TRIUMF Neutral Atom Trap: decay topics

- Tensor interaction constraints from singles recoil spin asymmetry
- Recoil momentum spectrum from I.C. of $^{86m}$Rb
- Hyperfine spectroscopy of Rb $5s_{1/2} \rightarrow 5d_{5/2}$
- Some foibles of electron timing with MCP's
- 'AC MOT' for $^{37}\overrightarrow{K}$: see D. Melconian

Not covered: $^{38m}$K $\beta$-$\nu$ correlation upgrade, except some prep

Meta: at ISAC large amounts of many Rb isotopes are available from several common targets. We test equipment for K experiments while doing Rb experiments.
TRIUMF Neutral-Atom Trapping “TRINAT” for this decay work

<table>
<thead>
<tr>
<th>UBC</th>
<th>TRIUMF</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>R. Pitcairn</strong></td>
<td>J.A.Behr</td>
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</tr>
<tr>
<td><strong>D. Roberge</strong></td>
<td>*A.Gorelov</td>
<td><strong>O. Aviv</strong></td>
<td>A. Gaudin</td>
</tr>
<tr>
<td><strong>T. Kong</strong></td>
<td>M.R. Pearson</td>
<td></td>
<td>B. Dej</td>
</tr>
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<td></td>
<td>K.P. Jackson</td>
<td>U. Manitoba</td>
<td>T. Wiebe</td>
</tr>
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<td>M. Dombsky</td>
<td>G. Gwinner</td>
<td>A. Chatwin-Davies</td>
</tr>
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<td></td>
<td>P. Bricault</td>
<td>Texas A&amp;M</td>
<td>A. Berman</td>
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<tr>
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<td></td>
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A new method for an old observable (Treiman '58)
Final nuclei angular distribution wrt initial spin
\[ W[\theta] = (1 + \frac{1}{3}cTx_2) - x_1(A_\beta + B_\nu)P \cos \theta - x_2 cT \cos^2 \theta \]
\[ x_1 \overset{Q \gg m}{\rightarrow} \frac{5}{8}; \ P = \langle M \rangle; \ T = \frac{l(l+1)-3\langle M^2 \rangle}{l(2l-1)} \]
- For pure Gamow-Teller, \( A_{\text{recoil}} = 0 \) in SM

\[ A_\beta + B_\nu = \lambda J'J(2C_TC'_T + \langle \frac{m}{E_\beta} \rangle (C_T + C'_T)) \]
Challenge: constrain \( \sim 0.01 \) recoil-order correction

\[ 86^m\text{Rb recoils} \]

\[ 80_{\text{Rb}} \]

Relatively clean Gamow–Teller decay

\[ 0^+ \quad 1^+ \quad 2^+ \]

\[ 0^{(+)} \quad 1.9\% \quad 5.9 \]
\[ 2^+ \quad 21.6\% \quad 5.2 \]
\[ 0^+ \quad 74.4\% \quad 4.9 \]

\[ 80_{\text{Kr}} \quad Q=4.698 \]

TRIUMF neutral atom trap: decays

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\[ H_{\text{int}} = \sum_{X=V,A,S,T} (\bar{\psi}_p O_X \psi_n) (C_X \bar{\psi}_e O_X \psi_\nu + C'_X \bar{\psi}_e O_X \gamma_5 \psi_\nu) \]

Standard Model $W^+$ exchange (coupling only to left-handed $\nu_L$) $\rightarrow C_V, C_A$ only, i.e. ‘V-A’

Severijns, Beck, Naviliat-Cuncic Rev Mod Phys 2006

global fit $C_T/C_A = 0.0086 \pm 0.0031$ assuming SM chirality for $C_T, C_S$ (and Serebrov 2005 $n t_{1/2}$)

Profumo Ramsey-Musolf Tulin PRD 2007: SUSY can produce $C_T \sim 0.001$ by left-right sfermion mixing
TRIUMF’s Neutral Atom Trap

- Isotope/Isomer selective
- Evade 1000x untrapped atom background by → 2nd MOT
- 75% transfer (must avoid backgrounds!); 10$^{-3}$ capture
- 0.7 mm cloud for $\beta$-Ar$^+$ → $\nu$ momentum → $\beta$-$\nu$ correlation
- $>97\%$ polarized, known atomically
\textbf{\textsuperscript{80}Kr daughter TOF, position; atomic e\textsuperscript{-} trigger}

● like Vetter LBL PRC’08

\textbf{Measure:}

$\theta_{\text{recoil}} \text{ wrt } \vec{I}$,

$|\vec{p}_{\text{recoil}}|$
MCP and electrostatic rings
**80 Rb Singles Recoil Asymmetry: data and fits**

\[
A_{\text{spin}}[\rho_{\text{recoil}}] = \frac{W[\theta, P] - W[\theta, -P]}{W[\theta, P] + W[\theta, -P]} \cdot \frac{PA_1[P_r]\cos\theta}{1 + cTF_2[P_r]\cos^2\theta}
\]

To extract the experimental asymmetry \(A_1[\rho_{\text{recoil}}]\),

Fit for 0.5 MeV recoil momentum bins:

E.g.: all Kr\(^+2\) data:

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**TRIUMF neutral atom trap: decays**

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Distinguishing new tensors from S.M. corrections

$A_1[p_{\text{recoil}}]$ differs for new tensor $C_T, C'_T$ vs. SM higher-order

$b$ weak magnetism

d QCD-induced tensor

Effects of $d$ can be separated this way

Non-SM contribution to the asymmetry:

$A_T = 0.015 \pm 0.029 \pm 0.019$

(Syst from $b/AM_{GT}=4.7\pm4.7$, nucleon value)
$^{80}\text{Rb}$ decay: Tensor constraints

- **Dash:** $C_T, C'_T, b, d$ all float limits not competitive
- **Green bar:**
  - set $b/AM_{GT}=4.7\pm4.7$,
  - assume $C_T + C'_T=0$
  - (Carnoy $^{14}\text{O}^{10}\text{C}$ 1991)
  - $A_T=0.015\pm0.029$ (stat)
  - $\pm0.019$ (syst) $\Rightarrow$
  - $|(C_T - C'_T)/C_A| < 0.36$
  - R. Pitcairn et al. PRC Jan 2009

- Complementary constraints to tensor couplings to $\nu_R$
  - compared to $^6\text{He} \beta-\nu$ correlation (Johnson ORNL PR 1963)
Improvements?

- constrain/measure $b$ by $A_\beta[p_\beta]$
- Use the higher-polarization methods demonstrated in $^{37}$K
- $^{82}$Rb for consistency
- $\gamma$ coincidence to correct for $1^+ \rightarrow 2^+$
- Could do experiment to 0.001; need nuclear structure theory
guidance for
\[
b/A = g_M M_{GT} + \langle f | \sum \tau^+_i \vec{l} | i \rangle
d_i/A = g_A \langle f | \sum \tau^+_i i \vec{\sigma} \times \vec{l} | i \rangle
\]

In Fermi decays or
Fermi/Gamow-Teller mirror decays, recoil-order corrections are given by electromagnetic moments: $^{38m}$K and $^{37}$K

 TRIUMF neutral atom trap: decays

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Exotic particles in isomer decay

\[ p = \sqrt{E^2_\gamma - m_x^2} \]

- Search for anything massive emitted from nuclear transition
- Independent of interaction in detector or lifetime
- If see a signal, could measure spin from polarized angular distribution

Models exist, but often need $10^{-6}$ sensitivity
Photoionization scheme

$^{86m}$Rb $\rightarrow$ $^{86g}$Rb neutral atom, 1.9 eV energy. Must photoionize:

A Doppler-free 2-photon transition resolves the daughter $^{86g}$Rb from the trapped $^{86m}$Rb AND excites atoms independent of velocity. Then 1064nm light from a fiber laser photoionizes the atoms.

- Technique works, efficiency is not enough
- We see off-resonant ionization of $^{86m}$Rb at about 1/sec
2% I.C. of trapped $^{86\text{m}}$Rb: $p=920$ keV calibration

Good signal/background
Intrinsic momentum resolution $<4\%$.
Test of sensitivity to MeV-mass $\nu$ in $^{81}$Rb EC decay
**γ-ray events, laser on/off, 8 hrs**

Less than 1 event/min

Background is probably most accidentals

Do γ’s ever produce ‘shakeoff’ e−’s?

Lower-velocity case $^{81m}\text{Rb}$ would give more time to photoionize and minimize transit time broadening, sensitivity to $10 \text{ keV} < m < 80 \text{ keV}$
PRELIMINARY High-statistics method on trapped atoms

Could measure hyperfine anomalies in the Rb chain

\[ I.S._{778} = -34.78 \pm 0.02 \quad A = -1.245 \pm 0.004 \quad B = 4.97 \pm 0.16 \]

\[ A_{s1/2} = 564.298 \pm 0.014 \]
Nez OC 1993 D5/2 is $0.9955 \pm 0.0005 \rightarrow 0.9955 \pm 0.0005$ → C magnetic octupole term? Tanner found C=0.56(7) kH in Cs P3/2 PRL 2003.

Need few KHz accuracy. We see 100KHz absolute shifts now, though A in 85,87Rb consistent at 20 KHz.

Statistical errors demonstrated. Turn off B field, linearly polarized light, more stable MOT and/or larger 778 nm beam, don’t dither scanning AOM, linearly polarized light in cell.

Fig. 3. Ratio of hyperfine constants normalized by the nuclear g factors showing hyperfine anomaly differences in $^{85}$Rb and $^{87}$Rb based on five different electronic states. The value for the $6S_{1/2}$ (circle) comes from the present measurement. See the text for the other references (squares).
\textbf{e}^− \textbf{MCP timing defects}

- e\(^−\) not hitting the channels backscatter or produce a secondary that can launch and return with enough energy to trigger MCP
- for \(V_{\text{trap}} < V_{\text{MCP}} < V_{\text{mesh}}\) time structures as some scattered e\(^−\)s escape into the mesh region and then return
Implications

- Exotic particle searches: simulates ‘tachyons’ so ‘OK’ BUT zero-momentum photoions now produce finite-momentum tails— we can reject events from MCP center.
- $\beta$-$\nu^{38mK}$: To measure the recoil momentum spectrum, must understand this timing for the $E_e$ spectrum produced in the $\beta$ decay. Big challenge. Will probably concentrate on the $\beta$-recoil technique.
- $A_{\text{recoil}}$ is OK
**AC MOT**

We have $97\pm1\%$ polarization of $^{\text{37}}\text{K}$, but can only chop MOT’s B field on and off on 2 msec timescales. Improve:

Harvey and Murray
Manchester
PRL 101
173201 2008

We want to use for polarized experiments: can switch B fields much faster, so atoms will not expand as much during the optical pumping process.

May also help with expelling dimers (Vetter PRC 77 35502 has identified this as a possibly serious background in $\beta$-$\nu$ correlations with atom traps.)
sparing slides
spares
Approved as a ‘Signature-based general search’

- $0^-$ particles favored in Magnetic transitions
- $0^+$ favored in Electric transitions (like E4 of $^{86}\text{mRb}$)

Pospelov hep-ph 0811.1030 explanation for PAMELA $\beta^+$ excess (but no $\bar{p}$ excess): SUSY dark matter heavy particle decays via new U(1)’ symmetry to massive boson, which then decays. Constraints on its coupling as a function of its mass:

- Constraints and searches welcome in any mass range.

Often need $10^{-6}$ sensitivity

TRIUMF neutral atom trap: decays
hyperfine anomaly in $^{86m}$Rb, $^{86g}$Rb

- We can deduce the 5D$_{5/2}$ specific mass shift, of atomic structure interest (testing many-body calculations, also for $\alpha$[redshift]). Also sharpen long-standing issues with Rb charge radius chain from 5S$_{1/2} \rightarrow$5P$_{3/2}$

- Precision on $A_{D5/2} < 4$ KHz $\rightarrow$ sensitivity to a ‘hyperfine anomaly’ $A_{D5/2}/A_{S1/2}$ different by 1% with 3$\sigma$ accuracy, depending on systematic errors (under evaluation).

Sensitive to the spatial distribution of the unpaired nucleons

$^{85}$Rb$^{48}$ 5/2$^−$ $\pi$1f$^{-1}_{5/2}$ $^{87}$Rb$^{50}$ 3/2$^−$ $\pi$2p$^{-1}_{3/2}$, full $\nu$1g$_{9/2}$

NNDC/NDS says predominant configurations:

$^{86g}$Rb $2^−$ $\pi$1f$^{-1}_{5/2}$ $\nu$1g$_{9/2}$ “$^{85}$Rb+n”

$^{86m}$Rb $6^−$ $\pi$2p$^{-1}_{3/2}$ $\nu$1g$_{9/2}$ “$^{87}$Rb-n”

Which will have larger valence nucleon radius?

$^{88,89}$Rb are possible, along with $^{76−84}$Rb and $^{90−97}$Rb
Photoionization Diagnostic → cloud position

MOT on/off 30 μs; Optical pumping off/on to polarize

Cloud shifts < 0.03 mm with spin flip ⇒ A correction < 0.0012 σ_A < 0.00005
TRIUMF-ISAC

TRIUMF neutral atom trap: decays
TOF of $^{80}\text{Kr}$ daughter with atomic $e^-$ trigger

- High-statistics technique
- Efficiency $\sim 50\%$

Counts

$^{80}\text{Kr}$–electron TOF [µs]

- fit
- $^{80}\text{Rb} \beta^+$ decay
- EC decay (1.4%)
- bkg from $\beta^+$
- $+3$

$^{80}\text{Kr}^+$
$^{80}\text{Kr}^+$

TRIUMF neutral atom trap: decays

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80\(^{\text{Rb}}\) Polarization diagnostics

\[ \beta \text{ asymmetry} \]

\( \beta - \text{Kr} \) coincidence (4 to 9)

\[ P = 0.533 \pm 0.028 \]
\[ \chi^2/N = 0.5 \]

Result: \( P = 0.55 \pm 0.05 \)

EC recoils, separated by TOF and high-momentum cut

TRIUMF neutral atom trap: decays

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