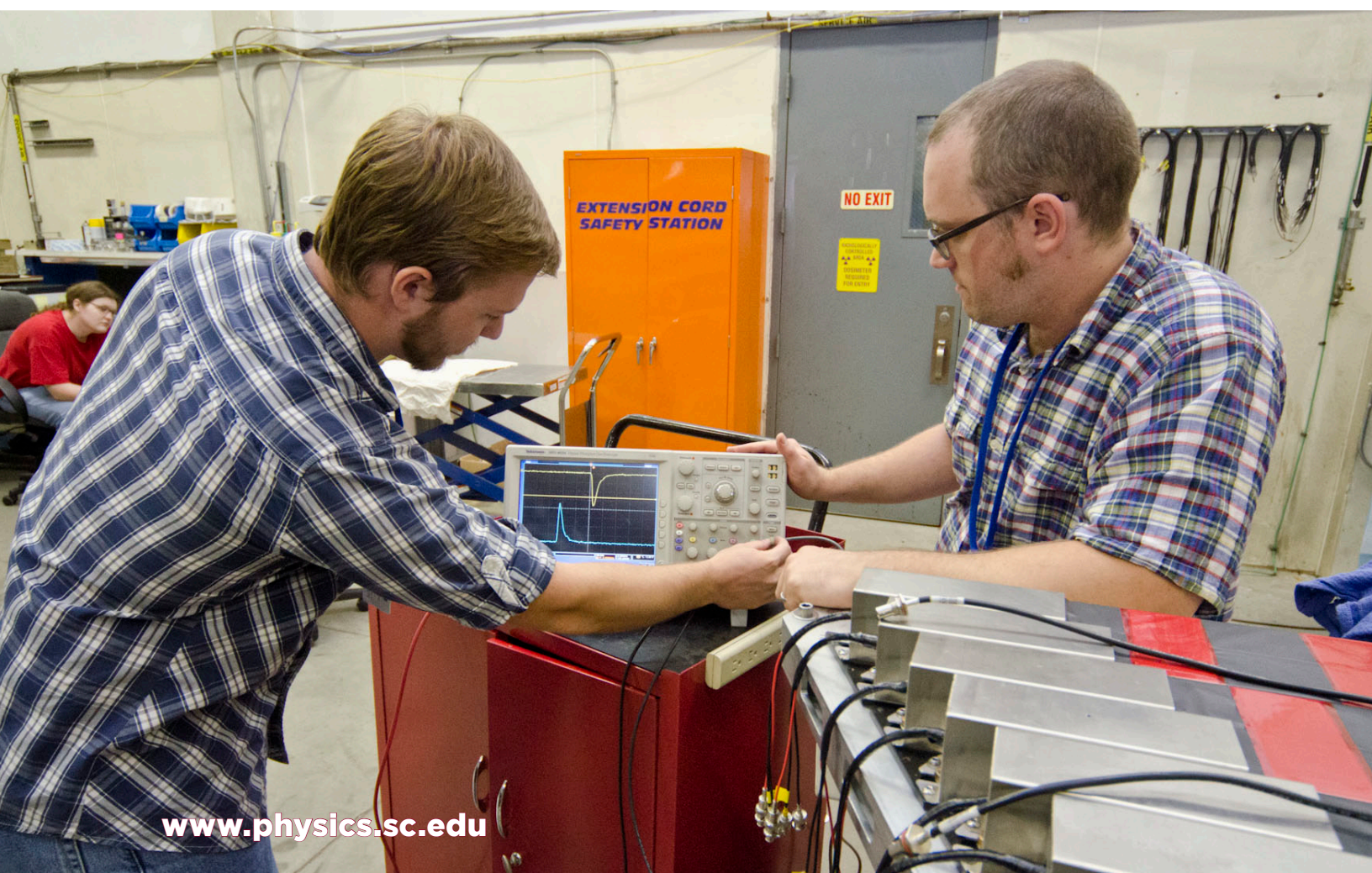


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Probing Matter at the Precision Frontier of Physics

By Evan Phelps, current graduate student



The Experimental Nuclear Physics (ENP) group at USC achieved world-record time resolution with their Time-of-Flight particle detector (TOF12) designed and constructed for Thomas Jefferson National Accelerator Facility's (TJNAF's or JLab's) large acceptance spectrometer, CLAS. In July of 2013, after almost ten years of work that included design, prototyping, construction, testing, and assembly, we shipped TOF12 to JLab for final integration and commissioning—on schedule, within budget, and surpassing design requirements. Serving as CLAS's primary device for particle identification, TOF12 will play a vital role in an international physics program that aims to answer basic questions about the universe: What is the universe made of? What holds everyday matter together? How is the mass of visible matter generated from almost nothing? Toward this end, USC's ENP group contributes significant data analyses and leads strategic coordination initiatives, establishing itself as one of the leaders in the international program. The group's full lifecycle ownership of the TOF12 project extended their program into the field of detector physics and provided even more opportunities for USC students and researchers to contribute to world-leading efforts focused on revealing the physics beyond, and hidden aspects of, the Standard Model. As a student, I was drawn to these rare opportunities to explore the basic questions while also developing expertise that spans many layers of experimental physics, from detector materials and hardware to data analysis and interpretation.

From its original operation in 1997 until its final 6-GeV experiments in 2011, the CLAS detector of the 6-GeV Continuous Electron Beam Accelerator Facility (CEBAF, and the "C" of CLAS) offered unique opportunities to investigate the transition between particle and nuclear physics. Based on the success of the 6-GeV program, the Department of

Energy's Office of Science prioritized the 12-GeV upgrade of CEBAF as its number one recommendation to deepen, with unprecedented precision, our view of the transition into its most rapidly evolving region. This precision frontier of physics might sound like a technical niche where our fundamental understanding is only refined; on the contrary, it is the key to understanding the dynamics of the strong interaction, which are responsible for the emergence of ground and excited nucleon states. The description of how the strong interaction, described by Quantum Chromodynamics (QCD), dynamically generates the nucleons and, with them, 98% of the mass of ordinary matter, could be the most significant and challenging part of the Standard Model yet to be explored. Filling this knowledge gap is the primary motivation of the 12-GeV Upgrade at JLab, which drove the requirements of the TOF12 detector.

The physics value and technical details of the CLAS detector are well documented, but the pedagogical merit of the TOF12 project at USC, from the perspective of a student, is rarely discussed. Offering both broad and deep research experience, the TOF12 project employed the efforts of more than twenty undergraduate and graduate students over six years. Student experiences ranged from semester-long sub-studies to full-lifecycle engagement. TOF12-related research fulfilled several Masters theses and, as in my case, complemented Ph.D. research with a component of detector physics and involvement in project management.

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In 2006, before, and in anticipation of, entering the graduate program, I started working on the TOF12 project under Professor Ralf Gothe, the primary investigator and manager of the project. Preliminary investigations had been performed by Dr. Gothe and graduate students under his guidance, but otherwise the opportunity was “ground-floor”: the lab was not built; the custom tools were not designed; the candidate components of the detector were not evaluated; and the measurement methods were not developed. I brought some non-academic skills from several years of professional software development, but I had no experience with lab setup, particle detection, or nuclear instrumentation. Starting with detailed studies and quantitative evaluations of the electronic building blocks of systems that translate detector signals into time and energy information, I slowly built a framework to put together and tune full systems of electronics and data acquisition. These systems allowed for the subsequent development of time resolution measurement methods and, in turn, testing of any combination of components, from detector materials to cable connector types. From the optimal configuration, we constructed prototypes to serve as benchmarks during the manual construction of the 384 “mini-detectors” that comprise the TOF12 detector.

During this bottom-up process, students were entrusted with the vast majority of tasks in a way that allowed for progression from labor-oriented, directly supervised work to goal-oriented, complex assignments with great latitude in method. Much like my experience in private industry, efforts and ideas were kept on track with weekly reviews of progress, allowing for

continuous feedback and improvement. This level of hands-on cultivation of student knowledge and skills within a “real-world” project proved to be unique within the larger 12-GeV Upgrade Project, which is most notably demonstrated by the official project, Technical Review, at JLab. Not only is the USC ENP group the only contributor whose technical presenters were graduate students, but our team also received top marks and statements of confidence from world-leading physicists appointed to evaluate the project. Moreover, the exposure gained by students led to excellent ties with physicists beyond USC, and the research experience played an important part in securing fellowships and other external funding for some students.

TOF12’s construction phase is complete, but the opportunities and value generated by the project are ongoing for both USC and individual students. As JLab’s 12-GeV era begins, the ENP group is poised to provide ongoing detector expertise and service to the CLAS collaboration as they work to complete our knowledge of the mostly unknown transition between particle and nuclear physics. The TOF12 development infrastructure serves as a long-term asset for prototyping and building new detectors for other facilities and for the laboratory portion of undergraduate and graduate physics courses. For individual students—even those not pursuing research careers—the hands-on hardware and software work adds unusual breadth to their experience and demonstrates to potential employers their ability to transform research-informed knowledge into practical applications. ♦

