A New Ultra-cold Neutron Source Available at Los Alamos

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The LANSCE UCN Source and its Test port
Measurements of density and velocity
Experiments using the Test port
The neutron lifetime experiment at LANL

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The future: a UCN User Facility at LANSCE

- UCN Sources in US
  - Around 1995, only source in world of extracted UCN for experiments – Steyerl rotor at ILL
  - 1995, superthermal LHe source development began at NIST for dedicated lifetime experiment
    - no extracted UCN capability
  - 1998, prototype SD2 source development began at LANL
  - 2004, first tests of production SD2 source at LANL
  - 2005, SD2 source development began at PULSTAR: much smaller than LANL source; first tests expected in 2010
  - 2007, superthermal LHe source development began at SNS for dedicated EDM experiment
    - no extracted UCN capability
- And of course PSI and TRIUMF sources are under construction in 2009

2009, LANL source is the only, operational source for extracted UCN in the US
# World’s UCN Projects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Ec (neV)</th>
<th>$\rho_{\text{UCN}}$ (UCN/cm³)</th>
<th>Status</th>
<th>Purpose</th>
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<tbody>
<tr>
<td>LANL</td>
<td>Spallation/D2</td>
<td>180</td>
<td>35</td>
<td>Operating</td>
<td>UCNA/ Users</td>
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<td>ILL</td>
<td>Reactor/turbine</td>
<td>250</td>
<td>40</td>
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<td>Users</td>
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<td>120</td>
<td>Construction</td>
<td>Users</td>
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<td>Spallation/D2</td>
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<td>Commiss’ing</td>
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<td>Spallation/HE-II</td>
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<td>10,000</td>
<td>Planning</td>
<td>n-EDM+</td>
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<td>Reactor/D2</td>
<td>250</td>
<td>10,000</td>
<td>R&amp;D</td>
<td>Lifetime, EDM</td>
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<td>Reactor/D2</td>
<td>180</td>
<td>4</td>
<td>Testing</td>
<td>Users?</td>
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<td>SNS</td>
<td>n beam/HE-II</td>
<td>130</td>
<td>400</td>
<td>R&amp;D</td>
<td>n-EDM</td>
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</table>

Martin
LANSCE Experimental Areas

- **Lujan Center**
  - National security research
  - Materials, bio-science, and nuclear physics
  - National user facility

- **WNR**
  - National security research
  - Nuclear Physics
  - Neutron Irradiation

- **Isotope Production Facility**
  - Medical radioisotopes

- **800 MeV Proton LINAC**
  - Up to 1 MW

- **UCN Hall**
LANSCE Area-B UCN Source

- 800 MeV proton beam hits a tungsten target.
  - ~25 uC in 0.2 s every 5 s: 5 uA average or 4 kW proton power
- Spallation neutrons interact with various parts of the source.
- >2 MeV neutrons undergo n-2n reactions in Be.
- Neutron thermalize in Graphite, Be, poly and solid deuterium.
- Cold neutrons scatter in the solid deuterium to ultra-cold state.
- UCN valve to increase source lifetime
- Warm poly added in 2007, yellow
Current Capabilities of LANSCE UCN Source

- Huge floor space, ample cryogenic cooling (dedicated He liquefier in room)
- ~30 UCN/cc at shield wall
- Test port available
- ~1 UCN/cc in UCNA spectrometer @ 99.8% polarization
- Negligible artificial backgrounds

$\beta$-decay rates:
- 2006: less than 2 Hz
- 2007: 6.5 Hz
- 2008: 20 Hz
Layout of Test Port Area

- Test Port
- Switcher
- Pre-Polarizer Magnet
- Gate Valve
- Zr Window
- Monitor Det.
- Shield Wall
- UCN from source (7 m of steel guides)
- To Polarizer and UCNA
User Experiment location in LANSCE Area B
Layout For Source Tests

- Helium-3 Wire Chamber UCN Detectors (Al window)
- Gate valve closed allows measurement of lifetime in source volume
- Gate valve open allows measurement of UCN flux
Adjust source model to reproduce measured parameters

Data Flapper running

\[ \tau_{source} = 30 \pm 1 \text{ sec} \]

- UCN flux per time at gate valve
- CN flux monitors
  - Argon activation
  - 3He monitor
- Proton monitors: toroid, “graphite” monitor

Monte Carlo

\[ \tau_{source} = 30 \text{ sec} \]

Loss/bounce=4e-4
Layout for Magnetic Field Scans

- Vary solenoid magnetic field from 0 T to 6 T
- Change in UCN flux allows extraction of UCN velocity spectrum
Normalize the MC to the data and predict the flapper closed density

UCN Detected as function of Magnetic Field strength

\[ \rho_{\text{UCN}} = 35 \pm 7 \ \text{UCN/cm}^3 \]

At the exit from the shielding package
UCN velocity spectrum is in fair agreement with a stainless steel guide potential.

A. T. Holley, NCSU

Using a magnetic field and Monte Carlo to determine the UCN speed distribution. The UCN velocity is axially analyzed by the magnet.
The Bottom Line

- Source and Test Port are available and running now
- Parameters:
  - LANSCE runs 6 months/year
  - Proton beam is shared with PRAD
    - available ~100 hrs/wk while accelerator is on
  - UCN source is shared with UCNA
    - Test port beam can be on 10 minutes per hour while UCNA runs
  - ~15 UCN/cc at Test Port (after PPM), 30 at shield wall, up to 180 neV (at 4 kW incident proton power)
  - UCNs at Test Port are polarized to be high-field seekers
  - Backgrounds outside of beam gate are largely natural
    - Beam gate is 0.2 s per 5 s
- Allocation by UCNA Executive Committee for now
  - But we hope for a PAC process soon
Future Improvements???

- Improved proton beam tune
  - $x \sim 2$
  - Requires $0.2$ M$ for new beam pipe and diagnostics
- Larger tungsten spallation target
  - $x \sim 2$
  - Requires $0.3$ M$ for design and construction
  - Must be replaced regardless
- Beam pattern: spread out pulses
  - $x \sim 2$
  - Requires $0.5$ M$ for safety equipment
- Lower loss, higher V guides
  - $x \sim 3$
  - Requires $0.3$ M$ and six months to replace guides
- Duty factor: kick beam to pRad
  - $x \sim 2$
  - Requires $3$ M$ for kicker and shield wall
He4 Gas Cooled Tungsten Target

Graphite

800 MeV Protons
5 uA

12 cm
(~400 MeV)

Aluminum Tray
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Possible Experiments for Test Port (and UCNA Spectrometer)

- Neutron EDM experiment engineering and optimization (nEDM collaboration)
- UCN transport development
- Neutron beta decay measurements
  - Neutron lifetime (Bowman)
  - Beta decay correlations (UCNb, abBA, UCNB)(Plaster)
  - D coefficient and time reversal (Mumm)
- Short ranged forces and quantum gravity (Baessler)
- Neutron interactions with surfaces and solids (Korobkina)
- NNbar development (Kamyshkov)
- UCN source technology development (Liu)
Neutron Electric Dipole Moment (n-EDM, $d_n$)

$$d_n \rightarrow \mathcal{I} \rightarrow \mathcal{CP}$$

New sources of CP violation are required to explain the baryon asymmetry of the universe.

Experimental technique:
- put UCN in a bottle with $E$, $B$-fields
- search for a change in spin precession frequency upon $E$ reversal.

$$h \nu = 2 \mu_n B \pm 2d_e E$$
Past and Future n-EDM efforts

- Sussex-RAL-ILL expt. \(d_n < 3 \times 10^{-26} \text{ e-cm}\)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (Sussex-RAL-ILL)
  - 1000 UCN/cc, in superfluid 4He
- SNS
  - 430 UCN/cc, in superfluid 4He
- PSI
  - 1000 UCN/cc, in vacuo
- TRIUMF: \(1-5 \times 10^4\) UCN/cc

Sussex-RAL-ILL experiment
nEDM Storage Time at LANSCE Area B

\[
\frac{1}{\tau} = \frac{1}{\tau_n} + \frac{1}{\tau_w} + \frac{1}{\tau_{\text{hole}}} + \frac{1}{\tau_3} + \frac{1}{\tau_{\text{up}}}
\]

Storage cell

Vacuum enclosure

New nEDM Storage apparatus

Switcher

Pre-polarizer

UCN Detectors

UCN from SD$_2$ Source

M. Cooper

Goal: 20 K

Previous data

Storage Time vs Temperature

Storage Time (s)

Temperature (K)

0 50 100 150 200 250 300 350

0 50 100 150 200 250 300 350

0 50 100 150 200 250 300 350

0 50 100 150 200 250 300 350

100K 300K

400S

M. Cooper
Surface UCN Depolarization in a Magnetic field

The depolarization is measured again with the test guide placed between the baseline guide and the shutter.

Components:
- Shutter (with 3/16” monitoring aperture)
- Guides Tested
  - Stainless Steel
  - DLC Copper Guide
  - Electro-Polished Cu Guide
  - Mechanically-Polished Cu Guide

Raymond Rios et al.
Depolarization Results

We see an increase depolarization of neutrons with lower magnetic holding fields using diamond-like coated and mechanically polished Copper guides.
• The error on lifetimes measured with UCN are lower.
• The red value is in dispute and not included in the PDG average.
• LANL and others will make a difference.
Overview of Magnetic Trap Neutron Lifetime Experiment

- Asymmetric compound toroidal trap
- UCN trapped by gravity in open-top bowl ("the bathtub")
- Permanent magnets repel UCN on bottom
- Minimize material interactions
Cleaning marginally trapped UCN

- Trap must minimize **quasi-bound orbits** (and *quickly*)!\[\tau_{\text{clean}} \ll \tau_n\]
- **Asymmetry** helps fills trap phase space.
- Halbach array and coils introduces **spatial ripples** in the magnetic field to further destroy quasi-bound orbits.
- See Bowman’s talk for more details
Sensitivity

- Effective trap volume is 0.6 m$^3$
- UCN may trap up to E = 48 neV
- LANSCE source can produce >10 UCN cm$^{-3}$ at gate valve
- Trap density >1 UCN/cc: 600,000 UCN per fill
- We hope for a sensitivity of 0.1 s
Construction progress
Summary

• The LANSCE UCN source is operating now and able to supply extracted UCNs
• The available UCN density is up to 30 UCN/cc (at the shield wall)
• Several experiments have already used the test port
• Our new lifetime experiment is next in the queue for 2010
• We hope there will be more to come!