Mitchell Institute Computing Report FY2020

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II. Summary of Research Projects: The Mitchell Institute includes a wide variety of research groups in multiple areas of physics and astronomy.

a. Particle Astrophysics (CDMS): Texas A&M is a major collaborating institution in the SuperCDMS dark matter search experiment. It has major roles analyzing the data from the experiment when it was in Soudan, as well as many tasks for the upgraded version under construction at the SNOLAB underground laboratory in Sudbury, Ontario. The Toback group at TAMU, along with a number of remote collaborators, develops and maintains the detector simulation software (based on Geant4), and produces large scale ($O(10^7)$ events) simulation datasets to model expected backgrounds in the experiment, the detector response to both background and hypothesized dark matter particles, and the performance of the data acquisition system with simulated data.

b. Experimental particle physics (CMS): Texas A&M has a strong presence in the CMS experiment based at CERN with a computing emphasis on the search for beyond standard model bosons using the proton-proton collision data (10^{16} collisions) taken during the LHC Run 2. In particular, the Kamon and Safonov groups have created a collaboration between TAMU, Rice and Florida Institute of Technology (FIT) to strengthen a unique physics analysis and re-invent how to explore physics with multi-muons.

c. Experimental particle physics (DUNE): Texas A&M has a long history of working in the area of experimental neutrino physics. Recently, the Toback group has begun working on the Deep Underground Neutrino Experiment (DUNE) stuff, taking a lead role in the simulations of how particles interact in the detectors. We expect to ramp up this task over the next three years.

d. Particle Physics Phenomenology: The phenomenology members of the Mitchell Institute, Dutta and Strigari groups, have a number of efforts on making theoretical and phenomenological predictions for high energy particle physics. This includes a focus on investigating searches for dark matter at stopped-pion neutrino experiments as well as large-dimensional global analysis of neutrino non-standard interactions by combining simulated and real data from neutrino scattering and oscillation experiments.

e. Astronomy (Macri): The Macri group measures the brightness of stars as a function of time ("time-series photometry") using images from various optical and near-infrared surveys of nearby galaxies to better understand the physical properties of several types of stars (Cepheids, RR Lyrae and Miras) that can be used to estimate the distances to other galaxies. Ultimately, these distances will contribute to measurements of the current local expansion rate of the Universe (the Hubble constant) which provides a critical test of the cosmological model.

f. Astronomy (Strigari/Marshall): The Strigari/Marshall group has a focus on studying different models of dark matter in our Universe. In particular, exploring models of self-interacting dark matter by studying the tidal disruption event of dwarf galaxies as they are accreted on to our Milky Way (MW) galaxy. If the self-interacting dark matter (SIDM) interacts by exchanging a light mediator particle such as a dark photon via a Yukawa scattering then the scattering angle between any two dark matter particles is preferentially in the forward direction.

g. Quantum Information Systems (QBits): Members of the Toback group work with PNNL and MIT Lincoln Labs to study solid state quantum computing devices. The Toback group leads the simulation effort to understand the interaction of phonons with qubits, and the evolution of decoherence, which informs device design for the project.

h. Quantum Science (Akimov): The Akimov group works in the area of quantum optics applications, including long-distance quantum networking and optical quantum computing. They focus on the design, fabrication, and characterization of nanobeam photonic crystal cavities based on silicon nitride at visible wavelengths which offers a promising platform for strong coupling in solid-state cavity QED experiments.

III. Publications in FY2020:

The MitchComp group just joined HPRC so there are a lot of activities in progress, but very few have completed to the point of submission.

a. Phenomenology:

- B Dutta, D Kim, S Liao, J-C Park, S Shin, L E Strigari, A Thompson, *Searching for Dark Matter Signals in Timing Spectra at Neutrino Experiments*, https://arxiv.org/pdf/2006.09386.pdf (planned for submission to JHEP)

- B Dutta, R F Lang, S Liao, S Sinha, L E Strigari, A Thompson, *A global analysis strategy to resolve neutrino NSI degeneracies with scattering and oscillation data*, https://arxiv.org/pdf/2002.03066.pdf (accepted for publication in JHEP)

b. Quantum Science

- Alajlan, A.; Cojocaru, I.; Akimov, A. V., *Compact Design of a Gallium Phosphide Nanobeam Cavity for Coupling to Diamond Germanium-Vacancy Centers*. *Opt. Mater. Express* **2019**, *9* (4), 1678–1688

- A Alajlan, M Khurana, X Liu, I Cojocaru, A V Akimov, *Free-standing silicon nitride nanobeams with efficient fiber-chip interface for cavity QED*, arXiv:2006.13580

IV. Applications:

a. Particle Astrophysics (CDMS): The high statistics simulations possible at HPRC provides the detail necessary to inform the design and shielding of the ultralow background SuperCDMS experiment, and the precision background spectra used to search for rare signals in the collected data. The Toback group at TAMU, along with a number of remote collaborators, develops and maintains the detector simulation software (based on Geant4), and produces large scale ($O(10^7)$ events) simulation datasets to model expected backgrounds in the experiment, the detector response to both background and hypothesized dark matter particles, and the performance of the data acquisition system with simulated data.

b. Experimental Particle Physics (CMS): The Rice-TAMU-FIT group combines computing resources from HPRC with those on the CMS grid to simulate and analyze Monte Carlo (MC) events with the CMS detector simulation infrastructure. This includes generating the MC samples remotely, converting them to ntuple files for storage on Terra, the development of analysis code based on the CMS central software (for use on analyzing ~100 TB datasets for billions of events), and perform millions of toy experiments for the expected confidence limits calculations as well as validation purposes. This allows for modelling of signals and backgrounds in order to maximize the discovery sensitivity for the new boson in Vetor Portal Dark Matter models. Recent results from an extension of the multi-muon analysis with models on dark gauge bosons and discussed the physics potential in HL-LHC in 2021 have been presented.

c. Experimental particle physics (DUNE): The use of the HPRC for running and analyzing simulated DUNE data has allowed the Toback group to be part of the Q-Pix consortium that was just granted $1M to do R&D for a major upgrade to the detector. The Toback group has a lead role in analyzing the simulations of how particles interact in the detectors

d. Particle Physics Phenomenology: The Dutta/Strigari group uses the HPRC resources extensively for high performance tasks in high energy particle phenomenology research. A recent focus has been on investigating searches for dark matter at stopped-pion neutrino experiments, utilizing the timing and energy data, which required a detailed simulation of the dark matter production and decay kinematics from the target to the detector. In addition, they performed a large-dimensional global analysis of neutrino non-standard interactions by combining simulated and real data from neutrino scattering and oscillation experiments. Combined, these projects consumed, roughly, 60,000 SUs on the Terra cluster.

e. Astronomy (Macri): Large scale image processing by the Macri group provides the statistics, and precision needed for accurate determination of the Hubble constant and tests of the cosmological model. A recent study required the processing of ~4,500 images, 10 Mpix each, containing a total of ~1.2 million resolved stars.

f. Astronomy (Strigari/Marshall): The Strigari/Marshall group used the HPRC to study different models of dark matter in our Universe. In particular, models of self-interacting dark matter which might cause a tidal disruption event of dwarf galaxies as they are accreted on to our Milky Way (MW) galaxy. By running N-body simulations or dark matter interactions, they found that the resulting tidal arms have markedly different morphologies compared to the case where dark matter doesn't interact or is the usual cold dark matter. In particular, we found the leading dwarf galaxy tidal arm in the SIDM case has significantly more stars than the trailing arm. We also found that the degree of this asymmetry is directly proportional to the magnitude of the scattering cross section. This asymmetry can be directly measured in terms of stellar count asymmetry in dwarf galaxy streams in our Galaxy such as the Sagittarius stream with the help of the sky observatories such Gaia and future ground based telescopes such as the Vera Rubin Observatory. We can then compare this asymmetry to our simulation models and obtain constraints on the model parameters of SIDM and possibly constrain the particle nature of dark matter.

g. Quantum Information Systems (QBits): Members of the Toback group have used the HPRC extensively to study solid state quantum computing devices using simulations to understand the interaction of phonons with qubits, and the evolution of decoherence. These studies will inform device design for the project, allow for comparison of data to understanding, and help produce better quantum computing in the future. This result will form the primary basis for the thesis of Richard Lawrence.

h. Quantum Science (Akimov): The Akimov group used the HPRC system using Finite-difference time-domain method to study the presented the design, fabrication, and characterization of nanobeam photonic crystal cavities based on silicon nitride at visible wavelengths. The design was calculated using TAMU . They were able to demonstrate devices with quality factors higher than 10^4 by scanning laser around the cavity resonance. The device offers promising a platform for strong coupling in solid-state cavity QED experiments. Specifically, we aim to integrate diamond color centers with silicon nitride photonics platform to realize an efficient light-matter interface. In addition to diamond color centers, our device can be used for other single photon emitters such as quantum dots and layered 2D materials. Moreover, we have developed a technique for coupling light from an optical fiber to on-chip suspended Si_3N_4 nanobeam photonic crystal cavities. Utilizing the coupling technique presented here, we demonstrated a coupling efficiency of 96% between an optical fiber mode and a cavity mode. This work is useful for quantum optics applications, including long-distance quantum networking and optical quantum computing.