Neutron Electric Dipole Moment Search with a Spallation Ultracold Neutron Source at TRIUMF

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I. MOTIVATION

If a non-zero EDM of a fundamental particle was discovered, it would signify a violation of time-reversal ($T$) symmetry. Through the CPT theorem of quantum field theory, $T$-violation signifies $CP$-violation (violation of charge conjugation and parity symmetry). The small amount of $CP$-violation present in the standard model leads to very tiny EDM's (for the neutron EDM, $10^{-31}$ e-cm). In many new physics scenarios, new sources of $CP$-violation are present. Often, such models seek a consistent description of the predominance of matter over antimatter in the universe, for which extra sources of $CP$ violation beyond the standard model are believed to be necessary. Such models often naturally generate nEDM's at the $10^{-27}$ e-cm level [1, 2]. The nEDM program is complementary to searches for EDM's in atomic and molecular systems.

The current experimental limit on the neutron EDM (nEDM) is $d_n < 2.9 \times 10^{-26}$ e-cm [3]. The next generation of experiments at the Institut Laue-Langevin (ILL, Grenoble, France), Paul Scherrer Institut (PSI, Villigen, Switzerland), and the Spallation Neutron Source (SNS, Oak Ridge, TN, USA) aim to constrain the nEDM to the $10^{-27} - 10^{-28}$ e-cm level. Our project has similar goals.

II. EXPERIMENTAL CONCEPT

The basic design of the experiment calls for a room-temperature EDM experiment to be connected to our cryogenic UCN source.

The UCN source is based on the design successfully deployed by the Japanese part of the collaboration, led by Y. Masuda [4]. Neutrons will be moderated and converted into Ultra Cold Neutrons (UCN) via down-scattering in superfluid He. A second generation source is nearing completion (cold tests are ongoing as of late 2011). The new source features improvements to the geometry, production volume, storage lifetime, transport efficiency, and higher-energy transported UCN, which are anticipated to result in higher UCN density. The source will be operated at the Research Center for Nuclear Physics (RCNP, Osaka) and then moved to TRIUMF (Canada’s National Laboratory for Particle and Nuclear Physics, Vancouver). This will result in a luminosity boost by a factor of 70 over the present luminosity at RCNP to 20 kW. Our goal is to achieve > 5000 UCN/cm$^3$ in an nEDM measurement cell.

An advantage of this type of source over spallation-driven solid deuterium sources (at e.g. LANL and PSI) is that the lifetime of UCN in the superfluid helium is much longer. This means that a longer pulse structure can be used to accumulate density over hundreds of seconds, resulting in competitive densities with smaller instantaneous beam power.

A prototype nEDM apparatus has also been characterized in beam tests at RCNP Osaka. Using this apparatus we have already demonstrated long UCN storage lifetimes, polarization lifetimes, and transverse spin relaxation times. It will serve as the basis for our future developments.

The EDM experimental apparatus has a few features which are unique compared to other experiments elsewhere. We intend to use a spherical coil within a cylindrical magnetic shield to generate the DC magnetic field. We intend to use a Xe-129 comagnetometer, which will act as its own buffer gas to address false EDM's due to a geometric phase effect (GPE). We will develop a room-temperature experiment based on our existing prototype. Anticipating higher UCN density, we will keep the measurement cell size considerably smaller than the previous ILL apparatus. While having a negative impact on statistics, the reduced cell size limits systematic effects, particularly from the GPE. Also, the reduced cell size will enable the use of modern magnetic shielding at reduced cost.

III. GOALS AND TIMELINE

In 2011, we will complete two new UCN source cryostats to increase UCN density. In 2012-13, we will develop an improved EDM experiment, including a new superconducting polarizer system for the UCN, and a demonstration of precision Xe comagnetometry. In 2013-14 we intend to complete an nEDM experiment at RCNP, with a goal precision (stated as an upper limit) of $d_n < 1 \times 10^{-26}$ e-cm, a factor of three better than the present world’s best.
The experiment and source will then be moved to TRIUMF and recommissioned (on a new proton beamline that we are also developing) in 2015-16. Further improvements to the magnetic shielding, comagnetometry, EDM cell, and detectors will be made, resulting in a precision of $d_n < 1 \times 10^{-27}$ e-cm. Our goal is to complete such a measurement by 2017. In 2018 and beyond, we would attempt further improvements to the apparatus, and some improvements to the UCN source itself, with the eventual goal of achieving $d_n < 1 \times 10^{-28}$ e-cm.

The project successfully completed a review by an international expert panel in September 2010, commissioned jointly by KEK, RCNP, and TRIUMF. A memorandum of understanding (MOU) between KEK, RCNP, TRIUMF, and the University of Winnipeg was completed in January 2011 for the UCN source and EDM Experiment. Canadian funds for the project were released shortly thereafter.

The collaboration intends ultimately to complete a number of physics experiments at the source and would accept participation from external groups. Experiments on the neutron lifetime in a magnetic trap, and on quantized energy-levels of neutrons confined above a mirror by Earth’s gravitational field, are considered as candidates for the long-term physics program.