Physics Session R

Room: 111 Keck

Time-Based Vertex Reconstruction in the Compact Muon Solenoid
Ben Bartlett
Mentors: Maria Spiropulu, Adi Bornheim, and Lindsey Gray

The Phase-II upgrades to the Large Hadron Collider will introduce a variety of new measurement devices to the CMS, including the High-Granularity Calorimeter (HGCAL). The increase in luminosity from these LHC upgrades will also have the undesired side effect of vastly increasing pileup to a level at which the current machine learning vertex selection algorithms will cease to be effective. This will necessitate the development of further vertex reconstruction (vertexing) algorithms. Using high precision timing measurements from simulated events in the HGCAL, we design a vertexing algorithm that requires only the spatiotemporal arrival coordinates to reconstruct the interaction vertex of a collision with sub-millimeter resolution. We also analyse how particle energy and simulated time smearing affect this resolution and we apply this algorithm to more complex data sets, such as \( H \to \gamma\gamma \), jets, and high-pileup events. For these, we implement a set of secondary algorithms and filters to remove poorly-reconstructed events, account for premature interactions, and resolve reconstruction ambiguity.

Study of the CMS ECAL Calibration and Timing Performance With \( \pi_0 \) Decays at 13 TeV
Kai Chang
Mentors: Maria Spiropulu, Adi Bornheim, and Emanuele Di Marco

The CMS ECAL is capable measuring the energy of high energy photons with a precision of about 1% and their time of arrival in the detector with a precision of around 100 ps. The calibration of the detector in situ with neutral pion decays into two photons is a crucial step to achieve the energy resolution performance. To date the timing response is calibrated with generic calorimeter clusters which have the characteristics of electromagnetic interactions. One important systematic effect limiting the timing performance is the radiation induced transparency change of the crystals. This modifies the optical path of the scintillation photons in the crystals which changes the time response. In this project the measurement of the crystal transparency will be used to study this dependency and derive a correction for the timing measurement. The \( \pi_0 \) calibration sample and analysis framework will serve as a clean benchmark sample to test the corrections.

Timing Resolution Studies of Hamamatsu Silicon Photomultipliers
Eric Liu
Mentors: Maria Spiropulu, Si Xie, Artur Apresyan, Anatoly Ronzhin, and Cristian Peña

Photodetection technology has wide application in modern scientific and commercial fields, from spectrometry to subatomic particle detection. Timing precision of detectors is critical in the performance of modern particle detectors, which calculate particle masses using strong magnetic fields and precise time-of-flight measurements. Silicon-based photodetectors are currently in use in the Large Hadron Collider (LHC), since silicon's performance and timing precision are largely unaffected by strong magnetic fields. The current detectors have a time resolution of 200-300 ps, which is an order of magnitude too large to handle the increased collision rate of the next LHC upgrade. Sample detectors from the next generation of silicon photodetectors were tested using picosecond-duration laser pulses.
Machine Learning for Fast Data Transfers at the Large Hadron Collider
Nikhil Krishnan
Mentors: Maria Spiropulu and Dorian Kcira

The Large Hadron Collider (LHC) is the most powerful particle collider in the world, and the Caltech Compact Muon Solenoid (CMS) group produces massive amounts of data in its experiments at the LHC. As a result, the CMS group has its own infrastructure for data transfers, implementing grid-based data analysis and global-scale networking. Because the CMS experiment generates voluminous amounts of data, there needs to be a way to improve the current data management tools to optimize speed of transfers and facilitate fast I/O access. Machine learning offers numerous methods for such an optimization, as the field allows us to look at the present state of the network and use information about recorded transfers to predict features about future data transfers, thereby reducing the number of variables the data management tool has to consider. Using logged information from PhEDEx, the CMS data transfer system, we created a large sample matrix of data transfers, partitioned it into testing and training samples, and conducted Principal Component Analysis, a machine learning method that projects a large multivariate dataset onto the two variables that most explain variance. We also worked on constructing a deep learning neural network between various nodes of the CMS group, allowing the data management tool to learn by itself over time and optimize data transfers based on completion time.

Developing a Search for Dark Matter Direct Production Using Razor Variables in Proton-Proton Collisions at 13 TeV
Jared Filseth
Mentors: Harvey Newman, Maria Spiropulu, Cristian Peña, and Javier Duarte

Dark matter makes up 27% of the mass-energy budget of the universe, but still remains elusive today. In recent years, searches for dark matter production in proton-proton (pp) collisions have been carried out up to a center of momentum energy of 8 TeV. This project involves improving and reengineering the analysis methods used on 8 TeV data, so that they can be applied to new 13 TeV data. These methods involve looking at razor variables, which are used to quantify the imbalance in transverse momenta in each collision. In order to update these methods, I have been measuring quantities such as the trigger and lepton efficiencies for simulated events as well as Compact Muon Solenoid (CMS) data. Further studies would involve finishing the search, using these methods, once a sufficient integrated luminosity has been recorded.

Development of a Control System to Stabilize Magnetic Fields Outside an nEDM Detector
Anita Kulkarni
Mentors: Bradley Filippone and Simon Slutsky

Experiments over the past several decades have attempted to measure a neutron electric dipole moment (nEDM) with greater and greater sensitivity. The presence of a nonzero nEDM would lend support to potential explanations of matter-antimatter asymmetry, among other ramifications. A highly uniform magnetic field is required to detect a dipole moment at high precision since non-uniformities can create false signals through the geometric phase effect. The uniformity of the field inside the detector can be improved by reducing the magnitudes of magnetic field disturbances outside the detector. To do this, we program a system that controls the currents flowing to a network of six large coils (connected in pairs) around the detector in three spatial directions. The currents are programmed to generate magnetic fields that counteract external field disturbances in real time. The system implements Proportional-Integral-Derivative (PID) control of currents based on magnetic field readings from eight probes near the detector. Continuous improvements are being made in the system’s performance, and finer control could be obtained in the future by powering the six coils separately and modifying the control system accordingly.

Magnetic Field Profile of a Third-Scale Model for the nEDM Experiment
Aritra Biswas
Mentors: Bradley Filippone and Simon Slutsky

Discovery of an electric dipole moment in neutrons (nEDM) would be a novel instance of CP violation, with implications for extending the Standard Model and potentially helping explain matter-antimatter asymmetry. Experiments using shifts in polarized neutron spin-precession frequency to measure the nEDM are prone to a geometric phase (GP) effect, caused by gradients of the magnetic field, that can create a false signal. Preventing the GP effect requires precise engineering to create a space-uniform magnetic field. We present a third-scale prototype of a shielded magnet suitable for a more precise nEDM measurement, with improvements over earlier models. The field is produced by a cos $\theta$ coil wound with superconducting (SC) wire. Two cylindrical shields made of ferromagnetic Metglas and SC lead surround the magnet; the lead shield is closed on top and bottom with SC lead endcaps. An aluminum shell surrounds these components and serves as a vacuum chamber, cooling its interior to 4 K such that the coil wire and lead shield become SC. A cavity in this shell serves as a warm bore, allowing a magnetic probe to explore the field around fiducial volumes which will be used to measure the nEDM in the full-scale experiment. A magnetic field profile of components of this prototype is presented.
Implementation of Dust Dynamics for Galaxy Formation Simulations
Hyunseok Lee
Mentor: Philip F. Hopkins

We study the behavior of large dust grains in turbulent molecular cloud. Interstellar dust plays a crucial role in many important processes in galaxy evolution, including conversion from neutral to molecular hydrogen and formation of low-mass stars in the early universe. While interstellar dust grains are often modeled to move with neighboring gas flow in numerical simulations, the dust grains in typical molecular cloud does not necessarily move with the gas. We therefore directly simulate dust dynamics in highly supersonic turbulent box. Under these conditions, we study how grain size and flow velocity affect local densities of dust and gas. The results exhibit dramatic fluctuations in the local dust-to-gas ratio, thereby implying large small-scale variations in abundances, dust cooling rates, and dynamics. Further researches can incorporate Lorentz forces and other physics neglected here.

Fabrication of Microlens Arrays Through the MicroAngelo Technique Using Thermocapillary Forces
Soon Wei Daniel Lim
Mentors: Sandra M. Troian and Kevin R. Fiedler

Plano-convex microlens arrays were fabricated using the one-step MicroAngelo technique, which uses strong thermal fields to modulate forces driven by surface tension gradients on a molten polymer nanofilm interface to achieve the desired surface topology. Spatially inhomogeneous temperature gradients were achieved by varying the heights of photoresist elements on a cold plate placed above the polymer film. The fabricated arrays will implement a Shack-Hartmann wavefront sensor, and its optical quality will be compared to that of a commercially available microlens array. The experimental results thus far show that with suitable control over the thermal field, MicroAngelo has the potential to form a diverse spectrum of ultra-smooth surface topologies in a single non-contact fabrication step.

Glass-Ceramic Scintillators for Gamma Ray Detection Applications
Kira Pyronneau
Mentors: Brent Wagner, Zhitao Kang, and William L. Johnson

Scintillators, materials that emit photons in the presence of radiation, have proven to be useful in gamma radiation detection technology. Currently, this technology is created using fragile and expensive single crystal scintillators. However, glass-ceramic scintillators have shown potential for being a cheaper and more durable alternative to what is currently available. For this project, glass-ceramic scintillators with various levels of the dopant samarium were formed. Data was collected on the photon emission of the scintillators in the presence of radiation of various wavelengths. Very defined emission peaks were observed at certain wavelengths in the spectrum. Also, as the amount of dopant was increased in the glass samples, an increase in photon emission was observed. Defined peaks with high amounts of photon emission are ideal for radiation detection in a device which indicates that glass-ceramic scintillators could be used for this application.

Resonating Valence Bond States of Majorana Zero Modes
Jun Ho Son
Mentors: Jason Alicea and Ryan Mishmash

Originally conceived by Anderson in 1973, the resonating valence bond (RVB) wavefunction has stood as the prototypical example of a quantum spin liquid state ever since. In its simplest incarnation in the context of spin-1/2 quantum magnets, the RVB takes the form of an equal amplitude superposition of all nearest-neighbor dimer coverings, where here a dimer represents placing the two spins into a maximally entangled spin singlet state. In this work, we consider generalizations of the canonical RVB concept to systems in which the spin degrees of freedom are replaced by non-Abelian Ising anyons binding Majorana zero modes. In our "Majorana-RVB"(M-RVB) state, a dimer represents fusing two Ising anyons into a particular, common fusion channel, say the identity channel (equivalently, the physical Dirac fermion formed by the two Majorana zero modes is taken to be, say, unoccupied). We proved that the M-RVB wave function on the 2D planar (open boundary condition) square lattice is suitable for Monte Carlo calculations, i.e., it is sign problem free. Based on this construction, we present large-scale numerical calculations of the M-RVB state and show that two-point Majorana-Majorana correlations decay exponentially with separation distance, while dimer-dimer (i.e., parity-parity)correlations decay as a power law. While this indicates that the square lattice state would be the ground state of a gapless local Hamiltonian, we postulate that placing the problem on a frustrated lattice may lead to a fully gapped, nontrivial topological phase.
In an effort to understand the origin of the universe by accurately imaging cosmic microwave background (CMB) radiation emitted right after the Big Bang, the Princeton experimental CMB group has been working on numerous experiments, including the current Atacama B-mode Search (ABS) and Atacama Cosmology Telescope (ACT), as well as the Multimoded Survey Experiment (MuSE) using the detector developed for the proposed Primordial Inflation Explorer (PIXIE) satellite mission at NASA Goddard Space Flight Center (GSFC). Both multimoded optics and the Fourier Transform Spectrometer (FTS) have provided increased sensitivity for CMB polarimetry, allowing better detection and characterization of the polarization signal from an early, inflating Universe. This two part study is the result of the coupled necessity of multimoded optics and the FTS: the objective of the first part is to develop a new user interface (UI) for the FTS to determine bandpasses of required detectors and components by incorporating a producer-consumer state-machine software structure; the second part is to model the frequency-dependent complex impedance and voltage responsivity of multimoded bolometers. While the updated UI will aid in more efficient data collection and control of the FTS for the user, the latter is another step in the optical testing required to further advance the MuSE and PIXIE projects and develop a better understanding of bolometer theory.