Optical Pumping for Beta-decay Neutrino Helicity Tests

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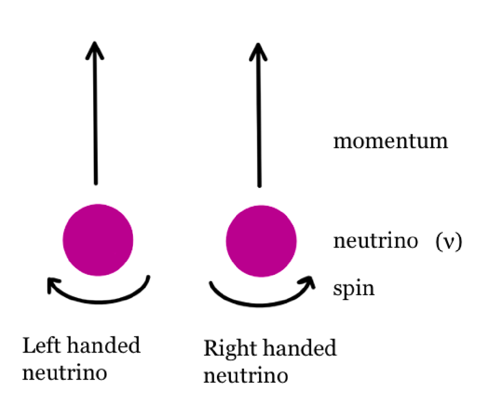
ABSTRACT

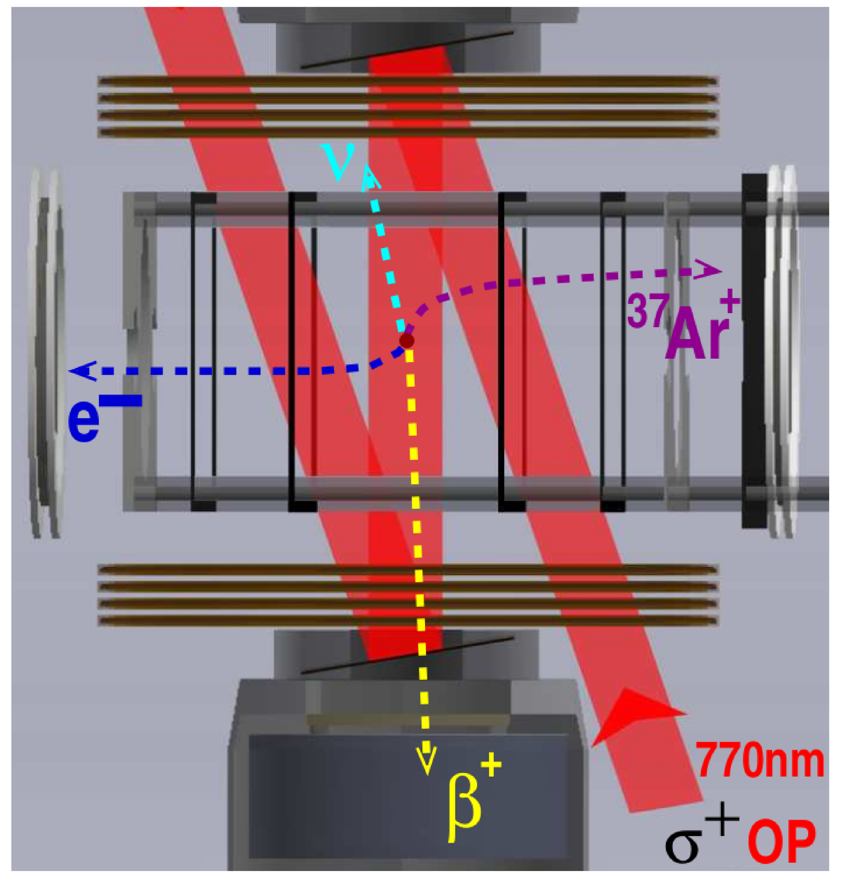
We seek to improve our measurements of beta and neutrino asymmetry of direction with respect to the nuclear spin, similar to the first measurements that demonstrated that parity was broken by the weak interaction. Our decay measurements depend on achieving high atomic (hence nuclear) spin polarization 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 (D. Roberge, M.Sc. UBC 2006) of 41K based on time dependence of atomic excitation after the start of optical pumping.

Motivation

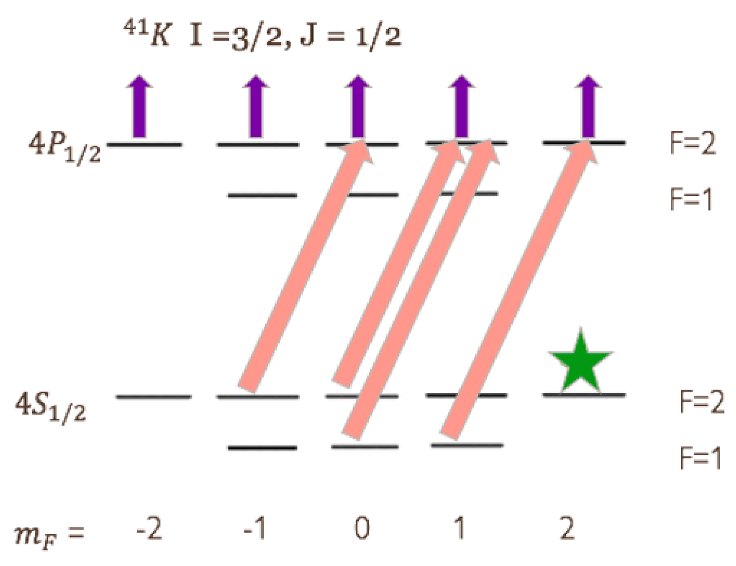


TRINAT investigates the Standard Model's predictions for the weak interaction by looking at parity violations. TRINAT searches for forbidden right-hand neutrinos by looking at β-decay of Potassium Isotopes. Due to the violation of parity, there is an asymmetry in the direction of the particles emitted after β-decay, and we must know the polarization in order to determine the asymmetry.

$$W(\theta) = 1 + PA_{\beta}cos(\theta)$$

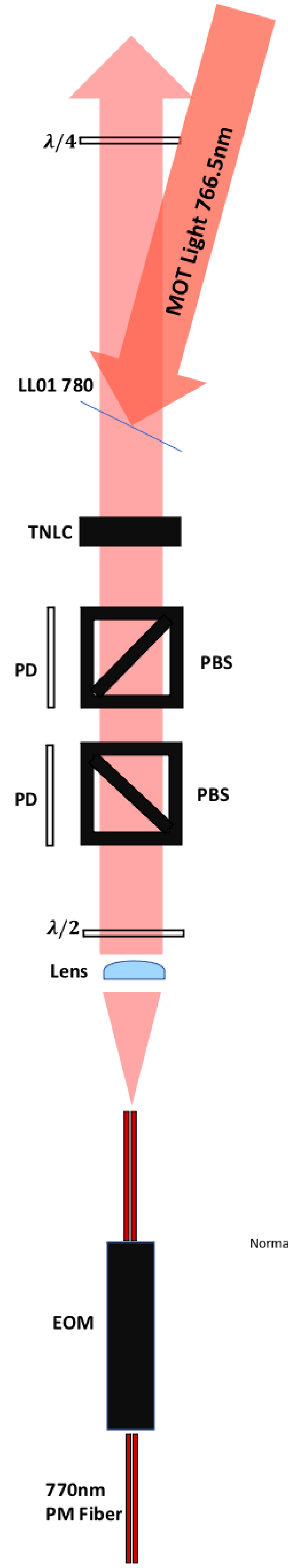


Optical Pumping



The atoms in the MOT are polarized by using optical pumping to move the atoms into the fully-stretched state. A 770nm circularly polarized laser is used so each cycle the excited atoms will be pushed one hyperfine splitting to right (for right circularly polarized light). The atoms then decay back down to the F=1 or F=2 state, and the process continues until the atom is stuck in the F = 2, mF = +2 state, called the fully-stretched state.

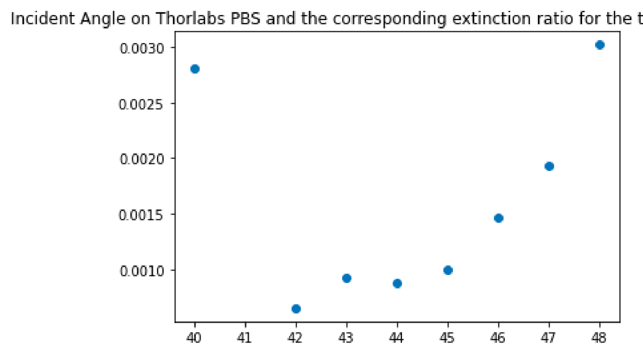
The hyperfine structure of Potassium 39, 41 and 45. The green star represents one of the fully stretched states. The red lines show possible excitation paths due to optically pumping with right circularly polarized light.



Experimental Setup: OP Arm

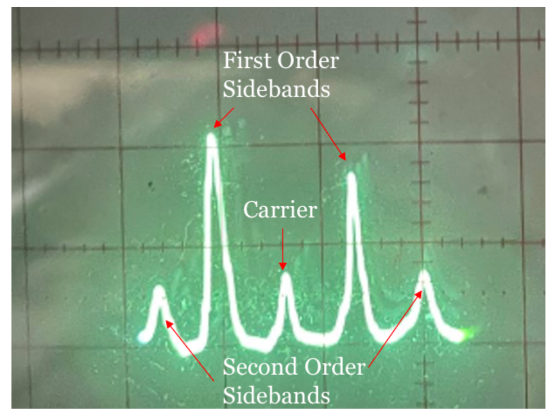
We optically pump using a 770nm laser. The TNLC, EOM, PBS and QWP all had to be carefully characterized to ensure good light polarization.

1. **EOM**, Adds sidebands onto the laser
2. **Polarizing Beamsplitters and Photodiodes**. Ensures good polarization of the light going through, and reflects away and monitors the opposing beam.
3. **Twisted Nematic Liquid Crystal**. Allows us to quickly convert between states of linear polarization by applying a voltage across the TNLC
4. **LL01 780nm** Combines the OP light and the MOT light
5. **Quater Wave Plate**. Converts linearly polarized light to circularly polarized light.

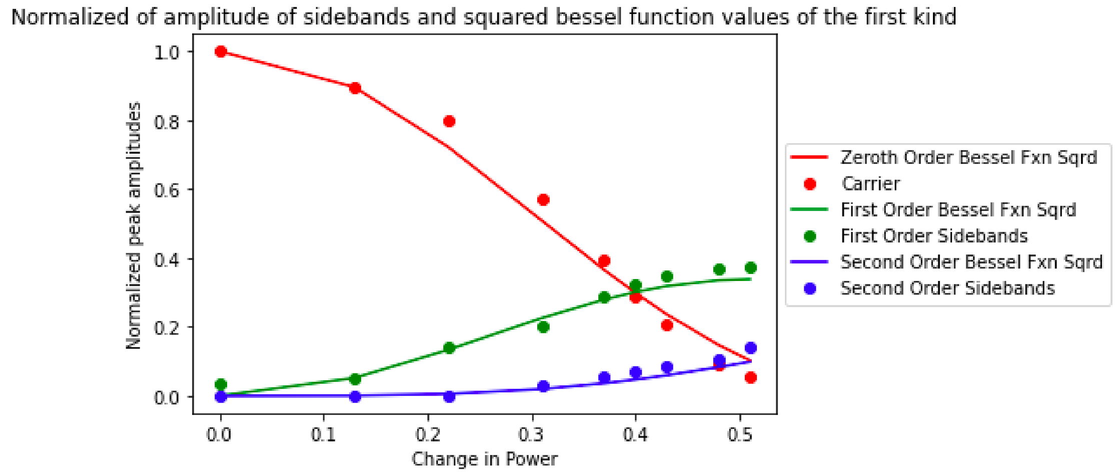


Fiber-Coupled EOM

Since atoms are pumped from both the F = 2 and the F = 1 state to the 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 allows for easier sideband location tuning as well as increases the lock stability. This allows us to do the the 3.3 GHz splitting required for 47K.



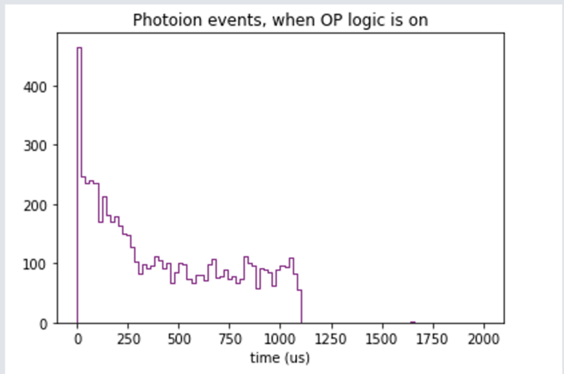
Used a scanning Fabray-Perot Interferometer to view frequencies and viewed on oscilloscope. For both the first and second order, the sidebands are asymmetrical, likely due to AM modulation superimposed on the FM modulation (cite paper). We average them to remove the AM component when doing the fit below.



Measuring the Polarization

Excited atoms in the P1/2 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.

Photoion Rates



More atoms are photoionized when the polarization is low rather than when the polarization is high. Therefore we see a peak of ions at the start of a cycle and then see a drop later on. The ratio between the tail and the peak is used to estimate the polarization.

Estimating the Polarization

Since the photoionization rate itself has no sensitivity to the distribution of the unpolarized population in the S1/2 states, we need to model the sublevel distribution of the partially polarized atoms.

There are 7 out of 8 possible states in the S1/2 level that are not accounted for by the photoionization rate. Therefore, we expect the polarization rate to to be proportional to $1 - \frac{7}{8}r$, where r is the tail to peak ratio.

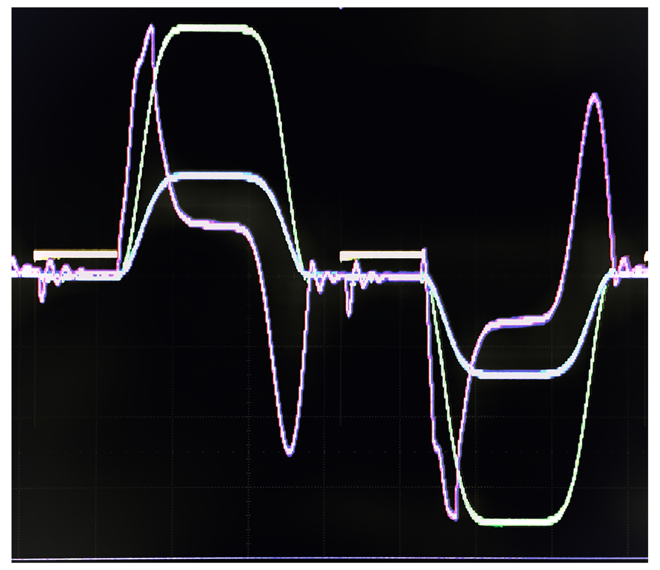
We also expect the populations in each state to be proportional to its nuclear polarization and the relative transitions strengths. For example, comparing the |F=2, mF=1> and the |F=1, mF=1> states, the transition from the same P1/2 state is 3x stronger to the F=1 state.

$$P \approx 1 - \frac{21}{64}r$$

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

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[2] S. Kobayashi, Y. Yamamoto, M. Ito, and T. Kimura. Direct frequency modulation in aigaas semiconductor lasers. *JOURNAL OF QUANTUM ELECTRONICS*, QE-18(4), 1982.