# Fundamental Symmetries and Neutrinos
## *In Search of the New Standard Model*

Report of the Fundamental Symmetries and Neutrinos Workshop
August 10-11, 2012 – Chicago, IL

September 6, 2012

# 1 Executive Summary and Recommendations

While the Standard Model (SM) successfully describes a wealth of phenomena over a wide range of energies, from atomic scales to hundreds of GeV, it has no answer to a number of questions about our universe: What is the origin of the observed matter-antimatter asymmetry? How do neutrinos acquire mass? What makes up dark matter? In addition to these "empirical" questions, a number of theoretical puzzles (such as the hierarchy of weak and Planck scales, fermion family structure, unification) indicate that the SM is incomplete, emerging most likely as the low-energy limit of a more fundamental theory involving new degrees of freedom and interactions – the "New Standard Model".

The quest for the New Standard Model (NSM) is an interdisciplinary field of research where atomic, high-energy, astro- and nuclear physics communities meet, with nuclear physics playing a central role in many experimental and theoretical developments. High-sensitivity searches for rare/forbidden processes and exquisitely precise measurements of electro-weak nuclear processes are uniquely suited to elucidate the NSM; allowing *discovery* of new sources of symmetry violation (B, L, CP,...) that are essentially inaccessible at the LHC, and helping to *discriminate* among various NSM models by exploiting the fact that each model generates a unique pattern of low-energy signatures.

As a result of current investments significant progress has been made over the last five years, leaving us poised for significant discoveries in the next decade. A few key examples include: the only measurement of the correlation between neutron spin and its decay electron's momentum, and thereby the weak axial-vector coupling constant using ultracold neutrons (UCNA) - considered together with new measurements of the neutron lifetime at NIST and abroad this gives a precise test of CKM unitarity; the most sensitive search for T-violation in $\beta$-decay by the emiT experiment; completion of the MuLan, TWIST, and MuCap experiments with high precision measurements of the muon Fermi constant, Michel parameters, and weak-pseudoscalar couplings, respectively; measurement of the neutrino oscillation parameters $\theta_{12}$, $\delta m^2_{12}$ (SNO and KAMLAND) and $\theta_{13}$ (Daya Bay, Double CHOOZ and RENO); recent limits on neutrinoless double $\beta$-decay set by EXO; commissioning of the NPDgamma experiment; and progress toward building the Majorana Demonstrator.

In preparation for the upcoming NSAC subcommittee deliberations a workshop [1] was held to gather and coordinate input from the scientific community working in this subfield. The outcome was a set of four recommendations that are crucial to achieving the community's scientific goals.

<u>Recommendation 1:</u> **Fundamental Symmetries and Neutrinos figure prominently in the 2007 NSAC Long Range Plan and subsequent assessments of the field, such as the 2012 NAS Nuclear Physics Report, the 2011 NAS Assessment of Science Proposed for DUSEL, and the 2011 NSAC Neutron subcommittee report. The community strongly endorses the recommendation of the 2007 NSAC Long Range Plan:** ***"We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet-unseen violations of time-reversal symmetry, and other key ingredients of the New Standard Model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to U.S. leadership in core aspects of this initiative."***

The workshop identified that this subfield is vibrant and continues to address compelling scientific issues with considerable discovery potential. In particular, for the short to medium term timescales, the workshop strongly endorses neutrinoless double $\beta$-decay, neutron EDM, parity violating electron scattering, and the g-2 experiment. In addition, we note that progress has been made toward establishing an underground laboratory for science within the U.S.; at the Sanford Underground Research Facility, the Davis Campus at 4,850 feet is operating and being used as a home for the Majorana Demonstrator as well as the (HEP funded) LUX dark matter experiment.

[1] "Fundamental Symmetries and Neutrinos", August 10-11, 2012. Linked talks and submitted two-page write-ups covering aspects of the subcommittee questions to the field can be found at http://www.phy.ornl.gov/funsym.

The targeted program of experiments to investigate neutrino properties and fundamental symmetries is envisioned to include next-generation neutrinoless double $\beta$-decay experiments, with one domestically led, that will extend our sensitivity to lepton-number violation by an order of magnitude, and a measurement of the neutron electric dipole moment with two orders of magnitude improvement over the current experimental limit.

It is important to recognize that this subfield is highly leveraged with facilities operations funded through offices other than Nuclear Physics. For example, the LANL LANSCE facility, operated by the NNSA, provides neutrons to the UCN source; the SNS, operated by Basic Energy Sciences, provides neutrons to the Fundamental Neutron Physics Beamline; neutron beamlines at the NIST Center for Neutron Research, operated by the Department of Commerce, provide neutrons for a suite of fundamental neutron experiments; Sanford Underground Laboratory, with future funding from the state of South Dakota and DOE High-Energy Physics, provides space and infrastructure for the MAJORANA DEMONSTRATOR; WIPP provides space for EXO. Furthermore, this community participates in several ongoing and relevant efforts such as the muon g-2 and Mu2e experiments that will be performed at Fermilab with a significant contribution expected from NSF and HEP.

**Recommendation 2: The federal research investment in Fundamental Symmetries and Neutrinos should be commensurate with its tremendous scientific opportunities and discovery potential.**

The second recommendation follows the 2012 NAS Nuclear Physics Report in recognizing the need to balance research funding and construction of new facilities. Fundamental Symmetries and Neutrinos has traditionally not required a large facility operations budget, and therefore represents a cost effective way to obtain tremendously valuable science. However, substantial investments are critical for some of the next-generation experiments needed to maintain scientific momentum and world competitiveness.

**Recommendation 3: In order to ensure the long-term health of Fundamental Symmetries and Neutrinos research, it is necessary to establish and maintain a balance between funding construction of new experiments and facilities with the needs of university and laboratory-based research programs performing existing experiments and developing new ideas and measurements that may have high impact.**

It is important to fund small R&D efforts to establish the feasibility of new ideas. These ideas range from measuring sterile neutrino signals at the Spallation Neutron Source, to small-scale experiments at reactors to understand reactor neutrino flux predictions and spectra, and to measure salient features of neutrino oscillations and investigate coherent neutrino scattering, to initial R&D towards a proton ring for measuring the proton electric dipole moment.

**Recommendation 4: The community urges strengthened support for nuclear theory in Fundamental Symmetries and Neutrinos in order to fully exploit, guide, and complement experimental efforts.**

Although relatively few in number, nuclear theorists from both universities and national laboratories have historically played a crucial role in developing Fundamental Symmetries and Neutrinos. Their efforts have been especially important in connecting the results of different experiments and providing an intellectual bridge to astrophysics and particle physics. It is crucial to strengthen these efforts to capture the opportunities this field represents. In addition, training the next generation of nuclear theorists starts at universities and we strongly encourage agency incentives to universities (for example, bridge appointments) in this subfield of nuclear theory.