Measurement of Spin-Polarized Observables in the $\beta^+$ decay of $^{37}$K

Benjamin Fenker

Texas A&M University Cyclotron Institute

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Outline

- Brief physics goals
- Outline of TRINAT’s double-MOT system
- Overview of recent run
Motivation: Fundamental Symmetries

- Standard model weak interaction is strictly Vector − Axial-Vector (V − A)
  - Parity is conserved in strong and EM interactions but violated in weak ones?
  - $SU(2)_L \otimes U(1)_Y \rightarrow SU(2)_R \otimes SU(2)_L \otimes U(1)_Y$
- Angular correlations in $\beta$-decay are sensitive to new physics

$$\frac{d^5 W}{dE d\Omega_e d\Omega_\nu} \sim 1 + a_{\beta\nu} \frac{\rho_e \rho_\nu \cos(\theta_{e\nu})}{E_e E_\nu} + b \frac{m_e}{E_e} + P \left( A_{\beta} \frac{\rho_e}{E_e} \cos(\theta_e) + B_{\nu} \frac{\rho_\nu}{E_\nu} \cos(\theta_\nu) \right)$$

Unpolarized

Polarized

$A_{\beta}^{SM} = -0.5702(6)$
$B_{\nu}^{SM} = -0.7692(15)$
TRINAT’s x2-MOT system

Collection trap is coupled to ISAC beamline

To avoid backgrounds from untrapped atoms, transfer to second trap for precision measurement
Overview

- Magneto-Optical Trap (MOT)
  - Provides a cold (∼ 1 mK), localized (∼ Ø1 mm) source of atoms
  - Shallow trap so products emerge unperturbed

![Diagram of Polarization Axis and Nuclear Detectors](Image)
Overview

- Magneto-Optical Trap (MOT)
- Optical Pumping Polarizes the Atoms
  - $\sigma^\pm$ lasers drive biased random walk towards $P_{\text{nucl}} = \pm 1$

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Overview

- Magneto-Optical Trap (MOT)
- Optical Pumping Polarizes the Atoms
- Nuclear Detectors
  - $\beta$-telescopes measure position, energy along polarization axis

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Types of events

- **Silicon Strip Detector**
- **BC408 Plastic Scintillator**

\[ \vec{B} \]

\[ \vec{E} \]

- **Shakeoff** e⁻
- **Ar⁺**

- **Nuclear polarization**

\[ \beta^+ \text{ in coincidence with either MCP} \]
\[ \nu \text{ is unobserved} \]

- **Only able to bias one MCP at a time**
- **Development to bias both will reduce background and systematics**
Types of events

- Monitor of trap position, size, temperature
- Ultra-clean measure of nuclear polarization
- Only able to bias one MCP at a time
- Development to bias both will reduce background and systematics
Photoionization signal

With time-of-flight and position cuts, this signal is very clean.
Optical Pumping

- Stretched state has $F = 2$, $M_F = 2$ or equivalently $I_z = \frac{3}{2}$, $J_z = \frac{1}{2}$
- An atom in this state is dark to the laser light and is trapped
- This state corresponds to total atomic and nuclear polarization

\[ \begin{align*}
\begin{array}{c}
F_z = -2 \\
F_z = -1 \\
F_z = 0 \\
F_z = 1 \\
F_z = 2 \\
\end{array}
\end{align*} \]

\[ \begin{align*}
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\} P_{1/2} \\
\{ F = 1 \\
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\end{align*} \]

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Energy

355 nm light

$P_{3/2}$

$P_{1/2}$

$S_{1/2}$

$F = 2$

$F = 1$

Angular Momentum $F_z$

$F_z = -2$ $F_z = -1$ $F_z = 0$ $F_z = 1$ $F_z = 2$
Polarized measurements must be done with MOT off. When MOT is off, cloud expands; therefore alternate counting/trapping.

Photoion events and duty cycle

- Quench B
- Optical Pumping
- MOT Collects, Cools

$\sigma \sim 0.9 \text{ mm}$
This great signal allows clean measurement of polarization. Online analysis gives \( P \gtrsim 0.990 \), but that is not even the full data set.

\[
t_{\text{op}} = 734 \ \mu s
\]
\[
B_{\text{bad}} = 0.012(5)(3)
\]
\[
\chi^2/581 = 1.044
\]
\[
\text{C.L.} = 22\%
\]
β+ energy spectrum

- Coincidence with silicon detector will reduce 511 background
- Have enough β-electron coincidences for < 0.5% measurement

300 μm thick 40 × 40 mm² silicon strip detector

β+ decay of 37 K
Recoil Ar\(^+\) time-of-flight spectrum

Recoiling Ar ion is swept to rMCP and detected in coincidence with \(\beta\). Time-of-flight spectrum can be used to measure

- Beta-neutrino correlation when \(^{37}\text{K}\) is unpolarized
- \(R_{\text{slow}}\) when \(^{37}\text{K}\) is polarized
Shake-off electron spectroscopy (S1446)

- Electrons deflected 1 cm by field of 2 G
- Position spectrum in perpendicular direction → energy spectrum
TRINAT’s x2 MOT system provides an ideal source of β-decaying atoms for studying fundamental symmetries of the weak interaction

- Highly spin-polarized with clean measurement of polarization
- Multiple physics observables all measured simultaneously
  - β-asymmetry with respect to polarization axis ($A_\beta$)
  - β-ν correlation ($a_{\beta\nu}$) with recoil time-of-flight spectrum
  - $R_{slow}$ is a sensitive probe of right-handed currents
  - Shakeoff electron energy spectrum down to a few eV

- Stay tuned, lots of analyses under way!
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- Thanks to the targets group for developing the HpTiC target
  - Consistently $2 \times 10^8 \ ^{37}K/s!$
  - 5-10 thousand atoms in the trap

- Thanks to Konstantin Olchanski and the DAQ group
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