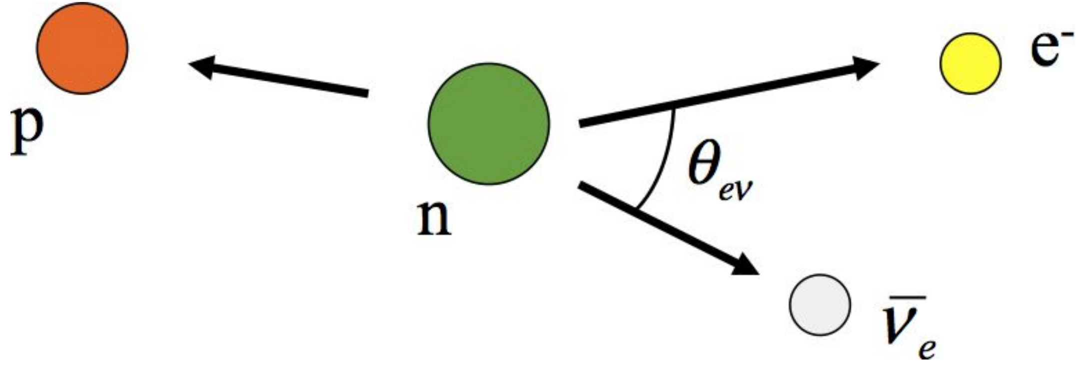
Preparing a Polarimetry Measurement for the Nab Experiment



Chelsea Hendrus
September 27, 2019

The Nab Experiment

$$\frac{\partial^5 \omega}{\partial E \partial \Omega_e \partial \Omega_\nu} \propto \left[1 + a\frac{\vec{p_e}\cdot\vec{p_\nu}}{E_e E_\nu} + b\frac{m_e}{E_e} + \langle\vec{\sigma_n}\rangle \cdot \left(A\frac{\vec{p_e}}{E_e} + B\frac{\vec{p_\nu}}{E_\nu} + D\frac{\vec{p_e}\times\vec{p_\nu}}{E_e E_\nu}\right)\right]$$

Experimental Goal

$$a = -0.1059 \pm 0.0028^*$$

$$\frac{\Delta a}{a} = 0.1\%$$

Quality	Parameters	$\Delta a/a$
Position	Δz <2mm	1.7×10^{-4}
Profile	Slope at edges <10%/cm	2.5×10^{-4}
Doppler Effect	(analytical corrections)	(small)
Beam Polarization	$P_n < 2\times10^{-5}$	1×10^{-4}

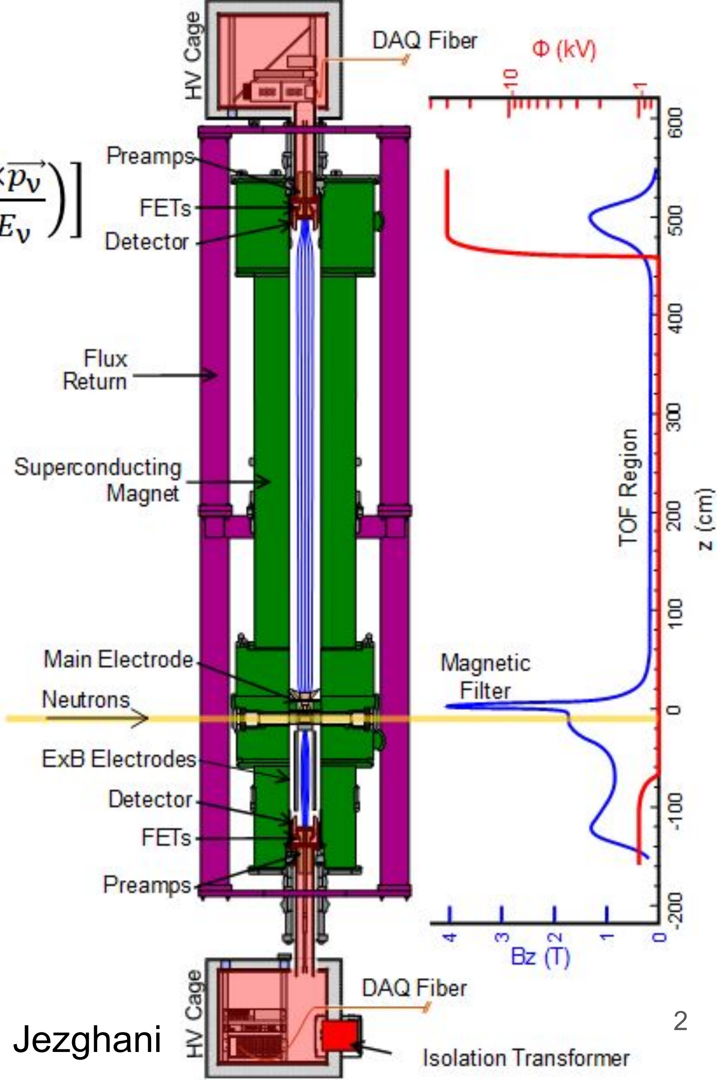
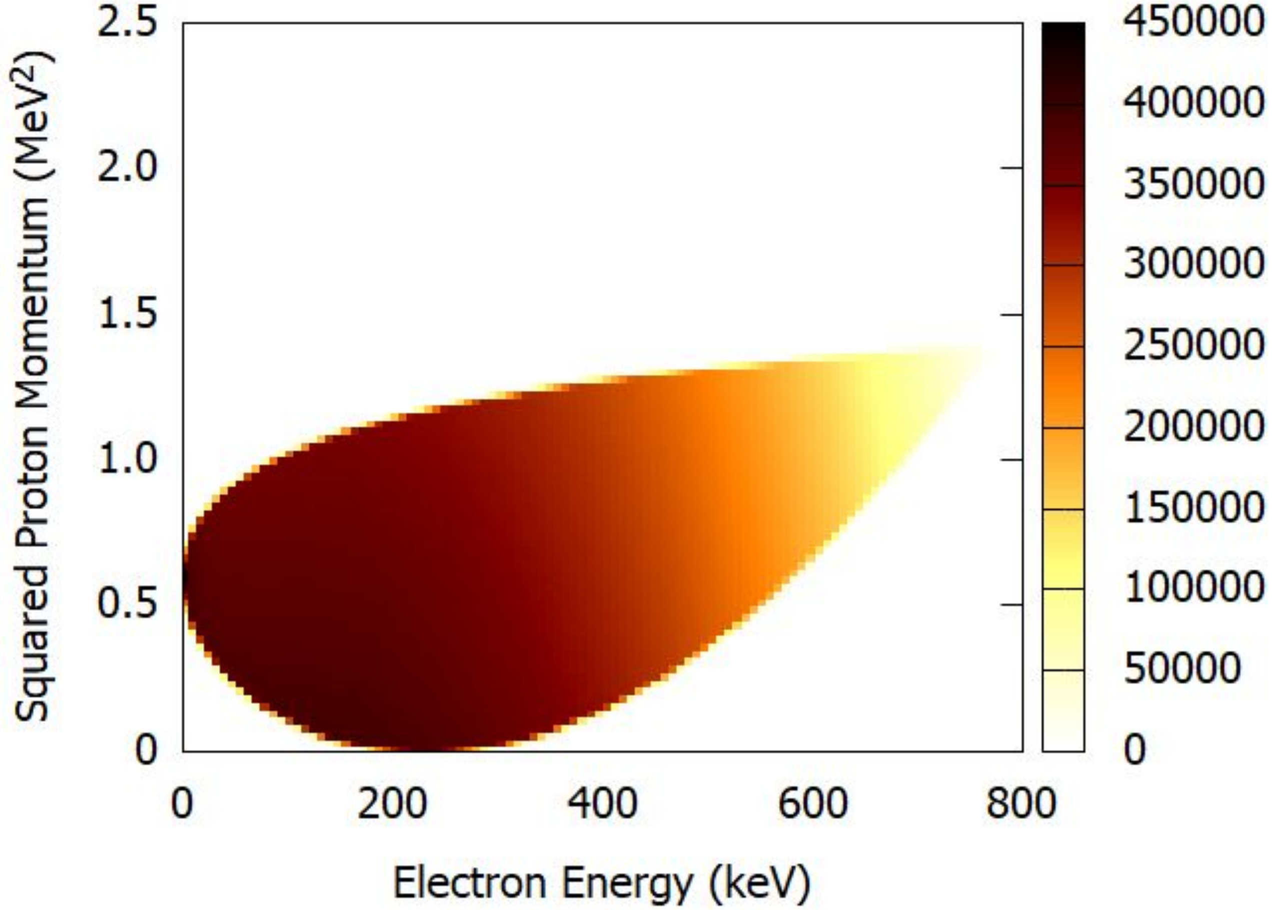


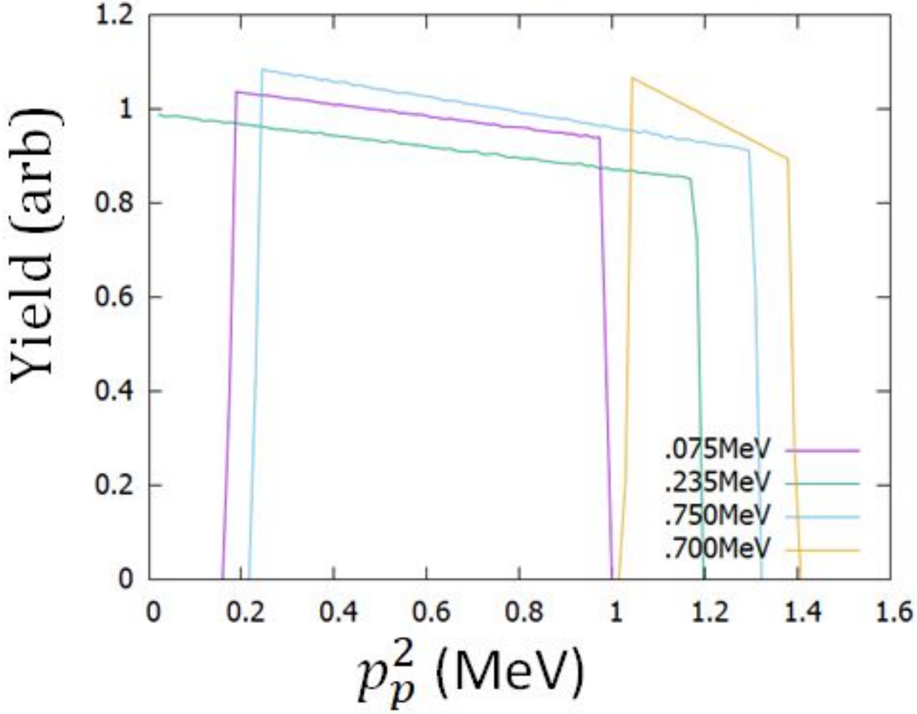
Image: A. Jezghani

The Nab Phase Space

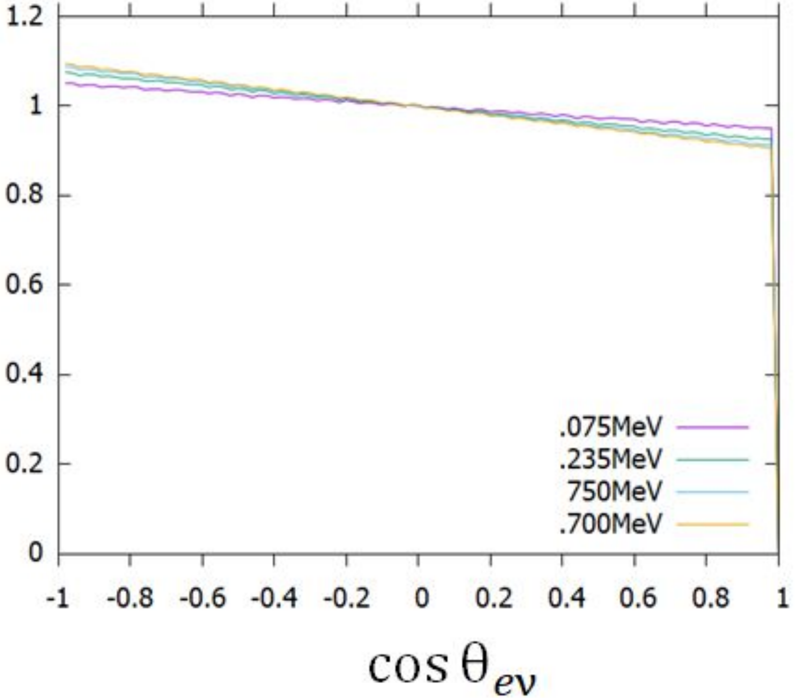


Without Polarization:

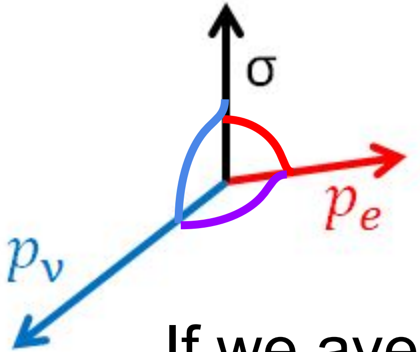
$$1 + a\frac{p_p^2 - p_e^2 - p_\nu^2}{2E_eE_\nu} + b\frac{m_e}{E_e}$$



$$1 + a\beta_e\cos\theta_{e\nu} + b\frac{m_e}{E_e}$$



A closer look at the polarized terms:



$$\langle\vec{\sigma_n}\rangle \cdot \left(A\frac{\vec{p_e}}{E_e} + B\frac{\vec{p_\nu}}{E_\nu} + D\frac{\vec{p_e}\times\vec{p_\nu}}{E_e E_\nu}\right)$$

$\cos\theta_e$, $\cos\theta_{e\nu}$ $\longrightarrow$ Independent

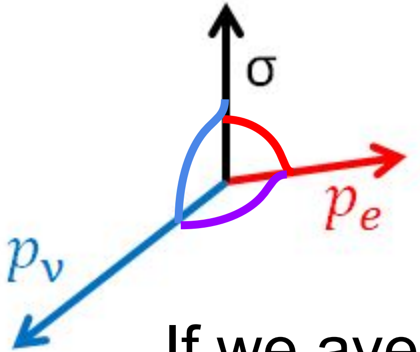
$$\cos\theta_\nu = \cos\theta_{e\nu}\cos\theta_e + \sin\theta_{e\nu}\sin\theta_e\cos\theta_c$$

If we average over all the events we can measure:

$$|\langle\sigma_n\rangle|(A\beta_e\langle\cos\theta_e\rangle + B\langle\cos\theta_e\rangle\ \cos\theta_{e\nu})$$

A closer look at the polarized terms:

$$\langle\overrightarrow{\sigma_n}\rangle \cdot \left(A\frac{\overrightarrow{p_e}}{E_e} + B\frac{\overrightarrow{p_\nu}}{E_\nu} + \times\right)$$



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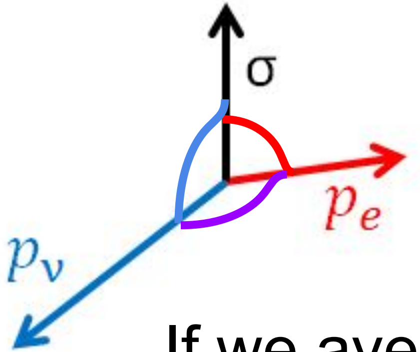

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$$|\langle\sigma_n\rangle|(A\beta_e\langle\cos\theta_e\rangle + \boxed{B\langle\cos\theta_e\rangle}\cos\theta_{e\nu})$$

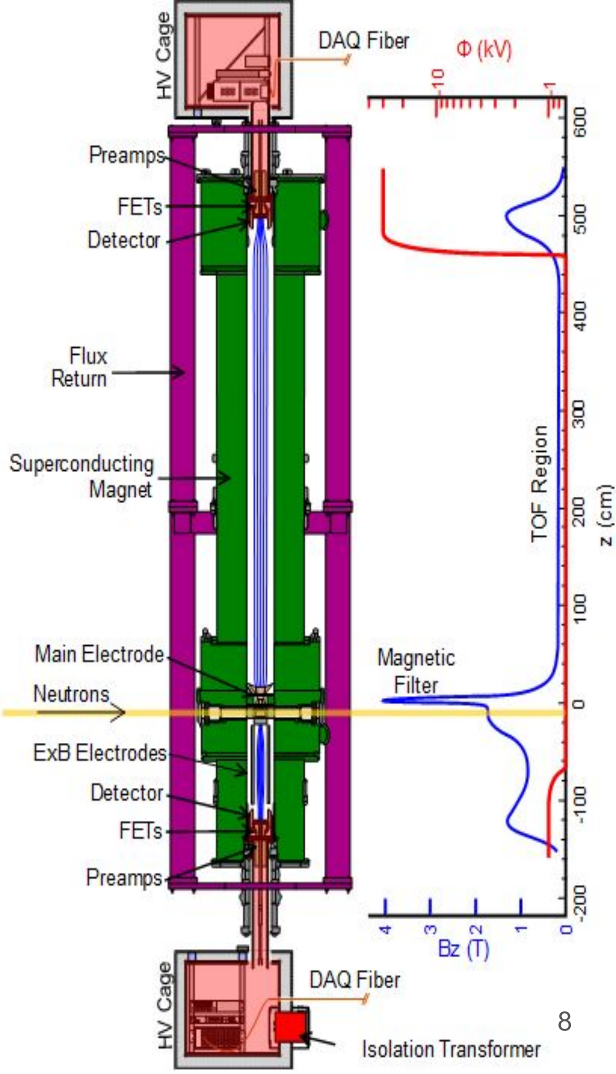
The Polarization Terms

$$|\langle\sigma_n\rangle|B\langle\cos\theta_e\rangle\ \cos\theta_{ev}$$

- $|\langle\sigma_n\rangle|$ Is the polarization we can measure
-B, according to the latest PDG Average: 0.9807±0.0030
-$\langle\cos\theta_e\rangle$~ {-1,1} this is averaged over all events
-This depends on the Spectrometer Cutoff angle

$$\cos\theta_{p_{min}} = \sqrt{1-\frac{B_D}{B_F}} \approx 0.75$$

This accounts for the fact that we only count coincidences where the proton reaches the upper detector within some reasonable cutoff time.

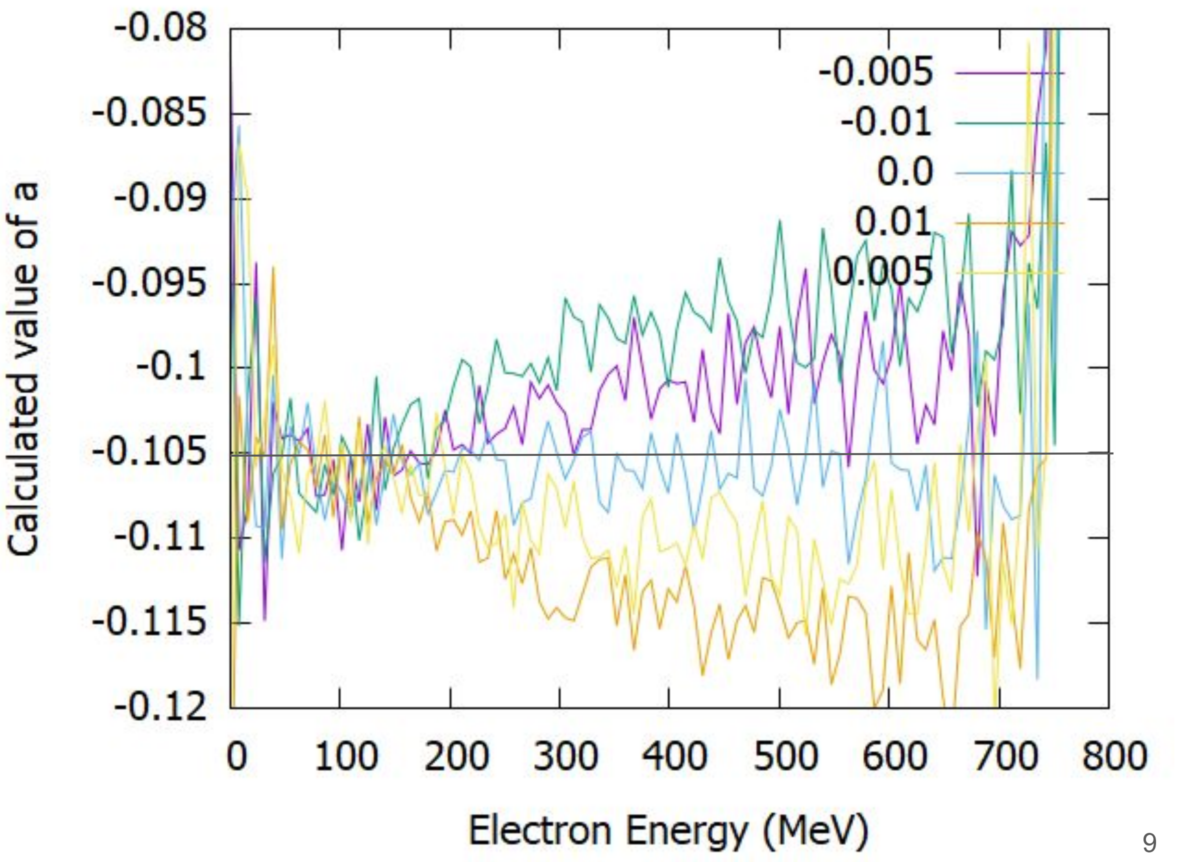


Simulated Large Polarization

Monte Carlo Event Generator

- Relativistic
- Constant Polarization
- Counting and binning
- Linear fit in $\cos\theta_{ev}$

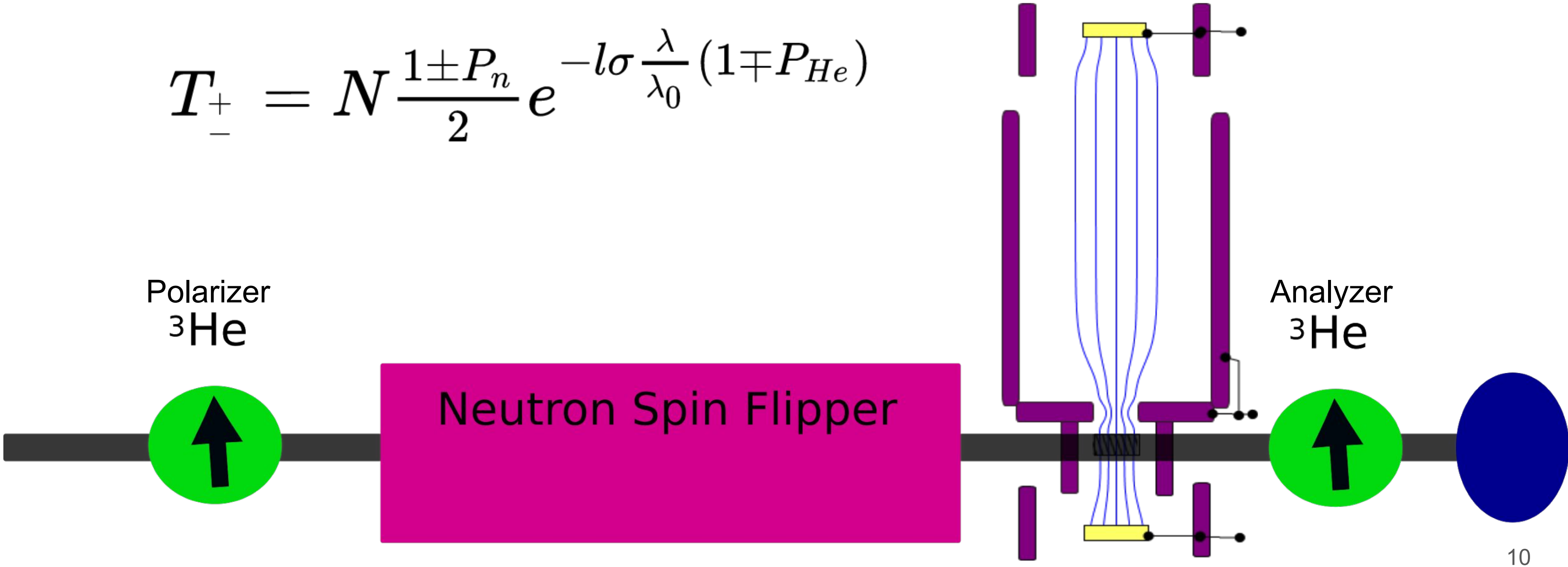
We can estimate that $\langle\cos\theta_e\rangle$ ~0.5, and caries some dependance on electron energy



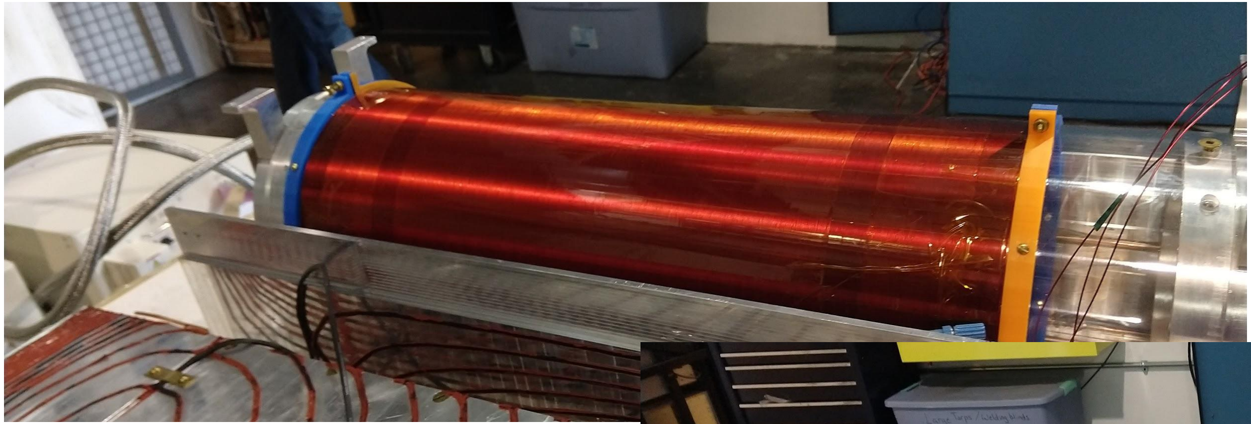
Measuring the Polarization

- 3He Polarizer and Analyzer
- Adiabatic Fast Passage Spin Flipper
- Transmission Ratios for beam polarization and Spin Flipper Efficiency

$$T_{\pm} = N\frac{1 \pm P_n}{2} e^{-l\sigma\frac{\lambda}{\lambda_0}(1 \mp P_{He})}$$

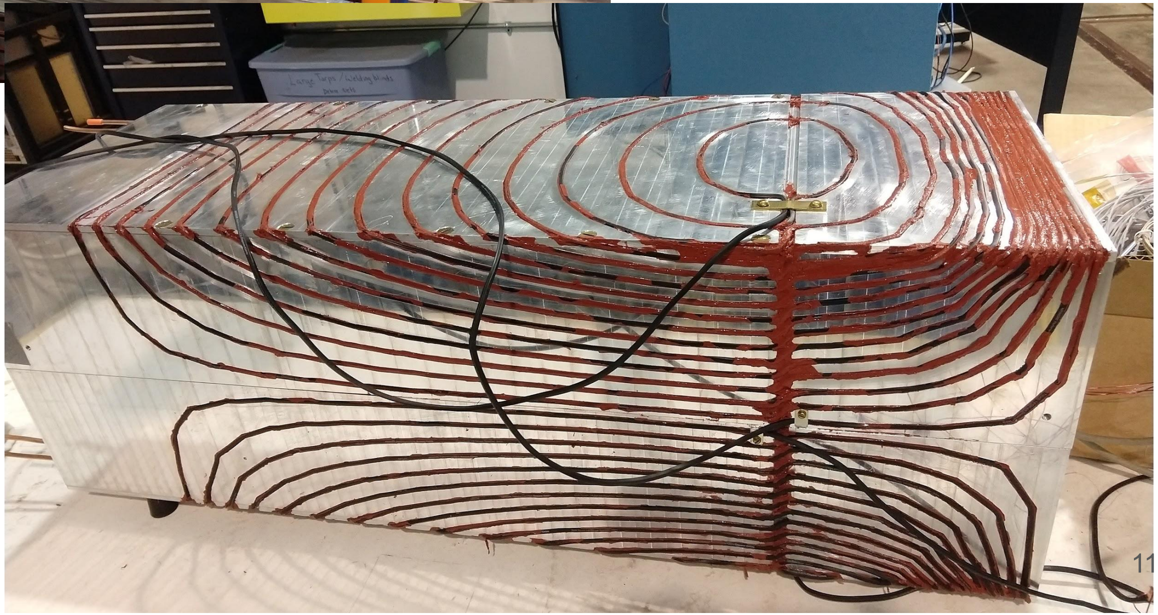


The Adiabatic Fast Passage Spin Flipper



RF Solenoid

Static Gradient Field



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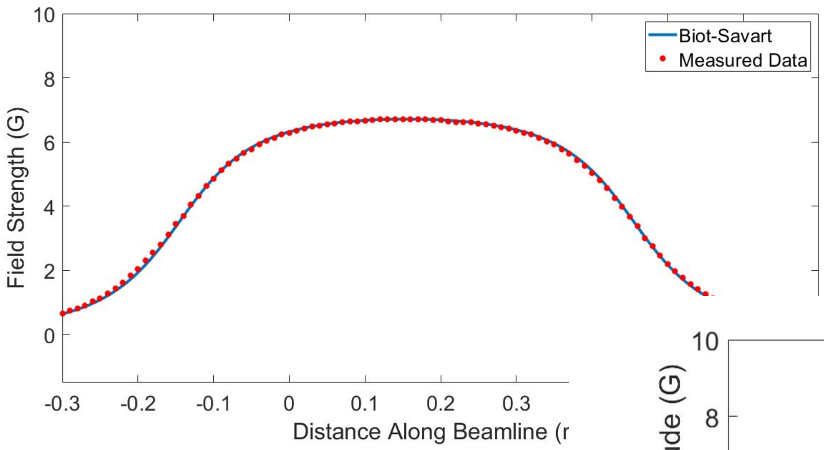

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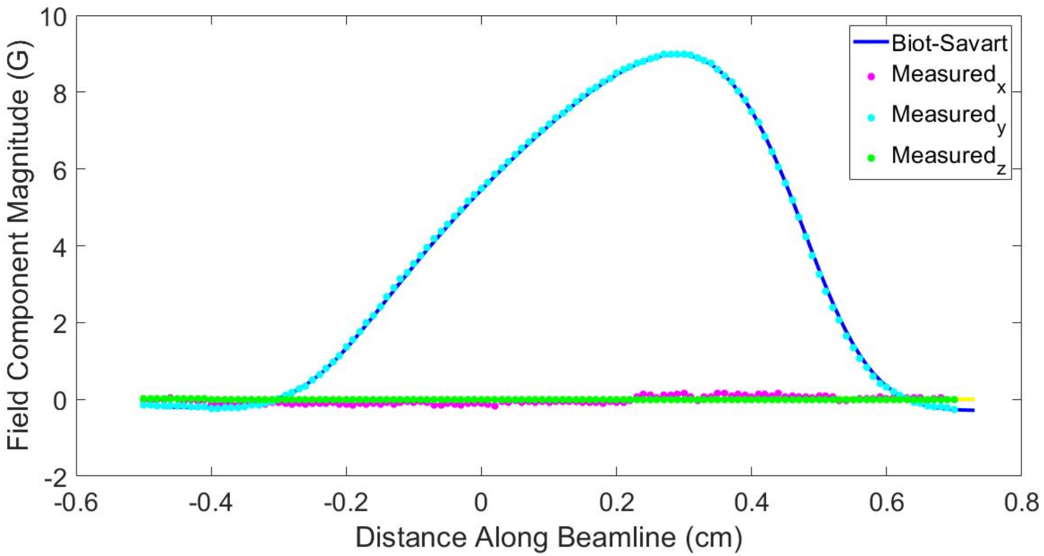

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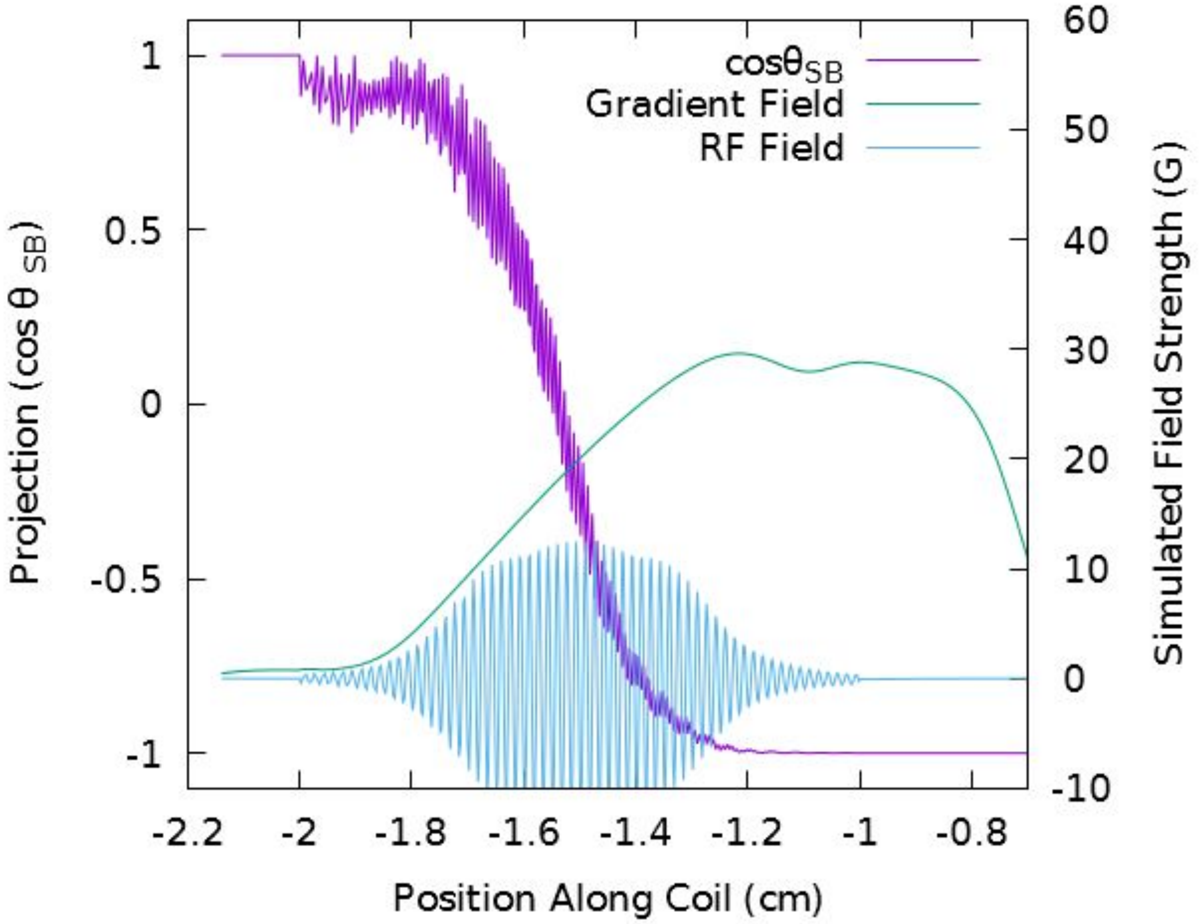
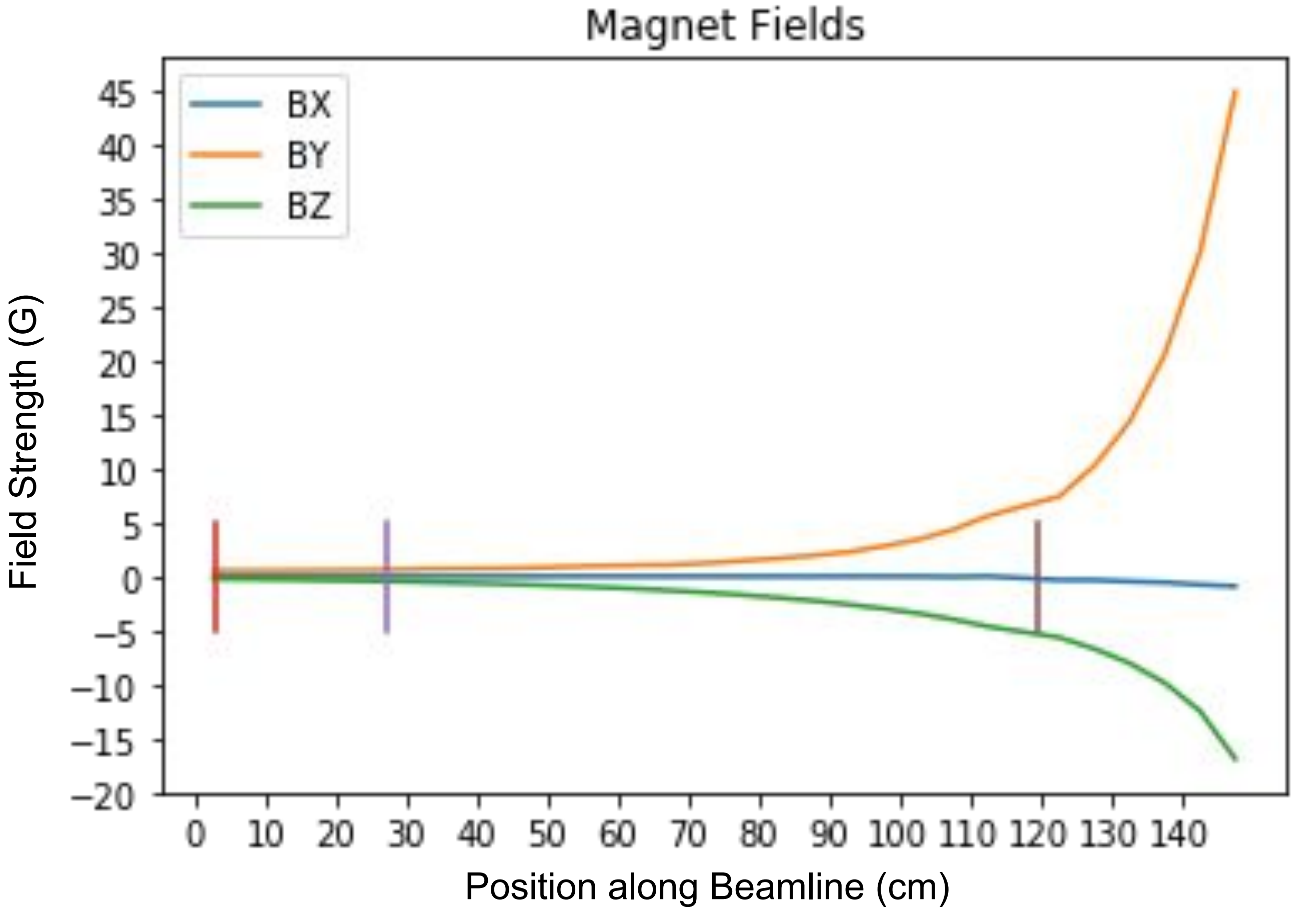


Complication: Spectrometer Fringe



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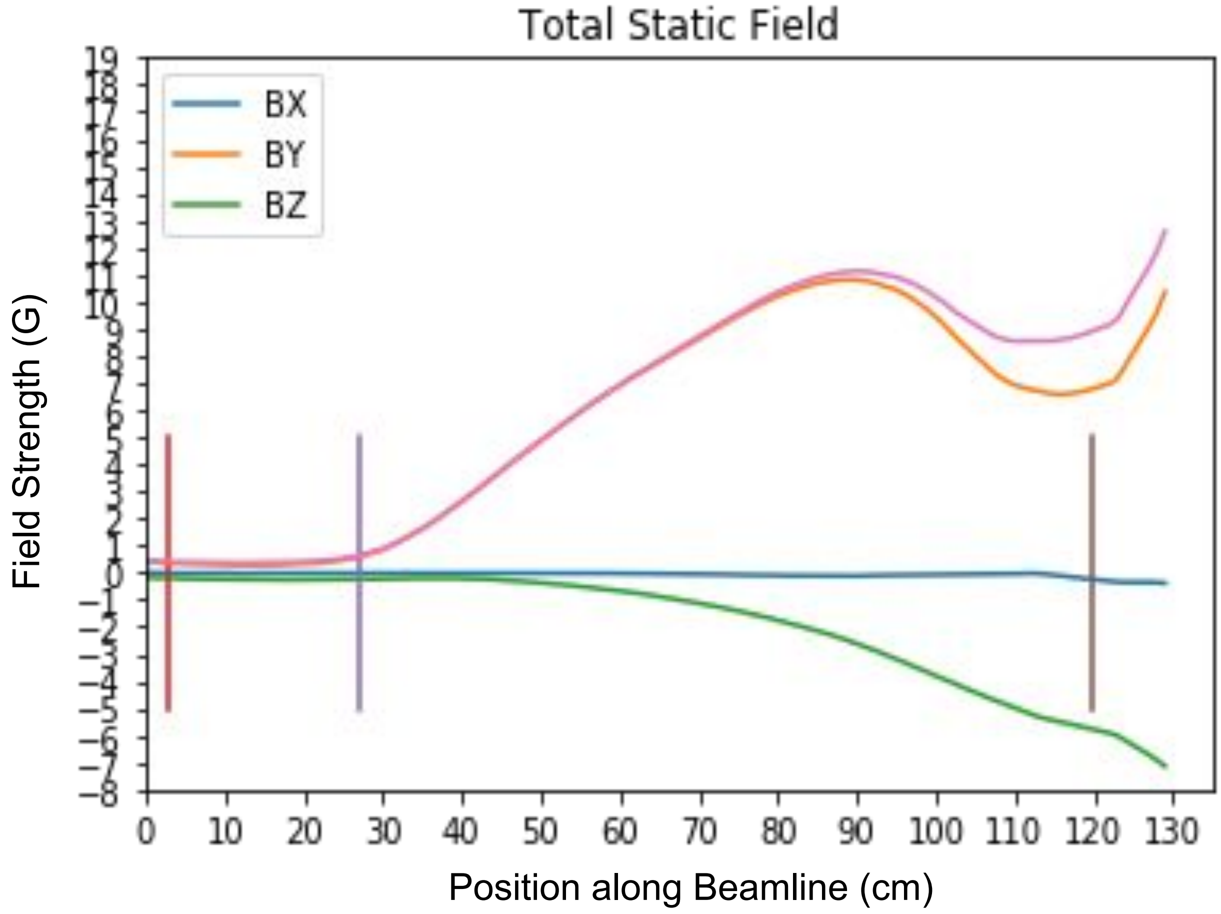

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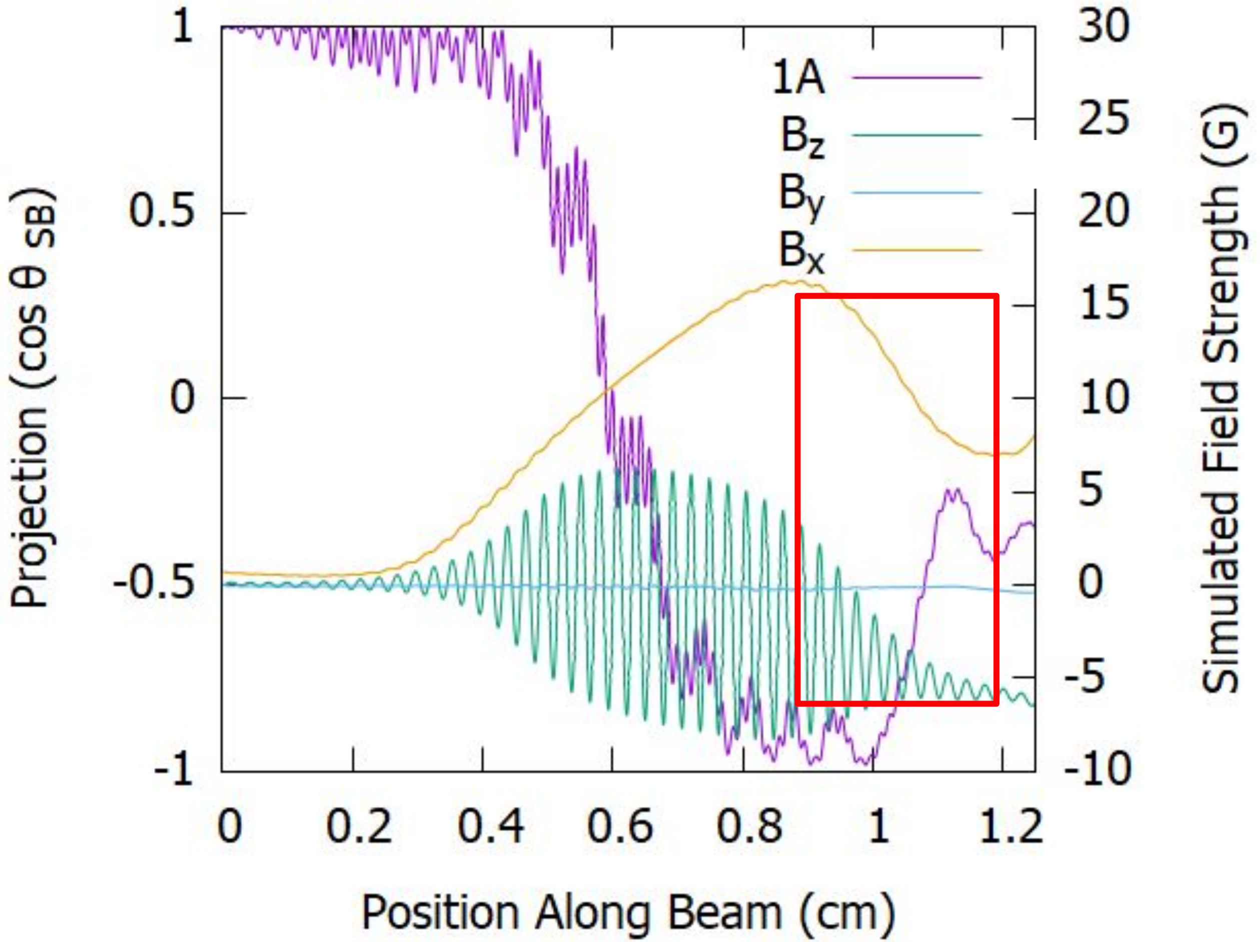
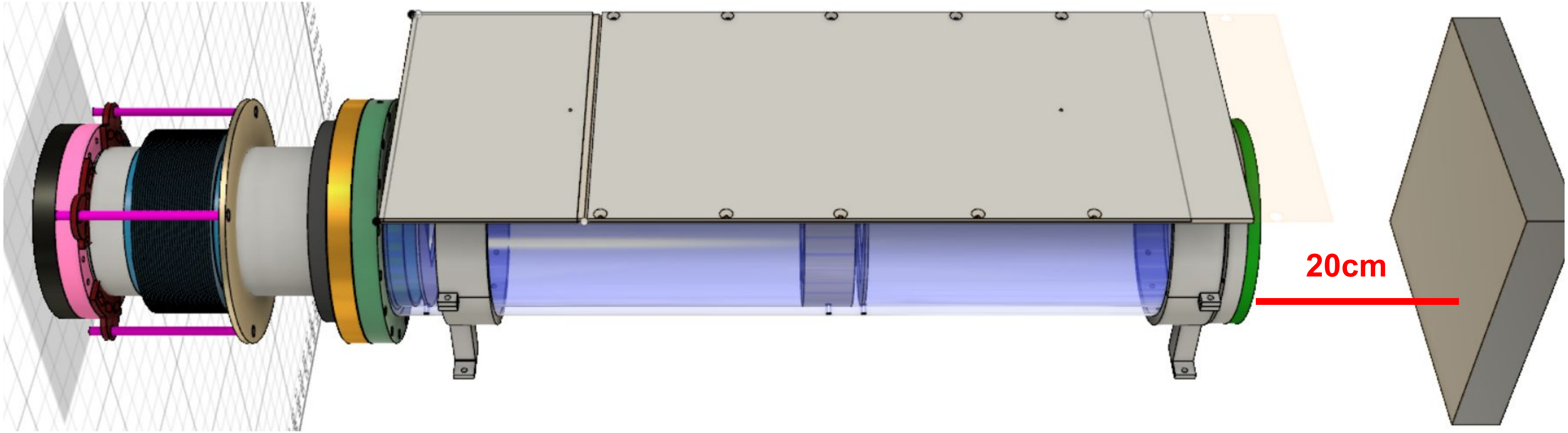


Field magnitude crosses back through resonance, causing a partial “return flip”

We can add compensation coils along the beamline, and adjust our SF magnitudes to compensate.

Complication: 3He Cell



Problem: We need a holding field for the 3He Polarizer for the polarization measurement.

- Field must be homogeneous
- Limited space- 20cm along beam
- Background gradients unreliable, need shielding

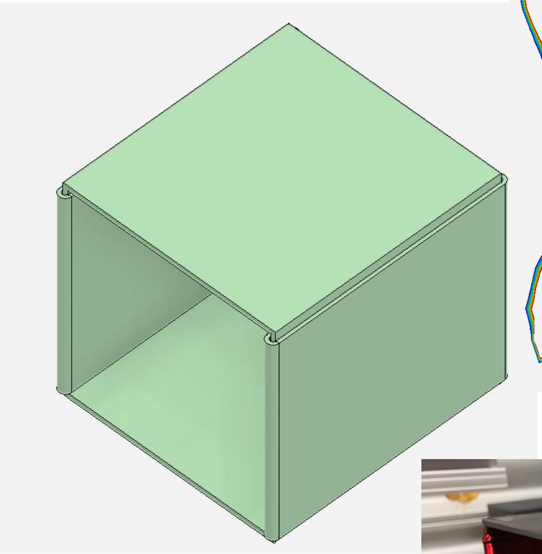
Complication: 3He Cell

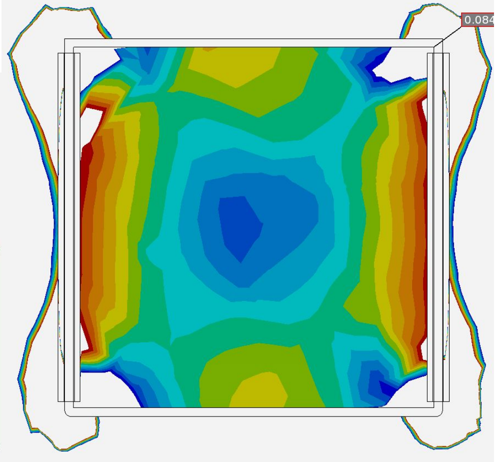
Solution 1: A Magic Box

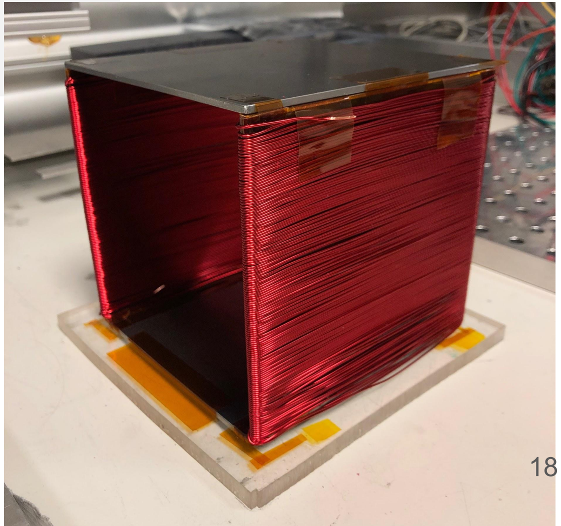
- 15x15x20 cm,
- Mu Metal, wrapped with Copper magnet wire
- ~16G at center of box

Calculated Relative Gradient at center of box:

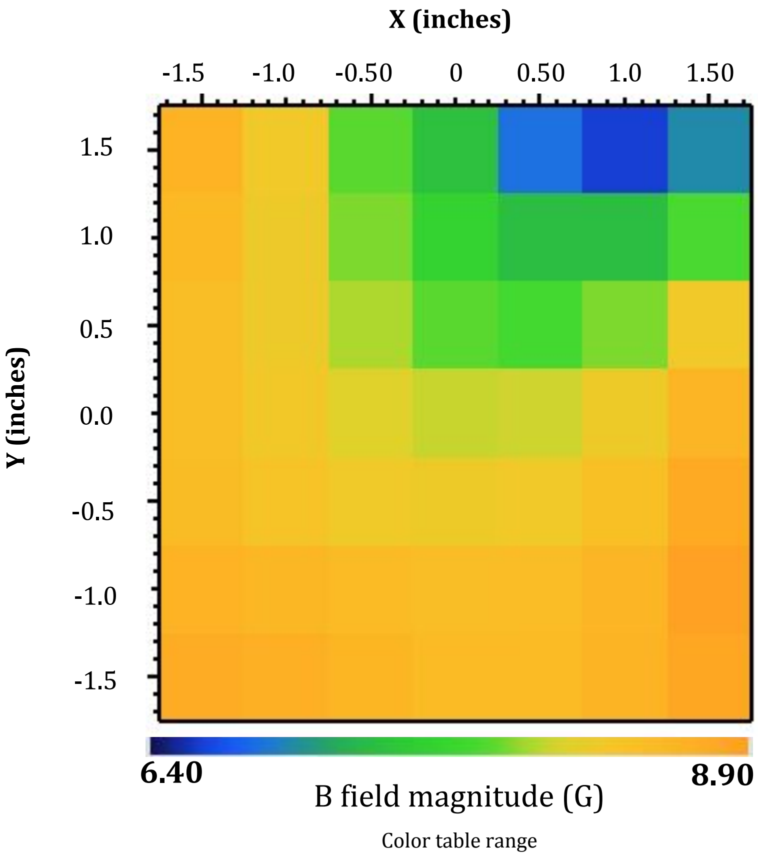
$$\left(\frac{dB_x}{dz} + \frac{dB_y}{dz}\right)\frac{1}{|B|} \approx 0.003400/\text{cm}$$

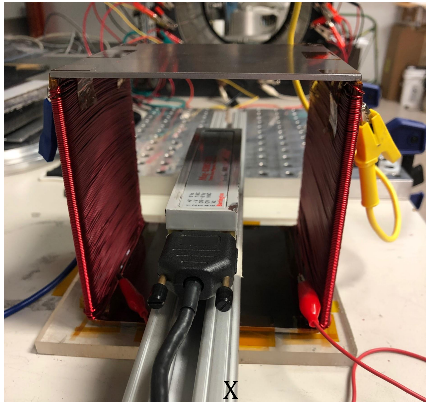






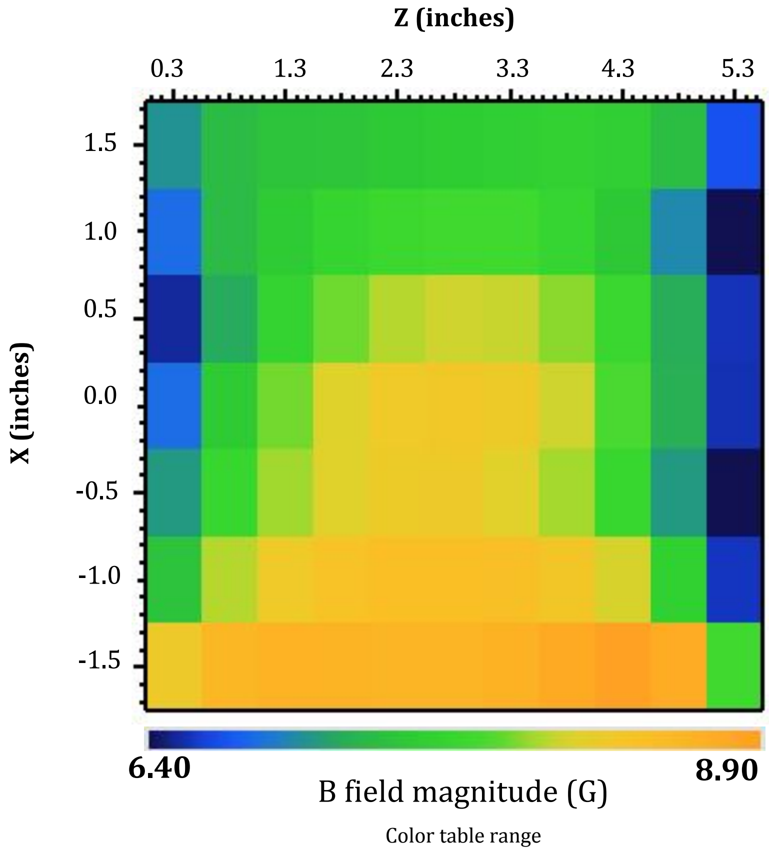
Magic Box Prototype

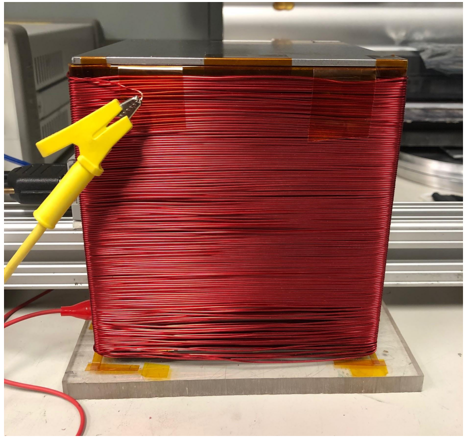


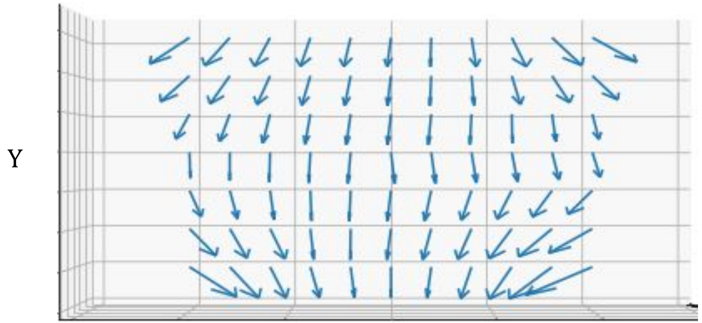


Work done by undergraduate student Veronica Alfaro

Magic Box Prototype







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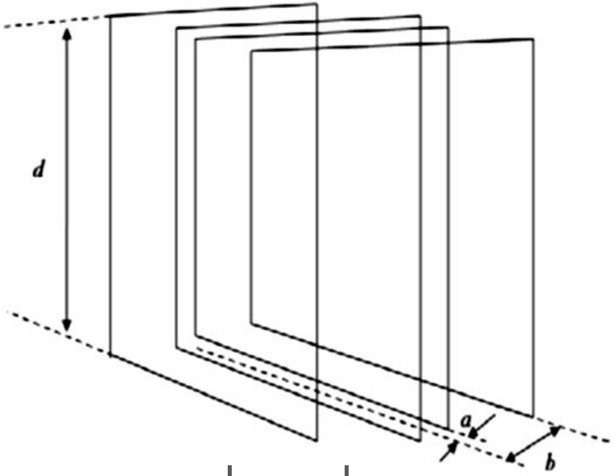
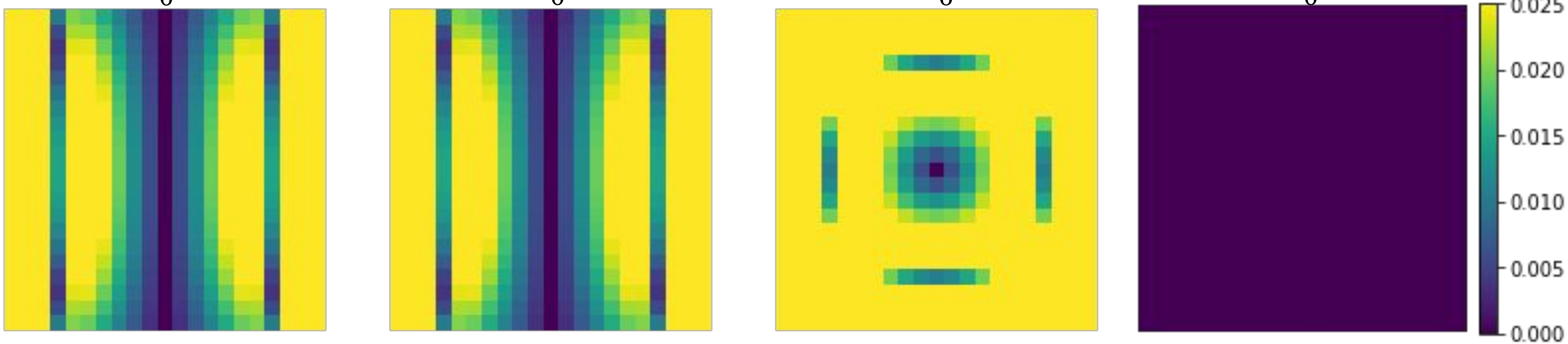
Solution 2: Merritt Coil



Simulated Parameters

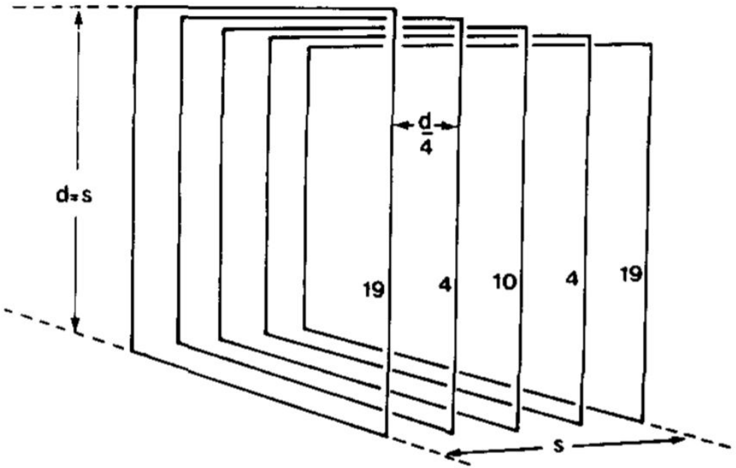
- d=20 cm
- a=2.56212
- b=10.10984cm
- Gradient averaged over 6cm cube at center
  0.01406 /cm

$\left|\frac{\nabla B_x+\nabla B_z}{B_0}\right|$ $\left|\frac{\nabla B_x}{B_0}\right|$ $\left|\frac{\nabla B_y}{B_0}\right|$ $\left|\frac{\nabla B_z}{B_0}\right|$



Merritt, R., C. Purcell, and G. Stroink. "Uniform magnetic field produced by three, four, and five square coils." *Review of Scientific Instruments* 54.7 (1983): 879-882.

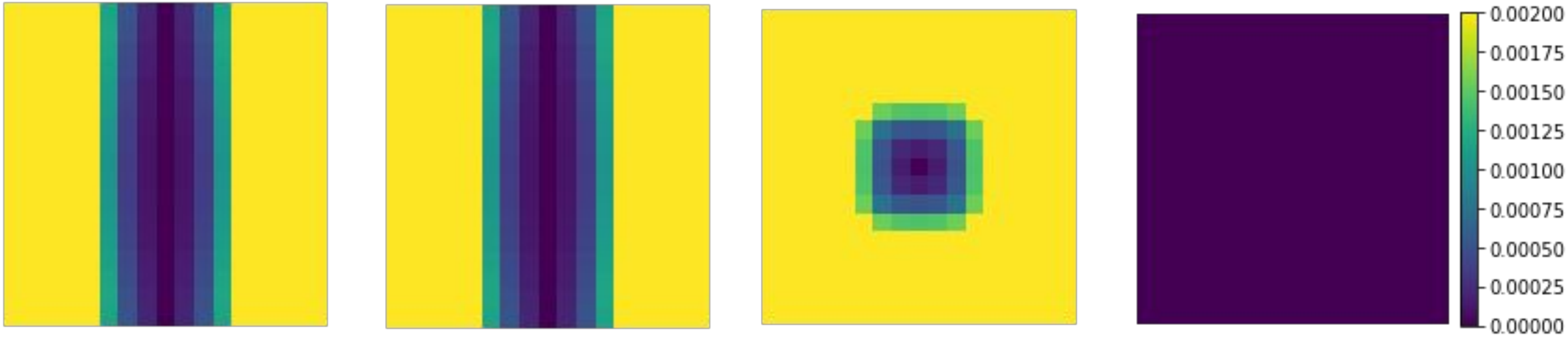
Solution 3: Ruben Coil



Simulated Parameters

- d=20 cm
- Gradient averaged over 6cm cube at center: **4.5242x10^{-4}/cm**

$\left|\frac{\nabla B_x + \nabla B_z}{B_0}\right|$ $\left|\frac{\nabla B_x}{B_0}\right|$ $\left|\frac{\nabla B_y}{B_0}\right|$ $\left|\frac{\nabla B_z}{B_0}\right|$



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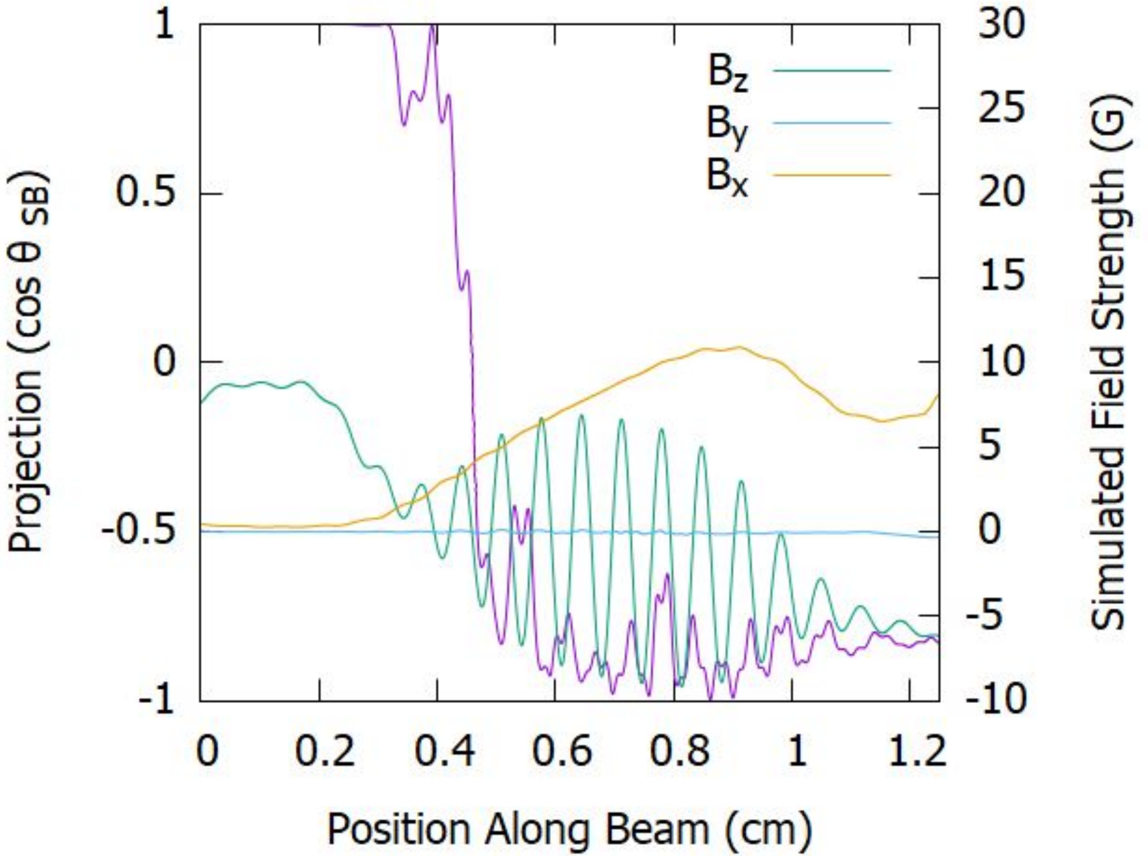
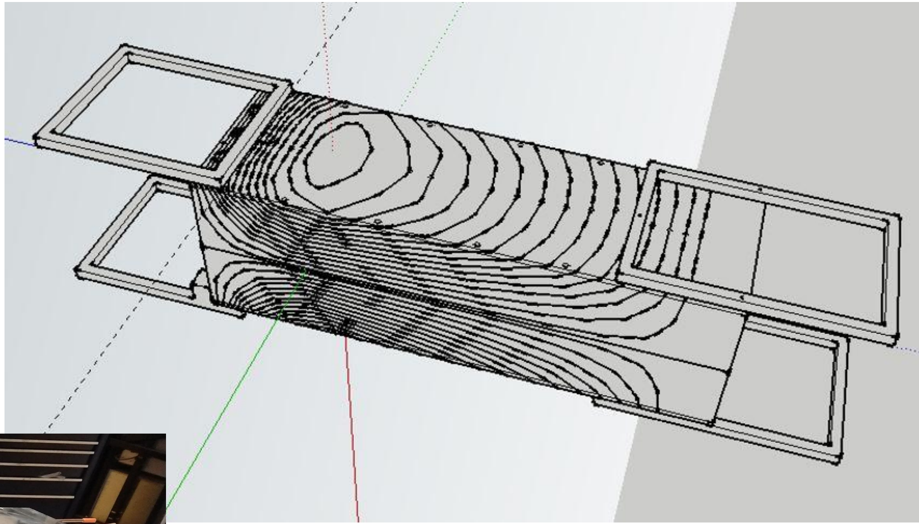
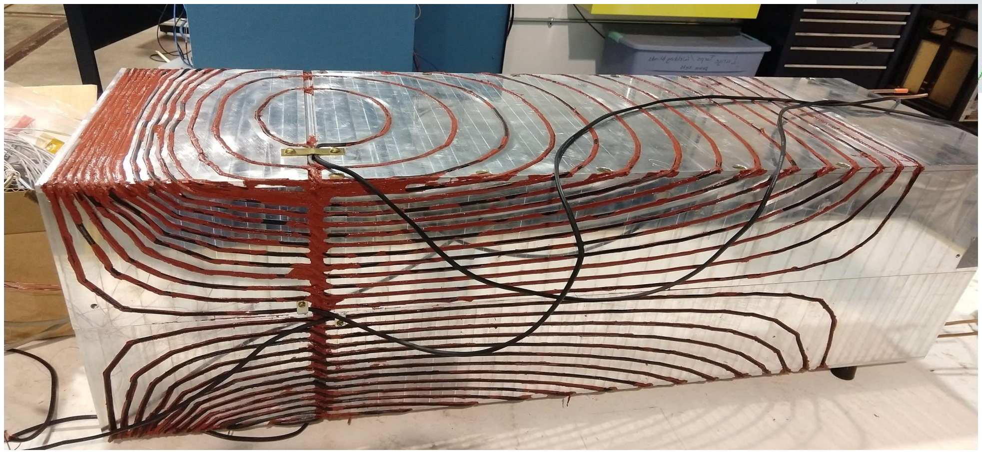
Spin Tracking with the Ruben Coil



What's Next?

- Mechanical design of holding field
- Holding field prototypes
- 3He lifetime testing
- Installation on FNPB
- Polarimetry





The Nab collaboration

Active and recent collaborators:

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