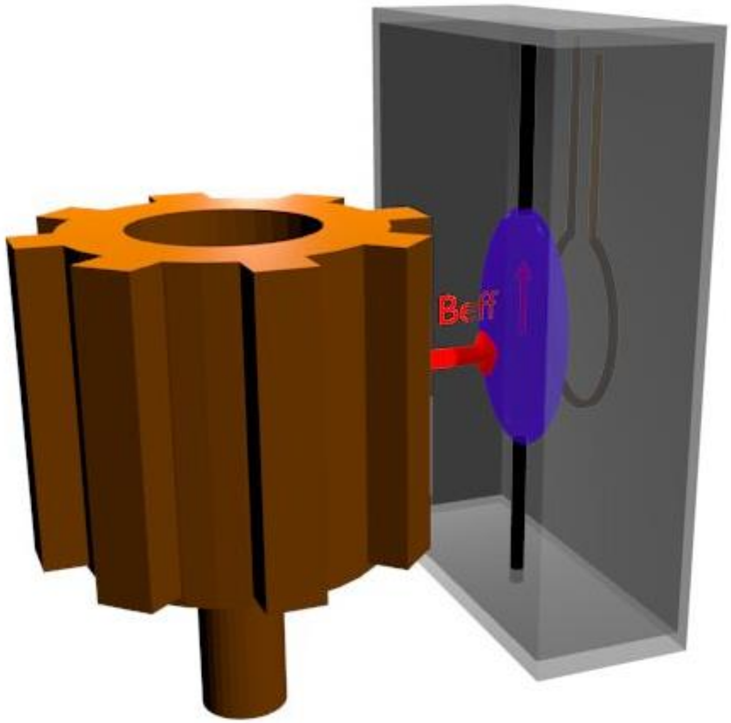
The Axion Resonant InterAction Detection Experiment (ARIADNE)



A. Arvanitaki and AG., *Phys. Rev. Lett*. 113,161801 (2014).

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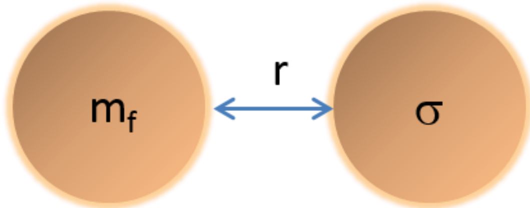
Spin-dependent forces



Monopole-Dipole axion exchange

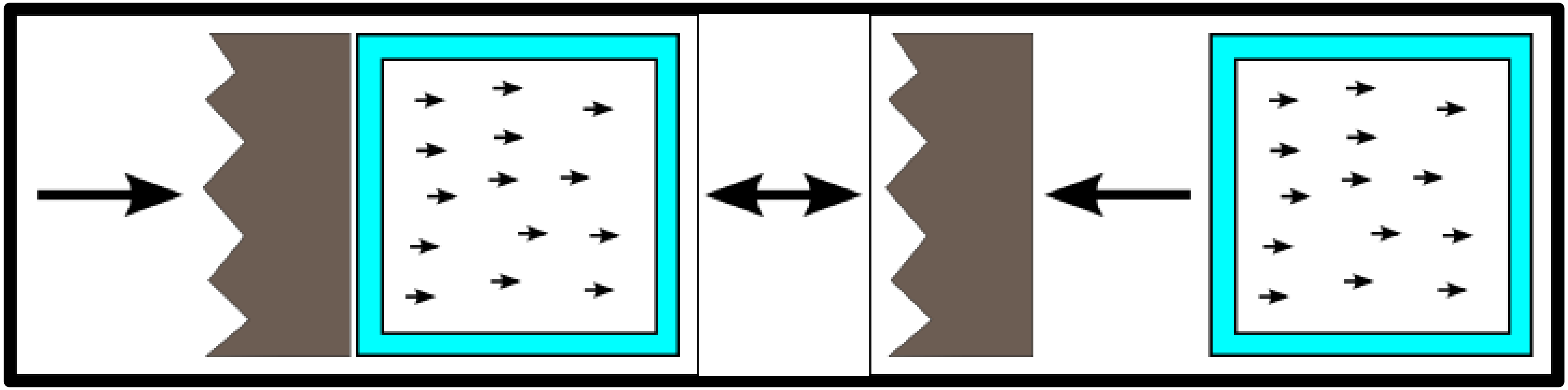
$$U(r) = \frac{\hbar^2 g_s^N g_p^N}{8\pi m_f}\left(\frac{1}{r\lambda_a} + \frac{1}{r^2}\right)e^{-r/\lambda_a}(\hat{\sigma}\cdot\hat{r}) \equiv \mu \cdot B_{\mathrm{eff}}$$

Acts as effective magnetic field

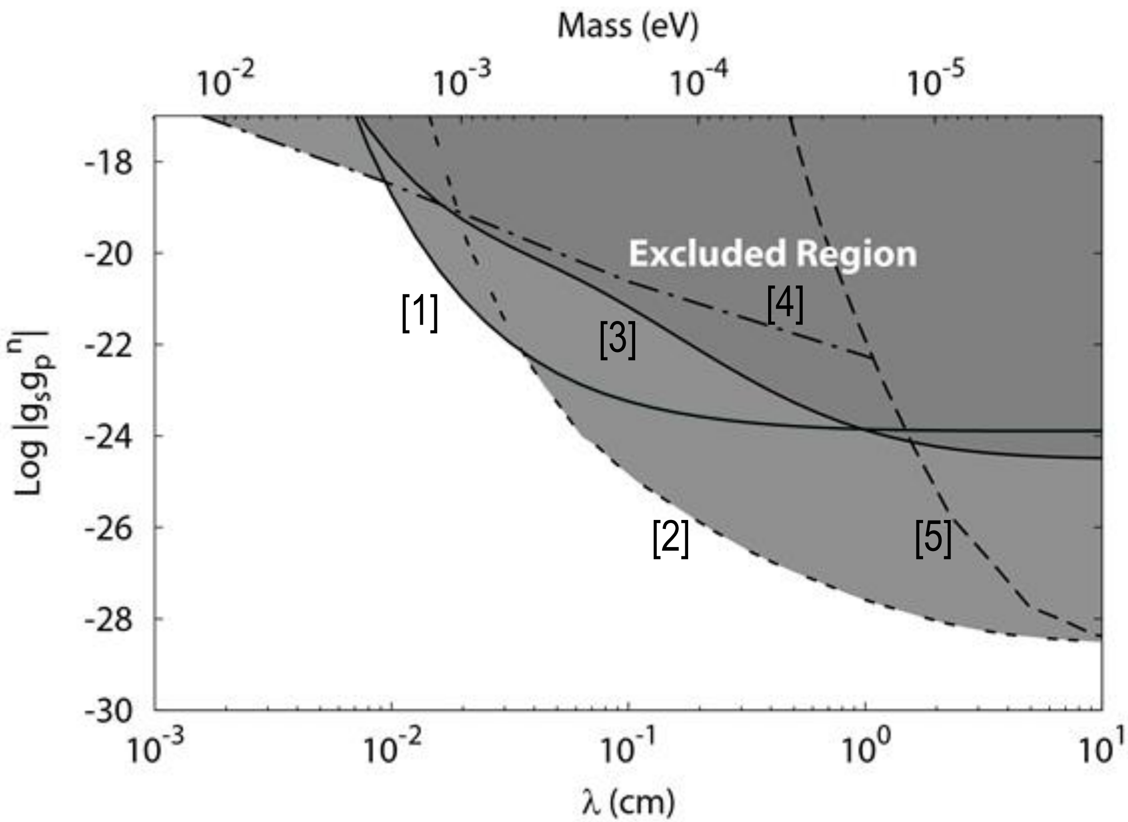
- Different than ordinary B field
- Does not couple to angular momentum
- Unaffected by magnetic shielding

A spin polarized sample acts as an indicator of the Axion potential

- A steep drop-off allows the effective field to be effectively turned on and off
- Repeated insertion and removal of this mass at the Larmor frequency allows resonant amplification of the effect
- Look for changes in the NMR frequency induced by B_{eff}



Current experimental limits

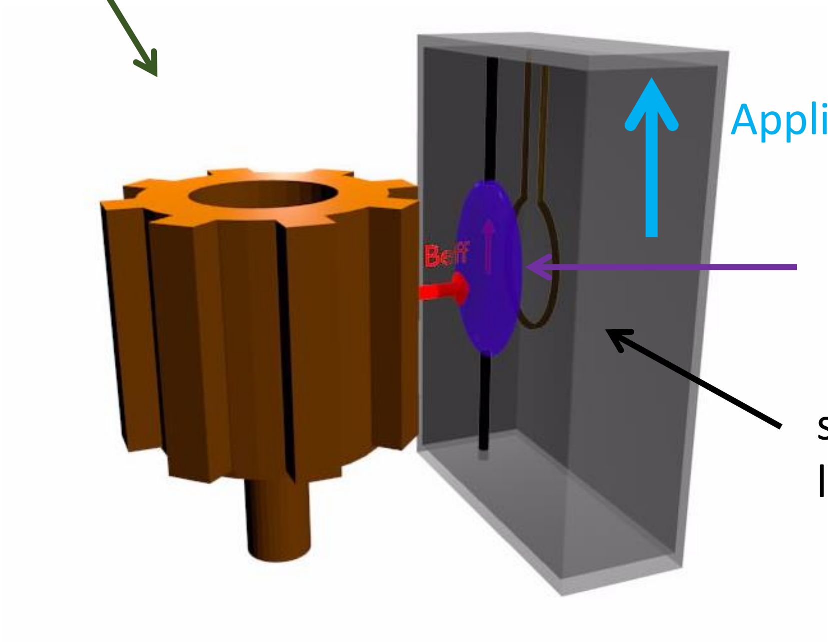


1) $^{129}Xe/^{131}Xe$ NMR
2) $^{3}He/^{129}Xe$ NMR with SQUID magnetometer
3) ^{3}He NMR with a 250μm window
4) ^{3}He Spin Relaxation with cell walls
5) $^{199}Hg/Cs$ co-magnetometer

[1] Phys. Rev. Lett. 111, 102001 (2013), [2] Phys. Rev. Lett. 111, 100801 (2013), [3] Phys. Rev. D 87, 011105(R) (2013), [4] Phys. Rev. Lett. 105, 170401 (2010), [5] Phys. Rev. Lett. 77, 2170 (1996)

Concept for ARIADNE

Unpolarized (tungsten) segmented cylinder sources B_{eff}



Applied Bias field B_{ext}

$$\omega = \frac{2\mu_N \cdot B_{ext}}{\hbar}$$

Laser Polarized ^{3}He gas senses B_{eff} (Indiana U)

squid pickup loop

Y.-H. Lee (KRISS)

Superconducting shielding (Stanford)

$$U(r) = \frac{\hbar^2 g_s{}^N g_p{}^N}{8\pi m_f}\left(\frac{1}{r\lambda_a} + \frac{1}{r^2}\right)e^{-r/\lambda_a}(\hat{\sigma}\cdot\hat{r}) \equiv \mu \cdot B_{eff}$$

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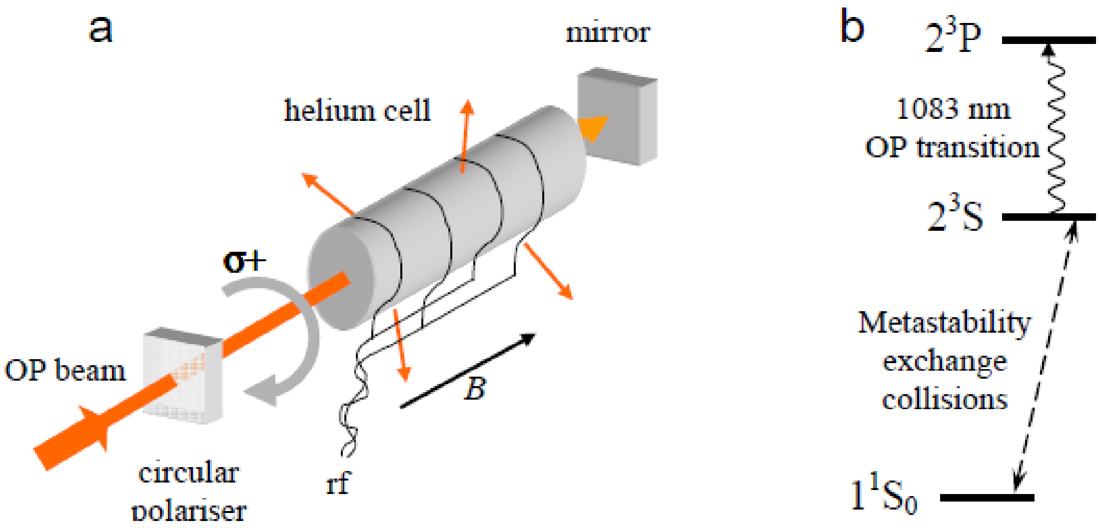
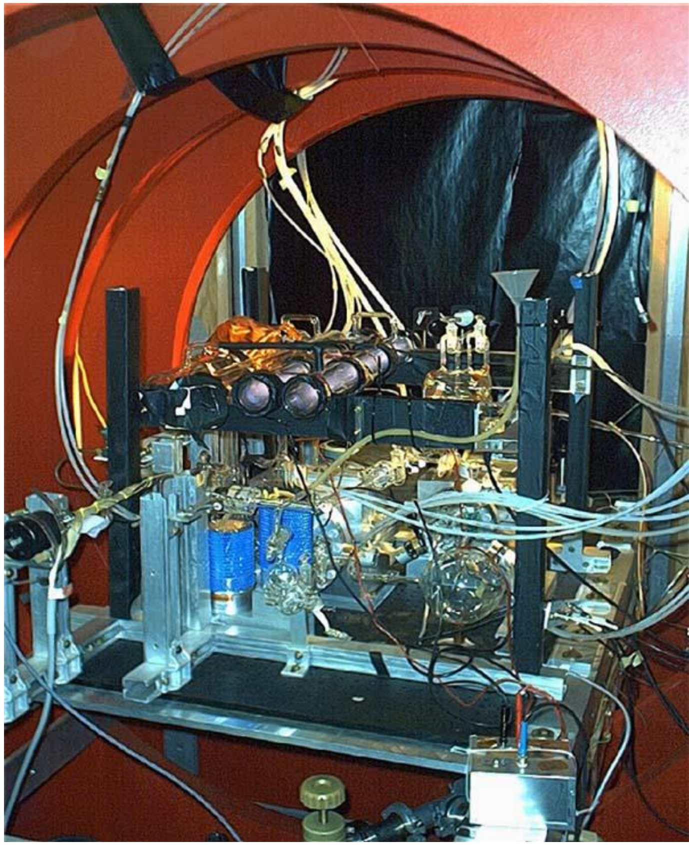
Polarized ^3He compression system

- **Modification and rebuilding of existing MEOP system**
- **New fiber laser and optical polarimeter**
- **Delivers compressed polarized ^3He at room temperature**

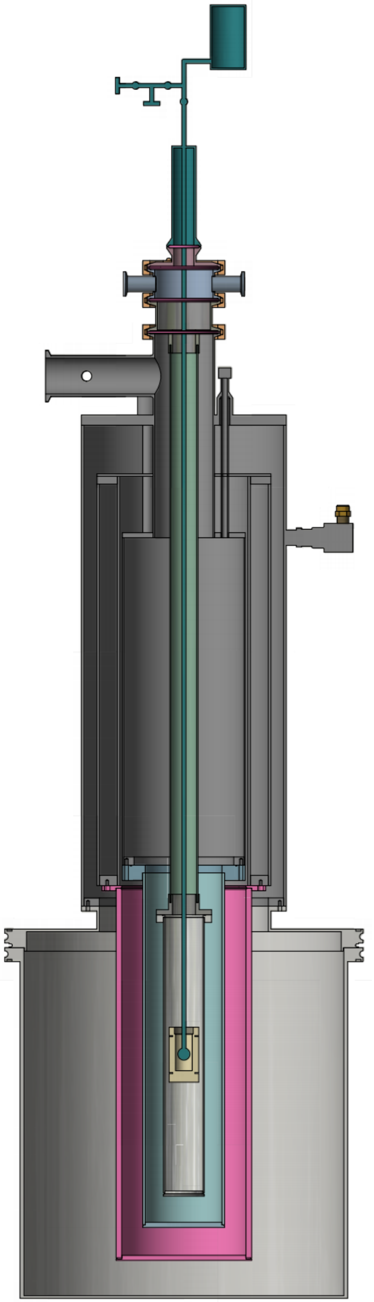




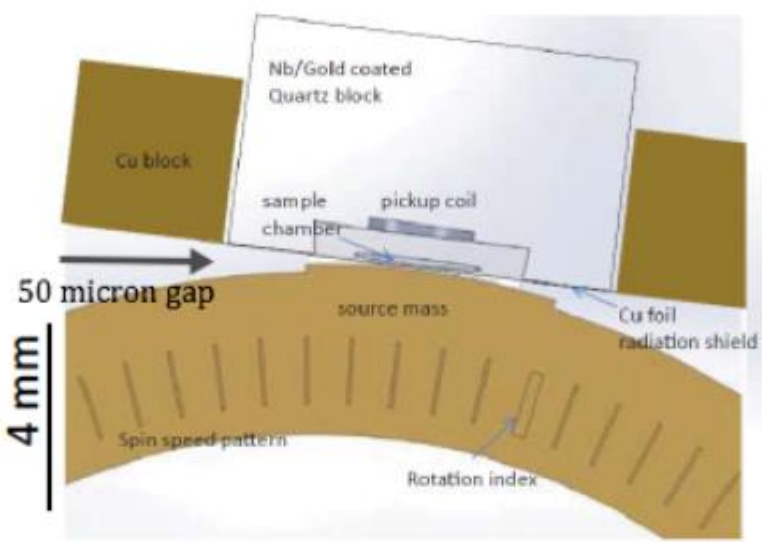
Rev. Sci. Instrum. 76, 053503 (2005)

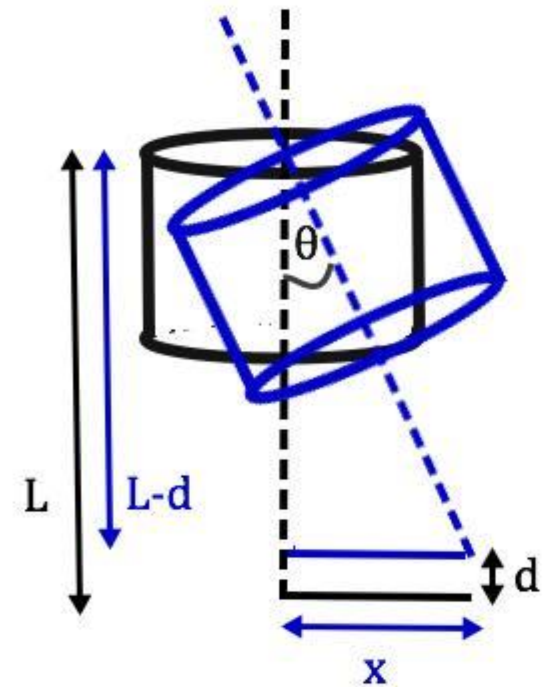
Test cryostat

- **Magnetic field coils**
- **Produce polarized ^3He at 4K**
- **Tests of NMR system**
- **Measurement of polarized ^3He relaxation time**

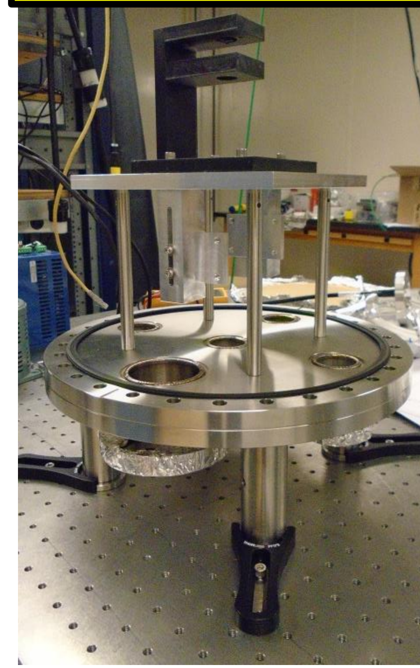


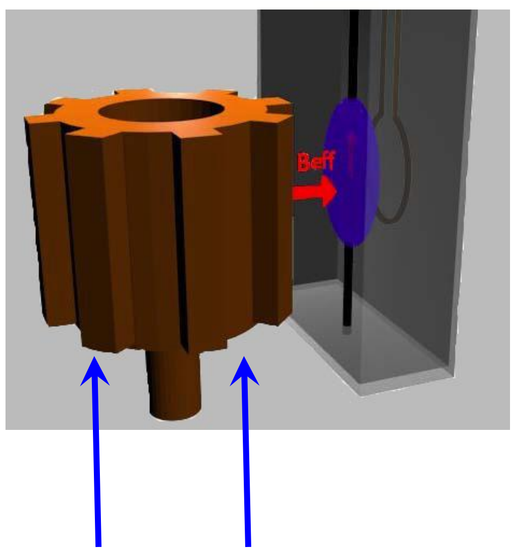
Rotary stage vibration and tilt





Rotary test chamber





Interferometers

- Build an interferometer to measure the change in distance (d).
- We can find theta (Θ) from:

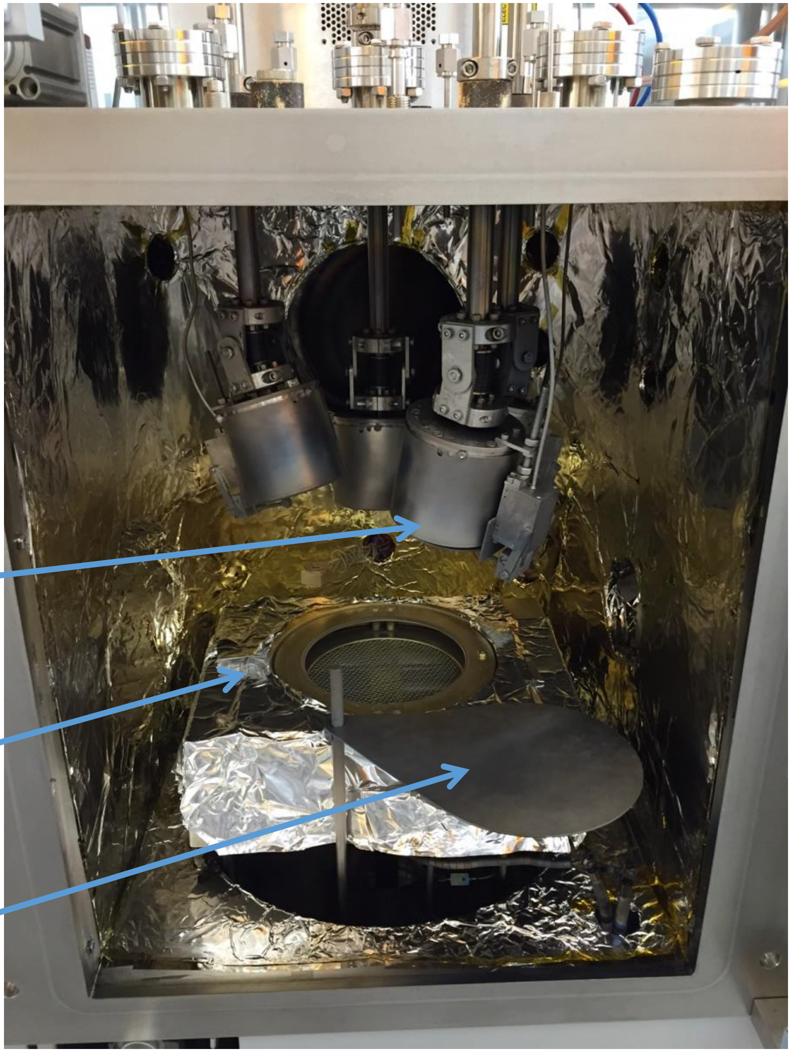
$$\Theta = \cos^{-1}((L-d)/L)$$

- We can solve for the wobble distance (X) by:

$$X = L\sin(\Theta)$$

Sputtered Niobium on Quartz

- **DC sputtering system**
- **300W deposition**
- **300V, 1A**
- **12.5nm/min rate**

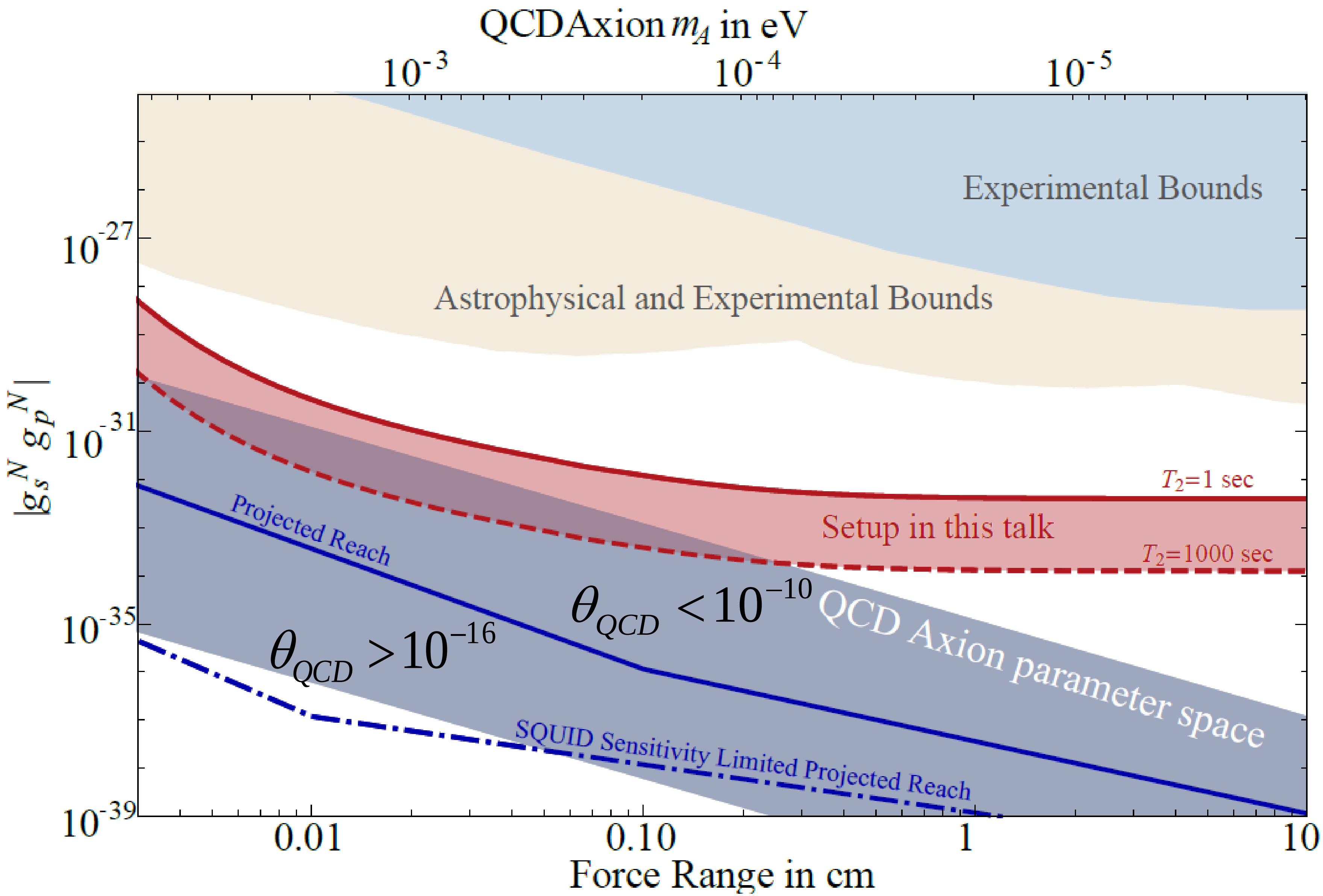


Gun – 3” Nb target, .25” thick

Water cooled
Rotation stage

Sample shutter

Sensitivity



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Summary

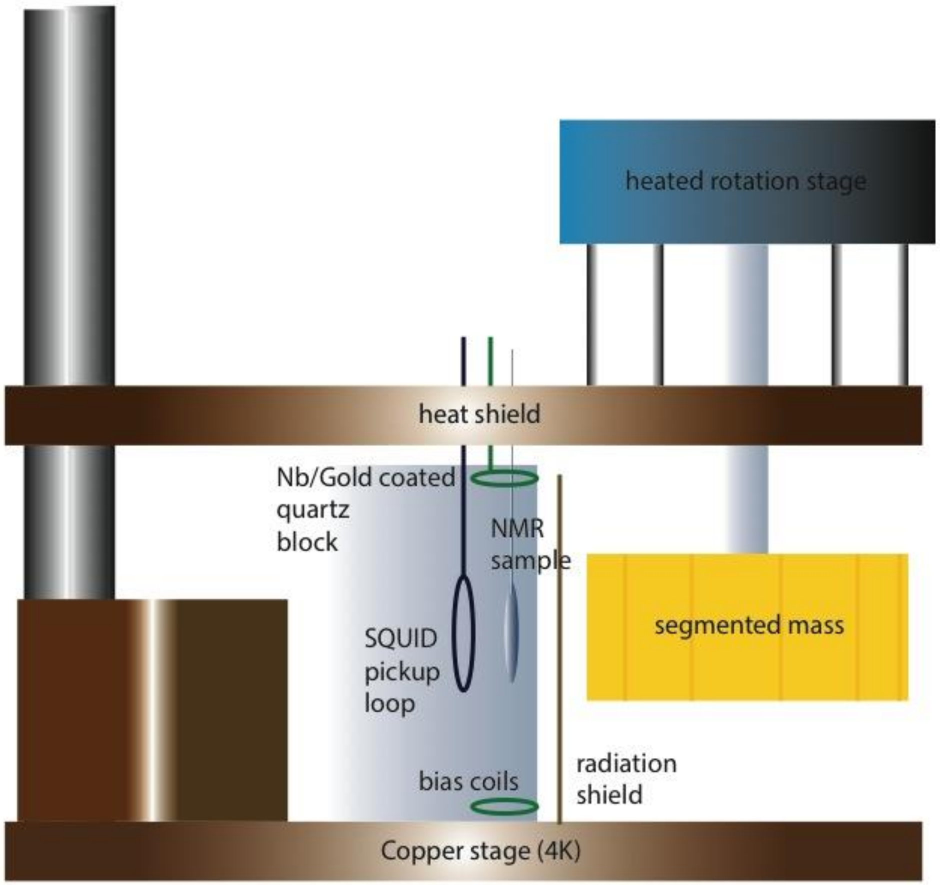
- **New resonant method to search for monopole-dipole interaction**

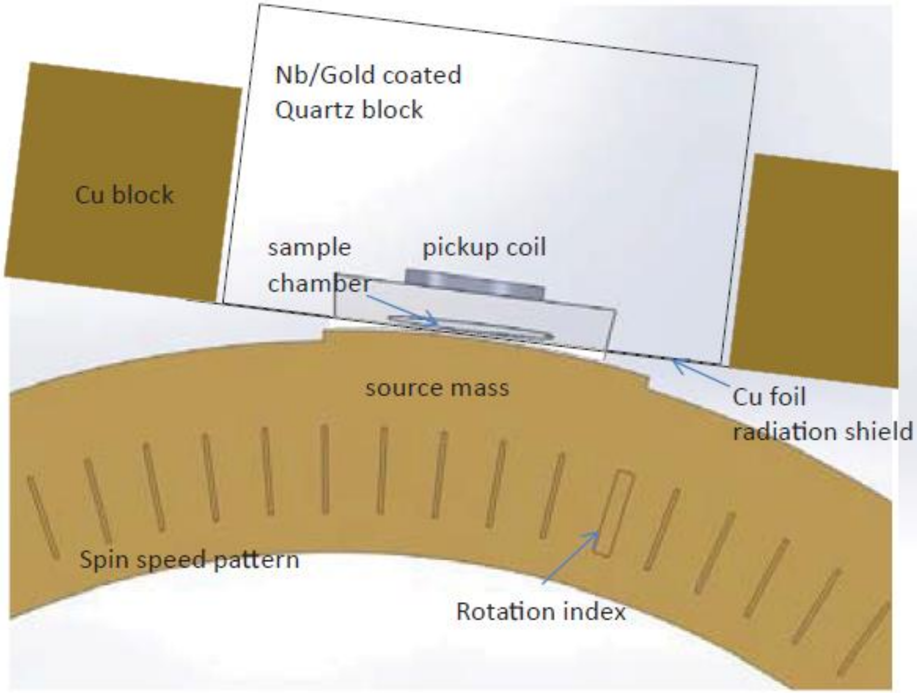
- **Sensitive to Axions in the 0.1meV $< m_a <$ 10 meV range**

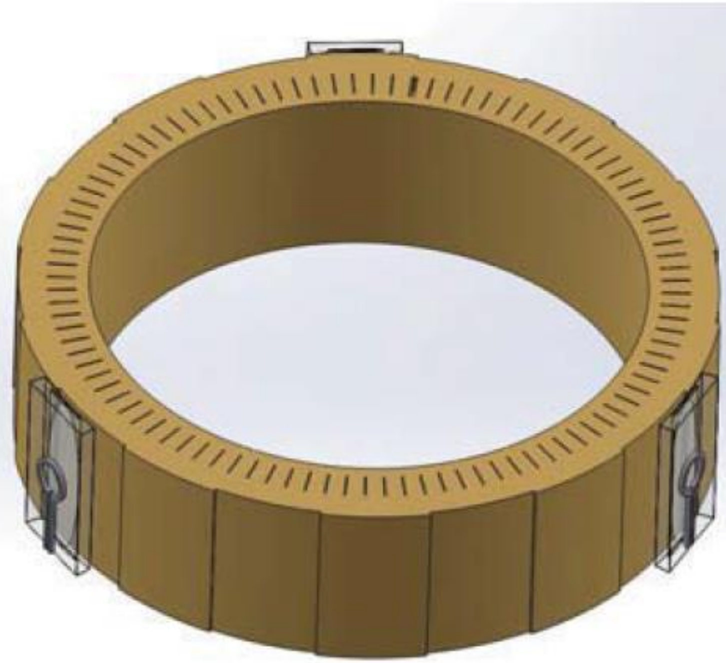
- **Hardware is being developed and tested for the experiment**

Conceptual drawing of apparatus

- Experiment is done at 4K
    - Allows for superconducting shielding
    - Reduces thermal noise
- Ellipsoidal sample allows near uniform magnetization
- Rotating segmented mass oscillates force in resonance to the Larmor precession
- SQUID pickup loop for NMR of sample
- Radiation and superconducting magnetic shielding used to minimize noise




Nb/Gold coated
Quartz block
Cu block
sample
chamber
pickup coil
source mass
Cu foil
radiation shield
Spin speed pattern
Rotation index



Experimental challenges

Systematic Effect/Noise source	Background Level	Notes
Magnetic gradients	3×10^{-6} T/m	Limits T_2 to ~ 100 s
		Possible to improve w/shield geometry
Vibration of mass	10^{-22} T	For 10 μm mass wobble at ω_{rot}
External vibrations	5×10^{-20} T/$\sqrt{\text{Hz}}$	For 1 μm sample vibration (100 Hz)
Patch Effect	$10^{-21}(\frac{V_{\text{patch}}}{0.1\text{V}})^2$ T	Can reduce with V applied to Cu foil
Flux noise in squid loop	2×10^{-20} T/$\sqrt{\text{Hz}}$	Assuming $1\mu\Phi_0/\sqrt{\text{Hz}}$
Trapped flux noise in shield	$7 \times 10^{-20} \frac{\text{T}}{\sqrt{\text{Hz}}}$	Assuming 10 cm^{-2} flux density
Johnson noise	$10^{-20}(\frac{10^8}{f})$T/$\sqrt{\text{Hz}}$	f is SC shield factor (100 Hz)
Barnett Effect	$10^{-22}(\frac{10^8}{f})$ T	Can be used for calibration above 10 K
Magnetic Impurities in Mass	$10^{-25} - 10^{-17}(\frac{\eta}{1\text{ppm}})(\frac{10^8}{f})$ T	η is impurity fraction (see text)
Mass Magnetic Susceptibility	$10^{-22}(\frac{10^8}{f})$ T	Assuming background field is 10^{-10} T
		Background field can be larger if $f > 10^8$

Table 1: Table of estimated systematic error and noise sources, as discussed in the text. The projected sensitivity of the device is $3 \times 10^{-19}(\frac{1000\text{s}}{T_2})$ T/$\sqrt{\text{Hz}}$

- Design/Simulation Work: Magnetic gradient reduction strategy
- Experimental testing in progress: Vibration tests, Shielding factor f test thin-film SC