1) PHYSICS-ENGINEERING

Characterizing correlated avalanches in silicon photomultipliers for the nEXO neutrino experiment

Principal Investigator: David Moore, Tutor: Avinay Bath

Liquid xenon (LXe) time projection chambers are a leading technology for several rare event searches in nuclear and particle physics, including searches for neutrinoless double beta decay. A key challenge in these detectors is to collect the vacuum ultraviolet (VUV) scintillation light from particle interactions in the LXe with high efficiency and using low radioactivity sensors. For this reason, the nEXO experiment on the search for neutrinoless double beta decay will employ approximately 4.5 m^2 of silicon photomultipliers (SiPMs) directly sensitive to 175 nm light. SiPMs are sensitive to single photoelectrons (PE) produced by incident photons, which induce an avalanche in a single pixel, giving high gain $>10^6$. However, in addition to the primary photon induced avalanche, secondary avalanches can be induced by processes such as cross talk between neighboring pixels or after pulsing. These sources of correlated avalanches can have important consequences for the detector-level resolution of systems employing SiPMs.

The goal of this project is to measure the level of correlated avalanches for candidate SiPM devices for nEXO for SiPM devices produced by two manufacturers: Fondazione Bruno Kessler (FBK) and Hamamatsu Photonics (HPK). This project will involve measuring candidate SiPMs cooled to -100 C in the LXe test stand at Wright Lab at Yale, analysis of the acquired data, and modeling of the expected impact on the nEXO detector resolution based on these results. Additional characterization measurements of the SiPMs including estimates of their photon detection efficiency from source calibration data and stability of operation over time in LXe can be pursued if time permits. The project will be carried out under the supervision of Asst. Prof. David Moore and postdoctoral scholar Dr. Avinay Bhat.

2) PHYSICS-ENGINEERING

Operation of a Liquid Argon TPC with pixelized charge readout

Principal Investigator: Antonio Ereditato, Tutor: Domenico Franco

The DUNE experiment is a project for neutrino physics studies in preparation in the US. It will consist of two large detectors along the world's most intense neutrino beam from Fermilab to the Sanford Underground Research Laboratory in South Dakota, 1300 kilometers downstream of the source, where the detectors will be located deep underground. The setup is complemented by a Near-Detector complex, whose task will be to track particle interactions near the source of the beam, at Fermilab. The core component of the complex will be the ArgonCube Liquid Argon detector. More specifically, ArgonCube introduces several improvements in TPC design and technology: 1) the use of a resistive shell for shaping the field required to drift electrons instead of a classical metal field cage; 2) pixelated charge readout instead of classical wires plane allows a 3D reconstruction for unambiguous particle tracking; 3) last, but not least, the detector features a large area photon detection system for an efficient collection of the primary scintillation light emitted by the liquid Argon.

Yale University, as part of the Near Detector DUNE Consortium, is carrying on a hardware project with the aim to provide a benchmark for ArgonCube operation, especially for charge and light readout. The Yale group is developing the LAr System (LArRY) in which a so-called "single cube" will be installed. The system will include the argon recirculation a purification circuit, a purity monitor, and a 30 cm x 30 cm TPC read by LArPixel and ArCLight. The student will be involved in various experimental activities, from building to running a cryogenic apparatus, testing light and charge readout, writing DAQ and slow control software, and designing, building, and assembling a LAr purity monitor. He/she will also acquire knowledge about running a full LArTPC, basic frontend electronics, and data analysis.

3) BIOLOGY-MEDICINE-CHEMISTRY-ENGINEERING

PET imaging of activated T cells in animal models of head and neck cancer

Principal Investigator: Bernadette Marquez-Nostra, Tutor: Samantha Katz

The goal of this project is to investigate the ability of a positron emission tomography (PET) molecule called ^{18}F-AraG to track the mobility of activated T cells in animals with head and neck cancer after treatment with immunotherapy. We will compare the PET imaging results with the levels of T cells in tumor tissues. The student will learn how to design experiments and analyze data for PET imaging, confocal microscopy, and autoradiography. The students will also learn how to establish tumors in mice. The most relevant instrumentation subjects will be: small animal PET scanner, fluorescence microscope, phosphor imager, microtome tissue slicer, and confocal microscopy.

4) BIOLOGY-MEDICINE

PET and fMRI of sleep disturbance and cigarette smoking

Principal Investigator: Evan Morris, Tutor: Jocelyn Hoye

There is a great interest in exploring the causal effects of sleep disturbance on substance use disorder. Dopamine release is central to feelings of craving and reward and thus critical to the understanding of substance abuse. Drug-induced dopamine release has also been linked to impulsivity and poor decision-making. Our group at Yale has previously established a relationship between the presence of a chemical stressor and enhancement of dopamine release in healthy subjects and in smokers. We are currently investigating the connections between sleep disorder and relapse to smoking in cigarette smokers using two types of functional brain imaging, PET (positron emission tomography) and fMRI (functional magnetic resonance imaging). PET and fMRI are complementary imaging modalities. In the present project, PET is used to image the dopamine system; fMRI is used to image the circuitry of inhibition. Smokers undergo PET and fMRI exams both in a sufficient-sleep and a sleep-disturbed state. The quality of sleep on the nights preceding the scans is monitored by a wearable device. This is a complicated experimental protocol that requires a team of investigators to exercise good communications skills, fast decision making, and prudent data analysis and interpretation. We have an opportunity for a summer intern to get involved in our project by helping us manage human volunteers during our experiments as well as to analyze data from brain scanners (images) and from the wearable devices. The student would be expected to be involved in all aspects of the project and to participate in all routine logistical and scientific meetings with the team of investigators.

5) BIOLOGY-MEDICINE-ENGINEERING-INFORMATICS

Perfusion imaging of brain metastases after gamma knife irradiation with DCE MRI.

Principal Investigator: Mariam Aboian, Tutor: Leon Jekel

The project is based on advanced novel imaging techniques for functional and microstructural characterization of brain metastases. The student will be involved in the application of novel dynamic contrast enhanced (DCE) perfusion and PET imaging for characterization of ambiguous cerebral lesions in patients with history of radio surgically treated brain metastases within the framework of the PURSUE and REVELATE study. These novel imaging techniques will allow for quantification of surrogate markers of metabolic activity, vascularity and capillary leakage and enable a better understanding of underlying biological mechanisms leading to radiation necrosis and tumor recurrence. This will ultimately improve differentiation of these pathologies, which poses a challenging task in clinical practice.

The student will gather first-hand experience in image interpretation of advanced MRI scans under close supervision on site, insights into neurooncological management of brain metastasis patients, obtaining knowledge of basics in 3D image processing and machine learning applications in neuroradiology, and knowhow of manuscript writing and good scientific practice in a computational lab. The experimental activities will include training in perfusion image reprocessing and interpretation of cerebral perfusion MRI and PET scans, data analysis, and the possibility to take part in development of machine learning model for differentiation of radiation necrosis from tumor recurrence in irradiated brain metastases

6) BIOLOGY-MEDICINE-ENGINEERING-INFORMATICS

Longitudinal volumetrics as a treatment assessment method in pediatric low grade gliomas with PACS based tools

Principal Investigator: Mariam Aboian, Tutor: Marc von Reppert

One ongoing research project of our group centers around pediatric brain tumors. The student will be studying imaging and molecular features of low-grade pediatric gliomas as well as recent innovations in rapid-protocol MRI such as synthetic MRI and AI-based reconstruction MRI. At the heart of the project lies the imaging analysis of two multi-institutional clinical trials conducted by the Pediatric Neuro-oncology Consortium (PNOC), which investigated response of everolimus (PNOC001) and vemurafenib (PNOC002) in pediatric patients with recurrent low-grade gliomas. As these are typically indolent and slow-growing tumors, an endpoint needs to be determined that accurately reflects therapeutic benefit at an early stage. We assess volumetrics of these pediatric tumors in our research PACS and compare changes in progression-free survival, inter-reader variability and discordance in overall response assessment. As of today, growth dynamics of pediatric low-grade gliomas which are characterized by their particularly variegated imaging appearance have not been described about individual components of the tumor such as enhancing, edematous and cystic portions.

The student will be involved in neuroradiology and recent advances in the field of radiology including the application of artificial intelligence in the medical field, with the possibility to collaborate in other ongoing projects such as a Reverse Image-Based Search tool that the group is developing. Through the work in our group the student will gain basic skills in the clinical interpretation of pediatric and adult brain tumors, potentially other clinical aspects as well, depending on their particular interests.

7) BIOLOGY-MEDICINE-ENGINEERING

Phantom development for prostate DWI

Principal Investigator: Gigi Galiana, Tutor: Nahla Elsaid

Diffusion weighted MRI is increasingly recognized as a critical tool in PC (https://www.pcf.org/c/prostate-mri-part-1/). We have invented and built an MRI hardware accessory that is expected to ultimately double signal and contrast in diffusion weighted MRI. The summer project proposed here will build an MRI-mimic, aka a "phantom", of a prostate with lesions of various grades, which will be used to initially test performance of the hardware. The student will research the solutions and concentrations needed to achieve the MRI properties of each tissue. They will then design and source (or 3D print) an appropriate container for the various compartments. Finally, they will build and image the phantom, which will allow us to quantify the achieved properties of the phantom.