# INTRODUCTION

CENPA pursues a broad program of research in nuclear physics, astrophysics and related fields. Research activities are conducted locally and at remote sites. CENPA is a major participant in the Sudbury Neutrino Observatory (SNO), the KATRIN tritium experiment and the Majorana double-beta decay experiment. The current program includes "in-house" research on nuclear collisions and fundamental interactions using the local tandem Van de Graaff, as well as local and remote non-accelerator research on fundamental interactions and user-mode research on relativistic heavy ions at large accelerator facilities in the U.S. and Europe.

We thank our external advisory committee, Baha Balantekin, Russell Betts, and Stuart Freedman, for their continuing valuable recommendations and advice. The committee reviewed our program in May, 2005.

A comprehensive analysis of the complete data taken in the Sudbury Neutrino Observatory when salt was present in the heavy water was completed and published. The SNO data provides a precise measure, $33.9^{+2.4}_{-2.2}$ degrees, of the "solar" mixing angle. In combination with other experiments (KamLAND in particular), the mass splitting $\Delta m^2_{12}$ is found to be $(8.0^{+0.6}_{-0.4}) \times 10^{-5}$ eV$^2$.

The Neutral-Current Detection array has been operating in production mode in SNO since November 2004. The solar-neutrino-live fraction has been good, $> 60$ %, and most of the remaining time is calibration data. The array produces a clear neutron signal at the level anticipated. The UW-designed data acquisition systems, ORCA for NCDs and SHaRC for the photomultiplier system, have been integrated and are operating successfully.

We finished a determination of the mass of the lowest T=2 state in $^{32}$S with a precision/accuracy of approx 0.3 keV. This allowed for a stringent test of the Isobaric Mass Multiplet Equation, where we found a significant discrepancy. Our result provides the best test of the limits of the approximations inherent in the IMME and of its utility for predicting masses away from the valley of stability.

Construction of the KATRIN experiment is proceeding apace with contracts placed for the major components and construction started on the experimental hall. Commissioning has started on the prespectrometer using the ORCA based data acquisition system. The prespectrometer's internal electrode, that was supplied by CENPA, has successfully passed the extreme high vacuum test. In the US, the detector design document and a project execution plan have been completed, allowing detailed design and cost estimating to begin. Using the CENPA electron gun, we have been working closely with manufacturers to optimize the properties of PIN diode arrays we are considering for the focal plane detector. The experiment remains on track to begin data taking in Fall '09.

The Majorana Scientific Collaboration proposes to search for neutrinoless double-beta decay by building an array of 86% enriched $^{76}$Ge segmented radiation detectors that serve as both source and detector. In September, the collaboration received a favorable review by the Joint NSAC-HEPAP Neutrino Scientific Assessment Group (NuSAG)[1] sub-committee.

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[1] Neutrino Scientific Assessment Group, *Recommendations to the Department of Energy and the National*

Efforts at CENPA this past year have concentrated on developing a conceptual design report, carrying out a variety of simulation studies within the Majorana- GERDA (MaGE) simulation framework, and R&D studies of the potential for future use of an active liquid Ar shield.

The Object Oriented Realtime Control and Acquisition (ORCA) system, which was developed at CENPA, has been expanded to support many additional CAMAC modules, several stepper motor controllers, and general process control capabilities. ORCA has been successfully taking production data for the SNO NCD experiment and, in addition, is being used in development systems at UW, LANL, PNNL, FZK, and MIT associated with the SNO, KATRIN, and Majorana projects.

In nuclear astrophysics, we have begun our precision $^4$He + $^3$He fusion cross section measurements, and we have produced several test $^{23}$Na and $^{22}$Na targets for our planned $^{22}$Na(p,$\gamma$)$^{23}$Mg study.

We have observed that much of the correlation structure in RHIC heavy ion collisions is dominated by low-$Q^2$ parton scattering and fragmentation, observed for the first time with our analysis techniques. Because low-$Q^2$ parton scattering is possibly the dominant formation mechanism and the best probe of the colored medium produced at RHIC we have pursued this phenomenon in elementary collisions, first in p-p collisions and more recently with an extensive analysis of $e^+$-$e^-$ fragmentation functions. A coherent picture of nonperturbative QCD processes at small energy scales is emerging.

The HBT interferometry analysis activity in the STAR experiment at RHIC continues to provide provocative results that challenge theoretical ideas. Our recent work in developing the distorted wave emission function (DWEF) model has proved very successful in simultaneously reproducing HBT radii and the magnitude and shape of the pion momentum spectrum. New results show that to explain STAR data the DWEF model prefers an emission temperature of 193 MeV, the same temperature that lattice gauge calculations predict for the transition from a quark-gluon plasma to a hadronic phase in the medium. We have also shown that the space-time part of the emission function can be scaled with participant number to the one-third power to fairly accurately predict the observables of non-central Au+Au collisions and central and non-central Cu+Cu collisions.

We have developed a “spin pendulum” for a novel torsion-balance test of CP and Lorentz symmetries. Our upper limit on the energy required to reverse the direction of an electron spin about an arbitrary direction fixed in inertial space is roughly $10^{-21}$ eV, which is comparable to the electrostatic energy of two electrons separated by 10 astronomical units. Our value is well below the benchmark expectation, based on the electron and Planck masses, $m_e^2/M_P = 2 \times 10^{-17}$ eV.

Our tests of the gravitational inverse-square law have shown that the law holds down to the “dark energy length scale” of 85 micrometers. We are developing a next-generation instrument that should increase our sensitivity at the 50 micron length scale by about a factor of 50.

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*Science Foundation on a United States Program in Neutrinoless Double Beta Decay: Report to the Nuclear Science Advisory Committee and the High Energy Physics Advisory Panel*, 2005.

Five CENPA graduate students obtained their PhD degree during the period of this report.

As always, we encourage outside applications for the use of our facilities. As a convenient reference for potential users, the table on the following page lists the capabilities of our accelerators. For further information, please contact Prof. Derek W. Storm, Executive Director, CENPA, Box 354290, University of Washington, Seattle, WA 98195; (206) 543-4080, or storm@npl.washington.edu. Further information is also available on our web page: http://www.npl.washington.edu.

We close this introduction with a reminder that the articles in this report describe work in progress and are not to be regarded as publications or to be quoted without permission of the authors. In each article the names of the investigators are listed alphabetically, with the primary author underlined, to whom inquiries should be addressed.

Derek Storm, Editor Barbara Fulton, Assistant Editor