Systematics of the UCN$\tau$ Experiment

R.W. Pattie Jr for the UCN$\tau$ Collaboration

Los Alamos National Lab

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Overview I

\[ \tau = \frac{4908.7 \pm 1.9}{1 + 3\lambda^2} \]

1. Combined with angular correlation parameter to determine \( |V_{ud}| \)
2. Directly impacts \(^4\text{He}\) abundance in the early universe

• \(\sim 4\sigma\) discrepancy between CN beam and UCN trap \(\tau_n\) measurements

Located at the LANSCE spallation UCN source
- Capable of loading the trap with \( \sim 50k \) UCN per fill
- Allows for \( \sim 1 \) s measurement in a weekend of running

Magneto-Gravitational Trap
- Permanent Halbach Array confines UCN from below
- Gravity holds UCN in from top
- Minimizes Material interactions

Multiple Counting Methods
- Traditional Fill and Dump
- Count the activation of Vanadium foil

Salvat et al., PRC 89, 052501 (2014)
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Overview III

UCN\(\tau\) Testbed:
- Magneto-gravitational storage vessel
- Halbach array of permanent magnets
- No material interactions during storage period
- In situ (V-foil activation) or ex situ (fill and dump) neutron detection possible

UCN\(\tau\) Testbed:
- In situ detector
- Ex situ monitor (\(^{10}\)B)
- Polarizer
- Spin flipper
- Al shutter

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Fill-and-Empty Measurement

UCN absorber

Al shutter

UCN monitor

UCN

Graph: Time [s] vs. UCN monitor counts
Measurement Cycle

Fill-and-Empty Measurement

UCN absorber

Al shutter

UCN monitor

UCN

Close shutter

[Graph showing time vs. UCN monitor counts]
Measurement Cycle

Fill-and-Empty Measurement

UCN absorber

Al shutter

UCN monitor

UCN monitor counts

time [s]

10^3

10^2

10^1

10^0

0

100

200

300

400

500

Beam off, close trap door, open shutter

Close shutter

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Overview

Measurement Cycle

Fill-and-Empty Measurement

[Diagram showing the measurement cycle with steps:
- Close shutter
- Beam off, close trap door, open shutter
- Raise cleaner

Graph showing the time [s] on the x-axis and UCN monitor counts on the y-axis, with data points indicating the count rate over time.]
Systematics of the UCN\(\tau\) Experiment

Overview

Measurement Cycle

Fill-and-Empty Measurement

UCN absorber

Al shutter

UCN monitor

Close shutter

Beam off, close trap door, open shutter

Raise cleaner

Drain trap

Storage time

UCN monitor counts vs. time [s]

0 100 200 300 400 500

10^0 10^1 10^2 10^3

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**Systematics of the UCN$\tau$ Experiment**

**Overview**

**Measurement Cycle**

**Fill-and-Detect Measurement**

- **UCN absorber**
- **Al shutter**
- **UCN monitor**
- **$\beta$ and $\gamma$ detectors**
- **UCN absorber**
- **Beam off, close trap door, open shutter**
- **Raise cleaner**

Graph showing time [s] vs. UCN monitor counts.
**Overview**

**Measurement Cycle**

**Fill-and-Detect Measurement**

- β and γ detectors
- Al shutter
- UCN absorber
- UCN monitor

Diagram showing the fill-and-detect measurement process:
1. Close shutter
2. Beam off, close trap door, open shutter
3. Raise cleaner
4. Lower V foil, then raise V foil into det.

Graph showing UCN monitor counts over time:
- Storage time is marked on the graph.

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Systematics of the UCNτ Experiment
**Fill-and-Detect Measurement**

- **UCN absorber**
- **Al shutter**
- **UCN monitor**
- **β and γ detectors**

### Measurement Cycle

1. **Fill-and-Detect Measurement**
2. **Storage Time**

- **UCN absorber**
- **Al shutter**
- **UCN monitor**
- **β and γ detectors**

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**Graph**

- **Time [s]**
- **UCN monitor counts**

**Legend**

- **Close shutter**
- **Beam off, close trap door, open shutter**
- **Raise cleaner**
- **Lower V foil, then raise V foil into det.**

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**Systematics of the UCNτ Experiment**

**Overview**

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**Fill-and-Detect Measurement**

- **UCN absorber**
- **Al shutter**
- **UCN monitor**

**Measurement Cycle**

1. **Fill-and-Detect Measurement**
2. **UCN absorber**
3. **Al shutter**
4. **UCN monitor**

**Storage Time**

\[ N_{52V} \exp\left(-\frac{t}{\tau_{52V}}\right) + B \]

**Simulated Decay Curve**

\[ y \approx \frac{W}{\tau_{52V}} N_{52V} \exp\left(-\frac{t}{\tau_{52V}}\right) + B \]
Major Systematic Effects

1. **Normalization**
   - Source Fluctuations
   - Insufficient fill time
   - Monitor Detector efficiency changes
   - Polarization fluctuations
   - Variation in trap cleaner height

2. **Losses in The Trap**

3. **Detector Response**
Major Systematic Effects

1. Normalization
2. Losses in The Trap
   - Residual Gas Scattering
   - Depolarization
   - UCN Heating
   - Leaking through trap door
   - Field holes (trap defects)
   - Material interactions
   - Marginally trapped UCN
3. Detector Response

\[ \frac{1}{\tau_{\text{trap}}} = \frac{1}{\tau_\beta} + \frac{1}{\tau_{\text{loss}}} \]
Major Systematic Effects

1. Normalization
2. Losses in The Trap
3. Detector Response
   - Energy dependent draining
   - Time dependent backgrounds
   - Phase space evolution
Two-point measurement

\[ N_1(t_1) = N_{01} e^{-t_1/\tau} + B_1 \]
\[ N_2(t_2) = N_{02} e^{-t_2/\tau} + B_2 \]
\[ \tau = \frac{\Delta t_{1,2}}{\ln\left(\frac{N_1(t_1) - B_1}{N_2(t_2) - B_2}\right) - \ln\left(\frac{N_{01}}{N_{02}}\right)} \]

- Ideal case \( N_{01} = N_{02} \), trap filled with same number of UCN each run
- Previous tests indicate spectral variations not a problem at 0.1% level

Normalization Variation
- Proton Current
- Source stability
Two-point measurement

- \( N_1(t_1) = N_{01} e^{-t_1/\tau} + B_1 \)
- \( N_2(t_2) = N_{02} e^{-t_2/\tau} + B_2 \)
- \( \tau = \frac{\Delta t_{1,2}}{\ln\left(\frac{N_1(t_1)-B_1}{N_2(t_2)-B_2}\right)-\ln\left(\frac{N_{01}}{N_{02}}\right)} \)

- Ideal case \( N_{01} = N_{02} \), trap filled with same number of UCN each run
- Previous tests indicate spectral variations not a problem at 0.1% level

- New density monitor detector (see Z. Wang’s talk next)

Normalization Variation
- Proton Current
- Source stability
Halbach Array and Holding Field

\[ |B| = B_{\text{rem}}(1 - e^{-kd})e^{-k\zeta} \]

(if continuous rotation of M)

- Holding field eliminates field zeros

1. Field zeros induced by reversing holding field coil current

2. Can study the effect of different holding fields on bottle lifetime
Halbach Array and Holding Field

\[ |B| = B_{\text{rem}}(1 - e^{-kd})e^{-k\zeta} \]

(if continuous rotation of M)

1. Trap defects are patched with Cu tape (∼ 42 cm²)
2. \( \tau_n \) correction of ∼ 0.3 s
3. Depolarization at 50 Gauss \( 10^{-11} \) per bounce and a correction of ∼ 10⁻⁵ s (ideal geometry)
Systematics of the UCN\textsubscript{\tau} Experiment

UCN transport Effects
Residual Gas Scattering

Losses Through Upscattering on Residual Gas

<table>
<thead>
<tr>
<th>Molecule</th>
<th>( \sigma_{\text{scattering}} ) (barns)</th>
<th>( \sigma_{\text{absorption}} ) (NIST)</th>
<th>( \tau_n/\text{mbar (sec)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)</td>
<td>20230 (4000)</td>
<td>222</td>
<td>3</td>
</tr>
<tr>
<td>D(_2)</td>
<td>3480 (700)</td>
<td>0.35</td>
<td>18</td>
</tr>
<tr>
<td>Ne</td>
<td>250 (50)</td>
<td>13</td>
<td>249</td>
</tr>
<tr>
<td>Ar</td>
<td>70 (20)</td>
<td>225</td>
<td>891</td>
</tr>
<tr>
<td>Xe</td>
<td>190 (40)</td>
<td>7967</td>
<td>328</td>
</tr>
<tr>
<td>CF(_4)</td>
<td>3320 (660)</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>CF(_4)</td>
<td>74100 (14800)</td>
<td>1109</td>
<td>1</td>
</tr>
<tr>
<td>Air</td>
<td>15730 (3150)</td>
<td>990</td>
<td>4</td>
</tr>
</tbody>
</table>

1. 1.28(26) s correction at 5 \( \times \) 10\(^{-5}\) mbar (of H\(_2\) and other hydrogenous gases)

2. 0.26(5) s correction at 1 \( \times \) 10\(^{-5}\) mbar

- UCN Up-scattering cross sections measured for several gases at LANSCE UCN source
- Installing RGA to monitor gas partial pressures

\(^{2}\text{S. Seestrom (manuscript in preparation)}\)
Cleaning Quasi-bound UCN

- Proof of principle upscattering measurement with $^3$He
- R&D on active cleaner

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**Movable Absorber for trap “cleaning”**

**Proof of principle upscattering measurement with $^3$He**

**R&D on active cleaner**

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**Los Alamos National Laboratory**

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Drain time possibly dependent on holding time

1. Drain time possibly dependent on holding time
2. $^{51}V + n \rightarrow ^{52}V \left( T_{1/2} = 3.74 \text{ min} \right)$
   - $^{52}V \rightarrow ^{52}Cr + \beta^- + \gamma (1.434 \text{ MeV})$
3. Detect $\beta$ and $\gamma$ in coincidence

S/N= 10
$\varepsilon_\beta = 0.8$
$\varepsilon_\gamma = 0.21$
Iodine Activation in NaI Detectors

1. Thermal neutrons capture on the Iodine in the NaI detectors
2. \( n + ^{127}I \rightarrow ^{128}I \rightarrow \beta\text{-decay or EC (} \sim 25 \text{ min)} \)
3. Generates time dependent background
4. Improved detector shielding to reduce this effect
1. 2013 run provided proof of principle for long storage time in trap
2. Significant improvements made for the 2014/2015 accelerator cycle
   - New trap door/shutter to improve transport into the trap
   - Better shielding around $^{51}$V detector system and new $\beta$-detector will increase $S/N$
3. Upcoming run cycle will focus on assessing systematics with the goal of a 1 second measurement of the trap lifetime
UCN$\tau$ Collaboration

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