Characterizing the AFP Spin Flipper for the Nab Experiment

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30 November 2023

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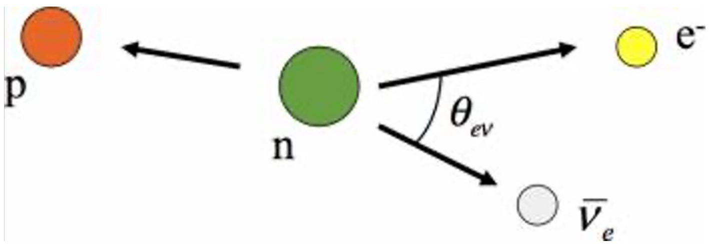
What is the Nab Experiment?



- Nab = Neutron “a” and “b”
  - *a*: the electron-neutrino correlation coefficient
  - *b*: the Fierz interference term

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

- Ultimate goal is to make a precise measurement of *a* which will be used to extract a value for V_{ud}

Why is polarimetry important in the Nab Experiment?

- Any residual polarization in the beam will contribute a false addition to the measurement of *a*
- To be within the error limit for *a*, our beam polarization must be less than 2 x 10^{-5}

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

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

$$\frac{\Delta a}{a} = \frac{B \langle cos\theta_e \rangle |\langle \sigma_n \rangle|}{\beta_e a} \approx 10^{-4}$$

$$|\langle \sigma_n \rangle| < 2 \times 10^{-5}$$

Experimental parameter	Main specification	$(\Delta a/a)_{syst}$
Magnetic field		
... curvature at pinch	$\Delta\gamma/\gamma = 2\%$ with $\gamma = d^2 B_z(z)/dz^2/B_z(0)$	**$5.3\cdot10^{-4}$**
… ratio $r_B = B_{TOF}/B_0$	$(\Delta r_B)/r_B = 1\%$	$2.2\cdot10^{-4}$
… ratio $r_{B,DV} = B_{DV}/B_0$	$(\Delta r_{B,DV})/r_{B,DV} = 1\%$	$1.8\cdot10^{-4}$
Length of the TOF region		none
Electric potential inhomogeneity:		
… in decay volume / filter region	$\lvert U_F - U_{DV}\rvert < 10$ mV	**$5\cdot10^{-4}$**
… in TOF region	$\lvert U_F - U_{TOF}\rvert < 200$ mV	$2.2\cdot10^{-4}$
Neutron beam:		
… position	$\Delta\overline{z_{DV}} < 2$ mm	$1.7\cdot10^{-4}$
… profile (including edge effect)	Slope at edges < 10%/cm	$2.5\cdot10^{-4}$
… Doppler effect		small
… Unwanted beam polarization	$\lvert\overline{P_n}\rvert \ll 10^{-4}$	$1\cdot10^{-4}$
Adiabaticity of proton motion		$1\cdot10^{-4}$
Detector effects:		
… Electron energy calibration	$\Delta E < 0.2$ keV	$2\cdot10^{-4}$
… Shape of electron energy response	fraction of events in tail to 1%	**$4.4\cdot10^{-4}$**
… Proton trigger efficiency	$\epsilon_p < 100$ ppm/keV	$3.4\cdot10^{-4}$
… TOF shift due to detector/electronics	$\Delta t_p < 0.3$ ns	$3.9\cdot10^{-4}$
Electron TOF		small
Residual gas	$p < 2\cdot10^{-9}$ torr	$3.8\cdot10^{-4}$ (prelim.)
TOF in acceleration region	$\Delta r_{ground\ el.} < 0.5$ mm	$3\cdot10^{-4}$ (prelim.)
Background / Accidental coincidences		small
Sum		**$1.2\cdot10^{-3}$**

How do we measure the beam polarization?

- Two ^{3}He devices will be used (one as a polarizer and one as an analyzer)
- The polarizer is placed upstream
- A spin flipper is placed after the polarizer upstream of the Nab spectrometer
- The analyzer is placed downstream with a neutron monitor placed after it
- The Nab spin flipper was designed by Chelsea Hendrus, PhD (University of Michigan)

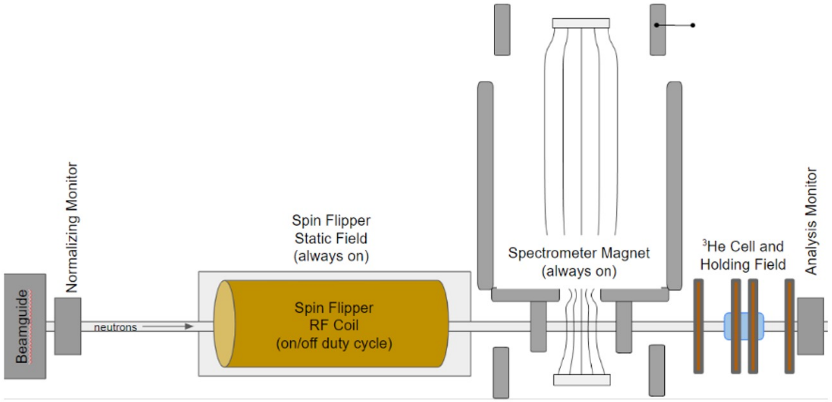
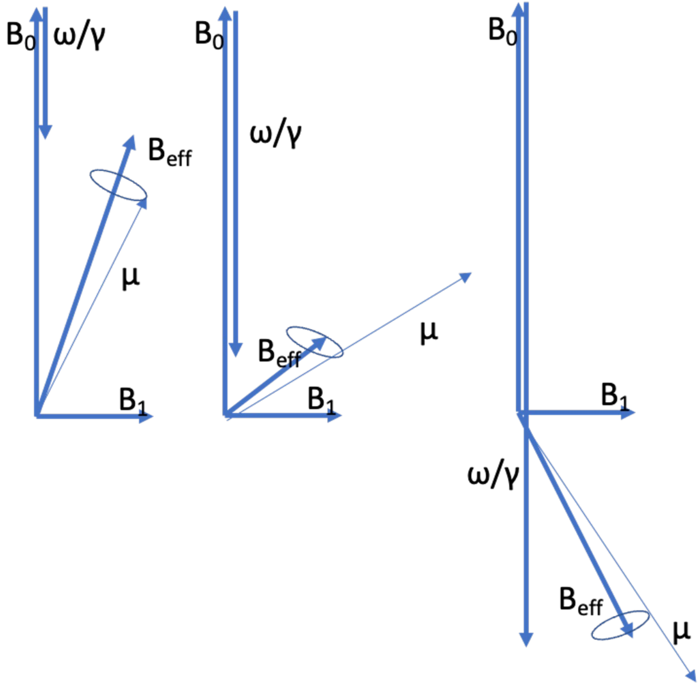


Image courtesy of C. Hendrus

Flipping the spin adiabatically

- When placed in a constant magnetic field, the neutrons will align either parallel or antiparallel to the field
- In this static field (B_0), the neutron precesses like a spinning top (Larmor precession)
- When an oscillating field (RF field, B_1), oscillates at the same frequency of the Larmor precession, the neutron flips its spin



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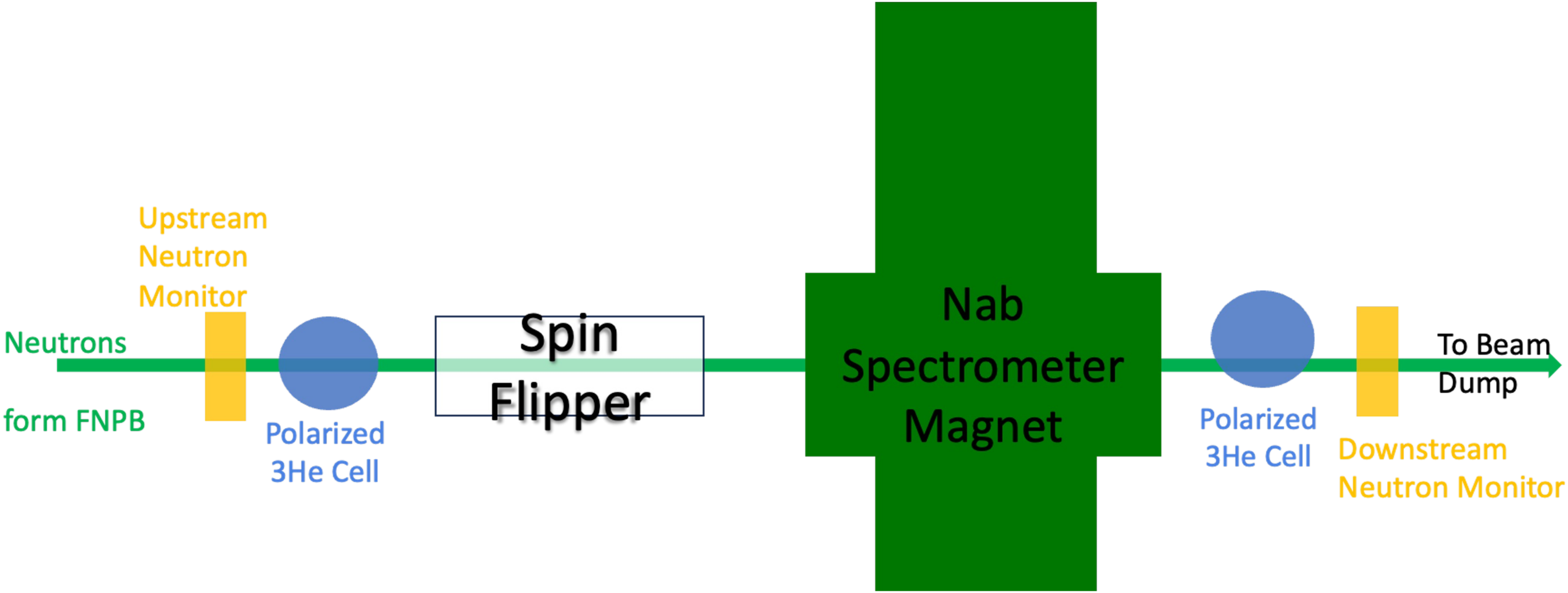
Polarimetry setup at BL13



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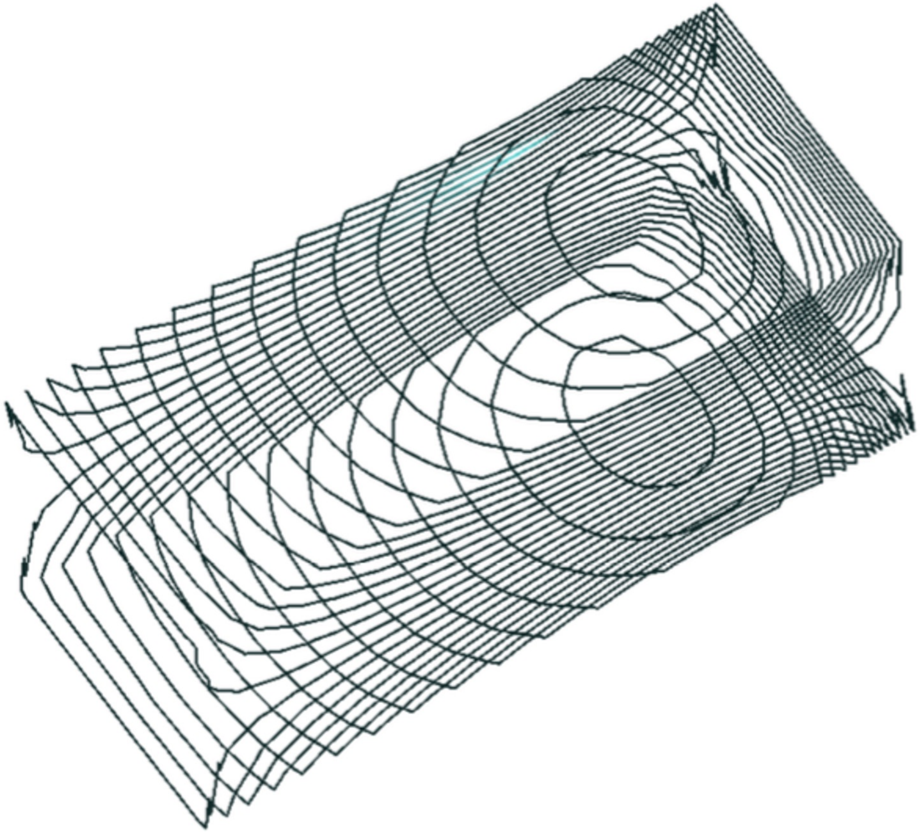

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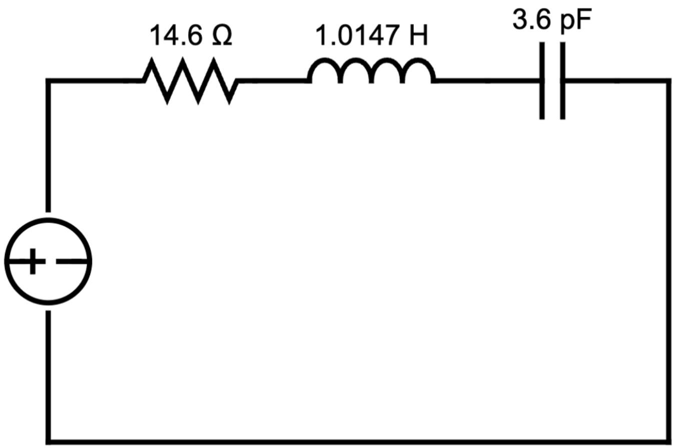
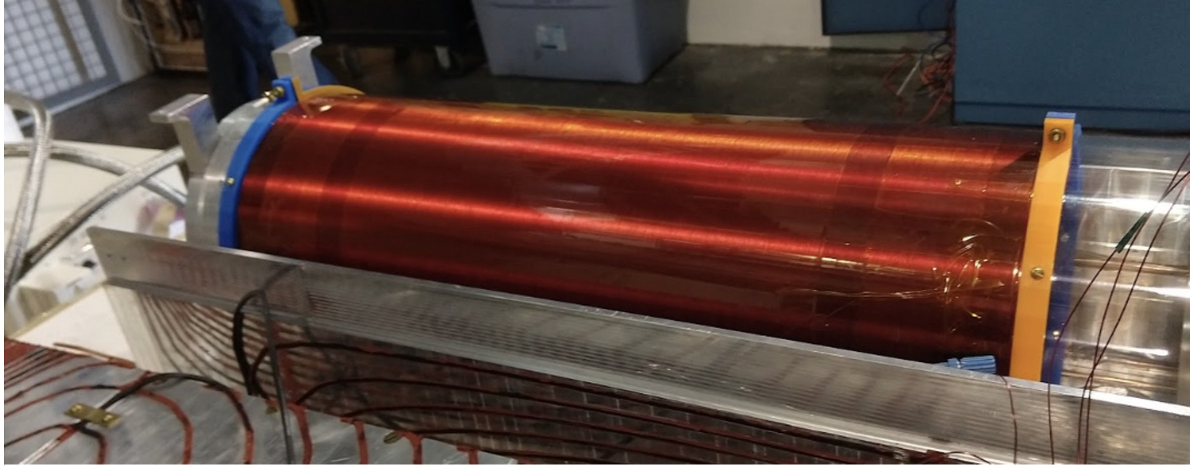
The static coil

Designed so that the neutrons move adiabatically through the magnetic field

- Neutrons are vertically aligned in the +z direction
- Field gradually increases where the wires are equidistant apart
- The peak of the field is at the center of the central loop of wire
- There is a steep drop-off of the field where the wires are bunched together





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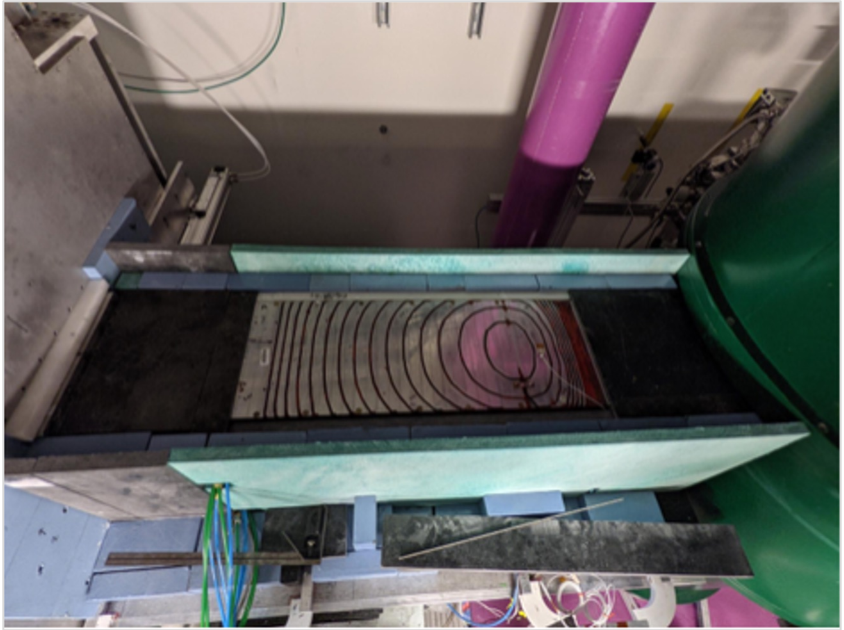
The RF coil

Designed to be a simple LCR circuit that resonates at the Larmor frequency

- 3 sections, all exactly next to each other
- 2 sections (center and downstream) are connected in series and experience a unified current
- The upstream section is left disconnected

Constructed spin flipper



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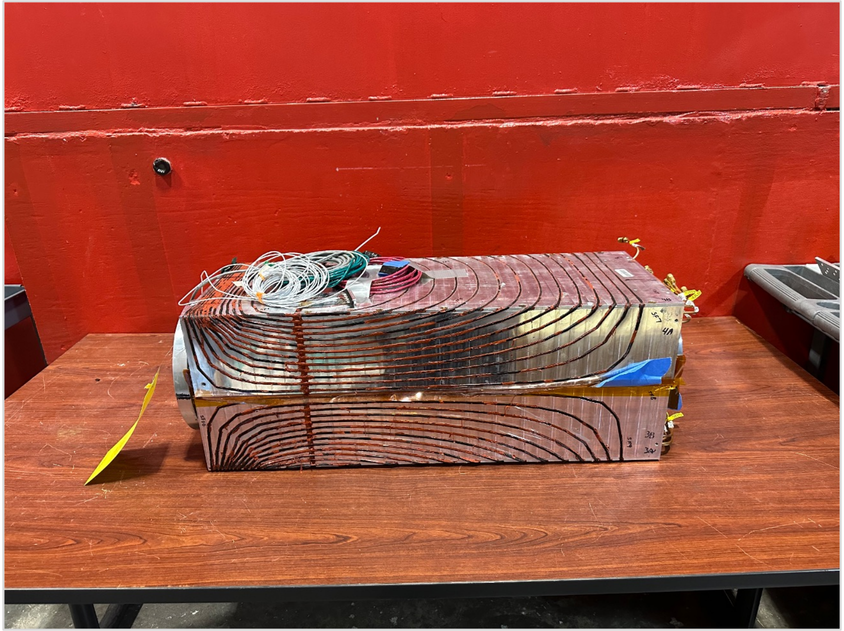
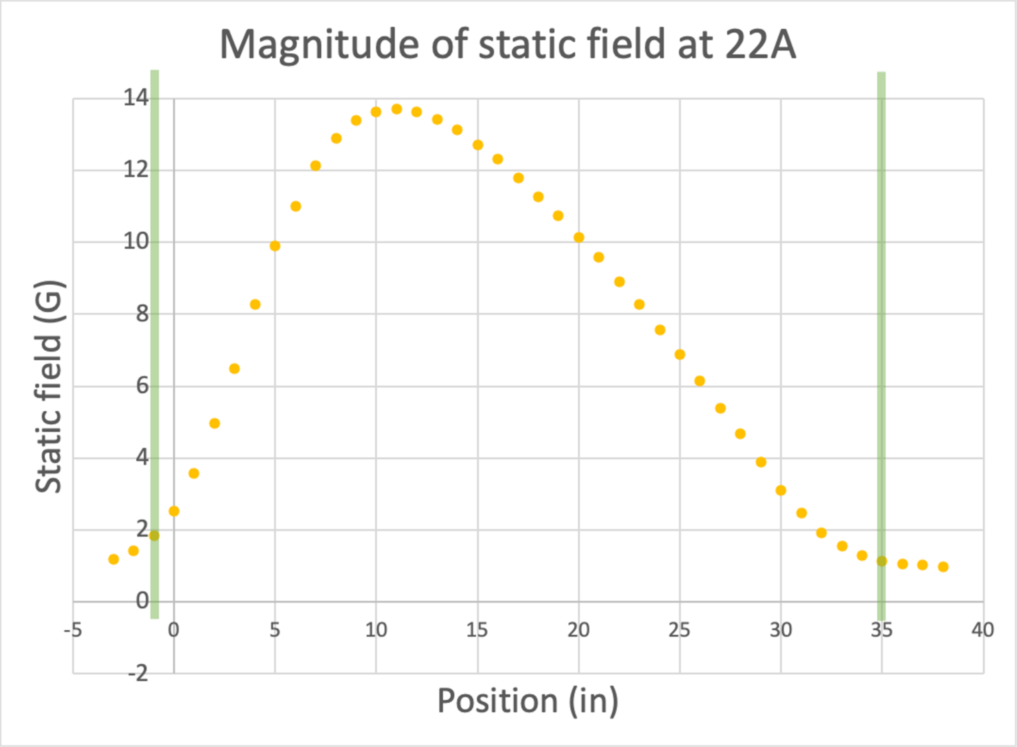
Installed on BL13

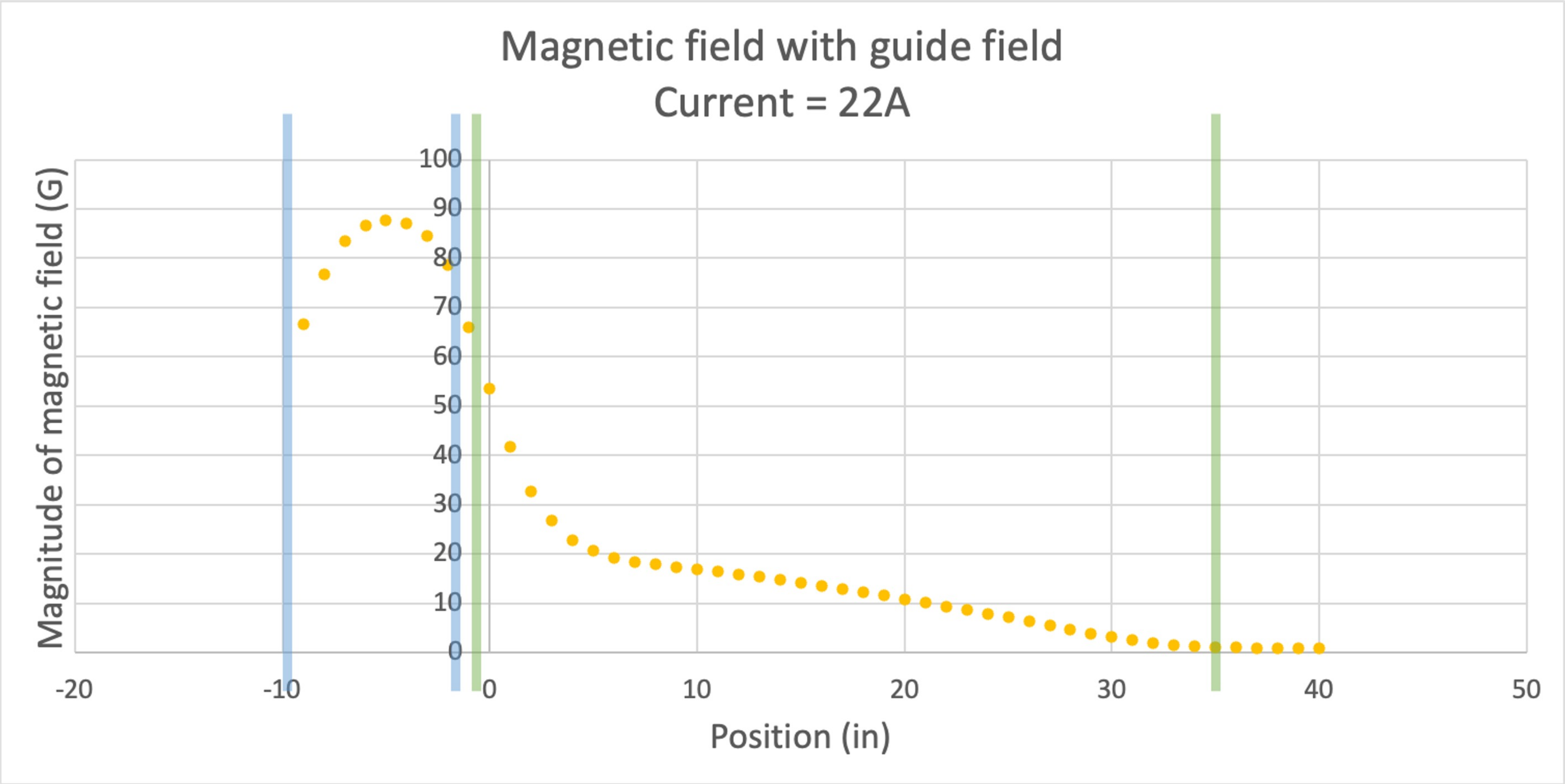


Outside of BL13

Mapping the magnetic field

- The intended resonance for the RF coil is ~38 kHz
- Our maximum static field is 13 G with a 10 G holding field
- A Hall probe was used to measure the static field through the spin flipper
- The maximum field was 13.6 G and was at the center of the central loop of wire (z = 12 inches)

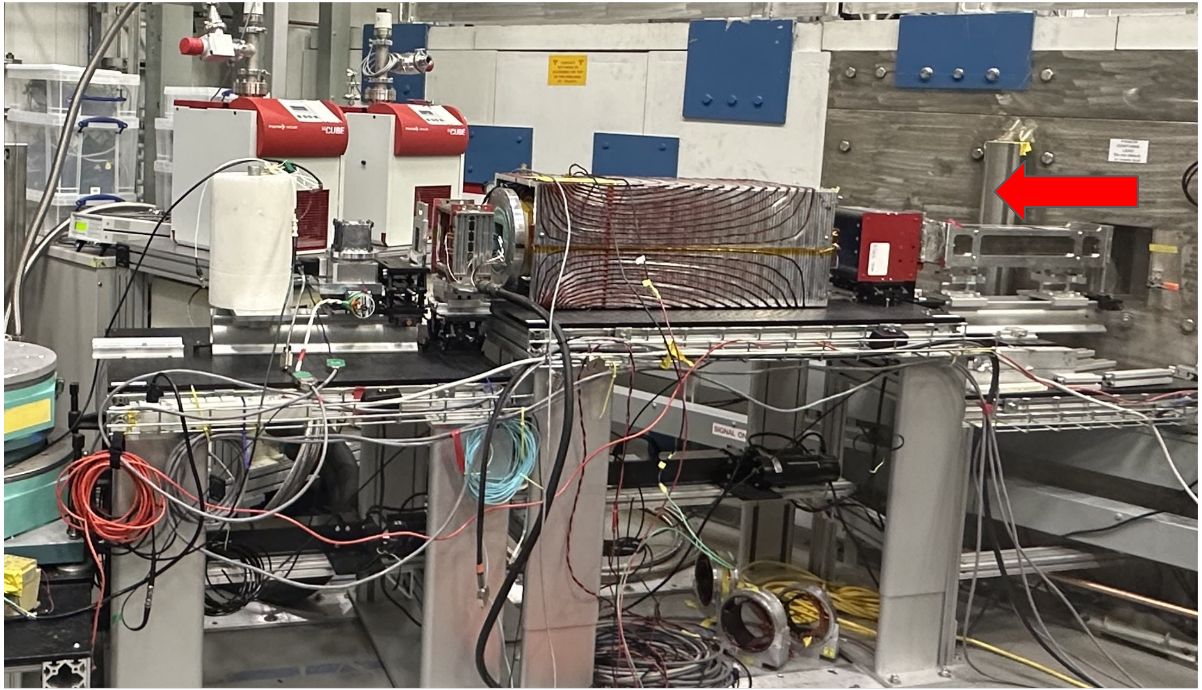




With the guide field, the maximum field was 15.892 G at z = 12 in

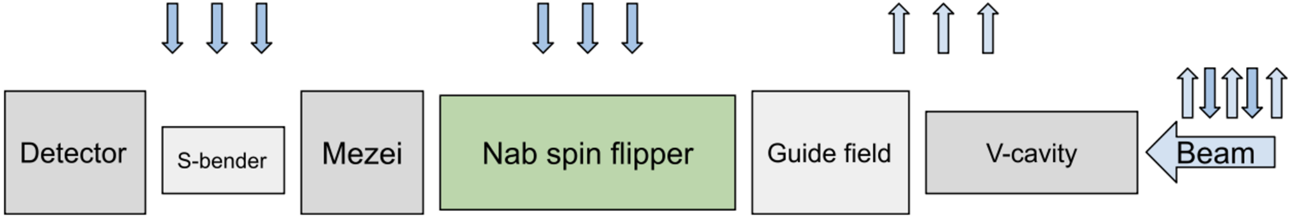
Characterization efforts at HFIR

- The spin flipper was taken to the High Flux Isotope Reactor (HFIR) in September 2023
- We used a V-cavity, guide field, Mezei flipper, S-bender, and detector in addition to our spin flipper



Supporting cast members at HFIR

- V-cavity: acts as a polarizer; the neutrons exit the V-cavity in one spin state
- Guide field: acts as a holding field as the neutrons make their way to the Nab spin flipper
- Mezei flipper: well-characterized secondary spin flipper
- S-bender: acts as an analyzer; for our measurements, this was polarized opposite of the V-cavity
- Detector: detects the neutrons that pass through the S-bender



Results from HFIR

- For the first time ever, the Nab spin flipper was shown to effectively flip the neutron spin
- The highest flipping ratio measured was 70
- The exact efficiency of the spin flipper cannot be measured from this experiment directly, but we can extrapolate a high efficiency
    - The combined efficiency of the V-cavity and S-bender is at least 95%
    - The efficiency of the Mezei flipper is 94%
    - The high flipping ratio of the Nab spin flipper combined with the high efficiency of the V-cavity, Mezei flipper, and S-bender implies a high efficiency for the Nab spin flipper

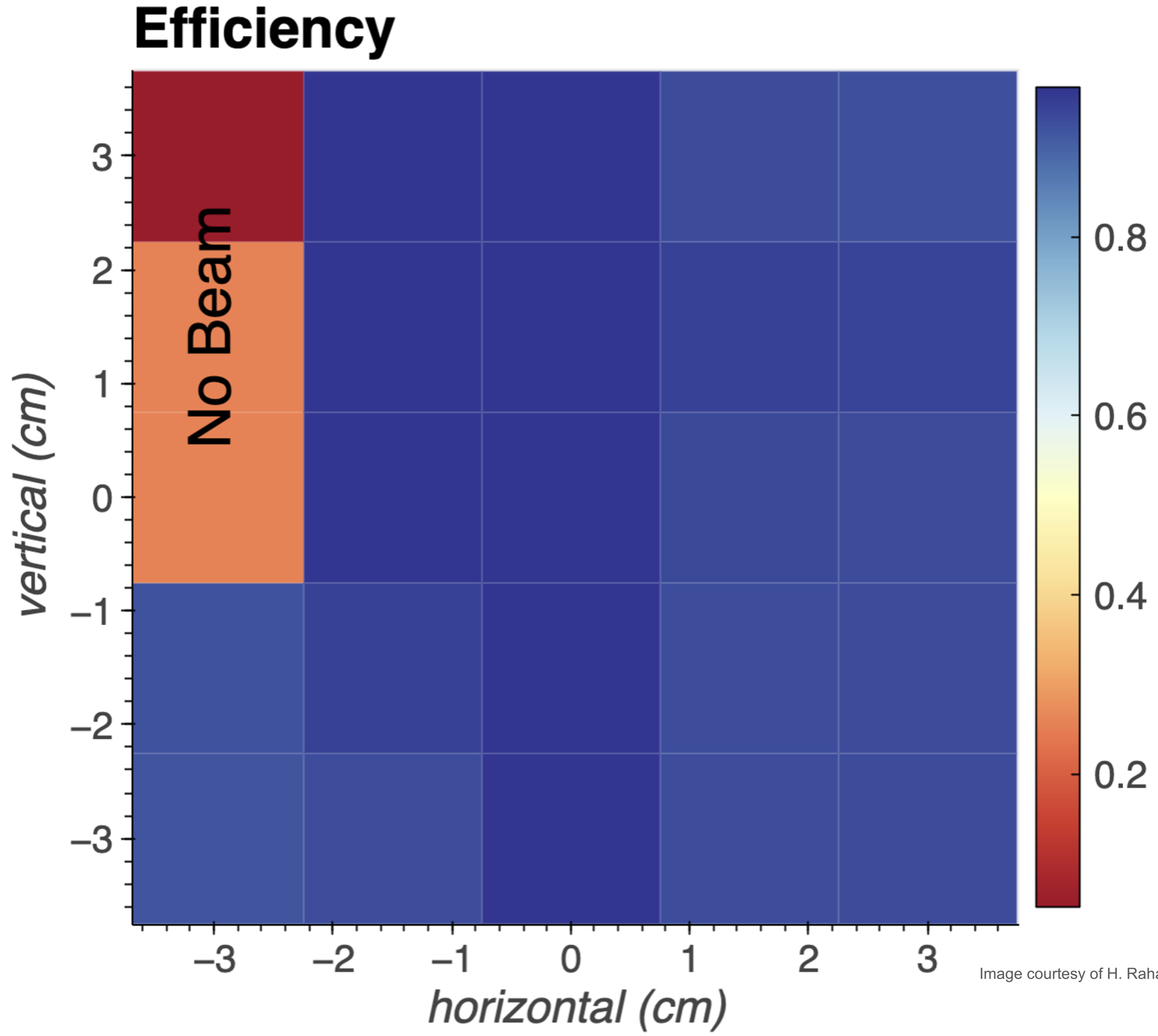


Image courtesy of H. Rahangdale

More results

- There is a slight change in the flipping ratio based on the position of the spin flipper
- The spin flipper is sensitive to temperature; we will need to connect it to the cooling system when installed on BL13

What comes next?

- Adding legs to the spin flipper to allow for better ventilation
- Further characterization experiments at HFIR
- Reimagining the polarimetry setup at BL13
    - Using an S-bender instead of a ^{3}He device
- Measuring the polarization of the neutron beam at BL13
- Future experiment: pNab

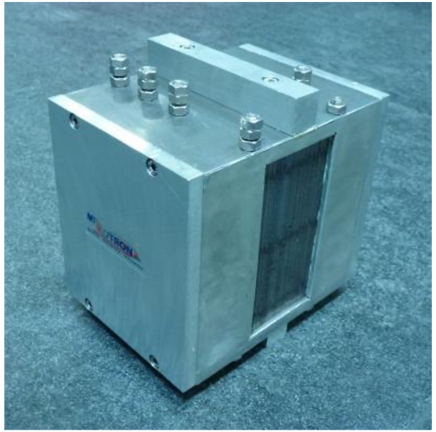


Image courtesy of Mirrotron

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics Fundamental Symmetries program under Award Number DE-FG02-03ER41258

Nab collaborating institutions:

Oak Ridge National Laboratory

Los Alamos National Laboratory

University of Virginia

The University of Tennessee Knoxville

Arizona State University

NC State University

Massachusetts Institute of Technology 1861

University of Kentucky

University of Michigan

Eastern Kentucky University

The University of Tennessee Chattanooga

University of Manitoba

The University of Winnipeg

GT

University of South Carolina,
Universität Karlsruhe (TH),
Universidad Nacional
Autónoma de México,
Western Kentucky University

Main project funding:

NSF

U.S. Department of Energy
Office of Science

Oak Ridge National Laboratory

University of Virginia