Polarized ^{3}He Target Installation Update for A_1^n, d_2^n

On Behalf of the JLab Polarized ^{3}He Target Group

Melanie Rehfuss
Temple University

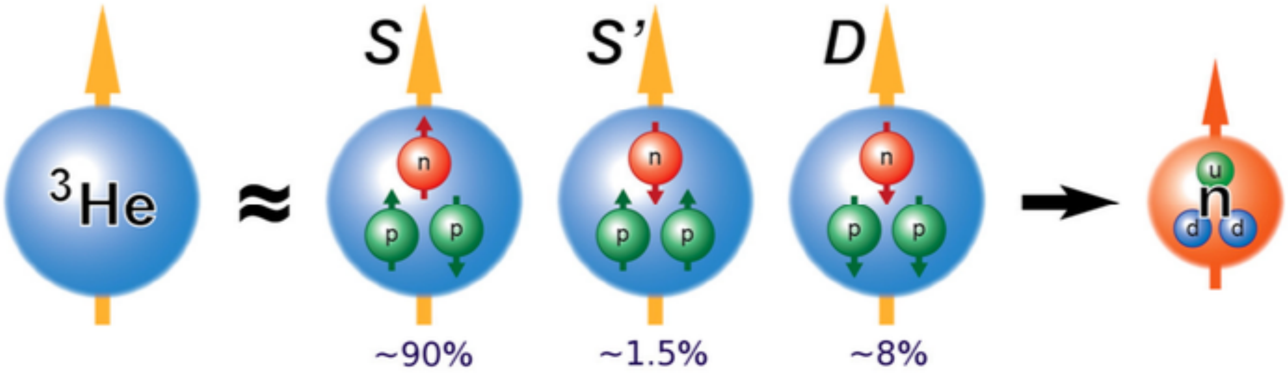
Hall A/C Collaboration Meeting, June 2019

Why ^{3}He?

- No free neutron targets exist: free neutrons are unstable, with a mean lifetime of ~ 15 minutes

- Deuterium $(1p + 1n)$ is one option, but large corrections due to the proton spin result in large uncertainties

✓ ^{3}He $(2p + 1n)$ has most of its spin carried by the neutron, with the proton spins canceling each other out



^{3}He serves as an effective neutron target

How to Polarize ^{3}He?

- Simplest method is inefficient: due to ^{3}He's low magnetic moment ($\mu = \frac{e\hbar}{2m}, \mu_N \ll \mu_e$), one would need a **very high field** at a **very low temperature** to create and sustain a high polarization

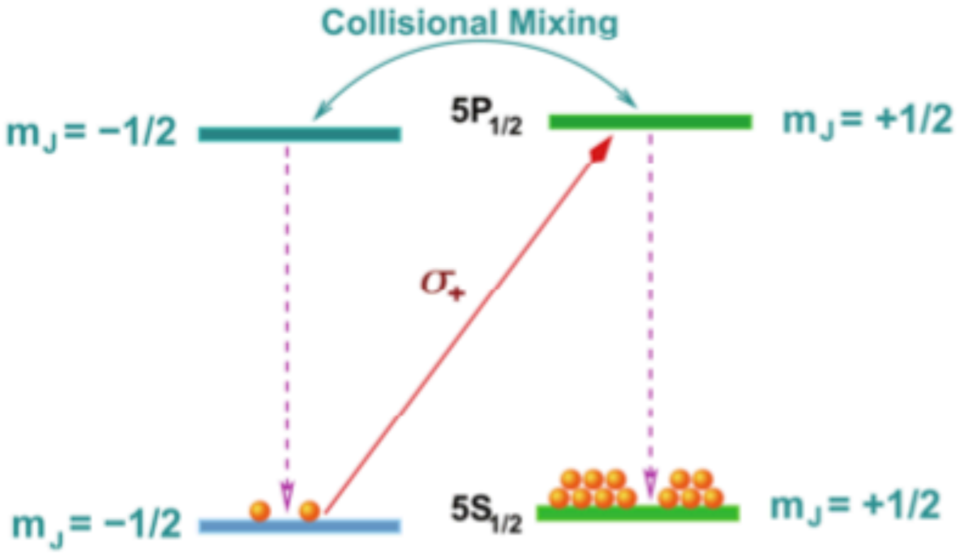
- ^{3}He electrons are in a spin singlet state → can't be directly polarized

- Metastability-Exchange Optical Pumping (MEOP): one electron is excited to a metastable state, which is then polarized via OP. Collisions between the electrons and ^{3}He nucleus result in nuclear polarization → only works for low-density targets

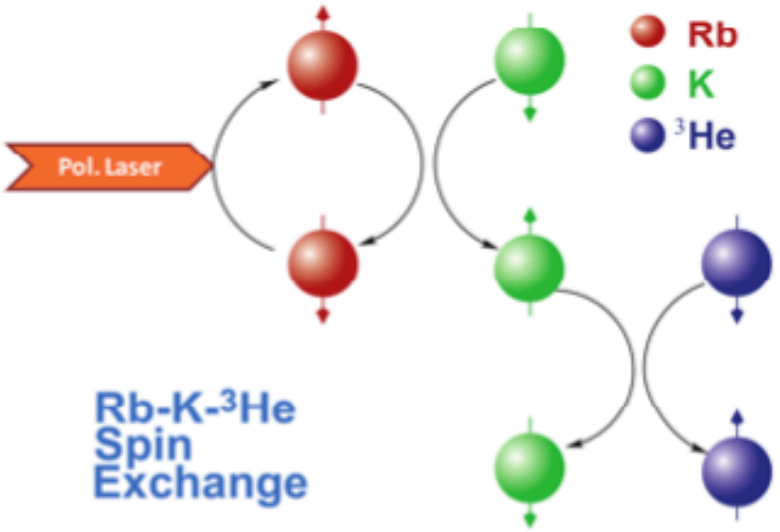
✓ **Spin-Exchange Optical Pumping** (SEOP): use polarized alkali atoms (1 valence electron) → works for high-density (high luminosity) targets!

Polarizing ^{3}He via Spin-Exchange Optical Pumping

- An external magnetic field H_0 is applied to split the alkali Zeeman levels ($\pm m_J$)



(a) Optical pumping of ^{85}Rb



(b) ^{85}Rb-^{39}K-^{3}He spin-exchange

a) ^{85}Rb vapor is optically pumped using a 795 nm circularly-polarized laser σ_+ to induce the D1 transition $5S_{\frac{1}{2}} \rightarrow 5P_{\frac{1}{2}}$

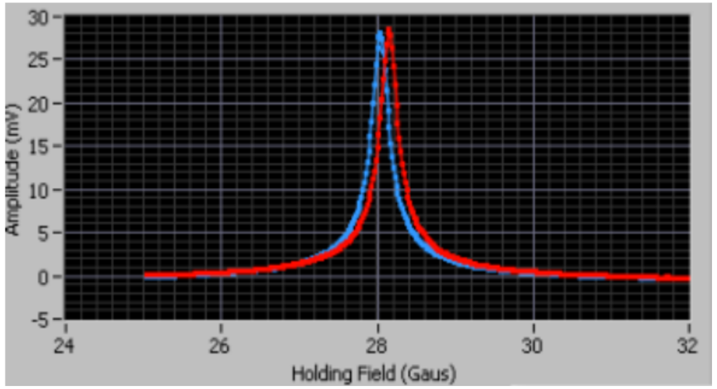
b) The polarization of the ^{85}Rb electrons is transferred to the ^{39}K electrons via spin-exchange binary collisions, which is then transferred to the ^{3}He nuclei via a hyperfine interaction

^{3}He Polarimetry Methods

Nuclear Magnetic Resonance (NMR) via Adiabatic Fast Passage (AFP)

- ^{3}He atoms are in a Holding field H_0 (~28 G) along $\hat{z}$, causing them to precess
- Small (< 100 mG) RF field H_1 applied along $\hat{x}$
- H_0 is swept across resonance (AFP), reversing the ^{3}He spin direction
- EM signal induced within the pick-up coils $\propto M_z$

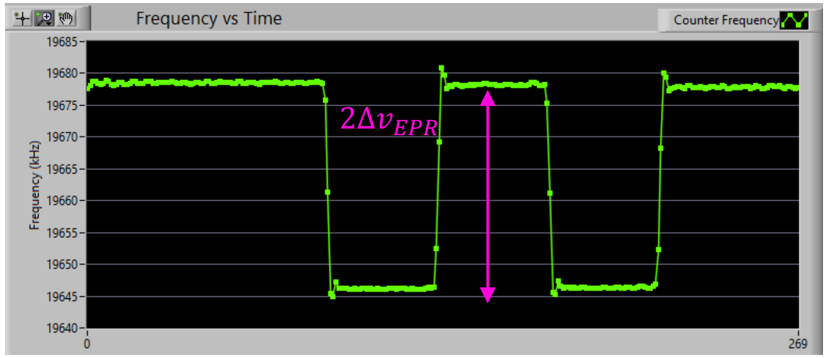
→ Calibrated with water NMR/EPR



Electron Paramagnetic Resonance (EPR)

- ^{39}K Zeeman splitting $\nu_{EPR} \propto H_0 + H_{^3He}$
- Uses AFP to flip the ^{3}He spins, canceling the contribution from H_0
- The shift in ^{39}K resonant frequency $2\Delta\nu_{EPR} \propto$ ^{3}He polarization

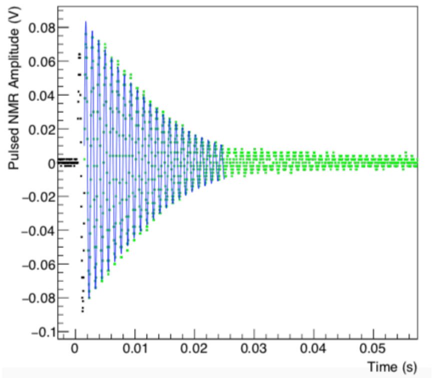
→ An absolute measurement



Pulsed NMR – new method

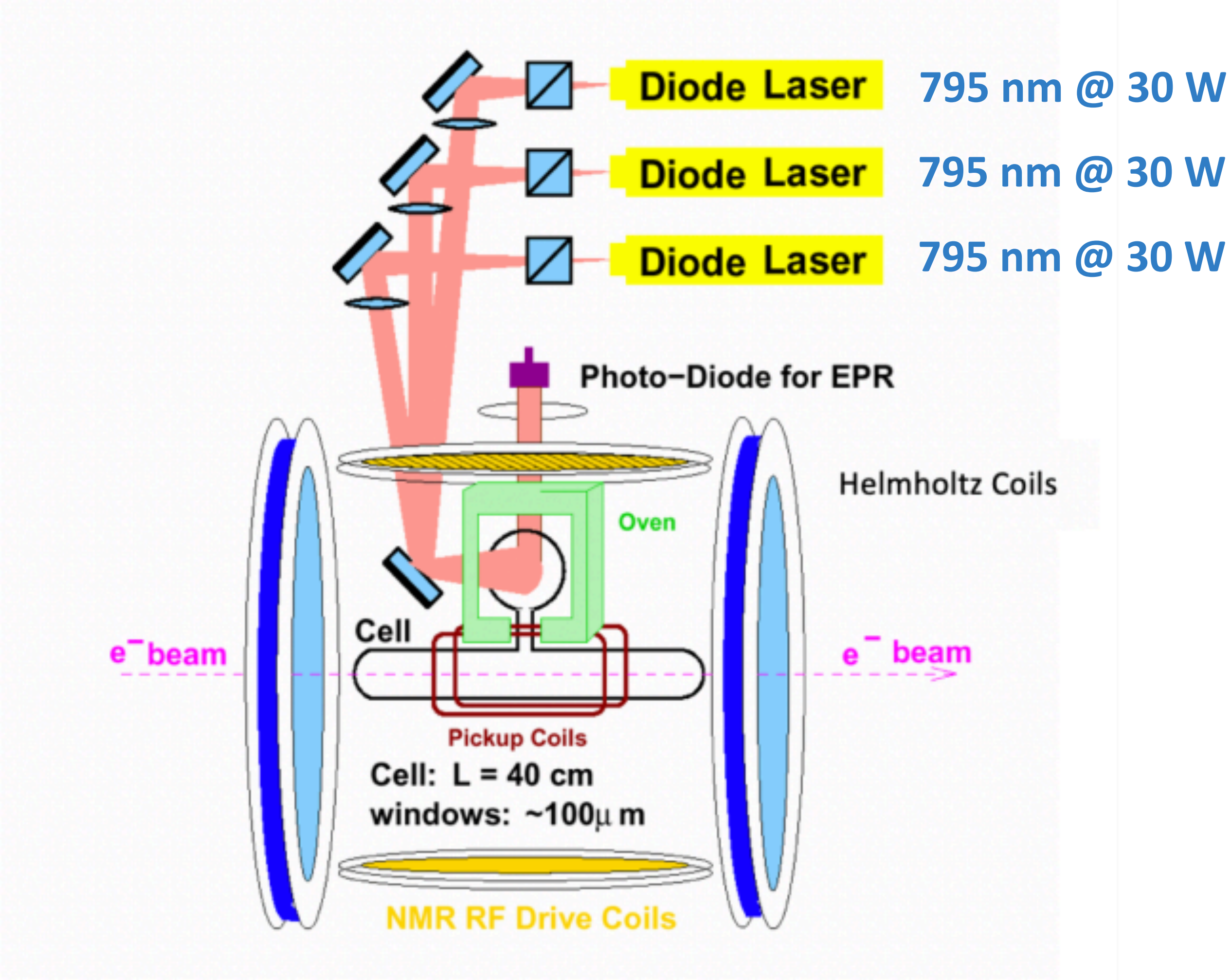
- An RF pulse tuned to the Larmor frequency ω (81 kHz for 25 G) is sent
- The precessing ^{3}He spins tip away from H_0: $\theta_{tip} = \frac{1}{2}\gamma H_1 t_{pulse}$
- Free Induction Decay: $S \propto M_z \sin(\theta_{tip})\, e^{-t/T_2} \sin(\omega t)$

→ Calibrated with NMR (needed for metal target windows required for higher currents > 30 μA)



TEMPLE UNIVERSITY

^{3}He Target Overview

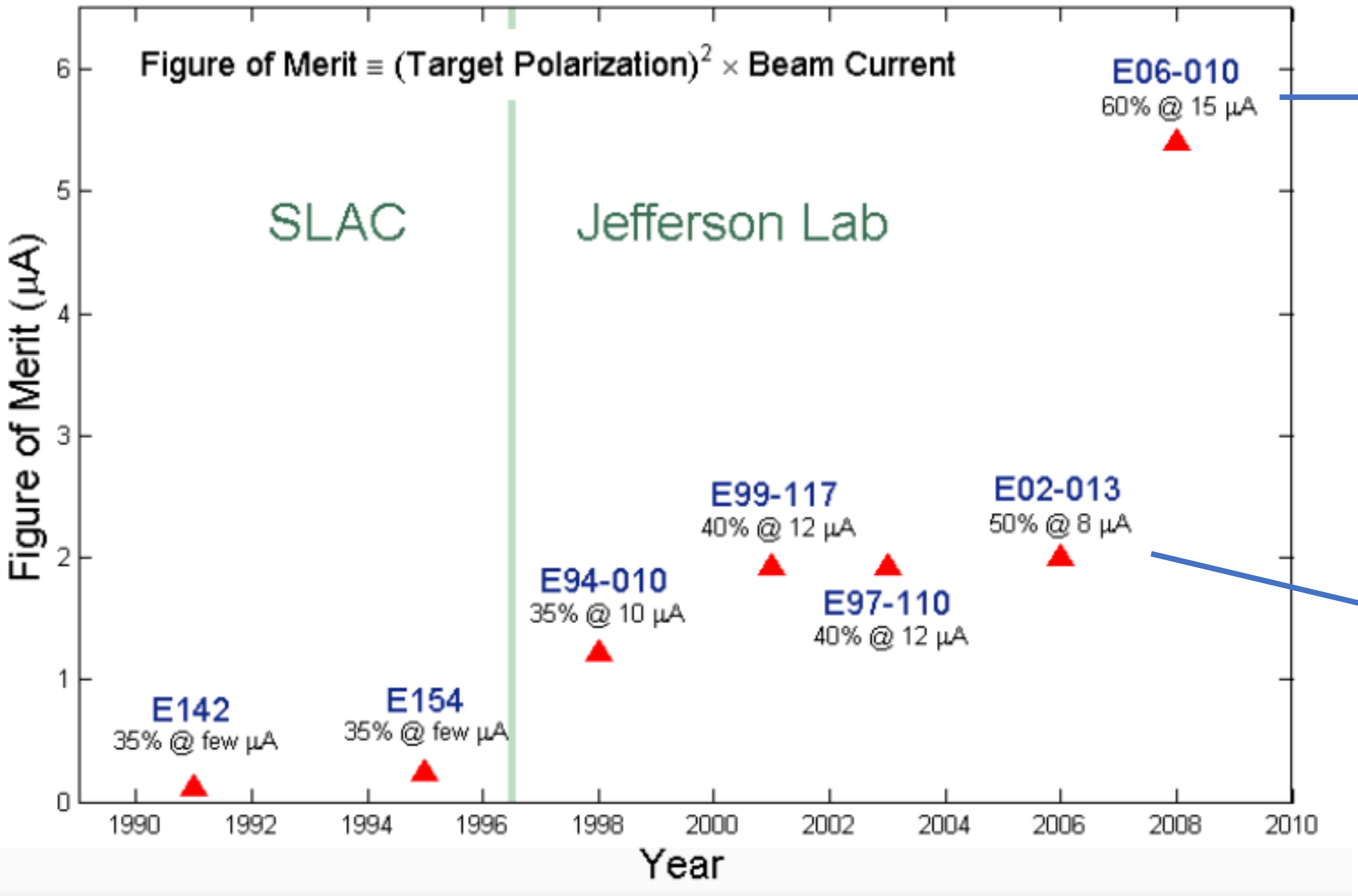


- ✓ 3D polarization capability (longitudinal, transverse, and vertical)
- ✓ Luminosity ~ 10^{36} cm^{-2}s^{-1} (**highest in the world**)

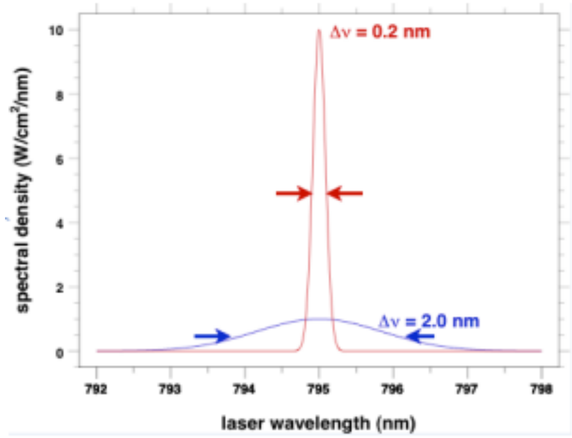
  → Will be doubled for 12 GeV
- ✓ High in-beam polarization ~ 60%
- ✓ Polarimetry: NMR/Water + EPR total uncertainty 3-5%

  → 3% required for 12 GeV
- ✓ 13 completed experiments
  7 approved with JLab 12 GeV (A/C)

^{3}He Performance during 6 GeV Experiments



Used spectrally-narrowed diode lasers



Used ^{85}Rb/^{39}K hybrid cell
(shortens time constant → improves spin-exchange efficiency)

Slide taken from Junhao Chen's talk, Hall A/C Winter Collaboration Meeting, January 2019

^{3}He Target Upgrade for 12 GeV: A_1^n, d_2^n

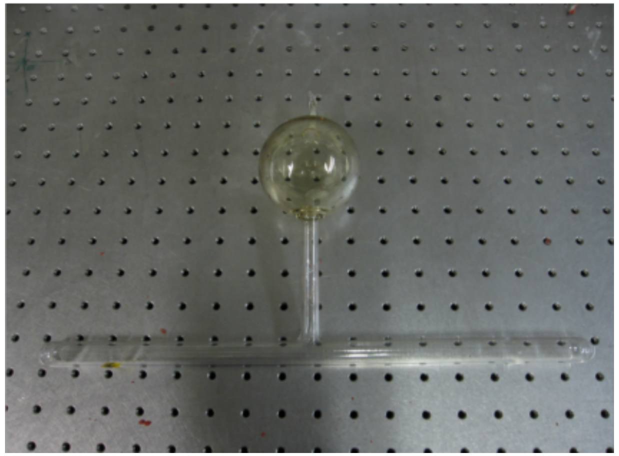
6 GeV Era Performance

- Beam Current: 15 μA
- Luminosity: 10^{36} cm^{-2}s^{-1}
- Polarimetry: 3% for Rb only, 5% for Rb/K hybrid

12 GeV (Stage I) Requirements

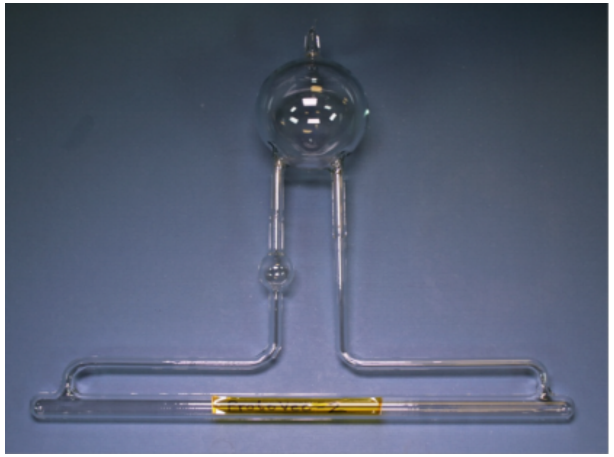
- Beam Current: 30 μA
- Luminosity: 2x10^{36} cm^{-2}s^{-1}
- Polarimetry: 3% for Rb/K hybrid

Approaches



- Diffusion Cell
- 3” Pumping Chamber
- 50 – 80 W laser power

- Convection Cell
- 3.5” Pumping Chamber
- ~100 W laser power



Slide taken from Junhao Chen’s talk, Hall A/C Winter Collaboration Meeting, January 2019

Target Upgrade Activities at JLab

(Wo)manpower @ JLab:

- 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

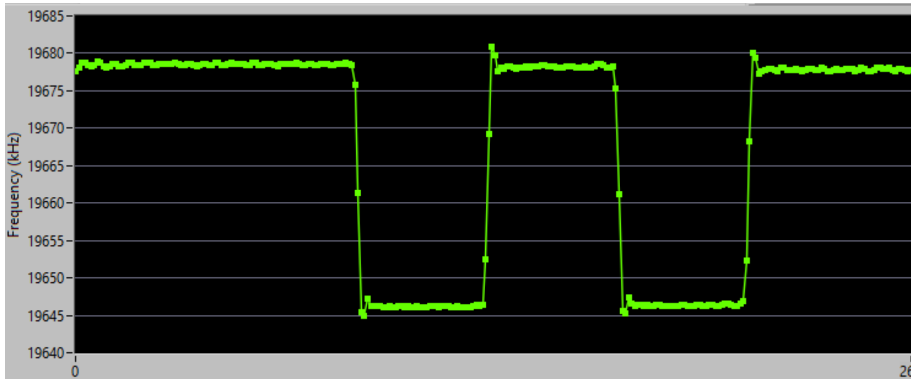
Overview of Responsibilities:

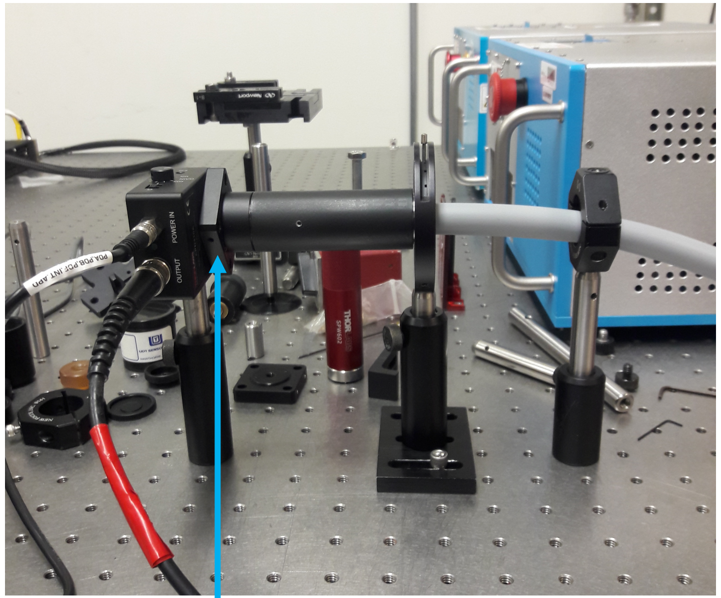
- ^{3}He Target Hall C Installation Design: Bert Metzger
- Pulsed NMR: Mingyu Chen
- EPR: Melanie Rehfuss
- Cell Characterization: (All)
- Instrumentation/Control Preparations: Junhao Chen
- Testing Components/Installation Preparations: (All)

EPR Status

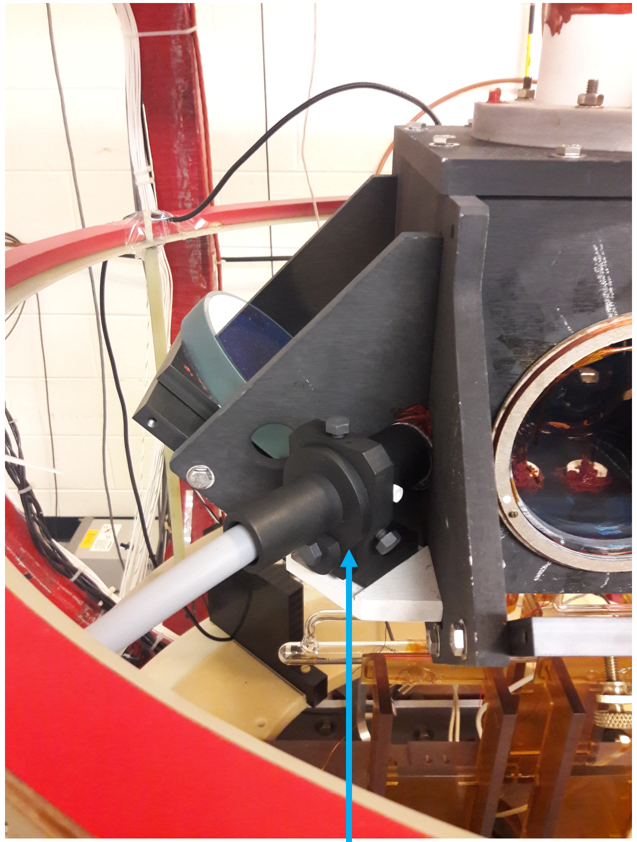
✓ EPR Upgrade (Raytum D2 Fiber Bundle + Thorlabs Avalanche Photodiode) completed with needed 3% precision

- Needed to protect photodiode from radiation damage





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



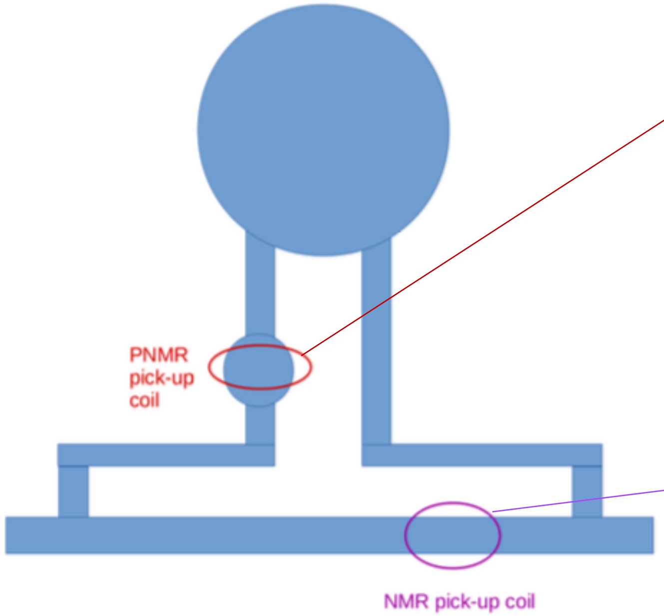
D2 fluorescence detected close to oven

pNMR Status (Mingyu Chen)

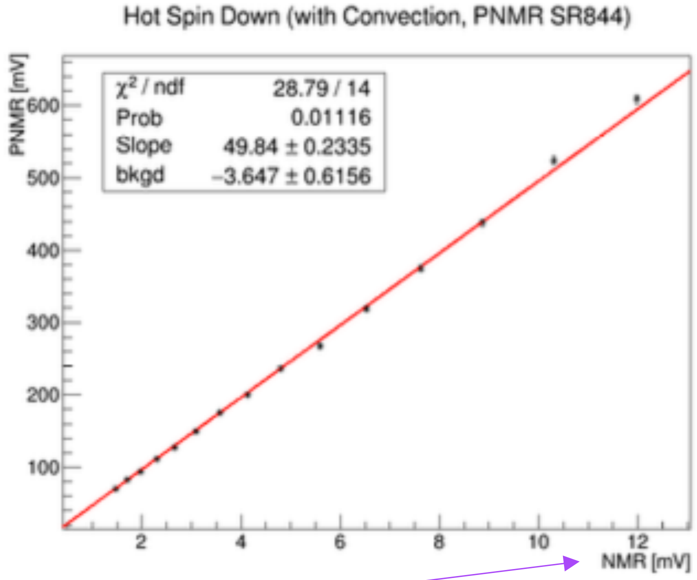
- Advantage: takes less time to complete than NMR-AFP → less depolarization
  - Will be required for future experiments with beam currents > 30 μA
- Correlation between NMR-AFP and pNMR signal reached 1% level using Mixer and Oscilloscope (Nguyen Ton)
- System has been upgraded with a Lock-in Amplifier and DAQ system

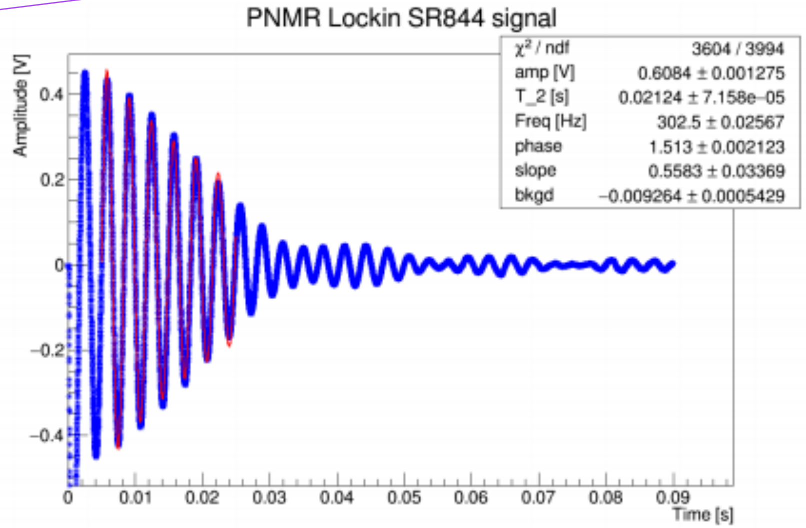
○ pNMR needs to be installed/tested on first new cell, *Savior*

pNMR @ transfer tube



NMR @ target chamber

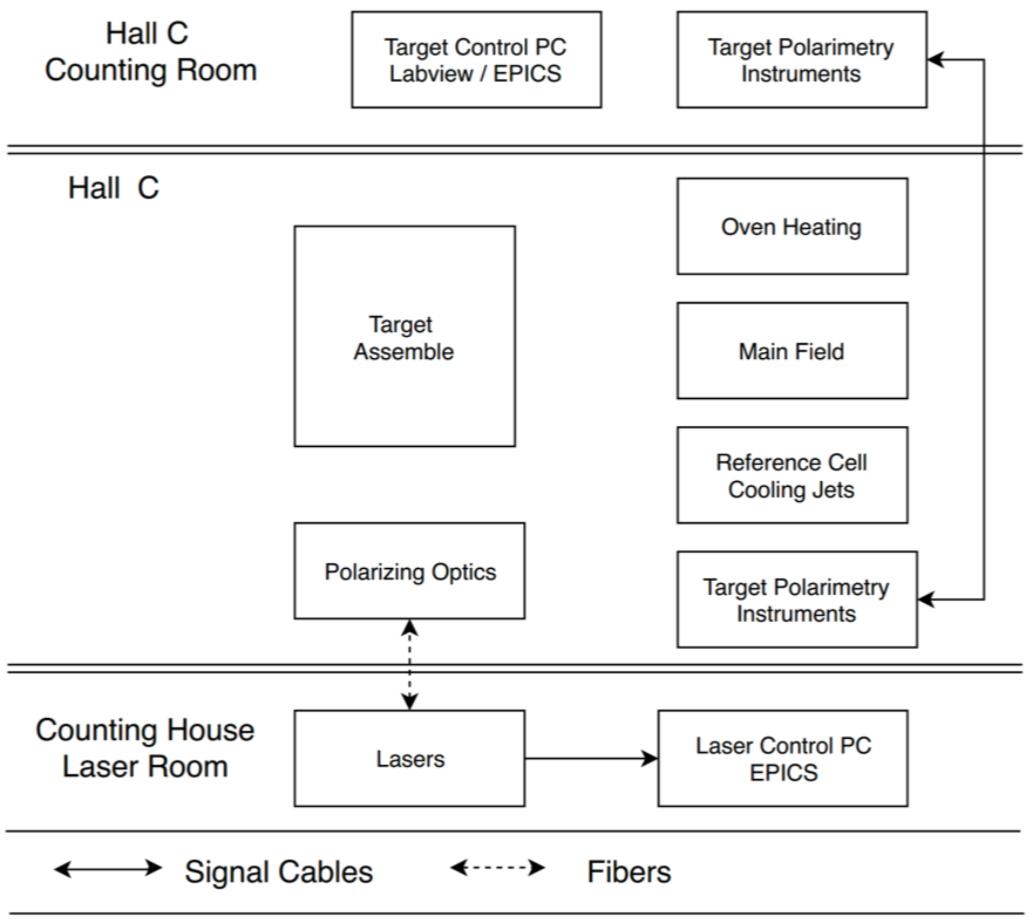




TEMPLE UNIVERSITY

Instrumentation & Controls (Junhao Chen)

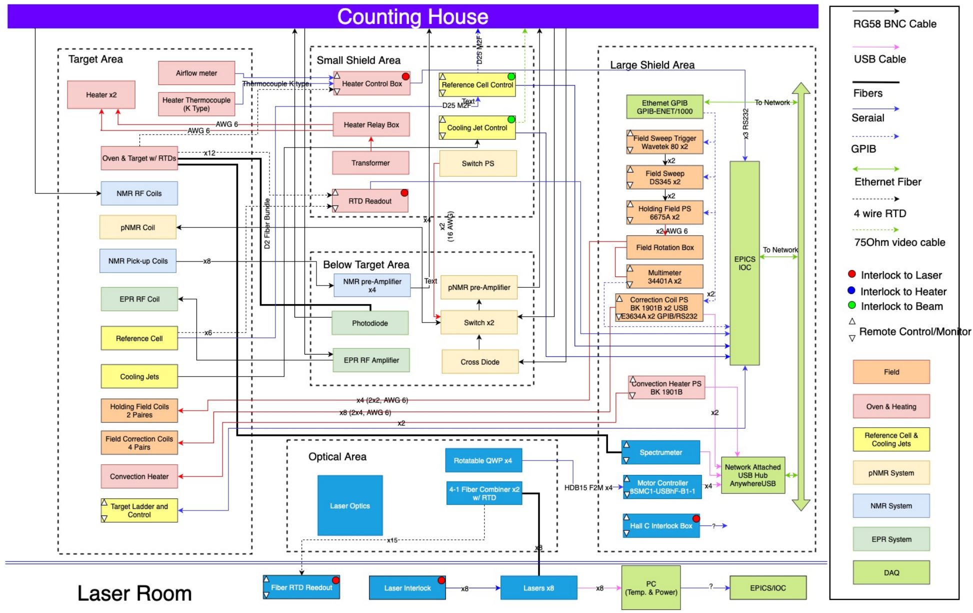
Polarized ^{3}He Target System Diagram



- All instruments ready
- Target Control System: mostly ready

  Still need:
  - Laser Control System
  - EPICS Implementation:

    EPICS group, Target Lab (softIOC)
- Cable list updated, long cables: Andy, Jack
- Reference Cell & Cooling Jets: Todd



Target Activities at User Institutions

- Cell Fabrication and Testing: UVA (Gordon Cates)
- κ_0 measurement (for EPR): W&M (Todd Averett), UVA
- Reference Cell System/Cooling Jets: W&M
- Field Direction Measurement: U. of Kentucky (Wolfgang Korsch)

Cell Production/Testing Status

- Test 12 GeV-era cells *Protovec-1* and *Protovec-II* have been characterized
- 3 cells were made in 2016
  - x 2 were bad
  - Good cell ***Savior*** (reported 60-65% polarization) is currently being tested/characterized at JLab
- ***Fulla*** and ***Brianna*** so far under spec @ ~ 50% polarization (testing ongoing @ UVA)

x ***Noah*** and ***Elle*** reported to be bad

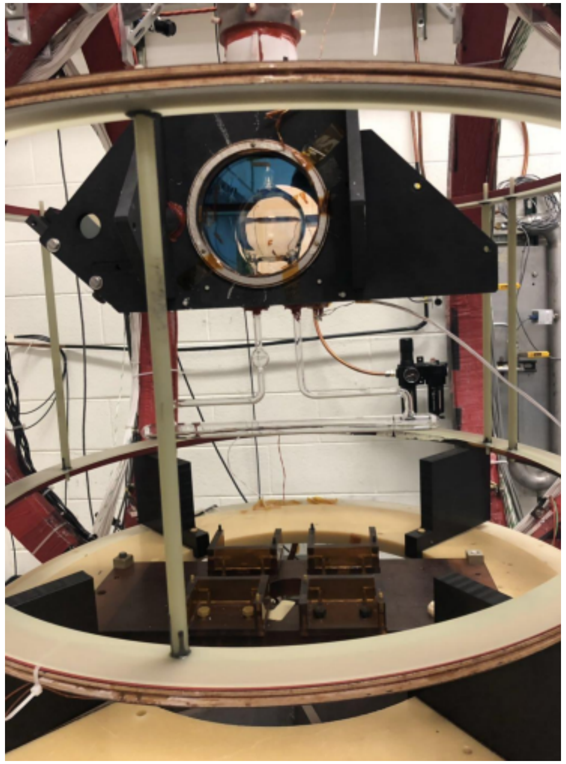
○ ***Florence*** might be usable, will be retested

○ ***Sandy*** was recently filled @ W&M, will be tested @ UVA

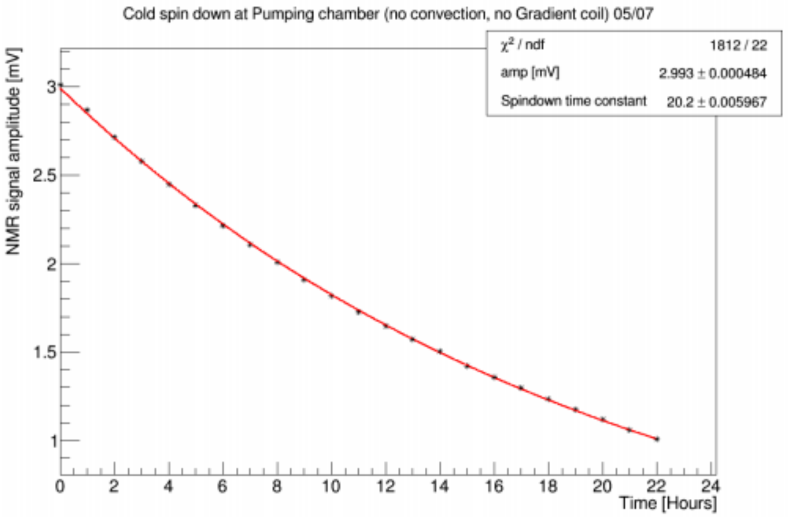
○ ***Phoenix*** is at UVA and will be filled

○ ***Victoria*** is at W&M and ready to be filled

→ Goal is to have 8 to 10 good cells for A1n, d2n **We're getting there…**



Savior mounted in oven at JLab's target lab



✓ *Savior* lifetime measured to be ~ 20 hours w/o AFP correction, ~ 27 hours with AFP correction

- Highest polarization seen so far is ~ 40% @ 91 W laser power (***EPR/NMR calibration on-going***)

Summary/Remaining Tasks

Polarimetry

- Finish *Savior* characterization (w/ and w/o convection)
  - NMR/EPR calibration
  - pNMR calibration
- Complete water cell calibration

Equipment

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

Software

- Laser control system
- Epics implementation

✓ Hall C Target Design completed
✓ Polarimetry working to needed precision
✓ Fabrication of mechanical parts in production
✓ Instruments/lasers/fibers are ready
→ Begin installation in mid-July!

For more information, register for the **A1n/d2n Collaboration Meeting** held on **July 24, 2019**

Thanks for listening!
Questions?