E1070
Upgrade of $^{38m}$K $\beta$-$\nu$ correlation

Trap $\rightarrow$ $\beta^+$–recoil coincidence $\Rightarrow$ $\nu$ momentum

Best general scalar Limits from $\beta$-$\nu$ correlation
Gorelov et al. PRL April 2005

The theory interpretation is clean, so we should do it better

We propose a 3x better measurement of $\tilde{a} = a / (1 + bm/E)$
and independent determination of $a$ and $b$

Method I, II: Upgrade of present method with higher yields, trapping efficiencies, and detection efficiencies

Method III:
New Tool: recoil- atomic e$^-$ coincidence
10-50x statistics, different systematics, simpler analysis
Vector and Scalar bosons and the $\beta$-$\nu$ angular distribution

For $^{38m}\text{K}$, $0^+ \rightarrow 0^+$ decay: (Just like $\pi \rightarrow e\nu$)

$W[\theta_{\beta\nu}] = 1 + b \frac{m}{E} + a \frac{v_\beta}{c} \cos \theta_{\beta\nu} \quad \Rightarrow \quad a = +1$

Corrections independent of nuclear structure to $<0.0002$: bremsstrahlung $\approx 0.002$ (in M.C., F. Glück), recoil order $\approx 0.0003$

For scalar exchange, lepton helicities are same: $a = -1$

Deviation $\Rightarrow$ non-standard model scalar interaction
Scalar Hamiltonian in ‘modern’ chirality notation

\[
H_S = [(C_S + C'_S)\bar{e}(1 - \gamma_5)\nu_e^{(L)} + (C_S - C'_S)\bar{e}(1 + \gamma_5)\nu_e^{(R)}]\bar{u}d
\]

\[
W[\theta_{\beta\nu}] = 1 + bm_\beta/\langle E_\beta \rangle + a\; \nu/c \cos[\theta_{\beta\nu}]
\]

\[
a = \frac{|C_V|^2 + |C'_V|^2 - |C_S|^2 - |C'_S|^2 + \left(\frac{\alpha Zm_p}{p}\right)2Im(C_S C_V^* + C'_S C'_V^*)}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}
\]

Note the sensitivity to \(Im(C_S + C'_S)\)

\[
b = \frac{-2\sqrt{1 - \alpha^2 Z^2} \; Re(C_S C_V^* + C'_S C'_V^*)}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}
\]

\[a \approx 1 - (|C_S|^2 + |C'_S|^2)\]

\[b \approx -Re(C_S + C'_S)\]
Sources of Scalars: Are there any?

Charged Higgs: Required in SUSY

• 1st generation couplings unknown

⇒ most general limits on 1st generation couplings are from nuclear $\beta$ decay

• Couplings in simplest MSSM:

  like S.M. Higgs, couplings $\propto$ masses: (Not so in less simple Higgs models (Langacker hep-ph/0503068))


\[ C_S + C'_S \approx 2g_s \frac{m_e m_d}{m_H^2} \tan^2 \beta \leq 5 \times 10^{-6} \]

for $\tan \beta \leq 65$ and $m_H \geq 69$ GeV neglects squark family mixing

• R-parity violating sleptons

  constrained by $\pi \rightarrow e\nu$, $C_S + C'_S$ can be $\sim -2 \times 10^{-3}$

• B. Campbell et al. NPB 709 419 (2005) limits from $\pi \rightarrow e\nu$

  Other searches:

$^{32}$Ar Garcia/Adelberger; WITCH $^{35}$Ar$^+$ Leuven/ISOLDE; $^{14}$O$^+$ ANL; superallowed ft $Q$-value dependence
\[ Q_{\beta^+} = 5.0215(6) \text{ MeV} \]

\[ \begin{array}{c}
\beta^+ + 3^+ \rightarrow \frac{38}{19}K \\
2^+ \rightarrow 3.9366 \quad 0.2\% \\
3^- \rightarrow 3.8101 \\
2^+ \rightarrow 2.16760 \quad 99.8\% \\
0^+ \rightarrow 0 \\
\end{array} \]

\[ \begin{array}{c}
0^+ \rightarrow 0.9239(6) \text{ sec} \\
3.8101 \quad 3.9366 \quad 0 \\
2.16760 \quad 99.8\% \\
0^+ \rightarrow 7.64 \text{ min} \\
\end{array} \]

\[ \begin{array}{c}
\beta^+ + \frac{38m}{19}K \\
\frac{38}{18}\text{Ar} \\
\end{array} \]

Excited-state branch known to be negligible

(Ground state makes a background in $\beta$ singles: we can deal with this better)
TRIUMF’s Neutral Atom Trap
- Isotope/Isomer selective
- Evade 1000x untrapped atom background by $\rightarrow$ 2nd MOT
- 75% transfer (must avoid backgrounds!); $10^{-3}$ capture
- 0.7 mm cloud for $\beta$-Ar$^+$ $\rightarrow$ $\nu$ momentum $\rightarrow$ $\beta$-$\nu$ correlation
Method I,II: $\beta$-recoil coincidences Raw data
In-situ calibrations

$E_\beta$ detector response for “monoenergetic” $\beta$’s from kinematics of other observables ($\beta$-recoil angle and recoil momentum)
Methods I and II agree:
I: recoil TOF[$T_\beta$], $T_\beta > 2.6$ MeV
   C.L. of total fit is 52%

II: Angular distribution
determined from other observables (except $E_\beta$).
Can simultaneously fit $E_{\text{recoil}}$-dependent shakeoff

$\tilde{a} = 0.9981 \pm 0.0030(\text{stat})$
$\pm 0.0037(\text{syst})$

(Adelberger $^{32}$Ar PRL 1999
$\tilde{a} = 0.9989 \pm 0.0052(\text{stat})$
$\pm 0.0039(\text{syst})$
still being re-evaluated)
$^{38m}$K $\beta^+ - \nu$ Error Budget $a = 0.9981 \pm 0.0030$ (stat)

<table>
<thead>
<tr>
<th>Error</th>
<th>PRL</th>
<th>Future</th>
</tr>
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<tbody>
<tr>
<td>$\bar{E}$ field/trap width :</td>
<td>0.17%</td>
<td>0.04%</td>
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<tr>
<td>$E$ field nonuniformity</td>
<td>0.14%</td>
<td>0.03%</td>
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<tr>
<td>$\beta^+$ backscattering bkgd</td>
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<td>None</td>
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<td>$E_{\beta^+}$ Detector Response:</td>
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<tr>
<td>Lineshape tail/total</td>
<td>0.06%</td>
<td>0.03%</td>
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<tr>
<td>$511$ keV Compton sum</td>
<td>0.09%</td>
<td>0.04%</td>
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<tr>
<td>Calibration, nonlinearity</td>
<td>0.17%</td>
<td>0.08%</td>
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<tr>
<td>MCP Eff[$E_{Ar^+}$]</td>
<td>0.07%</td>
<td>0.03%</td>
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<tr>
<td>MCP Eff[$\theta$]/XY position</td>
<td>0.08%</td>
<td>0.04%</td>
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<tr>
<td>$e^-$ shakeoff [$E_{recoil}$]</td>
<td>0.18%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Sum systematics</td>
<td>0.37%</td>
<td>0.14%</td>
</tr>
<tr>
<td>Total error</td>
<td>0.48%</td>
<td>0.19%</td>
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● Most systematic errors determined by statistics-limited data evaluation.
● Further improvements possible: use all kinematic information.
Constraints on scalars from ‘Fierz interference term’

\[ b_f = - Re(C_S + C'_S), \text{ scalars that couple to left-handed } \nu \text{ only} \]

\[ W[\theta_{\beta \nu}] = 1 + b_F m_\beta / \langle E_\beta \rangle + a \, v/c \cos[\theta_{\beta \nu}] \quad a \approx 1 - |C_S|^2 + |C'_S|^2 \]

- TRINAT present statistical error is 4x bigger
- Would improve systematics by using kinematic info for \( E_\beta \) at \( E_\beta < Q/2 \)
- Would achieve similar accuracy within one \( \beta-\nu \) experiment
- Goal: a window left open by \( \pi \rightarrow e\nu \) for sleptons at \( 2 \times 10^{-3} \)

[Herczeg Prog. Part. Nucl. Phys. 46/2 413 (2001)]
Method III: New: Geometry with e⁻ detector

For E1070:
- High-statistics
- free of β bias
- expect collection for all e⁻’s < 100 eV

Also with higher statistics:
- $^{80}$Rb tensor search by recoil singles: starts 16:00 today
- $^{37}$K $A_{recoil}$ gives Fermi/GT interference, right-handed currents; $A_β$
- $^{36}$K isospin mixing becomes practical: $A_{recoil}$, $A_β$
- $^{74}$Rb Q-value
- Efficiency $\approx 47\%$ for 1 eV photo-electrons
- Background $\sim 10\text{-}20$ Hz. (Expected 100 KHz.)

Other practical uses:
- Energy spectrum of atomic $e^-$'s (do they perturb recoils?)
- Photoionization makes an $e^-$ tag to measure ion MCP efficiency as a function of impact energy
SIMULATION
Recoil momentum spectrum
Sensitive to $a$ ($a$, $b$ highly correlated)
Can extract momentum dependence of shakeoff separately

From $10^6$ events $\sigma_a = 0.001$ (3 hours)
Superallowed Q-dependence of $b$ error 0.003: 1 shift
0.001 (sleptons) in 10 shifts
  - In reality will run under many conditions like other precision experiments
**Upgrade of $^{38m}$K $\beta$-$\nu$ correlation**

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Status</th>
<th>Time</th>
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<tr>
<td>C. Höhr</td>
<td>TRIUMF</td>
<td>Postdoc Research Associate</td>
<td>100%</td>
</tr>
<tr>
<td>New. Student</td>
<td>UBC</td>
<td>Student</td>
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<tr>
<td>or R. Pitcairn</td>
<td>UBC</td>
<td>M.Sc. Student–&gt;Ph.D.</td>
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<td>or D. Roberge</td>
<td>UBC</td>
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<tr>
<td>J. Behr</td>
<td>TRIUMF</td>
<td>Research Scientist</td>
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<td>M. Pearson</td>
<td>TRIUMF</td>
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<td>D. Ashery</td>
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<td>S.F.U.</td>
<td>Ph.D. Student until Mar06</td>
<td>E715</td>
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**Fr Electric Dipole Moment Fountain**

- Upgrade 38mK scalar
- 36K i.m.
- Tensor 80Rb
- 37K right-handed
- 37K D time reverse

**CFORT**
Summary: E1070 Upgrade $^{38m}$K $\beta$-$\nu$ correlation:

Pioneered Capabilities:

$\beta^+$-recoil coincidence $\Rightarrow \nu$ momentum

We have the best general scalar limits from $\beta$-$\nu$ correlation in $^{38m}$K

$\tilde{a} = 0.9981 \pm 0.0030 \pm 0.0037$

The limits on scalar interactions are model-independent (TRV, chirality) and free of nuclear structure-dependent corrections to $\approx 0.0002$

- Proposed: Improve accuracy by factor of 3
  - Separate $a, b$
  - Compete with $0^+ \rightarrow 0^+$ on Fierz term

- Shift request:
  - Method I, II: improvements of present $\beta$-recoil coincidence method: 30 shifts

Method III: atomic $e^-$-recoil TOF method: 20 shifts