Trimmed version of the CNAP PFC proposal to the NSF
(page numbers refer to those in the upper right-hand corners)

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 08-1 NSF 07-567 01/30/08	FOR NSF USE ONLY NSF PROPOSAL NUMBER
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TITLE OF PROPOSED PROJECT **Center for Neutrino and Astroparticle Physics (CNAP)**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 16,621,000	60 months	07/01/08	0753563

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
PHS Animal Welfare Assurance Number ________
☐ HUMAN SUBJECTS (GPG II.D.6) Human Subjects Assurance Number ________
Exemption Subsection ________ or IRB App. Date ________
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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Project Summary: Neutrino science has produced some of the most exciting physics discoveries in the past decade, opening completely new research avenues and prompting a wide range of new experiments – with the prospect not only of new insights into neutrino properties but a host of major breakthroughs in nuclear physics, particle physics, astrophysics, and cosmology. The need for a timely, integrated approach to this subject has been stressed by recent major reports issued by the American Physical Society, the National Science Foundation and the Department of Energy. This large and ambitious project aims to fill that need. A consortium of four research universities—Virginia Tech, North Carolina State University, University of North Carolina, and Duke University—proposes to establish the Center for Neutrino and Astroparticle Physics (CNAP), a novel entity that will unite the critical elements needed to spur transformative advances in the field, generating new insights, technologies, and research thrusts, greatly expanding the neutrino and astroparticle physics frontiers.

Intellectual merit: To accomplish its mission, CNAP will: assemble a core group of leading neutrino theorists and experimentalists working in particle, nuclear, solar, and astrophysical topics; provide a unique suite of facilities for rapid 'concept-to-prototype' development; and engage a steady flow of students and investigators in classes, seminars, and workshops. CNAP's pioneering research agenda will be organized around three interwoven areas of major activity:
Neutrino Phenomenology: extracting neutrino properties experimentally, quantifying their role in a variety of environments – solar, astrophysical, and cosmological;
Neutrino Technology: combining new insights and technologies to ensure a rapid 'concept–to–prototype' capability using a dedicated suite of facilities;
Neutrino Frontiers: providing a creative theoretical and experimental framework that fosters a new generation of experiments and observations, possibly in entirely unforeseen directions.
Major advances in neutrino physics will be accomplished by:

- **Focused activity in neutrino phenomenology** with workshops and faculty visitor programs that emphasize cross-fertilization of multiple disciplines in theory and experiment;
- **Promoting innovation in neutrino experimental development** via interaction of technical experts and facilities (on the surface and underground) for rapid concept-to-prototype detector development;
- **Innovative planning for the neutrino frontier** with promising experimental accessibility and informed decisions on large-scale projects through simulations and assessment in the global context.

Broader impacts: In addition to exciting research that will influence our most basic understanding of the structure of matter and the universe, the Center will manage integrated education and outreach plans that will:

- **Nurture the next generation of neutrino scientists** by attracting the best graduate students and postdoctoral fellows to innovative neutrino research. CNAP will also engage undergraduates locally and in partnership with two HBCU's: South Carolina State University and North Carolina Central University.
- **Involve public schools** by offering K-12 students and teachers professionally designed programs run by NCSU and Virginia Tech.
- **Engage the general public** through facility tours, public lectures tailored to younger audiences, and exhibits at the NC Nature Research Center. Postdoctoral fellowships with defined outreach activity will also be established.

Executive Summary

There is great excitement today in the physics community centered around neutrinos – their mass and flavor mixing, their nature, and possibly yet unrecognized roles of neutrinos in astrophysics and cosmology. They present the long sought window into the world of 'physics beyond the standard model' by establishing a non-zero neutrino mass and a new picture of neutrino flavor mixing, unexpected from analogous quark mixing. Looking ahead, perhaps *neutrinos* can shed light on the matter–anti-matter asymmetry of the universe. Perhaps *neutrinos* are the key to understanding supernova explosions and thus the synthesis of heavier elements. Perhaps *neutrinos* violate lepton number conservation. Perhaps *neutrinos* will reveal new secrets from within our sun's core and of the earth. The potential for further discovery is very real.

Worldwide, theorists and experimentalists are creating programs using the neutrino to tease out answers to some of the most challenging questions we have about Nature. Yet the neutrino has proved notoriously difficult to study, and progress is directly coupled to the development of new detection techniques. Optimizing a neutrino exploration program – asking the right questions, inventing the needed technology, conducting the critical experiments, interpreting the results, and envisioning the future – is extremely challenging. As the role of neutrinos becomes more apparent in diverse venues, researchers are discovering they face many common challenges and share many common goals. The proposed Center for Neutrino and Astroparticle Physics (CNAP) will provide the necessary forum and resources to tackle these challenges efficiently, enabling rapid 'concept to prototype' development with a unique suite of facilities, and fostering the vibrant interplay between theory and experiment which is needed to push the frontier of neutrino and astroparticle physics forward. Its unique environment will excite and train a new generation of researchers. Its vision is guided by a world-class advisory board, and the Center's concept has received strong endorsement from leaders in the field, nationally and internationally.

Context Four major research universities, each with an ongoing commitment to neutrino and astroparticle physics, have partnered to create CNAP: VT, NCSU, UNC and Duke. Their combined research teams consist of leading physicists representing major activities in neutrino science with access to a large college student pool of 45,000 (NC) + 28,000 (VA). Located in Virginia and North Carolina, the four partners serve both rural and urban communities. The longest drive between them is 3.5 hours. VT's main campus is only half an hour from its drive-in underground facility – offering the Center a *unique* opportunity to fill a pressing need in the US as we await DUSEL. The partners' proximity enables day visits to any of the locations, as is now regularly occurring, and video-conferencing will become a regular part of the Center activity.

Scope This Center builds on the proven strengths of its members – both in the theory of particles and astrophysics, and in the design and creation of new detectors to inform and test these ideas – in three major areas of science: particle and nuclear physics, solar physics, and astrophysics/cosmology. In all of these areas, neutrinos play a critical and continually growing role. The Center brings these strengths together, encourages known and new synergies to grow, and then organizes its efforts into three major activity areas designed to maximize the Center's overall impact on the science – both in the near term and long term:

1) Neutrino Phenomenology: *examining the nature of neutrinos and their role in a variety of settings – solar, astrophysical, and cosmological.*
2) Neutrino Technology: *adapting and developing technologies common to a wide range of near-term neutrino experiments.*
3) Neutrino Frontier: *providing a broad theoretical and experimental framework that stimulates creativity in neutrino science to envision a new generation of experiments and observations incorporating advances in neutrino phenomenology and technology.*

The Center expects to: attract and create future leaders in the field; discover enabling technology for next-generation detectors; capitalize on the in-house interplay of theorists and experimentalists; generate seminal ideas and an environment they can mature in; provide a unique cross-cutting training; develop tools to help our teachers, and improve awareness of this exciting science in the broader community.

To realize these results, a planning process identifies specific objectives, prioritizes them and then allocates resources, resulting in an Implementation Plan each year which is then executed and evaluated. This process is reflected in the current proposal by the identification of specific science and Center goals and the appropriate budgeting of 'core' and 'focus' funds.

Evolution since pre-proposal: Making use of advice from multiple sources, including our panel reviews, members of our advisory board, and colleagues with significant center experience, we adopted several changes between our preproposal and the current proposal. These proved to be natural, as interactions between our members became more Center-focused and the expected synergies started to make themselves manifest. We changed the management structure to explicitly have Center-wide responsibilities assigned to individuals, avoiding potential mini-centers at each institution. We changed from a 'collaborative' submission format to a lead institution with subawards. While several junior faculty are now listed as Senior Researchers (rather than co-PIs), the 'Center' concept is much better served in the new approach. We adopted an 'objective based' budgeting process which allows clearer identification of goals and Center allocation of resources to accomplish them. We added cross-listed video courses to provide common experiences to our students, a Center retreat, and a policy whereby graduate students are expected to spend time at partner institutions. We also standardized escalation rates across all the universities.

Education and Development The Center creates a vital educational hub with many spokes reaching into the scientific and broader community, and significant resources are dedicated to ensure their vitality and effectiveness. Elements of this program include speaker series, workshops, common graduate courses, summer mini-courses, an REU program, elementary education and 'cutting-edge' workshops, teacher training, and programs with science museums. The Center's reach and efficiency in running and evaluating these programs is greatly enhanced by partnering with The Science House at NCSU [Sci] and VT's Institute for Connecting Science Research to the Classroom (ICSRC) [ICS] (including hiring dedicated staff).

Diversity Promotion A special partnership with the HBCU universities NCCU and SCSU goes beyond the REU program and includes the use of Center focus funds to enable a limited year-round research program. The Center has identified such opportunities and already included them in its objective driven budget. To better engage students, build personal relationships, and move past simple recruiting, Center faculty will set up team-teaching opportunities at NCCU and SCSU, combining extended visits with a series of classroom lectures leading into Center related topics. In addition, students from NCCU and SCSU who participate in the REU program will have an opportunity to continue their summer research experiences at their home schools.

Shared experimental facilities Neutrino detectors require specialized techniques which push to the very extremes what is technically feasible. But they previously have taken many years and major investments for separate research groups to develop, even with exchange of ideas. The opportunity is creating a culture where everyone is aware of the unique but critical challenges. This is where the Center can have a major impact by creating a “concept-to-prototype” highway: a suite of dedicated facilities, designed and staffed by researchers fully cognizant of these types of issues. It also provides an excellent training environment for students and postdocs in whose hands future discoveries lie.

Key elements of this suite include:

1. New detector development laboratories at UNC-CH and NCSU
2. Detector development and scale-up facilities at VT
3. The Triangle Universities Nuclear Laboratory (TUNL)
4. The Kimballton Underground Research Facility (KURF)

Links beyond CNAP Many facets of the science driving the Center also drive large-scale detectors and accelerator programs envisioned at many national laboratories in the US and worldwide. The Center will provide independent critical insight and figure-of-merit comparisons which can help chart an optimum path to the needed physics.

Another critical and timely role for the Center is refining the science case for DUSEL, and allowing early development, testing, and design optimization for experiments which are envisioned as part of the initial suite of experiments.

Several detector technologies being advanced at CNAP are also very likely to find applications and partnerships with industry.

Management The management plan is designed to enable the Center to function as a cohesive unit, be objective driven, yet allow for natural evolution in direction. It incorporates advice from our International Science Advisory Board and feedback from within the Center and from the community being served. A key component is the development of annual Implementation Plans (including the use of ‘focus’ funds) by the Executive Committee and the management of resources from a Center perspective rather than an Institutional perspective. Further details are in the Management Plan section of the full proposal.

The following leaders in the field have agreed to serve on our International Science Advisory Board: Baha Balantekin (U. Wis/Madison), Arthur B. McDonald (Queens U., CA), Boris Kayser (FNAL), Rabindranath Mohapatra (U. Maryland), Hitoshi Murayama (Inst.Math & Phys of the Universe/JP), Henry Sobel (UCI), Atsuto Suzuki (KEK-JP), Sylvaine Turcke-Schieze (CEA-Saclay/Fr), John Wilkerson (U. Washington), Stan Wojcicki (Stanford), and Lincoln Wolfenstein (CMU)

Achievements Under Prior NSF Support and Other Pertinent Achievements

Center members have taken leadership roles in charting the U.S. nuclear, particle and astrophysics programs over the past decade. This includes active roles in formulating and writing two Nuclear Science Advisory Committee Long-Range Plans [NSA02,NWP07], helping formulate the science case for creating a Deep Underground Science and Engineering Laboratory (DUSEL) and membership on agency advisory committees. Members participated actively in the four division APS Neutrino Study and contributed key ideas and writing for the Neutrino Matrix report [APS] generated by this study. These roles were enabled by NSF and DOE support for ongoing research programs of the members.

Many seminal ideas and projects originated by center members are now part of the worldwide neutrino program. In particular, our center includes the founder of the international Borexino [Bor07] experiment and the LENS [LEN] (Low Energy Neutrino Spectroscopy) experiment. Other novel detector and science ideas from center members include: invention of chemical methods for metal loaded liquid scintillators [Rag04], charged and neutral current detection of ^{8}B solar neutrinos by excitation of nuclear states in ^{11}B (the BOREX program) [Rag86b, Rag88], tagged detection of neutrinos from the sun and from meson facilities using ^{40}Ar (the future ICARUS program) [Rag86a], neutrino mass measurement by laser detection of bound state beta-decay of tritium [Coh87], tagged detection of pp solar neutrinos via capture on ^{115}In (the LENS program) [Rag76], double beta decay studies using xenon in massive liquid scintillation based solar neutrino detectors [Rag94], geoneutrino detection in continental (GranSasso) and continental+oceanic (Kamioka) sites by large liquid scintillator detectors [Rag98], bolometric detection of low energy neutrinos by charged current and neutral current interactions in ^{7}Li in crystals [Rag93], the application of LENS technology to search for active-sterile neutrinos using a MCi radioactive source [Gri07], the measurement of the energy generation profile in the center of the sun via the spectral shape of pp neutrinos in LENS [Gri06], and recoilless resonant capture of antineutrinos in the bound state beta decay of tritium [Rag06]. Center members have made substantial contributions to designs of proposed experiments including the Braidwood reactor experiment [Sch03] to measure the neutrino mixing angle θ_{13}, concepts for design of large scale liquid scintillation detectors for solar neutrinos [Rag88b], the proposal for the Borexino experiment [Bel91] and the idea of a large liquid scintillation detector (Hyper Scintillation Detector – HSD) [Rag05] for a variety of physics uses. The extensive studies [Hub03a, Hub03b] of the relative merits of long-baseline and reactor methods of measuring the neutrino mixing angle θ_{13} had significant contributions from a center member. Examples of important original theoretical ideas contributed to by members of the center include: neutrino electromagnetic form factors [Vog88], neutrino-based explanations of the NuTeV anomaly [Loi3a], the role of sterile neutrinos in supernova explosions [Fet03], and the prospects for detecting supernova neutrino flavor oscillations [Ful99].

Recent physics results from major experiments with center members as participants include: Super-Kamiokande, which showed atmospheric neutrino oscillations [SuK98] and measured the solar ^{8}B neutrino flux [SuK99]; KamLAND, which used reactor neutrinos to confine the neutrino mixing parameters to the large-mixing angle solution in the MSW scheme [KAM03]; Borexino, which has now measured low-energy ^{7}Be solar neutrinos for the first time [Bor07]; and MiniBooNe [Min07], which ruled out the presence of sterile-neutrinos suggested by LSND. A center member is the leader of the Supernova Early Warning System (SNEWS)

[Ant04] which links many detectors to maximize the data output should a nearby supernova explode (SNEWS is also involved in extensive outreach activities with amateur astronomers).

In the theory sector, members provided sensitivity comparisons between reactor and accelerator neutrino experiments [Hub03b] which provided crucial input for initiating the Daya Bay reactor experiment; showed the role of neutrinos in gamma-ray burst, supernovae and r-process nucleosynthesis; examined neutrino physics possible with beta-beams; worked with the SciDAC-sponsored UNEDF collaboration to build a universal nuclear energy functional; calculated double-beta decay matrix elements in several nuclear structure schemes as well as in solvable models; calculated beta decay for r-process nucleosynthesis and WIMP-nucleus cross sections for many nuclei; evaluated the potential for neutrino experiments to discover new physics beyond the Standard Model; proposed a new physics explanation for the NuTeV anomaly [Loi3a, Loi3b, Loi04]; studied the possibility of using matter effects in neutrino oscillation to constrain various models [Hon06,Hon07]; and calculated neutrino loop effects to the lepton EDM to evaluate their sensitivities to new physics involving the neutrino [Ray07].

The membership of this center reflects the growing importance of neutrinos to multiple fields. Members with well-established and funded programs in nuclear physics, particle physics, astrophysics, cosmology and string theory are increasingly being drawn to neutrino physics as one of their main new research avenues. Examples include center members whose previous work was in areas including stellar nucleosynthesis, weak interaction physics, flavor physics, and nucleon structure physics.

Members are currently supported in many of the upcoming experimental neutrino efforts: Majorana [Maj], to detect neutrinoless double-beta decay if it exists; LENS [LEN], to measure the solar luminosity via neutrinos; Daya Bay [Day], to measure the θ_{13} neutrino mixing angle and thereby determine if CP violation in the neutrino sector could be observed in future experiments; and T2K [T2k], to measure similar neutrino parameters in the high energy long baseline experiments at JPARC.

The CNAP member institutions benefit from the presence of already strong education and outreach groups who will partner with the center to develop K-12 outreach programs based on the center's science. In the North Carolina Triangle region (Duke, NCSU, UNC) the efforts are led by The Science House [Sci], headquartered at North Carolina State University. The Science House annually reaches over 3,500 teachers and over 25,000 students from six offices spread across the state. Its mission is to increase student enthusiasm for science by partnering with K-12 teachers to promote hands-on inquiry-based science learning. Financial support for The Science House comes from a variety of corporate and governmental sources, including the National Science Foundation. In particular, The Science House has successfully implemented K-12 outreach programs to promote the science of other NSF funded centers at NCSU (NSF Science and Technology Center for Environmentally Responsible Solvents and Processes [Scia] and NSF Rice Blast Genomics Center [Scib]).

At Virginia Tech, science education and outreach activities are facilitated through the Institute for Connecting Science Research to the Classroom (ICSRC). The central mission of the ICSRC is to create synergy around innovative ways to integrate the STEM disciplines of science, technology, engineering and mathematics into K-12 teaching and learning experiences in such a manner that students are invited and encouraged to think like scientists and engineers. Financial support for the ICSRC is primarily from corporate sponsors (Bill and Melinda Gates

Foundation, Toyota USA Foundation, The Boeing Company) with some government support (NASA and the Virginia Department of Education). Many of the ICSRC's K-12 programs are built upon the TILT (**T**eaching **I**nquiry with the **L**atest **T**echnologies) model developed at Virginia Tech. It prepares pre-college students to participate in the global market of the future by addressing all four STEM (Science, Technology, Engineering, Mathematics) disciplines in a powerful way. All modules developed for TILT are standards-based, field-tested in pilot programs, and reviewed by external evaluation teams.

Below, we briefly summarize the overall funding picture and the achievements and activities at each of our institutions for NSF supported work that relates directly to the research (neutrino and astroparticle physics) and outreach goals of this PFC proposal:

Duke University: Duke University has active efforts in experimental nuclear and high energy physics. A broad range of experimental nuclear physics activities is carried out under the aegis of the DOE supported TUNL (Triangle Universities Nuclear Laboratory) facility by Calvin Howell. Particularly relevant to this proposal is work on the reactor neutrino experiment KamLAND, neutrinoless double beta decay searches in the Majorana experiment, neutrinoless double electron capture search on ^{112}Sn to a specific excited state, and two-neutrino double beta decay of ^{100}Mo and ^{150}Nd to excited states. Support for experimental high energy physics to Chris Walter and Kate Scholberg is primarily from DOE; the main experimental efforts are in the Super-Kamiokande and T2K oscillation experiments with atmospheric and long baseline accelerator neutrinos.

Specific NSF support for neutrino-related physics has been provided through several grants. A CAREER award (PHY-0349193, "CAREER: Next Steps for Neutrino Oscillation Physics") to Kate Scholberg supported a broad program in neutrino physics. The Supernova Neutrino Early Warning System (SNEWS) (PHY-0303196, PHY-0522001, Kate Scholberg, PI) supports an international collaboration of researchers representing a number of supernova neutrino detectors. The SNEWS system is designed to provide a completely automated early warning of a supernova's occurrence to the globe-wide astronomical community by exploiting the prompt signals from the neutrino detectors.

Duke also has a long-standing NSF REU program run at TUNL each summer (PHY-9912252, PHY-0243776, PHY-0552723) in which undergraduate students collaborate with faculty, postdocs and graduate students from all three universities (Duke, NCSU, UNC) in the ten week summer program. The program typically has 10 student participants each summer.

University of North Carolina: The University of North Carolina has active efforts in both experimental and theoretical nuclear physics. Art Champagne has primarily DOE support for a broad program in experimental nuclear astrophysics, including reaction rates relevant to main sequence stellar evolution and stellar explosions. The work is primarily performed at TUNL, but some work is performed with radioactive beam facilities, as well. Jon Engel has a DOE supported program in nuclear theory, with work focusing on nuclear structure and its applications to double beta decay matrix elements, CP violation in nuclei, and nucleosynthesis in supernovae.

The NSF provides support through PHY-0705014 ("Collaborative Research: DUSEL R&D at the Kimballton Underground Facility (ICP-MS confirmation, material assay, and radon reduction", Reyco Henning, PI, Art Champagne, co-PI). This grant (awarded in June 2007 for three years) is part of the joint NSF/DOE DUSEL (Deep Underground Science and Engineering Lab) R&D program. It is focused on using germanium gamma ray spectroscopy at the Kimballton Underground Research Facility (KURF) and at the Laboratori Nazionali del Gran Sasso to measure the internal radioactive backgrounds for materials used in rare event experiments like double beta decay, solar neutrino detection, and dark matter detection. In addition, the gamma spectroscopy material assay technique will be directly compared to the Inductively-Coupled Plasma Mass Spectrometry (ICP-MS) technique. Another aspect of the program is to develop and assess technologies for removing radioactive radon from the air in underground laboratories. These activities are currently ongoing in the KURF facility (see Facilities section of this document).

North Carolina State University: North Carolina State University has active efforts in both experimental and theoretical nuclear physics. Albert Young has NSF support (PHY-0100689, PHY-0354970, PHY-0653222) for precision neutron beta asymmetry measurements and development of a superthermal neutron source (PHY-0314114). Young and Henning Back are supported by DOE for the Majorana neutrinoless double beta decay experiment. Back is supported by DOE for "Collaborative Research: DUSEL R&D at the Kimballton Underground Facility (ICP-MS confirmation, material assay, and radon reduction)". This is part of the joint NSF/DOE support of research and development for DUSEL; this activity is done in collaboration with Art Champagne and Reyco Henning at UNC (see further details above). Gail McLaughlin is supported by DOE for nuclear theory work on the role of neutrinos in astrophysical environments and on neutrino scattering interactions. The primary thrusts of the research are gamma ray bursts, neutrino flavor transformation, and low energy beta beams.

Sharon Schulze and her collaborators at the The Science House at NCSU have developed K-12 outreach programs for two NSF funded centers. The Center for Environmentally Responsible Solvents **(**NSF Science and Technology Center**,** Cooperative Agreement CHE-9876674) was funded for a total of 10 years. The projects completed by The Science House included teacher workshops, an extensive webpage with materials free to teachers, a training program for graduate students, postdocs, and faculty to prepare them for classroom visits, development of activity manuals for middle and high school teachers, and a series called "Meet The Scientist" in which a diverse group of young faculty shared their backgrounds, passions, and reasons for choosing science as a career. Rice Blast Genomics Outreach (NSF grants DBI-0115642 and DBI-0443991) was a five year program which was specially noted for excellence in outreach for a program of studying the fungus that causes a virulent disease called Rice Blast. The outreach component included teacher workshops at partner sites across the country each year, a manual of activities suitable for teachers, an equipment loan program in which teachers could borrow electrophoresis equipment and get help from a scientist in implementing various genetics-related activities.

Virginia Tech: Virginia Tech has active efforts in experimental nuclear and high energy physics and theoretical high energy physics. Jonathan Link and Leo Piilonen are funded through DOE for experimental high energy physics, with participation in the Daya Bay reactor neutrino experiment being the most relevant to this proposal. Djordje Minic and Tatsu Takeuchi are supported by DOE for work in theoretical high energy physics, with work on "beyond the Standard Model scenarios" and exploring connections between neutrinos and the physics of dark energy being most relevant to this proposal. Mark Pitt and Bruce Vogelaar have NSF support (PHY-0099448, PHY-0401526, PHY-04700491) for precision neutron beta asymmetry measurements.

Specific NSF support for neutrino-related physics has been provided through several grants. Bruce Vogelaar and Raju Raghavan are funded (PHY-9972127 and PHY-0501118) for work on the Borexino solar neutrino experiment at Laboratori Nazionali del Gran Sasso in Italy. First results on the real-time detection of ^{7}Be solar neutrinos have been published recently [Bor07]. Raghavan is funded through PHY-0654212 ("Development of a Low-Energy Spectrometer to Measure the Neutrino Luminosity of the Sun") as part of the joint NSF/DOE DUSEL R&D program. This provides partial support for the construction and operation of a prototype detector to demonstrate the feasibility of a low energy solar neutrino detector based on capture on ^{115}In. This particular grant primarily funds the chemical work on the metal-loaded liquid scintillator.

Lay Nam Chang was funded through NSF Department of Undergraduate Education for PHY-9554889 ("A School-University Partnership Through Distance & Service Learning"). This grant enabled a partnership between the Virginia Tech physics department and science programs at high schools throughout Southwest Virginia. The project targeted the geographic and professional isolation of rural high schools and teachers that limits their access to the facilities, resources and research discoveries of major universities, and the academic isolation of advanced undergraduate and graduate science students who have little or no opportunity to communicate with populations outside of their highly specialized scientific field. The initial focus of the grant was Floyd County High School. The program was successful, and it evolved into a regular outreach program to many local schools that is funded and staffed through the physics department. It typically involves fifteen undergraduate students per term and serves about fifteen schools in the area.

Major Activities

There has never been a time of greater interest or better scientific motivation to study the neutrino than the present. Two of the most fundamental discoveries in physics in the past two decades were made using Nature's own neutrino beams, from solar and atmospheric sources – revealing that neutrinos have a tiny, but non-zero mass, and a flavor-mixing matrix dramatically different from that for quarks. These discoveries have opened completely new research avenues and prompted a wide range of new experiments. Neutrinos are very different from the ordinary building blocks of our world, the electrons and quarks – being electrically neutral, having masses much smaller than any other fundamental particle, and interacting extremely weakly with ordinary matter – and thereby offer new windows into many of the big questions in science, such as violation of CP symmetry in the lepton sector that can probe matter anti-matter asymmetry of the Universe. Neutrinos could contribute to dark matter (in scenarios with "hot and cold" dark matter) around the galaxies, might provide a unique probe of dark energy, or lead to experimental proof of fundamental predictions of the Big Bang. Neutrinos can also answer more immediate questions: Does our Sun hold further secrets? How does a supernova explosion evolve to create the elements we see? Is the neutrino its own anti-particle, implying violation of a major conservation law of nature?

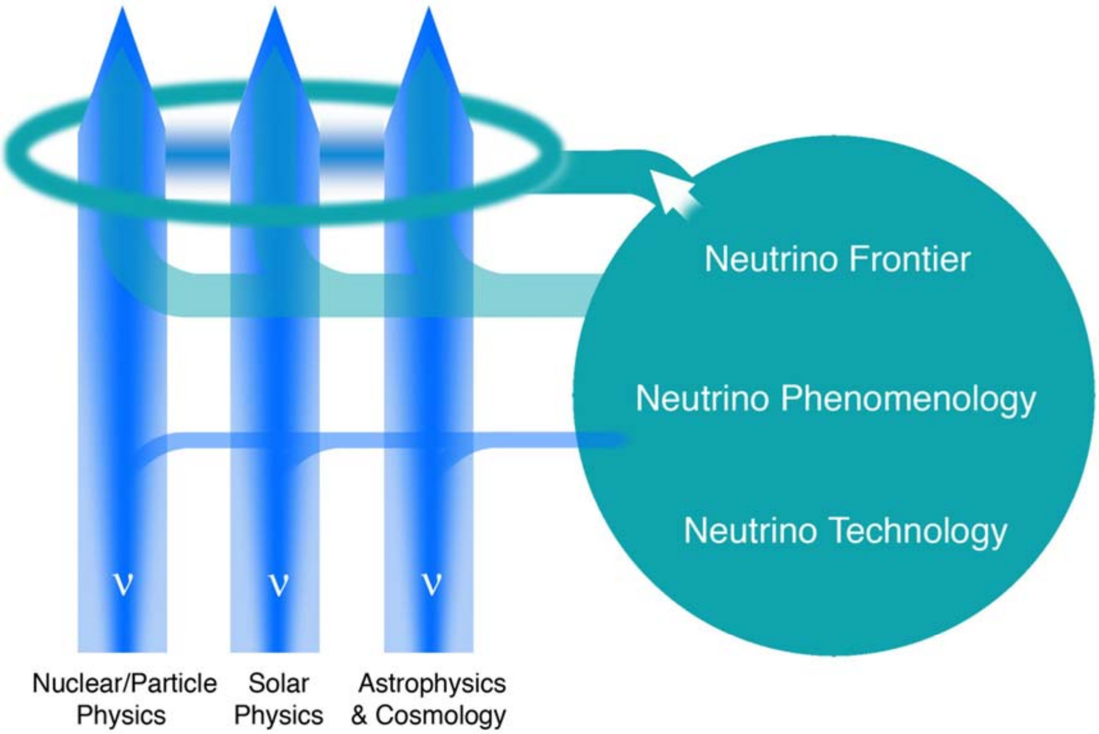
These fundamental questions helped motivate the recent four-division APS neutrino study ("The Neutrino Matrix" [APS]), the DUSEL S1 science report [Deep], numerous DOE and NSF committees and panels, and the community Long-Range Planning effort. While these questions are relatively easy to pose, they are, in fact, very hard – and often very expensive – to answer. Tremendous effort and creativity has gone into studying the intrinsic properties of neutrinos and their role in nuclear astrophysics and cosmology. By bringing these ideas together in a synergistic way, even greater progress is possible – both in theory and experiment – and we will have the best chance of answering these deep questions that lie at the 'rare-event' frontier, at energies well below a GeV.

At the Center for Neutrino and Astroparticle Physics (CNAP), leaders in neutrino physics can come together to share their visions, and build on them; theorists can tell us the implications of what we already know, and in which directions to head; creative new detector concepts can be discussed and simulated; and these novel detectors can be developed and tested. CNAP will provide the forum for forefront neutrino physics much like those that support and develop the physics programs at large particle-accelerator centers. CNAP could well create new directions for the latter programs. CNAP builds on the existing, proven strengths of its members – both in the theory of particles and astrophysics, and in the design and creation of new detectors to inform and test these ideas – in four major areas of science: nuclear physics, particle physics, solar physics, and astrophysics/cosmology. In all of these areas, neutrinos play a critical and continually growing role. The Center leverages these existing strengths into *three major activity areas* organized around the themes that are necessary for the maximum impact on the science – both in the near term and long term:

1) Neutrino Phenomenology: *examining the nature of neutrinos and their role in a variety of settings – solar, astrophysical, and cosmological.*

2) Neutrino Technology: *adapting and developing technologies common to a wide range of near-term neutrino experiments.*

3) Neutrino Frontier: *providing a broad theoretical and experimental framework that stimulates creativity in neutrino science to envision a new generation of experiments and observations incorporating advances in neutrino phenomenology and technology.*



The CNAP Center Concept

This structure is the most effective way to insure that the ideas and technologies from all the different science areas touched by neutrinos are synthesized and developed for the benefit of all of neutrino-related science. A coherent *Neutrino Phenomenology* effort will insure that data and observations from all neutrino-related phenomena are assimilated in developing our understanding of neutrinos and their role in the universe. The unique, shared facilities of the *Neutrino Technology* section of the Center will insure that novel technology ideas are applied to all relevant neutrino experiments. Finally, developments from both the *Neutrino Phenomenology* and *Neutrino Technology* activities will feed into the *Neutrino Frontier* activity, which will engage theorists and experimentalists in identifying the most exciting neutrino ideas to pursue and realistic plans for experiments to study them in the ~20-year timeframe. The unifying context is the realization that neutrinos significantly impact the workings of the Universe and yet are uniquely challenging from an experimental and theoretical perspective. CNAP will come to grips with this uniqueness, thereby transcending and complementing what can be addressed from a collider-driven perspective.

MA1: Neutrino Phenomenology

Senior Investigators: L. N. Chang (VT), **J. Engel** (UNC, Executive Committee representative), P. Huber (VT), G. McLaughlin (NCSU), D. Minic (VT), R. Raghavan (VT), T. Takeuchi (VT)

Postdoctoral scholar: 3 + "focus funds" postdoctoral scholar in Y1,Y2

Graduate Students: 3 + additional students from "focus funds"
Undergraduate students: 3-5

Neutrino phenomenology addresses a broad range of theoretical questions across many disciplines: particle physics, nuclear physics, astrophysics, and cosmology. What are the masses and flavor-mixings of the neutrinos, and why do they have these values? Are neutrinos Majorana particles that violate lepton-number conservation? Do they have measurable non-standard interactions? Do sterile neutrinos exist? What can neutrinos tell us about nuclei? What are their roles in the formation of heavy nuclei, in the explosions of massive stars, and in the formation of the large-scale structure of the universe? How can answers to these open questions be extracted from future experiments?

These related questions are best addressed through interdisciplinary work. For instance, the role of neutrinos in supernova explosions will depend on the presence of non-standard interactions (NSI) of the neutrino [Fog02], which in turn can be probed directly via matter effects in solar [Ber02, Fri04] and long-baseline neutrino-oscillation experiments [Fri06, Kop07, Hon07]. Similarly, supernovae neutrino data could constrain the interpretation of future observations at CERN's Large Hadron Collider.

The interdisciplinary nature of these questions are intrinsically synergistic and labor intensive, posing special logistical challenges that are addressed in the strategic plan of CNAP. Interdisciplinary projects require a high involvement of students and young researchers, intimate interaction among disparate theoretical efforts and close collaboration between theorists and experimentalists. Yet, the obstacles are many: the number of interdisciplinary experts are few, postdoctoral fellows with training in more than one subfield even fewer, and funding to bridge disciplines and facilitate travel among collaborating institutions almost nonexistent. The objectives of neutrino phenomenology go far beyond what is possible via typical individual investigator funding, but are naturally addressed within the CNAP framework.

CNAP will address the pressing issues in neutrino phenomenology by:

1. Leveraging the interdisciplinary skills of our faculty, who straddle many disciplines, with funding for graduate students, postdoctoral fellows, short- and long-term visitors, and travel by our members to collaborating institutions.
2. Training a new breed of young researchers with broad interdisciplinary skills and outlook, to prepare them for future leadership roles in this field. CNAP will allow graduate students and postdoctoral fellows to spend time with their peers and more senior members at CNAP and other institutions, broadening their perspective far beyond what they would achieve in a more parochial single-university setting.
3. Hosting summer schools for undergraduate and graduate students, taught by CNAP faculty, that will offer training in the many disciplines necessary for neutrino research.
4. Hosting frequent workshops on topics such as supernova neutrinos, nonstandard interactions, primordial neutrinos, and double-beta decay, where theorists and experimenters jointly address current developments, disseminate results, and focus

community attention on urgent issues. At local collaboration meetings, theorists can easily provide input for experiment and detector design for the other Major Activities of the center. The regional meeting in string and particle physics, encompassing the University of Cincinnati, University of Kentucky, and the Ohio State University, provides a concrete model for these gatherings.

The Center has set an initial suite of objectives for this MA deserving special focus, and these are reflected in the current distribution of Center resources in the following categories:

IP6 Neutrinos in Action
[Implementation Plan: Objective 6 – see center budget justification]

- Theoretical work in neutrino astrophysics
- Neutrinos in Cosmology
- Advance the calculation of matrix elements needed for neutrino experiments
- Exploring the origins of neutrino mass
- Extract limits on non-standard neutrino interactions from recent experiments

Here we discuss in detail some of the interdisciplinary neutrino science questions we will address in MA1. For each question, we emphasize the synergistic benefits of having the research conducted at CNAP, and point out ties to Major Activities 2 and 3.

1.1 What Role do Neutrinos Play in Core Collapse Supernova?
(J. Engel, P. Huber, G. McLaughlin, T. Takeuchi)

How do stars explode? Simulations in two dimensions have demonstrated a crucial role for neutrinos in supernovae [Bru06]. At the same time, it has become clear that new neutrino-oscillation phenomena occur in supernovae [Kne07a], yet the new oscillation phenomena have not been incorporated into simulations. In the interdisciplinary atmosphere at CNAP, two dedicated postdoctoral fellows and the CNAP faculty will engage with visiting researchers and with supernova-simulation groups elsewhere to help bring about a more complete picture of the character of supernova neutrinos and what they can tell us about the dynamics of the supernova explosion. It is essential to exploit the potential for supernova observation with all existing and future neutrino detectors. Our calculations and analyses will provide useful input for the development of neutrino technologies (MA2) targeted to supernova-neutrino detection.

An important step in developing tools that can be used to analyze a future supernova neutrino signal will be to examine the possible neutrino oscillation phenomenon that can occur in supernovae. The exciting new developments in oscillation theory, such as spectral swapping, which occurs through the inclusion of the background terms and finely grained phase effects that are manifest when multiple non-adiabatic resonances are encountered, mean that the possible outcomes are much more complex than was expected only a couple of years ago. In the first year, McLaughlin will implement Monte Carlo neutrino oscillation techniques [Kne06] in three flavors with input from recent spectral swapping [Dua07] models applied to the results of dynamical simulations of massive star explosions and then apply the results to potential signals in specific detectors such as CLEAN [Hor03], LENS and other experiments of interest to the CNAP and larger physics community.

The oscillations depend on fundamental neutrino parameters, not all of which are known yet. It is therefore important to consider the reach of experiments that intend to measure fundamental neutrino parameters. Future reactor experiments, such as Daya Bay, and long baseline experiments, such as T2K, will constrain or measure some of these parameters. Huber will provide the expertise necessary to predict the range of the flavor-mixing angle Θ_{13} that will be measurable with various terrestrial detectors. Huber and colleagues will provide a valuable contribution to the community by assessing the measurable range of other neutrino parameters in upcoming supernova-neutrino experiments. The parameter-dependence study in the supernova environment would, in turn, reveal which parameters, for example, the mass hierarchy, are most important for astrophysics and should be studied in other terrestrial detectors in the event of a positive long baseline measurement. This will become a valuable piece of information for the design of future neutrino experiments.

The observed neutrino signal from a supernova results from an interplay between fundamental neutrino properties and the astrophysics governing stellar explosion. For example, neutrinos that reach the Earth are affected by the energy spectrum of the neutrinos originally emitted from the core as well as the oscillations that the neutrinos undergo on their way out of the star. It is important to consider all possibilities for oscillations, as well as the effect of non-standard interactions that can play a role in determining the originally emitted spectrum. Takeuchi will provide the expertise to analyze various neutrino experiments, both existing and planned, to constrain and/or detect these non-standard interactions.

An additional complication for the disentanglement of a supernova neutrino spectrum has to do with uncertain nuclear physics within the terrestrial detector. For example, some supernova neutrinos will collide with Oxygen-16 nuclei in Super-Kamiokande [Lan96]. Engel will provide the nuclear physics expertise required to understand the neutrino-nucleus reaction cross sections for neutrinos at various detectors, including those under development by CNAP experimentalists.

While such a project could be undertaken in a limited way with a single investigator, CNAP will provide a natural mechanism for collaboration between four traditionally separate areas of neutrinos physics: astrophysics, nuclear physics, high energy physics, and detector design. The structure of CNAP will make possible such an extensive collaboration. Students and postdoctoral fellows will interact with senior researchers at all the institutions within CNAP and with external ones as well. For example, a collaboration will be continued with J. Kneller (University of Minnesota) with whom we have already run a version of the hydrodynamic code VH1 to simulate the outer layers of two dimensional aspherical supernova explosions coupled to neutrino flavor transformation equations that resolved finely grained phase effects due to multiple resonances [the first paper in Kne07a]. As an avenue for longer term continuation of this project, we would like to involve a computational center with which to collaborate. As a result of this type of interaction, students and postdoctoral fellows will learn a unique set of skills in all four areas.

1.2 How do Neutrinos Influence Nucleosynthesis?

(J. Engel, G. McLaughlin)

Many types of nucleosynthesis appear in core collapse supernovae. In addition to the generation of iron by explosive burning, a number of rare elements may be formed by other means. These include the r-process elements, the p-process elements, and the neutrino-process elements. If these elements are indeed formed in the supernova environment, their production is affected by the neutrinos. For the r-process and the p-process, the neutrinos determine, through the charged current reactions, the neutron-to-proton ratio, which is perhaps the most crucial quantity for determining the outcome of a nucleosynthesis process, e.g. [McL96]. In addition, it has been recently shown that, in the p-process, neutrino capture on free protons can create neutrons in the late stages of element formation, crucially fine-tuning the elemental abundances [Fro06].

We propose to use some of the results of our calculations on neutrino flavor transformation to re-examine these processes with the goal of determining its effect on nucleosynthesis dynamics. The neutrino-process, for example, occurs in the far outer layers of the supernova [Woo90], where the neutrinos may have already made several transformations [Yos06]. Depending on the relative differences in the energy spectra of neutrino species, this can radically alter the outcome of the neutrino-induced particle spallation reactions. McLaughlin will provide the astrophysics expertise to simulate the nucleosynthesis and Engel will provide the nuclear-structure expertise to determine the relevant cross sections. A similar effort will be directed at the r-process. There are small differences in halo star data in the region of the actinides [Ots02]; we will explore the possibility that they are related to neutrino post-processing. Similarly, some elements in the p-process have been suggested to come from electron neutrino capture on nuclei [Ful95], but these cross sections need updating.

Nucleosynthesis studies are relevant to the CNAP experimental community. The LENS-sterile collaboration proposes looking for a sterile neutrino in the parameter range crucial for the r-process [Gri07]. Our theoretical treatment will identify particular values of not only Θ_{13} but also important regions of mixing with additional sterile species of neutrino that are most relevant as targets for experimental measurement, both through traditionally studied oscillations in the exterior of the star and by the inclusion of multiple phase effects due to multi-dimensional hydrodynamical effects and estimates of the newly discussed spectral swapping.

1.3 What Can Neutrinos Tell Us About Nuclei?

(J. Engel, G. McLaughlin, K. Scholberg)

We propose to team with the CNAP experimentalists to better exploit opportunities to study low-energy neutrino-nuclear physics in existing or future experiments proposed for another primary purpose. An example of this is the CLEAR experiment, where neutrino-nucleus coherent scattering is proposed as a mechanism to measure the Weinberg angle [Sch06]. In fact, this experiment may also be used to study neutron density distribution [Ama07], accurate information about which is notoriously difficult to obtain. A neutrino measurement would be competitive with already existing hadronic probes and complementary to the measurement of the neutron mean-square radius in ^{208}Pb to be performed at the Thomas Jefferson National Laboratory in 2008. The CLEAR analysis will be carried out jointly by Engel, McLaughlin, and Scholberg.

The interdisciplinary focus of this activity exemplifies one of the strengths of CNAP. The center provides a natural vehicle for the development of the technologies to optimize the CLEAR experiment, as presented in the MA2 section. However, the ability to identify and expand the usefulness of the CLEAR experiment to provide a significant low energy nuclear physics measurement is a direct result of idea-sharing among CNAP's connected community of theorists and experimentalists.

1.4 Do Neutrinos Have Non-Standard Model Interactions?

(P. Huber, R. Raghavan, T. Takeuchi)

The discovery of neutrino masses and flavor mixings has provided new clues to the physics underlying the Standard Model (SM). Flavor mixing in the lepton sector, together with the well-studied mixing in the quark sector, may lead to a new understanding of what "flavor" is, why there are three generations of fermions, and where the quark- and lepton-mass hierarchies come from.

If neutrino were found to be Majorana-like in future double-beta decay experiments, lepton quantum number as well as lepton flavor would not be conserved, giving us additional insight into the nature of lepton and baryon quantum numbers. Several minor but nevertheless intriguing neutrino-related discrepancies already exist between experiment and the SM and could be signals of new physics beyond the SM. These anomalies are found in neutrino-nucleon deep inelastic scattering (NuTeV), the Z-boson invisible width (LEP), and the leptonic branching fractions of the W boson (LEP2). In fact, the current experimental constraints on non-standard interactions (NSIs) of the neutrino are surprisingly weak, allowing for potentially large deviations from the SM to be hiding in plain sight. A number of ongoing neutrino experiments may have the ability to detect them. Examples of such strategies proposed by CNAP members follow.

Raghavan and collaborators have pointed out that the Borexino detector can be used to detect NSIs by looking at the shape of the energy spectrum of the recoil electrons in neutrino-electron elastic scattering [Ber02]. This procedure measures the presence of NSIs directly, and can constrain the left-handed and right-handed NSIs separately, since they modify the shape of the electron energy spectrum differently. Unfortunately, it would seem that Borexino cannot measure the NSIs of individual neutrino flavors, since the neutrinos that arrive at Borexino from the Sun are an admixture of all three neutrino flavors.

Following a suggestion by Raghavan, Takeuchi and his student are revisiting this conclusion to see if, after all, the NSIs of the three flavors can be separately constrained with Borexino. The idea is to place a very powerful source of electron neutrinos (from Chromium-51 decays) near Borexino to measure the NSIs of the electron neutrino alone and to combine that information with Borexino's solar-neutrino data to extract the combined NSIs of the mu- and tau-neutrinos. Then, combining these results with constraints on the NSIs of the mu-neutrino from CHARM, NuTeV, and other similar experiments, one can extract indirect constraints on the NSIs of the tau-neutrino. To accomplish this, an accurate knowledge of the flavor composition of the ^{7}Be solar neutrinos at the Earth is necessary, which in turn requires a firm understanding of the constraints from Super-Kamiokande and SNO data, and how possible NSIs will affect those also [Bor07,.Fuk01, Sno04]. Capabilities of the proposed NuSOnG experiment at Fermilab in constraining the mu-neutrino NSIs also need to be explored.

Neutrino NSIs can be constrained in long-baseline neutrino oscillation experiments even if the NSIs are fairly small. Takeuchi and collaborators have shown that matter effects from NSIs that mimic the violation of neutral current universality can be disentangled from standard matter effects if the neutrinos have a high enough energy (>10 GeV), and the baseline is long enough

(~10000 km) to see oscillation at those energies [Hon06]. This analysis shows that a beam with parameters similar to the Fermilab NUMI beam, in its high-energy mode and aimed at the planned mega-ton Hyper-Kamiokande detector, could constrain muon-neutrino NSIs to 1 percent of the size of the Z-exchange interaction with 5 years of data, provided that the atmospheric mixing angle is known precisely (and is not too close to 45 degrees). Such constraints will complement those from direct searches at the LHC [Hon07].

In the above examples, the NSIs can only be extracted with precise knowledge of the neutrino mixing angles and masses. Huber and collaborators have carefully considered the interplay of Θ_{13} and NSIs at a future neutrino factory [Hub02]. Huber's expertise will be essential in assessing discovery potential of the experiments above as well.

1.5 What is the Most Promising Strategy to Determine the CP-Violating Phase in the Neutrino Mass Matrix?

(Huber, Engel)

Once the mixing angle Θ_{13} is measured, the next step will be to look for leptonic CP violation and determine the neutrino mass hierarchy. For non-negligible values of Θ_{13}, superbeams from terrestrial particle accelerators offer an attractive option to address these questions. The importance of systematic uncertainties with such beams is acknowledged in the existing literature but rarely quantified. Values quoted for systematic errors are assumed without justification to be smaller than any previously demonstrated values. This typically is attributed to a near detector, which in most cases is not explicitly included in the physics sensitivity calculations. Recently, Huber *et al.* [Hub07] showed that the cancellation of systematics between near and far detectors in an appearance experiment will always remain incomplete and additional information is required. Specifically, certain ratios of cross sections have to be known very well, *i.e.,* to better than a few percent. One very promising such ratio is the ratio of the ν_e to ν_μ quasi-elastic cross section around 1 GeV.

Clearly, a direct measurement of this ratio at the level of 10% or better is out of the question using conventional neutrino beams. Also, current data cannot constrain this ratio at all due to a lack of ν_e scattering experiments in the relevant energy range. Electro-weak interactions are flavor universal and, hence, the only difference from one for this ratio should arise due to the difference in final state lepton masses. However, neutrinos do not scatter off free quarks but rather off bound states in a nucleus. These corrections may have a strong dependence on the mass of the charged lepton. The following example illustrates the importance of this issue: if the ratio of ν_e to ν_μ cross section were known to 2%, the T2K experiment could achieve its projected sensitivity to CP violation with $1/10^{th}$ of its planned exposure.

CNAP will bring together the necessary expertise to accurately predict the sensitivity of a given experiment to the discovery of CP violation and to review and perform neutrino-nucleus cross section calculations. Also, the center has experimentalists in MiniBooNE [Agu07], which has collected one of the largest data samples on ν_μ carbon scattering to date. One specific problem is that the efforts in nuclear theory provide results that are not directly applicable to sensitivity studies. Here, Huber and Engel, working with experimentalists, can focus theory on the issues necessary to analyze long baseline experiments.

Once again, CNAP effectuates close collaboration between theorists specializing in different aspects of neutrino physics (in this case, Huber and Engel) and experimentalists active on the particular measurements required to address this question (Link, Scholberg and Walter, for example). There are a number of related experimental strategies to discover leptonic CP violation, such as off-axis beams at two baselines or a wide band beam at one baseline. The expertise at CNAP will allow us to compare the strategies and move forward with the best one.

1.6 Is the Neutrino a Majorana Particle that can Undergo Neutrinoless Double Beta-Decay? (Engel)

Measuring the rate of this process is the only practical way to determine whether neutrinos are Dirac or Majorana particles [Avi07]. Experimentalists in the field rely on theory for nuclear matrix elements that help determine the decay rate. An improved calculation of these matrix elements requires an accurate treatment of the nuclear many-body problem.

Two many-body methods are currently applied to calculating double-beta decay rates: the Quasiparticle Random Phase Approximation (QRPA) and the Nuclear Shell Model. The wave functions and interactions of the former are fairly simple, and one hopes that corrections to the simple wave functions are reasonably small and can be accounted for through a renormalization of the interaction or operator, which are fixed to reproduce two-neutrino double-beta decay and related observables. Unfortunately, there is no systematic way of assessing the accuracy of such calculations.

Similar statements can be made about the Nuclear Shell Model. The Shell Model omits parts of the wave function that the QRPA includes – high-lying single-particle excitations – but includes all possible correlations from near the Fermi surface. However, because its truncation scheme is based on energy, the Shell Model can more easily be corrected for the configurations it omits than can the QRPA. That is not to say that the corrections are easy; in fact, until now they have been possible only through perturbation theory, which is only partially successful in nuclei because there is no reliably small expansion parameter. But, the perturbative corrections need to be explored. Together with external collaborators, Engel is currently evaluating the lowest-order perturbative corrections to the neutrinoless-double-beta operator, in much the same way that theorists typically correct the bare Hamiltonian (via a G-matrix based expansion). Our first task in this area under CNAP funding will be to extend the calculation of the effective operator so that it includes all diagrams analogous to those in the construction of the effective interaction.

To improve accuracy, the interaction is usually tuned to experimental data after the perturbative construction. We can try to tune our effective operator to all neutrinoless decays that are measured. Ultimately, we need a construction that doesn't rely on fitting. Fortunately, nuclear theory is reaching the point where that is within reach. It is possible to calculate spectra on transitions from first principles in ^{12}C and beyond; coupled-cluster calculations, utilizing better-behaved nuclear Hamiltonians derived through renormalization-group methods, promise to get to A=40 and beyond. These methods all have no "core," that is, they work explicitly with all the nucleons, even those far below the Fermi surface [Bar05]. What hasn't really been attempted yet is the elimination of explicit states significantly <u>below</u> the Fermi surface, i.e., the "core" that is neglected in the shell model, through renormalized operators. But methods to do so exist. The "Similarity Renormalization Group," which can remove modes both above and below the Fermi surface, is already being used in nuclear physics to produce effective nucleon-nucleon interactions for use in the few-body problem [Bog07].

These and related computationally-intensive techniques are developing rapidly through work that is coordinated by the SciDAC UNEDF nuclear-structure-theory collaboration [Sci07].

Not many of the structure theorists pay attention to double-beta decay, however. With CNAP funding for postdoctoral fellows, visitors workshops, and computing resources, we can change that situation, working with external collaborators to implement new techniques. For example, current collaborative work with David Dean's group at ORNL and Alfredo Poves can be expanded to tackle the ambitious agenda laid out here. Scott Bogner at MSU and Joe Carlson at LANL are other possible collaborators.

Better calculations will affect the experimental side of CNAP. For example, they will allow Henning and Young to better assess the needs of the Majorana project, and permit Raghavan and Vogelaar to evaluate the feasibility of a xenon-based Borexino double-beta-decay experiment. In this case, experimentalists can further the calculations by measuring related observables, perhaps at the TUNL HIγS facility.

1.7 What Role Do Neutrinos Play in Cosmology and Other, More Speculative Questions?
(Minic, Raghavan, Engel)

We will focus on longer-term questions than those discussed above. One example is the possibility of detecting primordial 1.9K neutrinos from the Big Bang. Recently, Raghavan and Minic have been thinking about new ways of attacking this problem, perhaps through background-free measurements of very rare neutrino-induced decays. Other members of CNAP – Engel, Link, and Henning – are also interested. Another example is the possible connection between neutrinos and dark energy. Some physicists [Aba01, Kap04, Sel06] have speculated that variable neutrino masses might provide a natural source of the observed dark energy. The proposal has some possibly interesting experimental consequences, but there are problems from a theoretical point of view that particularly interest Minic. Finally, Minic has also started discussions with Link on an idea by Harvey *et al*. [Har07] that relates the physics of quantum anomalies to experimental anomalies reported by MiniBooNE.

MA1 Conclusion

Neutrino phenomenology ties together some of the most fundamental issues in nuclear and particle physics, astrophysics, and cosmology. The naturally interdisciplinary projects discussed above are just a start for CNAP. There are additional benefits to the community beyond internal collaboration: the interdisciplinary education of students and postdoctoral fellows, regular workshops hosted by CNAP to focus the community's attention on important problems in neutrino physics, and increased discussion among experts worldwide in the many subfields touched by neutrino physics.

MA2: Neutrino Technology

Senior Investigators: H. Back (NCSU), M. Blecher (VT), B. Crowe (NCCU), A. Champagne (UNC), Z. Chang (SCSU), ***R. Henning*** (UNC, executive committee representative), C. Howell (Duke), J. Link (VT), D. Markoff (NCCU), L. Piilonen (VT), M. Pitt (VT), R. Raghavan (VT), K. Scholberg (Duke), R.B. Vogelaar (VT), C. Walter (Duke), A. Young (NCSU)

Postdoctoral scholar: 3

Graduate Students: 3 + additional students from "focus funds"
Undergraduate students: 6-8

By their nature, neutrinos are extremely difficult to detect. Progress in neutrino physics is driven by technological advances such as the development of new detection techniques, the expansion of existing techniques to large scales, and industrial-scale manufacturing of low-radioactivity materials. The focus of MA2 is to continue this tradition of innovation by systematically studying new and novel neutrino detection techniques. This will benefit other experiments in underground physics, including those intended for DUSEL.

Neutrino experiments push to the very extreme what is technically feasible, taking many years and major investments from separate research groups to develop, even with close collaboration. CNAP can have a major impact on neutrino technology development by shortening the time that it takes for an idea to move from concept to prototype (which we refer to as the 'Concept-to-Prototype' highway), and by supporting programs to evaluate and develop new detection technologies. To accomplish this, we propose to pool our institutions' unique existing resources and expertise to create a suite of dedicated facilities, designed and staffed by researchers fully cognizant of these issues. We will combine the existing infrastructure at the Triangle Universities Nuclear Laboratory (TUNL) and the Kimballton Underground Research Facility (KURF) with new laboratories for detector development at UNC, NCSU and VT to be funded from CNAP. This suite of existing and new facilities would allow for the rapid development, characterization and prototyping of novel detector ideas in a low-background facility. The most promising of these tested ideas would then be shared with the community for incorporation into current or planned full-scale experiments.

The physics motivating new detector development is compelling, and members within this collaboration are pursuing several promising avenues with a goal of discovering and developing the *best* detection schemes to extract what neutrinos can tell us about our universe. Kimballton and TUNL provide a unique combination of *existing* resources coupled with a large group of physicists with expertise in neutrinos and low-background counting. This provides a unique basis that we can build upon to pursue high-risk, but potentially high-payoff ideas in neutrino detection. This PFC would provide an overall program and facilities to leverage existing resources and to provide new facilities to pursue these ideas.

The 'Concept-to-Prototype Highway'

The Center has set an initial suite of objectives for this portion of MA2 and these are reflected in the current distribution of Center resources in the following category:

IP3 Create the basic ‘Concept-to-Prototype’ highway

- Staff
- Facilities
- Equipment

A broad program of detector development requires a wide range of technical capabilities that are difficult to realize at any one institution. These include:

- **Detector Development Laboratories.** Construction of detector prototypes and handling of detector components must be done in a low radioactive-background environment. A detector development laboratory is basically a clean room with radon-scrubbed air outfitted with standard electronics testing equipment, clean-room supplies, radiation detectors, chemicals, fume hoods, etc.
- **Beam and Radiation Facilities.** Characterization of detectors requires radiation sources and beams to simulate signals from neutrinos and backgrounds. This in turn requires technical staff to maintain the accelerators and to ensure the proper handling of radioactive materials.
- **Low Radioactive Background Assay Program**. Neutrino experiments require that internal and external backgrounds be kept to an absolute minimum. Thus, there must be a means to assess the radio-purity of materials that will ultimately be incorporated into detectors.
- **Electronics Development.** All modern detectors rely on electronic signal amplification and digitization systems. In many instances these electronic systems are custom or novel and require experienced engineers to design. This requires an electronics shop with dedicated engineering and technical support.
- **Mechanical Engineering.** Many of the current and next-generation experiments are large, ranging from hundreds of kilograms to 50 kilotons. Other proposed detectors are on the megaton scale. To avoid unnecessary sources of radioactive backgrounds, some of these detectors have to be designed with as little mechanical support material as possible, which requires dedicated engineering. Developing the mechanical support and infrastructure for these detectors, as well as smaller prototypes is crucial.
- **Underground Laboratory.** Development of a prototype detector may require work in an underground laboratory where backgrounds and activation induced by cosmic rays can be mitigated. Ready access to such a facility would ensure rapid progress.

CNAP combines the technical infrastructure and capabilities of the member institutions to produce this suite of resources. Rapid progress from concept to prototype will be the result of collaboration and coordination within CNAP. The ‘Concept-to-Prototype’ highway makes use of several shared, linked facilities:

1. New detector development laboratories at UNC-CH and NCSU
2. Detector development and scale-up facilities at VT
3. The Triangle Universities Nuclear Laboratory (TUNL)
4. The Kimballton Underground Research Facility (KURF)

In the following, we describe these facilities and how they will be connected to move an idea from a concept to a detector prototype.

a) Detector development laboratories: exploring detector concepts. We plan to establish laboratories at UNC-CH and at NCSU to complement existing capabilities at VT. Together, they will provide the basic infrastructure to test ideas at the "table-top" experiment level. Facilities at VT include a dedicated scintillation chemical laboratory that is currently evaluating pure and metal-loaded scintillators for solar and reactor neutrino experiments. The laboratory at UNC-CH will include fume hoods, clean rooms, electronic supplies, access to the UNC machine shops, and cryogenic equipment. It will be managed by a dedicated Facility Director, supported by CNAP. NCSU offers a combination of unique facilities that expand the possibilities for neutrino detector development. The NCSU Analytical Instrumentation Facility is a resource for material characterization that has the potential to advance development of solid-state detectors. New laboratories in the physics department include a shared clean room, large-scale cryogenics laboratory, and chemistry facilities. In addition the nuclear engineering department runs a research reactor that can be used for neutron activation analysis. This technique is valuable for detecting trace contaminants in materials suitable for neutron activation analysis.

These laboratories will also provide dedicated electronic and mechanical technicians to support the activities of faculty, post-doctoral researchers and students. Each of the universities involved in CNAP have significant condensed matter and materials science groups, which have already proved to be an invaluable resource.

b) Detector characterization and testing at TUNL: The existing TUNL facility (located on the Duke campus) has a tandem van de Graaff accelerator and the High Intensity Gamma Source (HIγS). Beams from these accelerators will be used to determine the response of a new detector design to gamma, nuclear and neutron radiation. Neutrons are a ubiquitous background that is of particular concern for dark matter searches, since the nuclear recoil induced by a scattering neutron can mimic a WIMP scatter. The tandem accelerator can provide a high-quality neutron beam to help characterize the response of future dark matter detectors to this background and to study the efficacy of new or complex types of neutrons shielding. For example, TUNL can improve on existing measurements of neutron interactions in neon, which is relevant for noble liquid dark matter and solar neutrino detectors. TUNL also has significant infrastructure for radioactive materials handling, lab space, electronic equipment, existing detectors, and chemistry labs. It is also an ideal facility for measuring cross sections relevant for future neutrino experiments. Examples of past work include measurements of the $^{13}C(\alpha,n)$ reaction (for the KamLAND solar phase) and $Pb(n,n'\gamma)$ (relevant for Majorana and other double β-decay experiments).

c) Evaluating materials and detector prototypes at KURF: The Kimballton Underground Research Facility, near the Virginia Tech campus, is located at a depth of 1400 meters water equivalent (mwe), which is more than adequate for low background characterization and assay work. It provides 335 m^2 of enclosed space. A low-background assay facility is currently under construction at KURF with joint DOE/NSF support, and will be used to determine the radioactive background in new detector materials. It includes two low-background HPGe detectors that will be available to CNAP participants. KURF will be managed by a dedicated Kimballton Facilities Director, provided by CNAP.

To show how the Concept-to-Prototype Highway will function, imagine that a new scintillator material is proposed for neutrino detection. (In fact, a number of proposed experiments involve novel metal-loaded or noble-liquid scintillators.) Measurements of critical properties such as optical attenuation, stability and light yield would be measured in the development laboratories. Background events and proxy signals would be simulated using beams at TUNL, while radioactive assays of components are performed at KURF. This *coordinated* work would quickly establish whether the concept was promising enough to progress to the prototype stage. CNAP would provide electronics and mechanical expertise needed to scale up to the prototype stage. If required, the focus of activity would move to KURF, where the prototype would be evaluated and initial physics results might be obtained. This work would serve as the basis for a proposal to develop a full-scale detector for a future neutrino experiment.

Detector Development

The initial suite of objectives for this portion of MA2 are reflected in the current distribution of CNAP resources in the following category:

IP7 Detector Development

- Develop light-transport systems for neutrino detectors.
- Develop techniques in ultra-low background fabrication
- Perform research and development towards a measurement of the $0\nu\beta\beta$ lifetime of Xe dissolved in a large mass liquid scintillator detector.
- Solid state detector development for double beta decay experiments
- Trace element analysis for techniques for radioactive material assay
- Development of noble-liquid detectors
- Development of resistive plate chambers

A central objective of CNAP is to foster and nurture new ideas for neutrino detection. Presently, there is no shortage of these ideas among our members, but we lack the dedicated resources to fully develop them. CNAP would provide an overall framework to maximally leverage existing resources and create new facilities to pursue these ideas, particularly in the advanced-prototype stage. It will also provide an environment in which students and post-docs can interact directly with some of the leaders of the field and also participate in the development of potentially groundbreaking detection techniques. Examples of some of the techniques that we would like to evaluate through CNAP include:

- Scintillation lattice detectors
- Metal-loaded liquid scintillators
- HPGe detectors and low background materials screening
- Nanocrystal scintillators
- Cryogenic noble-gas scintillators
- Noble gases dissolved in liquid scintillators

The members of CNAP already have experience in these detector technologies and would like to explore methods for expanding the capabilities of these and other novel technologies. For example, we are currently developing the mini-LENS detector that will test the LENS concept to measure low-energy solar neutrinos. We are also studying the detailed characterization of pulse-shapes from HPGe detectors to fully extract the distribution of ionization inside the crystals. This is a powerful technique for background rejection in low-background experiments. Other CNAP members are involved in the DEAP/CLEAN direct dark matter search and the coherent neutrino scattering experiments at NuSNS; we also have interests in cryogenic liquid detectors..

These new techniques will also be critical for the success of the proposed suite of DUSEL experiments, including those outside of neutrino physics such as direct dark matter searches. Many of these next-generation DUSEL experiments will be large, complex detectors with many components that will require significant, dedicated research and development. The technology that we develop and our research results will be applicable to almost all aspects of these DUSEL experiments, including detection media, construction materials and data-analysis techniques. Studies performed by CNAP may also find applications in radiation detection and medicine, e.g., new types of neutron detectors, high-efficiency liquid scintillator radiation detectors with high-energy resolution and position reconstruction, etc.

Our initial focus will be on developing technologies for the MAJORANA double-β decay experiment, the LENS solar neutrino experiment, noble-liquid detectors (for the DEAP/CLEAN dark matter/solar neutrino experiment and the CLEAR neutrino scattering experiment) and resistive plate chambers. We will also continue to develop low-background counting as an ancillary tool in support of these activities. Subsequent work will focus on novel detection concepts such as using the Borexino detector with dissolved Xe gas for a measurement of double-β decay. Our initial studies are detailed below.

2.1 Neutrinoless Double β-decay and the MAJORANA Experiment

(Back, Henning, Howell, Young)

The proposed MAJORANA experiment will search for the neutrinoless double β-decay of ^{76}Ge. The observation of this process would have significant physical implications and force us to rethink our understanding of neutrinos and matter in general:

1. It would imply that the neutrino is a Majorana fermion. In other words, it is its own antiparticle [Sch82]. Neutrinoless double β-decay is the only practical experimental technique to probe the Majorana nature of the neutrino.
2. It would imply that total lepton number is violated.
3. It would confirm the result from neutrino oscillation measurements that the neutrino is massive.
4. The measured half-life of the decay could also provide a measurement of the effective Majorana electron neutrino mass.

The existence of Majorana neutrinos would have significant cosmological implications, since it is a general requirement of leptogenesis theories that explain the baryon asymmetry in the universe.

R. Henning has assumed the role of Level 2 Task Manager for Simulation and Analysis in the MAJORANA Work Breakdown Structure (WBS). He is also the current elected chair of the MAJORANA Executive Committee (the governing body of the collaboration with representatives from each participating institute). The members of CNAP expect to maintain two contributions to MAJORANA. The first is to continue a leading role in the MAJORANA simulation effort and in the development of an analysis framework and tools for MAJORANA. The other is the development of “detector characterization” systems. TUNL has assumed an important part of this effort, but CNAP would allow TUNL to assume the leading role in this task. Detector characterization involves the energy calibrations and measurement of charge-drift characteristics of the germanium crystals prior to installation into the MAJORANA cryostat. Current techniques for performing this are too slow for MAJORANA and dedicated research and development is required to develop new techniques [Vett06]. Detector characterization is also required in order to make full use of the powerful event-reconstruction capabilities provided by pulse-shape analysis of multiple detector segments, which is critical for background rejection.

We propose to perform a systematic study of the requirements for detector characterization facilities for MAJORANA and to test and evaluate new techniques for characterization. A detector characterization facility has to determine the following information for each crystal:

1. Physical dimensions.
2. Leakage current and other electrical properties.
3. Energy response and resolution at several calibration energy points (10 keV - 5 MeV).
4. Deadlayer characteristics.
5. An optimized collection of pulse shapes that adequately characterizes pulse-shape generation in the crystal and potentially helps to determine the orientation of the crystal axes.

The first 4 tasks are important but relatively simple. The last task is more complex and less well defined. We propose to explore the requirements for this task and to develop techniques for use in MAJORANA. The same techniques would also be useful for the Gretina project.

Many sophisticated analysis techniques are available that make use of segmentation and pulse-shape analysis. These techniques rely on a good determination of the drift characteristics of charge carriers inside the crystals as a function of position. One such is based on Compton-coincidence scanning using a pencil beam from a source and a coincidence detector to detect the Compton scattered γ-ray from the source. This is employed by the Gretina collaboration [Lee06, Vet06]. However, as noted earlier, this technique is too time consuming and labor intensive for MAJORANA. Another approach must be sought and some proposed alternative schemes are listed below. The main goal of our program is to demonstrate the feasibility of these techniques.

1. Pencil beam scanning without coincidence. A collimated pencil γ-ray beam from a source is directed at the crystal. This will generate a set of events along a known line inside the crystal. We would parameterize the drift velocity of charge carriers in the crystal as a function of position and attempt to compute these parameters by a minimizing the difference between the known distribution of hits inside the crystals and their reconstructed positions. This method would then not require the Compton coincidence and would be able to run with much higher efficiency than the coincidence method.
2. Plane Scanning. This is similar to the previous method, except that the source is collimated into a plane, providing a higher event rate and faster scanning. However, the restriction along one dimension is lost and careful Monte Carlo studies and measurements will have to be performed to test the validity of this approach.
3. Point Source Scanning. This involves locating a point source at several locations outside the crystal. Thus, there are no spatial restrictions on the calibration beam, but one can attempt to correlate this distribution of events with the distribution of pulse-shapes from Monte Carlo simulations. This is potentially the fastest way to characterize a crystal, but would require the most aggressive reliance on post-run data analysis and Monte Carlo to reconstruct the interaction points. This method would also require extensive validation with Monte Carlo and data runs before it can be implemented.

CNAP would provide its members with the infrastructure and operational funding to pursue this study and to have a significant level of participation in the MAJORANA project.

2.2 Low Energy Solar Neutrinos and LENS/MINILENS
(Back, Champagne, Chang, Link, Pitt, Raghavan, Vogelaar, Young)

There is now conclusive evidence that the flavor states of the neutrino are not mass eigenstates. This has led to new inquiries into the structure of the neutrino mixing matrix, and the nature of neutrino interactions and symmetries. Our goal is to acquire data with sufficient precision so that new aspects of particle interaction and symmetries can potentially be revealed.

Solar neutrinos will continue to play an important role in these studies because the sun offers a pure ν_e flavor at the source, the highest matter density, the longest baseline, and the highest flux at low energies as compared to any terrestrial machine. There is also continuing interest in what solar neutrinos can tell us about the sun. The low-energy part of the solar spectrum (E_ν <2 MeV) is particularly interesting because its different energy components can be used to probe the energy dependence of flavor survival, which provide detail that is lacking in the current MSW-LMA conversion model. In addition, a precise comparison of the solar luminosity inferred from the total neutrino flux with the observed photon luminosity has important implications for both astrophysics and for neutrino physics. These physics opportunities provide the motivation for development of the Low Energy Solar Neutrino Spectrometer (LENS).

LENS is based on inverse β-decay in the isotope ^{115}In:

$$\nu_e + {}^{115}\mathrm{In} \to e^- + 2\gamma + {}^{115}\mathrm{Sn}$$

in a detection medium consisting of an organic liquid scintillator containing 8-10% (by weight) of indium (~96% ^{115}In). Detection of low energy neutrinos via LENS is possible because of the uniquely low (114 keV) threshold of the capture reaction and the highly specific triple delayed coincidence, which provides a powerful means for background rejection at low energies. Another unique feature of LENS is that it is a *digital* detector: the detector volume is optically divided into cubic cells, which allows for three-dimensional event localization.

A major achievement has been the demonstration that a scintillator can be synthesized with a significant concentration of indium (~10%), excellent light yield (~50% of unloaded scintillator), light attenuation lengths in the range of several meters and a performance integrity on the scale of years. These qualities meet the design requirements of LENS.

Development of the LENS concept and technology has been led by CNAP collaborators (Raghavan is the spokesperson for the experiment). The advances made so far in the R&D phase of this project have demonstrated the feasibility of the LENS concept. The next stage in the development of the full experiment is practical development and testing of the design concept through the construction of a modest, scalable detector: mini-LENS. The basic goals for mini-LENS are to:

a. Implement scintillation lattice technology.
b. Scale-up production of In-loaded scintillator.
c. Demonstrate suppression of the ^{115}In background.
d. Observe cosmic pp (or other) proxy events.
e. Measure the Q-value for the β-decay of ^{115}In.
f. Optimize the scale-up route to LENS.
g. Establish the readiness of LENS.

Mini-LENS is designed to incorporate the same scintillator-lattice and scintillator technology described above. It will also serve as a test bed for the development of data acquisition hardware and software, and active and passive background suppression techniques. The various technical and engineering aspects associated with building this prototype will benefit critically by the support of CNAP and the surface and underground facilities at the disposal of CNAP.

The scintillation-lattice design may have more general applications and has significant operational advantages over other detector technologies:

a. The possibility of defining the interaction location places constraints on the spatial pattern for both signal and background.
b. Since the event location is digital, not analog, the location accuracy is independent of the hit energy (*i.e.*, number of photoelectrons). This is particularly important for low-energy events (neutrinos below 100 keV).
c. The time of arrival of light at each photomultiplier-tube for each event can be stored and used independently to further improve background rejection power.
d. The device operates as a tracking chamber, displaying the trajectories of particles such as muons (for tagging cosmogenic activity) and 3-D structures of γ-showers, both of which are important for identifying event types, topologies and physical origins.
e. More light is collected than in a collection of standard 1-D modules, which is crucial for background rejection.

CNAP will investigate the application of the scintillation lattice to other types of neutrino detectors.

2.3 Noble Liquid Detectors

(Champagne, Henning, Scholberg)

The proposed DEAP/CLEAN and CLEAR detectors use cryogenic liquid neon (LNe), liquid argon (LAr), and liquid xenon (LXe; for CLEAR only) as a detection medium to perform a direct search for dark matter (mini-CLEAN and DEAP), measure coherent neutrino scattering (CLEAR) and, in the future, measure the solar neutrino flux (CLEAN). The basic detector concept is a spherical array of photomultipliers, waveguides and wavelength shifters that face the detection volume. These photomultipliers will measure the bright scintillation light of nuclear recoils caused by a WIMP-nucleus collision or by coherent neutrino-nucleus scattering. The photomultiplier array is mounted inside a stainless steel vessel that in turn is submerged in water or an ice tank that provides shielding against neutrons and gammas from the environment.

Liquid neon and argon have the additional beneficial property that a significant amount of “late” light is produced in electronic recoils and almost none in nuclear recoils, owing to the differences in ionization charge density. Thus, the digitized pulses from the photomultipliers allow for powerful discrimination against background electronic recoils. DEAP/CLEAN will also be able to run with either LNe or LAr, allowing for a control experiment if a signal is observed. The DEAP/CLEAN concept is described in more detail in [McK00, Bou06]. CNAP is represented via R. Henning on the recently submitted mini-CLEAN proposal to the NSF for equipment capital. Mini-CLEAN is a phase of the DEAP/CLEAN project and is a proposed 400kg detector with 92 photomultipliers and a cross-section sensitivity for 100 GeV WIMPs at the level of 2×10^{-45} cm^2. Mini-CLEAN will be the focus of the U.S. part of the collaboration in the coming years while the Canadian members will focus on the longer-term DEAP/CLEAN experiment, which is about 10 times more massive than mini-CLEAN. Mini-CLEAN will be installed at a deep underground location (either SNOLab or DUSEL, depending on availability). CNAP will be involved in the development of the calibration system for the mini-CLEAN detector. The calibration system is comprised of external and internal sub-systems: The external system consists of removable sources in the water or inside the single-wall cryostat vacuum space while the internal system will place and manipulate low-energy γ- or β-emitting sources inside the sensitive volume. CNAP personnel will develop the manipulators to operate in the cryogenic liquid for the internal calibration system. CLEAR has also recently submitted a proposal to the NSF with K. Scholberg as the PI.

CNAP would allow its members to contribute more significantly to cryogenic noble liquid detector design. For example, it would provide a center where the CLEAR and DEAP/CLEAN groups can collaborate and share expensive cryogenic infrastructure, share postdoctoral fellows and graduate students and mitigate risks. It can also provide the operational funding to perform measurements of neutron elastic and inelastic cross sections on Ar and Ne at TUNL.

2.4 Resistive Plate Chamber Technology

(Link, Piilonen)

Resistive plate chambers (RPCs) are a very cost-effective way to cover large areas with active detector elements. Consequently, they are starting to find applications in neutrino physics both as cosmic ray veto detectors, and as the active element in large iron calorimeter detectors as has been proposed for the India-Based Neutrino Observatory (INO) [Ino07]. Center members J. Link and L. Piilonen, working in the context of the Daya Bay reactor neutrino experiment, are actively developing technology for RPCs. In Daya Bay, these RPCs will be used as part of the cosmic ray muon detection and tracking system. The VT group was responsible for the construction and maintenance of the BELLE Barrel RPC modules, which have been in successful operation for almost ten years [Aba00]. Currently, the group is developing custom high voltage electronics that use Power-over-Ethernet technology to create a locally-produced high-voltage supply. This is a better match to the needs of large arrays of detectors than the commercially available mainframe high voltage design. We anticipate that RPC detectors will continue to find applications in neutrino experiments and CNAP will further develop these detectors and the low-cost, low-maintenance high voltage, gas and readout systems needed for their operation. The center will also support the implementation of RPC detectors in large-scale experiments like INO.

2.5 Low-background Counting and Materials

(Back, Champagne, Henning)

CNAP personnel have been awarded grants by the NSF and DOE to perform the following tasks:

1. Commission and run low-background radioactive assay detectors at KURF and the Laboratori Nazionali Del Gran Sasso (LNGS). We are in the process of commissioning two detectors at KURF and assisting with the running of a third at LNGS. These facilities will provide assay capabilities to MAJORANA, LENS, mini-CLEAN and other CNAP initiatives. The broader impact of this project is an expanded ability to train students and expose them to the techniques of ultra-low background counting with the development of our program at KURF. Thus, our project not only provides a science program to develop background reduction and assay techniques useful for DUSEL, it also provides a conduit for a much larger body of local students to enter our field and contribute in the future.

2. Perform systematic studies of Radon mitigation in large volumes of air at underground facility.
3. A long-term goal of this effort is to perform a cross comparison between measurements with Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) and radioactive counting. ICP-MS has the potential for much greater sensitivity than normal background counting, but the two techniques need to be compared at existing levels.

The ability to perform low-background assay work locally will be critical to evaluating the feasibility the detector technologies developed in this MA.

Benefits to the community

CNAP will provide a unique environment and benefits for the first suite of DUSEL experiments and other neutrino efforts. It provides a venue, support and resources for members of the community to rapidly move new ideas from the conceptual into prototype phase. It will also provide an opportunity for students and postdoctoral fellows to work with some of the leaders in the field and participate in the development of groundbreaking detection techniques. These students and postdoctoral fellows will become the future researchers for the DUSEL program.

MA3: Neutrino Frontier

Senior Investigators: H. Back (NCSU), A. Champagne (UNC), L. Chang (VT), P. Huber (VT), ***J. Link*** (VT, executive committee representative), G. McLaughlin (NCSU), D. Minic (VT), M. Pitt (VT), R. Raghavan (VT), K. Scholberg (Duke), T. Takeuchi (VT), R.B. Vogelaar (VT) , C. Walter (Duke), A. Young (NCSU)

Postdoctoral Scholars: 2

Graduate Students: 2 + additional students from "focus funds"
Undergraduate students: 3-5

In the history of particle physics spanning the last several decades, important clues to the emerging Standard Model and, later, the key confirming discoveries were often connected to the advent of ever more energetic particle accelerators and related technologies such as colliding beams. Today, the field awaits the Large Hadron Collider (LHC), which is expected to discover the Higgs particle, the last major prediction of the Standard Model, and, perhaps, provide direct evidence of physics beyond the Standard Model and entirely new particle physics frameworks such as supersymmetry.

Over the last 40 years, a parallel sequence of development has resulted in equally important fundamental discoveries centered on neutrinos. The story of neutrinos covers a wide range of energies, which includes an evolving low-energy frontier. The work of scientists from many disciplines resulting in the discovery of neutrino mass is the first indication of physics beyond the Standard Model. They pushed the limits of discovery, not by increasing interaction energies, but by finding new sources of neutrinos and new methods of studying them. With few exceptions, each seminal experiment depended upon some clever new method or the application of an existing technology in a unique way that arose from intense synergy of many lines of expertise and insight. The challenge going forward is to create an intellectually fertile environment to ensure the continued flow of ideas on which the future of neutrino physics depends, and have the supportive environment, tools and resources available to actively develop them. In short, this is the goal of CNAP's Neutrino Frontier major activity (MA3).

This major activity will employ the combined experimental and theoretical expertise and creativity of the center's members, associates and visitors to explore far reaching physics questions with experimental time horizons that often extend beyond the initial five year term of the center. In some cases, the long time horizon is dictated by the scale and expense of the experimental approaches. CNAP will bring a broad perspective and develop the quantitative figures-of-merit needed to make an informed comparison of various options. Other new approaches have long time horizons due to their novel or speculative nature. In those cases, CNAP will provide a comprehensive framework for nurturing and developing such creative ideas and the facilities and expertise to apply these ideas using its `Concept to Prototype' highway. CNAP theorists will pursue frontier avenues unconstrained by experimental feasibility as well as interact with experimenters on practical realizations.

To succeed, MA3 will require a basic flexibility to react quickly to new ideas. Recent experience in neutrino physics makes the importance of this clear. For example, the realization of the critical need to measure the neutrino flavor-mixing angle θ_{13} and the development of an experimental program to address it happened in a matter of just a few years. To achieve this agility, the center will employ a number of tools including targeted workshops, extensive computer simulation capacity with VT's System X supercomputer, and the wide-ranging expertise of the center's members and associates.

As part of its mission of training scientists who will be leaders in the neutrino field, CNAP expects the center's younger members to participate in future planning for the field. To promote this, CNAP postdoctoral fellows and graduate students will be strongly encouraged to devote a fraction of their time to MA3 activities. The Center is uniquely able to facilitate this, supporting time spent at partner institutions while providing overall coherence and continuity to the experience.

The Center has set an initial suite of objectives for MA3, and these are reflected in the current distribution of Center resources in the following categories:

IP8 Quantitatively comparing the various beam/detector options for exploring leptonic CP violation and determining the neutrino mass hierarchy

IP9 Pushing the low-energy neutrino detection frontier

- Explore and test ideas for zero-threshold neutrino reactions
- Perform research and development towards detection of very low energy neutrinos via recoilless detection techniques

IP10 Perform detailed simulations of the physics potential of a 100 kiloton liquid scintillator detector

IP11 Pursue new applications for existing experiments and facilities

In order to facilitate rapid reaction to new ideas and experimental data the CNAP management structure has a mechanism for allocation of resources for new initiatives through its annual Implementation Plan process. In this process, the CNAP management will pay particular attention to the need to create an environment that promotes the invention and development of entirely new experimental concepts and avenues.

3.1 What further physics can be obtained from new activities in existing experiments?

Neutrino experiments often rely on massive detectors representing multimillion dollar investments on the part of funding agencies. Additionally, accelerator-based neutrino beams come with a hefty price tag. Frequently, neutrino experiments are constructed primarily with a single very important measurement in mind. Nevertheless, it is important to ask what more can be done with these valuable facilities. Time and again, this query has opened entirely new fields of neutrino science. In the simplest case, existing data can be analyzed in new ways – a task that requires only time and access to the original data. In more complicated cases one must modify the experiment to enable the new opportunity.

Recent examples of "spin off" experience include: Super-K, which added a long-baseline neutrino beam to become K2K [Oya98] (and later T2K [Ito01]); Fermilab's Booster neutrino beam, which was initially built for MiniBooNE but now also serves the SciBooNE experiment [Agu06] (which includes the recycled SciBar [Nit04] detector from K2K); and the SNO+ proposal, where heavy water in the core of the detector will be replaced by liquid scintillator to study geoneutrinos, low energy solar neutrinos, and neutrinoless double beta decay. One focus of MA3 will be to consider such value-added possibilities for existing and planned facilities. The following examples based on facilities with which CNAP members are already involved indicate starting points for CNAP activity.

3.1.1 New opportunities with the Borexino detector – geoneutrino detection, neutrinoless double beta decay in ^{136}Xe, probing for non-standard neutrino interactions (Pitt, Raghavan, Vogelaar)

The Borexino experiment at Gran Sasso National Laboratory (LNGS), Italy, in which Raghavan and Vogelaar have participated since its inception in 1988, is presently running and has demonstrated the practicality of real-time neutrino science at energies below 1 MeV. Indeed, it has directly observed the flux of 0.86-MeV solar neutrinos from ^{7}Be [Arp08] (see Figure 1). It further expects to measure the fluxes of lower-energy solar neutrinos arising from the CNO, pep and perhaps even the pp reactions.

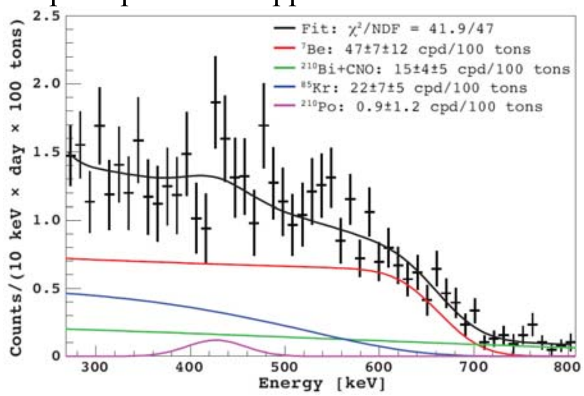


Figure 1: Fit of the signal spectrum in Borexino in the energy region 270-800 keV (containing the recoil electron spectrum of the 860 keV monoenergetic ν flux from ^{7}Be in the Sun. The peak due to ^{210}Po α particles has been statistically subtracted (a small remnant can be seen).

We thus have a demonstrated tool for direct observation of neutrinos at energies <1 MeV which can be used to address questions at the neutrino frontier. Anticipating this possibility, investigations in several other aspects of neutrino science and basic particle physics were foreseen in the original 1991 Borexino proposal [Bel91]. Some of these are currently in progress. In particular, antineutrinos from various sources can be studied simultaneously with solar ν_e detection because of the sharply discriminating delayed coincidence neutron capture following the $\overline{\nu}_e + p \rightarrow n + e^+$ reaction.

One source of antineutrinos is U and Th β decay deep in the interior of the earth that result in ν_e that are observable in Borexino. Quantitative measurements of these geoneutrinos will shed new light on the geophysical structure and evolution of the earth [Rag98]. Such studies in Borexino are of particular interest since the $\overline{\nu}_e$ background from nuclear reactors is minimal in Italy compared to that at KamLAND in Japan. Further, the geological structure of the earth's crust in Italy (continental) can be contrasted to that in Japan (continental+oceanic). Another topic is the search for the $\overline{\nu}_e$ magnetic moment via $\overline{\nu}_e$–e scattering using a MCi source of $\overline{\nu}_e$ (^{90}Sr). This awaits the installation of a source in the cavity constructed directly under the Borexino detector.

After the completion of the solar phase of Borexino, there exists an exciting opportunity to use the detector to study neutrinoless double beta decay (0νββ). The possibility of studying ββ decay in ^{136}Xe in Borexino (XeBeX for short) as well as in Borexino's counting test facility (based on liquid scintillation technology), has been studied in detail [Rag93]. Raghavan has reexamined the XeBeX option in the light of the current performance of Borexino. XeBeX takes advantage of the high solubility of xenon (2% by weight) in the organic liquids used as scintillator. With an operating mass of scintillator in Borexino of ~100 tons, the possibility of 0νββ studies with a *ton-scale* xenon source aimed at ~ 100 milli-eV scale ν masses was shown. By wide consensus, 0νββ experiments at the ~100 milli-eV scale are now one of the highest priorities for neutrino science.

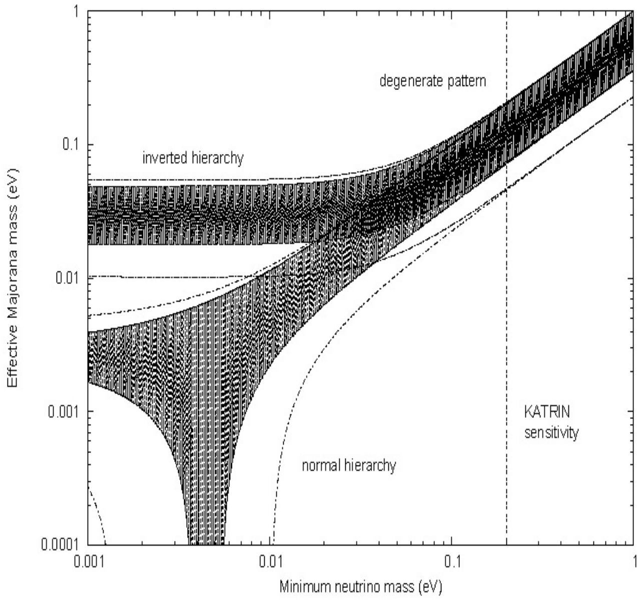


Figure 2: The relationship between the effective Majorana mass and the minimum neutrino mass of the lightest mass eigenstate, showing the importance of pushing experiments to smaller Majorana neutrino masses. The shaded areas indicate the possible Majorana mass with best fit neutrino parameters and the uncertainty of the unknown Majorana phases, while the dot-dashed lines include the uncertainty in the oscillation parameters The sensitivity limit of the Katrin experiment for direct measurement of the neutrino mass in Tritium β-decay is indicated by the vertical dashed line. (figure from [Nus05]).

Another important factor is that massive, liquid scintillation-based real time real-time solar neutrino detector technology, as exemplified by Borexino, has demonstrated the achievement of extraordinarily low radioactive and other background, which is an essential requirement for sensitive 0νββ experiments. In particular, Xe gas is arguably the additive of choice since it offers the best bet to introduce little or no radioactivity in the ββ signal window or degrade scintillator performance and the unique facility to measure the background in the Xe-free case by removing the source to confirm a positive 0νββ signal from Xe.

Recent data from Borexino show that the operating internal background is lower than design values and the energy resolution exceeds design values. The current *lower limit* on the 2νββ decay rate (which sets the interference with the 0νββ signal and thus, the demand on the energy resolution) is now four times longer than limits used in the initial study in [Rag94]. The ^{136}Xe isotope likely has the lowest 2ν/0νββ ratio and thus is the most favorable source for 0νββ studies. The 2νββ background estimated with the current energy resolution in Borexino, which is modest compared to those of solid state type detectors, does not appear to be a serious drawback.

XeBeX could be implemented relatively quickly since the detector is already constructed and the operating specifications for estimating sensitivities to the ν mass are derived directly from *measured* data with the operating detector. One needs only to add xenon to Borexino without the uncertainty or risk inherent in a virgin detector technology untried on the ton scale.

From preliminary data, it appears that XeBeX could be competitive with the best approaches currently under consideration.

CNAP is well positioned to take a leading role in the prospective XeBeX activities. In addition to experimental contributions from the Borexino members of CNAP the possibility of active theoretical collaboration with CNAP member Engel on the nuclear physics of ββ decay is attractive.

Non-standard interactions (NSI) of neutrinos with electrons can be revealed directly by ν-electron scattering experiments with a mono-energetic neutrino. Borexino provides a text book example since it detects the mono-energetic ^{7}Be neutrinos from the sun. In the presence of NSI the recoil electron profile is no longer the same as the standard profile for $\nu_e/\nu_{\mu,\tau}$. In the event that NSI are present at allowed levels, the τ component in a flavor-converted neutrino beam from the sun should create deviations due to NSI in comparison to the benchmark recoil electron spectrum of the standard theory (which can be measured directly using a radioactive MCi ν_e source installed in the cavity below the Borexino detector). Current models indicate a substantial τ neutrino component in solar neutrinos arriving at the earth. Thus, as pointed out by Raghavan and colleagues [Ber02], all conditions for a direct search for NSIs are present in Borexino. This approach is complementary to the search for NSIs in matter interactions in the sun which distort the standard MSW predictions of flavor survival vs. neutrino energy [Fri04] and might be detectable in solar-neutrino and other long-baseline experiments.

3.1.2 New opportunities with the LENS detector (Back, Champagne, Link, Pitt, Raghavan, Vogelaar, Young)

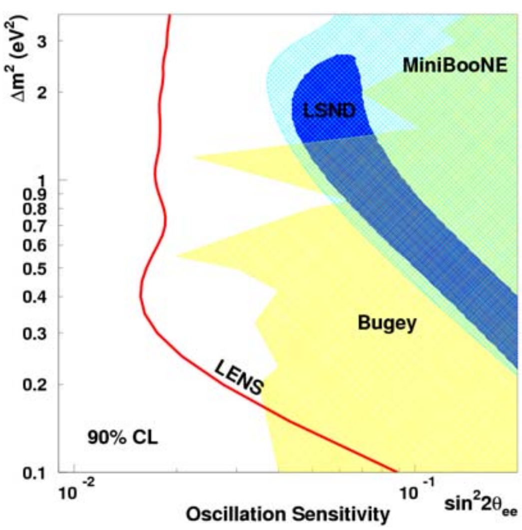


Figure 3: The projected sensitivity of LENS-Sterile compared to the results of MiniBooNE [Agu07], LSND [Agu01], and Bugey [Ach95].

The low energy capabilities of the LENS detector (see MA2) may have applications beyond solar neutrinos. Center members Link and Raghavan have recently proposed the use of this technology to search for large Δm^2 neutrino oscillations [Gri07]. The basic concept is to place a MCi-scale electron capture source, such as ^{51}Cr, which produces a mono-energetic, isotropic ν_e beam, at the center of the LENS detector. The low energy of the source (E_ν=753 keV for ^{51}Cr) means that for a Δm^2 consistent with the LSND experiment [Agu01] the oscillation maximum is on the order of one meter. In the full scale LENS detector (a cube of 5 meters on a side) with spatial resolution provided by the scintillation lattice the full oscillation pattern could be mapped out as a disappearance rate as a function of distance from the source. The LENS-Sterile sensitivity is shown in Figure 3. As a collaboration between people working on low energy solar neutrinos and people working on the search for sterile neutrino mediated oscillations [Agu07], LENS-Sterile is an excellent example of the kind of cross fertilization that we hope to foster in MA3.

An anticipated future direction for LENS is to study the impact of "mass-varying neutrinos" on solar neutrino fluxes (particularly the proton-proton flux). Initial work on this topic [Bar05] indicated the possibility of a unique signature for mass-varying neutrinos that would distinguish their effects from others such as non-standard interactions.

3.1.3 Future opportunities at the Spallation Neutron Source (McLaughlin, Scholberg)

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory will provide a high-intensity (and free) source of neutrinos in the few tens of MeV range from stopped-pion decay [Avi03]. The relatively close proximity of Oak Ridge to the center universities and the Partner University relationship (ORAU) between Oak Ridge and three of the CNAP member institutions (Duke, NCSU and VT) makes this a facility in which the center should participate strongly. Scholberg and McLaughlin are part of the team developing a detector facility based on the stopped-pion neutrino source provided by the SNS, known as νSNS [Sch07]. The main aim of this facility is the measurement of neutrino cross sections related to supernova interactions in a range of relevant materials.

A first-phase SNS neutrino experiment currently in the proposal stage is the CLEAR (Coherent Low Energy A(Nuclear) Recoils) experiment led by Scholberg. The aim of CLEAR is to measure the coherent elastic neutrino-nucleus scattering reaction [Sch06], also of relevance to supernova neutrino studies. Furthermore, because the cross-section is well-predicted in the SM and nuclear uncertainties are small, deviations from prediction could point to new physics [Bar07d]. In next-generation versions of CLEAR, nuclear physics can also be tested [Ama07] (see also section 1.3 in MA1). The cross-section for this reaction is relatively large; however nuclear recoil energies are tiny, and unobservable with standard neutrino detection technology. However, with novel detection technology developed for WIMP dark matter detection, the expected SNS neutrino-induced nuclear recoil energies of a few to a few tens of keV will be observable. The specific detector planned for the CLEAR program is a liquid Xe TPC similar to the successful XENON10 dark matter search experiment [Ang07]. The proposed configuration uses 50 kg of LXe 46 m from the SNS target, within an 8 m diameter water shield. Additionally, proposals exist to use the SNS neutrino source for short baseline neutrino oscillation experiments [Gar05].

3.2 What are the options for long baseline experiments for exploring leptonic CP violation and the neutrino mass hierarchy? (Link, Huber, Scholberg, Takeuchi, Walter)

Unraveling the properties of the neutrino will require major investments in large-scale accelerator experiments. Neutrinos have provided us with the first strong evidence for physics beyond the Standard Model and, therefore, it is natural to wonder whether they hold even more surprises. The fact that neutrinos are massive, opens completely new tools for studying phenomenological possibilities: for example, leptonic CP violation at very high energy scales may via leptogenesis be responsible for our very existence. Studying CP violation in neutrino oscillation is one of the very few venues to probe this idea, albeit indirectly. Given the very high temperatures at which leptongenesis would take place, indirect probes are the best we can reasonably hope for. Therefore the quest for leptonic CP violation has been recognized as priority in the long range strategy of high energy physics [Epp06].

The discovery of leptonic CP violation may not be within reach of existing or planned experiments [Hub04] like T2K [Ito01] or NOvA [Nov05]. Fortunately, many different plausible approaches may be available for this type of long baseline neutrino oscillation experiments. One (not too remote) possibility is the use of megawatt class proton "superbeams" in combination with detectors whose fiducial mass is a few 100 kilotons. More distant possibilities involve beta beams, where neutrinos arise from the beta decay of short lived isotopes, or neutrino factories, where neutrinos are produced by muon decay. For beams originating in muon decay, it will be necessary to identify the charge of the muon produced in charged current interactions. Charge identification requires the presence of a large magnetic field and hence iron calorimeters seem like a natural choice as detector. Examples of this type of detector are MINOS and INO (Indian Neutrino Observatory). However, more recently, the possibility of magnetizing large scintillator detectors or liquid argon has also been investigated. Thus, there are many combinations of beam and detector technologies (for a review see ref. [ISS07]). The question is which combination is the most cost effective and promising path to measuring leptonic CP violation and determining the mass hierarchy.

There is a large body of literature on these questions and there have been several large studies, like the joint BNL-FNAL study group [Bar07a] or the International Scoping Study for a Future Neutrino Facility (ISS) [ISS07]. There are currently ongoing studies and projects, like the International Design Study for a Neutrino Factory (IDS), whose goal it is to deliver a conceptual design report for a neutrino factory by 2012. More generally there is the Euro-Nu network, which is sponsored within the 7th framework program of the European Union. Finally there are many smaller scale activities with much narrower scopes. The majority of these activities, however, have taken place in Europe. These relatively large scale studies have primarily focused on only a subset of technologies and therefore, they all have to rely on external expertise to perform a comparison of the physics sensitivities of the various options. The GLoBES software package [Hub05, Hub07], developed by Huber, has become the tool of choice for all of the aforementioned studies to conduct their performance comparisons.

Beyond developing brand new ideas, the issue of technology selection is important. Choosing the right experimental approach clearly plays a crucial role in shaping the way discoveries in neutrino physics are made. In the context of superbeams the issue whether to use two detectors in an off-axis configuration or to use one detector in an on-axis, wide band beam setup is still not fully resolved [Bar07a, Bar07b, Bar07c]. The answer will depend on many factors including cross section uncertainties, which will be studied in MA1. Also, the question whether large HSD/LENA type scintillating detectors (see section MA3.3) can be used for superbeam experiments is largely unexplored. For this type of question it is very important to have a direct exchange between detector and simulation experts, as this center would provide.

CNAP offers a sandbox to test novel, undeveloped ideas. This requires close interactions between theorists and experimentalists, which sometimes is difficult to achieve without the right organizational framework. The idea for reactor neutrino experiments like Daya Bay [Guo07] and Double Chooz [Ard06] was examined in depth by Huber and collaborators [Hub03] within the context of the Sonderforschungsbereich (the German equivalent to a physics frontier center) in Munich. The close interaction with experimental groups was critical and is reflected in the design of the two experiments. We envisage that MA3 will promote this type of interaction in the community. For example, we plan to organize regular theory-experiment workshops (as was done with reactor neutrinos with the successful LENE Workshop series) where new, speculative ideas can be discussed and further pursued.

3.3 What is the physics potential of a 100 kiloton liquid scintillation detector? (Link, Huber, Raghavan, Scholberg, Takeuchi)

The study of neutrino interactions and other exceedingly rare processes has, in the past, led to the construction of kiloton scale detectors. Around the world, a new generation of detectors at the 100 kiloton to megaton scale is being contemplated with a variety of technologies. Each proposed detector is optimized for one or more specific physics topics, such as:

- Proton decay searches
- Prompt and relic supernova neutrino detection
- Long baseline neutrino oscillations
- Solar neutrinos
- Atmospheric neutrinos, and
- Neutrino astrophysics

The challenge will be to define an optimized program of one or more large-scale detectors that has the widest possible physics reach. A comprehensive series of studies have been made by the European consortium LAGUNA [Lag07] which have looked at several technological options including, water Čerenkov, liquid argon, and liquid scintillator, but generally without a specific site which dictates backgrounds. A US study specifically for a megaton water Cerenkov detector (UNO) [Uno05] sited at a US underground laboratory has been made. Similar studies (Hyper-K) [Hyp02] have been made in Japan with the Kamioka underground laboratory in mind. Extensive studies for a 50-100 kTon magnetized iron calorimeter (INO) [Ino07] located at an underground site in Southern India have been made. Recently INO has been funded (at ~170 M$).

One concept for large scale detectors is scintillation technology pioneered by CNAP members Raghavan and Vogelaar who helped develop the Borexino technology of kiloton scintillation detectors. This experience has led to the consideration of a Hyper-Scintillation Detector (HSD) in the 100 kiloton mass range (by Raghavan and other colleagues), following groups in Europe who originated such ideas with the name LENA.

The CNAP studies on HSD have specific US relevance since a 100 m^3 cavity is under consideration in the prospective DUSEL setting in the Homestake mine. The physics reach of HSD is dictated by the framework set by a specific site via detector design, background considerations at the site, and various other technical factors. Thus a complete design study of HSD will be basic objective of the CNAP work on the HSD.

The objectives of HSD cut across a wide swath of frontier questions in basic science that can be answered only by a detector of this type and size. The science portfolio of HSD includes:

1. Geophysical structure and the evolution of the Earth studied via global observation of antineutrinos from the earth's interior and measuring directly the radiogenic heat of the earth and its role in the total heat budget of the earth. HSD at Homestake offers a viable way to look for a postulated fission reactor at the center of the earth's core.
2. Supernova astrophysics (observation of live supernovae) and the observation of the supernova relic neutrino spectrum especially at lower energies (star formation rates and the probe of the high red shift universe from low energy relic neutrinos).

3. Proton decay, which can benefit from detecting heavy particles that are typically below Cerenkov threshold such as K^+ which allows a crucial tagging via delayed emission of its daughters.

The basic advantages of this multi-disciplinary scintillation detector approach are: sensitivity to events of both low and high energy ranging 4 orders of magnitude from the keV to GeV regimes; high sensitivity to heavy particles normally below Čerenkov thresholds; and high sensitivity to antineutrinos that can be specifically tagged by capture on protons. This point is particularly significant at Homestake where the background of antineutrinos from power reactors is particularly small (see Figure 4) allowing a greater reach in geoneutrinos and relic supernova neutrino searches.

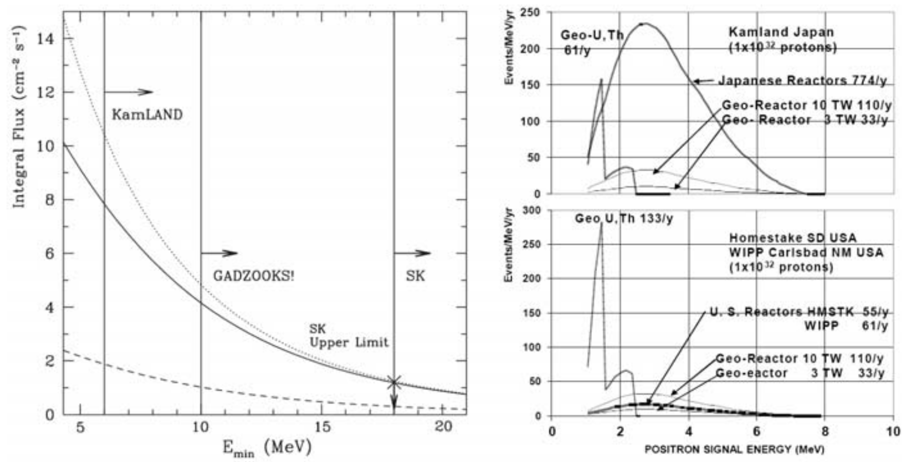


Figure 4: The figure on the left shows the relic supernova neutrino spectrum [Str04] with the relative reach in energy of a water Čerenkov detector (SK), a gadolinium loaded water Čerenkov detector (GADZOOKS!) and a liquid scintillator detector (KamLAND). The figures on the right show the reactor backgrounds for Kamioka, Japan (top right) and Homestake, SD (bottom right) relative to various geoneutrino signals [Rag02].

The possibility of a very large detector can be best justified if it addresses frontier questions in many disciplines. Questions related to geoneutrinos can only be addressed in a scintillation device which is sensitive to low energies (see Figure 4). Scintillating detectors bring comparable sensitivities to other rare processes such as proton decay and increases by as much as ×10 relative to a megaton scale water Čerenkov detector in some channels.

3.4 What opportunities are presented by the next galactic core collapse supernova? (J. Engel, G. McLaughlin, K. Scholberg)

The gravitational collapse of the core of a massive star in the Milky Way neighborhood would present a tremendous opportunity for physics and astrophysics [Sch06a]: see also the MA1 discussion. The neutrino burst's time, flavor and energy structure will bring information about the explosion mechanism, accretion, possible quark matter or black hole formation, and so on. In addition, we will learn about neutrinos themselves. The parameters governing neutrino oscillations will imprint themselves on the neutrino signal. As the neutrinos propagate through the stellar material, or the Earth, via matter effects there may be signatures of the unknown mixing angle θ_{13} and neutrino mass hierarchy. Furthermore, the neutrinos will provide an early warning of a galactic supernova: the NSF-funded SuperNova Early Warning System (SNEWS) [Ant04] project organized by Scholberg is an inter-experiment network of detectors. Many (maybe most) of the new neutrino detection technologies under consideration here will be valuable for supernova neutrino detection. For example, scintillation detectors will have excellent sensitivity to the low energy component of the flux and should be able to follow the proto-neutron star's cooling flux out to relatively late times. As another example, noble liquid detectors such as CLEAR and DEAP/CLEAN will have sensitivity to neutral current interactions via coherent elastic scattering [Hor03], which will be enormously valuable for extracting physics from a supernova neutrino signal. Both theorists and experimentalists of CNAP will explore capabilities of novel detector technologies in the context of supernova neutrino studies.

3.5 What are the most promising techniques for the detection of very low energy neutrinos? (D. Minic, R. Raghavan, T. Takeuchi)

An important aspect of MA3 is to meet the challenge of discovering pathways beyond the neutrino physics roadmaps envisioned today. As such, the best ideas in this quest are likely to be beyond the scope of our thinking at this time. One promising general direction is the low energy frontier as the following examples illustrate.

As mentioned in MA1, cosmic relic neutrinos are an area of interest for many of the center members. The existence of cosmic relic neutrinos is a central prediction of the big bang theory, on par with the cosmic microwave background. Observation of these neutrinos will require new techniques that are sensitive to neutrinos at meV energies. One possible idea is zero threshold reactions (proposed early by Weinberg [Wei62] and recently reexamined by Cocco, *et al.* [Coc07]). Practical methods for the difficult task of realizing such processes is of great importance. CNAP members are actively interested in this quest and have the nuclear physics competence for pursuing it.

In pursuit of neutrino science at ever lower energies, theoretical considerations have been made by Raghavan [Rag06] to explore conditions for observing *resonant* capture of $\bar{\nu}_e$ (the neutrino Mössbauer Effect) of energy as low as ~20 keV. The resonant character of the reaction presages $\bar{\nu}_e$ cross sections perhaps 10 orders of magnitude larger than the usual non-resonant $\bar{\nu}_e$+p reaction. Hence, the hope for θ_{13} oscillation studies on laboratory scale baselines and target masses <<1 kg. A possible specific technology was first proposed two years ago [Rag06]. Further R&D of these ideas is an example of a thrust of CNAP in unexpected directions towards the neutrino frontier.

Education, Development and Outreach

The Center creates a vital educational hub with many spokes reaching into the community, and significant resources are dedicated to ensure its vitality and effectiveness. Some appear individually in our budget as speaker series and workshops within the various Major Activities, while others obtain significant leverage through partnership with NCSU's Science House [Sci] and VT's Institute for Connecting Science Research to the Classroom (ICSRC) [ICS]. The overall vision is summarized in the following.

Physics Community: In addition to speaker series and specialized workshops, the Center will sponsor cross-cutting workshops designed to engage theorists with experimentalists and participation from beyond the Center's institutes, with possible themes such as "Finding an optimized approach to determining fundamental neutrino properties", or "Bringing astro-particle physics to the forefront in the careers of our students, future colleagues, and funding agencies".

The Next Generation: Recently, the APS announced a goal of doubling the number of physics majors [APS07]. To achieve this objective, the quality of science instruction at all levels must be improved. The Center is poised to lead those improvements in the southeastern US. We propose a broad range of programs focusing on K-12, undergraduate and graduate education, and public outreach. The scope of these activities will be local, regional and national.

The Education and Outreach program will be coordinated by The Science House, NCSU's premiere outreach program for K-12 teachers and students. With six offices located throughout the state, partnerships across the southeast, experience working with large center projects, and a high volume website, The Science House is uniquely positioned to lead a high quality outreach program that will have lasting impact. Dr. Sharon Schulze, Director of The Science House, has over 20 years of experience with public schools and 10 years of experience working in professional development partnerships in Texas and North Carolina.

The Science House will work in close partnership with the Institute for Connecting Science Research to the Classroom (ICSRC) at Virginia Tech. For more than a decade, the ICSRC has successfully brokered collaborations between the university and the K-12 world to bring real, hands-on science, technology, engineering and mathematics inquiry-based education to the classroom. The ICSRC's founding Director Dr. Joy Colbert has more than 30 years of experience with public schools and professional development partnerships.

K-12 education: Neutrino physics *per se* is not part of the K-12 curriculum. However, the broader scope of neutrino science (the sun, supernovae and cosmology plus topics in physics and chemistry) are relevant to K-12 education. There is a critical need for teacher training in the physical sciences at every level. We propose several ways to bring our work to students and teachers. All programming will be collaborative among Center partners and teachers will have the freedom to attend sessions at the site of their choice. Teachers and students from minority groups will be aggressively recruited using the networks of The Science House and the ICSRC.

Classroom Materials – The Center will provide assistance to teachers who wish to enhance the quality of science instruction in their classrooms. Materials-only mini-grants of $200 will be given to K-12 teachers who propose to introduce more physics into their classrooms. We will develop informational materials about Center research for students and teachers, including "Meet the Physicist" interviews and podcasts [CO2]. Materials will be produced in both English and Spanish.

Elementary Education – The Center will host K-5 teachers for a summer course in basic physical sciences content plus lab tours and lay-language explanations of Center research. Led by a master teacher and Center physicists, courses will be pedagogically sound and aligned with the NC and VA teaching standards, increasing the likelihood that teachers will use the content in their classrooms. The course will be offered each year of the project at VT and either NCSU, UNC, or Duke. We will then schedule sessions during the school year in which project-trained researchers go into classrooms to present hands-on, inquiry activities and interact on a personal level with the students.

Cutting Edge Physics Workshop for Teachers – The Center will host three-day sessions in which middle and high school teachers tour labs, engage with researchers, and learn activities related to the research content that also address state learning standards. The workshops will rotate among the three NC schools and VT in alternating years.

Summer Science Programs – The Center will host academic summer programs for high-school students and their teachers. Teacher/students teams will engage in content-based activities, including a research project related to Center research. Individual sessions will be held for teachers and students together as well as separately. The Summer Science program will begin in year 2, include attendees at the Cutting Edge workshop, be 2 weeks long and focus both on the science activities of the Center and on careers in science. Summer Science would be held at NC and VA sites in alternating years.

An Education Leader based at NCSU will coordinate Center activities at The Science House at NCSU and the ICSRC at VT. Dr. Schulze, Director of The Science House, will be actively engaged in the Executive Committee of the Center and will supervise the Education Leader in managing the Center's outreach efforts. Interactions with the Center will draw on existing outreach activities to create new, larger programs with wider impact in the region. Early explorations have turned up multiple potential sources of expansion and collaboration like expanding VA's "*Share the Skies*" program [Sha] time astronomical observations by K-5 students using a robotic telescope in Australia) to NC and bringing content-for-teachers expertise of The Science House to VA. The Center provides an otherwise unlikely opportunity for ICSRC and The Science House to work as one, with a synergy that will build upon past successes from other large programs (NSF STC for Environmentally Responsible Solvents and Processes and NSF Rice Blast Genomics Center at NCSU; Project TILT at VT) and become a regional resource for teacher and student learning that will be available and useful far into the future.

Public outreach**:** We plan to partner with the NC Museum of Natural Science. Since 1879, the Museum has been a proven source of quality, informal science in a dynamic learning environment. Over 650,000 annual visitors come to the Museum, making it the highest-attended museum in NC. The Museum is the largest natural science museum in the Southeastern United States and has been named one of the top science museums in North America. The Center will partner in existing public outreach of the museum by bringing neutrinos and astroparticle physics to existing Museum offerings, including bilingual programming for non-English speakers and the very successful Science Café series, in which the public interacts with leaders in the fields of science and technology in coffee shops, bars and restaurants.

The Nature Research Center (NRC), a new 80,000 square-foot Museum wing dedicated to science research, is scheduled to open in 2011. The mission of the NRC is to engage the public in understanding the scientific research that affects their daily lives. The NRC will provide research-grade laboratory space so that the public can interact with scientists performing research. We will explore the possibility of showcasing detector development activities at the NRC, engaging in discussions as the NRC is being built. Neutrino science will also be brought to a broad audience through public lectures and tours of some of the Center sites (e.g. the Kimballton Underground Research Facility).

Undergraduate and graduate: The Center will host a Research Experience for Undergraduates (REU) program with a focus on neutrino and astroparticle physics and technology. Applications for the Center-wide REUs will be solicited from across the country with an emphasis on Historically Minority Colleges and Universities, including SC State University and NC Central University. The Education Leader will gather and distribute applications for review by Center scientists and will assign students to Center labs. Labs will receive a stipend to offset material costs. REU students will receive travel to and from the lab site, housing, a stipend, and the opportunity to participate in a social community of other REUs at the host university. REU students will also receive encouragement and information regarding graduate school and career aspirations, and will develop and present a poster about a summer project.

A special partnership with NCCU and SCSU will include the use of Center focus funds to enable a limited year-round research program. CNAP has identified such opportunities and already included them in its objective driven budget. To better engage students, build personal relationships, and move past simple recruiting, Center faculty will set up team-teaching opportunities at NCCU and SCSU, combining extended visits with a series of classroom lectures leading into Center related topics. In addition, students from NCCU and SCSU who participate in the REU program will have an opportunity to continue their summer research experiences at their home schools.

We will also set up a regional summer school aimed at senior undergraduates and beginning graduate students, the South East Neutrino Student Retreat. This idea is based on the New England Particle Physics Student Retreat (NEPPSR) [NEP], which has been held in the New England area since 2002. First and second year graduate students and undergraduates considering graduate school will be given an introduction to current, exciting research topics, as well as introductory training on topics absent from some graduate or undergraduate curricula (e.g. statistical techniques, detector physics). The lectures and activities will be organized around topics related to neutrino physics and relevant instrumentation and other topics as appropriate. Lecturers will be a combination of Center and guest scientists. The weeklong school will include social activities and involvement in public outreach to the community at large.

Postgraduate: Postdoctoral researchers at the Center will have the opportunity to learn neutrino physics by working on frontier problems and interacting with researchers from the Center and visitors from around the world. The Center's infrastructure will provide support for creative ideas, which will provide post-docs with the opportunity to take ownership of important aspects of projects early-on in their careers. In addition, we propose to create Center Fellowships for outstanding candidates. This program will be modeled on the Lederman Fellowship at Fermilab, in which successful candidates will be expected to spend some time on outreach activities.

Evaluation of Programs: All outreach programs will be evaluated. A matrix of activities, desired outcomes, and data sources will be developed by education and outreach personnel from partner universities. Data will be gathered by The Science House from all outreach activities in the form of evaluation surveys, follow up conversations, and other means as appropriate. The Science House has a full-time evaluation professional who will oversee collection and analysis of the data. Evaluation results will be shared annually with all partners so that each year's activities will build upon the successes and lessons of previous years. By collecting data over an extended period of time we will be better able to track the career paths of students, identify the most effective and popular programs, and determine which aspects of the education and outreach efforts can be sustained if NSF funding for the Center ends.

Existing Facilities: "Concept to Prototype" Highway

Access policies: Access of center members to common facilities is unrestricted. However, those wishing to work underground at KURF more than four days a year must complete a full MSHA training program. The Center will offer classes to enable this. Those working at TUNL must receive radiation training.

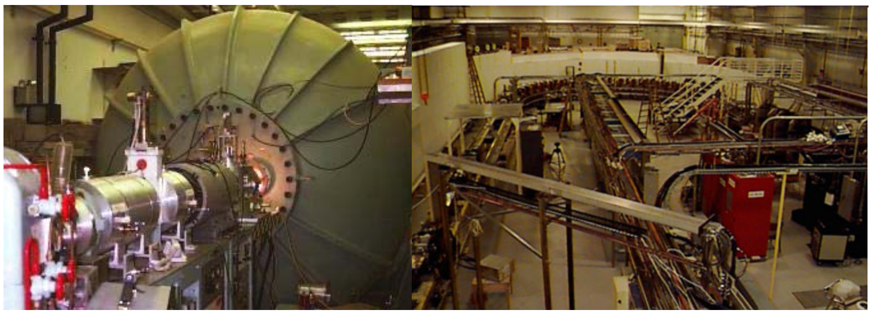
Office Space: The Skelton House at Virginia Tech is available for the Center. It offers modern office equipment, conference room, and numerous individual offices for administrative or visiting scholar stays.

Computing: The Virginia Tech Physics department currently maintains three computing clusters. The Thunderbird cluster consists of 137 dual Xeon 3.2GHz nodes, gigabit networking, and two terabytes of storage. Geared more towards production and student usage is the Tempest cluster consisting of eighty 1GHz AMD Athlon nodes. Additionally, all of the NUMBER computers used by students in the teaching laboratories reboot at night and on the weekends and can be used as individual workstations. Virginia Tech also hosts "System X", one of the world's fastest supercomputers, consisting of 1100 Apple Xserve G5 nodes, each with dual 2.3GHz PowerPC processors and 4GB of RAM, networked together with Infiniband 10 Gigabit switches.

Thunderbird Cluster and System X supercomputer

Laboratories: Two large laboratories are present in Robeson Hall on the Virginia Tech campus for limited usage for KURF related activities. The larger of the two laboratories houses a clean room, an overhead crane, a large ultrasonic bath, a mass spectrometer (GCMS), a deionized water system, and other useful instruments. The other laboratory, primarily set up for chemistry purposes, houses two large fume hoods, a spectrophotometer, and ample space for benchtop scale testing of processes.

TUNL (located on the Duke campus) is a cooperative laboratory, with participants from UNC-CH, NCSU and Duke University. It provides four accelerator systems: A high-intensity, tunable γ-ray source (HIγS), based at the Duke Free Electron Laser laboratory; a 9-MV model FN van de Graaff accelerator, which can accelerate beams of H and He and can produce secondary pulsed neutron beams; a minitandem accelerator (used to provide low-energy beams); and the coupled accelerators at the Laboratory for Experimental Nuclear Astrophysics (LENA). A full suite of electronics and detectors is also available. These facilities will be used for measurements of background processes and relevant reaction cross sections.



Facilities at TUNL:

(Left) The TUNL FN tandem accelerator.

(Right) A view of the HIγS storage ring.

Shops Virginia Tech houses its own machine and electronics shops, and its Chemistry department houses a glass shop. The machine shop employs three certified machinists and is equipped with state of the art CNC equipment. Machine shops with CNC capability are also available at UNC-CH, NCSU and Duke. The electronics shop has a large inventory of components, and the ability to fabricate custom circuit boards and enclosures. The Chemistry department’s glass shop provides custom glasswork fabrication and repair.

Kimballton Underground Research Facility (KURF) KURF is located a half hour away from Virginia Tech and allows drive-in access. The drift dimensions are 12.8 m (width), 8 to 32 m (height), and up to 1.5 km long. The overburden at the KURF location provides 1450 meters of water equivalent (mwe) shielding. The mining company removes seven hundred kilotons of rock per year, corresponding to about seven LNGS (Italy) size halls (20x20x100 meters). The radioactivity of the Kimballton limestone was measured by the Max Plank Institut für Kernphysik in Heidelberg Germany. The results of this measurement on two samples of rock gave:

$$^{40}\mathrm{K} \rightarrow 18\pm1,\ 13\ \pm1\ \mathrm{Bq/kg}$$
$$^{226}\mathrm{Ra} \rightarrow 1.2\pm0.1,\ 1.9\pm0.2\ \mathrm{Bq/kg}$$
$$^{226}\mathrm{Th} \rightarrow 0.6\pm0.1,\ 0.9\pm0.2\ \mathrm{Bq/kg}$$

Kimballton Underground Research Facility The primary enclosure (36’x20’x100’), on the 14th level, has space to comfortably house six standard shipping container laboratories. The tour bus is at the shop on the 8th level, and brought community leaders down to the site as part of the Virginia Tech College of Science advisory program.

This is a key facility for several future CNAP programs which must be sited underground. KURF already is host to an NSF-funded DUSEL R&D effort [Hen], a Naval Research Lab low-background detector development effort, and the TUNL ^{100}Mo double-beta decay experiment. Other groups have also expressed strong interest in using KURF, when it becomes more generally available.

Collaboration with Other Sectors

Many facets of the science driving CNAP are also driving other groups. These include large-scale detectors and accelerator programs envisioned at many national laboratories in the US and worldwide. We anticipate the Center will provide critical insight and figure-of-merit comparisons which can help chart an optimum path to the needed physics. This is especially important in an environment where program costs are extremely high, funding is uncertain, and projected time-lines are multiple years.

Examples of this have already taken place, where the work of Huber has been used to help highlight the advantages of a relatively cheap-and-fast reactor program targeting the measurement of θ_{13} versus the major investment needed for the more versatile accelerator programs.

Another critical and timely role for CNAP is refining the science case for **DUSEL**, and allowing early development, testing, and design optimization for experiments which are envisioned as part of the initial suite of experiments. Over the next several years as the plans for DUSEL are developed and the MRE-FC process moves forward, and then as construction takes place, the CNAP "concept to prototype" highway (and especially the use of KURF), provides an excellent avenue for critically needed development ***right now***. Kimballton is currently host to two projects funded through the joint NSF and DOE DUSEL R&D program: a materials testing facility for low-background experiments related to the Majorana experiment and miniLENS. As DUSEL approaches, CNAP will play a large role in transitioning these R&D efforts to full scale implementation at the national facility. It will also facilitate the development and testing of new ideas which could lead to next-generation of DUSEL experiments.

KURF is also available to host related experiments. For example, the ^{100}Mo $\beta\beta$ decay experiment formerly located at Duke is now being relocated underground, and a proposal from Princeton to examine and store low ^{39}Ar argon needed for future dark-matter searches is under review. The facility also continues to draw interest from the geoscientists and microbiologists due to the sedimentary rock environment.

CNAP is also well positioned to work with industry to optimize the development of next-generation germanium detectors, where segmentation can greatly improve particle identification and background rejection. The state-of-art detector electronics facilities envisioned for CNAP, with the low-background culture of the physicists is a powerful combination. The TUNL Majorana group has entered into a collaboration with Pat Sangsingkeow and the ORTEC detector group, to produce the first isotopically enriched lithographically segemented n-type ^{76}Ge detector for use in double beta-decay experiments. This prototype detector is functional and being prepared for transfer to a low-background geometry in the coming year.

The development of specialized scintillators for neutrino applications has had, and continues to have spin-off applications. For example, techniques developed by Raghavan [Obe00] to purify scintillator for low-background use in Borexino have been used industrially to remove contaminants from solvents used in the manufacture of semiconductors. The metal-loaded scintillators developed in collaboration with Brookhaven National Laboratory chemists Dick Hahn and Minfang Yeh, for the LENS and Daya Bay experiments have applications to homeland security as neutron detectors.

An additional application to homeland security and nuclear non-proliferation comes in the area of low-background counting at Kimballton. Ultra-low background counting technology developed for fundamental physics research is useful in the realm of nuclear non-proliferation. Further development of these detectors (in the public domain) is possible at KURF.

The strategic relationship between Virginia Tech, NCSU and Duke with Oak Ridge National Laboratory through their University Partners program means that increased university and lab resources are available to enhance collaboration with Oak Ridge. Center members Scholberg and McLaughlin are already participating in the development of a neutrino beam line and experimental facility at SNS.

International Collaboration

CNAP members have a long record of founding and/or collaborating in international experiments on leading topics in neutrino science. The experience and networking opportunities gained in these collaborations is a major asset of CNAP. Systematic opportunities to cut across national boundaries to advance scientific education and productivity arise naturally in neutrino science and will be actively promoted and supported by CNAP. Our junior members and students, in particular, will learn to internationalize their scientific and human scope through their participation in CNAP projects.

CNAP will organize international workshops and arrange for exchange visits that will promote direct interactions of members with colleagues from other parts of the world. Among the topics with a naturally international scope to be discussed during these workshops and visits are the Hyper-Scintillation Detector (modeling and analysis specific to a possible DUSEL site), the Indian Neutrino Observatory (theoretical analysis, technology of resistive plate counters similar to those that Virginia Tech constructed and installed for the Belle experiment at KEK), metal-loaded scintillation technology (for possible use in the Daya Bay reactor neutrino experiment in China), and new types of detectors for future double beta-decay and dark matter experiments. CNAP has an International Science Advisory Board consisting of highly reputable scientists in leadership positions in Canada, France, Japan, and the US, which will foster our international activities in a fundamentally effective way. CNAP is thus structured to expose all of our members to an effervescent mix of ideas, projects and future leaders throughout the world community of neutrino and astroparticle physics.

The following examples illustrate the current international collaborative activity of CNAP faculty. The Borexino Experiment at Gran Sasso Italy, consists of 100 scientists from France, Germany, Italy, Poland, Russia and the US. Raghavan was an original founder of this project and continues to be a member. Vogelaar is a senior member for 15 years. The CNAP members contributed to theory, research on ultra-high purity of materials, engineering design, data collection and analysis as well as forthcoming plans for high sensitivity experiments on double beta decay. The LENS experiment (also founded by Raghavan) is a US-Russia collaboration in which several CNAP members and institutions (UNC, NCSU and VT) are collaborating. Kate Scholberg and Chris Walter are longstanding collaborators in the SuperKamiokande experiment in Japan, the largest detector in the world based on water Cerenkov technology. They are also members of the T2K long-baseline neutrino experiment that will turn on in the near future. Howell is a member of the Kamland experiment, based on scintillation technology. The Daya Bay Reactor Neutrino Experiment is a collaboration of scientists from China, Taiwan, Hong Kong, the US, Russia, and the Czech Republic. It will begin taking data in 2009 at the Daya Bay nuclear power plant in Guangdong, China. Link and Piilonen are developing calibration systems and high voltage components for Daya Bay's muon veto detector. Huber is the chairman of the physics and performance evaluation group and member of the steering committee of the International Design Study for a Neutrino Factory (IDS). The IDS aims at providing a conceptual design report by 2012. The IDS has collaborators from all three major regions and India.

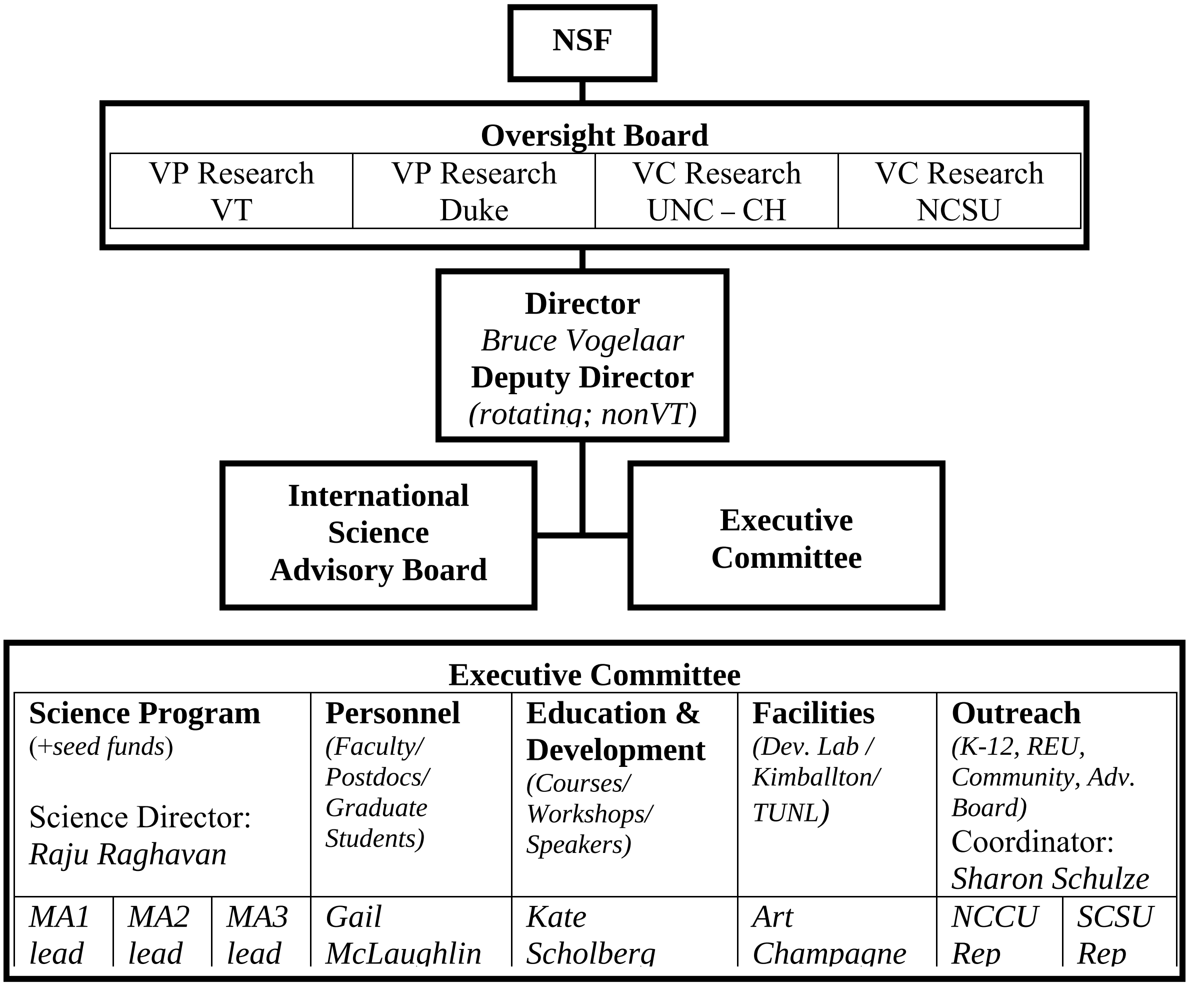
Seed Funding and Emerging Areas

New developments in neutrino and particle astrophysics can gain prominence very rapidly. CNAP's management plan is designed to be able to allocate resources on a short timescale in response to emerging scientific opportunities.

The main avenue for allocation of funds towards new endeavors will be via the Science Program coordinators, who may put forward proposals for new science objectives requiring new or diverted funds. New objectives based on emerging science should be put forward by the Science Director in consultation with the MA leads. Such proposals will be presented at the Executive Committee's quarterly “open science session” meetings. Specific activities related to these new proposed objectives within the purview of the personnel, education and development, facilities or outreach managers' responsibilities may also be presented. The Executive Committee will review the proposed objectives and activities using guidelines based on NSF scientific merit and broader impacts criteria. If a new science objective is approved by the Executive Committee, the Executive Committee will define the scope of the new related activities and determine the resources required. The Executive Committee recommendations will be incorporated into the Implementation Plan, for review by the International Scientific Advisory Board. After ISAB approval, the Director will authorize the new objective-driven budget.

For initiatives related to new science objectives that require faster action than can be achieved by the process described above, funds set aside in advance as seed funds may be used. The Executive Committee will allocate the amount of reserved seed funds annually in the Implementation Plan. The seed funds will be under the Science Director's oversight and can be used with agreement of the relevant MA lead(s).

Management
Center for Neutrino and Astroparticle Physics (CNAP) Organizational Chart



Annual Action	NSF	Director	Executive Committee	Advisory Board	Oversight Board
Fund PFC					
Define and Prioritize Science Goals					
Optimize Allocation of Funds					
Implementation Plan Review					
Authorize					
Manage and Track Progress					
Allocate Seed Funds					
Evaluate					
Report					
Review					

The management team is composed of the following components with the defined roles.

Oversight Board. Each partner institution provides formal oversight for the Center, consistent with established policies, through their respective Vice Presidents, Provosts, or Chancellors for Research. Individually and as a group, they will formalize their relationships using appropriate Memoranda of Understanding (MOUs), as they are developed, reviewed and authorized. The MOUs include this document as well as annual budgets and justifications from the Implementation Plan. In cases of conflicting policies, those of Virginia Tech, as the lead institution, will take precedence. Convening at least once each quarter in the first year, and semiannually thereafter, this group will interact directly with the Center Director to review the Center's administrative polices and Implementation Plan, assess progress toward stated goals, and provide input to the Center's annual reports to NSF.

Director *Bruce Vogelaar* The Director is responsible for the executive leadership of the overall Center and is the conduit for direct contact with the NSF on Center matters. The Director ensures that the goals of the Center are pursued in accordance with this document, institutional MOUs and University policies, and resolves issues brought forward by the Executive Committee. The Director's approval allows final disbursement of Center resources and in matters of contention, his judgment supersedes that of the Executive Committee. The Director is expected to be responsive to NSF requests, make effective use of the International Science Advisory Board, ensure timely generation of reports, and interact closely with the Oversight Board. The Director's office will be supported by a full time administrative and fiscal manager who will also support the Executive Committee. A change in the directorship would require the concurrence of the four institutions, the PIs, and NSF.

Deputy Director *Art Champagne (first year)* The Deputy Director works closely with the Director and chairs the Executive Committee meetings. In the absence of the Director, the Deputy Director fills that role. The position is for one year, renewable, and is elected by the Executive Committee with candidates drawn from Duke, NCSU or UNC. The Deputy Director helps maintain effective coherence and communication between the four institutions which might otherwise arise due to their physical separation.

International Science Advisory Board *Baha Balantekin (U. Wis/Madison), Arthur B. McDonald (Queens U., CA), Boris Kayser (FNAL), Rabindranath Mohapatra (U. Maryland), Hitoshi Murayama (Inst.Math & Phys of the Universe/JP), Henry Sobel (UCI), Atsuto Suzuki (KEK- JP), Sylvaine Turcke-Schieze (CEA-Saclay/Fr), John Wilkerson (U. Washington), Stan Wojcicki (Stanford), Lincoln Wolfenstein (CMU)* The ISAB is composed of recognized leaders in the field who are committed to helping the Center to function in the best interests of science and accomplish its broader mission in outreach. They also interact closely with the Science Director to help define science priorities, review and provide feedback to the annual implementation plan generated by the Executive Committee, and provide annual reports to the Director summarizing their concerns and suggestions. They meet as a group annually, and are provided quarterly progress reports generated by the Director and Science Director. Changes in membership, if required, will be determined by the grant PIs.

Executive Committee The Executive Committee defines, organizes, oversees and tracks internal operations of the Center. Membership includes all the co-PIs and others appointed by the Director (in consultation with the co-PIs and Center membership at large) to ensure representation from the 4+2 institutions, with individuals undertaking center-wide responsibilities. Meetings are on a monthly basis, and are chaired by the Deputy Director. It is supported by the administrative and fiscal manager from the Director's office, advice from the ISAB, and reports to the Director. The Director is an ex-officio member, who edits and distributes minutes from the meetings. The Executive Committee develops an annual Implementation Plan (grounded in identified science priorities and including allocation of Center resources consistent with established MOUs). In cases where consensus is not achieved in generating the implementation plan, a 2/3 majority will prevail at this stage. This plan is then reviewed by the ISAB, the Director, and the Institute Oversight members. Final approval (and adjustments if needed, with advice from the ISAB) is by the center Director. The following subsets of the Executive Committee manage center-wide activities. Center activities not specifically described herein are assigned to the Director's office.

Science Program *Raju Raghavan (Science Director), MA(1-3) leads (Jon Engel, Reyco Henning, Jon Link)* This group, guided by the Science Director, is responsible for developing and articulating science priorities for the Center. The MA lead positions are designed to promote the careers of young faculty, freeing them to focus more on science and less on the administration of a comprehensive center. At every third Executive Board meeting, a supplementary open science session is held, led by this group, where all Center members are invited and encouraged to participate. This group meets annually with the ISAB to help set CNAP science priorities and propose possible evolution of the MA definitions themselves (which would involve the full Executive Committee and Director to implement). The center *seed* funds, agreed on in the Implementation Plan, are managed and tracked by the Science Director with input from the MA leads.

Personnel *Gail McLaughlin* This person manages the Implementation Plan components addressing visiting faculty, postdocs, and graduate students, to optimize the Center's ability to successfully achieve its science program. Responsibilities include approving Center position advertisements, tracking recruitment success, evaluating whether these funds are in fact being appropriately used, and providing a direct contact into the Center management structure for academic personnel issues.

Education and Development *Kate Scholberg* This person manages the Implementation Plan components for courses, workshops and speakers, to optimize the Center's ability to successfully achieve its science program. Responsibilities include reviewing and approving themes, syllabi, and speaker invitations, and evaluating the success of these programs.

Facilities *Art Champagne* This person manages the Implementation Plan components for facilities, equipment, and related staff, and its allocation to optimize the Center's ability to successfully achieve its programs. Responsibilities include managing the staff and ensuring resources are judiciously procured or fabricated to enable the 'rapid concept-to-prototype' capability envisioned for the center.

Outreach *Sharon Schulze, NCCU rep, SCSU rep* This group, led by Schulze, manages the Implementation Plan components addressing the Center's outreach programs. They are supported by a staff member and an Outreach Advisory Board. They manage partnerships between the Center and established outreach programs, and the engagement of Center members.

Self Evaluation Ensuring a successful *frontier* center relies on establishing progressive metrics and a credible method of self-correction. In addition to feedback from our ISAB and the Oversight Board, there are several internal methods we will employ to track progress. The Center will document the career development of students which have come through our programs; the Director will conduct exit-interviews with graduate students and postdocs; the Science Director will meet with leaders in the field, and of major experimental programs, to determine if our programs are contributing in effective ways; and our outreach program will use well established evaluation procedures. The information thus gathered will be presented to the Executive Committee during its monthly meetings for consideration in making course corrections.

Intellectual Property All papers, presentations, and reports by Center members which are enabled, even in part, by Center resources will acknowledge the Center and the NSF. Those which arise directly from Center activities, even as a joint undertaking with an external collaboration, will be subjected to a *prior* internal review (by a subset of the Executive Committee) to ensure fair inclusion of Center members. Technologies which are developed using Center resources and are submitted for patent consideration will follow local institution rules. Where there are differences between institutions, those of Virginia Tech will prevail.

Modifications Modification to this management plan requires concurrence in writing by all the PIs on the Center grant and notification of the cognizant NSF program manager, and changes to standing MOUs require approval by the affected Oversight Board members. Additional Center bylaws (which do not counter the intent or specifics of this management plan) can be adopted or modified by the Executive Committee at any of their regular meetings by an absolute 2/3 majority.

Institutional and Other Commitments

Virginia Tech: Both the Virginia Tech physics department and upper administration have a proven commitment to neutrino science. This began a decade ago with the hire of a senior faculty member in the Borexino solar neutrino experiment. In the past three years, this effort has been strengthened with three new hires – a senior and junior neutrino experimentalist and a junior neutrino phenomenologist. The junior positions are both tenure-track. The associated start-up packages for these three hires total ~ $1.3 million, and about 1000 square feet of dedicated lab space is included.

The university also provided the funding necessary to establish the Kimballton Underground Research Facility (KURF). The administration recognizes the Center's programmatic need for a partner facility at the surface comparable to KURF (3600 sq. ft). They are working aggressively to locate space and construction funds to provide such a building.

Two additional in-field tenure-track faculty positions, the use of the Skelton House, limited teaching relief, and part of a Physics department staff support person are all offered, should the Center be funded.

University of North Carolina at Chapel Hill: The nuclear physics group at UNC-CH has identified neutrino physics as its future area of emphasis and this has been endorsed by an external review panel, the Department of Physics and Astronomy and the College of Arts and Sciences. To begin the transition process, one junior-faculty member in experimental neutrino physics has been hired (with a startup package of $300K). In addition, the Department has requested permission to offer a senior appointment to another identified target of opportunity. The offer (including a substantial startup package and support for activities that would complement the goals of CNAP) is in preparation. Finally, the Department will provide space for center activities, including the development laboratory.

North Carolina State University: NCSU's neutrino research program has grown steadily over the past decade, beginning with participation in the KamLAND experiment. An experimental hire in 2000 (A. R. Young) and a theoretical hire in 2001 (G. McLaughlin) established a long-term commitment to neutrino physics. Due to a state-funded facilities upgrade in the summer of 2007, the NCSU experimental nuclear group now has over 1800 sq. ft. of new laboratory space, including detector development, laser, and large scale cryogenics equipment. Clean-room space, chemistry labs, neutron activation analysis irradiation and assay facilities, and several computational clusters are available for neutrino research. Critical access for semiconductor detector development is available in materials development and characterization centers subsidized by NCSU. The Department of Physics is currently exploring expanding neutrino research at NCSU through joint positions at ORNL.

Duke University: Duke has made two neutrino faculty hires in the past four years, with startup support and laboratory space for work on Super-K and T2K. The university has also agreed to provide $120K of matching funds for the proposed CLEAR experiment. Duke is the host of TUNL, the Triangle Universities Nuclear Laboratory, which offers extensive laboratory resources, including a broad range of technical expertise. The researchers and staff at TUNL have substantial experience with involving undergraduate students in experimental physics research and have run an REU program for eight years. In addition, TUNL has invested in a portable laboratory to be deployed in the Kimballton mine for double beta decay measurements.

Summary Table of Requested NSF Support (k$)							
Activity	Year One	Year Two	Year Three	Year Four	Year Five	Five Year Total	%
Major Activity 1 Neutrino Phenomenology	458	570	552	610	670	2860	17.2
Major Activity 2 Neutrino Technology	681	527	680	679	687	3254	19.6
Major Activity 3 Neutrino Frontier	356	476	615	623	618	2688	16.2
Shared Facilities*	666	512	444	460	476	2558	15.4
Seed Funding and Emerging Areas	100	103	107	111	114	535	3.2
Education and Human Resources	269	279	288	298	309	1443	8.7
Outreach	239	445	327	338	350	1699	10.2
Administration**	331	297	308	318	330	1584	9.5
Total	3100	3209	3321	3437	3554	16621	100.0

* includes personnel at shared facilities
** includes center administrator, outreach coordinator, publications, advisory board related costs

References

[Aba00] A. Abashian, *et al.*, “The K_L/μ detector subsystem for the BELLE experiment at the KEK B-factory,” Nucl. Instum. Meth. A449, 112 (2000).

[Aba01] K. Abazajian, G. M. Fuller and M. Patel, "Sterile neutrino hot, warm, and cold dark matter," Phys. Rev. D **64**, 023501 (2001).

[Ach95] B. Achkar, *et al.,* “Search for neutrino oscillations at 15, 40, and 95 meters from a nuclear power reactor at Bugey,” Nucl. Phys. B 434, 1995.

[Agu01] A. Aguilar *et al.,* “Evidence for neutrino oscillations from the observation of $\bar{\nu}_e$ appearance in a $\bar{\nu}_\mu$ beam,” Phys. Rev. D **64** 112007, 2001.

[Agu06] A.A. Aguilar-Arevalo *et al.*, “Bringing the SciBar Detector to the Booster neutrino beam,” arXiv:0601022, 2006.

[Agu07] The MiniBooNE Collaboration [A. A. Aguilar-Arevalo et al.], “A Search for Electron Neutrino Appearance at the Δm2 ~ 1 eV2 Scale,” Phys. Rev. Lett. 98, 231801 (2007).

[Ama07] P. Amanik and G. C. McLaughlin, “Neutron Form Factor from Neutrino-Nucleus Coherent Scattering”, arXiv:0707.4191 [hep-ph], 2007.

[Ang07] J. Angle *et al.*, “First Results from the XENON10 Dark Matter Experiment at the Gran Sasso National Laboratory,” arXiv:0706.0039 [astro-ph], 2007.

[Ant04] Antonioli, Pietro and others, "SNEWS: The SuperNova Early Warning System", New J. Phys. **6**(2004)114. [astro-ph/0406214]

[APS] “The Neutrino Matrix – The DNP/DPF/DAP/DPB Joint Study on the Future of Neutrino Physics”, available at http://www7.nationalacademies.org/bpa/EPP2010_APS_Neutrino_Study.pdf

[APS07] *APS Board calls for doubling number of physics bachelors*; APS News; August/September 2007; Volume 16 No. 8

[Ard06] Double Chooz Collaboration (F. Ardellier *et al.*), “Double Chooz: A Search for the neutrino mixing angle θ_{13},” arXiv:hep-ex/0606025.

[Arp08] C. Arpesella *et al.*, “First real time detection of ^{7}Be solar neutrinos by Borexino,” Phys. Lett. B 658, 101 2008.

[Avi03] F. T. Avignone and Yu. V. Efremenko, “Neutrino nucleus cross-section measurements at intense, pulsed spallation sources,” J. Phys. G **29**, 2615, 2003.

[Avi07] See, e.g., Double Beta Decay, Majorana Neutrinos, and Neutrino Mass Frank T. Avignone III, Steven R. Elliott and Jonathan Engel, arXiv:0707.3761 (July 2007).

[Bar05] Effective operators within the *ab initio* no-core shell model, Ionel Stetcu and Bruce R. Barrett, Phys. Rev. C 71, 044325 (2005).

[Bar05] V. Barger, P. Huber, D. Marfatia, “Solar mass-varying neutrino oscillations”, Phys. Rev. Lett. **95**, 211802 (2005).

[Bar07a] V. Barger *et al*., “Report of the US long baseline neutrino experiment study,” arXiv:0705.4396, 2007.

[Bar07b] V. Barger, P. Huber, D. Marfatia, W. Winter, “Upgraded experiments with super neutrino beams: Reach versus Exposure,” Phys. Rev. D **76** 031301, 2007, arXiv:hep-ph/0610301.

[Bar07c] V. Barger, P. Huber, D. Marfatia, W. Winter, “Which long-baseline neutrino experiments are preferable?,” Phys. Rev. D **76** 053005, 2007.

[Bar07d] J. Barranco, O. Miranda and T. I. Rashba, “Low energy neutrino experiments to physics beyond the Standard Model", Phys. Rev. D **76**, 073008, 2007.

[Bel91] G. Bellini, M. Campanella, D. Giugni and R. S. Raghavan, "Borexino @ GranSasso," INFN Proposal, 1991 (Unpublished)

[Ber02] Z. Berezhiani, R. S. Raghavan and A. Rossi, "Probing non-standard couplings of neutrinos at the Borexino detector," Nucl. Phys. B 638, 62 (2002), [arXiv:hep-ph/0111138].

[Bog07] S. K. Bogner, R. J. Furnstahl and R. J. Perry, ``Three-Body Forces Produced by a Similarity Renormalization Group Transformation in a Simple Model," arXiv:0708.1602 (August 2007), S. K. Bogner, R. J. Furnstahl and R. J. Perry, ``Similarity Renormalization Group for Nucleon-Nucleon Interactions," nucl-th/0611045 (November 2006).

[Bor07] The Borexino Collaboration, "First Real Time Detection of ^{7}Be Solar Neutrinos by Borexino", arXiv:0708.2251v1[astro-ph]

[Bou06] M. G. Boulay and A. Hime, Astroparticle Physics **25**, 179 (2006).

[Bru06] S.W. Bruenn, C.J. Dirk, A. Mezzacappa, J.C. Hayes, J.M. Blondin, W.R. Hix, O.E.B. Messer, Modeling core collapse supernovae in 2 and 3 dimensions with spectral neutrino transport, J.Phys.Conf.Ser.46:393-402,2006. Adam Burrows , Luc Dessart, Christian Ott, Jeremiah Murphy , A new mechanism for core-collapse supernova explosions, Astrophys.J.640:878-890,2006, L. Scheck, H.-Th. Janka, T. Foglizzo, K. Kifonidis, Multidimensional supernova simulations with approximative neutrino transport. II. Convection and the advective-acoustic cycle in the supernova core, arXiv:0704.3001, 2007.

[CO2] see similar items at http://www.science-house.org/CO2/meetsci/focus/index.html

[Coc07] A.G. Cocco, G. Mangano, M. Messina, "Probing Low Energy Neutrino Backgrounds with Neutrino Capture on Beta Decaying Nuclei," arXiv:hep-ph/0703075.

[Coh87] S.G. Cohen, D.E. Murnick, and R.S. Raghavan, "Bound state β-decay and kinematic search for neutrino mass," Hyp. Interactions 33, 1 (1987).

[Day] "Daya Bay Reactor Neutrino Experiment," information available at http://dayawane.ihep.ac.cn/

[Deep] Deep Science – A Deep Underground Science and Engineering Initiative, available at http://www.jinaweb.org/dusel/docs/DUSEL_S1_Deep_Science_101706.pdf

[DNP] "Nuclear Science and the New Standard Model: Fundamental Symmetries and Neutrinos in the Next Decade", available at http://dnp.nscl.msu.edu/nplinks/2007lrpprep/2007_lrpwp_symmetries_neutrinos.pdf

[Dua07] Huaiyu Duan, George M. Fuller, J. Carlson, Yong-Qian Zhong , Neutrino Mass Hierarchy and Stepwise Spectral Swapping of Supernova Neutrino Flavors, arXiv:0707.0290 (2007), Georg G. Raffelt, Alexei Yu. Smirnov, Self-induced spectral splits in supernova neutrino fluxes, arXiv:0705.1830 (2007),Gianluigi L. Fogli, Eligio Lisi, Antonio Marrone , Alessandro Mirizzi, Collective neutrino flavor transitions in supernovae and the role of trajectory averaging, arXiv:0707.1998 (2007)

[Eji00] H. Ejiri, J. Engel, R. Hazama, P. Krastev, N. Kudomi, and R.G.H. Robertson, "Spectroscopy of Double-Beta and Inverse-Beta Decays from ^{100}Mo for

Neutrinos," Phys. Rev. Lett. 85, 2917 (2000).
[Eng88] J. Engel, P. Vogel, and M.R. Zimbauer, "Nuclear structure effects in double-beta decay," Phys. Rev. C37, 731 (1988).
[Epp06] Committee on Elementary Particle Physics in the 21st Century, National Research Council, The National Academic Press, 2006.
[Fet03] J. Fetter, G.C. McLaughlin, A.B. Balantekin, G.M. Fuller, "Active-sterile neutrino conversion: consequences for the r-process and supernova neutrino detection," Astropart. Phys. 18, 433 (2003).
[Fog02] G. L. Fogli, E. Lisi, A. Mirizzi and D. Montanino, "Revisiting nonstandard interaction effects on supernova neutrino flavor oscillations," Phys. Rev. D66, 013009 (2002), [arXiv:hep-ph/0202269].
[Fri04] A. Friedland, C. Lunardini and C. Pena-Garay, "Solar neutrinos as probes of neutrino - matter interactions," Phys. Lett. B594, 347 (2004), [arXiv:hep-ph/0402266]
[Fri06] A. Friedland and C. Lunardini, "Two modes of searching for new neutrino interactions at MINOS," Phys. Rev. D74, 033012 (2006) [arXiv:hep-ph/0606101]
[Fro06] C.Frohlich *et al*., "Neutrino induced nucleosynthesis of A > 64 nuclei: The nu p process," Phys. Rev. Lett. 96, 142502 (2006).
[Fuk01] Super-Kamiokande Collaboration [S. Fukuda *et al.*], "Constraints on neutrino oscillations using 1258 days of Super-Kamiokande solar neutrino data," Phys. Rev. Lett. **86**, 5656 (2001).
[Ful95] G.M.Fuller and B.S.Meyer, `Neutrino capture and supernova nucleosynthesis," Astrophys. J. 453, 792 (1995)
[Ful99] G.M. Fuller, W.C. Haxton, and G.C. McLaughlin, "Prospects for detecting supernova neutrino flavor oscillations," Phys. Rev. D59, 085005 (1999).
[Gar05] G.T. Garvey *et al.*, "Measuring active-sterile neutrino oscillations with a stopped pion neutrino source," Phys. Rev. D 72, 092001, 2005.
[Gri06] C. Grieb and R. S. Raghavan, "Probing the temperature profile of energy generation in the Sun", Phys. Rev. Letters, 98,141102-1 (2007).
[Gri07] C. Grieb, J. Link and R. S. Raghavan, "Probing active to sterile neutrino oscillations in the LENS detector," Phys. Rev. D75, 093006 (2007) [arXiv:hep-ph/0611178].
[Guo07] Daya Bay Collaboration (X. Guo *et al.*), "A Precision measurement of the neutrino mixing angle θ_{13} using reactor antineutrinos at Daya Bay," arXiv:hep-ex/0701029.
[Har07] J. A. Harvey, C. T. Hill, R. J. Hill, "Anomaly mediated neutrino-photon interactions at finite baryon density," Phys. Rev. Lett. 99, 261601, 2007.
[Hen] NSF PHY- 0705014, R. Henning, PI, "DUSEL R&D at the Kimballton Underground Facility (ICP-MS confirmation, material assay, and radon reduction)", see http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0705014
[Hon06] M. Honda, N. Okamura, and T. Takeuchi, "Matter Effects on Neutrino Oscillations from the Violation of Universality in Neutrino Neutral Current Interactions" VPI-IPPAP-06-02 [hep-ph/0603268]
[Hon07] M. Honda, Y. Kao, N. Okamura, A. Pronin and T. Takeuchi "Constraints on New
[Hor03] C. J. Horowitz, K. J. Coakley, and D. N. McKinsey, "Supernova observation via

neutrino-nucleus elastic scattering in the CLEAN detector", Phys. Rev. D 68, 23005, 2003.

[Hub02] P. Huber, T. Schwetz, J.W.F. Valle, Phys.Rev.Lett.88:101804,2002; P. Huber, T. Schwetz, J.W.F. Valle, Phys.Rev.D66:013006,2002.

[Hub03] P. Huber, M. Lindner, T. Schwetz, W. Winter, "Reactor neutrino experiments compared to superbeams," Nucl. Phys. B **665** 487-519, 2003.

[Hub03a] P. Huber, M. Lindner, M. Rolinec, T. Schwetz, and W. Winter, "Prospects of accelerator and reactor neutrino oscillation experiments for the coming ten years," Phys. Rev. D70, 073014 (2004).

[Hub03b] P. Huber, M. Lindner, T. Schwetz, W. Winter, "Reactor neutrino experiments compared to superbeams," Nucl. Phys. B665, 487 (2003).

[Hub04] P. Huber, M. Lindner, M. Rolinec, T. Schwetz, W. Winter, "Prospects of accelerator and reactor neutrino oscillation experiments for the coming ten years," Phys. Rev. D **70** 073014, 2004.

[Hub05] P. Huber, M. Lindner, W. Winter, "Simulation of long-baseline neutrino oscillation experiments with GLoBES (General Long Baseline Experiment Simulator)," Comput. Phys. Commun. **167** 195, 2005, arXiv:hep-ph/0407333.

[Hub07] P. Huber, J. Kopp, M. Lindner, M. Rolinec, W. Winter, "New features in the simulation of neutrino oscillation experiments with GLoBES 3.0: General Long Baseline Experiment Simulator," Comput. Phys. Commun. **177** 432-438, 2007, arXiv:.hep-ph/0701187.

[Hub07a] P. Huber *et al.*, arXiv07112950.

[Hyp02] Hyper-K – "Hyper-Kamiokande", eg. T. Nakaya, presented at the XXth Int. Conf. on Neutrino Physics and Astrophysics, Munich, May 2002.

[ICS] **"**Institute for Connecting Science Research to the Classroom (ICSRC) at Virginia Tech," information available at http://ww.icsrc.org

[Ino07] INO: "The Indian Neutrino Observatory," http://www.imsc.res.in/~ino

[ISS07] ISS Physics Working Group, "Physics at a future Neutrino Factory and super-beam facility," arXiv:0710.4947, 2007.

[Ito01] T2K Collaboration (Y. Itow *et al.*), "The JHF-Kamioka neutrino project," arXiv:hep-ex/0106019.

[KAM03] The KAMLAND Collaboraiton, "First Results from KAMLAND: Evidence for Reactor Anti-Neutrino Disappearance", Phys. Rev. Lett. **90**, 021802 (2003)

[Kap04] D. B. Kaplan, A. E. Nelson and N. Weiner, "Neutrino oscillations as a probe of dark energy," Phys. Rev. Lett. **93**, 091801 (2004).

[Kne06] James P. Kneller , Gail C. McLaughlin, "Monte Carlo neutrino oscillations", Phys.Rev.D73:056003,(2006).

[Kne07] James Kneller, Gail C. McLaughlin, Justin Brockman, Oscillation Effects and Time Variation of the Supernova Neutrino Signal, arXiv:0705.3835 , 2007, Basudeb Dasgupta, Amol Dighe, Phase effects in neutrino conversions during a supernova shock wave, Phys.Rev.D75:093002, 2007.

[Kne07a] James Kneller, Gail C. McLaughlin, Justin Brockman, Oscillation Effects and Time Variation of the Supernova Neutrino Signal, arXiv:0705.3835 , 2007, Basudeb Dasgupta, Amol Dighe, Phase effects in neutrino conversions during a supernova shock wave, Phys.Rev.D75:093002, 2007., Huaiyu Duan, George M. Fuller, J. Carlson, Yong-Qian Zhong , Neutrino Mass Hierarchy and Stepwise

Spectral Swapping of Supernova Neutrino Flavors, arXiv:0707.0290 (2007), Georg G. Raffelt, Alexei Yu. Smirnov, Self-induced spectral splits in supernova neutrino fluxes, arXiv:0705.1830 (2007),Gianluigi L. Fogli, Eligio Lisi, Antonio Marrone , Alessandro Mirizzi, Collective neutrino flavor transitions in supernovae and the role of trajectory averaging, arXiv:0707.1998 (2007)

[Kop07] J. Kopp, M. Lindner, T. Ota and J. Sato, "Non-standard neutrino interactions in reactor and superbeam experiments," arXiv:0708.0152 [hep-ph].

[KURF] The Kimballton Underground Research Facility (KURF), information available at http://www.kimballton.org/

[Lag07] LAGUNA: "Large Apparatus for Grand Unification and Neutrino Astrophysics," design study document available at: http://lartpc-docdb.fnal.gov/0002/000256/003/LAGUNA-FP7_PartB.pdf

[Lan96] K.Langanke, P.Vogel and E.Kolbe, ``Signal for supernova ν_μ and ν_τ neutrinos in water Cherenkov detectors," Phys. Rev. Lett. 76, 2629 (1996)

[Lee06] I-Y. Lee, Lawrence Berkeley National Laboratory, private communication.

[LEN] The Low Energy Neutrino Spectroscopy (LENS) Experiment, information available at http://www.phys.vt.edu/dusel-bin/lens/fs.pl/pub/homepage

[Loi03a] W. Loinaz, N. Okamura, T. Takeuchi, and L. C. R. Wijewardhana "The NuTeV Anomaly, Neutrino Mixing, and a Heavy Higgs Boson" Phys. Rev. D67 (2003) 073012 [hep-0210193]

[Loi03b] W. Loinaz, N. Okamura, S. Rayyan, T. Takeuchi, and L. C. R. Wijewardhana "Quark-Lepton Unification and Lepton Flavor Non-Conservation from a TeV-scale Seesaw Neutrino Mass Texture" Phys. Rev. D68 (2003) 073001 [hep-ph/0304004]

[Loi04] W. Loinaz, N. Okamura, S. Rayyan, T. Takeuchi, and L. C. R. Wijewardhana "The NuTeV Anomaly, Lepton Universality, and Non-Universal Neutrino-Gauge Couplings" Phys. Rev. D70 (2004) 113004 [hep-ph/0403306]

[Maj] The Majorana experiment, information available at http://majorana.npl.washington.edu/index.php

[McK00] D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. **118**, 153 (2000); D. N. McKinsey and K. Coakley, Astroparticle Physics **22**, 355 (2005); K. J. Coakley and D. N. McKinsey, Nucl. Inst. and Meth. A **522**, 504 (2004).

[McL96] G.~C.~McLaughlin, G.~M.~Fuller and J.~R.~Wilson, `The Influence of Nuclear Composition on the Electron Fraction in the Post-Core-Bounce Supernova Environment," Astrophys. J. 472, 440 (1996).

[Mcl99] G. C. McLaughlin, J. M. Fetter, A. B. Balantekin and G. M. Fuller, "An Active-Sterile Neutrino Transformation Solution for r-Process Nucleosynthesis," Phys. Rev. C59, 2873 (1999) [arXiv:astro-ph/9902106.

[Min07] The MiniBooNE Collaboration, "Search for Electron Neutrino Appearance at the $\Delta m^2 \sim 1$ eV^2 ", Phys. Rev. Lett. **98**, 231801 (2007)

[NEP] New England Particle Physics Student Retreat, http://physics.bu.edu/NEPPSR

[Nit04] K. Nitta *et al.*, "The K2K SciBar Detector," Nucl. Instrum. Meth. A 535, 147, 2004.

[Nov05] NOvA Collaboration (D.S. Ayres *et al.*), "NOvA: Proposal to build a 30 kiloton off-axis detector to study $\nu_\mu \rightarrow \nu_e$ oscillations in the NuMI beamline," arXiv:hep-ex/0503053.

[NSA02] "2002 NSAC Long Range Plan: Opportunities in Nuclear Science, A Long-Range Plan for the Next Decade", available at http://www.sc.doe.gov/np/nsac/docs/LRP_5547_FINAL.pdf

[Nus05] "Recommendations to the Department of Energy and the National Science Foundation on a United States Program in Neutrino-less Double Beta Decay", Neutrino Science Assessment Group, 2005 (http://www.er.doe.gov/np/nsac/docs/NuSAG_report_final_version.pdf)

[NWP07] "Nuclear Science and the New Standard Model: Fundamental Symmetries and Neutrinos in the Next Decade", available at http://dnp.nscl.msu.edu/nplinks/2007lrpprep/2007_lrpwp_symmetries_neutrinos.pdf

[Obe00] Y.S. Obeng, R.L Opila and R.S. Raghavan "Process for removing alkali metals from solvents used in the manufacture of semiconductor wafers," U.S. Patent 6,133,158, 2000.

[Ots02] K.Otsuki, G.J.Mathews and T.Kajino, ``Cosmochronology and the universality of the r-process abundances," arXiv:astro-ph/0207596.

[Oya06] K2K: arXiv:0606032, 2006.

[Rag 88b] "Design Concepts for Borex", R. S. Raghavan et al, AT&T Bell Labs Report (ATT-BX-88-01)

[Rag02] R. S. Raghavan, "Detecting a nuclear fission reactor at the center of the earth," hep-ex/0208038.

[Rag04] R.S. Raghavan, "New methods for high metal content loaded liquid scintillators," U.S. Patent No. 6809210 (2004)

[Rag05] R.S. Raghavan, "Hyper Scintillation Detector (HSD): Next Generation Detector for keV to GeV Particle Physics, Astrophysics, and Geophysics," http://www.phys.hawaii.edu/~sdye/raghavan.html

[Rag06] R. S. Raghavan, Submitted to Phys. Lett. B, hep-ph/0601079, 2006.

[Rag06] "Recoilless Resonant Capture of Antineutrinos from Tritium Decay" Phys. Letters (submitted) hep-ph/0601079 (2006).

[Rag76] R.S. Raghavan, "Inverse β Decay of ^{115}In $\rightarrow$ ^{115}Sn*: A New Possibility for Detecting Solar Neutrinos from the Proton-Proton Reacton," Phys. Rev. Lett 37, 259 (1976).

[Rag86a] R.S. Raghavan, "Inverse β^- decay of ^{40}Ar: A new approach for observing MeV neutrinos from laboratory and astrophysical sources," Phys. Rev. D34, 2088 (1986).

[Rag86b] R.S. Raghavan, S. Pakvasa, B.A. Brown, "New Tools for Solving the Solar-Neutrino Problem," Phys. Rev. Lett. 57, 1801 (1986).

[Rag88] R.S. Raghavan and S. Pakvasa, "Probing the nature of the neutrino: The boron solar-neutrino experiment," Phys. Rev. D37, 849 (1988).

[Rag93] R.S. Raghavan, P. Raghavan, and T. Kovacs, "Line-spectroscopic approach to study of solar neutrinos by cryogenic bolometry of charged and neutral current reactions on ^{7}Li", Phys. Rev. Lett. 71, 4295 (1993).

[Rag94] R.S. Raghavan, "New approach to the search for neutrinoless double beta decay," Phys. Rev. Lett. 72, 1411 (1994).

[Rag98] R.S. Raghavan, S. Schoenert, S. Enomoto, J. Shirai, F. Suekane, and A. Suzuki, "Measuring the Global Radioactivity in the Earth by Multidetector Antineutrino

Spectroscopy," Phys. Rev. Lett. 80, 635 (1998); R. S. Raghavan, "Neutrinos from the Earth," Invited talk, Proc. Neutrino 2006, Sante Fe, NM, 2006.

[Ray07] S. Rayyan, Ph.D. Thesis

[Sch03] M.H. Shaevitz and J.M. Link, "Using Reactors to Measure θ_{13}," hep-ex/0306031

[Sch06] K. Scholberg, "Prospects for measuring coherent neutrino nucleus elastic scattering at a stopped-pion neutrino source," Phys. Rev. D **73**, 033005, 2006.

[Sch06a] K. Scholberg, "Supernova Neutrino Detection", Proceedings of Neutrino 2006, astro-ph/0701081.

[Sch07] K. Scholberg, "Neutrinos at the Spallation Neutron Source," AIP Conf. Proc. 967, 72, 2007.

[Sch82] J. Schechter and J.W.F.Valle, Phys. Rev. D **25**, 2951 (1982)

[Sci] The Science House at NCSU, see http://www.science-house.org

[Sci07] http://www.scidac.gov/physics/unedf.html.

[Scia] The Science House K-12 Outreach program for the NSF Science and Technology Center for Environmentally Responsible Solvents and Processes, see http://www.science-house.org/CO2/activities/index.html for further information

[Scib] The Science House K-12 Outreach program for the NSF Rice Blast Genomics Project, see http://www.science-house.org/fungal/index.html for further information

[Sel06] U. Seljak, A. Makarov, P. McDonald and H. Trac, "Can sterile neutrinos be the dark matter?" Phys. Rev. Lett. **97**, 191303 (2006).

[Sha] "Share the Skies: International Student Telescope Network," information available at http://www.sharetheskies.org

[Sno04] SNO Collaboration [S. N. Ahmed *et al.*], "Measurement of the total active B-8 solar neutrino flux at the Sudbury Neutrino Observatory with enhanced neutral current sensitivity," Phys. Rev. Lett. **92**, 181301 (2004).

[Str04] L. E. Strigari *et al.*, "The Supernova relic neutrino backgrounds at KamLAND and Super-Kamiokande," JCAP 0403, 7, 2004.

[SuK98] The Super-Kamiokande Collaboration, "Evidence for oscillation of atmospheric neutrinos",Phys. Rev. Lett. **81,** 1562 (1998)

[SuK99] The Super-Kamiokande Collaboration, "Measurement of the Solar Neutrino Energy Spectrum Using Neutrino-Electron Scattering", Phys. Rev. Lett. **82**, 2430 (1999)

[T2k] The T2K (From Tokai to Kamioka) Experiment, information available at http://jnusrv01.kek.jp/public/t2k/

[Uno05] UNO: "Underground Nucleon Decay and Neutrino Observatory", further information can be found at http://ale.physics.sunysb.edu/uno/

[Vet06] K. Vetter, Lawrence Livermore National Laboratory, private communication.

[Vog88] P. Vogel and J. Engel, "Neutrino electromagnetic form factors," Phys. Rev. D39, 3378 (1989).

[Wei62] S. Weinberg, Phys. Rev. **128**, 1457 (1962).

[Woo90] S. E. Woosley, D. H. Hartmann, R. D. Hoffman and W. C. Haxton ``The Neutrino Process," Astrophys. J. 356, 272 (1990).

[Yos06] T.Yoshida, T.Kajino, H.Yokomakura, K.Kimura, A.Takamura and D.H.Hartmann, ``Neutrino oscillation effects on supernova light element synthesis," Astrophys. J. 649, 319 (2006)

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(b) Appointments

2007-present	*Director*, The Science House, North Carolina State University
2003-2007	*Associate Director*, The Science House, North Carolina State University
2000-2003	*Professional Development Specialist*, North Carolina School of Science and Mathematics
1997-2000	*Physics Teacher*, Mt. Lebanon High School, Mt. Lebanon, PA
1994-1997	*Physics Teacher*, Parkway West Area Vocational Technical School, Oakdale, PA
1992-1994	*Graduate Research Assistant, Learning Research and Development Center*, University of Pittsburgh
1990-1991	*Graduate Assistant*, Department of EDCU, Texas A&M University
1989-1990	*Interim Program Coordinator*, Brazos Valley School of Mathematics and Science (proposed)
1986-1989	*Physics Teacher*, L.V. Berkner High School, Richardson, TX
1986	*Mathematics Teacher*, Caldwell High School, Caldwell, TX

Tatsu Takeuchi
Associate Professor, Department of Physics
217 Robeson Hall, Virginia Tech, Blacksburg, VA 24061
(540) 231-5333, takeuchi@vt.edu

(a) Professional Preparation

University of Tokyo	B.S. Physics	1983
Yale University	M.S. Physics, M. Phil.	1985, 1988
Yale University	Ph.D., Physics	1989
SLAC	Postdoctoral Fellow	1989-1992
Fermilab	Postdoctoral Fellow	1992-1995
CERN	Postdoctoral Fellow	1995-1996

(b) Appointments

1997-2003	*Assistant Professor*, Department of Physics, Virginia Tech
2003-present	*Associate Professor*, Department of Physics, Virginia Tech

R. Bruce Vogelaar
Department of Physics, Robeson Hall
Virginia Tech, Blacksburg, VA 24061
(540) 231 – 8735, www.phys.vt.edu/~vogelaar

(a) Professional Preparation

Hope College, Holland, MI	B.S. Physics, Philosophy, Math	1982
California Inst. of Tech, Pasadena, CA	M.S. Physics	1984
California Inst. of Tech, Pasadena, CA	Ph. D. Physics	1989

(b) Appointments

1989 – 1991	*Head of Cyclotron Operations,* Princeton University
1991 – 1998	*Assistant Professor*, Princeton University
1998 – 2007	*Associate Professor,* Virginia Tech
2007 – present	*Professor,* Virginia Tech

Christopher William Walter
Department of Physics, Box 90305
Duke University, Durham, NC 27708
(919) 660-2535, chris.walter@duke.edu

(a) Professional Preparation

University of California at Santa Cruz	B.A. Physics	1989
California Institute of Technology	M.S. Physics	1991
California Institute of Technology	Ph.D. Physics	1997
Boston University	Postdoctoral Research Assoc	1997-2000

(b) Appointments

2004-present	*Assistant Professor*, Department of Physics, Duke University
2000-2004	*Research Assistant Professor*, Boston University

Albert R. Young
Department of Physics, 160C Riddick Hall
North Carolina State University, Box 8202, Raleigh, NC 27695
(919) 513-4596, albert_young@ncsu.edu

(a) Professional Preparation

University of Washington (Seattle)	B.S. Physics	1982
Harvard University	Ph.D. Physics	1990

(b) Appointments

2006-present	*Professor*, Department of Physics, NC State University
2001-2006	*Associate Professor*, Department of Physics, NC State University
2000-2001	*Assistant Professor*, Department of Physics, NC State University
1996-2000	*Assistant Professor*, Department of Physics, Princeton University
1994-1996	*Lecturer*, Princeton University
1992-1994	*Research Associate*, Princeton University
1990-1992	*Junior Research Fellow*, California Institute of Technology
1986-1987	*Teaching Fellow*, Harvard University
1983-1990	*Research Assistant*, Harvard University

Center Budget Justification

The Center requests funding to fulfill its priority objectives, which always involves engaging young scientists as the basic engine for pushing knowledge frontiers forward. Thus, the majority of our funding goes towards: Center Fellowships (direct per year (Y1): $55k salary; 9k travel; 6k M&S); Postdoctoral Scholars ($45k salary; 6k travel; 4k M&S); Graduate Students (local stipend and tuition); Undergraduates (local hourly rate); REU programs (managed by The Science House – see NCSU budget). The second major component targets dedicated hires for the 'concept-to-prototype' highway (senior researchers who assume this additional responsibility), an outreach coordinator (uniquely possible in a Center context), and a Center administrative/fiscal manager.

To facilitate planning, CNAP budgets are divided into three categories:

1) 'Core Center Functions': these represent long-term commitments by the Center and are therefore expected to remain relatively stable. Some specifically target building a sense of Center 'community', such as shared courses and graduate students, and visiting faculty.
2) 'Focus Funds': these are intended to address the anticipated evolution of the main research thrusts of the Center and to provide short-term support needed at the beginning of projects. Thus, there is flexibility in their application (prior to assignment they remain at VT). For example, focus funding was used to accelerate implementation of the 'concept-to-prototype' highway. In later years focus funding should enable additional graduate students to join exciting developments within the Center.
3) 'Seed Funds': these are set aside to address moments of opportunity, which require a rapid response. As a result, they will be allocated with the highest degree of flexibility.

The following table presents an overview grouped not by objective, but by type of cost:

Center Resource Allocation Overview

Type	**Category**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Budget * (k$)**
Graduate Students	Core	4	8	8	8	8	*1,870*
Postdoctoral Scholar	Core	7	7	7	7	7	*3,693*
Postdoctoral Scholar (Fellow)	Focus	1	1(1)	(2)	(1)	0	*743*
Undergraduates	Core	12	12	12	12	12	*513*
Staff (Admin, FM, KM, OC)†	Core	4	4	4	4	4	*2,676*
Staff	Focus	3.5	3.5	2.5	2.5	2.5	*1,326*
Outreach Programs (+REU)	Core	*232(k$)*	*240*	*249*	*257*	*266*	*1,245*
Outreach Programs (+REU)	Focus	*10*	*207*	*81*	*84*	*87*	*470*
Education & Development	Core	*259*	*223*	*231*	*239*	*247*	*1,198*
M&S, Capital Equipment	Core	*69*	*71*	*74*	*76*	*79*	*368*
M&S, Capital Equipment	Focus	*419*	*0*	*0*	*0*	*0*	*419*
to be targeted via Exec. Com.	Focus	*135*	*125*	*280*	*431*	*595*	*1,565*
to be targeted via Science Dir.	Seed	*100*	*103*	*107*	*111*	*115*	*535*
* includes benefits and indirect; includes $10-15k (travel+equip) per Scholar; ***not exact*** (ie: neglected *known* changes in tuition and indirect rates during the 5 years) † FM: Facilities Manager; KM: Kimballton Manager; OC: Outreach Coordinator							*16,621*

The Center management plan describes how our annual objective driven Implementation Plan is developed. The Executive Committee, guided by science goals arising through our Major Activity leads, Science Director and International Science Advisory Board, decides how 'focus' funds should be used to augment core commitments to critical goals, and sets the budget for the coming year. The table below shows this process at work:

Implementation Plan (IP) Overview

	Objective	Proposal Section	Resource	Type	VT	NCSU	UNC	Duke	Budget* (k$)
1	**Administration of Center**	Management	Administrator	Core	x				937
			ISAB Travel	Core	x				
			Publ. & Estab. subawards	Core	x				
2	**CNAP as a community**	Executive Summary	Retreat & Travel Pool	Core	x				378
			Summer School	Core				x	
			0.2 Ctr Fellow (Y2,3)	Focus		x			
			0.2 Ctr Fellow (Y3,4)	Focus	x				
3	**Create the basic 'Concept-to-Prototype' Highway**	MA 2.a-c	Facilities Manager	Core			x		2,558
			Kimballton Manager	Core	x				
			Facilities Operations	Core			x		
			Kimballton Technician	Focus	x				
			Facilities Tech. (Y1,2)	Focus			x		
			Kim Commission (Y1)	Focus	x				
4	**Establish Outreach Partnerships**	Outreach (note: programs at all four locations, but managed via NCSU and VT)	Outreach Coord	Core		x			3,060
			Res. Exp. Undergrads	Core	x	x			
			Elementary Ed.Workshops	Core	x	x			
			Cutting Edge Workshops	Core	x	x			
			Outreach Staff	Focus	x	x			
			Student Teacher Sum. Sch.	Focus	x	x			
			mini-grants	Focus	x	x			
			equip to NCCU (Y2)	Focus		x			
			equip to SCSU (Y2)	Focus		x			
5	**Interact with Science Community**	Education and Development	Workshops	Core	x				633
			Seminars	Core	x				
			Seminars	Core				x	
6	**Neutrinos in Action**	MA 1.1-7	Postdoc, Grad St, Ugd	Core		x			2,369
			0.5 Postdoc, Ugd	Core	x				
			Postdoc, Ugd	Core			x		
			Grad St (Y2-5)	Core	x		x		
			Postdoc (Y1,2)	Focus		x			
			0.4 Center Fellow (Y3,4)	Focus	x				
7	**Detector Development**	MA 2.1-5	Postdoc, Ugd	Core		x			2,514
			0.5 PostD, GrS, 2 Ugd	Core			x		
			0.5 PostD, GrS, Ugd	Core	x				
			0.5 Postdoc	Core				x	
			Grad St (Y2-5)	Core		x			
			0.4 Center Fellow (Y2,3)	Focus		x			
			DAQ (Y1)	Focus			x		
			Scint Lattice (Y1)	Focus			x		
			Low Bkgd Screen (Y1)	Focus			x		
8	**Quant. comparing beam/detectors for exploring leptonic CP violation and determining the neutrino mass hierarchy**	MA 3.2	0.5 Postdoc, Ugd	Core	x				581
			Undergraduate	Core				x	
			0.4 Center Fellow (Y3,4)	Focus	x				
9	**Pushing the low-energy neutrino detection frontier**	MA 3.5	0.5 Postdoc (Y3-5)	Core	x				235
			Undergraduate	Core	x				

10	**Detailed sims. of the physics potential of a 100 kiloton liquid scintillator detector**	MA 3.3	0.5 Postdoc (Y1,2) Grad. St (Y2-5) 0.4 Center Fellow (Y2,3)	Core Core Focus		x		x x	440
11	**New applications for existing experiments and facilities**	MA 3.1,4	0.5 Postdoc (Y3-5) Graduate Student 0.5 Postdoc (Y1,2)	Core Core Core	x		x	x x	817
12	**Special focus and seed funds**	Management	(determined by Executive Committee action)	Focus Seed					2,100
* includes benefits and indirect; includes $10-15k (travel+equip) per Scholar; ***not exact*** (ie: neglected *known* changes in tuition and indirect rates during the 5 years)									16,621

The resulting resource allocation to individual institutions is captured and detailed in their individual budget justifications. The subawards use ‘cost-reimbursement’ accounting, where invoices are considered by the Center management based on their responsiveness to the IP objectives (which are more detailed than shown in the above table).

Virginia Tech Budget Justification

– Due to the three page limit on budget justifications, we present only a brief summary

- **Personnel:** The personnel will work on CNAP objectives as shown in the Implementation Plan table above. The VT budget includes the following personnel (salaries scaled to Y1 values; 3.5% center-wide escalation): 2 postdoctoral fellows ($45k), 1 Center postdoctoral fellow (Y3 and 4 only, $55k), 2 graduate students ($24k), 4 undergraduate students ($5k), Center administrator ($55k), Kimballton facilities director ($65k), Kimballton technician ($40k), and a local outreach coordinator ($39k). Virginia Tech fringe benefit rates are: 36.5% for postdocs and other staff, 11.0% for graduate students, and 8.5% for undergraduate students.
- **Equipment:** Capital equipment is requested to outfit the Kimballton Underground Research Facility to meet CNAP’s objectives. It includes a data acquisition system, an environmental control system, a portable muon veto shield for the trailer modules, and a water purification system.
- **Travel:** This includes travel costs for personnel ($6k/yr. for postdocs, $9k/yr. for Center fellow postdocs, $2.5k/yr. for outreach coordinator), travel pool for other personnel ($15k/yr.), Center retreat costs ($5k/yr.), seminar series costs ($10k/yr.), and ISAB costs ($25k/yr.).
- **Participant Support Costs:** Costs for Center workshops and various activities through the outreach program; further details are in the NCSU budget justification.
- **Materials and supplies:** This includes materials and supplies costs for personnel ($4k/yr. for postdocs, $6k/yr. for Center fellow postdoc), for Kimballton commissioning ($40k in the first year), and for outreach activities (variable per year)
- **Publications:** $5k/yr. is allocated for publication costs.
- **Subawards:** given to UNC, NCSU, and Duke; VT indirect *only* on first $25k each.
- **Other costs:** VT tuition ($7.7k/yr. for first year), focus funds, and seed funds.

The Virginia Tech indirect cost rate is 58.5% (charged on all costs except graduate student tuition, capital equipment, participant costs and subawards).

BUDGET JUSTIFICATION

The budget for Duke includes:

- **Personnel:** These personnel would be based at Duke and work on projects related to CNAP objectives.
  - Support for one experimental postdoc. Duke fringe benefits for a postdoc are 20.8% in the first year and 21% thereafter.
  - Support for one graduate student in the first year, and two in subsequent years. Duke fringe benefits for a graduate student are 5.3%.
  - Support for three undergraduates per year, at $4K each, who will work either during the summer or during the semester. Duke fringe benefits for undergraduates are 7.7%.
- **Travel:** Included are travel for a postdoc ($6K per year), and travel for the seminar series ($19K per year). The postdoc will need to make several trips for travel between institutes, collaboration meetings and conferences: one $2K international trip per year and four $1K domestic trips are estimated. The seminar series funds include travel for speakers to come to the CNAP area from domestic and international locations. The estimated breakdown is: four international speakers at $2 K each and 11 domestic ones at $1K each.
- **Materials and Supplies:** An amount of $4K is allocated for a computer and other research-related expenses for the postdoc. An amount of $1K per year is allocated for materials and supplies related to the summer school.
- **Participant Costs:** $18K/year is allocated to cover lodging and food for approximately 15 CNAP institution students (both undergraduate and graduate) to attend the yearly summer school described in the Education and Outreach section. This number is based on costs for the New England Particle Physics Student Retreat. Participants in the school will include senior personnel, but funding priority will be given to students.

The indirect cost rate at Duke is 56%. Except where salaries and benefit rates are specified for a given year by Duke, the numbers in this budget include a 3.5% per year increase. Note that this increase was agreed on between CNAP member institutes.

Physics Frontiers Center – Center for Neutrino and Astroparticle Physics (C-NAP)

North Carolina State University
Physics Department
Budget Justification

NCSU is requesting funds for theoretical and experimental participation in the CNAP, as well as an outreach portion to benefit the K-12 education and the general public in North Carolina.

To correct for inflation and other cost increases annually, reoccurring costs are increased by 3.5%. Indirect costs are requested at the NCSU official negotiated rate of 48.5% MTDC (Modified Total Direct Costs, which is Total Direct Costs less participant support costs, equipment, and tuition/fees.)

Personnel costs are calculated using these fringe benefit rates: postdocs - 15%, science house coordinator - 25%, graduate students - 14% and undergraduate student - 8.45%. Post Doctoral Research Associates Funds are requested for three postdoctoral scholars in the first year, all with salaries of $45k. Two of these will be theoretical postdocs working on the supernova neutrino project, one from the NC State "base" funding for theory and one from the "special focus" pool. The final postdoc will be an experimental scholar who will join in the existing programs on the Majorana and LENS experiments. In the second year we expand to include a fourth postdoc with an outreach fellowship and a starting salary of $56,925. In the third year, one theory postdoc, the experimental scholar, and the fellowship postdoc have again been requested (the funding for the second theory postdoc has been returned to the general special focus pool held at VT to allow maximum flexibility in choice of projects). In the fourth and fifth years, two postdocs are requested, one theory and one experiment. Graduate students For the theoretical CNAP program we request one graduate student to start in the first year of the project, expanding to add an experimental graduate student in the second year of the project. Undergraduate students The experimental physics being pursued through C-NAP will provide an experience useful in several disciplines outside of physics: occupational health, national security, radiation medicine, etc. The theoretical physics being pursued at CNAP will provide students with a flavor of high energy, nuclear and astrophysics. We are requesting two ¼ FTE undergraduates at the physics department's standard $10 per hour. The students will work 30 hours per week during the summer and 6-8 hours per week during the academic year.

Travel Post docs will travel between internal and external institutions in order to facilitate their research, and to participate in both international and domestic conferences. We estimate that the approximate cost per trip will be $2k per trip for international and $1k per trip domestic, and calculate travel at $6k for each regular postdoc and 9k for the fellowship postdoc.

Materials and Supplies The experimental nuclear physics group at NC State will be making significant contribution towards the Center's goals for neutrino detector development. This will include solid state detector development for double beta decay experiments, the development of metal-loaded liquid scintillator detectors for solar neutrino experiments and trace element analysis techniques for radioactive material assay. The trace element analysis techniques will require irradiation in the NC State nuclear reactor operated by the Nuclear Engineering department, as well as gamma counting with detectors at NC State, Duke University, and the Kimballton Underground Research Facility. The costs associated with this material assay method will equal $2000 per annum. The solid state detector development will use existing infrastructure at NC State and other Center institutions, but there are costs associated with solid state device procurement and study. These cost include clean oxygen free environment for detector handling ($2000 per year), solid state detector procurement and cryogenic support ($5500; 11,500; 7500; 1500; 4000). For the theory effort, 4 workstations are requested for each of the first four years in order to perform the calculations of neutrino scattering and neutrino flavor transformation. Since 10% of these computers' use will be dedicated to administrative use, $2500 is requested from the sponsor for each computer and the remaining 10% of each computer's cost will be paid by the NCSU Physics Department.

Tuition and fees are requested for the graduate students at the NCSU rate of $8648.

Budget Justification
The Science House – NC State University

Salary is requested for a full-time outreach coordinator at The Science House who will bear day-to-day responsibility for coordinating outreach activities among all partners, including scheduling activities so they are equitably distributed among partner universities (1.0 FTE x 65,000=65,000).

Salary is requested for outreach director Dr. Sharon Schulze, who will serve on Center Administrative Board, participate in Center-wide outreach budget review, and supervise outreach coordinator. (.25 FTE x 90,000=22,500).

Salary is requested for teachers to lead summer programs (Elementary Ed workshop, Cutting Edge workshop, and student/teacher summer program) at a rate of $2000 per person week. In years 1, 3, and 5 we will hire 1 person for 1.6 weeks (2000 x 1.6=3200). In years 2 and 4 we will hire 1 person for 3 weeks (2000 x 3=6000).

Salary is requested for counselors to supervise students in the student/teacher summer program. In years 2 and 4 we will hire 3 counselors for 2 weeks at $750/week (3 x 2 x 750=4500).

Fringe benefits are charged at a rate of 25% of salary for the outreach coordinator and the outreach director and 8.45% of salary for teachers and counselors to lead summer programs.

Travel support is requested for staff travel to Virginia Tech for partnership meetings as well as conferences and center-related meetings to publicize and manage Center outreach and for REU students (undergraduates) to provide transportation from their homes to their REU sites. ($3500 for outreach + 15x500 for REUs in year 1; $3,000 for outreach + 15x500 in years 2-5)

Participant Support is requested for participant stipends and support as follows:
Elementary Ed teacher workshop – 20 participants x $1000 (Y 1-5)
Cutting Edge teacher workshop – 20 participants x $750 (Y 1, 3, 5)
Teachers in summer student/teacher program – 8 participants x $2000 (Y 2, 4)
Students in summer student/teacher program – 16 participants x $1000 (Y 2, 4)
Student/teacher program housing – 24 participants x $350 (Y 2, 4)
Student/teacher program subsistence – 24 participants x $425 (Y 2, 4)
Student/teacher program insurance and campus access – 24 participants x $25 (Y 2, 4)
REU stipends – 15 participants x $3500 (Y 1-5)
REU housing – 15 participants x $1300 (Y 1-5)
REU subsistence – 15 participants x $1500 (Y 1-5)
REU insurance and campus access – 15 participants x $50 (Y 1-5)
Mini-grants for teachers – 25 mini-grants/year x $200 (Y 1-5)

Materials and Supplies Since the precise materials to be used in teacher and student programs will be determined by content of the workshop or program, exact materials listing isn't possible, so we request the following based on typical materials costs for similar programs:
Elementary Ed teacher workshop – 20 participants x $200 (years 1-5)
Cutting Edge teacher workshop – 20 participants x $100 (years 1, 3, 5)
Student/teacher summer program – 24 participants x $250 (years 2, 4)
REU lab supplies – 15 participants x $1200 (years 1-5)

In Year 2, $50,000 in special focus funding is included for materials and supplies for use at North Carolina Central University and South Carolina State University ($25,000 per school). North Carolina Central and South Carolina State University will be prime recruiting grounds for students involved in Research Experiences for Undergraduates. The Materials and Supplies money ($25,000 for each school) will be used to provide support for REU students to continue the research projects begun during their Center REU experiences.

Equipment

In Year 2, $50,000 in special focus funding is included for equipment to be used at North Carolina Central University and South Carolina State University ($25,000 per school). North Carolina Central and South Carolina State University will be prime recruiting grounds for students involved in Research Experiences for Undergraduates. The equipment money will be used to purchase a piece of equipment for REU students to continue the research projects begun during their Center REU experiences.

Center for Neutrino and Astroparticle Physics: Budget Justification

The following is the budget justification for involvement by the University of North Carolina – Chapel Hill (UNC-CH) in the "Center for Neutrino and Astroparticle Physics" proposal. These funds are being requested from the NSF with no cost sharing. Costs are assumed to inflate at a rate of 3.5% in the out years and the indirect cost rate is based on the FY '09 negotiated rate of 47.5% of modified total direct costs (less equipment and tuition).

1. **Personnel**

a. Senior Personnel A. Champagne, J. Engel and R. Henning will supervise the activities of the Center at UNC-CH. No funds are requested for the senior personnel.

b. Facility Manager As part of the Center, a new neutrino and low-background detector development laboratory will be established at UNC-CH. The facility manager will oversee all activities of the laboratory, act as safety officer and provide technical and administrative support.

c. Technician A technician is requested for 2 years to assist with the setup of the development laboratory.

d. Postdoctoral Researchers We anticipate most of the post-docs and student working at the Center will be funded from other grants, but funds are requested for 2 post-docs dedicated to activities of the Center. One would work in the theory/phenomenology program while the second would pursue activities at the development laboratory. (Salary, healthcare and SSI support is requested)

e. Graduate Students The work of the Center offers an excellent training opportunity for students interested in neutrino physics. We have requested support (including tuition) for one full time graduate student in year 1 and two students in subsequent years (including healthcare and 2 semesters of tuition).

f. Undergraduate Students The activities associated with the center offer an exciting opportunity for young physics students. Our request would support 3 undergraduates during the summer months at 40hrs/wk (plus SSI). They would work primarily on development projects.

2. **Travel**

Funds are requested to support travel between the Center institutions and to give post-docs and students the opportunity to travel to meetings and experiments. These funds are intended to supplement travel funds in existing grants.

3. **Materials and Supplies**

The development laboratory will require an initial expenditure of materials and supplies to build up basic infrastructure. This budget includes basic electronic equipment, computers, chemicals, fume hoods, glove boxes and other supplies. More modest amounts are needed to maintain operation in the out years. Equipment specific to an R&D project will be funded from its separate grant or discretionary funding but we have included funds specifically for assays of materials and scintillation-lattice development. We also provide computing funds for post-docs and students supported by the Center.

NORTH CAROLINA MUSEUM of NATURAL SCIENCES

NORTH CAROLINA STATE MUSEUM OF NATURAL SCIENCES

Betsy Bennett, *Director*

January 22, 2008

Prof. R. Bruce Vogelaar
Department of Physics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Dear Dr. Vogelaar:

I am writing in support of your grant application," Center for Neutrino and Astroparticle Physics," to be submitted to the National Science Foundation's Physics Frontiers Center program.

As a natural history museum dedicated to piquing the public's interests in the sciences and natural environment, the North Carolina Museum of Natural Sciences ("Museum") whole-heartedly supports this endeavor. The mission of the Museum is to ***enhance the public's understanding and appreciation of the environment in ways that emphasize the natural diversity of North Carolina and the southeastern United States and relate the region to the world as a whole.***

If funded, the Museum has agreed to incorporate topical programming on neutrinos and astroparticles into existing Museum offerings, including bilingual programming for non-English speakers, lectures for adults, special events, and the Museum's successful Science Café series. The Museum has an annual attendance of over 600,000 visitors, with an additional 53,000 served through off-site outreach, and will be honored to disseminate information on neutrino and astroparticle physics to our audiences. The Museum is also excited about exploring the possibility of hosting some detector-development activities within its new facility, the Nature Research Center, and hopes that you will participate in planning discussions as the NRC is being developed to identify how C-NAP can best be engaged in activities of the NRC.

Should you have any questions or require additional information, please feel free to contact me at (919) 733-7450, extension 200, or Kimberly Kandros, Development Officer, at (919) 733-7450, extension 263.

Sincerely,

Betsy Bennett

Betsy Bennett
Museum Director

Letters of Support from the Community

1. Steven Brice, Fermi National Accelerator Laboratory, Co-Spokesperson of MiniBooNE
2. Steven R. Elliott, Los Alamos National Laboratory, Spokesperson of Majorana
3. Richard L. Hahn, Brookhaven National Laboratory
4. Francis Halzen, University of Wisconsin, Co-Spokesperson and Principal Investigator of IceCube, Hans-Thomas Janka, Max Planck Institute for Astrophysics
5. Manfred Lindner, Max Planck Institute for Nuclear Physics, Director of MPI-NP
6. William C. Louis, Los Alamos National Laboratory, Spokesperson of LSND and past Spokesperson of MiniBooNE
7. Peter Meyers, Princeton University
8. Sandip Pakvasa, University of Hawai'i
9. Georg Raffelt, Max Planck Institute for Physics
10. Sanjay Reddy, Los Alamos National Laboratory
11. Yoichiro Suzuki, University of Tokyo, Director of Kamioka Observatory and Spokesperson of Super-Kamiokande
12. Yi-Fang Wang, Institute of High Energy Physics, Beijing, Associate Director and Co-Spokesperson of Daya Bay