussed. The main parameters of the construction are based on a feasibility study performed by Oxford Instruments (special project division).

The system consists of 6 coils surrounding the beam axis. Each coil is separately contained in its individual vacuum chamber. The latter are connected to a support ring located upstream of the target.

Figure 1-1 shows a vertical cut (left) and a front view (right) of the magnet including the support structure of the coil cases. A hexagonal plate with a hole for the beam pipe connects the front end of the 6 coil cases. Through this plate the magnetic forces acting on the coil cases are compensated. The ring upstream of the target contains the electrical connections between the coils as well as the He and nitrogen cooling lines. No support structure is needed in the region where the drift chambers are placed. No material is placed in a 7^0 cone around the beam axis.

Each coil consists of a straight entrance and exit section connected by two arcs. The total current through a coil amounts to 500000 A turns. The angles of the entrance and exit sections of 40^0 and 45^0 were chosen to minimize the azimuthal deflection of particles over the whole range of polar angles of 18^0 to 85^0. Due to the V-shape of the coil a small net focusing with

[1]HADES Letter of Intent, GSI (1992)

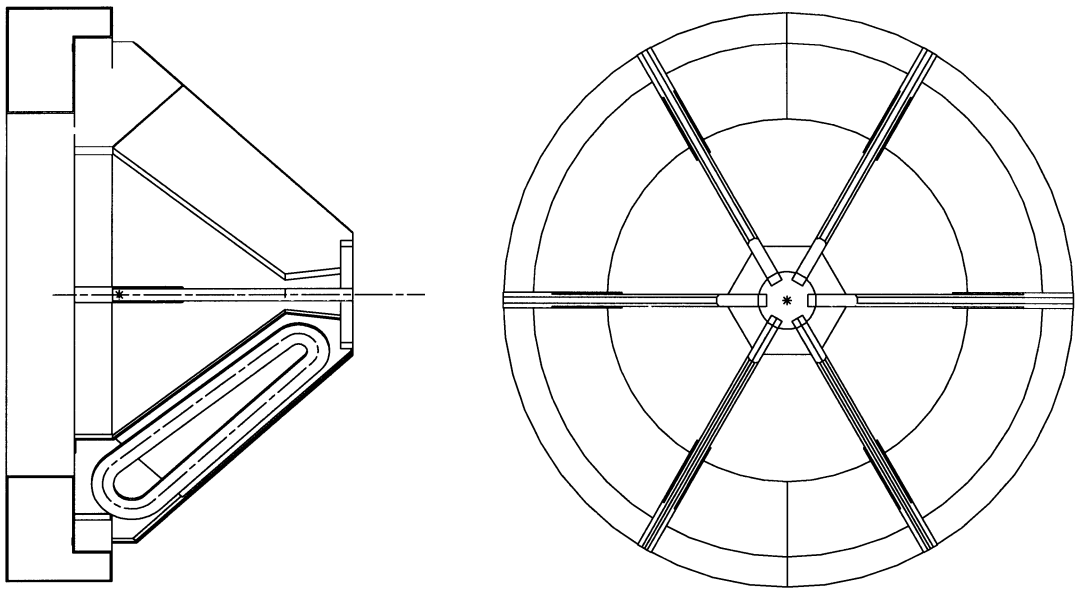

Figure 1-1: *Vertical cut (left) and front view (right) of the superconducting toroid (schematically). 6 coils are mounted in individual vacuum chambers which are connected by a support ring upstream of the target. A hexagonal front plate compensates the magnetic forces between the coil cases.*

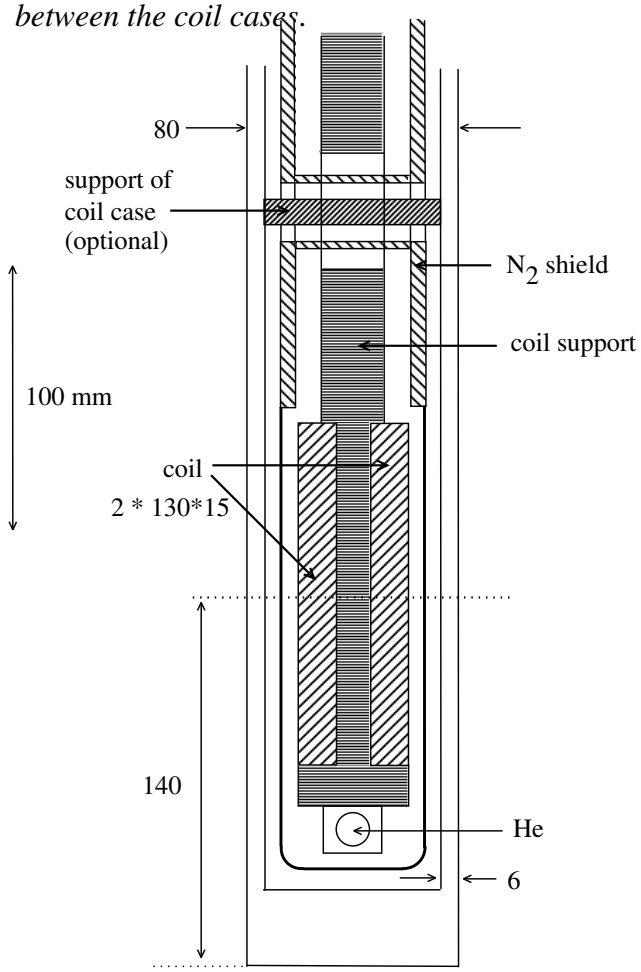

Figure 1-2: *Schematic cross section through a coil case showing the thermal shield, the superconducting coil and the coil support structure.*

θ [Degrees]	25	45	60	80
δp [MeV/c]	103	70	62	55

Table 1-1: *Transverse momentum kick for various polar angles at an azimuthal angle of 15°. A total current per coil of 500000 A turns is assumed.*

respect to the azimuthal angles is obtained. The shape and orientation of the coil results in a stronger transverse momentum kick at small polar angles (see table Table 1-1). For beam

energies of 1-2 AGeV, the transverse momentum kick provided by the field follows roughly the kinematical variation of the particle momenta with the polar angle.

Figure 1-2 shows a schematic cross section through one coil case. The double pancake: shaped coil of 2·140·15 mm^2 cross section is surrounded by a heat shield at liquid nitrogen temperature and the vacuum chamber. The coil consists of Al stabilized Cu(Nb/Ti) conductor. An Al to Cu(Nb/Ti) ratio of about 3:1 will be used. The average current density in the coil amounts to 120 A/mm^2. The forces (see Figure 1-3) on the coil reach values of up to nearly 400 kp/cm. The forces between the straight sections of the coil

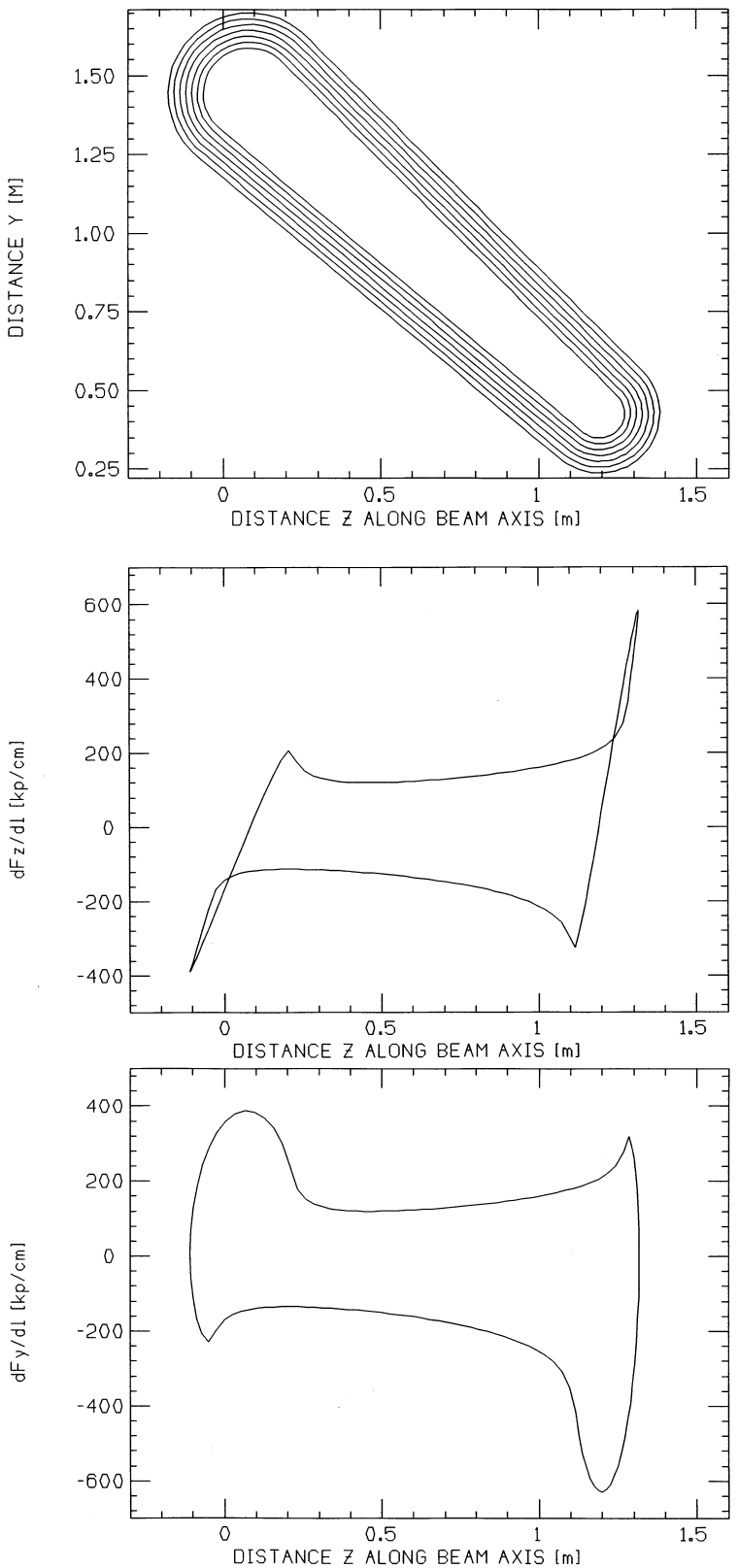

Figure 1-3: *Coil shape (top) and differential forces $\partial F_z/\partial l$ (center) $\partial F_y/\partial l$ (bottom), respectively, along the coil.*

nearly compensate each other. The net force on each coil amounts to 2.3 t. This force is transferred to the coil case by cold-to-warm support rods. The total energy stored in the magnetic field amounts to 1.4 MJ.

The effective thickness of the system relevant for secondary particle production was calculated as follows. For a given cross section of the coil case the areas covered by the various materials are divided by the respective radiation length and summed. By averaging along the coil a mean effective thickness is obtained. This effective thickness amounts to 415 mm for one coil including the support structure, the coil case and the heat shield. For simulation purposes a 10% higher value was assumed.

Figure 1-4 shows contour plots of the main magnetic field component at azimuthal angles of 0^0, 15^0 and 25^0, respectively. The maximum field of about 3.6 T is obtained at the coil surface inside the forward arc. In between the coils (Figure 1-4, top,left) the field extends over a significantly wider region as compared to the azimuthal region close to the coils (Figure 1-4, bottom).

1.4 Cryogenics

A cryogenic system for the superconducting magnet is already available at GSI. The system was donated by Bessy, Berlin. Its liquid He capacitance of about 40 l/h is sufficient. A

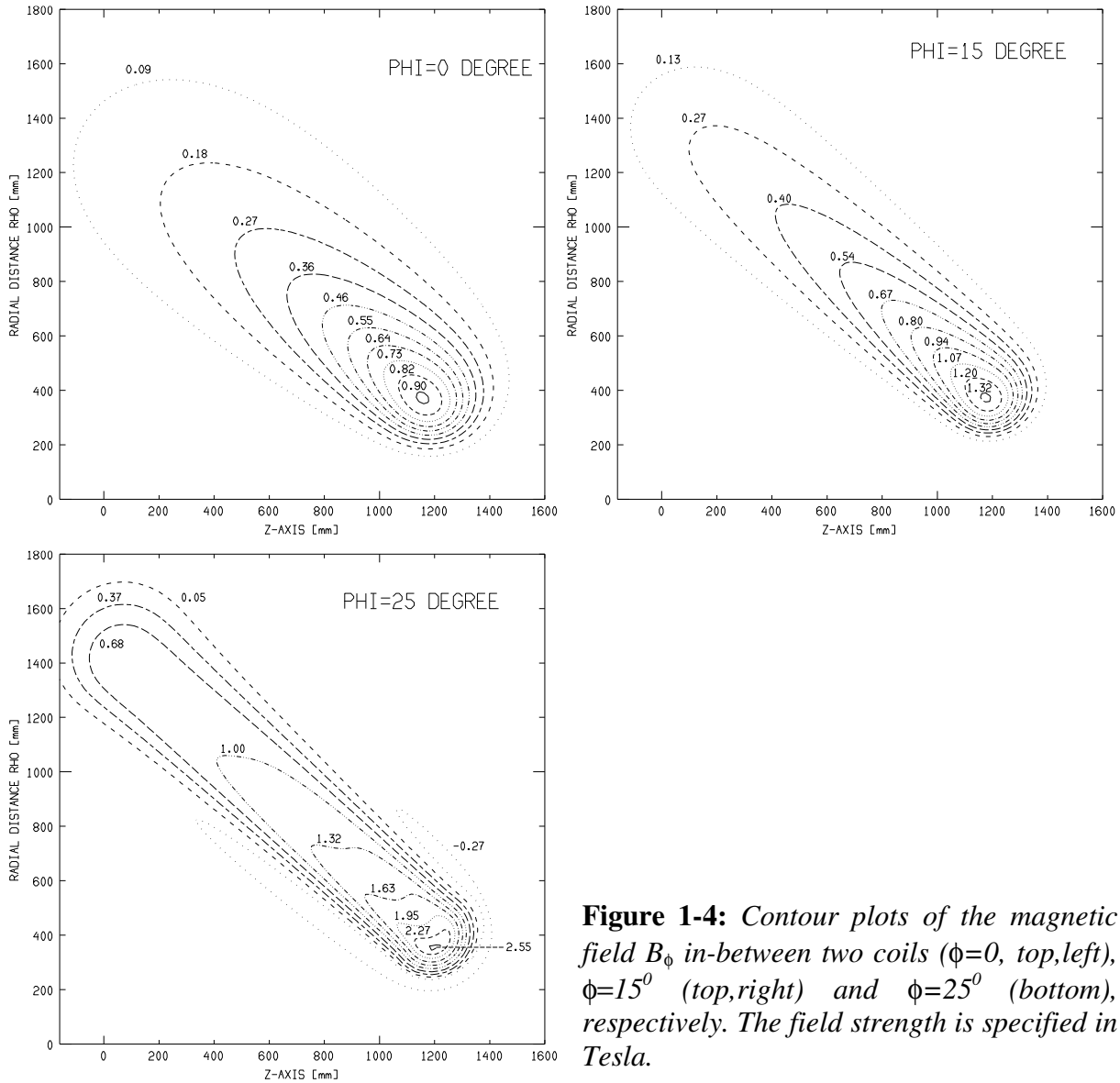

Figure 1-4: *Contour plots of the magnetic field B_ϕ in-between two coils (ϕ=0, top,left), ϕ=15^0 (top,right) and ϕ=25^0 (bottom), respectively. The field strength is specified in Tesla.*

detailed discussion of the performance of this system with Oxford instruments, special project division has shown, however, that some modifications are necessary, in order to match the output conditions (pressure, temperature) of the He with the input conditions needed for the magnet. In addition to the existing system, a He transfer line is needed. Questions related to the interface between the magnet and the existing liquifier, are currently investigated.

1.5 Outlook

The magnet will be delivered as a complete system by a company. Currently, a detailed design study of the magnet is performed by Oxford instruments, special projects group. In addition, several other companies from various european countries including Russia as well as from the USA and Japan will be included in the tender process.