Intellectual Merit

When I started studying at the Pennsylvania State University, I was curious about research and wanted to experience it as early as possible. After expressing this interest, I was invited to spend time observing various labs in the Department of Mechanical and Nuclear Engineering during my sophomore year. I found that I enjoyed the environment of a research lab, filled with knowledgeable individuals considering fundamental science questions. I chose to settle in the Intense Laser Laboratory, where I spent three semesters and a summer. I joined a team working on Direct Laser Acceleration, an acceleration scheme that uses the electromagnetic field from an intense laser pulse to rapidly accelerate electrons over a short distance. The motivation of the project is to realize a compact, portable accelerator with potential applications to medicine and nuclear security.

During this time, I was responsible for a variety of tasks. I started by designing and constructing unconventional breadboard supports and an adapter to fit the experiment into a constrained space and reduce the number of cables in our vacuum chamber. Together with a graduate student, I designed a laser compressor and shutter system capable of withstanding the laser intensity. Later, I constructed the system independently. I also gained experience in the software end of experiments by programming the user interface to position the gas jet used to generate a plasma waveguide. While working on the Direct Laser Acceleration project, we were able to generate plasma filaments. It was exciting for me to observe the creation of this plasma, and the experience helped me realize my interest in pursuing an experimental degree where it is possible to generate and observe phenomena that has otherwise only existed as a hypothesis. I dedicated the following summer to this project, funded by the Toshiba-Westinghouse Fellowship Program. During the summer, I shifted focus to the end goal of our project, devoting my full-time research efforts to teach myself to use the Geant4 toolkit to simulate the generation of bremsstrahlung from relativistic electrons.

This past summer, I gained significant research experience in another field, participating in the NSF-funded University of Michigan REU at CERN, the European Organization for Nuclear Research. There, I spent nine weeks working with scientists on the CMS detector, one of the detectors that confirmed the presence of the Higgs boson. I worked with jets, or sprays of hadrons resulting from radiated quarks or gluons. My task was to compare different quark jet reconstruction algorithms used to characterize a hadronic W boson. These jet characteristics were identified as functions of the momentum of the parent particle and amount of pileup in a given event. This project had the goal of identifying the algorithm that had the most stable characteristics and best resolution, so that future searches can be made with higher precision. The results of my study will be used in negotiations between the CMS and ATLAS experiments to determine a common cone size and grooming algorithm to use on future runs. My results showed that the current CMS default grooming algorithm, pruning, consistently produced the worst resolution of all the considered algorithms. Smaller cone sizes tend to produce better resolution, and considering smaller substructures when grooming leads to more stable jet characteristics. I also wrote a Monte Carlo program to show the characteristics of gluon jets under high pileup conditions, demonstrating that they will be easier to mistake for quark jets as the pileup increases. I had presented these results to multiple groups within CMS, and was frequently met with surprise. However, recent studies using different phenomena have since confirmed my conclusions and helped me gain

confidence in my work.

I enjoyed the environment at CERN, where I worked with researchers from a variety of countries, and they were excited by the big research questions being posed. This experience helped me to select my area of study in graduate school. I have decided to attend graduate school for experimental high-energy physics. Through my majors in Nuclear Engineering and Physics, I have been able to approach modern physics in different ways. Studying nuclear engineering teaches me how to apply modern physics, while studying physics allows me to understand these applications in terms of fundamental models. Between the two, I am particularly drawn to the physicists' approach of attempting to unify a wide range of phenomena using as few distinct theories as possible. After my intensive exposure to the field, I learned that there are still many scientific questions that can be explored at the Large Hadron Collider (LHC). Because of this, I opted to continue working with my advisor from CERN and make that work the object of my undergraduate thesis.

My current plan is to continue working on improving jet reconstruction algorithms. Over the summer, I showed that the mass resolution of a dijet system could be improved by increasing the efficiency of selecting the correct jets from a given decay. It will be more difficult to maintain or increase this efficiency during future runs of the LHC, since the pileup will increase. Even using the recently completed runs, the comparisons I made over the summer had never been done before by CMS, making me one of the youngest people to have worked on fundamental research with jets. This leaves me in a good position to be one of the leaders on jet reconstruction during the future runs of the LHC. Given my education in nuclear engineering, my curriculum had an unusual focus on the design and application of detectors. I have also gained experience in simulating particle transport through deterministic and stochastic means. These skills will help me to further evaluate current jet reconstruction algorithms based on detector capability and propose new methods and designs.

Broader Impacts

In addition to my research activities and studies, I have been an active member of the Penn State Student Section of the American Nuclear Society (ANS). After joining my freshman year, I served as governor my sophomore year, and vice president during my junior year. Every year, I attended the National ANS Student Conference. In the 2013 conference, I gave two presentations, winning the award for Best Undergraduate Presentation in Reactor Physics for explaining a Molten Salt Reactor model that I created as a class project. This year, the conference will be hosted by Penn State University. I am involved on the conference board as the Technical Lead. My responsibilities will include overseeing the review process of paper submissions, and assisting with scheduling the technical sessions. I will also help organize six expert panels that will be given throughout the conference.

Additionally, I have been involved in the outreach activities of ANS. Through ANS, boy scouts visit Penn State's research reactor, the Breazeale Reactor, to learn basic principles and applications of reactors and nuclear science, earning their Nuclear Science merit badge. Westinghouse also runs a program encouraging younger females and minorities to enter science and engineering, bringing high school students to the Breazeale Reactor. Through numerous outreach events, over 300 students visit each year. Volunteering for one of these events is one of my favorite ways to spend the weekend because the students find the subject

exciting, and they challenge me by asking difficult questions. I try my best to explain advanced nuclear science topics using basic concepts by punctuating my explanations with questions about what they have already learned in school. I find it exciting that phenomena appearing to be complicated can be understood in familiar terms. For example, explaining gamma rays as x-rays that come from nuclear energy transitions instead of atomic transitions frequently captures my audience's attention. It is rewarding when students approach me after a presentation to thank me.

Once a year, the Breazeale Reactor holds an open house during Parent's Weekend when crowds of students and their parents come to see the reactor. I volunteer to help the reactor staff handle the large number of visitors. Some of the visitors are excited, some are nervous, and I am there to answer their questions. Of course, under such situations, I get asked about many controversial topics, but I answer as accurately as possible. The nuclear industry faces complicated problems, and it is important to for people to correctly understand those problems. This will engage the public in constructive dialogs about nuclear energy.

In addition to short-lived weekend activities, I have had experience with long-term teaching commitments. During my sophomore year, I worked as a private instructor, taking on a number of second-year engineering students. My primary goal was to always relate new material to what the student was already familiar with. Through tutoring, I have experience helping students understand science using this approach. Every new concept was connected to the material that the students had learned before and was comfortable with. One of my biggest challenges as an instructor was working with a student who started partway into the semester, claiming he had "absolutely no idea what was happening" in Introduction to Electricity and Magnetism. I committed two hours each week to instructing him, and eventually, he performed well on the midterm and was confident going into the final exam. Helping students gain deeper understanding of fundamental science is something I hope to continue doing in the future.

I have also had the opportunity to reach out to a larger audience through the media. Onward State, a student-run blog that is popular among Penn State students, conducted an interview of me about my summer at CERN. The title of the published piece was "Penn Stater Returns from CERN: 10 Questions with Dan Abercrombie." During the interview I tried to convey what it was like working at such a large facility.

Attending graduate school for experimental high-energy physics would enable me to build upon my intellectual and outreach experiences in college. I would like to learn about the most fundamental questions that are being asked by particle physicists and be involved with addressing the challenges of creating and observing the predicted effects. Of course, there is the exciting possibility of observing something that is not understood, and that will give a chance for the scientific community as a whole to learn something new.

Many members of the public are also interested in learning about the physics that is studied at the LHC. After gaining experience there, I look forward to spending time teaching others. Through tutoring, study groups, and outreach, I found great joy helping people understand topics that they are curious about. I hope to continue teaching the public about the science and applications for nuclear and particle physics. I also look forward to helping other students understand the fundamental models of physics. My eventual goal after graduate school is to become a professor of physics.