OVERVIEW: Imagine the dream-like world of the future that we see in so many sci-fi blockbusters and shows. This fantastic vision of the future is what propels me to pursue a Ph.D. in experimental physics. I am applying for the NSF Graduate Research Fellowship, because being an NSF fellow would help me to immediately continue work in graduate school that I have already started as an undergraduate. Specifically, I am proposing a state-of-the-art research project to advance graphene-based sensor and laser technology. My goal as a scientist is to work on the edge of knowledge, creating new technologies based on new concepts in physics that will have **broad impacts on the world and help define the technologically advanced future**.

BACKGROUND: This is an exciting time to be alive, especially as a young scientist. My generation has a greater opportunity to make real technological achievements than perhaps any before. I have already been a part of some of the amazing forefronts of science with the following undergraduate research internships:

- Internationally, with a research semester at the **Large Hadron Collider** at **CERN** (Geneva, Switzerland)
- Nationally, as an intern at **Caltech** (Pasadena, CA) in **microwave astronomy**
- At my home institution, **Georgetown University** (Washington, DC), in **graphene nanoelectronics**

Pursuing a Ph.D. in experimental physics will give me the depth of knowledge and experience needed to conduct quality research that can lead to discoveries that will **contribute to everyday lives** as well as **set the stage for future technology advancements by others**.

In 2013 I graduated high school as valedictorian in my home state of New Hampshire. Of several universities that accepted me, I chose to attend Georgetown University in Washington, D.C., because it offers strengths in physics research and political science, has small class sizes, and is devoted to public service. Initially, I thought I might like to work on the policy side of science, promoting new discoveries politically. As I began my physics coursework, however, I found that I really loved studying physics and wanted to learn as much as possible. One day I would like to apply the scientific expertise I will gain from my Ph.D. and my desire to **promote science to the public** to make a science-savvy life accessible for everyone.

During the second semester of my freshman year, I joined the research group of Professor Paola Barbara where I began to learn about graphene nanoelectronics and methods of nanoscale device fabrication. I learned many amazing potential applications of graphene: a single-atom-thick layer of carbon, the world's first two-dimensional material. Graphene's optical absorption properties, flexibility, and ultra-high electrical conductance inspire many research ventures and ideas for cutting-edge applications. From flexible graphene solar cells built into clothing, to high-capacity graphene batteries with ultrafast charging times for the next era of electric vehicles, there are many exciting potential uses for graphene that seem to be out of a science-fiction dream. This excitement has become the passion that propels me into graduate school.

INTELLECTUAL MERIT: ***International and National Research Internships***
<u>~~ **Large Hadron Collider (**LHC), CERN, ATLAS Experiment. Geneva, Switzerland.</u>
<u>*What*</u>*:* One of five students selected nationwide to the University of Michigan CERN research semester, fall 2015. ATLAS Experiment. Mentor: Professor Richard Teuscher, Univ. of Toronto.
<u>*Rationale*</u>: CERN represented to me the height of achievement in the scientific world. Researchers at CERN are working to understand the most fundamental questions of the universe

and are developing the most sophisticated experiments in the world to test their theories. CERN is an international haven for scientists that I had dreamt about working at since my first physics class.

RESEARCH RESULTS: Proved that the most recent prototype for the new LHC Phase-II Upgrade read-out electronics for the ATLAS Detector's semiconductor tracker subsystem can withstand an acceptable threshold of total ionizing radiation.

Research Details: Wrote code in C++ to run scans of the custom electronics that register the semiconductor tracker subsystem's response to interaction with decay particles from the particle collisions in the LHC. Developed a system using thermoelectric Peltier tiles to cool the test devices to the operating temperatures of the ATLAS detector (-30 ^{o}C). Coded a graphical user interface (GUI) and designed an experiment to irradiate the electronics with x-rays to simulate the radiation-intense environment of the LHC. Ran a testing campaign for over a week, 24 hours per day. Gave presentations to my colleagues and published an Internal Note (10-page document) to the CERN document server of my work for use by the ATLAS Collaboration.

Why this is Exciting to Me: My research achieved an unexpected additional benefit: we prevented another group from forcing a shutdown of the LHC and wasting thousands of dollars.

At the time of our testing campaign, there was a problem with one of the inner detector layers of ATLAS. The readout electronics for this subsystem were drawing increasingly unsafe amounts of electrical current as a result of the ionizing radiation coming from the LHC. The theory of the behavior of these types of silicon electronics in response to radiation indicated that this current increase should subside after an annealing mechanism in the silicon manifest with more total dose. No one was entirely sure if the current gain would increase so much that it would destroy the electronics before this beneficial effect would take over.

The electronics we were studying were of a similar design, and should have had a similar response to total ionizing dose. The rise of this problem in this ATLAS subsystem coincided with the end our radiation testing period. We had an exciting rush to quickly present our results to scientists from groups in ATLAS concerned with the current rise in this other subsystem. Our analysis led to the conclusion that the silicon annealing mechanism in their devices should in fact take over and diminish the current increase before it would cause any harm to their electronics. The group heeded our advice and, after more exposure to radiation in the LHC environment, **the current safely diminished**. It was amazing to contribute to this collaboration of brilliant and passionate people of many different scientific specializations and cultural backgrounds.

~~ **Caltech**, Sub-MM/MM Astronomy. Pasadena, California.

What: Crafted a research proposal and successful application to the Caltech Summer Undergraduate Research Fellowship. Summer 2016. Mentor: Dr. C. Matt Bradford, Caltech/JPL.

Rationale: Caltech is affiliated with over 30 Nobel laureates and is one of the preeminent schools for physics in the world. It was home to my hero Richard Feynman. I got to work with scientists whose papers I had read – people who are expanding the field and inventing new technologies.

RESEARCH RESULTS: Built a new readout system using GPU acceleration for SuperSpec, a novel on-chip microwave spectrometer in development for sky surveys of high redshift galaxies.

Research Details: Used a waveform digitizer and a GPU to read-out the response to microwave radiation of the hundreds of kinetic inductance detectors connected to SuperSpec's frequency filter bank. Wrote code in MATLAB and C++ to calculate hundreds of million-point Fast-Fourier Transforms per second on the digitized waveform by exploiting the parallel architecture of the GPU. Proved that my system works reliably and effectively for all of our testing purposes. Presented a scientific poster at Caltech and wrote a final paper at the end of my fellowship.

Following my work and advice, the group has decided to continue with my readout system and use it to develop future prototypes of the SuperSpec spectrometer chips.
Why this is Exciting to Me: I had the opportunity to work with scientists who are pushing the boundaries of technology. The device we were working on is an application of a really new technology (kinetic inductance detectors, invented at Caltech). It was really **exciting to be on the forefront of applying new physics to real-world devices to create something that has never been possible before**. I was able to become something of an expert on this readout set-up and acted as a resource for my group, during and after my internship.
~~ **Georgetown University** Nanoscience and Microtechnology Lab
What: Undergraduate research at Georgetown in nanoscale electronic devices on 2-D graphene. For all four years as an undergraduate and one summer. Mentored by Professor Paola Barbara.
Rationale: Hands-on, independent research as an undergraduate in a very exciting field.
RESEARCH RESULTS: Active participant in experimental research (both successes and failures). Investigated graphene's response to mm-wave radiation by fabricating and analyzing custom detector devices on chemical vapor deposition (CVD) and epitaxial graphene samples.
Research Details: Independently performed research, generating new ideas and approaches to solving problems. Acquired cleanroom nano-fabrication skills (e.g., photolithography, metal deposition, e-beam lithography, wire-bonding). Additional experience in graphene growth (CVD) and transfer methods, as well as the growth of other 2-D materials such as molybdenum disulphide. Helped prepare work for publication, for which I am a co-author (In review, ACS Nano: *Facile Fabrication of Graphene/MoS_2 Heterostructure Devices on Arbitrary Substrates by Photolithography*). Took initiative to apply for summer research funding through the Georgetown University Hichwa Family Fellowship. Was selected as the sole recipient of this fellowship in 2015 and used it to continue my work during the summer after my sophomore year.
Why this is Exciting to Me: Our group works on really clever experiments that have led to impressive results worthy of publication. I have the opportunity to work closely with my team and absorb knowledge on a variety of topics. I am able to be a knowledgeable contributor in an extremely positive environment of creativity and collaboration, and from that I have learned a great deal. This work is very exciting to me because it could spur the creation of **new technologies and commercial applications on short timescales (years versus decades)**.

BROADER IMPACTS: Beside the broad impacts described in the section above about my research experiences, I have also worked in **science outreach and education**. I was a Teaching Assistant for a first-year electricity and magnetism course for two successive years. I also tutor pre-medical students struggling in their physics prerequisite courses. Finally, the summer after my freshman year I volunteered at the Massachusetts Audubon Society's Joppa Flats Education Center in Newburyport, MA, where I coordinated a science-themed kids program that focused on teaching children about both local New England ecology (e.g., live touch tank, tide-pooling adventures), and the fun of learning about the physical world (e.g., electricity, earth science)!

CONCLUSION*:* With a Ph.D. in experimental physics, I will gain the experience that will allow me to spend my life working on the edge of knowledge, and contribute to creating the bright technological future I dream about. My international and national physics internships have shown me both the fun of science and the future of science. I want to contribute to scientific discoveries and technological advancements that will have broad impacts on the future of the world and affect the lives of everyday people. The NSF Graduate Research Fellowship will allow me to continue my work in graphene optoelectronics (see proposal essay) as soon as I enter graduate school, and help me to contribute to creating the bright future ahead.