Magnetic Field Cloaking Device
RD2013-2 Progress Report
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EIC Advisory Committee Meeting; BNL, January 14, 2014
Goal: Measure particle momenta with dipole + tracker close to beam pipe

Magnetic Cloak:
- Shield fields up to 0.5 T
- No outside field disturbances
- Thin, > 1 m long
A simple cylindrical magnetic cloak

ferromagnetic  superconducting  combined

\[ R_1 \quad R_0 \quad R_1 \]

\[ R_2 \quad R_0 \quad R_2 \]

magnetic permeability (ferromagnetic): \( \mu_2 = \frac{R_2^2 + R_1^2}{R_2^2 - R_1^2} \)

Fedor Gömöry et al.
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Project Timeline

2013

- Jun: Project Approval
- Jul: Access Funds
- Aug: Test Superconductor
- Sep: Test Steel
- Oct: Measure field around cloak
- Nov: Test magnetic field shielding in accelerator
- Dec: Beginning of integration into RHIC with CAD

2014

- Jan: Access Funds
- Feb: Test Superconductor
- Mar: Test Steel
- Apr: Measure field around cloak
- May: Test magnetic field shielding in accelerator
- Jun: Beginning of integration into RHIC with CAD
- Jul: Access Funds
- Aug: Test Superconductor
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- Oct: Measure field around cloak
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Thanks to all our collaborators!

RIKEN
Y. Goto, I. Nakagawa

RIKEN BNL Research Center
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P. Karpov, Y. Ko, R. Lefferts,
A. Lipski, A. Quadri

MSI Student

Undergraduate Students
Test Superconductor

SC Tape (SuperPower):
12 mm wide, $I_c > 298$ A
no superconductor
First success!
Next step: Higher fields
## Soon: Test Steel Foil (Fe18Cr9Ni)

<table>
<thead>
<tr>
<th>Material</th>
<th>302 Stainless Steel</th>
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</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>0.127 mm</td>
</tr>
<tr>
<td>Width</td>
<td>152.4 mm</td>
</tr>
<tr>
<td>Length</td>
<td>1270 mm</td>
</tr>
<tr>
<td>Permeability</td>
<td>µ</td>
</tr>
</tbody>
</table>

![Graph showing permeability vs. cold reduction]
Soon: Measure field disturbance around cloak

Homogeneous field up to 0.5 T

Magnet commissioning?

L 1092 mm
Ø 718 mm
Soon: Test magnetic field shielding in Van de Graaff Accelerator

Switcher magnet

Cooling? Long cloak?

Van de Graaff
IV.1. Charge Exchange

It is important to investigate charge exchange because a charged particle will depolarize and then cause the nucleus to depolarize via hyperfine coupling. If a \( ^3\text{He}^+ \) and a \( ^3\text{He}^{++} \) ion undergo charge exchange, depolarization can propagate to the \( ^3\text{He}^{++} \) ion. We approximate the rate of charge exchange as:

\[
\rho_1 \rho_2 \bar{\nu} \sigma V
\]

where \( \rho_1 \) and \( \rho_2 \) are the densities of singly and doubly ionized \( ^3\text{He} \), \( \bar{\nu} \) is the average velocity, \( \sigma = r_q - \frac{1}{16} \) cm\(^2\), and \( V \) is the volume. We approximate the densities as both being \( \times r_q \), which implies the gas being ionized. Then the rate is:

\[
\rho_1 \rho_2 \bar{\nu} \sigma V \approx \rho_1 \rho_2 \bar{\nu} \sigma V \times r_q.
\]

Since the rate of ion extraction is approximately \( rq \), it is thought that even if singly charged ions depolarize and undergo charge exchange, the effects will be small.

IV.2. Processes in Pumping Cell and in Transport to EBIS

IV.2.1. Magnetic Field Gradients

The fringe fields of EBIS are on the order of \( rq \), which is strong enough for polarization. However, they contain strong gradients. A strong transverse magnetic field gradient can cause depolarization if it appears to oscillate in the particle's rest frame near the Larmor frequency. The polarization relaxation time of the \( ^3\text{He} \) is related to the strength of the transverse magnetic field gradients by the equation:

\[
\tau = \frac{\omega_0}{(r_q \| B_l \|^2 |\Delta B_t|^2 \sqrt{\tau_c \omega_0^2 \tau_c^2} \omega_0^2 \tau_c^2 \omega_0 \tau_c^2}).
\]

where for our system, \( \omega_0 = \frac{su}{\| B_l \|} \) kHz/Gauss and \( \tau_c \approx \frac{1}{16} \) s.

IV.2.1.1. Gradients Along Transfer Line

The optimal way to transfer the \( ^3\text{He} \) atoms into EBIS would be to align the transfer line along a magnetic field line, however, this is not always possible due to the EBIS configuration. The internal transfer line in EBIS from the entry port to the electron beam has two straight sections connected at a right angle. Depolarization there was calculated to be negligible, especially given the small time each atom spends in the transfer line.

IV.2.1.2. Gradients In Pumping Cell

Since a longitudinal field is necessary for polarization, the pumping cell is aligned along a field line in the EBIS fringe field; however, there are transverse fields. In order to correct this, a rectangular coil is placed on the same axis as the pumping cell. Thus, the longitudinal direction of the field is maintained, as is the approximate magnitude.

Potential Cloak Use In Polarized \( ^3\text{He} \) Ion Source at BNL

Preliminary ideas based on discussions with C. Epstein and R. Milner from MIT
Committee Questions (June 2013)

Has COMSOL already been used reliably for similar problems?

→ Yes, e.g. crosscheck with CERN’s ROXIE code.


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.

→ COMSOL expertise among collaborators, discussion with COMSOL representative.

Does the dependence of the permeability on magnetic field impact the simulation? Verify by measurements if needed.

→ COMSOL simulation with generic steel magentization curve shows no impact of curve on cloak behavior.
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.
## Additional Budget Request

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost Estimate [$]</th>
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<tbody>
<tr>
<td>Post-doc salary (3 months) + fringe benefits</td>
<td>12,500 + 5,125</td>
</tr>
<tr>
<td>Graduate student salary (1 year) + fringe benefits</td>
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<td><strong>Total</strong></td>
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<td><strong>Overhead (indirect)</strong></td>
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<td><strong>Total Additional Budget Request</strong></td>
<td><strong>65,533</strong></td>
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</table>
Summary

Test setup for superconductor cylinders built and working well.

Successfully shielded low (2 mT) magnetic field with cylinder made from superconductor tape.

Excellent opportunity for students to collect laboratory experience.

Project continues.
ADDITIONAL SLIDES
COMSOL: Cloak behavior is not affected by magnetization curve
COMSOL: Cloak Length Scaling
Type II superconductors

$B_{\perp}$

$B_{c1}$

$B_{c2}$

$T_c$

$T$

$B$

$B_{c1}$

$B_{c2}$

$T_c$

$T$

$B$

$B$

$B$

$B_{\perp}$
Van de Graaff Beam Pipe Dimension

37 mm

74.5 mm