Polarized ^{3}He Target for JLab 12 GeV Era

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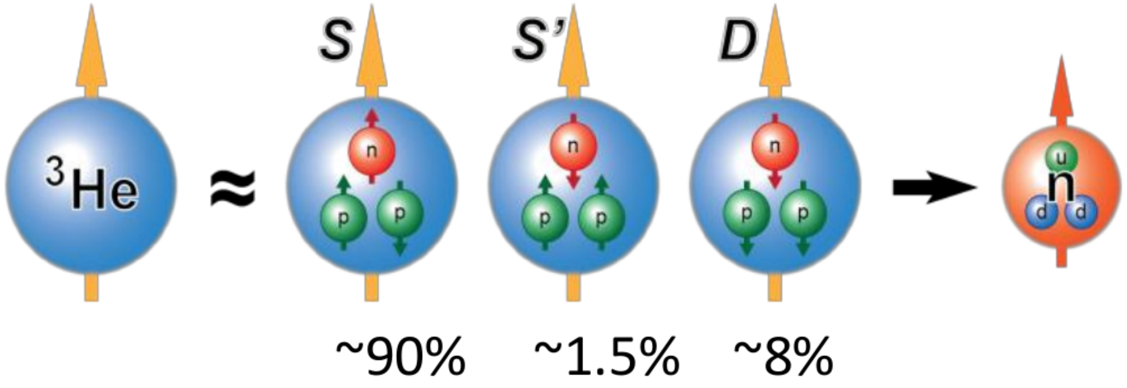
Outline:

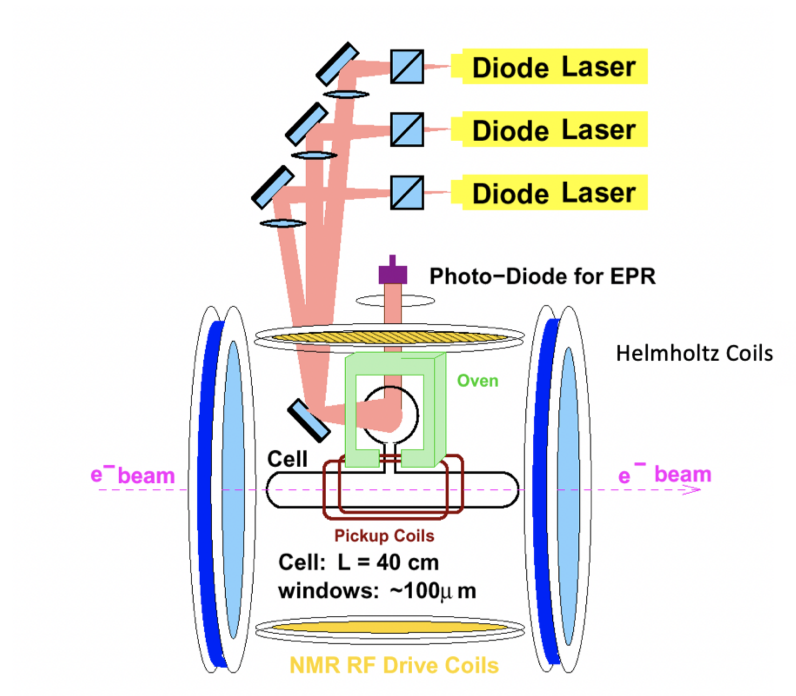
1. Introduction to ^{3}He Polarization
2. Target Cell Upgrade for 12 GeV Era
3. Typical Production Cell Performance
4. Summary

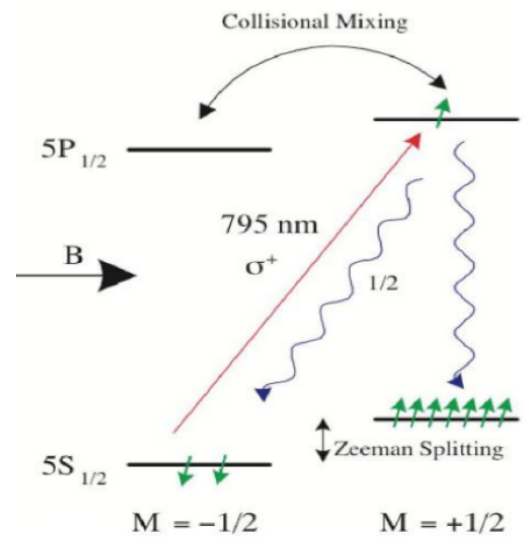
Introduction to ^{3}He Polarization



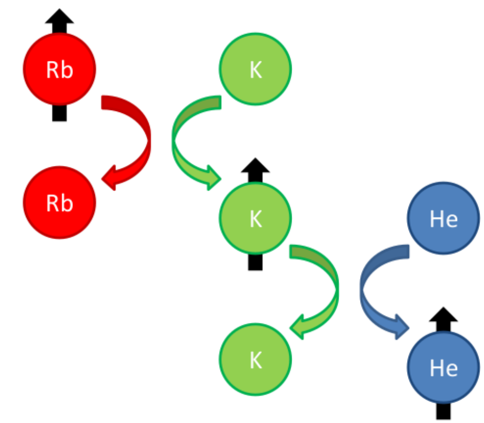
- Polarized target for study the spin structure of nucleon.
- Free neutron mean lifetime: 880.2 s.
- The unpaired neutron carries the majority of the ^{3}He nucleus polarization.
- Polarized ^{3}He is a good effective polarized neutron target.

Spin Exchange Optical Pumping
(SEOP)





1. Optical Pumping



2. Spin Exchange

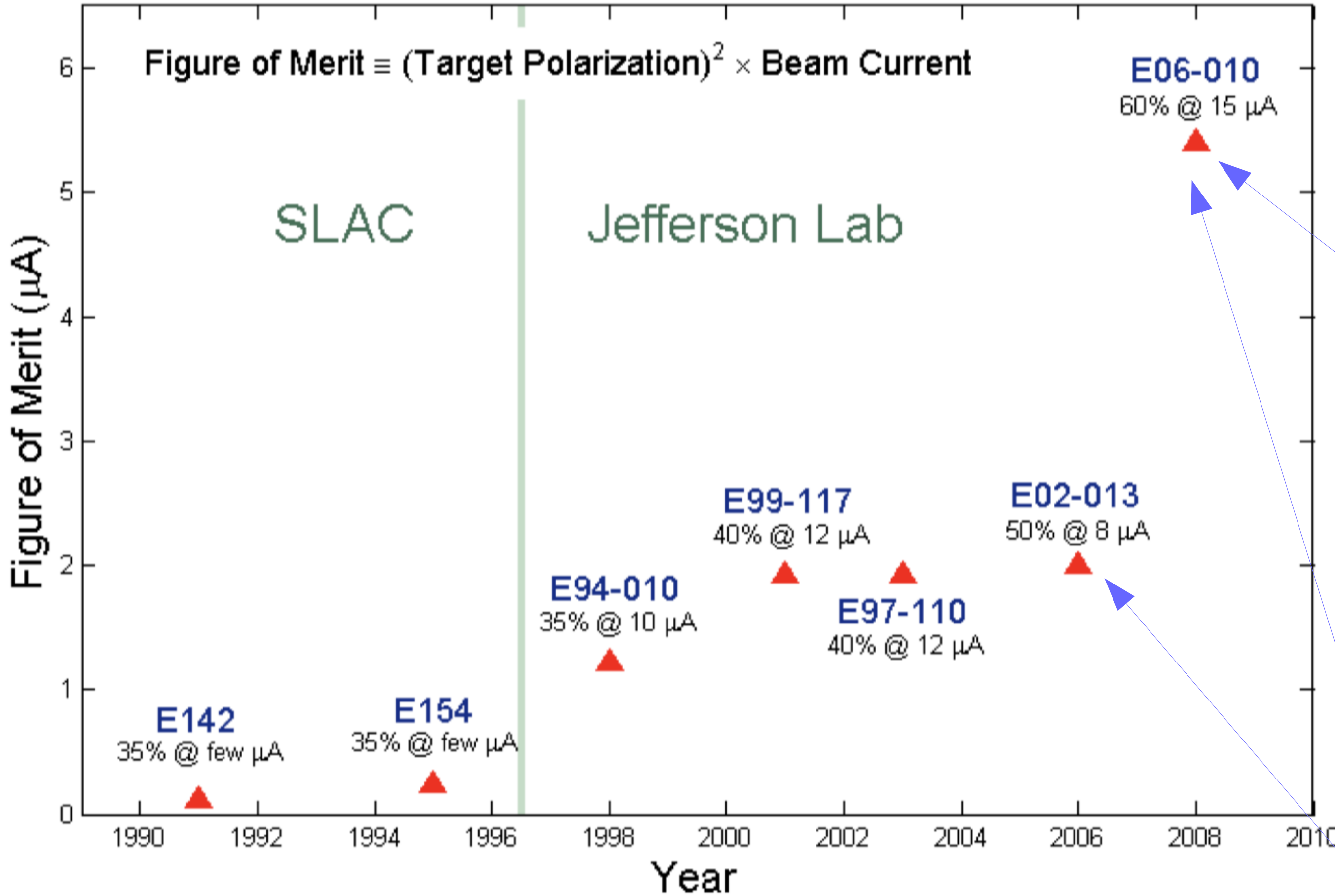
1. Optical Pumping

- With external B field, polarize the vaporized Rb atoms using circularly polarized laser.
- 795 nm D1 laser light excites electrons from $5S_{1/2}$ (M=-1/2) → $5P_{1/2}$ (M=1/2).
- Then electrons decay from excited state to ground states.
- Alkali atoms can reach ~95% polarization.

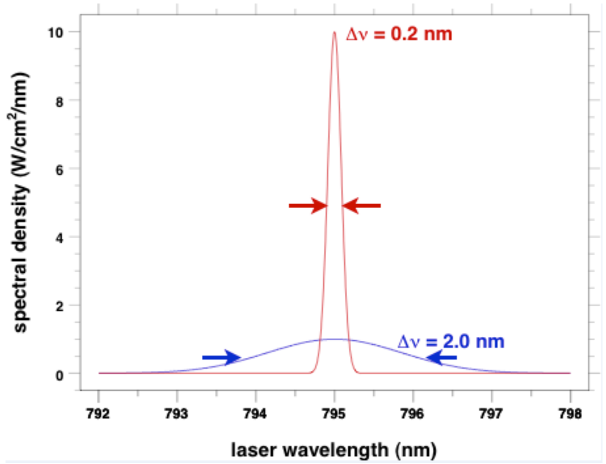
2. Spin Exchange

- Polarized Rb atoms transfer its polarization to ^{3}He nucleus.
- Use hybrid alkali with addition of K to increase the efficiency of spin exchange.
- Higher ^{3}He polarization ~80%.
- For our in-beam high pressure target at ~10 atm, depolarization effects reduce max polarization to 55-60%

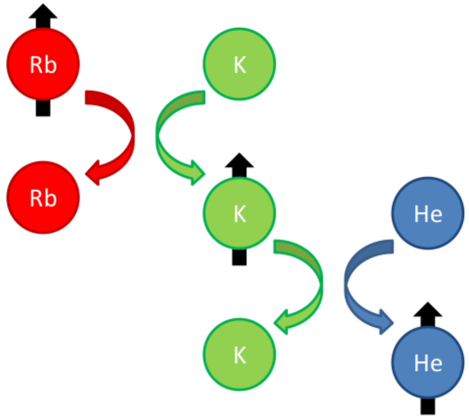
Polarized ^{3}He Targets for 6 GeV Experiments



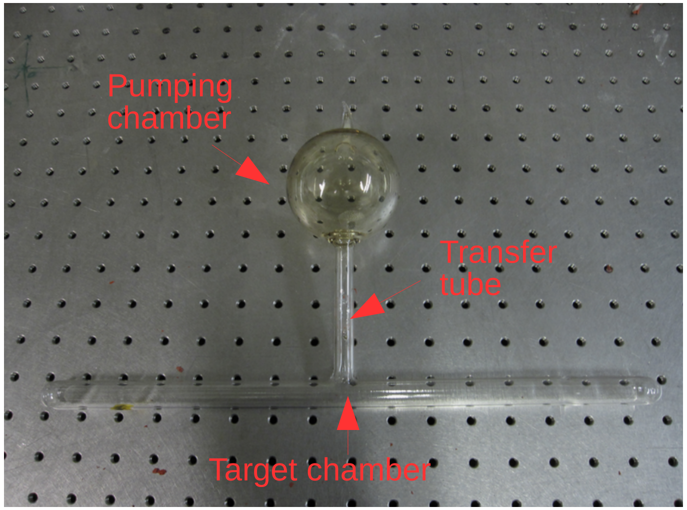
Transversity (E06-010):
Used narrow band laser.



G_E^n (E02-013):
Used Rb/K hybrid alkali cell.

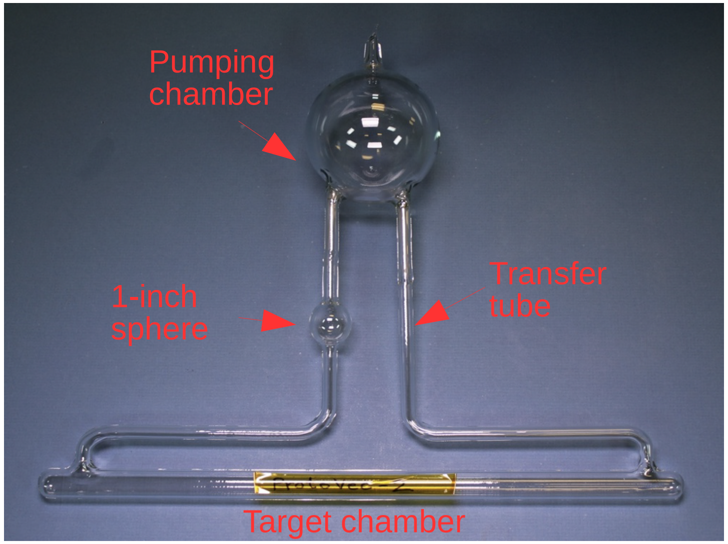


Upgrade of Polarized ^{3}He Target



Old JLab 6 GeV era target Cell:

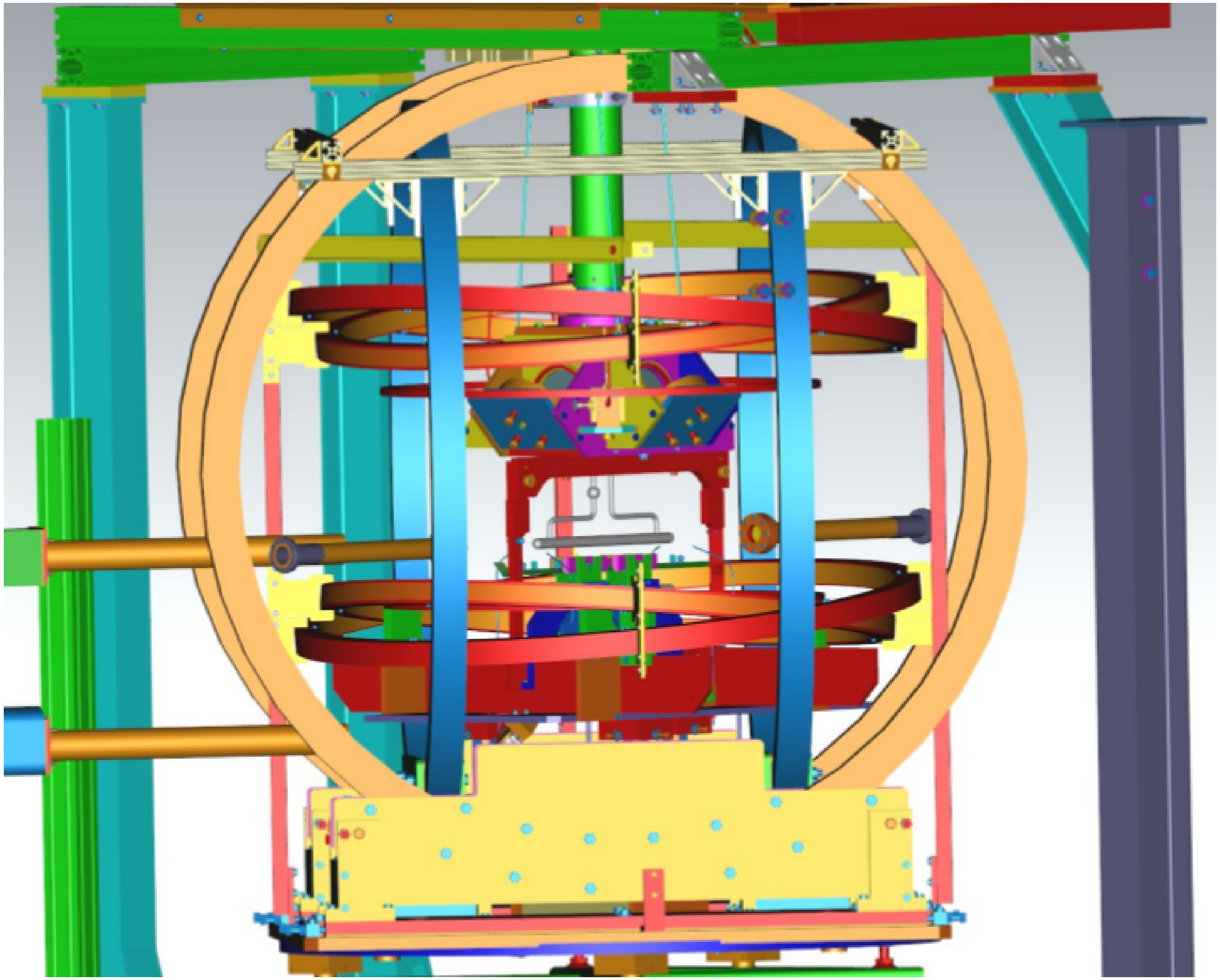
- Target chamber length: 40 cm
- Beam current: 15 uA
- High-density target: $10^{22}/cm^2$
- Luminosity: 10^{36} $cm^{-2}s^{-1}$ (world record)
- In beam polarization: 55-60%
- Diffusion cell
- Used for 13 completed JLab 6 GeV era experiments



Upgraded JLab 12 GeV era target cell:

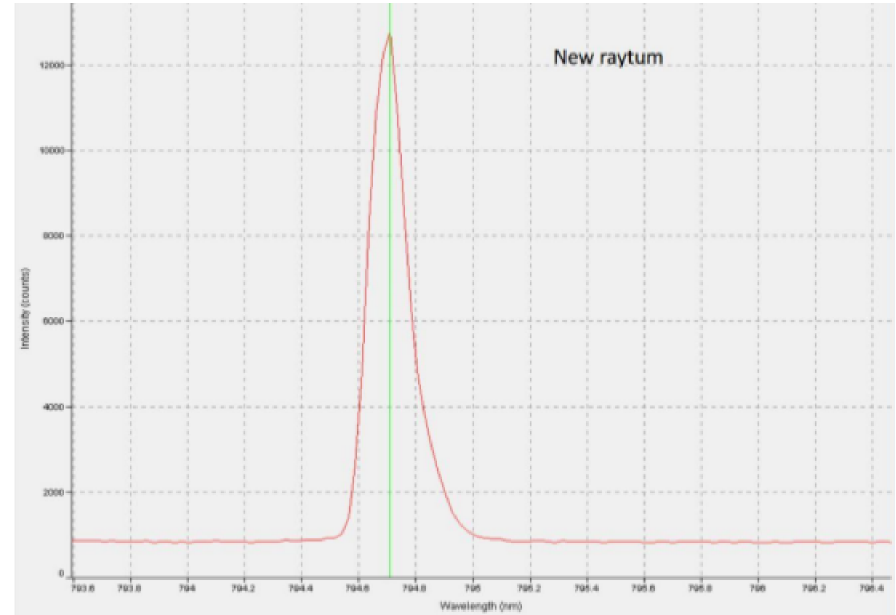
- Target chamber length: 40 cm
- Beam current: 30 uA
- High-density target: $10^{22}/cm^2$
- Luminosity: ~ 2.2×10^{36} $cm^{-2}s^{-1}$
- Expected in beam polarization: 55%
- Convection cell
- For upcoming A1n/d2n experiments which are the first of the 7 approved JLab 12 GeV ^{3}He polarized target experiments

Mechanical Design



- For upcoming A1n/d2n experiments (E12-06-110/E12-06-121) at Jefferson Lab Hall C which will begin in November, 2019.

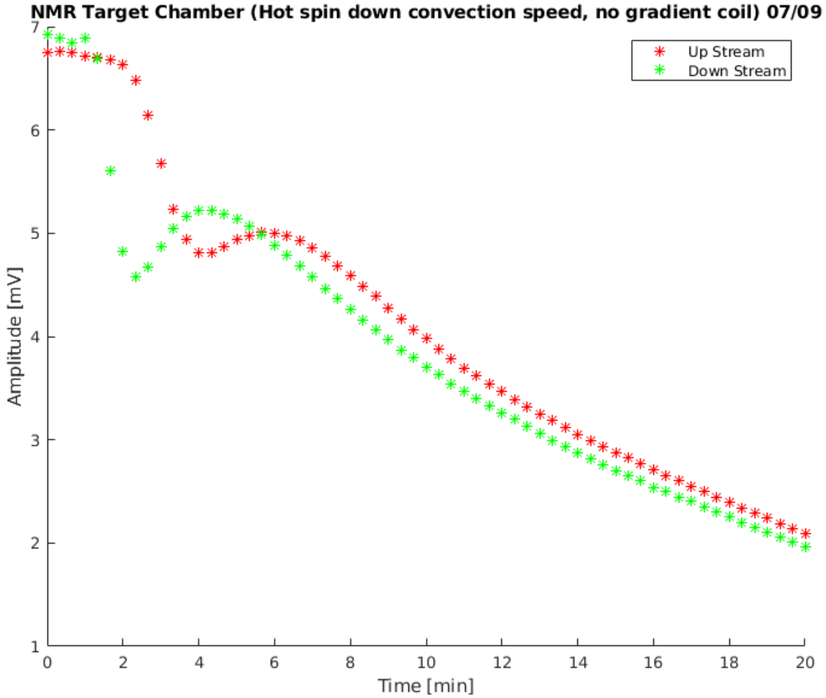
Lasers for SEOP

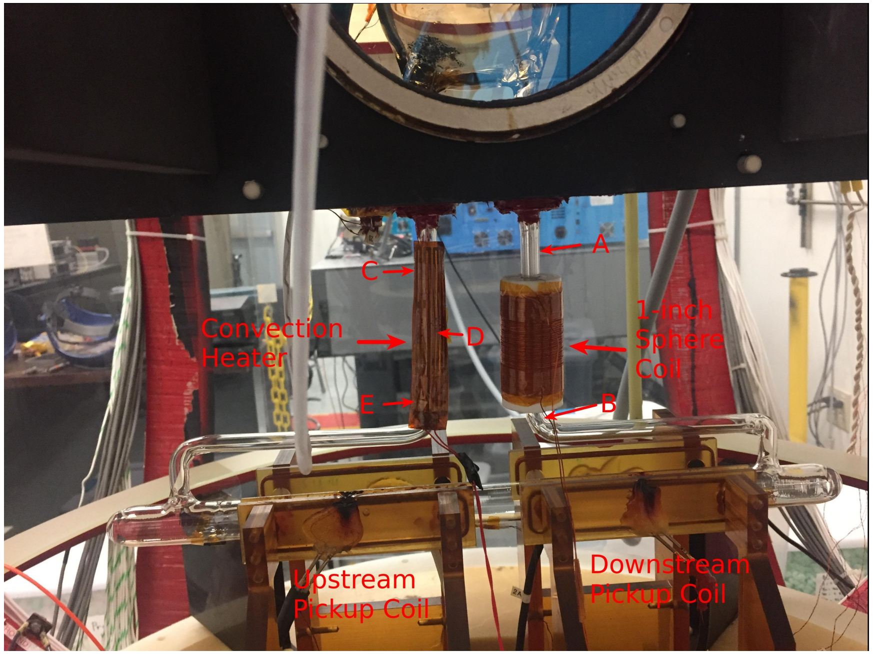


- Using Raytum high power laser at 30 W.

  (for laser room safety reasons; capable of providing max laser power output ~50 W)
- Wavelength at 794.7 nm, with width 0.2 - 0.3 nm.
- Combine the laser spots from three 30 W lasers into total of 90 W laser power to the pumping chamber.

Convection Speed Test





- Need convection to reduce the ^{3}He polarization gradient between pumping chamber and target chamber.

  (for diffusion cell, polarization gradient is 5% - 10%)

- Convection condition is established by adding a convection Kapton heater (polyimide film) on one of the transfer tube.
- For transfer tube temperature gradient ~+30 °C between point C and point A, the measured convection speed is ~5 cm/min.

  (convection reduce polarization gradient to ~1%)

Polarimetry for ^{3}He in Target Cell

1. Adiabatic Fast Passage Nuclear Magnetic Resonance (AFP-NMR)

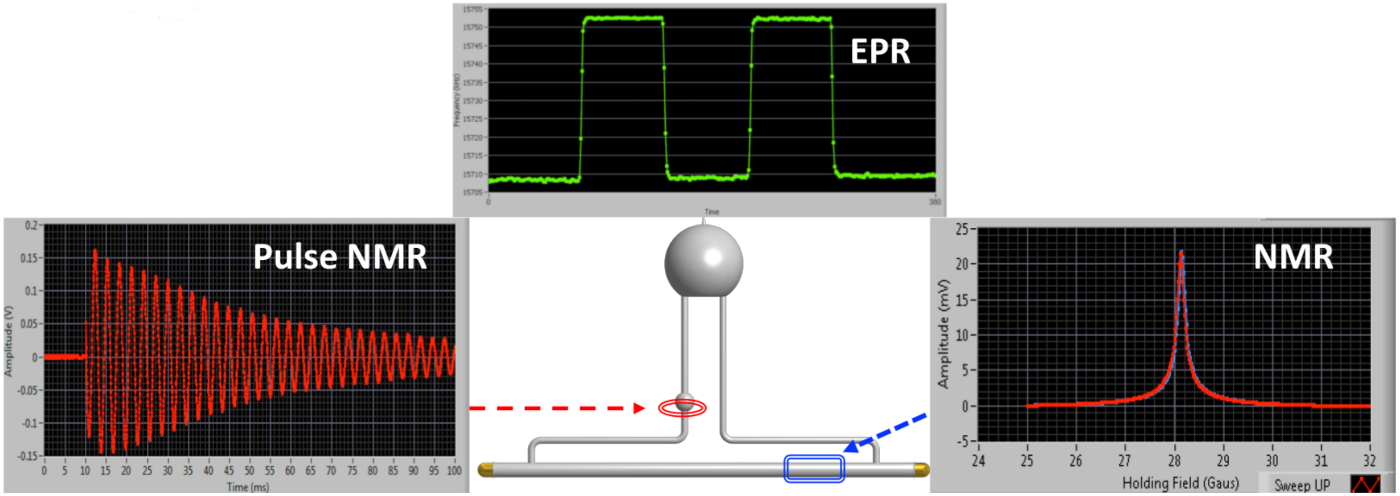
- Magnetic Resonance of ^{3}He Nucleus.
- Sweep the holding field under AFP condition to flip the Nucleon spin direction back and forth.
- Relative measurement, calibrate with water NMR or EPR.

2. Pulse NMR (for 12 GeV upgrade)

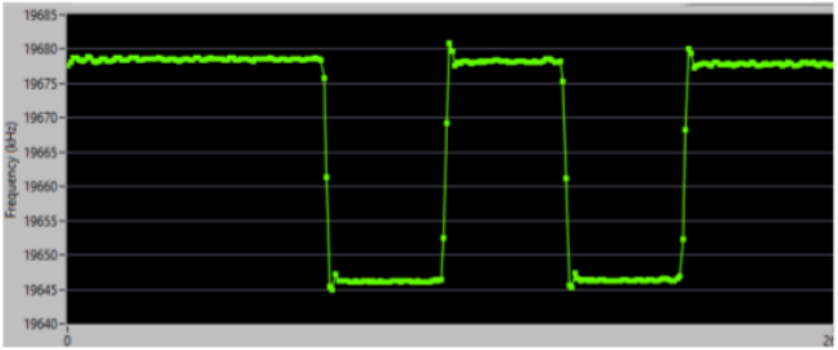
- Use resonance RF pulse to tilt the Nucleon spin to a certain angle.
- Relative measurement, calibrate with AFP-NMR.

3. Electron Paramagnetic Resonance (EPR)

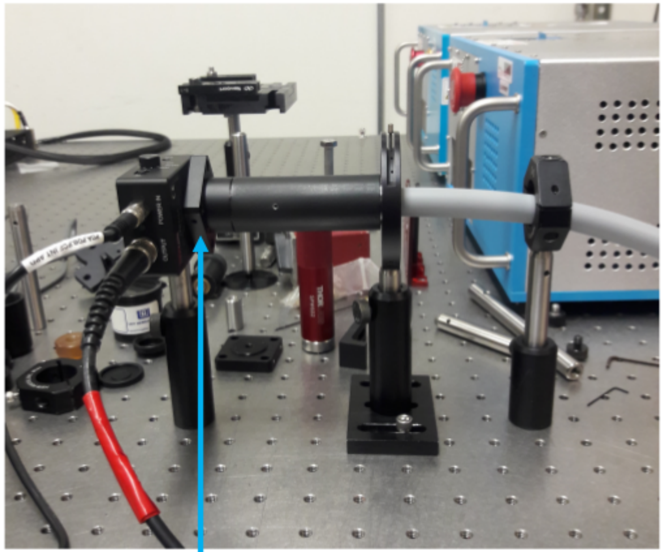
- Magnetic resonance of the alkali atoms.
- Resonance shifted due to polarized ^{3}He, get the resonance frequency difference by flipping the ^{3}He polarization direction.
- Get ^{3}He polarization from resonance frequency difference. Absolute measurement.



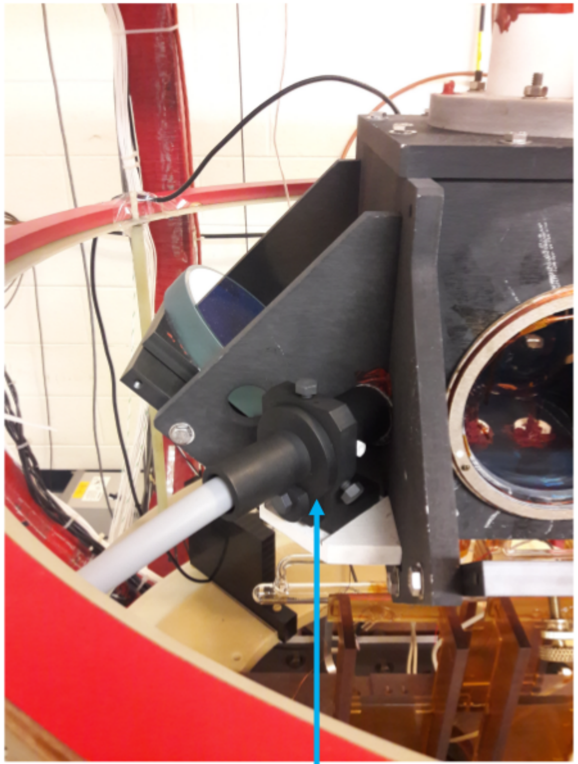
EPR/NMR Calibration



- Needed to protect photodiode from radiation damage from electron beam.
- EPR Upgrade:
Raytum D2 fiber bundle + Thorlabs avalanche photodiode.



- Use fiber bundle (~ 4 m) to transfer the D2 light to the photodiode which is away from target cell and covered by radiation shelter.



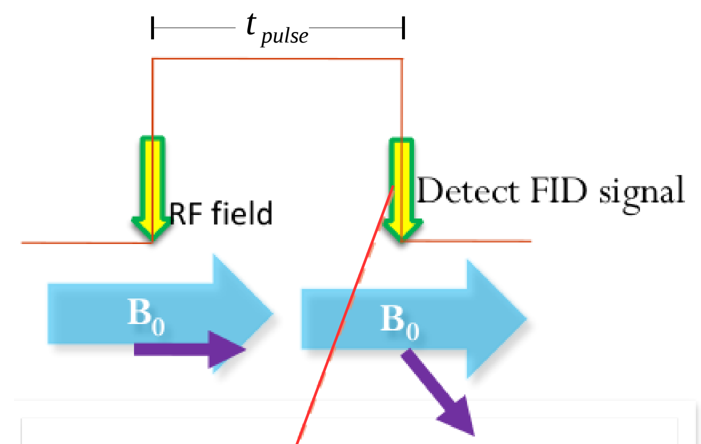
- D2 fluorescence from pumping chamber detected close to oven.

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

Pulse NMR Polarimetry

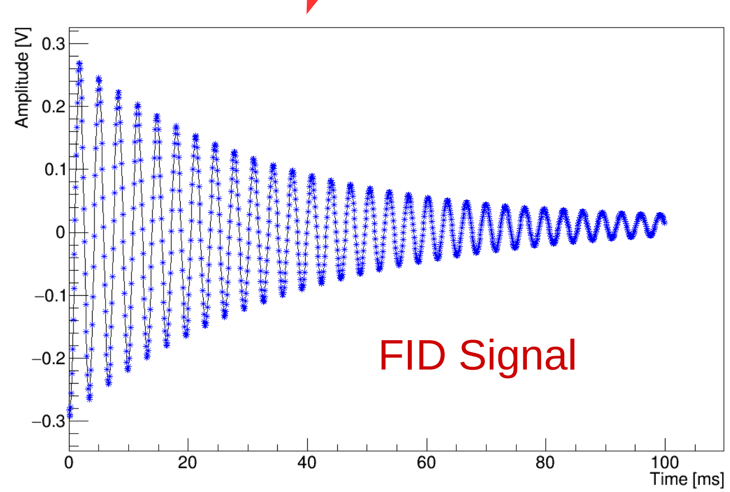
Advantage:

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



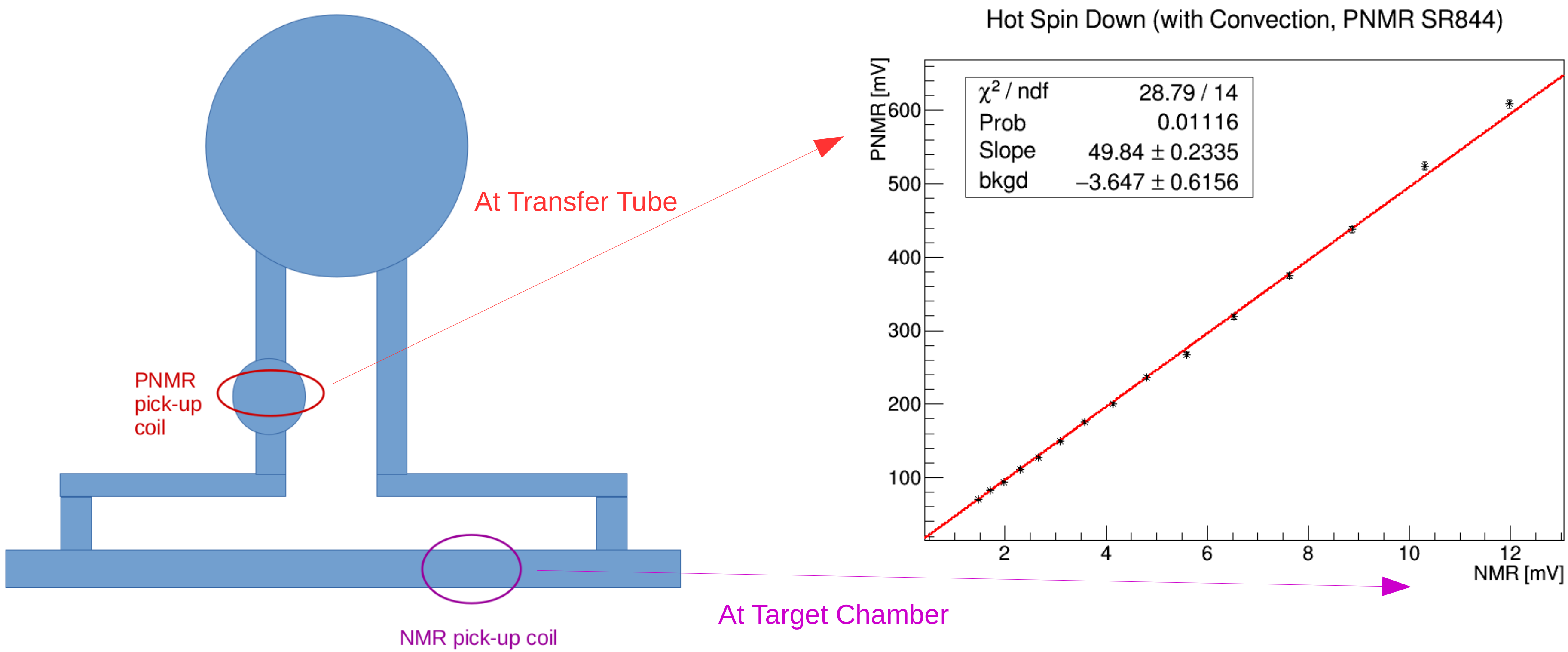
Principle:

- 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.



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

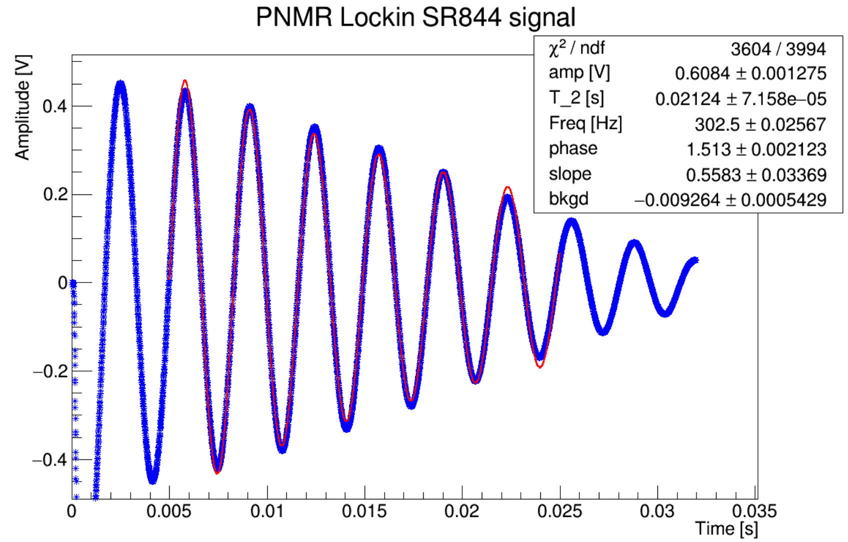
PNMR (at Transfer Tube) vs. NMR (at Target Chamber)



- Hot spin down with convection measurements. Pulse NMR measured around 1-inch sphere on the transfer tube.
- Current fit for the signal by the FID fitting function to obtain PNMR amplitude A_0.

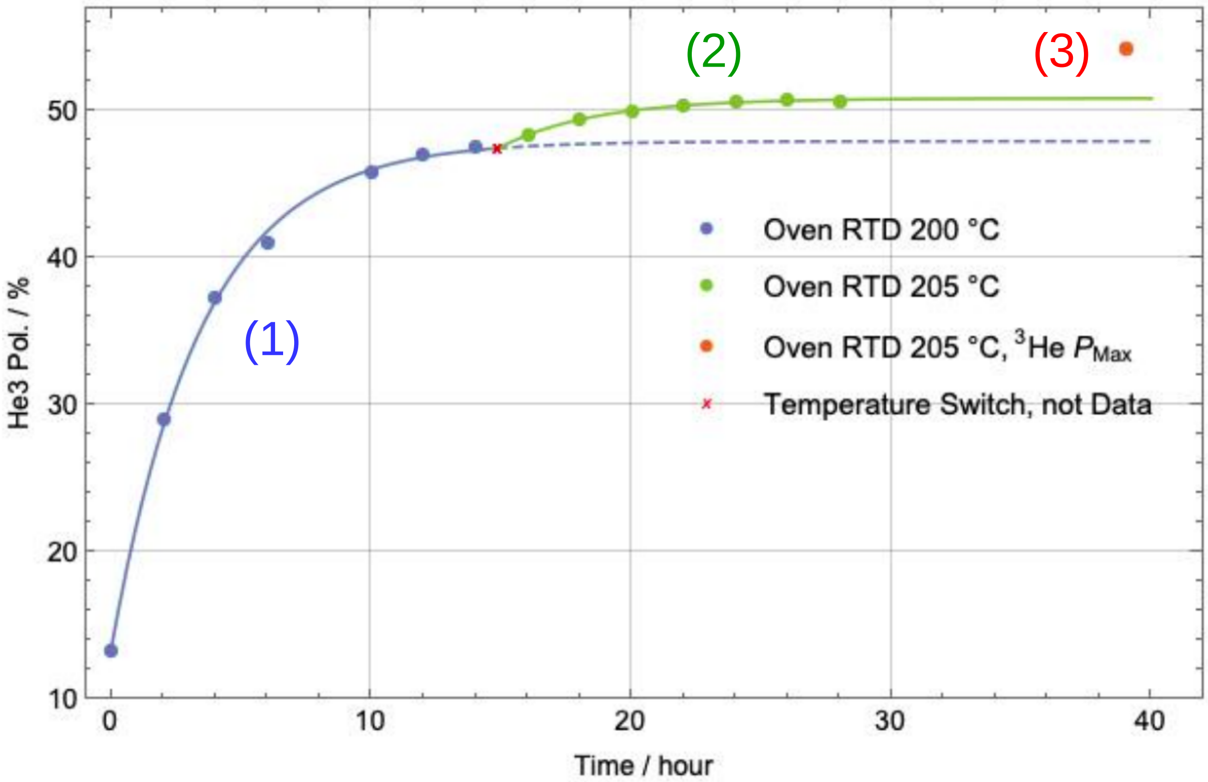
$$S(t)=FID(t)=A_0\cos(\omega t+\phi_0)e^{-t/T_2}+a*t+b$$

- Calibrate PNMR with NMR with linear fit.



Typical Production Cell Performance

(Cell “Fulla” for A1n/d2n experiment)



(1) EPR measurements of hot spin up curve at pumping chamber.

(2) Optimize the SEOP conditions to get higher ^{3}He polarization.

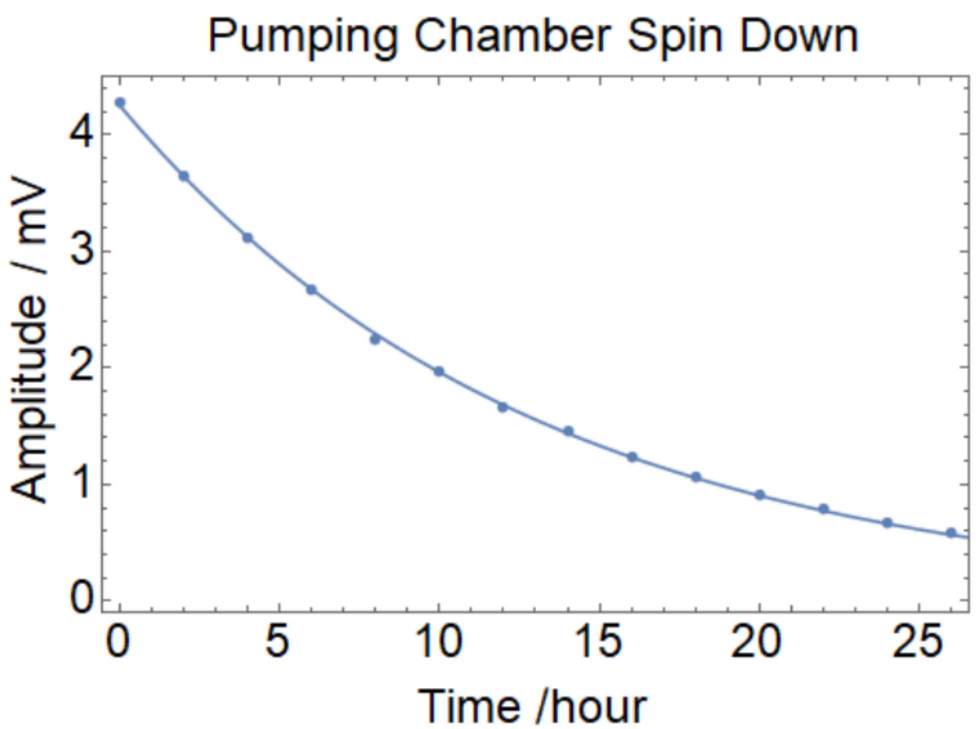
(adjust oven temp so we have right amount of alkali vapor to absorb all incident laser power ~ 90 W)

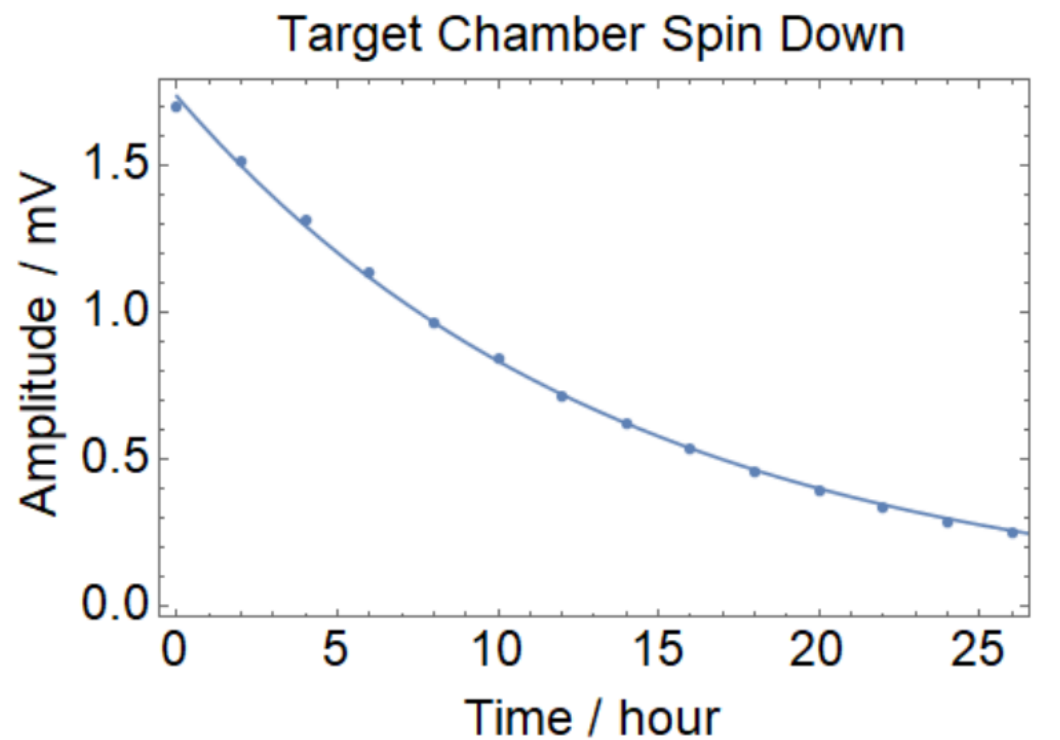
(3) Masing effect during EPR measurements reduce the max ^{3}He polarization.

Wait ~10 hrs for no measurement and the next EPR gives max ^{3}He polarization for “Fulla” to be ~54%.

Typical Production Cell Performance

(Cell “Fulla” for A1n/d2n experiment)





	Spin Down / h	AFP Loss per sweep
Pumping Chamber	14.23	0.8%
Target Chamber	13.92	0.13%

- “Fulla” lifetime measurement by cold spin down AFP-NMR.

Summary

- Polarized 3He targets was successfully implemented for JLab 6 GeV experiments. They have contributed a lot for study of nucleon structure.
- Complete the following upgrades of target system for JLab 12 GeV experiments:
  - Convection cell
  - EPR with D2 light collection optics
  - PNMR polarimetry
- The target system will be ready for the upcoming A1n/d2n experiments (E12-06-110/E12-06-121) begin in November, 2019.

Acknowledgements

Manpower at JLab:

- Graduate students:

  Junhao Chen (W&M, Todd's group)

  Mingyu Chen (Uva, Xiaochao's group)

  Melanie Rehfuss (Temple, Zein-Eddine's group)

  Murchhana Roy (U. of Kentucky, Wolfgang's group)

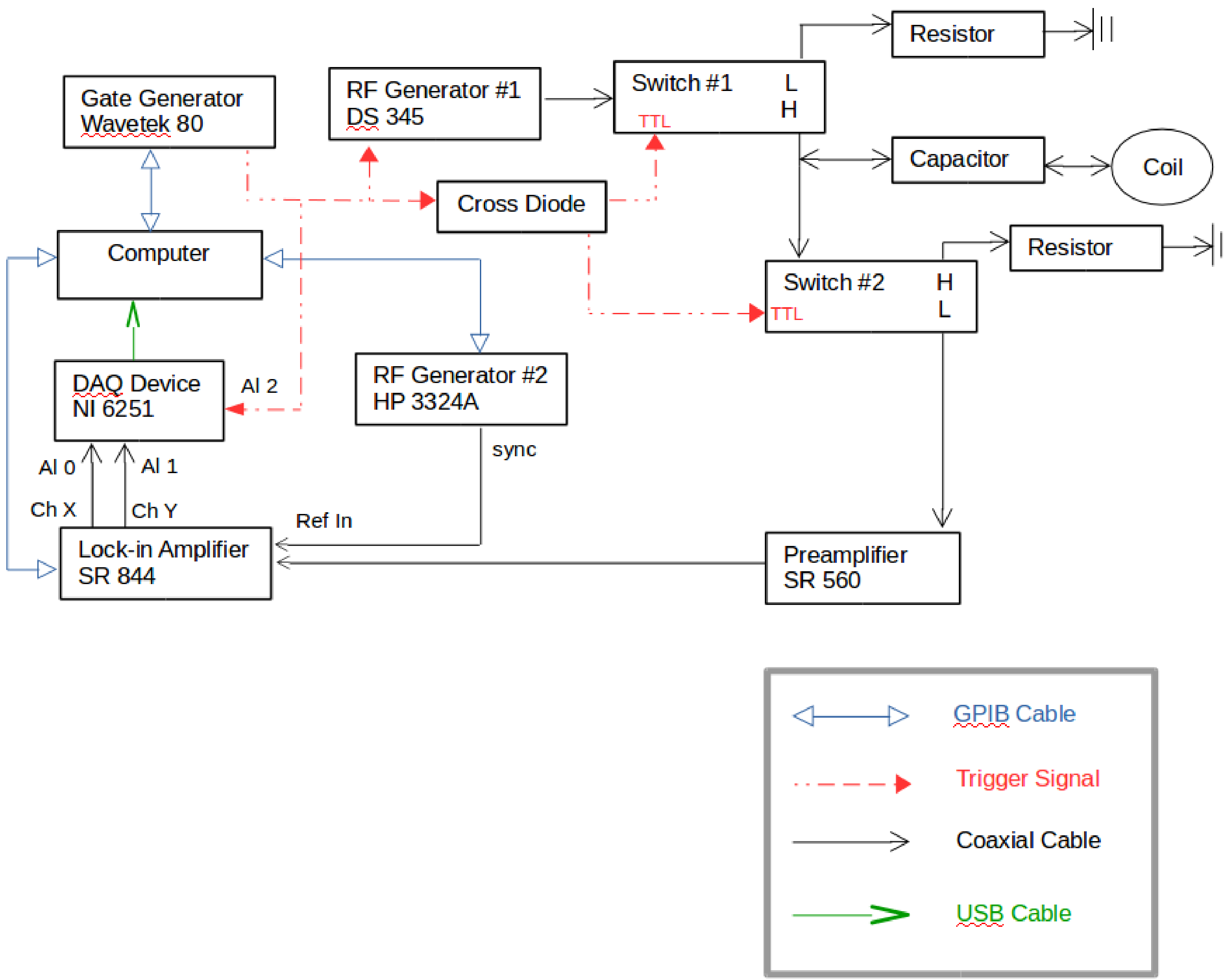
- Post-doc: Arun Tadepalli (JLab)
- Engineers/Designer: Bert Metzger
- Supervisor/Coordinator: Dr. Jian-Ping Chen

Target Activities at User Institutes:

- Convection Cell testing and fabrication: UVa (Gordon Cates), W&M (Todd Averett)
- k0 measurement (for EPR): W&M (Todd Averett), UVa
- Reference cell system/cooling jets: W&M (Todd Averett)
- Field direction measurement: Kentucky (Wolfgang Korsch)

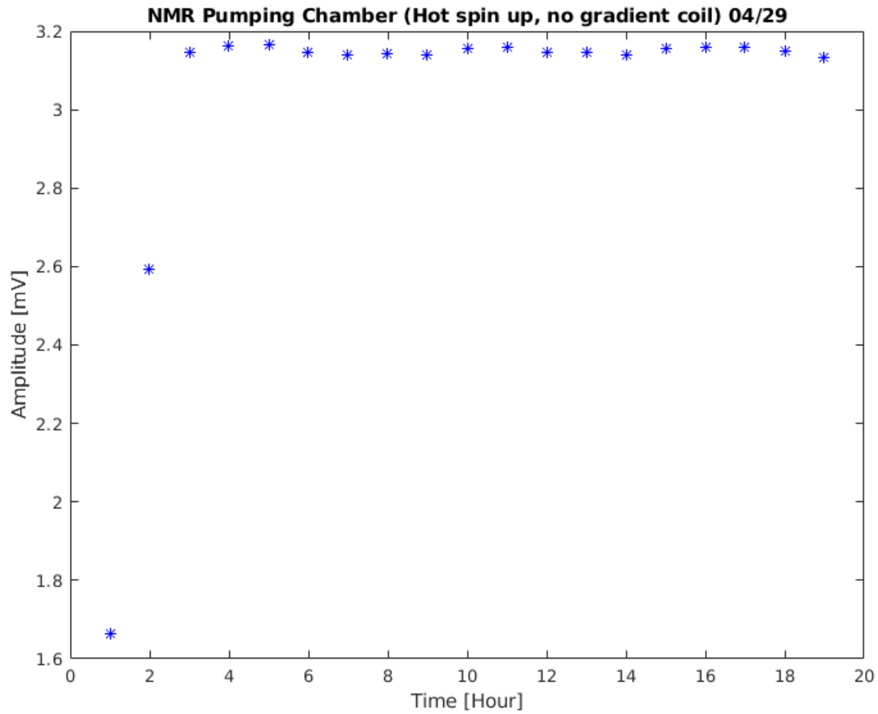
Backup Slides

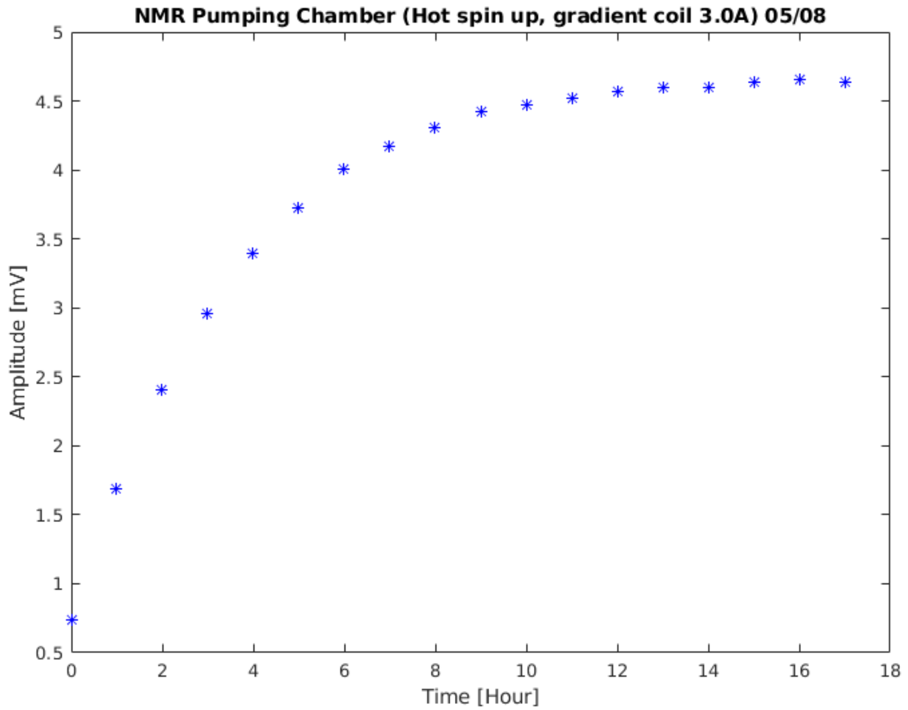
PNMR with Lockin SR844 and DAQ Setup



Masing Effect and Gradient Coil

(Cell "Savior")





- Phenomenon: Non-linear polarization loss during NMR or EPR measurements. Max ^3He polarization decreased to masing threshold.
- Principle: Coupling of transverse component of ^3He spin with pick-up coils. Induced transverse magnetic field will tip away ^3He spin from the main field.
- Fix: Add a gradient coil to generate additional magnetic field gradient along direction of main holding field.

Current Production Cells Performance

Cell name	Fill date	Cold spin down lifetime (hrs)	Max polarization measured	Expected in beam polarization
Dutch	08/22/2019		52% (UVa)	50%
Fulla	09/07/2018	17 (UVa); 14 (JLab)	53% (UVa); 54% (JLab)	50%
Tommy	09/11/2019			
Brianna	03/27/2019	23 (UVa)	53% (UVa)	48%
Savior	10/27/2016	42 (UVa, 2016); 28 (JLab); 14 (UVa, 2019)	65% (UVa, 2016); 38% (JLab)	60% (2016) →?
Flurence	09/28/2018	11 (UVa)	45% (UVa)	44%

- Production cells are fabricated and filled by Gordon's group at UVa. Professor Todd Averett at W&M helped to fill some of the cells.