Date: June 15, 2016

EIC Detector R&D
Progress Report and Proposal

Project ID: eRD2
Project Name: Magnetic Field Cloaking Device
Period reported: from **January 2016** to **June 2016**
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Abstract

The collisions at the Electron Ion Collider will be very asymmetric (due to the different momenta of the incoming particles) and yield a large number of final state particles at high pseudorapidities. A magnetic field oriented transversely to the beam line could significantly improve the momentum resolution for these particles over using only the fringe field of a solenoid. However, the collider beam has to be shielded from transverse fields to avoid deflection and depolarization. This project aims at demonstrating the viability of a magnetic field cloaking device to create a field free tunnel for an accelerator beam through a transverse magnetic field without disturbing the field outside of it.

Objectives and Achievements

For this reporting period, we planned to:

1. Measure the magnetic field shielding performance of cylinders made from 46 mm wide AMSC high-temperature superconductor wire insert with fields up to 0.5 T at liquid nitrogen temperatures.

2. Test the magnetic field shielding performance of cylinders made from 46 mm wide AMSC high-temperature superconductor wire insert and niobium-titanium low-temperature superconductor sheets with fields up to 0.5 T at liquid helium temperatures.

3. Demonstrate shielding of the Van de Graaff beam at Stony Brook University from a transverse magnetic field using our 1.3 m long superconductor shield made from five layers of 12 mm wide AMSC high-temperature superconductor wire (wrapped helically around a 1" copper tube).

The results we reported previously predicted that a cylinder made from 45 (10) layers of 46 mm wide AMSC high-temperature superconductor wire insert at liquid nitrogen (liquid helium) temperature could shield a magnetic field of 0.5 T. We have procured 20 m of wire insert to fabricate these prototypes. In the past, we created a four-layer prototype by wrapping the superconductor around a 1" copper core, where each layer consisted of two overlapping superconductor strips. However, this overlap adds to the shield thickness and deforms its perfectly cylindrical shape as the number of layers increases. Therefore, we modified our fabrication procedure and cut the wire insert using a paper cutter so that the two strips forming a single layer touch, but do not overlap. Figure 1 illustrates the shielding performance for a 4.5" long, 1" diameter superconducting shield with one layer of superconductor made from two strips with and without overlap of these strips. The measurement indicates that the no-overlap version shields less field than the overlap version, which we attribute to the imperfections in the cutting procedure done by hand. These imperfections may also lead to problematic shear forces when exposing the shield to fields of 0.5 T and above.

In order to improve the quality of a multi-layer superconductor shield, we followed a procedure outlined in [1] and [2] to laminate multiple layers of superconductor using a die, a mandrel, and solder. We fabricated the die

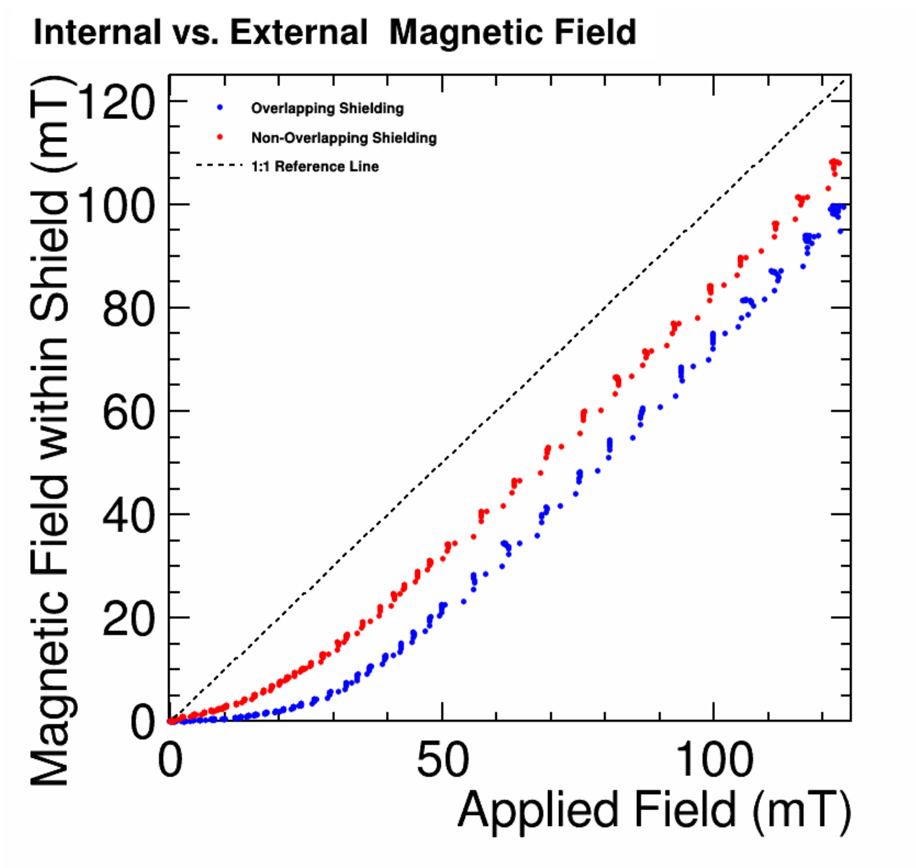


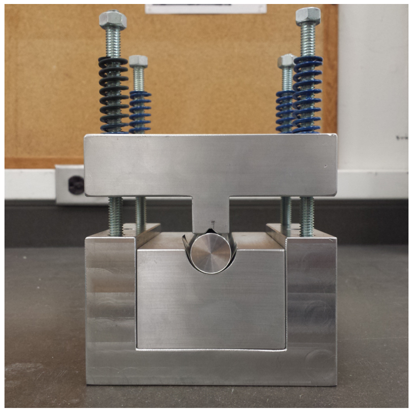
Figure 1: Comparing shielding performance of 1-layer superconducting cylinders made with overlap (blue) and without overlap (red).

and mandrel setup illustrated in Fig. 2a. Multiple layers of superconductor wire insert will be covered with solder paste, pressed by the mandrel into the die, and heated in a suitable oven available at Stony Brook (Fig. 2b). After soldering, we will use a milling machine to machine down the excess superconductor to create a precise semicylinder. Two of these semicylinders will form a full superconducting shield. Figure 2c shows the performance of small superconductor samples as a function of time in the oven at a temperature of 200 degrees celsius, which is 15 degrees above the melting point of the solder paste we plan to use. The measurement indicates that we can safely use the oven and solder to laminate multiple superconductor layers as long as the soldering process takes less than 20 minutes. We expect to receive the solder paste and do a first test of laminating ten layers of superconductor by the end of June.

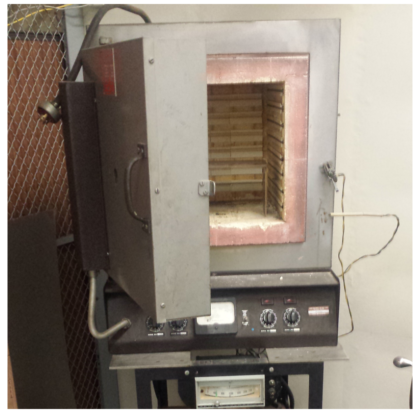
We started exploring the option to use an MRI magnet at Argonne National Lab to test the shielding performance of 4.5" long, 1" diameter superconductor cylinders made from multiple layers of high-temperature superconductor wire insert at liquid nitrogen temperature. The magnet (see Fig. 3a) has a bore of 68 cm and provides a maximum solenoidal field of 4 T. As Fig. 3b illustrates, this space is sufficient to place one of our superconductor cylinders in a box filled with liquid nitrogen transverse to the field and move a Hall sensor along the center of the cylinder. We will continue our discussions with the staff at Argonne to optimize the design of a potential measurement setup and schedule measurements as soon as we have fabricated suitable prototypes to test at these high fields.

We plan to test small samples of the AMSC high-temperature superconductor wire insert and NbTi/Nb/Cu sheets in a liquid Helium cryostat at Stony Brook during the summer of 2016. The setup we are exploring provides a 1" diameter solenoid with a field of several Tesla. The size of this solenoid and cryostat limit the sample size we can test. Unfortunately, we have not yet been able to identify a suitable option to test larger multi-layer high temperature superconductor cylinders and NbTi/Nb/Cu cylinders at liquid helium temperatures.

Previously, we reported that the 1.3 m long superconductor shield we fabricated for shielding a charged particle beam shielded 99% of an external 7 mT field when placed inside a liquid nitrogen bath. However, the installation of this prototype in a beam line required using the prototype's integrated cryostat inside a beam pipe and connections to feedthroughs in the vacuum system. We encountered multiple leaks when testing this system



(a)



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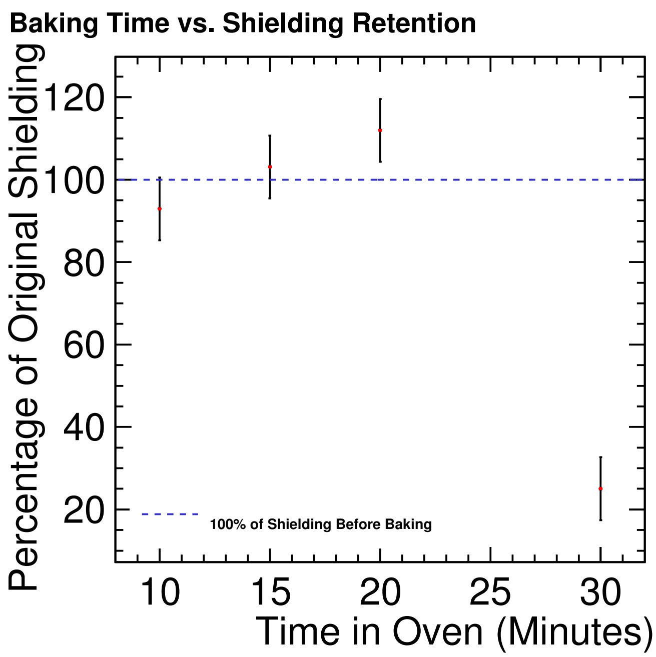
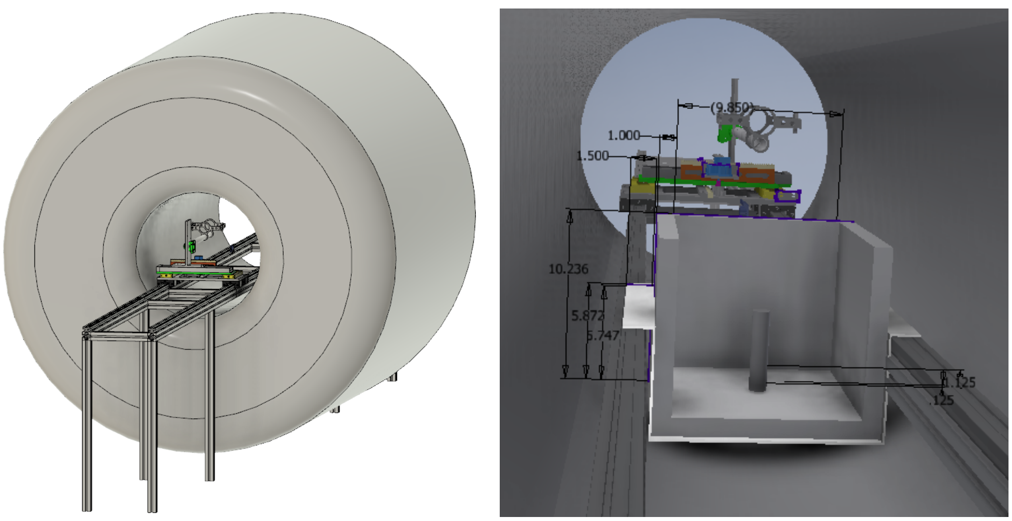


(c)

Figure 2: (a) Die and mandrel for laminating multiple layers of superconductor in a half-cylinder shape. (b) Oven at Stony Brook University for the soldering superconductor layers. (c) Effect of time in oven at 200 degrees centigrade on superconductor shielding performance.



(a) (b)

Figure 3: The MRI magnet with rail system and translation stage for a Hall sensor at Argonne National Lab (left) and a first concept of placing a superconducting cylinder transverse to the field inside the magnet in a liquid nitrogen cooling box (right).

and therefore designed and built an alternate beam shield prototype.

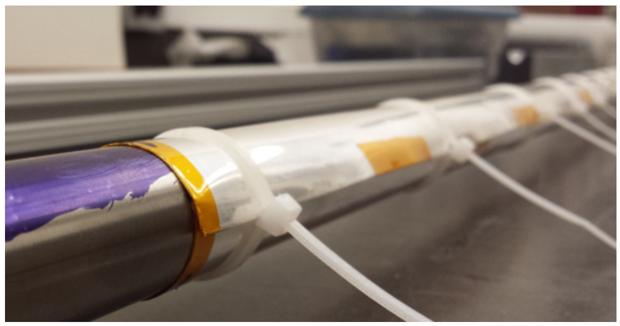
The central component of the new beam shield prototype is a 60" long, 1" OD stainless steel tube which directly connects to the vacuum pipe of a beam line. Two 40" long layers of 46 mm wide AMSC superconductor wire insert attached to this tube for the superconductor shield (Fig. 4a). We use an external liquid nitrogen bath contained inside an aluminum box with styrofoam cover to cool the superconductor. A dipole magnet placed around the center of the superconductor shield and liquid nitrogen bath creates the transverse magnetic field we want to shield. Figure 4b shows the planned beam test setup and Fig. 4c our first cooling test in our laboratory at Stony Brook (independently from an actual beam line). The field scan in Fig. 5 illustrates that the newly fabricated 40" superconductor shield successfully shields more than 95% of the dipole field at 22 mT.

By the time of this report, the repairs of the Van de Graaff accelerator at Stony Brook were still ongoing and we could not test our new beam shielding prototype with beam. Thus, we have successfully requested permission to use the tandem Van de Graaff accelerator at BNL for this test and are expecting to do the beam shielding measurements there before the end of June.

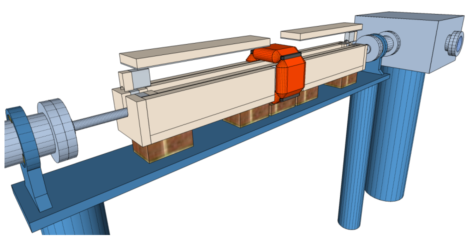
Future

For the short term future, we plan to test our 40" superconductor shield at the BNL tandem the Van de Graaff accelerator in the second half of June. At the same time, we expect to finalize the fabrication process for multi-layer superconductor shields soon and test these shields at high fields of 0.5 T and above. We are developing a plan to do the liquid nitrogen tests at these fields with the MRI magnet at Argonne National Lab. While we will test small samples of the superconductor we use at liquid Helium temperature, we are still looking for viable options to do the tests of 1" diameter superconducting cylinders with liquid Helium cooling.

For the longer-term future, we plan to work on a more detailed technical design of how a magnetic field cloak could integrate into a dipole-based forward spectrometer for an EIC detector and explore ways to collaborate with BNL CAD for achieve this.



(a)



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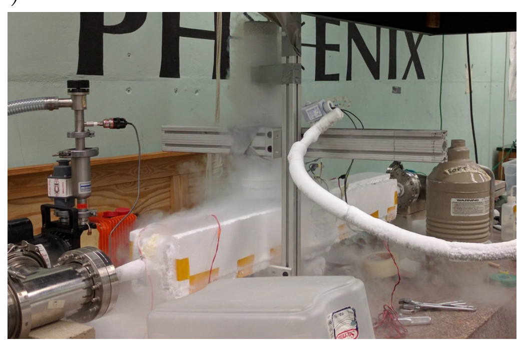

(c)

Figure 4: (a) 1" beam pipe covered with two layers of 46 mm wide superconducting wire. (b) Planned beam test setup at BNL with 1" OD tube connecting to the 4"OD BNL Van de Graaff beam line, Aluminum / Styrofoam box for liquid nitrogen, dipole magnet, and target chamber. (c) The superconducting shield inside the liquid nitrogen cooling box and the dipole magnet in our lab at Stony Brook.

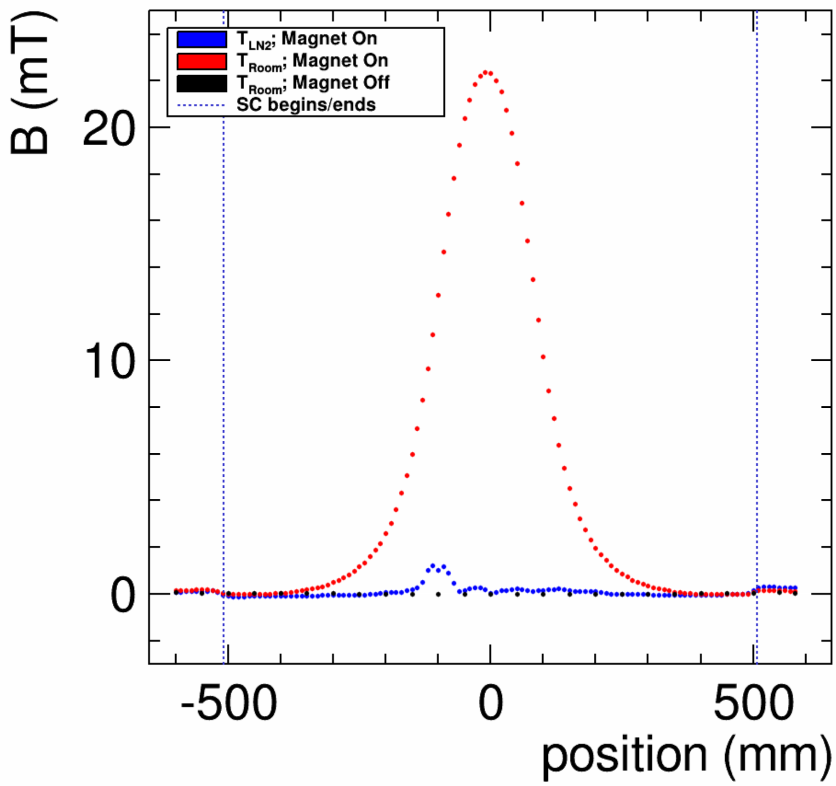

Figure 5: The magnetic field transverse to the beam tube as a function of position along the beam tube with the dipole magnet switched off (black), dipole magnet switched on and the superconductor shield at room temperature (red), and the dipole magnet switched on and the superconductor at liquid nitrogen temperature (blue).

Manpower

The progress documented in this report was achieved by a group of 14 Stony Brook undergraduate students working part-time. During the summer months, two of these undergraduate students were supported with EIC R&D funds. In addition, one Stony Brook faculty spent about 50% time training and supervising students and coordinating activities.

External Funding

No external funding was obtained for this project. All results presented in this report have been accomplished with EIC R&D funds only.

Publications

- Raphael Cervantes, *A Compact Magnetic Field Cloaking Device*, MSI thesis, Stony Brook University, August 2015.
- We are working toward publishing our results in a peer-reviewed journal as soon as possible.

Table 1: Budget request FY 2016

Item	**Cost [$]**
Travel	
Shielding tests with MRI magnet at Argonne National Lab (2 students and 2 PI's for one week)	7,500
Supplies	
Liquid nitrogen	1,000
Laboratory supplies	2,000
Other	
Miscellaneous machine shop services at Stony Brook	2,000
Total Direct Cost	12,500
Total Indirect Cost (Overhead)	7,250
Total Request	**20,000**

Budget request for FY 2017

Table 1 summarizes our budget request for FY 2017. To accomplish the test of the shielding performance of superconducting cylinders at liquid nitrogen temperature with the MRI magnet at Argonne National Lab at fields above 0.5 T, we ask for funds to support two students and two PI's traveling to Argonne National Lab for a week.

The preparations for these measurements require continued tests with liquid nitrogen in our laboratory and machine shop services. Therefore, we request funds to procure liquid nitrogen and other laboratory supplies and to use the services of the machine shop at Stony Brook.

Since we have not found a suitable facility to perform shielding tests with liquid helium cooling yet, we cannot estimate yet how much additional funds achieving that goal would require.

Bibliography

[1] F. Martin, S. J. St. Lorant, and W. T. Toner. A four-meter long superconducting magnetic flux exclusion tube for particle physics experiments. *SLAC-PUB-1040*.

[2] A. C. Newton, F. Martin, S. J. St. Lorant, and W. T. Toner. A method for producing long, cylindrical, superconducting flux shields. *SLAC-PUB-1102*.