HDice Safety coil design (DRAFT)

A. Deur (deurpam@jlab.org), L. Quettier (quettier@jlab.org)

June 28, 2010

1 Purpose

The polarized HD material needs to stay under a magnetic field or it would lose its polarization. Since it takes several months to build-up a usable polarization for a HD cell, accidentally depolarizing is a significant setback. The magnetic field is mainly provided by the main supraconducting 1 Tesla solenoid [1]. In case of quench or other problems, a secondary field needs to be provided. This is the purpose of the safety coil.

2 Design

2.1 Specifications and constrains

It is not well known what would be the minimal field magnitude in order to avoid significant polarization loss. However, experience from operations at BNL indicates that 100 Gauss is enough. This will be the specification. Other constrains are: 1) a minimal amount of material [2], 2) no significant gradients added to the main 1 Tesla field during NMR and spin operations, and 3) reliable operations (no failure or delay allowed in establishing the field).

2.2 Design and Field magnitude

Since the safety coil has to function in the event of a (partial) cryogen delivery failure, it has to be a non-supraconductor (if no cryogen at all is present in the cryostat, the issue becomes moot since the HD would lose its polarization and then vaporize). In the current In-Beam Cryostat (IBC) design, the coil is wound on a 10 mil Aluminum sheet itself supported by a rigid plastic foam Rohacell tube 1/2 inch thick. The internal radius of the coil is 5.76 inches and its length is 11 inches. It is centered on the HD cell. The safety coil is outside the ^{4}He bath in order to not add heat load and save space. Consequently, appropriate cooling has to be supplied and the larger diameter (compared to a in IBC design) implies higher current and more material. In order to reach 100 Gauss and keep the coil temperature low enough, we use 3 layers of Al. wires (0.1016 cm bare diameter and 0.111 cm of insulated diameter).

2.3 Cooling

Cooling should be provided by two means: 1) blowing cool Nitrogen gas on the cell, and 2) cooling the Al. sheet by heat sinking to the cryostat or by using a $\sim 5^o$ chiller. Assuming that the Al. sheet is a 5^o c thermostat and we have room temperature Nitrogen gas blowing, one can assume a 150 W/m^2 thermal coefficient. For 2 Al. wire layers and a 4.5 A current, this yields a 90^o c temperature, which is too high (Note: the Rohacell maximum service temperature in air is 180^oc. But 90^oc can lead to safety issues). We will thus use 3 layers with a 3A current.

(An alternate possibility investigated was using hollow tubes. This would provide much more cooling power. However, we could not find a company providing tubes suitable for our purpose.)

2.4 Operation

In order to circumvent the constrain of not adding significant gradients to the main solenoid field, we plan to turn off the safety coils during NMR measurements and spin transfer operations. Those are the only times during which having a flat magnetic field is critical. The field should be on during the rest of the time, which represents the bulk of the experiment. During NMR and spin transfers, the main solenoid will be turned off, but should be turned on at any sign of a ramp down or a quench of the main solenoid power supply. This can be achieved using a relay enabled when the main power supply ramps down below a set current value or when a magnetic field probe reads below a set field value. The relay operation and current establishment in the safety coil have to be fast enough so that the safety field reaches 100 Gauss before the end of the ramp down of the main power supply.

(The option of using the Cu stabilizer of the main solenoid supraconductor as the safety coil is attractive since no additional material in the path of the scattered particles is added. However, it is impractical because we cannot switch on fast enough and in a robust and reliable (i.e. simple) way the safety power supply, while the main power supply ramps down (in that option, the two power supplies would be on the same coil, since the main solenoid and safety solenoid would be the same magnet). The heat load would also overwhelm the cryostat.)

2.5 Radiation Length

This is discussed in [2]. We reproduce it here for convenience:

- Vacuum chamber: 1/2 inch Rohacell foam (polymethacrylimide. RL˜790 cm: took the RL of polymethylmethacrylate: 34.07cm and scaled by its density (1.19 g/cc) divided the density of Rohacell (0.0513 g/cc)): **0.16%**
- Epoxy and Al paint of Roacell chamber. This is neglected.
- Safety coil: 3 layers of 0.1 cm diameter Al. wires with insulation (total diameter: 0.111cm): RL=2.24%$\times\pi/4$=**2.64%**

- Plate of 1/4 mm Al: RL=**0.28%**

Hence the total radiation length is **3.08%** (for particles crossing the coils at 90^o angle)

2.6 Photon operation vs electron operation design

2.6.1 Shorter solenoids

Taking advantage of the facts that 1) the safety solenoid has a large diameter and 2) we can tolerate large gradients (as long as the minimal field does not go significantly below 100 Gauss), an alternate design is to use a shorter solenoid. The solenoid could also be offset upstream (to the beam). This would provide a larger angle below which the forward going particles would not cross the coil. This would be similar to e.g. the case of the polarized ammonia DNP target for which particles go through (relatively) small radiation lengths below a $\sim 40^o$ scattering angle (above this angle, the amount of material is so large that the particles are lost for all purposes).

The figure 1. provides the field for different lengths of solenoid. The fields are centered on the HD cell (0 cm), not shifted yet to account for a upstream offset. For a centered 11" solenoid, the opening angle for particles scattering at the beginning of the HD cell is $\theta_{blocked} \simeq tan^{-1}(\frac{7}{28/2+5/2}) \simeq 23^o$. 7 cm is the approximate inner solenoid diameter, 28 cm its approximate length and 5 cm the GD cell length. The table below gives $\theta_{blocked}$ for different solenoid lengths (the solenoids are centered on the cell, as in the figure):

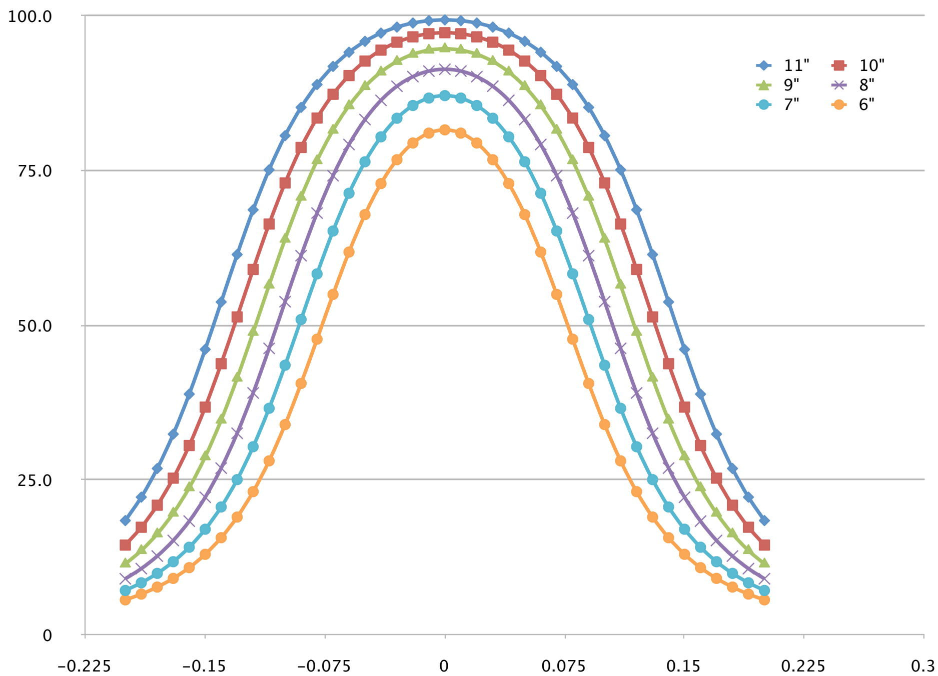
Length	$\theta_{blocked}$
11"	23^o
10"	25^o
9"	26.7^o
8"	29^o
7"	31.6^o
6"	34.6^o

The magnetic field gradient for the 6" result is about 4.3% over the target length and the maximum field is 82 Gauss. Offsetting the 6" solenoid 7 cm upstream yields $\theta_{blocked} = 47^o$ with a 31% gradient and maximum/minimum fields of 55/37.7 Gauss over the cell length (for 2 layers and I=4.5 A). This low field is not a problem since the radiation length is not an issue anymore and we can add as many layers of wire as necessary.

2.6.2 Discussion

The choice of having a shorter and offset solenoid is optimal for an electron run: due to very low counting rates, detecting electrons above 47^o is not important[1]. However, this is not the case for the photons which cross section is more

[1] I don't know about heavier particles (pions, protons). They penetrate matter more effectively but they could still be stopped if they have low energies. Here, I discuss only electrons



Magnetic field for different rllength of the safety coils. The current assumed is 4.5 A for 2 layers of wire.

isotropic. The shorter, offset solenoid would also have larger radiation length. Consequently the original design (11”, centered) seems best suited for photon experiments while a shorter and offset design could be used for an electron experiment. Switching solenoids should not be an issue given their simplicity. (Note: There is no need for switching to the shorter design during the electron test run that will follow the first photon experiment, as long as we are only interested in inclusive elastic electron scattering to monitor the HD polarization: 23^o is enough aperture for elastic scattering off protons with few GeV electron beam. If we care about reactions other than inclusive elastic, then the 11” solenoid may be inconvenient).

References

[1] A. Deur, Magnetic Fields for the HD cell transfer. HDice TN2: http://www.jlab.org/Hall-B/HDIce/technotes/hd_3fields.pdf

[2] A. Deur, List of outgoing radiation lengths. HDice TN3: http://www.jlab.org/Hall-B/HDIce/technotes/hd_rl.pdf