Raymond Hartig

Research Outline

Astroparticle Physics is a dynamic and ever changing field that works to examine the most basic building blocks in the structure of the universe. When my advisor and Physics Professor Jordan Hanson mentioned that he was conducting research on the matter, I was very interested and told him that I would appreciate the opportunity to work with him. Thankfully, everything worked out and we were able to begin almost immediately. Dr. Hanson taught me the prerequisites for the project, those being the mathematical field of complex analysis and learning the programming languages Python and Octave. The objective of the project is to derive a fully-analytic model of the energy of askaryan radiation caused by high energy cosmic rays (sometimes neutrinos) in ice. The reason that this is extremely important is that very little is actually known about cosmic rays, such as neutrinos, where they come from, and how they are created. It is thought that some of these particles are cosmogenic and will shed insight as to the origins of the universe itself. Prior to our work, there had not been a completely analytic model derived from this phenomena of scattering in ice before, as only simulations were used to probabilistically generate events in the ice. With an analytic model, much more insight is revealed as to why the scattering occurs the way it does, and also provides a path to the direction that the cosmic ray came from once it has been detected.

In the summer of 2020, we conducted the mathematical derivation of the on-cone and off-cone fields of the radiation taking place when the ray strikes the ice. This involved many integrals, and a few Taylor series approximations around certain parameters that can be taken to be small in size. The integrals were solved using methods of complex analysis, such as Cauchy integration in order to find a solution to the Fourier transform of the function of the energy from angular frequency to time. Once the equations for the on-cone and off-cone fields were completed, writing the findings in a paper was the next goal. During the school year, I was able to digitise graphs from previous papers about askaryan radiation and compare the new

analytic models to them, finding correlation coefficients of very high percentages (97-99 percent correlation). While doing this, Professor Hanson was keeping us on track while writing up our findings and creating code of his own to generate comparisons of the graphs that allowed for adjustments of certain parameters. I learned much about the details involved in creating a scientific paper. Professor Hanson calls this “the art of paper writing” as there is much creativity brought forward during this process.

For summer 2021, Professor Hanson allowed me to continue with him on the project by creating a summer job for me. We submitted the paper for peer review in Physics Review D, a Physics journal that deals with Astrophysics, High Energy Physics, and Field Theory. While the review was pending for publication, Professor Hanson took the time to get me familiar with Linux and the Unix command line. This skill was proven to be useful when we installed NuRadioMC, a particle physics simulation package based in Python, to our computers. Since NuRadioMC is based entirely in Python and can be installed only on Linux systems, I had the opportunity to learn an entirely new operating system and command line interface. Professor Hanson was always there to answer my (many) questions, and with his support, we currently have NuRadioMC up and running, and more importantly, are implementing the new analytic equations for the on-cone and off-cone fields implemented into the simulation package, ready to be run on personal computers anywhere. Our next step involves installation of the updated NuRadioMC software onto IceCube and IceCube Gen 2 (coming soon) detectors to give Physicists better tools at neutrino and cosmic ray detection.

A year of online school and a global pandemic can be quite difficult on one’s mental acuity. Professor Hanson including me in this project proved to be absolutely central to my well-being during these tough times, and kept me interested in all of the incredible things that nature has to offer.