Optical Pumping for Beta-decay Neutrino Helicity Tests

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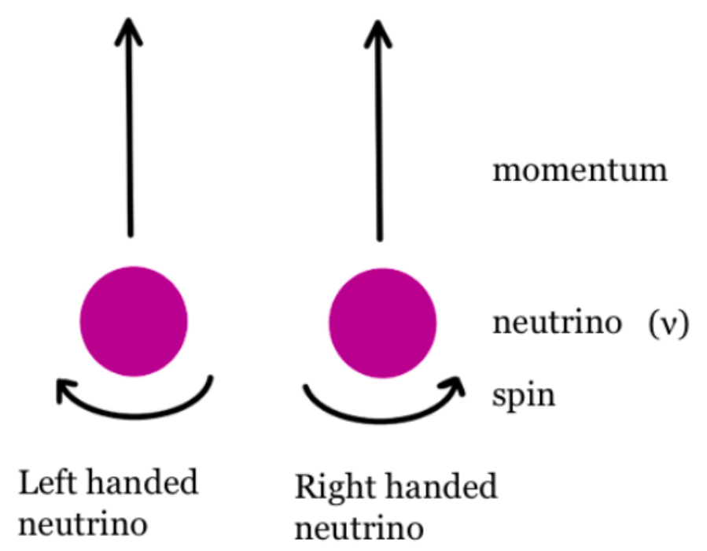
ABSTRACT

We seek to improve our measurements of beta and neutrino asymmetry of direction with respect to the nuclear spin, similar to the first measurements that demonstrated that parity was broken by the weak interaction. Our decay measurements depend on achieving high atomic (hence nuclear) spin polarization of laser-cooled potassium atoms. This poster summarizes long-term improvements of circularly polarized light quality for optical pumping, magnetic field switching from MOT configuration to constant field, and measurements of the resulting spin polarization of stable laser-cooled 41K atoms. We've improved diagnostics by replacing an absorptive polarizer with a plate beamsplitter polarizer. Characterization of the plate beamsplitter polarizer showed similar behavior in both directions on the transmitted beam: this allows us to extract the light from two counterpropagating beams after they optically pump the atoms. We also characterized and implemented fiber-coupled electro-optic modulators to add frequency sidebands onto the optical pumping lasers. This improves reliability over direct RF pumping of the laser diode, which creates frequency mode instability in an external cavity and complicates the number of Doppler-free peaks in saturation spectroscopy. For the analysis of the nuclear polarization of the trapped atoms, we adapted a scheme for estimating the polarization [3] of 41K based on time dependence of atomic excitation after the start of optical pumping.

Motivation



TRINAT investigates the Standard Model's predictions for the weak interaction by looking at parity violations.

- All known neutrinos are left-handed
- Measuring the angle distributions tests whether there are right handed neutrinos

$$W(\theta_\nu) = 1 + PB_\nu \cos(\theta_\nu)$$

Where B_ν is neutrino asymmetry

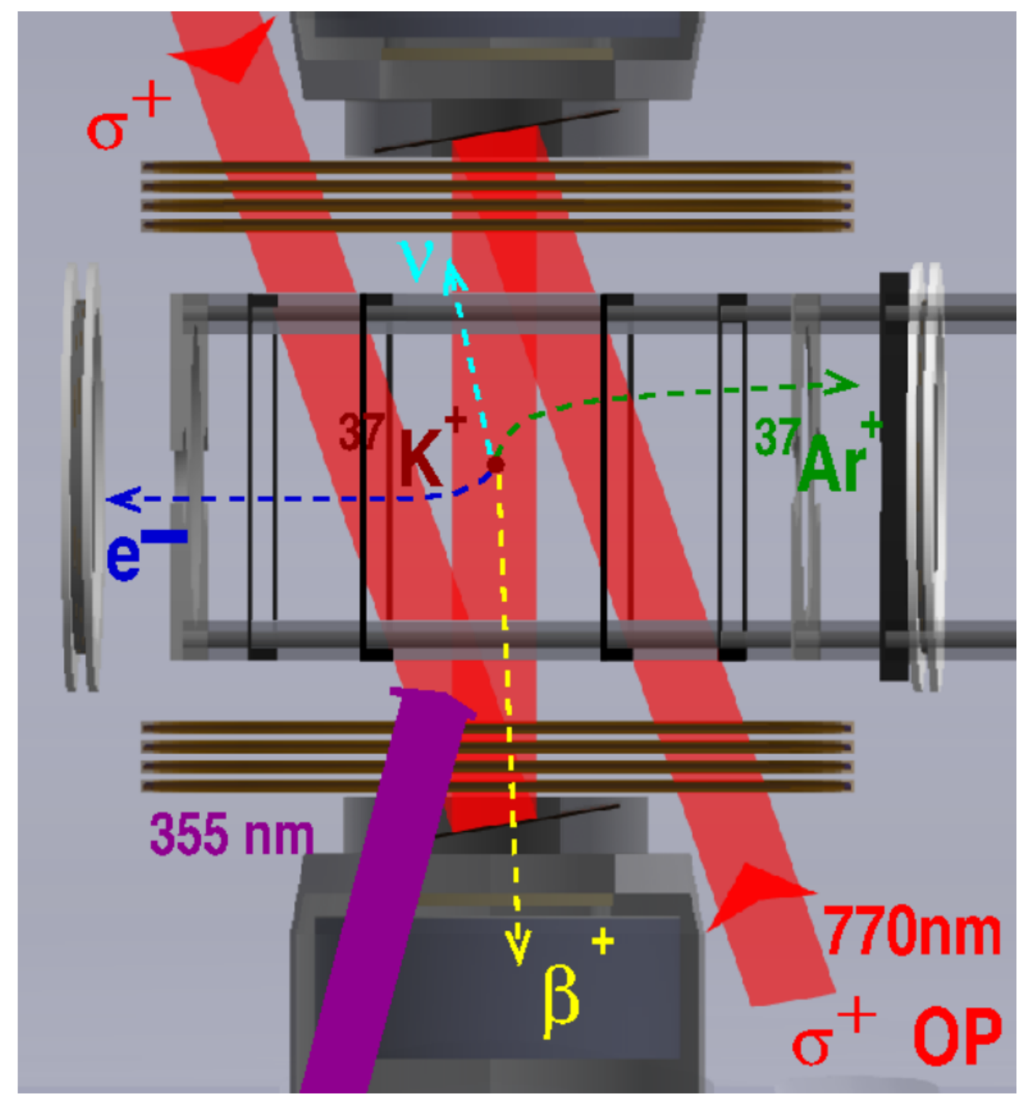
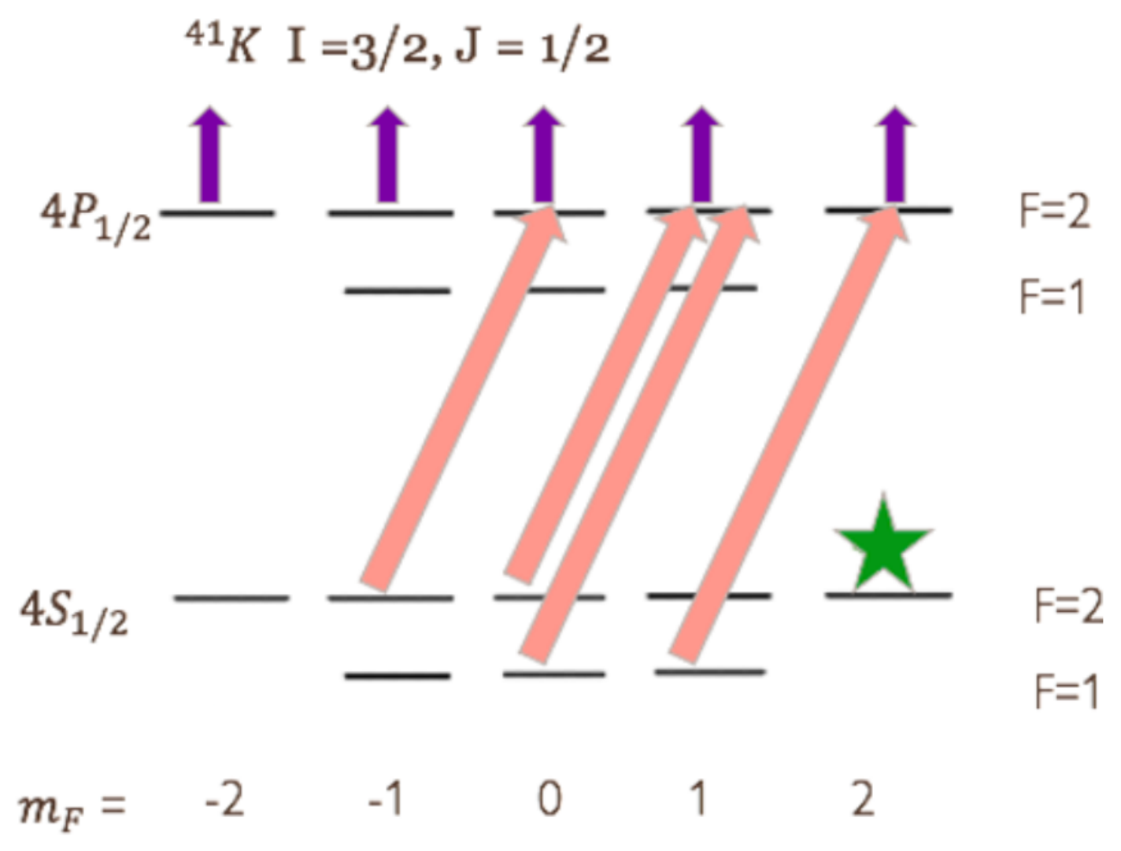


Fig. 1: ν can't go directly up in the above geometry due to angular momentum conservation

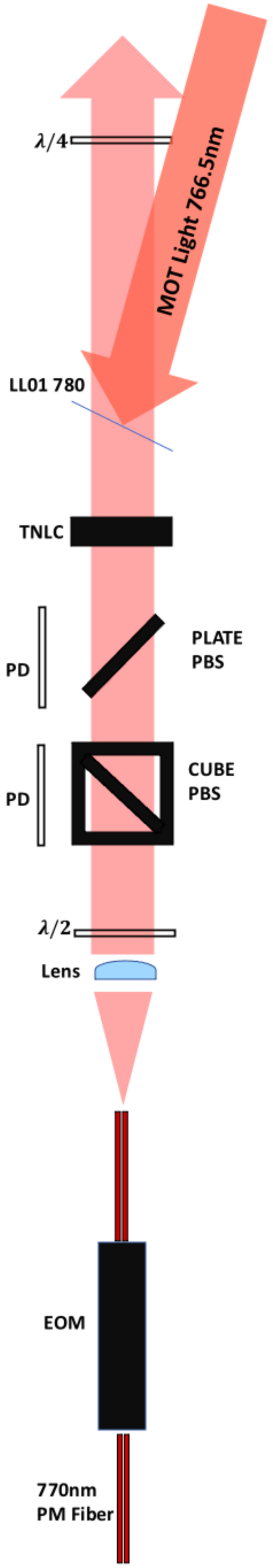
Optical Pumping



The atoms in the MOT are polarized by using optical pumping to move the atoms into the fully-stretched state.

- 770nm circularly polarized laser excites atoms one hyperfine splitting to the right
- Atoms then decay down to $F = 1$ or $F = 2$ state
- Process continues until atoms are collected in $|F = 2, m_F = +2\rangle$ (fully-stretched state)

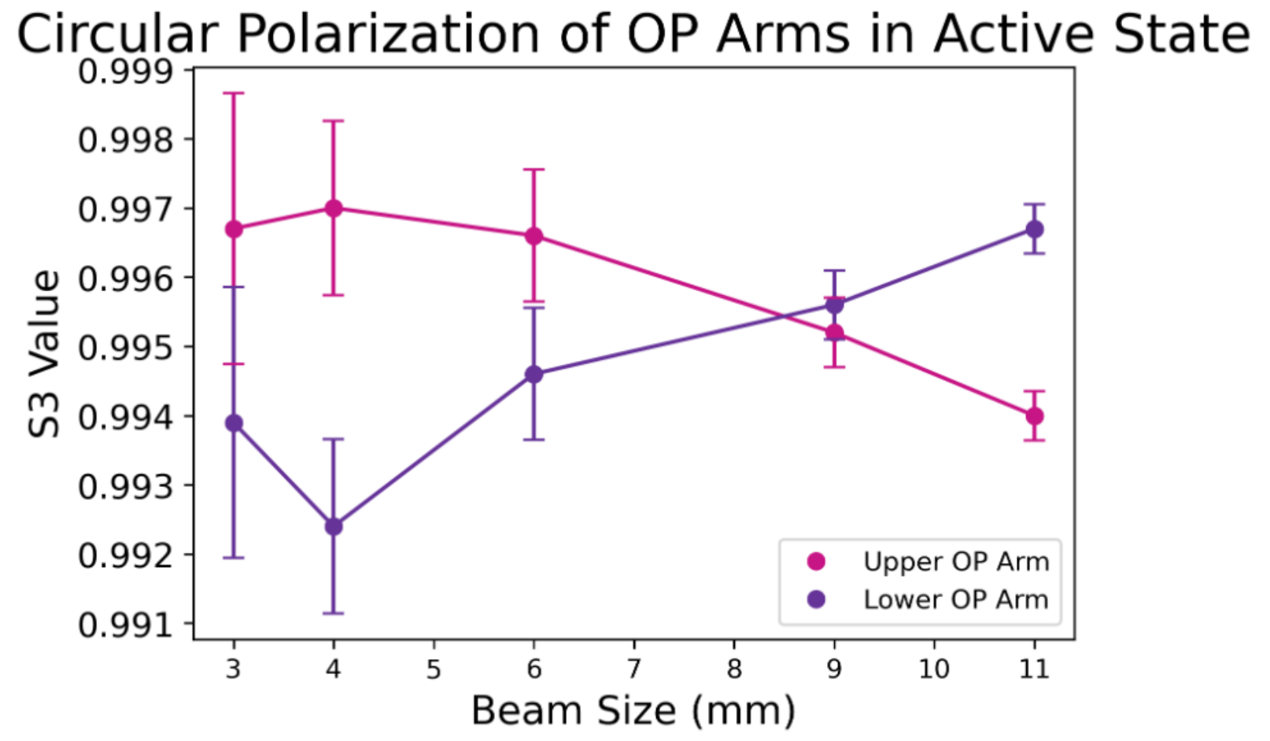
Fig. 2: The hyperfine structure of Potassium 39, 41 and 45. The green star represents one of the fully stretched states. The red lines show possible excitation paths due to optically pumping with right circularly polarized light.



Experimental Setup: OP Arm

We optically pump using a 770nm laser. Two counter-propagating beams are used to stop atoms sailing. The TNLC, EOM, PBS and QWP all had to be carefully characterized to ensure good light polarization.

1. **EOM**. Adds sidebands onto the laser
2. **Cube PBS and Photodiode**. Monitors and corrects for PM polarization drifts
3. **Plate PBS and Photodiode**. Monitors transmission of opposing beam, minimizes reflections
4. **Twisted Nematic Liquid Crystal**. Allows us to quickly convert between states of linear polarization by applying a voltage across the TNLC
5. **LL01 780nm**. Combines the OP light and the MOT light
6. **Quarter Wave Plate**. Converts linearly polarized light to circularly polarized light.

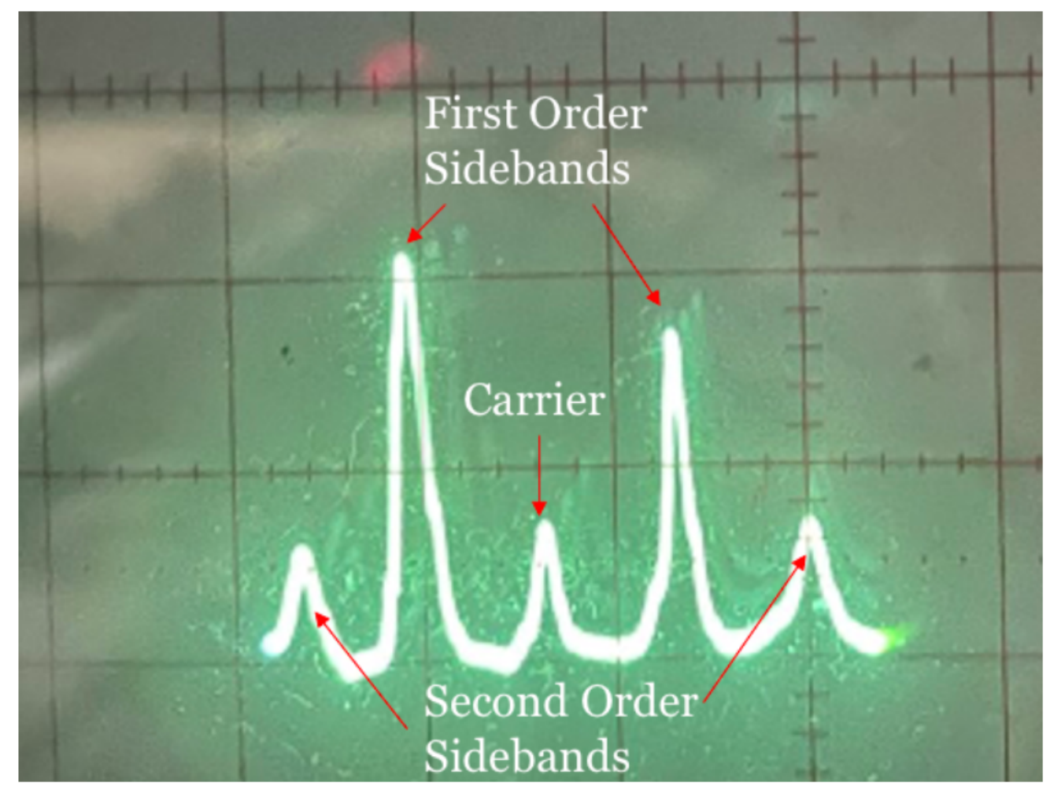


S3 projects to 99.6 % polarization for 37K

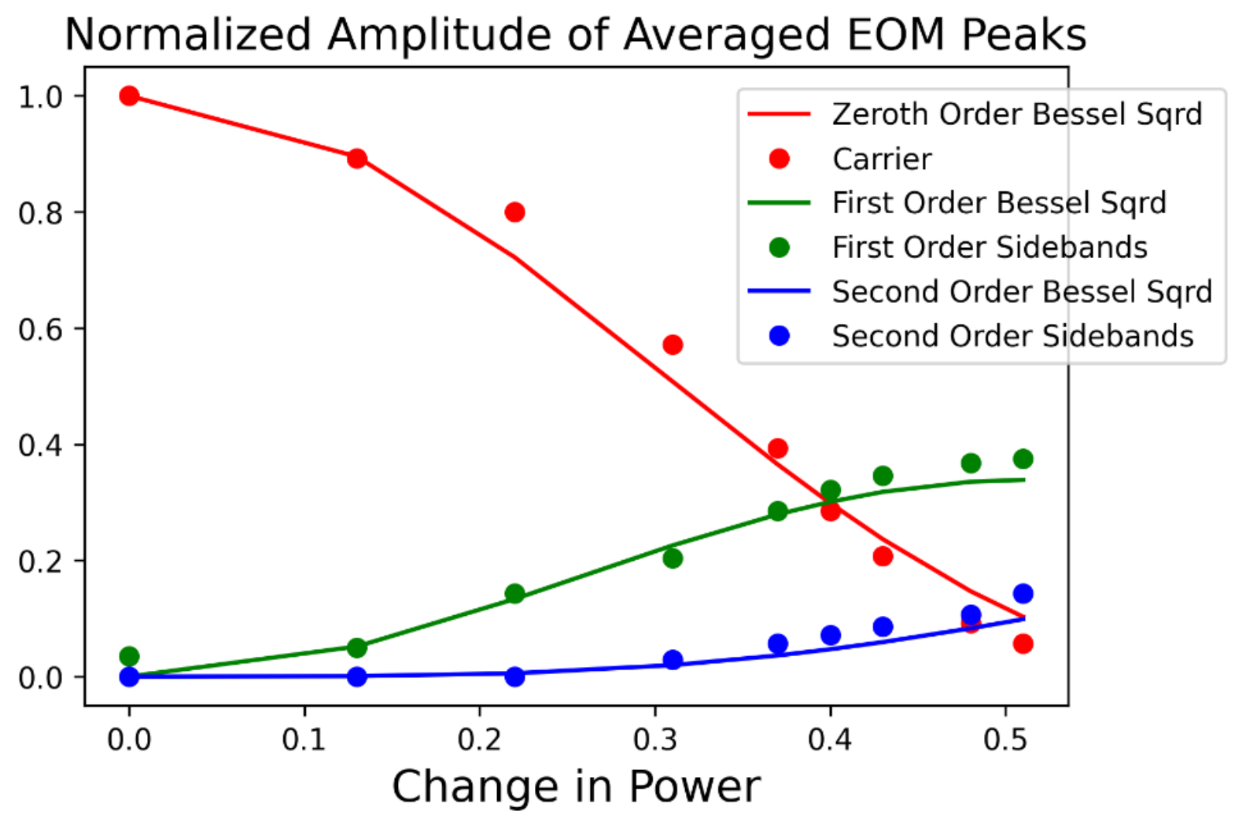
Fiber-Coupled EOM

Since atoms are pumped from $F = 2 \rightarrow F' = 2$ and $F = 1 \rightarrow F' = 2$, there are slightly different frequencies required and we use an **E**lectro-**O**ptic **M**odulator to achieve this. An EOM avoids using direct RF modulation which

- Makes sideband location tuning easier
- Increases the lock stability
- Allows for 3.3 GHz splitting required for 47K



- Use a Fabry-Perot Interferomter to view frequencies, viewed on oscilloscope
- The sidebands are asymmetrical, likely due to AM superimposed on the FM [2]. We average them to remove the AM component when doing the fit below.
- To avoid standing waves, will sweep sidebands and use a 10 m PM fiber.

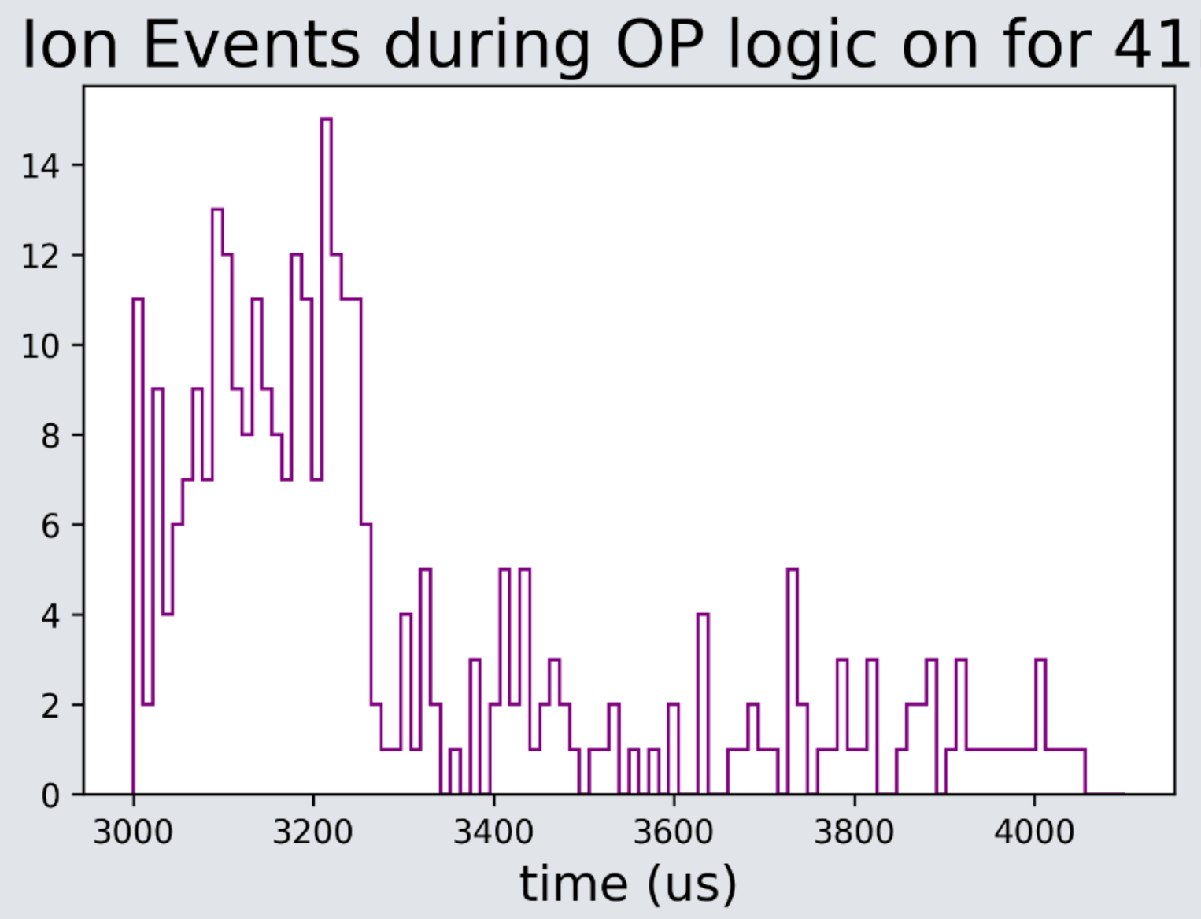


$$\begin{aligned} E &= J_0(\beta)E_0 \sin \omega_0 t \\ &+ J_1(\beta)E_0 \sin(\omega_0 + \omega_m)t \\ &- J_1(\beta)E_0 \sin(\omega_0 - \omega_m)t + \ldots \end{aligned}$$

Measuring the Polarization

Excited atoms in the $P_{1/2}$ state in the MOT are photoionized by a 355nm pulsed laser. The events from the resulting ions and electrons are monitored, and the rates are used to deduce the polarization of the atoms. A full calculation is laid out in Ref[1].

Photoion Rates



More atoms are photoionized when the polarization is low (start of cycle) rather than when the polarization is high (end of cycle). The ratio between the tail and the peak is used to estimate the polarization.

Estimating the Polarization

- Photoionization rate itself has no sensitivity to the distribution of the unpolarized population in the $S_{1/2}$ state → need to model the sublevel distribution of the partially polarized atoms [3]
- The polarization rate is proportional to $1 - \frac{7}{8}r$ since there are 8 states in the $S_{1/2}$level, where r is the tail to peak ratio
- The populations in each state should be proportional to its nuclear polarization and the relative transition strengths. For example, comparing the $|F = 2, m_F = 1\rangle$ and the $|F = 1, m_F = 1\rangle$ states, the transition from the same $P_{1/2}$ state is 3x stronger to the $F = 1$ state.

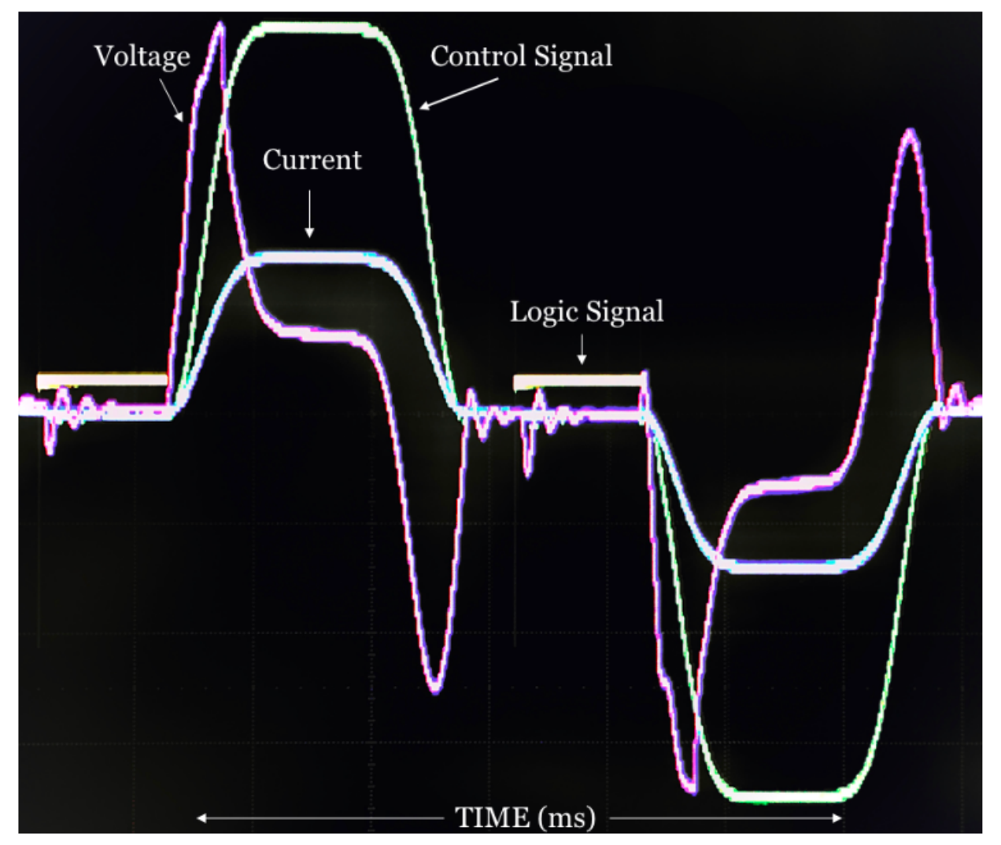
$$P \approx 1 - \frac{21}{64}r \qquad P = 0.96 \pm 0.04$$

We must minimize the transverse B-fields

In Progress: Magnetic Field Control

Two different magnetic fields are required during OP time and during the MOT time.

- Concerned about long-term eddy currents that would spoil the polarization of the atoms
- Need magnetic field during OP time to stay constant (described by a square wave).
- Magnetic field during trap time needs to flip every second cycle to reduce eddy currents.



References

[1] *B Fenker et al 2016 New J. Phys. 18 073028.*

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