The TUCAN Neutron Electric Dipole Moment Experiment

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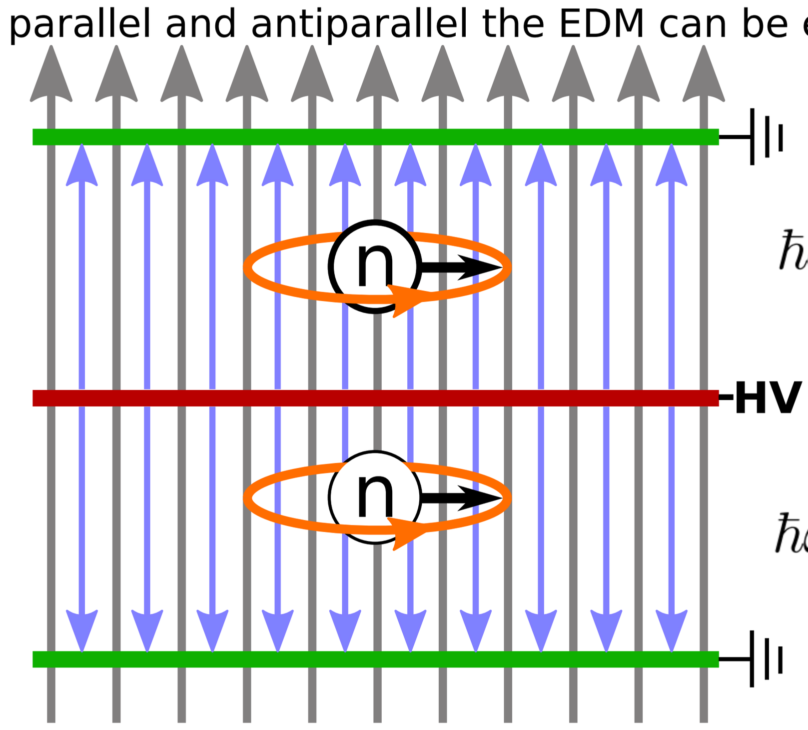
Introduction

The goal of the TRIUMF Ultra-Cold Advanced Neutron (TUCAN) Collaboration is to successfully make an new measurement of the neutron electric dipole measurement (nEDM) experiment with an uncertainty of 1×10^{-27} e-cm, a one order of magnitude improvement compared to the current world's best. 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.

Measurement Process

Neutrons in a combined magnetic and electric field will precess with a frequency depending on the magnetic dipole moment, μ, and the electric dipole moment (EDM), d. By comparing measurements of the precession frequency for the fields parallel and antiparallel the EDM can be extracted.



Measurement Cell Schematic

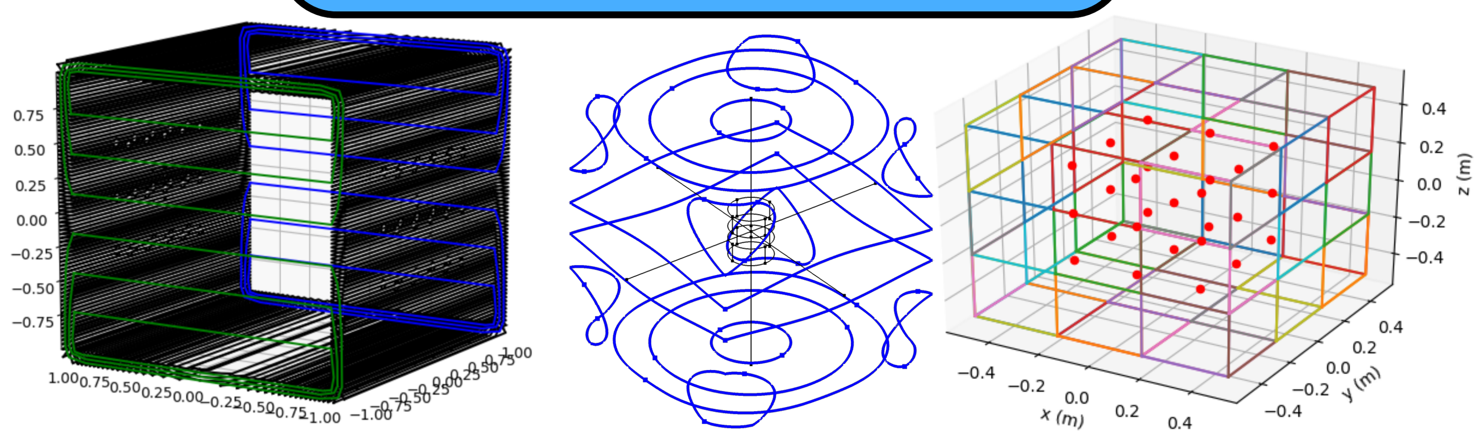
$$\hbar\omega_n^{\uparrow\uparrow} = \mu B + dE$$

$$\hbar\omega_n^{\uparrow\downarrow} = \mu B - dE$$

$$\hbar\omega_n^{\uparrow\uparrow} - \hbar\omega_n^{\uparrow\downarrow} = 2dE$$

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 π/2 magnetic field pulse are applied with a time delay between. After the last pulse a set of selective spin analyzers will measure the relative population of neutrons in each spin state from each cell which will allow the frequency difference to be extraced.

While the neutrons are precessing during the delay between the pulses it is critical to have a uniform and stable magnetic field, to accomplish this 3 sets of magnets will be used to provide the holding field, and to correct for any inhomogeneities in the magnetic fields inside the measurement cells.

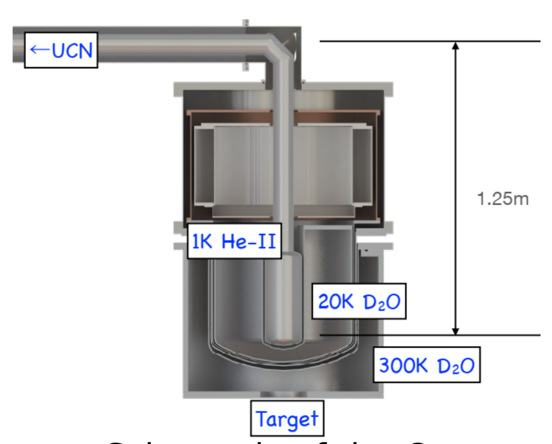


(a) B0 Coil (b) G_{l0} Coil (c) n x n Coils

UCN Source Upgrades

A UCN source was installed and produced its first UCN at TRIUMF in 2017. Since then developement has been underway of an upgraded source with a new moderator, UCN storage and extraction geomtries designed using the lessons learned from the first source to increase the available neutron densities.

One of the significant changes was to change from a vertical UCN storage bottle and extraction tube to a primarily horizontal design as shown in the large image to the right. This will allow the extraction of lower energy UCNs from the storage volume, which can be stored longer in material bottles.



Schematic of the Current Vertical Source Design that is being replaced.

The new design also 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 is used to pump heat away from the heat exchanger, the current cryostate has a cooling capacity of 0.4 W and is being replaced with a new 10 W crysotat to be able to handle the heat loads required for reaching higher UCN densities.

1. Protons pulses from the TRIUMF accelerator are directed onto a solid tungsten target to produce high energy neutrons

2. The energy of these neutrons will be reduced as they pass through a D20 and liquid D2 moderator.

3. Neutrons entering the interior volume will be converted into UCN by the superfluid helium and accumulated there.

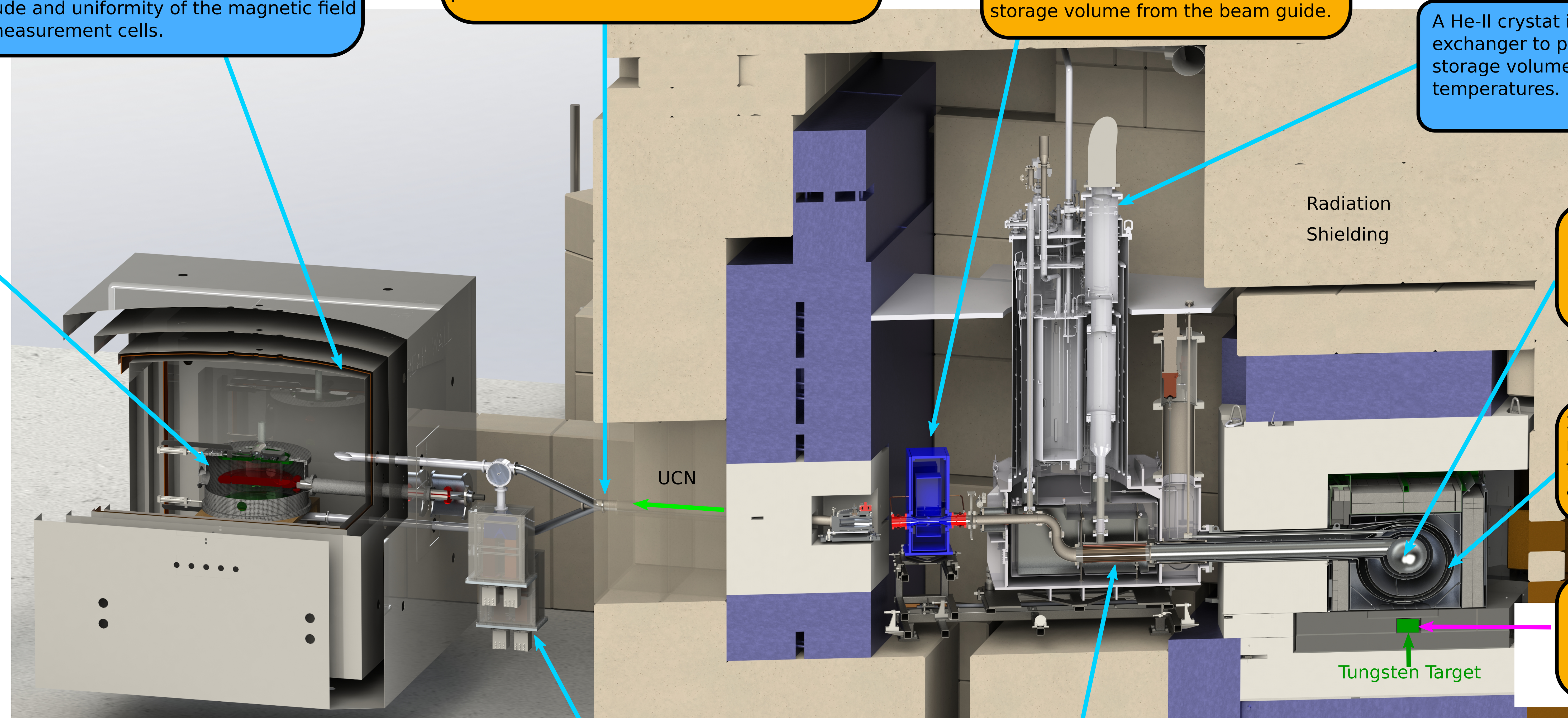
A He-II crystat is coupled to the heat exchanger to pump heat out of the storage volume to maintain the superfluid temperatures.

4. A Superconducting magnet will be used to create a 3.5T magnetic field in one section of the beam guide to polarize the neutron beam as only one spin state will be able to pass the field due to the low energy of the UCN. An aluminum foil is used to isolate the storage volume from the beam guide.

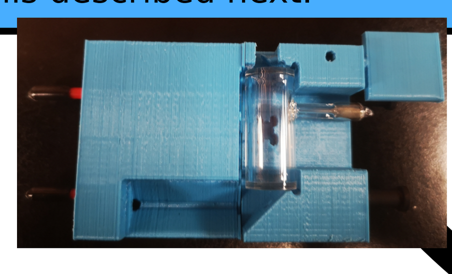
5. A UCN guide is used to to get the UCN to the measurement volume they are transfered down a nickle phosphorous coated guide. A guide coating facility is under developement at the University of Winnipeg. A Y is used to divide the neutrons between a pair of measurement cells.

A magnetically shielded room (MSR) is used to reduce external fields by a factor of 100,000 inside the room. This is critical as the measurement is very senstive to both the magnitude and uniformity of the magnetic field in the measurement cells.

6. The nEDM is measured by comparing the neutron precession frequency in the pair of measurement cells, one with parallel and the other with antiparallel magnetic and electric fields.



A set of 20 optical Cs magnetometers will be used to monitor the magnetic field inside the MSR and to make corrections to the field using the coils described next.



The uniform magnetic field inside the MSR is maintained by 3 sets of coils, the B0 coil that provides the constant field, the G_{l0} coils that are used to correct for specific field gradients, and the n x n coils that will be used to correct for arbitrary field inohomogeneities.

7. The measurement cycle is ended when the neutrons are released from the measurement cells and a set of two selective spin analyzers (SSA) are used to measure the population of each spin state from each cell

A heat exchanger will surround the tail end of the UCN storage volume to couple it to the cryostat. It is designed with a large surface area to ensure efficient heat transfer.

Repeat for 400 measurement days to reach the goal statistical accuracy

References

The TRIUMF UltraCold Advanced Neutron Source J.W. Martin et al., Nuclear Physics News, 2021

Current status of neutron electric dipole moment experiments, J.W. Martin 2020 J. Phys.: Conf. Ser. 1643 012002

First ultracold neutrons produced at TRIUMF, S. Ahmed et al. Phys. Rev. C 99, 025503 – 2019

A beamline for fundamental neutron physics at TRIUMF, , S. Ahmed et al. Nucl. Instrum. Methods. A , vol 927, 2019

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