MAGNET DESIGN OF THE ENC@FAIR INTERACTION REGION

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Abstract

The Electron Nucleon Collider, proposed as an extension to the High Energy Storage Ring (HESR), is currently investigated and a first layout of the Interaction Region (IR) proposed. The limited size of the machine, the low beam energy and the Lorentz force vector pointing in the same direction for both beams make the IR design demanding. In this paper we present the parameters of the IR magnets, show the boundary conditions given by the beam dynamics and the experiments. We present first 2D designs for the electron and proton triplet magnets along with the separating dipole next to the collision point. Different methods to shield the beam in the spectrometer dipoles are investigated and presented.

INTRODUCTION

A Lepton/Nucleon collider will extend the physics provided by the Facility for Antiproton and Ion Research (FAIR) at the GSI Helmholtzzentrum für Schwerionenforschung mbH to polarised Lepton/Nucleon Experiments [1]. This machine will reuse the High Energy Storage Ring (HESR) as the proton storage ring together with the P̄anda detector. A separate accelerator will be used for polarised electrons. Since the leptons will carry only 25% of the ion beam momentum, beam separation can be achieved by magnetic dipole fields in head on collisions. An IR [2] design achieved compliance with the requirements of the experiments while simultaneously allowing for a sufficiently low $\beta*$. This paper presents calculations on the field qualities and technological feasibility in the individual magnets of the IR.

INTERACTION REGION LAYOUT

The interaction region (IR, see Fig. 1) [2] will separate the two beams using two 0.33 Tm dipoles placed 0.6 m away from the interaction point (IP). Then the proton beam will be further deviated in the downstream spectrometer dipole, while the electron beam has to be shielded. On the other side an electron spectrometer will be installed, where the proton beam will be shielded. This will separate the beams by roughly 120 mm when 7m apart from the IP. At this location the final focusing triplets will be installed.

The parameters of the IR dipole as well as the strongest quadrupole of the proton and electron triplet are given in

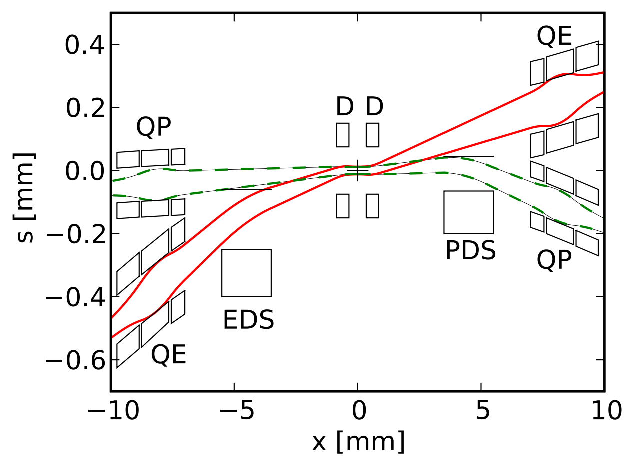

Figure 1: A sketch of the ENC IR region. Red solid line ...electrons, green dashed lines ...protons. large cross ...IP. Magnets: D ...separation dipole, PDS ...spectrometer dipole, EDS ...electron spectrometer dipole; QP ...proton triplet quadrupole, QE ...electron triplet quadrupole.

Table 1: The IR magnet parameters.

	field strength $[T/m^{(n-1)}]$	length [m]	radius [mm]
dipole (D)	0.66	0.5	75.
proton quadrupole (QP)	53	1.1	50.5
electron quadrupole (QE)	10.5	1.1	77.5

Table 1. The inner dipoles will have to be mounted within the P̄anda solenoid, integrated within the detectors. Dipole magnets operating in a background solenoid of 2T are best implemented as air coil magnets typically using superconductors further fulfilling the additional requirement of being small and of light mass.

The electron beam must be shielded within the spectrometer dipole, as otherwise the synchrotron radiation would reach an unacceptable power of 55KW [2]. The electron and proton beam size as well as their distance limit the shield thickness to 1 cm.

Given that the IR dipoles are built using superconductors and the beam separation is still only 120 mm at the location of the first quadrupole of the triplets, also the quadrupoles are proposed to be built as air coils using superconductors.

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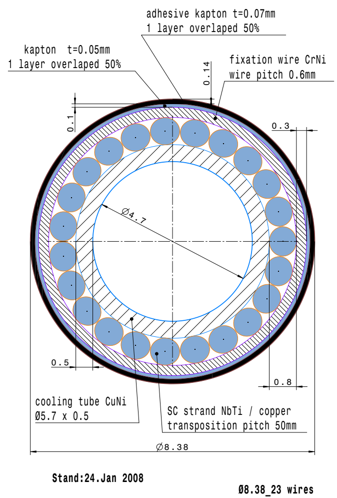

Figure 2: The high current cable and its parameters.

MAGNET DESIGN

The magnets have to fulfil the field quality requirements typical for accelerator magnets while filling as little space as possible as typically required for detector magnets. Classical multipoles

$$\mathbf{B}(z) = \sum_{n=1}^{\infty} \mathbf{C}_m \left(\frac{\mathbf{z}}{R_{Ref}} \right)^{n-1} \quad (1)$$

are used and appropriate to describe the magnetic field in the magnet aperture. Here $\mathbf{B}(\mathbf{z}) = \mathbf{B}(x + \mathrm{i}y) = B_y + \mathrm{i}B_x$ with x and y the Cartesian 2D coordinates and $R_{Ref} = 35\,mm$ the reference radius. The higher order harmonics $\mathbf{c}_n = b_n + \mathrm{i}a_n$ are given by $c_n = \frac{C_n}{C_m} 10^4$, with m the main multipole ($m = 1$ for the dipole). The relative multipoles are presented in units (1 unit = 100 ppm). $b_y(\mathbf{z})$ is defined by $b_y(\mathbf{z}) = (B_y(\mathbf{z}) - B_y(0)))/B_y$.

Selected Cable

As cable the Nuclotron cable was chosen [3], in particular the cable for the SIS 100 single layer dipole [4, 5, 6] (see Fig. 2) as it simplifies the cold mass design and can be cooled with a large continuous helium flow providing an ample recooling power. For the target field of $0.3\,Tm$ a current of roughly 10 kA is required, which can be distributed on the individual strands (23) thus giving an acceptable current of $\approx 434\,A$ [7, 8, 9]. Further all helium, required to cool the magnet is enclosed within the tube. This reduces significantly the amount of material, required to be helium leak tight simplifying the overall design. The cable support can be made of any material strong enough to withstand the Lorentz forces and chosen such that it minimises the background.

IR Dipole

Due to the $\bar{\text{P}}$anda detector operated at 2T, the inserted magnets must be iron free. An initial 2D design of the IR dipole was made using a single layer coil (see Fig. 3).

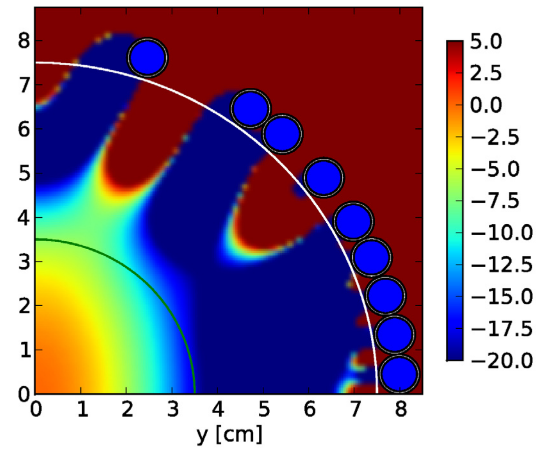

Figure 3: The cross section of the IR dipole. The blue circles denote the positions of the coil windings. The field quality b_y (in units) is depicted in the magnet aperture.

Table 2: The relative multipoles of the IR dipole (in units).

$B_1[T]$	$I[A]$	b_3	b_5	b_7	b_9	b_{11}	b_{13}	b_{15}
0.66	9749	0	0	0.13	-0.33	0.27	0.01	-0.02

As the magnet is iron free, the field quality is independent of the applied current. Thus the field quality is given only for one value (see Table 2).

IR Triplets

IR Electron Quadrupole The cable proposed can be also used for the electron quadrupole and will be operated at similar currents. A good field quality was found for a two layer design. The 2D design of the cross section is given in Fig. 4. The calculated (geometric) c_n are given in Table 3, which are close to zero, also attributed to the fact that the coil radius is much larger than the reference radius.

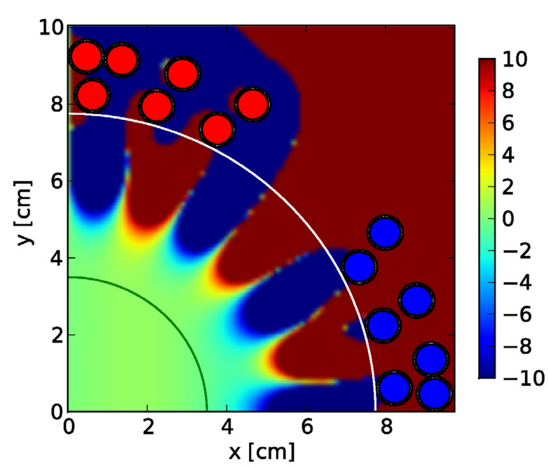

Figure 4: The 2D cross section of the IR electron quadrupole as well as the field homogeneity.

Table 3: Field of the electron (QE) and proton (QP) triplet quadrupoles.

	G [T/m]	I [A]	b_6	b_{10}	b_{14}
QE	10.5	8955	0	0	0.053
QP	53	24735	0	0	-3.45

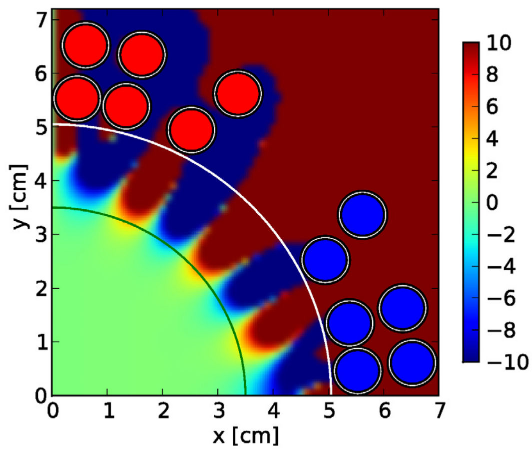

Figure 5: The 2D cross section of the IR proton quadrupole as well as its field homogeneity.

IR Proton Quadrupole The proton beam has a smaller diameter in the triplets, so the magnet diameter was adjusted. To achieve the requested gradient, the current has to be enlarged to $\approx$ 25 kA (or for the single wire $\approx 1075A$. The field of $\approx 2.6\,T$ together with the current are above the critical surface of this cable, thus the wire diameter will have to be increased for this cable and the design readapted. The 2D (geometric) multipoles b_n are given in Table 2 which are still rather small.

SHIELDING THE ELECTRON BEAM

After the solenoid the particle beams have to be further separated by the spectrometer dipoles, required for analysing the secondary particle beams. One of them is operated at 1 Tesla and used to further deflect the protons. The electrons must be shielded to limit the synchrotron radiation as well as to achieve the required beam separation.

An iron shield was investigated, but found to be of limited use, as a 1 cm thick iron tube will not reduce the field for the electrons to an acceptable level.

Superconductors have been used as magnetic shields, using their field expelling effect, since [10] and were reported to be used as shield up to levels of 3 [11] and 4 T [12] with an internal field level well below 5 mT [12]. The authors in [11] used a tube of 9 mm thickness, comparable with the requirements of this IR design.

So literature shows that such an shield is possible, but its design and performance have to be asserted in a dedicated R&D program.

CONCLUSION AND OUTLOOK

The proposed ENC IR design requires superconducting air coil dipoles as beam separators next to the IP. Thus all magnets are considered to be built using superconductors, which will allow to build them as slim magnets. These magnets are based on the Nuclotron cable, as it is used at GSI for SIS100, abandons a dedicated helium vessel and provides an ample recooling power if synchrotron or other radiation hits the magnet.

Superconducting shields, as foreseen for the electron beam in the spectrometer dipole, have been demonstrated; the particular design and performance must be tested on a model. Such a shield can be of further interest as an alternative to a superconducting septum magnet.

The gradient and current required for the IR proton triplet quadrupoles will require enlarging the wire diameter of the cable. Further the magnet designs presented here are of minimum size to provide a proof of concept. The quadrupole magnets provide the good field quality not for the whole tails of the beam. The space between the triplets allow increasing their diameter as well as adapting the interlayer distance for technological improvements. Further the mutual field distortion between the triplet quadrupoles (especially the ones nearest to the IP) has to be investigated and seen if an asymmetry shall be introduced in the windings to compensate them.

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