An Ultracold Neutron Source for TRIUMF

Jeff Martin (U. Winnipeg)


(KEK, TRIUMF, U. Manitoba, U. Winnipeg)

1. Introduction to Ultracold Neutrons (UCN)
2. UCN physics experiments
3. Source work at RCNP for TRIUMF
4. TRIUMF facility
5. CFI, relationship, collaboration, KEK
Ultracold Neutrons

- UCN are neutrons that are moving so slowly that they are totally reflected from surfaces of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - gravity: $V=mg\cdot h$ ($h < 3$ m)
  - weak interaction (allows UCN to decay)
  - magnetic fields: $V=-\mu\cdot B$ (100% polarization)
  - strong interaction
- Experiments at UCN sources are chronically limited by UCN density. TRIUMF has the potential to be a world leader in this regard.
UCN Source at TRIUMF would be a world-class facility

<table>
<thead>
<tr>
<th>Source type</th>
<th>E&lt;sub&gt;c&lt;/sub&gt; and τ&lt;sub&gt;s&lt;/sub&gt;</th>
<th>UCN density ρ&lt;sub&gt;UCN&lt;/sub&gt;(UCN/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIUMF 5 kW&lt;sub&gt;av&lt;/sub&gt; proton</td>
<td>E&lt;sub&gt;c&lt;/sub&gt; = 210 neV τ&lt;sub&gt;s&lt;/sub&gt; = 150 s</td>
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<td>E&lt;sub&gt;c&lt;/sub&gt; = 134 neV τ&lt;sub&gt;s&lt;/sub&gt; = 500 s</td>
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UCN Physics

- fundamental interactions of UCN
  - EDM
  - gravity
  - beta-decay
  - $n\bar{n}$ oscillations

- astrophysics
  - BBN
  - r-process

- surface physics

- development towards JPARC 2\textsuperscript{nd} target station UCN source
UCN quantum states in gravity

- test of gravity at 10 um scale
Measuring \( (n,\gamma) \) cross sections of the r-process (Buchmann)

132Sn stored in ring interacts with free neutron (UCN) target.

132Sn current 5e17 /s
UCN density 2e4 /cc
meter-long target
sigma ~ 100 mb
=> 50 interactions per hour
recoil separator
Surface Physics

- Many ideas to use UCN to study 10 nm thin surface films
  - (n, gamma)
  - UCN loss measurements
  - n scattering
  - reflectometry
    - polarization for magnetic films
- shown to be sensitive to low-frequency excitations (interesting for surface physics)
- In all cases, lack of UCN worldwide is the problem
How do we achieve this UCN density?

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Superthermal UCN production in He-II

Coherent inelastic neutron scattering in He-II

Born approximation
\[
\frac{d^2\sigma}{dQd\omega} = \frac{k_f}{k_i} a^2 S(Q,\omega) = \sigma_{coh}/4\pi \cdot \frac{k_f}{k_i} \cdot S(Q,\omega)
\]

M.R. Gibbs et al. (1999)
RCNP UCN Source (Masuda, et al)

1 ua protons at 400 MeV => 10 UCN/cc to expt.

Already has external users!
- e.g. Korobkina, Young (NCSU)
Gain Factors for TRIUMF

Horizontal He-II: $\phi_n \times 2$
$E_c 90 \rightarrow 210$ neV: $E_c^{3/2} \times 3.6$
UCN transport will be better
Storage time: $\times 5$

$E_p x I_p 390 W \rightarrow 20 kW$ (duty 1/4): $\phi_n \times 51$
Recent Progress on UCN at TRIUMF

- Aug. 2007 TUG working group (Canadians + Masuda), draft of white paper.
- Sept. 2007 International UCN Workshop (+ world experts).
- Sept. 2007 Presentation to Agency Committee on TRIUMF (ACT)
- Oct. 2007 phone meetings
- Nov. 2007 ACOT
International Workshop: UCN Sources and Experiments

September 13-14, 2007
TRIUMF, Vancouver, Canada
http://www.triumf.info/hosted/UCN

~25 speakers from all over the world
ILL, FRM-II, NCSU, LANL, PSI, KEK, Mainz, ...

Supported by TRIUMF and TUNL
Speakers at TRIUMF
UCN Workshop
Sept. 13-14, 2007

H. Abele, Heidelberg
S. Baessler, Mainz/UVa
L. Buchmann, TRIUMF
M. Daum, PSI
S. Gardner, U. Kentucky
P. Geltenbort, ILL
E. Gutsmedl, Munich FRM-II
R. Golub, NCSU
B. Filippone, Caltech
P. Huffman, NCSU
T. Ito, LANL
E. Korobkina, NCSU
C.-Y. Liu, Indiana U.
M. Makela, LANL

J.W. Martin, U. Winnipeg
Y. Masuda, KEK
P. Mumm, NIST
J. Nico, NIST
J. Ng, TRIUMF
M. Pospelov, U. Victoria/Perimeter Inst.
J.-M. Poutissou, TRIUMF
W.M. Snow, Indiana U.
F. Wietfeldt, Tulane U.
A. Young, NCSU
G. Hampel, Mainz
K. Hickerson, Caltech
Results of Workshop

• Very strong statement from the international UCN community (particularly R. Golub) that a He-II source should be pursued. Masuda clearly regarded as a leader in this field.

• TRIUMF would be an ideal venue for such a source.

• Many interesting physics experiments would be possible with the higher UCN densities achievable at this source.
Schedule

• Prior to 2010, pursue development of new UCN cryostat for TRIUMF at RCNP, Osaka.
  – This would allow us to demonstrate all the gain factors from horizontal extraction, better UCN guides. (aside from beam power)

• After 2010, begin construction of UCN source at TRIUMF (2010 = coincident with major reconstruction for ISAC 3).
Technical Issues for UCN

- Location.
- Beam sharing (dependent on location).
- Space (dependent on location).
- To carry out precision experiments, it is highly advantageous to pulse the UCN source. E.g. RCNP uses 1 min beam on, 3 mins beam off. During beam off, UCN can be counted (or their decays, etc.)
  - pulsing at ion source incompatible with ISAC.
  - achieve pulsing by diverting beam to well-shielded dump using kicker.
Conceptual to technical design for the UCN source and experiment

Issues:
- radiation
- cryogenics
- neutronics
- division of tasks
  - Masuda, Golub, others? very interested in cryogenics and neutronics
  - need TRIUMF support to bring to fruition
Based on LANL design

- 3m steel, 2m concrete
- W target 2 cm $\phi \times 10$ cm long
- He-gas cooling
- Remote extraction of target via removal of shielding block, cask
- Need better technical design of cryostats suitable for easier access/extraction
- LANL design has this amount of shielding, certified for 100 uA pk currents. (we desire 40 uA pk, at lower energy)
Cryogenics/Shielding Numbers from Masuda

- According to MC + estimates, for time-avg p-beam power of 12 kW in W target:
  - $0.45 \times 10^{12} \text{n/cm}^2/\text{s}$ in He-II
  - 2.3 W in He-II
  - 30-60 W in 20 K D2O
  - 1.7 kW in 300 K D2O
- Masuda's current 3He pump can take 8 W.
- Clever arrangement of 208Pb can reduce gamma-heating of He-II even lower.
- Radiation #'s consistent/lower cf. LANL.
Solutions Discussed for Technical Issues (thanks, accel group!)

- Location: BL4A area
  - UCN source viewed as an ISAC-3 target station, located in Proton Hall
  - Advantages:
    - UCN fully integrated into ISAC-3 program in terms of physics (fundamental symmetries) and facility (another ISAC-3 target station).
    - simultaneous operation with ISAC-3 by decoupling on kHz scale with kicker/ion source manipulation. Advantageous for ISAC-3: run all three targets simultaneously.
    - use another kicker to divert beam to dump in ISAC-3 area to achieve UCN pulsing (1 min on / 3 mins off).
    - recent designs of ISAC-3 BL4N take the beam further into Proton Hall (towards UCN). And more shielding already required in that area.
  - Disadvantages:
    - space in Proton Hall getting tight.
    - coupled to ISAC-3.
- Location: ISAC-3 target hall.
- Location: BL5 port (new port)
Achromatic Bend for ISAC (12m x 10m?)

UCN source (12m x 12m)

UCN expts (no shielding) (6m x 12m)

Enough space for kicker + septum?
Potential Layout in Proton Hall (rev. 9/6/07)

Jeff needs to fix for consistency
Cost

- Cryostat, LHe cooling costs very well-understood (1.4 M$ CAD)
- Masuda request to Japanese funding sources for 2.4 M$ CAD over the next four years (the above plus EDM development) explicitly mentions TRIUMF. (submitted Nov. 2007)
- Shielding, remote handling, etc., costs yet to be estimated. Base on experience from TRIUMF, LANL, and RCNP. (Prior to shielding simulations.)
Collaboration

• Strong interest from Canadian Subatomic Physics community (Winnipeg and Manitoba groups) and from world-wide UCN community

• strong KEK group who have already created a world-class facility (Masuda et al)

• well-attended working group at August TRIUMF townhall meeting

• big event: UCN workshop at TRIUMF Sept. 13-14, 2007
  – world experts in attendance

• Interest in submitting a CFI proposal for UCN source in 2008 from Canadian groups
Summary

• An opportunity exists to create the world's highest density UCN source at TRIUMF

• A flagship physics experiment done this facility would be world's best

• The UCN facility would be tied to the ISAC-3 program in terms of both physics and facility

• We would like to pursue this unique and timely opportunity
Back-ups
simultaneous operation with ISAC-3 by decoupling on kHz scale with kicker/ion source manipulation. Advantageous for ISAC-3: run all three targets simultaneously.

ion source current vs. time

I(t)

kick to ISAC-3-1

kick to ISAC-3-2

kick to ISAC-3-3 (UCN)

10 msec

1 msec
Solutions Discussed for Technical Issues

• Location:
  – BL5 area

• Advantages:
  – decoupled from ISAC 3.

• Disadvantages:
  – new beam port must be constructed
  – beam line must not conflict with cyclotron probe extraction point
  – high-power dump required to achieve pulsing with kicker.
  – space in Proton Hall tighter – likely requires excavation for dump.
International Workshop: 
UCN Sources and Experiments

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Supported by TRIUMF and TUNL
Aug. 1

morning - plenary session, charge, and introduction of working groups

12:00 lunch

13:00 Welcome + Charge (Martin) (10+5)
13:15 UCN Sources Worldwide and for TRIUMF (Masuda) (45+10)
14:10 Photofission, (gamma,n) Sources and UCN (Behr) (10+10)
14:30 coffee (30)
15:00 SCRF joint session: Electron Linac Design (Koscielniak) (20+10)
15:30 UCN Infrastructure and Proton Hall Floorplan (Davis) (10+10)
15:50 Proton Hall Radiation Limits (Trudel) (10)
16:00 Discussion (Chair: Davis) (30)
16:30 tour of proton hall? (if desired) (Davis) (30)

Aug. 2

09:00 Continued infrastructure Discussion (60)
10:00 UCN Physics Intro (Martin) (10+5)
10:15 UCN Beta Decay (Melconian) (20+10)
10:45 coffee (30)
11:15 n-EDM (Masuda and/or Hayden?) (20+10)
11:45 radioactive beams (Buchmann) (10+10)

12:05 lunch

13:15 gravity levels (Konaka) (5+10)
13:30 other physics (Martin) (15+10)
13:55 discussion of physics priorities and strategy (chair: Martin) (35)
14:30 begin writing
  more joint sessions
  draft Aug. 3 morning presentation

Aug. 3

morning - presentations of results from the working groups.
Outline of White Paper

- Physics
  - prioritized and realistic, as much as possible
- UCN Source
  - proposed intensity at TRIUMF
  - world context and relevance
- Required Infrastructure
  - floorspace, shielding
  - duty cycle
  - He liquefier
- Required funding
  - CFI and collaboration, and international