

Session X Abstracts

Construction and Testing of Low-Energy α - and β -Particle-Tracking Detector Prototype

Daniel Sotolongo

Mentors: Sunil Golwala and Robert Nelson

The Cryogenic Dark Matter Search is searching for evidence of Weakly-Interacting Massive Particles as a candidate for dark matter. The dominant background for this type of experiment is low-energy electrons emitted by radioactive contaminants on detectors' surfaces. Therefore, a detector capable of screening these crystal detectors for contamination at each step in their manufacturing process was needed. The proposed detector, dubbed the Betacage, is a drift chamber with energy resolution of a few keV. The Betacage is composed of several wire grids charged to $\sim 3\text{kV}$, a voltage that creates an electric field strong enough to cause an electron avalanche around a given wire from only a few ionized particles. These avalanches are read as pulses on the grids, which are reconstructed into a 3D path. The construction of the prototype, composed of only 1 grid and smaller than the final design, has revealed and resolved problems that would have been considerably more problematic at full scale. The prototype has confirmed the feasibility of the design, and work will soon begin on a larger-scale fully-functional prototype.

Pattern Formation With Two-Dimensional Array of Trapped Ions

Joon Ho Lee

Mentor: Michael Cross

Abstract is not available.

Analysis of Energy Estimation From NOvA Detector Data

James Scott

Mentor: Ryan Patterson

Determining the energy of a neutrino accurately is important for studying neutrino oscillations. The detector for NOvA, which is made of many cells of scintillator, is able to detect the outgoing particles from a neutrino interaction, which can then be used to reconstruct the event and thus the neutrino energy. Any reconstruction will have uncertainties introduced by limits in the resolution of the detector, as well as random variations and noise. Knowing the magnitude of the uncertainties is important not only for assigning uncertainty in measurements, but also in guiding detector calibration approaches and in determining the theoretical and practical limitations of the oscillation measurements. By analyzing simulated detector data the uncertainties can be determined for the various interactions.

Crowdsourcing for Event Classification in NOvA Particle Physics Experiment

Shiyu Zhao

Mentor: Ryan B. Patterson

The NuMI Off-axis ν_e Appearance Experiment (NOvA) aims to probe the nature of neutrinos through the phenomenon of neutrino oscillation. Its main goal is to search for the oscillation of muon neutrinos (ν_μ) to electron neutrinos (ν_e), which requires accurate discrimination between ν_e Charged Current (CC) events and other background events. Some of the background events, such as some Neutral Current (NC) events, may produce very similar patterns to ν_e CC events in the liquid scintillator detector, and are thus difficult to recognize by computers. We present a method that uses crowdsourcing for event identification. This method first filters out computer-recognizable events, such as most ν_μ CC events and some NC events, and then gathers the most ambiguous events into an event library for users to classify. We implement a prototype of such a crowdsourcing platform as a web application, capable of training and incentivizing users, and classify events according to user judgment. Upon further testing, this method may be used to improve the accuracy of event identification in NOvA.

Thermometry of He³ Fridge

Chen (Chris) Gong

Mentors: Keith Schwab and Emma Wollman

The Schwab group is in the process of building and testing a He³ fridge to measure the properties a microwave amplifier and graphene bolometer. The He³ fridge is designed to reach 300mK in its coldest stage. My work consists of the electronics of the fridge, which are the thermometry and the cryogen level detecting circuit. The precise measurement of the temperatures at various places in the fridge is a very important diagnostic tool for understanding the heat conduction circuit in the fridge. Since the measurements are done at very cool temperature, the design principle of the thermometry circuit is to limit the heat dissipation from the sensor as well

as the heat conducted through the wires. Using four-wire sensing and lock-in amplification in this circuit we are able to maintain a high sensitivity while limit the current which might generate heat. The two circuits are currently still in testing stage.

Barium Tagging for the Enriched Xenon Observatory

Lauren Gilbert

Mentors: Martin Briedenbach, Liang Yang, and Maria Spiropulu

One key component of the full Enriched Xenon Observatory (EXO) will be the in-situ tagging of xenon double beta decay daughter nucleus, barium. Such a tagging technique can significantly reduce radioactivity-induced background and increase the experiment sensitivity. Current R&D focuses on firstly, removing the barium from a platinum surface with a 750 mW Nd:YAG laser, and secondly, correctly identifying the barium ions with a time of flight spectrometer. While there is not enough data to draw any substantive conclusions, the early results look promising.

Analysis of the Electrical Characteristics of Micro-Superconducting Quantum Interference Devices (μ -SQUIDs) Fabricated Under a Trilayer Nb-AlO_x-Nb Process

Joshua Yoon

Mentors: Kathryn Moler and Keith Schwab

Superconducting quantum interference devices (SQUIDs) are known for its high field sensitivity, which has allowed magnetic and electronic materials research to take a leap forward in pursuit of new discoveries in many different areas. Although there is a growing number of books and articles that well-describe intrinsic properties of SQUIDs, it is of our interest to look at both its characteristic current-voltage (I-V) and flux-current (Φ -I) curves in our efforts to better understand its relationship with its unique fabrication process. Since SQUIDs reach a superconducting state only at low temperatures, we immerse it in liquid ⁴He, and using a four-terminal configuration, we apply a sinusoidal current through the device loop and measure its voltage. By extracting its primary electrical parameters from the data gathered, the modulation amplitude tells us the size of the signal available from the SQUIDs and the I-V curves provides us with critical current values and its dependence on external flux. Data analysis show critical current vs. applied flux curves which are shifted relative to each other for certain devices, indicating asymmetry in the junction arms. In addition, critical current values seem higher for some devices than others. These results indicate that the SQUIDs that were tested underwent a non-uniform fabrication process, consequently producing undesirable devices that have either too high or low of a critical current or too small of a modulation amplitude. By adjusting the fabrication procedure in some way, which is yet to be determined, a higher yield of SQUIDs with a critical current range of ~10-15uA is possible in the future.

Coherence of Majorana Qubit in a Topological Superconducting Wire Undergoing a Phase Slip Event

Samuel Goldberg

Mentors: Gil Refael, Doron Bergman, and David Pekker

Recently, it has been suggested that topological states of quantum matter, those determined by the global properties of the system, may provide a decoherence-free realization of quantum computing. We are investigating the properties of one possible candidate: the spin-polarized p-wave superconductor wire. The quantum information is stored as a pair of Majorana modes located at the ends of the wire that together form a delocalized fermion state of zero energy. The goal of this project is to calculate the effect of superconductor order parameter fluctuations on the state of the Majorana qubit. In particular, we investigated the effect of a phase slip event, a fluctuation where the order parameter vanishes at a point, allowing the superconducting phase to unwind. We have found that a phase slip changes the delocalized fermion number and creates a bulk quasiparticle excitation with the energy of the superconducting gap. A second phase slip returns the delocalized fermion number to its initial value and destroys the quasiparticle. However, the unoccupied component of the Majorana qubit gains a Berry phase of $-\pi$ relative to the occupied component. Phase slip events, therefore, will compromise the coherence of the qubit.

Chemical Effects of Ice Crystal Growth

Nina Budaeva

Mentor: Kenneth Libbrecht

The prediction of ice crystal growth rates and morphologies is a difficult problem which depends on nucleation dynamics, temperature history, chemical makeup of the sample, and many other parameters. This project investigates the effects of solute chemistry on the growth of ice crystals. By varying the physical parameter space of nucleation temperature and solution concentration, I am able to observe changes in the ice crystal growth of various water solutions.

The ice crystals are grown in a wire loop and are recorded on camera so that their growth rates and morphologies can be observed from the recordings. Solutions of particular interest are salt and sucrose solutions as well as nanoparticle suspensions and antifreeze protein solutions. The results of these experiments, besides providing scientific insight into an insufficiently-explored field, may also prove useful for direct applications such as in freeze-drying of pharmaceuticals.

Pauli-Based Local Commuting Projector Codes

Mohit Tiwari

Mentors: John Preskill and Jeongwan Haah

If A_i and B_i are commuting Pauli operators, then $P = \frac{1}{4}(1 + A_i + B_i + A_i B_i)$ is a projector. We can define a quantum code whose code space is the ground space of a governing Hamiltonian $H = \sum P_i$. We first provide a worked example with $A_1 = ZXZI$, $B_1 = YXYI$, $A_2 = IZXZ$, $B_2 = IYXY$. We then examine different choices of P_i and the Hamiltonian, which does not necessarily need to be taken to be the sum of the P_i , with the operators A_i and B_i taken to be the star and plaquette operators of the Toric Code proposed by Kitaev. We are interested in the logical operator algebra of such codes and implications for code distance and the existence of topological order in these systems.

Spectral Gap Scaling of One Dimensional Quantum Spin Chains

Travis Scholten

Mentors: John Preskill and Spiros Michalakis

Frustration-free Hamiltonians which are the sum of two-qubit projection operators have been considered as models for adiabatic quantum computation. The run time of such computation is determined by the scaling of the spectral gap with system size; in general, this property is not well understood. We show that the number of free parameters in any such Hamiltonian may be reduced to three real parameters and consider the decay of the gap with respect to the number of qubits. We present numerical results from a DMRG algorithm. For certain values of the real parameters, the scaling is shown to be an inverse polynomial of the system size.

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Matthew T. E. Heydeman

Mentor: John Preskill

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The Role of Elastic Interactions in Bacterial Chemoreceptor Organization and Function

Peter D. Koch

Mentors: Rob Phillips and Christoph A. Haselwandter

We investigate the role of membrane-mediated elastic interactions in the spatial organization and function of bacterial chemoreceptors. It is believed that the smallest functional units of chemoreceptors are trimers of dimers which, upon binding to periplasmic ligands, initiate the chemotaxis signaling cascade. Many types of membrane proteins, including chemoreceptors, exhibit a hydrophobic mismatch with the surrounding lipid bilayer, thereby inducing thickness and curvature deformations of the lipid membrane. The energies of the membrane deformations induced by chemoreceptor trimers can be calculated using elasticity theory. We numerically compute these energies using a finite difference scheme. We first study the energetics of two interacting chemoreceptor trimers and find that our numerical results are in good agreement with previous analytical calculations, as well as previous numerical studies of related problems. Next, we study the energetics of chemoreceptors in lattice structures, as recent electron cryo-tomography studies have shown that chemoreceptor trimers form regular lattices which appear to be conserved across the bacterial kingdom. In particular, we examine how the total membrane deformation energy depends on the type of lattice symmetry and on the orientations of the chemoreceptor trimers within the lattice. Lastly, recent *in vivo* FRET studies have shown that bacterial chemoreceptors engage in cooperative signaling, and various theoretical models have suggested that this cooperative behavior is crucial for the high sensitivity of the chemotaxis signaling pathway. We study whether elastic interactions may promote such cooperative behavior among chemoreceptors, and whether lattice symmetry and trimer orientation may provide a mechanism for the observed size of cooperative signaling teams of chemoreceptors.