Status of Target Testing

Mingyu Chen

University of Virginia

July 24, 2019

Outline:

1. PNMR with Lockin and DAQ
2. Masing effect and Gradient Coil
3. EPR/NMR Calibration
4. Characterization of Cell “Savior”
5. Convection Speed Test
6. Target Lab Remaining Work

Current Status

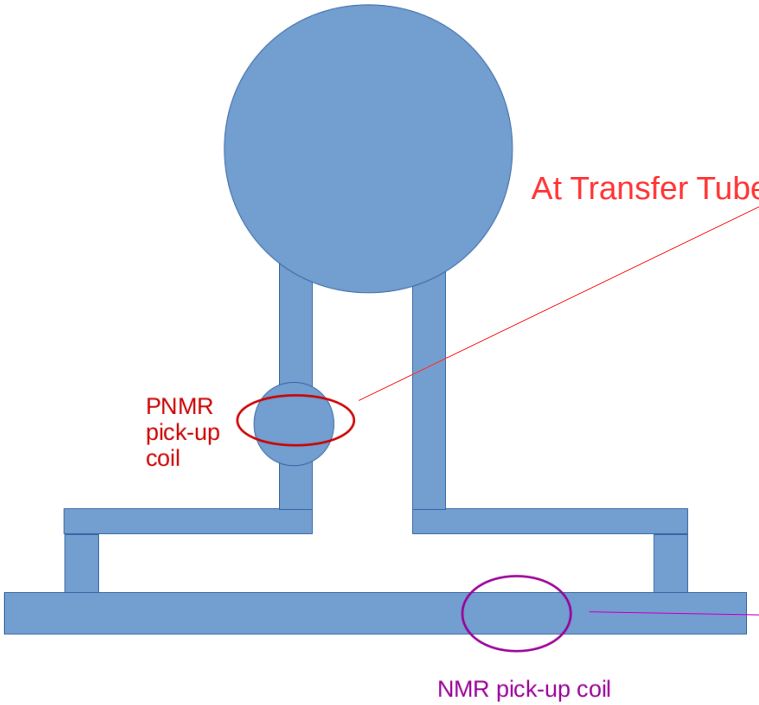
Completed Tasks:

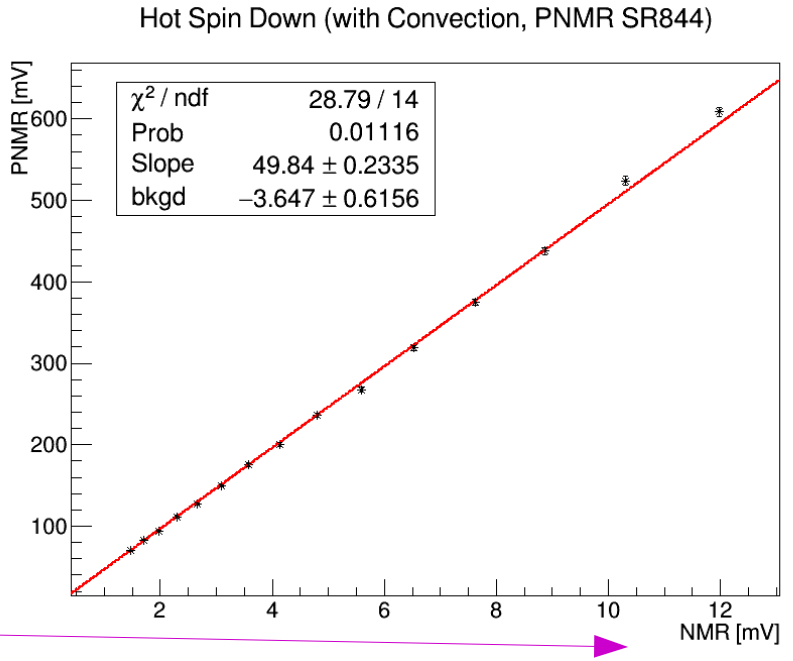
- PNMR with Lockin and DAQ
- EPR system upgrade with D2 light collection optics
- Characterize Cell “Savior”

Manpower:

- PhD students: Junhao Chen (W&M, Todd Averett), Mingyu Chen (UVA, Xiaochao Zheng), and Melanie Rehfuss (Temple, Zein-Eddine Meziani)
- Murchhana Roy (U. of Kentucky, Wolfgang Korsch) on-site in July
- Engineers/Designer: Bert Metzger
- Supervisor/Coordinator: Jian-Ping Chen

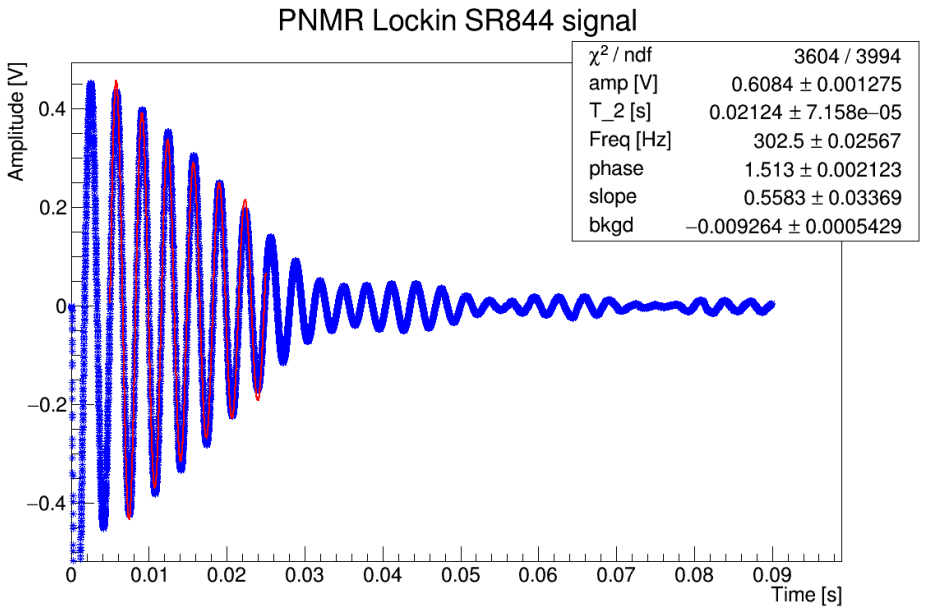
PNMR with Lockin and DAQ
(Cell “Protovec-I”)





Upgrade with Lockin and DAQ:

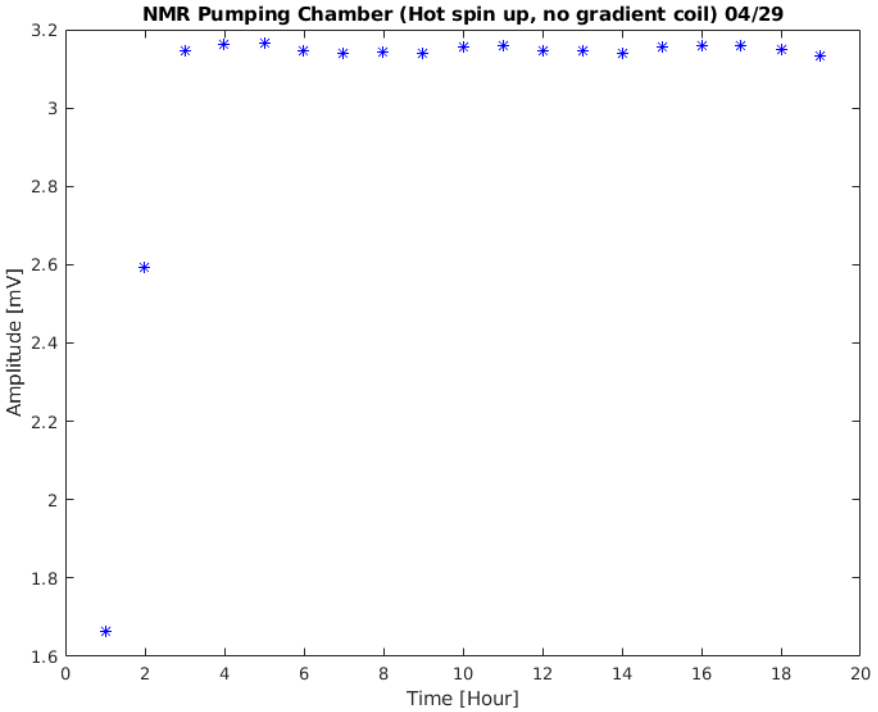
- Smaller resolution uncertainty (16 bit);
- Automatically adjust vertical scale (better performance when FID signal become smaller)

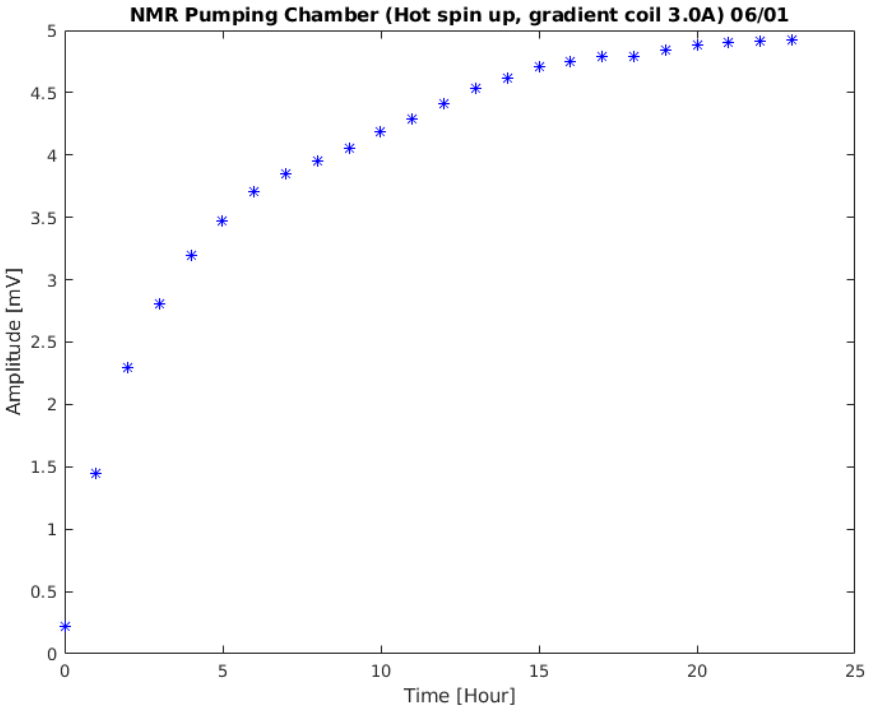


- Hot (oven temperature ~211 °C) spin down measurements (every hour). With convection.
- Calibrate PNMR with NMR with linear fit.

Masing Effect and Gradient Coil

(Cell “Savior”)





Field gradient ~2.7 mG/cm, Masing threshold for NMR amp ~3.1 mV.

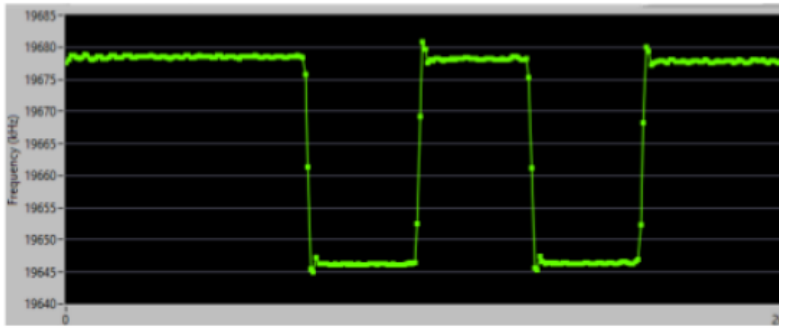
With gradient coil at 3.0A, field gradient is ~19 mG/cm, the threshold increased to ~4.9 mV.

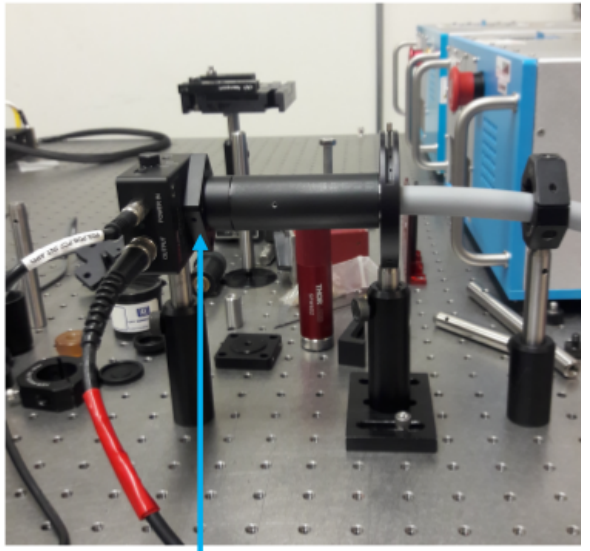
- Non-linear polarization loss (not AFP loss, not relaxation).
- Principle: coupling of transverse component of ^{3}He spin with NMR pick-up coil. Induced transverse magnetic field will tip away ^{3}He spin from the main field.
- Fix: add a gradient coil along direction of main holding field. So far gradient coil at 3.0 A has greatest increase on masing threshold.

EPR/NMR Calibration

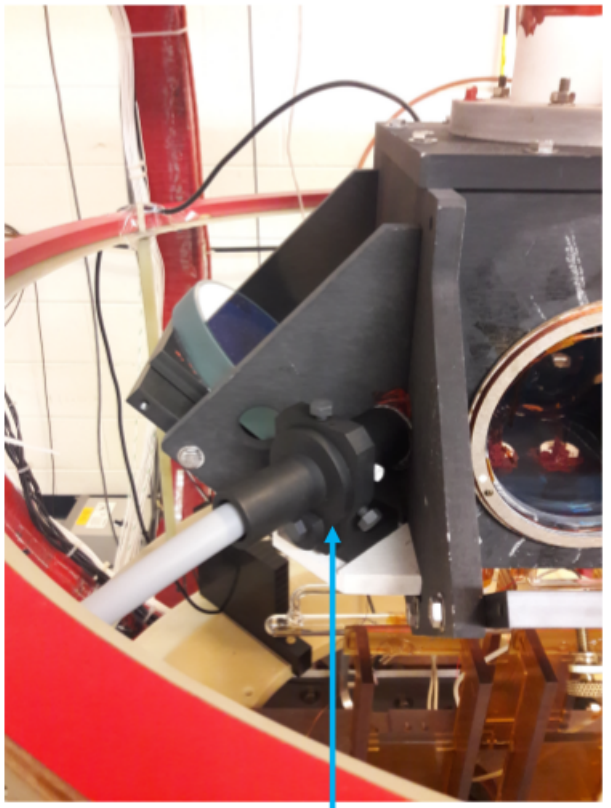
(by Melanie Rehfuss)

- ✓ EPR Upgrade (Raytum D2 Fiber Bundle + Thorlabs Avalanche Photodiode) completed with needed 3% precision
  - Needed to protect photodiode from radiation damage





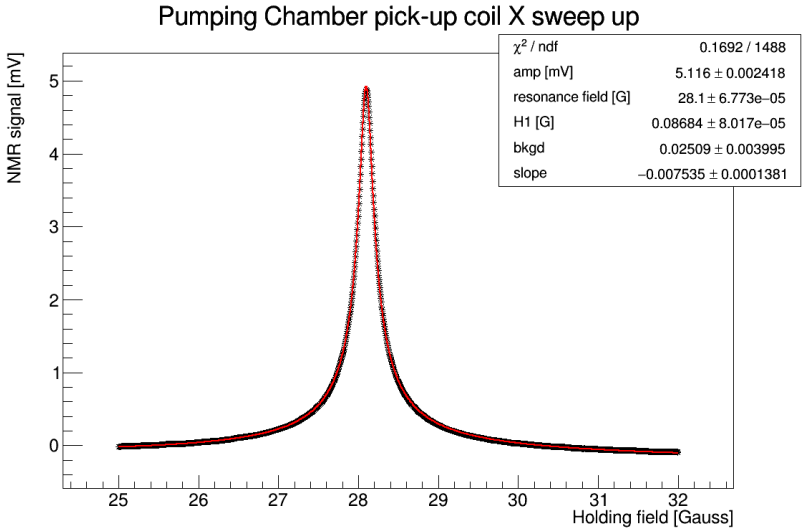
D2 light carried away with fiber (~ 4 meters) to APD

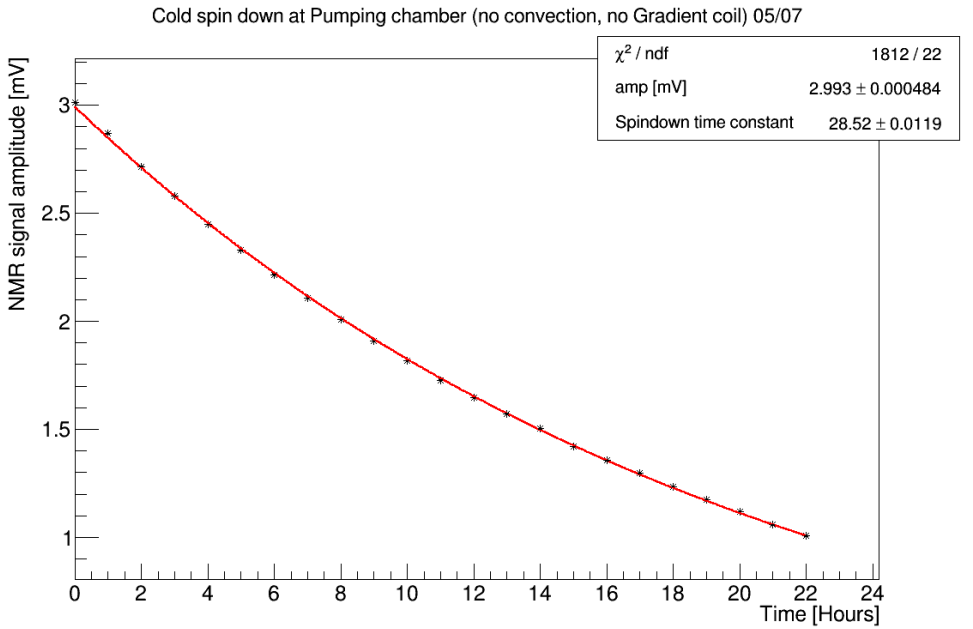


D2 fluorescence detected close to oven

SEOP Laser Helicity	C±ΔC (mV/kHz)	C±ΔC (%/mV)	EPR-AFP loss per sweep (%)
Left	0.083±0.001	7.117±0.079	1.05
Right	0.133±0.004	7.020±0.220	1.05

Characterization of Cell “Savior”





Maximum Polarization:

- Masing effect only occur when 3He in high energy Zeeman state.
- Using left circularly polarized Laser, with current holding field direction, ^{3}He will be polarized in low energy Zeeman state.
- Then the first NMR AFP measurement after ~20 hr SEOP with ~91 W laser power will give Maximum ^{3}He polarization in PC ~40%. (by EPR/NMR calibration)

  Note: During NMR AFP sweep, the ^{3}He spin will change direction and cause Masing effect.

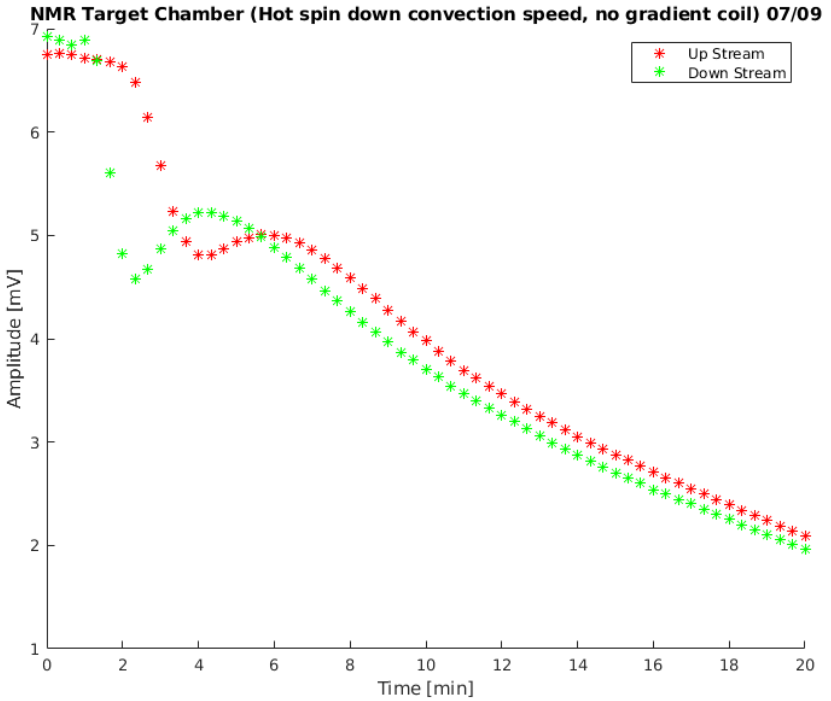
Cell Lifetime:

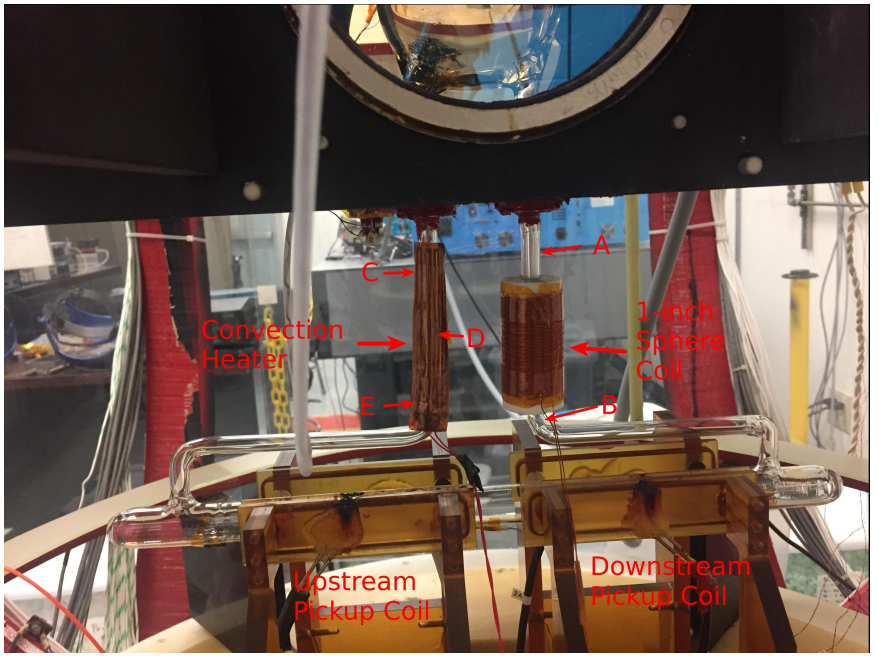
- With AFP loss correction, Savior lifetime measured to be ~28 hours at PC.

Life Time	PC (hr)	TC Upstream (hr)	TC Downstream (hr)
Cold without Convection	28.52	22.17	22.38
AFP Loss	**PC (%)**	**TC Upstream (%)**	**TC Downstream (%)**
Cold without Convection	0.72	0.12	0.13

Convection Speed Test

(Cell “Savior”)





- Need Convection to reduce the ^{3}He polarization gradient between PC and TC.
- Convection condition is established by adding a convection heater on one of the Transfer Tube.
- Heater power supply 11.0V, take NMR measurements every 20 sec. (Transfer tube temp gradient: A ~40 °C; C ~70 °C)
- Time difference between NMR amp dip is ~1.5 min, center of two pick up coil is apart by ~7.35 cm, then convection speed is ~4.9 cm/min.

  Note: Convection speed for “Protovec-1 ” is ~5.7 cm/min.

Target Lab Remaining Work

Polarimetry:

- Complete water cell calibration
- Characterize Cell “Fulla”

Equipment:

- Test 4-1 fiber coupling
- Complete ordering/making required cables

Software:

- Laser control system
- Epics implementation

Backup Slides

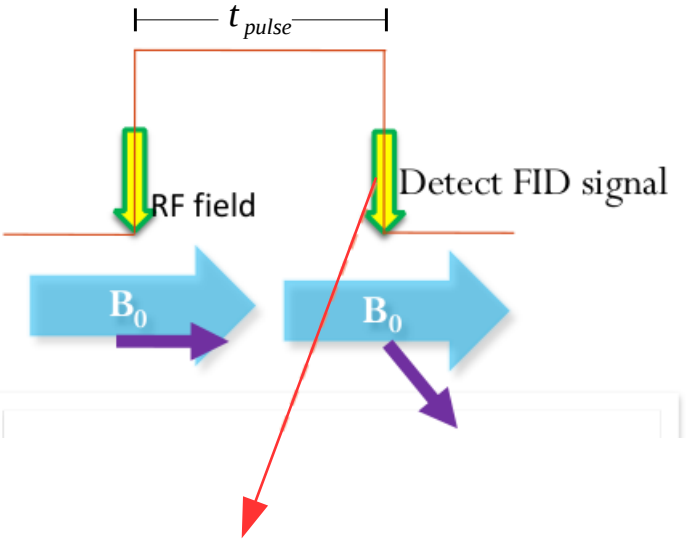
Pulse NMR Polarimetry

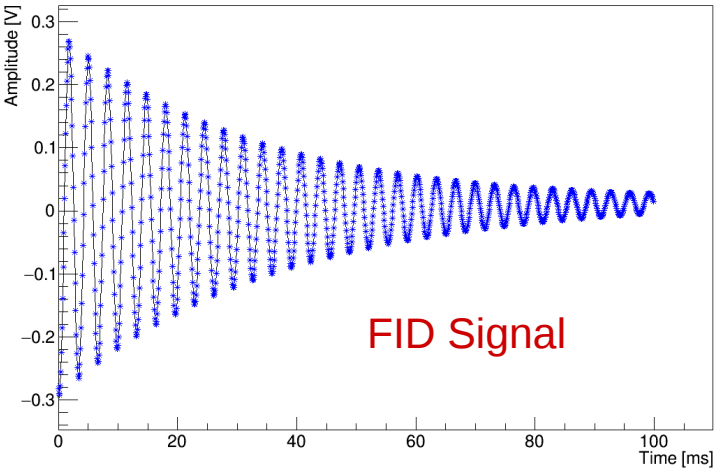
Advantage:

- Took shorter time to complete measurement, less depolarization compare to AFP-NMR.
- For future metallic end cells, provide local polarimetry at transfer tube.

Principle:

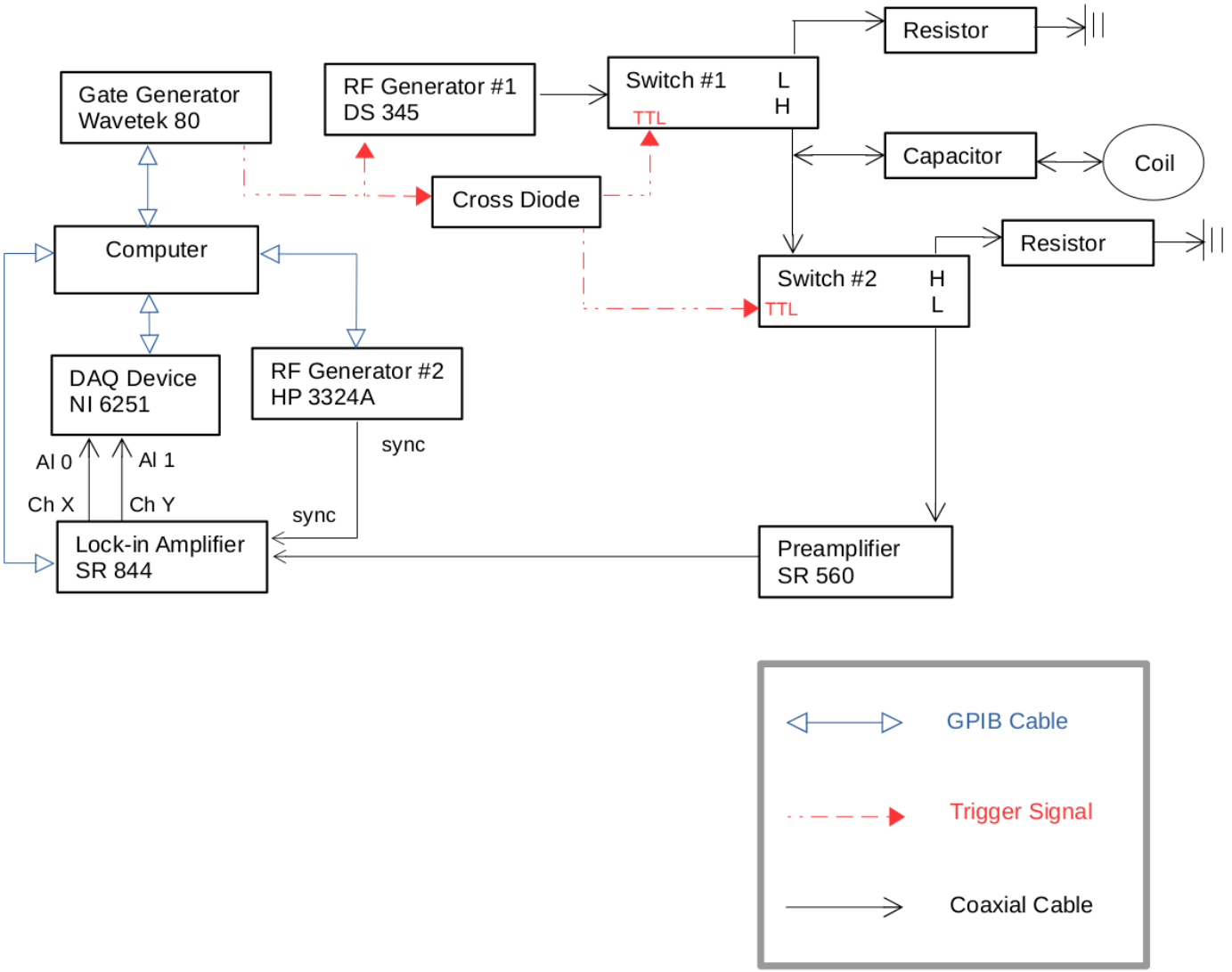
- Send a RF pulse at Larmor frequency which tips ^{3}He spin away from holding field axis: $\theta_{tip} = \frac{1}{2}\gamma H_1 t_{pulse}$
- When pulse ends, the spin precesses back to its initial state and experience free induction decay (FID).
- FID signal is picked up by the PNMR coil. Measure the transverse component of magnetic moment proportional to ^{3}He polarization.





$$S(t) \propto M_z \sin(\theta_{tip}) \cos(\omega t + \phi_0) e^{-t/T_2}$$

PNMR with Lockin SR844 and DAQ Setup



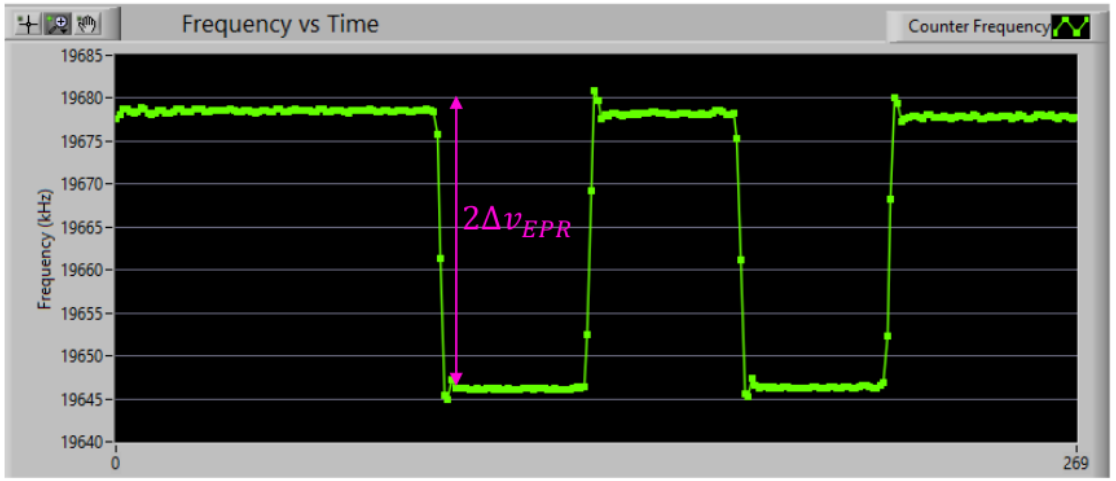
EPR Measurement

(by Melanie Rehfuss)

EPR Measurements of *Savior* (@ 91W laser power – 800 um fibers)

- 2 dBm RF Amplitude, 80% RF Gain, M = 50 APD Gain, 5 mV sensitivity, 200 ms time constant
- Laser helicity switched to **left-circularly** polarized (ν_{EPR} ~ 19 MHz) → low energy state
- Pumping Chamber max amplitude ~ -5.1 mV

^{39}K: (F=2, m_F = -2) ⟶ (F=2, m_F = -1), I = 3/2



$$2\Delta\nu_{EPR} = 2 * \frac{2\mu_0}{3}\frac{d\nu_{EPR}(F,m_F)}{dB}\kappa_0\mu_{^3He}[n_{3He}]P_{^3He}$$

$$\kappa_0^{39K}(T_{PC} = 256.0 \pm 4.0\ ^\circ\text{C}) = 6.47 \pm 0.16$$

n_{PC} = 6.115 amg (using n_0 = 7.263 amg)

$2\Delta\nu_{EPR}$ ~ 32.5 kHz
ν_1 ~ 19678.5 kHz
ν_2 ~ 19646 kHz
ν_{EPR} ~ 19662.250 kHz

- Polarization = **19.3 ± 0. 5% @ PC NMR: -2.6 mV**
- C = 7.4 ± 0.2 % / mV → **37.9% @ -5.1 mV** (max polarization)
- (or C = 0.08 mV/kHz)

- **B(ν_{EPR})** = B(19662.250 kHz) = **24.99657 G**
- $\frac{d\nu_{EPR}(F,m_F)}{dB(\nu_{EPR})}$ = 877.79656 kHz/G