2017 TUNL REU Nuclear Physics Projects

1. Physics Studies for a Large Liquid Argon Detector
Advisor: Kate Scholberg
Student: Cynthia Nunez

A 40-kton underground liquid argon detector is being designed for DUNE, the Deep Underground Neutrino Experiment. Physics capabilities include neutrino oscillations with a long-baseline beam, solar and atmospheric neutrinos, and supernova neutrinos. This project will involve participation in simulation and physics sensitivity studies for this detector. The student will gain experience with a variety of simulation and data analysis software tools. Programming experience will be useful but is not required.

(other options: Simulation and data analysis for COHERENT or Simulation studies of the HALO detector)

2. Using Proton Transfer Reactions to Constrain Stellar Reaction Cross Sections
Advisor: Richard Longland
Student: Keilah Davis

The 22Ne(p,g)23Na reaction is one of the most important reactions determining sodium production in Asymptotic Giant Branch (AGB) stars. As a consequence, it has long been the subject of experimental efforts to measure its cross section at the energies most important to astrophysics. These energies are low, making the cross section small. It's so small, in fact, that the first direct measurements of important resonances were only made in the last 3 years with advanced detector and beam technology. Indirect measurements, namely proton transfer reactions, were required before that, and are usually considered to be accurate at the 40% level. However, one key resonance in the 22Ne(p,g)23Na reaction exhibits an order of magnitude disagreement between direct and indirect measurements. The potential ramifications of this disagreement impacts our trust in numerous stellar reaction rates.

In this project, a new measurement of the proton transfer 22Ne(3He,d)23Na reaction will be performed to understand the reason for disagreement between the indirect and direct measurements. More precise data will be taken over a larger range of angles to determine the requirements for reliable proton transfer reactions. Reaction models will be calculated to infer physical quantities from the data and new statistical tools will be employed to communicate the results in a more meaningful manner than ever before.

3. Nuclear Data Evaluation
Advisor: John Kelley
Student: Michael Narijauskas

The nuclear data group at TUNL compiles, evaluates and disseminates nuclear structure data relevant to A=2-20 nuclides. Our activities primarily involve surveying literature articles and producing recommended values for inclusion into various US Nuclear Data Program databases. We have projects related to analyzing beta-decay lifetimes, compiling structure data from recently published articles, and producing full nuclear structure data evaluations of nuclides based on all existing literature. An involved student could select activities based on their interests.

4. Measurements of the ^{191,193}Ir(n,2n)^{190,192}Ir Reaction Cross Sections Between 8.0 and 20 MeV
Advisor: Krishichayan
Student: Elizabeth Wildenhain

Iridium isotopes are used in a variety of medical and industrial applications, ranging from cancer treatment to activation detectors used to probe the energy spectrum of a neutron fluence. Their efficacy often depends on a complete understanding of (n,xn) cross sections in general and (n,2n) in particular.

The REU student will measure the ^{191,193}Ir(n,2n)^{190,192}Ir cross section between the threshold (~ 8.0 MeV) and 20.0 MeV neutron energy. After neutron irradiation of Iridium foils, de-excitation gamma rays from the daughter nuclei will be recorded off-linewith a High-Purity Germanium (HPGe) detector in TUNL's Low-Background Counting Facility. Zirconium and/or gold monitor foils will be irradiated simultaneously with the Iridium foils for neutron fluence determination.

5. Calibration of a NaI Neutrino Detector
Advisor: Phil Barbeau
Student: Alleta Maier

The COHERENT Collaboration is in the midst of the deployment of 2 tons of NaI detector to the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. The detector will be sensitive to charged-current neutrino interactions, as well as the Coherent scattering of neutrinos off Na nuclei. One half of the detectors (128) are at TUNL, and need to be characterized to make sure that they are all have sufficient light yield, energy resolution, and intrinsically low backgrounds. This summer project will include the calibration of each of these detectors, as well construction of a low-background lead shield that will be used to characterize the backgrounds of each crystal. The project includes the development of a data acquisition system, the construction of the lead castle, and the analysis of the data. If we are lucky, it will also include the construction and deployment of a prototype NaI detector array to the SNS.

6. Searches for Neutrinoless Double Beta Decay with the MAJORANA DEMONSTRATOR
Advisor: John Wilkerson
Student: James Parkes

The MAJORANA DEMONSTRATOR is collecting data a mile underground at the Sanford Research Facility in Lead, SD searching for neutrinoless double beta decay using the atomic nucleus, ^{76}Ge. The experiment aims to address key questions related to neutrino properties and symmetries: (a) Is lepton number violated? (b) Are neutrinos their own antiparticles? (c) Why is there more matter than antimatter in the present universe?

The challenge of looking for such a rare decay mode is that one must go to extraordinary lengths to reduce all possible backgrounds. Currently, the best limits on neutrinoless double beta decay find half lives of greater than 10^{25} years. It is difficult to put such a large number into context, but roughly this would correspond to about 500 decays per year for a ton of material.

This REU project has two components: (1) Analysis of Demonstrator data in order to better understand potential backgrounds from alpha decays. The student will also become familiar with the analysis tools developed and used by the collaboration, which are based on computers at the NERSC facility at LBNL. (2) Hardware activities at the UNC clean-room facility where work is underway developing improved connectors and cables for use as an upgrade to the current Demonstrator experiment and R&D for the next generation LEGEND experiment. The exact activities will be tailored to the student's specific interests.

The overall goal of the project is to develop an understanding the physics of neutrinoless double beta decay, with an emphasis on potential backgrounds from alpha decays.

7. High Density Data Acquisition for Neutrino and Dark Matter Research
Advisor: Phillip Barbeau
Student: Samuel Belling

A number of the detectors and experiments that the Barbeau Group is developing make use of a large number of detector channels. As two examples, we have developed a neutron calibration facility that is being used to develop a number of dark matter experiments—the facility will have over 200 neutron detectors deployed in it by the end of the summer. We are also planning the deployment of a 9 Ton NaI detector array to the Spallation Neutron Source at the Oak Ridge National Lab to search for neutrinos; it will have over 1000 channels. This project will develop a Frequency Domain Multiplexed logic system to read out all of these channels on a single BNC cable. Each detector will be connected to a LRC circuit with it's own characteristic frequency. Once converted to the frequency domain, the signals will be actively combined onto a single BNC cable, where the frequency of the pulse will identify the channel, the amplitude of the pulse will represent the energy measured in the detector, and the phase of the signal will indicate the time that the event occurred. This project will develop this system for an array of NaI detectors, and will involve the development of an appropriate electronic circuit, PMT voltage dividers and active summing circuits. The project will also include the analysis of these NaI signals, and if successful, the technique will be applied to several other systems in the laboratory.

8. Imager for Fast Neutron Beams
Advisor: Calvin Howell
Student: Nathan Villiger

Collimated neutron beams in the energy range from 1 to 20 MeV are used to probe nuclear reaction mechanisms, nuclear structure and for recoil particle detector characterization. The shielded neutron sources at TUNL provide beams that have rectangular or circular cross sectional profiles with a variety of sizes. The use of these beams in experiments requires high-precision measurements of the beam cross-sectional profiles and the beam axis direction. The neutron beam axis is determined from the cross-section profiles measured at two locations along the optical axis of the collimator. Beam profile measurements must be performed each time the neutron collimator is changed. Currently the profiles are measured by scanning across the beam in discrete steps with a thin rectangular plastic scintillator mounted on a 5-cm diameter photomultiplier tube (PMT). The scan at each position takes about four hours, including setting up and aligning the scanner.

We propose to develop a device with the capability of directly measuring a two-dimensional image of the neutron beam. The initial concept is to use scintillating fibers with the light collected in position sensitive PMTs. The PMT output signals will be charge integrated, digitized, and read out using a standard data acquisition system at TUNL. The student on this project will work on concept development, device design, signal processing electronics, data acquisition, and image reconstruction software. The student will use the AutoCAD Inventor software for performing the mechanical designs. The final product will be a working imager system with a user manual.

9. Development of a Non-Helium, High-Mass, Noble Gas Leak Detector
Advisor: Paul Huffman
Student: Chad Barrow

This project proposes the development of a non-helium test gas leak detector. It is often necessary to use noble gases to test ultra-high vacuum environments for leaks. While helium is the cheapest and most readily available of these gases, it will diffuse through many composite materials such as epoxy-fiberglass composites (e.g. G-10) and glass due to its small atomic size. Such a system is needed for a large-scale experiment to measure the electric dipole moment of the neutron (nEDM) that employs large volumes constructed from G-10 for non-magnetic considerations.

The student working on this project will construct and test a neon or argon-based leak detector using a residual gas analyzer, turbo pump, dry roughing pump, a small PC, and calibrated noble gases. This system will be used with a small G-10 test volume to benchmark the composite central volume of the nEDM experiment.

10. Construction of a Gamma-Ray Assay Station for Radioisotope Identification
Advisor: Christian Iliadis
Student: Andrew Tillett

A gamma-ray coincidence spectrometer employing two NaI (Tl) detectors has recently been used at the University of North Carolina at Chapel Hill to measure radioactivity in a variety of enviromental samples (e.g Brazil nuts, tobacco, and soil). While this setup has the advantage of being able to reject much of the background radiation present, it fails to measure the activity from radioisotopes in which there are no coincidence decays or where they occur too infrequently to be counted in a reasonable period of time.

The student working on this project will build a lead-shielded, single HPGe detection setup at TUNL which will allow the decays from several more radioisotopes to be identified and measured in samples already assayed using the UNC spectrometer.

11. GEANT4 Simulations in Support of the COHERENT Neutrino Project
Advisor: Diane Markoff
Student: Shalane Hairston

The student involved in this project will learn how to use the GEANT4 software package developed at CERN in support of the ongoing activites of the COHERENT neutrino collaboration. The COHERENT experiment aims to measure coherent neutral current neutrino-nucleus elastic scattering at the Spallation Neutron Source at Oak Ridge National Laboratory (ORNL) in Tennessee. Simulation activities may include testing the ORNL accelerator and experiment hall geometry models, Ge target shielding, and proposed configurations of NaI detectors. The student will also be involved in hands-on activities in the Barbeau lab such as soldering bases and testing detectors for the COHERENT collaboration.

High Energy Physics / CERN Projects

1. Using Artificial Neural Networks to Enhance Charged Particle Tracking in ATLAS

Advisor: Ashutosh Kotwal
Student: Riley Xu

The ATLAS experiment at the LHC is acquiring data at a high rate and there are plans to increase this rate substantially. As the collision rate increases, the density of particles passing through the detector also increases. The detector uses silicon sensors to reconstruct the trajectories of these particles. At high particle density, multiple charged particles can pass through a sensor. Artificial Neural Networks are used to recognize the characteristic pattern of multiple charged particles passing through a sensor. This pattern can change as the sensors deteriorate due to radiation damage. The summer project consists of optimizing the parameters of these neural networks to improve their performance under the high-rate conditions.

2. Search for Particle X from W boson and Photon Decay

Advisor: Al Goshaw
Student: Taylor Contreras

The Standard Model describes the fundamental particles and forces. However, this model is not complete, as much phenomena are not described. The ATLAS experiment searches for evidence of new particles by using proton-proton collisions in the Large Hadron Collider. Our search focuses on a possible particle X, that may help describe the phenomena not described by the Standard Model. This project looks at the decay of particle X to a W boson and a photon. Standard Model interactions occurring in the ATLAS detector wll be simulated via Monte-Carlo techniques. We will compare our analysis on Monte-Carlo simulated data and our analysis on real data from the ATLAS detector. Any signicant differences in the Standard Model predicted analysis and the real interactions analysis will provide evidence for a particle not described in the Standard Model.

3. Characterization of the Cooling System for Testing Upgraded ATLAS Silicon Detector Modules

Advisor: Mark Kruse
Student: Elise Le Boulicaut

As part of a large scale upgrade project, the ATLAS detector at CERN is expected to run with an increased luminosity of by the middle of 2026. Because the current detector is not suited for such high levels of pile-up and radiation, all its parts will be modified. Specifically, the inner detector will be entirely replaced with new silicon modules. In order to optimize the performance of these modules, they must be tested under their expected operating conditions. The power required by the read-out chips on the modules would cause extreme heating, which could damage the detector. This is why a cooling system is needed while testing. The Duke High Energy Upgrade laboratory has built a cooling block and a shielding box for this purpose. The efficiency of the system is being characterized by measuring the temperature of a thermal mock-up of a module receiving the specified amount of power and placed inside the cooling box. The student on this project will work with a LabVIEW GUI to obtain the temperature data as well as a computer simulation of the expected temperature flow. By optimizing the performance of the silicon modules, the ATLAS detector will be able to efficiently handle higher luminosities, which could lead to new physics discoveries.

4. Study of Charged Particle Distributions in Gluon-Enriched Jet Samples
Advisor: Ayana Arce
Student: Marcos Flores

The glueball, a composite particle composed of only gluons, has been predicted to exist since the inception of Quantum Chromodynamics. Current Monte Carlo (MC) fragmentation simulations exclude the existence of glueballs. The inclusion of glueballs into existing MC fragmentation simulations may provide a more accurate recreation of the fragmentation process and allow for more accuracy when determining initiating particles. This project will implement glueballs into existing MC fragmentation simulations. The fraction of leading jet energy to total jet energy and charged particle multiplicity will be calculated using simulated output. Similar calculations will be performed using data from the ATLAS detector at CERN and the results of the two data sets will be compared.