EIC R&D Progress Report

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A Compact Magnetic Field Cloaking Device

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1 Objectives

We planned to simulate (using COMSOL), build and test a magnetic field cloaking device with dimensions close to those we expect for an experiment like an EIC detector. This includes constructing test set-ups and finding, testing and procuring suitable materials from commercial suppliers.

2 Timeline

Figure 1 shows a breakdown of the currently projected timeline for this project. The three phases are

- simulating, building and testing a first cloak prototype;
- testing a cloak prototype using a big solenoid to evaluate the surrounding magnetic field;
- installing a cloak prototype in the Van de Graaff accelerator to demonstrate the magnetic field shielding with a charged particle beam.

We have progressed on phase 1 significantly: we started building and testing the cloak. Preliminary results are presented in this report. We initiated phase 2, but in the commissioning stage for the big solenoid, asbestos was found in the drilling path for routing cooling and power lines. Alternate routes and possible solutions are being investigated. We are also proceeding with preparing phase 3 of the project using the Van de Graaf accelerator.

3 Achievements

With four Stony Brook undergraduate students (J. Chang, B. Coe, P. Karpov, Y. Ko) and one MSI student (R. Cervantes) we have completed the first steps towards the prototype construction and furthered our COMSOL simulation studies.

3.1 Prototype Construction

We constructed a cylinder with multiple layers from a sample of high-temperature superconductor tape (SuperPower® 2G HTS Wire Type SCS12050-AP, see Figures 2(a) and 2(b)) to measure the properties of such a cylinder, its magnetic field shielding capabilities and the gain from using multiple superconductor layers. Since late October, when the funding for the project became

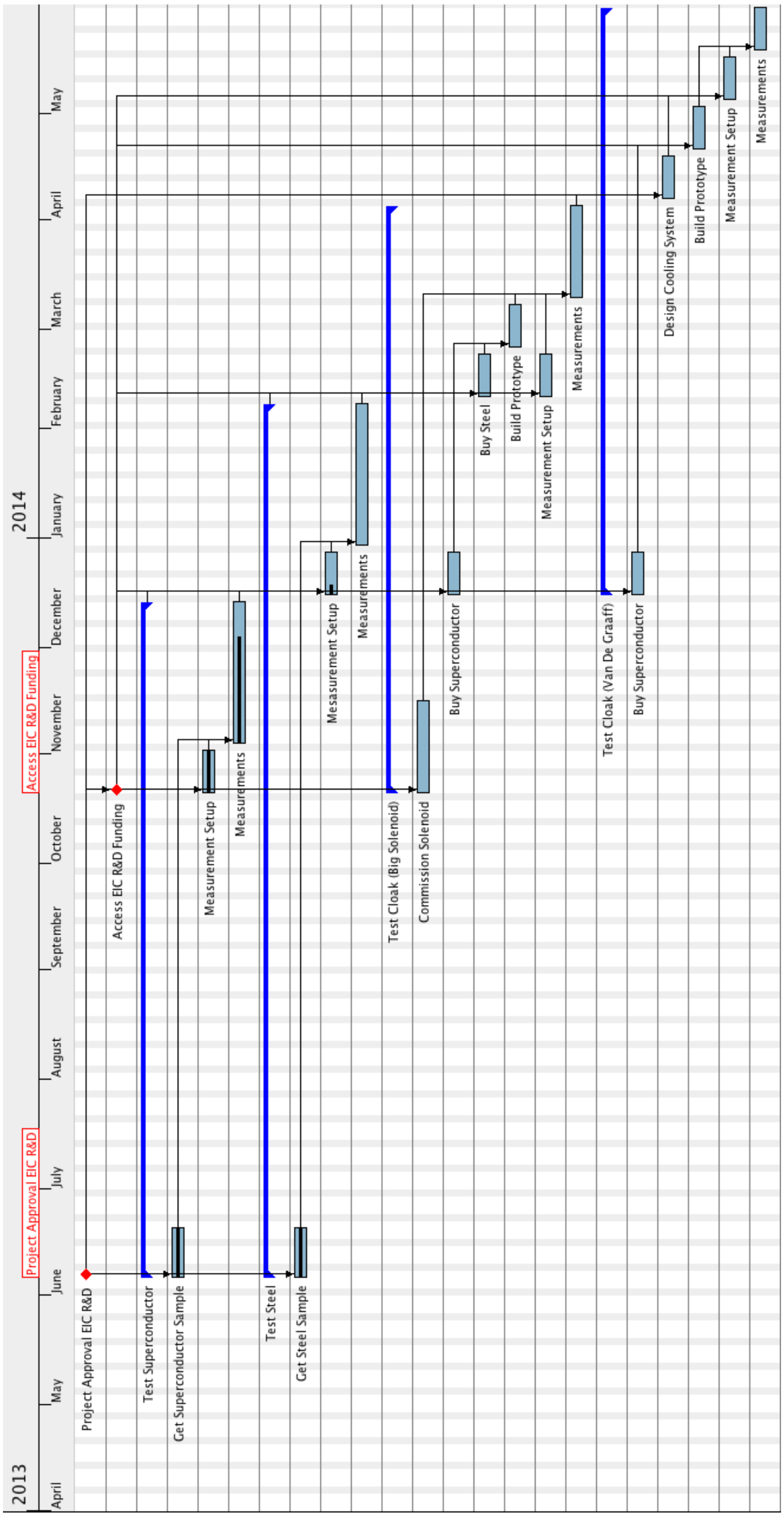
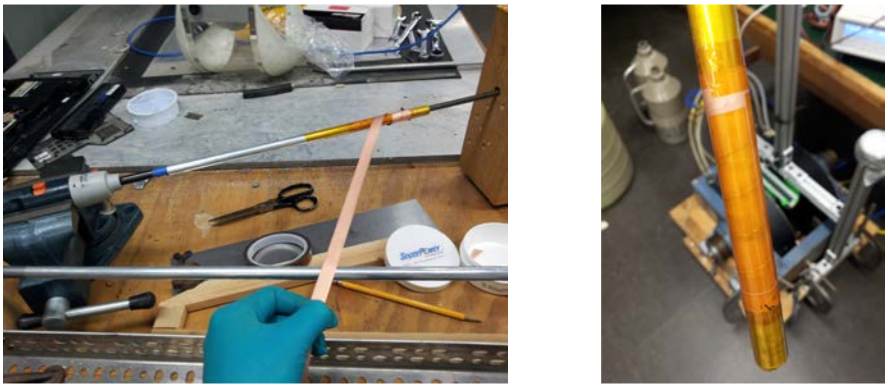


Figure 1: Projected timeline.



(a) (b)

Figure 2: (a) Wrapping a layer of superconductor tape around an Aluminum tube. (b) The first superconductor layer fixed in place with a Kapton layer.

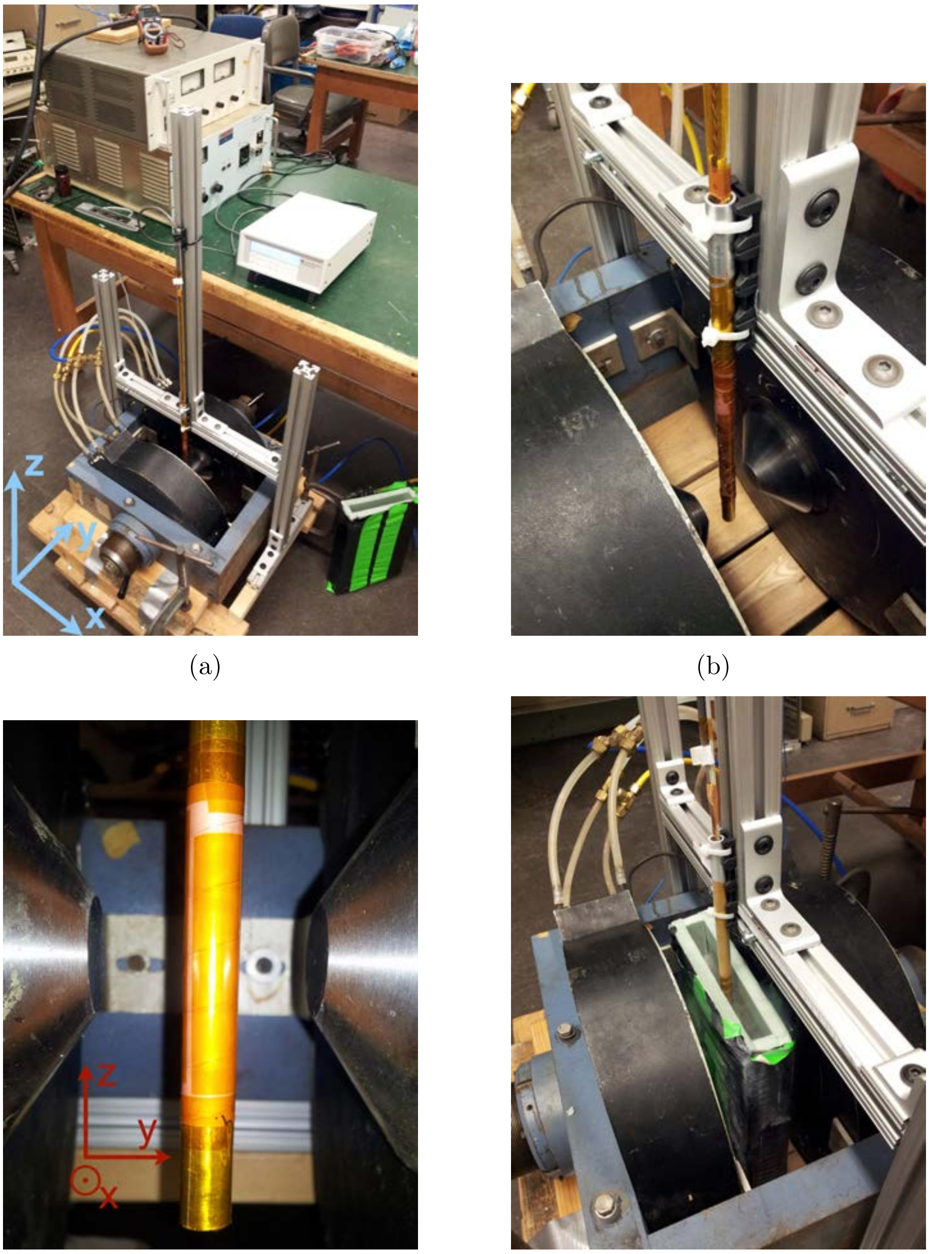
(a)

Figure 3: Cryogenic Hall probe and Gaussmeter.

available, we have been able to order and acquire the cryogenic and normal Hall probes and associated readout equipment for measuring the field inside (at liquid Nitrogen temperature, see Fig. 3(a)) and outside (at room temperature) the superconducting cylinder.

Figures 4(a)-4(d) show the setup we assembled. It holds the Aluminum tube with the superconducting tape wrapped around it and the Hall probe in an electromagnetic dipole. The magnet provides a maximum field of 0.6 T in the center for our configuration. The setup allows to move the Hall probe in three directions (up/down = z, left/right = x, forward/backward = y).

Figure 5 presents a map of the dipole magnetic field measured with the Hall probe attached to the setup. The profiles are centered around x_0, y_0, and z_0 and are smooth, which illustrates the good alignment of the zero position



(a) (b) (c) (d)

Figure 4: (a) Our setup for testing the superconductor tape using an electric dipole magnet. (b) The cryogenic Hall probe is inserted into the Aluminum tube. (c) Six turns of superconductor tape wrapped around the Aluminum tube and centered between the magnet pole shoes. (d) Cooling the superconductor with liquid Nitrogen in a styrofoam box.

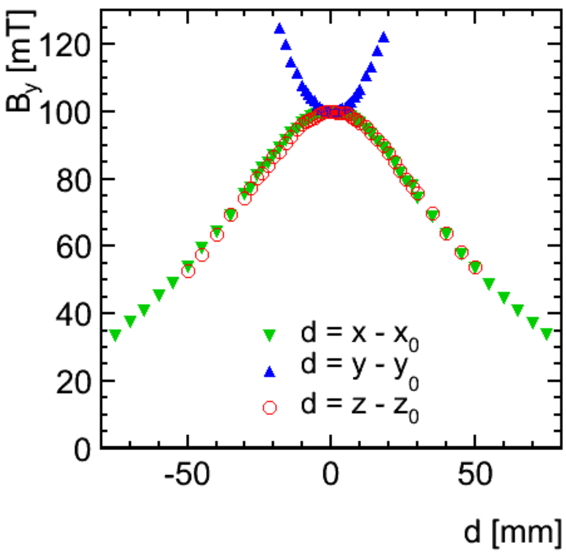


Figure 5: Dipole field map measured with our setup for three orthogonal directions x, y, and z around the nominal field center at x_0, y_0, z_0.

of our Hall probe with respect to the magnetic field center and the accuracy of our probe positioning.

Figure 6 shows the magnetic field inside the Aluminum tube at various positions along the z axis (tube centered in x and y). The plot includes measurements for zero to four superconducting layers. For only one superconducting layer, the profile features six minima with a distance of about 12 mm, which correspond to the six turns of superconductor tape (12 mm wide) used for this cylinder. For multiple superconducting layers, this structure disappears. This measurement demonstrates the suitability of our setup to evaluate the properties of our superconducting cylinder and the used tape. These tests were intentionally done at low fields (2 mT) to understand the physics and our instrumentation. We will proceed with tests at higher fields.

We obtained a test sample of a stainless steel foil (type 301) that could be used for the ferromagnetic layer of our magnetic cloak prototype. We are in contact with the condensed matter group at Stony Brook / BNL and are currently exploring methods to measure and change (cold working) the magnetic permeability of this material.

3.2 Simulation

Here we address the committee's questions from June 2012:

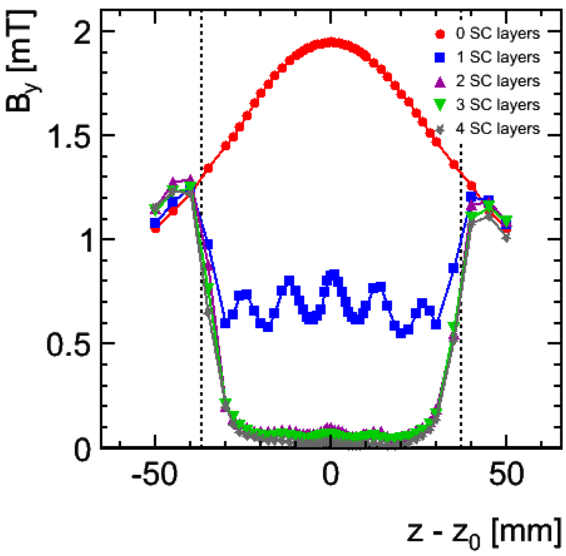


Figure 6: Magnetic field inside the Aluminum tube at various heights z for zero to four layers of superconducting tape wrapped around the tube. The dashed lines indicate beginning and end of the area covered by the superconductor tape.

- *Has COMSOL already been used reliably for similar problems?*
  Yes. Results from COMSOL and CERN's ROXIE code (which is widely used as reference for calculating accelerator magnets) are in very good agreement [2]. Also, COMSOL has already been used reliably for magnetic shielding simulations at fields up to several Tesla and the simulations were verified by measurements, see e.g. [3].

- *Are questions related to how to operate COMSOL correctly? Talk to an expert who has a real experience with this code for similar magnet applications.*
  There is COMSOL expertise among our collaborators. In addition, one of our collaborators attended a COMSOL workshop in NYC, discussed our implementation with a COMSOL representative and found no concerns.

- *Does the dependence of the permeability on magnetic field impact the simulation? Verify by measurements if needed.*
  We implemented the dipole as an iron yoke with magnetized sections. Using a generic steel magnetization curve instead of a fixed magnetic permeability has no visible effect on the cloak performance at 1 T field.

The following questions were not answered yet, since they need demonstration and learning about the actual cloaking device dimensions and properties. Once our demonstration is robust, we plan to address them in 2014. For completeness, we list the open questions here:

- *Provide some quantitative study of the physics benefit for a conceptual forward dipole spectrometer.*
- *Work closely with an accelerator expert to check what is the effect of the end-field on the accelerator performance.*
- *What is the effect of a possible cryostat and its flanges on the detector acceptance and performance at small angles?*
- *Investigate thermal effects due to accidental beam dumps to see if one could damage the structure.*
- *Check the radiation hardness of the ferromagnetic and superconducting material.*

4 Future

We will continue to evaluate the superconductor tape to determine the number of layers we need to build the prototypes for the subsequent phases of this project. In parallel, we will establish a procedure to measure the magnetic permeability of our ferromagnetic material and test methods to change it to the desired range. Afterwards, we will add the ferromagnetic layer to the cloak prototype and execute phase three.

After the successful completion of these tests, we have ideas to collaborate with the BNL CAD group to design and test a magnetic cloak prototype in a beam line at BNL. Also, we are exploring possible applications of our magnetic cloak in the context of polarized ^{3}He ions in EBIS [4].

5 Additional Budget Request

We plan to recruit a graduate student for one year and use three months of a post doc's time to proceed with the next steps of this program.

Item	Cost Estimate [$]
Post-doc salary (3 months) + fringe benefits	12,500 + 5,125
Graduate student salary (1 year) + fringe benefits	24,000 + 3,675
Total	49,988
Overhead (indirect)	15,545
Total Additional Budget Request	**65,533**

References

[1] S. Russenschuck, *ROXIE - the routine for the optimization of magnet X-sections, inverse field computation and coil end design.* 1st International Roxie Users Meeting and Workshop, CERN, Geneva, Switzerland, 1998.

[2] I. Rodriguez et al, *Benchmark of COMSOL vs. ROXIE Codes for the Calculation of a Particle Accelerator Quadrupole*. Proceedings of the 2011 COMSOL Conference in Stuttgart, 2011.

[3] G. Konrad et al, *Design of an Anti-Magnetic Screen for the Neutron Decay Spectrometer aSPECT*. Proceedings of the COMSOL Users Conference 2007 Grenoble, 2007.

[4] R. Milner and C. Epstein, *private communication.*