Ultracold Neutron detection with scintillating ZnS and 6Li detectors

Igal Press

The University of Winnipeg

For the TUCAN collaboration

Introduction

The ultracold neutron (UCN) experiments conducted by the TUCAN collaboration are aiming to uncover the secret behind the neutron electric dipole moment (nEDM) and whether it's non-zero. If an nEDM is found it signifies a charge parity (CP) violation which could lead to the discovery of a difference between particles and anti-particles. To measure the nEDM we must be able to effectively store and measure UCN with high efficiencies, and the purpose of this experiment is to create and characterize a high efficiency UCN detector that minimizes background radiation as well as to characterize their efficiencies for cold neutron (CN) detection.

The three ^{6}Li detectors functioned similarly to one another. When a neutron hits a ^{6}Li atom you get the below reaction that creates two photons of light[3].

$$^{6}\text{Li} + n \rightarrow \alpha(2.05\ \text{Mev}) + t(2.73\ \text{MeV}) \quad [4]$$

When a UCN hits the ^{10}B-ZnS:AG (ZnS) detector, the ^{10}B releases a ^{4}He atom and ^{7}Li where the energy of these molecules is converted into a photon[5].

$$^{10}\text{B} + n \rightarrow \alpha + {}^{7}\text{Li} + \gamma \quad [6]$$

When light gets released, it gets passed down photo-multiplier tubes (PMT) which generates electrons that get multiplied and passed down until they interact with the detector[1].

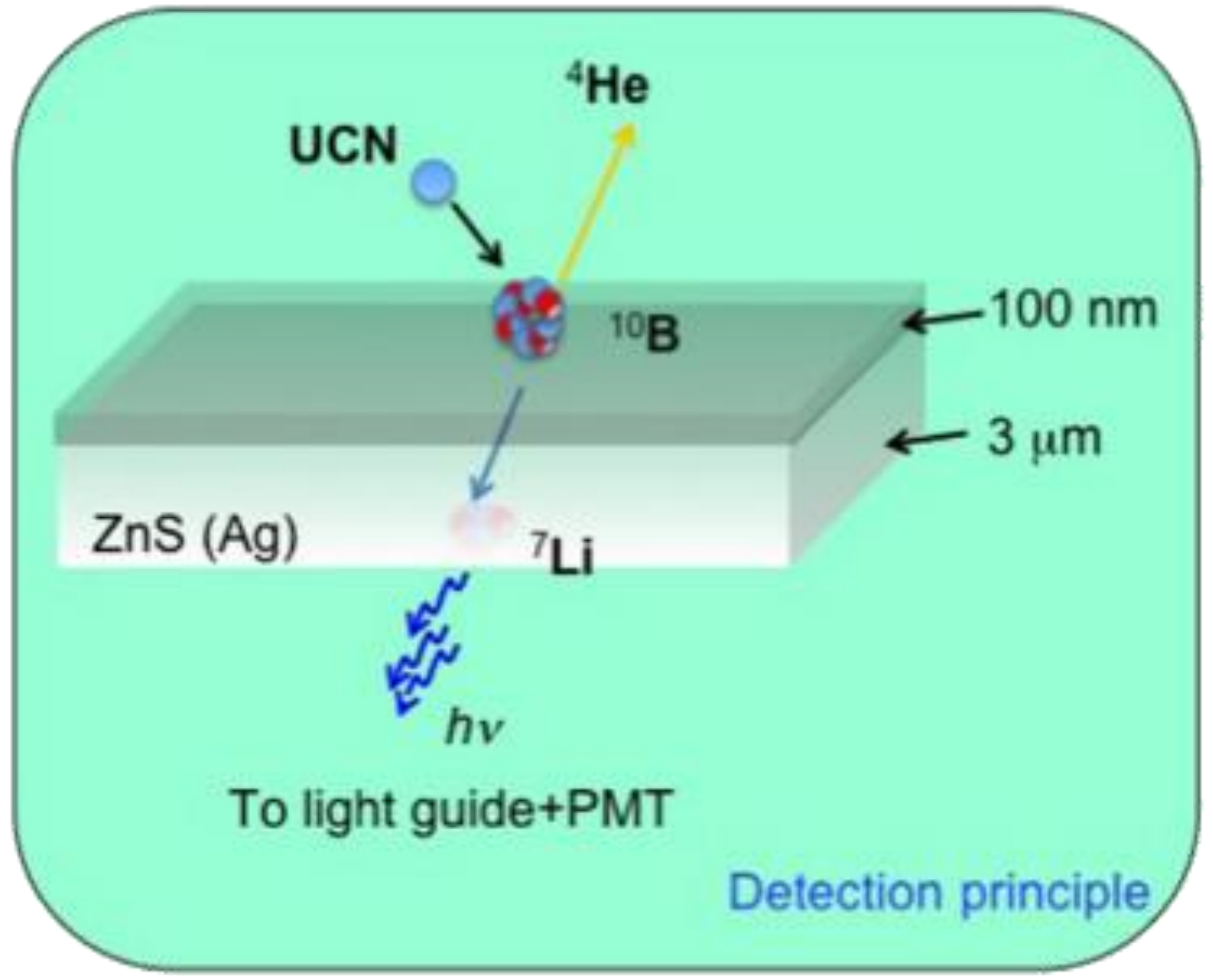

Figure 1: An illustrated decay scheme for UCN interaction with ^{10}B [4]

Experimental apparatus

Three groups of detectors were employed at the Japanese Proton Accelerator Research Complex (J-PARC), totaling to six detectors. The CN reference detector was a ^{3}He detector operating at 10atm of pressure[2], while the UCN reference detector used is known as the DUNia-10 proportional gas counting detector (Dunia). The second group was comprised of three ^{6}Li detectors. Each ^{6}Li detector was comprised of two pieces of lithium glass, the first being a lithium depleted layer and the second an enriched layer[3]. The final detector employed was a ZnS detector. A doppler shifter was employed for the creation of UCN to slow down CN into UCN[4].

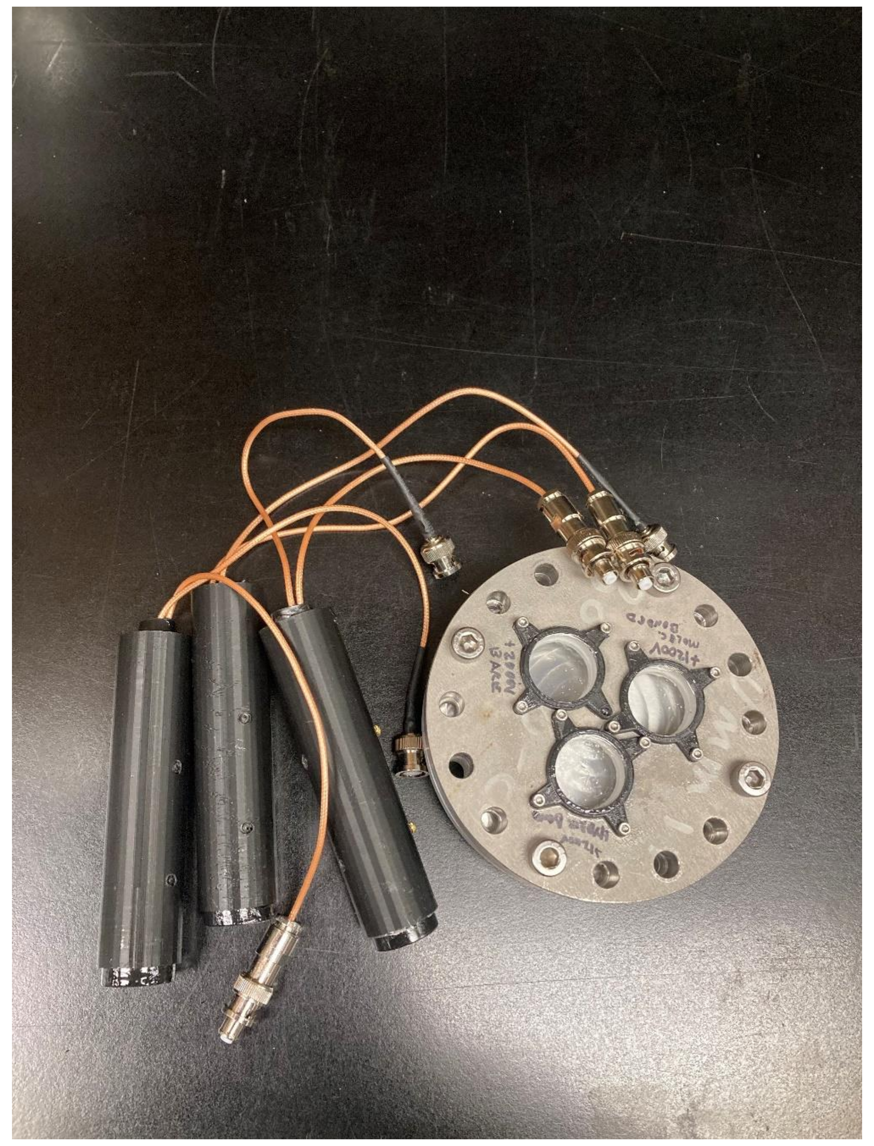

Figure 3: The ^{6}Li scintillating detector.

Detection methods and analysis

For UCN runs the detectors were attached directly to the doppler shifter. The time of flight (TOF) was used to determine the efficiency of the detectors for CN and UCN runs.

Code was written to normalize the histograms and subtract the foreground and background radiation and calculate the subsequent efficiency of the detectors.

Figure 2: The UCN detector setup. (Pictured: ZnS detector)

Results

For CN runs it appears that the ^{6}Li detectors are marginally more efficient than the ^{3}He reference detector and an order of magnitude more efficient than the Dunia reference detector.

For UCN runs the ZnS detector operated least efficient relative to the dunia reference detector, while the molecular bonded, hydroxide bonded, and bare detectors operated slightly more efficiently.

	Dunia (CN)	^{3}He (CN)	Dunia (UCN)
Molecularly bonded	(35±5)x	1.2x	(1.75±0.25)x
Hydroxide bonded	(25±5)x	1.1x	(1.0±0.2)x
Bare	(30±10)x	1.0x	(1.5±0.2)x
ZnS	0.2x	0.05x	0.4x

Table 1: Detector efficiency comparisons.

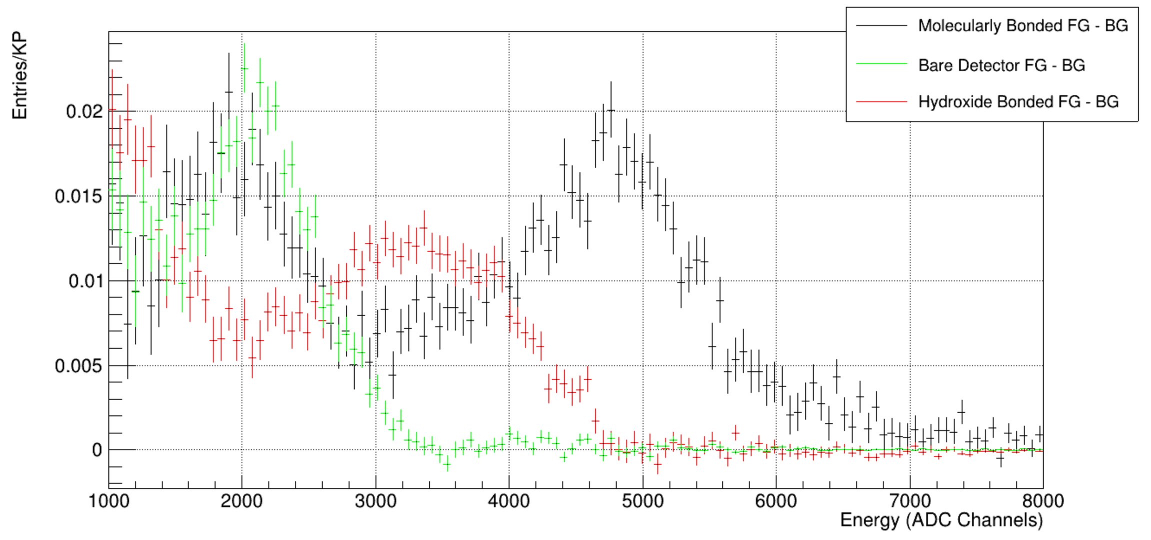

Figure 4: Detector energy spectra.

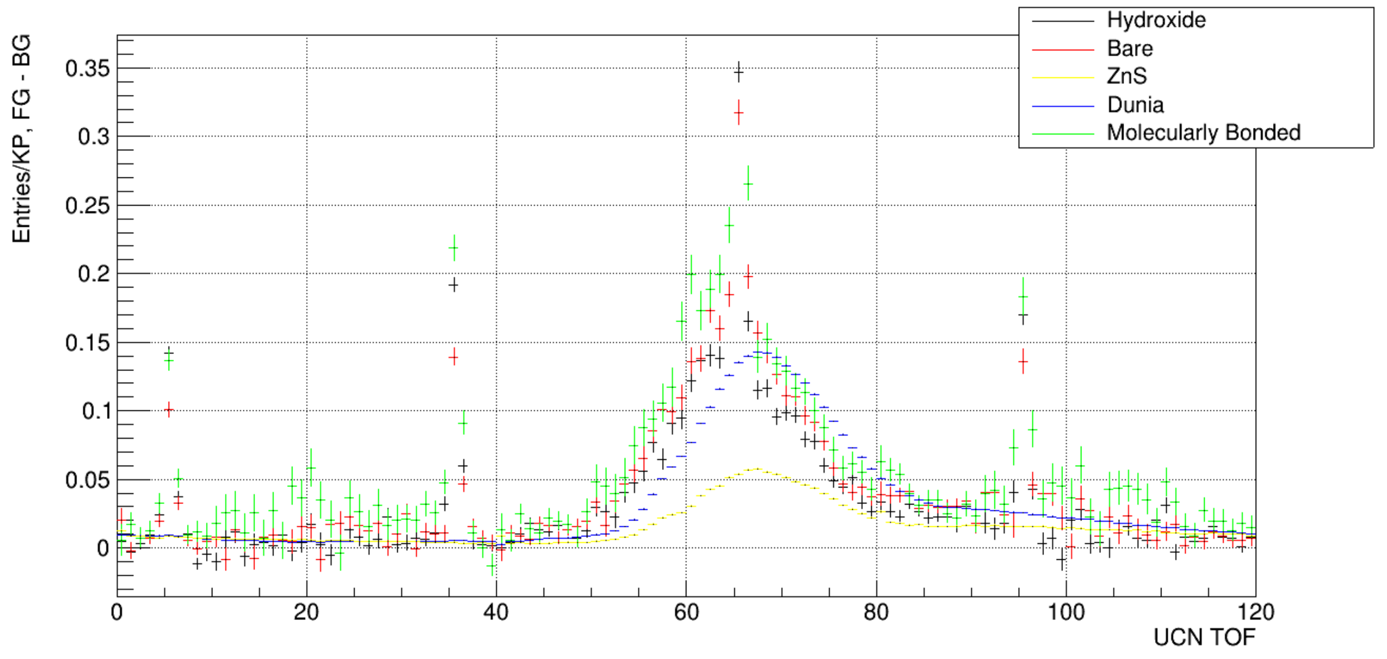

Figure 5: UCN TOF measurements comparing detector efficiencies.

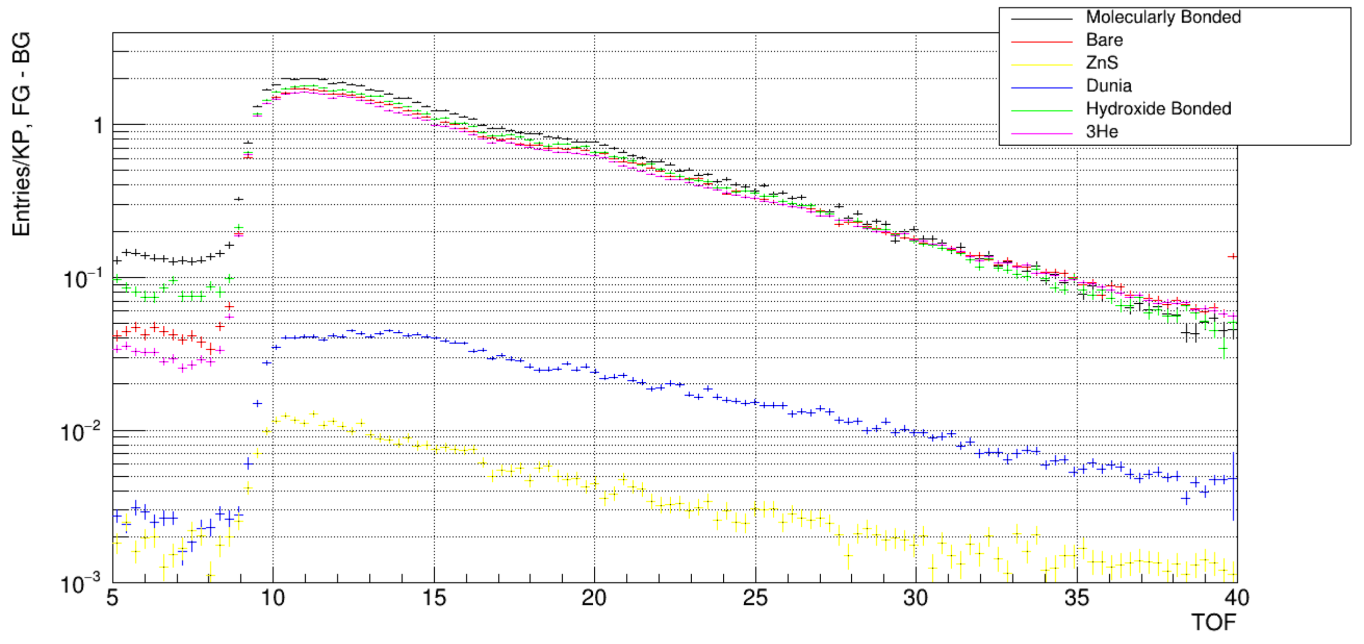

Figure 6: CN TOF measurements showing their CN sensitivity.

Conclusion

The ^{6}Li detectors were found to be more efficient than both reference detectors employed for use in UCN and CN measurements. The molecularly bonded detector was especially efficient for both types of measurements and should be employed in future UCN research.

On the other hand, ZnS detectors due to their inefficiency with detecting CN can be useful for UCN detection in high background environments.

The hydroxide bonded detector had never been tested before and appeared to be approximately as efficient as the Dunia and molecularly bonded detectors showing a successful bonding method.

References

[1] Golub, Robert, et al. *Ultra-Cold Neutrons*. Hilger, 1991.

[2] Imajo, Sohei. "Description of usual data analysis at J-PARC/MLF BL05", internal note (2022)

[3] Imajo, S., et al. "Pulsed Ultra-Cold Neutron Production Using a Doppler Shifter at J-PARC." *Prog. Theor. and Experimental Physics*, 2016, 13C02, (2016).

[4] Jamieson, B., et al. "Characterization of a Scintillating Lithium Glass Ultra-Cold Neutron Detector." *Eur. Phys. J. A* 53, 3 (2017).

[5] Knoll, Glenn F. *Radiation Detection and Measurement*. John Wiley, 2020.

[6] Wang, Zhehui, et al. "A Multilayer Surface Detector for Ultracold Neutrons." *Nucl. Instrum. Meth. A* 798, 30 (2015).

Acknowledgments

Dr. J. Martin: Professor, University of Winnipeg

Dr. S. Kawasaki: Associate Professor, High Energy Accelerator Research Organization (KEK)

Dr. K. Mishima: Associate Professor, KEK

MITACS Globalink Research Scholarship

Japanese Proton Accelerator Research Complex (J-PARC) MLF facilities S-type proposal 2019S03

Contacts

Email: Press.Igal@gmail.com

LinkedIn: linkedin.com/in/igal-press/

TUCAN

TRIUMF Ultra Cold Advanced Neutron source