

# Magnetic Field Requirements for the CLAS12 Polarized Target

Workshop on Polarized Sources, Targets, and Polarimetry  
9-23-2019

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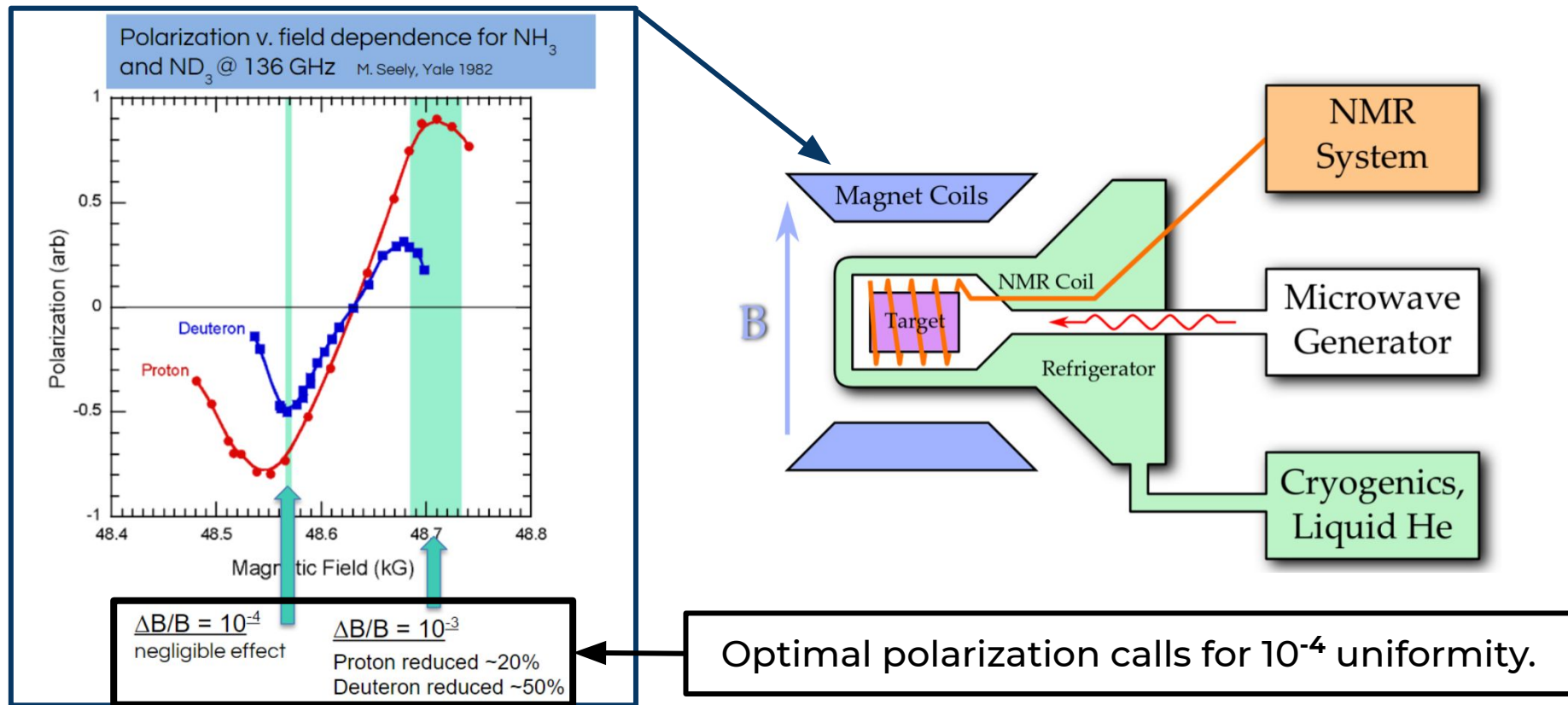
# Outline

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- Magnet Field Requirements for DNP
- CLAS12 Solenoid
  - Map
  - Model
- Correction Field Requirements
- Shim Coil Design Algorithm
- Testing
- Results

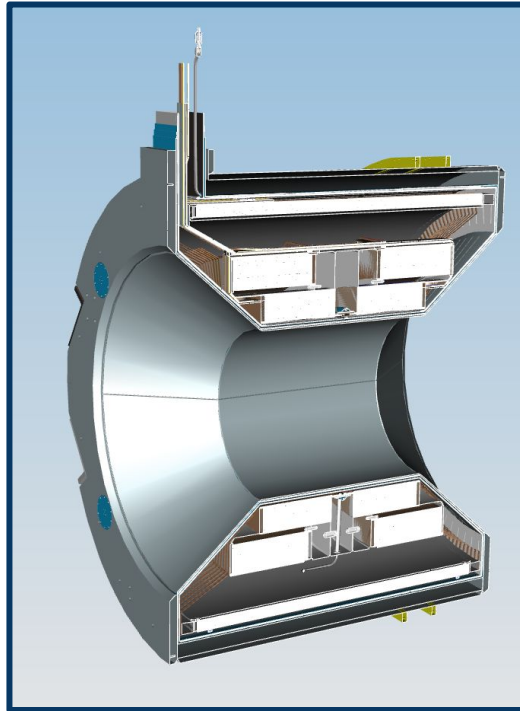
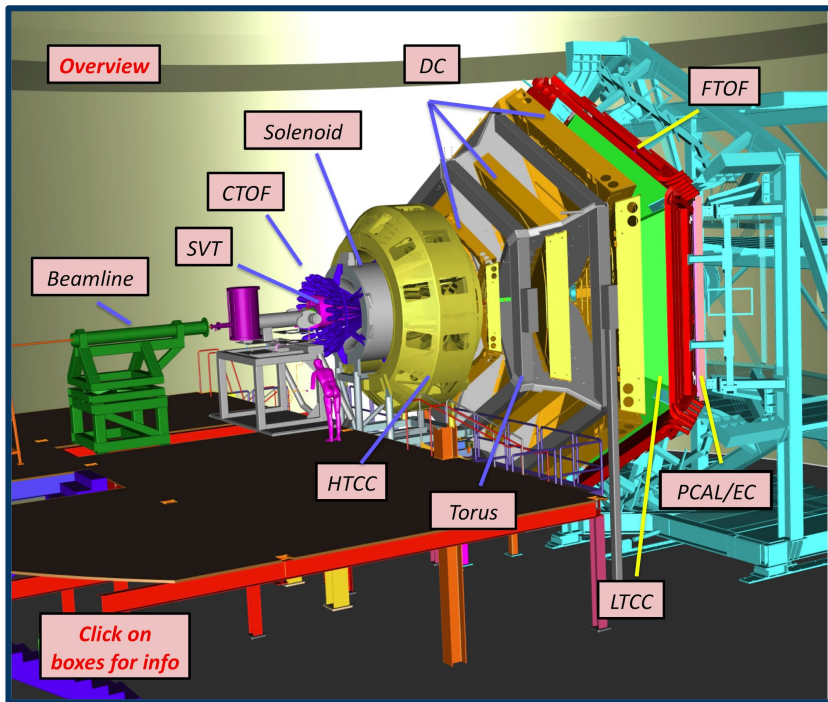
# Field Requirements for DNP

Polarization needs a strong but controlled magnetic field.



# CLAS12 Solenoid

The CLAS12 detector provides the overall polarizing field.

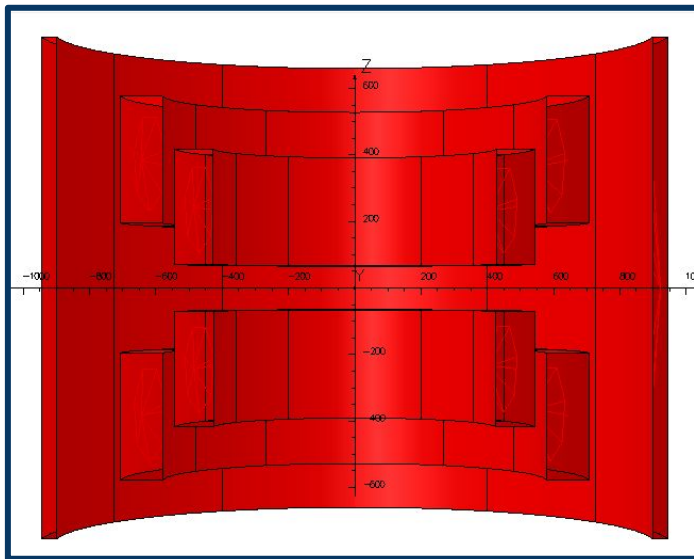
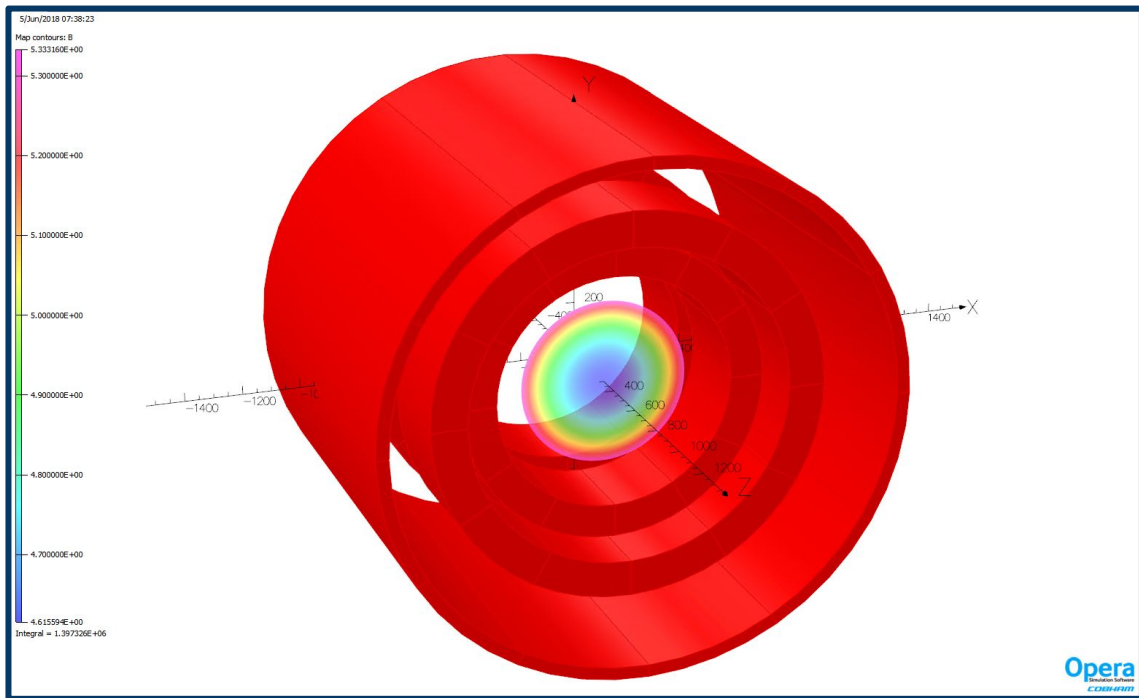


Strong 5T solenoid already incorporated into the detector system of CLAS12.

Designed to provide uniform field in central region while dropping off sharply on far ends.

# CLAS12 Solenoid

3D models were used to design and predict the field shape...



...but actual performance unknown until it was built, installed, and mapped.

# CLAS12 Mapping

Different locations,  
resolutions, angles, rotations

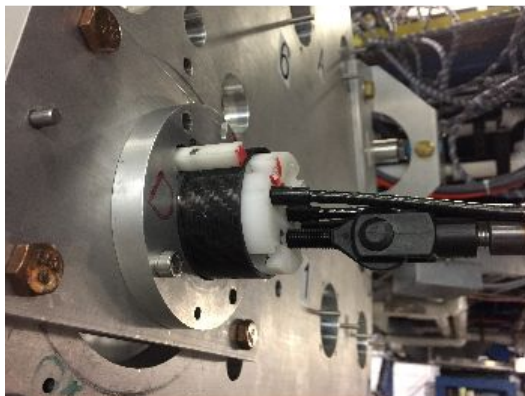
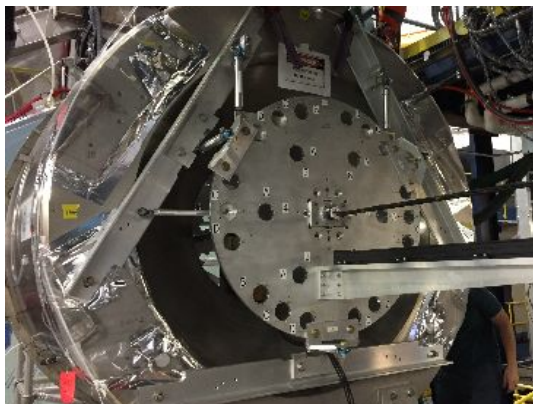
Followed the initial max field  
test in September 2017

Most with reduced field  
(1450 A = 3 T)

Measurements with 3D Hall  
probes along z

Roughly 50 “runs” at various  
positions in r and phi, and  
various orientations of the  
Hall probes

Some “long” (about 2 m) and  
some short (20 cm) runs.

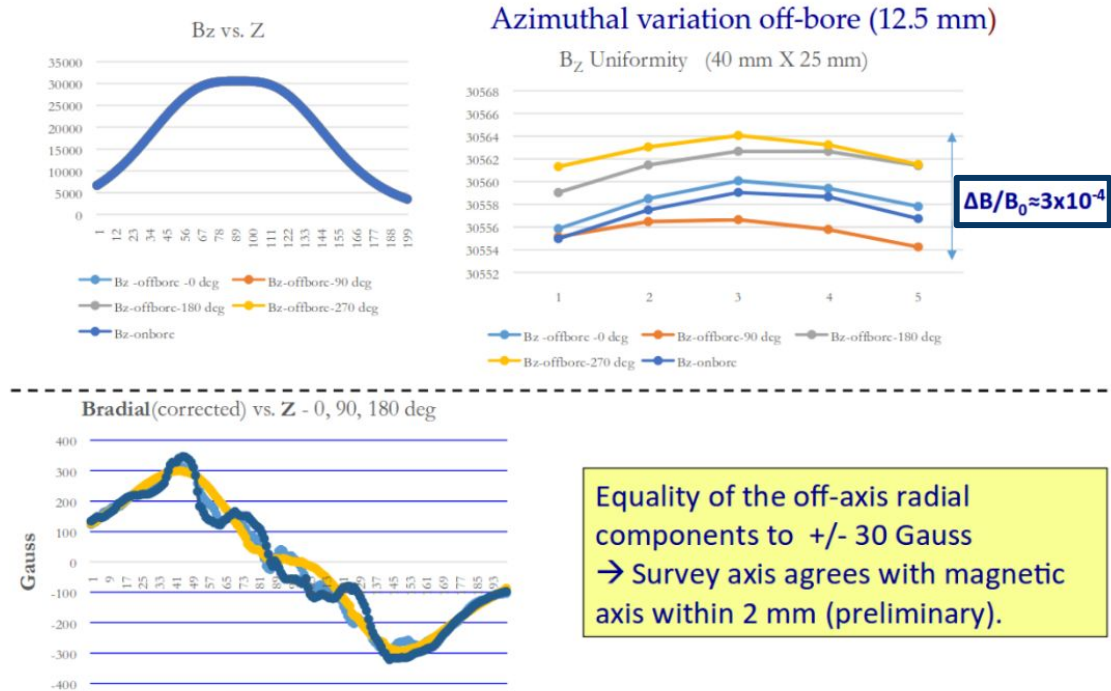


Short Runs (middle 10 cm, 1 mm steps)	
Radius (cm)	Phi
0	/
1.25	0, 90, 180, 270, 90, 45, 45, 45, 135, 225, 315
Long Runs (full length, 1 cm steps)	
Radius (cm)	Phi
0	/
1.25	0, 45, 45, 45, 90, 90, 135, 180, 225, 270, 315
30	0, 90, 270
Long Runs (probe rotated in place)	
Radius (cm)	Phi
0	/
1.25	90
30	0

# Map vs. Model

Credit: Mac Mestayer

## Solenoid Magnetic Main Field



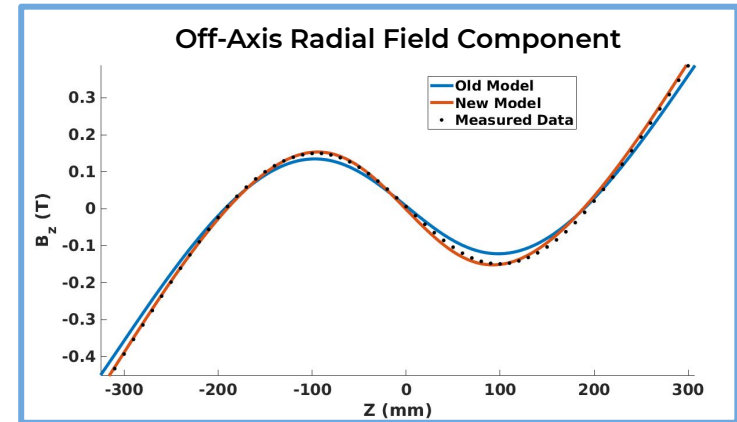
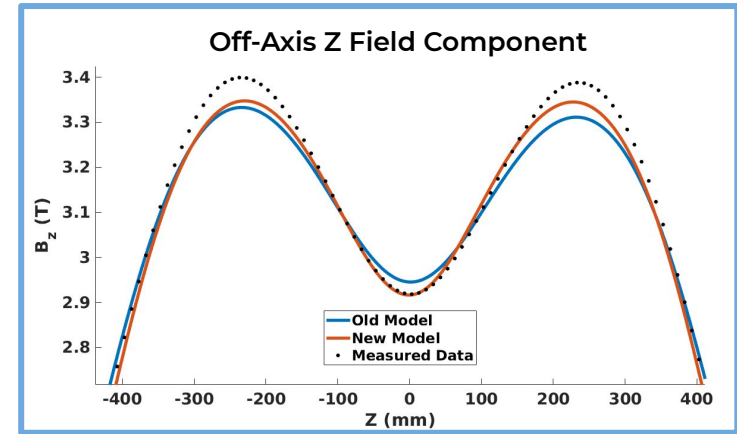
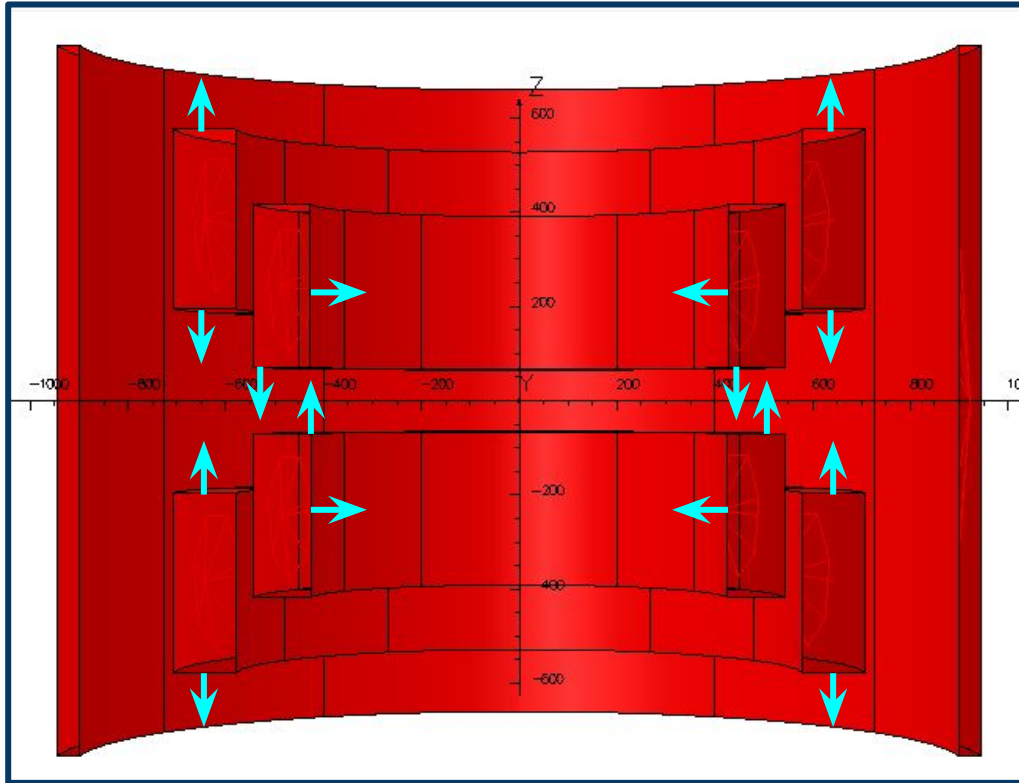
Preliminary results indicated a central field uniformity of around  $3 \times 10^{-4}$ .

However, due to inconsistencies with the fine and coarse resolution data, the original magnet model was reexamined.



# Map vs. Model

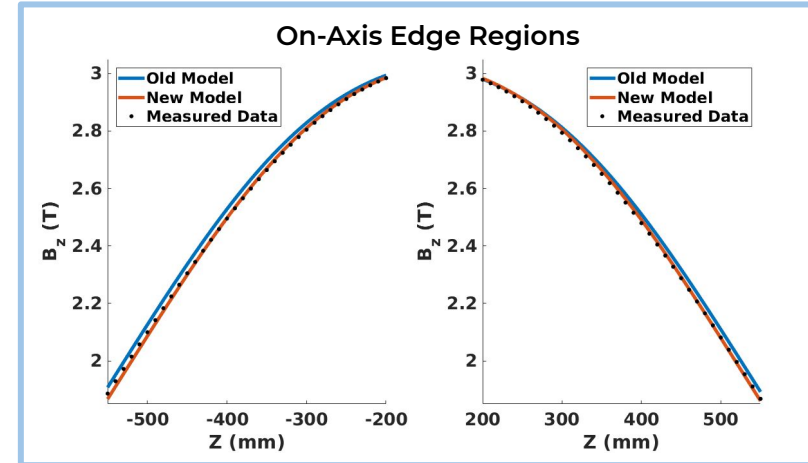
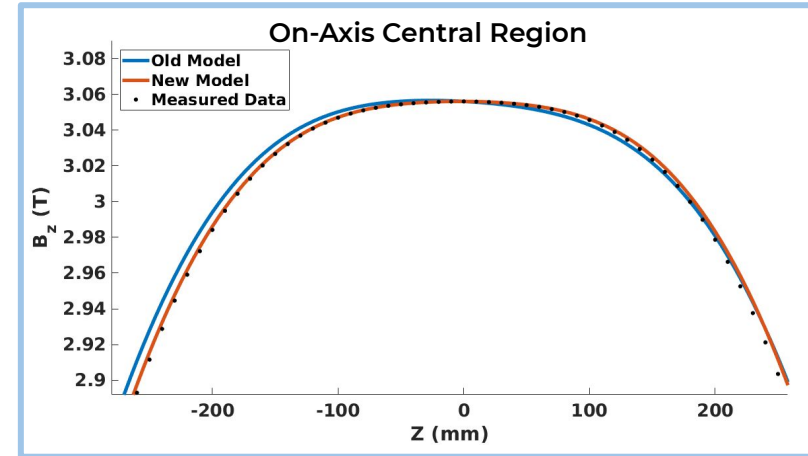
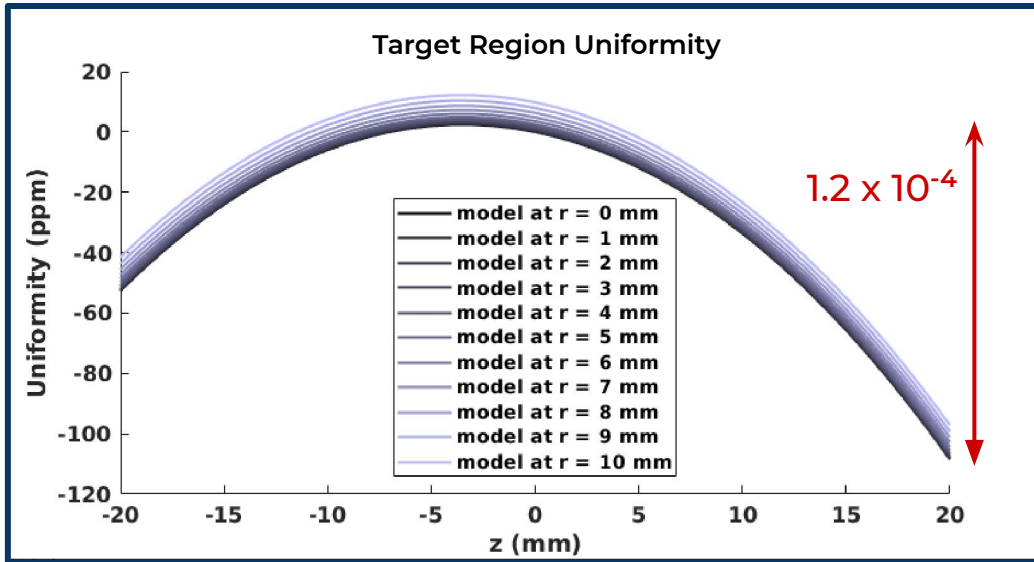
Adjustments were made to the model.





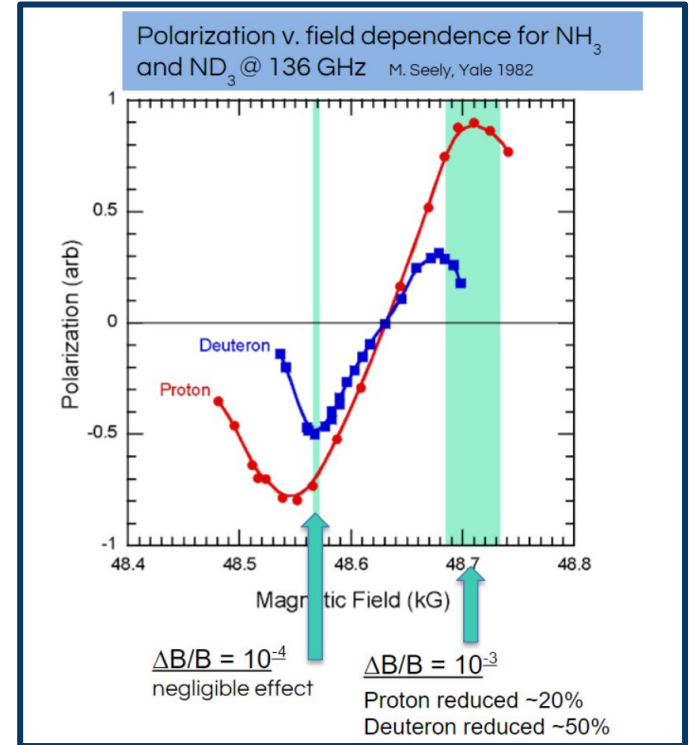
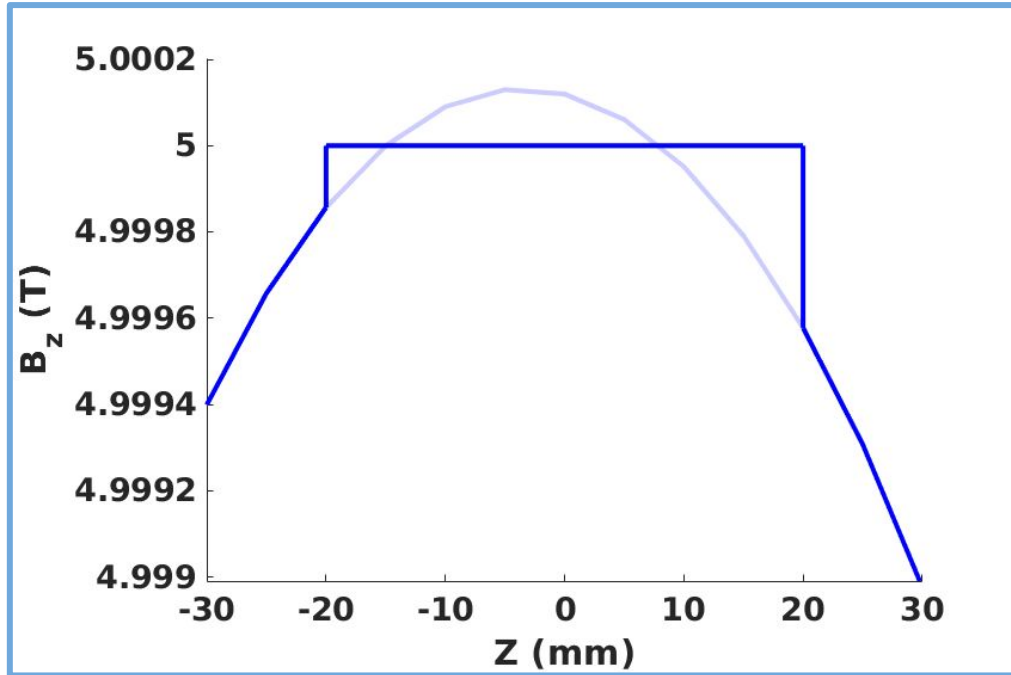
# Final Model Results

After optimizing the model to better match the data, the uniformity of the field in the target region appears to be improved by a factor of two but the real indicator will be polarization.



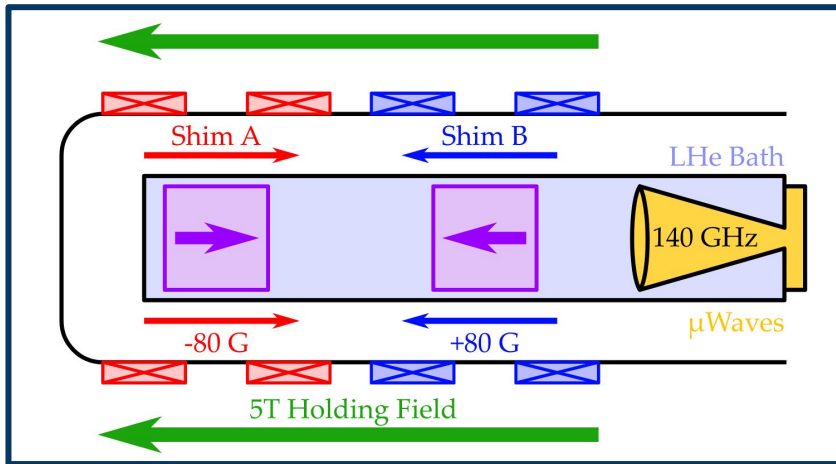
# Corrected Field Requirements

Supplementary coils are needed to bring target region closer to the ideal field but they also create additional functionality for the experiment.

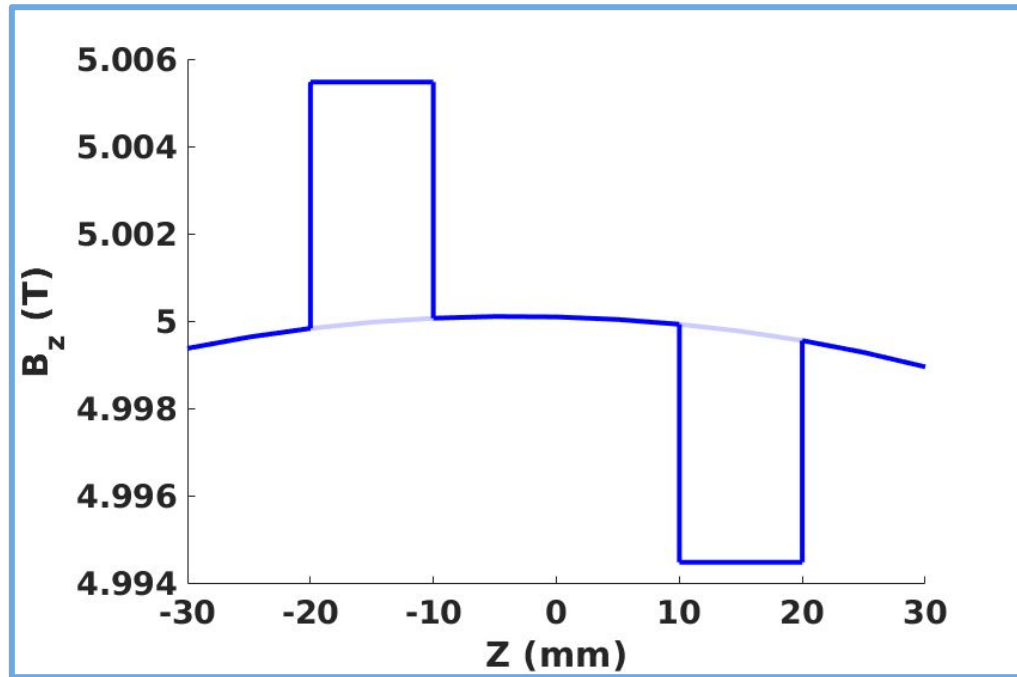


# Dual Polarization

Shim coils also allow for the opposite polarization of two adjacent targets.



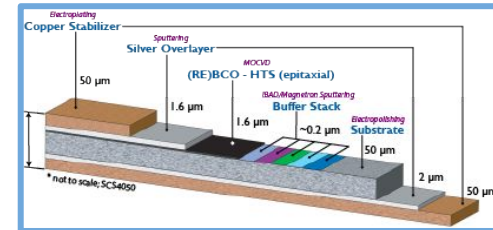
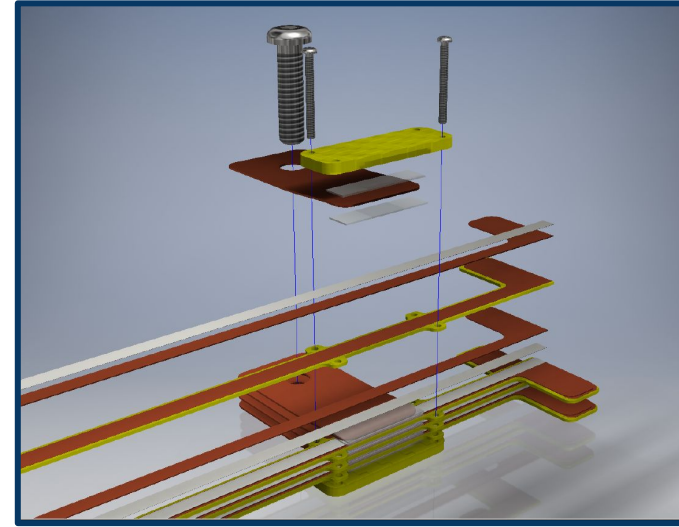
But the sharp change in magnetic field increases the required currents and demands a more precise coil design.



# Shim Design

## Design considerations:

- Physical limitations of space:  
CLAS12 only allows for ~2.5 cm radius  
Must leave room for other hardware
- Particle blocking:  
Minimize dense material around target
- Heat from coils  
High temperature superconducting leads  
Superconducting wire for coils
- Versatility  
Single configuration must serve multiple targets



# Design Algorithm

## Input:

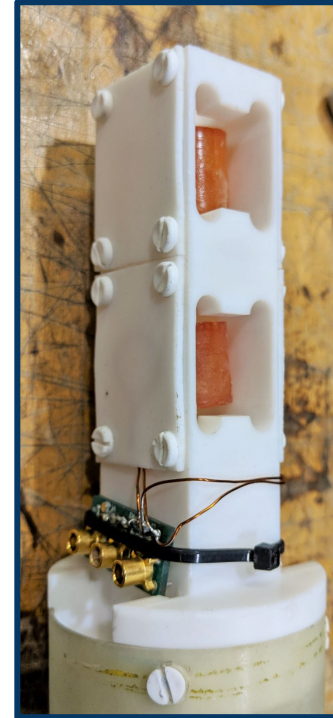
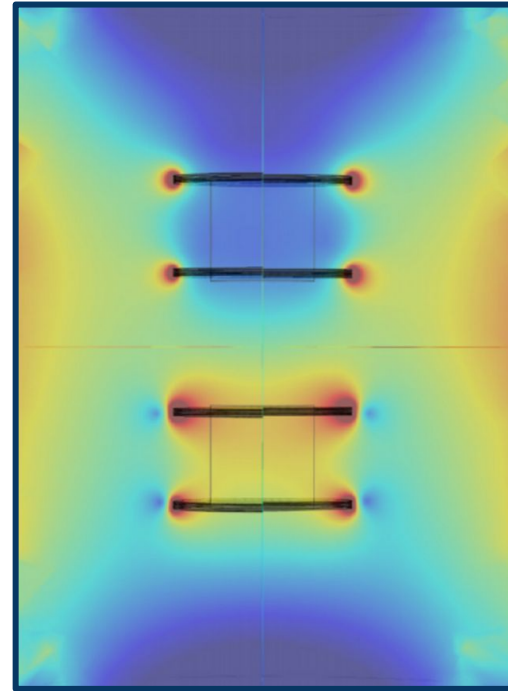
- Background Field
- Position of Target(s)
- Desired Field at Target(s)
- Weights of Minimization Parameters

## Minimization Parameters:

- Uniformity Over Target Region(s)
- Total Current
- Maximum Current
- Coil Sizes
- Distances from Target(s)

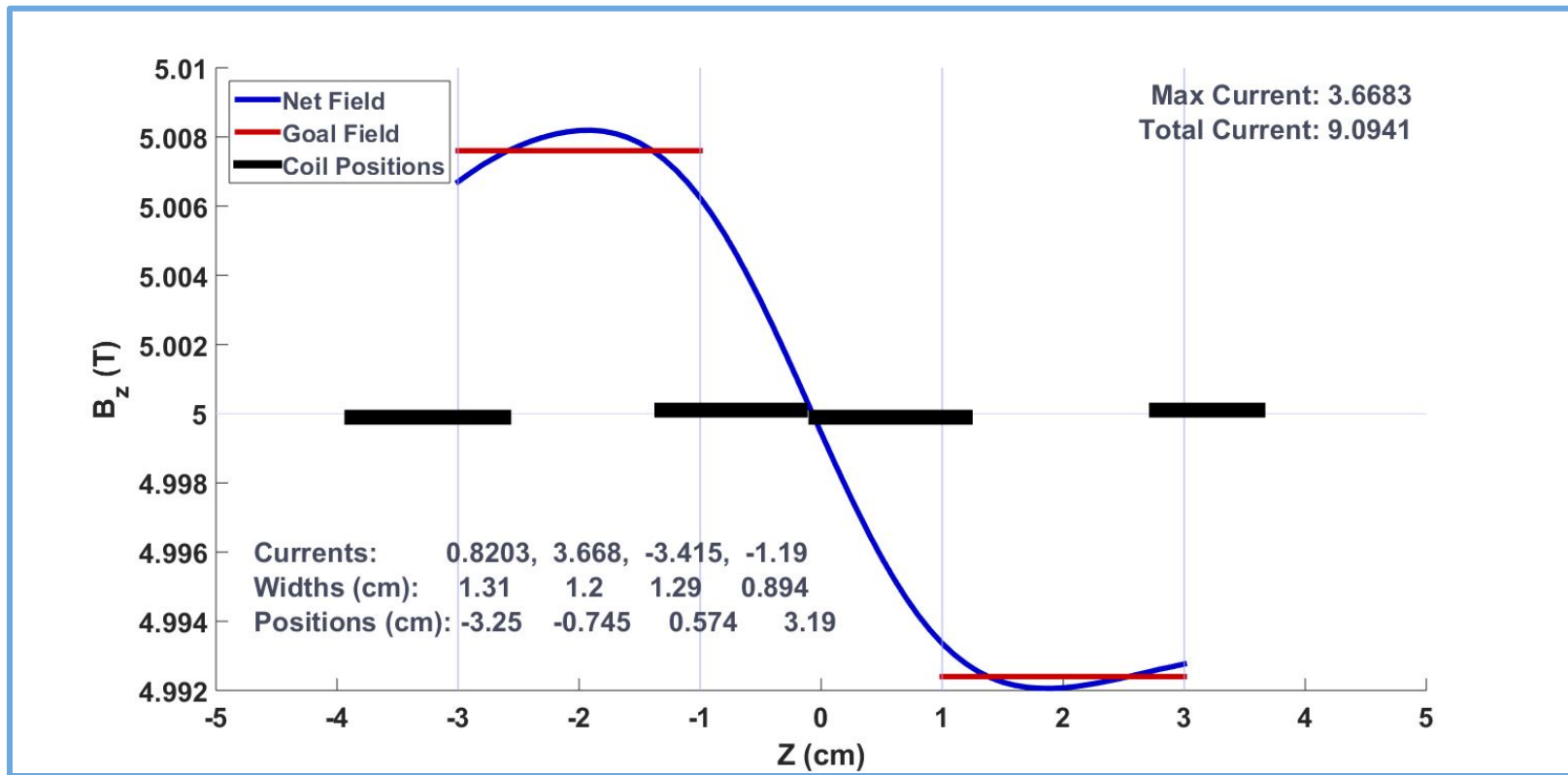
## Output:

- Position of Coils
- Coil Currents
- Resultant Field



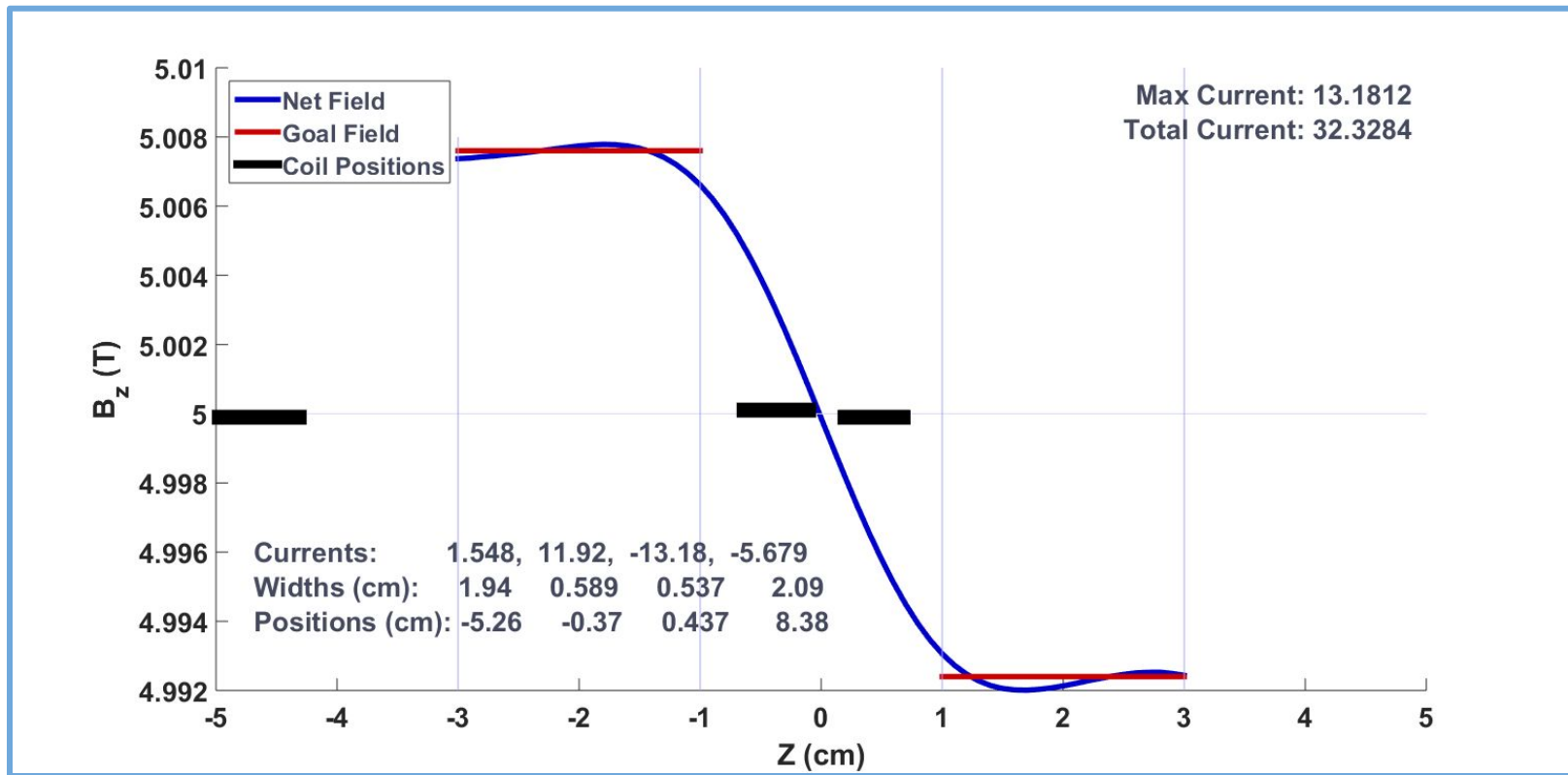
# Algorithm Output

## Matlab Optimization Results:



# Algorithm Output

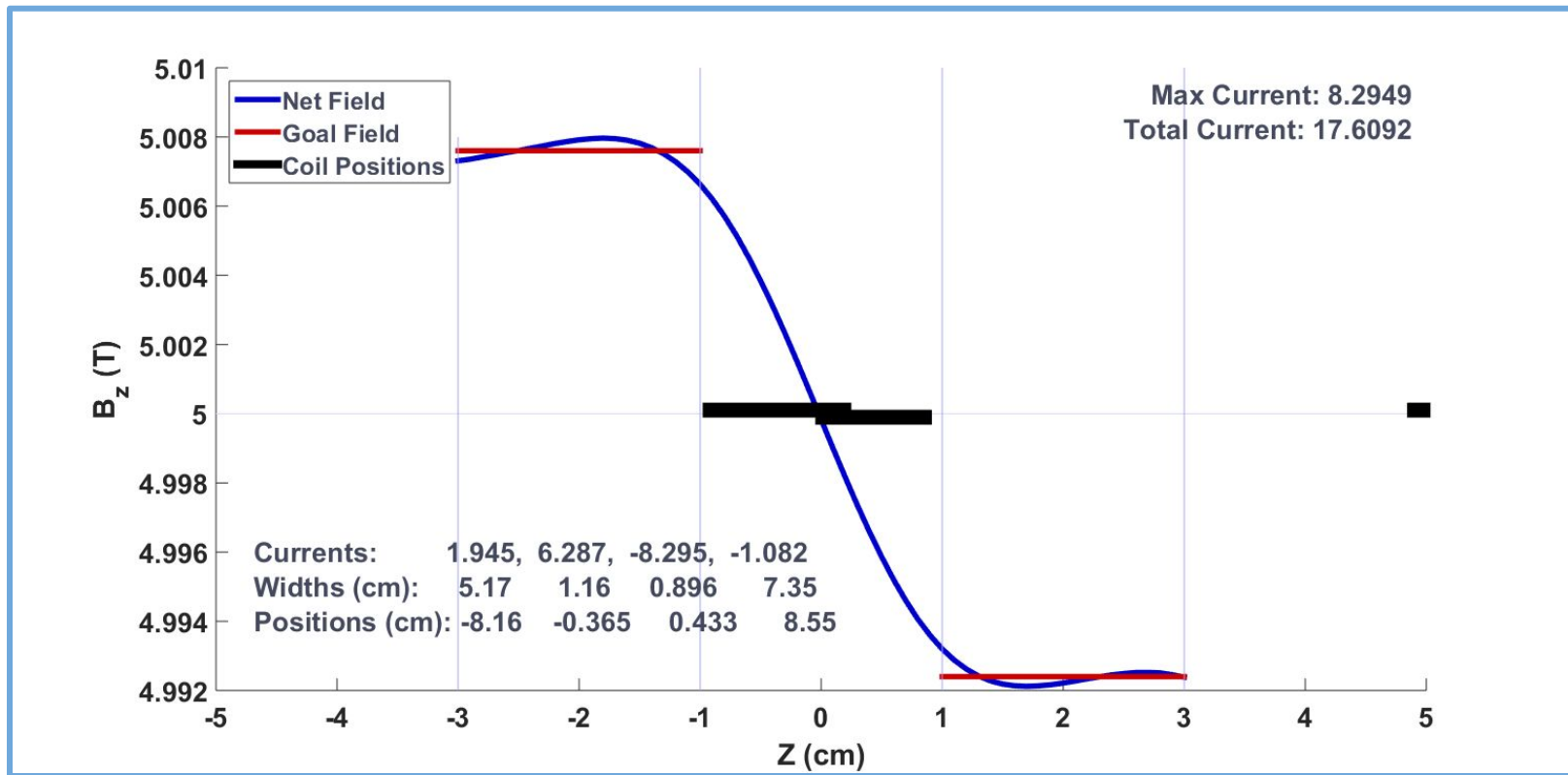
## Matlab Optimization Results:





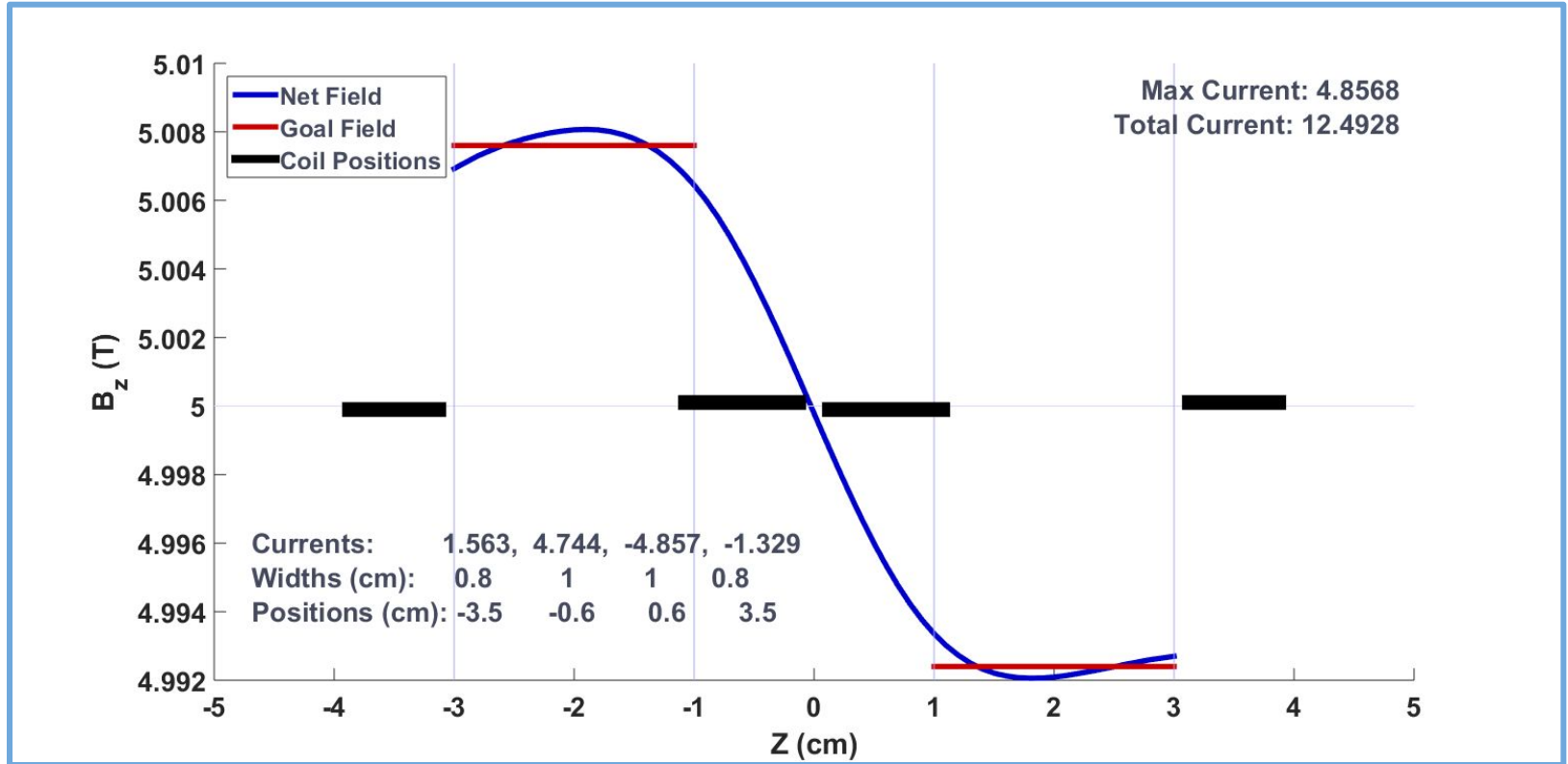
# Algorithm Output

## Matlab Optimization Results:



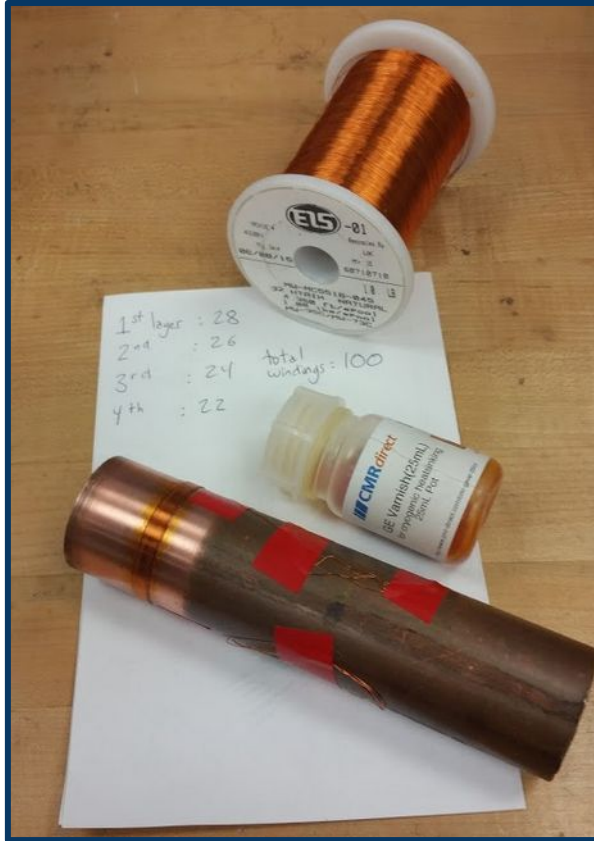
# Algorithm Output

## Chosen Configuration for Liquid Nitrogen Test:



# Shim Testing

Coils hand wound to test efficiency.



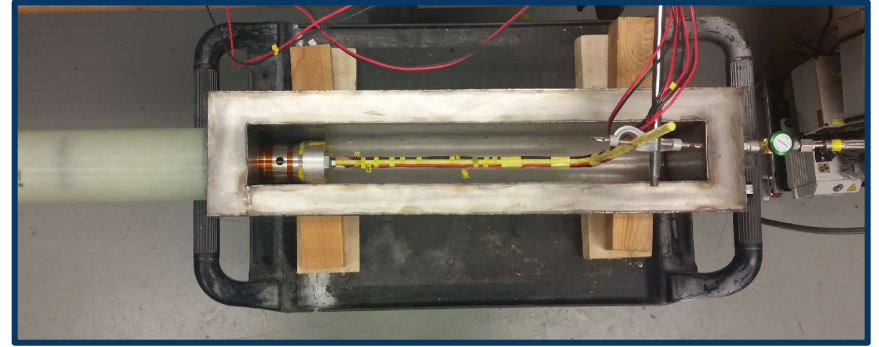
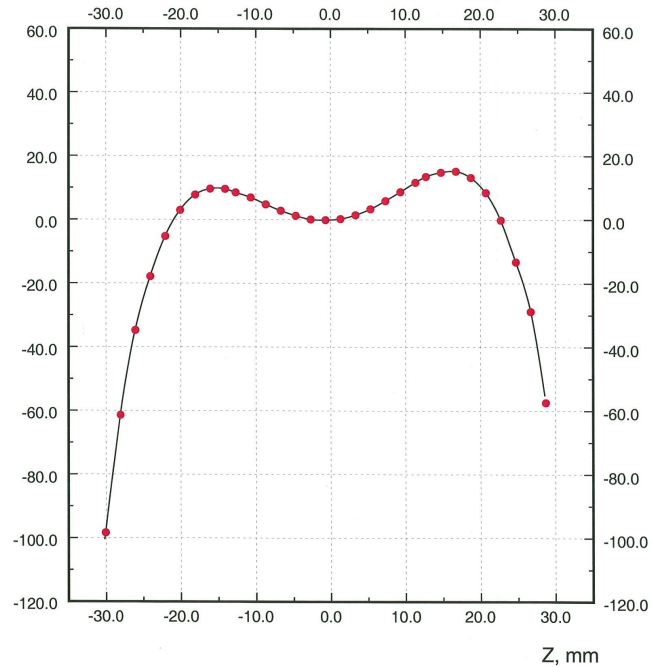
# Shim Testing

Frost magnet remapped for testing.

Field along central axes

( 2.0 Tesla NMR-probe )

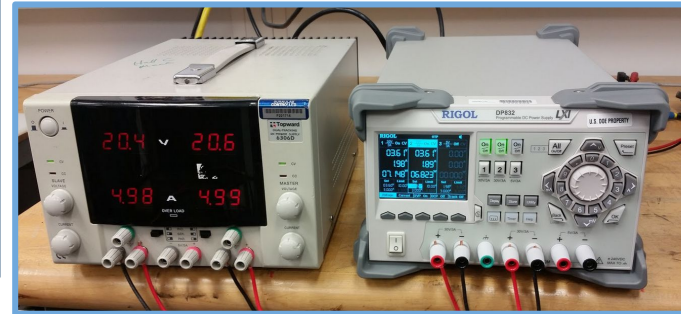
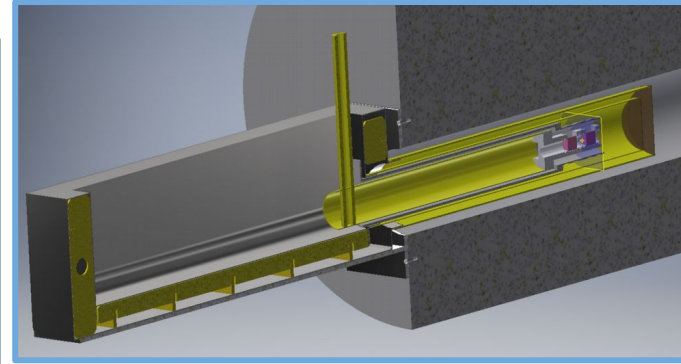
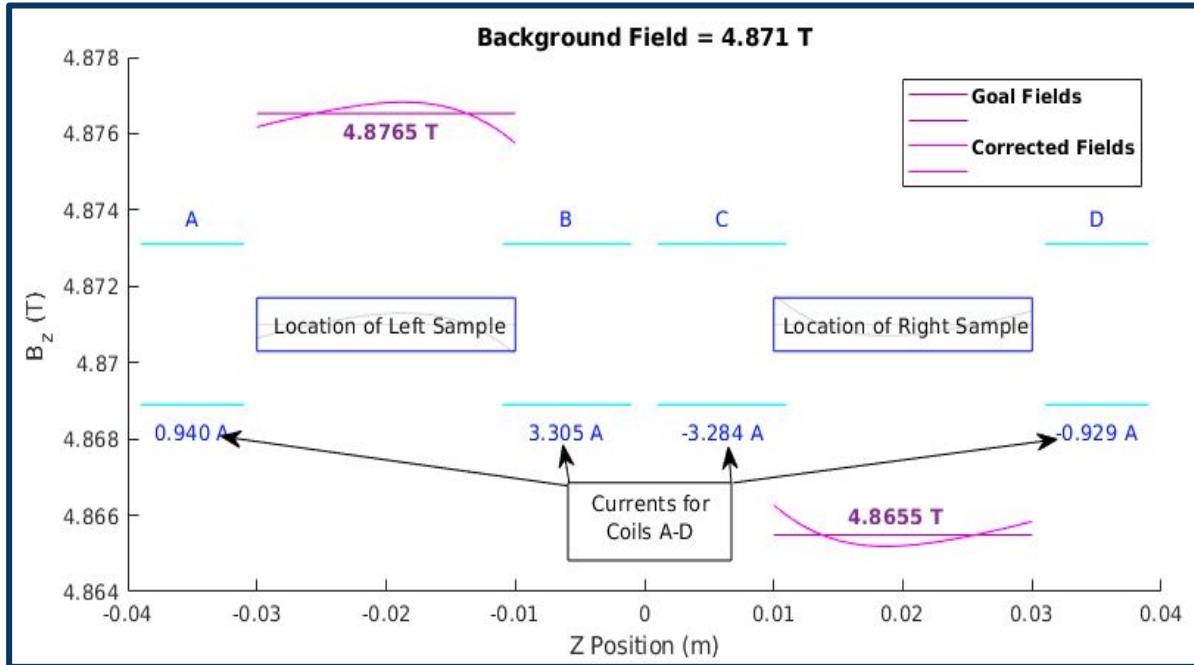
$(B - B_0) / B$ , ppm





# Shim Control

Mapped field used to determine currents to the four coils.



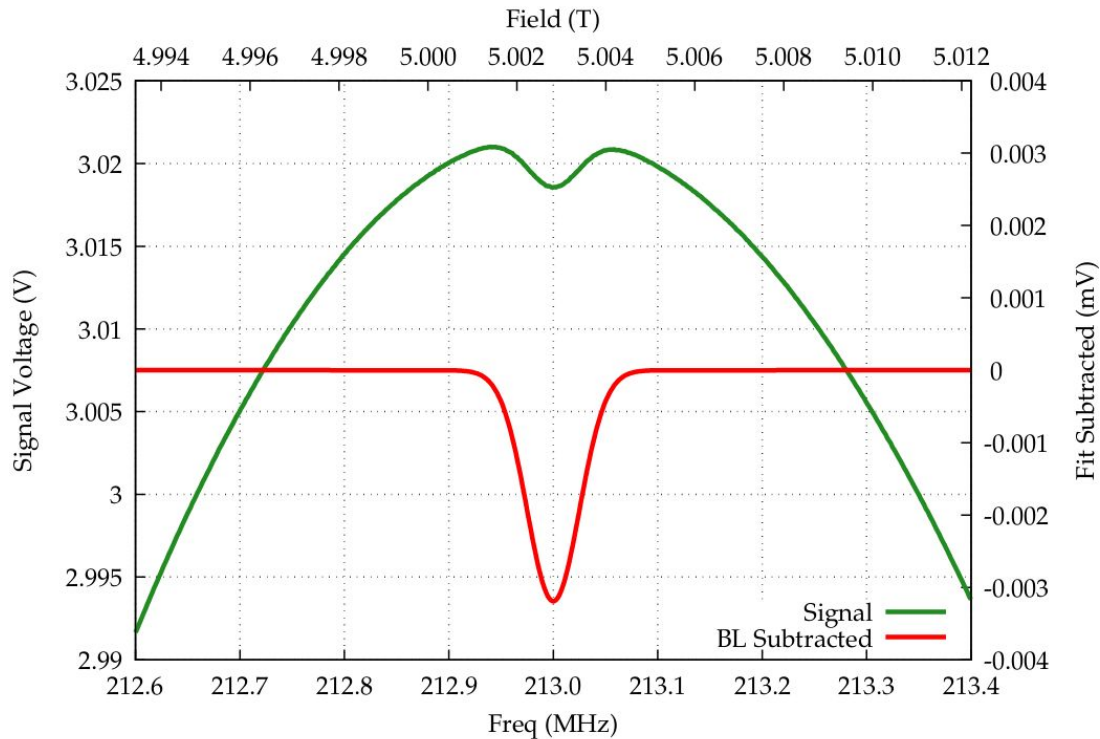
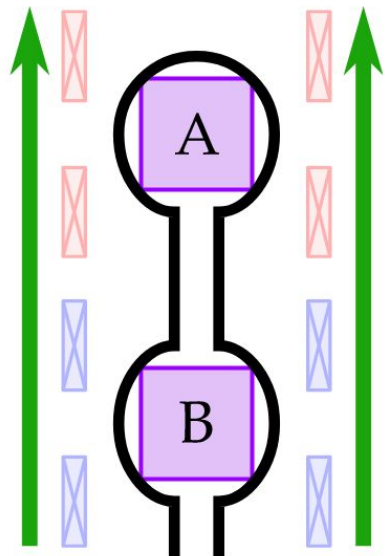
# Expected Result

Credit: James Maxwell

Background Field **On**

Dual Shims **Off**

Microwaves **Off**



2 cells with shims off

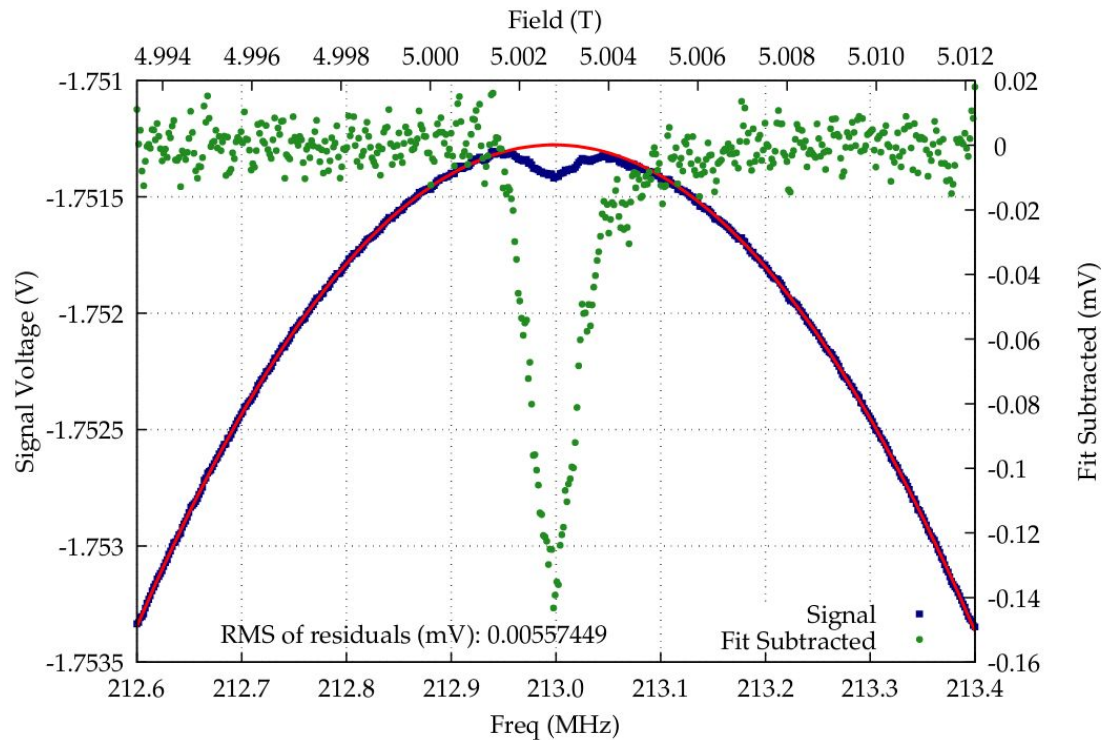
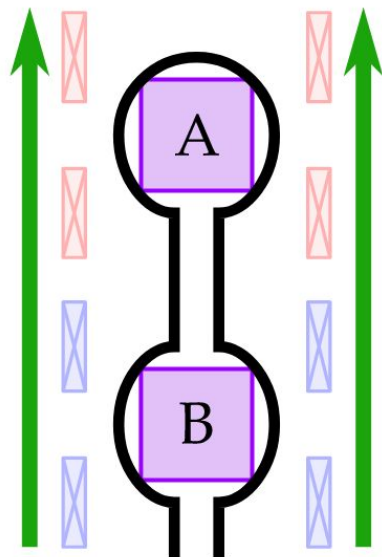
# Actual Result

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2 cells with shims off



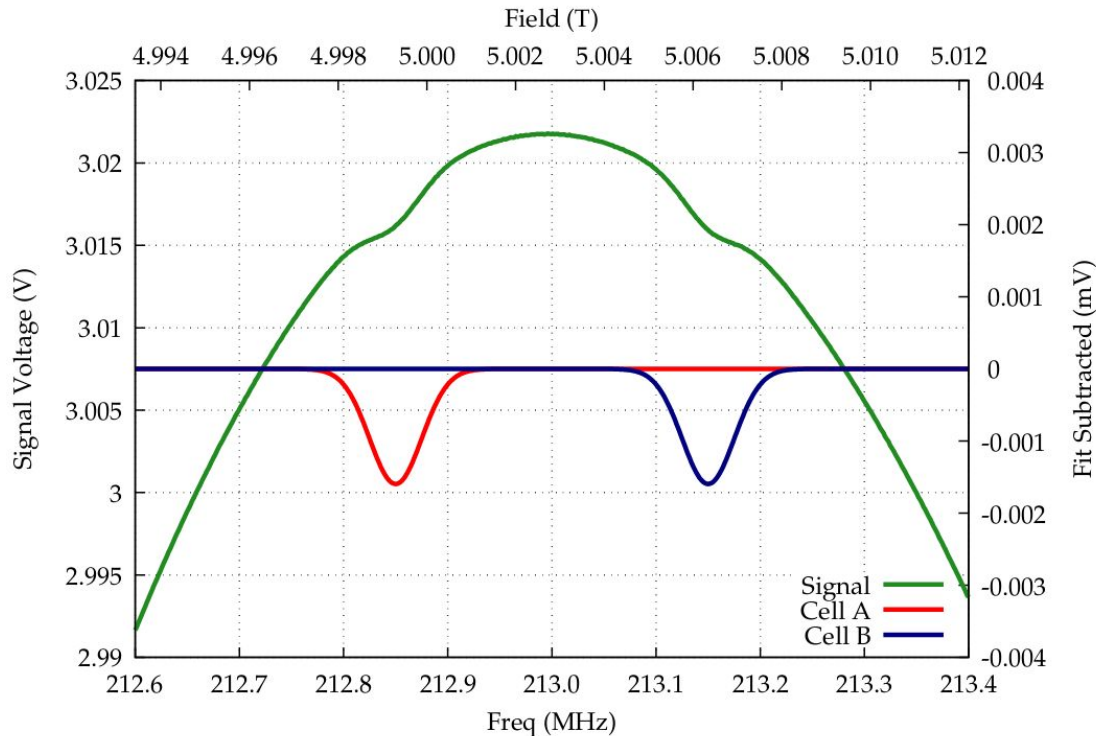
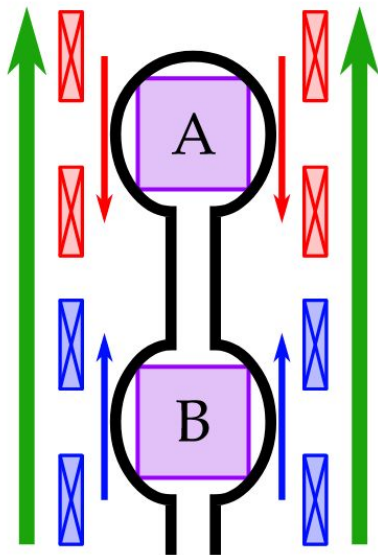
# Expected Result

Credit: James Maxwell

Background Field **On**

Dual Shims **On**

Microwaves **Off**

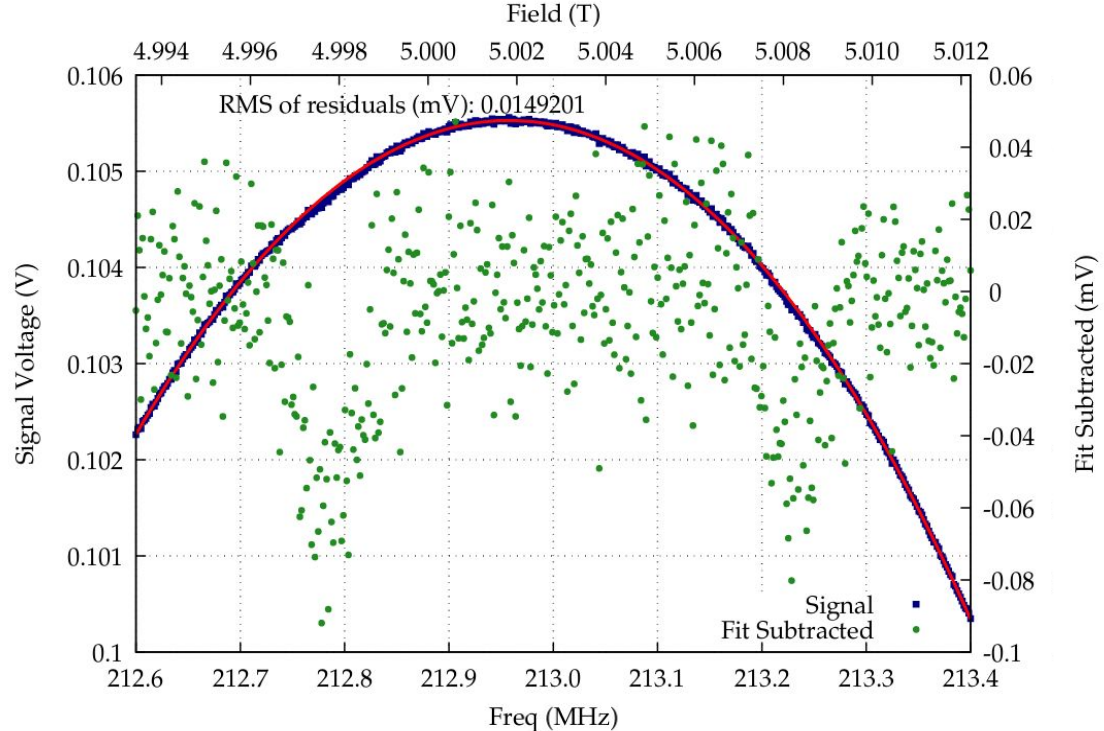
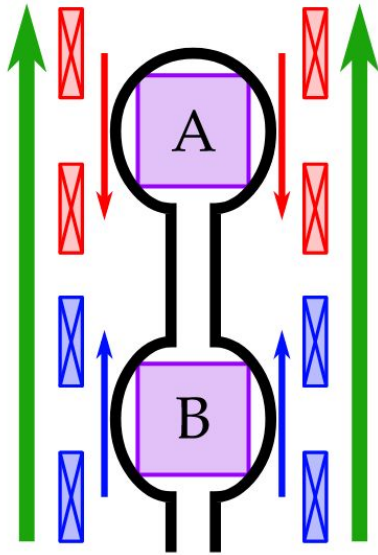


2 cell with shims separating signals from each cell

# Actual Result

Credit: James Maxwell

Background Field **On**  
Dual Shims **On**  
Microwaves **Off**



2 cell with shims separating signals from each cell

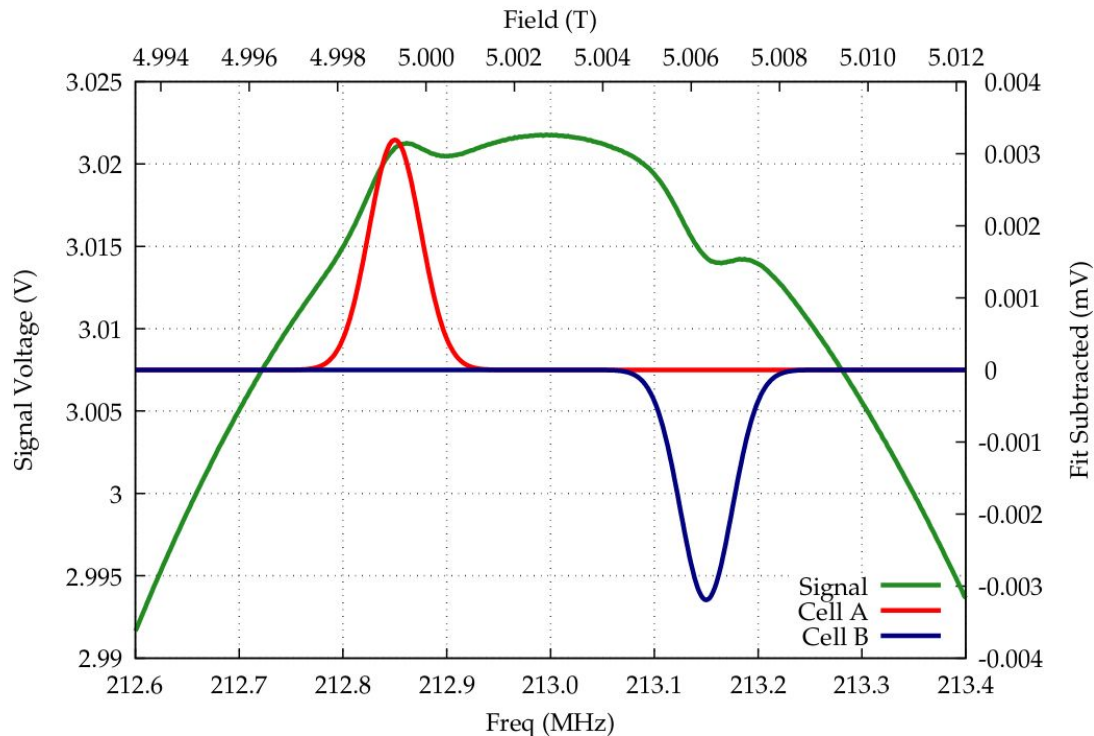
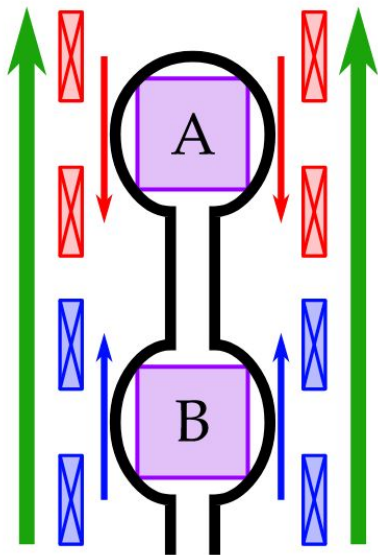
# Expected Result

Credit: James Maxwell

Background Field **On**

Dual Shims **On**

Microwaves **On**

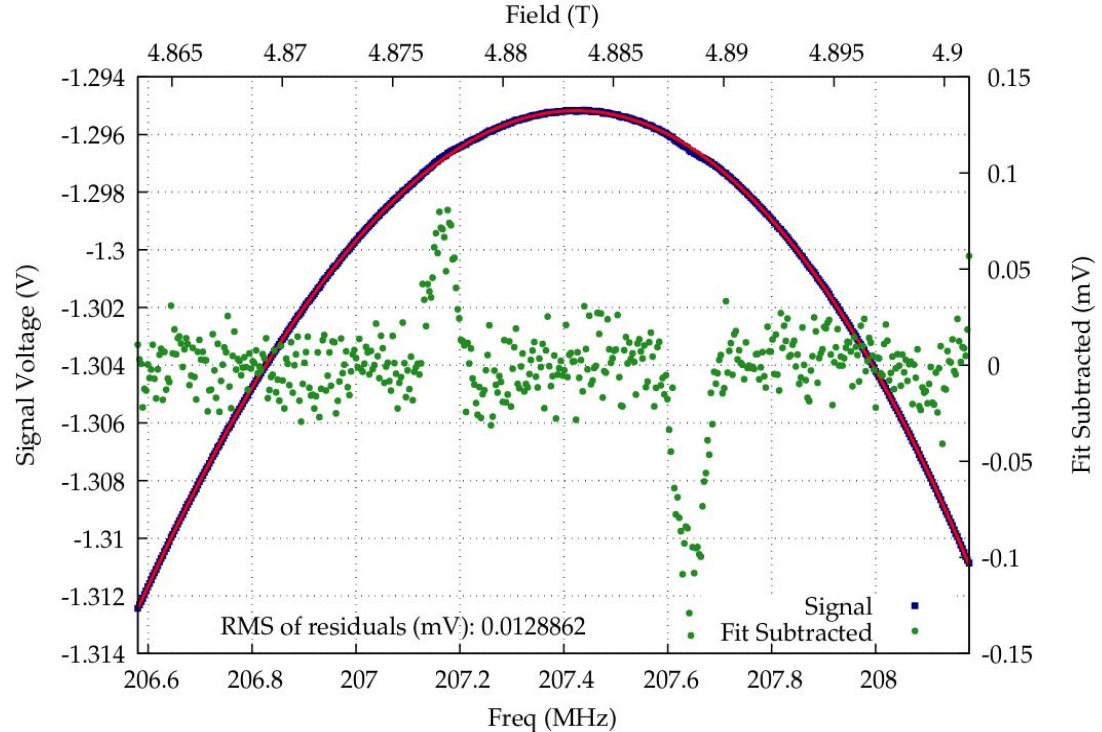
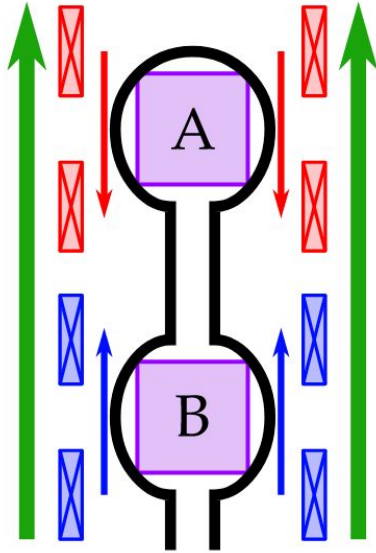


Single microwave frequency applied to polarize

# Actual Result

Credit: James Maxwell

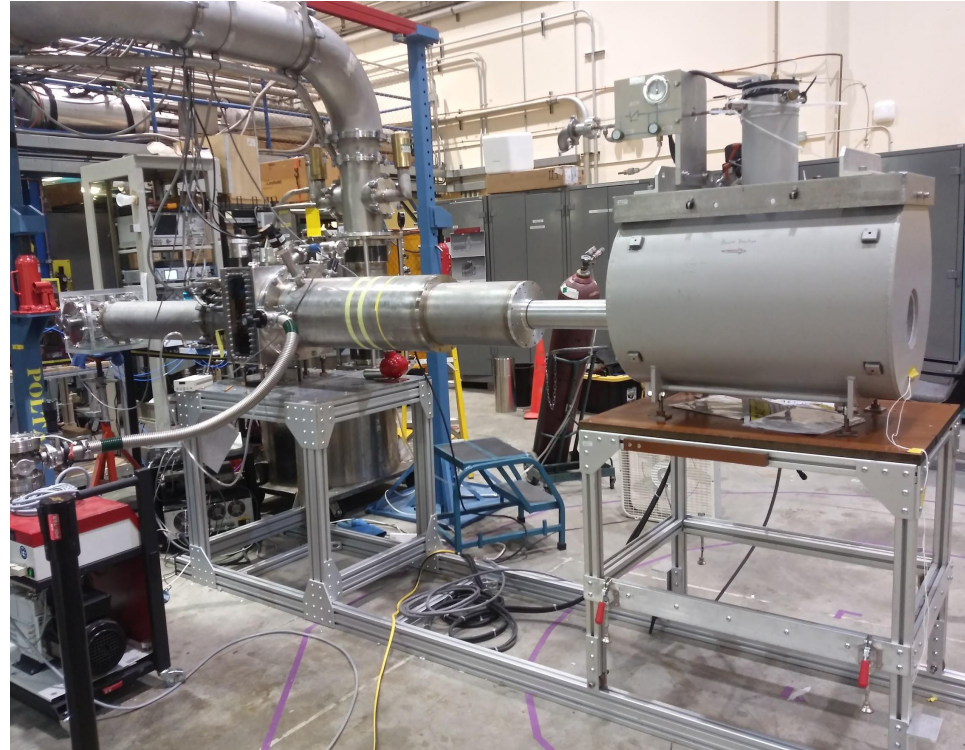
Background Field **On**  
Dual Shims **On**  
Microwaves **On**



Single microwave frequency applied to polarize

# Next Steps

- We've just finished a 2nd test of the helium refrigerator reaching sub-1K temperatures.
- Successfully measured NMR signal while polarizing with DNP using the Frost magnet.
- Ready to add shim coils to target cryostat.
- Transition from Frost magnet to CLAS12.



# Thank You

Special thank to:

Chris Keith  
James Maxwell  
James Brock