Jefferson Lab

RECENT ADVANCES OF POLARIZED ^{3}HE TARGET AT JEFFERSON LAB

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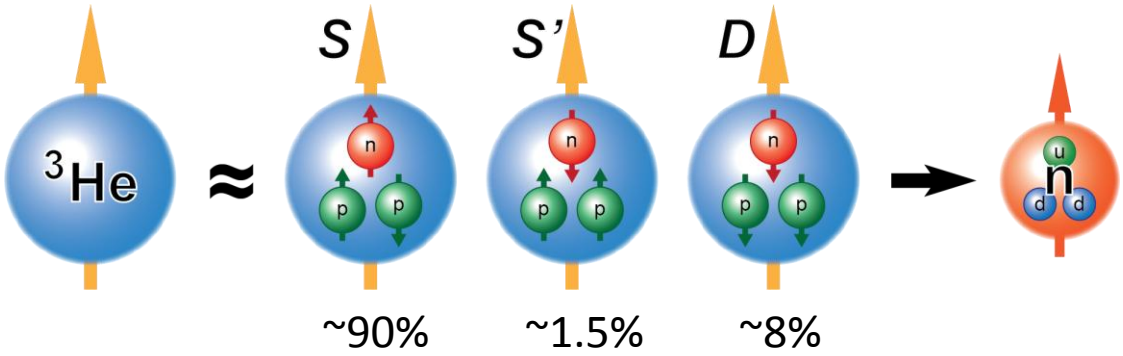
Meson-Nucleon Physics and the Structure of the Nucleon

Why Polarized ^{3}He Target ?

- Polarized targets bring insights into nucleon spin structure, complimentary information to the nucleon form factors and many more …
- Both polarized proton and neutron targets are necessary in flavor separation of nucleon structure.
- ^{3}He and Deuteron are two good candidates for a neutron target.
- 

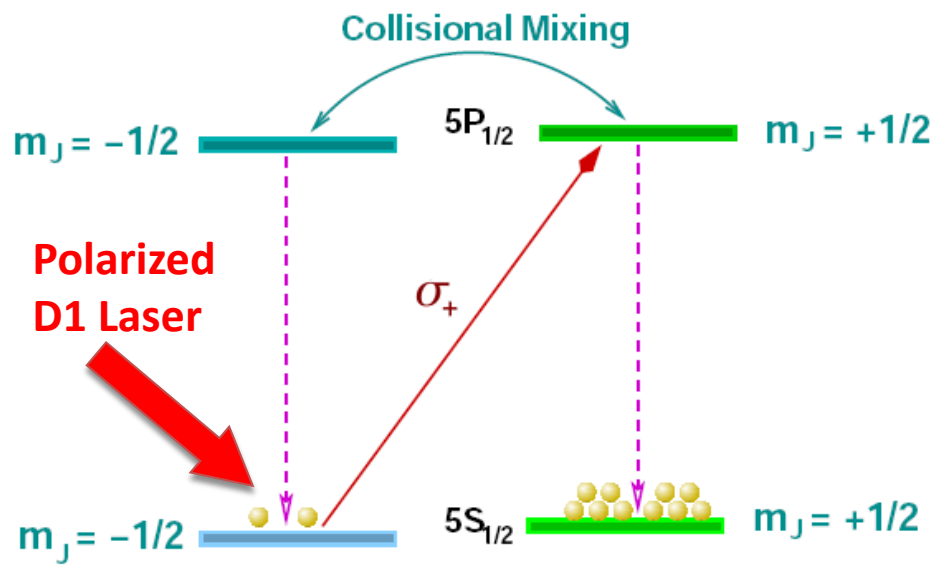
An Effective Polarized Neutron Target!

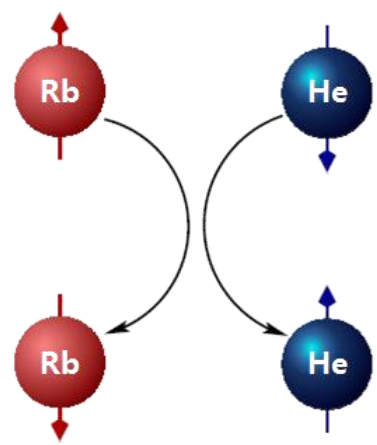
Ways to Polarize a ^{3}He Target

- Metastability-Exchange Optical Pumping
  - Developed early 1960s at Rice University
  - Used in MAINZ, DESY, NIKHEF, MIT-Bates …
  - Shorter polarization time: ~minutes
  - Lower pressure: ~mbar, needs compression
  - Mostly internal target
- **Spin-Exchange Optical Pumping**
  - In use since early 1990s at SLAC
  - Used in SLAC, MIT-Bates, JLab, HIGS …
  - Higher pressure: ~10 bar
  - Longer polarization time: ~10 hours
  - Mostly external target

Spin-Exchange Optical Pumping

- Alkali Optical Pumping
  - Splitting of alkali atomic states in magnetic field.
  - Polarized D1 transition: $S_{1/2} \rightarrow P_{1/2}$
  - Alkali atom polarized.
  - Added N_2 to increase pumping efficiency.
- Rb-^{3}He Spin-Exchange
  - Collisions with angular momentum conservation.

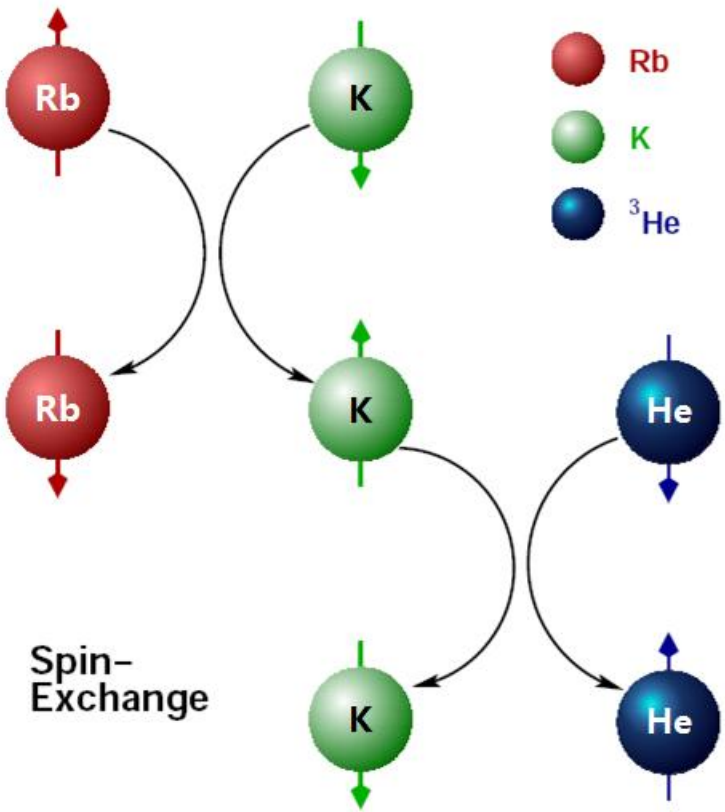




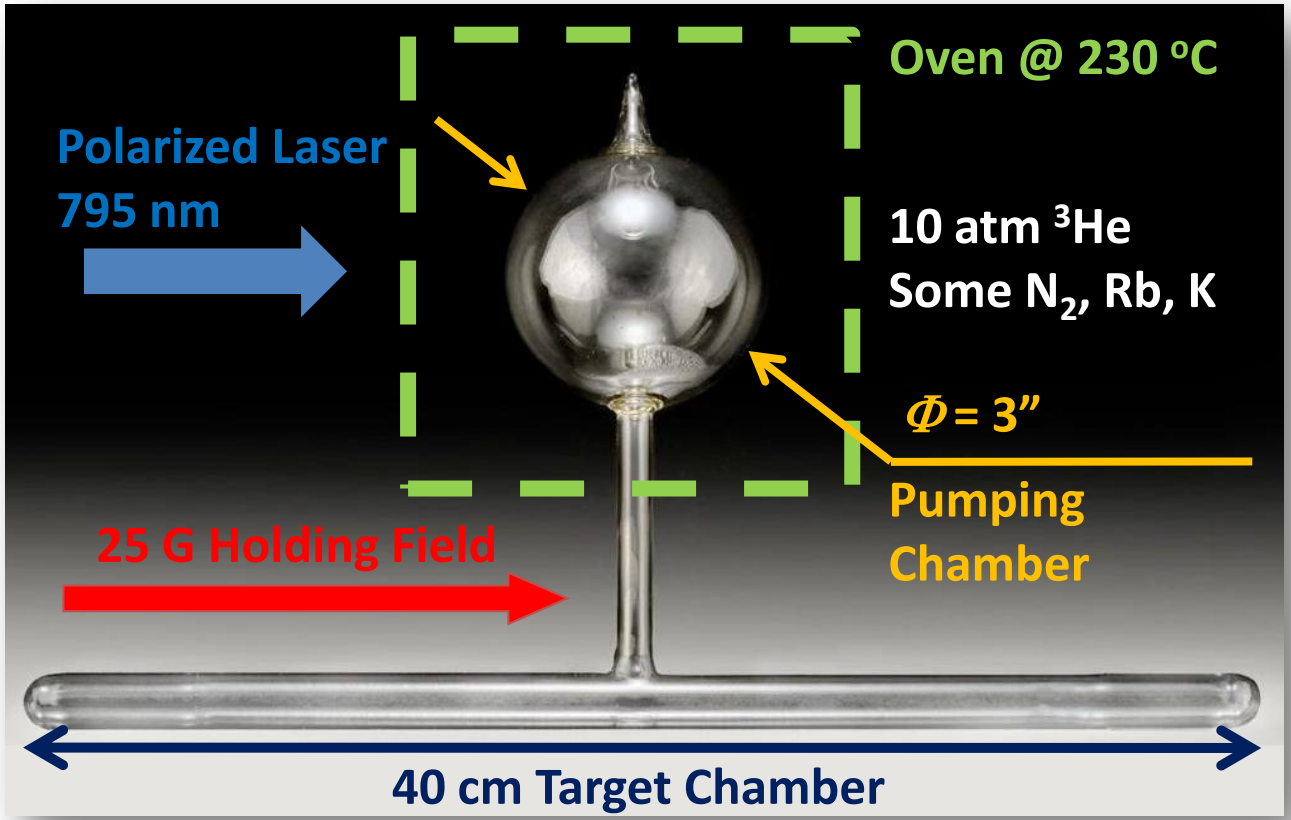
Rb-K Hybrid Cell

- Rb-K-^{3}He Spin-Exchange
  - K-^{3}He efficiency is much higher than Rb-^{3}He:

    1 kHz > 0.2 kHz
  - K-Rb strongly coupled > 100 kHz
  - K only solution is limited by the laser availability
  - Desired K/Rb ratio: 3 ~ 6
  - Shorter spin-up time
    - 10 → 4 hours
  - Higher in-beam polarization
    - 40% → 50%



Polarized ^{3}He Target in Jefferson Lab Hall A

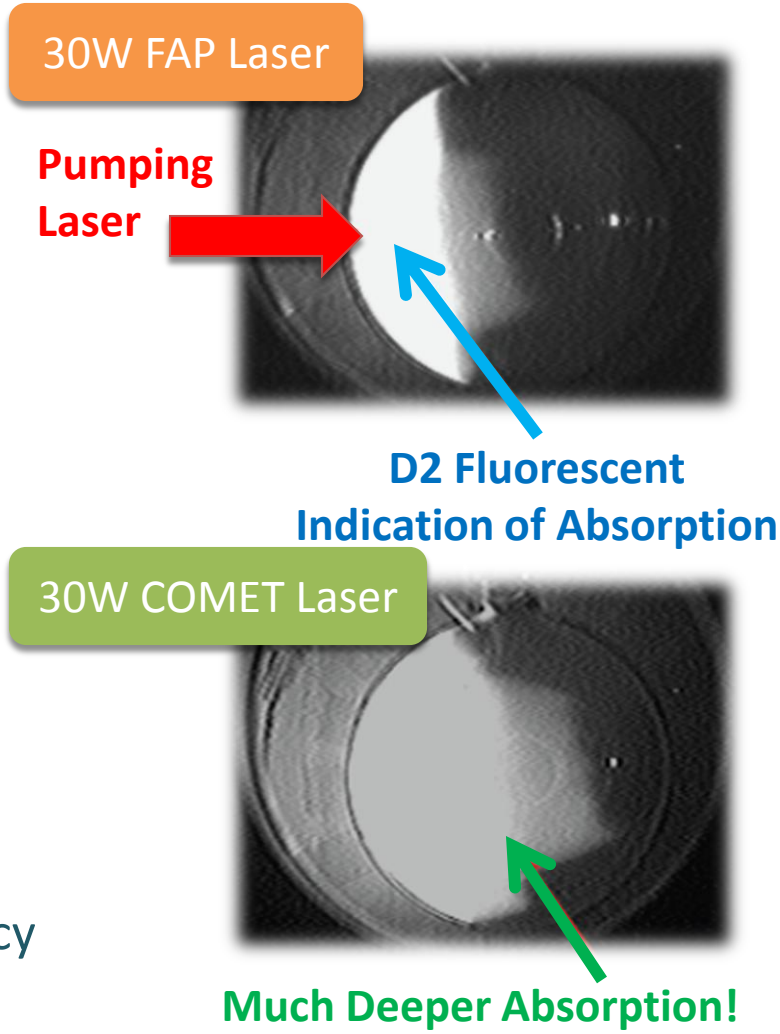


- 10 atm ^{3}He, Rb/K alkali mixture
- Luminosity with 15 μA electron beam
  - $L(n) = 10^{36}$ cm^2/s

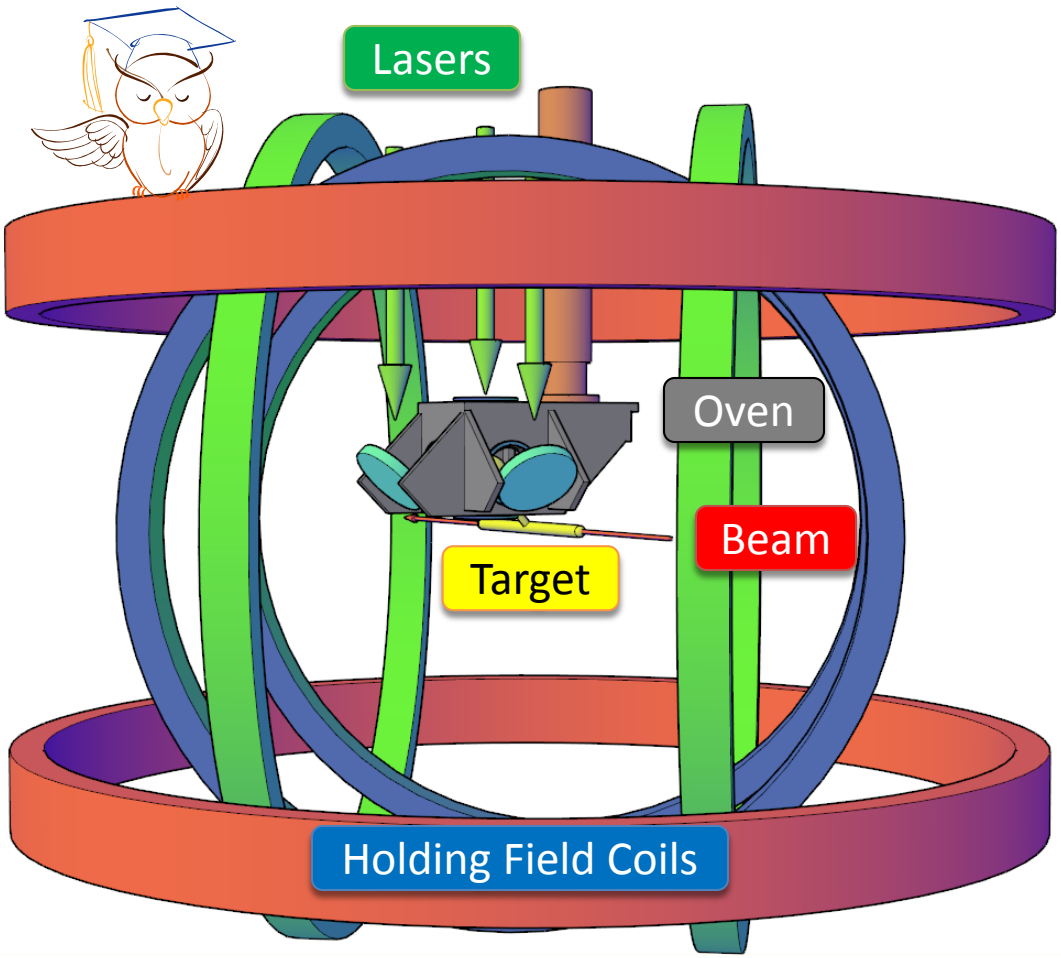
World Record

Narrow Width Lasers

- Rb D1 ($S_{1/2} \rightarrow P_{1/2}$) Width
  - $\Delta\nu$ = 0.3 nm
- COHERENT FAP diode lasers were originally used
  - $\Delta\nu$ = 2.0 nm
  - A lot of power wasted
  - Unabsorbed laser depolarizes target through thermal process
- NEWPORT recently brought new COMET narrow width diode laser
  - $\Delta\nu$ = 0.2 nm
  - Much more optical pumping efficiency
  - Improves target polarization to 65%



Target System Since October 2008



- New **COMET** lasers

  Narrow line with laser make more efficiency optical pumping.

- 3D Holding Field Control

  New **vertical** coil together with existing horizontal coils create holding field in any direction and cancel out any residue field.

- New Oven and Optics

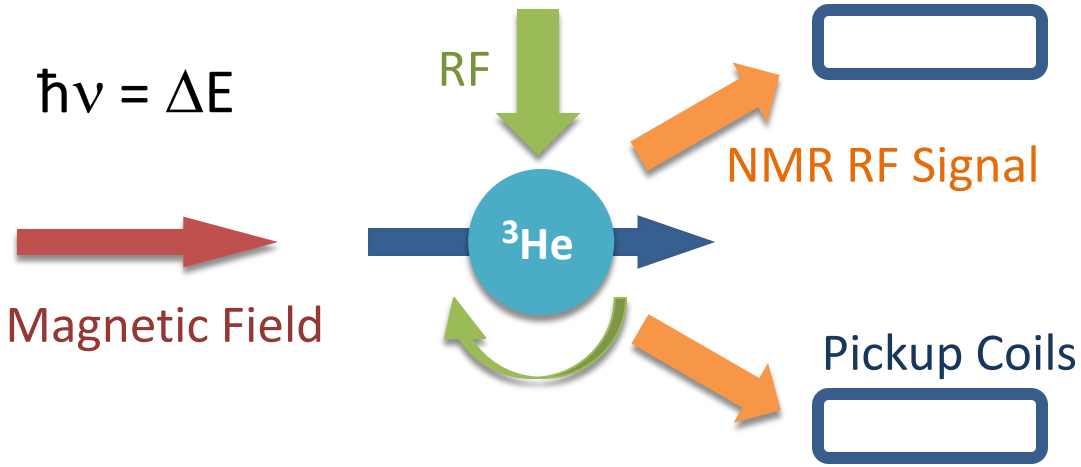
  Better insulation, lighter weight and **all three** pumping directions.

- A Smart Target

  Automatic spin flip every **20** minutes using Adiabatic Fast Passage (AFP). Log and alarm.

NMR Polarimetry

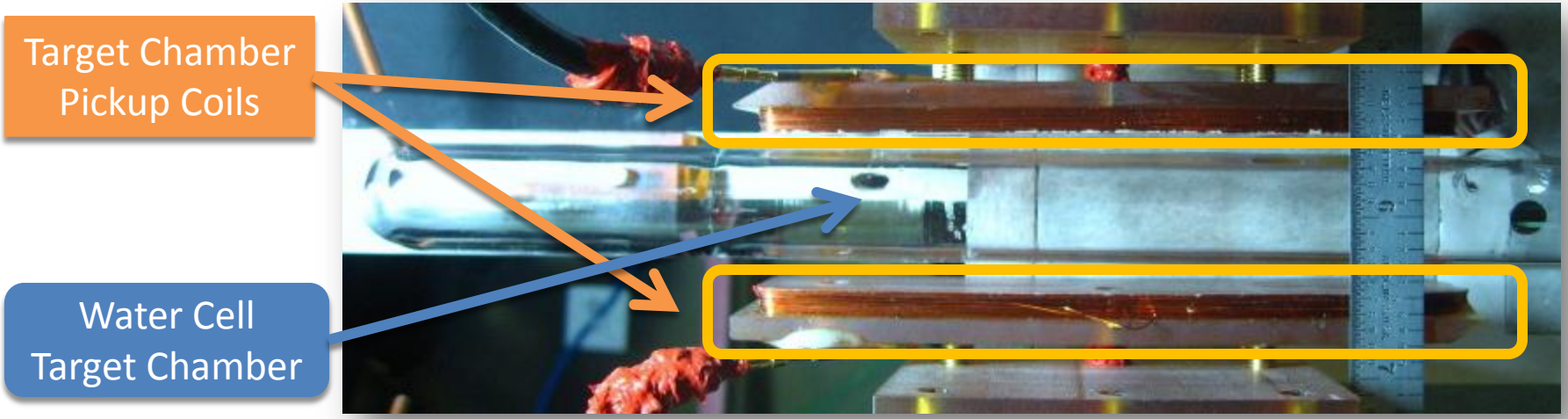
- **NMR**: Nuclear Magnetic Resonance
  - Measures the RF signal strength radiated by ^{3}He nuclei while being flipped through **adiabatic fast passage** (**AFP**).



  - Relative measurement, calibrated by **Water NMR** or **EPR**.
  - Free measurement while doing AFP spin flips.
  - 2 pairs of RF coils, 5 pairs of pickup coils (2 on TC & 3 on PC), field or frequency sweeps.

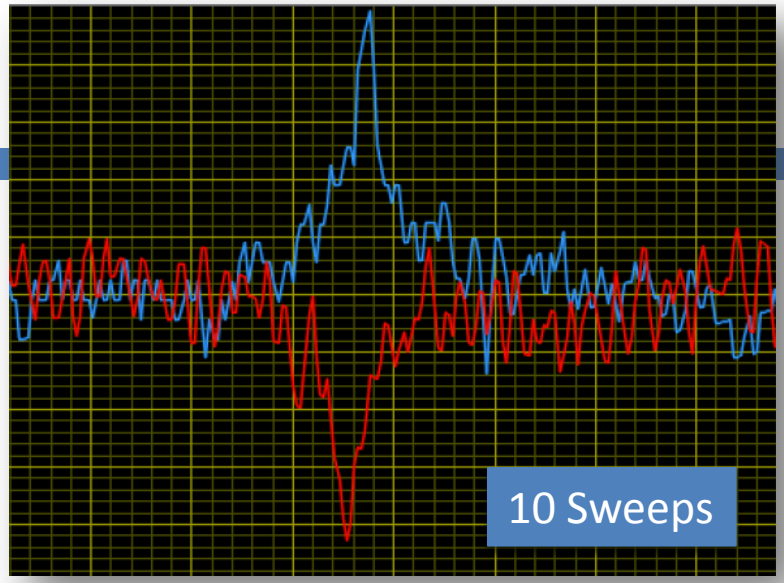
Water Calibration

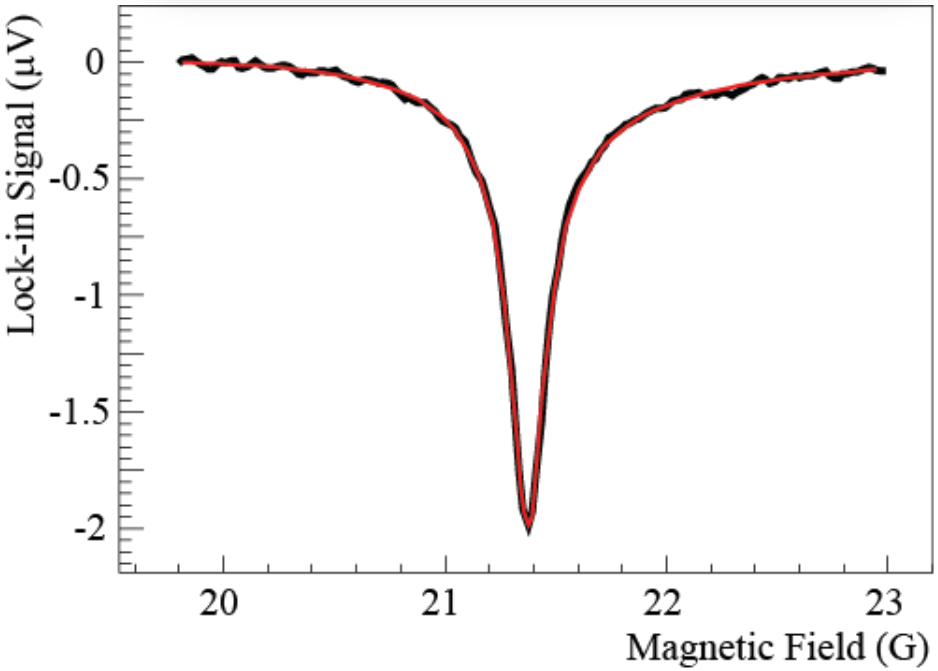
- Well known proton polarization in water
  - Water cell has same geometry as ^{3}He cells
  - A calibration of flux through pick-up coils
- A great challenges from background noises!
  - 5 order of magnitude smaller than ^{3}He signal
  - Only signals from target chamber are big enough ☹



Water Signal

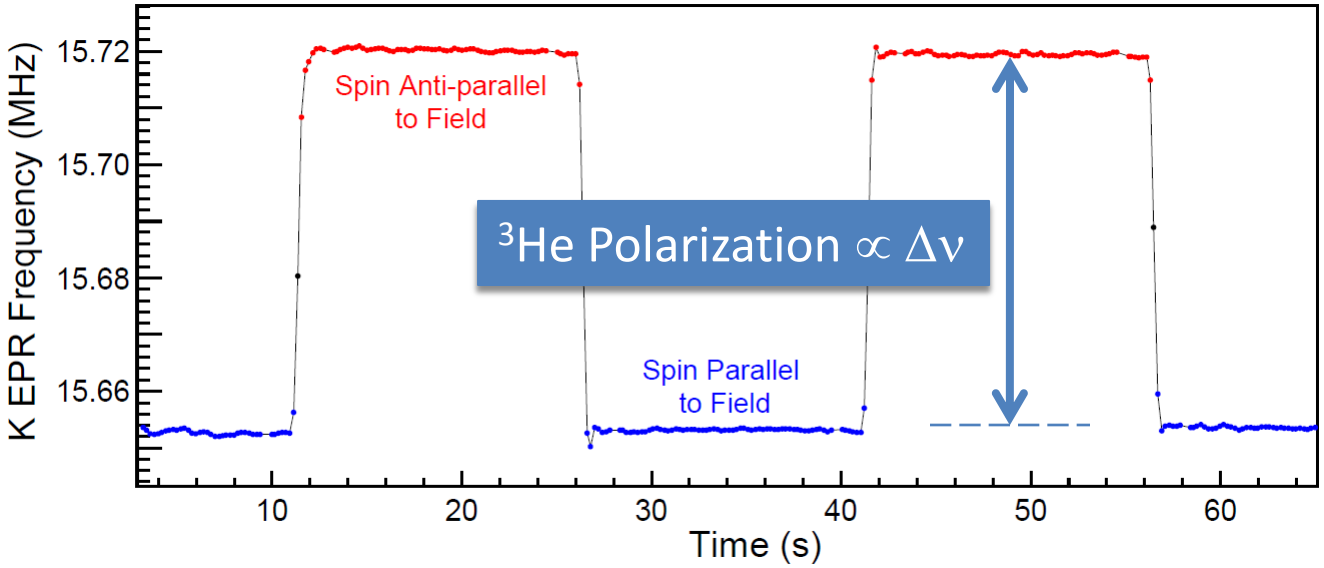
- Improvements
  - New pickup coil design for fine tuning.
  - New NMR code for faster data taking.
- Results
  - Clear signal after 10 sweeps.
  - Final statistics uncertainty better than 1%.





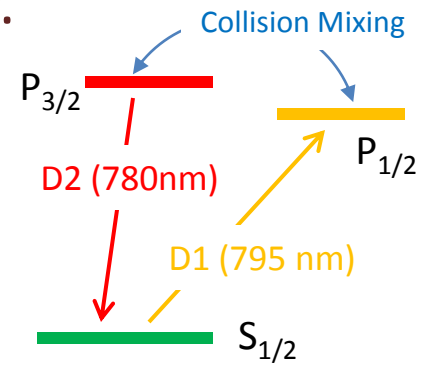
EPR Polarimetry

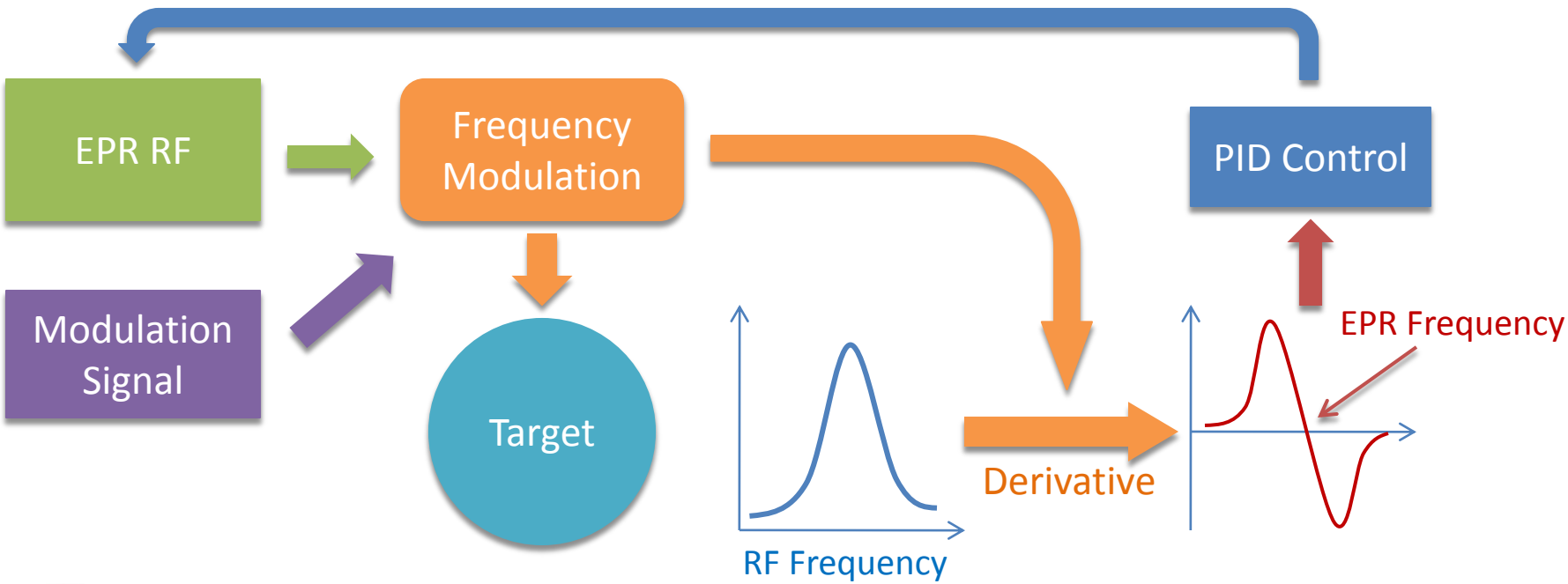
- **EPR**: Electron Paramagnetic Resonance
  - Measures the frequency shift of Zeeman splitting of alkali atoms with ^{3}He spin parallel and anti-parallel to the holding field.
  - Measures pumping chamber polarization only.



Lock of EPR Frequency

- A PID feed back loop is used to lock EPR frequency.
- EPR RF depolarizes the alkali atoms.
  - PID feedback: Any signal changing with EPR frequency.
  - Common choice: D2 light ($P_{3/2} \rightarrow S_{1/2}$), increases as alkali atoms absorb more laser.



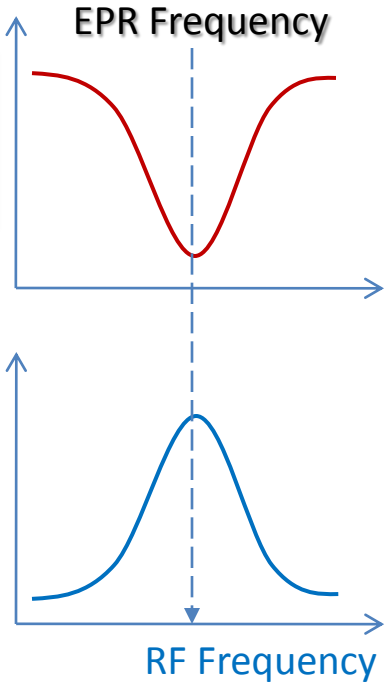


D1 EPR Signal

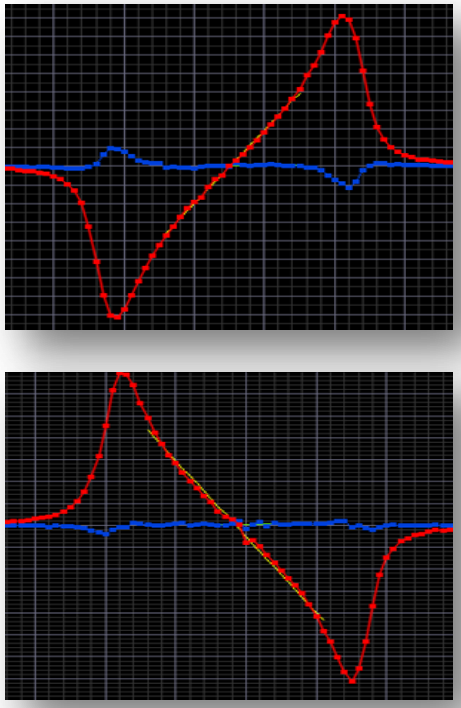
- D1 signal: absorption of pumping laser
  - Drops (more absorption) as alkali polarization drops.
  - Many time stronger than D2 signal!
  - Impossible to use for traditional FAP laser: too much background.
  - Possible with COMET laser!

D1 Signal: Absorption

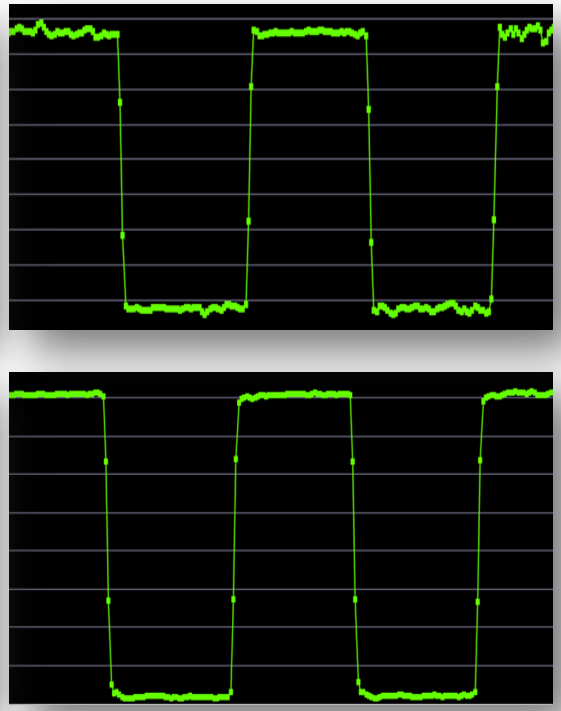
D2 Signal: Emission



FM Sweep

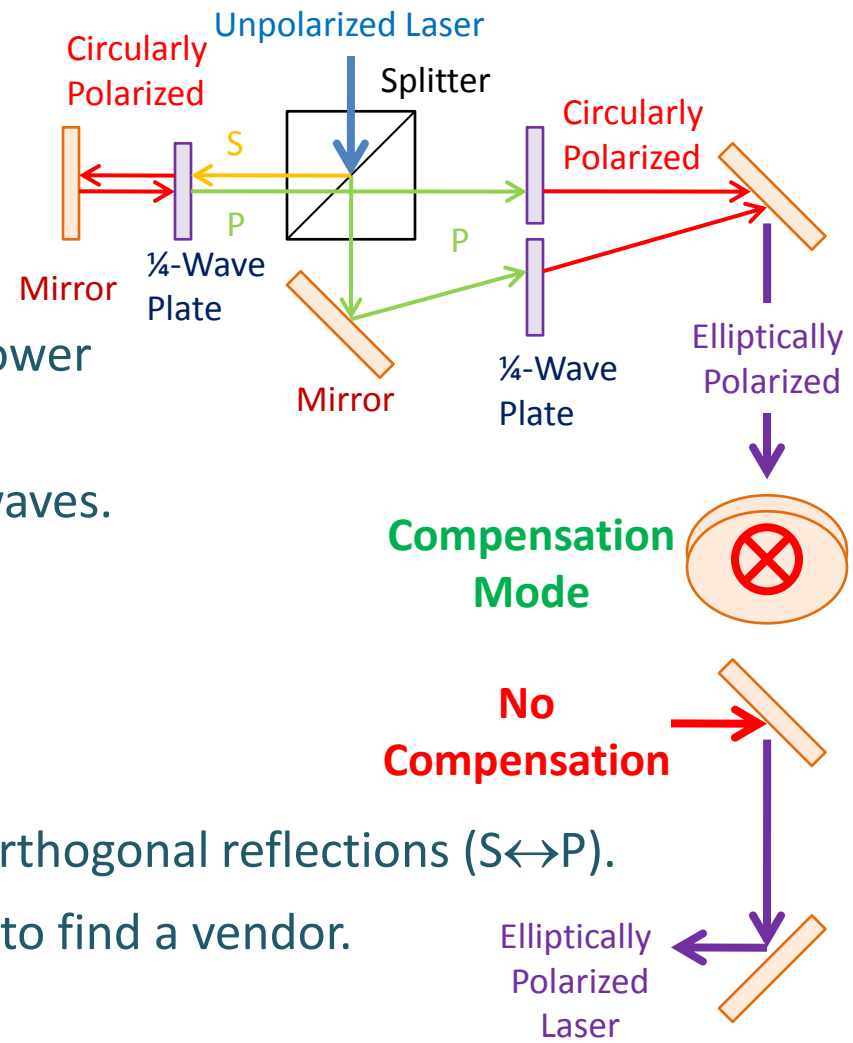


EPR AFP



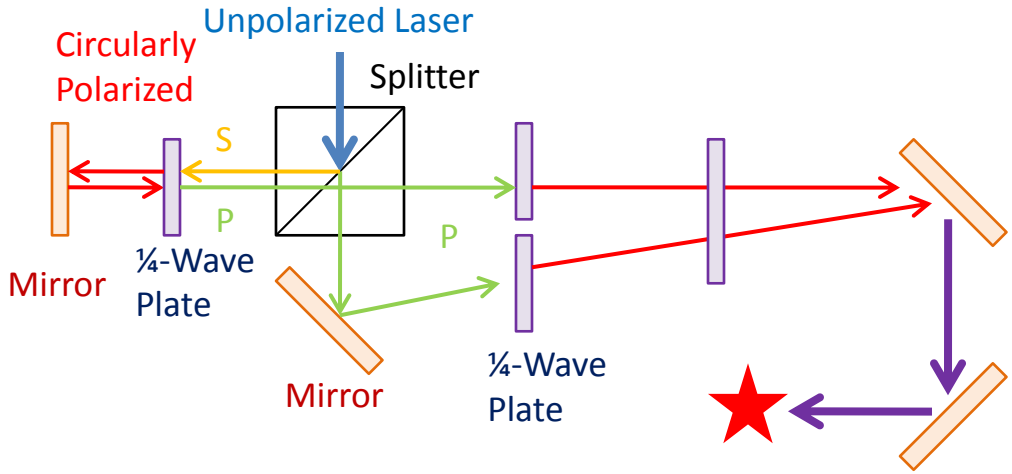
Problem with Non-Phase-Conservative Mirrors

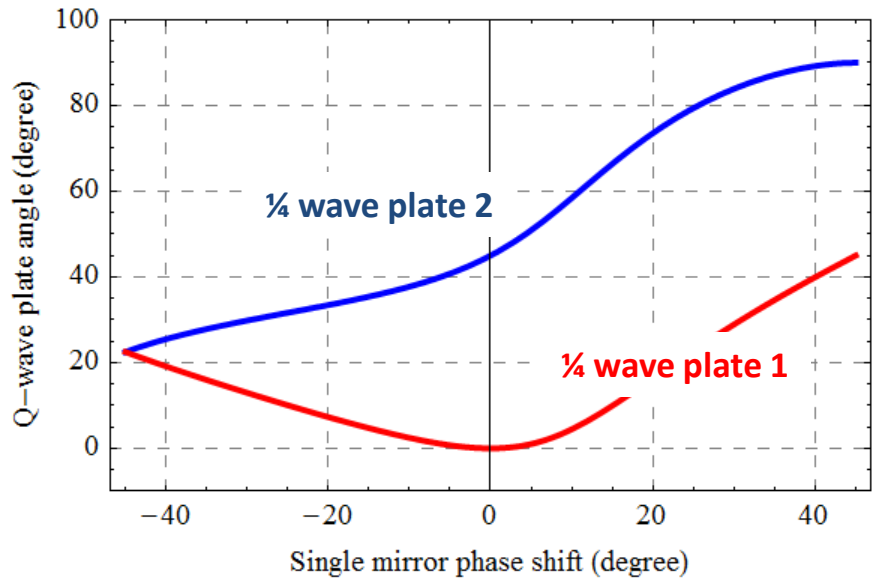
- Unpolarized laser gets polarized after optics first.
- Finally send laser to pumping chamber by mirrors
  - Our dielectric mirrors conserve power but NOT phase!
  - Different phase shift for S and P waves.
  - Circular → elliptical polarization.
  - Strong wave length dependence.
- Solutions
  - Compensation mode: 2 mirrors, orthogonal reflections (S↔P).
  - Phase-conservative Mirrors: hard to find a vendor.
  - Wait, we are using COMET lasers!



Add an Extra Degree of Freedom

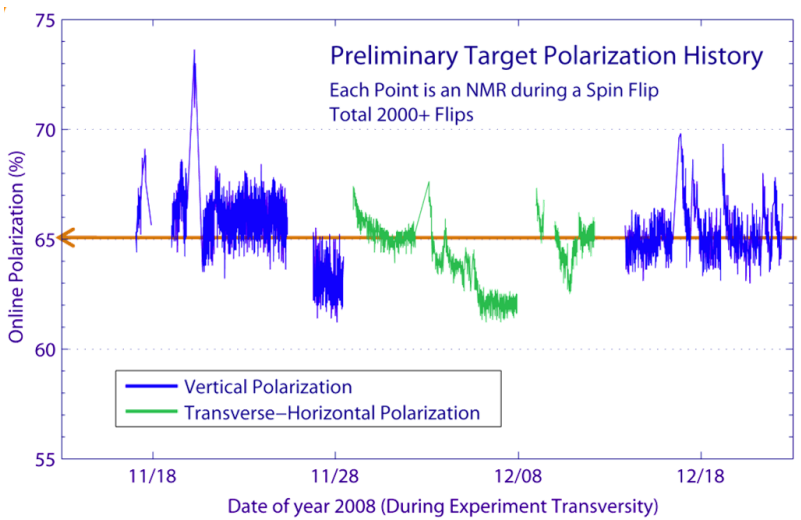
- Maybe, we can add another ¼ wave plate into the setup?
- After some math ...
- A perfect solution for narrow width lasers:
  - Theoretical 100% polarization with single wavelength.
  - > 99% with actual setup.
  - Used in one experiment.



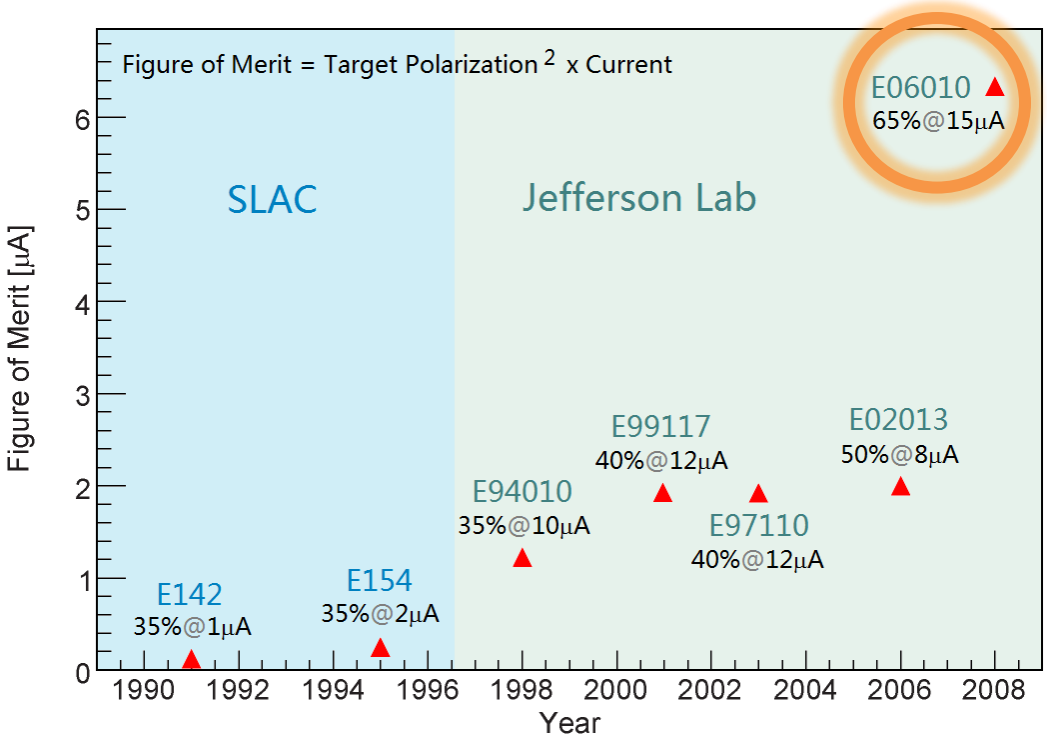


Target Performance

- Reached a steady **65%** polarization with 15 μA beam and 20 minute spin flip! **A NEW RECORD!**
- A series of experiments used this target:
  - Neutron Transversity
  - Neutron structure function: d_2^n
  - Two photon exchange: A_y
  - ^{3}He structure: e(^{3}He, e'd)p



History of Figure of Merit of Polarized ^{3}He Target



Acknowledgement

- JLab Polarized ^{3}He Target Group
  - **Jian-Ping Chen** (JLab), **Chiranjib Dutta** (Kentucky), **Joe Katich** (W&M), **Yi Zhang** (Lanzhou), **Jin Huang** (MIT), Xiaohui Zhan (MIT), Huan Yao (Temple), Xiaofeng Zhu (Duke)
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