Department of Physics: Advertised USRA/SUPRE Projects for Summer 2024

1 Fishing for Neutrinos in the Pacific Ocean

The new P-ONE detector being build 2km deep in the Pacific ocean off the coast of Vancouver Island will study extremely high energy neutrinos (E>10 TeV) interacting the in deep ocean water. Detecting when a neutrino interaction has occurred and reading out the detector is the job of the trigger system and is critical to studying physics at energies beyond the reach of even the Large Hadron Collider.

The deep ocean environment that the P-ONE detector operates in has light-pollution both from the decays of Potassium-40 in sea water and also from bioluminescence of marine organisms. These make it challenging to isolate light from neutrino events. The student project is to work on developing algorithms which can identify neutrino events and trigger the readout of the P-ONE detector. The project will involve working as part of the P-ONE research group simulating the detector response to neutrinos in order to estimate the efficiency of different algorithms, calculating the expected noise rates using data obtained from the STRAW pre-cursor detector that collected information on bioluminescence rates and adapting and testing new ideas to improve efficiency and increase background rejection.

Contact

Dr. Roger Moore (rwmoore@ualberta.ca)

2 Biological Physics

Predicting microbial evolution. We are studying how communities of pathogenic yeasts evolve drug resistance. This project involves assisting a physics PhD student to develop physics-based mathematical/computational models and to perform biophysics-microbiology laboratory experiments on *Candida* yeasts. The goal of this research is to develop a quantitative and predictive understanding of how multispecies pathogen communities evolve drug resistance to better treat patients with drug-resistant infections.

Contact

Dr. Daniel Charlebois (dcharleb@ualberta.ca)

3 Spin Mechanics

Join a small team building and commissioning a ‘mini-LIGO’ Fabry-Perot Michelson cavity interferometer, designed in this case to open a new window on magnetic resonance by detecting the miniscule mechanical (yes, mechanical!) disturbances that arise when spins flip inside a material.

The LIGO designers did such a good job in crushing the state-of-the-art for sensitive optical interferometry to detect gravitational radiation, that their technology is now enabling applications to other domains of physics and fostering a new growth industry of smaller-scale and lower-cost experiments in fundamental physics. This USRA position is an opportunity for hands-on exposure to an emerging thread of 21st century research.

Contact

Dr. Mark Freeman (mark.freeman@ualberta.ca)

4 Search for black holes and string states with the Large Hadron Collider at the CERN Laboratory in Geneva

The student will be part of the ATLAS group in the Centre for Particle Physics at the University of Alberta. The group consists of two professors, two postdoctoral fellows, three graduate students and an estimated three summer students. Our group is helping to analyze data recorded by the ATLAS experiment at the Large Hadron Collider near Geneva. My group is studying the possibility of the experiment being sensitive to higher-dimensional space beyond our common three dimensions. String theory is one possible theory that requires higher-dimensional space. For many years, string theory has guided the direction of the "theory of everything". One drawback is that it is extremely difficult to find a unique prediction of the theory that can be testable in current or future experiments. Low-scale gravity and string models based on intersecting D-branes have recently allowed a connection to be made between the theory and experiment. The student will develop the phenomenology of this theory in the context of the ATLAS experiment at the Large Hadron Collider by searching for black holes and highly-excited string states.

The student will perform the computer simulations, analyze and plot data, and present the results. She/he will also document the project and describe the significance of the results. In particular, the student will create an algorithm for searching for evidence of black holes and highly-excited string states at the Large Hadron Collider.

Contact

Dr. Douglas Gingrich (gingrich@ualberta.ca)

5 The Dynamic Radio Universe

We are entering the era of time-domain astronomy, where repeated observations of the sky reveal the dynamic Universe are performed at many different parts of the electromagnetic spectrum. We already expect to find exciting sources like the cataclysmic ends of massive stars (supernovae and gamma-ray bursts) and transient emission from neutron star and stellar-mass black holes that steal (accrete) material from a nearby star (X-ray binaries). However, we will undoubtedly reveal unknown sources (perhaps the electromagnetic counterparts to the sources of detectable gravitational waves and astrophysical neutrinos). The Very Large Array All Sky-Survey (VLASS) is an exciting survey being performed at radio wavelengths that will be made over several years, stitching together a relatively deep image of the entire sky visible from New Mexico, where the radio array is located. Three passes will be made providing information about transients. By the summer of 2021, VLASS will have started the second half of its second pass over the whole sky. Together, we will use data from the first two epochs to identify and classify transient radio sources.

Contact

Dr. Gregory Sivakoff (sivakoff@ualberta.ca)

6 Analysis of data from the PICO-40L dark matter detector at SNOLAB

Finding direct evidence of the particle nature of dark matter is one of the principle goals of particle physics with activities related to this at pretty much every lab around the world. The Canadian SNOLAB is an ideal site for such research as it is one of the deepest labs in the world, providing excellent shielding from cosmic radiation backgrounds. PICO is an international collaboration operating a large particle detector underground in SNOLAB aiming to detect dark matter by seeing bubbles in the boiling liquid of the PICO-40L bubble chamber. A student can contribute to this team effort by helping to analyze data, using tools such as machine learning, acoustic waveform analysis and optical pattern matching. Other projects to develop components for the new, larger PICO-500 detector are also available.

Contact

Dr Carsten B. Krauss (carsten.krauss@ualberta.ca)

7 Development of the P-ONE neutrino telescope in the Pacific Ocean

Neutrino events with energies above 1 PeV have been observed in the IceCube detector located in the ice of the South Pole glacier. In order to utilize such events for extracting particle physics we will need a new, large detector in the Pacific Ocean. We are in the process of developing a new such detector to be deployed in the Cascadia Basin already instrumented by Ocean Networks Canada. Students will use the existing framework of (python) programs to simulate and reconstruct how neutrinos in such a detector will been observed and what precision can be reached. We are also working on the development of a trigger system of distributed single board computers that is planned to be deployed in the ocean. Students will work on programming the computers to implement and performance test different trigger algorithms.

Contact

Dr Carsten B. Krauss (carsten.krauss@ualberta.ca)

8 Elastic field numerical modeling and Imaging

This project focuses on utilizing the Devito package, a specialized tool for solving partial differential equations (PDEs), to conduct elastic forward Born modeling and inversion. Our primary objective is to explore and analyze numerical parameter cross-talk issues. We aim to investigate whether introducing new parameterizations in the inverse problem can effectively reduce parameter crosstalk. A key requirement for participants is either existing proficiency in Python or a strong commitment to develop this skill within the first month of the internship.

Contact

Dr. Mauricio Sacchi (msacchi@ualberta.ca)

9 Design of a Geiger Mode Avalanche Diode for keV electron detection

Geiger Mode Avalanche Diodes, sometimes referred to as SPADs or SiPMs, are semiconductor devices built to count photons with excellent time resolution. Recently, they have been proposed as a candidate for detection of electrons with keV energies. In this project, we will explore these capabilities by simulating different configurations of these devices. We will study their efficiency, resolution and expected noise levels using software already written for this purpose. A student working here should have experience with data analysis in python or CERN's ROOT.

Contact:

Dr. Juan Pablo Yañez (j.p.yanez@ualberta.ca)

10 Shaping the electric field inside a photomultiplier tube

In the last year, students in my lab built a prototype of a novel type of photodetector. This detector works by transforming photons into electrons via the photoelectric effect, which are then accelerated towards an amplification stage. The acceleration stage is achieved by means of an electric field, whose configuration we can manipulate. The goal of this project is to explore different ways of configuring the electric field to achieve similar transit times for electrons from their production site to the detection site. The work will happen mainly using COMSOL, a design software that can solve for the electric field of complex configurations of elements. If time allows it, we will build the elements and test them inside the photodetector prototype.

Contact:

Dr. Juan Pablo Yañez (j.p.yanez@ualberta.ca)

11 Scattering in real time in two dimensions

Scattering is typically described in a time-independent fashion, with an eye on measuring the outcome well away from the target, and in a “steady-state” type of scenario. We have recently examined the detailed time-resolved one-dimensional scattering case, where the two outcomes are transmission and reflection. I would like to extend these studies to two (and ultimately) dimensions. The we will get to see real-time diffraction events, and explore some of the phenomena previously learned in a time-independent setting, plus much more!

Contact

Dr. Frank Marsiglio (fm3@ualberta.ca)

12 How do charged particles behave in the presence of a magnetic field?

Electrons reorganize their behaviour in profound ways in the presence of a magnetic field. They tend to form what are known as Landau levels, and form wave functions that are the analogue of their classical counterpart (i.e. cyclotron orbits). But when edges are present (they always are!) this behaviour changes (hence we get exotic phenomena like he Quantum Hall Effect) and we would like to study various geometries where the surface of the sample plays a significant role. You will get to explore gauge transformations, but in a “down to earth” way, and actually work some out on a computer!

Contact

Dr Frank Marsiglio (fm3@ualberta.ca)

13 A modified Airy function approach to tunnelling problems

The WKB (Wentzel-Kramers-Brillouin) approximation to solving tunneling and bound state problems in quantum mechanics works very well for energy eigenvalues. It is significantly less accurate for the wave functions themselves, and in some sense the procedure for determining the wave functions is not well-defined. In contrast, the modified Airy function approach is far more accurate for the wave functions. It would be nice to write a pedagogical journal article explaining these distinctions, and tackle a problem like the double well potential, for which both exact numerical and WKB results are available, but the modified Airy solution is not.

Contact

Dr Frank Marsiglio (fm3@ualberta.ca)

14 Surface vs Bulk Superconductivity

The theory of superconductivity (BCS) is best understood in wave vector space, where use is made of the translational invariance in the problem. Many experiments (e.g. tunneling via the STM (scanning tunneling microscope), only probe the surface; this region can look very different compared to the bulk. We wish to explore the key differences, including essential differences in the symmetry of the order parameter, and assess how faithfully so-called surface probes can determine the bulk properties of a superconductor.

Contact

Dr Frank Marsiglio (fm3@ualberta.ca)

15 Ultrasound imaging of long bones

The cortex of long bone is a hard tissue layer bounded above and below by soft tissue and marrow, resulting in high impedance contrast interfaces, and therefore is a natural waveguide for ultrasonic energy to propagate. The velocities of the guided modes are different and sensitive to the cortical thickness and the elasticity of the propagating medium. We are a research team to use ultrasound to study bone tissues. The research involves multi-disciplines involving signal/image processing techniques, numerical simulation, and machine learning. This is joint work with Professor Mauricio Sacchi. I am looking for a student who has good signal processing skills to analyze the data. Knowledge with machine learning is an asset. It is possible for qualified candidate to apply for NSERC summer internship.

Contact

Dr. Lawrence Le (lawrence.le@ualberta.ca)

16 Electromagnetic wave propagation in inhomogeneous plasmas.

Lasers can deliver and deposit energy in gases or solids creating new states of matter with applications to particle accelerators, thermonuclear fusion or laboratory astrophysics. Our research has explored many of these applications. They often involve basic properties of electromagnetic waves propagating in the inhomogeneous plasmas where the waves reach their turning points, will be reflected and give rise via mode conversion to new electrostatic and electromagnetic modes. We are seeking a student with a solid background in differential equations, special functions and an interest in classical electrodynamics who will be able to find analytical solutions to wave equations describing such electromagnetic wave propagation. Results of this study will be compared with and guided by the large scale kinetic simulations and experimental measurements.

Contact

Dr. Wojciech Rozmus (wrozmus@ualberta.ca)

17 Plan and design a nuclear magnetic resonance (NMR) detector

Spin-polarized noble gases are used in magnetometric applications such as magnetic resonance imaging (MRI) and chemical analysis via NMR. Our lab is developing a novel nuclear spin polarizer. NMR detection will be used to characterize the polarizer's performance. The project will aim to plan and design an NMR detector for this purpose. The student will design the coil system, estimate the magnetic field strength and uniformity through theoretical and numerical models (e.g. in COMSOL), and choose the detection scheme (e.g. adiabatic fast passage or free induction decay). The student will also design any necessary mechanical supports for custom fabrication and plan for the driving electronics. If time allows, the student will carry out experimental component fabrication and characterization.

Contact

Dr. Gil Porat (gporat@ualberta.ca)

18 Molecular Biophysics (Various Topics)

1) Mechanical properties of coronavirus RNA structures. We are studying a structure called a pseudoknot that is essential for coronavirus replication. This project involves using optical tweezers to unfold and refold single RNA pseudoknot molecules, looking at mutations that are known to reduce the ability of the virus to propagate. The goal is to understand better how the mechanics of the RNA folding/unfolding relate to the function of this structure in the virus.

2) Binding of small molecules to coronavirus RNA. We are investigating the use of small-molecule drugs that bind to RNA pseudoknots to treat coronavirus disease (even with effective vaccines for COVID-19 becoming available, treatments for coronaviruses are still needed). This project involves biophysical characterization of the interaction of potential drugs with coronavirus pseudoknots, using surface plasmon resonance and examining RNA from a wide range of coronaviruses to test for potential broad-spectrum activity.

3) Molecular dynamics simulations of coronavirus pseudoknots. Molecular dynamics simulations of RNA structure help us to interpret the results of optical tweezers measurements of folding and X- ray scattering studies of structure. This project involves performing all-atom simulations of coronavirus pseudoknots and important mutants that are being studied experimentally.

4) Single-molecule mass photometry of protein aggregation. Single molecules of protein can be "weighed" with interferometric light scattering measurements, because the scattered light is proportional to the mass. This project involves monitoring the growth of aggregates of proteins that cause neurodegenerative disease, watching how the populations of aggregates change over time and quantifying the effects of small-molecule inhibitors.

5) Single-molecule studies of protein misfolding. We study a variety of proteins that misfold to cause disease. This project involves using optical tweezers and/or other biophysical methods to understand better how these proteins misfold and how misfolding can propagate between molecules.

6) Studies of transition paths in folding. Transition paths are the most important part of folding reactions. This project involves experimental, theoretical, and/or computational study of transition path properties grounded in measurements using optical tweezers.

Contact

Dr Michael Woodside (mwoodsid@ualberta.ca)

19 Grey-body factors and quasinormal mode calculations of black holes

Black holes left in isolation may emit radiation by two mechanisms. Either by Hawking radiation or as a result of its ring-down after being formed, or some other perturbation. Both types of radiation are characteristic of the black hole and, in principle, allow a determination of it properties. Recent and future gravitational wave detectors aim to measure the characteristic quasinormal modes. These measures could allow alternative theories of gravity, that incorporate aspects of supposed quantum gravity, to be tested. The two most popular approaches to investing possible quantum aspects of gravity included loop quantum gravity and superstrings.

The student will perform numerical calculations of radiation transmission (grey-body factors) and complex frequencies of the radiation (quasinormal modes) for different black hole metrics. A knowledge of general relativity is desirable but now essential. A strong background in mathematical physics and computing would be an asset.

Contact

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