Optimization and Implementation of Magnet Correction Coils for the Jefferson Lab Polarized Target

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Jefferson Lab
Exploring the Nature of Matter

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UNIVERSITY

Outline

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- Apollo in CLAS12
- Field Requirements
- CLAS12 Magnet Mapping
- Physical Limitations

Optimization

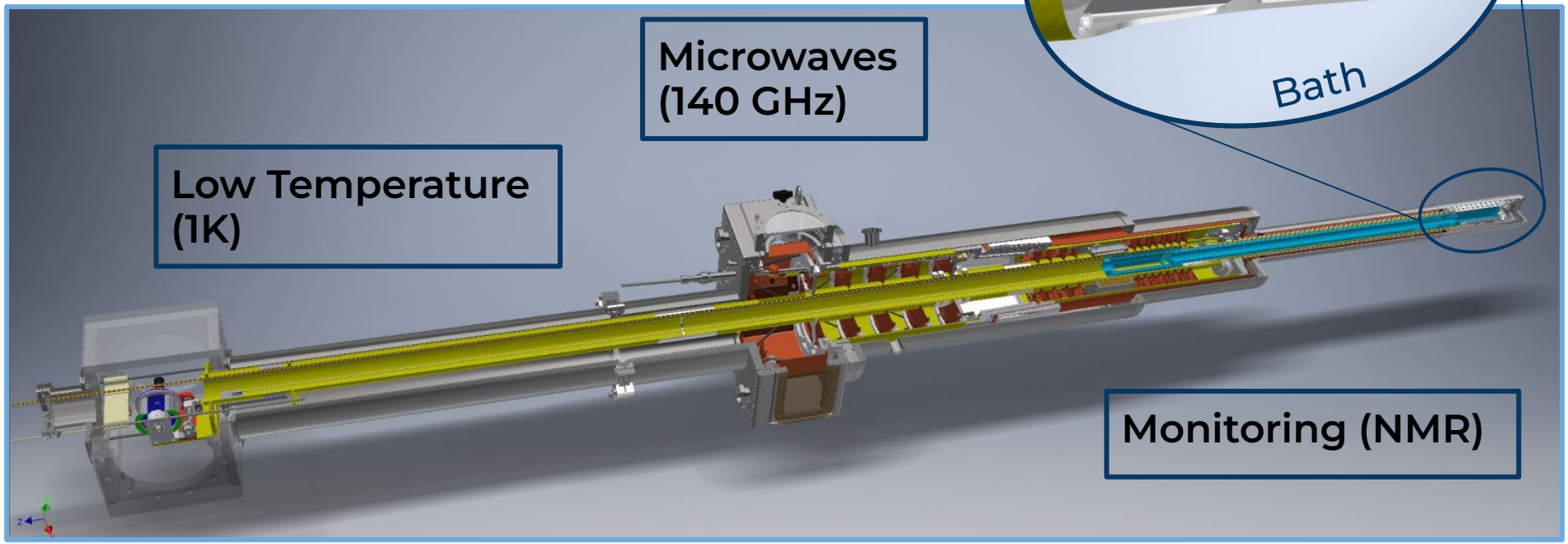
- Design Goals
- Algorithm Variables
- Method
- Final Design Result

Manufacture

- Mandrel / Winding
- Current Leads
- Controls
- Implementation

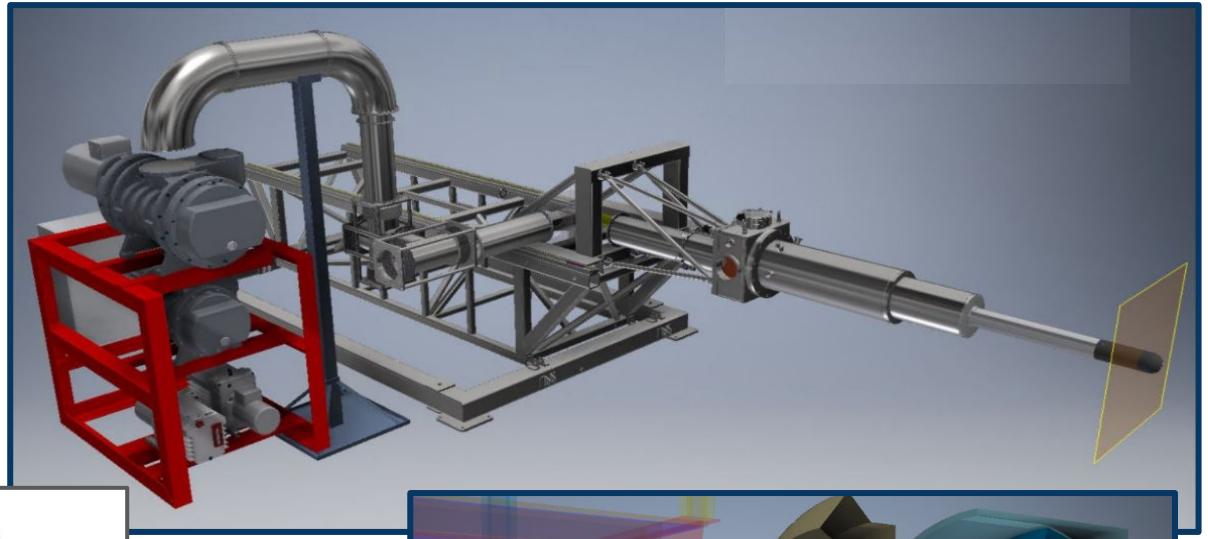
APOLLO

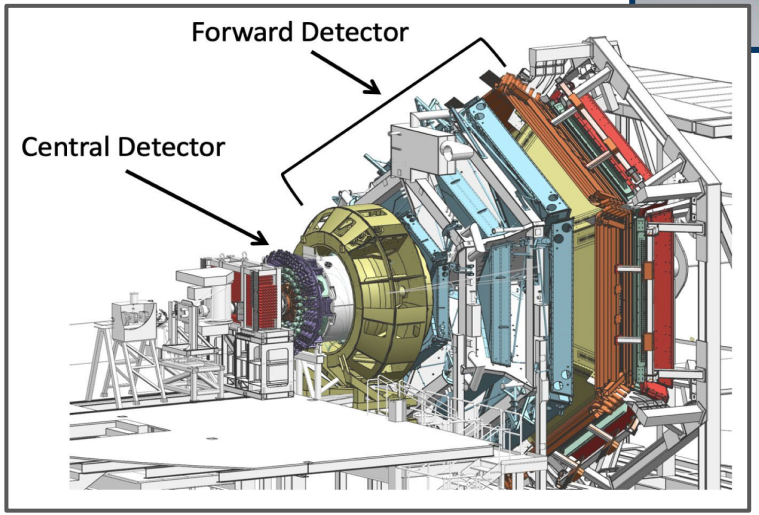
The APOLLO target is a longitudinal nuclear target which utilizes continuous DNP to polarize NH3 and ND3

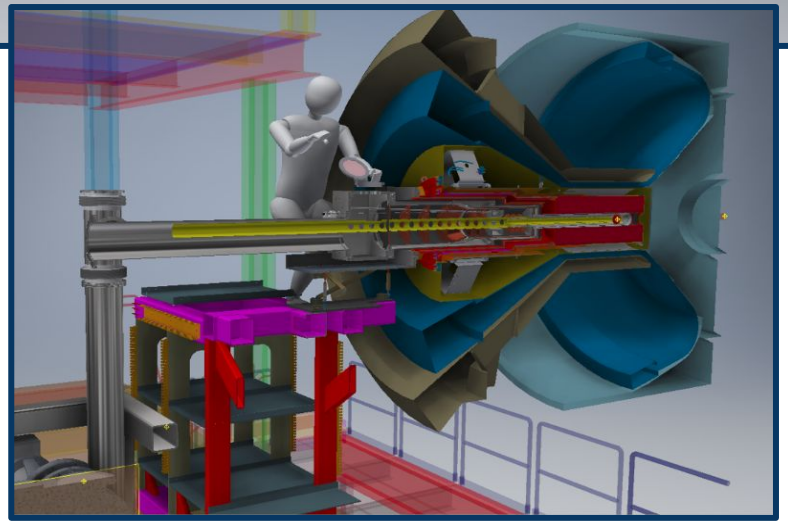


APOLLO

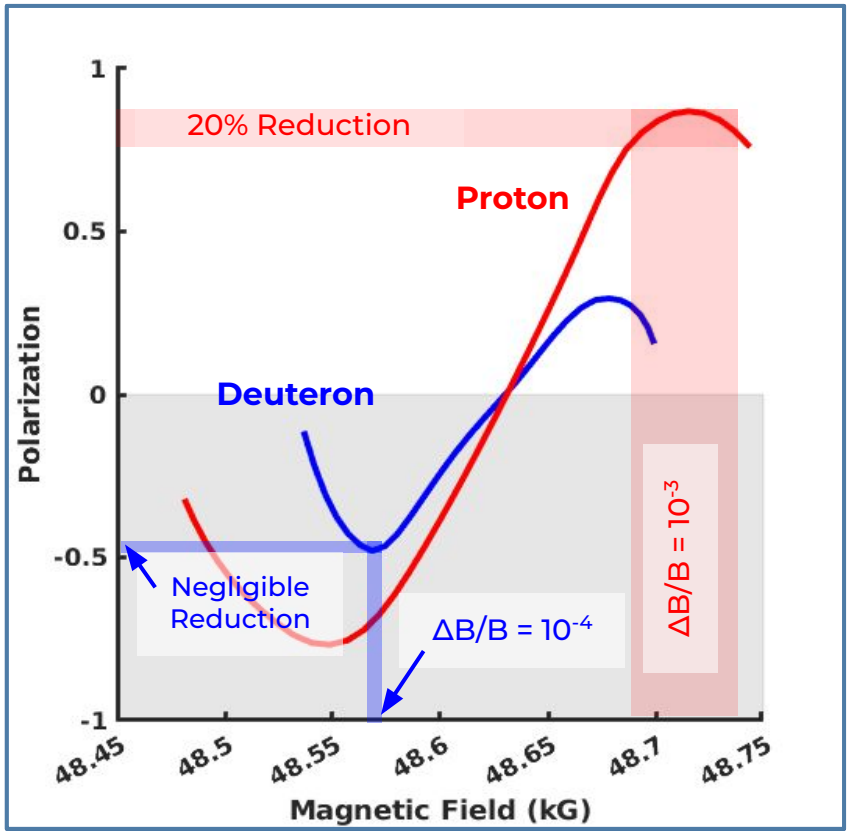
Polarizing field provided by the CLAS12 spectrometer magnet - a compound 5T solenoid



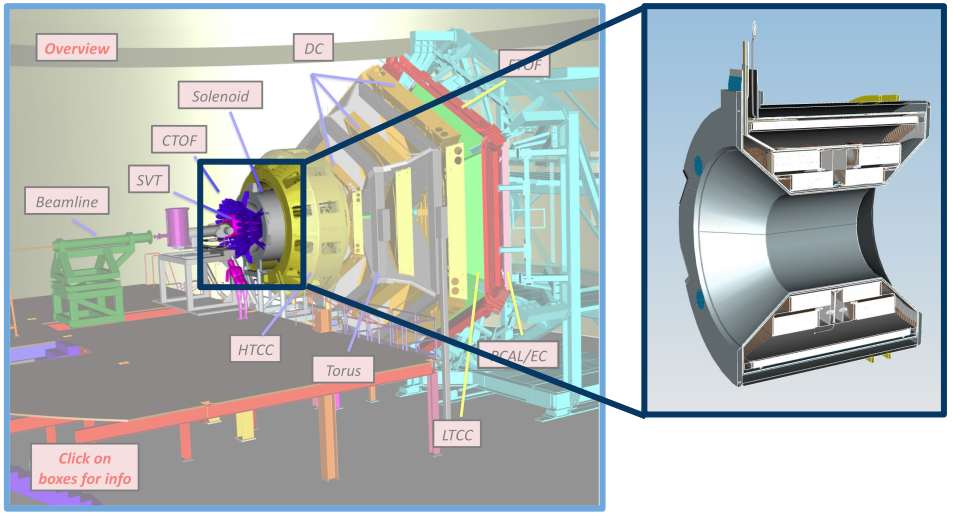




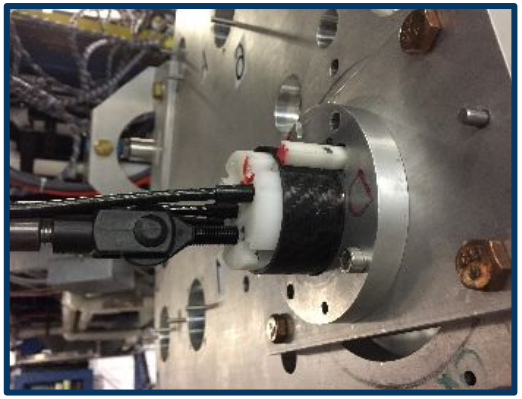
Field Requirements



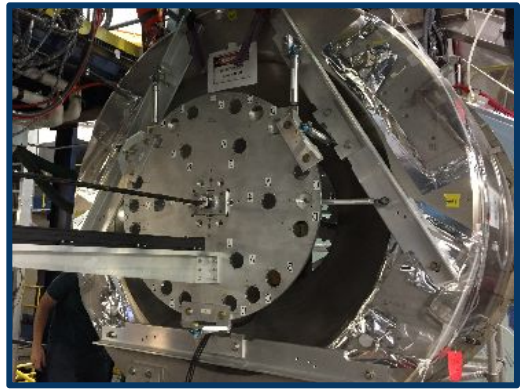
Although a polarizing field uniformity of 10^{-3} is sufficient for proton polarization, 10^{-4} is required for optimal deuteron polarization



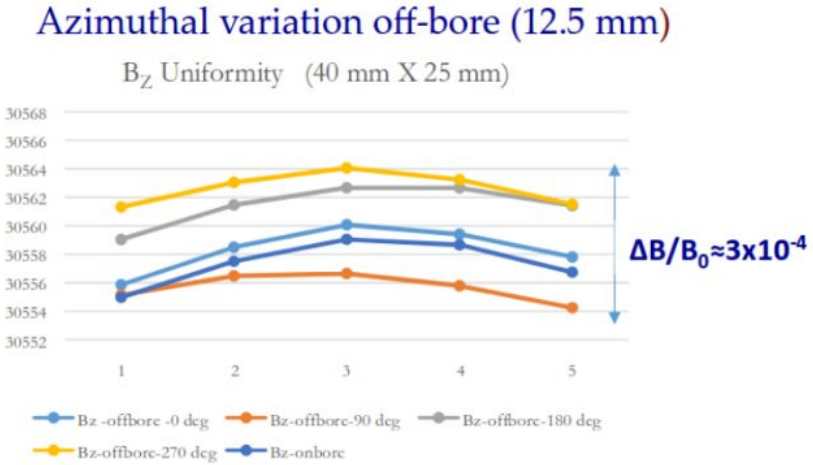
CLAS12 Magnet

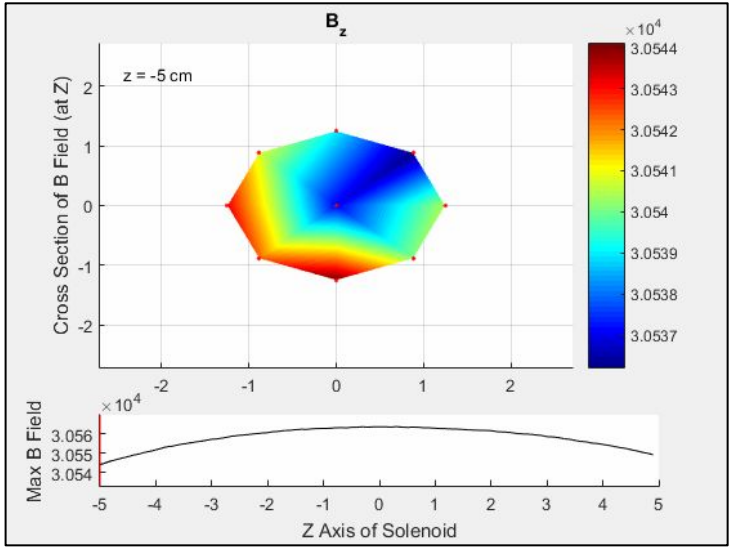


Initial mapping of the solenoid suggested nearly sufficient homogeneity



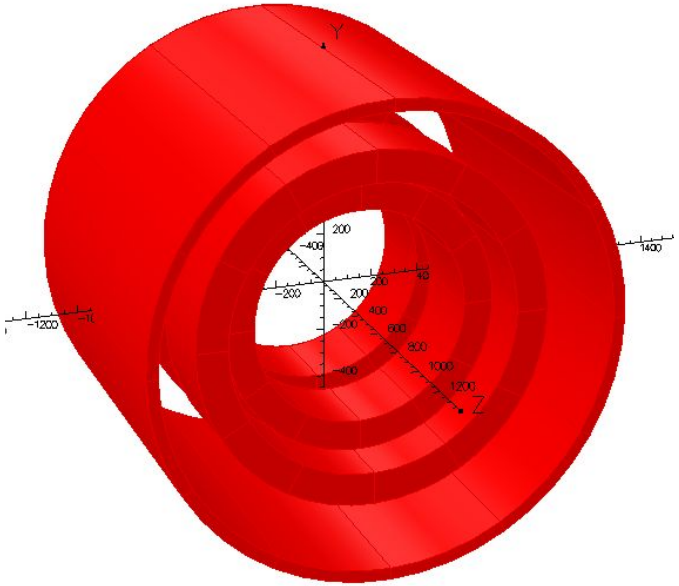
However, inconsistencies in the measurements introduced uncertainties in the data

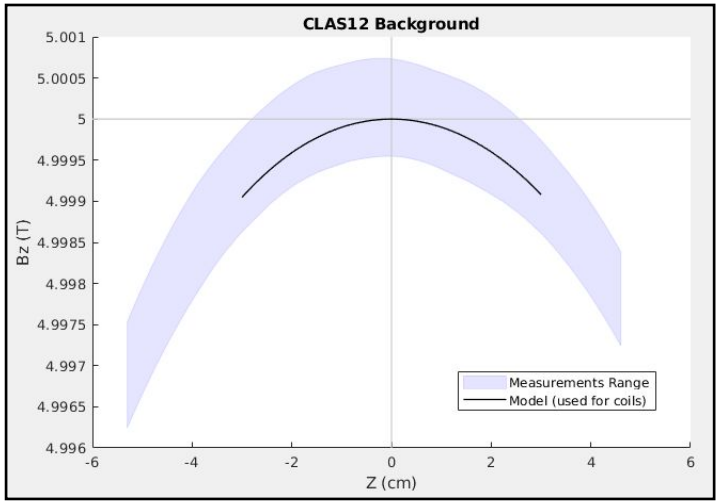


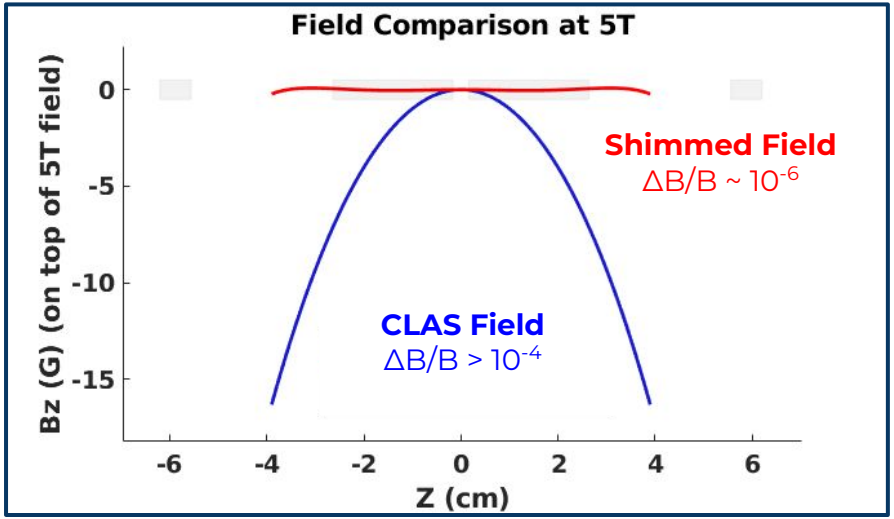


CLAS12 Magnet

After extensive modeling, it was determined that correction coils should be included in the APOLLO design to ensure uniformity and increase functionality

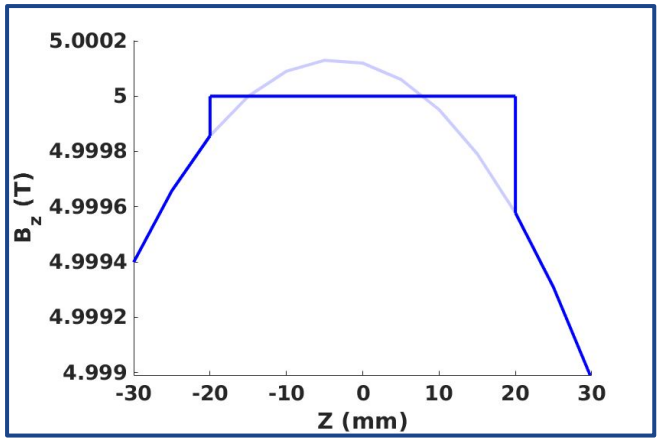




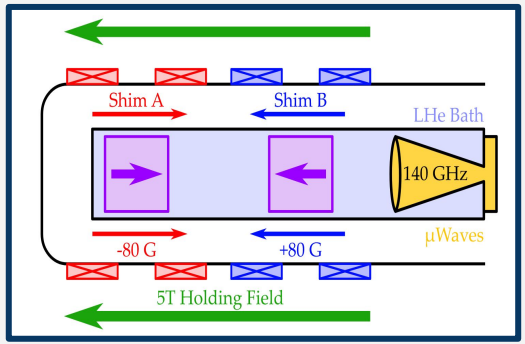


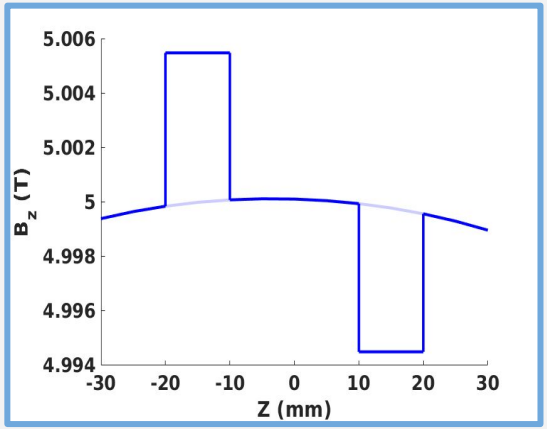
Field Goals

- Homogeneity of 10^{-5} over the complete target region
- Field Offset for Baseline NMR Measurements
- Dynamic Asymmetry Correction



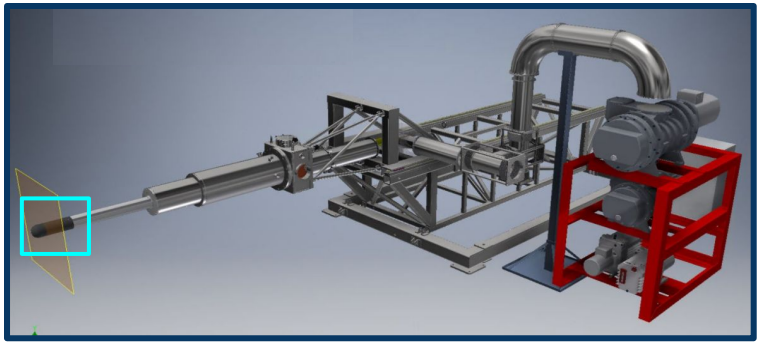
- Dual Cell Polarization?

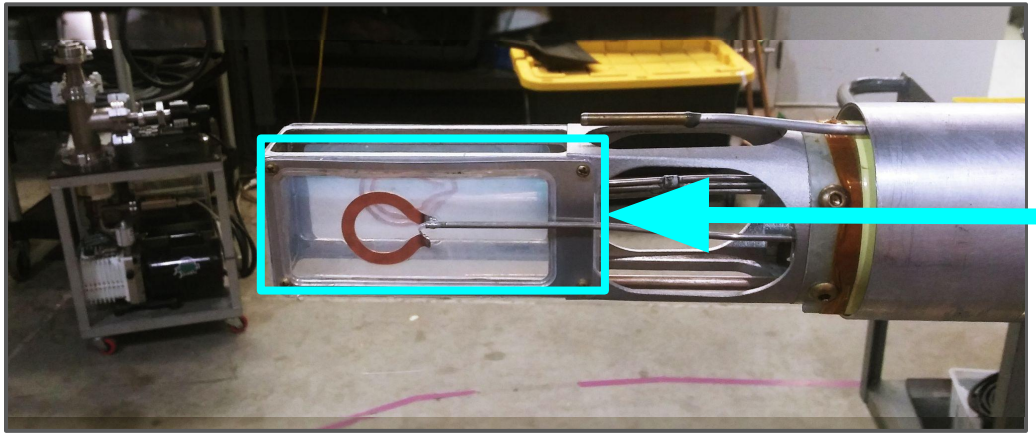


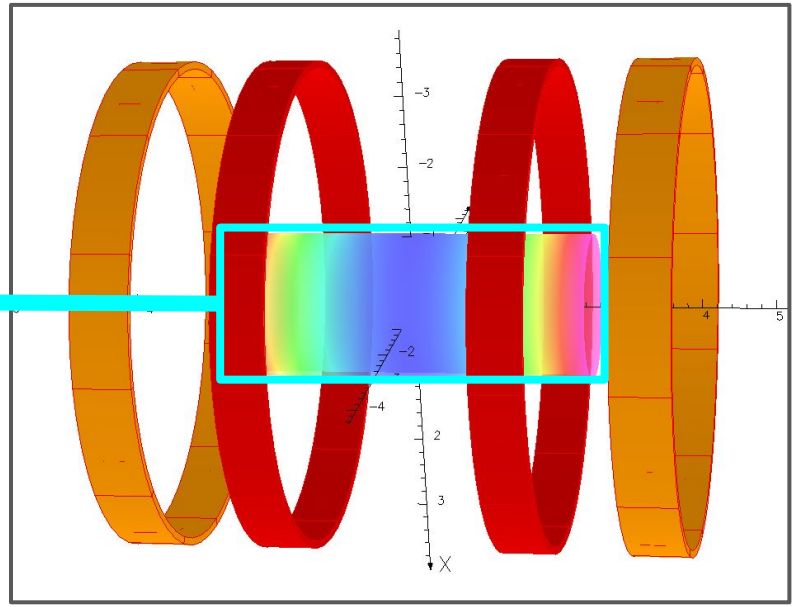


Shim Carrier

The space constraints within the Apollo target and CLAS12 set the dimensional limits of the shim coils







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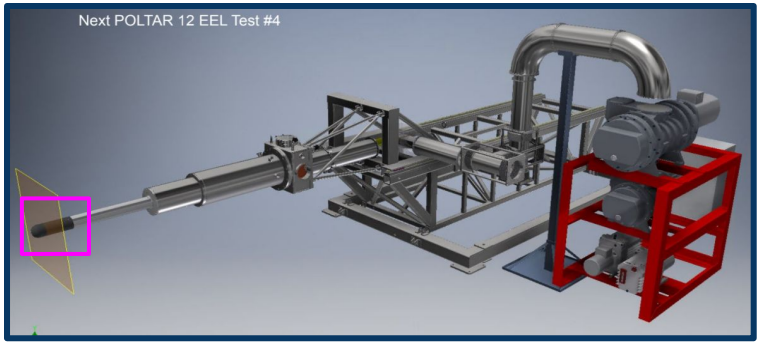
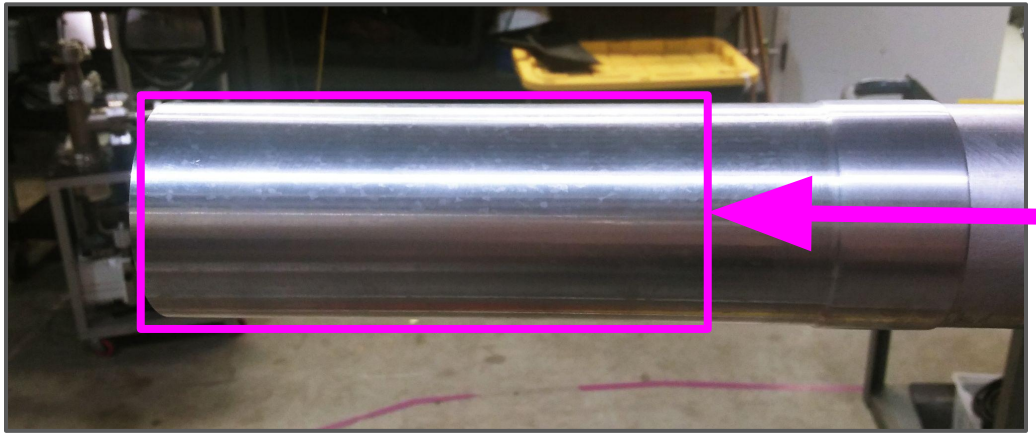
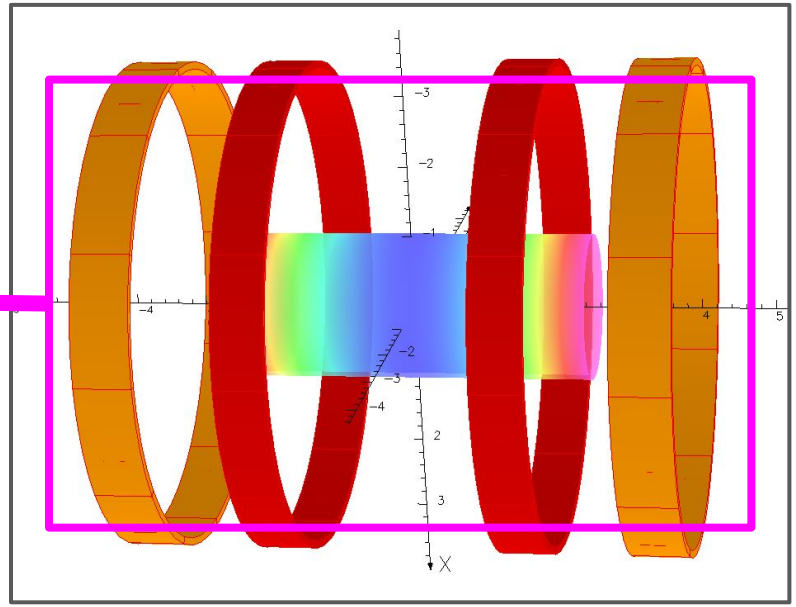




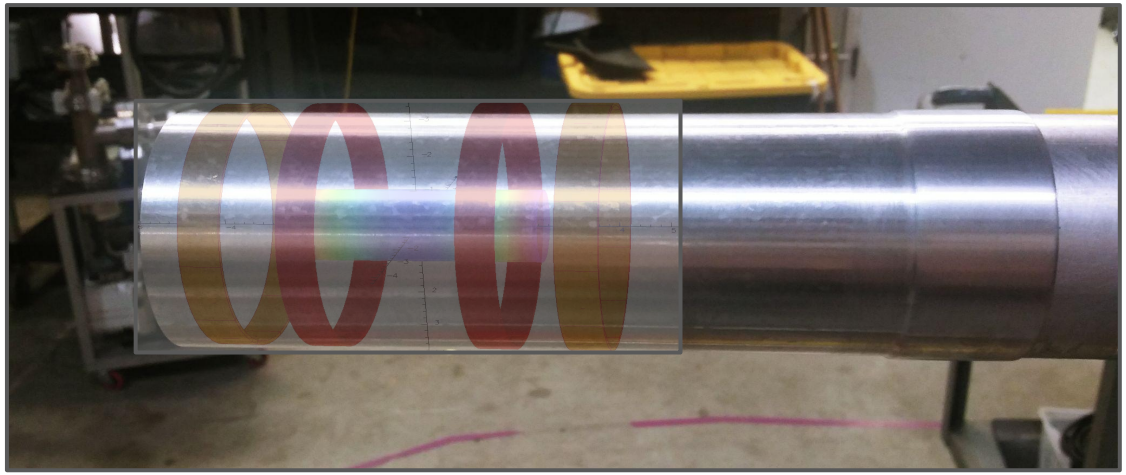


Physical Design Variables

- Radius
- Carrier Length
- Homogenized region

- Winding Density
  - Wire Gauge
  - Number of Layers

- Number of Coils
- Coil Widths
- Coil Positions
- Currents
  - Maximum Current



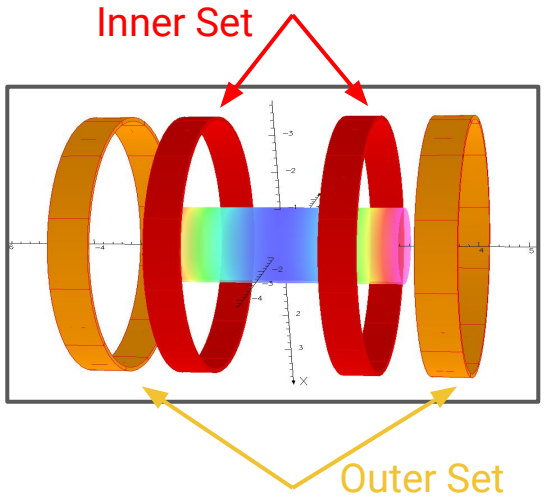
Algorithm Variables

Static Parameters
(these are held constant as the program runs but are easy to change between runs)

- Background Field
- Desired Field
- Target Length
- Mandrel Length
- Radius
- Winding Density / Number of Layers

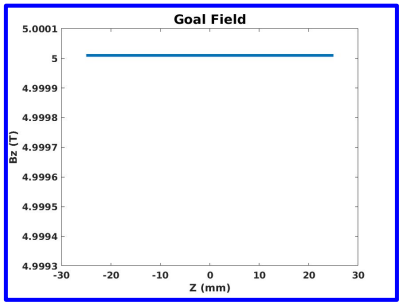
Dynamic Variables
(the minimizer varies these to find the best fit)

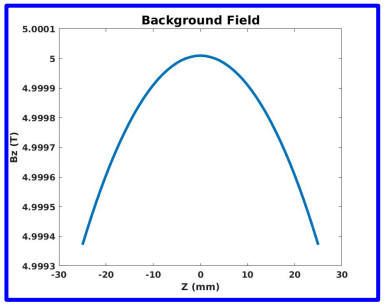
- Coil Position (2 - inner set and outer set)
- Coil Width (2 - inner set and outer set)
- Current (2 - inner set and outer set)

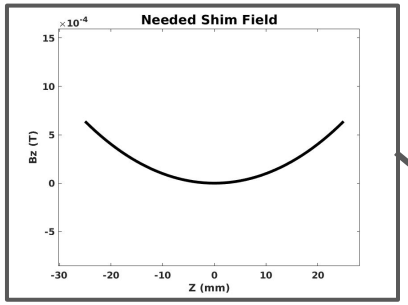


Minimizer

Static Parameters







Minimize Difference

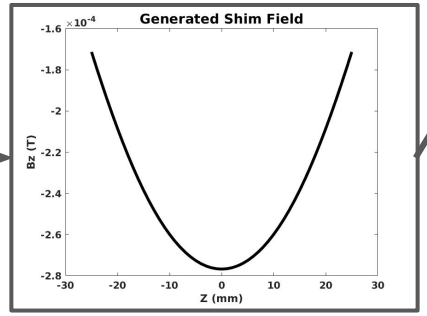
Dynamic Variables

Coil Widths
Coil Positions
Currents

Mandrel Length
Target Length
etc..

Static Parameters

Field Calculation



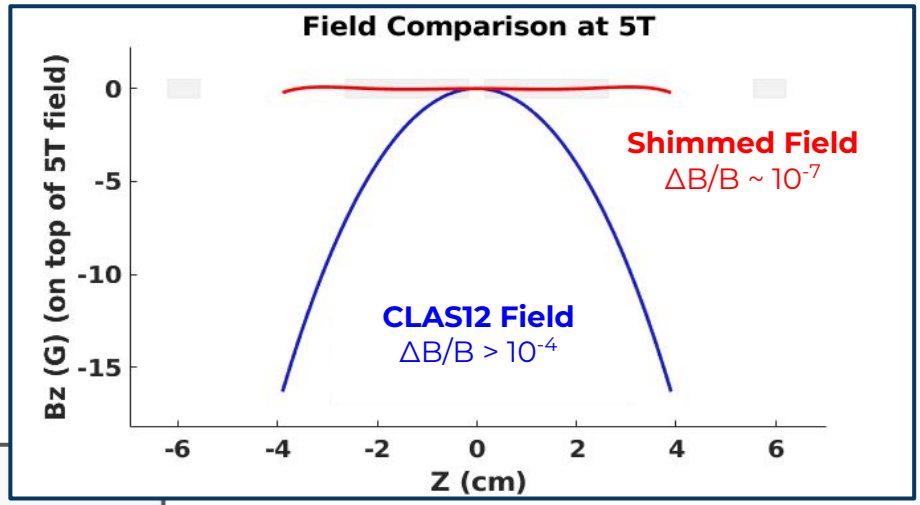
Optimized Geometry and **Uniformity Value**

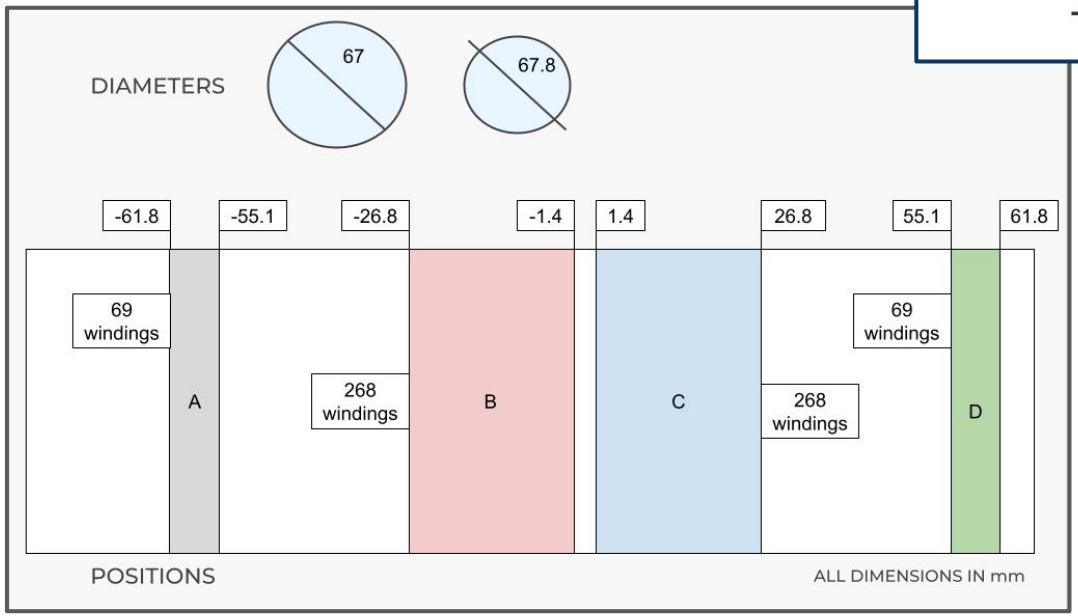
Algorithm

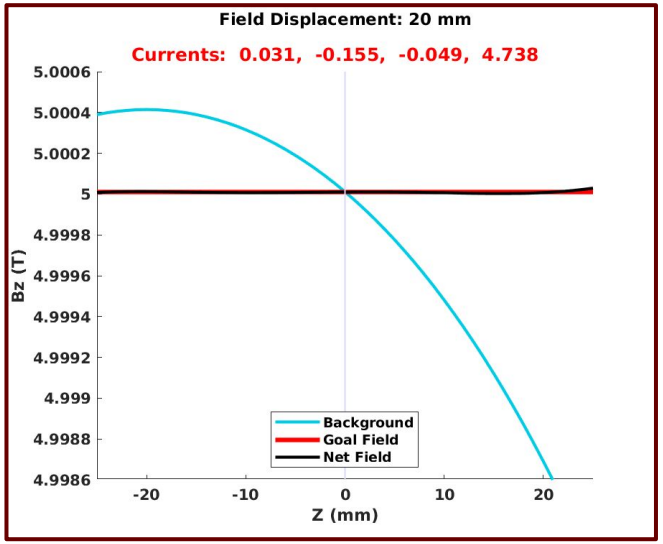
1. Select a set of static parameters (target length, etc..)
2. Perform sweep of initial values (optimizing for simple uniformity)
3. Select subset of results with comparable performance
4. Run individual optimizations on those geometries - optimizing for asymmetry correction
5. Select subset of results with comparable performance
6. Run individual optimizations on those geometries - optimizing for baseline offset
7. Compare and select best set of static parameters from all options
8. Minimize layers to reduce radiation length while maintaining functionality

Result

Final selection produces a uniformity of 10^{-7} (in ideal case), is able to shift the field by a percent (for NMR baselines) with only two layers of windings, and produces acceptable uniformity when correcting for potential asymmetries

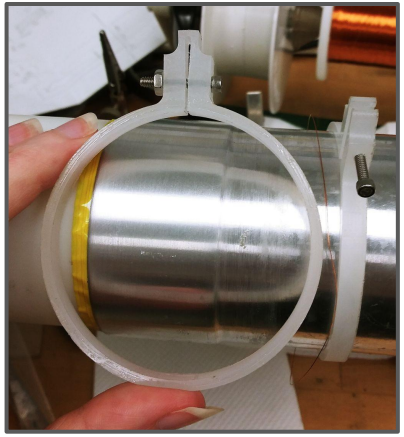


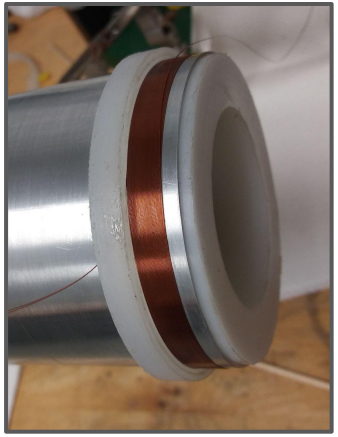


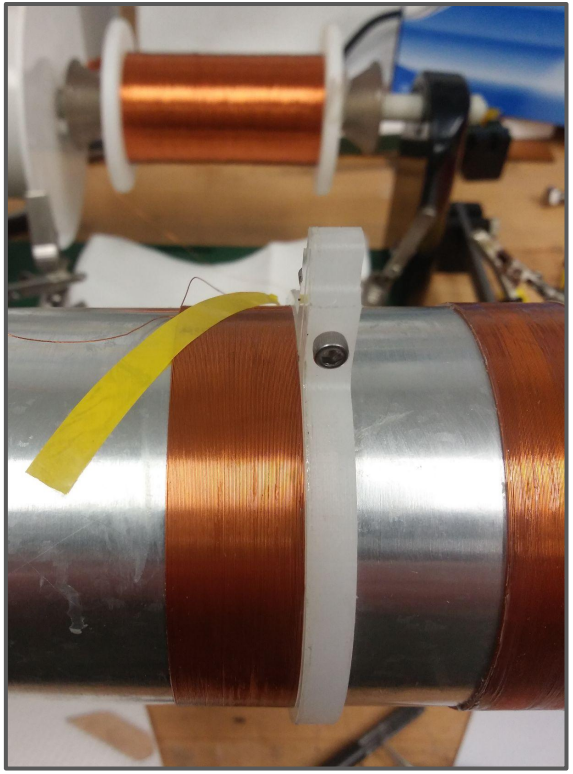


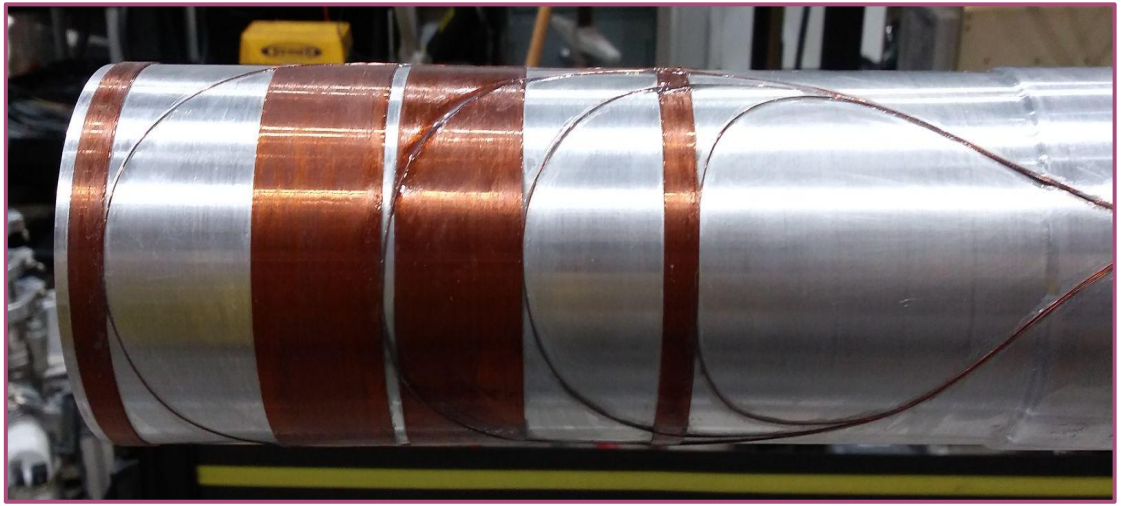
Winding

Wet-wound by hand on top of mandrel with cryogenic epoxy and bumpers



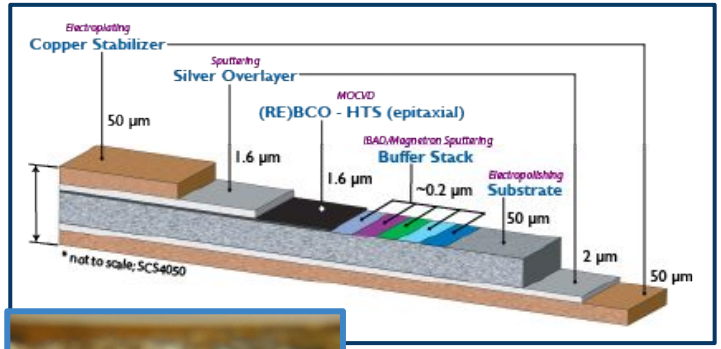


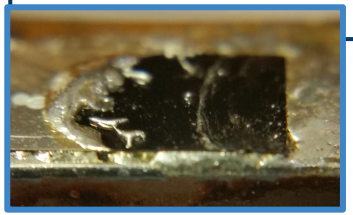


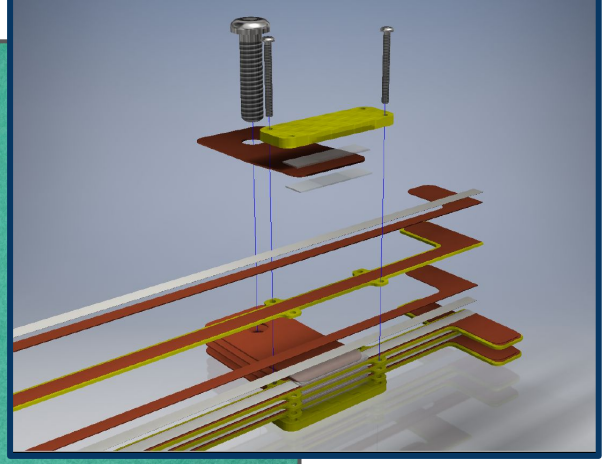


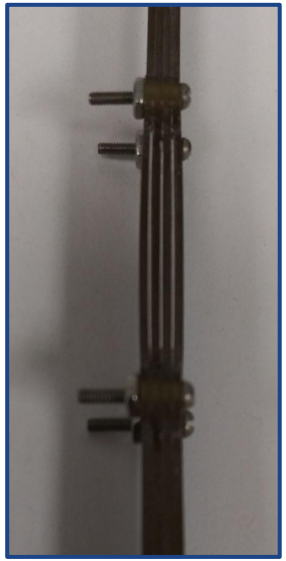
0.007” NbTi Formvar insulated magnet wire

Current Leads



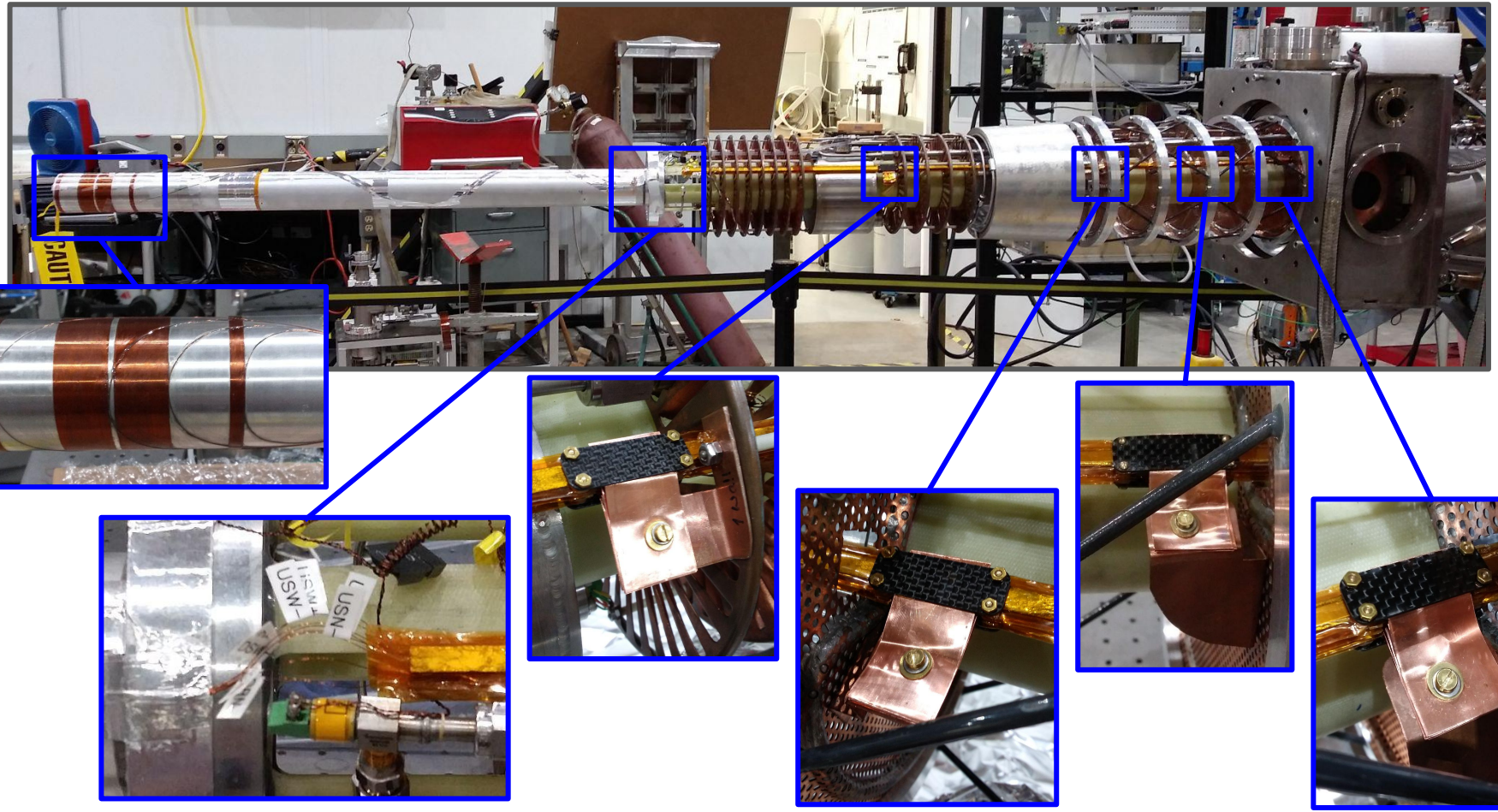






To deliver current to the shims while minimizing ohmic heating, HTC ribbons were stacked onto stabilizing frames and heat sunk along the cryostat.

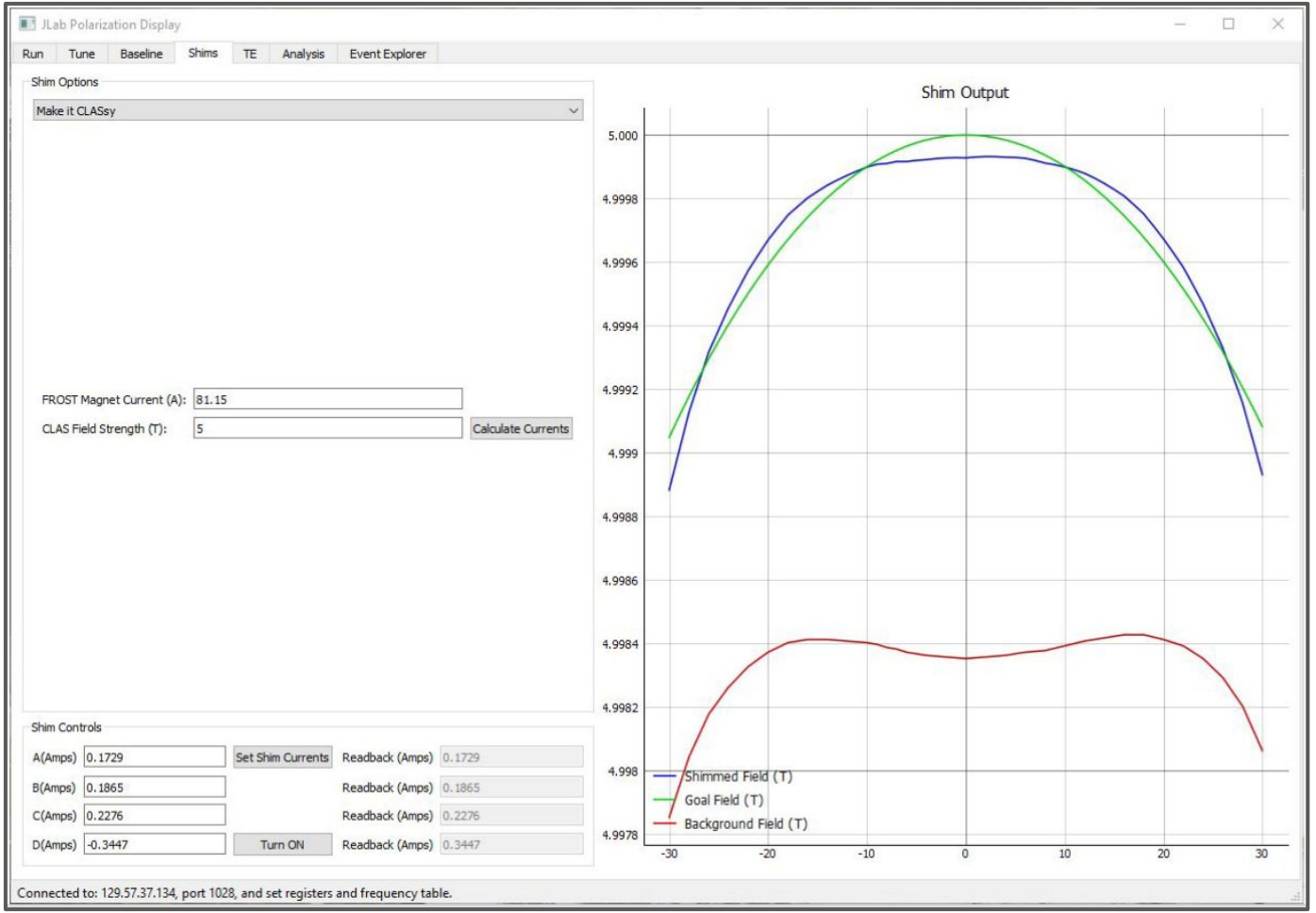
Current Path



Controls

Control of the shim coils is handled remotely through the NMR software

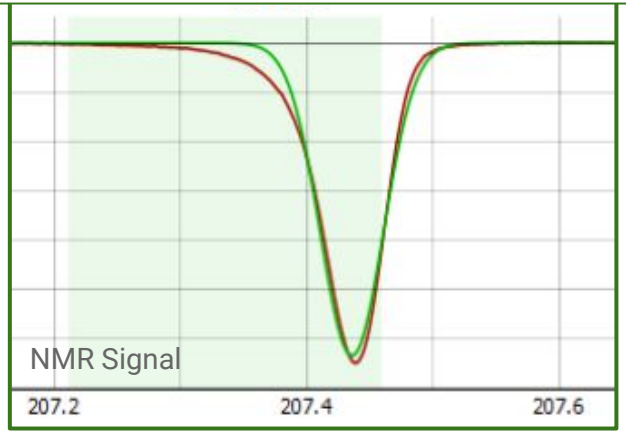
The same optimizer is run (with fixed coil geometry) allowing the user to specify the desired field strength and mode

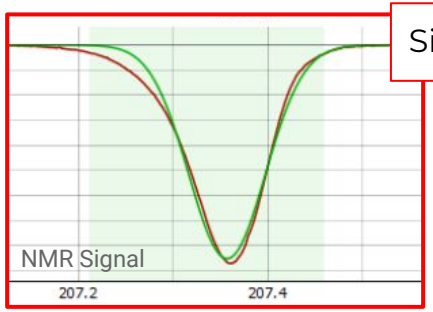


Outcome

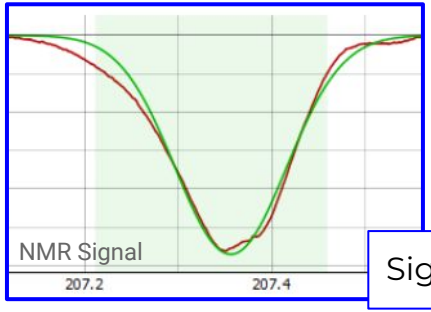
Correction coils successfully able to manipulate field as expected: Homogeneously moved a low field to the desired polarizing magnitude, shifted the field away for NMR baseline measurements, and investigated the effects of field inhomogeneity on polarization.

95G Field Increase - Signal Width 2.4e-2

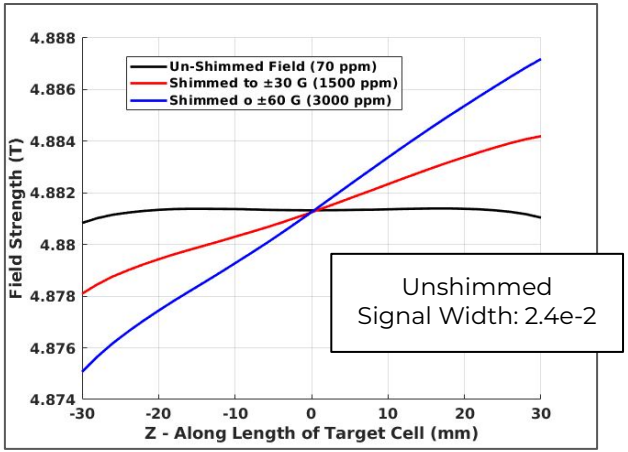




Signal Width: 4.06e-2



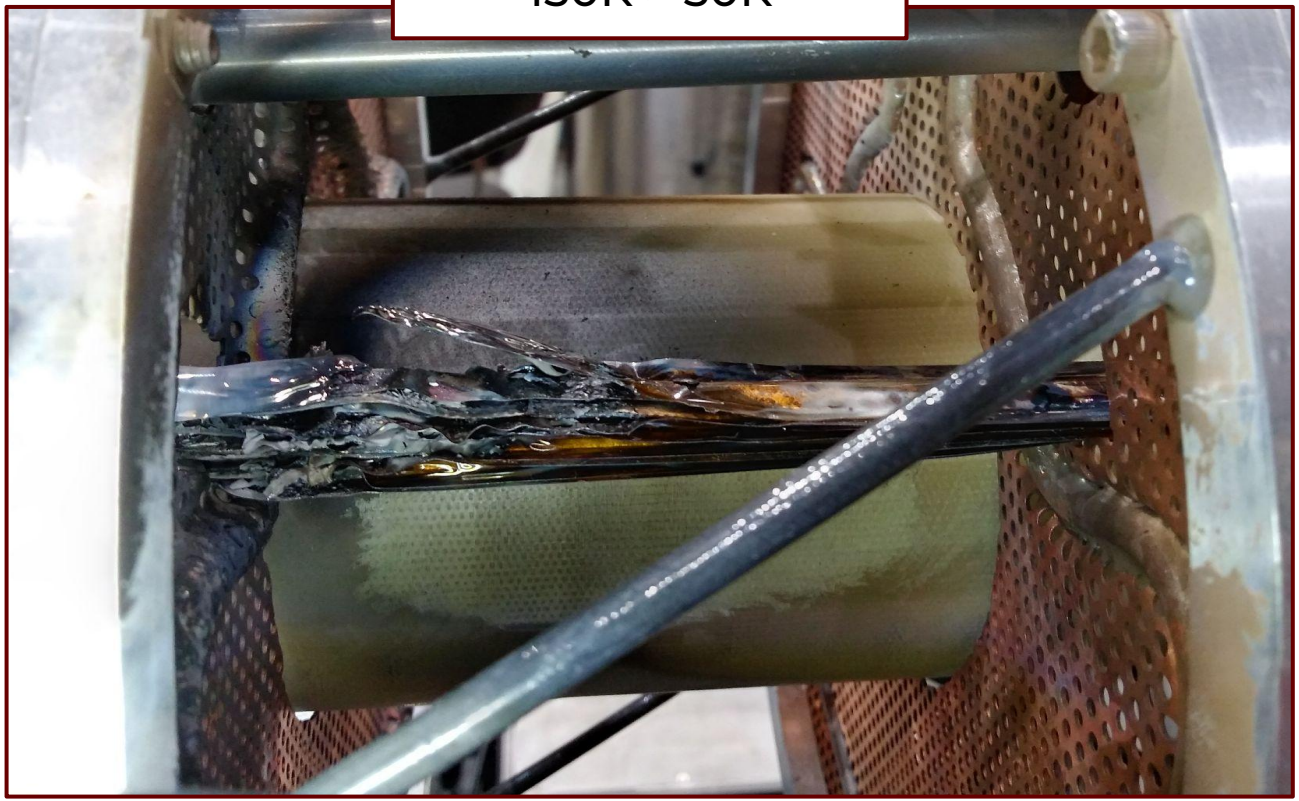
Signal Width: 5.92e-2



Unshimmed
Signal Width: 2.4e-2

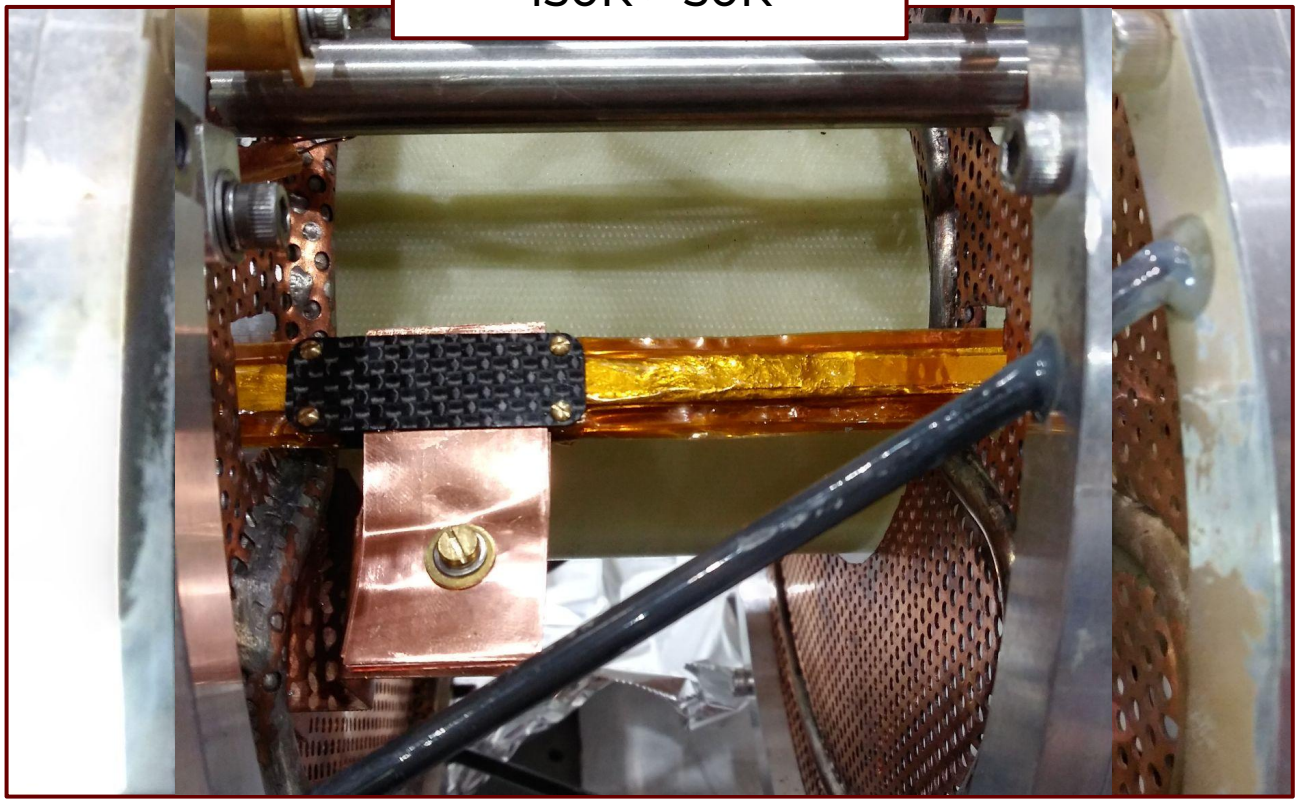
Outcome

150K > 50K



Outcome

150K > 50K

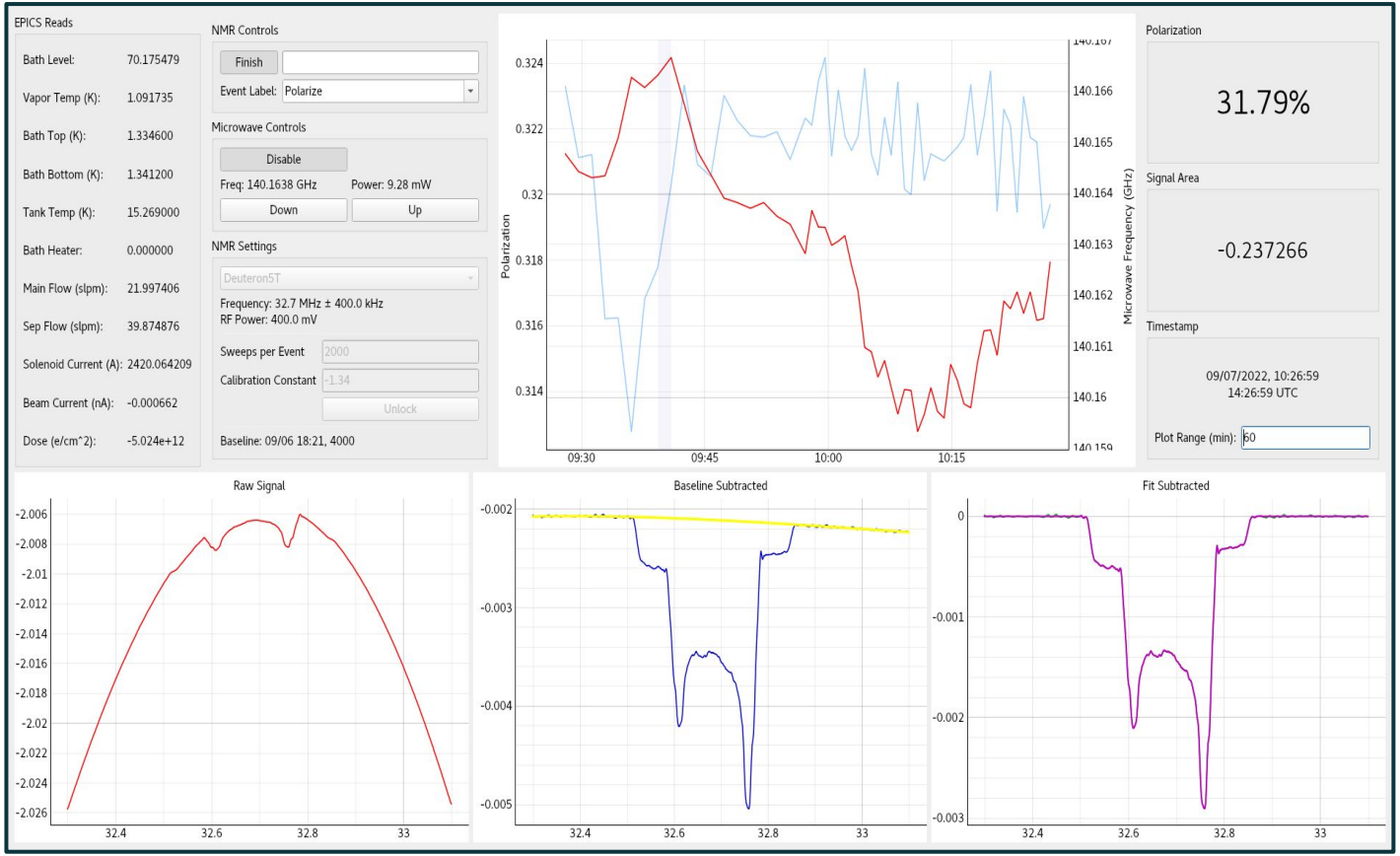


Outcome

Target has been in continuous operation since June

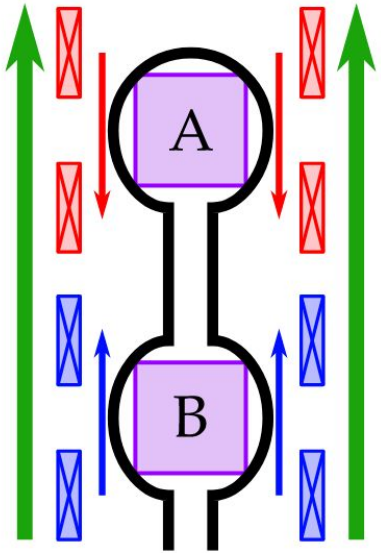
Small but measurable effect on ND3

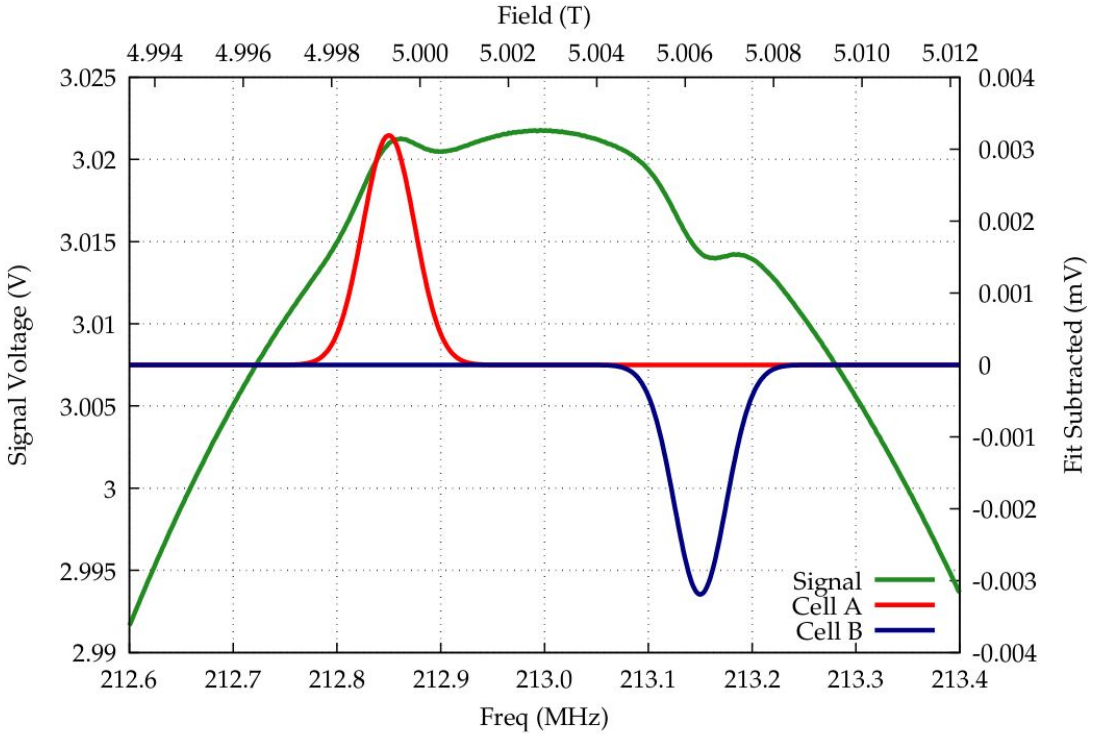
More studies to come..



Thank You

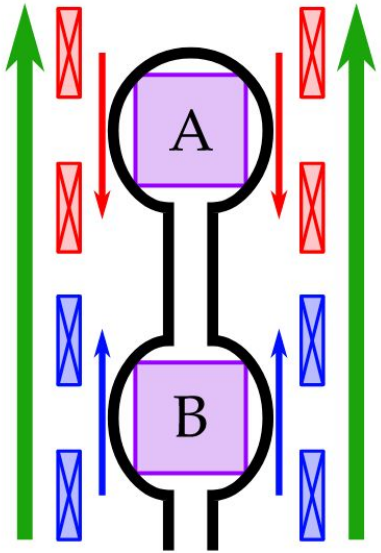
Dual Cell

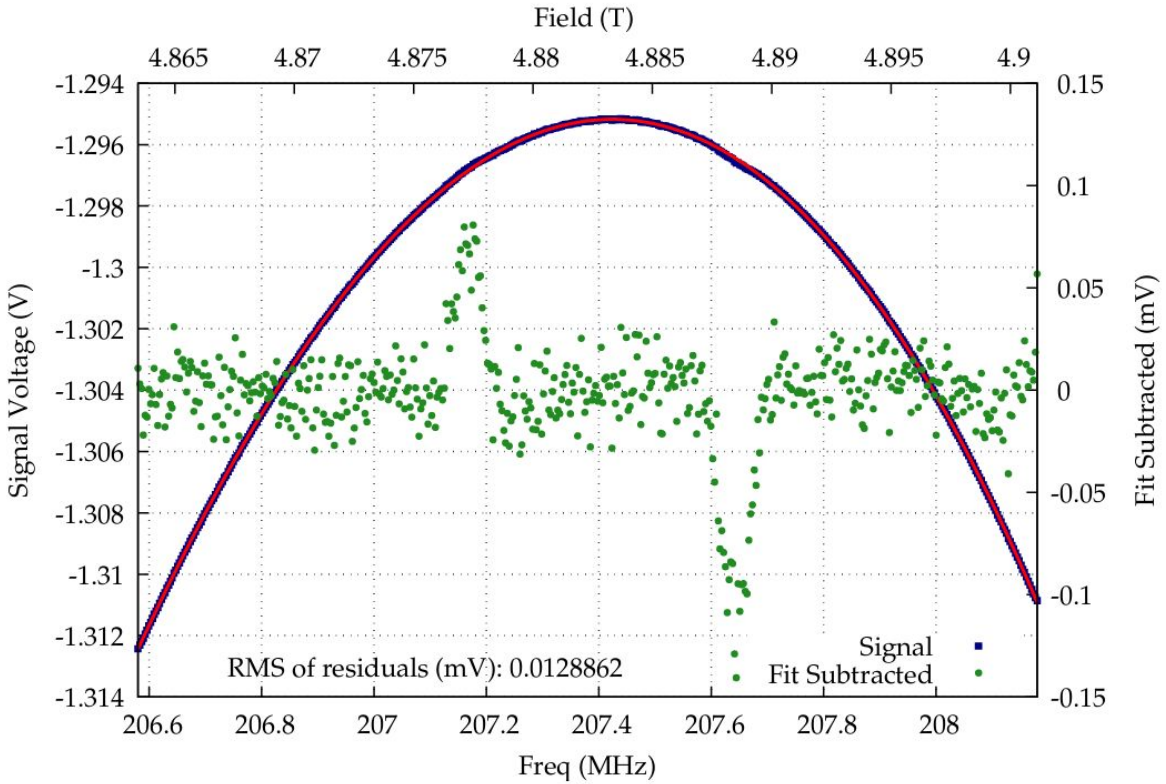




Single microwave frequency applied to polarize

Dual Cell





Single microwave frequency applied to polarize