High Rate Detectors for Ultra Cold Neutrons at TRIUMF

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Challenges of the world-wide experimental search for the electric dipole moment of the neutron
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Outline

● Overview of the measurement
● Review Detector Requirements
● Lithium glass scintillator detector
  – Mechanical Design for Prototype
  – Lithium glass side with 6Li
  – Tests with alpha source
● High rate readout
● Conclusions
Overview of nEDM Measurement

Detector measures number of neutrons of a given spin orientation at a time.

Spin orientation selected by Magnetized Iron foil. Change magnetization direction using coil.

Simplest case:
- Single experiment cell
- Single detector

Could extend this to:
- Two experiment cells
- Two detectors for each cell
- Measure both Spin states

Up to four detectors
- 2 for each cell
- Measure both Spin states
Overview of Measurement

Count particular spin neutrons for four NMR frequencies around Ramsey resonance frequency.

Visibility of fringes
\[ \alpha = \frac{N_{\text{max}} - N_{\text{min}}}{N_{\text{max}} + N_{\text{min}}} \]

Statistical uncertainty
\[ \sigma_{\omega_r} = \frac{\Gamma}{\pi \alpha \sqrt{N}} \]

Formula for determining Ramsey resonance
\[ N_{up}(\omega_i) \approx N_{up}^{\text{min}} + (N_{up}^{\text{max}} - N_{up}^{\text{min}}) \sin^2 \left( \frac{\pi}{2 \Gamma} (\omega_i - \omega_r) \right) \]

Also include counts from spin down neutrons as separate measurement.
UCN Detector Requirements

- diameter of 85 mm to cover the entrance pipe
- Rate ~1.5 MHz and ability to handle any effects of pile-up (based on expected UCN in the experiment cell, and draining simulations)
- Ability to account for backgrounds (gamma, beta, thermal neutron)
- A variation in efficiency better than 0.03% over an hour (based on 1/sqrt(N) better stability than statistical uncertainty, N=10^7)
- Ability to normalize for changes in UCN density (ie. Due to drifts in detector efficiency, changes in number of UCN produced, etc.)
Simulation to study different dropping geometries

Simulations run by Undergraduate student Sean Hansen-Romu

Geometry:
- Cell Radius and height 10 cm
- Guide Radius 42.45 mm
- Drain set to same as Guide Radius
- Guide Length initial at 50 cm
- Guide Length varied by 5 cm / run to a total of 1.5 m

100 000 Neutrons thrown each run

Bent Case specific:
- Bend Radius 1&2 are equal, and bent height kept at 20 cm (pic not to scale)
- Total guide length is likewise varied
- Vertical Guide 1 also kept at 20 cm

100% optimal detector

Loss and absorption during collisions with geometry is turned on

K.E. ~ Maxwell-Boltzmann Emax ~ 95 neV (quartz)

Simulations with Geant4-UCN code.
This code was also used to get arrival time profiles for different opening sizes.
Dropping simulation results

Simulations run by Undergraduate student Sean Hansen-Romu

Vertical K.E. distribution

Fraction of Events with Vertical KE>107neV

Increasing drop after bend

0.5 m → 1.5 m
Reminder of how the Li glass detector works

- Use Li-6 depleted glass on top (GS30) of Li-6 enriched glass (GS20)
- UCNs go through GS30 and capture within 1-2 microns of the surface of the GS20 via: \( n + ^{6}Li \rightarrow t (2.73 \text{MeV}) + \alpha (2.05 \text{MeV}) \)
- Full energy of triton and alpha produce scintillation light in the glass scintillator (very little edge effect)
  - Only need < 50 microns thick for each of scintillators to capture full energy
  - Have 100 um thick GS20 and 60 um thick GS30 optically contacted set prepared for us by Thales-SESO (10 pieces 29mm square)
Nominal PMT choice

- **R7600U:**
  - Gain $2 \times 10^6$
  - 30mm square
  - 200A/lm
  - 2nA dark current
  - 10 stages
  - 800V
  - 0.35ns time resol.

Main reasons for this choice:
Compactness, Size Matches our 29x29mm “pixels”

Graduate student Lori Rebenitsch has begun tests using this PMT, and we have 10 of these PMTs in Winnipeg to use in a prototype detector.
Li glass, acrylic lightguide, and PMT test set-up two

- Setup at left was used for looking at some simple scope traces
  - used to study dark rate
  - daq tests
  - test light collection with acrylic guides with different levels of polish (underway)
Waveforms from test setup
20 ns x 100 mV per division

Scintillator / Alpha Event

- Scintillation has a fast and short component
- Fast component ~50ns,
- Long component ~1us.
- UCN should look similar to alpha event

Cerenkov Event

- Cerenkov may have a large pulse, but short duration, ~ 20 ns.
- Notable pulse shape difference
Digitizer used for fast DAQ

- V1720 Digitizer from CAEN
  - 8-channel waveform digitizer with pulse shape analysis on FPGA

Figures from CAEN manuals.
Long and Short Charge for Alpha Source

- Save only Qs, Ql and time from digitizer
- Able to collect data up to 500kHz per channel
- Will need to do some online analysis to reduce data size!

Note: 70/300~0.23, expect ~0.3 from area change alone

5 MeV alpha with lightguide
- Mean ADC 4800
- Sigma 750
- ~15% resolution
- Estimate ~70 p.e.

5 MeV alpha no lightguide
- Mean ADC 22000
- Sigma 2400
- ~10% resolution
- estimate ~300 p.e.

Single p.e. peak due to PMT dark count
- Constant = 4525
- Mean 77.49
- Sigma 61.03

~15% resolution

Pulse and Digitizer Simulation

- Scintillation+PMT pulse simulation based on summing multiple gaussian single pe pulses
  - Model includes a short and long rate scintillation
- Can set pulse rate
- Add some gaussian white noise
- Digitizer simulation includes tunable long and short integration
- Able to set size of time bins, and trigger holdoff
- Also include fixed baseline, or average over some number of samples for baseline, similar to V1720 digitizer
- Using this to study digitizer behaviour for high rates

Need to add simulation of Cerenkov light
Detector Stability Tests

- Have done some initial studies of the rate stability at low rate
- Above is rate measured for an alpha source over a four hour period
- Still developing method to handle high rates with some pile-up
- May use some Qlong vs Qshort PDFs for no-pile up and with pile-up to try to statistically determine the correct number of neutrons
Li glass prototype detector design

- Make enclosure with low density non-magnetic material (Al)
- Lightguides are Ultra-violet transmitting acrylic
  - Use white o-rings around lightguides to make vacuum seal
- PMTs are in air, with darkbox holding them in place

For now opening and bolt pattern match RCNP guides, may want to go to a square opening to match the “pixels” (better distribute the rate).
Photos from test assembly before gluing lithium glass
Testing which side of Li glass stack is GS20

- Want to glue the scintillator stacks the right way up!
  - Look for alpha/tritium from $n(6\text{Li},t)\alpha$
  - Only from 6Li enriched side

Have tested all 10 samples this way – now ready for gluing to lightguides

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Dark box
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Li glass stack
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Si surface
Barrier detector
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1mCi AmBe source
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Borated wax
Shielding / moderator
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Energy (arb. units)
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Counts per energy division
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- Doped Side Up
- No Glass
- Depleted Side Up
Conclusion

- We have a design for a detector prototype and hope to test it with UCN
  - We are still studying the possibility of using air core lightguides to reduce Cerenkov light (Fleurette)
  - Initial indications are that we should see 50 p.e. for a UCN capture
- Methods of handling pileup with the digitizer are being investigated, after which high rate stability tests will be performed with a strong alpha source (Lori)
- We have found a way to check that we put the right side of the Lithium glass stack toward the UCN.
Backup
Tests of Gluing
Using acrylic and glass

- Best results followed TRIUMF scintillator shop suggestion
- Mix the bicron epoxy well, then pump out bubbles in vacuum
- Drop 3 drops of epoxy on the acrylic, then place the glass on top of the epoxy
- Gently press down from the center of the glass until the glue seeps out the corners (then wipe edges)

Above are good gluing jobs using method Described at right

Right shows crystal bond after being in vacuum for several days
Lithium glass stacks at Winnipeg now

- Li glass bought with last RTI grant
- Li glass bonding done using my CFI grant at Winnipeg
  - 10 sets are for prototype / final detector
    - These have very optical bonding and
      - 60um thick GS30 (no 6Li)
      - 120um thick GS20 (enriched 6Li)
  - 3 sets with corners not fully adhered
  - 2 sets with air bubbles
  - 1 set not adhered
  - 8 sets nicely optically bonded, but not thinned
    - 1mm thick of both GS20 and GS30
UVT Acrylic light guide

- Indices of refraction are fairly close
  - Acrylic: ~1.5
  - Li-glass: ~1.55

- Hold Li-glass using bicron optical epoxy
- Method of gluing tested with acrylic and glass slides

- Using optical grease from St. Gobain for PMT to light guide coupling (not in vacuum)
Prototype details – detector enclosure

- All aluminium to minimize amount of high density material
- Top flange is flat, and has 12 bolt holes
- Bottom has an o-ring groove, and part way through holes to match RCNP guide flange
- Extra notch in bottom flange to mount an LED for calibration purposes

Units are inches
Prototype details - Detector flange

- Has o-ring groove to make seal with detector enclosure
- Holes for light guides
- Several bolt holes to hold light guide o-rings and to hold dark box enclosure

Again all units are inches
Dark box

- Extra space on each side for foam inserts to hold PMTs
- Holes on top for PMT cables, to be made dark with black tape
Light guide seal

- Fits around light guides, and has grooves for o-ring seals
- Bolt pattern to hold it to the detector flange

Aluminium inches

Detail of o-ring groove