Neutron Electric Dipole Moment Experiment at Los Alamos Ultra Cold Neutron Source

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A search for the permanent electric dipole moment of the neutron at the level of 10^{-27} e·cm is a sensitive probe of "beyond the Standard Model" (BSM) CP violating interactions. The ultracold neutron (UCN) source at Los Alamos National Laboratory is one of the few operating UCN sources in the world and is the only one in North America. Currently, an effort is under way to improve its performance by an order of magnitude. With such an improvement, an nEDM experiment with a sensitivity goal of several $\times 10^{-27}$ e·cm based on the already proven Ramsey's separated oscillatory fields method with Hg comagnetometer at room temperature could be performed at the LANL UCN source. It could provide a venue for the US nEDM community to perform an nEDM experiment and obtain physics results, albeit less sensitive, in a shorter time scale with much less cost while development for the technically challenging SNS nEDM experiment continues.

I. EXECUTIVE SUMMARY

A search for the permanent electric dipole moment of the neutron at the level of 10^{-27} e·cm is a sensitive probe of "beyond the Standard Model" (BSM) CP violating interactions. The current limit is $d_n < 2.9 \times 10^{-26}$ e·cm [1]. As a consequence of the nEDM being an attractive probe of BSM physics, there are currently several efforts, some more advanced than others, throughout the world that are aiming at lowering the nEDM limit by one to two orders of magnitude. However, each project has been faced with its own set of difficulties. In particular, all of the advanced efforts are, at the minimum, held up by lack of a sufficient UCN density.

Los Alamos National Laboratory (LANL) currently operates a proton-beam-driven solid-deuterium-based UCN source [2], providing UCN for various neutron β decay experiments as well as R&D for the SNS nEDM experiment. The LANL UCN source is one of the few operating UCN sources in the world and is the only one in North America.

The density of unpolarized UCN currently obtainable at the exit from the biological shield of the LANL UCN source is ~ 50 UCN/cc [2]. An estimate shows that the combination of further optimization of the source geometry and cold moderator material, increased proton beam current, and more optimized proton pulse structure will give us a 10-fold increase in UCN source performance. With such an improvement, an nEDM experiment with a sensitivity goal of several $\times 10^{-27}$ e·cm based on the already proven Ramsey's separated oscillatory fields method with proven Hg comagnetometer technology at room temperature could be performed at the LANL UCN source.

Currently, a LANL internally funded effort (FY14-16) is under way to improve the UCN source and demonstrate a storage of the number of UCN sufficient for such an nEDM experiment in a prototype nEDM apparatus. If successful, the improved source at LANL could provide a venue for the US nEDM community to perform an experiment and obtain physics results, albeit less sensitive, in a shorter time scale with much less cost while development for the technically challenging SNS nEDM experiment continues. The cost necessary to complete the construction of the experiment after the current LANL internal funding is estimated to be approximately $5M, a large fraction of it being for magnetic shielding. If we could attract foreign collaborators with existing apparatus, the cost would be substantially lower.

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II. PHYSICS MOTIVATION

Permanent electric dipole moments (EDMs) of elementary systems violate invariance under parity (P) and time reversal (T), or equivalently CP, the combination of charge conjugation and parity. Given the smallness of Standard Model (SM) CP violating (CPV) contributions induced by quark mixing, a measurement of the nEDM at the level of 10^{-27} e·cm is a sensitive probe of "beyond the Standard Model" (BSM) CPV interactions originating at the TeV scale, which is expected to be a key ingredient to understanding why there is more matter than antimatter in the universe. Current limits on the neutron EDM are at the level of $d_n < 2.9 \times 10^{-26}$ e·cm [1]. The current limits are already probing BSM physics in the TeV region [3]. Further improvements by one to two orders of magnitude, accompanied by robust theoretical input, are highly desirable as they will (i) probe mass scales inaccessible at colliders and/or (ii) strongly constrain the CP symmetry properties of any weak-scale BSM physics that might be discovered at the LHC; (iii) as a consequence, EDM searches at this level will definitively probe the so-called weak scale baryogenesis scenario, in which the matter-antimatter asymmetry of the universe is generated at temperatures T $\sim$ 100 GeV. Conversely, if this scenario is successful in generating the asymmetry, one typically expects a non-zero EDM within reach of the next generation experiments.

III. EXPERIMENTAL LANDSCAPE

An nEDM experiment is typically performed by subjecting spin-polarized ultracold neutrons (UCN) to uniform magnetic and electric fields and looking for a minute change in the precession frequency upon reversal of the electric field direction with respect to the magnetic field direction. The statistical sensitivity of each such measurement scales as $1/(ET\sqrt{N})$, where E is the strength of the electric field, T the precession time, and N the number of stored UCNs. For the experiment that yielded the current limit [1], $E = 10$ kV/cm, $T = 130$ s, and $N = 14,000$ in a volume of 21 liters with a UCN density on the order of 1 UCN/cc. In order to further improve the limit on nEDM, a higher density UCN source is critically essential, as drastic improvements on E and T cannot be expected (although an increase in E is expected for nEDM experiments performed in LHe such as SNS nEDM experiment) and a drastic increase of the neutron trap volume is not realistic either. Therefore, a 10^{-27} e·cm nEDM experiment requires a stored UCN density of $\sim 50 - 100$ UCN/cc.

As a consequence of the nEDM being an attractive probe of BSM physics, there are currently several efforts, some more advanced than others, throughout the world that are aiming at lowering the nEDM limit by one to two orders of magnitude. Some of these efforts have made significant technological advancements, including the attainment of a uniform and stable magnetic field [4], necessary to keep certain systematic effects sufficiently low for next generation nEDM experiments. However, each project has been faced with its own set of difficulties. In particular, all of the advanced efforts are, at the minimum, held up by lack of a sufficient UCN density.

IV. CONCEPT FOR A NEUTRON EDM EXPERIMENT AT LANL

Los Alamos National Laboratory (LANL) currently operates a proton-beam-driven solid-deuterium-based UCN source [2], providing UCN for the UCNA, UCNB, and UCNτ experiments. The LANL UCN source is one of the few operating UCN sources in the world and is the only one in North America.

The density of unpolarized UCN currently obtainable at the exit from the biological shield of the LANL UCN source is $\sim$ 50 UCN/cc [2]. An estimate, based on calculations and measurements, shows that the combination of further optimization of the source geometry and cold moderator material, increased proton beam current, and more optimized proton pulse structure will give us a 10-fold increase in UCN source performance. With such an improvement, an nEDM experiment with a sensitivity goal of several $\times 10^{-27}$ e·cm based on the already proven Ramsey's separated oscillatory fields method at room temperature could be performed at the LANL UCN source.

Currently, a LANL internally funded effort (FY14-16) is under way to improve the UCN source and demonstrate a storage of the number of UCN sufficient for such an nEDM experiment in a prototype nEDM apparatus. The design of the improved UCN source is being finalized and some of the parts have already been fabricated. The new source is scheduled to be installed in the summer of 2015. Development of a prototype nEDM apparatus has also started. Testing of the new source and demonstration of UCN storage in a prototype nEDM apparatus will be performed in the 2015 and 2016 LANL beam cycles. A schematic of the layout of the LANL UCN experimental area with the envisioned location of the new nEDM experiment indicated is shown in Fig. 1.

If successful, the improved source at LANL could provide a venue for the US nEDM community to perform an nEDM experiment and obtain physics results, albeit less sensitive, in a shorter time scale with much less cost while development for the technically challenging SNS nEDM experiment continues. The cost necessary to complete the

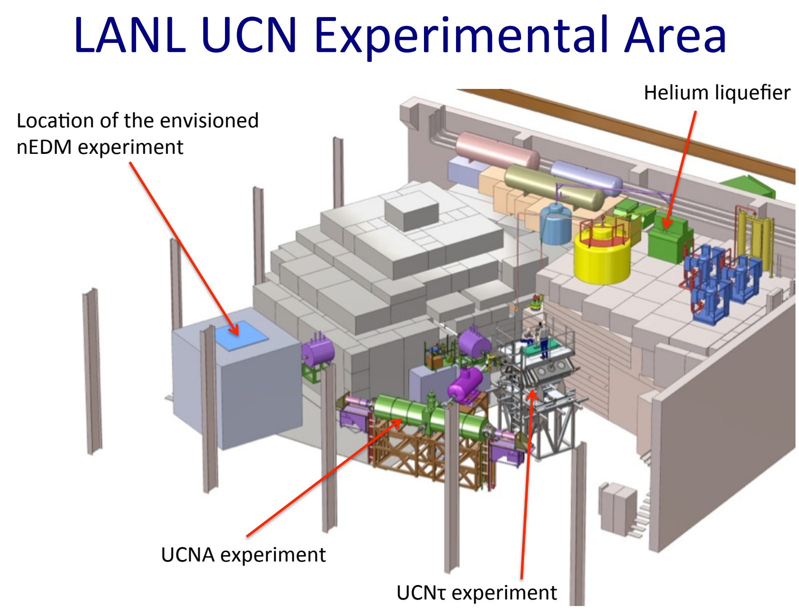

FIG. 1: Layout of the LANL UCN experimental area with the envisioned new nEDM experiment

construction of the experiment after the current LANL internal funding is estimated to be approximately $5M, a large fraction of it being for magnetic shielding. If we could attract foreign collaborators with existing apparatus, the cost would be substantially lower.

[1] C. A. Baker *et al.*, Phys. Rev. Lett. **97**, 131801 (2006).
[2] A. Saunders *et al.*, Review of Scientific Instruments **84**, 013304 (2013).
[3] J. Engel, M. J. Ramsey-Musolf, and U. van Kolck, Progress in Particle and Nuclear Physics **71**, 21 (2013).
[4] I. Altarev *et al.*, Review of Scientific Instruments **85**, 075106 (2014).