Research Experience for Undergraduates (REU) @ TUNL Projects for 2011

Simulation Studies of the HALO Detector

Advisor: Kate Scholberg

The HALO (Helium and Lead Observatory) detector is under construction at SNOlab in Sudbury, Canada. This detector, composed of lead and ^{3}He neutron detectors, will have a unique sensitivity to the burst of neutrinos from a nearby supernova. This project will involve participation in simulation and physics sensitivity studies for HALO. The student will gain experience with a variety of simulation and data analysis software tools. Programming experience will be useful but is not required.

Physics Studies for a Large Water Cherenkov Detector

Advisor: Kate Scholberg

A 100 kton water Cherenkov detector is being designed for the proposed Deep Underground Science and Engineering Laboratory in South Dakota. 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.

Statistical Gamma-ray Transitions in ^{88}Sr Measured via Inelastic Neutron Scattering

Advisor: Dr. Gencho Rusev

The study of chaotic systems has demonstrated that the knowledge of the fundamental laws of motion of dynamical systems does not necessarily make the system predictable. The concept of chaos has been considered in nuclear physics since the early day of the subject. Although not derived from first principles, but rather analogous to the problem regarding the instability of the linear differential equations, the fluctuations of the level energies, at high excitation energies, exhibit statistical behaviour characteristic of the chaotic systems. We want to study the deexcitation gamma-ray transitions from these high-energy levels in ^{88}Sr via inelastic neutron scattering. Monoenergetic neutron beams with energies of 10, 11 and 12 MeV, produced via d(d,n) reaction, will irradiate a sample isotopically enriched to ^{88}Sr. The emitted gamma rays will be measured with an array of four high-purity Germanium (HPGe) detectors.

The REU student involved in this research project will gain hands-on experience with work with HPGe detectors, associated pulse processing electronics and data acquisition system, while actively participating in the neutron-scattering experiment. In addition, the student is expected to assist in the analysis of acquired data.

Search for a Short-range Spin-dependent Force

Advisor: Prof. Haiyan Gao and Wangzhi Zheng

We are working on a search for a new type of force which is short-range, and spin-dependent between polarized and unpolarized matter. This spin dependent interaction is important because it violates Parity (P) and Time Reversal (T) symmetry transformations. If this new type of force is confirmed, it will provide an alternative source of P and T violation in addition to the P and CP violation (C stands for charge conjugation) discovered in weak interaction.

The high pressure ^{3}He cell will be used to search for this spin dependent force for two reasons. First of all, by spin exchange optical pumping, ^{3}He can obtain high spin polarization that helps increase the sensitivity of the experiment. The other reason is that the range of this force is expected to be in the sub-millimeter scale and the glass window of the ^{3}He cell has a thickness of only several hundred macrons which is within the force range. Therefore, the high pressure ^{3}He cell is the best candidate to explore the new short range P,T violating force.

The student working on this project will work extensively with high pressure ^{3}He cells and nuclear magnetic resonance technique (NMR), including construction of electronics and coding LabView programs. The student will also be familiar with lasers and optics and the spin-exchange optical pumping, a widely used technique to polarize ^{3}He spins. This project is ideal for a self-motivated and hard-working student, who is interested in table-top scale experiments.

A high-pressure polarized ^{3}He target

Advisor: Prof. Haiyan Gao and Georgio Laskaris

The High Intensity Gamma-ray Source (HIγS) program at the Duke Free Electron Laser Laboratory(DFELL) has an active program using a polarized ^{3}He target. A polarized target aligns the spins of the target material, in this case ^{3}He nuclei, so that some of its electromagnetic properties can be isolated. This target will be used to study neutron and ^{3}He structure by measuring the spin-related observables from polarized gamma-ray scattering.

The polarized ^{3}He target is based on the technique of spin-exchange optical pumping. In the last year, we have built a new polarized 3He target in order to carry out a double-polarized Compton scattering experiment. The standard Helmholtz holding field is replaced by a solenoid magnetic field setup. This newly built target is awaiting for testing.

The student working on this project will work with this new target apparatus to carry out studies and characterizations of polarized ^{3}He target cells in this new geometry. This project is ideal for a self-motivated student interested in a hands-on, table-top experiment dealing with lasers, optics and nuclear magnetic resonance (NMR) technique, and LabView software.

MAJORANA and DEAP/CLEAN

Advisors: Profs. John Wilkerson and Reyco Henning

Our group is involved with experiments that probe fundamental neutrino properties including neutrinoless double beta decay (the MAJORANA ^{76}Ge experiment) and a direct neutrino mass search (KATRIN). In addition, we are involved in efforts to perform direct searches for dark matter (DEAP/CLEAN & MAJORANA). All of these measurements must be performed underground to escape the ubiquitous cosmic-ray background at the surface. The experiments require extremely low radioactivity components. As part of our efforts we operate a low-background radio-assay program at the Kimballton mine in Virginia to measure the intrinsic radioactivity in construction materials for these detectors. We have projects relating to Monte Carlo computer simulations, data analysis, detector hardware development, and improved shielding design that could benefit from undergraduate involvement and further this program. We are also designing and constructing calibration systems for a dark matter experiment, developing hardware and DAQ systems for germanium detectors, and are operating a prototype MAJORANA/dark matter Ge detector at the mine in Virginia. All these experiments have numerous projects suitable for undergraduates.

Measurements of ^{187}Re(n,2nγ)^{186m}Re cross-section

Advisor: Prof. John Kelley

The aim of this project is to measure partial (n,2nγ) cross sections that lead to population of levels above a very long-lived state in ^{186m}Re ($T_{1/2}$=2.0 x 10^5 y). These data are needed in order to evaluate the production (and destruction) cross sections of ^{187}Re, and hence, to reduce the nuclear physics uncertainties for the ^{187}Re/^{187}Os cosmochronometer that is used to date the age of the r-process nucleosynthesis.

Late in the summer of 2010 we collected data at E_n=12 MeV using the monoenergetic neutron beams at the TUNL accelerator facility. A suite of high-resolution Ge detectors was used to detect prompt gamma-rays in both singles and coincidence modes. A student involved in this project will analyze the data to determine partial cross sections for $^{185\&187}$Re(n,xn gamma) reactions. The nuclear model codes TALYS and EMPIRE will be utilized in reconstructing the total ^{187}Re(n,2n) reaction cross-sections. We will also explore the impact of (n,2n) rates in nucleosynthesis when compared to (gamma,n) cross sections. In addition to analyzing these data, the student will also participate in experimental setup and data collection runs for Dr. Rusev's measurements on ^{88}Sr.

Development of Water Target for Radioisotope Production

Prof. Calvin Howell

The student assigned to this project will work with an experimental nuclear physics group in the Department of Physics at Duke University and the Triangle Universities Nuclear Laboratory (TUNL) to develop a target for producing nitrogen-13 tagged NO3- ions in an aqueous solution. The solution will be used to study plant physiology using radioisotope tracer techniques. The development and testing of the water target will be done in the tandem accelerator laboratory at TUNL. If time permits a measurement using the radio-tagged solution will be made to demonstrate nitrogen uptake in a plant using radioisotope labeling.

The topics covered in the project include: (1) radioactivity, (2) production of radioisotopes using charged-particle beams, (3) fluid dynamics, (4) general plant physiology, (5) substance transport in plants,(6) gamma-ray detection with inorganic scintillators, (7)substance tracing using positron annihilation and (8) data analysis techniques.

Analysis of Meteoroids at LENA
Prof. Christian Iliadis

The Laboratory for Experimental Nuclear Astrophysics (LENA), located in Durham NC, houses ion accelerators designed to measure nuclear fusion reactions that take place in stars. In order to determine the number of fusion reactions that occur per incident ion, we developed a very sensitive gamma-ray detection apparatus. It consists of a seminconductor (Germanium) detector, surrounded by a scintillator (NaI) annulus. The main idea behind this scheme is to gate on suitable gamma-gamma-coincidence events in order to reduce unwanted background radiation considerably (by orders of magnitude). Without this background reduction, the signals from the astrophysical fusion reactions would be too weak to be measured.

We are proposing to explore the use of our sensitive detection apparatus in a completely different context. "Meteoroids" are objects that are constantly bombarded by ultra-relativistic cosmic rays in outer space. Through spallation reactions between cosmic rays and meteoroid matter, radioactive nuclides, such as ^{22}Na or ^{26}Al, are produced. The half lives of these two isotopes amount to 2.6 years and 720,000 years, respectively. When the object falls onto the surface of the Earth, and becomes a "meteorite", the production of the radioisotopes ceases and they start to decay by emitting gamma-radiation. Interestingly, both ^{22}Na and ^{26}Al are positron emitters. More specifically, a given emitted positron annihilates within a cubic mm of the sample, giving rise to two photons of 511 keV energy each. In addition, The beta-decay proceeds to an excited level in the daughter nucleus, giving rise to an additional gamma-ray (of 1275 keV and 1809 keV for ^{22}Na and ^{26}Al, respectively). Placing a meteorite sample in the center of our sensitive apparatus, and requiring a triple-gamma-coincicdence, should greatly reduce the environmental background radiation, thus enabling us to measure very small amounts of radioisotopes present in the meteorite. Note that this procedure is based on the counting of gamma-rays and hence is entirely non-destructive.

Once the radioisotopes have been measured in a sample, Monte Carlo transport simulations (using the package Geant4) have to be performed in order to establish the absolute amount of ^{22}Na and ^{26}Al in the sample. With this information, a number of compelling questions can be explored, chief among them the determination of the time the meteoroid entered Earth (which should be consistent with the reported "find time") and the time period that the meteoroid was exposed to the cosmic rays (i.e., the time duration it traveled through the solar system).