Measurement of the $\beta$-asymmetry in the decay of magneto-optically trapped, spin-polarized $^{37}$K

Benjamin Fenker

TRIUMF Neutral Atom Trap
Texas A&M University Cyclotron Institute

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Acknowledgments

The TRINAT Collaboration

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- Texas A & M - Spencer Behling, Michael Mehlman, Dan Melconian, Praveen Shidling
- U of Manitoba - Melissa Anholm, Gerald Gwinner
- Tel Aviv - Daniel Ashery, Iuliana Cohen

TRIUMF & ISAC Target & Beam Delivery Group

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Testing the standard model with nuclear physics

Overview and recent result
  - Magneto-optical trapping
  - Optical pumping
  - $\beta$ detection

Outlook, conclusions
Motivation: Fundamental Symmetries

- Search for possible right-handed currents
  - \( SU(2)_L \otimes U(1)_Y \rightarrow SU(2)_R \otimes SU(2)_L \otimes U(1)_Y \)
- Contribute to independent check on the value of \( V_{ud} \)
- Energy dependence tests recoil-order corrections, weak magnetism, second-class currents

Angular correlations in \( \beta \)-decay are sensitive to new physics
- \( 10^{-3} \) precision constrains SM extensions, while \( 10^{-4} \) has discovery potential

\[
\frac{d^5 W}{dE d\Omega_e d\Omega_\nu} \sim 1 + a_{\beta\nu} \frac{p_e p_\nu \cos(\theta_{ev})}{E_e E_\nu} + b \frac{m_e}{E_e} + P \left( A_\beta \frac{p_e}{E_e} \cos(\theta_e) + B_\nu \frac{p_\nu}{E_\nu} \cos(\theta_\nu) \right)
\]
Why $^{37}$K?

- Atomic structure allows for laser-trapping AND optical pumping
- Isobaric analogue decay simplifies nuclear structure corrections
- Strong branch to ground state is a very clean decay
- $I^\pi = \frac{3}{2}^+ \rightarrow \frac{3}{2}^+$ is a mixed Fermi-Gamow Teller decay

$\Delta t_{1/2} = 0.08\%$
(Shidling et al. 2014)
$\Delta BR = 0.14\%$
$\Delta Q_{EC} = 0.003\%$

$^{37}\text{Ar}_{18} \rightarrow ^{37}\text{K}_{19}$

MIRROR
$^{37}\text{K}_{19}$

$^{3/2+}$

$^{5/2+}$

2.07% $Q_{EC} = 3.4$ MeV

97.89% $Q_{EC} = 6.1$ MeV
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\[ 37_{18}Ar_{19} \quad \text{MIRROR} \quad 37_{19}K_{18} \]

$\beta^+$

\[ 3/2^+ \quad 5/2^+ \quad 3/2^+ \]

$\text{MIRROR}$

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$A^\beta(0) = -0.5706(7)$
$\rightarrow \Delta A^\beta = 0.12\%$
Overview

- Magneto-Optical Trap (MOT)
  - Provides a cold ($\sim 1\, \text{mK}$), localized ($\sim \varnothing 1\, \text{mm}$) source of atoms
  - Shallow trap so products emerge unperturbed
Overview

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

Polarization Axis
Nuclear Detectors
Overview

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

- Stretched state corresponds to atomic and nuclear polarization
- Photoionization is a monitor of excited state population
- Use this to monitor trap size, position, temperature, polarization

355 nm light

E-field

MCP

Energy

Angular Momentum $F_z$

$F_z = -2$
$F_z = -1$
$F_z = 0$
$F_z = 1$
$F_z = 2$

$F = 1$
$F = 2$

$P_{3/2}$
$P_{1/2}$
$S_{1/2}$

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Optical Pumping

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Energy

- $355\,\text{nm light}$
- $\left\{ F = 2 \right\}$
- $\left\{ F = 1 \right\}$
- $P_{3/2}$
- $P_{1/2}$
- $S_{1/2}$
- $\left\{ F = 2 \right\}$
- $\left\{ F = 1 \right\}$

Angular Momentum $F_z$

- $F_z = -2$
- $F_z = -1$
- $F_z = 0$
- $F_z = 1$
- $F_z = 2$
Photoions monitor trap parameters

- Polarized measurements must be done with MOT off
- With MOT off, cloud expands; alternate counting/trapping

![Graph showing photoion events over time and Z position](image)
This strong signal allows clean measurement of polarization. Preliminary analysis gives $P = 0.994(3)$ with not even the full data set.
Scintillators record full energy; backgrounds from untrapped atoms, annihilation

Shake-off electron MCP tags events that decay from the trap

Silicon detectors suppress background from $\gamma$s
- Scintillators record full energy; backgrounds from untrapped atoms, annihilation
- Shake-off electron MCP tags events that decay from the trap
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![Energy vs Counts](chart.png)
Scintillators record full energy; backgrounds from untrapped atoms, annihilation
Shake-off electron MCP tags events that decay from the trap
Silicon detectors suppress background from γs
Scintillators record full energy; backgrounds from untrapped atoms, annihilation

Shake-off electron MCP tags events that decay from the trap

Silicon detectors suppress background from γs
Comparison with Geant4

Counts

PRELIMINARY

Energy [keV]

Data
Geant4 Simulation

β-asymmetry in the decay of magneto-optically trapped,
Improvements from 2012 run

- Increased target yield, trapping efficiency: $\langle N_{37} \rangle = 8900$
- More than double the MOT lifetime, $t_{1/2}^{\text{trap}} = 3.8(1)$ s
- Enough statistics for $< 0.5\%$ measurement of $A_\beta$
- Simultaneously measure $a_{\beta\nu}$ and $\beta$-recoil asymmetry

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**Time [ms]**

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<th>0</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
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<th>350</th>
<th>400</th>
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<td>900</td>
<td>1000</td>
<td>1100</td>
<td>1200</td>
<td>1300</td>
<td>1400</td>
<td>1500</td>
<td>1600</td>
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</table>

**$\beta$-decay events / cycle (summed)**

**Set A: $t_{1/2}^{\text{trap}} = 3.6(4)$ s**

**Rel. Counts**

- $a_{\beta\nu}^{\text{SM}} = 0.6661$
- $a_{\beta\nu}^{\text{SM}} + 10\%$
## Preliminary Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>% Uncert.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asymmetry (Stat.)</td>
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<td></td>
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<tr>
<td>Polarization (Stat.)</td>
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<tr>
<td>Calibration</td>
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<td>Est. from 2012 Data</td>
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<td>Silicon Threshold</td>
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<td>Est. from 2012 Data</td>
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<tr>
<td>Cloud Position</td>
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<td>Est. from 2012 Data</td>
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<td>Dead time</td>
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<td>Scattering</td>
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<td>OP Model</td>
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</tbody>
</table>

- Nearing completion of analysis of first (2%) measurement of $A_\beta$
- Second round of data enough for $<0.5\%$ measurement
- The goal of measuring correlation parameters to 0.1% is in sight
TRINAT’s x2-MOT System

- Collection trap is coupled to TRIUMF-ISAC beam line
- Transfer atoms to second trap for precision measurement
Types of events

- Silicon Strip Detector
- BC408 Plastic Scintillator
- Shakeoff $e^-$
- Nuclear polarization
- $\beta^+$ in coincidence with either MCP
- $\nu$ 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

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