2018 TUNL REU Nuclear Physics Projects

1. Simulation and Data Analysis for COHERENT
Advisor: Kate Scholberg
Student: Jessica Koros

Coherent neutral current neutrino-nucleus elastic scattering (CevNS) is a process in which a neutrino interacts with a nucleus, giving it a recoil kick. Although the probability for such a process to occur is relatively high, the process has never before been detected because typical nuclear recoil energies are very small. Because the rate of the process can be quite precisely predicted, a deviation of measurement from prediction could indicate new physics beyond the Standard Model. The COHERENT collaboration has made the first measurement of this process at the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee, and is currently pursuing further measurements. This project involves simulating neutrino interactions in a heavy water detector that is being planned. The student will gain experience with a variety of simulation and data analysis software tools while creating an event generator for neutrinos incident on deuterons. Programming experience will be useful but is not required.

2. Developing a Rutherford Backscattering Station for TUNL
Advisor: Richard Longland
Student: Andrew Wantz

Target materials for nuclear astrophysics measurements at TUNL are often produced in-house. This is accomplished either by evaporating pure materials onto a backing surface or by implanting them using accelerated beams. In either case, the target composition is often not well known, and needs to be determined experimentally. To achieve this, we use Rutherford Backscattering Spectrometry (RBS), which is a powerful tool for understanding the composition of materials. It's especially useful at TUNL, where fragile targets can be tested in a well-controlled environment before and after experiments. Alpha particles are scattered off targets and detected in silicon detectors. The RBS scattering chamber at TUNL is a sophisticated piece of equipment that allows the use of many detector configurations. However, after years of use, many of the components are in need of an upgrade. A new, more flexible data acquisition system and remote control system also need to be developed.

In this project, the RBS scattering chamber will be rebuilt, upgrading components as necessary. The vacuum system will be fully tested as well as electrical isolation, which is essential for clean RBS experimental data. As part of this project, a new data acquisition system will be developed, aimed at simplifying the pipeline from raw data to RBS analysis. All detectors and vacuum controls will be integrated into a new control system for automatic measurements. Once completed, the system will be used to perform an RBS experiment aimed at understanding sodium targets for astrophysics measurements. The student will have the opportunity to be involved in many other experiments in our group, utilizing those targets to understand nuclear reactions in stars.

3. Background Measurement of Gamma Rays, Muons, and Neutrons at LENA
Advisor: Art Champagne
Students: Clay Wegner

Radiation from gamma rays, muons, and neutrons can contaminate the energy spectrum detected from a particle beam incident on a target nucleus. At the Laboratory for Experimental Nuclear Astrophysics (LENA), the current target location is shielded by engineered components and by the structure of the building overhead. The installation of a new electrostatic accelerator in the next year will require a significant reconfiguration of the lab. The goal of this project is to measure the background radiation at opposite ends of the lab to determine the feasibility of relocating the target to the the far end. The flux of gamma rays, muons, and neutrons will be measured using a HPGe detector, a plastic scintillation detector, and a ^{3}He neutron detector, respectively. Flux values at the current target location will be compared with those at the other end of the lab. The results will also be compared to GEANT4 simulations for these detector backgrounds.

4. Detector Development Using Cerium Bromide for Nuclear Structure Studies
Advisor: Robert Janssens
Student: Samantha Johnson

Nuclei with a "magic number" of protons and/or neutrons are especially stable. Experiments utilizing Lanthanum Bromide (LaBr3) detectors are underway at the High Intensity Gamma Source (HIGS) facility to better understand the structure of these magic nuclei. LaBr3 detectors have high energy and timing resolution, but also have an inherent gamma-ray background which can mask data in the lower-energy experiments at HIGS. The goal of this project is to determine whether Cerium Bromide (CeBr3) detectors will be useful for these studies at HIGS in the place of LaBr3 detectors. To make this assessment, a CeBr3 detector will be examined to determine both its energy resolution and timing resolution as a function of energy. Similar measurements will be taken of a LaBr3 detector for comparison.

5. Characterizing NaI[Tl] Crystals for the COHERENT Experiment
Advisors: Phillip Barbeau & Sam Hedges
Student: Jesse Devaney

COHERENT is seeking to observe coherent elastic neutrino-nucleus scattering (CEvNS) in a variety of targets. Using neutrinos from the Spallation Neutron Source (SNS), the collaboration made the first observation of this process in a 14.6kg CsI[Na] detector in the summer of 2017. To demonstrate the N2 scaling of the cross section with neutron number, COHERENT is deploying a variety of detectors with different nuclei, including a multi-ton NaI[Tl] scintillating detector. In preparation for this deployment, individual NaI[Tl] crystals need to be characterized, and general properties of these scintillators needs to be studied. These properties include light yield non-linearities, decay time energy dependence, geometric dependence of light yield, temperature dependent effects, and pulse-shape discrimination. Additionally, the student will work to develop a standard operating procedure for crystal characterization and implement this procedure on crystals at TUNL. This project is ideal for someone comfortable programming in C++ and/or python, and will involve significant computational work. The student will gain hands-on experience working in a nuclear physics laboratory and become familiar with data acquisition.

6. A Wire Chamber for Dark Matter and Neutrino Studies
Advisors: Phillip Barbeau and Connor Awe
Student: Hannah Hasan

The student on this project will work with a senior graduate student on characterizing two wire chambers for future dark matter and neutrino studies. This will involve assembling a data acquisition system, hardware work, and calibrations of two wire chambers. There is potential for the student to also assist with the design of a time projection chamber.

7. Ionization Chamber Development for Tritium Detection
Advisors: Calvin Howell and Collin Malone
Student: Katherine Parham

A tritium gas target is planned for experiments at the HIγS facility. Because tritium is a radioactive gas, safety systems will be implemented to reduce risk of gas leakage out of the containment volumes. The safety protocol includes monitoring the intermediate containment chamber for a tritium gas leak. Tritium decays into ^{3}He (stable) by the emission of a beta particle and an anti-neutrino with a half-life of 12.3 years. Our plan is to use a combination of four ionization chambers to monitor this volume for tritium gas. Two of the chambers will be open to the atmosphere of the containment volume and will detect the beta particles directly. The other two ionization chambers will be sealed (i.e., gas tight and filled with one atmosphere pressure of nitrogen gas) and used to measure the background radiation from cosmic rays and the radioactivity in the room. The REU student will be responsible for constructing and testing four prototype ionization chambers that meet the technical specifications required for the tritium target safety system.

8. Searches for a Non-Zero Neutron Electric Dipole Moment
Advisor: Robert Golub
Student: Pierce Giffin

A non-zero neutron electric dipole moment would be a clear sign of physics beyond the standard model. There are several big projects around the world racing to be the first to discover it. At TUNL we are constructing a scaled down version of the experiment to develop some of the necessary advanced measurement techniques. For example, we are working with a dilution refrigerator at temperatures below 1K. The project would entail developing measurement methods using Si photo-multipliers to detect UV photons and and SQUIDS (superconducting quantum interference devices) to detect the spins of 3He atoms dissolved in 4He liquid.

9. Modeling and Prediction of ^{26}Al Yields in Massive Stars
Advisor: Art Champagne
Student: Thomas Chappelow

Tentative models suggest that the abundance of ^{26}Al in early solar systems has profound impacts on the chemical compositions of terrestrial planets. Evidence points to massive stars as the production sites for ^{26}Al, primarily through the ^{25}Mg(p,γ)^{26}Al reaction. However, there is significant uncertainty in the yields this reaction produces. By observing spectra resulting from the bombardment of ^{25}Mg targets at resonance energy 92.2 keV, one can measure the both the resonance strength of the reaction and the branching ratio for the ground state of ^{26}Al. In order to achieve reasonable count rates for the reaction of interest, this project will require the addition of a cooling system to the LENA evaporator station in order to make Mg targets thicker than is currently possible. These targets will then be evaluated using LENA's JN Van de Graaff accelerator before being used in the ^{26}Al measurements.

High Energy Physics / CERN Projects

1. Identifying Quarks and Gluons in Final Dijet States
Advisor: Ayana Arce
Student: Allyson Brodzeller

Quark-initiated and gluon-initiated jets leave similar signatures in pp-collision data recorded by the ATLAS detector. Improving the classification of jets would provide a clearer understanding of how quarks and gluons appear in the detector and has potential application for studies on jet substructures. Using simulated dijet data, a boosted decision tree (BDT) classifier will be trained using the Toolkit for Multivariate Analysis (TMVA) environment to tag the events as originating from a quark or gluon based on the kinematics of the jets. The results of this project could show whether a kinematic-based parton tagger can be used to train or validate other taggers based on jet substructure.

2. Tagging Quark and Gluon Jets
Advisor: Ayana Arce
Student: Phoebe Amory

Quarks and gluons are some of the most common particles produced at the LHC. Both are seen in the detector as jets, with slight differences between the jets left by quarks (signal) and those left by gluons (background). In this project, three taggers will be created using TMVA to discriminate between quarks and gluons. These taggers will use jets reconstructed by the particle flow algorithm as well as other substructure variables.

3. BDTs Enhanced for Supersymmetry Search
Advisor: Ayana Arce
Student: Adrian Gutierrez

One of the main goals of the LHC experiments is to search for evidence of supersymmetry (SUSY). Due to the big amount of data produce at the ATLAS detector we need to find efficient techniques to improve the sensitivity of our search. One particular technique that can be used to increase the efficiency of those searches is machine learning. Machine learning techniques use statistical methods to give the computer the ability to “learn” with data how to improve a specific task. In this research project the student will investigate the possibility of detecting pairs of gluinos (which are the supersymmetric partners of gluons) through their hypothesized decays to multiple heavy top quarks by applying machine learning techniques such as TMVA, xgBoosted and Sklearn.

4. Study of Background for X → Wγ Search at √S = 13 TeV
Advisor: Al Goshaw
Student: Muhammad Aziz

The goal of this project is to study the backgrounds for known Standard Model processes by comparing the theory predictions with the data obtained from the decay processes occurring at the Large Hadron Collider. The sensitivity of the search for new forces beyond those described by the Standard Model depend upon how well these backgrounds are understood. An invariant mass distribution of the outgoing partons of decay processes will be generated from simulations describing the standard model predictions and compared to the invariant mass distribution of the data obtained from the LHC by taking the ratio. If it is found that the distribution generated from the simulation scaled by this ratio provides an accurate description of the standard model data background, it could then be used to extrapolate the data at higher mass ranges.