Statement of Research

I developed a novel directional event reconstruction algorithm for high-energy $\gtrsim$GeV scale neutrinos while working with KamLAND (Kamioka Liquid Scintillation Antineutrino Detector), and demonstrated with data that this technique can be applied to indirect dark matter search by looking for a directional flux of neutrinos from the core of the Sun and Earth. Studies done with Monte Carlo suggest that the accuracy of deducing the neutrino direction using this new method is better than that of water-Cherenkov detectors (the conventional method for directional neutrino detection) by $\sim 10^\circ$ in this energy regime. This method was verified using never before observed neutrino events spilling into KamLAND from the T2K neutrino beam-line. The results were consistent with expectation. According to my knowledge, this is the first ever physics application of neutrino directionality in scintillator.

My work with KamLAND further involved demonstration of topological event imaging techniques, originally developed in the LENA (Low Energy Neutrino Astronomy) collaboration, using data for the first time. The $\sim 3.5\,\mathrm{ns}$ timing resolution of the PMTs (photomultiplier tubes) employed in KamLAND are not good enough to do a detailed imaging. Nevertheless $\gtrsim$GeV muon tracks can be well resolved as well as the overall direction of the final state particles to resolve the incoming neutrino direction. In addition $\frac{\mathrm{d}E}{\mathrm{d}x}$ profiles were investigated to perform unprecedented particle ID studies in scintillator.

The above studies required me to use the GENIE neutrino event generator and perform unusually high energy (1 GeV to 100 GeV) Geant4 Monte Carlo simulations in scintillator. The difficulty that lies here is in the large amounts of computing power necessary for a faithful reproduction of the physics with such a vast number of photons produced. The way I mitigated this problem was to do an initial *sparse* simulation only using certain physics in crucial detector parts first, and then, to control the evolution of the random number generator such that individual events can be hand picked at a later time to further simulate additional physics or detector volumes. In this way, I was able to reduce the computing time to a minimum while still incorporating precision physics. A paper for my work is currently under preparation.

In addition, I have worked as the lead Geant4 simulation designer for the mini-TimeCube collaboration at University of Hawaii at Manoa. mini-TimeCube is an ambitious project to build the world's smallest portable neutrino detector. In this project, I mentored 3 undergraduate students and worked in collaboration with them to conduct case studies for optimizing the detector design, test candidate neutron capture doping elements in plastic scintillator, and simulate the response of the multi-channel-plate (MCP) PMTs deployed in the detector. These studies were used during construction of the detector, and to develop directional algorithms that are now being tested in analyses of neutrons from test sources as well as neutrinos from nuclear reactors. Working with the mini-TimeCube project has further involved designing and fabricating PCB boards as well as contributing to the FPGA firmware for the readout electronics. A paper summarizing our accomplishments was published in 2016 (V. A. Li et al. Invited Article: miniTimeCube. Rev. Sci. Instrum., 87(2):021301, 2016, 1602.01405).

I have been involved with the CUORE (Cryogenic Underground Observatory for Rare Events) experiment at the University of California, Los Angeles since 2016. The main objective of the CUORE experiment is to hunt for neutrinoless double beta ($0\nu\beta\beta$) decay using ^{130}Te using a tonne-scale array of bolometers in a cryogenic environment. My current role is to lead the development of a precision alpha background model. The energy spectrum of the backgrounds in the so-called alpha region ($\gtrsim 2.5\,\mathrm{MeV}$) exhibits peculiar features that, if understood correctly will better explain the types of background sources and their distributions in the detector parts. This can help us to better understand our backgrounds and to extrapolate this knowledge to the energy region of interest (2465 keV to 2575 keV) for $0\nu\beta\beta$ decay search in ^{130}Te. I have also been heavily involved in the thermal modeling and optimization of the signal processing for the recent upgrade from CUORE-0 to CUORE which increased the detector mass by a factor of almost 20. A paper for our first $0\nu\beta\beta$ analysis using CUORE data was submitted for publication to PRL in late 2017, and is currently under review (https://arxiv.org/abs/1710.07988)