Warren J. Baker Endowment
for Excellence in Project-Based Learning
Robert D. Koob Endowment *for Student Success*

FINAL REPORT

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I. Project Title
Towards Radio Frequency Detection of High-Energy Neutrinos & Cosmic Rays

II. Project Completion Date
2/18/17

III. Student(s), Department(s), and Major(s)
(1) Caroline Paciaroni, Physics

IV. Faculty Advisor and Department
(1) Stephanie Wissel, Dept. of Physics
(2) Dean Arakaki, Dept. of Electrical Engineering

V. Cooperating Industry, Agency, Non-Profit, or University Organization(s)
SLAC-T510 group, especially Anne Zilles, Karlsrühe Institute of Technology

VI. Executive Summary
The goal of the project was to measure the impulse response of a bicone antenna used in am experiment done at the SLAC National Laboratory in 2014. The SLAC T-510 experiment measured a particle air shower in a lab environment by directing the SLAC particle beam into a dielectric material and measuring, with antennas, the resultant radio-frequency signal produced. The experiment is significant to understanding how extremely high-energy particles such as cosmic rays and neutrinos interact. These high-energy particles carry information about the extremely volatile events happening in universe. Potential sources of these particles include Active Galactic Nuclei (AGNs) and Gamma Ray Bursts (GRBs). This topic is vital to many particle physics experiments that are looking to detect these particles, whether through ground-based cosmic ray telescopes like LOFAR (Low-Frequency Array) or neutrino detection experiments like ANITA (ANtarctic Impulsive Transient Antenna) or ARA (Askaryan Radio Array). While the SLAC T-510 experiment team has analyzed their results for one of the antennas used, the low-frequency (30-300 MHz) bicone antennas analysis has yet to be completed, as the effective height of the antennas had not been measured at the time of the experiment. The effective height is a property that allows for comparison between the measured voltages of the antenna and the simulated electric field, and is required in order to make comparisons between the measured data and the theoretical model. As with any experiment, the ability to compare one's results to what is expected is vital to forming conclusions. Thus, the primary goal of this project was to measure the impulse response of these antennas, which leads directly towards the calculation of the effective height of the antenna, and the ability to analyze the results of the SLAC T-510 experiment.

Figure 1: Picture of impulse response test setup on Baker Science – Photo credit: Tenney Rizzo, COSAM

The impulse response testing was carefully designed to minimize noise in the data and to ensure useful results. The major problem in impulse response testing is minimizing reflections, where the transmitted signal bounces off of the ground or nearby structures and interferes with the direct signal. Significant time was spent looking for potential testing locations and calculating possible reflection paths, in order to determine whether the setup would be able to isolate the reflected pulse enough to not interfere. The best possible location was found to be placing the the transmit antenna as high up as possible, so we obtained permission to place it on the roof of the Warren J. Baker Center for Science and Mathematics, Cal Poly's tallest building. The transmit antenna was placed on the lawn below, raised on a specially modified antenna tripod, and controlled with a motor that allowed for full and precise rotation around 360°. With much help from both physics and electrical engineering students, we were able to take the required data in one day. The process of data analysis for this project was more substantial, and involved careful analysis of test parameters, such as cable attenuation and path loss, and the careful application of signal processing techniques and equations.

The final result of the project is the effective height of the bicone antennas. The effective height was then used to compare the simulated electric field, predicted by modeling, to the actual data (voltage) measured at the SLAC T-510 experiment. This is shown in Figure 2. While preliminary and qualitative, the comparison shows that the measured data shows the expected impulsive behavior, which suggests accuracy of the particle shower model at low frequencies. With the effective height, further analysis of the SLAC T-510 data can be performed, which will be able to make quantitative conclusions about the accuracy of the current theoretical model of particle showers. This will help to improve experiment designs, increasing chances of detecting these extremely energetic particles, and allowing for a new astronomical window into the events happening in the distant universe.

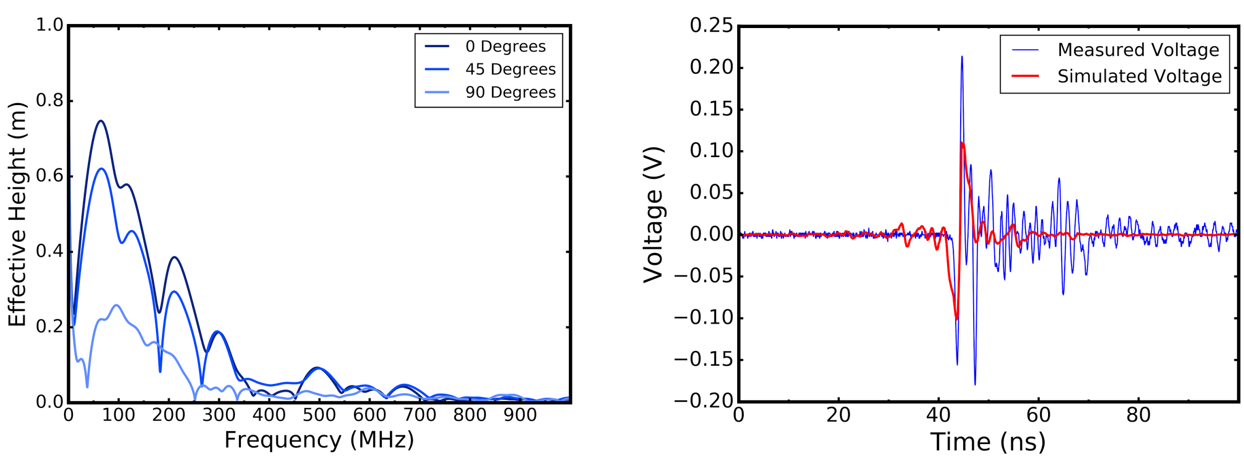

Figure 2: (a) Experimental result – measured effective height of the bicone antenna over full frequency band. (b) Comparison of voltage on bicone measured at the SLAC-T510 experiment to simulated model found with the effective height shows qualitative accuracy of the model.

VII. Major Accomplishments

(1) Designed, planned, and executed impulse response testing of bicone antennas on the roof of Baker Science (Building 180).

(2) Analyzed the resultant data to calculate the gain and effective height of the antennas.

(3) Used the measured effective height to make comparisons to the data taken by the SLAC-T510 group. Preliminary results corroborate previous conclusions of the group and with further

analysis results will be publishable.

(4) Presented research in the internal Cal Poly CSU Research Competition, in Cal Poly CSM Poster Sessions, and SLAC T-510 collaboration teleconference.

(5) Further analysis of the SLAC T-510 data will be my senior project, and will be presented at the APS Far West Section meeting in Nov. 2017.

VIII. Expenditure of Funds

The major expenditures were two fiberglass antenna tripods (~$400 each), a precision antenna rotator (~$300), and a high-voltage attenuator (~$800). Smaller amounts were used to buy necessary equipment like coaxial cables, high-duty outdoor extension cords, and smaller hardware and electronics.

IX. Impact on Student Learning

It is hard to express just how impactful this project has been to my learning. The process of finding a research topic, applying for a grant, designing and planning the experiment, going through the data analysis, and coming out with a useful result is exactly what I will be doing in a career in experimental physics. Working on the project has both increased my desire and motivation to pursue a PhD in experimental physics, as well as given me the skills to succeed. In designing the experiment, I learned how to carefully plan and measure experimental parameters. Not only did I have to find the best location for the testing, but I also had to order parts and figure out how to put them all together to make the experiment work. In actually performing the experiment, I learned how to manage the fact that those parts inevitably don't work like you planned them to, and how to adjust and fix things on the fly.

Finally, the data analysis itself was extremely important to my understanding of the physics, as well as my ability to apply physics principles to numerical modeling and data analysis via computer programming. The data analysis involved many lines of Python code, from importing and organizing data, implementing FFTs, running through the analysis, and checking and plotting results. I started with minimal coding ability, and through this project have increased my skill exponentially. Additionally, in the process of presenting my results I learned how to communicate my ideas effectively. I've presented my findings both to the SLAC T-510 group, and to the larger community through poster sessions and the CSU research competition. Finally, I hope to continue the data analysis of the SLAC T-510 experiment with the results of this project, and plan to turn the complete analysis into my senior project. It was truly a learn-by-doing experience that taught me skills I would not have learned in the classroom, skills that will be extraordinarily useful throughout the rest of my career.

Throughout this project I was helped substantially by the members of the Neutrino Radio (NuRad) Group at Cal Poly, consisting of both my fellow undergraduate researchers and my advisors. Without their help, I would never have succeeded. Additionally, I would like to sincerely thank the members of the SLAC T-510 team for providing me with this opportunity and all the resources I needed to be successful. Finally, I would like to express how important the Baker-Koob grant was to the success of this experiment. Without the funding I received, I would not have been able to perform the impulse response testing at all.