^{199}Hg magnetometry system in the LANL Neutron EDM experiment

Yi (Jennie) Chen 陳宜

University of Illinois Urbana-Champaign

nEDM2023 - The 5th Workshop on Searches for a Neutron Electric Dipole Moment

Hotel Santa Fe, Hacienda & Spa

November 6, 2023 – November 9, 2023

yic@illinois.edu

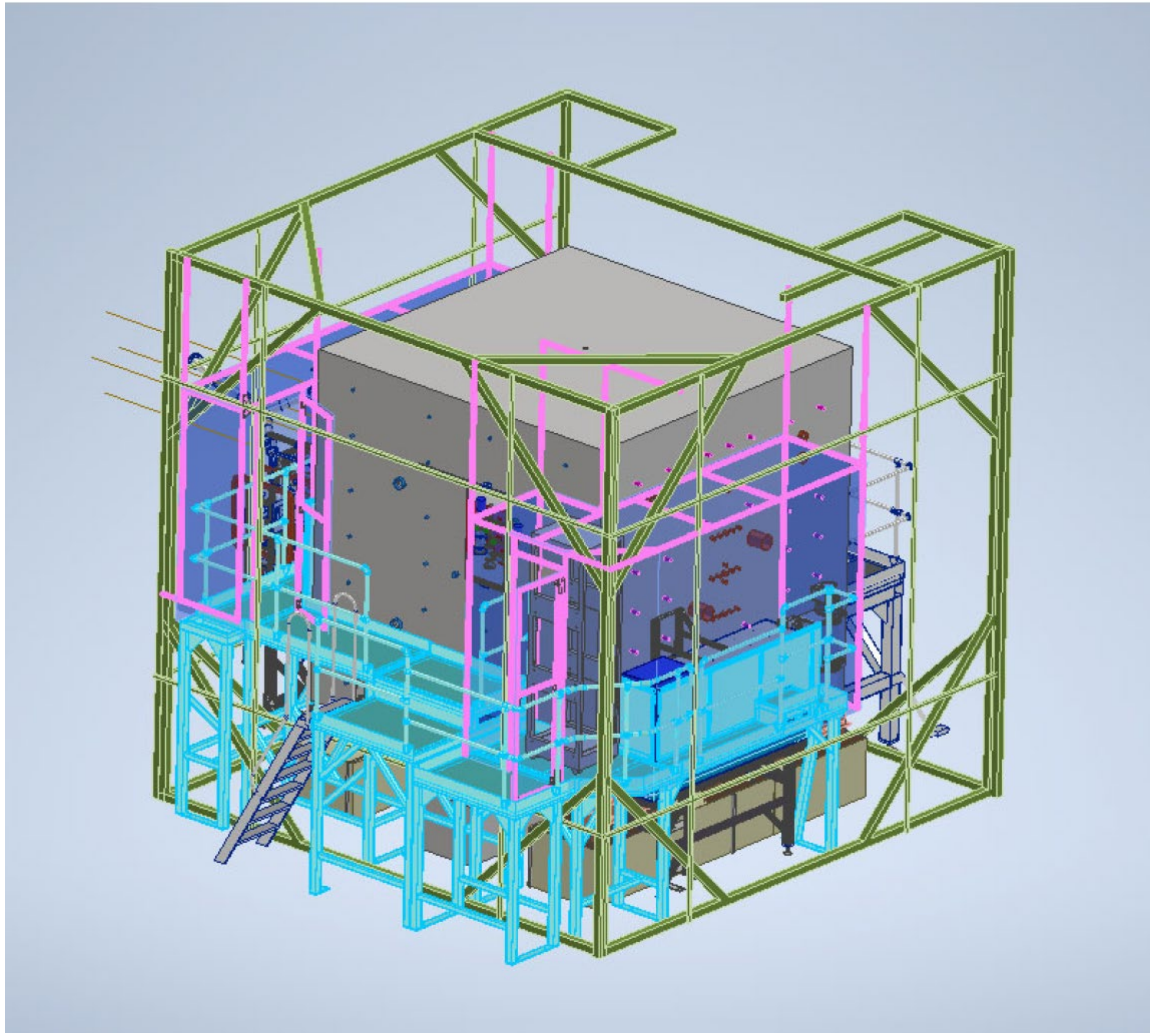
Collaboration: neutron Electric Dipole Moment experiment at Los Alamos National Laboratory (nEDM@LANL)

Los Alamos NATIONAL LABORATORY

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Hg magnetometry system at LANL

- Engineer structure
  - Personnel platform (3); optical table platform (2)
  - Laser safety enclosure/interlock system
- Laser
  - Frequency locking circuit
  - Photodiode readout
  - chopper, shutter, slide
  - Optics holding structure (2)
- Co-magnetometer vacuum system
  - Turbo pump
  - Vacuum handling system (control panel, gauges, fittings, etc.)
  - Coated tubes and coated polarizing chamber
  - Hg retort
  - Wall coating study
- HV external Hg cell
  - test cells



Above: Work platforms (sky blue), Field cage (green), and Laser enclosure (pink and navy blue)

Laser path in Hg Magnetometry in LANL nEDM

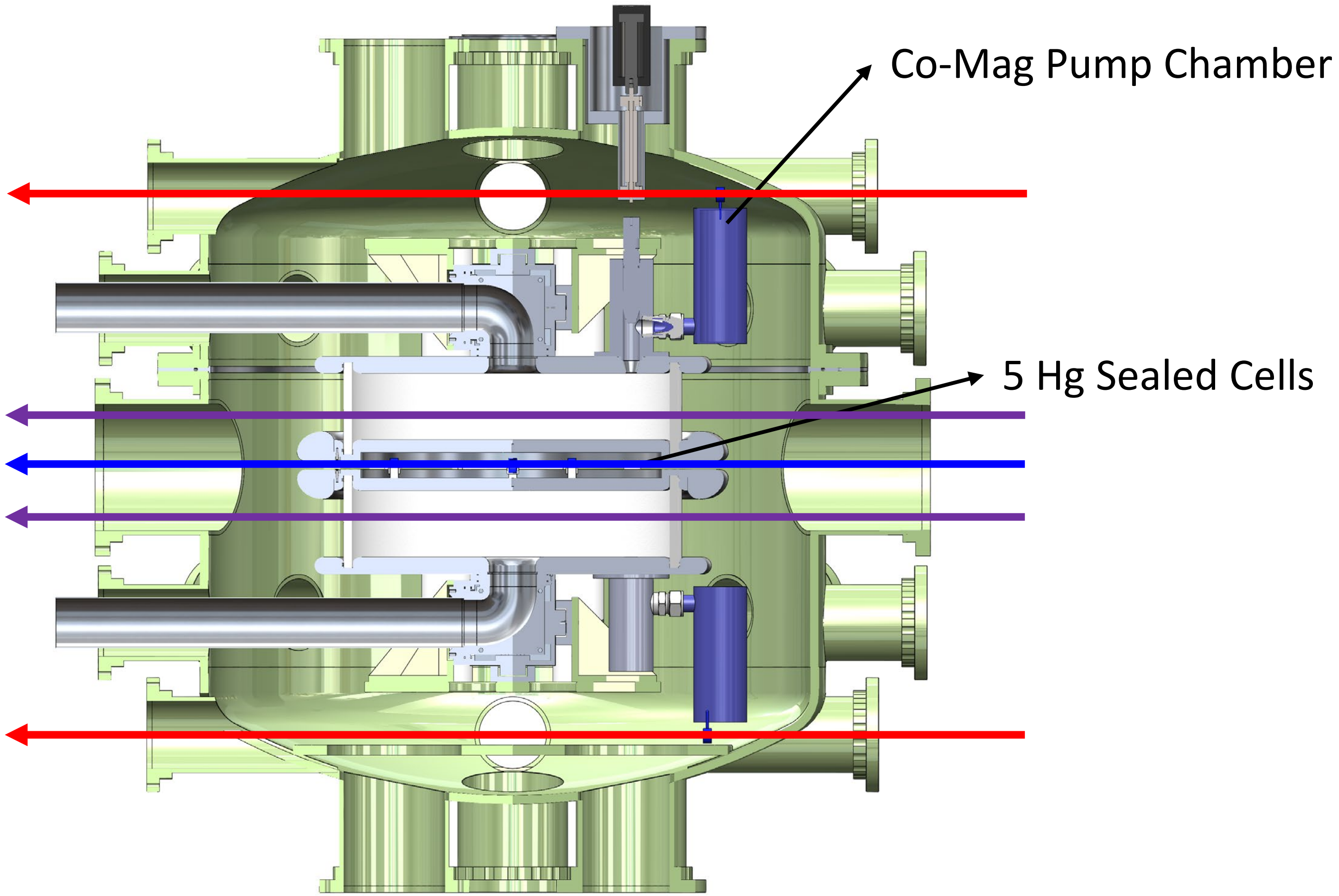
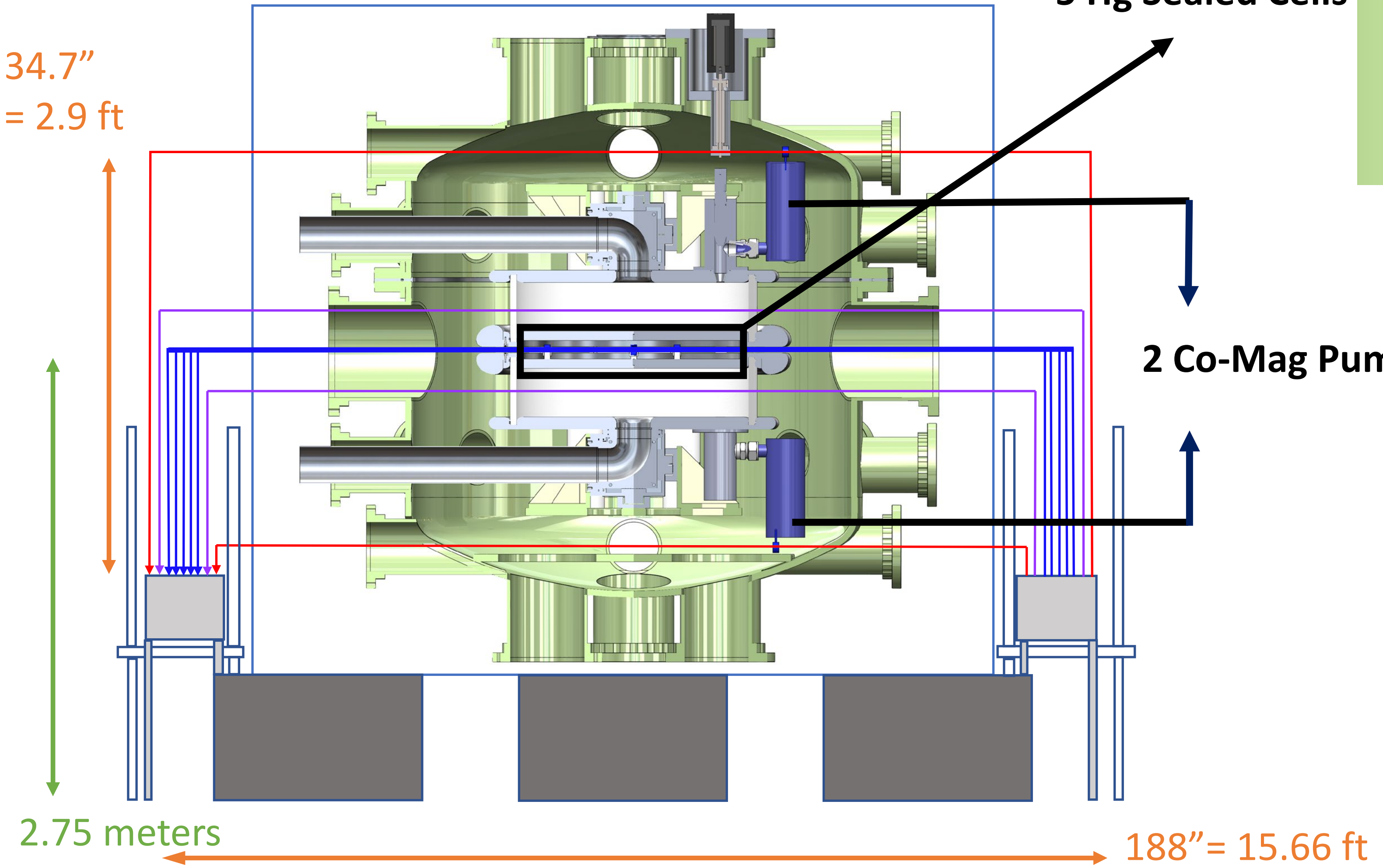
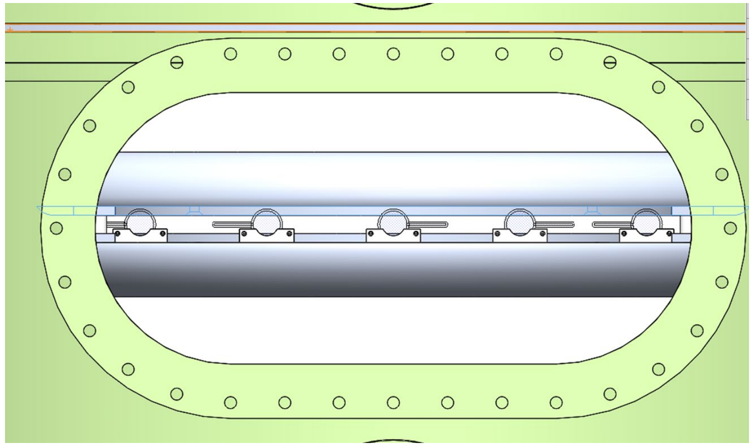


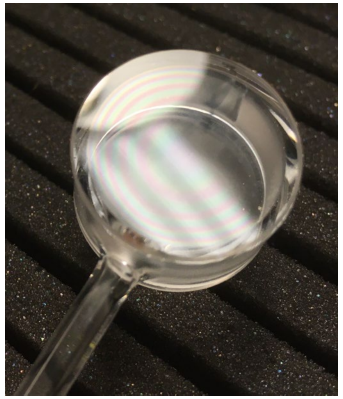
Image by Chris O'Shaughnessy

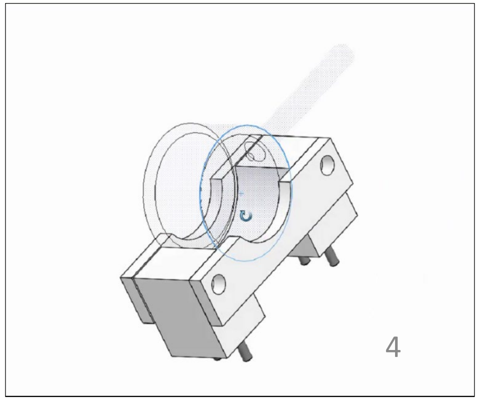
Hg-199 as co-magnetometer and magnetometers

- Optics design and test
- Hg sealed cell fabrication
    - Wall coating study
- Beam H = 3”; Optics table to the work platform = 28.25”; work platform to the floor = 30”

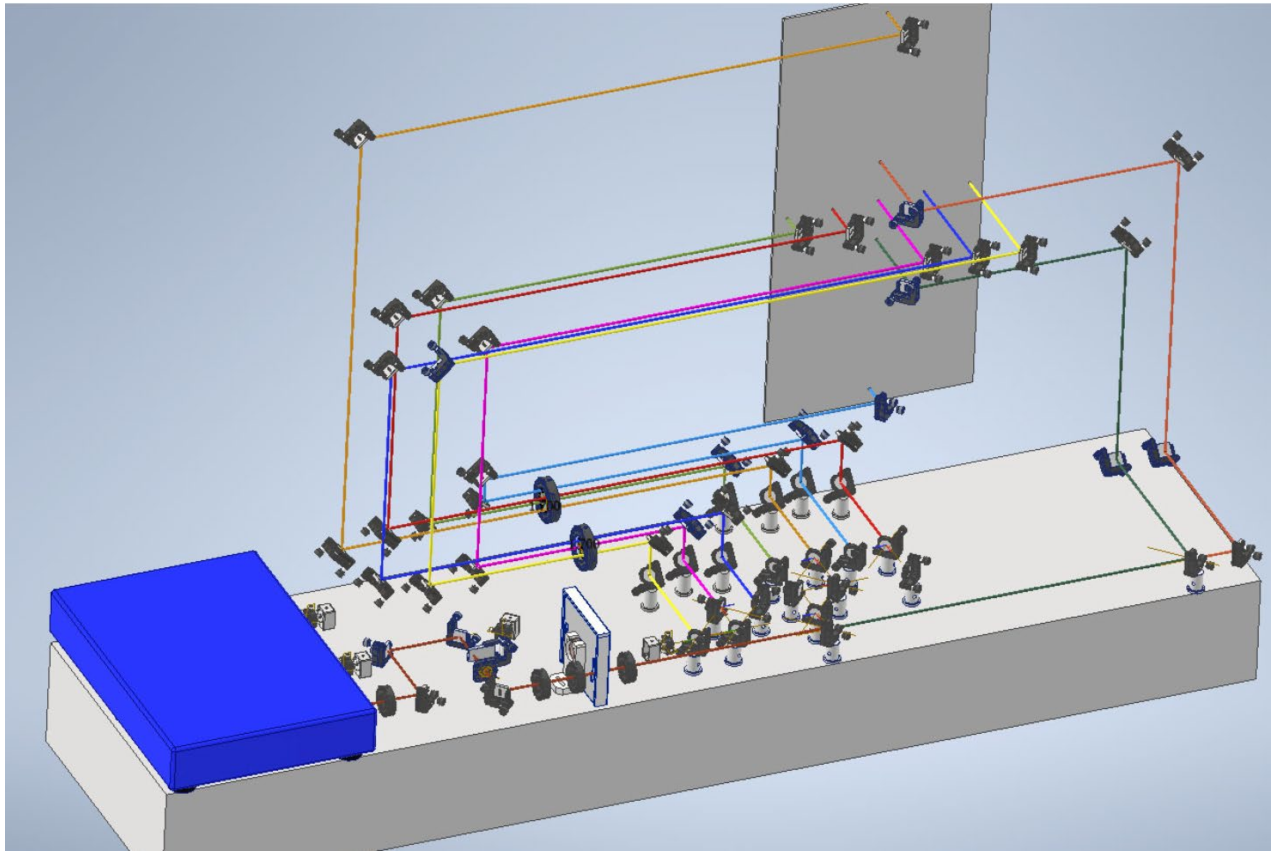




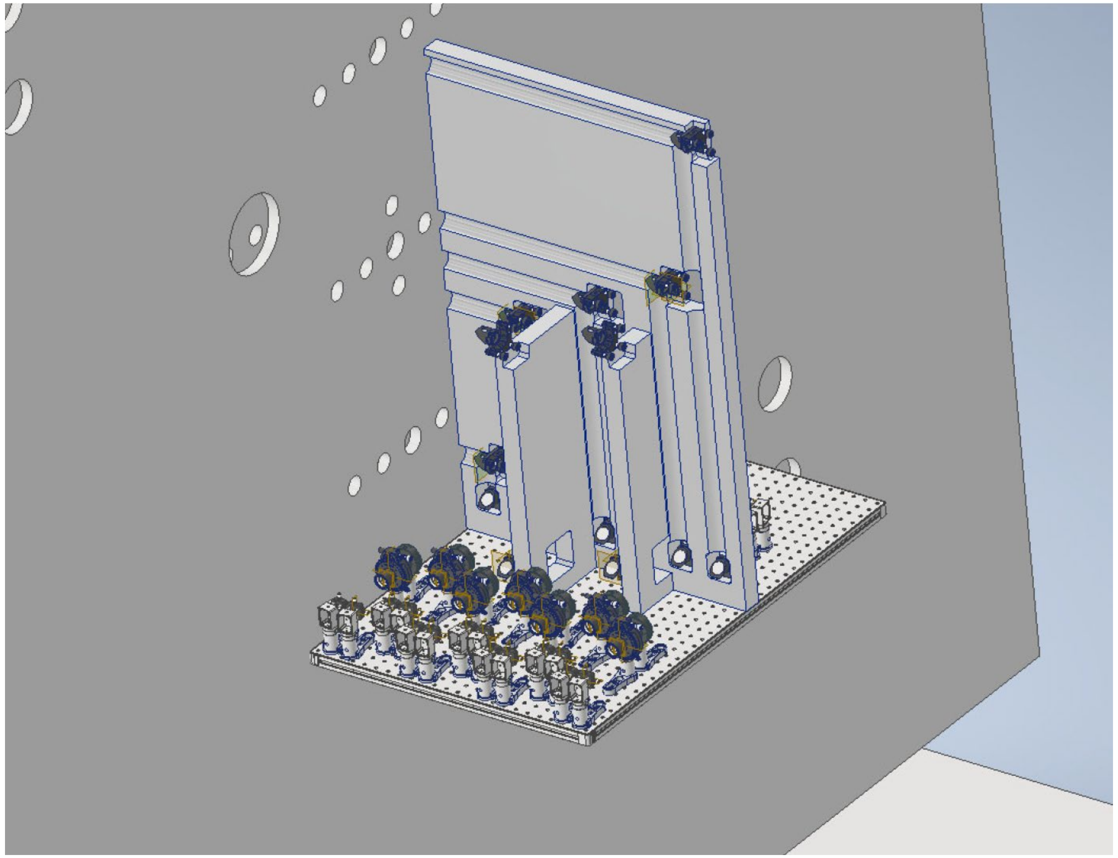




Optics design



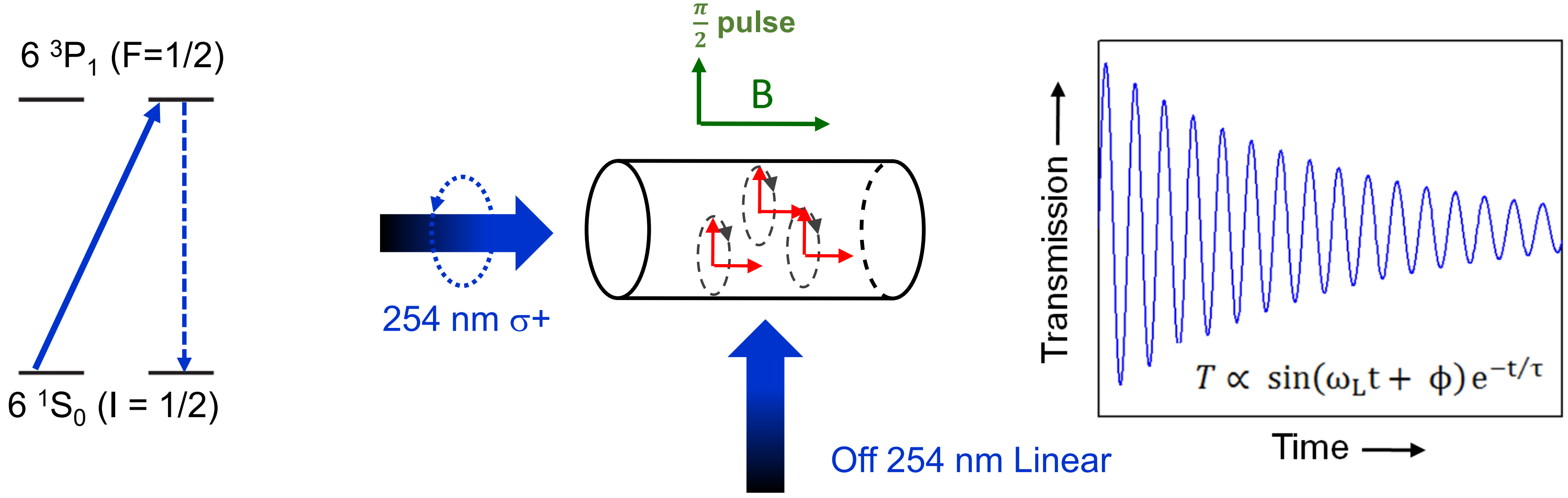
Entrance table



Exit table

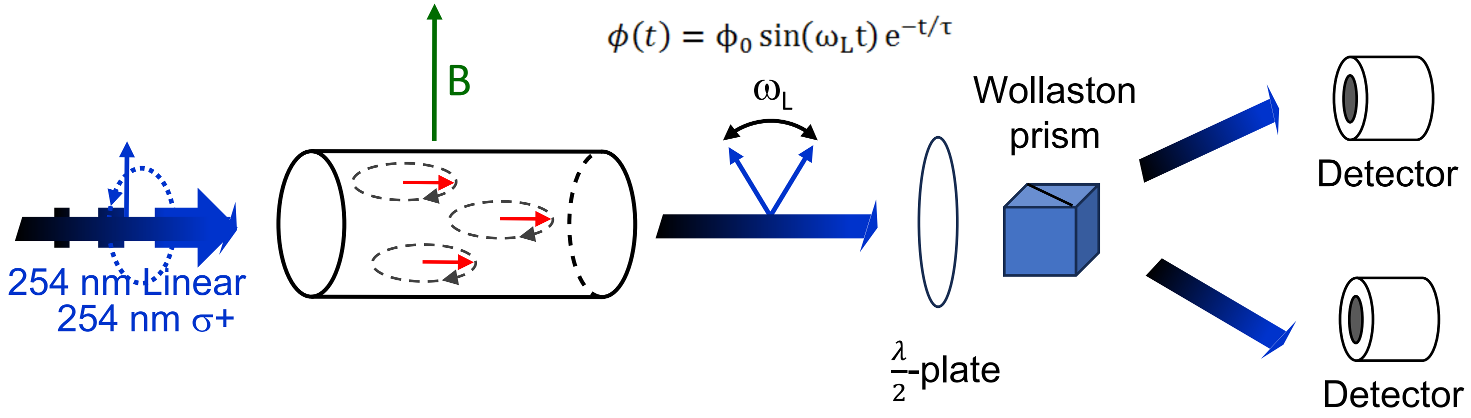
Two optical pumping methods and Optical Rotation

Longitudinal Optical Pumping, $\frac{\pi}{2}$ pulse to flip the spin



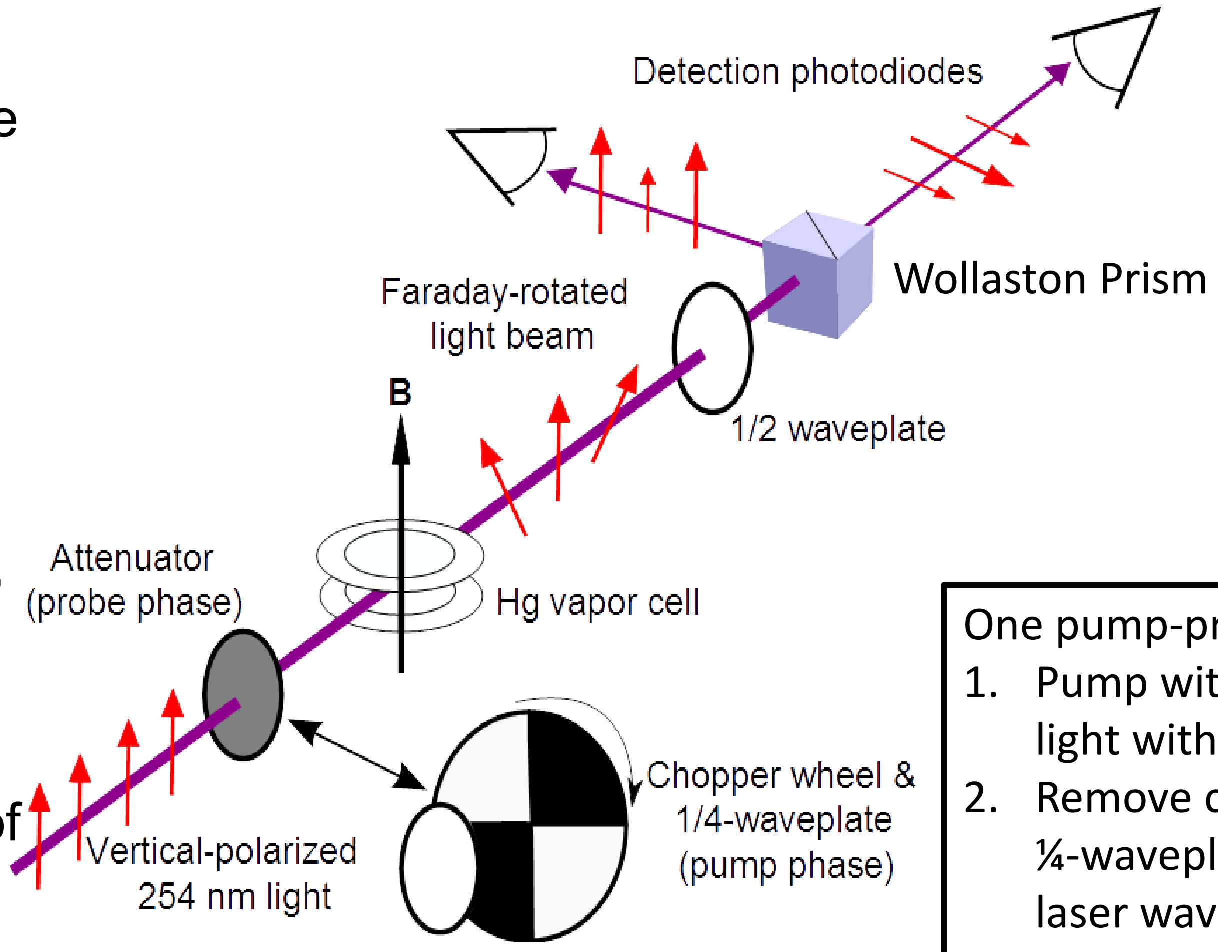
Transverse Optical Pumping

Measure ω_L via Optical Rotation



Faraday Rotation Detection

- Atomic polarization changes the index of refraction for σ_+ and σ_- light
- Incoming linearly polarized probe light is rotated
- Rotation angle oscillates at the Larmor frequency
- A polarizing beam splitter separates the beam into vertical, horizontal components
- Intensity of 2 orthogonal polarization states oscillate out of phase



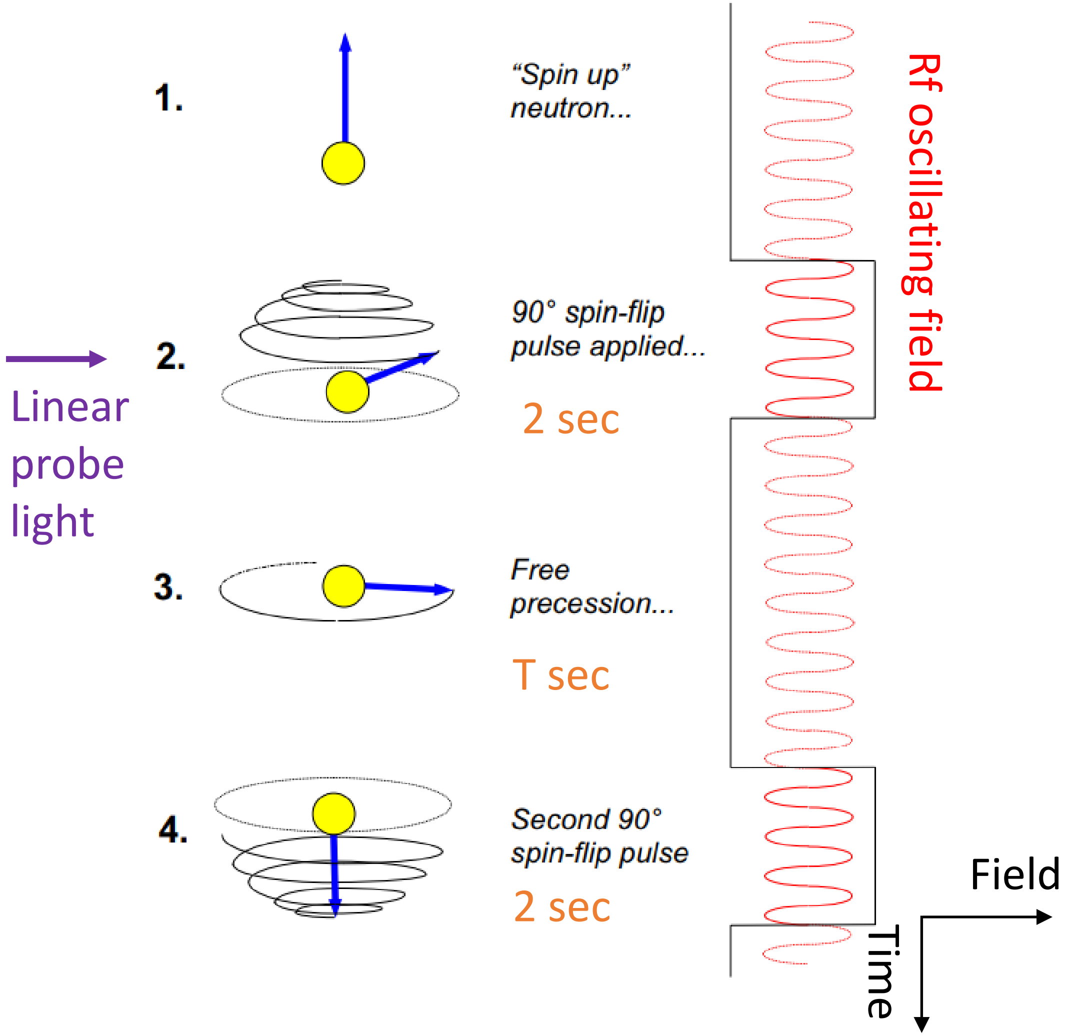
One pump-probe cycle

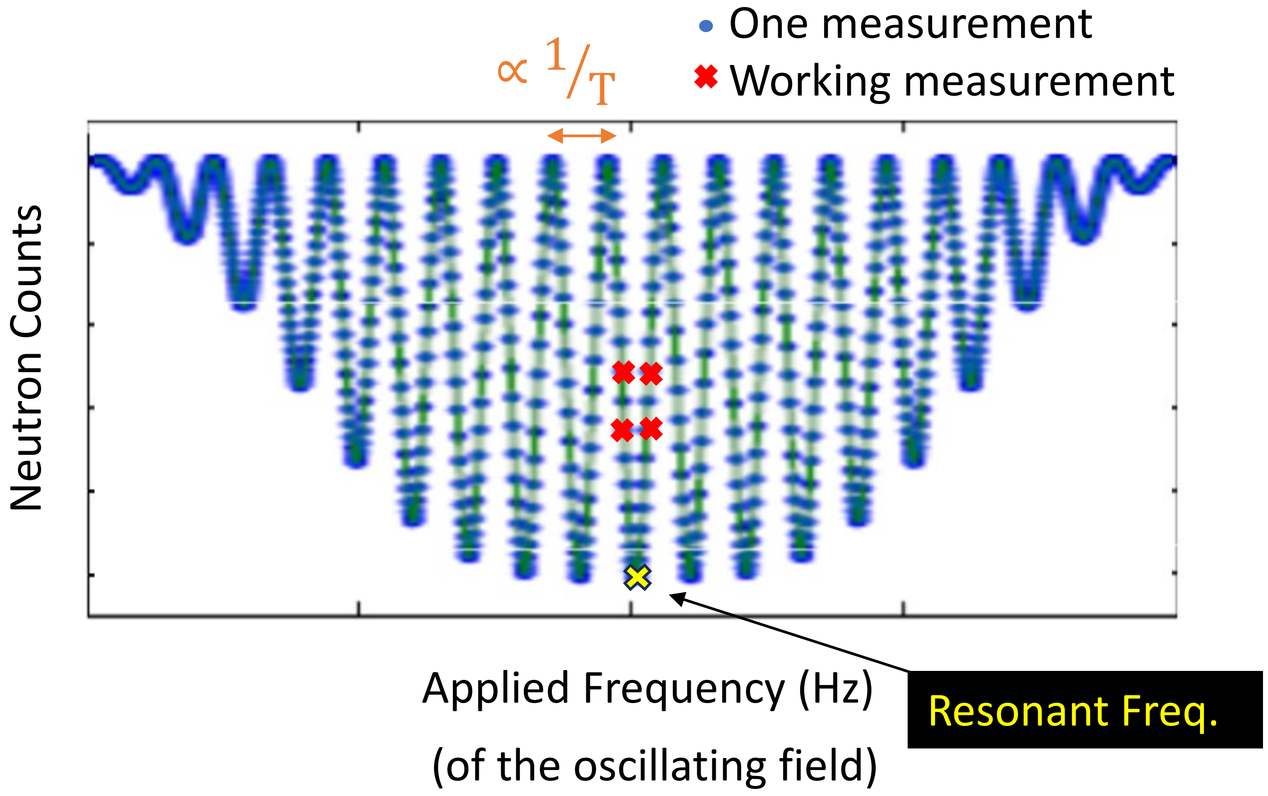
1. Pump with circular light with a chopper
2. Remove chopper and ¼-waveplate, change laser wavelength
3. Probe with linear light

The Ramsey method of separated oscillatory fields

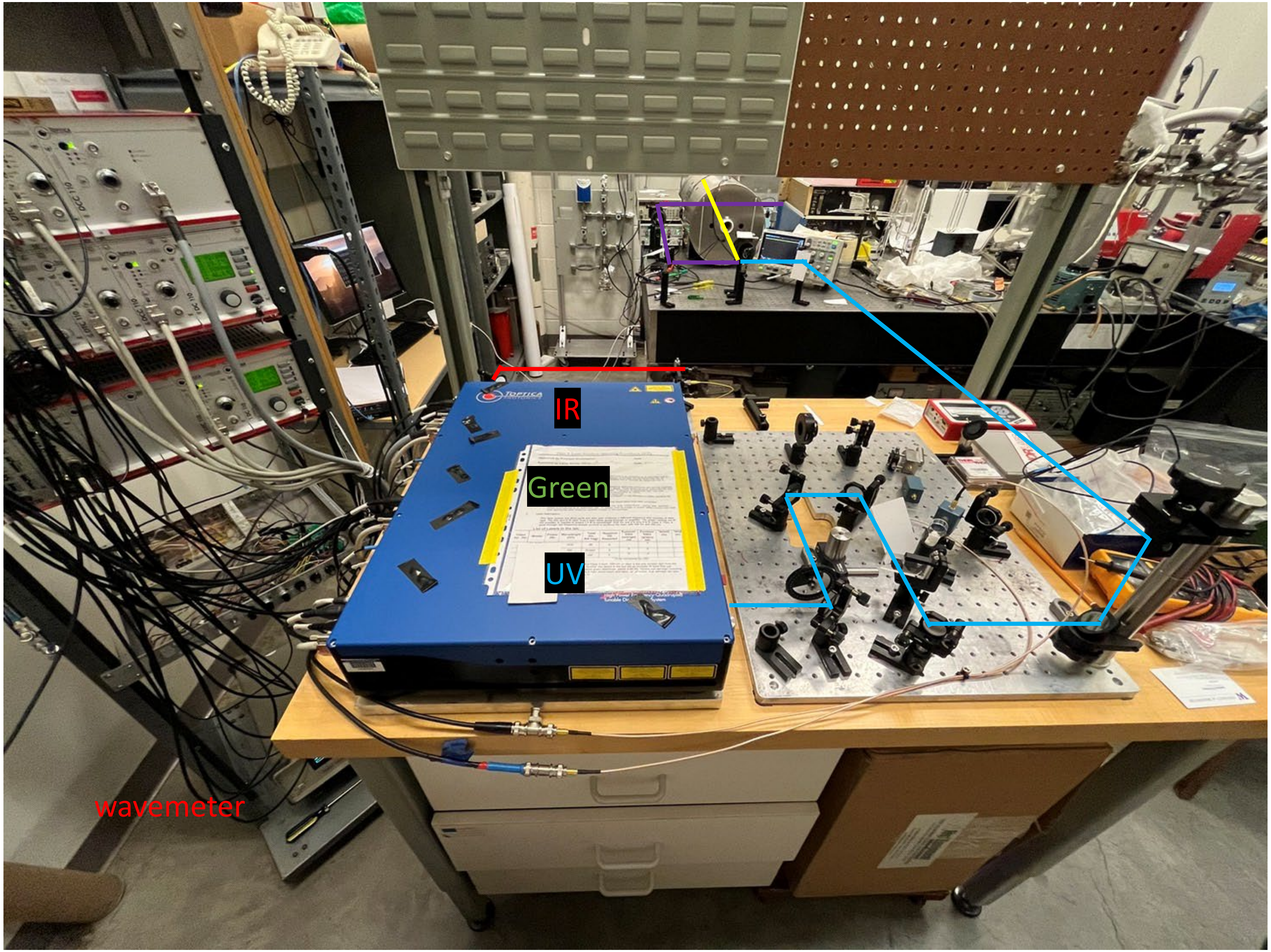
in the bloch vector representation

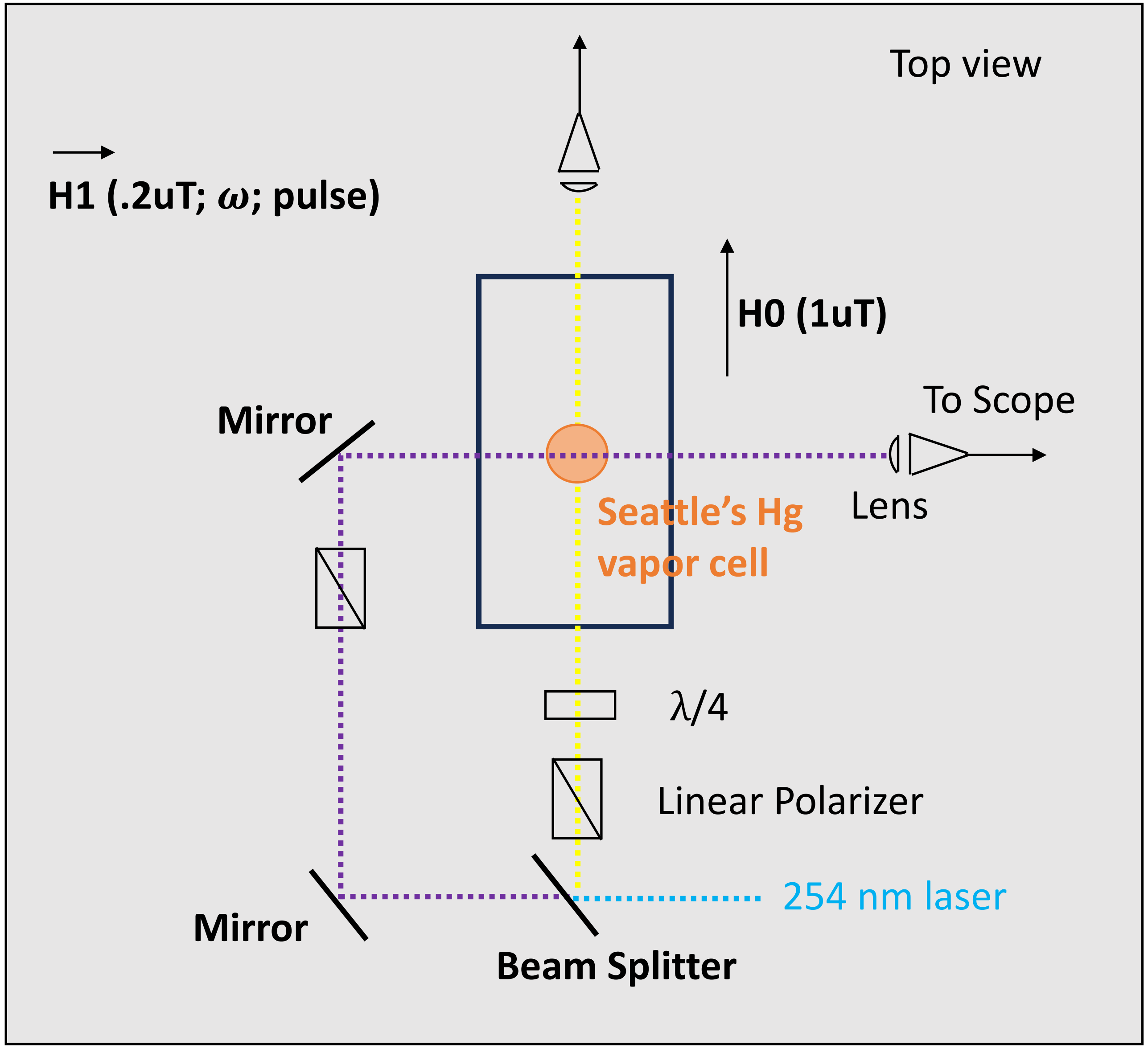
$$\vec{B} = B_0\hat{z} + B_1(\hat{x}\cos\omega t + \hat{y}\sin\omega t)$$

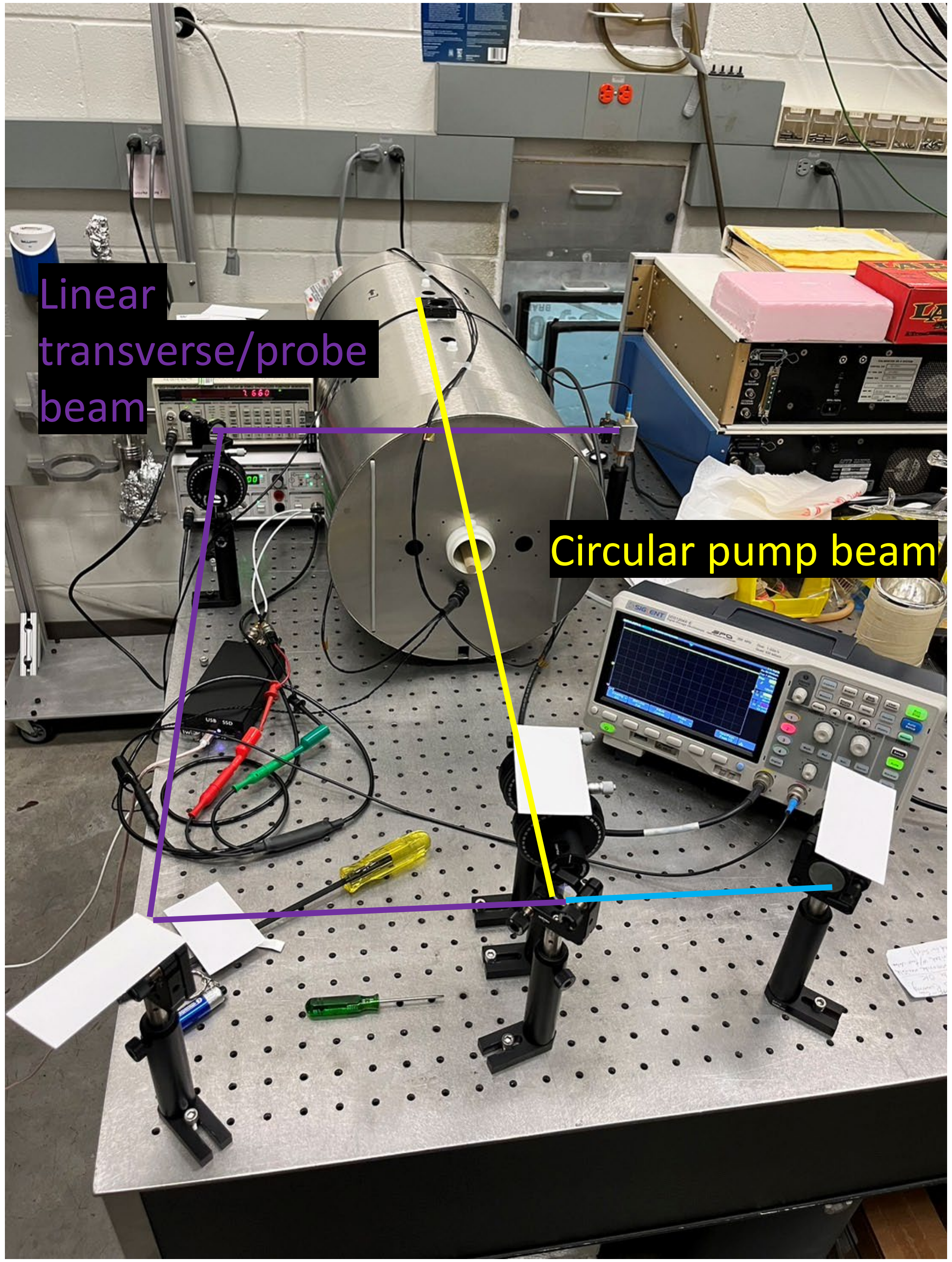


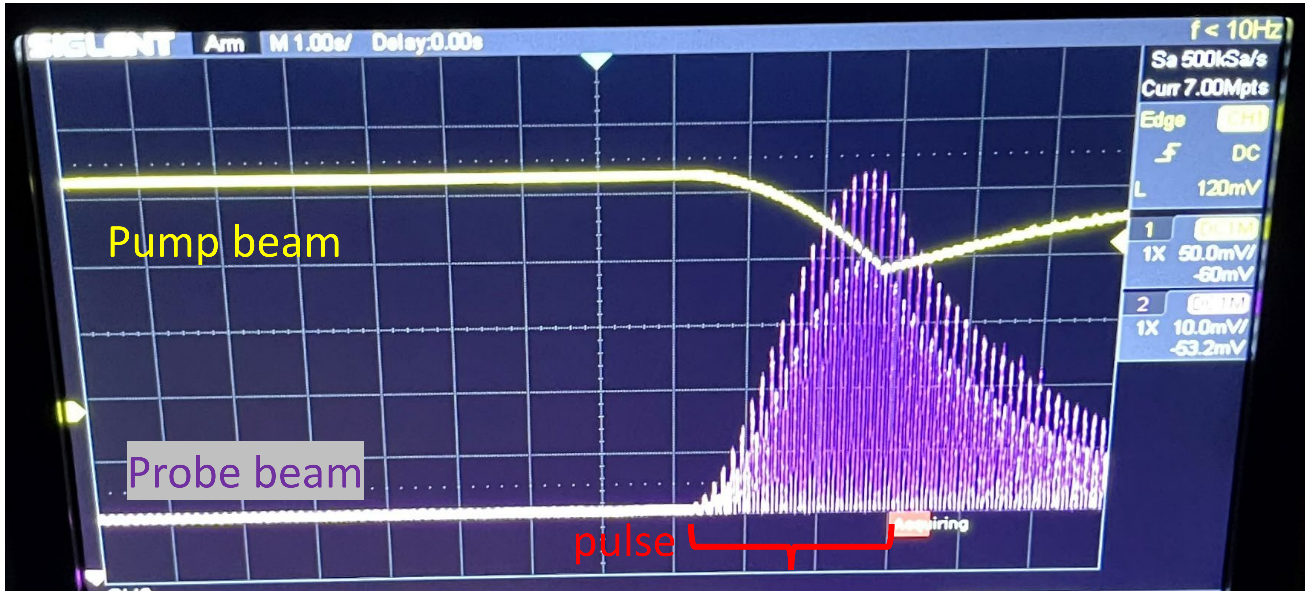


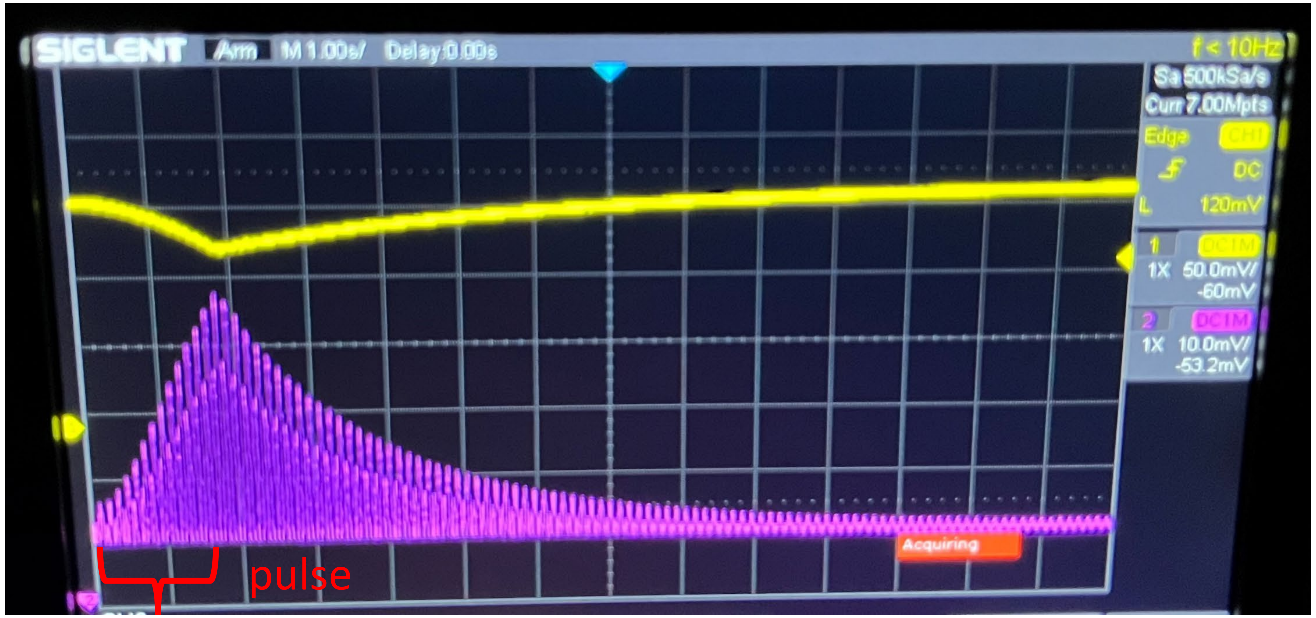
Baker et al doi:10.1016/j.nima.2013.10.005


IR
Green
UV
wavemeter


Top view
H1 (.2uT; ω; pulse)
H0 (1uT)
Mirror
To Scope
Seattle's Hg
vapor cell
Lens
λ/4
Linear Polarizer
254 nm laser
Mirror
Beam Splitter


Linear
transverse/probe
beam
Circular pump beam





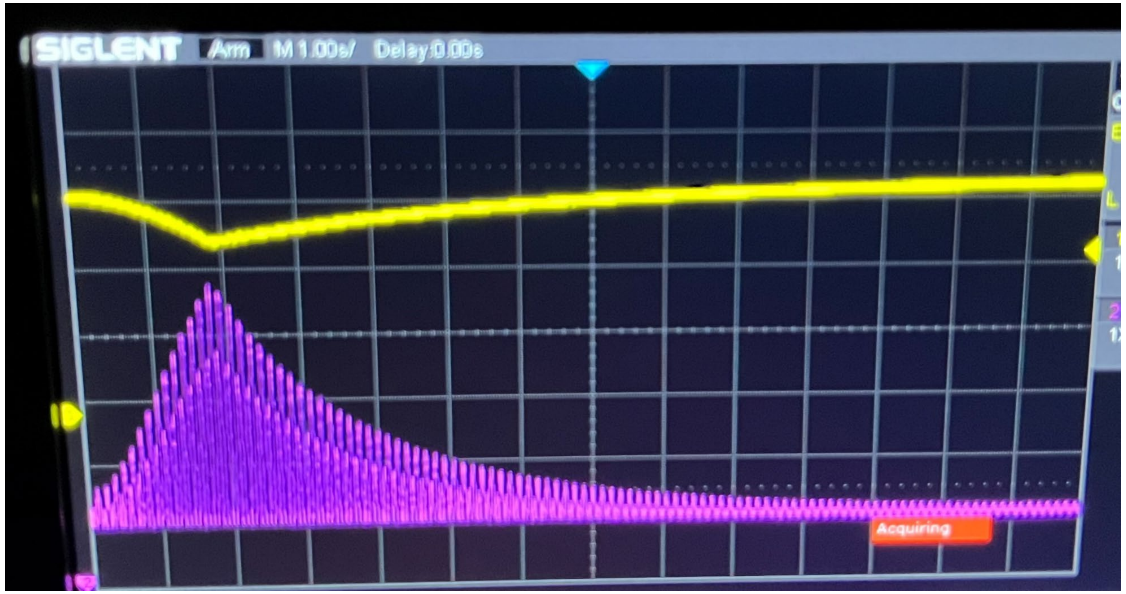
Observation on the spin tilting

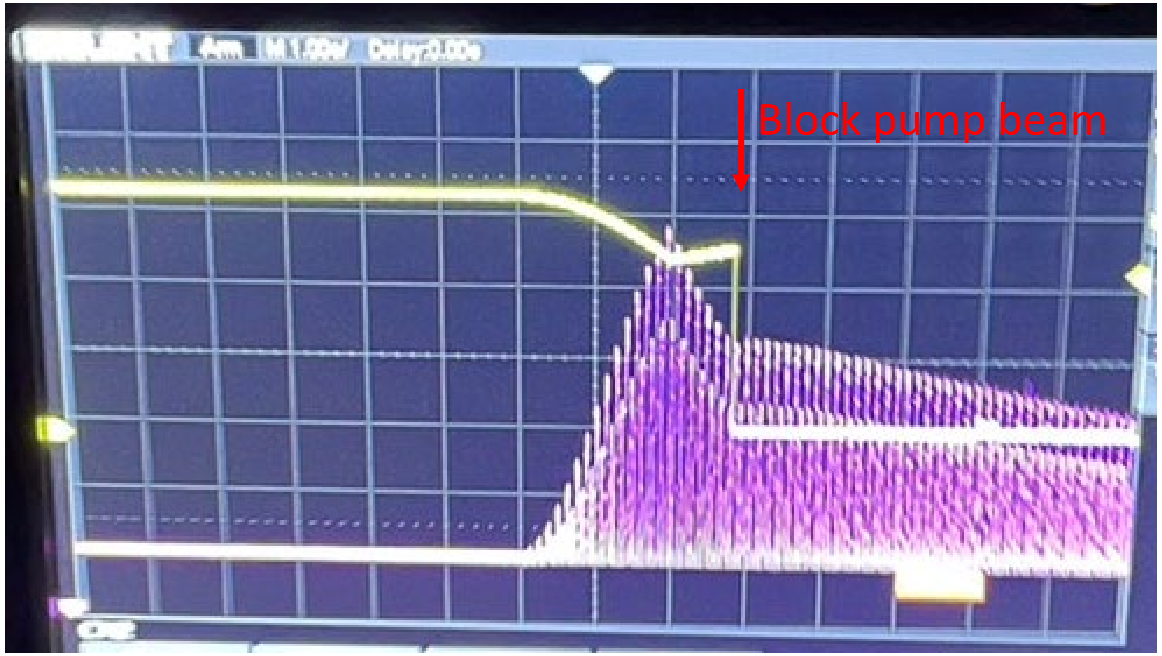
- Both pump and probe laser beams are at resonance frequency and circularly-polarized.

- Almost a $\frac{\pi}{2}$ pulse (top)
  - Pump beam's transmission drops a lot
  - The precession signal is larger due to the almost-$\frac{\pi}{2}$ tilt angle

- A short pulse (bottom)
  - the spin polarization is recovering after the pulse (yellow)

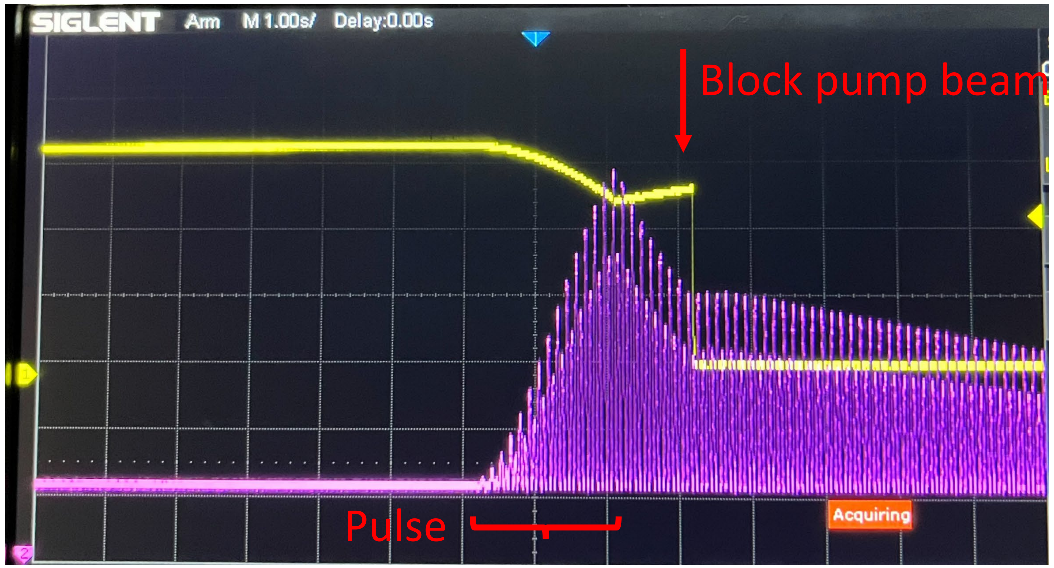
- lesson:
  - Timing the pulse to be $\frac{\pi}{2}$ to maximize the precession amplitude

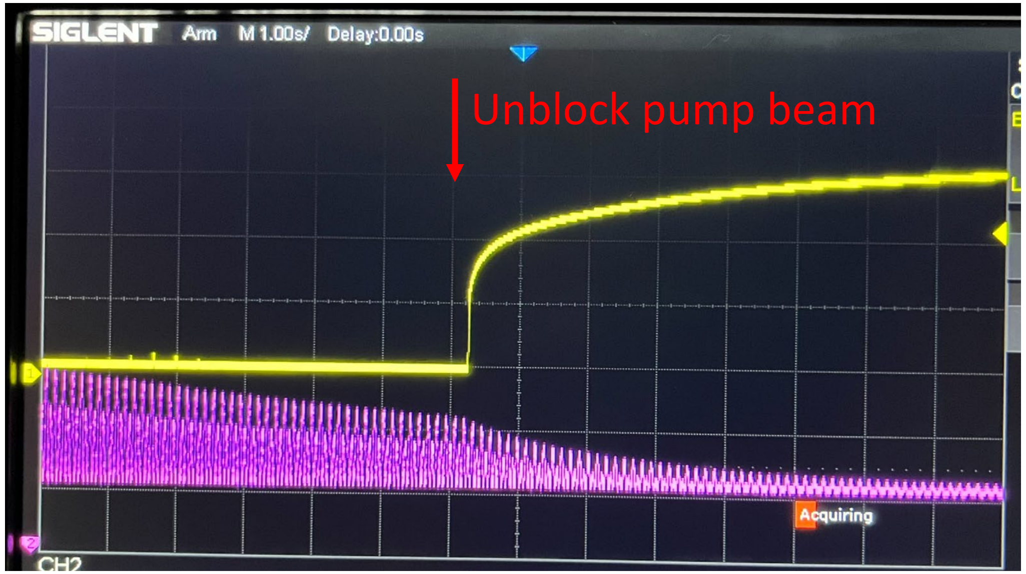




- The coherence time is shorter with pump beam on than with pump beam off

- lesson:
  - Blocking the pump beam while probing to maximize the precession amplitude and T2





(Above)

- T2 with/without the pump beam
- Pumping back the spin polarization quickly after unblocking the pump beam

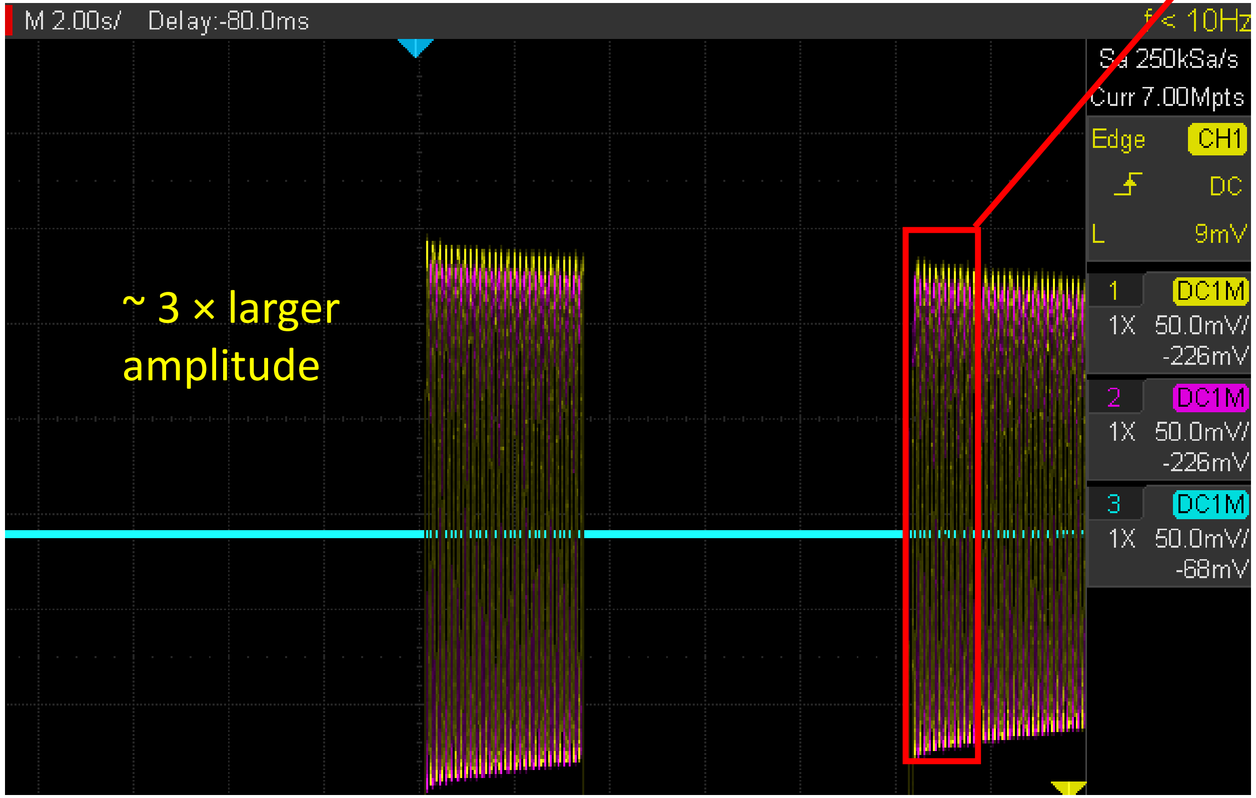
(Left)

- A long pulse with a smaller amplitude: the spin is tilting slowly and pass 90 degree

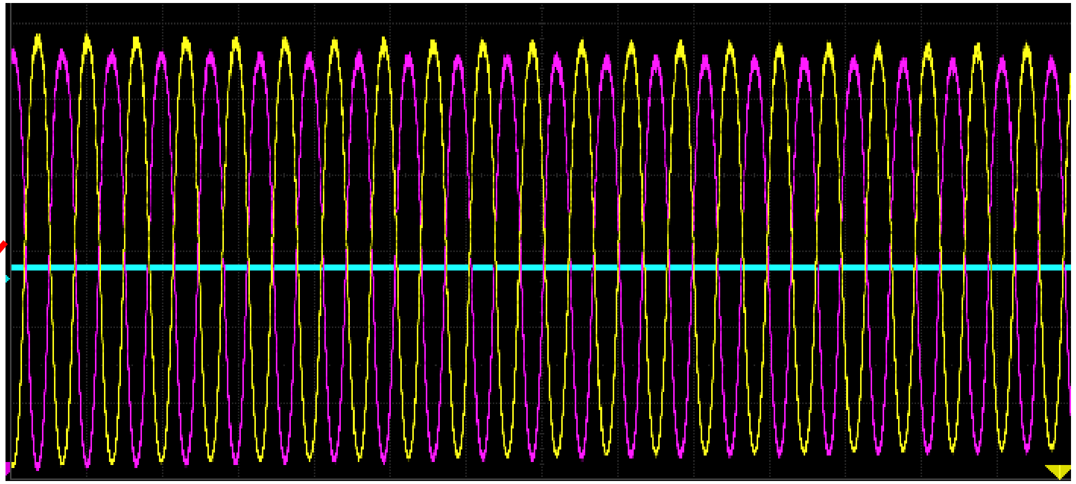
- lesson:
  - The tilt angle depends on the pulse duration and the amplitude of the pulse.

Precession signal with off-resonance probe

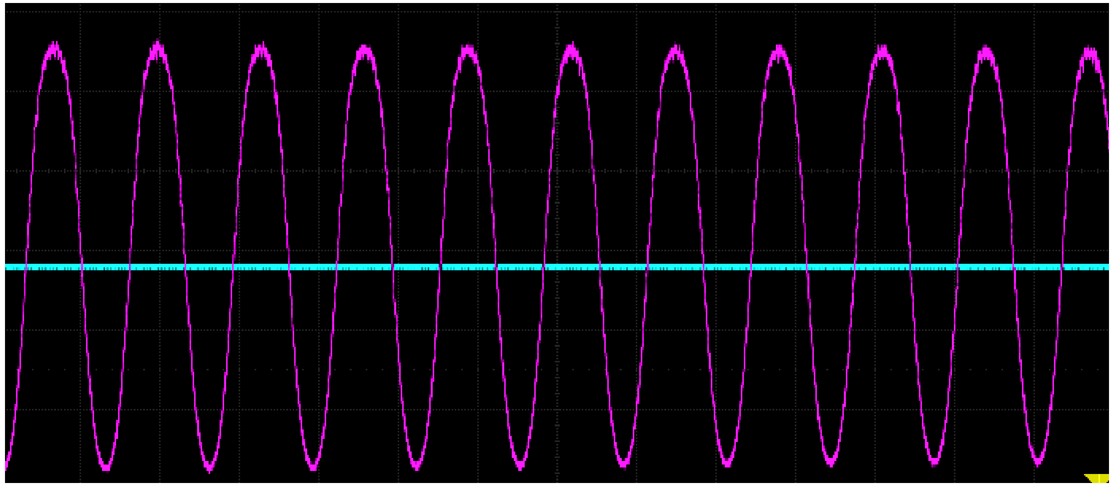
- Probing with linearly polarized light and away from the resonance frequency
- The spin rotation angle is oscillating at larmor frequency
- Signals of σ_+ and σ_-



Precession signal from two photodiodes (zoom in)



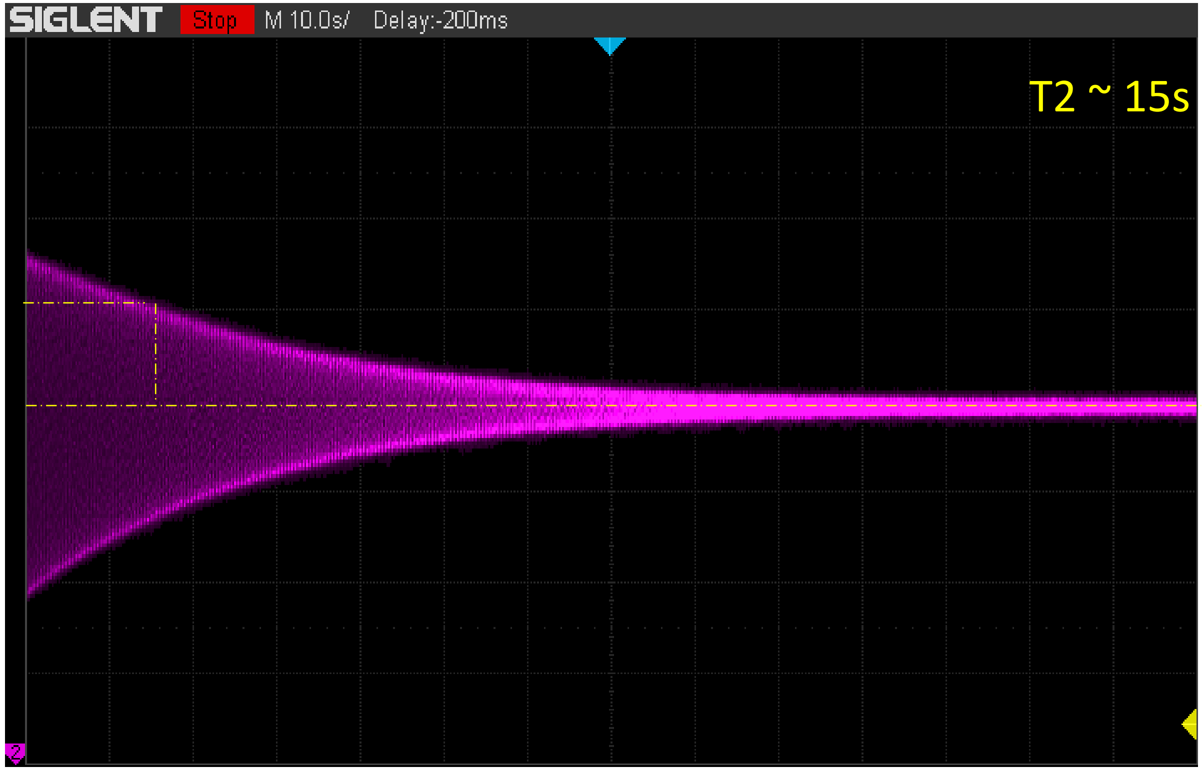
Precession signal from one photodiode (zoom in more)



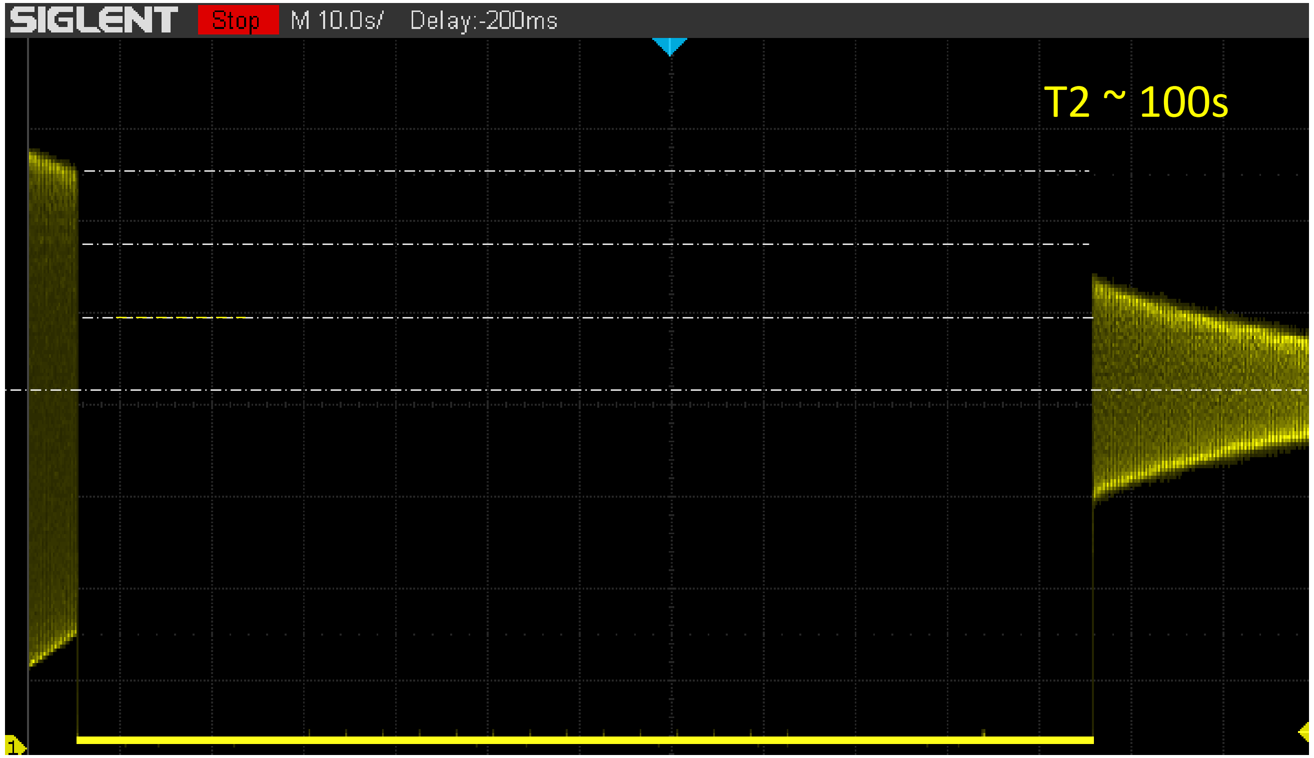
- Optimization: off-resonance probe freq, block pump/probe during the pulse, timing the pulse, probing with no pump beam, split sigma +/-
- Future optimization: weak probe intensity, field gradient, maybe probe freq

T2 in dark/light

A long probe: decaying sine wave

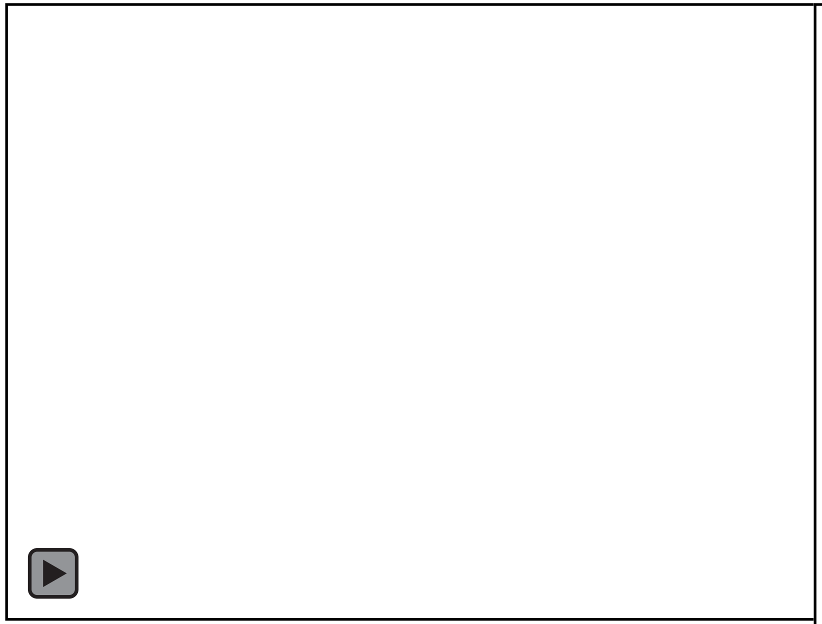


Two probes with longer T2 time

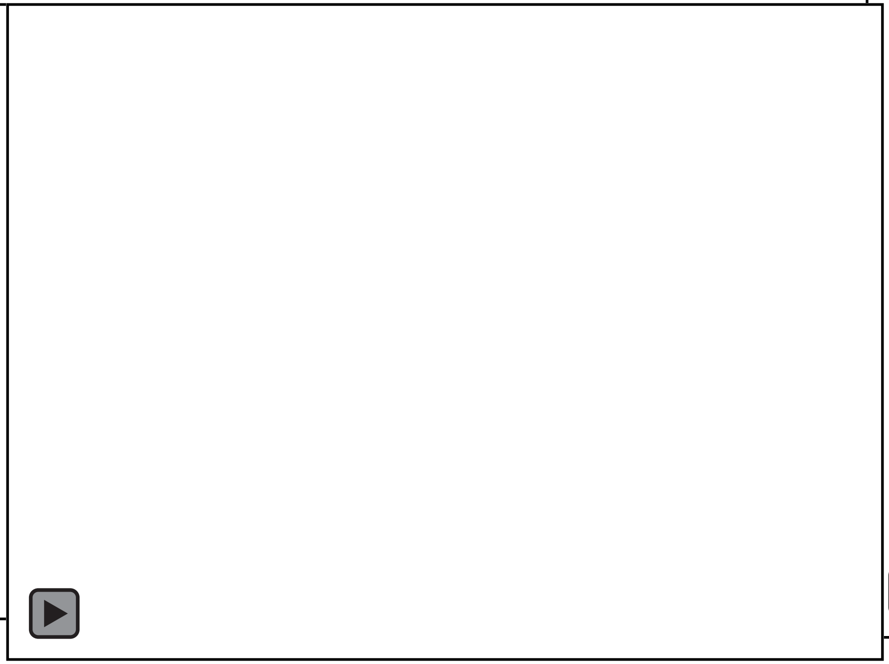


Spin tilting with a transverse pulse at on/off resonance

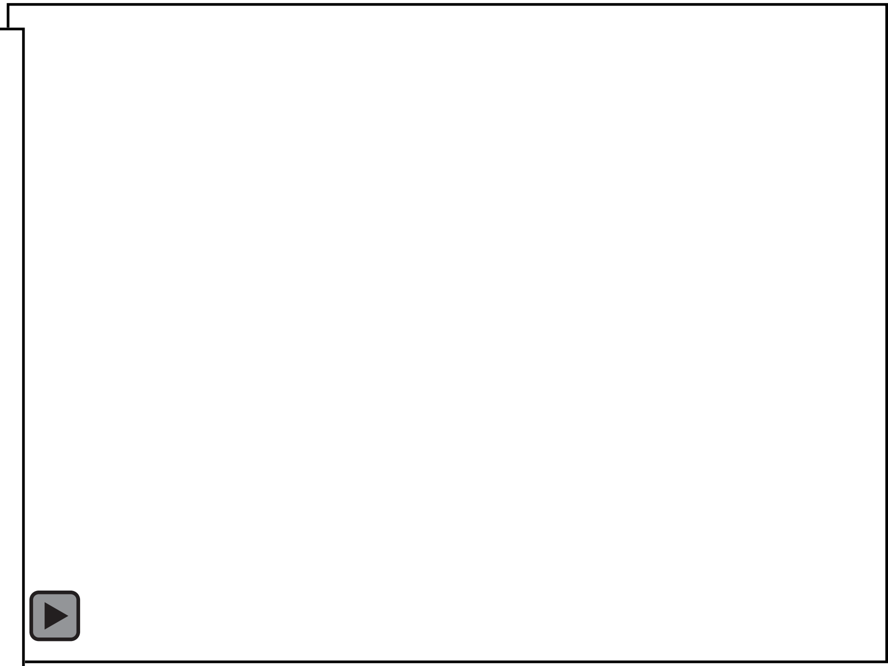
Off-resonance



On-resonance

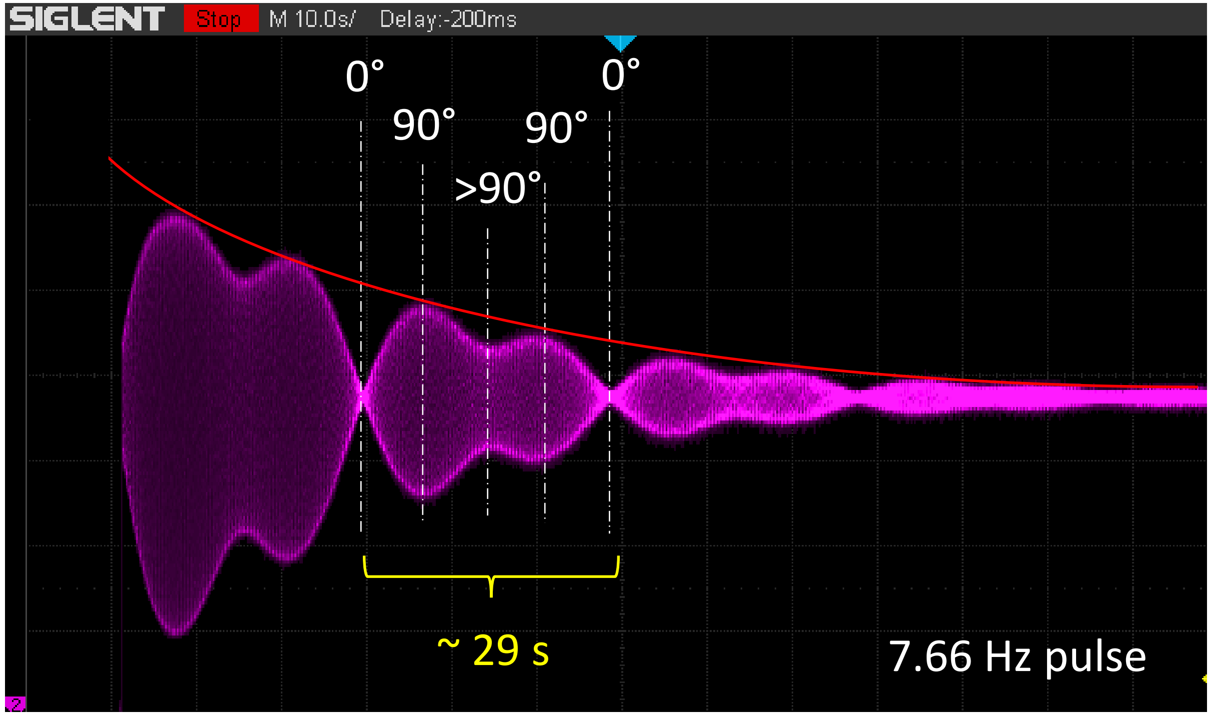


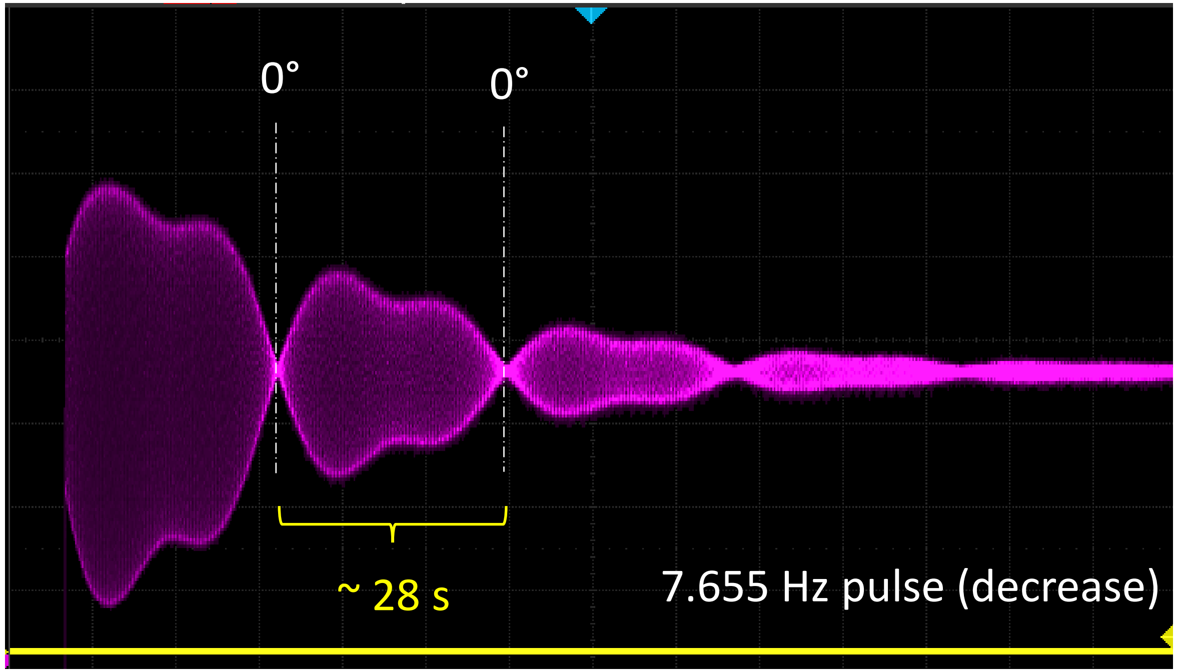
Also off-resonance

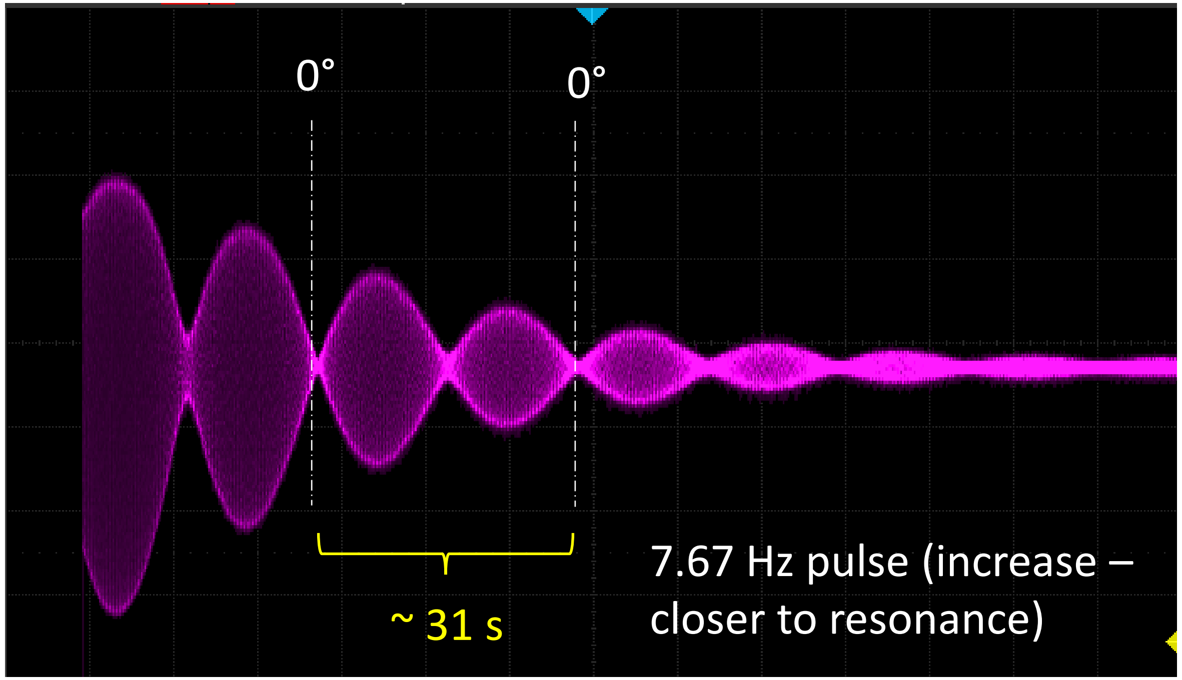


Observation of the spin tilting while precession along B_0

- when the pulse frequency ω_{pulse} does not match precession frequency ω_p
- Search for the precession frequency







Next steps

- Hardware and theory test
  - Task 1: Transverse pump + chopper
  - Task 2: Longitude/Transverse pump with LANL external test cell
  - Ultimate: Field mapping to see the correlation bt field gradients and Hg T2 time
- Co-mag prototype:
  - Finish up fabrication:
    - Coat the Al tubes and VCR copper gaskets with Teflon lubricating spray
    - Place fused silica windows on the large cell
  - Transport Hg from HgO to the large cell
    - Without glass wall coating
    - Study wall coatings

The collaboration of nEDM@LANL

- Los Alamos National Laboratory
  - Takeyasu Ito
  - Christopher O'Shaughnessy
  - Steven Clayton
  - Mark Makela
  - Lilian Lommel
  - Wade Uhrich
  - T. J. Schaub
  - Christopher Morris
  - Christopher Cude-Woods
  - Tom Bowles
- University of Illinois Urbana-Champaign
  - Chen-Yu Liu
  - Jennie (Yi) Chen
  - Douglas Wong
- University of Kentucky
  - Bradley Plaster
  - Alec Tewsley-Booth
  - Piya Amara Palamure
  - Dillon Buskirk
  - Rajan Bhattarai
  - Richard McDonald
  - Prakash Adhikari
- University of Michigan
  - Tim Chupp
  - Felicity B. Hills
  - Timothy Fanning
  - Aidan Meador-Woodruff
- East Tennessee State University
  - Robert Pattie
- Indiana University
  - Gerard Visser
  - Mark Luxnat
- Tennessee Tech University
  - Adam Holley
  - Austin Reid
- University of Washington
  - Blayne Heckel
- Yale University
  - Steve Lamoreaux

This work was supported by Los Alamos National Laboratory LDRD and the National Science Foundation, grants PHY-1828512 and PHY-1614545.

Thank you!!

yic@illinois.edu