PROCEEDINGS OF SCIENCE

# The TUCAN Neutron Electric Dipole Moment Experiment

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The goal of the TRIUMF Ultra-Cold Advanced Neutron (TUCAN) Collaboration is to successfully make a new measurement of the neutron electric dipole moment (nEDM) with an uncertainty of $1 \times 10^{-27}$ e-cm in 400 days of run time, a one order of magnitude improvement compared to the current world's best result. The experiment is unique in using a spallation-driven superfluid helium (He-II) source of ultracold neutrons (UCN). We are now at the stage of upgrading the UCN source to produce world-leading UCN densities, using a new He-II cryostat that has undergone cryogenic testing at KEK in 2020-21. We are also assembling the experimental components of the EDM experiment, including a magnetically shielded room, coils, and atomic magnetometers.

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## 1. nEDM Measurement Process

Neutrons in a combined magnetic and electric field will precess with a frequency depending on the magnetic dipole moment, $\mu$, and the electric dipole moment (EDM), $d$:

$$\hbar\omega_n = 2(\mu B + dE). \tag{1}$$

By comparing measurements of the precession frequency for parallel and antiparallel fields the EDM can be extracted,

$$\hbar\omega_n^{\uparrow\uparrow} = 2(\mu B + dE) \tag{2}$$

$$\hbar\omega_n^{\uparrow\downarrow} = 2(\mu B - dE) \tag{3}$$

$$\hbar\omega_n^{\uparrow\uparrow} - \hbar\omega_n^{\uparrow\downarrow} = 4dE. \tag{4}$$

The neutron electric dipole moment (nEDM) is of significant theoretical interest as it violates time reversal, and through the CPT theorem serves as a test of the CP symmetry[1]. Figure 1 shows a cartoon layout of the double measurement cells. This cell configuration will be used to allow parallel and antiparallel frequency measurement to be made simultaneously with identical field magnitudes.

To measure the difference in the precession frequencies between the neutrons in the different cells a Ramsey cycle will be used. In this measurement method, polarized neutrons are loaded into the cells and then a two $\pi/2$ magnetic field pulses are applied with a time delay between. After the last pulse a set of selective spin analyzers (SSA) will measure the relative population of neutrons in each spin state from each cell which will allow the frequency difference to be extracted. While the neutrons are precessing during the delay between the pulses it will be critical to have a uniform and stable magnetic field in the measurement cells.

## 2. New UCN Source and Experiment

To reach the statistical accuracy goal for the experiment a new ultra-cold neutron (UCN) source is being developed at TRIUMF that will be capable of providing the required UCN densities[2]. Figure 2 shows the layout of the source that is under development at TRIUMF. To begin the UCN production process high energy spallation neutrons will be produced by directing high energy

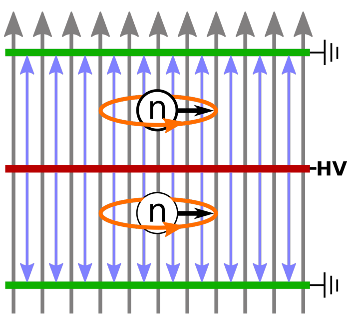



**Figure 1:** Cartoon Layout of the double nEDM measurement cell.

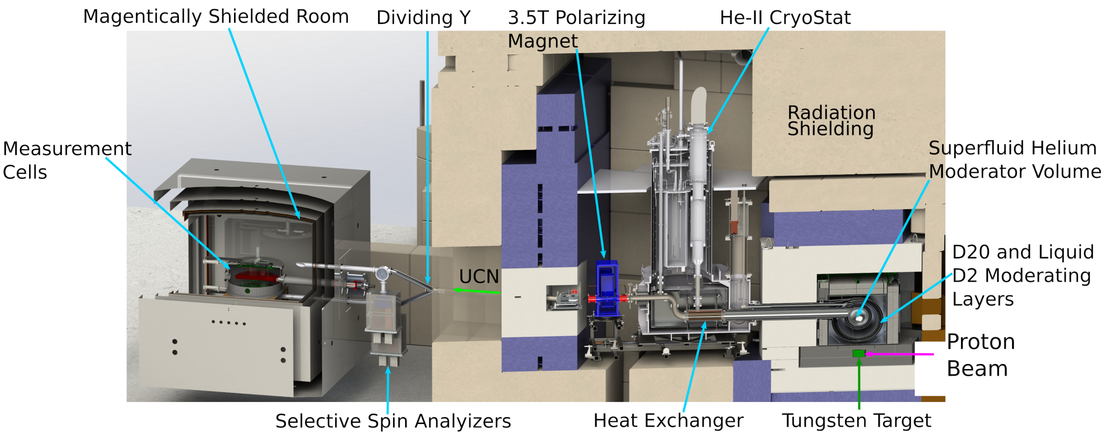
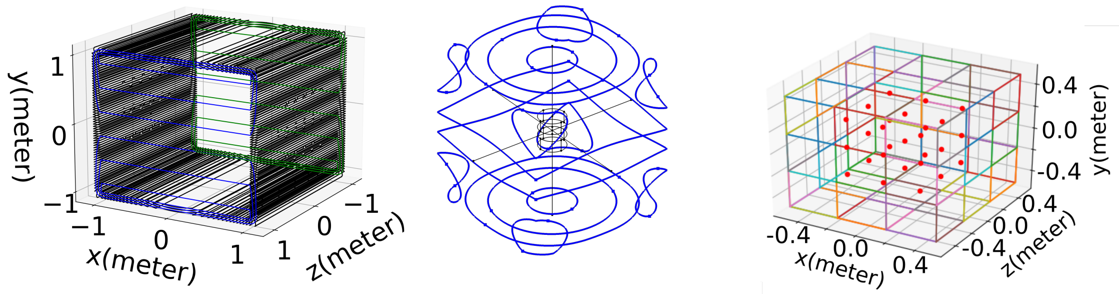



**Figure 2:** CAD model rendering of the new UCN source and experimental setup.




**(a)** B0 Coil **(b)** $G_{\ell 0}$ Example Coil **(c)** n×n Coil

**Figure 3:** Internal coils of the magnetically shielded room.

proton pulses from TRIUMF's accelerator onto a tungsten target, some fraction of these neutrons are moderated by passing through the $D_2O$ and a liquid $D_2$ moderating layers that will surround a superfluid He volume where low energy neutrons can be converted into UCN and accumulated while the spallation target is irradiated. This volume, and the UCN guides, will have a nickel phosphorous coating to maximize the numbers of neutrons that are trapped. A guide coating facility is under development at the University of Winnipeg. A Y shaped guide is used to divide the neutrons between the paired measurement cells.

To provide the required uniform 10 $\mu$T magnetic field throughout the measurement cells a magnetically shielded room (MSR) will be used to reduce external fields by a factor of 100,000 and three sets of magnetic coils, show in figure 3, will then be used to create the neutron precession field. The B0 coil will provide the main field, the the $G_{\ell 0}$ coils will be used to correct for specific systematic effects, and the n×n coil will be used to improve the overall field uniformity. A set of 20 optical Cs magnetometers will be used to monitor the magnetic field during measurements.

## 3. UCN Source Upgrades

A UCN source was installed and produced its first UCN at TRIUMF in 2017[3, 4]. Figure 4 shows a diagram of this source. Using the lessons learned from this source development has been

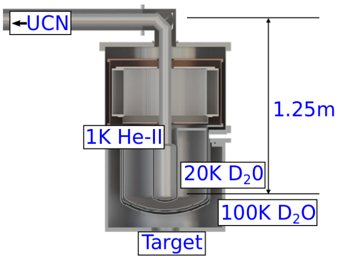



**Figure 4:** Schematic diagram of the original vertical source design.

underway of an upgraded source with a new moderator, UCN storage and extraction geometries designed to increase the available neutron densities. One of the significant changes was to move from a vertical UCN storage bottle and extraction tube to a primarily horizontal design as shown in figure 2. This will allow the extraction of lower energy UCNs from the storage volume, which can be stored longer in material bottles.

The new design has a larger diameter superfluid storage volume to increase the heat conductivity along the storage volume, and a larger heat exchanger for faster heat exchange to maintain the low temperatures in the superfluid He under the heat load from the spallation and neutron moderation process. This is critical to maximizing the UCN production rate and storage densities, as the higher the He temperature, the more likely UCN are to up scatter out of the storage volume. A He-II cryostat will be used to pump heat away from the heat exchanger, the current cryostate has a cooling capacity of 0.4 W and it is being replaced with a new 10 W crysotat to handle the increased heat loads required for reaching higher UCN densities.

## 4. Acknowledgements

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