2015 TUNL REU Nuclear Physics Projects

1. Development of a Software Package for Simulating Water Cherenkov Neutrino Detectors
Advisor: Chris Walter
Student: Nathan Perreau

Hyper-Kamiokande (Hyper-K) is a proposed future neutrino experiment which could be constructed in Japan some time in the mid-2020s. Hyper-K would be a multipurpose water Cherenkov detector with an ambitious physics program that seeks to answer important open questions in particle physics, such as: Does the proton decay? What does the neutrino signature from a supernova explosion look like? Why is there more matter than anti-matter in our Universe? What is the neutrino mass hierarchy?

This is an exciting time to be involved in the Hyper-K experiment as many important decisions about the detector design are being made. This summer project involves working with the software group to develop WCSim (https://github.com/WCSim/WCSim), an open-source Monte Carlo simulation package that will be used to predict the physics capabilities of the Hyper-K experiment. The student who takes on this project will also perform physics studies with WCSim to optimize the final detector configuration for the project. The student will gain experience with GitHub, coding (particularly with C++ and scripting languages), and will become familiar with the Geant software package which is used extensively in the particle physics community.

2. Simulation and data analysis for coherent elastic neutrino scattering
Advisor: Kate Scholberg
Student: Danielle Riggin

Coherent neutral current neutrino-nucleus elastic scattering 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. However, detection of the process may be within the reach of the new generation of low-threshold detectors. 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 experiment aims to perform this experiment at the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee. This project will involve participation in design, simulation and background evaluation work for a neutrino scattering experiment at the SNS. The student will gain experience with a variety of simulation and data analysis software tools. Programming experience will be useful but is not required.

3. Characterization of 3He-based neutron detector
Advisor: Hugon Karwowski

The project will involve the characterization of a 3He-based neutron detector which has been used in a series of measurements at HIGS. The work will involve simulation and experimental components. The detector response and efficiency will be modeled with Geant4 code, and then the simulation will be validated with measurements of detector response to neutron sources. The experimental component will be an opportunity to get hands-on experience with both traditional NIM signal processing and modern digitizer-based DAQs.

4. Commissioning the Enge Spectrometer's Focal Plane Detector
Advisor: Richard Longland
Student: Katie Kowal

The Enge Split-Pole spectrometer makes use of the Lorentz force to focus high-energy charged particles onto a focal plane. By measuring the energy, position, and rate of energy loss of these particles, they can be identified and used to measure nuclear reaction cross-sections. This measurement is done using a complex detector package located at the focal plane in the spectrometer. While the detector is built, it has not been fully tested and integrated with a data acquisition system.

The student involved in this project will help commission this detector. They will take charge of detector operation and signal-path routing through electronics hardware in order to analyze events. This project will involve construction of a test stand for characterizing the detector components with radioactive sources. The student will also work closely with other researchers to integrate detector signals with a data acquisition system ready for experiments, and will have the opportunity to work with the spectrometer and vacuum system.

5. Nuclear Data Evaluation
Advisor: John Kelley
Student: Susan Olmsted

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.

6. Measurements of the ^{63,65}Cu(n,γ)^{64,66} Cu reaction cross section from 0.4 to 7.6 MeV
Advisors: Megha Bhike and Werner Tornow
Student: Isabel Bray

Copper is being used as cooling and shielding material in a number of experiments aimed at discovering neutrino-less double-beta decay. In these experiments neutron-induced background can potentially mimic the signal of interest. Therefore, the cross section for neutron-induced reactions on copper must be known to estimate the expected background rate at the location of the experiment.

The REU student will measure the ^{63,65}Cu(n,γ)^{64,66}Cu cross section between 0.4 MeV and 7.6 MeV neutron energy using the reactions ^{3}H(p,n)^{3}He, ^{7}Li(p,n)^{7}Be, and ^{2}H(d,n)^{3}He. After neutron irradiation of small copper foils, de-excitation γ-rays from the daughter nuclei will be recorded off-line with a High-Purity Germanium (HPGe) detector in TUNL's Low-Background Counting Facility. Indium foils will be irradiated simultaneously with the copper foils for neutron fluence determination.

7. R&D for a Search for CP violation in Positronium Decay
Advisor: Reyco Henning
Student: Kadeem Nibbs

Positronium is a bound but unstable system of an electron and anti-electron. We are designing and performing test measurements for an experiment that will search for Charge-Parity (CP) violating correlations between the 3 gamma-rays emitted in the decay of the triplet positronium state. If observed, it would be the first detection of CP-violating interactions in leptons and would have profound impacts on our understanding of matter and the origin of the the matter/anti-matter asymmetry in the universe. For this summer we have potential REU projects related to testing and optimizing the data-acquisition system, developing algorithms for performing digital signal analysis, developing and testing the active source, and performing Monte Carlo simulations to quantify systematic uncertainties.

8. Investigating the use of propane as a neutrino and Dark Matter detector
Advisor: Phil Barbeau
Student: Kirollos Masood

The possibility of using a hydrogenated target with fine spatial resolution holds great promise for the possibility of observing inverse beta decay with reactor neutrinos. With fine spatial resolution, it is possible that an experiment could even point back to the source of the neutrinos. In addition, a large mass, low background and low-threshold detector could be a sensitive detector for spin-dependent WIMP searches.

The goal of this project is to build and characterize the response of both gas and liquid propane detectors as radiation detectors. An effort will be made to explore the lowest thresholds, to study the event topology, and to address radioactive backgrounds.

High Energy Physics / CERN Projects

1. Searches for new forces with the ATLAS experiment
Advisors: Al Goshaw and Andrea Bocci
Student: Oz Amram

In the summer of 2015 the ATLAS experiment will be taking data with the upgraded Large Hadron Collider which will provide proton-proton collisions at a CM energy of 13 TeV. This opens new ground for the discovery of physics beyond that described by the Standard Model of elementary particles. Our research focus this summer will be to develop a search for new gauge bosons (force carriers) that are predicted by many beyond-the-SM models such as SUSY. We will in particular search for charged and neutral vector bosons X^o and X^{+-} that decay to the SM electroweak bosons, W^{+-}, Z and photon.

This research will require learning about the ATLAS detector and methods used to access data with C++ programming. The research preparations would be done initially at Duke to become familiar with elementary particle physics and relativistic mechanics. The student would then move to CERN for about six weeks where the data taking will be in progress with the ATLAS detector.

2. Visualization studies for advanced jet tagging algorithms at ATLAS
Advisor: Ayana Arce
Student: Dave Elofson

Advanced algorithms to determine the nature of the detected signals from hadronically interacting particles have led to more precise measurements and more powerful searches for new particles at LHC experiments. Visually interpreting these signals and their classification is an important tool in defining more robust algorithms. In this project, the student will create an event display tool that incorporates jet reconstruction and tagging information, making clear, informative displays from ROOT-based input for use in event interpretation, publication, and outreach.

3. R&D for the ATLAS silicon strip tracker upgrade: Atlys board integration
Advisors: Ayana Arce and Mark Kruse
Student: Chloe Lindeman

For the LHC luminosity upgrade, ATLAS will install a new, all-silicon inner detector to measure charged particle trajectories. At Duke we are building infrastructure and procedures to test and characterize components of the silicon strip tracking detector, and one attractive possible basis for the testing infrastructure is a commercial, FPGA-based development platform (Atlys). This project involves setting up the Atlys-based platform for the readout infrastructure at Duke and comparing its performance to the existing HSIO-based platform. At CERN, the project will evolve into commissioning the new strip testing laboratory in SR1 at CERN.

4. R&D for the ATLAS silicon strip tracker upgrade: Environmental monitoring and interlocks
Advisors: Ayana Arce and Mark Kruse
Student: Adryanna Smith

For the LHC luminosity upgrade, ATLAS will install a new, all-silicon inner detector to measure charged particle trajectories. At Duke we are building infrastructure and procedures to test and characterize components of the silicon strip tracking detector, and will prepare a test environment for detector modules, which comprise electronic readout components and silicon sensors. To safely run tests on silicon sensors, the test-stand must include environmental (temperature, voltages, humidity) monitoring and interlocks to protect sensitive components. This project involves integrating environmental monitoring into the test-stand infrastructure and exploring interlock designs. At CERN, the project will evolve into commissioning the new strip testing laboratory in SR1 at CERN.