Statement of Intent

In this application, I hope to convince you of my candidacy for a masters at the University of British Columbia for the faculty of Physics & Astronomy. Ultimately, my goal is to pursue academia in physics as I have a passion for physics like no other. In this vein, I am applying to UBC for its world renown Physics & Astronomy department, and the research done in this department. To promote my candidacy, I will be covering my research experience in the field of physics, particularly my work at SNOLab and TRIUMF, my academic goals in theoretical physics, in differential geometry and general relativity, and will be concluding with my leadership experiences in my research positions and a previous work experience.

Research Experience

I have had two major research positions over my undergraduate career. I worked as an undergraduate research assistant at SNOLab under Chris Jillings, employed by Laurentian University, with the DEAP collaboration where I worked mainly on characterizing Photomultiplier Tubes (PMTs) for the experiment. The second research position was at TRIUMF under Mark Scott and Thomas Lindner in the T2K group working on the construction of the Multi-PMT prototype for the NuPrism extension of T2K.

My USRA at SNOLab with DEAP was over the Fall term of 2017, from September to December. The Dark Matter Experiment using Argon Pulseshape discrimination (DEAP) is a direct detection experiment for Weakly Interacting Massive Particles (WIMPs), which is a Dark Matter candidate. The experiment itself is 2 kilometers underground in Sudbury, Ontario and is a spherical acrylic vessel capable of carrying 3600 kg of liquid argon, the target for detection. During my time at SNOLab I worked under the supervision of Chris Jillings with whom I characterized PMTs used in the DEAP experiment, and checked Dark Rates.

My first task was to move the software used in PMT data monitering to a new cluster, where it was then updated to work properly. I then began in monitering the efficiency of PMTs through their collected data, and marking any underperforming or misbehaving PMTs. This task was important to the analysis of the data as it warned the analysts of data that should be considered incorrect. My final task was working on Dark Rate analysis for the PMTs and comparing with the results of another part of the group.

Many of the weekly results I obtained from PMT data monitoring were presented at the weekly group meetings, and I presented my work on Dark Rates to parts of the collaboration in Germany. My supervisor guided me in the work by providing end goals, but otherwise I was left to work out the problems on my own and required me to teach myself as much as I could. This involved learning a completely new coding language, `C++`.

My second relevant research experience was at TRIUMF working on T2K. T2K is a long baseline experiment based in Japan whose primary goal is to study neutrino oscillations. The experiment sends neutrinos produced in Tokai to a water Cherenkov tank in Kamioka (hence T2K), and uses the detected neutrino flavour, which is based off of the neutrino's interaction via the weak force. The main goal of the project was to assist in the construction of the Multi-PMT (mPMT) for the NuPrism extension, which is meant to provide an intermediate measurement of the neutrino beam and reduce errors in calculations.

Though a large priority of my work at TRIUMF was in the construction of the mPMT prototype via PMT testing and gelling, which lead to some down time. To make sure I had enough work to do, I approached my supervisors for simulation work, and thus I spent time working on tagging events in simulation software for the NuPrism detector with the mPMTs. In particular, my goal was to tag pile-up events in the detector, where ”pile-up” events are simply large occurrences of similar events in a small time frame, sometimes making them indistinguishable from single bright events. My first attempt was with a likelihood measure in which the number of PMTs hit and the time of hit was recorded to fit a loglikelihood distribution and provide an estimate on the number of possible neutrinos that produced the hits. This worked for large time delays between the neutrinos, but ultimately could not distinguish finer differences. My second attempt was with a Hough Transform, where I ultimately had to fit rings on the detectors surface to count the number of possible neutrinos.

During the term, I would have weekly presentations of the work I completed to that point to the local T2K group. At the end of the term, I summarized my work to the most important achievements and presented this at the TRIUMF Student Symposium.

Both of these experiences have a had a large impact on my academic aspirations. During my time at SNOLab, I found myself deeply interested in the particle nature of WIMPS. My time at TRIUMF helped me explore the simulation software of experimental particle physics and discover the beauty of neutrino oscillations and their impact on the standard model. Though both positions were rooted in experimental physics, I found myself gravitating towards the theory more than I might have initially expected. My passion for mathematics and physics has had me tend towards learning more about the theory than the experimental side.

Statement of Academic Goals

My research career up until now has been greatly focused on the experimental aspect of physics. This has given me a great appreciation for the difficulty of this area of research, but academically I have always found myself tending towards the more theoretical aspects with a focus on the underlying mathematics. This has become especially clear with the material covered in my courses and through my past research experiences. My greatest research interest lies in geometry, and in particular, its application to physics.

The study of geometry itself is quite large and has its roots in pure mathematics, where it comes to fruition. However, geometry holds great power in the area of theoretical physics and is evident in the study of black holes, quantum field theory (QFT) and string theory. These topics are all linked by a single goal, and that is the understanding of gravity; the force that still eludes physicists and is the end goal of many floating theories in the physics community.

Einstein's general theory of relativity predicts that gravity is an emergent phenomena of mass distorting the fabric of spacetime [8]. This elegant theory gives rise to one of the now most fundamentally accepted theories and has been used to predict many physical phenomena. The beauty of the theory truly shines when one begins to see predictions of interesting events that may have not been detected otherwise, like black holes. With Schwarzschild's solution to Einstein's field equations for stationary masses, one finds that there is an unsettling divergence in the curvature of spacetime for a particular radius of the mass [4].

At such a radius, one finds that the mass has become so dense that even light cannot escape its gravitational pull [8]. And yet, this is only for one such scenario where we have considered the mass to be stationary on its axis. What if we give the mass the freedom to rotate? Such a scenario is solved by Kerr solutions to the Einstein Field Equations [4]. This leads naturally into the behaviour of electromagnetic waves in Kerr geometry, and further into spin-$\frac{1}{2}$ fields in such a geometry [4]. This is an exciting topic to myself, and research in such a topic would involve learning even more about geometry and physics. This would give me the chance to not only contribute to the area of general relativity, but discover some beautiful emergent processes like black holes.

Delving deeper we can find that the *behaviour* of particles near a Kerr-Newmann black hole can lead to surprising insights; such as finding no bound states for Dirac particles in this Kerr-Newmann geometry [6][7]. Perhaps we can consider attempting to fix the singularities found in Einstein's general theory of relativity with Weyl conformal symmetry while remaining conformally symmetric to the Kerr metric [2]. This geometrical perspective provides a deep insight into physics and is the epitome of mathematical physics; theories that arise from the fundamentally mathematical structure of geometry, but have deep impacts in the physical interpretations. There are many questions one can pose and attempt to push forward in this field, and my hope is to be able to tackle them myself.

My interest in geometry and physics leads perfectly into this field, as I carry the intuition that comes with working on physics problems and continue to build a solid background in geometry from a mathematicians perspective. I am taking a grad level course in geometry under the pure math department, and will be taking courses in general relativity and particle physics in the winter to help strengthen my background in this field. My motivation to learn and my curiosity for general relativity places me in a position that is well suited to contributing to the geometrical nature of spacetime and the beauty that comes with it.

Leadership Experience

Much of my leadership experience comes from previous work I have done, which sheds light on my ability to work independently and shows my ability to take the lead in tasks. In particular, I will be highlighting my accomplishments at TRIUMF, SNOLab, and my work experience at Humber College.

At TRIUMF, the priority of my work with T2K was the construction and preparation of the mPMT meant to be used for the NuPrism extension. As such, I was tasked with testing and preparing the PMTs used in the construction of the mPMT. In this process I built and recorded a method of casting the PMTs with optical gel that would minimize the risk of the cast failing and provided a consistent methodology for further construction of prototypes. Thus, I produced a method that will be used as the basis for the final approach to mass producing the mPMTs to be used in the extension, with the assistance of my supervisor.

At SNOLab, the work I did was independently completed. My supervisor would provide me with tasks, such as building a Dark Rate check, or shifting an analysis structure to a computer cluster that used different management software, but it was up to me in which direction I would tackle the problem. This freedom meant that I would work for weeks at a time without any supervision and still successfully produce results in completing the tasks asked of me during a time crunch. My method of approaching this scenario was to first learn the pre-requisite material, planning a route of attack, and then attempting to execute the plan. In some cases, this meant learning an entirely new coding language, reading through the code that needed updating and then debugging my attempted fix, and in others it meant learning how a computing cluster accepted jobs, modifying the submission scripts accordingly, and then again debugging until that worked. In such a position, getting stuck meant I had another opportunity to learn something new, and forced me to explore options I may not have learned about if not for the issue arising; set-backs became opportunities to learn and improve.

As an initial co-op position, I worked at Humber College as a Math Centre tutor for eight months . The Centre is a drop-in based tutoring resource and acts as a multi-resource as lecturers would often provide office hours through the centre. This position involved more than just tutoring students, however, as a large part of my position was leading the volunteer tutors. I would both schedule, and give tours to the new peer tutors. Further, I led the ”mobile tutoring” incentive, a tutoring approach that would send a peer tutor to a remote location on campus to assist students that may not be able to directly visit the centre for any reason. This increased the publicity of the centre across campus and provided me with an opportunity to lead a project on my own to fruition.

Furthermore, due to my seniority in the position after the first 4 months, I was tasked with leading the other co-op students. I became the representative of the other students that worked there and collaborated with my supervisor to make sure everything went smoothly. This started from the first day the new co-op students arrived, where I assisted in introducing them to the work and provided a path of dialogue between them and our supervisor. Ultimately, this lead to me organizing the other co-op students and assisting my supervisor that much more.

My research history has provided me with experience in many aspects of leadership that were not directly related to leading others, but instead being able to work independently and successfully complete projects. On the other hand, my experience at Humber College has given me the chance to lead and work with a team to run a tutoring centre and provide the required services. These leadership based roles have provided me the tools with which I can work in a research environment, not only with a team, but also while successfully providing results independently.

Conclusion

My experience at TRIUMF and SNOLAB, in junction with my drive to learn more mathematics/physics in the field of geometry and general relativity place me as an excellent graduate student candidate. My experience in working independently at TRIUMF, SNOLAB, and leading a team at Humber have all prepared me for approaching a master’s thesis. I hope to use my experience in the field of research, my research ambitions and my leadership experience to impact the field of research in physics. The University of British Columbia provides an excellent environment for this through the Physics & Astronomy department, and I would be honored to be part of such an environment as a masters student.

References

[1] P.-A. Amaudruz, M. Baldwin, M. Batygov, et al. (DEAP-3600 Collaboration) *First results from the DEAP-3600 dark matter search with argon at SNOLAB*. `arXiv:1701.08042`. (2017)

[2] C. Bambi, Z. Cao, L. Modesto. *Testing Conformal Gravity with Astrophysical Black Holes*, High Energy Astrophysical Phenomena. Phys. Rev. D 98, (2018) 024007.

[3] S. Bhadra, A. Blondel, et al. *Letter of Intent to Construct a nuPRISM Detector in the J-PARC Neutrino Beamline*. `physics.ins-det`. High Energy Physics - Experiment. `arXiv:1412.3086`.

[4] S. Chandrasekhar. *The Mathematical Theory of Blackholes*. Revised reprint of the 1983 original. International Series of Monographs on Physics. Oxford Science Publications. The Clarendon Press, Oxford University Press, New York, 1992.

[5] Dirac, P.A.M. *Principles of Quantum Mechanics*. Internatial Series of Monographs on Physics (4th ed.). Oxford University Press (1982).

[6] F. Finster, N. Kamran, J. Smoller, and S.-T. Yau, *Non-existence of time-periodic solutions of the Dirac equation in an axisymmetric black hole geometry*, `gr-qc/9905047`, Comm. Pure Appl. Math. 53 (2000) 902-92.

[7] F. Finster, N. Kamran, J. Smoller, S.-T. Yau, *The Long-Time Dynamics Dirac Particles in the Kerr-Newman Black Hole Geometry*, `gr-qc/0005088`, Adv. Theor. Math. Phys. 7 (2003) 25-52.

[8] J. D. Nightingale, J. Foster. *A Short Course in General Relativity*. Springer, New York, NY. Springer-Verlag New York 2006.